2018 GROUNDWATER MANAGEMENT PLAN

Goliad County Groundwater Conservation District

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Adopted by GCGCD Board of Directors: _______________

GOLIAD COUNTY GROUNDWATER CONSERVATION DISTRICT MANAGEMENT PLAN 2018

The Goliad County Groundwater Conservation District ("GCGCD") was created in 2001 by authority of HB3651 of the 77th Texas Legislature. The District was created to serve a public use and benefit, and is essential to accomplish the objectives set forth in Section 59, Article XVI, of the Texas Constitution. The District's boundary is coextensive with the boundary of Goliad County and contains 551,040 acres of land with 90 percent of the acreage being utilized as rangeland for livestock production. The District is bounded on the north by DeWitt County, on the east by Victoria County, on the south by Refugio County, and on the west by Bee and Karnes Counties.

DISTRICT MISSION

The mission of the Goliad County Groundwater Conservation District is to develop rules to provide for the protection, preservation, and conservation of groundwater, and to prevent waste of groundwater from the Gulf Coast Aquifer System to the extent of which the District has jurisdiction.

The District is committed to manage and protect the groundwater resources within its jurisdiction and to work with others to ensure a sustainable, adequate, high quality and cost-effective supply of water, now and in the future. The District will strive to develop, promote, and implement water conservation and management strategies to protect water resources for the benefit of the citizens, economy, and environment of the District. The preservation of this most valuable resource can be achieved in a prudent and cost-effective manner through conservation, education, management, and cooperation

STATEMENT OF GUIDING PRINCIPLES

Goliad and surrounding counties have a large agricultural based rural community, which relies heavily on groundwater and exclusively on groundwater during periods of drought. Therefore, groundwater resources are of vital importance to the continued vitality of the citizens, economy and environment within the District area.

Goliad County is located over the recharge area of the Evangeline and Chicot segment of the Gulf Coast Aquifer System. It is imperative that the Gulf Coast Aquifer System be managed on a sustainable basis to protect the many shallow domestic and livestock supply wells in the District and many more in surrounding counties. These drinking water supply wells are the life-blood for maintaining the agricultural economy.

TIME PERIOD OF THIS PLAN

This District Groundwater Management Plan becomes effective immediately following adoption by the Goliad County Groundwater Conservation District Board of Directors and is approved as administratively complete by the Texas Water Development Board. This plan will remain in effect for a period of 5 years or until a revised or amended plan may be approved, whichever comes first.

GROUNDWATER RESOURCES

The outcrop area of the Evangeline Aquifer and the Chicot Aquifer, both components of the Gulf Coast Aquifer System, exist in Goliad County. The outcrop area for the Evangeline Aquifer is in the northern part of Goliad County and the outcrop area for the Chicot Aquifer is in the Southern part of Goliad County. Most of the wells in the County are producing from these two aquifers.

Gulf Coast Aquifer

The Gulf Coast Aquifer System forms a wide belt along the Gulf of Mexico from Florida to Mexico. In Texas, the aquifer provides water to all or parts of 54 counties and extends from the Rio Grande northeastward to the Louisiana-Texas border. Municipal and irrigation uses account for approximately 90 percent of the total pumpage from the aquifer. The aquifer consists of complex interbedded clays, silts, sands, and gravels of Cenozoic Era, which are hydrologically connected to form a large, leaky artesian aquifer system. This system comprises four major components consisting of the following generally recognized water-producing formations. The deepest is the Catahoula, which contains ground water near the outcrop in relatively restricted sand layers. Above the Catahoula is the Jasper Aquifer, primarily contained within the Oakville Sandstone. The Burkeville confining layer separates the Jasper from the overlying Evangeline Aquifer, which is contained within the Fleming and Goliad sands. The Chicot Aquifer, or upper component of the Gulf Coast Aquifer System, consists of the Lissie, Willis, Bentley, Montgomery, and Beaumont formations, and overlying alluvial deposits. Not all formations are present throughout the system, and nomenclature often differs from one end of the system to the other.

Water quality is generally good in the shallower portion of the aquifer. From the San Antonio River Basin southwestward to Mexico, quality deterioration is evident in the form of increased chloride concentration and saltwater encroachment along the coast. Little of this ground water is suitable for prolonged irrigation due to either high salinity or alkalinity, or both. In several areas at or near the coast, including Galveston Island and the central and southern parts of Orange County, heavy municipal or industrial pump age had previously caused an updip migration, or saltwater intrusion, of poor-quality water into the aquifer. Recent reductions in pumpage here have resulted in stabilization and, in some cases, even improvement of ground-water quality. Years of heavy pumpage for municipal and manufacturing use in portions of the aquifer have resulted in areas of significant water-level decline. Declines of 200 feet to 300 feet have been measured in some areas of eastern and southeastern Harris and northern Galveston counties. Other areas of significant water-level declines include the Kingsville area in Kleberg County and portions of Jefferson, Orange, and Wharton counties. Some of these declines have resulted in compaction of dewatered clays and significant land surface subsidence. Subsidence is generally less than 0.5 foot over most of the Texas coast, but has been as much as nine feet in Harris and surrounding counties. As a result, structural damage and flooding have occurred in many low-lying areas along Galveston Bay in Baytown, Texas City, and Houston. Conversion to surface-water use in many of the problem areas has reversed the decline trend. The portion of the Gulf Coast Aquifer System in the Goliad County area contains generally good quality water. The aquifer depth ranges from approximately 450 feet in north Goliad County to approximately 1200 feet in south Goliad County. Reference: Baker, E.T., Jr., 1979, Stratigraphic and hydrologic framework of part of the Coastal Plain of Texas: TWDB Report 236. http://www.twdb.texas.gov/publications/reports/numbered_reports/doc/R236/Report236.asp

GROUNDWATER RECHARGE

Recharge rates for the Major Aquifers (from TWDB Website) are decided as follows: The main techniques for estimating recharge are Darcy's law, groundwater modeling, and base flow. Recharge rates in the Gulf Coast Aquifer System range from 0.1 to 2 in/yr. An additional study conducted by the Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin, for TWDB in 2011 is attached in Appendix A. This study also provides graphic and tabular data showing that recharge in the Goliad County area is in the range of 0.25" to 1" per year. The complete report can be accessed at: www.twdb.texas.gov

GCGCD monitors water levels once or twice per year. This monitoring program was begun in 2003. The program has been expanding and currently the District is monitoring 90+ wells annually. The recorded water level results are provided in Appendix B. These results show significant drawdown in north Goliad County pumping from the Evangeline Aquifer with some drawdown in south Goliad County from the Chicot Aquifer. The recorded drawdown since 2003 far exceeds the modeled drawdown. This mismatch in values is not considered a result of a period of drought.

The historic values used for recharge in Goliad County may no longer be valid. The change in surface land use since the drought of the 1950's, especially over the Evangeline Aquifer, has had a major impact on recharge values. The EDYS ecological model (brush management) prepared for Goliad County provides extensive scientific data. Appendix C as follows:

1. Cultivated acreage decreased substantially during and following the drought of the 1950's. Cultivated land was replaced with native vegetation including brush and hardwoods. Page 103.
2. Change in surface land use has significantly increased evapotranspiration (ET) which in most years exceeds rainfall with a result of no recharge.

AMOUNT OF GROUNDWATER BEING USED WITHIN THE DISTRICT ANNUALLY

There are two sets of data provided. In Appendix D, Estimated Historic Water Use TWDB Data for years 2000 through 2016 is shown. In Appendix E, the last five years (2012-2015) prepared by GCGCD is shown. The last five years data provided by GCGCD is based on Historic Use Allocations on file, estimated exempt use, and permitted water use. The projected groundwater to be used in the District is shown in Appendix F.

TWDB GROUNDWATER AVAILABLILITY MODEL (GAM) RUN 12-018 v. 2 DATA

ANNUAL AMOUNT OF RECHARGE FROM PRECIPITATION TO THE GROUNDWATER RESOURCES IN THE DISTRICT is shown in Appendix G.

ANNUAL VOLUME OF WATER THAT DISCHARGES FROM THE AQUIFER TO SPRINGS AND SURFACE WATER BODIES is shown in Appendix G.

ESTIMATE OF THE ANNUAL VOLUME OF FLOW INTO THE DISTRICT, OUT OF THE DISTRICT, AND BETWEEN AQUIFERS IN THE DISTRICT is shown in Appendix G.

2017 TEXAS STATE WATER PLAN DATA

GCGCD has reviewed the Projected Water Supply Needs and the Projected Water Management Strategies tables in the Historical Water Use / State Water Plan related to groundwater. The District has considered the water supply needs and water management strategies included in the adopted state water plan. There are no water supply needs identified in the county. In addition, there are four water management strategies for municipal water conservation based on demand reduction which the District has considered.

PROJECTED SURFACE WATER SUPPLY WITHIN THE DISTRICT is shown in Appendix H.
PROJECTED TOTAL DEMAND FOR WATER WITHIN THE DISTRICT is shown in Appendix H.
WATER SUPPLY NEEDS is shown in Appendix H.
WATER MANAGEMENT STRATEGIES is shown in Appendix H.

MANAGEMENT OF GROUNDWATER SUPPLIES

The District will manage and conserve the supply of groundwater within the District in order to maintain the economic viability of the District, county, and region. This will be done through coordination with and cooperation with Groundwater Conservation Districts in GMA 15.

A monitor well observation network is established to track any changes in water level or quality. The District will make a regular assessment of conditions and report those conditions to the public.
The District will adopt and update rules to regulate groundwater withdrawals by means of well spacing and production limits. The District may deny a well construction permit or limit groundwater withdrawals in accordance with district rules.

Goliad County Groundwater Conservation District will manage groundwater availability from the Gulf Coast Aquifer System on a sustainable basis to the extent possible. Any permitted pumping will be subject to curtailment based on water levels recorded by multiple monitor wells throughout the District.

One permit for in-situ mining of uranium has been approved in Goliad County. Chapter 36 Texas Water Code does not address groundwater use and potential contamination associated with uranium exploration and mining.

The District has implemented an extensive baseline water quality testing program which will continue as required.

A necessary ingredient in the management of groundwater supplies is an accurate identification of historic, current and future use. GCGCD has determined that historic pumping has been greatly understated primarily for oil and gas exploration and for irrigation.

SURFACE WATER SUPPLIES

The San Antonio River runs through Goliad County. The only use of river water in the District is for irrigation. There is one major surface water lake in the District. Coleto Creek Reservoir is located at the boundary of Victoria and Goliad counties in the lower Guadalupe River Basin, and is a cooling reservoir for steam electric power generation. This constructed reservoir supplies water for steam-electric power generation at Coleto Creek Power Station located in Goliad County. Because the predominant agriculture product is the raising of livestock, there are numerous stock tanks located within the District. These stock tanks provide surface water for livestock and wildlife consumption and provide some aquifer recharge. Many of these stock tanks go dry during drought periods requiring additional pumping of groundwater. The District has participated in two programs with USGS and others to qualify and quantify interface between the Gulf Coast Aquifer System and the San Antonio River and between the Gulf Coast Aquifer System and the fifteen-mile Coleto Creek. Both studies concluded that the Aquifer provides a gaining stream to the two listed surface streams. The reports of these two studies can be accessed at www.goliadcogcd.org.

REGIONAL (L) WATER PLAN

As required by Texas Water Code Chapter 36.1071(b) this management plan and any amendments thereon shall be considered in the development of the regional water plan. Considering this local management plan will meet the intent of Senate Bill #1 and therefore, result in a regional management plan, which is consistent with this local management plan, resulting in the protection of the local control of groundwater management by the local people who elected the Board of Directors to operate the District.

ACTIONS, PROCEDURES, PERFORMANCE
AND AVOIDANCE FOR PLAN IMPLEMENTATION

The District will implement the provisions of this plan and will utilize the provisions of this plan as a guidepost for determining the direction of priority for District activities. Operations of the District, agreements entered into by the District and planning efforts in which the District may participate will be consistent with the provisions of this plan. A copy of the Rules of Goliad County Groundwater Conservation District may be found at www.goliadcogcd.org.

The District will update and adopt rules relating to the permitting of wells and the production of groundwater. The rules adopted by the District shall be pursuant to the TWC Ch36 and the provisions of this plan. All rules will be adhered to and enforced. The promulgation and enforcement of the rules will be based on the best technical evidence available.

The District shall treat all citizens with equality. Citizens may apply to the District for discretion in enforcement of the rules on grounds of adverse economic effect or unique local conditions. In granting of discretion to any rule, the Board shall consider the potential for adverse effect on adjacent landowners. The exercise of said discretion by the Board shall not be construed as limiting the power of the Board.

The District may amend the District rules as necessary to comply with changes to Chapter 36 of the Texas Water Code and to insure the best management practices of the groundwater in the District. The implementation of the rules of the District will be based on the best available scientific and technical data, and on fair and reasonable evaluation.

The District has encouraged and will continue to encourage public cooperation in the implementation of the management plan for the District.

ESTABLISHMENT OF DESIRED FUTURE CONDITIONS (DFC) AND ESTIMATE OF THE MODELED AVAILABLE GROUNDWATER

The District is a member of GMA-15 that is comprised of thirteen wholly or in part groundwater conservation districts. On April 29, 2016, GMA-15 members adopted a DFC to manage the groundwater resources to achieve no more than 13 feet of average drawdown in the Gulf Coast Aquifer System within the GMA-15 boundary at December 2069. As presented in GAM Run 16-025 MAG (Appendix I), the Districts DFC for Goliad County is 10 feet and the modeled available groundwater (overall pumping) is 11,539 acre-feet/year.

The resolution to adopt Desired Future Conditions, transmittal letter to submit the adopted DFC's for GMA-15, and Explanatory Report are included in Appendix J-L.

During the development of the DFC it became apparent that modeled available groundwater and associated drawdown was not compatible with the Districts pumping and drawdown data. GCGCD requested and was granted a greater variance for the District. See Appendix M.

During the next five-year GMA-15 planning cycle, GCGCD will continue efforts to remedy discrepancies between model and District data to provide for a long-term ability to manage groundwater in the District.

METHODOLOGY FOR TRACKING DISTRICT PROGRESS IN ACHIEVING MANAGEMENT GOALS

A Performance Review will be prepared by the general manager and staff of the District. The Performance Review will cover the activities of the District including information on the District's performance in regards to achieving management goals and objectives. The presentation of the report will occur during a monthly Board meeting in the first quarter of the next fiscal year beginning October 1, 2018. The report will include the number of instances in which each of the activities specified in the District's management objectives was engaged in during the fiscal year. Each activity will be referenced to the estimated expenditure of staff time and budget in accomplishment of the activity. The notations of activity frequency, staff time and budget will be referenced to the appropriate performance standard for each management objective describing the activity, so that the effectiveness and efficiency of the District's operations may be evaluated. The Board will maintain the report on file, for public inspection at the District's offices upon adoption and on the District website at www.goliadcogcd.org.

GOAL 1.0
PROVIDING THE MOST EFFICIENT USE OF GROUNDWATER

Management Objective - The District will maintain an aquifer water level program monitoring a minimum of 50 wells in the District annually.
Performance Standard - The District will include water level monitoring data on its website and in the Performance Review.
Management Objective - The District will continue to require the registration and location of all new and replacement wells drilled within the boundary of the District.
Performance Standard - The number of wells drilled each year will be included in the Performance Review. The wells are to be reported by category as replacement, new exempt, and new permitted.

GOAL 2.0
CONTROLLING AND PREVENTING WASTE OF GROUNDWATER

Management Objective - Each year, the District will sample the water quality in at least five (5) selected wells in order to monitor water quality trends and identify if contamination of groundwater is occurring. The District will also make available to well owners a service for well water quality analysis, to be paid for by the well owner.
Performance Standard – 1. Annual report of wells sampled for water quality by the District. 2. Annual report of wells sampled by the District upon request.
Management Objective - When processing an application for a production permit, the District will evaluate and recommend selection of efficient pumping and distribution equipment. For process applications, the District will evaluate reprocessing and recovery options.
Performance Standard - Recommendations will be included in the approved application.

GOAL 3.0
CONTROLLING AND PREVENTING SUBSIDENCE

Goliad County Groundwater Conservation District recognizes subsidence is a potentially important issue associated with the management of groundwater. Based on studies done in GMA-15, subsidence has occurred in some locations of the management area. In the studies conducted, Goliad County was not included. As information becomes available, GCGCD may adjust their management plan and groundwater rules to address subsidence if it becomes an issue. Therefore, this goal is not applicable.

GOAL 4.0
ADDRESSING CONJUNCTIVE SURFACE WATER MANAGEMENT ISSUES

Management Objectives - Each year the District will participate in the regional water planning process by attending at least one meeting of Region L Planning Group to encourage the development of alternative water supplies to reduce the reliance on groundwater.
Performance Standard - Report the number of Region L meetings attended.

GOAL 5.0
ADDRESSING NATURAL RESOURCE ISSUES THAT IMPACT THE USE AND AVAILABILITY OF GROUNDWATER AND WHICH ARE IMPACTED BY THE USE OF GROUNDWATER

Management Objectives - Each year the District will locate all of the wells drilled that year for compliance of well spacing including minimum distance from septic systems or other defined potential contamination.
Performance Standard - The District will include in the Performance Review a record of any deficiencies found and the corrective action that was taken.

GOAL 6.0
ADDRESSING DROUGHT CONDITIONS

Management Objectives - Semiannually the District will update the rainfall values for the District for the previous six months.
Performance Standard - The District will issue one report semiannually, listing the rainfall values for the county. This report will be entered on the District website and included in the Performance Review. The following link has much useful information and includes links to major drought reporting websites.
https://waterdatafortexas.org/drought

GOAL 7.0
ADDRESSING CONSERVATION, RECHARGE ENHANCEMENT, RAINWATER HARVESTING, PRECIPITATION ENHANCEMENT AND BRUSH CONTROL

CONSERVATION
Management Objective - The District will at least on two occasions each year provide public information on water conservation and waste prevention through presentations at public schools, civic organizations, newspaper articles, or articles posted on the District website.
Performance Standard - The District will report in the Performance Review the number of speaking appearances made by the District each year and the number of newspaper articles published in the local newspaper and on the District website each year addressing conservation.

RECHARGE ENHANCEMENT
Management Objective - The District recommends that the most efficient method for increasing recharge is continued brush and weed control.
Performance Standard - See "Brush Control" Goal.

RAINWATER HARVESTING

Management Objectives - The District will provide current information on rainwater harvesting on the District web site. The District will provide information to the public on rainwater harvesting through literature in the office.

Performance Standard - The District will include the number of persons receiving literature from the office on rainwater harvesting and report any known District application in the Performance Review.

PRECIPITATION ENHANCEMENT

The District has evaluated a precipitation enhancement program and has determined that it is not appropriate or cost effective. Therefore, the District has determined that a precipitation enhancement goal is not applicable at this time.

BRUSH CONTROL

Management Objective - Brush control is extensively practiced in the county and the practice is encouraged by the Farm Service Agency and the GCGCD. The District will continue to support an educational program to inform the stakeholders of the benefits of controlling brush on their property.

Performance Standard - The District will publish at least one article annually in the local newspaper on the benefits to the water cycle of controlling the amount of brush on your property. A copy of this article will be included in the Performance Review to the District Board of Directors and published on the District website.

GOAL 8.0
ADDRESSING THE DESIRED FUTURE CONDITIONS (DFC)

Management Objective - At the end of each fiscal year, the District will prepare an updated data sheet of the estimated total groundwater pumping in the District for the past year. The District Board of Directors will review the total groundwater pumping data along with the water level data from Goal 1 and make an evaluation for compliance to the DFC. The Board of Directors will also review the data and compare it to the Modeled Available Groundwater.

Performance Standard - The data and evaluation will be included in the Performance Review.

<u>**Goliad County Groundwater Conservation District Managment Plan Appendices 2018**</u>

Appendix A - Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin, for TWDB in 2011.

Appendix B - Water Level Monitoring Results Goliad County Groundwater Conservation District

Appendix C - Developemnt of an EDYS Ecological Model for Goliad County, Texas

Appendix D - Estimated Historical Water Use: TWDB Historical Water Use Survey

Appendix E - 2012-2016 Goliad County Historic Use Allocations

Appendix F - GCGCD Projected Groundwater Use Numbers from the 2017 State Water Plan Amended

Appendix G - GAM Run 12-018 v. 2

Appendix H - 2017 State Water Plan Data sets.

Appendix I - GAM Run16-025 MAG Modeled Available Groundwater for the Gulf Coast Aquifer System in Groundwater Management Area 15

Appendix J - GMA 15 Resolution to Adopt Desired Future Condistions For GMA 15 Aquifers

Appendix K - GMA 15 Transmittal Letter

Appendix L - DFC Explanatory Report for GMA 15

Appendix M - GCGCD Proposed Desired Future Conditions

Appendix A

Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin, for TWDB in 2011

Estimation of Groundwater Recharge to the Gulf Coast Aquifer in Texas, USA

Final contract Report to Texas Water Development Board

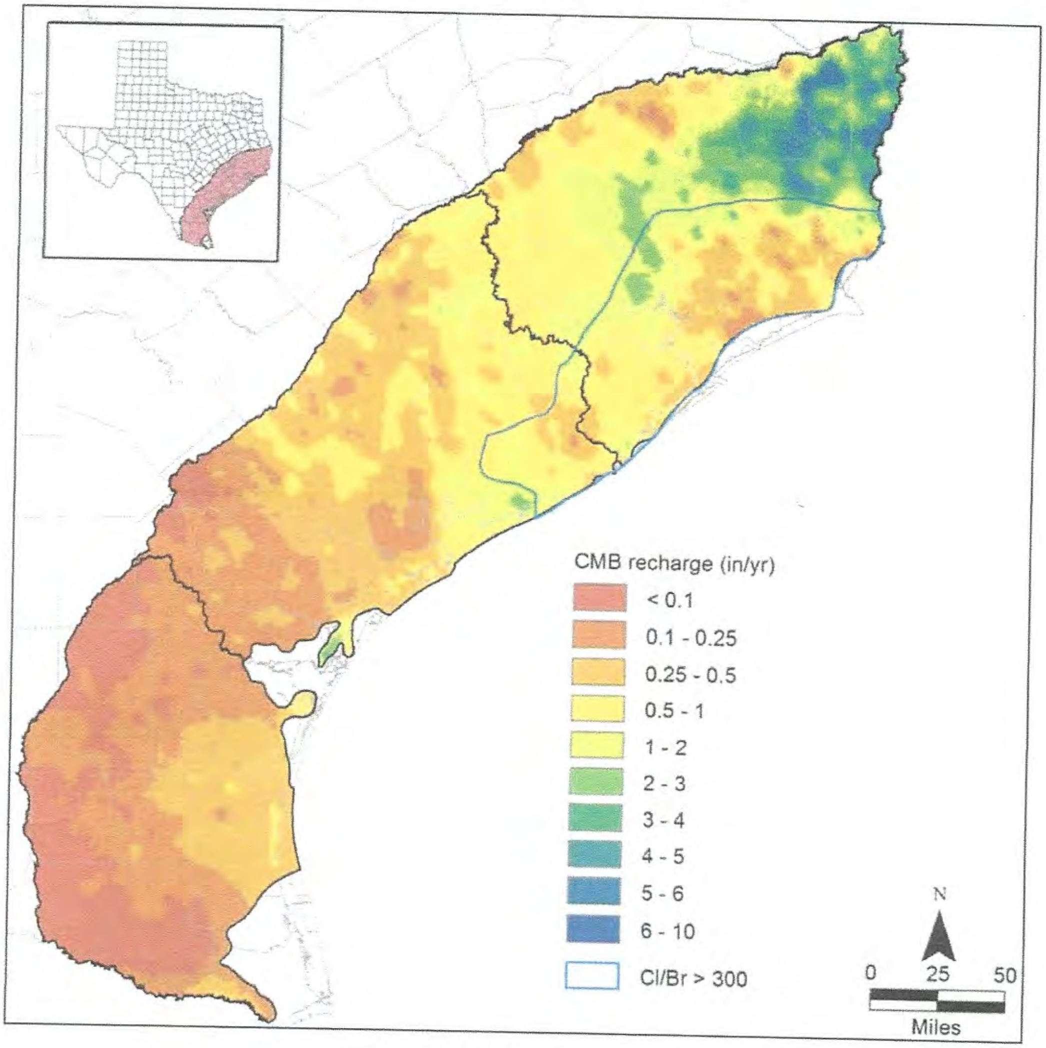
Bridget R. Scanlon, Robert Reedy, Gill Strassberg, Yun Huang, and Gabriel Senay

Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin

US Geological Survey - Sioux Falls, South Dakota

Appendix A

Estimation of Groundwater Recharge to the Gulf Coast Aquifer in Texas, USA



Final Contract Report

to

Texas Water Development Board

Bridget R. Scanlon, Robert Reedy, Gil Strassberg, Yun Huang, and Gabriel Senay*

Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin

***US Geological Survey, Sioux Falls, South Dakota**

Geoscientist Seal

The contents of this report (including figures and tables) document the work of the following licensed Texas geoscientists:

Bridget Scanlon, Ph.D., P.G. No. 1645

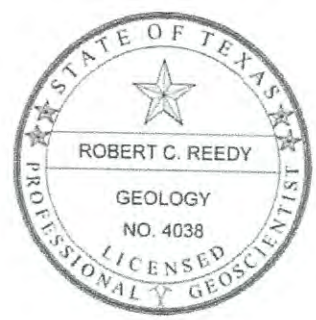
Dr. Scanlon was responsible for the introductory material and parts of the methods and discussion. The seal appearing on this document was authorized October 31, 2011, by

Bridget Scanlon

Robert C. Reedy, P.G. No. 4038

Mr. Reedy was responsible for project field work, data analysis, and parts of the methods and discussion. The seal appearing on this document was authorized October 31, 2011, by

Robert C. Reedy



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Executive Summary

Quantifying groundwater recharge is essential for managing water resources in aquifers. The objective of this study was to quantify spatial variability in recharge in the outcrop zones of the Gulf Coast aquifer in Texas. Regional recharge was estimated using the chloride mass balance approach applied to groundwater chloride data from the TWDB database in 10,530 wells, which represented the most recent samples from wells located in the region. Regional groundwater recharge was also estimated using streamflow hydrograph separation in 59 watersheds using USGS unregulated gage data. Recharge was also estimated by applying the chloride mass balance approach to unsaturated zone chloride data from 27 boreholes that represented a range of precipitation, land use, and soil texture settings in the central and southern Gulf Coast regions.

Groundwater chloride concentrations generally decrease from the southern to the northern Gulf Coast, qualitatively indicating increasing recharge in this direction with increasing precipitation. Ratios of chloride to bromide are < 150 to 200 throughout most of the Gulf Coast, suggesting a predominantly meteoric source for groundwater chloride. Recharge rates based on the chloride mass balance approach range from <0.1 in/yr in the south to 10 in/yr in the north, correlated with increasing precipitation. Stream flow ranges from ephemeral in parts of the southern Gulf Coast to perennial throughout the rest of the Gulf Coast based on flow duration curves. Hydrograph separation using Base-Flow Index (BFI) showed that recharge increased from south to north, similar to increases in recharge based on groundwater chloride data. Unsaturated zone profiles show high local variability in chloride concentrations, with mean concentrations below the root zone ranging from 7 to 10,200 mg/L. Resultant percolation rates below the root zone based on the chloride mass balance approach range from <0.1 to 6.8 in/yr. In some areas, variations in percolation rates are related to differences in soil texture whereas in other regions, they are related to differences in land use. However, there is no systematic variation in percolation rates throughout the region, unlike the trends in recharge with regional precipitation from groundwater chloride data and stream hydrograph separation.

Recharge rates based on groundwater chloride data can be considered to provide a conservative lower bound on actual recharge because many processes can add chloride to the system, resulting in lower recharge rates whereas there are no processes that can remove chloride from the system in the Gulf Coast. Stream hydrograph separation provides recharge rates in contributing basins that do not cover the entire Gulf Coast region. Recharge estimates from the chloride mass balance applied to groundwater and perennial stream hydrograph separation are highly correlated (r = 0.96) and differences between these two sets of recharge

estimates can be used to evaluate uncertainties in recharge rates in contributing basins to the stream gages. Recharge rates from groundwater chloride and streamflow hydrograph separation can be used to provide a range of recharge rates for future groundwater models of the Gulf Coast aquifer.

Introduction

Recharge is critical for estimating groundwater availability. Most models used to simulate groundwater availability require recharge rates as input and often calibrate the models by varying the recharge rates (Chowdhury and Mace, 2003; Chowdhury et al., 2004; Kasmarek and Robinson, 2004). The Gulf Coast aquifer is typical of dipping confined aquifers found along the Gulf Coast. Conceptual models of recharge in these aquifers generally include local and intermediate flow systems in the outcrop zones and regional flow systems into the deeper confined portions of the aquifers, based on Toth's original conceptual model (Toth, 1963). Much of the recharge occurring in local and intermediate flow systems discharges to streams, sometimes referred to as "rejected recharge". The remaining recharge moves downdip into confined aquifers and is sometimes termed "deep recharge".

Recharge can be derived from a variety of sources, including precipitation, irrigation return flow, and stream flow. In the Gulf Coast system, precipitation is the dominant source of recharge in the outcrop zones. Irrigation is mostly sourced by surface water near the Rio Grande and Colorado River, and return flow in these regions provides an additional source of groundwater recharge. Groundwater is also used for irrigation, primarily in Wharton and Matagorda counties near the Colorado River; however, return flow from groundwater-fed irrigation is simply recycling of water. Streams in the southern Gulf Coast are generally ephemeral and recharge the aquifer also.

Primary controls on recharge include precipitation, soil texture, and vegetation. To assess the maximum potential recharge in a region, Keese et al. (2005) simulated recharge using local climatic forcing (1961 – 1990 data) in sandy soil. Because finer textured soils, layering of soils, and vegetation all reduce recharge, omitting these in the simulations should result in the maximum potential recharge in response to climate forcing. Maximum recharge rates ranged from 50% of precipitation in Starr county in the south, 54% in Victoria County in the central region, and 60% in Liberty county in the north. These recharge estimates provide an upper bound on recharge in the system. Adding layered soils based on data from SSURGO reduced these recharge rates as a percentage of precipitation to 29% (Starr county), 10% (Victoria county), and 19% (Liberty county). Vegetation further reduced recharge rates to 5% (Starr county), 3% (Victoria county), and 10% (Liberty county). These simulations provide an indication of the relative importance of different controls on recharge rates. Many studies have shown that cultivating land can exert an important control on groundwater recharge (Scanlon et al., 2007). However, reconstructing past land use is difficult because records generally only extend back to the 1950s or 1960s (National Agricultural Statistics Services, Texas Agricultural Statistics Services).

A variety of techniques are available for estimating recharge. Techniques vary in the space/time scales covered, range of recharge rates that can be estimated, and reliability of recharge (Scanlon et al., 2002). Recharge rates for assessing groundwater availability generally require techniques that cover large spatial scales and decadal timescales. The range of recharge rates that can be estimated using different approaches varies. Depending on the level of *a priori* information on recharge rates in a region, it may be difficult to match appropriate techniques to actual recharge rates and an iterative approach may be required with reconnaissance estimates initially followed by more detailed studies. Recharge estimates based on different techniques vary in the reliability of their estimates. Potential recharge rates can be derived from surface-water and unsaturated-zone techniques, whereas actual recharge rates are based on groundwater data. Techniques for estimating recharge can be categorized as physical, chemical, and modeling techniques, and according to the source of data, including surface water, unsaturated zone, and groundwater (Scanlon et al., 2002). Water budgets are widely applied to develop a conceptual understanding of recharge in a system. However, recharge rates based on water budgets may have large uncertainties. Assuming a simplified system where the components of the water budget can be estimated within ±10% and using the following values results in (P (40±4 in/yr) – Roff (4±0.4 in/yr) - ET (33±3.3 in/yr) = R (3±5 in/yr). This calculation shows that the resultant recharge estimate has an uncertainty of 170%. Groundwater recharge can also be evaluated by examining groundwater discharge as baseflow to streams through hydrograph separation, using codes such as baseflow index (BFI) (Wahl and Wahl, 1995). The reliability of recharge estimates from streamflow hydrograph separation depends on the validity of the assumption that most baseflow equates to groundwater discharge. However, groundwater also discharges through pumpage and evapotranspiration while bank storage and wetlands can also contribute additional flow to the system during low flow periods (Halford and Mayer, 2000). However, previous analyses suggest that recharge estimates based on BFI may overestimate actual recharge rates because of impacts of bank storage (Halford and Mayer, 2000). Groundwater table fluctuations are also used to quantify recharge (Healy and Cook, 2002). The most widely used environmental tracer for recharge estimation is chloride, which can be used with groundwater or unsaturated zone chloride data. However, other stable and radioactive isotopes can also be used. Because recharge is difficult to estimate, it is important to apply as many different approaches as possible to constrain uncertainties.

There are certain issues that should be considered with respect to recharge for groundwater models. Because most groundwater models are only calibrated with hydraulic head data, these models can only estimate the ratio of recharge to hydraulic conductivity (R/K); therefore, reliability of recharge estimates from models depends on the accuracy of hydraulic conductivity data. The entire water budget is important for groundwater availability analysis. In some cases, high recharge rates are simulated during predevelopment, i.e. before large scale pumpage. Heads are matched by discharging most of the groundwater as ET and baseflow to streams. While this approach may not be a problem for predevelopment conditions, groundwater pumpage during aquifer development may capture water that was previously discharged as ET and this approach may overestimate water availability during development. Therefore, knowledge of ET is also important.

The objective of this study was to quantify spatial variability in recharge in the outcrop areas of the Gulf Coast aquifer. Unique aspects of the study include application of different approaches to estimate recharge, primarily chloride mass balance applied at regional groundwater scales and local unsaturated zone scales and streamflow hydrograph separation applied to streamflow gages, representing recharge to contributing groundwater basins. Comparison of recharge estimates from the different techniques provides information on the reliability of the recharge estimates. This study should significantly advance our understanding of recharge to the Gulf Coast aquifer. Quantitative estimates of recharge will improve reliability of future groundwater availability models of these aquifers.

Materials and Methods

Study Area

General Information

The Gulf Coast aquifer area is subdivided for the purposes of this study into three zones (southern, central, and northern) because of the large variability of climate conditions and other factors. The southern region is bounded by the Rio Grande River and the Nueces River, The central region is bounded by the Nueces River and the Brazos River, and the northern region is bounded by the Brazos River and Sabine River (Figure 1). The climate in the Gulf Coast ranges from subtropical subhumid to subtropical humid (Larkin and Bomar, 1983) with mean annual precipitation ranging from 21 to 62 in/yr (1971 – 2000; PRISM www.prism.oregonstate.edu) (Figure 1). Median annual precipitation is 26 in/yr in the southern region, 41 in/yr in the central region, and 53 in/yr in the northern region. The seasonal distribution in precipitation is dominated by precipitation from March through October in the southern and central regions whereas precipitation remains relatively high through the winter in the northern region (Figure 2). Precipitation is double peaked in the south and central region with peaks in May-June and September, whereas precipitation in the north is dominated by a peak in June. Winters are generally drier (20-30% of annual precipitation Nov–Feb). Precipitation is derived primarily from the Gulf of Mexico in the summer. Hurricanes from the Gulf of Mexico frequently result in heavy precipitation in the summer and early fall. In the winter, Pacific and Canadian air masses bring limited to moderate precipitation. Mean annual temperature decreases from 74°F in the south to 64°F in the north (Figure 3; PRISM 1971 – 2000).

Soil clay content in the Gulf Coast ranges from < 15% to 78% (Figure 4; SSURGO, USDA 1995). Soils are generally coarser grained in the south. More clay rich soils are found in the central and northern regions, primarily near the coast. Another band of finer grained soils is found near the inland margin in the central and northern regions of the Gulf Coast aquifer.

Current land use includes grass/pasture (31%), shrubland (18%), water/wetlands (17%), forest (12%), crops (12%) and developed areas (9%) (Figure 5; USGS National Land Cover Data, 2001). The distribution of these different land use/land cover types varies, with predominantly shrubland, grassland and cropland in the southern region, cropland, forest, and water/wetlands in the central region, and urban, forest, and water in the north. EPA has also defined ecoregions for the Gulf Coast, that include the Lower Rio Grande Alluvial Floodplain, Lower Rio Grande Valley, Coastal Sand Plain, Southern Subhumid and Northern Humid Gulf Coastal Prairies, floodplains and low terraces along the rivers, and flatwoods in the north (Griffith et al., 2004).

Geology

The geology of the different aquifers is summarized in Figures 6 and 7. The Gulf Coast aquifer consists of interbedded sands, silts, and clays of fluvial and marine origin (Ashworth and Hopkins, 1995). The hydrogeologic units crop out parallel to the coast and thicken downdip. The correspondence between the hydrogeologic and stratigraphic units is derived from Baker (1979) and the ages of the formations are based on Galloway et al. (2000).

The Gulf Coast aquifer deposits are underlain by sediments deposited from shallow inland seas during the Cretaceous that formed broad continental shelves covering most of Texas. In the Tertiary (starting 65 million years ago), the Rocky Mountains to the west started rising, and large river systems flowed toward the Gulf of Mexico, carrying abundant sediment, similar to today's Mississippi River. Most of Texas, particularly west Texas, was also uplifted, generating a local sediment source. Six major progradational events occurred where sedimentation built out into the Gulf Coast Basin. These progradational sequences include the most recent Vicksburg-Catahoula-Frio, Oakville-Fleming, and Plio-Pleistocene sand-rich wedges. Hydrostratigraphic units are defined in terms of flow (i.e., in terms of "shales" vs. "sands") and do not necessarily correspond to stratigraphic units which are defined in terms of age (Figure 7). The Gulf Coast aquifer system includes three main aquifers: the Jasper, Evangeline, and Chicot aquifers that broadly correspond to the Oakville Sandstone, the Goliad Sand, and Quaternary units, respectively. The Fleming Fm. is a confining unit between the Jasper and Evangeline aquifers and is named the Burkeville confining unit.

The component geologic units of the Gulf Coast aquifer are, from oldest to youngest, (1) Catahoula Fm., (2) Oakville Sandstone/Fleming Fm., (3) Goliad Fm., (4) Pleistocene formations (Willis Fm., Lissie Fm., and Beaumont Fm.), and (5) Quaternary terrace deposits and alluvium (Doering, 1935; Baker, 1979).

Catahoula (Gueydan) Formation is equivalent to the Catahoula Confining System. The Catahoula Fm. has a different lithology and provenance in the southwestern Gulf Coast than it does in the northeastern Gulf Coast. Baker (1979) noted that this unit is referred to as Catahoula Tuff in the southwest and Catahoula Sandstone to the northeast of the Colorado River, where it contains more sand and less volcanic material than in the southwest. In the southwest the Catahoula/Gueydan formations are unconformably overlain by either the Oakville Fm. or the Goliad Fm., whereas in the northeast they are overlain by the Fleming Fm. (Aronow et. al., 1987; Shelby et. al., 1992). Galloway (1977) described the Catahoula Fm. as being deposited by two separate fluvial systems, Gueydan in the southwest and Chita-Corrigan in the northeast parts of the Gulf Coast. The Gueydan bedload fluvial system was deposited in the Rio Grande embayment. The Chita-Corrigan mixed-load fluvial system was deposited in the Houston Embayment. Both depositional systems contain volcanic ash; however, Galloway (1977) cites differences in alteration clay minerals as evidence that Gueydan deposition occurred in an arid environment, whereas the depositional environment of Chita-Corrigan was more humid.

Oakville Sandstone/Fleming Formations – These two units are commonly grouped because they are both composed of varying amounts of interbedded sand and clay. In the central part of the Gulf Coast (Brazos River to central Duval County) they are easily recognized as stratigraphically adjacent units because the Oakville is sand-rich and the Fleming is more clay-rich. To the northeast of the Brazos River, the two units are indistinguishable. Baker (1979, 1986) assigned the Miocene Oakville/Fleming geologic units to the Jasper aquifer, which has been best characterized along the northeastern Texas Gulf Coast, north of the Brazos River. Galloway et al. (1982) described the Oakville in the southwest Gulf Coast as a sand-rich fluvial system overlying the Catahoula Fm. They associated the Oakville Sandstone with the Jasper aquifer and stated that the Evangeline aquifer includes most of the Fleming Fm.

Goliad Formation – The Goliad Fm. is only present at surface as far as Lavaca County, just south of the Colorado River as seen on the Seguin GAT sheet (Proctor et. al., 1974) and is absent farther to the northeast (not present on the Beaumont GAT sheet (Shelby et. al., 1992)). The Goliad Fm. was deposited during the Pliocene or as recently as 5 Ma. Hoel (1982) found the Goliad Fm. to be genetically and compositionally similar to the underlying Oakville and Catahoula formations as they exist in the southwest Gulf Coast. Hoel (1982) noted a distinct change in character of the Goliad Fm. along a line perpendicular to the coast, just north of the Nueces River roughly coincident with the San Patricio-Refugio county line. Southwest of this line the Goliad Fm. was deposited by rivers carrying bed load or very coarse sediments containing a large proportion of orthoclase and plagioclase feldspar crystals and volcanic rock fragments from a "distant western source." Northeast of this line the rivers carried finer grained sediments composed primarily of calc-lithic particles presumably derived from Edwards Plateau rocks of central Texas.

The Evangeline aquifer is composed of water-bearing zones primarily within the Goliad Sand and secondarily in underlying portions of the Fleming Fm. (Ryder and Ardis, 1991) The Goliad Sand is only identified as an aquifer unit in the TWDB well database within and to the south and west of Lavaca and Jackson counties. However, the Evangeline aquifer is present throughout the Gulf Coast aquifer in the northeast into Louisiana. Clearly there is a difference in the geologic units that compose the Evangeline aquifer in the southwest and northeast sections of the Gulf Coast aquifer. According to Baker (1979), the Evangeline aquifer was originally only defined as far west as Austin, Brazoria, Fort Bend, and Washington counties in Texas. He stated that extending the Evangeline farther west is speculative; however, in 1976 the USGS decided to extend the Evangeline to the Rio Grande.

Pleistocene and Recent Alluvial Deposits – Since Pleistocene time, packages of fluvial sediments representing successively younger progradational cycles have been deposited along the Texas Gulf Coast (Blum, 1992). The fluvial sediments range in texture from gravel to clay and are commonly poorly indurated. Decreasing dip of the strata toward the coast through time reflects changes in relative uplift of inland areas (southern Rocky Mountains, Great Plains, and the Edwards Plateau) and subsidence in the Gulf of Mexico (Doering, 1935; Blum, 1992). The older portions of this depositional sequence are coarser grained and dip 3 to 7 m per mile (Willis Sand), whereas the younger units are finer grained and dip only approximately 2×10^{-4} (1 ft/mi) (Beaumont Fm.) (Doering, 1935). Major Pleistocene to Recent formations along the Texas Gulf Coast, listed from oldest to youngest, include Willis Fm., Lissie Fm., Beaumont Fm., and Quaternary terrace deposits and alluvium (Doering, 1935; Baker, 1979). These units plus Quaternary alluvial deposits are all assigned to the Chicot aquifer.

Northeast of the Colorado River, Miocene- to Pliocene-age Fleming Fm. clay is unconformably overlain by the Willis Sand, which is in turn unconformably overlain by the sand and clay of the Lissie Fm. South of the Colorado River, the Pliocene-age Goliad Fm. is overlain by the Lissie Fm., which consists of sand, silt, clay, and minor amounts of gravel. The Lissie Fm. is overlain by clay, silt, and fine-grained sand of the Pleistocene-age Beaumont Fm. throughout the Texas Gulf Coast. Although the Beaumont Fm. as a whole is much finer grained than directly underlying formations, it contains localized sand channel deposits. The base of the Pleistocene (thought to be Willis Fm. in the northeast Gulf Coast and Lissie Fm. in southwest Gulf Coast) is very difficult to identify on geophysical logs (Baker, 1979). Because of this the bottom of the Chicot aquifer, which has in the past been defined as the base of the Pleistocene, is ambiguously defined and is often lumped together with the Evangeline aquifer.

Recharge Rates from Previous Studies

Recharge rates for Gulf Coast aquifer have been determined in many previous studies. A variety of approaches were used to estimate recharge, including Darcy's Law, environmental tracers, hydrograph separation, and numerical modeling.

Recharge rates in the Trinity River Basin ranged from 0.0 – 7.2 in/yr (median 0.9 in/yr) based on Darcian pedotransfer functions, 0.0 – 5.6 in/yr (median 0.4 in/yr) based on the chloride mass balance approach applied to unsaturated zone samples, and 0.0 – 4.1 in/yr (median 0.8 in/yr) based on chloride mass balance applied to groundwater data (Nolan et al., 2007). The regional recharge rates based on groundwater chloride data were not as variable as those based on unsaturated zone chloride data. Recharge rates based on Darcy's Law range from 1.2 to 1.3 in/yr in the Chicot and Evangeline aquifers in Colorado, Lavaca, and Wharton Counties (Loskot et al., 1982).

Recharge rates in the Chico and Evangeline aquifers were estimated using tritium isotopes in groundwater by Noble et al. (1996). An upper bound on the average recharge rate of 6 in/yr was estimated using the deepest penetration of tritium (80 ft) in 41 sampled wells in the Chicot and Evangeline outcrop areas.

Variations in recharge rates among groundwater models are attributed to differences in model grid size, hydraulic conductivity distribution, and degree of aquifer development. Recharge rates based on groundwater models may be biased because of scale issues (Johnston, 1997). Grid sizes in regional models are generally ≥ 1 mi^2. Therefore, in areas with large topographic relief with recharge discharging through streams within grid blocks, total recharge will be underestimated by the model because local and possibly intermediate flow systems are not captured in the larger grid blocks because they encompass both, and oftentimes only regional flow systems can be simulated.

Because most groundwater models of the Gulf Coast are calibrated using hydraulic head data alone, they can only simulate the ratio of recharge to hydraulic conductivity (Scanlon et al., 2002). Therefore, variations in recharge among the models are generally related to hydraulic conductivity, i.e. low recharge rates (0.0004 to 0.12 in/yr) associated with low hydraulic conductivity distribution (Hay, 1999).

Ryder (1988) estimated an average recharge rate of 0.74 in/yr in the outcrop areas of the upper Gulf Coast. Calibrated recharge rates in the southern Gulf Coast ranged from 0 – 4 in/yr for Goliad sand. A later model by Ryder and Ardis (2002) reported an average recharge rate of 0.12 in/yr. Simulated recharge rates of 0.1 to 0.4 in/yr were estimated by Dutton and Richter (1990) for the Chicot and Evangeline aquifers in Matagorda, Wharton, and Colorado counties.

Simulations of the northern Gulf Coast aquifer as part of the Groundwater Availability Modeling program resulted in predevelopment recharge rates in the aquifer outcrop zones of 0.14 in/yr in the Chicot and 0.41 in/yr in the Evangeline (Kasmarek and Robinson, 2004). Simulated transient recharge rates in the aquifer outcrop zones range from 0.4 in/yr in the Chicot and 0.12 in/yr in the Evangeline in 1977. Recharge increases to 0.55 in/yr in the Chicot in 2000 and decreases to 0.11 in/yr in the Evangeline. In the central and southern Gulf Coast GAMs, groundwater recharge was calibrated in the model as a uniform percent of distributed mean annual precipitation according to soil characteristics, which resulted in higher recharge rates in the central Gulf Coast because of higher precipitation relative to the southern Gulf Coast (Chowdhury et al., 2004, Chowdhury and Mace, 2003). Calibrated recharge rates were low in the Jasper Aquifer (≤ 0.1 in/yr) and higher in the Evangeline (0.1 – 0.2 in/yr) and Chicot (0.1 – 0.3 in/yr) aquifers based on results for 1980 1990, and 1999. Recharge in the lower Rio Grande Valley is derived from precipitation (47%) and from the Rio Grande seepage (0.53%).

