LAND-BASED WATER CONSERVATION & WATER YIELD PRACTICES IN REGION L: INFLUENCE OF LAND BASED CONSERVATION PRACTICES ON WATER YIELD

SUBMITTED TO
REGION L
SOUTH CENTRAL TEXAS REGIONAL WATER PLANNING GROUP
BY

TEXAS A&M Institute of Renewable Natural Resources

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GRAZINGLAND MANAGEMENT SYSTEMS, INC.

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Abstract

In this report we examine the potential for increasing water yield within region Region L though land management. Our assessment is based on the available literature and our own experience. The major land management practice which has the potential for affecting water yield would be that of reducing woody plant cover through brush control. Region L encompasses a large region in south-central Texas and includes several distinct vegetation and physiographic zones including the Edwards Plateau, South Texas Plains, Gulf Coast Prairies, Post Oak Savanna and Blackland Praire. The areas with the most potential for increasing water yield through brush control would be the Edwards Plateau overlying the Edwards Aquifer and the South Texas Plains that overly the Carrizo-Wilcox aquifer. The most current research indicates that within the Edwards Plateau, reducing ashe-juniper cover could result on average 40-60 mm of additional water yield per year. This translates into roughly an additional acre-ft of water for every 5-8 acres cleared. Within the South Texas plains, water yield (groundwater recharge) could be augmented up to10 - 20 mm/yr or about 1 acre-ft of water for every 15-30 acres cleared. Depending on the method and expense of brush clearing these estimates would translate into a cost of between $40 and $180 per acre-ft of water for the Edwards Plateau and $100 and $300 per acre-ft in regions of the South Texas Plains that overlie the Carrizo-Wilcox Aquifer

Executive Summary

Vegetation and Vegetation Management in the MLRA of Region L

Edwards Plateau

The northern parts of Uvalde, Medina, Bexar, Comal and Hays Counties of Region L are in the Edwards Plateau Major Land Resource Area (81C) immediately above the Balcones Escarpment. For the purpose of this report, soil series typical of the area are represented by a Low Stony Hill ecological site, an upland site with slope gradients mainly 1 to 8 percent but that can range up to 12 percent. The plant communities of a Low Stony Hill site are dynamic and vary in relation to grazing, fire and drought. Presettlement conditions were strikingly different than those found today. Large areas that were once open grasslands are now infested with heavy woody cover consisting of species such as Ashe juniper, liveoak, post oak, honey mesquite, agarito, Texas persimmon, elbowbush and lotebush.

Brush management treatment alternatives commonly used in the Edwards Plateau MLRA include mechanical and chemical practices, as well as prescribed fire and biological control associated with the use of goats. Ashe juniper is the primary target species for brush management a very high percentage of the time. Mechanical brush management treatments can be either broadcast when densities of plants are greater than 300 plants per acre or large enough to respond to treatments such as chaining or cabling, or individual plant treatments (IPT) when densities are low enough and/or plants are small enough to justify treating individual plants. Ashe juniper is non-sprouting species; that is, it will suffer mortality if all the above ground green material is removed. This allows top removal practices to be effective for brush management and the most popular of these methods currently is the use of a "skid-steer loader" equipped with a front-end attachment of hydraulically operated shears. The shears are placed with the skid steer at the base of a target plant species and the shears are then closed hydraulically so that they cut entirely through the trunk of the tree.

South Texas Plains

The South Texas Plains MLRA includes the largest portion of Region L. All or part of the following Region L Counties are in the MLRA; Uvalde, Zavala, Dimmitt, Medina, Frio, La Salle, Bexar, Atascosa, Wilson, Karnes, Goliad, DeWitt, and Gonzales. Upland soils are of three groups: dark, clayey soils over firm clayey subsoils; grayish to reddish brown, loamy to sandy soils; and brown loamy soils. Gray, clayey, saline, and sodic soils are extensive on the coastal fringe, along with Galveston deep sands. Bottomlands are typically brown to gray, calcareous silt loams to clayey alluvial soils. The original vegetation was an open grassland or savannah-type along the coastal areas and brushy chaparral-grassland in the uplands. The plant communities that can be found on this site range from a mid-grass dominant to a brush covered site with bare ground. This diversity in plant communities is in direct response to grazing management, fire, and drought. At this point the area is represented as a Shrubland with a canopy of brush greater than 20 percent and often reaching between 60 percent to total closure. In the heavy brush cover, understory vegetation will range from a cover of short and mid grasses to bare ground. Woody species include guajillo, blackbrush, condalia, wolfberry, pricklypear, Texas persimmon, paloverde , ceniza and coma.

The South Texas Plains are the heart of the Texas "Brush Country", sharing that designation with the western part of the Gulf Coast Prairie MLRA. Brush stands in the area are often aggregates of 15 or more species, most characterized by thorns or spines and existing in three strata – overstory of trees, mid-story of shrubs and an understory of subshrubs and cacti. Chaining and rootplowing where the most popular of the early mechanical practices utilized in the area and have been applied on hundreds of thousand of acres in the MLRA. The MLRA also has a long history of the use of broadcast chemical brush management treatments.

Other MLRAs in Region L

Other MLRAs in Region L include the Gulf Coast Prairies and Marshes consisting of all or part of Refugio, Calhoun, Victoria and Goliad Counties. The Post Oak Savannah and Blackland Prairies are two additional MLRA that include portions of Counties within Region L. Compared to the Edwards Plateau, Gulf Coast Prairies and Marshes and South Texas Plains, the land areas of the Post Oak Savannah and Blackland Prairies within Region L are small.

Potential to Augment Recharge and Streamflow Within Region L Through Shrub Control

In this section, we examine the scientific basis for using shrub control as a means of increasing groundwater recharge with an explicit focus on two of the landcover types within the Region L Planning area: (1) juniper woodlands within the Edwards Plateau Major Land Resource Area (MLAR) and (2) South Texas shrublands within the South Texas Plains MLRA—in particular those shrublands overlying the Carizzo-Wilcox recharge zone within Zavala and Dimmitt counties.

Rangeland areas with the most potential for increasing recharge through shrub control are those areas where deep drainage (water movement beyond the herbaceous rooting zone) can occur (Seyfried et al. 2005, Wilcox et al. 2006). This characteristic is found, for example, where soils are shallow and overlie relatively permeable bedrock (such as karst limestones). An example in Texas is the Edwards Plateau area, which supports large tracts of juniper woodlands and has considerably more "flowing water" than would be expected for a semiarid or subhumid climate (ca. 700 mm/yr). The explanation lies in the karst geology—a substrate of fractured limestone that allows rapid flow of water to the subsurface. Other soil types that may enable deep drainage are sandy soils. Shrublands in region L that exhibit these characteristics are the juniper shrublands within the Edwards Plateau and the South Texas shrublands overlying the recharge zone of the Carrizo-Wilcox Aquifer.

Edwards Plateau

On the basis of the literature available, our current best estimate is that conversion of Ashe Juniper woodlands into open savannas would result in an average increase in water yield (streamflow and recharge) of around 50 mm/year. The influence of Ashe juniper on the water budget has been the subject of some confusion and disagreement, in part because the implications of the scale at which measurements were made have not been fully considered. For example, at the tree scale, the most common measurement is some index of evapotranspiration by trees. After removal of trees, these numbers have often been extrapolated up without taking into account the compensatory effects of regrowth of trees or replacement by other vegetation. These measurements do not take into account water use by replacement vegetation, as the larger-scale studies do. For example, at the tree scale, for an area with an average annual precipitation of 750 mm/yr, an individual tree will intercept and transpire virtually all of the available water. At the stand scale, however, as estimated by Dugas *et al.* (1998), the difference in water consumption between a woodland and a grassland is between 40-50 mm/yr. Newer work suggests differences as high as 90 mm/year however. Water balance studies at the small-catchment scale (where springs exist) indicate water savings of around 50 mm/yr. (Huang et al. 2006).

South Texas Shrublands

Our estimate that for the South Texas shrublands, average recharge on sandy soils could be increased by shrub control anywhere from 10 -20 mm/year. All of the available data strongly suggest that in the presence of dense shrub cover, there will be little if any recharge. However, both the modeling and field work suggest that in the absence of shrubs, recharge will be appreciably higher—especially for sandy soils. For example, Weltz et al (1995) found that when rainfall was slightly above average, recharge was around 20 mm/year for grass covered areas. The implications of this then are that shrub control over the recharge area would in the long term increase distributed recharge.

Assessing the Cost Effectiveness of Brush Control to Enhance Off-site Water Yield

Estimates of added groundwater recharge cost reported herein are based only on the highly variable costs of the brush control practices and/or programs. Factors that influence brush control cost and contribute to the high variability include the type, size and density of the target brush species; the type, rock content and slope of soil in which the target species is growing; whether the target species sprouts re-growth from root buds; whether cost effective herbicides are available for controlling the target species; etc.

In addition, there are many other factors which would impact the ultimate costs; ie., program implementation and management, percent of costs born by landowners, extent of landowner participation, etc.

Edwards Plateau

In a previous section, it was reported that there are several different mechanical practices appropriate for use in the control of Ashe juniper. The costs of these various mechanical practices may vary from less than $100 to as much as $400 per acre (Pestman, 2007). Also in a previous section of this report the added ground water recharge estimated to result from control of Ashe juniper was reported to be 50mm/year. The inch equivalent of 50mm/yr. is 2 in. which is also equal to 0.167 ft. Therefore, control of Ashe juniper on an acre of land is estimated to result in 0.167 added ac.ft. of groundwater recharge per year.

The cost estimates are obtained by taking the per acre cost of the brush control practice, or cost of a program consisting of an initial plus follow-up practices, and dividing it by 0.167. This results in the estimated cost per acre foot of added groundwater recharge resulting from brush control if the practice, or program, is effective for only one year. If brush control programs were implemented and if provisions of the programs require participating landowners to reduce brush canopies to 5 percent and maintain them at this level or less for 10 years, then the costs per acre foot of added ground water recharge would be expected to range between $40 and $180 per acre foot in the Edwards Plateau.

South Texas Shrublands

In a previous section, it was stated that several herbicides and several different mechanical practices were appropriate for use in the control of mixed brush in South Texas. The costs of these various chemical practices are less variable and generally less costly than the mechanical practices in the Edwards Plateau as discussed above. In addition, the mechanical practices applicable to the control of mixed brush in South Texas would generally be less costly than when used in the Edwards plateau because the soils tend to be less rocky and the terrain is generally flatter in South Texas. Therefore, costs for mixed brush management in South Texas may vary from less than $50 to more than $100 per acre (Pestman, 2007). Also in a previous section of this report the added groundwater recharge estimated to result from control of mixed brush was reported to be between 10 and 20mm/year. To be conservative, we will use 10mm/year in the following analysis. The inch equivalent of 10mm/yr. is 0.4 in. which is also equal to 0.033 ft. Therefore, control of Ashe juniper on an acre of land is estimated to result in 0.033 added ac.ft. of groundwater recharge per year.

Using the same methods described for the Edwards Plateau, costs per acre foot of added ground water recharge would be expected to range between $100 and $300 per acre foot in The Carrizo – Wilcox Aquifer recharge area.

LAND-BASED WATER CONSERVATION & WATER YIELD PRACTICES IN REGION L: INFLUENCE OF LAND BASED CONSERVATION PRACTICES ON WATER YIELD

Vegetation and Vegetation Management in the MLRA of Region L

Edwards Plateau

General

General descriptions of soil, climate and vegetation resources for all Region L MLRA in this paper are from Hatch et al. (1990), Checklist of the vascular plants of Texas and adapted from the Natural Resources Conservation Service (NRCS) Ecological Site Descriptions (2007), web site: http://esis.sc.egov.usda.gov/ or were furnished upon request by NRCS as a proposed site description (Gray Sandy Loam for South Texas Plains 83B).

The northern parts of Uvalde, Medina, Bexar, Comal and Hays Counties of Region L are in the Edwards Plateau Major Land Resource Area (81C) immediately above the Balcones Escarpment. The Balcones Escarpment forms the distinct boundary of the Edwards Plateau on its eastern and southern borders. The area is a deeply dissected, rapidly drained stony plain having broad, flat to undulating divides.

Soil series typical of the area are included in a Low Stony Hill ecological site, an upland site with slope gradients mainly 1 to 8 percent but that can range up to 12 percent. The very shallow to shallow, well drained, moderately slow permeable soils of this site were formed in residuum over interbedded limestone, marls, and chalk. Soil thickness and depth to limestone ranges from 4 to 20 inches. Subrounded to angular pebbles, cobbles, and stones of limestone comprise 35 to 80 percent by volume of the soil. The soil is a clay soil and is alkaline to neutral. The depth of soil is one of the main factors affecting water holding capacity.

The climate is humid subtropical and is characterized by hot summers and relatively mild winters. The average first frost should occur around November 15 and the last freeze of the season should occur around March 19. The average relative humidity in mid-afternoon is about 50 percent. Humidity is higher at night, and the average at dawn is about 80 percent. The sun shines 70 percent of the time possible during the summer and 50 percent in winter. The prevailing wind direction is southeast. Approximately two-thirds of annual rainfall occurs during the April to September period. Rainfall during this period generally falls during thunderstorms, and fairly large amount of rain may fall in a short time. Mean annual precipitation ranges from over 30 inches in the eastern portion of the MLRA (Hays County) to about 24 inches in the western portion Uvalde County).

The plant communities of a Low Stony Hill site are dynamic and vary in relation to grazing, fire and drought. Presettlement conditions were strikingly different than those found today. One major vegetative difference was the presence of open prairies of tall grasses which were common throughout much of Texas. The historic climax plant community (HCPC) was greatly influenced by large herbivore grazing and fires. It is hypothesized that buffalo would come into an area, graze it down and then leave, not to come back for many months or even years, usually following a fire. This long deferment period allowed the better quality grasses and forbs to recover from heavy grazing. Fire was probably a very important factor in maintaining the original prairie vegetation and also had a major impact on the plant community structure. Species, such as Ashe juniper (*Juniperus ashei*), would invade the site, but not at the level we see today. Periodic fires, set either by Native Americans or by lightning, suppressed the range and density of Ashe juniper and other woody species. Woody plant control would vary in accordance to the intensity and severity of the fire encountered, which resulted in a mosaic of vegetation types within the same site.

While grazing was a natural component of this ecosystem, long-term overstocking and thus overgrazing by domestic animals had a tremendous impact on the site (Taylor 2004). Heavy grazing eliminates the possibility of fire and promotes the rapid encroachment of Ashe juniper. Continued overgrazing will lead to the demise of the higher quality grasses and forb species that are part of the HCPC. When site degradation is extreme, range planting may be the only means by which these species can be re-established on the site.

The HCPC, which was an open grassland with scattered oak (*Quercus* spp.) motts, included little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), Indiangrass (*Sorghastrum nutans*), and Eastern gamagrass (*Tripsacum dactyloides*). Continued overuse brought about the removal of these and many other species from a large portion of the site. Low successional, unpalatable grasses, forbs and shrubs have taken the place of the more desirable plant species. The loss of topsoil and soil organic matter makes it unlikely that these abused areas will return to the HCPC in a reasonable period of time. The diversity of native forbs and grasses has been reduced, while the presence of introduced and non-native species appears to be increasing. However, little bluestem and other native species will slowly return to the site with a sound range management program mimicking the historic management.

Ashe juniper, because of its dense low growing foliage, has the ability to retard grass and forb growth. Grass and forb growth can become almost nonexistent under dense juniper canopies. Many times there can be a resurgence of the better grasses, such as little bluestem and Indiangrass, when Ashe juniper is controlled and followed by proper grazing management.

The tallgrasses of the HCPC and similar community composition aided in increasing the infiltration of rainfall into the slowly permeable soil. The loss of soil organic matter due to overgrazing has a negative effect on infiltration. More rainfall is directed to overland flow, which causes increased soil erosion and flooding. Soils are also more prone to drought stress since organic matter acts like a sponge and aids in moisture retention for plant growth. Mulch buildup under the Ashe juniper canopy, following brush management and incorporation into the soil, can have a positive effect on increasing infiltration.

