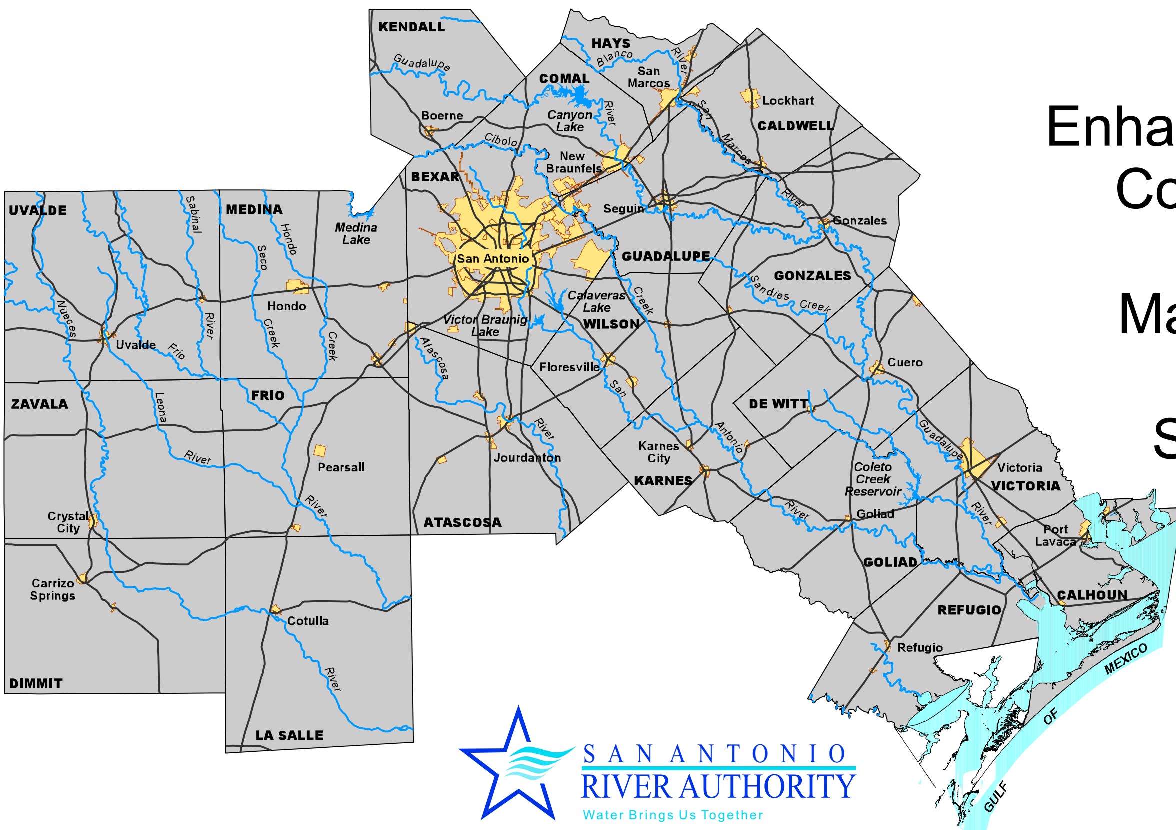
Region L
South Central Texas Regional Water Planning Group

Texas Water Development Board

2011 Regional Water Plan

Study 3
Enhanced Water Conservation, Drought Management, and Land Stewardship



SAN ANTONIO RIVER AUTHORITY
Water Brings Us Together

April 2009

Prepared by:

South Central Texas Regional Water Planning Group

With administration by:

San Antonio River Authority

With technical assistance by:

HDR Engineering, Inc.
Laura Raun Public Relations
Ximenes & Associates

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South Central Texas Regional Water Planning Area

2011 Regional Water Plan

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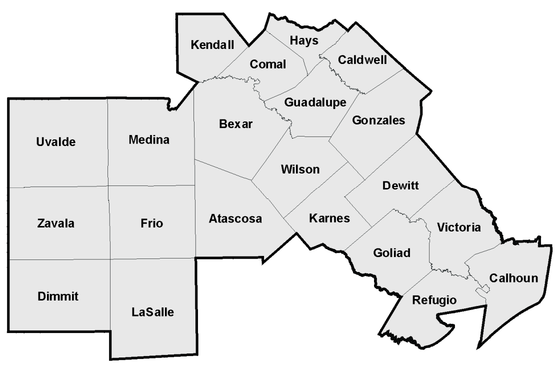

With technical assistance by:

HDR Engineering, Inc.
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April 2009

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Executive Summary

ES.1 Introduction

Study 3, Enhanced Water Conservation, Drought Management, and Land Stewardship of the First Biennium of the 2011 South Central Texas Regional Water Plan (SCTRWP) focuses on four subject areas of particular interest to the South Central Texas Regional Water Planning Group (SCTRWPG). These four subject areas are fundamental water conservation, as recommended to meet projected needs for additional water supply throughout the South Central Texas Regional Water Planning Area (Region L) in the 2006 South Central Texas Regional Water Plan (2006 SCTRWP), and enhanced water conservation through such means as condensate collection for water supply, drought management, and land stewardship.

ES.2 Water Conservation

The 2006 SCTRWP recommends water conservation as a fundamental water management strategy based on Best Management Practices (BMPs) to meet projected needs for additional water supply and to reduce water demands for all water user groups in Region L.

Municipal water conservation goals adopted by the SCTRWPG recommend a one percent reduction in per capita water use per year for cities and rural water suppliers that used more than 140 gallons per capita per day (gpcd) in year 2000 and a 0.25 percent reduction in per capita use per year for those presently, or at some point in the future, using less than 140 gpcd. Key recommended management practices for municipal water conservation are accelerated plumbing fixture and clothes washer retrofit and lawn watering restrictions. Furthermore, the SCTRWPG recognizes and encourages recycled water programs focusing on reuse of future treated wastewater volumes for non-potable purposes and rainwater harvesting in the Hill Country where local water supplies are limited. Reductions in Region L water needs achieved through implementation of recommended municipal water conservation practices are projected to exceed 72,000 acft/yr by year 2060.

Successful implementation of the recommended municipal water conservation water management strategy may affect the ability of some water user groups to attain currently expected percentage reductions in water use under drought management conditions. For example, a water user group could choose to implement a mandatory twice-a-week lawn watering schedule as part of its routine water conservation program in order to meet its per capita water use goals. This, in turn, could limit the effectiveness of its drought management program keyed to achieving significant use reductions by restriction of outdoor water uses. In general terms, the less discretionary water use allowed under a routine water conservation program, the less the percentage reductions in water use that can be reasonably expected under drought management conditions.

Recommended management practices for water conservation in the industrial, steam-electric power generation, and mining use sectors generally focus on reuse of future treated wastewater volumes from municipal facilities and on-site recycling. Potential reductions in water needs resulting from reuse and recycling in these use sectors and the municipal use sector total more than 47,000 acft/yr by year 2060.

Low Energy Precision Application (LEPA) systems and furrow-diking are recommended water conservation practices for the irrigation use sector. Associated reductions in water needs for irrigation are projected to reach a maximum of about 14,000 acft/yr during the planning period.

ES.3 Condensate Collection

Condensation collection is an on-site water conservation water management strategy in which the condensation from large air conditioning units is collected and piped throughout the building and/or landscape for non-potable uses (e.g., landscape irrigation, toilet flushing and sanitation, etc). Such collection and distribution systems could be recommended for new large building construction or as retro-fit for existing large buildings.

Using both Area and Temperature as independent variables in a multiple linear regression equation for estimation of condensate volume results in Equation 1, for which coefficients and the overall regression are deemed statistically significant by standard tests.

$$\text{Condensate Volume} = (6.4 * \text{Area}) + (77{,}174.8 * \text{Temperature}) - 7{,}033{,}910.1 \qquad (Eq.1)$$

Where:

Area = Building Square Footage (sq ft)
Temperature = Average Summer (May – Sept) High Temperature (deg F)
Condensate Volume = Amount of Condensate Water Collected (gal/yr)

An estimated condensate volume of about 2.6 acft/yr is computed for a hypothetical example 130,000 sq ft “Box Store” in Bexar County using Equation 1. Based on very limited available data, the estimated annual unit cost of water for this example might be about

$1,450/acft/yr including contingencies and other assumptions for consistency with other potentially feasible water management strategies. Site-specific system installation and operation characteristics and economies of scale can be significant factors in evaluating condensate collection system feasibility relative to other sources of water supply.

As the collection of condensate can only occur when air conditioning systems are operating, integration of storage in a condensate collection system is necessary to consider it a firm, rather than seasonal, source of supply. Such collection systems, however, do have the distinct advantages of water being generated on-site and most available during hot, summer periods when run-of-river surface water supply sources are least available and treatment, transmission, and distribution systems are stressed to meet peak-day demands.

ES.4 Drought Management

Texas Administrative Code (TAC), Chapter 357 Regional Water Planning Guidelines, states that "Regional water plan development shall include an evaluation of all water management strategies the regional water planning group determines to be potentially feasible, including drought management measures including water demand management [357.7(a)(7)(B)]." As defined for the purposes of this study, drought management means the periodic activation of approved drought contingency plans resulting in short-term demand reduction and/or rationing. This reduction in demand is then considered a "supply" source. Using this approach (for the purposes of this study), an entity may make the conscious decision not to develop firm water supplies greater than or equal to projected water demands with the understanding that demands will have to be reduced or go unmet during times of shortage.[1] Using this rationale, an economic impact of not meeting projected water demands can be estimated and compared with the costs of other potentially feasible water management strategies in terms of annual unit costs. Hence, the primary purposes of drought management studies presented herein were to demonstrate a general methodology for evaluating associated costs, thereby facilitating direct comparisons of this strategy to others.

When implementation of drought management as a water management strategy is deemed economically feasible by a water user group, it may allow that water user group to avoid or delay capital costs and environmental impacts associated with development of additional

[1] Implementing drought management, in general, does not require a corresponding reduction in available water supply and may be implemented by water user groups with existing supplies well in excess of projected water demands.

water supply sources. One potential benefit common to both drought management and water conservation strategies that limit peak water use (e.g., lawn-watering restrictions) is that water treatment plants, high service pumping facilities, and/or distribution system improvements for potable water service may be avoided or delayed.

An estimate of the annual economic impact associated with implementation of and adherence to a drought management strategy by a municipal water user may be obtained using Equation 2:

DM WMS Economic Impact = (Demand) X (% Demand) X (Risk Factor) X ($ Impact Factor) *(Eq.2)*

where:

Demand (acft/yr) = Projected "dry year" demand from TWDB based on year 2000 per capita use rate;

% Demand = Proportion of water demand associated with various use types (i.e., domestic, commercial, and manufacturing);

Risk Factor = Integrated chance of occurrence of potential annual demands in excess of planned supply based on historical per capita use variations for each entity;

$ Impact Factor ($/acft) = Economic impact factors developed by TWDB for lost sales for water-intensive commercial users, lost water and wastewater utility revenues, costs to non-water-intensive commercial businesses and households, and lost sales for manufacturing; and

DM WMS Economic Impact ($/yr) = Typical annual economic impacts of adhering to the drought management WMS.

For 20 selected water user groups with projected needs, annual unit costs of drought management strategies were developed assuming firm supplies of 5%, 10%, 15%, and 20% less than projected dry year demands in 2010. Annual unit costs based on a general methodology including uniform percentage reductions in water use across domestic, commercial, and manufacturing use sectors, excluding impacts associated with lost utility revenue, are summarized in Table ES-1. Application of a refined methodology which focuses initial demand reductions in the domestic outdoor use sector yields significantly different unit cost estimates for SAWS (Table ES-1, "SAWS Refined"). This is a result of avoiding reductions in the commercial and manufacturing use sectors and sewer sales for all drought management scenarios short of the scenario requiring 20 percent overall reductions in annual water use. The refined methodology is perceived to more accurately reflect SAWS drought management planning and TWDB procedures in evaluating economic impacts in the 2007 State Water Plan.

Table ES-1.
Average Unit Cost

Entity	Average Unit Cost			
	5%	10%	15%	20%
San Antonio (SAWS)	$8,227	$15,701	$18,329	$19,734
SAWS Refined	$711	$764	$773	$5,607
Lockhart	$2,294	$3,282	$3,868	$4,271
Boerne	$966	$1,209	$1,667	$2,180
Hondo	$2,043	$2,927	$3,384	$3,643
Uvalde	$ 13	$123	$313	$689
Lytle	$488	$963	$1,223	$1,500
San Antonio (BMWD)	$25,180	$26,663	$27,158	$27,405
Alamo Heights	$3,768	$4,563	$5,052	$5,421
Shavano Park	$536	$802	$1,228	$1,563
Hill Country Village	$134	$281	$362	$405
Hollywood Park	$203	$425	$657	$869
Point Comfort	$ 19	$ 28	$ 37	$134
New Braunfels	$4,535	$6,444	$9,289	$10,907
Garden Ridge	$544	$561	$668	$938
Gonzales County WSC	$435	$785	$1,041	$1,303
Schertz	$3,164	$4,213	$5,225	$6,212
San Marcos	$2,207	$2,605	$2,803	$2,918
Wood Creek	$1,553	$1,686	$1,871	$2,229
Kenedy + TDCJ	$516	$953	$1,196	$1,340
SS Water Supply Corp	$1,895	$1,989	$2,134	$2,206

A general methodology for estimating the economic impacts associated with implementation of drought management as a water management strategy is presented in this study. Application of this methodology for regional water planning purposes facilitates comparison of drought management to other potentially feasible water management strategies on a unit cost basis. While drought management appears potentially economically viable for some municipal water user groups in Region L, it is apparent that associated economic impacts for water user groups having significant commercial or manufacturing use sectors could be significant. As demonstrated for SAWS, however, water user groups having sufficient flexibility to focus on discretionary outdoor water use first and avoid water use reductions in the commercial and manufacturing use sectors may find some degrees of drought management to be economically viable and cost-competitive with other water management strategies. The SCTRWPG will have an opportunity to refine the general methodology described herein prior to consideration of drought management as a potentially feasible water management strategy for water user groups with projected needs by 2020 in the 2011 South Central Texas Regional Water Plan.

ES.5 Land Stewardship

Land stewardship involves a spectrum of resource conservation activities, including such measures as brush management, that have long been of interest to the SCTRWPG. In support of the regional water planning process, the Texas Wildlife Association Foundation (TWAF) has sponsored a series of studies by scientists at Texas A&M University (TAMU) focused on land-based water conservation and water yield practices. In the course of these studies, TAMU scientists have compiled and summarized research and extracted preliminary conclusions of relevance to the South Central Texas Regional Water Planning Area (Region L), including estimates of increased average water yield and expected costs of brush management practices to achieve such increases in average water yield. Furthermore, TAMU scientists have summarized methodologies for spatially explicit identification of lands most suitable for cost-effective land-based water conservation practices and described monitoring protocols for the measurement of short- and long-term effectiveness of such practices.

Increases in average water yield are not, however, equivalent to increases in firm yield or water supply available without interruption during a repeat of the most severe drought on record, the fundamental basis for regional water supply planning in accordance with TWDB rules and guidance. As part of the development of the 2011 South Central Texas Regional Water Plan, the information compiled by TAMU, spatially explicit methodologies for selection of preferred areas for brush management, and new hydrologic models capable of simulating surface water, groundwater, and interactions between the two will all be used in a more comprehensive technical evaluation of brush management as a potentially feasible water management strategy to meet projected needs in Region L. Pursuant to TWDB rules and guidance, this technical evaluation will include quantitative and qualitative assessments of firm yield, costs of water, environmental effects, water quality, and other factors in a manner consistent with the technical evaluations of other water management strategies in Region L.

1.0 Introduction

Study 3, Enhanced Water Conservation, Drought Management, and Land Stewardship of the First Biennium of the 2011 South Central Texas Regional Water Plan (SCTRWP) focuses on four subject areas of particular interest to the South Central Texas Regional Water Planning Group (SCTRWPG). These four subject areas are briefly introduced below, and discussed in the following sections of this report.

The SCTRWPG has recommended water conservation as a fundamental water management strategy to meet projected needs for additional water supply throughout the South Central Texas Regional Water Planning Area (Region L) in the 2006 South Central Texas Regional Water Plan (2006 SCTRWP). Summary information regarding the Region L water conservation water management strategy is provided in Section 2 and Appendix A of this report.

In the process of developing its recommended water conservation water management strategy, the SCTRWPG has identified condensate collection as a conservation strategy of interest and seeks to consider additional technical information regarding its potential feasibility for more common implementation in Region L. Section 3 summarizes information regarding several facilities that have installed systems to collect condensation from air-conditioning units and distribute this water for on-site irrigation and/or other non-potable uses. Section 3 also includes synthesis of this information into a general equation for estimating condensate volume and preliminary evaluation of an example condensate collection system for a large retail facility in Bexar County.

In its consideration of enhanced water conservation, the SCTRWPG has chosen not to recommend drought management as a water management strategy to meet projected needs in the 2001 and 2006 SCTRWPs. The SCTRWPG did, however, choose to identify drought management as requiring further study prior to implementation in the 2006 SCTRWP. In this context, a drought management strategy might be defined as the periodic activation of an approved drought contingency plan to reduce water demands, as an alternative to developing reliable water supplies to meet demands during drought. As this strategy is fundamentally different from almost all other potentially feasible water management strategies considered by the SCTRWPG, the purpose of drought management studies presented in Section 4 of this report is to demonstrate a methodology for evaluating associated costs, thereby facilitating direct comparisons of this strategy to others.

Land stewardship involves a spectrum of resource conservation activities, including such measures as brush management, that have long been of interest to the SCTRWPG. In both the 2001 and 2006 SCTRWPs, brush management was identified among several water management strategies requiring further study and funding prior to implementation. In support of the regional water planning process, the Texas Wildlife Association Foundation has funded such studies focused on brush management in Region L and performed by researchers at Texas A&M University (TAMU). These studies are introduced in Section 5 and summary documents prepared by TAMU are included as Appendices E through G.

2.0 Water Conservation

The 2006 South Central Texas Regional Water Plan (SCTRWP) recommends water conservation as a fundamental water management strategy to meet projected needs for additional water supply and to reduce water demands for all water user groups throughout the South Central Texas Regional Water Planning Area (Region L). The Region L water conservation water management strategy is described in presentation format in Appendix A of this report. Summary information regarding key elements of the Region L water conservation water management strategy and concepts of interest for enhanced water conservation are summarized in the following paragraphs.

2.1 Elements of the Region L Water Conservation Water Management Strategy

The Water Conservation water management strategy formulated by the South Central Texas Regional Water Planning Group (SCTRWPG) includes Best Management Practices (BMPs) for municipal, industrial, irrigation, steam-electric power, mining, and livestock water user groups.

Municipal water conservation goals adopted by the SCTRWPG recommend a one percent reduction in per capita water use per year for cities and rural water suppliers that used more than 140 gallons per capita per day (gpcd) in year 2000 and a 0.25 percent reduction in per capita use per year for those presently, or at some point in the future are projected to be, using less than 140 gpcd. Key recommended management practices for municipal water conservation are accelerated plumbing fixture and clothes washer retrofit and lawn watering restrictions. Furthermore, the SCTRWPG recognizes and encourages recycled water programs focusing on reuse of future treated wastewater volumes for non-potable purposes and rainwater harvesting in the Hill Country where local water supplies are limited. Reductions in Region L water needs achieved through implementation of recommended municipal water conservation practices are projected to exceed 72,000 acft/yr by year 2060.

Successful implementation of the recommended municipal water conservation water management strategy may affect the ability of some water user groups to attain currently expected percentage reductions in water use under drought management conditions. For example, a water user group could choose to implement a mandatory twice-a-week lawn watering schedule as part of its routine water conservation program in order to meet its per capita water use goals. This, in turn, could limit the effectiveness of its drought management program keyed to achieving significant use reductions by restriction of outdoor water uses. In general terms, the less discretionary water use allowed under a routine water conservation program, the less the percentage reductions in water use that can be reasonably expected under drought management conditions.

Recommended management practices for water conservation in the industrial, steam-electric power generation, and mining use sectors generally focus on reuse of future treated wastewater volumes from municipal facilities and on-site recycling. Potential reductions in water needs resulting from reuse and recycling in these use sectors and the municipal use sector total more than 47,000 acft/yr by year 2060.

Low Energy Precision Application (LEPA) systems and furrow-diking are recommended water conservation practices for the irrigation use sector. Associated reductions in water needs for irrigation are projected to reach a maximum of about 14,000 acft/yr during the planning period.

2.2 Concepts of Interest for Enhanced Water Conservation

In preparing the scope of work for special technical studies to support development of the 2011 SCTRWP, the SCTRWPG identified three concepts of interest for potential enhancement or expansion of water conservation recommendations in the 2006 SCTRWP. These three concepts are condensate collection, drought management, and land stewardship. Technical information regarding each is provided in the following sections of this report.

3.0 Condensate Collection Systems

3.1 Introduction

A potential on-site water conservation water management strategy is the practice of condensate collection, in which the condensation from large air conditioning units is collected and piped throughout the building and/or landscape for on-site use (landscape irrigation, toilet flushing and sanitation, etc). Such collection and distribution systems could be recommended for new large building construction or as retro-fit for existing large buildings. Seven examples of existing and/or planned condensation collection projects found through internet research and telephone inquiries are summarized in Table 3-1. These examples range from relatively small government facilities in Texas and Florida to a large health center in Ohio. Six of the seven collection systems are located in a warm, humid southern climate.

Table 3-1.
Condensation Collection Facility Data

Condensate Collection Project	Project Status	Location	Building Area (ft^2)	Average Summer Afternoon Humidity	Average High Summer Temperature (deg F)	Annual Condensate Recovery Volume (gal/yr)
Sea World Game Center	Existing	San Antonio, TX	28,000	57%	91	140,000
Sea World Restaurant	Existing	San Antonio, TX	12,000	57%	91	35,000
Houston EPA Laboratory	Existing	Houston, TX	39,408	62%	88	138,333
EPA Gulf Ecology Division Laboratories	Planned	Gulf Breeze, FL	79,450	62%	85	100,000
Emory University Winship Cancer Institute	Existing	Atlanta, GA	268,000	57%	80	900,000
Fulton County Health Center	Existing	Wauseon, OH	281,500	56%	73	353,000
Duke University Gross Chemistry Center and Levine Science Resource Center	Existing	Durham, NC	430,000	57%	80	9,000,000

The square footage area for each of these buildings, as well as the humidity and temperature data for each city, is also presented in Table 3-1 for each of the seven condensate collection facilities considered in this preliminary assessment. Average high summer temperatures for each city were acquired from http://www.weather.com. Average summer afternoon humidity values were obtained from http://www.cityrating.com for each city.

3.2 Procedure

Data in Table 3-1 were considered in order to determine which factors have a significant effect on the annual amount of condensate recovered from each facility. Intuitively, higher humidity levels would result in more condensate recovered, as greater amounts of water in the air would allow for greater condensation of water associated with air conditioning system operations. Likewise, lower temperatures would result in greater volumes of condensate recovered, encouraging the gas phase particles to lose energy promoting a transition to the liquid phase.

Condensate recovery for the Duke University facility is reported to be much higher (per square foot of building area) than the values for the rest of the facilities. Therefore, regressions were performed with and without the Duke University facility in order to see how the correlations were affected by these higher numbers. Ultimately, the Duke University facility was omitted as an outlier (as its data are inconsistent with reported data for other facilities), resulting in a better correlation for predicting condensate volume. In addition, EPA Gulf Ecology Division Laboratories data were excluded because the data available were planning estimates.

Stepwise single-variable regression analyses were performed for prediction of condensate volume at five facilities using Building Area (Area), Average High Summer Temperature (Temperature), and Average Summer Afternoon Humidity (Humidity) as independent variables. Standard tests of the regression coefficients and overall regressions indicate that only Area (Figure 3-1) and Temperature (Figure 3-2) are statistically significant predictors of condensate volume for the sample data considered.

Using both Area and Temperature as independent variables in a multiple linear regression equation for estimation of condensate volume results in Equation 1, for which coefficients and the overall regression are deemed statistically significant by standard tests. The coefficient of determination (r^2) for Equation 1 is 0.88 indicating that approximately 88 percent of the variation in condensate volume for the facilities considered can be explained by the regression equation. Figure 3-3 provides a comparison of actual condensate volume and predicted condensate volume using Equation 1.

$$\text{Condensate Volume} = (6.4 * \text{Area}) + (77{,}174.8 * \text{Temperature}) - 7{,}033{,}910.1 \qquad (Eq.1)$$

Where:

Area = Building Square Footage (sq ft)
Temperature = Average Summer (May – Sept) High Temperature (deg F)
Condensate Volume = Amount of Condensate Water Collected (gal/yr)

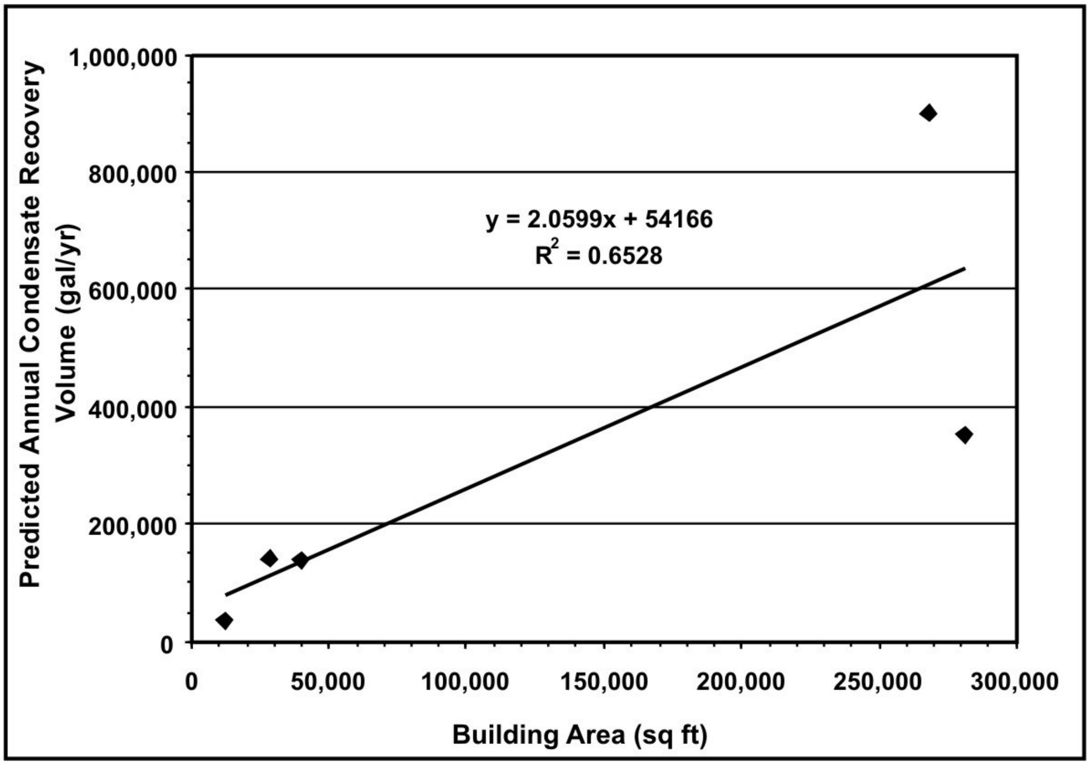

Figure 3-1. Effect of Building Area on Condensate Recovery Volume

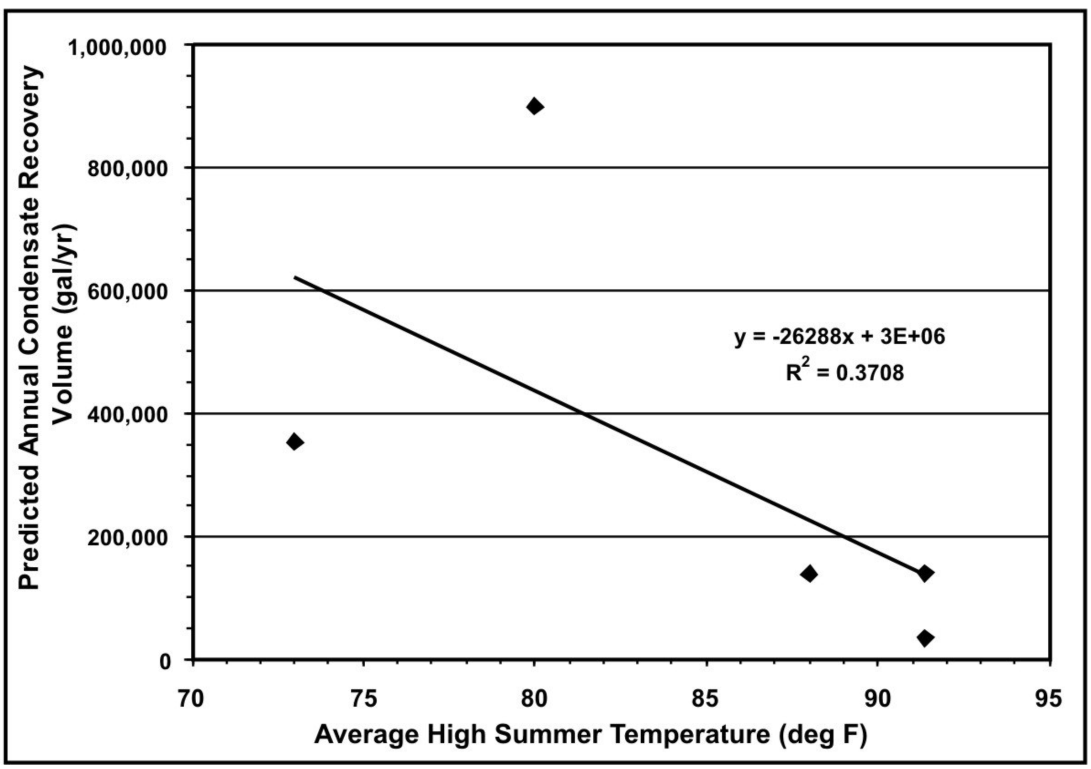

Figure 3-2. Effect of Average High Summer Temperature on Condensate Recovery Volume

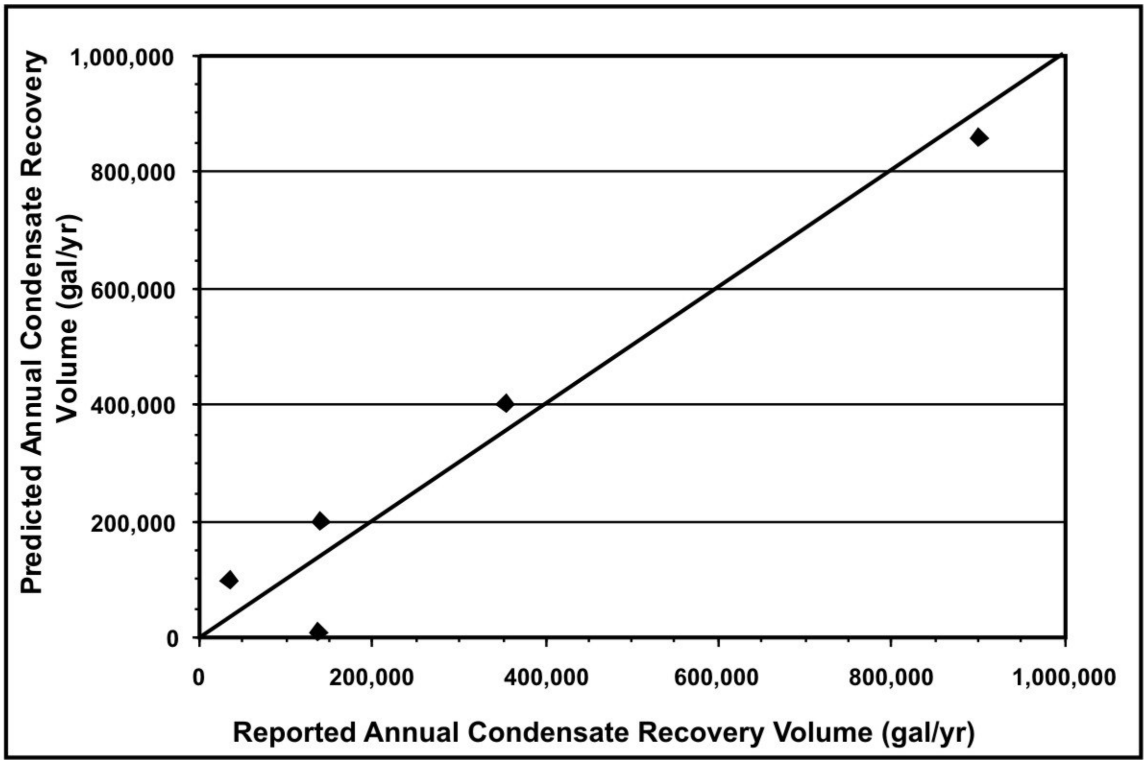

Figure 3-3. Actual Condensate Collection vs. Predicted Condensate Collection Using Equation 1

3.3 New Construction Example for "Box Store" in Bexar County, Texas

For the purpose of illustrating the technical evaluation of a condensation collection system project, a hypothetical "Box Store" in or around Bexar County is considered using Equation 1 to estimate potential condensation volume. New "box stores" generally range in size from 100,000 sq ft to 150,000 sq ft, while some are as large as 200,000 sq ft. For this example, a 130,000 sq ft "box store" is used. The average high summer temperature for San Antonio is 91.4^{o}F according to http://www.weather.com. Using these two values in Equation 1, the condensate volume is calculated to be 851,867 gal/yr (about 2.6 acft/yr).

Limited available data indicates that a condensate collection system in a new 130,000 sq ft facility might be installed for a capital cost of approximately $37,000 (based on $0.28 per sq ft). Adding in associated project costs (i.e., contingencies and engineering) and assuming the project is financed over 30 years for consistency with other potentially feasible water management strategies, the estimated annual unit cost of water is about $1,450/acft/yr for a condensate collection system for an example box store in Bexar County.

Data from SeaWorld San Antonio indicates that a smaller system (35,000 gal/yr of condensate collection for the SeaWorld Restaurant) was installed for about $6,400, which results in a unit cost of water of about $4,300/acft/yr. The apparent difference in unit cost as compared to the example box store is primarily a result of actual condensate collected (35,000 gal/yr) being about one-third of that predicted by Equation 1. Clearly, site-specific system installation and operation characteristics and economies of scale can be significant factors in evaluating condensate collection system feasibility relative to other sources of water supply.

3.4 Summary

Water supplies potentially available from condensate collection systems can be estimated from building area and average high summer temperature using an equation based on available performance data for five facilities in Texas, Georgia, and Ohio. As the collection of condensate can only occur when air conditioning systems are operating, integration of storage in a condensate collection system is necessary to consider it a firm, rather than seasonal, source of supply. Such collection systems, however, do have the distinct advantages of water being generated on-site and most available during hot, summer periods when run-of-river surface water supply sources are least available and treatment, transmission, and distribution systems are stressed to meet peak-day demands. The example presented in Section 3.3 illustrates that condensate collection systems may provide some water supplies at an annual unit cost comparable to some of the other potentially feasible water management strategies being considered for the South Central Texas Regional Water Planning Area.

