STATE WATER SUPPLY ENHANCEMENT PLAN

JANUARY 2017

Meeting Critical Water Conservation Needs and
Enhancing Public Water Supplies Through Brush Control

TEXAS STATE SOIL AND WATER CONSERVATION BOARD

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The State of Texas' comprehensive strategy for managing brush in all areas of the state where brush is contributing to a substantial water conservation problem.

TEXAS STATE SOIL AND WATER CONSERVATION BOARD

Texas State Soil and Water Conservation Board

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Since early 2012, TSSWCB staff has worked with a Stakeholder Committee, a Science Advisory Committee, and numerous others to discuss how best to implement changes to the WSEP that the Legislature directed. Both Committees have worked hard to ensure that the best available science is being used by the TSSWCB to direct State funds to those areas where the positive impacts of brush management to enhance public water supplies can best be realized. The recommendations by these Committees have guided the decisions the TSSWCB has made to implement the Legislative directives for the WSEP. The TSSWCB would like to express its sincere appreciation to all who contributed to the development of this *State Water Supply Enhancement Plan*.

Stakeholder Committee

Robert Mace, TWDB
Ken Rainwater, TTU
Jule Richmond, ATSWCD
Jason Skaggs, TSCRA
vacant, TCEQ

Science Advisory Committee

Tom Arsuffi, TTU (alternate)
Ryan Banta, USGS (alternate)
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Larry Hauck, TIAER
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Abbreviations, Acronyms, and Initialisms

AgriLife Extension	Texas A&M AgriLife Extension Service
AgriLife Research	Texas A&M AgriLife Research
ARS	USDA Agricultural Research Service
ATSWCD	Association of Texas Soil and Water Conservation Districts
BCP	Texas Brush Control Program
BMP	best management practice
BRA	Brazos River Authority
CRMWA	Canadian River Municipal Water Authority
CWA	federal Clean Water Act
EAA	Edwards Aquifer Authority
EDYS	Ecological DYnamics Simulation model
EQIP	USDA-NRCS Environmental Quality Incentives Program
ESRI	Environmental Systems Research Institute, Inc.
ET	evapotranspiration
FOTG	USDA-NRCS Field Office Technical Guide
FY	fiscal year
GBRA	Guadalupe-Blanco River Authority
GCD	groundwater conservation district
gpd	gallons per day
LBB	Legislative Budget Board
LCRA	Lower Colorado River Authority
MWA	municipal water authority
MWD	municipal water district
NRA	Nueces River Authority
NRCS	USDA Natural Resources Conservation Service
NRI	USDA-NRCS National Resources Inventory
PWS	public water supply
RFP	request for proposals
RRA	Red River Authority of Texas
RWPG	regional water planning group
SARA	San Antonio River Authority
SPUR	Simulating Production and Utilization of Rangeland model
SWAT	Soil and Water Assessment Tool
SWCD	soil and water conservation district
TAC	Texas Administrative Code
TAGD	Texas Alliance of Groundwater Districts
TCEQ	Texas Commission on Environmental Quality
TDA	Texas Department of Agriculture
TFS	Texas A&M Forest Service
TGPC	Texas Groundwater Protection Committee
TIAER	Texas Institute for Applied Environmental Research at Tarleton State University

TISCC	Texas Invasive Species Coordinating Committee
TPWD	Texas Parks and Wildlife Department
TSCRA	Texas and Southwestern Cattle Raisers Association
TSSWCB	Texas State Soil and Water Conservation Board
TTU	Texas Tech University
TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute, a unit of AgriLife Research
UCRA	Upper Colorado River Authority
UGRA	Upper Guadalupe River Authority
USEPA	United States Environmental Protection Agency
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
USIBWC	International Boundary and Water Commission, United States Section
WCAC	Water Conservation Advisory Council
WCID	water control and improvement district
WMS	water management strategy in the State Water Plan
WSEP	Water Supply Enhancement Program
WUG	water user group

Chapter 1 Introduction to WSEP and TSSWCB

POLICY OF THE STATE OF TEXAS – VOLUNTARY LAND STEWARDSHIP

It is the Public Policy of the State of Texas to provide for the conservation and development of the State's natural resources, including the voluntary stewardship of public and private lands to benefit waters of the State. [Water Code §1.003]

The Legislature finds that voluntary land stewardship enhances the efficiency and effectiveness of this State's watersheds by helping to increase surface water and groundwater supplies, resulting in a benefit to the natural resources of this State and to the general public. It is therefore the Public Policy of the State of Texas to encourage voluntary land stewardship as a significant water resource management tool. [Water Code §1.004(a)]

Land stewardship is the voluntary practice of managing land to conserve or enhance suitable landscapes and the ecosystem values of the land. Land stewardship includes land and habitat management, wildlife conservation, and watershed protection. Land stewardship practices include runoff reduction, prescribed burning, managed grazing, brush management, erosion management, reseeding with native plant species, riparian management and restoration, and spring and creek-bank protection, all of which benefit the waters of the State. [Water Code §1.004(b)]

Maintaining the biological soundness of the State's rivers, lakes, bays, and estuaries is of great importance to the public's economic health and general well-being. The Legislature encourages voluntary land stewardship to benefit the waters of the State. [Water Code §11.0235(b)]

Voluntary land stewardship, on a grand scale, is a cornerstone solution
for water supply issues in Texas. The efforts of private landowners
to control water-depleting brush are vitally important
to the ecological health of productive rangelands across the state.
Many Texans today, especially those in urban areas,
enjoy the public benefits, such as clean plentiful drinking water,
they derive from the voluntary land stewardship
provided by private landowners and agricultural producers throughout the state.

INTRODUCTION

Scarcity and competition for water have made sound water planning and management increasingly important. The demand for water in Texas is expected to increase by over 17%, to a demand of about 21.6M ac-ft in 2070; while existing water supplies are projected to decrease by nearly 11%, to about 13.6M ac-ft. With Texas' population expected to grow by 73% over the next 50 years, the availability of water supplies is essential for not only the Texans of today but also for those of tomorrow. (TWDB 2016)

Over at least the last century, rangeland vegetation in the United States has undergone a large-scale conversion from grasslands to woodlands and shrubland. Noxious brush, detrimental to water conservation, has invaded millions of acres of rangeland and riparian areas in Texas, reducing or eliminating stream flow and aquifer recharge through interception of rainfall and increased ET. Brush control has the potential to enhance water yield by conserving water lost to ET, recharge groundwater and aquifers, enhance spring and stream flows, improve soil health, restore native wildlife habitat by improving rangeland condition, improve livestock grazing distribution, protect water quality and reduce soil erosion, aid in wildfire suppression by reducing hazardous fuels, and manage invasive species.

In order to help meet the State's critical water conservation needs and ensure availability of public water supplies, the 82nd Texas Legislature, in 2011, established the WSEP administered by the TSSWCB, with the purpose of increasing available surface and ground water supplies through the targeted control of brush species that are detrimental to water conservation (e.g., juniper, mesquite, saltcedar).

The TSSWCB collaborates with SWCDs, and other local, regional, state, and federal agencies to identify watersheds across the state where it is feasible to implement brush control in order to enhance public water supplies. The TSSWCB uses a competitive grant process to rank feasible projects and allocate WSEP funds, giving priority to projects that balance the most critical water conservation need of municipal WUGs with the highest projected water yield from brush control.

In watersheds where WSEP funds have been allocated, the TSSWCB works through SWCDs to deliver technical assistance to landowners in order to implement brush control activities for water supply enhancement. 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, brush density to be maintained after treatment, and supporting practices to be implemented including livestock grazing management, wildlife habitat management, and erosion control measures. Financial incentives are provided through the WSEP to landowners implementing brush control activities on eligible acres consistent with their resource management plan.

More information on the WSEP is available at http://www.tsswcb.texas.gov/brushcontrol/.

Section 1.1 Texas Conservation Partnership

The TSSWCB, established in 1939, works in partnership with the State's 216 local SWCDs to encourage the wise and productive use of the State's natural resources in a manner that promotes a clean, healthy environment and strong economic growth. The TSSWCB

- administers Texas' soil and water conservation law;
- delivers coordinated natural resource conservation programs to agricultural producers throughout the state;
- is responsible for planning, implementing, and managing programs for preventing and abating agricultural and silvicultural (forestry-related) nonpoint sources of water pollution;
- administers the WSEP to increase available surface and ground water supplies through the targeted control of water-depleting brush in areas in need of water conservation;
- works to ensure the State's network of 2,000 flood control dams is protecting lives, private property, and public infrastructure from flood damage;
- works to improve border security along the Rio Grande through control of invasive carrizo cane; and,
- facilitates the Texas Invasive Species Coordinating Committee.

The TSSWCB is governed by a seven-member State Board composed of two Governor-appointed Members and five Members elected from across Texas by the Directors of the State's 216 SWCDs. All seven Members of the State Board must be landowners actively engaged in farming or ranching.

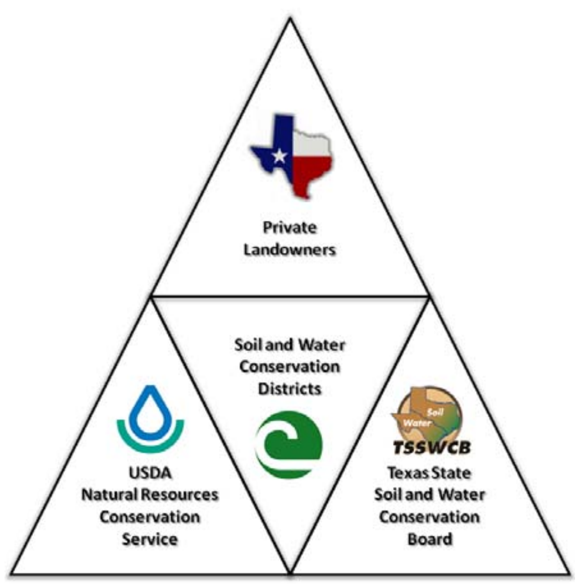

Figure 1.1.1 Texas Conservation Partnership – Providing Conservation Assistance to Agricultural Producers and Private Landowners

SWCDs are independent political subdivisions of State government, like a county or school district. The first SWCDs in Texas were organized in 1940 in response to the widespread agricultural and ecological devastation of the Dust Bowl of the 1930s. There are 216 SWCDs organized across the state, covering 100% of lands in the state. Each SWCD is governed by five Directors elected by landowners within the SWCD boundaries.

As illustrated in Figure 1.1.1, SWCDs serve as the State's primary delivery system through which technical assistance and financial incentives for natural resource conservation programs are channeled to agricultural producers and rural landowners. SWCDs work to combat soil and water erosion, protect water quality, and enhance public water supplies across the state by giving farmers and ranchers the opportunity to solve conservation challenges locally. SWCDs instill in landowners and citizens a stewardship ethic and individual responsibility for soil and water conservation.

Many of the TSSWCB's programs, including the WSEP, are coordinated through the conservation program delivery system of the 216 local SWCDs. SWCDs provide technical and planning assistance to help agricultural producers implement water conservation BMPs on their farms and ranches. Additionally, SWCDs assist federal agencies in establishing resource conservation priorities for federal Farm Bill and CWA programs based on locally-specific knowledge of natural resource concerns. SWCDs have organized themselves into a tax-exempt, non-profit organization, the Association of Texas Soil and Water Conservation Districts and into 13 Area Associations. The conservation program delivery system that SWCDs present for the State is one of the most efficient and effective mechanisms for conducting natural resource conservation programs targeted to agricultural producers and rural landowners (e.g., brush control for water supply enhancement).

Section 1.2 History of the WSEP

In 1985, the 69th Texas Legislature created the Texas Brush Control Program (SB1083) and designated the TSSWCB as the agency responsible for administering the Program. For the next 14 fiscal years (1986-1999), the BCP was unfunded, until 1999 when the 76th Texas Legislature appropriated funds to begin implementing the BCP. TSSWCB was appropriated varying amounts of funding for 12 fiscal years (2000-2011) to carry-out the BCP ($52.24M in total). The BCP's original purpose was to incentivize brush control on private lands for the purpose of enhancing water availability for all needs.

Notable actions by the Texas Legislature with respect to the BCP include, for the 2002-2003 biennium, the 77th Legislature required proceeds from Agricultural Water Conservation Bonds be transferred from the TWDB as a grant of $15M to the TSSWCB to be used for brush control projects and as a grant of $1M to the TDA to be used for the Pecos River Ecosystem Project for saltcedar control. Additionally, the 80th Legislature directed the TCEQ to submit a report to the LBB and the Governor by the end of FY2008 providing the following information on brush control activities being conducted by the TSSWCB: evaluation of the current monitoring programs at the treated sites; identification of proper monitoring approaches where upgrades are needed; and estimation of water enhancement in areas of the state that are characterized by saltcedar, juniper, and mesquite. Further, many of the BCP's project areas were specifically identified in Appropriation Riders over the six bienniums. For example, Riders directed over $16M to be used for a pilot brush control project in the North Concho River watershed.

Table 1.2.1 Biennial Appropriations for the BCP and the WSEP

Legislature	FYs	Program	Amount	Source
76	2000-2001	BCP	$ 9,163,189	General Revenue
77	2002-2003	BCP	$ 24,163,189	General Revenue & Agricultural Water Conservation Bond
78	2004-2005	BCP	$ 3,722,599	General Revenue
79	2006-2007	BCP	$ 3,690,185	General Revenue
80	2008-2009	BCP	$ 4,417,853	General Revenue
81	2010-2011	BCP	$ 9,087,282	General Revenue
82	2012-2013	WSEP	$ 4,270,826	General Revenue
83	2014-2015	WSEP	$ 4,270,826	General Revenue
84	2016-2017	WSEP	$ 5,276,826	General Revenue
			$ 68,062,775	

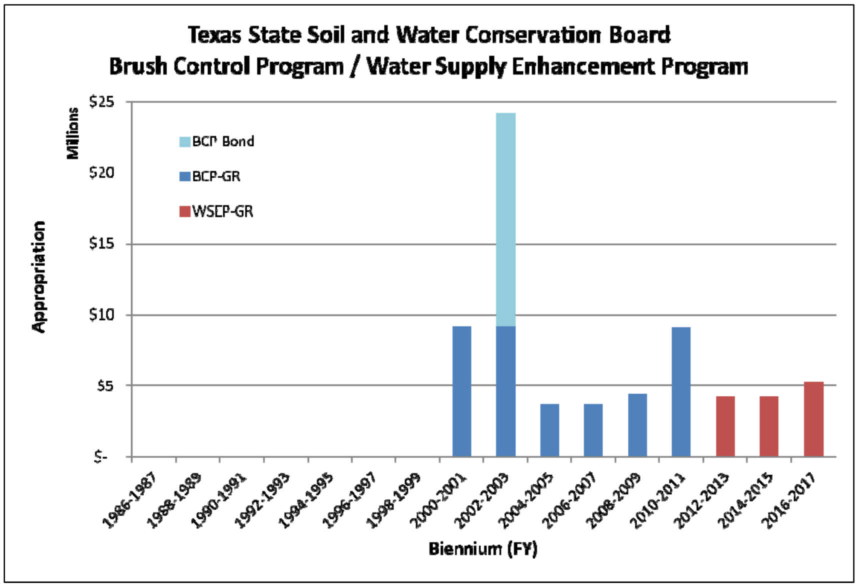

Figure 1.2.1 Appropriations by the Texas Legislature to the TSSWCB for the BCP and the WSEP

SUNSET REVIEW

The Texas Sunset Advisory Commission identifies and eliminates waste, duplication, and inefficiency in State government agencies. The 12-member Commission reviews the policies and programs of about 130 government agencies every 12 years. The Commission questions the need for each agency, looks for potential duplication of other public services or programs, and considers new and innovative changes to improve each agency's operations and activities. The Sunset Commission recommends actions on each agency under review to the full Texas Legislature.

The Sunset Advisory Commission conducted a review of the TSSWCB in 2009-2011. During this process, the Sunset Commission adopted recommendations to address several issues identified with TSSWCB programs. One issue concluded that the then current framework of the BCP was not effective for meeting the State's critical water conservation needs. As a result of the Sunset Commission's recommendations for improving the program, in 2011, the 82nd Texas Legislature enacted HB1808 which delineated significant changes to TSSWCB's programs, including the elimination of the BCP effective September 2011. HB1808 established a new program for the agency, the WSEP, with the purpose of increasing available surface and ground water supplies through the targeted control of brush species detrimental to water conservation. TSSWCB has been appropriated funds for six fiscal years (2012-2017) to implement this "new" WSEP ($13.82M in total).

SUNSET IMPLEMENTATION

HB1808 intensified the agency's focus on enhancing ground and surface water supplies by requiring the TSSWCB to establish goals for the WSEP which must describe the intended use of a PWS enhanced by the WSEP and the populations that the WSEP will target. The legislation also required the TSSWCB to develop a system to prioritize project proposals for each funding cycle, giving priority to projects that balance the most critical water conservation need of municipal WUGs with the highest projected water yield from brush control.

In order to provide recommendations to the agency and guide the decisions of the State Board in implementing the Legislative directives for the WSEP (i.e., provisions of HB1808, 82nd Texas Legislature), the TSSWCB established a Stakeholder Committee of program beneficiaries and a Science Advisory Committee of technical experts. Since early 2012, the TSSWCB has worked with these two Committees to discuss how best to implement changes to the WSEP. Both Committees have worked hard to ensure that the best available science is being used by the TSSWCB to direct State funds to those areas where the positive impacts of brush management to enhance public water supplies can best be realized.

The Stakeholder Committee has provided recommendations for WSEP goals, the proposal ranking process, and the ranking index. The Stakeholder Committee is currently comprised of:

- Robert Mace, TWDB
- Ken Rainwater, TTU
- Jule Richmond, ATSWCD
- Jason Skaggs, TSCRA
- vacant, TCEQ

The Science Advisory Committee has provided recommendations regarding requirements for feasibility studies and computer models, and the method for prioritizing acreage for brush control, and will evaluate proposed new feasibility studies. Due primarily to public comments received on the *State Water Supply Enhancement Plan* in summer 2014, membership of the Science Advisory Committee has expanded since it was initially established. The Science Advisory Committee is currently comprised of:

- Tom Arsuffi, TTU (alternate)
- Ryan Banta, USGS (alternate)
- vacant, TWDB
- Larry Hauck, TIAER
- Chad Norris, TPWD
- Kristy Oates, USDA-NRCS (alternate)
- George Ozuna, USGS
- Ken Rainwater, TTU
- Anne Rogers, TPWD (alternate)
- Ken Spaeth, USDA-NRCS
- David Villarreal, TDA
- Mike White, USDA-ARS
- vacant, AgriLife Extension

The TSSWCB adopted comprehensive rules (31 TAC Chapter 517, Subchapter B) in March 2012 (effective April 2012) addressing many aspects of the Sunset legislation, transitioning the rules from the "old" BCP to the "new" WSEP. Further amendments to the rules were adopted by the TSSWCB in July 2014 (effective September 2014) to continue implementing provisions of HB1808 and ensure consistency with programmatic policies and documents.

On May 15, 2014, the State Board approved a revised *Policy on Allocation of Grant Funds for the WSEP*. This policy was originally approved on March 6, 2013 and revised on July 18, 2013. This policy describes the WSEP's purpose and goals, the competitive grant process and proposal ranking criteria, factors that must be considered in a feasibility study, the geospatial analysis methodology for prioritizing acreage for brush control, and how the agency will allocate funding.

On May 15, 2014, the State Board approved a revised *Policy on Brush Control Feasibility Studies for the WSEP*. This policy was originally approved on July 18, 2013. This policy describes the requirements for computer modeling for water yield predictions in feasibility studies and the process to review applications for funding to conduct new feasibility studies.

On May 15, 2014, the State Board approved a *Policy on Funding Technical Assistance for Brush Control through SWCDs for the WSEP*. In order to maximize the effective and efficient use of WSEP grant funds, this policy describes the options SWCDs have for providing technical assistance to landowners and administering the cost-share incentive program. This policy provides a foundation for the TSSWCB in considering the administrative capacities of an entity that will manage a water supply enhancement project.

These three *Policies* were incorporated into the WSEP rules (31 TAC Chapter 517, Subchapter B) and this *State Water Supply Enhancement Plan*.

PUBLIC INVOLVMENT SINCE ADOPTION OF 2014 STATE PLAN

After an extensive and inclusive public comment process during summer 2014, including a required public hearing, the TSSWCB adopted the *State Water Supply Enhancement Plan*, with changes to the draft version made based on public comments received, on July 28, 2014. When the TSSWCB adopted the *State Plan*, agency staff was directed to continue working with those interested in improving the *State Plan*, particularly those who provided comments during the public comment period. Some of the issues were referred to the Stakeholder Committee and/or the Science Advisory Committee. A series of public outreach meetings was held during the first half of 2015 to discuss specific topics with the public and receive constructive input on refining the *State Plan*.

On January 8, 2015 and January 29, 2015, TSSWCB hosted two WSEP public outreach meetings in Temple; about 30 people attended each meeting. The first meeting focused on aspects of the WSEP related to conservation plans for landowners and soil erosion potential from brush control. The second meeting focused on aspects of the WSEP related to feasibility studies, computer modeling, geospatial analysis, and project prioritization criteria.

On May 12, 2015, TSSWCB hosted a WSEP field tour at a private ranch in Kerr County; over 20 people attended the tour. This public outreach event focused on aspects of the WSEP related to conservation plans for landowners and soil erosion potential from brush control.

On April 27, 2016, TSSWCB hosted a WSEP Science Advisory Committee meeting in Austin. Topics that were discussed at the meeting included: proposed edits to the *State Plan*; obtaining aquifer recharge and groundwater yield in brush control feasibility study models; status of several on-going studies related to huisache ET (Subsection 2.6.4), model development, and uncertainty analysis; and results from several recently completed studies related to the O.H. Ivie Reservoir lake basin (Hauck and Pandey 2015) and groundwater availability in Gonzales County (HDR 2015).

Since summer 2014, agency staff participated in a variety of meetings in order to communicate and exchange ideas regarding the *State Water Supply Enhancement Plan*. Agency staff made presentations on the WSEP to the Groundwater Management Area 7, the Hill Country Water Summit, the Laredo and Valley Environmental Summits, the TAGD, the Texas Agriculture Council, the Texas Homeland Security Council, the Texas Invasive Plant and Pest Council, the Texas Wildlife Association, the TGPC, the TGPC Public Outreach and Education Subcommittee, the UGRA Board of Directors, the USIBWC Lower Rio Grande Citizen's Forum, the WCAC, and the Wes-Tex GCD. Additionally, TSSWCB staff worked with many of the 16 RWPGs, and the TWDB, to ensure the Groups were aware of the changes to the WSEP as they developed their 2016 regional water plans and the *2017 State Water Plan*. Agency staff made presentations on the WSEP to Regions B, F, G, H, K, L, M, N, and O.

During FY2014, the TSSWCB's internal auditor completed an audit of the WSEP. The objective of the audit was to assess the WSEP in order to determine compliance with HB1808. The *Final Report* on the audit (Jansen and Gregorczyk 2014) concludes that the agency "has implemented the necessary administrative rules, policies, and operating procedures to comply with all provisions of HB1808 related to the WSEP" and that the agency "is doing an excellent job of implementing the directives of the Legislature as it makes changes to the overall operations of the WSEP." Further, the auditor made no recommendations for improvement to the WSEP.

In January 2015, the Sunset Advisory Commission published the *Compliance Report – Implementation of Sunset Legislation*. The *Report* highlights findings from the special purpose review conducted on TSSWCB programs, including the WSEP. The review was limited to the evaluation of the TSSWCB's implementation of HB1808. In the *Report*, the Sunset Commission concluded that all provisions of HB1808 related to the WSEP have been fully implemented.

On September 23, 2014, the Texas House of Representatives Committee on Agriculture and Livestock held a public hearing relating to the Committee's interim charges. Invited and public testimony was provided on brush management and the WSEP. The Committee's *Interim Report to the 84th Legislature* (January 2015) includes an in-depth discussion of the WSEP and implications of programmatic changes made by the TSSWCB in order to comply with HB1808. In the *Interim Report*, the Committee concluded that, because many changes to the WSEP were put in place only a few years ago, the WSEP should continue to operate as currently being implemented by the TSSWCB.

On June 20, 2016, the Texas State Senate Committee on Agriculture, Water, and Rural Affairs held a public hearing relating to the Committee's interim charge to study and make recommendations on improving the process of developing and executing the *State Water Plan*. Invited testimony was provided on voluntary land stewardship, water conservation, brush management, and the WSEP.

Section 1.3 Purpose of State Water Supply Enhancement Plan

Scarcity and competition for water have made sound water planning and management increasingly important. The demand for water in Texas is expected to increase by over 17%, to a demand of about 21.6M ac-ft in 2070; while existing water supplies are projected to decrease by nearly 11%, to about 13.6M ac-ft. With Texas' population expected to grow by 73% over the next 50 years, the availability of water supplies is essential for not only the Texans of today but also for those of tomorrow. (TWDB 2016)

In fall 2008, Texas citizens were surveyed about their perceptions and attitudes related to water resources. Nearly 45% of all respondents believed water supply issues were definitely not or probably not a problem where they live. A slightly larger number (almost 48%) responded that water supply was definitely or probably a concern. Respondents also were asked to evaluate the likelihood of their area having an adequate water supply to meet its needs in the next 10 years. Only 20% of respondents thought there was a high chance of their area having adequate water resources, while about 41% thought there was only a medium chance, and 30% thought there was a low chance that their area will have adequate water. (Boellstorff et al. 2010)

In another survey of Texans conducted in spring 2013, water issues ranked fifth among a list of ten major issues facing the country. While most respondents believed that short-term changes in annual rainfall are a major cause of water shortages, they also cited overuse and inadequate management of water resources, and increased demand as additional important factors affecting drought. Respondents also believed that over the next five years diminishing water resources will result in more conflicts over water use, higher water costs, greater wildfire danger, increased food prices, a loss of recreational opportunities, and damage to plant and animal species. (Stoutenborough and Vedlitz 2013)

The demand for water in Texas is expected to increase by over 17%, from about 18.4M ac-ft per year in 2020 to a demand of about 21.6M ac-ft in 2070. Existing water supplies are projected to decrease by nearly 11%, from about 15.2M ac-ft in 2020 to about 13.6M ac-ft in 2070. If no action is taken to implement the *State Water Plan*, approximately 82% of Texans would face at least a 10% water shortage in their cities and residences in 2070, and approximately one-third of Texas' municipal water users would have less than half of the water supplies that they require to live and work by 2070. (TWDB 2016)

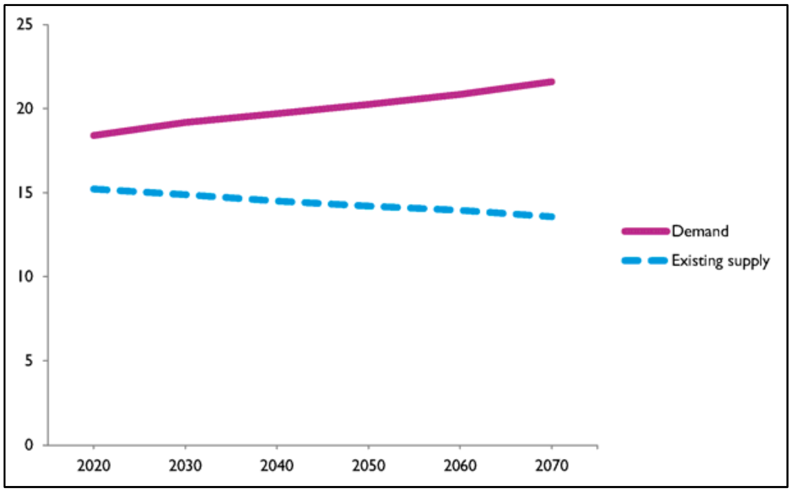

Figure 1.3.1 Projected Water Demand and Existing Supply (millions of ac-ft). (TWDB 2016)

Over at least the last century, rangeland vegetation in the United States has undergone a large-scale conversion from grasslands to woodlands and shrubland. Noxious brush, detrimental to water conservation, has invaded millions of acres of rangeland and riparian areas in Texas, reducing or eliminating stream flow and aquifer recharge through interception of rainfall and increased ET. The USDA-NRCS estimated that as much as 10M ac-ft of water could be made available annually through a comprehensive brush management program (Rechenthin and Smith 1967). More recently, brush control feasibility studies conducted for the TSSWCB (16 studies published by multiple entities between 1999 and 2016) have a total projected annual water yield of 2.41M ac-ft of water that could be conserved in 24 watersheds. Brush control has the potential to enhance water yield by conserving water lost to ET, recharge groundwater and aquifers, enhance spring and stream flows, improve soil health, restore native wildlife habitat by improving rangeland condition, improve livestock grazing distribution, protect water quality and reduce soil erosion, aid in wildfire suppression by reducing hazardous fuels, and manage invasive species. Economic benefits of the use of brush control to enhance water yield have been estimated by several feasibility studies conducted for the TSSWCB by various partnering entities. Brush control is an economically feasible option for water yield enhancement in a number of the watersheds studied. (UCRA 1999, CRMWA 2000, HDR 2000a, HDR 2000b, HDR 2000c, LCRA 2000, RRA 2000, UCRA 2000, LCRA 2002, RRA 2002, BRA 2003a, BRA 2003b, Bumgarner and Thompson 2012, McLendon et al. 2012, Hauck and Pandey 2015, and Harwell et al. 2016)

Water needs and potential water yields that may be captured and used for public benefit are the primary considerations for determining the location of publicly funded (i.e., cost-share incentives) brush control projects. Public benefit, in the form of additional water, depends on landowner participation and proper implementation and maintenance of the appropriate brush control practices. It is also important to understand that landowner participation in a brush control project will primarily depend on the landowner’s expected economic consequences resulting from participation. In order to achieve restoration of ecosystem functions (i.e., enhanced water yield from brush control), solutions must be socially accepted, economically bearable, and based on environmental goals (Adams 2006) (Figure 1.3.2).

Figure 1.3.2 Social, Economic, and Environmental Considerations to Achieve Ecosystem Restoration and Enhanced Water Yield [Adams 2006 (here modified by TSSWCB)]

Therefore, in order to help meet the State's critical water conservation needs and ensure availability of public water supplies, the WSEP, as administered by the TSSWCB will increase available surface and ground water supplies through the targeted control of brush species that are detrimental to water conservation.

In accordance with Agriculture Code §203.051, the TSSWCB must prepare and adopt this *State Water Supply Enhancement Plan*. The *State Plan* serves as the State's comprehensive strategy for managing brush in all areas of the state where brush is contributing to a substantial water conservation problem. The *State Plan* also serves as the programmatic guidance for the WSEP.

The statutorily-defined (Agriculture Code §§203.001-203.002) purpose of the WSEP is to increase available surface and ground water through:

- the selective control, removal, or reduction of noxious brush species, such as juniper, mesquite, saltcedar, or other phreatophytes, that consume water to a degree that is detrimental to water conservation; and,
- the revegetation of land on which this noxious brush has been controlled, removed, or reduced.

The *State Water Supply Enhancement Plan* must document the goals, processes, and results the TSSWCB has established for the WSEP under Agriculture Code §201.029, including:

- a goal describing the intended use of a PWS enhanced or conserved by the Program, such as agricultural purposes or drinking water purposes; and,
- a goal describing the populations that the WSEP will target.

As the programmatic guidance for the WSEP, the *State Water Supply Enhancement Plan* also discusses the competitive grant process, the proposal ranking criteria, factors that must be considered in a feasibility study, the geospatial analysis methodology for prioritizing acreage for brush control, how the agency will allocate funding, priority watersheds across the state for water supply enhancement and brush control, and how success for the WSEP will be assessed and how overall water yield will be projected.

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Chapter 2 Brush Management and Water Yield

Section 2.1 Encroachment of Brush Across the State

Within the past 160 years, rangeland vegetation in the United States has undergone a large-scale conversion from grasslands and savannas to woodlands and shrubland (Scholes and Archer 1997). This shift is termed brush encroachment because the brush species that have always existed within the landscape have increased in extent and/or density (Arrington et al. 2002). Numerous written descriptions by early European settlers, summarized by Smeins et al. (1997), characterize most of Texas rangelands as grassland or open savanna. Prior to European settlement, grazing pressure tended to be light and/or periodic, thus allowing a robust stand of grass to establish. Most tree seeds deposited in a healthy grassland die soon after they germinate because they are unable to compete with the established grass for water and light. The few tree seedlings that are able to survive the competition with grass tend to perish in wildfires which periodically occur in “natural” rangelands. Thus, with fire and light grazing pressure, grasslands and savannas are stable and sustainable ecosystems characteristic of many Texas rangelands.

European settlement of rangelands altered the grazing and fire characteristics which had previously enabled grasslands to dominate the landscape. Continuous, often heavy, livestock grazing pressure reduced the ability of grasses to suppress tree seedling establishment. Furthermore, some woody species (e.g., juniper and mesquite) have noxious chemicals in their leaves, resulting in livestock tending to avoid browsing the tree seedlings while repeatedly grazing the adjacent, palatable grasses. This selective grazing behavior gives unpalatable tree seedlings a competitive advantage over grasses. European settlers tended to aggressively suppress fire, a task made easier because continuous, heavy grazing pressure removed the fuel needed to carry a fire. Removal of fire and added heavy grazing pressure created an environment that favored increased dominance of shrubs and trees in what had previously been grasslands or savannas. This pattern of vegetation change coincides with European settlement of rangelands throughout the world (Archer 1994). Overgrazing, fire suppression, and droughts caused a gradual ecological change that promoted the spread of noxious brush (RRA 2002; Arrington et al. 2002; Van Auken 2000).

Large increases in woody cover can adversely affect ranching operations by increasing the costs of management and decreasing the livestock carrying capacity. Therefore, ranchers have a vested interest in controlling brush. For example, analysis of the 80 mi^2 Cusenbary Draw watershed near Sonora revealed that investments in brush control by ranchers were able to keep overall brush cover within the watershed between 22-24% between 1955 and 1990 (Redeker et al. 1998). Some of the pastures within the watershed did not have any brush control applied. Brush cover on those sites increased to 37% over the same period. This illustrates the increase in shrub cover over a 35-year period that is possible without a proactive policy of brush control.

Ranches throughout several regions of Texas are increasingly being subdivided into smaller parcels that are used mainly for recreation (Rowan and White 1994). A Texas survey found that the primary goals of landowners investing in brush management were to increase forage production and conserve water (Kreuter et al. 2005). Other reasons included improvement of aesthetic values, benefit the next generation, improve wildlife habitat, and improve real estate value.

The Texas Land Trends report (Lopez et al. 2014) is published every five years, following the availability of the USDA Census of Agriculture data (most recently, 2012), and serves to describe the status and recent changes in land use, ownership size, and land values of privately owned Texas farms, ranches, and forests, collectively known as working lands. Texas is comprised of 142M ac of private farms, ranches, and forests, leading the nation in land area devoted to privately-owned working lands. These working lands account for 83% of the state's entire land area. By the end of 2012, the USDA Census of Agriculture accounted for nearly 249,000 farming and ranching operations in the state, representing a 9% increase since the 1997 Census. Texas gained about 1,400 new working farms and ranches annually while the land base for Texas agriculture decreased by approximately 1.1M ac (1997-2012). Average ownership size decreased from 581 ac in 1997 to 521 ac in 2012. Statewide trends in ownership fragmentation were observed from the data (1997-2012), with a net increase of >500,000 ac for ownerships comprised of <100 ac tracts, and nearly 26,000 individual operations – an increase of more than 20% since 1997. The total number of individual small ownerships (all tracts <500 ac in size) in 2012 included nearly 210,000 individual operations or approximately 17% of the ac devoted to working lands. More than 54% of total land conversion occurred in the state's 25 fastest growing counties. (Lopez et al. 2014)

According to survey data from the Edwards Plateau, landowners are less inclined to invest in brush control if they are not reliant on livestock income (Garriga 1998). As the demographics of rangeland owners shift away from an emphasis on livestock production, and as long as fire continues to be suppressed, it is likely that woody cover will continue to increase unless financial incentives are provided to encourage brush management.

Subsection 2.1.1 NRI Rangeland Resource Assessment (Juniper and Mesquite)

The National Resources Inventory is a statistical sample survey, using scientific principles and procedures, designed to help gauge natural resource status, conditions, and trends on the nation's non-federal land. Non-federal land includes privately owned lands, tribal and trust lands, and lands controlled by State and local governments. The NRI is conducted by the USDA-NRCS in cooperation with Iowa State University's Center for Survey Statistics and Methodology. Information about the condition of the land and related natural resources is needed at many different scales to inform decision makers.

The USDA-NRCS gathers rangeland on-site data as part of the NRI. The NRI Rangeland Resource Assessment (NRCS 2014a; Herrick et al. 2010) focuses on information derived from data collected in the field on rangeland during the period 2004 to 2011. The findings reported focus on key issues in rangeland science, including rangeland health, native invasive woody plant species, bare ground, inter-canopy gaps, and soil surface aggregate stability.

Rangeland is defined by the NRI as a land cover/use category on which the climax or potential plant cover is composed principally of native grasses, grass-like plants, forbs, or shrubs suitable for grazing and browsing, and introduced forage species that are managed like rangeland. Grasslands and savannas, among other categories, are considered to be rangeland. Certain communities of low shrubs, such as mesquite or chaparral, are also included as rangeland. NRI rangeland data has been collected in 17 western states, including Texas.

RANGELAND HEALTH

Rangeland health provides information on types, patterns, and severity of problems in rangeland ecosystems relative to an agreed upon standard ("reference") for each site. Land managers and policy-makers need this information to support strategic decisions and to identify the ecosystem processes that must be restored to improve services that the land provides and to maintain or improve profitability.

The status of three broad attributes of rangeland health (soil and site stability, hydrologic function, and biotic integrity) is reported based on an assessment of 17 indicators at each survey point. These three attributes collectively reflect the status of key ecological processes which are related to the land's potential to support ecosystem services.

The rangeland health assessment provides information about how ecological processes are functioning relative to ecological potential. Because ecological potential varies both locally and regionally, NRI assessments of rangeland health use unique reference information for ecological sites. Ecological sites are climate and soil groupings that differ in their ability to produce specific kinds, amounts, and proportions of plants, and in their response to management.

