

**DEVELOPMENT OF AN EDYS ECOLOGICAL MODEL OF THE UPPER LLANO
RIVER WATERSHED AND EVALUATION OF POTENTIAL ENHANCEMENT OF
WATER YIELD FROM BRUSH CONTROL**

FINAL REPORT



PREPARED FOR:

TEXAS STATE SOIL AND WATER CONSERVATION BOARD

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EXECUTIVE SUMMARY

The Llano River is one of the major rivers flowing through the Edwards Plateau of Texas, supplying water to the region as well as being a major contributor to the Greater Colorado River Watershed, one of the largest river systems of Texas. The North Llano and South Llano Rivers form the headwaters of the Llano River, with the two rivers converging near Junction, Texas to form the Llano River. The Texas State and Soil and Water Conservation Board (TSSWCB) was a major contributor to the development of the Upper Llano Watershed Protection Plan. Part of the role of TSSWCB was to provide quantitative estimates of the impacts of various land management practices and natural climatic fluctuations on the surface water and groundwater supplies affecting the Upper Llano River system. These estimates were produced by use of the ecological simulation model EDYS. In addition, TSSWCB is interested in the development of county-wide simulation models to evaluate potential enhanced water yields from control of woody species. To meet both these needs, an EDYS model was developed for the Upper Llano River Watershed. This report presents a description of this model and results of simulations evaluating the potential for enhanced water yields from brush control.

Description of the Model

The spatial domain of the model is the combined watersheds of the North Llano and South Llano Rivers. It includes large portions of four counties (Edwards, Kimble, Real, and Sutton) and smaller portions of another three counties (Kerr, Menard, and Schleicher). The entire area included in the model footprint is about 2625 mi² (1.7 million acres), located in the southwestern part of the Edwards Plateau.

The basic spatial unit of the EDYS model is the cell, the size of which is flexible. The basic cell size in the Upper Llano model is 40 m x 40 m (0.40 acre). This resulted in an overall spatial footprint of 4.2 million cells. To improve run times and reduce memory requirements, six separate models were constructed for the Upper Llano watershed, three modeling the uplands and three modeling the rivers and floodplains. The six models were linked to form a single overall functional model, with the upland models using the 40 m x 40 m cell sizes and the river and floodplain models using a 10 m x 10 m cell grid to more precisely simulate dynamics in these wetland sites.

Surface topography in the model is defined by an average elevation for each cell, with slope and aspect determined by differences in elevation among adjacent cells, using USGS 10-m DEM data. Each cell also has an average depth to groundwater value, from which a depth to groundwater grid was defined for the entire model footprint.

The spatial domain was divided into seven precipitation zones, with separate precipitation files used for the cells in each zone. The model simulates rainfall on a daily basis. For each of the seven zones, a 120-year (1893-2012) daily precipitation record was created based on statistical relationships among recorded precipitation data from 20 stations in a 10-county region.

A detailed soil profile description was assigned to each of the 4.2 million cells in the model. These profiles were developed from NRCS soil survey descriptions of the included counties and from additional data available in the literature. A total of 48 soil types are included in the Upper Llano model and each cell is assigned one of the 48 soils based on the location of the cell on the spatial landscape. Each of the 48 soil types is divided into 20 layers, with the thickness and physical and chemical characteristics of each layer varying among the types. Some of the soil variables remain constant throughout a simulation (e.g., soil texture) while values of other variables (e.g., soil moisture) change by layer on a daily basis depending on environmental factors such as amount of rainfall received and amount of water and nutrients extracted by plants.

The number of plant species included in a specific EDYS application is flexible. A total of 51 species are included in the Upper Llano model. Dynamics of each species are modeled by use of 346 parameter variables, with each variable having different values for each species. Changes in vegetation are modeled in EDYS on a plant species (or plant part) basis by simulating differential responses, defined by the different parameter values, to changes in environmental factors (e.g., rainfall, grazing, season).

The spatial footprint of the model was divided into plant communities and land management units (e.g., cultivated, orchards, urban) by assigning each cell type to one of 63 plot types (upland vegetation, aquatic vegetation, and land-use types). The locations of the land-use types were based on 2012 NAIP aerial photographs and the locations of the vegetation types were based on NRCS soil survey maps, with some adjustment based on the NAIP aerial photographs. Each vegetation type was further divided based on amount of woody plant cover present, with these values visually estimated from the NAIP aerial photographs. Initial (i.e., start of each simulation) biomass values were entered for each plant species in each plot type based on species composition of each type. Biomass (above- and belowground) values change for each plant species and each plant part (e.g., fine roots, trunks, leaves) per species at each time step (daily) during an EDYS simulation.

The animal component in EDYS models consists of the effects of herbivory by different types of animals, both domestic and wildlife, on the vegetation. Herbivory is modeled as a plant-part and plant-species specific process, where selection of plant parts and plant species varies by animal species. Densities of each animal species are entered, and the model calculates the quantity of plant material the animals would consume daily and then determines how much of each species is removed based on selectivity, accessibility, and competitiveness among the animals. Four animal species (or groups) were included in the Upper Llano models: cattle, white-tailed deer, cottontail rabbits, and insects. Cattle were used to represent livestock because of lack of specific ratios of cattle, sheep, and goats for each ranch in the spatial domain. An average white-tailed deer density of 1 deer per 10 acres was used in the model. Cattle stocking rates were calculated for each vegetation type and averaged 24-33 ac/AU (varied between 7-106 ac/AU) for native rangeland across the four counties.

Calibration

Calibration in EDYS consists of making adjustments to parameter values, if needed, to achieve target values for the output variables under consideration. Target values are taken from independent validation data, either experimental validation studies or existing field data, if these data are available. In the absence of independent validation data, values from the literature and values based on professional judgment are used.

Independent validation data were not available for the use in the Upper Llano models. Therefore, data from published studies in the Edwards Plateau and adjacent regions and professional judgment were used to calibrate the vegetation and hydrologic dynamics of the models. Ten-year simulations for six plot types (plant communities) were used in the vegetation calibration process. Results of simulated vegetation change in response to fluctuations in rainfall, time (succession), and grazing were compared to published results from 16 studies and to our professional experience in the region. The simulation results compared favorably with the patterns and levels expected from these studies and regional experience. Overall, there was an increase in trees, primarily Ashe juniper and mesquite, over time. This is expected in a woodland-grassland ecotone in the absence of fire. Grasses increased under average and wet precipitation regimes but decreased on most sites under the dry regime. In proportion to initial values, cane bluestem was the midgrass species that had the greatest increase and purple threeawn and curly mesquite were the shortgrasses with the greatest increase in biomass.

Three ecohydrological components were assessed in the model calibration: 1) evapotranspiration (ET), 2) surface runoff, and 3) groundwater use by vegetation. The ecohydrological calibration data were taken from the same six plot types used in the vegetation calibration. Average annual ET on the six types varied between 15.4 and 27.9 inches. Overall, this was equal to 94.4% of annual precipitation under the average precipitation regime. This compares with reported values of 95% for an oak-grassland on the Sonora Experiment Station and 93% for mesquite-grasslands in the Rolling Plains. Simulated daily ET rates on the clay loam type (38% woody cover) averaged 1.7 mm (12-month basis) or 2.5 mm (growing season basis), compared to literature values of 1.7-2.6 mm for mesquite grasslands and 2.8 mm (growing season basis) for an Ashe juniper woodland in the eastern Edwards Plateau.

Runoff from the relatively level types in the simulations averaged 0.3-0.5 inch per year, which is similar to reported values in the literature of 0.2-1.2 inches for similar sites. Runoff was higher from the steeper-slope sites, averaging 2.8 inches per year. Literature values for juniper sites in the Edwards Plateau are in the range of 1.1-1.9 inches per year. The two upland types in the calibration simulations did not utilize any groundwater. However, groundwater use by vegetation in the other four types averaged 1.4 inches per year, or about 6% of annual transpiration on these sites.

Results

Four 25-year simulation scenarios were conducted to evaluate the response of the Upper Llano subwatersheds to fluctuations in precipitation and to evaluate the potential for enhanced water supply from brush control. Scenario 1 was the baseline scenario where the average precipitation regime (the 25 continuous years that had overall average annual precipitation nearest to the long-term annual average precipitation) was used with no brush control. Scenario 2 was the same as Scenario 1 except the driest 25-year precipitation regime was used. Scenario 3 was also the same as Scenario 1 except the wettest 25-year precipitation regime was used. Scenario 4 used the average precipitation regime, but brush control was added. The brush control option consisted of removing 100% of all woody species (except only 50% of live oak) from all cells with 50% or more woody plant cover. This option was applied in the first year of the 25-year simulation and there was no re-treatment. Woody species were allowed to regrow during the 25 years. A moderate stocking rate for cattle was used in all four scenarios.

Tree biomass increased on most types over the 25-year simulation under the average precipitation regime. Ashe juniper and mesquite were the two species that had the greatest consistent increases. On the clay loam sites with an initial woody-plant cover of 38%, Ashe juniper increased 85% over the 25 years and mesquite increased 7%. Both species decreased slightly on the low stony hill sites (10% and 9%, respectively). Midgrasses and shortgrasses varied among types in their successional responses. Midgrasses increased on some types and decreased on others, as did shortgrasses. In most cases, if there was an increase in one grass type there was a decrease in the other. Cane bluestem, sideoats grama, and little bluestem were the midgrasses that increased most often and purple threeawn, curly mesquite, and Texas wintergrass were the most consistent increasers among the shortgrasses.

Response to changes in precipitation regime varied by vegetation type and by species. In general, Ashe juniper was favored by the dry regime (10% average decrease from the average regime) on the more level types and by the wet regime (14% average increase over the average regime) on the steep sites. Live oak and mesquite were most favored by the wet regime on all types. Midgrasses were most favored by the wet regime on most types, with the greatest increase over average precipitation on the bottomland type. Cane bluestem, King Ranch bluestem, sideoats grama, and little bluestem were all more productive under the wet regime. On most sites, shortgrasses decreased under the wet regime in response to increased competition from the midgrasses. Both midgrasses and shortgrasses decreased on most sites under the dry regime.

Annual precipitation averaged 24.03 inches under the average precipitation regime, averaged over the entire watershed. In the absence of brush control (baseline), ET accounted for 86.4% of annual precipitation, or an annual average of 20.46 inches. This is similar to values reported for an oak-grassland community at the Sonora Experiment Station (95%) and an Ashe juniper community in the eastern Edwards Plateau (83%). Of the 20.46 inches of average ET, 0.27 inch (1.3% of ET) was from groundwater use by the vegetation. Surface runoff averaged 0.86 inch per year (3.6% of annual precipitation) and recharge into groundwater averaged 0.07 inch per year (0.3% of annual precipitation). The 3.6% of annual precipitation value compares favorably with measured values from research sites in the Edwards Plateau (2.9-4.2%).

Under baseline conditions averaged over the 25-year simulation, total annual water supply (precipitation plus groundwater usage) averaged 2,479,083 acre-feet. Of this, ET accounted for 85.4%, runoff 3.5%, groundwater recharge 0.3%, seep and spring flow 0.5%, and storage within the soil and subsoil system (including karst features) 10.3%. The brush control scenario resulted in a slight (0.5%) increase in ET and a small (1.0%) decrease in groundwater use by vegetation. Runoff decreased by 9.7% and groundwater recharge increased by 11.0%.

Potential for Enhanced Water Supply

The effects of brush control on potential enhanced water yield vary spatially across watersheds and therefore brush control should not be expected to result in substantial enhancement of water yield if applied indiscriminately across a watershed. Instead, specific areas with high potential for enhanced water yield should be identified and brush control applied to the identified areas. A primary purpose in this application of the Upper Llano EDYS models was to make such an evaluation. The brush control simulations assumed no re-treatment following the initial brush control and a 25-year projection. Higher enhanced yields would likely result with retreatment or with shorter project lifetimes.

The Upper Llano watershed is divided into 49 subwatersheds. Potential for enhanced water yield from brush control varied substantially among these subwatersheds. Half (25) of these subwatersheds were found to have potential for enhanced water yield under average precipitation conditions and under the brush control and grazing scenario that was simulated. The average annual enhanced yield from these 25 subwatersheds was 7,938 acre-feet (2,587 million gallons) per year, a 12% increase over baseline conditions. Five of the 25 subwatersheds held the highest potential for enhanced water yield and of these five, the enhanced yield from three of them accounted for 5,313 acre-feet (1,731 million gallons), or 67% of the total simulated enhanced yield.

Only parts of each subwatershed were subjected to brush control in these simulations (i.e., those areas with 50% or more total woody-plant cover and less than 12% slope). This amounted to 25,475 acres in the three subwatersheds with the highest potential for enhanced yield. The simulated brush control treatment on these 25,475 acres resulted in an enhanced annual yield of 5,313 acre-feet, or 0.21 acre-feet (67,777 gallons) per treated acre per year. Totaled over 25 years, this would equal 5.20 acre-feet (1,694,425 gallons) of enhanced yield per treated acre.

The total treated area combined over all 49 subwatersheds was 368,373 acres. When combined over all 49 subwatersheds and assuming no re-treatment, there was no enhanced water yield (i.e., brush control was not effective in enhancing water yield). The total treated area combined for the 25 subwatersheds showing some enhanced yield was 177,326 acres and the resulting enhanced yield was 7,938 acre-feet, or 0.045 acre-feet per treated acre (1.13 acre-feet over the 25 years). The difference between the per-acre yield from the three subwatersheds (5.20 acre-feet) and the yield from the 25 subwatersheds (1.13 acre-feet) is one measure of the value of the models as a decision-making tool.

1.0 INTRODUCTION

Water is one of our most valuable resources, critical to both natural and anthropogenic systems. Even without human impacts, water supplies fluctuate in response to variations in precipitation and vegetation change. Human activities have greatly increased demands on the water supply and have altered natural cycles. These natural and anthropogenic impacts have direct effects on surface water and groundwater supplies. Therefore, understanding potential impacts of various supply and demand factors is of primary importance in developing water management programs.

The Llano is one of the major rivers flowing through the Edwards Plateau of Texas, supplying water to the region as well as being a major contributor to the Greater Colorado River Watershed, one of the largest river systems of Texas. The Upper Llano River consists of two branches, the North Llano River and the South Llano River, located in the southwest portion of the Edwards Plateau. These two branches converge at Junction to form the Llano River, from where it continues to flow northeastward across the central Edwards Plateau before joining the Colorado River near Kingsland in Llano County, just upstream from Lake LBJ.

In addition to its role in supplying water to the Llano and Colorado River systems, the Upper Llano River is a critical source of water and wetland habitats in a region covering over 1.7 million acres. This Upper Llano watershed is currently considered to be a healthy system, with no water quality impairments (Broad et al. 2016). A watershed protection plan was completed in 2016 for the purpose of proactively addressing threats to the watershed and to improve the sustainability of the Upper Llano River (Broad et al. 2016).

The Texas State Soil and Water Conservation Board (TSSWCB) was a major contributor to the development of the Upper Llano River Watershed Protection Plan. Part of the role of TSSWCB was to provide quantitative estimates of the impacts of various land management practices and natural climatic fluctuations on the surface and groundwater supplies affecting the Upper Llano River system. Of particular importance was the evaluation of woody plant management on potential enhancement of water supply under various precipitation regimes. These estimates were produced by use of ecological simulation modeling. Ecological simulation modeling is a tool that allows complex hydrologic, ecological, and management responses to be integrated in a practical and scientifically valid manner, the results of which can substantially improve land-use planning and decision-making.

The EDYS model was the ecological simulation model used to evaluate potential benefits to various land management scenarios in the Upper Llano River watershed. EDYS is a mechanistic, spatially-explicit, dynamic ecosystem simulation model that has been applied widely to land management decision-making and environmental compliance and restoration (Ash and Walker 1999; Childress and McLendon 1999; Childress et al. 1999a, 2002; USAFA 2000; McLendon et al. 2000, 2012a, 2015; MWH 2003; Chiles and McLendon 2004; Price et al. 2004; McLendon and Coldren 2005, 2011; Naumburg et al. 2005; Amerikanuak 2006; Johnson and Coldren 2006; Johnson and Gerald 2006; Mata-Gonzalez et al. 2007, 2008; Coldren et al. 2011a, 2011b, HDR 2015; Broad et al. 2016). Medium- to large-scale watershed EDYS models have been developed for Camp Bullis, Texas (McLendon et al. 2001a), Cibolo Creek and Honey Creek Watersheds, Texas (Price et al. 2004, McLendon and Coldren 2007), Clover Creek Watershed, Utah (McLendon et al. 2000), Jacks Valley Training Area, USAFA Colorado (USAFA 2000), Townsville Training Center, Queensland (Ash and Walker 1999), 29 Palms MCAGCC, California (McLendon et al. 2001b) and county-wide models were developed for Goliad, Gonzales, Karnes, and Wilson Counties, Texas (McLendon et al. 2012a, 2015, 2016).

This document describes the EDYS model developed for the Upper Llano River Watershed and presents results of simulations of various management scenarios on vegetation and hydrologic responses. Of particular emphasis is potential enhanced water yield estimates from management of woody vegetation.

2.0 SPATIAL FOOTPRINT

The spatial domain of the model is the combined watersheds of the North Llano and South Llano Rivers (Fig. 2.1). It includes large portions of four counties and smaller portions of another three counties. Included in this footprint is the western half of Kimble County, the eastern half of Sutton County, the northern half of Edwards County, and the northwestern portion of Real County. Also included are small portions of the southern parts of Menard and Schleicher Counties and a small portion of the northwestern part of Kerr County. Although, the Upper Llano River watershed does not extend into Schleicher County, a small part of that county was included in the model domain to for spatial completeness. No water was moved in the simulations from Schleicher County into the Upper Llano River.

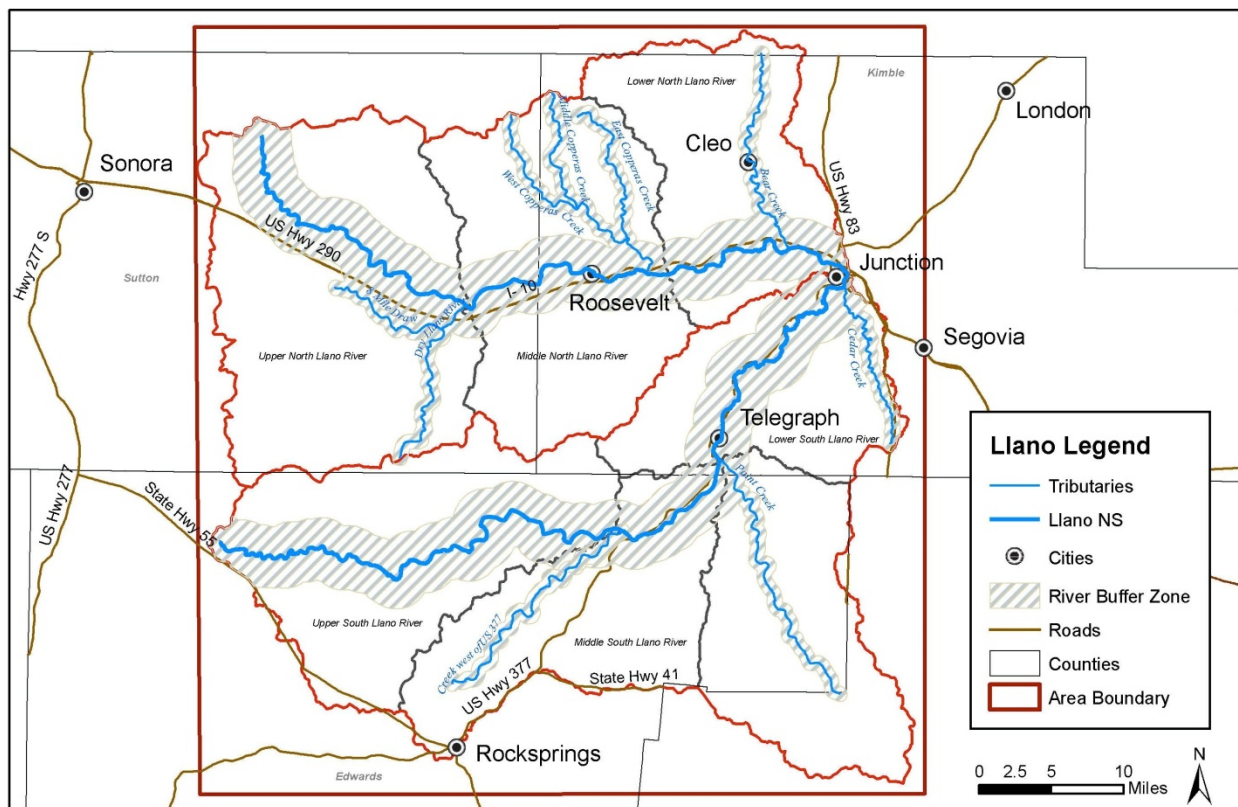


Figure 2.1 Spatial footprint of the Upper Llano River watershed model (area within the red rectangle). The hatched areas indicate the general footprints of the floodplain models.

The area included in the model footprint is about 2625 mi² (1.7 million acres), with about 884 mi² in Edwards County, 728 mi² in Sutton County, 652 mi² in Kimble County, 133 mi² in Real County, and 83 mi² in Kerr County. The North Llano River extends about 46 miles from its source in northcentral Sutton County to its confluence with the South Llano River at Junction. The South Llano River extends about 43 miles from its source in northwest Edwards County to its confluence with the North Llano River.

In EDYS, the spatial footprint is divided into cells. A cell is the smallest unit that EDYS simulates in a particular application and it can be of any size, 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. The smaller the cell size, the more spatially precise the simulation is. However, smaller cell sizes result in more cells and a larger number of cells results in slower run times per time step and more memory requirement. The primary cell size selected for the Upper Llano model is 40 m x 40 m (0.40 acre), resulting in approximately 4.2 million cells in the combined footprint. The following components (discussed in following sections of the report) are included for each cell: topography (elevation, slope, aspect), soil, depth to groundwater, vegetation, and land use.

A practical upper limit for efficient EDYS operation (relative to run time and memory requirement) on appropriate PCs is about 1.5 million cells. Combining multiple counties into a single model while retaining the 40 m x 40 m cell size is impractical because the spatial domain increases to well over the 1.5 million cell limit. The alternative approach is to keep each county model separate and then link the models, where output from one model can be used as input into another model. This has two primary advantages. First, it allows large spatial domains to be included while retaining small cell sizes. Secondly, it allows for separate individual models that can be run either as linked models or separately as individual models. An advantage in having separate models available is that simulations can be run for the separate domains much faster than if there was only one large model.

The spatial footprint for the entire Upper Llano model included about 4.2 million cells. The footprint was therefore divided into three models, with output linkages among the three. The spatial domain was divided along county lines (indicated in Fig. 2.1 by the three rectangles within the large red rectangle). The northwest model included the area of eastern Sutton County and a small portion of southeast Schleicher County. The northeast model included the area of western Kimble County and a small portion of southwestern Menard County. The south model included the area of Edwards County, northern Real County, and a small part of western Kerr County.

EDYS has the ability to simulate selected areas at a finer resolution than the primary cell size used in the overall model. This capability is particularly useful for simulating ecological and hydrologic dynamics in critical areas where a smaller scale becomes important. This option was used in the Upper Llano model to model the North Llano and South Llano floodplains (Fig. 2.1). In each of the three larger models (northwest, northeast, south), a river buffer zone was created by clipping out the 2-4 primary cells (80-160 m width) that included the immediate river floodplain in the larger model. These cells were subdivided into 10 m x 10 m cells (16 smaller cells imbedded in each primary cell), with these cells linked both perpendicular to the river (north-south) and downstream. Surface and subsurface water movement (including sediments) from the larger (upland) models were distributed along the floodplain by dividing the flows from each of the lowest elevation upland cells (40 m x 40 m) evenly among each of the corresponding highest elevation floodplain cells (10 m x 10 m). In effect, this created six models, an upland model for each of the three county units and three corresponding floodplain models.

3.0 TOPOGRAPHY

Surface topography is an important component in EDYS simulations. It controls the flow pattern and velocity of runoff water, inundation depth of flood water, water depth in ponds and lakes, and tidal depths and patterns in coastal wetlands, and it influences movement patterns for some wildlife species, foot and vehicle traffic, some management options (e.g., limitations to mechanical brush control because of steepness of slope), and fire events.

Elevation, slope, and aspect are the three topographic variables used in EDYS. All three are derived by EDYS from elevation data input. Surface topography is developed in EDYS based on differences in elevation among adjacent cells. Average elevation (USGS DEMs, or LIDAR data if available) is entered

for each cell. From these elevations, EDYS determines slope (angle from horizontal) and aspect (direction). 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. Direction based on the differences in elevation (i.e., aspect) determines the direction of surface flow. USGS DEM data (10-m resolution) were used to develop the initial elevation grid in the Upper Llano River model (Fig. 3.1).

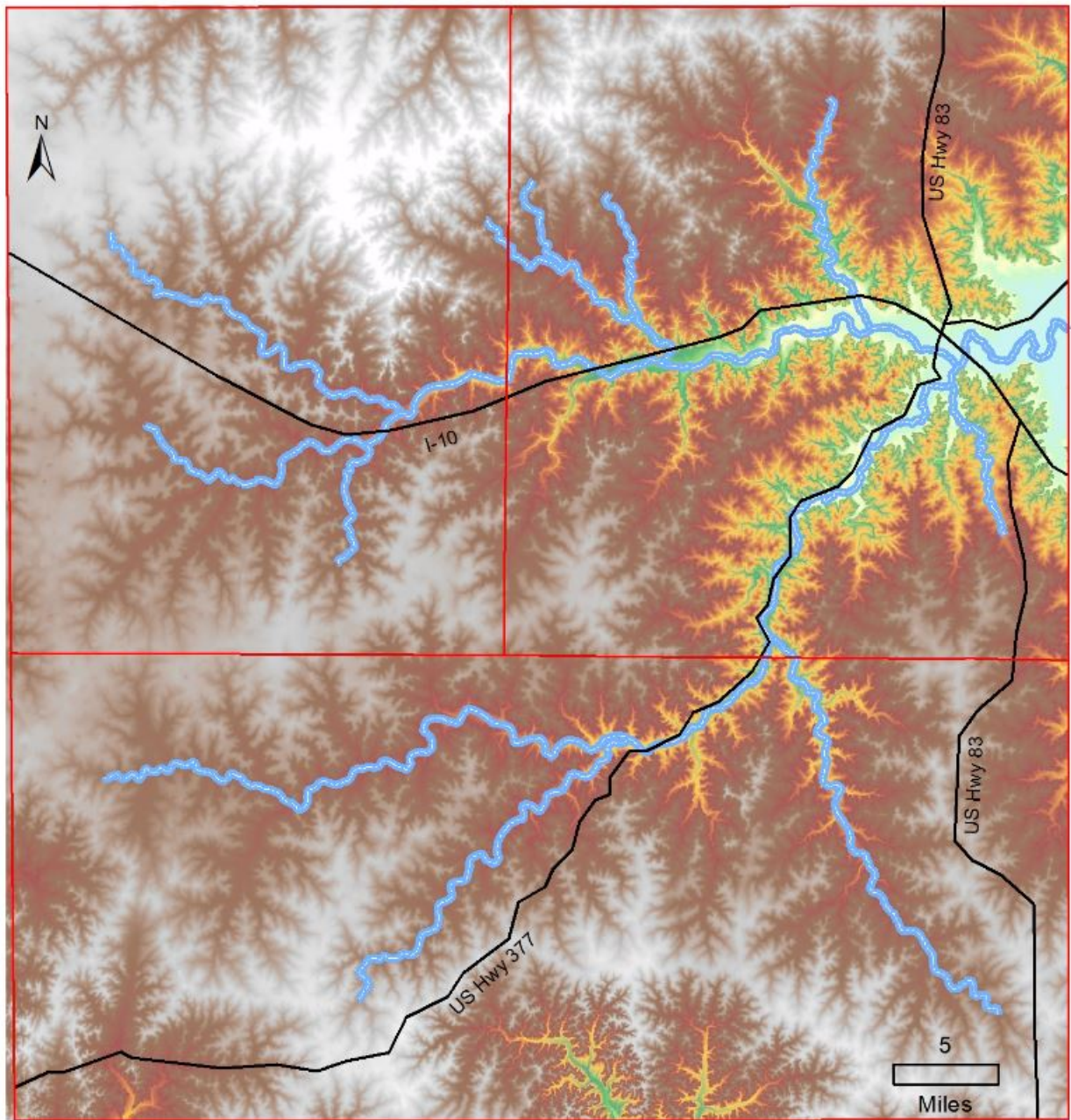


Figure 3.1 Topographic map of the Upper Llano River Watershed based on USGS 10-m DEM data. Highest elevations are presented in white/light gray and lowest elevations in green/pale blue.

In EDYS, precipitation is applied to each cell (Section 4.0). If that cell has the same elevation as all four adjacent cells (i.e., flat topography), there is no runoff and the water has maximum opportunity to infiltrate into the soil profile, the only loss in this case is from evapotranspiration. This condition in EDYS is termed “ponding”. If any of the adjacent cells have lower elevations than the central cell, some water flows from the central cell to the adjacent cells that have lower elevations. The amount of water that flows to the lower cells depends on the infiltration rate of the soil in the central cell, the magnitude of the slope between the central cell and each lower-elevation adjacent cell, and the intensity of the rainfall event. If an adjacent cell has a higher elevation than the central cell, water flows from the higher-elevation cell to the central cell, that amount of water is added to the quantity in the central cell that is available for runoff, and the total amount in excess of infiltration is moved to the adjacent lower-elevation cells. This process continues as a downslope process until all runoff water is moved to the lowest elevation cells or removed from the spatial footprint (surface flow export).

Once runoff water reaches a drainage, stream, or river channel, the water continues to flow downstream in response to the elevational gradient of the channel. In many cases, especially in limestone karst systems such as in the Edwards Plateau, there can exist “pools” in the channel beds. These are areas where the elevations are lower than those of surrounding cells within the channel. In these cases, water fills the pools until the capacity of the pool is reached, after which any additional flow moves downstream. There can also be subsurface losses, either along the channel or as surface flows (runoff) occur over the upland or floodplain surfaces.

During a simulation run, elevations can change because of erosion, deposition, or management activities (e.g., creation of roads, pads, cultivated areas). This process is discussed in more detail in the soils section (Section 5.0).

4.0 PRECIPITATION

Precipitation is an important driving variable for many ecological processes. Both temporal and spatial variations are ecologically important.

4.1 Temporal Variability

Precipitation varies at different time steps, e.g., minute to hourly during a rainfall event, daily, seasonally, annually, and long-term. EDYS inputs precipitation on a daily basis. Use of shorter-term periods (e.g., hourly) is possible in EDYS and can be used in simulations if necessary. The value of precipitation data in simulation modeling, as in most ecological studies, increases substantially as the length of the period of record increases. Long-term (more than 100 years) precipitation data are not available for most recording stations, and the data from most stations are not complete for the reported period of record (i.e., there are missing data). Constructed precipitation data sets (Section 4.3) are used in EDYS models to 1) account for missing values in the recorded data sets and 2) extend the length of the data set.

Precipitation patterns typically vary on short-, medium-, and long-term scales. Short-term fluctuations include 1) annual variations around a mean, with some years being either drier or wetter than average, and 2) series of below- or above-average precipitation years, the series often lasting 2-5 years but sometimes lasting a decade or more. Kerrville has one of the longest and most complete precipitation data sets for locations in the Edwards Plateau. The long-term (1902-2015) mean annual rainfall recorded at Kerrville (excluding four years with incomplete data) is 30.50 inches. The driest year on record was 12.33 inches in 1917 (40% of long-term mean), and the wettest year on record was 57.59 inches in 1919 (189% of long-term mean) two years after the driest year on record. The driest short-term (four continuous years) period on record was 2011-14, during which annual precipitation averaged 20.34 inches (67% of long-

term mean), and the wettest short-term (four continuous years) period on record was 1957-60, during which annual precipitation averaged 39.57 inches (130% of long-term mean).

Short-term periodicity at Kerrville involves wet-dry cycles of 10-29 years (length of full cycle = wet + dry period), with an average of 17 years (Fig. 4.1). Above-average (wet) cycle periods have an average length of 9.4 years (range = 4-22 years), with average annual means of approximately 30-40 inches (average annual = 34.21 inches). Below-average (dry) cycle periods have an average length of 7.0 years (range = 3-11 years), with average annual means of approximately 21-29 inches (average annual = 25.65 inches). Therefore, wet periods tend to last longer than dry periods, but dry periods tend to be more severe (greater average departure from long-term mean). There have been seven of these wet-dry cycles since 1902 and the average difference in annual rainfall between the dry and wet periods was 8.56 inches (Fig. 4.1). The current cycle has the largest difference in mean annual precipitation (13.45 inches) between the wet (2000-2007) and dry (currently 2008-2014) of any cycle since 1902.

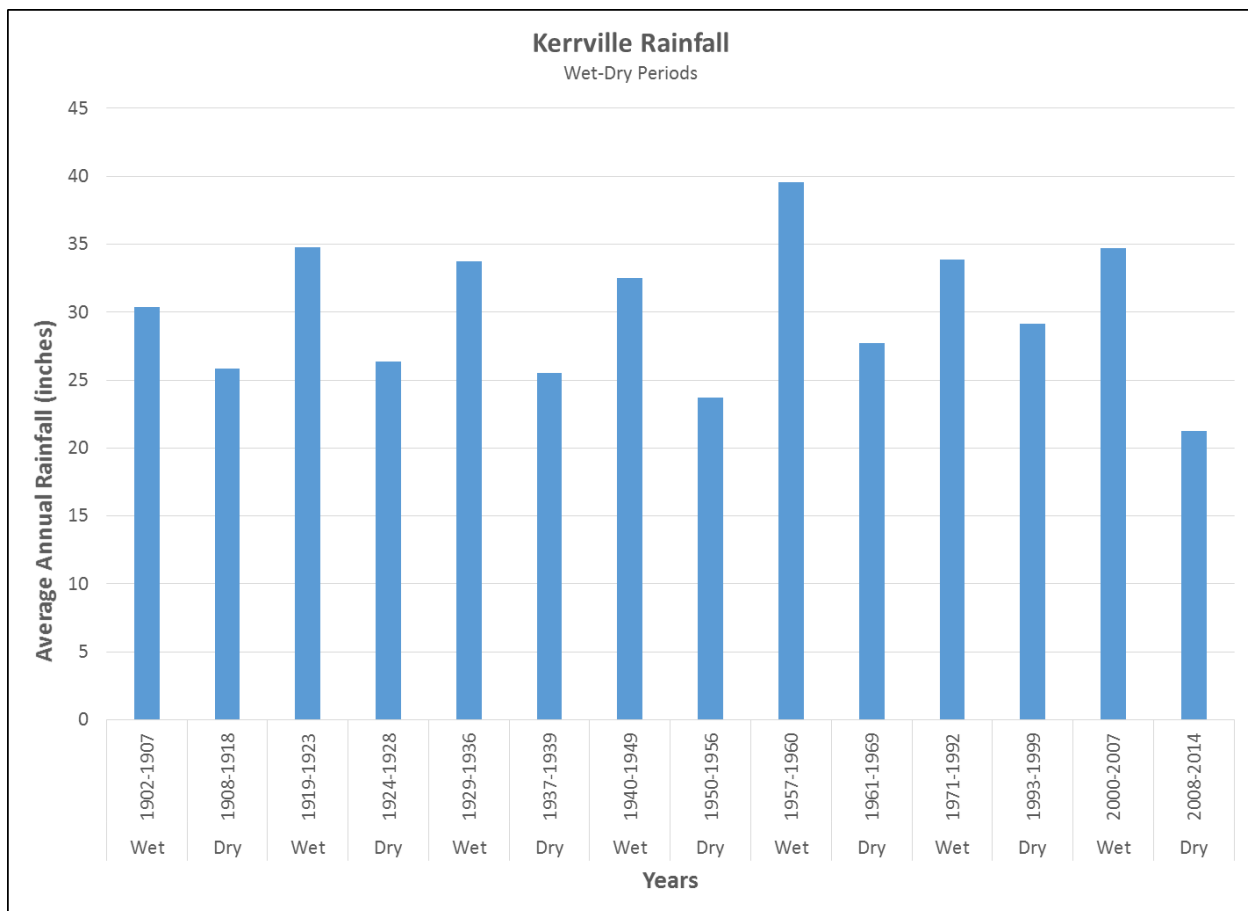


Figure 4.1 Mean annual precipitation (inches) during seven consecutive wet-dry periods at Kerrville, Texas (1902-2014).

Medium-term changes tend to be on the order of 40-60 years and, in the southwestern United States, are correlated with the Pacific Decadal Oscillation and the Atlantic Multidecadal Oscillation (Cayan et al. 1999, Hidalgo 2004, Mann et al. 2009, Steinman et al. 2015). These multidecadal cycles result in major

shifts in rainfall patterns in the Southwest, including the Edwards Plateau, which have major impacts on ecological and hydrological systems. For example, average annual rainfall at Kerrville during 1902-1956 (55 years) was 29.50 inches (Fig. 4.2). Average annual rainfall during the following 47 years (1957-2007) was 32.74 inches, an increase of 3.24 inches per year (14.4%) for 47 years. Over the past eight years (2008-2015), annual rainfall averaged 24.21 inches. The increased rainfall during the 45-50 years following the drought of the 1950s is also reflected at locations throughout the region (Table 4.1).

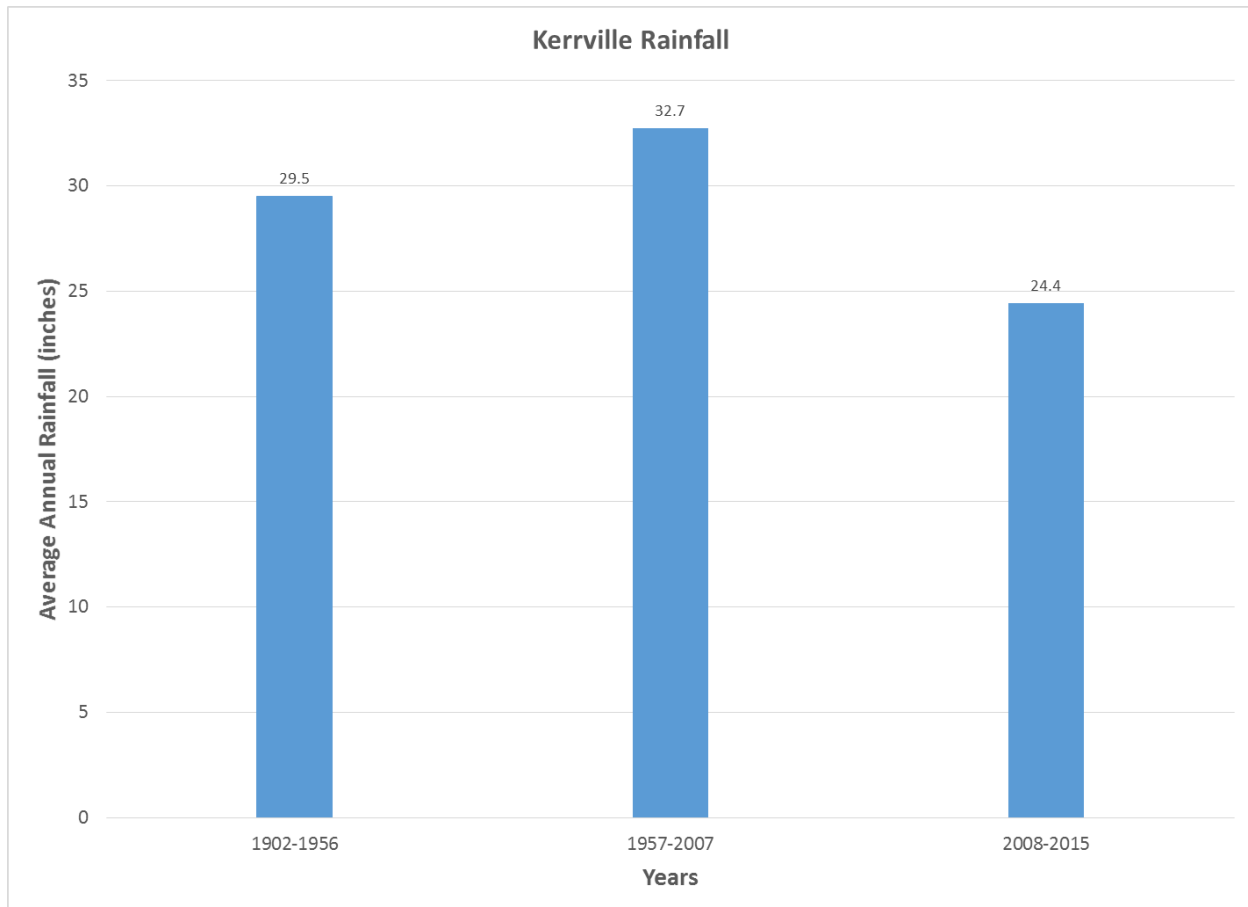


Figure 4.2 Average annual rainfall (inches) at Kerrville, Texas, during two multidecadal periods (1902-1956 and 1957-2007) and the most recent eight years (2008-2015).

Table 4.1 Average annual precipitation (PPT; inches) at six sites in the Edwards Plateau before the end of the drought of the 1950s and following the drought of the 1950s.

Location	Mean PPT	Before the End of the Drought			Following the Drought			After/Before
		Period	Years ¹	PPT	Period	Years ¹	PPT	
Cottonwood	28.87	1921-1956	33	27.12	1957-2007	43	30.98	1.14
Kerrville	30.50	1902-1956	55	29.50	1957-2007	47	32.74	1.11
Llano	26.66	1893-1954	57	25.72	1957-2004	47	28.12	1.09
Menard	22.94	1915-1956	35	22.32	1957-2007	50	24.19	1.08
San Antonio	29.12	1892-1956	65	26.10	1957-2004	48	32.57	1.29
Sonora Exp Sta	22.63	1919-1956	38	21.83	1957-2007	51	24.14	1.11
MEAN								1.14

¹ Years refers to number of years during the respective period for which there are no missing data.

These medium-length precipitation fluctuations are not confined to arid or semi-arid regions. Humid regions experience similar cycles. Tree-ring data from North Carolina indicate that region has undergone alternating wet-dry cycles of about 30 years each and that 1956-1984 was one of the wettest periods in the past 1600 years (Stahle et al. 1988). Oxygen ratios from stalagmites in Belize indicate that major droughts have occurred in the Yucatan at 100-200 year intervals over the past 1800 years and have lasted 50-80 years each occurrence (Kennett et al. 2012).

In addition to these annual and decadal fluctuations, precipitation patterns change over longer periods, e.g., centuries and millennia. Climatic patterns may be relatively stable for periods on the order of centuries and then, relatively rapidly (e.g., decades), change sufficiently to cause major vegetation shifts (Bjorck et al. 1996; Keigwin 1996; Tierney and deMenocal 2013). Much of the western United States underwent a 2000-year period of increasing aridity beginning about 2600 years ago, during which many woodlands in the region decreased in extent and shrublands increased (Tausch et al. 2004). Then, about 650 years ago, the Little Ice Age began and conditions became much cooler, resulting in an increase in extent of woodlands and wetlands. During that period, vegetation patterns were very different from current patterns (Tausch et al. 2004). Little Ice Age conditions lasted until about 120 years ago when climate shifted again, once more with increasing aridity. Much of northwestern Iowa was covered in deciduous forest from 9100-5400 BP, then changed to prairie grassland in 5400-3500 BP, and shifted to oak savanna after 3500 BP (Chumbley et al. 1990). These shifts in vegetation correspond to periods of rapid warming (3° C) followed by cooling (4° C) (Dorale et al. 1992). Nielson (1986) suggested that the black grama (*Bouteloua eriopoda*) desert grasslands encountered in the northern Chihuahuan Desert 100-150 years ago were a vegetation type established under, and adapted to, 300 years of Little Ice Age conditions and are only marginally supported, and perhaps not likely to be re-established, under present climatic conditions.

For 47 years, mean annual rainfall at Kerrville was 3.2 inches per year more than in the previous 55 years. That amount of increased rainfall over that long (3 inches per year for 47 years) is likely to have resulted in major shifts in vegetation composition and hydrologic yields. As annual average precipitation increases, the dominant species on grasslands shift from short-, to mid-, and then to tallgrasses. Areas receiving an annual average of 12-25 inches tend to be dominated by shortgrasses and mid- and tallgrass prairie commonly occurs on areas receiving 20-40 inches of precipitation annually (Weaver and Clements 1938:517; Weaver 1954:7; Stoddart and Smith 1955:51; Shelford 1963:329-334; Stoddart et al. 1975:28-32; Smeins and Diamond 1983; Dahl 1994; Miller 1994; Smeins 1994a; Bailey 1995:46, 62). As average annual precipitation increases above about 30 inches per year, tallgrasses begin to replace midgrasses as the dominant vegetation type. Above about 40 inches of annual precipitation, woodlands and forests begin to replace grasslands (Weaver and Clements 1938:510; Engle 1994; Bailey 1995). Stoddart and Smith (1955:48) suggested 38 inches as the upper limit of the tallgrass prairie.

Average annual rainfall at Kerrville was 32.74 inches from 1957-2007. This is only slightly below the level where the vegetation would shift from grassland to woodland. Rock surfaces increase the effectiveness of rainfall in supporting vegetation because water is concentrated in the cracks and openings among the rock surfaces. This increases the amount of rainfall per unit of surface area available for establishment of plants, thereby allowing more mesic vegetation to be supported on the site. With 20% surface cover of rock for example, the 32.74 inches of average annual rainfall would be the equivalent of about 41 inches of rainfall on the 80% of the surface not covered by rock, thereby providing ample moisture for growth of trees such as Ashe juniper (*Juniperus ashei*) and live oak (*Quercus virginiana*), and 47 years is ample time for trees to respond to this increased moisture. Thus it is likely that woody vegetation increased in abundance on the Edwards Plateau following the drought of the 1950s. That increase in deep-rooted species (e.g., Ashe juniper, live oak, mesquite) would also probably have increased the amount of groundwater used by the vegetation and decreased the amount of potential

groundwater recharge. This response to change in woody vegetation is discussed in more detail in Section 8.1.

4.2 Spatial Variability

Precipitation varies spatially as well as temporally, often at relatively short distances. Two recording stations at Junction (4SSW and Airport) are located about 4 miles apart (Table 4.2). Based on data from 23 years common to both stations, their annual averages differed by 0.9 inch (5% of the average value for the Airport station), and the average annual difference between the two sites was 1.5 inch (8.2% of the annual mean at the Airport). Two stations in the Rocksprings area (Rocksprings and 11 SW) are about 11 miles apart. Their annual average rainfall, for 24 common years, was 1.0 inch higher at the southwest location and the average annual difference between the two sites was 4.0 inches. Cottonwood and Harper are located about 7 miles apart in Gillespie County and based on common data years in 1949-1982, their annual precipitation differed by an average of 3.9 inches.

Table 4.2 Comparison of annual precipitation (inches) at three sets of nearby recording sites in the Edwards Plateau.

Junction				Rocksprings				Cottonwood-Harper (1949-82)			
Year	4SSW	Airport	Diff	Year	Rockspr	11SW	Diff	Year	Cottnwd	Harper	Diff
1948	25.34	24.96	0.38	1965	16.57	21.71	5.14	1949	35.97	32.74	3.23
1949	33.34	32.65	0.69	1966	24.81	27.22	2.41	1950	18.18	19.88	1.70
1950	21.24	22.93	1.69	1967	20.69	18.53	2.16	1951	16.21	15.50	0.71
1951	11.83	10.24	1.59	1968	24.62	24.64	0.02	1952	36.20	28.20	8.00
1952	13.31	12.00	1.31	1969	21.55	32.68	11.13	1953	25.49	14.63	10.86
1953	11.40	10.87	0.53	1970	18.92	14.59	4.33	1954	16.28	9.28	7.00
1954	10.61	11.37	0.76	1972	22.54	23.06	0.52	1955	27.27	24.59	2.68
1955	18.87	20.62	1.75	1973	23.76	26.02	2.26	1957	41.97	37.46	4.51
1956	11.17	11.37	0.20	1976	31.79	38.80	7.01	1958	41.16	41.14	0.02
1999	14.44	16.85	2.41	1977	21.34	16.72	4.62	1959	36.74	31.47	5.27
2000	30.17	29.41	0.76	1978	19.34	27.83	8.49	1963	19.40	19.53	0.13
2001	23.75	20.94	2.81	1979	22.93	16.17	6.76	1964	24.89	25.55	0.66
2002	18.76	18.00	0.76	1980	16.47	14.94	1.53	1966	21.56	23.80	2.24
2003	20.58	17.23	3.35	1981	42.82	45.85	3.03	1967	27.37	23.51	3.86
2004	27.31	29.75	2.44	1982	22.64	16.61	6.03	1970	18.06	18.26	0.20
2005	20.16	20.09	0.07	1983	21.83	29.13	7.30	1971	34.86	31.84	3.02
2006	15.88	17.46	1.58	1984	21.15	16.21	4.94	1973	34.50	30.57	3.93
2007	31.66	29.84	1.82	1986	28.89	33.59	4.70	1974	43.60	34.15	9.45
2008	14.14	12.78	1.36	1992	21.75	25.69	3.94	1976	31.26	27.76	3.50
2009	33.98	27.24	6.74	2008	12.72	13.64	0.92	1977	31.00	24.26	6.74
2010	20.04	20.66	0.62	2009	19.12	17.43	1.69	1978	39.19	31.41	7.76
2011	11.56	11.12	0.44	2010	24.88	22.57	2.31	1979	32.82	30.43	2.39
2012	16.19	16.78	0.59	2011	12.85	11.28	1.57	1980	30.00	25.12	4.88
				2012	18.22	21.59	3.37	1981	36.82	31.69	5.13
								1982	21.83	22.10	0.27
MEAN	19.38	18.48	1.51	MEAN	22.18	23.19	4.01	MEAN	29.71	26.19	3.93

Data are for years with complete data for both stations of a comparison.
Diff = absolute value of the differences.

These spatial differences can be very important in accounting for ecological dynamics across a landscape. In EDYS, precipitation is entered cell by cell across the spatial footprint. Use of precipitation data from a single station may not provide realistic estimates of these spatial patterns. To account for at least some of this spatial variation, the EDYS spatial footprint is divided into precipitation zones, each zone associated with a precipitation station. As a first approximation, all cells in a zone receive precipitation values associated with their respective station. Although this results in sudden changes in values as zone

boundaries are crossed (i.e., a step function response), a more realistic pattern is achieved than if data from only one station were used. If precipitation differences between zones seem sufficiently large, a linear difference approach can be used that provides cell-by-cell differences in precipitation based on average differences among adjacent stations. In the Upper Llano models, the first approximation approach was used.

In determining precipitation zones in EDYS, data are summarized from all available stations in a region, the region consisting of the counties included in the model plus immediately adjacent counties. Stations with data for 20 or more years are considered as primary stations (Table 4.3) and stations with data for less than 20 years are considered secondary stations.

Table 4.3 Mean annual precipitation (inches), period included, and number of years with complete data at the 20 primary stations used for precipitation data in the Upper Llano EDYS model.

Station	County	Mean Annual Precipitation	Period Included	Complete Data Years
Junction 4SSW	Kimble	23.90	1897-2012	83
Junction Airport	Kimble	20.88	1940-2012	35
Rocksprings	Edwards	23.35	1895; 1940-2012	55
Sonora Exp Sta	Edwards	22.77	1919-2012	94
Carta Valley	Edwards	24.20	1963-2012	39
Sonora	Sutton	21.36	1900-2012	60
Humble Pump Station	Sutton	22.11	1948-2012	39
Camp Wood	Real	26.82	1940-2012	57
Leakey	Real	30.38	1894-96;1989-2012	20
Prade Ranch	Real	27.59	1955-2012	44
Eldorado	Schleicher	20.28	1958-89;2003-2012	35
Fort McKavett	Menard	22.55	1852-83;1990-2012	27
Menard	Menard	22.94	1893-2012	97
Mason	Mason	26.64	1941-2012	59
Llano	Llano	26.68	1893-2012	112
Harper	Gillespie	26.78	1909-19;1948-2012	61
Fredericksburg	Gillespie	29.42	1896-1915;1939-2012	84
Cottonwood	Gillespie	28.89	1920-2012	81
Hunt	Kerr	28.64	1941-1999	48
Kerrville	Kerr	30.34	1897-2012	107

Caution should be used when directly comparing means among stations because of differences in years used to calculate the means.

The Upper Llano River drainage was divided into seven segments, each segment consisting of an approximately equal length of the North Llano, the South Llano, or the reaches of both rivers immediately above their confluence (Fig. 4.3). The NW Llano segment (#1, Fig. 4.3) corresponds to the upper portion of the North Llano River from its source to its southern-most curve before turning north towards Roosevelt. The NC (northcentral) Llano segment (#2, Fig. 4.3) includes the stretch from the end of the NW Llano segment to slightly east of the point where the North Llano River crosses I-10 east of Roosevelt. The NE Llano segment (#3, Fig. 4.3) stretches from the end of the NC segment to about the point where the North Llano River again crosses I-10 about 4 miles west of the confluence. The SW Llano segment (#4, Fig. 4.3) stretches along the South Llano River from its source to the northern-most bend in the river in Edwards County directly south of the Kimble-Sutton County line. The SC (southcentral) Llano segment (# 5 Fig. 4.3) stretches from this northern bend in Edwards County to where the river crosses the Edwards-Kimble County line south of Telegraph. The SE Llano segment (# 6, Fig. 4.3) extends from the Edwards-Kimble County line to about 4 miles south of its confluence with the

North Llano River. The Confluence segment (# 7, Fig. 4.3) contains the last 4-mile segments of the two rivers before their confluence and then east to where the river crosses under I-10.

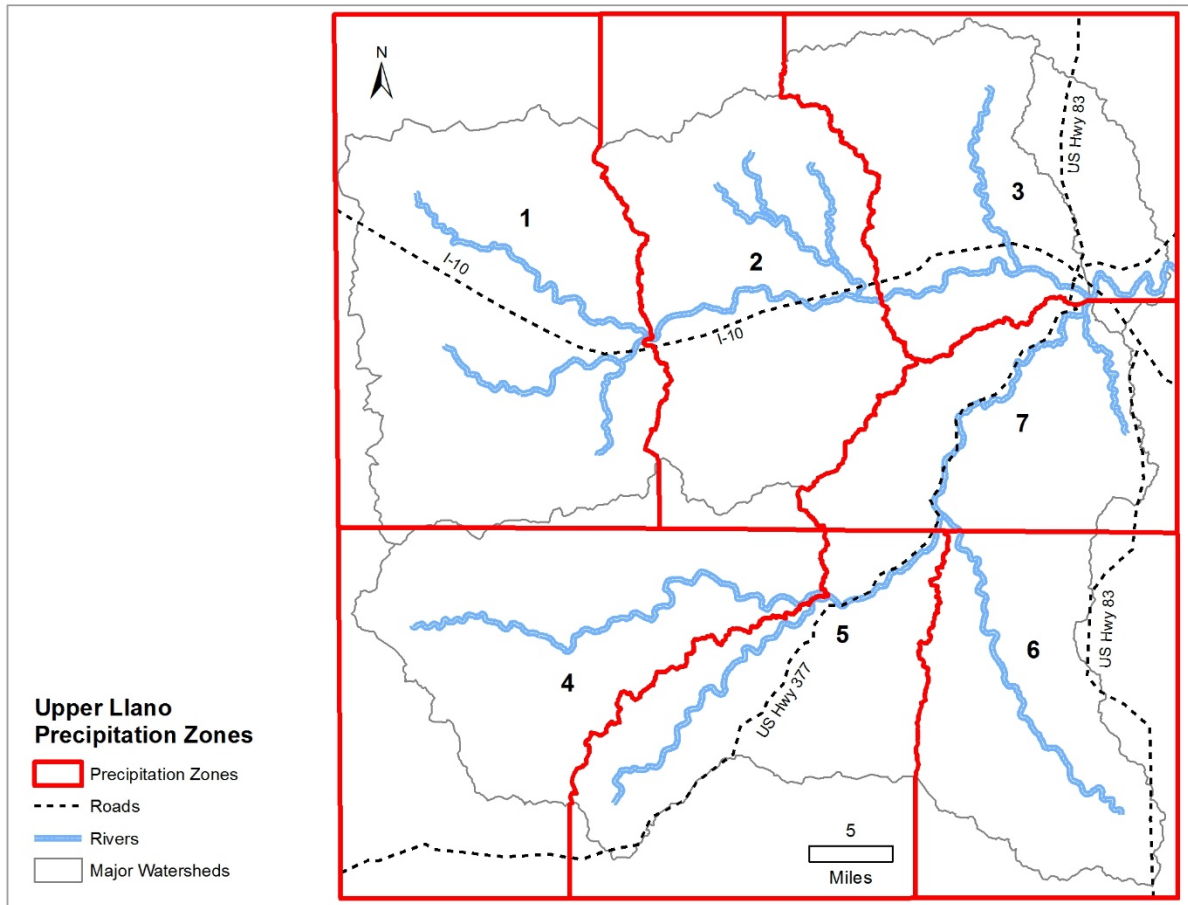


Figure 4.3 Division of the model domains into seven precipitation zones.

Each of these seven segments was assigned a precipitation regime developed using data from the nearest precipitation stations to the respective segment (Section 4.4). The first step in developing the regimes was to determine distances and directions from the primary stations to each segment (Table 4.3). Approximate mid-points of each segment were used for the distance calculations. The stations were ranked in order of their proximity to each segment and the closest 6-7 stations to each segment were identified. A station was included in the list for a particular segment based on relative distance and direction. Stations were selected for each segment that included at least one station from each of the four cardinal directions in order to account for directional variation in precipitation. Once the primary stations were selected for each segment (Table 4.4), a long-term constructed precipitation data set was developed for that segment.

Table 4.4 Primary precipitation stations selected for each of the seven river segments of the Upper Llano watershed, with distance (miles) and direction from the mid-point of the segment to the station.

NW Llano Segment		NC Llano Segment		NE Llano Segment	
11 S	Humble Pump Sta 5	13 SW	Humble Pump Sta 5	7 SE	Junction 4SSW
18 W	Sonora	19 E	Junction 4SSW	13 E	Junction Airport
20 SW	Sonora Exp Sta	22 N	Fort McKavett	21 NW	Fort McKavett
26 NE	Fort McKavett	26 E	Junction Airport	23 SW	Humble Pump Sta 5
28 NW	Eldorado	33 NE	Menard	28 N	Menard
33 E	Junction 4SSW	33 S	Rocksprings	37 SW	Rocksprings
SW Llano Segment		SC Llano Segment		SE Llano Segment	
13 SE	Rocksprings	13 NW	Humble Pump Sta 5	9 NE	Junction 4SSW
13 N	Humble Pump Sta 5	19 SW	Rocksprings	15 NE	Junction Airport
23 NW	Sonora Exp Sta	23 SE	Prade Ranch	24 W	Humble Pump Sta 5
33 NW	Sonora	23 NE	Junction 4SSW	32 S	Prade Ranch
33 SE	Prade Ranch	27 NE	Junction Airport	33 SW	Rocksprings
35 NE	Junction 4SSW	34 NW	Sonora Exp Sta	35 NW	Fort McKavett
38 SE	Camp Wood	38 S	Camp Wood	37 N	Menard
Confluence					
2 S	Junction 4SSW	30 N	Menard	31 SW	Humble Pump Sta 5
3 NE	Junction Airport	30 NW	Fort McKavett	33 SE	Harper

Annual precipitation received at each of the 16 primary stations most useful in estimating precipitation patterns over the spatial footprint were compared. For each two-station comparison, the amounts received in each year in which complete (12-month) data were available for both stations were compared and then the absolute difference between the amounts received at each station was taken. From these differences, a mean difference and a standardized mean difference were calculated (Appendix Table A.1). The standardized mean difference was calculated by subtracting the difference in mean annual precipitation between the two stations (using common years) from the mean difference in annual precipitation. This standardization accounted for overall differences in average precipitation between the stations. For example, assume that the mean annual precipitation at one station was 30 inches and 28 inches at the other station. Now assume that annual precipitation did not vary at either station. There would still be a two-inch difference in annual precipitation, but precipitation at one station could be 100% accounted for by using the data from the other station.

These calculations indicate that there is not a clear relationship between the variability in precipitation received at two stations and the distances between the two stations. For example, the Junction 4SSW and Menard stations are about 33 miles apart, and their standardized mean difference in annual precipitation is 3.62 inches (Appendix Table A.2), i.e., on average the amount of precipitation received at each station differs by 3.62 inches more than the difference in the respective means. In contrast, the standardized mean difference in annual precipitation between Junction 4SSW and Kerrville, 50 miles apart, is 1.05 inches or less than 30% of that between Junction 4SSW and Menard. These statements refer to variability in annual precipitation, not amount of annual precipitation. Comparing years with complete data for both locations, the difference in mean annual precipitation between Junction 4SSW and Menard is 0.36 inches (23.84 and 23.48 inches, respectively) and between Junction 4SSW and Kerrville it is 6.77 inches (23.78 and 30.55 inches, respectively).

4.3 Constructed Precipitation Data Sets

Because of these temporal fluctuations and spatial variations in precipitation and because of their potential effects on the dynamics of the ecological systems, it is desirable to have a precipitation data set for the Upper Llano EDYS model that is relatively long-term and spatially representative. No continuous long-term (more than 100 years) precipitation data set exists for the Upper Llano area. The longest and most continuous data set is for Llano, 112 years of complete data during the period 1893-2012 (Table 2.1). However, Llano is relatively distant from the Upper Llano area. Four other stations that are much closer have more than 80 years of complete data, beginning in 1893 (Menard), 1897 (Junction 4SSW and Kerrville), and 1919 (Sonora Experiment Station). Data for 12 earlier years (1854-1882, most years with incomplete data) are available for Fort McKavett, Menard County.

Constructed precipitation data sets are long-term data sets that include recorded data for those dates when these data are available for a particular station plus estimated values for dates where recorded data are not available or where the recorded values are strongly suspect. The purposes for using constructed data sets in EDYS models are to 1) extend the length of the data set, 2) account for missing data, 3) adjust for apparent errors in the recorded data, and 4) provide data for all dates over a common period of record so that sites can be more appropriately compared. The estimated values in the constructed precipitation data sets are not presented as precise estimates of the actual amounts received. Instead, they represent reasonable estimates based on the temporal and spatial patterns of the area.

Twelve stations, in various combinations, comprise the primary precipitation stations for the seven river segments of the Upper Llano EDYS footprint (Table 4.4). Constructed precipitation data sets were prepared for each of these 12 stations for 1893-2012. The starting year was set as 1893 because complete annual data are available for at least one of the 16 primary stations for every year beginning in 1893 (Table 4.5).

Table 4.5 Annual precipitation (inches) at the 16 primary stations used to develop the precipitation input data for the EDYS Upper Llano model. The stations are arranged in a roughly west (left) to east (right) gradient but ignoring the north-south gradient.

Year	Eldr	Sonr	SExp	FMcK	RckS	Wood	Leak	Jnc4	JncA	Mnrd	Masn	Hrpr	Hunt	Kerr	Fred	Llno
1854	----	----	----	16.8	----	----	----	----	----	----	----	----	----	----	----	----
1856	----	----	----	24.3	----	----	----	----	----	----	----	----	----	----	----	----
1857	----	----	----	22.1	----	----	----	----	----	----	----	----	----	----	----	----
1858	----	----	----	21.6	----	----	----	----	----	----	----	----	----	----	----	----
1873	----	----	----	25.4	----	----	----	----	----	----	----	----	----	----	----	----
1874	----	----	----	33.8	----	----	----	----	----	----	----	----	----	----	----	----
1875	----	----	----	15.4	----	----	----	----	----	----	----	----	----	----	----	----
1876	----	----	----	20.7	----	----	----	----	----	----	----	----	----	----	----	----
1877	----	----	----	23.1	----	----	----	----	----	----	----	----	----	----	----	----
1878	----	----	----	24.1	----	----	----	----	----	----	----	----	----	----	----	----
1879	----	----	----	15.3	----	----	----	----	----	----	----	----	----	----	----	----
1882	----	----	----	29.0	----	----	----	----	----	----	----	----	----	----	----	----
1893	----	----	----	----	----	----	----	----	8.5	----	----	----	----	----	----	11.1
1894	----	----	----	----	----	----	----	----	15.5	----	----	----	----	----	----	23.7
1895	----	----	----	----	21.7	----	28.5	----	----	21.6	----	----	----	----	----	22.7
1896	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	21.9
1897	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	17.8
1898	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	21.2
1899	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	24.2
1900	----	----	----	----	----	----	----	----	----	----	----	----	----	----	41.1	32.5
1901	----	----	----	----	----	----	----	----	21.2	----	----	----	----	----	15.8	11.8
1902	----	----	----	----	----	----	----	21.2	----	24.2	----	----	----	30.6	32.8	25.4

Table 4.5 (Cont.)