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4.0 Drought Management

Texas Administrative Code (TAC), Chapter 357 Regional Water Planning Guidelines, states that "Regional water plan development shall include an evaluation of all water management strategies the regional water planning group determines to be potentially feasible, including drought management measures including water demand management [357.7(a)(7)(B)]." As defined for the purposes of this study, drought management means the periodic activation of approved drought contingency plans resulting in short-term demand reduction and/or rationing. This reduction in demand is then considered a "supply" source. Using this approach (for the purposes of this study), an entity may make the conscious decision not to develop firm water supplies greater than or equal to projected water demands with the understanding that demands will have to be reduced or go unmet during times of drought.[1] Using this rationale, an economic impact of not meeting projected water demands can be estimated and compared with the costs of other potentially feasible water management strategies in terms of annual unit costs. When implementation of drought management as a water management strategy is deemed economically feasible by a water user group, it may allow that water user group to avoid or delay capital costs and environmental impacts associated with development of additional water supply sources. One potential benefit common to both drought management and water conservation strategies that limit peak water use (e.g., lawn-watering restrictions) is that water treatment plants, high service pumping facilities, and/or distribution system improvements for potable water service may be avoided or delayed.

4.1 Planning with Drought Management Water Management Strategy

Figure 4-1 shows how water supply planning was done in the 2007 State Water Plan and 2006 Regional Water Plans. For each Water User Group (WUG) with an identified shortage or need during the planning period, a future water supply plan was developed consisting of one or more water management strategies. In each case, the planned future water supply was greater than the projected dry weather demand to allow for drought more severe than the drought of record, uncertainty in water demand projections, and/or available supply from recommended water management strategies. This difference between planned water supply and projected dry weather demand is called management supply in Region L.

[1] Implementing drought management, in general, does not require a corresponding reduction in available water supply and may be implemented by water user groups with existing supplies well in excess of projected water demands.

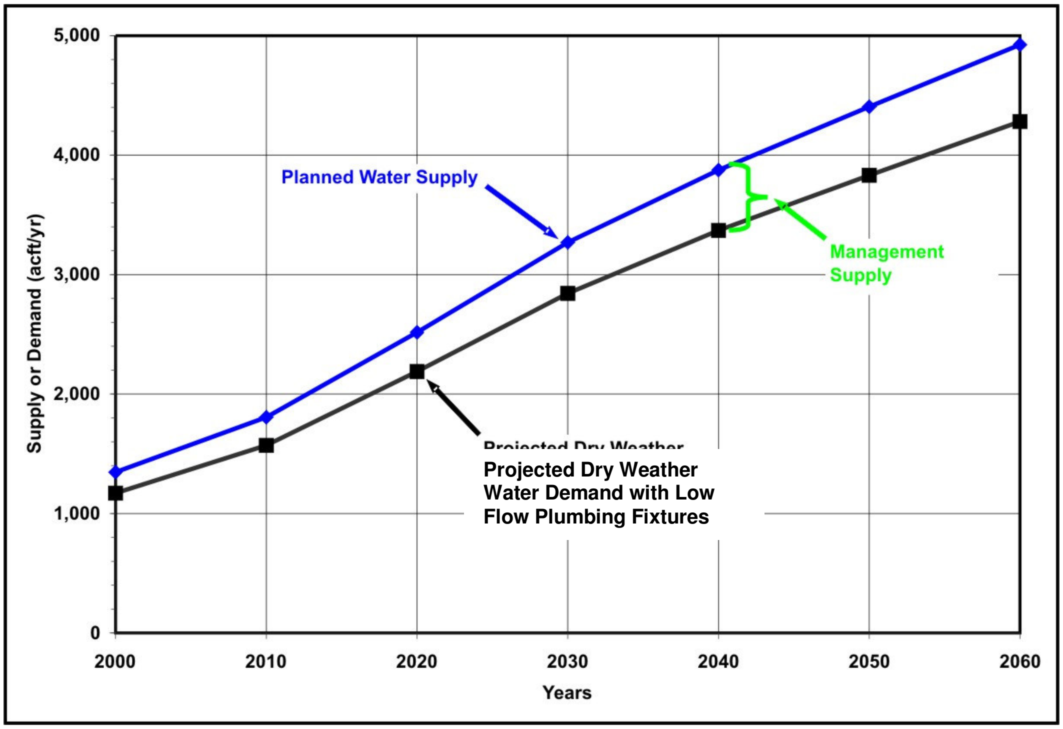

Figure 4-1. Typical Planning in 2006 Regional Water Plan

Figure 4-2 illustrates how a drought management water management strategy (WMS) could alter the planning paradigm for WUGs with projected needs. Instead of identifying water management strategies to meet the projected need, planned water supply remains below the projected dry weather water demand. The difference between these two lines represents the drought management WMS. Under this concept, a WUG's water demand would be reduced by activating a drought contingency plan to reduce demands, resulting in unmet needs. This strategy of demand reduction or water rationing could negate the need for water management strategies to meet the full projected need of the WUG. Basically, using this approach, the WUG is planning to manage water shortages through drought contingency plan activation or water rationing, if needed.[2] This concept is more fully illustrated in Figure 4-3, which shows that, in any given year, the actual demand may be above or below the planned supply. During times in which the demand exceeds supply, the WUG would experience shortages and incur associated economic impacts.

[2] As mentioned in Section 2.1, the less discretionary water use allowed under a routine water conservation program, the less the percentage reductions in water use that can be reasonably expected under drought management conditions.

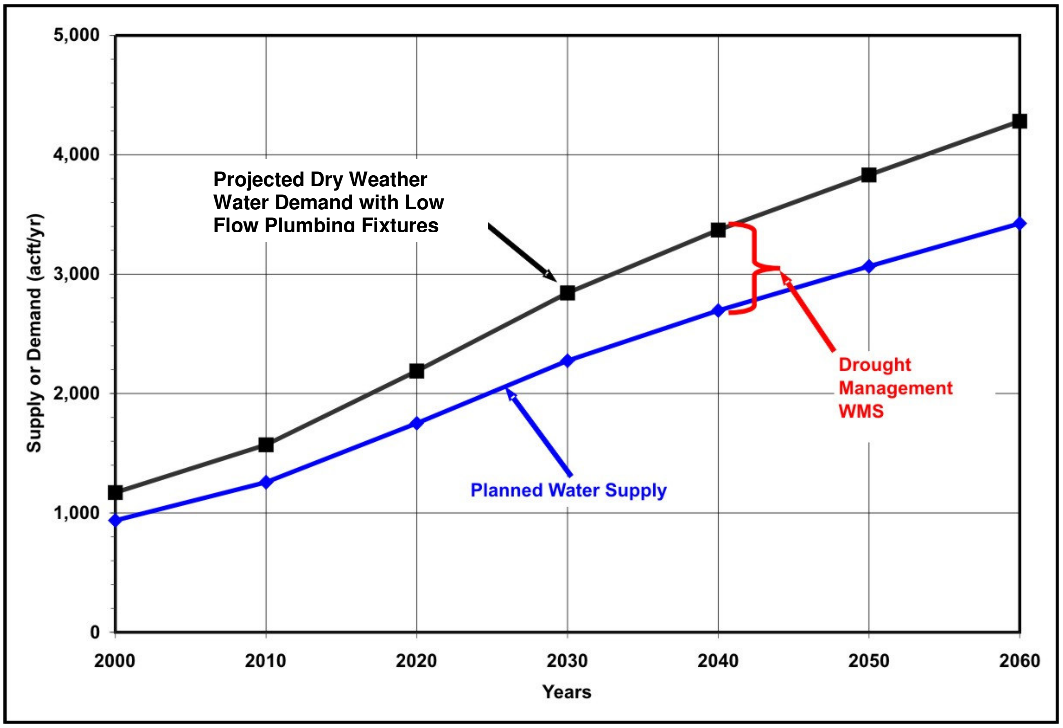

Figure 4-2. Planning with Drought Management Water Management Strategy

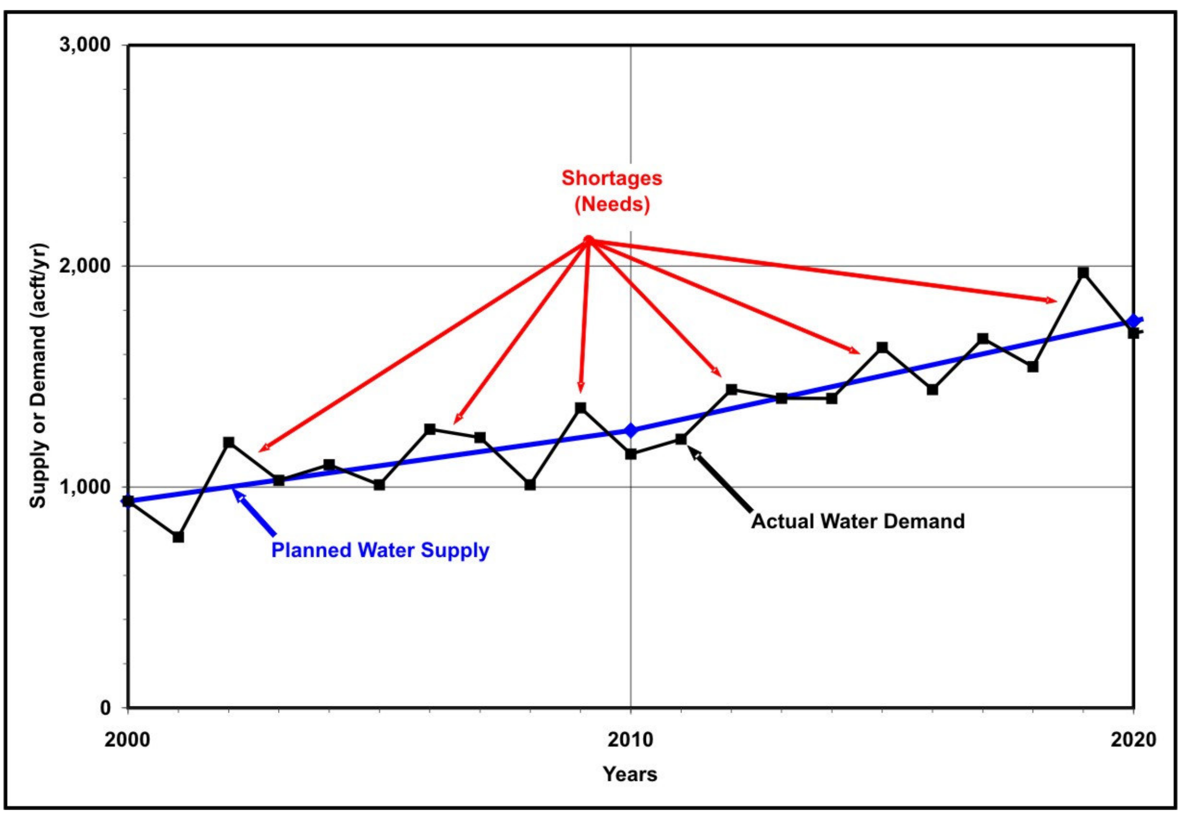

Figure 4-3. Example Drought Management Water Management Strategy

4.2 Drought Management Strategy Methodology

As shown in Figure 4-4, there are a number of incremental steps to calculating a unit cost for this strategy so that it can be compared to other strategies. The first step in the process is to calculate a risk factor for the base case, 5% reduction, 10% reduction, 15% reduction, and 20% reduction cases. Figure 4-5 illustrates the base case and 5% reduction scenarios. The risk factor is defined as the integrated chance of occurrence of potential annual demands in excess of planned supply based on historical per capita variations for each entity. The base risk factor is defined as the risk of shortages occurring when planned supply is equal to the projected demand based on Texas Water Development Board (TWDB) selection of 2000 as a representative dry year demand. A 5% Drought Management WMS, for example, equates to planned supply that is 95% of projected demand.

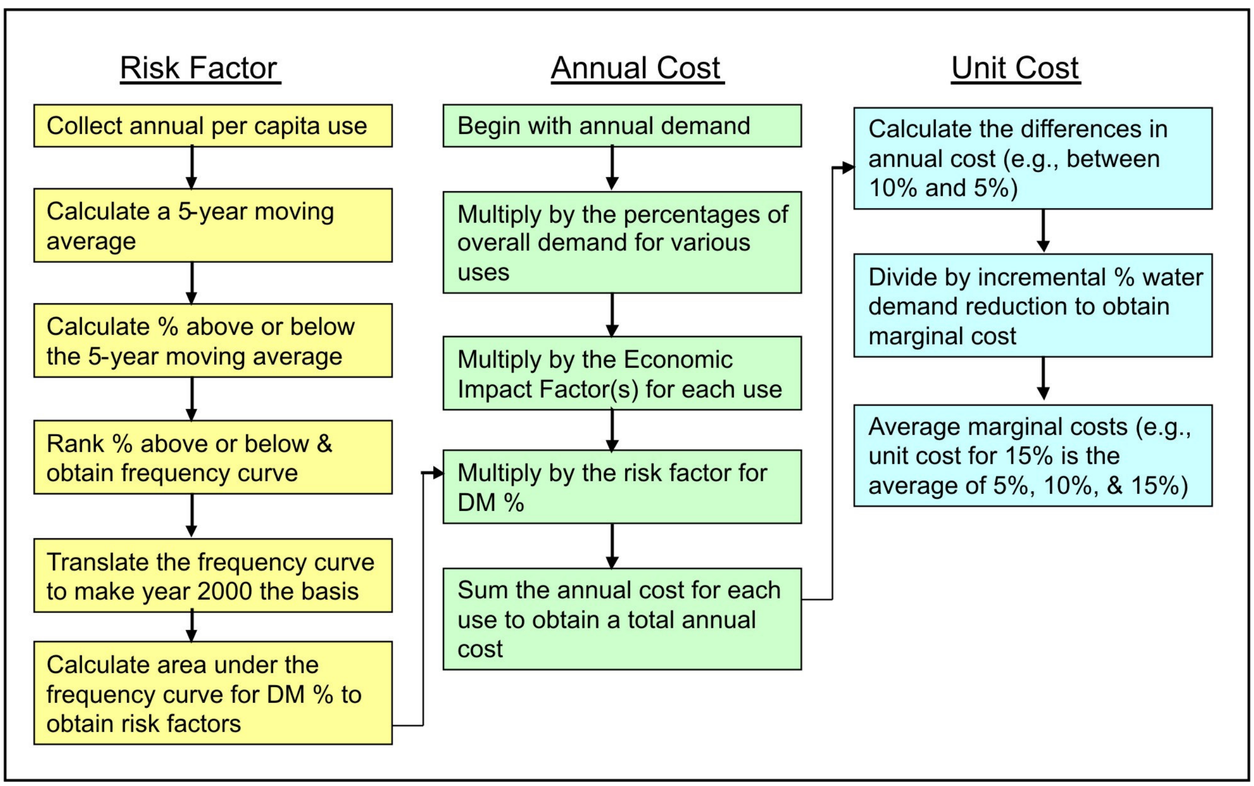

Figure 4-4. Methodology Flowchart

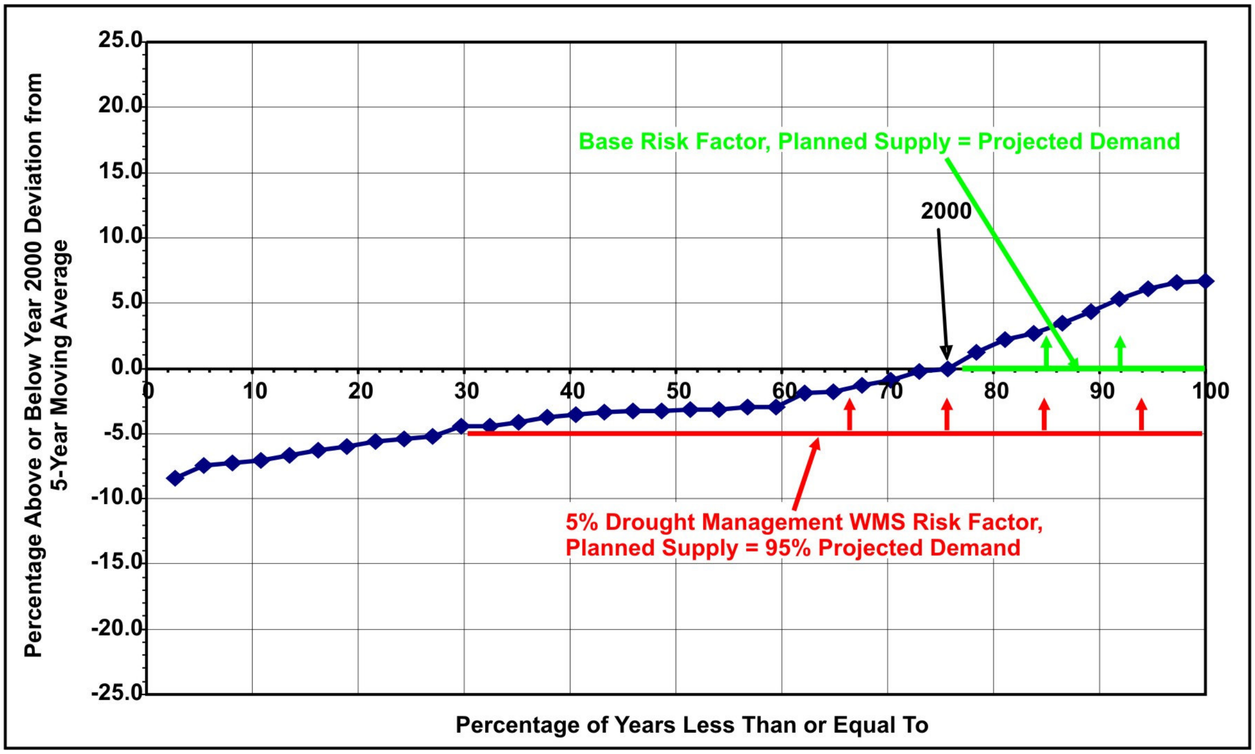

Figure 4-5. Frequency of Per Capita Water Use Variations Adjusted to Basis of Demand Projections

The first step in determining the risk factors was to obtain historical annual per capita water use values. These data were obtained from the TWDB for the period 1964 to 2004, if available (see Appendix C).[3] From these data, a 5-year moving per capita water use average was calculated in order to limit the effects of trends in per capita water use rates. Next, an annual percentage above or below the 5-year moving average was calculated. These values were then ranked lowest to highest. A frequency curve was then plotted using these data with the percentage above or below the 5-year moving average on the y-axis and the percentage of years less than or equal to that value on the x-axis. Finally, this curve was translated so that the year 2000 value was placed at 0 on the y-axis (Figure 4-5) because year 2000 was used by the TWDB as the basis for demand projections in the 2006 regional water plans. From a plot like Figure 4-5, the integrated area under the frequency curve was calculated as the risk factor.

[3] Graphical review of data in Appendix C indicates the presence of trends (decreasing magnitude and variability) in some per capita use rates over time. These trends are due, in many cases, to conservation and recent Edwards Aquifer pumpage restrictions during drought. Fully adjusting for these trends would necessitate hydrologic and climate modeling beyond the scope of this study in order to quantify unconstrained per capita use.

Risk factors were calculated in a Microsoft Excel workbook with specific cell equations being unique for each water user group. Referring to Figure 4-5 (which is based on data for the San Antonio Water System), the risk factor for the base case is the area between the frequency curve (in blue) and the x-axis (in green). Likewise, the risk factor for the 5% drought management scenario is calculated as the area between the frequency curve (in blue) and the 5% deviation or reduction line (in red). This process was repeated for the 10%, 15%, and 20% drought management reduction scenarios.[4] Alternative risk factor calculation procedures may be considered for refined drought management strategy evaluations in the 2011 Region L Water Plan.

After risk factors for each scenario were calculated, an annual economic impact was then calculated using the following formula:

(Demand) X (%Demand) X (Risk Factor) X ($ Impact Factor) = DM WMS Economic Impact *(Eq.2)*

where:

- Demand (acft/yr) = Projected "dry year" demand from TWDB based on year 2000 per capita use rate;
- % Demand = Proportion of water demand associated with various use types (i.e., domestic, commercial, and manufacturing);
- Risk Factor = Integrated chance of occurrence of potential annual demands in excess of planned supply based on historical per capita use variations for each entity;
- $ Impact Factor ($/acft)[5] = Economic impact factors used by TWDB (see Table 4-1) to calculate economic impacts of not meeting needs. TWDB factors used include (a) lost sales for water-intensive commercial users; (b) lost water and wastewater utility revenues; (c) costs to non-water-intensive commercial businesses and households; and (d) lost sales for manufacturing; and

[4] For some water user groups, it is understood that per capita water use during the drought year 2000 may have deviated from the 5 year moving average to a lesser degree than indicated by similar drought years earlier in the period of record because of Edwards pumpage restrictions. This fact, in turn, lowers the rank of the year 2000 percentage deviation among all such deviations, thereby increasing the base risk factor and risk factors associated with various drought management scenarios and, ultimately, increasing the annual economic impacts and unit costs associated with drought management scenarios. Calculation of unrestricted per capita use rates for drought years 2000 (and 1996) could minimize this problem, but would require substantial effort beyond the scope of this conceptual study.

[5] For a more detailed discussion of the TWDB impact factors, see Appendix B.

- DM WMS Annual Economic Impact ($/yr) = Typical annual economic impacts of adhering to the Drought Management WMS for that water use type. The annual economic impact for each use type (i.e., domestic, commercial, and manufacturing) were then summed to obtain a total annual economic impact. This annual economic impact does take into account lost utility revenue due to declining water and sewer sales.

The final step in this process was to convert the annual economic impact to a unit cost so that this strategy could be compared to other potentially feasible water management strategies. In order to do this, the lost utility revenues were first subtracted, then the difference between the annual economic impact for each scenario were first calculated (i.e., between 10% and 5%). This value was then divided by a 5% water demand reduction from the year 2010 demand to obtain a marginal cost. Finally, the marginal cost values were averaged to obtain a unit cost (i.e., the unit cost for 15% is the average of 5%, 10%, and 15%).

An example cost calculation for the City of Uvalde is provided in Tables 4-2 and 4-3. Using data supplied by the TWDB (Table 4-1), the "Share of WUG Demand" row is populated. In this case, 90% of the demand is applied to Domestic/Residential use and 10% to Commercial use. There is no demand associated with Manufacturing for the City of Uvalde. Next, the demand associated with each water use is determined by multiplying the total year 2010 demand times the percentage associated with each use type (i.e., 6,087 acft x .90 = 5,478 acft for domestic/residential demand). Using the methodology described above, the risk factor was determined for each scenario. Next, the economic impact factor was determined for each use type using the data supplied by the TWDB and shown in Table 4-1. These factors are constant from one drought management scenario to the next, with the exception of the factors for Domestic/Residential which were determined by taking the average of the values supplied by the TWDB up to the point associated with that scenario. For example, for the 5% drought management scenario for the City of Uvalde, the associated economic impact factor for domestic/residential is $549; however, for the 10% reduction scenario, the economic impact factor is $798 (i.e., the average of $549 and $1,047). Next the total economic impact for each use type is calculated by multiplying the proportional demand times the risk factor times the economic impact factor (i.e., 609 acft x 0.0001 x $57,884/acft = $3,523 for the commercial sector). This same formula was used to determine the economic impact for each use type. Next, the economic impacts for each use type were summed to obtain a total economic impact (i.e.,

$301 + $3,523 + $421 + $164 = $4,409). This type of process was used to determine the total economic impact for the 10%, 15%, and 20% drought management scenarios as well.

To determine the approximate unit cost for the 10% drought management scenario for Uvalde, the following steps were completed. First, marginal costs for both the 5% and 10% scenarios were calculated. For the 5% scenario, this is simply the total economic impact minus the impacts associated with lost water and sewer revenue, divided by 5% of the total year 2010 demand (i.e., $3,824 / 304 acft = $13/acft). For the 10% scenario, a marginal cost must first be calculated. This is calculated as the difference in total economic impact, minus the impacts associated with lost water and sewer revenue, between the 10% and 5% drought management scenarios, divided by 5% of the total year 2010 demand (i.e., ($75,058 - $3,824) / 304 acft = $234/acft). To calculate the approximate unit cost for the 10% drought management scenario, the marginal costs of the 5% and the 10% scenario are averaged (i.e., ($13 + $234) / 2 = $123/acft).

Table 4-1. Economic Impact Factors ($/AF) Year 2010

			Domestic water use									
			Domestic water use impacts*					horticultural and landscaping industries impact due to restricting non-agricultural outdoor landscape irrigation				
	County	City	5% reduction	10% reduction	15% reduction	20% reduction	25% reduction	5% reduction	10% reduction	15% reduction	20% reduction	25% reduction
1	Atascosa	Lytle	$529	$1,027	$1,556	$2,085	$2,583	$91	$91	$91	$91	$91
2	Bexar	Alamo Heights	$529	$1,027	$1,556	$2,085	$2,583	$474	$474	$474	$474	$474
3	Bexar	Hill Country Village	$529	$1,027	$1,556	$2,085	$2,583	$157	$157	$157	$157	$157
4	Bexar	Hollywood Park	$529	$1,027	$1,556	$2,085	$2,583	$172	$172	$172	$172	$172
5	Bexar	San Antonio (BMWD)	$529	$1,027	$1,556	$2,085	$2,583	$1,002	$1,002	$1,002	$1,002	$1,002
6	Bexar	San Antonio (SAWS)	$529	$1,027	$1,556	$2,085	$2,583	$798	$798	$798	$798	$798
7	Bexar	Schertz	$529	$1,027	$1,556	$2,085	$2,583	$827	$827	$827	$827	$827
8	Bexar	Selma	$529	$1,027	$1,556	$2,085	$2,583	$372	$372	$372	$372	$372
9	Bexar	Shavano Park	$529	$1,027	$1,556	$2,085	$2,583	$282	$282	$282	$282	$282
10	Caldwell	Lockhart	$529	$1,027	$1,556	$2,085	$2,583	$406	$406	$406	$406	$406
11	Calhoun	Point Comfort	$529	$1,027	$1,556	$2,085	$2,583	$814	$814	$814	$814	$814
12	Comal	New Braunfels	$529	$1,027	$1,556	$2,085	$2,583	$326	$326	$326	$326	$326
13	Comal	Garden Ridge	$529	$1,027	$1,556	$2,085	$2,583	$308	$308	$308	$308	$308
14	Dewitt	Gonzales County WSC	$529	$1,027	$1,556	$2,085	$2,583	$284	$284	$284	$284	$284
15	Hays	San Marcos	$529	$1,027	$1,556	$2,085	$2,583	$344	$344	$344	$344	$344
16	Hays	Wood Creek	$529	$1,027	$1,556	$2,085	$2,583	$398	$398	$398	$398	$398
16	Hays	Wood Creek Utilities Inc.	$529	$1,027	$1,556	$2,085	$2,583	$282	$282	$282	$282	$282
17	Karnes	Kenedy + TDCJ	$529	$1,027	$1,556	$2,085	$2,583	$120	$120	$120	$120	$120
18	Kendall	Boerne	$529	$1,027	$1,556	$2,085	$2,583	$860	$860	$860	$860	$860
19	Medina	Hondo	$529	$1,027	$1,556	$2,085	$2,583	$49	$49	$49	$49	$49
20	Uvalde	Uvalde	$529	$1,027	$1,556	$2,085	$2,583	$20	$20	$20	$20	$20
21	Wilson	SS Water Supply Corp	$529	$1,027	$1,556	$2,085	$2,583	$383	$383	$383	$383	$383

			Domestic water use					Commercial				
			Total Combined for Domestic (A)					*Total* (B)				
	County	City	5% reduction	10% reduction	15% reduction	20% reduction	25% reduction	5% reduction	10% reduction	15% reduction	20% reduction	25% reduction
1	Atascosa	Lytle	$620	$1,118	$1,647	$2,176	$2,674	$22,715	$22,715	$22,715	$22,715	$22,715
2	Bexar	Alamo Heights	$1,003	$1,501	$2,030	$2,559	$3,057	$47,016	$47,016	$47,016	$47,016	$47,016
3	Bexar	Hill Country Village	$686	$1,184	$1,713	$2,242	$2,740	$16,334	$16,334	$16,334	$16,334	$16,334
4	Bexar	Hollywood Park	$701	$1,199	$1,728	$2,257	$2,755	$17,792	$17,792	$17,792	$17,792	$17,792
5	Bexar	San Antonio (BMWD)	$1,531	$2,029	$2,558	$3,087	$3,585	$98,134	$98,134	$98,134	$98,134	$98,134
6	Bexar	San Antonio (SAWS)	$1,327	$1,825	$2,354	$2,883	$3,381	$78,462	$78,462	$78,462	$78,462	$78,462
7	Bexar	Schertz	$1,356	$1,854	$2,383	$2,912	$3,410	$81,236	$81,236	$81,236	$81,236	$81,236
8	Bexar	Selma	$901	$1,399	$1,928	$2,457	$2,955	$37,164	$37,164	$37,164	$37,164	$37,164
9	Bexar	Shavano Park	$811	$1,309	$1,838	$2,367	$2,865	$28,452	$28,452	$28,452	$28,452	$28,452
10	Caldwell	Lockhart	$935	$1,433	$1,962	$2,491	$2,989	$36,456	$36,456	$36,456	$36,456	$36,456
11	Calhoun	Point Comfort	$1,343	$1,841	$2,370	$2,899	$3,397	$10,107	$10,107	$10,107	$10,107	$10,107
12	Comal	New Braunfels	$855	$1,353	$1,882	$2,411	$2,909	$89,195	$89,195	$89,195	$89,195	$89,195
13	Comal	Garden Ridge	$837	$1,334	$1,864	$2,393	$2,890	$14,903	$14,903	$14,903	$14,903	$14,903
14	Dewitt	Gonzales County WSC	$813	$1,311	$1,840	$2,369	$2,867	-	-	-	-	-
15	Hays	San Marcos	$873	$1,371	$1,900	$2,429	$2,927	$60,343	$60,343	$60,343	$60,343	$60,343
16	Hays	Wood Creek	$927	$1,425	$1,954	$2,483	$2,981	$27,781	$27,781	$27,781	$27,781	$27,781
16	Hays	Wood Creek Utilities Inc.	$811	$1,309	$1,838	$2,367	$2,865	$20,046	$20,046	$20,046	$20,046	$20,046
17	Karnes	Kenedy + TDCJ	$649	$1,147	$1,676	$2,205	$2,703	$20,615	$20,615	$20,615	$20,615	$20,615
18	Kendall	Boerne	$1,389	$1,887	$2,416	$2,945	$3,443	$30,815	$30,815	$30,815	$30,815	$30,815
19	Medina	Hondo	$578	$1,076	$1,605	$2,134	$2,632	$26,145	$26,145	$26,145	$26,145	$26,145
20	Uvalde	Uvalde	$549	$1,047	$1,576	$2,105	$2,603	$57,884	$57,884	$57,884	$57,884	$57,884
21	Wilson	SS Water Supply Corp	$912	$1,410	$1,939	$2,468	$2,966	$26,145	$26,145	$26,145	$26,145	$26,145

			Manufacturing					Impacts to be Applied to all types of uses				
			Total (C)					Lost Utility Revenues (Water Sales) (D)				
	County	City	5% reduction	10% reduction	15% reduction	20% reduction	25% reduction	5% reduction	10% reduction	15% reduction	20% reduction	25% reduction
1	Atascosa	Lytle	-	-	-	-	-	$692	$692	$692	$692	$692
2	Bexar	Alamo Heights	-	-	-	-	-	$692	$692	$692	$692	$692
3	Bexar	Hill Country Village	-	-	-	-	-	$692	$692	$692	$692	$692
4	Bexar	Hollywood Park	-	-	-	-	-	$692	$692	$692	$692	$692
5	Bexar	San Antonio (BMWD)	$74,691	$74,691	$74,691	$74,691	$74,691	$692	$692	$692	$692	$692
6	Bexar	San Antonio (SAWS)	$74,691	$74,691	$74,691	$74,691	$74,691	$692	$692	$692	$692	$692
7	Bexar	Schertz	-	-	-	-	-	$692	$692	$692	$692	$692
8	Bexar	Selma	-	-	-	-	-	$692	$692	$692	$692	$692
9	Bexar	Shavano Park	-	-	-	-	-	$692	$692	$692	$692	$692
10	Caldwell	Lockhart	-	-	-	-	-	$692	$692	$692	$692	$692
11	Calhoun	Point Comfort	-	-	-	-	-	$692	$692	$692	$692	$692
12	Comal	New Braunfels	$9,390	$9,390	$9,390	$9,390	$9,390	$692	$692	$692	$692	$692
13	Comal	Garden Ridge	-	-	-	-	-	$692	$692	$692	$692	$692
14	Dewitt	Gonzales County WSC	-	-	-	-	-	$692	$692	$692	$692	$692
15	Hays	San Marcos	$13,640	$13,640	$13,640	$13,640	$13,640	$692	$692	$692	$692	$692
16	Hays	Wood Creek	-	-	-	-	-	$692	$692	$692	$692	$692
16	Hays	Wood Creek Utilities Inc.	-	-	-	-	-	$692	$692	$692	$692	$692
17	Karnes	Kenedy + TDCJ	-	-	-	-	-	$692	$692	$692	$692	$692
18	Kendall	Boerne	-	-	-	-	-	$692	$692	$692	$692	$692
19	Medina	Hondo	$13,214	$13,214	$13,214	$13,214	$13,214	$692	$692	$692	$692	$692
20	Uvalde	Uvalde	-	-	-	-	-	$692	$692	$692	$692	$692
21	Wilson	SS Water Supply Corp	-	-	-	-	-	$692	$692	$692	$692	$692

			Impacts to be Applied to all types of uses					Share of Water Use (F)			
			Lost Utility Revenues (Sewer Sales - if applicable) (E)								
	County	City	5% reduction	10% reduction	15% reduction	20% reduction	25% reduction	Domestic	Commercial	Manufacturing	
1	Atascosa	Lytle	$449	$449	$449	$449	$449	97%	3%	0%	100%
2	Bexar	Alamo Heights	$449	$449	$449	$449	$449	90%	10%	0%	100%
3	Bexar	Hill Country Village	$449	$449	$449	$449	$449	90%	10%	0%	100%
4	Bexar	Hollywood Park	$449	$449	$449	$449	$449	90%	10%	0%	100%
5	Bexar	San Antonio (BMWD)	$449	$449	$449	$449	$449	72%	23%	5%	100%
6	Bexar	San Antonio (SAWS)	$449	$449	$449	$449	$449	72%	23%	5%	100%
7	Bexar	Schertz	$449	$449	$449	$449	$449	92%	8%	0%	100%
8	Bexar	Selma	$449	$449	$449	$449	$449	92%	8%	0%	100%
9	Bexar	Shavano Park	$449	$449	$449	$449	$449	92%	8%	0%	100%
10	Caldwell	Lockhart	$449	$449	$449	$449	$449	92%	8%	0%	100%
11	Calhoun	Point Comfort	$449	$449	$449	$449	$449	98%	2%	0%	100%
12	Comal	New Braunfels	$449	$449	$449	$449	$449	80%	19%	1%	100%
13	Comal	Garden Ridge	$449	$449	$449	$449	$449	95%	5%	0%	100%
14	Dewitt	Gonzales County WSC	$449	$449	$449	$449	$449	98%	2%	0%	100%
15	Hays	San Marcos	$449	$449	$449	$449	$449	95%	3%	2%	100%
16	Hays	Wood Creek	$449	$449	$449	$449	$449	98%	2%	0%	100%
16	Hays	Wood Creek Utilities Inc.	$449	$449	$449	$449	$449	95%	5%	0%	100%
17	Karnes	Kenedy + TDCJ	$449	$449	$449	$449	$449	95%	5%	0%	100%
18	Kendall	Boerne	$449	$449	$449	$449	$449	90%	10%	0%	100%
19	Medina	Hondo	$449	$449	$449	$449	$449	88%	11%	1%	100%
20	Uvalde	Uvalde	$449	$449	$449	$449	$449	90%	10%	0%	100%
21	Wilson	SS Water Supply Corp	$449	$449	$449	$449	$449	98%	2%	0%	100%

* Average value for a 30% shortage $ 3,112

Source: TWDB, "Socioeconomic Impacts of Unmet Water Needs in the South Central Water Planning Area," April 2006

Table 4-2.
5% Drought Management Scenario (City of Uvalde)

	Domestic/ Residential (including Horticultural Impact)	Com-mercial	Manu-facturing	Lost Revenue (Water Sales)	Lost Revenue (Sewer Sales)	Total/ Combined
Share of WUG Demand (%)	90%	10%	0%	100%	60%	
Proportional Demand (acft)	5,478	609	0	6,087	3,652	
5% DM WMS Risk Factor	0.0001	0.0001	0.0001	0.0001	0.0001	
5% Reduction Economic Impact Factor ($/acft)	$549	$57,884	-	$692	$449	
5% DM WMS - Total Economic Impact ($)	$301	$ 3,523		$421	$164	$4,409

Table 4-3.
10% Drought Management Scenario (City of Uvalde)

	Domestic/ Residential (including Horticultural Impact)	Com-mercial	Manu-facturing	Lost Revenue (Water Sales)	Lost Revenue (Sewer Sales)	Total/ Combined
Share of WUG Demand (%)	90%	10%	0%	100%	60%	
Proportional Demand (acft)	5,478	609	0	6,087	3,652	
10% DM WMS Risk Factor	0.0019	0.0019	0.0019	0.0019	0.0019	
10% Reduction Economic Impact Factor ($/acft)	$798	$57,884	-	$692	$449	
10% DM WMS - Total Economic Impact ($)	$8,286	$66,772		$7,982	$3,106	$86,146

An inherent assumption in the application of this general methodology is that demand reductions would be applied uniformly across domestic (indoor and outdoor), commercial, and manufacturing water use sectors. While this may be a reasonable assumption for some WUGs, it is certainly not appropriate in all cases. For example, drought management activities of the San Antonio Water System (SAWS) seek to achieve significant reductions in discretionary outdoor water uses before placing restrictions on commercial and manufacturing water users. This targeted strategy minimizes, and typically avoids, the substantial economic impacts associated with unmet commercial and manufacturing demands during drought. Using information provided by SAWS[6,7] and considering SAWS 2008 conservation ordinance, supplemental refined results are included for SAWS that portray their drought management strategies and the associated economic impacts more realistically than does the general methodology. The supplemental refined results presented for SAWS are based on the following assumptions: 1) All use reductions are focused in the domestic outdoor (landscape) water use sector until such use is effectively eliminated; 2) Additional use reductions are focused in the domestic indoor sector until overall annual reductions reach 25 percent of combined (indoor and outdoor) domestic use; and 3) Any additional use reductions are prorated among the commercial and manufacturing use sectors. These assumptions simply represent a potential refinement of the general methodology and are not intended to replicate complex drought management strategies developed by SAWS in explicit detail. Examples showing how the annual economic impacts of the refined SAWS methodology for 5% and 20% reductions were calculated are shown in Tables 4-4 and 4-5, respectively. These tables exclude the economic impacts associated with lost water and sewer revenues.

