APPLICATION OF THE EDYS DECISION TOOL FOR MODELING OF TARGET SITES [in Gonzales County] FOR WATER YIELD ENHANCEMENT THROUGH BRUSH CONTROL

FINAL REPORT

Submitted by

Terry McLendon[1,2], Cindy R. Pappas[1,2], Cade L. Coldren[3], Ernest B. Fish[2], Micah J. Beierle[2], Annette E. Hernandez[4], Kenneth A. Rainwater[4], and Richard E. Zartman[5]

[1] KS2 Ecological Field Services, LLC, Anton, TX
[2] Department of Natural Resources Management, Texas Tech University, Lubbock, TX
[3] Environmental Research and Development Center, US Army Corps of Engineers, Vicksburg MS
[4] Water Resources Center and Department of Civil and Environmental Engineering, Texas Tech University, Lubbock TX
[5] Department of Plant and Soil Science, Texas Tech University, Lubbock, TX

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Texas State Soil and Water Conservation Board
622 South Oakes Street, Suite H-2
San Angelo, TX 76903-7013

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EXECUTIVE SUMMARY

Water is becoming an increasingly valuable resource. Demand for water is increasing but its supply is limited and annual renewal through precipitation is becoming more erratic. One cause of reduced supply in many regions is the increase in woody plants, resulting in an increase in water use by these plants through evapotranspiration (ET). There have been considerable efforts by watershed managers in Texas and other semiarid regions to decrease ET by reducing the amount of woody vegetation to enhance the supply of water to aquifers and runoff into surface water bodies. A major challenge in these enhancement efforts has been to reasonably quantify estimates of the amount of water that would likely shift from ET to recharge and runoff.

Simulation modeling is one tool that can be used to quantify estimates of enhanced water yields through reduction of woody plants and to prioritize areas to be treated to maximize yields. EDYS is a general ecosystem simulation model that has been used for watershed management decision-making in Texas, other western states, and in Australia. The Texas State Soil and Water Conservation Board (TSSWCB) is interested in the possible use of EDYS as a management tool in their efforts to enhance water yields from brush management. To evaluate EDYS for such purposes, TSSWCB funded a project through Texas Tech University for a model of Gonzales County to quantify potential enhanced water yields and identify areas with highest potential yields.

Gonzales County covers 1,070 square miles (684,800 acres) and the entire area was modeled at a spatial resolution of 60 m x 60 m (0.89 acre), resulting in approximately 770,000 cells, divided among 44 sub-watersheds. The model also provides the capability of modeling smaller areas within the county (e.g., treated areas) at finer-scale resolution (10 m x 10 m cells). Elevation, topography, soils, and depth to groundwater data were included for each cell, along with data for 63 plant species, including both woody and herbaceous species. Vegetation composition, including woody plant cover, was estimated for each cell from aerial photographs. Daily precipitation data for 2002-2011 were used for the 10-year simulation runs.

Four sets of model simulations were conducted. Scenario 1 consisted of baseline conditions, i.e., current conditions without further brush treatment. Scenario 2 represented maximum theoretical water-yield enhancement from removal of 100% of woody plants from all areas where any combination of the four target species (huisache, eastern red cedar, mesquite, and McCartney rose) were the most abundant woody species. The primary purpose of Scenario 2 was to prioritize the sub-watersheds on the basis of maximum potential water-yield enhancement from brush control. Scenario 3 consisted of 90% removal of the four target species, along with removal of lesser amounts of non-target species from the root-plowing treatment, on the 16 areas recently treated in cooperation with TSSWCB. Scenario 4 consisted of the same treatment and to the same acreage as the sum of the 16 areas, but applied to the sub-watershed with the highest potential water yield as identified in Scenario 2. Detailed water budgets that included ET, runoff, soil storage, deep soil storage (i.e., potential recharge), and groundwater use by vegetation were developed for each of the four scenarios.

The simulation results indicated that under baseline conditions (i.e., no further brush management) annual water yield in Gonzales County under the precipitation scenario used

(2002-11) was about 2.3 inches when averaged over the entire county. This amount includes runoff, net storage in the soil profile, and recharge into groundwater and waterways. Net yield varied substantially among sub-watersheds, with the highest yields about 4-5 inches per year and the lowest around a minus 1-3 inches (net loss) per year. Averaged over the entire county, ET accounted for about 93% of annual precipitation, surface runoff less than 3%, and probable recharge 2% of annual precipitation. On average, vegetation utilized almost 2 inches of groundwater per year although this amount varied considerably across the County, with about half of the sub-watersheds not utilizing any groundwater.

Under Scenario 2 (maximum theoretical removal of target species), net water yield, compared to baseline, increased on all 44 sub-watersheds. Enhanced yields varied among the sub-watersheds, with increases of less than 1 inch per year on 9 of the sub-watersheds and increases of more than 3 inches per year also on 9 sub-watersheds. The maximum potential increased yield was 4.76 inches per year on Sub-watershed 21, compared to a County-wide average of 1.89 inches.

Scenario 3 evaluated the amount of water-yield enhancement from brush control on the 5,133 acres included in the 16 areas treated as part of the cooperative program by TSSWCB in Gonzales County. The results indicated that brush control resulted in an average increase over baseline of about 3 inches per year, averaged over the 16 treated areas. Based on a value of $ 500 per acre foot for water, this average increased yield would have a monetary value of about $ 122 per year for each acre treated. About half of the 16 treated areas had high potential enhanced yields (about 4 inches or more per year, or more than $ 150 per acre annual return) while 6 areas had low yields (about 0.5 inch per year or less, or less than $ 25 per acre per year).

Under Scenario 4, a similar acreage (5,123 acres) as Scenario 3 received the simulated treatment but the acreage was concentrated in Sub-watershed 21 (highest potential yield) and in areas with the heaviest cover of the four target woody species. Hence, this scenario represented the most efficient use of the treatments for enhancing water yield. Scenario 4 resulted in 282% more water yield than Scenario 3 (treatment of the 16 individual areas). Average increase in yield over baseline was 11.75 inches, compared to 2.93 inches with Scenario 3, or a monetary value of $ 490 per acre treated compared to $ 122 under Scenario 3. The estimated potential annual water yield (runoff, soil storage, and probably recharge) from brush control on 5,123 treated acres under Scenario 4 was 5,016 acre-feet, compared to 1,314 acre-feet under Scenario 3.

The results of the EDYS simulations indicate that brush control did likely enhance water yield in Gonzales County on the 16 areas that were treated in cooperation with TSSWCB and that higher amounts of enhancement are possible by selection of the most promising sites. The results showed EDYS to be a useful tool to quantify water budgets in a likely and realistic manner, and therefore it provides a useful tool to assist management in water resource decision making.

1.0 INTRODUCTION

Water is becoming an increasingly valuable resource throughout the United States, particularly in Texas and other western states. As the demand for water increases, its supply is becoming more limited and more erratic on an annual basis. One cause of the reduced supply in many western regions is the increase in woody plant coverage, resulting in an increase in evapotranspiration (ET). As ET increases, the residual amount of precipitation-supplied water available for aquifer recharge and surface and subsurface flow into creeks, rivers, and lakes decreases. In addition, deep-rooted woody species may extract substantial amounts of existing groundwater, thereby decreasing the amount of groundwater available for other uses.

There have been considerable efforts by watershed managers throughout the western United States to decrease ET by reducing the amount of woody vegetation and thereby increase the amount of recharge into aquifers and runoff into surface water bodies. A major challenge in these efforts has been to reasonably estimate the amount of water that would likely be shifted from ET to recharge and runoff by vegetation management on specific areas of a watershed. Complicating this decision-making challenge is the fact that the vegetation management scenarios are not the only factors affecting the ecohydrology of the watershed. The complexity of ecological interactions across the watershed, the variability in climatic conditions over the period of the project, vegetation change over time (e.g., succession), and potential changes in land use combine to make watershed decision-making even more challenging. Because of these complexities, effective watershed management requires the use of effective, efficient, and accurate tools to assist in decision making. EDYS is a tool that has been used to evaluate the direct effects of vegetation management and the interacting direct and indirect effects of associated ecological and anthropogenic factors on ecological water budgets at numerous sites, in particular the impacts of increases and decreases in woody plants.

EDYS is a general ecosystem simulation model that is mechanistically-based and spatially-explicit. It has been used for ecological evaluations, watershed management, land management decision making, environmental planning, and revegetation and restoration design analysis by federal and state agencies, municipal and water authorities, and corporations in 12 states and internationally. In Texas, EDYS has been used to simulate landscape and watershed dynamics at Forts Bliss and Hood, Camps Bullis and Stanley, portions of Big Bend National Park, the Upper Cibolo Creek watershed in Bexar County, the Honey Creek Experimental Watershed in Comal County, and the San Antonio Bay and surrounding area in Aransas, Calhoun, and Refugio counties. EDYS has been used for regulatory compliance and is included as part of the US Army Corps of Engineers System-Wide Resources Research Program (SWWRP) as a primary terrestrial model. Results of EDYS projects have been published in over 40 scientific and technical publications and presented at over 30 scientific meetings.

The Texas State Soil and Water Conservation Board (TSSWCB) is active in working with Texas landowners in vegetation management programs targeting removal of portions of woody vegetation for the purposes of enhancing water yields. The TSSWCB is interested in the possible use of EDYS as a watershed management tool to assist in determining which areas within a selected watershed afford the highest probability of increasing water yields through brush management.

In December 2010, KS2 Ecological Field Services LLC (KS2) submitted a proposed Scope of Work (SOW) to the Water Resources Center at Texas Tech University on behalf of the TSSWCB. That SOW ("Development of an EDYS Ecological Model for Gonzales County, Texas for Use in a Watershed Management Tool to Evaluate Landuse Options on Ecohydrological Responses") proposed that KS2 develop an EDYS model encompassing all of Gonzales County, Texas (Fig. 1.1), and that KS2 would use this model to evaluate brush management on various watersheds and sub-watersheds in Gonzales County on the basis of enhanced water yields from brush management.

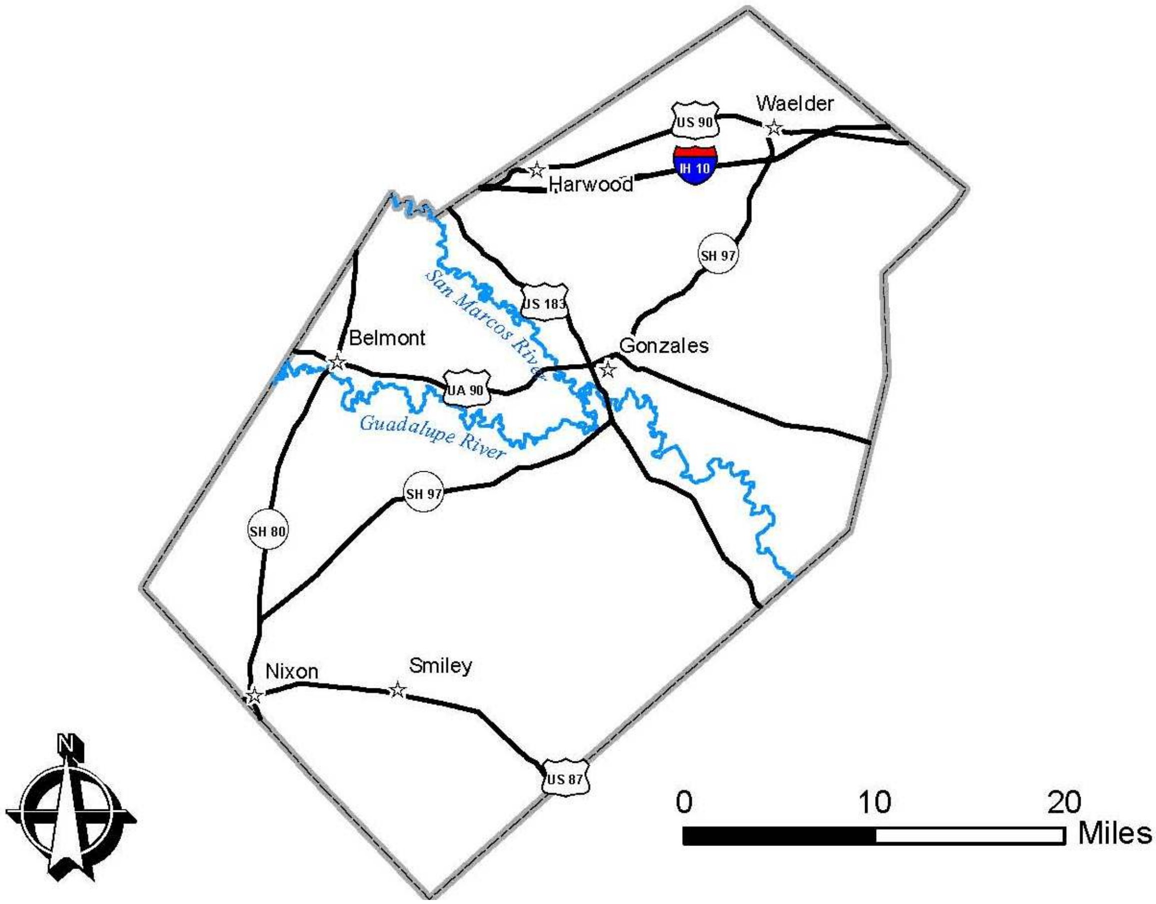

Figure 1.1 General map of Gonzales County, Texas.

KS2 received notification from Texas Tech University to implement this SOW beginning on 1 June 2011 and to complete the SOW by 31 August 2012 (Subcontract No. 22C072-01 under Prime Contract No. 13007-2011-01). This report presents the results produced under that SOW.

2.0 MODEL DEVELOPMENT

2.1 Spatial Footprint

The first step in developing an EDYS model application is to define the spatial domain (i.e., the spatial footprint). For the Gonzales County application, the entire County was the spatial domain. Gonzales County covers 1070 square miles (684,800 acres). In EDYS, the spatial footprint is divided into cells. A cell is the smallest unit that EDYS simulates in a particular application and can be of any size, as determined by the requirements of the application. EDYS averages values for each variable across an individual cell, therefore the cell size selected is a balance between (1) the largest size for which average values are acceptable and (2) reasonable simulation run times and memory requirements (i.e., the larger the number of cells in an application the slower the run time per time step and the larger the memory requirement).

Three levels of spatial resolution (cell sizes) were used in the Gonzales model. The County was modeled using 60 m x 60 m cells (0.89 acre each), or about 770,000 cells overall. This cell size was used for simulation runs that include the entire County. EDYS also allows for sub-units of the footprint to be modeled at a finer scale. Simulation results for these higher resolution "pop-ups" can be displayed individually (i.e., separate from the overall model footprint) but they are linked to the larger model so landscape processes simulated by the larger model also affect the fine-scale model and results from the fine-scale model affect the adjacent portions of the large-scale model. High-resolution pop-up models are used in EDYS applications to simulate ecological and hydrological dynamics of critical areas of interest where the increased resolution is necessary for both (1) accurately simulating the processes in that area and (2) providing sufficiently accurate simulation results. The two other levels of spatial resolution in the Gonzales models used this finer-scale capability.

The second level was for sub-watersheds. The County was subdivided into 44 sub-watersheds (Fig. 2.1). For simulations of single sub-watersheds, 30 m x 30 m cells can be used. These are created in EDYS by dividing each of the larger 60 m x 60 m cells into four equal parts.