Methods

Actual evapotranspiration (ETa) was estimated to ensure that ET used in future groundwater models in this region does not exceed actual ET estimates. In addition, reference ET (ET_0)was also evaluated to compare with actual ET at station locations. Various techniques were used to estimate aquifer recharge. The primary techniques are chloride mass balance approach applied to groundwater and unsaturated zone chloride data, water table fluctuations, and streamflow hydrograph separation. Additional data were collected to further constrain recharge rates. For example, chemical data from streams were compared with those from groundwater during low flow conditions to evaluate reliability of baseflow discharge estimates from stream data.

Estimation of Evapotranspiration

Reference Evapotranspiration

Evapotranspiration is generally the second largest parameter in the water budget in most regions. Reference ET refers to ET that is not limited by water availability in the soil profile and is only controlled by meteorological parameters such as radiation, temperature, wind, and relative humidity. Reference ET was estimated using the Penman Monteith approach (Allen et al., 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad (1)$$

where ET_0 = reference evapotranspiration [mm day-1],

R_n = net radiation at the crop surface [MJ m^2/ d],

G = soil heat flux density [MJ/m^2 d],

T = mean daily air temperature at 2 m height [°C],

u_2 =wind speed at 2 m height [m/ s],

e_s =saturation vapor pressure [kPa],

e_a =actual vapor pressure [kPa],

Δ = slope of vapor pressure curve [kPa/°C],

γ = psychrometric constant [kPa/ °C].

Reference ET was obtained for 10 stations in and surrounding the Texas Gulf Coast region from the TexasET Network (Table 1). This network is partially supported through a federal program, the "Rio Grande Basin Initiative," and administered by the Texas Water Resources Institute of the Texas A&M University System and other groups. TexasET contains weather information, current and average ET data, and irrigation watering recommendations. The standard Penman-Monteith method is used to calculate ET_0 from the weather station data. Reference ET was also estimated using stations from The National Solar Radiation Database (NSRDB) established by the National Renewable Energy Lab (NREL). Eight class I stations in the Gulf Coast region were selected for ET_0 estimation (Table 2). Hourly data from 1991 to 2005 for each station were extracted from the archive and hourly ET_0 was calculated using Penman-Monteith equation. Annual ET_0 by station was summarized from hourly values. Monthly and annual ET_0 were calculated for all stations (Table 2).

Atmometers (2) were installed to monitor reference ET in a riparian setting adjacent to the Colorado River at La Grange, Fayette County. One atmometer was installed in a small clearing receiving full sunlight and another was installed under the tree canopy in full shade, both separated by a distance of about 150 ft. The atmometers (Model E, ETGage, Loveland, CO, www.etgage.com) consist of a reservoir of distilled water connected to a porous ceramic evaporator through an electronic measuring device that records evaporation in 0.01-inch increments. The ceramic is covered by a canvas diffusion cover designed to simulate reference ET (ET_0). The reservoir has a capacity to supply 12 in of evaporation.

Actual Evapotranspiration

Actual ET is generally the parameter of most interest to hydrologists and is impacted by land use/land cover and soil moisture. Remote sensing is widely used to develop regional estimates of ETa A variety of codes are available to estimate ETa including SEBAL, METRIC, SSEB (Gowda et al., 2008). In this study, SSEB was used to estimate ETa in the Gulf Coast region.

All of these approaches estimate ETa or latent heat flux as the residual term in the surface energy balance equation:

$$ETa = LE = Rn - G - H \tag{2}$$

where LE is latent heat flux (energy consumed by ET), Rn is net radiation at the surface, G is ground heat flux, and H is sensible heat flux, all in units of W/m^2. The Simplified Surface Energy Balance (SSEB) approach was developed at USGS/Center for Earth Resources Observation and Science (EROS) for operational applications (Senay et al., 2007). The SSEB approach produces ETa estimates using a combination of ET fractions generated from thermal imagery and global reference ET over homogeneous areas with similar climate zones where differences in surface temperature are mainly caused by differences in vegetation water use rates. ETa is a product of ET fraction (ET_f) and ET_0: ET_f is calculated from Moderate Resolution Imaging Spectroradiometer (MODIS) thermal image. Average 8 day MODIS data are used because of problems with cloudiness for daily data. Reference ET (ET_0) is calculated globally from assimilated meteorological datasets of the Global Data Assimilation System of NOAA (Senay et al., 2008). The 8 day average temperature of hot and cold pixels are used to calculate proportional fractions of ET on a per pixel bases based on the assumption that hot pixels have ET close to 0 (Allen and Tasumi, 2005) and cold pixels represent maximum ET. Using Normalized Difference Vegetation Index (NDVI) from MODIS, hot pixels are selected from dry and bare areas and cold pixels from well-watered, vegetated areas. The ET fraction ($ET_{f,}$) is calculated for each pixel "x" by applying the following equation to each of the 8-day MODIS land surface temperature grids.

$$ET_{f,x} = \frac{TH - Tx}{TH - TC} \tag{3}$$

where TH and TC are the averages of hot and cold pixels selected for a given scene, and T_X is the land surface T for any given pixel in the composite scene.

Theory of Recharge Estimation Approach

Chloride Mass Balance Approach

Chloride is produced naturally in the Earth's atmosphere and has been widely used to estimate recharge rates since the late 1970s (Allison and Hughes 1978). The chloride mass balance (CMB) approach is used to estimate the recharge rate in which the chloride input to the soil profile from precipitation is balanced by chloride output in percolation below the root zone which is equated to recharge at the water table. The CMB approach can be applied to unsaturated zone profiles or to groundwater chloride data:

$$P \times Cl_P = Pe_{CMB} \times Cl_{UZ} = R_{CMB} \times Cl_{UZ} \tag{4}$$

$$P \times Cl_P = R_{CMB} \times Cl_{GW} \tag{5}$$

$$R_{CMB} = \frac{P \times Cl_P}{Cl_{UZ}} = \frac{P \times Cl_P}{Cl_{GW}} \tag{6}$$

where P is precipitation, subscripts P, UZ, and GW are precipitation, unsaturated zone, and groundwater, Pe is percolation rate (in/yr), and R is recharge rate. Percolation/recharge rates are inversely related to chloride concentrations in the unsaturated zone or groundwater; high percolation/recharge rates correspond to low chloride concentrations because chloride is flushed through the system whereas low percolation/recharge rates correspond to high chloride concentrations because chloride accumulates. Therefore, chloride concentrations can be used qualitatively to assess recharge rates. Quantitative percolation/recharge estimates require application of equations 4 through 6. The accumulation time represented by chloride in unsaturated zone profiles can be determined by dividing the cumulative total mass of chloride for the depth interval of interest by the chloride input:

$$t = \frac{\int_0^z \theta \times Cl_{UZ}\ dz}{P \times Cl_p} \tag{7}$$

Chloride concentrations generally increase through the root zone as a result of evapotranspiration and then remain constant below this depth. Bulge-shaped chloride profiles in unsaturated profiles in the High Plains have been attributed to higher recharge during the Pleistocene glacial period and chloride accumulation during the drier Holocene period (Scanlon and Goldsmith, 1997).

The chloride mass balance approach assumes that precipitation is the only source of groundwater chloride. However, groundwater chloride can also be derived from underlying more saline aquifers. Mass concentration (mg/L) ratios of groundwater Cl/Br and Cl/SO_4 can be used to distinguish chloride of meteoric origin from precipitation from chloride derived from upward flow of saline groundwater from deeper aquifers, as was done in the Central High Plains (Scanlon et al., 2010).

Estimation of Recharge Rates

Chloride Deposition

Applying the chloride mass balance (CMB) approach to estimate recharge requires information on chloride input into the system. Chloride concentration data are generally obtained from the National Atmospheric Deposition Program (NADP) in the US (www.nadp.org). These data include wet chloride deposition only because the precipitation collectors are only open when it is raining. The CMB approach requires information on wet and dry chloride deposition or bulk chloride deposition. Many previous studies in the Texas High Plains doubled the wet chloride deposition as an estimate of bulk chloride deposition based on estimates of bulk chloride deposition from $^{36}Cl/Cl$ ratios below the root zone (Scanlon et al., 2010). There are no $^{36}Cl/Cl$ data available for the Gulf Coast region. We examined literature data to assess relative amounts of wet and dry deposition near coastal zones. Measurements from coastal zones in Spain showed that dry deposition accounts for up to 50% of bulk deposition.

Application of the CMB approach requires information on chloride deposition (equation 6). Many studies have indicated that chloride deposition varies markedly with distance from the coast. Blackburn and McLeod (1983) suggested exponential reduction in chloride deposition near the coast, but attributed most of the reduction to variations in dry deposition. Keywood et al. (1997) also approximated changes in chloride deposition from the coast by exponential relationships based on a W-E and N-S transects in bulk deposition and attributed the changes in deposition to a fast portion characterized by rapid removal of chloride near the coast with a decay constant of ~ 60 km and a slow portion with a decay constant of ~700 km. They also noted that reduction in precipitation from the coast is also important. Biggs (2006) suggested that a higher correlation was obtained using mass rather than volume concentrations and indicated that reductions from the coast can penetrate to 300 to 400 km from the coast. Alcala and Custodio (2008) noted that dry deposition only accounted for up to 50% of bulk deposition based on data from Spain.

As a result of these studies, we developed a relationship for chloride deposition with distance from the coast using 20 stations from the NADP. The stations are located within approximately 5 to 200 miles from the Gulf Coast and include stations in Texas, Louisiana, Mississippi, Alabama, Georgia, and Florida. The median annual deposition rate for the period of record for each station was used. Mass concentrations (kg/ha) rather than volume concentrations (mg/L) were used based on the findings from Biggs (2006). A high correlation ($r^2 = 0.98$) was obtained between chloride mass deposition (Cl_{PM}) and distance from the coast (x) (Figure 8). To convert wet mass deposition (Cl_{PM}, kg/ha) to concentration (Cl_P, mg/L), the following is used:

$$Cl_P = \frac{Cl_{PM}}{P} = \frac{42 - 14.6\ln x + 1.39(\ln x)^2}{P} \times 2450 \qquad (8)$$

where the second-order equation in the numerator represents a least-squares fit to NADP median mass concentration deposition versus distance from the coast is in miles, precipitation (P) is in inches, and 2450 is a units conversion factor.

To gain insight into the relative amount of dry deposition in the study area, precipitation collectors were installed adjacent to the two NADP stations in the Gulf Coast to collect bulk chloride deposition. Additional collectors were installed at 8 other locations (Figure 9). Unlike the NADP precipitation collectors, which open mechanically during precipitation events and are closed at other times, the deployed collectors are open at all times. The open collectors located at the NADP sites are sampled on the same schedule as the NADP wet-only collectors for direct comparison to NADP results (weekly), while open collectors at the remaining sites are sampled at intervals varying approximately from weekly to monthly. However, the region has been in a drought since installation of these collectors and there is insufficient data to modify the chloride deposition function based on the NADP data.

Unsaturated Zone Field Studies and Chemical Analysis

Field studies were designed to drill and sample boreholes in different settings to estimate percolation using the chloride mass balance approach. A total of 18 boreholes were drilled and core samples collected for analysis of texture, water content, and anion concentrations in pore water (Figure 10). In addition, results from nine boreholes drilled in a previous study in the southern Gulf Coast were used to estimate recharge in this region (Scanlon et al., 2005). Continuous soil cores were obtained using a direct push drill rig (Model 6620DT, Geoprobe, Salina, KS). Borehole depths ranged from 8.0 to 47.5 ft (Table 3). Core samples were collected in plastic sample sleeves and capped.

Subsamples of the core from depth intervals varying between 1 and 5 ft were analyzed for soil water content and texture. Chemical parameters analyzed included water-extractable anion concentrations, including chloride, sulfate, and nitrate-N in water leached from the samples. Core subsamples (25 g) were leached using 40 mL of double deionized water. The mixture was placed in a reciprocal shaker for 4 hr, centrifuged at 7,000 rpm for 20 min, and the supernatant was filtered (0.2 um). Core subsamples were then oven dried at 105°C for 48 hr to determine gravimetric water content. Ionic concentrations were analyzed using ion chromatography (Dionex ICS 2000, EPA Method 300.0). Water-extractable ion concentrations are expressed on a mass basis as mg ion per kg of dry soil and were calculated by multiplying ion concentrations in the supernatant by the extraction ratio (g water/g soil). Ion concentrations are also expressed as mg ion per L of soil pore water and were calculated by dividing concentrations in mg/kg by gravimetric water content and multiplying by water density. Soil texture analyses were conducted using hydrometer methods at the Soil Water and Plant Analysis Laboratory at the University of Arizona to determine percentages of sand, silt, and clay.

Chloride Mass Balance Applied to Groundwater Data

Groundwater chloride concentrations (Cl_{GW}) were used to estimate regional recharge rates on the basis of equation (6). Chloride data were obtained from 8,721 wells in the outcrop area of the Jasper, Evangeline, and Chicot aquifers from Texas Water Development Board (TWDB) database (www.twdb.state.tx.us). Chloride concentrations in precipitation were obtained from the National Atmospheric Deposition Program (NADP, http://nadp.sws.uiuc.edu/). Mass concentration (mg/L) ratios for subsets of the chloride data for groundwater Cl/Br (1,339 wells) and Cl/SO_4 (8,086 wells) were used to distinguish chloride of meteoric origin from precipitation from chloride derived from upward flow of saline groundwater from deeper aquifers. The chloride and sulfate concentration data represent samples analyzed between 1913 and 2009 (median 1966). The bromide concentration data for the region represent samples analyzed between 1990 and 2009 (median 2001).

Water Table Fluctuation Method

The water table fluctuation (WTF) method (Healy and Cook, 2002) was applied to groundwater level data from the TWDB database. The WTF method is based on the premise that rises in groundwater levels in unconfined aquifers are due to recharge water arriving at the water table. Recharge is calculated as

$$R = Sy\frac{D\Delta h}{\Delta t} \tag{9}$$

where *Sy* is specific yield, *h* is water-table height, and *t* is time (Healy and Cook, 2002). The method has been applied to groundwater level rises that occurred over several years in the High Plains aquifer (Scanlon et al., 2010). Difficulties in applying the method are related to ensuring that fluctuations in water levels are due to recharge following precipitation and are not the result of recovery after pumping, changes in atmospheric pressure, presence of entrapped air, ET, or other phenomena. Determining a representative value for specific yield can also be problematic. The method is only applicable to unconfined aquifers and is best applied to shallow water tables that display sharp water-level changes.

Wells in the TWDB database that were deeper than 50 ft were eliminated from consideration as they are more likely to be completed in confined water-bearing units. Wells were further eliminated that have a measurement frequency of greater than about 60 days, considered a minimum required to capture water level fluctuation related to precipitation events, and that had sufficient records to span at least one full year. These criteria resulted in only 30 wells out of the approximately 16,600 wells in the database. All of the selected wells are completed in the Chicot aquifer and a uniform specific yield value of 0.05 was used.

Stream Hydrograph Separation

This section presents various estimates for shallow recharge that discharges to rivers and streams within the Gulf Coast aquifer. This discharge, which is typically called baseflow, occurs when the water table in an aquifer is at a higher elevation than the water surface of the river. Under these conditions, the river is said to be gaining, because water flows from the aquifer to the river. Flow duration curves were developed to determine whether streams are gaining or losing. Baseflow represents the relatively steady portion of river flow that occurs between periods of surface runoff. By analyzing the portion of river flow that occurs as baseflow, it is then possible to determine the amount that discharges from the aquifer to the river system. Streamflow hydrograph separation was conducted using the Base-Flow Index (BFI) code developed by Wahl and Wahl (1995). BFI is an automated procedure for determining baseflow on a consistent basis from reach to reach, so that they may be compared. BFI is the ratio of baseflow to streamflow. Values of BFI range from 0 (for no baseflow contribution to streamflow) to 1 (for 100% streamflow as baseflow). This program has two options, the first is the Institute of Hydrology method (1990), and the other is referred to as the Modified method. These methods locate low points on the streamflow record (referred to as turning points) and interpolate daily values between these low points. The Institute of Hydrology method was used in this study. The parameter N, number of days, was set to 5 based on an initial sensitivity analysis using selected gage data. The turning point, F, was set to 0.9, which is the default value in the BFI code. Results were not very sensitive to the F parameter.

For this study, 59 unregulated stream gages with drainage areas intersecting the Gulf Coast aquifer were selected and hydrograph separation completed for all the years of record during the time the drainage area upstream of the gage was unregulated. Shallow areal recharge flux in inches was then calculated by dividing the estimated baseflow rate by the drainage area. With baseflow calculated for multiple years it was then possible to estimate the average baseflow at a given stream gage. While using the Base Flow Index code is a fairly simple task, several criteria must be satisfied when selecting gages to be analyzed. If one of these criteria is not fully met then the estimate of recharge may not be valid. The criteria used in this study are listed below:

1. The gage should be on a stream that is considered to be gaining.
2. The catchment area of the gage should be primarily in the aquifer.
3. If the contributing area is outside the aquifer then an upstream gage must be utilized in order to subtract the effects of the upstream area.
4. The majority of the contributing area must be unregulated.

The first criterion ensures that the baseflow separation calculation can be accomplished. For a river with perennial flow (gaining) most of the basin yield usually comes from baseflow, indicating that a large portion of the rainfall is infiltrated into the basin and reaches the stream as subsurface flow (Chow, 1988). However, if the gage was located on an intermittent stream then an estimate of baseflow would only be valid during times when the stream was flowing. The second and third criteria ensure that gains/losses are calculated for the aquifer being analyzed and the fourth criteria ensures that gains to the system are due to groundwater sources instead of discharge from reservoirs. Estimates of the time periods where a stream was regulated (influenced by reservoir discharge) are available in a USGS report (Slade et al., 2002). This report lists beginning and ending years of regulation for many active and discontinued streamflow gaging stations in Texas. Calculations of baseflow were made based on the unregulated years reported by Slade (2002). Note that Slade (2002) only lists regulated years up to the year 2000, because that was the most recent data at the time of the report. For the current study, if a gage was unregulated in 2000, it was assumed that it continued to be unregulated to the present time as no reservoirs have reportedly become active in the Gulf Coast region in the last decade.

Results and Discussion

Evapotranspiration

Reference ET (ET_0) refers to the ability of the atmosphere to remove water and is controlled by meteorological forcing. Reference ET refers to the maximum possible ET for fully watered vegetation. Based on historical periods of record for TexasET network stations in the region, ET_0 ranges from 52.7 to 57.0 in/yr, with an overall trend toward higher values from north to south and also increasing inland from the coast (Table 1). Seasonal ET_0 is lowest from November through February (~20% of annual total) and highest in other months (~80% of annual total), with maximum monthly totals occurring between June and August for different locations. Values of ET_0 calculated from the NSRDB database (Table 2) and from the TexasET network generally agree within ±10%.

Annual mean actual ET (ETa) ranges from 32 in/yr in the south to 36 in/yr in the central and 42 in/yr in the north region (2000 – 2009) (Figure 11). Although ETa might be expected to be greater in the south where temperatures are highest, ETa in this region is limited by water availability. In contrast, ETa is greatest in the north because precipitation and water availability are highest in this region. Interannual variability is greatest in the south, with annual ETa ranging from 24 to 42 in/yr with a coefficient of variance (CV, standard deviation divided by the mean) of 20% (Figure 12). ETa ranges from 27 to 44 in/yr in the central region (CV = 14%) and from 39 to 48 in/yr in the north (CV = 6%). Average monthly ETa varies systematically with the seasons in all regions, with minimum values (0.3 to 0.7 in) occurring in January and maximum values (5.0 to 6.5 in) occurring in July (Figure 13). Differences among regions are greatest in the summer and least during fall and early winter.

Regional Recharge Rates from Groundwater Chloride Data

Groundwater chloride concentrations range from 3 to 1,700 mg/L and decrease regionally from south to north (Figure 14). Chloride concentrations are generally highest within the southern region in areas that surround a lower concentration (100 – 300 mg/L) zone corresponding to a sand dune area (Figure 4). Within the central region, higher concentrations are generally limited to the southern coastal area and concentrations decrease toward the northeast. Chloride concentrations are lowest overall in the northern region, with regional higher concentrations limited to a narrow zone near the coast.

The CMB approach assumes that all chloride is derived from precipitation. To assess the validity of this assumption, ratios of Cl/Br and Cl/SO_4 were evaluated to determine the chloride contribution from possible upward movement of more saline water from underlying geologic units (Figures 15 and 16). Mass ratios of Cl/Br typical of precipitation range from 50 to 150, and those typical of fresh groundwater range from 100 to 200, whereas ratios in groundwater impacted by salt dissolution range from 1000 to 10,000 (Davis et al., 1998). Ratios of Cl/Br throughout much of the Gulf Coast generally range from 80 to 300, mostly within the range of those typical of precipitation and fresh groundwater; however, Cl/Br ratios in the north near the coast are generally higher (300–600) and suggest an additional source of chloride input, possibly as upward cross formational flow of saline water from deeper aquifers in this region (Figure 15). The region of elevated Cl/Br ratios is ~ 7,000 mi^2 in area and is coincident with a large cluster of salt domes (Hamlin, 2006). The high Cl/Br ratios are attributed to low Br concentrations typical of recrystallized halite. Ratios of Cl/SO_4 greater than 20 are also characteristic of this region and are generally consistent with the high Cl/Br (>300) area (Figure 16), suggesting that groundwater throughout this region may be impacted by upward cross-formational flow. Therefore, groundwater Cl data should provide a lower bound on actual recharge rates in this region.

Estimated recharge rates based on groundwater chloride concentrations range from <0.1 to 10 in/yr throughout the Gulf Coast aquifer (Figure 17). Median recharge rates range from 0.12 in/yr in the southern region, 0.39 in/yr in the central region, to 1.26 in/yr in the northern region (excluding the region with Cl/Br >300). Most recharge in the southern region falls within the range of <0.1 to 0.25 in/yr with a zone of slightly higher recharge generally corresponding to a sand dune area (Figure 4). In the central region, recharge generally ranges from 0.25 to 0.5 in/yr in the southwest to 0.5 to 1 in/yr in the northeast and near the northeast coast. Recharge in the northern region is lowest along the inland margin and is higher along a band across the center ranging from about 1 in/yr in the southwest to a maximum of about 10 in/yr in the northeast.

Estimated recharge rates in the Gulf Coast represent <0.1 to 16% of mean annual precipitation (Figure 18). Recharge rates in the southern region range from 0.1 to 2.2% (median 0.5%, mean 0.7%) of mean precipitation. Recharge rates in the central region range from 0.1 to 9% (median 1.0%, mean 1.2%) of mean precipitation. Recharge rates in the northern region range from 0.2 to 16% (median 2.6%, mean 3.5%) of mean precipitation (excluding the Cl/Br >300 region). These recharge rates are generally lower than those predicted using the precipitation model by Keese et al. (2005), which, for texturally variable vegetated soils, predicts recharge as a percentage of precipitation of 1.9% in the southern region, 5.9% in the central region, and 11% in the northern region.

Many studies have noted high correlations between groundwater nitrate concentrations and recharge to shallow aquifers (Nolan et al., 2002; Fram and Belitz, 2011). Therefore, we examined variations in groundwater nitrate concentrations to determine if these variations are related to recharge. Nitrate concentrations were generally low throughout the Gulf Coast aquifer, ≤1 mg/L NO_3-N in most of the northern Gulf Coast, ≤ 2 mg/L throughout much of the central Gulf Coast. Higher concentrations are restricted to the southern Gulf Coast (2- 13 mg/L) and are greatest near the Rio Grande (Figure 19). Generally low nitrate concentrations throughout most of the north and central Gulf Coast could reflect limited input from nitrate fertilizer application, denitrification associated with reducing conditions, or low recharge rates. To assess the distribution of anthropogenic input, the probability of nitrate concentrations exceeding 2 mg/L NO_3-N, which is considered background levels, was calculated and the data kriged. Results indicate higher probabilities in the south where recharge rates are generally low and much lower probabilities in the central and northern regions (Figure 20).

Relationships between Precipitation, Soil Texture, and Land Use with CMB Recharge

Relationships between precipitation, land use, soil texture, and groundwater CMB recharge rates were investigated using multiple linear regression. Groundwater CMB recharge rates (log-transformed) for each well were compared to long-term average annual total precipitation depth (Figure 1), soil clay content percentage (Figure 4), and land use category (Figure 5). Various combinations of these variables were modeled to characterize which, if any, might demonstrate a significant ability to predict the groundwater CMB recharge rates. The numerical values for precipitation and soil clay content at each well location were derived from the respective maps. For land use, coded variables (1's and 0's) representing the dominant land use category within 500 m of each well location were used. In this approach, the dominant land use category is assigned a value of "1" and all other categories are assigned a value of "0". Additionally, one category is implicitly omitted from the model for comparison (this is required to prevent the model from being "over-specified"). The "Pasture" category was selected for comparison as it represents the dominant land use near approximately one-third of the wells in the study area. Models were run encompassing the entire Gulf Coast region and separately for the Northern, Central, and Southern subregions. Overall model statistics including correlation (r) and standard errors of prediction were used to compare the results of the models. Results indicate that both regionally and within each subregion, precipitation has the greatest effect with $r = 0.61$ regionally and ranging from 0.37 to 0.54 for the individual subregions. The regional land use model had $r=0.40$ and ranged from 0.14 to 0.48 within subregions. The regional soil clay content model had

21) and represent from 5.7% to 20% (median 9.5%) of local mean precipitation with corresponding short chloride accumulation times ranging from 5 to 87 yr (median 27 yr) to the total depth sampled (Table 6). Sulfate concentrations were also low in these profiles (64 to 150 mg/L, median 97 mg/L), consistent with flushing. Some of the higher percolation rates may reflect recharge to shallow perched aquifers rather than to the regional system, as one profile (Fay10-04) encountered saturated conditions at a depth of 18 ft while a groundwater well approximately 300 ft distant indicated a depth to water of about 130 ft.

A total of five profiles have slightly higher chloride (90 to 190 mg/L, median 140 mg/L), with three of the profiles having low sulfate concentrations (110 to 180 mg/L) and the remaining two having elevated sulfate concentrations (430 and 660 mg/L) (Table 5). Calculated percolation rates range from 0.35 to 0.73 in/yr (median 0.52 in/yr) for these five profiles, representing from 1.1% to 3.4% (median 1.4%) of local precipitation (Table 6, Figure 21).

The remaining profiles (14) have high chloride concentrations (560 – 10,200 mg/L, median 2,400 mg/L) and high sulfate concentrations (550 – 15,300 mg/L, median 1,400 mg/L) (Table 5), with very low calculated percolation rates ranging from 0.01 to 0.16 in/yr (median 0.03 in/yr) and represent only 0.02% to 0.16% (median 0.1%) of local mean precipitation (Table 6, Figure 21). Accumulation times in this group are up to 13,000 yr, with a median accumulation time of 4,000 yr for boreholes between 20 and 37 ft deep. Chloride profiles show increasing or stable concentration at depth.

Nitrate is sometimes used to fingerprint water fluxes associated with cultivation and fertilization (Scanlon et al., 2010). Most profiles in the Gulf Coast have low nitrate concentrations (median 0.1 – 2 mg/L) (Table 5). A few profiles have slightly higher nitrate levels (3-8 mg/L). The remaining profiles with high mean nitrate concentrations (31 – 275 mg/L) have high levels in the shallow subsurface in some profiles (Bee10-01, Kar10-01) and high levels towards the base in other profiles (Hid05-01, and Liv10-02). The latter have increased nitrate levels coincident with chloride concentration increases, suggesting release of nitrate at the beginning of cultivation, similar to profiles in the High Plains (Scanlon et al., 2008). One of the profiles (Liv10-01) is unusual in that high nitrate extends to 6 m depth, although chloride concentrations are extremely high. The clay content in this profile is extremely high and deep penetration of nitrate may suggest preferential flow.

In summary, there are no regional trends in percolation with precipitation from unsaturated zone profiles, with low and high percolation rates found throughout the sampled region. There is no systematic variation in percolation rate with soil texture. Locally, soil texture may exert a dominant control, e.g. percolation is limited (0.01 in/yr) at a location in Nueces County by clayey soils under a rainfed agricultural setting whereas percolation is much higher (4.91 in/yr) in sandy soils in Kenedy County despite heavy forest/shrub vegetation (efficient at using water) (Figure 22). Land use also plays an important role locally in determining percolation rates. In Karnes County, two boreholes separated by about 300 ft differ only in land use history (Figure 23). One borehole (Kar10-01) is located in pastureland that was cleared of trees in 1975, is currently grassland with sparse shrubs, and has high Cl and SO_4 concentrations indicating essentially no percolation (0.03 in/yr). The other borehole location (Kar10-02) was cleared in ~1910 and was under continuous cultivation until 1972 when it was allowed to revert to pastureland, is currently covered in grasses similar to Kar10-01, and has low Cl and SO_4 concentrations indicative of flushing with a percolation rate of 5.65 in/yr.

Land use history was difficult to determine accurately for many of the pasture sites sampled because current landowners are only aware of relatively recent land use. Cotton was an important regional crop in the past and much of the current pastureland may have been previously cultivated for cotton.

Regional Recharge Rates from Streamflow Hydrograph Separation

Recharge rates from previous streamflow hydrograph analyses are provided in Appendix 2. Flow duration curves were calculated to determine whether streams are ephemeral or perennial. The curves for all gages are presented in Appendix 3. Two example flow duration curves are shown in Figure 24. From the flow duration curve for gage 8115500, in the southwestern Gulf Coast, ~65% of the time the stream at this location becomes dry and has no flow. In contrast, the flow duration curve for gage 8117500, located in the more humid Brazos River basin, terminates near 100%, which is characteristic of a perennial stream.

Streamflow hydrograph separation was conducted on stream gages whose flow duration curves indicated that they are perennial. Temporal trends in baseflow were first examined prior to estimating recharge rates for contributing basins (Appendix 4). In some areas, such as in the Lower Colorado River Basin, groundwater pumping has varied dramatically through time, and the impact may be evident in the temporal trends of baseflow. Groundwater levels in the Gulf Coast aquifer reached their minimum in the area in approximately 1985-1990 (URS, 2004).

Results from the streamflow hydrograph separation analysis are presented in Tables 7 and 8. Statistics describing baseflow temporal variability are also presented to show the standard deviation and range of values calculated for each gaging station during the period of unregulated flow. Figure 26 shows the locations of the drainage areas analyzed for baseflow recharge and the associated average recharge rates in relation to groundwater CMB recharge rates in the corresponding drainage basin areas. The results are consistent and indicate that average recharge increases from south to north with increasing precipitation, as expected. Average recharge is negligible in the south, and increases to up to 7 in/yr in the north near the Sabine River.

Comparison of Recharge Rates from Different Approaches

Regional recharge estimates from groundwater chloride data may be considered a lower bound because various processes can add chloride to groundwater whereas no process removes chloride from groundwater in the Gulf Coast. For comparison with the groundwater chloride mass balance results, the streamflow hydrograph results were grouped into four categories based on results of the hydrograph analysis, including (1) perennial streams where the flow duration curves indicate flow persisted for at least 99% of the time, (2) perennial streams as in (1) but that have BFI values below 7%, (3) perennial streams as in (1) that exhibit strong increasing temporal trends in BFI (all located in the Houston area), and (4) nonperennial streams where the flow duration curves indicate flow persisted for less than 99% of the time. Category 1 represents all hydrograph results that indicate a persistent hydraulic connection between the stream and the groundwater in the drainage area while the remaining categories indicate changing or nonpersistent connections.

The trend in groundwater CMB recharge rates is highly correlated with the 24 perennial streamflow hydrograph separations ($r = 0.96$, Figure 27) with most data pairs falling within about 25% of the 1:1 line. The high level of agreement between these two independent methods serves to reinforce the results of the recharge estimates for both methods. Within the remaining hydrograph categories, all of the perennial hydrographs showing strong temporal BFI trends plot above the 1:1 line while all but one of the nonperennial and low BFI hydrographs plot below the 1:1 line. Higher BFI recharge estimates in the former category suggests that these estimates may be impacted by increased streamflow over time in the Houston area while the lower BFI recharge estimates in the latter categories are indicative of basins with nonpersistent connections between surface water and groundwater.

Summary

A variety of approaches were used to assess recharge to the Gulf Coast aquifer. The techniques were primarily chosen to provide regional recharge estimates for input to future groundwater availability models of these aquifers. The chloride mass balance approach was applied to groundwater chloride data to estimate recharge throughout the Gulf Coast and

Appendix B

Water Level Monitoring Data 2003-2016:
Goliad County Groundwater Conservation District

Appendix B
Water Level Monitoring Results

Landowners Name	Tag Number	Latitude	Longitude	First Date Measured	Water Level	Last Date Monitored	Water Level	Difference in Water Level
Abrameit, Elder Hugo	1	28.8286	-97.44103	4/29/03	99.75	10/2/2017	107.08	-7.33
Abrameit, Elder Hugo	2	28.83187	-97.44137	4/29/03	110.35	10/31/2016	118.3	-7.95
Dohmann, A.	4	28.79782	-97.42313	4/29/03	121.10	10/2/2017	128.97	-7.87
Dohmann, A.	6	28.841667	-97.424467	4/29/03	36.75	10/25/2017	48.5	-11.75
Dohmann, A.	7	28.8439	-97.43169	4/29/03	10.10	10/25/2017	16.21	-7.2
Dohmann, A.	8	28.84389	-97.43167	4/29/03	51.20	10/25/2017	40.15	11.05
Worley, Jim	9	28.86947	-97.45477	4/29/03	105.70	10/2/2017	115.04	-9.34
Jacob, Bobby	10	28.818933	-97.2785	11/11/2003	78.50	11/15/2016	82.4	-3.9
Jacob, Don	11	28.77465	-97.21466	11/11/2003	49.70	11/30/2017	53.86	-4.16
Seiler, Arthur	12	28.81313	97.23324	11/11/2003	79.80	11/30/2017	78.02	1.28
Wexford Cattle Co.	13	N28 29.857	W97 19.151	5/2/03	29.50	10/31/2017	34.4	-4.9
Wexford Cattle Co.	14	28.47385	-97.273667	5/2/03	18.40	10/31/2017	21.89	-3.49
Wexford Cattle Co.	15	28.469933	-97.3120833	5/2/03	25.20	10/31/2017	29.87	-4.67
Jacob, Don	16	28.721133	-97.31355	2/27/03	52.98	11/8/2017	56.99	-4.01
Dreier, John	17	28.694067	-97.32505	2/27/03	52.58	11/8/2017	56.82	-4.24
Landgrebe, Leroy	18	28.88218	-97.39616	6/6/03	83.90	10/25/2017	91.05	
Lemke, Keith	21	28.92248	-97.40919	6/6/03	9.20	10/25/2017	16.3	-7.1
Borgfield, Joyce	22	28.851867	-97.449067	6/5/03	23.30	5/31/2017	24.4	-1.1
Biamonte	24	28.7703	-97.418967	12/9/08	83.8	10/2/2017	95	-11.2
Wexford Cattle Co.	26	28.5618	-97.2045833	5/2/03	36.40	10/31/2017	38.65	-2.25
Worley, Jim	28	28.85705	-97.45466	2/24/2003	63.60	10/2/2017	75	-11.4
Roberts, Ronnie	33	28.4009166	-97.37433	10/29/2008	1/2 gallon/5 min.	11/15/2017	1gal. 9.5 Min.	0
Walter Taber, Jr.	34	28.40253	-97.39197	3/9/2004	35.15	10/24/2014	39.6	-4.45
Walter Taber, Jr	35	28.40202	-97.38967	3/9/2004	20.1	10/24/2016	24	-3.9

Appendix B

Water Level Monitoring Results

Walter Taber, Jr. Artesian Well	36	28.40225	-97.38945	3/9/2004	trickling	4/11/2014	not flowing	not flowing
Walter Taber, Jr. Artesian Well	37	28.40751	-97.3892	3/9/2004	flowing	10/24/2014	flowing	flowing
Taber	39	28.40825	-97.3934166	3/9/2004	40.3	4/29/2013	45.35	-5.05
Parma, Ben	40	28.89363	-97.37844	11/8/2004	39.66	10/25/2017	49.52	-9.86
Parma, Ben	41	28.89565	-97.37772	11/8/2004	13.62	10/25/2017	23.68	-10.06
Ward, Roy	42	28.8944	-97.38151	6/13/2003	32.6	10/25/2017	49.84	-17.24
Deibel Family	43	28.85033	-97.51233	1/15/2005	72.95	10/2/2017	85.82	-12.87
Neal, Beverly	44	28.749833	-97.53015	3/20/2006	116.6	5/15/2013	125	-8.4
Neal, Beverly	45	28.752717	-97.530467	3/20/2006	137.8	11/28/2017	149.5	-11.7
Poses, Joe B. 361-946-9546	46	28.40538	-97.36906	10/29/2008	34.7	7/27/2015	30.5	4.2
Travis Dye/Forrest Dye(DYE Estate)	50	28.765564	-97.43933	10/8/2008	53.75	10/2/2017	66.31	-12.35
Harwell, Mai Joy	53	28.848167	-97.44167	11/9/2004	43.8	10/25/2017	54.81	-11.01
Dohmann, Leon 361-212-6175	56	28.82779	-97.41455	4/4/2005	12.3	10/6/2015	32.3	-20
Dohmann, Leon	57	28.82917	-97.41264	4/14/05	83.72	10/25/2017	96.02	-12.3
Brumby, Kirby	59	28.8146	-97.47196	10/9/2008	124.4	6/2/2017	133	-8.6
Brumby, Kirby	60	28.81667	-97.46873	10/8/2008	63.8	10/2/2017	78.51	-14.71
Billo, B. H.	61	28.827833	-97.43015	10/21/2008	87.55	10/2/2017	97.82	-10.27
Forrest & Travis Dye (DYE Estate)	62	28.76425	-97.43395	12/9/2008	72.75	10/2/2017	80.02	-7.27
Dohmann, Felton	63	28.86225	-97.475633	10/9/2008	58.4	5/31/2017	68.4	-10
Reitz, Maurice	65	28.84853	-97.47564	4/14/05	86.55	10/2/2017	99.87	-13.32
Fromme, Cliff	73	28.59194	-97.62675	12/27/2007	63	11/15/2017	88.5	-25.5
Travis & Forrest Dye (DYE Estate)	74	28.76361	-97.43091	12/9/2008	67.45	10/2/2017	79.05	-11.6
Pam Christopher (DYE Estate)	75	28.765483	-97.429067	12/9/2008	92.35	10/2/2017	100.49	-8.14
Willke, Louis	76	28.76748	-97.43389	12/9/2008	86.15	10/25/2017	94.36	-8.21
Christopher W. W.	77	28.76938	-97.431967	12/9/2008	64.2	10/2/2017	75.5	-11.3
Salyer, Jeanette	86	28.736166	-97.30633	10/5/2006	63.2	6/23/2016	67.1	-3.9

Appendix B
Water Level Monitoring Results

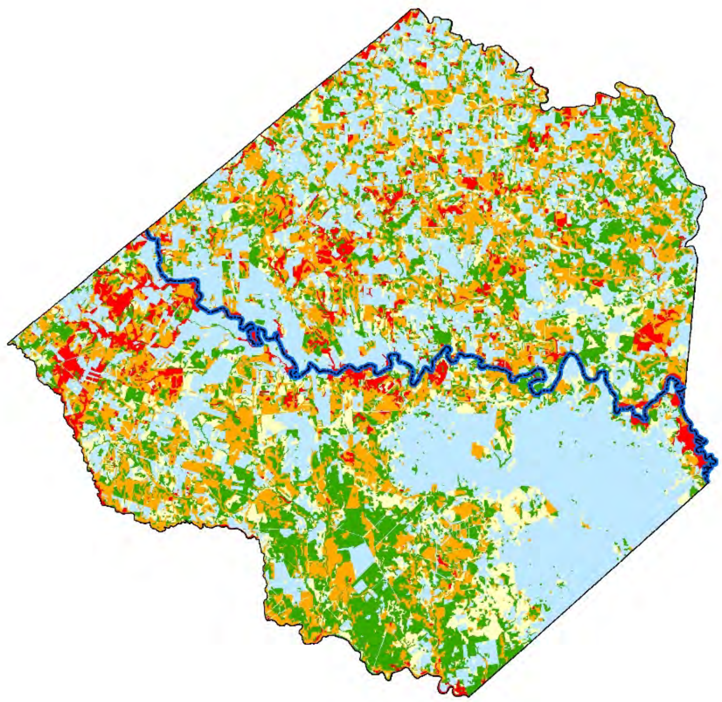
Roberts, Ronnie	90	28.39864	-97.37049	10/29/2008	23	11/15/2017	25.38	-2.33
Travis & Forrest Dye (DYE Estate)	91	28.76734	-97.43934	12/9/2008	32.6	10/2/2017	44	-11.4
Wexford Cattle Co.	96	28.49533	-97.24523	9/2/2004	17.55	10/31/2017	23.04	-5.49
James & Helen Friedel	99	28.8694	-97.42175	8/9/2005	59.4	10/25/2017	70.88	-11.48
Willke, Louis	100	28.76806	-97.43671	10/12/2008	84.33	10/2/2017	91.2	-6.87
Bob Gayle	104	28.59306	-97.50164	11/21/2008	88.9	11/15/2017	80.28	-8.62
Richard Ball	105	28.59323	-97.5108	11/21/2008	79.2	11/15/2017	86.95	-7.75
Raymond Arnold	107	28.88629	-97.36115	10/9/2008	52.35	10/25/2017	55.55	-3.2
Ty Luddeke	108	28.89046	-97.37759	10/9/2008	59.21	10/25/2017	66.19	-6.98
Roy Ward	110	28.88572	-97.38656	10/9/2008	75.6	10/25/2017	81.06	-5.46
Craig Duderstadt	111	28.875467	-97.35189	4/22/2008	52.8	10/25/2017	57.1	-4.3
Craig Duderstadt	112	28.875467	-97.35225	12/19/08	50.1	10/25/2017	57.46	-7.36
Warren Borgfeld	114	28.81929	-97.48663	10/8/2008	38.5	3/30/2015	52.45	-13.95
Art Dohmann	115	28.790817	-97.419583	10/9/2008	79.12	10/2/2017	96.1	-16.98
Christopher W. W.	116	28.76982	-97.43112	12/9/2008	71.15	10/2/2017	79.52	-8.37
Pamela Christopher (Dye Estate)	117	28.77197	-97.42549	12/9/2008	70.7	10/2/2017	83.9	-13.2
Cravens, Chico	119	28.3913	-97.4017	7/6/2009	9.9	10/24/15	12.00	-2.1
Nick Arredondo	122	28.40632	-97.37969	11/19/09	38.65	6/1/2016	36.85	1.8
Nick Arredondo	123	28.40564	-97.38155	11/19/09	46.4	6/1/2016	42.75	3.65
Larry Sisson	124	28.84025	-97.30061	08/11/09	45.41	11/30/2017	47.78	-2.37
Art Dohmann	125	28.84349	-97.42737	05/22/09	12.33	10/25/2017	12.58	-0.25
Wexford Cattle Co.	136	28.52155	-97.24815	5/31/2011	21.5	10/31/2017	22.28	-0.78
Wexford Cattle Co.	137	28.495867	-97.28285	5/31/2011	28.55	10/31/2017	30.33	-1.78
Walter Taber, Jr.	139	28.40401	-97.39478	10/24/2011	44.3	10/24/2014	46.8	-2.5
TWDB	148	28.69066	-97.54343	3/6/2002	42.1	11/28/2017	26.17	-15.93
Ty Luddeke	149	28.88756	-97.38267	10/23/2013	71.87	10/25/2017	71.71	-0.16
Ball, Richard & Cathy	151	28.60014	-97.50979	10/25/2007	107	11/15/2017	105.65	-1.35
Jody Ramirez	153	28.73755	-97.6336	6/2/2017	54.5	11/28/2017	55.09	-0.59
William Niemeier	154	28.77557	-97.61128	6/2/2017	60.1	11/28/2017	59.2	0.9

Appendix C

Development of an EDYS Ecological Model for Goliad County, Texas

DEVELOPMENT OF AN EDYS ECOLOGICAL MODEL FOR GOLIAD COUNTY, TEXAS

FINAL REPORT



PREPARED FOR:

SAN ANTONIO RIVER AUTHORITY

AND

TEXAS STATE SOIL AND WATER CONSERVATION BOARD

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EXECUTIVE SUMMARY

San Antonio River Authority (SARA) is interested in developing an integrated set of ecological simulation models for the San Antonio River system. To accomplish this, EDYS ecological models are being developed for each county along the San Antonio River. The first two models of this project were developed for Karnes County and Wilson County. This report presents the description of the third model in the series, Goliad County, along with the calibration process and ecological and hydrological results from ten land management simulation scenarios.

Texas State Soil and Water Conservation Board (TSSWCB) is also interested in the development of county-wide simulation models. In particular, TSSWCB is interested in these models being used to evaluate potential enhanced water yields from control of woody species. Goliad County is one of the counties selected by TSSWCB to have a model available to evaluate enhanced water yield and has co-operated with SARA in the development of the Goliad County EDYS model.

Description of the Models

Goliad County covers about 859 mi^2 (549,984 acres) located along the boundary between South Texas and the Texas Coastal Prairies. The San Antonio River flows through the center of Goliad County, flowing in an approximately NNW to SSE direction.

The basic spatial unit of the EDYS model is the cell. The cell size for the San Antonio River models is 40 m x 40 m (0.40 acre). This results in the Goliad County model containing about 1.4 million cells. Each cell contains data on topography, soil, depth to groundwater, vegetation, and land use.

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. The elevation data used in the Goliad County model are USGS 10-m DEM. Each cell also has an average depth to groundwater value, from which a depth to groundwater grid is defined for the county.

The spatial domain is divided into four 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 four zones, a 122-year (1893-2014) daily precipitation record was created based on statistical relationships among recorded precipitation data from 30 stations in a 12-county region surrounding Goliad County.

A detailed soil profile description was assigned to each of the 1.4 million cells in the model. These profiles were developed from NRCS soil survey descriptions of Goliad County soils and from additional data available in the literature. A total of 24 soil types are included in the Goliad County model and each cell is assigned to one of the 24 types based on the location of the cell on the spatial landscape. Each of the 24 soil types is divided into 35 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 84 species are included in the Goliad County 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 initially divided into plant communities and land management units (e.g., cultivated, urban, road) by assigning each cell type to one of 34 plot types (vegetation and land-use types). The locations of the vegetation types were based on NRCS soil survey maps and the locations of land-use types were based on 2012 NAIP aerial photographs. Each vegetation type was further divided based on amount of woody plant cover present, with these values visually estimated from the 2012 NAIP aerial photographs. Initial (i.e., start of a simulation) biomass values were entered for each plant species in each plot type, based on species composition for 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) are included in the Goliad County model: cattle, deer, rabbits, and insects. An average white-tailed deer density of 1 deer per 15 acres was used in the model. Cattle stocking rates were calculated for each vegetation type and averaged 14.7 acres/AU for native rangeland. Horses and feral hogs can be added but were not included in the model because of lack of information on densities and distributions of these two species.

Calibration

Calibration in EDYS consists of making adjustments of 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 judgement are used.

Only very limited independent validation data are currently available for Goliad County. Therefore, data from published studies in South Texas and the Central Texas Coast and professional judgement were used to calibrate the vegetation and hydrologic dynamics of the model. 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, grazing, and time (succession) were compared to published results from 23 studies and to our professional experience in the region. The simulation results compared favorably to the patterns and levels expected from these studies and regional experience. Under the moderate rainfall regime and with livestock grazing, there was a 10% increase in overall biomass on the clay loam type at the end of the 10-year simulation. Huisache increased by 12% and there was an increase in major shrubs (whitebrush, granjeno, prickly pear). Midgrasses increased 20% and shortgrasses decreased by 50%. Plains bristlegrass and silver bluestem were the midgrasses that increased the most. Under moderate grazing by cattle, midgrasses decreased by 43% compared to the ungrazed scenario and shortgrasses increased by 155%. Forage production in the simulations (tenth year) was 237, 262, and 552 g/m^2 on the clay loam, sandy loam, and cordgrass types compared to 164, 252, and 543 g/m^2 on similar sites reported in literature studies in South Texas.