[6] Personal Communication, Calvin Finch, SAWS, Indoor and outdoor percentages of residential water use in SAWS service area, December 19, 2008.

[7] Personal Communication, Calvin Finch, SAWS, Comments on draft of Study 3, November 19, 2008.

Table 4-4.
5% Drought Management Scenario (SAWS)

Water User Group	San Antonio (SAWS)						
	Domestic/ Residential	Horticultural	Commercial	Manufacturing	Lost Revenue (Water Sales)	Lost Revenue (Sewer Sales)	Total/ Combined
Share of SAWS Demand (%)	56%	16%	23%	5%			
Proportional Demand (acft)	110,726	31,595	45,464	9,883	0	0	
5% DM WMS Risk Factor	0.0000	0.2880	0.0000	0.0000	0.0000	0.0000	
5% Reduction Economic Impact Factor ($/acft)	$529	$798	$78,462	$74,691	$692	$449	
5% DM WMS - Economic Impact ($)	$-	$7,265,102	$ -	$-	$ -	$-	$7,265,102

Table 4-5.
20% Drought Management Scenario (SAWS)

Water User Group	San Antonio (SAWS)						
	Domestic/ Residential	Horticultural	Commercial	Manufacturing	Lost Revenue (Water Sales)	Lost Revenue (Sewer Sales)	Total/ Combined
Share of SAWS Demand (%)	56%	16%	23%	5%			
Proportional Demand (acft)	110,726	31,595	45,464	9,883	0	0	
20% DM WMS Risk Factor	0.0228	0.9780	0.0455	0.0455	0.0000	0.0000	
20% Reduction Economic Impact Factor ($/acft)	$529	$798	$78,462	$74,691	$692	$449	
20% DM WMS - Economic Impact ($)	$1,332,664	$24,671,074	$162,306,131	$33,588,108	$-	$-	$221,897,977

4.3 Drought Management Strategy Results

For each selected WUG, risk factors for the base case, 5%, 10%, 15%, and 20% drought management scenario reductions were calculated (Table 4-6). For the base case scenario, the risk factors ranged from 0.000 for the Cities of Uvalde and Point Comfort, indicating there is very little risk of a higher per capita use rate occurring that what occurred in the year 2000, to 0.078 for the City of Alamo Heights, indicating a much greater risk of demand being greater than supply. For the 20% scenario, the risk factors ranged from a low of 0.012 for the City of Point

Table 4-6.
Risk Factors

Entity	Risk Factors				
	Base	5%	10%	15%	20%
San Antonio (SAWS)	0.010	0.028	0.078	0.128	0.178
Lockhart	0.060	0.097	0.142	0.195	0.253
Boerne	0.007	0.018	0.031	0.055	0.091
Hondo	0.064	0.101	0.144	0.193	0.243
Uvalde	0.000	0.000	0.002	0.007	0.020
Lytle	0.012	0.026	0.058	0.096	0.147
San Antonio (BMWD)	0.077	0.124	0.174	0.224	0.274
Alamo Heights	0.078	0.118	0.159	0.205	0.255
Shavano Park	0.007	0.016	0.031	0.056	0.085
Hill Country Village	0.010	0.016	0.022	0.031	0.039
Hollywood Park	0.007	0.011	0.021	0.038	0.061
Point Comfort	0.000	0.001	0.002	0.003	0.012
New Braunfels	0.003	0.016	0.039	0.079	0.121
Garden Ridge	0.004	0.019	0.035	0.053	0.085
Gonzales County WSC	0.011	0.029	0.067	0.106	0.149
Schertz	0.009	0.028	0.058	0.098	0.151
San Marcos	0.034	0.060	0.099	0.140	0.182
Wood Creek	0.014	0.045	0.086	0.126	0.180
Kenedy + TDCJ	0.020	0.029	0.056	0.088	0.122
SS Water Supply Corp	0.030	0.066	0.109	0.159	0.209

Comfort to a high of 0.274 for Bexar Metropolitan Water District (BMWD). Table 4-7 summarizes supplemental refined risk factors for SAWS based on assumptions outlined in Section 4.2. Under this scenario, risk factors vary by type of use, economic impact category, and drought management scenario.

Table 4-7.
SAWS Supplemental Refined Risk Factors

Use Type or Impact Category	Risk Factors				
	Base	**5%**	**10%**	**15%**	**20%**
Domestic/Indoor					0.023
Domestic/Outdoor/Landscape	0.010	0.288	0.608	0.918	0.978
Commercial					0.046
Manufacturing					0.046
Lost Water Sales	0.010	0.028	0.078	0.128	0.178
Lost Sewer Sales					0.046

As described above, these risk factors were then used to determine an annual economic impact for a planned supply less than demand for the year 2010 (Table 4-8). The annual economic impact presented in Table 4-8 is inclusive of lost utility revenue due to declining water and sewer sales. For the base case scenario, the annual economic impact ranged from $0 for the Cities of Uvalde and Point Comfort to an impact of almost $56 million for BMWD. The two most important factors driving the annual economic impact are the risk factor and whether or not that WUG supplies water for commercial and manufacturing purposes, as these uses have high impact factors. According to the data supplied by the TWDB, all selected entities have a commercial use component, but only five entities (San Marcos, Hondo, New Braunfels, SAWS, and BMWD) have manufacturing use components. As indicated in Table 4-8, refined annual economic impacts for SAWS are substantially less than those derived for SAWS using the general methodology. This is a result of excluding reductions in the commercial and manufacturing use sectors and sewer sales for all drought management scenarios short of the scenario requiring 20 percent overall reductions in annual water use.

Finally, the annual cost data were used to calculate a unit cost so that comparisons could be made with other potentially feasible water management strategies (Table 4-9). It is important to note that lost utility revenues are **not** included in the unit cost calculation as they represent a financial transfer (a financial loss to the utilities that corresponds to a short-term financial savings to customers). For the 5% scenario (supply equal to 95% of dry condition demand), the unit costs ranged from $14/acft/yr for the City of Uvalde to a high of $27,568/acft/yr for

Table 4-8.
Total Annual Economic Impact

Entity	Total Annual Economic Impact				
	Base	5%	10%	15%	20%
San Antonio (SAWS)	$44,762,783	$131,366,215	$369,897,962	$612,492,217	$858,683,035
SAWS Refined	$1,554,024	$11,094,583	$26,005,277	$40,663,771	$248,664,423
Lockhart	$839,789	$1,349,025	$1,978,967	$2,722,480	$3,530,357
Boerne	$64,753	$167,500	$301,094	$540,884	$886,209
Hondo	$612,614	$967,634	$1,381,535	$1,848,246	$2,328,308
Uvalde	$0	$4,409	$86,146	$326,450	$954,390
Lytle	$16,740	$40,427	$89,353	$148,785	$228,050
San Antonio (BMWD)	$55,153,726	$89,136,231	$125,017,545	$160,898,859	$196,780,173
Alamo Heights	$1,202,833	$1,827,527	$2,463,992	$3,180,321	$3,955,862
Shavano Park	$21,592	$56,424	$111,299	$216,836	$344,837
Hill Country Village	$35,959	$54,156	$77,553	$106,149	$135,290
Hollywood Park	$64,716	$113,631	$210,205	$377,027	$601,496
Point Comfort	$0	$347	$962	$1,836	$8,557
New Braunfels	$619,572	$3,163,640	$7,783,488	$16,061,727	$24,764,349
Garden Ridge	$5,992	$29,373	$54,507	$88,976	$156,102
Gonzales County WSC	$32,694	$101,593	$264,919	$465,984	$721,222
Schertz	$324,263	$1,056,723	$2,269,756	$3,934,266	$6,048,979
San Marcos	$1,247,122	$2,336,950	$3,842,264	$5,446,373	$7,081,190
Wood Creek	$0	$29,861	$61,802	$98,945	$152,359
Kenedy + TDCJ	$53,515	$80,400	$152,888	$240,554	$332,963
SS Water Supply Corp	$145,838	$348,001	$575,441	$839,906	$1,104,371

Note: Economic impact values in this table include the lost revenue associated with declines in water and sewer sales.

Table 4-9.
Average Unit Cost

Entity	Average Unit Cost			
	5%	10%	15%	20%
San Antonio (SAWS)	$8,227	$15,701	$18,329	$19,734
SAWS Refined	$735	$776	$781	$5,613
Lockhart	$2,294	$3,282	$3,868	$4,271
Boerne	$966	$1,209	$1,667	$2,180
Hondo	$2,043	$2,927	$3,384	$3,643
Uvalde	$ 13	$123	$313	$689
Lytle	$488	$963	$1,223	$1,500
San Antonio (BMWD)	$25,180	$26,663	$27,158	$27,405
Alamo Heights	$3,768	$4,563	$5,052	$5,421
Shavano Park	$536	$802	$1,228	$1,563
Hill Country Village	$134	$281	$362	$405
Hollywood Park	$203	$425	$657	$869
Point Comfort	$ 19	$ 28	$ 37	$134
New Braunfels	$4,535	$6,444	$9,289	$10,907
Garden Ridge	$544	$561	$668	$938
Gonzales County WSC	$435	$785	$1,041	$1,303
Schertz	$3,164	$4,213	$5,225	$6,212
San Marcos	$2,207	$2,605	$2,803	$2,918
Wood Creek	$1,553	$1,686	$1,871	$2,229
Kenedy + TDCJ	$516	$953	$1,196	$1,340
SS Water Supply Corp	$1,895	$1,989	$2,134	$2,206

Note: Average unit cost values do not include lost revenue associated with declines in water and sewer sales.

BMWD. For the 20% scenario (supply equal to 80% of dry condition demand), the unit costs ranged from $191 for the City of Point Comfort to a high of $28,723 for BMWD. Again, the high unit costs for BMWD are primarily due to the high risk factors (i.e., the year 2000 per capita was lower than in many previous years) and the high economic impact factors associated with commercial and manufacturing uses. As shown in Table 4-9, refined unit costs for SAWS are substantially less than those calculated for SAWS using the general methodology. This is a result of avoiding reductions in the commercial and manufacturing use sectors and sewer sales for all drought management scenarios short of the scenario requiring 20 percent overall reductions in annual water use.

Appendix D shows the drought management WMS unit cost for each WUG compared to other potentially feasible water management strategies recommended in the 2006 Regional Water Plan. All figures presented in Appendix D, unless otherwise noted, are based on application of the general methodology which includes the assumption of demand reductions being applied on a uniform percentage basis across domestic, commercial, and manufacturing use sectors. Application of a WUG-specific, refined methodology which focuses initial demand reductions in the domestic outdoor use sector yields significantly different results for SAWS (Figure 4-6).

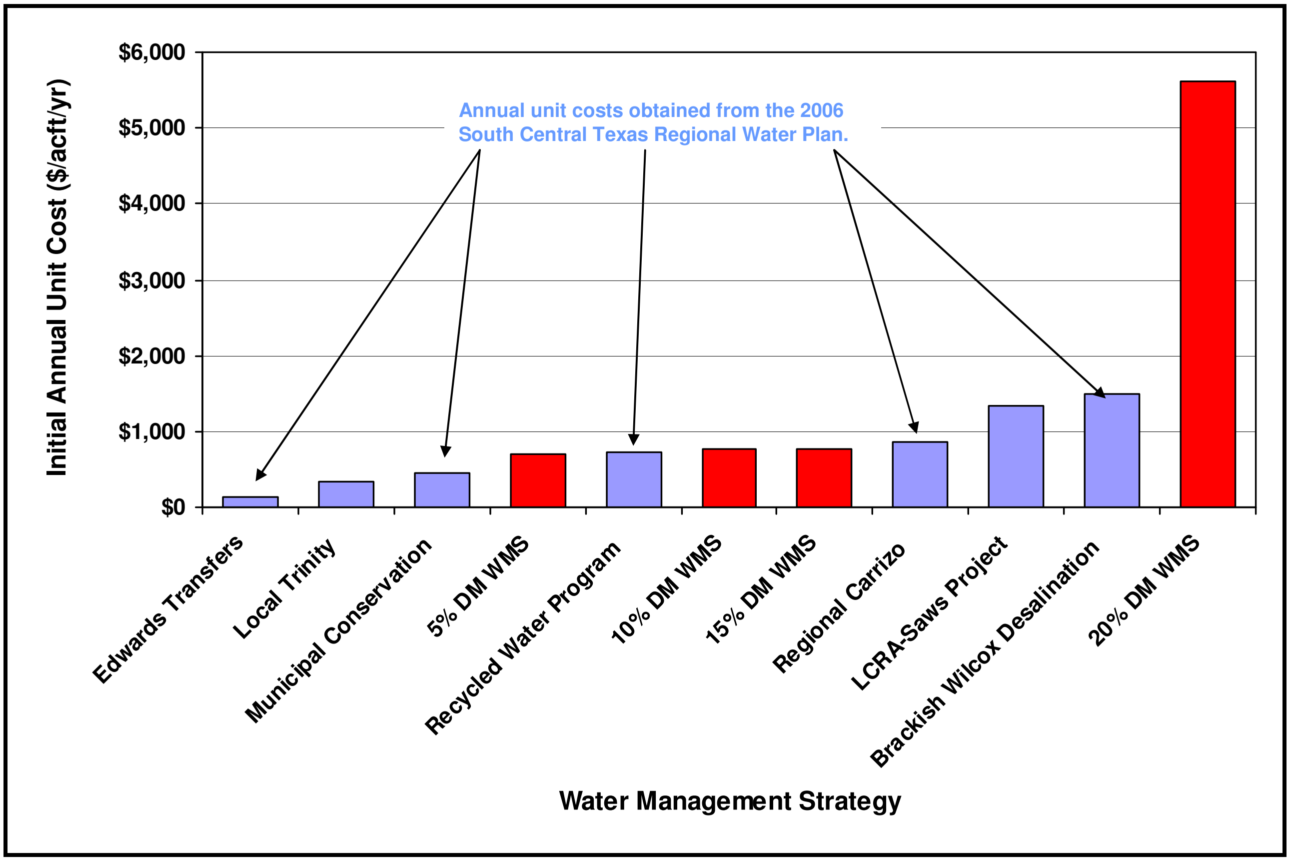

Figure 4-6. Comparison of Refined Annual Unit Costs for SAWS Drought Management Strategies to Recommended Water Management Strategies in the 2006 Regional Water Plan

4.4 Summary

A general methodology for estimating the economic impacts associated with implementation of drought management as a water management strategy is presented in this study. Application of this methodology for regional water planning purposes facilitates comparison of drought management to other potentially feasible water management strategies on a unit cost basis. While drought management appears potentially economically viable for some municipal water user groups in Region L, it is apparent that associated economic impacts for water user groups having significant commercial or manufacturing use sectors could be significant. As demonstrated for SAWS, however, water user groups having sufficient flexibility to focus on discretionary outdoor water use first and avoid water use reductions in the commercial and manufacturing use sectors may find some degrees of drought management to be more economically viable and cost-competitive with other water management strategies than indicated in Appendix D. The SCTRWPG will have an opportunity to refine the general methodology described herein prior to consideration of drought management as a potentially feasible water management strategy for water user groups with projected needs by 2020 in the 2011 South Central Texas Regional Water Plan.

5.0 Land Stewardship

In support of the regional water planning process, the Texas Wildlife Association Foundation (TWAF) has sponsored a series of studies by scientists at Texas A&M University (TAMU) focused on land-based water conservation and water yield practices. In the course of these studies, TAMU scientists have compiled and summarized research and extracted preliminary conclusions of relevance to the South Central Texas Regional Water Planning Area (Region L), including estimates of increased average water yield and expected costs of brush management practices to achieve such increases in average water yield (see Appendix E for complete report). Furthermore, TAMU scientists have summarized methodologies for spatially explicit identification of lands most suitable for cost-effective land-based water conservation practices (Appendix F) and described monitoring protocols for the measurement of short- and long-term effectiveness of such practices (Appendix G). Key elements and findings of each of these studies are found, in the authors' own words, in the Abstracts on the second page of each referenced appendix.

It is important to note, however, that increases in average water yield are not equivalent to increases in firm yield or water supply available without interruption during a repeat of the most severe drought on record, the fundamental basis for regional water supply planning in accordance with Texas Water Development Board (TWDB) rules and guidance. As part of the development of the 2011 South Central Texas Regional Water Plan, the information compiled by TAMU, spatially explicit methodologies for selection of preferred areas for brush management, and new hydrologic models capable of simulating surface water, groundwater, and interactions between the two will all be used in a more comprehensive technical evaluation of brush management as a potentially feasible water management strategy to meet projected needs in Region L. Pursuant to TWDB rules and guidance, this technical evaluation will include quantitative and qualitative assessments of firm yield, costs of water, environmental effects, water quality, and other factors in a manner consistent with the technical evaluations of other water management strategies in Region L.

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Appendix A
Water Conservation in the 2006 South Central Texas Regional Water Plan

South Central Texas Regional Water Planning Group

Water Conservation
in the
2006 South Central Texas
Regional Water Plan

Basic Water Planning Requirements

- Water Code amended in 2001 to require water conservation and drought management strategies in Regional Water Plans;
- Water Planning Groups must include water conservation strategies for each water user group with a need (projected shortage);
- Water Planning Groups must also consider drought management strategies for each identified need and must include strategies for each water user group with a need;
- If a Water Planning Group does not adopt a water conservation strategy for an identified need, it must document the reason;
- If a drought management strategy is not selected as a water management strategy, the reasons must be documented.

Water Conservation Water Management Strategies in the South Central Texas Regional Water Plan

- The SCTRWPG decided to recommend water conservation for all WUGs, regardless of projected needs for additional water supply;
- Water Conservation Goals for Municipal WUGs are:
  - WUGs with water use of 140 gpcd and greater in 2000 —reduce per capita water use by one percent per year until the level of 140 gpcd is reached, after which, the goal is to reduce per capita water use by one-fourth percent per year for the remainder of the planning period; and
  - WUGs having year 2000 water use of less than 140 gpcd — the goal is to reduce per capita water use by one-fourth percent per year (0.25% per year).
- Water Conservation for Industry, Steam-Electric Power Generation, Irrigation, Mining, and Livestock is based upon "best management practices" and computed from information available.

Water Conservation Data and Information Used in the South Central Texas Regional Water Plan

- In 1991, the Texas Legislature established minimum standards for plumbing fixtures sold in Texas (SB 587):

Fixture	***Standard***
Wall-mounted Flushometer Toilets	2.00 gallons per flush
All Other Toilets	1.60 gallons per flush
Shower Heads	2.75 gpm at 80 psi
Urinals	1.00 gallon per flush
Faucet Aerators	2.20 gpm at 80 psi

The TWDB has estimated that the new plumbing fixtures can reduce per capita water use by 18 gallons per capita per day (gpcd):

Plumbing Fixture	*Water Savings (gpcd)*
Toilets – 1.6 gallons per flush	***11.5***
Shower Heads – 2.75 gallons per minute	***4.0***
Faucet Aerators – 2.2 gallons per minute	***2.0***
Urinals – 1.0 gallon per minute	***0.3***
Drinking Fountains (self-closing)_	***0.1***
Total	***17.9 (18 gpcd)***

The Water Conservation Implementation Task Force identified and described 21 Best Management Practices (BMPs) and provided a BMP Guide for use by Regional Water Planning Groups in the development of the 2006 Regional Water Plans.

The list of BMPs for municipal water users is as follows:

1. **System Water Audit and Assessment of Water Loss;**
2. **Water Conservation Pricing;**
3. **Prohibition on Wasting Water;**
4. **Showerhead, Aerator, and Toilet Flapper Retrofit;**
5. **Residential Ultra-Low Flow Toilet Replacement Programs;**
6. **Residential Clothes Washer Incentive Program;**
7. **School Education;**
8. **Water Survey for Single-Family and Multi-Family Customers;**
9. **Landscape Irrigation Conservation and Incentives;**
10. **Water-Wise Landscape Design and Conversion Programs;**
11. **Athletic Field Conservation;**
12. **Golf Course Conservation;**
13. **Metering of all New Connections and Retrofitting of Existing Connections;**
14. **Wholesale Agency Assistance Programs;**
15. **Conservation Coordinator;**
16. **Reuse of Reclaimed Water;**
17. **Public Information;**
18. **Rainwater Harvesting and Condensate Reuse;**
19. **New Construction Graywater;**
20. **Park Conservation; and**
21. **Conservation Programs for Industrial, Commercial, and Institutional Accounts.**

A Texas Water Development Board Report, “Quantifying the Effectiveness of Various Water Conservation Techniques in Texas,” provided estimates of quantities saved and costs of water conservation measures.*

Costs of municipal water conservation in the 2006 regional water plan are as follows:

Plumbing fixture and clothes washer retrofit

- **Rural areas………………………………………………........$588 per acre-foot;**
- **Suburban areas…………………………………………..…..$520 per acre-foot; and**
- **Urban areas………………………………………………......$458 per acre-foot.**

Lawn watering and landscape water conservation… $400 per acre-foot.

* GDS Associates, Appendix VI, Region L, Austin, Texas, July 2003.

The Water Conservation Implementation Task Force list of Best Management Practices (BMPs) for irrigation is as follows:

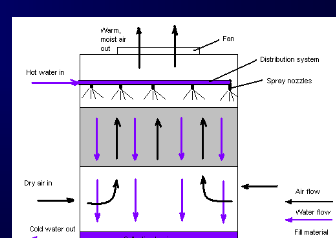
1. **Irrigation Scheduling;**
2. **Volumetric Measurement of Irrigation Water Use;**
3. **Crop Residue Management and Conservation Tillage;**
4. **On-farm Irrigation Audit;**
5. **Furrow Dikes;**
6. **Land Leveling;**
7. **Contour Farming;**
8. **Conversion of Irrigated Farmland to Dry-Land Farmland;**
9. **Brush Control/Management;**
10. **Lining of On-Farm Irrigation Ditches;**
11. **Replacement of On-/farm Irrigation Ditches with Pipelines;**
12. **Low Pressure Center Pivot Sprinkler Irrigation Systems;**
13. **Drip/Micro-Irrigation System;**
14. **Gated and Flexible Pipe for Field Water Distribution Systems;**
15. **Surge Flow Irrigation for Field Water Distribution Systems;**
16. **Linear Move Sprinkler Irrigation Systems;**
17. **Lining of Irrigation Canals;**
18. **Replacement of Irrigation Canals and Laterals with Pipelines;**
19. **Tailwater Recovery and Use System; and**
20. **Nursery Production Systems.**

Principal methods of irrigation water conservation on irrigated farms of Region L are:

- ❑ **Low-pressure sprinklers (LESA);**
- ❑ **Low-energy precision application systems (LEPA); and**
- ❑ **Irrigation scheduling.**

The Water Conservation Implementation Task Force list of Best Management Practices (BMPs) for industry is as follows:

1. Industrial Water Audit;
2. Industrial Water Waste Reduction;
3. Industrial Submetering;
4. Cooling Towers;
5. Cooling Systems Other than Cooling Towers;
6. Industrial Alternative Sources and Reuse of Process Water;
7. Rinsing/Cleaning;
8. Water Treatment;
9. Boiler and Steam Systems;
10. Refrigeration (including Chilled Water);
11. Once-through Cooling;
12. Management and Employee Programs;
13. Industrial Landscape; and
14. Industrial Site-Specific Conservation.



Counterflow type design

Region L Water Conservation Calculations

- The Municipal Water Demand Projections were made with estimated effects of low Flow Plumbing Fixtures phased in over time as remodeling and new housing and business construction installs the Low Flow Plumbing Fixtures (the TWDB provided estimates of the reductions in per capita water use for each Municipal WUG).
- The Municipal Water Conservation WMS incorporated additional Low Flow Plumbing Fixtures at an accelerated rate to reach the maximum of 18 GPCD by 2020; and then used clothes washer retrofit and lawn watering to accomplish the municipal water conservation goals established by the SCTRWPG.
- The Irrigation Water Conservation WMS calculations included implementation of LEPA Systems with Furrow Dikes. Acreages were adequate to meet projected irrigation water needs in Atascosa, Bexar, and Medina Counties, however, total projected irrigation needs could not be met in Kendall and Zavala Counties.

Water Conservation Effects Upon Municipal Water Demand

	Units	2000	2010	2020	2030	2040	2050	2060
Population	No.	2,042,221	2,460,599	2,892,933	3,292,970	3,644,661	3,984,258	4,297,786
Municipal Water Demand with Low Flow Plumbing Fixtures	acft	340,030	395,996	451,111	503,375	547,136	592,344	637,236
Water Conservation Water Management Strategies*	acft							
Low flow Plumbing Fixtures and Clothes Washer Retrofit	acft		12,013	13,734	15,231	14,961	15,083	19,163
Lawn Watering	acft		1,218	9,008	16,386	25,567	38,842	53,407
Total	acft		13,231	22,742	31,617	40,528	53,925	72,570
Municipal Water Demand with Water Conservation Water Management Strategies	acft	340,030	382,765	428,369	471,758	506,608	538,419	564,666
Per Capita Water Use								
Regional Plan with Low Flow Plumbing Fixtures	gpcd	149	144	139	136	134	133	132
Water Conservation Water Management Strategies (WMSs)	gpcd		5	7	9	10	12	15
Regional Plan with Water Conservation WMSs	gpcd	149	139	132	127	124	121	117

acft means acre-feet, and gpcd means gallons per person per day.
* 2006 Water Conservation Goals:
* For Water User Groups (WUGs) with per capita water use in year 2000 of 140 gpcd and greater, reduce gpcd by 1 % per year until reach 140 gpcd, and then continue reduction of gpcd at rate of 0.25% per year thereafter.
* For Water User Groups (WUGs) with per capita water use in year 2000 less than 140 gpcd, reduce gpcd by 0.25 % per year throughout planning period.

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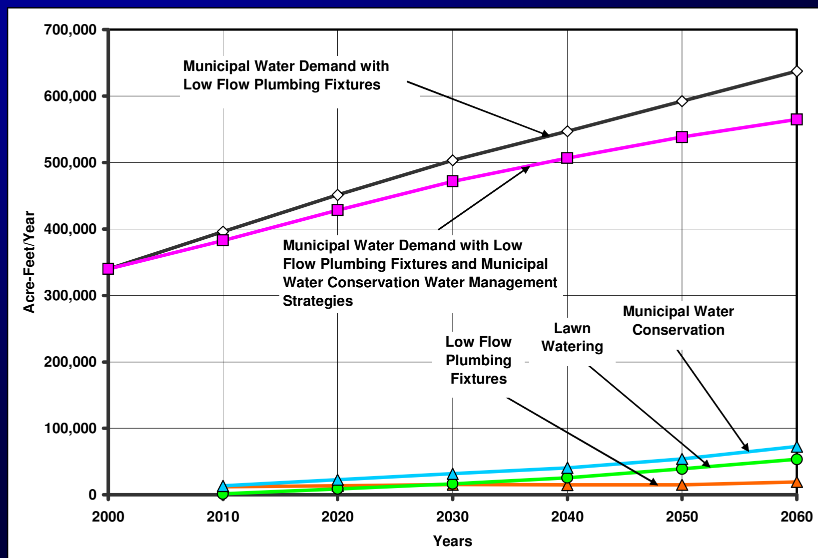
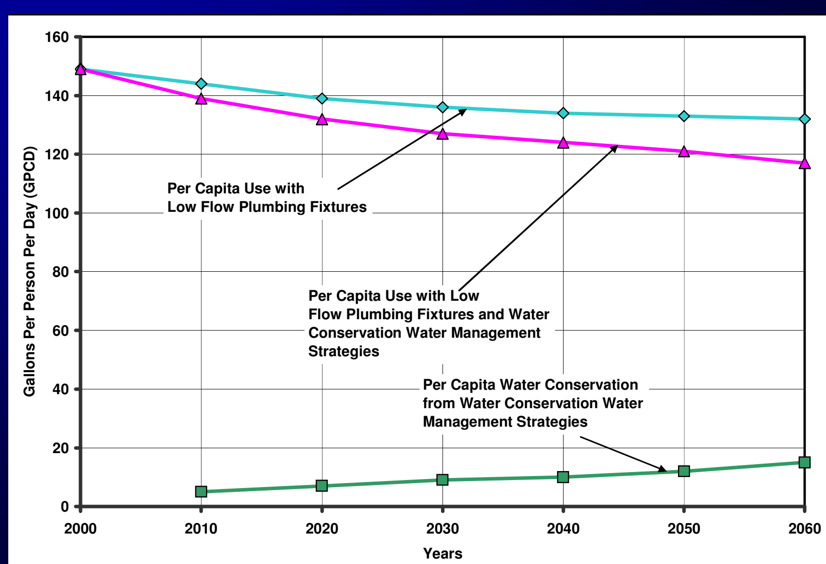
Projected Municipal Water Demand and Water Conservation Estimates of the 2006 Region L Water Plan



Projected Municipal Per Capita Water Use



Estimated Costs of Municipal Water Conservation in Region L

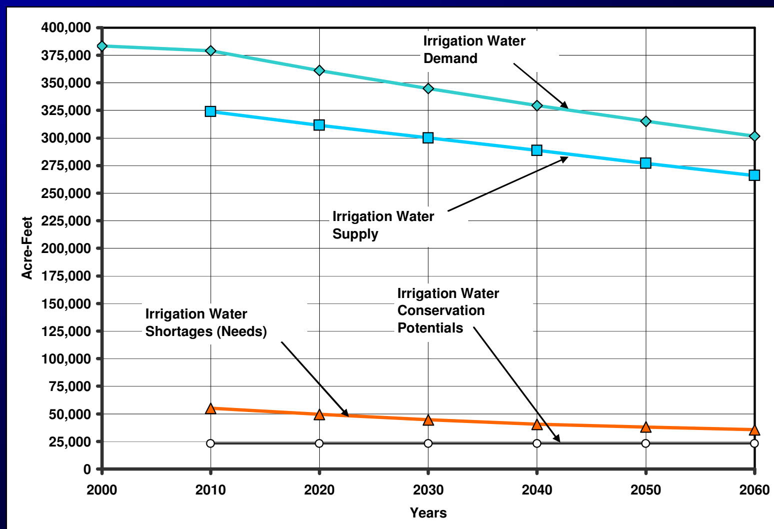
		2010	2020	2030	2040	2050	2060
Water Conservation Water Management Stategies							
Low Flow Plumbing Fixtures and Clothes Washers	acft	12,013	13,734	15,231	14,961	15,083	19,163
Lawn Watering	acft	1,218	9,008	16,386	25,567	38,842	53,407
Total		13,231	22,742	31,616	40,528	53,925	72,570
Water Conservation Water Management Stategies							
Low Flow Plumbing Fixtures and Clothes Washers	$/yr	6,054,278	6,859,314	7,546,424	7,444,681	7,694,605	9,976,317
Lawn Watering	$/yr	487,240	3,603,020	6,554,251	10,226,875	15,536,793	21,362,786
Total	$/yr	6,541,518	10,462,334	14,100,675	17,671,556	23,231,398	31,339,103
Costs Per Acre Foot							
Low Flow Plumbing Fixtures and Clothes Washers	$/acft	504	499	495	498	510	521
Lawn Watering	$/acft	400	400	400	400	400	400
Total	$/acft	494	460	446	436	431	432

Region L: Irrigation Water Demands, Supplies, Shortages, and Conservation

Topic		2000	2010	2020	2030	2040	2050	2060
Irrigation Water Demand	acft	383,332	379,026	361,187	344,777	329,395	315,143	301,679
Irrigation Water Supply	acft	383,332	323,917	311,639	300,175	288,763	277,056	266,044
Irrigation Water Shortages (Needs)	acft	0	55,109	49,548	44,602	40,632	38,087	35,635
Irrigation Water Conservation Potentials	acft		23,074	23,074	23,074	23,074	23,074	23,074
Irrigation Water Conservation Costs *	$/yr		2,559,868	2,559,868	2,559,868	2,559,868	2,559,868	2,559,868
Irrigation Water Conservation Costs	$/acft		113	113	113	113	113	113

* Total Capital Costs are $35,810,854

Region L: Irrigation Water Demands, Supplies, Shortages, and Conservation



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Industrial, Steam-Electric Power, and Mining Water Conservation

- In industry, steam-electric power generation, and mining activities water is used for several different purposes, including as an integral part of manufactured products, cleaning and waste removal, waste heat removal, dust control, and landscaping.
- The projected need (shortage) of water for manufacturing, steam-electric power generation, and mining is 8,493 acft/yr in 2010 and is projected to increase to 70,465 acft/yr in 2060.
- BMPs, such as air cooling in electric power generation, collection of runoff at mining sites, and treatment and reuse of municipal and industrial wastewater can perhaps meet a part of the projected needs for these industries.
- Data are not available with which to compute estimates of quantities and costs of these measures.