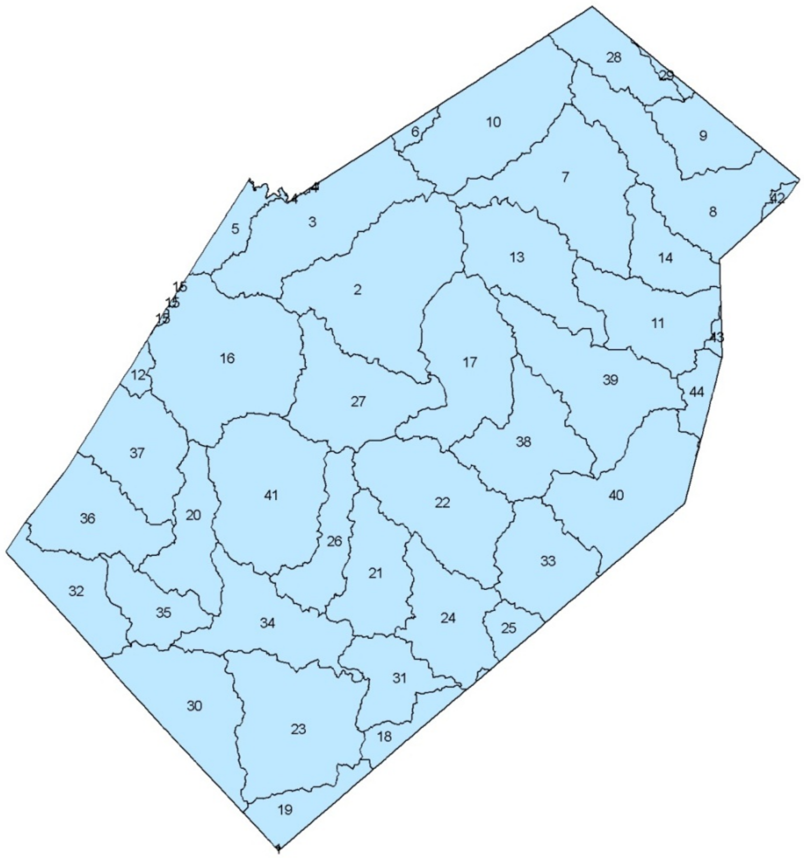

Figure 2.1 Spatial distribution of the 44 sub-watersheds used in the EDYS model application for Gonzales County, Texas.

The third level was for treatment areas. There are 16 TSSWCB associated brush-management treatment areas in Gonzales County, ranging in size from 12 to 1,088 acres (Fig. 2.2). The pop-up function was applied to each of these 16 treatment areas, and each was modeled on a 10 m x 10 m cell size, or 9 cells within each sub-watershed level 30 m x 30 cm cell.

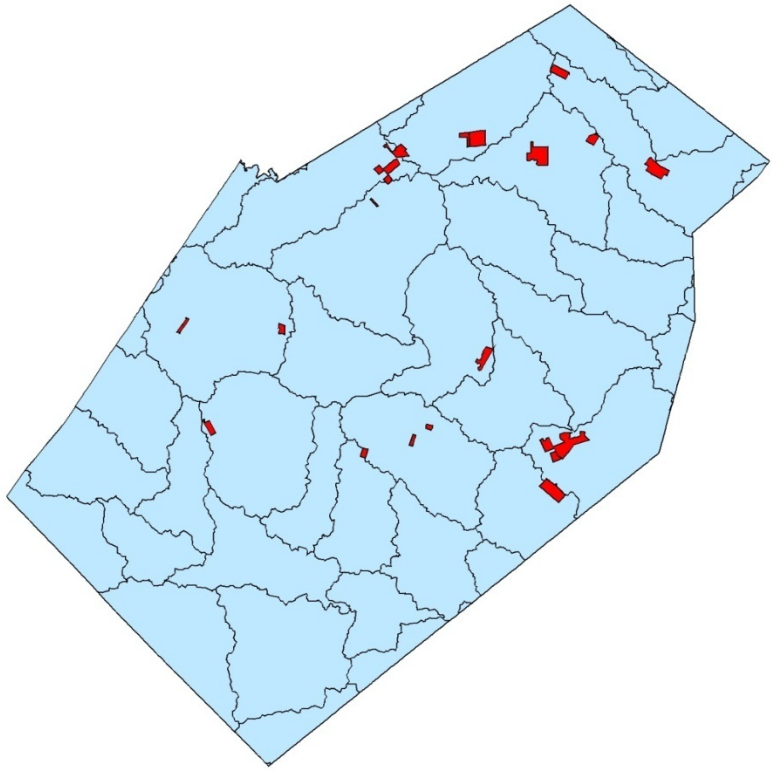

Figure 2.2 Locations of the 16 TSSWCB-associated brush treatment areas (red polygons) in Gonzales County.

2.2 Precipitation

Precipitation is a major factor affecting ecological responses in most ecosystems. As such, it is an important input (driving) variable in EDYS. Numerous aspects of precipitation are ecologically important, including (1) amount, (2) seasonality, (3) intensity, and (4) variability. In EDYS, precipitation is entered as a daily amount, with simulation of shorter-period (e.g., hourly) effects possible if necessary (e.g., effects of high-intensity storms).

Precipitation variability is also important ecologically. In order to simulate as much of this variability as feasible, the precipitation input data used in EDYS are based on as long a period as necessary or possible for an application. The Gonzales County application simulations are 10-year simulations. The period January 2002-December 2011 was chosen for these runs. This period was the most recent for which annual data were available. The results of the simulations are influenced by the precipitation data, therefore the use of a different time period will alter the specifics of the results somewhat.

Precipitation data used in this application were from the NWS weather station at Gonzales. Mean annual precipitation for the 10 years used in the simulation was 32.15 inches (Table 2.1) and was below the 1971-2000 mean of 36.02 inches. Of the 10 years (2002-2011), 4 were dry (< 21 inches), 3 were moderate (32-36 inches), and 3 were wet (> 44 inches).

Table 2.1 Annual precipitation (inches) for Gonzales, Texas, 2002-2011.

2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Mean
44.35	20.08	48.32	20.79	32.55	47.66	20.81	35.10	35.29	16.55	32.15

2.3 Depth to Groundwater

Another potential source of water to vegetation is groundwater. Groundwater utilization by vegetation is not a simple linear relationship between water uptake and depth to groundwater (Dawson and Ehleringer 1991; Schulze et al. 1996; Snyder and Williams 2003; Chimner and Cooper 2004; Cook and O'Grady 2006; McLendon et al. 2008; McLendon 2011). Important factors affecting groundwater use by vegetation include (1) depth to groundwater, (2) type and species of the vegetation, (3) availability of soil moisture, and (4) presence of restrictive soil layers.

EDYS simulates groundwater use on a plant species basis. At each time step (e.g., day), the potential water use demand for each species is calculated. Potential uptake from each soil layer is calculated, with potential uptake determined by the amount of roots of a particular species in each soil layer relative to roots of other species and the amount of available soil moisture in that layer. Uptake is then calculated by adding potential uptake by layer, beginning in the topmost layer and continuing downward until the demand is met. If demand cannot be met by accessing soil moisture, the remaining portion of demand is taken from groundwater, if groundwater is within the rooting depth for that species. Potential uptake of groundwater is also controlled by maximum potential uptake, which is depth dependent.

Depth to groundwater data were taken from the Texas Water Development Board (TWDB) well database. From these data, an interpolated surface of the water table was developed using the following procedure. A general query for wells at depths above the confining layer was made and exported. The shallow groundwater aquifer map developed by Deeds et al. (2003) was used to select wells that were not affected by confining layer conditions, as affected wells produced an artificially high water table. After selecting wells that accurately represented the water table, the depth to surface was exported as a layer in ArcGIS and krigged to create a continuous surface defining the depth to ground water. This depth to groundwater layer was then imported into EDYS.

2.4 Topography and Elevations

Surface topography is an important component in EDYS simulations. Topography determines the patterns (directions of flow) and rates of water movement across the landscape and therefore also affects erosion and movement of sediments and organic matter.

An average elevation is entered for each cell in an EDYS application. The elevations (above mean sea level) for the Gonzales model were taken from USGS DEMs. EDYS calculates slope and aspect based on elevation differences among adjacent cells. Differences in elevation among adjacent cells allow water to move from higher elevations to lower elevations and the greater the difference in elevation between two cells, the higher the velocity the water moves downslope and hence the greater the erosive potential and sediment carrying capacity. As the differences in elevation become smaller, water velocity decreases, and sediments and litter carried by the water begin to drop out and are deposited in cells with more gradual slopes.

2.5 Soils

Each cell in the spatial footprint is assigned a soil type, with the corresponding soil profile and physical, chemical, and biological variables. The soil types and their spatial distributions were taken from Natural Resource Conservation Service (NRCS) county soil survey for Gonzales County (Griffin et al. 2006). Based on the NRCS soil survey for Gonzales County, 112 soil types were included in the model (Appendix Table 1). These types consisted of 68 soil series plus 44 variations resulting from differences in slope or erosion. Additional data on soil properties and appropriate values for soil variables were taken from other literature sources and from the EDYS data bank.

2.6 Vegetation

Gonzales County occurs in an ecological transition area. Texas contains 254 counties and the vegetation of Texas is commonly divided into 10 vegetation regions (Gould 1975). Gonzales County contains portions of 3 of these 10 regions: post oak savanna, blackland prairie, and South Texas Plains. Griffin et al. (2006) included 31 ecological sites in Gonzales County and listed 132 major plant species characteristic of these 31 ecological sites. Information from other authors (Diamond and Smeins 1984; Smeins 1994a, 1994b) added an additional 28 species, for a total of 160 major species in the County.

The number of plant species included in an EDYS application is flexible. How many and which species are included depends on the requirements of the application and the level of complexity desired. The inclusion of more species increases the potential for the model to simulate the ecological complexity common to most landscapes, but it also increases the run times and memory requirements.

A total of 160 species is too many to include in a county-wide EDYS model for a number of reasons.

- Sufficient ecological data are not available for most of these species. Estimates can be made, but these estimates are largely based on a smaller number of species that would otherwise be included in the model. Hence, there would be little increase in predictive accuracy of the model by including all 160 species because little new information would be included.
- Including 160 species in the data matrices, even using estimated data, would increase the parameterization time substantially without increasing the predictive ability of the model by much, if at all.
- Run time would increase because of the additional calculations required.
- Interpretation time of the simulation results would be increased substantially, and much of this additional interpretation would be artificial because of the lack of unique data.

Consequently, the list of 160 species was reduced to 63 for inclusion in the model (Table 2.2). Selection of the 63 species was based on (1) availability of a reasonable amount of ecological data for that species, (2) overall ecological importance of the species in this area, and (3) inclusion of species representative of each lifeform. Species were also included if they were previously included in the Cibolo Creek Watershed (Price et al. 2004), Honey Creek Watershed (McLendon and Coldren 2005; McLendon et al. 2009), or San Antonio Bay (McLendon 2012) EDYS models because parameterization data were available in the EDYS Data Base. The 63 species consisted of 7 trees, 7 shrubs, 2 vines, 1 cacti, 29 grasses, 2 grass-likes, and 15 forbs.

Table 2.2 Plant species included in the Gonzales County EDYS model.

Lifeform	Scientific Name	Common Name
tree	*Acacia farnesiana*	huisache
tree	*Carya illinioensis*	pecan
tree	*Celtis laevigata*	hackberry
tree	*Juniperus virginiana*	eastern red cedar
tree	*Prosopis glandulosa*	mesquite
tree	*Quercus stellata*	post oak
tree	*Quercus virginiana*	live oak
shrub	*Acacia rigidula*	blackbrush
shrub	*Baccharis texana*	prairie baccharis
shrub	*Borrichia frutescens*	sea oxeye
shrub	*Celtis pallida*	granjeno
shrub	*Rhus microphylla*	littleleaf sumac
shrub	*Rosa bracteata*	McCartney rose
shrub	*Sesbania drummondii*	rattlepod
vine	*Smilax bona-nox*	greenbriar
vine	*Vitis mustangensis*	mustang grape
cacti	*Opuntia lindheimeri*	Texas pricklypear
grass	*Andropogon gerardii*	big bluestem
grass	*Andropogon virginicus*	broomsedge bluestem
grass	*Aristida purpurea*	purple threeawn
grass	*Bothriochloa ischaemum*	King Ranch bluestem
grass	*Bothriochloa saccharoides*	silver bluestem
grass	*Bouteloua curtipendula*	sideoats grama
grass	*Bouteloua hirsuta*	hairy grama
grass	*Bromus unioloides*	rescuegrass
grass	*Buchloe dactyloides*	buffalograss
grass	*Cenchrus incertus*	sandbur
grass	*Chloris cucullata*	hooded windmillgrass
grass	*Chloris pluriflora*	trichloris
grass	*Cynodon dactylon*	bermudagrass
grass	*Distichlis spicata*	saltgrass
grass	*Elymus virginicus*	Virginia wildrye
grass	*Panicum coloratum*	kleingrass
grass	*Panicum virgatum*	swithchgrass
grass	*Paspalum floridanum*	Florida paspalum
grass	*Paspalum lividum*	longtom
grass	*Paspalum plicatulum*	brownseed paspalum
grass	*Schizachyrium scoparium*	little bluestem

Table 2.2 (Cont.)

Lifeform	Scientific Name	Common Name
grass	*Setaria leucopila*	plains bristlegrass
grass	*Sorghum halepense*	Johnsongrass
grass	*Sorghastrum nutans*	indiangrass
grass	*Spartina spartinae*	gulf cordgrass
grass	*Sporobolus airoides*	alkali sacaton
grass	*Sporobolus asper*	tall dropseed
grass	*Sporobolus indicus*	smutgrass
grass	*Stipa leucotricha*	Texas wintergrass
grass-like	*Carex microdonta*	littletooth sedge
grass-like	*Fimbristylis puberula*	fimbry
forb	*Ambrosia psilostachya*	western ragweed
forb	*Amphiachyris dracunculoides*	annual broomweed
forb	*Aster spinosus*	spiny aster
forb	*Chamaecrista fasciculata*	partridge pea
forb	*Croton texensis*	Texas doveweed
forb	*Dalea purpurea*	purple prairieclover
forb	*Hedyotis nigricans*	prairie bluets
forb	*Helianthus annuus*	sunflower
forb	*Lupinus texensis*	Texas bluebonnet
forb	*Neptunia lutea*	yellow neptunia
forb	*Ratibida columnifera*	prairie coneflower
forb	*Rhynchosia americana*	snoutbean
forb	*Ruellia nudiflora*	ruellia
forb	*Simsia calva*	bush sunflower
forb	*Zexmenia hispida*	orange zexmenia

Each cell in an EDYS application receives an initial vegetation composition. For each cell, this can be any combination of the species included in the application (Table 2.2). The variation in species composition, and corresponding initial biomass values, among the cells provides the method for establishing the spatial vegetation mosaic across the simulation landscape.

In large applications (e.g., > 500,000 cells) such as the Gonzales County application, allocating unique vegetation composition to each cell and keeping track of changes in each cell during a simulation generally results in slow run times and large memory requirements. To shorten the run times and reduce the memory requirements, cells with similar initial species composition can be pooled into groups, each group representing a plant community. Vegetation responses are then simulated on the plant community level rather than the cell level. If however, environmental conditions change in one part of the group differently than in another (e.g., fire burns across part of the community, one part is grazed by livestock at a different stocking rate, only part of the community is subjected to brush control), EDYS divides the group into parts with each part representing the area subjected to a specific environmental response and including only those cells subjected to that response. From that point in the simulation, each of the differently impacted areas is simulated as a separate plant community (plot type). It is not unusual in an EDYS simulation for the number of plot types (plant community types) to quadruple from the starting number.

In the Gonzales County model, the spatial domain (entire County) was divided into polygons, each polygon corresponding to a NRCS soil mapping unit (Griffin et al. 2006). Each polygon was then assigned a plant community based on the ecological site description associated with the respective soil type. There were 112 initial combinations (Appendix Table 1).