Twenty-five year calibration simulations were used for the hydrologic variables. The longer period was used to include greater fluctuations in rainfall. Simulated amounts of evapotranspiration (ET) and surface runoff were compared to literature values for the region and for similar types of vegetation. The simulated ET values corresponded well with reported values in the literature. On the clay loam type (38% average woody plant cover), ET averaged 2.3 mm/day, compared to 2.6 mm/day on a mesquite-granjeno site in South Texas. The simulated ET was equal to 96% of annual rainfall compared to 94-97% on sites with similar vegetation reported in the literature.

Simulated runoff values also compared favorably with published values. For example, annual runoff on the clay loam type used in the calibration averaged 0.85 inch compared to 0.6 inch on a USGS gauged clay rangeland site in San Patricio County. The average annual runoff for the seven vegetation types used in the calibration was 1.85 inches, or 5.5% of annual rainfall. Average annual runoff from three USGS gauged sites in San Patricio County was 1.86 inches, or 3.1% of annual rainfall.

Averaged over the entire county over the 25-year calibration simulation at the moderate rainfall regime, annual sediment load was 47 g/m^2 (0.208 tons per acre). This value corresponds well with published values for rangeland systems in the western Edwards Plateau (33 g/m^2), northern Edwards Plateau (34 g/m^2), and the Rolling Plains of North Texas (83 g/m^2).

There are two gauge stations in Goliad County that were used to compare measured flow rates with estimated flow from the EDYS simulations. The gauge station at Goliad measures flow of the San Antonio River at near Goliad. That flow includes flow entering from Karnes County plus runoff and subsurface flow in 33 watersheds in, or partially in, Goliad County. The difference in average monthly flow rate between the Goliad gauge and the next upstream gauge (at Runge) was 7,419 acre-feet for the period June 2011-March 2016. About half that amount likely entered the river between Runge and the Goliad-Karnes County line. Surface runoff plus maximum lateral subsurface seepage in the EDYS simulations for the Goliad portion of the watershed accounted for 1,064 acre-feet, or 28% of the expected increase in flow.

The second gauge used in the calibration is located on the Perdido Creek and its associated watershed is entirely within Goliad County. Comparison of gauged data to EDYS simulation of surface runoff over a seven-year simulation period indicated that the EDYS simulation accounted for 85% of the total flow recorded at the gauge. However, the EDYS runoff and peak flows at the gauge often did not coincide on a monthly basis. Part of the reason for this difference in monthly patterns was likely because of the timing of water movement. EDYS runoff tended to enter the creek soon after a rainfall event and there was often a lag-time before the flow was recorded at the gauge.

Results

Ten 25-year scenarios were simulated as examples of how the models can be used. Three scenarios were included to illustrate the response to fluctuations in rainfall patterns. Only rainfall was varied in these three scenarios. One was baseline, which used the rainfall data from the 25 continuous years (1928-1952) which had a mean nearest the long-term mean. The second scenario used the rainfall data from the driest 25 continous years (1915-1939) and the third scenario used the rainfall data from the wettest 25 continuous years (1957-1981). Five scenarios illustrated responses to brush management. In Scenario 4, 100% of the woody biomass (except for live oak) was removed from areas with 30% or more woody cover and which had less than 12% slope. Brush removal was simulated in the first year only and this scenario used the baseline (moderate) rainfall regime (1928-1952). Scenario 5 was similar to Scenario 4 except that 50% of the live oak was also removed. Scenario 6 was similar to Scenario 5 except the dry rainfall regime (1915-1939) was used. Scenario 7 was similar to Scenario 5 except the wet rainfall regime (1957-1981) was used. Scenario 10 (maximum woody plant removal) was similar to Scenario 5 except the woody species were removed from all non-urban areas. The remaining two scenarios illustrated the impact of increased area in cultivation. In Scenario 8, 6.5% of the total land area of the county was placed under cultivation by removing the native vegetation and replacing it with cultivation of grain sorghum under the moderate rainfall regime. Scenario 9 was similar to Scenario 8 except the amount of cultivated land was increased to 21% of the total area of the county. The report presents the results of each of these ten scenarios on vegetation and hydrology.

Vegetation Changes

Vegetation change in the simulation scenarios varied by plot type and management scenario. Two of the major plot types were clay loam and loamy sand. Under the baseline scenario (average rainfall, moderate grazing by cattle, no brush control), there was a slight increase in woody species on the clay loam type overall but major changes in species composition. Huisache, whitebrush, granjeno, and prickly pear increased (13%, 47%, 6%, and 4%; respectively) while blackbrush, baccharis, and wolfberry decreased. On the loamy sand type, there was a 10% decrease in woody plant cover. Midgrasses increased on both types but much more so on the loamy sand type. Silver bluestem was the major midgrass that increased on the clay loam site and sideoats grama, sliver bluestem, and little bluestem increased on the loamy sand site. Shortgrasses also increased substantially on both sites, with most of increase coming from purple threeawn and buffalograss.

Under the dry regime (11% lower rainfall), woody species decreased by about 1% compared to baseline and herbaceous species decreased by 11%. Grass production was strongly affected by the dry regime, with lower production especially for the midgrasses. Under the wet regime (15% higher rainfall), woody species increased 3% overall compared to baseline and herbaceous production increased 21%.

Brush control substantially reduced woody plant cover. Under most of the brush control scenarios, woody plant biomass was only 10% of initial values at the end of 25 years. This assumed an initial removal of 100% of most woody species in the first year. A 95% rate would be more likely under field conditions. At 95% initial removal, the regrowth would likely be around 15-25% after 25 years, rather than the 10% at 100% initial removal.

Brush control substantially increased herbaceous production on some sites but not on others. On the clay loam site, grass production increased by 62% over baseline at the end of 25 years and 33% on the loamy bottomland site, but did not increase on the loamy sand site. These differences in responses were primarily the result of differences in soils and soil moisture responses. On clay loams, there was a substantial increase in silver bluestem, plains bristlegrass, and buffalograss following brush control. On the loamy bottomlands, Johnsongrass was the primary species that benefited, and on the loamy sand sites brownseed paspalum and little bluestem benefited the most from brush control.

Ecohydrology

Averaged over the entire county and under the moderate rainfall regime, an average of 1.3% of annual rainfall entered the creeks and river as surface runoff under the baseline scenario and ET accounted for an average of 116% of annual rainfall. This high ET rate was the result of high groundwater use by vegetation. There was also high annual variability in runoff and ET because of variability in annual rainfall. In the 25-year moderate rainfall regime, annual rainfall varied between 17.0 and 44.9 inches and annual surface runoff varied between less than 1000 acre-feet to more than 50,000 acre-feet and annual ET varied between 1.3 million acre-feet (93% of annual rainfall) and 2.2 million acre-feet (146% of annual rainfall). Annual groundwater use by vegetation varied between 130,000 and 424,000 acre-feet, with an annual average of 172,000 acre-feet (3.8 inches per year).

Under the dry regime, surface runoff decreased by an average of 64% compared to baseline and it increased by an average of 72% over baseline under the wet regime. The brush control scenarios had little effect on surface runoff under any of the rainfall regimes primarily because herbaceous vegetation was slow to recover following brush control. Increasing the amount of cultivated land decreased the amount of surface runoff, but not substantially (decrease of 820 acre-feet per year when 21% of the area was in cultivation).

Evapotranspiration (ET) averaged 38.0 inches per year (116% of annual rainfall) under baseline conditions, or an annual average of about 1,726,000 acre-feet. Brush control reduced this to an annual average of 1,620,000 acre-feet (35.7 inches per year), or an annual reduction of about 106,000 acre-feet. Under the 25-year dry regime, annual reduction in ET from brush control was even greater (132,000 acre-feet). An increase in cultivated acres also decreased ET. When 6.5% of the area was cultivated, annual ET was reduced by 50,600 acre-feet and when 21% of the area was cultivated annual ET was reduced by 155,000 acre-feet.

Under most of the scenarios, there was a negative annual water balance. This was the result of 1) high groundwater use and 2) depletion of stored soil moisture. A negative annual water balance cannot be maintained indefinitely. Either more groundwater will be used or water use by the vegetation will decrease, the later of which will lead to a reduction in vegetation structure and production. Much of this negative balance is likely the result of an increase in woody species over the past 25-50 years. The two exceptions to the negative balances were 1) brush control under the wet regime and 2) the 21% of area under cultivation scenario. Under the wet rainfall regime with brush control, there was an average annual surplus of almost 41,000 acre-feet, or slightly under 1 inch per year. Under the moderate rainfall regime, an annual surplus could probably be achieved if woody species were reduced substantially in 40-50% of the county. When area under cultivation was increased to 21%, there was an average annual surplus of 32,800 acre-feet under the moderate rainfall regime. This is about twice the amount of area under cultivation as was under cultivation around 1950.

A maximum brush control scenario was run to estimate the upper limit to what could theoretically be achieved in water yield enhancement from brush control. This scenario removed all woody species (except pecan and 50% of live oak) from all non-urban areas. As such, it is not a practical scenario, but was used to estimate maximum potential yield. Maximum potential enhanced water yield from this scenario averaged 287,000 acre-feet per year, 47% of which was from reduced groundwater use by deep-rooted species and 53% was from reduced ET use of annual rainfall.

Summary

The Goliad County EDYS model provides a tool that is useful for quantifying vegetation and hydrologic responses to various environmental and management changes, especially for quantifying relative differences. Vegetation dynamics, changes in both production and species composition, are simulated in an ecologically reasonable manner, with results comparable with those from published research studies. Flow, surface runoff, and sediment load dynamics fit both patterns and amounts indicated by gauged data and published literature values. Evapotranspiration values are compatable with published values and responses to changes in rainfall and vegetation management are ecologically reasonable and consistent with published values.

1.0 INTRODUCTION

The San Antonio River begins in Bexar County and flows southeastward through five counties before merging with the Guadalupe River and then flowing into San Antonio Bay on the central Texas Coast. Goliad is the middle county through which the San Antonio River flows (Fig. 1.1).

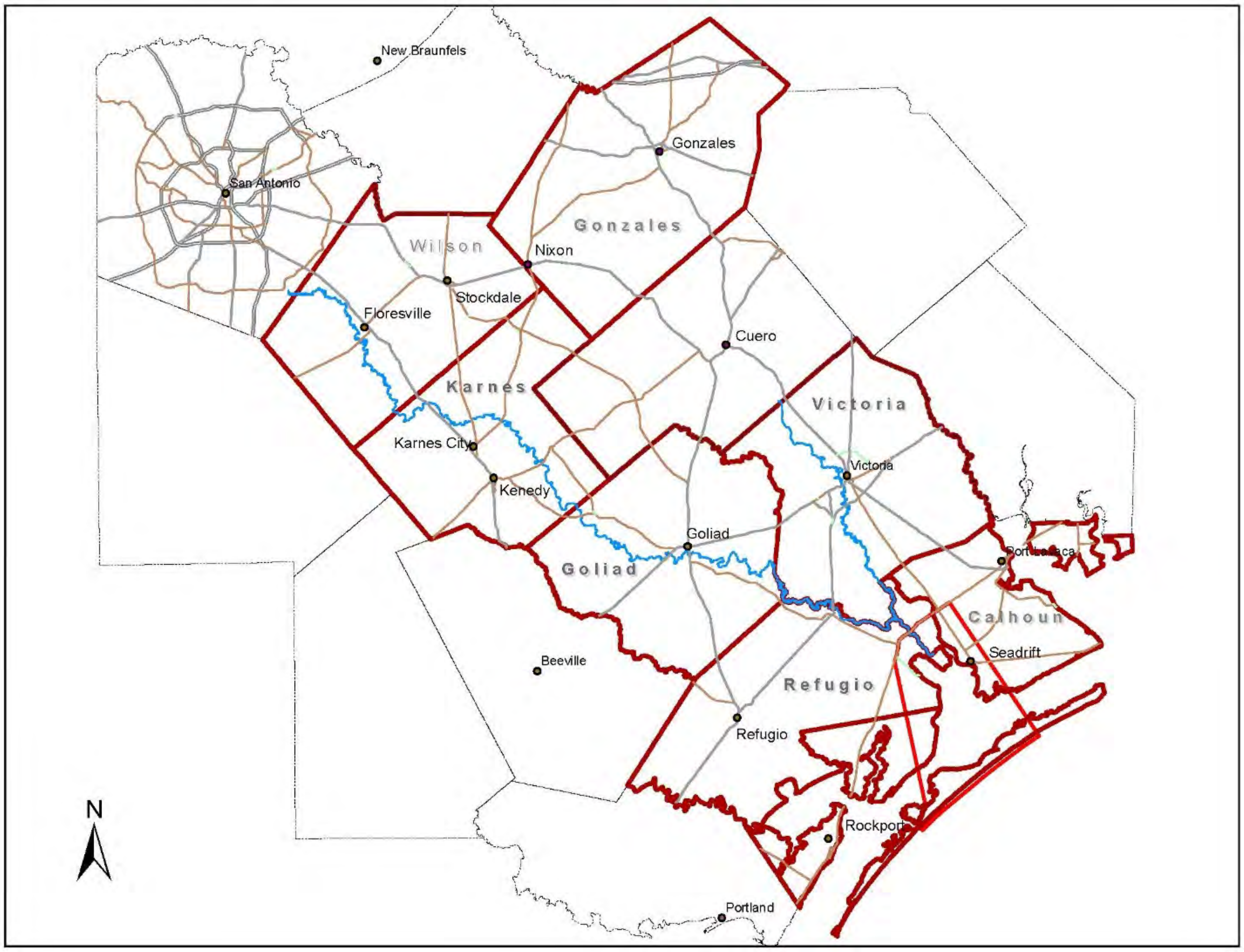

Figure 1.1 Map of the region of the San Antonio River watershed.

The San Antonio River Authority (SARA) has the dual responsibility of managing water quality and water quantity in the San Antonio River and its tributaries. The quality and quantity of river water are affected by both in-stream factors and characteristics of the respective watershed. SARA recognizes the importance of understanding the effects of in-stream responses and watershed ecohydrology to making good management decisions relative to the San Antonio River system.

Natural and anthropogenic changes across the landscape can have major impacts on the water quality and quantity of the river. Management tools that integrate spatial and temporal ecological dynamics at multi-species and multi-scale levels provide valuable support to the environmental decision-making process. 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.

SARA is interested in developing an integrated set of ecological models for the entire San Antonio River system for the purpose of supporting their decision-making process related to the management of the San Antonio River. In June 2011, SARA began the application of the EDYS model to San Antonio Bay as the first step in developing this set of integrated ecological models. EDYS is a mechanistic, spatially-explict, dynamic ecosystem simulation model that has been widely applied to land management decision making (Ash and Walker 1999; Childress and McLendon 1999; Childress et al. 1999a, 2002; USAFA 2000; McLendon et al. 2000, 2012e, 2015; MWH 2003; Chiles and McLendon 2004; Price et al. 2004; McLendon and Coldren 2005, 2011; Naumburg et al. 2005; Amerikanuak, Inc. 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). In June 2013, SARA began the expansion of this model development to include up-river segments of the linked river-bay system. Karnes and Wilson Counties were selected as the first two counties to be included in the integrated model complex. These two models were completed in December 2014 (McLendon et al. 2015). In September 2013, SARA expanded work on the linked-model complex to include Goliad, Refugio, and Victoria Counties.

Texas State Soil and Water Conservation Board (TSSWCB) is also interested in the development of county-wide simulation models. In particular, TSSWCB is interested in the development and application of simulation models to be used to evaluate potential enhanced water yields from control of woody species. TSSWCB previously supplied funding for the development of EDYS models for Gonzales County (McLendon et al. 2012e; McLendon 2013) and most of Edwards, Kimble, Real, and Sutton Counties. In August 2013, TSSWCB provided funds to supplement those provided by SARA to develop EDYS models for Goliad and Victoria Counties.

This document reports on the results of the development of an EDYS model for Goliad County. It provides an overview of the model and presents results of a set of simulation scenarios.

2.0 SPATIAL FOOTPRINT

Goliad County covers 859.35 mi^2 (549,984 acres), located along the boundary between South Texas (South Texas Plains, Hatch et al. 1990) and the Texas Coastal Prairies (Diamond and Smeins 1984). The San Antonio River flows through the center of Goliad County, flowing in an approximately NNW to SSE direction.

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 a slower run time per time step and more memory requirement.

The primary cell size selected for the Goliad model is 40 m x 40 m (0.40 acre), resulting in approximately 1.38 million cells for Goliad County. The following components (discussed in following sections) 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 and retaining the 40 m x 40 m cell size is impractical because the spatial domain increases to well over 1.5 million cells. 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 with 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. Having separate, but linked, models for each county also allows for the linked model to be easily expanded so that additional counties (e.g., Gonzales, Karnes, and Wilson) can be added.

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 dynamics in critical areas where the smaller scale becomes important (e.g., some aquatic systems, critical habitat areas, urban development patterns). These critical areas have not yet been defined for the needs of SARA and TSSWCB in Goliad County. One of the purposes of developing the current models may be to investigate some of these areas. Once these areas are identified, finer-scale models can be developed for them and then added to the larger-scale model. The fine-scale models (1 m x 1 m cell size) developed for the validation plots in Atascosa, Karnes, and Goliad Counties are examples of this approach.

3.0 TOPGRAPHY

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), and fire events.

Elevation, slope, and aspect are the three topographic variables used in EDYS. All three are derived by EDYS from input elevation data. Surface topography is developed in EDYS based on differences in elevations 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 of the difference in elevation (i.e., aspect) determines the direction of surface flow.

Initial elevations are entered from DEM or LIDAR data. For the Goliad County model, USGS DEM data are 10-m resolution were used to develop the initial eleveation grid (Fig. 3.1). LIDAR data, supplied by SARA, were available for some locations. We tried to use these data where available spatially and fill in the gaps using 10-m DEM data but the fit using these two data sets was not smooth. Therefore, we used the 10-m DEM data throughout the county.

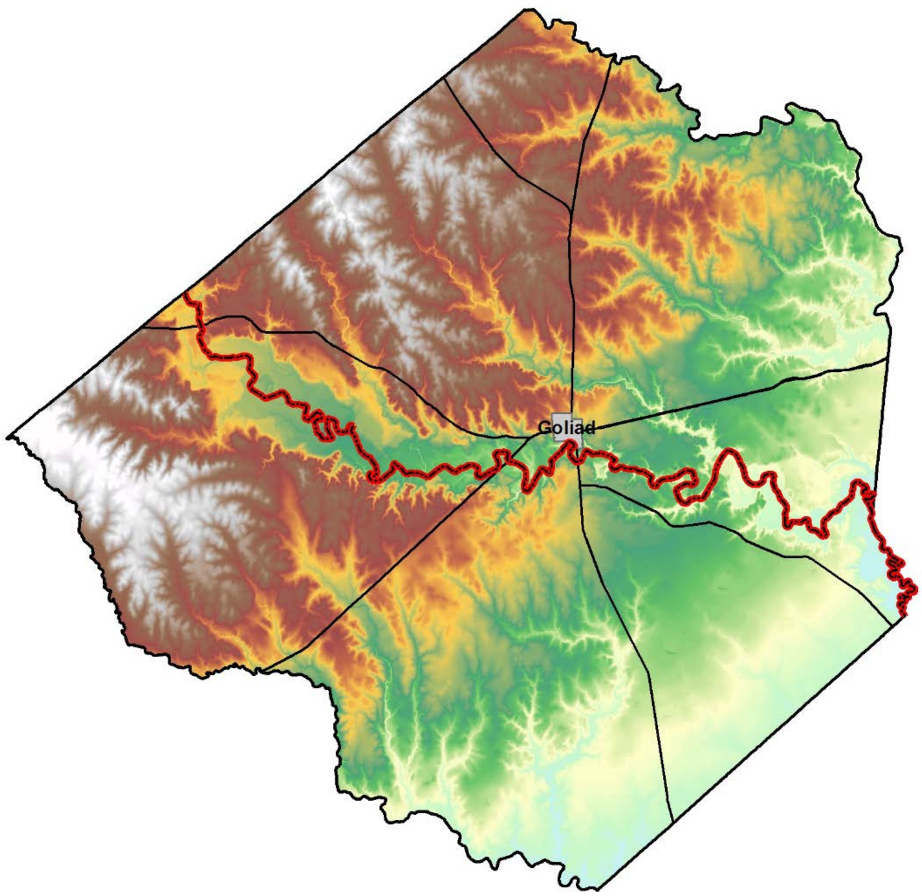

Figure 3.1 Topographic map of Goliad County based on USGS 10-m DEM data.

In EDYS, precipitation is applied to each cell. 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 for infiltration in the soil profile, the only loss in this case is from evaporation. 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 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, this 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).

During a simulation run, elevations can change because of erosion or deposition. 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 when 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 data in the recorded data 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. For example, the long-term (1913-2015) mean annual rainfall recorded at Goliad (excluding years with incomplete data) is 34.84 inches. The driest year on record was 9.73 inches in 1917 (28% of long-term mean) and the wettest year on record was 59.48 inches in 1981 (171% of long-term mean)(Appendix Table A.1). The driest short-term (four continuous years) period on record was 1915-18, during which annual precipitation averaged 20.88 inches (60% of long-term mean) and the wettest short-term (four continuous years) period on record was 1973-76, during which annual precipitation averaged 46.00 inches (132% of long-term mean).

Short-term periodicity at Goliad involves wet-dry cycles of 3-20 years (average of 8 years)(Fig. 4.1). Above-average cycle periods (wet) have an average length of 8.5 years (range = 4-20 years), with average annual means of approximately 35-44 inches (average annual = 39.21 inches). Below-average cycle periods (dry) periods have an average length of 5.6 years (range = 3-10 years), with average annual means of approximately 20-30 inches (average annual = 26.89 inches). There have been six of these dry-wet cycles since 1915 (a seventh cycle began in 2011) and the average difference in annual rainfall between the dry and wet periods is 9.48 inches (Fig. 4.1).

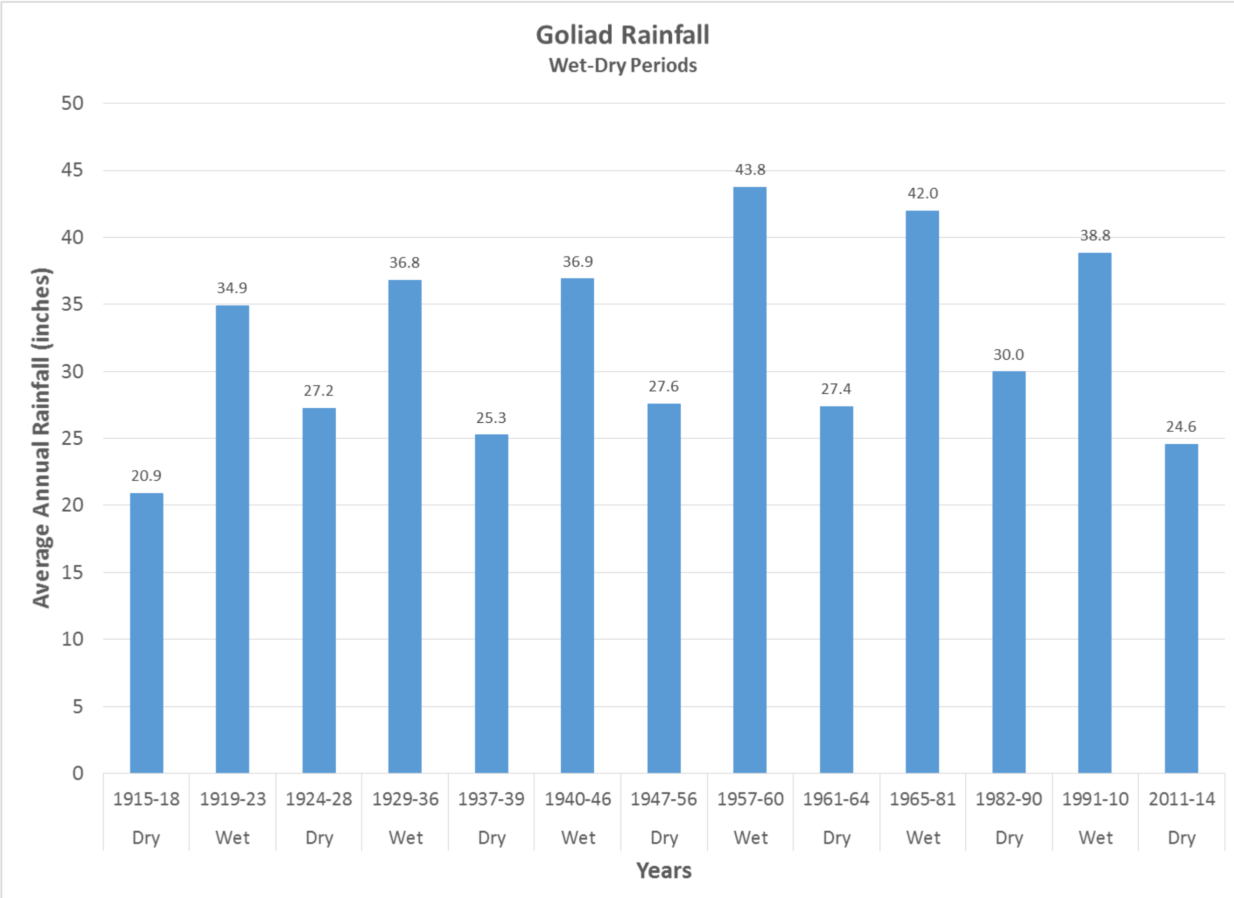

Figure 4.1 Mean annual precipitation (inches) during six consecutive wet-dry periods at Goliad, Texas (1915-2014).

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). These multidecadal cycles result in major shifts in rainfall patterns in the Southwest, including South Texas, which have major impacts on ecological and hydrological systems. For example, average annual rainfall at Goliad during 1915-1956 (42 years) was 30.91 inches (Fig. 4.2). Average annual rainfall during the following 54 years (1957-2010) was 36.00 inches, an increase of 5.1 inches per year (16.4%) for 54 years. Over the last five years (2011-2015), annual rainfall has averaged 29.60 inches. This increase in rainfall following the drought of the 1950s is reflected at locations throughout the region (Table 4.1).

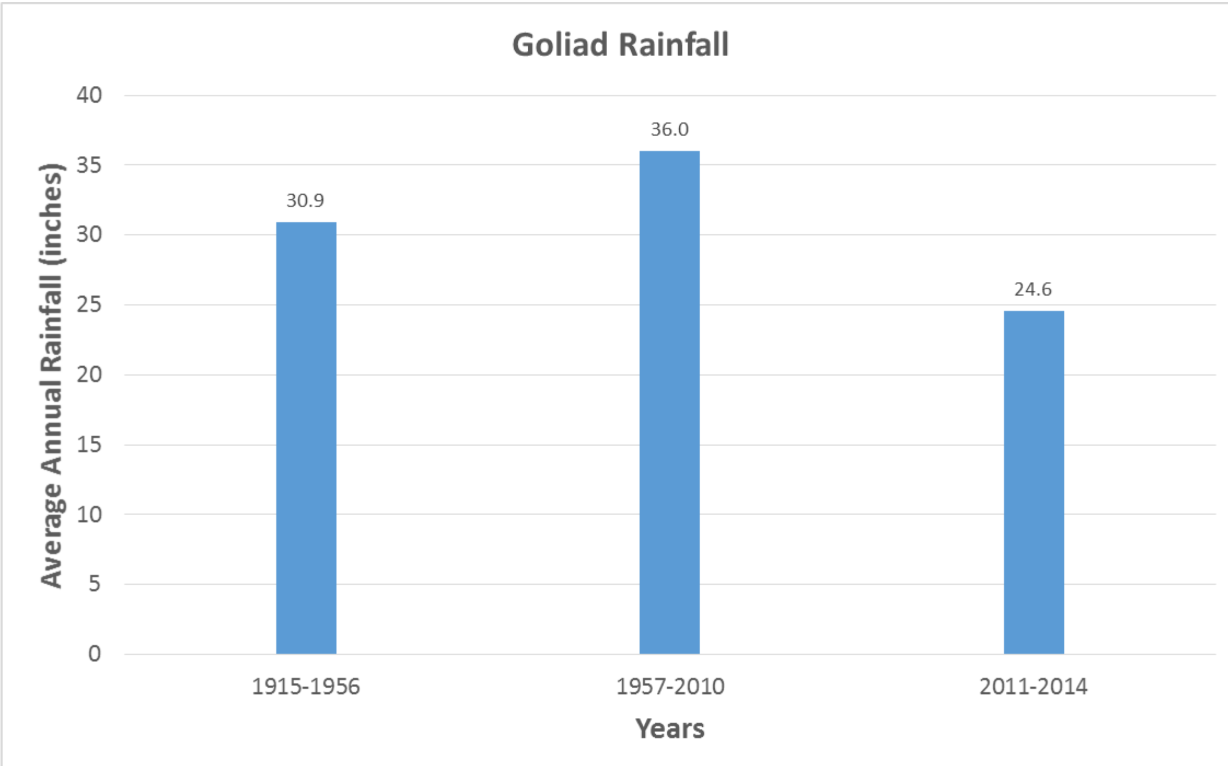

Figure 4.2 Average annual rainfall (inches) at Goliad, Texas, during two multidecadal periods (1915-1956 and 1957-2010) and the most recent four years (2011-2014).

Table 4.1 Average annual precipitation (PPT; inches) at eight sites in South Texas before the end of the drought of the 1950s and following the drought of the 1950s.

Location	Mean PPT	Period	Years[1]	PPT	Period	Years[1]	PPT	After/Before
Beeville	31.18	1903-1956	51	31.88	1957-2004	46	33.49	1.05
Cuero	34.48	1902-1956	54	33.98	1957-2004	39	35.93	1.06
George West	27.05	1916-1956	38	26.64	1957-2004	44	28.40	1.07
Goliad	34.82	1915-1956	42	30.91	1957-2010	54	36.00	1.16
Runge	30.25	1896-1956	48	29.09	1957-2005	48	32.29	1.11
San Antonio	29.12	1892-1956	65	26.10	1957-2004	48	32.57	1.29
Victoria	36.86	1898-1956	56	34.20	1957-2005	49	40.04	1.17
Mean								1.13

[1] Years refers to number of years during the 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 five wettest periods of 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 changes 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. 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 150 years ago when climate shifted again, with aridity again increasing. 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^{o} C) followed by cooling (4^{o} 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 54 years, mean annual rainfall at Goliad was 5.1 inches per year more than in the previous 42 years. That amount of increased rainfall over that long (5 inches per year for 54 years) is likely to have resulted in major shifts in vegetation composition and hydrologic yields. Mid- and tallgrass prairie commonly occurs on areas receiving 20-40 inches of rain annually (Weaver and Clements 1938:517; Weaver 1954:7; Shelford 1963:334; Stoddart et al. 1975:28; Smeins and Diamond 1983; Smeins 1994a; Bailey 1995:46). 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 precipitation limit of the tallgrass prairie. The upper limit on the Coastal Prairies of Texas is about 36 inches (Drawe 1994). In drier environments, sandy soils tend to support woodlands at lower precipitation levels than can be supported on adjacent clay or loam soils.

Average annual rainfall at Goliad was 36.00 inches from 1957-2010. This is the approximate level where the vegetation would shift from grassland to woodland and 54 years is ample time for trees to respond to this increased moisture. Therefore it is likely that woody vegetation became much more abundant in Goliad County following the drought of the 1950s than was present prior to the drought. That increase in deep-rooted woody species (e.g., mesquite, live oak, huisache) would also have probably increased the amount of groundwater use 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 9.2.

4.2 Spatial Variability

Precipitation also varies spatially, often at relatively short distances. For example, there are two stations at Goliad and they are approximately 1 mile apart. For the period of record where data are available for the same years at both locations (37 years) the average annual rainfall at the northern station is 35.83 inches compared to 32.19 inches at the southern station. The difference in average annual rainfall between the two stations is 3.64 inches, or 11% of the annual mean of the southern station. In contrast, the average annual rainfall at Runge for those years in common (35) with the southern Goliad Station is 30.55 inches compared to 32.61 inches for the same years at the southern Goliad station. The difference between these two means is 2.06 inches, or 6% of the mean at the southern Goliad station, although Runge is 26 miles west of the southern Goliad station.

Spatial variations across a landscape can also change over time. Karnes County is the county directly northwest of Goliad County. Karnes City is located near the center of Karnes County and Runge is located 12 miles east of Karnes City. From 1920 through 1958, annual average rainfall was higher in Karnes City than in Runge (31.59 and 28.92 inches, respectively for the 35 common years between the two stations). From 1959 through 2005, annual average rainfall was lower in Karnes City than in Runge (29.31 and 31.67 inches, respectively for the 35 common years). Over those 86 years, the pattern of annual rainfall had reversed.

These spatial differences may 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 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 within 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 Goliad County model, the first approximation approach is currently used.

In determining precipitation zones in EDYS, data were summarized from all available stations in a region, the region consisting of the counties included in the model (Goliad in this case) and surrounding counties (Aransas, Bee, Calhoun, DeWitt, Jackson, Karnes, Lavaca, Matagorda, Refugio, San Patricio, and Victoria in this case). Stations with data for more than 20 years are considered as primary stations (Table 4.2) and stations with data for 20 years or less are considered secondary stations.

Table 4.2 Primary precipitation stations, with corresponding data summaries, used in the Goliad County EDYS model.

County	Station	Mean Annual Precipitation (inches)	Period of Record	Number of Years With Complete 12-mo Data
Goliad	Goliad	34.84	1912-2015	95
Goliad	Goliad (1 SE)	32.40	1949-2005	35
Aransas	Aransas NWR	38.60	1941-2013	66
Aransas	Rockport	34.87	1901-2013	73
Bee	Beeville	31.18	1894-2013	105
Bee	Chase NAS	30.99	1945-1992	37
Calhoun	Point Comfort	43.35	1957-2013	50
Calhoun	Port Lavaca	38.33	1901-2013	49
Calhoun	Port O'Connor	39.25	1948-2013	39
DeWitt	Cuero	34.48	1901-2013	100
DeWitt	Yorktown	34.14	1940-2013	60
Jackson	Edna	40.22	1909-2013	91
Karnes	Cestohowa	27.94	1944-1982	21
Karnes	Karnes City	30.18	1919-2006	72
Karnes	Kenedy	30.50	1948-1977	24
Karnes	Runge	30.25	1895-2013	102
Lavaca	Hallettsville	36.92	1893-2013	115
Lavaca	Speaks	44.49	1967-2013	38
Lavaca	Yoakum	38.25	1917-2013	75
Matagorda	Bay City	45.17	1909-2013	61
Matagorda	Matagorda	42.61	1910-2013	95
Matagorda	Palacios	43.13	1943-2013	66
Refugio	Austwell	33.46	1897-2013	53
Refugio	Refugio	38.21	1948-2013	57
Refugio	Woodsboro	31.48	1916-64, 2007-12	44
San Patricio	Aransas Pass	32.41	1897, 1943-71	24
San Patricio	Mathis	31.00	1917-2013	48
San Patricio	Sinton	32.54	1921-2013	69
San Patricio	Welder WR	36.68	1964-2013	43
Victoria	Victoria	36.86	1893-2013	112

Primary stations are used to define precipitation zones. Distances between Goliad and each primary station were calculated (Table 4.3). The nearest station to Goliad in each direction was noted and lines drawn connecting each of these nearest stations to Goliad. Mid-points along each line were determined. If a mid-point was near the county line or fell outside Goliad County, the area included in that sector was not separated into a new zone. Instead, it was included in the zone that includes the Goliad station. If the mid-point was located in Goliad County at a sufficient distance from the county line to be considered significant, a new zone was designated for the area from the mid-point to the county line. For example, Victoria is the closest primary station northeast of Goliad. It is approximately 26 miles from Goliad to Victoria and it is about 14 miles from Goliad to the county line in the direction of Victoria. Mid-point along this line would be about one mile in Goliad County. That distance was considered to be too small to separate out a separate precipitation zone in the northeast part of Goliad County. In contrast, the intersection of lines connecting the mid-point between Runge and Beeville (representing the western part of Goliad County) and Goliad fell about 15 miles within Goliad County. Therefore, a separate zone was designated for this southwestern part of Goliad County.

Table 4.3 Distances between Goliad and surrounding primary precipitation stations and mean annual precipitation (PPT; inches) for each station (period of record for each station). Mean annual precipitation at Goliad (1913-2015 = 34.84 inches).

Relative Direction	Station	County	Distance (mi)	Mean Annual PPT
North of Goliad				
	Cuero	Yoakum	31	34.48
	Yoakum	Lavaca	45	38.25
Northeast of Goliad				
	Victoria	Victoria	26	36.86
	Edna	Jackson	48	40.22
	Hallettsville	Lavaca	57	36.92
	Speaks	Lavaca	57	44.49
	Bay City	Matagorda	87	45.17
East of Goliad				
	Port Lavaca	Calhoun	46	38.33
	Point Comfort	Calhoun	50	43.35
	Port O'Connor	Calhoun	63	39.25
	Palacios	Matagorda	71	43.13
	Matagorda	Matagorda	87	42.61
Southeast of Goliad				
	Austwell	Refugio	40	33.46
	Aransas NWR	Aransas	48	38.60
	Rockport	Aransas	51	34.87
	Aransas Pass	San Patricio	57	32.41
South of Goliad				
	Refugio	Refugio	27	38.21
	Woodsboro	Refugio	33	31.48
	Welder WR	San Patricio	39	36.68
	Sinton	San Patricio	45	32.54
Southwest of Goliad				
	Beeville	Bee	30	31.18
	Chase NAS	Bee	33	30.99
	Mathis	San Patricio	47	31.00
West of Goliad				
	Whitsett	Live Oak	57	26.34
Northwest of Goliad				
	Yorktown	DeWitt	23	34.14
	Runge	Karnes	23	30.25
	Kenedy	Karnes	31	30.50
	Karnes City	Karnes	37	30.18
	Cestohowa	Karnes	42	27.94
	San Antonio	Bexar	84	29.12

Based on this procedure, Goliad County was divided into four precipitation zones (Fig. 4.3). If a primary precipitation station is located in a precipitation zone, data for that station is used for the precipitation input data (daily) for that entire zone. If no primary station is located in the zone, the precipitation data for that zone is calculated as the average of the nearest surrounding primary stations. Precipitation data for Goliad was used for most of the spatial extent of the Goliad County model but three zones along the northwest, southwest, and south edges of the county used averaged data (Table 4.4).

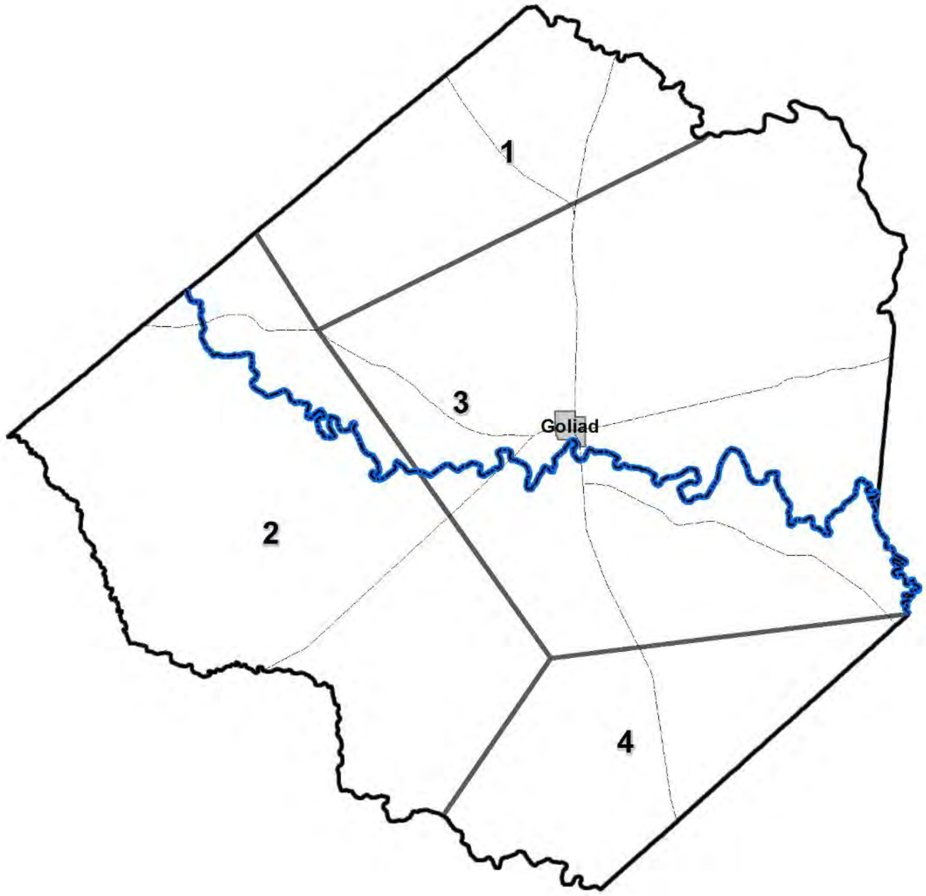

Figure 4.3 Location of the four precipitation zones used in the Goliad County EDYS model.

Table 4.4 Source of precipitation data for the four precipitation zones of the Goliad EDYS model.

Precipitation Zone	Station Data Used
Zone 1 (Northwest)	(Goliad + Yorktown + Runge)/3
Zone 2 (Southwest)	(Goliad + Beeville + Runge)/3
Zone 3 (Central and East)	(Goliad)
Zone 4 (South)	(Goliad 1SE + Beeville + Refugio)/3

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 available for only three of the six stations used to supply data for the four precipitation zones (Table 4.4) and the periods of record vary substantially among the stations. In addition, none of the six stations or the 24 other primary precipitation stations have complete data sets for their respective period of record (i.e., there are some years with missing data for at least one month of the respective year). Consequently, constructed precipitation data sets were developed for each of the six stations.

Constructed precipitation data sets are long-term data sets that include recorded data for those dates where 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.

The first step in developing the constructed data sets was to determine the relationships between precipitation patterns at each two-station combination involving the six selected primary stations plus the 24 additional primary stations in the surrounding counties. For each two-station comparison, a conversion ratio was calculated (Table 4.5). This is the ratio of the average annual precipitation at the station being estimated to the average annual precipitation for the same year at the station being used to estimate, with the averages calculated only using years with complete (12-month) data for years in common between the two stations.

Table 4.5 Conversion ratios for the calculation of values for missing annual precipitation (PPT) data for the six primary stations (columns) used to estimate precipitation in the four precipitation zones in the Goliad County 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.

Station Data Used	Station Calcluated For					
To Calculate From	Goliad	Goliad 1SE	Beeville	Refugio	Runge	Yorktown
Goliad	1.000	0.899	0.895	1.046	0.863	0.926
Goliad 1SE	1.112	1.000	0.956	1.181	0.946	1.036
Aransas NWR	0.938	0.860	0.811	0.961	0.790	0.854
Aransas Pass	1.029	0.886	0.857	1.071	0.906	0.963
Austwell	0.939	0.880	0.880	1.000	0.837	0.911
Bay City	0.755	0.680	0.661	0.786	0.641	0.703
Beeville	1.118	1.046	1.000	1.210	0.958	1.059
Cestohowa	1.291	1.199	1.070	1.340	1.063	1.160
Chase NAS	1.193	1.137	1.037	1.283	0.999	1.099
Cuero	0.994	0.932	0.901	1.079	0.871	0.970
Edna	0.857	0.757	0.789	0.888	0.762	0.814
Hallettsville	0.909	0.823	0.827	0.971	0.791	0.867
Karnes City	1.143	1.093	1.036	1.298	0.995	1.136
Kenedy	1.111	0.965	0.954	1.214	0.970	1.043
Matagorda	0.811	0.749	0.720	0.874	0.701	0.756
Mathis	1.194	1.005	1.051	1.281	1.007	1.143
Palacios	0.835	0.769	0.723	0.878	0.706	0.773
Point Comfort	0.862	0.767	0.745	0.906	0.714	0.793
Port Lavaca	0.875	0.786	0.783	0.910	0.747	0.800
Port O’Connor	0.903	0.853	0.778	0.963	0.782	0.836
Refugio	0.956	0.847	0.826	1.000	0.804	0.887
Rockport	1.025	0.908	0.901	1.068	0.878	0.954
Runge	1.158	1.057	1.044	1.244	1.000	1.103
Sinton	1.088	0.960	0.965	1.144	0.923	1.013
Speaks	0.861	0.785	0.744	0.890	0.707	0.782
Victoria	0.942	0.881	0.846	1.000	0.825	0.876
Welder WR	1.033	0.973	0.900	1.051	0.860	0.950
Woodsboro	1.023	0.915	0.923	1.085	0.894	0.930
Yoakum	0.942	0.890	0.918	0.998	0.797	0.890
Yorktown	1.080	0.965	1.031	1.127	0.907	1.000

To calculate an estimated value for one of the six primary sites the recorded value from another station for that date is multiplied by the conversion factor. For example, if data from Beeville were being used to estimate a value for Goliad, the Beeville value for that date would be multiplied by 1.118 (Table 4.5). Conversely, if data from Goliad were being used to estimate a value for Beeville, the Goliad value for that date would be multipled by 0.895.

Which station to use to estimate a missing value for another station is determined by a substitution list (Table 4.6), which is based on distance from the primary station (Table 4.3) and average difference between monthly values for common years. For a specific date with a missing value for one of the six stations used to determine precipitation zone values (Goliad, Goliad 1SE, Beeville, Refugio, Runge, Yorktown) the first station in the substitution list is checked to determine if that station had a value for that date. If so, that value is multiplied by the appropriate conversion ratio (Table 4.5) and the product is entered as the estimated value for the missing value. If the first station in the list does not have a recorded value for that date, the next station in the list is checked. If the second station in the list does not have a value for that date, the third station is checked. This process continues until a station is found that does have a value. These estimated values are used only for dates with missing data. When a recorded value is available for the particular station, the recorded value is used.

Table 4.6 Selection order for stations to select for precipitation data to be used to estimate missing values for the primary stations.

Primary Station	Selection Order (Substitution List)
Goliad	Goliad 1SE, Victoria, Runge, Yorktown, Refugio, Cuero, Beeville, Kenedy, Chase NAS, Woodsboro, Karnes City, Austwell, Cestohowa, Sinton, Yoakum, Mathis, Port Lavaca, Aransas NWR, Edna, Point Comfort, Rockport, Hallettsville, Speaks, Aransas Pass, Whitsett, Port O'Connor, Palacios, San Antonio, Matagorda, Bay City
Goliad 1SE	Same as for Goliad, except Goliad substituted for Goliad 1SE
Beeville	Chase NAS, Goliad, Goliad 1SE, Kenedy, George West, Karnes City, Runge, Three Rivers, Sinton, Mathis, Welder WR, Woodsboro, Falls City, Cestohowa, Yorktown, Refugio, Rockport, Aransas Pass, Victoria, Cuero, Floresville, Whitsett, Austwell, Aransas NWR, Yoakum, San Antonio, Port Lavaca, Port O'Connor, Point Comfort, Edna, Hallettsville, Speaks, Palacios
Refugio	Woodsboro, Welder WR, Sinton, Rockport, Goliad, Austwell, Chase NAS, Beeville, Aransas NWR, Aransas Pass, Victoria, Mathis, Port Lavaca, Runge, Yorktown, Kenedy, Point Comfort, Cuero, Port O'Connor, Karnes City, Edna, Palacios, Cestohowa, Yoakum, Speaks, Matagorda, Hallettsville, Bay City, San Antonio
Runge	Kenedy, Karnes City, Yorktown, Cestohowa, Goliad, Goliad 1SE, Falls City, Nixon, Cuero, Stockdale, Beeville, Floresville, Whitsett, Three Rivers, Yoakum, George West, Gonzales, Jourdanton, Seguin, Poteet, San Antonio
Yorktown	Runge, Yoakum, Nixon, Cuero, Goliad, Goliad 1SE, Stockdale, Kenedy, Karnes City, Cestohowa, Falls City, Gonzales, Hallettsville, Speaks, Victoria, San Antonio, Edna, Beeville, Chase NAS, Seguin, Woodsboro, Austwell, Aransas NWR, Rockport, Port Lavaca, Point Comfort, Port O'Connor, Bay City, Palacios, Matagorda

Some stations in the Selection Order are not listed in Table 4.5. Those values were calculated for the Karnes-Wilson models (McLendon et al. 2015).