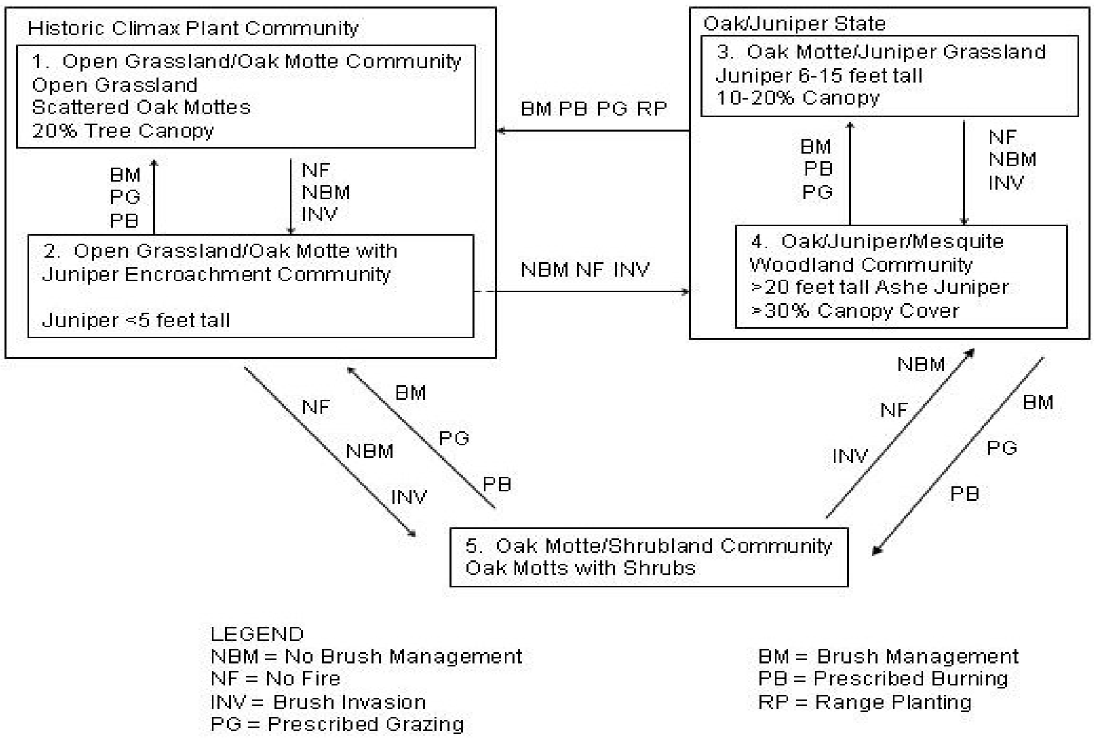
The Edwards Plateau is 98 percent rangeland; arable lands are found only along narrow streams and some divides. The rangeland is used primarily for mixed livestock (combinations of cattle, sheep, and goats) and wildlife production. The area is known as the major wool-and mohair-producing region in the United States, however in recent years there has been a move to greater meat goat production and a reduction in angora goats. The area also supports the largest deer population in North America. Most ranches in the area maintain livestock production, but wildlife has become increasingly important and may equal or exceed livestock in management emphasis and income on many ranch operations. Exotic big-game ranching is also important, and axis, sika, and fallow deer and blackbuck antelope have increased in numbers. 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.

The increasing concern for wildlife habitat, especially white-tailed deer, over the past four decades has dictated a change in the approach to rangeland vegetation manipulation with brush control practices from wide-scale broadcast treatments, such as chaining, to a more limited “sculpted” approach. However, brush management for increased forage production for domestic livestock is still an important practice in the area.

Specific Reference to a Dominant Ecological Site

Ecological Site Descriptions (ESD) developed by the Natural Resources Conservation Service provide a detailed means to view landscapes in the MLRA. For the purpose of this paper, a dominant ecological site in the Edwards Plateau will be used to show the vegetation steady states and transitions that occur from the HCPC through the process of retrogression to those communities more commonly existing today. A Low Stony Hill ecological site is one of the most commonly occurring sites in the MLRA.The ESD for a Low Stony Hill site includes the state and transition model shown in Figure 1.

Figure 1. State and Transition model for a Low Stony Hill Site, Edwards Plateau MLRA



The HCPC for the site is shown as plant community 1. In its pristine (HCPC) condition, this site is a fire-climax, open grassland with scattered oak mottes with about 20 percent tree canopy. The liveoaks (*Quercus virginiana*) are most abundant along water courses, where elm (*Ulmus* spp.) and hackberry (*Celti*s spp.) trees also grow. The herbaceous plant community is dominated by little bluestem. Indiangrass and big bluestem are subdominants, and may even dominate locally. Also native to the site, but occurring less frequently or in lesser amounts are the wildryes (*Elymus* spp.), sideoats grama (*Bouteloua curtipendula*), tall dropseed (*Sporobolus compositus*), feathery bluestems (*Bothriochloa* spp.), green sprangletop (*Leptochloa dubia*), vine mesquite (*Panicum obtusum*), Texas wintergrass (*Nassella leucotricha*) and Texas cupgrass (*Eriochloa sericea*). The site also grows an abundance of climax forbs, shrubs and woody vines.

Retrogression from the HCPC to plant community 2 is indicated by reduction in the occurrence of fire on the site, no brush management and the invasion of woody plants, primarily Ashe juniper. The model indicates that communities 1 and 2 are contained within the same steady state (large box) and that community 1 can be restored from community 2 by brush management, prescribed burning and prescribed grazing. However, as retrogression continues to occur, a new steady state, an oak/juniper state, develops that includes plant communities 3 and 4. Alternatively, steady state 5 can establish as an oak motte/shrubland community from either of the other steady states.

Brush management, prescribed burning and prescribed grazing can be used to restore the site to more closely resemble the HCPC, but as the size of juniper increases beyond that effectively controlled with prescribed fire, so does the cost of brush management. For example, in the oak/juniper steady state costly practices, such as mechanical removal of juniper must be employed, as well as range planting in areas where the native seed source is judged to be depleted. Representative composition by different plant types and total annual production of the HCPC are provided in Table 1.

Table 1. Annual Production by Plant Type (HCPC)

	Annual Production (lbs/AC)		
Plant Type	Low	Representative Value	High
Forb	65	110	135
Grass/Grasslike	1950	3250	3900
Shrub/Vine	45	75	90
Tree	180	300	360
Total:	2240	3735	4485

As a contrast and to show the influence of heavy invasion on the site from Ashe juniper and other woody species, Table 2 provides plant types and production from plant community 4, the Oak/Juniper Woodland community. Community 4 has developed as a result of a severe vegetation shift from an original plant community which was a grassland with scattered oak mottes to a plant community which is predominately tall woody plants and limited tallgrass vegetation. This community will exhibit Ashe juniper 20 feet tall and taller, with canopies in excess of 30%. Grass and grasslike vegetation is significantly reduced due to the severe competition that Ashe juniper and other woody species present regarding sunlight and moisture.

Large areas that were once open grasslands are now infested with heavy woody cover consisting of species such as Ashe juniper, liveoak, post oak (*Quercus stellata*), honey mesquite (*Prosopis glandulosa*), agarito (*Mahonia trifoliata*), Texas persimmon (*Diospryos texana*), elbowbush (*Forestiera pubescens*) and lotebush (*Ziziphus obtusifolia*)

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Table 2. Annual Production by Plant Type (Community 4)

Plant Type	Low	Annual Production (lbs/ac) Representative Value	High
Forb	30	50	70
Grass/Grasslike	400	650	800
Shrub/Vine	100	150	200
Tree	720	1200	1450
Total:	1250	2050	2520

Management alone will not allow this community to shift back towards the climax community. Implementation of brush management programs involving heavy equipment and very high treatment cost is the only option if decision-makers desire to transition this site back towards the historic plant community. By implementing other conservation measures, such as prescribed burning and prescribed grazing, land managers can maintain the community as a grassland community following initial brush management practices.

As the plant community degenerates to community 4, big and little bluestem, Indiangrass and the wildryes decrease and Sideoats grama, tall dropseed, silver bluestem, Texas wintergrass and buffalograss (*Bouteloua dactyloides*) are initial increasers on the site. Prolonged overuse of these plants usually results in a community of Texas wintergrass, curlymesquite *(Hilaria belangeri*), buffalograss and woody species. The following grasses and forbs are commonly found on this site in a deteriorated condition: western ragweed (*Ambrosia psilostachya*), broomweed (*Amphiachyris* spp.), prairie coneflower (*Ratibida columnifera*), snow-on-the-Mountain (Euphorbia marginata), silverleaf nightshade (*Solanum elaeagnifolium*), milkweeds (*Asclepias* spp.), Leavenworth eryngo (*Eryngium leavenworthii*), two-leaf senna (*Cassia roemariana*), gray goldaster (*Heterotheca canescens*), horehound (*Marrabium vulgare*), evax (*Evax* spp.), buffalograss, *curlymesquite, Texas grama (Bouteloua rigidiseta), hairy tridens (Erioneuron* pilosum), red grama (*Bouteloua trifida*), tumblegrass (*Schedonnardus panniculatus*), windmillgrasses (*Chloris* spp.) and annual bromegrasses (*Bromus* spp.).

Woody species dominate the site in this community with Ashe juniper being the dominant. Shade tolerant species such as cedar sedge (*Carex planostachys*) and uniola species (*Uniol*a spp.) dominate the understory that is void of sunlight. The majority of the soil surface on this densely canopied site will have a thick mat of cedar leaves and other woody tree and shrub leaf material. The open areas between canopies will produce a grass cover of primarily low successional species such as gramas (*Bouteloua* spp.), three-awns (*Aristida* spp.), tridens (*Tridens* spp.), and dropseeds (*Sporobolus* spp.). The total grasslike production potential for this community is severely restricted.

A key difference between plant community 1 and 4 is herbaceous forage production. Plant community 1 can produce up to 3900 lbs./acre of grass/grasslike plants in an above average year versus only 800 lbs./acre in plant community 4. It is significant that these same plants, the grass and grasslike species, are also the fine fuel that can potentially carry effective fires contributing to control of Ashe juniper.

Brush Management Practices

Brush management treatment alternatives commonly used in the Edwards Plateau MLRA include mechanical and chemical practices, as well as biological control associated with the use of goats. Selection of these treatments depends on the size and density of the woody plant species, primarily Ashe juniper. Some ranchers will remove oak species with brush management practices, but these are more likely shinoak species or oaks that are thinned within mottes, rather than mature oaks. Live oaks, Spanish oaks, post oaks, or other oak species are generally not considered in brush management scenarios, meaning that Ashe juniper is the target woody plant species a very high percentage of the time. Mechanical brush management treatments can be either broadcast when densities of plants are greater than 300 plants per acre or large enough to respond to treatments such as chaining or cabling, or individual plant treatments (IPT) when densities are low enough and/or plants are small enough to justify treating individual plants.

Chaining is usually accomplished by pulling a ships anchor chain between two crawler tractors, commonly D7 size or greater, depending on the size and density of the target species. The tractors are arranged in a "J" configuration, with one tractor moving slightly ahead of the other and the chain or cable being pulled in-between the tractors to make a swath width that is roughly equal to one-half the length of the chain. Commonly used chain lengths vary from 150-300 ft., giving a swath width of about 75-150 ft. Again, the length of chain and swath width would depend on the density and size of the juniper and the power of the tractors (Scifres 1980). Keeping the swath width at one-half the chain length allows the chain to be pulled from directly behind the tractor and reduces pull from the side that causes maintenance problems. Chaining or cabling work best when trees are large enough to provide significant resistance to the pull of the chain so that they can be uprooted rather than broken off or simply bent over and allowed to remain connected to the subterranean root structure. Mortality of the target species associated with chaining or cabling is usually in direct proportion to the stature of the trees and the degree of uprooting that is accomplished. Two-way chaining, covering the area twice in opposite directions, usually gives better control than one-way chaining (Welch 1985). Raking and stacking may be necessary to remove woody debris after chaining of heavy brush cover to allow maximum development and utilization of range forages and to minimize livestock handling problems. The degree of slope on the land must be considered as a hazard to use of equipment in the area, with slopes of 15% or greater limiting the application of these practices.

In areas of the MLRA where soils are deep, rootplowing is an option for removal of woody vegetation. Rootplowing is a nonselective treatment used to sever woody plants below ground. This practice is very energy intensive and costly, but results in a high degree of mortality of the target plant species. A rootplow is pulled behind a crawler tractor, normally of D7 or D8 size. The rootplow is a heavy steel V-shaped blade that is attached to shanks carried on a toolbar behind the tractor. The rootplow blade travels under and parallel to the soil surface cutting through all the subterranean root material of plants. Depth of the blade beneath the soil surface will vary, but in deep soils it may be 12-16 inches, depending on the density and size of the trees, soil texture, soil moisture and power of the tractor. Rootplowing causes a high level of soil disturbance and can destroy most perennial grasses. Thus, seeding is often necessary as a follow-up treatment. If rootplowed areas are not seeded, the majority of forage production for the first year or two may be from annuals and other plants low on the successional scale. The flush of forbs on rootplowed areas may dramatically improve wildlife forage until perennial grasses become dominant (Welch 1985).

Bulldozing has been used many years for clearing Edwards Plateau rangeland of unwanted woody plant species. When Ashe juniper is the target species, all plants attacked by bulldozing will suffer mortality if they are either uprooted or sheared off from their roots below the lowermost above ground green growth. Conversely, resprouting species, such as honey mesquite, will produce multiple new sprouts from buds in the stem base and root crown area of the plant (Welch 1991).The bulldozer can place the cleared trees in piles or windrows.

Since Ashe juniper is a non-sprouting species, this allows top removal practices to be effective for brush management and the most popular of these methods currently is the use of a "skid-steer loader" equipped with a front-end attachment of hydraulically operated sheers. The sheers are placed with the skid steer at the base of a target plant species and the shears are then closed hydraulically so that they cut entirely through the trunk of the tree. The hydraulic system on the skid steer can be used to place cut trees in piles or in windrows, or they can be left in place on the soil surface. Both bulldozing and sheering of Ashe juniper have been shown to produce enough soil disturbance to provide an adequate seedbed for seeding Mannel (2007.)

Another broadcast brush management practice that is infrequently used in the MLRA is roller chopping. Roller chopping is accomplished with a heavy drum-type roller with blades mounted on the surface of the drum parallel to the axis. The blades cut through woody plants as the roller chopper is pulled over them by a crawler tractor, commonly D6 to D8 size. The drums can be filled with water to increase their overall weight and the weight per unit of blade surface area contact with woody stems that results in greater cutting performance. Roller chopping has limited capability to cause mortality on woody species, since it is a simple top removal practice that leaves a high percentage of plant subterranean material in place and often does not remove all of the above ground plant material necessary to result in mortality of Ashe juniper. Roller chopper blades may penetrate the soil several inches deep, depending on soil texture and moisture and the size and weight of the chopper. Thus, soil disturbance may be significant, resulting in improved water infiltration. Seeded grass stands have been established on seedbeds prepared by offset, tandem roller choppers.

Hydraulic shredders, such as the "Hydro Axe" are also used for woody plant control and are effective on Ashe juniper if the cut by the shredder is below the lowermost green plant material. A Hydro-Axe shredder is mounted on the front of a large rubber-tired tractor and is powered by a hydraulic motor. The entire shredding unit can be raised and lowered to shred down large trees. While the shredders can take down larger trees, they are probably most economically efficient in brush with 3-6 inch stem diameters. With the exception of Ashe juniper as stated above, most undesirable plants will resprout vigorously following shredding. Like roller chopping, shredding may increase browse availability and quality by increasing the number of young, succulent sprouts. Prescribed fire can be used as a follow-up to roller chopping or shredding to suppress woody regrowth.