Year	Eldr	Sonr	SExp	FMcK	RckS	Wood	Leak	Jnc4	JncA	Mnrd	Mson	Hrpr	Hunt	Kerr	Fred	Llno
1903	----	22.8	----	----	----	----	----	22.6	----	21.6	----	----	----	27.9	31.3	20.6
1904	----	21.6	----	----	----	----	----	----	----	26.6	----	----	----	27.1	28.2	30.5
1905	----	23.9	----	----	----	----	----	----	----	----	----	----	----	35.5	----	----
1906	----	29.4	----	----	----	----	----	----	----	----	----	----	----	27.4	----	16.1
1907	----	----	----	----	----	----	----	----	----	----	----	----	----	33.7	29.9	19.4
1908	----	22.0	----	----	----	----	----	27.2	----	----	----	----	----	28.5	21.8	----
1909	----	17.6	----	----	----	----	----	----	----	----	----	----	----	26.0	21.9	----
1910	----	----	----	----	----	----	----	----	----	----	----	16.6	----	22.8	22.6	----
1911	----	----	----	----	----	----	----	24.8	----	----	----	23.9	----	20.9	20.4	14.0
1912	----	----	----	----	----	----	----	12.5	----	----	----	----	----	19.1	20.6	21.0
1913	----	----	----	----	----	----	----	----	----	----	----	----	----	38.5	38.5	33.5
1914	----	34.1	----	----	----	----	----	37.2	----	----	----	----	----	29.4	27.9	28.8
1915	----	23.0	----	----	----	----	----	31.7	----	23.8	----	----	----	29.2	----	26.8
1916	----	----	----	----	----	----	----	14.8	----	15.4	----	----	----	29.4	----	20.0
1917	----	----	----	----	----	----	----	9.0	----	----	----	----	----	12.3	----	10.2
1918	----	----	----	----	----	----	----	31.2	----	20.8	----	----	----	28.2	----	27.8
1919	----	----	33.6	----	----	----	----	44.8	----	36.5	----	----	----	57.6	----	49.9
1920	----	----	25.5	----	----	----	----	30.9	----	23.9	----	----	----	29.7	----	30.8
1921	----	----	17.3	----	----	----	----	17.6	----	12.5	----	----	----	25.2	----	18.4
1922	----	----	25.1	----	----	----	----	25.3	----	21.8	----	----	----	26.2	----	29.1
1923	----	----	31.7	----	----	----	----	44.7	----	37.1	----	----	----	35.2	----	34.6
1924	----	----	19.6	----	----	----	----	22.1	----	----	----	----	----	22.2	----	20.4
1925	----	----	21.9	----	----	----	----	27.2	----	----	----	----	----	21.2	----	23.6
1926	----	----	19.3	----	----	----	----	31.7	----	----	----	----	----	31.2	----	32.6
1927	----	----	25.0	----	----	----	----	23.9	----	21.7	----	----	----	31.8	----	26.7
1928	----	----	26.0	----	----	----	----	24.3	----	26.3	----	----	----	25.4	----	27.5
1929	----	----	22.7	----	----	----	----	21.2	----	16.7	----	----	----	31.8	----	27.6
1930	----	----	27.9	----	----	----	----	19.9	----	23.2	----	----	----	34.6	----	30.8
1931	----	----	26.6	----	----	----	----	28.1	----	28.2	----	----	----	35.1	----	27.0
1932	----	----	39.3	----	----	----	----	34.9	----	33.8	----	----	----	41.6	----	32.9
1933	----	----	13.0	----	----	----	----	16.9	----	8.7	----	----	----	19.2	----	18.1
1934	----	----	11.9	----	----	----	----	16.6	----	21.9	----	----	----	24.2	----	----
1935	----	----	41.5	----	----	----	----	41.4	----	37.4	----	----	----	49.3	----	41.6
1936	----	----	28.0	----	----	----	----	29.6	----	28.3	----	----	----	47.7	----	48.4
1937	----	----	17.0	----	----	----	----	22.7	----	----	----	----	----	27.1	----	24.4
1938	----	----	20.5	----	----	----	----	22.4	----	27.0	----	----	----	21.0	----	24.2
1939	----	----	17.4	----	----	----	----	26.4	----	----	----	----	----	28.4	----	22.0
1940	----	----	21.0	----	----	----	----	28.5	----	26.7	----	----	----	39.1	38.6	41.5
1941	----	----	28.4	----	----	----	----	32.3	----	----	----	----	----	39.7	33.8	32.8
1942	----	----	18.9	----	----	----	----	21.2	----	30.2	26.7	----	23.6	29.2	27.8	27.2
1943	----	----	21.8	----	24.6	----	----	22.7	----	18.9	28.4	----	----	21.4	23.8	17.6
1944	----	----	22.9	----	19.7	----	----	30.0	----	31.6	32.1	----	----	36.9	42.3	36.1
1945	----	----	17.2	----	16.8	18.7	----	----	----	23.4	----	----	----	33.9	----	29.5
1946	----	----	19.0	----	22.4	25.5	----	22.9	----	19.6	22.5	----	----	34.5	35.4	29.1
1947	----	----	19.6	----	17.7	----	----	21.1	----	19.2	----	----	18.2	27.2	19.4	23.3
1948	----	----	24.5	----	23.8	17.3	----	25.3	25.0	17.8	22.2	----	----	24.2	20.9	21.1
1949	----	----	36.7	----	38.2	42.7	----	33.3	32.7	31.7	32.3	32.7	33.6	38.8	28.6	26.7
1950	----	17.7	21.2	----	17.6	17.6	----	21.2	22.9	19.5	22.4	19.9	----	22.7	24.2	17.4
1951	----	----	6.1	----	10.3	----	----	11.8	10.2	7.7	11.7	15.5	17.3	18.2	16.3	17.6
1952	----	7.8	6.9	----	12.7	----	----	13.3	12.0	21.9	29.2	28.2	30.0	40.9	44.1	41.5
1953	----	10.7	12.0	----	----	18.7	----	11.4	10.9	9.2	18.2	14.6	18.7	26.4	17.6	21.1
1954	----	13.0	15.6	----	----	19.3	----	10.6	11.4	10.9	11.4	9.3	16.2	14.7	12.8	12.4
1955	----	13.8	16.7	----	----	21.8	----	18.9	20.6	13.4	20.7	24.6	22.7	28.9	26.7	----
1956	----	----	10.4	----	----	8.9	----	11.2	11.4	14.8	12.8	----	13.9	14.1	11.3	----
1957	----	39.0	25.2	----	----	30.6	----	----	35.9	28.8	32.2	37.5	34.2	55.1	41.1	36.0
1958	----	26.7	34.0	----	----	42.4	----	----	27.2	25.4	26.7	41.1	34.8	36.7	37.7	33.5
1959	23.5	----	18.8	----	25.9	33.0	----	----	24.2	20.7	28.0	31.5	29.9	29.3	34.7	38.5
1960	----	15.8	22.8	----	20.4	28.3	----	----	26.7	18.7	28.2	----	32.3	37.1	31.9	29.8
1961	24.2	19.8	25.4	----	----	26.2	----	----	23.1	23.5	25.6	20.2	15.9	26.7	20.0	21.8

Table 4.5 (Cont.)

Year	Eldr	Sonr	SExp	FMcK	RckS	Wood	Leak	Jnc4	JncA	Mnrd	Masn	Hrpr	Hunt	Kerr	Fred	Llno
1962	16.1	20.2	16.4	----	----	14.6	----	----	13.0	13.4	----	19.9	18.3	17.2	20.3	25.4
1963	12.9	15.6	14.9	----	18.2	26.3	----	----	18.2	11.7	----	19.5	19.0	21.4	18.2	16.2
1964	15.2	25.9	25.3	----	----	27.8	----	----	22.3	22.0	28.1	25.6	31.6	----	20.7	29.9
1965	----	18.0	18.0	----	16.6	25.0	----	----	23.6	22.0	24.9	----	27.4	40.9	42.1	28.7
1966	20.3	21.1	28.0	----	24.8	21.8	----	----	21.2	20.2	22.7	23.8	31.5	27.6	24.2	19.2
1967	18.8	19.8	17.6	----	20.7	26.3	----	----	23.2	23.8	25.8	23.5	27.9	27.9	24.9	24.5
1968	19.8	----	21.5	----	24.6	33.2	----	----	27.0	32.1	32.3	33.4	31.2	31.6	31.5	37.7
1969	24.8	----	24.7	----	21.6	34.2	----	----	----	30.8	35.9	----	29.0	28.8	41.2	35.1
1970	15.4	15.7	20.5	----	18.9	22.3	----	24.7	----	19.9	20.2	18.3	18.4	----	22.4	20.0
1971	25.6	26.6	28.6	----	30.7	37.4	----	22.7	----	31.2	35.8	31.8	32.3	34.5	30.1	28.5
1972	19.0	26.9	27.3	----	22.5	----	----	18.2	----	23.6	----	20.3	25.8	28.4	29.9	20.8
1973	21.3	22.4	21.4	----	22.8	35.2	----	29.2	----	34.4	----	30.6	33.0	33.3	33.0	27.9
1974	34.6	34.5	39.2	----	25.9	25.9	----	33.4	----	37.4	----	34.2	33.0	----	37.9	34.2
1975	20.0	22.3	28.4	----	27.7	31.7	----	25.0	----	24.7	----	26.6	28.0	29.3	31.7	27.8
1976	26.6	35.2	31.6	----	31.8	43.9	----	33.1	----	32.3	28.0	27.8	----	34.7	34.9	28.6
1977	15.3	18.1	21.8	----	21.3	25.1	----	20.0	----	20.9	18.1	24.3	32.8	23.6	25.3	24.5
1978	22.5	24.1	26.4	----	19.3	21.6	----	21.2	----	22.0	24.7	31.4	39.3	44.3	40.0	28.0
1979	16.2	14.7	36.6	----	22.9	20.6	----	23.5	----	24.2	21.3	30.4	30.3	42.3	29.3	27.6
1980	18.2	19.0	18.8	----	16.5	25.4	----	29.4	----	26.6	29.1	25.1	29.4	27.5	28.7	23.6
1981	----	----	29.1	----	42.8	38.3	----	27.1	----	24.4	35.5	31.7	33.3	41.5	40.5	29.0
1982	16.1	16.3	22.4	----	22.6	21.4	----	----	----	22.5	23.4	22.1	----	----	25.0	23.9
1983	14.6	18.8	20.3	----	21.8	25.7	----	----	----	18.3	24.2	21.4	21.5	25.1	29.9	28.7
1984	20.0	19.2	15.5	----	21.2	----	----	----	----	20.9	27.5	29.3	27.4	22.5	27.2	22.3
1985	21.8	19.5	20.1	----	20.8	28.6	----	----	----	18.6	----	27.8	32.3	36.0	31.5	26.7
1986	28.5	32.8	31.1	----	28.9	33.8	----	30.5	----	27.6	37.7	32.3	39.0	38.2	41.9	33.2
1987	25.9	22.6	22.9	----	----	37.1	----	25.6	----	27.3	27.8	37.1	47.3	42.1	34.6	31.8
1988	17.3	----	22.0	----	----	17.1	----	13.1	----	18.6	19.7	16.9	29.0	30.9	----	19.6
1989	----	17.9	14.9	----	----	19.3	20.4	16.6	----	21.6	27.5	24.6	24.1	23.2	24.2	25.1
1990	----	----	30.2	----	----	----	35.0	24.4	----	34.4	28.6	35.8	32.3	33.6	30.7	25.2
1991	----	21.5	22.2	----	----	35.3	43.7	27.9	----	30.6	28.6	29.6	35.1	44.5	45.5	41.6
1992	----	25.8	23.1	----	21.8	26.3	34.1	23.2	----	25.7	33.9	34.5	38.1	41.4	39.4	34.6
1993	----	----	16.6	----	12.9	----	----	16.6	----	22.4	25.6	17.0	20.9	23.1	26.5	24.0
1994	----	----	22.1	----	----	----	39.1	----	----	21.5	31.4	31.1	32.9	38.8	31.3	26.0
1995	----	----	21.2	----	18.9	22.0	----	----	----	26.7	----	27.8	----	28.3	29.0	23.4
1996	----	17.2	23.2	----	27.6	21.6	----	----	----	19.3	24.1	27.0	30.2	26.2	27.8	27.3
1997	----	18.2	24.2	----	30.5	34.5	----	33.9	----	23.7	43.4	42.9	41.1	37.7	36.5	26.7
1998	----	24.6	29.7	20.1	32.3	34.3	34.9	25.2	----	20.0	31.6	28.9	34.4	32.4	31.7	----
1999	----	14.0	20.6	20.2	20.3	16.9	20.7	14.4	16.9	17.5	12.2	22.4	----	17.8	18.0	24.4
2000	----	22.6	25.2	29.0	38.9	32.3	35.6	30.2	29.4	28.1	32.5	32.0	----	33.4	29.7	29.8
2001	----	16.7	20.8	23.0	18.7	39.3	28.6	23.8	20.9	22.2	----	30.7	----	30.2	34.5	33.0
2002	----	26.4	23.5	24.2	----	27.2	42.1	18.8	18.0	----	27.2	30.2	----	45.5	39.0	28.0
2003	----	21.6	25.7	19.8	24.1	28.7	28.9	20.6	17.2	19.9	35.0	26.8	----	23.9	28.2	30.5
2004	----	42.1	33.0	33.3	43.4	38.4	42.2	27.3	29.8	29.9	35.5	38.4	----	45.6	37.8	39.4
2005	27.8	21.5	23.0	30.3	26.7	20.3	24.3	20.2	20.1	24.0	21.9	----	----	26.5	24.5	17.9
2006	16.7	13.8	21.6	12.5	17.8	18.9	25.2	15.9	17.5	15.8	17.9	26.2	----	21.6	24.9	21.3
2007	29.4	30.7	34.0	38.1	45.2	----	41.4	31.7	29.8	37.9	46.4	45.6	----	51.1	50.9	34.7
2008	16.6	16.7	11.1	17.7	12.7	----	17.0	14.1	12.8	20.8	19.8	11.9	----	14.7	17.5	18.0
2009	21.9	25.4	16.4	25.4	19.1	----	----	34.0	27.2	22.6	----	26.3	----	32.7	35.1	35.6
2010	18.2	14.5	23.2	17.6	24.9	23.9	24.2	20.0	20.7	21.1	34.9	28.5	----	30.1	29.3	26.3
2011	7.9	7.6	15.5	12.0	12.9	14.2	11.8	11.6	11.1	10.1	13.7	10.5	----	13.1	12.2	15.2
2012	17.2	15.1	13.8	14.0	18.2	23.0	30.2	16.2	16.8	20.6	26.2	24.1	----	25.0	28.7	30.8

Eldr = Eldorado, Sonr = Sonora, SExp = Sonora Experiment Station, FMcK = Fort McKavett, RckS = Rocksprings, Wood = Camp Wood, Leak = Leakey, Jnc4 = Junction 4SSW, JncA = Junction Airport, Mnrd = Menard, Masn = Mason, Hrpr = Harper, Hunt = Hunt, Kerr = Kerrville, Fred = Fredericksburg, Llno = Llano.

For each constructed data set, site-specific values were used for those years where these are available for that station. For years when no data (annual or monthly) are available for that station, estimated annual totals were used. Total annual precipitation values (complete years) were compared among all two-way combinations of the 16 primary stations. Each two-way combination compared only those years with complete data for both stations. Mean annual precipitation was calculated for each station in each two-way combination and a ratio was calculated comparing the two means (Table 4.6). The estimated annual total for a particular station was obtained by multiplying the ratio of that particular station to the annual total of 1) the nearest station with an annual total for that year or 2) the station with the lowest mean difference for that station (Appendix Table A.2). Which of the two (nearest station or station with least mean difference) was used in each case was based on a balance between the relative differences in the two.

Table 4.6 Conversion ratios for calculation of values for missing data for the 12 primary stations (columns) used to estimate precipitation in the seven precipitation zones in the Upper Llano EDYS model. Ratios were calculated from means of annual precipitation using only values from common years with complete data for both stations of a comparison (Appendix Table A.1).

Station Compared	Station of Interest (Numerator of Ratio)											
	Jnct4	JnctA	RckS	Mnrd	Sonra	SExpS	FMcK	Eldor	CWood	Hmble	Prade	Harpr
Junction 4	-----	0.976	1.023	0.985	0.917	0.952	1.042	0.837	1.188	0.933	1.203	1.192
Junction A	1.024	-----	1.075	0.981	0.955	0.993	1.102	0.875	1.198	0.964	1.226	1.241
Camp Wood	0.841	0.834	0.883	0.839	0.776	0.846	0.807	0.735	-----	0.773	1.034	0.986
Carta Val	0.947	0.840	1.040	1.008	0.932	0.995	0.820	0.918	1.163	0.958	1.190	1.176
Cottonwood	0.816	0.748	0.810	0.794	0.705	0.775	0.788	0.680	0.916	0.704	0.935	0.922
Eldorado	1.195	1.142	1.120	1.207	1.115	1.157	-----	-----	1.360	1.120	1.238	1.292
Ft McKavett	0.960	0.908	1.135	0.991	0.929	1.000	-----	-----	1.239	1.106	1.222	1.244
Fredericks	0.780	0.761	0.776	0.777	0.715	0.742	0.763	0.709	0.920	0.704	0.917	0.914
Harper	0.839	0.806	0.881	0.847	0.782	0.828	0.802	0.774	1.014	1.280	0.994	-----
Humble Sta	1.072	1.037	1.116	1.110	0.971	1.022	1.106	0.893	1.294	-----	0.783	1.280
Hunt	0.762	0.811	0.783	0.792	0.706	0.764	-----	0.715	0.938	0.735	0.942	0.925
Kerrville	0.778	0.714	0.766	0.746	0.686	0.717	0.760	0.679	0.868	0.690	0.885	0.874
Leakey	0.707	0.701	0.888	0.784	0.699	0.748	0.766	0.770	0.894	0.711	0.980	0.922
Llano	0.891	0.790	0.857	0.847	0.761	0.819	0.824	0.760	0.995	0.777	0.999	1.002
Mason	0.826	0.836	0.876	0.852	0.771	0.827	0.814	0.762	1.017	0.769	1.040	1.010
Menard	1.015	1.019	1.011	-----	0.926	0.975	1.009	0.828	1.192	0.901	1.183	1.181
Prade Ranch	0.831	0.816	0.891	0.846	0.785	0.829	0.819	0.808	0.967	0.783	-----	0.994
Rocksprings	0.978	0.931	-----	0.989	0.880	0.954	0.881	0.893	1.132	0.896	1.122	1.135
Sonora	1.091	1.047	1.136	1.081	-----	1.066	1.077	0.896	1.288	1.030	1.274	1.278
Sonora ExpS	1.051	1.007	1.048	1.026	0.938	-----	1.000	0.864	1.182	0.978	1.206	1.208

Ratio = (annual mean for station of interest)/(annual mean for station being compared to).

For years in which there were data for some, but not all, months of a particular year for a specific station, an estimate of total annual precipitation was made using a combination of two methods. First, the values for the months in which data were available for that station in that year were used for those particular months. For months of that year when data were not available for that station, the ratio between precipitation at that station and precipitation at the nearest station, or station with least mean difference, with data available for the particular month was multiplied by the monthly precipitation at the nearest station (or station with least mean difference).

The beginning year of the constructed data sets was chosen to be 1893 (Table 4.7). This was the earliest year for which relatively continuous data were available for any of the primary stations (Table 4.5). A summary of the constructed values for each of the 12 stations used in the precipitation zones is presented in Table 4.8. Over the 120-year period of the constructed data set, use of least standardized mean

difference or use of nearest station estimators provided similar estimates. For example, using least standardized mean difference resulted in a total 120-year precipitation sum of 2784.58 inches for the Junction 4SSW station, or an annual mean of 23.20 inches. Use of nearest station estimators resulted in a sum of 2819.32 inches, or an annual mean of 23.49 inches, a difference of 1.2%.

Table 4.7 Total annual precipitation in the constructed long-term precipitation data sets for each of the 12 stations used to estimate precipitation patterns at the seven segments of the North and South Upper Llano in the EDYS model.

Year	Jnc4	JncA	RckS	Mnrd	Sonr	SExp	FMcK	Eldr	Wood	HmbI	Prde	Hrpr
1893	8.64	8.78	9.52	8.51	7.88	8.30	8.59	7.05	10.14	7.67	11.10	11.13
1894	18.81	20.04	20.97	15.47	14.33	20.34	15.61	12.81	24.14	13.94	28.48	23.72
1895	20.14	19.97	21.68	21.61	20.01	20.68	21.80	17.89	24.54	19.47	27.92	22.70
1896	16.30	15.73	23.21	26.24	24.38	23.10	27.29	21.85	27.46	23.74	22.15	21.93
1897	19.05	15.57	19.04	15.62	12.81	19.02	14.70	14.15	26.38	14.18	21.09	20.66
1898	28.16	27.48	21.02	16.34	24.45	19.35	15.65	22.38	23.01	20.07	22.92	21.26
1899	21.60	19.15	26.44	20.53	18.45	25.49	19.97	18.42	30.29	23.81	30.07	24.29
1900	33.18	31.24	31.85	31.89	30.17	31.83	32.86	27.26	39.27	14.13	39.43	37.52
1901	12.83	11.83	12.29	21.20	19.63	20.67	21.39	17.55	15.16	19.10	15.19	14.47
1902	21.23	21.82	23.62	24.23	21.68	20.21	24.45	20.06	25.22	19.81	27.05	29.98
1903	22.57	19.92	21.37	21.58	22.82	24.33	21.77	20.45	26.83	23.50	24.69	28.64
1904	25.15	24.19	20.76	26.60	21.58	23.00	26.84	19.34	29.55	22.23	23.98	25.76
1905	21.59	21.03	27.22	16.54	23.91	25.49	17.17	21.42	25.61	24.63	31.45	29.34
1906	25.49	24.65	21.02	21.33	29.43	31.37	19.85	26.37	30.00	30.31	24.28	18.42
1907	30.02	29.06	25.84	25.16	30.37	24.28	28.24	20.61	35.38	18.40	29.85	27.32
1908	27.24	26.61	21.82	21.25	22.01	23.46	28.41	19.72	32.38	22.67	25.21	19.87
1909	20.97	19.42	19.93	19.41	17.55	18.71	17.65	15.72	22.59	18.08	23.03	20.37
1910	18.55	18.10	17.46	17.00	15.79	16.61	19.35	14.29	22.04	16.16	20.17	16.58
1911	24.82	24.20	16.01	15.59	24.80	23.61	25.84	22.57	29.46	23.14	18.50	23.85
1912	12.54	12.24	14.59	14.21	9.05	11.94	13.07	8.11	14.90	9.32	16.86	15.25
1913	32.68	31.43	29.48	28.71	27.73	28.73	32.43	25.02	29.33	28.43	33.97	43.07
1914	37.24	36.33	22.51	24.07	34.07	36.32	36.68	30.53	44.22	35.09	26.00	32.01
1915	31.73	30.96	22.34	23.75	23.04	24.56	23.96	20.64	37.68	23.73	25.81	22.36
1916	14.77	14.42	22.53	15.42	12.89	14.06	15.56	12.77	17.55	13.77	26.03	20.03
1917	9.02	8.80	9.44	9.39	8.62	8.59	9.34	8.09	10.72	8.42	10.91	10.18
1918	31.22	30.48	21.59	20.80	19.26	29.73	21.99	17.22	37.10	29.14	24.94	27.83
1919	44.78	43.70	35.22	36.50	31.53	33.61	36.83	29.04	53.19	32.87	50.95	49.98
1920	30.91	30.17	26.73	23.94	23.93	25.51	24.16	22.04	36.72	24.95	26.24	33.13
1921	17.59	17.17	18.10	12.50	16.20	17.27	12.61	14.92	20.78	16.89	22.26	20.92
1922	25.29	24.67	26.27	21.82	23.52	25.07	22.02	21.66	21.75	24.52	23.17	21.89
1923	44.73	43.66	33.17	37.05	29.69	31.65	37.42	27.41	34.67	30.95	31.08	35.90
1924	22.14	21.62	20.55	14.32	18.40	19.61	14.41	16.94	16.07	19.18	19.66	16.17
1925	27.24	26.59	22.97	17.86	20.56	21.92	18.19	18.94	21.12	21.44	18.74	21.26
1926	31.74	30.98	20.18	21.80	18.07	19.26	27.33	16.64	27.90	18.84	27.63	28.08
1927	23.86	23.30	26.15	21.71	23.40	24.95	21.91	21.56	31.43	24.40	28.10	31.63
1928	24.32	23.74	27.20	26.29	24.34	25.95	26.53	22.42	23.40	25.38	22.43	23.55
1929	21.17	20.67	23.74	16.65	21.25	22.65	16.80	19.57	24.54	22.15	28.13	24.70
1930	19.94	19.47	29.25	23.16	26.18	27.91	23.37	24.11	28.80	27.28	30.59	28.99
1931	28.09	27.42	27.91	28.19	24.98	26.63	28.44	23.01	26.64	26.04	31.04	26.81
1932	34.93	34.09	24.68	33.79	36.83	39.26	34.09	34.04	28.76	38.40	32.78	28.95
1933	16.89	16.47	10.84	8.66	12.17	12.97	8.74	11.23	14.36	12.68	12.71	14.46
1934	16.63	16.23	12.17	21.88	11.20	11.94	22.08	10.32	18.16	11.68	14.74	15.44
1935	41.41	40.42	41.05	37.45	38.94	41.51	37.79	35.86	45.17	40.60	49.32	45.46
1936	29.64	28.94	29.30	28.25	26.23	27.96	28.50	24.16	40.26	27.34	42.20	38.77
1937	22.68	22.15	17.82	22.35	15.95	16.99	20.29	14.69	21.40	16.63	23.98	21.55
1938	22.39	21.86	24.00	26.98	19.19	20.46	27.22	20.68	19.16	20.31	18.04	19.29
1939	26.38	25.74	18.18	20.54	16.27	17.35	20.28	14.99	22.52	16.97	25.15	22.66
1940	28.54	27.84	22.04	26.63	19.73	21.03	26.87	18.17	38.69	20.57	34.64	38.95
1941	32.30	31.52	32.96	40.46	26.61	28.37	38.29	24.51	27.41	27.75	34.00	27.59

Table 4.7 (Cont.)

Year	Jnc4	JncA	RckS	Mnrd	Sonr	SExp	FMcK	Eldr	Wood	Hmbl	Prde	Hrpr
1942	21.17	20.66	27.85	30.25	17.75	18.92	30.52	16.35	24.29	18.50	37.87	24.45
1943	23.65	23.08	24.55	18.87	20.42	21.77	19.04	18.81	19.40	21.29	27.51	19.53
1944	30.00	29.28	19.65	31.63	21.44	22.86	31.91	19.75	29.13	22.36	29.40	33.26
1945	22.81	21.92	16.82	23.35	16.14	17.21	23.56	14.87	18.69	16.83	19.33	23.63
1946	22.85	22.30	22.38	19.63	17.85	19.03	19.81	16.64	25.48	18.61	26.35	30.80
1947	21.08	20.57	17.69	19.22	18.42	19.64	19.39	16.97	27.37	19.21	25.77	20.70
1948	25.34	24.96	23.81	17.76	22.97	24.49	17.92	21.16	17.30	28.63	17.89	21.78
1949	33.34	32.65	38.16	31.70	34.47	36.72	32.99	31.03	42.75	36.28	44.20	32.74
1950	21.24	22.93	17.56	19.46	17.66	21.21	19.63	15.82	17.63	19.12	18.23	19.88
1951	11.83	10.24	10.27	7.64	7.22	6.13	7.71	6.51	13.71	8.37	15.60	15.50
1952	13.31	12.00	12.66	21.86	7.82	6.91	22.06	7.01	15.80	8.00	14.19	28.20
1953	11.40	10.87	13.57	9.22	10.64	11.96	9.30	9.53	18.68	12.68	19.32	14.64
1954	10.61	11.37	18.61	10.93	12.96	15.62	11.03	11.61	19.30	17.90	19.96	9.27
1955	18.87	20.62	15.71	13.41	13.76	16.70	13.53	12.33	21.76	15.00	23.01	24.60
1956	11.17	11.37	6.90	14.80	9.17	10.41	14.93	8.24	8.93	10.18	10.35	11.37
1957	37.70	35.90	35.27	28.82	38.98	25.20	29.08	34.93	30.55	24.51	34.30	37.46
1958	26.53	27.19	32.78	25.40	26.73	34.04	25.63	23.95	42.44	40.54	41.60	41.14
1959	22.77	24.17	25.92	20.71	23.92	18.79	20.90	23.51	33.05	29.64	25.22	31.48
1960	24.60	26.65	20.37	18.72	15.74	22.75	18.89	16.02	28.35	22.45	25.38	26.94
1961	23.67	23.12	20.13	23.44	19.74	25.41	23.65	24.19	26.23	22.23	25.90	20.22
1962	13.97	13.04	19.49	13.42	20.22	16.35	13.54	16.13	14.59	13.38	18.08	19.90
1963	18.64	18.20	18.23	11.64	15.58	14.90	11.74	12.93	26.26	16.55	16.95	19.52
1964	24.05	22.29	22.45	21.95	25.91	25.30	22.15	15.14	27.83	21.50	30.76	25.54
1965	24.18	23.61	16.57	21.97	18.01	17.95	22.17	13.33	24.97	19.25	25.12	26.01
1966	21.67	21.16	24.81	20.21	21.05	28.03	20.39	20.32	21.74	28.52	31.28	23.80
1967	21.21	23.24	20.69	23.76	19.81	17.56	23.94	18.77	26.32	24.42	27.46	23.51
1968	27.67	27.02	24.62	32.03	21.24	21.51	32.32	19.76	33.14	30.96	26.33	33.44
1969	28.51	28.66	21.55	30.77	19.35	24.66	31.05	24.82	34.16	33.75	35.59	32.51
1970	24.67	24.09	18.92	19.84	15.71	20.46	20.02	15.35	22.26	15.20	27.68	18.27
1971	22.67	22.12	30.70	31.23	26.57	28.57	31.51	25.57	37.37	25.71	38.72	31.85
1972	18.16	17.70	22.54	23.61	26.84	27.33	23.82	18.94	21.76	22.30	26.23	20.29
1973	29.16	28.44	23.76	34.44	22.42	21.43	34.75	21.30	35.17	23.79	30.48	30.55
1974	33.42	32.60	25.85	37.38	34.51	39.16	37.72	34.56	25.85	30.38	26.42	34.15
1975	25.03	24.42	27.74	24.66	22.33	28.37	24.88	19.99	31.64	29.30	25.85	26.61
1976	33.05	32.26	31.79	32.28	35.16	31.63	32.57	26.62	43.88	26.08	29.84	27.76
1977	19.95	19.48	21.34	20.90	18.15	21.78	21.09	15.26	25.06	18.02	25.10	24.25
1978	21.19	20.68	19.34	21.95	24.09	26.37	22.15	22.52	21.62	20.06	19.59	31.41
1979	23.49	22.95	22.93	24.14	14.68	36.62	24.36	16.19	20.60	16.41	25.69	30.41
1980	29.39	28.68	16.47	26.55	18.95	18.80	26.79	18.21	25.43	17.04	23.19	25.10
1981	27.13	26.48	42.82	24.33	26.42	29.13	24.55	24.49	38.27	25.16	45.43	31.69
1982	14.79	14.38	22.64	22.48	16.28	22.42	22.68	16.06	21.41	17.83	21.98	22.09
1983	14.82	16.99	21.83	18.33	18.77	20.25	18.50	14.61	25.73	18.60	26.60	21.42
1984	23.32	21.21	21.15	20.94	19.20	15.48	21.13	20.00	20.53	21.07	21.16	29.34
1985	20.46	22.47	20.80	18.58	19.46	20.06	18.75	21.82	28.63	22.10	29.60	27.79
1986	30.54	29.80	28.89	27.60	32.83	31.05	27.85	28.46	33.77	31.51	34.92	32.24
1987	25.55	24.94	24.01	27.29	22.60	22.91	27.54	25.93	37.09	28.82	38.35	37.08
1988	13.08	12.77	23.10	18.62	11.75	22.04	18.79	17.26	17.11	26.01	21.83	16.86
1989	16.61	16.21	15.58	21.60	17.93	14.87	21.79	16.07	19.30	15.18	19.23	24.55
1990	24.43	23.84	30.66	34.42	43.98	30.21	34.73	38.70	36.28	35.71	39.71	35.82
1991	27.88	27.21	23.76	30.57	21.51	22.21	30.85	19.27	35.32	23.92	48.13	29.62
1992	23.24	22.68	21.75	25.65	25.83	23.09	25.88	23.14	27.27	21.73	33.65	34.53
1993	16.58	16.19	12.92	22.41	36.40	16.57	22.61	32.63	21.47	21.33	17.91	17.03
1994	24.00	25.15	25.05	21.45	22.19	22.07	21.64	20.23	35.52	26.24	34.40	31.06
1995	23.57	20.18	18.94	26.73	22.53	21.20	26.97	20.19	21.99	16.62	27.21	27.79
1996	22.45	18.15	27.55	19.28	17.22	23.19	19.45	15.43	21.63	16.93	31.56	26.96
1997	33.93	33.12	30.53	23.66	18.16	24.17	23.69	16.27	34.45	25.68	36.84	42.92
1998	25.17	20.26	32.26	19.96	24.59	29.73	20.12	22.03	34.29	28.53	35.03	28.90
1999	14.44	16.85	20.29	17.49	14.02	20.64	20.23	12.56	16.90	15.82	19.50	22.37
2000	30.17	29.41	38.93	28.07	22.55	25.24	28.98	20.20	32.29	21.77	35.57	31.98

Table 4.7 (Cont.)

Year	Jnc4	JncA	RckS	Mnrd	Sonr	SExp	FMcK	Eldr	Wood	Hmbl	Prde	Hrpr
2001	23.75	20.94	18.69	22.17	16.64	20.79	22.99	14.91	39.30	17.12	34.30	30.64
2002	18.76	18.00	22.21	22.34	26.36	23.51	24.23	23.62	27.13	19.45	30.33	30.22
2003	20.58	17.23	24.06	19.90	21.57	25.66	19.80	16.97	28.71	23.39	32.87	26.76
2004	27.31	29.75	43.36	29.88	42.11	32.96	33.31	30.42	38.42	35.36	45.82	38.37
2005	20.16	20.09	26.70	23.95	21.49	23.00	30.27	27.78	20.27	22.25	20.35	23.79
2006	15.88	17.46	17.83	15.85	13.77	21.64	12.46	16.71	18.88	18.62	22.63	26.24
2007	31.66	29.84	45.19	37.90	30.71	33.97	38.06	29.42	40.57	37.81	43.60	45.65
2008	14.14	12.78	12.72	20.81	16.71	11.07	17.71	16.60	11.04	11.22	9.80	11.92
2009	33.98	27.24	19.12	22.56	25.41	16.42	25.42	21.89	24.79	22.58	19.25	26.26
2010	20.04	20.66	24.88	21.09	14.48	23.20	17.59	18.17	23.88	20.05	26.64	28.54
2011	11.56	11.12	12.85	10.05	7.59	15.46	12.01	7.85	14.19	10.24	14.03	10.50
2012	16.19	16.78	18.22	20.60	15.14	13.84	13.97	17.24	23.02	13.13	22.21	24.09

Table 4.8 Comparison of constructed long-term (1893-2012) precipitation (PPT; inches) metrics for 12 precipitation stations in the Upper Llano River watershed.

Metric	Jnc4	JncA	RckS	Mnrd	Sonr	SExp	FMcK	Eldr	Wood	Hmbl	Prde	Hrpr
Mean PPT	23.49	22.87	22.95	22.56	21.51	22.62	23.06	19.68	26.06	21.90	26.92	26.10
Estimated mo	302	674	568	146	570	312	1255	959	672	733	850	613
Percent estimated	21.0	46.8	38.8	10.1	39.6	21.7	87.2	66.6	46.7	50.9	59.0	42.6

Estimated mo = number of months for which data were estimated. Percent estimated = [(estimated mo)/1440]100.

The stations used to estimate missing data for a particular station in a particular year often differed from those used to estimate missing data for another station in the same year. When the two stations with missing data were particularly close to each other, this occasionally resulted in substantial differences in estimated precipitation for the two near-by stations for the same year. However, recorded data also occasionally differed substantially between nearby stations in the same year (Table 4.5). To account for possible unrealistic differences between same-year values at nearby stations, the maximum difference between the two stations in any particular year with recorded data at both stations was used as the upper acceptable limit to estimated differences. If the estimates differed by more than this amount, the estimated value at the station with the shortest period of record was re-calculated using the stations used to estimate the value at the station with the longest period of record.

For example, the Junction 4SSW and Junction Airport stations are about 4 miles apart and have a mean standardized difference of 0.99 inch (Appendix Table A.2). The maximum annual difference in precipitation between the stations is 6.74 inches (2009; Table 4.5) and the second greatest difference was 2.81 inches (2001). These stations have 23 years in common, and 5 of these years (22%) have differences of greater than 2 inches. Junction 4SSW has the longer period of record (83 and 35 years, respectively; Table 4.3). If annual precipitation in the constructed data set differed between the two stations by more than 2.81 inches, the estimate for Junction Airport was re-calculated based on the stations used to estimate the Junction 4SSW value in that year (or the recorded Junction 4SSW value was used if available). The 2.81-inch upper limit was used in this case rather than the maximum difference of 6.74 inches because the 6.74-inch value seemed unusually high.

Based on recorded precipitation data (in contrast to constructed data), which do not include all of the same years or the same period of record, there is a decrease in average annual precipitation over the region from the southeast (wetter) to the northwest (drier)(Fig. 4.4). The constructed precipitation data are consistent with this regional pattern (Table 4.8).

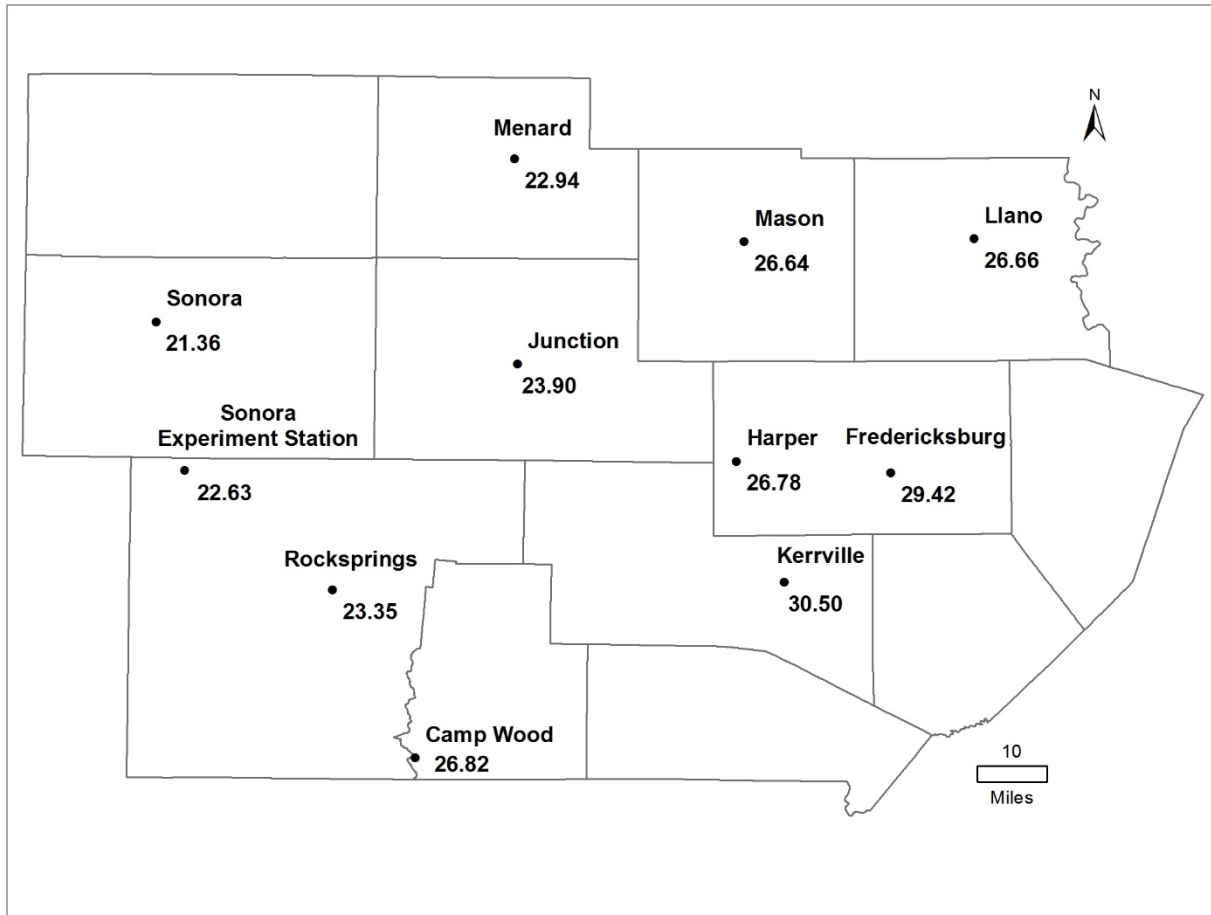


Figure 4.4 Average annual precipitation pattern (inches) across the Edwards Plateau. Values are annual means based on recorded data for periods of record at each station. Periods of record and years with complete (12-month) data vary among stations.

4.4 Precipitation Regimes by Spatial Segment

The constructed precipitation data (Table 4.7) were used to develop precipitation regimes for each of the seven segments of the spatial footprint. For each segment, an equation was developed (Table 4.9) based on the weighted average distances of each of the respective precipitation stations to the center of the segment. A long-term precipitation data set was calculated for each segment using these equations. The resulting seven long-term precipitation data sets were then entered into EDYS and used for model simulations.

Table 4.9 Equations used to calculate simulated precipitation events in each of the seven segments of the Upper Llano spatial footprint, based on constructed precipitation values for 12 precipitation stations (Table 4.8).

$$\text{NW Segment} = 0.302(\text{Humble Station}) + 0.184(\text{Sonora}) + 0.166(\text{Sonora Exp Sta}) + 0.128(\text{Fort McKavett}) + 0.119(\text{Eldorado}) + 0.101(\text{Junction 4SSW})$$

$$\text{NC Segment} = 0.281(\text{Humble Station}) + 0.192(\text{Junction 4SSW}) + 0.167(\text{Fort McKavett}) + 0.140(\text{Junction Airport}) + 0.110(\text{Menard}) + 0.110(\text{Rocksprings})$$

$$\text{NE Segment} = 0.383(\text{Junction 4SSW}) + 0.206(\text{Junction Airport}) + 0.127(\text{Fort McKavett}) + 0.116(\text{Humble Station}) + 0.096(\text{Menard}) + 0.072(\text{Rocksprings})$$

$$\text{Confluence} = 0.520(\text{Junction 4SSW}) + 0.346(\text{Junction Airport}) + 0.035(\text{Menard}) + 0.035(\text{Fort McKavett}) + 0.033(\text{Humble Station}) + 0.031(\text{Harper})$$

$$\text{SE Segment} = 0.330(\text{Junction 4SSW}) + 0.198(\text{Junction Airport}) + 0.124(\text{Humble Station}) + 0.093(\text{Prade Ranch}) + 0.090(\text{Rocksprings}) + 0.085(\text{Fort McKavett}) + 0.080(\text{Menard})$$

$$\text{SC Segment} = 0.249(\text{Humble Station}) + 0.171(\text{Rocksprings}) + 0.140(\text{Prade Ranch}) + 0.140(\text{Junction 4SSW}) + 0.120(\text{Junction Airport}) + 0.095(\text{Sonora Exp Sta}) + 0.085(\text{Camp Wood})$$

$$\text{SW Segment} = 0.246(\text{Humble Station}) + 0.246(\text{Rocksprings}) + 0.139(\text{Sonora Exp Sta}) + 0.097(\text{Sonora}) + 0.097(\text{Prade Ranch}) + 0.091(\text{Junction 4SSW}) + 0.084(\text{Camp Wood})$$

5.0 SOILS

Two soil components are included in an EDYS model. First, a soils map is constructed that indicates the spatial location of each soil unit (soil series or soil type) included in the spatial footprint of the model. Second, profile descriptions are developed for each of the soil units.

5.1 Soils Map

A total of 77 soil units were identified as occurring in the spatial domain of the Upper Llano model based on data from NRCS soil surveys for the respective counties (Blum 1982, Coffee 1967, Dittmore and Coburn 1986, Gabriel et al. 2009, Wiedenfeld 1980, Wiedenfeld and McAndrew 1968). Some of these soil units were similar to at least one other soil unit, differing in slope or relatively minor profile characteristics. To reduce the spatial complexity of the models, and thereby improve run times and reduce memory requirements, this group of 77 soil units was reduced to 48 for inclusion in the model (Table 5.1). The primary criteria used was whether or not the differences between the soil units were likely to result in measurable and ecologically significant differences in vegetation, hydrology, or management responses. The locations of each of these soils were mapped as soil polygons on the model spatial footprint (Fig. 5.1), and each 40 m x 40 m EDYS cell was assigned to one of the 48 soil units, based on the location of the cell in relation to the spatial distribution of the soil polygons.

Table 5.1 Soils included in the Upper Llano EDYS model.

County	Soil	Symbol	County	Soil	Symbol
Edwards-Real	Dev-Riverwash complex	DeB	Menard	Dev	Ds
Edwards-Real	Dina-Eckrant complex	DnD	Menard	Kavett silty clay	KaB
Edwards-Real	Eckrant-Rock outcrop 1-20% slope	EcF	Menard	Tarrant	Ta
Edwards-Real	Eckrant-Rock outcrop 20-50% slope	EcG	Menard	Tarrant-Brackett association	Tb
Edwards-Real	Ector gravelly silty clay loam	ErB	Menard	Tobosa clay	TsA
Edwards-Real	Irion clay	IrA	Menard	Valera silty clay	VaB
Edwards-Real	Leakey silty clay loam	LkB			
Edwards-Real	Oakalla-Dev complex	OdA			
Edwards-Real	Prade-Eckrant complex	PeB			
Edwards-Real	Rio Diablo silty clay	RdB			
Kerr	Denton silty clay	DnB	Schleicher	Cho association	2
Kerr	Eckrant-Rock outcrop	ERG	Schleicher	Dev-Rioconcho association	3
Kerr	Oakalla silty clay loam	Oa	Schleicher	Kavett-Tarrant association	5
Kerr	Purves-Tarrant association	PTD	Schleicher	Tarrant association	8
Kerr	Spives-Tarpley association	STC	Schleicher	Tobosa clay	10
Kerr	Tarrant-Eckrant association	TTC	Schleicher	Valera-Mereta-Kavett	11
Kimble	Cho gravelly loam	CoC	Sutton	Caliche pits	CLP
Kimble	Dev gravelly loam	De	Sutton	Ector	Es
Kimble	Frio silty clay loam	Fr	Sutton	Frio-Dev association	FD
Kimble	Gravel pit/Quarry	GP	Sutton	Kavett-Tarrant complex	Kt
Kimble	Kavett-Tarrant association	KTb	Sutton	Angelo silty clay loam	Ky
Kimble	Menard fine sandy loam	MnB	Sutton	Reagan silty clay loam	Rc
Kimble	Nuvalde clay loam, 1-3% slope	NuB	Sutton	Tobosa clay	Tc
Kimble	Oben-Hext complex	OhC	Sutton	Tarrant-Rock outcrop complex	Tr
Kimble	Real-Brackett complex, hilly	RbF	Sutton	Tarrant	Ts
Kimble	Tarrant, undulating	TaC			
Kimble	Tarrant-Rock outcrop	TrG			

Soils with the same name, but listed in multiple counties, have sufficiently different profiles to be modeled as separate soils.

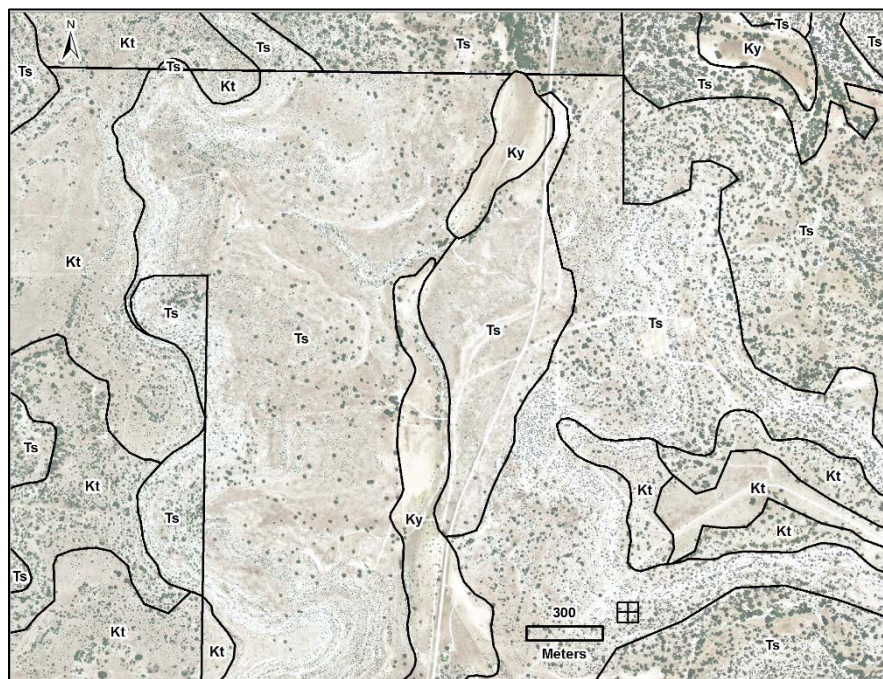


Figure 5.1 Example of the spatial distribution of NRCS soil units on a portion of the Kimble County landscape. The four squares near the distance scale represent 40 m x 40 m plots.

5.2 Profile Descriptions

A soil profile is a vertical section of a particular soil. Soils are composed of layers, called horizons, with each horizon differing in some major physical or chemical variable from the layer above and the layer below it. Horizons are designated by capital letters (e.g., A, B, C) in a top-down order. Horizons are often subdivided, and these subdivisions are designated by lower-case letters (e.g., Ap, Bk, Bt) the letters referring to specific types of soil conditions, and/or numbers (e.g., A1, A2, Bt1, Bt2), with the number indicating vertical order within the horizon (capital letter). General profile descriptions of each soil occurring in a particular county are provided in the NRCS Soil Survey for that county. An example, the Oben fine sandy loam, is presented in Table 5.2.

Table 5.2 NRCS profile description of the Oben fine sandy loam in Kimble County (Blum 1982).

Horizon	Depth (cm)	Texture	Color	Structure
A1	00-15	fine sandy loam	dark reddish brown	weak fine subangular blocky
B21t	15-30	sandy clay loam	reddish brown	weak medium subangular blocky
B22t	30-48	sandy clay loam	yellowish red	weak medium subangular blocky
R	48-63	limestone conglomerate	yellowish red	weakly to strongly cemented, fractured

EDYS soil profiles are based on the NRCS profiles, but differ in two primary ways. First, the EDYS profiles contain more layers and extend to greater depths than their respective NRCS profiles. The usual time step in EDYS simulations is daily. Daily changes in belowground components that affect plant growth (e.g., available soil moisture, root growth, availability of soil nutrients) occur at finer spatial scales (soil depths) than those designated for NRCS soil horizons. For example, many precipitation events supply only small amounts of water. The median summer precipitation event in many semi-arid regions is less than 5 mm (Schwinning and Sala 2004). In many soils, a 5-mm rainfall event will supply water to only the top 5 cm of the soil profile and at that shallow depth will be rapidly extracted (two days, Sala and Lauenroth 1982) by evaporation before most of it can be used by plants in transpiration. In contrast, a 10-mm rainfall event on the same soil will supply some moisture to a depth of perhaps 10 cm and, at that depth, some of the water would be extracted by evaporation and some by transpiration. Only that water used in transpiration would be available to support plant growth. Therefore, small differences in soil depth can substantially affect plant growth responses. For this reason, thinner soil layers are used in EDYS.

Each soil has a unique soil profile associated with it. Each EDYS profile in the Upper Llano model consists of 20 soil layers, with the thickness (depth) of each layer varying among soils. The 20 EDYS layers are subdivisions of the naturally occurring soil horizons. Soil horizons are subdivided into layers, but layers do not cross horizon boundaries. For example, no single EDYS layer would include the 25-35 cm depth of the Oben fine sandy loam (Table 5.2) because that would combine portions of different horizons.

NRCS profile descriptions do not include the subsoil material. EDYS profiles extend much deeper than the NRCS profiles. Deeper soil layers (subsoil layers, beneath the soil profile) are added in EDYS to allow for deep drainage of water and penetration of deep-rooted species. Characteristics of these deep soil (parent material) layers are based on estimates of the characteristics of the parent material. These lower EDYS layers are thicker than the upper soil layers because daily changes in moisture inputs and root dynamics are not as dynamic as those in the upper layers and because less information is available relative to the characteristics of the lower layers. If the underlying material is rock, estimates are made of

the amount of cracks and fissures. If the material is consolidated bedrock with no cracks or fissures, the depth of the EDYS profile ends at the bedrock surface, in which case deep-percolating water is assumed to move laterally over the face of the bedrock.

Thickness of each layer remains constant unless erosion or deposition occurs. If deposition occurs, the thickness of the top layer increases by the amount deposited. If erosion occurs, the thickness of the top layer decreases by the amount eroded. If erosion is sufficient to remove the entire top layer, then erosion shifts to the second layer, with the process continuing through additional layers as long as erosion continues.

The second primary way that EDYS profiles differ from NRCS profiles is that there are some differences in the variables included. Variables included in NRCS profiles are largely descriptive variables, i.e., those useful in classifying soils. Variables included in EDYS profiles are functional variables, i.e., variables that affect ecological responses. For example, soil color is a major classification variable in NRCS profile descriptions (Table 5.2) but soil color has little direct impact on ecological or hydrological responses and is therefore not included in EDYS profiles. Conversely, total available moisture content is a very important variable influencing plant growth but is not useful in classifying a soil, hence it is included in EDYS profile descriptions but not in NRCS profile descriptions. Data used to provide values for the EDYS soil variables are taken from NRCS soil surveys, other literature sources, and estimates based on existing information.

Eleven variables are included in EDYS for each soil layer (Table 5.3), the values of which vary by soil. EDYS simulates belowground dynamics (exclusive of root architecture and microbial dynamics) based on these 11 variables and the changes in their values that occur during a simulation. Five soil variables (soil texture, bulk density, maximum moisture content at saturation, field moisture capacity level, permanent wilting moisture level) are static within a specific profile (unless altered by soil deposition). Five variables (moisture content, nutrient content, organic matter content, salinity levels, and contents of any contaminants) change during a simulation as resources enter or exit the various soil layers.

Table 5.3 Soil variables used in EDYS simulations.

Variable	Unit	Comment
Layer thickness	cm	Initial values entered as inputs.
Soil texture (sand, silt, clay)	%	Not directly used as input variables. Used to calculate soil water holding capacities and infiltration and percolation rates.
Bulk density	g/cc	Not directly used as input variable. Used to calculate pore space.
Max moisture content at saturation	g/layer	Calculated from (pore space – organic matter content).
Field capacity level	g/layer	Calculated from soil texture, unless specific laboratory data are available.
Permanent wilting level	g/layer	Calculated from soil texture, unless specific laboratory data are available.
Available moisture content	g/layer	Calculated from (amount of water in layer – amount held at permanent wilting).
Nutrient levels (e.g., N, P)	g/layer	Initial values entered as inputs.
Organic matter content	g/layer	Initial values entered as inputs.
Salinity levels	ppm	Initial values entered as inputs.
Contaminant levels	ppm	Initial values entered as inputs, if present.

Three moisture level variables are utilized by EDYS: saturation, field capacity, and wilting (Table 5.4). The values entered for each of these variables is the level (% dry weight of soil) that corresponds to the upper limit for that condition in the soil of the particular soil layer. These values were determined using the NRCS soil moisture calculator (Saxton and Rawls 2006). The value for saturation corresponds to the maximum pore space for that layer (i.e., the water content at saturation). The field capacity value corresponds to the % water content at field capacity (~ -0.03 MPa). The difference between saturation and field capacity is drainage (gravitational) water. The value for wilting corresponds to the water content (%) at permanent wilting (~ -1.5 MPa). The difference between water held at field capacity and water held at permanent wilting is the amount of water available to plants. That difference, expressed as a percent, multiplied by the weight of the soil layer (bulk density x thickness of the layer) equals the available water content (g/m²; Table 5.4). Saturation capacity, field capacity, and wilting values are constant for a particular layer unless the texture or bulk density changes (by erosion or compaction). Available water content is a dynamic variable, i.e., its value changes during a simulation in response to precipitation, evaporation, and plant water uptake (transpiration).

Table 5.4 Constructed EDYS soil profile data for the Denton silty clay soil, Upper Llano model.

Layer	Depth (mm)	Thickness (mm)	Bulk Density (g/cm ³)	Soil Texture			Organic Matter		Nitrogen		Moisture Level (%)			Available Water (g/m ²)
				Sand (%)	Silt (%)	Clay (%)	(%)	(g/m ²)	(%)	(g/m ²)	Saturation	Field Capacity	Wilting	
01	00000-00025	0025	1.03	2	41	57	4.00	1,033	0.32	83	61.0	51.4	36.4	11.0
02	00025-00075	0050	1.22	2	41	57	3.00	1,824	0.24	147	54.1	50.8	35.8	21.7
03	00075-00125	0050	1.22	2	41	57	2.75	1,672	0.22	135	54.1	50.7	35.6	21.6
04	00125-00200	0075	1.22	2	41	57	2.00	1,824	0.16	147	54.1	50.2	35.2	32.0
05	00200-00300	0100	1.22	2	41	57	1.50	1,824	0.12	147	54.1	50.0	34.9	42.4
06	00300-00425	0125	1.28	30	33	37	1.00	1,599	0.08	129	51.7	35.1	21.1	35.2
07	00425-00550	0125	1.28	30	33	37	0.80	1,279	0.06	103	51.7	35.0	21.0	35.0
08	00550-00700	0150	1.28	30	33	37	0.60	1,151	0.05	93	51.7	34.9	20.9	41.8
09	00700-00875	0175	1.28	30	33	37	0.50	1,119	0.04	90	51.7	34.8	20.8	48.7
10	00875-01050	0175	1.46	46	24	30	0.40	1,020	0.03	82	45.0	25.7	15.4	35.9
11	01050-01250	0200	1.46	46	24	30	0.20	583	0.02	47	45.0	25.6	15.3	40.9
12	01250-01425	0175	1.46	30	20	50	0.01	26	0.001	2	24.7	15.0	10.0	21.9
13	01425-02000	0575	1.46	30	20	50	0.01	84	0.001	7	24.7	15.0	10.0	71.9
14	02000-04625	2625	1.46	30	20	50	0.01	382	0.001	31	24.7	15.0	10.0	328.4
15	04625-07250	2625	1.46	30	20	50	0.01	382	0.001	31	24.7	15.0	10.0	328.4
16	07250-09875	2625	1.46	30	20	50	0.01	382	0.001	31	24.7	15.0	10.0	328.4
17	09875-14375	4500	1.46	20	30	50	0.01	656	0.001	53	30.0	25.0	05.0	675.0
18	14375-18875	4500	1.46	20	30	50	0.01	656	0.001	53	30.0	25.0	05.0	675.0
19	18875-23375	4500	1.46	20	30	50	0.01	656	0.001	53	30.0	25.0	05.0	675.0
20	23375-28000	4625	1.46	20	30	50	0.01	674	0.001	54	30.0	25.0	05.0	694.8

Note: Denton silty clay typically has bedrock beginning at 125-150 cm. This corresponds to EDYS layers 12-20. The Table 5.4 values for those layers are for the soil in cracks in the limestone. For calculations of amounts, an assumption of 5% cracks by volume was made. Soil characteristic values for the soil in the cracks were estimated.

Two other dynamic soil variables are included for each layer: organic matter and nitrogen content. An initial value for organic matter content (%) is included and EDYS then calculates the amount of organic matter (g/m²) contained in the particular layer. These values change during a simulation as organic matter is added (transport of litter, translocation of soil organic matter among layers, death of belowground plant and animal material) and lost (decomposition, translocation out of the layer). An initial value is also included for nitrogen (N), which is entered as % total N and is estimated as 1% of organic matter, unless soil specific data are available. The value for total N changes during a simulation, based on input of N into the top layer from precipitation, release of N during mineralization of organic matter, transport of N into and out of the layer, and plant and microbial uptake of available N. Available N is calculated by

EDYS as 1% of total N (4%; Paschke et al. 2000), and this calculation is made on a daily time step, based on rate of mineralization.

Water is a major factor controlling both above- and belowground dynamics. Terrestrial plants uptake the water they need for maintenance and growth from the soil (including groundwater in the subsoil). The location (depth) of water stored in the soil (i.e., soil moisture) in relation to root architecture of the various plant species is an important factor controlling the competition among these species. Nutrients and contaminants become available for plant uptake as they enter into soil solution and their concentrations vary as amounts are moved among layers by water movement. Organic matter is also moved among layers by water movement and the decomposition and mineralization rates of organic matter are controlled, in part, by the moisture content of the soil.

In EDYS, water can arrive at the surface layer of a spatial cell in two ways, by a precipitation event and by surface movement from adjacent cells (i.e., run-on). Some of this water can enter the soil profile (infiltration) and some exits the cell as runoff. Litter on the soil surface has first opportunity for absorption of water in EDYS. If litter is present and is at less than its maximum moisture content, it can absorb sufficient water to bring it up to maximum moisture content. The remaining water is available for infiltration into the soil profile and runoff from the cell.

In EDYS, the amount of water that can potentially enter into the soil profile during a rainfall event is modeled as a step function. The amount of rain in each daily rainfall event is divided into five parts (10%, 20%, 40%, 20%, and 10% of the total amount). The amount of water in Step 1 (10% of the rainfall event) is compared to the available storage capacity (saturation capacity minus current moisture content) of the first layer. If the amount of water is less than or equal to the available storage capacity, that entire quantity of water (10% of the event) is moved into the first layer. If the amount is in excess of available storage capacity, the excess amount is moved to adjacent cells as runoff. This process is repeated through each of the next four steps, with number of layers used to calculate available storage capacity increasing by one layer at each step (e.g., Step 3 = 40% of rainfall event compared to available storage capacity of top three layers).

Once water moves into a soil layer, it is moved downward using a “tipping bucket” algorithm. Any water in excess of field capacity of the first layer moves into the second layer. Any water in excess of field capacity for that layer is moved into the third soil layer. This process continues in a top-down manner until the all of the water is stored in the various soil layers, or if some remains once the wetting front reaches saturated soil (groundwater), the surplus amount is added to groundwater. If the groundwater is unconstrained (i.e., groundwater lateral flow can occur), this amount of added water is removed as “export”. If the groundwater is constrained, then the water content of the layer immediately above the saturated layer increases above field capacity. This increase can continue until the saturation level is reached for that layer, at which time the process continues in an upward manner into the next unsaturated layer.

As water moves downward by percolation (or upward by saturation or capillarity), soluble materials (nutrients, contaminants, organic matter) can be moved with the water. As water moves into the next layer at each time step, the concentrations of the soluble materials in that layer are recalculated based on the amount of those materials in the layer prior to entry of the new water and the new concentration resulting from all the surplus water (not just field capacity) that at least temporarily moves into that layer. Then if some water continues to move downward out of that layer, that water transports with it the amount of nutrients, contaminants, and organic matter corresponding to its relative concentration.

Soil water (including groundwater) is extracted from each layer at each time step by plant uptake (transpiration). The amount removed from each layer is determined by the amount of roots of each plant

species in that layer, the depth of the layer (root uptake is modeled as a top-down process), and the amount of water transpired by each species. Soil water can also be extracted by evaporation. However, evaporation occurs directly only from the surface soil layer. Stored soil moisture can be moved from upward to the surface soil layer (capillarity) and then lost to evaporation, but only from a maximum of the next three soil layers. This is a time-step controlled process and plant roots get first priority use of the water as it moves upward from the second, third, and fourth soil layers.