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Additional Water Conservation Water Management Strategies of 2006 Regional Water Plan

- The following water conservation practices are in use within Region L and, in the 2006 plan, are recommended to be expanded as quantities of municipal wastewater increase with population growth:
  - Recycle water use for non-potable purposes to meet 20 percent of SAWS projected municipal and industrial water demands, including additional quantities of 18,700 acft/yr in 2010 and 36,250 acft/yr in 2060 at estimated cost of $434 per acft/yr;
  - Recycle water use for non-potable purposes to meet part of demands in Comal, Guadalupe, and Hays Counties; and
  - Rainwater Harvesting for domestic (County Other) uses, especially by households located in Kendall, Comal, and Hays Counties of Region L.

Water Conservation Water Management Strategies of 2006 Plan Needing Further Study

- The following water conservation water management strategies need further research to determine location and optimum scale, quantity of supply available during drought, cost of implementation, and environmental effects:
  - **Brush Management and Land Stewardship;**
  - **Small Aquifer Recharge Dams;**
  - **Drought Management; and**
  - **Recycle Water for Non-Potable Uses:**
    - **Irrigation of Golf Courses, Parks, and Open Spaces of cities,**
    - **Landscape Irrigation of Office and Business Complexes,**
    - **Cooling of Office and Business Complexes,**
    - **Steam-Electric Power Plant Cooling,**
    - **Process and Wash Water for Mining Operations,**
    - **Irrigation of Farms that Produce Livestock Feed and Forage Crops,**
    - **Irrigation of Farms that Produce Sod, Ornamentals, and Landscape Plants, and**
    - **Instream Uses for Riverwalks and Urban and Rural Waterways.**

Water Conservation and Drought Management Evaluations for Region L 2011 Regional Water Plan (First Biennium)

- Review and refinement of recommendations of 2006 Regional plan:
  - Condensate collection and use,
  - Drought Management, and
  - Land Stewardship.
- Assessment of overlapping elements of water conservation and potential drought management practices focusing on lawn watering.

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Appendix B
Texas Water Development Board Impact Factors

Synopsis of Methodology for Estimating Socioeconomic Impacts for Municipal and Manufacturing Water User Groups in the 2007 State Water Plan

Tuesday, April 01, 2008

When analyzing the economic impacts of unmet water needs in the 2007 state water plan, the TWDB applied various approaches for different water use categories and water user groups (WUGs). For the drought management study currently underway, categories discussed below may be appropriate when assessing the economic impacts of water restrictions imposed as part of a drought management plan. It is important to note that the TWDB has and is refining the socioeconomic methodology used in the state water plan, some of which is discussed below.

Municipal Water User Groups

Municipal water needs were analyzed using several important assumptions. First, if needs for a given municipal WUG were less than 50 percent of total municipal water demand for that WUG, then we assumed that the shortage/need would apply to domestic water use and first type of use that would be eliminated to account for the need would be outdoor landscape irrigation and other "non-essential" uses such as swimming pools and car washing, which can account for anywhere between 20 to 50 percent of total municipal water use depending upon location. To value this lost consumption, we relied on a literature value from a study that assessed municipal water supply reliability in communities throughout Texas. According to the study, on average across all income levels surveyed, households would be willing to pay $36 per month to avoid an annual water shortage of 30 percent. On per acre-foot basis, we estimated this average value to be $3,112 for Region L.

This average value was applied to any need less than 50 percent of total municipal demand to arrive at an economic value of forgone water use. Ideally, one would estimate a non-linear demand function to value these losses using marginal analysis; however this requires a considerable amount of effort and data and for a high level planning study such as the state water plan, an average value is expedient and appropriate. In a more detailed utility level study, such as one assessing the incremental economic costs of drought management, marginal values may be more appropriate. In the data provided, to approximate marginal values we took the average value of $3,112 and did a simple linear extrapolation to estimates marginal values for shortages of 5 percent, 10 percent, 15 percent, 20 percent and 25 percent. But again, a non-linear demand function based on actual data would be more accurate.

In addition to the lost consumer welfare of unmet needs that fall into the category described above, elimination or reduction in water available for outdoor landscape irrigation would likely result in negative economic impacts to the landscaping and horticulture industry in the region. To account for this in the 2007 state water plan, sales revenues for the landscaping and horticultural business sectors were reduced in proportion to the percentage reduction in water unavailable for landscape irrigation at the regional level. As a refinement, our current socioeconomic methodology will likely apply a tiered approach similar to that used for most manufacturing, steam-electric, mining and irrigation WUGs where a measure of "output elasticity" is applied (described below under manufacturing).

Impacts described above apply to any water shortage less than 50 percent of municipal water use for a given WUG. For any amount greater than 50 percent, we assumed that municipal water consumers would have to seek emergency alternative water sources. Thus, costs or impacts to residential and non-water intensive commercial operations (i.e., those that use water only for sanitary purposes) are based on the most likely alternative source of water in the absence of water management strategies. In this case, the most likely alternative is assumed to be "hauled-in" water from other communities at estimated annual cost of $6,530 per acre-foot for small rural WUGs and $10,995 per acre-foot for metropolitan WUGs. In addition, when needs exceeded 50 percent of total municipal water demand, we assumed business activity (i.e., sales) among "water intensive" commercial sectors would decline according to the severity of projected shortages. Water intensive sectors are defined as non-medical related commercial sectors that are heavily dependent upon water to provide their services including:

- car-washes,
- laundry and cleaning facilities,
- sports and recreation clubs and facilities including race tracks,
- amusement and recreation services,
- hotels and lodging places, and
- eating and drinking establishments.

An example will illustrate the breakdown of municipal water needs and the overall approach to estimating impacts of municipal needs. Assume City B has an unmet need of 50 acre feet in 2020 and projected demands of 200 acre-feet. In this case, residents of City B could eliminate needs via restricting all outdoor water use. City A, on the other hand, has an unmet need of 150 acre-feet in 2020 with a projected demand of 200 acre-feet. Thus, total shortages are 75 percent of total demand. Emergency outdoor and indoor conservation measures would eliminate 50 percent of projected needs; however, 50 acre-feet would still remain. This remaining portion would result in costs to residential and commercial water users. Water intensive businesses such as car washes, restaurants, motels, race tracks would have to curtail operations (i.e., output would decline), and residents and non-water intensive businesses would have to have water hauled-in assuming it was available.

The last element of municipal water shortages considered was lost water utility revenues. Estimating these was straightforward. We used annual data from the "Water and Wastewater Rate Survey" published each year by the Texas Municipal League to calculate an average value per acre-foot for water and sewer. For water revenues, averages rates multiplied by total water needs served as a proxy. For lost wastewater, total unmet needs were adjusted for return flow factor of 0.60 and multiplied by average sewer rates for the region. Needs reported as "county-other" were excluded under the presumption that these consist primarily of self-supplied water uses. In addition, 15 percent of water demand and needs were considered non-billed or "unaccountable" water that comprises things such leakages and water for municipal government functions (e.g., fire departments).

Manufacturing Water User Groups

For the 2007 state water plan, manufacturing needs were evaluated as a distinct category that included industrial sectors that rely on process water such as refineries, food processors and paper mills. The analysis did not distinguish between self-supplied operations (most of the larger facilities including refineries are self-supplied), and operations that rely on utility water from city. Thus, for the costs calculated for the drought management study, we had to try and identify which industrial sectors in the IMPLAN county level database rely on public utilities for their process water. Unit costs do not include self-supplied manufacturing sectors or sectors that use minimal or no process water.

As mentioned above, to account for uncertainty regarding the relative magnitude of impacts to manufacturers, the analysis employed the concept of output elasticity. Elasticity is a number that shows how a change in one variable will affect another. In this case, it measures the relationship between a percentage reduction in water availability and a percentage reduction in output. For example, an elasticity of 1.0 indicates that a 1.0 percent reduction in water availability would result in a 1.0 percent reduction in economic output. An elasticity of 0.50 would indicate that for every 1.0 percent of unavailable water, output is reduced by 0.50 percent and so on. Output elasticities used in the 2007 state water plan are as follows:

- if unmet water needs were less than 5 percent of total water demand, no corresponding reduction in output is assumed;

- if water shortages were 5 to 30 percent of total water demand, for every 1.0 one percent of unmet need, there is a corresponding 0.25 percent reduction in output;

- if water shortages were 30 to 50 percent of total water demand, for every 1.0 one percent of unmet need, there is a corresponding 0.50 percent reduction in output; and

- if water shortages were greater than 50 percent of total water demand, for every 1.0 one percent of unmet need, there is a corresponding 1.0 percent (i.e., a proportional reduction).[1]

This was a general rule. However, when we developed unit costs for SAWs and the Bexar Met Water District, we did not apply elasticities given that industries served by SAWs have "hard" demands meaning that they already use water very efficiently and more than likely they could not find ways to increase efficiency in the event of a shortage. Thus, reductions in activity in these sectors for SAWs and Bexar Met were reduced in proportion to the hypothetical shortage amounts (i.e., a 5 percent would result in a 5 percent reduction in output and so on).

Components of Estimated Unit Costs for Water Intensive Commercial Operations and Manufacturing

In the 2007 state water plan, impacts for each water user category were reported as changes in: 1) output (total sales revenues), 2) income or value-added, 3) employment and 4) business taxes. Reported unit costs for the drought management study were calculated by dividing total annual demand for economic sectors included by valued-added plus business taxes, which collectively were referred to as "income" in the 2007 state water plan. In the context of regional economic impact models, total sales are not an appropriate measure to describe economic losses when dealing with multiple business sectors.

The Phasing-in of Water Shortages to Calculate Economic Impacts

The TWDB estimates the economic impacts of not meeting water needs from the perspective of water user groups rather than the perspective of water utilities. This is a requirement mandated by administrative rules as specified Section 357.7(4) of the Texas Administrative Code. Thus, municipal and manufacturing water user groups are treated as separate entities in the regional planning process.

Water shortages as reported by regional planning groups are the starting point for economic impact analyses. No adjustments or assumptions regarding the magnitude or distributions of unmet needs among different water use categories are incorporated in the TWDB analyses. Any such adjustments must be requested by a planning group.

When estimating the economic impacts of not meeting water needs for municipal water user groups, the TWDB assumes that:

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1 Elasticities are based on one of the few empirical studies that analyze potential relationships between economic output and water shortages in the United States. The study, conducted in California, showed that a significant number of industries would suffer reduced output during water shortages. Using a survey based approach researchers posed two scenarios to different industries. In the first scenario, they asked how a 15 percent cutback in water supply lasting one year would affect operations. In the second scenario, they asked how a 30 percent reduction lasting one year would affect plant operations. In the case of a 15 percent shortage, reported output elasticities ranged from 0.00 to 0.76 with an average value of 0.25. For a 30 percent shortage, elasticities ranged from 0.00 to 1.39 with average of 0.47. For further information, see, California Urban Water Agencies, "*Cost of Industrial Water Shortages*." Prepared by Spectrum Economics, Inc. November, 1991.

- a region and each water user group within a region is experiencing drought of record conditions;

- for a given municipal water user group, all unmet needs that are less than 30 percent of total average annual water demand would be eliminated by restricting all outdoor residential water use;

- for unmet water needs that range from 30 to 50 percent of total average annual water demand, all domestic outdoor water use would be restricted as would a portion of indoor domestic water use;

- if unmet needs exceed 50 percent of total average annual water demands, all of the above conditions would hold true, and in addition water intensive commercial businesses such as car washes, restaurants, recreational venues would be forced to reduce water use and domestic water consumers would have to further reduce water consumption.

For manufacturing water user groups, TWDB economic analysis assumes that producers would implement emergency measures to alleviate water shortages (note that these efforts are not planned programmatic or long-term operational changes); assumptions for manufacturing include:

- if unmet water needs are 0 to 5 percent of total water demand, no corresponding reduction in output (i.e., gross sales) is assumed;

- if water shortages are 5 to 30 percent of total water demand, for every 1.0 one percent of unmet need, there is a corresponding 0.25 percent reduction in output;

- if water shortages are 30 to 50 percent of total water demand, for every 1.0 one percent of unmet need, there is a corresponding 0.50 percent reduction in output; and

- if water shortages are greater than 50 percent of total water demand, for every 1.0 one percent of unmet need, there is a corresponding 1.0 percent reduction in output (i.e. a proportional reduction).

Valuation of Residential Water Shortages

Valuation of residential water shortages are based on statewide average values reported by the TWDB in the 2007 state water plan, and adapted for this study via a linear extrapolation. Ideally, estimates of the value of residential water shortages should be based on non-linear demand functions (i.e., constant elasticity demand curves) estimated at the utility level. These values would be more accurate when measuring shortages of different magnitudes, and lower than the values applied in this study for small shortages. In other words, the impacts of a small deficit relative to total annual water use (e.g., less than five percent) would be minimal. As the magnitude of shortages grew, the impacts increase in a non-linear fashion, and values at the other extreme would be much higher than those using the values in this study. Theoretically, as shortages approach 100 percent, the value of water becomes infinite assuming there were no readily alternatives available. In reality, alternatives to utility supplied tap water would likely be available such as bottled water or water delivered by tanker (“hauled in” water). For example, costs per acre-foot of delivered water can be very high ranging anywhere from $20,000 to $70,000, and the cost of retail bottled water is approximately $162,000 per acre-foot. To value residential shortages using constant elasticity demand curves requires a considerable amount of effort and data, and was beyond the scope of this study. However, it would be a very useful refinement in any future studies that quantify economic impacts of drought."

Appendix C
Per Capita Water Use Provided by
Texas Water Development Board

Appendix C. Per Capita Water Use Provided by Texas Water Development Board

Entity	Year																			
	1964	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**
Alamo Heights	268	253	275	330	270	252	290	348	262	295	294	275	229	245	354	197	392	372	379	402
Boerne	173	123	117	145	124	140	157	171	149	147	161	163	174	182	237	156	170	145	163	148
Garden Ridge																				
Gonzales County WSC																				
Hill Country Village																				
Hollywood Park								264	218	218	217	201	219	351	355	318	406	318	438	367
Hondo	130	135	122	201	176	202	181	217	206	164	208	173	186	214	217	216	254	220	263	232
Kenedy + TDCJ	150	140	139	173	161	192	204	256	225	158	163	227	133	128	132	130	158	144	166	180
Lockhart	101	105	100	114	102	105	112	130	122	111	130	113	112	141	153	132	160	114	157	134
Lytle								196	204	173	196	210	131	167	189	182	202	195	179	158
New Braunfels	204	224	187	210	173	178	187	229	221	185	191	182	201	224	225	215	249	257	235	207
Point Comfort								103	98	101	95	107	111	104	116	121	122	124	126	91
San Antonio (BMWD)																				
San Antonio (SAWS)	157	156	153	178	159	171	179	197	187	171	158	163	166	177	181	182	208	182	207	180
San Marcos	143	147	160	158	122	120	146	131	200	151	172	220	285	172	186	165	237	233	238	218
Schertz	87	91	93	106	101	115	127	158	134	159	161	142	141	131	131	117	134	142	160	127
Selma																				
Shavano Park																	355	209	216	256
SS Water Supply Corp																				
Uvalde	328	303	301	335	278	305	311	216	311	261	233	277	291	192	302	298	300	255	275	241
Wood Creek																				

Entity	Year																				
	1984	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Alamo Heights	489	291	321	256	328	354	303	275	246	257	248	257	271	249	265	279	244	253	245	237	218
Boerne	173	142	140	125	139	200	164	138	163	186	170	145	168	151	159	91	169	164	169	168	174
Garden Ridge							222	252	184	250	246	184	172	144	171	209	217	187	189	203	186
Gonzales County WSC		125	129	157	174	181	213	150	227	196	234	258	209	238	277	265	264	223	209	136	189
Hill Country Village							396	345	280	312	353	319	362	414	538	502	731	795	219	219	219
Hollywood Park	393	243	424	422	488	567	539	259	311	324	351	348	395	458	537	547	667	767	219	219	219
Hondo	291	234	236	214	248	265	216	173	165	229	214	213	230	187	210	236	181	177	161	168	168
Kenedy + TDCJ	175	148	131	138	143	172	162	139	143	151	161	169	81	95	182	200	194	177	131	131	131
Lockhart	139	126	128	127	129	148	176	140	149	157	165	161	186	149	155	143	138	130	158	135	129
Lytle	193	183	170	157	188	237	191	165	157	166	154	163	182	145	162	157	174	166	160	160	138
New Braunfels	244	254	271	236	206	224	204	174	177	191	191	186	192	168	178	197	204	181	188	184	160
Point Comfort	96	100	113	94	129	154	129	108	75	79	125	115	157	148	91	84	160	97	136	158	185
San Antonio (BMWD)		100	99	104	113	109	98	96	95	101	81	81	86	115	94	94	80	83	83	91	92
San Antonio (SAWS)	195	168	173	162	177	177	159	148	145	139	143	149	147	143	145	142	147	142	144	142	140
San Marcos	234	213	203	215	217	216	196	184	187	201	188	183	162	168	158	165	152	134	147	144	124
Schertz	194	149	196	176	173	163	130	108	119	127	116	117	129	119	126	150	143	139	119	125	139
Selma																	421	411	254	329	213
Shavano Park	361	356	332	344	437	500	439	436	385	366	473	378	361	323	365	368	408	394	269	250	210
SS Water Supply Corp								95	101	109	106	121	132	149	117	113	110	104	113	105	91
Uvalde	285	229	216	197	248	289	237	239	199	240	219	218	247	225	272	309	363	243	214	196	170
Wood Creek							156	142	131	159	165	160	155	133	133	133	132	124	126	100	100

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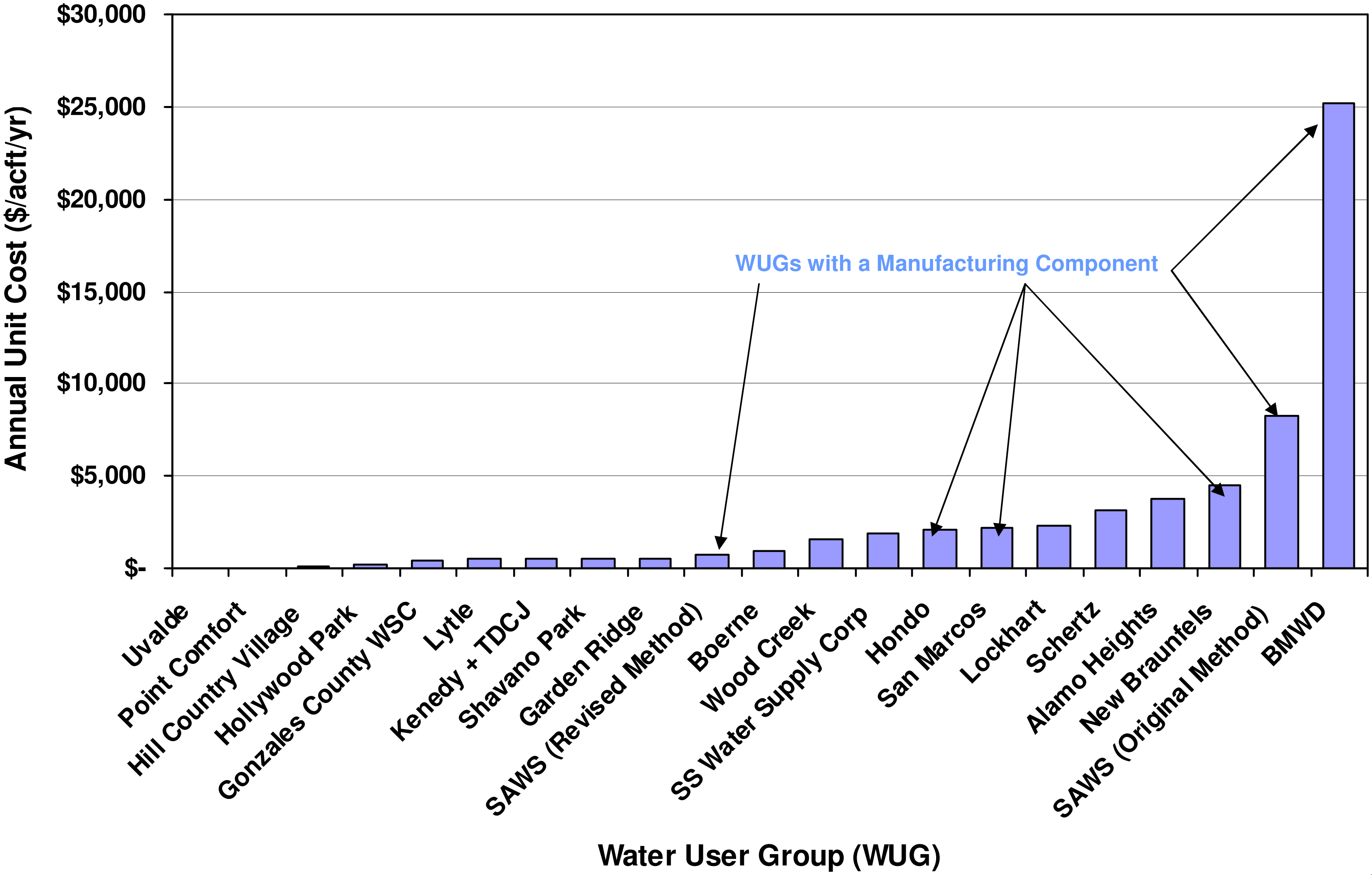
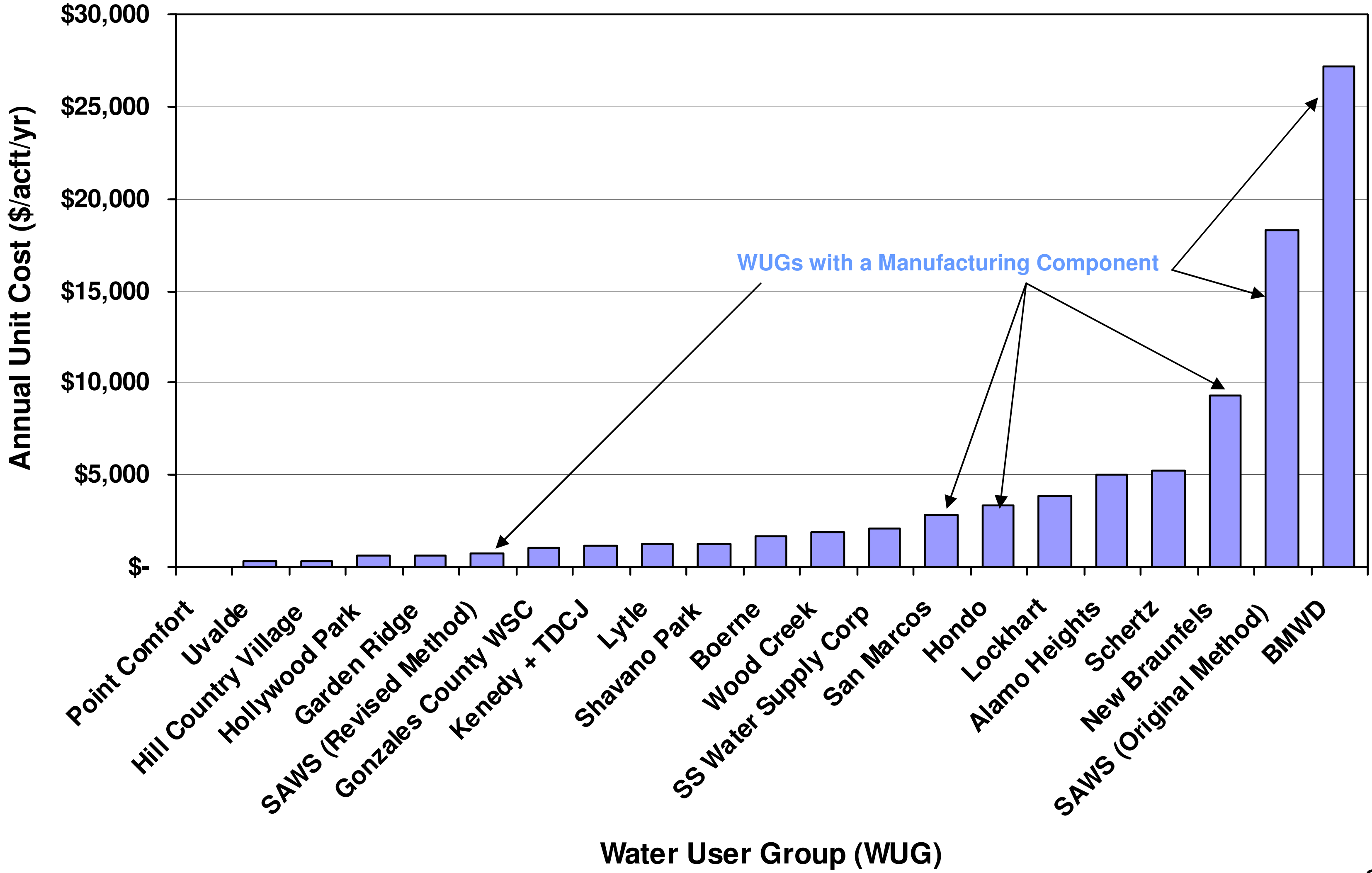
Appendix D
Drought Management WMS Unit Costs Compared to Unit Costs for Other Potentially Feasible WMS

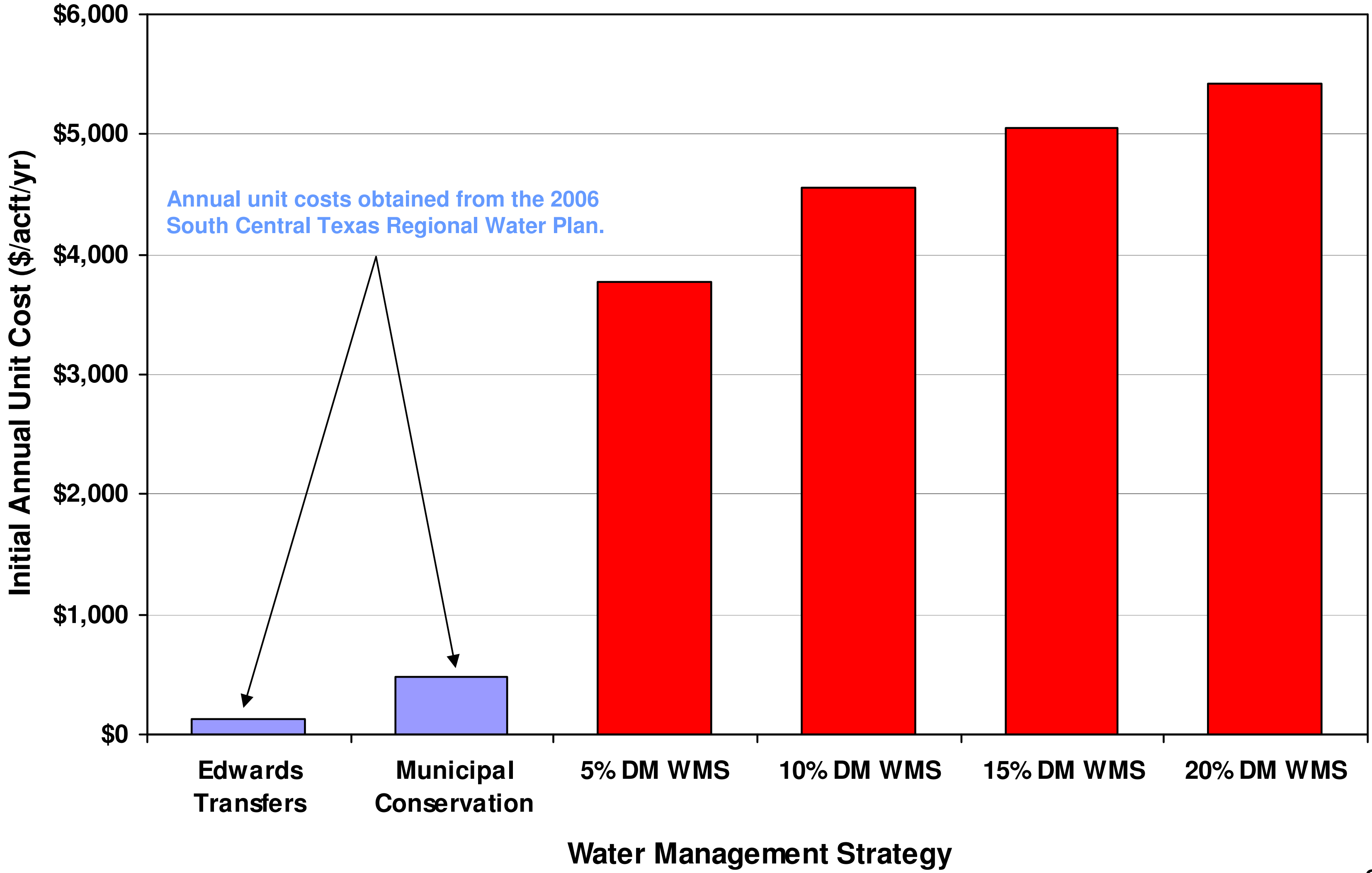
5% Reduction Drought Management Strategy



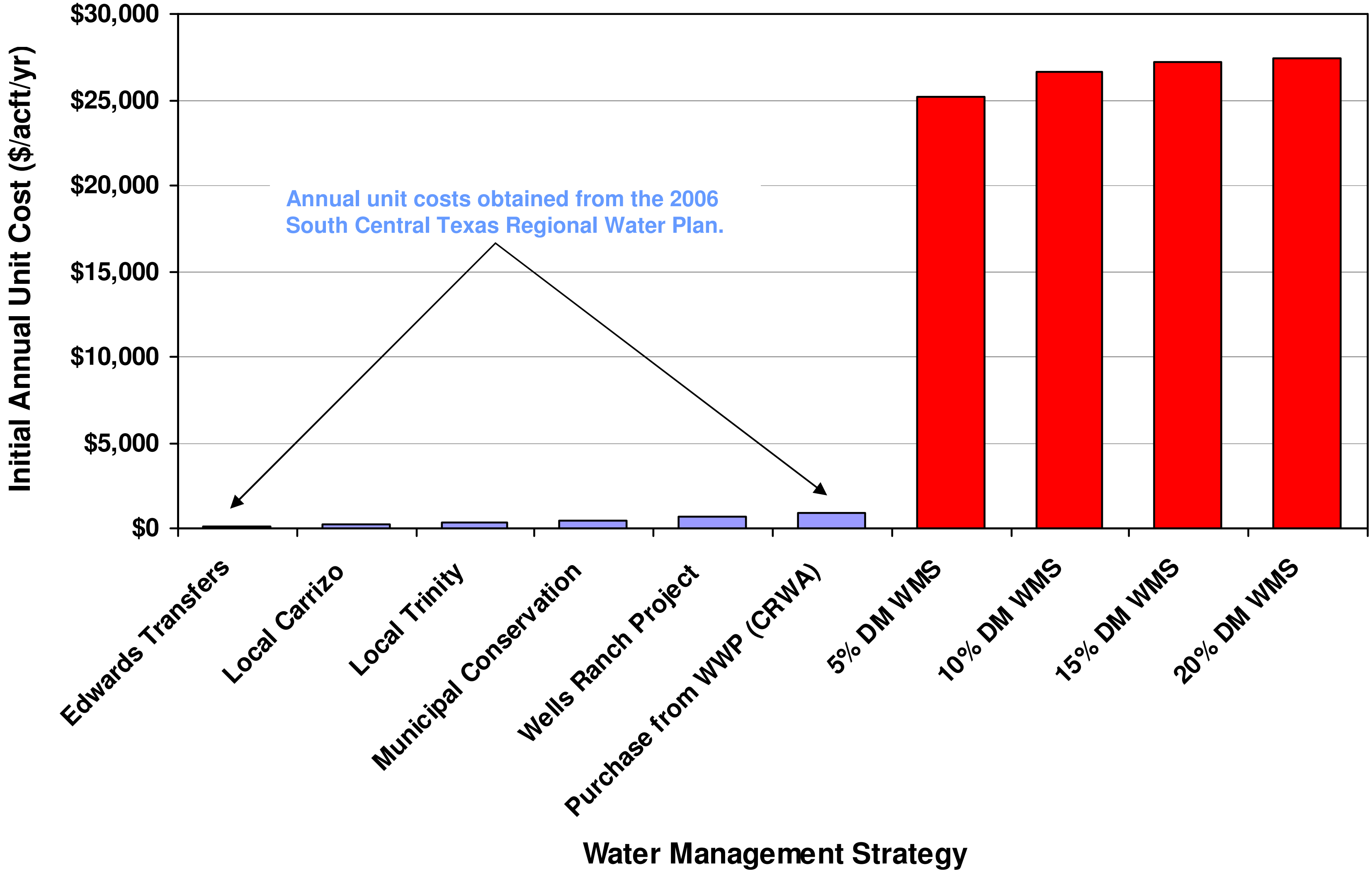
15% Reduction Drought Management Strategy



