Recommended Land Management for the Water Quality Protection Lands Austin, Texas

Submitted by the
Lady Bird Johnson Wildflower Center
to the
Wildland Conservation Division
Austin Water Utility
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1 Background and Assumptions

1.1 Overview

In 1998, voters in the City of Austin approved two separate utility bonds: Proposition 2 in May and Proposition 8 in November. These bonds made funds available for purchase of title or easements on lands deemed critical for watershed protection in southwestern Travis and adjacent northern Hays counties, Texas. By October 1999, over twenty tracts had been purchased in either fee simple or conservation easements. All of these properties were placed under the stewardship of the City of Austin Water and Wastewater Utility.

In September 1999, the City hired the Land Management Planning Group (LMPG) to develop a land management plan for these properties, which have been since termed the Water Quality Protection Lands (WQPL). The LMPG was a consortium of both for-profit environmental consulting firms and non-profit organizations assembled to conduct a wide range of natural resource inventories, oversee an involved public stakeholder process, develop a GIS database and recommend site-specific land management. The consortium was led by the Lady Bird Johnson Wildflower Center and also included Loomis Austin, Inc., The Nature Conservancy of Texas and American YouthWorks. Work on this project was also conducted by the U.S.D.A. Natural Resource Conservation Service, Glenrose Engineering, Inc., Paul Price and Associates and Selah, Bamberger Ranch.

In 2008, the City of Austin hired the Lady Bird Johnson Wildflower Center to update the original plan to take into account new properties purchased and new land management research. This document represents the updated land management plan for the WQPL.

As of January 2009 Austin's Water and Wastewater Utility had purchased 9075 acres in full fee, in addition to land purchased in conservation easement (see Figure 1.1-1). No surveys were undertaken by the Land Management Planning Group previously, or the Lady Bird Johnson Wildflower Center in this update on land where only a conservation easement was owned by the city. All properties lie within either the contributing or recharge zone of the Barton Springs segment of the Edwards Aquifer that has as one of its discharge points the Barton Springs swimming pool (see Figure 1.1-2).

Attempts were made to purchase full-fee parcels adjoining one another to create contiguous habitat and preserve greater ecological function for water quality protection. Full-fee properties can be grouped into six watersheds along Bull Creek (61 acres full fee), Barton Creek (1681 acres full fee), Slaughter Creek (682 acres full fee), Bear Creek (2598 acres full fee), Little Bear Creek (1500 acres full fee) Onion Creek (2556 acres full fee). The Barton Creek watershed has non-contiguous properties which will be discussed as "Upper" and "Lower" based on their north/south location in the watershed. Two tracts, J-17 Fortune and 118 Edward's Crossing, are actually in the Slaughter Creek watershed, but will be discussed as residing in the Upper Bear Creek watershed as they are contiguous with those properties.

Most of the properties consist of gently rolling topography bordering or surrounding creeks and riparian zones with several properties including caves or sinkholes. Vegetation ranges between mature oak/juniper woodlands, to young juniper thickets, native grass savannas, and non-native pastures.

Most of the sites have been historically used for the production of either livestock or exotic game, and many show evidence of poor grazing management, such as a lack of robust vegetative cover. This contributed to erosion problems that were evident upon purchase. The slumping, sheet erosion and gully formation that were in evidence on older properties have been largely addressed. These problems currently exist on some newly purchased properties and will need to be addressed to meet the water quality goals of the land. The brief descriptions below pertain to the properties that the City owns in full fee. Full results of plant surveys, plant species lists, and warbler surveys conducted by the LMPG between 2000 and 2002 are included in the appendix of the 2001 Management Plan, and summaries of this information are included in Section 2.0 of this report.

1.1.1 Bull Creek Management Unit

The Stenis tract is the only property in this management unit. This 61-acre tract contains a hiking trail that was opened in November of 2007. The tract includes property on both sides of Bull Creek, with the northeast side of the creek being very steep but a well-vegetated slope. The southwest side of the creek is more gently sloping and includes both mixed woodlands (dominated by live oak (*Quercus virginiana*), Spanish oak (*Q. buckleyi*) and Ashe juniper (*Juniperus ashei*) and meadow openings vegetated with primarily native grass and herbaceous species. The upland mixed woodlands have between 25 and 50% herbaceous cover beneath the canopy, while the woodlands nearer to the creek have between 60 and 80% herbaceous cover. Herbaceous cover is an important contributor to soil stability and water quality. In 2001, some areas were experiencing moderate to severe erosion in the form of slumping and gully erosion. These have been primarily addressed, and significant erosion problems have been arrested. Slumping and gully formation were addressed by improving herbaceous cover in both the upland and riparian areas through selective thinning and limbing up of woody species in the uplands, placing cut brush in windrows and seeding native grasses. Rare plant surveys have documented three species of interest: Texas amorpha (*Amorpha roemeriana*), scarlet leatherflower (*Clematis texensis*) and Buckley tridens (*Tridens buckleyanus*). The site was surveyed for golden-cheeked warblers (*Dendroica chrysoparia,* GCW) in 1993 by Horizon Environmental Services, Inc. but no warblers were encountered, and the site was evaluated to be of limited value due to the “low habitat quality and extent of disturbance and noise on the site.” However, two male warblers have since been detected. Surface geology at the site is both Walnut and Glen Rose limestone.

1.1.2 Upper Barton Creek Management Unit

The Little Barton property is the only full-fee tract in the Upper Barton Creek Management Unit, and is adjacent to the largest conservation easement that the city owns (the Shield-Ayres Ranch). This 930-acre tract is primarily oak/juniper woodlands (dominated by Ashe juniper and live oak) of varying stand ages, with some woodland stands having 100% closed canopy and a few open meadows. Very little herbaceous cover exists beneath the closed canopy. Additionally, bare ground, pedestalled grasses and soil crust exist between juniper stands. All of which will need to be addressed to meet water quality goals. Two plant species of interest, Texas barberry (*Mahonia swaseyi*) and Buckley tridens, were documented through rare plant surveys on this tract. SWCA Inc. conducted golden-cheeked warbler surveys on this property in 1998, and warblers were found in several areas. Golden-cheeked warbler territorial surveys have been undertaken and several territories delineated. The tract is in the contributing zone of the Barton Springs segment of the Edwards Aquifer. Surface geology is entirely Glen Rose limestone.

1.1.3 Lower Barton Creek Management Unit

The full-fee tracts in the Lower Barton Creek Management unit are Morgan A and C, Knoll and Parkhouse, totaling 676-acres. In 2001, these tracts were primarily oak/juniper woodlands and forests (dominated by Ashe juniper and live oak) with varying stand ages, with some woodland stands having 100% closed canopy, particularly the more northern tracts. Native grassland meadows remain in tracts to the south and in patches within the northern tracts. One plant species of interest, Heller's marbleseed (*Onosmodium helleri*), was documented by the rare plant surveys on these tracts. Golden-cheeked warbler surveys were conducted in 2000 as part of the LMPG natural resource inventory. Warblers were found in several areas of the property. Past land use and resulting erosion had significantly reduced and, in some cases, eliminated topsoil from many locations on this site at the time of purchase. Juniper individuals under 10 feet tall and less than 4 inches diameter at breast height (DBH) were cleared from portions of the site as part of the land management strategy. Coarsely crushed slash was left on the ground, and cleared areas were overseeded using the recommended seeding mix from the 2001 report. The herbaceous cover of this site has recovered considerably and as result the soil loss from the site has been significantly reduced.

The tracts are in the contributing zone of the Barton Springs segment of the Edwards Aquifer. Surface geology is Glen Rose limestone.

A disconnected full fee tract called Shudde Fath is also located in the Barton Creek watershed. This 77 acre tract, located in an urban area, consists primarily of mixed canopy woodland. It is heavily invaded by exotic species such as Chinaberry (*Melia azedarach*) and *Ligustrum* spp. This tract is in the recharge zone of the Barton Springs segment of the Edwards Aquifer.

1.1.4 Slaughter Creek Management Unit

The Slaughter Creek Management unit is composed of the Baker, Hafif, and Hielscher tracts, totaling 646-acres. These tracts are primarily open oak savanna with several young juniper savannas and a small portion of immature juniper woodland. In 2001, the riparian corridor was highly degraded, lacking most of the characteristic tallgrass and woody species that would help to stabilize the creek banks during flood events. Attempts to plant tree seedlings have met with some success, and roughly 200 trees have been established. Brush management followed by overseeding in the uplands has resulted in considerable recovery of native grasses. Prior to treatment, there was concern that brush management activities would result in soil loss and runoff. However, this has not been the case. Native grasses, such as little bluestem (*Schizachyrium scoparium*), have quickly appeared even in areas that have not been seeded. No plant species of interest were documented through the rare plant surveys. Golden-cheeked warbler surveys were conducted in the 2000 LMPG natural resource inventory. Only one warbler was seen on site, and the site was deemed to be questionable habitat with very little nesting potential. The site was resurveyed in 2002 and 2003 and no warblers were regularly sited, thus no habitat is believed to exist on this tract. Half of the tract is in the recharge zone and half is in the contributing zone of the Barton Springs segment of the Edwards Aquifer. Surface geology is entirely Glen Rose limestone.

A disconnected tract called Brodie Wild is also in the Slaughter Creek watershed. This is a small tract, totaling 4 acres, that lies in an urban area. Brodie Wild is in the recharge zone of the Barton Springs segment of the Edwards Aquifer.

1.1.5 Bear Creek Management Unit

The Bear Creek Management unit (formerly Upper Bear) is composed of the J-17, Edward’s Crossing, Reavley, Tabor, Andrewartha, AARAL, Bliss Spillar and Lancaster tracts, totaling 1263-acres. These tracts contain a variety of habitats ranging from immature, closed-canopy woodland dominated by juniper, to open savanna composed of live oak, juniper and mesquite (*Prosopis glandulosa*), with limited amounts of cedar elm (*Ulmus crassifolia*), post oak (*Quercus stellata*), shin oak (*Q. sinuata*) and Spanish oak. Grasslands are primarily native, ranging from mid- to short-grasses, probably dependent on past grazing intensity. This management unit has undergone significant brush thinning followed by prescribed summer and winter burns. These treatments have led to substantial recovery of native grasses. However, the brush cover is still high in some areas and emerging species such as mesquite could become a problem in the future. The riparian corridor along Bear Creek is healthy, having a diverse woody overstory and herbaceous layer. Texas fescue (*Festuca versuta*) was the only plant of interest found during the rare plant inventory. While portions of this property appear to be moderate habitat for the golden-cheeked warbler, surveys conducted in 2010 indicate that no territories have been established in this tract. The management unit is in the recharge zone of the Barton Springs segment of the Edwards Aquifer and is riddled with several large caves, numerous sinkholes and small recharge features. Surface geology is entirely Edwards limestone formation.

1.1.6 Little Bear Creek Management Unit

The former management units Lower Bear Creek and Little Bear Creek have been combined into one unit, entitled Little Bear Creek. The northern portion of this unit (formerly Lower Bear) is composed of the Hays County Ranch tract, totaling 1325-acres, and the Wenzel tract, totaling 85-acres. The southern portion of the unit (formerly Little Bear) totals 1500 acres. The Hays County Ranch tract is primarily an oak/juniper savanna with a large component of Texas persimmon (*Diospyros texana*) and Texas mountain-laurel (*Sophora secundiflora*) in the understory, sometimes so thick as to create an impenetrable thicket. Yaupon holly (*Ilex vomitoria*) is emerging and could become a problem in the future. Grasslands are primarily native mid-and tallgrasses. Common species include big bluestem (*Andropogon gerardii*), Indiangrass (*Sorghastrum nutans*) and little bluestem. Given the quality of the grass component on this site, and despite the heavy brush present in some areas, this site has the best potential for excellent tallgrass savanna of all the units. Brush management and prescribed burning have been conducted on the tract. Little bluestem is recovering well in areas that have been burned but is not recovering to the same extent in areas that have not been burned.

No plants of interest were found during the plant inventory. A significant population of feral hogs exists on this property. This tract appears to be very poor habitat for the golden-cheeked warbler. During the 2003 golden-cheeked warbler survey, warblers were detected in the north end of the Hays County Ranch tract; however, the observations were inconsistent which suggests that the birds had not established territories in the area. One warbler was detected regularly in the south section of Hays County Ranch but was believed to have established territory to the east of the property. Two black-capped vireos (*Vireo atricapillus*) were detected near the west boundary of Hays County Ranch in 2003, but follow-up surveys conducted in 2009 and 2010 failed to detect the birds.

The Wenzel tract is dominated by an inactive quarry. The quarry and the area immediately surrounding it have been heavily impacted by mining activities. The soil is severely compacted with a large amount of crushed rock on the surface resulting in sparse vegetation and leaving a significant amount of bare soil. The vegetative community is dominated by early successional species such as Roosevelt weed (*Baccharis neglecta*) and poverty dropseed (*Sporobolus vaginiflorus*). Of particular concern, was the presence of the highly invasive species tamarisk (*Tamarix* spp.). Tamarisk species transpire a significant amount of water, form deep tap roots and quickly form dense thickets. As such, their presence is incompatible with the goals of the WQPL. Successful treatment of this infestation began in 2003. The population was reduced to the point that only a few individuals are now encountered each year and these individuals are treated with methods established in 2003.

Plans exist to divert part of the flow of Bear Creek, when it is high, into the quarry in order to directly recharge the aquifer. Additionally, wetland restoration is underway in a portion of the quarry where water seeps through the quarry wall. Berms of crushed gravel and rock have been arranged to slow the flow of water and crushed gravel mixed with compost has been added and then seeded. Several native species are emerging from the quarry floor due to this effort.

The southern portion of the management unit (formerly Little Bear) totals 1500 acres. The terrain is rough with stair stepping topography. The vegetative community is primarily oak savanna, dominated by large oaks (primarily live oak with scattered post oak) and King Ranch bluestem (*Bothriochloa ischaemum*).. Brush species such as Texas mountain-laurel and Texas persimmon become more common, particularly under oak canopy, toward the northern end of the property. Young juniper are also emerging.

The management unit is in the recharge zone of the Barton Springs segment of the Edwards Aquifer. The unit is suspected to have numerous recharge features. The Wenzel tract's quarry could serve as a significant recharge feature. Surface geology is Edwards limestone formation.

1.1.7 Onion Creek Management Unit

The Onion Creek Management unit is composed of a portion of what has been called the Rutherford Ranch tract, the Lloyd tract and the Orr tract, totaling 2556 acres. These tracts are primarily open grassland with several small oak/juniper woodlands. The grassland is a mixture of native short and mid-grasses. The presence of small juniper has been significantly reduced by management activities. Larger juniper and oaks remain. Scattered small mesquite are also present. Summer prescribed fires conducted on this unit have been able to control larger brush individuals than the cool season burns conducted in the area. Following the summer burns, the native grass recovery is not as immediately apparent as following winter burns. Initially, the grass biomass is lower and the sites tend to become dominated by early successional species such as broomweed (*Amphiachyris dracunculoides*). However, upon closer inspection, several desirable native grass species can be seen emerging beneath the broomweed, and the presence of the formerly dominant invasive species King Ranch bluestem is reduced. Given time, the early successional species will give way to the native grasses. Additionally, the cool season burns have a less significant impact on the site's woody coverage. A plant inventory, undertaken in 2008, documented over 400 species of plants 19 of which are endemic to Texas and 10 that are endemic to the Edwards Plateau. The unit is in the recharge zone of the Barton Springs segment of the Edwards Aquifer and is suspected to have numerous recharge features. Surface geology is Edwards limestone formation.

1.2 Assumptions Guiding the Management Plan

In 1998, two bond elections were passed to create the Water Quality Protection Lands. In May of 1998, Proposition 2 passed under the bond language, “The issuance of $65 million utility revenue supported bonds for the improvement to the city water and wastewater system, to-wit, acquisition of land in fee title and easements in the Barton Springs contributing and recharge zone to provide for the conservation and to maintain the safety of part of the City's water supply." In November, another bond, Proposition 8, was also passed under the caption, “The issuance of $19,800,000 in Utility System Revenue Bonds for making improvements and expansions to the City's waterworks system (improve and develop facilities to preserve and expand the City's water supply including the purchase of land such as the Stenis Tract).” In November of 2006 a bond was passed which allowed additional land purchases for the Water Quality Protection Lands. This bond, Proposition 2, was passed under the bond language, “The issuance of $145,000,000 in tax supported General Obligation Bonds and Notes for designing, constructing, and installing improvements and facilities for flood control, erosion control, water quality, and stormwater drainage, and acquiring land, open spaces, and interests in land and property necessary to do so, including, without limitation, acquisition of land including fee title and easements in the Barton Springs contributing and recharge zones to provide for the conservation of the region’s water quality; and the levy of a tax sufficient to pay for the bonds and notes.”

This language has shaped the guiding philosophy of the City of Austin staff charged with the supervision and management of the Water Quality Protection Lands, who have continually stressed that these lands are to be managed for the protection and enhancement of water quality and quantity. From this philosophy, the following goals were developed by the City of Austin staff, and have been used to guide the land management plan.

1.2.1 Goals

1. Address issues in land management planning and implementation which directly affect water quality and quantity. These include (by priority):

- Vegetation management for water quality improvement and infiltration including trees and brush.
- Balancing land treatment and land use options with protection of water quality and quantity.
- Working to reduce runoff contamination from on-site and off-site activities. Contaminants will include those originating from point sources and non-point sources.
- Create, protect or enhance riparian areas and riparian buffer strips in order to enhance water quality.
- Enhance the capture of precipitation and its recharge into the aquifer.
- Manage wildlife populations and habitat, including white-tailed deer (*Odocoileus virginianus*) and endangered species, for the benefit of habitat and watershed function.

- Work with the city, stakeholders, and other partners to acquire adequate budget for successful project implementation.

2. Address issues which relate to ecosystem restoration for the purpose of protecting and/or enhancing the ecosystem services beyond water quality and water quantity. Ecosystem services are goods and services of direct or indirect benefit to humans that are produced by ecosystem processes involving the interaction of living elements, such as vegetation and soil organisms, and non-living elements, such as bedrock, water and air. Potential ecosystem services include, but are not limited to:

- Soil formation
- Improved air quality
- Hazard mitigation—reducing vulnerability to damage from flooding, storm surge, wildfire and drought
- Waste decomposition and treatments
- Wildlife habitat
- Global climate regulation
- Local climate regulation
- Pollination

(adapted from (Sustainable Sites Initiative 2009))

3. Address issues which do not directly affect water quality but are critical to project success. These include (by priority):

- Manage an appropriate public participation process. This will give stakeholders ownership of the project to help fund actions and build public support, address public access issues, and help build relationships between stakeholders and the City of Austin.
- Address infrastructure needs to provide for security, staff access and public access.
- Provide for public education and information about the land, its management, and activities occurring there.
- Monitor results of land treatment, land management, and public activities on the land.

4. Address issues which are not critical to water quality or quantity, and are not critical to the success of the project, but will enhance the overall quality of the project. These include (by priority):

- Seek funding to support future acquisition of land.
- Support natural resources-related education and information activities.
- Maintain the rural character of these lands and preserve cultural and historic resources associated with them.
- Assist with research to develop or improve watershed best management practices for central Texas.

1.3 Managing Land for Water Quality and Quantity

The Water Quality Protection Lands consist of lands deemed critical for watershed protection in southwestern Travis and adjacent northern Hays counties, Texas. One of the primary results of preserving this land will be the permanent removal of these properties from consideration for development and consequent urbanization. A quantitative difference in water quality and water quantity between properties with and without development has been widely recognized (Schueler 1995, Chan 1997, Barrett et al. 1998, Chan and Limited 1999).

The following impacts have been associated with increased levels of impervious cover and land development, all of which compromise water quality and water quantity for drinking water and potable use:

(a) Water Quality Degradation;
(b) Increased Storm Runoff Volumes and Flooding;
(c) Erosion and Stream Channel Enlargement;
(d) Baseflow Reduction.

Many of these impacts can be reduced or minimized through a combination of engineered structural controls and careful site design. However, the most direct and permanent means of accomplishing water quality and quantity protection for creeks and aquifers is to maintain the watersheds contributing to these streams and aquifers in (1) an undeveloped state and (2) a properly managed condition. The first step has been accomplished for the Water Quality Protection Lands: they have been permanently protected from urbanization. This act alone will accomplish much toward achieving water quality and quantity goals by preserving pervious cover and ensuring the basic hydrologic regimen is maintained.

The second step in protecting water quality and quantity is that of ensuring proper land management. Properly functioning ecosystems can provide a suite of ecosystem services, one of which is optimized water quantity and quality. Intact ecosystems exert control over limiting resources (soil, water, nutrients, organic materials) and primary ecosystem processes (hydrology, nutrient cycling and energy capture) (Whisenant 1999). Ecosystem function can be damaged through direct alteration of ecosystem structure (e.g. adding roads or removing native species), or by the alteration of the natural disturbance regime (e.g. fire suppression in a fire adapted system). The goal of land management is to restore ecosystem function so that the system can better provide ecosystem services.

Wildlands are by nature less extensively modified than urbanized or suburbanized areas. Relative to their urban counterparts, they have few roads, buildings, artificial drainage systems or other impervious surfaces that so dramatically affect the hydrologic cycle of cities and suburbs. However, because the type and pattern of woody vegetation also affects the quality and quantity of groundwater recharge and streamflow in water limited environments (Wilcox 2002, Huxman et al. 2005, Scanlon et al. 2005, Newman et al. 2006, Bautista et al. 2007), even ranching activities have altered the natural hydrologic system. Beginning in the late 1800s, livestock overgrazing and the suppression of wildfires transformed the landscape of the Edwards Plateau, and much of the soil profile was eroded and lost. As a consequence, the balance between types of vegetation—specifically between grasses, forbs, and woody vegetation—was altered (Van Auken 2000). Woody species, such as Ashe juniper and honey mesquite, became a much more dominant component of the landscape. Prior to settlement, much of the Water Quality Protection Lands was open savanna with the woody component making up less than 30 percent of the landscape and mainly concentrated on steep slopes and riparian areas (USDA-NRCS 2008). With these changes came significant changes to the groundwater regime (Thurow and Hester 1997, Seyfried et al. 2005, Wilcox et al. 2005a, Newman et al. 2006, Wilcox and Thurow 2006). These negative changes are not irreversible, however, and much research and experimentation has been done to find the best ways of restoring ecosystem function. Properly functioning ecosystems will be better able to provide the ecosystem services, such as improved water quality and quantity, that are the goals of WQPL management. Proper land management practices can help establish and maintain vegetation composition and structure that will enhance hydrologic function.

As part of the Land Management Planning Group's original assessment of the Water Quality Protection Lands in 2001, a literature review was undertaken to assess the best land management techniques to enhance water quality and quantity from rangeland sites. Additionally, data from that review was used to model the relationship between woody canopy and groundwater infiltration. This literature review has been updated for the 2008 plan, and these results are summarized here. The annotated bibliography created during literature review update can be found in Appendix 8.2.

The relevant literature indicates an inverse (Hollon 2000), possibly non-linear relationship between woody species cover and deep groundwater infiltration, particularly when precipitation is out of phase with primary evapotranspiration and the physical surface allows for rapid infiltration (Wilcox and Thurow 2006). Research suggests that the removal of woody vegetation (trees and shrubs) and the subsequent establishment of herbaceous vegetation (grass and forbs) in its place can increase the "water yield" from rangelands (Hibbert 1983, Gee et al. 1994, Thurow and Hester 1997, Dugas et al. 1998, Bednarz et al. 2000, Wu et al. 2001, Brown and Raines 2002, Bednarz et al. 2003, Olenick et al. 2004b, Afinowicz et al. 2005, Huxman et al. 2005, Seyfried et al. 2005, Wilcox et al. 2005a, UCRA 2006, Wilcox et al. 2006b, Wilcox and Thurow 2006). Studies indicate that woody species not only uptake more water via their extensive and deep root systems, but they also intercept a large portion of annual rainfall in their canopies, a significant portion of which is lost to evaporation (Thurow et al. 1987, Thurow and Hester 1997, Hicks and Dugas 1998, Schuster 2001, Owens and Lyons 2002, Owens et al. 2006). Therefore, when juniper, oak and other woody species are removed and are replaced with herbaceous cover, more deep drainage can occur. In the contributing and recharge zones of the Edwards Aquifer, this will directly feed the subsurface aquifer and/or eventually re-emerge as springflow or baseflow in creeks. Studies indicate that the greatest amount of aquifer recharge is obtained by keeping woody plant canopy coverage below 15% (Hollon 2000, Wu et al. 2001). A recent literature review (McCaw 2009, Appendix 8.3), indicates that the relationship between woody cover and water yield is likely exponential, with the most significant gains appearing as woody cover falls below 15%. Any gains made from brush control must be followed up in succeeding years with additional maintenance activities to avoid a reversal of initial yield gains due to subsequent woody regrowth. Although not directly related to water yield, strategies of removing trees and shrubs must also consider the effects of removing juniper, oaks and other plants on total habitat quality. All of these native plants serve as a source of food and habitat for wildlife and management activities must be conducted in a way that ensures the net ecosystem effects are positive. However, loss of prairie and savanna habitat to brush encroachment represents a significant loss of remaining habitat to species that rely on these systems. Prairie/savanna bird species such as dick cissels, quail and painted buntings as well as numerous other plant, insect and mammal species are positively impacted by this work. These species are less likely to become threatened and/or endangered because of this work. Also, the studies reviewed focused principally upon woody cover. Other key factors affecting water yield and water quality that were not reviewed include protection and restoration of soils and the proper management of livestock and fire.

Some controversy exists over the use of brush management to increase water yield. It has been argued that many of the studies used to justify the practice have been at the tree or catchment level and that water yield is a landscape scale process (Wilcox et al. 2005b, Wilcox et al. 2006b, Wilcox and Thurow 2006). However landscape scale field experiments are difficult and expensive to perform. Therefore modelling studies are often used to simulate landscape scale field studies. Several modelling studies support brush management for increased water yield (Bednarz et al. 2000, Wu et al. 2001, Bednarz et al. 2003, Olenick et al. 2004a, Olenick et al. 2004b, Afinowicz et al. 2005, Huxman et al. 2005, UCRA 2006, Wilcox et al. 2006b) Modelling studies tend to estimate higher water yields than field studies, so the data gleaned from them should be used with caution.

Reviews of the ecohydrology of water limited environments have provided the insights that follow in the paragraphs below (Wilcox 2002, Wilcox et al. 2005a, Newman et al. 2006, Wilcox et al. 2006a, Wilcox and Thurow 2006).

The impact of brush management on water yield increases as rainfall increases (Wilcox and Thurow 2006), with the greatest gains appearing when an area receives at least 18 inches per year (Hibbert 1983). The Water Quality Protection Lands fit this requirement as the average rain for the Austin area is around 35 inches per year. In fact, even during the 2008 drought, which has been the fourth worst drought in the last 100 years, this area still received over 18 inches of rain.

In water limited environments, brush management has the best chance of success in areas in which: 1) physical characteristics exist that facilitate rapid subsurface movement of water from the site. This usually requires shallow soil with properties that hasten infiltration and percolation and that overlie either a fractured geologic substrate or an impervious layer (Wilcox and Thurow 2006). 2) significant precipitation is out of phase with evapotranspiration. The majority of the Water Quality Protection Lands have shallow soils overlying karst geology which provides for rapid subsurface transmission.