The NRI findings summarize rangeland health at a regional scale where the three attributes represent various levels (e.g., moderate, moderate-to-extreme, or extreme-to-total) of departure from the reference state as described in the ecological site description for that land area. The range of reference conditions is based on the natural variation of plant communities within the reference state which includes but is not limited to the historic climax plant community. Only two attributes are discussed below.

Hydrologic function characterizes the capacity of an area to capture, store, and safely release water from rainfall and snowmelt (where relevant), to resist a reduction in this capacity, and to recover this capacity when a reduction does occur.

Biotic integrity is defined as the capacity of the biotic community to support ecological processes within the normal range of variability expected for the site, to resist a loss in the capacity to support these processes, and to recover this capacity when losses do occur. The biotic community includes plants, animals, and microorganisms occurring both above and below the ground.

REGIONAL INTERPRETATION – TEXAS AND OKLAHOMA

Regional interpretations provide basic trend information that is relative to that specific region (Figure 2.1.1). The regions are based on level IV ecoregion boundaries defined by the USEPA. Five regions are represented, including “Texas and Oklahoma”.

The regional interpretations focus on rangeland health determinations for the following attributes: biotic integrity, soils and site stability, and hydrologic function. Ecological sites where the rangeland health attributes show moderate departure from reference conditions are more likely to have the potential to be brought back to an improved status through good management practices than those with ratings of moderate-to-extreme or extreme-to-total departure. Lands with significant departure may have crossed ecological thresholds; therefore, they may not be sufficiently resilient to recover naturally from degradation. The spatial patterns provide general information on the extent to which different types of ecosystem services from rangeland have been modified.

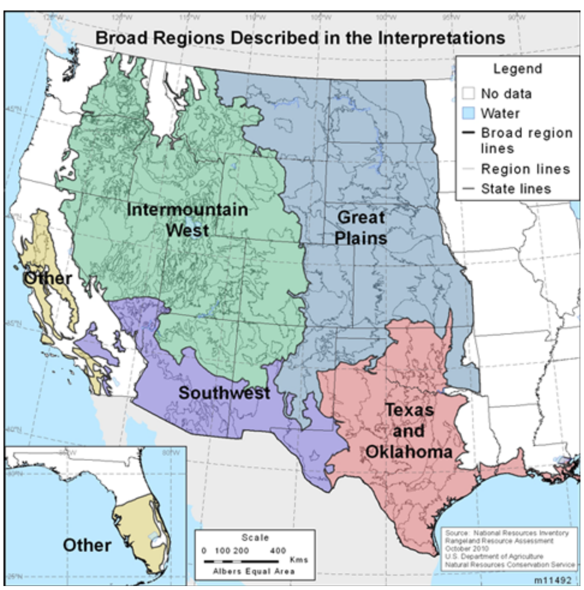

Figure 2.1.1 Broad Regions Described in the NRI Interpretations (NRCS 2014a)

Rangelands delineated in the “Texas and Oklahoma” region are extremely diverse and include Gulf prairies and marshes, post oak savannahs, Blackland prairies, tall- and mixed-grass prairie, cross timbers and prairies, south Texas plains, and eastern fringe of the Edwards Plateau and Rolling Plains. This region exemplifies high diversity of rangeland plant community types: tallgrass and shortgrass prairies, thorn-shrub, and savannah. Shrub invasion of juniper

(*Juniperus* spp.) and honey mesquite (*Prosopis glandulosa*) is a common problem and is exacerbated by a combination of events such as recurring drought, subsequent overgrazing, and lack of prescribed fire (Weltz and Spaeth 2012; Weltz et al. 2014). The potential for high runoff and erosion expands as juniper overstory increases and understory vegetation decreases (Pierson et al. 2007; Pierson et al. 2010; Weltz and Spaeth 2012; Weltz et al. 2014).

REGIONAL INTERPRETATION – HYDROLOGIC FUNCTION

Hydrologic function generally shows patterns of departure from reference conditions greater than that of soil and site stability, with even higher proportions of land showing at least moderate departure in many parts of the region (Figure 2.1.2). This is due to the sensitivity of hydrologic function to both soil degradation, and changes in plant community composition associated with invasive native woody plants. Juniper (Figures 2.1.4, 2.1.5, 2.1.6) and mesquite (Figures 2.1.7, 2.1.8, 2.1.9) are particularly widespread in this region. While native, they increase in heavily-grazed conditions and with the absence of fire. Where increased woody cover is associated with reduced grass cover, infiltration capacity can decline with increased runoff in interspace areas between shrubs (Pierson et al. 2007; Pierson et al. 2010; Weltz et al. 2014). Accelerated runoff over time can result in changes of natural water flow paths and the formation of interspace rills, which may develop into gullies (Weltz and Spaeth 2012; Weltz et al. 2014). If soil loss over time is excessive, recovery to reference conditions may be unattainable (Weltz and Spaeth 2012). In contrast, sites with dense native grass cover and thick and deeper root mass have higher infiltration capacity, where water can percolate into the subsoil, more stable soil aggregates, and overall better soil health (Weltz and Spaeth 2012; Weltz et al. 2014).

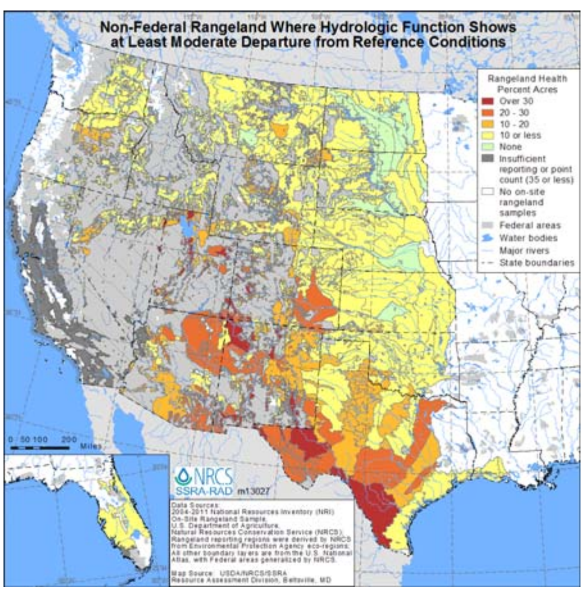

Figure 2.1.2 Non-Federal Rangeland Where Hydrologic Function Shows at Least Moderate Departure from Reference Conditions (NRCS 2014a)

REGIONAL INTERPRETATION – BIOTIC INTEGRITY

Shifts in biotic integrity throughout Texas and Oklahoma are significant and generally have even greater departure from reference conditions than soil and site stability and hydrologic function. Moderate and greater departure from reference conditions for biotic integrity (Figure 2.1.3) in this region are associated with shifts in plant community composition associated with increased dominance of invasive species, both grasses and shrubs. The dominant invasive shrubs in this region are juniper (Figures 2.1.5, 2.1.6) and mesquite (Figures 2.1.8, 2.1.9) which are native plants throughout this region, but are expanding to areas where they were not part of the reference conditions (Figures 2.1.4, 2.1.7). Where juniper is invasive, mainly due to lack of fire and improper grazing management, a loss of understory vegetation is common. Typically when juniper canopy cover reaches about 30% (depending on slope, soil profile characteristics, and other factors), soil stability, hydrologic, and biotic thresholds are often reached (Weltz and Spaeth 2012; Weltz et al. 2014). Juniper canopy closure rapidly increases from that point forward. As juniper canopy increases and closes in, understory grasses and forbs become depauperate, and bare soil increases between mature junipers (Pierson et al. 2007; Pierson et al. 2010; Weltz and Spaeth 2012; Weltz et al. 2014). The three rangeland health attributes are closely related and when shrub invasion is severe, they degrade in concert. For example, on degraded and disturbed rangelands, an increase in runoff and soil loss is typical because of the increased connectedness of bare soil patches that allow the formation of concentrated flow paths, which, in turn, initiates accelerated soil loss, rills, and gullies.

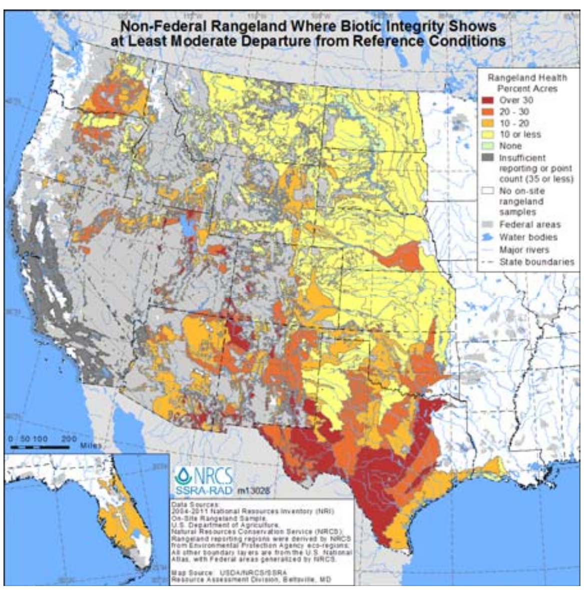

Figure 2.1.3 Non-Federal Rangeland Where Biotic Integrity Shows at Least Moderate Departure from Reference Conditions (NRCS 2014a)

NATIVE INVASIVE WOODY SPECIES

Once established, certain native woody plant species may become invasive and have the potential to outcompete native grasses and forbs in communities where they typically would be only minor components or absent from the plant community. Loss of native herbaceous species negatively impacts forage and watershed functions and can lead to land degradation and erosion. Land managers and policy makers need this information to support strategic decisions and to identify areas of risk and implement strategies to eradicate and control the spread of native invasive species.

The NRI findings provide information about native invasive woody plant species growing on non-federal rangeland. Some native woody shrubs such as juniper and mesquite can invade areas replacing native grasses and forbs. Dense stands can alter nutrient and energy cycles, affect hydrology, and reduce wildlife habitat and forage for domestic animals and wildlife. Deep root systems of woody species such as mesquite can reduce water availability to other native plants and eventually animals.

Native invasive woody species groups include Southern Juniper Species and Mesquite Species, among other groups. The Southern Juniper Species summary group includes Ashe juniper (*Juniperus ashei*) and redberry juniper (*J. pinchotii* and/or *J. coahuilensis*). The Mesquite Species summary group includes honey mesquite (*Prosopis glandulosa*).

KEY FINDINGS – SOUTHERN JUNIPER SPECIES

In Texas, Southern juniper species are present but excluded from reference conditions on 3.9% of non-federal rangeland (Figure 2.1.4). In Texas, Southern juniper species cover at least 30% of the soil surface on 3.7% of non-federal rangeland (Figure 2.1.5). In Texas, Southern juniper species make up at least 50% of the relative plant canopy cover (composition) on 1.4% of non-federal rangeland (Figure 2.1.6).

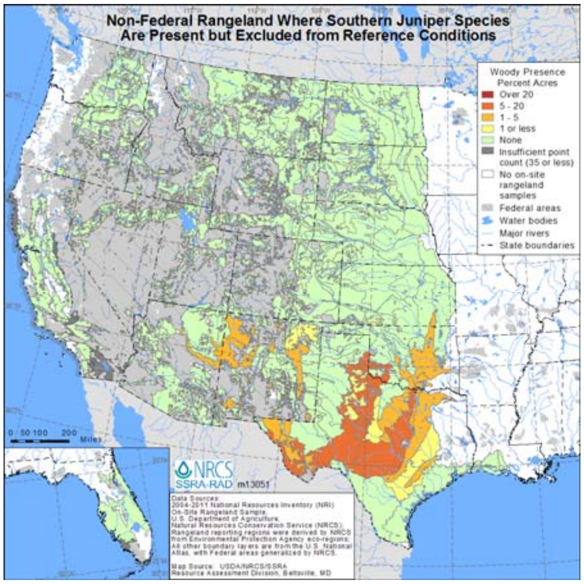

Figure 2.1.4 Non-Federal Rangeland Where Southern Juniper Species Are Present but Excluded from Reference Conditions (NRCS 2014a)

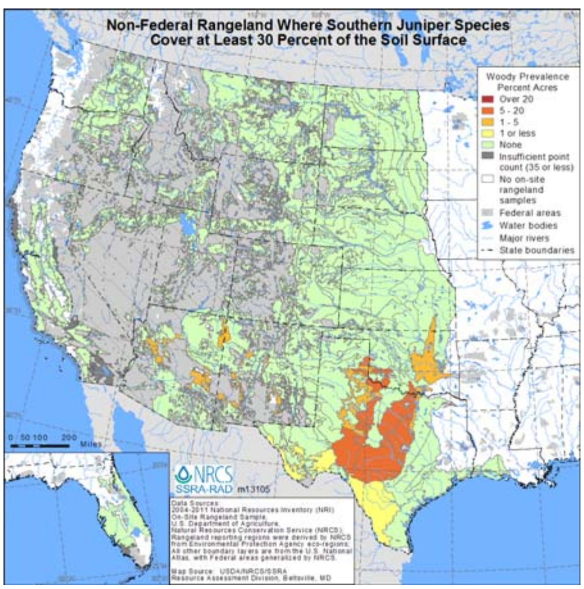

Figure 2.1.5 Non-Federal Rangeland Where Southern Juniper Species Cover at Least 30% of the Soil Surface (NRCS 2014a)

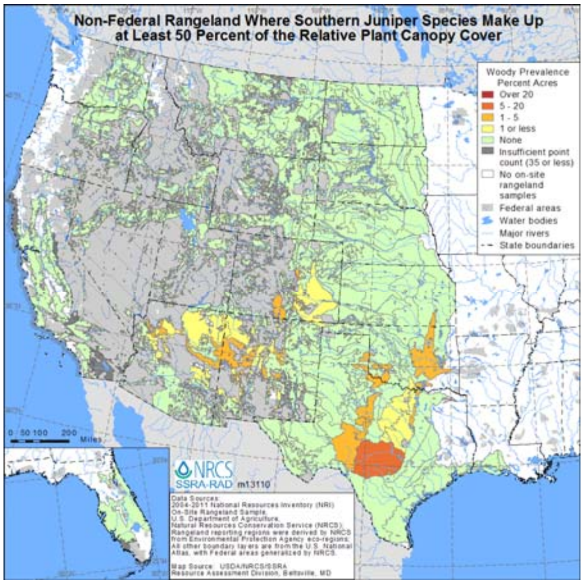

Figure 2.1.6 Non-Federal Rangeland Where Southern Juniper Species Make Up at Least 50% of the Relative Plant Canopy Cover (Composition) (NRCS 2014a)

KEY FINDINGS – MESQUITE SPECIES

In Texas, mesquite species are present but excluded from reference conditions on 17.2% of non-federal rangeland (Figure 2.1.7). In Texas, mesquite species cover at least 30% of the soil surface on 7.5% of non-federal rangeland (Figure 2.1.8). In Texas, mesquite species make up at least 50% of the relative plant canopy cover (composition) on 1.8% of non-federal rangeland (Figure 2.1.9).

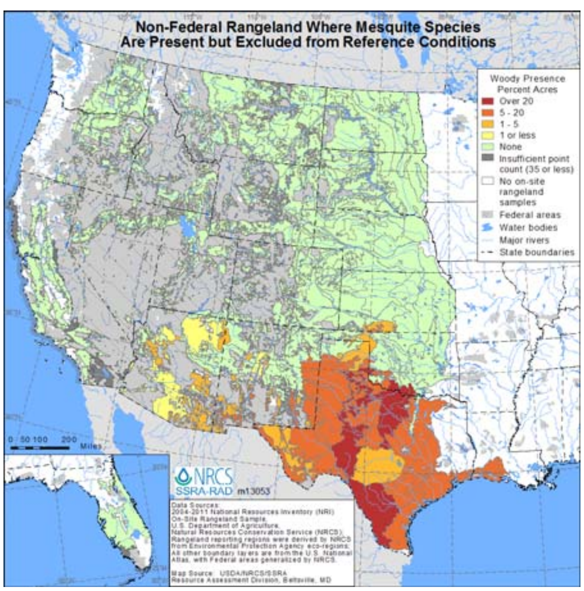

Figure 2.1.7 Non-Federal Rangeland Where Mesquite Species Are Present but Excluded from Reference Conditions (NRCS 2014a)

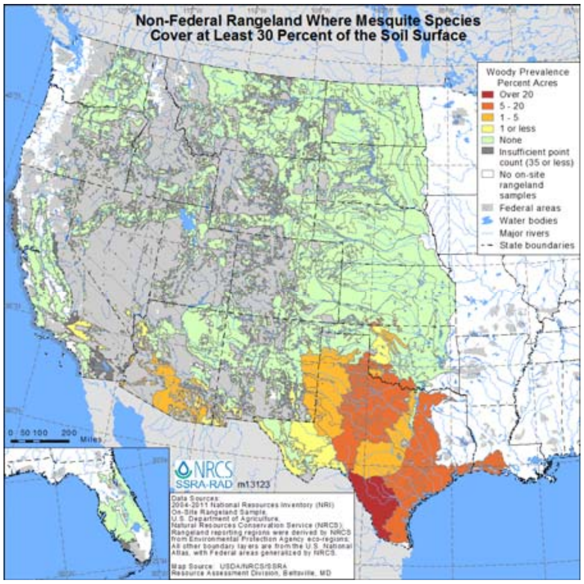

Figure 2.1.8 Non-Federal Rangeland Where Mesquite Species Cover at Least 30% of the Soil Surface (NRCS 2014a)

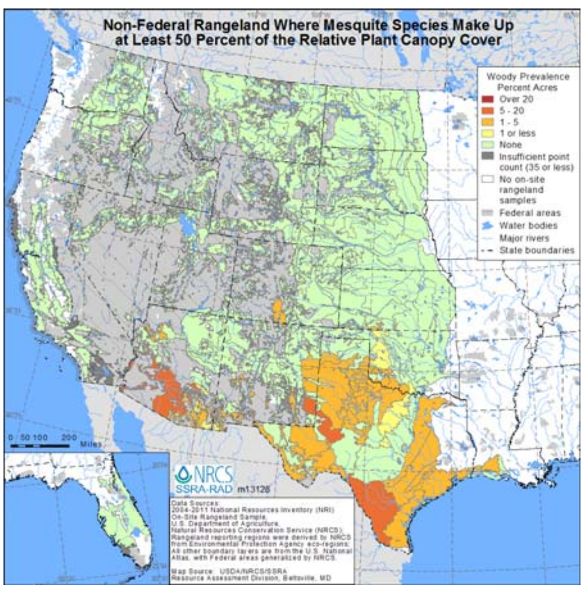

Figure 2.1.9 Non-Federal Rangeland Where Mesquite Species Make Up at Least 50% of the Relative Plant Canopy Cover (Composition) (NRCS 2014a)

NATIVE INVASIVE WOODY SPECIES – SIGNIFICANCE OF FINDINGS

“Stewardship of vegetation composition, cover, and production is the foundation of sustainable rangeland management. A key component of rangeland ecosystem management is maintaining vegetation ground cover and productivity within a desirable mix of herbaceous and woody plants.” (Archer et al. 2011)

“One of the most striking land cover changes on rangeland worldwide over the past 150 years has been the proliferation of trees and shrubs at the expense of perennial grasses. In some cases, native woody plants are increasing in stature and density within their historic geographic ranges; and in other cases non-native woody plants are becoming dominant. These shifts in the balance between woody and herbaceous vegetation represent a fundamental alteration of habitat for animals (microbes, invertebrates, and vertebrates) and hence a marked alteration of ecosystem trophic structure.” (Archer et al. 2011)

“In arid and semi-arid regions, increases in the abundance of xerophytic shrubs at the expense of mesophytic grasses represents a type of desertification often accompanied by accelerated rates of wind and water erosion. In semi-arid and subhumid areas, encroachment of shrubs and trees into grasslands and savannas may substantially promote primary production, nutrient cycling, and accumulation of soil organic matter but potentially reduce stream flow, ground water recharge, livestock production, and biological diversity.” (Archer et al. 2011)

Subsection 2.1.2 Saltcedar

Saltcedar poses a somewhat different problem. According to Shafroth (2006), "in the latter part of the 19th Century, species of the non-native shrub saltcedar (*Tamarix* spp.) were introduced to the United States for use as ornamental plants and for erosion control. By 1877, some naturalized populations had become established, and by the 1960s, tamarisk was present along most rivers in the semi-arid and arid parts of the West and was quite abundant along downstream reaches of the major southwestern rivers such as the Rio Grande and Pecos (Figure 2.1.6). The principal period of tamarisk invasion coincided with changing physical conditions along western rivers. In many cases, these altered physical conditions appear to have been more favorable for tamarisk than native riparian competitors like cottonwoods and willows." Once established, saltcedar dominates all vegetation along rivers, lakes, and streams and consumes vast quantities of water. According to Sheng et al. (2007), "the distribution of saltcedar in North America includes waterways and reservoirs throughout the greater southwestern United States and portions of Mexico. Saltcedar reproductive attributes and greater tolerance to stressors such as water table fluctuation and salinity facilitated the conversion from more diverse native plant communities to saltcedar-dominated communities."

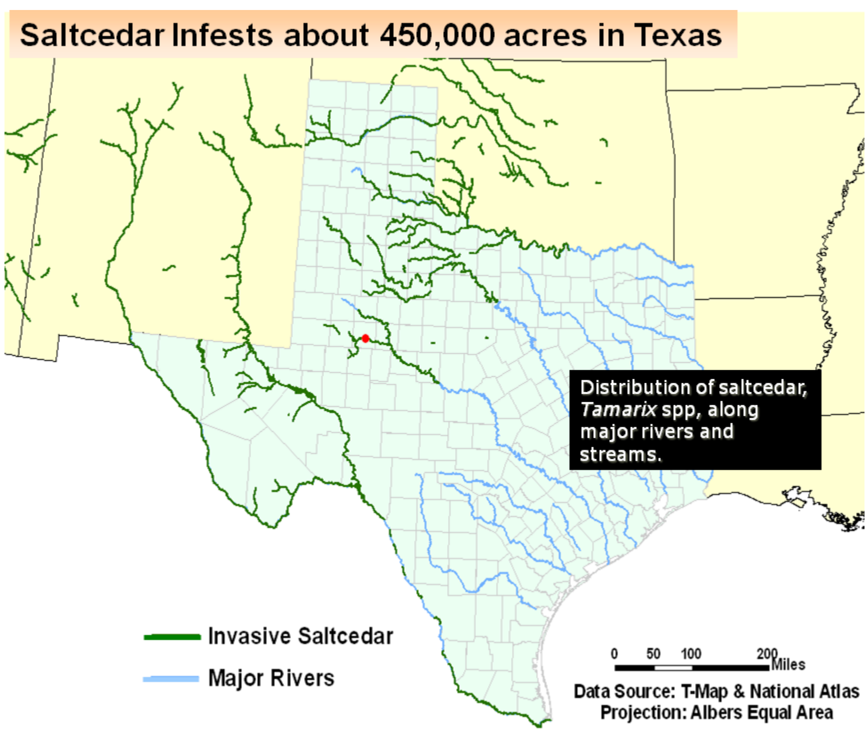

Figure 2.1.10 Saltcedar Infestation in Texas (Knutson 2013)

Section 2.2 Increasing Water Yields with Rangeland Management

Water yield following brush control has been investigated in several areas of the state. Studies by Thurow and Hester (1997), Carlson et al. (1990), and Weltz and Blackburn (1995) show that at sites with precipitation ranging from about 12 to 35 in per year, the majority of precipitation is used for ET. Following brush removal (original cover: 36% juniper, 24% oak), 16% of the precipitation went to deep drainage compared to none for the untreated watershed, an amount equal to 100,500 gal/ac/yr (Thurow and Hester 1997).

A major difference between controlling juniper compared to mesquite is that control of juniper results in a much greater reduction in ET. This difference is due to greater interception of rainfall by juniper and its evergreen nature, and because juniper is normally associated with shallow sites, which facilitates deep percolation of water not lost to ET.

Literature summarizing water yield studies in the western United States and data from the Edwards Plateau in Texas indicate that a significant increase in water yield is possible if brush cover is converted to grassland or open savanna and if the area receives about 18 in/yr or more of rainfall (Thurow 1998).

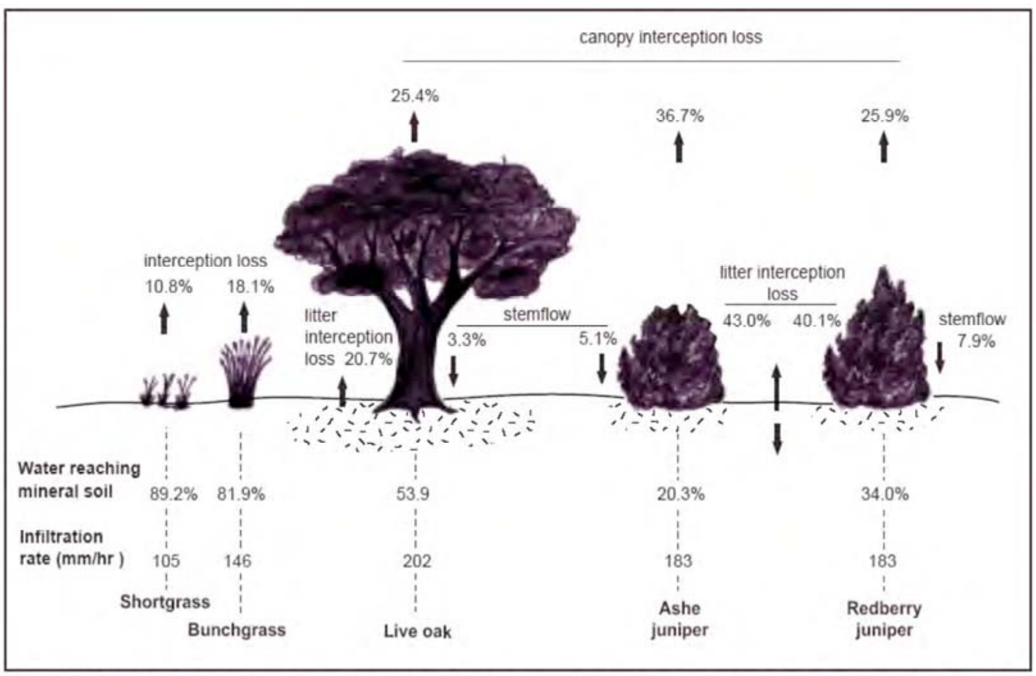

Figure 2.2.1 Influence of canopy cover on amount of precipitation reaching soil (Thurow and Hester 1997)

Though water supply enhancement following brush control has been investigated in several areas of Texas, the economic benefits and overall productivity of a brush control project may vary significantly depending on geology, physical characteristics of the water source that may be affected by the brush management efforts, quantity of brush, brush species, and potential impacts on threatened or endangered species.

ROCKY CREEK

Moseley (1983) (also, TSSWCB 1987; UCRA 2000) tells the story of West Rocky Creek, a West Texas creek dry for decades that started flowing again, near San Angelo, thanks to ranchers and their conservation work in a 74,000 ac watershed.

> "In the early 1960s landowners on five ranches, covering about half the watershed, began rootplowing, reseeding, treedozing, aerial spraying, and chaining. The ranchers received technical assistance and cost-share for this work through the Great Plains Conservation Program. The program was administered through local SWCDs in selected Great Plains counties by USDA-NRCS.
>
> West Rocky Creek flowed yearlong until the drought of 1918-1919, when it became an intermittent stream. By 1935, springs feeding the creek had been dried up by mesquite and other invading woody plants. Located in the Edwards Plateau region, West Rocky Creek is a tributary of the Middle Concho River about 20 miles west of San Angelo.
>
> In 1964, following the accelerated range conservation program, one of the five ranchers noticed that a spring – dry since 1935 – had started flowing again. By replacing the water-hungry brush with a good grass cover, more rainfall soaked into the aquifer, recharging the dormant springs. By 1970, springs had begun flowing on all five ranches. All the conservation work was done in a manner that would benefit white-tailed deer and turkey.
>
> The role of sound grazing management cannot be overlooked. The grazing management on each ranch enhanced the cover of grasses on the watershed. This grass cover retarded the reinvasion of brush and helped hold water and soil on the land. The turf decreased the sediment load in surface water supplies. Although the brush succession was retarded, these ranchers periodically did maintenance brush work just to keep things in the desired balance.
>
> Even though the rangeland improvements reduced erosion in the watershed and increased forage production for the ranchers' livestock, the story of West Rocky Creek may be more important to the residents of San Angelo. Water from the creek supplements the city's water supply reservoirs. The West Rocky Creek watershed yielded an estimated 525.6M gal annually. If the West Rocky Creek brush treatment were expanded to the entire watershed above San Angelo, one could predict a long lasting supply of clear water, increased livestock and wildlife production, and decreased sedimentation of downstream water supplies."

Field studies in Texas have attempted to measure water yield enhancement by brush control at a catchment scale. Discussion of three watersheds follows.

CUSENBARY DRAW

Research on the AgriLife Research field station at Sonora shows that there is a very significant water yield potential associated with converting brush to grassland on a site with these characteristics: over 18 in/yr of rain; shallow soils with high infiltration rates overlying fractured limestone (i.e., karst); and dense juniper-oak woodland cleared and replaced with shortgrass and midgrass species. These data were collected over a 10-year period from seven 10 ac catchments and supplemented with data on water movement through the soil using lysimeters (Redeker et al. 1998).

Similar estimates of vegetation effects on water yield were made for the Cusenbary Draw watershed, which includes part of the AgriLife Research field station at Sonora. The Cusenbary Draw watershed estimates were derived independently of the field data estimates and were obtained using the SPUR-91 model (Redeker et al. 1998). The SPUR-91 model has been validated to be an effective tool for estimating water yield and livestock carrying capacity on rangeland sites throughout Texas (Carlson et al. 1995, Carlson and Thurow 1996). The amount of woody cover in 1955 and 1990 and the rate of change between these dates were calculated using image analysis technologies of aerial photography on each of the five rangeland sites delineated within the watershed (Redeker 1998). Literature and expert opinion were used to validate and refine the estimates of woody (juniper, oak, mesquite) and herbaceous (bunchgrass, shortgrass, forbs) cover. Based on ET regression curves and GIS analysis, no brush management would result in a 35% decrease in water yield, while a hypothetical brush management program would increase water yield by 43% over the 1990 level (Wu et al. 2001).

Both the field study and modeling investigations conclude that water yield increases exponentially as brush cover declines in the treated area (i.e., very little change in water yield from dense brush canopy cover to about 15% brush canopy cover and a rapid rise in water yield from 15% to 0% brush canopy cover). These findings imply that it is necessary to remove most of the brush in the treatment area to maximize water yield potential (Figure 2.2.2) (Thurow et al. 1997). This conclusion is corroborated by numerous anecdotal observations by ranchers and agency personnel with brush control experience in the region (Kelton 1975, Willard et al. 1993). The exponential pattern of water yield increase relative to a decrease in brush cover has also been postulated for the Colorado River basin (Hibbert 1983). Wu et al. (2001) indicated that for the Cusenbary Draw watershed there was an apparent threshold woody cover (approximately 20%) above which simulated ET changed little with increasing woody cover. The exponential relationship is believed to occur because the intraspecific competition among trees (Ansley et al. 1998) and interspecific competition with herbaceous vegetation results in little increase in water yield until the tree density becomes sparse. In other words, trees have a capability for luxuriant water use. If a stand is thinned, the remaining trees will in a short time expand their root systems to use the extra water. Only when the thinning reduces tree cover to less than about 15% in a specific area is there a potential for significant yields of water. It should be noted that the brush canopy reflects the average density over the treated area, not necessarily the total number of plants in a watershed.

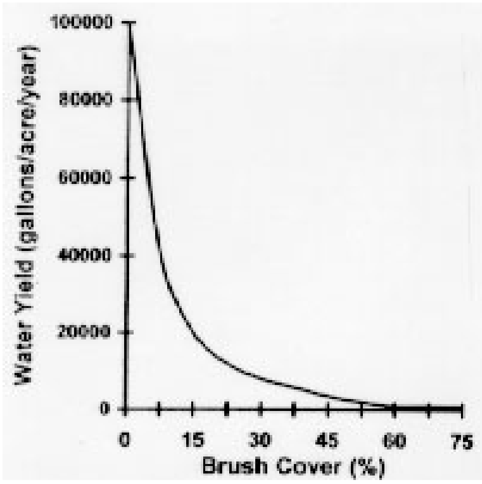

Figure 2.2.2 Inverse and exponential relationship between estimated water yield and percent brush cover (Thurow et al. 1997)

NORTH CONCHO RIVER

Beginning in 1999, the Texas Legislature directed the TSSWCB to begin implementing the BCP in the North Concho River watershed. This pilot brush control project was appropriated funds in FY2000-2003. There are numerous previously published materials from the TSSWCB and collaborating partners pertaining to the pilot North Concho project. All of these documents have been historically available to the public. A compilation of these previously published materials is available at http://www.tsswcb.texas.gov/brushcontrol/northconcho. Many of the changes implemented in the Program due to HB1808 stem from lessons learned during the implementation of the North Concho River pilot brush control project.

The results of a TSSWCB-funded multi-year study (Saleh et al. 2009) on the net water consumptive effects of upland mesquite control on ET found that significant water savings can be realized from control of upland mesquite. The study was conducted using a paired site approach in the North Concho River watershed at which ET measurements were collected using the eddy covariance technique and comparatively analyzed. The two adjacent mesquite-dominated experimental sites each consisted of about 200 ac. The field data indicated that the measured ET at the mesquite-treated site was lower than that of the untreated site during the mesquite growing season. For instance, the largest difference in measured ET (about 25%) between the treated and untreated sites was recorded during the peak mesquite growing season in 2008. Based on 952 daily ET measurements, the experimental data indicated that during the four-year study, the mesquite-dominated untreated site had a net consumption of over 1.8 in more water than the treated site. The findings indicate that during the four year period 2005-2008, the treated site consumed approximately 0.7 in/yr less water than did the control site. These results, when extrapolated to the entire North Concho River watershed, very closely align with values predicted in the North Concho River watershed feasibility study (UCRA 1999), which indicated water savings of about 26,400 gal/ac/yr for treating heavy mesquite in an area that receives about 20 in of average annual rainfall.

HONEY CREEK

The USGS, in cooperation with USDA-NRCS, TSSWCB, SARA, EAA, TPWD, GBRA, and the San Antonio Water System, evaluated the hydrologic effects of ashe juniper removal as a brush management conservation practice in and adjacent to the Honey Creek State Natural Area in Comal County. By removing the ashe juniper and allowing native grasses to reestablish in the area, the hydrology in the watershed might change. Using a simplified mass balance approach of the hydrologic cycle, the incoming rainfall was distributed to surface water runoff, ET, or groundwater recharge. After hydrologic data were collected in adjacent watersheds for three years, brush management occurred on the treatment watershed while the reference watershed was left in its original condition. Hydrologic data were collected for another six years. Groundwater recharge was not directly measured but potential groundwater recharge was calculated using a simplified mass balance approach.

The resulting hydrologic datasets were examined for differences between the watersheds and between pre- and post-treatment periods to assess the effects of brush management. The daily ET rates at the reference watershed and treatment watershed sites exhibited a seasonal cycle during the pre- and post-treatment periods, with intra- and interannual variability. Statistical analyses indicate the mean difference in daily ET rates between the two watershed sites is greater during the post-treatment than the pre-treatment period. During the post-treatment period, the percent average annual unit runoff in the reference watershed was similar to that in the treatment watershed; however, the difference in percentages of average annual ET and potential groundwater recharge were more appreciable between the reference and treatment watersheds than during the pre-treatment period. (Banta and Slattery 2011)

Suspended-sediment loads were calculated from samples collected at the reference watershed and treatment watershed. The relation between suspended-sediment loads and streamflow calculated from samples collected did not exhibit a statistically significant difference during the pre-treatment period, whereas during the post-treatment period, relation between suspended-sediment loads and streamflow did exhibit a statistically significant difference. The relations indicate that for the same streamflow, the suspended-sediment loads calculated from the treatment watershed were generally less than suspended-sediment loads calculated from the reference watershed during the post-treatment period (Figure 2.2.3). (Banta and Slattery 2011)

This reduction in sediment load may be a result of the replacement grasses acting as an obstruction to overland flow, causing overland flow to move in a slower, more tortuous path, thereby resulting in deposition of some of the suspended sediment before the overland flow reaches the stream channel (Thurow et al. 1986).

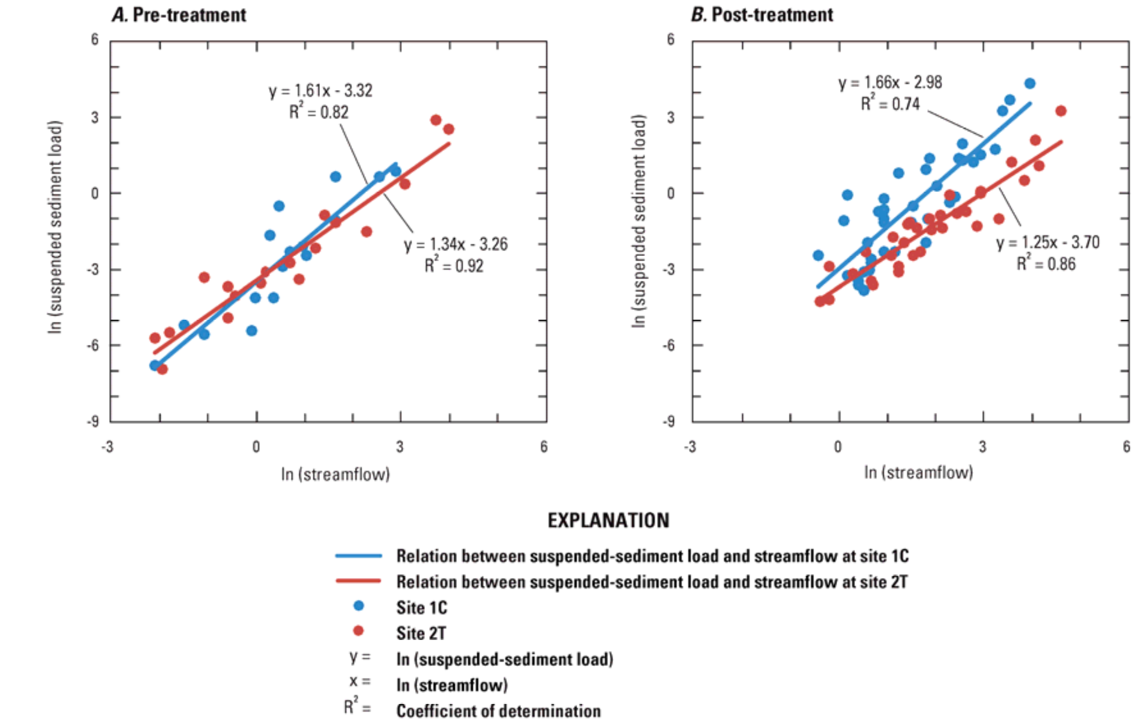

Figure 14. Suspended-sediment loads compared to streamflow during *A*, pre- and *B*, post-treatment periods at the reference watershed streamflow-gaging station site 1C (U.S. Geological Survey station 08167347 Unnamed tributary of Honey Creek site 1C near Spring Branch, Texas) and the treatment watershed streamflow-gaging station site 2T (U.S. Geological Survey station 08167353 Unnamed tributary of Honey Creek site 2T near Spring Branch, Tex.). Both datasets have been transformed through natural logarithm (ln), and the axes are ln scale.