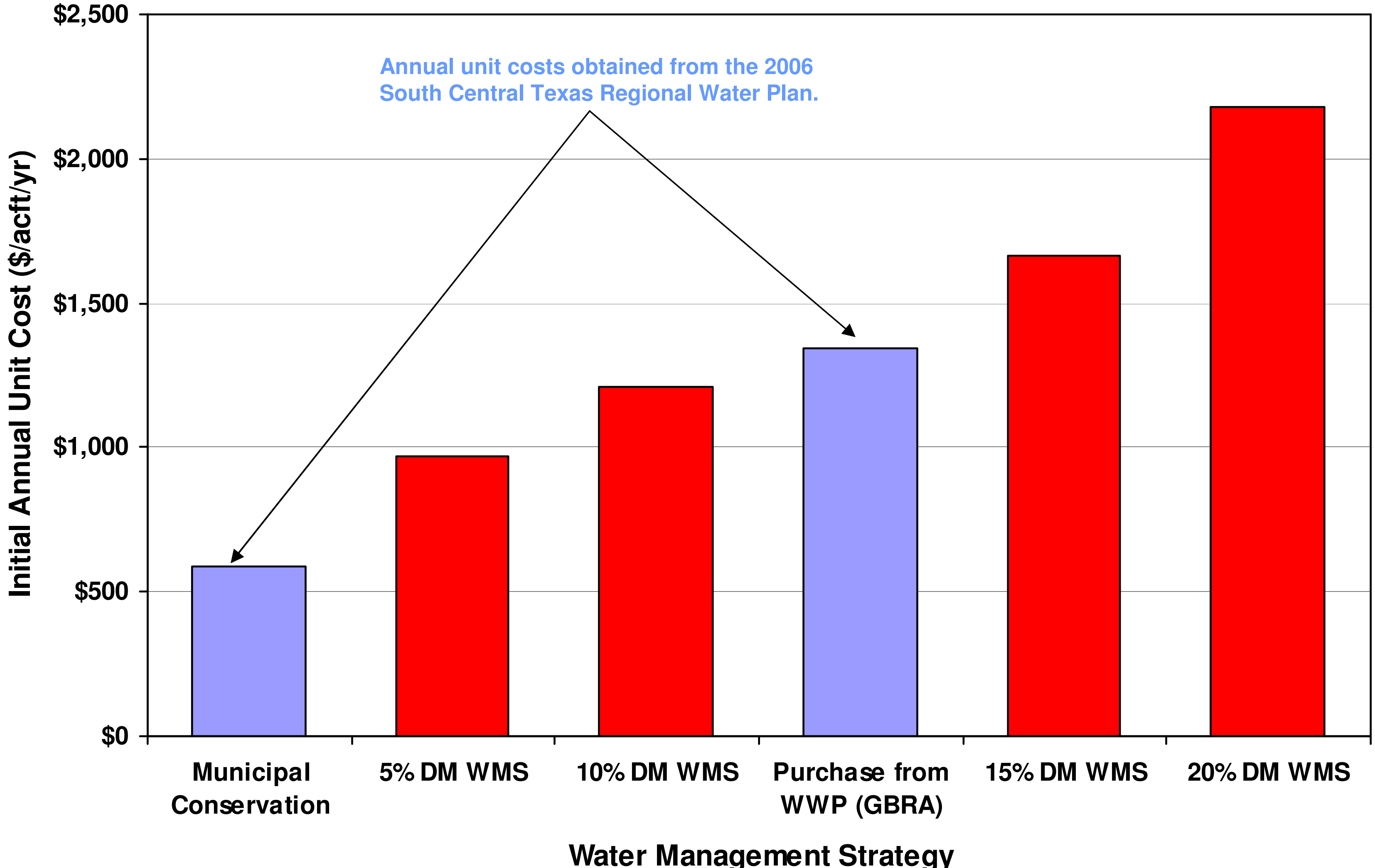
Alamo Heights – Recommended and DM WMS



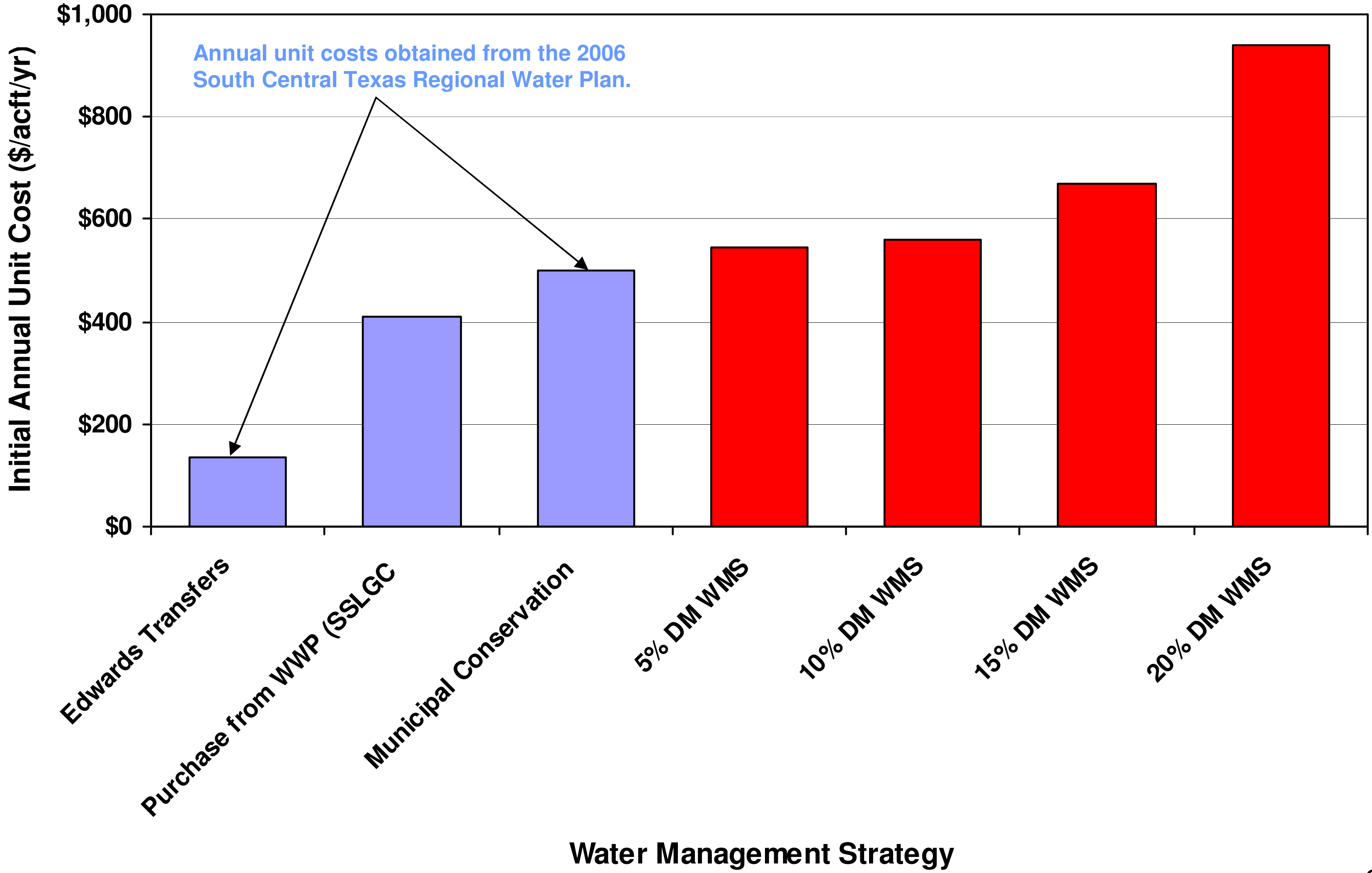
BMWD – Recommended and DM WMS



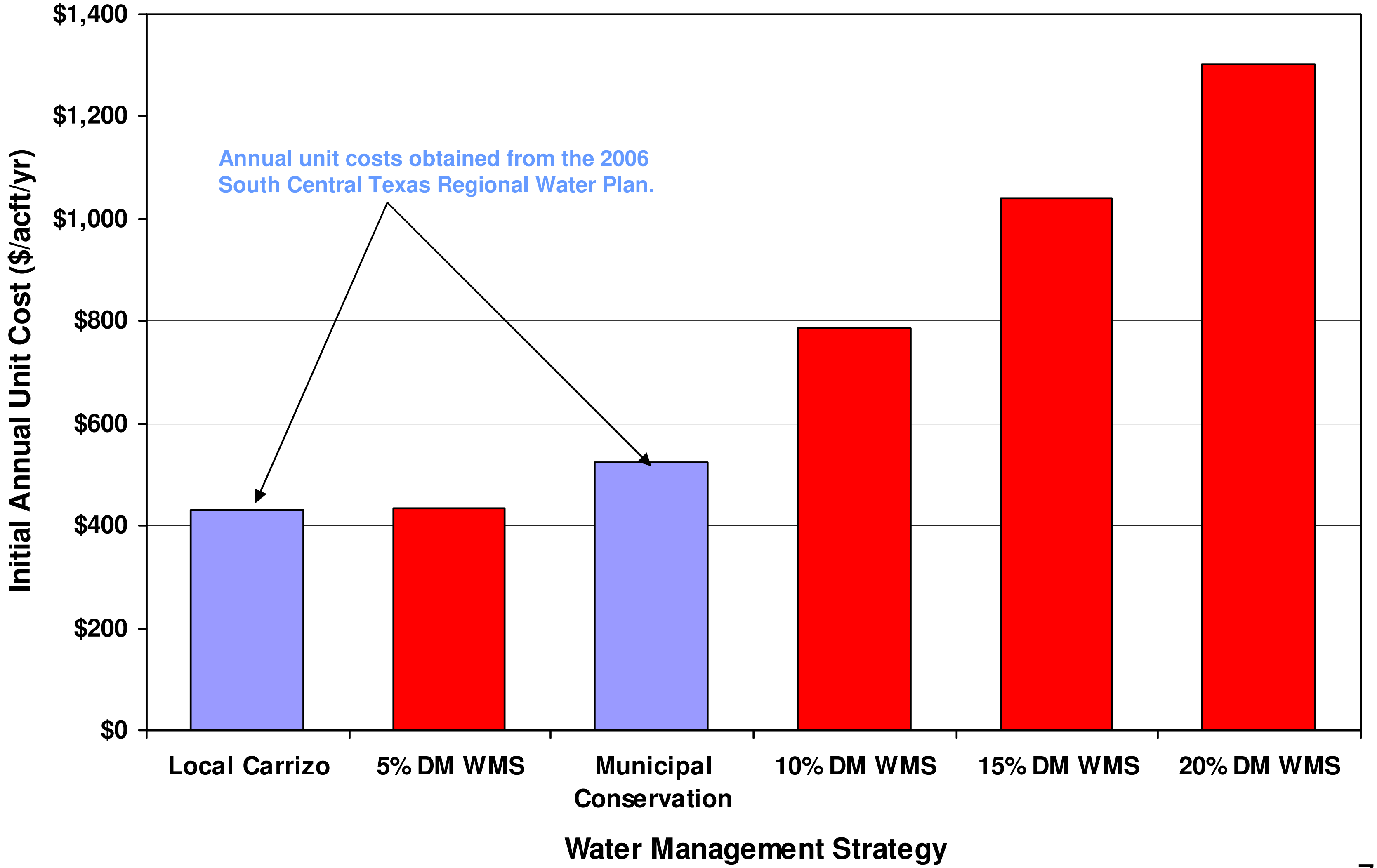
Boerne – Recommended and DM WMS



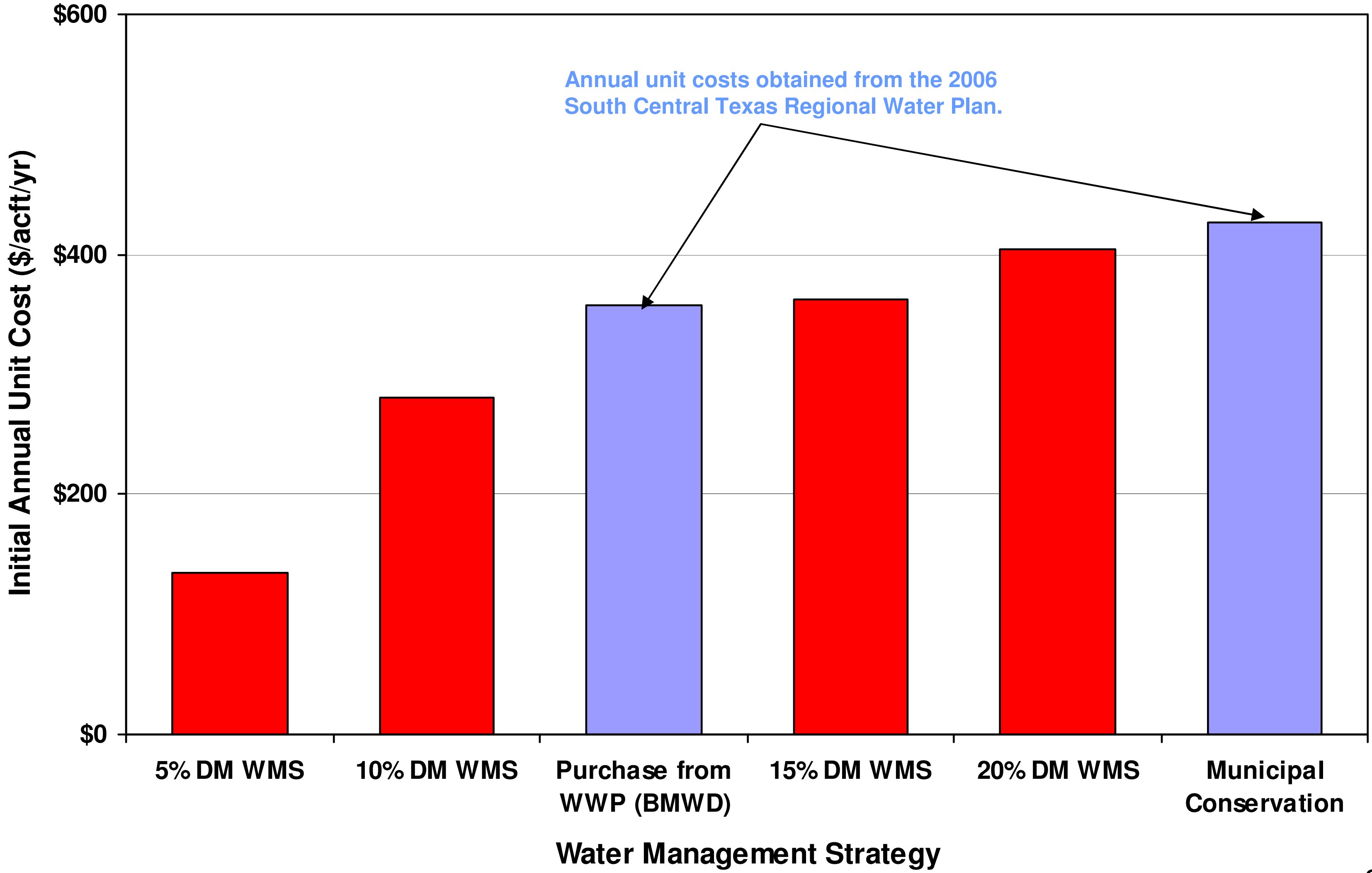
Garden Ridge – Recommended and DM WMS



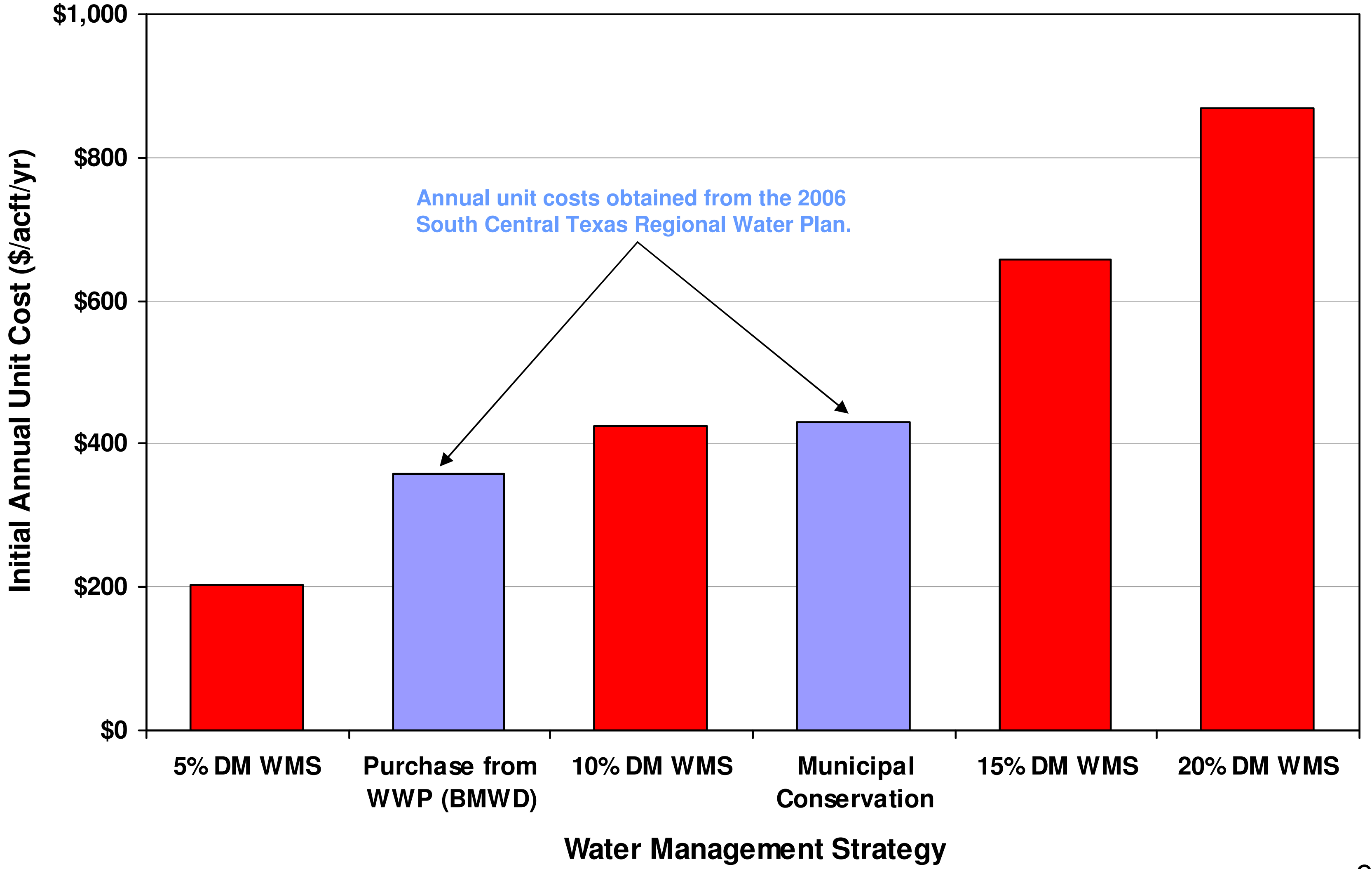
Gonzales County WSC – Recommended and DM WMS



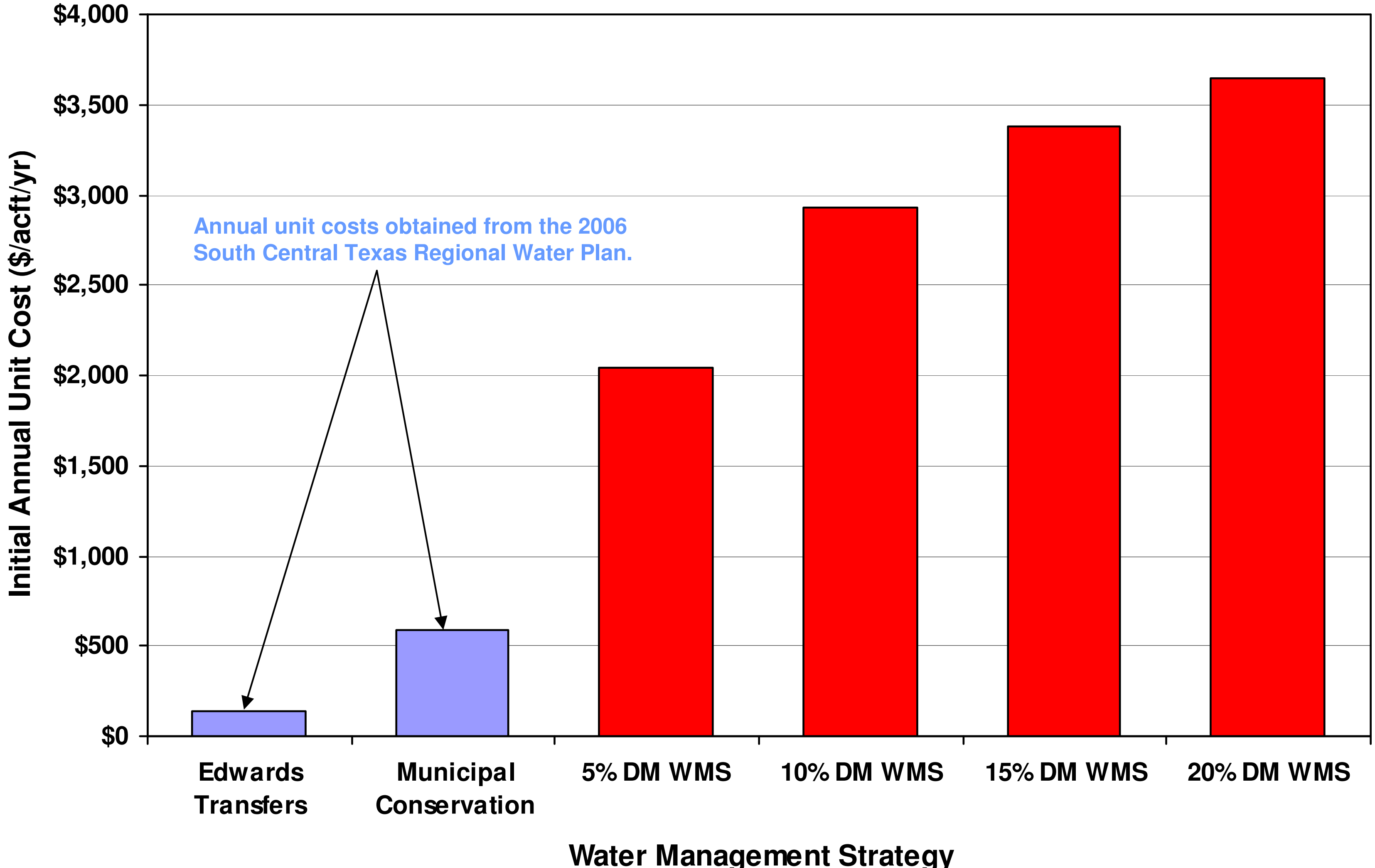
Hill County Village – Recommended and DM WMS