NRCS ecological site descriptions are based on late-successional conditions for the particular site. In Gonzales County, as in many other locations, there have been substantial changes in the vegetation relative to late-successional conditions. One major change has been an increase in woody plants. To account for these changes, aerial photographs were used to estimate percent woody plant cover in each polygon. Species composition of the woody vegetation was estimated based on information in the NRCS ecological site descriptions (Griffin et al. 2006), other published sources (Powell and Box 1967; Box and White 1969; Drawe et al. 1978; Diamond and Smeins 1984; McLendon 1991, 1994; Drawe 1994; Smeins 1994a, 1994b), and professional judgment. Initial biomass values for each species were then entered for each cell based on the species composition and cover values.

A second major variation in current vegetation from that listed in ecological site descriptions is from land-use changes. These land uses include cultivation, improved pasture, urban areas, and disturbed sites (e.g., oil and gas production, caliche and gravel pits). These types were identified from aerial photographs and vegetation cover, composition, and production values were modified accordingly.

3.0 SIMULATION APPROACH

3.1 Water Budget Calculations

EDYS documents a number of components of the simulated water dynamics. Evapotranspiration (ET) is separated into three components (interception, evaporation, and transpiration) and each component is documented separately. Total ET is calculated as the sum of these three components.

Only a portion of precipitation received at the surface enters the soil profile. This amount is equal to precipitation minus interception and runoff. The remaining portion of precipitation (infiltration) is added to the amount of soil moisture in storage in the soil profile (by soil layers) and becomes available for transpiration (from all layers within the rooting zone) and evaporation (from upper two layers only).

Plants also potentially have access to another source of water, i.e., groundwater. EDYS also documents the amount of groundwater used by the vegetation. Therefore, transpiration includes water from two possible sources, stored soil moisture and groundwater. In EDYS, groundwater use is completely used in transpiration because this amount of groundwater is actually removed by plants. The remaining portion of transpiration is from soil moisture, which can be from a combination of two sources, from an accounting standpoint. One source is recently infiltrated precipitation and the second source is previously stored soil moisture. Over time, if transpiration minus groundwater use exceeds precipitation infiltration, stored soil moisture declines. If transpiration minus groundwater use is less than precipitation infiltration, stored soil moisture increases. A simple calculation of the amount of stored soil moisture at any particular time is then given by

$$SM_{t+1} = SM_t + PPT_I - TRANS_t + GRNDW_t$$

where,

SM_{t+1} = stored soil moisture at time step t+1,
SM_t = stored soil moisture at the previous time step,
PPT_I = precipitation infiltration in time step t,
$TRANS_t$ = amount of water extracted by transpiration in time step t, and
$GRNDW_t$ = amount of groundwater used in transpiration in time step t.

As long as the amount of stored soil moisture does not exceed the storage capacity of the soil profile, this equation describes the water balance dynamics of the soil system. However, if the amount of stored soil moisture exceeds the storage capacity of the soil profile, the excess enters groundwater. Because the structure of the deep sub-soil portions of the profiles is unknown, we cannot model where the draining soil moisture goes once it leaves the simulated soil profile. Similarly, some of the soil moisture percolating through the deeper layers of the profile may instead move laterally and surface at lower elevations of the landscape as spring flow or seepage, or could enter adjacent creeks or the Guadalupe River. The dynamics of these deep flows are determined by such factors as type and fracturing of the bedrock, presence of deep impervious layers, karst features, and deep root channels. Without knowing their locations, water movement patterns cannot be accurately modeled.

Because of these unknown characteristics of the deep profile, our calculated soil moisture storage value is probably high, i.e., some of the moisture we simulate as being in the lower subsoil probably moves into groundwater or moves laterally and becomes spring, creek, or river flow. Consequently, our calculated "Net Yield" is conservative because some of the water we allocate to soil storage probably leaves the soil system.

Net Yield is calculated as the amount of precipitation received minus total ET. Precipitation minus total ET and runoff is the amount of moisture that enters soil storage (at least temporarily). Some unknown amount of this stored soil moisture may eventually enter aquifers or surface water pathways.

Deep storage is the amount of water that moves through the soil profile past the maximum rooting depth or that moves into a zone of saturated soil. This water is recharge, but it is unknown as to where this recharge eventually moves. EDYS can be linked with a groundwater flow model, but this was not part of this Scope of Work.

3.2 Simulation Scenarios

Four simulation scenarios were conducted, each for 10 years. The first scenario consisted of simulating vegetation change and changes in water dynamics under baseline conditions, i.e., no brush management or other changes in land-use practices during the 10-year simulation period, on each of the 44 sub-watersheds. The purpose of this scenario was to establish the background values against which the various treatment responses would be compared. Differences in vegetation and water dynamics between baseline and a particular treatment provided the results of the treatment. In this manner, effects of precipitation variation and succession can be accounted for and separated from the effects resulting from the treatment.

The second simulation scenario was for 100% removal of woody species from all vegetation types where any combination of four target species composed more canopy cover than the most abundant non-target woody species. The four target species were eastern red cedar, huisache, mesquite, and McCartney rose. Removal of all woody species, rather than only the target species, was based on the assumption that the brush control method would be root plowing. Root plowing tends to be relatively non-selective in the species being removed. Although 100% removal of any woody species is not likely, this scenario provided an estimate of maximum potential yields from brush control and therefore can be used as the upper limit to potential benefits. In addition to removal of the woody species, all of the treatment simulations also removed 50% of the biomass of all herbaceous species, as an effect of root plowing. Following the initial biomass removal, regrowth of each species over time is simulated based on species-specific responses. Post-treatment regrowth is simulated in all scenarios receiving brush control treatments.

The spatial criteria for treatment used in this scenario (i.e., vegetation types where any combination of four target species composed more canopy cover than the most abundant non-target woody species) provides a logical and practical selection criteria. Root plowing is not likely to be applied to areas where the target species are not present or to areas where the target species are only a minor component of the vegetation. This scenario was simulated for each of the 44 sub-watersheds.

Results from the first two scenarios were compared on a sub-watershed basis. Each sub-watershed was then ranked, from 1 to 44, based on its relative potential increased water yield. The sub-watershed with the largest difference between baseline and 100% treatment was ranked 1 and the sub-watershed with the smallest difference was ranked 44. This ranking provided an indication of where the greatest potential benefits from brush control were likely to occur.

The third simulation scenario was applied to only the 16 designated treatment areas. Within each of these 16 areas, 90% of aboveground biomass of all of the target woody species, 70% of aboveground biomass of non-target woody species, and 50% of aboveground biomass of herbaceous species were removed from all vegetation types in the treated areas. This scenario provided an estimate of potential benefits from the brush control program supported by TSSWCB in Gonzales County. The lower removal rate (70%) for non-target woody species was used because it was assumed that large oak, pecan, or hackberry trees would likely be purposely left on the landscape during root plowing. Treatment of all vegetation types within the treated area in Scenario 3, rather than only types containing large amounts of the target species, was simulated because these areas had been previously selected by TSSWCB for treatment.

The final simulation scenario was to apply the same treatment as the third scenario, but to apply it to a single area instead of the 16 smaller areas in the third scenario. The total treated acreage remained the same, i.e., the single treated area in Scenario 4 contained approximately the same number of acres as the sum of the 16 treated areas in Scenario 3. The treatment area in Scenario

4 was located in the sub-watershed with the highest potential yield ranking, as determined in Scenario 2. Comparison of the results from Scenario 4 to the results from Scenario 3 provide an indication of the increase in water yields that are likely when contiguous areas are treated.

4.0 SIMULATION RESULTS

4.1 Baseline Conditions

Average annual water yield under baseline conditions was 2.33 inches (Table 4.1), or 7.2% of average annual precipitation. Net yield varied considerably by sub-watershed, ranging from a high of 5.89 inches to a low of - 3.29 inches. Sub-watersheds with the highest annual yields (Sub-watersheds 33, 40, and 43) utilized little or no groundwater and sub-watersheds with the lowest annual yields (Sub-watersheds 02, 07, 13, 29, and 36) had relatively high groundwater use (annual average of 5.5-6.5 inches per year, Table 4.1).

Table 4.1 Average annual water balance values (inches) for each of the 44 sub-watersheds in Gonzales County based on EDYS simulations under baseline conditions (values are 10-year means: 2002-2011).

SUBWSD	PPT	INTRCP	EVAPOR	TRANSP	TOTAL ET	RUNOFF	UPSTOR	DPSTOR	GRNDWT	NET YIELD
01	32.15	0.82	0.72	27.83	29.37	1.01	3.43	0.00	1.66	2.78
02	32.15	1.24	1.36	31.16	33.76	0.67	2.90	1.33	6.51	- 1.61
03	32.15	1.14	1.51	25.56	28.21	0.83	2.76	0.35	0.00	3.94
04	32.15	1.16	0.65	26.84	28.65	0.50	2.40	0.60	0.00	3.50
05	32.15	1.12	1.29	26.59	29.00	0.45	2.62	0.08	0.00	4.15
06	32.15	1.21	0.66	26.39	28.26	0.63	2.86	0.40	0.00	3.89
07	32.15	1.39	1.38	31.10	33.87	0.87	2.79	0.54	5.92	- 1.72
08	32.15	1.07	1.45	26.18	28.70	0.70	2.80	0.74	0.79	3.45
09	32.15	1.00	1.03	25.74	27.77	0.98	2.70	0.71	0.01	4.38
10	32.15	1.10	0.89	25.83	27.82	0.91	2.92	0.50	0.00	4.33
11	32.15	1.10	0.78	26.11	27.99	0.60	2.62	1.13	0.19	4.16
12	32.15	1.17	0.98	26.56	28.71	0.52	2.52	0.40	0.00	3.44
13	32.15	1.41	1.22	31.81	34.44	0.65	2.83	0.06	5.83	- 3.29
14	32.15	1.26	0.73	26.19	28.18	0.62	2.53	0.84	0.02	3.97
15	32.15	1.47	0.64	26.86	28.97	0.55	2.25	0.38	0.00	3.18
16	32.15	1.14	2.11	28.27	31.52	0.90	2.68	0.49	3.44	0.63
17	32.15	0.92	6.10	25.30	32.32	0.64	3.14	0.21	4.16	- 0.17
18	32.15	1.10	0.71	26.24	28.05	0.75	2.93	0.42	0.00	4.10
19	32.15	1.28	1.55	25.40	28.23	0.70	3.11	0.11	0.00	3.92
20	32.15	1.48	1.52	25.59	28.59	0.55	3.04	0.07	0.00	3.56
21	32.15	1.11	0.81	31.08	33.00	1.49	2.76	1.00	6.10	- 0.85
22	32.15	1.04	1.08	30.20	32.32	0.62	2.68	1.52	4.99	- 0.17
23	32.15	1.18	0.97	29.44	31.59	0.98	3.56	0.29	4.27	0.56
24	32.15	1.20	0.74	29.58	31.52	1.50	2.58	1.62	5.07	0.63
25	32.15	1.13	0.90	25.92	27.95	0.72	2.86	0.62	0.00	4.20
26	32.15	1.10	0.96	26.29	28.35	0.68	2.95	0.17	0.00	3.80
27	32.15	1.10	1.64	25.66	28.40	0.80	2.92	0.12	0.09	3.75
28	32.15	1.04	1.23	29.71	31.98	0.69	2.93	0.15	3.60	0.17
29	32.15	1.01	0.67	32.54	34.22	0.77	2.78	0.08	5.70	- 2.07
30	32.15	1.41	2.61	24.13	28.15	0.62	3.30	0.08	0.00	4.00
31	32.15	1.20	0.76	29.44	31.40	0.96	2.66	1.13	3.98	0.75
32	32.15	1.04	1.62	25.55	28.21	0.62	2.86	0.47	0.01	3.94
33	32.15	1.24	0.88	24.14	26.26	2.23	2.54	1.12	0.00	5.89
34	32.15	1.29	1.48	25.68	28.45	0.74	3.17	0.09	0.30	3.70
35	32.15	1.37	0.86	26.45	28.68	0.63	2.80	0.04	0.00	3.47

Table 4.1 (Cont.)

SUBWSD	PPT	INTRCP	EVAPOR	TRANSP	TOTAL ET	RUNOFF	UPSTOR	DPSTOR	GRNDWT	NET YIELD
36	32.15	1.19	0.92	31.80	33.91	0.53	2.62	0.59	5.50	- 1.76
37	32.15	1.23	1.11	31.00	33.34	0.53	2.63	0.55	4.90	- 1.19
38	32.15	1.02	3.68	23.02	27.72	0.74	3.04	0.65	0.00	4.43
39	32.15	1.06	1.10	31.36	33.52	0.78	2.68	1.36	6.19	- 1.37
40	32.15	1.04	0.87	25.04	26.95	1.70	2.76	0.74	0.00	5.20
41	32.15	1.42	2.35	24.67	28.44	0.63	3.07	0.01	0.00	3.71
42	32.15	1.10	0.67	25.81	27.58	0.83	2.84	1.94	1.04	4.57
43	32.15	1.08	0.67	25.55	27.30	0.67	2.78	1.40	0.00	4.85
44	32.15	1.04	0.99	28.34	30.37	0.57	3.03	2.12	3.94	1.78
MEAN	32.15	1.16	1.29	27.36	29.82	0.80	2.83	0.62	1.91	2.33

SUBWSD = sub-watershed; PPT = annual precipitation; INTRCP = canopy interception; EVAPOR = evaporation from soil surface;
TRANSP = transpiration; TOTAL ET = INTRCP + EVAPOR + TRANSP; RUNOFF = surface runoff;
UPSTOR = storage in soil profile = PPT + GRNDWT - RUNOFF - TOTAL ET - DPSTOR;
DPSTOR = deep storage (potential recharge); GRNDWT = groundwater use; NET YIELD = PPT - TOTAL ET

Average annual total evapotranspiration (ET) varied between about 26.7 and 34.4 inches and averaged 29.82 inches across the 44 sub-watersheds under baseline conditions (Table 4.1). Average annual ET was therefore equal to 92.8% of average annual precipitation. The vegetation in Gonzales County is a mixture of woodlands and grasslands. Values of ratios of ET to precipitation reported for oak-juniper woodlands in the nearby Edwards Plateau range from 63% (Jackson et al. 1999) to 96% (Wu et al. 2001) and 98-99% for mesquite woodlands in the Rolling Plains of Texas (Carlson et al. 1990) and in South Texas (Weltz and Blackburn 1995). Ratios in a South Texas grassland averaged 95% (Weltz and Blackburn 1995). Similar ratios have been reported for semi-arid grasslands in Colorado (100%, Ferretti et al. 2003) and New Mexico (98%, Reynolds 2000).

Groundwater use by vegetation varied substantially among sub-watersheds (Table 4.1). Vegetation on 18 of the sub-watersheds used no groundwater. Groundwater use on the other 26 sub-watersheds varied from 0.01 to 6.51 inches and averaged 3.24 inches. Averaged over all 44 sub-watersheds, the vegetation utilized 1.91 inches of groundwater per year. Total ET averaged 29.82 inches (Table 4.1), therefore an average of 6.4% of ET was from groundwater. This value is less than 25% of the amount reported by Jackson et al. (2000) for juniper woodlands in the Edwards Plateau.

Runoff also varied considerably by sub-watershed, varying from an annual average of 0.45 inch to 2.23 inches (Table 4.1). Averaged over all 44 sub-watersheds, mean annual runoff was 0.80 inch.

Summarizing the water budget under baseline conditions and averaged over all 44 sub-watersheds, an average of 32.15 inches of precipitation were received, 0.80 inch was exported as runoff, and 2.45 inches were returned as evaporation (1.16 inches as interception, 1.29 inches as evaporation from ground surface; Table 4.1), leaving 28.90 inches to infiltrate into the soil. Vegetation transpired an average of 27.36 inches, of which 1.91 inches were groundwater and 25.45 inches were soil moisture, leaving a balance of 3.45 inches of infiltrated water. Of these 3.45 inches, some would be stored in the soil and subsoil, some would likely percolate into the groundwater as recharge, and some would likely move laterally and eventually surface as spring or stream flow. In the EDYS simulations, these 3.45 inches were further divided into two components, upper soil storage (2.83 inches) and deep storage (0.62 inch), where deep storage is likely recharge into groundwater.