Figure 2.2.3 Suspended Sediment Loads from USGS Honey Creek Study (Banta and Slattery 2011)

CONCLUSIONS

In summarizing scientific findings about the effects of brush control on rangelands, with emphasis on Texas and the southwestern United States, Jones and Gregory (2008) conclude:

> “For several decades, land managers have cleared brush species, such as mesquite and juniper, and observed increases in spring and stream flows. Scientists have also conducted numerous studies in which they have measured the effects of brush removal of different species on rangeland hydrology. These include the amount of rainfall that is intercepted and held by the plant leaves, surface runoff, spring flow, water use by individual plants and plant communities, fluctuation of shallow water tables, and streamflows. Considering this very diverse information, many scientists agree on several points:
>
> - The roots of some brush species extract water from greater depths than do grasses and forbs, and brush control can reduce the total amount of water used by vegetation.
> - Brush and other deep-rooted vegetation growing over shallow aquifers near streams can be expected to use large amounts of groundwater, likely reducing the amount in both the stream and aquifer.

- Removal of brush, like juniper and live oak, from upland areas some distance from streams may increase streamflow and/or recharge aquifers especially when:
    - The brush canopy is dense and intercepts substantial amounts of rainfall (e.g., dense juniper or live oak stands), effectively reducing the amount of rainfall reaching the soil surface, and
    - Soils, subsoils, and/or geologic strata are permeable, and streams in the area are fed by seeps and springs. Water can quickly percolate below the roots of grasses and forbs and move through subsurface pathways to local streams or aquifers.
- Brush control in upland areas is unlikely to increase significantly water yields if soils and geologic formations are not conducive to increased runoff and/or subsurface flows to streams or to aquifers.
- For brush control to have substantial long-term impacts on water yield, most or all of the woody vegetation in the treated area should be killed, and regrowth of brush and herbaceous vegetation should be controlled so that it is less dense and more shallow rooted than the pretreatment vegetation.
- New science-based tools (e.g., GIS and spatial analysis) can help pinpoint locations where brush control should substantially increase water flows in streams.
- A geographically targeted brush control program with careful scientific verification of impacts is needed to guide long-term brush control policies."

Rainwater et al. (2008) discusses various factors critical to estimation of water yield enhancement:

> "Changes in the water delivery characteristics of watersheds resulting from vegetative manipulations have been explored, studied, and reported for many years across a multitude of ecological settings. If there is one common thread in all of these reports, it is the fact that the results frequently are not consistent with expectations (Wilcox et al. 2008). Stated in a more practical vernacular, the response to a question "What will happen if?" should probably be, "It depends."
> - it depends on all of the specific physical characteristics of a given watershed (such as geology, soils, topography, and land use)
> - it depends on the sequence of meteorological events that may or may not lead to the generation of runoff or infiltration
> - it depends on the general climatic conditions present on the watershed
> - it depends on the type and species of vegetation that is being manipulated
> - it depends on how the vegetation was manipulated (e.g., chemically, mechanically, by fire)

- it depends on the type and species of vegetation (if any) that replaces the one being manipulated
- any reliable conclusions depend on having accurate water yield data before and after treatment upon which to base judgments as to the impact of the particular treatment"

Archer et al. (2011) critically evaluated brush management as a rangeland conservation strategy for the USDA-NRCS Conservation Effects Assessment Project:

> "Understanding the drivers of shrub encroachment can help identify when, where, how, and under what conditions management might most effectively prevent or reverse woody plant proliferation. Traditional explanations center around intensification of livestock grazing, changes in climate and fire regimes, the introduction of non-native woody species, and declines in the abundance of browsing animals. Likely all these factors have interacted to varying degrees, and the strength and nature of these interactions likely varies from one biogeographic location to another. Woody plant encroachment has long been of concern to rangeland managers (Leopold 1924).
>
> Integrated brush management systems (Scifres et al. 1985; Brock 1986; Hamilton et al. 2004) are long-term planning processes that move away from a purely livestock production perspective and toward management of rangelands for multiple uses and values. The integrated brush management systems planning process begins by identifying management goals and objectives for a specific site. These might include increasing forage production; maintaining or promoting suitable wildlife habitat; augmenting stream flow or groundwater recharge; controlling invasive species; reducing wildfire risk; or preserving grassland and savanna ecosystems. Specific objectives are refined on a comprehensive inventory of ecosystem components (plants, animals, and soils), projecting the responses of those components to brush treatment alternatives, and considering the effects of treatment alternatives on management goals on other sites (Hanselka et al. 1996). Brush management techniques (chemical, mechanical, biological, and prescribed burning) differ with respect to environmental impacts, implementation costs, efficacies, and treatment longevities. Thus, the integrated brush management systems approach advocates consideration of the type and timing of a given brush management technology and makes explicit allowances for consideration of the type and timing of follow-up treatments."

Section 2.3 Variables Influencing Water Yield

Water yield (runoff, recharge, and seepage) can be estimated using the following simplified water balance equation:

> Runoff + Recharge + Seepage = Precipitation + GWUse – Evapotranspiration – SoilStorage.

The components of the water balance equation are defined as follows:

> *Evapotranspiration*. The combination of transpiration and evaporation where:
>
> > *Transpiration.* The process by which water vapor is released to the atmosphere by passing through leaf tissue.
> >
> > *Evaporation.* The process by which water vapor enters the atmosphere from the soil or surface water. Another source of evaporation is precipitation that has adhered to plants which then directly passes back to the atmosphere — this is known as interception loss.
>
> *Groundwater Use*. Water removed by vegetation from soil layers and saturated zones.
>
> *Soil Storage*. Water entering the soil system and not exported; held by field capacity, which is the amount of soil moisture held in the soil after excess water has drained away.
>
> *Seepage*. Water in soil profile in excess of available field capacity that is stored as saturated layers and perched water tables which then moves laterally and becomes seepage or spring flow.
>
> *Runoff.* Water that exits the watershed via overland flow.
>
> *Recharge.* Water that exits the watershed via percolating through the soil beyond the reach of plant roots.

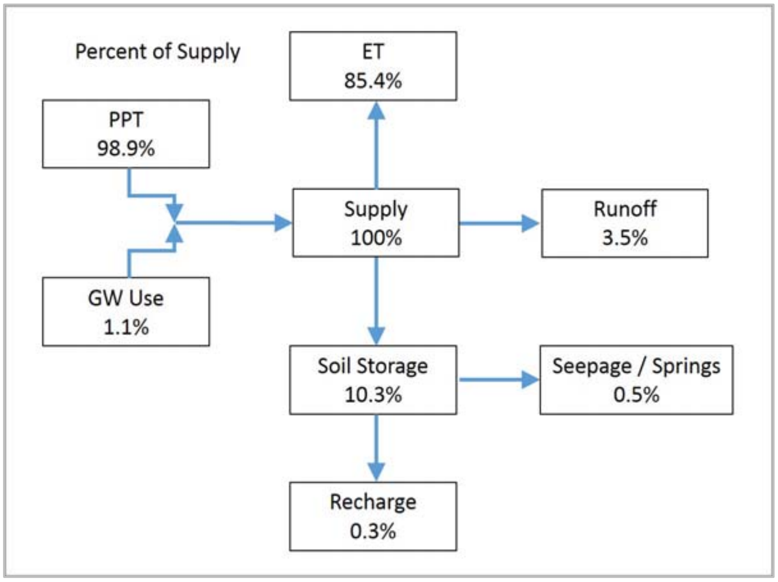

Figure 2.3.1 Hypothetical Water Balance (McLendon et al 2017)

This implies that water yield can be increased if ET can be decreased through vegetation management (Thurow 1998). Many variables influence the degree to which water will exit a site via ET, runoff, or deep drainage.

CLIMATIC FACTORS

Precipitation characteristics such as amount, intensity, distribution over time, and form (i.e., rain or snow) influence the likelihood of runoff and deep drainage. It is more likely that runoff will occur when the rainfall is intense and/or occurs as large, prolonged storms. Deep drainage is most likely during prolonged rainy periods. If the rainfall is gentle and occurs in a series of small storms the chance for water yield is much lower.

The potential ET rate is influenced by temperature, humidity, and wind. In an arid environment the water will quickly evaporate from the soil and the transpiration demand from plant leaves will be very high. A high potential ET rate lowers the chances that water will have the time needed to percolate through the soil profile and escape uptake by plant roots. Many aquifers have a better chance of recharging during the winter because many of the plants have lost their leaves and because the low temperature results in a low ET rate.

VEGETATION FACTORS

The leaf surface area and type of cover determine the amount of water that can be held in the canopy and evaporate back to the atmosphere (interception loss). At the AgriLife Research field station at Sonora it was documented that juniper and the associated leaf litter have an annual interception loss averaging 73% of precipitation, compared with 46% interception loss for live oak and 14% interception loss for grass (Thurow and Hester 1997). These data dramatically indicate that the amount of water reaching the soil is markedly different among vegetation types. The leaf surface area and type of cover also influence the amount of water lost via transpiration. On rangelands with a dense juniper cover essentially all of the rainfall returns to the atmosphere by either evaporation (i.e., interception loss) or transpiration (i.e., water that does reach the soil is taken up by the trees). Therefore, rangeland with dense juniper cover would have little potential for water yield compared to grassland, which has a much lower ET loss and allows more water to leave the site via either runoff or deep drainage.

The amount and type of cover are often the most important variables affecting infiltration rate (water movement into the soil) at a particular site. Plant cover dissipates the erosive energy of raindrops before they strike the soil. If cover is not present, the pores into the soil will likely be clogged with soil particles dislodged by raindrop impact. This creates a “wash-in” layer at the soil surface which restricts infiltration and accelerates erosion.

Since maintenance of productivity potential is an inherent characteristic of sound range management, accelerated erosion resulting from degraded infiltration characteristics is not acceptable. It is, therefore, important to maintain a type of cover that will protect the soil while having as little ET loss as possible. On Texas rangelands, a healthy grass cover can hold the soil in place and will have the lowest ET (and highest water yield) of the sustainable cover options.

SOIL FACTORS

The texture and structure of the soil is a primary determinant of how fast water can percolate through the soil and, combined with soil depth, how much water can be stored in the soil after it has had a chance to drain (field capacity). The geologic characteristics underlying the soil influence the amount of and rate at which water will exit a site via deep drainage. For example, the Edwards Plateau is characterized by shallow soils with a rapid infiltration rate underlain by fractured limestone. Consequently, the potential for deep drainage leading to aquifer recharge is high. Deep, coarse-textured soils, such as those overlying the Carrizo-Wilcox aquifer, also have a high aquifer recharge potential because of their rapid transmissive characteristics and low water retention capacity. These characteristics make it likely that much of the water yield associated with a change from brush to grass dominance will occur as deep drainage. In contrast, a typical site in the Rolling Plains ecoregion of North Central Texas is characterized by deep silty clay soil with a high water retention capacity and a slow drainage rate. As a result, very little water is lost to deep drainage (Carlson et al. 1990). Any extra water yield associated with a change from brush to grass dominance on a site with poor deep drainage potential will likely occur as runoff.

TOPOGRAPHIC FACTORS

The steepness and length of slope affects the potential for runoff and the erosion hazard. It is a generally accepted forestry practice that trees should not be cleared from hillsides with a 20% slope or more (FAO 1977). Many areas in central Texas with slopes of this magnitude were historically forested “cedar breaks,” probably because the associated rocky character made it difficult for them to sustain a natural fire. These sites should not be considered for brush control efforts intended to increase water yield.

CONCLUSIONS

The basis for using brush management to increase water yield is founded on the premise that shifting vegetation composition from species associated with high ET potential (trees and shrubs) to species with lower ET potential (grass) will increase water yield (runoff and/or recharge). Water yield tends to decrease as woody cover increases because, compared to grasses, trees and shrubs have:

- a more extensive canopy which catches precipitation which evaporates back to the atmosphere (i.e., interception loss),
- a greater leaf area from which transpiration can occur,
- a more extensive root system with greater access to soil water,
- a greater ability to extract water from very dry soil, and
- many invasive woody species are evergreen allowing rapid resumption of water use when it becomes available (as opposed to most grasses which senesce during dry periods and require time to re-establish green tissue).

Climate and soil traits influence whether reduction in transpiration and interception losses resulting from brush-to-grass conversion would be offset by increased evaporation from soil. An analysis of climate, ET, and field runoff measurements indicated that sites with tree and shrub communities in the Colorado River basin of the western United States need to receive over 18 in/yr of precipitation and need to have a potential ET of over 15 in/yr to yield significantly more water if converted to grasslands (Hibbert 1983). Since all regions of Texas have a potential ET of over 15 in/yr, these data suggest that a reasonable criterion for deciding where brush control is likely to increase water yield is to concentrate on areas that receive at least 18 in/yr of rain. See also General Brush Control Area in Chapter 3.

In general, conversion of cover from brush to grass does not influence water yield on sites that receive less than 18 in/yr because the extra water that reaches the ground and the reduced transpiration loss is offset by high evaporation from the soil. An exception to this is saltcedar which grows in riparian areas and extracts water from shallow aquifers recharged by the source stream or waterbody. Studies in many other forest and rangeland ecosystems throughout the world corroborate that a water yield increase can occur when the dominant vegetation cover is shifted from brush to grass (Douglass 1983; Jofre and Randal 1993) in areas that receive at least 18 in/yr precipitation and have at least 15 in/yr potential ET.

Section 2.4 Brush Species in Texas

All major land resource areas in Texas have significant brush infestations; however, different species predominate in different regions. Table 2.4.1 shows the major brush species and level of infestation in Texas based on brush surveys conducted by USDA-NRCS (1982 and 1987 NRI) (compiled in TSSWCB 1991). While the surveys are dated (29-34 years), these acreages still illustrate the magnitude of Texas' brush encroachment problem. While not all species of brush are significant users of water (e.g., prickly pear), others have been shown to drastically reduce water yield in a watershed.

Table 2.4.1 Acres of brush for different species and density ranges in Texas (TSSWCB 1991)

Species	Light Canopy 1-10% Cover		Moderate Canopy 11-30% Cover		Heavy Canopy >30% Cover	
	1982	1987	1982	1987	1982	1987
Agarito	8,370,500	5,336,100	303,500	272,700	29,500	11,600
Ashe juniper	4,398,300	2,875,300	2,000,800	1,949,300	1,214,700	1,904,400
Baccharis	288,800	122,000	44,200	25,700	7,000	9,000
Blackbrush	3,780,100	2,167,200	2,068,400	2,445,000	602,200	623,000
Blackjack oak	765,700	401,700	365,700	164,200	52,500	50,500
Broom snakeweed	5,560,300	2,607,700	1,987,700	2,512,800	270,600	967,200
Catclaw acacia	7,045,400	3,554,200	611,600	335,700	13,700	1,700
Cenizo	258,300	107,300	12,500	21,000	0	0
Chinese Tallow[1]	-	-	-	-	-	507,400
Condalias/lotebush	9,168,400	6,991,700	551,100	594,000	88,300	23,100
Creosotebush	4,830,600	4,212,500	3,027,000	2,324,300	246,200	134,800
Eastern redcedar	633,800	374,700	166,900	101,000	97,000	27,900
Elbowbush	331,600	174,800	69,700	60,800	13,600	1,600
Elms	1,939,800	996,000	671,400	553,500	315,600	341,100
Granjeno	4,939,400	3,374,100	486,000	735,000	86,800	1,200
Guajillo	1,975,400	1,162,300	981,200	1,081,600	239,600	401,200
Huisache	745,700	589,900	194,000	145,500	63,500	46,600
Live oak	6,067,500	4,321,000	3,401,500	4,141,600	1,112,500	1,076,100
Macartney rose	176,100	70,300	56,900	146,000	21,900	0
Mesquite	32,162,700	24,936,500	14,690,900	16,670,800	4,262,900	5,610,000
Post oak	2,027,200	1,277,500	1,642,300	1,524,900	1,642,400	1,536,200
Prickly pear	28,688,500	19,642,000	1,686,100	2,176,200	170,900	189,200
Redberry juniper	6,900,600	6,133,600	2,532,400	2,707,800	414,700	558,300
Saltcedar[2]	-	-	-	-	563,500	-
Sand sagebrush	2,764,300	2,494,600	1,032,700	1,168,800	239,800	292,700
Sand shinoak	301,600	60,100	350,200	257,200	362,000	600,900
Tarbush	2,301,600	2,083,300	791,300	594,900	50,300	85,500
Tasajillo	4,475,800	3,092,000	271,500	283,100	16,600	0
Texas persimmon	5,833,600	3,315,900	850,600	767,600	124,200	54,400
Twisted acacia	1,061,500	748,000	156,800	181,600	0	0
Whitebrush	2,593,500	1,663,000	605,800	763,000	184,400	318,800
Yaupon	831,000	515,900	568,700	654,100	322,600	205,300
Yucca	13,353,800	8,279,600	601,300	499,300	12,600	0

1 Chinese tallow infestation for 1990 from a 1991 survey by USDA-NRCS. Infestation by the year 2000 was estimated at over 900,000 acres. Percent canopy cover was not provided.

2 Saltcedar infestation from 1982 USDA-NRCS brush survey.

Section 2.5 General Vegetative Communities Across Texas – Gould's Ecoregions

Texas is a diverse state with a broad range of climate and soil types. Within the combinations of soils and climates, there are distinctive vegetative communities that predominate. Gould, et al. (1960) described 10 vegetative communities across the state.

Figure 2.5.1 Gould's Ecoregions of Texas [Gould et al. 1960 (here modified by TPWD 2011)]

BLACKLAND PRAIRIE

The Blackland Prairie intermingles with the Post Oak Savannah in the southeast and has divisions known as the San Antonio and Fayette Prairies. This rolling and well-dissected prairie represents the southern extension of the true prairie that occurs from Texas to Canada. The soils are inherently productive and fertile, but many have lost productivity through erosion and continuous cropping.

This once-luxuriant tallgrass prairie was dominated by little bluestem, big bluestem, indiangrass, tall dropseed (*Sporobolus asper* var. *asper*), and Silveus dropseed (*S. silveanus*). Minor species such as sideoats grama (*Bouteloua curtipendula*), and buffalograss (*Buchloe dactyloides*) have increased with grazing pressure. Mesquite, huisache, oak, and elm are common invaders on poor-condition rangelands and on abandoned cropland. Oak, elm, cottonwood, and native pecan (*Carya*) are common along drainages.

About 98% of the Blackland Prairie was cultivated to produce cotton, sorghum, corn, wheat, and forages during the latter part of the 19^{th} Century and the first part of the 20^{th} Century. Since the 1950s, pasture and forage crops for the production of livestock have increased, and now only about 50% of the area is used as cropland. Pastures occupy more than 25% of the land area, and the rest is used as rangeland. Small remnants of native vegetation exist for grazing or for hay production. Livestock production with both cow-calf and steer operations are the major livestock use. Winter cereals are used extensively for livestock grazing in conjunction with pasture forages. Mourning dove and bobwhite quail on the uplands and squirrel along streams are the most important game species.

CROSS TIMBERS

The Cross Timbers and Prairies area in North Central Texas includes the Cross Timbers, Grand Prairie, and North Central Prairies land resource areas. This area represents the southern extension of the Central Lowlands and the western extreme of the Coastal Plains. The wide variances in geologic formations bring about sharp contrasts in topography, soils, and vegetation.

Climax vegetation is composed primarily of big bluestem, little bluestem, indiangrass, switchgrass, Canada wildrye, minor amounts of sideoats grama, blue grama (*Bouteloua gracilis*), hairy grama, Texas wintergrass, and buffalograss. The minor species have generally increased with grazing.

Past management and cultivation have caused the uplands to be covered mostly by scrub oak, mesquite, and juniper with mid- and shortgrass understories. The bottomland trees are primarily hardwoods such as pecan, oak, and elm but have been invaded by mesquite.

About 75% of the Cross Timbers and Prairies area is used as range and pasture. Major crops on the sandy Cross Timber soils are peanuts, fruits, sorghum, wheat, oats, corn, and forages. Dairy operations are common, but beef cattle cow-calf operations are the predominant livestock activities. Sheep and goat operations occur in the southern parts. Most holdings are small mixed farming and ranching operations.

White-tailed deer, raccoon, squirrel, quail, and mourning dove are locally plentiful and provide some commercial hunting. Stock ponds and lakes on tributaries of the Brazos River and the Trinity River provide recreational fishing.

EDWARDS PLATEAU

The Edwards Plateau area includes 1.45M ac known as the Granitic Central Basin in Llano and Mason Counties. The Balcones Escarpment forms the distinct boundary of the Edwards Plateau on its eastern and southern borders and outlines what is known as the Texas Hill Country.

The area is a deeply dissected, rapidly drained stony plain having broad, flat to undulating divides. The original vegetation was grassland or open savannah-type plains with tree or brushy species found along rocky slopes and stream bottoms. Tallgrasses such as cane bluestem (*Bothriochloa barbinodis* var. *barbinodis*), big bluestem, indiangrass, little bluestem, and switchgrass are still common along rocky outcrops and protected areas having good soil moisture. These tallgrasses have been replaced on shallow xeric sites by midgrasses and shortgrasses such as sideoats grama, buffalograss, and Texas grama.

The western part of the area comprises the semi-arid Stockton Plateau, which is more arid and supports short- to midgrass mixed vegetation.

Common woody species are live oak, sand shin oak (*Quercus havardii*), post oak, mesquite, and juniper. The eastern and southern edges of the Stockton Plateau support dense stands of ashe juniper (*Juniperus ashei*), whereas redberry juniper (*Juniperus pinchotii*) increases to the north and west.

The Edwards Plateau is 98% rangeland; arable lands are found only along narrow streams and some divides. The rangeland is used primarily for mixed livestock (combinations of cattle, sheep, and goats) and wildlife production. The area is the major wool- and mohair-producing region in the United States, providing perhaps 98% of the nation's mohair. It also supports the largest deer population in North America. Most ranches are managed for livestock as the major enterprise, but wildlife production is increasingly important. Exotic big game ranching is important, and axis, sika, and fallow deer and blackbuck antelope are increasing in number (Traweek 1985). Management for all resources, livestock, wildlife, and recreation, provides the best use of the rangeland although other products such as cedar oil and wood products have local importance. Forage, food, and fiber crops such as sorghum, peanuts, plums, and peaches are well-adapted to arable land.

GULF PRAIRIES

The Gulf Prairies and Marshes, covering approximately 500,000 ac, are on a narrow strip of lowlands adjacent to the coast and the barrier islands, which extend from Mexico to Louisiana. The Gulf Prairies, about 9M ac, include the nearly flat plain extending 30 to 80 miles inland from the Gulf Marshes.

The Gulf Prairies and Marshes are a low, wet, marshy coastal area, commonly covered with saline water, and range from sea level to a few feet in elevation. The Gulf Prairies are nearly level and virtually undissected plains having slow surface drainage and elevations from sea level to 250 ft.

The original vegetation types of the Gulf Prairie were tallgrass prairie and post oak savannah. However, trees and shrubs such as honey mesquite (*Prosopis glandulosa*), oaks (*Quercus*), and acacia (*Acacia*) have increased and thicketized in many places. Characteristic oak species are live oak (*Quercus virginiana*) and post oak (*Q. stellata*). Typical acacias are huisache (*Acacia farnesiana*) and blackbrush (*A. rigidula*).

Principal climax grasses of the Gulf Prairie are Gulf cordgrass (*Spartina spartinae*), big bluestem (*Andropogon gerardii* var. *gerardii*), little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutans*), eastern gamagrass (*Tripsacum dactyloides*), gulf muhly (*Muhlenbergia capillaris*), tanglehead (*Heteropogon contortus*), and many species of panicum and paspalum.

The Gulf Marsh areas, being variously salty, support species of sedges (*Carex* and *Cyperus*), rushes (*Juncus*), bulrushes (*Scirpus*), several cordgrasses (*Spartina*), seashore saltgrass (*Distichlis spicata* var. *spicata*), common reed (*Phragmites australis*), marshmillet (*Zizaniopsis miliacea*), longtom (*Paspalum lividum*), seashore dropseed (*Sporobolus virginicus*), and knotroot bristlegrass (*Setaria geniculata*).

The low marshy areas provide excellent natural wildlife habitat for upland game and waterfowl. The higher elevations of the Gulf Marshes are used for livestock and wildlife production. Ranch units are mostly in large landholdings. These marshes and barrier islands contain a National Seashore, and many TPWD State Parks and Wildlife Management Areas and USFWS National Wildlife Refuges. Urban, industrial, and recreational developments have increased in recent years. Most land is not well-suited for cultivation because of periodic flooding and saline soils. The Gulf Prairies are used for crops, livestock grazing, wildlife production, and increasingly for urban and industrial centers. About one-third of the area is cultivated mostly for rice, sorghum, corn, and pastures. Bermudagrass and several introduced bluestems are common pasture grasses.

In the Gulf Prairies and Marshes, ranches are primarily cow-calf operations that use forage produced from rangeland and pasture. Some of the area is cropped. Recreation, hunting, and fishing provide excellent multiple-use opportunities in the Gulf Prairies and Marshes.

HIGH PLAINS

The High Plains area is part of the Southern Great Plains. It is separated from the Rolling Plains by the Llano Estacado Escarpment and dissected by the Canadian River breaks in the northern part. Notable canyons include Tule and Palo Duro along the Caprock. This relatively level plateau contains many shallow siltation depressions, or playa lakes, which sometimes cover as much as 40 ac and contain several feet of water after heavy rains. These depressions support unique patterns of vegetation within their confines.

The original vegetation of the High Plains was variously classified as mixed prairie, shortgrass prairie, and in some locations on deep, sandy soils as tallgrass prairie. The High Plains area characteristically is free from brush, but sand sagebrush and western honey mesquite (*Prosopis glandulosa* var. *torreyana*) have invaded the sandy and sandy loam sites along with prickly pear and yucca (*Yucca*).

About 60% of the area is cropland, half of which is irrigated. Cotton, corn, sorghum, wheat, vegetables, and sugar beets are major crops. Winter cereals are used for stocker operations in preparation for feedlotting on the extensive grain supplies produced on the High Plains. Rangeland grazing is important on about 40% of the area. Few cow-calf operations exist, but stocker operations are common.

High winds, dry winters, and low annual rainfall present problems for cultivation and erosion control. As groundwater availability diminishes, use of pasture and range for livestock production increases.

Pronghorn antelope were once common, but now only remnant populations provide hunting. Quail and mourning dove are abundant, and mule deer, turkey, and exotic aoudad sheep provide hunting along the breaks and canyons of the Caprock. Many playa lakes provide excellent migratory waterfowl habitat.

PINEYWOODS

The Pineywoods lie entirely within the Gulf Coastal Plains, which extend into Texas for 75 to 125 miles west of the Louisiana border. The area is a nearly level to gently undulating, locally hilly, forested plain. The dominant vegetation type is a mixed pine-hardwood forest on the uplands and a mixed hardwood forest on the lowlands. Native pines are loblolly (*Pinus taeda*), shortleaf (*P. echinata*), and longleaf (*P. palustris*). Slash pine (*P. elliottii*), a native of the southeastern United States, has been widely planted on thousands of acres. Hardwoods grow in mixed stands with pines in the uplands but are generally dominant along major streams. The principal hardwoods in the region are sweetgum (*Liquidambar styraciflua*), oaks (*Quercus*), water tupelo (*Nyssa aquatica*), blackgum (*N. sylvatica*), magnolias (*Magnolia*), elms (*Ulmus*), cottonwoods (*Populus*), hickories (*Carya*), walnuts (*Juglans*), maples (*Acer*), American beech (*Fagus grandifolia*), ashes (*Fraxinus*), and baldcypress (*Taxodium distichum*).

Many species of shrubs, vines, forbs, and grasses occupy the forest floor, prairies, and cutover areas not used for cropland.

Common understory shrubs and vines are southern wax-myrtle (*Myrica cerifera*), American beautyberry (*Callicarpa americana*), grapes (*Vitis*), blueberries (*Vaccinium*), hawthorns (*Crataegus*), greenbriars (*Smilax*), rattan-vine (*Berchemia scandens*), trumpet honeysuckle (*Lonicera sempervirens*), dewberries (*Rubus*), and poison ivy (*Toxicodendron radicans*). The area is noted for its flowering understory shrubs such as dogwoods (*Cornus*), redbud (*Cercis canadensis*), and black-haws (*Viburnum*).

Timber production is the leading land use in the Pineywoods. Forest grazing, pasture, feed grains, forages, fruits, and vegetables are secondary common land uses. Pine plantations and pastures currently occupy many areas previously forested or cultivated. Introduced grasses and the cultivation of legumes and use of fertilizer make this a highly productive pasture area. The forests, rangelands, and pastures are used for timber, livestock, wildlife habitat, recreation, and water production. The major livestock enterprise is the cow-calf operation. Herbage production in forests is generally negatively influenced by forest overstory canopy. Reservoirs provide recreation, including fishing, hunting, and swimming.

POST OAK SAVANNAH

The Post Oak Savannah lies just to the west of the Pineywoods and mixes considerably with the Blackland Prairies area in the south. This area includes the entire Claypan land resource area of Texas, which is part of the Southern Coastal Plains. The Post Oak Savannah is a gently rolling, moderately dissected wooded plain.

Short oak trees occur in association with tallgrasses. Thicketization occurs in the absence of recurring fires or other methods of woody plant suppression. This distinctive pattern of predominantly post oak and blackjack oak (*Quercus marilandica*) in association with tallgrasses also characterizes the vegetation of the Cross Timbers and Prairies vegetational area. Associated trees are elms, junipers (*Juniperus*), hackberries (*Celtis*), and hickories. Characteristic understory vegetation includes shrubs and vines such as yaupon (*Ilex vomitoria*), American beautyberry, coralberry (*Symphoricarpos orbiculatus*), greenbriar, and grapes.

Climax grasses are little bluestem, indiangrass, switchgrass (*Panicum virgatum*), silver bluestem (*Bothriochloa saccharoides*), Texas wintergrass (*Stipa leucotricha*), brownseed paspalum, purpletop, narrow leaf woodoats (*Chasmanthium sessiliflorum*), and beaked panicum (*Panicum anceps*).

The area is well-suited to grain crops, cotton, vegetables, and fruit trees. It was extensively cropped through the 1940s, but many acres have since been returned to native vegetation or pastures. Pasturelands have frequently been seeded with introduced species such as bermudagrass, bahiagrass, and clover.

Deer, turkey, quail, and squirrel are perhaps the most economically important wildlife species for hunting enterprises although many other small mammals and birds exist in the region. The major livestock enterprise is mixed cow-calf operations with many small herds on small landholdings. Livestock use either pastures, or the woodland areas for forage throughout the year. Wheat, oats, and rye are often planted for winter pasture.

ROLLING PLAINS

The Rolling Plains area (24M ac) coincides with the Rolling Plains land resource area of the southern Central Lowlands. The area is between the High Plains and the Cross Timbers in the northern part of the state. It is a nearly level to rolling plain having moderate to rapid surface drainage.

The original prairie vegetation included tall-, mid-, and shortgrasses such as little bluestem, big bluestem, sand bluestem (*Andropogon gerardii* var. *paucipilus*), sideoats grama, indiangrass, switchgrass, hairy grama, blue grama, and buffalograss on the uplands, and Canada wildrye and western wheatgrass (*Elytrigia smithii*) on the moister sites. Plant retrogression under continued overgrazing and suppression of fires is from a mid- and tallgrass-dominated community to shortgrasses, shrubs, and annuals.

Mesquite, lotebush, prickly pear, algerita (*Berberis trifoliolata*), and tasajillo are common invaders on all soils. Shinnery oak and sand sagebrush (*Artemisia filifolia*) invade the sandy lands, and redberry juniper has spread from rocky slopes to grassland areas. Dense stands of these species can be found throughout the Rolling Plains on overgrazed rangeland and abandoned cropland.

More than 75% of the area is rangeland, but dryland and irrigated sorghum, small grain, cotton, and forages are important crops. Livestock production, the major enterprises being cow-calf and yearling operations, includes use of rangeland forage, crop residue, and winter cereals. The intermixing of rangeland and cropland allows habitat for wildlife such as mourning dove, quail, white-tailed deer, and turkey, providing good to excellent recreational hunting opportunities.

SOUTH TEXAS PLAINS

The South Texas Plains lie south of a line from San Antonio to Del Rio. This area is the western extension of the Gulf Coastal Plains merging with the Mexico Plains on the west. The area is a nearly level to rolling, slightly to moderately dissected plain.

The original vegetation was an open grassland or savannah along the coastal areas and brushy chaparral-grassland in the uplands. Originally, oaks and mesquite and other brushy species formed dense thickets only on the ridges, and oak, pecan, and ash were common along streams. Continued grazing and suppression of fires altered the vegetation to such a degree that the region is now commonly called the Texas Brush Country. Many woody species have increased, including mesquite, live oak, acacia, Brazilian bluewood (*Condalia obovata* Hook.), spiny hackberry (*Celtis pallida*), whitebrush (*Aloysia gratissima*), lime pricklyash (*Zanthoxylum fagara*), Texas persimmon (*Diospyros texana*), shrubby blue sage (*Salvia ballotiflora*), and lotebush (*Zizyphus obtusifolia*).

Because the South Texas Plains lie almost entirely below the hyperthermic line, introduced tropical species do well. The introduced species buffelgrass (*Cenchrus ciliaris*) has proliferated and is common on loamy to sandy soils in the western half of the area. Coastal bermudagrass, kleingrass (*Panicum coloratum*), and rhodesgrass (*Chloris gayana*) are also common introduced species in pastures.

Range is the major land use, but irrigated and dryland cropping of cotton, sorghum, flax, small grains, and forages are also important. Citrus, vegetables, and sugarcane do well in the Lower Rio Grande Valley. Many acres are in large landholdings, such as the King Ranch. Livestock production is primarily cow-calf range operations, and wildlife production for hunting and recreational use is important. The South Texas Plains area is known nationwide for its large white-tailed deer. Quail, mourning dove, turkey, feral hogs, and javelina are other major game species. Stocker operations and feedlot operations are intermixed with cow-calf operations. Sheep and goat enterprises, once common throughout the area, are now confined mostly to the northern part because of coyote predation. Integrated use of range, crops, and forages is increasing as is vegetable and peanut production where irrigation is possible.

TRANS-PECOS

The Trans-Pecos area in Far West Texas is traversed by the eastern chain of the Rocky Mountains into the Basin and Range Province and is typical of the southwestern United States. Guadalupe Peak, having an elevation of 8,751 ft, of the Guadalupe Mountains, is the highest point in Texas. Surrounding peaks are El Capitán, Shumard, Bartlett, and Pine Top, all exceeding 8,000 ft. Mount Emory in the Chisos Mountains and Mount Locke in the Davis Mountains are 7,825 ft and 8,382 ft high, respectively. Notable canyons and gorges are Santa Elena, Boquillas, and Mariscal on the Big Bend of the Rio Grande; and McKittrick in the Guadalupe Mountains.

The original vegetation ranged from desert grassland and desert shrub on lower slopes and elevations through juniper, pinyon pine (*Pinus edulis*), and Mexican pinyon (*P. cembroides*) at mid elevations. The mountains support ponderosa pine (*Pinus ponderosa*) and forest vegetation on the higher slopes. Principal vegetation types of the basins are creosotebush (*Larrea tridentata*), tarbush (*Flourensia cernua*), catclaw acacia (*Acacia greggii*), catclaw mimosa (*Mimosa biuncifera*), whitethorn (*Acacia constricta*), yucca and juniper savannahs, and tobosa flats. Alkali sacaton and species of saltbush (*Atriplex*) occur on saline soils. Characteristic species of the plateaus and canyons are chino grama (*Bouteloua breviseta*), leatherstem (*Jatropha dioica* var. *dioica*), ocotillo (*Fouquieria splendens*), candelilla (*Euphorbia antisyphilitica*), lechuguilla (*Agave lecheguilla*), and sotols (*Dasylirion*).

The grass vegetation, especially on the higher mountain slopes, includes many southwestern and Rocky Mountain species not present elsewhere in Texas. Examples are Arizona fescue (*Festuca arizonica*) and mountain muhly (*Muhlenbergia montana*).

Under poor grazing management, rangeland sites become more xeric, and perennial grassland vegetation gives way to desert shrub and annual forbs and grasses. Creosotebush and tarbush complexes now cover some 15M ac of former desert grassland in the Trans-Pecos area. Tobosa draws, which once produced considerable forage, were invaded by burrograss and annuals as grazing pressure increased. Without the cover of perennial grass, the soils are subject to sheet and arroyo erosion from the intense summer thunderstorms.

More than 95% of the area remains as rangeland. Irrigated crops along the Rio Grande and other small drainages contribute to the economy. Cotton, alfalfa, sorghum, cantaloupe, sugar beets, grapes, and vegetables are grown. Most ranching operations are for livestock (cattle and sheep) production although management for mule deer, antelope, dove, and quail is important. Most livestock operations are cow-calf, and some stockers are carried over to use forages and irrigated fields.

Section 2.6 Eligible Brush Species Detrimental to Water Conservation

Target species for the WSEP are those noxious brush species that consume water to a degree that is detrimental to water conservation (i.e., phreatophytes). Brush control activities for these species are eligible for cost-share incentives.