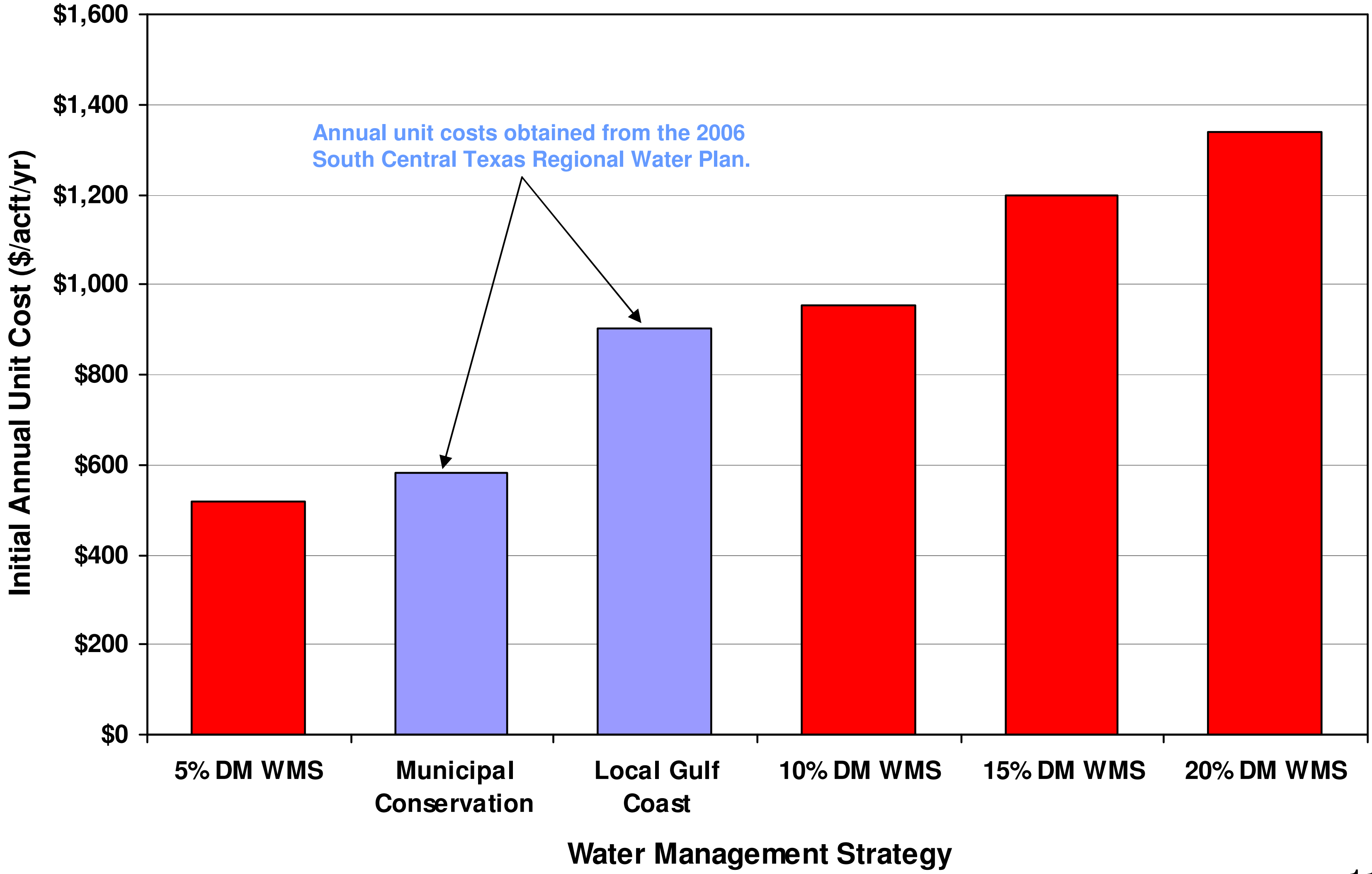
Hollywood Park – Recommended and DM WMS



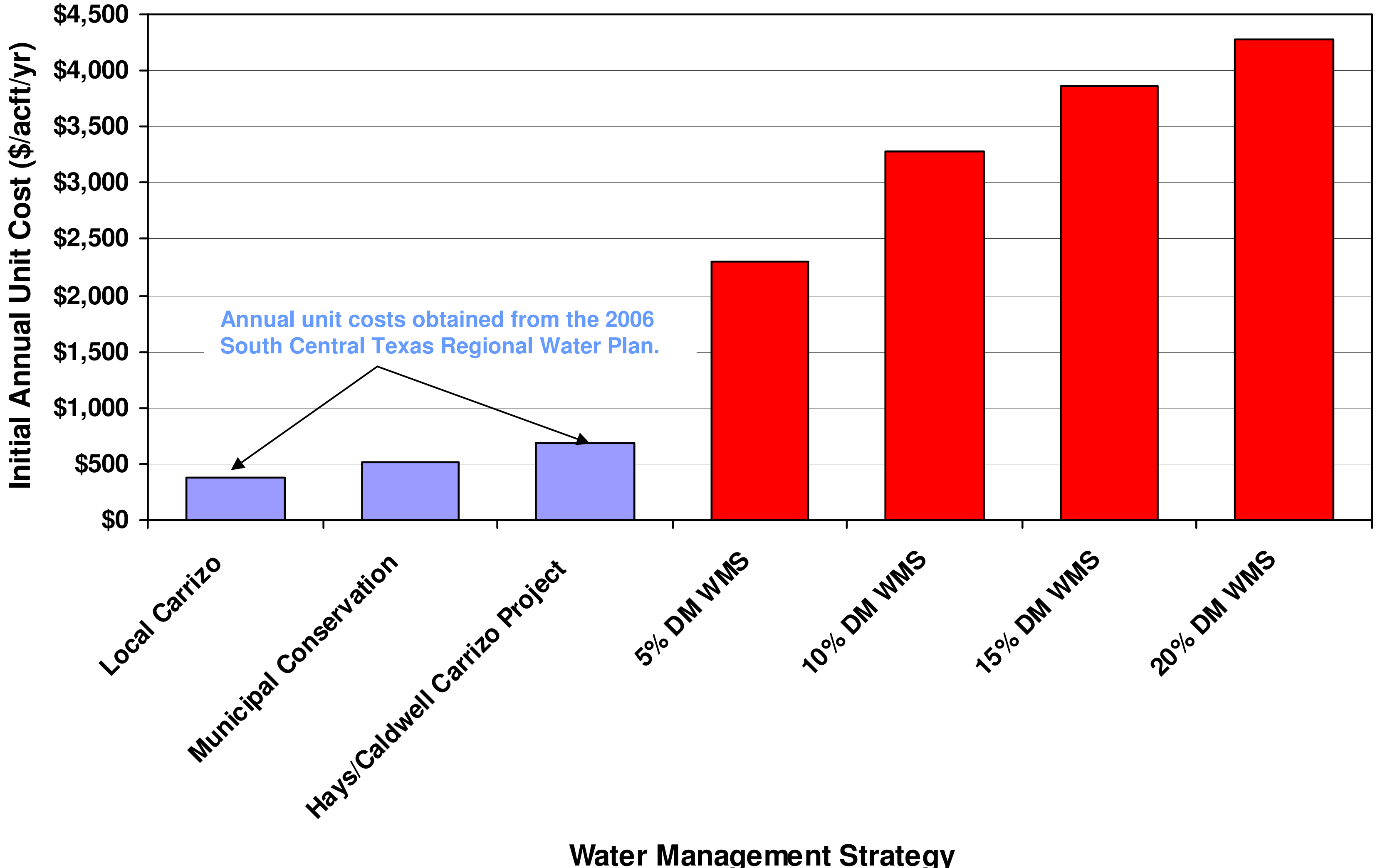
Hondo – Recommended and DM WMS



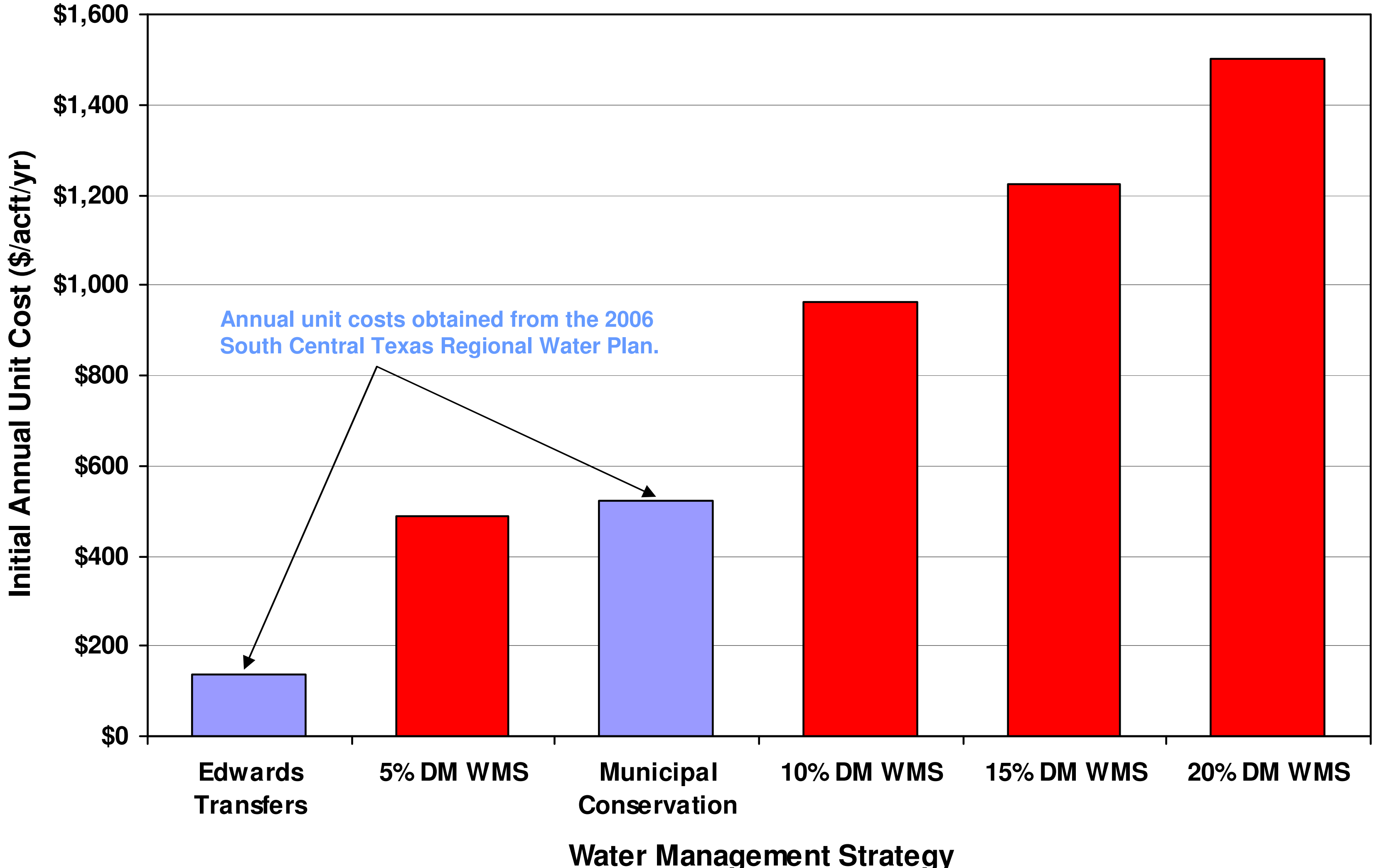
Kenedy – Recommended and DM WMS



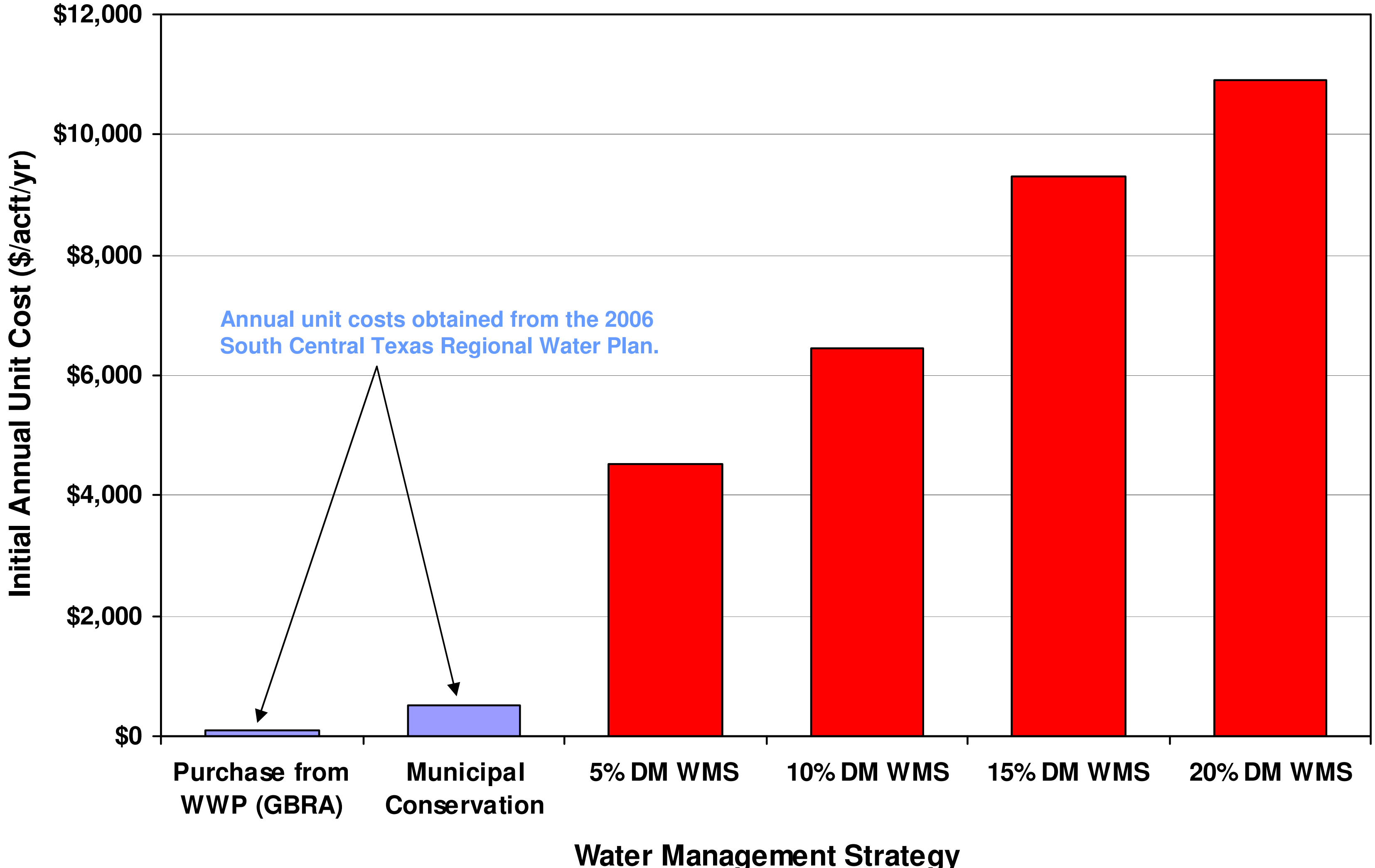
Lockhart – Recommended and DM WMS



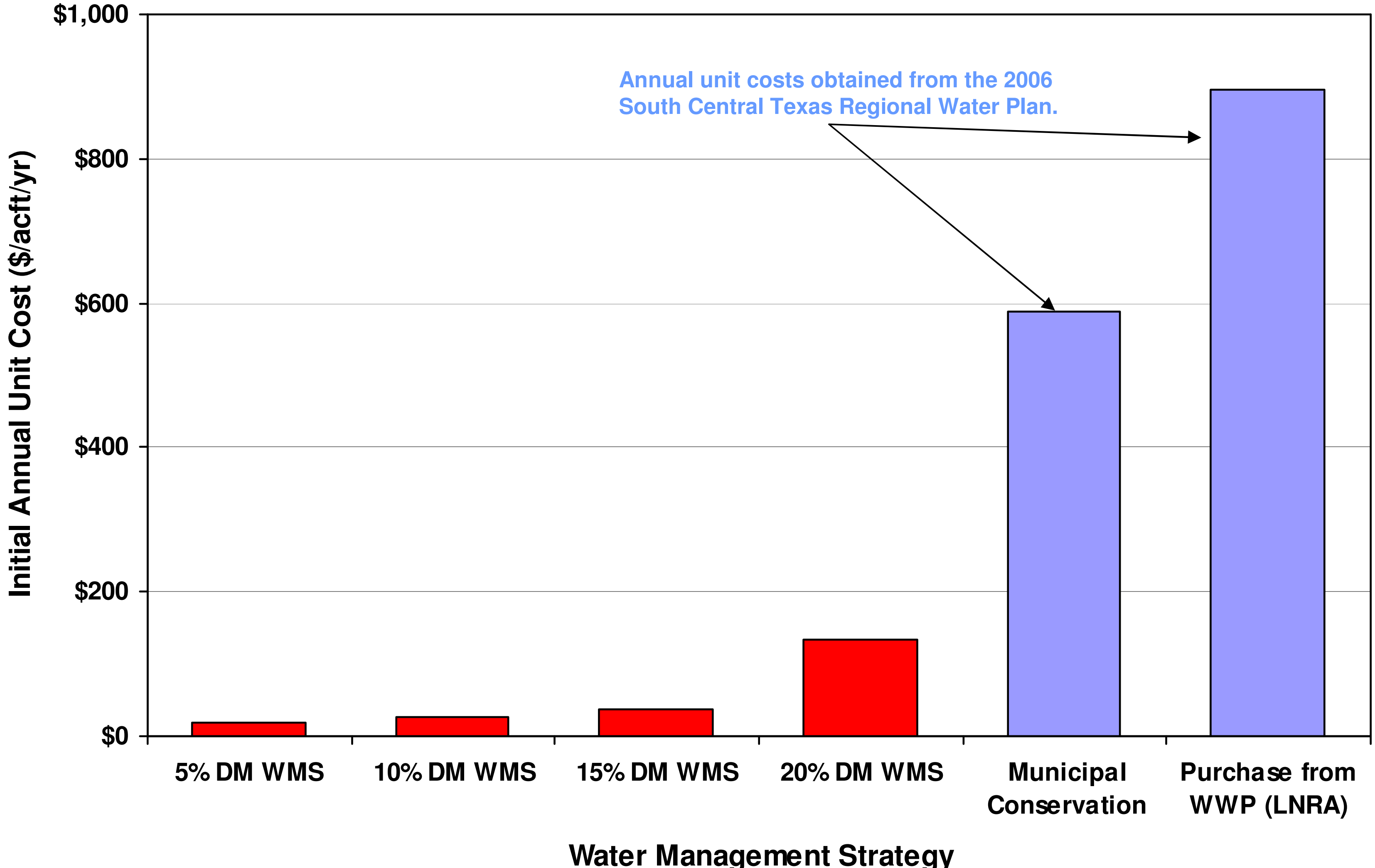
Lytle – Recommended and DM WMS



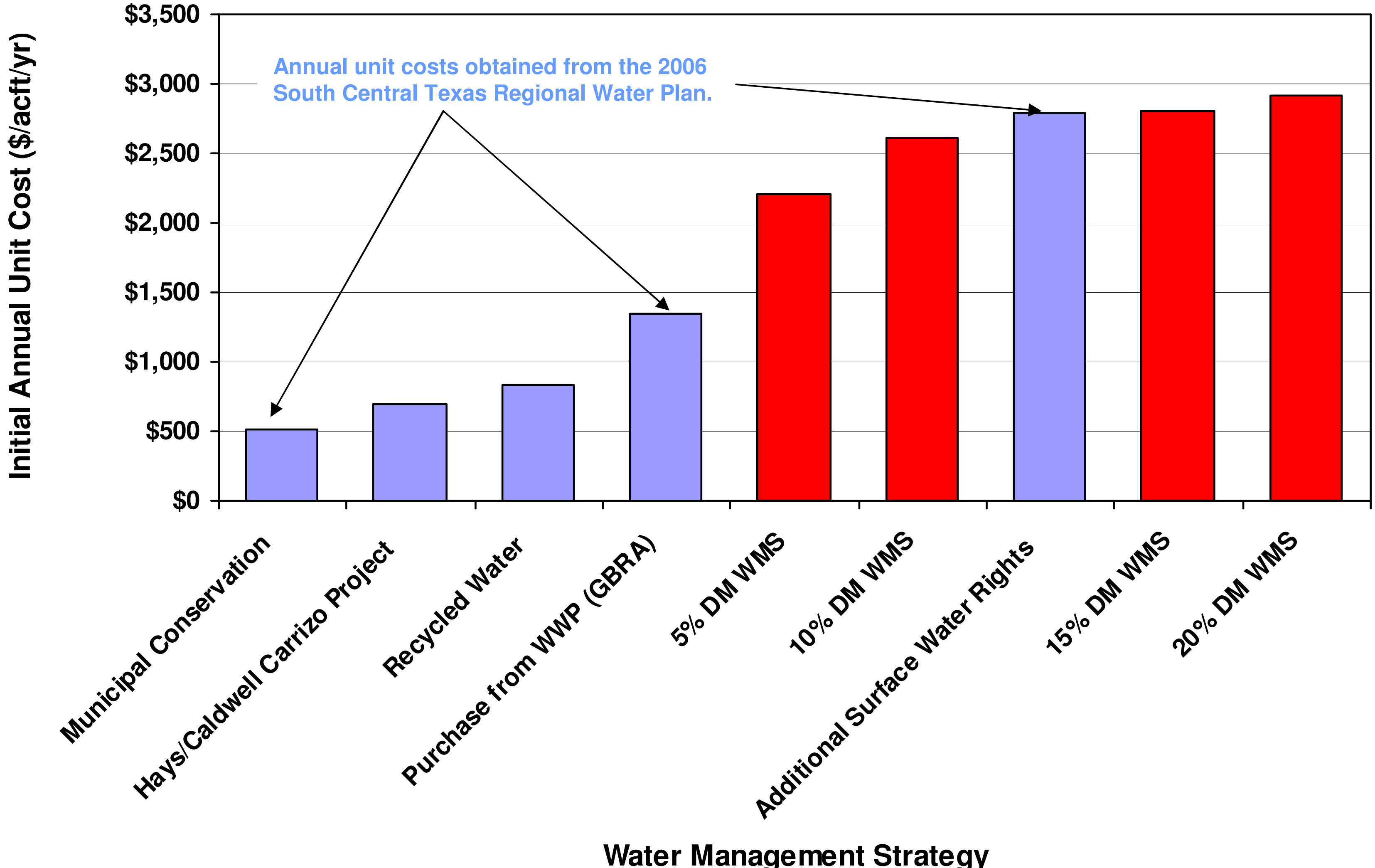
New Braunfels – Recommended and DM WMS



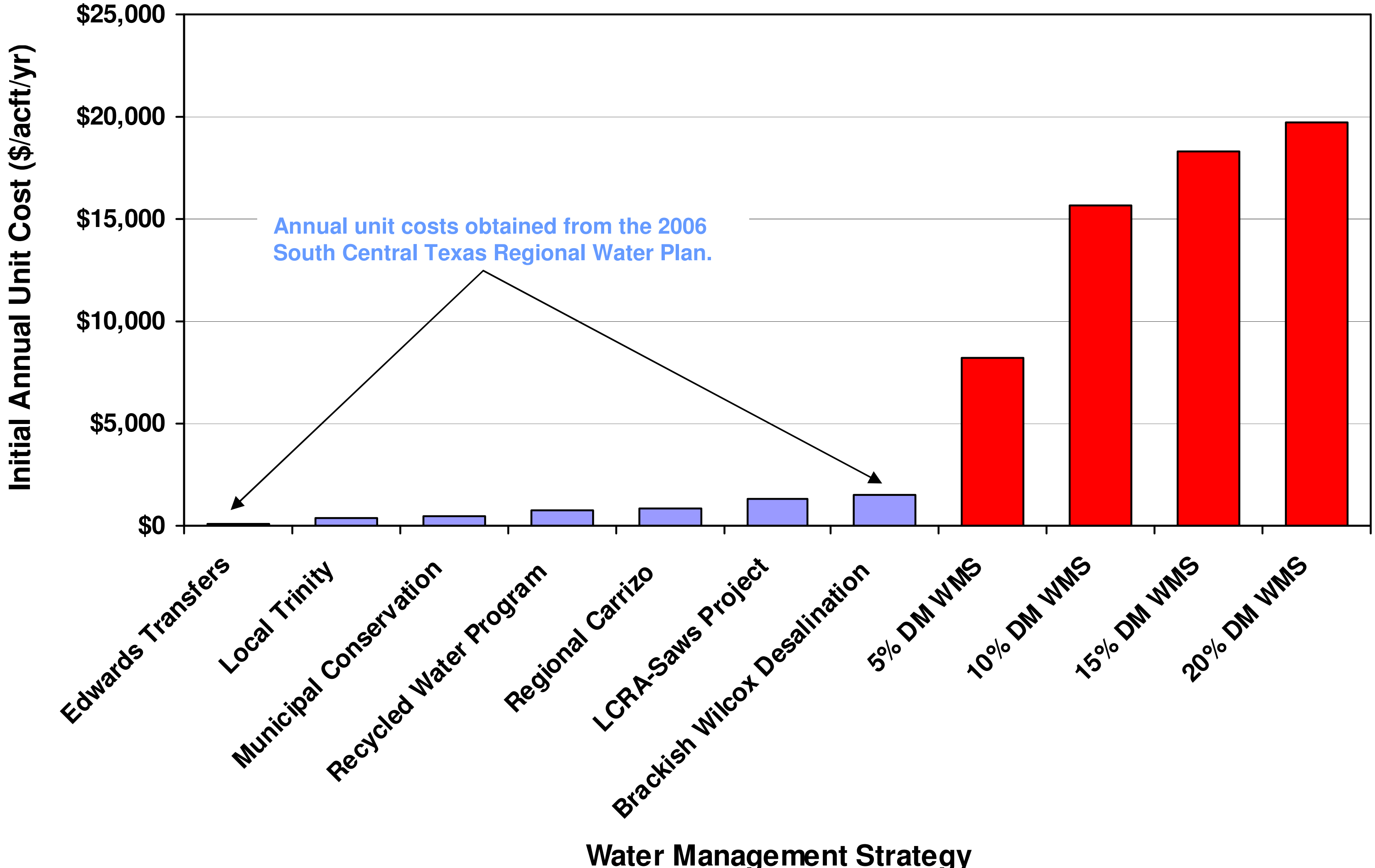
Point Comfort – Recommended and DM WMS



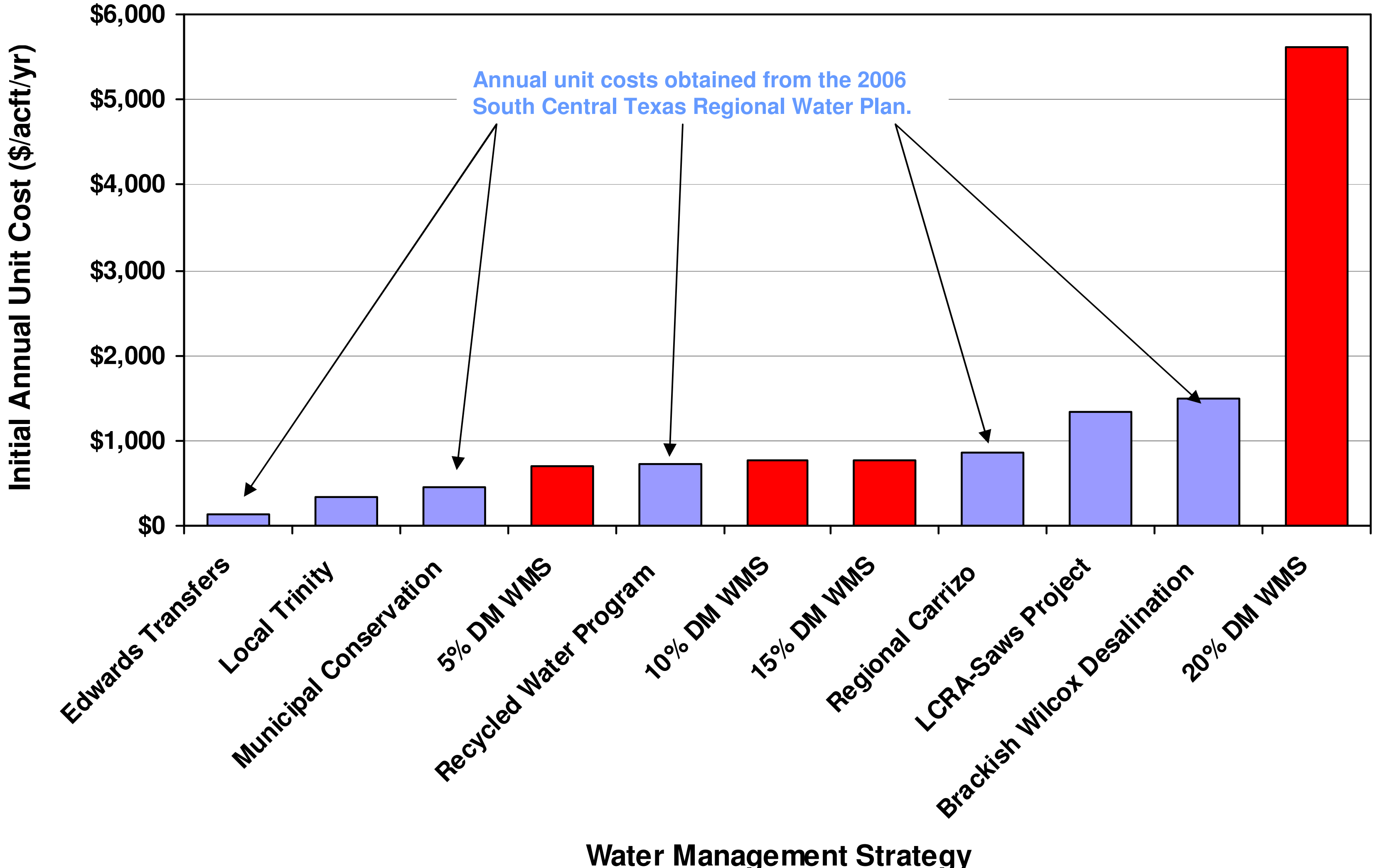
San Marcos – Recommended and DM WMS



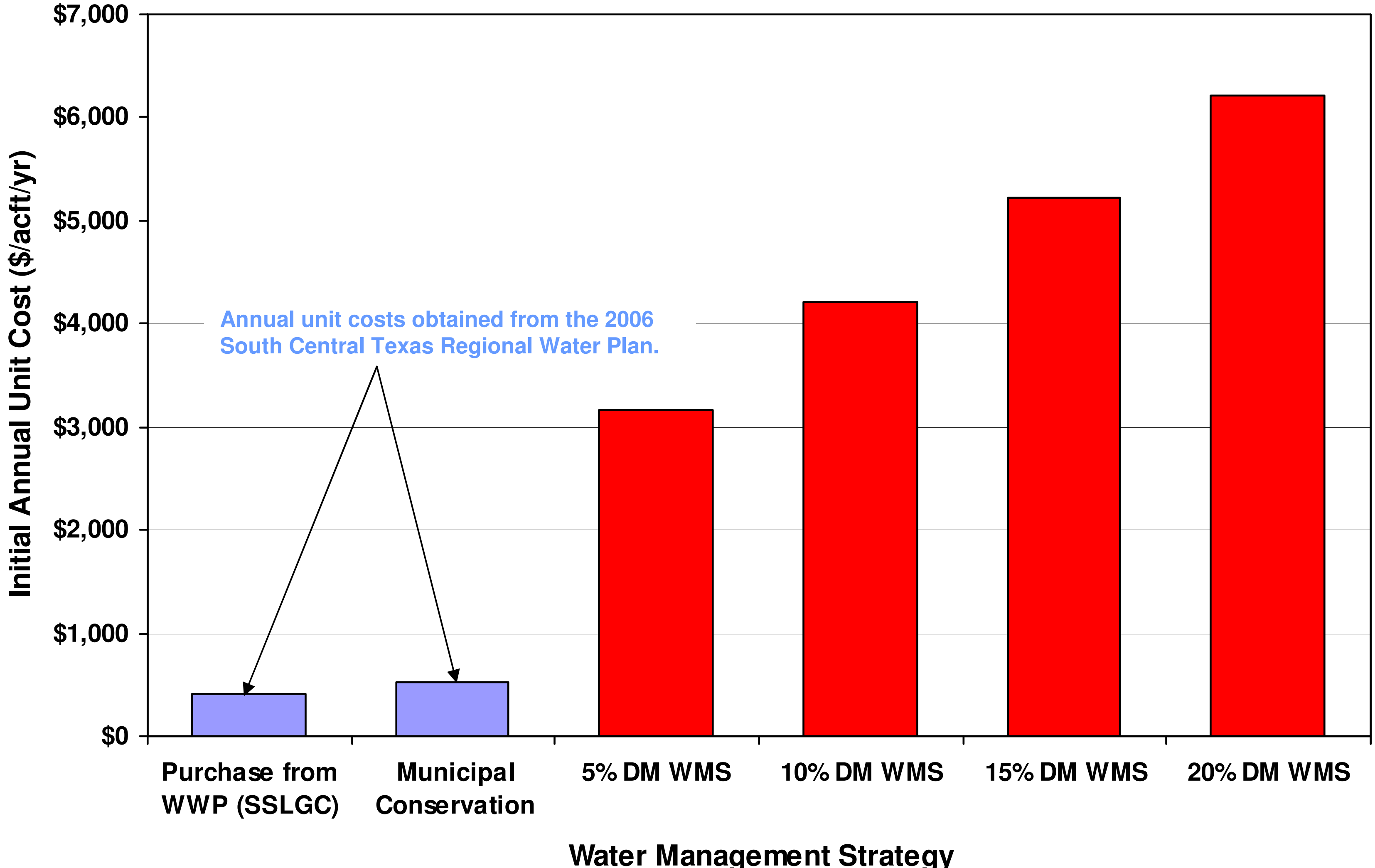
SAWS – Recommended and DM WMS (Original Method)



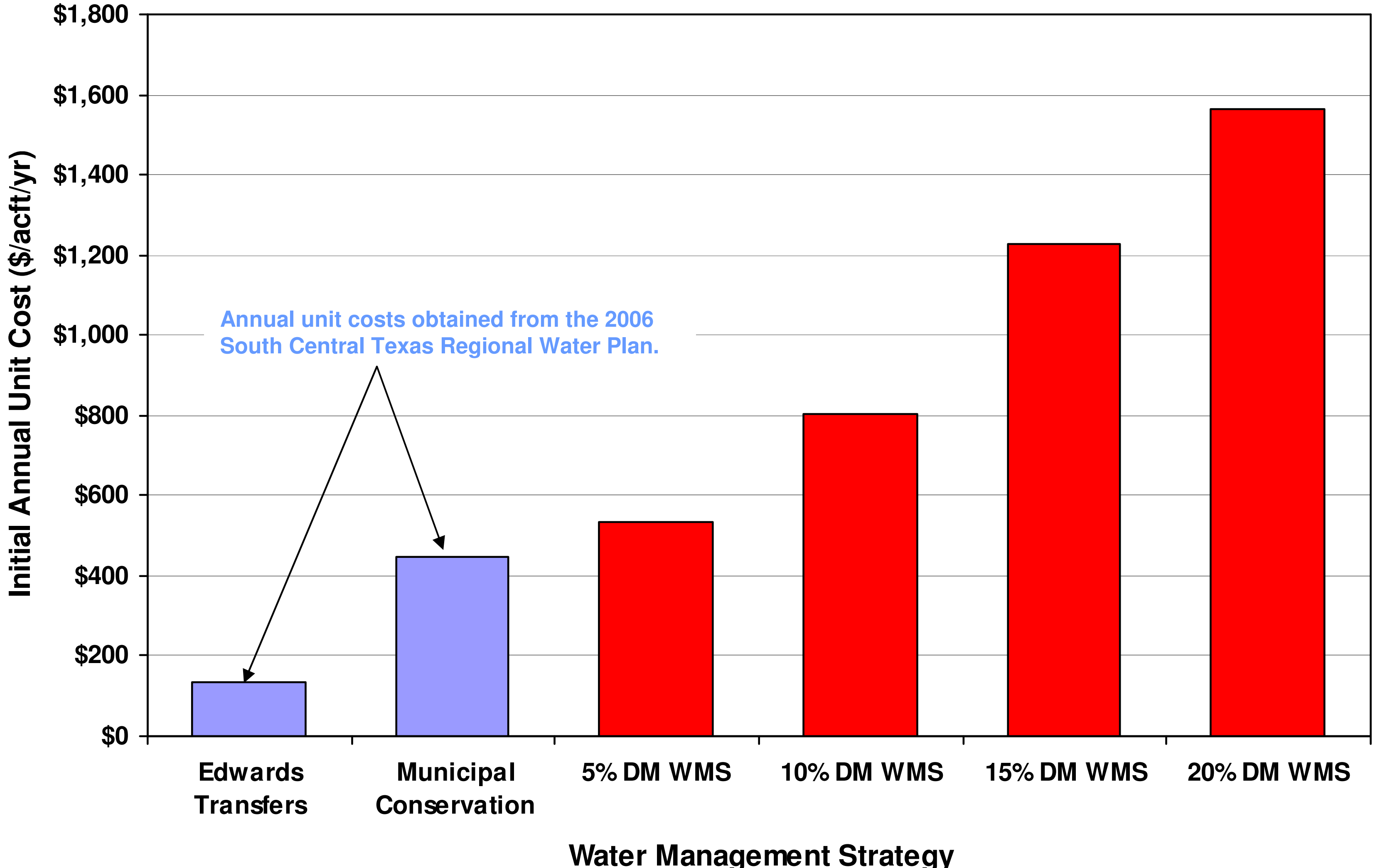
SAWS – Recommended and DM WMS (Revised Method)



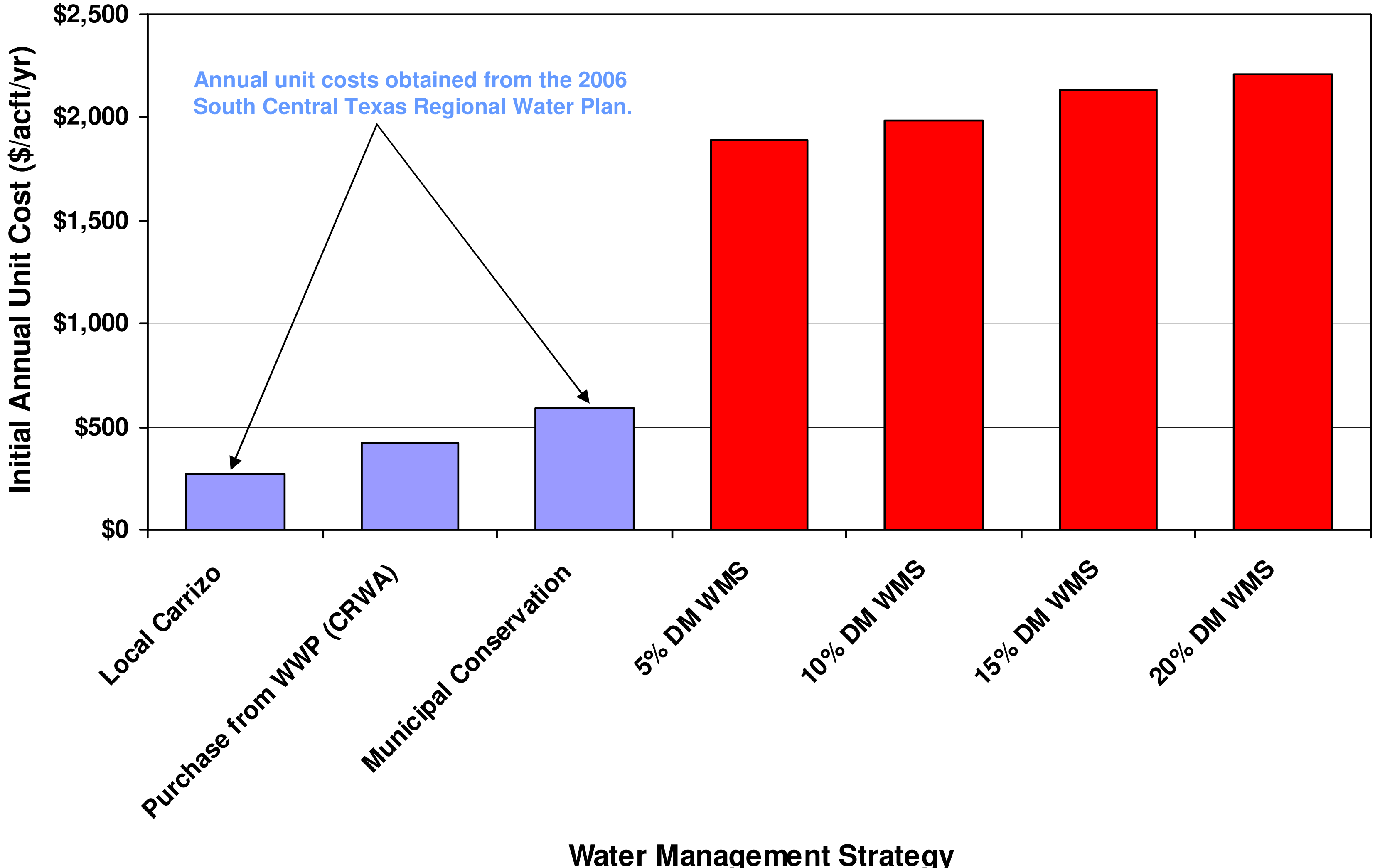
Schertz – Recommended and DM WMS



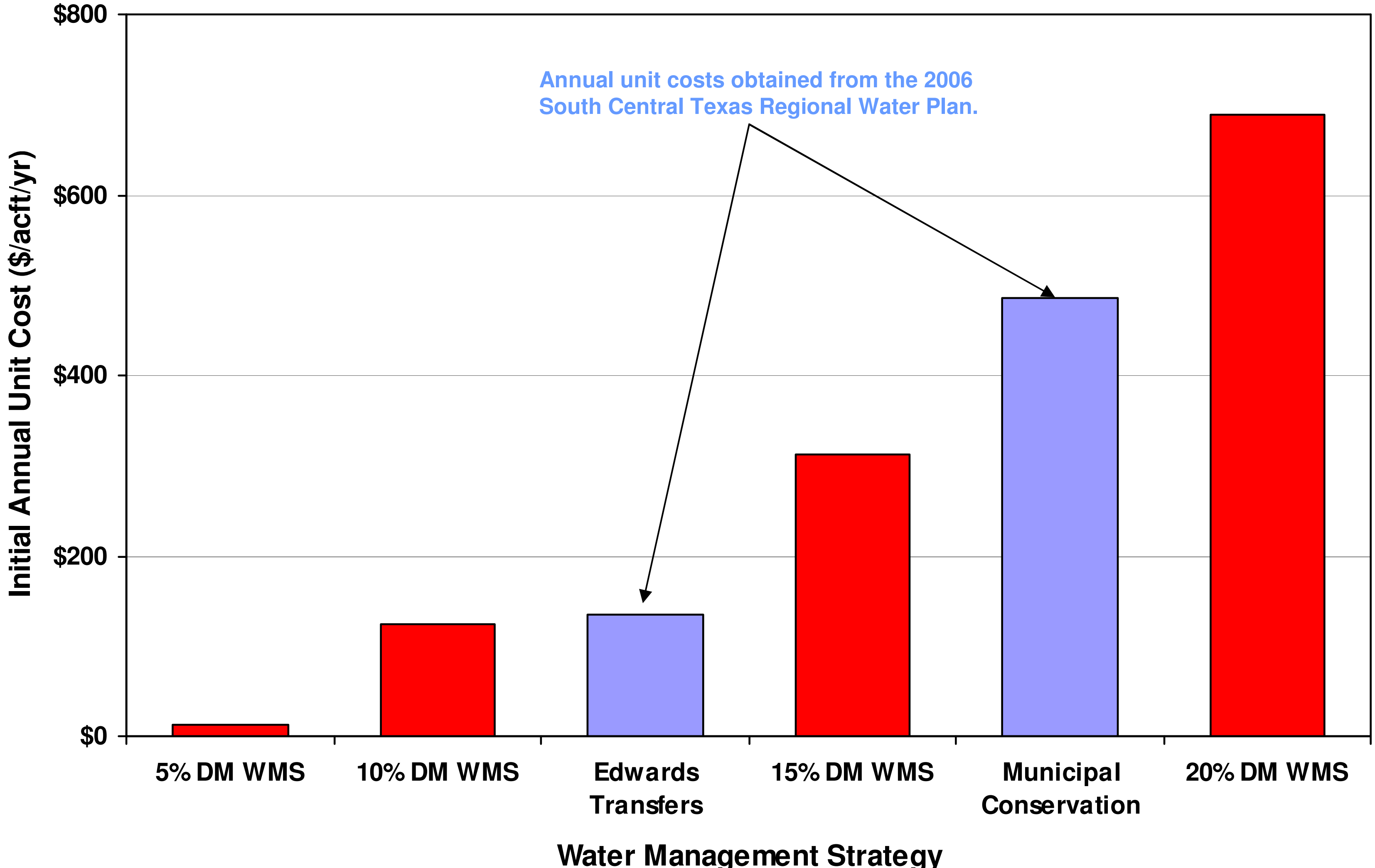
Shavano Park – Recommended and DM WMS



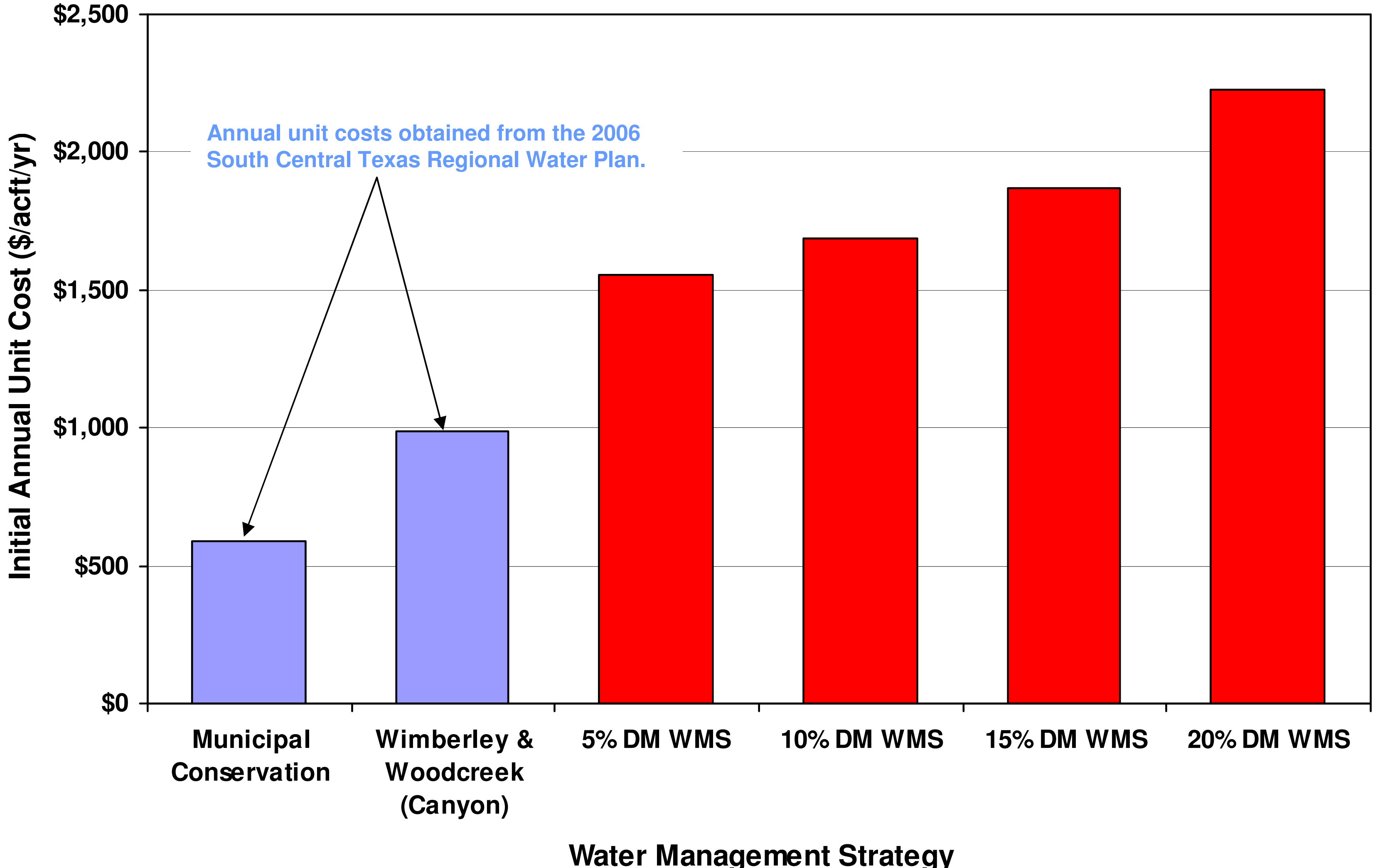
SS WSC – Recommended and DM WMS



Uvalde – Recommended and DM WMS



Woodcreek – Recommended and DM WMS



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Appendix E

Land-Based Water Conservation & Water Yield Practices in Region L: Influence of Land-Based Conservation Practices on Water Yield

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

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

TEXAS A&M | Institute of Renewable Natural Resources

&

GRAZINGLAND MANAGEMENT SYSTEMS, INC.