Annual precipitation does not always follow a pattern where the bulk of the rainfall occurs in winter months. The region has a bimodal precipitation pattern, with peaks in the spring and fall.

Based on these criteria, the Water Quality Protection Lands are at least good candidates for brush management for the purpose of increasing water yield.

Some sites within the Water Quality Protection Lands are currently below 15% canopy cover, while others greatly exceed it. Effort should be made to reduce the canopy cover over much of the WQPL below 15%, unless otherwise stated (such as along riparian corridors).

In conclusion, overall recommendations to guide the management of the Water Quality Protection Lands are as follows:

1. Do not allow development or urbanization of the lands.
2. Ensure full mitigation of the effects of any improvements (e.g., roads, trails, etc.).
3. Manage the lands to best protect and improve water quality and quantity through restoration of prairie, savanna and riparian vegetative communities.

For item number 3 above, recommendations to guide the selection of sites within the Water Quality Protection Lands for brush removal as part of prairie and savanna restoration to enhance water yield are as follows:

1. Prioritize sites where a high percentage of existing woody cover is second-growth,
2. there is relatively flat terrain (less than 10% slope),
3. there is no occupied golden-cheeked warbler habitat and
4. setbacks from surface water are provided for mechanical or chemical treatments.
5. In upland areas, prioritize shallower soils.
6. Avoid soil disturbance near sensitive sites, such as riparian corridors and internal drainage basins associated with karst features.
7. Evaluate experimental treatments on a small-scale to ensure desired results before widespread implementation.
8. Minimize any significant soil disturbance by mechanical equipment. Ensure that limited soil disturbance needed for seed application or to break up soil crusts is protected from erosion by slash or light mulch cover.
9. Remove enough brush to be effective (reduce woody cover below 15% of total area).
10. Ensure long-term maintenance of grassland vigor and brush reduction.
11. Monitor the results.

The Water Quality Protection Lands offer an excellent opportunity to provide increased sources of clean water to the Barton Springs segment of the Edwards Aquifer. The prevention of urbanization on these tracts and a long-term commitment to their proper management will help assure that clean water flows from them permanently.

1.4 Species of Concern

Literature reviews of both published and unpublished material as well as actual property surveys were utilized to identify tracts containing plant or animal species that could affect land management (termed "species of concern"). These species could be 1) desirable native species that are either federally listed as threatened or endangered, 2) desirable native species known to be regionally uncommon, or 3) native or non-native undesirable species, known to cause ecological problems in land management.

1.4.1 Faunal Species of Concern

1.4.1.1 Karst Invertebrates

The many caves and other karst features that riddle the limestone geology of central Texas support a unique array of subterranean fauna. Travis County caves contain six endangered karst insects and arachnids: Tooth Cave pseudoscorpion (*Tartarocreagris texana)*, Tooth Cave spider (*Neoleptoneta myopica*), Tooth Cave ground beetle (*Rhadine persephone*), Kretschmarr Cave mold beetle (*Texamaurops reddelli*), Bone Cave harvestman (*Texella reyesi*), and Bee Creek Cave harvestman (*Texella redelli*). Additionally, there are 25 karst species of concern in Travis County (Veni 2000). Almost all the invertebrates are found in Edwards Limestone Group (Campbell 1995, Farmer 1999a).

These endangered species are troglobites, species that never leave the karst environment. Although all nutrients of the cave ecosystem flow in from the surface, the distribution of the invertebrates can descend far into the karst feature. They feed on other insects or organic matter washed into the caves in rain events or carried in by fauna such as cave crickets. These species require the high humidity and constant temperatures found in the cave environment (Campbell 1995).

The only karst feature to be fully surveyed on Water Quality Protection Lands has been Flint Ridge Cave, though survey work on other features is underway. Flint Ridge Cave is listed in the Balcones Canyonlands Conservation Plan (BCCP) regional 10(a) permit as one of the 62 caves that will be protected by the City of Austin and Travis County (USFWS 1996). This feature is in the Bear Creek Management Unit. Surveys of that cave have determined that it is habitat for both the spider (*Cicurina cueva*) and the ground beetle (*Rhadine austinica*), two of the 25 karst invertebrates of concern listed in the BCCP permit (Elliot 1997, Veni 2000). There are a number of unsurveyed caves and other karst features, particularly on the Little Bear and Bear Creek units which likely contain endangered toglobites. The eastern half of the Stenis tract (Bull Creek management unit) lies on Edwards Limestone, but no significant karst features have been found on that site (Sherrod 1993b). Many of the other tracts yet to be surveyed are within Edwards Limestone and it is possible that these could also contain karst features containing karst species of concern (Veni 2000, Russell and Jenkins 2001a).

Anything that changes the humidity, structure or nutrient flow into caves is a threat to these arthropods (Culver 1982). Filling or covering of caves with impervious cover has destroyed 20% of the known caves in Travis County (Farmer 1999a). Land management activities in a cave's drainage area that alter the surface flow into karst features or the nutrient level (by removal of native vegetation or adding synthetic fertilizers) can be equally damaging and should therefore be avoided (Veni 2000).

The red imported fire ant (*Solenopsis invicta*) is also a serious threat. It forages into caves, eating the invertebrates directly and eating the eggs and nymphs of cave crickets. Cave crickets forage outside of caves at night and bring nutrients and organic matter into karst features. Disruption of their lifecycle by fire ants can impact entire cave systems (Campbell 1995).

1.4.1.2 Fisheries

No endangered fish are known or suspected to occur in any of the waters occurring on the Water Quality Protection Lands, but surveys have not been undertaken. Many of the water bodies and even the creeks are ephemeral and do not support populations of fish. Those that are permanent are relatively small and support only the most tenuous populations of fishable species. The fishing of these populations is most likely not sustainable, and a full population and species analysis should be undertaken before any significant fishing is allowed.

1.4.1.3 Salamanders

The Barton Springs Salamander (*Eurycea sosorum*) is found in Barton Springs Pool and the three springs that feed it: Eliza Springs, Sunken Garden Springs and Upper Barton Springs. It grows to a length of 2.5 inches long and lives its entire lifecycle underwater. Its skin is highly permeable and it retains gills throughout its life.

The permeable skin of the salamander makes it very susceptible to changes in water quality. Water flows very quickly through the Barton Springs section of the Edwards Aquifer, sometimes traveling several miles per day. It is not heavily filtered when it travels through the limestone. Development within the Barton Springs section of the Edwards Aquifer recharge and contributing zone must be undertaken in such a way that water quality is not negatively impacted. Toxins reaching the springs feeding the pool could destroy much of the salamander population. Maintaining a healthy vegetative cover over the Barton Springs recharge zone and Barton Creek Watershed will help keep the water clean (City of Austin 2000).

All of the Water Quality Protection Lands are within either the contributing or recharge zones for the Barton Springs segment of the Edwards Aquifer, and therefore have the potential to impact the species.

The Texas Blind Salamander (*Eurycea rathbuni*) is known to occur in the subterranean waters of the Edwards Aquifer near San Marcos, Texas (Campbell 1995), and could also occur in the subterranean waters fed by the karst features on the Water Quality Protection Lands, though no inventory of the subterranean waters in the area have been undertaken. As in managing for the Barton Springs Salamander, ensuring that the water entering the aquifer remains clean and free of toxins is the best way to ensure that this species is not impacted, should it occur in the area.

1.4.1.4 Endangered Birds

The golden-cheeked warbler (*Dendroica chrysoparia*) is a 4.5- to 5-inch long songbird that nests in central Texas. It is found along the southern and eastern edge of the Edward's Plateau and into the Lampasas Cut Plains. It has a yellow cheek with a black stripe through its eye (Campbell 1995, Ladd and Gass 1999, Campbell 2003).

The warbler has an insectivorous diet and nests in April after it returns from its winter range in southern Mexico, Honduras, Nicaragua and Guatemala. Clutch size is usually three to four eggs. Nesting territories are between three to six acres, but foraging areas are between five to twenty acres per pair (Campbell 1995).

Golden-cheeked warblers live in mixed juniper and hardwood woodlands and forests. They require a canopy coverage of 35% or greater. Some of the juniper must be mature, for the warblers use the bark as nest material. Warblers are unlikely to be found in stands of small Ashe juniper averaging less than 15 feet tall and 5 inch diameter at breast height (DBH), monocultures of mature Ashe juniper, open park-like woodlands or savannas or in areas where small junipers are coming up under larger hardwoods where junipers have been removed in the last 20 years (Campbell 2003). Although they will nest in suitable habitat in both uplands and bottomlands, they most commonly occupy sloped hills and canyons (Campbell 1995).

Golden-cheeked warbler numbers have declined due to habitat destruction and nest parasitism. The clearing of old-growth juniper stands for development or livestock has reduced warbler habitat. Once an area is completely cleared, it might take up to 40 years for a woodland to reach the maturity needed by the warbler (Campbell 1995, Ladd and Gass 1999, Ladd 2001).

The loss of deciduous hardwoods can harm golden-cheeked warbler habitat. Over-browsing by deer and goats (*Capra aegagrus hircus*) may prevent the regeneration of hardwoods. The increase of juniper stands, aided by fire suppression and overgrazing, does not benefit the warbler as these new stands do not have the hardwood diversity they require (Campbell 1995; Farmer 1999). The spread of oak wilt constitutes another habitat threat (Farmer 1999b).

The brown-headed cowbird (*Molothrus ater*) lays its eggs in warbler nests in an attempt to have the warbler raise its young. The rates of parasitism are not currently known, but are higher near the urban areas, agricultural fields, and livestock pastures preferred by the cowbird (Campbell 1995).

The Water Quality Protection Lands which have potential habitat have been surveyed for golden-cheeked warbler presence, with the most recent surveys completed in 2010. Results are discussed in Section 2.4.

The black-capped vireo (*Vireo atricapillus*) is a small, 4.5-inch songbird that nests in central and west Texas. A white eye-ring contrasts with the black crown and upper head from which its name derives (Grzybowski 1999).

The vireo arrives in Texas in March or early April from its wintering grounds along the western coast of Mexico and typically resides in the area until October (Grzybowski 1999). The black-capped vireo nests from the eastern edge of the Edwards Plateau to the Chisos Mountains in the west. The southern edge of the Edwards Plateau demarks the southern boundary of its range.a

The vireo is mostly insectivorous. A female may lay two or more clutches in the spring, each consisting of two to four eggs (Grzybowski 1999). Vireos can live for more than five years and often return to the same territories each year. Territory size varies with habitat quality, but can range from one to sixteen acres. The most common territory size is from two to four acres (Campbell 1995).

Vireo habitat varies widely in regard to plant species composition, temperature, and rainfall. It does require a specific vegetation structure for its habitat. Dense shrubby stands ranging from the ground to up to six feet in height separated by open grasslands make up the preferred habitat. The shrub stands may cover 35% or more of the area (Farmer 1999c). It can tolerate scattered to moderate tree coverage, but abandons areas with a large amount of trees. Preferred trees and shrubs are typically broadleaf and shrubby, although juniper (*Juniperus ashei)* is often present in occupied habitat at low densities (Campbell 1995).

Black-capped vireo numbers have declined because of habitat destruction, habitat alteration, changes in ecosystem processes (e.g. fire) and parasitism. The suppression of the shrub layer to create better cattle rangeland prevents the creation of vireo habitat. Over-browsing by deer, goats and exotic animals reduces the lower shrub layer, destroying vireo habitat (Campbell 1995). Fire suppression leads to the elimination of vireo habitat, allowing the system to move from shrubland and open grassland to closed-canopy woodland. In the past, both natural and human-made fires would have favored shrubby, resprouting species and kept them at heights favored by the vireo. Also, the fire-intolerant Ashe juniper increases relative to the broad-leaf shrubs preferred by the vireo when fire is suppressed. Vireos prefer land that is in an early successional stage, and land must be actively managed to insure disturbances such as fire (Farmer 1999c). The brown-headed cowbird lays its eggs in vireo nests, attempting to have the vireo raise its young. The vireo abandons parasitized nests and tries to renest when this happens. Cowbirds infect 10% to 90% of vireo nests depending on the abundance of cowbirds. Cowbirds are more common near agricultural fields, grazed rangelands, and urban areas, and use telephone and electrical wires as places to watch for prey (Campbell 1995).

Vireos have been sporadically sighted near the western boundary of the Hays County Ranch tract and have been found in areas with suitable habitat in close proximity to WQPL tracts such as the Barton Creek Habitat Preserve and Balcones Canyonlands National Wildlife Refuge (Farmer 1999c).

Land management involving the clearing or thinning of juniper woodlands and/or the introduction of prescribed fire may create areas of suitable habitat for the vireo. Should habitat become occupied, land management activities during the breeding season will need to be curtailed (Campbell 2003).

1.1.4.5 Mammal Species of Concern

White-tailed deer (*Odocoileus virginianus*) are common on the Water Quality Protection Lands and, while native, have the potential to overpopulate an area due to a lack of large predators or significant hunting pressure. This causes a decline in the health of the vegetation due to over-browsing of hardwood species. White-tailed deer are both grazers and browsers and have a large dietary range, though over 90 percent of their diet comes from browsing. Forbs can form a significant portion of their diet in the spring (Davis and Schmidly 1994).

City staff have conducted deer surveys on the Water Quality Protection Lands. Specific population management recommendations will be discussed in Section 3.4.1 and addressed on a watershed-by-watershed basis in Section 5.0. As with other animals, overpopulation will lead to overgrazing and overbrowsing, resulting in reduced vegetative cover, degraded water quality and reduced infiltration. Additionally, reduction of vegetative cover can lead to significant erosion. For this reason, populations should be monitored and evaluated to ensure that deer numbers remain below the level at which hydrologic function is impaired. Should the population approach or exceed this level, the deer will need to have some form of population control initiated (e.g. hunting).

Blackbuck (*Antilope cervicapra*) were once common in the Onion Creek unit, but control efforts have significantly reduced their population size. These animals are native to India and Pakistan, but were released into the area for hunting purposes. Unlike white-tailed deer, blackbuck are primarily grazers of short- to mid-grasses, though they will also browse to some extent (Davis and Schmidly 1994). Like white-tailed deer, the blackbuck population has only limited natural controls other than disease and starvation since large predators are no longer common. Blackbuck pose a greater threat to water quality than do white-tailed deer since, as primarily grazers, they have the potential to significantly reduce the grass cover. Populations should be monitored and evaluated to ensure that vegetation damage is minimized. As this species is not native and can have potentially adverse effects on water quality and quantity, complete elimination of this species from Water Quality Protection Lands would be consistent with other exotic species management. Specific population management recommendations will be discussed in Section 3.4.1 and Section 5.0.

Feral pigs (*Sus scrofa*) are present on some of the properties. These animals are descended from wild European hogs (introduced for hunting) and escaped domestic swine. Pigs are generalist omnivores, feeding primarily on vertebrates, invertebrates, the eggs of ground-nesting birds, forbs, roots and mast, particularly in woodland areas. Pigs can have a significant adverse effect on riparian ecosystems and on other wildlife. Extensive soil and vegetation disturbance occurs as a result of their rooting activities. The disturbed area is prone to erosion, and may cause a shift in plant succession on the site (Davis and Schmidly 1994). Unlike other problem mammals, a single pig can do considerable riparian damage and thereby significantly deteriorate water quality. On sites where their presence is evident, hunting or trapping should be used to eliminate this species from the site.

Feral cats (*Felis catus*) and dogs (*Canis lupus familiaris*) may also be a problem on the sites. Predation by feral, stray and free-ranging domestic cats is a significant cause of wildlife mortality, particularly rodents, reptiles and birds (Schaefer 1999). Diseases of domestic cats may also pose serious threats to native species. The damaging effects of cats on wildlife are particularly severe on oceanic islands, in "islands" of wildlife habitat in urbanized areas, and in other wild lands and open spaces near urban areas (Jurek 1994). Because feral cats are rarely territorial, their populations can result in high predation rates for their chosen game (Coleman et al. 1997). Predation by domestic cats has caused, or significantly contributed to, the extinction of many animal species around the world (Jurek 1994).

Free-roaming or feral dogs may be less of a problem on the Water Quality Protection Lands, from an ecosystem function standpoint, as these may serve as large predators. Though they are also known to kill rodents, reptiles, and birds, they typically do not have as significant an effect on native wildlife (Schaefer 1999). However, free-roaming dogs are known to cause problems for livestock, particularly sheep and goats and, unlike coyotes, for humans.

The City of Austin has a feral cat-trapping program and the Water Quality Protection Lands staff should participate in this program whenever cats are seen on the property, though trapped feral cats should not be released back onto the properties. If adverse effects are seen as the result of free-roaming dogs, these too should be trapped or other methods used to control their population.

1.4.2 Floral Species of Concern

1.4.2.1 Desired Rare Plant Species

The full-fee properties were surveyed for the 2001 Management Plan to locate populations of any of a suite of eight primary and sixteen secondary target taxa of conservation interest (see Table 2.3-1). This set of targets includes all plant species included in the Balcones Canyonlands Plan, all species of interest to the Wildlife Diversity Program (formerly the Texas Natural Heritage Program) of the Texas Parks and Wildlife Department, and a number of other species not normally mentioned in discussions of rare plants of the Austin area. None of these species has any status with the U. S. Fish and Wildlife Service; i.e., none is ranked Endangered, Threatened, or Category 1. Out of these, four primary targets—Buckley tridens, Texas barberry, Heller's marbleseed, and Texas amorpha—and two secondary targets—scarlet leatherflower and Texas fescue—were encountered. These populations should be preserved. Newly purchased properties should be surveyed. The full report of findings of this rare plant inventory is included in the Appendix of the 2001 Management Plan.

1.4.2.2 Invasive Plant Species

There are nine common invasive plant taxa in the general area of the Water Quality Protection Lands: Johnsongrass (*Sorghum halepense*), King Ranch bluestem, bermudagrass

(*Cynodon dactylon*), thistles (*Carduus* spp.), pricklypear cactus (*Opuntia* spp.), mesquite, Ashe juniper, Chinaberry, Chinese tallow tree (*Triadica sebifera*), Tree of Heaven (*Ailanthus altissima*), tamarisk and privet (*Ligustrum* spp.). Of these, three are native (pricklypear, juniper and mesquite) and the rest are exotic. Two of these invasive species, King Ranch bluestem and bermudagrass, were planted in the past as pasture grasses. Most of the rest have spread accidentally due to past land management and all are present on the Water Quality Protection Lands in some quantity.

These species only present a threat to water quality and quantity when they dominate a system to such an extent that they reduce overall herbaceous coverage and thereby increase erosion or shade out desirable grasses. For this reason, many of these species will not need to be intensively managed, but efforts should be taken to limit the further spread of these species. Invasive species control can also be performed under management goal 2, ecosystem restoration. Invasive species can reduce biodiversity (Gabbard and Fowler 2007) which can interfere with ecosystem function and resilience to disturbances such as disease, fire or drought (Levine and D'Antonio 1999, Loreau 2000, Smith et al. 2004, Tilman et al. 2006). The most common approach to management of all of these species except Ashe juniper, which can be managed through mechanical cutting and prescribed fire, is through the use of chemical herbicides. These are costly, but typically effective. Care must be taken to select herbicides that are appropriate for use within the aquifer recharge areas and conform to City policy. The best management plan for the WQPL will be an integrated approach that will use a combination of all the tools at their disposal including prescribed fire, cutting, mowing, grazing and herbicide use as last resort (Hanselka et al. 1999). An integrated pest management (IPM) plan is currently in place for the WQPL and should be adhered to when problem species are encountered.

1.5 Public Access

Throughout the development of the original land management plan for the Water Quality Protection Lands, as well as this update to the plan, there has been the expectation, both within the City staff as well as the general public, that there would be some level of public access on the Water Quality Protection Lands. The initial management plan identified some areas where trail access was appropriate—for various user groups depending on location and tract sensitivity—should funds for construction and maintenance of these trails be raised outside of the City of Austin Water Utility. To date, two of the trails which were identified as potential trails in the 2001 plan have been constructed and are now open to the public (on Bull Creek and Slaughter Creek Management Units). This section addresses the general principles that have guided initial discussions of public access, a description of the public participation process used initially in 2001 whereby stakeholders were involved in the decision making surrounding public access on WQPL, a description of the anticipated impacts that could occur as a result of the proposed public access activities, and a discussion of some of the mitigation measures that could be employed to decrease or eliminate adverse impacts. Additional discussions for trails in other sections of the Water Quality Protection Lands are currently underway. There is general consensus that this more recent trail planning effort will also follow the general principles laid out here.

1.5.1 Guiding Principles for Public Access

In keeping with the bond language and conservation easement agreements as well as the goals developed by City staff as outlined in Section 1.3, the following guiding principles have been used in considering public access:

- No public access is granted or precluded as a part of any conservation easements and is entirely at the discretion of the landowner.
- Some level of public access will occur on Water Quality Protection Lands.
- Any access occurring on lands held in full fee should have their negative impacts fully mitigated, with the goal of having no net loss to water quality and quantity, and hopefully, a net gain to water quality and quantity.
- The WQPL are not part of a parks system and should not function as such. They must primarily serve to enhance the City of Austin's water supply in perpetuity. All access occurring on the WQPL must support this mission.
- The WQPL are owned and maintained by the City of Austin Water and Wastewater Utility, which receives its funding from its customers. Providing funding for more than limited education-related access is beyond its mandate. Therefore, more intense public access must find methodologies for the development, maintenance and mitigation of any activity from outside of the Water and Wastewater Utility.
- Only limited utility staff time is available to be used towards development, maintenance and mitigation activities as part of public access on WQPL.

For these reasons, the Land Management Planning Group has lead a multi-layered process designed to assess the types of desired public access activities and to develop a public stakeholder base of support to help select, implement, and manage public access on Water Quality Protection Lands. The next section describes this process.

1.5.2 Public Stakeholder Process

In the initial proposal to the City, the Land Management Planning Group had identified 46 groups that should be contacted concerning public access on the Water Quality Protection Lands. By December 1999, the LMPG had increased that list to over 100 and had begun to send out a survey to assess their desires for public access on WQPL. Additionally, the survey form was available upon request from the Lady Bird Johnson Wildflower Center and on the City of Austin Water and Wastewater Utility's web site. (This address was featured in two newspaper articles.) A full list of those contacted and the summary report of the stakeholder survey are included in Appendix 7.3.

The LMPG received 55 survey responses from 42 different stakeholder organizations and 13 individuals without associations. The leading interests and concerns expressed by those returning the surveys were:

- Preservation of habitat
- Public access and use
- Recreational trails (hiking and cycling)
- Horseback riding
- Public education

The leading proposed uses were:

- Recreational trails (hiking and cycling)
- Other passive uses
- Horseback riding

The leading "hopes, wishes or vision" were:

- Preservation of the land and its natural resources
  --balanced with--
- Passive uses such as trails, horseback riding and education

Respondents were willing to make significant contributions of volunteer time and in some cases more, to the ongoing management and operation of the Water Quality Protection Lands. Approximately 70% of those responding said they would contribute something. Over 90% of those responding were interested in participating in a public involvement process to determine the best use of the city-owned Water Quality Protection Lands.

Following this survey, the LMPG invited all interested parties to participate in a facilitated Stakeholder Steering Committee to help determine what public access would be allowed, where it would be allowed, and how the access would be funded and maintained. The Committee's recommendations then went to the Water and Wastewater Commission for approval and then to City Council for final approval.

The facilitated stakeholder meetings began in late September 2000 and frequent meetings continued over an 18 month period. The Stakeholder Steering Committee continues to meet once a year, or more often if necessary. Initial recommendations from this group were developed in late April 2001, and it is the intention of City staff that the involvement of these stakeholders would continue into the future. The group has emphasized that educational activities should occur on all of the properties and that several multi-use trails should be constructed and maintained on tracts where trails are expected to have the least adverse impact and have the greatest potential for mitigation. (See Section 1.5.3 for a discussion of impacts and possible mitigation measures). Should these initial public access projects successfully go forward without adverse impact to water quality and quantity, the City will begin to initiate activities on locations that the stakeholders (with the help of the City and LMPG) have determined to be more sensitive and pose a greater potential threat to water quality and quantity. It is quite likely that some of the tracts will never have open public access due to their sensitive nature, but even on those sites, the Stakeholder Steering Committee would like to see them have occasional use for education purposes. The stakeholder-developed conceptual plan for public use on the Water Quality Protection Lands is contained in Appendix 7.4 of the 2001 Management Plan.

1.5.3 Anticipated Impacts from Suggested Uses

1.5.3.1 General

Recreational use, such as hiking, biking, horseback riding, camping, picnicking, and hunting, can impact physical, biological, and cultural resources of natural areas (Cole 1990, Sun and Walsh 1998). Primary impacts include:

1. Soils altered physically, and hence biologically, from compaction or erosion.
2. Vegetation abundance and composition (damaged, lost or additions).
3. Animal behavior: altered due to habitat change or human presence (attraction or repulsion).
4. Aesthetic environment ("wilderness" perception diminished). (This is not dealt with in this section. See (Roggenbuck et al. 1993)).

   (adapted from Cole (1993); Sun and Walsh (1998))
5. Interference with, or prevention of, land management activities that are necessary to preserve and enhance the water quality and quantity values derived from these lands.

Secondary impacts include gully erosion, sedimentation of streams, habitat fragmentation and invasive plant species introduction. A varying amount of research has been conducted within each of these categories, which will aid design and management of recreational facilities within natural areas.

Additionally, these activities could require the provision of road and parking facilities. Such infrastructure involves the use of some level of impervious cover. This type of impact can be avoided by connecting to existing trials or parking facilities or be mitigated by using the design and mitigation techniques already in the City of Austin construction guidelines for areas within the recharge zone.

1.5.3.2 Soils

A healthy soil structure is critically important to sustain high water quality and quantity. Soils interact with vegetation to receive, store, infiltrate and purify rainfall and rainfall runoff. Water infiltrated into soils is used by plants, moves through the soil to reemerge as creek baseflow or is stored underground in aquifers. Both the baseflow and groundwater storage paths are fundamental to the recharge of the Edwards Aquifer. Changes in the natural soil structure which reduce infiltration (e.g., compaction, imposition of impervious cover, etc.) serve to increase surface runoff and erosion and are detrimental to water quality and quantity. Proposed recreational uses should be evaluated for their effect on soil structure and function.

Different types of traffic (e.g. hikers, bicyclists, horseback riders) can have different levels of effects on the soils of intensively utilized recreational sites (Wilson and Seney 1994). To avoid adverse impact on the recreational area in general, the variables of soil type and depth should be considered in relation to precipitation, traffic density, traffic type, trail design and topographic slope (see (Tinsley and Fish 1985) for review).

Soil erosion may be considered the greatest potential problem from poorly constructed and managed trails. In most terrestrial systems, erosion, defined as the "wearing away of material on the earth's surface" (Foster 1979), will occur naturally. However "accelerated erosion" may occur where this process is enhanced due to the human influence (Tinsley and Fish 1985). Trail traffic can increase erosion due to both soil loosening (particle detachment), and compaction (increasing run-off), as well as concentrating water flow into channels thereby increasing down-trail sediment transport (Deluca et al. 1998). Wet soil conditions exacerbate these processes.