Net water yield is calculated as precipitation (32.15 inches) minus total ET (29.82 inches), or 2.33 inches. Of this 2.33 inches, some is runoff (0.80 inch), some is net change in groundwater (- 1.29 inches = 0.62 inch of deep storage - 1.91 inches of groundwater used in transpiration), and some is stored in the soil profile (2.83 inches).

4.2 Scenario 2: 100% Removal of Target Species

Scenario 2 represents the maximum potential effect of brush management of the four target species. It is not likely to be achievable because root-plowing does not remove 100% of the target plants (e.g., 96% on level terrain in South Texas; Powell and Box 1967). However, it is useful because it provides an upper limit for evaluation purposes.

Average annual water yield under 100% removal was 4.22 inches (Table 4.2), or a 81.1% increase over baseline. This 81.1% increase in water yield (1.89 inches annual increase) is the average for all parts of the County. Many of the areas would not realistically be cleared. One of the practical aspects of the EDYS application is the ability to select which areas would respond sufficiently to clearing to justify the expense. A first step in this process is to evaluate which sub-watersheds have the greatest potential for increased yield. The model can then be used to select specific areas within that (or multiple) sub-watershed in order to prioritize clearing operations.

Table 4.2 Average annual water balance values (inches) for each of the 44 sub-watersheds in Gonzales County based on EDYS simulations under Scenario 2 (100% removal of target woody species). Values are 10-year means: 2002-2011.

SUBWSD	PPT	INTRCP	EVAPOR	TRANSP	TOTAL ET	RUNOFF	UPSTOR	DPSTOR	GRNDWT	NET YIELD
01	32.15	0.82	1.23	24.70	26.75	1.19	4.22	0.00	0.01	5.40
02	32.15	1.14	1.57	28.56	31.27	0.68	3.24	1.71	4.75	0.88
03	32.15	1.08	1.78	24.16	27.02	0.83	3.57	0.73	0.00	5.13
04	32.15	1.16	0.83	25.60	27.59	0.50	3.10	0.96	0.00	4.56
05	32.15	1.04	1.65	24.79	27.48	0.47	3.92	0.28	0.00	4.67
06	32.15	1.16	0.87	24.96	26.99	0.63	3.70	0.83	0.00	5.16
07	32.15	1.20	1.59	28.07	30.86	0.89	3.31	0.67	3.58	1.29
08	32.15	1.00	1.71	24.40	27.11	0.72	3.29	1.27	0.24	5.04
09	32.15	0.93	1.41	24.01	26.35	1.01	3.57	1.23	0.01	5.80
10	32.15	1.07	1.14	24.31	26.52	0.92	3.55	1.16	0.00	5.63
11	32.15	1.04	1.06	24.42	26.52	0.61	3.01	2.09	0.08	5.63
12	32.15	1.17	1.12	25.66	27.95	0.52	2.92	0.76	0.00	4.20
13	32.15	1.18	1.43	28.42	31.03	0.67	3.58	0.09	3.22	1.12
14	32.15	1.14	0.96	25.03	27.13	0.64	2.73	1.65	0.00	5.02
15	32.15	1.15	1.16	24.45	26.76	0.56	4.36	0.47	0.00	5.39
16	32.15	1.10	2.30	26.37	29.77	0.91	3.22	0.75	2.50	2.38
17	32.15	0.85	6.25	22.82	29.92	0.65	3.62	0.25	2.29	2.23
18	32.15	1.05	1.11	24.48	26.64	0.75	3.81	0.95	0.00	5.51
19	32.15	1.08	1.88	24.24	27.20	0.73	4.03	0.19	0.00	4.95
20	32.15	1.16	1.74	24.69	27.59	0.58	3.81	0.17	0.00	4.56
21	32.15	1.06	1.28	25.90	28.24	1.50	3.34	1.99	2.92	3.91
22	32.15	0.99	1.34	27.36	29.69	0.64	3.15	1.98	3.31	2.46
23	32.15	1.11	1.28	25.60	27.99	0.99	4.21	0.75	1.79	4.16
24	32.15	1.10	1.09	25.56	27.75	1.52	2.67	2.89	2.68	4.40
25	32.15	1.10	1.18	24.66	26.94	0.74	3.39	1.08	0.00	5.21
26	32.15	1.07	1.23	25.25	27.55	0.68	3.70	0.22	0.00	4.60
27	32.15	1.04	1.83	24.87	27.74	0.81	3.43	0.22	0.05	4.41
28	32.15	0.95	1.60	26.15	28.70	0.71	4.17	0.22	1.65	3.45
29	32.15	1.01	1.02	29.23	31.26	0.80	3.86	0.12	3.89	0.89
30	32.15	1.15	2.79	23.58	27.52	0.64	3.88	0.11	0.00	4.63
31	32.15	1.13	1.13	26.55	28.81	0.96	2.97	1.86	2.45	3.34
32	32.15	1.00	1.93	23.89	26.82	0.64	3.64	1.05	0.00	5.33
33	32.15	1.08	1.11	23.12	25.31	2.23	2.62	1.99	0.00	6.84
34	32.15	1.14	1.71	24.70	27.55	0.75	3.82	0.14	0.11	4.60
35	32.15	1.11	1.22	25.10	27.43	0.66	3.92	0.14	0.00	4.72
36	32.15	1.10	1.27	27.56	29.93	0.55	3.73	0.95	3.01	2.22
37	32.15	1.16	1.37	27.52	30.05	0.55	3.31	0.93	2.69	2.10
38	32.15	0.96	3.87	22.16	26.99	0.75	3.39	1.02	0.00	5.16
39	32.15	1.03	1.37	27.33	29.73	0.80	3.21	1.74	3.33	2.42
40	32.15	0.95	1.19	23.69	25.83	1.72	3.27	1.33	0.00	6.32
41	32.15	1.08	2.54	24.12	27.74	0.66	3.72	0.03	0.00	4.41
42	32.15	0.94	0.88	24.49	26.31	0.85	2.90	2.93	0.84	5.84
43	32.15	0.95	0.97	23.90	25.82	0.69	3.16	2.48	0.00	6.33
44	32.15	0.90	1.25	26.68	28.83	0.59	3.18	3.23	3.68	3.32
MEAN	32.15	1.06	1.57	25.30	27.93	0.82	3.48	1.04	1.12	4.22

SUBWSD = sub-watershed; PPT = annual precipitation; INTRCP = canopy interception; EVAPOR = evaporation from soil surface;
TRANSP = transpiration; TOTAL ET = INTRCP + EVAPOR + TRANSP; RUNOFF = surface runoff;
UPSTROR = storage in soil profile = PPT + GRDWT - RUNOFF - TOTAL ET - DPSTOR;
DPSTOR = deep storage (potential recharge); GRNDWT = groundwater use; NET YIELD = PPT - TOTAL ET

All of the 44 sub-watersheds had increased water yield under the 100% removal scenario as compared to baseline. Although the 100% removal treatment resulted in increased yields on all of the sub-watersheds, the magnitude of these increases varied substantially (Fig. 4.1). The increase over baseline was less than 1 inch per year on 9 sub-watersheds (20%), 1-2 inches on 19 sub-watersheds (43%), 2-3 inches on 7 sub-watersheds (16%), and more than 3 inches per year on 9 sub-watersheds (20%). Sub-watershed 21 had the largest increase (4.76 inches). The primary cause of the increased water yield following 100% removal of the target woody species was decreased transpiration. Annual transpiration averaged 25.30 inches under Scenario 2 (Table 4.2) compared to 27.36 inches under baseline (Table 4.1).

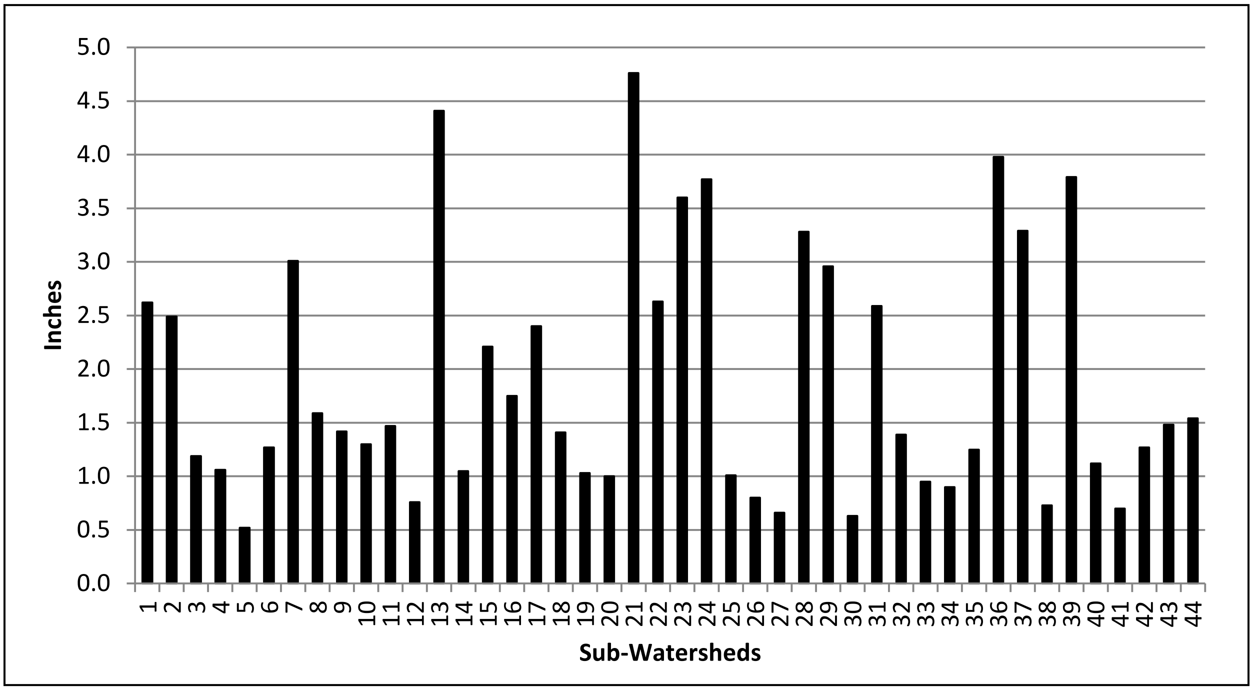

Figure 4.1 Potential average annual increase in water yield from 100% removal of target species compared to baseline on 44 sub-watersheds in Gonzales County, Texas, based on EDYS simulations.

Based on these differences in water yield between baseline and the 100% treatment, the sub-watersheds can be ranked as to which provides the greatest overall potential for increases in water yield from removal of the target woody species and which have the least potential (Fig. 4.2). However, a second important consideration is the acreage in each sub-watershed. A sub-watershed may have a high average potential yield but the area included in the sub-watershed might be small, thereby resulting in a low to modest total potential yield. On the other hand, a large sub-watershed might have a lower average potential yield but its larger size might result in a greater total potential yield than from the smaller sub-watershed. Based on total potential yield (average per acre yield x acres), Sub-watershed 23 has the highest potential for increasing water yield (Table 4.3).

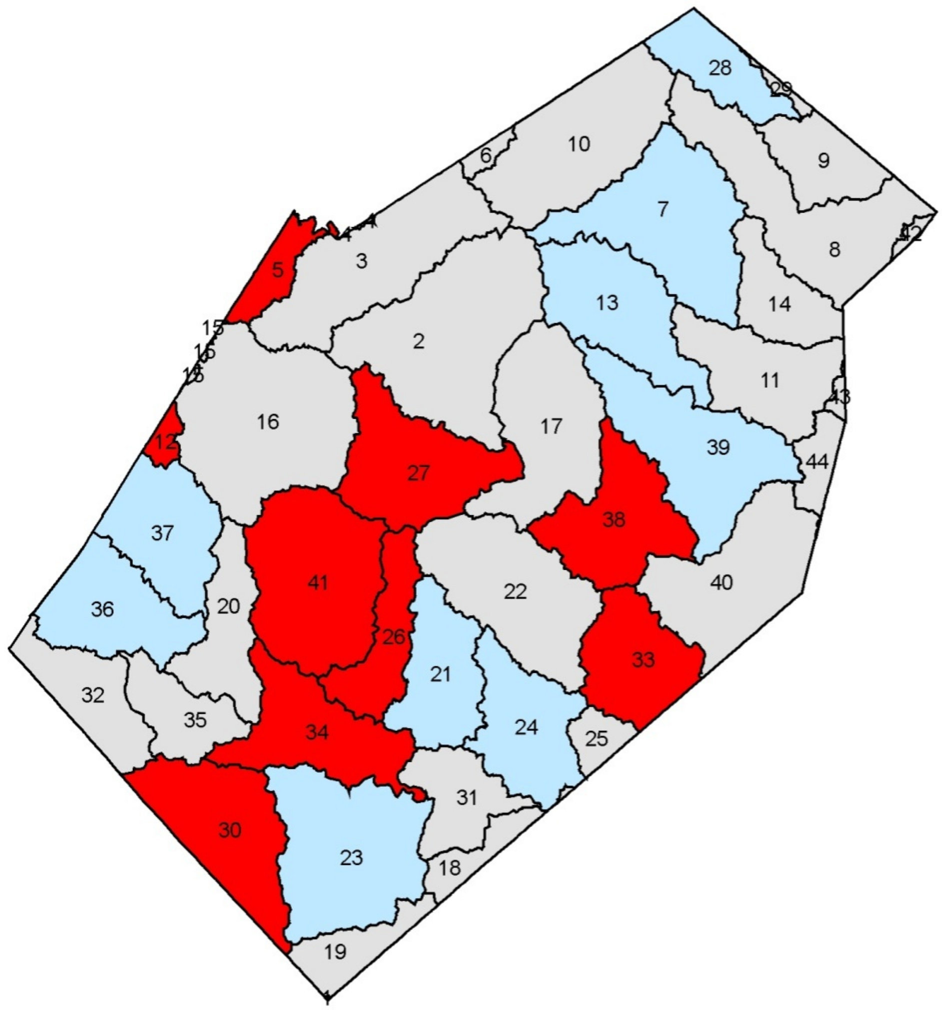

Figure 4.2 The 9 sub-watersheds with the highest potential for increased water yields (> 3 inches per year) from removal of the target woody species (blue), 26 sub-watersheds with intermediate potential (1-3 inches per year) for increased yields, and the 9 sub-watersheds with the lowest potential (< 1 inch per year) for increased yields (red) based on EDYS simulations.

Table 4.3 Difference in net annual water yield and potential increased annual water yield resulting from the 100% removal of target woody species (Scenario 2) compared to no treatment (baseline, Scenario 1) on each of 44 sub-watersheds in Gonzales County based on EDYS simulations. Values are 10-year means: 2002-2011.