Individual plant treatment (IPT) mechanical practices include "lopping" with manual sheers that cut Ashe juniper plants near ground level and result in a high level of control. In recent years the use of "track hoes" or "excavators", large self-propelled backhoes on tracks that have a reach of about 25 feet in 180 degrees, has become popular, especially in the western Edwards Plateau where redberry juniper, a sprouting species, requires extirpation below the bud zone (Wiedemann 2004). These large grubbers cover a 50 ft. Swath when moving in a straight line and can be used for other resprouting species, as well as for Ashe juniper if desired, particularly in areas where the size of trees or soils (primarily rockiness) may limit the use of smaller grubbing equipment. The bucket, equipped with rock-digging teeth, is very effective for removing junipers from rocky soil and stacking them. A U-shaped grubbing blade can be used in place of the bucket (Wiedemann 2004). Low-energy grubbing can also be used in some soils for juniper control. "Low–energy" grubbers are those that use hydraulic power in the grubbing unit to offset the need for tractor horsepower (Wiedemann 2004). Rotating cutter blades mounted on heavy duty "Weed Eaters" are also effective for quick removal of Ashe juniper up to 2 inches in stem diameter at ground level.

There are no currently recommended broadcast chemical treatments for Ashe juniper control. However, there are IPT practices that are recommended for use, including picloram (Tordon 22k), Hexazinone liquid (Velpar L) and Hexazinone pellets (Pronone Power Pellets). All of these treatments will give a very high level of Ashe juniper mortality if properly applied. Texas Cooperative Extension Bulletin 1466 (2007) provides explicit instructions for selection, mixing and application of herbicides.

Perhaps the most economically effective treatment alternative for Ashe juniper control is prescribed burning. Fire can be very effective for causing mortality of small Ashe juniper plants that are up to about 3 feet tall and even taller if the fine fuel load is adequate in amount and continuity to carry an effective fire. When small, Ashe juniper can be effectively controlled with cool season prescribed burns that limit risk compared to hot summer burns. Combination of prescribed burning with other practices, such as mechanical or chemical control is highly recommended to preserve the benefits of high cost initial practices by low-cost maintenance practices. An excellent discussion on the use of fire in juniper ecosystems can be found in Blair et al. (2004).

Biological control is accomplished in the MLRA via the use of goats. Angora goats are still significant in the area, but have declined in numbers over the past decade. Meat goats, including Spanish and Boer goats and crosses thereof, as well as other meat breeds, have increased in the area during this same time period. Overall, goats are still very much present and have an impact on woody plant competition with herbaceous species. For example, goats will utilize seedling cedar plants or young regrowth until the plants have reached a threshold when leaf material age diminishes use with the increased content of terpenoids (Taylor 2000). Goats also utilize oak sprouts and harvest buds, leaves and small twigs of trees up to a browse line of about 6 feet. Goats can be concentrated in high densities and rotated through pastures to help suppress woody plants. They can also be used following mechanical brush management practices to utilize woody plant regrowth when it is succulent and within reach. The Texas Agricultural Experiment Station at Sonora is experimenting with goats that will consume a higher percent of juniper in their diets in order to maximize biological control (Taylor 2004).

Gulf Coast Prairies and Marshes

General

All of Refugio and Calhoun Counties, most of Victoria County and a small portion of Goliad County that are contained within Region L are included within the Gulf Coast Prairies and Marshes MLRA. The USDA NRCS divides the MLRA into two components, the Gulf Coast Marshes (150B), covering approximately 500,000 acres, that are on a narrow strip of lowlands adjacent to the coast and the barrier islands (e.g., Padre Island) and which extend from Mexico to Louisiana, as well as the Gulf Coast Prairies (150A), about 9 million acres, that include the nearly flat plain extending 30 to 80 miles inland from the Gulf Marshes.

The Gulf Coast 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 Coast Prairies are nearly level and virtually undissected plains having slow surface drainage and elevations from sea level to 250 feet.

Soils of the Gulf Coast Marshes are dark, poorly drained sandy loams and clays, and light neutral sands, typically showing little textural change with depth. The loamy and clayey soils are commonly saline and sodic. Prairie soils are dark, neutral to slightly acid clay loams and clays in the northeastern parts. Further south in the subhumid Coastal Bend, the soils are less acidic. A narrow band of light acid sands and darker loamy to clayey soils stretches along the coast. Inland from the dark clayey soils is a narrow belt of lighter acid fine sandy loam soils with gray to brown, and red mottled subsoils. Soils of the river bottomlands and broad deltaic plains are reddish brown to dark gray, slightly acid to calcareous, loamy to clayey alluvial.

The climate of MLRA is humid subtropical with mild winters. Canadian air masses that move southward across Texas and out over the Gulf in winter produce cool, cloudy, rainy weather. Precipitation is most often in the form of slow and gentle rains. Spring weather is variable though moderate overall. March is relatively dry while thunderstorm activities increase in April and May. Summer weather varies little by having abundant sunshine and drier than in the spring. Occasional slow-moving thunderstorms or other weather disturbances may dump excessive amounts of precipitation on the area. Fall has moderate temperatures. Fall experiences an increase of precipitation and frequently has periods of mild, dry, sunny weather. Heavy rain may occur early in fall in association with tropical disturbances, which moves westward from the gulf. Tropical storms are a threat to the area in the summer and fall but severe storms are rare.

The total annual precipitation ranges from 28 inches in the southwest part of the region to 44 inches in the eastern part of the region. On average, approximately 38 inches occur around Victoria. Approximately 65 percent of the rainfall falls between April and September which includes the growing season for most crops. In two years out of ten, the rainfall for April through September is less than twenty inches. Thunderstorms occur on about fifty days each year and most occur during the summer.

The Gulf Coast 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*). Marshmillet and maidencane (*Panicum hemitomon*) are two of the most important grasses of the fresh-water marshes of the upper coast. Common aquatic forbs are pepperweeds (*Lepidium*), smartweeds (*Polygonum*), docks (*Rumex*), bushy seedbox (*Ludwigia alternifolia*), green parrotfeather (*Myriophyllum pinnatum*), pennyworts (*Hydrocotyle*), water lilies (*Nymphaea*), narrowleaf cattail (*Typha domingensis*), spiderworts (*Tradescantia*), and duckweeds (*Lemna*). Common halophytic herbs and shrubs on salty sands are spikesedges (*Eleocharis*), fimbries (*Fimbristylis*), glassworts (*Salicornia*), sea-rockets (*Cakile*), maritime saltwort (*Batis maritima*), morningglories (*Ipomoea*), and bushy sea-ox-eye (Jones 1982).

The low marshy areas provide excellent natural wildlife habitat for upland game and waterfowl. The higher elevations of the Gulf Coast Marshes are used for livestock and wildlife production. Ranch units are mostly in large landholdings. These marshes and barrier islands contain most of our National Seashore parks. 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 Coast 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 tame pastures. Bermudagrass and several introduced bluestems (*Dichanthium* and *Bothriochloa*) are common tame pasture grasses.

Ranches in both components of the MLRA are primarily cow-calf operations that use forage produced from rangeland and tame pasture. Zebu or crossbreeds having Zebu blood are the most widely adapted and used cattle. Recreation, hunting, and fishing provide excellent multiple-use opportunities in the Gulf Prairies and Marshes.

The original vegetation types of the Gulf Coast Prairies 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 smallii*) and blackbrush (*A. rigidula*). Bushy sea-ox-eye (*Borrichia frutescens*), a dwarf shrub, is also typical.

Principal climax grasses of the Gulf Coast Prairies 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. Common increasers and invaders are yankeeweed (*Eupatorium compositifolium*), broomsedge bluestem (*Andropogon virginicus*), smutgrass (*Sporobolus indicus*), western ragweed (*Ambrosia psilostachya*), tumblegrass (*Schedonnardus paniculatus*), threeawns (*Aristida*), and many annual forbs and grasses. Pricklypear (*Opuntia*) are common throughout the area. Characteristic forbs include asters (*Aster*), Indian paintbrush (*Castilleja indivisa*), poppy mallows (*Callirhoe*), phloxs (*Phlox*), bluebonnets (*Lupinus*), and evening primroses (*Oenothera*) (Jones 1982).

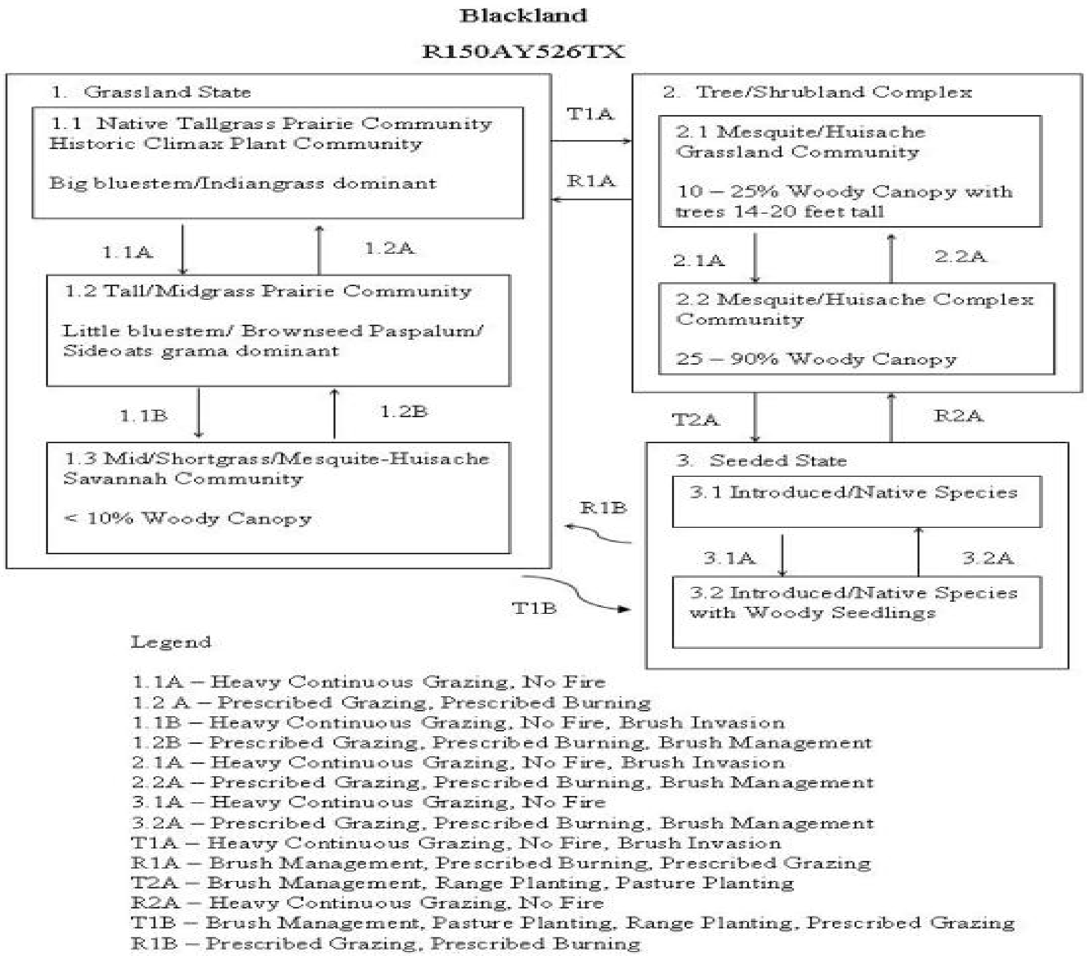
<u>Specific Reference to a Dominant Ecological Site</u>

Ecological Site Descriptions (ESD) developed by the Natural Resources Conservation Service provide a detailed means to view landscapes in the MLRA. For the purpose of this paper, a dominant ecological site in the Gulf Coast Prairies (150A) will be used to show the vegetation steady states and transitions that occur from the HCPC through the process of retrogression to those communities more commonly existing today. A Blackland ecological site is one of the most commonly occurring sites in the Gulf Coast Prairie component of the MLRA.The ESD for a Blackland site includes the state and transition model shown in Figure 2.

The Blackland site in MRLA 150A was formed by clayey fluviodeltaic sediments in the Beaumont Formation of Late Pleistocene age. These nearly level to very gently sloping soils are on the South Texas coastal plain. Slopes are mainly less than 1 percent but can range as high as 8 percent. Runoff is medium on 0 to 1 percent, high on 1 to 3 percent, and very high on slopes greater than 3 percent. Undisturbed areas exhibit gilgai microrelief. Elevation ranges from 15 to 200 feet.

The average relative humidity in mid afternoon is about 60 percent. Humidity is higher at night and the average at dawn is about 90 percent. The sun shines 70 percent of the time possible in summer and 50 percent in winter. The prevailing wind is from the south-southeast. Average windspeed is highest, about 12 miles per hour, in spring.

Figure 2. State and Transition Model for a Blackland Site, Gulf Coast Prairies and Marshes MLRA



The HCPC for the site is shown as plant community 1 (Grassland state). It was composed of tall and midgrasses and is the reference plant community for the site. Tallgrasses make up over 60% of annual production percent, midgrasses approximately 30 percent, and associated grasses, forbs, shrubs and woody vines make up the remainder. Bison grazing was intermittent and fires were both frequent (3 to 8 years) and intense. Annual forbs occur in greater or lesser amounts in response to grazing intensity, fire, drought, or excessive precipitation. This prairie site was extensively heavily grazed by large numbers of domestic livestock by the late 1800's. Overgrazing with no rest was exacerbated by the introduction of barbed wire fencing and water development. Overgrazing resulted in reduced production of biomass, reduced litter accumulation, loss of tallgrass and some midgrass species and reduction of fire frequency and intensity. Some mid and shortgrasses increased as a result of this overgrazing and eventually annual forbs and grasses replaced some perennials. Representative composition by different plant types and total annual production of the HCPC are provided in Table 3.

Table 3. Annual Production (lbs/ac) by Plant Type (HCPC)

	Annual Production (lbs/ac)		
Plant Type	Low	Representative Value	High
Forb	325	400	475
Grass/Grasslike	5850	7200	8550
Shrub/Vine	325	400	475
Tree	0	0	0
Total:	6500	8000	9500

As a contrast and to show the influence of heavy invasion on the site from woody species, Table 4 provides plant types and production from plant community 2.2, Mesquite/Huisache Complex Community of the S/T model.

Over time, with continued heavy grazing, no fire, and no brush management, the Blackland Site may be transformed into a Mesquite-Huisache and Macartney rose Woodland community with canopies of 90 percent. The herbaceous community is greatly reduced and is dominated by low panicums and paspalums, Texas wintergrass, gaping panicum, bentgrass, sedges, and annual forbs and grasses.

Major cultural inputs, both chemical and mechanical, are often required and applied to restore this community to grassland or a savannah state. A common practice is the use of aerial applied herbicides to reduce the canopy, allow sunlight to penetrate to the soil surface, and grow enough herbaceous fuel loads for suitable burning. Aerial spraying is followed by the use of prescribed fire to remove some of the woody vegetation and maintain semi-open wooded grassland for several years following treatment. Although these practices kill some of the woody vegetation, much of it remains and re-sprouts from the crown and in a relatively short period of time will again attain a dominating woody plant canopy. Often with this community, mechanical means such as rootplowing and raking are utilized and the land is converted to cropland or tame pasture (see seeded state in S/T model Figure 2). A key difference between plant community 1 and 2.2 is herbaceous forage production. Plant community 1 can produce up to 8,500 lbs./acre of grass/grasslike plants in an above average year versus only 750 lbs./acre in plant community 2.2. This difference in production on the same site is the result of retrogression from the tall and midgrass community to the brush dominated state that is prevalent over much of the rangeland in the MLRA today.

Table 4. Annual Production (lbs/ac) by Plant Type (Community 2.2)

Plant Type	Low	Annual Production (lbs/AC) Representative Value	High
Forb	200	250	300
Grass/Grasslike	300	500	750
Shrub/Vine	400	450	550
Tree	500	650	975
Total:	1400	1850	2575

Distribution of woody vegetation follows the major soil types on the Coastal Prairie. Live oak savannahs are common in the southern and western portions. Live oak forms dense, almost pure stands on deep sands or is associated on the heavier soils with various *acacias*, such as huisache and with species such as spiny hackberry and lotebush. Post Oak and blackjack oak occur with live oak or in isolated communities in the northwest part of the Coastal Prairie. The post oak-blackjack oak vegetation type is characterized by moderate to dense stands of underbrush including many species characteristic of the Post Oak Savannah.