Eligible Species:

- mesquite (*Prosopis* spp.) – primarily honey mesquite (*P. glandulosa*)
- juniper (*Juniperus* spp.) – primarily Ashe juniper (*J. ashei*) or redberry juniper (*J. pinchotii* and/or *J. coahuilensis*)
- saltcedar (*Tamarix* spp.)
- huisache (*Acacia farnesiana*)
- carrizo cane (*Arundo donax*)

Rainwater et al. (2008) provides summary information on the potential for water yield enhancement via vegetative manipulations involving three specific plant groups: mesquite, juniper, and saltcedar. Each of the following three subsections (Rainwater et al. 2008) focuses on one of these groups while at the same time attempting to make comparisons between groups as appropriate. Research on mesquite, while not as prolific in terms of sheer numbers of studies, has probably been more comprehensive with respect to all of the plant's morphological and ecophysiological aspects. More research on various types of control mechanisms has been conducted on mesquite than on any of the other groups. The least research has been done with respect to water use by juniper, although geographic distribution of juniper is probably more extensive than either of the other groups. Research on saltcedar, as a plant that makes excessive use of water, is probably the most abundant. As it is critical to consider all factors when making predictions as to water use by specific plants or water savings resulting from their removal, each of the species-specific subsections provides a reasonable summary of the current understanding for mesquite, juniper, and saltcedar.

Subsection 2.6.1 Mesquite

WATER USE BY MESQUITE

It has been estimated that a mesquite tree in Sonoran Desert washes would transpire 15 gpd (Nilsen et al. 1983). In another study by Ansley et al. (1998), they found that five years after mesquite density was reduced from 121 to 32 trees per acre, daily water use per tree increased from 13 to 44 gpd. By using sap flow techniques, Dugas and Mayeux (1991) determined the total seasonal water use of 1,600 L per mesquite tree, or 2.8 gpd based on a 150-day growing season. It is interesting to note that the reported value of 44 gpd water use by a single mesquite tree is far greater than the maximum tree-level daily water use of 32.2 gpd by saltcedar derived from sap flux measurement (Owens and Moore 2007). By tracking changes in water content in a 1.5-m soil profile and surface runoff over a period of seven years, Richardson et al. (1979) reported that following mesquite removal, ET was lower and soil moisture higher by 80 mm/yr, and runoff increased 30 mm/yr. In most Texas rangelands, most of the precipitation is retained in the upper 1 m of the soil profile where mesquite and herbaceous plants have similar root density (Weltz and Blackburn 1995), and there is little deep drainage. Therefore, water savings from removing mesquite cover from these rangelands would be minimal except in the riparian ecosystems.

DISTRIBUTION AND GROWTH HABITATS

Mesquite (*Prosopis* spp.) is a group of trees and shrubs that are widespread throughout the world. Mesquite is recognized as a rangeland invader in the southwestern United States. It has a wide distribution, from the semi-arid high plains of Texas to the Sonoran, Mojave, and Chihuahuan Deserts of the southwest United States. Depending on the growth habitats and local climate, mesquite can grow as a shrub or a tree. In the semi-arid grasslands of Texas where most precipitation occurs in the summer, and the water table is usually inaccessible, mesquite mostly relies on its lengthy shallow lateral roots to grow (Heitschmidt et al. 1988; Ansley et al. 1991), and it is more like a facultative phreatophyte (Thomas and Sosebee 1978).

In areas where most annual precipitation occurs as summer rainfall, deep drainage is unlikely to occur because immediate evaporation from soil surfaces reduces amounts of drainage, and also because of the changes in rooting patterns between woody and herbaceous species. Woody species such as mesquite tend to be more shallowly rooted in climates with summer rainfall regimes, as compared to more deeply rooted in climates with substantial winter precipitation (Schenk and Jackson 2002). Consequently, mesquite growing in the upland on Texas plains utilizes water from the unsaturated soil horizons. Dugas and Mayeux (1992) compared sap flow of mesquite from west Texas during the wet versus the dry season. They found that sap flow was 62% higher when soil was wet than dry, suggesting these plants rapidly utilized surface moisture when available.

In semi-arid west Texas rangelands with an annual precipitation of 450 mm, an argillic horizon has developed in the soil. The argillic horizon is rich in clay content (35-37%), which restricts the depth of water percolation. The wettest soil layers on these rangelands usually occur at depths of 60-75 cm during the growing season, and the water table is often more than 10 m deep. These impenetrable argillic horizons also restrict root growth. Therefore, the plants often have less developed tap roots. The majority of mesquite roots grow in the upper 60-cm soil profile, although 40% of roots were distributed below 67¬cm depths in regions with higher precipitation (Heitschmidt et al. 1988). In ecosystems where the water table is beyond exploitation of the deep roots, mesquite trees often respond rapidly to moisture in the upper soil layers with their extended shallow lateral roots (Easter and Sosebee 1975; Thomas and Sosebee 1978; Brown and Archer 1990; Wan and Sosebee 1991; Ansley et al. 1991). Lateral roots of mesquite can extend 30 ft or more from the tree center, and most of them are distributed 30 cm below the surface, a little deeper than grass roots (Ansley et al. 1991). Rapid water uptake by mesquite from the 60-cm soil profile following summer precipitation led to more than three times higher transpiration rates in the rainy season as compared to the dry season (Wan and Sosebee 1991). This condition suggests that mesquite lateral roots used rainwater very effectively. When lateral roots of mesquite were severed, the whole plant leaf area was reduced by 50% in the first growing season as compared to the non-severed plants (Ansley et al. 1991).

HOW MUCH WATER CAN A MESQUITE PLANT USE?

How much water can mesquite trees transpire? On upland sites at Vernon, Ansley et al. (1991) found that leaf transpiration rate on a sunny mid-summer day is about 227 g of water per leaf area (ft^2) per day. A typical 12 ft mesquite tree in a dense stand has about 130 ft^2 of leaf area. The calculated water use per day would come to 8 gpd per tree in a dense stand (200 trees per acre). The total water use per year by a mesquite stand represents 32% of annual precipitation (660 mm). When mesquite stand density declined to 120 trees per acre, water use per tree increased to 13 gpd, and annual water use per acre showed little change, as 31% of annual precipitation was used by mesquite. This finding is in sharp contrast to the water use pattern of saltcedar in a riparian ecosystem by Dahm et al. (2002), who showed annual ET over a saltcedar stand along the middle Rio Grande reach was 570 mm/yr; and the ET almost doubled in a much denser stand. Since the lateral roots of mesquite in west Texas rangelands can extend 30 ft from the tree center, the denser the stand, the less water was available to each individual tree, resulting in lower water use per tree (from 13 to 8 gpd).

WATER YIELD FROM MESQUITE CONTROL

In regions with strong hydrological sensitivity, removal of mesquite increased water yield. Rechenthin and Smith (1964) estimated that a comprehensive brush control program could save “12,000M m^3 of water in the Rio Grande Plains of Texas.” They assumed that removal of woody plants would reduce ET and increase grass production and water yield. However, their estimate was based on research conducted mainly in Arizona and California. In the Blackland Prairie of Texas (annual precipitation 860 mm/yr), heavy clay soils develop extensive cracking that allows deep drainage. By tracking changes in water content in a 1.5-m soil profile and surface runoff over a period of seven years, Richardson et al. (1979) reported that following mesquite removal, ET was lower and soil moisture higher by 80 mm/yr, and runoff increased 30 mm/yr. Surface runoff from these high-clay soils is substantial, averaging about 30% of the water budget.

Wilcox (2002) concluded, "Shrub control on mesquite dominated rangelands is unlikely to affect streamflow significantly for four reasons:

- Evaporative demand is high, and typical herbaceous replacement vegetation uses most of the available soil water;
- Soils on these sites are typically deep, effectively isolating the groundwater zone from the surface;
- Runoff is generated primarily as Horton overland flow; and
- Runoff is very flashy in nature, generated by flood producing events, overwhelming other factors."

Subsection 2.6.2 Juniper

WATER USE BY JUNIPER

Juniper changes landscape water balances for a plant community by intercepting a significant proportion of precipitation with its dense canopy and litter (Young et al. 1984; Thurow 1991; Eddleman and Miller 1992; Hester 1996; Thurow and Hester 1997; Lyons et al. 2006; Owens et al. 2006). The interception loss associated with the canopies of redberry juniper (*J. pinchotii*) and Ashe juniper was 25.9% and 36.7% of gross precipitation, respectively (Hester 1996). Juniper is an evergreen, and therefore its canopy maintains a high interception potential throughout the year when compared to saltcedar or mesquite. Rainwater that passes through the canopy must also pass through the litter layer prior to entering the soil. The amount of interception loss associated with the litter layer is considerably greater for redberry juniper (40.1%) and Ashe juniper (43%) than for western juniper species (2-27%) (Young et al. 1984; Thurow and Hester 1997). As a result of interception loss via the canopy and litter, only 20.3% and 34% of annual rainfall reaches mineral soil under the canopy of Ashe juniper and redberry juniper, respectively.

Owens and Ansley (1997) conducted research at various sites in the Edwards Plateau of Texas, and found that daily water use by redberry juniper and Ashe juniper was 46.8 and 33.1 gpd, respectively. Dugas et al. (1998) estimated that removing woody plant cover reduced ET by 40 mm/yr for a period of at least two years. A study at the small-catchment scale by Huang et al. (2006) estimated that removal of juniper will increase streamflow by 46 mm/yr, representing about 5% of precipitation. A much higher water savings was reported in a study that was conducted at the AgriLife Research station in Sonora (Thurow and Hester 1997). The soils at their research sites were 6-18 in deep, which overlay a fractured limestone substrate. Their data indicate that substantial water yield can be achieved through conversion of pasture vegetation from juniper to grass dominance. Although the area received an annual precipitation of only 574 mm/yr, deep drainage occurred due to karst geology. The estimated deep drainage was 94 mm/yr in a 100% grass pasture as compared to 0 mm/yr in a juniper/oak/grass community. This difference was largely caused by a three-fold greater interception loss in the juniper/oak/grass community. The water yield following juniper removal is equivalent to 100,500 gal/ac/yr. There was little runoff from these pastures, because the cut juniper maintained very high infiltration rates after the trees were removed. The moderately grazed pastures also had a good herbaceous cover in the juniper interspaces. Therefore, the added precipitation reaching the soil as a result of reduced interception losses did not runoff of the pasture but was instead channeled into the soil.

DISTRIBUTION AND GROWTH HABITATS

The genus *Juniperus*, represented by 17 species in the western United States (Owens and Ansley 1997), has invaded many semi-arid rangelands. Junipers are among the most drought-tolerant of evergreens. When juniper trees invade a rangeland, herbaceous production is generally reduced; when the tree community matures, the herbaceous production is further diminished under closed canopies. This lack of herbaceous biomass reduces livestock production, wildlife diversity, and watershed protection. While juniper may grow over a broad range of habitat types, most juniper populations are found in the upland or non-riparian rangelands.

Juniper trees can strongly impact soil water content and landscape water balance of a plant community. The most direct negative impact is to use more water than the herbaceous vegetation they are replacing. Juniper trees have very large leaf area that transpires large quantities of water. The trees remain green all year long, and can transpire when other plants are dormant. Junipers have deep root systems. The trees proliferate in regions where deep drainage is available. *Juniper ashei* has wide distribution in the Edwards Plateau of central Texas where the geology is characterized as a karst system. Karst geology has two important features, namely, shallow soils, which cannot hold much water, and fractured parent material, which allows rapid, deep drainage of rainfall, and facilitates the presence of springs (Wilcox et al. 2006). These shallow soils are underlain with limestone containing deep fractures and underground caves and streams.

A study by McCole (2003), which was conducted on the Edwards Plateau of Texas, found that Ashe juniper trees derived 72-100% of their water from groundwater during dry periods of the year (late summer and winter). During the wet periods of the year (spring and fall), between 45-100% of water use by juniper was derived from soil water. This study indicates that juniper reduce groundwater resources both by lateral roots intercepting potential recharge during the wet season and direct uptake of groundwater by deep roots during the dry season. In another study, Leffler et al. (2002) found that Utah juniper (*J. osteosperma*) dried the soil from the surface downward to a depth of about 1 m. Because juniper uses large quantities of soil water, growth of herbaceous plants is suppressed under juniper overstory. Cutting juniper trees was effective in increasing total understory biomass, cover, and diversity; and herbaceous biomass was nine times greater in cut versus woodland treatments in the second year post-cutting (Bates et al. 2000).

Juniper also changes landscape water balances of a plant community by intercepting a significant proportion of precipitation with its dense canopy and litter (Young et al. 1984; Thurow 1991; Eddleman and Miller 1992; Hester 1996; Thurow and Hester 1997; Lyons et al. 2006; Owens et al. 2006). This intercepted rainfall results in high evaporation losses directly back to the atmosphere from wetted canopy and litter. This phenomenon has been estimated to reduce winter soil moisture recharge by more than 50% in dense juniper stands (Eddleman and Miller 1992). The interception loss associated with the canopies of redberry juniper (*J. pinchotii*) and Ashe juniper was 25.9% and 36.7% of gross precipitation, respectively (Hester 1996). Ashe juniper typically has a very dense canopy and thus more surface area to intercept rainfall, which is then evaporated to the atmosphere. Rainwater that passes through the canopy must also pass through the litter layer prior to entering the soil. The amount of interception loss associated with the litter layer is considerably greater for redberry juniper (40.1%) and Ashe juniper (43%) than for western juniper species (2-27%) (Young et al. 1984; Thurow and Hester 1997). As a result of interception loss via the canopy and litter, only 20.3%

and 34% of annual rainfall reaches mineral soil under the canopy of Ashe juniper and redberry juniper, respectively. In contrast, as high as 81.9% and 89.2% of annual precipitation reaches the soil under bunchgrass and shortgrass cover, respectively (Thurow and Hester 1997).

HOW MUCH WATER CAN A JUNIPER PLANT USE?

How much water can a single juniper tree use on daily basis? It depends on the tree size, annual precipitation, depth to water table, density of the stand, and environmental conditions. Generally, juniper trees transpire much more water than herbaceous vegetation because juniper transpires throughout the year, typically has more leaf area, and can access water at great depths. Owens and Ansley (1997) conducted research at various sites in the Edwards Plateau of Texas, and found that daily water use by redberry juniper and Ashe juniper was 46.8 and 33.1 gpd, respectively. With an average daily water use of 39.8 gal/tree, the juniper transpiration was equivalent to 400 mm/yr. Owens (1996) reported that more than 20-year old Ashe juniper transpired 33 gal per tree on a daily basis, which is close to that of Owens and Ansley (1997). Compared with other phreatophytes such as mesquite, juniper uses water twice as much on a per tree basis, and has lower water use efficiency. For example, redberry juniper daily water use was 46.8 gal/tree as compared to 20.9 gal/tree for honey mesquite (Owens and Ansley 1997), which was due to much larger leaf area of juniper. Using density estimates combined with a canopy model, Owens and Ansley (1997) predicted water use by juniper in a non-grazed pasture transpired an average of 1.4 ac-ft/yr (420 mm/yr), in a lightly browsed pasture transpired 0.97 ac-ft/yr, and in a heavily browsed pasture transpired 0.34 ac-ft/yr. It is logical that removal of juniper trees could lead to more water available for herbaceous plants and streamflow.

WATER YIELD FROM JUNIPER CONTROL

There is a potential for water savings by removing juniper. Wilcox et al. (2006) stated at the tree scale, for an area with an average annual precipitation of 750 mm, an individual tree will intercept and transpire virtually all of the available water. Therefore, the hypothetical potential water savings from removal of juniper would be substantial. Juniper cover can influence overland flow, streamflow, and/or groundwater recharge. There are, however, conflicting reports on the magnitude of the impact of juniper removal on rangeland hydrology.

Rangeland runoff dynamics are influenced by juniper cover. A widely held view is that overland flow and erosion will be increased by higher coverage of woody plants. Increases in runoff and erosion following juniper encroachment are the result of overgrazing of the diminishing herbaceous cover (Thurow and Hester 1997). Dugas et al. (1998) reported dramatic reductions in Horton overland flow following juniper eradication. On many juniper-dominated sites, tree canopy cover is between 20-35%, leaving up to 80% of the area with reduced vegetation or litter cover for protection (Miller et al. 2005). Frederick et al. (2007) reported 15 times higher runoff on juniper-dominated sites. Removal of juniper increased ground cover in the interspaces between trees from 16-36%, improved infiltration capacity, and reduced runoff by 67%. The effects of juniper woodlands on infiltration rates and erosion may be site-specific

(Blackburn and Skau 1974) and depend on slope, soil type, disturbance, vegetation cover, and frost dynamics (Wilcox 1994).

In contradiction to the widely held view, Blackburn (1975) found that infiltration through surface soil was actually higher in Ashe juniper areas than in grass-covered areas. The surface runoff should be higher following juniper removal. Wright et al. (1976) reported that Horton overland flow was significantly greater for two to three years following removal of juniper by burning; presumably it took this much time for the vegetation to completely recover. In the North Concho River watershed, Wu et al. (2007) found that when junipers were cleared on two sites, 7.7% and 10.7% of rainfall events produced runoff during the 2005-2007 study period. In a 4-year study in the Edwards Plateau, Huang et al. (2006) found that runoff made up 22% of the water budget, with baseflow from the spring accounting for about half of the total flow. The mean runoff after a rainfall event was 5.5 mm for the pre-treatment period and 8.8 mm for the post-treatment period, an increase of 60% after removal of juniper (Huang et al. 2006). Wilcox (2002) pointed out that effects of shrub control on surface runoff depend on how the control method modifies surface conditions. Therefore, shrub control could result in either an increase or decrease in Horton overland flow.

Water balance studies on the Edwards Plateau suggest that on average 15% of precipitation ends up as recharge for the underlying Edwards Aquifer, most of it via transmission losses from stream channels that cross the Edwards Aquifer recharge zone (Maclay 1995). Since juniper trees can access groundwater, it is reasonable to expect that removal of juniper trees would contribute to recharge of groundwater stores. ET estimation based on the Bowen ratio method at the juniper stand suggests the direct recharge in this landscape following juniper removal could be substantial (Dugas et al. 1998). They estimated that removing woody plant cover reduced ET by 40 mm/yr for a period of at least two years. A study at the small-catchment scale by Huang et al. (2006) estimated that removal of juniper will increase stream-flow by 46 mm/yr, representing about 5% of precipitation. From these limited studies, it appears that conversion of Ashe juniper woodlands to grasslands or open savannas will translate to increases in spring flow and groundwater recharge at the small-catchment scale.

Another important issue relating to water yield is how much juniper cover is removed. Bosch and Hewlett (1982) proposed that the amount of vegetation cover removed is proportional to changes in water yield and that, for many areas, removing less than 20% of the cover would not yield detectable changes in streamflows. This conclusion is understandable because, as Lyons et al. (2006) pointed out, when juniper cover increased from 20 to 100%, the amount of water lost to interception increased to 12.6 in/yr, or was 5.2 times higher. That amount was just interception by the canopy and the litter layer, which was then evaporated into the atmosphere; if transpiration was taken into account, there would be a huge difference in water consumption between 20 and 100% juniper cover. Thus, when juniper cover is reduced from 100 to 20%, there would hypothetically be a substantial water savings. However, Hibbert (1983) stated that the relationship between percentage of vegetation removal and reduced transpiration is non-linear, and that meaningful reductions in transpiration in arid environments are only achieved at high levels of removal. For instance, removing half of the deep-rooted vegetation may hypothetically result in only a 20% reduction in transpiration.

The fundamental controlling factor in determining water yield appears to be the availability of groundwater (Wilcox et al. 2006) as, for example, in riparian environments. For an upland site with a calcic soil horizon, such as in west Texas, the soil water is mainly in the upper 1 m of the profile, and downward flux of water is very small. In regions where junipers are found on deep soils, the subsurface flow does not occur. Eradication in these regions is unlikely to increase water yield or streamflow. For an upland area to be hydrologically sensitive to changes in woody plant cover, there must be a reservoir of water available to deep-rooted plants that is not available to shallow-rooted plants. In rangelands not characterized by groundwater within a few meters of the surface, the geological conditions must allow deep drainage to maintain these reservoirs. These areas are in the relatively mesic rangelands situated in karst geologic settings with shallow soils underlain by fractures of the parent material and underground caves where rapid recharge occurs after rainfall. There are reports of spring flow appearing or increasing after shrub control for juniper rangelands on the Edwards Plateau (Wright 1996) and for pinyon-juniper watersheds in Utah (McCarthy and Dobrowolski 1999).

Much higher water savings were reported in a study that was conducted at the AgriLife Research station at Sonora (Thurow and Hester 1997). The soils at the research sites were 6-18 in deep, which overlay a fractured limestone substrate. The data indicated that substantial water yield can be achieved through conversion of pasture vegetation from juniper to grass dominance. Although the area received an annual precipitation of only 574 mm/yr, deep drainage occurred due to karst geology. The estimated deep drainage was 94 mm/yr in a 100% grass pasture as compared to 0 mm/yr in a juniper/oak/grass community. This result was largely caused by a three-fold greater interception loss in the juniper/oak/grass community. The water yield following juniper removal was equivalent to 100,500 gal/ac/yr. There was little runoff from these pastures, because the cut juniper maintained very high infiltration rates after the trees were removed. The moderately grazed pastures also had a good herbaceous cover in the juniper interspaces. Therefore, the added precipitation reaching the soil as a result of reduced interception losses did not runoff of the pasture but was instead channeled into the soil.

Subsection 2.6.3 Saltcedar

WATER USE BY SALTCEDAR

It has been reported that saltcedar can use 200 gpd of water (Tribe 2002), but this number has been questioned by many researchers (Wilcox et al. 2006; Owens and Moore 2007). The literature cited by Owens and Moore (2007) indicated that daily water use of an individual saltcedar tree is in the range of 0.4 to 57 L, or less than 15 gpd (Davenport et al. 1982; Sala et al. 1996; Smith et al. 1996; Cleverly et al. 1997; Devitt et al. 1997a/b; Wullschleger et al. 2001; Nagler et al. 2003). A variety of techniques have been used to estimate water use by saltcedar at the stand scale. Dahm et al. (2002) found that saltcedar stands on floodplains had higher ET rates than those in non-flooding areas (1,000 vs. 750 mm/yr). In the Virgin River of southern Nevada, Devitt et al. (1998) reported ET for saltcedar stands of 750 mm/yr during a dry year and 1,500 mm/yr during a wet year. On the landscape scale, Culler et al. (1982) estimated that water consumption by saltcedar stands was about 1,090 mm/yr along the Gila River in Arizona. When the phreatophytes were removed, measurements revealed that water savings came to 480 mm/yr after the replacement vegetation was established. In the Middle Rio Grande, Cleverly et al. (2006a/b) found that a dense saltcedar stand frequently consumes up to 11.5 mm/day, especially when flooded. Conversion from a dense monoculture of saltcedar to a sparse saltcedar/saltgrass woodland was predicted to save 200 mm/yr (0.7 ac-ft/ac/yr), based upon both ET and leaf area index changes in such a conversion.

DISTRIBUTION AND GROWTH HABITATS

Saltcedar (*Tamarix* spp.) is an invasive weed that occupies vast areas in New Mexico, Arizona, California, Nevada, and Texas. Saltcedar species are exotic phreatophytes, with deep roots tapping the water tables, that depend on groundwater for their water supply (Anderson 1982). They grow mainly in riparian habitats, along stream channels and on floodplains. Saltcedar is capable of invading river banks and stream channels, replacing native phreatophytes and other native species, and forming solid dense stands. It is estimated that, in Texas alone, nearly a half million acres are infested by saltcedar (Knutson 2013).

Unlike native phreatophytes such as cottonwoods and willows, saltcedar species also have extensive shallow root systems. Saltcedar seedlings can grow a root system over 1 m deep in the first growing season and then grow up to 2 m by the end of the second growing season (Smith et al. 1997). Their roots easily develop from submerged or buried stems. The dual root systems enable saltcedar to use soil water wherever it is available, thus they are facultative phreatophytes, or opportunistic water users. Because of rapid root growth and dual root systems, saltcedar seedlings have competitive advantages in soil water uptake.

Saltcedar species are extravagant water users and compete successfully with the native phreatophytes for limited water supply. In the Rio Grande basin, for example, native cottonwoods are declining in most areas, and half of the wetlands in the drainage were lost in just 50 years. Invasion by non-native phreatophytic trees such as saltcedar and Russian olive

(*Elaeagnus angustifolia*) have dramatically altered riparian forest composition. Without changes in water management, exotic species will likely dominate riparian zones within half a century (Jackson et al. 2001).

When the water table drops below the root depths of the native obligate phreatophytes (e.g., cottonwoods, willows), these plants are severely stressed. For example, cottonwood prefers areas with groundwater less than 6.5 ft from the soil surface (Cleverly et al. 2006a). In contrast, saltcedar's primary taproot can easily penetrate 15 ft, or even grow down as deep as 40 to 50 ft (Tribe 2002; Wilson et al. 2004), or 75 ft (Morrison 2003). Once the taproot reaches the water table, secondary root branching becomes profuse (Di Tomaso 1998). Unlike obligate phreatophytes, such as cottonwoods and willows, saltcedar is often able to survive under conditions where groundwater is inaccessible (Devitt et al. 1997b; Di Tomaso 1998). Therefore, saltcedar water use is less affected by water table declines from drought or groundwater pumping due to its deeper rooting and effective use of summer rainfall by its shallow roots (Devitt et al. 1997a; Mounsif et al. 2002).

Water use by saltcedar trees has been a subject of debate. It has been reported that saltcedar can use 200 gpd (Tribe 2002), but this number has been questioned by researchers (Wilcox et al. 2006; Owens and Moore 2007). The large discrepancy in daily water use could be related to plant canopy size, plant age, depth to water table, and environmental conditions. Depending on the habitat and plant age, saltcedar can grow as a small shrub or a big tree.

Glenn and Nagler (2005) believe that the ecophysiological traits of saltcedar make it a formidable competitor of the native vegetation, and eventually the dominant species and largest water user in the riparian ecosystems.

HOW MUCH WATER CAN A SALTCEDAR PLANT USE?

Water use by saltcedar could vary greatly depending on growth habitats, soil moisture availability, and atmospheric demand. A variety of techniques have been used to estimate water use by saltcedar at the stand scale, including sap flow measurements, groundwater monitoring, large-lysimeter measurements, remote sensing, and micrometeorology. By using eddy covariance to estimate season-long ET along the middle Rio Grande, Dahm et al. (2002) found that saltcedar stands on floodplains had higher ET rates than those in non-flooding areas (1,000 vs. 750 mm/yr). In the Virgin River of southern Nevada, Devitt et al. (1998) reported ET for saltcedar stands of 750 mm/yr during a dry year and 1,500 mm/yr during a wet year.

Mature saltcedar plants are tolerant of a variety of stress conditions, including heat, cold, drought, flooding, and high salinity (Di Tomaso 1998; Smith et al. 1998; Glenn and Nagler 2005). These ecophysiological traits enable them to develop dense monocultures that replace native vegetation; as stand density and plant size increase, so does water use. Saltcedar accumulates salt in its leaf glands that is then transferred to the soil when plants drop their leaves. Increased soil salinity under saltcedar stands impairs germination and establishment of many native species. In the meantime, saltcedar seedlings can rapidly colonize moist areas after summer rains. Morrison (2003) observed that saltcedar can live in soils 25 times saltier than either willows or cottonwood can stand. It moves salt from the bottom of its 75-ft to 100-ft rooting depth to the soil surface. Over time, these accumulated salts may kill any other plants below or around it. It was reported that saltcedar can tolerate salt content of 8,000-10,000 ppm (Di Tomaso 1998; Nagler et al. 2006), which inhibits growth of competing species. Walker and Smith (1997) pointed out that the most single important way the invasion of saltcedar fundamentally alters ecosystems is through salinization of floodplain habitats. Therefore, they suggested that in many ecosystems being reclaimed from saltcedar invasion, only a return of annual floods, which leach the soil of salts, will allow the ecosystem to be re-vegetated with former dominants such as cottonwood and willow.

WATER YIELD FROM SALTCEDAR CONTROL

Water salvage estimates show a significant reduction in system water loss after saltcedar treatment (Culler et al. 1982; Weeks et al. 1987; Hays 2003; Bawazir et al. 2006; Groeneveld et al. 2006; Cleverly et al. 2006b). Clearing high density saltcedar stands has greater effect on water salvage than treating low density stands (Hays 2003). Hays (2003) did a paired analysis between herbicide treated and untreated plots in the Colorado River basin and found potential water savings of 400 mm/yr, based on the assumption of 49% mortality with top kill of saltcedar. From a before-after comparison, Groeneveld et al. (2006) estimated water savings of 3.1 ac-ft/ac on approximately 6,000 ac treated along the Pecos River, and the annual salvage came to 18,600 ac-ft. Bawazir et al. (2006) investigated water salvage by chemically controlling saltcedar at the Elephant Butte Delta of New Mexico, and found that estimated ET for non-treated saltcedar was 1,002 mm when compared to measured ET of 386 mm at the treated site, a difference of 61% for 189 days.

More realistic estimations on water salvage should be based on data collected after re-establishment of the native vegetation. On the landscape scale, Culler et al. (1982) estimated that water consumption by saltcedar stands was about 1,090 mm/yr along the Gila River in Arizona. When the phreatophytes were removed, subsequent measurements revealed that water savings came to 480 mm/yr after the replacement vegetation was established. In the Middle Rio Grande, Cleverly et al. (2006b) found that conversion from a dense monoculture of saltcedar to a sparse saltcedar/saltgrass woodland is predicted to save 200 mm/yr (0.7 ac-ft/ac-yr), based upon both ET and leaf area index changes in such a conversion.

Some field studies by the USGS indicated that measurable water salvage following saltcedar clearing is only 0 to 1.5 ac-ft/yr due to ET of replacement vegetation, increased evaporation, loss to groundwater, or other sinks (Culler et al. 1982; Weeks et al. 1987; Shafroth et al. 2005).

Preliminary results from a project in the Pecos River in Texas (Hart et al. 2004) indicate that there is a great potential for water salvage by saltcedar control. A study on the Pecos River by Sheng et al. (2007) conservatively estimates water salvage of 0.5-1.0 ac-ft per treated acre from control of saltcedar, and suggests that salvaged water most likely contributes to aquifer recharge rather than increased streamflow.

Subsection 2.6.4 Other Species

These other species of interest are also eligible as target species for the WSEP.

HUISACHE

Huisache (*Acacia farnesiana*) is a perennial woody shrub that occurs throughout South Texas. In many areas it is a serious brush problem on rangelands, where it can occur either in pure stands or as a member of mixed-brush communities. Botanical surveys indicate that the species has become more widespread in geographical distribution over the last 150 years. There are several reasons why huisache is a successful invader of rangelands. The species produces abundant amounts of seed which has an impermeable seed coat, and can persist for many years in the soil. A prolific seed producer, huisache can overtake a grassland prairie in a generation, and can readily out-compete native grasses for space. Huisache seedlings have a tap root system that rapidly extends deeply into the soil soon after germination, assuring the seedling an adequate supply of water. The extensive tap root system allows the plant to access both shallow and deeper groundwater. Huisache plants, similar to honey mesquite, form a meristematic zone just below the soil surface during their first or second year of growth. Once this zone is established, the plants can resprout if the tops are mechanically removed or killed by fire. In addition, huisache roots are colonized by bacteria of the genus *Rhizobium*, which allows them to use atmospheric nitrogen gas as a nitrogen source. This provides the plants with a competitive advantage in nitrogen-deficient soils. Temperature and rainfall appear to limit the distribution of huisache. (Wood 2014; Rechenthin and Smith 1964)

Potential changes in the hydrologic budget as a result of huisache removal needs to be better quantified to evaluate the effects of vegetative land cover changes at a watershed scale. A 5-year study (2015-2019), funded in part by the TSSWCB through the WSEP, is examining the effects of huisache removal on ET in south central Texas. Entities conducting the science for the study include the USGS and the Desert Research Institute. Cooperators providing funding for the project include USDA-NRCS, TSSWCB, SARA, and the Victoria County GCD. Other cooperators on the project include the Victoria SWCD #346 and the McFaddin Ranch. USGS will evaluate the effects of brush management (in this case, huisache removal) on the hydrologic budget using a paired site approach, similar to studies conducted on juniper at the Honey Creek State Natural Area. Measurements of ET by eddy covariance will be used to evaluate changes in the hydrologic budget before and after brush management has occurred. In addition, the use of remote sensing (satellite imagery) will be evaluated for applicability to estimate ET rates at a regional scale. These data will help inform future water resources management decisions, as well as be incorporated in future hydrologic watershed models. ET and rainfall will be measured on two adjacent sites located between the San Antonio River and Guadalupe River in Victoria County. One site is managed grassland, and the other site is a huisache-dominated area. ET and rainfall will be measured at both sites for two years. After two years, the huisache site will be treated (i.e., remove the huisache), and native grasses will be allowed to re-establish. ET and rainfall data collection will then continue at both sites for another 2 years. (USGS 2016)

CARRIZO CANE

Arundo donax (also known as giant reed/cane, carrizo cane, arundo, river cane/reed, Spanish cane/reed, bamboo reed, el ladron de agua, wild cane, elephant grass) is one of the largest size perennial grass species in the region. A colonial plant that grows in dense stands, it is found in many subtropical and warm-temperature areas of the world. It is thought to be originally native to eastern Asia, but the precise extent of its native distribution is unknown. Stands along the Upper Nueces River are the same genotype that grows on the Rio Grande, which originated from the Seville region of Spain (Tarin et al. 2013). *A. donax* was introduced around the world as an ornamental/crop species, for erosion control, and for production of reeds. It has become invasive in many places throughout the world, primarily in riparian habitats.

Where *A. donax* invades, it often forms dense stands. *A. donax* is a hydrophyte, achieving its greatest growth near water. However, it adapts to many different habitat conditions and soil types, and once established, is drought tolerant and able to grow in fairly dry conditions. It consumes prodigious amounts of water, as much as 2,000 L/m^2 per year of standing *A. donax*, to supply its incredible rate of growth. The plant's thick fibrous root system enables *A. donax* to create large monocultures along stream banks and consume large quantities of water. It is also known that *A. donax* can transpire extremely large quantities of water, especially within stream channels where unlimited access to water fuels explosive growth. (Gary and Kromann 2013) Watts and Moore (2011) concluded that *A. donax* transpires at high rates similar to other riparian reeds resulting in high stand-level estimates of water use; annually, approximately 1,700 mm may be a reasonable estimation for *A. donax* stands in the Rio Grande watershed.

Several studies (Zembal and Hoffman 2000; Oakins 2001; Jackson et al. 2002) have indicated that carrizo cane's water use is three times that of native vegetation. Other studies (Jackson et al. 2002; Iverson 1994) indicate that carrizo cane can consume 3.8-5.6 ac-ft of water per ac of cane per year. Control of carrizo cane infestations along the Rio Grande (estimated at 30,000 to 60,000 ac [Yang et al. 2011]) alone could yield as much as 76,000 to 224,000 ac-ft of water savings. Since 2009, the USDA-ARS has been releasing biological control agents (a wasp and a scale insect) along the Rio Grande to combat carrizo cane infestations. Scientists have estimated that a 22-32% reduction in carrizo cane above-ground biomass and significant regrowth of native vegetation with stands along the Rio Grande, which is attributed to biological control along the Rio Grande over the period 2009-2014, had water savings of 6,593 ac-ft per year, even accounting for water use by regrowth of native riparian plants (Goolsby et al. 2016, Moran et al. 2017). A third biological control agent, the leafminer, was released in 2016 which causes defoliation of the cane and continued decline of above-ground biomass. USDA-ARS has also developed a biological control plus mechanical topping technique that allows for immediate visibility of the Rio Grande and accelerates the impacts of the biological control agents (Racelis et al. 2013).

Section 2.7 Other Benefits of Brush Control Beyond Water Supply Enhancement

Torell, McDaniel, and Ochoa (2005) have noted that if brush control projects are to be profitable expenditures of public funds then the unmeasured benefits of ecosystem services to non-livestock entities must exceed the state, county, or federal cost-share necessary to induce livestock producers' participation in brush control projects.

Beyond enhancing water yield by conserving water lost to ET, recharging groundwater and aquifers, and enhancing spring and stream flows, brush control provides other ecosystem services including the potential to:

- improve soil health,
- restore native wildlife habitat by improving rangeland condition,
- improve livestock grazing distribution,
- aid in wildfire suppression by reducing hazardous fuels,
- protect water quality and reduce soil erosion, and
- manage invasive species.

The USDA-NRCS (2014b) recognizes six purposes for undertaking brush management:

- Create the desired plant community consistent with the ecological site.
- Restore or release desired vegetative cover to protect soils, control erosion, reduce sediment, improve water quality, or enhance stream flow.
- Maintain, modify, or enhance fish and wildlife habitat.
- Improve forage accessibility, quality, and quantity for livestock and wildlife.
- Manage fuel loads to achieve desired conditions [to protect life and property from wildfire hazards]

WATER QUALITY

The relationship between water quality and the hydrologic nature of flow is readily apparent in waterbodies in the arid regions of Texas. The loss of discharge directly results in the concentration of pollutant loadings and the loss of critical aquatic habitat, affecting the State's ability to accomplish water quality goals. Historical hydrologic data has demonstrated a relationship between loss of perennial stream flows and the encroachment of woody brush. Brush control can restore aquatic habitat, improve water quality, and help achieve other beneficial uses of waterbodies and water quality goals. While the TSSWCB WSEP is targeted to watersheds based on priorities associated with water conservation needs and projected water yields, this program also supports the State's water quality goals and contributes to achieving the goals and objectives of the *Texas Nonpoint Source Management Program* and agency priorities for abating agricultural and silvicultural nonpoint sources of water pollution.

GROUNDWATER PROTECTION

Coordinating the State's groundwater protection efforts is the task assigned to the Texas Groundwater Protection Committee. The TGPC improves coordination between member agencies and works to protect groundwater as a vital resource. The TGPC implements the State's groundwater protection policy. The primary goals of the TGPC's Public Outreach and Education Subcommittee are to develop and implement educational outreach programs for landowners concerned with groundwater protection and environmental health issues and to facilitate interagency communication and coordination to provide support for landowner educational outreach projects. Activities include developing educational materials, coordination of outreach programs and special projects. The TSSWCB WSEP is a focus area for the Subcommittee in its efforts to implement the second edition of the *Groundwater Educational Outreach Plan*.