Sub-watershed	Net Yield (inches) Baseline	Treated	Difference	Acres	Potential Increased Annual Yield (ac-ft)
01	2.78	5.40	2.62	20	4.4
02	- 1.61	0.88	2.49	36,853	7,647.0
03	3.94	5.13	1.19	27,695	2,746.5
04	3.50	4.56	1.06	101	8.9
05	4.15	4.67	0.42	5,782	202.4
06	3.89	5.16	1.27	1,669	176.7
07	- 1.72	1.29	3.01	28,757	7,213.2
08	3.45	5.04	1.59	27,852	3,690.4
09	4.38	5.80	1.42	10,897	1,289.5
10	4.33	5.63	1.30	27,407	2,969.1
11	4.16	5.63	1.47	18,251	2,235.7
12	3.44	4.20	0.76	2,010	127.3
13	- 3.29	1.12	4.41	21,119	7,761.2
14	3.97	5.02	1.05	11,213	983.4
15	3.18	5.39	2.21	302	55.6
16	0.63	2.38	1.75	36,075	5,261.0
17	- 0.17	2.23	2.40	24,731	4,946.2
18	4.10	5.51	1.41	5,491	927.2
19	3.92	4.95	1.03	7,928	680.5
20	3.56	4.56	1.00	13,756	1,166.3
21	- 0.85	3.91	4.76	15,913	6,312.2
22	- 0.17	2.46	2.63	26,818	5,877.5
23	0.56	4.16	3.60	29,999	8,999.7
24	0.63	4.40	3.77	17,894	5,621.8
25	4.20	5.21	1.01	4,024	338.7
26	3.80	4.60	0.80	12,077	805.1
27	3.75	4.41	0.66	22,524	1,238.8
28	0.17	3.45	3.28	10,844	2,964.1
29	- 2.07	0.89	2.96	1,115	275.0
30	4.00	4.63	0.63	22,354	1,173.6
31	0.75	3.34	2.59	11,598	2,503.2
32	3.94	5.33	1.39	13,568	1,571.7
33	5.89	6.84	0.95	16,348	1,294.2
34	3.70	4.60	0.90	19,978	1,499.2
35	3.47	4.72	1.25	10,683	1,112.9
36	- 1.76	2.22	3.98	17,969	5,959.7
37	- 1.19	2.10	3.29	17,824	4,886.6
38	4.43	5.16	0.73	19,978	1,215.4
39	- 1.37	2.42	3.79	26,687	8,428.6
40	5.20	6.32	1.12	24,825	2,317.1
41	3.71	4.41	0.70	29,605	1,726.1
42	4.57	5.84	1.27	916	96.8
43	4.85	6.33	1.48	880	108.5
44	1.78	3.32	1.54	4,767	611.8
MEAN			1.89		

Net yield values were taken from Table 4.1 for baseline and Table 4.2 for 100% treatment.

4.3 Scenario 3: 90% Removal of Target Species on 16 Treated Areas

In order to evaluate the effectiveness of treatments on the 16 areas relative to water yield enhancement, water yield under baseline conditions first had to be determined. Average annual net yield on these 16 areas varied between -7.27 inches and 18.18 inches (Table 4.4). The high yield on Treatment Area 05 was the result of low vegetation cover and high runoff. Groundwater use by vegetation was high (> 3 inches) on eight of the treatment areas. Five treatment areas had negative net yields and all five areas had high groundwater use.

Table 4.4 Average annual water balance values (inches) for each of the 16 treatment areas in Gonzales County based on EDYS simulations under baseline conditions (no brush treatment). Values are 10-year means: 2002-2011.

Area	PPT	INTRCP	EVAPOR	TRANSP	TOTAL ET	RUNOFF	UPSTOR	DPSTOR	GRNDWT	NET YIELD
01	32.15	1.63	0.67	34.51	36.81	0.72	2.68	0.00	8.06	- 4.66
02	32.15	1.02	0.65	29.81	31.48	0.61	2.67	0.57	3.18	0.67
03	32.15	0.85	0.67	28.35	29.87	0.56	2.78	0.83	1.89	2.28
04	32.15	1.06	0.74	26.52	28.32	0.72	2.92	0.19	0.00	3.83
05	32.15	1.00	0.55	12.42	13.97	16.57	1.20	0.41	0.00	18.18
06	32.15	1.16	0.72	26.28	28.16	0.80	3.73	0.00	0.54	3.99
07	32.15	0.81	0.67	28.10	29.58	0.45	3.14	0.00	1.02	2.57
08	32.15	1.21	0.63	22.20	24.04	5.79	1.95	0.37	0.00	8.11
09	32.15	2.17	0.66	30.20	33.03	0.87	2.86	0.00	4.61	- 0.88
10	32.15	0.91	0.66	30.34	31.91	1.14	2.96	0.92	4.78	0.24
11	32.15	1.16	0.65	29.46	31.27	0.88	2.86	0.73	3.49	0.88
12	32.15	1.03	0.71	26.83	28.57	0.38	3.20	0.00	0.00	3.58
13	32.15	1.40	0.65	30.53	32.58	0.56	2.84	0.21	3.94	- 0.43
14	32.15	0.85	0.67	26.25	27.77	0.60	2.90	0.88	0.00	4.38
15	32.15	1.29	0.66	37.47	39.42	0.71	2.50	0.00	10.48	- 7.27
16	32.15	1.19	0.64	32.59	34.42	0.53	2.40	0.00	5.20	- 2.27

PPT = annual precipitation; INTRCP = canopy interception; EVAPOR = evaporation from soil surface;
TRANSP = transpiration; TOTAL ET = INTRCP + EVAPOR + TRANSP; RUNOFF = surface runoff;
UPSTOR = storage in soil profile = PPT + GRNDWT - RUNOFF - TOTAL ET - DPSTOR;
DPSTOR = deep storage (potential recharge); GRNDWT = groundwater use; NET YIELD = PPT - TOTAL ET

Based on the EDYS simulations, the brush treatments increased water yields on all treatment areas except Area 12 (Table 4.5). Net yield on Area 12 was only slightly less after brush treatment than under baseline (Tables 4.4 and 4.5). The general increase in net yield following treatment, as compared to baseline, was primarily because of decreased transpiration following treatment. Mean annual transpiration averaged over the 16 areas was 28.24 inches under baseline conditions (Table 4.4) and 25.38 inches following treatment (Table 4.5), or a 10% decrease following treatment. Dugas et al. (1998) reported the same level of reduction in ET following juniper control on the Seco Creek in the Edwards Plateau. Groundwater use was also reduced by the brush treatment. Groundwater use averaged 2.95 inches per year under baseline conditions compared to 0.41 inch following treatment.

Table 4.5 Average annual water balance values (inches) for each of the 16 treatment areas in Gonzales County based on EDYS simulation under Scenario 3 (90% removal of target species). Values are 10-year means: 2002-2011.

Area	PPT	INTRCP	EVAPOR	TRANSP	TOTAL ET	RUNOFF	UPSTOR	DPSTOR	GRNDWT	NET YIELD
01	32.15	1.45	0.69	27.75	29.89	0.75	2.95	0.00	1.44	2.26
02	32.15	1.04	0.70	25.71	27.45	0.62	3.37	0.94	0.23	4.70
03	32.15	0.82	0.70	26.12	27.64	0.58	3.18	1.06	0.31	4.51
04	32.15	1.02	0.74	26.48	28.24	0.72	2.95	0.24	0.00	3.93
05	32.15	0.71	0.62	12.45	13.78	16.43	1.27	0.67	0.00	18.37
06	32.15	1.13	0.73	25.84	27.70	0.80	3.72	0.00	0.07	4.45
07	32.15	0.81	0.71	26.45	27.97	0.47	3.77	0.00	0.06	4.18
08	32.15	1.03	0.66	21.91	23.60	5.80	2.09	0.66	0.00	8.55
09	32.15	2.11	0.65	26.35	29.11	0.89	2.81	0.00	0.66	3.04
10	32.15	0.84	0.70	25.48	27.02	1.17	3.16	1.31	0.51	5.13
11	32.15	1.22	0.70	25.52	27.44	0.90	2.66	1.33	0.28	4.71
12	32.15	0.84	0.74	27.02	28.60	0.39	3.16	0.00	0.00	3.55
13	32.15	1.01	0.69	26.81	28.51	0.62	2.75	0.62	0.35	3.64
14	32.15	0.82	0.71	25.72	27.25	0.64	2.87	1.39	0.00	4.90
15	32.15	1.14	0.69	28.78	30.61	0.74	2.79	0.00	1.99	1.54
16	32.15	1.21	0.70	27.69	29.60	0.54	2.65	0.00	0.64	2.55

PPT = annual precipitation; INTRCP = canopy interception; EVAPOR = evaporation from soil surface;
TRANSP = transpiration; TOTAL ET = INTRCP + EVAPOR + TRANSP; RUNOFF = surface runoff;
UPSTOR = storage in soil profile = PPT + GRANDWT - RUNOFF - TOTAL ET - DPSTOR; DPSTOR = deep storage (potential recharge);
GRNDWT = groundwater use; NET YIELD = PPT - TOTAL ET - GRNDWT

Compared to baseline, the 90% removal treatment increased annual net water yield by 2.93 inches, averaged over the 16 treatment areas (Table 4.6). Based on a value of $ 500 per acre-foot for water, the average value of the water enhancement was $ 122 per acre per year. Total potential increased annual yield, summed over the 5,133 acres treated was 1,314 acre-feet per year. It should be emphasized that these 1,314 acre-feet of water includes runoff, decreased use of groundwater, storage in the soil and sub-soil, as well as recharge into groundwater and lateral recharge through springs, streams, and rivers.

Table 4.6 Difference in net annual water yield, monetary value of difference, and potential annual water yield resulting from 90% removal of target woody species compared to no treatment (baseline) on each of the 16 treated areas in Gonzales County based on EDYS simulations. Values are 10-year means: 2002-2011.

Area	Net Yield (inches)			Monetary Value of Difference ($ ac^{-1} yr^{-1})	Acres Treated	Potential Increased Annual Yield (ac-ft)
	Baseline	Treated	Difference			
01	- 4.66	2.26	6.92	288.33	628	362.15
02	0.67	4.70	4.03	167.92	274	92.02
03	2.28	4.51	2.23	92.92	12	2.23
04	3.83	3.93	0.10	4.17	89	0.74
05	18.18	18.37	0.19	7.92	526	8.33
06	3.99	4.45	0.46	18.33	158	72.68
07	2.57	4.18	1.61	67.08	74	9.93
08	8.11	8.55	0.44	18.33	1,088	39.73
09	- 0.88	3.04	3.92	163.33	251	81.99
10	0.24	5.13	4.89	203.75	593	241.65
11	0.88	4.71	3.83	159.58	371	118.41
12	3.58	3.55	- 0.03	-1.25	146	-0.37
13	- 0.43	3.64	4.07	169.58	95	32.22
14	4.38	4.90	0.52	21.67	485	21.02
15	- 7.27	1.54	8.81	367.08	280	205.57
16	- 2.27	2.55	4.82	200.83	63	25.31
Total					5,133	1,313.61
Mean			2.93	122.35		

Net yield values were taken from Tables 4.4 and 4.5.
Difference = (Treated Net Yield) - (Baseline Net Yield).
Monetary value of difference was calculated on the basis of $ 500 per acre-foot.

Both increase in net yield (90% treatment compared to baseline) and number of acres treated varied substantially among the 16 areas (Table 4.6). Brush removal resulted in large increases (more than 4 inches per year) in net water yield in 6 of the treatment areas (01, 02, 10, 13, 15, and 16; Table 4.6). Moderate increases in annual net yield (1.5-4.0 inches) occurred in 4 of the treatment areas and low increases or loss (less than 0.6 inch) occurred in 6 of the areas. The lowest returns from brush treatment occurred in two Treatment Areas, 05 and 12. In Treatment Area 05, runoff was very high and vegetation sparse even under baseline. Under those conditions, brush removal should not be expected to result in substantial increases in water yield. In Treatment Area 12, there was a substantial increase in herbaceous production, especially ragweed, and rapid regrowth of huisache. These two factors combined to keep transpiration relatively high.

The acreages of the treated areas varied between 12 and 1,088 acres (Table 4.6). Potential increased yield is the product of acreage and yield per acre. Based on these simulations, treating the 5,133 acres resulted in an average increase in annual yield of 1,314 acre-feet (Table 4.6), or about 0.25 acre-feet per year per acre treated.

Based on a value of $ 500 per acre-foot for water, the average value of the increase in water yield of the 90% treatment compared to baseline was $ 122 per year (Table 4.6). The highest value was on Treatment Area 16 ($ 367 per year) and the lowest was on Treatment Area 12 (- $ 1.25 per year).

4.4 Scenario 4: 90% Removal of Target Species Concentrated in Sub-Watershed 21

Sub-watershed 21 had the highest potential yield from brush treatment of any of the 44 sub-watersheds, when evaluated on the basis of the average for the entire sub-watershed (Table 4.3). The combined acreage of the 16 treated areas was 5,133 acres (Table 4.6). For Scenario 4, a similar acreage (5,123 acres) was selected in Sub-watershed 21 by first locating the largest contiguous areas containing large amounts of the four target woody species and then determining the combination that resulted in the fewest areas adding up to the nearest acreage to 5,133 acres. This process resulted in the selection of a mixture of large and small blocks within the sub-watershed (Fig. 4.3).

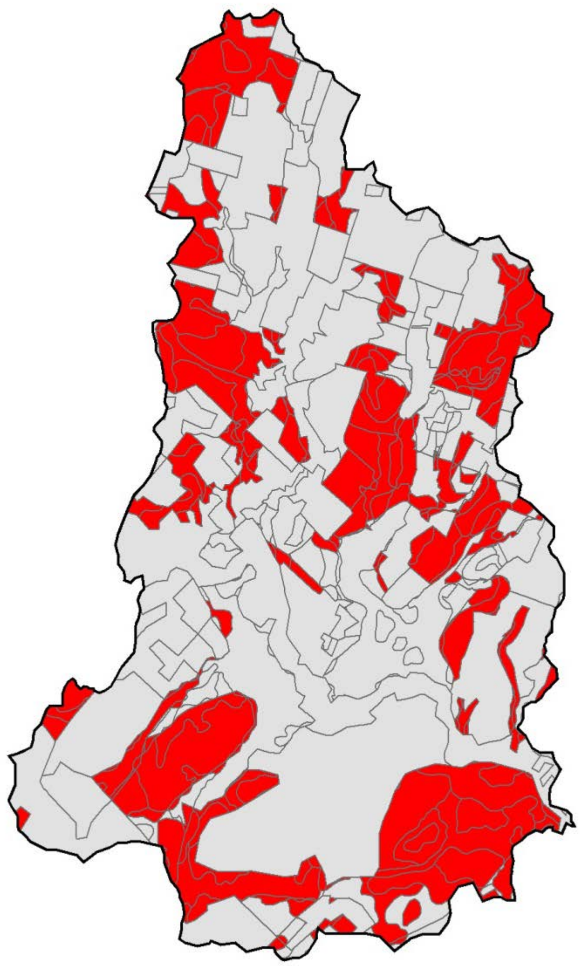

Figure 4.3 Areas in Sub-watershed 21 receiving brush treatment in Scenario 4.

Applying the same 90% removal treatment to these areas in Sub-watershed 21 that was applied to the 16 treatment areas of Scenario 3 resulted in an average increase in net annual water yield of 11.75 inches over baseline (Table 4.7). Summed over the 5,123 treated acres, this treatment resulted in an average annual increased yield of 5,016 acre-feet, or about 0.98 acre-feet per acre per year. The monetary value of this increased yield would be $ 490 per acre per year, at a rate of $ 500 per acre-foot (Table 4.7). Compared to Scenario 3 (16 treated areas), Scenario 4 resulted in a 282% greater return (Fig. 4.4).

Table 4.7 Difference in net annual water yield, monetary value of difference, and potential annual water yield resulting from 90% removal of target woody species compared to no treatment (baseline) in 5,123 acres in Sub-watershed 21 in Gonzales County, based on EDYS simulations. Values are 10-year means: 2002-2011.