The nature of the surface itself may influence erosion potential. More massive, weakly-structured soils with low infiltration rates may be more susceptible to erosion than well-aggregated soils (Eckert et al. 1979). Furthermore, other studies have shown that shallow-soiled, 'rocky'-surfaced trails tend to be more resistant to erosion and compaction (Bryan 1977, Eckert et al. 1979), however vegetation growing in these soils is less able to recover from damage than similar vegetation growing under more favorable conditions (Liddle 1975, Leung and Marion 2000), which will be further discussed in the next section.

The U.S. Department of Agriculture has developed the Revised Universal Soil Loss Equation (RUSLE) for predicting the amount of erosion (in pounds of soil that would be lost per acre) resulting from rainfall and associated overland water flow under different management uses, in different climate and rainfall regions, and across different soil types. This formula is based on empirical studies and was intended to be used to calculate erosion rates for agricultural fields, rangeland, construction and mining operations. As such, it is not directly relevant to most of the proposed activities, but several of the component parts can help to predict the times of year and the soil types with the lowest potential for erosion (Renard et al. 1991, Renard 1992, Renard et al. 1997, Anonymous 2001).

RUSLE is the product of six factors:

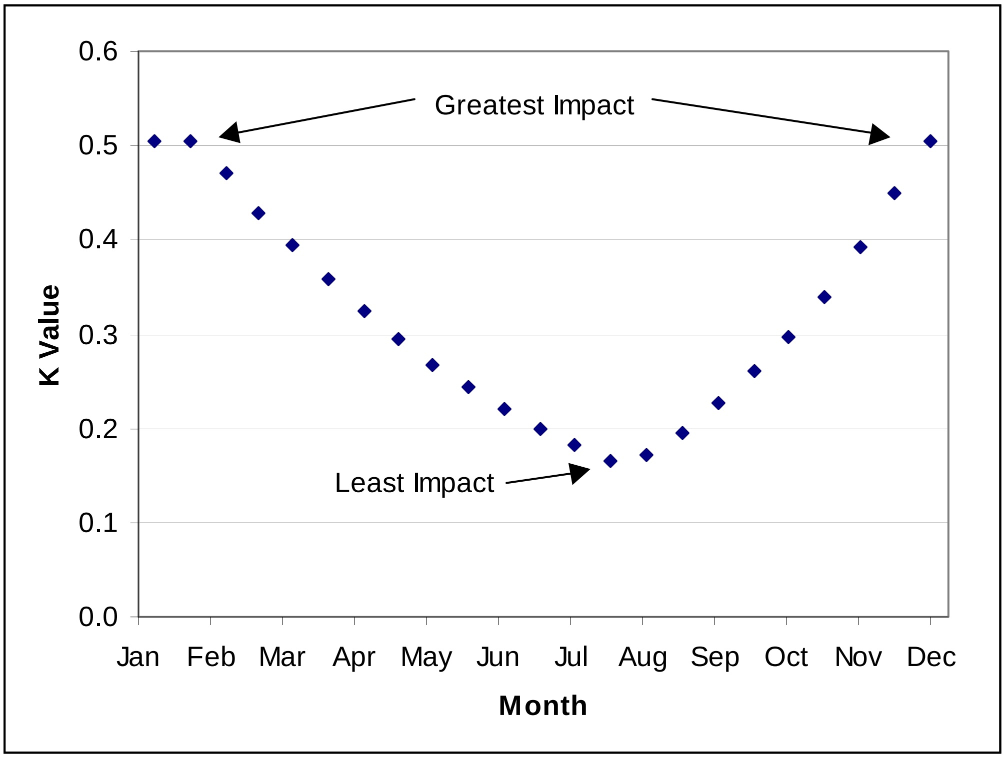
- the erosivity of the climate (R),
- an empirical measure of soil erodibility for each soil type related to the percentage of silt, sand, and organic matter, as well as soil structure and permeability (K),
- the slope of the area (S),
- the length downslope (L),
- the vegetative cover and management of the area (C),
- and the effect of conservation practices such as strip cropping, terraces, grass hedges, silt fences, etc. (P).

While the above formula (RUSLE= R*K*S*L*C*P) was designed to be utilized on large areas with constant management and use (such as a pasture for grazing or for row crops), several of the factors (R, K, S and L) can be very informative in considering how best to minimize any impacts on the landscape (Renard 1992).

Soils with higher K values are more susceptible to sheet and rill erosion by water. Soil erodibility (K) values for soils on the Water Quality Protection Lands range from 0.1 to 0.32. Soils in Travis County range from 0.1 to 0.43, with soils across the United States generally falling within the range of 0.02 to 0.64. One strategy to minimize erosion is to avoid public access on areas with higher K values. However, soils with higher K values tend to be relatively thin. Thin soils provide a less hospitable growing environment for plants than deeper soils, so plants growing in them are less able to recover from damage than similar plants growing under more favorable conditions. This is a tradeoff that will have to be taken into account as public access is considered.

A second way to minimize erosive effects is to ensure that, development or construction of the infrastructure for public access (e.g. trails, parking, etc.) is undertaken during times of the year when the potential for erosion by water is at its lowest (i.e., minimize R). Another strategy is to close or restrict access when the site has its greatest potential for erosion. Due to rainfall patterns in the Austin area, soils are most prone to erosion from November through March, and least prone to erosion in June through August. In effect, R increases or decreases K. This can be more clearly seen when examining the calculated K value for Volente soils and how this changes over the course of the year. The standard K value for Volente soil is 0.32 but when this is considered in relation to Austin’s rainfall pattern, the following table more accurately states the soil’s erosion potential (Renard et al. 2001).

Graph 1.5.3-1
K Values for the Volente Soil Complex after Adjustment for Climate and Rainfall
(in half-month increments)



It is clear that in order to reduce erosion, activities with the potential to cause significant erosion, such as trail construction, should occur from late April through early October, with the least erosive times typically occurring in July and August (Renard et al. 2001).

Two final factors to consider in reducing erosion as a part of access activities is to minimize the slope (S) and downhill length (L) in which the activity is to occur. Dispersed-use activities should occur on generally flat topography, and concentrated-use activities should follow contour lines. Trails should utilize switchbacks, steps terraces and other means to reduce the downhill length that water can run. More specific design considerations associated with different proposed activities are included below.

Studies have shown that sediment yield from trails used by hikers was greater than that from non-trail areas, and generally, erosion increases in a curvilinear fashion with increased traffic of any type (DeLuca et al. 1992). One study suggests that bicycle traffic produces the least amount of sediment available for erosion, followed by pedestrian, with horse traffic causing the greatest amount of erosion, particularly on wet trails (Wilson and Seney 1994). The results of this study, however, are somewhat questionable as the treatments (types of traffic) occurred on different soil types with differing levels of natural erosion. Deluca et al. (1998), suggests that soil detachment is the primary mechanism for increased sedimentation, and that moist soils are particularly vulnerable. Furthermore, evidence also suggests that climatically dryer soils (semi-arid) (Tinsley and Fish 1985) are less prone than more mesic or tropical soils (e.g. (Wallin and Harden 1996)) to erosion. Research conducted in the Guadalupe Mountains of West Texas on geology similar to central Texas (limestone derivative), but with less precipitation and soil, suggests that on these soil types, simple, unsurfaced trails do not present significant erosion when compared to conditions off the trail (Tinsley and Fish 1985). However, these conditions also limit vegetation's ability to recover, so trail scars tend to persist for long periods of time. In addition, precipitation is an important driver of sedimentation (Bautista 2007), and so trails located in central Texas, with its higher precipitation rates, can be expected to produce more sediment than trails in west Texas under similar geologic and use conditions, though this has not been well tested in central Texas.

In summary, compared to many soils, the relatively shallow, well drained, and sometimes rocky soils of the Edwards Plateau may allow for trails without undue peripheral erosion. With adequate design and maintenance, the development of erosive features can be minimized. However, a trade off exists between soil erodibility and the resilience, or ability to recover, of the plants growing in the soil. Simply put, shallow, rocky soil is less erodible but plants growing under these conditions are less able to recover from damage than similar plants growing in deeper soil. The potential impacts to vegetation must be considered along with direct impacts to soil because the state of the vegetation strongly influences soil characteristics, the overall erosion from an area, and water quality and quantity. The interaction of soil and vegetation and the influence of both on erosion will be further discussed in the next section.

Finally, more sensitive areas, such as internal drainage basins associated with karst features, riparian areas or wetlands, will require additional care, or perhaps the land should be excluded from recreational use altogether. Even with precautions, it is highly probable that the site itself (trailbed) will suffer considerable degradation unless it is surfaced or subject to infrequent use. The siting of any road or parking areas should be especially carefully selected to protect existing soils from erosion both during and after construction.

1.5.3.3 Vegetation

Vegetation serves to protect and build soils and to provide shade and habitat. A healthy mix of vegetation is of paramount importance to maintain high water quality and quantity in streams and the groundwater. Loss of vegetation often leads to a loss of soil, increased runoff and erosion, and a resulting decrease in water quality and quantity.

Trampling of vegetation is frequently among the primary effects of recreational use of natural areas, and has been extensively studied (Cole 1990, Marion and Cole 1996). Although light trampling may have no effect (Kutiel et al. 2000) or may even enhance growth of some species, more detrimental effects include crushing, shearing, and even uprooting. Continual disturbance of exposed roots can even result in tree death (Cole 1990). As mechanisms of disturbance, trampling in the longer term may result in the removal of more trample-sensitive species within the disturbed area, and may encourage those species that respond positively to disturbance to increase (Cole 1990) including invasive and/or exotic species.

Other significant modes of disturbance include soil characteristics (water retention and absorption ability, aggregate size, compaction, etc.) and change in the light environment (from trail/parking construction). The overall effect is to alter the community composition. Around trails this altered zone may be narrow (Dale and Weaver 1974), but may be extensive around more dispersed recreation activities such as camping or trailheads. In addition, impacts can extend far beyond the primary impact zone as sediment moves across the landscape or if introduced exotic species alter the plant dynamics of the surrounding area (Leung and Marion 2000). The increase in abundance of alien (invasive or otherwise) species is a potentially serious consequence of increased disturbance around recreation areas. The abundance of alien species increases as exotic seed is imported with traffic and plant communities are rendered more vulnerable to invasion by the weakening of individual plants and the disruption of ground cover. This is particularly common in areas where there is both high traffic and high visitor residence time.

Wildfire is another notable risk associated with all forms of recreational activity (Sun and Walsh 1998). While many systems may exhibit plant adaptations to fire, an elevated fire frequency could have severe detrimental effects on the ecology in the long term, in addition to the threat to human life and property. On the other hand, having a large number of visitors may increase scheduling problems associated with prescribed burning, and thereby lead to decreased fire frequency, which would reduce the ability to manage for healthy grasslands. Additionally, fewer prescribed fires will result in higher fuel loading which will lead to more intense wildfires. The ecosystem will have decreased resiliency to these wildfires and the threat to life and property will be increased.

The overall vegetational effect of trail traffic is that although the species composition within the feature itself may be dramatically altered, this response decreases with distance from the feature. Additionally, impacts will be most severe near the trailhead (Bright 1986). Taking precautions beyond careful trail design to prevent erosion, such as surfacing the trail, should be considered in high impact areas such as trail heads and in areas of high sensitivity, such as riparian areas or areas with a high concentration of karst features.

1.5.3.4 Fauna

Immediate short-term impact on wildlife, such as temporary flight of birds or land animals, can be expected by the presence of walkers, bikers or horses on the trail (e.g. (Burger and Gochfeld 1998)). Long-term effects caused by habitat interference due to trail construction may be significant, particularly on micro-scale organisms, are unavoidable, and cannot be mitigated. Campsites tend to have more impact on fauna over a broader area and over the longer term. General traffic in the surrounding area, the collection of firewood, the presence of trash, water supplies, etc., all significantly modify the habitat (Cole 1990), expelling some species while attracting others. The presence of humans alone also directly affects many animals (by inducing stress in individual animals, which in turn alters behavior) (Cole 1990). Where high densities of visitors prevail over longer time periods, most animal species will experience population reduction. There is also the chance that a few species may be attracted to these areas due to available water sources, litter, light sources, etc. (see (Cole 1990) for review).

1.5.3.5 Interference with Land Management

The land management activities on the WQPL are designed to ensure that the goals outlined in section 1.2.1. are met, and disruption of these activities will impede progress toward program goals. Public access can interfere with land management by directly impacting activities or by diverting resources away from land management.

The City of Austin Water Utility has no mandate for public access within the WQPL beyond a limited allowance for the purpose of public education, and the majority of the WQPL's limited funds are intended to serve program goals, outlined in Section 1.2.1. If significant public access is to proceed, the majority of funds for construction, operations and mitigation must be raised outside of the City of Austin Water Utility. However, public access will require some management by WQPL staff even if a separate trail management and funding structure exists. Trail users will periodically leave the trail, damage property etc. and these situations will have to be dealt with to some extent by WQPL staff. Additionally, the presence of a trail will increase the cost and complexity of any management activities that must be performed near the trail. For example, the trail will be closed in advance of activities such as prescribed fire or deer population control. However, staff will still need to devote resources not only to closing the trail, but also to patrolling the trail after closure to ensure there is no unauthorized access. Finally, it is likely that some program funds will need to be used for the mitigation of trail impacts.

1.5.3.6 Mitigation Measures

Adequate design of concentrated recreational features such as trails is essential to reduce the danger of soil degradation. Main principles for trail construction include: following contours as much as possible, out-sloping the trail bed, avoiding sharp turns, preventing spontaneous 'shortcuts', and arranging frequency of cross drains (water bars) and dips according to soil type and grade (USDA 1985, Felton 2004). Additionally, trails should maintain a buffer of at least 100 feet from creeks and completely avoid riparian zones where this buffer is inadequate except at constructed creek crossings to avoid streamside damage. Whenever possible, trails should be kept far enough from creeks and other bodies of water that trail users cannot see them in order to discourage social trails to the water. Recommendations specific for soil type and grade can be found in several publications (USDA 1985, Birkby 1996, USDA 1999).

Additionally, should roadway or parking facilities be developed, they must be carefully sited and designed. All impervious infrastructure should be mitigated such that the runoff from these facilities be treated and infiltrated to mimic the pre-development hydrology to the greatest extent possible. Alternative paving systems, such as grid pavers or pervious pavement, should be considered to reduce impervious cover. All roads and parking areas should have structural controls for treatment, regardless of whether the total impervious cover on the site exceeds any minimum ordinance threshold. All roads and parking areas should include an engineered design for runoff to ensure maximum sheet flow, maximum opportunities for infiltration (e.g., through bioretention filter devices), and flow conveyance via vegetated swales and natural channels. No pipe and gutter systems should be used.

Limitation of access should also be considered. As discussed above, some areas are so sensitive that they may warrant limitation from almost any access (e.g., riparian areas, wetlands, or areas with extensive karst features or internal drainage basins associated with karst features). Even in less sensitive areas, it will be appropriate to prohibit public access for a period of time following rainfall events until the soils are sufficiently dry. Such policies would be similar to those used by sports fields to prevent significant damage.

There will be some immediate effect on vegetation during the construction and use of trails. Standards suggested by the USDA Forest Service restrict trail width and height to 4 by 8 feet for hikers and 8 by 10 feet for horses (Cole 1990). Although these changes are dramatic, the effect on the adjacent vegetation (e.g. light modification) will be limited from 8 to 20 feet from trail center, depending on vegetation (Cole 1990). From the trail design perspective, minimizing the impact on vegetation is best achieved by following the same guidelines aimed at avoiding soil erosion (USDA 1985).

It should also be noted that construction of trails could also be used as a restoration tool. Examples include the improvement of topographic structure and construction of trails in areas currently experiencing problems with erosion from past management practices or upstream sources.

Certain plant communities may be considered particularly valuable or sensitive, and may be unsuitable for recreational development, in particular, those found on very shallow soils and in wetland areas. Habitat for endangered or protected species, such as golden-cheeked warbler and karst-dwelling invertebrates, will require particular attention.

Generally, some impact from these collective activities is inevitable but justifiable if impacts can be fully mitigated and if access allows the public to be educated about the importance of healthy ecosystems to improved water quality and quantity. This knowledge can then be taken back to affect a much larger area than that of the public lands. Impacts that cannot be fully mitigated should be avoided.

The development of sports fields is not recommended. These fields are typically vegetated with bermudagrass, an invasive, non-native species. Additionally, to maintain a dense cover of turf grass, fertilizer application and supplemental watering is required. Beyond the actual playing field, significant additional parking and restroom facilities would be needed. It is not known how mitigation of these effects could be accomplished in practice, and a review of the literature produced no examples where these impacts had been mitigated on a sports field. Because these lands must be maintained to enhance water quality and quantity, it is the recommendation of this management team that no improved playing fields be allowed on Water Quality Protection Lands at this time.

During the design phase of any public access activity, it is imperative that comprehensive soil, floral, and faunal surveys are implemented to ensure the most efficient design of trails and recreational areas. Additionally, once constructed, these must be adequately monitored to detect positive or negative trends.

A comprehensive list of the possible impacts of activities suggested by the survey described and summarized in Section 1.5 could not be gathered from the literature. We have, however, assembled a qualitative assessment of the possible impacts that the proposed activities could conceivably have on water quality as well as other effects. This assessment is presented in Table 1.5.3-2. That table presents the possible unmitigated impacts that the proposed public use activities could have on the Water Quality Protection Lands. These impacts were ranked based on general concepts in the RUSLE calculations (Renard et al. 1991), the material discussed in the literature review above, and general concepts of environmental science and ecology. It is not intended to eliminate activities, but to identify likely negative impacts that should be addressed with regard to such activities. The benefits of access will have to be weighed against the cost and practicality of mitigation when public access is considered. Impacts that cannot be mitigated should be avoided. In the Table 1.5.3-2, scores range from 0 to 4, with 4 being the greatest impact and a blank space representing no impact.

Table 1.5.3-2: Potential Unmitigated Impacts and a Qualitative Estimate of their Severity
(blank = no impact, 1 = slight impact, to 4 = significant impact).

Potential Impacts	Direct Water Quality Concerns														Other Concerns								
Proposed Use / Activity	Increased Sheet (Dispersed) Erosion	Increased Rill (Concentrated) Erosion	Stream bank Erosion	Degradation of Riparian Corridor	Increased Fertilizer Contamination	Human Waste Concentration	Animal Waste Concentration	Oil & Grease Contamination	Pesticide Contamination	Decreased Infiltration	Litter	Karst Feature Adversely Affected	Possible Construction Impacts	**Water Quality Totals**	Flora Adversely Affected	Fauna Adversely Affected	GCW Affected	Exotic Species Spread	Human Injury Risks	Accidental Fire Hazard	Security for Neighbors	Excludes other uses	**Totals, Including Additional Concerns**
Trails																							
Pedestrian		1				1				1	1	1	2	7	1	1	2		1		2		14
Bike		2				1				1	1	1	2	8	1	1	2		1		2	1	16
Horse		2				1	2			1	1	2	2	11	2	1	2	3	2		2	1	24
Mixed (Foot, Bike, & Horse)		2				1	2			1	1	2	3	12	2	2	2	3	2		2		25
Dispersed Use																							
Camping	3					3	2			2	2	1	3	16	2	3	3	1	2	3	3		33
Hunting	1					1					2	1	1	6	1	1			4	2	2	3	19
Birdwatching	1					1					1	1	1	5	1	2	1		1		2		12
Fishing	1		1	2		2					2	1		9	2	1	2		2		2		18
Picnicing	2					2	2		2	2	2	1	3	16	2	1	1			3	2		25
Swimming	1	1	3	3		3					1	1	1	14	3	3	3		3		2		28
Intensive Use																							
Soccer	2	2			4	3		3	3	3	3	4	4	31	4	4	4	2	2		3	4	54
Organic Gardening	4	2			3		3			1	1	4	4	22	4	1	4				3	4	38
Access Road and Parking	3	4	3	2				4		4	3	4	4	31	4	4	4	1	3	2	3	4	56

Section 2
Natural Resource Information

2 Natural Resource Information

2.1 Geology

No geological analysis has been conducted as a portion of this contract, though a significant amount of geological analysis has been done on the region underlying the recharge zone that feeds the Barton Springs Segment of the Edwards Aquifer. Information presented here, unless otherwise noted, comes from the Barton Springs/Edwards Aquifer Conservation District or the Texas Cave Management Association. Figure 2.1-1 illustrates the geology in the Recharge Zone of the Barton Springs Segment of the Edwards Aquifer. The geologic units that comprise the Recharge Zone are the seven members of the Edwards Limestone and the Georgetown Formation. The Marine member is present only in the southern portion of the Recharge Zone. The Leached/Collapsed member outcrops over large areas along the eastern edge of the Recharge Zone, and contains many caves. The Regional Dense member acts as a confining unit and concentrates water flow, which promotes cavern development. The Grainstone member is a relatively massive unit that protects the numerous caves that occur in the underlying Kirschberg member. The Dolomitic member is not as prolific a cave-forming member but contains larger sized passages due to the nature of the bedrock. The Walnut member is a very marly limestone, i.e. limestone with a large clay content. This member is not a good cave-forming layer. Beneath the Edwards is the Glen Rose limestone, a relatively impervious member that is hydrologically connected to the Edwards Aquifer. The fracturing along and adjacent to the numerous small faults along the eastern edge of the Recharge Zone tend to increase the amount of recharge and thus the sensitivity of this area (Russell and Jenkins 2001b).

Cave and karst systems are important for two major reasons. First, the overwhelming majority of the nation's freshwater comes from groundwater. About 25% of the groundwater is located in cave and karst regions. Veni has pointed out that at least 44 million m^3/year must enter the Barton Springs Segment of the Edwards Aquifer as recharge since this is the average discharge from the aquifer, and recharge and discharge must be in balance in a natural steady-state groundwater system (Veni 2000). In actuality, this number must underestimate recharge since this would not take into account non-natural discharge from this aquifer (i.e. wells). While the most significant recharge occurs in stream channels, 15% of the recharge occurring within the Recharge Zone is suspected to occur in the interstream areas of the Barton Springs Segment of the Edwards Aquifer (Slade Jr. et al. 1986). Veni (2000) estimates that 3.63% of the mean precipitation in the Recharge Zone reaches the aquifer. However, a recent study suggests that significantly more recharge may occur via uplands than previously anticipated (Hauwert et al. 2005). The protection and management of these vital water resources are critical to public health and to sustainable economic development. As identified by the National Geographic Society, water resources are a critical concern as our society enters the twenty-first century (Kerbo 1998).

2.2 Soils and Ecological Sites

The Water Quality Protection Lands are composed of 57 distinct soil types (Werchan et al. 1974, Batte 1984). Soil type is based on the general slope of the area, composition of the parent material, and subsequent percentages of clay, silt, sand and rock in the soil. As mentioned in Section 1.6, each of these soil types has been evaluated for a range of factors, the most important of which for this study is the erosion potential (*K*). A table containing soil types in or around Water Quality Protection Lands and their associated ecological sites is given in Table 2.2-1. The soil types within each watershed unit are mapped in Figures 2.3-1 to 2.3-10.

Soil types that have historically supported similar vegetation communities are grouped into ecological sites. Each ecological site description includes the average annual biomass production, an assessment of its suitability for grazing, the historical climax plant community (HCPC), the plant species that appear and disappear under heavy grazing and the huntable wildlife native to the area. A useful analysis of the current condition of a given piece of land can be obtained by comparing the current assemblage and biomass of species to the historical climax system described in the ecological site description. The ecological sites within each management unit are mapped in Figures 2.3-11 to 2.3-21.

Table 2.2-1: Soil Types and K factors for Water Quality Protection Lands

Name	Ecological Site	K Factor
Anhalt clay	Deep Redland	0.32
Brackett soils	Adobe	0.37
Brackett soils, rock outcrop	Steep Adobe	0.37
Crawford clay	Deep Redland	0.32
Comfort rock outcrop	Low Stony Hills	0.1
Denton silty clay	Clay Loam	0.32
Eckrant rock outcrop	Steep Rocky	0.1
Ferris-Heiden complex	Eroded Blackland	0.32
Heiden clay	Blackland	0.32
Krum clay	Clay Loam	0.32
Lewisville silty clay	Clay Loam	0.32
Mixed alluvial land	Loamy Bottomland	0.151
Oakalla complex	Loamy Bottomland	0.32
Patrick soils	Chalky Ridge	0.32
Purves clay	Shallow	0.32
Rumple comfort complex	Gravely Redland	0.17/.10
San Saba clay	Redland	0.32
Speck clay loam	Redland	0.32
Speck stony clay loam	Redland	0.32
Tarpley clay	Redland	0.32
Tarrant soils	Low Stony Hills	0.32
Tarrant and Speck soils	Low Stony Hills	0.32
Tarrant soils and rock outcrop	Steep Rocky	0.32
Volente complex	Clay Loam	0.32
W		

The majority of the ecological sites found within the WQPL historically supported savanna communities which had less than 30% woody cover. The historical climax plant communities associated with the ecological sites found within the Water Quality Protection Lands are listed in Table 2.2-2

Table 2.2-2: Ecological Sites and Historic Climax Plant Communities (HCPC) of the Water Quality Protection Lands

Ecological Site	Historical Climax Plant Community	Historic Woody Canopy Percent Cover
Adobe	**Open grassland/Oak Hillside:** Fire maintained community of tall and midgrasses and scattered oaks	10%
Blackland	**Tallgrass Prairie:** Fire maintained community dominated by warm-season, perennial tallgrasses with warm-season, perennial midgrasses filling most of the remaining species composition	5%
Chalky Ridge	**Tallgrass Prairie:** Fire maintained community tallgrass prairie with significant component of midgrasses, scattered trees and low growing shrubs	less than 15%
Clay Loam	**Tallgrass Savanna:** Fire maintained tallgrass plant community interspersed with occasional perennial forbs and woody species	less than 10%
Deep Redland	**Post Oak Savanna:** Fire maintained savanna composed of tallgrasses and scattered post oaks	less than 10%
Eroded Blackland	**Tallgrass Prairie:** Fire maintained mosaic of tallgrass and midgrass plant communities. Midgrasses dominate shallower eroded areas	less than 5%
Gravelly Redland	**Mixed Grass Prairie:** Fire maintained midgrass community with scattered tallgrasses, trees and shrubs	less than 10%
Loamy Bottomland	**Hardwood Grassland:** Fire maintained tallgrass bottomland typical of first level bottomland near a river or perennial creek. Characterized by a mix of tallgrasses and hardwood and high plant diversity.	20—50%
Low Stony Hills	**Open Grassland with Oak Mottes:** Fire maintained open grassland with scattered oak motts	20%
Redland	**Oak Savanna:** Fire maintained savanna composed of tallgrasses and scattered post oaks	less than 10%
Shallow	**Tall & Midgrass Prairie:** Fire maintained tall and midgrass prairie with widely scattered live oak trees and mottes	less than 5%
Steep Adobe	**Texas Oak/Live Oak Savanna:** Plant communities of this steeper site (slope 12-60%) have a larger component of woody species (occurring in bands perpendicular to the slope) than the Adobe site.	20%
Steep Rocky	**Tall & Midgrass/Oak Hillside:** Mixture of many woody species along with tallgrasses, midgrasses and forbs. Fire was less frequent here than on adjacent flatter slopes. Density and frequency of woody vegetation dependent on presence or absence of fractured limestone and exposure. Where non-fractured geology exists, canopies will be less dense. North facing exposures have higher canopy covers and larger trees than southern exposures. Referred to as "cedar brake" by early explorers.	35%

2.3 Golden-cheeked Warbler Surveys

Land management decisions should take into account the presence or absence of golden-cheeked warbler (GCW) habitat. Golden-cheeked warblers require mature oak/juniper woodlands that do not regenerate quickly after severe disturbances, especially where deer populations are high. All properties not previously surveyed but deemed to be possible habitat (Type 1) by the U.S. Fish and Wildlife were surveyed as a part of the contract for the 2001 Management Plan, and surveys of remaining areas were completed in 2010.