Honey mesquite occurs throughout the Coast Prairie but more sparsely than in other parts of the state except for the Pineywoods. Honey mesquite inhabits deep loams and clays in the eastern portion of the area (Refugio, Bee and Victoria Counties). It intermingles with post oak, blackjack oak, and live oak on lighter soils and with low-growing, xerophytic mixed brush characterized by *acacias* on the uplands.

In addition to honey mesquite, the most characteristic troublesome species of the Coastal Prairie are huisache and Macartney rose. These species combine to form unique communities in some areas, especially on the heavy, slowly permeable soils. Such communities are typical in Victoria County on Victoria and Lake Charles clays where brush control is practiced regularly. Huisache is distributed throughout the Coast Prairie. It may form dense, almost pure stands on lowland areas, and it thrives on the more mesic upland in association with species typical of mixed-brush communities. Macartney rose may occur with an overstory of honey mesquite and huisache but may dominate the vegetation on heavier soils.

Brush Management Practices

The western portion, or the more inland side of the Gulf Coast Prairies and Marshes MLRA, is joined by the South Texas Plains MLRA and shares the same reputation as being part of the "South Texas brush Country". Rangeland areas of both MLRA are often heavily invaded by a wide array of woody plant species that suppress herbaceous forage production, while at the same time providing a significant component of high quality habitat for income producing wildlife, primarily white-tailed deer and quail. Therefore, land managers commonly seek ways to modify brush stands to optimize a dual vegetation composition between herbaceous and woody plant species.

The Brush management treatment alternatives commonly used in the Gulf Coast Prairies and Marshes MLRA include mechanical and chemical practices and prescribed fire. When considered in combination with the South Texas Plains, no other MLRA in Texas have had greater implementation of brush management practices. The two most prevalent broadcast mechanical practices, chaining and rootplowing, were used early and frequently over vast acreages in the area beginning as early as the 1930's (Hamilton and Hanselka 2004). The mechanics of these practices are explained in the section of this paper for the Edwards Plateau MLRA. However, unlike the shallow, rocky soils that dominate the Edwards Plateau, the soils of the Gulf Coast Prairies are mostly deep and well suited to use of rootplowing. The practice is used for brush management; that is, to remove the resident woody plant composition and allow native herbaceous plant species to be restored, or, in other cases, rootplowed areas are seeded to promote more rapid response of grasses, commonly introduced species, such as buffelgrass (*Cenchrus ciliaris)*. There is a variety of degrees of treatment involved with rootplowing for brush management. Since the practice leaves the land very rough and with large amounts of debris from downed woody plants, it is often followed by raking to gather the debris, both from the surface and below ground in the plowed portion of the soil profile. The raking, usually followed by stacking and burning of brush piles, breaks up the massive clods left by the rootplow and smoothes the soil surface, greatly enhancing seedbed preparation and subsequent stands of seeded species. A still greater degree of land clearing that follows rootplowing involves raking in two directions, stacking and burning piles, additional cleanup, such as hand picking or the use of farm-type tractors to finally prepare the land for planting. At this point, the land can be changed from rangeland to pastureland use, denoting a perennial forage species that will receive some cultural inputs for maintenance, or even to cropland (annual crops) based on the management objective for land use.

Chaining was accomplished in the MLRA on many thousands of acres beginning in the 1930's and 40's, but like rootplowing, primarily with greatest emphasis in the post-World War II era when powerful crawler tractors became more readily available. The greatest value of chaining is the low initial cost of quickly knocking down, uprooting and thinning out moderate to dense stands of medium to large trees. Chaining alone generally offers only temporary benefits, particularly if the trees in the treated area are not large enough to allow uprooting. If a high percentage of the woody plants are not uprooted by the chain, regrowth from the species composing the brush complex in the region is extremely fast, quickly reducing the initial benefits of greater forage plant production. However, when used in combination with other methods, such as prescribed fire and/or chemical treatments, it may contribute to significant brush control for extended time periods. Chaining is also used in the region as the initial treatment in dense stands of very large plants to take down trees prior to rootplowing for brush control or land use conversion to pastureland or cropland. It should be noted that rootplowing and chaining, as well as other mechanical practices applied in the MLRA, are known to spread pricklypear

(*Opuntia* spp.). Any method that breaks the pricklypear plant into individual cladophylls (pads) and scatters the pads simply serves to transplant the species. Therefore, where pricklypear exists in the stand of brush to be treated mechanically, an additional treatment, such as a modified front-end stacker that can remove a high percentage of the pricklypear plants (Hamilton and Hanselka 2004), or an effective chemical treatment, such as the broadcast use of picloram (Tordon 22K®, may be necessary to prevent an increased density of the pricklypear.

Broadcast simple top removal practices, such as roller chopping or shredding, are also used in the MLRA, but the resprouting ability of the plants in the brush complex greatly limits the time that relief from woody plant competition can be expected. Studies have shown that several of the woody species in the area are capable of replacing 50% of more of their pretreatment height within the same growing season following spring top removal (Hamilton et al. 1981, Rasmussen et al. 1983). Bulldozing that cuts off woody plants and leaves the root system in place below ground is equally ineffective at causing plant mortality compared to roller chopping and shredding. Still, roller chopping and shredding are used to reduce the stature of brush, increase visibility, improve cattle working and increase forage production. Much the same as with broadcast herbicides, roller chopping and shredding can be done in patterns that optimize the benefits of the treatment for both increased forage production and wildlife habitat.

In addition to the standard or traditional-type roller chopper described in the section of this report for the Edwards Plateau, a unit known as an "aerator/renovator", but that functions in brush as a roller chopper, is being used effectively in the Coastal Prairie and South Texas Plains. This recent advancement in roller choppers is the use of small blades welded to the heavy drums in a staggered, cylindrical pattern. The advantage of the aerators is that the small blades chop debris and form basins in the soil to capture and hold rainfall. In addition, the staggered, cylindrical blade pattern prevents the vibration caused by the longitudinal blade placement on a standard roller chopper. The blade design and positioning on the drums direct more of the total weight of the unit to the area of contact with woody plant material, thus improving the cutting effect. The aerators are usually two drums mounted on a frame similar to on offset disk, and are pulled by a crawler tractor or a specially-equipped rubber-tired tractor. The drum diameters measure from 18 to 42 inches and can be filled with water for increased weight. Aerators are used in moderate to dense shrub-infested rangeland or pastures to remove top growth of shrubs and to improve rainfall retention. Removal of top growth produces a flush of regrowth. This is desirable for browsing animals when used on palatable brush species in the region. When seeding is used in combination with chopping, the basins enhance seedbed preparation and seedling establishment (Weidemann 2004).

Heavy disks suitable for use on rangeland are another option for broadcast brush management given an appropriate soil and brush species for the equipment to work. Blade diameters for rangeland disks usually range from 24 to 36 inches and many are scalloped. Thirty-six inch disks are used for brush management, while the smaller disks are normally used for seedbed preparation. Disk units can range in width from 8 to 12 feet. Whitebrush and blackbrush acacia are species that have been successfully controlled with disking in the South Texas Plains and Gulf Coast Prairie. Several other species, including, Texas colubrina (*Colubrina texensis*), desert yaupon (*Schaefferia cunnefolia*), shrubby blue sage (*Salvia ballotiflora*) and small blackbrush (*Acacia rigidula*), are also susceptible to disking. Disking is especially suited to species that have relatively shallow and lateral roots, rather than tap-rooted plants, such as huisache and mesquite.

The high density of woody species that generally exist on rangeland in the MLRA makes broadcast treatments more economically efficient for initial treatments, rather than individual plant treatments (IPT). However, once brush densities have been reduced by broadcast treatments, IPT may be effective as a follow-up or maintenance practices. There are a variety of chemical IPT that can be used, as well as the practice of mechanically grubbing individual plants. Among the IPT mechanical practices, the low-energy grubbers are effective and economical depending on plant density of up to about 300 plants per acre. These grubbers have the capacity in the deep soils to remove all the below ground plant tissue that can potentially produce new sprouts.

The MLRA has a long history of the use of broadcast chemical brush management treatments. Prior to the late 1960's when picloram was labeled for use in Texas, 2,4-D and 2,4,5-T were the "standby" chemicals for broadcast weed and brush control in Texas. Of the two compounds, 2,4,5-T was superior for woody plant control. Dow Chemical Co. marketed a product, Tordon 225E®, a mixture of 2,4,5-T with picloram (Tordon 22k®) in a 1:1 ratio applied at 1.0 lb. per acre for brush control. This product was more effective for mesquite control and improved the spectrum of woody species that could be controlled in the south Texas mixed brush complex. Since this time there have been several new products introduced that are effective for individual species and mixed species composition. For example, Bulletin 1466 that provides guidance to herbicides for rangeland brush and weed control suggests the following application for south Texas mixed brush that includes blackbrush, catclaw acacia (*Acacia greggii*), guajillo (*Acacia berlandieri*), spiny hackberry (*Celtis pallida*), mesquite, pricklypear, retama (*Parkinsonia aculeata*), tasajillo (Opuntia leptocaulis) and twisted acacia (*Acacia Schaffneri*): a broadcast application of a mixture of 2 pints [.5 lb.active ingredient (a.i.)] picloram (Tordon 22k) + 1 pint (.5 lb.a.i.) triclopyr (Remedy®) applied aerially as a 4 gallon per acre oil-in-water emulsion (1 quart to 1 gallon diesel fuel oil and water to make 4 gallon per acre (1:5 oil to water ratio is optimum.). This application is expected to give an overall moderate level of mortality (36-55%) of the target species when applied under optimum conditions.

Certain herbicide compounds provide more optimum results for individual target plant species. For example, clopyralid (Reclaim®) applied broadcast alone or in combination with picloram or triclopyr will give a moderate to high (36-75%) mortality of honey mesquite. The soil applied herbicide tebuthiuron (Spike 20P®) provides a very high level (76-100%) of mortality on oak species. Several of the approved herbicides for broadleaf weed control will give very high levels of mortality.

Individual plant treatments with herbicides, either foliar applied or stem basal spray, offer moderate to very high levels of control of several problem species in the Gulf Coast

Prairie, including huisache, mesquite and pricklypear These woody species are included in the “Brush Busters” IPT method for brush control that is highly effective. Other species common to the area can be successfully controlled with herbicides shown in Bulletin 1466 with rates of applications, mixing instructions, timing of application and other information.

South Texas Plains

General

The South Texas Plains MLRA includes the largest portion of Region L. All or part of the following Region L Counties are in the MLRA; Uvalde, Zavala, Dimmitt, Medina, Frio, La Salle, Bexar, Atascosa, Wilson, Karnes, Goliad, DeWitt, and Gonzales. The area is the western extension of the Gulf Coast Plains merging with the Mexico Plains on the west. The area is a nearly level to rolling, slightly to moderately dissected plain. Scifres and Hamilton (1993) adapted Welch and Haferkamp (1987) to delineate four components within the area considered the South Texas Plains, the Northern Rio Grande Plains, Western Rio Grande Plains, Central Rio Grande Plains and Lower Rio Grande Valley. Other authors have divided the area into many more physiognomic regions and vegetation types (McMahan et al. 1984). Therefore, it is noted that much more detailed information related to soils and vegetation is available. For the purposes of this paper, the South Texas Plains MLRA will follow Hatch et al. (1990) which encompasses the area that lies roughly south of a line from San Antonio to Del Rio, Texas and continues until it joins the Gulf Coast Prairies and Marshes on the east and the Rio Grande River on the south and west.

Upland soils are of three groups: dark, clayey soils over firm clayey subsoils; grayish to reddish brown, loamy to sandy soils; and brown loamy soils. Gray, clayey, saline, and sodic soils are extensive on the coastal fringe, along with Galveston deep sands. Bottomlands are typically brown to gray, calcareous silt loams to clayey alluvial soils.

South Texas climate is recognized as unique, being the only east-coast subtropical steppe anywhere on earth, and a question exists among meteorologists as to why a semiarid climate lies where it should not, immediately downwind of the great moisture reservoir of the Gulf of Mexico (Trewartha 1968, Norwine and Bingham 1985).Mean annual precipitation ranges from near 36 inches in the eastern part of the area (DeWitt and Gonzales Counties) to 20 inches in the extreme western portion (Dimmitt County). The area is notoriously prone to great fluctuations in precipitation, ranging from extreme droughts to floods, primarily from Gulf disturbances in the late summer and fall. In a study by Norwine and Bingham (1985), “normal years”, those with precipitation between 90 and 110 percent of the long-term median rainfall, were observed only 30 percent of total years, while 36 percent of the years had rainfall less than normal and 34 percent had rainfall of more than 110 percent of the median.

The original vegetation was an open grassland or savannah-type along the coastal areas and brushy chaparral-grassland in the uplands (Johnston 1963). Originally, oaks and mesquite and other brushy species formed dense thickets only on the ridges, and oak, pecan, and ash were common along streams (Inglis 1964). Continued grazing and cessation 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, acacias, brazil (*Zizyphus obovata*), spiny hackberry (*Celtis Pallida*), whitebrush (*Aloysia gratissima*), lime pricklyash (*Zanthoxylum fagara*), Texas persimmon (*Diospyros texana*), shrubby blue sage (*Salvia ballotiflora*), and lotebush (*Zizyphus obtusifolia*).

Characteristic grasses of the sandy loam soils are seacoast bluestem (*Schizachyrium scoparium* var. *littorale*), bristlegrasses (*Setaria*), paspalums, windmillgrasses (*Chloris*), silver bluestem, big sandbur (*Cenchrus myosuroides*), and tanglehead. The dominants on the clay and clay loams are silver bluestem, Arizona cottontop (*Digitaria californica*), buffalograss, common curlymesquite (*Hilaria belangeri*), and species of *Setaria, Pappophorum, and Bouteloua*. Low saline areas are characterized by gulf cordgrass, seashore saltgrass, alkali sacaton (*Sporobolus airoides*), and switchgrass. Forbs include orange zexmania (*Zexmania hispida*), bush sunflowers (*Simsia*), velvet bundleflower (*Desmanthus velutinus*), tallowweeds (*Plantago*), lazy daisies (*Aphanostephyus*), Texas croton (*Croton texensis*), and western ragweed. Grasses of the oak savannahs are mainly little bluestem, Indiangrass, switchgrass, crinkleawn (*Trachypogon secundus*), and species of Paspalum. Pricklypear is characteristic throughout most of the area. Forbs generally associated with all but the most saline soils are bush sunflower, orange zexmania, shrubby oxalis (*Oxalis berlandieri*), white milkwort (*Polygala alba*), American snoutbean (*Rhynchosia americana*), and greenthread (*Thelesperma nuecense*).