Net Yield (inches)			Monetary Value of	Acres	Potential Increased Annual
Baseline	**Treated**	**Difference**	**Difference ($ ac^{-1} yr^{-1})**	**Treated**	**Yield (ac-ft)**
- 2.02	9.73	11.75	489.58	5,123	5,016.3

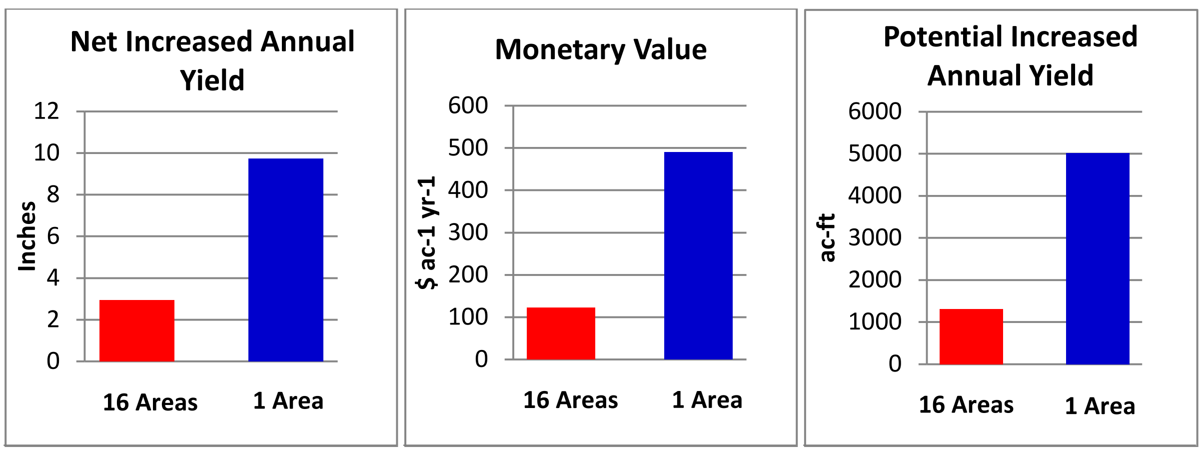

Figure 4.4 Net increased annual yield from baseline, monetary value of difference from baseline, and potential annual increase in water yield resulting from 90% removal of target woody species on 16 treated areas compared to the same acreage treated in a single sub-watershed (Sub-watershed 21) in Gonzales County, based on EDYS simulations. Values are 10-year means (2002-2011).

The difference in potential water yield enhancement from brush control between Scenario 3 (5,133 acres treated in 16 different parcels) and Scenario 4 (5,123 acres treated in a single sub-watershed) was substantial (+ 282%). The reason for this substantial increase in effectiveness was that the treated area in Scenario 4 had the highest concentration of target species in the sub-watershed with the highest potential yield (Table 4.3). By comparison, the 16 treated areas in Scenario 3 consisted of sites with a wide range of potential yields scattered among sub-watersheds with various potentials for increased yield (Table 4.3).

5.0 SUMMARY AND CONCLUSIONS

The EDYS simulations provided a method for evaluating both the water dynamics associated with the vegetation throughout Gonzales County and the effectiveness of brush control for water yield enhancement. It should be remembered that the simulations used precipitation data from 2002-11 combined with general soils data (NRCS Soil Survey for Gonzales County) and estimated vegetation conditions based on aerial photographs provided in Griffins et al. (2006). Therefore, the simulation results should not be taken as absolute values, but as reasonable estimates of relative differences in responses among water balance components, among sub-watersheds, and between treatments.

The results indicate that under baseline conditions (i.e., no brush treatment other than what was evident in the aerial photographs), annual water yield in Gonzales County was about 2.3 inches when averaged over the entire county for the period 2002-11. This amount includes runoff, net storage in the soil profile, and recharge into groundwater and waterways. Net yield varied substantially among sub-watersheds, with the highest yields around 4-5 inches per year (12 of the 44 sub-watersheds) and the lowest around minus 1-3 inches (net loss) per year (7 of the sub-watersheds). Annual precipitation averaged 31.2 inches during the simulation period and evapotranspiration (ET) was the single largest component (29.8 inches) of the overall water budget accounting for 93% of precipitation, when averaged over all 44 sub-watersheds.

Surface runoff under baseline conditions averaged 0.8 inch per year, or less than 3% of annual precipitation. Probable recharge into groundwater and waterways averaged 0.6 inch per year, or 2% of annual precipitation. Vegetation utilized about 1.9 inches of groundwater annually as part of the transpiration component of ET. Groundwater use by vegetation county-wide was therefore about 2.5 times the average recharge rate. Like ET, groundwater use by vegetation varied substantially across the county, with about half (23) of the sub-watersheds not using groundwater or using less than 0.1 inch per year and about one-third (16) of the sub-watersheds using 3.5 inches or more each year.

Maximum increase in net yield from brush control was estimated by simulating 100% removal of four target woody species (huisache, eastern red cedar, mesquite, McCartney rose). Although 100% removal is not practical, this scenario provided an upper limit to potential increased yield and provided a method for ranking the sub-watersheds relative to potential increased yields.

Net water yield increased on all 44 sub-watersheds as a result of the 100% removal of the target woody species but the magnitude varied among the sub-watersheds. The 100% removal resulted in increased yields of less than 1 inch per year on 9 of the sub-watersheds, 1-2 inches on 19 sub-watersheds, 2-3 inches on 7, and more than 3 inches per year on 9 sub-watersheds. Sub-watershed 21 had the largest amount of increase (4.76 inches per year).

TSSWCB identified 16 areas where brush control had been applied as part of their cooperative program for water enhancement. These 16 areas varied in size between 12 and 1,088 acres and were located in 12 of the 44 sub-watersheds (Fig 2.2). The effectiveness of these treatments were simulated by comparing water yields under baseline conditions in each of the 16 areas to water yields following brush control. The brush control was simulated as root plowing that removed 90% of the standing biomass of the target woody species, 70% of the standing biomass of other woody species, and 50% of the standing biomass of herbaceous species. Root plowing was simulated in March of 2002 with no follow-up treatment. All species were allowed to recover naturally following treatment.

The results indicated that brush control resulted in an average increase in water yield of 2.9 inches per year, averaged over the 16 treatment areas. Based on a value of $ 500 per acre foot, this average increased yield (2.9 inches) would have a monetary value of about $ 122 per year for every acre treated. About half (7) of the 16 areas had high potential yields (about 4 inches or more per year, or more than $ 150 per acre annual return) from the treatment, while 6 areas had low yields (about 0.5 inch per year or less and less than $ 25 per acre per year).

The 16 treated areas contained a total of 5,133 acres. When the yields were multiplied by the respective acreage treated, the total simulated yield for the 16 areas together averaged 1,314 acre-feet per year. Over half of this total (809 acre-feet) was generated on 3 of the 16 areas, and these 3 areas contained less than 30% (1501 acres) of the treated acreage.

Under Scenario 4 of the simulations, an equivalent acreage was treated within a single sub-watershed. The sub-watershed selected was Sub-watershed 21, which had the highest potential per-acre yield overall. Within Sub-watershed 21, acreage for treatment was selected that contained the highest cover of the four target woody species and that summed to about the same acreage (5,123 acres) as treated in the total of the 16 areas. The same brush control treatment was simulated as was simulated on the 16 areas. The purpose of Scenario 4 was to evaluate the potential effect on water yields of concentrating treatment in high-yield areas.

The Scenario 4 treatment resulted in 282% more water yield than treating the 16 separate areas. Average increase in yield over baseline was 11.75 inches per year, compared to 2.93 inches on the 16 areas, or a monetary value of $ 490 per acre treated compared to $ 122 on the 16 areas. Total average annual yield from the 5,123 treated acres in Sub-watershed 21 was 5,016 acre-feet compared to 1,314 acre-feet on the 5,133 treated acres on the 16 areas.

The results of the EDYS simulations indicate that brush control did likely enhance water yield in Gonzales County on the 16 areas treated in cooperation with TSSWCB. The results also indicate that almost three times as much water enhancement could have taken place if the treated acreage had been concentrated in areas of highest potential yield.

Again, it is emphasized that the increased water yields indicated in these simulations are likely manifested in three components: (1) runoff, (2) increased soil storage, and (3) recharge into groundwater and waterways. The amount manifested as runoff would be a direct and immediate contribution to surface water resources in the County. Most of the water manifested as soil storage will not likely be a direct contribution to the water resources in the County but would benefit the vegetation and would likely reduce the use of groundwater by vegetation over time. Some of this water would however, likely move laterally along cracks, fissures, root channels, and layers of coarse material and eventually emerge as spring flow or input into the creek and river system. Hence, some of this soil storage component may, in fact, be recharge. Therefore, the estimate of recharge in EDYS is probably conservative.

The amount manifested as recharge is more difficult to track, both spatially and temporally. In EDYS, this amount is the water that moves below the rooting zone of the vegetation. Without knowing the details of the geological structures (e.g., faults, fractures, layers of different conductivities) it is impossible to know where, and when, this water will move to a particular location. Some may move laterally relatively rapidly and emerge as spring flow or sub-surface flow into the creek and river system. Other amounts may move rapidly into groundwater, while some may take long periods of time to transverse to locations where it can be detected.

The results of this application have shown EDYS to be a useful tool in quantifying water budgets in a likely and realistic manner. In addition, it provides a tool whereby plans and options regarding brush control, as well as other land management options, for water enhancement can be evaluated such that maximum effectiveness is achieved for a given level of input. As such, it provides a useful tool to assist management in water resource decision making.

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Appendix Table 1. Soil series and corresponding NRCS ecological sites, included in the spatial footprint of the Gonzales County EDYS model.

Symbol	Soil Series	NRCS Ecological Site
AmB	Alum	loamy sand
ApC	Arenosa	very deep sand
ArA	Arol	claypan savanna
ArB	Arol	claypan savanna
AxB	Axtell	claypan savanna
AxC	Axtell	claypan savanna
AxE	Axtell	claypan savanna
BnB	Benchley	clay loam
BoA	Bosque	loamy bottomland
BpA	Bosque	loamy bottomland
BrA	Branyon	blackland
BtB	Bryde	tight sandy loam
BuA	Buchel	clayey bottomland
BvA	Buchel	clayey bottomland
BwB	Burlewash	claypan savanna
BwC2	Burlewash, eroded	claypan savanna
BwE	Burlewash	claypan savanna
CaB	Cadell	claypan prairie
CbB	Carbengle	clay loam
CbC	Carbengle	clay loam
CbC2	Carbengle, eroded	clay loam
CbE	Carbengle	clay loam
ChA	Chazos	sandy loam
ChB	Chazos	sandy loam
ChC	Chazos	sandy loam
CoA	Cost	salty prairie
CpB	Coy	rolling blackland
CrB	Crockett	claypan prairie
CrC2	Crockett, eroded	claypan prairie
CsB	Crockett	claypan prairie
CsC2	Crockett, eroded	claypan prairie
CuB	Cuero	clay loam
DeA	Degola	loamy bottomland
DfA	Degola	loamy bottomland
DmB	Dimebox	blackland
DyC2	Dreyer, eroded	eroded blackland
DyE	Dreyer	eroded blackland
EcB	Ecleto	shallow
EcC	Ecleto	shallow
EdB	Edge	claypan savanna
EdC2	Edge, eroded	claypan savanna
EdD3	Edge, severely eroded	claypan savanna
EdE2	Edge	claypan savanna
EgC	Edge	claypan savanna
EgE	Edge	claypan savanna

Appendix Table 1 (Cont.)

Symbol	Soil Series	NRCS Ecological Site
EkB	Elmendorf	blackland
EkC	Elmendorf	blackland
EsB	Eloso	rolling blackland
FnB	Flatonia	clay loam
FsB	Frelsburg	blackland
FsC	Frelsburg	blackland
GfA	Ganado	clayey bottomland
GkC	Gillett	tight sandy loam
GkF	Gillett	tight sandy loam
GrB	Greenvine	blackland
GrC	Greenvine	blackland
GtB	Griter	tight sandy loam
GtC2	Griter, eroded	tight sandy loam
ImA	Imogene	tight sandy loam
JsC	Jedd	sandstone hill
JsE	Jedd	sandstone hill
KuB	Kurten	claypan savanna
LeB	Leming	loamy sand
LkA	Luckenbach	clay loam
LkB	Luckenbach	clay loam
LuB	Luling	blackland
LuC	Luling	blackland
LuC2	Luling, eroded	blackland
MaA	Mabank	claypan prairie
MeA	Meguin	loamy bottomland
MfA	Meguin	loamy bottomland
MoB	Monteola	blackland
MoC	Monteola	blackland
NaA	Navasota	clayey bottomland
NmB	Normangee	claypan prairie
NmC	Normangee	claypan prairie
NuC	Nusil	loamy sand
PaC	Padina	deep sand
PbA	Papalote	loamy sand
PbB	Papalote	tight sandy loam
PkB	Pavelek	shallow
RhC	Rhymes	loamy sand
RoB	Rosanky	sandy loam
RoC2	Rosanky, eroded	sandy loam
RsB	Rosenbrock	rolling blackland
RvA	Rutersville	claypan savanna
SaD	Sarnosa	gray sandy loam
ScC	Schattel	sloping clay loam
ShC	Shalba	claypan savanna
SnC	Shiner	chalky ridge

Appendix Table 1. (Cont.)

Symbol	Soil Series	NRCS Ecological Site
SnE	Shiner	chalky ridge
SoC	Shiro	sandy loam
SsC	Silstid	loamy sand
SvD	Silvern	gravelly
SwA	Singleton	claypan savanna
SwC	Singleton	claypan savanna
SxB	Styx	loamy sand
SyC	Sunev	clay loam
SyE	Sunev	clay loam
TbA	Tabor	sandy loam
TbB	Tabor	sandy loam
TnA	Tinn	clayey bottomland
ToA	Tinn	clayey bottomland
TrB	Tordia	rolling blackland
TtC	Tremona	loamy sand
WaA	Waelder	loamy bottomland
WeA	Waelder	loamy bottomland
WsC	Weesatche	sandy loam
WwA	Wilson	claypan prairie
ZkB	Zack	claypan prairie
ZuB	Zulch	claypan prairie

QUANTIFICATION OF EFFECTS OF DISTANCES FROM DRAINAGE AND FROM OUTLET ON WATER YIELD ENHANCEMENT FROM BRUSH CONTROL [in Gonzales County]

REPORT PREPARED FOR:

TEXAS STATE SOIL AND WATER CONSERVATION BOARD

SUBMITTED BY:

Terry McLendon, PhD
KS2 Ecological Field Services, LLC
Box 502
Anton, Texas 79313
970-297-8557

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EXECUTIVE SUMMARY

The Texas State Soil and Water Conservation Board (TSSWCB) is active in working with Texas landowners and managers in vegetation management programs targeting removal of woody vegetation for the purpose of enhancing water yields from selected watersheds. Researchers at Texas Tech University, in cooperation with TSSWCB, have developed general guidelines for spatial evaluation of watersheds to assist in selection of areas with high potential for enhanced water yields from brush control. It would be useful to TSSWCB for planning purposes if these potential increases using the guidelines could be quantified. TSSWCB contracted KS2 Ecological Field Services (KS2) to quantify the effects of two of the primary guideline factors, distance from drainage channel and distance from drainage outlet, on potential water yield enhancement from two watersheds in Gonzales County, using the EDYS model previously developed for Gonzales County.

Results of the 10-year simulations indicated that both distance from the drainage channel and distance from the outlet had an effect on water enhancement from brush control. In both watersheds, water yield enhancement was highest nearest the channel and nearest the outlet, as predicted by the general guidelines. Averaged over the two watersheds, net water enhancement was 18% greater per treated acre when brush control was applied 20-120 m from the channel than when applied 120-220 m from the channel and 41% greater than when applied 420-520 m from the channel. Averaged over both watersheds, brush control was 29% more effective on a per treated acre basis for water enhancement when applied nearest the channel (20-120 m) than over all four 100-m strips that were more distant (120-520 m from the channel).