Victoria is the station with the longest period of record for rainfall data in the region. The Victoria data date back to 1893 (Table 4.2) and that year was selected as the starting date for the constructed precipitation data sets used in the Goliad County model. A constructed data set was developed for each of the six primary stations (annual totals presented in Appendix Table A.2) and from these six data sets daily constructed rainfall amounts were calculated for each of the four precipitation zones used in the Goliad County model. The annual totals for the four zones are presented in Table 4.7. Although constructed annual precipitation values are presented in Table 4.7, the precipitation input data used in EDYS are daily values.

Table 4.7 Long-term (122 years) constructed annual precipitation data (inches) for the four precipitation zones used in the Goliad County EDYS model.

Year	Zone 1 Northwest	Zone 2 Southwest	Zone 3 Central	Zone 4 South	Year	Zone 1 Northwest	Zone 2 Southwest	Zone 3 Central	Zone 4 South
1893	16.87	16.70	16.75	16.52	1954	15.32	15.09	16.11	16.97
1894	24.01	25.79	26.49	28.20	1955	22.84	21.58	25.22	20.21
1895	30.14	29.47	24.78	28.47	1956	17.30	18.74	19.47	21.55
1896	28.77	28.18	24.43	27.73	1957	46.19	44.88	51.45	44.70
1897	13.76	14.36	11.45	13.43	1958	40.21	37.17	42.97	40.42
1898	23.85	23.56	24.26	24.34	1959	32.46	31.42	32.31	36.14
1899	28.92	28.55	34.72	34.26	1960	45.49	45.00	48.17	50.24
1900	44.34	43.64	57.34	49.50	1961	25.36	24.49	28.96	24.44
1901	23.31	22.26	21.67	20.00	1962	29.37	29.91	31.64	28.16
1902	37.74	33.86	30.14	31.12	1963	20.43	20.20	23.56	20.28
1903	50.08	49.90	55.60	52.91	1964	25.82	25.06	25.14	24.99
1904	31.25	29.66	31.96	33.89	1965	40.67	39.43	43.93	35.87
1905	37.77	38.75	42.67	42.98	1966	30.83	30.80	37.57	31.21
1906	25.39	27.24	25.42	28.37	1967	46.34	43.45	44.00	43.42
1907	29.92	27.23	41.43	31.65	1968	37.11	35.00	42.03	40.71
1908	34.86	35.08	37.84	37.89	1969	37.11	35.25	35.40	33.18
1909	24.05	27.35	32.32	34.01	1970	29.27	28.96	30.15	32.85
1910	29.23	28.54	28.47	28.97	1971	36.66	38.54	39.56	44.86
1911	30.97	28.55	34.31	28.20	1972	40.31	39.54	52.80	43.87
1912	26.37	27.08	29.13	30.38	1973	53.05	49.75	51.07	53.10
1913	32.92	32.55	34.16	38.27	1974	33.41	32.24	38.20	34.72
1914	42.49	43.01	42.12	45.53	1975	31.14	31.55	39.33	35.58
1915	21.64	18.27	21.44	20.40	1976	50.25	47.99	55.28	47.89
1916	19.22	20.58	19.97	21.31	1977	35.75	34.15	38.51	33.05
1917	12.77	11.80	9.72	10.02	1978	31.24	32.50	29.45	35.66
1918	32.32	30.86	32.28	28.89	1979	40.81	38.44	40.70	38.76
1919	47.83	46.80	47.17	50.62	1980	30.84	33.63	35.52	36.59
1920	26.05	24.05	24.27	22.86	1981	49.97	48.84	59.38	56.49
1921	31.46	29.61	31.17	34.50	1982	26.90	23.49	26.61	24.22
1922	29.36	31.13	26.30	30.78	1983	32.62	32.97	36.50	43.27
1923	47.97	45.91	45.72	42.92	1984	26.30	25.94	28.36	29.63
1924	22.03	21.63	22.66	22.78	1985	38.19	35.44	38.02	35.01
1925	20.80	25.52	29.95	29.96	1986	33.11	33.52	35.69	38.26
1926	33.98	32.64	34.05	33.40	1987	32.00	32.32	29.04	32.82
1927	23.10	21.76	22.42	22.37	1988	19.14	19.13	19.75	16.45
1928	25.91	29.76	29.56	34.15	1989	23.17	20.74	22.61	21.36
1929	39.30	39.27	44.53	39.77	1990	27.92	29.69	33.76	37.61
1930	20.52	23.25	25.88	28.56	1991	44.36	41.00	47.35	41.07
1931	38.94	38.09	40.00	40.34	1992	37.91	40.64	40.88	46.16
1932	30.62	34.93	35.11	37.68	1993	31.35	33.12	37.89	39.57
1933	28.35	28.89	31.62	33.04	1994	40.02	39.55	43.20	41.68
1934	39.54	36.82	41.86	37.18	1995	26.30	25.69	33.54	28.71
1935	45.00	39.42	39.81	38.21	1996	22.84	25.78	23.89	23.28
1936	34.15	33.85	36.49	39.13	1997	47.54	44.62	53.75	48.89
1937	22.75	23.25	26.74	27.17	1998	45.47	43.00	51.44	40.54
1938	20.40	21.48	27.25	28.30	1999	21.15	20.70	22.92	24.15
1939	20.70	19.23	21.63	18.73	2000	38.61	34.76	37.05	32.82
1940	42.48	39.38	38.23	33.53	2001	41.45	41.58	45.84	41.19
1941	41.91	42.31	37.99	46.64	2002	41.40	39.91	42.33	36.62

Table 4.7 (Cont.)

Year	Zone 1 Northwest	Zone 2 Southwest	Zone 3 Central	Zone 4 South	Year	Zone 1 Northwest	Zone 2 Southwest	Zone 3 Central	Zone 4 South
1942	35.41	36.09	41.02	43.06	2003	34.66	33.91	34.43	37.13
1943	30.09	31.69	33.44	33.12	2004	45.11	46.84	47.87	44.46
1944	31.79	30.83	32.02	32.14	2005	31.40	31.29	28.87	31.47
1945	25.00	25.76	29.38	29.33	2006	28.80	29.12	32.71	30.64
1946	45.34	42.81	45.89	45.49	2007	46.85	48.61	51.77	52.80
1947	27.46	29.88	30.87	30.51	2008	20.38	19.36	22.51	21.65
1948	24.83	23.90	26.70	24.22	2009	37.06	33.46	35.92	32.56
1949	38.33	36.39	35.39	36.73	2010	37.04	40.10	41.33	44.93
1950	16.49	15.79	18.65	14.96	2011	18.86	16.83	17.24	17.64
1951	30.18	29.94	37.44	29.69	2012	24.14	24.61	28.99	28.45
1952	35.97	34.17	37.15	34.76	2013	24.71	25.70	27.76	29.78
1953	24.96	23.48	28.43	24.79	2014	26.41	22.10	25.63	23.85

Annual rainfall (constructed values) varied spatially across the county (Table 4.7). Averaged over the 122 years, there was an average maximum annual difference among the four zones of 5.10 inches (Table 4.8). This average spatial variability (5.10 inches) is equal to about 55% of the temporal variability between dry and wet periods (9.48 inches; Fig. 4.1). Although there were differences in mean annual rainfall among the four zones when averaged over the 122 years, there was no consistent pattern as to which zone was wetter or drier than the others in any particular year.

Table 4.8 Maximum difference among constructed annual rainfall (inches) for the four precipitation zones (Table 4.7) in the Goliad County EDYS model.

Year	Difference	Year	Difference	Year	Difference	Year	Difference	Year	Difference	Year	Difference
1893	0.35	1914	3.41	1935	6.79	1955	5.01	1975	8.19	1995	7.85
1894	4.19	1915	3.37	1936	5.28	1956	4.25	1976	7.39	1996	2.94
1895	5.36	1916	2.09	1937	4.42	1957	6.75	1977	5.46	1997	9.13
1896	4.34	1917	3.05	1938	7.90	1958	5.80	1978	6.21	1998	10.90
1897	2.91	1918	3.43	1939	2.90	1959	4.72	1979	2.37	1999	3.45
1898	0.78	1919	3.82	1940	8.95	1960	5.24	1980	5.75	2000	5.79
1899	6.17	1920	3.19	1941	8.65	1961	4.52	1981	10.54	2001	4.65
1900	13.70	1921	4.89	1942	7.65	1962	3.48	1982	3.41	2002	5.71
1901	3.31	1922	4.83	1943	3.35	1963	3.36	1983	10.65	2003	3.22
1902	7.60	1923	5.05	1944	1.31	1964	0.83	1984	3.69	2004	3.41
1903	5.70	1924	1.15	1945	4.38	1965	8.06	1985	3.18	2005	2.60
1904	4.23	1925	9.16	1946	3.08	1966	6.77	1986	5.15	2006	3.91
1905	5.21	1926	1.41	1947	3.41	1967	2.92	1987	3.78	2007	5.95
1906	2.98	1927	1.34	1948	2.80	1968	7.03	1988	3.30	2008	3.15
1907	14.20	1928	8.24	1949	2.94	1969	3.95	1989	2.43	2009	4.50
1908	3.03	1929	5.26	1950	3.69	1970	3.89	1990	9.69	2010	7.89
1909	9.96	1930	8.04	1951	7.75	1971	8.20	1991	6.35	2011	2.03
1910	0.76	1931	2.25	1952	2.98	1972	13.26	1992	8.25	2012	4.85
1911	6.11	1932	7.06	1953	4.95	1973	3.30	1993	8.22	2013	5.07
1912	4.01	1933	4.69	1954	1.88	1974	5.96	1994	3.65	2014	4.31
1913	5.72	1934	5.04								
MEAN	5.27	MEAN	4.32	MEAN	4.75	MEAN	5.37	MEAN	5.88	MEAN	5.07

Overall, Zone 3 (central) was the wettest, with an annual average of 34.02 inches, and Zone 2 (southwest) was the driest (mean = 31.46 inches). Zone 1 (northwest) had a similar mean to that of Zone 2 (31.97 inches) and Zone 4 was intermediate (mean = 33.31 inches). 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, the highest annual precipitation occurs toward the southeast (Gulf of Mexico direction) and decreases in both the southeast to northwest and northeast to southwest directions (Fig. 4.4). The constructed precipitation data are consistent with this regional pattern.

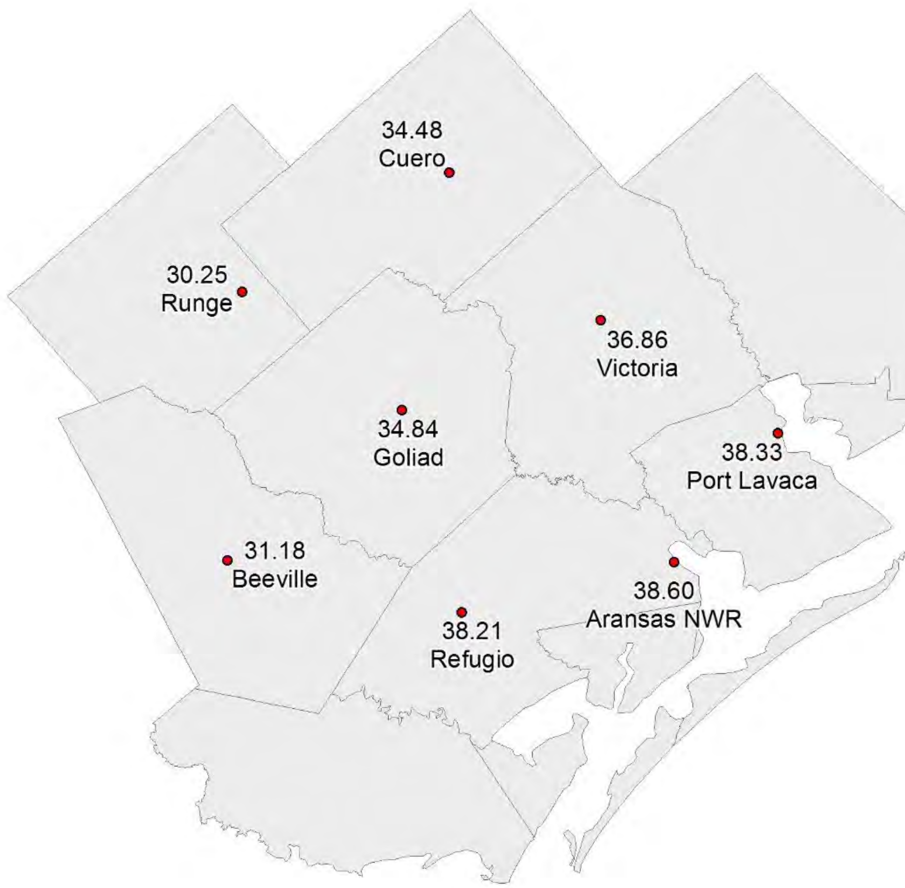

Figure 4.4 Average annual precipitation (inches) pattern across the Goliad County region. Values are annual means based on recorded data for periods of record at each station. Periods of record and years with complete (12-month) data vary among stations.

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 78 soil units are defined and mapped by the Natural Resource Conservation Service (NRCS) as occurring in Goliad County (Wiedenfeld 2010). Many of these are sub-divisions of soil series based on differences in slope, frequency of flooding, or thickness of an upper soil horizon. For example, the soil unit BsA is Buchel clay, 0-1% slope, occasionally flooded, whereas BuA is Buchel clay, 0-1% slope, frequently flooded; CrA is Clareville sandy clay loam, 0-1% slopes, rarely flooded and CrB is Clareville sandy clay loam, 1-3% slopes, rarely flooded. As such, these differences likely have little significance in affecting ecological responses. This is attested to by the fact that most of the sub-divisions have the same ecological site assigned to them (Wiedenfeld 2010).

In order to keep the number of cell types in the Goliad County EDYS model within practical limits, similar soil units were combined. 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. Based on this criteria, the 78 soil units were reduced to 24 soil types (Table 5.1). This set of 24 soil types provided a unique soil to be assigned to each NRCS ecological site.

Table 5.1 Soil types included in the Goliad County EDYS model, along with their corresponding ecological site types.

Musym	Soil Type	Surface Texture	Surface Horizon Depth (inches)	Ecological Site
AnB	Ander	fine sandy loam	12	Tight Sandy Loam
BsA	Buchel	clay	7	Clayey Bottomland
CnA	Cieno	loam	7	Lowland Coastal
CyB	Coy	clay loam	6	Rolling Blackland
EdA	Edroy	clay	7	Lakebed Coastal
GrA	Greta	fine sandy loam	5	Salty Prairie
KyB	Kuy	fine sand	12	Deep Sand
LaA	Laewest	clay	12	Blackland Coastal
MoA	Monteola	clay	6	Blackland RG Plains
NuC	Nusil	fine sand	5	Sandy
OmD	Olmedo	very gravelly loam	6	Shallow Ridge
PrB	Parrita	sandy clay loam	6	Shallow Sandy Loam
PtC	Pernitas	sandy clay loam	11	Gray Sandy Loam
PuC	Pettus	loam	11	Gravelly Ridge
RaB	Raisin	loamy fine sand	5	Loamy Sand
RoA	Realitos	clay	6	Lakebed RG Plains
ScB	Sarco	coarse sand	5	Claypan Savannah
StC	Schattel	sandy clay loam	13	Sloping Clay Loam
SwA	Sinton	sandy clay loam	17	Loamy Bottomland
TeA	Telferner	fine sandy loam	9	Loamy Prairie
WcC	Weesatche	fine sandy loam	5	Sandy Loam
WeB	Weesatche	sandy clay loam	5	Clay Loam
WyA	Wyick	fine sandy loam	6	Claypan Prairie
ZaA	Zalco	sand	10	Sandy Bottomland

The NRCS mapped soil units were displayed on an aerial photograph (Fig. 5.1) and each 40 m x 40 m EDYS cell was then assigned one of the 78 original soil units based on the location of the cell in relation to the spatial locations of the soil units. This 78-unit classification was then converted to the 24-type (Table 5.1) classification by combining units as appropriate.

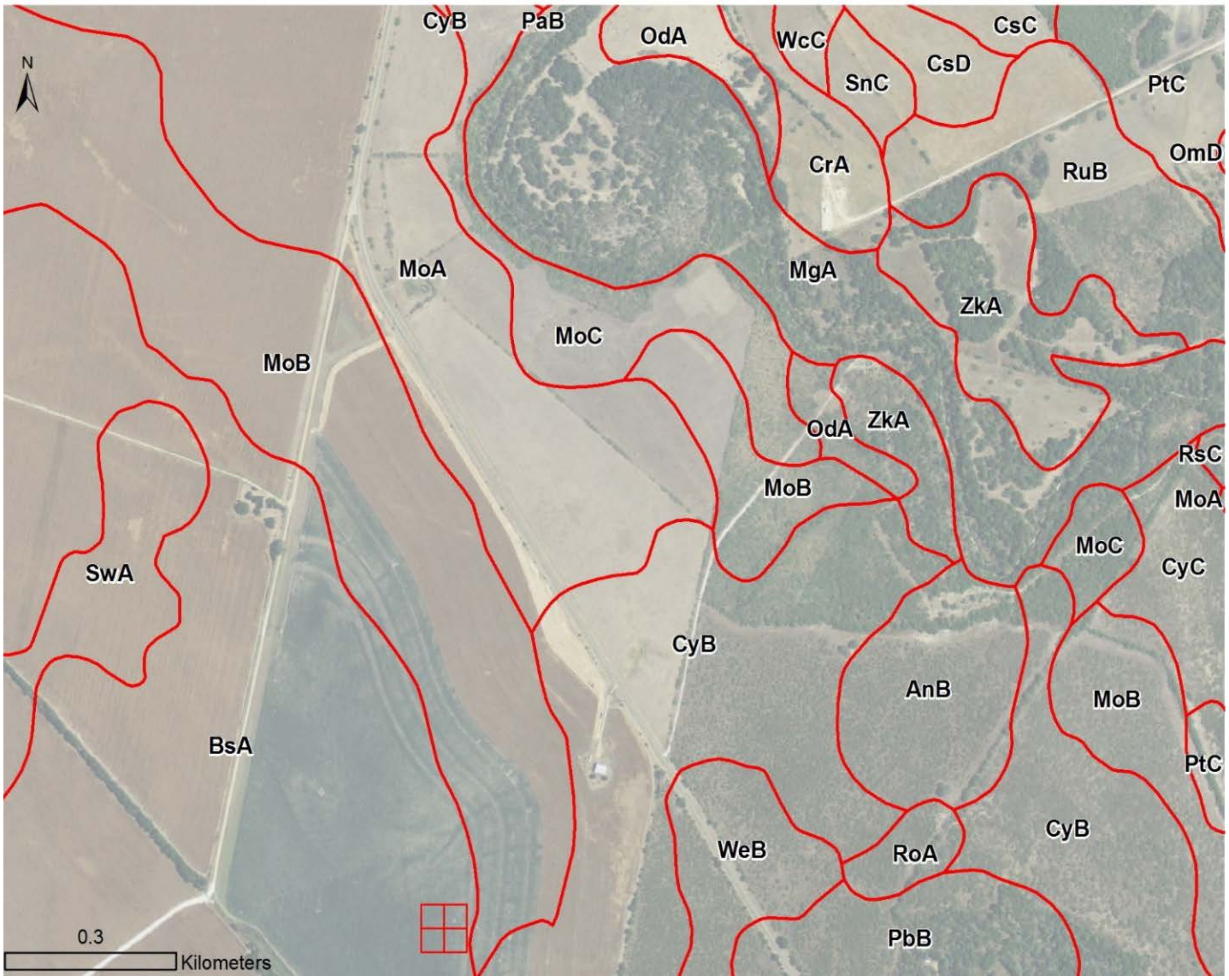

Figure 5.1 Example of the spatial distribution of NRCS soil units on a portion of the Goliad County landscape. The four red squares in the lower portion represent 40 m x 40 m cells in EDYS.

5.2 Profile Descriptions

A soil profile is a vertical section of a particular soil. Soils are composed of layers, called horizons, 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 designating 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. The Weesatche sandy clay loam, the soil covering the most area in Goliad County, is presented as an example (Table 5.2).

Table 5.2 NRCS profile description of the Weesatche sandy clay loam (Wiedenfeld 2010).

Horizon	Depth (cm)	Texture	Color	Structure	Alkalinity
A	000-013	sandy clay loam	dark brown	weak subangular blocky	slight
Bt1	013-031	sandy clay loam	dark gray	moderate prismatic	slight
Bt2	031-070	sandy clay	brown	moderate prismatic	slight
Btk	070-094	clay loam	light brown	moderate prismatic	moderate
Bk1	094-154	silt loam	light brown	weak prismatic	moderate
Bk2	154-203	clay loam	brown	moderate subangular blocky	moderate

EDYS soil profiles are based on the NRCS profiles, but differ in two primary ways. First, 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 processes 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 rainfall event in many drier 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 (2 inches) of the soil and at that depth most of the rainfall-supplied water will be extracted by evaporation before it can be used by plants in transpiration. In contrast, a 10-mm rainfall event on the same soil might supply some moisture to a depth of 10 cm or more and, 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.

The number of soil layers is flexible in EDYS, but commonly 35 layers are used per soil. This is the case for the Goliad County model. Although there are 35 soil layers in each of these EDYS soil profiles, the thickness (depth) and characteristics of each layer vary among soils. EDYS soil layers are subdivisions of NRCS horizons and subhorizons, with each NRCS horizon or subhorizon divided into one or more EDYS layers. However, no EDYS layer combines parts of more than one NRCS horizon or subhorizon. For example, no EDYS layer would include the 010-015 cm depth of the Weesatche sandy clay loam (Table 5.2) because that would combine different horizons (lower part of A and upper part of Bt1). There could however be EDYS horizons of 010-013 cm and 013-015 cm because the first would be from the A horizon and the second from the Bt1 horizon.

NRCS profile descriptions do not include the subsoil material. Most NRCS profiles extend to only 203 cm (80 inches). EDYS profiles extend much deeper, the lower depth based on the maximum potential rooting depth of the deepest-rooted plant species included in the particular EDYS application (Appendix Table E.9). These deeper depths are included in EDYS because plant roots extend into these zones and those zones contain moisture and nutrients that can be accessed by the plants. The thickness and other characteristics of the lower EDYS soil layers are estimated from parent material information provided in the NRCS soil surveys and from other literature sources. 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 about the characteristics of the lower layers.

The second primary way in which EDYS profiles differ from NRCS profiles is that some soil variables are included in the EDYS profiles that are not included in the NRCS profiles and some NRCS soil variables are not included in the EDYS profiles. Variables included in the 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 processes. 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 because it changes rapidly and frequently. 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 soil variables are included, by soil layer, for each EDYS soil profile (Table 5.3). EDYS simulates belowground dynamics based on these 11 variables and the changes in their values that occur during a simulation. Five variables (soil texture, bulk density, maximum moisture content at saturation, field moisture capacity level, permanent wilting moisture level) remain constant during a simulation. 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. Thickness of each layer remains constant unless erosion or deposition occurs. If deposition occurs, the thickness of the top layer increases by the corresponding amount. If erosion occurs, the thickness of the top layer decreases by the corresponding amount. If erosion is sufficient to remove all the top layer, then the process shifts to the second layer and this process continues as long as erosion continues.

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 an input variable. Used to calculate soil water holding capacities and infiltration and percolation rates.
Bulk density	g/cm^3	Not directly used as an input variable. Used to calculate pore space.
Maximum 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: (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.

Water is the major factor controlling 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 the 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 of a spatial cell in two ways, by a precipitation event and by surface movement from a surrounding cell (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 the 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 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, all that 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 the 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 of the second layer is moved into the third layer. This process continues in a top-down manner until the amount of 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 entire layer, at which time the process continues in an upward manner into the next unstaturated layer.

As water moves downward by percolation, soluable materials (nutrients, contaminants, organic matter) are moved with the water. As water moves into the next layer at each time step, the concentrations of the soluable 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 a maximum of the next three soil layers upward to the surface soil layer and then lost by evaporation, but 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 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 plant species and decomposition rates that are influenced by moisture content and nitrogen availability.

6.0 VEGETATION

6.1 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 includes ecological data on over 250 species, not all of which occur in South Texas 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 of the area, based on both ecological and management importance. Ecological importance includes dominant and sub-dominant species for each of the included plant communities, as well as species important successionally and threatened and endangered species if they are present.
- There must be sufficient ecological data available for the included species such 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 these factors, 84 plant species are included in the model (Table 6.1).

Table 6.1 Plant species included in the Goliad County EDYS model.

Lifeform	Scientific Name	Common Name
Tree	*Acacia farnesiana*	huisache
Tree	*Carya illinioensis*	pecan
Tree	*Celtis laevigata*	sugar hackberry
Tree	*Prosopis glandulosa*	mesquite
Tree	*Quercus stellata*	post oak
Tree	*Quercus virginiana*	live oak
Shrub	*Acacia berlandieri*	guajillo
Shrub	*Acacia rigidula*	blackbrush
Shrub	*Aloysia lycioides*	whitebrush
Shrub	*Baccharis texana*	prairie baccharis
Shrub	*Borrichia frutescens*	sea oxeye
Shrub	*Celtis pallida*	granjeno
Shrub	*Lycium carolinianum*	wolfberry
Shrub	*Mahonia trifoliolata*	agarito
Shrub	*Rosa bracteata*	McCartney rose
Shrub	*Sesbania drummondii*	rattlepod
Vine	*Vitis mustangensis*	mustang grape
Cacti	*Opuntia lindheimeri*	prickly pear
Perennial grass	*Andropogon gerardii*	big bluestem
Perennial grass	*Andropogon glomeratus*	bushy bluestem
Perennial grass	*Aristida purpurea*	purple threeawn
Perennial grass	*Bothriochloa ischaemum*	King Ranch bluestem
Perennial grass	*Bothriochloa saccharoides*	silver bluestem
Perennial grass	*Bouteloua curtipendula*	sideoats grama
Perennial grass	*Bouteloua hirsuta*	hairy grama
Perennial grass	*Bouteloua trifida*	red grama
Perennial grass	*Buchloe dactyloides*	buffalograss
Perennial grass	*Cenchrus incertus*	sandbur
Perennial grass	*Chloris cucullata*	hooded windmillgrass
Perennial grass	*Chloris pluriflora*	trichloris
Perennial grass	*Cynodon dactylon*	bermudagrass
Perennial grass	*Digitaria californica*	Arizona cottontop
Perennial grass	*Distichlis spicata*	saltgrass
Perennial grass	*Elymus virginicus*	Virginia wildrye
Perennial grass	*Eriochloa sericea*	Texas cupgrass
Perennial grass	*Leptochloa dubia*	green sprangletop
Perennial grass	*Panicum coloratum*	kleingrass
Perennial grass	*Panicum maximum*	guineagrass
Perennial grass	*Panicum obtusum*	vine-mesquite
Perennial grass	*Panicum virgatum*	switchgrass
Perennial grass	*Paspalum lividum*	longtom

Table 6.1 (Cont.)

Lifeform	Scientific Name	Common Name
Perennial grass	*Paspalum plicatulum*	brownseed paspalum
Perennial grass	*Paspalum setaceum*	thin paspalum
Perennial grass	*Phragmites australis*	common reed
Perennial grass	*Schizachyrium scoparium*	little bluestem
Perennial grass	*Setaria geniculata*	knotroot bristlegrass
Perennial grass	*Setaria leucopila*	plains bristlegrass
Perennial grass	*Setaria texana*	Texas bristlegrass
Perennial grass	*Sorghastrum nutans*	indiangrass
Perennial grass	*Sorghum halepense*	Johnsongrass
Perennial grass	*Spartina spartinae*	gulf cordgrass
Perennial grass	*Sporobolus asper*	tall dropseed
Perennial grass	*Sporobolus cryptandrus*	sand dropseed
Perennial grass	*Sporobolus indicus*	smutgrass
Perennial grass	*Stipa leucotricha*	Texas wintergrass
Annual grass	*Sorghum bicolor*	milo
Annual grass	*Triticum aestivum*	wheat
Annual grass	*Zea mays*	corn
Grass-like	*Carex microdonta*	littletooth sedge
Grass-like	*Cyperus odoratus*	flatsedge
Grass-like	*Typha latifolia*	cattail
Perennial forb	*Ambrosia psilostachya*	ragweed
Perennial forb	*Aphanostephus ramossissimus*	lazydaisy
Perennial forb	*Aster spinosus*	spiny aster
Perennial forb	*Baptistia leucophaea*	wild indigo
Perennial forb	*Clematis drummondii*	old-mans beard
Perennial forb	*Desmanthus velutinus*	bundleflower
Perennial forb	*Phyla nodiflora*	frogfruit
Perennial forb	*Ratibida columnifera*	prairie coneflower
Perennial forb	*Rhynchosia americana*	snoutbean
Perennial forb	*Ruellia nodiflora*	ruellia
Perennial forb	*Rumex crispus*	curly dock
Perennial forb	*Sagittaria falacata*	bulltongue
Perennial forb	*Salicornia virginica*	glasswort
Perennial forb	*Simsia calva*	bush sunflower
Perennial forb	*Smilax bona-nox*	greenbriar
Perennial forb	*Verbena halei*	Texas verbena
Perennial forb	*Zexmenia hispida*	orange zexmenia
Annual forb	*Ambrosia trifida*	giant ragweed
Annual forb	*Amphiachyris dracunculoides*	annual broomweed
Annual forb	*Chamaecrista fasciculata*	partridge pea
Annual forb	*Croton texensis*	Texas doveweed
Annual forb	*Helianthus annuus*	sunflower
Annual forb	*Thymophylla tenuiloba*	dogweed

6.2 Vegetation Formations

A vegetation formation is a subdivision of a biome (McLendon 1991), with the subdivision based on either a general environmental factor (e.g., sandy prairie, riparian woodland) or the dominant genus or species (e.g., oak woodland). Twelve major vegetation formations occur in Goliad County (Table 6.2), with several to numerous plant communities in each formation.

Table 6.2 Major vegetation formations in Goliad County, Texas.

Woodlands	Shrublands	Grasslands	Aquatic	Agricultual
Huisache woodlands	Mesquite shrublands	Clay/clay loam prairies	Lakes/ponds	Cultivated
Mesquite woodlands	Xeric shrublands	Sand prairies	River/creeks	Pasture
Oak woodlands				
Riparian woodlands				

6.2.1 Woodlands

Riparian woodlands occur along the banks of the San Antonio River and banks of the larger creeks. These woodlands commonly have a continuous or nearly continuous canopy cover of trees. The trees tend to be medium-sized to large and of mixed composition. The width of the community generally increases as the size and flow of the associated drainage increases. This bottomland community can extend outward 100-200 m, or more, from each bank of the San Antonio River in some areas, or be as narrow as 10-20 m along some areas of the mid-sized creeks.

Huisache (*Acacia farnesiana*) is a small- to medium-sized tree that can form dense stands on frequently flooded sites, recently disturbed areas, and grassland sites (both native and pasture). It is an aggressive, mid-seral colonizer. Huisache is particularly well-adapted to relatively wet sites, where the surface is frequently flooded and the water table is near the surface. However, it also forms extensive, but less dense, stands on drier sites. On drier, especially clay loam, sites huisache has a competitive advanatage over mesquite (*Prosopis glandulosa*) earlier in succession but mesquite tends to have the competitive advantage over time.

In Goliad County, mesquite woodlands are particularly well-developed on clay loam sites with relatively deep soils that are not frequently flooded. Mesquite woodlands often occur as strips along the drier edges of the riparian woodlands and along the edges of oak woodlands. In these areas, the mesquite can become large (1-m diameter trunks) and form nearly continuous canopies. Many former grassland sites now support mesquite woodland because of long-term overgrazing by livestock.

Oak woodlands occur on sites where the soils are moderate to deep sands. Some oak, especially live oak (*Quercus virginiana*), are common components of the riparian woodlands. But as the soils become sandier, oaks tend to become the dominant species on wooded sites. Post oak (*Q. stellata*) woodlands tend for form somewhat continouous stands across the landscape, whereas live oak woodlands tend to form mottes, some of which can be extensive. However, both species can occur in relatively extensive stands or in large clusters.

6.2.2 Shrublands

There are two primary shrubland formations in Goliad County, mesquite shrublands and xeric shrublands. Mesquite shrublands occur mostly on clay and loam sites that are either drier than those supporting mesquite woodlands or have been more recently or more frequently disturbed. The drier nature of these sites often occurs because there is either a deeper water table or a caliche layer nearer the surface, as compared to soils supporting mesquite woodlands. The mesquite on these shrubland sites tend to be smaller than those in the woodlands, although they can obtain tree size (e.g., 3-8 m tall). Shrubs are abundant in this formation, often forming dense stands under the canopies of scattered mequite. Granjeno (*Celtis pallida*), prickly pear (*Opuntia lindheimeri*), whitebrush (*Aloysia lycioides*), and brasil (*Condalia hookeri*) are common in the shrub component, but mixtures of 10-20 species are common (McLendon 1991).

The xeric shrublands occur mostly on shallow, limestone (caliche) sites. These sites are scattered throughout the county but are most common in the central and western parts. The soils are thin (5-40 cm) over a generally fractured limestone substrate, the upper portion of which varies between somewhat soft to dense, indurated caliche. The vegetation on theses sites tends to be short (2-4 m tall), dense shrublands. Blackbrush (*Acacia rigidula*) is the most common dominant and often occurs as very dense, almost monoculture, stands with little understory (Dodd and Holtz 1972; McLendon 1991). Numerous other xeric shrubs occur in this formation, along with small, scattered mesquite.

6.2.3 Grasslands

Native grasslands were probably extensive in Goliad County in the past, but cultivation, conversion to improved pastures, and increases in woody species have reduced their extent. There is relatively little area in native clay or clay loam grasslands remaining. In the past, these were concentrated in the western part of the county. Those that do currently exist have mostly been restored, either from previously cultivated land or from brush control. These clay/clay loam grasslands were midgrass prairie, dominated mostly by silver bluestem (*Bothriochloa saccharoides*) and little bluestem (*Schizachyrium scoparium*), with substantial amounts of other midgrass species such as sideoats grama (*Bouteloua curtipendula*), trichloris (*Chloris pluriflora*), plains bristlegrass (*Setaria leucopila*), Arizona cottontop (*Digitaria californica*), and Texas cupgrass (*Eriochloa sericea*). More mesic sites such as low-lying areas and ecotones to the riparian woodlands also contained large amounts of tallgrasses such as big bluestem (*Andropogon gerardii*), indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), and eastern gamagrass (*Tripsacum dactyloides*). The non-natives Johnsongrass (*Sorghum halepense*) and guineagrass (*Panicum maximum*) are now abundant on many of these sites.

Sand prairies in Goliad County have also been reduced in area over time but there are still substantial amounts remaining, primarily in the southeast part of the county (Goliad and McFaddin Prairies) and mixed in strips and mottes of the oak woodlands in the eastern and northern part of the county. The sand prairies are also midgrass prairies, typically dominated by little bluestem (in the north), seascoast bluestem (*Schizachyrium scoparium* var. *littoralis*; in the south), and tall dropseed (*Sporobolus asper*). Other important midgrasses are arrowfeather threeawn (*Aristida purpurescens*), Pan-American balsamscale (*Elyonurus tripsacoides*), tanglehead (*Heteropogon contortus*), brownseed paspalum (*Paspalum plicatulum*), and thin paspalum (*P. setaceum*). Forbs are common in these prairies and, when moisture is sufficient, extensive stand of bluebonnets (*Lupinus texensis*), Indian paintbrush (*Castilleja indivisa*), coreopsis (*Coreopsis tinctoria*), and Indian blanket (*Gaillardia pulchella*) can be spectacular.

6.2.4 Aquatic Systems

The only major lake in Goliad County is the Coleto Creek Reservoir along the eastern edge of the county. There are abundant ponds and small lakes, mostly man-made, throughout the county. The vegetation associated with these, including stock tanks, varies by size, depth, and perennial water-holding capability of the pond or lake, but is typical of this type of wetland vegetation in the region. There is commonly an open water surface with little emergent or surface vegetation. As water depth decreases, floating species may occur if the pond has permanent water. Next is a zone of emergent vegetation, typically cattails (*Typha* spp.) and bulrushes (*Scirpus* spp.), then a zone of wetland species including cutgrass (*Leersia hexandra*), sedges (*Carex* spp.), spikerushes (*Eleocharis* spp.), flatsedges (*Cyperus* spp.), longtom (*Paspalum lividum*), and rattlepod (*Sesbania drummondii*). These zones can be narrow (25-50 cm) or wider (e.g., 10 m) depending on the size, structure, and permanency of the pond. Heavy use by livestock often reduces the size and diversity of these zones.

The San Antonio River flows through the center of the county and numerous small to medium-sized creeks flow into the river. Vascular plant development in the river and larger creeks is limited because of high turbidity. In most sections of the river, it is relatively slow moving. Therefore, vegetation along the edges of the river, and similarly along the edges of the larger creeks, is similar to that along the edges of the ponds when the river and creek banks have a gradual slope. Where the river and creek banks drop abruptly into the river, the aquatic vegetation is limited to a thin strip of wetland species. In many of these abrupt areas, the canopies of the riparian trees overhang much of the river. Upslope from the river and creek banks, the vegetation transitions to riparian or mesquite woodland, a wetland, or a shrubland depending on conditions adjacent to the bank.

Many of the mid-sized and smaller creeks are ephemeral streams. Along these creeks, the banks generally support mesquite or huisache woodlands, the widths of which may vary from 10-100 m. The streambeds are often bare of vegetation if water flows fairly frequently, but most of these streambeds are covered with forbs and grasses during dry periods. Giant ragweed (*Ambrosia trifida*), also known as bloodweed, is the most common of these species and often forms dense stands 2-3 m tall.

6.2.5 Agricultural

Approximately 8,500 acres (1.5%) in Goliad County are under cultivation, with an additional 19,000 acres in improved pasture (Wiendenfeld 2010). The major crops are corn, cotton, grain sorghum, wheat, and soybeans. Major improved pasture species are kleingrass (*Panicum* *coloratum*), bermudagrass (*Cynodon dactylon*), King Ranch bluestem (*Bothriochloa ischaemum*), and Johnsongrass. Larger portions of the county were in cultivation in the past, but were either abandoned to cultivation and reverted to native, often woody, vegetation or were converted to improved pasture. Improved pastures in Goliad County are subject to invasion by woody species, especially huisache and mesquite. Woody plant invasion is slower in pastures that are routinely hayed, but woody species still tend to invade over time, especially huisache which has the ability to spread low-growing branches horizontally beneath the cutting height for hay production. Because of invasion by woody plants, improved pastures must be routinely maintained or they will evert to savannas (open stand of small trees with grass understory) in 10-20 years and woodlands in 20-40 years.

6.3 Plant Communities

In EDYS, each cell is assigned an initial vegetation composition based on some combination of the plant species included in the application (Table 6.1). Because species composition field data are not available for each cell in the spatial footprint, initial vegetation assignments are made on the basis of plant communities. A first-approximation of species composition of each plant community, as well as their spatial distribution, is made using NRCS soil survey maps (Wiedenfeld 2010). Each soil series is assigned an initial plant community based on NRCS ecological site descriptions (Table 5.1), other available literature (Appendix C), and professional experience. NRCS ecological site descriptions are largely based on late-successional conditions, which seldom occur on site. Instead, the sites are generally in a lower successional stage and often have some level of woody plant cover. Estimates of lower successional conditions and amounts of woody plant cover (estimated from aerial photographs) are used to adjust the literature data to arrive at initial estimates of species composition and biomass levels for each plant community.

An initial plant community may closely coincide spatially with its associated soil type. However, in some cases the plant communities associated with two or more soil types may be very similar and therefore was pooled. Conversely, visual observations from the aerial photographs may indicate that two or more areas in the same soil type have very different woody plant coverage, in which case they were separated into two or more plant communities.

Once all plant communities have been defined and mapped, all cells within a particular plant community are given the same initial species composition data. 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. Differences in topographic features, precipitation zones, depths to groundwater, natural disturbances (e.g., fire), and management impacts (e.g., livestock grazing intensity, brush control) often result in some cells in the same initial vegetation type changing sufficiently that they for a separate vegetation type.

In addition to literature data and aerial photographs, some ground truthing of the initial spatial distribution of the vegetation is generally conducted. The level of this field mapping depends on the needs of the project and is defined in the scope of work. Once the initial spatial footprint, including vegetation patterns, has been developed and initial simulations conducted, it may be deemed desirable to conduct additional field surveys to increase the detail of the spatial mapping. This can be done and updates incorporated into EDYS with a reasonable amount of effort.

Twenty-four initial native plant communities were identified for the Goliad County model (Table 6.3). These 24 communities were derived from the NRCS range sites and modified on the basis of information from the literature and from amounts of woody plant coverage (Appendix Table C.2). Woody plant coverage was estimated from NAIP aerial photographs and averaged 36.6% for Goliad County overall (Appendix Table C.28). Literature data used to modify the NRCS range site descriptions of the vegetation (Appendix C) were taken from Archer (1990), Archer et al. (1988), Bovey et al. (1970, 1972), Box (1961), Box and White (1969), Buckley and Dodd (1969), Diamond and Smeins (1984), Dodd and Holtz (1972), Drawe (1994), Drawe and Box (1969), Drawe et al. (1978), Garza et al. (1994), Johnston (1963), McLendon (1991, 1994, 2015), McLendon and Dahl (1983), McLendon and DeYoung (1976), McLendon et al. (2012a. 2012b, 2012c, 2012d, 2013a, 2013b), Powell and Box (1967), Scifres et al. (1980), Smeins (1994a, 1994b), and Smeins and Diamond (1983).

Table 6.3 Initial native plant communities used in the Goliad County EDYS model, with their associated NRCS range sites and primary associated soil type.

Plant Community	Range Site	Primary Soil Type
Clay Soils		
Mesquite-hackberry-ragweed	Clayey Bottomland	Buchel clay
Huisache-mesquite-purple threeawn	Blackland RG Plains	Laewest clay
Huisache-mesquite-buffalograss	Blackland Coastal	Monteola clay
Clay Loam Soils		
Mesquite-silver bluestem-buffalograss	Rolling Blackland	Coy clay loam
Live oak-little bluestem-trichoris	Loamy Bottomland	Sinton sandy clay loam
Mesquite-huisache-buffalograss	Sloping Clay Loam	Schattel sandy clay loam
Mesquite-huisache-silver bluestem	Clay Loam	Weesatche sandy clay loam
Mesquite-silver bluestem-little bluestem	Shallow Sandy Loam	Parrita sandy clay loam
Loam Soils		
Huisache-seacoast bluestem-longtom	Lowland Coastal	Cieno loam
Sandy Loam Soils		
Mesquite-huisache-hooded windmillgrass	Gray Sandy Loam	Pernitas snady clay loam
Huisache-mesquite-little bluestem	Loamy Prairie	Telferner fine sandy loam
Huisache-little bluestem-knotroot bristlegrass	Claypan Prairie	Wyick fine sandy loam
Huisache-gulf cordgrass-sea oxeye	Salty Prairie	Greta fine sandy loam
Mesquite-live oak-silver bluestem	Sandy Loam	Weesatche fine sandy loam
Mesquite-silver bluestem-trichloris	Tight Sandy Loam	Ander fine sandy loam
Sandy Soils		
Live oak-little bluestem-Virginia wildrye	Sandy Bottomland	Zalco sand
Post oak-mesquite-little bluestem	Claypan Savannah	Sarco coarse sand
Live oak-mesquite-little bluestem	Loamy Sand	Raisin loamy fine sand
Mesquite-live oak-little bluestem	Sandy	Nusil fine sand
Live oak-little bluestem-ragweed	Deep Sand	Kuy fine sand
Shallow Soils		
Blackbrush-purple threeawn-buffalograss	Gravelly Ridge	Pettus loam
Blackbrush-ragweed-Texas wintergrass	Shallow Ridge	Olmedo very gravelly loam
Wetland Sites		
Huisache-longtom-knotroot bristlegrass	Lakebed RG Plains	Realitos clay
Huisache-longtom-flatsedge	Lakebed Coastal	Edroy clay

Ten land-use types were also included in the model (Table 6.4). These include urban areas, industrial sites, mineral developments, disturbed areas, cultivation, improved pastures, and areas subjected to brush control. They are treated in EDYS in a manner similar to vegetation types.

Table 6.4 Land-use types included in the Goliad County EDYS model.

Land-Use Type	Vegetation	Comment
Urban houses	mesquite-live oak-bermudagrass	50% of area vegetated (lawns)
Buildings/industrial	mesquite-huisache-baccharis	% woody plant cover from aerial photographs
Disturbed area	mesquite-huisache-bacchairs	% woody plant cover from aerial photographs
Oil/drill pad	mesquite-huisache	% woody plant cover from aerial photographs
Caliche pit	huisache-blackbrush-baccharis	% woody plant cover from aerial photographs
Road	none	
Tilled (cultivated)	milo (grain sorghum)	
Orchard	pecan	
Improved pasture	bermudagrass-huisache-mesquite	% woody plant cover from aerial photographs
Brush control	mesquite-silver bluestem-buffalograss	% woody plant cover from aerial photographs; grasses = 10% of rolling blackland type

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

Woody plant cover in cells that were classified as buildings/industrial, disturbed areas, caliche pits, or oil/drill pads was considered to consist of combinations of mesquite, huisache, blackbrush, and baccharis (*Baccharis texana*). This vegetation was considered to be either on areas not cleared when the sites were disturbed or the plants were the result of re-invasion. Amount of canopy cover was estimated from aerial photographs.

Crops grown on individual cultivated fields vary throughout the county. No effort was made to distinguish different crops from the aerial photographs. Instead, all cultivated areas were assumed to be planted each year to milo (grain sorghum). All orchards were assumed to be pecan orchards.

There are several improved pasture species that are common in Goliad County. Most common are coastal bermudagrass, kleingrass, King Ranch bluestem, Kleberg bluestem (*Dichanthium annulatum*), Johnsongrass, and various types of forage sorghums (*Sorghum* spp.). Wheat is sometimes planted as a winter forage crop. Regardless of the species planted, other species tend to invade these improved pastures over time. Common invading woody species include huisache, mesquite, hackberry, and baccharis. Common invading herbaceous species include Johnsongrass, King Ranch bluestem, ragweed (*Ambrosia psilostachya*), and sunflower (*Helianthus annuus*).

The initial forage species planted in the improved pastures, the potential productivity of the pasture, and the most common invading species all vary by soil type, the pre-planting vegetation, and the surrounding vegetation (Appendix Table C.22). Determining what the current composition is for each of the improved pasture polygons would require a substantial effort. As a first approximation, only one improved pasture type (sandy loam, Appendix Table C.22) was used for the initial biomass estimates for all improved pasture polygons. Even though they were all initially set with the same biomass values, changes in these improved pastures can occur during model simulation runs because of differences in precipitation zones and management.

Brush control is a management option in the model. However, it was apparent from the aerial photographs that some areas had been subjected to mechanical brush control without being converted to improved pastures. This was most often the case where brush had been removed in strips, with other strips or blocks left brush. This is a common practice in South Texas, used especially to improve wildlife habitat. The brush strips are left to provide wildlife shelter and the cleared strips are used to provide food, in particular forbs, for wildlife, along with clearing viewing areas for hunting.