In addition to movement by water, organic matter can be added to a soil layer by death of plant material (roots) in that particular layer and by some movement of surface litter into the upper soil layer. The deposition of this material is based on root death rates specific to each species and decomposition rates that are influenced by moisture content and nitrogen availability.

6.0 VEGETATION

An EDYS application utilizes two broad types of plant data: parameter data for individual plant species and data on the composition of vegetation communities.

6.1 Selection of Plant Species

The number of plant species included in a specific EDYS application is flexible. How many and which species to be 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 complexity common to most landscapes, but it also increases run times and memory requirements.

The EDYS data-base contains ecological data on over 250 species, not all of which occur in the western Edwards Plateau and not all of which have data for all plant parameter variables used in EDYS. In each EDYS application, a subset of all species occurring in the spatial domain is used. Several factors are considered in the selection of this subset.

- The subset should include the major species for the area, based on both ecological and management importance. Ecological importance includes dominant and sub-dominant species for each of the included plant communities, species important successional, any threatened and endangered species, and any major invasive species or other species of concern.
- There must be sufficient ecological data available for the included species that the required parameter variable values can be determined or reasonably estimated. Data for all parameter variables may not be available for a major species. In such cases, reasonable estimates can often be made based on available data for closely-related or ecologically-similar species.
- For species where a substantial amount of their parameter values are estimated, care must be taken that the estimates are not based largely on data from species used to estimate values for other included species. Otherwise, little new information is actually included in the model by adding another species.
- The inclusion of the species should be expected to sufficiently increase the ability of the model to simulate ecological responses to justify any associated increase in run time, memory requirements, or time required to interpret results.

- The inclusion of the species should not unduly increase unaccounted error (i.e., “noise”) into the model output.

Based on the factors listed above, 51 species were included (Table 6.1).

Table 6.1 Plant species (51) included in the Upper Llano River EDYS model.

Lifeform	Species	Common Name
Trees (7)	<i>Carya illinoensis</i>	pecan
	<i>Celtis laevigata</i>	sugar hackberry
	<i>Diospyros texana</i>	Texas persimmon
	<i>Juniperus ashei</i>	Ashe juniper
	<i>Prosopis glandulosa</i>	mesquite
	<i>Quercus buckleyi</i>	Texas red oak
	<i>Quercus virginiana</i>	live oak
Vines (1)	<i>Vitis mustangensis</i>	mustang grape
Shrubs (6)	<i>Baccharis texana</i>	prairie baccharis
	<i>Forestiera pubescens</i>	elbowbush
	<i>Mahonia trifoliolata</i>	agarito
	<i>Nolina texana</i>	sacahuista
	<i>Rhus virens</i>	evergreen sumac
	<i>Yucca constricta</i>	yucca
Succulents (1)	<i>Opuntia lindheimeri</i>	Texas prickly pear
Grasses (22)	<i>Arundo donax</i>	giant cane
	<i>Aristida purpurea</i>	purple threeawn
	<i>Bothriochloa barbinodis</i>	cane bluestem
	<i>Bothriochloa ischaemum</i>	King Ranch bluestem
	<i>Bouteloua curtipendula</i>	sideoats grama
	<i>Bouteloua hirsuta</i>	hairy grama
	<i>Bouteloua trifida</i>	red grama
	<i>Cynodon dactylon</i>	bermudagrass
	<i>Elymus canadensis</i>	Canada wildrye
	<i>Eragrostis intermedia</i>	plains lovegrass
	<i>Eriochloa sericea</i>	Texas cupgrass
	<i>Hilaria belangeri</i>	curly mesquite
	<i>Leptochloa dubia</i>	green sprangletop
	<i>Panicum obtusum</i>	vine-mesquite
	<i>Panicum virgatum</i>	switchgrass
	<i>Schizachyrium scoparium</i>	little bluestem
	<i>Sorghastrum nutans</i>	indiangrass
	<i>Sorghum halepense</i>	Johnsongrass
	<i>Sporobolus asper</i>	tall dropseed
	<i>Sporobolus cryptandrus</i>	sand dropseed
	<i>Stipa leucotricha</i>	Texas wintergrass

Table 6.1 (Cont.)

Lifeform	Species	Common name
Grass-Likes (4)	<i>Triticum aestivum</i>	wheat
	<i>Cyperus odoratus</i>	flatsedge
	<i>Eleocharis palustris</i>	spikerush
	<i>Scirpus acutus</i>	bulrush
Forbs (10)	<i>Typha latifolia</i>	cattail
	<i>Ambrosia psilostachya</i>	ragweed
	<i>Aphanostephus ramossissimus</i>	lazydaisy
	<i>Desmanthus velutinus</i>	bundleflower
	<i>Gaillardia pulchella</i>	Indian blanket
	<i>Helianthus annuus</i>	sunflower
	<i>Lemna minor</i>	duckweed
	<i>Lupinus texensis</i>	Texas bluebonnet
	<i>Ratibida columnifera</i>	prairie coneflower
	<i>Simsia calva</i>	bush sunflower
	<i>Zexmenia hispida</i>	orange zexmenia

6.2 Plant Parameter Variables

EDYS is a mechanistic model. It simulates ecological dynamics by modeling how the various ecological components function. For plants, this is accomplished by using mathematical algorithms to model how plants grow and respond to various environmental stressors, such as drought, fire, and herbivory.

There is a large number of algorithms associated with plant dynamics in the EDYS model (Childress et al. 1999b; Coldren et al. 2011a). Each algorithm is applied to each plant species at each time step during a simulation to simulate the change in that plant or plant part from one time-step to the next. Each algorithm contains 1-6 plant response variables (parameters). Differential responses among plant species are achieved in EDYS by assigning species-specific values to each of these plant parameters. For example, one of the algorithms is plant growth, more specifically, increase in plant biomass. This algorithm contains a number of parameters, one of which is “water to production”. This parameter (water to production) is the amount of water (in kilograms) required to produce one gram (dry-weight) of new plant biomass and it is species specific (i.e., the water-use efficiency varies by species). Two of the major perennial grasses in the Upper Llano model are little bluestem (*Schizachyrium scoparium*) and curly mesquite (*Hilaria belangeri*). The water-to-production value for little bluestem is 0.90 and the value for curly mesquite is 0.65. Curly mesquite is the more xeric of the two grasses and indeed has the higher water-use efficiency.

There are 346 plant parameter variables in EDYS and each one of these has a specific value for each species in an application (51 species in the case of the Upper Llano model). These variables are arranged into 40 plant parameter matrices (Table 6.2). The data are entered from the EDYS Data Base, which contains values collected from the scientific literature and from field and greenhouse studies conducted as parts of previous EDYS applications. Values for selected plant parameter matrices and sources of these data are presented in Appendix C. If species-specific data are not available for a particular species for

one or more of the plant parameter values, estimates are made based on data on most-similar (ecologic or taxonomic) species.

Table 6.2 List of plant parameter matrices used in EDYS applications.

Matrix	Variables
01 General lifeform	growth form, lifespan, legume or not
02 Tissue allocation (mature)	proportion of coarse roots, fine roots, trunk, stems, leaves, seeds; root:shoot ratio
03 Tissue allocation (new)	proportion of new production allocated to each plant part
04 Tissue allocation (green-out)	proportion of new production allocated to each plant part during green-out
05 Tissue allocation (seed mo)	proportion of new production allocated to each plant part during flowering
06 Tissue N concentration	nitrogen concentration of each plant part
07 Required N concentration	minimum nitrogen concentration of each plant part
08 Nitrogen resorption	proportion of current nitrogen concentration that is resorbed at dormancy
09 Root architecture	root distribution by depth for each species; maximum potential rooting depth
10 Root uptake & competition	uptake capacity, growth rate, saturation death loss, fine:coarse roots at dormancy
11 Physiological response	months when green-out, dormancy, seed set, and seed germination occur
12 Biomass conversion factors	moisture content, canopy interception rate, basal cover:trunk biomass ratio
13 Water-use factors	maintenance requirement (old, new biomass), water-use efficiency, green-out
14 Growth rate controls	maximum monthly growth rate, max aboveground biomass, max drought loss
15 Monthly growth rates	proportion of maximum monthly growth rate each species can have in each month
16 Plant part productivity	potential photosynthetic rate of each plant part
17 Green-out production	amount of biomass in each plant part converted to new-production at green-out
18 Physiological controls	maximum root:shoot ratios; seed germination rate; seedling growth rate
19 Dormancy dieback	proportion of each plant part lost (annual) during dormancy
20 Shading effect	reduction in production in each species by shading from each other species
21 Dieback fate	where dead plant biomass, by plant part, is located following death
22 Groundwater response	amount of water that can potentially be extracted by soil depth, by species
23 Flooding effects	maximum number of days species can tolerate flooding
24 Salinity effects	salinity levels at which growth is reduced (reduction = 0%, 50%, 100%)
25 Fuel load contribution	heat load factor for each plant part, by species
26 Plant loss to fire	proportion of plant part, by species, lost to a moderate-intensity fire
27 Vehicle impacts	proportion of plant part, by species, lost to a single pass of a standard vehicle
28 Foot traffic impacts	proportion of plant part, by species, lost to a single step of a human
29 Cattle preference	selection of plant parts by species by cattle
30 Cattle competition	rank of cattle among all herbivores in ability to consume plant parts by species
31 Cattle accessibility	amount of each plant part, by species, that can be consumed by cattle
32 Deer preference	selection of plant parts by species by white-tailed deer
33 Deer competition	rank of white-tailed deer among all herbivores in ability to consume plant parts
34 Deer accessibility	amount of each plant part, by species, that can be consumed by white-tailed deer
35 Rabbit preference	selection of plant parts by species by rabbits
36 Rabbit competition	rank of rabbits among all herbivores in ability to consume plant parts
37 Rabbit accessibility	amount of plant part, by species, that can be consumed by rabbits
38 Insect preference	selection of plant parts by species by insects (grasshoppers)
39 Insect competition	rank of insects (grasshoppers) among all herbivores in ability to consume plants
40 Insect accessibility	amount of plant part, by species, that can be consumed by insects (grasshoppers)

General characteristics of each species are presented in Matrix 01. Matrices 02-05 are the tissue allocation matrices. At each time-step, EDYS calculates the amount of new biomass produced by each species. This amount is based on 1) amount of current photosynthetically active biomass, 2) potential growth rate, and 3) amount of required resources available to the species (function of amount of each resource available in the rooting zone and the competitive ability of the specific species to secure this

resource). The amount of new biomass produced by each species is then allocated to the various plant parts based on the values in the allocation matrices.

Matrix 02 provides the information that EDYS uses to allocate the beginning biomass values (Appendix Tables B.1-3) to the various plant parts to begin a simulation. During a simulation, new biomass production is allocated during each time-step to the various plant parts based on the values in Matrix 03. For example, if 10 g of new biomass is produced by Ashe juniper, 0.8 g would be added to coarse roots, 3.0 g would be added to fine roots, 1.1 g would be added to trunk, 2.0 g would be added to stems, and 3.1 g would be added to leaves (Appendix Table C.3). These ratios are used throughout the growing season, except in months when the species flowers or undergoes green-out. Green-out occurs following winter dormancy, drought dormancy, or following severe defoliation. For months when green-out occurs, the values from Matrix 04 are used instead of those from Matrix 03, and for months for seed-set (flowering) the values from Matrix 05 are used.

Root architecture varies substantially among plant species and these variations are important in determining competitive responses among species for belowground resources (e.g., water and nutrients). Two components of root architecture of primary importance are distribution of roots by soil depth and maximum potential rooting depth. Matrix 09 provides the values for these two parameters for each of the species in the model. These values are used in EDYS to determine the initial spatial distribution of root biomass.

The amount of roots for a particular species at the beginning of a simulation is determined by multiplying the coarse and fine root allocation values (Matrix 02) by the initial biomass value for that species in a given plot type (Appendix Tables B.1-3). The values in Matrix 09 are then used to allocate this root biomass (coarse and fine) by soil depth. This is calculated as the product of:

$$(\text{total root biomass})(\% \text{ in a portion of the rooting depth})(\text{maximum potential rooting depth}).$$

For example, 1% of the roots of Ashe juniper are assumed to be located in the first 1% of the rooting depth of Ashe juniper (Appendix Table C.9). The maximum reported rooting depth of Ashe juniper is 8 m (Jackson et al. 1999), therefore 1% of the initial root biomass of Ashe juniper is located in the upper 80 mm (3.1 inches) of the soil. If the maximum depth of a soil in a particular plot types is less than the maximum potential rooting depth, the maximum soil depth is used instead.

The values in Matrix 09 are used to calculate the initial distribution of roots in an EDYS simulation. At each time-step during a simulation, new root biomass is added (e.g., Matrix 03). This new root biomass is added to the current root biomass in those soil depths where active root uptake of water and nutrients are taking place. This results in potential changes in root distribution during a simulation caused by resource distribution.

Matrix 11 provides values used to determine when specified physiological processes occur. These processes are 1) green-out (breaking of winter dormancy), 2) beginning of winter dormancy, 3) months in which flowering and seed production can occur, and 4) months in which seed germination can occur.

Matrix 13 provides values used to determine water requirements of each species for maintenance and production of new biomass. Maintenance water requirements (old and new growth) refer to the amount of water used each month to support existing biomass. Water to production is the amount of water required to produce 1 g (dry-weight) of new biomass (i.e., water-use efficiency). Green-out water requirement is the amount of water required to support the production of new biomass during green-out.

At each time-step during the growing season for a particular species (Matrix 11), EDYS calculates the amount of water that species would require if it produced at its maximum potential rate (Matrix 14) plus

the amount required to maintain existing tissue. EDYS then calculates how much soil moisture is available to that species at that time-step, as determined by the distribution of moisture in the soil at that time and the competition for that water among all species with roots in each particular soil layer. If the amount of water available is equal to or greater than the amount required, the plant produces that much new biomass and that quantity of water is removed from the respective soil layers. If the amount of water available to the species is less than the amount required, maintenance requirements are met first and any remaining water is used to produce new biomass, the amount of which is proportional to what can be produced on the remaining amount of water (water to production).

EDYS also determines nutrient requirements in a manner similar to water requirements (Matrix 07). If nutrients are more limiting to plant growth than water requirements at that time-step, the amount of new growth produced is determined by the amount of nutrients available rather than the amount of water available, and the amount of water used is reduced proportionately.

Matrix 14 provides values used to determine maximum potential growth rate, maximum size of the plants, and the maximum rate of tissue loss from drought. Maximum potential growth rate is the maximum rate that new biomass can be produced under optimum conditions for that species. Maximum potential growth rate is genetically determined for each species. Actual growth rate is most often less than this value because of resource limitations and tissue loss (e.g., herbivory, trampling). The values in Matrix 14 are multiplied by the amount of photosynthetically-active tissue (Matrix 16) present in that species at that time-step. The product is the maximum amount of new tissue that species can produce in that particular month. The actual amount produced is generally less than this maximum amount, based on resource limitations (water, nutrients, light, temperature).

Maximum aboveground biomass is the maximum amount of standing crop biomass (g/m^2) that is possible for that species. This variable limits the accumulation of biomass to realistic levels for each species. Maximum old biomass drought loss is the maximum amount (proportion of existing biomass) that can be lost in one month from drought.

Matrix 15 provides a seasonal growth function for each species. A value of 1.00 indicates that the species can potentially grow at its maximum rate (Matrix 14) during that month. Values less than 1.00 result in proportional decreases in the maximum potential growth rate during those months. The values in Matrix 14 are estimates based on responses to both temperature and photoperiod.

Maximum potential growth rates (Matrix 14) are based on photosynthetically-active tissue. For most species, the tissue with the highest potential photosynthetic rate are leaves. Cacti are an exception. Cacti leaves are their thorns. Stems and pads are the photosynthetically-active tissue in cacti. Roots and trunks of most species are structural tissues and do not contribute directly to photosynthesis, although there are exceptions (e.g., trunks or retama and paloverde trees). Stems of many species contribute somewhat to photosynthesis, but generally at a lower rate than leaves. Matrix 16 provides values for the photosynthetic potential of each plant part for each species. The values are proportions of maximum rates for that species (leaves for most species).

Green-out in plants, whether as spring green-up or recovery from defoliation, requires an energy source. Carbohydrates stored in various tissues are used to produce the new biomass. Some storage is in areas near the meristematic regions (e.g., bud zones) whereas other storage is in more distant tissues (e.g., coarse roots, bases of trunks) and must be translocated to the points of new growth. In both cases, there is a loss of biomass (weight) in some tissue because of the loss of stored carbohydrates. Matrix 17 provides values used to determine how much current biomass (stored carbohydrates) can be used to produce new tissue during green-out. A value of 1.00 indicates (Appendix Table C.17) that the amount of tissue in that plant part can be doubled during a green-out month. A value of 0.10 indicates that 10% of the biomass in

that plant part can be transformed into new biomass during one month of green-out. During a green-out month, that amount of biomass is removed from the supplying plant part and transferred to new biomass and allocated according to the ratios in Matrix 04.

Matrix 18 contains values for four physiological control variables. These variables are used in EDYS to assure that plant structure does not become unbalanced and that the conversion from seeds to new plant biomass occurs properly. Each species has a characteristic root:shoot ratio (Matrix 02). This is the relative amount of roots and shoots for that species. However, these ratios change during the growing season as new aboveground biomass is added and over years as perennial tissues accumulate belowground. Growing season maximum root:shoot ratio is a control to keep too much root biomass from accumulating over time. If this value is exceeded during a growing season, no new biomass is allocated to roots until the value drops below this maximum value. Growing season green-out shoot:root ratio has a similar function. Maximum 1-month seed germination limits the amount of the seed bank that can germinate in any one month. Maximum first-month seedling growth provides the value to convert germinated seed biomass to new plant biomass. The amount of germinated seed biomass is multiplied by this value and the product becomes new plant tissue for that species.

At the end of the growing season plants enter winter dormancy (or summer dormancy for cool-season species) and lose some of their tissue (Matrix 11). An obvious example is deciduous trees shedding their leaves in the fall. But other tissue losses also occur. Some stems die. There can be some loss of trunk biomass. Root death occurs. Matrix 19 provides the values used to calculate these losses.

A major factor in competition among plant species in many areas is shading, i.e., competition for light. Tall plants have a shading effect on shorter plants. Matrix 20 provides for this competitive response. The values listed are reductions in maximum potential growth rate of the **shaded** species that would result from 100% canopy cover of the **shading** species. The values in Matrix 20 (Appendix Table C.20) do not represent the entire competitive effect of overstory species on understory species, only the direct effect of shading. Overstory species also affect the growth of understory species in other ways, e.g., competition for moisture and nutrients. Those competitive effects are simulated in EDYS using other parameters. The shading parameter only reflects competition for light.

In EDYS, values are averaged within a cell (Section 2.0), which are 40 m x 40 m on the uplands in the Upper Llano model. Within each cell, estimates are made of the amount of woody plant cover (e.g., 10-25%) based on aerial photographs (Section 6.3.1). A 25% cover of woody plants could result from various combinations of clusters (mottes) of trees and shrubs. In effect, the cell would consist of at least two vegetation types, one associated with the woody-species clusters and distributed over 25% of the surface of the cell and the other associated with herbaceous vegetation in the interspaces and distributed over the remaining 75% of the cell. However, the EDYS routine is to average the two types across the cell because the cell is the smallest subdivision in an EDYS application. In effect, this reduces the size of the woody plants (25% of the actual size in this example) and assumes that biomass is average (uniform) across the cell. If the shading factor is ignored, this averaging does not substantially alter the vegetation and hydrologic dynamics of the cell. With shading, the effect is to reduce herbaceous understory vegetation across the entire cell instead of just under the woody-plant clusters which should cover only 25% of the cell.

An update is being developed that will account for this spatial heterogeneity within a cell. That update is not complete and therefore was not included in the Upper Llano model. Instead, the shading factor was utilized to simulate the effect of woody species on other woody species (i.e., under the woody plant canopy) and not for the shading effect of woody species on herbaceous species. The shading factor was also used to simulate the shading effect of herbaceous species on other herbaceous species (e.g., midgrasses shading shortgrasses). This dual-component approach allows dynamics of herbaceous species

to be simulated in the portion not covered by woody species, while maintaining the major aspect of shading within the area covered by woody plants. This dual pattern is a major characteristic of shrub and woodland mosaics, which have little herbaceous vegetation under dense woody canopies but relatively abundant grasses and forbs in the interspaces (Drawe et al. 1978; McLendon 1991). In addition, reduction in herbaceous species under woody plant canopies may not occur until cover of woody species increases above 30-50% (Scifres et al. 1982; Fuhlendorf et al. 1997).

Plants can utilize groundwater when it, or its capillary fringe, is within their rooting zones. Although this is a potential source of water to plants, its actual contribution depends on the plant species, depth to groundwater (DTW), and availability of soil moisture. Soil water extraction by plants can be viewed in terms of the amount of energy required to access and move the water (Gardner 1991; Adiku et al. 2000). As a result, most species tend to utilize soil moisture in upper soil zones (if it is available) rather than groundwater, even when their roots are in contact with groundwater. However, there are often substantial differences in relative amounts of deep soil moisture and groundwater used by various species, even among the same lifeforms (e.g., trees, shrubs) when growing at the same locations (Flanagan and Ehleringer 1991; Donovan and Ehleringer 1994; Cook and O'Grady 2006). Matrix 22 provides values used in EDYS to adjust groundwater usage by depth and by species.

Two vegetation components that are important in determining the impact of fire on vegetation are fuel load and susceptibility of species and plant parts to fire. Matrix 25 provides values for relative fuel load for each plant part. Factors included are size (e.g., fine fuel, wood), moisture content, and presence of oils in the tissue. Matrix 26 provides values used to determine sensitivity of various plant parts and species to fire and various intensities determined by fuel load (Matrix 25).

Herbivory is a major factor influencing vegetation dynamics. These effects are simulated in EDYS differentially by animal species on the various plant species. These parameters are provided in Matrices 29-40, and are discussed in more detail in Section 7.

6.3 Plant Communities

In EDYS, each cell is assigned an initial vegetation composition based on some combination of the plant species included in application (Table 6.1). Because actual species composition data are not available for each cell in the spatial footprint, initial vegetation assignments are made on the basis of plant communities. A vegetation map is prepared by dividing the spatial footprint into polygons, each polygon representing a localized occurrence of a particular plant community or land-use type (e.g., cultivated field, lake/pond, roadway, caliche/gravel pit, building). If detailed vegetation maps are available, the polygons are assigned to specific plant communities based on the site-specific information (e.g., McLendon et al. 2010, 2013). Most often, as was the case for the Upper Llano River model, these detailed vegetation maps are not available. In these cases, a first-approximation classification of the polygons is made using the soil maps from the NRCS soil surveys (Coffee 1967; Wiedenfeld and McAndrew 1968; Wiedenfeld 1980; Blum 1982; Dittmore and Coburn 1986; Gabriel et al. 2009) along with their associated ecological sites (range site descriptions in earlier soil surveys). This provides the preliminary vegetation map. Each 40 m x 40 cm cell is then assigned to its respective vegetation type based on its spatial location on the landscape.

6.3.1 Terrestrial Vegetation

The initial definitions of the plant communities (species composition and biomass values) are based on NRCS range or ecological site descriptions. These NRCS descriptions are then modified based on information from published scientific references, unpublished field studies, and professional judgment. A common modification relates to successional stage (range condition) of the plant community. The NRCS

site descriptions are based primarily on estimated potential late-successional conditions (excellent range condition). Most ranges are in earlier successional stages, with species composition and productivity levels different from those listed in the site descriptions. In addition, the NRCS site descriptions need to be modified to account for increased cover of woody plants. The NRCS site descriptions assume a relatively low amount of woody plant cover under late successional conditions. For example, the 13 range sites described for Kimble County have an average woody plant cover of 11% (Blum 1982). Most of the native rangeland in Kimble County has more than 11% cover of woody species. To account for woody plant cover, the vegetation polygons were superimposed on 2012 NAIP aerial photographs and the amount of woody plant coverage in each polygon was visually estimated. If there are substantially different amounts of woody plant coverage in different parts of the polygon, the polygon was subdivided on the basis of amount of woody plant coverage. Each subdivision is then assigned a different variation of the plant community, each variation having a species composition and productivity reflecting its level of woody plant coverage.

In general, current vegetation conditions have more woody plants, more shortgrasses, less midgrasses, and lower herbaceous productivity than under late-successional conditions (Table 6.3). Based on data from the NRCS soil surveys (Coffee 1967, Wiedenfeld and McAndrew 1968, Wiedenfeld 1980, Blum 1982, Dittmore and Coburn 1986, Gabriel et al. 2009) and published research data (Reardon and Merrill 1976, Smeins et al. 1976, McGinty et al. 1979, Taylor et al. 1980, Shaw and Smeins 1983, McCalla et al. 1984, Thurow et al. 1986, Ralphs et al. 1990, Fuhlendorf et al. 1997, Wu et al. 2001), adjustments were made to account for earlier successional conditions in herbaceous composition. An example for the stony hill range site is provided in Table 6.4. The values in Table 6.4 assume average precipitation. EDYS accounts for variations in precipitation by adjusting the productivity of each species relative to precipitation received and competition for this moisture among the species present (herbaceous and woody).

Table 6.3 Comparison of species composition on a low stony hill range site in Sutton County based on NRCS soil survey (Wiedenfeld and McAndrew 1968) and research data from the Sonora Experiment Station (Smeins et al. 1976, McGinty et al., 1979, Taylor et al. 1980, Ralphs et al. 1990).

NRCS Soil Survey

Average forage production = 275 g/m² (2500 lbs/acre) Average woody plant cover = 15%
 Major forage species: sideoats grama, silver bluestem, little bluestem, green sprangletop, plains lovegrass,
 Texas wintergrass, plains bristlegrass, tall dropseed, Neally grama, Canada wildrye, vine-mesquite, indiagrass

Sonora Experiment Station

Average forage production = 148 g/m² (1300 lbs/acre) Average woody plant cover = 18%
 Major forage species: curly mesquite, sideoats, threeawns, hairy tridens, Texas wintergrass, Texas cupgrass,
 Caucasian bluestem, red grama, hairy grama, cane bluestem, fall witchgrass, King Ranch bluestem

Both sites have Tarrant and Ector soils.

Table 6.4 Estimated aboveground clippable biomass (g/m^2) in grassland openings on low stony hill range sites in Edwards, Kimble, and Sutton Counties, Texas, in years of average precipitation, under each of four range condition classes.

Species	Range Condition Class			
	Excellent	Good	Fair	Poor
Curly mesquite	70	80	40	30
Sideoats grama	30	30	5	2
Texas wintergrass	20	20	15	10
Cane bluestem	15	10	1	0
Purple threeawn	10	20	20	10
Hairy grama	10	15	20	5
Texas cupgrass	10	10	1	0
King Ranch bluestem	5	10	15	20
Red grama	0	5	10	10
Indian blanket	10	7	3	1
Orange zexmenia	8	5	2	1
Lazydaisy	5	3	1	1
Bundleflower	5	3	1	0
Prairie coneflower	2	1	1	0
Ragweed	0	1	5	10
Total herbaceous	200	220	140	100

Initial species composition values are entered into EDYS to begin a simulation. Initially, all cells in a particular plant community are given the same species composition. Although each cell in a vegetation polygon (initial plant community) has the same initial species composition, it does not necessarily remain the same during a simulation. Once the simulation begins, composition can change in response to the ecological dynamics that occur during the simulation. Differences in topographic features, precipitation zones and depths to groundwater, natural disturbances (e.g., fire), and management impacts (e.g., livestock grazing intensity, reseeding, brush control) often result in some cells within an initial vegetation community changing sufficiently that they form a separate vegetation type.

Initial species composition values were calculated for each soil type, based on the plant community assigned to that soil type, assuming fair range condition (Appendix Tables B.1-B.3). In addition to literature data and aerial photographs, limited ground truthing of the vegetation maps was conducted, primarily along the rivers. Some field sampling was also conducted in Kimble County to investigate the spatial distribution of herbaceous vegetation in juniper communities. Should more site-specific information on range condition or species composition become available, these values can be changed for the appropriate polygons.

In addition to successional stage of the herbaceous vegetation, adjustments were made to account for woody plant coverage. As woody plant cover increases, there is a shift in species composition of the woody species and a decrease in herbaceous production. On the low stony hill range site for example, the increase in woody plant cover comes primarily from an increase in Ashe juniper and live oak, with Ashe juniper increasing more than live oak (Table 6.5). At 15% woody plant cover, the site might be in good range condition with herbaceous production at about 90% of what it would be in a pure grassland (Table 6.5). As woody cover increases, both range condition and herbaceous production decrease. With 90% cover of woody plants range condition would be poor and herbaceous production low (15% of potential

production under poor condition without woody plants; Table 6.5). Species composition of the woody plant community also varies with plant community (Appendix Tables B.5-B.7).

Table 6.5 Species composition (% absolute cover) and herbaceous production (% of pure grassland at same range condition class) on wooded low stony hill range sites in Edwards, Kimble, and Sutton Counties, Texas.

Species	Woody Plant Cover			
	15%	25%	35%	90%
Ashe juniper	5	9	10	45
Live oak	5	9	10	27
Mesquite	1	1	1	1
Texas persimmon	1	2	3	1
Elbowbush	1	1	1	<0.1
Agarito	1	1	1	<0.1
Prickly pear	1	1	1	<0.1
Herbaceous	90% of good condition	80% of fair condition	70% of fair condition	15% of poor condition

Sufficient field data are not available to account for this effect of woody plant cover on productivity and composition of the herbaceous understory. As a first-approximation estimator, composition is addressed in this version of the Upper Llano model by assuming the plant communities are in fair range condition (Appendix Tables B.1-B.3) rather than in excellent condition as presented in the NRSC Soil Surveys. The values listed in Appendix Tables B.1-B.3 are for fair condition with no woody plant cover. To account for the effect of woody plant cover on herbaceous productivity, these values (by species) were adjusted by the formula (Appendix Table B.12):

$$\text{herbaceous biomass}_w = (\text{herbaceous biomass}_g)[1.00 - (0.8)(\text{woody plant cover})], \text{ where}$$

herbaceous biomass_w = herbaceous biomass with woody plant cover,

herbaceous biomass_g = herbaceous biomass without woody plants (Appendix Tables B.1-B.3),

woody plant cover = % total woody plant cover expressed as a decimal (e.g., 50% = 0.50).

Forty-six initial native plant communities were identified for the Upper Llano model. There are 16 basic herbaceous understory communities (Table 6.6). Species composition and aboveground biomass production data are presented in Appendix Tables B.1-B.3. These 16 communities were increased to the 46 initial native plant communities to account for differences in soil type and precipitation regime. The plant communities also differ in the amount of woody plant cover present (estimated from 2012 NAIP aerial photographs). We visually estimated woody plant cover on the basis of seven classes (0-1%, 1-10%, 10-25%, 25-50%, 50-75%, 75-90%, 90-100%). The 46 communities with a potential of 7 woody plant coverage classes results in a potential total of 322 vegetation types. However, only 247 of these possible combinations occurred in the model domain. Initial biomass of the herbaceous understory also decreases in the model is response to increases in overstory woody plant cover.

Table 6.6 Initial native plant communities, overstory and understory, used in the EDYS model of the Upper Llano River Watershed, with associated NRCS range sites (bold type) and primary associated soil types.

NRCS Range Site	EDYS Communities	Soils (Counties)
Loamy bottomland	Overstory: Pecan-hackberry-mesquite Understory: Sideoats-Canada wildrye-little bluestem	Oakalla-Dev complex (Edwards-Real) Oakalla silty clay loam (Kerr) Frio silty clay loam (Kimble) Frio-Dev association (Sutton)
Clay flat	Overstory: Mesquite-agarito Understory: Sideoats-curly mesquite-Texas wintergrass	Irion clay (Edwards-Real) Tobosa clay (Menard, Schleicher, Sutton)
Clay loam	Overstory: Mesquite-live oak-Ashe juniper Understory: Sideoats-cane bluestem-curly mesquite	Rio Diablo silty clay (Edwards-Real) Denton silty clay (Kerr), Nuvalde clay loam (Kimble) Valera silty clay (Menard), Valera-Mereta Kavett (Schleicher)
Clay loam	Overstory: Mesquite-live oak-Ashe juniper Understory: Curly mesquite-threeawn-sideoats	Angelo silty clay loam (Sutton)
Loamy	Overstory: Mesquite-live oak-hackberry Understory: Curly mesquite-threeawn-sideoats	Reagan silty clay loam (Sutton)
Deep Redland	Overstory: Mesquite-Ashe juniper-live oak Understory: Sideoats-little bluestem-curly mesquite	Leakey silty clay loam (Edwards-Real) Spires-Tarpley association (Kerr)
Gravelly Redland	Overstory: Ashe juniper-live oak-mesquite Understory: Sideoats-little bluestem-curly mesquite	Dina-Eckrant complex (Edwards-Real)
Red sandy loam	Overstory: Mesquite-Ashe juniper-live oak Understory: Sideoats-little bluestem-threeawn	Oben-Hext complex (Kimble)
Sandy loam	Overstory: Mesquite-live oak-Ashe juniper Understory: Little bluestem-sideoats-curly mesquite	Menard fine sandy loam (Kimble)
Steep adobe	Overstory: Ashe juniper-live oak-Texas red oak Understory: Little bluestem-sideoats-hairy grama	Real-Brackett complex (Kimble)
Draw	Overstory: Hackberry-mesquite-Ashe juniper Understory: Little bluestem-sideoats-Texas wintergrass	Dev-Riverwash complex (Edwards-Real) Dev gravelly loam (Kimble) Dev (Menard) Dev-Rioconcho association (Schleicher)
Limestone hill	Overstory: Ashe juniper-live oak-mesquite Understory: Sideoats-curly mesquite-threeawn	Ector gravelly silty clay loam (Edwards-Real), Ector (Sutton)
Low stony hill	Overstory: Ashe juniper-live oak-mesquite Understory: Curly mesquite-sideoats-threeawn	Eckrant-Rock outcrop (Edwards-Real) Tarrant-Eckrant association (Kerr) Tarrant, undulating (Kimble, Menard)
Low stony hill	Overstory: Ashe juniper-live oak-mesquite Understory: Curly mesquite-sideoats-threeawn	Tarrant association (Schleicher) Tarrant (Sutton)

Table 6.6 (Cont.)

NRCS Range Site	EDYS Communities	Soils (Counties)
Steep Rocky	Overstory: Ashe juniper-live oak-Texas red oak Understory: Sideoats-little bluestem-threeawn	Eckrant-Rock outcrop (Edwards-Real) Eckrant-Rock outcrop (Kerr) Tarrant-Rock outcrop (Kimble) Tarrant-Brackett association (Menard)
Steep Rocky	Overstory: Ashe juniper-live oak-Texas red oak Understory: Curly mesquite-sideoats-threeawn	Tarrant-Rock outcrop (Sutton)
Shallow	Overstory: Mesquite-live oak-Ashe juniper Understory: Curly mesquite-threeawn-hairy grama	Purves-Tarrant association (Kerr) Kavett-Tarrant association (Kimble) Kavett silty clay (Menard)
Shallow	Overstory: Mesquite-live oak-Ashe juniper Understory: Curly mesquite-sideoats-threeawn	Kavett-Tarrant association (Scheicher) Kavett-Tarrant association (Sutton)
Very shallow	Overstory: Ashe juniper-mesquite-live oak Understory: Sideoats-cane bluestem-curly mesquite	Prade-Eckrant complex (Edwards-Real) Cho gravelly loam (Kimble) Cho association (Schleicher)

6.3.2 Land-Use Types

Eleven land-use types were also included in the models (Table 6.7). Locations of areas included in each of these types were identified from NAIP aerial photographs and the respective 40 m x 40 m cells included in each. The original soil types from NRCS soil surveys were used for these cells. Specific vegetation types were assigned to each land-use plot type, based on an estimate of the vegetation likely to be present. Woody plant cover was assigned from aerial photographs, using the same seven coverage categories used for the native vegetation.

Table 6.7 Land-use types included in the EDYS models of the Upper Llano River Watershed.

Land-Use Type	Vegetation	Comment
Urban houses (towns)	mesquite-live oak-bermudagrass	50% of area vegetated (lawns)
Buildings/industrial	mesquite-sumac-KR bluestem	% woody plant cover from aerial photographs
Disturbed area	mesquite-sumac-KR bluestem	% woody plant cover from aerial photographs
Oil/drill pad	Ashe juniper-mesquite	% woody plant cover from aerial photographs
Road	none	
Gravel/caliche pit	Ashe juniper-mesquite-sumac	% woody plant cover from aerial photographs
Tilled (cultivated)	wheat	
Irrigated (cultivated)	wheat	
Orchard	pecan-bermudagrass	
Improved pasture	bermudagrass-mesquite-Ashe juniper	% woody plant cover from aerial photographs
Brush control	Ashe juniper-mesquite	recent root plowing, % woody plants from aerial photographs; herbaceous = 20% of clay loam type

The urban houses type was considered to consist of 50% of the cell covered with buildings and pavement and 50% in some type of yard. The grass component of the yards was considered to be bermudagrass and the woody plants were considered to be 75% live oak and 25% mesquite, with the amount of tree canopy cover estimated from aerial photographs.

Woody plant cover in cells classified as buildings/industrial, disturbed areas, or oil/drill pads was considered to consist of a combination of mesquite and sumac. These were considered to be either areas not cleared when the sites were disturbed or the plants were the result of re-invasion. Total woody plant coverage was estimated from aerial photographs. Herbaceous vegetation was estimated to consist of King Ranch bluestem, cane bluestem, threeawns, red grama, sand dropseed, ragweed, and sunflower. Vegetation on gravel and caliche pits was considered to be similar to other disturbed sites, except that Ashe juniper was also a component.

The crops grown on individual cultivated fields vary throughout the six counties. The two most common crops in the area are wheat and grain sorghum. No effort was made to try and distinguish different crops using aerial photographs. Instead, all cultivated areas were assumed to be planted each year in October to wheat. All orchards were assumed to be pecan orchards, with a sparse understory of bermudagrass.

Improved pastures are difficult to distinguish on aerial photographs from native grasslands with low woody plant cover, tilled areas, and some areas recently receiving brush control. Because of this difficulty, improved pastures were treated as native grassland with the appropriate level of woody plant coverage estimated from aerial photographs. Should these areas be identified in the future specifically as improved pastures, the composition and initial biomass values can be changed. Common improved pasture species in the area include King Ranch bluestem, bermudagrass, and kleingrass (*Panicum coloratum*), all of which have been included in other EDYS models in Texas and could be added to these models. Common invading woody species include Ashe juniper, mesquite, and sumac. Invading herbaceous species include King Ranch bluestem, purple threeawn, Johnsongrass (*Sorghum halepense*), ragweed, and sunflower.

Brush control is a management option in the models. However, it was apparent from the aerial photographs that some areas had been subjected to mechanical brush control in the recent past (e.g., 1-5 years). In small-scale applications of EDYS, each of these treated areas can be simulated as separate plot types, based on amount of brush regrowth and apparent herbaceous production. On large-scale applications however, this effort becomes too complex. Therefore, average values were used for the vegetation in these brush control polygons. The initial vegetation data was based on that for the clay loam type in the respective counties (Appendix Tables B.1-3), along with the same amounts of forbs. Grass biomass was reduced by 80%, with composition based on the clay loam composition but with more biomass of early-seral species and less of mid-seral species. The amount of woody plant cover in these polygons was estimated from the aerial photographs.

6.3.3 Aquatic Types

The aquatic module was applied to a one-cell wide (40 m) strip centered on the river channels and the channels of the major tributary creeks (Fig. 2.1). Cells adjacent to this one-cell wide strip, but within the respective drainages, were classified as either loamy bottomland or draw plot types (Table 6.6). The cells included in the aquatic module were subdivided into 10 m x 10 m cells to allow for more precise simulations of aquatic dynamics. Each of the 10 m x 10 m aquatic cells were classified into one of seven possible aquatic types (Table 6.8) based on estimates from aerial photographs and data from the field verification surveys conducted along the rivers. The substrate used for all aquatic cells was consolidated limestone rock. Modifications to this assumption can be made as additional data become available. Examples of useful modifications are 1) inclusion of fractures in the rock and 2) various types of bottom

substrates such as gravel, sand, and fine sediments. The bare rock and standing water types were considered to be barren of any topsoil. The remaining aquatic types were assigned soil profiles corresponding to the top three layers of the respective loamy bottomland soil in each county (Table 6.6). The top three layers were used to represent a shallow soil overlying the bedrock along the drainages.

Table 6.8 Aquatic plot types used in the EDYS models of the Upper Llano River Watershed.

Plot Type	Vegetation
Bare rock	None
Standing water	Duckweed, algae
Freshwater marsh	Cattails, bulrush, spikerush, flatsedge
Giant cane stands	<i>Arundo donax</i>
Grass wetlands	Bermudagrass with patches of mid-grasses and perennial forbs
Baccharis stands	Willow baccharis with some grass understory
Riparian groves	Pecan and hackberry, with baccharis and sumac shrub understory

The bare rock type has no vegetation. The standing water type contains duckweed and algae. Low levels of algae were used for initial conditions and biomass of both components was assumed to be directly correlated with nutrient content of the standing water. Initial vegetation composition of the five vegetated aquatic types was assumed to be constant throughout the drainages (Table 6.9). Initial herbaceous biomass was also considered constant throughout the drainages, but woody plant biomass varied in relation to woody plant coverage, estimated from aerial photographs.

Table 6.9 Initial species composition of the five vegetated aquatic types in the Upper Llano River Watershed models. Values for herbaceous species are aboveground biomass (g/m^2). Values for woody species are proportion (%) of woody coverage (estimated from aerial photographs).

Species	Standing water	Freshwater marsh	Giant cane	Grass wetland	Baccharis stand	Riparian grove
Pecan	---	---	---	---	---	35
Hackberry	---	---	---	---	---	50
Willow baccharis	---	---	---	---	100	10
Evergreen sumac	---	---	---	---	---	5
Giant cane	---	---	1400	---	---	---
Cane bluestem	---	---	---	15	5	2
King Ranch bluestem	---	---	---	10	5	5
Sideoats grama	---	---	---	5	1	2
Bermudagrass	---	---	---	300	20	20
Canada wildrye	---	---	---	20	5	15
Texas cupgrass	---	---	---	40	5	10
Green sprangletop	---	---	---	20	5	10
Vine-mesquite	---	---	---	20	2	10
Switchgrass	---	---	---	40	2	10
Little bluestem	---	---	---	10	5	15
Indiangrass	---	---	---	5	---	2
Johnsongrass	---	---	---	100	5	10
Tall dropseed	---	---	---	5	10	5
Flatsedge	---	120	---	10	---	---
Spikerush	---	70	---	5	---	---
Bulrush	---	150	---	---	---	---
Cattail	---	300	---	---	---	---
Ragweed	---	---	---	10	15	10
Duckweed	50	10	---	---	---	---
Bush sunflower	---	---	---	---	---	4
Total herbaceous	50	650	1400	615	85	130

Dashed lines (---) indicate zero values.

7.0 ANIMALS

The animal component in the Upper Llano River Watershed EDYS model consists of herbivory by different types of animals, both domestic and wildlife. Population dynamics and habitat requirements were not included. Four types of herbivores were included in the Upper Llano model: insects, rabbits, deer, and cattle.

Herbivory in EDYS is simulated using three matrices for each animal species included in the model. Examples are provided for cattle (Appendix Tables C.21-23) and white-tailed deer (Appendix Tables C.24-26). The first matrix for each animal species is the preference matrix (Appendix Tables C.21 and C.24). For each plant part-species combination, a preference rating is assigned for each animal species. A ranking of 1 indicates that the plant part of that plant species is among the highest preferred foods for that particular animal. A low ranking (23 in the case of cattle, 20 for deer) indicates the material is largely avoided by that animal.

The second matrix is the competition matrix (Appendix Tables C.22 and C.25). The values in this matrix indicate the order that animal (cattle in the case of Appendix Table C.22, deer in the case of Appendix Table C.25) has access to that plant part (whether they actually prefer it or not). In general, insects are considered to have first access (value = 1) to most plant parts.

The third matrix is the utilization matrix (Appendix Tables C.23 and C.26). These values indicate how much (percent) of that plant material the animal species could utilize if it desired that plant part. For example, cattle cannot consume 100% of the basal portions of most grasses because of their mouth structure. By contrast, deer and horses can harvest this material to ground level, and below ground level by hoof action.

Actual consumption of plant material in EDYS is a three-step process. First the amount of daily consumption is calculated by multiplying the amount of the animal species (either biomass or number, depending on the species) by a daily consumption value. Stocking rates of each species is flexible in EDYS. The second step is to determine what the animal species consumes that day. This is accomplished by use of the preference, competition, and utilization matrices. If 100% of the daily consumption is available to that species (competition and utilization matrices) in the most highly preferred plant parts and plant species (preference matrix), the animal consumes that amount of the most preferred plant part. If that much is not available, whether because there is insufficient standing crop biomass of that plant part or other herbivores have a higher priority in its consumption, the animal consumes what is available of that plant part and then selects from the next most-preferred plant parts and plant species. This process continues until the daily consumption amount is achieved. The third step is to subtract the quantity consumed from the standing crop biomass of that plant species and plant part.

7.1 Insects

Insect herbivory is modeled in the Upper Llano model as consumption by grasshoppers, with grasshoppers serving as surrogates for all herbivorous insects. An average density of 3 grasshoppers/m² was used. This was an average density for juniper and mesquite habitats in the southern Rolling Plains of Texas (Parajulee et al. 1997). Average consumption rate was estimated at 0.1 g/m²/day (Cottam 1985).

7.2 Rabbits

Rabbits were considered to be eastern cottontails in the Upper Llano model. An average density of about 0.3/ha (1 cottontail per 8 acres) was used. Rabbits were assumed to consume an amount of plant material equivalent to 5.4% of their body weight per day (average of Arnold and Reynolds 1943; Hansen 1972;

Kanable 1977; Warren and Kirkpatrick 1978), or about 73 g per cottontail per day. This equals 0.0022 g forage/m²/day.

7.3 White-tailed deer

Daily food intake (dry-weight basis) by white-tailed deer on the Sonora Experiment Station has been estimated to be 2.2% of live body weight (Bryant et al. 1979). This is lower than measured intake on high-quality feed in South Texas (3.2% of live body weight; Wheaton 1981). Mature does on the Sonora Experiment Station average about 45 kg (Bryant et al. 1979). On the Welder Wildlife Refuge on the central Texas Coast, does average 43 kg and mature bucks about 63 kg (Knowlton et al. 1979), or an average of 53 kg per deer.

An average stocking rate of 0.247 deer/ha (1 deer/10 acres) was used in the Upper Llano model. Using an average deer weight of 53 kg and a daily feed intake of 2.7% of body weight, average daily feed intake would be 1.43 kg/deer or about 0.035 g/m² (0.32 lbs/ac).

White-tailed deer on the Edwards Plateau consume a combination of shrubs, forbs, and grasses, with the specific combinations dependent on vegetation conditions of the site. Consumption on the Sonora Experiment Station was found to average 61% shrubs, 31% forbs, and 8% grasses (Bryant et al. 1979). In South Texas, white-tailed deer tend to consume less shrubs and more herbaceous material. In a mixed shrubland in Kleberg County, diets of free-ranging white-tailed deer (bite count method) consisted of 45% shrubs, 34% forbs, and 21% grasses (Graham 1982). In that study, a total of 141 plant species were consumed by deer over an 18-month period, with 22 plant species comprising 80% of the diet. On the Welder Wildlife Refuge in San Patricio County, deer consumed 70-90% forbs, 10-20% grasses, and 3-10% forbs (Chamrad et al. 1979; Kie et al. 1980). Based on preference ratings, deer on the Welder Wildlife Refuge selected mostly for forbs (69%), then for grasses (18%), and browse (13%) (Drawe and Box 1968). In Jim Hogg County, deer were found to consume 37% forbs, 33% browse, 18% cacti, and 2% grasses, with 10% of rumen contents consisting of unidentifiable material (Everitt and Drawe 1974).

7.4 Cattle

Cattle are primarily grazers (consumers of herbaceous species) instead of browsers (consumers of leaves and twigs of woody species) (Stoddart et al. 1975:257). In many systems, grasses make up 85-99% of the diets of cattle (Sanders 1975; Durham and Kothmann 1977; Frasure et al. 1979). Cattle consume some forbs, especially during seasons when grasses are dormant and forbs are growing. Cattle also consume some shrubs, especially as a source of additional protein (Dalrymple et al. 1965; Herbel and Nelson 1966) or during the winter (Everitt et al. 1981) or drought periods. Cattle diets in South Texas often contain higher proportions of shrubs (6-10%; Drawe and Box 1968; Frasure et al. 1979; Everitt et al. 1981; Smith and McLendon 1981; McLendon et al. 1982) than in many other areas because of the abundance and diversity of shrubs in South Texas.

The amount of forage intake by cattle depends on a number of factors, including type of forage, size of animal, and reproductive state. Of particular importance are protein content, moisture content, and digestibility of the forage species. A general rule for herbivores is that their daily intake, expressed on a dry-weight basis, equals about 3% of their body weight. Using this rule, a 1000-lb cow (1 AU) would consume about 30 lbs of forage per day. Published results from nine vegetation types in five grazing studies indicate a range in daily forage intake of from 20 lbs/AUD (animal unit day) in a desert grassland in New Mexico to 59 lbs/AUD on fertilized sand prairie on the Texas Coast, with an average of 33.3 lbs/AUD (Table 7.1).

Table 7.1 Forage consumption rate (forage disappearance) by cattle in selected studies reported in the literature.

Vegetation	Location	Amount/AUD		Reference
		lbs	grams	
Black grama desert grassland	New Mexico	20	9,080	Paulsen & Ares 1962
Bluestem prairie, upland	Kansas	45.33	20,580	Anderson et al. 1970
Bluestem prairie, limestone breaks	Kansas	24.59	11,164	Anderson et al. 1970
Bluestem prairie, upland	Kansas	56.09	25,465	Owensby & Anderson 1967
Bluestem prairie, limestone breaks	Kansas	30.28	13,747	Owensby & Anderson 1967
Bluestem coastal prairie	Texas	27.29	12,390	Drawe & Box 1969
Pasture, coastal bermuda	Texas	32.25	14,642	McCawley 1978
Pasture, kleingrass	Texas	36.11	16,394	McCawley 1978
Pasture, Bell rhodesgrass	Texas	28.09	12,753	McCawley 1978
MEAN		33.33	15,135	

AUD = animal unit day = amount of forage (dry weight) consumed by a 1000-lb cow for one day.

Forage disappearance refers to the amount of forage removed by an animal while grazing. This quantity consists of two parts. One part is the amount ingested by the animal and the second part is the amount removed from the plant but not consumed. This second part includes plant material that is dropped or trampled during grazing. In most rangelands in the Southwest, this second part contributes about one-third of the amount removed. Three studies reported forage intake on rangelands near or applicable to the Edwards Plateau (Table 7.2). Converting these AUD values to forage disappearance by dividing by 0.67 and combining the resulting three values with the nine values from Table 7.1 results in an overall average of 31.09 lbs/AUD (14,115 g/AUD). This value, 31.1 lbs/AUD (14,115 g/AUD) was used as the daily forage requirement for the Upper Llano model.

Table 7.2 Forage intake by cattle in several range plant communities.

Vegetation	Location	Intake (% of Body Wt)	Amount/AUD		Reference
			lbs	grams	
Blackbrush-curly mesquite	Maverick Co., TX	1.5	15	6810	Launchbaugh et al. 1990
Mesquite-sideoats grama	Rolling Plains, TX	1.9	19	8626	Pinchak et al. 1990
Mesquite-mesa dropseed	Jornada ExpR, NM	1.5	15	6810	Hakkila et al. 1987
MEAN			16.3	7415	

Long-term moderate stocking rates under good management are often based on removal of 40-60% of annual forage production (Paulsen and Ares 1962; Duvall and Linnartz 1967; Owensby and Anderson 1967; Drawe and Box 1969; Anderson et al. 1970). Average annual forage production for each ecological type, under late-seral condition, for the Upper Llano counties are presented in the respective NRCS Soil Surveys (Wiednefeld and McAndrew 1968, Blum 1982, Gabriel et al. 2009). Average current forage production, accounting for the fact that most rangelands on the Edwards Plateau are not in late-seral condition, was estimated at 70% of the values presented in the Soil Surveys (Appendix Tables B.1-3). Proper management stocking rates were assumed to be based on 50% harvest of available forage. These

amounts were further reduced to account for the amount of woody plant cover present (Appendix Table B.12).

The estimated amount of annual available forage was used to arrive at an estimated stocking rate for each EDYS plot type (Appendix Table D.1). Daily forage consumption rate (31.1 lbs/AUD) was multiplied by 365 to arrive at an annual animal unit (AU) forage requirement. This value (11,352 lbs/AU = 5,152 kg/AUD) was divided by the estimated amount of annual available forage for each type (Appendix Table D.1). Averaged over all types, the mean stocking rate was 13.9 ac/AU in Edwards and Real Counties, 16.8 ac/AU in Kimble County, and 12.9 ac/AU in Sutton County, for areas devoid of trees and shrubs (Appendix Table D.1). When adjusted for woody cover, these increased to 27.8 Ac/AU in Edwards and Real Counties, 33.4 Ac/AU in Kimble County, and 23.6 Ac/AU in Sutton County.

These stocking rates compare favorably with those reported at the Sonora Experiment Station. Moderate stocking rate with continuous grazing at the Sonora Station is 20 ac/AU. Under a Merrill Four-Pasture rotation system, the rate is 16 ac/AU (Bryant et al. 1979). Typical continuous year-round stocking rates in the Rolling Plains immediately north of the Edwards Plateau are 18-27 ac/AU (Brock et al. 1982; Pluhar et al. 1987).

7.5 Sheep and Goats

Sheep and goats are important livestock species on the Edwards Plateau. EDYS has the ability to include these livestock types in the simulations, but this was not done in the Upper Llano application. The reason sheep and goats were not included was because of uncertainty in assigning proper livestock mixes (cattle, sheep, goats) on a ranch by ranch, or even pasture by pasture, basis. Should future applications of the model be made in this region on a smaller scale, or at a large scale if the livestock mixture is known, sheep and goats can be included in the management options in the model.

7.6 Feral Hogs

Feral hogs are a major species of concern throughout Texas. They are physically destructive to many habitats, especially wetlands, they compete with native wildlife and domestic livestock for food and habitat space, and their numbers are increasing. Modeling the impacts of feral hogs at large landscape scales, such as the Upper Llano River Watershed, is difficult and perhaps counter-productive because both animal numbers and distribution patterns are not documented on a county-wide basis. Therefore, any scenarios that included such estimates would be subject to substantial speculation. A more productive approach would be to model a specific scenario without feral hogs included and then compare those results to results from the same scenario except with specific spatial and density assumptions made relative to feral hog populations. This was the approach taken in one of the scenarios conducted using the Upper Llano EDYS model in the Upper Llano River Watershed Protection Plan (Broad et al. 2016).

8.0 CALIBRATION

Calibration in EDYS consists of adjustments of parameter values, if needed, to achieve target values for the variables under consideration. Target values are from independent validation data, either from experimental validation studies or from existing field data, if these data are available. In the absence of independent validation data, values based on professional judgement are used.

8.1 Vegetation

Independent validation data are not currently available for vegetation dynamics in the Upper Llano watersheds. In the absence of site-specific field data, data reported in the literature and professional judgement were used to evaluate the calibration results.

8.1.1 General Procedure

The approach used in the calibration process is to begin with one vegetation type, obtain reasonable results for that type, and then add a second type, the second type having a substantially different combination of species. Once acceptable calibration results are obtained for both types in combination, then a third type is added. This iterative process is continued until a sufficient number of types are included that, in combination, include all the major species used in the model. In addition to adding types, variations in woody plant cover are also included in the validation process.

EDYS contains a large number of variables (parameters), the values of any combination of which can be adjusted during the calibration process. The following general procedure is used to determine which parameters are adjusted and to what extent.

Prior experience has shown vegetation responses in EDYS to be more sensitive to changes in some parameters than others. We start the calibration process with those parameters we expect the model to be most sensitive to changes in. Examples include allocation of current production, growth rate, water-use efficiency, root architecture, and end of season dieback. For most of the parameter variables, the EDYS data-base contains a range in values that have been compiled from various literature references and from our own studies. For example, root architecture data are included for little bluestem (*Schizachyrium scoparium*) from ten root profiles reported in seven published studies (Weaver and Zink 1946; Weaver 1947, 1958, 1968; Weaver and Darland 1949; Coupland and Bradshaw 1953; Jurena and Archer 2003) plus field data from the upper 20 cm from three other studies (Johnson 2005; McLendon et al. 2001c; McLendon unpublished data). As we begin the calibration process, we use the mean of these ten profiles. If necessary, we can change the values of initial root biomass in each layer (Appendix Table D.9) to provide a better fit with expected changes in little bluestem biomass values in the model simulations. However, the changes made in root architecture parameters for little bluestem must not exceed the range of values in our data-base (i.e., the parameter values remain consistent with reported values in the literature). A second example is water-use efficiency. Curly mesquite (*Hilaria belangeri*) is a major perennial shortgrass in the Upper Llano watershed models. McGinnies and Arnold (1939) reported an average water-use efficiency in production of new biomass for curly mesquite of 470 g water/g aboveground biomass in a study in southern Arizona. However, they reported a range during the three-years of the study of 205-711, depending on season and amount of water available. Our calibration converged on a value of 650 (Appendix Table D.13), which is within the range of values reported by McGinnies and Arnold (1939) and intermediate among three of their 11 values (590, 643, and 711). Our value of 650 was in the highest 25% of their reported values, and this would seem logical given that the Edwards Plateau is more mesic than the desert grasslands of southern Arizona and water-use efficiency tends to increase (ratio values decrease, i.e., less water per unit of biomass) in many plants as aridity increases.

By comparing changes in biomass of various species within a vegetation type and changes in biomass of the same species among vegetation types between calibration runs, as parameter values are modified, it can be determined which variables are controlling the changes (sensitivity analysis). Values in these parameter sets can be changed and the results compared in the next simulation. Once the values of the major plant species have stabilized near their target values, the vegetation calibration process is considered to be complete. It should be emphasized that the completed calibration process results in

single values for each of the parameters, i.e., the same value is used for that particular species for the respective parameter for all vegetation types in the model. The benefit of this approach is that simulated responses are consistent across vegetation types throughout the landscape.

8.1.2 Examples

Six vegetation types were used to calibrate the model. Ten-year simulations were conducted for each calibration run. Calibration began with an average precipitation regime (1978-1987) and without livestock grazing (but including white-tailed deer, rabbits, and insects). Initial calibration was conducted without livestock grazing for two reasons. First, studies of vegetation change over time (especially successional studies) often utilize grazing exclosures. This is done in order to determine natural patterns of secondary succession. Likewise, the calibration process must first determine if changes in species composition in the simulations are proceeding in a realistic ecological manner (e.g., annuals decrease and perennial grasses increase during succession; midgrasses replace shortgrasses, and shrubs and trees replace midgrasses provided there is sufficient moisture). The second reason for initially excluding livestock grazing during calibration is that the level of livestock grazing is unknown for many of the spatial units in a county-wide model. Therefore if grazing was included initially, the resulting calibration results would most likely reflect the effects of grazing levels entered into the model, which may or may not be accurate stocking rates, rather than successional effects and responses to rainfall variations.

Once the 10-year calibration scenarios were completed for each of the six types under average rainfall conditions, similar 10-year calibration scenarios were run for dry (1947-1956) and wet (1918-1927) regimes. This phase of the calibration process was considered complete when the simulated changes in vegetation patterns reflected the expected responses to changes in precipitation (e.g., shortgrasses increased during dry periods and midgrasses increased during wet periods).

The next step in the calibration process was to include cattle grazing. Estimated stocking rates were calculated (Section 7) based on initial biomass of forage species. The average-, dry-, and wet-regimes were re-run, with cattle grazing included. These results were compared to those without cattle grazing to determine if the simulated responses realistically reflected effects of cattle grazing at moderate stocking rates.

The final step in the calibration process was to compare hydrologic responses, under grazed conditions, of the six types under the three precipitation regimes. The simulated responses were compared to published values from similar types of vegetation and topography.

Summaries of the vegetation calibration results of each of the six vegetation types are presented below, along with brief descriptions of the results. Hydrological responses are presented in Section 8.2.

8.1.2.1 Clay Loam (5% Woody Cover)

Calibration began with Plot Type 2601 (NRCS type = Clay loam, Table 6.6), with 5% average initial cover of woody species and using precipitation values from Zone 1 (central North Llano River watershed; Fig. 4.3). This type is a mixed grassland with scattered mesquite and some live oak (*Quercus virginiana*) and Ashe juniper (*Juniperus ashei*) trees. Initial conditions for each calibration simulation represented a mesquite-sideoats-curly mesquite community (Table 8.1). Total aboveground biomass (including woody portions of tree and shrub species) was set at 451 g/m² (4027 lbs/ac), 31% of which was tree biomass. Shrubs, including prickly pear, comprised 10% of the biomass and forbs comprised 6%. The grass component was about equally divided between midgrasses (27% of total aboveground biomass) and shortgrasses (26%). Major herbaceous species were sideoats grama (*Bouteloua curtipendula*), curly mesquite, and Texas wintergrass (*Stipa leucotricha*), with purple threeawn (*Aristida purpurea*), hairy

grama (*Bouteloua hirsuta*), cane bluestem (*Bothriochloa barbinodis*), plains lovegrass (*Eragrostis intermedia*), tall dropseed (*Sporobolus asper*), and little bluestem as secondary species.

Table 8.1 Simulation of aboveground standing crop biomass (g/m²; initial, Year 10, and 10-year mean) for three rainfall regimes (dry, average, wet) for clay loam range type with 5% or 38% average initial canopy cover of woody species (Plot Types 26 and 28, respectively).

Species	5% Initial Woody Cover							38% Initial Wood Cover						
	Initial	Year 10			10-Year Mean			Initial	Year 10			10-Year Mean		
		Dry	Ave	Wet	Dry	Ave	Wet		Dry	Ave	Wet	Dry	Ave	Wet
Ashe juniper	19	15	17	16	17	18	18	141	160	467	218	146	217	171
Mesquite	87	108	112	99	102	103	99	531	617	719	670	607	652	641
Live oak	32	26	27	26	28	30	28	481	421	507	469	446	504	490
Elbowbush	18	10	10	10	11	11	11	134	79	81	79	99	100	98
Agarito	4	4	4	3	4	4	4	27	39	35	30	36	35	32
Yucca	7	10	10	8	9	9	8	54	94	99	72	76	79	68
Prickly pear	18	12	14	11	15	16	14	133	166	141	126	155	147	133
Cane bluestem	16	23	26	21	26	22	26	11	14	17	16	18	13	19
KR bluestem	8	3	5	2	5	5	5	5	1	3	2	3	3	4
Sideoats grama	44	41	52	37	48	42	51	30	33	54	39	37	34	43
Canada wildrye	6	1	1	1	2	2	2	4	1	1	1	1	1	1
Plains lovegrass	16	4	5	4	8	8	7	11	3	3	3	5	5	5
Green sprangletop	4	*	*	*	2	2	2	3	*	*	*	1	1	1
Little bluestem	13	11	15	11	13	12	15	8	6	10	9	9	8	11
Indiangrass	2	1	2	1	2	2	2	2	1	1	1	1	1	1
Tall dropseed	15	8	12	11	13	11	15	10	9	7	8	14	8	11
Purple threeawn	19	69	295	158	50	104	108	13	43	86	145	31	29	100
Hairy grama	18	4	7	7	7	8	9	12	2	2	3	4	4	4
Curly mesquite	41	46	77	69	62	54	73	27	38	35	60	37	34	54
Vine-mesquite	4	1	2	2	2	3	5	3	1	2	3	2	2	4
Texas wintergrass	33	5	14	19	13	15	19	22	6	2	8	11	5	9
Ragweed	4	7	7	4	11	11	10	3	4	12	6	9	13	15
Lazy daisy	4	*	*	*	*	*	*	2	*	*	*	*	*	*
Sunflower	5	0	0	0	*	*	*	3	0	0	0	*	*	*
Bush sunflower	8	8	8	8	12	8	13	5	4	15	10	9	11	15
Orange zexmenia	6	2	2	1	3	2	2	4	*	1	1	1	1	2
Trees	138	149	156	141	147	151	145	1153	1198	1693	1357	1199	1373	1302
Shrubs	47	36	38	32	39	40	37	348	378	356	307	366	361	331
Midgrasses	124	92	118	88	119	106	125	84	68	96	79	89	74	96
Shortgrasses	115	125	395	255	134	184	214	77	90	127	219	85	74	171
Forbs	27	17	17	13	26	21	25	17	8	28	17	19	25	32
Total	451	419	724	529	465	502	546	1679	1742	2300	1979	1758	1907	1932
Litter	100	81	65	163	71	84	113	100	84	63	147	69	70	105

Asterick (*) indicates a trace amount (< 0.5 g/m²).