Averaged over both watersheds, brush control applied nearest the outlet (one-third of the drainage nearest the outlet) was 44% more effective in water enhancement than when applied to the middle one-third of the drainage and 50% more effective than when applied to the most distant one-third of the drainage. Although this pattern of increased enhancement nearest the outlet was the same for both watersheds, there were differences in the magnitude of the responses between the two watersheds. These differences were most likely the result of differences in vegetation patterns between the two watersheds.

The model simulations indicated that there was little effect of brush control on either runoff leaving the watershed or recharge in these two watersheds. A similar response has been reported by other researchers, whose results have been used to suggest that there is little benefit from brush control in increasing water yields from semiarid woodlands and shrublands. However, our results indicate that brush control does affect groundwater use by these woody plants and this reduction in groundwater use is what results in water yield enhancement. The effect of brush control on reduced groundwater use has not been addressed by most previous studies dealing with potential enhancement of water yield from brush control. Conclusions based only on runoff and recharge from precipitation may not provide for an adequate evaluation of the benefits from brush control on water yield enhancement.

1.0 INTRODUCTION

Water is becoming an increasingly valuable resource throughout the United States and particularly in Texas and other western states. As the demand for water is increasing, the supply is becoming more limited and more erratic on an annual basis. One cause of the reduced supply in many western regions is the increase in woody plant coverage and the resulting increase in water use through evapotranspiration (ET) by the woody vegetation. The Texas State Soil and Water Conservation Board (TSSWCB) is active in working with Texas landowners and managers in vegetation management programs targeting removal of woody vegetation, especially juniper, saltcedar, and mesquite, from portions of their land for the purpose of increasing water yields from selected watersheds.

Researchers at Texas Tech University in cooperation with TSSWCB have developed general guidelines for spatial evaluation of watersheds to assist in the selection of areas with high potential for enhanced water yields from brush control (Fish and Rainwater 2007). Two primary factors identified in these guidelines are 1) distance from the associated drainage channel and 2) distance from the watershed outlet. The guidelines suggest that the effectiveness of a given amount of brush control on water yield enhancement should increase the closer the area of application is to the drainage and to the watershed outlet.

The guidelines that were produced are qualitative guidelines. It would be useful to TSSWCB for planning purposes if this potential increase in effectiveness could be quantified. One method of providing quantification is by using simulation modeling. TSSWCB previously funded Texas Tech University to provide a simulation model of Gonzales County, Texas to be used to evaluate enhanced water yields from brush control in that county (McLendon et al. 2012). In April 2013, KS2 Ecological Field Services (KS2) submitted a Scope of Work to TSSWCB to use that Gonzales County model to quantify the effects of distances from drainage and from outlet on water yield enhancement from brush control, using two watersheds in that model. TSSWCB authorized KS2 to conduct that evaluation under Professional and Consulting Services Contract No. 2013-13007-27068-3. This report presents the results of that evaluation.

2.0 APPROACH

The basic hypothesis defining this task is that location on the landscape affects potential water enhancement from brush control. The logic is that the nearer the treatment area is to 1) the drainage channel and 2) the outlet point of the watershed, the greater the potential increase in water yield given the same type of vegetation and same size of treatment area. This logic is based on several assumptions, two of which are of primary importance. One major assumption is that sites nearer the drainage and nearer the outlet have less distance for surface runoff water to move across. Hence, less runoff water is likely to infiltrate and be stored in the soil and less subsurface water is likely to be transpired by vegetation. A second major assumption is that woody vegetation is likely to transpire more water per acre nearer the drainage and nearer the outlet than in more distant, and generally higher elevation, areas. This is because woody vegetation tends to be more developed nearer more available sources of water and depth to groundwater is less nearer the drainages. Both of these factors tend to result in higher transpiration rates nearer drainages and at lower elevations along drainages than at higher and more distant locations.

The hypothesis is logical. However, it would be helpful from a management standpoint if the effect (i.e., increase in potential enhancement) could be quantified. If so, then management decisions could be based, in part, on this information when attempting to define which areas should be selected to receive treatment. It is not practical to implement field studies to quantify this response at every location likely to be needed. The practical alternative is to use simulation modeling.

The scope of the task of this report was to use the Gonzales County EDYS model (McLendon et al. 2012) to simulate spatial effects on water enhancement from brush control in two watersheds in Gonzales County, Texas. The two watersheds were selected, in cooperation with Dr. Ernest Fish at Texas Tech University, on the basis of 1) overall potential water enhancement from brush control (based on results of the Gonzales County modeling; McLendon et al. 2012), 2) general watershed characteristics (e.g., sufficient size to provide spatial variations in yields, minimal effects of adjacent watersheds), 3) minimal urban or cultivated areas, and 4) appropriate vegetation (e.g., abundance of target woody species).

Nine simulations were conducted for each watershed: one to establish baseline conditions, five to evaluate effect of distance from the main drainage channel, and three to evaluate effect of distance from outlet. To evaluate the effect of distance from main drainage channel, each watershed was divided into six bands (strips). The first band was a 20-m buffer strip running approximately parallel to the center of the channel and extending the entire distance of the watershed, from the outlet to the highest elevation of the main drainage channel and then extending to the upper elevation edge of the watershed at that location. This buffer strip received no brush treatment in any of the simulations. The second band consisted of a 100-m wide strip running approximately parallel to the upslope side of the buffer strip. The third-sixth bands each consisted of a 100-m wide strip running approximately parallel to the upslope side of the previous band.

The second through sixth bands were the treatment areas. One simulation was conducted for each of the five bands. In each case, the brush treatment was applied only to the specific band. Brush treatments were the same as in Scenarios 3 and 4 of the Gonzales County model, i.e., removal of 90% of the biomass of the target woody species, 70% removal of non-target woody species, and 50% removal of herbaceous species. The target woody species were eastern red cedar (*Juniperus virginiana*), huisache (*Acacia farnesiana*), mesquite (*Prosopis glandulosa*), and McCartney rose (*Rosa bracteata*). Ninety percent removal, rather than 100%, of the target species was used because brush control treatments rarely remove all individuals of the target species. The brush control treatment was assumed to be root-plowing. Root-plowing also removes some non-target woody species and some herbaceous species. Vegetation regrowth following brush control was allowed in the simulations and no follow-up brush treatment was simulated. Ten-year simulations were used, with 1 January 2002 being the starting date for each simulation.

A similar approach was used to evaluate effect of distance from the drainage outlet. In this case, the watershed was divided into three zones. The main drainage channel was divided into three segments. The first segment was the lowest one-third between the outlet and the highest elevation of the drainage, the second segment was the middle one-third, and the third segment was the upper (highest elevation) one-third of the drainage. The three respective zones included the area of the watershed extending upslope on both sides of the drainage along the respective segment. One simulation was conducted for each zone, with the brush treatment applied only to the respective zone in each simulation. The same brush treatment was used for these simulations as was used in the distance from drainage simulations.

The effect of brush control on water enhancement was evaluated on the basis of four output variables: 1) amount of surface runoff, 2) recharge (deep soil storage + groundwater recharge), 3) groundwater use by vegetation, and 4) net water yield. The amount of area treated in each simulation varied because of different amounts and densities of the brush in each band or zone and the different size (area) included in each band or zone. Although all five bands were 100 m wide, their lengths differed somewhat because of topography. Surface area included in each zone also differed because of the differences in lateral distances from the center of the channel to the outer edges of the watershed in each zone. To account for these differences in surface area, the values of the output variables were averaged over the amount of actual treated area in each simulation.

An alternative approach would have been to select areas of approximately equal size in each band and in each zone and treat only these selected areas. That approach was not taken for three reasons. First, no two areas are uniform across a landscape. Secondly, at least some of the differences among bands or zones are the result of spatial variation characteristic of the bands and zones and these differences are part of what should be included in an evaluation of the effects of differences in the respective distances. Lastly, averaging across a band or zone is the more practical approach. It is unlikely that evaluations will be conducted on each block of potentially treated area. Instead, management decisions will be based on relative locations on the landscape, as well as type and density of woody species.

3.0 RESULTS

3.1 Selected Watersheds

The two watersheds that were selected were Watershed 13 Denton Creek Watershed and Watershed 39 Mitchell Creek-Peach Creek Watershed (Figure 1). Watershed 13 covers 21,119 acres and Watershed 39 covers 26,687 acres.

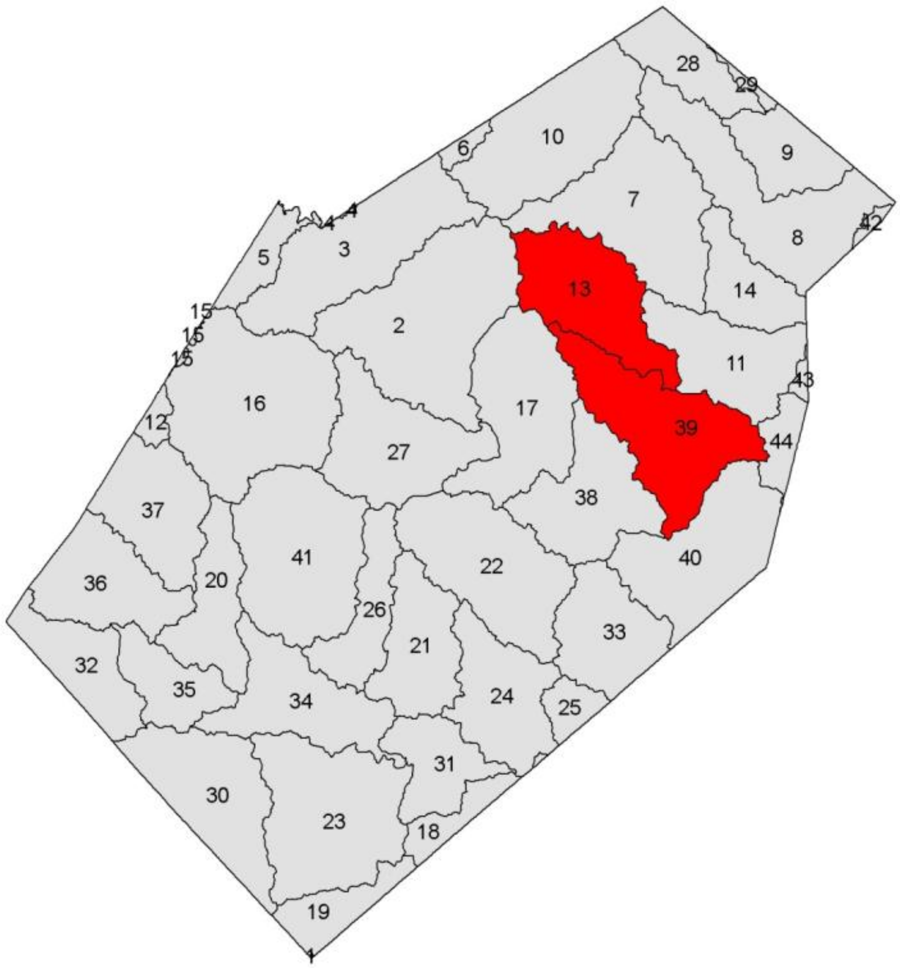

Figure 1. Locations of the two Gonzales County watersheds (13 and 39), shown in red, used in the model simulations to quantify the effect of distance on brush control effectiveness for water enhancement.

Both watersheds contained substantial amounts of each of the target species (Table 1). The acreage covered by each species was estimated by multiplying the area of each vegetation polygon by the percent coverage of that species within the polygon. The vegetation polygons in the Gonzales County model were delineated based on available data (McLendon et al. 2012) and the percent coverage of woody species was estimated from aerial photographs included in the NRCS soil survey for Gonzales County (Griffin et al. 2006).

Table 1. Estimated area (acres) covered by major woody species in non-riparian areas of two watersheds in Gonzales County.

Species	Scientific Name	Denton Creek Watershed 13	Mitchell Creek-Peach Creek Watershed 39
Huisache	*Acacia farnesiana*	777	871
Eastern red cedar	*Juniperus virginiana*	366	555
Mesquite	*Prosopis glandulosa*	1361	1894
Target tree total		2504	3320
Pecan	*Carya illinioensis*	25	27
Hackberry	*Celtis laevigata*	266	236
Post oak	*Quercus stellata*	814	986
Live oak	*Quercus virginiana*	97	147
Non-target tree total		1202	1396
Blackbrush	*Acacia rigidula*	0	9
Prairie baccharis	*Baccharis texana*	203	61
Granjeno	*Celtis pallida*	142	143
McCartney rose	*Rosa bracteata*	203	61
Shrub total		548	274

Based on the spatial data from the NRCS soil survey, the two watersheds have similar vegetation. Watershed 13 contains about 2,700 acres of target woody species, including McCartney rose, (Table 1) and this is almost 13% of the area of the watershed. Watershed 39 contains about 3,400 acres of target woody species, and this is also about 13% of that watershed. Based on acreage covered by target and non-target woody species in non-riparian areas, 20% of Watershed 13 is covered in woody species compared to 18.7% in Watershed 39. About 31% of the acreage covered by target woody trees in Watershed 13 is covered by huisache, compared to about 26% in Watershed 39. Conversely, Watershed 39 contains proportionately slightly more eastern red cedar and mesquite than does Watershed 13 (74% and 69%, respectively).

3.2 Effects of Distance from Drainage Channel

3.2.1 Watershed 13

Under baseline conditions (i.e., no brush control treatments), net annual water yield from Watershed 13 was - 0.323 acre-inches, averaged over the 10 years (2002-2011) of the EDYS simulation. Surface runoff averaged 0.648 acre-inches and there was a slight amount of net recharge (including soil storage). However, there was an average of 1.018 acre-inches of groundwater use by the vegetation which resulted in the negative annual yield in this watershed.

When averaged over the entire watershed and over the 10-year simulation period, brush control in any of the five bands had no effect on net watershed surface runoff. Any effect that brush control had on runoff from a treated area was negated by the surrounding untreated areas.

Brush control in all five of the bands increased recharge slightly compared to baseline. The increase was small and when averaged over the entire watershed and over the 10 years it was the same amount (0.002 acre-inch per year) for each band.

Based on the model simulations, the primary effect on enhanced water yield from brush control in Watershed 13 was the result of decreased groundwater use by the woody vegetation. Under baseline conditions (no brush control), vegetation used an average of 1,791 acre-feet of groundwater per year during 2002-11 (Table 2). Brush control in Band 1 (020-120 m from drainage channel) resulted in the largest reduction in groundwater use (93 acre-feet less per year; Table 2). There was less reduction in groundwater use in the subsequent bands.

Table 2. Effect of distance from drainage channel (m) on groundwater use by vegetation and change in net water yield on Watershed 13. Groundwater use and water yield values are annual averages, 2002-11.

	Baseline	**020-120**	**120-220**	**220-320**	**320-420**	**420-520**
Treated area in band (acres)	0	1,114	1,009	945	891	848
Total groundwater use (ac-ft/21,119 ac)	1,791	1,698	1,716	1,718	1,728	1,730
Enhanced net water yield (ac-ft/21,119 ac)	0	96.7	78.0	77.4	66.8	62.0
Enhanced net water yield (ac-ft/treated ac)	0	0.087	0.078	0.082	0.075	0.073

Enhanced net water yield (annual average, 2002-11) is the increase in net water yield compared to baseline for the entire watershed, expressed on a watershed (21,119 ac) and a per treated acre basis.
Increase in net water yield = 3.52 acre-feet of increased recharge + decrease in total groundwater use.

Although groundwater use was reduced the most when brush control was applied in Band 1, more acres were treated in Band 1 than in the other bands (Table 2). When accounting for difference in area treated, and adding the 3.52 acre-feet of increased recharge achieved in all the bands, Band 1 still had the highest net water yield enhancement (0.087 acre-feet per acre treated per year).