In small-scale EDYS applications, these brush strips and adjacent cleared strips can be treated as separate plot types and the composition of both brush and cleared strips can be varied across the landscape. On large-scale applications, such as Goliad County, 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 Rolling Blackland Range Site (Appendix Table C.2). The same woody plant composition was used for the brush control plots as for the Rolling Blackland Site, along with the same amounts and composition of forbs. However, grass biomass was reduced by 90% with composition remaining the same. The amount of woody plant cover in these polygons was estimated from the aerial photographs.

These brush control polygons were previously-treated areas. These are different from areas receiving brush control treatments in the simulation scenarios (Section 9). In the areas receiving the brush control treatment in the scenarios, the existing vegetation is treated in the first year of the simulation.

6.4 Spatial Heterogeneity of Vegetation

Simulation run times and memory requirements increase as the complexity of the model application increases. Model application complexity is determined by a number of factors. Of these, spatial heterogeneity has the greatest effect. Spatial heterogeneity includes several components. One component is number of cells, which is determined by cell size (40 m x 40 m in the Goliad County model) and the size of the overall spatial footprint of the model. A practical upper limit is about 1.5 million cells (Section 2.0).

Although EDYS can keep track of changes in condition in all 1.5 million cells at each time step, that is too many cells on which to simulate all ecological and hydrologic dynamics. Instead, EDYS simulates these dynamics for plot types and then applies the resulting value, at each time step, to all cells containing that particular plot type. For example, an area of mesquite-granjeno shrubland might contain 100 cells, each with the same vegetation and the same soil. Instead of making 100 sets of calculations for that area (polygon) at each time step, EDYS makes one set of calculations and then applies the results of those calculations to all 100 cells.

A plot type is a unique combination of soil, vegetation type (including land-use types), amount of woody plant cover, and precipitation zone. The Goliad County model contains 24 soil-vegetation types (Table 5.1) plus 10 land-use types (Table 6.4). There are seven potential woody plant coverage categories (0-1%, 1-10%, 10-25%, 25-50%, 50-75%, 75-90%, 90-100%), but all coverage categories do not occur in all vegetation types. Accounting for woody plant coverage, there are 154 vegetation-coverage types (Appendix C.27). There are four precipitation zones. This results in a potential for 616 initial plot types (154 x 4), although not all soil-vegetation-landuse types occur in all precipitation zones.

Plot types often become subdivided during EDYS simulations. This happens when some disturbance or treatment factor (e.g., fire, sediment deposition, brush control, cross fencing, placement of water facilities) affects one part of the plot type but not another part. The affected part, including all cells in it, then becomes a different plot type (e.g., root-plowed mesquite-granjeno community). Depending on the length of the simulation run and the number of management options applied, this plot proliferation can increase the number of plot types during the simulation run by a factor of 4-5. The use of different precipitation zones (Fig. 4.3) also increases the number of plot types. Two areas with the same initial plot type but that occur in different precipitation zones will function as different plot types because they receive different amounts of precipitation.

Because of plot type proliferation, the number of potential plot types in the Goliad County model may increase from about 600 at the beginning of the simulation run to 3,000 or more at the end of the run. The upper limit to number of plot types in an EDYS application that has about a million cells (e.g., the Goliad County model) is approximately 1700.

There are two approaches that can be taken to account for plot proliferation. One approach is to not allow it. This approach fixes the number of plot types at the original number. The advantage in using this approach is that greater initial ecological spatial heterogeneity can be included. The disadvantage is that no spatial changes can occur during a simulation. The vegetation can change within a polygon but the polygon cannot be subdivided as a result of disturbance or management.

The alternative approach is to reduce the number of initial plot types and then allow proliferation to occur during the simulation. The advantage of this approach is that the landscape becomes spatially dynamic as well as temporally dynamic. The disadvantage is that less ecological spatial heterogeneity can be included at the beginning of the simulation.

Which approach is selected depends on the relative importance of spatial dynamics versus increased spatial ecological complexity. For the Goliad County model, the second approach was selected. Spatial changes across the landscape, resulting from both natural and anthropogenic factors, were considered of high importance. In addition, much of the increased spatial complexity in ecological factors was considered to be of lesser importance. For example, differences in over two-thirds of the NRCS soil units (54 out of 78) were relatively minor variations based on slope and frequency of flooding (Section 5.1). Likewise, much of the fine-scale changes in plant species composition among vegetation types cannot be determined without substantial on-site vegetation mapping.

The 616 potential plot types used in the Goliad County model allows for an average of almost three subdivisions per plot type during a simulation run. This seems to be a reasonable balance between initial ecological spatial heterogeneity and spatial dynamics during the simulation.

6.5 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 are 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 one or more 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 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 Goliad County model are little bluestem and buffalograss (*Buchloe dactyloides*). The water-to-production value for little bluestem in 0.90 and the value for buffalograss is 0.74. Buffalograss is the more xeric of the two grasses and indeed has a higher water-use efficiency.

There are 346 plant parameter variables in EDYS and each one of these has a specifc value for each species in an application (84 species in the case of the Goliad County model). These variables are arranged into 37 matrices (Coldren et al. 2011a). Selected examples are presented in Appendix E, along with corresponding values for each of the species included in the Goliad County model.

General characteristics of each species are presented in Appendix Table E.1. Appendix Tables E.2-E.4 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 system 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.

Appendix Table E.2 provides the information that EDYS uses to allocate the beginning biomass values (Appendix Table C.2) 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 Appencix Table E.3. For example, if 10 g of new biomass is produced by huisache, 0.8 g would be coarse roots, 2.0 g would be fine roots, 0.9 g would be added to the trunk, 2.2 g would be added to stems, and 4.1 g would be added to leaves. 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 Appendix Table E.4 are used instead of the values from Appendix Table E.3.

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. Appendix Table E.9 provides the values for these two parameters for each of the species included 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 (Appendix Table E.2) by the initial biomass value for that species in a given plot type (Appendix Table C.2). The values in Appendix Table E.9 are then used to allocate this root biomass (coarse and fine) by soil depth. This is calculated as the product of:

(total root biomass)(% in a portion of the rooting depth)(maximum potential rooting depth).

For example, 4% of the roots of huisache are assumed to be located in the first 1% of the rooting depth of huisache, which is 12.62 m (Appendix Table E.9). Therefore, 4% of the initial root biomass of huisache is located in the upper 126 mm of the soil. If the maximum depth of a soil in a particular plot type is less than the maximum potential rooting depth, the maximum soil depth is used instead.

The values in Appendix Table E.9 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., Appendix Table E.3). This new root biomass is allocated to the current root biomass in those soil depths where active root uptake of water and nutrients is taking place. This results in potential changes in root distribution during a simulation caused by resource distribution.

Appendix Table E.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) those months in which flowering and seed production can occur, and 4) those months in which seed germination can occur.

Appendix Table E.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) refers 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 of new biomass (i.e., water-use efficiency). Green-out 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 (Appendix Table E.11), EDYS calculates the amount of water that species would require if it produced at its maximum potential rate (Appendix Table E.14) plus the amount required for maintenance of 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 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. If nutrients are more limiting to plant growth than water requirements at that time step, the amount of new growth produced in determined by the amount of nutrients available rather the amount of water available, and the amount of water used in reduced proportionately.

Appendix Table E.14 provides values used to determine maximum potential growth rate, 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 Appendix Table E.14 are multiplied by the amount of photosynthetically-active tissue (Appendix Table E.16) present in that species at that time step. The product in 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 the species. Maximum old biomass drought loss is the maximum amount (proportion of existing biomass) that can be lost in one month from drought.

Appendix Table E.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 (Appendix Table E.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 the table are estimates based on responses to both temperature and photoperiod.

Maximum potential growth rates (Appendix Table E.14) are based on photosynthetically-active tissue. For most species, the tissue with the highest potential photosynthetic rate are the leaves. Cacti are an exception. Cacti leaves are their thorns. Cacti stems 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 of retama and paloverde trees). Stems of many species contribute somewhat to photosynthesis, but generally at a lower rate than leaves. Appendix Table E.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. Appendix Table E.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 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 Appendix Table E.4.

Appendix Table E.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 (Appendix Table E.9). This is the relative amount of roots and shoots for that species. However, these ratios change during the growth 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 (Appendix Table E.11), plants enter winter dormancy (or summer dormancy for cool-season species) and loose some of their tissue. 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. Appendix Table E.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. Appendix Table E.20 provides for this competitive response. The values listed are a reduction in maximum potential growth rate of the **shaded** species resulting from 100% canopy cover of the **shading** species. The values are estimates based on 1) relative heights of the species, 2) canopy foliage characteristics, and 3) shade-tolerance of the understory species. The values in Appendix Table E.20 do not represent the 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 light 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 in the Goliad County model. Within each cell, estimates are made of the amount of woody plant cover (e.g., 10-25%) based on aerial photographs (Section 6.4). 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 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. But with shading, the effect is to reduce herbaceous understory vegetation across the entire cell instead of just under the woody plant clusters which cover 25% of the cell.

We are working on an update that will account for this spatial heterogeneity within a cell. However, that update is not complete and cannot be included in the initial version of the Goliad County model. In the interim, the shading factor is utilized in this version for the effect of woody species on other woody species (i.e., under the woody plant canopy) but not for the shading effect of woody species on herbaceous species. The shading factor is included 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 the shrub and woodland mosaics of South Texas, which have little herbaceous vegetation under the 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).

7.0 ANIMALS

The animal component of EDYS consists of herbivory by different types of animals, both domestic and wildlife. Population dynamics and habitat requirements are not currently included in most applications, but can be included if required. Four types of herbivores are included in the Goliad County model (cattle, deer, rabbits, insects) and others can be added as needed.

Herbivory in EDYS is simulated using three matrices for each animal species included in the model. Examples are provided in Appendix E for cattle. The first matrix is the preference matrix (Appendix Table E.21). Each plant part (live and standing dead) are listed for each plant species in the model. For each part-species combination, a preference ranking 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 (30 in the case of cattle) indicates the material is largely avoided by that animal.

The second matrix is the competition matrix (Appendix Table E.22). The values in this matrix indicate the order in which that animal (cattle in the case of Appendix Table E.22) has access to that plant part (whether they actually prefer it or not). In general, insects are considered to have first access (value = 1). The third matrix is the utilization matrix (Appendix Table E.23). 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. On the other hand, horses and deer can harvest this material to ground level.

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. The second step is to determine what the animal species consumes that day. That 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, 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 Goliad County model as consumption by grasshoppers. An average density of 3 grasshoppers/m^2 is used, with an average consumption rate of 0.1 g/m^2/day.

7.2 Rabbits

Rabbits are considered to be eastern cottontails in the Goliad County model. An average density of about 0.3/ha (1 cottontail per 8 acres) was used. Rabbits are assumed to consume an amount of plant material equivalent to 5.4% of their body weight each day (Kanable 1977), or about 73 g per cottontail per day. This equals about 0.0022 g forage/m^2/day.

7.3 Deer

Daily food intake (dry-weight basis) by white-tailed deer in South Texas is equal to about 3.23% of their live body weight for high-quality feed (Wheaton 1981). Daily intake in the western portion of the Edwards Plateau has been estimated to be 2.2% of live body weight (Bryant et al. 1979). Mature white-tailed does average about 43 kg (95 lbs) on the Welder Wildlife Refuge (central Texas Coast) and mature bucks average about 63 kg (139 lbs)(Knowlton et al. 1979), and mature does in the western part of the Edwards Plateau weight about 45 kg (Bryant et al.

1979). Deer in the central portion of South Texas tend to be larger than deer along the central Texas Coast and deer in the Edwards Plateau.

An average stocking rate of 0.164 deer/ha (1 deer/15 acres) was used in the Goliad County model. Using an average deer weight of 53 kg and a daily feed intake of 2.7% of body weight, this corresponds to an average daily feed intake of 1.43 kg/deer, or about 0.235 g/m^2 (2.1 lbs/ac).

In South Texas, deer consume a combination of shrubs, forbs, and grasses, with the specific combinations dependent on vegetation conditions of the site. 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 a total of 80% of the diet. On the Welder Wildlife Refuge in San Patricio County, deer consumed 70-90% forbs, 10-20% grasses, and 3-10% shrubs (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 their rumen contents consisting on unidentifiable material (Everitt and Drawe 1974). White-tailed deer on the Sonora Experiment Station in the southwestern part of the Edwards Plateau were found to consume 61% shrubs, 31% forbs, and 8% grasses (Bryant et al. 1979).

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), although the proportion of grasses may be lower (75%) in South Texas (Drawe and Box 1968; Everitt et al. 1981). They consume some forbs, especially during seasons when grasses are dormant and the 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). Cattle diets in South Texas often contain higher proporitons of shrubs (6-10%: Drawe and Box 1968; Frasure et al. 1979; Smith and McLendon 1981; McLendon et al. 1982) than cattle diets 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 the 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 would consume about 30 lbs of forage per day. Published results from six grazing studies indicate a range in daily forage intake of 20 lbs/AUD in a desert grassland in New Mexico to 59 lbs/AUD on fertilized sand prairie on the Texas Coast, with an average of 34.9 lbs/AUD (Table 7.1). An average of 34 lbs/AUD was used as the estimated forage requirement in the Goliad County model.

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

Vegetation	Location	Amount/AUD lbs	Amount/AUD grams	Reference
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 prairie, medium stocking	Louisiana	34	15,436	Duvall & Linnartz 1967
Bluestem prairie, heavy stocking	Louisiana	26	11,804	Duvall & Linnartz 1967
Bluestem coastal sand 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		34.00	15,438	

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

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 Goliad County is presented in the NRCS Soil Survey (Wiedenfeld 2010). Average current forage production, accounting for the fact that most rangelands in South Texas are not in late-seral condition, was estimated at 70% of the values presented in the Soil Surveys (Appendix Table C.2). Proper management stocking rates were assumed to be based on 50% harvest of average available forage (Appendix Table C.22). These amounts were further reduced on the basis of amount of woody plant cover present (Appendix Table C.27).

The estimated amount of annual available forage was used to arrive at an estimated stocking rate for each EDYS plot type (Appendix Tables D.1 and D.2). Daily forage consumption rate (34 lbs/AUD, Table 6.1) was multiplied by 365 to arrive at an annual animal unit (AU) forage requirement. This value (12,410 lbs/AU) was divided by the estimated amount of annual available forage for each plot type (50% of forage production, Table 7.2). The medium stocking rates were used as the default values in the model. Averaged over all types, the mean stocking rates was 9.7 acres/AU for areas devoid of trees and shrubs (Table 7.2). This increased to 14.7 acres/AU when adjusted for woody plant cover.

Table 7.2 Cattle stocking rates, initial forage estimates, and mean woody plant cover used in the Goliad County EDYS model. Values are averages over various woody plant cover values per type.

Range or Land Use Type	Annual Forage Production				Stocking Rates		Woody Cover
	No Woody Cover		Mean Woody Cover		No Woody Cover (ac/AU)	Mean Woody Cover (ac/AU)	Mean (%)
	(g/m^2)	(lbs/ac)	(g/m^2)	(lbs/ac)			
Blackland, RG Plains	261	2331	136	1212	10.63	20.33	60.1
Blackland, Coastal	522	4661	426	3803	5.33	6.53	23.0
Clayey Bottomland	286	2554	140	1251	9.73	19.84	66.3
Clay Loam	286	2554	190	1696	9.73	14.63	42.0
Claypan Prairie	379	3384	345	3079	7.33	8.06	11.3
Claypan Savanna	306	2733	191	1708	9.10	14.53	46.9
Deep Sand	243	2170	163	1452	11.41	17.09	41.4
Gravelly Ridge	178	1590	116	1035	15.64	23.98	43.6
Gray Sandy Loam	260	2322	143	1279	10.71	19.41	56.1
Lakebed RG Plains	276	2465	187	1674	10.09	14.83	40.2
Lakebed Coastal	350	3126	285	2545	7.95	9.75	23.3
Loamy Bottomland	431	3849	237	2113	6.94	11.75	56.4
Loamy Prairie	410	3661	323	2881	6.79	8.62	26.6
Loamy Sand	295	2634	219	1957	9.41	12.68	32.1
Lowland Coastal	447	3992	345	3078	6.21	8.06	28.6
Rolling Blackland	260	2322	144	1289	10.71	19.26	55.7
Salty Prairie	520	4644	478	4272	5.35	5.81	10.1
Sandy	297	2652	208	1859	9.34	13.35	37.4
Sandy Bottomland	369	3295	203	1816	7.52	13.67	56.1
Sandy Loam	342	3054	290	2593	8.14	9.58	18.9
Shallow Ridge	134	1197	96	858	20.78	28.93	35.4
Shallow Sandy Loam	210	1875	100	889	13.26	27.92	65.8
Sloping Clay Loam	186	1661	140	1247	14.97	19.90	31.1
Tight Sandy Loam	285	2545	204	1822	9.73	13.62	35.5
Improved Pasture	566	5054	560	4998	4.92	4.97	1.4
Mean	324	2893	235	2096	9.67	14.68	

The range or land-use types are divided in the model on the basis of amount of woody plant coverage, and stocking rates are adjusted proportionately. No woody cover = forage production and stocking rates without woody plants coverage (Appendix Table C.2). Mean woody plant cover = values averaged (weighted by number of cells) over all woody coverage classes for that type (Appendix Table C.27), i.e., reduced forage production because of woody plants.

The moderate stocking rates used in the model (Table 7.2) compare well with rates reported in published research studies in the coastal region. Light stocking rate (32% forage utilization) on a sandy loam site on the Welder Wildlife Refuge in San Patricio County was 15 acres/AU (Drawe and Box 1969), which compares with a moderate stocking rate of 8.1 acres/AU on sandy loam and 11.4 acres/AU on deep sand sites in the model (Table 7.2). A moderate stocking rate (46% utilization) on silt loam bluestem sites in central Louisiana was 8.1 acres/AU (Duvall and Linnartz 1967). The stocking rate used in the model on clay loam sites was 9.7 acres/AU. A moderate to heavy stocking rate (61% utilization) on a seacoast bluestem clay prairie in Calhoun County, Texas, was 4.5 acres/AU (Durham and Kothmann 1977). The moderate stocking rate on coastal blackland sites in the model was 5.3 ac/AU. The average stocking rate in these three published studies was 9.2 acres/AU, with a corresponding average utilization of 46%. The corresponding values in the model are 8.3 acres/AU with an average utilization of 50%.

7.5 Horses

The model has the capability of including horses in the grazing options. However, at present they are not included because of lack of information on stocking rates and locations. Although there are a substantial number of horses in Goliad County, most of these do not consume most of their feed from range vegetation. Instead, substantial portions are provided as hay and concentrates. In addition, their numbers are not distributed evenly across the landscape. Most horses in Goliad County are maintained for pleasure and are confined to areas near urban areas or farmsteads. These uneven distribution and supplemental feed factors make it likely that uniform modeling assumptions will lead to more inaccurate estimates in the simulations than if horses are excluded at this point in the modeling effort. When included in the model, horses are considered to have the grazing equivalent of 1.25 AU (Stoddart et al. 1975), i.e., one horse consumes an equivalent amount of forage as 1.25 1000-lb cows.

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 Goliad County model, is difficult and perhaps counter-productive for the same reasons that modeling the impacts by horses is difficult on a landscape basis. The density and distribution patterns of feral hogs are not documented on a county-wide scale. Therefore, any scenarios including these 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, for example, in EDYS modeling of feral hog impacts in the Upper Llano River Watershed Protection Plan (Broad et al. 2016). No such scenarios were included in the ten scenarios simulated for the Goliad County report.

8.0 CALIBRATION

Calibration in EDYS consists of adjustments of parameter values, if needed, to achieve target values for the output variables under consideration. Target values are derived 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 literature data and professional judgement are used.

8.1 Vegetation

Independent validation data are being collected in Goliad County, as well as Karnes and Wilson Counties, but these data were not available in time to be used in the development of the Goliad County model. Field validation studies were established in August 2014 and those data will be used to validate the model. Because field validation data were not available, reasonable ecological estimates were used as target values for calibration comparisons.

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 interative process is continued until a sufficient number of types are included that, in combination, include all the major species included in the model. In addition to adding types, variations in woody plant cover and differences in rainfall regimes are included in the calibration process.

EDYS contains a large number of variables (parameters; Section 6.5), the values of any combination of which can be adjusted during the calibration process. The following general procedure is used to determine which parameters area 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 more sensitive to changes in. Examples include water-use efficiency, root architecture, potential growth rate, allocation of current production, and end of growing season dieback. For most of these variables, we have a range in values in our data base that have been compiled from various literature references and from our own field and greenhouse studies. For example, we have root architecture data for little bluestem (*Schizachyrium scoparium*) from 13 profiles taken from nine published studies (Sperry 1935; Weaver and Zink 1946; Weaver 1947, 1950, 1954, 1958; Weaver and Darland 1949; Coupland and Bradshaw 1953; Jurena and Archer 2003). We begin the calibration process using the mean of these 13 profiles. If necessary, we can change the values of initial root biomass in each layer (Appendix Table E.9) to provide a better fit with expected little bluestem biomass values changes in the model simulations. However, whatever changes are made in the 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. Siver bluestem is another major perennial grass species in the Goliad County model. McGinnies and Arnold (1939) reported an average water-use efficiency in production of new biomass for silver bluestem of 685 g water/g aboveground biomass. However, they reported a range over a two-year period of 337-1221, depending on season and amount of water available. Our calibration converged on a value of 760 (Appendix Table E.13), which is very near the mean (765) of the values reported by McGinnies and Arnold (1939) for the period May-September in their study and well within the overall range of values they reported.

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 spatial landscape.

8.1.2 Examples

Six vegetation types were used to calibrate the model. Ten-year simulations were conducted for each calibration run. For each calibration run, initial composition and associated standing crop biomass values were defined for all vegetation types in the model (Section 6.3) and the entire model was run of a 10-year simulation. This allowed for surface hydrology interactions among all the vegetation types over time. Standing crop biomass values for each species were downloaded for each of the calibration types at the end of October (approximate end of growing season for most species in the model) of each year of the simulation.

Calibration was first conducted without grazing by livestock for two reasons. First, studies of vegetation change over time (especially successional studies) generally 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 proceding in a realistic ecological manner (e.g., trees and midgrasses increase during periods of higher rainfall and xeric shrubs and shortgrasses increase during periods of lower rainfall, forbs decrease as midgrasses increase and increase as midgrasses decrease). The second reason for excluding livestock grazing during calibration is that the actual level of livestock grazing is unknown for most, and perhaps all, the various spatial units (e.g., pastures, ranches) in a county-wide model. Therefore, if grazing was included the calibration the results would most likely reflect the effects of the grazing levels entered into the model rather than successional effects and responses to rainfall variations. Once the models were calibrated without livestock grazing, livestock grazing was included and the calibration simulations re-run to affirm that the response of grazing was reasonable.

Four calibration scenarios were conducted for each of the six vegetation types. The first scenario utilized a moderate precipitation regime (1940-49 daily rainfall data, annual mean = 35.14 inches) without livestock grazing. The second scenario used a 10-year dry precipitation regime (1947-56 daily rainfall data, annual mean = 27.59 inches) without livestock grazing. The third scenario used a 10-year wet precipitation regime (1972-81 daily rainfall data, annual mean = 44.08 inches). The fourth scenario utilized the moderate precipitation regime (1940-49) but included cattle grazing at moderate stocking rates (Table 7.2).

8.1.2.1 Clay Loam

Calibration began with Plot Type 137 (NRCS type = clay loam; Appendix Table C.2), with 25-50% (38% mean) woody plant cover, using the moderate precipitation regime. The clay loam type is the most common vegetation type in northeastern South Texas (Drawe et al. 1978; McLendon 1991) and is the most abundant type in the Goliad County model footprint, containing 24% of the area within the spatial footprint (Appendix Table C.28). It also contains 38 of the 84 (45%) plant species included in the model. Much of this type was probably once midgrass prairie with scattered shrub mottes, but now it commonly supports moderate to dense shrublands unless recently cleared by brush control.

This type is a clay loam grassland with scattered mottes (clusters) of woody species covering 25-50% of the surface. The mottes are characterized by a mixture of mesquite trees with understory shrubs and scattered to moderately dense stands of huisache. Total initial aboveground biomass was initially set at 2,487 g/m^2, of which 49% was tree biomass (mesquite and huisache) and 39% was shrub biomass (mostly granjeno, blackbrush, whitebrush, and prickly pear). The remaining 12% (308 g/m^2; 2744 lbs/ac) was from grasses and forbs, which primarily occurred the interspaces between the woody mottes. The herbaceous biomass consisted mostly of shortgrasses (hooded windmillgrass [*Chloris cucullata*], buffalograss, purple threeawn [*Aristida purpurea*]), with lesser amounts of midgrasses (plains bristlegrass, silver bluestem) and forbs (mostly ragweed).

Under the moderate rainfall regime (1940-49; mean annual rainfall = 35.14 inches) and without livestock grazing, there was a moderate increase (10.2%) in total aboveground biomass (Table 8.1). This increase suggests that the system has not reached overall equilibrium with precipitation. This was not an unexpected result because the initial herbaceous biomass was set at about 70% of the amount hypothesized by the NRCS for excellent range condition (Appendix Table C.2). The absence of livestock grazing combined with some increase in woody species easily accounts for the 10% increase in the calibration simulation value.

Table 8.1 Calibration results for 10-year simulations for the clay loam, 25-50% woody cover, vegetation type (Plot Type 137), Goliad County EDYS model. Values are total aboveground biomass (g/m²) in October (end of growing season) under three precipitation (PPT) regimes.

Lifeform/Species	Initial	Year 10, No Grazing			Year 10, Grazed
		Mod PPT	Dry PPT	Wet PPT	Moderate PPT
Trees	1221	1298	1240	1311	1278
Shrubs	958	1178	1045	1167	1040
Midgrasses	90	109	62	192	62
Shortgrasses	150	124	77	214	316
Forbs	68	32	16	45	17
Total	2487	2741	2440	2929	2713
Huisache	351	428	417	475	399
Mesquite	870	870	823	836	879
Blackbrush	191	179	164	177	120
Whitebrush	190	276	228	257	302
Baccharis	101	160	126	165	50
Granjeno	276	310	271	296	331
Wolfberry	21	20	18	18	14
Agarito	4	3	4	3	5
Prickly pear	175	230	234	251	218
Silver bluestem	24	34	19	53	50
Sideoats grama	4	3	2	6	3
Trichloris	6	2	2	4	6
Arizona cottontop	2	1	1	1	*
Little bluestem	6	3	2	6	2
Plains bristlegrass	34	56	32	101	0
Indiangrass	1	*	*	*	*
Johnsongrass	9	8	3	18	0
Tall dropseed	4	2	1	3	1
Purple threeawn	23	30	9	61	131
Hairy grama	3	1	1	1	1
Buffalograss	39	50	26	56	111
Hooded windmillgrass	68	23	28	42	73
Vine-mesquite	1	*	*	1	*
Brownseed paspalum	10	15	9	28	0
Knotroot bristlegrass	3	*	*	*	*
Texas wintergrass	3	5	4	25	*
Ragweed	13	6	2	8	9
Wild indigo	4	6	4	7	0
Old-man’s beard	5	15	9	23	2
Bundleflower	2	*	*	*	*
Frogfruit	3	1	*	1	1
Prairie coneflower	3	*	*	*	0
Snoutbean	4	*	*	1	0
Ruellia	4	*	*	1	0
Bush sunflower	9	3	1	3	4
Orange zexmenia	7	1	*	1	1
Annual broomweed	7	0	0	0	0
Sunflower	7	0	0	0	0

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

Aboveground biomass of trees increased by 6.3%, with all of this increase coming from huisache. Huisache increased by 12% over the ten years. In comparison, huisache increased by 46% on mesquite-mixed grass communities of the Welder Wildlife Refuge over a period of 16 years (Box et al. 1979). Shrub aboveground biomass also increased (23%) during the 10-year simulation, with whitebrush and baccharis increasing the most (45% and 58%, respectively).

Both of these species are aggressive invading species under moist conditions. Prickly pear and granjeno also increased (31% and 12%, respectively), but there was a decrease in blackbrush. A decrease of blackbrush over a 15-year period following the end of the drought of the 1950s was also reported for the chaparral-mixed grass community on the Welder Wildlife Refuge (Drawe et al. 1978).

There was an increase in midgrasses with a corresponding decrease in shortgrasses over the 10-year simulation. This is the expected pattern under conditions of moderate rainfall and no livestock grazing. Midgrasses increase during secondary succession on the coastal prairies and shortgrasses during periods of lower rainfall or under heavy grazing (Drawe et al. 1978). In the central Great Plains, replacement of shortgrasses by midgrasses following drought takes about 8-12 years (Weaver 1954). Plains bristlegrass and silver bluestem were the primary midgrasses that increased (65% and 42%, respectively). Both of these species are mid-seral grasses that are among the first midgrasses to respond to a reduction in grazing pressure (Box 1961; Powell and Box 1967; Drawe et al. 1978). Of the three major shortgrass species on this type at the beginning of the simulation, two increased (purple threeawn and buffalograss) and one decreased (hooded windmillgrass). Hooded windmillgrass is the earliest seral species of the three and would therefore be expected to decrease first once the midgrasses increased.

There was an overall decrease in forbs over the 10 years, which would also be expected as secondary succession proceeded from earlier to later stages (Drawe et al. 1978). Forb abundance is less in late seral conditions in bluestem prairie and greater in earlier (weedy) stages. Ragweed is an early-seral species and it decreased by 46%. Conversely, old-man's beard (*Clematis drummondii*) increased in abundance, which is consistent with results reported for the Welder Wildlife Refuge (Drawe et al. 1978).

Changing the rainfall regime affected the vegetation dynamics (Table 8.1), which was the expected result. Under the dry regime (1947-56, mean = 27.59 inches), there was an increase in huisache but at a slower rate than under the moderate rainfall regime and there was a decrease (5.4%) in mesquite. Mesquite decreases in cover during drought periods in South Texas (Archer et al. 1988). Compared to their respective values under the moderate rainfall regime, all shrub species had lower values after 10 years except for prickly pear. Prickly pear is well-adapted to drought conditions and was also benefited by the decrease in competition from other woody species. Compared to their respective values under the moderate rainfall regime, all herbaceous species except hooded windmillgrass had equal or lower values under the dry regime. Hooded windmillgrass is a relatively xeric seral-seral species that was benefited by the lower level of competition from the other herbaceous species. The two midgrasses that maintained their biomass levels under the dry regime were trichloris and Arizona cottontop, both of which are relatively xeric midgrasses.

Under the wet regime (1972-81, mean = 44.08 inches), huisache increased more than it did under the moderate regime and mesquite decreased slightly (Table 8.1). A decrease in mesquite cover following the return of relatively high rainfall levels following the drought of the 1950s was reported on clay and clay loam soils on the Welder Wildlife Refuge (Drawe et al. 1978). There was little overall difference in shrub biomass between moderate and wet rainfall regimes, and this was also true for most individual shrub species. This lack of shrub increase under the wet regime was likely the result of increased competition from the herbaceous component and from huisache. Almost all herbaceous species increased in biomass under the wet regime compared to the moderate regime. There were substantial increases in most midgrasses, which is typical of successional dynamics in bluestem grasslands (Weaver 1954; Jensen and Schumacher 1969). In particular, there were substantial increases (percentage-wise) in silver bluestem, sideoats grama, plains bristlegrass, and little bluestem. These are species that increased in abundance on the Welder Wildlife Refuge during the relatively wet period of the 1960s and early 1970s (Drawe et al. 1978). The shortgrass species that had the greatest increase percentage-wise under the wet regime was Texas wintergrass (*Stipa leucotricha*). This is the only shortgrass species specifically mentioned as increasing significantly on clay loam sites of the Welder Wildlife Refuge following the drought of the 1950s (Drawe et al. 1978).

Livestock grazing also had an impact on vegetation change in the calibration simulation (Table 8.1). The major difference between grazed and ungrazed was a decrease in midgrasses and an increase in shortgrasses under the grazing regime. Compared to ungrazed conditions at the end of 10 years, midgrass biomass was 43% lower and shortgrass biomass was 155% higher. This is what would be expected to occur. Most of the midgrasses are more preferred forage species by cattle than most of the shortgrasses. Therefore, the midgrasses receive a higher proportion of the grazing pressure. Two midgrass species, plains bristlegrass and Johnsongrass, decreased the most. Both of these species are highly palatable to cattle. Silver bluestem and trichloris both increased under grazing. Both of these species are less preferred by cattle than most of the other midgrasses, hence they would be expected to increase as the more preferred midgrasses decreased. Most shortgrasses increased under the grazing scenario which should be expected because of less competition from the midgrasses. The two exceptions were brownseed paspalum and Texas wintergrass. Brownseed paspalum is a more highly preferred forage species by cattle than most shortgrasses and Texas wintergrass is heavily utilized by cattle during winter months when it is one of the few forage species providing green forage.

Huisache biomass decreased slightly under the grazing scenario, compared to the ungrazed scenario, whereas mesquite increased. Huisache is a palatable browse species whereas mesquite leaves are relatively unpalatable. The decrease in huisache was the result of greater browsing pressure, from cattle in early spring and during drier periods but especially from increased browsing from deer. As cattle removed more of the herbaceous material by their grazing, deer shifted more to browse. This also explains most of the differential responses of the shrub species to the grazing scenario. Blackbrush, wolfberry (*Lycium carolinianum*), and prickly pear decreased compared to the ungrazed scenario and all three of these species are important browse species to deer. Whitebrush increased substantially under cattle grazing and it is a relatively unpalatable browse species. Baccharis decreased under grazing and it is not a particularly preferred browse species but it is similar in ecological and successional status to whitebrush. Therefore the decrease in baccharis under the grazing scenario was likely the result of increased competition from whitebrush. Granjeno is an important browse species and it increased in biomass under the grazing scenario. This was most likely the result of lower competition from other woody species.

Total aboveground biomass of herbaceous species was 395 g/m^2 in the tenth year with livestock grazing (Table 8.1). Total aboveground biomass in EDYS simulations includes the basal crown (trunk) biomass that is rarely sampled in clipping studies. Trunk biomass accounts for about 40% of total aboveground biomass of herbaceous species in EDYS simulations. Adjusting total aboveground herbaceous biomass to account only for clippable biomass results in a value of 237 g/m^2 of clippable biomass. This compares with 164 g/m^2 on a moderately grazed pasture on the Welder Wildlife Refuge 10 years after drought and heavy grazing (Box and White 1969) and 141 g/m^2 on a heavily-grazed pasture in Goliad County (Dodd and Holtz 1972).

8.1.2.2 Other Types

Five other vegetation plot types were used in the calibration process (Table 8.2). Combined with the area included in the clay loam type, the six types include 61% of the area included in the spatial footprint of the model and 63 of the 84 (75%) plant species. Although all four calibration scenarios were run for each of the five additional types, only results of the moderate-rainfall no grazing scenarios are presented (Table 8.2) and discussed.

Woody species (trees and shrubs) decreased over the ten years on all these sites except the loamy bottomland. Live oak decreased the most, followed by mesquite and with huisache least. Live oak is experiencing a decline on many sites in South Texas and the results of the calibration scenarios suggest that at least part of the reason may be that live oak requires above average rainfall to maintain or increase in abundance. This supports the suggestion that much of the larger live oak type in South Texas may be a relict of past climatic conditions (Drawe et al. 1978). There has also been a slight decrease in mesquite canopy on many sites on the Welder Wildlife Refuge (Drawe et al. 1978) and Archer et al. (1988) suggested that mesquite will likely decrease along drainages in central South Texas under average or above average rainfall as larger species with more dense canopies increase in abundance. On the loamy bottomland site in the calibration simulations, pecan (*Carya illinioensis*) and huisache increased while mesquite, hackberry (*Celtis laevigata*), and live oak decreased.

Shrub biomass varied by species and by vegetation type (Table 8.2). Blackbrush and whitebrush remained relatively stable and prickly pear decreased, especially on the sand and sandy loam types. This is consistent with what has been reported on the Welder Wildlife Refuge (Drawe et al. 1978). Granjeno and baccharis decreased in the loamy bottomland type, perhaps in response to the increase in huisache. Granjeno also decreased on the blackland type but increased on the sand and sandy loam types. The blackland type occurs on Monteola clay soils (Table 6.3) and these soils are more droughty than sands and loams except during wetter periods. Biomass of all lifeforms decreased on this type over the 10-year simulation. This may suggest that the initial biomass values were set too high to begin the simulations (i.e., the site cannot support as high a grassland productivity as suggested by the NRCS under moderate rainfall).

Table 8.2 Initial (00) and tenth-year (10) values (aboveground biomass, g/m^2) for lifeforms and major plant species in six of the vegetation types used in the vegetation calibration process (ungrazed, moderate rainfall scenario). Percentages refer to amount of woody plant cover.

Lifeform/Species	Plot 046 Blackland, Coastal 1-10%		Plot 118 Bottomland, Loamy 50-75%		Plot 004 Tight Sandy Loam 25-50%		Plot 090 Loamy Sand 25-50%		Plot 031 Salty Prairie 1-10%	
	00	10	00	10	00	10	00	10	00	10
Trees	246	231	6684	7178	3469	3286	5344	5084	315	301
Shrubs	73	58	853	709	650	717	384	427	96	101
Midgrasses	203	93	154	142	128	212	123	302	587	815
Shortgrasses	412	327	69	37	96	164	134	82	68	86
Grass-likes	0	0	33	57	0	0	0	0	0	0
Forbs	184	79	70	69	61	26	73	53	19	19
Total	1118	788	7863	8192	4404	4405	6058	5948	1085	1322
Huisache	126	121	582	1268	0	0	0	0	277	263
Pecan	0	0	801	824	0	0	0	0	0	0
Hackberry	7	6	1232	1179	0	0	0	0	0	0
Mesquite	99	91	481	432	1305	1302	1015	921	38	38
Live oak	14	13	3588	3475	2164	1984	4329	4163	0	0
Blackbrush	13	8	0	0	287	287	0	0	0	0
Whitebrush	15	10	158	162	0	0	0	0	0	0
Baccharis	0	0	168	79	0	0	0	0	0	0
Sea oxeye	0	0	0	0	0	0	0	0	96	101
Granjeno	22	18	153	117	276	368	184	256	0	0
Agarito	*	*	0	0	0	0	0	0	0	0
Mustang grape	0	0	374	351	0	0	113	112	0	0
Prickly pear	23	22	0	0	87	62	87	59	0	0
Big bluestem	4	2	6	2	0	0	0	0	0	0
Bushy bluestem	0	0	3	6	0	0	0	0	0	0
Silver bluestem	27	23	7	2	49	124	13	21	0	0
Sideoats grama	5	2	16	13	14	34	26	143	0	0
Trichloris	6	1	28	4	52	47	0	0	0	0
Arizona cottontop	0	0	0	0	2	*	2	1	0	0
Virgnia wildrye	0	0	9	1	0	0	0	0	0	0
Texas cupgrass	0	0	2	*	0	0	0	0	0	0
Switchgrass	12	3	16	6	0	0	7	7	1	*
Common reed	0	0	0	0	0	0	0	0	5	7
Little bluestem	36	12	35	21	0	0	69	119	5	1
Plains bristle	52	33	14	15	11	7	6	11	0	0
Indiangrass	8	1	0	0	0	0	0	0	2	*
Johnsongrass	31	10	18	72	0	0	0	0	0	0
Gulf cordgrass	0	0	0	0	0	0	0	0	574	807
Tall dropseed	22	6	0	0	0	0	0	0	0	0
Purple threeawn	62	46	0	0	27	151	17	23	0	0
Hairy grama	14	3	0	0	10	2	8	2	0	0
Red grama	0	0	0	0	5	*	0	0	0	0
Buffalograss	179	201	18	1	0	0	0	0	0	0
Sandbur	0	0	0	0	16	5	13	6	0	0
Hooded windmill	55	12	0	0	38	6	19	3	0	0
Bermudagrass	0	0	4	1	0	0	0	0	7	2
Saltgrass	0	0	0	0	0	0	0	0	18	11
Vine-mesquite	5	1	6	2	0	0	0	0	0	0
Longtom	0	0	0	0	0	0	0	0	16	3
Brownseed paspalum	37	27	16	30	0	0	52	45	0	0
Thin paspalum	0	0	0	0	0	0	25	3	0	0
Knotroot bristle	22	2	11	1	0	0	0	0	27	70
Texas wintergrass	38	35	14	2	0	0	0	0	0	0
Littletooth sedge	0	0	14	1	0	0	0	0	0	0
Flatsedge	0	0	19	56	0	0	0	0	0	0

Table 8.2 (Cont.)

Lifeform/Species	Blackland, Coastal 1-10%		Bottomland, Loamy, 50-75%		Tight Sandy Loam 25-59%		Loamy Sand 25-50%		Salty Prairie 1-10%	
Ragweed	37	5	14	3	16	14	28	40	0	0
Spiny aster	0	0	6	1	0	0	0	0	7	1
Wild indigo	63	33	0	0	0	0	0	0	0	0
Old-man's beard	31	40	10	30	0	0	0	0	0	0
Bundleflower	4	*	1	*	1	*	2	*	0	0
Frogfruit	0	0	2	*	0	0	0	0	6	14
Prairie coneflower	0	0	0	0	2	*	3	*	0	0
Snoutbean	0	0	4	1	6	0	6	0	0	0
Ruellia	11	1	4	1	0	0	0	0	0	0
Bush sunflower	0	0	0	0	20	12	16	13	0	0
Greenbriar	0	0	15	34	0	0	0	0	0	0
Giant ragweed	0	0	7	0	0	0	0	0	0	0
Partridge pea	0	0	*	0	2	0	1	0	0	0
Texas doveweed	0	0	0	0	4	0	17	0	0	0
Sunflower	38	0	7	0	10	0	0	0	0	0
Glasswort	0	0	0	0	0	0	0	0	0	0

An asterick (*) indicates a trace amount (< 0.5 g/m^2).

Biomass of midgrasses increased on the tight sandy loam, loamy sand, and salty prairie types (Table 8.2), as would be expected under conditions of moderate rainfall and no grazing. Biomass of shortgrasses also increased on the tight sandy loam and salty prairie types, but decreased on the loamy sand type. The decrease on the loamy sand type was likely the result of increased competition from the substantial increase in midgrasses (146%) and the increase in granjeno. Most of the increase in midgrasses came from silver bluestem (tight sandy loam), sideoats grama and little bluestem (loamy sand), and gulf cordgrass (*Spartina spartinae*; salty prairie). These are major mid- or late-seral dominants on these grasslands (Drawe et al. 1978; Scifres et al. 1980; Diamond and Smeins 1984; McLendon 1991; Garza et al. 1994) and therefore should increase in abundance under moderate-rainfall conditions with no livestock grazing. Purple threeawn was the only shortgrass species to increase on the tight sandy loam and loamy sand sites. It is a vigorous mid-seral species that would be expected to decrease over time as the midgrasses continue to increase. However, threeawns are also important components of late-seral sandy prairies in South Texas and the Texas Coast (Diamond and Smeins 1984; McLendon 1991). Knotroot bristlegrass (*Setaria geniculata*) was the shortgrass that increased in the salty prairie type and this species is a common secondary species in gulf cordgrass communities (Scifres et al. 1980). Johnsongrass was the major grass species to increase on the loamy bottomland site and this species can form dense stands on these mesic sites in the absence of livestock grazing.

Aboveground forage production (adjusted to reflect clippable biomass) was 241 g/m^2 on the tight sandy loam type, 262 g/m^2 on the loamy sand type, and 552 g/m^2 on the salty prairie type. These compare favorably with values reported in the literature for South Texas and the Texas Coast (Table 8.3).

Table 8.3 Aboveground biomass (g/m^2, clippable) on sandy grassland and gulf cordgrass communities in South Texas and the Texas Coast.

Type	Location	Biomass	Reference
Seacoast bluestem community	Aransas National Wildlife Refuge	380	McLendon 2014
Seacoast bluestem community	Dimmit County	187	McLendon 1977
Fine sandy loam	Welder Wildlife Refuge	238	Drawe and Box 1969
Sandy loam	Victoria County	203	Bovey et al. 1972
Gulf cordgrass community	Welder Wildlife Refuge	543	Garza et al. 1994

8.2 Ecohydrology

Three ecohydrological components were assessed in the model calibration: 1) evapo-transpiration, 2) surface runoff and sedimentation, and 3) groundwater use by vegetation. These components were also combined to develop several basic water balances. Direct field data were not available 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 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 and evaporation is the amount of water evaporated from the soil (including bare ground, litter, and 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 determining the amount of ET are 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 measurement of evaporation from a free-water surface. Evaporation rates from exposed surfaces (e.g., leaf surfaces, rocks, surface of the litter) may approximate this rate. 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, for example by vegetation cover, 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 whre the evaporation actually occurs. This movement of water is in response to a water potential gradient 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. 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 transpiration **rate** 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 about 37% higher than on bare soil in wet years, but only about 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 about 64% on vegetated sites.

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

Vegetation	---------- 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-threeawn 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. Therefore, any moisture that percolates past these surface layers is largely protected from loss by evaporation. Red grama (*Bouteloua trifida*) and threeawn are relatively shallow-rooted grass species, but they can extract soil moisture from deeper soil 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 threeawn. Therefore, there is additional soil moisture available to them than is available to the shortgrasses. Consequently, the ET values on the shrubland was 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 that had been stored during previous wetter years. Conversely, the ET of the shallower-rooted grasses was less than the annual rainfall. In the wet year, the amount of rainfall received exceeded the annual ET capacity of both the shrubland and the grasses, 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 containing 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 depth 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*), which is a deep-rooted perennial grass. In a similar 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 Evaporation (ET) and depth to groundwater for two communities on 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 because of shading. In the Owens Valley of eastern California, a part of the Mojave Desert with a high water table, ET for three species of grasses with an average canopy cover of 37% had an average E:T ratio of 55:45, with a range of 40-69% evaporation (Evans et al. 2013; Mata-Gonzalez et al. 2014). 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

The clay loam (Plot Type 137) is a mixed grass community with moderate amounts (average of 38% cover) of woody species, mostly mesquite and huisache (Table 8.1). Annual rainfall used in a 25-year calibration simulation varied between 15.79 and 42.81 inches, with an annual average of 31.49 inches. Simulated annual ET averaged 33.50 inches, or 106% of annual precipitation. This equates to an ET rate of 3.5 mm/day for a 245-day growing season (March-October) or an annual (365-day) ET rate of 2.3 mm/day. These are reasonable rates based on literature values. 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) and 2.5 mm for a mesquite riparian community in southern Arizona (Scott et al. 2000, 2006). The simulated ET equivalent of 106% of annual precipitation is higher than the 97% value reported for mesquite-grasslands in the Rolling Plains of Texas (Carlson et al. 1990), 95% for oak-grasslands in the Edwards Plateau (Thurow et al. 1988), and 94% on bluestem prairie in Kansas (Bremer et al. 2001). However, the EDYS simulations indicated that an annual average of 3.36 inches of groundwater were transpired on the clay loam type. Reducing the simulated total average annual ET (33.50 inches) by this amount results in a rainfall-supported average ET of 30.14 inches, or 96% of annual rainfall.

The ratio of annual ET to annual rainfall fluctuates among years, in part because the supply of soil water is not entirely dependent on the amount of rainfall received in the particular year. Some soil water may be carried over from a previous year and late-season rainfall may not be fully utilized by plants in the year the rainfall was received (Table 8.6). ET exceeded annual rainfall in one-third of the years in the Rolling Plains study (Table 8.6). By comparison, ET exceeded annual rainfall in 60% of the years of the calibration simulations (Table 8.7). The higher rate in the calibration simulations was because of groundwater usage by the vegetation on the clay loam sites in Goliad County.