Golden-cheeked warblers inhabit portions of the Water Quality Protection Lands, although some units have superior habitat to others. The best habitat occurs in the Upper and Lower Barton Creek management units on the Little Barton Creek, Morgan C, and Morgan A tracts. Most of the golden-cheeked warbler observations occurred on these tracts. Parkhouse and Knoll in the Lower Barton Creek management unit, contained golden-cheeked warblers, but the habitat is not considered high quality because of the low density of deciduous trees. The northern section of the Hays County Ranch tract in the Little Bear Creek management unit contains habitat, but a surveyed section of this tract in the south contains no habitat.

Observations of golden-cheeked warblers occurred on some of the other tracts, but the quality of habitat is low and the tracts are unlikely to be heavily utilized. All habitat found in the Bull Creek and Upper Bear Creek management units is classified as marginal. Approximate sighting locations and habitat delineations are given in Figures 2.3-22 to 2.3-28.

2.3.1 Bull Creek Management Unit

Horizon Environmental Services Inc. surveyed this unit in 1993. They characterized the habitat as marginal to fair because of the high percentage of juniper to deciduous species and the large amount of noise. No golden-cheeked warblers were observed in the survey that was conducted in 1993 (Sherrod 1993b), however birds have been documented here more recently during BCP monitoring.

2.3.2 Upper Barton Creek Management Unit

SWCA Inc. Environmental Consultants surveyed the Little Barton Creek tract and published the results in July 1998. Eleven male golden-cheeked warblers were observed, and their territories mapped. Although no searches were conducted for female and juvenile warblers, six females and four separate groups of fledglings were observed (SWCA 1998). Numerous territories were delineated during the 2010 surveys (Figure 2.3-22)

2.3.3 Lower Barton Creek Management Unit

The rest of the Lower Barton Creek unit has been surveyed multiple times and survey results, including the most recent 2010 surveys, can be found in figure 2.3-23. The Nature Conservancy (TNC) first surveyed the Lower Barton Creek unit. Because of the variety of habitats, the unit is discussed here on a tract-by-tract basis. Morgan C contains good to excellent nesting habitat and a number of golden-cheeked warblers were observed, mostly along Thomas Springs Branch and Grape Creek Watersheds (Ettel

2000). Although Morgan A does not contain as much high quality habitat as Morgan C (due to some areas having a monoculture of second growth juniper), Morgan A contains some good habitat. Golden-cheeked warblers were found in many locations, but were concentrated near Grape Creek. Habitat on Knoll is very poor, consisting of monocultures of second growth juniper. Golden-cheeked warblers were recorded at three locations, but they were likely transient birds (Ettel 2000). Most of the area on Parkhouse was believed to be unsuitable for habitat, although they observed two locations that did contain golden-cheeked warblers. The lack of mature juniper limits the habitat on this tract (Ettel 2000).

SWCA Environmental consultants surveyed the Knoll and Parkhouse tracts in 2002 and 2003. Three males were observed on Parkhouse in 2002, with the northernmost ranging onto the southwestern edge of the Knoll tract. Another warbler was observed in the northwest corner of the Knoll tract in 2002. Two males were observed on the Parkhouse tract in 2003 while none were detected in that year on the Knoll tract. The warblers observed on or adjacent to the Knoll tract are believed to have been detected while travelling outside their defended territory. However, the warblers appear to visit the areas where they were observed regularly, so portions of the tract have been delineated low quality habitat (see Figure 2.3-23) (SWCA 2003). Based on the 2000, 2002 and 2003 surveys the Parkhouse tract supports golden-cheeked warblers habitat (SWCA 2003). However, because warbler densities are low and territory size is great no high quality is believed to be present (SWCA 2003). Areas where warblers were observed in 2002 and 2003 area considered moderate quality habit and areas where warblers were observed only in 2002 or 2003 are considered low quality habitat.

Several territories were delineated in the northern and central portions of the Lower Barton Creek unit in 2010.

2.3.4 Slaughter Creek Management Unit

Both Loomis Austin, Inc. and the Nature Conservancy (TNC) surveyed these tracts in 2000. Loomis Austin, Inc did not observe golden-cheeked warblers on these tracts. They characterized the habitat as marginal due to the small number of deciduous trees and the lack of mature junipers (Hunter 2000). TNC recorded one golden-cheeked warbler on the Baker tract, but none on Heilsher or Hafif (see Figure 2.3-24). They concluded the entire habitat was questionable, small, and patchy with very little nesting potential. The Hafif tract has no golden-cheeked warbler habitat (Ettel 2000). The Baker tract was resurveyed in 2002 and 2003 by SWCA Environmental Consultants and no warblers were detected. SWCA asserts that the warber detected in 2000 was transient because it was only detected during one of the five visits to the property in 2000. SWCA concludes no golden-cheeked warbler habitat is present on the Baker tract because no warblers were found to occur regularly on the tract in 2000, 2002 or 2003 (SWCA 2003).

2.3.5 Bear Creek Management Unit

Loomis Austin surveyed this unit in April and May of 2000. Loomis Austin did not observe any golden-cheeked warblers and classified the habitat as marginal (Hunter 2000). One golden-cheeked warbler was heard on the western section of the Tabor tract

(Figure 2.3-25). This observation was within an area identified as occupied habitat by Balcones Canyonlands Conservation Plan Maps (Hunter 2000). One golden-cheeked warbler was seen on the north side of Bear Creek on the Lancaster tract, but it did not display any territorial behavior. The small number of deciduous oak trees makes the habitat on this tract marginal (Hunter 2000).

SWCA Environmental Consultants surveyed this unit in 2002 and 2003. One male golden-cheeked warbler was present on the Tabor tract during the first three visits of 2003 but not on subsequent visits (SWCA 2003). The vegetation in the area the bird was found, just north of Bear Creek, is not composed of typical warbler habitat (SWCA 2003). No warbler habitat is present on this property (SWCA 2003).

No golden-cheeked warbler s were detected on the Bliss Spillar or Reavely tracts in 2000, 2002 or 2003. No warbler habitat is present on these properties (SWCA 2003).

2.3.6 Little Bear Creek Management Unit

The Nature Conservancy surveyed the northern portion of this unit in 2000. This tract contains “virtually no golden-cheeked warbler habitat”. On the first day of surveying, one male golden-cheeked warbler was observed, but it was not present upon subsequent visits (Ettel 2000). Additional surveys were conducted in 2003 and 2010 and the results can be found in Figure 2.3-26.

SWCA Environmental Consultants surveyed this unit in 2003, though the Wenzel tract was not surveyed. Two golden-cheeked warblers were detected in the north end of the Hays County Ranch on 11 April, one was detected on 6 May, and none were detected on subsequent visits. The inconsistency of observations suggests that the birds were wandering through the area rather than holding territory there (SWCA 2003). The vegetation present in the area is not similar to typical warbler habitat, but because golden-cheeked warblers were detected, a portion of the woodland in the area was delineated low quality warbler habitat (Figure 2.3-27) (SWCA 2003). If no warblers are found in subsequent surveys, the area will likely be considered to have no warbler habitat (SWCA 2003).

One golden-cheeked warbler was regularly detected near the eastern Hays County Ranch property boundary, north of the Wenzel tract (SWCA 2003). The bird is believed to hold territory to the east of the property and this portion of the Hays County Ranch is not considered to have any golden-cheeked warbler habitat (SWCA 2003).

Territories were delineated in the northern and central portions of the unit in 2010.

Two male black-capped vireos were detected near the west boundary of Hays County Ranch in an area supporting semi-open scrub composed primarily of Texas persimmon, mountain laurel, live oak, Ashe juniper, and elbowbush (*Foresiera pubescens*) (SWCA 2003). At least one male was detected in this area by SWCA in 1999, 2000, 2001, and 2002, however no black-capped vireos were found in the area in 2009 or 2010.

2.3.7 Onion Creek Management Unit

This unit was purchased after the breeding season in 2000 and was not surveyed at that time. Surveys were completed in 2010 and territories were delineated in the southeastern portion of the property, near Onion Creek (Figure 2.3-27).

2.3.8 Shudde Fath Management Unit

Horizon Environmental Services Inc. surveyed the Shudde Fath site in 1990, 1991, 1992, 1993, 1994, and 1996. They observed only two transient golden-cheeked warblers in this time, but no nesting areas. Some of the property does have suitable golden-cheeked warbler habitat. Golden-cheeked warblers were heard outside of the tract’s boundaries on the City of Austin’s Barton Creek Greenbelt (Sherrod 1993a, Horizon Environmental Services 1997). Golden-cheeked warblers were documented in 2010 (Figure 2.3-28) within the site.

2.4 Native and Exotic Deer Survey and Incidental Counts

For the 2001 Management Plan, spotlight deer surveys were conducted by City staff on properties where incidental counts suggested deer populations might be high. These surveys were carried out from 8:00pm to 1:00am along three specific routes in the watershed units of concern, in the fall of 2000. Summary results from these surveys are included in Table 2.4-1. Summary results from surveys done in 2007 and 2008 are found in Table 2.4-2. Texas Parks and Wildlife (TPWD) estimates that the maximum deer density that can exist in this area before serious ecological degradation occurs is 10-15 acres per deer (Reagan 2000). This number provides a useful benchmark, but the optimal deer density will vary from site to site depending on the site’s characteristics (primary productivity, topography, etc.) and the ecosystem services desired from the site. Deer densities should be reduced to a level at which ecosystem function, particularly hydrologic function, is no longer negatively impacted. WQPL land managers should work with Texas Parks and Wildlife Department to calculate optimal deer densities, based on restoration goals and ecological monitoring, on a site by site basis

Table 2.4-1: Average number of acres per deer and blackbuck as calculated by the 2000 spotlight deer survey.

Management Unit	Acres/Deer	Acres/ Blackbuck
Upper Barton Creek	6.8	0
Slaughter Creek	5.5	0
Bear Creek	2.2	0
Little Bear Creek	7.8	0
Onion Creek	3.1	2.9

Table 2.4-2: Average number of acres per deer as calculated by 2007 and 2008 spotlight deer surveys

Management Unit	Acres/Deer	Survey Year
Slaughter Creek	2.84	2007
Bear Creek	8.56	2008
Onion Creek	2.84	2008

2.5 Karst Feature Inventory

Karst evaluation studies have not been conducted on all portions of the Water Quality Protection Lands. This report provides a summary of the preliminary karst work completed by other parties on the Bear Creek management unit as well as karst features encountered on both Little Bear and Onion Creek units. Although it is not part of the work being conducted in this contract, it is recommended that all Water Quality Protection Lands be fully inventoried for karst features, particularly in those areas where public access is proposed. All features revealed should be protected and avoided in order to minimize negative impact. Currently, karst surveys are conducted following prescribed fires utilizing volunteers to document features. Feature attributes are placed in a database for the Watershed Protection Department to follow up on as time permits. Karst surveys conducted between July and October of 2009 in support of the Walk for a Day project located over 400 potential karst features on the Bear, Little Bear and Onion Creek management units. A discussion of these features can be found in the Walk for a Day environmental assessment.

2.5.1 Bear Creek Management Unit

Six caves are currently known from the J-17 Fortune tract, including Headquarters Flat Cave, a significant recharge feature. The tract is crossed by several faults and bisected by a drainage, making the tract especially sensitive, as runoff from areas adjacent to caves, faults, and drainages are likely to be directly recharged into the aquifer (Russell and Jenkins 2001b).

Currently, six caves, five sinks and numerous cracks and holes have been discovered on the southern portions of the Tabor tract containing federally-listed species of concern and artifacts such as: short troglobitic millipedes, *Rhadine* beetles, cave adapted harvestman, cave crickets, a human jaw bone, one of the largest cave rooms, and the largest underground bat colony in Travis County (Russell 1996, Veni 2000, Russell and Jenkins 2001a, b). At least one significant karst feature is in the channel of Bear Creek between the Tabor and Reavley tracts. Management or protection recommendations are being developed by the Texas Cave Management Association, but have not been completed for these karst features (Russell and Jenkins 2001a).

Currently, one cave, one sink and numerous minor features have been discovered on the Reavley tract containing small cave cricket and bat colonies. The known portions of the

Reavley cave are very marginal habitat for cave-adapted invertebrates. The main objective should be to preserve the bat population (Russell and Jenkins 2001a).

2.5.2 Little Bear Creek Management Unit

Several karst features are known to exist on this unit, one of which has had past structural manipulation to allow a pond to form around it. Most of the area within this unit has not been surveyed for karst features.

2.6 Other Fauna of Interest

While no full survey work for any other species has been undertaken, evidence of feral hogs has been seen in the Bull Creek, Bear Creek, Little Bear Creek and Onion Creek management units. Damage, particularly in the riparian areas, has already been noted as a result of feral hog activity. Occasional feral or free-ranging domestic cats have been seen on several of the units.

2.7 Archeological Sites

Nine of the property tracts (Morgan A, Morgan C, Knoll, Parkhouse, Baker, Hafif, Edwards Crossing 118 acres, Reavley and Hays) have not been investigated for the presence of cultural resources. The other seven tracts (Little Barton, Hielscher, J-17, Edwards Crossing 200 acres, Tabor, Lancaster, Onion and Stenis) have had limited cultural investigations; the work has been project specific or education related in the case of Onion and sometimes confined to the localized linear areas of direct impact from a trail, pipeline or roadway. Of the thirteen identified historic properties, eleven were recommended for avoidance or further assessment and three were recommended for no further work. The possibility that there are cultural properties as yet undiscovered is high given that the properties are located next to active creeks (Price 2000).

Future development will have to consider both direct (trails, pipelines, buildings etc.) and indirect impacts (increased public access) to cultural properties. Most of the sites that have been recorded have been surficial and/or shallowly buried, making them particularly vulnerable to both direct and indirect impacts while deeply buried cultural deposits may be sufficiently protected from surficial impacts and casual collecting.

It should be emphasized that assessment of cultural resources on land tracts conducted early in a project will have a cost and time benefit as projects can be modified to minimize or avoid impacts to historic sites. The full report on documented archeological sites has already been filed with Water Quality Protection Lands staff.

Section 3
General Discussion of Land Management

3 General Discussion of Land Management

3.1 Restoring Historic Communities

For most climatic zones of the world, there are a number of different stable ecological systems that could exist there, with the current ecosystem a result of historic events such as glaciations, catastrophic fire, normal periodic disturbance, past faunal use (including humans) or similar events. These historical events interact with soil and climatic extremes to result in the current ecological system, but this system is only very rarely the only one that has or could exist on the site (Egan and Howell 2001). Those ecological systems that are self-sustaining within limits and require few inputs are referred to as stable ecological states. These states resulting from climatic conditions and historical events or recent management are resistant to change and require a shift in current management or another catastrophic event in order to move from one stable state to another. The energy required for this shift varies between systems (Laycock 1991, McPherson 1997, Peterson et al. 1998, Anonymous 2000).

The Edwards Plateau is a good example of the same climactic area having a number of stable ecological states. Most sites on the Edwards Plateau have the potential to be open grassland, savanna and woodland. All three of these conditions are stable states and once present, are often resistant to change under the normal climatic and disturbance regime (Smeins 1980, Smeins 1982, McPherson et al. 1988, Smeins and Merrill 1988, Archer 1989, 1990, Fowler and Simmons 2008). However, it is important to understand that the disturbance regime of the Edwards Plateau has been altered. Periodic fire and bison grazing events played an important role in establishing and maintaining communities in central Texas (Fuhlendorf et al. 1996, Fuhlendorf and Smeins 1997a, Fuhlendorf and Smeins 1997b). Fire suppression and the transition from free roaming bison to pastured livestock has dramatically affected the vegetative communities of this region.

There are a wide variety of tools and methodologies available to the land manager to help move between these various stable ecological states. Figure 3.1-1 shows the different stable states that would be appropriate on most of the Water Quality Protection Lands and the tools and methods that are commonly employed to move between the states. These ecological states (grassland, savanna or woodland) once achieved, are considered stable in that they do not require significant inputs in order to be maintained, but most will require some form of routine management (Smeins 1982, McPherson et al. 1988, Archer 1989, 1990, Archer and Smeins 1991, Scanlan and Archer 1991, Archer 1996, Fuhlendorf et al. 1997, McPherson 1997, Scholes and Archer 1997). In Figure 3.1-1, examples of routine management are shown on the interior boxes, with more intensive management shown by the arrows exterior to the boxes. These intensive management methodologies can be used to move between differing stable or intermediary states but may be impractical to use on Water Quality Protection Lands based on the amount of resources needed to undertake them, resulting soil disturbance, or conflicting neighboring land use.

Based on the studies summarized in Section 1.3 and included in Appendices 8.1, 8.2 and 8.3, the best management technique for the optimization of water quality and quantity is to move toward grassland or savanna conditions. A large number of sites, however, are clearly stable oak/juniper and juniper woodlands that would require significant energy and expense in order to stabilize as savannas or grasslands. For this reason, priority management will be given to 1) preventing woody plant encroachment in existing grasslands and savannas, 2) reducing canopy cover in these areas, and then 3) expanding these areas over time.

3.1.1 Species Diversity in Central Texas Grasslands

In central Texas, the Blackland Prairie and Edwards Plateau ecoregions merge to form an ecotone which contains characteristics of both. Of these two systems, the Blackland prairie is now more rare, and in an odd twist common in academia, more fully studied. The Blackland prairie is a part of the Grand prairie and runs from the San Antonio area east of what is now the Interstate 35 corridor to the Red River (Collins et al. 1975, Riskind and Collins 1975, Diamond and Smeins 1985, Diamond and Smeins 1993, Windhager 1999). It is part of the true prairie ecosystem (Weaver 1954) and as such is dominated by perennial tallgrass species and in healthy systems, almost entirely lacking trees except along riparian corridors (Dyksterhius 1946, Weaver 1968, Riskind and Collins 1975). An intact remnant of the Blackland prairie in Round Rock has been documented as having over 200 species (Gee and Campbell 1990). Researchers have documented at least six distinct vegetative communities making up the Blackland prairie (Collins et al. 1975).

The literature available for the Edwards Plateau vegetation describes the region as a savanna system with widely separated motts (clumps) of oaks with juniper primarily being restricted to steep slopes (Buechner 1944, Smeins et al. 1976, Knight et al. 1984, Fowler 1988) with the woody species probably being kept in check by a combination of periodic fire and high intensity/short duration grazing by bison (Fuhlendorf et al. 1996, Fuhlendorf and Smeins 1997a, Fuhlendorf and Smeins 1997b).

Most of the Water Quality Protection Lands reside in the ecotone between the Blackland Prairie and Edwards Plateau but possess characteristics primarily of the Edwards Plateau. The Lady Bird Johnson Wildflower Center site is in the same ecotone and is in fact adjacent to some of the WQPL properties. While far from being a pristine remnant of this system, it still has an overall richness of 302 native plant species on its 165 acres of natural areas. The Nature Conservancy Barton Creek Habitat Preserve has documented over 400 plant species on the over 4000 acre unit (Carr 2001).

In addition to the academic studies listed above, the U.S.D.A. Natural Resources Conservation Service (NRCS) has described each of the ecological sites (see Section 2.2) contained within the Water Quality Protection Lands. Each of these ecological site descriptions describes the multiple steady states that the ecological site can support and identifies the Historic Climax Plant Community. The descriptions list the common species and their approximate percent of the biomass that would compose the site in each state (typically 20 to 30 species).

3.1.2 Commercially Available Native Seed

Many of the Water Quality Protection Lands will need to have the seed of desirable species added to promote vigorous growth of the herbaceous community. Many of the species that are common both historically and currently in the region are readily available from commercial sources. These species include sideoats grama (*Bouteloua curtipendula*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), buffalograss (*Buchloe dactyloides*) green sprangletop (*Leptochloa dubia*), switchgrass (*Panicum virgatum*), big bluestem (*Andropogon gerardii*), plains coreopsis (*Coreopsis tinctoria*), horsemint (*Monarda citriodora*), prairie verbena (*Verbena bipinnatifida*), Indian blanket (*Gailardia pulchella*), Maximillian sunflower (*Helianthus maximiliani*), purple prairie clover (*Petalostemum candidum*), Texas bluebonnet (*Lupinus texensis*), black-eyed Susan (*Rudbeckia hirta*), bush sunflower (*Simsia calva*), Missouri primrose (*Oenothera missouriensis*), pink evening primrose (*Oenothera speciosa*), clasping coneflower (*Rudbeckia amplexicaulis*), pitcher sage (*Salvia azurea*), scarlet sage (*Salvia coccinea*), mealy blue sage (*Salvia farinacea*), and purple coneflower (*Echinacea purpurea*).

While all of these species are appropriate additions to property in the region, a subset of these species are recommended for rapid revegetation of disturbed areas (Table 3.1.2-1). Currently, forbs are not included in seeding efforts within areas with large deer populations, but as populations are reduced to sustainable levels, the use of forbs can be considered. Table 3.1.2-2 is a recommended seeding mix for areas in full shade that need to be revegetated, Table 3.1.2-3 is an herbaceous seed mix for riparian areas, and Table 3.1.2-4 is a rapid revegetation seed mix for use on shallow soil, such as that commonly found on Adobe ecological sites. This mix can be used in addition to or in place of Table 3.1.2-1 on areas in which the soil is deemed too shallow to immediately support larger grass species. This table also includes diversity species that should be added when funding allows, but are not intended to be part of the basic mix. In all of these lists (Tables 3.1.2-1 through 3.1.2-4) the pounds needed are calculated based on an acre, and the seeding rate assumes a no-till drill or similar method with a high germination rate (see Section 3.1.2-4). If other seed dispersal techniques are utilized, or a more dense stand is desired, the seeding rate for all species should be doubled.

Table 3.1.2-1. Recommended seed mix for the purposes of rapid revegetation on most areas of the Water Quality Protection Lands. "Ideal pounds needed" is calculated for a single acre. If the area has little or no vegetation cover, the rates given below should be tripled.

	Species	**Seed rate (lbs/acre)**	**Ideal % in Mix**	**Ideal lbs needed**
Forbs				
Plains coreopsis	*Coreopsis tinctoria*	2	5%	0.1
Indian blanket	*Gaillardia pulchella*	20	3%	0.6
Maximillian sunflower	*Helianthus maximiliani*	2	3%	0.03
standing cypress	*Ipomopsis rubra*	12	3%	0.18
Texas bluebonnet	*Lupinus texensis*	40	5%	1
horsemint	*Monarda citriodora*	9	5%	0.15
pink evening primrose	*Oenothera speciosa*	3	2%	0.02
purple prairie clover	*Petalostemum purpurea*	12	2%	0.16
pitcher sage	*Salvia azurea*	6	5%	0.15
mealy blue sage	*Salvia farinacea*	6	5%	0.3
bush sunflower	*Simsia calva*	8	2%	0.018
	Totals		40%	4.5
Grasses				
big bluestem	*Andropogon gerardii*	15	7%	1.2
purple three awn	*Aristida purpurea*	4	10%	0.4
sideoats grama	*Bouteloua curtipendula*	7	16%	1.12
buffalograss	*Bouteloua dactyloides*	75	10%	7.5
Canadian wildrye	*Elymus canadensis*	25	10%	2.5
green sprangletop	*Leptochloa dubia*	6	15%	0.9
upland switchgrass	*Panicum virgatum*	8	10%	0.8
little bluestem	*Schizachyrium scoparium*	20	5%	1
Indiangrass	*Sorghastrum nutans*	18	8%	1.44
eastern gamagrass	*Tripsacum dactyloides*	25	8%	2
	Totals		100%	18.9

Table 3.1.2-2. Recommended seed mix for revegetation in areas with shade on the Water Quality Protection Lands.

	Species	Typical seed rate (lbs/acre)	Ideal % in Mix	Ideal lbs needed
Forbs				
scarlet sage	*Salvia coccinea*	8	10%	0.8
frostweed	*Verbesina virginica*	6	30%	1.8
	Totals		40%	2.6
Grasses				
inland sea oats	*Chasmanthium latifolium*	12	10%	1.2
Canadian wildrye	*Elymus canadensis*	25	45%	11.25
little bluestem	*Schizachyrium scoparium*	20	5%	01
purpletop	*Tridens flavus*	11	10%	1.1
	Totals		70%	14.5

Table 3.1.2-3. Recommended seed mix for revegetation of herbaceous riparian communities on the Water Quality Protection Lands.

	Species	Typical seed rate (lbs/acre)	Ideal % in Mix	Ideal lbs needed
Forbs				
pitcher sage	*Salvia azurea*	3	5%	0.15
scarlet sage	*Salvia coccinea*	8	5%	0.4
frostweed	*Verbesina virginica*	6	5%	0.3
western ironweed	*Veronia baldwinii*	6	5%	0.3
horsemint	*Monarda citriodora*	3	5%	0.15
Missouri primrose	*Oenothera missouriensis*	5	5%	0.25
pink evening primrose	*Oenothera speciosa*	3	10%	0.3
	Totals		40%	1.85
Grasses				
big bluestem	*Andropogon gerardii*	15	10%	1.5
inland sea oats	*Chasmanthium latifolium*	25	10%	2.5
Canadian wildrye	*Elymus canadensis*	25	20%	5
green sprangletop	*Leptochloa dubia*	6	20%	1.2
switchgrass	*Panicum virgatum*	8	10%	0.8
little bluestem	*Schizachyrium scoparium*	20	10%	2
Indiangrass	*Sorghastrum nutans*	18	10%	1.8
eastern gamagrass	*Tripsacum dactyloides*	8	10%	0.8
	Totals		100%	19.3

Table 3.1.2-4. Recommended seed mix for shallow soil.

	Species	Typical seed rate (lbs/acre)	Ideal % in Mix	Ideal lbs needed
Grasses				
sideoats grama	*Bouteloua curtipendula*	7	30%	2.1
buffalograss	*Buchloe dactyloides*	75	15%	11.25
green sprangletop	*Leptochloa dubia*	6	30%	1.8
upland swichgrass	*Panicum virgatum*	8	5%	0.4
little bluestem	*Schizachyrium scoparium*	20	5%	1
Indiangrass	*Sorghastrum nutans*	18	5%	0.9
sand dropseed	*Sporobolus cryptandrus*	1	10%	0.1
	Totals		100%	17.55
Diversity Species				
cane bluestem	*Bothriochloa barbinoidis*	15	N/A	N/A
curley mesquite	*Hilaria belangeri*	4	N/A	N/A

Woody species should be added to riparian areas in the form of seed or very small container stock. A mixture of species that would be expected to germinate rapidly and those that would be expected to lay dormant in the soil for a time should be used. Appropriate species for the area include, but are not limited to, pecan (*Carya illinoinesis*), willow species (*Salix spp.*), cedar elm (*Ulmus crassifolia*), live oak (*Quercus virginiana*) and hackberry (*Celtis laevigata*). However, cedar elm, live oak and hackberry will likely emerge naturally and will not need to be seeded or planted. Seed that can remain viable in the soil for long periods of time include gum elastic (*Sideroxylon lanuginosa*), though it tends to form low dense thickets, rusty blackhaw viburnum (*Viburnum rufidulum*), escarpment black cherry (*Prunus serotina* var. *exima*), Mexican plum (*Prunus mexicana*), redbud (*Cercis canadensis*), sumac species (*Rhus* spp.),

3.1.3 Harvesting Seed

Many grass species that may be unavailable commercially would still be very useful for use in revegetation and soil stabilization on Water Quality Protection Lands. Species included in this category are bushy bluestem (*Andropogon glomeratus*), silver bluestem (*Bothriochloa saccharoides*), hairy grama (*Bouteloua hirsuta*), Texas grama (*Bouteloua rigidiseta*), red grama (*Bouteloua trifida*), curly-mesquite (*Hilaria belangeri*), seep muhly (*Muhlenbergia reverchonii*), big muhly (*Muhlenbergia lindheimeri*), Texas wintergrass (*Nassella leucotricha*), and meadow dropseed (*Sporobolus asper*). Many of these species are annuals or short-lived perennials that are particularly effective at quickly establishing cover on bare ground.