INVASIVE SPECIES

The Texas Invasive Species Coordinating Committee was established in 2009 by the 81st Texas Legislature. The TISCC provides a forum for developing effective and timely interagency strategies and policies for invasive species control. The TISCC makes recommendations to the leadership of state agencies regarding research, technology transfer, and management actions related to invasive species control. A myriad of invasive plant and animal species, both aquatic and terrestrial, plague the water resources of Texas. Water quality is impaired, water quantity is diminished, and aquatic ecosystems are affected. For example, riparian areas infested by saltcedar (a non-native, invasive species) impact salinity levels in waterbodies. Saltcedar can also intensify water quality problems due to its ability to reduce groundwater supplies and streamflow through ET. Work by the TSSWCB WSEP supports the State's invasive species management goals and contributes to achieving the goals and objectives of the TISCC.

BORDER SECURITY

In order to help meet the Governor's border security priorities, the 84th Texas Legislature, in 2015, directed the TSSWCB, through SB1734, to develop and implement a program to eradicate carrizo cane (*Arundo donax*) along the Rio Grande. Large dense stands of carrizo cane along the banks and floodplains of the Rio Grande present considerable obstacles for the protection of the international border by law enforcement. Carrizo cane is a noxious brush species that consumes water to a degree that is detrimental to water conservation. As a result of this weed's high ET capacity, infestations threaten water supplies for agricultural and municipal drinking water uses. Comprehensively addressing the impacts of carrizo cane on border security are paramount to the program, while also accruing benefits to water user groups in South Texas. While achieving border security objectives, the program will also enhance water savings by conserving water lost to ET by the cane, even accounting for water use by regrowth of native riparian plants.

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Chapter 3 Priority Watersheds for Water Supply Enhancement

In 1985, TSSWCB and TWDB developed a list of water supply reservoirs where brush control could possibly enhance water supplies (Table 3.1) (TSSWCB 1999). The following criteria were used:

- Where surface reservoirs have vacant storage and can accept an increase in surface flow.
- Watershed of approximately 500 mi^2 or less and boundary conditions are minimized.
- A record of historical baseflow.
- Where brush clearing would progress upstream from a reservoir site.
- Where zero or minimal stream diversions occur.
- Where annual runoff averages more than 0.5 in and less than 5.0 in.
- Where rainfall is between 15 and 36 in per year.
- Where trees can remain along streams, and channelization is not necessary.
- Where state and federal regulations regarding wetland and pollution will not be violated.
- Where brush and/or phreatophyte infestation exceeds 20%.
- Where dissolution of near-surface salts is minimal and such areas can be identified.
- Where municipalities have water supply problems.
- Where the best historical data is available such as, streamflow and groundwater level.
- Where groundwater recharge and storage can be increased.
- Where hydrogeological conditions are favorable.
- Where the ratio of water use by brush/phreatophyte covered areas converted to grasslands or other vegetation is favorable. Also, where the ratio of the soil moisture with and without the brush is favorable to induce groundwater recharge.

Most areas historically considered under the above criteria could expect an increase in surface water flow. With respect to groundwater augmentation, however, the hydrogeological setting played an important role in the selection. For example, streams should traverse the recharge outcrops of aquifers; and if faulting exists, this would be even better.

Brush control feasibility studies have since been conducted on several of the reservoirs included on this list.

Table 3.1 Water supply reservoirs where brush control could enhance supplies [TSSWCB 1999 (here modified)]

#	County	Public Water Supply	Waterbody	Water User Group	Comments
33	Montague	Lk Amon Carter	Sandy Crk	Bowie	
16	Erath	Bailey's Lk	Kickapoo Crk	Lipan	
5	Blanco	Blanco Rvr	Blanco Rvr	Blanco	
7	Bosque	Bosque Rvr	Bosque Rvr	Meridian	
8	Bosque	Bosque Rvr	Bosque Rvr	Clifton	proposed reservoir
40	Real	Camp Wood Crk	Camp Wood Crk	Camp Wood	
28	Kendall	Boerne City Lk	Cibolo Crk	Boerne	
30	Mills	Goldthwaite City Lk	Colorado Rvr	Goldthwaite	
20	Goliad	Coleto Crk Rsrvr	Coleto Crk	GBRA	power cooling reservoir
52	Victoria	Coleto Crk Rsrvr	Coleto Crk	GBRA	power cooling reservoir
26	Jones	Fort Phantom Hill Rsrvr	Elm Crk	Abilene	
46	Stephens	Hubbard Crk Rsrvr	Hubbard Crk	West Central Texas MWD	
6	Blanco	Johnson City Lk	Pedernales Rvr	Johnson City	run-of-river lake
47	Taylor	Lk Abilene	Elm Crk	Abilene	
24	Jim Wells	Lk Alice	Chiltipin Crk	Alice	
2	Archer	Lk Arrowhead	Little Wichita Rvr	Wichita Falls	
13	Clay	Lk Arrowhead	Little Wichita Rvr	Wichita Falls	
11	Callahan	Lk Baird	Mexia Crk	Baird	
42	Runnels	Lk Ballinger	Valley Crk	Ballinger	
9	Brown	Lk Brownwood	Pecan Bayou	Brownwood WCID	irrigation and municipal supply
15	Eastland	Lk Cisco	Sandy Crk	Cisco	
25	Johnson	Lk Cleburne	Nolan Rvr	Cleburne	
12	Callahan	Lk Clyde	N Prong Pecan Bayou	Clyde	
14	Coleman	Lk Coleman	Jim Ned Crk	Coleman	
31	Mitchell	Lk Colorado City	Morgan Crk	Colorado City	
45	Stephens	Lk Daniel	Gonzales Crk	Breckenridge	base flow decline
10	Burnet	Lk Georgetown	N Fork San Gabriel Rvr	BRA	
53	Williamson	Lk Georgetown	N Fork San Gabriel Rvr	BRA	
55	Young	Lk Graham	Salt Crk	Graham	
23	Jack	Lk Jacksboro	Lost Crk	Jacksboro	
27	Kimble	Lk Junction	Llano Rvr	Junction	
1	Archer	Lk Kickapoo	N Fork Little Wichita Rvr	Wichita Falls	
48	Taylor	Lk Kirby	Cedar Crk	Abilene	
49	Taylor	Lk Lylte	Lylte Crk	Abilene	
18	Falls	Lk Marlin	Big Sandy Crk	Marlin	
3	Bandera	Lk Medina	Medina Rvr	Medina Irrigation Company	
37	Palo Pinto	Lk Mingus	Gibson Crk	Mingus	
32	Montague	Lk Nocona	Farmers Crk	Nocona	
54	Young	Lk Olney/Cooper	Mesquite Crk	Olney	
19	Falls	Lk Rosebud		Rosebud	
22	Haskell	Lk Stamford	Paint Crk	Stamford	
35	Nolan	Lk Sweetwater	Bitter Crk	Sweetwater	
34	Nolan	Lk Trammel	Sweetwater Crk	Sweetwater	
39	Parker	Lk Weatherford	Clear Fork Trinity Rvr	Weatherford	
56	Young	Lk Whiskey Crk	Whiskey Crk	Newcastle	
41	Runnels	Lk Winters	Elm Crk	Winters	
21	Hamilton	Leon Rvr	Leon Rvr	Hamilton	above Proctor Lk
50	Uvalde	Leona Rvr	Leona Rvr		increase base flow
29	Llano	Llano City Lk	Llano Rvr	Llano	
43	Shackelford	McCarty Lk	Salt Prong Hubbard Crk	Albany	
4	Baylor	Millers Crk Rsrvr	Millers Crk	North Central Texas MWA	not more than 20% canopy
36	Palo Pinto	Palo Pinto Rsrvr	Palo Pinto Crk	Palo Pinto MWD	
44	Somerville	Paluxy Rvr	Paluxy Rvr		
51	Val Verde	San Felipe Crk	San Felipe Crk	Del Rio	San Felipe springs
17	Erath	Thurber Lk	Gibson Crk	Thurber	
38	Palo Pinto	Tucker Lk	Russell Crk	Strawn	
57	Zavala	Upper Nueces Rvr	Nueces Rvr		irrigation

GENERAL BRUSH CONTROL AREA

The amount of precipitation is a key factor to determine whether water yield can be achieved from brush removal; Wilcox (2002) suggests precipitation is perhaps the most fundamental of these factors. Bosch and Hewlett (1982) found no increases in water yield in areas averaging less than 17.7 in/yr of annual precipitation. Hibbert (1979) stated if brush management is expected to increase water supply for an area, the annual precipitation should be greater than 18 in/yr. Wilcox (2002) also stressed that there is little prospect of increasing streamflows where mean annual precipitation is less than 19.7 in/yr.

The most widely used spatial climate datasets in the United States are those developed by Oregon State University's PRISM Climate Group, named for the PRISM climate mapping system. PRISM products are the official spatial climate datasets of the USDA, and are used by thousands of agencies, universities, and companies worldwide.

The general area eligible for feasibility studies statewide is based on the location of infestations of mesquite, juniper, saltcedar, huisache, and carrizo cane. Areas in Texas with infestations of these species located between the 16-inch isohyet and the 36-inch isohyet may be considered for feasibility studies (Figure 3.1). This map uses 30-year average annual precipitation datasets from 1981-2010 (PRISM Climate Group, Oregon State University). Proposed feasibility studies for watersheds located outside of this area may be reviewed by the TSSWCB on a case-by-case basis.

Figure 3.1. Map of the 16- to 36-inch average annual precipitation area of Texas, 1981-2010.

Section 3.1 Completed Feasibility Studies and Project Watersheds

Since 1998, TSSWCB has collaborated with many partnering entities to conduct assessments of the feasibility of conducting brush control for water supply enhancement in watersheds across Texas. These feasibility studies identify watersheds where it is feasible to enhance public water supplies through targeted brush control. The computer models used in these feasibility studies provide estimates of the projected water yield enhanced through brush control.

For a watershed to be considered eligible for allocation of WSEP cost-share incentive funds, a feasibility study must demonstrate increases in projected post-treatment water yield as compared to the pre-treatment conditions.

Feasibility studies have been conducted and published, and the reports accepted by the TSSWCB as designated WSEP Project Watersheds, for 24 watersheds:

- Lake Alan Henry (Harwell et al. 2016)
- Lake Arrowhead (RRA 2002)
- Lake Brownwood (LCRA 2002)
- Upper Guadalupe River above Canyon Lake (Bumgarner and Thompson 2012)
- Gonzales County [Carrizo-Wilcox Aquifer Recharge Zone and Guadalupe River] (McLendon et al. 2012)
- Frio River above Choke Canyon Reservoir (HDR 2000b)
- Nueces River above Lake Corpus Christi [above confluence Frio River] (HDR 2000c)
- Edwards Aquifer Recharge Zone (HDR 2000a)
    - Frio River
    - Hondo Creek
    - Medina River
    - Upper Nueces River
    - Sabinal River
    - Seco Creek
- North Concho River [O.C. Fisher Lake] (UCRA 1999)
- O.H. Ivie Reservoir (lake basin) (Hauck and Pandey 2015)
- O.H. Ivie Reservoir (watershed) [Upper Colorado River and Concho River] (UCRA 2000)
- Wichita River above Lake Kemp (RRA 2000)
- Canadian River above Lake Meredith (CRMWA 2000)
- Palo Pinto Reservoir (BRA 2003b)
- Fort Phantom Hill Reservoir (BRA 2003a)
- E.V. Spence Reservoir [Upper Colorado River] (UCRA 2000)
- Lake J.B. Thomas [Upper Colorado River] (UCRA 2000)
- Pedernales River [Lake Travis] (LCRA 2000)
- Twin Buttes Reservoir [including Lake Nasworthy] (UCRA 2000)

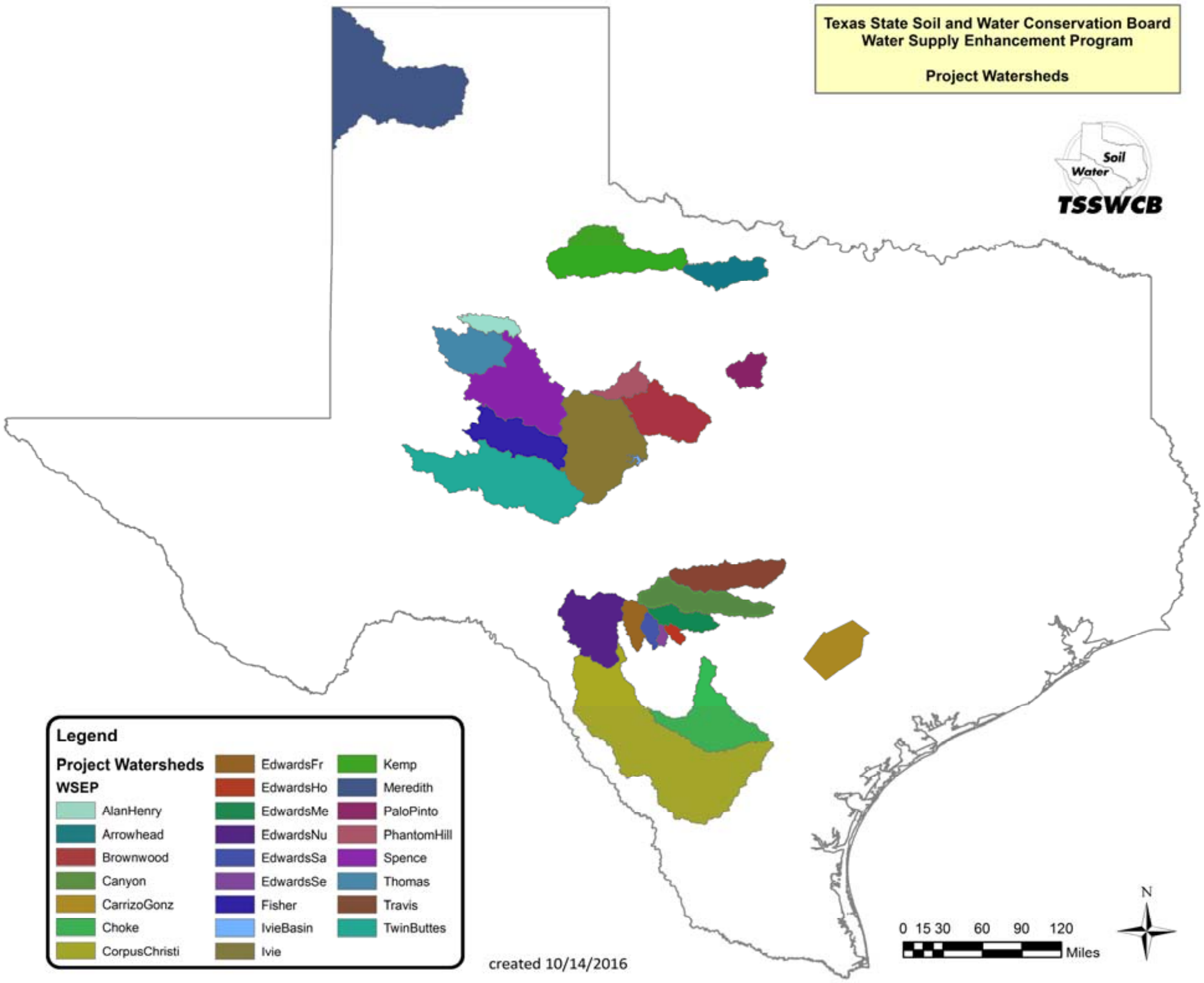

Figure 3.1.1 Map of Project Watersheds

Section 3.2 Feasibility Studies In Progress

Several feasibility studies are in progress; that is, computer models are being developed for these watersheds. Once these studies are completed, if they demonstrate increases in projected post-treatment water yield as compared to the pre-treatment conditions, the TSSWCB may consider accepting the feasibility studies and designating these areas as WSEP Project Watersheds.

Feasibility studies in progress, being conducted either solely with funds from the TSSWCB WSEP or collaboratively with funds from third-parties:

- Victoria and Goliad Counties, including lower San Antonio and Guadalupe Rivers
- Upper Llano River, including South and North Llano Rivers
- Wilson, Karnes, and Refugio Counties (third-party funding; SARA)
- Edwards Aquifer Recharge Zone – Upper Nueces River (carrizo cane specific) (third-party funding; NRA and EAA) [not shown on map] (Jain 2014; Jain et al. 2015)

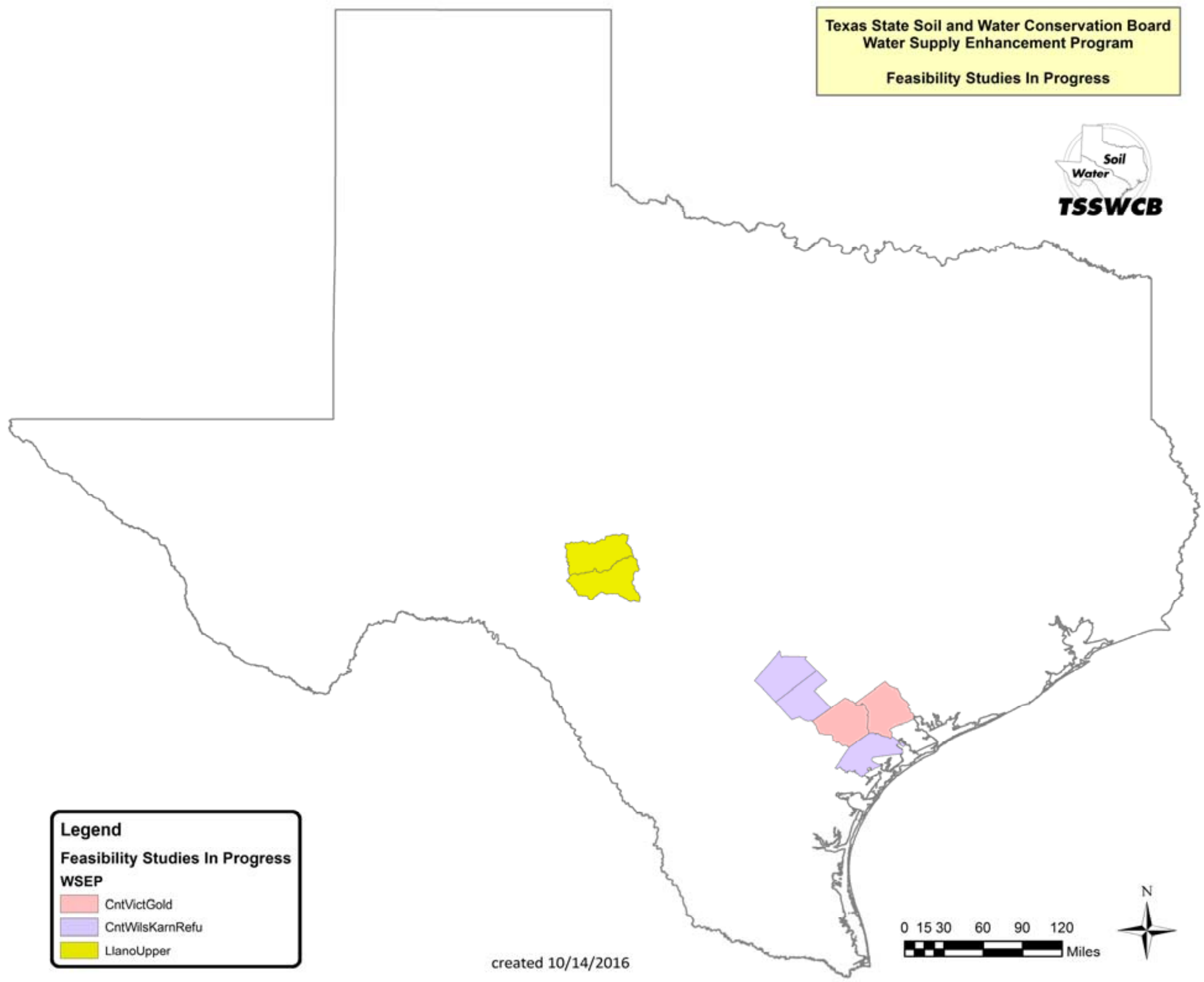

Figure 3.2.1 Map of Feasibility Studies In Progress

Section 3.3 Proposed Feasibility Studies

Local sponsors across the state have either applied for WSEP funding to conduct new feasibility studies or informally proposed new feasibility studies. As funds are appropriated by the Texas Legislature, and at the recommendation of the Science Advisory Committee, the TSSWCB may consider allocating WSEP funds to complete any of these proposed feasibility studies for watersheds that do not have an acceptable study.

Proposed feasibility studies to be considered in the future:

- Ballinger City Lake (saltcedar specific)
- Barton Springs segment of the Edwards Aquifer (Barton and Onion Creeks) [not shown on map]
- Carrizo-Wilcox Aquifer Recharge Zone in Burleson, Lee, Milam, and Williamson Counties
- Carrizo-Wilcox Aquifer Recharge Zone in Caldwell and Guadalupe Counties
- DeWitt County, including lower Guadalupe River and Lavaca River
- Greenbelt Reservoir (saltcedar specific) [not shown on map]
- Hill Country Priority Groundwater Management Area, Travis County portion only
- Hubbard Creek Reservoir (saltcedar specific)
- Lake Altus-Lugert (impounds North Fork Red River; lake in Oklahoma but approximately two-thirds of watershed in Texas) [not shown on map]
- Lake Buchanan, including San Saba River, Brady Creek, and lower Pecan Bayou
- Lake Graham[not shown on map]
- Lake LBJ, primarily Llano River below confluence of South and North Llano Rivers
- Lake Whitney, including Steele Creek
- Mackenzie Reservoir
- Medina River over Edwards Aquifer Recharge Zone (groundwater availability)
- Rio Grande (carrizo cane specific) [not shown on map]
- Stillhouse Hollow Reservoir (impounds Lampasas River)
- Trinity Aquifer Recharge Zone in Hood, Montague, Parker, and Wise Counties
- Upper Blanco River over Edwards Aquifer Recharge Zone
- Upper Brazos River above Possum Kingdom Reservoir (saltcedar specific)
- Upper Cibolo Creek over Edwards Aquifer Recharge Zone
- White River Reservoir (saltcedar specific)

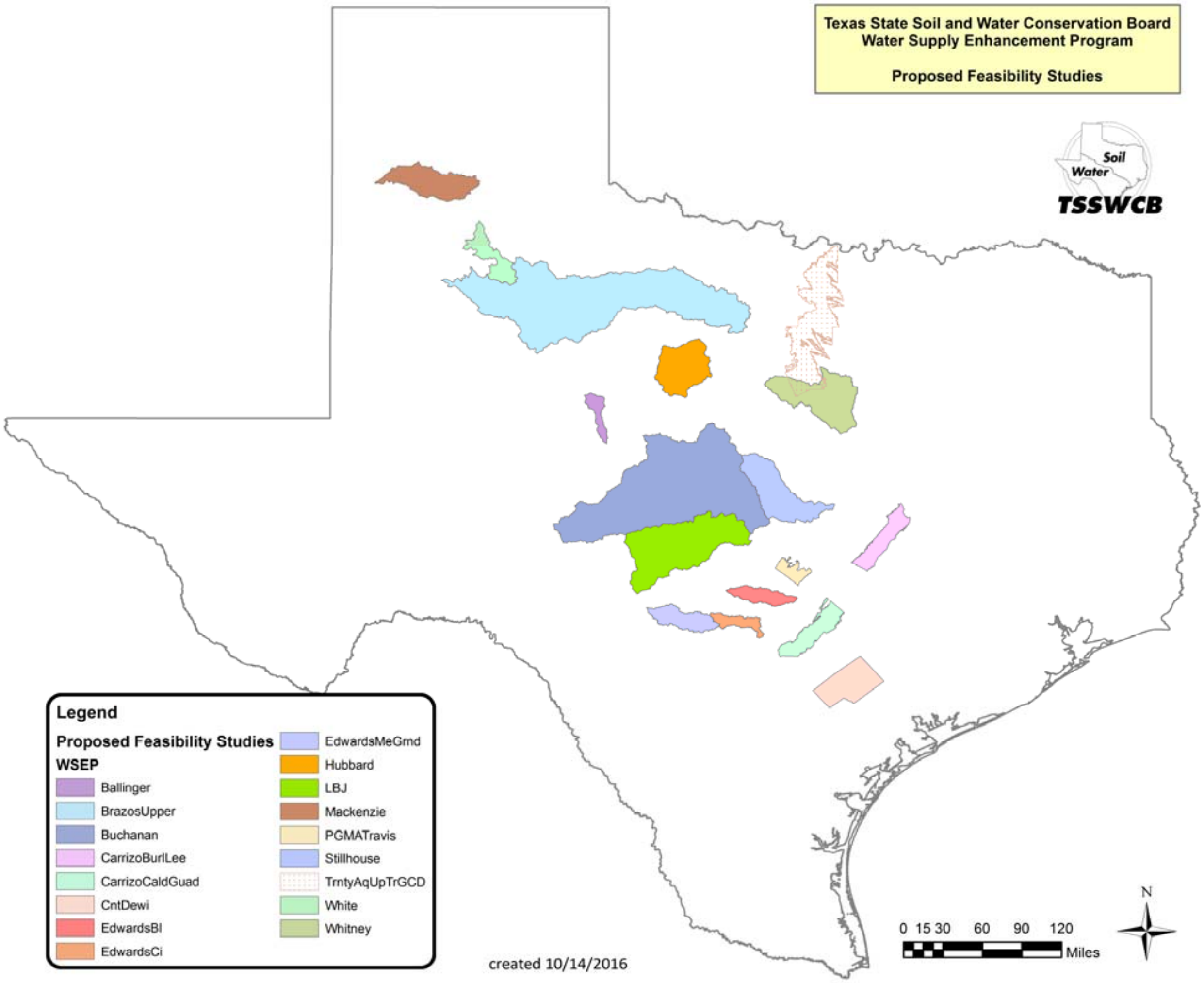

Figure 3.3.1 Map of Proposed Feasibility Studies

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Chapter 4 Program Goals and Evaluation Criteria

The primary focus of the Sunset review of the TSSWCB (2009-2011) was on accountability for state-funded grant programs administered by the agency. HB1808 required that for each state-funded grant program, goals had to be established along with evaluation criteria, compliance monitoring, and methods for analysis. Program goals, as recommended by the Stakeholder Committee on February 22, 2012, were adopted by TSSWCB *Policy* on March 6, 2013 and describe the intended use of a water supply enhanced by the WSEP and the populations that the WSEP will benefit. The two specific goals are directly related to the Ranking Index and the geospatial analysis.

GENERAL GOALS

- Enhance domestic and municipal uses, including water for sustaining human life and the life of domestic animals, agricultural and industrial uses (which means processes designed to convert materials of a lower order of value into forms having greater usability), commercial value, and environmental flows.

- Enhance mining and recovery of minerals, power generation, navigation, recreation and pleasure, and other beneficial uses.

SPECIFIC PROGRAM GOALS

- Implement project proposals that most enhance water quantity to the municipal water supplies most in need. [related to Ranking Index]

- Direct program grant funds toward acreage within an established project that will yield the most water. [related to geospatial analysis]

Section 4.1 Specific Goal 1

Specific Goal

- Implement project proposals that most enhance water quantity to the municipal water supplies most in need.

Evaluation Criteria

- Public water supplies expected to be benefited by the project
- Water supply yield enhancement to target water supplies, which is the projected water yield from a feasibility study
- WUGs relying on water supplies
- Percent of target water supplies used by WUGs
- Population of WUGs
- A calculated Ranking Index that gives a measure of the yield benefit per capita for each project proposal

Compliance Monitoring

- Performance certifications are carried out to verify initial treatment, and status reviews are performed to verify compliance with follow-up treatment requirements that specify the brush canopy is being maintained at 5% or less (target species only) of what was established after initial treatment during the 10-year contract.

Analysis

- The feasibility studies provide simulated water yields; therefore, based on the project's progress (number of acres treated) at a given point in time the amount of water yielded can be estimated. Additionally, the results of status reviews provide the agency a measure of compliance with follow-up treatment that can be used to estimate continuing water yield benefits over the course of the 10-year contract with the participant. Acres not in compliance may be eliminated from water yield calculations. Finally, when available, water quantity monitoring data is analyzed to observe actual impacts on water supplies.

Publishing

- Program results are documented in the statutorily-required *Annual Report* and this *State Plan*.

Section 4.2 Specific Goal 2

Specific Goal

- Direct program grant funds toward acreage within an established project that will yield the most water.

Evaluation Criteria

- A geospatial analysis is used to rank zones within a project's overall watershed into categories of high, medium, and low potential to yield water; a not-eligible category is also included. The evaluated characteristics include:
    - Soil Type
    - Slope
    - Brush Density
    - Proximity to waterbodies and other hydrologically sensitive areas
    - Proximity to watershed outlet

Compliance Monitoring

- Performance certifications, carried out to verify initial treatment, provide verification that the treated area is within a specified zone.

Analysis

- Treatment of acreage not within the scope of the contract is not reimbursed through the Program.

Publishing

- Program results are documented in the statutorily-required *Annual Report* and this *State Plan*.

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Chapter 5 Interaction with State Water Plan and Regional Water Planning Groups

The *State Water Plan* is developed through a process where local and regional stakeholders are tasked with developing regional water plans for how to meet water needs during times of drought. The Texas Legislature established this water planning process in 1997. The 16 RWPGs (see Figure 5.1) represent a variety of interests, including agriculture, industry, environment, public, municipalities, business, water districts, river authorities, water utilities, counties, GCDs, groundwater management areas, and power generation. Each RWPG is responsible for developing its own regional water plan for a 50-year planning horizon. RWPGs make decisions on quantifying current and projected water demands and supplies, identifying water surpluses and needs, and evaluating WMS to meet needs. The TWDB then develops a comprehensive *State Water Plan* compiled from information in the 16 regional water plans and other sources. While the *State Water Plan* incorporates information from the regional water plans, it is more than just the sum of the regional plans; the *State Water Plan* serves as a guide to State water policy and provides recommendations to the Texas Legislature. (TWDB 2013)

In developing their regional water plans, after the RWPGs compare water demand and supply and complete needs analyses, the Groups evaluate potentially feasible WMS to meet the needs for water within their regions. A WMS is a plan that may require a specific project to meet a need for additional water by a WUG, which can mean increasing the total water supply or maximizing an existing supply. Strategies can include development of new ground or surface water supplies; conservation; reuse; or less conventional methods like weather modification, brush control, and desalination.

On May 19, 2016, the TWDB adopted the *2017 State Water Plan* (TWDB 2016), including the 2017 Interactive State Water Plan website. Brush control, a voluntary land stewardship practice, is included as a recommended WMS by several RWPGs. A summary of brush control related WMS recommended in the *2017 State Water Plan* is provided in Table 5.1. Additional information is available at http://www.twdb.texas.gov/waterplanning/swp/2017/index.asp.

To meet the needs for water during a repeat of the drought of record, RWPGs evaluated and recommended approximately 5,500 unique WMS resulting in a total, if implemented, of 8.5M ac-ft/yr of additional water supplies by 2070. The estimated total capital cost to design, construct, and implement approximately 2,400 WMS projects recommended by the RWPGs is $62.6B. Throughout the *2017 State Water Plan*, brush control WMS are included in the “Other Strategies” category (TWDB 2016).

A report prepared for the TWDB in 2000 (Research and Planning Consultants, Inc.) assessed brush control as a WMS and concluded that the selection of watersheds for brush management projects to produce additional water for specific water supply purposes should be considered by the RWPGs or a specific WUG to gage local support for cost-sharing brush control.

An issue raised by several RWPGs and the TWDB is that brush control may not result in “firm” yield during times of drought. Specifically, in the *State Water Plan*, the TWDB concludes that since water produced by brush control during a drought when little rainfall occurs is difficult to quantify, it is not often recommended as a strategy to meet municipal needs.

A recently published study (Asquith and Bumgarner 2014) conducted by the USGS with funding from the TSSWCB examined this issue. The study linked the Upper Guadalupe River SWAT model created for the feasibility study with the TCEQ-authorized version of the Guadalupe River water availability model (WAM). WAMs are used in water rights permitting and in regional water planning. The study quantified brush management water yields during periods lacking abundant rainfall, defined as when Canyon Lake storage was below the 25th percentile. The USGS concluded that brush control in the watershed does increase lake levels during times of the lowest quartile precipitation, that is, during drought-like conditions. All of the brush management scenarios resulted in an increase on average to monthly water supply storage in Canyon Lake during the drought quartile through the SWAT-WAM linkage: 110 ac-ft (20% brush treated); 448 ac-ft (40% brush treated); 754 ac-ft (60% brush treated); 1,080 ac-ft (80% brush treated); and 1,090 ac-ft (100% brush treated).

In August 2015, TSSWCB and HDR Engineering, Inc. finalized the project final report *Brush Management in Gonzales County as a Water Management Strategy* (HDR 2015). This study was conducted by HDR, with funding from the TSSWCB, in order to link the Gonzales County brush control feasibility study (McLendon et al. 2012) to the Carrizo-Wilcox Aquifer groundwater availability model (TWDB) in Gonzales County in order to evaluate brush management as a WMS for potential inclusion in the *2016 South Central Texas Regional Water Plan* (Region L). The model scenarios show that implementing a brush management program in Gonzales, Caldwell, and Guadalupe Counties could potentially increase the groundwater levels and the subsequent modeled available groundwater (MAG) in these counties by 1,370 to 13,910 ac-ft/yr depending on landowner participation levels. Ultimately, Region L did not recommend this potential WMS.

Brush control for water supply enhancement is addressed differently by the 16 RWPGs in their regional water plans making incorporation into the *State Water Plan* complex. This presents challenges in interpreting how brush control for water supply enhancement is assimilated in the *State Water Plan*. It has been described as brush control or brush management, vegetative management, or land stewardship, or range management. It might be included as a recommended or alternative WMS which may have a quantified yield or a zero yield; the *2017 State Water Plan* identifies only five regions where brush control was a recommended WMS with a quantified yield. Brush control also may be included in policy recommendations included in each regional water plan.

Five RWPGs (F, G, J, K, and M) recommended brush control as a WMS with quantified water yields. The *2017 State Water Plan* includes 32 recommended WMS for brush control (Table 5.1). By the 2070 planning horizon, together these brush control WMS contribute 9,656 ac-ft/yr to the total supply volume from all recommended WMS in the *2017 State Water Plan*. Four

RWPGs (A, B, C, and O) recommended brush control as a WMS, but with no quantified water yields. These strategies are not reflected in the *2017 State Water Plan*; rather, these strategies are only included in each respective regional water plan. Nine RWPGs (A, B, F, G, H, K, L, M, and O) included policy recommendations regarding brush control in their respective regional water plan; however, in this iteration of the *State Water Plan*, the TWDB did not aggregate policy recommendations from the RWPGs. Three RWPGs (D, I, and N) determined that brush control was not a feasible strategy for their region due to a variety of reasons, while three other RWPGs (E, H, and P) did not discuss brush control at all in their plans.

Agriculture Code §203.053 requires that, in prioritizing water supply enhancement projects for funding, the TSSWCB must consider the need for conservation of water resources within the territory of a proposed project, based on the *State Water Plan* as adopted by the TWDB. The TSSWCB also considers whether or not a RWPG has identified brush control as a recommended WMS in the *State Water Plan*. Table 5.1 provides a summary of brush control related WMS in the *2017 State Water Plan*.

More information on the *State Water Plan* and the regional water planning process is available at http://www.twdb.texas.gov/waterplanning/.