On a per treated acre basis, water enhancement was 6-19% greater in Band 1 (nearest the channel) than in the other bands (Table 3). Compared to brush treatment in the 100 m nearest the 20-m buffer strip, water enhancement decreased 6-10% when brush control was applied 120-320 m from the channel and by 14% when applied 320-520 m from the channel.

Table 3. Ratios of enhanced net water yield per treated acre per year (Table 2) among the five brush control treatment bands in Watershed 13.

	Numerator				
Denominator	**020-120**	**120-220**	**220-320**	**320-420**	**420-520**
020-120	1.000	0.897	0.943	0.862	0.839
120-220	1.115	1.000	1.051	0.962	0.936
220-320	1.061	0.951	1.000	0.915	0.890
320-420	1.160	1.040	1.093	1.000	0.973
420-520	1.192	1.068	1.123	1.027	1.000

3.2.2 Watershed 39

Under baseline conditions, net annual water yield from Watershed 39 was - 0.126 acre-inches, averaged over the 10 years (2002-2011) of the EDYS simulation. Surface runoff averaged 0.780 acre-inches and net recharge (including soil storage) averaged 1.132 acre-inches. However, these positive inputs were offset by an average of 2.038 acre-inches of groundwater use by vegetation.

As was the case with Watershed 13, runoff from the entire watershed was unaffected by brush control in any of the bands. Recharge, averaged over the entire watershed, was also unaffected by brush control in any of the bands. In both cases, runoff and recharge, the amount of land treated was insufficient compared to the area of the watershed to affect either variable.

Based on the model simulations, groundwater use by vegetation was affected by brush control and by the location of the brush control. Under baseline conditions, vegetation used an average of 4,532 acre-feet of groundwater per year (Table 4), or about 2.5 times as much as used in Watershed 13 (Table 2). Brush control in Band 1 (020-120 m from drainage) resulted in a reduction in groundwater use of 216 acre-feet (Table 4). The effect of brush control decreased with each subsequent band.

Table 4. Effect of distance from drainage channel (m) on groundwater use by vegetation and change in net water yield on Watershed 39. Groundwater use and water yield values are annual averages, 2002-11.

	Baseline	**020-120**	**120-220**	**220-320**	**320-420**	**420-520**
Treated area in band (acres)	0	735	639	576	548	531
Total groundwater use (ac-ft/26,687 ac)	4,532	4,317	4,381	4,412	4,426	4,437
Enhanced net water yield (ac-ft/26,687 ac)	0	215.7	151.2	120.1	105.8	95.6
Enhanced net water yield (ac-ft/treated ac)	0	0.294	0.237	0.209	0.191	0.180

Enhanced net water yield (annual average, 2002-11) is the increase in net water yield compared to baseline for the entire watershed, expressed on a watershed (26,687 ac) and a per treated acre basis.

The effect of distance from the drainage on enhanced net water yield was similar on a per treated acre basis (Table 4). Brush control in Band 1 resulted in an annual enhancement of 0.29 acre-feet per acre treated, compared to 0.18 acre-feet per year in Band 5. Water enhancement was about 20% less when the brush control was applied to Band 2 than to Band 1, and almost 40% less when applied to Band 5 (Table 5).

Table 5. Ratios of enhanced net water yield per treated acre per year (Table 4) among the five brush control treatment bands in Watershed 39.

	Numerator				
Denominator	**020-120**	**120-220**	**220-320**	**320-420**	**420-520**
020-120	1.000	0.806	0.711	0.649	0.612
120-220	1.241	1.000	0.882	0.806	0.759
220-320	1.407	1.134	1.000	0.914	0.861
320-420	1.539	1.241	1.094	1.000	0.942
420-520	1.633	1.317	1.161	1.061	1.000

3.3 Effects of Distance from Drainage Outlet

3.3.1 Watershed 13

Averaged over the entire watershed and over the 10-year simulation period, brush control in any of the three zones did not affect runoff but did have a slight effect on recharge. Brush control applied to Zone 1 (lower third and nearest the outlet) increased recharge by an average of 15.84 acre-feet (total for the entire watershed) per year and when applied to Zone 2 (middle third) it increased annual recharge by 8.90 acre-feet. Brush control applied to Zone 3 (upper third) did not increase recharge over that of baseline.

Brush control applied to 967 acres in the lower one-third of the watershed reduced groundwater use in the simulations by an average of 116 acre-feet per year, compared to baseline (Table 6). This compares with about 74 acre-feet enhancement from treating 938 acres in the middle one-third and less than 9 acre-feet from treating 1,024 acres in the upper one-third. Adding the small amount of increased recharge, total net enhancement averaged 0.137 acre-feet per treated acre per year in the lower one-third of the watershed, 0.086 acre-feet per treated acre in the middle one-third, and less than 0.01 acre-feet per treated acre in the upper one-third of the watershed (Table 6). On a percentage basis, brush control was 59% more effective for water enhancement when applied to the lower one-third of the watershed than to the middle one-third and 15 times more effective than when applied to the upper one-third (Table 7).

Table 6. Effect of distance from drainage outlet on groundwater use by vegetation and change in net water yield on Watershed 13. Groundwater use and water yield values are annual averages, 2002-11.

	Baseline	Zone 1 (Lower third)	Zone 2 (Middle third)	Zone 3 (Upper third)
Treated area in the zone (acres)	0	967	938	1,024
Total groundwater use (ac-ft/21,119 ac)	1,791	1,676	1,718	1,783
Enhanced net water yield (ac-ft/21,119 ac)	0	116.1	74.1	8.8
Enhanced net water yield (ac-ft/treated acre)	0	0.137	0.086	0.009

Enhanced net water yield (annual average, 2002-11) is the increase in net water yield compared to baseline for the entire watershed, expressed on a watershed (21,119 ac) and a per treated acre basis.
Increase in net water yield = decrease in total groundwater use over baseline + increased recharge.
Increased annual recharge = 15.84 ac-ft for Zone 1, 8.90 ac-ft for Zone 2, and 0 ac-ft for Zone 3.

Table 7. Ratios of enhanced net water yield per treated acre per year (Table 6) among the three brush control treatment zones in Watershed 13.

		Numerator	
Denominator	**Zone 1 (lower)**	**Zone 2 (middle)**	**Zone 3 (upper)**
Zone 1 (upper)	1.000	0.628	0.066
Zone 2 (middle)	1.593	1.000	0.105
Zone 3 (lower)	15.222	9.556	1.000

3.3.2 Watershed 39

Based on the model simulations, brush control had only a small effect on runoff when calculated for the entire watershed. Average annual surface runoff for the entire watershed under baseline conditions was 173.47 acre-feet. This amount did not change when brush control was applied to the upper one-third of the watershed but increased by an average of 2.22 acre-feet per year when applied to the lower one-third and decreased by about the same amount when applied to the middle one-third of the watershed.

The simulated brush control treatments increased recharge when applied to all three zones, but by only small amounts. Average annual recharge for the entire watershed was increased over baseline by 11.12 acre-feet per year when brush control was applied to the lower one-third of the watershed, by 6.11 acre-feet per year when applied to the middle one-third, and by 15.57 acre-feet when applied to the upper one-third.

Groundwater-use by vegetation was reduced by brush control in all three zones (Table 8). Brush control applied to 981 acres in the lower one-third of the watershed reduced groundwater use in the simulations by an average of 258 acre-feet per year, compared to baseline. This compares with an average of 215 acre-feet per year enhancement from treating 1,027 acres in the middle one-third and 262 acre-feet per year from treating 1,030 acres in the upper one-third. Adding the respective amounts from runoff and from recharge, total net water enhancement averaged 0.276 acre-feet per treated acre per year in the lower one-third zone, 0.214 acre-feet in the middle zone, and 0.266 acre-feet in the upper zone (Table 8). On a percentage basis, brush control was 29% more effective for water enhancement when applied to the lower one-third of the watershed than to the middle one-third and only slightly more effective (4%) than when applied in the upper one-third (Table 9).

Table 8. Effect of distance from drainage outlet on groundwater use by vegetation and change in net water yield on Watershed 39. Groundwater (GW) use and water yield values are annual averages.

	Baseline	Zone 1 (Lower third)	Zone 2 (Middle third)	Zone 3 (Upper third)
Treated area in the zone (acres)	0	981	1,027	1,030
Total groundwater use (ac-ft/26,687 ac)	4,532	4,274	4,317	4,270
Decrease in GW use over baseline (ac-ft)	0	258.0	215.7	262.4
Increase in runoff over baseline (ac-ft)	0	2.2	-2.2	0.0
Increase in recharge over baseline (ac-ft)	0	11.1	6.1	15.6
Enhanced net water yield (ac-ft/26,687 ac)	0	271.3	219.6	278.0
Enhanced net water yield (ac-ft/treated acre)	0	0.276	0.214	0.266

Table 9. Ratios of enhanced net water yield per treated acre per year (Table 8) among the three brush control treatment zones in Watershed 39.

		Numerator	
Denominator	**Zone 1 (lower)**	**Zone 2 (middle)**	**Zone 3 (upper)**
Zone 1 (upper)	1.000	0.775	0.964
Zone 2 (middle)	1.290	1.000	1.243
Zone 3 (upper)	1.038	0.805	1.000

4.0 DISCUSSION

Both distance from the drainage channel and distance from the outlet had an effect on water enhancement from brush control in the model simulations of these two watersheds. In both watersheds, water yield enhancement was highest nearest the channel and nearest the outlet.

Averaged over the two watersheds, net water enhancement was 18% greater on a per treated acre basis when brush control was applied 20-120 m from the channel than when applied 120-220 m from the channel and 41% greater than when applied 420-520 m from the channel. In both watersheds, water enhancement was greater in the nearest band (20-120 m) than in all of the other four bands. Averaged over the four bands (120-520) and over both watersheds, this average increase was 29%.

Although the pattern was the same between the two watersheds, the magnitude of the response was greater in Watershed 39. The average increase in water enhancement on the nearest band (20-120 m from the channel) over enhancement on the other bands (120-520 m distance) was 45% in Watershed 39 compared to 13% in Watershed 13 (Tables 3 and 5). Vegetation differences between the two watersheds probably contributed to these differences in the magnitude of the response to brush control (Wu et al. 2001; Wilcox and Thurow 2006). Improved pastures were common in both watersheds and although many of these improved pastures had various levels of re-establishment of woody species such as huisache and mesquite, they generally had lower woody plant cover than most un-treated areas (Figure 2). In addition, lower-elevation sites tended to have denser woody vegetation (Figure 3) which also included a higher composition of non-target species. The areas included in the five treatment bands in both watersheds had substantial amounts of improved pasture that had low to moderate (< 65%) coverage of woody plants (57% of the area in Watershed 13 and 49% in Watershed 39). However, the five bands in Watershed 39 had a higher amount of dense (65-95%) woody coverage than in Watershed 13 (47% and 17%, respectively). In addition, 78% of the area in Band 1 of Watershed 39 was in dense woody vegetation compared to 37% in Band 1 of Watershed 13.

Figure 2. Mosaic of improved pastures with varying amounts of woody plant re-establishment and untreated areas in Gonzales County.

Figure 3. Dense woody vegetation common along drainages in Gonzales County.

The greatest water enhancement from brush control also occurred in the zone nearest the drainage outlet in both watersheds (Tables 7 and 9). Brush control in Zone 1 (nearest the drainage outlet) increased water enhancement by 44% compared to treatment in Zone 2 (middle zone), on a per treated acre basis. The pattern was the same in both watersheds, but the increase was greater in Watershed 13 than in Watershed 39 (59% and 29%, respectively).

Comparisons between Zones 1 and 3 are more difficult to make between the two watersheds. Water enhancement was greater in Zone 1 than in Zone 3 in both watersheds, but the magnitudes suggest major differences between the two watersheds. Brush control in Zone 3 (upper portion) of Watershed 13 had little effect on water enhancement (Table 6). Whatever benefits were achieved was quickly lost by regrowth of the vegetation and increased water losses downstream. This is what would be predicted from the general guidelines presented in Fish and Rainwater (2007). In Watershed 39, water enhancement was much greater in Zone 3 than it was in Zone 3 of Watershed 13, but there was only a 4% increase in water enhancement between treating brush in Zone 1 compared to Zone 3 in Watershed 39. This low value is likely the result of differences in vegetation between the zones in Watershed 39. Dense riparian-type vegetation with high woody plant coverage, but with many non-target species, occurred along drainages in all three zones of both watersheds (Figure 3). In Watershed 39, 54% of the treated area in Zone 1 (nearest the outlet) was dense woody vegetation with many non-target species (Figure 3) compared to only 19% of the treated area in Zone 3. Therefore, brush removal in Zone 3 of Watershed 39 was effective because of the high proportion of target species, and brush removal in Zone 1 was effective because the woody vegetation was dense.

Because of these differences in vegetation between Zones 1 and 3 in Watershed 39, the small difference in water enhancement between the two zones may be atypical. However, the very high percentage from Watershed 13 may also be somewhat atypical. Rather than averaging the two percentages, a more reasonable approach is to sum the amounts (Enhanced net water yield (ac-ft/treated acre); Tables 6 and 8) and take the mean of those. That approach results in an average yield of 0.207 ac-ft in Zone 1 and 0.138 ac-ft in Zone 3, or a 50% increase in Zone 1 compared to Zone 3.

5.0 CONCLUSIONS

The general guidelines for ranking of locations in a watershed for water enhancements through brush control that were developed by Fish and Rainwater (2007) indicated that locations nearer drainage channels and locations nearer the drainage outlet from the watershed were more likely to have greater potential for water enhancement than locations farther from drainage channels or from drainage outlets. The results of the simulation modeling study that are presented in this report support those two guideline points.

Results of this study indicate that, at least on the two watersheds that were evaluated, average net water enhancement was 18% greater on a per treated acre basis when the brush control was conducted near (20-120 m) the drainage channel than when it was applied 120-220 from the channel, 41% greater than when applied 420-520 m from the channel, and 29% greater when averaged over the applications from 120-520 m. The model simulations also indicated that net water enhancement was 44% greater when the brush control was applied in the zone nearest the drainage outlet (nearest one-third of the watershed) than in the middle one-third of the watershed, and an average of 50% greater than when applied in the one-third of the watershed the furthest from the outlet.

Although the specific enhancement values varied between the two watersheds in the simulations, the pattern of greater enhancement nearer the channel and nearer the outlet was valid for both watersheds. At least part of the variability in values can likely be attributed to differences in vegetation in the various zones that were modeled.

It would be useful if these same simulation modeling exercises would be conducted on a watershed in a different locale, especially a locale with very different vegetation and topography. A possibility would be the EDYS model being developed in the Upper Llano River project currently being funded by TSSWCB in the western part of the Edwards Plateau (KS2 Ecological Field Services 2012).

The results of this study also relate to another major topic often associated with potential water enhancement from brush control. Some studies in the central Texas region indicate a substantial potential increase in water yield from brush control (Thurow et al. 2000, Wu et al. 2001). Results from other studies have been used to argue that there is little potential water enhancement from removal of woody plants (Dugas et al. 1998; Wilcox and Thurow 2006). This argument is often based on data indicating little increase in streamflow following brush control (Wilcox 2002; Wilcox et al. 2006). However, the studies providing those data fail to account for change in groundwater use by woody vegetation following brush control. This amount is likely to be substantial. One study has suggested that 20% of the water used by woody plants in the Edwards Plateau may come directly from deep sources of water (Jackson et al. 2000).

The results of this study may help to clarify the issue. Our simulation results indicate that little increase in runoff and shallow recharge occurred following brush control (given the conditions in the two watersheds that were modeled and the time period over which they were modeled). However, our results also indicate that most of the water enhancement benefits coming from brush control in these simulations were from decreased use of groundwater. In any water enhancement program, water saved should be just as valuable as water gained.

6.0 LITERATURE CITED

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