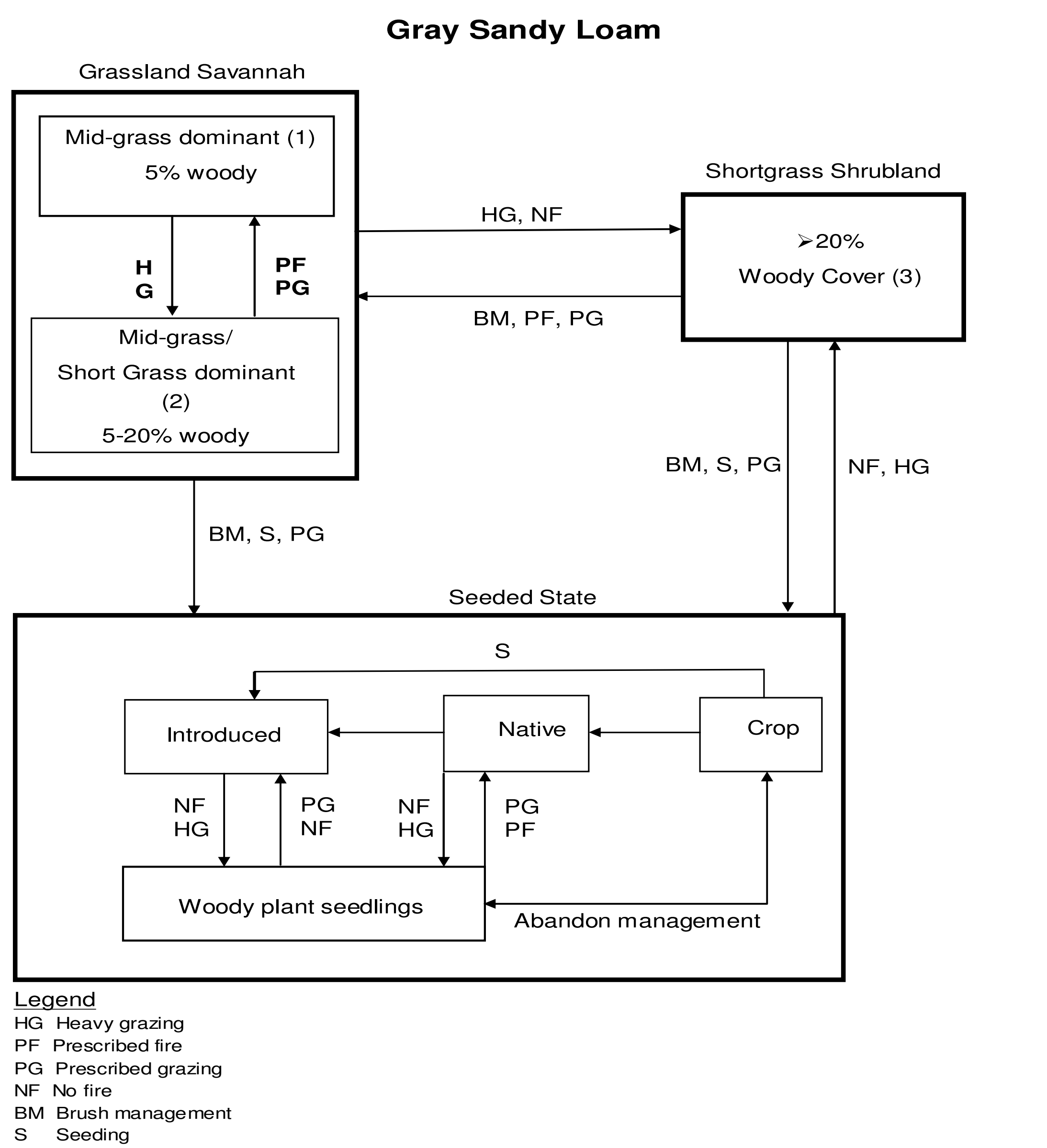
Because the South Texas Plains lie almost entirely below the hyperthermic line, introduced tropical species do well. The introduced species buffelgrass (*Cenchrus ciliaris*) has proliferated and is common on loamy to sandy soils in the western half of the area. Coastal bermudagrass, kleingrass (*Panicum coloratum*), and rhodesgrass (*Chloris gayana*) are also common introduced species in tame 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 (825,000 acres). Livestock production is primarily cow-calf range operations, and wildlife production for hunting and recreational use are becoming increasingly important. The South Texas Plains vegetational area is known nationwide for its large white-tailed deer (*Odocolieus virginianus*). Quail (*Colinus virginiana*), mourning dove (*Zenaida macroura*), turkey (*Meleagris gallopavo*), feral pigs (*Sus scrofa*), and javelina (*Dicotyles tajacu*) 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 northernmost part because of coyote predation. Integrated use of range, crops, and forages is increasing as is vegetable and peanut production where irrigation is possible.

Specific Reference to a Dominant Ecological Site

For the purpose of this paper, a proposed ecological site (submitted but not yet available in approved ESD on NRCS web site) in the South Texas Plains (83B) will be used to illustrate the vegetation steady states and transitions that occur from the HCPC through the process of retrogression to those communities more commonly existing today. A Gray Sandy Loam ecological site is a commonly occurring sites in the MLRA.The proposed ESD for a Gray Sandy Loam site includes the state and transition model shown in Figure 3.

Figure 3. State and Transition model (proposed), Gray Sandy Loam site, South Texas Plains PE 19-31.



The plant communities that can be found on this site range from a mid-grass dominant to a brush covered site with bare ground. This diversity in plant communities is in direct response to grazing management, fire, and drought.

The historic climax plant community (1) was composed of predominantly mid-grasses such as, trichloris (*Chloris spp*.), Plains bristlegrass (*Setaria macrostachya*), pink pappusgrass (*Pappophorum bicolor*), Arizona cottontop (*Digitaria californica*), silver bluestem (*Bothriochloa laguroides*), green sprangletop (*Leptochloa dubia*), sideoats grama and lovegrass tridens (*Tridens eragrostoides*). A small percentage of woodies such as guajillo, blackbrush, spiny hackberry, vine ephedra (*Ephedra antisyphilitica*), condalias (*Condalia* spp.) and many others were scattered across the landscape. Numerous perennial forbs occurred on the site including snoutbean, velvet bundleflower, sensitivebrier, bush sunflower, orange zexmenia, gaura, skeletonleaf goldeneye and numerous annual forbs. It was maintained by periodic grazing by roaming herds of wildlife, and numerous fires that were set by lightning and the native Americans. The site was productive, and maintained a high percentage of ground cover with forage production ranging from 1000 (low year) to 3400 (high year) pounds per acre (Table 5). Runoff of rainfall was medium, being in the hydrologic group B, with a hydrologic curve number of about 60. Soil fertility and available water-holding capacity are low to medium.

After settlement by European man, the area was fenced and in many instances stocked beyond its natural capacity with livestock. Fires were stopped by the reduction of fine fuel due to over grazing and the efforts of ranchers to extinguish wildfires to protect their investments in forage, livestock, facilities, and life. The combination of these activities coupled with periodic drought natural to the area, caused the plant community to change.

In the historic climax plant community, the mid-grasses dominated the short grasses due to their ability to capture sunlight and shade the shorter grasses. The mid-grasses also had deeper root systems that allowed them to capture the deep moisture while the short grasses had shorter root systems and could capture only the shallow moisture. Due to these differences, the mid-grasses maintained dominance over the short grasses as they could produce more food and maintain a higher state of health and vigor in times of drought. Fire occurred on a regular basis as there was normally good fine fuel. When fires started They could often burned for days, as there was nothing but rivers or denuded low producing ecological sites to stop them. These fires maintained the woody component to a small percentage of the total production, as well as canopy cover. Fires assisted in maintaining a good component of perennial forbs on the site by opening the ground cover to allow their establishment and regeneration and breaking the dormancy of the seeds.

As the stocking rates exceeded the carrying capacity of he land and the natural graze-rest cycles were broken by continuous grazing, the mid-grasses were grazed to the point that they could no longer produce the food in their leaves to maintain there health and vigor. When they were consistently grazed to the point where little leaf area was left, they stopped supplying the root system with food, as all available food produced was being used to grow more leaf area to enhance the food manufacturing process. If overgrazing persisted, root systems of the overgrazed plants continued to recede. In time, with continued close grazing, the mid-grasses would become more shallow rooted, weaker plants with small leaf area less able to survive the frequent droughts in the area. Long-term over utilization of the mid-grasses caused these species to decline and fostered spread of the short grasses on the site. These short grasses were fall witchgrass (*Panicum dichotomiflorum*), sand dropseed (*Sporobolus cryptandrus*), hooded windmillgrass (*Chloris cucullata*), curlymesquite (*Hilaria belangeri*), buffalograss (*Buchloe dactyloides*), perennial threeawn (*Aristida* spp.), and slim tridens (*Tridens muticus*). If heavy continuous grazing continued, common invaders were croton, ragweed (*Ambrosia* spp.), tumblegrass (*Schedonnardus paniculatus*), perennial broomweed (*Gutierrezia sarothrae*), grassbur (*Cenchrus incertus*), Texas bristlegrass (*Setaria texana*), and halls panicum (*Panicum hallii*).

As this reduction of mid-grasses and expansion of short grasses was occurring, fires were reduced as explained above. This allowed guajillo to dominate the site to form a dense canopy together with blackbrush, condalia, wolfberry (Lycium berlandieri), pricklypear, Texas persimmon (*Diospyros texana*), paloverde (*Parkinsonia texana*), ceniza (*Leucophyllum frutescens*) and coma (*Bumelia* spp). With their domination, these plants now captured the sunlight first and occupied the soil profile with root systems, therefore placing the short grasses and the remnants of mid-grasses in a sub-dominant position. At this point the area is represented by the Shrubland site (3) with a canopy of brush greater than 20 percent and often reaching between 60 percent to total closure. In the heavy brush cover, understory vegetation will range from a cover of short and mid grasses to bare ground. The Shrubland state is a new steady state that will exist until energy is applied to reduce the brush competition, increase the mid-and tallgrass species through proper grazing and a brush management maintenance program. The area may need to be seeded with a seed source of native seeds and a good grazing management program established to maintain the health and vigor of the forage component.

Plant community 1 in the S/T model (Table 5) represents the HCPC. It is a fire climax, midgrass plant community that has less than 5 percent canopy of woody plants. The grasses are trichloris, Arizona cottontop, Plains bristlegrass, pink pappusgrass, silver bluestem, green sprangletop, sideoats grama, lovegrass tridens, fall witchgrass, sand dropseed, hooded windmillgrass, curlymessquite, buffalograss, perennial threeawn, and slim tridens. The woody plants are blackbrush, spiny hackberry, vine ephedra, condalias, wolfberry, guajillo, guayacan, Texas persimmon, paloverde, cactus, desert yaupon, Texas kidneywood, allthorn, ceniza coma and mesquite. There are numerous forbs including snoutbean, velvet bundleflower, sensitivebrier, dalea bushsunflower, orange zexmenia gaura, skeletonleaf goldeneye and numerous annual forbs. Recurrent fire and grazing by bison and other wildlife were natural components of the ecosystem.

With settlement by European man came long-term overstocking the range with domestic animals. Naturally occuring fires no longer provided control of the woody plants as the fine fuel (primarily grasses) was reduced so that it would not carry a fire, or the fire was stopped by ranchers to protect their investment. The change of these two very important components of the ecosystem caused a dramatic change in the plant communities. The midgrasses gave way to the short grasses and the brush started to increase causing a shift to the Mid-grass/ Short Grass Dominant, 5-20 % canopy phase, plant community (2). This phase can be managed back to the Mid-grass Dominant, 5% woody phase through the use of prescribed grazing and prescribed fire. Once the woody canopy exceeds approximately 20 %, a threshold will have been passed to the Shrubland steady state. In this case, energy in the form of heavy equipment and/or herbicides will be required along with prescribed grazing to shift the plant community back to the Grassland Savannah steady state.

The Grassland Savannah steady state can be converted to the Seeded steady state by controlling the brush and seeding to native or introduced grasses. It may also be plowed and converted to cropland.

Table 5. Annual Production (lbs/ac) by Plant Type (HCPC)

Plant Type	Low	Representative Value	High
Grass/Grasslike·	750	2295	3060
Forb	100	128	170
Shrub/Vine	150	127	170
Total	1000	2550	3400

This phase of the Grassland Savannah steady state (community 2) still exhibits a savannah plant structure with the woody species canopy being as much as 20%. Guajillo is the major increaser brush species with blackbrush, condalia, wolfberry, pricklypear, Texas persimmon, paloverde, ceniza and coma. This is a result of fire being removed as a component of the site. Heavy continuous grazing takes many of the mid-grasses out of the site and they are replaced by short grasses such as hooded windmillgrass, sand dropseed, perennial threeawn, slim tridens, buffalograss, and curly mesquite. If heavy grazing continues, tumblegrass, grassbur, Texas bristlegrass, halls panicum, croton, and ragweed invade the site. This phase can still be managed back to the Midgrass Dominant, 5% woody phase if desired. It will take the introduction of fire to the ecosystem or some method of brush management that allows selective removal of the plants. A Prescribed Grazing plan will be essential to reverse the trend toward the short grass dominant community and increasing the midgrasses in the plant community.

Table 6. Annual Production (lbs/ac) by Plant Type (Community 2)

Plant Type	Low	Representative Value	High
Grass/Grasslike	360	1560	1850
Forb	100	200	300
Shrub/Vine	440	440	600
Total	900	2200	2750

If prolonged heavy grazing continues, and with the exclusion of fire, community 2 will transition to the Shortgrass Shrubland, >20% Woody Cover steady state. This plant community is a result of an irreversible transition from the Grassland Savannah to the Shrubland steady state. This threshold is passed when the woody canopy becomes such that insufficient fuel is produced to carry a fire that will control the woody canopy. The under story is very limited in production due to the competition for sunlight, water and nutrients. Guajillo dominates the site and forms a dense canopy together with blackbrush, condalia, wolfberry, pricklypear, Texas persimmon, paloverde, ceniza and coma. Invading forbs are croton, ragweed and perennial broomweed. Tumblegrass, grassbur, Texas bristlegrass and halls panicum invade the site. At this point there is very little under story production. There is much bare ground. Water infiltration is reduced on the site. Water infiltration does occur directly under some of the woody species such as mesquite as it moves down the trunk of the tree to the base. During the growing season, light showers are captured in the canopy of the shrubs and evaporate. Energy flow is predominantly through the shrubs and most nutrients are used by the shrubs. Winter rains can produce under story forage by the cool season annual forbs and grasses. Notice the decline in the high level of production of grass/grasslike from 3060 lbs/ac in community 1 to 1850 lbs/ac in community 2 and 300 lbs/ac in community 3. This represents a dramatic decrease in both forage resources and potential fuel load for prescribed fires.

Table 7. Annual Production (lbs/ac) by Plant Type (Community 3)

Plant Type	Low	Representative Value	High
Grass/Grasslike	50	200	300
Forb	50	200	300
Shrub/Vine	1200	1300	1400
Total	1300	1500	2000

Brush Management Practices

The South Texas Plains are the heart of the Texas "Brush Country", sharing that designation with the Gulf Coast Prairie, as previously noted. Brush stands in the area are often aggregates of 15 or more species, most characterized by thorns or spines and existing in three strata – overstory of trees, mid-story of shrubs and an understory of subshrubs and cacti. Frequently the cover is so heavy that only shade-tolerant herbaceous plants exist and the access to grazing animals is precluded.

The brush management practices described for the Gulf Coast Prairies earlier in this paper are similar for the South Texas Plains. Chaining and rootplowing where the most popular of the early mechanical practices utilized in the area and have been applied on hundreds of thousand of acres in the MLRA. While rootplowing may obtain near 100 percent mortality of the existing woody plant species on the treated area, the soil seed bank ensures that most species will eventually recover on the treated sites. However, there is a differential recovery rate by species, with some of the least desirable browse species, such as mesquite and twisted acacia recovering much more quickly than the better browse plants, such as spiny hackberry (Hamilton et al.1981). With proper grazing management, rootplowing is expected to provide an increase in forage production for as long as 15-20 years when used on heavily brush infested sites in the area. If follow-up maintenance practices, such as IPT chemical or mechanical are used, the increase in productivity of the site can be extend for many additional years.

Chaining was used primarily in the 1940' and 50's on the original stands of large mesquite infesting the area. Where the practice was applied on sandy or sandy loam soils (rather than heavy clay soils) and/or if soil moisture was optimum, large areas were essentially cleared of mesquite or other large trees in the same treatment area. However, as has been well documented, the shrubby species that were present at the time of chaining and that were not uprooted grew vigorously in the post-treatment are a following their release form the over story mesquite competition. Chaining and rootplowing are credited also with the spreading of pricklypear on many sites (Dodd 1968). Other mechanical practices, including roller chopping, shredding, disking, bulldozing and grubbing are all used in the region, both as broadcast treatments or as IPT when feasible based on brush size and densities. The resprouting nature of woody species in the area limits the effectiveness of the skid steer loaders and shears, however, some operators are using a "cut stump" herbicide application on the plants immediately following shearing. The herbicide application equipment is built into the machine so that the shearing and herbicide applications are done in a single operation.