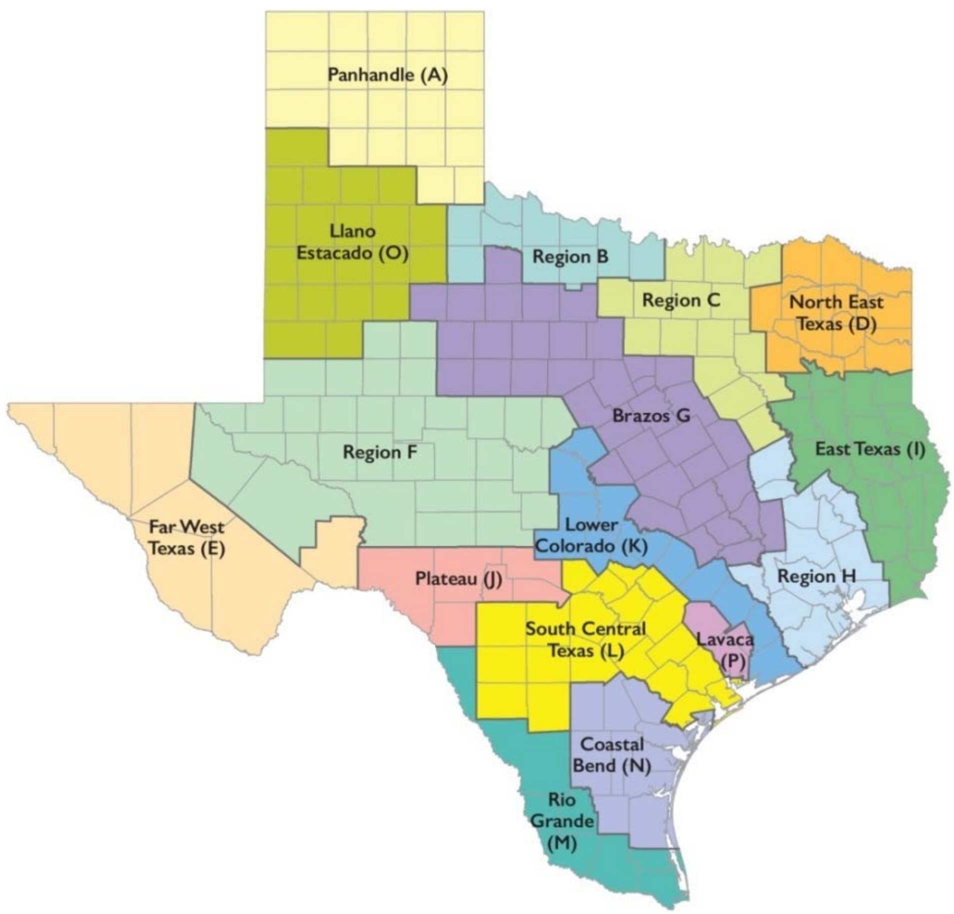

Figure 5.1 Regional Water Planning Areas (TWDB 2016)

Table 5.1 Summary of Brush Control in 2017 State Water Plan

WUG RWPG	WUG	WMS RWPG	Recommended WMS	WMS supply volume by planning decade (ac-ft/yr) 2020	2030	2040	2050	2060	2070
F	COUNTY-OTHER, TOM GREEN	F	BRUSH CONTROL - SAN ANGELO	41	25	29	26	28	31
F	MANUFACTURING, TOM GREEN	F	BRUSH CONTROL - SAN ANGELO	98	75	90	83	98	113
F	SAN ANGELO	F	BRUSH CONTROL - SAN ANGELO	747	576	661	781	693	793
G	ABILENE	G	BRUSH CONTROL-FORT PHANTOM HILL WATERSHED	0	0	0	0	0	0
J	COUNTY-OTHER, BANDERA	J	BCRAGD - VEGETATIVE MANAGEMENT	0	0	0	0	0	0
J	COUNTY-OTHER, EDWARDS	J	EDWARDS COUNTY OTHER - VEGETATIVE MANAGEMENT - ARUNDO DONAX	0	0	0	0	0	0
J	COUNTY-OTHER, KERR	J	KERR COUNTY OTHER - VEGETATIVE MANAGEMENT - ASHE JUNIPER	0	0	0	0	0	0
J	COUNTY-OTHER, KINNEY	J	KINNEY COUNTY OTHER - VEGETATIVE MANAGEMENT - ARUNDO DONAX	0	0	0	0	0	0
J	COUNTY-OTHER, REAL	J	REAL COUNTY OTHER - VEGETATIVE MANAGMENT (ARUNDO DONAX)	0	0	0	0	0	0
J	COUNTY-OTHER, VAL VERDE	J	VAL VERDE COUNTY OTHER - VEGETATIVE MANAGEMENT (ARUNDO DONAX)	0	0	0	0	0	0
K	COUNTY-OTHER, BLANCO	K	BRUSH CONTROL	425	425	425	425	425	425
K	COUNTY-OTHER, BURNET	K	BRUSH CONTROL	425	425	425	425	425	425
K	COUNTY-OTHER, GILLESPIE	K	BRUSH CONTROL	425	425	425	425	425	425
K	COUNTY-OTHER, HAYS	K	BRUSH CONTROL	425	425	425	425	425	425
K	COUNTY-OTHER, LLANO	K	BRUSH CONTROL	425	425	425	425	425	425
K	COUNTY-OTHER, MILLS	K	BRUSH CONTROL	425	425	425	425	425	425
K	COUNTY-OTHER, SAN SABA	K	BRUSH CONTROL	425	425	425	425	425	425
K	COUNTY-OTHER, TRAVIS	K	BRUSH CONTROL	425	425	425	425	425	425

WUG RWPG	WUG	WMS RWPG	Recommended WMS	WMS supply volume by planning decade (ac-ft/yr) 2020	2030	2040	2050	2060	2070
M	IRRIGATION, CAMERON	M	ARRUNDO DONAX BIOLOGICAL CONTROL	1,087	1,198	1,310	1,426	1,547	1,661
M	IRRIGATION, HIDALGO	M	ARRUNDO DONAX BIOLOGICAL CONTROL	1,954	2,152	2,344	2,525	2,694	2,892
M	IRRIGATION, MAVERICK	M	ARRUNDO DONAX BIOLOGICAL CONTROL	162	183	207	233	263	282
M	IRRIGATION, STARR	M	ARRUNDO DONAX BIOLOGICAL CONTROL	41	39	35	29	20	21
M	IRRIGATION, WEBB	M	ARRUNDO DONAX BIOLOGICAL CONTROL	23	27	31	36	41	44
M	IRRIGATION, WILLACY	M	ARRUNDO DONAX BIOLOGICAL CONTROL	212	243	279	320	368	397
M	IRRIGATION, ZAPATA	M	ARRUNDO DONAX BIOLOGICAL CONTROL	14	16	17	19	20	22
M	IRRIGATION, CAMERON	M	BRUSH CONTROL	0	0	0	0	0	0
M	IRRIGATION, HIDALGO	M	BRUSH CONTROL	0	0	0	0	0	0
M	IRRIGATION, MAVERICK	M	BRUSH CONTROL	0	0	0	0	0	0
M	IRRIGATION, STARR	M	BRUSH CONTROL	0	0	0	0	0	0
M	IRRIGATION, WEBB	M	BRUSH CONTROL	0	0	0	0	0	0
M	IRRIGATION, WILLACY	M	BRUSH CONTROL	0	0	0	0	0	0
M	IRRIGATION, ZAPATA	M	BRUSH CONTROL	0	0	0	0	0	0
				7,779	7,934	8,403	8,878	9,172	9,656

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Chapter 6 Annual Program Process

The TSSWCB collaborates with SWCDs, and other local, regional, state, and federal agencies to identify watersheds across the state where it is feasible to conduct brush control in order to enhance public water supplies. The agency has established detailed guidance on factors that must be considered in a feasibility study. Once a feasibility study is completed, if it demonstrates increases in projected post-treatment water yield as compared to the pre-treatment conditions, the TSSWCB may consider designating the studied area as a priority WSEP Project Watershed, making the watershed eligible for allocation of WSEP cost-share incentive funds.

The TSSWCB uses a competitive grant process to rank and select feasible projects and allocate WSEP cost-share incentive funds. Project proposals must relate to a water conservation need, based on information in the *State Water Plan* as adopted by the TWDB. A feasibility study must have been completed for the watershed in each proposal. Proposals are prioritized for each funding cycle, giving priority to projects that balance the most critical water conservation need of municipal WUGs with the highest projected water yield from brush control. Applications are ranked using a calculated Ranking Index that gives a measure of the projected water yield increased per capita user for each proposal. TSSWCB utilizes the Ranking Index and other statutorily-required considerations to prioritize proposals and allocate funding.

In project watersheds where WSEP cost-share incentive funds have been allocated, the TSSWCB performs a geospatial analysis to delineate and prioritize the acreage eligible for cost-share of brush control activities. This geospatial analysis maximizes the positive impacts of brush control on water supply enhancement and the effective and efficient use of allocated funds by prioritizing the acreage that has the highest potential to yield water within the project watershed. Characteristics that are assessed in the geospatial analysis include soils, slope, brush type and density, proximity to waterbodies and other hydrologically sensitive areas, and proximity to the watershed outlet. The geospatial analysis results in four brush control priority zones for each watershed: high, medium, low, and not-eligible.

In project watersheds where WSEP cost-share incentive funds have been allocated, the TSSWCB works through SWCDs to deliver technical assistance to landowners in order to implement brush control activities for water supply enhancement. A 10-year resource management plan is developed for each property enrolled in the WSEP, in accordance with technical standards and specifications within the USDA-NRCS FOTG. These plans are designed to implement brush control, sound range management practices, and other soil and water conservation land improvement measures; these plans meet landowner goals and address wildlife considerations. These resource management plans describe the extent and method of brush control activities to be implemented, follow-up treatment requirements, brush density to be maintained after treatment, and supporting practices to be implemented including livestock grazing management, wildlife habitat management, and erosion control measures.

Cost-share incentive funding is made available through the WSEP to landowners implementing brush control activities on eligible acres (in project watersheds) consistent with their resource management plan. The TSSWCB and the local SWCD enter into cost-share agreements with individual landowners. Cost-share agreements must be based on an approved resource management plan developed for the property. Upon completion of brush control as described in the cost-share agreement, the local SWCD or TSSWCB inspects the work to verify the practice was performed and implemented in accordance with specifications set forth in the FOTG. Canopy cover of target brush species must be reduced to less than 5% to be certified. A performance certification is completed which then results in the cost-share payment being made by the TSSWCB to the participant.

All WSEP resource management plans that received cost-share assistance are subject to periodic status reviews conducted by the TSSWCB. Status reviews are conducted within three to five years after initial treatment of brush to determine if the canopy (target species only) is above 5%. A second status review is performed eight to nine years after initial treatment. If the participant is found out of compliance, they will not be eligible for another WSEP contract for a period of ten years.

The TSSWCB publishes a statutorily-required WSEP *Annual Report* which serves as a comprehensive analysis of the program's effectiveness during the preceding calendar year. The *Annual Report* documents program results, assesses the program, reports on program participant compliance with resource management plans, and reports overall projected water yield enhanced.

Section 6.1 State Plan Approval

Agriculture Code §203.051 requires the TSSWCB to prepare and adopt this *State Water Supply Enhancement Plan*.

Before the TSSWCB adopts the *State Plan*, the TSSWCB shall call and hold a hearing to consider a proposed plan. Not less than 30 days before the date the hearing is to be held, the TSSWCB shall mail written notice of the hearing to each SWCD. Written comments on the proposed plan are accepted. At the hearing, persons may present suggestions for any changes in the proposed plan.

After the conclusion of the hearing, the TSSWCB shall consider the testimony, including the information and suggestions made at the hearing and in written comments, and after making any changes in the proposed plan that it finds necessary, the TSSWCB shall adopt the *State Water Supply Enhancement Plan*.

2016 PROCESS

On November 17, 2016, the TSSWCB approved publishing notice in the *Texas Register* of the availability, for public review and comment, of the proposed revision to the *State Water Supply Enhancement Plan*. On December 2, 2016, notice was published in the *Texas Register*. The public comment period on the proposed revision of the *State Plan* was open for 39 days, through January 9, 2017. A letter was sent to all SWCDs (November 30, 2016) and an agency news release was also published (December 2, 2016).

On January 5, 2017, TSSWCB staff conducted a statutorily-required public hearing in Temple to receive oral comments on the proposed revision to the *State Water Supply Enhancement Plan*; no one from the public attended the hearing.

The agency received 15 sets of comments (100 individual comments) from various citizens and entities on the proposed revision to the *State Water Supply Enhancement Plan*. TSSWCB staff developed responses to comments received. Changes were made to the document as a result of comments received during the public comment period. A summary of public comments received and the State's responses is included as Appendix A.

On January 19, 2017, the TSSWCB adopted the revision to the *State Water Supply Enhancement Plan*, as proposed with changes made based on public comments received.

Section 6.2 Request for Proposals

For each funding cycle, the TSSWCB issues a *Request for Proposals for Water Supply Enhancement Projects* seeking program funding to conduct brush control under the WSEP. Proposed projects should focus on watersheds with a demonstrated water conservation need and where brush control has been shown, using a computer model, to be a feasible strategy to enhance surface and/or ground water supplies. A competitive proposal review process is used so that the most appropriate and effective projects are selected for funding.

Project proposals must relate to a water conservation need, based on information in the *State Water Plan* as adopted by the TWDB. Project proposals are evaluated giving priority to projects that balance the most critical water conservation need of municipal WUGs with the highest projected water yield from brush control.

WSEP funds will only be allocated to projects that have a completed feasibility study that includes a watershed-specific computer-modeled water yield component developed by a person with expertise as described in Agriculture Code §203.053(b). For a watershed to be considered eligible for allocation of WSEP cost-share incentive funds, the feasibility study must demonstrate increases in projected post-treatment water yield as compared to the pre-treatment conditions.

The proposal submission packet includes the application for proposed water supply enhancement projects, a set of instructions that provides explanations of questions on the form and resources for answering those questions, and a set of guidelines that details project eligibility requirements and provides additional information critical for successful applications.

PROCESS FOR ACCEPTING AND RANKING WSEP PROJECTS

1. An application is submitted for consideration. A feasibility study is required. Proposals for cost-share incentive funds that are associated with a watershed that does not have a feasibility study will be considered as an application for agency funding to complete the required study.

2. Applications are ranked according to the process developed by the Stakeholder Committee using a calculated Ranking Index.

3. Geospatial analysis is performed to identify zones of high, medium, and low potential water yield. Zones of high potential water yield are considered eligible acres within a project area. A not-eligible zone is also identified.

Section 6.3 Project Establishment

Brush management will be accomplished through a series of watershed or sub-watershed projects in which brush management shows a strong potential to increase water yield.

The TSSWCB may delineate brush control areas in which a water need exists based on the most recent *State Water Plan* and in which brush control has a strong potential to increase water yield. Brush control area delineation will be based on feasibility studies, brush infestation, and water needs.

SWCDs will manage individual projects. Within a brush control area (i.e., WSEP Project Watershed), SWCDs may develop brush control projects where there is sufficient local support. Project proposals will be submitted to the TSSWCB for approval. After receiving a project proposal, the TSSWCB may conduct additional feasibility studies of the project area. A project that meets all requirements may then be approved by the TSSWCB. If there are more project proposals than can be supported by available cost-share incentive funds, the TSSWCB will prioritize the projects, favoring the areas with the most critical water conservation need of municipal WUGs and the projects with the highest project water yield from brush control and are cost-effective.

The TSSWCB will approve brush control methods on the State level and the SWCDs will use the methods in developing individual landowner resource management plans. The TSSWCB, with the input of local SWCDs and landowners, will set cost-share rates for individual projects. SWCDs may contract with landowners to develop and implement individual resource management plans within project areas. Landowners may then implement resource management plans and receive cost-share payments upon completion of the brush control practices specified in the individual plans.

Section 6.4 Allocating Funds

Based on application ranking (using the Ranking Index) and the geospatial analysis, funds will be allocated to specific projects. An allocation is calculated based on the number of high ranking eligible acres, the desired number of eligible acres the proposal identifies for treatment, the average cost of brush control per method for each eligible acre, and the amount of time required to treat the number of acres targeted in the proposal. Funds will be allocated to projects in highest ranking order. Proposals may be partially funded if the allocation is at least 25% of the original request on the application.

Allocated funds may only be obligated to landowners for brush control 1) in the designated subwatershed, and 2) only in the high priority zone within that subwatershed as per the geospatial analysis. Allocated funds may not be obligated to landowners for brush control in 1) the medium or low zones within the designated subwatershed as per the geospatial analysis, or 2) other subwatersheds identified on the application or in the feasibility study.

On a date set by the TSSWCB Executive Director, each project's progress at obligating allocated cost-share incentive funds to landowners shall be assessed. This assessment will be used to determine if unobligated funds should be de-allocated from a project and re-allocated to another project in order to maximize expenditure of WSEP funds during the fiscal year.

Section 6.5 Program Assessment

The TSSWCB publishes a statutorily-required WSEP *Annual Report* which serves as a comprehensive analysis of the program's effectiveness during the preceding calendar year. The *Annual Report* documents program results, assesses the program, reports on program participant compliance with resource management plans, and reports overall projected water yield enhanced.

The number of acres of brush treated per project watershed using WSEP cost-share incentive funds are reported in the *Annual Report*. Utilizing the modeled water yield for each subwatershed from the published feasibility studies, the projected water yield from the brush treated using cost-share is also reported in the *Annual Report*. Each feasibility study includes a target number of acres to be treated in each subwatershed which is compared to the running total of actual treated acres utilizing cost-share. This allows the approximate percentage toward project completion to be estimated, and thus the progress toward yielding the total predicted amount of water.

In accordance with 31 TAC §517.36(b)(3)-(4), TSSWCB staff conduct status reviews on lands under contract to perform brush control activities and receive cost-share. Status reviews are conducted within three to five years after initial treatment of brush to determine if the canopy (target species only) is above 5%. A second status review is performed eight to nine years after initial treatment. If the participant is found out of compliance with the 5% brush density requirement, he will not be eligible for another WSEP contract for a period of ten years. The number of status reviews conducted and the number of contracts found to be out of compliance are also reported in the *Annual Report*.

The feasibility studies provide simulated water yields, therefore based on the project's progress (number of acres treated) at a given point in time the amount of water yielded can be estimated. Additionally, the results of status reviews provide the agency a measure of compliance with follow-up treatment that can be used to estimate continuing water yield benefits over the course of the ten-year contract with the participant. Acres not in compliance may be eliminated from water yield calculations.

Section 6.6 State Plan Revision

Agriculture Code §203.054 requires that, at least every two years, the TSSWCB shall review, and may amend, the *State Water Supply Enhancement Plan* to take into consideration changed conditions. Amendments to the plan shall be made in the manner provided for adopting the original plan.

Chapter 7 Project Establishment Process

PROJECT PROPOSALS, FEASIBILITY STUDIES, AND RANKING

A statutory requirement for the WSEP requires that there be a competitive aspect to the program so that all areas of the state would have an opportunity to propose a water supply enhancement project for local water supplies. In response, the agency developed an application and a process for entities to propose the establishment of projects.

A feasibility study, to include a computer model that estimates the projected water yield for the proposed project, is required to be completed prior to the project being established.

The feasibility study and the projected water yield are required so that the information can be used to rank proposals according to a set of criteria (i.e., the Ranking Index).

The ranking criteria were developed by the Stakeholder Committee. In addition to establishing criteria to rank proposals based on water yield and conservation needs, the agency has established a process to further refine implementation of the program within the scope of an established project. Through geospatial analysis, the agency will identify and target the acreage within project sub-basins that are most likely to result in the greatest water yield.

BRUSH CONTROL AREA DELINEATION

In order for a project to be eligible for State funding, it must be in a brush control area delineated by the TSSWCB (i.e., Project Watershed). However, being in a Project Watershed does not guarantee that a specific project will be funded since the need for brush control cost-share incentive funds is much greater than the available funding. The TSSWCB will delineate areas eligible for projects and cost-share incentive funding where a water need exists based on the most recent *State Water Plan* (as adopted by the TWDB) and where brush control has a strong potential to increase water yield. Water yield potential is based on a completed feasibility study.

Because of the many factors involved in developing a successful project such as willingness of the local people to participate, landowner cooperation, social and economic considerations, and wildlife concerns, project applications should come from the local level.

Section 7.1 Applications for Funding

PROJECT DEVELOPMENT

Local SWCDs or other agencies in cooperation with SWCDs may develop project proposals within the state. The proposals will be submitted to the TSSWCB for its prioritization and approval. The TSSWCB, on its own initiative, may initiate project development in cooperation with local SWCDs.

SPONSORSHIP BY SOIL AND WATER CONSERVATION DISTRICTS

Local SWCDs, along with landowners, will be the key to the development of successful water supply enhancement projects. SWCDs have experience in the development and implementation of locally initiated projects. When local interest is such that action is deemed necessary, someone must lead and coordinate the effort. SWCDs are qualified to assume this role. They are accessible to anyone and they especially have considerable experience in working with landowners and land users, both individually and as a group. If a potential project area is larger than a single SWCD, several SWCDs may cooperate on the project development and implementation.

An SWCD may administer aspects of the WSEP within any Project Watershed located within the jurisdiction of that SWCD. The TSSWCB must prepare information on the WSEP and procedures for cost-sharing and provide this information to each SWCD. SWCDs may accept, review, and comment on individual applications for cost-share, and submit them to the TSSWCB for action. SWCDs may inspect and supervise projects within their jurisdictions. SWCDs, landowners, and other agencies will have the opportunity for input into all aspects of brush control projects.

REQUIREMENTS OF PROJECT PROPOSALS

1. A proposal must denote sufficient interest by a group of landowners and operators in a Project Watershed designated by the TSSWCB to allow for the eventual completion of the project.
2. A valid proposal must show adequate sponsorship by one or more SWCDs. Enlisting additional sponsors, such as cities, counties, or other political subdivisions, could be beneficial to the project and is encouraged.
3. The SWCD involved must agree to take leadership and coordinate the project through implementation or agree to work with a regional conservation technician.
4. The project area proposed in the proposal should be of sufficient size to provide a significant potential gain in the water yield from the Project Watershed where the project is located.

5. The proposal should provide as much evidence as possible that the acreage to be treated within the project area does have the potential to improve water yields. Subjects that should be addressed are:
   (a) size and location of the area
   (b) brush – type, density, and canopy cover
   (c) water needs or potential needs
   (d) potential yield
   (e) wildlife compatibility to the project
   (f) landowner cooperation
   (g) ability of participants to pay their share of the cost
   (h) types of treatment measures
   (i) completion schedule
6. Proposals should be submitted as required by the TSSWCB.

The TSSWCB will provide assistance to SWCDs in the development of project proposals as needed.

Section 7.2 Feasibility Studies

As funding becomes available, feasibility studies will be used as a tool for delineating critical areas. These studies may be done in cooperation with other State or federal agencies, universities, and local entities. These studies will be conducted in watersheds in the general brush control area (Figure 3.1) and where designated by the TSSWCB in consultation with SWCDs, other State, federal, and local agencies, and universities or as determined by the Texas Legislature. Feasibility studies may also be conducted by other entities and then submitted to the TSSWCB for consideration for project establishment.

At the recommendation of the Science Advisory Committee, funds may be allocated to complete a feasibility study for watersheds that do not have an acceptable study.

WSEP funds will only be allocated to projects that have a completed feasibility study that includes a watershed-specific computer-modeled water yield component developed by a person with expertise as described in Agriculture Code §203.053(b).

For a watershed to be considered eligible for allocation of WSEP cost-share incentive funds, the feasibility study must demonstrate increases in projected post-treatment water yield as compared to the pre-treatment conditions.

Feasibility studies must, at a minimum, have examined the following necessary input information to characterize the watershed under consideration for brush control:

- Watershed Delineation. The contributing drainage area that includes the treatment area should be identified using the USGS National Hydrography Dataset and the USGS Watershed Boundary Dataset (12-digit hydrologic units), and confirmed with a digital elevation model.
- Topography. Ten-meter digital elevation models from the USGS National Elevation Dataset should be used.
- Hydrology. Appropriate data from the USGS National Hydrography Dataset and analysis of the digital elevation model should confirm the locations of surface waterbodies, including stream and river channels, impoundments, and reservoirs within the area of interest, and other hydrologically sensitive areas critical to streamflow and aquifer recharge. Flood control dams (e.g., PL-566 floodwater retarding structures) must also be included in the hydrologic dataset.
- Soil Types and Distribution. The USDA Soil Survey Geographic database should be used to demonstrate the variations in soil type and other physical parameters that impact runoff and infiltration across the area of interest.
- Vegetation and Land Use. The USGS National Land Cover Dataset 2011 provides different land cover classifications at 30-m resolution which should be analyzed. Additionally, the Ecological Mapping System of Texas dataset published by the TPWD should be utilized in the analysis. For more recent land use descriptions as well as vegetation descriptions, digital orthophoto quarter quadrangles can be obtained from the USDA and assembled as a mosaic to envelop the watershed of interest; 1-meter

National Agriculture Imagery Program orthophotos from 2014 are available from the Texas Natural Resources Information System. Ground-truthing site visits are necessary to confirm vegetation types and locations.
- Roads and Highways. ESRI datasets include features such as streets, county roads, highways, freeways, and other transportation infrastructure that may affect local watershed behavior.

Proposals for cost-share incentive funds that are associated with a watershed that does not have a feasibility study will be considered as an application for agency funding to complete the required study. Applications for funding to complete a new feasibility study will be referred to the Science Advisory Committee for review.

In considering the project's anticipated impact on water yield and in reviewing the applications for funding a new feasibility study, the Science Advisory Committee will at least consider:
- Recommendations in the *State Water Plan* or a regional water plan to conduct a feasibility study in the watershed of the proposed project.
- Published science that suggests the proposed project may yield water in Texas.

Once applications are considered, the TSSWCB, with guidance from the Science Advisory Committee, will direct applying entities to an appropriate modeler [per Agriculture Code §203.057(a)] to conduct the feasibility study. If agency funds are allocated to complete a feasibility study, the TSSWCB may contract either with the entity who proposed the project, or directly with a qualified modeler chosen by both parties to conduct the feasibility study.

Subsection 7.2.1 Requirements for Computer Modeling for Water Yield Predictions

These requirements, developed by the Science Advisory Committee, provide detailed guidance for application of appropriate computer models for feasibility studies that predict water yield resulting from proposed brush control projects. For a proposed brush control project to be considered eligible for allocation of cost-share incentive funds from TSSWCB, the feasibility study must demonstrate increases in post-treatment water yield as compared to the pre-treatment conditions. The projected water yield will be included in the WSEP proposal evaluation criteria and ranking system. These requirements provide the minimum criteria for the watershed description, model calibration and hydrologic data, and model simulations to accomplish this goal.

As required by Agriculture Code §203.053(b) and §203.057(a), the feasibility study, and more specifically the computer modeling, must be conducted and developed by "a person with expertise in hydrology, water resources, or another technical area pertinent to the evaluation of water supply."

To balance WSEP consistency and comparability between feasibility studies with the practical limitation on how strictly prescriptive these requirements should be, it is recommended that for all new feasibility studies the Soil and Water Assessment Tool (SWAT) be used, or alternatively the Ecological DYnamics Simulation (EDYS) model. Justification for selecting a different model must be provided if either of the two recommended models is not utilized; in order to ensure that the selected model's capabilities are sufficient and that the model is employed properly, the adequacy of this justification will be reviewed by the Science Advisory Committee. All 12 of the original feasibility studies conducted by Texas A&M University in the early 2000s for the BCP utilized SWAT.

WATERSHED DESCRIPTION

The following list summarizes the input information necessary to characterize the watershed under consideration for brush control. All digital maps must be geo-referenced with sufficient metadata to allow overlays with other digital map layers.

- Watershed Delineation. The contributing drainage area that includes the treatment area should be identified using the USGS National Hydrography Dataset (NHD) and the USGS Watershed Boundary Dataset (12-digit hydrologic units), and confirmed with a digital elevation model (DEM).
- Topography. DEMs (10-meter) from the USGS National Elevation Dataset should be used and will likely require mosaic assembly to contain the watershed of interest.
- Hydrology. Appropriate data from the NHD and analysis of the DEM should confirm the locations of surface waterbodies, including stream and river channels, impoundments, and reservoirs within the watershed of interest, and other hydrologically sensitive areas

critical to streamflow and aquifer recharge. Flood control dams (e.g., PL-566 floodwater retarding structures) must also be included in the hydrologic dataset.

- Soil Types and Distribution. The USDA Soil Survey Geographic database (SSURGO) provides polygon-type maps that demonstrate the variations in soil type and other physical parameters that impact runoff and infiltration across the watershed of interest. These maps must also be joined in a mosaic form.
- Vegetation and Land Use. The USGS National Land Cover Dataset (NLCD) 2011 provides different land cover classifications at 30-m resolution which should be analyzed. Additionally, the Ecological Mapping System of Texas dataset published by the TPWD should be utilized in the analysis. For more recent land use descriptions as well as vegetation descriptions, digital orthophoto quarter quadrangles can be obtained from the USDA and assembled as a mosaic to envelop the watershed of interest; 1-meter National Agriculture Imagery Program orthophotos from 2014 are available from the Texas Natural Resources Information System. Ground-truthing site visits are necessary to confirm vegetation types and locations.
- Roads and Highways. ESRI datasets include features such as streets, county roads, highways, freeways, and other transportation infrastructure that may affect local watershed behavior.

MODEL CALIBRATION AND HYDROLOGIC DATA

Model calibration determines the degree to which a model represents a real-world system and establishes the usefulness of the model for evaluating factors affecting water yield and predicting changes in the water yield from brush control scenarios. Calibration is a systematic procedure of testing and tuning model input parameters that result in model predictions that best match a set of observational data. Calibration is completed through use of graphical and statistical methods to evaluate the degree to which the model corresponds to reality.

For WSEP consistency and comparability between feasibility studies, the period for calibration for all new feasibility studies is defined as 1995-2010.

Such models require historical daily rainfall data within, or at least near, the watershed of interest. These datasets can be collected from the National Climatic Data Center. Data from the defined calibration period should be collected to represent both wet and dry conditions. Other periods can be considered and may also be included if the range of observed rainfall conditions can be justified as being more representative of future conditions.

The model will need appropriate parameters to account for the abstractions that prevent part of the rainfall from reaching the stream and river channels as runoff. The selection of a simulation model and parameters must be based on an appropriate conceptual model that properly represents the conditions of the watershed. For example, the NRCS curve number method allows assignment of curve numbers based on soil type and condition, land use, and vegetation. The model's loss method must represent changes in runoff generation or streamflow caused by the removal of the target brush species. The parameter values must be supported by appropriate documentation, whether from field data collection, published values from the hydrologic literature, or the model's user guidance.

If the watershed of interest contains USGS streamflow gages, those flow data must be collected for comparison with the historical rainfall data and used in model calibration. Data from the defined calibration period should be sufficient to match the rainfall records. If the watershed of interest does not contain a USGS gage, data from either the nearest downstream gage or a gage in a neighboring watershed may be used to calibrate the model. The decision to use data from either a downstream gage or a gage in a neighboring watershed should be based on an analysis of the similarities in hydrology and land use to the watershed of interest.

The model should have a mathematical representation of spatially distributed infiltration losses. The model will also estimate ET of water from the root zone. The combination of the infiltration and ET amounts can be used as estimates of potential recharge to the shallowest aquifer in the watershed. These simulation methods must be clearly explained and their uncertainty estimated based on the model's user guidance and the hydrologic literature.

Optimally, rainfall and streamflow data from the complete defined calibration period will be available for calibration of the model over multiple seasonal variations. This situation would allow site-specific adjustment of the watershed parameters to best fit the observed rainfall-streamflow conditions. The calibrated model would represent pre-treatment conditions.

The modeler might have only local or nearby rainfall data for the defined calibration period and no observed streamflow data for calibration. In this situation, the most sensitive watershed characteristics must be identified, and ranges of reasonable values should be employed in multiple combinations to demonstrate a range of possible streamflow results with the pre-treatment conditions.

MODEL SIMULATIONS

After completion of the pre-treatment simulations, the model's watershed characterization input data must then be modified to represent the effects of brush control for water supply enhancement. The post-treatment simulations should employ the same rainfall data from the defined calibration period, and the post-treatment model results will demonstrate the impacts of brush control on surface water flows (and aquifer recharge) through comparison with observed or modeled pre-treatment flows. The primary indication of effectiveness on streamflow will be the total annual flow volume change per treated acre. The pre- and post-treatment losses to infiltration and ET can also be compared as at least qualitative contributions to groundwater recharge in terms of volume per treated acre.

Treatment scenarios for brush control to be simulated with the model must at least include the removal of 100% of <u>treatable</u> brush within the watershed of interest. Treatable brush is unique to each watershed and varies based on factors such as slope, brush density, proximity to waterbodies, and endangered species habitat. Factors that define treatable brush for the watershed of interest must be clearly described in the feasibility study.

As described in Agriculture Code §203.053(c), TSSWCB shall define a standard method of reporting the projected water yield of each proposed project as modeled in a feasibility study. As such, projected water yield for the brush treatment scenarios for each sub-basin shall be reported in a feasibility study as the average annual gallons of water yielded per treated acre of brush, averaged over the simulation period used in the computer model.

Subsection 7.2.2 Models

SWAT

The Soil and Water Assessment Tool (SWAT) is a public domain model jointly developed over 25 years by USDA-ARS, USDA-NRCS, and AgriLife Research, part of The Texas A&M University System. SWAT is a small watershed to river basin-scale model developed to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. This dynamic and highly flexible computer model has over 1,700 articles in the peer-reviewed literature describing SWAT development, validation, and assessment (see https://www.card.iastate.edu/swat_articles/). SWAT is widely used in assessing soil erosion prevention and control, nonpoint source water pollution control, and regional management in watersheds. The model has been extensively validated with respect to land use change (138 peer reviewed articles) and specifically to brush control (Lemberg et al. 2002 [Frio River]; Olenick et al. 2004; Afinowicz et al. 2005 [North Fork of the Upper Guadalupe River]; Wang et al. 2010 [Cowhouse Creek]). (http://swat.tamu.edu/)

EDYS

The Ecological DYnamics Simulation (EDYS) model is a general ecosystem simulation model that is mechanistically-based and spatially-explicit. It simulates natural and anthropogenic-induced changes in hydrology, soil, plant, animal, and watershed components across landscapes, at spatial scales ranging from 1 m^2 or less to landscape levels (1,000 km^2 or larger). It is a dynamic model, simulating changes on an hourly (for aquatic) or daily (most terrestrial) basis, over periods ranging from months to centuries. EDYS has been linked with groundwater (MODFLOW) and surface runoff (GSSHA, CASC2D, HSPF) models. EDYS has been used for ecological evaluations, watershed management, land management decision making, environmental planning, and revegetation and restoration design analysis. Examples of land/water management scenarios that have been evaluated using EDYS include grazing, natural and prescribed burns, fire suppression, invasive plant eradication, drought assessment, water quantity, reclamation, restoration, revegetation, brush management. (Coldren et al. 2011)

Section 7.3 Ranking Applications and Requests for Feasibility Studies

COMPETITIVE GRANT PROCESS

A competitive grant process will be used to select projects and allocate WSEP cost-share incentive funds for each fiscal year. Project proposals must relate to a water conservation need, based on information in the *State Water Plan* as adopted by the TWDB. A feasibility study must have been completed for the watershed in each project proposal. Project proposals will be prioritized for each funding cycle, giving priority to projects that balance the most critical water conservation need of municipal WUGs with the highest projected water yield from brush control. TSSWCB will issue a request for proposals that includes an application and describes the process for entities to propose projects.

PROPOSAL EVALUATION CRITERIA AND RANKING

Funding for project proposals will be allocated through a competitive grant process that will rank applications based on projected water yield using evaluation criteria established by the Stakeholder Committee. Evaluation criteria include:

- Public water supplies expected to be benefited by the project
- Water supply yield enhancement to target municipal water supplies, which is the projected water yield from a feasibility study
- WUGs relying on the water supplies
- Percent of enhanced water supply used by WUGs
- Population of WUGs

A Ranking Index (RI) will be calculated that gives a measure of the water yield increased per capita user for each proposal:

- RI = Reliance on source * (Yield Benefit ÷ Population)
  - Yield Benefit per Population
    - Larger ac-ft/yr/capita increases RI
  - Reliance of a WUG on a specific water supply
    - Larger reliance increases RI
    - Reliance on source = percent of water being supplied from a specific source
    - Higher priority is given to those populations who rely solely on the specified water supply.

Being in a Project Watershed does not guarantee that a proposal will be funded since the need for brush control cost-share incentive funds is much greater than the available funding. If more projects have been submitted than funds are available to support, the TSSWCB will prioritize the projects.

PROJECT PRIORITIZATION CRITERIA

The system that the TSSWCB uses to prioritize projects for each funding cycle gives priority to projects that balance the most critical water conservation need of municipal WUGs with the highest projected water yield from brush control. The specific criteria and factors that the TSSWCB considers in prioritizing projects for funding are detailed in 31 TAC §517.25, including:

- the need for conservation of water resources within the watershed based on the *State Water Plan*;
- the projected water yield of the project, based on soil, slope, land use, types and distribution of brush, and proximity of brush to rivers, streams, channels, and aquifer recharge features;
- any method the project may use to control brush;
- cost-sharing contract rates within the territory of the project (the WSEP rules [31 TAC §517.25(f)(3)] define a method for adjusting the Ranking Index for projects that propose a more favorable cost-sharing contract rate);
- the location and size of the project;
- the budget of the project and any associated requests for grant funds;
- the implementation schedule of the project;
- the administrative capacities of the TSSWCB and the SWCD that will manage the project;
- scientific research on the effects of brush removal on water supply; and
- any other criteria that the TSSWCB considers relevant to assure that the WSEP can be effectively, efficiently, and economically implemented.

PROCESS TO REVIEW APPLICATIONS FOR FUNDING NEW FEASIBILITY STUDIES

Applications for TSSWCB grant funding to complete new feasibility studies of conducting brush control for water supply enhancement will be referred to the Science Advisory Committee for review. The Science Advisory Committee will review the applications and make recommendations to the TSSWCB on which new feasibility studies should be conducted with agency funds.

In reviewing the applications and formulating recommendations, the Science Advisory Committee will consider the science-oriented questions below. In formulating recommendations for funding to the State Board, TSSWCB staff will consider recommendations from the Science Advisory Committee and the programmatic- and policy-oriented questions below.

1. Does the application indicate the proposed study will conform to the Requirements for Computer Modeling for Water Yield Predictions in Feasibility Studies? Does it appear that conformity can be reasonably achieved?
    - Does there appear to be sufficient streamflow and rainfall data for the watershed of the proposed project to satisfy the defined period for model calibration?

- Will the proposed study utilize either of the recommended models, or does the application provide adequate justification for selecting a different model?
- If the application indicates a modeler has already been selected by the applying entity, is the modeler a person with expertise in hydrology, water resources, or another technical area pertinent to the evaluation of water supply as required by Agriculture Code §203.053(b) and §203.057(a)?

2. Is there an apparent "conflict of interest" between the modeler (performing entity and/or person) who will be conducting the computer modeling for the proposed study (including any entity providing matching funds) and any potential beneficiaries of the proposed project (i.e., WUGs, water providers/sellers)?

3. Are matching funds being provided to conduct the proposed study?
   - Are the matching funds ≥75% of project costs?
   - Are the matching funds ≥50% of project costs?

4. Is the budget for conducting the proposed study accurate and reasonable? Are appropriate costs budgeted? Is the timeframe for completing the proposed study reasonably expeditious?

5. What is the capacity and ability of the performing entity to fulfill all commitments specified in the application? Past performance by the entity on projects previously funded by TSSWCB is taken into account.

6. Is a need for conservation of water resources within the watershed of the proposed project documented in the *State Water Plan* (as adopted by the TWDB)?

7. Does the *State Water Plan* or a regional water plan include a recommendation to conduct a feasibility study in the watershed of the proposed project?

8. What is the reliance per capita of the WUG on the PWS expected to be benefited by the proposed project (utilize method for Ranking Index from cost-share applications)?

9. Is the primary purpose of the proposed study an assessment of the feasibility of conducting brush control for water supply enhancement in a particular watershed?

10. Does the application include a statement of the anticipated impact on water resources as required by Agriculture Code §203.057(c)?

11. Is the application's statement of the anticipated impact on water resources supported by published science that suggests the proposed project may yield water in Texas?
    - Was the published science conducted in the watershed of the proposed project?
    - Was the published science conducted in a similar watershed in Texas?
    - Was the published science conducted in a similar watershed outside of Texas?

12. Will the proposed study examine brush species identified as detrimental to water conservation in the *State Water Supply Enhancement Plan*?