STUDY SPONSORED BY
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San Antonio, Texas
February 7, 2008

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Abstract

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

Executive Summary

Vegetation and Vegetation Management in the MLRA of Region L

Edwards Plateau

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

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

South Texas Plains

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

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

Other MLRAs in Region L

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

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

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

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

Edwards Plateau

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

South Texas Shrublands

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

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

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

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

Edwards Plateau

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

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

South Texas Shrublands

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

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

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

Vegetation and Vegetation Management in the MLRA of Region L

Edwards Plateau

General

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

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

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

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

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

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

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

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

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

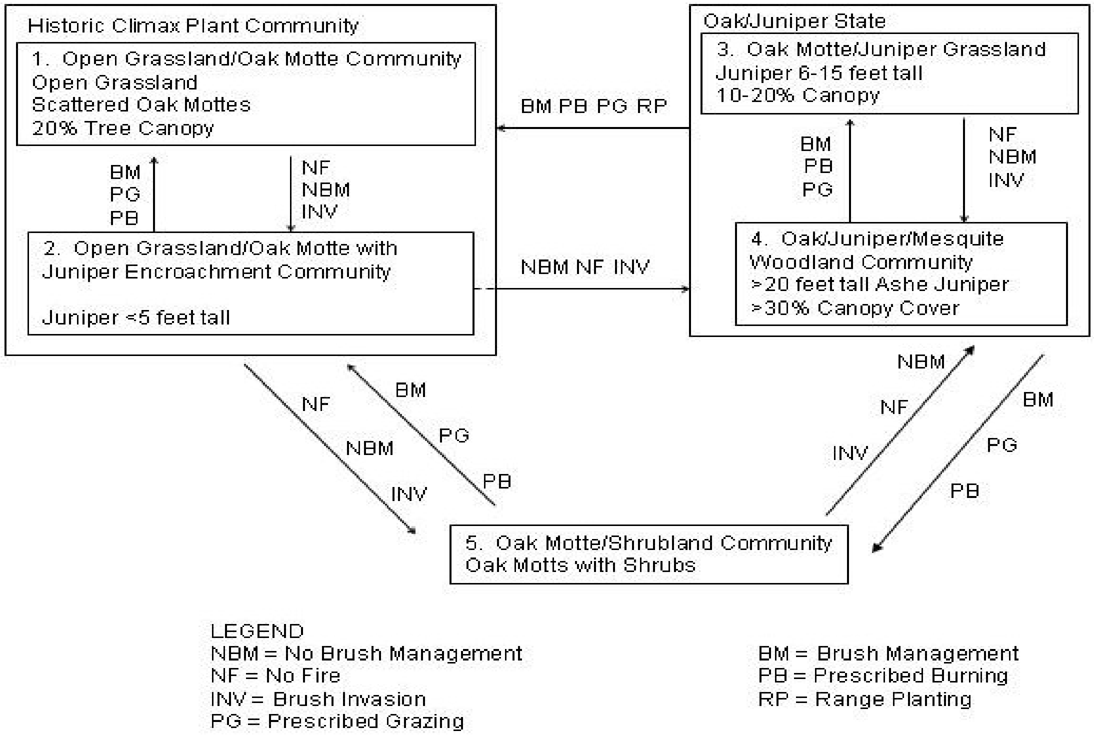
The Edwards Plateau is 98 percent rangeland; arable lands are found only along narrow streams and some divides. The rangeland is used primarily for mixed livestock (combinations of cattle, sheep, and goats) and wildlife production. The area is known as the major wool-and mohair-producing region in the United States, however in recent years there has been a move to greater meat goat production and a reduction in angora goats. The area also supports the largest deer population in North America. Most ranches in the area maintain livestock production, but wildlife has become increasingly important and may equal or exceed livestock in management emphasis and income on many ranch operations. Exotic big-game ranching is also important, and axis, sika, and fallow deer and blackbuck antelope have increased in numbers. Management for all resources, livestock, wildlife, and recreation, provides the best use of the rangeland, although other products such as cedar oil and wood products have local importance. Forage, food, and fiber crops such as sorghum, peanuts, plums, and peaches are well adapted to arable land.

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

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

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

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



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

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

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

Table 1. Annual Production by Plant Type (HCPC)

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

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

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

.

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

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

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

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

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

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

Brush Management Practices

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

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

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

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

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

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

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

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

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

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

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

Gulf Coast Prairies and Marshes

General

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

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

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

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

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

The Gulf Coast Marsh areas, being variously salty, support species of sedges (*Carex* and *Cyperus*), rushes (*Juncus*), bulrushes (*Scirpus*), several cordgrasses (*Spartina*), seashore saltgrass (*Distichlis spicata* var. *spicata*), common reed (*Phragmites australis*), marshmillet (*Zizaniopsis miliacea*), longtom (*Paspalum lividum*), seashore dropseed (*Sporobolus virginicus*), and knotroot bristlegrass (*Setaria geniculata*). Marshmillet and maidencane (*Panicum hemitomon*) are two of the most important grasses of the fresh-water marshes of the upper coast. Common aquatic forbs are pepperweeds (*Lepidium*), smartweeds (*Polygonum*), docks (*Rumex*), bushy seedbox (*Ludwigia alternifolia*), green parrotfeather (*Myriophyllum pinnatum*), pennyworts (*Hydrocotyle*), water lilies (*Nymphaea*), narrowleaf cattail (*Typha domingensis*), spiderworts (*Tradescantia*), and duckweeds (*Lemna*). Common halophytic herbs and shrubs on salty sands are spikesedges (*Eleocharis*), fimbries (*Fimbristylis*), glassworts (*Salicornia*), sea-rockets (*Cakile*), maritime saltwort (*Batis maritima*), morningglories (*Ipomoea*), and bushy sea-ox-eye (Jones 1982).

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

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

The original vegetation types of the Gulf Coast Prairies were tallgrass prairie and post oak savannah. However, trees and shrubs such as honey mesquite (*Prosopis glandulosa*), oaks (*Quercus*), and acacia (*Acacia*) have increased and thicketized in many places. Characteristic oak species are live oak (*Quercus virginiana*) and post oak (*Q. stellata*). Typical acacias are huisache (*Acacia smallii*) and blackbrush (*A. rigidula*). Bushy sea-ox-eye (*Borrichia frutescens*), a dwarf shrub, is also typical.

Principal climax grasses of the Gulf Coast Prairies are Gulf cordgrass (*Spartina spartinae*), big bluestem (*Andropogon gerardii* var. *gerardii*), little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutans*), eastern gamagrass (*Tripsacum dactyloides*), gulf muhly (*Muhlenbergia capillaris*), tanglehead (*Heteropogon contortus*), and many species of Panicum and Paspalum. Common increasers and invaders are yankeeweed (*Eupatorium compositifolium*), broomsedge bluestem (*Andropogon virginicus*), smutgrass (*Sporobolus indicus*), western ragweed (*Ambrosia psilostachya*), tumblegrass (*Schedonnardus paniculatus*), threeawns (*Aristida*), and many annual forbs and grasses. Pricklypear (*Opuntia*) are common throughout the area. Characteristic forbs include asters (*Aster*), Indian paintbrush (*Castilleja indivisa*), poppy mallows (*Callirhoe*), phloxs (*Phlox*), bluebonnets (*Lupinus*), and evening primroses (*Oenothera*) (Jones 1982).

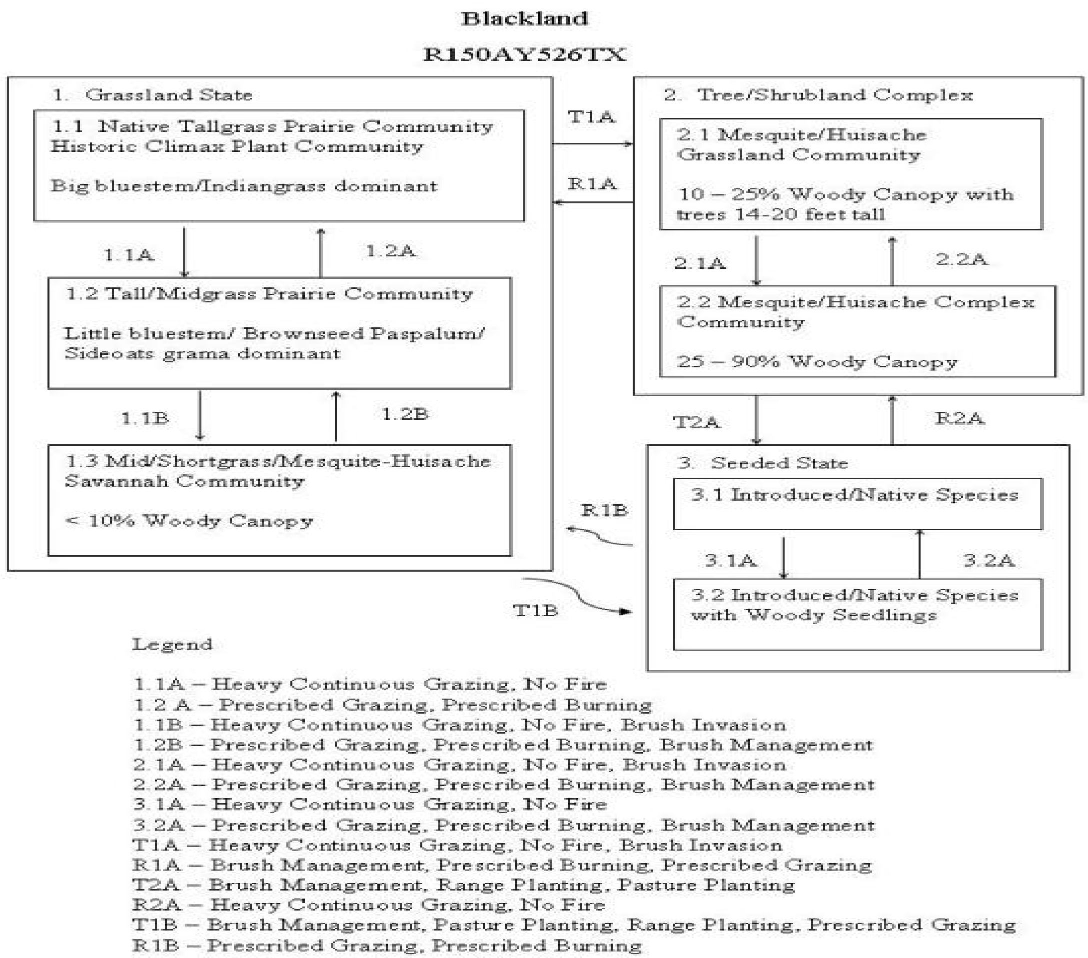
Specific Reference to a Dominant Ecological Site

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

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

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

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



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

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

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

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

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

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

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

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

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

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

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

Brush Management Practices

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

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

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

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

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

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

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

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

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

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

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

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

South Texas Plains

General

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

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

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

The original vegetation was an open grassland or savannah-type along the coastal areas and brushy chaparral-grassland in the uplands (Johnston 1963). Originally, oaks and mesquite and other brushy species formed dense thickets only on the ridges, and oak, pecan, and ash were common along streams (Inglis 1964). Continued grazing and cessation of fires altered the vegetation to such a degree that the region is now commonly called the Texas Brush Country. Many woody species have increased, including mesquite, live oak, acacias, brazil (*Zizyphus obovata*), spiny hackberry (*Celtis Pallida*), whitebrush (*Aloysia gratissima*), lime pricklyash (*Zanthoxylum fagara*), Texas persimmon (*Diospyros texana*), shrubby blue sage (*Salvia ballotiflora*), and lotebush (*Zizyphus obtusifolia*).

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

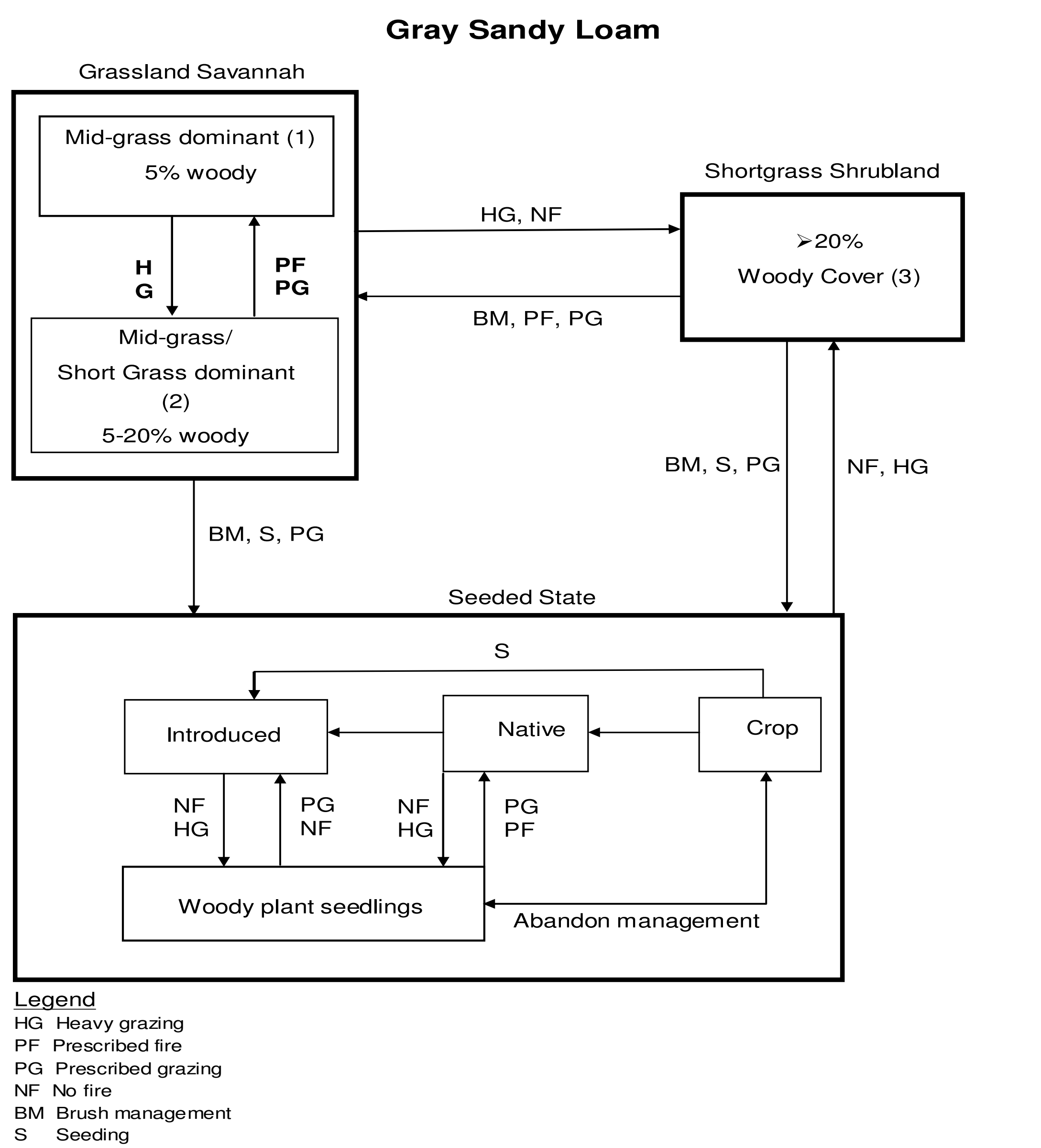
Because the South Texas Plains lie almost entirely below the hyperthermic line, introduced tropical species do well. The introduced species buffelgrass (*Cenchrus ciliaris*) has proliferated and is common on loamy to sandy soils in the western half of the area. Coastal bermudagrass, kleingrass (*Panicum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

Range is the major land use, but irrigated and dryland cropping of cotton, sorghum, flax, small grains, and forages are also important. Citrus, vegetables, and sugarcane do well in the Lower Rio Grande Valley. Many acres are in large landholdings, such as the King Ranch (825,000 acres). Livestock production is primarily cow-calf range operations, and wildlife production for hunting and recreational use are becoming increasingly important. The South Texas Plains vegetational area is known nationwide for its large white-tailed deer (*Odocolieus virginianus*). Quail (*Colinus virginiana*), mourning dove (*Zenaida macroura*), turkey (*Meleagris gallopavo*), feral pigs (*Sus scrofa*), and javelina (*Dicotyles tajacu*) are other major game species. Stocker operations and feedlot operations are intermixed with cow-calf operations. Sheep and goat enterprises, once common throughout the area, are now confined mostly to the northernmost part because of coyote predation. Integrated use of range, crops, and forages is increasing as is vegetable and peanut production where irrigation is possible.

Specific Reference to a Dominant Ecological Site

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

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



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Brush Management Practices

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

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

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

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

POST OAK SAVANNAH and BLACKLAND PRAIRIES

<u>General</u>

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

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

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

Upland soils are gray, slightly acid sandy loams, commonly shallow over gray, mottled or red, firm clayey subsoils. They are generally droughty and have claypans at varying depths, restricting moisture percolation. The bottomland soils are reddish brown to dark gray, slightly acid to calcareous, loamy to clayey alluvial. Short oak trees occur in association with tallgrasses. Thicketization occurs in the absence of recurring fires or other methods of woody plant suppression. This distinctive pattern of predominantly post oak and blackjack oak (*Quercus marilandica*) in association with tallgrasses also characterizes the vegetation of the Cross Timbers and Prairies vegetational area. Associated trees are elms, junipers (*Juniperus*), hackberries (*Celtis*), and hickories (*Carya* spp.). Characteristic understory vegetation includes shrubs and vines such as yaupon (*Ilex vomitoria*), American beautyberry, coralberry (*Symphoricarpos orbiculatus*), greenbriar, and grapes.

Climax grasses are little bluestem, indiangrass, switchgrass (*Panicum virgatum*), silver bluestem (*Bothriochloa saccharoides*), Texas wintergrass (*Stipa leucotricha*), brownseed paspalum, purpletop, narrow leaf woodoats (*Chasmanthium sessiliflorum*), and beaked panicum (*Panicum anceps*). Lower successional species include brownseed paspalum, threeawn, broomsedge bluestem, splitbeard bluestem (*Andropogon ternarius*), rosette grasses, and lovegrasses (*Eragrostis*).

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

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

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

The Blackland Prairies area intermingles with the Post Oak Savannah in the southeast and has divisions known as the San Antonio and Fayette Prairies. This rolling and well-dissected prairie represents the southern extension of the true prairie that occurs from Texas to Canada.

The upland blacklands are dark, calcareous shrink-swell clayey soils, changing gradually with depth to light marls or chalks. Bottomland soils are generally reddish brown to dark gray, slightly acid to calcareous, loamy to clayey and alluvial. The soils are inherently productive and fertile, but many have lost productivity through erosion and continuous cropping.

This once-luxuriant tallgrass prairie was dominated by little bluestem, big bluestem, indiangrass, tall dropseed (*Sporobolus asper* var. *asper*), and Silveus dropseed (*S. silveanus*). Minor species such as sideoats grama (*Bouteloua curtipendula*), hairy grama (*B. hirsuta*), Mead's sedge (*Carex meadii*), Texas wintergrass, and buffalograss (*Buchloe dactyloides*) have increased with grazing pressure. Common forbs are asters (*Aster* spp.), prairie bluet (*Hedyotis nigricans* var. *nigricans*), prairie-clover, and late coneflower (*Rudbeckia serotina*). Common legumes include snoutbeans (*Rhynchosia* spp.) and vetch. Mesquite, huisache, oak, and elm are common invaders on poor-condition rangelands and on abandoned cropland. Oak, elm, cottonwood, and native pecan (*Carya*) are common along drainages.

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

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

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

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

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

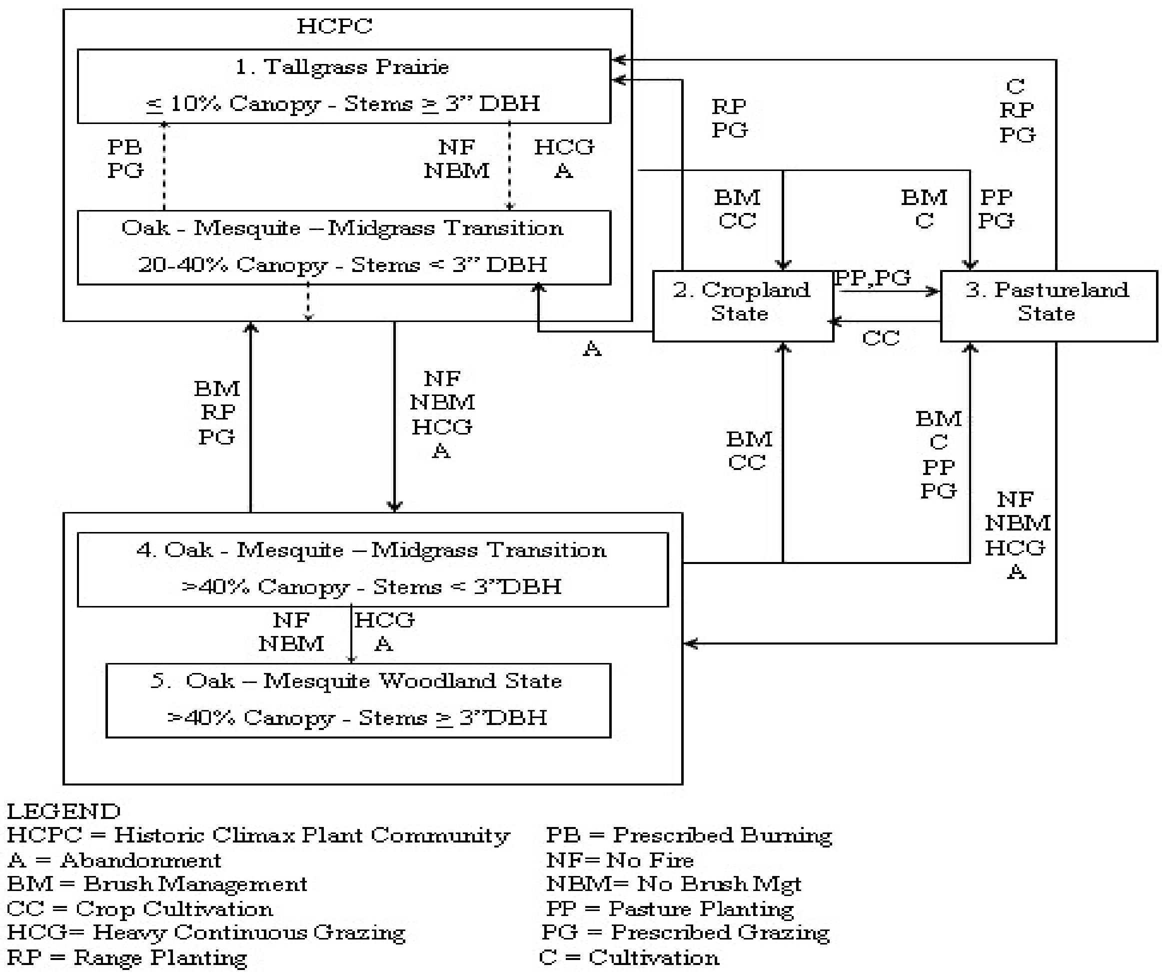
Table 8. Climatic data for a Claypan Prairie site, Blackland MLRA

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

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

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

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



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

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

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

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

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

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

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

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

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

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

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

Brush Management Practices

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

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

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

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

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

General Overview-Shrub Control and Water

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

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

Part I: Ashe Juniper Woodlands of the Edwards Plateau

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

<u>Tree Scale</u>

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

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

Stand Scale

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

Small Catchment Scale

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

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

Landscape Scale

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

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

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

Part II: South Texas Shrublands

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

Field Studies

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

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

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

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

Hydrological Modeling

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

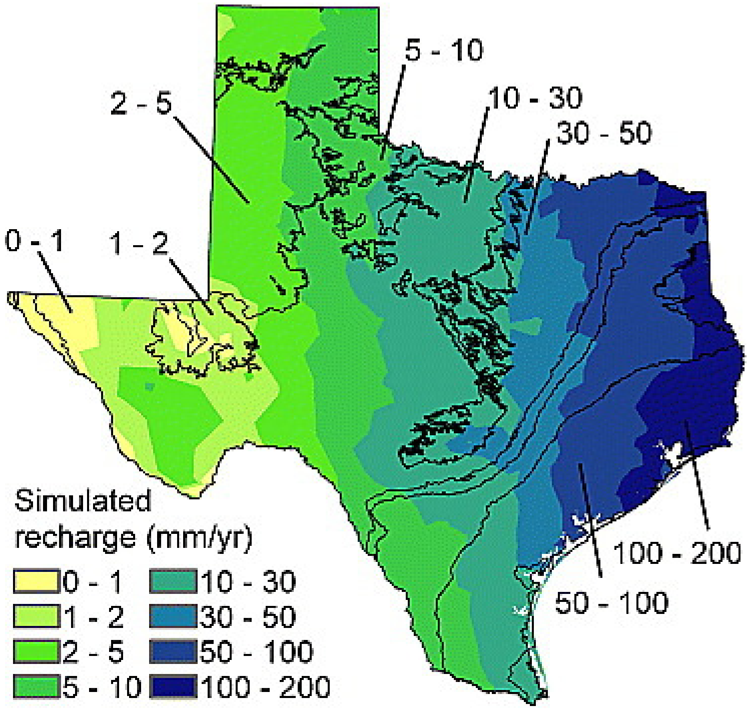


Figure 5. Simulated recharge rates for the state of Texas (Keese et al. 2005).

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

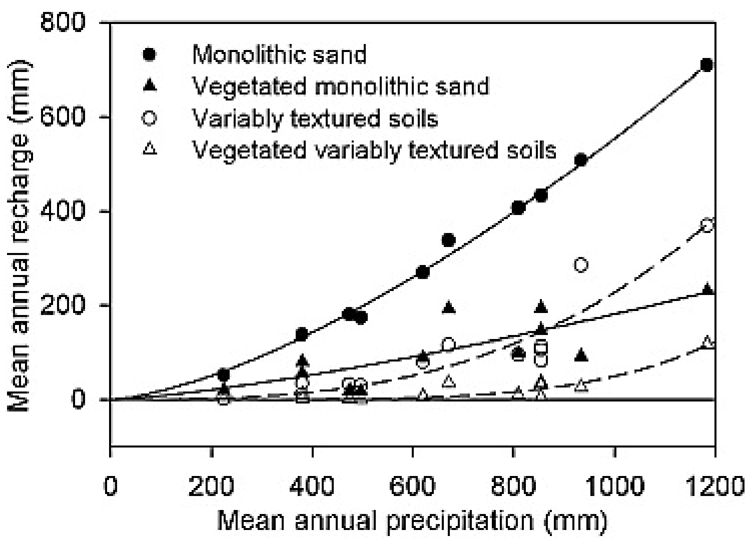


Figure 6. Results from the Keese et al. (2005) modeling study showing the relationship between simulated recharge, vegetation cover and soil texture.

Summary and Implications

Ashe Juniper Rangelands on the Edwards Plateau

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

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

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

South Texas Shrublands

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

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

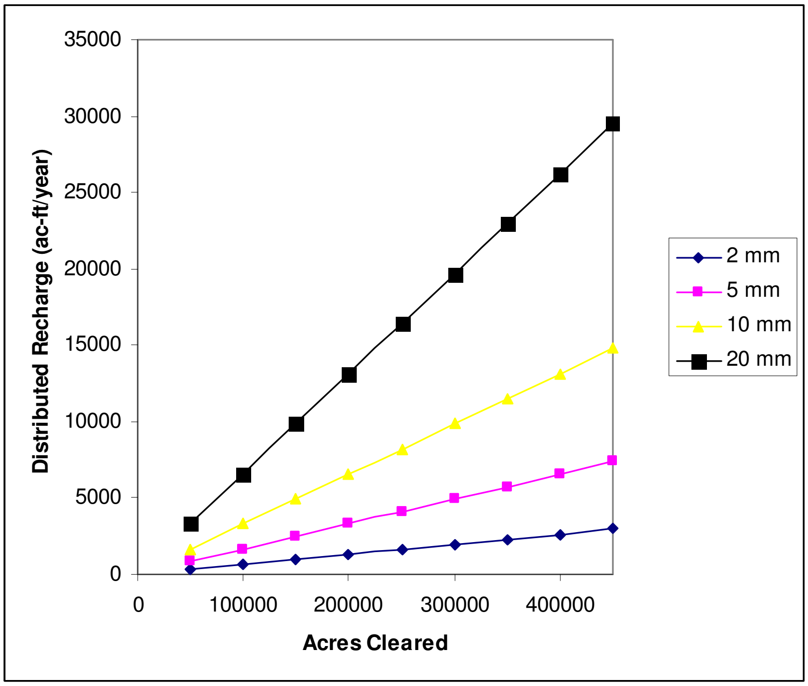


Figure 7. The potential increase in recharge from shrub control over the recharge zone in the Wintergarden Groundwater Area.

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

Introduction

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

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

Cost of Brush Control Methods

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

<u>Edwards Plateau</u>

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

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

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

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

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

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

South Texas Shrublands

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

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

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

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

Cost Effectiveness Summary

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

Additional Considerations

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

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

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

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

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

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

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

Future Reports

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

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

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Appendix F
Land-Based Water Conservation & Water Yield Practices in Region L: Guidelines for Spatial Analysis and Recommended Brush Management Practices

LAND-BASED WATER CONSERVATION & WATER YIELD PRACTICES IN REGION L: GUIDELINES FOR SPATIAL ANALYSIS AND RECOMMENDED BRUSH MANAGEMENT PRACTICES

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

TEXAS A&M Institute of Renewable Natural Resources

&

GRAZINGLAND MANAGEMENT SYSTEMS, INC.

STUDY SPONSORED BY
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ABSTRACT

Spatial analysis is to be conducted for three sub-areas of Region L: the Carrizzo-Wilcox aquifer recharge zone, the Edwards aquifer recharge zone and the Guadalupe River watershed above Canyon Lake. The spatial analysis should delineate: aquifer/watershed and county boundaries, land cover by type, canopy density category for brush, land ownership (public/private), tract size of privately owned land, areas with slope > 15%, areas with moderate to high probability of containing golden-cheeked warbler (GCW) habitat and for the Carrizzo-Wilcox aquifer recharge zone, areas with deep sandy soils.

Brush management practices in the Edwards Plateau and Guadalupe watersheds will be primarily directed at Ashe juniper, a non-sprouting species that suffers mortality when the above ground live plant material is removed. Both individual plant treatments (IPT) and broadcast mechanical treatments are recommended for Ashe juniper control. Chemical treatment is limited to IPT. Fire is an especially effective treatment alternative for Ashe juniper and is, under some conditions, used as an initial reclamation practice or, most commonly, as a maintenance practice to extend benefits from an initial mechanical practice. South Texas brush is a composite of as many as 20 species, the majority of which are resprouting species that do not suffer mortality from top removal. Brush management practices for south Texas include both mechanical and chemical as IPT or broadcast treatments, depending on plant density and need for revegetation. Because of the regrowth potential, rootplowing, a whole plant removal broadcast practice, is especially effective for south Texas brush stands. Recommended maintenance treatments that follow initial applications include mechanical and chemical IPT, as well as prescribed fire. Costs of the various treatment alternatives vary widely due to different plant densities, size and regrowth potential of the species.

GUIDELINES FOR SPATIAL ANALYSIS

Spatial analysis is to be conducted for three sub-areas of Region L:

1. Carrizzo-Wilcox aquifer recharge zone in Dimmit, Caldwell, Guadalupe, Bexar, Atascosa, Wilson, Medina, and Zavala counties. Counties outside the boundary of Region L which also contain areas of the Carrizzo-Wilcox aquifer recharge zone and which may also be considered for inclusion in the program are Maverick and Webb.
2. Edwards aquifer recharge zone in Uvalde, Medina, Bexar, Comal and Hays counties. Kinney, Travis, Williamson and Bell counties are outside of the Region L boundary, but contain parts of the Edwards aquifer recharge zone and could be considered for inclusion in the program.
3. The Guadalupe River watershed above Canyon Lake including Comal and Kendall counties which are in Region L and Blanco and Kerr counties which are outside the Region L boundary.

The spatial analysis should delineate:

Aquifer/watershed boundaries
County boundaries
Land cover by type (brush –other) and by canopy density category for brush (eg., < 20%, 20-40%, and > 40%)
Land ownership (public/private) and for private land, tract size (eg., < 25ac, 25-50ac, 50-100ac, > 100ac, etc.)
For private land, with Tract sizes > 50 ac, areas with slope > 15%
For private land, with Tract sizes > 50 ac, areas with low, moderate and/or high probability of containing GCW habitat
For the Carrizzo-Wilcox aquifer recharge zone, delineate areas of the recharge zone with deep sandy soils.

The spatial analysis report should provide maps showing locations and acres of parcels of private land that were within the aquifer/watershed boundaries, with parcel size of 50 acres or more, with > 10% shrub/brush canopy cover and slopes < 15% and, for the Carrizzo-Wilcox aquifer recharge zone, areas with deep sandy soils. The report should also indicate which such parcels have low, moderate or high probability of containing GCW habitat.

RECOMMENDED BRUSH MANAGEMENT PRACTICES

Introduction

All herbicide applications must follow EPA label directions and be in accordance with state and county restrictions. Applications will be made during weather conditions and at distances from critical off-target areas conducive to the avoidance of herbicide drift. It is recommended that Texas AgriLife Extension bulletin 1466 be used as a basis for matching herbicide compounds with target plant species and for instructions in timing, additives and application methods. The use of prescribed fire should be under the direction of Certified Prescribed Burn Managers and applied within guidelines provided by the State of Texas for outdoor burning and any county or other regulations that may be in effect. All brush management applications; chemical, mechanical and prescribed fire, will avoid adverse impacts to rare, threatened or endangered species and other sensitive environmental resources found in the area to be treated.

Edwards Plateau and Guadalupe Watershed

Brush management treatment alternatives commonly used in the Edwards Plateau MLRA include mechanical and chemical practices, as well as prescribed fire and biological control associated with the use of goats. Selection of these treatments depends on the size and density of the woody plant species, primarily Ashe juniper (*Juniperus ashei*). Some ranchers will remove oak species (*Quercus spp*.) with brush management practices, but these are more likely shinoak species or oaks that are thinned within mottes, rather than mature oaks. Live oaks, Spanish oaks, post oaks, or other oak species are generally not considered in brush management scenarios, meaning that Ashe juniper is the target woody plant species a very high percentage of the time.

Mechanical brush management treatments can be either broadcast when densities of plants are greater than 300 plants per acre or large enough to respond to treatments such as chaining or cabling, or individual plant treatments (IPT) when densities are low enough and/or plants are small enough to justify treating individual plants. It should be remembered that all brush management is temporary, even when a very high percentage of the resident target species suffer mortality from the initial brush management practice. For example, Ashe juniper will recover very quickly in an area following effective control from seeds in the soil profile that germinate and establish seedlings. Maintenance or "follow-up" practices, either IPT mechanical or chemical or the use of prescribed fire or goats that will utilize juniper seedlings are highly recommended. When fire is used, it is highly recommended that it be under the direction of a Certified Prescribed Burn Manager. It is also recommended that landowners using prescribed fire join the prescribed burning association in their county, if one has been organized. Information on available prescribed burning associations in the Edwards watershed can be obtained from the Edwards Plateau Prescribed Burning Association at the Texas A&M research Station at Sonora, Texas.