Chemical brush management practices also have a long history of use in the MLRA and are similar to the Gulf Coast Praires previously described herein. Mesquite and pricklypear tend to be greater problems in the South Texas Plains, while huisache is reduced in significance compared to the Gulf Coast Prairies, especially in the more western counties, such as Zavala and Dimmitt.

POST OAK SAVANNAH and BLACKLAND PRAIRIES

General

There are two additional MLRA that include portions of Counties within Region L. The Post Oak Savannah includes portions of DeWitt, Guadalupe and Caldwell Counties, as well as very minor portions of Victoria, Goliad, Gonzales and Wilson Counties. The

Blackland Prairies includes portions of Hayes, Comal, Bexar, Guadalupe, Caldwell, Gonzales and DeWitt Counties. Compared to the Edwards Plateau, Gulf Coast Prairies and Marshes and South Texas Plains, the land areas of the Post Oak Savannah and Blackland Prairies within Region L are very small and will be included together for this paper.

The Post Oak Savannah lies just to the west of the Pineywoods and mixes considerably with the Blackland Prairies area in the south. The Post Oak Savannah is a gently rolling, moderately dissected wooded plain.

Upland soils are gray, slightly acid sandy loams, commonly shallow over gray, mottled or red, firm clayey subsoils. They are generally droughty and have claypans at varying depths, restricting moisture percolation. The bottomland soils are reddish brown to dark gray, slightly acid to calcareous, loamy to clayey alluvial. 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 (*Carya* spp.). 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*). Lower successional species include brownseed paspalum, threeawn, broomsedge bluestem, splitbeard bluestem (*Andropogon ternarius*), rosette grasses, and lovegrasses (*Eragrostis*).

Forbs similar to the true prairie species are wild indigo, indigobush (*Amorpha fruticosa* var. *augustifolia*), senna, tickclover, lespedezas (*Lespedez* spp.), prairie clovers (*Petalostemon* spp.), western ragweed, crotons (*Croton* spp.), and sneezeweeds (*Helenium*).

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

Deer, 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-yearling operations with many small herds on small landholdings. Livestock use either tame pastures, native pastures, or the woodland areas for forage throughout the year. Wheat, oats, and rye are often planted for winter pasture.

The Blackland Prairies area 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 upland blacklands are dark, calcareous shrink-swell clayey soils, changing gradually with depth to light marls or chalks. Bottomland soils are generally reddish brown to dark gray, slightly acid to calcareous, loamy to clayey and alluvial. 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*), hairy grama (*B. hirsuta*), Mead's sedge (*Carex meadii*), Texas wintergrass, and buffalograss (*Buchloe dactyloides*) have increased with grazing pressure. Common forbs are asters (*Aster* spp.), prairie bluet (*Hedyotis nigricans* var. *nigricans*), prairie-clover, and late coneflower (*Rudbeckia serotina*). Common legumes include snoutbeans (*Rhynchosia* spp.) and vetch. 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 percent of the Blackland Prairie was cultivated to produce cotton, sorghum, corn, wheat, and forages during the latter part of the 19th century and the first part of the 20th century. Since the 1950's, pasture and forage crops for the production of livestock have increased, and now only about 50 percent of the area is used as cropland. Tame pastures occupy more than 25 percent of the land area, and the rest is used as rangeland. Small remnants of native vegetation exist for grazing or for native 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 tame pasture forages. Potential is good for increased production of food and fiber crops as well as forages. Mourning dove and bobwhite quail on the uplands and squirrel along streams are the most important game species.

<u>Specific Reference to an Ecological Site</u>

A Claypan Prairie site is typical of the Blackland Prairie MLRA and will also be used to illustrate the Post Oak Savannah MLRA as well. This tallgrass prairie site evolved and was maintained by the grazing and herding effects of native large ungulates, by rodents and rabbits, and by insects as well as the occurrence of periodic fire. Extreme climatic fluctuations over time may also have been important in the maintenance of the historic plant community.

The soils of this site are deep, noncalcareous sandy loams and clay loams. The topsoil is underlain at rather shallow depths by dense, hard, clayey material which restricts air, water movement, and root growth. The soils take in water slowly, but can hold large amounts of water and plant nutrients. The soils of this site give up water grudgingly to growing plants. Plants may wilt even though the soil has comparatively high moisture content. Heavy surface crusts develop in the absence of good vegetative cover.

The first killing frost occurs about November 15th and the last killing frost about March 15th. The growing season is about 300 days. Site specific weather data should be used for land management decision making. For site specific weather conditions, obtain data from a weather station close to the site. Site specific weather data may be obtained at NRCS county offices or from the Internet at http://www.wcc.nrcs.usda.gov/water/wetlands.html.

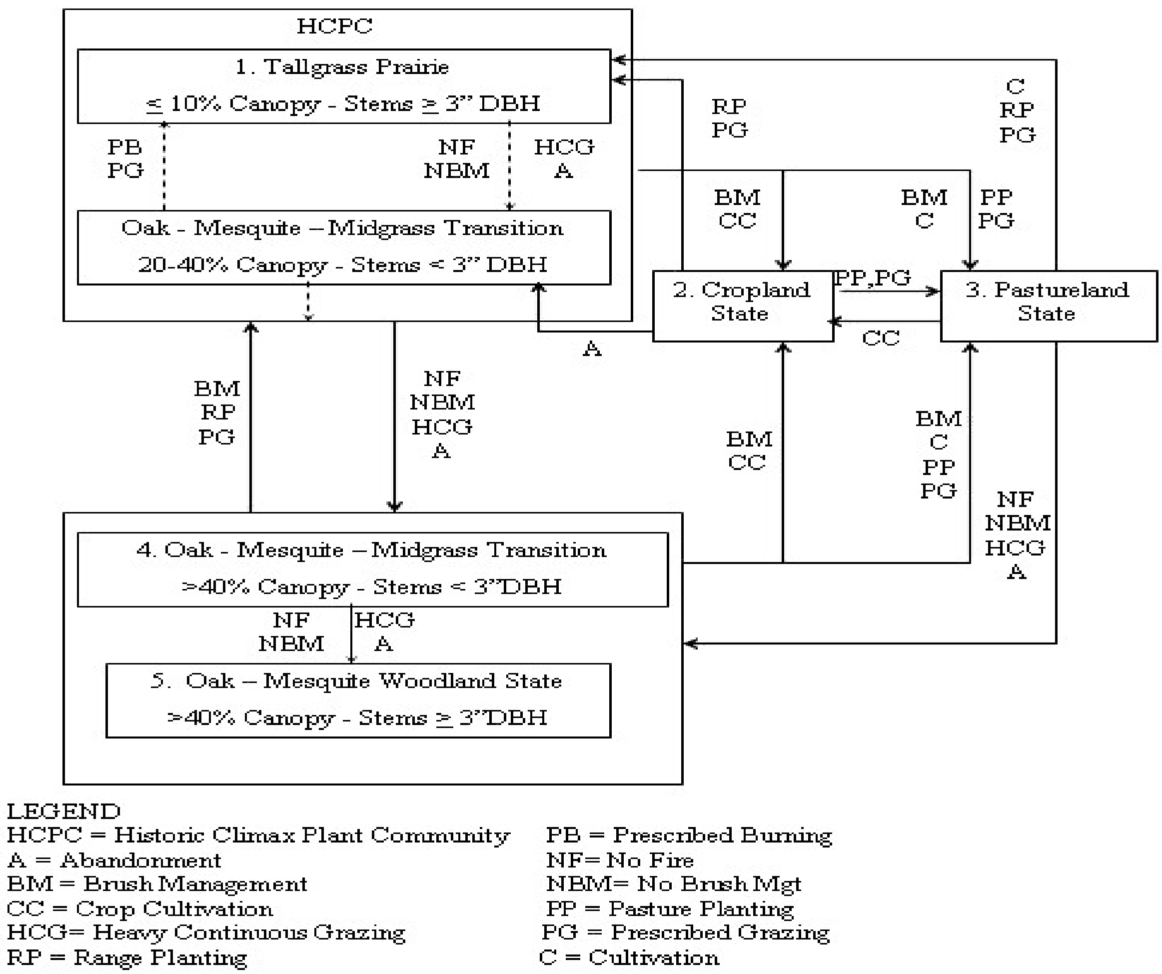
Table 8. Climatic data for a Claypan Prairie site, Blackland MLRA

	Minimum	Maximum
Frost-free period (days):	266	274
Freeze-free period (days):	298	302
Mean annual precipitation (inches):	34.0	42.0

Continuous overgrazing by confined livestock or wildlife and the suppression of fire degrades the historic climax plant community. Continuous grazing will remove big bluestem (*Andropogon gerardii*), Indiangrass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*), switchgrass (*Panicum virgatum*), and preferred forbs such as Engelmanndaisy (*Engelmannia peristenia*), Illinois bundleflower (*Desmanthus illinoensis*), gayfeather (*Liatris* spp.), and compass plant (*Silphium* spp.). These plants will be replaced by less productive perennial and annual grasses and forbs including silver bluestem (*Bothriochloa laguroides*), windmillgrass (*Chloris* spp.), threeawns (*Aristida* spp.), croton (*Croton* spp.), annual broomweed (*Amphiachyris dracunculoides*), and snow on the prairie (*Euphorbia bicolor*). With continued overgrazing, no brush management, and the absence of fire, a community dominated by woody species including mesquite (*Prosopis glandulosa*), post oak (*Quercus stellata*), hackberry (*Celtis* spp.), winged elm (*Ulmus alata*), and Eastern red cedar (*Juniperus virginiana*) will replace the grassland.

The historic climax plant community (HCPC) of this site is a prairie or very open savannah. Live oak (Quercus virginiana), winged elm, or hackberry may occur along water courses or in scattered motts and provide 5 to 10 percent canopy cover. Large old post oak trees may be widely scattered over this site. The herbaceous plant community is dominated by little bluestem and Indiangrass which usually constitutes 50 to 65 percent of the total annual yield. Switchgrass, big bluestem, Florida paspalum (*Paspalum floridanum*), sideoats grama (*Bouteloua curtipendula*), silver bluestem, and tall dropseed (*Sporobolus compositus*) are important components of the warm season grass population. Virginia (*Elymus virginicus*) and Canada (*Elymus canadensis*) wildrye and Texas wintergrass (*Nassella leucotricha*) are components of the cool season grass population. Important forbs include Engelmanndaisy, gayfeather (*Liatris* spp.), bundleflower, prairie petunia (*Ruellia humilis*), and yellow neptunia (*Neptunia lutea*). Grazing prescriptions that permit acceptable grazing periods and allow adequate rest periods along with prescribed fire every three to five years are important in the maintenance of the historic climax plant community and the prairie landscape structure. Continuous overgrazing or over-rest and the absence of fire tend to favor a vegetative shift towards woody species such as mesquite, elm, hackberry, post oak, persimmon (*Diospyros virginiana*), and honey locust (*Gleditsia triacanthos*). Without corrective measures, this shift will continue to a mesquite-oak shrub dominated community.

Figure 4. State and Transition Model, Claypan Prairie Site, Blackland Prairie MLRA



As with other sites discussed previously, the S/T Model for the Claypan Prairie site indicates the dramatic decline in production of forage species as retrogression away from the HCPC occurs. To illustrate this for a site representative of the MLRA, the following annual production tables are provided. The first table (Table 9) shows at the high level of production 6050 lbs/ac, of which 4850 lbs/ac is from grass and grasslike plants. Most of this production is from tall and midgrasses..

Table 9. Annual Production (lbs/ac) by Plant Type (HCPC)

	Annual Production (lbs/AC)		
Plant Type	Low	Representative Value	High
Forb	300	450	600
Grass/Grasslike	2425	3600	4850
Shrub/Vine	150	225	300
Tree	150	225	300
Total:	3025	4500	6050

Table 10 provides the annual production (lbs/ac) for the Oak-Mesquite-Midgrass transition state in the S/T model. This plant community is a transitional community between the prairie, pastureland, or cropland and the oak-mesquite woodland state. It develops in the absence of fire or mechanical or chemical brush management treatments. It is usually the result of abandonment following cropping or yearly continuous grazing. In addition to the naturally occurring winged elm, hackberry, bumelia (*Sideroxylon lanuginosum*), live oak, and post oak - mesquite and Eastern red cedar increase in density and canopy coverage (20 to 40 percent). In some cases, especially in abandoned cropland situations, mesquite may dominate the woody component of the community. Species whose seed is windblown (elm) or animal dispersed (mesquite, Eastern red cedar, bumelia) are the first to invade and dominate the site. Remnants of little bluestem and Indiangrass may still occur, but the herbaceous component of the community becomes dominated by lesser producing grasses and forbs. Silver bluestem (*Bothriochloa saccharoides*), windmill grass (*Chloris* spp.), white tridens (*Tridens albescens*), fall witchgrass (*Digitaria cognata*), threeawn (*Aristida* spp.), Texas wintergrass (*Nassella leucotricha*), Halls panicum (*Panicum hallii*), western ragweed (*Ambrosia psilostach*ya), croton (*Croton* spp.), annual broomweed (*Amphiachyris dracunculoides*), and snow on the prairie (*Euphorbia bicolor*) commonly occur.

If the woody shrub canopy has not exceeded 40 percent prescribed burning on a 3 to 5 year interval in conjunction with prescribed grazing is a viable option for returning this community to a tallgrass prairie that may resemble the historic clima x plant community. If the woody canopy has exceeded 40 percent (Oak-Mesquite-Midgrass transition state, community 4), chemical or mechanical brush control must be applied to move this transitional community back towards the historic plant community. Total production on the site has dropped from 6050 lbs/ac in the HCPC community to 4200 lbs/ac in the Oak-

Mesquite-Midgrass transitional community (4). Grass and grasslike species provide approximately 2400 lbs/ac, most of which is composed of mid and short grasses that are less desirable as forage plants than plant community 1.

Table 10. Annual Production (lbs/ac) by Plant Type (Plant Community 4)

	Annual Production (lbs/AC)		
Plant Type	Low	Representative Value	High
Forb	300	450	600
Grass/Grasslike	1200	1800	2400
Shrub/Vine	450	675	900
Tree	150	225	300
Total:	2100	3150	4200

The final Community (5) used to contrast site production based on deviation from the HCPC steady state is the Oak-Mesquite-Woodland state (Table 11). This plant community is dominated by woody species including post oak, mesquite, hackberry, Eastern red cedar, honey locust, prickly ash, and bumelia. Canopy cover exceeds 40 percent. Understory shrubs and vines include coral berry, greenbriar (Smilax sp.), grape (Vitis sp.), prickly pear (Opuntia sp.), and baccharis (Baccharis halimifolia). Herbaceous composition and production is directly related to canopy cover. Texas wintergrass, purpletop tridens (Tridens flavus), silver bluestem, threeawn, sedges (Carex sp.), croton, and annual broomweed commonly occur. If the site is not abandoned cropland, chemical brush control along with prescribed grazing and prescribed burning is a viable treatment option for moving this community back towards the historic plant community. Mechanical brush control and seeding is usually the most viable treatment option when the objective is to return this state to a community that resembles the historic climax plant community. Production of forage species is dramatically reduced, with the shrubs, vines and trees making up over 55 percent of total site production at the high level. Grass and grasslike plants account for only 1200 lbs/ac at the high level of production. It is also significant that at the low level of production, indicative of frequent drought conditions, community 5 produces only about 600 lbs/ac of grass and grasslike plants.