At the end of the 10-year simulation under the average precipitation regime and with cattle grazing, total aboveground biomass increased 61% (Table 8.1). Most of the increase was from purple threeawn. Compared to initial conditions, mesquite increased 29% and curly mesquite increased 88%. There was an overall decrease (5%) in midgrasses. Three of the nine midgrasses increased (cane bluestem, sideoats grama, and little bluestem), indiagrass (*Sorghastrum nutans*) remained the same, and the other five midgrasses decreased. Of the five shortgrasses, purple threeawn and curly mesquite increased, while hairy grama, vine-mesquite (*Panicum obtusum*), and Texas wintergrass decreased. Of the five species of forbs, ragweed (*Ambrosia psilostachya*) increased, bush sunflower (*Simsia calva*) remained the same, and

lazydaisy (*Aphanostephus ramosissimus*), sunflower (*Helianthus annuus*), and orange zexmenia (*Zexmenia hispida*) decreased.

These patterns were considered to be reasonable. The type was considered to be in high fair range condition at the beginning of the simulation. Potential forage production on this type is on the order of 340 g/m² (3000 lbs/ac) in average rainfall years and 500 g/m² (4500 lbs/ac) in wet years (Blum 1982). The simulated forage production in Year 10 was 513 g/m², which was probably high for average rainfall. However, the 10-year mean forage production was 290 g/m² (Table 8.1), which is reasonable under good range condition. The simulations indicated an increase in shortgrasses, especially purple threeawn and curly mesquite, and a decrease in midgrasses. This is realistic under moderate grazing and average rainfall. The species that increased the most in the simulations was purple threeawn, which is a less-palatable grass than those that decreased. The simulated increase in mesquite (29%) over the 10-year period was the same decadal average (29%) reported for a mesquite-dominated woodland in South Texas between 1960 and 1983 (Archer et al. 1988). Ragweed was the forb species that increased over the ten years and this is also realistic. It is not a preferred species by either cattle or white-tailed deer, although both herbivores will consume some during periods when more palatable species are not available in adequate amounts.

Average annual rainfall in the dry regime was 24% less than under the average regime (17.38 and 22.89 inches, respectively). At the end of the 10-year dry regime, total aboveground biomass decreased 7% compared to initial conditions and 42% compared to the average regime (Table 8.1). Compared to the average precipitation regime, biomass of all nine midgrasses decreased, with the largest differences being in sideoats grama, little bluestem, indiangrass, and tall dropseed. Of the five shortgrasses, all had lower biomass than under the average regime. Purple threeawn and curly mesquite had higher biomass than under initial conditions, but the increases were much lower than under average rainfall. Based on average biomass over the 10 years, purple threeawn produced only half as much biomass under the dry regime as it did under average conditions while curly mesquite produced 15% more. Based on average 10-year production, curly mesquite was the most competitive herbaceous species under dry conditions with grazing. Mesquite increased under the dry regime (24%), but not as rapidly as under average conditions (29%). Averaged over the 10 years, forb biomass was 24% higher under the dry regime than under the average regime, with the increase coming from bush sunflower and orange zexmenia, both of which are relatively xeric species. Forbs typically increase, relative to perennial grasses, during dry periods because of less competition from the grasses.

The wet regime had an annual average precipitation of 25.89 inches, or 13% more than under the average regime. Under the wet regime, average annual aboveground biomass was 9% higher than under the average regime. Tree and shrub biomass values were slightly less than under average conditions, most likely because of increased competition from grasses. Grass biomass (midgrasses and shortgrasses combined) was 17% higher under the wet regime than under the average regime (339 and 290 g/m², respectively) and forb biomass was 19% higher. Of the nine midgrasses, four had increased biomass under the wet regime (cane bluestem, sideoats grama, little bluestem, and tall dropseed). Of the five shortgrasses, all had increased biomass under the wet regime, but the increases were not as much as they were for the midgrasses.

There are several general trends that are apparent from the calibration runs for this type under moderate grazing by cattle. First, mesquite is likely to increase regardless of precipitation regime. It will increase most rapidly under average conditions, but it is likely to increase even under dry conditions. Second, shortgrasses will be favored, relative to midgrasses, by dry conditions and midgrasses will be favored by more mesic conditions. Some species in each group are likely to increase or decrease under either extreme, but in general, shortgrasses tolerate dry conditions better than most midgrasses. With a moderate cattle stocking rate, grass species most likely to increase over time are purple threeawn, curly

mesquite, cane bluestem, and sideoats grama. Under more mesic conditions, little bluestem and indianguass are also likely to increase, and the midgrasses may largely replace the shortgrasses if more mesic conditions should continue for longer periods. On clay loam sites on the Welder Wildlife Refuge in South Texas, shortgrasses were the dominant herbaceous species at the end of the drought of the 1950s (Box 1961; Box and Chamrad 1966) and curly mesquite was the second most abundant herbaceous species. Within 10-15 years of the return of higher rainfall, midgrasses had replaced shortgrasses as the herbaceous dominants (Drawe et al. 1978). Similarly, replacement of shortgrasses by midgrasses following drought in the central Great Plains takes about 8-12 years (Weaver 1954).

8.1.2.2 Clay Loam (38% Woody Cover)

This is the same type as the previous type, except with an increase in cover of woody species and a corresponding decrease in the amount of herbaceous species (Table 8.1). Under initial conditions, this type supported a total aboveground biomass of 1679 g/m², of which almost half (46%) was trees and 30% was shrubs. Mesquite and live oak were the major trees and elbowbush (*Forestiera pubescens*) and prickly pear (*Opuntia lindheimeri*) were the major shrubs, although there were also substantial amounts of agarito (*Mahonia trifoliolata*) and yucca (*Yucca constricta*). The herbaceous component was only two-thirds that of the clay loam type with 5% woody cover. Most abundant herbaceous species were sideoats grama, curly mesquite, and Texas wintergrass, with lesser amounts of purple threeawn, hairy grama, cane bluestem, little bluestem, and tall dropseed.

Under the 10-year average precipitation regime and with moderate grazing by cattle, there was a substantial increase in trees. At the end of 10 years, tree biomass increased 48%, with most of the increase coming from an increase in Ashe juniper and mesquite. Mesquite increased 35% over initial conditions, but Ashe juniper increased 231%. There was a slight increase (5%) in live oak. At the end of the 10 years, the site was still a mesquite-live oak woodland, but Ashe juniper had increased to level that it was near to replacing live oak and the sub-dominant tree. Changes also occurred in the shrub component. There was very little change in overall biomass of the shrubs, but there was a shift in composition. Yucca doubled in biomass, agarito increased 44%, prickly pear increased 25%, and elbowbush decreased by 41%.

Despite the increase in woody plant cover, there was also an increase in the herbaceous component. Midgrasses increased by 14%, shortgrasses by 65%, and forbs by 59%. Overall, herbaceous biomass increased 41% over initial conditions at the end of the 10 years. This compares to an increase of 107% on the clay loam site with 5% initial cover of woody species. Herbaceous production does not decrease linearly as cover of woody species increases. There is a threshold of about 20% cover of woody species that needs to be crossed before herbaceous production begins to decrease (McDaniel et al. 1982; Scifres et al. 1982). A study on the Welder Wildlife Refuge indicated that at 60% cover of woody species, herbaceous production averaged 46% of the level at 0-10% woody plant cover (Scifres et al. 1982). The simulated increase in tree biomass on the clay loam site was 48%, which if linearly projected to the 38% initial woody cover for this type would result in a 56% woody cover in Year 10 $[(0.38)(1.48) = 0.56]$. Comparing the 10-year changes in herbaceous biomass on the two clay loam types (5% and 38% initial woody cover), the type with the heavier woody plant cover (estimated to be 56% in Year 10) had an increase in herbaceous biomass of 38% $(0.41/1.07 = 0.38)$ compared to the increase on the clay loam site with the lighter woody cover. This is similar to the 46% difference reported by Scifres et al. (1982) comparing herbaceous production on sites with 60% woody cover to those with 0-10% woody cover. This result suggests that the effect of the increase in woody plants on herbaceous dynamics in the calibration simulation is reasonable.

The same grass species increased on this type that increased on the clay loam site with 5% initial woody cover, but not by the same proportions. Purple threeawn and curly mesquite, both shortgrasses, increased

proportionally less on the heavier wooded site than on the lightly wooded site, indicating that they were less competitive under the heavier wooded conditions. Conversely, sideoats grama increased more proportionally under the heavier wooded conditions, indicating it was more tolerant than the shortgrasses of these conditions. Of the forbs, ragweed and bush sunflower both increased more proportionally under the denser woody cover.

Under the dry regime (24% less precipitation than under the average regime), there was only a slight increase in tree biomass (+ 4%) as well as shrub biomass (+ 9%). Most of the increase in trees was from mesquite. Live oak declined by about 12% under the dry scenario. Agarito, yucca, and prickly pear increased under the dry regime and both agarito and prickly pear increased more than they did under the average precipitation regime. Compared to initial conditions, midgrasses declined during the dry regime and shortgrasses increased (- 19% and + 17%, respectively). There was a slight increase in cane bluestem and sideoats grama, but all the other seven midgrasses declined. The increase in shortgrasses was because of an increase in purple threeawn and curly mesquite. The other three shortgrasses declined.

Tree biomass increased 18% over initial conditions at the end of the 10 years of wet regime. Ashe juniper and mesquite both increased, but there was a slight decrease in live oak, most likely the result of competition from the other two tree species. There was a net decrease in shrubs, with elbowbush and prickly pear decreasing and agarito and yucca increasing. Averaged over the 10 years of the wet regime (13% average increase in annual precipitation), midgrass biomass was almost 30% more than under the average precipitation regime and biomass of shortgrasses was 131% greater. The greatest increase in midgrasses was from sideoats grama and little bluestem, and the greatest increase in shortgrasses was from purple threeawn and curly mesquite. Ragweed, bush sunflower, and orange zexmenia all had higher average biomass under the wet regime than under average conditions.

8.1.2.3 Sandy Loam (38% Woody Cover)

Initial conditions for this type was a live oak-mesquite open woodland with some Ashe juniper and Texas persimmon (*Diospyros texana*) and with the openings supporting a mixed grassland of mid- and shortgrass species (Table 8.2). Woody plant cover averaged 38%. The major grasses were sideoats grama, little bluestem, curly mesquite, and sand dropseed, with lesser amounts of Texas wintergrass, hairy grama, and purple threeawn. There was a mixture of forb species and some scattered shrubs (yucca, agarito, and prickly pear). Total aboveground biomass was 1817 g/m², of which 90% was from woody species. Total herbaceous aboveground biomass was 190 g/m² (1700 lbs/ac). Livestock (cattle) stocking rate was considered to be 19 acres/AU.

Table 8.2 Simulation of aboveground standing crop biomass (g/m²; initial, Year 10, and 10-year mean) for three rainfall regimes (dry, average, wet) for Sandy loam and Loamy bottomland range types with 38% average initial canopy cover of woody species (Plot Types 24 and 13, respectively).

Species	Sandy Loam									Loamy Bottomland								
	Initial	Year 10			10-Year Mean			Initial	Year 10			10-Year Mean						
		Dry	Ave	Wet	Dry	Ave	Wet		Dry	Ave	Wet	Dry	Ave	Wet				
Pecan	---	---	---	---	---	---	---	1730	1594	1618	1598	1667	1682	1672				
Sugar hackberry	---	---	---	---	---	---	---	4265	3639	3754	3681	3934	3991	3945				
Texas persimmon	127	102	102	102	111	111	111	253	204	204	204	221	221	221				
Ashe juniper	282	492	909	716	353	450	451	141	120	233	262	130	153	170				
Mesquite	531	562	605	571	584	615	591	199	187	189	203	196	199	212				
Live oak	601	527	546	569	560	572	601	---	---	---	---	---	---	---				
Agarito	27	31	29	21	33	33	27	27	33	31	31	29	29	31				
Evergreen sumac	---	---	---	---	---	---	---	118	69	71	73	85	86	90				
Yucca	32	50	40	27	42	42	35	---	---	---	---	---	---	---				
Prickly pear	27	11	14	12	19	22	21	---	---	---	---	---	---	---				
Mustang grape	---	---	---	---	---	---	---	103	82	83	80	91	92	90				
Cane bluestem	3	4	4	5	4	3	5	14	26	56	46	27	28	38				
KR bluestem	---	---	---	---	---	---	---	10	8	11	14	11	8	15				
Sideoats grama	30	28	40	39	33	31	41	34	70	131	111	62	60	84				
Canada wildrye	2	*	*	*	*	*	*	34	5	6	5	8	8	7				
Plains lovegrass	5	1	1	1	2	2	2	8	2	2	2	3	3	3				
Switchgrass	---	---	---	---	---	---	---	4	3	5	5	3	3	5				
Little bluestem	30	15	28	33	25	24	34	27	42	71	58	40	39	54				
Indiangrass	2	1	1	1	1	1	2	3	2	3	4	2	2	5				
Sand dropseed	21	6	5	7	16	12	19	---	---	---	---	---	---	---				
Purple threeawn	10	7	4	93	10	5	41	13	2	22	34	5	10	23				
Hairy grama	12	2	2	2	3	3	3	---	---	---	---	---	---	---				
Curly mesquite	27	2	5	4	13	13	13	26	1	2	1	8	9	9				
Vine-mesquite	---	---	---	---	---	---	---	5	*	2	1	3	4	4				
Texas wintergrass	11	1	1	1	4	3	3	33	2	2	2	5	5	4				
Ragweed	8	35	59	44	56	61	80	5	8	29	23	14	18	32				
Lazy daisy	6	*	*	*	*	*	*	5	*	*	*	*	*	*				
Indian blanket	5	*	*	*	*	*	*	---	---	---	---	---	---	---				
Sunflower	---	---	---	---	---	---	---	7	0	0	0	*	*	*				
Texas bluebonnet	7	0	0	0	0	0	0	---	---	---	---	---	---	---				
Bush sunflower	11	11	42	27	27	32	43	8	6	24	17	11	13	24				
Orange zexmenia	---	---	---	---	---	---	---	8	1	1	1	3	2	3				
Trees	1541	1683	2162	1958	1608	1748	1754	6588	5744	5998	5948	6148	6246	6220				
Shrubs	86	92	83	60	94	97	83	248	184	185	184	205	207	211				
Midgrasses	93	55	79	86	81	73	103	134	158	285	245	156	151	211				
Shortgrasses	60	12	12	100	30	24	60	77	5	28	38	21	28	40				
Forbs	37	46	101	71	83	93	123	33	15	54	41	28	33	59				
Total	1817	1888	2437	2275	1896	2035	2123	7080	6106	6550	6456	6558	6665	6741				
Litter	100	79	62	125	67	67	90	100	82	64	102	78	67	93				

Asterisk (*) indicates a trace amount (< 0.5 g/m²).

Dashed lines (---) indicate that the species was not included in the type.

Under the average precipitation regime, there were major vegetation changes over the 10-year simulation period. Averaged over the 10 years, Ashe juniper increased 60%, grass production decreased 37%, and forb biomass increased 151% (Table 8.2). Mesquite, agarito, and yucca also increased (14%, 22%, and 31%, respectively) and live oak decreased by about 5%. Midgrass biomass decreased by 22%, with little bluestem and sand dropseed decreasing the most (20% and 43%, respectively). Sideoats grama increased slightly (3%) and cane bluestem neither increased nor decreased. Biomass of shortgrasses decreased

60%, or three times the average decrease of midgrasses. Rainfall percolates deeper in sandy soils than on adjacent clays or clay loams, and midgrasses tend to have deeper root systems than most shortgrasses. For example, the maximum reported rooting depth of sideoats grama and little bluestem, both midgrasses, are 396 and 244 cm, respectively (Tomanek and Albertson 1957; Weaver and Fitzpatrick 1934), compared to 183 and 107 cm for the shortgrasses purple threeawn and hairy grama (Albertson 1937; Weaver 1926). Therefore, midgrasses have a competitive advantage over shortgrasses on sandy sites, provided there is sufficient rainfall to percolate to deeper soil layers. Ragweed and bush sunflower were the forbs that increased substantially over the 10-year period of average rainfall. Ragweed increased almost seven-fold, from an initial value of 8 g/m² to an average of 61 g/m² over the 10 years, and bush sunflower almost tripled. Increases in both of these species are common on sandy sites under moderate to heavy grazing. Herbaceous biomass averaged 190 g/m² over the 10-year simulation. This compares favorably with a value of 239 g/m² over a three-year period on a sandy loam site on the Welder Wildlife Refuge in South Texas (Drawe and Box 1969), during which annual rainfall averaged about 20% more the average regime used in the 10-year simulation.

Ashe juniper and mesquite also increased during the 10 years of the dry regime, but at lower levels (25% and 10%, respectively) than under average precipitation. Live oak decreased by 7%, compared to 5% under the average regime. Shrubs increased at about the same rate under the dry regime as they did under the average regime. Grasses decreased less under the dry regime than under the average regime (27% and 37%, respectively), in part because forbs did not increase as much. The increase in forbs under the dry regime was 10 g/m² less than it was under the average regime, and the decrease in grasses was 14 g/m² less under the dry regime (Table 7.2). All midgrasses except plains lovegrass and indiangrass increased more under the dry regime than under the average regime, although the amount of increase was small. Most shortgrasses produced the same amount under the dry regime as under the average regime, except for purple threeawn, which produced more biomass under the dry regime.

The wet regime favored all lifeforms except shrubs. Shrub biomass decreased 14% compared to the average regime in response to increased production from trees and grasses. Tree biomass increased only slightly (less than 1%) in the wet regime compared to the average regime. Live oak had the largest increase (5% over average), Ashe juniper and Texas persimmon remained stable, and mesquite had a small decrease. Biomass of all three herbaceous lifeforms increased in the wet regime (Table 7.2). Midgrasses increased 41% more than under the average regime, shortgrasses 150%, and forbs 30%. The herbaceous species grow faster than woody species and are able to respond to more favorable conditions more rapidly. All midgrass species except plains lovegrass increased under the wet regime, with large increases in biomass occurring in sideoats grama, little bluestem, and sand dropseed. Of the four species of shortgrasses, only one species, purple threeawn, had higher biomass in the wet regime than in the average regime. However, the increase from purple threeawn was substantial. Purple threeawn is an early mid-successional species with a high potential growth rate and can respond rapidly to favorable climatic conditions. In addition, of the four shortgrasses it is the least preferred forage species by cattle. Therefore, grazing pressure was higher on the other three species, which provided additional successional advantage to purple threeawn.

8.1.2.4 Loamy Bottomland (38% Woody Cover)

This type includes riparian woodlands and flats, and smaller wooded drainages. Overstory composition in the initial conditions consisted of about 65% sugar hackberry (*Celtis laevigata*) and 26% pecan (*Carya illinoensis*), with lesser amounts of Texas persimmon, mesquite, and Ashe juniper (Table 8.2). This ratio of hackberry to pecan is reversed from what is reported along floodplains in the eastern Edwards Plateau (Ford and Van Auken 1982), but pecan decreases in abundance from east to west across the region (Riskind and Diamond 1986). The shrub component consisted mostly of evergreen sumac (*Rhus virens*) and mustang grape (*Vitis mustangensis*). The herbaceous understory consisted of a mix of midgrasses,

shortgrasses, and forbs. Major species were sideoats grama, Canada wildrye (*Elymus canadensis*), little bluestem, Texas wintergrass, and curly mesquite. Total herbaceous aboveground biomass was 244 g/m² (2180 lbs/ac) and livestock (cattle) stocking rate was 12.4 acres/AU.

Under the average precipitation regime, total aboveground biomass of trees decreased from initial conditions by about 5%, averaged over the 10 years of the simulation. Shrub biomass decreased by almost 20%, midgrasses increased by about 15%, shortgrasses decreased by over 60%, and forbs remained stable (Table 8.2).

The dry regime resulted in only a slight (2%) decrease in total aboveground biomass compared to the average regime (Table 7.2). All lifeforms except midgrasses decreased and the increase in midgrasses was minor (5 g/m² = 3%). This slight increase was from King Ranch bluestem (*Bothriochloa ischaemum*), sideoats grama, and little bluestem. All tree species decreased in biomass under the dry regime except for Texas persimmon, which remained stable. Of the shortgrasses, Texas wintergrass remained stable and the largest decrease was in purple threeawn. Curly mesquite and vine-mesquite biomass decreased, but by only minor amounts. The dry regime resulted in less ragweed and bush sunflower, but a slight increase in orange zexmenia, which is the most xeric of the perennial forbs.

There was a slight increase (1%) in total aboveground biomass under the wet regime, compared to the average precipitation regime. However, there was a substantial increase (46%) in herbaceous species. Herbaceous species, grasses and forbs, were able to uptake the increased rainfall faster than the woody species and were able to fully utilize the increased moisture. Midgrasses increased by 40%, shortgrasses by 43%, and forbs by 79%. Both ragweed and bush sunflower, the more mesic of the forb species, almost doubled in biomass under the wet regime. The midgrasses with the greatest percentage-wise increased under the wet regime were switchgrass (67%), King Ranch bluestem (88%), and indiangrass (150%). Switchgrass and indiangrass are the two most mesic of the midgrasses and King Ranch bluestem is an introduced species with a high potential growth rate under mesic conditions (Kapinga 1982). There were also substantial percentage increases in cane bluestem (36%), little bluestem (38%), and sideoats grama (40%). Of the four shortgrasses, only purple threeawn had higher biomass (+ 130%) under the wet regime than under the average regime. These responses from the herbaceous species are what might be expected under wetter conditions. The more mesic and the more rapidly growing species had the greatest increases in biomass, and the more xeric and slower growing species did not increase because of competition from the more mesic species.

8.1.2.5 Low Stony Hill (38% Woody Cover)

The vegetation of this type was modeled as an open woodland with a moderate stand of shrubs and a sparse grass understory consisting mostly of shortgrasses (Table 8.3). The overstory was dominated by sugar hackberry (31% of tree biomass), live oak (28%), and Ashe juniper (23%), with lesser amounts of Texas persimmon (12%) and mesquite (6%). Of the total aboveground biomass, 86% was from trees and 9% was from shrubs. The major shrubs were evergreen sumac and elbowbush. The herbaceous component (122 g/m² = 1090 lbs/ac) consisted primarily of shortgrasses (79%), with curly mesquite the most abundant species. King Ranch bluestem and sideoats grama were the most abundant midgrasses and ragweed was the most abundant forb. Livestock (cattle) stocking rate was set at 28.3 ac/AU.

Table 8.3 Simulation of aboveground standing crop biomass (g/m²; initial, Year 10, and 10-year mean) for three rainfall regimes (dry, average, wet) for Low stony hill and Steep adobe range types with 38% average initial canopy cover of woody species (Plot Types 42 and 36, respectively).

Species	Low Stony Hill							Steep Adobe						
	Initial	Year 10			10-Year Mean			Initial	Year 10			10-Year Mean		
		Dry	Ave	Wet	Dry	Ave	Wet		Dry	Ave	Wet	Dry	Ave	Wet
Sugar hackberry	711	591	592	591	645	645	644	---	---	---	---	---	---	---
Texas persimmon	253	206	205	205	224	224	222	---	---	---	---	---	---	---
Ashe juniper	494	459	463	469	484	483	491	564	875	1171	1202	755	810	886
Mesquite	133	119	120	117	127	128	125	133	123	123	123	131	131	131
Texas red oak	---	---	---	---	---	---	---	420	383	382	381	405	403	402
Live oak	601	529	532	540	565	565	574	601	683	879	931	712	813	864
Elbowbush	67	37	37	37	48	48	48	67	40	41	41	48	48	49
Agarito	11	6	6	6	8	8	8	11	6	6	6	8	8	8
Evergreen sumac	118	74	74	74	93	93	92	---	---	---	---	---	---	---
Yucca	22	22	23	16	22	23	19	13	12	10	12	17	17	17
Prickly pear	13	9	10	9	12	12	11	13	9	10	10	11	12	12
Cane bluestem	1	*	1	*	1	1	*	5	15	21	15	10	10	11
KR bluestem	8	2	2	2	3	4	3	---	---	---	---	---	---	---
Sideoats grama	5	3	3	2	4	4	3	17	37	50	38	26	24	25
Texas cupgrass	1	*	*	*	*	*	*	---	---	---	---	---	---	---
Little bluestem	1	*	*	*	1	1	1	17	26	37	29	19	19	20
Tall dropseed	---	---	---	---	---	---	---	4	1	1	1	2	2	2
Sand dropseed	---	---	---	---	---	---	---	4	*	1	1	1	1	1
Purple threeawn	17	62	189	131	41	55	90	4	1	1	1	1	1	1
Hairy grama	18	12	16	21	14	12	24	15	3	3	3	5	5	6
Red grama	10	16	29	15	26	24	28	5	*	*	*	1	1	1
Curly mesquite	37	85	136	93	76	75	88	9	2	2	3	5	4	5
Texas wintergrass	14	6	19	15	9	14	12	---	---	---	---	---	---	---
Ragweed	3	6	5	2	11	9	7	---	---	---	---	---	---	---
Lazy daisy	1	0	*	*	*	*	*	---	---	---	---	---	---	---
Bundleflower	1	*	*	*	*	*	*	---	---	---	---	---	---	---
Indian blanket	2	*	*	*	*	*	*	---	---	---	---	---	---	---
Prairie coneflower	1	0	*	*	*	*	*	---	---	---	---	---	---	---
Bush sunflower	2	3	2	1	4	2	3	---	---	---	---	---	---	---
Orange zexmenia	---	---	---	---	---	---	---	4	13	17	17	11	8	1
Trees	2192	1904	1912	1922	2045	2045	2056	1718	2064	2555	2637	2003	2157	2283
Shrubs	231	148	150	142	183	184	178	104	67	67	69	84	85	86
Midgrasses	16	5	6	4	9	10	7	47	79	110	84	58	56	59
Shortgrasses	96	181	389	275	166	180	242	33	6	6	7	12	11	13
Forbs	10	9	7	3	15	11	10	4	13	17	17	11	8	1
Total	2545	2247	2464	2346	2418	2430	2493	1906	2229	2755	2814	2168	2317	2442
Litter	100	84	70	152	69	77	102	100	80	63	121	68	65	87

Asterisk (*) indicates a trace amount (< 0.5 g/m²).

Dashed lines (---) indicate that the species was not included in the type.

Under the average precipitation regime, there was a 6% decrease in tree biomass, suggesting that the initial values may have been set too high. All tree species decreased in biomass during the 10-year simulation, but the decreases were relatively more in hackberry and live oak than in Ashe juniper, Texas persimmon, and mesquite (Table 8.3). This species response pattern is reasonable, given that hackberry and live oak are more mesic species and the other three species are more xeric. All five shrub species also decreased during the simulation, but the decreases were minor for yucca and prickly pear, both of which are xeric species. Biomass of shortgrasses increased during the 10-year simulation, with the largest increases for purple threeawn and curly mesquite. Red grama (*Bouteloua trifida*) also increased, Texas

wintergrass was stable, and hairy grama decreased. Of the forbs, ragweed increased substantially and there was a more modest increase in bush sunflower. The other four forb species decreased in abundance, probably because of consumption by deer.

The dry regime had very little effect on tree and shrub biomass values (Table 8.3). The shallow soils and rock substrate of this type apparently allowed sufficient moisture to move deeper into the profile and the deeper-rooted woody species were able to extract sufficient moisture from deeper layers of the profile. Midgrass and shortgrass biomass declined about 10% under the dry regime, which was about half the decline in annual rainfall under the dry regime (24%). King Ranch bluestem was the only midgrass that had a decrease in biomass under the dry regime, and three species of shortgrasses had a modest increase in biomass, compared to the average regime. The three species are hairy grama, red grama, and curly mesquite, and all three are more adapted to drier conditions than is purple threeawn, which had a 25% decrease in biomass under the dry regime. Both ragweed and bush sunflower increased under the dry regime, and both of these forb species commonly increase during drier conditions when competition from grasses decreases.

Under the wet regime, tree biomass increased, with the increase coming from live oak and Ashe juniper (Table 8.3). Shrub biomass was slightly lower under the wet regime, primarily because of a decrease in yucca. The primary response to increased rainfall under the wet regime was from shortgrasses, which increased by 34% compared to the average regime. Shortgrasses were the major herbaceous lifeform under initial conditions on this plot type and they subsequently provided the largest amount of increased biomass under favorable conditions. Of the five species of shortgrasses, both purple threeawn and hairy grama experienced substantial increases in biomass, hairy grama doubling compared to average conditions and purple threeawn increasing by 64%. There was a slight decrease in midgrasses and in forbs resulting from the increased competition from the shortgrasses. Overall, the 13% increase in precipitation under the wet regime increased herbaceous biomass by 29%.

8.1.2.6 Steep Adobe (38% Woody Cover)

The initial plant community on this plot type was a live oak-Ashe juniper-Texas red oak community (Table 8.3). The shrub component was about half that of the Low Stony Hill type and consisted mostly of elbowbush. The herbaceous component was much different from the Low Stony Hill type. Midgrasses were more abundant on the Steep Adobe site and shortgrasses and forbs were less abundant. The major midgrasses were sideoats grama and little bluestem and the major shortgrass was hairy grama. Total initial biomass of grasses on the Steep Adobe site was less than on the Low Stony Hill type (80 and 112 g/m², respectively). Only one forb species, orange zexmenia, was included for the Steep Adobe type. Livestock (cattle) stocking rate was set at 36.4 Ac/AU.

Ten years under the average precipitation regime resulted in major changes on this type (Table 8.3). Tree biomass increased 26%, with most of the increase coming from Ashe juniper (44% increase) and live oak (35% increase). Shrub biomass decreased by 18% because of increased competition from the trees, although there was a 31% increase in yucca. Midgrasses increased by 19% over the ten years, with increases occurring in cane bluestem (120%), sideoats grama (47%), and little bluestem (17%). There was a substantial decrease (67%) in shortgrasses, with all four species decreasing. There are major differences in soils between the Steep Adobe and Low Stony Hill types, with the Steep Adobe type having shallower topsoils and a substrate that has deeper fractures and more unconsolidated rock. These edaphic differences result in less soil moisture being available in the shallower zones on the Steep Adobe type, but more moisture moving to deeper layers and eventually to groundwater. From a vegetation standpoint, deeper-rooted species are more favored on the Steep Adobe site and shallower-rooted species on the Low Stony Hill site, and total plant biomass is less on the Steep Adobe site.

Under the dry regime, tree biomass decreased by 7% compared to the average regime, with the decrease coming from lower production of Ashe juniper and live oak. Production of shrubs and grasses remained at about the same levels as under the average regime, but production of orange zexmenia, a xeric forb, increased. Total overall biomass production declined by 6% compared to the average regime. Biomass increased in the wet regime, but only by about 5% compared to average conditions. Most of the increase came from Ashe juniper and live oak.

This type had a relatively minor response to changes in precipitation regime. A 24% decrease in average 10-year rainfall resulted in a 7% decrease in total aboveground plant biomass and a 13% increase in precipitation resulted in a 5% increase in plant biomass. In both cases, most of the changes occurred as responses of Ashe juniper and live oak to fluctuating precipitation. This relative insensitivity to precipitation fluctuations on this type is probably the result of the site being a fairly dry site that has a larger proportion of plant-available moisture located in deeper soil and sub-soil layers.

8.1.2.7 Summary of Vegetation Responses

The calibrated model produced reasonable and ecologically valid responses to both succession (development over the 10 years) and variation in moisture (dry, moderate, wet years). Overall, there was an increase in trees, primarily Ashe juniper and mesquite, over time. This is expected in a woodland-grassland ecotone in the absence of fire. Grasses increased under average and wet precipitation regimes but decreased on most sites under the dry regime. In proportion to initial values, cane bluestem was the midgrass species that had the greatest increase, and purple threeawn and curly mesquite were the shortgrasses with the greatest increase in biomass. Because these simulated responses were consistent with expected successional responses and responses to variation in moisture, the Upper Llano EDYS model was considered to be properly calibrated.

8.2 Ecohydrology

Three ecohydrological components were assessed in the model calibration: 1) evapotranspiration, 2) surface runoff, and 3) groundwater-use by vegetation. These components were also combined to develop several basic water balances. Direct field data were not available for these three variables for use in these calibrations. Instead, literature values and professional judgment were used.

8.2.1 Evapotranspiration

In EDYS, evapotranspiration (ET) is separated into its two primary components: evaporation (E) and transpiration (T). Evaporation is the conversion of liquid water to water vapor, with the subsequent movement of the water vapor into the atmosphere. Transpiration is the process of water loss from plants by evaporation through their stomates. In EDYS, transpiration is accounted for as a function of water use by individual plant species. Evaporation is subdivided into interception and evaporation, where interception is the amount of water intercepted by the vegetation canopy and then evaporated, whereas evaporation is the amount of water evaporated from the soil surface (including bare ground, litter, rocks, and other bare surfaces) and open water surfaces.

The amount of ET varies widely among plant communities, regions, seasons, and years. Three primary variables determine the amount of ET: 1) temperature, 2) available moisture, and 3) vegetation. Warmer regions, or warmer seasons, have higher ET rates than cooler regions or seasons, other factors held constant. Under the same temperature regime, an increase in available moisture results in an increase in ET. Conversely, as conditions become drier, less water is available for evaporation and transpiration and therefore ET decreases. However, drier regions are often warmer than mesic regions and this increase in temperature also has an effect on ET rates. Potential evaporation rates are often estimated for a locale

from measurements of evaporation from a free-water surface. Evaporation rates from exposed surfaces (e.g., leaf surfaces, rocks, surface of the litter layer) may approximate this rate if sufficient moisture is present. Evaporation from a soil surface is generally less than the maximum potential rate because the water is being translocated to the surface from which evaporation actually occurs and this translocation process slows the rate of evaporation. If the soil surface is shaded, the lower temperature also reduces the evaporation rate.

Plants move water from various soil depths, into their roots, through the plant, and into stomatal cavities where the evaporation actually occurs. This movement of water is in response to a gradient in water potential between the various soil layers and the atmosphere at the leaf surface. The largest gradient occurs when the atmosphere is very dry and the soil is very wet. Conversely, very little transpiration occurs when the atmosphere is moist (high relative humidity) or when the soil is very dry. In the first case, the water potential gradient is too weak to result in much water movement. In the second case, there is too little water to move.

Therefore the **rate** of transpiration is largely dependent on the water potential gradient and the amount of water available to the roots. However, the **amount** of transpiration is largely dependent on the amount and type of vegetation present and the amount of water available to the plants. As the amount of transpiring surface (primarily leaf surface area) increases, the amount of water transpired increases, provided there is sufficient moisture available in the rooting zone of the particular vegetation. For example, ET in mesquite-shrublands at a site in South Texas was 37% higher than on bare soil in wet years, but only 30% higher on adjacent shortgrass sites than on bare soil (Table 8.4). In dry years, ET from bare soil decreased by almost 68% compared to wet years and ET decreased by 64% on vegetated sites. In wet years, ET was less on bare soil than in dry years because more of the rainfall in dry years occurred in small rainfall events, resulting in proportionately more water remaining in the upper soil zone and therefore subject to evaporation.

Table 8.4 Evapotranspiration (ET; mm) and annual precipitation (PPT; mm) in dry and wet years on the La Copita Experiment Station in South Texas (data from Weltz and Blackburn 1995).

	Dry Year			Wet Year		
	PPT	ET	ET/PPT	PPT	ET	ET/PPT
Mesquite-granjeno shrubland	310	330	1.06	887	881	0.99
Red grama-threawn grassland	310	298	0.96	887	833	0.94
Bare soil	310	208	0.67	887	643	0.72

The ET from the bare soil was all from evaporation (E) and evaporation from a soil surface is limited to the upper soil layers. Any moisture that percolates past these surface layers is largely protected from loss by evaporation. Red grama (*Bouteloua trifida*) and threawn are relatively shallow-rooted grass species, but they can extract soil moisture from deeper depths than can be extracted by evaporation alone. Consequently, the ET values on the grassland were higher than ET values on the bare soil (Table 8.4). Mesquite and granjeno are woody species that have deeper root systems than red grama and threawn. Therefore, there is additional soil moisture available to them than is available to the shortgrasses. As a result, the ET values on the shrubland were higher than on the grassland.

Under conditions of limited available moisture, the effect of plant species on ET rates is primarily a function of different rooting depths among species. In dry years, the mesquite-granjeno community ET exceeded the amount of rainfall received that year (Table 8.4), indicating the use of deeper soil moisture stored from previous wetter years. In contrast, the ET of the shallower-rooted grasses was less than the

annual rainfall in that year. In the wet year, the amount of rainfall exceeded the annual ET of both the shrubland and grassland, resulting in a net storage of soil moisture in the deeper soil layers.

Differences in root architecture can also have a substantial effect on ET when deeper soil layers contain higher soil moisture. On an arid site in eastern California, a saltgrass (*Distichlis spicata*) community with some rabbitbrush (*Chrysothamnus nauseosus*) had an annual ET of 47.2 cm (18.6 inches) and a nearby rabbitbrush-sacaton community had an annual ET of 60.5 cm (23.8 inches)(Duell 1990). Both communities had similar depths to groundwater (3.3 and 3.2 m, respectively). The reason for the higher ET in the rabbitbrush-sacaton community was because of the abundance of the deeper-rooted rabbitbrush shrubs and alkali sacaton (*Sporobolus airoides*), a deep-rooted perennial grass. In a study in southern Arizona, a big sacaton (*Sporobolus wrightii*) community had an ET of less than half that of an adjacent, deeper-rooted mesquite community at similar depths to groundwater (Table 8.5).

Table 8.5 Evapotranspiration (ET) and depth to groundwater for two plant communities of the San Pedro River floodplain in southern Arizona (data from Scott et al. 2000, 2006).

	Big Sacaton Grassland		Mesquite Woodland	
Depth to groundwater (m)	2.5	3.0	2.0	10.0
Evapotranspiration (cm)	40.6	27.2	84.8	63.8
Evapotranspiration (inches)	16.0	10.7	33.4	25.1

In arid regions, evaporation often comprises the greater portion of ET because vegetative cover is low. In more mesic regions, transpiration comprises the greater portion of ET because of higher vegetative cover, less bare ground, and cooler soil surfaces resulting from shading. In the Owens Valley of eastern California, a part of the Mojave Desert with a high water table, three species of grasses with an average canopy cover of 37% had an average E:T ratio of 55:45, with 40-69% of ET coming from evaporation (Evans et al. 2013; Mata-Gonzalez et al. 2014) and a desert site in North Africa had an average E:T ratio of 57:43, with a range of 38-78% evaporation (Floret et al. 1982).

8.2.1.1 Clay Loam Type

The clay loam type is an open woodland of live oak, Ashe juniper, and mesquite, with a mixed-grass community occupying the interspace openings (Table 8.1). In the calibration, we used two levels of cover of woody species, 5% and 38%. For the 5% cover type, we used the precipitation data from Zone 1 (central North Llano River watershed; Fig. 4.3) for the 5% woody cover type. Annual precipitation varied during the 10-year calibration simulations from a low of 17.96 inches (Year 6) to a high of 29.76 inches (Year 9), and averaged 22.89 inches (Table 8.6). For the 38% woody cover type, we used precipitation data from Zone 3 (western North Llano River watershed). Annual precipitation for this type varied between 17.02 inches (Year 6) to 29.76 inches (Year 9), with an average of 23.02 inches.

Table 8.6 Plot-level hydrology calibration results (inches): 10-year annual means, Upper Llano Watersheds.

Range Type	Woody Cover (%)	PPT Regime	PPT	Evap	Transpir	ET	GW-Use	Runoff	Export	Storage	ET/PPT
Clay loam	05	Dry	17.38	2.48	14.38	16.86	0.00	0.08	0.00	+ 0.44	0.970
Clay loam	05	Ave	22.89	3.46	18.52	21.98	0.00	0.30	0.00	+ 0.61	0.960
Clay loam	05	Wet	25.89	3.93	21.03	24.96	0.00	0.19	0.00	+ 0.72	0.964
Clay loam	38	Dry	17.49	2.21	16.65	18.86	1.87	0.10	0.00	+ 0.40	1.078
Clay loam	38	Ave	23.02	2.28	21.39	23.67	1.83	0.50	0.00	+ 0.68	1.028
Clay loam	38	Wet	27.31	3.61	24.03	27.64	1.36	0.22	0.00	+ 0.81	1.012
Sandy loam	38	Dry	17.49	1.85	17.44	19.29	2.12	0.07	0.00	+ 0.25	1.103
Sandy loam	38	Ave	23.02	2.04	22.31	24.35	2.10	0.41	0.00	+ 0.36	1.058
Sandy loam	38	Wet	27.31	2.71	25.14	27.85	1.42	0.16	0.00	+ 1.80	1.020
Loam bottomland	38	Dry	17.49	2.83	14.56	17.39	0.45	0.04	0.00	+ 0.51	0.994
Loam bottomland	38	Ave	23.02	3.16	18.86	22.02	0.38	0.39	0.00	+ 0.99	0.957
Loam bottomland	38	Wet	27.31	3.48	22.94	26.42	0.39	0.16	0.00	+ 4.60	0.967
Low stony hill	38	Dry	17.49	2.23	11.71	13.94	0.00	3.14	0.00	+ 0.41	0.797
Low stony hill	38	Ave	23.02	2.78	14.75	17.53	0.00	5.01	0.00	+ 0.48	0.761
Low stony hill	38	Wet	27.31	3.09	16.19	19.28	0.00	7.49	0.00	+ 0.54	0.706
Steep adobe	38	Dry	17.49	1.50	13.92	15.42	0.00	0.13	1.12	+ 0.72	0.882
Steep adobe	38	Ave	23.02	1.82	18.91	20.73	0.00	0.64	0.76	+ 0.89	0.901
Steep adobe	38	Wet	27.31	1.75	22.16	23.91	0.00	0.56	1.99	+ 2.60	0.876

PPT = annual precipitation. Evaporation (Evap) values include both Interception and Evaporation.

Transpir = transpiration (from soil and from groundwater combined).

ET = evapotranspiration = Evap + Transpir. GW-Use = groundwater used by vegetation in transpiration.

Under the average precipitation regime, ET averaged 21.98 inches at 5% woody cover and 23.97 inches at 38% woody cover (Table 8.6). These amounts were equal to 96.0 and 102.8% of annual precipitation, respectively. The higher amount of woody species resulted in almost 3 inches higher ET each year on the 38% woody cover plots, and this exceeded rainfall by 2.5 inches per year. Average annual ET was less than average annual rainfall on plots with lower woody cover, suggesting that a net storage was occurring in the soil profile on these plots. The deeper-rooted woody species on the 38% cover plots were extracting soil moisture from lower layers of the soil profile in excess of the amount replenished each year and from groundwater. On the 38% woody cover plots, these deeper-rooted woody species were extracting an average of 1.83 inches of groundwater each year (Table 8.6).

The 21.98 inches of ET on the 5% woody cover plots equates to an average daily ET rate of 2.28 mm, based on a 245-day growing season (March-October) or an annual (365 days) rate of 1.53 mm per day. The corresponding daily ET rates for the 38% woody cover plots are 2.49 mm (245-day) and 1.67 mm (365-day). These are reasonable rates based on literature values. Daily ET (growing season) on grazed bluestem prairie in Kansas receiving 33.8 inches of precipitation was 3.6 mm/d (Bremer et al. 2001). Adjusted for the difference in annual precipitation, that would equate to a rate of 2.6 mm/d at 23.98 inches of annual precipitation. Average daily ET (three-year mean) on a grassland in the Rolling Plains of North Texas where mesquite had been removed was 1.83 mm compared to 1.76 mm on an adjacent site where the mesquite had not been removed (Carlson et al. 1990). Scott et al. (2000, 2006) reported similar daily rates (2.4-2.6 mm) for mesquite in southern Arizona and adjacent stands of big sacaton (1.7 mm). An average daily rate for a mesquite-granjeno community on a sandy loam site in South Texas was 2.6 mm (Weltz and Blackburn 1995). Growing season ET rates in an Ashe juniper woodland in the eastern Edwards Plateau varied between 4 mm/day in June to 1.5 mm/day in August (Banta and Slattery 2011).

8.2.1.2 Other Vegetation Types

Average annual ET varied between 15.4 and 27.9 inches per year on the six types evaluated in the calibration (Table 8.6). The highest average annual ET was on the sandy loam, clay loam, and loamy bottomland types. The bottomland site had relatively high amounts of mature trees and shallow groundwater. The clay loam and sandy loam types had abundant mesquite and this deep-rooted species utilized substantial amounts of groundwater. All three types occurred on relatively level areas with groundwater at shallow to moderate depths. Scott et al. (2006) reported an annual ET of 25.1 inches for a mesquite-grassland on a floodplain in southern Arizona with a depth to groundwater of 10 m (33 ft). Similar ET rates have been reported for mesquite shrublands in the Rolling Plains of Texas (25.3 inches, when precipitation averaged 27.2 inches; Carlson et al. 1990) and South Texas (23.8 inches, when rainfall averaged 23.6 inches; Weltz and Blackburn 1995). These values compare favorably with the values of 23.7-24.4 inches of ET on the clay loam (38% woody cover) and sandy loam types in the calibration simulations (Table 8.6).

These three types utilized an average of 1.44 inches of groundwater (Table 8.6). This equaled 6.0% of their average annual ET. Although the amount of groundwater use increased only marginally under the dry regime (1.48 inches, Table 8.6), the proportion of annual ET contributed by groundwater increased to 7.8%. Under the wet regime, groundwater use decreased substantially, both in absolute terms (1.06 inches; Table 8.6) and as a proportion of annual ET (3.8%). These groundwater use variations are consistent with reported values. For example, Cramer et al. (1999) reported decreases of 50-57%, depending on tree species, in groundwater use between dry and wet years in the semiarid woodlands they studied.

ET was less on upland sites (17.5 inches, low stony hill; 20.7 inches, steep adobe) where access to groundwater was more limited. Banta and Slattery (2011) reported an annual ET rate for an Ashe juniper site in Comal County (eastern Edwards Plateau) of 25.4 inches at a site receiving 30.0 inches average annual rainfall during the study period. The average annual rainfall for the simulation was 23.0 inches (Table 8.6), or 77% of the Comal County value. Reducing the Comal County ET value by 23% results in an adjusted value for the Upper Llano simulations of 19.5 inches, which is in the range of the simulated values (17.5-20.7 inches) for Ashe juniper-live oak upland sites.

The six types utilized an average of 94.4% of annual precipitation in ET, under the average precipitation regime (Table 8.6). This is similar to values reported in the literature for similar vegetation types: 95% for oak-grassland at the Sonora Experiment Station (Thurow et al. 1987), 83% for an Ashe juniper woodland in the eastern Edwards Plateau (Banta and Slattery 2011), 97% for mesquite grasslands in the Rolling Plains (Carlson et al. 1990), and 98% for a mesquite shrubland in South Texas (Weltz and Blackburn 1995). Under the dry regime, simulated ET averaged 96.9% of annual precipitation and this decreased to 92.4% under the wet regime.

8.2.2 Surface Runoff

Surface runoff (overland flow) occurs when the rate at which the supply of water exceeds the infiltration rate into the soil. This most commonly occurs during intense rainfall events or when surface soils become saturated because of an extended rainfall period. As runoff water flows downslope, it can increase in quantity as runoff water for adjacent locations is added to the flow or the quantity can decrease if the runoff water flows across a drier soil or a fractured surface. In addition to the supply rate of incoming water, the amount of runoff is affected by slope (as slope increases, amount of runoff increases), soil texture (related to infiltration rate), and surface roughness. Surface roughness refers to the microtopography of the soil surface, including the presence of objects at the soil surface (e.g., rocks, litter,

and plant stems, crowns, and trunks). Other factors held constant, runoff decreases as surface roughness increases.

There are both spatial and temporal aspects to the dynamics of runoff. Runoff changes spatially across a landscape in response to differences in topography, soils, and vegetation. Ockerman (2002) reported runoff from a loamy sand range site and a nearby clay range site on the Welder Wildlife Refuge. Both sites received approximately the same amount and intensity of rainfall on the same dates. Surface runoff averaged 2.7 inches/year on the loamy sand site but only 0.6 inch/year on the clay site. Wright et al. (1976) reported runoff from adjacent sites on the northern edge of the Edwards Plateau, one site with 3% slope and one with 13% slope. Runoff averaged 0.5 inch/year on the 3% slope and 2.7 inches on the 13% slope.

Temporal changes in runoff occur for a variety of reasons. Intensity of the rainfall event is a primary factor influencing the amount of runoff. Most rainfall events do not result in measurable runoff. Along the central Texas Coast, rainfall events measuring less than two inches generally do not result in runoff (Ockerman and Petri 2001; Ockerman 2002) and in the Edwards Plateau the threshold level is about 0.7 inch (Thurow et al. 1988). During a two-year study period in San Patricio County, Texas, there were only nine runoff events recorded, and five of these were minor (0.07 inch or less; Ockerman 2002). Even at the lower threshold level in the Edwards Plateau (0.7 inch), there was an average of only nine runoff events per year over a six-year period (Thurow et al. 1988).

Amount of runoff is also affected by antecedent soil moisture conditions. A specific rainfall event is likely to result in much different runoff amounts when the event occurs following a dry period than when the soil is near field capacity. A 4.7-inch rain event in October 2000 resulted in less than 0.02 inch of runoff at a site in San Patricio County, compared to 0.34 inch of runoff from a 4.2-inch rain in November of the following year (Ockerman 2002). The October 2000 event was preceded by a very dry period and the November 2001 event occurred 10 weeks after a 7.5-inch rainfall event. A 4.6-inch rainfall event in early October 1998 resulted in 1.0 inch of runoff from an agricultural watershed in Kleberg and Nueces Counties in South Texas, and a 5.5-inch rainfall event later than month produced 2.7 inches of runoff from the same, but now rain-soaked, watershed (Ockerman and Petri 2001).

A third important factor affecting landscape-level runoff dynamics is vegetation, and vegetation is itself dynamic. Carlson et al. (1990) compared runoff from nearby locations in the Rolling Plains of Texas where the vegetation had been manipulated. Annual runoff, averaged over three years, was 1.2 inches on sites with mesquite overstory plus a grass understory, 0.4 inch where the mesquite had been removed but the grasses remained, and 3.8 inches where both mesquite and grasses were removed. Grazing management can also have a substantial impact on runoff. On the Sonora Experiment Station, runoff averaged 2.9% of annual precipitation on a continuously-grazed pasture and 3.5% on a nearby site grazed under a four-pasture rotation system (Thurow et al. 1988). Both sites were moderately-stocked. Brush control methods can also affect amount of runoff. Wright et al. (1976) measured runoff on plots in the northern Edwards Plateau that had been previously bulldozed to reduce juniper density. Plots that were burned to remove the juniper slash and regrowth had 10% less runoff than on plots where the slash and regrowth had not been removed.

Average annual surface runoff varied between 0.3 and 0.5 inches on the relatively level sites (clay loam, sandy loam, loamy bottomland) in the calibration simulations under the average precipitation regime (Table 8.6). This compares favorably with reported values for a clay loam mesquite shrubland in South Texas (0.6 inch per year, Ockerman 2002), a grassland in the northern Edwards Plateau (0.2 inch, Wright et al. 1976), and a grassland (0.4 inch) and mesquite-grassland (1.2 inches) in the Rolling Plains (Carlson et al. 1990). Under the dry regime, runoff averaged less than 20% as much as under average precipitation

on the relatively level sites in the simulations (Table 8.6). Runoff was also less under the wet precipitation regime than under the average regime in the simulations. This was the result of increased grass cover under the wetter conditions (Tables 8.1 and 8.2).

On the two types with steeper slopes in the calibration simulations (low stony hill and steep adobe), average annual runoff was greater than on the level sites, averaging 0.6 inch per year on the steep adobe type and 5.0 inches per year on the low stony hill type (Table 8.6). Wright et al. (1976) reported an annual average runoff of 1.1 inches per year on their 13% slope study site in the northern Edwards Plateau and Banta and Slattery (2011) reported average rates of 1.6-1.9 inches per year on their study sites in the eastern Edwards Plateau. The simulated rate of 5.0 inches per year on the low stony hill site was higher than reported values because of the steep slopes and relatively sparse vegetation on the simulated type. The simulated average runoff on the steep adobe type (0.6 inch) equaled 2.6% of annual precipitation, which is very near the reported value (2.9%) for continuously grazed sites at the Sonora Experiment Station (Thurow et al. 1988) and a site in the northern Edwards Plateau with a 13% slope (3.9% of annual precipitation; Wright et al. 1976).

In summary, the runoff values in the calibration simulations corresponded well with measured values from similar sites in Texas. These results indicate that the EDYS runoff values, both amount and in proportion to rainfall, are reasonable.

8.2.3 Groundwater Use

Except in wetlands, groundwater use by vegetation is largely confined to use by deep-rooted woody species. Most grasses have maximum rooting depths of less than 10 feet (3 m). Conversely, some woody species have root systems extending more than 25 feet (8 m) deep. Ashe juniper root systems have been reported as deep as 26 feet (Jackson et al. 1999), live oak as deep as 65 feet (Jackson et al. 1999), and mesquite roots deeper than 170 feet (Phillips 1963). One-seeded juniper (*Juniperus monosperma*) is another juniper species that occurs in the Edwards Plateau and it is reported to have roots extending as deep as 79 feet (Tierney and Foxx 1987).

In riparian and other wetland environments, vegetation is dependent on a shallow water table (high groundwater). Many of the species occurring in these areas are obligate phreatophytes, at least in arid and semiarid regions. The abundance of water at these sites results in high ET rates, substantially exceeding rates that could be sustained on precipitation alone. The difference between these ET rates and precipitation is approximately equal to the amount of groundwater utilized.

In general, groundwater use by vegetation varies along a typical toposequence, where usage is high in the lower riparian and wetland areas, intermediate in the upper floodplains, and low in the higher-elevation uplands. However, exceptions to this pattern are common. Some riparian trees growing adjacent to streams and rivers have been found to utilize little or no stream water (Dawson and Ehleringer 1991, Smith et al. 1991). Proportions of water usage from groundwater can vary substantially among co-occurring trees on floodplains even when each species has roots in contact with groundwater (Cook and O'Grady 2006). Some upland species utilize relatively large amounts of groundwater. In the fractured limestone ecosystems of the Edwards Plateau, groundwater may supply as much as 24% of the water used by Ashe juniper (Jackson et al. 1999, 2000).

The amount of groundwater or other deep moisture sources used by vegetation can also vary in response to climatic and other environmental factors. Many woody species utilize deep moisture during dry periods, but shift to precipitation-derived sources in the upper soil profile when those become available (Sala et al. 1981; Comstock and Ehleringer 1992; Flanagan et al. 1992a, 1992b; Dawson 1993; Dawson and Pate 1996; Smith et al. 1997; Gebauer and Ehleringer 2000; Williams and Ehleringer 2000; Zeneich

et al. 2002; Chimner and Cooper 2004). Therefore during wet years, vegetation may use proportionately less groundwater than during dry years. Age and condition of the plants may also affect the relative amounts of groundwater they use. Tree saplings in riparian zones may utilize stream water whereas mature trees of the same species may use very little (Dawson and Ehleringer 1991). Defoliation was found to alter the source of water accessed by mesquite trees (Snyder and Williams 2003).

Groundwater use in the calibration simulations occurred on the loamy bottomland and sandy loam types, and on the clay loam sites under heavier (38%) brush cover (Table 8.6). Groundwater usage was 1.4 inches per year, averaged over the three types under the average precipitation regime, or about 6% of annual transpiration. Groundwater usage increased by about 3% per year under the dry regime compared to the average precipitation regime, and decreased by 24% under the wet regime.

9.0 SCENARIO RESULTS

A scenario in EDYS consists of a specific simulation run. Each scenario is defined by a selection of inputs that can include any combination of precipitation, stressor, management, and time factors. The specific combination defining a scenario can be applied across the entire spatial footprint or can be localized. In addition to the use of the Upper Llano EDYS models to evaluate enhanced water yield from brush management (this report), the models were also used to provide simulation scenario results for the Upper Llano River Watershed Protection Plan (Broad et al. 2016). Fourteen scenarios were completed for the Protection Plan, many of which dealt with restoration scenarios. Of those 14 scenarios, four were most pertinent to enhanced water yield from brush management. Results of those four scenarios are presented in this report. A 25-year simulation period was used for each of the scenarios.

- 1. Baseline.** No changes in land management options; daily precipitation data from 1958-1982 were used as most indicative of long-term average conditions (1897-2012 annual mean for Junction = 23.90 inches (Table 4.3); 1958-1982 annual mean for Junction = 23.98 inches).
- 2. Dry Cycle.** Same as Scenario 1 except the daily precipitation data used were from 1945-1969, the driest 25 consecutive years for Junction (annual mean = 21.56 inches = 0.902 of long-term mean).
- 3. Wet Cycle.** Same as Scenario 1 except the daily precipitation data used were from 1918-1942, the wettest 25 consecutive years for Junction (annual mean = 27.24 inches = 1.139 of long-term mean).
- 4. Brush Management.** All woody species, except live oak, were removed from cells supporting 50% or more woody plant cover. Only 50% of live oak was removed, allowing larger live oak trees to remain. There was no re-treatment following the initial removal and the system was allowed to recover by natural secondary succession, including regrowth of the woody species. There was no re-seeding in this scenario, livestock stocking rates were not altered from the other three scenarios, and an average precipitation regime was used.

9.1 Effects of Precipitation Regime

9.1.1 Vegetation

The effects of precipitation on vegetation and hydrology were evaluated using three simulation scenarios, each corresponding to either a dry, average, or wet precipitation regime. Each regime used the same initial conditions, including grazing by cattle and white-tailed deer, and varied only in the amount of daily precipitation received. The simulations were conducted for 25 years, using the respective precipitation

regime from the 25 continuous years with the driest average annual precipitation (1945-1969; 90% of the annual mean under the average regime), average annual precipitation nearest the long-term mean (1958-1982), or the wettest average annual precipitation (1918-1942; 114% of the annual mean under the average regime). Simulation results for six types are presented as examples of vegetation dynamics under the three precipitation regimes (Table 9.1).

9.1.1.1 Clay Loam Type, Without Brush Control

Averaged over the 25-year simulation period, both the dry and wet scenarios resulted in more woody plant biomass than did the average precipitation regime (Table 9.1). Ashe juniper increased more on this type under the dry regime (compared to average precipitation) and mesquite and live oak increased more under the wet regime. The clay loam type occurs on relatively level areas with moderate depths to groundwater. On these sites, Ashe juniper is better adapted to drier conditions than either mesquite or live oak, which are more favored by more mesic conditions. Of the four shrub species modeled on this type, yucca and prickly pear increased more under the dry regime and elbowbush increased more under the wet regime. Agarito was largely unaffected by precipitation regime.

Grass biomass averaged 31% less under the dry regime than under average precipitation on clay loam sites with 38% initial woody plant cover and decreased slightly under the wet regime. The decrease under the wet regime was the result of increased competition from woody species and from forbs. There were also shifts in species composition within the grass component. Cane bluestem, sideoats grama, and little bluestem increased under both the dry and wet regimes and plains lovegrass was favored by the wet regime. Most shortgrasses decreased under both dry and wet regimes, an exception being the more mesic vine-mesquite which increased under the wet regime.

When initial woody plant cover was lower (5%), midgrasses and forbs increased under the wet regime and midgrasses decreased under the dry regime. Most of the increase in midgrasses came from plains lovegrass, little bluestem, and tall dropseed. There was an overall decrease in shortgrasses under the wet regime, but there were increases in hairy grama, vine-mesquite, and Texas wintergrass. Overall, the effect of the dry regime was less severe to grasses when woody species were less abundant. Grass biomass decreased 23% under the dry regime compared to average conditions when initial woody cover was 5%, compared to a decrease of 31% when initial woody cover was 38%.

9.1.1.2 Sandy Loam Type, Without Brush Control

The effects of precipitation regime on the sandy loam type were similar to those on the clay loam type. Woody species biomass increased under both dry and wet regimes (Table 9.1). Texas persimmon, mesquite, and live oak were favored by the wet regime, while Ashe juniper was favored by the dry regime. Mesquite and live oak also increased under the dry regime, compared to average conditions, but less so than under the wet regime.

Midgrasses increased 24% under the wet regime on the sandy loam type, with little bluestem and sideoats being the major contributors to this increase. Midgrasses decreased by 21% under the dry regime. Both responses, to wet and dry regimes, were greater proportionately than were the changes in precipitation. Precipitation under the wet regime was 14% greater than under the average regime, but midgrasses increased by 24%. Precipitation under the dry regime was 10% below average, but midgrasses decreased by 21%. These patterns result from interactions between change in precipitation and change in species composition (i.e., competitive interactions). Shortgrasses decreased under both dry and wet regimes. The decrease under the dry regime was largely the result of decreased moisture. The decrease under the wet regime was the result of increased competition from midgrasses and forbs. Under average precipitation, the most abundant herbaceous species were purple threeawn (41% of herbaceous biomass), sideoats

grama (11%), and curly mesquite (11%). Under the wet regime, ragweed became the most abundant species (28%), followed by purple threeawn (23%) and sideoats (14%). Under the dry regime, purple threeawn contributed 33% of herbaceous biomass, sideoats 13%, and ragweed 11%.

9.1.1.3 Loamy Bottomland Type, Without Brush Control

Tree biomass increased under the wet regime and decreased slightly under the dry regime (Table 9.1). All tree species except Ashe juniper increased under the wet regime. The decrease in Ashe juniper was the result of increased competition from the taller species. Overall, precipitation regime had a minor effect on tree biomass on this type because of access to groundwater.

Biomass of midgrasses and forbs increased substantially under the wet regime on this type. Midgrass biomass increased by 58% and forb biomass almost tripled. This is the most mesic of the six types and midgrasses and ragweed are favored as available moisture increases. Sideoats grama, little bluestem, and cane bluestem were especially favored by the wet regime on this type. Shortgrasses decreased under the wet regime because of increased competition from the midgrasses and forbs. Production of midgrasses did not decrease under the dry regime on this type because of access to groundwater. However, production by the shallower-rooted shortgrasses did decrease.

9.1.1.4 Low Stony Hill Type, Without Brush Control

Tree biomass was not substantially affected by the dry regime but increased by 10% under the wet regime (Table 9.1). All tree species increased under the wet regime, but the greatest increases were for hackberry, live oak, and Ashe juniper. Midgrasses were a minor component on this type and were largely unaffected by precipitation regime. Of the shortgrasses, Texas wintergrass and hairy grama increased under the wet regime. Hairy grama also increased under the dry regime but the other shortgrasses decreased, although only by small amounts.

9.1.1.5 Steep Adobe Type, Without Brush Control

Tree biomass increased under the wet regime on this type and decreased under the dry regime, but by relatively minor amounts (4% and 2%, respectively). All tree species increased under the wet regime, but only Ashe juniper increased under the dry regime. The increase in Ashe juniper under the dry regime was the result of reduced competition from live oak. Live oak decreased substantially (11%) under the dry regime on this type.

Production by midgrasses decreased on this type under the wet regime, but production of shortgrasses increased. The increase in trees and shrubs under the wet regime apparently had a substantial effect on the midgrasses. Production of both midgrasses and shortgrasses also decreased under the dry regime, but by much less than under the wet regime. This smaller decrease under the dry regime supports the conclusion about competition from woody species because there was a decrease in woody plant biomass under the dry regime.

Table 9.1 Simulated annual aboveground biomass (g/m²) in six plot types averaged over 25 years under each of three precipitation regimes (dry, average, wet), Upper Llano Watershed EDYS Model. Values are for plot types located in the central North Llano precipitation zone. Percent woody plant cover (5% or 38%) refers to initial average coverage.