13. Is the watershed of the proposed study identified in the *State Water Supply Enhancement Plan* as a priority for conducting a new feasibility study?
    - If not identified as a priority, was a feasibility study previously published for the watershed of the proposed study but for a different species of brush?
    - As a factor of holistic and synergistic watershed management, are other watershed planning and management activities ongoing in the watershed of the proposed study?

Once applications are considered, the TSSWCB, with guidance from the Science Advisory Committee, will direct applying entities to an appropriate modeler [per Agriculture Code §203.057(a)] to conduct the new feasibility study.

Section 7.4 Prioritizing Acreage within a Project Area through Geospatial Analysis

Determination of the efficiencies with which controlling brush can yield additional water requires the evaluation of the properties of the geology, soil, flora, and topography unique to each watershed and their interactions with each other in response to climatic conditions. Other criteria to be considered for selecting sites for brush control include the potential impact on endangered or threatened species.

Numerous scientific studies conducted in Texas and across the United States have attempted to evaluate the impacts of brush on the water cycle and what potential water savings may be realized by controlling a given brush species. A focused approach that targets hydrologically sensitive areas of a watershed is thought to have the greatest potential for increasing water yield (increased streamflow or groundwater recharge) from a given watershed. Based on this premise, a multi-layered geospatial analysis is used by TSSWCB as a tool to prioritize areas of a selected watershed that, based on the criteria used, have the most potential for increased water yield resulting from brush control. This methodology was initially described for TSSWCB by Fish and Rainwater (2007).

This analysis will consider multiple landscape characteristics available for a selected watershed and will assign a ranking to all areas of the watershed based on the overall number of these characteristics that apply to a specific location.

In order to maximize the positive impacts of brush control on water supply enhancement and the effective and efficient use of allocated funds, a geospatial analysis will be performed to delineate and prioritize the acres eligible for cost-share incentive funds that have the highest potential to yield water within the project watershed and thereby increase water supplies. Characteristics that will be assessed in the geospatial analysis include:

- Soil Type – relative to hydrologic properties such as runoff potential or recharge/infiltration rate
- Slope – sufficiently steep to affect runoff potential or infiltration rate but not impair method of brush control
- Brush Density – type and density of brush to be treated in fraction of the area with treatable brush
- Proximity to Waterbodies – including riparian areas and other hydrologically sensitive areas critical to streamflow and aquifer recharge
- Proximity to Watershed Outlet

The Science Advisory Committee will be consulted on the multiple criteria for each characteristic for each watershed. The geospatial analysis results in four brush control priority zones for each watershed: high, medium, low, and not-eligible. Funds allocated to the sub-basin may only be obligated to landowners for brush control on acreage within the high priority zone.

When collectively considered, these factors will assign a priority to all areas of a selected watershed based on the total number of criteria that they meet. Areas of the selected watershed that exhibit the majority of these parameters will receive the highest ranking and those that have fewer characteristics will receive lower priority.

Due to the sensitive nature of the following areas, they are automatically excluded from the potential areas where brush control should occur.

- Areas that are designated as project habitat or endangered species habitat
- Slopes greater than 16%

The ranking system is based on site characteristics for each of the five factors and their impacts on the goal of a specific water supply enhancement project. Two ranking systems (Manage Brush for Aquifer Infiltration Enhancement and Manage Brush for Surface Water Enhancement) were developed according to the intended goal of the brush management effort. Areas of the watershed that receive the lowest value from this system will be the most feasible areas for improving water yield for their respective goal.

When planning a brush control effort, other factors must be considered in order to minimize potential negative impacts to the landscape, the receiving waterbody, and downstream water users. Adhering to brush control guidelines set forth in the USDA-NRCS FOTG and this *State Water Supply Enhancement Plan* will be first steps in preventing negative impacts. Some potential negative impacts are:

- increased erosion and pollutant transport to the receiving waterbody as a result of poorly managed brush control practices
- brush control conducted too close (within 35 ft) to stream could cause increases in sediment and pollutant loading
- chosen method of brush control may harm project or sensitive habitat.

Chapter 8 Project Implementation

Section 8.1 Allocation of Grant Funding for Established Projects

PROCESS FOR ALLOCATING FUNDS TO ESTABLISHED PROJECTS

Based on application ranking and the geospatial analysis, funds will be allocated to specific projects. An allocation is calculated based on the number of high ranking eligible acres (from the geospatial analysis), the desired number of eligible acres the proposal identifies for treatment, the average cost of brush control per method for each eligible acre, and the amount of time required to treat the number of acres targeted in the proposal. Funds will be allocated to projects in highest ranking order. Proposals may be partially funded if the allocation is at least 25% of the original request on the application.

Allocated funds may only be obligated to landowners for brush control 1) in the designated subwatershed, and 2) only in the high priority zone within that subwatershed as per the geospatial analysis. Allocated funds may not be obligated to landowners for brush control in 1) the medium or low zones within the designated subwatershed as per the geospatial analysis, or 2) other subwatersheds identified on the application or in the feasibility study.

PROJECT ASSESSMENT AND POSSIBLE REALLOCATION OF FUNDS

On a date set by the TSSWCB Executive Director, each project's progress at obligating allocated cost-share incentive funds to landowners shall be assessed. This assessment will be used to determine if unobligated funds should be de-allocated from a project and reallocated to another project in order to maximize expenditure of WSEP funds during the fiscal year.

If less than 50% of the original allocation is not yet obligated, and project partners do not have a reasonable expectation of obligating the remaining allocated funds, then funds may be de-allocated.

If funds are de-allocated, funds will be reallocated to 1) projects that received an original allocation which only partially funded the application, in order of original highest ranking, 2) projects that received an original allocation and have demonstrated progress at obligating cost-share funds and a need for additional cost-share funds, in order of original highest ranking, 3) conduct new feasibility studies, or 4) other projects that did not receive an original allocation in order of original highest ranking.

Section 8.2 Implementation

Voluntary land stewardship and the efforts of private landowners to control water-depleting brush are vitally important to the ecological health of productive rangelands across the state.

Once a project has been approved and funding made available, the responsible SWCD will begin implementation. The TSSWCB may provide agency grant funds to SWCDs in order to provide technical assistance to landowners for brush control and to administer the water supply enhancement cost-share program.

In order to maximize the effective and efficient use of WSEP grant funds, an SWCD participating in a water supply enhancement project must choose one of two options to provide technical assistance to landowners for brush control and to administer the cost-share program.

This policy provides a foundation for the TSSWCB in considering the administrative capacities of an entity that will manage a water supply enhancement project, as required by Agriculture Code §203.053(d)(8) when prioritizing proposed projects.

OPTION A – COOPERATIVE AGREEMENT FOR REGIONAL CONSERVATION TECHNICIAN

The participating SWCD agrees to allow a regional conservation technician, funded by the TSSWCB through a different SWCD, to perform all duties and responsibilities associated with implementing a water supply enhancement project within the jurisdiction of the participating SWCD on behalf of the participating SWCD. The participating SWCD will cooperate with the regional conservation technician and TSSWCB staff to implement the water supply enhancement project. The participating SWCD will not be eligible for reimbursement of any costs associated with implementing the water supply enhancement project within the jurisdiction of the participating SWCD.

OPTION B – PARTICIPATING SWCD PROVIDES FOR TECHNICAL ASSISTANCE

If a participating SWCD chooses to administer the WSEP within the jurisdiction of that SWCD, as provided for by Agriculture Code §203.101, then the participating SWCD agrees to employ a district conservation technician to perform all duties and responsibilities necessary to provide technical assistance and to administer the cost-share program within the jurisdiction of the participating SWCD. TSSWCB staff and regional conservation technicians will not perform any duties and responsibilities associated with the provision of technical assistance or administering the cost-share program, but will provide guidance and direction to the participating SWCD on WSEP rules, policies, and procedures.

The participating SWCD may be reimbursed by the TSSWCB for actual costs incurred associated with implementing the WSEP, up to 15% of the cost-share allocation for that water supply enhancement project.

Duties and responsibilities related to providing technical assistance and administering the cost-share program include, but are not limited to:

- Soliciting landowners to participate in a water supply enhancement project
- Developing water supply enhancement resource management plans for participating landowners
- Writing cost-share contracts for participating landowners
- Conducting performance certifications of brush control work completed
- Communicating with TSSWCB staff and regional conservation technicians on progress to implement the water supply enhancement project

Subsection 8.2.1 Water Supply Enhancement Plans for Landowners

The foundation of the WSEP is the 10-year resource management plans developed for and implemented by landowners on properties voluntarily enrolled in the Program. These conservation plans are based on the USDA-NRCS practice standards for brush management, prescribed grazing, and wildlife habitat management as published in the FOTG. The conservation delivery system is critical for this aspect of the WSEP; local SWCDs are responsible for developing and approving these landowner plans.

A water supply enhancement plan is a site-specific resource management plan for implementation of brush control, sound range management practices, and other soil and water conservation land improvement measures. It includes a record of the eligible person's decisions made during planning and the resource information needed for implementation and maintenance of the plan that has been reviewed and approved by the SWCD. A plan describes the brush control activities to be implemented, follow-up treatment requirements, brush density to be maintained after treatment, and supporting practices to be implemented. These landowner conservation plans mitigate the impact of brush control on other natural resources. These conservation plans include appropriate and essential land treatment practices, production practices, management measures, or technologies needed to achieve a level of brush control and management necessary to increase watershed yield, meet landowner goals, and address wildlife considerations.

A water supply enhancement plan must contain an implementation schedule. The implementation schedule, as far as is practicable, should balance the need for increasing water conservation with the needs of agricultural producers to have sufficient time to implement practices in an economically feasible manner. No other entity is more qualified to make this determination than a SWCD. This places tremendous responsibility on SWCDs, because these types of decisions require judgment and local knowledge.

During plan development, consideration must be given to local conditions and economy and must place appropriate importance on conserving water resources. Highest priority will be given to the implementation of the most cost effective and highest water yielding areas.

PLAN DEVELOPMENT

The responsible SWCDs will assist landowners with development of individual plans for brush management for the purposes of increasing water yield. The extent and methods of brush management included in each plan will be determined in accordance with specifications in the NRCS FOTG, as approved by the local SWCDs. Each plan will include implementation of sound grazing management following brush treatment. Based on these plans, the SWCD may enter into contracts with the landowners for cost-share of brush management.

The planning process outlined in the NRCS National Planning Procedures Handbook will be used to develop, implement, and evaluate water supply enhancement plans. The TSSWCB requires that water supply enhancement plans meet Resource Management System standards as defined in the NRCS FOTG for the conservation management units planned. In addition to these resources, the following guidelines should be followed.

ASSESSING BRUSH DENSITY

For the purpose of obtaining uniformity in determining brush density, all measurements will be made using the open crown intercept method. First, observe the site and select a uniform area that is representative of the site to be treated. Next, pace or measure the crown intercept along lines across, or in, the brush to be treated (mesquite and juniper). The percent of paces, or measurements, under the crown canopy of the brush in relation to the total number of paces or measurements will give the approximate percent of crown canopy of the brush. The distance and number of lines to pace to obtain a reasonably reliable sample will vary with the uniformity of the brush stand.

If the brush stand is uniform, two to four lines of 200 paces should give a suitable sample, or a single line all the way across the brush stand may be representative. Where the brush stand is not uniform or when the canopy is near the moderate or heavy canopy thresholds, more samples will typically be needed.

A record will be made of the percent crown canopy, and where sample measurements were taken. These records will be kept in the resource management plan.

ASSESSING BRUSH TYPE

Because average costs differ according to brush type, it is imperative that brush type is accurately assessed. If only one brush category is present, then perform canopy counts on a pasture basis. However, if multiple brush categories are present, then canopy counts should be completed on a NRCS ecological site basis. In order to do this, the planner must use NRCS soil surveys and ecological site descriptions to determine the different possible ecological sites and where they are located.

According to this assessment, to be classified as mesquite, the site must contain pure stands of mesquite, or mixed mesquite, juniper and other species where the target species canopy is at least 10% and the juniper canopy is less than 5%.

To be classified as juniper, the site must contain pure stands of juniper or mixed juniper, mesquite, and other species where the juniper is the dominant species and its canopy is at least 10%.

To be classified as mixed, the site must contain mixed juniper and mesquite where juniper is not the dominant species but: (1) the juniper canopy exceeds 10%, or (2) when the juniper canopy is 5-10%, then juniper must comprise at least 33% of the total canopy cover.

ESTABLISHMENT OF PRACTICE STANDARDS

The criteria for the resource management plans are defined by the TSSWCB to be the practice standards issued by the USDA-NRCS in their FOTG. Practice standards will be based on specific local conditions. Practice standards will be those included in the NRCS FOTG; however, modification of those practice standards will be made as necessary.

The TSSWCB adopted the NRCS FOTG as the criteria applicable for water supply enhancement resource management plans. This guide is specifically tailored for the geographic area of each SWCD.

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, brush density to be maintained after treatment, and supporting practices to be implemented.

The essential key practices utilized in all water supply enhancement resource management plans are:

- Brush Management (314)
- Prescribed Grazing (528) [i.e., livestock grazing management]
- Upland Wildlife Habitat Management (645)

If planned brush management is expected to increase the risk of soil erosion, then erosion control measures (e.g., buffers, filter strips, reseeding) may be included in the resource management plan.

The TSSWCB, in consultation with SWCDs, will approve a list of practices that are eligible for cost-share statewide (Section 8.3). These practices may include chemical and mechanical methods and prescribed burning. Results of watershed studies may be used to evaluate control options and their feasibility.

Identifiable units must be established for each practice. An identifiable unit must be either all or an essential part or subdivision of a practice that when carried out is complete within itself and can be clearly identified. An identifiable unit also can be managed independently as to maintenance of the practice. Establishment of identifiable units and an average cost or a specified maximum cost permits cost-share payments to be made to producers when an identifiable unit is treated. A list of practices, applicable cost-share rates, average costs or specified maximum costs will be developed for each identifiable unit.

DEFERMENT

A 5% incentive is offered to landowners who defer grazing from treated areas for 90 days during the growing season following treatment to allow re-establishment of vegetation. Deferment can only begin once treatment is completed in a pasture. When deferment begins, the landowner must contact the SWCD. At least one status review will be conducted during the deferment. The 5% incentive is based on the actual amount paid for treatment in the deferred pasture.

REVEGETATION

Consistent with the practice standard for Brush Management (314) (NRCS 2014b), mechanically treated brush control areas must be re-vegetated if 40% or more of the existing grass cover is destroyed by mechanical disturbance or if reseeding from existing seed sources will not provide adequate cover. In this case, the Range Planting practice standard (550) is supporting.

Further, rootplowing (a specific type of mechanical treatment) may cause significant structural changes of plant communities. As such, all rootplowed brush control areas must be seeded and/or planted to permanent vegetation. In this case, the Range Planting practice standard (550) is supporting.

COMPLETION SCHEDULE

Proper timing and sequence of land treatment practices are essential to successful implementation of any conservation program. This is true concerning either the entire project or individual landowner plans. One major factor that must be considered is the time limit placed on the use of State money. State funds are appropriated on a biennial basis. This will allow only two-year contracts at a maximum to implement brush control and request reimbursement even though the entire project may take several years to complete. Landowners are responsible for obtaining their own contractors to perform the brush control work.

Each cost-share agreement will include a maintenance agreement by which the landowner agrees to maintain the brush management practice for a period of ten years after implementing the initial treatment.

Subsection 8.2.2 Wildlife Considerations

In Texas, the loss of native grassland habitats has been substantial; for example, Samson and Knopf (1994) report a 90% reduction of tallgrass prairie, a 30% reduction of mixed-grass prairie, and an 80% reduction of shortgrass prairie since European settlement. For many grassland-associated wildlife species, this habitat loss is compounded by brush encroachment (Arrington et al. 2002). This large-scale conversion from grasslands and savannahs to shrublands over the last 160 years has significantly impaired uplands and reduced percolation and surface flow of water from rainfall causing changes and loss in basic aquatic and terrestrial wildlife habitat (Arrington et al. 2002).

When compared with the TSSWCB feasibility studies, where brush control was assumed to occur on all land that had moderate or heavy brush, Arrington et al. (2002) suggests that both stream flow increases and water yield increases would not be significantly affected if brush control strategies that account for wildlife (e.g., slope and riparian restrictions) were imposed.

In order to meet objectives of restoring ecological function, properly designed resource management plans should account for the habitat requirements needed to maintain viable populations of brush- or woodland-associated wildlife species while improving habitat for grassland-associated wildlife species. However, as there is with any change in habitat, any brush management strategy implemented across the landscape will result in a shift in the wildlife community resulting in gains or losses for particular species, depending on changes in habitat. (Arrington et al. 2002)

The basic concern of the wildlife manager in implementing any brush management system has to do with the design and retention of a brush mosaic. Patterning of brush treatments is driven by wildlife considerations more than by any other set of management objectives. The design of a favorable habitat mosaic will be considered for each specific resource management plan.

The types of brush control patterns used will depend upon the terrain in the area to be treated. To a great degree, natural terrain features will dictate the types and conformation of patterns.

Sufficient brush cover should be left along watercourses, which usually serve as wildlife travel lanes. The width of the strips to be left for most wildlife can be determined by visual inspection. The strips of brush should be wide enough to prevent seeing through them at most points from December through February when most species have lost their leaves. All natural wildlife travel ways, which would include watercourses, saddles between ridges, headers or canyon beginnings, extensions of ridges, and any unusually high-quality wildlife food plants should be left.

When cleared strips extend for great distances, a belt or block of brush should be left every 200-300 yd to break up the open spaces and provide covered travel lanes for wildlife. In South Texas where the terrain is relatively flat with no prominent features, alternate strips of cleared areas and brush produce good results, although clearing in an irregular pattern is more desirable. In large areas the strips can be established in gently curving patterns to block excessive views, and belts or blocks of brush can be left at desirable intervals across cleared areas. Brush strips should be left along drainage areas or draws used as natural travel ways by wildlife.

Where cleared areas tend to be excessively large, islands of brush should be left interspersed within the cleared areas to provide escape cover. As with brush strips, the islands should be large enough that wildlife cannot be seen through from December through February. Where islands do not provide sufficient escape cover, extensions or necks of brush can be left for escape cover and travel ways to prominent terrain features frequented by wildlife.

During the initial development of a resource management plan, extreme care should be taken to retain the many different types of woody food and cover plants necessary to maintain a resident wildlife population of all species. For example, woody plants or brush species are necessary to wild turkey populations, not only as food producing plants, but also as cover and roosting timber. Existing winter roost timber should be left standing. In association with this, brush and smaller trees under or adjacent to the roosting areas should be retained. Turkeys require cover as they enter and depart the roost and while loafing under the roost trees. Sufficient quantities of food-producing woody species such as chittum, hackberry, lotebush, oak, pecan, and elm also should be maintained.

Following mechanical treatment, some areas will require reseeding. The seeding mix should include forbs that benefit wildlife.

The improvement in range conditions through brush management will increase the available food supply for wildlife and domestic livestock. This additional food supply will improve the quality of the animals being produced. Brush should be managed in conjunction with sound range management practices.

Although some basic rules for brush management may be applied to all treated areas, the topography, types of vegetation, and wildlife species present on each unit and even from pasture to pasture within a ranch will be different. Therefore, an on-the-ground inspection of the entire property is necessary prior to formulating sound management plans.

It is likely that only a few candidate pattern/treatment combinations will emerge for which equipment is locally available and which suits the preferences of the landowner. These should be ranked by wildlife specialists in terms of their utility for satisfying game management objectives from a biological point of view. Interaction and compromise among management objectives should result in further limitation of options and finally result in identification of the candidate system that shows most promise for meeting the goals of the WSEP and the landowner.

Subsection 8.2.3 Soil Erosion Potential

During the public review and comment period for the proposed *State Water Supply Enhancement Plan* in summer 2014, TSSWCB received several public comments that raised issues regarding the effects of brush control on soil erosion potential. Four observations are made below in response to the concerns raised.

First, the TSSWCB is the lead state agency responsible for planning, implementing, and managing programs and practices for preventing and abating agricultural and silvicultural nonpoint sources of water pollution (Agriculture Code §201.026). The agency's WSEP is designed to reinforce that mission. The required landowner conservation plans are designed to mitigate the impact of brush control on other natural resources.

Second, in all of the completed feasibility studies, the target brush to be controlled is replaced with native grass rangeland in the modeled simulations of brush control. As such, the projected water yields enhanced are not based on runoff from bare ground; treated areas are not assumed to be bare ground.

Third, the USDA-NRCS Practice Standard for brush management (NRCS 2014b) recognizes that where erosion and sedimentation are resource concerns as a result of woody plant encroachment, brush management is undertaken for the purpose of restoring desired vegetative cover to control erosion and reduce sediment. Further, the NRCS Conservation Practice Physical Effects documentation indicates a slight-to-moderate decrease in sheet and rill soil erosion when brush management is performed.

Fourth, as previously discussed in Section 2.2, the USGS also collected suspended-sediment data during the study at the Honey Creek State Natural Area which evaluated the hydrologic effects of ashe juniper removal. Suspended-sediment loads were calculated from samples collected at the reference watershed and the treatment watershed. USGS found that during the post-treatment period, the relation between suspended-sediment loads and streamflow did exhibit a statistically significant difference (Figure 2.2.3). The data indicate that for the same streamflow, the suspended-sediment loads calculated from the treatment watershed were generally less than suspended-sediment loads calculated from the reference watershed during the post-treatment period. (Banta and Slattery 2011)

Section 8.3 Cost-Share Program

ELIGIBILITY FOR COST-SHARE PROGRAM

Cost-share assistance may only be allocated:

- To An Eligible Person,
- For Eligible Purposes,
- On Eligible Land,
- For Eligible Brush,
- For Eligible Practices.

Eligible Person – Any individual, partnership, administrator for a trust or estate, family-owned corporation, or other legal entity who as an owner, lessee, tenant, or sharecropper participates in an agricultural or wildlife operation within a WSEP Project Watershed, has adequate operational control (i.e., a written lease equal to the length of the WSEP contract or longer), and is a cooperator with the local SWCD shall be eligible for cost-share assistance.

Eligible Purposes – Cost-share assistance shall be available only for brush control included in an approved water supply enhancement resource management plan and contract and determined to be needed by SWCDs to conserve water.

Eligible Land – Agricultural or wildlife land within a designated WSEP Project Watershed that is privately owned by an eligible person, leased by an eligible person over which the applicant has adequate control extending through the term of the WSEP contract period and written permission of the landowner, or owned by the State, a political subdivision of the State, or a nonprofit organization that holds land in trust for the State.

Ineligible Land – Cost-share funds shall not be used on land outside of a designated Project Watershed or on land not used for agricultural or wildlife production. Any land that is simultaneously receiving any cost-share money for brush control on the same acreage from a state, federal, or local government program (i.e., federal Farm Bill programs, TSSWCB Water Quality Management Plan Program, CWA §319(h) Nonpoint Source Grant) is not eligible, unless the TSSWCB finds that joint participation of the WSEP and any other programs will enhance the efficiency and effectiveness of a project and lessen the State's financial commitment to the project.

Eligible Brush – Moderate, heavy, and extra heavy mesquite, juniper, and mixed mesquite and juniper. In the O.H. Ivie Reservoir watershed, moderate (i.e., normal) is defined as 9-19% canopy cover and heavy is defined as 20% or greater canopy cover. In all other watersheds, moderate is defined as 10-29% canopy cover, heavy is defined as 30-39% canopy cover, and extra heavy is defined as 40% or greater canopy cover. Canopy cover is determined for target species only (mesquite and juniper). Saltcedar, huisache, and carrizo cane are assessed on a site-specific basis.

Eligible Practices – Those brush control measures (including deferment) included in an approved water supply enhancement plan, according to the USDA-NRCS FOTG.

COST-SHARE RATE

The TSSWCB will establish practices eligible for cost-share and their standards, specifications, maintenance, and expected life. The TSSWCB will establish the maximum cost-share rate for practices approved for the WSEP. Cost-share payments will be based on the most cost effective methods. The TSSWCB will establish average costs based on recommendations provided annually by the USDA-NRCS EQIP.

Subsection 8.3.1 General Criteria

Agriculture Code §203.151 creates a cost-sharing program to be administered under rules adopted by the TSSWCB.

The TSSWCB adopted rules to administer the brush control cost-share program (31 TAC §§517.22-517.39) with the following program characteristics:

1. Not more than 70% of the total cost of a single brush control project may be made available as the State's share in cost-sharing.
2. Requests for allocations will be part of brush control project proposals submitted by SWCDs.
3. Approval of allocations. The TSSWCB shall consider, approve, reject, or adjust funding requests based on priority of projects and amount of available funding. Only SWCDs for which the TSSWCB has approved a Project Watershed are eligible for cost-share funds.

Subsection 8.3.2 Cost-Share Agreement

SWCDs may enter into cost-share agreements with individual landowners. Cost-share agreements must be based on an approved water supply enhancement plan developed by the landowners with technical assistance provided through the SWCD. Only those costs directly associated with removal of brush, as specified in the feasibility study for that watershed, are eligible for cost-share assistance.

A producer having a water supply enhancement plan may apply for cost-share by completing the appropriate TSSWCB forms.

SWCD COST-SHARE APPROVAL PROCESS

Only after approval of a water supply enhancement plan should the SWCD consider approval of a cost-share contract. SWCD approval of a water supply enhancement plan and cost-share assistance contract should be based on conformity with the USDA-NRCS FOTG, adherence to established priorities and policies, and the following considerations:

- Whether the brush control is to be carried out in a WSEP Project Watershed;
- the method of control that is to be used by the applicant;
- the plans for revegetation;
- the total cost of the brush control;
- the amount of land to be included;
- whether the applicant is financially able to provide his share of the money for the brush control;
- the cost-share percentage, if an applicant agrees to a higher degree of financial commitment;
- any comments and recommendations of the TPWD; and
- any other pertinent information considered necessary by the SWCD or the TSSWCB.

Subsection 8.3.3 Brush Control Methods

The TSSWCB is directed to approve all methods of brush control used under this program. The TSSWCB may approve methods of controlling brush based on a finding that the method:

1. has proven effective and efficient for controlling brush;
2. is cost efficient;
3. will have a beneficial impact on the development of water sources and wildlife habitat;
4. will maintain topsoil to prevent erosion or siltation of rivers or streams; and
5. will allow for revegetation of the area after the brush is removed with plants that are beneficial to stream flows, groundwater levels, and livestock and wildlife.

The TSSWCB will approve brush control methods for each project based upon information from the feasibility study along with other data or information the TSSWCB deems relevant. Approved methods will be transmitted to the appropriate SWCDs when funding allocations are approved.

It is the policy of the TSSWCB to provide cost-share on the basis of actual cost not to exceed the average cost. Where possible, cost-share assistance will be limited to the least costly methods. The least costly method must be technically acceptable with regard to wildlife considerations and effective in controlling problem species. No cost-share assistance will be provided for raking and piling except where this is required prior to root plowing.

Subsection 8.3.4 Maintenance of Brush Management and Follow-Up Treatment

Cost-share agreements between the TSSWCB and landowners contain a commitment on the part of the landowner, at no cost to the State, to maintain areas for which cost-share funding for brush control was received for a period of ten years after the initial brush control is accomplished.

Maintenance includes periodically re-treating the area with appropriate brush control methods to prevent brush reinfestation over the duration of the 10-year contract period. Maintenance, or follow-up, treatments will be scheduled as described below and according to specifications in the FOTG.

Statute, recently clarified by HB1808, emphasizes that follow-up brush control is entirely the landowner's financial responsibility and they cannot receive any additional State funds to do the follow-up brush control (Agriculture Code §203.162(c)).

FOLLOW-UP TREATMENT REQUIREMENTS

In accordance with the Agriculture Code, follow-up brush control treatment is required by the landowner on participating lands at no cost to the State.

Follow-up treatment shall be generally scheduled in water supply enhancement landowner resource management plans as follows:

- Mesquite, Mixed Brush, Saltcedar: Follow-up treatment is scheduled three years after initial treatment if canopy (target species only) is above 5%.

- Juniper: Follow-up treatment is scheduled eight years after initial treatment if canopy (target species only) is above 5%.

Subsection 8.3.5 Certification of Practice Implementation

Upon completion of brush control activities on any identifiable unit of land, the SWCD must certify to the TSSWCB that the practice has been implemented in accordance with specifications on that portion of the planned area.

Performance certifications are conducted when practices to be cost-shared are implemented. The SWCD must then certify that the practice meets the standards set forth in the FOTG. Canopy cover of target species must be reduced to less than 5% to be certified.

Subsection 8.3.6 Cost-Share Payments

Based upon certification by the SWCD that brush control has been implemented according to specifications on all or any identifiable unit of land in a water supply enhancement plan, the TSSWCB may process a request for payment of cost-share funds and cause payment to be made directly to the landowner.

It is the policy of the TSSWCB to provide cost-share on the basis of actual cost not to exceed the average cost established in the project's implementation plan. Landowners are responsible for 100% of the costs that exceed the average costs established in the project's implementation plan.

The SWCD shall determine eligibility of the applicant to receive payment of cost-share assistance and provide certification to the TSSWCB that practices have been installed consistent with established standards.

Payments are based on the number of acres treated times the cost-share rate times the actual cost not to exceed the average cost set by the project's implementation plan.

The project's implementation plan may establish maximum cost-share limits less than the amount set by the TSSWCB.

Partial payment can be made for completed practices that are listed separately on the application for cost-share.

Subsection 8.3.7 Status Reviews

The TSSWCB performs status reviews of cost-share contracts to verify compliance with follow-up treatment requirements over the course of the 10-year contract and resource management plan.

The method for assessing brush density and brush type shall be the same as used when developing the landowner's resource management plan (Subsection 8.2.1). The method for canopy cover assessments will be used for

1) initial brush assessment to develop each landowner plan,
2) performance certification of brush control conducted for cost-share, and
3) status review of maintenance and follow-up treatment.

STATUS REVIEW SCHEDULE

All water supply enhancement landowner resource management plans and cost-share contracts will include requirements for status reviews to be conducted in accordance with the established schedule below:

- Status reviews will be conducted within three to five years after initial treatment of brush to determine if the canopy (target species only) is above 5%.

- A second status review will be performed eight to nine years after initial treatment.

If the producer is found out of compliance, they will not be eligible for another WSEP contract for a period of ten years.

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Chapter 9 Statewide WSEP Water Yield Estimate

Water yield projections originate from computer models described in published brush control feasibility studies.

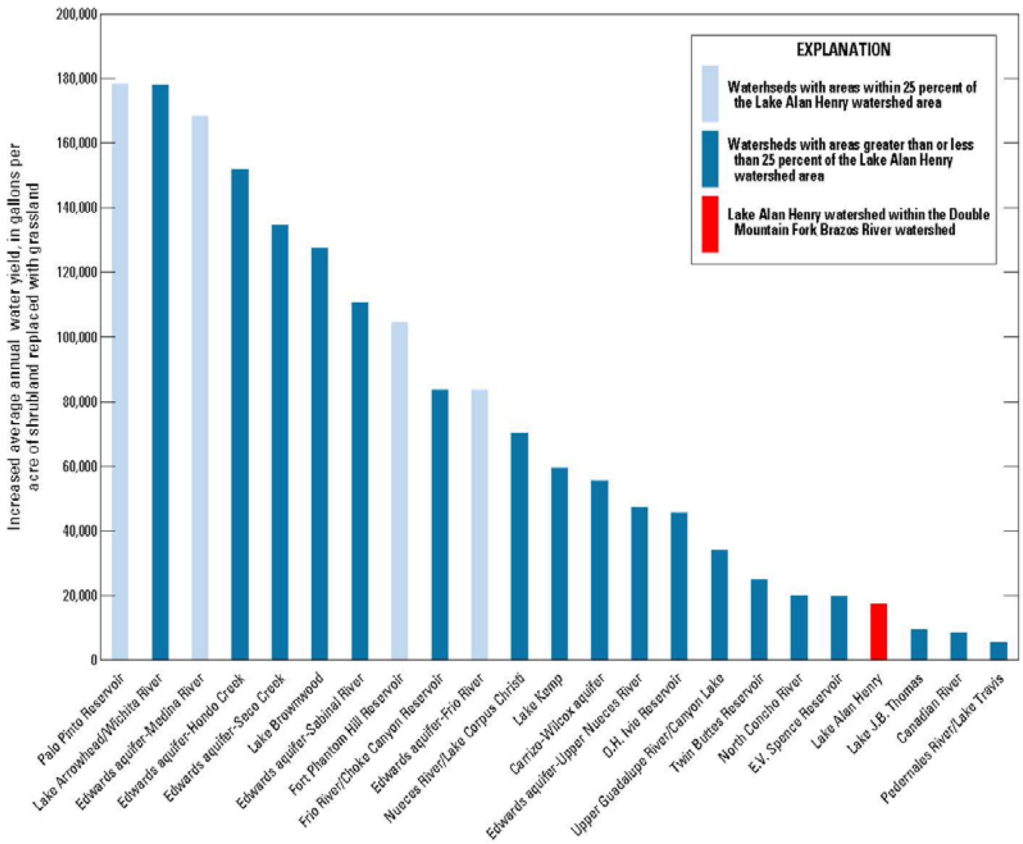

Figure 9.1 Modeled increases in average annual water yield resulting from brush management in 23 watersheds for which feasibility studies have been completed (Harwell et al. 2016)

Since the beginning of a statewide comprehensive strategy for managing brush where it is contributing to a water conservation problem, through the WSEP and its predecessor the BCP, over 841,488 ac of brush have been treated (FY2000-2015) in various priority watersheds across the state (Table 9.1). Projected water conserved through the programs is also shown in Table 9.1. Water conserved is based on acres of brush treated during the project period (usually ten years) and is calculated according to water yield projections in published feasibility studies. Realization of projected water conserved depends greatly upon the extent of voluntary landowner compliance with follow-up treatment requirements and on the climatic conditions across the state that influence the sequence of drought and rainfall events.

Table 9.1. Projected Water Yield Enhanced from Brush Control Under the WSEP (or BCP) through FY2015

Watershed	State Cost per Treated Ac	Treated Ac	gal/ac per yr	gal/yr Based on Treated Ac	Total Water Yield for Life of Project[1]
Lk Alan Henry					
Lk Arrowhead / Wichita Rvr	$ 20.92	53,507	162,035	8,670,006,745	86,700,067,450
Lk Brownwood	$ 146.34	6,362	95,696	608,817,952	6,088,179,520
Canadian Rvr / Lk Meredith[3]	$ 92.49	16,850	817,651	13,777,419,350	55,109,677,400
Gonzales County	$ 226.54	464	96,106	44,593,348	445,933,480
Carrizo-Wilcox Aquifer					
Guadalupe Rvr					
Edwards Aquifer Recharge Zone	$ 155.75	6,731	217,790	1,465,944,490	14,659,444,900
Frio Rvr					
Hondo Crk					
Medina Rvr					
Upper Nueces Rvr					
Sabinal Rvr					
Seco Crk					
Ft Phantom Hill Rsrvr	$ 164.50	1,632	103,460	168,846,720	1,688,467,200
Frio Rvr / Choke Canyon Rsrvr	$ 24.22	14,274	73,056	1,042,801,344	10,428,013,440
Upper Guadalupe Rvr	$ 123.71	8,241	217,790	1,794,807,390	17,948,073,900
Canyon Lk					
Nimitz Lk					
O.H. Ivie Rsrvr (watershed)					
Lk Ballinger	$ 45.00	7,800	55,354	431,761,200	4,317,612,000
Oak Creek Lk	$ 47.00	16,224	47,225	766,178,400	7,661,784,000
O.H. Ivie Rsrvr (lake basin)					
Lk Kemp		854	183,388	156,613,677	1,566,136,765
North Concho Rvr	$ 45.50	322,000	26,068	8,393,896,000	83,938,960,000
O.C. Fisher Lk	$ 104.98	10,066	26,068	262,400,488	2,624,004,880
Nueces Rvr / Lk Corpus Christi	$ 27.65	18,433	73,056	1,346,641,248	13,466,412,480
Palo Pinto Rsrvr	$ 139.48	1,063	195,455	207,768,665	2,077,686,650
Pedernales Rvr / Lk Travis	$ 72.00	75,301	217,790	16,399,804,790	163,998,047,900
E.V. Spence Rsrvr		14,285	26,205	374,338,425	3,743,384,250
Lk Champion	$ 43.00	14,994	31,535	472,835,790	4,728,357,900
Lk J.B. Thomas					
Twin Buttes Rsrvr	$ 68.03	236,417	25,028	5,917,044,676	59,170,446,760
Lk Nasworthy					
Steele Crk[4]	$ 162.50	1,894	26,068	49,372,792	493,727,920
Lower Guadalupe Rvr[4]	$ 111.69	1,000			
Pecos Rvr / Upper Colorado Rvr[3, 4]	$ 70.78	10,580	1,450,037	15,341,391,460	61,365,565,840
Greenbelt Rsrvr[3, 4]	$ 87.50	571	977,553	558,182,763	2,232,731,052
Hubbard Creek Rsrvr[3, 4]	$ 58.75	506	977,553	494,641,818	1,978,567,272
Mountain Creek Lk[4]	$ 49.00	1,440	46,389	66,800,160	668,001,600
TOTAL		841,489		78,812,909,691 = 241,868 ac-ft	607,099,284,559 = 1,863,117 ac-ft

[1] The total water yield is based on the watershed projects having a lifespan of 4 or 10 years depending on the type of brush treated.

[3] Life of Project = 4 year lifespan

[4] gal/ac per yr is not based on WSEP feasibility study

Brush control for water supply enhancement is one of the more cost-effective water management strategies. During FY2014 and FY2015, through the WSEP, 29,406 ac of brush management was incentivized by the State. For these acres, landowners received cost-share incentive funding through the program totaling $2,123,992 in state funding ($72.23 per treated ac of brush). Based upon the computer models used in the feasibility studies, this work is projected to enhance public water supplies by 8,826.45 ac-ft per year ($240.64 per acre-foot of water) over the next 10 years. A straight-forward analysis of the cost per ac-ft of water conservation savings provides a degree of comparability to other recommended WMS in the *State Water Plan* (TWDB 2016). For comparison, some aquifer storage and recovery projects approved as WMS by RWPGs cost in the range of $675 to $2,500 per ac-ft of water conserved (2.8 to 10.4 times as much as brush control). For comparison, some brackish groundwater desalination projects approved as WMS by RWPGs cost in the range of $2,100 to $5,300 per ac-ft of water conserved (8.7 to 22.0 times as much as brush control).