Table 11. Annual Production (lbs/ac) by Plant Type (Plant Community 5)

		Annual Production (lbs/AC)	
Plant Type	Low	Representative Value	High
Forb	150	225	300
Grass/Grasslike	600	900	1200
Shrub/Vine	500	750	1000
Tree	850	1275	1700
Total:	2100	3150	4200

Brush Management Practices

When a Claypan Prairie site has retrogressed to plant communities 4 and 5, there is a thicketizing of woody vegetation that may include trees, such as post oak, elms, mesquite and hackberry, large enough to be effectively controlled with chaining. Soils on the site are deep and favorable in many areas for use of rootplowing. Bulldozing to push and uproot large trees is also a common practice. For woody species that are smaller than mature trees and where tree density is low (100-200 trees/ac), power grubbing is another mechanical treatment alternative. In low tree densities and where size is not limiting (stem diameters of <4 inches), low-energy grubbing is also a mechanical alternative. Understory vegetation including yaupon, coralberry, greenbrier and others will quickly expand in density following overstory removal. Simple top removal practices, such as shredding and roller chopping will give temporary relief from these shrub species, but should be followed with prescribed fire or IPT mechanical or chemical treatments to maintain brush control. For individual plants that occur in the woody plant composite and that are not resprouting species, sheering with a skid-steer loader would be an option. Eastern red cedar that occurs on the site is an example of a non-sprouting species that can be effectively controlled by sheering. The mechanical equipment discussed here has been described in detail in other sections of the paper.

Innovative IPT equipment, such as “El Tiburon”, the shark, has been developed to uproot woody plants with stem diameters up to 5 inches. This equipment operates on a 3-point hitch behind a rubber-tired tractor and “grabs” the tree trunk with two claw-type arms by closing hydraulic cylinders and then pulls the plant from the soil profile.

Chemical control on the site can be very effective for oak species. Broadcast chemical treatment with tebuthiuron (Spike 20P) at a rate of 10 lbs. of pellets (2 lbs. a.i.) will give a very high level of mortality of blackjack oak, post oak and winged elm. For other woody species, including hackberry, baccharis, elm, greenbrier, yaupon, Chinese tallow and pricklyash, chemical IPT provides a very high level of control (76-100% mortality). Eastern red cedar is effectively contolled chemically with IPT using picloram (Tordon 22K) or hexazinone (Velpar L® or Pronone Power Pellets®). Chemical control methods for huisache and mesquite will be the same as described earlier in this paper for these species. For example, clopyralid (Reclaim®) applied broadcast alone or in combination with picloram (Tordon 22k) or triclopyr (Remedy) will give a modenate to high (36-75%) mortality of honey mesquite. Huisache and retama do not respond as well to broadcast chemicals as mesquite, but can be controlled to a moderate level (36-55%) of mortality with several herbicide compounds, including combinations of picloram (Tordon 22k) and triclopyr (Remedy) or picloram and clopyralid (Reclaim). Huisache can also be controlled at the same level with boardcast applications of fluroxypyr and picloram (1:1) (Surmount) and picloram (Tordon 22k) alone. Both mesquite and huisache can be effectcively controlled (very high mortality 76-100%) with IPT chemical treatments applied as either stem basal, cut stump or foliage sprays.

Potential to Augment Recharge and Streamflow Within Region L Through Shrub Control

In this section, we examine the scientific basis for using shrub control as a means of increasing groundwater recharge with an explicit focus on two of the landcover types within the Region L Planning area: (1) juniper woodlands within the Edwards Plateau Major Land Resource Area (MLAR) and (2) South Texas shrublands within the South Texas Plains MLRA—in particular those shrublands overlying the Carizzo-Wilcox recharge zone within Zavala and Dimmitt counties. We are focusing on these two areas because they offer the greatest opportunities for enhanced recharge through land management.

General Overview-Shrub Control and Water

Despite the uncertainties that remain, we are confident of a number of things regarding the connection between woody plants and streamflow. We know, for example, that this connection becomes stronger as annual rainfall and/or available water increases. There is extensive literature showing that in forests, streamflow increases following a reduction in the number of trees (Bosch and Hewlett 1982, Stednick 1996, Zhang et al. 2001). For rangelands, however, relatively fewer studies have shown that streamflow and or recharge can be increased by reducing the cover of woody plants. In most but not all semiarid regions, the energy available for evaporation of water is sufficiently high that most of the comparatively low amount of precipitation is “lost” to evapotranspiration, regardless of the type of vegetation present.

Rangeland areas with the most potential for increasing recharge through shrub control are those areas where deep drainage (water movement beyond the herbaceous rooting zone) can occur (Seyfried et al. 2005, Wilcox et al. 2006). This characteristic is found, for example, where soils are shallow and overlie relatively permeable bedrock (such as karst limestones). An example in Texas is the Edwards Plateau area, which supports large tracts of juniper woodlands and has considerably more “flowing water” than would be expected for a semiarid or subhumid climate (ca. 700 mm/yr). The explanation lies in the karst geology—a substrate of fractured limestone that allows rapid flow of water to the subsurface. Other soil types that may enable deep drainage are sandy soils. Shrublands in region L that exhibit these characteristics are the juniper shrublands within the Edwards Plateau and the South Texas shrublands overlying the recharge zone of the Carrizo-Wilcox Aquifer. In this report, we summarize the available literature for both of these two areas.

Part I: Ashe Juniper Woodlands of the Edwards Plateau

The presence of springs is an excellent indication that subsurface flow exists in a region. On Texas rangelands, springs are most commonly associated with limestone or karst geology. Two important features of such sites—namely, shallow soils (which cannot store much water) and fractured parent material (which allows rapid, deep drainage of rainfall)—facilitate the presence of springs. Rangelands of this type, which in Texas mainly occupy the central part of the state, are typically dominated by Ashe juniper and live oak. There is a significant body of work examining how Ashe juniper affects the water cycle. We summarize these findings for the following spatial scales: (1) individual tree or small plot (the space occupied by a single tree); (2) hillslope or stand (large enough to encompass many trees, and thereby to manifest important hillslope processes such as overland flow, depression storage, and sediment deposition); (3) small catchment (large enough to incorporate channel and groundwater flow processes); and (4) landscape (encompasses watersheds of 20 km^2 or larger).

<u>Tree Scale</u>

Evergreen shrubs such as juniper have a large capacity for capturing precipitation, not only because they retain their leaves year round, but because they have a high leaf area per tree (Hicks and Dugas 1998). Owens *et al.* (2006) estimated that the canopy and litter layer of an Ashe juniper tree together intercept about 40% of the precipitation that falls on the tree annually. At the same time, the percentage varied dramatically depending on the size of the storm: close to 100% of the rainfall from small storms (<12 mm) was captured by interception, whereas a much smaller percentage (around 10%) was intercepted and evaporated during large storms. Transpiration from an Ashe juniper community should be greater than that from an herbaceous community because Ashe juniper transpires throughout the year, typically has a much greater community leaf area, and can access water at greater depths. Owens and Ansley (1997), on the basis of direct measurement of Ashe juniper transpiration rates, concluded that a mature Ashe juniper tree transpired as much as 150 l/d, which they estimated would be equivalent to 400 mm/yr.

In summary, dense stands of juniper intercept and transpire large quantities of water. In regions where juniper cover is extensive and dense, therefore, this species can have a major impact on the water cycle at the tree scale. However, because removal of juniper may result in increased growth and density of other vegetation, which would also transpire and intercept water, it is uncertain how much water would be “saved” by juniper removal. As discussed below, larger-scale studies are required to make such an assessment.

Stand Scale

At this scale, the primary measurements of evapotranspiration have been direct estimates made by means of micrometeorological technology. We know of only one such study for Ashe juniper communities: Dugas *et al.* (1998) measured evapotranspiration from an Ashe juniper community using the Bowen ratio/energy balance method. Two paired areas, each 200 x 600 m in size, were selected for measurement over a 5-year period. After the first 2 years, all Ashe juniper trees were removed from one of the areas by hand-cutting and burning. For the 2-year period following this treatment, the difference in evapotranspiration between the two areas was about 40 mm/yr; but this treatment effect disappeared in the third year of the study, after which evapotranspiration was similar in the treated and untreated areas. Some very recent work, also using micrometeorological technology, however estimates that evapotranspiration rates may be as much as 90 mm higher for woodlands than grasslands (James Heilman—personal communication)

Small Catchment Scale

Small catchments with springs. Over the past 150 years, many springs in Texas have dried up, perhaps owing to increased groundwater pumping (Brune 2002) and/or the spread of woody plant cover. There are many anecdotal accounts of springs drying following the encroachment of woody plants, and of spring flow returning after woody plant cover was removed or reduced. Increases in discharge from springs or spring-fed catchments following the removal of Ashe juniper have been documented in two studies. Wright (1996), working on a 3-ha catchment in the Seco Creek Watershed of central Texas, reported an increase in spring flow from 11.7 l/min during the 2-year pre-treatment period to 14.4 l/min following partial removal of Ashe juniper—this despite the fact that precipitation was lower in the post-treatment period. This increase in flow translates to about 40 mm/yr of additional water. Similarly, Huang et al. (2006) estimate that runoff from a small spring-fed catchment increased by about 45 mm/yr following removal of Ashe juniper from around 60% of the catchment.

Small catchments without springs. A few studies have examined the effect of juniper removal on small catchments where no springs were present. Richardson et al. (1979) compared runoff from two 3.7-ha catchments for an 11-year period. Juniper was removed from one of the catchments the fifth year, by root plowing. Surface runoff (presumably generated as Horton overland flow) was about 20% (13 mm/yr) lower following this treatment, but this was attributed to increased surface roughness that enhanced shallow surface storage. In another paired-catchment study (in the Seco Creek watershed), Dugas *et al*. (1998) found that when juniper cover was removed by hand-cutting, the treatment had little influence on surface runoff from these small (6- and 4-ha) catchments. Runoff accounted for about 5% of total precipitation and occurred only when precipitation intensity was high. Similarly, Wilcox *et al.* (2005) concluded that changes in density of Ashe juniper had little influence on streamflow from small catchments in the western portion of the Edwards Plateau.

Landscape Scale

For Ashe juniper rangelands, no large-scale experiments have been conducted. However, we may be able to infer information from analysis of historical streamflow.

Streamflow data going back to the early 1900s are available for many of the major rivers in Texas. These long-term data can provide insight into the nature and variability of streamflow and the relationship of streamflow to climate. In addition, such records may shed light on the sensitivity of streamflow to landscape-scale changes in vegetation cover. For example, we have good evidence that woody plant cover on the Edwards Plateau increased dramatically during the last century (Smeins et al. 1997). Therefore, if there is indeed a strong connection between streamflow and woody plant cover, we should be able to detect a decrease in streamflow that is independent of precipitation differences.

To date, only a few attempts at such analysis have been made for the Edwards Plateau. One of these studies, by the Lower Colorado River Authority, examined flow from 1939 to 2000 on one of the major rivers in the region, the Pedernales, which drains an area of over 2300 km^2 (LCRA 2000). The results showed no evidence of changes in streamflow that were independent of changes in climate during this period. If woody plant cover has increased in this basin, as it has throughout much of the Edwards Plateau (Smeins et al. 1997), then these results would indicate that at very large scales, rivers are relatively insensitive to changes in woody plant cover. Unfortunately, since there has been no detailed assessment of vegetation change in the Pedernales basin, we cannot definitively say to what extent woody plant cover has changed during the last 60 years—if it has changed at all.

Part II: South Texas Shrublands

Within the South Texas Shrublands MLRA, the areas with the most potential for enhanced groundwater recharge through vegetation management, would be those overlying sandy soils. Of particular importance would be those areas overlying the recharge zone of the Carrizo-Wilcox aquifer.

Field Studies

There have been relatively few investigations in the South Texas Plains that examine the influence of woody plants on recharge. We will review what literature is available and then relate it to work in other landscapes.

The only published study completed in South Texas is that by Weltz et al. (1995). This work was conducted at the La Copita Research Area in Jim Wells County. Dominant woody plants at this location are mesquite, brasil, spiny hackberry, and lime prickly ash. Soils on the site were within the Delfina fine sand loam-Miguel fine sandy loam soil complex. This study compared recharge rates on three vegetation type: bare, herbaceous cover, and woody plants. Recharge was estimated on the basis of soil water monitoring to a depth of 2 meters. Monitoring occurred for two years, but rainfall during one of those years was well below normal and no recharge occurred on any of the sites. During the other year, when rainfall was 887 mm recharge was 78, 22, and 0 on the bare, grass, and shrub plots respectively. On the basis of this study, we would conclude (1) that little to no recharge occurs if woody plants dominate (2) if woody plants are removed there will be some recharge that is equivalent to around 3% of rainfall and finally (3) recharge may be around 10% of rainfall in the complete absence of vegetation cover. This would perhaps be comparable to fallow dryland agriculture.

There have been no other studies conducted in South Texas but the results of this study are generally consistent with work conducted elsewhere in Texas (Wilcox 2002, Wilcox et al. 2006). Work on mesquite rangelands in the Rolling Plains of Texas suggests that annual recharge rates are 3 mm or less for mesquite covered areas and 5-10 mm if the mesquite are removed. In the absence of vegetation annual recharge was around 15 mm (Carlson et al. 1990). Mesquite removal had a much larger effect on deep recharge in the Blackland Prairie region of Texas and recharge in general was much higher(Richardson et al. 1979). This is because the soils in the Blackland Prairie will form deep cracks during dry periods which periodically provide opportunities for significant and deep recharge. In all of the studies mentioned above, recharge rates were determined by monitoring soil moisture. An alternative approach is that of using flux towers for determining evapotranspiration rates. A study of this type on mesquite rangelands of North Texas (Dugas and Mayeux 1991) concluded that recharge rates were little affected by mesquite removal.

The studies that have been completed in Texas are generally consistent with work in other semiarid locations which highlights the strong control that vegetation cover has on recharge (Sandvig and Phillips 2006, Scanlon et al. 2006). Almost without exception, recharge rates are low to zero under shrub canopies (Seyfried et al. 2005). Also, the complete removal of vegetation generally results in significant increases in recharge (Scanlon et al. 2005).

Hydrological Modeling

Hydrological models can provide insight concerning recharge dynamics. A comprehensive modeling exercise of recharge dynamics for the state of Texas has just been completed (Keese et al. 2005). This work highlights the strong influence of climate, soils and vegetation on recharge (Figure 5). Their simulations would suggest that for the Region L area, recharge would be less than 5-10 mm/year.

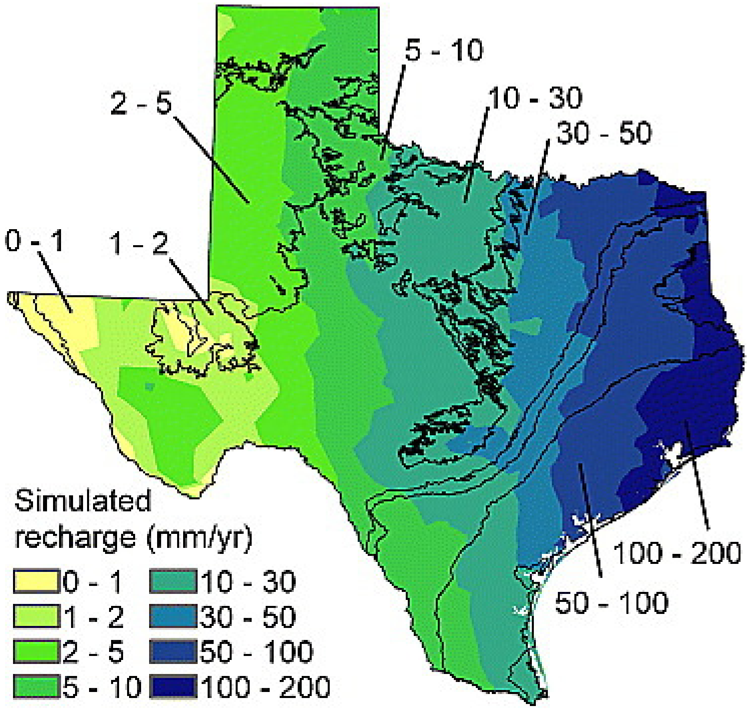


Figure 5. Simulated recharge rates for the state of Texas (Keese et al. 2005).

The influence of soil texture and vegetation on simulated recharge is summarized in Figure 6 below. Keese et al. (2005) found that the recharge rate declined by a factor of 2-30 times when vegetation was added to the model. These results would suggest that vegetation management on sandy soils can have a strong affect on recharge.