Lifeform or Species	Clay Loam 5% Woody			Clay Loam 38% Woody			Sandy Loam 38% Woody			Bottomland 38% Woody			Low Stony Hill 38% Woody			Steep Adobe 38% Woody		
	Dry	Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet
Trees	165	156	143	1381	1259	1309	1898	1761	1792	5919	5931	6119	1836	1832	2013	2208	2264	2352
Shrubs	37	37	35	371	367	324	67	71	76	171	178	202	146	150	169	66	67	80
Midgrasses	101	105	116	101	65	89	60	76	94	142	138	218	5	5	5	149	186	73
Shortgrasses	213	303	240	104	233	197	76	167	80	11	79	45	278	307	263	7	9	11
Forbs	16	14	23	11	9	26	37	24	103	19	17	50	4	4	8	17	28	15
Total	532	615	557	1968	1933	1945	2138	2099	2145	6262	6343	6634	2269	2298	2458	2447	2554	2531
Litter	75	80	106	71	83	99	70	78	90	70	75	89	74	77	99	70	73	87
Trees																		
Pecan	---	---	---	---	---	---	---	---	---	1563	1546	1647	---	---	---	---	---	---
Sugar hackberry	---	---	---	---	---	---	---	---	---	3577	3532	3857	569	568	627	---	---	---
Texas persimmon	---	---	---	---	---	---	98	98	108	197	197	216	199	198	217	---	---	---
Ashe juniper	18	17	17	353	261	179	735	637	511	404	475	190	439	440	483	951	905	948
Mesquite	121	113	99	588	569	647	536	506	583	178	181	209	116	114	123	120	122	128
Texas Red Oak	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	371	371	395
Live oak	26	26	27	440	429	483	529	520	590	---	---	---	513	512	563	766	866	881
Shrubs																		
Elbowbush	9	9	10	79	79	93	---	---	---	---	---	---	38	38	45	40	40	46
Agarito	4	4	4	33	34	31	23	24	25	24	26	30	6	6	7	6	6	8
Evergreen sumac	---	---	---	---	---	---	---	---	---	68	72	85	72	78	87	---	---	---
Yucca	11	10	8	121	89	69	30	31	32	---	---	---	21	20	19	12	12	15
Prickly pear	13	14	13	138	165	131	14	16	19	---	---	---	9	8	11	8	9	11
Mustang grape	---	---	---	---	---	---	---	---	---	79	80	87	---	---	---	---	---	---
Midgrasses																		
Cane bluestem	21	24	25	20	12	18	4	3	5	25	25	41	*	*	*	30	33	14
King Ranch bluestem	3	3	5	2	2	3	---	---	---	6	5	15	2	2	2	---	---	---
Sideoats grama	50	48	47	54	30	40	27	34	39	67	60	90	3	3	3	64	85	31
Canada wildrye	1	1	1	1	1	1	*	*	*	4	5	6	---	---	---	---	---	---
Plains lovegrass	4	4	7	3	3	5	1	1	2	1	2	2	---	---	---	---	---	---
Green sprangletop	1	1	1	*	1	1	---	---	---	---	---	---	---	---	---	---	---	---
Switchgrass	---	---	---	---	---	---	---	---	---	3	2	5	---	---	---	---	---	---
Little bluestem	10	12	14	9	6	10	18	21	32	34	37	55	*	*	*	53	66	25
Indiangrass	2	2	2	1	1	1	---	---	---	2	2	4	---	---	---	---	---	---
Tall dropseed	9	10	14	11	9	10	---	---	---	---	---	---	---	---	---	1	1	2
Sand dropseed	---	---	---	---	---	---	10	17	16	---	---	---	---	---	---	1	1	1

Table 9.1 (Cont.)

Lifeform or Species	Clay Loam 5% Woody			Clay Loam 38% Woody			Sandy Loam 38% Woody			Bottomland 38% Woody			Low Stony Hill 38% Woody			Steep Adobe 38% Woody		
	Dry	Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet	Dry	Ave	Wet
Shortgrasses																		
Purple threeawn	168	195	137	70	133	124	66	127	65	5	70	30	154	164	114	1	1	1
Hairy grama	4	5	9	2	4	4	2	2	3	---	---	---	16	4	23	3	11	5
Red grama	---	---	---	---	---	---	---	---	---	---	---	---	9	35	24	1	1	1
Curly mesquite	31	93	73	25	83	58	6	34	10	3	5	7	92	95	90	2	3	4
Vine-mesquite	1	2	4	1	2	3	---	---	---	1	2	4	---	---	---	---	---	---
Texas wintergrass	9	8	17	6	11	8	2	4	2	2	2	4	7	9	12	---	---	---
Forbs																		
Ragweed	6	5	9	4	3	12	22	14	67	9	8	27	3	3	6	---	---	---
Lazy daisy	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	---	---	---
Sunflower	*	*	*	*	*	*	*	*	*	0	*	*	---	---	---	---	---	---
Bush sunflower	9	7	12	6	5	13	15	10	36	9	8	21	1	1	2	---	---	---
Orange zexmenia	1	2	2	1	1	1	---	---	---	1	1	2	---	---	---	17	28	15

9.1.2 Ecohydrology

Ecohydrological responses over the 25-year simulations for the six types were similar to the responses from the 10-year calibration simulations (Section 8.6). ET increased on all six types under the wet regime and decreased under the dry regime (Table 9.2). Averaged over the six types, ET increased by an average of 8.1% under the wet regime and decreased by an average of 11.4% under the dry regime. The increase under the wet regime was greatest on the clay loam type with the more abundant (38%) woody cover and was negligible on the low stony hill type. The decrease under the dry regime was greatest on the clay loam site with low (5%) woody cover. This type was dominated by grasses and the grasses were unable to extract groundwater on this type (Table 9.2).

Table 9.2 Simulated hydrology (inches) in six plot types averaged over 25 years under each of three precipitation regimes (dry, average, wet), Upper Llano EDYS Model. Values are for plot types located in the central North Llano precipitation zone. Percent woody plant cover (5% or 38%) refers to initial average coverage.

Plot Type	Woody Cover (%)	PPT Regime	PPT	Evap	Transpir	ET	GW-Use	Runoff	Export	Storage	ET/PPT
Clay loam	05	Dry	21.08	3.88	16.55	20.43	0.00	0.09	0.00	+ 0.56	0.969
Clay loam	05	Ave	23.97	4.52	18.96	23.48	0.00	0.10	0.00	+ 0.07	0.980
Clay loam	05	Wet	25.32	4.39	20.18	24.57	0.00	0.42	0.00	+ 0.33	0.970
Clay loam	38	Dry	21.17	2.54	19.43	21.97	1.21	0.11	0.00	+ 0.30	1.038
Clay loam	38	Ave	23.98	3.95	20.38	24.33	0.83	0.16	0.00	+ 0.32	1.014
Clay loam	38	Wet	26.12	4.15	25.47	29.62	4.14	0.31	0.00	+ 0.33	1.134
Sandy loam	38	Dry	21.17	2.45	19.41	21.86	0.93	0.09	0.00	+ 0.15	1.033
Sandy loam	38	Ave	23.98	3.64	20.97	24.61	0.93	0.12	0.00	+ 0.18	1.026
Sandy loam	38	Wet	26.12	3.71	22.54	26.25	0.69	0.28	0.00	+ 0.28	1.005
Loam bottomland	38	Dry	21.17	2.37	18.50	20.87	0.17	0.06	0.00	+ 0.41	0.986
Loam bottomland	38	Ave	23.98	3.29	20.33	23.62	0.16	0.09	0.00	+ 0.43	0.985
Loam bottomland	38	Wet	26.12	3.56	22.08	25.64	0.17	0.21	0.00	+ 0.44	0.989
Low stony hill	38	Dry	21.17	3.62	13.45	17.07	0.00	3.74	0.00	+ 0.36	0.806
Low stony hill	38	Ave	23.98	3.94	15.26	19.20	0.00	4.52	0.00	+ 0.26	0.801
Low stony hill	38	Wet	26.12	3.86	15.36	19.22	0.00	6.64	0.00	- 0.74	0.801
Steep adobe	38	Dry	21.17	2.29	17.74	20.03	0.00	0.20	0.52	+ 0.42	0.946
Steep adobe	38	Ave	23.98	2.72	20.16	22.88	0.00	0.29	0.35	+ 0.46	0.954
Steep adobe	38	Wet	26.12	2.31	21.75	24.06	0.00	0.71	1.02	+ 0.33	0.921

Evap = Interception + Evaporation

Under the wet regime, ET accounted for 80-103% of annual precipitation under average precipitation (Table 9.2). Average annual ET exceeded annual average precipitation on two of the six types. In both cases, groundwater usage accounted for more than the deficit, allowing a slight increase in soil storage over the 25 years. The increase in groundwater use on the clay loam (38%) type under the wet regime was the result of the increase in deep-rooted trees (Table 9.1).

Runoff was greatest (19% of annual precipitation) on the low stony hill type (Table 9.2), which was expected because of the topography associated with this type. Runoff was minor (less than 1% of annual precipitation) on the relative level types. Runoff increased by 50-300% under the wet regime and decreased by 10-33% under the dry regime.

9.2 Watershed-Wide Ecohydrology: Baseline Conditions

The Upper Llano spatial domain was divided into 49 subwatersheds (Fig. 9.1). Of these, 23 drained into the North Llano River, 24 into the South Llano River, and 2 drained into the Llano River immediately below the confluence of the North and South Llano Rivers. The ecohydrologic results of the simulations were summarized by subwatershed and averaged over the 25-year simulations, for the baseline and brush control scenarios under the average precipitation regime.

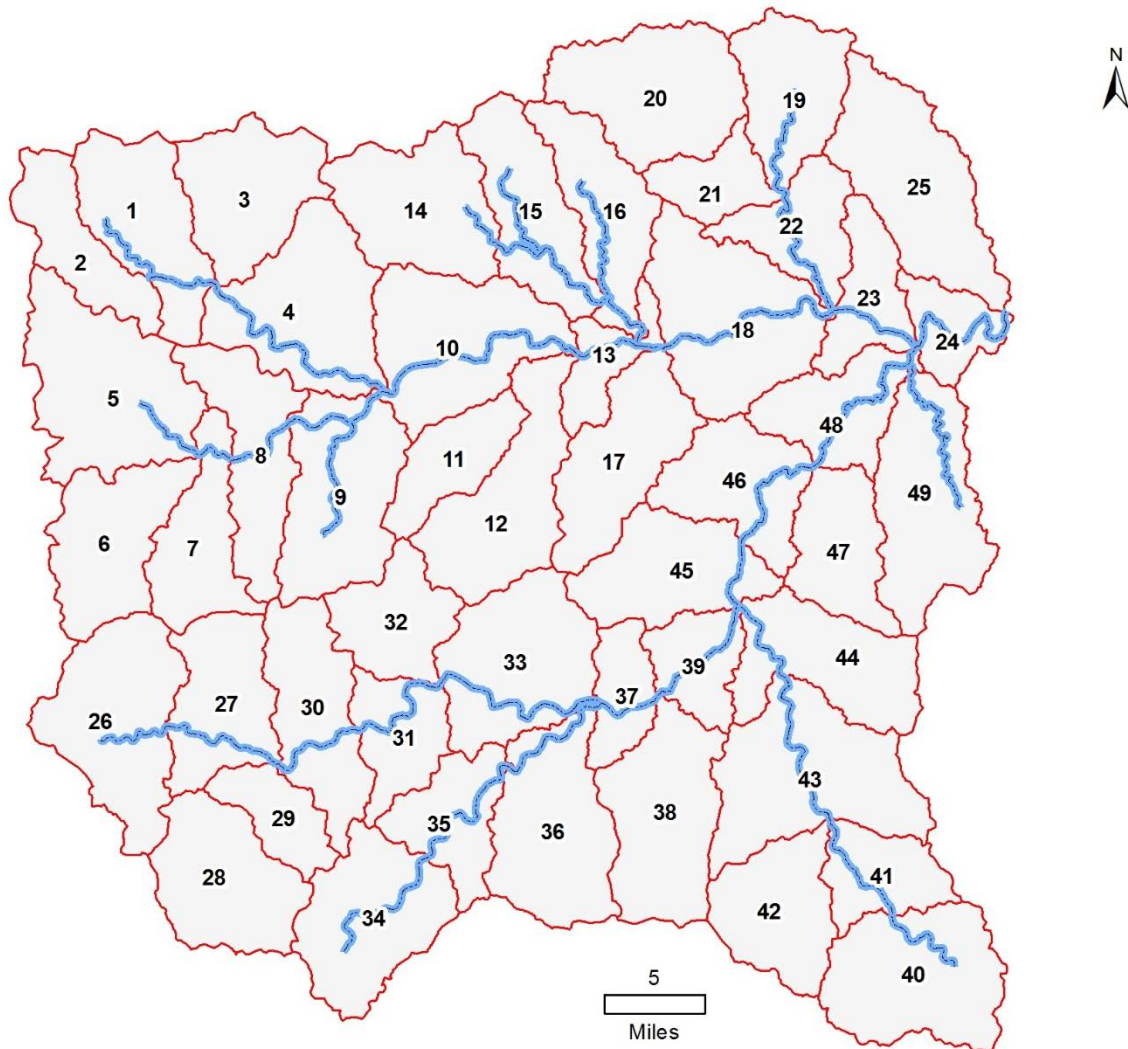


Figure 9.1 Locations of the 49 subwatersheds in the Upper Llano River EDYS model.

Values for the basic ecohydrological variables (by subwatershed, by drainage, and overall) of a water balance calculation are presented in Table 9.3. Values are annual averages under the average precipitation regime under baseline conditions (no brush control, vegetation as per Table 9.1).

Table 9.3 Average annual water balance components by watershed simulated for 25-year baseline scenario, expressed as watershed totals, using the Upper Llano EDYS model.

Watershed	Area (acres)	Precipitation (acre-feet)	Watershed Totals (acre-feet)					
			Runoff	ET	GW-Use	Recharge	Direct Yield	Storage + Seepage
North Llano								
01	26,792	51,651	3,480	44,730	22	0	3,458	3,463
02	18,057	34,947	210	30,852	0	13	223	3,872
03	26,231	50,758	645	42,382	0	18	663	7,713
04	35,054	67,830	6,008	54,883	117	0	5,891	7,056
05	38,991	75,448	940	65,956	65	85	960	8,532
06	26,167	50,742	1,072	44,809	0	77	1,149	4,784
07	20,872	40,438	1,026	35,688	0	0	1,026	3,724
08	25,004	48,382	2,542	42,796	21	0	2,521	3,065
09	32,671	63,218	404	53,113	136	0	268	9,837
10	34,955	69,853	1,199	59,129	3,934	173	- 2,562	13,286
11	15,603	31,167	215	25,535	0	0	215	5,417
12	30,991	61,931	2,394	53,560	181	89	2,302	6,069
13	10,530	21,042	7,123	23,833	5,162	129	2,090	- 4,881
14	29,712	59,374	518	46,444	25	0	493	12,437
15	25,216	50,391	154	43,033	1,577	18	- 1,405	8,763
16	22,872	45,707	168	40,768	3,356	85	- 3,103	8,042
17	27,400	54,754	3,632	47,445	297	20	3,355	3,954
18	38,576	77,122	1,637	63,678	804	876	1,709	11,735
19	22,598	45,178	3,987	36,248	603	30	3,414	5,516
20	32,646	65,265	1,195	52,555	82	0	1,113	11,597
21	11,577	23,144	8,768	18,425	58	100	8,810	- 4,091
22	17,043	34,072	221	28,460	369	131	- 17	5,629
23	15,067	30,122	507	25,863	666	647	488	3,771
Total	584,625	1,152,536	48,045	980,185	17,475	2,491	33,061	139,290
South Llano								
26	35,294	72,030	196	65,027	0	372	568	6,435
27	24,006	48,933	7,248	44,010	0	72	7,320	- 2,397
28	28,207	57,591	303	51,712	0	106	409	5,470
29	12,377	25,271	4,383	22,588	31	65	4,417	- 1,734
30	26,669	54,227	4,062	48,735	22	60	4,100	1,392
31	15,996	32,659	80	29,258	40	72	112	3,289
32	18,456	36,974	478	32,327	15	40	503	4,144
33	33,315	67,715	491	61,299	361	101	231	6,185
34	30,460	62,901	221	56,045	0	136	357	6,499
35	17,814	36,786	1,253	32,702	0	66	1,319	2,765
36	32,829	67,793	645	60,349	0	146	791	6,653
37	11,698	24,147	116	21,524	127	104	93	2,530
38	32,080	66,247	1,865	59,401	0	192	2,057	4,789
39	13,605	28,004	2,035	24,646	45	30	2,020	1,338
40	33,723	68,346	417	60,193	0	149	566	7,587
41	15,168	30,741	3,305	26,847	13	77	3,369	525
42	23,416	47,456	350	42,303	0	139	489	4,664
43	39,629	80,315	3,833	71,395	0	176	4,009	4,911
44	27,294	55,202	436	47,943	23	119	532	6,727
45	26,212	52,446	1,826	42,109	219	158	1,765	8,572
46	23,218	46,436	1,306	37,532	1,568	297	35	8,869
47	19,666	39,349	1,799	31,250	33	26	1,792	6,307
48	19,170	38,340	599	35,543	5,210	889	- 3,722	6,519
49	32,883	65,794	906	53,568	603	179	482	11,744
Total	593,185	1,205,703	38,153	1,058,306	8,310	3,771	33,614	113,783
Llano								
24	11,214	22,418	253	20,380	1,010	1,122	365	1,673
25	35,563	71,097	1,041	59,090	534	197	704	11,303
Total	46,777	93,515	1,294	79,470	1,544	1,319	1,069	12,976
Overall	1,224,587	2,451,754	87,492	2,117,961	27,329	7,581	67,744	266,049

Annual precipitation averaged 24.03 inches, averaged over the entire watershed. Annual precipitation was slightly lower in the North Llano River drainage (23.66 inches) and higher in the South Llano River drainage (24.39 inches). The South Llano River drainage is slightly (1.5%) larger than the North Llano River drainage.

Runoff is direct surface runoff that would be measured at the respective point of exit (e.g., lowest point of the subwatershed). The annual average runoff in this scenario averaged 87,492 acre-feet, or 3.6% of annual precipitation. This compares favorably with measured values from three studies in the Edwards Plateau: 2.9% and 3.5% on two sites at the Sonora Experiment Station (Thurow et al. 1988), 3.9% on a 13% slope area in the northern Edwards Plateau (Wright et al. 1976), and 4.2% on a site in the eastern Edwards Plateau (Banta and Slattery 2011). Runoff varied substantially among subwatersheds in the simulations, ranging from 154 acre-feet to 8,768 acre-feet per year. This variability was primarily the result of differences in slope, soils, and vegetation among the subwatersheds, rather than size of the subwatershed. Averaged over the entire basin, mean annual runoff was equal to 0.86 inches per acre.

Evapotranspiration (ET) averaged 2,117,961 acre-feet per year (Table 9.3), or 86.4% of annual precipitation. This is similar to values reported for an oak-grassland at the Sonora Experiment Station (95%, Thurow et al. 1987) and an Ashe juniper woodland in the eastern Edwards Plateau (83%, Banta and Slattery 2011). The simulated value was equal to 20.46 inches per year, averaged over the entire basin.

EDYS simulates vegetation water use by tracking water removal at each soil layer, at each time step, by each plant species. Included in that accounting is water taken from saturated zones, i.e., groundwater. **Groundwater-use (GW-Use, Table 9.3)** is the sum of that water usage over the respective subwatershed. Under baseline conditions (Table 9.3), the vegetation utilized an average of 27,329 acre-feet of groundwater per year. This amount was equal to 0.27 inch per acre annually, or 1.3% of total ET. Groundwater usage varied among the subwatersheds, with highest use in subwatersheds 13 and 48 which both had large amounts of their respective areas in floodplains (Fig. 3.1). Subwatersheds with no groundwater use were generally located in upper elevation areas.

Recharge is the amount of water entering into groundwater. It is the amount that moves through the soil profile, either at the point of origin or by surface movement (runoff) that then enters the profile. Recharge in the baseline simulation (Table 9.3) averaged 7,581 acre-feet per year over the entire basin. This was equal to 0.07 inch per acre per year, or 0.3% of annual precipitation.

Direct yield is the minimum amount of average annual water yield from the respective subwatershed. It was calculated as:

$$\text{direct yield} = \text{runoff} + \text{recharge} - \text{groundwater use.}$$

This calculation is a conservative calculation (i.e., actual direct yield is probably greater than this amount) because some of what EDYS calculates as soil storage probably enters either the surface water or groundwater pools by movement through cracks, channels, and fissures in the underlying rocks. Direct yield under baseline conditions averaged 67,744 acre-feet per year for the basin (Table 9.3), or 0.66 inch per acre per year. This is equal to 2.8% of annual precipitation.

Storage is the average annual amount of water entering the soil system (infiltrated water) and not exported by ET or recharge. It is the net balance in water retained in the soil, by soil layer. It is calculated by:

$$\text{Storage} = \text{precipitation} + \text{groundwater use} - \text{ET} - \text{runoff} - \text{recharge.}$$

Some of this water likely exits the soil system as seepage and spring flow and should therefore be added to direct yield. However, without knowing the subsurface geologic structures, we cannot directly model that lateral flow. Under the baseline scenario (Table 9.3), 266,049 acre-feet of water was added to the soil profile each year. This equals 2.61 inches per year, or 10.9% of annual precipitation.

Seepage. The potential available water holding capacity of a typical soil in the models is about 15% by volume in the upper 1.25 m, 5% in the next 8.5 m, and 1% in the lowest layers down to 28 m (Table 5.4). This would equal a total potential available water holding capacity of 80 cm, or 31.5 inches. Averaged over all soil types by area covered, the mean available water holding capacity for the EDYS soil profiles across the entire watershed is 28.50 inches. An average annual storage value of 2.61 inches (previous paragraph) would equal a 25-year total soil storage of 65.75 inches, or over twice the available waterholding capacity of the profiles. In EDYS, this water in excess of available water holding capacity is stored as saturated zones within the soil profile (i.e., perched water tables and pooled water in karst structures). In fact, some would likely be held as perched water tables or pockets of free water in karst features and some would likely move laterally and become seepage or spring flow. If all of the surplus storage water (36.5 inches averaged across the watershed) became seepage or spring flow, this would equal 56% of the calculated annual soil storage value. This would increase direct yield by 148,987 acre-feet per year. More likely, only part of this surplus would become direct yield, the remaining portion being retained in the soil profile.

Median flow of the Llano River at Junction is 109 cfs (Broad et al. 2016), or 78,916 acre-feet per year. The EDYS baseline direct yield is 67,744 acre-feet per year. The difference between these two values, 11,172 acre-feet per year, is one estimate of the amount of EDYS storage that moves into the surface water supply as lateral flow to seeps and springs. This amount (11,172 acre-feet) is 7.5% of the storage water in excess of maximum available water holding capacity. This seems reasonable. Based on the total storage value (266,049 acre-feet, Table 9.3), this estimated seep and spring flow from storage would equal 4.2% of total storage.

In summary, under baseline conditions averaged over the 25-year simulation total annual water supply (precipitation plus groundwater usage) was 2,479,083 acre-feet (Fig. 9.2). Of this, ET accounted for 85.4%, runoff 3.5%, groundwater recharge 0.3%, seep and spring flow 0.5%, and storage within the soil and subsoil system 10.3%.

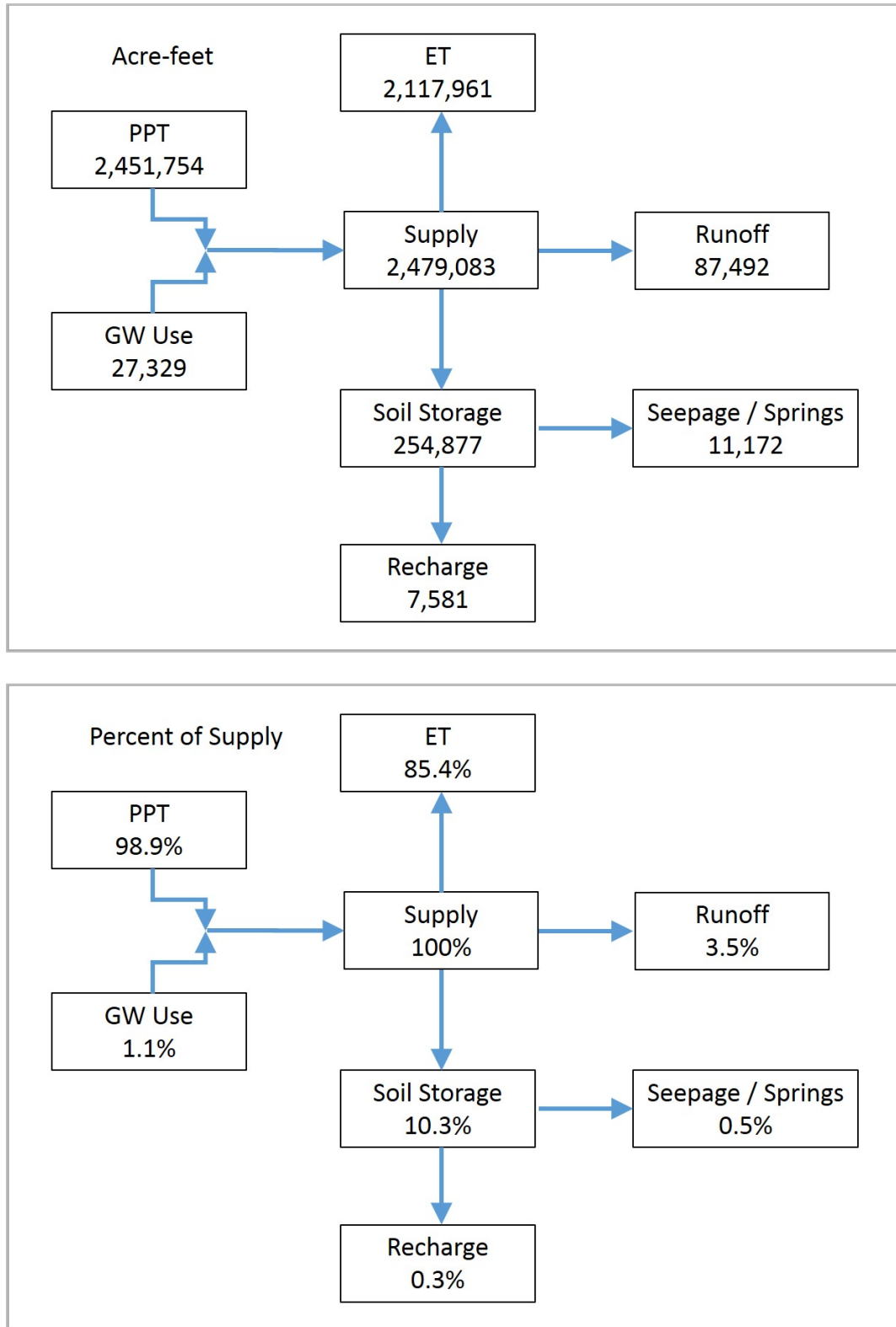


Figure 9.2 Annual (25-year mean) water-balance (acre-feet and % of supply) for the Upper Llano River watershed under baseline (average precipitation regime, no brush control).

9.3 Watershed-Wide Ecohydrology: Brush Control Scenario

Under the brush control scenario, there was a slight increase (0.5%) in ET and a small (1.0%) decrease in groundwater use by vegetation (Table 9.4) compared to baseline conditions. The increase in ET was the result of two factors. First, there was an increase in production by herbaceous species following the reduction in density of woody plants. Second, there was regrowth of the tree and shrub species over time. The regrowth was more productive on an annual basis than the previous old-growth trees. In practice, re-treatment of brush controlled areas is necessary in order to maintain the benefits of brush removal. Without retreatment, the woody species will regain dominance because of secondary succession. The decrease in groundwater use was the result of an initial reduction in deeper-rooted woody species. This benefit decreased over time as the woody species re-established.

Runoff decreased by 9.7% in response to brush control. This was the result of increased herbaceous production, which slowed runoff and allowed more water to enter into the soil. Brush control increased recharge by 11.0% because of increased infiltration (i.e., reduced runoff) and less use of deep soil moisture by woody vegetation. Direct yield, when measured only by runoff and recharge, decreased by 10.8% (7,342 acre-feet per year) because the decrease in runoff exceeded the increase in recharge.

Table 9.4 Average annual water balance components by watershed simulated for brush control (50-100% cover) scenario, expressed as watershed totals, using the Upper Llano EDYS model.

Watershed	Area (acres)	Precipitation (acre-feet)	Watershed Totals (acre-feet)					
			Runoff	ET	GW-Use	Recharge	Direct Yield	Storage + Seepage
North Llano								
01	26,792	51,651	2,996	44,797	0	0	2,996	3,858
02	18,057	34,947	317	30,867	0	13	330	3,750
03	26,231	50,758	900	42,447	22	18	896	7,415
04	35,054	67,830	4,973	55,029	117	0	4,856	7,945
05	38,991	75,448	954	66,086	98	85	941	8,421
06	26,167	50,742	1,061	44,852	0	77	1,138	4,752
07	20,872	40,438	1,023	35,740	17	0	1,006	3,692
08	25,004	48,382	2,763	42,858	63	0	2,700	2,824
09	32,671	63,218	483	53,276	245	0	238	9,704
10	34,955	69,853	1,199	60,149	4,721	151	- 3,371	13,075
11	15,603	31,167	286	25,691	13	0	273	5,203
12	30,991	61,931	2,071	54,309	310	91	1,852	5,770
13	10,530	21,042	5,497	26,353	7,541	132	- 1,912	- 3,399
14	29,712	59,374	1,416	46,642	0	0	1,416	11,316
15	25,216	50,391	239	43,643	1,745	18	- 1,488	8,236
16	22,872	45,707	231	42,427	4,176	71	- 3,874	7,154
17	27,400	54,754	2,940	48,313	594	20	2,366	4,075
18	38,576	77,122	1,717	64,064	804	882	1,795	11,263
19	22,598	45,178	3,265	37,378	622	31	2,674	5,126
20	32,646	65,265	1,183	53,780	54	0	1,129	10,356
21	11,577	23,144	7,557	18,705	48	101	7,610	- 3,171
22	17,043	34,072	274	28,659	355	131	50	5,363
23	15,067	30,122	484	25,939	603	660	541	3,642
Total	584,625	1,152,536	43,829	992,004	22,148	2,481	24,162	136,370
South Llano								
26	35,294	72,030	279	64,998	0	372	651	6,381
27	24,006	48,933	5,906	43,950	0	90	5,996	- 1,013
28	28,207	57,591	381	51,665	0	148	529	5,397
29	12,377	25,271	4,298	22,588	31	65	4,332	- 1,649
30	26,669	54,227	2,933	48,713	22	80	2,991	2,523
31	15,996	32,659	85	29,218	13	84	156	3,285
32	18,456	36,974	488	32,327	15	54	527	4,120
33	33,315	67,715	528	61,354	389	126	265	6,096
34	30,460	62,901	233	55,994	0	181	414	6,493
35	17,814	36,786	1,219	32,687	0	92	1,311	2,788
36	32,829	67,793	700	60,239	0	243	943	6,611
37	11,698	24,147	133	21,368	20	155	268	2,511
38	32,080	66,247	1,827	59,294	0	287	2,114	4,839
39	13,605	28,004	1,862	24,646	79	80	1,863	1,495
40	33,723	68,346	459	60,165	0	223	682	7,499
41	15,168	30,741	2,136	26,796	0	99	2,235	1,710
42	23,416	47,456	655	42,244	0	156	811	4,401
43	39,629	80,315	2,708	71,263	0	293	3,001	6,051
44	27,294	55,202	544	47,921	23	178	699	6,582
45	26,212	52,446	1,762	42,350	109	159	1,812	8,284
46	23,218	46,436	1,417	36,874	523	307	1,201	8,361
47	19,666	39,349	1,680	31,791	33	40	1,687	5,871
48	19,170	38,340	593	32,538	1,918	827	- 498	6,300
49	32,883	65,794	926	54,116	219	203	910	10,768
Total	593,185	1,205,703	33,752	1,055,099	3,394	4,542	34,900	115,704
Llano								
24	11,214	22,418	250	20,221	776	1,138	612	1,585
25	35,563	71,097	1,216	60,631	741	253	728	9,738
Total	46,777	93,515	1,466	80,852	1,517	1,391	1,340	11,323
Overall	1,224,587	2,451,754	79,047	2,127,955	27,059	8,414	60,402	263,397

9.4 Selection of Subwatershed for Treatment

The effects of brush control on potential enhanced water yield vary spatially across watersheds (Fish and Rainwater 2007, McLendon et al. 2012a, McLendon 2013). Because of spatial variation, brush control should not be expected to result in substantial enhancement of water yield when applied indiscriminately across a watershed. Instead, specific areas with high potential for enhanced water yield should be identified and brush control applied to these identified areas.

Potential for enhanced water yield from brush control varied substantially among the 49 Upper Llano River subwatersheds (Fig. 9.3). Increases in direct yield from the brush control simulation occurred in half (25) of the Upper Llano River subwatersheds. The average annual enhanced yield from these 25 subwatersheds totaled 7,938 acre-feet per year (Table 9.5). This would equal a 12% increase in direct yield over baseline conditions (Table 9.3).

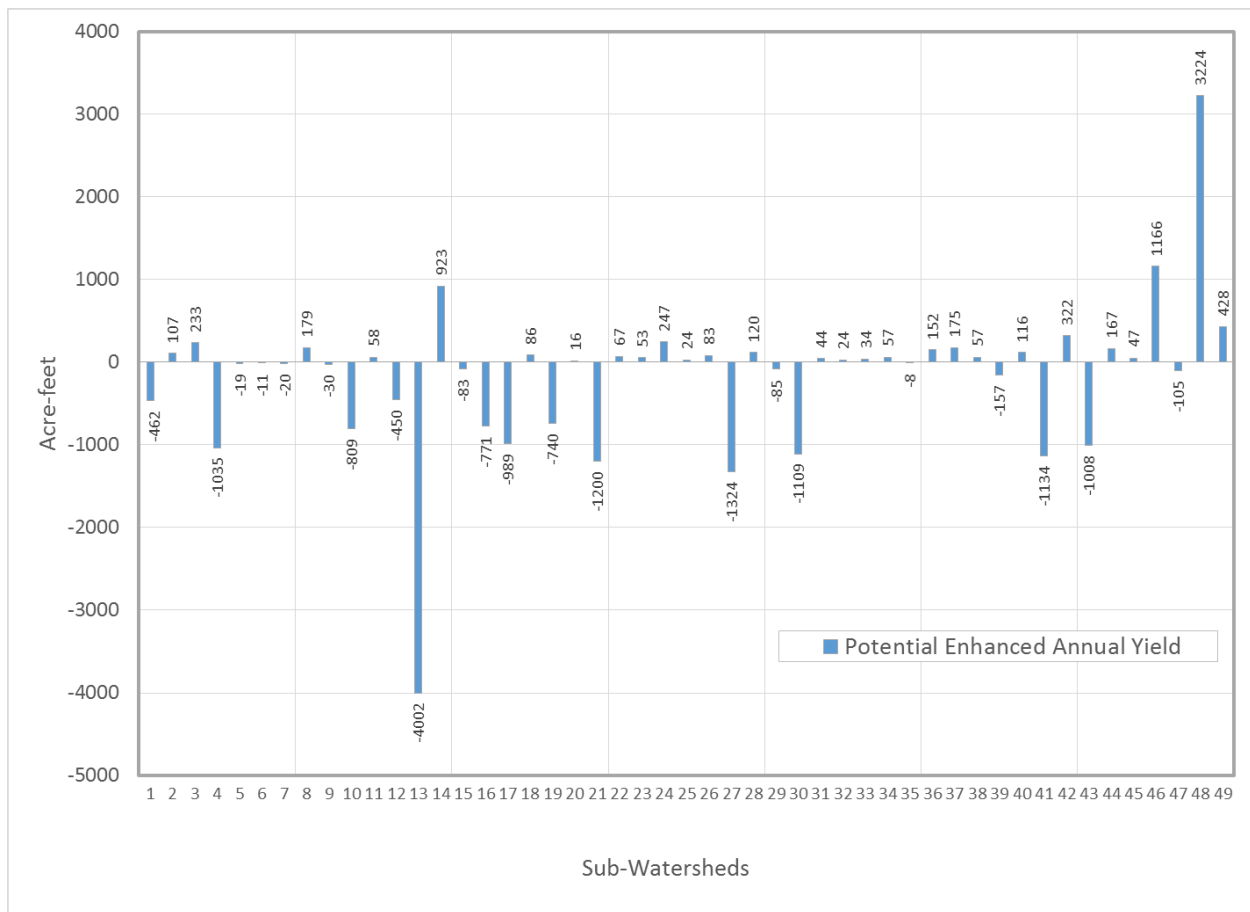


Figure 9.3 Potential for increased water yield (acre-feet per year) from brush control in the 49 subwatersheds of the Upper Llano River watershed. Values are 25-year means under the average precipitation regime.

Table 9.5 Direct water yield and net storage under baseline (Table 9.3) and brush control (Table 9.4) scenarios, 25-year annual means at moderate precipitation, Upper Llano EDYS model.

Watershed	Direct Yield (ac-ft)		Enhancement (ac-ft)	Storage + Seepage (ac-ft)		Enhancement (ac-ft)
	Baseline	Brush Control	(BC – Baseline)	Baseline	Brush Control	(BC – Baseline)
North Llano						
01	3,458	2,996	- 462	3,463	3,858	395
02	223	330	107	3,872	3,750	- 122
03	663	896	233	7,713	7,415	- 298
04	5,891	4,856	- 1,035	7,056	7,945	889
05	960	941	- 19	8,532	8,421	- 111
06	1,149	1,138	- 11	4,784	4,752	- 32
07	1,026	1,006	- 20	3,724	3,692	- 32
08	2,521	2,700	179	3,065	2,824	- 241
09	268	238	- 30	9,837	9,704	- 133
10	- 2,562	- 3,371	- 809	13,286	13,075	- 211
11	215	273	58	5,417	5,203	- 214
12	2,302	1,852	- 450	6,069	5,770	- 299
13	2,090	- 1,912	- 4,002	- 4,881	- 3,399	1,482
14	493	1,416	923	12,437	11,316	- 1,121
15	- 1,405	- 1,488	- 83	8,763	8,236	- 527
16	- 3,103	- 3,874	- 771	8,042	7,154	- 888
17	3,355	2,366	- 989	3,954	4,075	121
18	1,709	1,795	86	11,735	11,263	- 472
19	3,414	2,674	- 740	5,516	5,126	- 390
20	1,113	1,129	16	11,597	10,356	- 1,241
21	8,810	7,610	- 1,200	- 4,091	- 3,171	920
22	- 17	50	67	5,629	5,363	- 266
23	488	541	53	3,771	3,642	- 129
Total	33,061	24,162	- 8,899	139,290	136,370	- 2,920
South Llano						
26	568	651	83	6,435	6,381	- 54
27	7,320	5,996	- 1,324	- 2,397	- 1,013	1,384
28	409	529	120	5,470	5,397	- 73
29	4,417	4,332	- 85	- 1,734	- 1,649	85
30	4,100	2,991	- 1,109	1,392	2,523	1,131
31	112	156	44	3,289	3,285	- 4
32	503	527	24	4,144	4,120	- 24
33	231	265	34	6,185	6,096	- 89
34	357	414	57	6,499	6,493	- 6
35	1,319	1,311	- 8	2,765	2,788	23
36	791	943	152	6,653	6,611	- 42
37	93	268	175	2,530	2,511	- 19
38	2,057	2,114	57	4,789	4,839	50
39	2,020	1,863	- 157	1,338	1,495	157
40	566	682	116	7,587	7,499	- 88
41	3,369	2,235	- 1,134	525	1,710	1,185
42	489	811	322	4,664	4,401	- 263
43	4,009	3,001	- 1,008	4,911	6,051	1,140
44	532	699	167	6,727	6,582	- 145
45	1,765	1,812	47	8,572	8,284	- 288
46	35	1,201	1,166	8,869	8,361	- 508
47	1,792	1,687	- 105	6,307	5,871	- 436
48	- 3,722	- 498	3,224	6,519	6,300	- 219
49	482	910	428	11,744	10,768	- 976
Total	33,614	34,900	1,286	113,783	115,704	1,921
Llano						
24	365	612	247	1,673	1,585	- 88
25	704	728	24	11,303	9,738	- 1,565
Total	1,069	1,340	271	12,976	11,323	- 1,653
Overall	67,744	60,402	- 7,342	266,049	263,397	- 2,652

The simulated brush treatment was not applied to the entire area within each of the 25 subwatersheds with potential water enhancement. Only those areas within the subwatershed with 50% or more woody plant cover and less than 12% slope were included in the brush treatment. The total area in these 25 subwatersheds with potential for water enhancement was 642,190 acres, or 52.4% of the total area of the watershed (1,224,587 acres). Of the 642,190 acres in the 25 subwatersheds with potential for water enhancement, only 177,326 acres (27.6%) were treated (Table 9.6). Therefore, the potential increase in water yield (7,938 acre-feet per year = 2,586,605,000 gallons) would be the result of the treatment of 177,326 acres. This amount can be expressed as an annual increased yield of 0.045 acre-feet (14,663 gallons) of increased yield per treated acre, or a 25-year total return of 1.13 acre-feet (368,212 gallons) per treated acre. Two-thirds (5,313 acre-feet = 1,731,246,363 gallons) of the total potential enhanced yield resulted from treatment of 25,475 acres in three subwatersheds (14, 46, and 48; Table 9.6). The potential enhanced yield from treatment of these three subwatersheds was 0.208 acre-feet (67,777 gallons) per treated acre per year, or 5.20 acre-feet (1,694,425 gallons) over the 25 years.

Table 9.6 Potential annual enhanced water yield from the brush control (50-100% cover) scenario, 25-year mean at moderate precipitation regime, Upper Llano EDYS model.

Watershed	Area (acres)		Treated/ Total	Potential Enhanced Annual Yield				Storage + Seepage	
	Total	Treated		Overall (10 ³ gallons)	(ac-ft)	Per Treated Acre (gallons)	(inches)	Overall (10 ³ gallons)	Treated Acre (gallons)
North Llano									
01	26,792	5,520	0.206	150,543	462	27,272	1.004	1,257,133	227,742
02	18,057	3,235	0.179	34,866	107	10,778	0.397	1,221,941	377,725
03	26,231	10,156	0.387	75,923	233	7,476	0.275	2,416,185	237,907
04	35,054	12,129	0.346	337,256	1,035	27,806	1.024	2,588,886	213,446
05	38,991	12,869	0.330	6,191	19	481	0.018	2,743,991	213,225
06	26,167	9,576	0.367	3,584	11	374	0.014	1,548,444	161,700
07	20,872	5,959	0.286	6,517	20	1,094	0.040	1,203,042	201,887
08	25,004	7,559	0.302	58,327	179	7,716	0.284	920,203	121,736
09	32,671	8,662	0.259	9,776	30	1,129	0.042	3,162,058	365,049
10	34,955	11,797	0.338	263,613	809	22,346	0.823	4,260,502	361,151
11	15,603	7,213	0.462	18,899	58	2,620	0.096	1,695,403	235,048
12	30,991	12,794	0.413	146,633	450	11,461	0.422	1,880,160	146,956
13	10,530	3,683	0.349	304,056	4,002	354,074	13.039	1,107,568	300,724
14	29,712	9,943	0.335	300,760	923	30,248	1.114	3,687,330	370,847
15	25,216	6,662	0.264	27,046	83	4,060	0.150	2,683,709	402,838
16	22,872	11,227	0.491	251,231	771	22,377	0.824	2,331,138	207,637
17	27,400	9,037	0.330	322,267	989	35,661	1.313	1,327,843	146,934
18	38,576	11,839	0.307	28,023	86	2,367	0.087	3,670,060	309,997
19	22,598	13,095	0.579	241,130	740	18,414	0.678	1,670,312	127,553
20	32,646	15,522	0.475	5,214	16	336	0.012	3,374,513	217,402
21	11,577	6,409	0.554	391,021	1,200	61,011	2.247	1,033,274	161,222
22	17,043	5,247	0.308	21,832	67	4,161	0.153	1,747,539	333,055
23	15,067	4,251	0.282	17,270	53	4,063	0.150	1,186,749	279,169
Total Mean	584,625	204,384	0.350	-2,899,748	- 8,899	- 14,188	- 0.522	44,436,301	217,416
South Llano									
26	35,294	6,184	0.175	27,046	83	4,373	0.161	2,079,255	336,231
27	24,006	2,308	0.096	431,427	1,324	186,927	6.884	330,087	143,019
28	28,207	6,086	0.216	39,102	120	6,425	0.236	1,758,618	288,961
29	12,377	1,185	0.096	27,697	85	23,373	0.861	537,328	453,442
30	26,669	2,171	0.081	361,369	1,109	166,453	6.130	822,122	378,684
31	15,996	2,454	0.153	14,337	44	5,842	0.215	1,070,421	436,194
32	18,456	2,743	0.148	7,820	24	2,851	0.105	1,342,506	489,430
33	33,315	4,809	0.144	11,079	34	2,304	0.085	1,986,388	413,056
34	30,460	5,009	0.164	18,574	57	3,708	0.136	2,115,751	422,390
35	17,814	1,287	0.072	2,607	8	2,025	0.068	908,473	705,884
36	32,829	6,445	0.196	49,529	152	7,685	0.283	2,154,201	334,244
37	11,698	3,658	0.313	57,024	175	15,589	0.574	818,212	223,677
38	32,080	6,927	0.216	18,574	57	2,681	0.099	1,576,793	227,630
39	13,605	3,265	0.240	51,159	157	15,669	0.577	487,147	149,203
40	33,723	10,093	0.299	37,799	116	3,745	0.138	2,443,557	242,104
41	15,168	2,851	0.188	369,515	1,134	129,609	4.773	557,205	195,442
42	23,416	3,926	0.168	104,924	322	26,725	0.984	1,434,070	365,275
43	39,629	16,236	0.410	328,458	1,008	20,230	0.745	1,971,724	121,442
44	27,294	8,113	0.297	54,417	167	6,707	0.247	2,144,751	264,360
45	26,212	5,272	0.201	15,315	47	2,905	0.107	2,699,350	512,016
46	23,218	7,495	0.323	379,942	1,166	50,693	1.867	2,724,440	363,501
47	19,666	7,633	0.383	34,214	105	4,482	0.165	1,913,071	250,632
48	19,170	8,037	0.419	1,050,544	3,224	130,713	4.814	2,052,861	255,426
49	32,883	15,110	0.460	139,464	428	9,230	0.340	3,508,764	232,215
Total Mean	593,185	139,297	0.235	419,044	1,286	3,008	0.111	37,702,264	270,661
Llano									
24	11,214	3,945	0.352	80,485	247	20,402	0.751	516,474	130,919
25	35,563	20,747	0.583	7,820	24	377	0.014	3,173,137	152,944
Total Mean	46,777	24,692	0.528	88,305	271	3,576	0.132	3,689,611	149,425
Overall Mean	1,224,587	368,373	0.301	- 2,392,399	- 7,342	- 6,495	- 0.239	85,828,176	232,993

Based on potential enhanced per-acre water yields from the simulations, five subwatersheds have the highest potential and 16 subwatersheds have a moderate potential for enhanced water yield from brush control (Table 9.7 and Fig. 9.4).

Table 9.7. Ranking of watersheds in order of potential annual enhanced water yield (gallons per treated acre and inches per treated acre) from the application of brush control to areas supporting 50-100% woody plant cover scenario, 25-year mean values at moderate precipitation regime, Upper Llano EDYS model.

Watershed	Yield (gallons)	Yield (inches)	Watershed	Yield (gallons)	Yield (inches)
Higher Potential Yield			Moderate Potential Yield		
48 South Llano	130,713	4.81	37 South Llano	15,589	0.57
46 South Llano	50,693	1.87	02 North Llano	10,778	0.40
14 North Llano	30,248	1.11	49 South Llano	9,230	0.34
42 South Llano	26,725	0.98	08 North Llano	7,716	0.28
24 Llano	20,402	0.75	36 South Llano	7,685	0.28
			03 North Llano	7,476	0.28
			44 South Llano	6,707	0.25
			28 South Llano	6,425	0.24
			31 South Llano	5,842	0.22
			26 South Llano	4,373	0.16
			22 North Llano	4,161	0.15
			23 North Llano	4,063	0.15
			40 South Llano	3,745	0.14
			34 South Llano	3,708	0.14
			45 South Llano	2,905	0.11
			32 South Llano	2,851	0.11
Lower Potential Yield			Negative Potential Yield		
38 South Llano	2,681	0.10	06 North Llano	- 374	- 0.01
11 North Llano	2,620	0.10	05 North Llano	- 481	- 0.02
18 North Llano	2,367	0.09	07 North Llano	- 1,094	- 0.04
33 South Llano	2,304	0.09	09 North Llano	- 1,129	- 0.04
25 Llano	377	0.01	35 South Llano	- 2,025	- 0.07
20 North Llano	336	0.01	15 North Llano	- 4,060	- 0.15
			47 South Llano	- 4,482	- 0.17
			12 North Llano	- 11,461	- 0.42
			39 South Llano	- 15,669	- 0.58
			19 North Llano	- 18,414	- 0.68
			43 South Llano	- 20,230	- 0.75
			10 North Llano	- 22,346	- 0.82
			16 North Llano	- 22,377	- 0.82
			29 South Llano	- 23,373	- 0.86
			01 North Llano	- 27,272	- 1.00
			04 North Llano	- 27,806	- 1.02
			17 North Llano	- 35,661	- 1.31
			21 North Llano	- 61,011	- 2.25
			41 South Llano	-129,609	- 4.77
			30 South Llano	-166,453	- 6.13
			27 South Llano	-186,927	- 6.88
			13 North Llano	-354,074	-13.04

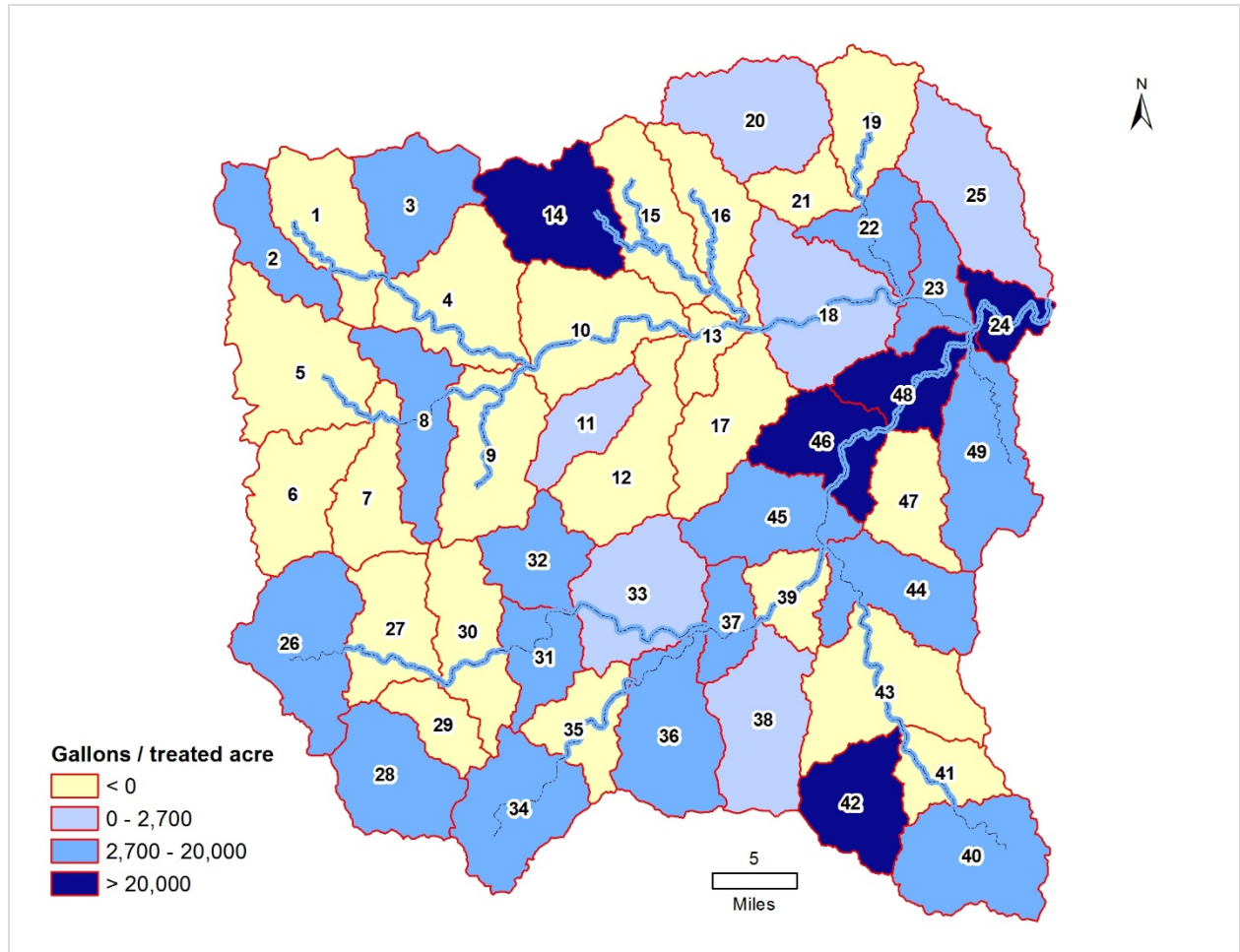


Figure 9.4 Location of subwatersheds ranked in order of potential for enhanced water yield (gallons per treated acre per year) from brush control on areas supporting 50-100% woody plant cover, under the average precipitation regime, Upper Llano River EDYS models.

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APPENDIX A: PRECIPITATION

Appendix Table A.1 Comparisons of annual precipitation (inches) between primary stations and each primary or secondary station in the Upper Llano River watershed region: mean annual precipitation, mean difference, and standardized mean difference (mean difference – difference between annual means). Comparisons were made in each case only using years with complete (12-month) data for both stations. Annual means are listed in order of the station names in the comparison.

Comparison	Annual Means		Mean Difference	Standardized Mean Difference	Number of Years
Junction 4SSW-Camp Wood	22.60	26.86	5.88	1.62	38
Junction 4SSW-Carta Valley	23.52	24.84	7.55	6.23	29
Junction 4SSW-Cottonwood	23.62	28.94	6.83	1.51	64
Junction 4SSW-Eldorado	25.47	21.32	5.27	1.12	11
Junction 4SSW-Fort McKavett	21.58	22.48	4.15	3.25	15
Junction 4SSW-Fredericksburg	23.02	29.52	7.68	1.18	57
Junction 4SSW-Harper	22.51	26.84	5.78	1.45	43
Junction 4SSW-Humble Station 5	23.66	22.07	4.34	2.75	33
Junction 4SSW-Hunt	22.13	29.04	7.54	0.63	30
Junction 4SSW-Junction Airport	19.81	19.34	1.46	0.99	23
Junction 4SSW-Kerrville	23.78	30.55	7.82	1.05	81
Junction 4SSW-Llano	24.17	27.14	5.53	2.50	78
Junction 4SSW-Lealey	21.22	30.00	8.78	0.00	18
Junction 4SSW-Mason	21.72	26.29	5.53	0.96	43
Junction 4SSW-Menard	23.84	23.48	3.98	3.62	71
Junction 4SSW-Prade Ranch	22.71	27.32	7.14	2.53	30
Junction 4SSW-Rocksprings	23.57	24.10	5.07	4.54	39
Junction 4SSW-Roosevelt	20.68	19.10	2.94	1.36	10
Junction 4SSW-Sonora	23.31	21.37	4.61	2.67	41
Junction 4SSW-Sonora Exp Sta	24.00	22.84	4.40	3.24	73
Junction 4SSW-Telegraph	23.70	25.00	3.19	1.89	34
Junction Airport-Camp Wood	21.27	25.49	5.60	1.38	30
Junction Airport-Carta Valley	21.83	26.00	6.97	2.80	15
Junction Airport-Cottonwood	20.56	27.48	7.38	0.46	30
Junction Airport-Eldorado	21.52	18.84	3.72	1.06	8
Junction Airport-Fort McKavett	20.56	22.65	3.95	1.86	14
Junction Airport-Fredericksburg	20.86	27.41	7.29	0.74	35
Junction Airport-Harper	20.79	25.81	5.72	0.70	30
Junction Airport-Humble Station 5	20.73	19.99	3.45	2.71	17
Junction Airport-Hunt	20.76	25.59	5.77	0.94	19
Junction Airport-Kerrville	20.82	29.15	8.39	0.06	34
Junction Airport-Lealey	20.05	28.61	8.56	0.00	13
Junction Airport-Llano	21.16	26.78	7.01	1.39	33
Junction Airport-Mason	21.00	25.11	4.91	0.80	31
Junction Airport-Menard	20.95	20.56	3.25	2.86	34
Junction Airport-Prade Ranch	21.59	26.47	6.16	1.28	26
Junction Airport-Rocksprings	21.46	23.06	4.40	2.80	25
Junction Airport-Roosevelt	18.34	17.83	2.96	2.45	9
Junction Airport-Sonora	20.69	19.76	4.16	3.23	29
Junction Airport-Sonora Exp Sta	20.86	20.72	4.20	4.06	35
Junction Airport-Telegraph	22.38	24.17	2.38	0.59	16

Appendix Table A.1 (Cont.)

Comparison	Annual Means		Mean Difference	Standardized Mean Difference	Number of Years
Camp Wood-Carta Valley	27.21	23.40	6.52	2.71	35
Camp Wood-Cottonwood	26.71	29.17	5.05	2.59	49
Camp Wood-Eldorado	28.01	20.59	8.60	1.18	19
Camp Wood-Fort McKavett	26.44	21.33	7.33	2.22	12
Camp Wood-Fredericksburg	27.14	29.51	5.47	3.10	55
Camp Wood-Harper	27.55	27.18	4.54	4.17	49
Camp Wood-Humble Station 5	28.29	21.86	6.93	0.50	33
Camp Wood-Hunt	27.66	29.48	5.51	3.69	39
Camp Wood-Kerrville	27.00	31.09	6.55	2.46	53
Camp Wood-Leakey	26.61	29.77	4.91	1.75	15
Camp Wood-Llano	27.10	27.25	4.86	4.71	54
Camp Wood-Mason	26.80	26.34	3.90	3.44	48
Camp Wood-Prade Ranch	26.74	27.64	4.05	3.15	37
Carta Valley-Llano	23.90	27.30	7.86	4.46	38
Cottonwood-Llano	29.15	27.29	4.14	2.18	76
Cottonwood-Carta Valley	24.37	30.01	9.03	3.39	35
Eldorado-Carta Valley	20.83	22.69	5.69	3.83	16
Eldorado-Cottonwood	20.74	30.51	9.77	0.00	15
Eldorado-Fredericksburg	20.50	28.93	8.85	0.42	20
Eldorado-Harper	20.28	26.21	6.40	0.47	19
Eldorado-Humble Station 5	21.62	24.21	3.77	1.18	10
Eldorado-Hunt	20.18	28.24	9.09	1.03	19
Eldorado-Kerrville	20.30	29.88	9.59	0.01	16
Eldorado-Leakey	19.13	24.86	6.74	1.01	7
Eldorado-Llano	20.50	26.97	6.87	0.40	21
Eldorado-Mason	20.45	26.82	6.37	0.20	14
Eldorado-Prade Ranch	20.28	25.10	6.29	1.47	15
Fort McKavett-Carta Valley	23.37	28.51	6.97	1.83	11
Fort McKavett-Cottonwood	22.48	28.54	7.60	1.54	15
Fort McKavett-Fredericksburg	22.48	29.45	8.07	1.10	15
Fort McKavett-Harper	21.92	27.32	6.44	1.04	14
Fort McKavett-Humble Station 5	22.41	20.26	4.38	2.23	13
Fort McKavett-Kerrville	22.48	29.58	8.33	1.23	15
Fort McKavett-Leakey	22.27	29.06	7.79	1.00	14
Fort McKavett-Llano	22.65	27.49	7.09	2.25	14
Fort McKavett-Mason	22.21	27.28	7.59	2.52	13
Fort McKavett-Prade Ranch	22.48	27.46	8.28	3.30	15
Fredericksburg-Carta Valley	31.05	24.34	9.08	2.37	38
Fredericksburg-Cottonwood	29.82	29.39	3.18	2.75	61
Fredericksburg-Humble Station 5	31.39	22.11	9.53	0.25	39
Fredericksburg-Leakey	30.40	30.48	3.49	3.41	19
Fredericksburg-Llano	29.93	26.98	4.47	1.52	78
Fredericksburg-Prade Ranch	30.08	27.59	5.74	3.25	44
Harper-Carta Valley	28.12	23.91	7.85	3.64	36
Harper-Cottonwood	27.17	29.48	3.96	1.65	52
Harper-Fredericksburg	26.94	29.47	4.11	1.58	60
Harper-Humble Station 5	28.28	22.10	6.60	0.42	37

Appendix Table A.1 (Cont.)

Comparison	Annual Means		Mean Difference	Standardized Mean Difference	Number of Years
Harper-Hunt	27.18	29.38	3.66	1.46	42
Harper-Kerrville	26.90	30.79	5.44	1.55	57
Harper-Leakey	28.43	30.82	4.48	2.09	18
Harper-Llano	26.95	26.90	4.24	4.19	58
Harper-Mason	27.13	26.86	3.93	3.66	49
Harper-Prade Ranch	28.13	28.31	4.29	4.11	41
Humble Station-Carta Valley	23.12	24.14	4.98	3.96	27
Humble Station-Cottonwood	21.38	30.36	9.51	0.53	35
Humble Station-Llano	21.95	28.26	7.44	1.13	38
Humble Station-Prade Ranch	21.91	28.00	7.56	1.47	30
Hunt-Carta Valley	30.64	22.58	9.43	1.37	27
Hunt-Cottonwood	29.29	29.73	4.20	3.76	39
Hunt-Fredericksburg	28.71	29.78	4.21	3.14	47
Hunt-Humble Station 5	32.10	23.58	8.94	0.42	24
Hunt-Kerrville	28.78	31.52	4.50	1.66	45
Hunt-Leakey	32.81	34.52	4.27	2.56	6
Hunt-Llano	29.05	27.34	5.30	3.59	45
Hunt-Mason	29.27	26.74	4.60	2.07	40
Hunt-Prade Ranch	29.56	27.85	4.66	2.95	28
Leakey-Carta Valley	30.95	27.16	5.69	1.90	15
Leakey-Cottonwood	30.48	29.79	3.18	2.49	19
Leakey-Humble Station 5	30.10	21.39	8.80	0.00	17
Leakey-Llano	30.14	27.60	4.86	2.32	19
Leakey-Mason	30.58	28.04	6.28	3.74	18
Leakey-Prade Ranch	30.48	29.88	3.70	3.10	19
Kerrville-Carta Valley	32.06	24.83	9.22	1.99	35
Kerrville-Cottonwood	30.84	28.98	3.34	1.48	75
Kerrville-Fredericksburg	30.57	29.58	3.39	2.40	78
Kerrville-Humble Station 5	31.72	21.90	9.94	0.12	38
Kerrville-Leakey	31.18	30.48	3.36	2.66	19
Kerrville-Llano	30.95	27.19	5.58	1.84	99
Kerrville-Prade Ranch	31.13	27.54	5.88	2.29	42
Mason-Carta Valley	27.77	24.41	7.45	4.09	35
Mason-Cottonwood	26.35	28.87	5.24	2.72	53
Mason-Fredericksburg	26.76	29.74	5.13	2.15	58
Mason-Humble Station 5	28.48	21.90	7.31	0.73	33
Mason-Kerrville	26.78	31.22	6.51	2.07	56
Mason-Llano	26.90	27.11	4.64	4.43	56
Mason-Prade Ranch	27.23	28.32	5.33	4.24	36
Menard-Carta Valley	24.52	24.33	6.61	6.42	38
Menard-Cottonwood	23.11	29.09	7.04	1.06	72
Menard-Camp Wood	22.50	26.81	5.85	1.54	56
Menard-Eldorado	24.75	20.50	5.06	0.81	20
Menard-Fort McKavett	22.16	22.35	2.58	2.39	14
Menard-Fredericksburg	22.90	29.49	7.40	0.81	73
Menard-Harper	22.81	26.94	5.53	1.40	58

Appendix Table A.1 (Cont.)