All of these species are already present on Water Quality Protection Lands and could therefore be harvested at limited expense beyond labor costs. This is an excellent activity for volunteer groups to undertake. The Lady Bird Johnson Wildflower Center routinely uses volunteers to gather seed of hard- to-find species for either greenhouse production or restoration of natural areas. Seed collection should be conducted in such a way that existing populations are not threatened. Collection should occur only from well established stands of native grasses and collection should not occur every year.

Mechanical equipment is also available for the small-scale harvesting of seeds. Since this equipment is expensive, mechanical harvesting is an activity that will probably only be practical undertaken by contract or trade with companies or groups already possessing this equipment.

3.1.4 Sowing Seed

Warm season grasses can be sown in the spring, fall or winter. Many of these grasses release their seed in the late summer or fall, so seeding at this time mimics their natural cycles. This allows the seed to be naturally weathered if necessary. However, seed sown in the fall has a greater chance of being eaten, washed or blown away. Most warm season grasses can also be sown in the early spring which reduces the risk of seed predation or loss to the elements, but additional processing may be necessary prior to seeding. In general, forbs should be sown in the fall.

Processed seed, obtained from a commercial seed company, can be very effectively planted with either a no-till drill or a Brillion seeder. Several distributors have developed versions of these seeding machines adapted for native seed by incorporating three separate seed bins for the three main types of seed: light fluffy seed, small hard seed and large hard seed. By using this type of range seeding equipment, all of the seed can be planted in one pass.

Uncleaned seed, as obtained by hand or mechanical harvest, is best applied with a broadcast seeder, by hand or shredded and applied with a hydromulch. Before any of these techniques are used, the soil should be lightly disturbed with a disk or similar implement.

3.1.5 Container Grown Stock and Salvaged Material

In some instances, it is important to have immediate above ground production on revegetation sites. In these instances, bare-root seedlings, container plants or salvaged material should be used to quickly revegetate the area. Tree plantings in particular can be very effectively undertaken with bare-root seedlings when deer populations are under control. If possible, when transplanting any of these types of materials, fill the hole with water, add the plant material, and then backfill, with the soil forming a muddy consistency. Field trials at the Lady Bird Johnson Wildflower Center have indicated that this method results in the greatest survivorship of the transplanted material, even if no subsequent water can be offered to the transplant.

Cuttings may be useful in wetter areas. However, cuttings may not be the best choice in drier areas that are subject to extreme desiccation between flood events. If cuttings are used, the best results would probably come from deep insertion of black willow (*Salix nigra*) or possibly roughleaf dogwood (*Cornus drummondii*). Black willow is one of the easier locally native trees to root, but many of the WQPL sites are likely too dry for willow. Deep planting of whip cuttings (typically 5-8 feet long, less than 1 inch caliper) could be successful. The whip cuttings should be planted as deeply as possible so that the bottom of the stick is in a saturated area, providing sustenance, and allowing additional adventitious roots to form further up the stem. Many species, such as pecan or oak, will not be able to handle this treatment. Black willow would be a good choice. Best results would be obtained if the cuttings are allowed to root before they are planted. This deep planting could provide prolonged access to wet soil and make the cuttings more resistant to being washed out by flood events before becoming firmly rooted, and more resilient after attacks by beaver or nutria due to larger energy reserves in the underground portions.

Other species that could work as direct planted dormant cuttings are *Eupatorium havanense* and *Forestiera pubescens*, though these are shrubs rather than trees, they could provide good perch sites for birds which could increase seed deposition in the area.

An alternate to planting dormant cuttings or large potted specimens would be planting of “liners”, little whippy plugs that require less water for establishment. This method has been successful at Lady Bird Lake with no supplemental irrigation.

3.2 Routine Historical Disturbance

3.2.1 Historical Vegetation

Models of the formation of plant species assemblages at the community- and landscape-scale invoke the association of environment, climate and time (Begon et al. 1986). These, in turn, interact with the changes in population and distribution of floral and faunal species. In North America, however, with the spread of human activity over the last 10,000 years, the growing influence of agriculture, industry and society has had an even more dramatic impact on vegetation change.

Historical accounts describe the landscape in central Texas becoming progressively woodier over the last 150 years (Smeins 1982). It is generally accepted to be a combination of the interacting effects of fire (or lack of it), grazing practice and drought. Although the central Texas vegetation was probably less woody than today, there were extensive juniper breaks, savannas and thickets of juniper and oak, particularly on shallow soils, rocky slopes and in canyons (Smeins 1980). Moreover, early accounts during the18th and 19th centuries describe the preponderance of woody species (chiefly oak and juniper) dominating many upland areas in central Texas (Weniger 1988). Data collated from early land surveys (Weniger 1988) includes descriptions of increasing grass density in the east (Burnet County), south (Kerr County), and west (Menard County) of the region. Indeed, early eyewitness accounts of low tree density in Kerr County (205 trees/ha) compare dramatically with densities of 815-1983 trees/ha on the Balcones Escarpment (Weniger 1988). There are a variety of mechanisms that maintained this mosaic of ecosystems historically.

Fire in many ecosystems represents part of the dynamic equilibrium, which maintains the balance between productivity and decomposition (Pyne 1982). Both wild and anthropogenic fire have drastically shaped the North American landscape. Several times during the Pleistocene, the Siberian land bridge between North America and Asia opened up as fluctuating global temperatures caused repeated drops in sea level. This allowed passage of fauna and flora between the two continents (Kreech 1999). Evidence from both North and South America suggests that humans successfully started colonizing the continent as early as 13,000 or 14,000 years ago (Kreech 1999). There is evidence of occupation and active land management practices on the Edwards Plateau for the last 11,000 years (Taylor and Smeins 1994). Although the early Paleo-Indians may have indirectly influenced landscape through hunting large herbivores, perhaps the greatest impact was the technology of fire.

3.2.2 Humans and Fire

Most plant communities around the world are to a greater or lesser extent fire-prone. Plants will burn under the right conditions, and many have evolved to survive under pressure of frequently occurring fire. Many plants are fire-adapted, either dependent (e.g. smoke or heat-triggered germination) or tolerant (e.g. fire resistant bark, post-fire resprouting etc.). Because of this, in most ecosystems, higher fire frequency enhances plant diversity, by repeatedly disturbing succession, resulting in a more heterogeneous environment supporting a larger suite of plant species (Wright and Bailey 1982).

The degree to which fire plays a role in a natural system can be assessed from a number of indicators (Bond and van Wilgen 1996, Pyne et al. 1996a, Burrows et al. 1999):

1. Historic factors: traditional aboriginal use of fire.
2. Climatic indicators: season and amount of rainfall and lightning frequency.
3. Floral factors: post-fire regeneration strategies (seeders/resprouters), post-fire floristic changes, fire toleration (bark thickness) presence of fire sensitive taxa.

In Texas, although lightning strikes undoubtedly significantly contributed to wildfires, it is proposed that the arrival of Paleo-Indians increased fire frequency in some areas, and possibly introduced it into landscapes that may have escaped fire for long periods of time.

There is some direct observational evidence from South Texas that Native Americans were using prescribed burning in Texas. Cabaza de Vaca, in 1528, records two such events:

> "The Indians go about with a firebrand, setting fire to the plains and timber so as to drive off the mosquitoes, and also to get the lizards and similar things they eat, to come out of soil." (Smeins 1997)
>
> "They [Coahuiltecans] are accustomed also to killing deer by encircling them with fires. The pasturage is taken from the cattle [bison] by burning, that necessity may drive them to seek it in places where it is desired they should go." (Newcomb 1999)

Similarly in East Texas the Caddoes practiced crop production of beans, maize and squash, reportedly used prescribed burning for land preparation (Newcomb 1999).

These practices would have resulted in the elevation of local fire frequencies. Examination of fire-scarred trees has demonstrated changes in season and frequency of fire in some areas could be attributed to frequent visits from the Mescalero Apache who inhabited West Texas and southeastern New Mexico (Kaye and Swetnam 1999).

Such evidence that Native Americans made a significant contribution to fire frequency in central Texas is additionally supported from extensive reports of the practices of other Native American tribes throughout North America, who used prescribed burning regularly for different objectives. It has been suggested that Native Americans had at least 70 different reasons for firing vegetation (Williams 2000). These may be broadly summarized into the following categories (adapted from (Kreech 1999, Williams 2000)):

> *Active driving of wild game*. Fires were used to drive wild game into other areas where they would be easier to hunt, for example: open grasslands, canyons, cliffs and other areas. Smoke and fire could also be used to drive alligators out of swamps, and raccoons and bears from trees.

Indirect driving of game though range management. Open areas of prairie, savannas and riparian areas could be maintained by burning. This removes herbaceous species and reduces the encroachment of woody species, thereby encouraging wild game into these areas, or for maintaining pasture for domesticated horses. Conversely, forage areas decimated by fire would force animals into other areas. For example, fire was used in thickets to reduce mistletoe populations, favored by some browsers, which would be forced to go in search of the browse in more open areas or areas nearer settlement.

Crop management. Fire could be used to increase productivity of several wild crops for example: blackberries, strawberries, and huckleberries. The removal of leaf litter and standing herbaceous biomass could aid forage of fallen acorns.

Small animal harvest. Grass fires would produce a harvest of edible lizards, moths, crickets and grasshoppers.

Pest management. Setting fires could control several pest species such as mosquitoes, blackflies, snakes and rodents.

Fireproofing. Prescribed fire around areas of settlements would act as an effective firebreak against potentially lethal wildfire.

Warfare and signaling. Not only could fire remove potential enemy hiding places, or flush them out, but also provide an effective screen during attack. Indirectly, enemy-managed pastures could be sabotaged with fire.

Visibility/Accessibility. Fires were used to clear areas around habitation for defense, trails for frequent travel, and popular hunting sites.

3.2.3 Lightning and Fire

Prior to the arrival of humans, lightning was the primary source of wildland fires in North America. Most lightning is cloud to cloud, but a significant proportion is cloud to ground. The area around Austin has an average of 8-13 lightning strikes per square mile per year, peaking during April through September (Reap 1994). This coincides with seasonal peak of biomass production. In spite of this these strikes often do not cause wildfires. For fuel ignition to occur, a continuing electric current must take place. Of all cloud-to-ground strikes, about 25% are of this category (Pyne et al. 1996a). Additionally, the fuel itself must be of significant fuel moisture content to burn. For fine fuels (grasses), only an hour or two of dry conditions are needed to carry a fire. For larger sized fuels, including living trees, longer periods of dry conditions are needed to increase flammability. Meteorologists state that so-called "dry lightning" (strikes outside precipitation areas) are most responsible for wildland fires (Rorig and Ferguson 1999). However many wildland fires result from "holdover" fires, those that smolder for days or weeks before weather conditions allow a spread to a more extensive fire (Pyne et al. 1996a). From these estimates we can see that for a single square mile, the chance of a fire starting within this area in any one year was slim. However, spreading this chance over an entire landscape, where there were few obstacles to prevent fire spread, it can readily be seen that the chance of a single wildland fire per year, in any one place, was a distinct possibility.

While it is difficult to specifically assess the extent and frequency of fires for this region, the little local narrative evidence we do have (Smeins 1997), combined with that from other areas in North America, suggest that fires did indeed occur and would have long-term effects on vegetation, such that non-woody plants dominated (Smeins 1997). Burn cycles in the southern plains have been estimated to be three to five years (Flores 1990). On the western Edwards Plateau over the last 100 years or so, the increase in population of redberry juniper (*Juniperus pinchotii*), a resprouting species that can become reproductive from seven to twelve years (Uechert 1997), suggests that if fire is responsible for repression of this species, they must have occurred at this return interval at least.

In central Texas these fires would vary from extensive (occurring over large areas of continuous fuel under prime burning conditions), to patchy (occurring in more heterogeneous environments where fuels were patchy due to changes in topography or vegetation as found in savannas) (Wells 1970). Overall the historic vegetation pattern was probably one of a "moving mosaic" of different plant communities, ranging from regions that burnt frequently to areas that rarely experienced fire, if ever.

3.2.4 Cattle versus Bison

With the increase of settlement of the area from 1700 onward, there was a transition from grazing and browsing native herbivores to free ranging and eventually confined livestock (Smeins 1980). Prior to European settlement, bison was the dominant large grazer. There are reports of extensive herds of bison throughout the region up to 1900 (e.g. (Lincecum and Phillips 1994); and (Smeins 1980) for review) This would have had significant impact on the system. Following settlement, the removal of grazing pressure by declining populations of these native herbivores, followed by (initial) low stocking rates of domestic cattle by settlers during several years of abundant rains (1874 to 1884), created more forage than could be utilized (Smith 1899). However, following this period, increased settlement and higher stocking rates decreased herbaceous productivity, and resulted in increase in brush species (such as mesquite, prickly pear (Smith 1899) and juniper (Smeins 1984b)). It can be seen that the impact of managed cattle had a significantly different effect than that of bison. Migrating bison produced short duration but very intense grazing events, similar in some ways to a fire. Land often had several years to recover between bison grazing events. Domestic cattle, on the other hand, caused continual disturbance, of varying intensity, of rangeland throughout the entire year. When continual or near-continual grazing keep herbaceous biomass suppressed, two things happen: populations of palatable species collapse at a local scale, which in turn aids the spread of woody species by reducing competition between woody and herbaceous species (Walker 1993). This phenomenon is exacerbated by simultaneous drought. Cattle have marginally different diets from bison, which although slight can have dramatic difference on vegetation. The spread of mesquite throughout central Texas has been largely attributed to the ingestion of mesquite pods and consequent defecation of seeds (Brown and Archer 1989). The differing grazing patterns and distribution of cattle and bison has contributed to changes in the distribution of mesquite. Specifically, the more widespread distribution of cattle as a vector of dispersal, combined with reduction of fire frequency, which in top-killing mesquite individuals retards pod production, has caused increased establishment of mesquite.

3.3 Management Techniques

3.3.1 Prescribed Burning

Prescribed burning can be defined as the systematically planned application of burning to meet specific management objectives (Scifres and Hamilton 1993). It is one of the most important tools available to the land manager and the success of the land management system will depend on its use. It can be used for a variety of applications such as brush control, to increase forage (Scifres and Hamilton 1993), reduction of fuel load to reduce wildfire risk (Pyne et al. 1996b), removal of invasive weeds (Britton et al. 1987), or part of a disturbance regime to maintain floral diversity (Bond and van Wilgen 1996). Whatever the objective, a prescribed burn requires thorough planning including statement of objectives, description of burn technique and follow-up assessment and monitoring. Broadly speaking, prescribed fire is used to maintain or manipulate systems that experience, or once experienced, historical or anthropogenic fires (see above). Details concerning how to implement prescribed burns relevant to Texas ecosystems can be found in a number of available publications (Landers Jr , McPherson et al. 1986, White and Hanselka 1989, Scifres and Hamilton 1993, McPherson 1997).

Fire as a form of disturbance has a marked effect on the ecology of any system. Its primary effect of combustion of living and dead fuels has two consequences: the interference or removal (not necessarily death) of existing plants and plant litter, and a redistribution of the nutrients as ash or smoke, which once were sequestered in plant material. This compositional rearrangement may stimulate regeneration from seed of existing species, resprouting of those individuals still alive, or the arrival or germination of species which were apparently absent prior to the burn (Bond and van Wilgen 1996, Pyne et al. 1996b). The fire itself, although a discrete event, possesses variable characteristics in intensity, frequency and season of burn. Manipulation of these variables is available to the land manager and can be used to affect vegetative growth, seed production and seed germination, which in turn drive the function, composition and structure of a plant community (Bond and van Wilgen 1996, Pyne et al. 1996b, McPherson 1997). For example, in central Texas a moderately intense fire any time of year is likely to cause high mortality of Ashe juniper (Smeins 1997) less than five feet in height. However, only a very intense fire is likely to cause significant death of the resprouting redberry juniper (Uechert 1997), or of larger Ashe juniper individuals. With herbaceous species, winter fire will repress spring forb production but will frequently favor spring and summer grass production.

3.3.2 Prescribed Grazing

Similar to fire events (described above) the varying characteristics of grazing can be utilized to manipulate ecological systems through management of grazing livestock. The timing and duration of grazing events with phenology of grazed species can affect not only overall productivity but also species composition in the long and short term. Therefore, intensity, frequency, duration, and season of grazing can all be manipulated to manage the landscape.

The characteristics of grazing such as season and intensity (stocking rate) can be similarly manipulated toward a desired management objective. There is a range of established methods of grazing management, which combine grazing, deferment (delay), and rotation (see (Holechek et al. 1989) for details), and techniques that ensure a more uniform use of the unit by livestock (such as numerous water sources and small mineral blocks). Simulation of historic grazing use by bison can be achieved using cattle management techniques such as short-duration grazing (Savory and Parsons 1980), and high-intensity, low-frequency grazing (Howell 1978). Both of these methods have undergone trials in Texas (see (Holechek et al. 1989) for review). Although the implementation of grazing as a method or tool for vegetation management at the landscape scale has been used, it must be stressed that in comparison,, rainfall, or the lack of it, has been frequently demonstrated to have a greater effect on productivity, and more significantly, species composition, than any other prescription tool (Biondini and Manske 1996).

3.3.3 Prescribed Mowing

Mowing can be used to mimic some aspects of grazing. It does however have obvious differences in impact. Mowing is non-selective with regard to species. Plant material is cut and evenly redistributed across the ground as litter, as opposed to digestion and concentrated defecation by herbivores. These processes suggest that mowing will have a different impact on the plant community dynamic compared to grazing and fire. They have been shown however to exhibit some equivalence in effect (Collins and Gibson 1990, Collins et al. 1998) but may in the long term result in thatch accumulation which may have differential effect on species propagation. Collecting the cut material (haying) will reduce thatch accumulation and may be financially self-supporting if the hay is traded for the mowing services, but may cause nutrient depletion. The advantages, on a small scale, of ease and variety of implementation (e.g. season, cut height, etc.) may render this technique useful in certain circumstances. However, given the size and topographical roughness of many of the Water Quality Protection Lands, mowing will be logistically difficult or impossible. In addition, maintaining properties like those contained within the WQPL with mowing is, in many cases, much more costly over time than maintenance with prescribed burning.

3.3.4 Brush Removal and Invasive Species Control

The change in ecological process caused by human interaction with the landscape, such as fire suppression and overgrazing, combined with drought events, are considered to be partially responsible for the increase in the woody component throughout Texas (Smeins 1984a). Not only does this lead to loss of herbaceous productivity, but also to decreases in plant diversity (locally and regionally) and to changes in hydrological characteristics of watersheds (Thurow and Carlson 1994) and possibly to its suitability for habitat for golden-cheeked warblers and black-capped vireos (Campbell 1995). There is considerable effort required to convert shrublands to a grassland or savanna state (Hanselka et al. 1996, Hanselka et al. 1999) mainly due to the biological characteristics of these invasive species: most are basally resprouting and readily propagated. With this in mind, any technique implemented to remove these species must take into account plant material both above- and belowground. A variety of brush management methods, outlined below, tailored to individual species have been demonstrated (Hanselka et al. 1999). Brush and invasive species management is best approached by integrating individual tools into a management system, and land managers should refer to the current IPM plan.

3.3.4.1 Hand Removal

Hand brush removal involves the use of chainsaws or hand pulling by crews operating on foot. This approach can be a very effective method in areas that are somewhat sensitive or are difficult to access with heavy machinery. Hand brush removal avoids the use of bulldozers and other heavy equipment, does less damage to the soil structure, and can be more targeted than mechanical removal. However, it requires significant labor expense, may be cost-prohibitive for large areas and may require additional stump treatment with herbicide for some plant species (as would be the case with other brush removal techniques). Groups such as American Youthworks Environmental-Corps (E-Corps) can provide cost-effective labor, provided the crews have the necessary skills. When large volunteer groups can be used, a significant amount of young juniper can be cut in a short amount of time with the proper equipment (manual loppers or, if they are properly trained, chainsaws). This method should be employed whenever additional sensitivity is required (such as internal drainage basins for karst features), when these groups are available and when they can function efficiently and effectively .

3.3.4.2 Prescribed fire

Prescribed fire can be used to control the encroachment of immature woody species as well as reduce woody cover. Although the use of prescribed fire is extremely effective in controlling non-resprouting species such as juniper (Smeins 1997), it has had varying results with resprouting species. Very intense (e.g. summer) fires may have effectively controlled such species in the past, and similar prescribed burns have had some recent success (Uechert 1997). While intense fires top-kill mesquite, it quickly resprouts from the base resulting in a multi-stemmed plant and a denser canopy. Low intensity fires have the benefit of reducing the number of stems and maintaining apical dominance to result in single-trunked trees with a raised branching structure (Wright et al. 1976, Ansley et al. 1995a, Ansley et al. 1995b). Low intensity fires have also been shown to control seedling emergence and establishment for mesquite (Kramp et al. 1999). Research in north Texas has found that multi-stemmed mesquite thickets can be pushed toward more open savannas of single stemmed trees by repeated low intensity burns (Ansley et al. 1995a, Ansley and Jacoby 1998). Evidence to date suggests that summer burns conducted on the Water Quality Protection Lands have had a significant impact on woody cover overall and have effectively removed cut material left on the ground. Evidence from Lady Bird Johnson Wildflower Center fire studies on degraded grasslands have also shown that summer burns do not result in the immediate increase in grass biomass that winter burns do (Ewing et al. 2005), but do result in a more diverse mix of native grasses and forbs (Simmons and Windhager 2009 pers comm.). Immediately following the summer burns on the Water Quality Protection Lands a diverse mix of forbs often dominate early in the first growing season. However, after a single growing season perennial grasses resume dominance of the site. Additionally, King Ranch bluestem dominance can be reduced following summer burns under certain conditions. But there is variability in grass response and some summer fires appear to have little longterm impact on King Ranch bluestem (pers comm. Matt McCaw 2009). It does appear however that many native grasses are unaffected by summer fire and repeated implementation of summer fire in degraded grasslands may help to drive the grassland toward a more desirable condition (Simmons et al. 2007).

Ideally, prescribed fire regimes will include a mixture of burn intensities, burn season and return intervals. Typically, initial (restoration) return intervals will be shorter (2 to 3 years) than maintenance return intervals. Maintenance return intervals of 4 to 12 years can be instated once the desired vegetative structure and composition is achieved. However, the appropriate return interval and fire intensity for a site will be influenced by many factors, the primary factors being ecological site, current condition and target condition. A moderate return interval (3 to 7 years) is appropriate for much of the WQPL and will likely be the most commonly used maintenance interval in savanna areas. However, areas with thin soils will take longer to accumulate fuel and will typically need longer return intervals (4 to 10 years) even during the restoration phase. Areas that are being managed for savanna with a higher woody percent cover target or as open woodland will need longer intervals. Alternately, areas with deep soils and/or a significant population of resprouting species will need shorter intervals (2 to 3 years) during the restoration phase. As woody populations are brought under control, these areas may move to moderate schedules. An important factor to consider when determining maintenance intervals is the time it takes the predominant woody species found on or near the site to mature to a stage at which they become less susceptible to fire. Height enhances survival because a greater proportion of aerial structures survive the fire (Brown et al 2000). For example, Ashe juniper individuals become more likely to survive low intensity fires when they reach five feet tall, while resprouting species such as mesquite and yaupon holly can survive fire much sooner/shorter because they can resprout after a complete loss of above ground structures. All areas should be at least annually examined to monitor plant composition, vegetative structure and soil conditions, and the results of these examinations should be used to determine appropriate fire regimes. For further discussion of this topic, see section 5.1.1, Adaptive Management.

3.3.4.3 Mechanical Removal

Mechanical methods are those that involve the use of machinery such as skid steers to physically cut or grub vegetation. Such methods should be implemented carefully to avoid compounding the problem due to distribution of living plant material and multi-stemmed resprouting. However such methods as roller chopping can be effective when used in conjunction with other brush control techniques outlined in this section (Hanselka et al. 1999). Use of several of these methods, however, is likely to cause excessive soil disturbance and would be inappropriate on the Water Quality Protection Lands. Preferred mechanical removal is the use of skid steer-mounted tree shears, which cut woody material at the surface without excessive soil disturbance, or mulching heads which grind plant material off above the soil surface. Avoiding the stacking of brush can substantially decrease soil compaction associated with repeated driving over the same ground to stack cut materials. WQPL’s current specifications require cutting at ground level and shattering the cut brush to a height less than 2 ft. This decreases soil compaction and simultaneously decreases the price for such work.

3.3.4.4 Chemical Removal

Brush can also be removed chemically through the use of herbicides. Herbicide is often the most efficient method for the control of certain resprouting brush species. These species, if cut or top-killed without herbicide will only resprout, compounding the original problem (Hanselka et al. 1996, Hanselka et al. 1999). The most effective technique where control of mesquite is necessary is a foliar spray of Reclaim© and Remedy©. Studies have shown this method to have a 92% kill rate at a cost of only $0.12 per plant (Lyons 1998), however very specific conditions are required for this technique to be effective. Water Quality Protection Lands staff, in conjunction with Watershed Protection Department staff, have developed an Integrated Pest Management Plan (IPM) which includes appropriate chemical removal practices for use on the WQPL, allows for a variety of approaches to increase effectiveness and efficiency of work and provides guidelines for treating undesirable species in a variety of environments. This plan should be followed whenever chemical treatment is recommended.

3.3.4.5 Biological Controls

Biological control is a developing management technique specifically for the control of non-native plant and animal species that lack predatory control in the system which they have invaded. Most of the work to date has been conducted on agricultural weeds such as exotic thistles. Insects are available to be released which target these species (Jackman et al. 1992, Boldt and Jackman 1993, Shea and Kelly 1998). These control agents are not without risk, however (Simberloff and Stiling 1996). Several released agents have also had adverse impacts on native species (Louda et al. 1997). Any use of these species should be cautious, and a full evaluation of possible unintended impacts should be conducted before their release.