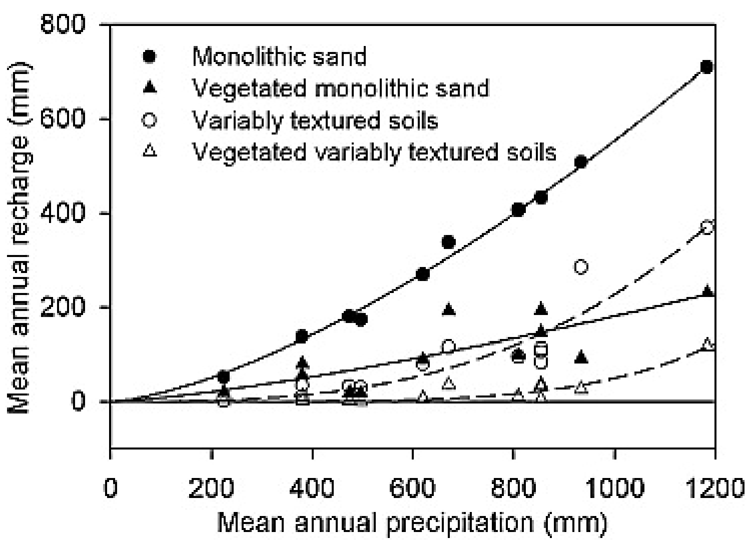


Figure 6. Results from the Keese et al. (2005) modeling study showing the relationship between simulated recharge, vegetation cover and soil texture.

Summary and Implications

Ashe Juniper Rangelands on the Edwards Plateau

The influence of Ashe juniper on the water budget remains the subject of some confusion and disagreement, in part because the implications of the scale at which measurements were made have not been fully considered. For example, at the tree scale, the most common measurement is some index of evapotranspiration by trees. After removal of trees, these numbers have often been extrapolated up without taking into account the compensatory effects of regrowth of trees or replacement by other vegetation. These measurements do not take into account water use by replacement vegetation, as the larger-scale studies do. For example, at the tree scale, for an area with an average annual precipitation of 750 mm/yr, an individual tree will intercept and transpire virtually all of the available water. At the stand scale, however, as estimated by Dugas *et al.* (1998), the difference in water consumption between a woodland and a grassland is between 40-50 mm/yr. Newer work suggests differences as high as 90 mm/year however. Water balance studies at the small-catchment scale (where springs exist) indicate water savings of around 50 mm/yr. (Huang et al. 2006).

From these results, we are increasingly confident that conversion of Ashe juniper woodlands to grasslands or more open savannas will translate to increases in spring flow and/or groundwater recharge at the small catchment scale. But it remains uncertain whether similar results will be seen at larger scales. At the landscape scale we have not found evidence of water savings due to changes in vegetation cover. The reason for this lack of evidence is not yet clear—whether (1) there has been no net change in woody plant cover; (2) there has been a change in woody plant cover but this has no influence on streamflow; or (3) there has been a change in woody plant cover and it has affected streamflow, but the signal cannot be detected because of too much "noise" in the data.

On the basis of the literature available, our current best estimate is that conversion of Ashe Juniper woodlands into open savannas would result in an average increase in water yield (streamflow and recharge) of around 50 mm/year.

South Texas Shrublands

On the basis of this review, we believe that recharge in the South Texas shrublands is very limited if shrub cover is dense. All of the available data strongly suggest that in the presence of dense shrub cover, there will be little if any recharge. However, both the modeling and field work suggest that in the absence of shrubs, recharge will be appreciably higher—especially for sandy soils. For example, Weltz et al (1995) found that when rainfall was slightly above average, recharge was around 20 mm/year for grass covered areas. The implications of this then are that shrub control over the recharge area would in the long term increase distributed recharge.

Our estimate that for the South Texas shrublands, average recharge on sandy soils could be increased by shrub control anywhere from 10 -20 mm/year. In the figure below, we make a rough calculation of the potential increase in recharge that may occur if shrubs were removed within the Carrizo Wilcox recharge zone. For example, distributed recharge would be around 5000 ac-ft / year if shrubs were cleared on 200,000 acres of rangeland if recharge rates were about 10 mm/ year.

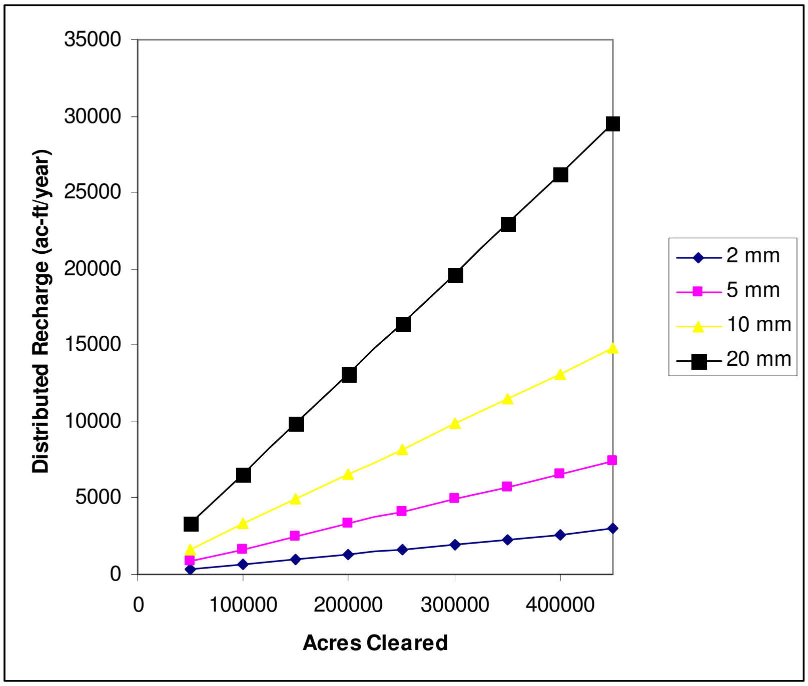


Figure 7. The potential increase in recharge from shrub control over the recharge zone in the Wintergarden Groundwater Area.

Assessing the Cost Effectiveness of Brush Control to Enhance Off-site Water Yield

Introduction

This section reports the assumptions and methods for estimating the cost effectiveness of a program to encourage rangeland owners to engage in brush control for purposes of enhancing groundwater recharge. Vegetative cover, applicable methods of brush control and the estimation of increased water yield from control of the dominate brush species are described in earlier sections of this report.

This section provides details on how the costs per acre foot (ac.ft.) of added water resulting from brush control were calculated for the different brush types-regions. The estimates of additional groundwater recharge resulting from the control of Ashe juniper in the areas of the Edwards Plateau which contribute to recharge of the Edwards Aquifer and estimates of additional groundwater recharge resulting from the control of mixed brush on sandy soils in the areas of Dimmit and Zavala counties which contribute to recharge of the Carrizo-Wilcox Aquifer are used along with brush control cost estimates from other studies to obtain estimates of per acre-foot costs of added water.

Cost of Brush Control Methods

Data on costs of various brush control practices for Texas have recently been obtained from an array of contractors, technical experts and agricultural technical service agency personnel in conjunction with another study being conducted by two of the authors of this report (Pestman, 2007). The data indicate that brush control costs are highly variable. Factors that influence cost and contribute to the high variability include the type, size and density of the target brush species; the type, rock content and slope of soil in which the target species is growing; whether the target species sprouts re-growth from root buds; whether cost effective herbicides are available for controlling the target species; etc.

<u>Edwards Plateau</u>

In a previous section, it was reported that any of several different mechanical practices were appropriate for use in the control of Ashe juniper. The costs of these various mechanical practices may vary from less than $100 to as much as $400 per acre (Pestman, 2007). Also in a previous section of this report the added ground water recharge estimated to result from control of Ashe juniper was reported to be 50mm/year. The inch equivalent of 50mm/yr. is 2 in. which is also equal to 0.167 ft. Therefore, control of Ashe juniper on an acre of land is estimated to result in 0.167 added ac.ft. of groundwater recharge per year.

Another consideration in estimating the cost of the added groundwater recharge is the duration of the impact of the brush control practice on the increase in the annual rate of groundwater recharge. For example, if the brush control program is limited to only the initial practice, then re-growth of the brush will occur, such that 5 to 10 years after the initial treatment, the brush canopy will approach its pre-treatment level and there will no longer be any increase in groundwater recharge. Alternatively, by using follow-up brush control practices after the initial treatment to control the brush re-growth, the increased groundwater recharge gained from the initial brush control practice can be maintained for many more years into the future.

Fortunately, the follow-up brush control practices, like prescribed fire or chemical or mechanical individual plant treatments, are relatively inexpensive compared to the cost of the initial treatments. Therefore, brush control programs consisting of an initial practice plus appropriate follow-up practices at 3-6 year intervals after the initial practice can result in maintaining brush canopy at low levels and also maintaining the resulting increases in ground water recharge for many years into the future.

The results of extending the years of reduced brush canopy, and the resulting increased groundwater recharge, on the cost per acre foot of added groundwater recharge are illustrated in Table 12. below. The cost estimates or obtained by taking the per acre cost of the brush control practice, or cost of a program consisting of an initial plus follow-up practices, and dividing it by 0.167. This results in the estimated cost per acre foot of added groundwater recharge resulting from brush control if the practice, or program, is effective for only one year. Results of this calculation for several alternative levels of brush control costs are shown in the second column of Table 12. Alternatively, the third and fourth columns illustrate the per acre foot costs of added groundwater recharge resulting from brush control if the brush control practice, or program, is effective for a period of five and ten years respectively.

Table 12. Cost/ac.ft. of added water for selected control costs and years of life of brush control practice – Edwards Plateau

Brush control cost/ac	Years brush control effective		
	1yr	5yr	10yr
$ 70.00	$ 419.16	$ 83.83	$ 41.92
$ 150.00	$ 898.20	$ 179.64	$ 89.82
$ 200.00	$1,197.60	$ 239.52	$ 119.76
$ 300.00	$1,796.41	$ 359.78	$ 179.64

South Texas Shrublands

In a previous section, it was stated that several herbicides and several different mechanical practices were appropriate for use in the control of mixed brush in South Texas. The costs of these various chemical practices are less variable and generally less costly than the mechanical practices in the Edwards Plateau as discussed above. In addition, the mechanical practices applicable to the control of mixed brush in South Texas would generally be less costly than when used in the Edwards plateau because the soils tend to be less rocky and the terrain is generally flatter in South Texas. Therefore, costs for mixed brush management in South Texas may vary from less than $50 to more than $100 per acre (Pestman, 2007). Also in a previous section of this report the added groundwater recharge estimated to result from control of mixed brush was reported to be between 10 and 20mm/year. To be conservative, we will use 10mm/year in the following analysis. The inch equivalent of 10mm/yr. is 0.4 in. which is also equal to 0.033 ft. Therefore, control of Ashe juniper on an acre of land is estimated to result in 0.033 added ac.ft. of groundwater recharge per year.

The need for follow-up practices to extend the effective life of initial control practices for mixed brush is as critical as it is for Ashe juniper control in the Edwards Plateau. The results of extending the years of reduced brush canopy, and the resulting increased groundwater recharge, on the cost per acre foot of added groundwater recharge is illustrated in Table 13. below. The cost estimates or obtained by taking the per acre cost of the brush control practice, or cost of a program consisting of an initial plus follow-up practices, and dividing it by 0.033. This results in the estimated cost per acre foot of added groundwater recharge resulting from brush control if the practice, or program, is effective for only one year. Results of this calculation for several alternative levels of brush control costs are shown in the second column in Table 13. Alternatively, the third and fourth columns illustrate the per acre foot costs of added groundwater recharge resulting from brush control if the brush control practice, or program, is effective for a period of five and ten years respectively.

Table 13. Cost/ac.ft. of added water for selected control costs and years of life of brush control practice – Carrizo - Wilcox

Brush control cost/ac	Years brush control effective		
	1yr	5yr	10 yr
$ 35.00	$1,060.61	$ 212.12	$ 106.06
$ 50.00	$1,515.15	$ 303.03	$ 151.52
$ 75.00	$2,272.73	$ 454.55	$ 227.27
$ 100.00	$3,030.30	$ 606.06	$ 303.03

Cost Effectiveness Summary

If brush control programs were implemented for the two regions described above, and if provisions of the programs require participating landowners to reduce brush canopies to 5 percent and maintain them at this level or less for 10 years, then the costs per acre foot of added ground water recharge would be expected to range between $40 and $180 per acre foot in the Edwards Plateau and between $100 and $300 per acre foot in The Carrizo – Wilcox Aquifer recharge area. It should be noted that these estimates of added groundwater recharge cost are based only on the highly variable costs of the brush control practices and/or programs. There are many other factors which would impact the ultimate costs, several of which are discussed in the next section.

Additional Considerations

It should be noted that public benefit in the form of additional water depend 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 program primarily depends on the landowner's expected economic consequences resulting from participation (Bach and Conner , 1998). With this in mind, the analyses described in this report are predicated on the objective of limiting rancher costs associated with participation in the program to no more than the benefits that would be expected to accrue to the landowner as a result of participation. Landowner benefits are usually based on expected increases in net returns from the typical livestock (cattle, sheep, or goats) and wildlife enterprises that would be reasonably expected to result from implementation of the brush control program (Conner and Bach, 2000). Previous studies based on these limits to landowner costs have shown that landowner's share of brush control costs would vary from 37 to 8 percent of total direct costs of brush control programs (Olenick, et al., 2004a) .

It is explicitly assumed that the difference between the total cost of the brush control practices and the value of the practice to the participating landowner would have to be contributed by the state in order to encourage landowner participation. Thus, the state (public) must determine whether the benefits, in the form of additional water for public use, are equal to or greater than the state's share of the costs of the brush control program.

Success of each brush management scenario in improving groundwater recharge depends on the willingness of landowners to participate. One reason why landowners may be reluctant to participate is the perceived impacts to hunting enterprises, especially deer hunting. These impacts could include loss of wildlife habitat due to fragmentation, loss of thermal and/or escape cover, loss of wildlife diversity, and a potential loss of food sources (Rollins, 2000). Another reason that less than 100% of the brush will be enrolled is that many of the tracts containing brush will be so small that it will be infeasible to enroll them in the control program. Similarly, much of the brush infested land, particularly in the Edwards Plateau, will have more than 15% slope, and thus not practical for mechanical brush control practices due to safety considerations (Olenick, et al., 2004a).

Another reason why brush management programs may cause landowners to be reluctant to participate is the importance of brush to property values. The top motives for the purchase of the majority of landholdings throughout the state are recreation followed by the desire for rural homesites (Wilkins et al., 2000). Agriculture production, which generally benefits from decreased levels of brush, is not the driving force behind property purchases that it once was.

One cost not incorporated into the cost effectiveness calculations is the transaction costs associated with implementing any cost-share program. These include costs associated with contract development, monitoring, and any public hearings.

In order for brush control programs to work, the public must be willing to enroll their land in such a program. Landowner surveys conducted by the TAES (Narayanan, et al., 2002; Olenick , et al., 2005) indicate that landowners in the Edwards Plateau would include only 49.15 percent of their moderate cover and 52.73 percent of their heavy cover in a brush management program. An additional consideration is found in research work by Thurow, et. al. that indicated that only about 66% of ranchers surveyed were willing to enroll their land in a similarly characterized program.

Finally, some aspects of the expected changes in ecosystem health and services, including groundwater recharge, provided by brush control practices can be extremely difficult or impossible to economically quantify (Olenick, et al., 2004b). Improvements in ecosystem stability and resilience, changes in non-game animal composition and abundance, and alterations of carbon sequestration capacity, all important concepts from an ecological viewpoint, are not addressed in this analysis.

Future Reports

Two additional reports on Land-based Water Conservation & Water Yield Practices in Region L will be produced if the Sponsor desires to continue this contract. Report II will contain a prioritized set of spatially explicit recommendations based on the information obtained and described in this report. Report II will include recommendations for the most cost effective land-based water conservation practices that could be implemented to enhance ground and/ or surface water availability.

Report III will include recommended monitoring protocols that, if used with the implemented conservation practices to be delineated in Report II, would provide effective measures of the effectiveness of each practice implemented. The recommendations would be consistent with Texas Water Development Board protocols.

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