Comparison	Annual Means		Mean Difference	Standardized Mean Difference	Number of Years
Menard-Humble Station 5	24.61	22.18	4.32	1.89	22
Menard-Hunt	22.73	28.71	7.21	1.23	47
Menard-Kerrville	23.10	31.09	8.47	0.48	89
Menard-Leakey	23.32	29.76	6.98	0.54	19
Menard-Llano	23.16	27.34	5.86	1.68	93
Menard-Mason	22.69	26.63	5.03	0.09	58
Menard-Prade Ranch	23.27	27.52	6.77	2.52	43
Menard-Sonora	22.58	20.89	4.23	2.54	54
Menard-Sonora Exp Sta	23.28	22.70	4.42	3.84	81
Prade Ranch-Carta Valley	29.34	24.65	7.54	2.85	29
Prade Ranch-Cottonwood	28.13	30.07	5.70	3.76	37
Prade Ranch-Llano	27.82	27.85	5.39	5.36	42
Rocksprings-Camp Wood	24.28	27.49	5.35	2.14	43
Rocksprings-Carta Valley	25.58	24.59	4.96	3.97	33
Rocksprings-Cottonwood	23.49	28.99	7.04	1.54	46
Rocksprings-Eldorado	23.36	20.86	4.49	1.99	17
Rocksprings-Fort McKavett	25.36	22.35	5.74	2.73	14
Rocksprings-Fredericksburg	23.50	30.27	8.18	1.41	53
Rocksprings-Harper	23.92	27.15	5.31	2.08	44
Rocksprings-Humble Station 5	24.11	21.61	4.61	2.11	33
Rocksprings-Hunt	23.17	29.61	7.37	0.96	32
Rocksprings-Kerrville	23.43	30.57	7.69	0.55	51
Rocksprings-Leakey	25.29	28.49	4.86	1.66	15
Rocksprings-Llano	23.18	27.04	7.06	3.20	54
Rocksprings-Mason	24.00	27.41	6.05	2.64	42
Rocksprings-Menard	23.35	23.09	5.13	4.87	54
Rocksprings-Prade Ranch	23.79	26.70	4.17	1.26	33
Rocksprings-Sonora	23.56	20.74	5.08	2.26	40
Rocksprings-Sonora Exp Sta	23.38	22.30	3.67	2.59	54
Sonora-Camp Wood	20.88	26.90	7.34	1.32	46
Sonora-Carta Valley	21.72	23.31	4.89	3.30	34
Sonora-Cottonwood	20.69	29.36	9.25	0.58	44
Sonora-Eldorado	22.45	20.12	3.04	0.71	17
Sonora-Fort McKavett	20.88	22.48	4.22	2.62	15
Sonora-Fredericksburg	21.14	29.57	9.00	0.57	59
Sonora-Harper	21.06	26.92	7.07	1.21	48
Sonora-Humble Station 5	20.79	21.41	3.21	2.60	33
Sonora-Hunt	20.84	29.51	9.42	0.75	35
Sonora-Kerrville	21.23	30.95	10.16	0.44	56
Sonora-Leakey	20.76	29.71	8.94	0.00	17
Sonora-Llano	21.45	26.87	7.09	1.67	55
Sonora-Mason	20.55	26.65	7.22	1.12	43
Sonora-Prade Ranch	21.90	27.91	8.14	2.13	37
Sonora Exp Sta-Camp Wood	22.68	26.81	6.11	1.98	57
Sonora Exp Sta-Carta Valley	24.08	24.20	4.79	4.67	39
Sonora Exp Sta-Cottonwood	22.38	28.89	7.36	0.85	81
Sonora Exp Sta-Eldorado	23.72	20.50	3.83	0.61	20
Sonora Exp Sta-Fort McKavett	22.48	22.48	4.55	4.55	15

Appendix Table A.1 (Cont.)

Comparison	Annual Means		Mean Difference	Standardized Mean Difference	Number of Years
Sonora Exp Sta-Fredericksburg	22.14	29.82	8.69	1.01	71
Sonora Exp Sta-Harper	22.36	27.00	6.40	1.64	59
Sonora Exp Sta-Humble Station 5	22.60	22.11	3.31	2.82	39
Sonora Exp Sta-Hunt	21.93	28.71	7.79	1.01	48
Sonora Exp Sta-Kerrville	22.38	31.22	9.07	1.13	80
Sonora Exp Sta-Leakey	22.80	30.48	8.07	0.39	19
Sonora Exp Sta-Llano	22.81	27.85	6.66	1.62	76
Sonora Exp Sta-Mason	22.02	26.64	6.37	1.75	59
Sonora Exp Sta-Prade Ranch	22.88	27.59	6.13	1.42	44
Sonora Exp Sta-Sonora	22.28	20.90	4.00	2.62	61

Appendix Table A.2 Spatial distances, direction, and standardized mean differences in annual precipitation between primary precipitation stations. Direction is from the first station to the second.

Stations Being Compared	Spatial Distance (miles)	Direction	Standardized Mean Difference (inches)
Junction 4SSW-Junction Airport	4	NE	0.99
Junction 4SSW-Telegraph	13	SW	1.89
Junction 4SSW-Roosevelt	17	W	1.36
Junction 4SSW-Humble Pump Station 5	30	SW	2.75
Junction 4SSW-Fort McKavett	31	NW	3.25
Junction 4SSW-Menard	33	N	3.62
Junction 4SSW-Harper	34	E	1.45
Junction 4SSW-Hunt	37	SE	0.63
Junction 4SSW-Cottonwood	37	SE	1.51
Junction 4SSW-Rocksprings	39	SW	4.54
Junction 4SSW-Mason	39	NE	0.96
Junction 4SSW-Prade Ranch	41	S	2.53
Junction 4SSW-Kerrville	48	SE	1.05
Junction 4SSW-Leakey	51	S	0.00
Junction 4SSW-Sonora	53	W	2.67
Junction 4SSW-Sonora Experiment Station	53	SW	3.24
Junction 4SSW-Eldorado	54	NW	1.12
Junction 4SSW-Camp Wood	55	S	1.62
Junction 4SSW-Fredericksburg	57	E	1.18
Junction 4SSW-Llano	70	NE	2.50
Junction 4SSW-Carta Valley	70	SW	6.23
Junction Airport-Telegraph	18	SW	0.59
Junction Airport-Roosevelt	20	W	2.45
Junction Airport- Menard	28	N	2.86
Junction Airport-Fort McKavett	29	NW	1.86
Junction Airport-Harper	32	SE	0.70
Junction Airport-Humble Pump Station 5	33	SW	2.71
Junction Airport-Mason	34	NE	0.80
Junction Airport-Cottonwood	38	SE	0.46
Junction Airport-Hunt	40	SE	0.94
Junction Airport-Rocksprings	44	SW	2.80
Junction Airport-Prade Ranch	46	S	1.28
Junction Airport-Kerrville	50	SE	0.06
Junction Airport-Sonora	54	W	3.23
Junction Airport-Fredericksburg	55	SE	0.74
Junction Airport-Leakey	55	S	0.00
Junction Airport-Eldorado	56	NW	1.06
Junction Airport-Camp Wood	56	S	1.38
Junction Airport-Sonora Experiment Station	57	SW	4.06
Junction Airport-Llano	65	NE	1.39
Junction Airport-Carta Valley	75	SW	2.80
Camp Wood-Leakey	16	E	1.75
Camp Wood-Prade Ranch	20	NE	3.15
Camp Wood-Rocksprings	25	NW	2.14
Camp Wood-Carta Valley	39	W	2.71
Camp Wood-Hunt	50	NE	3.69
Camp Wood-Humble Pump Station 5	52	NW	0.50
Camp Wood-Cottonwood	57	NE	2.59

Appendix Table B-2 (Cont.)

Stations Being Compared	Spatial Distance (miles)	Direction	Standardized Mean Difference (inches)
Camp Wood-Sonora Experiment Station	58	NW	1.98
Camp Wood-Kerrville	60	NE	2.46
Camp Wood-Harper	63	NE	4.17
Camp Wood-Sonora	74	NW	1.32
Camp Wood-Fort McKavett	80	N	2.22
Camp Wood-Fredericksburg	81	NE	3.10
Camp Wood-Menard	87	N	1.54
Camp Wood-Mason	88	NE	3.44
Camp Wood-Eldorado	89	NW	1.18
Camp Wood-Llano	113	NE	4.71
Eldorado-Sonora	21	S	0.71
Eldorado-Fort McKavett	31	E	NCY
Eldorado-Sonora Experiment Station	40	S	0.61
Eldorado-Humble Pump Station 5	40	SE	1.18
Eldorado-Menard	50	E	0.81
Eldorado-Rocksprings	66	SE	1.99
Eldorado-Carta Valley	75	S	3.83
Eldorado-Mason	83	E	0.20
Eldorado-Prade Ranch	83	SE	1.47
Eldorado-Cottonwood	84	SE	0.00
Eldorado-Harper	90	SE	0.47
Eldorado-Hunt	97	SE	1.03
Eldorado-Leakey	99	SE	1.01
Eldorado-Kerrville	108	SE	0.01
Eldorado-Fredericksburg	115	SE	0.42
Eldorado-Llano	118	E	0.40
Fort McKavett-Menard	18	NE	2.39
Fort McKavett-Humble Pump Station 5	33	SW	2.23
Fort McKavett-Sonora	37	SW	2.62
Fort McKavett-Sonora Experiment Station	52	SW	4.55
Fort McKavett-Mason	53	E	2.52
Fort McKavett-Rocksprings	58	S	2.73
Fort McKavett-Harper	61	SE	1.04
Fort McKavett-Cottonwood	67	SE	1.54
Fort McKavett-Prade Ranch	68	SE	3.30
Fort McKavett-Hunt	71	SE	1CY
Fort McKavett-Carta Valley	78	SW	1.83
Fort McKavett-Leakey	80	SE	1.00
Fort McKavett-Kerrville	81	SE	1.23
Fort McKavett-Fredericksburg	83	SE	1.10
Fort McKavett-Llano	86	E	2.25
Harper-Cottonwood	7	S	1.65
Harper-Hunt	17	S	1.46
Harper-Kerrville	21	SW	1.55
Harper-Fredericksburg	24	E	1.58
Harper-Mason	31	N	3.66
Harper-Prade Ranch	44	SW	4.11
Harper-Llano	47	NE	4.19
Harper-Leakey	49	SW	2.09

Appendix Table A.2 (Cont.)

Stations Being Compared	Spatial Distance (miles)	Direction	Standardized Mean Difference (inches)
Harper-Menard	54	NW	1.40
Harper-Humble Pump Station 5	60	W	0.42
Harper-Rocksprings	61	SW	2.08
Harper-Sonora Experiment Station	82	W	1.64
Harper-Sonora	83	NW	1.21
Harper-Carta Valley	91	SW	3.64
Humble Pump Station-Sonora Exp Sta	22	SW	2.82
Humble Pump Station-Sonora	25	NW	2.60
Humble Pump Station-Rocksprings	27	S	2.11
Humble Pump Station-Prade Ranch	46	SE	1.47
Humble Pump Station-Menard	47	NE	1.89
Humble Pump Station-Carta Valley	47	SW	3.96
Humble Pump Station-Leahey	56	SE	0.00
Humble Pump Station-Hunt	61	SE	0.42
Humble Pump Station-Cottonwood	63	SE	0.53
Humble Pump Station-Kerrville	67	SE	0.12
Humble Pump Station-Mason	67	NE	0.73
Humble Pump Station-Fredericksburg	83	E	0.25
Humble Pump Station-Llano	97	NE	1.13
Leahey-Hunt	35	NE	2.56
Leahey-Kerrville	43	NE	2.66
Leahey-Cottonwood	46	NE	2.49
Leahey-Carta Valley	55	W	1.90
Leahey-Fredericksburg	65	NE	3.41
Leahey-Mason	77	NE	3.74
Leahey-Llano	96	NE	2.32
Menard-Mason	35	SE	0.09
Menard-Sonora	56	SW	2.54
Menard-Cottonwood	61	SE	1.06
Menard-Hunt	65	SE	1.23
Menard-Sonora Experiment Station	66	SW	3.84
Menard-Llano	68	E	1.68
Menard-Rocksprings	68	SW	4.87
Menard-Kerrville	73	SE	0.48
Menard-Fredericksburg	73	SE	0.81
Menard-Prade Ranch	73	S	2.52
Menard-Leahey	83	S	0.54
Menard-Carta Valley	95	SW	6.42
Prade Ranch-Leahey	12	S	3.10
Prade Ranch-Rocksprings	27	NW	1.26
Prade Ranch-Hunt	31	NE	2.95
Prade Ranch-Kerrville	41	NE	2.29
Prade Ranch-Cottonwood	41	NE	3.76
Prade Ranch-Carta Valley	53	SW	2.85
Prade Ranch-Sonora Experiment Station	58	NW	1.42
Prade Ranch-Fredericksburg	63	NE	3.25
Prade Ranch-Mason	68	SW	4.24
Prade Ranch-Sonora	71	NW	2.13
Prade Ranch-Llano	81	NE	5.36

Appendix Table A.2 (Cont.)

Stations Being Compared	Spatial Distance (miles)	Direction	Standardized Mean Difference (inches)
Rocksprings-Leakey	33	SE	1.66
Rocksprings-Carta Valley	33	SW	3.97
Rocksprings-Sonora Experiment Station	33	NW	2.59
Rocksprings-Sonora	46	NW	2.26
Rocksprings-Hunt	53	E	0.96
Rocksprings-Cottonwood	60	NE	1.54
Rocksprings-Kerrville	65	E	0.55
Rocksprings-Mason	78	NE	2.64
Rocksprings-Fredericksburg	83	NE	1.41
Rocksprings-Llano	105	NE	3.20
Sonora-Sonora Experiment Station	20	S	2.62
Sonora-Carta Valley	55	S	3.30
Sonora-Leakey	78	SE	0.00
Sonora-Mason	85	NE	1.12
Sonora-Hunt	86	SE	0.75
Sonora-Cottonwood	88	SE	0.85
Sonora-Kerrville	97	SE	0.44
Sonora-Fredericksburg	105	SE	0.57
Sonora-Llano	118	NE	1.67
Sonora Experiment Station-Carta Valley	36	S	4.67
Sonora Experiment Station-Leakey	67	SE	0.39
Sonora Experiment Station-Hunt	80	SE	1.01
Sonora Experiment Station-Cottonwood	84	E	0.85
Sonora Experiment Station-Mason	89	NE	1.75
Sonora Experiment Station-Kerrville	92	SE	1.13
Sonora Experiment Station-Fredericksburg	105	E	1.01
Sonora Experiment Station-Llano	122	NE	1.62

APPENDIX B: VEGETATION

Appendix Table B.1 Aboveground clippable biomass (g/m²) of herbaceous species and presence of woody species (---) by soil type in Kimble and Menard Counties, Texas. Values are for August of average precipitation years and assume fair range condition.

Species	Kimble County										Menard County					
	CoC	De	Fr	KTB	MnB	NuB	OhC	RbF	TaC	TrG	Ds	KaB	Ta	Tb	TsA	VaB
pecan		---	---													
hackberry		---	---	---					---	---	---		---	---	---	
Texas persimmon		---	---	---	---		---		---	---		---	---	---		
Ashe juniper	---	---	---	---	---	---	---	---	---	---	---	---	---	---		---
mesquite	---	---	---				---	---				---	---		---	---
Texas red oak								---		---				---		
live oak				---	---	---	---	---	---	---		---	---	---		---
mustang grape		---	---								---					
elbowbush				---	---	---	---		---	---		---	---	---		---
agarito	---	---	---	---	---			---	---	---		---	---	---		---
sumac																
yucca	---			---			---	---	---	---		---	---	---		---
prickly pear	---			---		---	---	---	---	---		---	---	---	---	---
purple threeawn	5	15	15	20	12	15	20	5	20	20	15	20	20	20	25	13
cane bluestem	10	20	25	1	5	20	10	10	1	5	20	1	1	5	20	20
KR bluestem		20	20	15		10			15		20	15	15		5	10
sideoats grama	20	30	40	6	35	35	25	20	6	30	30	6	6	30	50	35
hairy grama	15			18	12	12	5	15	18	12		18	18	12	5	12
red grama	5			10				3	5	10	7		10	10	7	5
Canada wildrye		30	40		2	5	1				30					5
plains lovegrass		15	16		10	20	5				15				4	20
Texas cupgrass				1					1	2		1	1	2	4	
curly mesquite	20	30	28	40	30	30	15	10	40	10	30	40	40	10	50	30
green sprangletop						5				5				5	5	5
vine-mesquite		10	10			5						10			20	5
switchgrass		4	5									4				
little bluestem	10	30	32	1	35	10	15	20	1	20	30	1	1	20	10	10
indiangrass		3	4		2	2	2			5	3			5	2	2
tall dropseed						12			5							12
sand dropseed					25				5							
Texas wintergrass	10	35	35	15	12	23	7		15	10	35	15	15	10	30	25
ragweed		10	10	5	15	5			5		10	5	5		20	5
lazydaisy	5	9	10	1	12	5	6		1	2	9	1	1	2	5	5
bundleflower				1					1			1	1		5	
Indian blanket				3	10				3			3	3			
sunflower		15	10			5					15					5
Texas bluebonnet					10											
prairie coneflower				1					1			1	1			
bush sunflower		15	10		13	6			2	3	15		2	3	5	6
orange zexmenia		9	10	2		5	6	5		4	9	2		4		5
total herbaceous	100	300	320	140	240	230	120	100	140	135	300	140	135	140	270	230

Appendix Table B.2 Aboveground clippable biomass (g/m^2) of herbaceous species and presence of woody species (---) by soil type in Sutton and Schleicher Counties, Texas. Values are for August of average precipitation years and assume fair range condition.

Species	Sutton County								Schleicher County					
	Es	Fd	Kt	Ky	Rc	Tc	Tr	Ts	002	003	005	008	010	011
pecan														
hackberry	---	---	---	---	---			---	---		---	---	---	
Texas persimmon	---	---	---					---	---		---	---	---	
Ashe juniper	---	---	---					---	---		---	---	---	---
mesquite	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Texas red oak	---	---	---					---	---		---	---	---	
live oak	---	---	---	---	---			---	---		---	---	---	---
mustang grape	---	---	---					---	---		---	---	---	
elbowbush	---	---	---					---	---		---	---	---	---
agarito	---	---	---				---	---	---	---	---	---	---	---
sumac	---	---	---	---	---			---	---		---	---	---	
yucca	---	---	---					---	---		---	---	---	
prickly pear	---	---	---	---	---	---	---	---	---	---	---	---	---	---
purple threeawn	25	15	25	50	50	25	25	25	10	15	25	20	15	20
cane bluestem	5	25	5	10	10	20	5	5	15	25	5	5	10	25
KR bluestem	5	20	5	5	5	5	5	5		5	5	1	5	5
sideoats grama	30	40	25	30	30	50	30	30	35	30	25	20	40	45
hairy grama	20		20	5	5	5	20	20	15		20	10	5	15
red grama	10	10	10	10	10	5	10	10	5		10	10	5	5
Canada wildrye		30		10	10					10				
plains lovegrass	1	15	1	5	5	4	1	1		5	1	1	2	5
Texas cupgrass	5	10	5	5	5	4	5	5	5		5	4	2	20
curly mesquite	40	30	45	55	55	50	40	40	40	30	45	35	40	40
green sprangletop						5							5	10
vine-mesquite		10		10	10	20				5			10	5
switchgrass		5								4			1	
little bluestem	8	30	5	5	5	10	8	8	10	20	5	5	10	10
indiangrass	1	2				2	1	1		3		1		2
tall dropseed														
sand dropseed														5
Texas wintergrass	15	30	20	30	30	30	15	15	20	30	20	15	25	35
ragweed	5	20	5	20	20	20	5	5		10	5	5	15	15
lazydaisy	2	8	2	5	5	5	2	2	5	9	2	1	3	3
bundleflower	1		1			5	1	1			1	1	2	
indian blanket	2		1				2	2			1	1		
sunflower		10		10	10					10				5
Texas bluebonnet														
prairie coneflower	1		1	5	5		1	1			1	1		
bush sunflower		10		10	10	5				10			5	5
orange zexmenia	4	10	4				4	4		9	4	4		5
total herbaceous	180	330	180	280	280	270	180	180	160	230	180	140	200	280

Appendix Table B.3 Aboveground clippable biomass (g/m^2) of herbaceous species and presence of woody species (---) by soil type in Edwards, Real, and Kerr Counties, Texas. Values are for August of average precipitation years and assume fair range condition.

Species	Edwards and Real Counties										Kerr County					
	DeB	DnD	EcF	EcG	ErB	IrA	LkB	OdA	PeB	RdB	DnB	ERG	Oa	PTD	STC	TTC
pecan	---								---							
hackberry	---		---		---				---				---	---		
Texas persimmon	---	---	---	---	---		---					---	---	---	---	---
Ashe juniper	---		---	---	---		---		---	---		---	---	---	---	---
mesquite	---	---			---	---	---	---	---	---		---	---		---	---
Texas red oak			---		---											
live oak		---	---	---	---		---	---		---		---		---	---	---
mustang grape	---							---					---			
elbowbush	---	---	---	---	---		---			---		---		---	---	---
agarito	---	---	---	---	---		---		---			---	---	---	---	---
sumac			---	---	---		---	---				---			---	---
yucca			---		---		---		---				---	---	---	---
prickly pear		---	---	---	---	---	---		---	---		---		---	---	---
purple threeawn	10	25	30	15	20	20	30	20	15	20	30	15	20	30	30	20
cane bluestem	10	10	10	5	5	10	20	45	15	20	30	5	30	5	20	10
KR bluestem	5						5	20		5	5		20	5	5	5
sideoats grama	20	40	40	20	20	20	40	50	30	40	40	25	50	15	40	20
hairy grama		10	20	10	15	5	10	5	20	10	10	5		25	10	15
red grama		5	10	5		2			10			5		15		10
Canada wildrye	10	5						40		5	5		35			
plains lovegrass	5	10				2	10	10		10	10		10		10	
Texas cupgrass		10	5	5	5	2	10	30	3	10	15	2	20	5	10	5
curly mesquite	20	40	15	10	25	25	40	30	30	35	40	10	30	50	40	38
green sprangletop		10	10	5		1	10	20		5	10	2	10		10	
vine-mesquite	5					5	10	20		5	5		10		10	
switchgrass	2						5	10					5		5	
little bluestem	15	30	30	10	10	5	35	40	15	15	25	15	40	5	35	10
indiangrass	2	20	5	5	2		10	5		3	3	1	5		10	
tall dropseed		10								10	10					
sand dropseed																
Texas wintergrass	20	35	15	10	10	10	30	25	15	25	40	10	30	25	30	15
ragweed	10	20			5	8	10	25	5	5	15		15	10	10	5
lazydaisy	2		2	2	1	1		5	2	2	2	1	5	2		1
bundleflower		5				2	2							2	2	1
indian blanket														1		2
sunflower	10							15		5	5		10			
Texas bluebonnet																
prairie coneflower														1		
bush sunflower	10		3	3		2	3	15		5	5	2	15		3	1
orange zexmenia	4	5	5	5	2					5	5	2		4		2
total aboveground	160	290	200	110	120	120	280	430	160	240	310	100	360	200	280	160

Appendix Table B.4 Aboveground biomass (g/m²) for woody species included in the Upper Llano EDYS model (values based on 100% canopy cover of the respective woody species).

Species	Trunk	Stems	Leaves	Total
pecan	23,680	9,000	592	33,272
hackberry	28,847	10,962	649	40,458
Texas persimmon	4,676	1,870	421	6,967
Ashe juniper	2,856	628	228	3,712
mesquite	2,662	878	373	3,913
Texas red oak	6,177	1,544	309	8,030
live oak	4,866	1,217	243	6,326
mustang grape	1,178	118	353	1,649
elbowbush	527	1,054	268	1,849
agarito	233	280	119	632
sacahuista	65	130	525	720
sumac	1,123	1,291	337	2,751
yucca	168	336	806	1,310
prickly pear	599	1,198	0	1,797

Appendix Table B.5 Composition (% relative cover) of woody plant components of plant communities in Edwards, Real, and Kerr Counties, by soil type and by woody coverage class.

Soil Cover	pecan	hackberry	TXprsmn	juniper	mesquite	red oak	live oak	grape	elwbwsh	agarito	sumac	yucca	ppear
Edwards-Real													
DeB <10	5	40	5	10	20	--	--	5	--	5	10	--	--
10-50	15	30	10	10	15	--	--	10	--	5	5	--	--
>50	20	10	10	30	10	--	5	10	--	--	5	--	--
DnD <10	--	--	--	40	25	--	5	--	5	5	10	5	5
10-50	--	--	5	30	20	--	20	--	5	5	5	5	5
>50	--	--	5	40	20	--	20	--	5	--	5	--	5
EcF <10	--	5	5	40	5	--	25	--	5	5	5	--	5
10-50	--	5	10	30	5	--	30	--	5	5	--	5	5
>50	--	5	5	50	5	--	30	--	1	1	--	1	2
EcG <10	--	5	5	35	--	5	20	--	5	5	10	5	5
10-50	--	5	5	35	--	5	30	--	5	5	--	5	5
>50	--	1	3	60	--	5	25	--	1	1	2	1	1
ErB <10	--	5	5	30	15	5	10	--	5	5	10	5	5
10-50	--	5	5	30	10	5	20	--	5	5	5	5	5
>50	--	2	2	45	15	5	25	--	1	1	2	1	1
IrA <10	--	--	--	--	80	--	--	--	--	10	--	--	10
10-50	--	--	--	--	90	--	--	--	--	5	--	--	5
>50	--	--	--	7	90	--	--	--	--	2	--	--	1
LkB <10	--	--	2	25	35	--	10	--	6	4	10	4	4
10-50	--	--	5	25	35	--	15	--	5	3	6	3	3
>50	--	--	5	40	30	--	15	--	2	1	5	1	1
OdA <10	15	40	5	5	20	--	--	5	--	5	5	--	--
10-50	15	30	10	10	15	--	--	10	--	5	5	--	--
>50	20	20	5	10	25	--	10	5	--	--	5	--	--
PeB <10	--	--	--	40	30	--	5	--	--	5	10	5	5
10-50	--	--	--	45	30	--	10	--	--	2	10	2	1
>50	--	--	--	50	20	--	20	--	--	1	7	1	1
RdB <10	--	--	--	10	50	--	10	--	10	5	--	5	10
10-50	--	--	--	10	40	--	20	--	10	5	--	5	10
>50	--	--	--	15	50	--	25	--	5	3	--	1	1
Kerr													
DnB <10	--	--	--	10	50	--	10	--	10	5	--	5	10
10-50	--	--	--	10	40	--	20	--	10	5	--	5	10
>50	--	--	--	15	50	--	25	--	5	3	--	1	1
ERG <10	--	5	5	35	--	5	20	--	5	5	10	5	5
10-50	--	5	5	35	--	5	30	--	5	5	--	5	5
>50	--	1	3	60	--	5	25	--	1	1	2	1	1
Oa <10	15	40	5	5	20	--	--	5	--	5	5	--	--
10-50	15	30	10	10	15	--	--	10	--	5	5	--	--
>50	20	20	5	10	25	--	10	5	--	--	5	--	--
PTD <10	--	--	5	15	35	--	15	--	5	5	10	5	5
10-50	--	--	5	15	35	--	20	--	5	3	10	4	3
>50	--	--	5	30	30	--	25	--	2	1	5	1	1
STC <10	--	--	2	25	35	--	10	--	6	4	10	4	4
10-50	--	--	5	25	35	--	15	--	5	3	6	3	3
>50	--	--	5	40	30	--	15	--	2	1	5	1	1
TTC <10	--	5	5	40	5	--	25	--	5	5	5	3	2
10-50	--	5	10	30	5	--	30	--	5	5	5	3	2
>50	--	5	5	50	5	--	30	--	1	1	1	1	1

Appendix Table B.6 Composition (% relative cover) of woody plant components of plant communities in Kimble and Menard Counties, by soil type and by woody coverage class.

Soil Cover	pecan	hackberry	TXprsmn	juniper	mesquite	red oak	live oak	grape	elwbush	agarito	sumac	yucca	ppear
Kimble													
CoC <10	--	--	--	40	30	--	5	--	--	5	10	5	5
10-50	--	--	--	45	30	--	10	--	--	2	10	2	1
>50	--	--	--	50	20	--	20	--	--	1	7	1	1
De <10	5	40	5	10	20	--	--	5	--	5	10	--	--
10-50	15	30	10	10	15	--	--	10	--	5	5	--	--
>50	20	10	10	30	10	--	5	10	--	--	5	--	--
Fr <10	15	40	5	5	20	--	--	5	--	5	5	--	--
10-50	15	30	10	10	15	--	--	10	--	5	5	--	--
>50	20	20	5	10	25	--	10	5	--	--	5	--	--
KTB <10	--	--	5	15	35	--	15	--	5	5	10	5	5
10-50	--	--	5	15	35	--	20	--	5	3	10	4	3
>50	--	--	5	30	30	--	25	--	2	1	5	1	1
MnB <10	--	--	5	20	40	--	20	--	--	5	--	5	5
10-50	--	--	5	20	40	--	25	--	--	5	--	3	2
>50	--	--	6	25	40	--	25	--	--	1	--	2	1
NuB <10	--	--	--	10	50	--	10	--	10	5	--	5	10
10-50	--	--	--	10	40	--	20	--	10	5	--	5	10
>50	--	--	--	15	50	--	25	--	5	3	--	1	1
OhC <10	--	--	5	25	35	--	15	--	5	5	--	5	5
10-50	--	--	5	30	35	--	20	--	4	2	--	2	2
>50	--	--	5	35	35	--	20	--	2	1	--	1	1
RbF <10	--	--	--	35	5	10	20	--	5	5	10	5	5
10-50	--	--	--	40	10	15	25	--	5	2	--	2	1
>50	--	--	--	45	10	15	25	--	2	1	--	1	1
TaC <10	--	5	5	40	5	--	20	--	5	5	5	5	5
10-50	--	5	10	35	10	--	25	--	5	2	5	2	1
>50	--	5	5	45	5	--	30	--	2	1	5	1	1
TrG <10	--	5	5	35	--	5	20	--	5	5	10	5	5
10-50	--	5	5	35	5	5	30	--	5	2	5	2	1
>50	--	1	3	55	5	5	25	--	1	1	2	1	1
Menard													
Ds <10	5	40	5	10	20	--	--	5	--	5	10	--	--
10-50	15	30	10	10	15	--	--	10	--	5	5	--	--
>50	20	10	10	30	10	--	5	10	--	--	5	--	--
KaB <10	--	--	5	15	35	--	15	--	5	5	10	5	5
10-50	--	--	5	15	35	--	20	--	5	3	10	4	3
>50	--	--	5	30	30	--	25	--	2	1	5	1	1
Ta <10	--	5	5	40	5	--	20	--	5	5	5	5	5
10-50	--	5	10	35	10	--	25	--	5	2	5	2	1
>50	--	5	5	45	5	--	30	--	2	1	5	1	1
Tb <10	--	5	5	35	--	5	20	--	5	5	10	5	5
10-50	--	5	5	35	5	5	30	--	5	2	5	2	1
>50	--	1	3	55	5	5	25	--	1	1	2	1	1
TsA <10	--	--	--	--	80	--	--	--	--	10	--	--	10
10-50	--	--	--	--	90	--	--	--	--	5	--	--	5
>50	--	--	--	7	90	--	--	--	--	2	--	--	1
VaB <10	--	--	--	10	50	--	10	--	10	5	--	5	10
10-50	--	--	--	10	40	--	20	--	10	5	--	5	10
>50	--	--	--	15	50	--	25	--	5	3	--	1	1

Appendix Table B.7 Composition (% relative cover) of woody plant components of plant communities in Sutton and Schleicher Counties, by soil type and by woody coverage class.

Soil Cover	pecan	hackberry	TXprsmn	juniper	mesquite	red oak	live oak	grape	elwbush	agarito	sumac	yucca	pppear
Sutton													
Es <10	--	5	5	30	15	5	10	--	5	5	10	5	5
10-50	--	5	5	30	10	5	20	--	5	5	5	5	5
>50	--	2	2	45	15	5	25	--	1	1	2	1	1
Fd <10	15	40	5	5	20	--	--	5	--	5	5	--	--
10-50	15	30	10	10	15	--	--	10	--	5	5	--	--
>50	20	20	5	10	25	--	10	5	--	--	5	--	--
Kt <10	--	--	5	15	35	5	10	--	5	5	10	5	5
10-50	--	--	5	15	35	5	15	--	5	3	10	4	3
>50	--	--	5	30	30	5	20	--	2	1	5	1	1
Ky <10	--	--	--	10	50	--	10	--	10	5	5	5	5
10-50	--	--	--	20	40	--	20	--	5	3	5	5	2
>50	--	--	--	25	40	--	25	--	2	1	5	1	1
Rc <10	--	10	5	5	40	--	15	--	5	5	10	3	2
10-50	--	10	5	10	40	--	20	--	5	2	5	2	1
>50	--	10	5	20	40	--	20	--	1	1	1	1	1
Tc <10	--	--	--	--	80	--	--	--	--	10	--	--	10
10-50	--	--	--	--	90	--	--	--	--	5	--	--	5
>50	--	--	--	7	90	--	--	--	--	2	--	--	1
Tr <10	--	5	5	35	--	5	20	--	5	5	10	5	5
10-50	--	5	5	35	--	5	30	--	5	5	5	3	2
>50	--	1	3	60	--	5	25	--	1	1	2	1	1
Ts <10	--	5	5	35	5	5	20	--	5	5	5	5	5
10-50	--	5	10	30	5	5	25	--	5	5	--	5	5
>50	--	5	5	50	5	5	25	--	2	1	--	1	1
Schleicher													
002 <10	--	--	--	40	30	--	5	--	--	5	10	5	5
10-50	--	--	--	45	30	--	10	--	--	2	10	2	1
>50	--	--	--	50	20	--	20	--	--	1	7	1	1
003 <10	5	40	5	10	20	--	--	5	--	5	10	--	--
10-50	15	30	10	10	15	--	--	10	--	5	5	--	--
>50	20	10	10	30	10	--	5	10	--	--	5	--	--
005 <10	--	--	5	15	35	5	10	--	5	5	10	5	5
10-50	--	--	5	15	35	5	15	--	5	3	10	4	3
>50	--	--	5	30	30	5	20	--	2	1	5	1	1
008 <10	--	5	5	35	5	5	20	--	5	5	5	5	5
10-50	--	5	10	30	5	5	25	--	5	5	--	5	5
>50	--	5	5	50	5	5	25	--	2	1	--	1	1
010 <10	--	--	--	--	80	--	--	--	--	10	--	--	10
10-50	--	--	--	--	90	--	--	--	--	5	--	--	5
>50	--	--	--	7	90	--	--	--	--	2	--	--	1
011 <10	--	--	--	10	50	--	10	--	10	5	--	5	10
10-50	--	--	--	10	40	--	20	--	10	5	--	5	10
>50	--	--	--	15	50	--	25	--	5	3	--	1	1

Appendix Table B.8 Data sources and calculations for information in Appendix Table B.4. Plant sizes are estimates unless referenced with a source.

Pecan (*Carya illinoensis*)

Trunk diameter = 40 cm; height = 15 m trunk volume = $(0.5)(3.14)(20 \text{ cm})^2(1500 \text{ cm}) = 942,000 \text{ cm}^3$
 Wood density = 45 lb/cu ft (air-dry) = 0.72 g/cm³ (Forbes and Meyer 1961, p. 14-30)
 Trunk weight = $(942,000 \text{ cm}^3)(0.72 \text{ g/cm}^3) = 668,240 \text{ g}$
 Canopy diameter = 6 m Area per tree = $(3.14)(3 \text{ m})^2 = 28.26 \text{ m}^2$
 Trunk weight = $(668,240 \text{ g})/28.26 \text{ m}^2 = 23,682 \text{ g/m}^2$ (44,226 g/m² late-seral TN deciduous forest; Whittaker 1975)

Stem biomass = 0.38(trunk biomass) = mean for trees (Appendix Table B.9) = 9000 g/m²
 Leaf biomass = 0.025(trunk biomass) = 2.0(deciduous forest; Appendix Table B.9) = 592 g/m²
 (407 g/m² oak-pine forest, 351 g/m² deciduous forest, Whittaker 1975; 599 g/m² cottonwood, McLendon 2010)

Sugar hackberry (*Celtis laevigata*)

Trunk diameter = 34 cm; trunk height = 8 m (75% of Louisiana values; Fowells 1965)
 Trunk volume = $(1.0)(3.14)(17 \text{ cm})^2(800 \text{ cm}) = 725,968 \text{ cm}^3$
 Wood density = 49 lb/cu ft (air-dry) = 0.78 g/cm³ (Vines 1960)
 Trunk weight = $(725,968 \text{ cm}^3)(0.78 \text{ g/cm}^3) = 566,255 \text{ g}$
 Canopy diameter = 5 m Area per tree = $(3.14)(2.5 \text{ m})^2 = 19.63 \text{ m}^2$
 Trunk weight = $(566,255 \text{ g})/19.63 \text{ m}^2 = 28,847 \text{ g/m}^2$

Stem biomass = 0.38(trunk biomass) = mean for trees (Appendix Table B.9) = 10,962 g/m²
 Leaf biomass = 0.025(trunk biomass) = 2.0(deciduous forest; Appendix Table B.9) = 649 g/m²

Texas persimmon (*Diosyros texana*)

Trunk diameter = 30 cm; tree height = 8 m (trunk height = 2 m); (50% maximum values, Correll & Johnston 1970)
 Trunk volume = $(1.0)(3.14)(15 \text{ cm})^2(200 \text{ cm}) = 141,300 \text{ cm}^3$ Wood density = 0.65 g/cm³
 Trunk weight = $(141,300 \text{ cm}^3)(0.65 \text{ g/cm}^3) = 91,845 \text{ g}$
 Canopy diameter = 5 m Area per tree = $(3.14)(2.5 \text{ m})^2 = 19.63 \text{ m}^2$
 Trunk weight = $(91,845 \text{ g})/19.63 \text{ m}^2 = 4,676 \text{ g/m}^2$

Stem biomass = mean of *Cercidium floridum*, *Prosopis glandulosa*, *Prosopis velutina*, *Robinia pseudoacacia* (Appendix Table B.9) = 0.40(trunk biomass) = 1870 g/m² (1639 g/m² young oak-pine forest; Whittaker 1975)
 Leaf biomass = mean of *Cercidium floridum*, *Prosopis glandulosa*, *Prosopis velutina*, *Robinia pseudoacacia* (Appendix Table B.9) = 0.09(trunk biomass) = 421 g/m²

Ashe juniper (*Juniperus ashei*)

Trunk diameter = (3 stems)(15 cm); tree height = 4.8 m (Hicks and Dugas 1998); trunk height = 2 m
 Trunk volume = $3[(1.0)(3.14)(7.5 \text{ cm})^2(200 \text{ cm})] = 105,975 \text{ cm}^3$ Wood density = 0.59 g/cm³ (Vines 1960)
 Trunk weight = $(105,975 \text{ cm}^3)(0.59 \text{ g/cm}^3) = 62,525 \text{ g}$
 Canopy diameter = 5.28 m canopy diameter/tree height = 1.10 (Hicks and Dugas 1998)
 Area per tree = $(3.14)(2.64 \text{ m})^2 = 21.89 \text{ m}^2$
 Trunk weight = $(62,525 \text{ g})/21.89 \text{ m}^2 = 2,856 \text{ g/m}^2$

Stem biomass = 0.22(trunk biomass) = mean of *Pseudotsuga menziesii* and oak-pine forest (Appendix Table B.9) = 628 g/m²
 Leaf biomass = 0.08(trunk biomass) = mean of *Pseudotsuga menziesii* and oak-pine forest (Appendix Table B.9) = 228 g/m² (407 g/m² in young oak-pine forest; Whittaker 1975)

Appendix Table B.8 (Cont.)

Mesquite (*Prosopis glandulosa*)

Trunk diameter = (2 stems)(15 cm); tree height = 10 m (Vines 1960); trunk height = 3 m
 Trunk volume = $(2)(3.14)(7.5 \text{ cm})^2(300 \text{ cm}) = 105,975 \text{ cm}^3$ Wood density = 0.71 g/cm^3 (Ayensu 1980)
 Trunk weight = $(105,975 \text{ cm}^3)(0.71 \text{ g/cm}^3) = 75,242 \text{ g}$ (75,920 g for *P. velutina*; Barth and Klemmedson 1982)

Canopy diameter = 6 m Area per tree = $(3.14)(3 \text{ m})^2 = 28.26 \text{ m}^2$ (20.9 m² *P. velutina*; Barth & Klemmedson 1982)
 Trunk weight = $(75,242 \text{ g})/28.26 \text{ m}^2 = 2,662 \text{ g/m}^2$ (1,293 g/m² for *P. velutina*; Barth & Klemmedson 1982)

Stem biomass = $0.33(\text{trunk biomass}) = \text{mean of } P. \text{ glandulosa and } P. \text{ velutina}$ (Appendix Table B.9) = 878 g/m^2
 Leaf biomass = $0.14(\text{trunk biomass}) = \text{mean of } P. \text{ glandulosa and } P. \text{ velutina}$ (Appendix Table B.9) = 373 g/m^2

Texas red oak (*Quercus buckleyi*)

Trunk diameter = 20 cm; tree height = 10 m (Vines 1960); (tree height/trunk diameter = 24; Fowells 1965)
 Trunk volume = $(0.5)(3.14)(10 \text{ cm})^2(1000 \text{ cm}) = 157,000 \text{ cm}^3$
 Wood density = 57 lb/cu ft (Vines 1960) = 0.91 g/cm^3 Trunk weight = $(157,000 \text{ cm}^3)(0.91 \text{ g/cm}^3) = 142,870 \text{ g}$

Tree density = 175 trees/acre at 8-inch diameter trunks (Fowells 1965) Area per tree = $4047 \text{ m}^2/175 = 23.13 \text{ m}^2$
 Trunk weight = $(142,870 \text{ g})/23.13 \text{ m}^2 = 6,177 \text{ g/m}^2$

Stem biomass = $0.25(\text{trunk biomass}) = \text{mean of oak-pine and deciduous forests}$ (Appendix Table B.9) = 1544 g/m^2
 (1639 g/m² young oak-pine forest, 6026 g/m² late-seral TN deciduous forest; Whittaker 1975)

Leaf biomass = $0.05(\text{trunk biomass}) = \text{mean of oak-pine and deciduous forests}$ (Appendix Table B.9) = 309 g/m^2
 (407 g/m² young oak-pine forest, 351 g/m² late-seral TN deciduous forest; Whittaker 1975)

Live oak (*Quercus virginiana*)

Trunk diameter = 20 cm; tree height = 10 m; trunk height = 3.5 m
 Trunk volume = $(1.0)(3.14)(10 \text{ cm})^2(350 \text{ cm}) = 109,900 \text{ cm}^3$
 Wood density = 59 lb/cu ft (Vines 1960) = 0.94 g/cm^3 Trunk weight = $(109,900 \text{ cm}^3)(0.94 \text{ g/cm}^3) = 103,306 \text{ g}$

Canopy diameter = 5.2 m (canopy diameter/trunk thickness = 26; Fowells 1965)
 Area per tree = $(3.14)(2.6 \text{ m})^2 = 21.23 \text{ m}^2$ Trunk weight = $(103,306 \text{ g})/21.23 \text{ m}^2 = 4,866 \text{ g/m}^2$

Stem biomass = $0.25(\text{trunk biomass}) = \text{mean of oak-pine and deciduous forests}$ (Appendix Table B.9) = 1217 g/m^2
 Leaf biomass = $0.05(\text{trunk biomass}) = \text{mean of oak-pine and deciduous forests}$ (Appendix Table B.9) = 243 g/m^2

Mustang grape (*Vitis mustangensis*)

Trunk diameter = 10 cm (maximum of 15 cm; Vines 1960); vine length = 8 m (maximum of 40 ft; Vines 1960)
 Trunk volume = $(0.5)(3.14)(5 \text{ cm})^2(800 \text{ cm}) = 31,400 \text{ cm}^3$ Vine density = 0.3 g/cm^3
 Main vine weight = $(31,400 \text{ cm}^3)(0.3 \text{ g/cm}^3) = 9,420 \text{ g}$

Assume half the vine length is height and half is horizontal, along the tops of trees. Assume the area covered by the horizontal length of the vine is a rectangle with length = the horizontal length and width = $(0.5)\text{horizontal length}$.
 Area per vine = $(4 \text{ m})(2 \text{ m}) = 8 \text{ m}^2$ Main vine weight = $(9,420 \text{ g})/8 \text{ m}^2 = 1,178 \text{ g/m}^2$

Stem biomass = $0.10(\text{trunk biomass}) = 118 \text{ g/m}^2$
 Leaf biomass = $0.30(\text{trunk biomass}) = \text{mean of tree and shrub means}$ (Appendix Table B.10) = 353 g/m^2

Appendix Table B.8 (Cont.)

Elbowbush (*Forestiera pubescens*)

Trunk diameter = 5 cm (one-third of maximum; Vines 1960)

Shrub height = 150 cm (one-third of maximum; Vines 1960; Scifres 1980)

Trunk volume = $(0.5)(3.14)(2.5 \text{ cm})^2(150 \text{ cm}) = 1,472 \text{ cm}^3$

Wood density = 39 lb/cu ft (*F. acuminata*; Vines 1960) = 0.63 g/cm³

Trunk weight = $(1,472 \text{ cm}^3)(0.63 \text{ g/cm}^3) = 927 \text{ g}$

Canopy diameter = 1.5 m Area per shrub = $(3.14)(0.75 \text{ m})^2 = 1.76 \text{ m}^2$ Trunk weight = $927 \text{ g}/1.76 \text{ m}^2 = 527 \text{ g/m}^2$

Stem biomass = 2.0(trunk biomass) = mean for shrubs (Appendix Table B.10) = 1054 g/m²

Leaf biomass = 0.51(trunk biomass) = mean for shrubs (Appendix Table B.10) = 268 g/m²

Agarito (*Mahonia trifoliolata*)

Trunk diameter = 2.5 cm; shrub height = 150 cm (Scifres 1980)

Trunk volume = $(0.5)(3.14)(1.25 \text{ cm})^2(150 \text{ cm}) = 367 \text{ cm}^3$ Wood density = 0.5 g/cm³

Trunk weight = $(367 \text{ cm}^3)(0.5 \text{ g/cm}^3) = 184 \text{ g}$

Canopy diameter = 100 cm Area per shrub = $(3.14)(0.5 \text{ m})^2 = 0.79 \text{ m}^2$ Trunk weight = $184 \text{ g}/0.79 \text{ m}^2 = 233 \text{ g/m}^2$

Stem biomass = 1.20(trunk biomass) = *Artemisia spinescens* (Appendix Table B.10) = 280 g/m²

Leaf biomass = 0.51(trunk biomass) = mean for shrubs (Appendix Table B.10) = 119 g/m²

Sacahuista (*Nolina texana*)

Stem diameter = 15 cm; stem height = 50 cm (Correll and Johnston 1970)

Stem volume = $(1.0)(3.14)(7.5 \text{ cm})^2(50 \text{ cm}) = 883 \text{ cm}^3$ Stem density = 0.25 g/cm³

Stem weight = $(883 \text{ cm}^3)(0.25 \text{ g/cm}^3) = 221 \text{ g}$

Canopy diameter = 1.2 m Area per plant = $(3.14)(0.6 \text{ m})^2 = 1.13 \text{ m}^2$ Stem weight = $221 \text{ g}/1.13 \text{ m}^2 = 195 \text{ g/m}^2$

Leaf biomass = 2.69(stem biomass) = *Sporobolus airoides* (McLendon 2010) = 525 g/m²

Evergreen sumac (*Rhus virens*)

Trunk diameter = 5 cm; shrub height = 3.5 m (Vines 1960; Correll and Johnston 1970)

Trunk volume = $(0.5)(3.14)(2.5 \text{ cm})^2(350 \text{ cm}) = 3,434 \text{ cm}^3$

Wood density = 32 lb/cu ft (*R. copallina*; Vines 1960) = 0.51 g/cm³

Trunk weight = $(3,434 \text{ cm}^3)(0.51 \text{ g/cm}^3) = 1,751 \text{ g}$

Canopy diameter = 2.5 m Area per plant = $(3.14)(1.25 \text{ m})^2 = 1.56 \text{ m}^2$

Trunk weight = $1,751 \text{ g}/1.56 \text{ m}^2 = 1,123 \text{ g/m}^2$

Stem biomass = 1.15(trunk biomass) = mean of tree and shrub means (Appendix Table B.10) = 1291 g/m²

Leaf biomass = 0.30(trunk biomass) = mean of tree and shrub means (Appendix Table B.10) = 337 g/m²

Yucca (*Yucca constricta*)

Stem diameter = 6 cm; stem height = 20 cm (Correll and Johnston 1970)

Stem volume = $(1.0)(3.14)(3 \text{ cm})^2(20 \text{ cm}) = 565 \text{ cm}^3$

Pulp density = 0.25 g/cm³ (less than 0.29 g/cm³ for northern white cedar; Forbes and Meyer 1961)

Stem weight = $(565 \text{ cm}^3)(0.25 \text{ g/cm}^3) = 142 \text{ g}$

Canopy diameter = 60 cm Area per plant = $(3.14)(0.3 \text{ m})^2 = 0.28 \text{ m}^2$

Stem weight = $142 \text{ g}/0.28 \text{ m}^2 = 504 \text{ g/m}^2$

Leaf biomass = 1.60(stem biomass) = mean of shrub leaf/trunk (Appendix Table B.10) and *Sporobolus airoides* leaf/stem (McLendon 2010) = 806 g/m²

Appendix Table B.8 (Cont.)

Prickly pear (*Opuntia lindheimeri*)

Trunk diameter = 12 cm; trunk height = 50 cm (half of maximum; Vines 1960)

Trunk volume = $(1.0)(3.14)(6 \text{ cm})^2(50 \text{ cm}) = 5,652 \text{ cm}^3$ Trunk density = 0.25 g/cm^3

Trunk weight = $(5,652 \text{ cm}^3)(0.25 \text{ g/cm}^3) = 1,413 \text{ g}$

Patch diameter = 1.5 m Area per plant = $(3.14)(0.75 \text{ m})^2 = 2.36 \text{ m}^2$

Trunk weight = $(1,413 \text{ g})/2.36 \text{ m}^2 = 599 \text{ g/m}^2$

Pads = 25 cm long and 20 cm wide (Correll and Johnston 1970)

Stem (pad) biomass = $2.0(\text{trunk biomass}) = 1198 \text{ g/m}^2$

Appendix Table B.9 Aboveground biomass allocations for trees.

Species	Biomass				Proportion				Reference
	Trunk	Stems	Twigs	Leaves	Trunk	Stems	Twigs	Leaves	
<i>Cercidium floridum</i>	544	171	17	3	0.74	0.23	0.02	0.01	Barth & Klemmedson 1982
<i>Populus fremontii</i>	3075	745	1002	302	0.60	0.14	0.20	0.06	McLendon 2008
<i>Prosopis glandulosa</i>	304	186	24	88	0.50	0.31	0.04	0.15	Barth & Klemmedson 1982
<i>Prosopis velutina</i>	759	83	3	34	0.86	0.10	t	0.04	Barth & Klemmedson 1982
<i>Pseudotsuga menziesii</i>	2543	229	7	172	0.86	0.08	t	0.06	Gower et al. 1992
<i>Quercus gambelii</i>	1573	985	775	---					McLendon et al. 1999
<i>Robinia pseudoacacia</i>	1373	553	364	108	0.57	0.23	0.15	0.05	McLendon 2008
<i>Salix laevigata</i>	597	281	363	150	0.43	0.20	0.26	0.11	McLendon 2008
Oak-pine forest NY	4317	1639	---	407	0.68	0.26	----	0.06	Whittaker 1975
Deciduous forest TN	4427	603	---	35	0.87	0.12	----	0.01	Whittaker 1975
MEAN					0.68	--	0.26	--	0.06

Biomass units vary among species but are constant within species.

Appendix Table B.10 Aboveground biomass allocations for shrubs.

Species	Biomass				Proportion				Reference		
	Trunk	Stems	Twigs	Leaves	Trunk	Stems	Twigs	Leaves			
<i>Ambrosia dumosa</i>	34	139	33	20	0.15	0.61	0.15	0.09	McLendon 2010		
<i>Artemisia spinescens</i>	57	54	17	14	0.40	0.38	0.12	0.10	McLendon 2010		
<i>Artemisia tridentata</i>	270	1411	---	124	0.15	--	0.78	--	0.07	McLendon (unpublished)	
<i>Artemisia tridentata</i>	488	754	280	249	0.27	0.43	0.16	0.14	McLendon 2010		
<i>Artemisia tridentata</i>	--	760	--	74	178	--	0.75	--	0.08	0.17	Sturges 1977
<i>Artemisia tridentata</i>	--	272	--	---	65				0.19	Uresk et al. 1977	
<i>Atriplex canescens</i>	181	311	98	121	0.25	0.44	0.14	0.17	McLendon 2010		
<i>Atriplex confertifolia</i>	--	339	--	23	99	--	0.74	--	0.05	0.21	Caldwell et al. 1977
<i>Atriplex confertifolia</i>	70	90	129	56	0.20	0.26	0.38	0.16	McLendon 2010		
<i>Atriplex torreyi</i>	435	804	501	862	0.17	0.31	0.19	0.33	McLendon 2008		
<i>Atriplex torreyi</i>	238	347	227	220	0.23	0.34	0.22	0.21	McLendon 2010		
<i>Ceratoides lanata</i>	--	161	--	9	32	--	0.80	--	0.04	0.16	Caldwell et al. 1977
<i>Chrysothamnus nauseosus</i>	134	360	259	74	0.16	0.44	0.31	0.09	McLendon 2010		
<i>Ephedra nevadensis</i>	82	119	54	0	0.32	0.47	0.21	0.00	McLendon 2010		
<i>Hymenoclea salsola</i>	138	123	82	98	0.31	0.28	0.19	0.22	McLendon 2010		
<i>Psoralea argemone</i>	477	639	151	111	0.35	0.46	0.11	0.08	McLendon 2010		
<i>Quercus havardii</i>	---	699	---	380					0.35	Sears et al. 1986	
<i>Rosa woodsii</i>	214	83	15	51	0.59	0.23	0.04	0.14	McLendon 2010		
<i>Salix exigua</i>	310	256	54	64	0.45	0.38	0.08	0.09	McLendon et al. 1999		
<i>Salix exigua</i>	217	201	40	39	0.44	0.40	0.08	0.08	McLendon 2010		
<i>Sarcobatus vermiculatus</i>	260	403	433	228	0.20	0.30	0.33	0.17	McLendon 2010		
<i>Suaeda moquinii</i>	59	95	47	86	0.21	0.33	0.16	0.30	McLendon 2010		
<i>Tetradymia axillaris</i>	128	214	154	15	0.25	0.42	0.30	0.03	McLendon 2010		
Mean of Observations					0.28	0.39	0.17	0.16			
Mean of Species					0.29	0.39	0.17	0.15			

Biomass units vary among species but are constant within species.

Appendix Table B.11 Species composition and initial biomass values for land-use types in the Upper Llano River Watershed models. Values for woody species are in % of total woody cover and impervious surfaces are in % of total area. Values for herbaceous species are g/m².

Species	Urban Houses	Buildings Industrial	Disturbed Areas	Gravel Pits	Tilled Fields	Orchard	Brush Control
Pecan	0	0	0	0	0	100	0
Ashe juniper	0	0	24	30	0	0	30
Mesquite	25	50	24	25	0	0	25
Live oak	75	0	2	5	0	0	5
Elbowbush	0	0	0	0	0	0	5
Evergreen sumac	0	50	50	40	0	0	30
Prickly pear	0	0	0	0	0	0	5
Purple threeawn	0	10	20	10	0	0	3
Cane bluestem	0	10	5	20	0	0	4
King Ranch bluestem	0	30	20	10	0	5	2
Sideoats grama	0	0	0	0	0	0	5
Red grama	0	5	5	10	0	0	3
Bermudagrass	150	0	0	0	0	75	0
Sand dropseed	0	5	10	5	0	0	3
Wheat	0	0	0	0	20	0	0
Ragweed	0	30	40	20	0	5	15
Sunflower	0	20	30	20	10	5	10
Impervious surface	50%	50%	0%	75%	0%	0%	0%

To determine biomass of woody species, multiply the percent cover by species (Appendix Table B.18) by the percent total woody plant cover, by the biomass values in Appendix Table B.7.

Appendix Table B.12 Effect of woody cover on grass production on two rangelands in Texas.

	Mesquite Canopy (%)				Huisache Canopy (%)							
	2- 3	7- 8	13	24	00	10	20	30	40	50	60	70
Production (g/m ²):	126	135	145	96	415	425	365	320	290	235	190	135
Proportion of 2-3% canopy:	1.00	1.07	1.15	0.76	1.00	1.02	0.88	0.77	0.70	0.57	0.46	0.33

Mesquite = Rolling Plains near Vernon (McDaniel et al. 1982); huisache = Welder Wildlife Refuge, San Patricio County (Scifres et al. 1982).

Approximate grass production = (amount at 0% cover)[1.00 – (0.8)(woody plant cover)]

APPENDIX C PLANT PARAMETERS

Appendix Table C.1 General characteristics for species used in the Upper Llano River EDYS models.

Species	Growth Form	Legume	Biennial
Pecan	deciduous tree	0	no
Sugar hackberry	deciduous tree	0	no
Texas persimmon	deciduous tree	0	no
Ashe juniper	evergreen tree	0	no
Mesquite	deciduous tree	1	no
Texas red oak	deciduous tree	0	no
Live oak	evergreen tree	0	no
Prairie baccharis	deciduous shrub	0	no
Elbowbush	deciduous shrub	0	no
Agarito	evergreen shrub	0	no
Sacahuista	evergreen shrub	0	no
Evergreen sumac	evergreen shrub	0	no
Yucca	evergreen shrub	0	no
Mustang grape	deciduous vine	0	no
Prickly pear	cacti	0	no
Giant cane	perennial grass	0	no
Purple threeawn	perennial grass	0	no
Cane bluestem	perennial grass	0	no
King Ranch bluestem	perennial grass	0	no
Sideoats grama	perennial grass	0	no
Hairy grama	perennial grass	0	no
Red grama	perennial grass	0	no
Bermudagrass	perennial grass	0	no
Canada wildrye	perennial grass	0	no
Plains lovegrass	perennial grass	0	no
Texas cupgrass	perennial grass	0	no
Curly mesquite	perennial grass	0	no
Green sprangletop	perennial grass	0	no
Vine-mesquite	perennial grass	0	no
Switchgrass	perennial grass	0	no
Little bluestem	perennial grass	0	no
Indiangrass	perennial grass	0	no
Johnsongrass	perennial grass	0	no
Tall dropseed	perennial grass	0	no
Sand dropseed	perennial grass	0	no
Texas wintergrass	perennial grass	0	no
Wheat	annual grass	0	no
Flatsedge	perennial grass-like	0	no
Spikerush	perennial grass-like	0	no
Bulrush	perennial grass-like	0	no
Cattail	perennial grass-like	0	no
Ragweed	perennial forb	0	no
Lazydaisy	perennial forb	0	no
Bundleflower	perennial forb	1	no
Indian blanket	perennial forb	0	no
Sunflower	annual forb	0	no
Duckweed	annual forb	0	no
Texas bluebonnet	annual forb	1	no
Prairie coneflower	perennial forb	0	no
Bush sunflower	perennial forb	0	no
Orange zexmenia	perennial forb	0	no

Appendix Table C.2 Tissue allocation in mature plants, by plant part (proportion of total), and root:shoot ratio (R:S) for species included in the Upper Llano River EDYS model.