3.3.4.6 Goating

Directed browsing by goats could be used to reduce the cover and vigor of brush communities, particularly in areas where resprouting species such as live oak and Texas persimmon need to be controlled. However, it should be noted that mountain laurel, which is also present in high numbers, is potentially toxic to goats. Advantages to using goats to control resprouting species may include reduced use of herbicides and less soil disturbance than would result from mechanical methods of control. Also, goats can access areas that would be difficult to treat by other means, such as steep slopes. Disadvantages include the need for time and money for fencing, water, additional food, protection from predators, medical care etc. However, several contractors exist that will assume responsibility for all goat management which includes transportation, fencing installation and removal, providing additional food, water and medical care, and protection from predators. Costs can range from $1.00/acre for rangeland to $750/acre near urban areas. There are no standard rates for contractors and contractors instead evaluate the individual situation and bid on the project. Contractors would be responsible for all goat management, which includes fencing installation and removal, providing water, and transportation. It is important to note that goats would be used as a tool for brush management. This is not an arrangement intended to improve the goats for market. The goats would be placed in areas the WQPL land manager deems appropriate, and without supplemental food goats will gain limited weight and may in fact lose weight. In addition, a strict accounting of goat numbers, incoming and outgoing, must be provided so that goats are not allowed to remain on the property following the completion of work, becoming a management issue themselves.

3.4 Wildlife Population Management

3.4.1 White-Tailed Deer and Blackbuck

Preliminary population surveys for white-tailed deer and black buck indicated that populations are high on several of the tracts. Due to their high rate of reproduction, these populations are most effectively controlled by lethal means. Since most of the large predators in the area have been eliminated, this means that land managers must assume the role of population control. On those properties deemed to be large enough (typically greater than 500 acres), regulated rifle hunting will be an effective management tool (McCullough 1979). In addition, it has been shown to be the most effective technique for removing deer (Ellingwood and Caturano 1988). In smaller units where deer population is high, the use of low integrity ammunition in rifles or shotgun hunting from elevated stands will offer a way to cull the deer population without posing risk to neighbors.

Experienced sharpshooters will be the most effective and efficient method to reduce population size. Trapping has also been used in the region, and while this method has not been thoroughly evaluated, its costs are exceptionally high. In this method, deer are trapped, netted, or immobilized so that they can be captured and relocated to an area where they are desired. One 1984 study in Wisconsin has shown trapping costs to range between \$113 to \$570 per deer (Ishmael and Rongstad 1984). Survival rates of relocated deer are frequently low, with rates ranging from 55% to 85% mortality (O'Bryan and McCullough 1985). Fertility control agents have also been used to control deer populations, though results seem to suggest that the reduced fertility is still not enough to keep populations at or below carrying capacity (Harder and Peterle 1974). This method too is very costly and requires frequent use of contraceptive-laced bait, dart injection, or annual capture and injection. Because of the proportion of the population that must receive the contraception, these methods are exceptionally difficult to use on a free-roaming population (Ellingwood and Caturano 1988).

If deer populations are not controlled, populations can increase dramatically, with the possibility of doubling in a single year (McCullough 1979, Ellingwood and Caturano 1988). If this happens, overuse of the habitat will result, causing decreased vegetative cover, increased erosion, and eventually a catastrophic die off of deer population, only to have this cycle repeat itself (Ellingwood and Caturano 1988) or in an extreme case, the complete die off of the deer herd (Smith 1986).

3.4.2 Feral Hogs

Experienced sharpshooters or trapping and lethal control can be used to control feral hog populations.

3.4.3 Other Feral Animals

Whenever feral or free-roaming domestic cats or dogs are seen on the property, it is recommended that the City of Austin Animal Control be informed and live traps be used to capture the animals and remove them from the site.

Section 4
Discussion of WQPL Land Management

4 Discussion of WQPL Land Management

4.1 Goals

Management recommendations are made based on the goals provided in section 1.3.

4.2 Objectives

Management activities will be structured to restore or ecologically "push" the systems toward, or maintain them at, a target vegetative community composition and structure. The target communities were chosen based on which community would best serve the stated goals, the Historic Climax Plant Communities given in the NRCS ecological site descriptions, the current condition of the site, and the practicality of moving toward a given community. An overview of vegetative goals and general treatment regimes can be found in figures 5.1-2 and 5.1-3.

4.2.1 Riparian Areas

The target community in riparian areas is a properly functioning gallery forest dominated by bottomland hardwood species with an herbaceous layer beneath, composed primarily of species with NRCS stability ratings between 6 and 9 (Nelle 2009). Stability ratings will be further discussed in section 5.1.3. Historically, the riparian areas along perennial and frequently flowing intermittent streams on the Edwards Plateau were of this community type. This community was chosen because it best supports the goal of enhanced water quality along stream channels by enhancing bank stability, removing nutrients and other pollutants such as sediments, helping to agrade stream channels and slow water velocities. However, riparian areas over the recharge zone have proven challenging to restore to these standards and more frequently resemble nearby upland communities, while contributing zone lands meet these standards comparatively easily.

4.2.2 Upland Areas

The target community for the majority of upland areas is a tall or midgrass savanna with a woody cover below 15%. Savanna is defined as scattered trees within a grassland matrix. This is the Historic Climax Plant Community for much of the WQPL. Improper grazing practices and fire suppression have allowed woody species, particularly Ashe juniper, to increase dramatically in percent cover and density. Restoration to savanna or prairie supports the goals of enhanced water quality and quantity, as discussed in section 1.3, and of ecosystem restoration.

4.2.3 Endangered Species

Recommendations will adhere to current state and national requirements for land management activities in and around endangered species habitat. Management activities in and around endangered species habitat can be modified to provide greater protection to endangered species where conditions warrant.

4.2.4 Invasive Plant Species

Invasive species reduce biodiversity and, in some cases, can work against the WQPL's aquifer recharge enhancement goal. Invasive species should be managed according to the IPM plan in place for the WQPL.

4.2.5 Animal Overpopulation

Populations of species such as white-tailed deer should be managed to prevent ecosystem damage as discussed in section 1.4.1.5. WQPL staff should consult with the Texas Parks and Wildlife Department regarding harvest goals on a management unit basis.

4.2.6 Oak Wilt

Oak wilt is a fungal disease infecting primarily red oaks (such as Spanish oak, Texas red (*Quercus buckleyi*) oak, Shumard oak (*Quercus shumardii*), blackjack oak (*Quercus marilandica*)) and live oaks. This disease is spread via the root system or through insect vectors. The most common control measure for large areas involves trenching around affected trees to sever the root grafts between trees and thereby control the spread of the fungus. Additionally, individual trees may be treated with a fungicide injection which can control the symptoms of infection but this treatment typically requires periodic injections for the rest of the life of the tree in order to be effective. Due to the high expense of fungicide application, this treatment is typically reserved for only very high value trees, typically in urban or suburban areas. In general, aggressive control of oak wilt within the interior of the WQPL is not recommended. Trenching disrupts the soil which leads to reduced water quality and provides a pathway for invasive species establishment. Additionally, trenching is very expensive. Saving oak trees lies outside the primary goal of protecting water quality and quantity, and in general the WQPL's limited funds should be used in the service of the primary goal of protecting water quality and quantity. Finally, 10% (Johnk et al. 2006) of oaks will typically survive exposure to oak wilt and those that do could serve as a seed source of fungus resistant progeny.

Trees found to have oak wilt can be evaluated on a case by case basis. Situations in which treatment may be warranted include: (1) Trees found in and around golden-cheeked warbler habitat because the Texas red oak and the insects that feed on it are an important food source for the birds. However, endangered species habitat enhancement is not a primary goal of the WQPL, so this action should be taken only as funds allow. (2) Near property boundaries where it is possible for oak wilt to spread beyond the boundaries of the WQPL.

General precautions should be followed to avoid spreading oak wilt

- Avoid wounding oaks between February and June when fungal mats are most likely to form
- Paint any cuts in oak trees with a tree coating material
- Disinfect any tools used on infected trees
- If infected trees are cut down, avoid storing the wood near healthy trees
- The fungus is heat sensitive, so there is no danger of spreading the fungus via prescribed burning

4.2.7 Woodland Health

Though the general vegetative goal for upland areas is grassland, some areas are not appropriate for grassland restoration. This can be due to factors such as the presence of golden-cheeked warbler habitat, cost, rough terrain that would make mechanical brush treatment impractical, or some characteristic of the property (small size, location near developments) that makes maintenance with prescribed fire impractical or inadvisable. The management objective for these areas should be increased woodland health. The past suppression of natural disturbances such as fire has allowed many of the woodlands found on the WQPL to develop into juniper monocultures, often with even-aged stands and little to no herbaceous layer. Additionally, recruitment of young hardwoods is often prevented by excess browsing pressure from species such as white-tailed deer. In this state, the woodland is less resilient to disturbance and provides poor habitat for species such as the golden-cheeked warbler, which requires both mature juniper for nesting material and broadleaved trees and shrubs to harbor the insects the warbler feeds on.

Increased woodland health can be encouraged through restoration of natural processes, such as fire, or activities that mimic natural disturbances such as disease and insect kill which create canopy openings that vary in size, shape and location. This encourages the woodland to move toward a state with mixed age stands, increased species diversity and a diverse herbaceous layer. To this end, Ashe juniper can be selectively thinned to allow recruitment of other species. Thinning should be done in small patches to mimic natural canopy openings. Following thinning, the opening can be seeded with appropriate hardwood and herbaceous species. Juniper seedlings emerging in the area will need to be mechanically controlled. It may be necessary to control white-tailed deer and perhaps to fence or mechanically protect young hardwoods. Tree architecture may also be modified to "limb up" trees simulating the effect of low intensity ground fires which kill lower branches of many woody species and promote herbaceous growth. Prescribed fire may also be a tool on some sites either as a follow up to mechanical thinning, or, in some cases in place of mechanical thinning where a continuous herbaceous layer could carry a surface fire without risk of significant impacts to the canopy. Smaller woodlands within larger savanna burn units may be allowed to burn through if fire behavior modelling indicates a low likelihood of extensive crown fires or widespread torching. Fire in golden-cheeked warbler habitat may proceed if not otherwise prohibited by the U.S. Fish and Wildlife Service (USFWS). As stated previously, land managers should consult with USFWS when planning land management activities within occupied golden-cheeked warbler habitat that could impact canopy cover.

Section 5
Management Recommendations

Section 5. Management Recommendations

5.1 Site-Specific Recommended Management

Each of the WQPL management units has been subdivided into treatment units based on past land use, ecological sites and physical features (such as roads, creeks, etc.), and each has been assigned an overall vegetative goal and treatment regime. An overview of vegetative goals and general treatment regimes can be found in Figures 5.1-2 and 5.1-3. Figures 5.2-1 to 5.2-9 contain maps of the treatment units in each management unit. These treatment units are numbered within each management unit, and these numbers will be used to refer to them in the recommendations that follow.

Management recommendations are made based on the goals provided in Section 1.3 and the current ecological state of the treatment unit with a desire to prioritize management on those areas that will provide the greatest benefits with the least inputs. However, management strategies will need to evolve to reflect changing site conditions. This approach is called adaptive management and is discussed more fully in Section 5.1.1. In addition, areas may exist within treatment units that require a management approach differing from that applied to the larger unit. Typically this occurs within occupied endangered species habitat, within riparian corridors or in the vicinity of particularly sensitive features such as springs, seeps or recharge features. Full discussions of the management techniques recommended in this section are contained in Sections 3.0 and 4.0.

5.1.1 Adaptive Management

Overview

This management plan is intended to provide guidance for the next 10 years. However, natural systems change over time in response to factors such as management inputs, weather, disturbance, etc., and management strategies should evolve with changing conditions. This approach is called adaptive management. Adaptive management is defined here as a decision-making process in which management is informed, in part, by monitoring of the site conditions and, where feasible, functionality of the targeted ecosystem services. This process should be employed on the WQPL. Additionally, research on ecosystem response to management tools such as prescribed fire should be incorporated into the cycle of management action and monitoring whenever possible.

Data collected during ecological monitoring can be assessed either by comparing conditions found on the management site to those of a reference ecosystem with similar soil, biota and climate, or by comparing structural, compositional and functional measures of the management site to a model compiled by data of various sources and types to re-construct either pre-settlement conditions or conditions under which desired ecosystem services are optimized. The latter approach is more appropriate for the WQPL in part for practical reasons such as the lack of appropriate reference sites, but also because the goals of the WQPL are driven by ecosystem function. Assessment parameters should be selected based on the goals for the site, practicality of implementation and availability of funding. Selected parameters should provide insight into the baseline condition of the site and the impact of management action or inaction. Monitoring will need to be done at several spatial and temporal scales to be meaningful.

Large scale monitoring needs to be done to understand context and overall management progression, but small scale monitoring is also important so that mechanisms of change can be understood (Whisenant 1999). Ideally, monitoring activities should include both rapid visual assessments that can be done frequently over a large area and less frequent, but higher resolution studies.

Adaptive Management for the WQPL

The primary goal of the WQPL is to produce the optimum level of clean water from project lands to recharge the Barton Springs segment of the Edwards Aquifer. This goal is achieved by restoration of properly functioning ecosystems, specifically savanna and prairie ecosystems. The restoration of properly functioning ecosystems capable of providing an array of ecosystem services is, in itself, a secondary goal. Therefore, assessment parameters that provide information on hydrologic function should be given priority. Direct measures of hydrologic function, such as evapotranspiration, infiltration, runoff, hydraulic conductivity, deep drainage and water balance are the most desirable and should be assessed when possible. However, measuring these parameters is often expensive, logistically complicated, and sometimes impossible. A more practical, albeit indirect, measure of success would be to use models of ecosystem services as functions of community parameters, for example recharge as related to canopy cover. Vegetative composition and structure will provide insight into the progress toward the target community and the hydrologic function of the site, thus changes in dominant species composition as well as woody, herbaceous and litter soil cover should be high priority. In addition, these parameters provide information on the transition of sites between ecological states, such as from open savanna to woodland. Changes in these parameters can signal when gains made by previous management are in danger of being compromised without timely maintenance, or when an area is on the point of becoming more difficult to restore. Restoration to savanna becomes increasingly challenging and expensive as woody cover and height increases and herbaceous cover decreases, primarily because the effectiveness of prescribed fire as a brush management tool declines under these conditions. Vegetative community monitoring will help managers anticipate this transition. Assessments of soil surface conditions (physical crusting, erosion features, litter, vegetative cover, microbiotic crust cover and microtopography) can provide information on the hydrologic and nutrient cycling of the site as well as information on erosion (Whisenant 1999). In summary, monitoring both the community and its function are necessary. Monitoring function is more desirable, but is more expensive and sometimes not possible, so functional assessments should be supplemented with community assessments.

Prescribed fire is one of the most important management tools available to WQPL land managers and its effects will need to be monitored. Vegetative recovery from fire is similar to recovery from other disturbances in that recovery will be successional in nature. It is important to monitor at different stages, both before and after fire to determine the trajectory of community development. Burn return intervals and target intensities should be determined in part by the current and target species composition and structure of the site, fuel load, fuel type, soil type and depth, topography, wildland-urban interface concerns and the presence of endangered species.

5.1.2 Brush Management

To reduce canopy cover below 15%, it will often be necessary to remove other woody species in addition to juniper. Where woody biomass is high, removal should occur in stages, allowing recovery time between removal events. For example, woody populations can be categorized and removed by size class, beginning with the smallest size class. This will simplify contract administration, slash management and will reduce the fuel load created with each removal event. Whenever possible, when woody material is recommended to be cut, it should be shattered or compressed to a maximum height of two feet and left in place. This level of compression will ensure that the majority of the material will be consumed during the next prescribed burn on the site and reduces ember production during follow-up prescribed fire. In addition, shattered material can protect grass and forb seedlings emerging after brush clearing and provide erosion control between mechanical cutting and prescribed fire. Only as a last resort should this material be piled and burned on site. Burn piles can sterilize the soil, leave the soil bare for extended periods during which invasive species can become established, and can lead to increased erosion when placed on slopes (Wright et al. 1982). In addition, creating piles requires more driving of equipment which exacerbates erosion and general site disturbance. If on-site burn piles must occur, they should be located where they will have the least chance for erosion and should be reused. When burning is complete, the areas should be reseeded in the spring with the seed mix described in Table 3.1.2-1. Light disking or harrowing may be necessary to break the soil crust. Brush management activities should be coordinated with prescribed burn planning. It is important that any thinning be followed up with regular prescribed burns to prevent regrowth of woody species.

The percent of woody species recommended to be cut is based on the current woody coverage of the site, soil and NRCS ecological site description. The target woody cover over much of the WQPL upland areas should be less than 15% in order to maximize water yield. An exponential relationship appears to exist between percent cover and water yield, with the most significant increases in yield beginning at 15% cover and increasing as percent cover falls toward 0% (McCaw 2009). However, it is not practical to reduce the percent woody cover to less than 15% across all of the upland areas, and sometimes it is not ecologically advisable. Examples of situations in which reduction of woody cover below 15% would not be advisable include occupied golden-cheeked warbler or black-capped vireo habitat, property edges and areas adjacent to external roadways where a woody buffer would serve as a barrier to invasive species seed (and discourage people from entering at unauthorized points), very steep or rocky ground which will make mechanical treatment less practical, or areas where prescribed fire is impractical or inadvisable.

Additionally, there are some areas that are better targets than others for significant levels of woody reduction. Upland areas should be prioritized for brush management as follows:

1. Soils shallow and underlain by fractured geologic substrate, such as that found within the recharge zone
2. Areas with ecological site descriptions that indicate a historic climax plant community of grassland or savanna with a woody cover below 30%.
3. Efficient use of resources
    - Current condition
        - Target areas that are at a tipping point between savanna and dense brush. These are areas that retain prairie vegetation, but have a high percentage of scattered young juniper, typically with less than 50 % canopy cover, and/or are acquiring characteristics that will make prescribed fire less effective or more difficult to perform, such as increasing brush height (e.g. juniper approaching 5 ft tall) coupled with decreasing herbaceous coverage/fine fuels.
        - Current savanna. Maintenance of current savanna is much less expensive than reclaiming one from dense brush.
    - Practicality
        - Access
        - Property size
        - Wildland-urban interface concerns
        - Current uses

5.1.3 Riparian Areas

Larger waterways (perennial and intermittent) should be restored to gallery forest. Many of the strategies discussed in Section 4.2.7, Woodland Health, can be successfully employed in riparian areas. Increased native diversity should be encouraged through selective juniper thinning and seeding of native woody and herbaceous species such as those listed in Table 3.1.2-3. Primary goals guiding species selection in the riparian areas are enhanced bank stability and water quality. Many species found in central and southwest Texas have been given draft stability ratings based on their contribution to bank stability (Nelle 2009). Stability ratings range from 1 to 10, with 1 approximating the bare ground and 10 anchored rock. Ideally, riparian areas will be dominated by plants with stability ratings between 6 and 9. Stability ratings of 7 or higher are considered to be the minimum for acceptable bank stability. However, combinations of species, particularly woody species in association with grasses or sedges, can provide higher stabilities than reflected in individual species ratings (Nelle 2009). In addition to stability ratings, USFWS wetland indicator status should be considered. Riparian areas should contain a mix of obligate wetland, facultative wetland and facultative species, dependent on water availability. Perennial waterways, generally found in the contributing zone, can support a larger complement of obligate and facultative wetland species and intermittent waterways, generally found in the recharge zone, will require a higher proportion of facultative species. Regardless of the mix, it is important that all riparian areas contain some species from the facultative groups to provide stability as water availability fluctuates (S. Nelle pers. comm.).

Native woody species are most likely to establish during a flood year (Glenn & Naglar 2005). However, rainfall prediction is difficult so emphasis should be shifted from container grown plants to seeding when adding plant material. Seed can be relatively inexpensively added each year. Cuttings could be used in wetter areas, but most of the riparian areas on these properties will be too dry to allow for their survival. Further discussion of use of cuttings can be found in section 3.1.5.

5.1.4 Endangered Species Habitat

The land management recommendations for areas containing occupied golden-cheeked warbler or black-capped vireo habitat will adhere to the guidelines outlined for Texas Parks and Wildlife in Campbell 2003.

Potential golden-cheeked warbler habitat was delineated as part of the 2001 WQPL Land Management Plan. Potential habitat was then surveyed for the presence or absence of golden-cheeked warblers over successive years. Surveys of potential habitat were completed for the currently held fee simple properties in the summer of 2010.

A discussion of potential golden-cheeked warbler habitat characteristics is included below for informational purposes and to aid land managers during initial assessments of properties acquired in the future. Properties acquired in the future that have not been examined for golden-cheeked warbler habitat, will need to have potential delineated. Areas identified as potential habitat, which have not already been surveyed, will then need to be surveyed for both the presence of vegetative communities capable of supporting golden-cheeked warblers and for the presence or absence of warblers. The habitat maps created for the Hays County Habitat Conservation Plan, authored by Loomis Austin, will be a helpful starting point for dileneating potental habitat. Figure 5.1-1 displays potential habitat in the region of the WQPL. The methods used by Loomis Austin to create the Hays County Habitat Conservation Plan potential golden-cheeked warbler habitat maps are summarized below and a full discussion can be found in Appendix 8.4.

Potential golden-cheeked warbler habitat is generally defined in the Hays County Habitat Conservation Plan as areas with an average tree cover of at least 30% within a 10 acre neighborhood. The following three classes of potential habitat are recognized:

> **Class 1**: Potential Low Quality GCW Habitat (average neighborhood canopy cover of 30-50% and within 90m of high or medium quality habitat
> **Class 2**: Potential Medium Quality GCW Habitat (average neighborhood canopy cover 50-70%)
> **Class 3**: Potential High Quality GCW Habitat (average neighborhood canopy cover 80-100%)

These are broad classes that have been delineated using remotely sensed woodland and forest canopy cover. The potential habitat classes are further refined based on the probability of occupancy by golden-cheeked warblers. The probability of occupancy analysis is based on work by Magness et al. (2006) who found that 40% of the landscape must have woodland cover to be occupied by golden-cheeked warblers and that 80% woodland cover is required for the probability of occupancy to exceed 50%. The probability of occupancy is divided into three classes:

- "not likely to be occupied" – the percentage of potential habitat in the landscape was between 0 and 40%
- "may be occupied" – the percentage of potential habitat in the landscape was between 40 and 80%
- "likely to be occupied" – the percentage of potential habitat in the landscape was between 80 and 100%

Areas classified as potential habitat based on this model that have not previously been examined for golden-cheeked warbler habitat will need to be surveyed by a certified wildlife biologist familiar with the species to determine if the area is likely to support golden-cheeked warblers. If the biologist feels the area could support golden-cheeked warbler, presence/absence surveys should be done. Campbell 2003 defines the following habitats in terms of the likelihood that they can support golden-cheeked warblers.

Class 3: Habitat types where GCW are expected to occur (protection efforts should be focused in these habitat types)

- Woodland with mature Ashe juniper (15 feet tall, 5 inch diameter at breast height (DBH)) in a natural mix with oaks, elms and other hardwoods, in mesic areas such as steep canyons and slopes, and adjacent uplands
- Nearly continuous canopy cover, with 50-100% canopy closure, overall woodland canopy height of 20 feet or more

Habitat of this type is also important to deer, turkey, other songbirds and others because of the diversity of the vegetation and topography and often proximity to water. Woodlands like this should be retained wherever they occur, especially along creeks and draws.

Class 2: Habitat types that may be used by GCW

Texas Parks and Wildlife has identified four habitat types which are occasionally used by golden-cheeked warbler with tree canopy cover ranging from 35 to 100%. WQPL staff should treat habitat of this type as "occupied" until ground surveys determine if the sites support warblers.

- Stands of mature Ashe juniper (shredding bark) greater than 15 feet tall and 5 inch DBH, with scattered live oaks (at least 10% of cover), where total canopy is greater than 35% and canopy height of at least 20 feet
- Bottomlands along creeks and drainages with at least 35% canopy of deciduous trees (canopy height of 20 feet) with mature Ashe juniper
- Mixed stands of post oak and or blackjack oak (10-30% canopy cover) with scattered mature Ashe juniper, where total canopy cover exceeds 35%, overall woodland canopy height is 20 feet
- Mixed stands of shin oak (10-30% canopy cover) with scattered mature Ashe juniper, total canopy cover greater than 35%, canopy height 20 feet

This type of habitat is most often used by warblers when adjacent to or near high quality habitat and may have little value to golden-cheeked warblers if high quality habitat is not nearby.

Class 1: Areas where GCW are not expected to occur
These habitat areas are unlikely to be used by golden-cheeked warblers unless adjacent to other higher value warbler habitat.

- Stands of small Ashe juniper, averaging less than15 feet in height and 5 inches DBH. Includes small juniper invading range and old fields. Often dry and flat, lack oaks and other broad-leaved trees and shrubs. Often have been cleared in last 20 years and are not considered habitat
- Pure stands of larger Ashe juniper with few or no oaks or other hardwoods
- Open park-like woodlands or savannahs (even with old juniper) where canopy cover is less than 35%. Often have scattered live oak and other trees
- Small junipers and other trees along fences
- Small junipers coming up under larger hardwoods where junipers have been removed in the last 20 years

General recommendations for Golden-cheeked warbler habitat
The goal of management in and around potential golden-cheeked warbler habitat will be to minimize negative impacts or improve occupied habitat while restoring savanna and grassland in appropriate areas outside of occupied habitat**.**

Potential Type 1, 2 and 3 habitat should be delineated based on remote sensing data. The starting point for this delineation, for areas that have not been previously examined, should be the Potential Golden-cheeked warbler Habitat map created for the Hays County Regional Habitat Conservation Plan (Figure 5.1-1). Potential habitat should then be surveyed by a certified wildlife biologist familiar with golden-cheeked warblers for appropriate vegetative composition and structure and for the presence/absence of golden-cheeked warblers. Treat all potential habitat as occupied habitat until presence/absence surveys show a site to be unoccupied**.** Given that golden-cheeked warbler surveys of currently held WQPL properties were completed in 2010, this recommendation applies only to properties acquired in the future. Also note, only areas occupied during the breeding season require special management considerations**.** A 300 foot buffer of woodland vegetation should be maintained adjacent to golden-cheeked warbler habitat to minimize indirect impacts to the birds.

Where golden-cheeked warblers have been sighted, or are likely to occur, all management that could potentially disrupt golden-cheeked warbler breeding and rearing of young should be limited to times when warblers are not present (August 1 to February 28, Ladd and Gass 1999). No management activities, other than non-invasive monitoring, should occur within the core warbler breeding season, between March 14 to May 15 within occupied habitat(Campbell 2003). Within the occupied/likely occupied habitat itself and within the 300 foot buffer surrounding occupied/likely occupied habitat, all management should occur between August 1 and February 28.

When called for by the treatment parameters of the surrounding treatment unit, selective removal of small juniper, less than 15 feet tall and 5 inches diameter at breast height (DBH), can be done without damaging habitat as long as the tree canopy is not significantly reduced. Reducing the percentage of young juniper should help to meet ecosystem restoration goals without negatively impacting golden-cheeked warbler habitat (Campbell 1995, 2003).

WQPL staff should collaborate with the U.S. Fish and Wildlife Service when planning management activities within occupied habitat that could disrupt canopy cover, such as mechanical canopy opening and prescribed burning intended to improve woodland health.