Table 8.6 Annual rainfall and evapotranspiration (ET) at sites in the Rolling Plains (Carlson et al. 1990) and in South Texas (Weltz and Blackburn 1995) in wet and dry years.

	Rolling Plains						South Texas			
	Grassland			Mesquite-Grassland			Grassland		Mesquite-Granjeno	
Rainfall (mm)	769	677	629	769	677	629	310	887	310	887
ET (mm)	644	804	555	658	756	511	298	833	330	881
Balance (mm)	+125	-127	+ 74	- 79	+118	+ 12	+ 12	+ 54	- 20	+ 6
ET/Rainfall	0.86	1.19	0.88	0.86	1.12	0.81	0.96	0.94	1.06	0.99

Table 8.7 Annual rainfall (inches) and evapotranspiration (ET) variables (inches) for the 25-year baseline calibration simulation for the clay loam type, Goliad County EDYS model.

PPT Year	Rainfall	Interception	Evaporation	Total Evaporation	Transpiration	ET	Balance (Rainfall – ET)	ET/Rainfall
1928	29.76	1.36	6.25	7.61	17.64	25.25	4.51	0.848
1929	39.27	1.68	1.75	3.43	35.51	38.94	0.33	0.992
1930	23.25	1.78	1.57	3.35	27.21	30.56	- 7.31	1.314
1931	38.09	1.86	2.29	4.15	34.09	38.24	- 0.15	1.004
1932	34.93	2.10	2.28	4.38	34.69	39.07	- 4.14	1.119
1933	28.89	2.39	1.86	4.25	29.62	33.87	- 4.98	1.172
1934	36.82	1.74	2.32	4.06	29.25	33.31	3.51	0.905
1935	39.42	3.04	2.54	5.58	40.58	46.16	- 6.74	1.171
1936	33.85	3.73	2.97	6.70	34.20	40.90	- 7.05	1.209
1937	23.25	1.56	1.00	2.56	18.58	21.14	2.11	0.914
1938	21.48	1.64	1.84	3.48	24.89	28.37	- 6.89	1.321
1939	19.23	1.61	1.12	2.73	21.88	24.61	- 5.38	1.280
1940	39.38	2.52	1.16	3.68	30.89	34.57	4.81	0.878
1941	42.31	4.89	3.46	8.35	41.56	49.91	- 7.60	1.180
1942	36.09	3.31	4.24	7.55	30.08	37.63	- 1.54	1.043
1943	31.69	2.37	4.09	6.46	23.66	30.12	1.57	0.950
1944	30.83	2.93	3.22	6.15	29.79	35.94	- 5.11	1.166
1945	25.76	2.79	2.41	5.20	23.36	28.56	- 2.80	1.109
1946	42.81	4.55	3.17	7.72	34.85	42.57	0.24	0.994
1947	29.88	3.74	2.60	6.34	26.10	32.44	- 2.56	1.086
1948	23.90	3.08	2.33	5.41	24.21	29.62	- 5.72	1.239
1949	36.39	3.61	2.40	6.01	28.34	34.35	2.04	0.944
1950	15.79	1.87	2.18	4.05	17.95	22.00	- 6.21	1.393
1951	29.94	2.56	1.81	4.37	24.52	28.89	1.05	0.965
1952	34.17	2.19	3.13	5.32	25.03	30.35	3.82	0.888
MEAN	31.49	2.60	2.56	5.16	28.34	33.50	- 2.01	1.064[1]

[1] Calculated on the basis of (Mean ET)/(Mean Rainfall) instead of 25-year mean of ET/Rainfall.

The clay loam vegetation intercepted an annual average of 2.60 inches of rainfall in the calibration simulations (Table 8.7), or an average of 8% of annual rainfall. This is comparable with values reported in the literature for various vegetation types: 4% for shadscale shrubland in Utah (West and Gifford 1976), 8% for California grasslands (Corbett and Crouse 1968), 8% for huisache woodlands in Nuevo Leon (Carlyle-Moses 2004), and 11% for curly mesquite (*Hilaria belangeri*) and 18% for sideoats grama in the Edwards Plateau (Thurow et al. 1987). Transpiration accounted for 85% of total ET in the simulations, compared to 15% for evaporation (Table 8.7).

8.2.1.2 Other Vegetation Types

Average annual ET varied between 27.9 and 48.4 inches per year on the seven types evaluated in the calibration (Table 8.8). The highest average annual ET was on the loamy bottomland type where there was an abundance of mature trees and groundwater was near the surface. Average annual groundwater use by vegetation on this type was 16.80 inches, or 35% of total annual ET. Substantial use of shallow groundwater by trees has been reported in the literature. Ashe juniper (*Juniperus ashei*) has been reported to utilize up to 25% of its transpirational water from groundwater in some areas of the Edwards Plateau (Jackson et al. 2000), mature sugar maple (*Acer saccharum*) trees utilized groundwater almost exclusively when groundwater was at 3 m (Dawson 1996), and ET in mesquite riparian woodlands in southern Arizona was 33% higher when depth to groundwater was 2 m rather than 10 m (Scott et al. 2000, 2006). During drier periods of the year, velvet mesquite (*Prosopis velutina*) in southern Arizona primarily used groundwater (70% of transpiration)(Snyder and Williams 2003). In shallow groundwater semiarid woodlands in Australia, trees utilized primarily groundwater 50-70% (depending on species) of the year in lower rainfall sites and 25-40% for the same species in higher rainfall areas (Cramer et al. 1999). In the dry season in the Northern Territory of Australia, riparian woodlands utilize 50% or more of the water they transpire from groundwater (Lamontagne et al. 2005) and during the drier portions of summers in wet forests of coastal British Columbia, Douglas fir (*Pseudotsuga menziesii*) trees extracted 15% of their transpired water from their deepest rooting depth (Nnyamah and Black 1977).

Table 8.8 Average annual rainfall (inches) and evapotranspiration (ET) variables (inches) for the 25-year calibration simulations for seven vegetation plot types, Goliad County EDYS model.

Type	Rainfall	Interception	Evaporation	Total Evaporation	Transpiration	ET	ET/Rainfall
Clay loam	31.49	2.60	2.56	5.16	28.34	33.50	1.064
Blackland	33.79	2.02	3.18	5.20	22.69	27.89	0.825
Tight sandy loam	33.79	1.98	3.10	5.08	29.30	34.38	1.017
Loamy sand	33.79	2.17	2.74	4.88	29.41	34.29	1.015
Loamy bottomland	33.79	2.49	2.41	4.90	43.51	48.41	1.433
Salty prairie	33.79	1.88	3.09	4.97	24.37	29.34	0.868
Shallow ridge	31.49	5.38	1.00	6.38	28.88	35.26	1.120
Mean	33.13	2.65	2.58	5.23	29.50	34.73	1.049

The clay loam, tight sandy loam, and loamy sand types were grasslands with substantial amounts of woody species (25-50% canopy cover). Annual ET on these sites averaged 33.5-34.4 inches (Table 8.8). These values are typical ET values for mesquite shrublands in South Texas. Weltz and Blackburn (1995) reported an average annual ET of 33.7 inches in mesquite shrubland in South Texas. The salty prairie type had a simulated average annual ET of 29.3 inches, which compares to 24.5-32.3 inches reported for salt meadows in eastern California with depth to water of 1.8-2.4 m (Duell 1990). The simulated annual ET rate of 29.3 inches equates to an average daily ET rate of 2.0 mm, which compares favorably with daily ET rates of 2.2 mm for saltgrass in Nevada (Grosz 1972) and 2.4 mm for sacaton grasslands in Arizona and New Mexico (Weeks et al. 1987; Scott et al. 2006).

Excluding the bottomland type, the remaining six types utilized an average of 98.5% of annual rainfall in ET (Table 8.8). This is a similar value to those reported in the literature for similar vegetation types: 94% for bluestem grassland (Bremer et al. 2001), 95% for oak-grassland (Thurow et al. 1988), and 97% for mesquite grasslands in the Rolling Plains (Carlson et al. 1990) and 98% for mesquite shrublands in South Texas (Weltz and Blackburn 1995).

The average canopy interception rate for the seven types was 8% of average annual rainfall (Table 8.8). This compares favorably with reported rates of 8% for huisache woodlands in northeast Mexico (Carlyle-Moses 2004) and chaparral communities in southern California (Hamilton and Rowe 1949), 13% for *Acacia* woodlands in Australia (Pressland 1973), 8% for bluestem prairie in the Great Plains (Corbett and Crouse 1968), and 11-18% for grasslands in the Edwards Plateau (Thurow et al. 1987).

8.2.2 Surface Runoff

Surface runoff (overland flow) occurs when the rate of water supply at the soil surface exceeds the infiltration rate of the soil. This most commonly occurs during intense rainfall events or when soils become saturated because of an extended rainfall period. As runoff water flows downslope, it can increase in quantity as runoff water from 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 roughnes 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 and soils. 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 at 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 from a site. 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). In San Patricio County, there were only nine runoff events recorded over a two-year period 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 antecendent 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 rainfall 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 that 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. Runoff on the Sonora Experiment Station located on the western edge of the Edwards Plateau 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 methoeds 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.

8.2.2.1 Clay Loam

Simulated annual runoff varied between 0.0 and 3.4 inches for the clay loam plot type (Table 8.9). Annual runoff averaged 0.85 inch in the simulations, compared to 0.6 inch on a gauged clay rangeland watershed on the Welder Wildlife Refuge over a two-year period (Ockerman 2002). The clay loam plot type in Goliad County had more rolling topography than the clay site on the Welder Wildlife Refuge, therefore runoff might be expected to be higher in Goliad County. The ratio of annual runoff to annual rainfall in the simulations varied from 0.000 to 0.088 and averaged 0.025 (2.5% of annual rainfall)(Table 8.9). This compares favorably with values reported in the literature of 1.1% for clay rangeland in San Patricio County, 2.9% for continuously grazed oak-mixed grass sites in the western Edwards Plateau, and 4.2% for mesquite-grassland in the Rollings Plains (Table 8.10).

Table 8.9 Annual rainfall (inches), surface runoff (inches), and ratio of runoff to rainfall on clay loam and loamy sand types for the 25-year calibration simulation, Goliad County EDYS model.

Rainfall	Clay Loam Type			Loamy Sand Type		
Year	Rainfall	Runoff	Runoff/Rainfall	Rainfall	Runoff	Runoff/Rainfall
1928	29.76	0.53	0.018	29.56	1.37	0.046
1929	39.27	1.29	0.033	44.53	4.01	0.090
1930	23.25	0.00	0.000	25.88	0.00	0.000
1931	38.09	3.36	0.088	40.00	3.48	0.087
1932	34.93	1.70	0.048	35.11	2.44	0.069
1933	28.89	0.08	0.003	31.62	1.46	0.046
1934	36.82	1.32	0.036	41.86	3.89	0.093
1935	39.42	0.58	0.015	39.81	0.88	0.022
1936	33.85	0.02	0.001	36.49	1.51	0.041
1937	23.25	0.35	0.016	26.74	0.58	0.022
1938	21.48	0.66	0.031	27.25	2.84	0.104
1939	19.23	0.25	0.013	21.63	1.00	0.046
1940	39.38	1.44	0.036	38.23	1.31	0.034
1941	42.31	0.37	0.009	37.99	0.45	0.012
1942	36.09	2.92	0.081	41.02	5.41	0.132
1943	31.69	0.20	0.006	33.44	0.56	0.017
1944	30.83	0.21	0.007	32.02	0.87	0.027
1945	25.76	0.00	0.000	29.38	0.22	0.007
1946	42.81	0.47	0.011	45.89	2.18	0.048
1947	29.88	0.00	0.000	30.87	1.69	0.055
1948	23.90	0.00	0.000	26.70	0.00	0.000
1949	36.49	0.57	0.016	35.39	0.07	0.002
1950	15.79	0.00	0.000	18.65	0.45	0.024
1951	29.94	2.06	0.069	37.44	5.68	0.152
1952	34.17	2.88	0.084	37.15	1.82	0.049
Mean	31.49	0.85	0.025	33.79	1.77	0.049

Table 8.10 Examples of average annual runoff values (inches) in Texas reported in the literature, with corresponding runoff:precipitation ratios (RO/PPT).

Vegetation Type	Location	Runoff	RO/PPT	Reference
Mesquite-grassland	Rolling Plains	1.22	0.042(0.021-0.081)	Carlson et al. 1990
Grassland (mesquite removed)	Rolling Plains	0.43	0.015(0.004-0.036)	Carlson et al. 1990
Bare soil	Rolling Plains	3.82	0.141(0.087-0.195)	Carlson et al. 1990
Grassland, nearly level	N Edwards Plateau	0.24	0.008	Wright et al. 1976
Grassland, 13% slope	N Edwards Plateau	1.10	0.039	Wright et al. 1976
Oak-mixed grass (HILF)	W Edwards Plateau	----	0.050	Thurow et al. 1988
Oak-mixed grass (4-pasture)	W Edwards Plateau	----	0.035	Thurow et al. 1988
Oak-mixed grass (continuous)	W Edwards Plateau	----	0.029	Thurow et al. 1988
Rangeland + cultivated	San Patricio Co.	2.40	0.039(0.001-0.148)	Ockerman 2002
Loamy sand rangeland	San Patricio Co.	2.56	0.041(0.000-0.174)	Ockerman 2002
Clay rangeland	San Patricio Co.	0.63	0.011(0.000-0.042)	Ockerman 2002
Cultivated (PPT = 12.9 in)	Kleberg-Nueces Cos.	0.04	0.004(0.000-0.042)	Ockerman & Petri 2001
Cultivated (PPT = 26.7 in)	Kleberg-Nueces Cos.	4.06	0.152(0.012-0.488)	Ockerman & Petri 2001
Cultivated (PPT = 38.1 in)	Kleberg-Nueces Cos.	6.38	0.167(0.003-0.502)	Ockerman & Petri 2001

RO/PPT values outside parentheses are annual mean, values inside parentheses are ranges for individual PPT events.
HILF = high-intensity low-frequency grazing system; 4-pasture = 4-pasture rotation grazing system.

8.2.2.2 Loamy Sand

Simulated annual runoff varied between 0.0 and 5.7 inches for the loamy sand plot type (Table 8.9). Annual runoff averaged 1.77 inches over the 25-year simulations, compared to 2.56 inches on a gauged loamy sand rangeland watershed on the Welder Wildlife Refuge over a two-year period (Ockerman 2002). The ratio of annual runoff to annual rainfall in the simulations varied from 0.000 to 0.152 and averaged 0.049 (4.9% of annual rainfall). These values compare favorably with values reported from a gauged watershed on a loamy sand site in San Patricio County (0.000-0.174 of annual rainfall, with a mean of 0.041; Table 10). The simulations therefore produced results that are reasonable, based on comparisons to gauged data from a similar loamy sand type.

8.2.2.3 Other Vegetation Types

Annual runoff in the calibration simulations, averaged over seven vegetation types and over 25 years, was 1.85 inches or 5.5% of annual rainfall (Table 8.11). Annual runoff from gauged field studies on uncultivated sites typically range between 0.2 and 3.8 inches (Table 8.10), with an average of 1.43 inches. The average for three range sites in San Patricio County was 1.86 inches (Table 8.10). Annual runoff averaged 3.1% of annual rainfall on uncultivated sites in the measurement studies (Table 8.10) and varied between 0.8 and 5.0%.

Table 8.11 Average annual rainfall (inches), surface runoff (inches), and ratio of runoff to rainfall for seven vegetation types for the 25-year calibration simulation, Goliad County EDYS model.

	Blackland Coastal	Clay Loam	Loamy Bottomland	Loamy Sand	Salty Prairie	Shallow Ridge	Tight Sandy Loam	Mean
Runoff	5.56	0.85	1.78	1.77	1.74	0.32	0.94	1.85
Rainfall	33.79	31.49	33.79	33.79	33.79	31.49	33.79	33.13
Runoff/Rainfall	0.164	0.027	0.053	0.052	0.051	0.010	0.028	0.055

The runoff/rainfall values for clay loam and loamy sand differ slightly from the mean values in Table 8.10. The values in Table 8.11 were calculated as the ratio of the two means whereas the values in Table 8.10 were calculated as the mean of 25 annual ratios.

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

8.2.3 Sediment Loadings

The amount of sediments transported in runoff water is of major importance in watershed management. Sediment loadings tend to increase as the amount and intensity of rainfall events increase and as surface roughness, especially vegetation cover, decreases. For example, typical sediment loadings at the Sonora Experiment Station are 25-50 $g/m^2/yr$ (Thurow et al. 1988), but following a high-intensity event (0.8 inch in 30 minutes) increased to 387 $g/m^2/yr$ (McCalla et al. 1984), a ten-fold increase. Similarly, annual sediment loadings on a mesquite-grassland in the

Rolling Plains of Texas averaged 140 g/m^2 compared to 2,337 g/m^2 on nearby bare soil (Carlson et al. 1990).

Type, as well as amount, of vegetation cover also affects the amount of sedimentation. Grass cover tends to decrease both soil erosion (dislodging of soil particles) and sediment transport (movement of water-borne particles), compared to cover by woody species. Mesquite-grasslands in the Rolling Plains had annual sediment loadings of 140 g/m^2 compared to 25 g/m^2 on adjacent grassland sites where the mesquite had been removed. Sediment loadings on sites at the Sonora Experiment Station supporting midgrasses (e.g., sideoats grama and bluestems) were less than 40% the loadings on adjacent sites supporting shortgrasses (e.g., curly mesquite and hairy grama)(McCalla et al. 1984).

Typical sediment loadings from rangelands in Texas vary between about 2 and 140 g/m^2/yr, or an equivalent of 0.03-2.13 g/m^2/cm of annual precipitation (Table 8.12). A sediment loading of 2 g/m^2/yr is equivalent to about 5 g/m^2/inch of rainfall or about 50 lbs/ac/inch of rainfall.

Table 8.12 Examples of measured sediment loadings on sites in the Edwards Plateau and the Rolling Plains of Texas.

Vegetation	Location	Amount (g/m^2/yr)	Sediments/Rainfall (g/m^2/cm PPT)	Reference
Oak-mixed grass (rotation)	W Edwards Plateau	41	0.74	Thurow et al. 1988
Oak-mixed grass (continuous)	W Edwards Plateau	25	0.45	Thurow et al. 1988
Grassland (level, unburned)	N Edwards Plateau	2	0.03	Wright et al. 1976
Grassland (level, burned)	N Edwards Plateau	2	0.03	Wright et al. 1976
Grassland (13% slope unburned)	N Edwards Plateau	17	0.23	Wright et al. 1976
Grassland (18% slope, burned)	N Edwards Plateau	51	0.61	Wright et al. 1976
Mesquite-grassland	Rolling Plains	140	2.13	Carlson et al. 1990
Grassland (mesquite removed)	Rolling Plains	25	0.38	Carlson et al. 1990
Bare soil	Rolling Plains	2337	35.52	Carlson et al. 1990

Annual sediment loadings, averaged over the entire county and over the 25-year simulation period under the moderate rainfall regime, were 46.73 g/m^2 (0.208 tons per acre). This is a weighted average (total sediments divided by total acres), adjusting for differences in sizes of the various watersheds. An annual sediment loss of 47 g/m^2 is similar to values reported for mixed woodland-grassland systems in the Edwards Plateau and about one-third of the value for mesquite-grasslands in the Rolling Plains of North Texas (Table 8.12).

Sediment loss was highest in the north and west parts of Goliad County and least in the central and southern portions (Table 8.13). Across the entire county, average annual sediment loss ranged from 0-216 g/m^2, with most watersheds having losses of 10-100 g/m^2. These values are consistent with reported values in other areas of Texas (Table 8.12). Although site-specific values for sediment loss are not available for Goliad County, the EDYS values appear to be reasonable based on comparisons to values resported for other regions.

Table 8.13 Average annual sediment loadings (tons per acre and g/m^2) by watershed (WSHD) under the moderate rainfall regime, per Goliad County EDYS model simulations (25-year means).

Northeast Sector			West Sector			Central Sector			South Sector		
WSHD	T/acre	g/m^2	WSHD	T/acre	g/m^2	WSHD	T/acre	g/m^2	WSHD	T/acre	g/m^2
1101	0.382	85.70	594	0.000	0.04	672	0.611	136.94	1124	0.020	4.56
1102	0.811	181.89	602	0.033	7.45	674	0.029	6.45	1125	0.160	35.91
1103	0.352	78.85	604	0.006	1.39	676	0.066	14.70	1126	0.181	40.59
1105	0.158	35.43	606	0.196	43.97	686	0.093	20.88	1127	0.152	34.14
1106	0.202	45.20	608	0.008	1.80	688	0.123	27.51	1128	0.333	74.69
1108	0.130	29.07	610	0.218	48.77	690	0.259	58.05	1129	0.007	1.60
1136	0.812	182.10	612	0.111	24.80	692	0.080	17.87	1130	0.045	10.16
1137	0.191	42.71	614	0.221	49.53	694	0.165	37.08	1131	0.067	14.94
			616	0.291	65.23	696	0.090	20.25	1132	0.009	1.95
			618	0.006	1.27	698	0.001	0.25	1133	0.020	4.52
			620	0.216	48.41	700	0.147	32.90	1134	0.017	3.84
			622	0.044	9.79	702	0.098	22.03	1135	0.020	4.55
			624	0.354	79.42	704	0.097	21.81			
			626	0.033	7.50	706	0.083	18.69			
			628	0.185	41.36	708	0.034	7.71			
			630	0.001	0.20	710	0.077	17.20			
			632	0.011	2.51	712	0.016	3.55			
			634	0.205	45.96	714	0.016	3.60			
			636	0.114	25.57	716	0.005	1.03			
			638	0.110	24.60	718	0.012	2.60			
			640	0.593	133.03	720	0.066	14.63			
			648	0.051	11.48	722	0.108	24.10			
			650	0.384	85.97	724	0.028	6.32			
			652	0.272	61.03	726	0.018	3.95			
			654	0.103	23.03	728	0.009	1.98			
			656	0.035	7.79	730	0.019	4.15			
			658	0.966	216.48	732	0.001	0.26			
			660	0.126	28.16	734	0.000	0.00			
			662	0.192	43.08						
			664	0.037	8.31						
			666	0.023	5.03						
			668	0.632	141.67						
			670	0.384	86.08						
MEAN	0.380	85.12	MEAN	0.187	41.87	MEAN	0.084	18.80	MEAN	0.086	19.29

Means in Table 8.13 are simple arithmetic means and do not account for differences in areas within each watershed.

8.2.4 Flow Rates

Flow data are available for two gauge stations in Goliad County (8177300, 8188500; Fig. 8.1). There are two additional gauge stations (8176900, 8177400) but the watersheds associated with these two stations are only partially in the spatial footprint of the Goliad County model. Therefore, they cannot be used for calibration purposes.

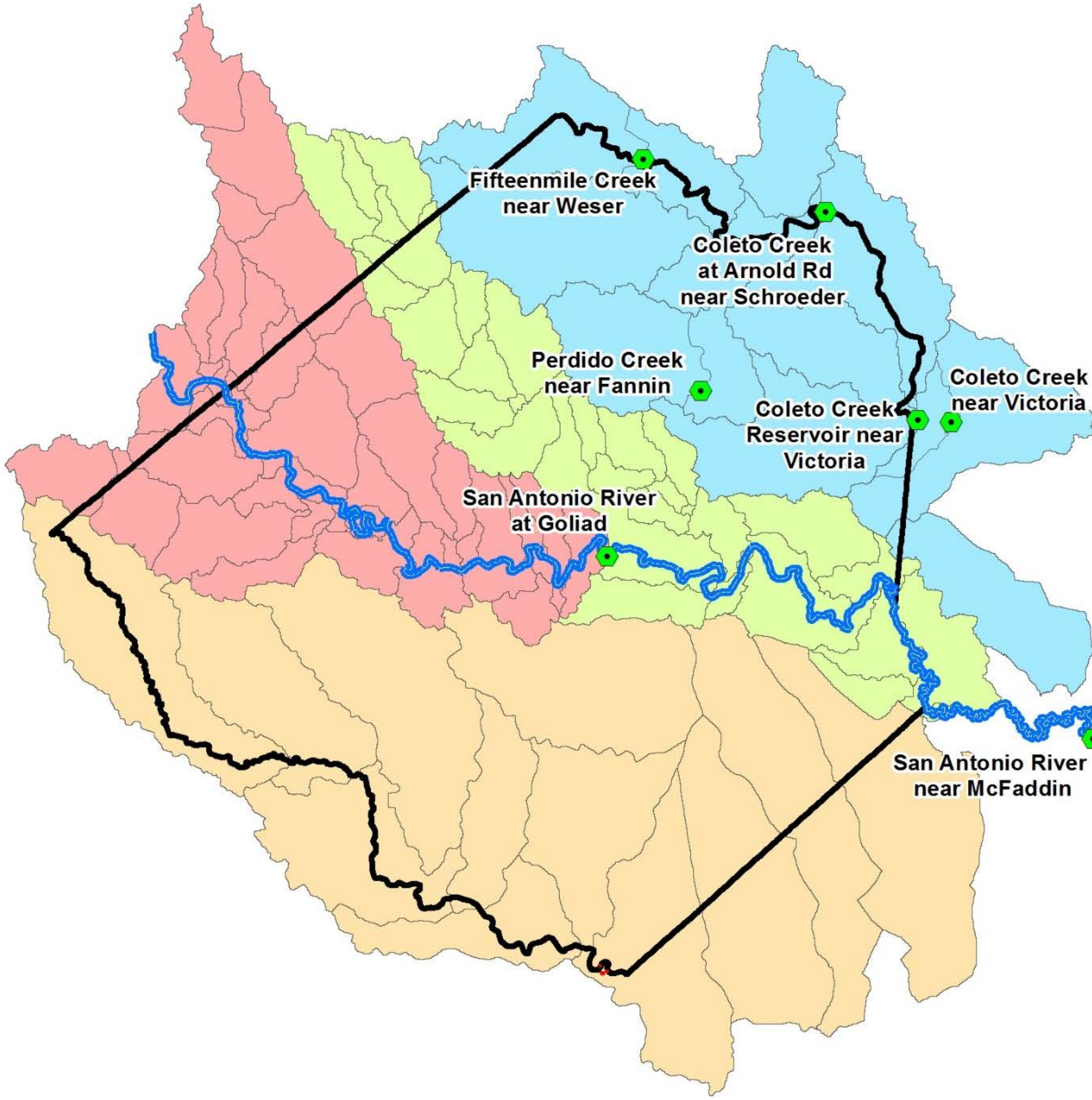

Figure 8.1 Locations of the four gauge stations and their associated watersheds in Goliad County.

There are 81 numbered watersheds in Goliad County (Fig. 8.2). Of these, 33 flow into the San Antonio River above the Goliad gauge station. This group of watersheds is designated as the West Sector for reporting purposes. Twenty-eight watersheds flow into the San Antonio River below the Goliad gauge station. This group is designated as the Central Sector. Eight watersheds (Northeast Sector) are in the northeast part of Goliad County and do not flow directly into the San Antonio River within Goliad County. The remaining 12 watersheds (South Sector) drain to the south and southeast.

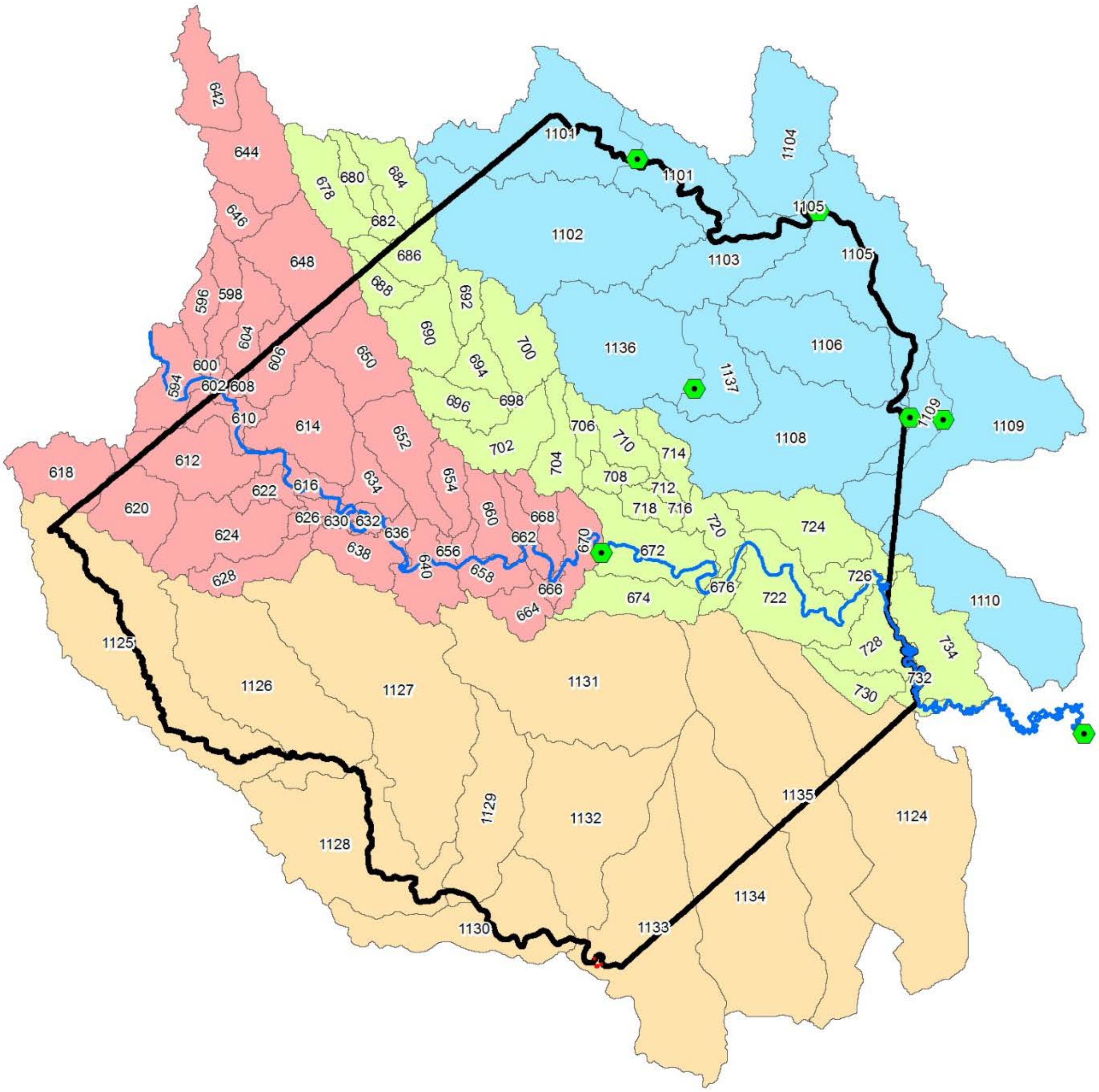

Figure 8.2 Locations of the 81 numbered watersheds in Goliad County divided into four sectors (West = red; Central = green; Northeast = blue; South = tan).

Gauge Station 8188500 is located on the San Antonio River. Water measured at the station includes both the San Antonio River flow entering Goliad County from Karnes County and the addition of runoff and subsurface flow from 33 subwatersheds located between the gauge station and the Karnes County line. Twenty-three of the subwatersheds are located entirely in Goliad County, and therefore modeled by the Goliad County model, and ten are only partially located in Goliad County (Fig. 8.2). The portions of those ten subwatersheds that are located in Goliad County are included in the Goliad County model. Gauge Station 8177300 receives flow from one subwatershed (1136) and it is located entirely in Goliad County. Only data from stations 8177300 and 8188500 were used in the calibration process.

8.2.4.1 Gauge 8188500, San Antonio River at Goliad

There are two components to the flow at this gauge: 1) San Antonio River flow entering from Karnes County and 2) water entering the San Antonio River from the assocated watershed in Goliad County. There is no gauge on the San Antonio River at the Goliad-Karnes county line. The nearest upstream gauge is the station near Runge. It is about 10 miles along the river between this station and the Goliad County line and about 25 miles along the river between the Goliad County line and the gauge station at Goliad.

Monthly flow data from June 2011 through March 2016 were used to compare flows between the Runge and Goliad stations. Over this period, the average monthly flow at Goliad exceeded the average monthly flow at Runge by 7,419 acre-feet (Table 8.14). About 51% of the watershed monitored by the Goliad gauge (i.e., the combined Karnes-Goliad portion between the Runge and Goliad gauge stations) is located in Goliad County, the remaining 49% being in Karnes County. Assuming a linear relationship between watershed area and increased flow between Runge and Goliad, 49% of this increased flow may have originated in Karnes County, leaving 3,784 acre-feet that originated in the Goliad County part of the watershed.

Table 8.14 Total and average monthly flow (acre-feet) at the Runge and the Goliad gauge stations, June 2011 through March 2016.

Period	Rainfall (inches)		Total Flow			Average Monthly Flow		
	Goliad	Runge	Goliad	Runge	Difference	Goliad	Runge	Difference
Jun-Dec 2011	10.28	8.39	97,987	74,152	23,835	13,998	10,593	3,405
Jan-Dec 2012	29.00	15.49	407,560	338,332	69,228	33,963	28,194	5,769
Jan-Dec 2013	27.77	12.96	308,695	234,787	73,908	25,725	19,566	6,159
Jan-Dec 2014	25.63	17.72	267,053	208,997	58,056	22,254	17,416	4,838
Jan-Dec 2015	28.17	28.17	781,535	574,458	207,077	65,128	47,872	17,256
Jan-Mar 2016	5.11	5.11	97,155	98,987	- 1,832	32,385	32,996	- 611
Overall	125.96	87.84	1,959,985	1,529,713	430,272	33,793	26,374	7,419

EDYS simulation of surface runoff averaged 362 acre-feet per month for the Goliad County portion of this watershed for the period Jun 2011-Mar 2016, or about 9.6% of the increase in river flow. The EDYS simulations also accounted for a monthly average of an additional 702 acre-feet entering the watershed soils during the runoff process, a portion of which would move laterally into the river as seepage. Combining surface runoff with maximum seepage results in a total of 1,064 acre-feet per month flowing into the river, or about 28% of the estimated increase in flow within Goliad County. This leaves 72% of the increase in river flow (2,720 acre-feet per month) unaccounted for (Fig. 8.3).

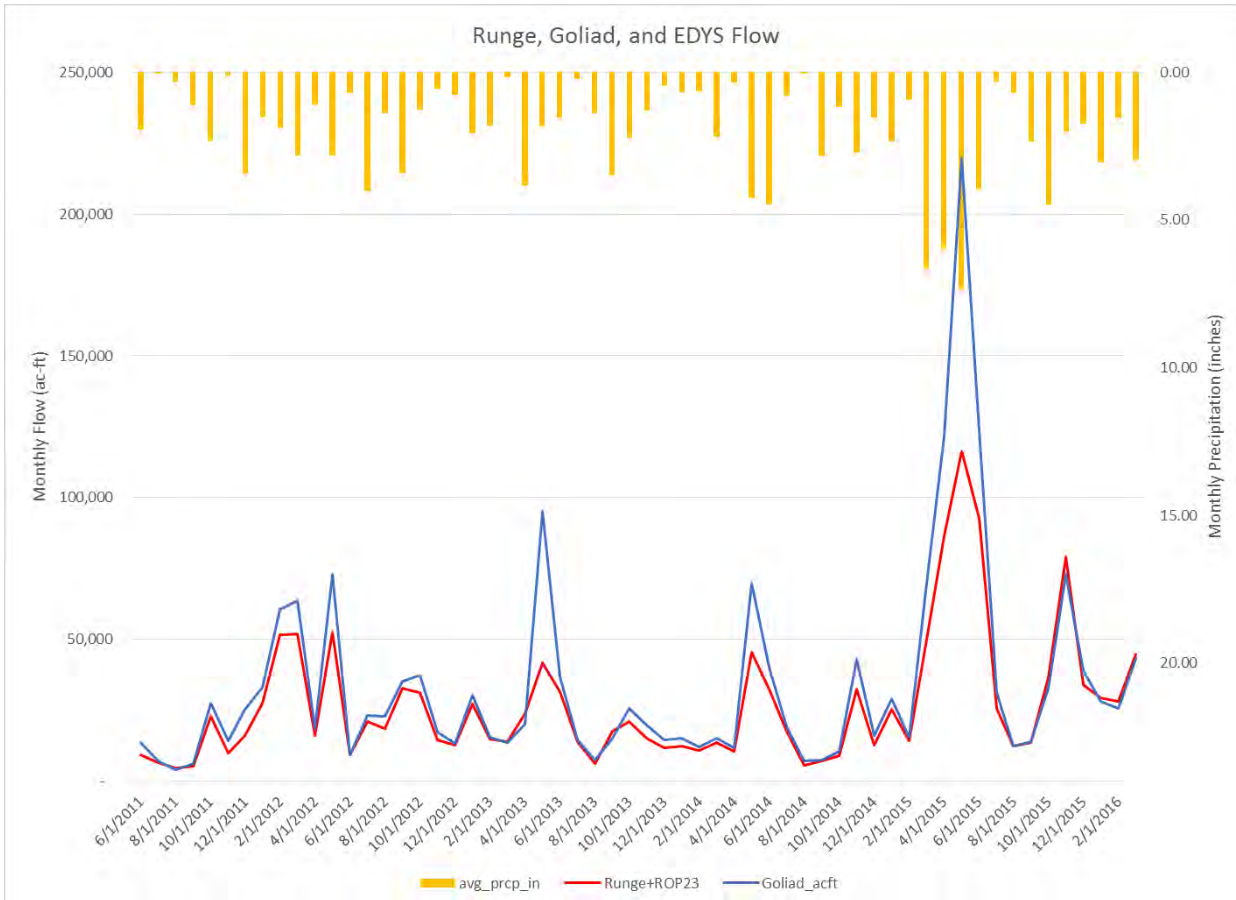

Figure 8.3 Comparison of gauged (blue) and simulated (red) monthly flows (acre-feet) at the Goliad station on the San Antonio River, June 2011-March 2016.

8.2.4.2 Gauge 8177300, Perdido Creek

The Perdido watershed (Watershed 1136) is a gauged watershed completely within Goliad County (Fig. 8.1). Therefore it provides a good example to use to estimate how well the EDYS simulations are matching gauged flows. Creek flow is measured at the USGS gauge. Flow is partially estimated from EDYS output by using runoff. However, runoff is not the only contribution to flow. Flow also includes lateral seepage and any spring flows plus some water that EDYS calculates as recharge (export = water infiltrating below the root zone or to groundwater, whichever is shallower). Without accounting for this lateral movement (seepage, spring flow, groundwater lateral flow), EDYS estimates of flow will likely be less than recorded flow. This is the case for the Perdido watershed. When summed over the seven-year period of record, EDYS runoff accounted for 85% of the recorded flow (Table 8.15). The remaining 15% is a first-approximation of subsurface lateral flow into the creek.

Table 8.15 Annual flow at USGS Gauge 8177300 and simulated surface runoff for the same watershed using the Goliad County EDYS model, 2008-2014.

Period	Goliad Rainfall (inches)	USGS Flow (ac-ft/yr)	EDYS Runoff (ac-ft/yr)	EDYS/USGS
Jan-Dec 2008	22.51	2.56	62.09	
Jan-Dec 2009	35.90	942.31	882.32	
Jan-Dec 2010	41.32	2,000.06	678.59	
Jan-Dec 2011	17.24	263.95	101.66	
Jan-Dec 2012	29.00	73.38	111.47	
Jan-Dec 2013	27.77	22.08	836.85	
Jan-Dec 2014	25.63	34.21	175.75	
Total 2008-14	199.37	3,338.55	2,848.73	0.853

Summed over the seven years, the EDYS surface runoff values gave a reasonable estimate (85%) of USGS gauged flow. However when viewed on a monthly or annual basis, there was a poor match between EDYS runoff and gauged flow (Fig. 8.4). In general, EDYS indicated surface runoff to the creek more often than flow was recorded at the gauge, although gauged flow was greater than EDYS runoff overall. EDYS recorded runoff in 55 of the 84 months of 2008-14 while there were only 23 months with gauged flow (Table 8.16).

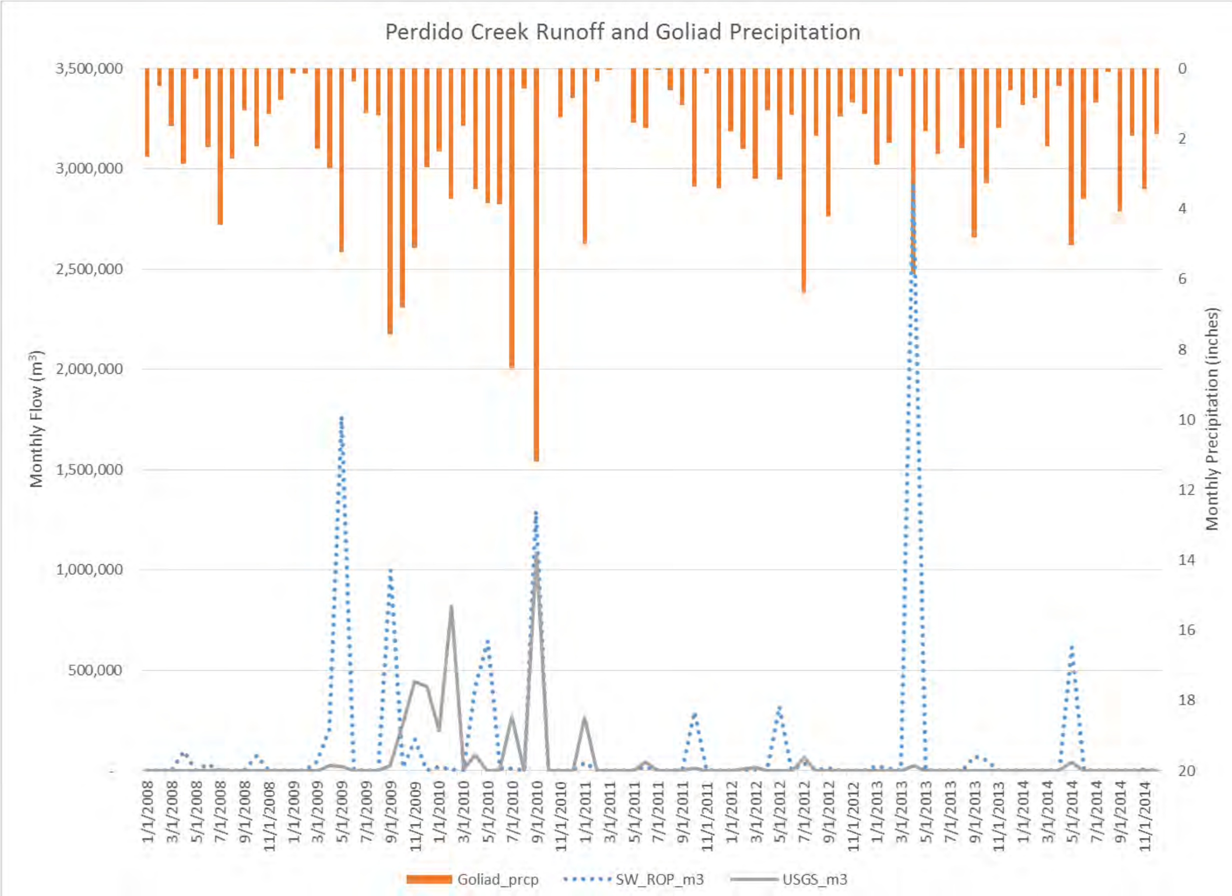

Figure 8.4 Comparison of gauged (blue) and simulated (red) monthly flows (acre-feet) at the Perdido Creek gauge station, Goliad County, 2008-14, and monthly rainfall (inches; vertical bars).

Table 8.16 Monthly gauged flow for the Perdido Watershed and EDYS surface runoff. Rainfall is in inches and flow and runoff are in acre-feet.

Month	Rainfall	Gauged Flow	EDYS Runoff	Month	Rainfall	Gauged Flow	EDYS Runoff
Jan 2008	2.52	0.00	1.03	Jul 2011	0.03	0.00	0.00
Feb 2008	0.50	0.00	0.00	Aug 2011	0.62	0.00	0.00
Mar 2008	1.65	0.00	0.00	Sep 2011	1.04	2.20	0.07
Apr 2008	2.70	0.00	29.90	Oct 2011	3.35	9.87	83.54
May 2008	0.30	0.00	0.00	Nov 2011	0.15	0.00	0.00
Jun 2008	2.24	0.00	8.98	Dec 2011	3.41	0.00	0.27
Jul 2008	4.47	2.57	0.70	Jan 2012	1.80	0.00	0.79
Aug 2008	2.57	0.00	0.36	Feb 2012	2.29	7.28	0.66
Sep 2008	1.18	0.00	0.00	Mar 2012	3.13	14.53	1.89
Oct 2008	2.21	0.00	21.20	Apr 2012	1.18	0.00	0.06
Nov 2008	1.29	0.00	0.01	May 2012	3.17	0.00	92.26
Dec 2008	0.88	0.00	0.00	Jun 2012	1.31	0.00	0.00
Jan 2009	0.14	0.00	0.00	Jul 2012	6.38	51.65	10.38
Feb 2009	0.14	0.00	0.00	Aug 2012	1.91	0.00	2.03
Mar 2009	2.28	0.00	12.64	Sep 2012	4.22	0.00	2.92
Apr 2009	2.83	20.35	59.95	Oct 2012	1.36	0.00	0.00
May 2009	5.23	18.02	485.11	Nov 2012	0.97	0.00	0.07
Jun 2009	0.37	0.00	0.00	Dec 2012	1.28	0.00	0.53
Jul 2009	1.26	0.00	0.03	Jan 2013	2.74	0.00	7.07
Aug 2009	1.34	0.00	0.00	Feb 2013	2.11	0.00	2.84
Sep 2009	7.58	22.09	276.01	Mar 2013	0.22	0.00	0.00
Oct 2009	6.81	183.17	4.66	Apr 2013	5.85	22.10	790.27
Nov 2009	5.11	360.18	43.73	May 2013	1.79	0.00	0.29
Dec 2009	2.81	339.62	1.23	Jun 2013	2.44	0.00	0.01
Jan 2010	2.36	164.48	5.54	Jul 2013	0.01	0.00	0.00
Feb 2010	3.70	665.99	2.44	Aug 2013	2.25	0.00	1.15
Mar 2010	1.64	6.96	0.05	Sep 2013	4.80	0.00	20.32
Apr 2010	3.43	62.38	121.67	Oct 2013	3.25	0.00	15.84
May 2010	3.82	0.00	182.40	Nov 2013	1.69	0.00	0.06
Jun 2010	3.85	3.99	3.32	Dec 2013	0.62	0.00	0.00
Jul 2010	8.53	218.88	3.21	Jan 2014	1.04	0.00	0.00
Aug 2010	0.58	0.00	0.00	Feb 2014	0.83	0.00	0.00
Sep 2010	11.19	879.75	360.74	Mar 2014	2.21	0.00	0.22
Oct 2010	0.00	0.00	0.00	Apr 2014	0.49	0.00	0.00
Nov 2010	1.38	0.00	0.01	May 2014	5.03	34.25	172.05
Dec 2010	0.84	0.00	0.00	Jun 2014	3.72	0.00	0.46
Jan 2011	5.00	216.73	13.25	Jul 2014	0.96	0.00	0.00
Feb 2011	0.37	0.00	0.00	Aug 2014	0.08	0.00	0.00
Mar 2011	0.04	0.00	0.00	Sep 2014	4.05	0.00	1.05
Apr 2011	0.00	0.00	0.00	Oct 2014	1.92	0.00	0.00
May 2011	1.55	0.00	0.74	Nov 2014	3.43	0.00	1.86
Jun 2011	1.68	35.47	4.19	Dec 2014	1.87	0.00	0.32

Gauged flow and EDYS runoff were both minimal (less than 0.1 acre-foot) when rainfall was less than 1.5 inches (Table 8.15), with one exception for each (Sep 2011 for gauged; Dec 2012 for EDYS). This is consistent with results from experimental studies in the area. For example, rainfall events of less than two inches produced little or no runoff on gauged watersheds in San Patricio, Kleberg, and Nueces Counties (Ockerman and Petri 2001; Ockerman 2002).