Full implementation of brush control, as modeled in all published feasibility studies for the 24 approved WSEP Project Watersheds, has a total projected annual water yield of 2.41M ac-ft of water that could be conserved if the State was able to provide cost-share incentive funding to landowners to treat 15.86M ac of brush in those watersheds (Table 9.2). These projections depend greatly upon the extent of voluntary landowner participation and on the climatic conditions across the state that influence the sequence of drought and rainfall events.

Economic analysis, included in 20 of the published feasibility studies, estimates that the total capital cost (i.e., the State's cost-share) for full implementation of brush control, as modeled, is over $1.18B (for comparability, costs from feasibility studies were adjusted for inflation to 2016 dollars). For FY2000-2017, the TSSWCB was appropriated $68.06M to implement the WSEP and its predecessor the BCP (Table 1.2.1 and Figure 1.2.1); this is only 5.8% of needed funds as estimated in the brush control feasibility studies.

Table 9.2. Projected Water Yield from Feasibility Studies based on Full Implementation

Watershed	# of Sub-basins	Total Watershed Area (ac)	Brush Treatment Area (ac)	Total Annual Water Yield (ac-ft)	Total Cost for Implementation[1]
Lk Alan Henry[2]	35	261,266	107,255	5,719.4	
Lk Arrowhead	28	529,352	277,656	151,621.6	$ 23,335,372
Lk Brownwood	48	997,040	462,138	180,780.7	$ 66,429,686
Lk Meredith	312	4,712,828	3,949,974	102,820.3	$ 108,160,007
Carrizo-Wilcox Aquifer[2]	44	682,850	687,097	115,498.9	
Edwards Aquifer - Frio Rvr	23	244,850	81,141	20,810.2	$ 11,652,583
Edwards Aquifer - Hondo Crk	5	57,551	20,006	9,321.7	$ 3,023,032
Edwards Aquifer - Medina Rvr	25	301,832	99,105	51,198.0	$ 14,809,193
Edwards Aquifer - Upper Nueces Rvr	18	1,075,052	776,730	112,892.0	$ 119,351,302
Edwards Aquifer - Sabinal Rvr	11	135,605	51,324	17,422.9	$ 7,939,750
Edwards Aquifer - Seco Crk	13	32,406	14,627	6,040.1	$ 2,313,213
Ft Phantom Hill Rsrvr	17	301,118	138,394	44,350.0	$ 13,249,621
Choke Canyon Rsrvr	26	1,329,094	882,882	226,756.6	$ 90,824,311
Canyon Lk[2]	23	918,791	197,905	21,088.2	
O.H. Ivie Rsrvr (watershed)	46	1,935,140	733,402	102,658.4	$ 60,535,647
O.H. Ivie Rsrvr (lake basin)[2]	1	17,657	7,986	722.1	
Lk Kemp	48	1,311,305	833,415	152,004.5	$ 60,294,918
O.C. Fisher Rsrvr	18	953,382	363,062	22,103.2	$ 16,013,026
Lk Corpus Christi	95	4,283,443	3,188,796	688,861.8	$ 347,791,116
Palo Pinto Rsrvr	22	296,400	139,425	76,268.3	$ 18,636,663
Lk Travis	35	800,275	203,752	133,496.4	$ 23,754,298
E.V. Spence Rsrvr	26	3,130,262	1,324,333	79,789.0	$ 93,848,083
Lk J.B. Thomas	7	1,103,800	301,765	8,742.9	$ 17,521,495
Twin Buttes Rsrvr	82	2,423,857	1,015,404	77,990.0	$ 76,765,779
TOTAL	1,008	27,835,156	15,857,574	2,408,957.0	$ 1,176,249,095

[1] Total "capital" cost (i.e., State's cost-share) for full implementation of brush treatment acres identified in Feasibility Studies. For comparability, costs from Feasibility Studies adjusted for inflation to 2016 dollars.

[2] No economic analysis was performed with this Feasibility Study.

The need for brush control cost-share incentive funds is much greater than the appropriated funding. For example, based on appropriated funds, the TSSWCB was only able to meet 33% of the demand for cost-share incentive funding as requested for the eligible projects received during the WSEP FY2016 request for proposals, leaving an unmet demand for over $3.5M in cost-share incentive funding for that year. The WSEP is not substantially funded to achieve significant water conservation; this need is identified in the TSSWCB's *Strategic Plan for Fiscal Years 2017 to 2021* as an impediment to effective agency operations. Increased appropriations by the Texas Legislature for landowner cost-share incentives would allow the TSSWCB to more substantially implement the WSEP, potentially conserving up to 2.41M ac-ft of water per year from brush control.

Section 9.1 Monitoring Effectiveness of WSEP

Fish and Rainwater (2007) described an approach for implementing a monitoring program to assess the effectiveness of the WSEP.

> "The major concern of the program is enhancement of streamflow. In order to measure such flows, it is necessary to install continuous streamflow recorders at the outlets of the treated subwatersheds. It would be best to have both pre- and post-treatment data to demonstrate the ranges of flow values. The typical flow recording system would most likely be a water level sensor, such as a pressure transducer, installed at a fixed channel cross-section, such as a paved low-water crossing, broad-crested weir, or a fixed measuring flume. The system would have a relationship between water surface elevation in the stream and flow rate, and allow continuous data collection so that baseflow and runoff components could always be observed. Pressure transducers typically come with electronic data loggers that can be downloaded.
>
> Continuous observation of rainfall is just as important as streamflow, so that the source of the runoff can be estimated. Multiple recording rain gauges, such as the tipping bucket type that can sense rainfall to the nearest 0.01 in, should be placed at strategic locations across the watershed to allow estimation of the areal and temporal distribution of rainfall for each storm event. These rain gauges can store data in data loggers for occasional downloading.
>
> Observation of local groundwater conditions should be done through monitoring wells in the shallow alluvial aquifer in and near the streambed. The elevations of the groundwater table in the monitoring wells can be compared to each other and to the elevation of the water surface in the stream to demonstrate which way the groundwater is flowing and the changes in groundwater storage over time. The groundwater levels can be continuously monitored with pressure transducers, or manually measured less often if readily accessible.
>
> Estimation of ET losses through vegetation within the target areas of the treated subwatershed can be done by using site visits, aerial photography, and satellite imagery to identify the effectiveness of brush management over the treated areas of the subwatershed. Potential ET can be estimated with local weather stations that measure and record wind speed, relative humidity, net solar radiation, and temperature. Actual ET can then be estimated as proportional to the potential ET based on plant type and seasonal variations in water consumption.

The best situation for application of hydrologic monitoring to confirm positive impacts of brush control would be to have several years of pre-treatment data to compare to several years of post-treatment data. Unfortunately, this situation is unlikely for the subwatersheds that have already been or will soon be treated. It is possible that two similar subwatersheds can be selected, instrumented, and observed with one receiving brush treatment and the other left untreated. The hydrologic behaviors of the two subwatersheds over several years could then be later compared to determine the impact of treatment.

An over-riding concern about hydrologic monitoring for streamflow enhancement, or any other purpose, is that the longer the observation period is the more confident one is in the findings. Installation of equipment to measure streamflow often seems to cause a drought. All those concerned with streamflow enhancement, whether through brush control or other watershed management techniques, are encouraged to be patient and allow multiple years of data collection and analyses to observe a reasonable range of weather conditions over time."

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Appendix A: Summary of Public Comments Received and the State's Responses

The public comment period extended from December 2, 2016 through January 9, 2017. A public hearing was held on January 5, 2017 in Temple. Notice regarding the comment period and hearing were published in the *Texas Register* on December 2, 2016 and an agency news release was published. Fifteen (15) sets of comments were received in response to the published proposed revision of the *State Water Supply Enhancement Plan*.

PREAMBLE – In 2011, the 82nd Texas Legislature passed H.B. 1808 which established the new WSEP administered by TSSWCB. As directed by the Legislature and codified in statute, the TSSWCB must prepare and adopt a *State Water Supply Enhancement Plan*. The TSSWCB respects and appreciates the wide difference of constructive opinions reflected in the comments regarding brush control and water supply enhancement. The *State Plan* is a "living" document that must be frequently revised. TSSWCB is committed to examining every issue and concern in depth and will work with those interested in making this *Plan* and Program the best it can be for the citizens of Texas.

Tracking Number	Date Received	Affiliation of Commenter	Summary of Comment	Summary of TSSWCB Action or Explanation
01-01	12-02-2016	Ellen Temple	What are the guidelines for brush control in each eco region? You don't want to leave the impression that widespread, indiscriminate clearing is good for the land and the wildlife.	The document was revised in response to this comment.
01-02	12-02-2016	Ellen Temple	Restoring grasslands is a long process which requires much expense and patience. Guidance for landowners is important.	No changes to the document were made in response to this comment.
01-03	12-02-2016	Ellen Temple	If landowners clear without a plan to restore grasslands, then soil will just wash away with the rains.	No changes to the document were made in response to this comment.
02-01	12-05-2016	Ben Eldredge, Cibolo Nature Center and Farm	I highly encourage you to consider encouraging the construction of swales on contour to capture runoff and eroding soil.	No changes to the document were made in response to this comment.
03-01	12-20-2016	Larry Dement, Chairman, Karnes County SWCD #343	We appreciate all the time, work and money that the State expends in implementing conservation practices to help with water conservation. We understand that controlling brush is a large part of solution.	No changes to the document were made in response to this comment.
03-02	12-20-2016	Larry Dement, Chairman, Karnes County SWCD #343	We believe, however, that substantial amounts of water could also be conserved by utilizing soil health practices as well.	No changes to the document were made in response to this comment.
03-03	12-20-2016	Larry Dement, Chairman, Karnes County SWCD #343	On May 12, 2015, Ron Nichols, USDA-NRCS, posted the following article: "A Hedge against Drought: Why Healthy Soil is Water in the Bank." This article has much information to support soil health practices as a way to conserve water.	No changes to the document were made in response to this comment.
03-04	12-20-2016	Larry Dement, Chairman, Karnes County SWCD #343	Healthy soil acts much like a sponge, with its ability to absorb and hold much of its volume in water.	No changes to the document were made in response to this comment.
03-05	12-20-2016	Larry Dement, Chairman, Karnes County SWCD #343	Healthy soils capture and store much more water - which can come in handy during dry spells.	No changes to the document were made in response to this comment.

Tracking Number	Date Received	Affiliation of Commenter	Summary of Comment	Summary of TSSWCB Action or Explanation
03-06	12-20-2016	Larry Dement, Chairman, Karnes County SWCD #343	According to the Kansas State Extension Agronomy e-Updates, Number 357, July 6, 2012, "Every 1% increase in organic matter results in as much as 25,000 gallons of available soil water per acre".	No changes to the document were made in response to this comment.
03-07	12-20-2016	Larry Dement, Chairman, Karnes County SWCD #343	Cover crops are a great way to help improve the health of the soil. Benefits of cover crops are erosion control and beneficial organisms. Cover crops help to slow down runoff allowing more moisture infiltration and can reduce pollution by preventing the runoff of nutrients and pesticides into surface water. Earthworms also help to improve water infiltration.	No changes to the document were made in response to this comment.
03-08	12-20-2016	Larry Dement, Chairman, Karnes County SWCD #343	This is only a brief summary of the ways soil health is important to water conservation. We hope that soil health can be implemented into the State Water Supply Enhancement Plan.	No changes to the document were made in response to this comment.
04-01	12-23-2016	Richard Thorpe, President, Texas and Southwestern Cattle Raisers Association	TSCRA supports best management practices and voluntary land stewardship on range and pasture lands that will reduce and/or eliminate invasive brush species, while also preventing soil erosion.	No changes to the document were made in response to this comment.
04-02	12-23-2016	Richard Thorpe, President, Texas and Southwestern Cattle Raisers Association	TSCRA supports the WSEP and its recommendations to comprehensively and selectively control brush species that are detrimental to water conservation and that increase the available amount of surface and ground water.	No changes to the document were made in response to this comment.
04-03	12-23-2016	Richard Thorpe, President, Texas and Southwestern Cattle Raisers Association	TSCRA values its long-standing partnership with the TSSWCB and the work that has been done thus far towards water supply enhancement and the many other issues of importance to landowners throughout Texas.	No changes to the document were made in response to this comment.
05-01	01-04-2017	Matt Wagner	As past president of the Texas Section Society for Range Management (TSSRM), and Texas Chapter of The Wildlife Society, I encourage the TSSWCB to work with TSSRM to revise this plan.	No changes to the document were made in response to this comment.
05-02	01-04-2017	Matt Wagner	The TSSRM annual meeting in Uvalde, in October 2016, was focused on the issue of brush management for municipal water supplies. A resolution will be forthcoming from that meeting. The TSSRM is the professional society especially equipped to address this issue.	The document was revised in response to this comment.
05-03	01-04-2017	Matt Wagner	There are too many variables that need to be researched before the costs and benefits of brush management for water supply can be quantified. At the very least, a portion of your cost share dollars should go to researching the effects of brush management on municipal water supply.	No changes to the document were made in response to this comment.
05-04	01-04-2017	Matt Wagner	Better yet, cost share dollars should be made in more eastern portions of the state, where rainfall is more abundant and predictable. For example, yaupon control over the recharge zone of the Carrizo-Wilcox aquifer, east of I-35 may yield positive results. Brad Wilcox at TAMU would be interested in researching this idea.	No changes to the document were made in response to this comment.
06-01	01-04-2017	Steve Nelle	The commenter requested a summary of the proposed changes in the WSEP.	No changes to the document were made in response to this comment.

Tracking Number	Date Received	Affiliation of Commenter	Summary of Comment	Summary of TSSWCB Action or Explanation
06-02	01-04-2017	Steve Nelle	The commenter expresses doubt that public comments are actually taken into consideration but if he knew what revisions are proposed it would help him understand the program better.	No changes to the document were made in response to this comment.
07-01	01-06-2017	Suzanne Scott, General Manager, San Antonio River Authority	SARA supports the adoption of the proposed revisions to the State Water Supply Enhancement Plan. As a regional entity SARA advocates for a regional approach to addressing water quality and quantity issues.	No changes to the document were made in response to this comment.
07-02	01-06-2017	Suzanne Scott, General Manager, San Antonio River Authority	The proposed revisions to the State Water Supply Enhancement Plan recognizes SARA projects such as the EDYS studies in Wilson, Karnes, Goliad, Reftigio and Victoria counties as ongoing water supply enhancement feasibility studies. The proposed revisions to the plan also notes the SARA and USGS study determining the effects of huisache removal on ET in South Central Texas as a study that is critical to the WSEP. SARA is pleased these studies are acknowledged as supporting the TSSWCB's State Water Supply Enhancement Plan.	No changes to the document were made in response to this comment.
07-03	01-06-2017	Suzanne Scott, General Manager, San Antonio River Authority	One other initiative SARA has implemented since 2015 provides for $100,000 in cost share support for the implementation of prioritized conservation practices within the Goliad, Karnes, Wilson and Alamo SWCDs.	No changes to the document were made in response to this comment.
07-04	01-06-2017	Suzanne Scott, General Manager, San Antonio River Authority	SARA supports the adoption of the proposed revisions to the State Water Supply Enhancement Plan as well as conservation practices aimed at protecting and improving water quality and quantity throughout our jurisdiction.	No changes to the document were made in response to this comment.
08-01	01-08-2017	Elizabeth McGreevy	The 2016 State Water Supply Enhancement Plan states several times that junipers are "detrimental to water conservation in Texas". Basically, it is believed that clearing junipers will increase water supplies. This assumption is based on laboratory calculations that never consider the bigger picture.	No changes to the document were made in response to this comment.
08-02	01-08-2017	Elizabeth McGreevy	One of these junipers is the Ashe juniper that grows across the eastern Edwards Plateau. Most parts of the eastern Edwards Plateau have thin, degraded soils as a result of a broken terrain, extended droughts followed by flash floods and decades of clearcutting and overgrazing. In many places, the only plants that can produce a solid, dense cover of vegetation to protect the ground and act as a soil building machine is the Ashe juniper.	No changes to the document were made in response to this comment.

Tracking Number	Date Received	Affiliation of Commenter	Summary of Comment	Summary of TSSWCB Action or Explanation
08-03	01-08-2017	Elizabeth McGreevy	Whenever brush is cleared, the typical result is a sparse cover of grass that looks nice from a distance. However, once you walk into it and look down, you realize each pitiful clump of grass is surrounded by a sea of eroded caliche. This does not allow water to infiltrate sufficiently. So most of the water that we see filling up those creeks is really just overland flows full of silt. Making matters worse, the exposed caliche bakes in the sun, thus increasing soil evaporation. When more soil evaporation happens over vegetation transpiration, the climate grows hotter and drier…and moves a region towards desertification.	No changes to the document were made in response to this comment.
08-04	01-08-2017	Elizabeth McGreevy	Because these sparse covers of grasses do not produce much organic matter, they have low soil carbon. According to the NRCS, soils high in organic matter have more soil carbon and can hold more water, which means they both capture and store more rainfall while reducing runoff and the resulting flooding. High carbon soils are less vulnerable to erosion and are more resistant to drought.	No changes to the document were made in response to this comment.
08-05	01-08-2017	Elizabeth McGreevy	On the other hand, a 2014 study discovered that Ashe juniper “encroachment in Central Texas savannas increased the carbon sink strength [more than grasses] by increasing the carbon inputs into the ecosystem” (Thijs, A. 2014) This means Ashe juniper is better for the soil and long term water supply.	No changes to the document were made in response to this comment.
08-06	01-08-2017	Elizabeth McGreevy	More importantly, since the 1950s, as brush cover has increased, river flows in the Blanco, Nieces, Frio, Guadalupe and Llano Rivers had increased (Bradford Wilcox and Yun Huang TAMU, and Jack Hollon, independent research).	The document was revised in response to this comment.
08-07	01-08-2017	Elizabeth McGreevy	If Ashe junipers are improving our water situation, then why does the state continue to clear brush in the name of water conservation? We need to turn the focus to rebuilding the soil and boosting soil biology and health. This will allow the soil to act as a larger sponge to absorb more water and reduce erosion and flooding. More healthy soil that holds more water can then future more vegetation and still have plenty of water left over to sustain spring flows. This is the ecological approach…not the out-dated range management approach.	No changes to the document were made in response to this comment.
08-08	01-08-2017	Elizabeth McGreevy	Stop describing all “brush” as bad, and all grass as good.	No changes to the document were made in response to this comment.
08-09	01-08-2017	Elizabeth McGreevy	Stop burning large slash piles. These kill the soil underneath, pollute the air, and eliminate a potential resource.	No changes to the document were made in response to this comment.
08-10	01-08-2017	Elizabeth McGreevy	Stop spraying chemicals.	No changes to the document were made in response to this comment.
08-11	01-08-2017	Elizabeth McGreevy	Keep brush and trees on hillsides with at least 25% slope. Also, keep trees on areas with subsurface slab limestone. These areas need to be covered with thickets or woodlands.	No changes to the document were made in response to this comment.

Tracking Number	Date Received	Affiliation of Commenter	Summary of Comment	Summary of TSSWCB Action or Explanation
08-12	01-08-2017	Elizabeth McGreevy	Cut brush on flat to more rolling terrains. Bury the brush on contours and ignite. This will sequester atmospheric carbon to increase soil carbon to feed the bacteria that benefit grasses.	No changes to the document were made in response to this comment.
08-13	01-08-2017	Elizabeth McGreevy	Spray flat to rolling terrains with grassland bacterias to shift soil biology to favor grass.	No changes to the document were made in response to this comment.
08-14	01-08-2017	Elizabeth McGreevy	Encourage inter-ranch rotational grazing. Keep livestock away from riparian corridors allow for riparian restoration to increase groundwater levels. Better yet, reintroduce buffalo.	No changes to the document were made in response to this comment.
08-15	01-08-2017	Elizabeth McGreevy	Use techniques such as water ranching on slopes to increase litter accumulation and water infiltration. Allow for the regrowth of slope woodlands.	No changes to the document were made in response to this comment.
08-16	01-08-2017	Elizabeth McGreevy	Install rainwater collection tanks everywhere. Collect water from the highway system.	No changes to the document were made in response to this comment.
08-17	01-08-2017	Elizabeth McGreevy	Clearing brush every 5 years is not the answer. It's just a short term fix for some instantaneous gratification. We need to turn our focus to soil restoration to produce ecological results that are sustainable.	No changes to the document were made in response to this comment.
08-18	01-08-2017	Elizabeth McGreevy	Only by storing water in the land itself will the land be able to sustain spring flows.	No changes to the document were made in response to this comment.
09-01	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	As noted in the comments, the TWDB seat on the Science Advisory Committee is currently vacant, and the draft document should be changed accordingly. Following formal adoption of the State Water Supply Enhancement Plan, Dr. Mindy Conyers will serve as the designated representative for the TWDB.	The document was revised in response to this comment.
09-02	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	We applaud the efforts of this committee and hope the TSSWCB will consider hosting multiple meetings per year to facilitate more collaboration to carry out their responsibilities using the best available science.	No changes to the document were made in response to this comment.
09-03	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 5. Carla Guthrie is not designated as the official TWDB representative on the Science Advisory Committee. This position should be listed as vacant, currently.	The document was revised in response to this comment.
09-04	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 19. Same comment as #1 regarding the vacancy for the TWDB representation on the Science Advisory Committee.	The document was revised in response to this comment.
09-05	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 24. Consider listing the "other brush control feasibility studies" referenced here.	The document was revised in response to this comment.
09-06	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 25. figure 1.3.2 (and associated text) needs a source.	The document was revised in response to this comment.
09-07	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 28 (and elsewhere throughout). Text taken directly from a source with little to no paraphrasing should appear in quotation marks.	No changes to the document were made in response to this comment.

Tracking Number	Date Received	Affiliation of Commenter	Summary of Comment	Summary of TSSWCB Action or Explanation
09-08	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 41. first paragraph concludes with a reference to Redeker, E.J., T.L. Thurow, and X. Wu. 1998. Brush Management on the Cusenbary Draw Watershed: History and Ramifications. Rangelands 20(5):12-14. Please consider double-checking that reference as the Redeker et al. paper does not contain the information included in this paragraph.	The document was revised in response to this comment.
09-09	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 47. Consider elaborating on how the simplified water balance equation considers variables such as soil moisture and field capacity in the calculations.	The document was revised in response to this comment.
09-10	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 91. Remove "consensus-based" from the first sentence.	The document was revised in response to this comment.
09-11	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 91. Add GMAs to the end of the third sentence.	The document was revised in response to this comment.
09-12	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 91. Second paragraph. Please revise this sentence as follows, "A WMS is a plan that may require a WMS project to meet a need for additional water by a WUG..."	The document was revised in response to this comment.
09-13	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 91. Third paragraph. Consider replacing "and voluntary land stewardship are" with "is". (Brush control is/may be a recommended strategy, but not voluntary land stewardship.)	The document was revised in response to this comment.
09-14	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 91. Last sentence. Consider clarifying the conclusions reached in the Research and Planning Consultants' report. "A report prepared for the TWDB in 2000 (Research and Planning Consultants, Inc.) assessed brush control as a WMS and concluded that the selection of watersheds for brush management projects to produce additional water for specific water supply purposes should be considered by the RWPGs or a specific WUG to gage local support for subsidizing brush control." Further, the report states that "actual measured results over a period of time sufficient to yield valid scientific data must be viewed as the determinant factor when judging the ultimate benefit of brush control for water yield."	The document was revised in response to this comment.
09-15	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 92, third paragraph: Summary of the Region L brush control strategy fails to mention that the brush strategy that was evaluated was not actually recommended by the planning group primarily due to its unit cost and permitting issues.	The document was revised in response to this comment.

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09-16	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 92, second to last paragraph and page 93, first sentence: The report does not recognize the alternative approach to linking proposed brush control projects to the state water plan. The issue was discussed most recently at an interagency meeting on March 3, 2015, between TWDB and the TSSWCB staff at which the methodology was outlined (below) regarding how TSSWCB may tie proposed brush control projects to water "needs" (potential water shortages) in the state water plan, regardless of whether the specific brush control project was recommended in the state water plan. This methodology was based on the TSSWCB rules that were in place at the time and which referred to "needs" in the state water plan. The method and process for how TSSWCB could obtain and directly associate state water plan "needs" (potential water shortages) with proposed brush control projects when ranking projects for funding is suggested.	No changes to the document were made in response to this comment.
09-17	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 93. Consider including a table with the "needs" of the specific WUGs and PWS that brush control might benefit.	No changes to the document were made in response to this comment.
09-18	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 117. Consider addressing any potential conflicts of interest presented by applicants or modelers being members of the Science Advisory Committee.	No changes to the document were made in response to this comment.
09-19	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 109 and Page 118. Agriculture Code §203.057 requires the TSSWCB to provide this assistance. It seems inappropriate to require the Science Advisory Committee to direct applying entities to an appropriate modeler to conduct feasibility studies.	The document was revised in response to this comment.
09-20	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 141-2. Consider altering the text in the first full paragraph: "Water conserved through the programs is Modeled increases in water yield are also shown in Table 9.1." Similarly, consider changing the title of Table 9.1 to reflect that water volumes shown in the table are modeled or projected values rather than observed water yielded from brush control projects.	The document was revised in response to this comment.
09-21	01-09-2017	Jeff Walker, Executive Administrator, Texas Water Development Board	Page 143. Consider comparing the cost of brush control to the conservation water management strategies, instead of brackish desalination and aquifer storage and recovery. Water yields from brush control and the recommended conservation strategies are somewhat more similar in nature than that of the water yields from new water supply infrastructure projects.	No changes to the document were made in response to this comment.
10-01	01-09-2017	Molly Stevens, Westcave Outdoor Discovery Center	The commenter expresses support for the State Water Supply Enhancement Plan.	No changes to the document were made in response to this comment.
11-01	01-09-2017	Dr. Tom Arsuffi and Tyson Broad, Llano River Field Station, Texas Tech Univeristy	The Llano River Field Station (LRFS) at TTU in Junction appreciates the continued commitment of the TSSWCB to this process.	No changes to the document were made in response to this comment.

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11-02	01-09-2017	Dr. Tom Arsuffi and Tyson Broad, Llano River Field Station, Texas Tech Univeristy	As you are aware, the LRFS, in partnership with stakeholders and TWRI, recently completed the Upper Llano River WPP. The WPP, funded through the TSSWCB and the USEPA, was accepted in the fall of last year. One of the major Management Measures identified by stakeholders in developing the WPP is Brush Control for Range Improvement and Water Supply Enhancement. The LRFS general comments regarding the State Water Supply Enhancement Plan are based on our experiences evaluating brush control methods to improve water quantity and quality.	No changes to the document were made in response to this comment.
11-03	01-09-2017	Dr. Tom Arsuffi and Tyson Broad, Llano River Field Station, Texas Tech Univeristy	In developing the Upper Llano WPP, the LRFS utilized an EDYS model for the Upper Llano. Model results show that over the course of 25 years, removing 9,000 acres of brush annually in the watershed annually decreases evapotranspiration by 75,000 acre-feet approximately 11 years after initial treatment. Due to the hydrogeology of the Upper Llano, decreases in evapotranspiration are assumed to result primarily in increased recharge and resulting increase in baseflows to rivers and creeks, many of which are often perennial.	No changes to the document were made in response to this comment.
11-04	01-09-2017	Dr. Tom Arsuffi and Tyson Broad, Llano River Field Station, Texas Tech Univeristy	Based on these positive hydrologic results, stakeholders developing the WPP viewed brush control as an important management strategy for addressing water quality issues associated with low flows in the watershed, primarily bacteria and low dissolved oxygen. Stakeholders also recognized that this management strategy also provides additional benefits of increased agricultural water supply and improved aquatic habitat.	No changes to the document were made in response to this comment.
11-05	01-09-2017	Dr. Tom Arsuffi and Tyson Broad, Llano River Field Station, Texas Tech Univeristy	Based on our experience developing the Upper Llano WPP, we suggest that the WSEP be expanded to incorporate the potential benefits of increased agricultural water supply and improved water quality and aquatic habitat.	No changes to the document were made in response to this comment.
11-06	01-09-2017	Dr. Tom Arsuffi and Tyson Broad, Llano River Field Station, Texas Tech Univeristy	As currently drafted, Section 7.3 of the State Plan (Proposal Evaluation Criteria and Ranking) focuses only on water supply enhancement for public water supply systems, leaving brush control projects, such as those associated with the Upper Llano WPP, at a potential disadvantage.	No changes to the document were made in response to this comment.
11-07	01-09-2017	Dr. Tom Arsuffi and Tyson Broad, Llano River Field Station, Texas Tech Univeristy	Criteria for Accepting and Prioritizing Water Supply Enhancement Projects, as outlined in Section 203.053(d)(1) of HB 1808, does require prioritization to consider need for conservation based on the state water plan. In many of the regional water plans, including Region J brush control is a recommended water supply strategy recommended primarily to increase agricultural and rural (County-other) water supplies, rather than municipal water supplies.	No changes to the document were made in response to this comment.

Tracking Number	Date Received	Affiliation of Commenter	Summary of Comment	Summary of TSSWCB Action or Explanation
11-08	01-09-2017	Dr. Tom Arsuffi and Tyson Broad, Llano River Field Station, Texas Tech Univeristy	As nothing in H.B. 1808 suggests that only municipal water supplies be considered in ranking and prioritizing brush control projects for water supply enhancement, we suggest Section 7.3 of the State Water Supply Enhancement Plan be expanded to include and equally consider projects that enhance rural and agricultural water supplies, as well as projects that are part of an USEPA-approved WPP. We feel that such an amendment will facilitate the development and implementation of a more robust WSEP and be responsive to rural needs and benefits of brush control.	No changes to the document were made in response to this comment.
11-09	01-09-2017	Dr. Tom Arsuffi and Tyson Broad, Llano River Field Station, Texas Tech Univeristy	A range of costs per acre associated with brush control of target species in different regions of the State would be helpful to the reader.	No changes to the document were made in response to this comment.
11-10	01-09-2017	Dr. Tom Arsuffi and Tyson Broad, Llano River Field Station, Texas Tech Univeristy	For Figures 2.1-4-6, we find these figures to be confusing as figure title does not match the map explanation. For example, the title references a 50% relative plant canopy cover, while the map key references a cover of 'over 20%'.	No changes to the document were made in response to this comment.
11-11	01-09-2017	Dr. Tom Arsuffi and Tyson Broad, Llano River Field Station, Texas Tech Univeristy	In Table 5.1, for Region J, Vegetative Management (Arundo donax) should read 'Vegetative Management (i.e. Arundo donax)' as listed in the Region J Plan. The way it currently read might suggest that only control of Arundo is considered.	No changes to the document were made in response to this comment.
12-01	01-09-2017	Dr. Alexis Racelis, University of Texas Rio Grande Valley	Stands along the Upper Nueces River are the same genotype that grows on the Rio Grande, which originated from the Seville region of Spain (Tarin et al. 2013).	The document was revised in response to this comment.
12-02	01-09-2017	Dr. Alexis Racelis, University of Texas Rio Grande Valley	Control of carrizo cane infestations along the Rio Grande (estimated at 30,000 to 60,000 ac Yang et al. 2011) alone could yield as much as 76,000 to 224,000 ac-ft of water savings.	The document was revised in response to this comment.
12-03	01-09-2017	Dr. Alexis Racelis, University of Texas Rio Grande Valley	Scientists have estimated that a 32 % 22% reduction in carrizo cane above-ground biomass and significant regrowth of native vegetation with stands along the Rio Grande, which is attributed to biological control along the Rio Grande over the period (Goolsby et al. 2015, Moran et al. 2017).	The document was revised in response to this comment.
12-04	01-09-2017	Dr. Alexis Racelis, University of Texas Rio Grande Valley	A third biological control agent, the arundo leafminer was released in 2016 which causes defoliation of the cane and continued decline of above ground biomass. USDA-ARS has also developed a biocontrol plus mechanical topping technique that allows for immediate visibility of the Rio Grande and accelerates the impacts of the biological control agents (Racelis et al. 2013).	The document was revised in response to this comment.
13-01	01-09-2017	Dwight Head	I appreciate all the time, work and money that the State expends in implementing conservation practices to help with water conservation. I understand that controlling brush is a large part of solution.	No changes to the document were made in response to this comment.
13-02	01-09-2017	Dwight Head	I believe, however, that substantial amounts of water could also be conserved by utilizing soil health practices as well.	No changes to the document were made in response to this comment.

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13-03	01-09-2017	Dwight Head	On May 12, 2015, Ron Nichols, USDA-NRCS, posted the following article: "A Hedge against Drought: Why Healthy Soil is Water in the Bank." This article has much information to support soil health practices as a way to conserve water.	No changes to the document were made in response to this comment.
13-04	01-09-2017	Dwight Head	Healthy soil acts much like a sponge, with its ability to absorb and hold much of its volume in water.	No changes to the document were made in response to this comment.
13-05	01-09-2017	Dwight Head	Healthy soils capture and store much more water – which can come in handy during dry spells.	No changes to the document were made in response to this comment.
13-06	01-09-2017	Dwight Head	According to the Kansas State Extension Agronomy e-Updates, Number 357, July 6, 2012, "Every 1% increase in organic matter results in as much as 25,000 gallons of available soil water per acre."	No changes to the document were made in response to this comment.
13-07	01-09-2017	Dwight Head	Cover crops are a great way to help improve the health of the soil. Benefits of cover crops are erosion control and beneficial organisms. Cover crops help to slow down runoff allowing more moisture infiltration and can reduce pollution by preventing the runoff of nutrients and pesticides into surface water. Earthworms also help to improve water infiltration.	No changes to the document were made in response to this comment.
13-08	01-09-2017	Dwight Head	This is only a brief summary of the ways soil health is important to water conservation. I hope that soil health can be implemented into the State Water Supply Enhancement Plan.	No changes to the document were made in response to this comment.
14-01	01-09-2017	Dr. Tom Vaughan, Texas A&M International University	As a resident of the Rio Grande Watershed and as an observer of the local environment, especially of the growth of the highly invasive Carrizo Cane, I am interested in seeing a reduction of this plant along with the revegetation of the river banks with native plants.	No changes to the document were made in response to this comment.
14-02	01-09-2017	Dr. Tom Vaughan, Texas A&M International University	I understand and fully support the dual purposes for Carrizo cane control: both border security and water conservation.	No changes to the document were made in response to this comment.
14-03	01-09-2017	Dr. Tom Vaughan, Texas A&M International University	It is clear to me that the most viable long term control will be achieved by a combination of biological and mechanical methods. I have observed the efficacy of the method developed by the USDA-APHIS of topping the cane mechanically and the introduction of biological control agents including the arundo wasp and the arundo scale insect. It is my understanding that a third biocontrol agent has recently been approved for release and should enhance the rate of cane control along the Rio Grande without introducing more herbicides into the watershed.	The document was revised in response to this comment.
14-04	01-09-2017	Dr. Tom Vaughan, Texas A&M International University	As the State Water Supply Enhancement Plan is implemented I would like to see more collaboration between the TSSWCB and the USDA in controlling arundo along the Rio Grande.	No changes to the document were made in response to this comment.
15-01	01-09-2017	Dr. Ali Fares, Prairie View A&M University	We hope that these comments will strengthen a well-developed State Water Supply Enhancement Plan. we are looking forward to contribute to its implementation.	No changes to the document were made in response to this comment.

Tracking Number	Date Received	Affiliation of Commenter	Summary of Comment	Summary of TSSWCB Action or Explanation
15-02	01-09-2017	Dr. Ali Fares, Prairie View A&M University	This team has been working on investigating the effects of brush management on hydrologic fluxes, in the parts of Texas where brush is a dominant component of the landscape (Ray et al., 2014). We used a hydrologic modeling approach to investigate the impact of brush control on water enhancement in two hydrologically distinct sub-basins. It was concluded that it is important to verify the effectiveness of brush removal on increasing groundwater recharge and surface water through field experiment.	The document was revised in response to this comment.
15-03	01-09-2017	Dr. Ali Fares, Prairie View A&M University	Moreover, brush management needs regular maintenance to control its re-growth and if it is not managed properly, it may harm wildlife habitat and enhance soil erosion which is also important to take into consideration.	No changes to the document were made in response to this comment.
15-04	01-09-2017	Dr. Ali Fares, Prairie View A&M University	Although the Science Advisory Committee recommended feasibility studies and computer models, and methods for prioritizing acreage for brush control, we think that the WSEP should also include a strong experimental component to evaluate all hydrological aspects resulting from brush control, e.g. qualitative and qualitative enhancement of surface and groundwater, and impact on soil erosion.	No changes to the document were made in response to this comment.
15-05	01-09-2017	Dr. Ali Fares, Prairie View A&M University	It is also important to evaluate what we accomplished by brush control since 1999 when the 76th Legislature appropriated funds to begin implementing the BCP.	No changes to the document were made in response to this comment.
15-06	01-09-2017	Dr. Ali Fares, Prairie View A&M University	There is a need for an update of the inventory of the current brush types across the state as the latest version used in this report dates back to more than 3 decades ago as detailed in Table 2.41 on page 50. We need to keep track of brush's spatial-temporal distribution across the state.	No changes to the document were made in response to this comment.
15-07	01-09-2017	Dr. Ali Fares, Prairie View A&M University	In its current version, there is no reference in this plan to climate variability especially the reference to potential impact of climate variability on the water budget components and weather especially, rainfall, evapotranspiration, and air temperature. We recommend including potential impact of future climate variability on the magnitudes and frequencies of the major hydrological components, mainly rainfall and evapotranspiration, and consequently on water yield under different brush removal scenarios. Our recent analysis of the potential impact of future climate and climate extremes in the Brazos Headwaters Basin indicates that basin average maximum and minimum temperatures are expected to increase; however, annual precipitation is more likely to decrease for all studied future periods (Awal et al., 2016).	The document was revised in response to this comment.
15-08	01-09-2017	Dr. Ali Fares, Prairie View A&M University	In conclusion, this is a well-developed complete plan; we are looking forward to help in its implementation.	No changes to the document were made in response to this comment.

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