Woody plant species in the watershed will be distinguished for recommended brush management practices and cost estimates as follows:

<u>Ashe Juniper and Ashe Juniper – Oak (Quercus spp.) mix</u>

- Individual Plant Treatment (IPT)

  Mechanical
  Chemical
- Broadcast

  Mechanical
  Chemical

<u>Ashe juniper</u>

Ashe juniper is non-sprouting species that it will suffer mortality if all the above ground green material is removed. This allows top removal practices to be effective for brush management and the most popular of these methods currently is the use of a “skid-steer loader” equipped with a front-end attachment of hydraulically operated shears. Since the skid-steer is used to attack individual plants, it can be considered an IPT practice and is recommended primarily for Ashe juniper densities of 300 plants per acre or less. Light to high densities should range in cost between $80 and $300 per acre. Mortality of Ashe juniper treated with this method should be near 100%. The advantage of the skid-steer and IPT is that it is very selective and can remove juniper without damage to associated oaks of other desirable woody speice.s. An alternate selective IPT mechanical method would be use of an excavator, ranging in cost between $40 and $140 per acre depending on density of the juniper.

The recommended IPT chemical treatment for Ashe juniper is a soil applied spot treatment with Hexazinone or picloram liquid at an estimated cost of between $6 and $10 per 100 plants using a $7.00 per hour charge for labor. Mortality of Ashe juniper treated with this method would be very high (76-100% mortality).

When Ashe juniper densities exceed 300 plants per acre, it is generally recommended that broadcast treatments be considered rather than IPT. The use of a crawler tractor and bulldozer blade is a standard practice for broadcast treatment of Ashe juniper and is recommended. Costs will vary widely with density and size of trees, but should be in the range of $75-$150 per acre. Mortality of the target species will be very high. When the topography (slope and surface roughness) are within acceptable levels, two-way chaining of heavy juniper stands is a recommended broadcast treatment alternative. Two-way chaining will cost an estimated $30-$50 per acre. However, chaining cannot be discriminating for oak or other desirable species that will suffer mortality or be damaged. In limited areas of the Edwards Plateau where soil depth and slope permit, rootplowing may be a broadcast alternative mechanical practice. If juniper is in very large, dense stands, a pre-treatment of bulldozing may be required. Rootplowing alone is estimated to cost $110 per acre and pre-dozing $60 per acre when needed. Seeding to restore grasses following rootplowing would cost an additional $40 per acre (total cost $210 per acre).

There are no recommended broadcast chemical treatments for Ashe juniper control.

Ashe juniper – Oak mix

Where oak species are mixed with Ashe juniper, it is assumed that the juniper will be the target species for brush management and that tree shearing with a skid loader will be the IPT treatment in order to selectively take out the juniper and leave the oak. Light to high densities of juniper should range in cost between $80 and $300 per acre. Mortality of Ashe juniper treated with this method should be near 100%. An alternate selective IPT mechanical method would be use of an excavator, ranging in cost between $40 and $140 per acre depending on density of the juniper.

Chemical IPT for mixed Ashe juniper and oak stands would present a problem if oak trees were considered desirable. The chemical compounds for oak control, hexazinone and tebuthiuron are both soil applied herbicides. Hexazinone and picloram soil applied herbicides are recommended for Ashe juniper control. The possibility of damage to desirable trees with the use of any of these compounds would be high. However in areas where it can be used, hexazinone IPT would cost $10 per 100 plants.

Broadcast mechanical treatments would also present a problem for juniper-oak mixed stands. The use of treatments such as chaining would not be practical in order to leave the oak. Use of a bulldozer would be acceptable to take out primarily the juniper while working around the oak, although in mixed stands the likelihood of some oak removal would be moderate to high. Bulldozing would cost between $75-$150 per acre depending on the density of the juniper in the stand.

There are no recommended broadcast chemical treatments for Ashe juniper control and the use of a broadcast treatment for oak in the Edwards Plateau would not be likely. However, Tebuthiuron is effective for oak control as a broadcast application at a cost of $80 per acre.

South Texas

The South Texas Plains are dominated by a woody plant complex of a dozen or more species, most of which have vigorous resprouting potential after top removal. Resprouting is primarily from basal stem buds and buds contained in the crowns of these woody plants near the soil surface or several inches below the soil surface. Honey mesquite (*Prosopis glandulosa*) is often the dominant species in the mixed brush complex, but other individual species that can dominate on certain ecological sites include pricklypear cactus (*Opuntia berlandieri*), blackbrush acacia (*Acacia rigidula*), and oak (*Quercus spp*.). These species will be addressed as the dominate species in mixed brush stands in the recommendations for brush management treatment alternatives and costs as follows:

- Individual Plant treatment (IPT)
  - Mechanical
  - Chemical
- Broadcast
  - Mechanical
  - Chemical

<u>Mesquite dominated mixed brush</u>

For densities of mesquite less than 300 plants per acre, IPT is recommended. For plants up to 5 inches in stem diameter a “low-energy” grubber can be used effectively. Low-energy grubbing can be accomplished for an estimated cost of $30-$40 per acre. For low densities of mesquite trees that are larger than 5 inches stem diameter, a larger power grubber, is recommended with an estimated cost of $40 -$100 per acre.

Chemical IPT for mesquite includes more than a dozen treatments that provide a very high level of plant mortality. These treatments include foliar herbicide applications to individual plants, stem basal herbicide applications, and a cut stump treatment. For the purpose of these recommendations, a stem basal treatment with triclopyr (concentrate) (a general use herbicide) and diesel at a cost of $10 per 100 plants (smooth barked) and $14 (rough barked) will be used. Mortality of treated plants is expected to be very high, 76-100%.

For a broadcast treatment of mesquite dominated areas, rootplowing is recommended. This practice gives the highest level of mortality and moderate term relief from significant brush reinfestation. Rootplowing alone is estimated to cost and average of $110 per acre, however, it should be noted that in very heavy, dense stands of mesquite and mixed brush, a pre-treatment to rootplowing may be required consisting of bulldozing or the use of a brush stacker. This will increase the cost to approximately $170 per acre. In many instances it is advisable to reseed areas following rootplowing that suffer loss of the resident perennial grass composition. It is also common to rake or disk areas following rootplowing in order to smooth the soil surface left very rough by the rootplowing treatment and to prepare a seedbed for planting. The added seedbed preparation and seeding costs will increase the total cost to approximately $210 per acre.

Broadcast chemical treatments of mesquite dominated areas in south Texas include many options similar to the IPT alternatives, but only one (clopyralid) will give a high level of mesquite control with a broadcast foliar application. Clopyralid is recommended at a cost of $39 per acre (fixed wing application) where mesquite is highly dominant and other species greatly subordinate. If there are significant other species in the mix, then picloram plus clopyralid is recommended at a cost of $50 per acre (fixed wind application). If a helicopter is used to apply the herbicides, add $8.50 per acre to the cost.

Pricklypear dominated mixed brush

There are no mechanical IPT recommended for pricklypear. Pricklypear infestations can be controlled mechanically with a broadcast treatment that uses a large, modified front-end rake called a brush stacker. The cost of stacking averages about $65 to $90 per acre. “Railing” is another broadcast mechanical practice that can be used for pricklypear control at an estimated cost of $30-$40 per acre. Although the brush stacker and railing have the potential to reduce pricklypear infestation, most of the mechanical practices have the potential to spread prickly pear by breaking the cladophylls away from the plants and spreading them across the soil surface where they will root. Where pricklypear is present, a chemical control application should be considered prior to broadcast mechanical treatments, such as rootplowing or chaining.

Chemical IPT for pricklypear includes several choices, all of which will give a very high level of mortality. However, recent research and demonstrations indicate that a combination of picloram and fluroxypyr (1:1) provides a faster kill of the pear than other recommended treatments at the same or slightly less cost. The cost for this treatment is estimated to be $3.20 per 100 plants. Another IPT combination treatment of a low rate application of picloram following fire in the spring will provide a very high level of pricklypear control at an estimated cost of $20 per acre.

The same chemical combination used for IPT for pricklypear control is recommended for broadcast treatment. Picloram:floroxypyr (1:1) will give an estimated high level of mortality (55-76%) on pricklypear plants at an estimated cost of $22 per acre assuming a fixed wing aerial application method. If a helicopter is used add $8.50 per acre.

Shinnery oak

There are no mechanical IPT or broadcast treatments recommended for shinnery oak. While it is unlikely that shinnery oak will occur in densities suitable for chemical IPT, recommendations for IPT can be applied as spot treatments.The recommended chemical treatment for this plant is tebuthiuron (20%) applied IPT at an estimated cost of $47 per 100 plants, or as a broadcast treatment at a cost of $44 per acre.

Tree-type Oak

The recommended mechanical treatment alternative for large tree-type oak control would be two-way chaining followed by raking and stacking . This practice is estimated to cost between $110 and $190 per acre.

Tebuthiuron (20%) is recommended for control of tree-type oaks as a broadcast application at a cost of $80 per acre.

Blackbrush acacia

For densities of blackbrush less than 300 plants per acre, IPT with low-energy grubbing can be used effectively for an estimated cost of $30-$40 per acre and will provide a very high level of plant mortality.

Blackbrush usually does not have stem diameters greater than 2-3 inches and shredding can be used as a broadcast treatment for top removal. In heavy densities of the largest stem diameters of blackbrush and associated species, a self-propelled hydraulic shredder, such as the "Hydro Axe", is recommended for a cost ranging from $115.00 - $230.00 per acre. For light densities of smaller stature plants, a drag-type modified farm shredder can be used for a cost of approximately $20-$35 per acre. However, blackbrush is a resprouting species following top removal and followup maintenance practices will be necessary to maintain control. Rootplowing alone is estimated to cost an average of $110 per acre, however, it should be noted that in very heavy, dense stands of mesquite and mixed brush, a pre-treatment to rootplowing may be required consisting of bulldozing or the use of a brush stacker. This will increase the cost to approximately $170 per acre. In many instances it is advisable to reseed areas following rootplowing that suffer loss of the resident perennial grass composition. It is also common to rake or disk areas following rootplowing in order to smooth the soil surface left very rough by the rootplowing treatment and to prepare a seedbed for planting. The added seedbed preparation and seeding costs will increase the total cost to approximately $210 per acre.

Triclopyr (concentrate) + diesel can be used for IPT in low densities of blackbrush as a stem basal application and will give a very high level of plant mortality. This application will cost approximately $13 per 100 plants.

There is no recommended broadcast chemical treatment for blackbrush that will give a very high level of expected plant mortality. While several chemical compound combinations are recommended for moderate levels of control, only one, tebuthiuron (20%) pellets, will provide a high level of mortality (55-76%) at a cost of approximately $114 per acre. This treatment cost is over twice those recommended for chemical treatments that give the moderate control level.

Edwards Plateau and Guadalupe Watersheds

Species	Treatment	IPT Cost 100 plants	Broadcast Cost/Acre	Alternative	IPT Cost 100 plants	Broadcast Cost/Acre
Ashe juniper	Tree Shear		$80-$300[1]	Excavator		$40-$140[1]
	Hexazinone/picloram	$6.00-10.00				
	Bulldozer		$75-$150	Two-way chain		$30-$50
	Rootplow		$110-$210			
Juniper-Oak	Tree shear		$80-$300[1]	Excavator		$40-$140[1]
	Bulldozer		$75-$150			
	Hexazinone	$10.00				
	Tebuthiuron		$80.00			
South Texas Watersheds						
Mesquite	Low-energy grub	$30-$40				
	Power Grub	$40-$100				
	Triclopyr + diesel	$10-$14				
	Rootplowing		$110-$210			
	Clopyralid		$39			
	Clopyralid + picloram		$50			
Pricklypear	Brush Stacker		$65-$90	Railing		$30-$40
	Picloram + fluroxypyr	$3.20				
	PIcloram + fire	$20.00				
	Picloram + fluroxypyr		$22.00			
Oak[2]	Tebuthiuron (20%)	$47.00				
	Tebuthiuron (20%)		$44.00			
Oak[3]	Tebuthiuron (20%)		$80.00			
	2-way chain/stack		$110-$190			
Blackbrush	Low-energy Grub	$40-$100				
	Hydro-Axe		$115-$230			
	Farm Shredder		$20-$35			
	Rootplow		$110-$210			
	Triclopyr + diesel	$13.00				
	Tebuthiuron (20%)		$114.00			

[1]Practice can be used IPT or broadcast

[2]Running or shinnery oak

[3]Tree type oak

Appendix G
Land-Based Water Conservation & Water Yield Practices in Region L: Monitoring Strategies

LAND-BASED WATER CONSERVATION & WATER YIELD PRACTICES IN REGION L: MONITORING STRATEGIES

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

TEXAS A&M | Institute of Renewable Natural Resources

&

GRAZINGLAND MANAGEMENT SYSTEMS, INC.

STUDY SPONSORED BY
TEXAS WILDLIFE ASSOCIATION FOUNDATION

San Antonio, Texas
May 1, 2008

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ABSTRACT

The goal of the monitoring program is to determine the amount, if any, of additional recharge and/or streamflow results from managing woody plants. An effective monitoring program would need to include multiple measurements at several different scales. Monitoring approaches include remote sensing, watershed comparisons, small catchment studies, micrometeorological towers and soil moisture measurements. For the Region L area we recommend the following: (1) incorporate and apply the large scale remote sensing technology across the Region L area; (2) in each of the target areas have a network of evaptranspiration (ET) towers in treated and untreated locations; (3) in the Carrizo-Wilcox area, complement ET tower measurements with detailed monitoring of soil moisture in treated and untreated areas: and (4) in the Guadalupe Watershed monitor spring flow in as many locations in treated and untreated areas (ET towers would be in the same areas).

LAND-BASED WATER CONSERVATION & WATER YIELD PRACTICES IN REGION L: MONITORING STRATEGIES

We have determined that there are three distinct areas within Region L that offer the most potential for increased streamflow through management of woody plants. These include (1) the Carrizo-Wilcox aquifer recharge zone with special emphasis in Dimmit and Zavala Counties (2) the Edwards aquifer recharge zone in Uvalde, Medina, Bexar, Comal and Hays Counties, and (3) the Guadalupe River watershed above Canyon Lake including Comal and Kendall counties. Each of the areas are different and have a distinct regional hydrology that must be taken into account in developing monitoring protocols that are aimed at evaluating the hydrological effect of brush control.

There are two major recharge zones within the Region L Area—the Carrizo-Wilcox and the Edwards Aquifer. As noted above the recharge zones and the aquifers that they supply are very different in character. The Edwards Aquifer is a karst system and as such is very dynamic and capable of very rapid recharge as well as discharge. It is a renewable groundwater resource meaning that recharge is roughly equivalent to discharge, including groundwater pumping. Recharge occurs largely within stream channels that traverse the recharge zone. There is likely some distributed recharge outside of the stream channels but as of yet there have been no reliable estimates of how important distributed recharge may be.

The Carrizo-Wilcox aquifer, by contrast, is not a renewable aquifer and recharge is lower than ground water pumping, with the result being that groundwater levels are declining. Recharge occurs where the Carrizo Sands and Wilcox formation are exposed at the surface. Soils are quite sandy and infiltration rates are high (little runoff). Water that moves beyond the rooting zone is available for recharge.

The third area that we have identified as having a potential for augmenting water supply through brush control is the area of the Guadalupe Watershed above Canyon Lake. The presence of Canyon Lake affords the opportunity for storing any additional water that may result from land management activities.

The goal of this report to lay out some potential strategies and techniques that may be employed for determining the extent to which, if any, water supply is augmented through brush management. Because each area is so distinct, a different suite of monitoring protocols will be required for each.

POTENTIAL MONITORING STRATEGIES

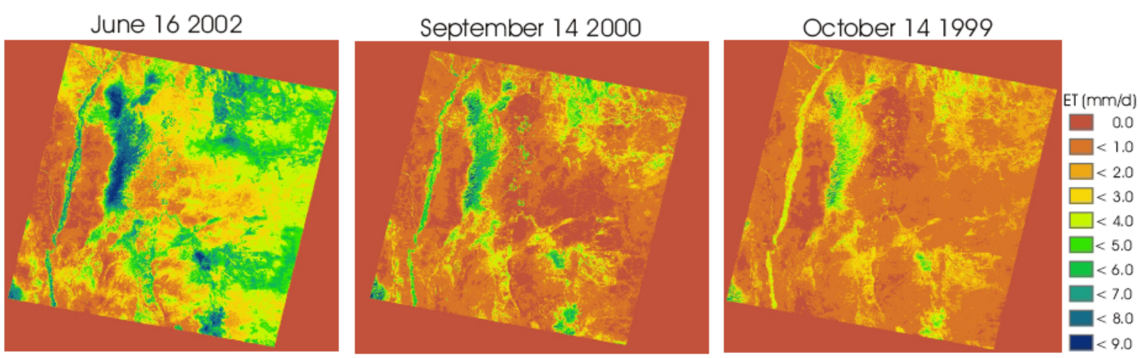
The fundamental challenge posed is that of determining how much, if any, additional water has resulted from particular land management practices. This requires determining both how much recharge (or streamflow) occurs AND whether or not it is higher than would have been in the absence of the land management practice. The variability of climate often makes this a difficult and time consuming proposition. In addition, in order to determine if there is a difference we have to be able to make a comparison of different treatments either in time or space.

Regional scale

Remote sensing

Emerging technology now exits for estimating evapotranspiration using remote sensing imagery. This is relatively new technology but there is the potential to map evapotranspiration across very large areas within Region L and relating evapotranspiration rates to vegetation cover (the presence or absence of woody plant cover). This approach could potentially allow for a comprehensive evaluation of the potential for releasing more groundwater recharge through shrub control. Specifically, tracking evapotranspiration rates across several years could answer specific questions such as (1) can shrub clearing lead to enhanced recharge (2) where would shrub clearing be most effective (3) would the effect be the same or different for wet and dry years.

The technique has been successfully applied in New Mexico. An example from the Rio Grande Valley in New Mexico is presented below (Hong and Hendrickx, 2006). This example provides a nice illustration of the spatial and temporal resolution that is possible.



Challenge: This technique is still experimental and would require implementation and evaluation by remote sensing experts

Application Area: This technique could be effectively applied in each of the three target areas

Intermediate scale (100-10000 km^2)

Large Watershed Studies

Watershed experiments in which streamflow is continuously monitored in one or more watersheds offer the potential of assessing land management practices. These kinds of experiments have been conducted in many settings, with considerable success(Bosch and Hewlett, 1982; Stednick, 1996). However, there are significant challenges in successfully completing such experiments. A typical approach is using a pair of watersheds where one is treated and the other is not. For these kinds of experiments to work, considerable time is required (years), both to insure that the watersheds are comparable and also having sufficient time after implementation of the treatment. Another approach is that of using a single watershed and implementing the treatment after several years of monitoring. The effectiveness of the North Concho shrub control project has recently been evaluated using this kind of approach (Wilcox et al. 2008). Similarly, Trimble et al. (1987) used long term streamflow records to demonstrate that streamflows in Tennessee have been diminished because of expanding forests.

Challenge: Time and expense. Large watershed studies require significant time and resources to be successfully implemented

Application Area: Guadalupe River above Canyon Lake.

Field Scale

At smaller scales more detailed measurements of water fluxes can be measured and several approaches are available, both of which have advantages and disadvantages

Evapotranspiration Micrometeorology Towers

The technology is now available to directly measure evapotranspiration over areas the size of a football field using instrumentation that is mounted on towers. The most common approach for doing this relies on the Eddy Covariance technique. Similarly, the Bowen Ratio approach has been applied with some success. Direct measurements of evapotranspiration at the field scale can provide estimates of water savings resulting from vegetation management. These techniques have been used with good success for assessing the effects of vegetation on the water cycle (Dugas *et al.*, 1998; Dugas and Mayeux, 1991; Scott *et al.*, 2003) and for best results these measurements should be complemented by field measurements of surface runoff.

Challenge: Operation of evapotranspiration towers require skilled technicians and good data management systems.

Application Area: All areas

Small catchments experiments

Monitoring runoff and springflow at the scale of a few acres can provide insight as to the effects of vegetation manipulation. The same logic ideas and constraints apply as for the very large watershed scale studies discussed above. Small catchment studies have been done with some success in the Edwards Plateau in evaluating the effect of vegetation management (Huang *et al.*, 2006; Wilcox *et al.*, 2005).

Challenge: As with the large watershed studies, catchment experiments required many years of observation. In addition, it can be very difficult to find suitable catchments for paired experiments.
Application Area: Guadalupe River above Canyon Lake.

Plot Scale

Monitoring water in the vadose zone

One of the best ways of determining the influence of plants on recharge is that of making detailed measurements soil water both within and below the plant root zone. Ideally measurements would be made repeatedly in both time and space. The technology is available for continuous monitoring of soils moisture and a variety of techniques and approaches are available. This approach has been used with great success including several studies in South Texas (Weltz and Blackburn, 1995; Moore *et al.*, 2008)

Challenge: Soil monitoring is difficult if not impossible in the Edwards Plateau region because of shallow, rocky soils.

Application Area: Carrizo-Wilcox recharge zone.

Plant level measurements of transpiration and interception

Woody plants affect the water cycle because they transpire water and they also intercept rainwater—both of which are very important. Transpiration and interception by shrubs can be directly measured and there are examples of this kind of work in the Edwards Plateau and south Texas (Owens *et al.*, 2006; Owens, 1996; Owens and Schreibe, 1992).

Challenge: Tree level measurements can be made but it is often difficult to determine what they mean on a landscape scale

Application Area: all areas

RECOMMENDATIONS

Each of the target areas are different and each pose opportunities and challenges in terms of monitoring.

Recommendation 1: Incorporate and apply the large scale remote sensing technology across the Region L area. In addition to addressing the effectiveness of the brush management program, it will provide very useful regional information related to water resources

Recommendation 2: In each of the target areas have at a network of ET towers in treated and untreated locations. These measurements should be complemented by monitoring of surface runoff so that recharge could be estimated by difference.

Recommendation 3: In the Carrizo-Wilcox area, complement ET tower measurements with detailed monitoring of soil moisture in treated and untreated areas

Recommendation 4: In the Guadalupe Watershed monitor spring flow as many locations in treated and untreated areas (ET towers would be in the same areas).

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Appendix H
Comments from Texas Water Development Board and Responses

ATTACHMENT 1

TWDB Contract No. 0704830697

Region L, Region-Specific Studies 1-5:

<u>TWDB Comments on Draft Final Region-Specific Study Reports:</u>
1) Lower Guadalupe Water Supply Project for GBRA Needs
2) Brackish Groundwater Supply Evaluation
3) Enhanced Water Conservation, Drought Management and Land Stewardship
4) Environmental Studies
5) Environmental Evaluations of Water Management Strategies

Region-Specific Study 3:
Enhanced Water Conservation, Drought Management and Land Stewardship

1. There does not appear to be discussion regarding assessment on overlapping elements of conservation and potential drought management practices as included in task 1 of the Scope of Work. Please discuss overlapping elements of conservation and potential drought management practices.

<u>Response</u> – References to the overlapping elements of conservation and potential drought management practices will be added to the Executive Summary (Sections ES.2 and ES.4), Section 2.1, and Section 4.2.

2. Section ES.4: Please briefly describe; the potential effects of implementing drought management strategies upon other water management strategies; and, the potential benefits associated with drought management strategies per Scope of Work tasks 3 (d) and (e).

<u>Response</u> – Brief descriptions of the potential benefits of drought management strategies and their effects on other water management strategies will be added to Sections ES.4 and 4.0.

3. Page ES-3, first paragraph, second sentence: Because the planning guidance under 357.7(a)(7)(B) is not restricted to consideration only of approved drought management plans and to avoid confusion, please clarify that the rule interpretation presented in the report applies only for the purposes related to the particular methodology used in this study.

<u>Response</u> – Referenced text will be revised for clarity in Sections ES.4 and 4.0.

4. Page ES-3, first paragraph: Please clarify that it is for the purpose of the study's particular methodology that drought management is specifically characterized within this report as "*the conscious decision not to develop firm water supplies greater than or equal to projected water demands with the understanding that demands will have to be reduced or go unmet during times of shortage.*" Implementing drought management, in general, does not require a corresponding reduction in available water supply and may occur regardless of available water supplies on hand or in the future.

<u>Response</u> – Referenced text will be revised for clarity in Sections ES.4 and 4.0.

5. Page ES-3, first paragraph, Section 4.2, Table 4-6, and Appendix C: The report states that the "*economic impact of not meeting projected water demands can be estimated and compared with the costs of other potentially feasible water management strategies in terms of annual unit costs.*" In making these comparisons, the lost utility revenues have been included in the drought management unit 'costs' (e.g. Figure 4-6) per the data provided by TWDB in Table 4-1. While these lost revenues are a recognized 'economic impact' they should not be included as costs when making comparisons to potentially feasible water management strategies as they represent a financial transfer; a financial loss to the utilities that corresponds to a financial savings to customers. Adding together both the economic impact to the customers of shortage and the lost utility revenue double counts this economic impact. Please do not include lost revenues in cost estimates of drought management when directly comparing them to the unit costs of potentially feasible WMSs (e.g. Figure 4-6, Appendix C).

<u>Response</u> – Title of Table 4-6 will be revised to "Total Annual Economic Impact." Average unit cost values in Table 4-7 will be revised to exclude economic impacts associated with lost water and wastewater utility revenues. Similarly, unit cost values in Figure 4-6 and throughout Appendix C will be revised to exclude economic impacts associated with lost water and wastewater utility revenues for direct comparison to the unit costs of other potentially feasible water management strategies. Text throughout Sections ES.4 and 4 will be revised accordingly.

6. Page ES-4, first paragraph, third sentence: The term 'alternative' might suggest that a different methodology was used. Please clarify that the "alternative methodology" (applied only in SAWS' case due to budget and time constraints) was a refinement to the same methodology that generally more accurately reflects: a) the actual design and implementation of drought management plans; and, b) the TWDB methodology used in evaluating economic impacts in the 2007 State Water Plan.

<u>Response</u> – Requested clarification will be provided and the words "alternative methodology" replaced with "refined methodology" in Sections ES.4 and 4.

7. Page ES-4, second paragraph, fourth sentence: Sentence refers to SAWS having the "flexibility" to avoid reductions to commercial and manufacturing water use but does not

also acknowledge the focus on reducing outdoor water use first. Please include additional language explaining that reduced economic impacts were also partially due to focusing on reducing outdoor water use first.

Response – Requested explanatory language will be added to Sections ES.4 and 4.4.

8. Section 4.2: Report does not present the historic per capita water use estimates that are the basis of the calculated risk factors. For reference, please include a table presenting the annual per capita water use rates that were used to calculate the risk factors (e.g. in an appendix).

Response – A summary table of historical per capita use estimates provided by the TWDB for each water user group will be included as an appendix to the study report.

9. Section 4.2, Figure 4-4: The method of calculating the risk factors effectively assumes that the historic annual per capita water use numbers occur during drought-of-record water supplies. It is likely that some of the annual per capita water use numbers that are greater than the year 2000 per capita water use numbers occurred during non-drought years when available water supplies were greater. Please discuss the implications that this might have on the resulting calculated risk factors and resulting calculated unit costs of drought management strategies.

Response – Additional discussion will be added to Section 4.2 regarding potential implications of observed trends in per capita use rates on methodology development, magnitude of risk factors, and unit costs. Discussion will also clarify that such trends are due, in part, to recent Edwards Aquifer pumpage restrictions during drought and that accounting for these trends would necessitate hydrologic and climate modeling beyond the scope of this study in order to quantify unconstrained per capita use.

10. Section 4.2: Report does not address the degree to which drought management had already impacted the annual historic per capita water use numbers as this was not part of the Scope of Work. Embedded drought management might reduce the ability to implement further drought strategies and could increase the expected costs of implementation. Please briefly discuss what impact this factor might have on: the potential water savings from drought management; and, the magnitude of the expected economic impacts resulting from implementation of drought management strategies.

Response – See proposed response to Comment #9. Additional discussion will be added to Section 4.2 regarding effects of embedded drought management on the magnitude of economic impacts resulting from a drought management strategy.

11. Page 15, Second paragraph: Methodology does not explain how the risk factor values were actually measured/calculated. Please explain how the risk factors (e.g. areas under

the curves) were actually measured/calculated (e.g. auto-generated on computer or graphically by hand).

<u>Response</u> – Risk factors were calculated in a Microsoft Excel workbook with equations being unique to each water user group. Alternative procedures may be considered for refined drought management strategy evaluations in the 2011 Region L Water Plan.

12. Page 17, Table 4-1: The 'A'-'F' graphical notations on Table 4-1 do not address the SAWS 'alternative' analysis. If practical, please annotate Table 4-1 to indicate how SAWS 'alternative' analysis was constructed.

<u>Response</u> – See proposed response to Comment #13.

13. Page18: Tables 4-2, 4-3, and 4-5, for example, do not illustrate how to calculate the 'alternative' SAWS economic impact estimates. Please add an additional example table similar in format to Tables 4-2 and 4-3 that illustrates how the 'alternative' SAWS analysis was developed and that; splits domestic water use showing Horticultural Impacts separately; and, shows the elimination of the associated Lost Sewer Revenue impacts.

<u>Response</u> – Supplemental tables will be added to Section 4 to demonstrate calculations for SAWS refined methodology.

14. Page 19, first paragraph, last sentence: Includes a reference to averaging the 5% and 10% scenarios to arrive at the 10% scenario. Please confirm that these do not need to be weighted averages.

<u>Response</u> – The words "unit cost" will be replaced with "approximate unit cost" in the referenced sentence.

15. Page 19, second paragraph: Referenced "information provided by SAWS" is not summarized. Please briefly present the information that SAWS provided to facilitate the SAWS 'alternative' analysis.

<u>Response</u> – Key information provided by SAWS included the relative percentages of indoor and outdoor water use in the domestic/residential sector as well as written comments suggesting refinements to the general methodology in order to more accurately represent SAWS drought management strategies. A footnote will be added to acknowledge these contributions.

16. Page 25, Section 4.4, fourth sentence: Sentence does not mention that a key reason for the lower expected economic impacts of the SAWS 'alternative' analyses were initial water reductions focused on outdoor domestic water uses. Please add language explaining how outdoor uses were split out and that outdoor water use was targeted first for reductions and how this resulted in lower estimated economic impacts including the elimination of associated 'Lost Sewer Revenues'.

Response – **See proposed response to Comment #7.**

17. Page 25, Section 4.4: Summary doesn't address whether or not the per capita water use rates used to calculate risk factors included embedded drought management water savings. Please discuss whether or not per capita water use rates used to calculate the risk factors may already have embedded drought management water savings and the implications this may have on the potential effectiveness and economic impacts of implementing drought management strategies.

Response – **See proposed response to Comments #9 and #10.**

18. Page 27: Please note that, to adopt brush management as a recommended water management strategy in a regional water plan, it will require a technical evaluation of: water supply yield (i.e. firm yield) during drought of record; calculated total costs and unit costs of water; and, consideration of environmental, water quality and any other factors used to evaluate water management strategies by the planning group.

Response – **The following sentence will be added at the end of Section 5.0. *"Pursuant to TWDB rules and guidance, this technical evaluation will include quantitative and qualitative assessments of firm yield, costs of water, environmental effects, water quality, and other factors in a manner consistent with the technical evaluations of other water management strategies in Region L."***

19. Appendix B: For clarity, please consider adding the following additional language to the end of the TWDB methodology contained in Appendix B as follows:

"***The Phasing-in of Water Shortages to Calculate Economic Impacts***

The TWDB estimates the economic impacts of not meeting water needs from the perspective of water user groups rather than the perspective of water utilities. This is a requirement mandated by administrative rules as specified Section 357.7(4) of the Texas Administrative Code. Thus, municipal and manufacturing water user groups are treated as separate entities in the regional planning process.

Water shortages as reported by regional planning groups are the starting point for economic impact analyses. No adjustments or assumptions regarding the magnitude or distributions of unmet needs among different water use categories are incorporated in the TWDB analyses. Any such adjustments must be requested by a planning group.

When estimating the economic impacts of not meeting water needs for municipal water user groups, the TWDB assumes that:

- *a region and each water user group within a region is experiencing drought of record conditions;*

- *for a given municipal water user group, all unmet needs that are less than 30 percent of total average annual water demand would be eliminated by restricting all outdoor residential water use;*

- *for unmet water needs that range from 30 to 50 percent of total average annual water demand, all domestic outdoor water use would be restricted as would a portion of indoor domestic water use;*

- *if unmet needs exceed 50 percent of total average annual water demands, all of the above conditions would hold true, and in addition water intensive commercial businesses such as car washes, restaurants, recreational venues would be forced to reduce water use and domestic water consumers would have to further reduce water consumption.*

For manufacturing water user groups, TWDB economic analysis assumes that producers would implement emergency measures to alleviate water shortages (note that these efforts are not planned programmatic or long-term operational changes); assumptions for manufacturing include:

- *if unmet water needs are 0 to 5 percent of total water demand, no corresponding reduction in output (i.e., gross sales) is assumed;*

- *if water shortages are 5 to 30 percent of total water demand, for every 1.0 one percent of unmet need, there is a corresponding 0.25 percent reduction in output;*

- *if water shortages are 30 to 50 percent of total water demand, for every 1.0 one percent of unmet need, there is a corresponding 0.50 percent reduction in output; and*

- *if water shortages are greater than 50 percent of total water demand, for every 1.0 one percent of unmet need, there is a corresponding 1.0 percent reduction in output (i.e. a proportional reduction).*

Valuation of Residential Water Shortages

Valuation of residential water shortages are based on statewide average values reported by the TWDB in the 2007 state water plan, and adapted for this study via a linear extrapolation. Ideally, estimates of the value of residential water shortages should be based on non-linear demand functions (i.e., constant elasticity demand curves) estimated at the utility level. These values would be more accurate when measuring shortages of different magnitudes, and lower than the values applied in this study for small shortages. In other words, the impacts of a small deficit relative to total annual water use (e.g., less than five percent) would be minimal. As the magnitude of shortages grew, the impacts increase in a *non-linear fashion, and values at the other extreme would be much higher than those using the values in this study. Theoretically, as shortages approach 100 percent, the value of water becomes infinite assuming there were no readily alternatives available. In reality, alternatives to utility supplied tap water would likely be available such as bottled water or water delivered by tanker ("hauled in" water). For example, costs per acre-foot of delivered water can be very high ranging anywhere from $20,000 to $70,000, and the cost of retail bottled water is approximately $162,000 per acre-foot. To value residential shortages using constant elasticity demand curves requires a considerable amount of effort and data, and was beyond the scope of this study. However, it would be a very useful refinement in any future studies that quantify economic impacts of drought.*"

<u>Response</u> – Language suggested by the TWDB will be added to Appendix B verbatim.

20. Appendix C slides (e.g. pages 1, 2, and 8) do not include the 'alternative' economic impact analysis for SAWS which show significantly lower impacts. Please include the SAWS 'alternative' drought management unit costs in all relevant graphical comparisons in addition to the non-alternative SAWS cost estimates. The alternative SAWS impacts, for example, could be foot-noted in the figures as a refined estimate of expected costs.

<u>Response</u> – SAWS alternative or refined unit cost estimates for drought management strategies will be added to relevant graphical comparisons in Appendix C.

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