As rainfall increased above 1.5 inches, both runoff and flow increased as would be expected. However, there were a number of inconsistencies in the relationship between rainfall and both flow and runoff. There were eight months when monthly flow was greater than 100 acre-feet (Table 8.17). Three of these months received less than 5 inches of rainfall, and rainfall in the previous month was greater than 2.3 inches in each case. However, there were 22 months with rainfall between 2.4 and 5.0 inches that had less than 100 acre-feet of flow, and 17 of these months had less than 10 acre-feet of flow. Of the 22 months, 5 received more than 2.3 inches of rainfall in the previous month. The second highest flow month was Feb 2010, with 666 acre-feet of flow. That month received 3.70 inches of rainfall and the previous month received 2.36 inches. In contrast, 3.72 inches of rainfall was received in Jun 2014 and 5.03 inches were received in the previous month, but there was no flow (0.00 acre-feet) that month. Ten months received 5 inches or more of rainfall. In those ten months, flow exceeded 180 acre-feet in 5 months and was less than 52 acre-feet in each of the other 5 months.

Table 8.17 Comparison of monthly rainfall (inches; months > 1.5 inches) to monthly flow (acre-feet) at the USGS gauge station and monthly runoff (acre-feet) simulated by the EDYS Goliad County model for the Perdido watershed.

Month	Rainfall	Gauged Flow	EDYS Runoff	Previous Month Rainfall	Month + Previous Month Rainfall	Month Rainfall + 50% Previous Month Rainfall
May 2011	1.55	0.00	0.74	0.00	1.55	1.55
Mar 2010	1.64	6.96	0.05	3.70	5.34	3.49
Mar 2008	1.65	0.00	0.00	0.50	2.15	1.90
Jun 2011	1.68	35.47	4.19	1.55	3.23	2.46
Nov 2013	1.69	0.00	0.06	3.25	4.94	3.32
May 2013	1.79	0.00	0.29	5.85	7.64	4.72
Jan 2012	1.80	0.00	0.79	3.41	5.21	3.51
Dec 2014	1.87	0.00	0.32	3.43	5.30	3.59
Aug 2012	1.91	0.00	2.03	6.38	8.29	5.10
Oct 2014	1.92	0.00	0.00	4.05	5.97	3.95
Feb 2013	2.11	0.00	2.84	2.74	4.85	3.48
Oct 2008	2.21	0.00	21.20	1.18	3.39	2.80
Mar 2014	2.21	0.00	0.22	0.83	3.04	2.63
Jun 2008	2.24	0.00	8.98	0.30	2.54	2.39
Aug 2013	2.25	0.00	1.15	0.01	2.26	2.26
Mar 2009	2.28	0.00	12.64	0.14	2.42	2.35
Feb 2012	2.29	7.28	0.66	1.80	4.09	3.19
Jan 2010	2.36	164.48	5.54	2.81	5.17	3.77
Jun 2013	2.44	0.00	0.01	1.79	4.23	3.34
Jan 2008	2.52	0.00	1.03	0.63	3.15	2.84
Aug 2008	2.57	0.00	0.36	4.47	7.04	4.81
Apr 2008	2.70	0.00	29.90	1.65	4.35	3.53
Jan 2013	2.74	0.00	7.07	1.28	4.02	3.38
Dec 2009	2.81	339.62	1.23	5.11	7.92	5.37
Apr 2009	2.83	20.35	59.95	2.28	5.11	3.97
Mar 2012	3.13	14.53	1.89	2.29	5.42	4.28
May 2012	3.17	0.00	92.26	1.18	4.35	3.76
Oct 2013	3.25	0.00	15.84	4.80	8.05	5.65
Oct 2011	3.35	9.87	83.54	1.04	4.39	3.87
Dec 2011	3.41	0.00	0.27	0.15	3.56	3.49
Apr 2010	3.43	62.38	121.67	1.64	5.07	4.25
Nov 2014	3.43	0.00	1.86	1.92	5.35	4.39
Feb 2010	3.70	665.99	2.44	2.36	6.06	4.88
Jun 2014	3.72	0.00	0.46	5.03	8.75	6.24
May 2010	3.82	0.00	182.40	3.43	7.25	5.54
Jun 2010	3.85	3.99	3.32	3.82	7.67	5.76
Sep 2014	4.05	0.00	1.05	0.08	4.13	4.09
Sep 2012	4.22	0.00	2.92	1.91	6.13	5.18
Jul 2008	4.47	2.57	0.70	2.24	6.71	5.59
Sep 2013	4.80	0.00	20.32	2.25	7.05	5.93
Jan 2011	5.00	216.73	13.25	0.84	5.84	5.42
May 2014	5.03	34.25	172.05	0.49	5.52	5.28
Nov 2009	5.11	360.18	43.73	6.81	11.92	8.52
May 2009	5.23	18.02	485.11	2.83	8.06	6.65
Apr 2013	5.85	22.10	790.27	0.22	6.07	5.96
Jul 2012	6.38	51.65	10.38	1.31	7.69	7.04
Oct 2009	6.81	183.17	4.66	7.58	14.39	10.60
Sep 2009	7.58	22.09	276.01	1.34	8.92	8.25
Jul 2010	8.53	218.88	3.21	3.85	12.38	10.46
Sep 2010	11.19	879.75	360.74	0.58	11.77	11.48

EDYS runoff values were correlated more closely with monthly rainfall than were gauged flows, but there was also substantial variability in the runoff values (Table 8.17). EDYS runoff values exceeded 100 acre-feet in 7 months and rainfall exceeded 3.4 inches in each of these months. However, rainfall exceeded 3.4 inches in 14 other months and runoff was less than 5 acre-feet in 10 of these 14 months. Runoff exceeded 15 acre-feet in 6 months receiving less than 3.4 inches of rainfall and previous-month rainfall exceeded 1 inch in each of these months. However, previous-month rainfall exceeded 1 inch in 16 months receiving less than 3.4 inches of rainfall and runoff was less than 15 acre-feet in each of these months.

Amount of monthly rainfall is not the only factor affecting amount of monthly runoff. Intensity of the rainfall events is also a major factor. EDYS utilizes daily rainfall amounts as input. These daily amounts are divided into segments, each segment corresponding to a duration of the rainfall event, as a method of estimating rainfall intensity. Another factor affecting landscape-level runoff is antecedent moisture conditions (e.g., Ockerman and Petri 2001). The same amount of rainfall will result in different amounts of runoff depending on the moisture conditions of the soil at the time of the rainfall event. EDYS accounts for this adequately on the plot (cell) level. On the landscape-level, where surface runoff is moving across a watershed, EDYS appears to be under-estimating flow under high-rainfall conditions. This issue has been identified in other applications and discussed in the respective reports (McLendon et al. 2015; Booker and McLendon 2015, 2016). A modification of the EDYS code is currently being developed to improve this accuracy but these upgrades are not yet available. A mathematical approximation, which forms the basis on which the mechanistic algorithms of the updated code are developed, is available. This approximation is a step function that divides precipitation periods into three groups (dry, medium, wet) and applies a different equation to calculate accumulated runoff under each respective precipitation group. In effect, this results in lower landscape runoff in drier periods and higher runoff in wetter periods than the respective values using the current algorithms. Whereas the current approach results in total surface runoff being equal to 85% of the gauged flow along the Perdido Creek (Table 8.15), the application of the mathematical approximation equations results in total runoff being equal to gauged flow when totaled over the seven years (although values still differ on a monthly basis).

Flow is also affected by factors other than amount of rainfall received in a particular month or previous month. There is often a lag time between a rainfall event, or series of events, and flow being recorded at a gauge station. Flow is composed of both runoff and subsurface movement of water into the drainage. The Perdido watershed gauge recorded 340 acre-feet of flow in Dec 2009, a month receiving 2.81 inches of rain (Table 8.17). That gauge recorded 20 acre-feet of flow in Apr 2009 when 2.83 inches of rainfall occurred. The difference in flows could be attributed to differences in previous month rainfall. In Nov 2009 there was 5.11 inches of rain compared to 2.28 inches in Mar 2009. Part of the Dec 2009 flow was likely from subsurface lateral movement of water that originated as rainfall in the previous month.

The high flow from October 2009 through February 2010 was the result of five consecutive months of relatively high rainfall (Table 8.16). The monthly flows during that time were undoubtedly a function of both rainfall and subsurface lateral flow. Rainfall-to-flow relationships in other months, where there was not such a series of wet months, are more erratic. For example, there were four months, excluding Nov 2009, were rainfall was 5.0-6.0 inches

(Table 8.17). Monthly flow was 18-34 acre-feet in three of those months and 217 acre-feet in the other, and the high-flow month did not have high rainfall in the previous month.

In summary, EDYS simulations tended to give reasonable estimates of total flow into the Perdido Creek watershed (85% of gauged flow) but the timing of the events were often different between EDYS and the gauge data. The reason likely being that EDYS moved water more rapidly than what actually occurred because of lateral flow rates (lag-time) into the creek. EDYS did not account as well for change in flow rates between the Runge (Karnes County) and Goliad (Goliad County) gauge stations. Runoff and maximum subsurface flow in the EDYS simulations accounted for only about 28% of the expected increase in river flow.

9.0 SCENARIOS

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. Ten scenarios were defined as examples to be included in this report. A 25-year simulation period was used for each of the 10 scenarios.

1. Baseline. No changes in land management options; daily precipitation data from 1928-1952 were used as most indicative of long-term average conditions (1913-2015 annual mean for Goliad = 34.84 inches; 1928-1952 annual mean for Goliad = 33.77 inches).

2. Dry Cycle. No changes in land management options; daily precipitation data from 1915-1939; 1915-1939 were the driest 25 consecutive years on record for Goliad (annual mean = 30.96 inches = 0.889 of long-term mean).

3. Wet Cycle. No changes in land management options; daily precipitation data from 1957-1981 used; 1957-1981 were the wettest 25 consecutive years on record for Goliad (annual mean = 39.92 inches = 1.146 of long-term mean).

4. Brush Management, Average Rainfall Pattern. 100% of aboveground biomass of woody species and 50% of aboveground biomass of herbaceous species removed in Year 1 (root plowing) on all non-urban areas with more than 30% cover of woody species and less than 12% slope; average rainfall pattern (1928-1952); moderate grazing by livestock maintained.

5. Brush Management, Reduced Live Oak Removal. Same as Scenario 4 except only 50% of the aboveground biomass of live oak was removed.

6. Brush Management, Dry Rainfall Pattern. Same as Scenario 4 except dry rainfall pattern (1915-1939) was applied.

7. Brush Management, Wet Rainfall Pattern. Same as Scenario 4 except wet rainfall pattern (1957-1981) was applied.

8. Cultivated Land (6.5%). 6.5% of total land in the county placed under cultivation; native vegetation (randomly selected) changed to cultivation; average rainfall pattern (1928-1952).

9. Cultivated Land (21%). 21% of total land in the county placed under cultivation; native vegetation (randomly selected) changed to cultivation; average rainfall pattern (1928-1952).

10. Maximum Potential Water Enhancement from Brush Control. Same as Scenario 4 except brush control was applied to all non-urban areas.

9.1 Vegetation

9.1.1 Baseline

9.1.1.1 Clay Loam Type

Under baseline conditions (average rainfall over 25 years, moderate stocking rate of cattle), there was a slight decrease in woody plants (trees and shrubs) in the simulations for the clay loam type overall, but this decrease was not uniform among woody species (Table 9.1). Huisache and whitebrush increased substantially (13% and 47%, respectively) and there were more moderate increases in granjeno (6%) and prickly pear (4%). Huisache and whitebrush are both aggressive invading species, especially under early- and mid-seral conditions. Conversely, there were substantial decreases in blackbrush, baccharis, and wolfberry and a slight decrease (2%) in mesquite. The decreases in these four woody species were most likely the result of competitive from the more aggressive huisache and whitebrush.

In addition to changes in the woody plants (i.e., the overstory species in the shrub and woodland mosaic), there were also changes in both standing crop biomass and species composition of the herbaceous component (Table 9.1). At the beginning of the simulations, the herbaceous component of the clay loam type had an average standing crop biomass of 144 g/m^2 (1284 lbs/ac) at the end of the growing season. This consisted of about 50% shortgrasses (hooded windmillgrass, buffalograss, purple threeawn [*Aristida purpurea*]), 30% midgrasses (silver bluestem, plains bristlegrass), and 20% forbs (mostly ragweed). By the end of the 25-year simulation, herbaceous standing crop had increased to 452 g/m^2 (4032 lbs/ac). This is a realistic level for silver or little bluestem grasslands under moderate grazing by cattle (355-422 g/m^2 = 3167-3764 lbs/ac; Hazell 1967).

Species composition also changed by the end of the simulation period. Shortgrasses increased as the type dominants, with most of this being purple threeawn (Table 9.1). Buffalograss increased in biomass, but not as much proportionately as did purple threeawn. Silver bluestem became the major midgrass, and trichloris also increased. These two species are major midgrasses under mid-seral conditions in the bluestem grasslands of South Texas (Box 1961, Box and White 1969, McLendon 1991). Little bluestem and plains bristlegrass decreased during the 25-year simulation. These changes in composition are consistent with what would be expected under moderate grazing. The more palatable species (little bluestem, Arizona cottontop, plains bristlegrass) received more grazing pressure than the less palatable species (silver bluestem, trichloris, purple threeawn) and therefore decreased in abundance. Within the shortgrasses, buffalograss is more palatable to cattle than purple threeawn, and therefore purple threeawn increased by a greater amount than buffalograss. All forb species decreased on this type because of browsing pressure by deer and increased competition from the grasses.

Table 9.1 Aboveground biomass (g/m²), by lifeform and major species, in seven plot types[1] at the end of growing season in the first (01) and last (25) years of a 25-year simulation under the baseline scenario, Goliad County EDYS model.

Lifeform or Species	Blackland Coastal		Clay Loam		Loamy Bottomland		Loamy Sand		Salty Prairie		Shallow Ridge		Tight Sandy Loam	
	01	25	01	25	01	25	01	25	01	25	01	25	01	25
Trees	246	213	1247	1278	6623	6028	5181	4695	320	323	444	558	3402	2952
Shrubs	72	37	976	898	851	739	394	324	96	138	1592	1561	648	397
Midgrasses	63	62	49	67	52	388	74	471	527	740	17	3	73	547
Shortgrasses	229	548	71	383	26	4	38	256	37	55	29	3	37	284
Grass-likes	0	0	0	0	17	230	0	0	0	0	0	0	0	0
Forbs	67	1	34	2	32	24	37	5	13	57	14	54	28	4
Total aboveground	677	861	2377	2628	7601	7413	5724	5751	993	1313	2096	2179	4188	4184
Huisache	125	116	364	411	620	536	---	---	281	269	---	---	---	---
Pecan	---	---	---	---	810	820	---	---	---	---	---	---	---	---
Sugar hackberry	6	4	---	---	1228	747	---	---	---	---	---	---	---	---
Mesquite	101	82	883	867	484	375	1034	826	39	54	444	558	1332	1078
Live oak	14	11	---	---	3481	3550	4147	3869	---	---	---	---	2070	1874
Guajillo	---	---	---	---	---	---	---	---	---	---	525	165	---	---
Blackbrush	11	5	186	76	---	---	---	---	---	---	974	1349	274	113
Whitebrush	15	6	198	291	155	343	---	---	---	---	---	---	---	---
Baccharis	---	---	99	27	158	45	---	---	---	---	---	---	---	---
Sea oxeye	---	---	---	---	---	---	---	---	96	138	---	---	---	---
Granjeno	22	13	283	300	157	81	192	220	---	---	---	---	287	254
Wolfberry	---	---	21	8	---	---	---	---	---	---	---	---	---	---
Agarito	t	t	5	4	---	---	---	---	---	---	---	---	---	---
Mustang grape	---	---	---	---	381	270	114	66	---	---	---	---	---	---
Prickly pear	24	13	184	192	---	---	88	38	---	---	93	47	87	30
Big bluestem	1	10	---	---	1	115	---	---	---	---	---	---	---	---
Bushy bluestem	---	---	---	---	7	t	---	---	---	---	---	---	---	---
Purple threeawn	27	260	9	255	---	---	6	254	---	---	3	1	11	276
Silver bluestem	19	42	17	57	3	1	10	40	---	---	---	---	40	323
Sideoats grama	2	1	2	2	7	162	14	313	---	---	4	1	6	2
Hairy grama	8	8	1	t	---	---	3	1	---	---	4	1	5	6
Red grama	---	---	---	---	---	---	---	---	---	---	3	t	2	0
Buffalograss	140	267	24	92	7	t	---	---	---	---	---	---	---	---
Sandbur	---	---	---	---	---	---	1	0	---	---	---	---	1	0
Hooded windmill	26	6	33	36	---	---	6	1	---	---	4	1	18	2
Trichloris	2	t	2	7	7	2	---	---	---	---	1	t	22	224
Bermudagrass	---	---	---	---	3	t	---	---	6	t	---	---	---	---
Arizona cottontop	---	---	1	t	---	---	1	t	---	---	1	t	1	t
Saltgrass	---	---	---	---	---	---	---	---	6	0	---	---	---	---
Virginia wildrye	---	---	---	---	2	t	---	---	---	---	---	---	---	---
Texas cupgrass	---	---	---	---	1	t	---	---	---	---	---	---	---	---
Green sprangletop	---	---	---	---	---	---	---	---	---	---	1	t	---	---
Vine-mesquite	3	0	1	t	3	4	---	---	---	---	---	---	---	---
Switchgrass	4	1	---	---	5	14	3	4	t	t	---	---	---	---
Longtom	---	---	---	---	---	---	---	---	4	0	---	---	---	---
Brownseed paspalum	4	0	1	0	3	0	10	0	---	---	---	---	---	---
Thin paspalum	---	---	---	---	---	---	12	t	---	---	---	---	---	---
Common reed	---	---	---	---	---	---	---	---	1	0	---	---	---	---
Little bluestem	18	4	3	1	14	94	43	114	2	t	7	2	---	---
Knotroot bristle	9	1	1	t	5	t	---	---	21	55	---	---	---	---
Plains bristlegrass	5	0	20	0	3	0	3	0	---	---	---	---	4	0
Texas bristlegrass	---	---	---	---	---	---	---	---	---	---	8	0	---	---
Indiangrass	3	1	t	t	---	---	---	---	1	t	---	---	---	---

Table 9.1 (Cont.)

Lifeform or Species	Blackland Coastal		Clay Loam		Loamy Bottomland		Loamy Sand		Salty Prairie		Shallow Ridge		Tight Sandy Loam	
	01	25	01	25	01	25	01	25	01	25	01	25	01	25
Johnsongrass	2	0	2	0	2	0	---	---	---	---	---	---	---	---
Gulf cordgrass	---	---	---	---	---	---	---	---	523	740	---	---	---	---
Tall dropseed	7	3	2	t	---	---	---	---	---	---	---	---	---	---
Sand dropseed	---	---	---	---	---	---	---	---	---	---	4	t	---	---
Texas wintergrass	12	6	1	t	5	t	---	---	---	---	6	t	---	---
Littletooth sedge	---	---	---	---	6	t	---	---	---	---	---	---	---	---
Flatsedge	---	---	---	---	11	230	---	---	---	---	---	---	---	---
Ragweed	26	t	11	1	9	2	28	2	---	---	13	54	16	2
Spiny aster	---	---	---	---	1	t	---	---	2	t	---	---	---	---
Wild indigo	5	0	1	0	---	---	---	---	---	---	---	---	---	---
Old-mans beard	30	1	6	t	10	5	---	---	---	---	---	---	---	---
Bundleflower	2	0	1	t	1	t	t	t	---	---	---	---	t	0
Frogfruit	---	---	5	t	2	t	---	---	8	55	---	---	---	---
Coneflower	---	---	1	0	---	---	t	t	---	---	---	---	t	0
Snoutbean	---	---	1	0	1	0	1	0	---	---	---	---	2	0
Ruellia	3	0	1	0	1	0	---	---	---	---	---	---	---	---
Glasswort	---	---	---	---	---	---	---	---	3	2	---	---	---	---
Bush sunflower	---	---	4	1	---	---	7	3	---	---	---	---	9	2
Greenbriar	---	---	---	---	6	17	---	---	---	---	---	---	---	---
Orange zexmenia	---	---	2	t	---	---	---	---	---	---	---	---	---	---
Giant ragweed	---	---	---	---	1	0	---	---	---	---	---	---	---	---
Annual broomweed	---	---	1	0	---	---	---	---	---	---	1	0	---	---
Partridge pea	---	---	---	---	t	0	t	0	---	---	---	---	1	0
Texas doveweed	---	---	---	---	---	---	1	0	---	---	---	---	---	---
Sunflower	1	0	t	0	t	0	---	---	---	---	---	---	t	0

Dashes (---) indicate that the species was not included in the simulation for that type.
A trace amount (< 0.5 g/m^2) is indicated with at "t".

9.1.1.2 Loamy Sand Type

There was a substantial decrease (10%) in woody plant biomass over the 25-year simulation on the loamy sand type, with a corresponding increase (550%) in grass biomass (Table 9.1). Both mesquite and live oak decreased but there was a 14% increase in granjeno. The decrease in tree biomass was likely in response to the amount of rainfall simulated in this scenario. The average annual rainfall in the baseline scenario was 33.77 inches (85.8 cm). This amount of annual rainfall is marginal for support of woodlands. Forty inches of annual rainfall is a general estimate of the level where woodlands dominate over grasslands (Weaver and Clements 1938:510; Engle 1994; Bailey 1995). Stoddart and Smith (1955:48) suggested 38 inches for the transition to tallgrass prairie and Drawe (1994) considered 36 inches to be the transition point on the Coastal Prairies of Texas. Trees are supported at lower moisture levels on sandy soils than on adjacent clay or loamy soils, therefore the transition point on sands in South Texas is probably close to the 36 inches suggested by Drawe (1994). This level is still above the annual mean under the baseline scenario, which would suggest that trees, especially live oak, might be expected to decrease over the 25 years. In contrast, granjeno is a shrub species that is well-adapted to annual rainfall regimes of 20-35 inches (McLendon 1991) and therefore might be expected to be favored by the 33-34 inches rainfall regime of the baseline scenario.

The substantial increase in grasses on the loamy sand type over the 25 years of the baseline scenario is likely to have been the result of two primary factors. First, is the rainfall regime. Mid- and tallgrass prairie commonly occurs on areas receiving 20-40 inches of rain annually (Weaver and Clements 1938:517; Weaver 1954:7; Shelford 1963:334; Stoddart et al. 1975:28; Smeins and Diamond 1983; Smeins 1994a; Bailey 1995:46). Consequently, the 33-34 inches average annual rainfall level is near the upper level for grasslands and therefore would favor relatively high production by grasses. Second, the livestock stocking rate was held to a moderate level for the initial conditions (112 g/m^2 of grasses = 1000 lbs/ac). As grass production increased, stocking rate did not increase and therefore the stocking rate became light over time. A low stocking rate combined with abundant moisture resulted in an increase in grasses.

The improved conditions for the grasses also resulted in a change in species composition (Table 9.1). Sideoats grama and purple threeawn were secondary species initially. They had become site dominants by the end of 25 years. Sideoats is a midgrass that can rapidly increase under favorable environmental conditions because of its relatively rapid growth rate, high seed production, and production of rhizomes. Sideoats had become the dominant herbaceous species on this site by Year 25, producing 43% of total aboveground herbaceous biomass. Purple threeawn is a rapidly-growing species characteristic of early mid-seral conditions. It rapidly increases once grazing pressure is reduced, and then begins to decrease once production of midgrasses increases substantially. Purple threeawn contributed 35% of total aboveground herbaceous biomass in Year 25. Little bluestem is a midgrass that is likely to become the dominant species on this site over time. However, it has a slower rate of increase than sideoats. By Year 25, little bluestem production had increased almost two-fold over initial conditions and contributed 16% of total aboveground herbaceous biomass.

Ragweed is a native perennial forb that increases under heavy grazing and other stress disturbances (e.g., drought). Standing crop biomass of ragweed on the loamy sand type was 28 g/m^2 initially, comprising 19% of total aboveground herbaceous biomass (Table 9.1). By Year 25, ragweed produced only 2 g/m^2 and this was less than 0.2% of total aboveground herbaceous biomass. The species was replaced successionally by the grasses, which is the expected response under the conditions of the baseline scenario.

9.1.1.3 Other Types

Results of the simulations for the other selected types also reflect expected ecological responses (Table 9.1). On the loamy bottomland type, tree biomass decreased overall but biomass of the late-seral trees (pecan, live oak) increased. All shrubs decreased except for whitebrush, which is well-adapted to the moderate rainfall conditions of the baseline scenario and is a shrub species that can form dense stands under conditions of moderate shading. Big bluestem is a tallgrass adapted to mesic conditions. It increased ten times more on the loamy bottomland type than on the blackland (coastal) type, which would be expected because of higher water availability on the bottomland type. The other herbaceous species that increased substantially on the loamy bottomland site were sideoats grama, little bluestem, and flatsedge (*Cyperus odoratus*). All three of these species would be expected to have substantial increases on this relatively wet site.

The salty prairie type occurs on wet sites that are saline. Gulf cordgrass and sea oxeye (*Borrichia frutescens*) increased substantially on this type and both species are salt-tolerant wetland species. Two other species, knotroot bristlegrass and frogfruit (*Phyla nodiflora*), also increased on this type and both of these are species that tolerate frequent flooding.

The shallow ridge type initially supported a blackbrush-guajillo-mesquite shrubland, with a sparse herbaceous component consisting of 46 g/m^2 of grasses and 14 g/m^2 of forbs (Table 9.1). At the end of the 25-year simulation, total woody plant biomass remained about the same as at the beginning of the simulation but blackbrush and mesquite increased and guajillo (*Acacia berlanderi*) decreased. Guajillo is a relatively palatable shrub for deer, and for cattle during winter and in dry periods. Livestock stocking rate was not decreased during the 25-year simulation and the amount of available grasses was low throughout the simulation. Therefore, grasses were heavily utilized by both cattle and deer, reducing grass production to 6 g/m^2 compared to 46 g/m^2 at the beginning of the simulation. Production of the palatable guajillo also decreased because of browsing by deer and cattle, while production of the less-palatable blackbrush and the unpalatable mesquite increased because of less competition from guajillo. In addition, production of the relatively unpalatable ragweed also increased, from 13 g/m^2 in Year 1 to 54 g/m^2 in Year 25. In summary, the shallow ridge type changed from a blackbrush-guajillo-mesquite community with a weak understory of perennial grasses to a blackbrush-mesquite-guajillo community with a ragweed understory.

9.1.2 Dry Cycle

The dry cycle scenario was simulated as the baseline scenario except with the rainfall input changed from that of 1928-1952 (average rainfall cycle, annual mean = 33.77 inches) to that of 1915-1939 (dry rainfall cycle, annual mean = 30.96 inches). Initial conditions, including livestock stocking rates, were the same for both the baseline and dry scenarios.

Overall mean aboveground biomass, averaged over the seven plot types, in Year 25 was 3,372 g/m^2, of which 2,838 g/m^2 (84%) were from woody species and 534 g/m^2 (16%) were from herbaceous species (Table 9.2). Under the baseline scenario, these values were 3,475 g/m^2 total, 2,877 g/m^2 woody, and 598 g/m^2 herbaceous (Table 9.1). Rainfall for the dry scenario was 8.3% less than under the baseline scenario. The reduction in rainfall resulted in total aboveground biomass decreasing by 3.0%. However, the effect of the reduced rainfall was not uniform over lifeforms. Herbaceous species biomass decreased by 10.7% whereas woody species decreased by only 1.4%.

The smaller effect of the dry cycle on woody species was the result of the greater rooting depth of woody species compared to herbaceous species, with the corresponding ability of woody species to access deep moisture, especially groundwater. The relatively large increase in huisache (11%; Table 9.3) was the result of reduced competition by grasses for soil moisture. Within the shrub component, most species were largely unaffected ($\pm$ 5% of baseline) by the dry cycle (Table 9.3). The exceptions were blackbrush and whitebrush. Blackbrush was unaffected by the dry cycle except on the shallow ridge type (Table 9.2), where blackbrush production was about half that under baseline conditions. The shallow ridge type is the most xeric of the types supporting blackbrush, therefore it is logical that production would be most affected on this type.

Whitebrush increased under the dry cycle on most types. This was likely the result of reduced competition from grasses.

Table 9.2 Aboveground biomass (g/m^2), by lifeform and major species, in seven plot types at the end of the growing season in Year 25 of a 25-year simulation under dry and wet precipitation scenarios, Goliad County EDYS model. Average annual rainfall for the dry scenario = 30.96 inches and for the wet scenario = 39.92 inches.

Lifeform or Species	Blackland Coastal		Clay Loam		Loamy Bottomland		Loamy Sand		Salty Prairie		Shallow Ridge		Tight Sandy Loam	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Trees	213	209	1217	1203	6153	5528	4582	4656	340	326	735	477	2898	2910
Shrubs	34	36	874	771	1005	533	353	340	145	135	885	1993	431	390
Midgrasses	75	221	54	187	46	34	501	619	680	769	t	9	410	446
Shortgrasses	580	660	314	642	1	55	197	270	31	55	t	3	299	458
Grass-Likes	0	0	0	0	151	473	0	0	0	0	0	0	0	0
Forbs	3	2	2	2	31	79	3	3	4	62	355	10	5	4
Total aboveground	905	1128	2461	2805	7387	6702	5636	5888	1200	1347	1975	2492	4043	4208
Huisache	116	114	411	413	558	596	---	---	283	268	---	---	---	---
Pecan	---	---	---	---	823	723	---	---	---	---	---	---	---	---
Sugar hackberry	4	4	---	---	743	741	---	---	---	---	---	---	---	---
Mesquite	82	80	806	790	373	370	838	817	57	58	735	477	1100	1088
Live oak	11	11	---	---	3656	3098	3744	3839	---	---	---	---	1798	1822
Guajillo	---	---	---	---	---	---	---	---	---	---	161	173	---	---
Blackbrush	5	5	76	77	---	---	---	---	---	---	688	1755	113	114
Whitebrush	6	6	298	222	600	155	---	---	---	---	---	---	---	---
Baccharis	---	---	26	28	46	42	---	---	---	---	---	---	---	---
Sea oxeye	---	---	---	---	---	---	---	---	145	135	---	---	---	---
Granjeno	13	13	280	272	76	80	248	237	---	---	---	---	279	246
Wolfberry	---	---	8	7	---	---	---	---	---	---	---	---	---	---
Agarito	t	t	5	3	---	---	---	---	---	---	---	---	---	---
Mustang grape	---	---	---	---	283	256	66	66	---	---	---	---	---	---
Prickly pear	10	12	181	162	---	---	39	37	---	---	36	65	39	30
Big bluestem	16	29	---	---	7	3	---	---	---	---	---	---	---	---
Purple threeawn	284	292	214	285	---	---	195	269	---	---	t	1	290	282
Silver bluestem	53	165	46	167	1	1	37	65	---	---	---	---	239	260
Sideoats grama	t	2	1	2	16	10	346	376	---	---	0	6	5	2
Hairy grama	35	48	t	3	---	---	1	t	---	---	0	1	6	174
Buffalograss	256	309	68	278	t	t	---	---	---	---	---	---	---	---
Hooded windmill	5	6	32	76	---	---	1	1	---	---	0	1	3	2
Trichloris	t	9	6	17	2	2	---	---	---	---	t	t	166	184
Vine-mesquite	0	t	t	t	1	2	---	---	---	---	---	---	---	---
Switchgrass	1	2	---	---	5	4	4	4	t	t	---	---	---	---
Little bluestem	3	4	1	1	15	14	114	174	t	t	0	3	---	---
Knotroot bristle	t	t	t	t	t	t	---	---	31	55	---	---	---	---
Indiangrass	t	2	t	t	---	---	---	---	t	t	---	---	---	---
Gulf cordgrass	---	---	---	---	---	---	---	---	680	769	---	---	---	---
Tall dropseed	2	8	t	t	---	---	---	---	---	---	---	---	---	---
Texas wintergrass	t	5	t	t	t	53	---	---	---	---	0	t	---	---
Flatsedge	---	---	---	---	151	473	---	---	---	---	---	---	---	---
Ragweed	1	1	1	1	1	2	1	1	---	---	355	10	2	2
Old-mans beard	2	1	t	t	21	69	---	---	---	---	---	---	---	---
Frogfruit	---	---	t	t	t	t	---	---	3	59	---	---	---	---
Glasswort	---	---	---	---	---	---	---	---	1	3	---	---	---	---
Bush sunflower	---	---	1	1	---	---	2	2	---	---	---	---	3	2
Greenbriar	---	---	---	---	9	8	---	---	---	---	---	---	---	---

Grass production was strongly reduced under the dry cycle, and midgrasses more than shortgrasses (Table 9.3). The largest proportional decrease in grasses was for big bluestem. Big bluestem is a tallgrass, adapted to mesic conditions. It is therefore not surprising that it was strongly affected by the lower rainfall regime of the dry cycle. Little bluestem was the second-most strongly affected and it is the second-most mesic of the midgrass group. Silver bluestem is the most drought-resistant of the midgrasses (e.g., water-use efficiency of 620 g water/g dry biomass compared to 712 for sideoats grama; McGinnes and Arnold 1939) and it was the least affected except for gulf cordgrass. Gulf cordgrass occurs on low-elevation sites which receive surface runoff and have relatively high water tables. Therefore, it would be expected to be less affected than the more upland species.

Table 9.3 Aboveground biomass (g/m^2) of major species in seven plot types at end of the 25-year simulation under three rainfall regimes, Goliad County EDYS model. Values averaged over the seven types (Tables 9.1 and 9.2).

Species	Mean Aboveground Biomass			Proportion of Medium-Regime Biomass		
	Dry	Medium	Wet	Dry	Medium	Wet
Trees						
Huisache	1368	1232	1391	1.110	1.000	1.129
Pecan	823	820	723	1.004	1.000	0.882
Sugar hackberry	747	751	745	0.995	1.000	0.992
Mesquite	3991	3840	3680	1.039	1.000	0.958
Live oak	9209	9304	8770	0.990	1.000	0.943
Shrubs						
Blackbrush	882	1543	1951	0.572	1.000	1.264
Whitebrush	904	640	383	1.413	1.000	0.598
Sea oxeye	145	138	135	1.051	1.000	0.978
Granjeno	896	868	848	1.032	1.000	0.977
Mustang grape	349	336	322	1.039	1.000	0.958
Prickly pear	305	320	306	0.953	1.000	0.956
Midgrasses						
Big bluestem	23	125	32	0.184	1.000	0.256
Silver bluestem	376	463	658	0.812	1.000	1.400
Sideoats grama	368	481	398	0.765	1.000	0.827
Trichloris	174	233	212	0.747	1.000	0.910
Little bluestem	133	215	196	0.619	1.000	0.912
Gulf cordgrass	680	740	769	0.919	1.000	1.039
Shortgrasses						
Purple threeawn	983	1046	1128	0.940	1.000	1.078
Hairy grama	42	16	226	2.625	1.000	14.125
Buffalograss	324	359	587	0.903	1.000	1.635
Knotroot bristlegrass	31	56	55	0.554	1.000	0.982
Forbs						
Ragweed	361	61	17	5.918	1.000	0.279
Old-mans beard	23	6	70	3.833	1.000	11.667

Knotroot bristlegrass, a shortgrass, is most commonly found on wet sites or sites with poor drainage. Of the four shortgrasses listed (Table 9.3), it was the species most affected by the dry cycle. Hairy grama is a drought-tolerant shortgrass that is abundant throughout the Southwest United States and northern Mexico. McGinnes and Arnold (1939) reported an average water-use efficiency of 483 (g water/g dry-weight aboveground production) for hairy grama, compared to 620 for silver bluestem and 712 for sideoats grama. In the simulations, hairy grama increased substantially under the dry cycle and this increase can be attributed to reduced competition from the other more drought-sensitive grasses. The dry cycle shifted the moisture conditions to those more similar to areas were hairy grama is most abundant. Similarly, the perennial forbs ragweed and old-mans beard increased substantially under the dry cycle. This was also most likely the result of reduced competition from grasses and the ability of ragweed to tolearate relatively dry conditions.

9.1.3 Wet Cycle

The wet cycle scenario was simulated as the baseline and dry scenarios except with the rainfall input changed to that of 1957-1981. Average annual rainfall during 1957-1981 was 39.92 inches, an increase of 5.25 inches (18.2%) per year.

Overall mean aboveground biomass in Year 25 under the wet cycle scenario was 3,510 g/m^2 (Table 9.2). This was only slightly higher than as under the baseline scenario (3,475 g/m^2). Although overall production did not increase much, the composition of the various lifeforms and species changed substantially. Average woody aboveground biomass for woody species was 2,787 g/m^2 and 723 g/m^2 for herbaceous species. This was a 3.1% decrease in woody species biomass compared to baseline and a 20.9% increase in herbaceous biomass.

Relatively wet conditions occurred in South Texas beginning in 1957, following the drought of 1950-1956. Despite above-average rainfall mesquite, granjeno, and prickly pear decreased in cover on the Welder Wildlife Refuge in San Patricio County over a 15-year period following the drought while huisache increased (Drawe et al. 1978). These were the same responses as those in the simulations under the wet scenario. Mesquite decreased by 4%, granjeno decreased by 2%, prickly pear decreased by 4%, and huisache increased by 13% (Table 9.3).

Whereas drought-tolerance and water-use efficiency were the primary factors explaining vegetation responses under the dry cycle, growth rate and maximum potential productivity were the major factors under the wet cycle. Herbaceous species decrease more rapidly under dry conditions than do woody species and they increase more rapidly than woody species under wet conditions. The 40-inch average annual rainfall level of the wet cycle is the approximate level at which woodlands replace grasslands as the dominant vegetation type (Section 9.1.1.2). At this rainfall level (i.e., 40 inches per year), the successional pattern beginning with the initial (Year 1; Table 9.1) conditions used in the simulations would likely be an increase in grasses until the maximum production of these species is reached, then an increase in mid-successional woody species, followed by an increase in late-seral species. The transition to mid- and late-successional trees would likely take more than the 25 years of the simulation.

Within the herbaceous component, production by midgrasses was about equal to that under the baseline scenario (362 and 359 g/m^2, respectively) but production by shortgrasses increased substantially over baseline (314 and 219 g/m^2, respectively). As rainfall increases, competitive advantage should shift from shortgrasses to midgrasses in the absence of grazing by livestock. Conversely, as grazing intensity increases there is a competitive shift back to shortgrasses. A moderate stocking rate by cattle was simulated under both the baseline and wet scenarios. This level of grazing was sufficient to keep midgrass production at baseline levels while allowing shortgrasses to increase.

Overall grass production (midgrasses + shortgrasses) averaged 676 g/m^2 over the seven vegetation types under the wet scenario (Table 9.2). This amount includes basal crown biomass, which is generally not included in biomass values reported in literature studies of grassland production. Clippable biomass, which is what most literature studies report, for grasses in EDYS simulations varies by species, but it averages about 60% of aboveground biomass. Converting the total aboveground value of 676 g/m^2 to clippable would equal 406 g/m^2 of aboveground biomass of grasses under a precipitation regime that averaged 39.9 inches per year. This compares favorably with published values for bluestem grasslands (Table 9.4).

Table 9.4 Aboveground production (g/m^2 clippable biomass) and annual precipitation (PPT; inches) reported for various bluestem and coastal prairie communities.

Community	Location	PPT	Production	Reference
Big bluestem-little bluestem	Kansas	34.4	357	Briggs & Knapp 1995
Big bluestem-little bluestem	Kansas	31.9	325	Owensby & Anderson 1967
Big bluestem-little bluestem	Oklahoma	44.8	349	Brummer et al. 1988
Little bluestem-big bluestem	Oklahoma	32.7	422	Hazell 1967
Tall dropseed-silver bluestem	Oklahoma	32.7	355	Hazell 1967
Sandhill bluestem-splitbeard bluestem	Louisiana	57.9	340	Duvall & Linnartz 1967
Sandhill bluestem-splitbeard bluestem	Louisiana	57.9	377	Grelen & Epps 1967
Little bluestem-tall dropseed	Texas	31.5	208	McLendon et al. 2001
Buffalograss-silver bluestem	Texas	28.3	164	Box & White 1969
Knotroot bristlegrass-plains bristlegrass	Texas	28.3	249	Box & White 1969
Gulf cordgrass-bermudagrass	Texas	35.0	543	Garza et al. 1994
MEAN		36.9	335	

Of the major species of midgrasses, two increased (silver bluestem, gulf cordgrass) and four decreased under the wet regime when compared to baseline (Table 9.3). Three of the four midgrasses that decreased are decreaser species, i.e., they are among the first species to decrease as grazing intensity increases. The exception, trichloris, is an earlier mid-successional species that would be expected to decrease in response to an incease in other midgrasses (e.g., silver bluestem). Silver bluestem is less preferred by cattle than big bluestem, little bluestem, or sideoats and would therefore increase under moderate grazing before there was an increase in the other three grasses. Silver bluestem was the major midgrass species that increased over a 15-year period following reduction in grazing pressure on the Welder Wildlife Refuge (Drawe et al. 1978).

Gulf cordgrass also increased during the wet regime. This species forms almost monospecific stands in saline depressions in the coastal prairie region. Although average rainfall in the wet scenario increased 18% over baseline, production of gulf cordgrass increased by only 4% (Table 9.3). The corresponding aboveground biomass value of 769 g/m^2 is probably approaching the upper limit of potential productivity of this species (Garza et al. 1994).

Of the four major species of shortgrasses, three increased (Table 9.3). Purple threeawn has a lower preference rating for cattle than many other grasses and it is not surprising that it increased under more favorable growing conditions. Buffalograss is one of the first species to begin to increase once more favorable conditions return (Box and White 1969).

Of the two major perennial forb species, one decreased and one increased. Ragweed is an upright perennial forb most abundant in lower successional semi-arid grasslands. It decreased under the wet regime, most likely because of competition from the grasses. Old-mans beard is a trailing vine that can form dense stands under mesic conditions (Drawe et al. 1978). This species increased under the wet scenario. The relative importance of these two forb species reversed between the baseline and wet scenarios. Under baseline, ragweed averaged 61 g/m^2 and old-mans beard averaged 6 g/m^2 (Table 9.3). Under the wet scenario, ragweed averaged 17 g/m^2 and old-mans beard averaged 70 g/m^2.

9.1.4 Brush Management

Five brush management scenarios were simulated. In each case, the basic brush treatment was the same: 100% of the aboveground woody biomass and 50% of the aboveground herbaceous biomass were removed from all non-urban areas that initially had 30% or more woody plant cover and less than 12% slope. Brush control was simulated to occur in March of Year 1. Pecan and live oak were excluded from the brush control operation, assuming that these trees would be left as desirable species. If the 50% level was selected for live oak, it was to allow large live oak trees to remain on the landscape. The removal of 50% of herbaceous vegetation was included because the brush management method being simulated was root-plowing, which disturbs the soil surface thereby removing a portion of established herbaceous plants.

The five brush management scenarios were: 1) the basic brush treatment applied under the average rainfall regime (daily rainfall amounts corresponding to 1928-1952), 2) the basic brush treatment applied under average rainfall regime, but removing 50% of oak biomass, 3) the basic brush treatment applied under the dry rainfall regime (daily rainfall amounts corresponding to 1915-1939) and removing 50% of oak biomass, 4) the basic brush treatment applied under the wet rainfall regime (daily rainfall amounts corresponding to 1957-1981) and removing 50% of oak biomass, and 5) the basic brush treatment applied under the moderate rainfall regime and removing 100% of woody species from all non-urban sites (i.e., not restricted to >30% woody cover and <12% slopes).

In four of the scenarios, brush management (root-plowing) was applied only to those areas with relatively dense (30% or more cover) stands of woody species. In actual practice, this would not likely be the case on a county-wide basis. In practice, different landowners throughout the county would make brush control decisions based on conditions specific to their particular land and management goals and therefore the density of brush treated would likely vary across the county. However, simulating treatment of the densest stands throughout the county should provide an estimate of the maximum effect that brush control might have on ecohydrology, given the specific amount of area treated. The actual area treated in each of the first four brush management scenarios was 18.4% of the area of Goliad County.

Each of the affected vegetation-soil-precipitation zone cell types responded differently to the brush management scenarios, as would be expected because of the ecological diversity. The ecological responses are integrations of the vegetation and land-use mosaics over each watershed. However, reporting vegetation responses for each vegetation type would be a substantial effort. There were 91 cell types that received brush control in these simulations. Instead of reporting each individually, results of vegetation responses on four major vegetation types are presented to illustrate the effects of the brush management on vegetation (Tables 9.6-9.8).

Brush control substantially reduced woody plant biomass even after 25 years on the clay loam site (Table 9.5). Under most scenarios, mesquite recovered to less than 10% of its initial biomass and huisache was largely eliminated from this site. Recovery of all woody species combined (trees and shrubs, Table 9.5) was 9.5%. This simulation assumed 100% removal of aboveground biomass of these two species from the initial root-plowing operation. In practice, a 95% rate would be more realistic. With a 95% initial removal, mesquite regrowth would likely be at least twice that of a 100% aboveground removal. Therefore, aboveground biomass of mesquite might be 10-20% of initial conditions after 25 years and total woody species perhaps 15-25%. Based on average height of shrub stands, Drawe et al. (1978) reported a 60% recovery of brush in the chaparral-mixed grass community on the Welder Wildlife Refuge in San Patricio County 30-35 years after root-plowing and that only half that increase, or about 30% recovery, occurred in 20-25 years. Based on the data from San Patricio County, the EDYS simulation values for brush recovery seem reasonable, but slightly on the low side. Instead of 10% recovery after 25 years from 100% removal (15-25% from 95% removal), recovery would probably be more on the order of 10-15%.

Table 9.5 Aboveground biomass (g/m^2) on the clay loam plot type (38% initial woody plant cover), by lifeform and by major species, at the end of 25 years following brush management in Year 1 under five brush control scenarios[1], Goliad County EDYS model.

Lifeform/Species	No BC Mod PPT	100% BC Mod PPT	50% Oak Mod PPT	50% Oak Dry PPT	50% Oak Wet PPT	All Sites Mod PPT
Trees	1278	54	54	16	2	52
Shrubs	898	152	151	143	133	173
Midgrasses	67	231	231	168	337	274
Shortgrasses	383	499	499	469	552	453
Forbs	2	24	25	26	20	24
Total Aboveground	2628	960	960	822	1044	976
Huisache	411	t	t	t	t	t
Mesquite	867	54	54	16	1	52
Blackbrush	76	t	t	t	t	t
Whitebrush	291	1	0	1	t	3
Baccharis	27	5	5	12	t	t
Granjeno	300	3	2	1	t	4
Prickly pear	192	143	144	130	133	166
Silver bluestem	57	174	173	120	250	169
Sideoats grama	2	14	14	6	16	21
Trichloris	7	8	8	11	32	6
Little bluestem	1	4	4	3	5	6
Plains bristlegrass	0	30	30	25	31	60
Johnsongrass	0	1	1	1	1	11
Purple threeawn	255	277	277	287	290	276
Buffalograss	92	203	204	162	239	163
Hooded windmillgrass	36	16	16	19	21	12
Wild indigo	0	16	16	16	14	17
Old-man's beard	t	4	4	6	1	2

[1] Brush control scenarios: No BC = no brush control (baseline, moderate rainfall); 100% BC = removal of 100% of woody species (except live oak) on sites >30% woody cover and <12% slopes; 50% Oak = removal of 100% of woody species (except 50% of live oak), on sites >30% woody cover and <12% slopes, under moderate (Mod), dry, and wet rainfall regimes; All Sites = removal of 100% of woody species (50% live oak) on all non-urban sites. Dashes (---) indicate that the species was not included in the simulation for that type.
A trace amount (< 0.5 g/m^2) is indicated with a "t".