Black-capped Vireo

Summary of TPWD Management Guidelines for Black-capped Vireo (Campbell 2003)

Black-capped vireos occupy a mosaic of shrubs and open grassland with abundant woody foliage below 10 feet and reaching ground level for nesting. Open grassland between clumps of shrubs is also important for good vireo habitat. Prescribed burning can be a good tool to maintain or create the desired vegetation structure. Cool season burns (before March 15) can be used to control small juniper and maintain open shrubland. More intense fires can help create vireo habitat Growing-season burns should be done only in areas that do not currently support black-capped vireos. Selective brush management can also be used to maintain or create vireo habitat, though creating endangered species habitat is not a goal or requirement of the WQPL. Good nesting habitat generally has between 30-60% shrub canopy. Selective brush removal of species such as juniper, mesquite and pricklypear, during the non-breeding season (September-February) can be used to keep the habitat favorable by maintaining the proper shrub canopy and encouraging growth of broad-leaved shrubs. Radical changes in shrub canopy from one year to the next should be avoided. Grazing and browsing management should be employed because excessive browsing destroys the thick woody growth needed for nest concealment.

Recommendations for Black-capped Vireo habitat within the WQPL

At least one black-capped vireo has been sighted near the boundary of the Hays County Ranch tract and the Little Bear Creek tract. A certified wildlife biologist, familiar with black-capped vireos should delineate potential habitat within the WQPL. Surveys were completed in summer 2010. Areas identified as potential habitat should then be resurveyed during future breeding seasons to determine they are occupied. Selective brush clearing in occupied habitat areas should not reduce the shrub canopy below 30%-60% and should be undertaken during the non-breeding season (September-February). Additionally, brush management via goating and warm season burns should be avoided within occupied habitat.

5.2 Management Unit Recommendations

The target canopy cover for much of the WQPL is less than 15%, unless otherwise stated. Areas in which the canopy cover should not be reduced below 15% include occupied golden-cheeked warbler habitat, occupied black-capped vireo habitat and wooded riparian corridors. Removal of woody vegetation should be guided and regulated by best management practices concerning soil disturbance, herbicide use and the stated goals of the WQPL. The best management practices in place for the WQPL have been informed by years of experience with the site and should not, in the future, be derived from some other source. However, continued peer to peer networking and review of scientific and technical literature will allow continued innovations.

Appropriate fire return intervals will change over time. In general, early in the restoration process, return intervals will need to be short (2-4 years). As restoration progresses and woody populations are brought under control, longer maintenance intervals (4 to 12 years) can be employed. In addition, return intervals may need to be shorter (2-4 years) on savanna targeted sites with deeper soils that can support more rapid vegetative regrowth and on sites with a large component of resprouting woody species. Longer return intervals (4-10 years) are appropriate for sites with shallower soil that will take longer to accumulate fuel and on sites where the desired woody cover is higher than 15%. A moderate return interval (3-7 years) is appropriate for savanna sites lying between these two extremes both in terms of soil depth and current condition. The return interval for a particular site should be determined based on the goal for the site and its condition (fuel load, woody cover, species composition. soil type, etc.). Because current condition is an ever changing variable, decisions on return interval, season and intensity of fire will need to be based on careful monitoring as discussed in Section 5.1.1, Adaptive Management.

Survey results provide the most accurate assessment of a site's golden-cheeked warbler or black-capped vireo habitat potential. Golden-cheeked warbler and black-capped vireo surveys of WQPL were completed in the summer of 2010, and the results of these, and previous, surveys are displayed in Figures 2.3-22 to 2.3-27.

WQPL staff should collaborate with USFWS when planning management activities within occupied golden-cheeked warbler or black capped vireo habitat that could disrupt canopy cover.

5.2.1 Bull Creek Management Unit

The Bull Creek management unit has been divided into two treatment units (Figure 5.2-1). No golden-cheeked warbler were found during a 1993 survey of this property, but the habitat was characterized as marginal to fair (Sherrod 1993), and warblers have been detected since the 1993 survey. Management activities in occupied habitat should be conducted between August 1 and February 28. This unit contains a hiking trail that is open year round. Studies are underway to determine what impact, if any, this has on water quality and quantity. The trail could have a negative impact on golden-cheeked warbler habitat in the area.

Unit 1 is primarily a Clay Loam ecological site containing a combination of mixed woodland and savanna areas that are being invaded by juniper. Upon purchase, this unit was primarily composed of shallow-rooted, early successional grasses, though mixed hardwood and juniper woodland, overlying a Steep Adobe ecological site, also existed. Several areas contained significant gully erosion. The site has seen some recovery of mid and tallgrass species as result of management activities. Some of the juniper encroaching on open areas has been hand cut or limbed up and the cut material was placed in windrows. These activities were done in conjunction with seeding native grasses. Currently there is little evidence of gully erosion, though the soil remains very thin.

Juniper along the perimeter of the property should be left to maintain a visual and noise buffer to Spicewood Springs Road. Open areas can be seeded with the seed mix given in Table 3.1.2-1 with a no-till drill, though seeding into dense stands of King Ranch bluestem will be met with limited success. Seeding primarily into areas disturbed by fire, brush management activities, trail modification/use etc. may be the most effective strategy. Where terrain prohibits the use of machinery, soil should be lightly disturbed (by hand with a dirt rake, or lightly disked if possible), and the seed broadcast by hand. All junipers encroaching in the currently open areas should be cut. If prescribed fire is a possibility in these open areas, cut material should be shattered or compressed to a maximum height of two feet. However, prescribed burning on this unit will be complicated by the unit's small size, the presence of a hiking trail and the potential for smoke impacts to surrounding development. Though the site would provide a good opportunity to educate the public about prescribed burning and its place in land management for water yield. The site should be monitored for the reemergence of gullies, though gullies should not reappear as long as the herbaceous layer remains intact. Mesquite is beginning to emerge and should be chemically controlled. Most of the woodland areas in this unit are composed entirely of young juniper. If these areas are found to contain no occupied golden-cheeked warbler habitat and if resources are available, these stands could be completely removed and reseeded to promote herbaceous growth, or woodland health practices can be employed. Within occupied habitat, juniper under 15 feet or less than 5 inches diameter at breast height (DBH) can be selectively thinned. Slash should be shattered or compressed to a maximum height of 2 feet or removed from the site. As grass accumulates, prescribed burns should be used to maintain and stimulate grass vigor. If the area cannot be burned, haying (mowing if this is not possible) on a four year cycle should be sufficient to repress woody regrowth and maintain the vigor of the herbaceous community.

Unit 2 contains primarily a mixed hardwood woodland and a riparian community. The unit has a slight over-dominance of young juniper. Woodland health practices should be employed as appropriate to enhance both woody and herbaceous diversity. Cut material should be shattered, compressed or removed from the site. Within occupied golden-cheeked warbler habitat, overall canopy cover should not be significantly reduced, but juniper under 15 feet or less than 5 inches DBH can be selectively thinned. Reducing the percentage of young juniper in this area should help to meet ecosystem restoration goals without negatively impacting golden-cheeked warbler habitat (Campbell 1995). Thinned areas should then be seeded with the seed mix described in Table 3.1.2-2.

The riparian community, situated on Clay Loam and Steep Adobe ecological sites, has a mixed hardwood overstory and an intact herbaceous layer. The cliff face on the eastern side of Bull Creek harbors three plant species of interest: Texas amorpha, scarlet leatherflower and Buckley tridens. Because of this and the steepness of the terrain, this area should primarily be left alone. Along the creek channel itself as well as on the more classic riparian zone on the western side of the creek, the area should be seeded with the seed mix described in Table 3.1.2-3, particularly following soil disturbance.

The unit as a whole should be monitored for increases in juniper dominance, reduction of herbaceous cover and emergence of invasive species. Woodland health practices should be employed as appropriate (see section 4.2.7, Woodland Health).

5.2.2 Upper Barton Creek Management Unit

The Upper Barton Creek management unit, which is still being explored, is being managed as a single treatment unit (Figure 5.2-2). The unit is dominated by closed canopy woodland, much of which has an overabundance of small juniper and very little herbaceous vegetation. Bare soil is frequently exposed in the spaces between juniper brakes. Some areas retain populations of mid and tall grasses, but many of the individuals are pedestalled, providing evidence of erosion. Riparian areas within the unit are frequently dominated by juniper and lack the diverse woody canopy required for riparian health. Numerous golden-cheeked warbler sightings have occurred on the site and several territories were delineated during the 2010 surveys. Occupied habitat should be buffered by 300 feet and all management within these areas should occur when warblers are not present (August 1 to February 28) (Ladd and Gass 1999). Examples of the rare Texas madrone (*Arbutus xalapensis* var. *texana*), Texas barberry and Buckley tridens occur on this site. Deer populations on this tract are likely typical for the area, but lower than other management units.

The overall goal for the unit is woodland and riparian health. This goal was selected because of the density of woody species, the presence of occupied golden-cheeked warbler habitat and the presence of woodland plant species of interest. However, areas with existing grassland should be protected from further encroachment and, in some cases, expanded to allow connectivity and to increase the presence of this important community. Creation of black-capped vireo (BCV) habitat has also been discussed for portions of this unit. Creation of endangered species habitat is not a goal or requirement of the WQPL but can be undertaken in support of general ecological health, so long the primary goals of the WQPL are not compromised.

Woodland health techniques, as discussed in Section 4.2.7, should be judiciously employed in woodland areas. Control of the deer population will aid in the recruitment of hardwood seedling and forbs. Junipers can be selectively thinned in areas where they are dominant to allow for hardwood release. Inside occupied golden-cheeked warbler habitat and buffered zones, juniper above 5 inches DBH or 15 ft tall should not be thinned, but smaller trees can be removed without damaging golden-cheeked warbler habitat (Campbell 2003). Cut material should be left in place to protect hardwood seedlings. The thinned areas can be left to regenerate naturally or can be seeded/planted with hardwoods. The openings should be protected from browsing if deer populations are not at sustainable levels. Openings should also be maintained to prevent reestablishment of dense juniper canopy. Prescribed burning should be deferred in these areas to allow the mixed hardwood/juniper woodland to mature. Prescribed fire may be used judiciously as a tool on some sites either as a follow up to mechanical thinning, or, in some cases in place of mechanical thinning where a continuous herbaceous layer could carry a surface fire without risk of significant impacts to the canopy. WQPL staff should collaborate with the U.S. Fish and Wildlife Service when planning management activities within occupied golden-cheeked warbler habitat that could disrupt canopy cover, such as mechanical canopy opening and prescribed burning intended to improve woodland health.

Dispersed through this unit are several areas that would benefit from restoration/management goals other than woodland health. These areas will be identified through site analyses which combine remote analysis (of soils, topography etc.) and on the ground observations. Remote analysis provides overall context, helps to identify landscape scale patterns and helps to focus ground work. On the ground observation provides detailed site specific information (vegetative community structure/composition, species of concern presence/absence, soil condition, access routes etc.) which is critical to proper land management planning. Adaptive management is important throughout the WQPL, but is particularly important on this unit. Site analysis has begun on Upper Barton and two possible alternate goals, savanna and creation of black-capped vireo habitat, have been identified for some areas. These areas will not be called out into separate treatment units because they are relatively small and widely dispersed and because the management unit as a whole is still being explored.

The most common alternate goal called for, outside of occupied golden-cheeked warbler habitat, is savanna with <15% cover. The site characteristics of areas best managed for savanna include: remnant grassland populations, less than 100% woody canopy and, among woody individuals present, a size class distribution weighted toward shorter individuals. These factors are important because they provide evidence of recent woody encroachment and because prescribed fire, one of the most important tools in savanna management, will be more effective if they are present. Woody species become less susceptible to fire as they grow taller, and the herbaceous cover necessary to carry fire decreases as woody canopy increases.

Prescribed fire, paired with appropriate mechanical and chemical brush management and seeding, should be the primary management tool employed in areas selected for savanna management. The seasonality, intensity and return interval of prescribed burns should vary to achieve desired outcomes. The effects of seasonality of fire are discussed in section 3.3.1. The appropriate return interval will vary between 2 and 12 years and should be determined by the ecological site, the current vegetation and the goal. Areas with thin soils and lower woody density and will need less frequent fire than areas with deeper soils, higher woody density and/or a prevalence of resprouting species. Additionally, prescribed fire will need to be more frequent during the restoration phase than during the subsequent maintenance phase. Prescribed fire can be used alone to maintain currently open areas if sufficient herbaceous material exists to carry the fire. However, fire's effectiveness can be enhanced with the use of mechanical and chemical brush management. Non-resprouting species such as juniper can be mechanically thinned in advance of fire to allow herbaceous recovery, expand existing openings and to remove larger individuals that may not be controlled by fire alone. Cut material should be shattered or compressed to a maximum height of 2 feet and left in place, though slash should be moved away from planned burn lines. Fire can effectively control recruitment of resprouting species, such as mesquite, but established individuals that are top killed will often resprout following fire and will require chemical control. Individuals can be chemically treated in advance of prescribed fire for the reasons discussed above, or managers can defer chemical treatment until after the burn so that only resprouts must be treated. Deferring treatment reduces the amount of herbicide that must be used and often site access is improved following fire. The appropriate application method and overall strategy will be determined by the species present, size and number of individuals to be treated, existing herbaceous cover, and the presence or absence of sensitive features such as riparian zones. The IPM plan in place for the WQPL should be adhered to. Any herbicide used must be appropriate for use within the recharge zone. Disturbed areas should be sown with the seed mixes found in Tables 3.1.2-1 or 3.1.2-2, as appropriate for the soil.

Development of black-capped vireo (BCV) habitat has been discussed for portions of the Upper Barton Creek management unit. This will require creation or maintenance of the patchy, low growing shrub structure required by black-capped vireo. In central Texas, black-capped vireo preferred habit tends to be low growing shrubland with between 30 and 60% woody cover, average shrub height below 10 feet tall and dominated by shrubs that are densely branched to the ground (Campbell 2003). This is an early successional shrubland community that is created and maintained as periodic disturbance, historically fire, top kills existing shrubs encouraging them to grow back in the in a form usable by the vireos and discourages 100% closed canopy. Without periodic disturbance shrubland, not stunted by thin soils, will progress to woodland and become inhospitable to the vireos.

Several currently unoccupied ridge-top areas within the unit are being considered for black-capped vireo habitat management. Generally, the ridge tops under consideration have thin soil and an existing shrub structure and composition that lends itself to black-capped vireo habitat. With the reintroduction of the appropriate disturbance regime, the vegetational structure of these areas can be shifted to accommodate the habitat requirements of black-capped vireos. Prescribed burning, paired with appropriate mechanical and chemical brush management, will be the preferred tool to maintain or create the desired vegetation structure. Fires intense enough to top kill shrubs, stimulating them to resprout densely from the base, can help create vireo habitat. Though growing season burns should be used only in areas that are currently unoccupied. In situations in which prescribed fire is not a practical option, such as adjacent to occupied golden-cheeked warbler habitat, mechanical mastication (mulching) of shrubs can be substituted. Experiments with this method at Fort Hood, located in central TX, have met with success (Kostecke 2009). Trees under 15cm DBH were mulched to the ground with a hydroaxe, and slash was left in place. The machinery's rubber tires, coupled with the thick mulch created, limited soil damage. Three years after treatment black-capped vireos began nesting within treated areas. This method was effective but extremely expensive, costing on average $500/acre. In addition, the thick layer of mulch suppressed herbaceous regrowth which did not damage habitat value, but which could interfere with the WQPL's water quality and quantity goals. This method could be used for very small areas where fire is not possible, or as an preliminary treatment. Alternately, shrubs could be mulched in a row or grid pattern to proved some habitat, without treating an entire area (Charlotte Reemts pers. comm.).

Once habitat is occupied, growing season fires should be avoided, though low intensity fires conducted in the non-breeding season (September to February) and selective brush management of species such as juniper, mesquite and prickly pear could help maintain habitat by controlling small juniper, maintaining the proper shrub canopy and encouraging the growth of broad-leaved shrubs. However, low intensity fires may raise canopy of existing shrubs which would be undesirable in this case. Radical changes in shrub canopy within occupied habitat from one year to the next should be avoided. Grazing and browsing management should not be employed because excessive browsing destroys the thick woody growth needed for nest concealment. When treatments are considered within occupied habitat that could change canopy cover, managers should coordinate with the U.S. Fish and Wildlife Service. Further discussion on treatment of occupied habitat is found in section 5.1.4. Left untreated, habitat will degrade as shrubs grow too tall for use and the shrub canopy changes. If this occurs, and the habitat is no longer occupied, the area can be reset with intense prescribed fires and/or mechanical mulching. Since it can take a few years for shrubs to recover from initial treatment to the point that habitat is usable, a possible strategy would be work in rotating patches so that at any given time usable habitat exists in the vicinity of recently treated areas.

Riparian areas located within this unit and are typically found on Loamy Bottomland ecological sites. Management for riparian health is very similar to that for woodland health and is discussed in sections 4.2.7. Additional discussion of riparian management can be found in section 5.1.3. Within riparian corridors, brush thinning should be done by hand. Frequently, these corridors are dominated by juniper and lacking the diverse woody canopy necessary for riparian health. In these areas, the juniper canopy should be opened, sown with the seed mix described in Table 3.1.2-3 and, if possible, be seeded or planted with species such as cedar elm (*Ulmus crassifolia*), walnut (*Juglans* spp.), bald cypress (*Taxodium distichum*), cottonwood (*Populus deltoids*), Texas mulberry (*Morus microphylla*), black willow (*Salix nigra*) and pecan trees (*Carya illinoinensis*). Additional species can be found in section 3.1.2. Planted trees should be protected from deer with wire cages or similar protection methods. The area should be monitored for feral hog populations and these should be trapped and controlled by lethal means whenever possible. Any soil disturbance should be sown with the seed mix described in Table 3.1.2-3.

5.2.3 Lower Barton Creek Management Unit

The Lower Barton Creek management unit has been divided into seven treatment units (Figure 5.2-3). Occupied golden-cheeked warbler habitat occurs within the unit (Figure 2.3-23). Within occupied habitat, the management goal is woodland health, and all management should occur when warblers are not present (August 1 to February 28) (Ladd and Gass 1999). A 300 foot buffer should be placed around occupied habitat and/or territories. Deer surveys conducted for the 2001 Management Plan on this site contained too much variation to be fully reliable (due to the limited sight distance), but suggest that the deer population is above sustainable levels. Deer census data should be repeated with greater sampling effort to better ascertain the population on the site. If browse pressure is intense, steps should be taken to lower the population, though this is a low priority.

Units 1 and 2 are mixed hardwood and juniper woodlands on Low Stony Hills and Clay Loam ecological sites. A creek channel, overlying a Loamy Bottomland ecological site, exists which contains a population of the plant species of interest, Heller's marblesed. Woodland health is the goal for both units. Both units contain occupied golden-cheeked warbler habitat and these areas can be managed for woodland health when the warblers are not present (August 1 to February 28). Small juniper (less than 15 feet in height and 5 inches DBH) can be selectively thinned within woodlands to allow recruitment of hardwoods. A 300 foot buffer should be placed around occupied habitat and/or territories. Woodland health practices should be judiciously employed in areas outside of golden-cheeked warbler habitat as well. Outside of occupied golden-cheeked warbler habitat, juniper exceeding 15 feet tall/5 inches DBH can be selectively thinned if necessary to promote woodland health.

Unit 3 lies on an Adobe ecological site and contains mixed woodland and savanna which has lost a significant portion of topsoil in the past. Because of the potential presence of golden-cheeked warbler habitat and the effort and expense required to change the system from its current stable state, brush management has been a low priority on this site. However, no occupied golden-cheeked warbler habitat has been found in this unit, and other high priority areas have been thinned, so brush control on low priority units like this one may now be warranted. The vegetative goal for this unit is savanna with <15% woody cover. The site should be restored with low frequency prescribed fire paired with mechanical and chemical brush management, informed by the WQPL's IPM plan. Thinning will be necessary prior to prescribed fire in many areas to allow enough herbaceous material to accumulate to carry fire. The site should be seeded, following disturbance, with the thin soil mix found in Table 3.1.2-4.

Unit 4 has sections of both savanna and nearly closed-canopy oak/juniper woodland on both Adobe and Steep Adobe ecological sites. Isolated warbler sightings have occurred on both the extreme northeastern and northwestern portions of the unit. Following three years of surveys, these areas were delineated as low quality golden-cheeked warbler habitat. Occupied golden-cheeked warbler habitat and a 300 foot buffer around it should be maintained as closed-canopy oak/juniper woodland, with a vegetative goal of woodland health. The vegetative goal outside of occupied golden-cheeked warbler habitat is savanna with <15% woody cover. Selective cutting of young juniper under 10 feet and less than 4 inches DBH has occurred in areas outside of warbler territories to enable some of the existing grassland openings to be expanded. Cut material has been left in place and shattered or compressed. This cut material has acted to protect emerging seedlings and the entire area has seen significant native grass recovery. Reducing woody cover below 15% will require removal of juniper that exceed 10 feet in height and 4 inches DBH. Cut material should be left in place and shattered or compressed to a maximum height of two feet. These areas should be sown with the seed mix described in Table 3.1.2-1 after cutting. The unit will need to be maintained by low frequency prescribed fire.

Unit 5 is a small section of Clay Loam ecological site with both open and closed savanna habitats. Golden-cheeked warbler habitat has been delineated in the northwestern corner of the property. This area and a 300 foot buffer around it should be maintained as closed canopy juniper/hardwood woodland, with a goal of woodland health. Management within occupied golden-cheeked warbler habitat should occur when warblers are not present. The goal for the remainder of the unit is savanna with <15% woody cover. The unit should be maintained with prescribed fire with a moderate return interval, paired with mechanical and chemical treatment as necessary. 50 to 70% of young juniper under 10 feet and less than 4 inches DBH have been cleared from these areas. Larger juniper can now be removed to further reduce woody canopy in this area below 15%. These areas should be sown with the seed mix described in Table 3.1.2-1 after cutting. Cut material should be shattered or compressed in place to a maximum height of 2 feet.

Unit 6 s a mixed hardwood/juniper woodland occurring over Adobe, Steep Adobe and Clay Loam ecological sites. Little topsoil is left on the site due to past erosion. The unit contains a population of Heller's marbleseed along the creek channel. The vegetative goal for the unit is woodland health. SWCA (2003) delineated several portions of this unit as golden-cheeked warbler habitat as did the 2010 surveys. These areas and a 300 foot buffer around them should be maintained as closed canopy juniper/oak woodland. If funds allow, golden-cheeked warbler habitat could be enhanced along with the rest of the unit with woodland health practices such as the selective thinning of small juniper (less than 15 feet tall and 5 inches DBH) to encourage the growth of larger trees and hardwood recruitment. Within occupied golden-cheeked warbler habitat all management should occur when warblers are not present.

Unit 7 is composed of primarily open savanna with some oak/juniper woodlands occurring on Steep Adobe, Adobe and Clay Loam ecological sites. SWCA (2003) delineated several portions of this unit as golden-cheeked warbler habitat. Occupied habitat and a 300 foot buffer around it should be maintained as closed canopy juniper/oak woodland. The vegetative goal within occupied habitat is woodland health and juniper dominance should be prevented by selective thinning of juniper that is less than 5 inch DBS or 15 feet tall. The target vegetative community outside of occupied golden-cheeked warbler habitat is savanna with <15% woody cover. This unit had initial thinning of juniper, less than 4 inches DBH or 10 ft. tall, conducted around existing habitat in 2005, and larger juniper can now be removed to reach the target cover. Cut material should be shattered or compressed to a maximum height of 2 feet and left in place. These areas should be sown with the seed mix in Table 3.1.2-1 after cutting. The remainder of the site retains a healthy grassland community and should be maintained through low frequency prescribed fire and seeding as necessary.

5.2.4 Slaughter Creek Management Unit

The Slaughter Creek management unit has been divided into 5 treatment units (Figure 5.2-4). After multiple years of surveys, no golden-cheeked warbler habitat has been found on this tract (Figure 2.3-24). Deer surveys done in support of the 2001 Management Plan, and most years since, suggested that the deer population of the site was well above sustainable levels. Steps should be taken to manage this population if it can be accomplished in such close proximity to neighborhoods.

Unit 1 is the riparian corridor along Slaughter Creek which lies on a Loamy Bottomland ecological site. The vegetative goal for this site is enhanced riparian health. Upon purchase, the site lacked much of the woody overstory and tall grasses that would serve to stabilize the deep soil of the stream banks against flood events. Tree planting has been conducted in this unit and roughly 200 trees have been established. In addition, there has been good switchgrass recovery. The small juniper under the drip lines of large trees in this unit should be cut by hand to maintain the health of the larger individuals. Exotic species should also be removed in accordance with the IPM plan. Chinese tallow, chinaberry and ligustrum have been found within the unit in the past.

Units 2 and 3 have are steeply sloped open savanna. The primary ecological site is the thin soiled Adobe ecosite, though small areas of Blackland, Deep Redland and Clay Loam sites are present. The vegetative goal for both units is savanna with <15% cover. Given the topography and thin soils of the units, the preferred management treatment is low frequency prescribed fire. However, prescribed fire treatments should not be so infrequent that brush management gains are lost to woody regrowth. Appropriate chemical and mechanical brush treatment can be used, in conjunction with prescribed fire, to reduce woody cover below 15% and to encourage a vigorous grassland community. Treatments should be in accordance with the IPM plan.

Significant juniper thinning has been done on both units and many areas are experiencing native grass recovery. Native grasses returned very quickly following brush removal activities. Species such as little bluestem are returning in treated areas even where they have not been seeded. Much of the juniper below 10 feet in height and 4 inches DBH has been removed, and it will now be necessary to remove juniper larger than this to reach the target woody cover. This removal should be done through either hand-cutting or mechanical removal. Cut material should be shattered or compressed to a maximum height of 2 feet and left in place, and the area should be seeded with the seed mix described in Table 3.1.2-1. In addition, woody species other than juniper may need to be chemically or mechanically treated, as outlined in the IPM plan in place for the WQPL.

One golden-cheeked warbler was detected within this unit. However, following three years of surveys, SWCA (2003) has concluded the unit contains no golden-cheeked warbler habitat.

Unit 4 is primarily an open savanna with mature live oak on a variety of ecological sites, many of which have relatively deep soils. Ecological sites present include, Deep Redland, Clay Loam, Blackland and Adobe. No occupied golden-cheeked warbler habitat has been found on this treatment unit. The vegetative goal for the site is savanna with <15% woody cover. The preferred management for the unit is moderately frequent prescribed fire paired with chemical and mechanical brush management and appropriate seeding. Woody species targeted for removal should be treated as outlined in the IPM in place for the WQPL. A 50-foot buffer of woody species can be maintained along the northwestern portion of the unit that abuts to FM 1826, any portion abutting housing developments, and the boundary shared with Circle C Metro Park as a visual and sound barrier.

Small juniper (less than 10 feet in height and 4 inches DBH) have been removed from many portions of this unit. Much of the remaining woody cover is composed of live oak with occasional post oaks. Remaining woody cover should be reduced through either hand cutting, mechanical removal or chemical treatment as outlined in the IPM plan. Reaching the target woody percent cover will require removal of juniper larger than 10 feet and 4 inches DBH. In addition it will require removal of species other than juniper. This can be done at the discretion of the land manager as removing resprouting species such as live oak is much more involved than removing juniper. Cut material should be compressed to a maximum height of 2 feet and left in place or moved to a unit that will undergo prescribed burning. The area should be reseeded with the seed mix described in Table 3.1.2-1.