Species	Coarse Roots	Fine Roots	Trunk	Stems	Leaves	Seeds	R:S Ratio
Pecan	0.32	0.11	0.40	0.12	0.05	0.00	0.75
Sugar hackberry	0.16	0.06	0.55	0.17	0.06	0.00	0.28
Texas persimmon	0.32	0.11	0.40	0.12	0.05	0.00	0.75
Ashe juniper	0.15	0.05	0.56	0.18	0.06	0.00	0.25
Mesquite	0.14	0.10	0.39	0.28	0.09	0.00	0.32
Texas red oak	0.20	0.07	0.51	0.16	0.06	0.00	0.36
Live oak	0.24	0.08	0.48	0.15	0.05	0.00	0.46
Prairie baccharis	0.26	0.12	0.34	0.19	0.09	0.00	0.61
Elbowbush	0.28	0.12	0.33	0.18	0.09	0.00	0.66
Agarito	0.35	0.14	0.28	0.15	0.08	0.00	0.97
Sacahuista	0.29	0.13	0.32	0.08	0.18	0.00	0.73
Evergreen sumac	0.32	0.14	0.30	0.16	0.08	0.00	0.84
Yucca	0.35	0.15	0.27	0.12	0.11	0.00	1.00
Mustang grape	0.23	0.10	0.35	0.17	0.15	0.00	0.50
Prickly pear	0.16	0.08	0.37	0.38	0.01	0.00	0.31
Giant cane	0.18	0.18	0.18	0.26	0.20	0.00	0.36
Purple threeawn	0.33	0.32	0.07	0.14	0.14	0.00	1.89
Cane bluestem	0.31	0.31	0.08	0.15	0.15	0.00	1.60
King Ranch bluestem	0.31	0.30	0.08	0.16	0.15	0.00	1.59
Sideoats grama	0.31	0.31	0.08	0.15	0.15	0.00	1.60
Hairy grama	0.18	0.18	0.21	0.06	0.37	0.00	0.56
Red grama	0.18	0.18	0.21	0.06	0.37	0.00	0.56
Bermudagrass	0.28	0.27	0.15	0.05	0.25	0.00	1.21
Canada wildrye	0.31	0.31	0.08	0.15	0.15	0.00	1.65
Plains lovegrass	0.18	0.18	0.13	0.26	0.25	0.00	0.58
Texas cupgrass	0.26	0.26	0.10	0.19	0.19	0.00	1.06
Curly mesquite	0.40	0.26	0.11	0.03	0.20	0.00	1.98
Green sprangletop	0.23	0.23	0.11	0.22	0.21	0.00	0.86
Vine-mesquite	0.23	0.23	0.11	0.22	0.21	0.00	0.85
Switchgrass	0.25	0.25	0.10	0.20	0.20	0.00	0.98
Little bluestem	0.31	0.31	0.08	0.15	0.15	0.00	1.63
Indiangrass	0.37	0.36	0.05	0.11	0.11	0.00	0.86
Johnsongrass	0.35	0.34	0.06	0.13	0.12	0.00	2.21
Tall dropseed	0.26	0.26	0.10	0.19	0.19	0.00	1.10
Sand dropseed	0.24	0.23	0.11	0.21	0.21	0.00	0.88
Texas wintergrass	0.28	0.28	0.13	0.04	0.27	0.00	1.26
Wheat	0.23	0.24	0.11	0.21	0.21	0.00	0.88
Flatsedge	0.39	0.38	0.05	0.09	0.09	0.00	3.33
Spikerush	0.41	0.41	0.04	0.13	0.01	0.00	4.62
Bulrush	0.39	0.38	0.05	0.09	0.09	0.00	3.33
Cattail	0.39	0.38	0.05	0.09	0.09	0.00	3.33
Ragweed	0.28	0.28	0.09	0.18	0.17	0.00	1.26
Lazydaisy	0.29	0.29	0.08	0.17	0.17	0.00	1.38
Bundleflower	0.29	0.30	0.08	0.16	0.17	0.00	1.46
Indian blanket	0.29	0.29	0.08	0.17	0.17	0.00	1.38
Sunflower	0.08	0.07	0.17	0.34	0.34	0.00	0.17
Duckweed	0.12	0.11	0.15	0.31	0.31	0.00	0.30
Texas bluebonnet	0.20	0.20	0.12	0.24	0.24	0.00	0.66
Prairie coneflower	0.29	0.29	0.08	0.18	0.17	0.00	1.38
Bush sunflower	0.28	0.28	0.09	0.18	0.17	0.00	1.26
Orange zexmenia	0.28	0.28	0.09	0.18	0.17	0.00	1.26

Data Sources (Appendix Table C.2)

Root:Shoot Ratios

Pecan:	slow-growing hardwoods (Odum 1971:375)
Sugar hackberry :	<i>Fagus</i> sp. (Garelkov 1973)
Texas persimmon:	slow-growing hardwoods (Odum 1971:375)
Ashe juniper:	<i>Juniperus osteosperma</i> (McLendon unpublished data)
Mesquite:	[twice the value reported by Barth et al. (1982) + mean(control and natural)Ansley et al. 2014]/2
Texas red oak:	Mean of <i>Quercus alba</i> (Nadelhoffer et al. 1985), <i>Q. rubra</i> (Nadelhoffer et al. 1985), <i>Q. robur</i> (Andersson 1970, Duvigneaud et al. 1971, Rodin & Bazilevich 1967), <i>Q. robur</i> (Duvigneaud et al. 1971), <i>Q. velutina</i> (Nadelhoffer et al. 1985)
Live oak:	Mean of <i>Quercus alba</i> and <i>Q. velutina</i> (Nadelhoffer et al. 1985)
Elbowbush:	Mean of <i>Arctostaphylos pungens</i> (Kummerow et al.1977), <i>Cornus florida</i> (Blair 1982), <i>Fallugia paradoxa</i> (Ludwig 1977), <i>Flourensia cernua</i> (Ludwig 1977), <i>Grayia spinosa</i> (Wallace et al. 1974), <i>Ilex vomitoria</i> (Blair 1982), <i>Krameria parvifolia</i> (Wallace et al. 1974), <i>Lycium andersonii</i> (Wallace et al. 1974)
Sacahuista:	<i>Dasyllirion-Bouteloua</i> shrubland, Big Bend NP (McLendon, unpublished data)
Evergreen sumac:	Mean of <i>Cornus florida</i> (Blair 1982), <i>Ilex vomitoria</i> (Blair 1982), <i>Salix exigua</i> (Evans et al. 2013)
Yucca:	<i>Yucca elata</i> (Ludwig 1977)
Prickly pear:	<i>Opuntia lindheimeri</i> Big Bend NP (McLendon, unpublished data)
Giant cane:	<i>Typha angustifolia</i> (Shipley & Peters 1990)
Purple threeawn:	Briske et al. (1996), Fernandez & Reynolds (2000), McLendon (unpublished), Vinton & Burke (1995)
Cane bluestem:	<i>Bouteloua curtipendula</i> (Scifres & Halifax 1972; McLendon unpublished)
KR bluestem:	Coyne and Bradford (1986)
Sideoats grama:	Scifres and Halifax (1972); McLendon (unpublished field data from Big Bend NP)
Hairy grama:	<i>Bouteloua rigidiseta</i> (Briske et al. 1996)
Red grama:	<i>Bouteloua rigidiseta</i> (Briske et al. 1996)
Bermudagrass:	Beaty et al. (1973), Guglielmini & Satorre (2002), Hons et al. (1979), Huang et al. (1997), Impithuksa et al. (1979), Rodriguez et al. (2002), Stoddart et al. (1975:136)
Canada wildrye:	Mean of <i>Elymus cinereus</i> (Blank & Young 1998), <i>E. lanceolatus</i> (Aguirre & Johnson 1991), <i>E. triticoides</i> (Evans et al. 2013)
Plains lovegrass:	Mean of <i>Eragrostis curvula</i> (Masters & Britton 1990), <i>E. lehmanniana</i> (Fernandez & Reynolds 2000)
Texas cupgrass:	Mean of <i>Agropyron inerme</i> (Mack 1986:151), <i>Agrostis scabra</i> (Tilman & Wedin 1991), <i>Dactylis glomerata</i> (Davidson 1969)
Curly mesquite:	<i>Buchloe dactyloides</i> (McLendon, unpublished data)
Green sprangletop:	Mean of <i>Agropyron repens</i> (Tilman & Wedin 1991), <i>Agrostis scabra</i> (Tilman & Wedin 1991), <i>Calamagrostis rubescens</i> (Stourt et al. 1983), <i>Festuca ovina</i> (Whittingham & Reed 1982), <i>Hyparrhenia rufa</i> (Peters & Baruch 1997), <i>Poa pratensis</i> (Tilman & Wedin 1991), <i>Sporobolus cryptandrus</i> (Paschke et al. 2000)
Vine-mesquite:	Fernandez and Reynolds (2000)
Switchgrass:	Brejda et al. (1993); Johnson (1998); Scifres and Halifax (1972)
Little bluestem:	Tilman and Wedin (1991)
Indiangrass:	Mean of <i>Andropogon gerardii</i> (Tilman & Wedin 1991), <i>Panicum virgatum</i> (Brejda et al.1993)
Johnsongrass:	Mean of <i>Andropogon gerardii</i> (Tilman & Wedin 1991), <i>Bothriochloa caucasica</i> (Coyne & Bradford 1986), <i>Bouteloua curtipendula</i> (McLendon, unpublished), <i>Bromus inermis</i> (McLendon et al. 1999, Johnson 2005), <i>Elymus triticoides</i> (Evans et al. 2013), <i>Festuca arundinacea</i> (Overman 1995), <i>Panicum virgatum</i> (Brejda et al. 1993), <i>Paspalum notatum</i> (Hons et al. 1979, Impithuksa et al. 1979, Fiala et al. 1991)
Tall dropseed:	<i>Sporobolus flexuosus</i> (Fernandez & Reynolds 2000)
Sand dropseed:	Paschke et al. (2000)

Texas wintergrass:	<i>Stipa comata</i> (Vinton & Burke 1995; Burleson & Hewitt 1982)
Wheat:	Buyanovsky et al. (1987)
Flatsedge:	Mean of <i>Carex acutiformis</i> (Aerts & de Caluwe 1994), <i>C. diandra</i> (Aerts & de Caluwe 1994), <i>C. douglasii</i> (Manning et al. 1989), <i>C. nebrascensis</i> (Manning et al. 1989), <i>C. rostrata</i> (Aerts & de Caluwe 1994), <i>Juncus roemerianus</i> (Gallagher et al. 1977)
Spikerush:	<i>Juncus balticus</i> (Evans et al. 2013; Manning et al. 1989)
Bulrush:	Same as flatsedge.
Cattail:	Same as flatsedge.
Ragweed:	Mean of <i>Centaurea maculosa</i> (Olson & Wallander 1997; Velagala et al. 1997), <i>Centaurea repens</i> (Lowe et al. 2002), <i>Parthenium incanum</i> (Ludwig 1977) and <i>Rumex acetosa</i> (Gigon & Rorison 1972)
Lazydaisy:	Mean of <i>Salvia mellifera</i> (Hellmers et al. 1955), <i>Verbascum thapsus</i> (McLendon unpublished)
Bundleflower:	Mean of <i>Astragalus micropterus</i> (Barbour 1973), <i>Hedysarum borale</i> (Johnson et al. 1989)
Indian blanket:	Same as lazydaisy.
Sunflower:	Goodman and Ennos (1999)
Duckweed:	Mean of <i>Leersia oryzoides</i> (Shiple & Peters 1990) and <i>Zizania aquatica</i> (Bray 1963)
Texas bluebonnet:	Mean of <i>Trifolium repens</i> (Davidson 1969; Haystead et al. 1988; McNeill & Wood 1990) and <i>T. subterraneum</i> (Smith 1982)
Prairie coneflower:	Same as lazydaisy.
Bush sunflower:	Same as ragweed.
Orange zexmenia:	Same as ragweed.

Aboveground Tissue Allocation (Trunk:Stem:Leaves)

Trees:	0.70:0.22:0.08
Shrubs:	0.55:0.30:0.15
Herbaceous (stemmy):	0.2:0.4:0.4
Herbaceous (short):	0.3:0.1:0.6

Proportions of coarse and fine roots (coarse;fine root ratio).

Species	Coarse	Fine	Reference
<i>Pinus ponderosa</i>	0.73	0.27	Cox (1958)
<i>Pseudotsuga menziesii</i>	0.91	0.09	Gower et al. (1992)
<i>P. menziesii</i> (annual prod)	0.40	0.60	Gower et al. (1992)
White Mtns NH young forest	0.62	0.38	Park et al. (2007)
Mean Coniferous Trees	0.67	0.33	
<i>Prosopis glandulosa</i>	0.61	0.39	Ansley et al. (2014)
Mean Deciduous Trees	0.61	0.39	
<i>Acamptopappus shockleyi</i>	0.77	0.23	Wallace et al. (1980)
<i>Ambrosia dumosa</i>	0.73	0.27	Wallace et al. (1980)
<i>Artemisia tridentata</i>	0.63	0.37	Sturges (1977)
<i>Atriplex canescens</i>	0.70	0.30	Wallace et al. (1980)
<i>Atriplex confertifolia</i>	0.07	0.93	Hodgkinson et al. (1978)
<i>Atriplex confertifolia</i>	0.68	0.32	Wallace et al. (1980)
<i>Chrysothamnus teretifolius</i>	0.98	0.02	Manning & Barbour (1988)
<i>Ephedra nevadensis</i>	0.76	0.24	Wallace et al. (1980)
<i>Haplopappus cooperi</i>	0.76	0.24	Manning & Barbour (1988)
<i>Krameria parvifolia</i>	0.64	0.36	Wallace et al. (1980)
<i>Larrea tridentata</i>	0.75	0.25	Wallace et al. (1980)
<i>Lycium andersonii</i>	0.75	0.25	Wallace et al. (1980)
<i>Lycium pallidum</i>	0.74	0.26	Wallace et al. (1980)
Mesquite-granjeno shrubland	0.40	0.60	Hibbard et al. (2001)
Mean Shrubs	0.67	0.33	
<i>Poa nevadensis</i>	0.48	0.52	Manning et al. (1989)
Herbaceous, mesquite-granjeno	0.59	0.41	Hibbard et al. (2001)
Mean Grasses	0.54	0.46	
<i>Carex douglasii</i>	0.47	0.53	Manning et al. (1989)
<i>Carex nebrascensis</i>	0.42	0.58	Manning et al. (1989)
<i>Juncus balticus</i>	0.53	0.47	Manning et al. (1989)
Mean Grass-Likes	0.47	0.53	

Appendix Table C.3 Allocation of new biomass production by plant part (proportion of total) for species included in the Upper Llano River EDYS models.

Species	Coarse Roots	Fine Roots	Trunk	Stems	Leaves	Seeds
Pecan	0.11	0.32	0.15	0.08	0.34	0.00
Sugar hackberry	0.06	0.16	0.27	0.08	0.43	0.00
Texas persimmon	0.11	0.32	0.20	0.06	0.31	0.00
Ashe juniper	0.08	0.30	0.11	0.20	0.31	0.00
Mesquite	0.08	0.30	0.12	0.19	0.31	0.00
Texas red oak	0.07	0.20	0.25	0.08	0.40	0.00
Live oak	0.10	0.20	0.15	0.07	0.48	0.00
Prairie baccharis	0.05	0.20	0.05	0.20	0.50	0.00
Elbowbush	0.06	0.23	0.08	0.16	0.47	0.00
Agarito	0.07	0.25	0.10	0.10	0.48	0.00
Sacahuista	0.10	0.24	0.02	0.04	0.60	0.00
Evergreen sumac	0.08	0.25	0.10	0.15	0.42	0.00
Yucca	0.08	0.24	0.02	0.05	0.61	0.00
Mustang grape	0.03	0.20	0.10	0.15	0.52	0.00
Prickly pear	0.10	0.22	0.20	0.46	0.02	0.00
Giant cane	0.15	0.25	0.10	0.20	0.30	0.00
Purple threeawn	0.12	0.25	0.08	0.10	0.45	0.00
Cane bluestem	0.12	0.24	0.05	0.25	0.34	0.00
King Ranch bluestem	0.12	0.25	0.10	0.05	0.48	0.00
Sideoats grama	0.12	0.24	0.05	0.26	0.33	0.00
Hairy grama	0.09	0.18	0.10	0.06	0.57	0.00
Red grama	0.10	0.25	0.08	0.10	0.47	0.00
Bermudagrass	0.12	0.25	0.10	0.05	0.48	0.00
Canada wildrye	0.12	0.23	0.05	0.30	0.30	0.00
Plains lovegrass	0.12	0.24	0.08	0.25	0.31	0.00
Texas cupgrass	0.12	0.23	0.10	0.24	0.31	0.00
Curly mesquite	0.16	0.27	0.10	0.12	0.35	0.00
Green sprangletop	0.12	0.24	0.08	0.25	0.31	0.00
Vine-mesquite	0.11	0.21	0.06	0.30	0.32	0.00
Switchgrass	0.11	0.24	0.06	0.25	0.34	0.00
Little bluestem	0.13	0.25	0.05	0.26	0.31	0.00
Indiangrass	0.10	0.24	0.05	0.30	0.31	0.00
Johnsongrass	0.12	0.23	0.05	0.30	0.30	0.00
Tall dropseed	0.11	0.24	0.05	0.30	0.30	0.00
Sand dropseed	0.12	0.24	0.06	0.30	0.28	0.00
Texas wintergrass	0.10	0.20	0.05	0.40	0.25	0.00
Wheat	0.25	0.25	0.10	0.20	0.20	0.00
Flatsedge	0.18	0.35	0.06	0.12	0.29	0.00
Spikerush	0.16	0.30	0.06	0.48	0.00	0.00
Bulrush	0.18	0.20	0.06	0.25	0.31	0.00
Cattail	0.20	0.20	0.04	0.28	0.28	0.00
Ragweed	0.15	0.20	0.10	0.30	0.25	0.00
Lazydaisy	0.10	0.25	0.10	0.15	0.40	0.00
Bundleflower	0.08	0.18	0.10	0.32	0.32	0.00
Indian blanket	0.10	0.20	0.10	0.16	0.44	0.00
Sunflower	0.12	0.20	0.10	0.30	0.23	0.05
Duckweed	0.16	0.17	0.20	0.07	0.40	0.00
Texas bluebonnet	0.16	0.17	0.20	0.07	0.40	0.00
Prairie coneflower	0.12	0.24	0.08	0.30	0.26	0.00
Bush sunflower	0.12	0.25	0.12	0.26	0.25	0.00
Orange zexmenia	0.13	0.25	0.12	0.25	0.25	0.00

Appendix Table C.4 Allocation of biomass production in green-out months by plant part (proportion of total) for species included in the Upper Llano EDYS model.

Species	Coarse Roots	Fine Roots	Trunks	Stems	Leaves	Seeds
Pecan	0.00	0.24	0.00	0.05	0.71	0.00
Sugar hackberry	0.00	0.12	0.00	0.06	0.82	0.00
Texas persimmon	0.00	0.24	0.00	0.05	0.71	0.00
Ashe juniper	0.00	0.23	0.00	0.15	0.62	0.00
Mesquite	0.00	0.15	0.00	0.10	0.75	0.00
Texas red oak	0.00	0.15	0.00	0.06	0.79	0.00
Live oak	0.00	0.18	0.00	0.05	0.77	0.00
Prairie baccharis	0.00	0.19	0.00	0.20	0.61	0.00
Elbowbush	0.00	0.17	0.00	0.42	0.41	0.00
Agarito	0.00	0.26	0.00	0.37	0.37	0.00
Sacahuista	0.00	0.18	0.00	0.41	0.41	0.00
Evergreen sumac	0.00	0.19	0.00	0.41	0.40	0.00
Yucca	0.00	0.18	0.00	0.41	0.41	0.00
Mustang grape	0.00	0.17	0.00	0.23	0.60	0.00
Prickly pear	0.10	0.15	0.05	0.69	0.01	0.00
Giant cane	0.02	0.19	0.00	0.40	0.41	0.00
Purple threeawn	0.00	0.19	0.00	0.03	0.78	0.00
Cane bluestem	0.00	0.18	0.00	0.41	0.41	0.00
King Ranch bluestem	0.01	0.19	0.00	0.04	0.76	0.00
Sideoats grama	0.01	0.18	0.00	0.41	0.40	0.00
Hairy grama	0.00	0.14	0.00	0.03	0.83	0.00
Red grama	0.00	0.19	0.00	0.05	0.76	0.00
Bermudagrass	0.01	0.19	0.00	0.03	0.77	0.00
Canada wildrye	0.00	0.17	0.00	0.41	0.42	0.00
Plains lovegrass	0.00	0.18	0.00	0.41	0.41	0.00
Texas cupgrass	0.00	0.17	0.00	0.42	0.41	0.00
Curly mesquite	0.00	0.20	0.00	0.09	0.71	0.00
Green sprangletop	0.00	0.18	0.00	0.41	0.41	0.00
Vine-mesquite	0.01	0.16	0.00	0.15	0.68	0.00
Switchgrass	0.00	0.18	0.00	0.41	0.41	0.00
Little bluestem	0.01	0.18	0.00	0.40	0.41	0.00
Indiangrass	0.01	0.18	0.00	0.41	0.40	0.00
Johnsongrass	0.01	0.17	0.00	0.41	0.41	0.00
Tall dropseed	0.00	0.18	0.00	0.41	0.41	0.00
Sand dropseed	0.00	0.18	0.00	0.41	0.41	0.00
Texas wintergrass	0.00	0.19	0.00	0.03	0.78	0.00
Wheat	0.25	0.25	0.10	0.20	0.20	0.00
Flatsedge	0.00	0.26	0.00	0.20	0.54	0.00
Spikerush	0.00	0.22	0.00	0.78	0.00	0.00
Bulrush	0.02	0.15	0.00	0.42	0.41	0.00
Cattail	0.02	0.15	0.00	0.43	0.40	0.00
Ragweed	0.00	0.15	0.00	0.43	0.42	0.00
Lazydaisy	0.00	0.19	0.00	0.41	0.40	0.00
Bundleflower	0.00	0.14	0.00	0.43	0.43	0.00
Indian blanket	0.00	0.15	0.00	0.43	0.42	0.00
Sunflower	0.16	0.17	0.13	0.27	0.27	0.00
Duckweed	0.16	0.17	0.20	0.07	0.40	0.00
Texas bluebonnet	0.16	0.17	0.20	0.07	0.40	0.00
Prairie coneflower	0.00	0.18	0.00	0.41	0.41	0.00
Bush sunflower	0.00	0.19	0.00	0.41	0.40	0.00
Orange zexmenia	0.00	0.19	0.00	0.41	0.40	0.00

General guidelines for greenout allocation (Appendix Table. C.4):

Trees: coarse roots, trunks, and seeds = no allocation; fine roots and stems = 75% of new growth allocation; leaves = remainder of allocation.

Shrubs, midgrasses, and perennial forbs: coarse roots, trunks, and seeds = no allocation; fine roots = 75% of new growth allocation; stems + leaves = remainder of allocation (exception = rhizomatous grasses, which have coarse roots = 10% of new growth allocation).

Shortgrasses = coarse roots, trunks, and seeds = no allocation; fine roots = 75% of new growth allocation; stems = 50% of new growth allocation; leaves = remainder of allocation (exceptions = rhizomatous grasses which have coarse roots = 10% of new growth allocation and stoloniferous grasses which have stems = 75% of new growth allocation).

Annuals = new growth allocation.

Appendix Table C.9 Root architecture (percent of root biomass by percent of maximum rooting depth) and maximum potential rooting depth (mm) for plant species included in the Upper Llano EDYS model.

Species	Percent of Root Biomass by Percent of Maximum Rooting Depth												Maximum Rooting Depth
	00-01	01-05	05-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	
Pecan	2	9	14	20	15	5	6	6	2	6	8	7	6250
Sugar hackberry	2	9	14	20	15	5	6	6	2	6	8	7	6000
Texas persimmon	2	9	14	20	15	5	6	6	2	6	8	7	5300
Ashe juniper	1	6	9	14	14	14	13	9	9	5	3	3	8000
Mesquite	14	14	20	15	9	7	6	5	4	3	2	1	53400
Texas red oak	4	14	15	21	12	8	8	7	4	4	2	1	7000
Live oak	4	14	15	21	12	8	8	7	4	4	2	1	22000
Prairie baccharis	1	5	9	12	18	17	11	11	7	6	2	1	1900
Elbowbush	3	13	14	17	14	12	9	6	5	4	2	1	2400
Agarito	3	10	12	19	13	12	10	9	5	4	2	1	3000
Sacahuista	2	9	10	17	14	11	8	7	10	6	4	2	990
Evergreen sumac	2	9	14	20	15	5	6	6	2	6	8	7	3530
Yucca	2	9	10	17	14	11	8	7	10	6	4	2	1400
Mustang grape	5	12	15	17	13	11	9	7	5	3	2	1	3660
Prickly pear	2	9	12	19	13	20	11	6	4	2	1	1	840
Giant cane	2	9	11	23	9	9	8	8	7	6	5	3	3500
Purple threeawn	4	14	16	18	18	12	6	4	4	2	1	1	1830
Cane bluestem	10	22	20	20	10	6	3	3	2	2	1	1	2380
KR bluestem	4	16	21	18	14	8	6	4	3	2	2	2	1200
Sideoats grama	10	20	23	21	14	5	2	1	1	1	1	1	3960
Hairy grama	5	13	14	18	13	11	9	9	4	2	1	1	1070
Red grama	4	13	14	20	13	10	9	7	4	3	2	1	600
Bermudagrass	5	14	17	15	12	10	8	6	5	4	3	1	900
Canada wildrye	4	12	16	18	14	12	8	6	4	3	2	1	720
Plains lovegrass	3	9	11	19	14	12	10	7	6	4	4	1	1200
Texas cupgrass	4	15	17	19	12	7	7	5	4	4	4	3	1040
Curly mesquite	5	15	16	18	11	10	9	4	4	3	3	2	1700
Green sprangletop	3	13	15	18	13	11	9	6	4	4	3	1	1150
Vine-mesquite	3	11	13	19	14	10	8	6	5	4	4	3	2020
Switchgrass	9	17	23	12	10	8	7	6	4	3	2	1	3350
Little bluestem	8	22	25	18	8	5	4	3	3	2	1	1	2440
Indiangrass	6	25	21	15	10	7	5	4	3	2	1	1	2430
Johnsongrass	3	12	17	18	14	10	9	7	5	3	1	1	2410
Tall dropseed	4	15	17	20	11	8	6	5	5	4	4	1	2130
Sand dropseed	6	19	19	27	9	4	3	3	3	3	2	2	2700
Texas wintergrass	3	11	13	18	14	10	8	8	6	4	3	2	1950
Wheat	2	5	7	15	16	15	13	10	8	5	3	1	3000
Flatsedge	2	5	8	15	13	12	12	10	9	7	4	3	630
Spikerush	5	10	15	30	16	5	5	3	3	3	3	2	700
Bulrush	1	2	5	12	13	13	12	12	12	9	6	3	600
Cattail	3	12	13	18	10	9	8	8	7	6	4	2	1400
Ragweed	6	20	20	27	10	4	3	3	2	2	2	1	1830
Lazydaisy	2	5	8	13	12	11	11	12	10	7	5	4	600
Bundleflower	3	9	14	23	12	5	4	5	9	7	6	3	2100
Indian blanket	1	7	10	17	17	14	10	7	7	6	3	1	2070
Sunflower	6	24	6	9	12	16	10	7	2	3	3	2	3100
Duckweed	1	4	7	15	15	13	10	10	12	8	4	1	110
Texas bluebonnet	2	9	14	37	16	5	3	3	3	2	2	4	1040
Prairie coneflower	4	16	14	23	14	6	6	4	4	4	3	2	1830
Bush sunflower	4	14	18	29	11	6	5	4	3	3	2	1	2620
Orange zexmenia	3	8	13	30	11	8	7	7	5	4	3	1	2640

Data Sources (Appendix Table C.9)**Root Architecture**

- Pecan, sugar hackberry, Texas persimmon: *Acer saccharum* (Dawson 1993)
 Ashe juniper: *Juniperus occidentalis* (Young & Evans 1986)
 Mesquite: mean of Heitschmidt et al. (1988) and Montana et al. (1995)
 Texas red oak, live oak: mean of *Acer saccharum* (Dawson 1993), *Leucaena leucocephala* (Toky & Bisht 1992), *Nothofagus Antarctica* and *N. pumila* (Schulze et al. 1996), *Populus fremontii* (McLendon 2008), *Prosopis glandulosa*, *Quercus havardii* (Sears et al. 1986)
- Prairie baccharis: *Pulchea sericea* (Gary 1963)
 Elbowbush: mean of *Krameria parvifolia*, *Lycium andersonii*, *L. pallidum* (Wallace et al. 1980) and *Tetradymia spinosa* (Branson et al. 1976)
 Agarito: mean of *Ephedra nevadensis* (Wallace et al. 1980), *Larrea tridentata* (Wallace et al. 1980; Moorhead et al. 1989; Montana et al. 1995; Ogle et al. 2004), *Tetradymia spinosa* (Branson et al. 1976)
 Sacahuista: mean of *Hilaria mutica* (Montana et al. 1995), *Spartina pectinata* (Sperry 1935), and *Sporobolus airoides* (McLendon 2008)
 Evergreen sumac: *Acer saccharum* (Dawson 1993)
 Yucca: mean of *Hilaria mutica* (Montana et al. 1995), *Spartina pectinata* (Sperry 1935), and *Sporobolus airoides* (McLendon 2008)
 Mustang grape: mean of 25 shrubs
 Prickly pear: mean of *Opuntia acanthocarpa* (Nobel & Bobich 2002), *O. humifusa* (Sperry 1935), and *O. polyacantha* (Dougherty 1986)
- Giant cane: mean of *Cirsium arvense* (Hodgson 1968), *Lepidium latifolium* (Renz et al. 1997), *Spartina pectinata* (Weaver 1958)
 Purple threeawn: modified from Weaver & Clements (1938)
 Cane bluestem: mean of *Bouteloua curtipendula* and *Schizachyrium scoparium*
 King Ranch bluestem: Coyne & Bradford (1986)
 Sideoats grama: Weaver & Darland (1949), Hopkins (1953), Weaver (1954)
 Hairy grama: mean of *Aristida purpurea* (Weaver & Clements 1938) and *Bouteloua gracilis* (Weaver & Clements 1938; Weaver 1947, 1958; Weaver & Zink 1947; Weaver & Darland 1949; Hopkins 1953; Lorenz & Rogler 1967; Redente et al. 1989; Lee & Lauenroth 1994; Gill et al. 1999)
 Red grama mean of *Aristida purpurea* (Weaver & Clements 1938), *Bouteloua gracilis* (Weaver & Clements 1938; Weaver 1947, 1958; Weaver & Zink 1947; Weaver & Darland 1949; Hopkins 1953; Lorenz & Rogler 1967; Redente et al. 1989; Lee & Lauenroth 1994; Gill et al. 1999), *Hilaria jamesii* (Moore & West 1973; Daddy 1985), *Sporobolus cryptandrus* (Albertson 1937; Weaver & Darland 1949; Hopkins 1953)
 Bermudagrass mean of *Axonopus compressus* (Fiala & Herrera 1988), *Distichlis spicata* (Seliskar 1983; Dahlgren et al. 1997; McLendon 2008), *Hilaria mutica* (Montana et al. 1995)
 Canada wildrye mean of *Agropyron trachycaulum* and *Poa compressa* (McLendon 2001)
 Plains lovegrass mean of *Aristida purpurea* (Weaver & Clements 1938), *Cenchrus ciliaris* (Chaieb et al. 1996), *Muhlenbergia cuspidata* (Sperry 1935), *Panicum coloratum* (Hons et al. 1979), *Redfieldia flexuosa* (Weaver & Clements 1938), *Sporobolus cryptandrus* (Albertson 1937; Weaver & Darland 1949; Hopkins 1953)
 Texas cupgrass mean of *Agropyron trachycaulum* (McLendon 2001) and *Schizachyrium scoparium* (Sperry 1935; Weaver & Zink 1946; Weaver 1947, 1950, 1954, 1958; Weaver & Darland 1949; Coupland & Bradshaw 1953; Jurena & Archer 2003).
 Curly mesquite mean of *Buchloe dactyloides* (Weaver & Clements 1938; Weaver & Darden 1949; Hopkins 1953) and *Hilaria jamesii* (Moore & West 1973; Daddy 1985)
 Green sprangletop mean of *Aristida purpurea* (Weaver & Clements 1938), *Festuca scabrella* (Coupland & Bradshaw 1953), *Muhlenbergia cuspidata* (Sperry 1935), *Panicum coloratum* (Hons et al. 1979), *Sporobolus cryptandrus* (Albertson 1937; Weaver & Darland 1949; Hopkins 1953)
 Vine-mesquite mean of *Bouteloua curtipendula* (Weaver & Darland 1949; Hopkins 1953; Weaver 1954; Pettit & Jaynes 1971), *Distichlis spicata* (Seliskar 1983; Dahlgren et al. 1997; McLendon 2008), *Hilaria mutica* (Montana et al. 1995)
 Switchgrass Weaver & Darland (1949), Hopkins (1953), Pettit & Jaynes (1971)

Little bluestem Sperry (1935), Weaver & Zink (1946), Weaver (1947, 1950, 1954, 1958), Weaver & Darland (1949), Coupland & Bradshaw (1953), Jurena & Archer (2003)
 Indiangrass mean of *Andropogon gerardii* (Sperry 1935; Weaver & Zink 1946; Weaver & Darland 1949; Coupland & Bradshaw 1953; Hopkins 1953; Weaver 1954), *Panicum virgatum* (Weaver & Darland 1949; Hopkins 1953; Pettit & Jaynes 1971), and tallgrass prairie (Dahlman & Kucera 1965)
 Johnsongrass mean of *Panicum virgatum* (Weaver & Darland 1949; Hopkins 1953; Pettit & Jaynes 1971) and *Zea mays* (Weaver & Clements 1938)
 Tall dropseed mean of *Muhlenbergia cuspidata* (Sperry 1935), *Schizachyrium scoparium* (Sperry 1935; Weaver & Zink 1946; Weaver 1947, 1950, 1954, 1958; Weaver & Darland 1949; Coupland & Bradshaw 1953; Jurena & Archer 2003), *Sporobolus cryptandrus* (Albertson 1937; Weaver & Darland 1949; Hopkins 1953)
 Sand dropseed Albertson (1937), Weaver & Darland (1949), Hopkins (1953)
 Texas wintergrass mean of *Stipa comata* (Melgoza & Nowak 1991), *S. lagascae* (Chaleb et al. 1996), *S. spartea* (Sperry 1935; Coupland & Bradshaw 1953)
 Wheat Weaver et al. (1924), Weaver & Clements (1938)

Flatsedge mean of *Carex nebrascensis* (Manning et al. 1989; Svejcar & Trent 1995; Kauffman et al. 2004) and *Scirpus validus* (Weaver & Clements 1938)
 Spikerush *Juncus balticus* (Manning et al. 1989)
 Bulrush mean of *Scirpus validus* (Weaver & Clements 1938) and *Spartina pectinata* (Sperry 1935)
 Cattail mean of *Carex nebrascensis* (Manning et al. 1989), *Distichlis spicata* (Seliskar 1983; Dahlgren et al. 1997, McLendon 2008), *Lepidium latifolium* (Renz et al. 1997), *Paspalum notatum* (Hernandez & Fiala 1992), *Scirpus validus* (Weaver & Clements 1938), *Spartina pectinate* (Sperry 1935)

Ragweed Sperry (1935)
 Lazydaisy mean of *Aster multiflorus* and *A. oblongifolius* (Sperry 1935)
 Bundleflower mean of *Oxytropis lambertii* (Weaver & Clements 1938), *Petalostemum purpureum* (Sperry 1935), *Potentilla diversifolia* and *P. gracilis* (Holch et al. 1941)
 Indian blanket mean of *Echinacea pallida* (Sperry 1935) and *Gaillardia aristata* (Holch et al. 1941)
 Sunflower Stone et al. (2001)
 Duckweed *Phacelia glandulosa* (Holch et al. 1941)
 Texas bluebonnet *Oxytropis lambertii* (Weaver & Clements 1938)
 Prairie coneflower *Ratibida pinnata* (Sperry 1935)
 Bush sunflower *Helianthus scaberrimus* (Sperry 1935)
 Orange zexmenia mean of *Helianthus scaberrimus* (Sperry 1935) and *Parthenium hispidum* (Sperry 1935)

Maximum Potential Rooting Depth

Pecan mean of *Celtis laevigata* (Jackson et al. 1999), *Juglans nigra* (Canadell et al. 1996), *Ulmus americana* (Jackson et al. 1999), *Ulmus crassifolia* (Jackson et al. 1999)
 Sugar hackberry Jackson et al. (1999)
 Texas persimmon mean of *Malus pumila* (Weaver & Clements 1938), *Rhus glabra* (Weaver 1926)
 Ashe juniper Jackson et al. (1999)
 Mesquite Phillips (1963)
 Texas red oak mean of *Q. durandii* and *Q. sinuata* (Jackson et al. 1999)
 Live oak Jackson et al. (1999)
 Prairie baccharis mean of *Baccharis glutinosa* (Gary 1963) and *B. pilularis* (Wright 1928)
 Elbowbush mean of *Corylus americana* (Weaver 1919), *Fallugia paradoxa* (Foxy & Tierney 1986), *Lycium berlanderi* (Gibbens & Lenz 2001), *Rhus trilobata* (Albertson 1937)
 Agarito *Berberis repens* (Weaver 1919)
 Sacahuista Cottle (1931)
 Evergreen sumac mean of *Rhus copallina* (Duncan 1935), *R. glabra* (Weaver 1926), *R. trilobata* (Albertson 1937)
 Yucca mean of *Yucca angustissima* (Tierney & Foxy 1987), *Y. elata* (Gibbens & Lenz 2001), *Y. glauca* (Weaver 1958)
 Mustang grape *Toxicodendron radicans* (Tolstead 1942)

Prickly pear	mean of <i>Opuntia imbricata</i> (Dittmer 1959) and <i>O. polyacantha</i> (Tierney & Foxx 1987)
Giant cane	mean of <i>Lepidium latifolium</i> (Renz et al. 1997), <i>Spartina pectinata</i> (Weaver 1958)
Purple threeawn	Albertson (1937)
Cane bluestem	mean of <i>Bouteloua curtipendula</i> (Tomanek & Albertson 1957), <i>Heteropogon contortus</i> (Cable 1980), <i>Schizachyrium scoparium</i> (Weaver & Fitzpatrick 1934), <i>Sporobolus asper</i> (Weaver & Albertson 1943)
KR bluestem	Boyne & Bardford (1986)
Sideoats grama	Tomanek & Albertson (1957)
Hairy grama	Weaver (1926)
Red grama	mean of <i>Bouteloua hirsuta</i> (Weaver 1926), <i>Erioneuron pulchellum</i> (Gibbens & Lenz 2001), <i>Hilaria rigida</i> (Robberecht et al. 1983)
Bermudagrass	Garrot & Mancino (1994)
Canada wildrye	Weaver (1958)
Plains lovegrass	mean of <i>Digitaria californica</i> (Cable 1980), <i>Eragrostis lehmanniana</i> (Gibbens & Lenz 2001), <i>Muhlenbergia arenacea</i> (Gibbens & Lenz 2001), <i>Oryzopsis hymenoides</i> (Reynolds & Fraley 1989), <i>Sporobolus flexuosus</i> (Gibbens & Lenz 2001)
Texas cupgrass	mean of <i>Dichanthelium scribnerianum</i> (Weaver 1954) and <i>Digitaria californica</i> (Cable 1980)
Curly mesquite	mean of <i>Buchloe dactyloides</i> (Weaver & Clements 1938), <i>Hilaria jamesii</i> (Weaver 1958)
Green sprangletop	mean of <i>Digitaria californica</i> (Cable 1980), <i>Festuca arizonica</i> (Schuster 1964)
Vine-mesquite	mean of <i>Distichlis spicata</i> (Shantz & Piemeisel 1940), <i>Hilaria mutica</i> (Cottle 1931), <i>Panicum virgatum</i> (Weaver 1954)
Switchgrass	Weaver (1954)
Little bluestem	Weaver & Fitzpatrick (1934)
Indiangrass	Albertson (1937)
Johnsongrass	mean of <i>Sorghastrum nutans</i> (Albertson 1937), <i>Zea mays</i> (Weaver 1926)
Tall dropseed	Weaver & Albertson (1943)
Sand dropseed	Weaver & Hanson (1939)
Texas wintergrass	<i>Stipa comata</i> (Wyatt et al. 1980)
Wheat	Hamblin & Tennant (1987)
Flatsedge	mean of <i>Carex nebrascensis</i> (Chambers et al. 1999), <i>Juncus balticus</i> (Manning et al. 1989), <i>Scirpus validus</i> (Weaver & Clements 1938)
Spikerush	mean of <i>Carex nebrascensis</i> (Chambers et al. 1999), <i>Juncus balticus</i> (Manning et al. 1989)
Bulrush	<i>Scirpus validus</i> (Weaver & Clements 1938)
Cattail	mean of <i>Lepidium latifolium</i> (Renz et al. 1997), <i>Scirpus validus</i> (Weaver & Clements 1938), <i>Spartina pectinata</i> (Weaver 1958)
Ragweed	Weaver (1958)
Lazydaisy	mean of <i>Aster commutatus</i> (Holch et al. 1941), <i>A. multiflorus</i> (Sperry 1935), <i>A. oblongifolius</i> (Sperry 1935)
Bundleflower	<i>Desmanthus cooleyi</i> (Gibbens & Lenz 2001)
Indian blanket	mean of <i>Echinacea pallida</i> (Weaver 1954), <i>Gaillardia aristata</i> (Coupland & Johnson 1965)
Sunflower	Schwarzbach et al. (2001)
Duckweed	mean of <i>Mimulus bigelovii</i> and <i>Polygonum aviculare</i> (Forseth et al. 1984)
Texas bluebonnet	mean of <i>Cassia bauhinioides</i> (Gibbens & Lenz 2001), <i>Hoffmanseggia drepanocarpa</i> (Gibbens & Lenz 2001), <i>Medicago lupulina</i> (Cole & Hatch 1941), <i>Lupinus caudatus</i> (Foxx & Tierney 1986)
Prairie coneflower	Hopkins (1951)
Bush sunflower	mean of <i>Arnica pumila</i> (Holch et al. 1941), <i>Balsamorhiza sagittata</i> (Weaver 1958), <i>Chrysopsis villosa</i> (Weaver 1958), <i>Helianthus laetifolius</i> (Weaver 1954), <i>Parthenium integrifolium</i> (Sperry 1935), <i>Veronica baldwinii</i> (Weaver 1919)
Orange zexmenia	mean of <i>Artemisia dracunculus</i> (Foxx & Tierney 1986), <i>Chrysopsis villosa</i> (Weaver 1958), <i>Helianthus laetifolius</i> (Weaver 1954), <i>Machaeranthera pinnatifida</i> (Hopkins 1951), <i>Parthenium integrifolium</i> (Sperry 1935)

Appendix Table C.11 Values for months when physiological responses occur in plant species included in the Upper Llano EDYS model.

Species	Green-Out	Dormancy	Seed-Set	Seed Germination
Pecan	3	10	4 -- 9	3 -- 9
Sugar hackberry	3	10	4 -- 8	3 -- 9
Texas persimmon	1	12	3 -- 8	3 -- 9
Ashe juniper	3	2	7 -- 9	3 -- 10
Mesquite	3	11	4 -- 8	3 -- 9
Texas red oak	3	10	4 -- 8	3 -- 7
Live oak	3	2	4 -- 8	3 -- 7
Prairie baccharis	2	11	6 -- 10	2 -- 10
Elbowbush	3	11	3 -- 8	3 -- 9
Agarito	1	12	4 -- 8	2 -- 10
Sacahuista	1	12	3 -- 7	3 -- 10
Evergreen sumac	1	12	6 -- 9	3 -- 10
Yucca	1	12	4 -- 6	3 -- 9
Mustang grape	2	12	6 -- 10	3 -- 9
Prickly pear	1	12	7 -- 8	2 -- 11
Giant cane	3	11	9 -- 11	4 -- 10
Purple threeawn	3	12	7 -- 11	4 -- 9
Cane bluestem	3	11	5 -- 7	4 -- 9
King Ranch bluestem	3	11	6 -- 10	4 -- 10
Sideoats grama	3	11	6 -- 10	4 -- 9
Hairy grama	3	11	6 -- 10	4 -- 10
Red grama	3	11	5 -- 9	4 -- 9
Bermudagrass	3	11	5 -- 8	4 -- 10
Canada wildrye	9	6	3 -- 5	10 -- 5
Plains lovegrass	3	10	6 -- 9	4 -- 9
Texas cupgrass	3	10	6 -- 9	4 -- 9
Curly mesquite	3	11	5 -- 10	4 -- 9
Green sprangletop	3	11	5 -- 9	4 -- 9
Vine-mesquite	3	12	5 -- 10	4 -- 10
Switchgrass	3	11	7 -- 9	5 -- 9
Little bluestem	3	11	7 -- 9	5 -- 9
Indiangrass	3	11	7 -- 9	5 -- 9
Johnsongrass	3	11	7 -- 10	4 -- 9
Tall dropseed	3	11	5 -- 8	4 -- 9
Sand dropseed	3	11	5 -- 9	4 -- 10
Texas wintergrass	10	6	3 -- 5	10 -- 5
Wheat	10	5	4 -- 5	10 -- 4
Flatsedge	2	12	4 -- 9	3 -- 10
Spikerush	1	12	3 -- 5	3 -- 9
Bulrush	2	12	5 -- 10	4 -- 10
Cattail	3	12	6 -- 8	4 -- 10
Ragweed	3	10	5 -- 10	3 -- 9
Lazydaisy	2	10	3 -- 7	3 -- 9
Bundleflower	3	11	5 -- 10	4 -- 9
Indian blanket	2	10	3 -- 8	3 -- 8
Sunflower	2	11	5 -- 9	2 -- 10
Duckweed	2	11	5 -- 9	3 -- 10
Texas bluebonnet	2	6	4 -- 5	1 -- 5
Prairie coneflower	2	10	4 -- 8	2 -- 8
Bush sunflower	3	11	5 -- 9	3 -- 9
Orange zexmenia	3	11	5 -- 9	4 -- 9

Appendix Table C.13 Values for water use variables used in the Upper Llano EDYS model.

Species	Maintenance (mm/g bio/mo)	New Biomass Maintenance (mm/g biomass/mo)	Water to Production (kg/g)	Green-Out (g/g biomass)
Pecan	0.0000085	0.04	0.88	0.55
Sugar hackberry	0.0000090	0.05	0.90	0.45
Texas persimmon	0.0000080	0.04	0.90	0.45
Ashe juniper	0.0000070	0.03	0.80	0.40
Mesquite	0.0000085	0.04	1.10	0.50
Texas red oak	0.0000080	0.04	0.90	0.45
Live oak	0.0000080	0.03	0.80	0.45
Prairie baccharis	0.0000090	0.05	0.81	0.70
Elbowbush	0.0000090	0.05	0.87	0.70
Agarito	0.0000080	0.04	1.47	0.60
Sacahuista	0.0000080	0.04	0.83	0.70
Evergreen sumac	0.0000090	0.05	0.82	0.70
Yucca	0.0000080	0.04	0.83	0.70
Mustang grape	0.0000090	0.05	0.90	0.70
Prickly pear	0.0000080	0.04	0.30	0.80
Giant cane	0.0000200	0.06	0.73	0.70
Purple threeawn	0.0000150	0.04	0.68	0.65
Cane bluestem	0.0000160	0.04	0.76	0.70
King Ranch bluestem	0.0000150	0.04	0.70	0.67
Sideoats grama	0.0000160	0.04	0.87	0.65
Hairy grama	0.0000150	0.03	0.60	0.60
Red grama	0.0000140	0.03	0.56	0.60
Bermudagrass	0.0000160	0.04	0.91	0.70
Canada wildrye	0.0000180	0.05	1.00	0.70
Plains lovegrass	0.0000160	0.04	0.79	0.70
Texas cupgrass	0.0000170	0.05	0.82	0.75
Curly mesquite	0.0000145	0.03	0.65	0.60
Green sprangletop	0.0000160	0.04	0.76	0.70
Vine-mesquite	0.0000150	0.04	0.90	0.65
Switchgrass	0.0000180	0.05	1.00	0.75
Little bluestem	0.0000170	0.05	0.90	0.65
Indiangrass	0.0000175	0.05	0.89	0.75
Johnsongrass	0.0000175	0.06	0.89	0.70
Tall dropseed	0.0000160	0.04	0.71	0.70
Sand dropseed	0.0000140	0.04	0.85	0.65
Texas wintergrass	0.0000120	0.03	0.99	0.65
Wheat	0.0000120	0.04	0.76	0.70
Flatsedge	0.0000200	0.06	0.73	0.70
Spikerush	0.0000180	0.05	0.79	0.60
Bulrush	0.0000250	0.06	0.76	0.70
Cattail	0.0000225	0.06	0.85	0.70
Ragweed	0.0000140	0.03	0.91	0.72
Lazydaisy	0.0000140	0.03	0.67	0.70
Bundleflower	0.0000140	0.03	0.67	0.72
Indian blanket	0.0000150	0.04	0.52	0.72
Sunflower	0.0000200	0.06	0.55	0.70
Duckweed	0.0000300	0.04	0.38	0.72
Texas bluebonnet	0.0000150	0.06	0.64	0.70
Prairie coneflower	0.0000160	0.06	0.69	0.67
Bush sunflower	0.0000200	0.07	0.85	0.75
Orange zexmenia	0.0000180	0.05	0.70	0.60

Data Sources (Appendix Table C.13): Water to Production

Pecan, sugar hackberry, Texas persimmon, Texas red oak, live oak: *Populus fremontii* (Anderson 1982)
 Ashe juniper: *Pinus ponderosa* (DeLucia & Heckathorn 1989)
 Mesquite: Dwyer & DeGarmo (1970)

Prairie baccharis: 0.9(*Populus fremontii*) = *Baccharis salicifolia* (Glenn et al. 1998)
 Elbowbush: mean of *Atriplex canescens* (Watson 1990), *Larrea tridentata* (Lajtha & Whitford 1989), *Sarcobatus vermiculatus* (Trent et al. 1997)
 Agarito: *Larrea tridentata* (mean of Dwyer & DeGarmo 1970; Lane et al. 1984)
 Sacahuista: mean of *Agave lechuguilla* (Nobel et al. 1989), *Distichlis spicata* (El-Haddad & Noaman 2001), *Hilaria mutica* (Dwyer & DeGarmo 1970), *Sporobolus wrightii* (Cox 1985)
 Evergreen sumac: mean of *Baccharis salicifolia* (Glenn & Brown 1998), *Populus fremontii* (Anderson 1982), *Prosopis glandulosa* (Dwyer & DeGarmo 1970), *Salix goodingii* (Glenn et al. 1998)
 Yucca: mean of *Agave lechuguilla* (Nobel et al. 1989), *Distichlis spicata* (El-Haddad & Noaman 2001), *Hilaria mutica* (Dwyer & DeGarmo 1970), *Sporobolus wrightii* (Cox 1985)
 Mustang grape: *Populus fremontii* (Anderson 1982)
 Prickly pear: *Opuntia basilaris* (Nobel 1976)

Giant cane: *Phragmites australis* (Mueller et al. 2005)
 Purple threeawn: McLendon et al. (unpublished)
 Cane bluestem: *Bothriochloa saccharoides* (McGinnes & Arnold 1939)
 KR bluestem: Coyne & Bradford (1986)
 Sideoats grama: McGinnes & Arnold (1939)
 Hairy grama: McGinnes & Arnold (1939)
 Red grama: mean of *Bouteloua filiformis*, *B. hirsuta*, and *B. rothrockii* (McGinnes & Arnold 1939)
 Bermudagrass: mean of McDonald & Hughes (1968) and Wiedenfeld (1988)
 Canada wildrye: *Leymus junceus* (mean of Hunt 1962; Power 1985; Frank & Berdahl 1999)
 Plains lovegrass: mean of *Digitaria californica* (McGinnes & Arnold 1939), *Eragrostis curvula* (Wiedenfeld 1988), *Sporobolus airoides* (Benton & Wester 1998), *Sporobolus flexuosus* (Dwyer & DeGarmo 1970)
 Texas cupgrass: mean of *Cenchrus ciliaris* (Kapinga 1982), *Digitaria californica* (McGinnes & Arnold 1939), *Heteropogon contortus* (McGinnes & Arnold 1939), *Schizachyrium scoparium* (Weaver 1941)
 Curly mesquite: McGinnes & Arnold (1939)
 Green sprangletop: mean of *Digitaria californica* (McGinnes & Arnold 1939), *Panicum coloratum* (McCawley 1978), *Sporobolus airoides* (Benton & Wester 1998)
 Vine-mesquite: *Hilaria mutica* (Dwyer & DeGarmo 1970)(0.9)
 Switchgrass: mean of *Andropogon gerardii* (Weaver 1941), *Panicum antidotale* (Wright & Dobrenz 1970)
 Little bluestem: mean of Weaver (1941) and McLendon et al. (unpublished)
 Indiangrass: mean of *Andropogon gerardii* and *Schizachyrium scoparium* (Weaver 1941)
 Johnsongrass: mean of *Andropogon gerardii* (Weaver 1941), *Chloris gayana* (Kapinga 1982), *Panicum antidotale* (Wright & Dobrenz 1970), *Phragmites australis* (Mueller et al. 2005), *Sorghum bicolor* (Briggs & Shantz 1913)
 Tall dropseed: *Sporobolus flexuosus* (Dwyer & DeGarmo 1970)
 Sand dropseed: mean of *Sporobolus airoides* (Benton & Wester 1998), *S. flexuosus* (Dwyer & DeGarmo 1970), and sand dropseed prairie (Weaver 1941)
 Texas wintergrass: *Stipa viridula* (Fairboourn 1982)
 Wheat: Briggs & Shantz (1913)

Flatsedge: *Phragmites australis* (Mueller et al. 2005)
 Spikerush: *Juncus roemerianus* (Giurgevich & Dunn 1978)
 Bulrush: mean of *Juncus roemerianus* (Giurgevich & Dunn 1978), *Phragmites australis* (Mueller et al. 2005), *Spartina alterniflora* (Gallagher et al. 1980)
 Cattail: mean of *Juncus roemerianus* (Giurgevich & Dunn 1978), *Paspalum vaginatum* (Biran et al. 1981), *Phalaris aquatica* (Morison & Gifford 1984), *Phragmites australis* (Mueller et al. 2005), *Spartina alterniflora* (Gallagher et al. 1980)

Ragweed: *Ambrosia artemisifolia* (Shantz & Piemeisel 1927)
Lazydaisy: mean of *Boerhaavia torreyana* (McGinnes & Arnold 1939), *Eschscholtzia mexicana* (McGinnes & Arnold 1939), *Lactuca scariola* (Shantz & Piemeisel 1927)
Bundlflower: mean of *Lotus humistrutis* (McGinnes & Arnold 1939), *Melilotus alba* (Shantz & Piemeisel 1927)
Indian blanket: *Lactuca scariola* (Shantz & Piemeisel 1927)
Sunflower: mean of Shantz & Piemeisel (1927), Morison & Gifford (1984), Larcher (1995), Mueller et al. (2005)
Duckweed: mean of *Allenrolfea occidentalis* (Glenn et al. 1998), *Iva xanthifolia* (Shantz & Piemeisel 1927), *Phalaris aquatica* (Morison & Gifford 1984)
Texas bluebonnet: mean of *Astragalus cicer* (Fairbourn 1982), *Lotus humistrutis* (McGinnes & Arnold 1939), *Trifolium pretense* (Mueller et al. 2005)
Prairie coneflower: mean of *Ambrosia artemisifolia*, *Grindelia squarrosa*, *Helianthus petiolaris*, *Polygonum aviculare* (Shantz & Piemeisel 1927)
Bush sunflower: mean of *Helianthus petiolaris* and *Polygonum aviculare* (Shantz & Piemeisel 1927)
Orange zexmenia: bush sunflower(0.8)

Appendix Table C.14 Growth rate control factor values for plant species included in the Upper Llano EDYS model.

Species	Maximum Growth Rate (per mo)	Maximum Aboveground Biomass (g/m ²)	Maximum Old Biomass Drought Loss (per mo)
Pecan	0.40	28,000	0.10
Sugar hackberry	0.50	14,000	0.10
Texas persimmon	0.30	3,600	0.05
Ashe juniper	0.40	10,000	0.05
Mesquite	0.90	6,400	0.05
Texas red oak	0.35	15,000	0.10
Live oak	0.40	29,000	0.10
Prairie baccharis	1.20	2,800	0.40
Elbowbush	1.00	1,500	0.20
Agarito	0.25	1,200	0.10
Sacahuista	0.50	1,200	0.20
Evergreen sumac	1.00	3,000	0.30
Yucca	0.15	1,000	0.10
Mustang grape	1.00	2,000	0.40
Prickly pear	0.05	2,400	0.10
Giant cane	3.26	2,100	0.15
Purple threeawn	2.75	300	0.20
Cane bluestem	2.75	600	0.25
King Ranch bluestem	2.50	800	0.20
Sideoats grama	2.75	600	0.25
Hairy grama	1.75	250	0.20
Red grama	1.75	150	0.20
Bermudagrass	2.50	600	0.25
Canada wildrye	2.75	600	0.40
Plains lovegrass	2.50	400	0.20
Texas cupgrass	2.50	600	0.30
Curly mesquite	1.75	300	0.20
Green sprangletop	2.50	400	0.30
Vine-mesquite	2.75	450	0.30
Switchgrass	2.75	800	0.30
Little bluestem	2.50	600	0.30
Indiangrass	2.75	750	0.30
Johnsongrass	2.75	800	0.35
Tall dropseed	2.75	600	0.30
Sand dropseed	2.75	400	0.20
Texas wintergrass	2.00	300	0.25
Wheat	2.00	350	0.30
Flatsedge	1.50	500	0.30
Spikerush	1.00	250	0.30
Bulrush	3.00	1000	0.40
Cattail	1.00	800	0.50
Ragweed	3.12	600	0.20
Lazydaisy	2.00	60	0.25
Bundleflower	2.00	80	0.20
Indian blanket	2.00	80	0.25
Sunflower	3.00	750	0.30
Duckweed	1.00	200	0.70
Texas bluebonnet	1.00	80	0.30
Prairie coneflower	2.00	60	0.30
Bush sunflower	1.75	300	0.20
Orange zexmenia	1.35	200	0.15

Maximum growth rate = maximum per month increase in standing crop photosynthetic tissue.

Maximum biomass = maximum aboveground biomass (g/m²).

Maximum old biomass drought loss = maximum amount of current aboveground tissue that can be lost per month from drought.

Data Sources (Appendix Table C.14)**Maximum growth rate**

Giant cane	<i>Phragmites australis</i> (McLendon 2014)
Purple threeawn	<i>Aristida glabrata</i> (McGinnies & Arnold 1939)
Cane bluestem	<i>Bothriochloa saccharoides</i> (McGinnies & Arnold 1939)
Sideoats grama	McGinnies & Arnold (1939)
Hairy grama	McGinnies & Arnold (1939)
Curly mesquite	McGinnies & Arnold (1939)
Ragweed	1.5(average rate): McLendon (2014)

Maximum Aboveground Biomass

Giant cane	Twice <i>Spartina patens</i> - <i>Phragmites australis</i> community (McLendon 2014)
King Ranch bluestem	<i>Dichanthium annulatum</i> (Kapinga 1982)
Bermudagrass	Kapinga (1982)

Appendix Table C.15. Monthly growth rates (proportion of maximum potential growth rate; Appendix Table D.14) for plant species in the Upper Llano EDYS model.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pecan	0.00	0.00	0.50	0.80	1.00	1.00	1.00	1.00	0.70	0.30	0.10	0.00
Sugar hackberry	0.00	0.00	0.60	0.90	1.00	1.00	1.00	1.00	0.70	0.30	0.10	0.00
Texas persimmon	0.20	0.40	0.60	0.90	1.00	1.00	1.00	1.00	0.80	0.40	0.20	0.10
Ashe juniper	0.10	0.20	0.70	1.00	1.00	1.00	0.90	0.80	0.80	0.50	0.20	0.10
Mesquite	0.00	0.10	0.80	1.00	1.00	1.00	1.00	1.00	0.80	0.50	0.20	0.05
Texas red oak	0.00	0.00	0.50	0.80	1.00	1.00	1.00	1.00	0.60	0.30	0.10	0.00
Live oak	0.30	0.40	0.80	0.90	1.00	1.00	1.00	1.00	0.80	0.60	0.40	0.30
Prairie baccharis	0.10	0.40	0.70	0.90	1.00	1.00	1.00	1.00	0.80	0.60	0.30	0.10
Elbowbush	0.00	0.10	0.60	0.90	1.00	1.00	1.00	1.00	0.80	0.50	0.20	0.00
Agarito	0.10	0.20	0.70	0.90	1.00	1.00	1.00	1.00	0.90	0.70	0.20	0.10
Sacahuista	0.10	0.20	0.50	0.90	1.00	1.00	1.00	1.00	0.80	0.60	0.40	0.20
Evergreen sumac	0.20	0.30	0.60	0.90	1.00	1.00	1.00	1.00	0.90	0.70	0.50	0.30
Yucca	0.10	0.20	0.50	0.90	1.00	1.00	1.00	1.00	0.80	0.40	0.20	0.10
Mustang grape	0.00	0.20	0.60	1.00	1.00	1.00	1.00	1.00	0.80	0.40	0.20	0.00
Prickly pear	0.10	0.10	0.60	0.90	1.00	1.00	1.00	1.00	1.00	0.70	0.30	0.10
Giant cane	0.00	0.10	0.50	0.90	1.00	1.00	1.00	1.00	1.00	0.70	0.30	0.10
Purple threeawn	0.10	0.20	0.80	1.00	1.00	1.00	1.00	1.00	0.85	0.60	0.20	0.10
Cane bluestem	0.05	0.15	0.60	0.80	1.00	1.00	1.00	1.00	0.80	0.50	0.20	0.05
King Ranch bluestem	0.10	0.20	0.60	0.90	1.00	1.00	1.00	1.00	0.80	0.50	0.20	0.10
Sideoats grama	0.10	0.15	0.60	0.80	1.00	1.00	1.00	1.00	0.60	0.30	0.20	0.10
Hairy grama	0.10	0.15	0.40	0.80	1.00	1.00	1.00	1.00	0.80	0.50	0.20	0.10
Red grama	0.10	0.15	0.40	0.80	1.00	1.00	1.00	1.00	0.80	0.50	0.20	0.10
Bermudagrass	0.00	0.05	0.20	0.50	1.00	1.00	1.00	1.00	0.90	0.60	0.20	0.00
Canada wildrye	0.50	0.80	1.00	1.00	0.90	0.40	0.10	0.10	0.30	0.50	0.60	0.50
Plains lovegrass	0.00	0.00	0.50	0.80	1.00	1.00	1.00	1.00	0.80	0.40	0.20	0.05
Texas cupgrass	0.00	0.10	0.60	0.90	1.00	1.00	1.00	1.00	0.80	0.60	0.30	0.10
Curly mesquite	0.05	0.10	0.50	0.80	1.00	1.00	1.00	1.00	0.90	0.40	0.20	0.10
Green sprangletop	0.05	0.10	0.40	0.80	1.00	1.00	1.00	1.00	0.90	0.40	0.10	0.05
Vine-mesquite	0.10	0.20	0.40	0.80	1.00	1.00	1.00	1.00	0.80	0.50	0.30	0.15
Switchgrass	0.05	0.10	0.40	0.80	1.00	1.00	1.00	1.00	0.80	0.50	0.30	0.10
Little bluestem	0.05	0.10	0.40	0.80	1.00	1.00	1.00	1.00	0.80	0.40	0.10	0.05
Indiangrass	0.05	0.10	0.40	0.70	1.00	1.00	1.00	1.00	0.80	0.40	0.20	0.05
Johnsongrass	0.00	0.00	0.50	0.90	1.00	1.00	1.00	1.00	0.90	0.40	0.10	0.00
Tall dropseed	0.10	0.20	0.40	0.80	1.00	1.00	1.00	0.90	0.70	0.40	0.20	0.10
Sand dropseed	0.05	0.10	0.50	0.90	1.00	1.00	1.00	1.00	0.80	0.40	0.20	0.05
Texas wintergrass	0.70	0.80	1.00	1.00	0.70	0.40	0.10	0.00	0.20	0.40	0.60	0.70
Wheat	0.80	0.90	1.00	1.00	0.70	0.30	0.00	0.00	0.00	0.20	0.40	0.80
Flatsedge	0.10	0.20	0.60	0.90	1.00	1.00	1.00	0.90	0.70	0.30	0.20	0.10
Spikerush	0.20	0.40	0.80	1.00	1.00	1.00	1.00	0.90	0.70	0.40	0.20	0.20
Bulrush	0.20	0.30	0.60	0.90	1.00	1.00	1.00	1.00	0.80	0.50	0.30	0.20
Cattail	0.10	0.20	0.40	0.80	1.00	1.00	1.00	1.00	0.80	0.40	0.20	0.10
Ragweed	0.00	0.10	0.50	0.90	1.00	1.00	1.00	0.90	0.50	0.30	0.10	0.00
Lazydaisy	0.00	0.50	0.90	1.00	1.00	1.00	1.00	0.80	0.40	0.20	0.10	0.00
Bundleflower	0.10	0.20	0.50	0.70	1.00	1.00	1.00	0.80	0.60	0.40	0.20	0.10
Indian blanket	0.10	0.30	0.90	1.00	1.00	0.90	0.80	0.60	0.30	0.20	0.10	0.10
Sunflower	0.00	0.10	0.40	0.80	1.00	1.00	1.00	0.90	0.60	0.40	0.20	0.00
Duckweed	0.10	0.30	0.60	0.80	1.00	1.00	1.00	0.90	0.60	0.40	0.20	0.00
Texas bluebonnet	0.40	0.80	1.00	1.00	0.70	0.20	0.00	0.00	0.10	0.20	0.30	0.30
Prairie coneflower	0.10	0.30	0.70	1.00	1.00	1.00	1.00	0.80	0.50	0.30	0.20	0.10
Bush sunflower	0.00	0.10	0.40	0.90	1.00	1.00	1.00	1.00	0.90	0.30	0.00	0.00
Orange zexmenia	0.00	0.10	0.50	0.90	1.00	1.00	1.00	1.00	0.90	0.30	0.00	0.00

Appendix Table C.16. Plant part productivity rates (proportion of maximum photosynthetic rate) for plant species in the Upper Llano EDYS model.

Species	Coarse Roots	Fine Roots	Trunks	Stems	Leaves	Seeds
Pecan	0.00	0.00	0.00	0.00	1.00	0.00
Sugar hackberry	0.00	0.00	0.00	0.00	1.00	0.00
Texas persimmon	0.00	0.00	0.00	0.00	1.00	0.00
Ashe juniper	0.00	0.00	0.00	0.01	1.00	0.00
Mesquite	0.00	0.00	0.00	0.02	1.00	0.00
Texas red oak	0.00	0.00	0.00	0.00	1.00	0.00
Live oak	0.00	0.00	0.00	0.00	1.00	0.00
Prairie baccharis	0.00	0.00	0.00	0.00	1.00	0.00
Elbowbush	0.00	0.00	0.00	0.00	1.00	0.00
Agarito	0.00	0.00	0.00	0.02	1.00	0.00
Sacahuista	0.00	0.00	0.01	0.10	1.00	0.00
Evergreen sumac	0.00	0.00	0.00	0.00	1.00	0.00
Yucca	0.00	0.00	0.00	0.00	1.00	0.00
Mustang grape	0.00	0.00	0.00	0.00	1.00	0.00
Prickly pear	0.00	0.00	0.02	1.00	0.00	0.00
Giant cane	0.00	0.00	0.00	0.10	1.00	0.00
Purple threeawn	0.00	0.00	0.05	0.20	1.00	0.00
Cane bluestem	0.00	0.00	0.00	0.20	1.00	0.00
King Ranch bluestem	0.00	0.00	0.05	0.30	1.00	0.00
Sideoats grama	0.00	0.00	0.05	0.10	1.00	0.00
Hairy grama	0.00	0.00	0.10	0.20	1.00	0.00
Red grama	0.00	0.00	0.05	0.20	1.00	0.00
Bermudagrass	0.00	0.00	0.10	0.20	1.00	0.00
Canada wildrye	0.00	0.00	0.00	0.10	1.00	0.00
Plains lovegrass	0.00	0.00	0.05	0.20	1.00	0.00
Texas cupgrass	0.00	0.00	0.05	0.20	1.00	0.00
Curly mesquite	0.00	0.00	0.10	0.20	1.00	0.00
Green sprangletop	0.00	0.00	0.05	0.20	1.00	0.00
Vine-mesquite	0.00	0.00	0.10	0.20	1.00	0.00
Switchgrass	0.00	0.00	0.00	0.10	1.00	0.00
Little bluestem	0.00	0.00	0.00	0.10	1.00	0.00
Indiangrass	0.00	0.00	0.00	0.10	1.00	0.00
Johnsongrass	0.00	0.00	0.05	0.20	1.00	0.00
Tall dropseed	0.00	0.00	0.05	0.10	1.00	0.00
Sand dropseed	0.00	0.00	0.05	0.20	1.00	0.00
Texas wintergrass	0.00	0.00	0.10	0.20	1.00	0.00
Wheat	0.00	0.00	0.02	0.20	1.00	0.00
Flatsedge	0.00	0.00	0.00	0.20	1.00	0.00
Spikerush	0.00	0.00	0.10	1.00	0.00	0.00
Bulrush	0.00	0.00	0.00	0.10	1.00	0.00
Cattail	0.00	0.00	0.00	0.10	1.00	0.00
Ragweed	0.00	0.00	0.00	0.10	1.00	0.00
Lazydaisy	0.00	0.00	0.05	0.10	1.00	0.00
Bundleflower	0.00	0.00	0.10	0.10	1.00	0.00
Indian blanket	0.00	0.00	0.10	0.05	1.00	0.00
Sunflower	0.00	0.00	0.05	0.20	1.00	0.00
Duckweed	0.00	0.00	0.00	0.20	1.00	0.00
Texas bluebonnet	0.00	0.00	0.00	0.10	1.00	0.00
Prairie coneflower	0.00	0.00	0.00	0.05	1.00	0.00
Bush sunflower	0.00	0.00	0.05	0.10	1.00	0.00
Orange zexmenia	0.00	0.00	0.00	0.10	1.00	0.00

Appendix Table C.17. Green-out plant part productivity conversion rates (proportion of biomass weight converted to new production at green-out) for plant species in the Upper Llano EDYS model.