The unit contains several formerly cultivated pastures which are undergoing mesquite and juniper invasion, many of which are young. Juniper encroachment should be controlled with prescribed fire and/or mechanical cutting and mesquite encroachment should be controlled through the use of herbicide that is appropriate for use over the recharge zone. Invading juniper were hand cut in 2007 and 2008. Mesquite were treated most recently on this site in 2008. Moderately frequent prescribed burns followed by seeding with the mix found in Table 3.1.2-1, should be used to enhance the health and vigor of the grassland community and prevent reinvasion by woody species such as mesquite and juniper. A combination of prescribed fire and seeding with the mix in Table 3.1.2-1 will help restore the area to diverse grassland.

Unit 5 is primarily open savanna on Deep Redland, Clay Loam and Blackland ecological sites. Most of the unit has moderately deep soils. The vegetative goal for the site is savanna with <15% woody cover. The appropriate treatment for the site is prescribed fire with a moderate return interval, paired with mechanical and chemical brush management. Seeding should follow prescribed burning or other disturbance.

A summer wildfire occurred on one portion of this unit in 2000, which significantly retarded brush encroachment. Small juniper which survived the fire have been cut, however, mesquite was released after juniper removal. Mesquite invasion also occurred on two former pasture areas located within the unit. Mesquite was treated in 2008 and the site should be monitored for reinvasion. The site should be maintained through moderate to frequent prescribed burns followed by chemical treatment of surviving mesquite and reseeding after burns.

This unit contains a knoll that is more similar to units 2 and 3 than to the remainder of unit 5. This area, located in the northwestern corner of the unit lies on Shallow and Adobe ecological sites, both of which have thin soils. This area is a quickly closing oak/juniper savanna which can be allowed to develop into closed-canopy oak/juniper woodland, or juniper can be cut to maintain and expand the grass-dominated areas. Follow cutting by seeding with seed mix described in Table 3.1.2-2. Areas opened with mechanical or hand cutting will need to be maintained with moderately frequent prescribed fire. Because of the area's small size and location, it would be logical to include it in the burn planning for the remainder of unit 5.

The unit also contains a small isolated woodland on a Redland ecological site. The woodland can be left without management or included with surrounding areas.

5.2.5 Bear Creek Management Unit

The Bear Creek management unit has been divided into five treatment units (Figure 5.2-5). Golden-cheeked warblers were detected during the 2000 and 2003 surveys, though much of the habitat is considered marginal. Survey results can be found in figure 2.3-25). Significant karst features exist on this unit and care should be taken when using heavy machinery on the property to avoid damaging these features. In 2001, the deer survey from the site revealed the concentration of deer (2.2 acres per deer) to be unacceptably high. Steps have been taken to lower this population over the entire management unit and these efforts should be continued in order to maintain the population at sustainable levels (1 deer to 15 acres).

Unit 1 is a mix of oak/juniper woodland and savanna on Redland and Low Stony Hills ecological sites. The target vegetative community for the site is savanna with < 15% woody cover. The general treatment regime for the unit is prescribed fire with a moderate return interval, paired with appropriate mechanical and chemical brush management and seeding. The unit has been impacted by the creation of a flood control structure along a drainage that feeds Slaughter Creek. A house, tennis courts and garage were removed from the unit in 2004. In addition, a roughly 60 acre area was deferred from treatment while research on internal drainage basins was conducted. Unless research is continued, this area will be treated along with the rest of the unit. As of 2001, many young juniper had begun to invade the savanna areas. Much of this young juniper has been removed. The area was examined by a BCP biologist in 2007, and consultant surveyors in 2010, and no golden-cheeked warblers were found. The canopy should be reduced to less than 15% with a combination of mechanical removal and prescribed burning. This will require removal of juniper trees exceeding 4 inch DBH and 10 feet tall and the removal of additional woody species. Cut material should be shattered or compressed to a height of 2 feet and left on the unit. Over much of this unit, removing the juniper may not reduce the canopy significantly. Other species that could be targeted include live oak, cedar elm, mountain laurel and Texas persimmon. However many of these species will resprout after being cut and will need to be chemically treated following cutting. Alternately, resprouts could be chemically treated following prescribed burns Mesquite is encroaching on the unit and should be chemically treated using a chemical and surfactant appropriate for use on the aquifer recharge zone and in accordance with the IPM plan. Mechanical and chemical brush thinning should be coordinated with prescribed burn planning. Slash should be moved away from burn lines. After mechanical removal of juniper and prescribed burns, the area should be reseeded with the seed mix described in Table 3.1.2-1. in any areas where the soil has been disturbed. At present, a moderate prescribed fire return interval is appropriate, however, if invasion by resprouting species such as mesquite intensifies, or is not brought under control by current efforts, a shorter return interval may need to be considered.

There have been several golden-cheeked warbler sightings on the western side of this unit which have been buffered. A 300 foot wooded buffer should be placed around occupied habitat and management within this area should occur between August 1 and February 28. No juniper above 5 inch DBH and 15 feet tall should be cut within occupied habitat.

Unit 2 follows a riparian corridor surrounding Bear Creek on Loamy Bottomland and Chalky ridge ecological sites. The goal for this unit is enhancement of woodland and riparian health. This community is mostly intact except that it is severely infested with the non-native species, Chinaberry, which tends to reduce the mid-story and understory beneath their canopy thus reducing effectiveness of the function of the riparian community. These trees are highly invasive along riparian zones within the Edwards Plateau and tend to follow zones of disturbance. It is recommended that these species be hand cut when not in seed (the spring or summer) and the cambium of their stumps painted or sprayed with a general herbicide, as indicated in the IPM plan, within five minutes of the initial cut. The debris can either be removed or left in place. See sections 4.2.7 and 5.1.3 for discussions on enhancement of riparian and woodland health.

Care should be taken to look for damage caused by feral hogs and revegetated using the seed mix described in Table 3.1.2-3. Feral hogs should be removed by trapping and or hunting.

Unit 3 is primarily a closing juniper savanna on both a Low Stony Hills and Redland ecological sites. The vegetative goal for the unit is savanna with <15% cover and the preferred treatment regime is prescribed fire with a moderate return interval. A single golden-cheeked warbler was sighted in the unit, but the habitat is considered to be marginal. Portions of the unit are deciduous woodland which have undergone brush thinning. As result of this thinning and prescribed fire, juniper is no longer the dominant woody species. If the woody cover is to be brought below 15%, juniper larger than 4 inch DBH and 10 feet tall will need to be removed as well as species other than juniper. If maintenance resources are low, the highest priority areas for cutting are those areas adjacent to existing grassland meadows. Reseed with the mixture described in Table 3.1.2-1 in areas of soil disturbance and following prescribed burns. Much of this area can be managed as a deciduous woodland or pushed towards a more open savanna.

Unit 4 is a combination of closed-canopy juniper woodland with a limited herbaceous layer in the northwest, more open mixed live oak/cedar elm/juniper woodland in the northeast and open savanna to the southeast. The majority of the unit lies on a Redland ecological site, but Rolling Blackland, Chalky Ridge and Deep Upland ecological sites are also present. The northwestern juniper woodland has a significant component of mature juniper and was identified as potential golden-cheeked warbler habitat in 2002 (SWCA 2003). However, it was concluded in 2003 that no warbler habitat exists on this site because no warblers have been detected in three years of surveys (SWCA 2003). The density of woody material will most likely preclude the use of prescribed fire over most of the site as a management tool in its current state. A woody buffer should be maintained within riparian areas. However, juniper in this area can be selectively thinned to allow for hardwood release and regeneration of the herbaceous layer. Juniper in the riparian area should be cut with hand crews to minimize soil disturbance. Exotic woody species, such as Chinaberry trees, found in this area should be hand cut when not in seed (the spring or summer) and the stumps treated with an appropriate herbicide as described in the IPM plan. The debris can either be removed or left in place. Beyond this buffer zone, juniper may be mechanically removed with tree shears, with priority cutting going to those areas with existing grass cover. In areas of soil disturbance, reseed with the mixture described in Table 3.1.2-1. This cutting should open up the areas enough that prescribed fire can be used after the initial cutting. Alternately, the closed canopy woodland can be managed as woodland with the techniques discussed in section 4.2-7, woodland health.

The open savanna located to the southeast is undergoing significant mesquite invasion and contains a high proportion of small mesquite. Juniper and persimmon are also present, but are a smaller component of the vegetative community. Mesquite should be chemically treated as described in the IPM plan. Larger mesquite could be left but the area will need to be monitored to keep reproduction under control. Over most of the unit, the target canopy cover is less than 15%. Juniper should be removed mechanically. Soil disturbance areas should be reseeded with the mixture described in Table 3.1.2-1. The preferred management is frequent prescribed fire.

Unit 5 is primarily series of formerly cultivated fields dominated by the non-native grass King Ranch bluestem. Two isolated oak woodlands exist along the northern border. The site contains Deep Redland, Clay Loam, Chalky Ridge and Blackland ecological sites. The unit is experiencing some mesquite encroachment. The mesquite was chemically treated in 2007 and 2008, and the unit had a prescribed fire in 2003. The unit should be maintained by prescribed fire on a moderate to frequent return interval. Alternately, the unit could be maintained by haying or mowing if prescribed fire cannot be applied, though prescribed fire is the preferred strategy. The isolated woodlands can be maintained as woodland in which the juniper canopy is maintained below 25% with hand cutting, or they can be managed along with the rest of the unit and converted to savanna.

5.2.6 Little Bear Creek Management Unit

(formerly Lower and Little Bear Creek Management Units)

The former Lower Bear Creek and Little Bear Creek management units adjoin one another, so they have been combined into one unit referred to as the Little Bear Creek Management unit. The combined management unit has been divided into 8 treatment units (Figure 5.2-6). The results of golden-cheeked warbler and black capped vireo surveys of this unit can be found in figure 2.3-26.

Two golden-cheeked warblers were detected in one of the treatment units in 2000. In 2003, two golden-cheeked warblers were detected on the former Lower Bear Creek unit. Two black-capped vireos were observed during the 2003 golden-cheeked warbler survey on the former Lower Bear Creek unit. Both golden-cheeked warblers and black-capped vireos were detected during the 2010 surveys. Golden-cheeked warbler habitat has been delineated in several areas. Occupied habitat should be buffered by 300 feet. Management within occupied golden-cheeked warbler and black-capped vireo habitat is discussed in section 5.1.4.

Much of the Little Bear Creek management unit is dominated by Texas persimmon and Texas mountain-laurel. Both of these species will resprout if they are cut or top-killed by fire, so maintaining or expanding grassland habitat will be challenging. The dominance of these woody species needs to be significantly reduced over much of the unit in order to enhance water quantity. Mechanical treatments will need to be paired with prescribed burning and judicious use of chemical treatment. However, little research is available on the control of these species on a landscape scale, so management recommendations given here should be considered provisional. Because these species lack significant underground reserves (as mesquite has), they may be unable to resprout after being top-killed several times. Mechanical treatments to top kill the thickets of these species and other brush will quickly eliminate the canopy and allow for increased grass production, thus quickly facilitating conditions that support prescribed burning, though the shrubs will resprout densely. Repeated burns, especially in the summer, should continue to top-kill these resprouting species. Alternatively, initial studies have shown that mountain-laurel, at least, can be controlled by herbicides applied in a basal stream (Lyons 1996). A carrier such as vegetable oil could be substituted for the diesel used in the study and should follow the IPM plan. Finally, portions of this unit are good candidates for prescribed goating. Land managers should test several of these treatments under research conditions, potentially in cooperation with universities or others to ascertain which yields the most desirable result. Units containing abundant mountain laurel may be inappropriate for prescribed grazing, as the plant is poisonous to livestock. The deer survey conducted for the 2001 Management Plan indicated populations well above sustainable levels. Deer populations should be maintained at sustainable levels. The management unit has an abundance of feral hogs which should be controlled by lethal means.

Unit 1 is a quickly-closing savanna composed of live oak, Texas persimmon, Texas mountain laurel and juniper. Though this community is not typical of golden-cheeked warbler habitat, warblers have been consistently detected in this area (SWCA 2003), and territories have been delineated. Management should occur between August 1 and February 28 within occupied habitat. The vegetative goal for this unit is woodland health (see Section 4.2.7). The western portion of this unit is known to contain several springs and ephemeral wetlands and any cutting near these features should be done by hand.

Unit 2 is an open savanna on Low Stony Hills, Gravelly Redland, Shallow and Clay Loam ecological sites. The overstory is dominated by oaks with Texas persimmon and mountian-laurel beneath. Juniper is also present but is less abundant than persimmon and mountain laurel. The canopy of the unit is closing, but is still open in some areas. No golden-cheeked warbler were detected in this unit during 2010 surveys, but one black-capped vireo was detected. The target community for this unit, outside of occupied black-capped vireo habitat (if present), is savanna with <15% woody cover. The overall treatment regime is prescribed fire with a moderate return interval.

Low intensity prescribed fire could be used to maintain those areas currently dominated by grass However, low intensity fire will not carry through denser shrub areas. In these areas, mechanical brush treatments to allow herbaceous recovery can be paired with fire. Fires with higher intensities are more likely to top-kill resprouting shrub species. These fires can be paired with additional mechanical or chemical treatments to reduce woody cover or can be used to create a lower shrub canopy. Prescribed goating is also an alternative on this unit. Roller chopping should not be attempted on this unit due to the danger of resprouting unless it has demonstrated success on other units. Chemical control could be used if a foliar or basal spray effective on these species can be found that is acceptable for use in the recharge zone of the aquifer. However, chemical control, as indicated in the IPM, should be used judiciously after other control methods are employed. Any experimental treatments should be evaluated on a small plot scale before unit wide treatments are attempted.

Unit 3 contains mixed woodlands and open savanna lying on Shallow, Low Stony Hills, Redland and Gravelly Redland ecological sites. Black-capped vireo have been detected within the unit, though no habitat has been delineated. Golden cheeked warbler habitat has be delineated within the unit. The overall vegetative goal for the unit, outside of occupied golden-cheeked warbler and black-capped vireo habitat, is savanna with <15% woody cover. Given the density of resprouting woody species and the soils present in the unit, a high frequency fire return interval is called for, paired with appropriate chemical and mechanical brush control. In several areas, mechanical and chemical brush control, in accordance with the IPM, will be necessary prior to prescribed fire to allow the herbaceous component of the site to recover to the point that it can carry fire.

Native grasses, such as little bluestem, are recovering in areas that have been burned, whereas this recovery is not evident in unburned areas. Yaupon holly is emerging in some areas and could become a problem in the future. Yaupon holly is challenging to control once it has become established. Prescribed fire will limit recruitment and temporarily open the canopy but will have limited success on its own reducing established populations. Therefore it is important that prescribed fire be employed often enough to prevent the spread of yaupon holly as well as that of the other woody species discussed. To reduce established populations of yaupon holly, prescribed fire should be paired with mechanical and chemical treatment. Unfortunately reducing established populations requires intensive management. Prescribed fire, used alone, must be conducted yearly for several years to significantly control established yaupon and mechanical treatments such as mowing and mulching must occur several times a year (G. Creacy, personal communication). Neither of these options are feasible on a large scale. Mitchell et al. (2005) found that chemical treatment 6 months after prescribed fire effectively controlled yaupon, and a similar strategy could be employed in selected areas with an effective and appropriate herbicide/surfactant combination. Chemical control is expensive and must be used judiciously, as described in the IPM plan. This strategy should focus on areas where yaupon control would expand currently open areas and enhance connectivity of open areas. Finding a combination of prescribed fire, mechanical and chemical control that effectively controls yaupon, and other resprouting species, on a large scale will require experimentation. It is possible that several years of frequent fire followed by selected chemical application would be an effective strategy, though the details of that strategy (minimum return interval, number of cycles etc.) must be established through experimentation.

Two male black-capped vireos were observed in the central portion this unit during the 2003 golden-cheeked warbler survey, though 2009 and 2010 surveys did not detect black-capped vireos in this area. However, black-capped vireo were detected for the first time at the southern portion of the unit, near unit 6. Within occupied black-capped vireo habitat brush management should not reduce the shrub canopy below 30 to 60% and should be undertaken during the non-breeding season (September to February). However, prescribed fire conducted outside of breeding season could enhance habitat by creating the low shrubby structure that vireos prefer. Brush management via goating and warm season burns should be avoided within occupied black-capped vireo habitat. Portions of this unit have been delineated as golden-cheeked warbler habitat. Occupied habitat should be given a 300 foot buffer and all management within occupied golden-cheeked warbler habitat should occur between August 1 and February 28. Within occupied golden-cheeked warbler habitat, selective thinning of juniper below 5 inches DBH and 15 feet tall can be done to enhance woodland health.

The preferred overall management strategy for this unit is frequent prescribed fire, conducted often enough to prevent the spread of woody species. Ashe juniper is currently only a problem in isolated areas and if these are controlled mechanically, further encroachment may never require significant management action beyond periodic prescribed fire. Resprouting species such as yaupon should be selectively controlled when the benefits of this action outweigh the fiscal and ecological costs. The target canopy cover, outside of occupied golden-cheeked warbler and black-capped vireo habitat, is less than 15%.

Unit 4 lies primarily on a Gravelly Redland ecological site, but has small portions of Steep Adobe, Shallow and Redland ecological sites. This site is oak savanna with patches of juniper woodland. Much of the unit is fairly open with scattered large oaks, primarily live oak but with occasional post oak. Juniper and mesquite are beginning to invade, but individuals are small and scattered. King Ranch bluestem is the dominant grass. Mountain laurel and persimmon appear in the northern portion of the unit, particularly under oak canopy. Woody species density, in general, increases toward the north. The target canopy cover for this unit is less than 15%. A moderate fire frequency is appropriate for the site. Juniper cover should be reduced mechanically. In areas of high density, reduction in stages would be prudent to allow time for herbaceous recovery. Mesquite should be chemically treated in accordance with the IPM plan.

Unit 5 is similar to unit 4, though woody cover is lower. The target vegetative community is savanna with < 15% cover. The preferred treatment regime is prescribed fire with a moderate return interval, paired with appropriate mechanical and chemical brush management.

Unit 6 is a riparian area with a vegetative goal of enhanced woodland and riparian health (see sections 4.2.7 and 5.1.3).

Unit 7 is a quarry with very little vegetation. Its structure ensures significant water capture and its fractured geology and contiguity to the upper zone of the Edward's aquifer suggest that it could likely be used to enhance aquifer recharge. Current efforts should focus on controlling tamarisk and other invasive species and continuing the vegetation establishment activities currently underway.

Unit 8 has been heavily impacted by quarrying activities. The soil is severely compacted and it supports a sparse, early successional, vegetative community. In this area, fairly aggressive recharge enhancement projects are possible. A recharge enhancement channel has been proposed that would divert part of Little Bear Creek during high flow events into the quarry to recharge the aquifer. Prior to this action, water testing should be done on Little Bear Creek, both during normal flow and after storm events, to determine how aquifer water quality could be affected by such a diversion. Potentially, the area could be re-graded with rock debris from the channel cuttings to promote water flow into the quarry and then restored. However, the potential impacts, particularly to water quality, of this type of activity need to be further researched. Vegetation management should focus on controlling invasive species, particularly tamarisk.

5.2.7 Onion Creek Management Unit

The Onion Creek Management unit has been divided into four treatment units (Figure 5.2-7). Golden-cheeked warbler inventories have been completed for this unit and a limited amount of occupied habitat was found near Onion Creek (Figure 2.3-27). Significant karst features exist on this management unit and care should be taken when using heavy machinery on the property to avoid damaging these features. Deer surveys completed on this site for the 2001 Management Plan suggested that both white-tailed deer and blackbuck antelope populations were well above sustainable levels. Steps have been taken, as recommended by TPWD, to lower the population of white-tailed deer and possibly eliminate the non-native blackbuck over the entire management unit (Reagan 2000). Occasional rifle hunting is still used to keep the numbers of white-tailed deer at a sustainable level and to keep blackbuck and other exotics to a minimum with eradication the ultimate goal. The property was significantly affected by blackbuck and livestock populations (shift from tallgrass to shortgrass species, numerous rill and gully sites forming). Deer control, brush management and prescribed burning have resulted in significant recovery of native herbaceous communities. This has, in turn, reduced or eliminated evidence of erosion from much of the site.

The preferred land management strategy for this management unit is prescribed fire. This unit has had both cool and warm season fires applied to it. The cool season burns have resulted in rapid grass recovery. However, warm season burns have more significantly reduced woody cover. The warm season burns do not result in dense grass cover as rapidly as the cool season fires which may be because under certain conditions the dominant King Ranch bluestem does not recover as well from warm season burns as native species. In the season after the burn, the most visually dominant herbaceous species are early-successional forbs. However, expectedly, and by definition, these species become less dominant in a few seasons following fire and give way once more to perennial herbaceous species. It is expected that the competitive advantage of many native grasses over King Ranch bluestem after summer fire (Simmons et al. 2007) will stimulate a transition to native dominance which, over time, should improve grassland resilience to the occasional growing-season burns needed to reduce or maintain canopy cover. A combination of cool and warm season prescribed fire should be used to maintain this management unit.

Unit 1 is a small parcel experiencing significant invasion by woody species such as mesquite, juniper and chinaberry. Mesquite should be controlled chemically and juniper should be removed mechanically. Chinaberry should be cut and the stumps treated with an herbicide appropriate for use over the aquifer. Treatments should be guided by the IPM plan. The target canopy cover for this unit is <15% and the preferred management alternative is prescribed fire. Mechanical and chemical brush management should be used to allow the herbaceous biomass of the unit to increase to the point that it can carry fire. Once sufficient herbaceous biomass has accumulated, prescribe fire is the preferred alternative though mechanical and chemical brush management will need to be continued. High frequency fire should be used during the restoration phase because of the unit's deep soils and high density of resprouting woody species. This unit is a low priority because of its small size. In addition, this unit is a likely trail head location for the Walk for a Day project which should be considered as management activities are planned for the site.

Unit 2 is primarily grassland with some areas of open savanna over a Gravelly Redland ecological site. The target community for this site is savanna with <15% canopy cover. A significant amount of brush management coupled with prescribed burning has been done on this unit and as result the unit is approaching its target condition. The native grass community is recovering and woody coverage has been dramatically reduced. Remaining woody species are primarily widely spaced large oaks and larger juniper which can now be controlled. Mesquite is beginning to invade and will need to be chemically controlled in accordance with the IPM plan. Prescribed fire, applied in both the growing and dormant seasons, is the preferred long term management alternative.

Currently a moderate return interval is appropriate for most of the unit, though a shorter interval may need to be considered, along with judicious chemical control, in areas being invaded by mesquite or other resprouting woody species. In all areas, prescribed fire should be coupled with mechanical and chemical brush management as necessary. Cut material should be shattered or compressed to a maximum height of two feet and left in place. However the cost of mechanical control is much greater than that of prescribed burning, and the goal over time is to reduce the amount of mechanical and chemical treatment done in favor of prescribed fire. Native grasses and forbs should be seeded after disturbances. As an alternative to seeding the entire site, seed can be concentrated in islands, rows or on disturbed soil.

A portion of this unit, located in the southeast corner of the unit, overlying the deeper soiled Redland ecological site (Figure 2.3-19), has abundant mesquite, juniper and persimmon as well as a small area that remains wet year-round. This area will initially require significant chemical treatment of mesquite as well as mechanical treatment of juniper. In addition, a shorter return interval may need to be considered here during the restoration phase. As woody populations are brought under control the moderate return interval employed on the rest of the unit should be appropriate in this area as well. Note that, particularly in the area that remains wet year-round, clearing activities should be done by hand around any creeks, streams, ponds or karst features in order to minimize any adverse water quality issues associated with erosion from clearing. Disturbed soil should be reseeded with the mixture described in Table 3.1.2-1. The wet area provides an opportunity to encourage more mesic species if funds and staff time allow.

Unit 3 is, broadly speaking, the riparian corridor and nearby uplands along Onion Creek. The unit overlies mainly Gravelly Redland, but also small sections of Low Stony Hills, Loamy Bottomland and Steep Rocky ecological sites. Oak/juniper woodlands currently predominate, and the vegetative goal is enhanced riparian and woodland health. Golden-cheeked warbler habitat has been delineated within this unit. Juniper dominance in this unit is increasing and should be controlled over the long term by fire and cutting to allow for hardwood release. Though extreme caution should be used when burning in or near golden-cheeked warbler habitat, and managers should coordinate with USFWS when treatment is considered that could significantly change canopy cover within occupied habitat. Low intensity, infrequent, fires can be used to maintain mature riparian areas, but fire will impede riparian restoration so should be held outside of nascent riparian corridors. The woody diversity along the riparian corridor has been degraded, and stability of the area could be greatly enhanced through woody planting. However tree planting efforts here have met with limited success because of the lack of available water for seedlings. Emphasis should be shifted from tree seedlings to seed. The planting should include cedar elm, walnut (*Juglans* spp.), bald cypress (*Taxodium distichum*), cottonwood (*Populus deltoids*), sycamore (*Platanua occidentalis*), buttonbush (*Cephalanthus occindentalis*), Texas mulberry (*Morus microphylla*), Mexican buckeye (*Ungnadia speciosa*) black willow (*Salix nigra*) and pecan trees (*Carya illinoinensis*). Grass seeding in the area has met with more success and should be continued. Suggested species can be found in Table 3.1.2-3. Encouraging herbaceous cover here and further upland will reduce the amount of sediment that reaches karst features and will thus improve water quality.

Unit 4 is an open savanna on a Gravelly Redland range site. The target vegetative community is savanna with less than 15% canopy cover and the preferred long term management alterative is prescribed fire. The mesquite population is increasing rapidly on this site. Currently prescribed fire with a moderate to short return interval, paired with chemical treatment of mesquite, in accordance with the IPM, is appropriate for the site. As the mesquite population is brought under control a transition to a moderate return interval may be appropriate. Top killed mesquite individuals should be chemically treated as they resprout.

5.2.8 Shudde Fath Management Unit

Shudde Fath Management unit consists of one treatment unit (Figure 5.2-8).

This management unit lies in an urban area, though it is bounded on the north by the Barton Creek Greenbelt. The vegetative goal for the site is woodland health. Golden-cheeked warbler habitat was found within the unit in 2010 (Figure 2.3-28). The property is heavily infested with invasive species and management activities should focus on controlling these species. Selective thinning followed by seeding can be done here to increase diversity, but large scale brush management is not recommended because the property's size and location prohibits maintenance via prescribed fire. This property could be considered for an educational hiking trail. The conditions that make it unsuitable for intensive management for water yield, namely its size and location, make it more suitable for a public trail than most of the properties within the WQPL. Additionally, this property adjoins the Barton Creek Greenbelt to the north, so a trail could be potentially tied into the trail system along Barton Creek. However, this suggested use does not contribute to improved water quality or quantity and would thus be a low priority.

5.2.9 Brodie Wild Management Unit

The Brodie Wild Management unit contains of one treatment unit (Figure 5.2-9).

This management unit is a small (4 acres), wooded unit overlying Low Stony Hills and Redland ecological sites. The unit lies within a developed urban area. Given the small size and urban location, this property is of low priority for management. Mechanical brush management should be restricted to hand methods here. Note a plan is in place that represents a cooperative agreement between the WQPL, the Native Plant Society of Texas and the Native Prairie Association of Texas that allows these organizations to manage the site according to the mutually agreed upon plan that has the same general goals as the rest of the WQPL.

Section 6.0
Bibliography

Section 6. Bibliography

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