Species	Coarse Roots	Fine Roots	Trunks	Stems	Leaves	Seeds
Pecan	0.02	0.00	0.01	0.02	1.00	0.00
Sugar hackberry	0.01	0.00	0.01	0.03	1.00	0.00
Texas persimmon	0.01	0.00	0.01	0.02	1.00	0.00
Ashe juniper	0.02	0.00	0.01	0.03	1.00	0.00
Mesquite	0.02	0.00	0.01	0.05	1.00	0.00
Texas red oak	0.01	0.00	0.01	0.02	1.00	0.00
Live oak	0.01	0.00	0.01	0.02	1.00	0.00
Prairie baccharis	0.04	0.00	0.04	0.10	1.00	0.00
Elbowbush	0.02	0.00	0.02	0.05	1.00	0.00
Agarito	0.02	0.00	0.02	0.05	1.00	0.00
Sacahuista	0.05	0.00	0.04	0.05	1.00	0.00
Evergreen sumac	0.04	0.00	0.02	0.10	1.00	0.00
Yucca	0.04	0.00	0.03	0.05	1.00	0.00
Mustang grape	0.01	0.00	0.02	0.10	1.00	0.00
Prickly pear	0.01	0.00	0.02	0.00	0.00	0.00
Giant cane	0.10	0.00	0.10	0.25	1.00	0.00
Purple threeawn	0.05	0.00	0.05	0.50	1.00	0.00
Cane bluestem	0.05	0.00	0.10	0.50	1.00	0.00
King Ranch bluestem	0.05	0.00	0.10	0.50	1.00	0.00
Sideoats grama	0.10	0.00	0.10	0.50	1.00	0.00
Hairy grama	0.05	0.00	0.05	0.50	1.00	0.00
Red grama	0.05	0.00	0.05	0.50	1.00	0.00
Bermudagrass	0.10	0.00	0.10	0.50	1.00	0.00
Canada wildrye	0.05	0.00	0.05	0.50	1.00	0.00
Plains lovegrass	0.05	0.00	0.05	0.50	1.00	0.00
Texas cupgrass	0.05	0.00	0.05	0.50	1.00	0.00
Curly mesquite	0.05	0.00	0.05	0.50	1.00	0.00
Green sprangletop	0.05	0.00	0.05	0.50	1.00	0.00
Vine-mesquite	0.10	0.00	0.10	0.50	1.00	0.00
Switchgrass	0.05	0.00	0.10	0.50	1.00	0.00
Little bluestem	0.05	0.00	0.10	0.50	1.00	0.00
Indiangrass	0.05	0.00	0.10	0.50	1.00	0.00
Johnsongrass	0.10	0.00	0.10	0.50	1.00	0.00
Tall dropseed	0.05	0.00	0.05	0.50	1.00	0.00
Sand dropseed	0.05	0.00	0.05	0.50	1.00	0.00
Texas wintergrass	0.05	0.00	0.05	0.50	1.00	0.00
Wheat	0.00	0.00	0.10	0.50	1.00	0.00
Flatsedge	0.10	0.00	0.10	0.50	1.00	0.00
Spikerush	0.10	0.00	0.10	0.00	0.00	0.00
Bulrush	0.20	0.00	0.20	0.25	1.00	0.00
Cattail	0.30	0.00	0.20	0.30	1.00	0.00
Ragweed	0.10	0.00	0.10	0.40	1.00	0.00
Lazydaisy	0.05	0.00	0.10	0.30	1.00	0.00
Bundleflower	0.05	0.00	0.10	0.40	1.00	0.00
Indian blanket	0.05	0.00	0.10	0.20	1.00	0.00
Sunflower	0.00	0.00	0.20	0.50	1.00	0.00
Duckweed	0.00	0.00	0.10	0.10	1.00	0.00
Texas bluebonnet	0.00	0.00	0.20	0.20	1.00	0.00
Prairie coneflower	0.10	0.00	0.10	0.30	1.00	0.00
Bush sunflower	0.10	0.00	0.20	0.40	1.00	0.00
Orange zexmenia	0.10	0.00	0.10	0.40	1.00	0.00

Appendix Table C.18 Physiological control constants for plant species in the Upper Llano EDYS model.

Species	Growing Season Max Root:Shoot Ratio	Growing Season Green-Out Shoot:Root Ratio	Max 1-month Seed Germination	Max First Month Seedling Growth
Pecan	1.50	0.67	0.73	5
Sugar hackberry	0.56	1.78	0.80	10
Texas persimmon	1.50	0.67	0.70	10
Ashe juniper	0.50	2.00	0.42	10
Mesquite	0.64	1.56	0.50	10
Texas red oak	0.72	1.25	0.63	8
Live oak	0.92	1.09	0.63	8
Prairie baccharis	1.22	0.82	0.94	10
Elbowbush	1.32	0.76	0.63	10
Agarito	1.94	0.52	0.79	10
Sacahuista	1.46	0.68	0.29	10
Evergreen sumac	1.68	0.60	0.58	15
Yucca	2.00	0.50	0.87	10
Mustang grape	1.00	1.00	0.64	10
Prickly pear	0.62	1.61	0.70	10
Giant cane	0.72	1.25	0.01	10
Purple threeawn	3.78	0.26	0.16	20
Cane bluestem	3.20	0.31	0.54	20
King Ranch bluestem	3.18	0.31	0.60	30
Sideoats grama	3.20	0.31	0.72	20
Hairy grama	1.12	0.89	0.39	20
Red grama	1.12	0.89	0.39	20
Bermudagrass	2.42	0.41	0.85	20
Canada wildrye	3.10	0.30	0.70	20
Plains lovegrass	1.16	0.86	0.80	20
Texas cupgrass	2.12	0.47	0.53	20
Curly mesquite	3.96	0.25	0.14	20
Green sprangletop	1.72	0.58	0.79	20
Vine-mesquite	1.70	0.59	0.37	20
Switchgrass	1.96	0.51	0.48	20
Little bluestem	3.26	0.31	0.48	20
Indiangrass	1.72	0.58	0.63	20
Johnsongrass	4.42	0.23	0.88	20
Tall dropseed	2.20	0.45	0.80	20
Sand dropseed	1.76	0.57	0.80	20
Texas wintergrass	2.52	0.40	0.13	20
Wheat	1.76	0.57	0.94	20
Flatsedge	6.66	0.17	0.46	20
Spikerush	9.24	0.11	0.30	10
Bulrush	6.66	0.17	0.51	20
Cattail	6.66	0.17	0.65	20
Ragweed	2.52	0.40	0.60	20
Lazydaisy	2.76	0.36	0.70	10
Bundleflower	2.92	0.35	0.42	20
Indian blanket	2.76	0.36	0.55	20
Sunflower	0.34	2.94	0.82	30
Duckweed	0.60	1.67	0.78	10
Texas bluebonnet	1.32	0.76	0.64	20
Prairie coneflower	2.76	0.36	0.50	20
Bush sunflower	2.52	0.40	0.38	20
Orange zexmenia	2.52	0.40	0.50	20

Growing season max root:shoot ratio = twice the initial root:shoot ratio value (Appendix Table E.2).

Growing season green-out shoot:root ratio = half the inverse of initial root:shoot ratio (Appendix Table E.2).

Examples of field root:shoot ratios include: *Quercus robar* 0.35 (Rodin & Bazilevich 1967); *Q. velutina* 0.54 (Nadelhoffer et al. 1985); *Larrea tridentata* 0.42 (Chew & Chew 1965), 1.08 (Wallace et al. 1974); *Bouteloua gracilis* 2.39 (Samuel & Hart 1992), 4.10 (Coupland & Johnson 1965), 6.90 (Vinton & Burke 1995); *Cynodon dactylon* 0.62 (Rodriguez et al. 2002), 1.60 (Hons et al. 1970), 2.90 (Beaty et al. 1975); *Distichlis spicata* 1.10

(Seliskar & Gallagher 2000); *Hilaria jamesii* 5.31 (Moore & West 1973); *Hilaria rigida* 0.57 (Robberecht et al. 1983); *Oryzopsis hymenoides* 2.62 (Orodho & Trlica 1990); *Paspalum notatum* 2.27 (Fiala et al. 1991), 2.50 (Beaty et al. 1975); *Schizachyrium scoparium* 2.76 (Cerligione et al. 1987); tallgrass prairie 0.90 Oklahoma (Sims & Singh 1978), 0.97 Missouri (Buyanovskyh et al. 1987); Kansas midgrass prairie 1.76 (Sims & Singh 1978); shortgrass plains 1.87 Colorado (Sims & Singh 1978), 2.21 Texas (Sims & Singh 1978); *Carex nebrascensis* 5.62 (Manning et al. 1989); *Juncus roemerianus* 1.55 (Gallagher et al. 1977).

Seed germination data were taken primarily from Vories (1981), Fulbright et al. (1982), and Redente et al. (1982). The primary sources for those data are as follows:

Ashe juniper: *Juniperus communis* (Johnsen & Alexander 1978)
 Live oak: *Quercus turbinella* (Olsen 1974b)
 Prairie baccharis: *Baccharis glutinosa* (Horton et al. 1960)
 Elbowbush: *Forestiera neomexicana* (Swingle 1939)
 Agarito: *Mahonia repens* (McDonough 1969)
 Sacahuista: mean of *Sporobolus giganteus* (Steffered 1948), *Yucca angustissima* (McCleary & Wagner 1973)
 Evergreen sumac: *Rhus glabra* (Boyd 1943 and Brinkman 1974f)
 Mustang grape: *Vitis riparia* (Swingle 1939)
 Yucca: *Yucca glauca* (Eddleman 1977)
 Giant cane: Gould (1975)
 Purple threeawn: mean of *Muhlenbergia arenicola* (Wilson 1931), *Stipa viridula* (Atkins & Smith 1967)
 Cane bluestem: mean of *Andropogon gerardii* (Atkins & Smith 1967), *Schizachyrium scoparium* (Wolff 1951)
 KR bluestem: *Andropogon gerardii* (Atkins & Smith 1967)
 Sideoats grama: Wolff (1951), Wheeler & Hill (1957)
 Hairy grama: Wolff (1951), Wheeler & Hill (1957)
 Red grama: *Bouteloua hirsuta* (Wolff 1951; Wheeler & Hill 1957)
 Bermudagrass: Wheeler & Hill (1957)
 Canada wildrye: Wheeler & Hill (1957), Atkins & Smith (1967)
 Plains lovegrass: *Eragrostis trichodes* (Wheeler & Hill 1957; Atkins & Smith 1967)
 Texas cupgrass: *Paspalum dilatatum* (Wolff 1951)
 Curly mesquite: *Hilaria jamesii* (Wilson 1931)
 Green sprangletop: *Eleusine indica* (Fulwider & Engel 1959)
 Vine-mesquite: Wolff (1951)
 Switchgrass: Wolff (1951)
 Little bluestem: Wolff (1951)
 Indiangrass: Stefferud (1948), Wolff (1951), Wheeler & Hill (1957)
 Johnsongrass: Harrington (1916)
 Tall dropseed: Stefferud (1948)
 Sand dropseed: Stefferud (1948)
 Texas wintergrass: *Stipa comata* (Steffered 1948)
 Wheat: *Avena fatua* (Sharma et al. 1976)
 Flatsedge: *Cyperus esculentus* (Hill et al. 1963)
 Spikerush: mean of 24 species of *Carex* (Fulbright et al. 1982)
 Bulrush: mean of *Cyperus esculentus* (Hill et al. 1963) and *Typha latifolia* (Swingle 1939)
 Cattail: *Typha latifolia* (Swingle 1939)
 Ragweed: *Ambrosia artemisiifolia* (Taylorson 1972)
 Lazydaisy: *Erigeron strigosus* (Sorensen & Holden 1974)
 Bundleflower: half of *Desmantis illinoensis* (Swingle 1939)
 Indian blanket: *Gaillardia pinnatifida* (Swingle 1939)
 Sunflower: Swingle (1939)
 Duckweed: *Barbarea orthoceras* (Maguire & Overland 1959)
 Texas bluebonnet: *Lupinus argenteus* (Swingle 1939)
 Prairie coneflower: half reported by Eddleman (1977)
 Bush sunflower: *Vernonia fasciculata* (Sorensen & Holden 1974)
 Orange zexmenia: mean of *Chrysopsis villosa* (Swingle 1939) and *Helianthus rigidus* (Eddleman 1977)

Appendix Table C.19 End of growing season dieback (proportion of tissue lost at onset of dormancy) for plant species in the Upper Llano EDYS model.

Species	Coarse Roots	Fine Roots	Trunks	Stems	Leaves	Seeds
Pecan	0.01	0.05	0.01	0.02	1.00	1.00
Sugar hackberry	0.01	0.05	0.01	0.05	0.98	1.00
Texas persimmon	0.01	0.05	0.01	0.05	0.50	1.00
Ashe juniper	0.01	0.05	0.01	0.06	0.49	1.00
Mesquite	0.01	0.05	0.01	0.02	0.90	1.00
Texas red oak	0.01	0.05	0.01	0.02	1.00	1.00
Live oak	0.01	0.05	0.01	0.02	0.74	1.00
Prairie baccharis	0.04	0.15	0.05	0.15	0.85	1.00
Elbowbush	0.02	0.10	0.02	0.10	0.95	1.00
Agarito	0.02	0.10	0.02	0.10	0.20	1.00
Sacahuista	0.05	0.15	0.05	0.10	0.35	1.00
Evergreen sumac	0.03	0.10	0.02	0.12	0.90	1.00
Yucca	0.04	0.10	0.03	0.10	0.35	1.00
Mustang grape	0.04	0.15	0.01	0.08	0.95	1.00
Prickly pear	0.04	0.10	0.02	0.08	0.05	1.00
Giant cane	0.03	0.10	0.05	0.80	0.90	1.00
Purple threeawn	0.10	0.20	0.05	0.95	0.95	1.00
Cane bluestem	0.05	0.15	0.05	0.90	0.95	1.00
King Ranch bluestem	0.10	0.20	0.08	0.95	0.98	1.00
Sideoats grama	0.05	0.15	0.03	0.90	0.98	1.00
Hairy grama	0.15	0.30	0.08	0.95	0.90	1.00
Red grama	0.15	0.30	0.15	0.95	0.95	1.00
Bermudagrass	0.10	0.20	0.15	0.70	0.90	1.00
Canada wildrye	0.10	0.20	0.05	0.90	0.95	1.00
Plains lovegrass	0.10	0.20	0.05	0.90	0.95	1.00
Texas cupgrass	0.10	0.20	0.10	0.95	0.95	1.00
Curly mesquite	0.15	0.30	0.10	0.85	0.95	1.00
Green sprangletop	0.15	0.30	0.15	0.95	0.90	1.00
Vine-mesquite	0.10	0.20	0.05	0.90	0.95	1.00
Switchgrass	0.05	0.15	0.03	0.90	0.95	1.00
Little bluestem	0.10	0.20	0.04	0.90	0.98	1.00
Indiangrass	0.05	0.15	0.03	0.90	0.95	1.00
Johnsongrass	0.10	0.20	0.10	0.90	0.95	1.00
Tall dropseed	0.10	0.20	0.05	0.95	0.97	1.00
Sand dropseed	0.15	0.30	0.10	0.90	0.95	1.00
Texas wintergrass	0.15	0.30	0.15	0.95	0.95	1.00
Wheat	1.00	1.00	1.00	1.00	1.00	1.00
Flatsedge	0.15	0.30	0.15	0.97	0.95	1.00
Spikerush	0.10	0.20	0.05	0.40	0.40	1.00
Bulrush	0.10	0.20	0.05	0.90	0.90	1.00
Cattail	0.10	0.20	0.05	0.95	0.90	1.00
Ragweed	0.18	0.35	0.20	0.95	0.99	1.00
Lazydaisy	0.20	0.40	0.15	0.80	0.99	1.00
Bundleflower	0.10	0.20	0.12	0.60	0.95	1.00
Indian blanket	0.15	0.30	0.20	0.84	0.95	1.00
Sunflower	1.00	1.00	1.00	1.00	1.00	1.00
Duckweed	1.00	1.00	1.00	1.00	1.00	1.00
Texas bluebonnet	1.00	1.00	1.00	1.00	1.00	1.00
Prairie coneflower	0.15	0.30	0.20	0.70	0.95	1.00
Bush sunflower	0.10	0.20	0.20	0.95	0.99	1.00
Orange zexmenia	0.10	0.20	0.20	0.95	0.98	1.00

Data Sources

Weaver & Zink (1946); Caldwell & Camp (1974); Peek et al. (2005).

Appendix Table C.20 Shading effect on species included in the Upper Llano EDYS model. Values are the proportional decrease in maximum potential production of the **shaded species** resulting from 100% cover of the **shading species**.

Shaded Species	Spading Species												
	pecan	hackbr	persim	junipr	mesqit	redoak	liveoak	bacchr	elbowb	agarto	sacahu	sumac	yucca
Pecan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar hackberry	0.02	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Texas persimmon	0.05	0.02	0.00	0.03	0.01	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Ashe juniper	0.04	0.01	0.00	0.00	0.00	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Mesquite	0.06	0.01	0.00	0.02	0.00	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Red oak	0.03	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Live oak	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prairie baccharis	0.03	0.02	0.01	0.05	0.02	0.02	0.03	0.00	0.00	0.00	0.00	0.01	0.00
Elbowbush	0.04	0.03	0.01	0.05	0.02	0.02	0.03	0.02	0.00	0.00	0.00	0.02	0.00
Agarito	0.04	0.03	0.01	0.04	0.01	0.02	0.03	0.01	0.00	0.00	0.01	0.02	0.00
Sacahuista	0.03	0.02	0.01	0.03	0.01	0.02	0.03	0.01	0.00	0.00	0.00	0.01	0.00
Evergreen sumac	0.02	0.01	0.00	0.02	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Yucca	0.04	0.03	0.01	0.05	0.01	0.02	0.04	0.01	0.00	0.00	0.01	0.02	0.00
Mustang grape	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prickly pear	0.04	0.02	0.01	0.03	0.01	0.02	0.04	0.01	0.00	0.00	0.01	0.01	0.00
Giant cane	0.02	0.01	0.00	0.01	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Purple threeawn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cane bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KR bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sideoats grama	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hairy grama	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Red grama	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bermudagrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canada wildrye	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plains lovegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas cupgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Curly mesquite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Green sprangletop	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vine-mesquite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Switchgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Little bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indiangrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Johnsongrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tall dropseed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sand dropseed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas wintergrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Flatsedge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spikerush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulrush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cattail	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ragweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lazydaisy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bundleflower	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indian blanket	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sunflower	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Duckweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas bluebonnet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prairie coneflower	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bush sunflower	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Orange zexmenia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table C.20 (Cont.)

Shaded Species	Shading Species												
	msgrape	prpear	gtcane	thrawn	canebl	KRblu	sidoat	hgrama	redgrm	bermu	wldrye	ploveg	cupgrs
Pecan	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar hackberry	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas persimmon	0.08	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ashe juniper	0.07	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mesquite	0.07	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Red oak	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Live oak	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prairie baccharis	0.07	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Elbowbush	0.07	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agarito	0.06	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sacahuista	0.06	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Evergreen sumac	0.07	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yucca	0.06	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mustang grape	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prickly pear	0.07	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Giant cane	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Purple threeawn	0.00	0.00	0.10	0.00	0.05	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Cane bluestem	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KR bluestem	0.00	0.00	0.05	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sideoats grama	0.00	0.00	0.06	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hairy grama	0.00	0.00	0.10	0.00	0.08	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Red grama	0.00	0.00	0.10	0.00	0.08	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Bermudagrass	0.00	0.00	0.02	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Canada wildrye	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plains lovegrass	0.00	0.00	0.08	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas cupgrass	0.00	0.00	0.05	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Curly mesquite	0.00	0.00	0.10	0.00	0.05	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Green sprangletop	0.00	0.00	0.05	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vine-mesquite	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Switchgrass	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Little bluestem	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indiangrass	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Johnsongrass	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tall dropseed	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sand dropseed	0.00	0.00	0.10	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Texas wintergrass	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Flatsedge	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spikerush	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulrush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cattail	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ragweed	0.00	0.00	0.05	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lazydaisy	0.00	0.00	0.10	0.00	0.10	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Bundleflower	0.00	0.00	0.10	0.00	0.05	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Indian blanket	0.00	0.00	0.10	0.00	0.05	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Sunflower	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Duckweed	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas bluebonnet	0.00	0.00	0.10	0.00	0.05	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Prairie coneflower	0.00	0.00	0.10	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Bush sunflower	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Orange zexmenia	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table C.20 (Cont.)

Shaded Species	Shading Species												
	crmesq	grsprn	vinmsq	switch	ltlblue	indian	Johnsn	talldrp	snddrp	Txwntr	wheat	fltsedg	spkrsh
Pecan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar hackberry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas persimmon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ashe juniper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mesquite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Red oak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Live oak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prairie baccharis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Elbowbush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agarito	0.00	0.00	0.00	0.05	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Sacahuista	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Evergreen sumac	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yucca	0.00	0.00	0.00	0.02	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Mustang grape	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prickly pear	0.00	0.00	0.00	0.02	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Giant cane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Purple threeawn	0.00	0.00	0.00	0.10	0.05	0.10	0.10	0.03	0.00	0.00	0.00	0.00	0.00
Cane bluestem	0.00	0.00	0.00	0.02	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
KR bluestem	0.00	0.00	0.00	0.05	0.01	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Sideoats grama	0.00	0.00	0.00	0.02	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Hairy grama	0.00	0.00	0.00	0.10	0.05	0.10	0.10	0.03	0.00	0.00	0.00	0.03	0.00
Red grama	0.00	0.00	0.00	0.10	0.05	0.10	0.10	0.03	0.00	0.00	0.00	0.05	0.00
Bermudagrass	0.00	0.00	0.00	0.10	0.05	0.05	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Canada wildrye	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plains lovegrass	0.00	0.00	0.00	0.02	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Texas cupgrass	0.00	0.00	0.00	0.02	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Curly mesquite	0.00	0.00	0.00	0.10	0.05	0.10	0.10	0.03	0.00	0.00	0.00	0.03	0.00
Green sprangletop	0.00	0.00	0.00	0.05	0.02	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Vine-mesquite	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Switchgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Little bluestem	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indiangrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Johnsongrass	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tall dropseed	0.00	0.00	0.00	0.03	0.01	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Sand dropseed	0.00	0.00	0.00	0.05	0.03	0.05	0.05	0.03	0.00	0.00	0.00	0.00	0.00
Texas wintergrass	0.00	0.00	0.00	0.05	0.01	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Wheat	0.00	0.00	0.00	0.10	0.05	0.10	0.10	0.05	0.00	0.00	0.00	0.03	0.00
Flatsedge	0.00	0.00	0.00	0.10	0.05	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Spikerush	0.00	0.00	0.00	0.05	0.02	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Bulrush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cattail	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ragweed	0.00	0.00	0.00	0.10	0.05	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Lazydaisy	0.00	0.00	0.00	0.10	0.07	0.10	0.10	0.05	0.00	0.00	0.00	0.05	0.00
Bundleflower	0.00	0.00	0.00	0.10	0.07	0.10	0.10	0.04	0.00	0.00	0.00	0.01	0.00
Indian blanket	0.00	0.00	0.00	0.10	0.05	0.10	0.10	0.04	0.00	0.00	0.00	0.02	0.00
Sunflower	0.00	0.00	0.00	0.05	0.01	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Duckweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Texas bluebonnet	0.00	0.00	0.00	0.10	0.05	0.10	0.10	0.05	0.00	0.00	0.00	0.02	0.00
Prairie coneflower	0.00	0.00	0.00	0.10	0.03	0.10	0.10	0.02	0.00	0.00	0.00	0.01	0.00
Bush sunflower	0.00	0.00	0.00	0.05	0.01	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Orange zexmenia	0.00	0.00	0.00	0.05	0.02	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table C.20 (Cont.)

Shaded Species	Shading Species											
	bulrsh	cattail	ragwed	lazdsy	bundfl	indblnk	sunflr	duckwd	Txblb	coneflr	bshsun	zexmn
Pecan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar hackberry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas persimmon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ashe juniper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mesquite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Red oak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Live oak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prairie baccharis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Elbowbush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agarito	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sacahuista	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Evergreen sumac	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yucca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mustang grape	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prickly pear	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Giant cane	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Purple threeawn	0.10	0.10	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.01
Cane bluestem	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KR bluestem	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sideoats grama	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hairy grama	0.10	0.10	0.05	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.04	0.01
Red grama	0.10	0.10	0.05	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.05	0.02
Bermudagrass	0.05	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canada wildrye	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plains lovegrass	0.05	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas cupgrass	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Curly mesquite	0.10	0.10	0.05	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.01
Green sprangletop	0.05	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vine-mesquite	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Switchgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Little bluestem	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indiangrass	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Johnsongrass	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tall dropseed	0.05	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sand dropseed	0.10	0.10	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas wintergrass	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wheat	0.10	0.10	0.05	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.05	0.02
Flatsedge	0.03	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spikerush	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulrush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cattail	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ragweed	0.08	0.08	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Lazydaisy	0.10	0.10	0.10	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.05	0.02
Bundleflower	0.08	0.08	0.05	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.01
Indian blanket	0.10	0.10	0.10	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.04	0.01
Sunflower	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Duckweed	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas bluebonnet	0.10	0.10	0.10	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.03	0.01
Prairie coneflower	0.10	0.10	0.10	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.03	0.01
Bush sunflower	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Orange zexmenia	0.08	0.08	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.00

Appendix Table C.21 Cattle preference factors for plant parts, by species, in the Upper Llano EDYS model. Values are relative rankings (1 = highest, 23 = lowest). High rankings indicate the plant part and species is highly preferred by cattle.

Species	CRoots	FRoots	Trunk	Stems	Leaves	Seeds	SDStms	SDLvs	SdlgR	SdlgS	SeedBank
Pecan	20	19	22	16	11	19	19	13	8	7	19
Sugar hackberry	20	19	22	15	10	15	19	11	6	5	17
Texas persimmon	20	19	22	17	10	4	19	12	6	5	17
Ashe juniper	21	19	23	16	15	16	19	17	9	8	17
Mesquite	20	19	22	17	14	3	19	15	8	7	17
Red oak	20	19	22	17	12	16	19	13	7	6	16
Live oak	20	19	22	17	13	16	19	15	7	6	16
Prairie baccharis	19	18	21	15	11	12	18	17	7	6	17
Elbowbush	19	18	21	15	7	15	16	9	6	5	17
Agarito	19	18	21	16	16	16	18	17	7	6	17
Sacahuista	19	18	20	16	11	16	18	17	8	7	17
Evergreen sumac	19	18	20	16	10	11	18	12	7	6	17
Yucca	19	18	20	16	11	3	18	17	8	7	17
Mustang grape	19	18	21	16	9	4	18	11	6	5	17
Prickly pear	19	18	20	8	8	3	18	18	3	2	17
Giant cane	19	18	15	11	4	5	18	8	5	4	17
Purple threeawn	18	17	5	3	3	3	4	4	3	2	17
Cane bluestem	18	17	5	2	2	2	4	4	2	1	10
King Ranch bluestem	18	17	5	2	2	2	5	5	2	1	9
Sideoats grama	18	17	4	1	1	1	3	3	2	1	8
Hairy grama	18	17	4	2	2	2	3	3	3	2	8
Red grama	18	17	4	3	3	3	3	3	3	2	8
Bermudagrass	18	17	4	1	1	1	3	3	2	1	8
Canada wildrye	18	17	5	2	2	2	4	4	2	1	9
Plains lovegrass	18	17	4	1	1	1	3	3	2	1	8
Texas cupgrass	18	17	4	1	1	1	3	3	2	1	7
Curly mesquite	18	17	4	1	1	1	3	3	3	2	8
Green sprangletop	18	17	4	1	1	1	3	3	2	1	8
Vine-mesquite	18	17	4	1	1	1	3	3	2	1	6
Switchgrass	18	17	5	1	1	1	4	4	2	1	8
Little bluestem	18	17	5	2	2	2	4	4	2	1	9
Indiangrass	18	17	5	1	1	1	4	4	2	1	3
Johnsongrass	18	17	4	1	1	1	4	4	2	1	3
Tall dropseed	18	17	5	2	2	2	4	4	3	2	8
Sand dropseed	18	17	4	2	2	2	3	3	2	1	8
Texas wintergrass	18	17	4	1	1	1	3	3	3	2	9
Wheat	18	16	2	1	1	1	5	5	2	1	3
Flatsedge	18	17	6	4	3	3	5	5	3	2	9
Spikerush	18	17	6	3	3	3	5	5	3	2	9
Bulrush	18	17	9	9	6	9	18	8	4	3	10
Cattail	18	17	9	9	6	9	18	8	4	3	10
Ragweed	18	17	11	9	9	9	16	16	5	3	8
Lazydaisy	18	17	4	3	3	3	5	5	3	2	8
Bundleflower	18	17	4	3	3	3	5	5	2	1	8
Indian blanket	18	17	5	4	4	4	6	6	3	2	8
Sunflower	18	17	9	9	6	5	19	9	4	3	6
Duckweed	18	17	3	3	3	3	4	4	2	1	8
Texas bluebonnet	18	17	5	5	5	5	6	6	4	3	8
Prairie coneflower	18	17	5	4	4	4	6	6	2	1	8
Bush sunflower	18	17	9	9	7	7	17	8	4	3	7
Orange zexmenia	18	17	5	3	3	3	4	4	2	1	7

SD Stems = standing dead stems; SDLvs = standing dead leaves; SdlgR = seedling roots; SdlgS = seedling shoots.

Appendix Table C.22 Cattle competition factors for plant parts, by species, in the Upper Llano EDYS model. Values are relative rankings among competing herbivores for the respective plant material (1 = most competitive of the herbivores, 6 = least competitive).

Species	CRoots	FRoots	Trunk	Stems	Leaves	Seeds	SDStms	SDLvs	SdlgR	SdlgS	SeedBank
Pecan	6	6	6	5	5	5	5	5	6	6	6
Sugar hackberry	6	6	6	5	5	5	5	5	6	6	6
Texas persimmon	6	6	6	5	5	5	5	5	6	6	6
Ashe juniper	6	6	6	5	5	5	5	5	6	6	6
Mesquite	6	6	6	5	5	5	5	5	6	6	6
Red oak	6	6	6	5	5	5	5	5	6	6	6
Live oak	6	6	6	5	5	5	5	5	6	6	6
Prairie baccharis	6	6	6	5	5	5	5	5	6	6	6
Elbowbush	6	6	6	5	5	5	5	5	6	6	6
Agarito	6	6	6	6	6	6	6	6	6	6	6
Sacahuista	6	6	6	6	6	6	6	6	6	6	6
Evergreen sumac	6	6	6	6	5	5	5	5	6	6	6
Yucca	6	6	6	6	6	6	6	6	6	6	6
Mustang grape	6	6	6	5	5	5	5	5	6	6	6
Prickly pear	6	6	6	6	6	6	6	6	6	6	6
Giant cane	6	6	6	5	5	5	5	5	6	6	6
Purple threeawn	6	6	6	6	6	6	6	6	6	6	6
Cane bluestem	6	6	6	6	6	5	6	6	6	6	6
King Ranch bluestem	6	6	6	6	6	6	6	6	6	6	6
Sideoats grama	6	6	6	6	6	5	6	6	6	6	6
Hairy grama	6	6	6	6	6	6	6	6	6	6	6
Red grama	6	6	6	6	6	6	6	6	6	6	6
Bermudagrass	6	6	6	6	6	6	6	6	6	6	6
Canada wildrye	6	6	6	6	6	6	6	6	6	6	6
Plains lovegrass	6	6	6	6	6	6	6	6	6	6	6
Texas cupgrass	6	6	6	6	6	6	6	6	6	6	6
Curly mesquite	6	6	6	6	6	6	6	6	6	6	6
Green sprangletop	6	6	6	6	6	6	6	6	6	6	6
Vine-mesquite	6	6	6	6	6	6	6	6	6	6	6
Switchgrass	6	6	6	6	6	5	6	6	6	6	6
Little bluestem	6	6	6	6	6	5	6	6	6	6	6
Indiangrass	6	6	6	6	6	5	6	6	6	6	6
Johnsongrass	6	6	6	6	6	5	6	6	6	6	6
Tall dropseed	6	6	6	6	6	5	6	6	6	6	6
Sand dropseed	6	6	6	6	6	6	6	6	6	6	6
Texas wintergrass	6	6	6	6	6	6	6	6	6	6	6
Wheat	6	6	6	6	6	6	6	6	6	6	6
Flatsedge	6	6	6	6	6	5	6	6	6	6	6
Spikerush	6	6	6	6	6	6	6	6	6	6	6
Bulrush	6	6	5	5	5	5	5	5	5	5	5
Cattail	6	6	5	5	5	5	5	5	5	5	5
Ragweed	6	6	6	6	6	5	6	6	6	6	6
Lazydaisy	6	6	6	6	6	6	6	6	6	6	6
Bundleflower	6	6	6	6	6	6	6	6	6	6	6
Indian blanket	6	6	6	6	6	6	6	6	6	6	6
Sunflower	6	6	6	6	6	5	6	6	6	6	6
Duckweed	4	4	4	4	4	4	4	4	4	4	4
Texas bluebonnet	6	6	6	6	6	6	6	6	6	6	6
Prairie coneflower	6	6	6	6	6	6	6	6	6	6	6
Bush sunflower	6	6	6	6	6	6	6	6	6	6	6
Orange zexmenia	6	6	6	6	6	6	6	6	6	6	6

SDStems = standing dead stems; SDLvs = standing dead leaves; SdlgR = seedling roots; SdlgS = seedling shoots. Competing herbivores: cattle, white-tailed deer, axis deer, feral hogs, rabbits, insects (grasshoppers).

Appendix Table C.23. Accessibility of plant parts, by species, for consumption by cattle in the Upper Llano EDYS model. Values are percentages of standing crop biomass of mature plants that could be accessed by cattle.

Species	CRoot	FRoot	Trunk	Stems	Leavs	Seeds	SDStm	SDLv	SdlgR	SdlgS	SeedBank
Pecan	00	00	01	01	01	00	01	01	00	80	05
Sugar hackberry	00	00	01	02	02	01	02	02	00	25	00
Texas persimmon	00	00	01	05	05	02	05	05	00	50	00
Ashe juniper	00	00	02	25	25	10	25	25	00	50	00
Mesquite	00	00	01	10	10	10	10	10	00	40	02
Red oak	00	00	01	05	05	04	05	05	00	50	02
Live oak	00	00	01	05	05	04	05	05	00	50	02
Prairie baccharis	00	00	05	90	90	50	90	90	00	10	00
Elbowbush	00	00	10	95	90	70	90	90	00	10	00
Agarito	00	00	80	95	95	95	95	95	00	05	00
Sacahuista	00	00	80	90	95	90	90	95	00	05	00
Evergreen sumac	00	00	10	50	50	40	50	50	00	50	00
Yucca	00	00	90	90	95	95	90	95	00	05	00
Mustang grape	00	00	05	05	05	04	05	05	00	05	00
Prickly pear	00	00	50	95	95	95	95	95	00	05	00
Giant cane	00	00	20	80	80	50	80	80	00	20	00
Purple threeawn	00	00	05	95	95	90	95	95	00	05	00
Cane bluestem	00	00	05	95	95	90	95	95	00	10	00
King Ranch bluestem	00	00	05	90	90	95	90	90	00	05	00
Sideoats grama	00	00	05	95	95	90	95	95	00	10	00
Hairy grama	00	00	02	90	90	90	90	90	00	02	00
Red grama	00	00	02	80	85	80	80	85	00	01	00
Bermudagrass	00	00	02	80	80	80	80	80	00	02	00
Canada wildrye	00	00	05	95	95	95	95	95	00	10	00
Plains lovegrass	00	00	05	95	95	95	95	95	00	05	00
Texas cupgrass	00	00	05	95	95	90	95	95	00	10	00
Curly mesquite	00	00	02	80	85	85	80	85	00	05	00
Green sprangletop	00	00	05	95	95	95	95	95	00	10	00
Vine-mesquite	00	00	05	80	85	90	80	85	00	05	00
Switchgrass	00	00	05	95	95	95	95	95	00	10	00
Little bluestem	00	00	05	95	95	95	95	95	00	10	00
Indiangrass	00	00	05	95	95	95	95	95	00	10	00
Johsongrass	00	00	05	95	95	95	95	95	00	10	00
Tall dropseed	00	00	05	95	95	95	95	95	00	10	00
Sand dropseed	00	00	05	95	95	90	95	95	00	05	00
Texas wintergrass	00	00	05	90	90	90	90	90	00	05	00
Wheat	00	00	05	95	95	95	95	95	00	10	01
Flatsedge	00	00	05	90	85	90	90	85	00	05	00
Spikerush	01	01	02	60	60	80	60	60	00	01	00
Bulrush	05	05	50	90	90	80	90	90	00	10	00
Cattail	05	05	50	90	90	80	90	90	00	10	00
Ragweed	00	00	05	95	95	95	95	95	00	05	00
Lazydaisy	00	00	01	90	70	80	90	70	00	01	00
Bundleflower	00	00	05	90	80	80	90	80	00	02	00
Indian blanket	00	00	02	90	60	80	90	60	00	01	00
Sunflower	00	00	05	95	95	90	95	95	00	05	00
Duckweed	05	05	10	90	90	90	90	90	00	00	00
Texas bluebonnet	00	00	02	90	70	90	90	70	00	05	00
Prairie coneflower	00	00	02	90	70	90	90	70	00	05	00
Bush sunflower	00	00	05	90	85	95	90	85	00	05	00
Orange zexmenia	00	00	05	90	85	90	90	85	00	05	00

SDStm = standing dead stems; SDLv = standing dead leaves; SdlgR = seedling roots; SdlgS = seedling shoots.

Appendix Table C.24 White-tailed deer preference factors for plant parts, by species, in the Upper Llano EDYS model. Values are relative rankings (1 = highest, 20 = lowest). High rankings indicate the plant part and species is highly preferred by white-tailed deer.

Species	CRoots	FRoots	Trunk	Stems	Leaves	Seeds	SDStems	SDLvs	SdlgR	SdlgS	SeedBank
Pecan	18	17	19	14	3	17	18	6	3	3	18
Sugar hackberry	18	17	19	8	1	3	18	3	1	1	18
Texas persimmon	18	17	19	8	2	2	18	4	2	2	18
Ashe juniper	18	17	19	14	8	6	18	10	7	7	18
Mesquite	19	18	20	16	10	3	18	12	8	8	19
Red oak	19	18	20	15	3	4	18	6	3	3	17
Live oak	19	18	20	15	3	4	18	6	3	3	17
Prairie baccharis	15	14	16	14	8	9	18	10	7	7	18
Elbowbush	15	14	16	12	2	2	18	4	2	2	18
Agarito	16	15	17	16	15	4	18	17	13	13	18
Sacahuista	14	13	15	14	11	12	18	13	10	10	18
Evergreen sumac	15	14	16	13	5	4	18	7	4	4	18
Yucca	14	13	15	13	12	1	18	14	11	11	18
Mustang grape	15	14	16	13	3	1	18	5	2	2	18
Prickly pear	14	13	15	3	19	2	8	20	2	2	18
Giant cane	12	13	15	13	3	12	18	7	3	3	19
Purple threeawn	5	4	6	5	5	5	7	7	4	4	19
Cane bluestem	4	3	5	4	1	1	8	5	1	1	18
KR bluestem	3	2	4	3	1	1	6	5	1	1	18
Sideoats grama	3	2	4	3	1	1	6	4	1	1	17
Hairy grama	4	3	5	4	4	5	5	5	3	3	18
Red grama	4	3	5	4	4	4	5	5	3	3	18
Bermudagrass	4	3	5	4	3	3	6	5	2	2	18
Canada wildrye	3	2	4	3	1	1	6	4	1	1	18
Plains lovegrass	3	2	4	3	2	2	6	4	1	1	18
Texas cupgrass	2	1	3	2	1	1	5	3	1	1	18
Curly mesquite	2	1	3	2	2	2	3	3	1	1	18
Green sprangletop	3	2	4	3	2	2	6	4	1	1	18
Vine-mesquite	2	1	3	2	1	1	5	3	1	1	17
Switchgrass	3	2	4	3	1	1	9	4	1	1	18
Little bluestem	3	2	4	3	1	1	9	5	1	1	18
Indiangrass	3	2	4	3	1	1	9	5	1	1	17
Johnsongrass	2	2	3	2	1	1	7	4	1	1	17
Tall dropseed	4	3	5	4	3	2	7	5	2	2	18
Sand dropseed	4	3	5	4	3	2	7	5	2	2	18
Texas wintergrass	3	2	4	3	2	3	5	4	1	1	19
Wheat	1	1	2	1	1	1	10	3	1	1	16
Flatsedge	6	5	7	6	4	6	9	7	3	3	18
Spikerush	4	3	5	4	4	4	7	7	3	3	18
Bulrush	12	11	13	12	7	7	15	10	5	5	18
Cattail	8	12	13	12	7	7	15	10	5	5	18
Ragweed	6	5	7	6	5	4	9	7	3	3	18
Lazydaisy	1	1	2	1	1	1	3	3	1	1	18
Bundleflower	1	1	2	1	1	1	3	3	1	1	18
Indian blanket	1	1	2	1	1	1	5	4	1	1	18
Sunflower	6	5	7	6	5	2	10	7	3	3	5
Duckweed	3	2	4	3	3	3	5	5	2	2	18
Texas bluebonnet	6	5	7	6	6	5	8	8	5	5	18
Prairie coneflower	1	1	2	1	1	1	4	3	1	1	18
Bush sunflower	4	3	5	4	3	3	7	5	2	2	18
Orange zexmenia	3	2	4	3	1	1	5	3	1	1	18

SDStems = standing dead stems; SDLvs = standing dead leaves; SdlgR = seedling roots; SdlgS = seedling shoots.

Appendix Table C.25 White-tailed deer competition factors for plant parts, by species, in the Upper Llano EDYS model. Values are relative rankings among competing herbivores for the respective plant material (1 = most competitive of the herbivores, 6 = least competitive).

Species	CRoots	FRoot	Trunk	Stems	Leaves	Seeds	SDStems	SDLvs	SdlgR	SdlgS	SeedBank
Pecan	5	5	5	4	4	4	4	4	5	5	5
Sugar hackberry	5	5	5	4	4	4	4	4	5	5	5
Texas persimmon	5	5	5	4	4	4	4	4	5	5	5
Ashe juniper	5	5	5	4	4	4	4	4	5	5	5
Mesquite	5	5	5	4	4	4	4	4	5	5	5
Red oak	5	5	5	4	4	4	4	4	5	5	5
Live oak	5	5	5	4	4	4	4	4	5	5	5
Prairie baccharis	5	5	5	5	4	4	4	4	5	5	5
Elbowbush	5	5	5	5	4	4	4	4	5	5	5
Agarito	5	5	5	5	5	5	5	5	5	5	5
Sacahuista	5	5	5	5	5	5	5	5	5	5	5
Evergreen sumac	5	5	5	5	4	4	4	4	5	5	5
Yucca	5	5	5	5	5	5	5	5	5	5	5
Mustang grape	5	5	5	4	4	3	4	4	5	5	5
Prickly pear	5	5	5	5	5	5	5	5	5	5	5
Giant cane	5	5	5	4	4	4	4	4	5	5	5
Purple threeawn	5	5	5	5	5	5	5	5	5	5	5
Cane bluestem	5	5	5	5	5	4	5	5	5	5	5
KR bluestem	5	5	5	5	5	5	5	5	5	5	5
Sideoats grama	5	5	5	5	5	4	5	5	5	5	5
Hairy grama	5	5	5	5	5	5	5	5	5	5	5
Red grama	5	5	5	5	5	5	5	5	5	5	5
Bermudagrass	5	5	5	5	5	5	5	5	5	5	5
Canada wildrye	5	5	5	5	5	5	5	5	5	5	5
Plains lovegrass	5	5	5	5	5	5	5	5	5	5	5
Texas cupgrass	5	5	5	5	5	5	5	5	5	5	5
Curly mesquite	5	5	5	5	5	5	5	5	5	5	5
Green sprangletop	5	5	5	5	5	5	5	5	5	5	5
Vine-mesquite	5	5	5	5	5	5	5	5	5	5	5
Switchgrass	5	5	5	5	5	4	5	5	5	5	5
Little bluestem	5	5	5	5	5	4	5	5	5	5	5
Indiangrass	5	5	5	5	5	4	5	5	5	5	5
Johnsongrass	5	5	5	5	5	4	5	5	5	5	5
Tall dropseed	5	5	5	5	5	4	5	5	5	5	5
Sand dropseed	5	5	5	5	5	5	5	5	5	5	5
Texas wintergrass	5	5	5	5	5	5	5	5	5	5	5
Wheat	5	5	5	5	5	5	5	5	5	5	5
Flatsedge	5	5	5	5	5	4	5	5	5	5	5
Spikerush	5	5	5	5	5	5	5	5	5	5	5
Bulrush	5	5	4	4	4	4	4	4	4	4	4
Cattail	5	5	4	4	4	4	4	4	4	4	4
Ragweed	5	5	5	5	5	4	5	5	5	5	5
Lazydaisy	5	5	5	5	5	5	5	5	5	5	5
Bundleflower	5	5	5	5	5	5	5	5	5	5	5
Indian blanket	5	5	5	5	5	5	5	5	5	5	5
Sunflower	5	5	5	5	5	4	5	5	5	5	5
Duckweed	3	3	3	3	3	3	3	3	3	3	3
Texas bluebonnet	5	5	5	5	5	5	5	5	5	5	5
Prairie coneflower	5	5	5	5	5	5	5	5	5	5	5
Bush sunflower	5	5	5	5	5	5	5	5	5	5	5
Orange zexmenia	5	5	5	5	5	5	5	5	5	5	5

SDStems = standing dead stems; SDLvs = standing dead leaves; SdlgR = seedling roots; SdlgS = seedling shoots. Competing herbivores: cattle, white-tailed deer, axis deer, feral hogs, rabbits, insects (grasshoppers).

Appendix Table C.26 Accessibility of plant parts, by species, for consumption by white-tailed deer in the Upper Llano EDYS model. Values are percentages of standing crop biomass of mature plants that could be accessed by white-tailed deer.

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SDStem	SDLvs	SdlgR	SdlgS	SeedBank
Pecan	00	00	01	05	04	01	05	04	00	95	05
Sugar hackberry	00	00	01	05	04	01	05	04	20	90	01
Texas persimmon	00	00	05	20	20	10	20	20	20	95	02
Ashe juniper	00	00	05	25	30	20	25	30	10	90	01
Mesquite	00	00	02	20	20	10	20	20	05	75	05
Red oak	00	00	01	10	10	05	10	10	05	90	05
Live oak	00	00	01	15	15	05	15	15	05	90	05
Prairie baccharis	00	00	10	50	50	05	50	50	05	75	00
Elbowbush	00	00	25	90	90	50	90	90	05	75	01
Agarito	00	00	50	95	95	90	95	95	05	50	01
Sacahuista	00	00	90	95	95	90	95	95	05	50	00
Evergreen sumac	00	00	10	50	50	50	50	50	05	90	00
Yucca	00	00	90	95	95	95	95	95	10	80	01
Mustang grape	00	00	20	05	05	05	05	05	05	90	00
Prickly pear	01	00	90	95	95	95	95	95	10	80	00
Giant cane	01	01	50	70	80	01	70	80	01	90	00
Purple threeawn	00	00	80	90	90	90	90	90	10	50	00
Cane bluestem	00	00	80	90	90	90	90	90	10	70	00
KR bluestem	01	00	80	80	80	90	80	80	10	60	00
Sideoats grama	01	00	80	90	90	90	90	90	10	70	00
Hairy grama	00	00	70	90	90	90	90	90	05	30	00
Red grama	00	00	70	90	90	90	90	90	05	25	00
Bermudagrass	01	00	50	80	80	90	80	80	05	25	00
Canada wildrye	00	00	80	90	90	90	90	90	10	70	01
Plains lovegrass	00	00	80	90	90	90	90	90	10	60	00
Texas cupgrass	00	00	80	90	90	90	90	90	10	70	00
Curly mesquite	00	00	50	80	80	90	80	80	05	30	00
Green sprangletop	00	00	70	90	90	90	90	90	10	60	00
Vine-mesquite	01	00	60	80	80	90	80	80	05	60	00
Switchgrass	00	00	70	90	90	80	90	90	10	70	00
Little bluestem	00	00	80	90	90	90	90	90	10	70	00
Indiangrass	00	00	80	90	90	90	90	90	10	70	01
Johnsongrass	01	00	80	90	90	90	90	90	10	70	01
Tall dropseed	00	00	80	90	90	90	90	90	05	60	00
Sand dropseed	00	00	80	90	90	90	90	90	05	50	00
Texas wintergrass	00	00	70	90	90	80	90	90	05	40	00
Wheat	02	01	90	95	95	95	95	95	10	90	50
Flatsedge	00	00	80	80	80	90	80	80	10	60	00
Spikerush	02	00	50	90	90	90	90	90	05	40	00
Bulrush	05	05	50	70	80	50	70	80	10	50	00
Cattail	10	05	50	80	90	50	80	90	10	60	00
Ragweed	00	00	90	90	90	90	90	90	05	25	00
Lazydaisy	00	00	90	90	90	95	90	90	05	25	00
Bundleflower	00	00	80	90	90	90	90	90	05	25	00
Indian blanket	00	00	70	90	90	95	90	90	05	30	00
Sunflower	00	00	90	95	95	90	95	95	10	50	01
Duckweed	10	10	90	80	80	80	80	80	25	50	00
Texas bluebonnet	00	00	70	90	90	95	90	90	05	25	05
Prairie coneflower	00	00	70	90	90	95	90	90	05	25	00
Bush sunflower	00	00	80	90	90	95	90	90	05	30	00
Orange zexmenia	00	00	80	90	90	90	90	90	05	30	00

SDStem = standing dead stems; SDLvs = standing dead leaves; SdlgR = seedling roots; SdlgS = seedling shoots.

APPENDIX D ANIMAL DATA

Appendix Table D.1 Estimation of cattle stocking rates (moderate level) for vegetation plot types in the three spatial domains (Edwards-Real, Kimble, Sutton) of the Upper Llano EDYS model. Values assume fair range condition and no woody plant cover.

Range Type	Soil Type	Annual Forage (g/m ²)	Available Forage (g/m ²)	AU Forage Requirement (g/AUD)(365 d)	Stocking Rate (m ² /AU)	(ac/AU)
Edwards-Real						
Clay flat	IrA	110	55	5,151,975	93,690	20.67
Clay loam	RdB	225	112	5,151,975	45,998	11.36
Deep redland	LkB	267	133	5,151,975	38,737	9.57
Draw	DeB	130	65	5,151,975	79,261	19.58
Gravelly redland	DnD	270	135	5,151,975	38,155	9.43
Limestone hill	ErB	115	57	5,151,975	90,386	22.33
Loamy bottomland	OdA	375	187	5,151,975	27,551	6.81
Low stony hill	EcF	197	98	5,151,975	52,571	12.99
Shallow	PTD	188	94	5,151,975	44,170	10.91
Steep rocky	EcF	197	98	5,151,975	52,571	12.99
Very shallow	PeB	155	77	5,151,975	66,909	16.53
Mean						13.93
Kimble						
Clay flat	TsA	245	122	5,151,975	42,229	10.43
Clay loam	NuB	214	107	5,151,975	48,149	11.89
Draw	De	260	130	5,151,975	39,631	9.79
Loamy bottomland	Fr	290	145	5,151,975	35,531	8.78
Low stony hill	TaC	129	64	5,151,975	80,500	19.89
Red sandy loam	OhC	120	60	5,151,975	85,866	21.21
Sandy loam	MnB	192	96	5,151,975	53,666	13.26
Shallow	KTB	131	65	5,151,975	79,261	19.58
Steep adobe	RbF	100	50	5,151,975	103,040	25.45
Steep rocky	TrG	132	66	5,151,975	78,060	19.28
Very shallow	CoC	100	50	5,151,975	103,040	25.45
Mean						16.82
Sutton						
Clay flat	Tc	245	122	5,151,975	42,229	10.43
Clay loam	Ky	235	117	5,151,975	44,035	10.88
Draw	3	200	100	5,151,975	51,520	12.73
Limestone hill	Es	172	86	5,151,975	59,907	14.80
Loamy	Rc	235	117	5,151,975	44,035	10.88
Loamy bottomland	FD	290	145	5,151,975	35,531	8.78
Low stony hill	Ts	172	86	5,151,975	59,907	14.80
Shallow	Kt	173	86	5,151,975	59,907	14.80
Steep rocky	Tr	172	86	5,151,975	59,907	14.80
Very shallow	2	160	80	5,151,975	64,400	15.91
Mean						12.88

Soil types are listed in Table 5.1 and range types in Table 6.6.

Annual Forage = fair range condition (Appendix Tables B.1-B.3).

Available Forage = (Annual forage)(0.5), where 0.5 is proper management harvest rate.

AU Forage Requirement = 14,115 g/AUD (Tables 7.1 and 7.2).

Stocking Rate = (AU Forage Requirement)/(Available Forage)

Appendix Table D.2 Estimated cattle stocking rates accounting for woody plant cover (average woody plant cover per EDYS type) in the three spatial domains of the Upper Llano EDYS model. Moderate stocking and fair range condition are assumed.

Range Type	Woody Cover (%)	Available Forage (g/m ²)	Stocking Rate (m ² /AU)	Stocking Rate (ac/AU)
Edwards-Real				
Clay flat	0	55	93,690	20.67
Clay flat	5	53	97,207	24.01
Clay flat	18	47	109,616	27.08
Clay flat	83	18	286,221	70.71
Clay loam	5	108	47,703	11.78
Clay loam	18	96	53,666	13.26
Clay loam	38	78	66,051	16.32
Clay loam	63	56	92,000	22.73
Clay loam	83	37	139,243	34.40
Clay loam	95	27	190,814	47.14
Deep redland	5	128	40,250	9.97
Deep redland	18	115	44,800	11.07
Deep redland	38	93	55,398	13.68
Deep redland	63	66	78,060	19.28
Draw	5	62	83,096	20.53
Draw	18	56	92,000	22.73
Draw	38	46	112,000	27.67
Draw	63	32	160,999	39.77
Draw	83	22	234,181	57.85
Draw	95	16	321,998	79.54
Gravelly redland	5	130	39,631	9.81
Gravelly redland	18	117	44,034	10.88
Gravelly redland	38	95	54,231	13.40
Gravelly redland	63	67	76,895	19.00
Gravelly redland	83	45	114,488	28.28
Limestone hill	5	55	93,672	23.14
Limestone hill	18	49	105,142	25.97
Limestone hill	38	40	128,799	31.82
Limestone hill	63	28	183,999	45.45
Limestone hill	83	19	271,157	66.98
Loamy bottomland	5	180	28,622	7.07
Loamy bottomland	18	161	32,000	7.91
Loamy bottomland	38	141	36,539	9.03
Loamy bottomland	63	93	55,398	13.68
Loamy bottomland	83	62	83,096	20.53
Loamy bottomland	95	45	114,488	28.28
Low stony hill	5	94	54,808	13.54
Low stony hill	18	84	61,333	15.15
Low stony hill	38	69	74,666	18.45
Low stony hill	63	49	105,142	25.97
Low stony hill	83	33	156,120	38.57
Low stony hill	95	24	214,666	53.03
Shallow	5	90	57,244	14.14
Shallow	18	81	63,605	15.71
Shallow	38	66	78,060	19.28
Shallow	63	47	109,616	27.08
Shallow	83	31	166,193	41.06
Shallow	95	23	223,999	55.34
Steep rocky	5	94	54,808	13.54
Steep rocky	18	84	61,333	15.15
Steep rocky	38	69	74,666	18.45
Steep rocky	63	49	105,142	25.97
Steep rocky	83	33	156,120	38.57
Steep rocky	95	24	214,666	53.03
Very shallow	5	74	69,621	17.20
Very shallow	18	66	78,060	19.28
Very shallow	38	54	95,407	23.57
Very shallow	63	38	135,578	33.49
Very shallow	83	26	198,153	48.95
Very shallow	95	18	286,221	70.71

Appendix Table D.2 (cont.)

Range Type	Woody Cover (%)	Available Forage (g/m ²)	Stocking Rate (m ² /AU)	Stocking Rate (ac/AU)
Kimble				
Clay flat	5	117	44,034	10.88
Clay flat	38	86	59,907	14.80
Clay loam	5	103	50,019	12.36
Clay loam	18	92	56,000	13.83
Clay loam	38	75	68,693	16.97
Clay loam	63	53	97,207	24.01
Clay loam	83	36	143,110	35.35
Clay loam	95	26	198,153	48.95
Draw	5	125	41,216	10.18
Draw	18	112	46,000	11.36
Draw	38	91	56,615	13.99
Draw	63	65	79,261	19.58
Draw	83	43	119,813	29.60
Draw	95	31	166,193	41.06
Loamy bottomland	5	139	37,065	9.16
Loamy bottomland	18	125	41,216	10.18
Loamy bottomland	38	102	50,117	12.38
Loamy bottomland	63	72	71,555	17.68
Loamy bottomland	83	48	107,333	26.52
Loamy bottomland	95	35	147,199	36.36
Low stony hill	5	61	84,459	20.86
Low stony hill	18	55	93,672	23.14
Low stony hill	38	45	114,488	28.28
Low stony hill	63	32	160,999	39.77
Low stony hill	83	21	245,332	60.61
Low stony hill	95	15	343,465	84.85
Red sandy loam	18	50	103,039	25.45
Red sandy loam	63	30	171,732	42.42
Sandy loam	38	67	76,895	19.00
Sandy loam	63	48	107,333	26.52
Shallow	0	65	79,261	19.58
Shallow	5	62	83,096	20.53
Shallow	18	56	92,000	22.73
Shallow	38	46	112,000	27.67
Shallow	63	32	160,999	39.77
Shallow	83	22	234,181	57.85
Shallow	95	16	321,998	79.54
Steep adobe	5	48	107,333	26.52
Steep adobe	18	43	119,813	29.60
Steep adobe	38	35	147,199	36.36
Steep adobe	63	25	206,079	50.91
Steep adobe	83	17	303,057	74.87
Steep adobe	95	12	429,248	106.04
Steep rocky	5	63	81,777	20.20
Steep rocky	18	57	90,386	22.33
Steep rocky	38	46	111,999	27.67
Steep rocky	63	33	156,120	38.57
Steep rocky	83	22	234,181	57.85
Steep rocky	95	16	321,998	79.54
Very shallow	5	48	107,333	26.52
Very shallow	18	43	119,813	29.60
Very shallow	38	35	147,199	36.36
Very shallow	63	25	206,079	50.91
Sutton				
Clay flat	0	122	42,229	10.43
Clay flat	5	117	44,034	10.88
Clay flat	18	105	49,066	12.12
Clay flat	38	85	60,611	14.97
Clay flat	63	61	84,459	20.86
Clay flat	83	41	125,658	31.04

Appendix Table D.2 (cont.)

Range Type	Woody Cover (%)	Available Forage (g/m ²)	Stocking Rate (m ² /AU) (ac/AU)	
Clay loam	5	112	46,000	11.36
Clay loam	18	101	51,010	12.60
Clay loam	38	82	62,829	15.52
Clay loam	63	58	88,827	21.94
Clay loam	83	39	132,102	32.61
Clay loam	95	28	183,999	45.45
Draw	5	96	53,666	13.26
Draw	38	70	73,600	18.18
Draw	63	50	103,039	25.45
Limestone hill	5	83	62,072	15.33
Limestone hill	83	29	177,654	43.89
Loamy	38	82	62,829	15.52
Loamy bottomland	5	139	37,065	9.16
Loamy bottomland	18	125	41,216	10.18
Loamy bottomland	38	102	50,117	12.38
Loamy bottomland	63	72	71,555	17.68
Loamy bottomland	83	48	107,333	26.52
Low stony hill	5	83	62,072	15.33
Low stony hill	18	74	69,621	17.20
Low stony hill	38	60	85,866	21.21
Low stony hill	63	43	119,813	29.60
Low stony hill	83	29	177,654	43.89
Low stony hill	95	21	245,332	60.61
Shallow	5	83	62,072	15.33
Shallow	18	74	69,621	17.20
Shallow	38	60	85,866	21.21
Shallow	63	43	119,813	29.60
Shallow	83	29	177,654	43.89
Shallow	95	21	245,332	60.61
Steep rocky	5	83	62,072	15.33
Steep rocky	18	74	69,621	17.20
Steep rocky	38	60	85,866	21.21
Steep rocky	63	43	119,813	29.60
Steep rocky	83	29	177,654	43.89
Very shallow	5	77	66,909	16.53
Very shallow	18	69	74,666	18.45
Very shallow	38	56	92,000	22.73
Very shallow	63	40	128,799	31.82

Available forage adjusted for woody plant cover = (amount at 0% woody cover)[1.00 – (0.8)woody plant cover].

Forage requirement = 14,115 g/AUD (Tables 7.1 and 7.2).

Stocking rate = (forage requirement)(365 days)/(available forage).

Appendix Table D.3 Estimated cattle stocking rates on disturbed sites, accounting for woody plant cover, in the three spatial domains of the Upper Llano EDYS model. Moderate stocking is assumed.

Disturbance Type	Woody Cover (%)	Available Forage (g/m ²)	Stocking Rate	
			(m ² /AU)	(ac/AU)
Edwards-Real				
Brush controlled	5	10	515,198	127.27
Brush controlled	18	96	53,666	13.26
Brush controlled	38	78	66,051	16.32
Pit	5	28	183,999	45.45
Kimble				
Brush controlled	5	10	515,198	127.27
Brush controlled	18	92	56,000	13.83
Brush controlled	38	75	68,693	16.97
Brush controlled	63	53	97,207	24.01
Sutton				
Brush controlled	0	10	515,198	127.27
Brush controlled	5	10	515,198	127.27
Brush controlled	18	101	51,010	12.60
Brush controlled	38	82	62,829	15.52
Brush controlled	63	58	88,827	21.94
Brush controlled	83	39	132,102	32.61
Pits caliche	18	28	183,999	45.45

Available forage for 0 and 5% brush controlled and pits = 0.5(grass biomass value from Appendix Table B.11).

Available forage for 18-83 brush controlled = available forage value for clay loam sites (Appendix Table D.2) at respective woody plant coverage and spatial domain.

Forage requirement = 14,115 g/AUD (Tables 7.1 and 7.2).

Stocking rate = (forage requirement)(365 days)/(available forage).