The brush control scenarios increased herbaceous production substantially. Total herbaceous aboveground biomass was 452 g/m^2 on the clay loam type under baseline conditions (no brush control, moderate rainfall regime) and 754 g/m^2 with brush control (Table 9.5), or an increase of 67% at the end of 25 years. Total aboveground herbaceous biomass in EDYS simulations includes the basal crown (trunk) biomass, which is rarely sampled in clipping studies. Trunk biomass varies by species but in general accounts for about 40% of total aboveground biomass of herbaceous species in EDYS simulations (Appendix Table D.2). Adjusting the total aboveground herbaceous biomass values to clippable biomass results in values of 271 g/m^2 for the clay loam type under the baseline scenario and 452 g/m^2 with brush control, or an increase of 181 g/m^2 (1611 lbs/ac) in clippable biomass.

Production of midgrasses more than tripled following brush control (+ 164 g/m^2 = + 245%) and shortgrasses increased by 30% (+ 116 g/m^2)(Table 9.5). The major increase in midgrasses was from silver bluestem, with a smaller increase in plains bristlegrass. Buffalograss was the primary shortgrass that increased. Silver bluestem and buffalograss were two of the major species that increased on the clay and clay loam sites on the Welder Wildlife Refuge over 8 years following reduction in livestock grazing (Box 1961; Box and White 1969) and silver bluestem increases as shrub density decreases on these clay loam sites (Drawe et al. 1978).

Similar patterns occurred in the brush control scenarios under dry and wet rainfall regimes as occurred under the moderate rainfall regime (Table 9.5). Total aboveground biomass was lower under the dry regime than under the moderate regime and was higher under the wet regime. Under the dry regime, there was a smaller increase in biomass for silver bluestem, sideoats grama, plains bristlegrass, and buffalograss than under the moderate regime but a larger increase in trichloris, purple threeawn, and hooded windmillgrass. The last three species are more xeric species than the first four and would therefore be expected to be favored more, in relation to the more mesic species, by drier conditions. Conversely, silver bluestem, sideoats grama, little bluestem, and buffalograss increased more under the wet regime. Trichloris also increased under the wet regime. It is a midgrass and although more xeric than silver bluestem, it also responded favorably to the increased moisture.

Woody species did not recover as quickly under the wet regime as they did under the moderate rainfall regime. The likely reason was competition for moisture from the herbaceous species. The 100% removal of aboveground parts of the woody species effectively reduced these species to the seedling stage during early recovery. The dense stand of more rapidly growing grasses that then developed largely out-competed the small shrub plants. The trees and shrubs would be expected to continue to slowly grow and over a longer period of time would eventually replace the grasses. However, under the conditions of these simulations it will take longer than 25 years.

On the loamy bottomland site, the brush control operations effectively reduced the target woody species (Table 9.6). Under the 100% brush control scenario, no live oak was removed. Under these conditions, Johnsongrass and greenbriar (*Smilax bona-nox*) dominated the understory community. Production of other herbaceous species, except for the perennial grass brownseed paspalum and the vine-like old-man's beard, was reduced compared to baseline conditions. When 50% of the live oak was removed, Johnsongrass and brownseed paspalum increased even more, greenbriar production remained about the same, but production of old-man's beard decreased. The dry regime favored most of the other grasses at the expense of Johnsongrass, but both greenbriar and old-man's beard increased.

Johnsongrass strongly dominated the herbaceous community under the wet regime, producing 70% of the aboveground biomass of all herbaceous species combined. Plains bristlegrass and old-man's beard also increased under the wet regime, but at a lesser rate than Johnsongrass. The plant community developing under the wet regime consisted of a discontinuous overstory of live oak trees with a dense stand of grasses, mostly Johnsongrass, as an understory. Aboveground biomass of grasses and grass-likes was 740 g/m^2, or about 440 g/m^2 (4000 lbs/ac) clippable. This level of annual herbaceous production is typical of bluestem grasslands in mesic regions of Kansas, Louisiana, and Oklahoma (340-420 g/m^2: Grelen and Epps 1967; Hazell 1967; Brummer et al. 1988; Briggs and Knapp 1995) and almost as much as improved pastures on the Coastal Plains (500-1100 g/m^2; McCawley 1978, Kapinga 1982).

Table 9.6 Aboveground biomass (g/m^2) on the loamy bottomland type (63% initial woody plant cover), by lifeform and by major species, at the end of 25 years following brush management in Year 1 under five brush control scenarios[1], Goliad County EDYS model.

Lifeform/Species	No BC Mod PPT	100% BC Mod PPT	50% Oak Mod PPT	50% Oak Dry PPT	50% Oak Wet PPT	All Sites Mod PPT
Trees	6028	3315	1670	1636	1576	2435
Shrubs	739	253	249	256	253	250
Midgrasses	388	486	519	450	708	515
Shortgrasses	4	34	42	19	31	33
Grass-Likes	230	11	1	5	1	1
Forbs	24	234	208	289	110	194
Total Aboveground	7413	4333	2689	2655	2679	3429
Huisache	536	t	t	t	t	t
Pecan	820	5	6	2	t	771
Sugar hackberry	747	1	1	1	t	1
Mesquite	375	3	4	1	t	3
Live oak	3550	3308	1659	1632	1575	1659
Whitebrush	343	t	t	t	t	t
Baccharis	45	t	t	t	t	t
Granjeno	81	t	t	t	t	t
Mustang grape	270	253	248	256	253	250
Big bluestem	115	18	14	31	7	13
Sideoats grama	162	50	41	38	6	33
Switchgrass	14	10	10	10	7	10
Little bluestem	94	56	49	60	49	44
Plains bristlegrass	0	22	22	14	42	21
Johnsongrass	0	324	378	291	592	390
Brownseed paspalum	0	27	32	11	2	28
Texas wintergrass	t	t	t	t	24	t
Flatsedge	230	11	1	5	1	1
Old-man's beard	5	28	6	35	40	13
Greenbriar	17	204	200	255	69	179

[1] Brush control scenarios: No BC = no brush control (baseline, moderate rainfall); 100% BC = removal of 100% of woody species (except live oak) on sites >30% woody cover and <12% slopes; 50% Oak = removal of 100% of woody species (except 50% of live oak), on sites >30% woody cover and <12% slopes, under moderate (Mod), dry, or wet rainfall regimes; All Sites = removal of 100% of woody species (50% live oak and 0% pecan) on all non-urban areas.
Dashes (---) indicate that the species was not included in the simulation for that type.
A trace amount (<0.5 g/m^2) is indicated with a "t".

Brush control had less of a positive effect on herbaceous production on both the tight sandy loam type (Table 9.7) and the loamy sand type (Table 9.8). When 50% of the oak was removed under the moderate rainfall regime there was only a 3% increase in herbaceous production on the tight sandy loam type and a 4% increase on the loamy sand type. This was likely because the woody species were primarily utilizing deeper soil moisture, rather than shallower moisture that was also in the rooting zone of the herbaceous species. Therefore, removal of the woody species had little effect on the amount of moisture available to the herbaceous species.

Table 9.7 Aboveground biomass (g/m^2) on the tight sandy loam type (38% initial woody plant cover), by lifeform and by major species, at the end of 25 years following brush management in Year 1 under five brush control scenarios[1], Goliad County EDYS model.

Lifeform/Species	No BC Mod PPT	100% BC Mod PPT	50% Oak Mod PPT	50% Oak Dry PPT	50% Oak Wet PPT	All Sites Mod PPT
Trees	2952	1947	1118	942	941	1010
Shrubs	397	37	39	61	41	39
Midgrasses	547	578	580	493	493	580
Shortgrasses	284	277	276	296	408	278
Forbs	4	5	6	6	5	6
Total Aboveground	4184	2844	1919	1798	1888	1913
Mesquite	1078	18	25	18	t	9
Live oak	1874	1929	993	923	941	1001
Blackbrush	113	t	t	t	t	t
Granjeno	254	t	t	t	t	t
Prickly pear	30	36	38	61	41	38
Silver bluestem	323	304	314	248	271	309
Sideoats grama	2	66	62	95	55	79
Trichloris	224	207	202	147	166	190
Purple threeawn	276	273	272	292	281	273
Hairy grama	6	2	1	1	125	1

[1] Brush control scenarios: No BC = no brush control (baseline, moderate rainfall); 100% BC = removal of 100% of woody species (except live oak) on sites >30% woody cover and <12% slopes; 50% Oak = removal of 100% woody species (except 50% of live oak), on sites >30% woody cover and <12% slopes, under moderate (mod), dry, and wet rainfall regimes; All Sites = removal of 100% of woody species (50% live oak) on all non-urban areas.
Dashes (---) indicate that the species was not included in the simulation for that type.
A trace amount (< 0.5 g/m^2) is indicated with a "t".

Table 9.8 Aboveground biomass (g/m^2) on the loamy sand type (38% initial woody plant cover), by lifeform and by major species, at the end of 25 years following brush management in Year 1 under five brush control scenarios[1], Goliad County EDYS model.

Lifeform/Species	No BC Mod PPT	100% BC Mod PPT	50% Oak Mod PPT	50% Oak Dry PPT	50% Oak Wet PPT	All Sites Mod PPT
Trees	4695	4056	2167	1998	1998	2098
Shrubs	324	119	117	121	117	117
Midgrasses	471	400	460	513	597	426
Shortgrasses	256	254	299	215	300	310
Forbs	5	4	5	4	1	4
Total Aboveground	5751	4873	2968	2851	3013	2955
Mesquite	826	3	5	1	t	4
Live oak	3869	4053	2082	1997	1998	2094
Granjeno	220	t	t	t	t	t
Mustang grape	66	83	81	84	81	81
Prickly pear	38	36	36	38	36	36
Silver bluestem	40	30	32	35	55	34
Sideoats grama	313	248	303	351	410	267
Switchgrass	4	3	4	4	8	4
Little bluestem	114	115	118	122	123	113
Plains bristlegrass	0	3	3	4	2	7
Purple threeawn	254	250	255	169	275	250
Brownseed paspalum	0	41	41	44	23	55

[1] Brush control scenarios: No BC = no brush control (baseline, moderate rainfall); 100% BC = removal of 100% of woody species (except live oak) on sites >30% woody cover and <12% slopes; 50% Oak = removal of 100% of woody species (except 50% live oak) on sites >30% woody cover and <12% slope, under moderate (Mod), dry, and wet rainfall regimes; All Sites = removal of 100% woody species (50% live oak) on all non-urban sites.
Dashes (---) indicate that the species was not included in the simulation for that type.
A trace amount (< 0.5 g/m^2) is indicated with a “t”.

Under most of the brush control scenarios, herbaceous production was higher on the tight sandy loam type (Table 9.7) than on the loamy sand type (Table 9.8). This was the result of the higher sand content on the loamy sand type. Conversely, woody plant production was higher on the loamy sand type than on the tight sandy loam type. This was in response to higher soil moisture at deeper soil depths on the sand.

The vegetation relationships mentioned in this section up to this point are comparisons at the end of the 25 years. The model also simulates successional dynamics during the 25 years that occur in each of these types. For example, hooded windmillgrass, plains bristlegrass, and Johnsongrass are early- to mid-seral species on the clay loam type. Their abundance increases following brush control and then begins to decrease as other species become more abundant. Conversely, silver bluestem and buffalograss tend to increase later in succession. These were the responses simulated in the brush control scenarios (Fig. 9.1). Likewise, bushy bluestem (*Andropogon glomeratus*) is an early-seral species on the wetter sites. On the bottomland site following brush control, bushy bluestem production was 8 g/m^2 in the first year, increased to 63 g/m^2 by the fifth year, and then decreased to 2 g/m^2 by Year 25.

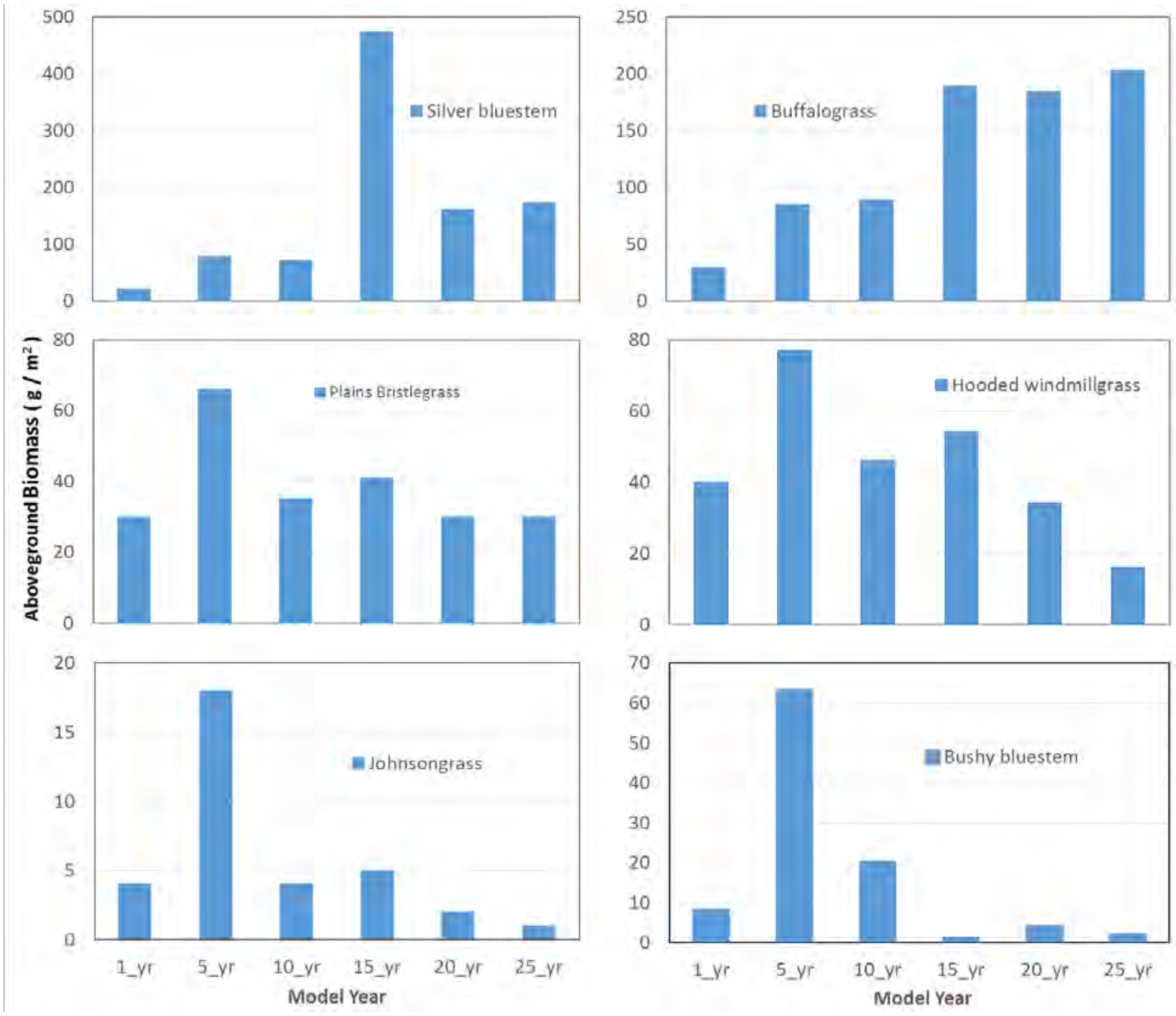

Figure 9.1 Changes in aboveground biomass (g/m^2) of selected herbaceous species on the clay loam and loamy bottomland (bushy bluestem) type over a 25-year simulation following brush control under a moderate rainfall regime, Goliad County EDYS model.

9.2 Ecohydrology

9.2.1 Water Balance: Average Rainfall

Rainfall averaged 32.76 inches per year over the 25-year simulation under the average rainfall regime (Table 9.9). The difference in this amount from the 33.77 inches in the stated average rainfall scenario (Section 9.0) was the result of spatial variability across the County (Section 4.2). An average of 1.3% of annual rainfall left the landscape as surface runoff. This is about half as much as reported from gauged watersheds in San Patricio County (Ockerman 2002). The gauged watersheds in San Patricio County were much smaller than the area included in the Goliad County simulations and runoff would be expected to decrease across large landscapes because of increased surface roughness and longer transport distances. Evapotranspiration (ET) was 16% more than rainfall when averaged over the 25 years (Table 9.9). This was possible because of a relatively high amount of groundwater use by the vegetation and by extraction of stored soil moisture. Groundwater use equaled almost 12% of annual rainfall and thus accounted for almost 75% of the amount that ET exceeded rainfall (12 out of 16 percentage points).

Table 9.9 Annual fluctuations in simulated hydrologic variables averaged over the entire Goliad County under the baseline (average rainfall regime) conditions.

Year	Rainfall (inches)	Rainfall (ac-ft)	Runoff (ac-ft)	Runoff/ Rainfall	ET (ac-ft)	ET/ Rainfall	GW Use (ac-ft)	GW Use/ ET	Net Soil Storage (ac-ft)
01	30.36	1,378,370	13,188	0.010	1,682,213	1.248	424,164	0.252	+ 107,133
02	41.64	1,889,942	37,880	0.020	2,007,592	1.062	197,197	0.098	+ 41,667
03	24.70	1,120,559	794	0.001	1,637,262	1.461	228,397	0.138	- 289,100
04	39.34	1,784,981	50,335	0.028	1,893,274	1.061	176,053	0.094	+ 17,425
05	33.79	1,578,504	27,986	0.018	1,887,143	1.196	193,431	0.103	- 143,194
06	30.54	1,385,587	10,384	0.007	1,783,913	1.287	196,237	0.110	- 212,473
07	39.46	1,790,059	37,024	0.021	1,672,730	0.934	179,817	0.107	+ 260,122
08	40.24	1,825,392	15,577	0.009	2,153,829	1.180	154,269	0.072	- 189,475
09	35.71	1,620,658	12,128	0.007	2,047,857	1.264	168,963	0.083	- 270,364
10	25.20	1,143,483	6,861	0.006	1,214,303	1.062	170,726	0.141	+ 93,045
11	24.70	1,120,640	25,690	0.023	1,523,016	1.359	159,143	0.104	- 268,923
12	20.42	926,631	8,687	0.009	1,321,310	1.426	161,881	0.123	- 241,485
13	38.61	1,751,956	18,797	0.011	1,660,962	0.948	143,372	0.086	+ 215,569
14	40.94	1,858,033	5,374	0.003	2,187,408	1.177	130,144	0.060	- 204,605
15	39.02	1,770,682	61,625	0.035	1,947,041	1.100	142,871	0.073	- 95,113
16	32.43	1,471,614	5,668	0.004	1,605,112	1.091	139,490	0.087	+ 324
17	31.66	1,436,587	7,400	0.005	1,775,597	1.236	144,795	0.082	- 201,615
18	27.70	1,256,563	2,128	0.002	1,537,608	1.224	140,001	0.091	- 143,172
19	44.86	2,035,293	22,274	0.011	2,114,782	1.039	143,689	0.068	+ 41,936
20	30.08	1,364,976	11,949	0.009	1,648,704	1.208	145,033	0.088	- 150,644
21	25.30	1,147,991	284	0.000	1,607,639	1.400	157,903	0.098	- 302,029
22	36.29	1,646,512	4,994	0.003	1,757,201	1.067	152,776	0.087	+ 37,093
23	17.04	773,153	3,110	0.004	1,279,204	1.655	158,559	0.124	- 350,602
24	33.23	1,507,469	54,365	0.036	1,567,823	1.040	148,307	0.095	+ 33,588
25	35.81	1,624,816	33,199	0.020	1,642,890	1.011	148,522	0.090	+ 97,249
Mean	32.76	1,487,218	19,094	0.013	1,726,256	1.161	172,230	0.100	- 85,902

Rainfall Year is the year from which the annual rainfall data were taken.
ET = evapotranspiration. GW Use = groundwater used by vegetation in transpiration (included as part of ET).
Net Soil Storage = Rainfall + GW Use – ET - Runoff.

The remaining amount of ET in excess of rainfall came from extraction of stored soil moisture. On average, there was an annual deficit of 85,900 acre-feet of soil moisture per year (Table 9.9). EDYS begins a simulation with a specified amount of soil moisture in each soil layer. This amount can be set at any level but is commonly set at 50% of field capacity for each layer. The amount of water corresponding to this level of soil moisture in each soil layer is available to plants for those layers within the rooting zone of each particular species. In this baseline scenario for the Goliad County model, there was soil moisture recharge in 11 years and an annual deficit in 14 years (Table 9.9). Both the direction and magnitude of this annual dynamic is dependent on a number of factors, including amount of rainfall, when the rainfall occurred, and vegetation composition and production.

In the baseline simulation, there was a net deficit over the 25 years and a deficit could not be continued indefinitely. Over a sufficiently long period, soil moisture would eventually be depleted and vegetation would adjust to a level and composition that could be supported by rainfall and groundwater only. The 85,900 acre-feet of annual deficit simulated in the baseline scenario for the entire County equals an average of 1.58 inches of soil water per year. At a 20% average field capacity, this equals to a dewatering rate of 7-8 inches per year. In 10-15 years, this rate would effectively dewater the rooting zone of most grasses and therefore make them dependent only on annual rainfall in most years. Deeper rooted woody species would continue to have access to deeper soil moisture for several decades longer and on groundwater as long as the water table did not decrease substantially.

Annual rainfall varied between 17.04 and 44.86 inches in the simulation and this variation resulted in substantial hydrologic variability (Table 9.9). Runoff was less than 1000 acre-feet county-wide in two years and was more than 50,000 acre-feet in three years. ET varied from less than 1.3 million acre-feet to almost 2.2 million acre-feet and from 93% of annual rainfall to 146% of annual rainfall. Groundwater use by vegetation varied between 130,000 acre-feet and 424,000 acre-feet.

9.2.2 Runoff

Runoff varied by year (Table 9.9) and under the different scenarios (Table 9.10). Annual variation resulted in large part because of 1) changes in amount of rainfall, 2) timing of the rainfall, and 3) changes in vegetation.

Table 9.10 Annual rainfall (inches) and annual runoff (acre-feet) averaged over the entire Goliad County under various 25-year EDYS simulations.

Scenario	Annual Runoff (ac-ft)	Runoff/Acre/Yr (inches)	Annual Rainfall (inches)	Runoff/Rainfall
Baseline	19,094	0.42	32.76	0.013
Dry Regime	15,900	0.35	29.80	0.012
Wet Regime	34,477	0.76	37.99	0.020
Brush Control				
100% Oak; Ave PPT	19,101	0.42	32.76	0.013
50% Oak; Ave PPT	19,121	0.42	32.76	0.013
50% Oak; Dry PPT	15,923	0.35	29.80	0.012
Brush Control, No Grazing				
50% Oak; Ave PPT	19,043	0.42	32.76	0.013
Maximum Brush Control				
All non-urban areas	19,149	0.42	32.76	0.013
Cultivation 6.5% of Area	18,897	0.41	32.76	0.013
Cultivation 21% of Area	18,281	0.40	32.76	0.013

Brush Control scenarios include 100% removal of all woody species except live oak. The amount of live oak removed is either 100% or 50%.
Cultivation scenarios replaced 6.5% or 21% of current vegetation in the County with cultivated land.
Average annual rainfall amounts in Table 9.10 do not equal those listed for the scenarios because of spatial variation over the County. The amounts listed for the scenarios are for the Goliad station.

Runoff decreased in drier years and increased in wetter years (Table 9.11). On average, runoff in dry years (average rainfall = 24 inches) decreased by 64% compared to runoff in moderate-rainfall years when rainfall averaged 40% more (mean = 33 inches). Runoff in wet years averaged 72% more than runoff in moderate-rainfall years. Rainfall increased by an average of 23% in these wet years compared to moderate rainfall years. By comparison, a 43% increase in annual rainfall resulted in a 57% increase in runoff on cultivated clay sites in Kleberg and Nueces Counties (Ockerman and Petri 2001). On average in the Goliad model simulations, one inch of annual rainfall resulted in 228 acre-feet of runoff in dry years, 549 acre-feet in moderate-rainfall years, and 768 acre-feet in wet years.

Table 9.11 Annual runoff (acre-feet, county-wide), annual rainfall (inches), and previous-year rainfall (inches) in EDYS simulations for dry, moderate, and high rainfall years, Goliad County EDYS model.

	Dry Years (< 29 in)			Moderate (29-38 in)			Wet Years (> 38 in)		
	Annual Rainfall	Annual Runoff	Previous Rainfall	Annual Rainfall	Annual Runoff	Previous Rainfall	Annual Rainfall	Annual Runoff	Previous Rainfall
	17.04	3,110	36.29	30.08	11,949	44.86	38.61	18,797	20.42
	20.42	8,687	24.70	30.36	13,188	-----	39.02	61,625	40.94
	24.70	794	41.64	30.54	10,384	33.79	39.34	50,335	24.70
	24.70	25,690	25.20	31.66	7,400	32.43	39.46	37,024	30.54
	25.20	6,861	35.71	32.43	5,668	39.02	40.24	15,577	39.46
	25.30	284	30.08	33.23	54,365	17.04	40.94	5,374	38.61
	27.70	2,128	31.66	33.79	27,986	39.34	41.64	37,880	30.36
				35.71	12,128	40.24	44.86	22,274	27.70
				35.81	33,199	33.23			
				36.29	4,994	25.30			
Mean	23.58	6,793	32.18	32.99	18,126	33.92	40.50	31,111	31.59

Although there was a strong relationship between runoff and average annual rainfall, there was high variation among years (Table 9.11). The four lowest runoff years occurred in the dry rainfall group, as would be expected. However, one dry year that received 24.7 inches of rainfall had as much runoff as a moderate-rainfall year that received 33.8 inches and more runoff than four of the high-rainfall years. Three of the high-rainfall years that received about the same amount of rainfall (40.2, 40.9, and 41.6 inches) had annual runoff that varied between 5,374 and 37,880 acre-feet. This among-year variability in runoff was not likely to have been the result of antecedent rainfall because average previous-year rainfall was similar among the three categories (dry, moderate, wet) and there was no consistent relationship among amount of runoff, previous-year rainfall, and annual rainfall.

The factors that most likely affected runoff on an annual basis were timing of the rainfall and vegetation condition at the time of rainfall. For example, annual rainfall was similar in Years 16 (1943 = 32.4 inches) and 24 (1951 = 33.2 inches), but annual runoff in Year 16 was 5,668 acre-feet compared to 54,365 acre-feet in Year 24 (Table 9.9). Monthly rainfall in Year 16 (1943) was less than 5 inches, except for May when it was about 6 inches. In Year 24 by contrast, nearly 9 inches was received in May and over 13 inches was received in September. Vegetation cover in Year 24 (1951) was low because of the beginning of the dought of the 1950s. Therefore, Year 24 received high rainfall in two months and had relatively low herbaceous cover, resulting in high runoff. Rainfall in Year 16 (1943) was more uniform and herbaceous cover was higher because the three previous years received above average rainfall. Consequently, runoff in Year 16 was low.

Under the dry scenario (29.80 inches average annual rainfall), annual runoff decreased by about 3,100 acre-feet compared to baseline (32.76 inches average annual rainfall; Table 9.10). This was a 17% decrease in runoff corresponding to a 9% decrease in average annual rainfall. This response ratio to decreased rainfall over a 25-year period (17% decrease in runoff/9% decrease in rainfall = 1.9) is similar to the ratio indicated in the dry vs. moderate periods of the baseline scenario (64%/29% = 2.2; Table 9.11). Therefore, surface runoff may be expected to decrease at a rate (% basis) equal to twice that of the decrease in rainfall.

Under the wet scenario (37.99 inches average annual rainfall), annual runoff increased by about 15,500 acre-feet compared to baseline (Table 9.10). This was an 81% increase in runoff corresponding to a 16% increase in rainfall sustained over 25 years. This equals a 5.1 response ratio (81% increase in runoff/16% increase in rainfall = 5.06). The corresponding numbers for the moderate and wet years within the baseline scenario (Table 9.11) are a 61% increase in runoff at a 23% increase in rainfall, or a response ratio of 2.7 (61%/23%). The higher response ratio under the wet scenario was because there were more extreme events in the wet scenario. The wet scenario had 10 years (40%) receiving more than 42 inches per year, whereas only one year in eight (13%) exceeded 42 inches in the wet-year grouping under baseline conditions (Table 9.11), and five of the 25 years (20%) under the wet scenario received more than 50 inches of rainfall. Under rangeland conditions on the central Texas Coast, rainfall events of more than 4 inches produced six times as much surface runoff as moderate events (1.9-2.6 inches; Ockerman 2002). The response ratio in that study was 2.5 over a period of two years. That was very similar to the 2.7 response ratio for the EDYS simulations over the eight wet years of the baseline scenario.

Brush control had very little impact on surface runoff, under either average or dry rainfall scenarios (Table 9.10). This result was because herbaceous vegetation did not increase substantially following brush control. Woody plants have a substantial impact on ET and groundwater use, but herbaceous cover has a greater impact on influencing surface runoff. To achieve an increase in herbaceous cover following brush control, it is necessary to decrease livestock grazing for a long enough period (1-3 years) to allow the grasses to recover from the root plowing and to respond to the decrease in woody species. Without this rest period, livestock will consume the new growth before the plants can develop increased perennial structures. In many areas, reseeding of grasses is also required to achieve an increase in grass production in a reasonable period (e.g., less than 10 years).

Another brush control scenario was run to determine the effect of livestock grazing on hydrology following brush control. This scenario (Brush Control, No Grazing: Table 9.10) was the same as the 50% oak, average rainfall brush control scenario except that all livestock grazing was eliminated from the treated areas. It would not be practical to eliminate all livestock grazing for 25 years, but this scenario was run to determine what the maximum effect would be. Runoff decreased by almost 90 acre-feet per year (Table 9.10).

The brush control treatments were applied to about 102,400 acres county-wide (18% of the area) and these treated areas formed a mosaic throughout the county. Part of any increase in runoff from treated acreage can be reduced as it moves onto an adjacent untreated area, thereby reducing the overall effect of brush control on runoff. This also likely contributed to the minor effect of brush control on surface runoff.

There is relatively little cultivated land in Goliad County (8,527 acres; Wiedenfeld 2010). The normal scenarios used in EDYS applications to evaluate potential impacts from cultivation are to increase or decrease cultivation by a specified percentage, usually 25 or 50%. However, with such a small acreage of cultivated land included in baseline, increasing or decreasing this amount by 50% was not likely to have a noticeable effect on county-wide hydrology. Instead, two cultivation scenarios were run for Goliad County to evaluate potential impacts of cultivation on hydrology. In both scenarios, native vegetation was replaced by cultivated land (grain sorghum as a crop). In one scenario, cultivated land was increased to equal 6.5% of the total area in the county and in the other scenario 21% of the area of the county was placed into cultivation.

More land in Goliad County was under cultivation in the past. In 1954, 43,334 acres were under cultivation, mostly in corn, cotton, and milo (Dallas Morning News 1958), or about 7.9% of the area of the County. Cultivated acreage decreased substantially during and following the drought of the 1950s. Between 1950 (first year of the drought) and 1954, cultivated acreage had decreased by almost 10%. Therefore, the 6.5% area under cultivation scenario approximates the amount of cultivated land in Goliad County in the mid-1950s. The maximum potential amount of cultivated land in Goliad County, based on the USDA prime farmland classification (Wiedenfeld 2010:107), is 392,735 acres or nearly 71% of the County. Therefore, the 21% area under cultivation scenario would include about 30% of the maximum potential.

An increase in cultivation decreased surface runoff on a county-wide basis, but only by a small amount (Table 9.10). When cultivation was increased to 6.5% of the county (about 36,000 acres under cultivation), average annual runoff decreased by about 200 acre-feet. When cultivation was increased to 21% of the county (about 114,400 acres), average runoff decreased by about 820 acre-feet, compared to baseline. Surface runoff is generally lower from cultivated land than from areas covered in native vegetation because cultivation increases the porosity of the surface soil, thereby increasing infiltration, and cultivation generally reduces average slope. Furrowing also decreases runoff by restricting off-site flow of water. Ockerman and Petri (2001) reported surface runoff to be substantially lower on cultivated subwatersheds in Kleberg and Nueces Counties of South Texas, compared to adjacent rangeland subwatersheds.

9.2.3 Evapotranspiration

Evapotranspiration (ET) averaged 38.0 inches over the 25-year simulation period under baseline conditions, or about 116% of annual rainfall, but varied substantially from year to year (Table 9.9). In dry years (annual rainfall less than 29 inches), ET averaged 31.9 inches, 38.4 inches in moderate-rainfall years, and 43.1 inches in wet years (more than 38 inches)(Table 9.12). Although ET increased as rainfall increased, the ratio of annual ET:annual rainfall decreased (1.37 in dry years, 1.17 in moderate, and 1.06 in wet years; Table 9.12). This decrease was the result of rainfall becoming increasingly sufficient to supply the moisture requirements of the vegetation, i.e., less groundwater was required.

Table 9.12 Annual evapotranspiration (ET; acre-feet, county-wide), annual rainfall (inches), and previous-year rainfall (inches) in EDYS simulations for dry, moderate, and high rainfall years, Goliad County EDYS model.

	Dry Years (< 29 in)				Moderate (29-38 in)				Wet Years (> 38 in)			
	Annual Rainfall	Annual ET	ET/ Rainfall	Previous Rainfall	Annual Rainfall	Annual ET	ET/ Rainfall	Previous Rainfall	Annual Rainfall	Annual ET	ET/ Rainfall	Previous Rainfall
	17.04	28.20	1.66	36.29	30.08	36.36	1.21	44.86	38.61	36.60	0.95	20.42
	20.42	29.16	1.43	24.70	30.36	37.08	1.25	-----	39.02	42.95	1.10	40.94
	24.70	33.60	1.36	41.64	30.54	39.36	1.29	33.79	39.34	41.63	1.06	24.70
	24.70	36.12	1.46	25.20	31.66	39.12	1.24	32.43	39.46	36.84	0.93	30.54
	25.20	26.76	1.06	35.71	32.43	35.39	1.09	39.02	40.24	47.39	1.18	39.46
	25.03	35.40	1.40	30.08	33.23	34.56	1.04	17.04	40.94	48.23	1.18	38.61
	27.70	33.84	1.22	31.66	33.79	41.63	1.20	39.34	41.64	44.29	1.06	30.36
					35.71	45.12	1.26	40.24	44.86	46.56	1.04	27.70
					35.81	36.23	1.01	33.23				
					36.29	38.75	1.07	25.30				
Mean	23.58	31.87	1.37	32.18	32.99	38.36	1.17	33.92	40.50	43.06	1.06	31.59

When groundwater is too deep for any significant use by vegetation, vegetation is dependent on precipitation, both current-year and stored soil moisture unused from previous years. This effectively limits maximum ET to an average of about 1.00 of annual precipitation when averaged over several years. Annual ET can exceed annual precipitation is some years because of use of stored moisture. For example, ET in a mesquite-granjeno shrubland in South Texas was 1.06 of annual rainfall in a dry year (13.0 inches ET) compared to 0.99 in a wet year (ET = 34.6 inches)(Weltz and Blackburn 1995). In the Rolling Plains of Texas, the annual ET:rainfall ratio varied over a three-year study period between 0.81 and 1.12 on a mesquite-grassland site and between 0.86 and 1.19 on an adjacent grassland site (Carlson et al. 1990).

Conversely, when groundwater is within reach of the vegetation root systems ET generally exceeds annual precipitation. The amount that it exceeds annual precipitation is dependent on depth to groundwater and the maximum productivity (and therefore maximum water requirement) of the vegetation. Mesquite woodland in southeastern Arizona had 33.4 inches of annual ET when depth to groundwater (DTW) was 6.5 feet, compared to 25.1 inches when DTW was at 32.6 feet (Scott et al. 2000, 2006).

Under simulated current conditions (baseline, no brush control), average annual ET was 38.04 inches, which was equal to 1,726,256 acre-feet of water removed county-wide (Table 9.13). The brush control scenario reduced that to 35.71 inches, or an average of 1,620,937 acre-feet per year. This was a reduction in water lost to ET of 105,319 acre-feet per year. In the dry-regime scenario, brush control reduced water lost to ET by 132,484 acre-feet per year. The maximum brush control scenario (removing all woody plants in non-urban areas) reduced ET substantially. This scenario is discussed in detail in Section 9.2.7.

Table 9.13 Effect of brush control and cultivation on annual evapotranspiration (ET) and annual groundwater use by vegetation averaged over 25-year simulations of the Goliad County EDYS model.

Scenario	Annual Rainfall (inches)	Annual ET (inches)	Annual ET (ac-ft)	ET/Rainfall	Annual Groundwater Use (inches)	Annual Groundwater Use (ac-ft)
Baseline, Average PPT	32.76	38.04	1,726,256	1.16	3.79	172,230
Baseline, Dry PPT	29.80	35.40	1,640,361	1.19	3.67	166,383
Brush Control						
50% Oak; Ave PPT	32.76	35.71	1,620,937	1.09	2.68	121,510
50% Oak; Dry PPT	29.80	33.23	1,507,877	1.12	2.63	118,991
Maximum; Ave PPT	32.76	31.71	1,439,006	0.97	0.80	36,326
Cultivation 6.5% of Area	32.76	36.92	1,675,645	1.13	3.48	157,674
Cultivation 21% of Area	32.76	34.42	1,561,468	1.05	2.76	125,343

An increase in cultivation also reduced ET (Table 9.13). When cultivation was increased to include 6.5% of the area of the county, ET was 50,611 acre-feet less than under baseline conditions (average rainfall regime). When cultivation was increased to 21% of the area, ET was 154,893 acre-feet less than under baseline conditions.

9.2.4 Groundwater Use by Vegetation

The baseline scenario indicated that present vegetation in Goliad County was utilizing an average of 172,230 acre-feet of groundwater per year, or an equivalent of 3.79 inches per year. This groundwater use was primarily by deep-rooted woody species such as mesquite, live oak, hackberry, and pecan. Brush control reduced this useage by an average of 50,720 acre-feet per year under the baseline rainfall regime and by an average of 57,392 acre-feet per year under the dry regime (Table 9.13). This reduction was because of the removal of most of the deep-rooted woody species.

Cultivation also had an effect on groundwater use by vegetation (Table 9.13). Under baseline conditions (average rainfall regime), groundwater use was reduced by 14,556 acre-feet per year when 6.5% of the area was under cultivation and by 46,887 acre-feet when cultivation increased to 21% of the area.

9.2.5 Change in Water Balance

In the most basic form, a landscape water balance compares water inputs, exports, and storage across the landscape. For the terrestrial component (i.e., excluding river and stream flows) of the Goliad County model, inputs are from rainfall and groundwater use. Exports are ET, surface runoff, and groundwater recharge (if any). Storage refers to moisture stored in the soil profile. The basic water balance equation is therefore given by:

rainfall + groundwater use = ET + runoff + groundwater recharge + soil storage, where the soil storage factor is a change (+ or –) in annual amount.

All scenarios except brush control under the wet regime and 21% of County in cultivation resulted in an average net water deficit over the 25-year simulation period (Table 9.14). The deficit increased under the dry regime as compared to the moderate rainfall regime and decreased under the wet regime. In the baseline scenarios (no brush control and no increase in cultivation), the wet regime (18% increase in average annual rainfall compared to the moderate regime), which used the daily rainfall data from 1957-1981, resulted in conditions where water losses were almost offset by water inputs. However, there was an average net annual deficit even under this wet regime. This suggests that under the present vegetation conditions, especially the amount of woody species present, it is unlikely that any consistent recharge will occur in Goliad County as a whole.

Table 9.14 Effect of moisture regime, brush control, and cultivation on average annual water balance components (acre-feet) simulated for 25-year scenarios using the Goliad County EDYS model.

Scenario	Rainfall	Groundwater Use	Runoff	ET	Net Storage
Moisture Regime					
Baseline, Ave PPT	1,487,218	172,230	19,094	1,726,256	- 75,902
Baseline, Dry PPT	1,365,762	166,383	15,900	1,604,361	- 88,116
Baseline, Wet PPT	1,723,842	155,747	34,477	1,855,027	- 9,915
Brush Control					
100% Oak; Ave PPT	1,487,218	131,096	19,101	1,641,010	- 41,797
50% Oak; Ave PPT	1,487,218	121,510	19,121	1,620,939	- 31,332
50% Oak; Dry PPT	1,365,762	118,991	15,923	1,507,877	- 39,047
50% Oak; Wet PPT	1,723,842	111,476	34,498	1,759,930	+ 40,890
Cultivation					
6.5% of County Area	1,487,218	157,674	18,897	1,675,645	- 49,650
21% of County Area	1,487,218	125,343	18,281	1,561,468	+ 32,812

Baseline = no brush control or change in amount of cultivated land.
Brush Control: all woody species oak and pecan removed from all areas with >30% woody plant cover and less than 12% slope. In 100% oak scenario, all oak also removed. In 50% oak scenarios, only 50% oak removed.
Cultivation scenarios are at the moderate (baseline) rainfall regime.

Negative net soil water storage cannot be maintained indefinitely. In the model scenarios, the initial soil moisture condition throughout the soil profile was set at 50% of field capacity in each layer. Once this stored water is depleted by plants, the vegetation will either 1) utilize more groundwater or 2) adjust to the lower amount of available moisture by reducing the amount of vegetation present and its productivity. The model scenarios were for 25-year simulations. The 75,900 acre-feet deficit under the baseline, average rainfall scenario (Table 9.14) equals an average annual deficit of about 1.5 inches of water per year, averaged over the entire County. This corresponds to dewatering about 15-20 inches of soil per year (at 8-10% available water holding capacity), or about 30-40 feet over the 25-year simulation. The actual depth of dewatering varies from year to year as more moisture is added from the top during wet periods and greater amounts are transpired from lower levels during dry periods. In addition, dewatering patterns are very different on wooded sites than on adjacent sites supporting mostly grasses.

The brush control scenarios decreased by annual water deficits by 50-60%, reducing the annual deficit to about 31,000 acre-feet in moderate-rainfall years and 39,000 acre-feet in dry years (Table 9.14). This reduction was achieved by reductions in vegetation biomass and in groundwater use. Under the 50% oak, 100% other woody species scenario reduced ET by 105,000 acre-feet per year, of which 45,000 acre-feet were from less transpiration of groundwater. The remaining 60,000 acre-feet resulted from a lower amount of transpired soil moisture because of lower vegetation demands. Under the dry regime, brush control reduced ET by 96,000 acre-feet per year, of which 47,000 acre-feet were from reduced transpiration of groundwater and 49,000 acre-feet were from reduced use of soil moisture.

When the wet regime (rainfall corresponding to 1957-81) was used in conjunction with brush control, there was a positive net storage of almost 41,000 acre-feet per year (Table 9.14). This amount of increased soil moisture storage equals about 0.9 inches of soil moisture per year, or a re-wetting of about 10 inches of the soil profile per year (assuming 8-10% available water-holding capacity). If this moisture regime continued sufficiently long to bring the soil profile above the water table up to field capacity, then this amount of water (41,000 acre-feet) would be added to groundwater or lateral flow to creeks and the river each year. In addition, 34,500 acre-feet would be added directly to creeks and the river each year from surface runoff (Table 9.14).

Only about 18% of the area of the County was treated in each of the brush control scenarios. Although these areas supported the densest stands of woody species, brush control on additional acres would reduce the annual water deficit even more. If woody species were substantially reduced on 40-50% of the area of the County, it is likely that there would be a water surplus in most years. This surplus would first recharge the soil profile and once the profile reached field capacity, additional water would likely move into groundwater recharge.

Cultivation had a similar effect on water balance as did brush control, for much the same reason (i.e., removal of deep-rooted woody species). When 6.5% of the County was modeled as cultivated land, annual water deficit was reduced to 50,000 acre-feet, or a reduction of about 35% compared to baseline (Table 9.14). This was equal about 60% of the reduction accomplished by applying brush control to 18% of the County. The increased effectiveness of water storage under cultivation compared to brush control is the result of the cultivated land being fallow for a large part of the year. And much of the fallow period is when the area receives much of its annual rainfall.

When cultivation was increased to 21% of the area, there was an annual surplus of moisture when averaged over the 25 years (Table 9.14). The annual surplus (32,812 acre-feet) is equal to about 0.72 inch per year averaged over the entire County, or 3.5 inches per acre of cultivated land, under the moderate rainfall regime. Around 1950, about 9% of the area of Goliad County was under cultivation. Under a moderate rainfall regime, that level of cultivation might result in a county-wide deficit of about 30,000 acre-feet per year, compared to a deficit under current conditions of 76,000 acre-feet. Under a wet regime, the deficit might shift to a 5,000-10,000 acre-feet surplus.

9.2.6 Water Balance by Watershed

The water balance information presented previously was, for the most part, averaged over the entire county. However, landscape hydrology varies widely across the county because of differences in topography, soil, vegetation, and depth to groundwater. There are 81 watersheds delineated in Goliad County (Table 9.15), some of which have part of their area outside Goliad County (Fig. 9.2). The watersheds vary in size from less than 100 acres to more than 38,000 acres (Table 9.15).

Table 9.15 Average annual water balance components by watershed simulated for 25-year baseline scenario, expressed as watershed totals and per-acre averages, using the Goliad County EDYS model.

Watershed	Area	Rainfall	Watershed Totals (acre-feet)			Per-Acre (inches)		
	(acres)	(acre-feet)	GW-Use	ET	Runoff	GW-Use	ET	Runoff
Northeast Sector								
1101	10,392	27,109	2,365	29,710	340	2.73	34.31	0.39
1102	28,956	75,549	4,690	79,890	632	1.94	33.11	0.26
1103	9,076	25,112	3,139	29,263	381	4.15	38.69	0.54
1105	11,398	31,730	3,517	36,043	535	3.70	37.95	0.56
1106	14,382	40,039	3,696	43,932	418	3.09	36.66	0.35
1108	24,500	68,207	8,584	78,853	1,488	4.20	38.62	0.73
1136	18,068	49,876	4,893	56,046	690	3.25	37.22	0.46
1137	7,321	20,380	1,790	22,161	299	2.93	36.32	0.49
SUM	124,093	338,002	32,674	375,898	4,783	3.16	36.35	0.46
West Sector								
594	62	162	20	195	1	3.87	37.74	0.18
602	295	765	153	1,019	27	6.22	41.45	1.10
604	277	719	136	956	9	5.89	41.42	0.39
606	3,567	9,263	755	10,268	80	2.54	34.54	0.27
608	224	582	88	728	7	4.71	39.00	0.33
610	2,452	6,361	887	7,725	140	4.34	37.81	0.69
612	7,502	19,465	2,649	23,624	190	4.50	37.79	0.30
614	9,962	25,873	1,646	27,625	239	1.98	33.28	0.29
616	2,930	7,603	1,652	10,475	139	6.77	42.90	0.53
618	358	930	65	1,023	9	2.18	34.29	0.30
620	6,606	17,138	2,127	20,441	135	3.86	37.13	0.24
622	2,089	5,420	849	6,853	57	4.83	39.36	0.32
624	9,236	23,964	3,258	29,328	200	4.23	38.10	0.26
626	1,188	3,081	235	3,398	63	2.37	34.32	0.64
628	4,600	11,935	1,534	14,480	99	4.00	31.25	0.26
630	366	950	173	1,257	11	5.67	42.21	0.36
632	982	2,547	718	3,828	72	8.77	46.78	0.89
634	3,298	8,662	604	9,186	208	2.20	33.42	0.76
636	1,262	3,292	478	3,982	98	4.55	37.87	0.93
638	4,362	11,316	1,252	13,202	109	3.44	36.32	0.30
640	5,490	14,359	1,657	16,918	175	3.62	36.98	0.38
648	1,766	4,607	422	5,135	63	2.87	34.89	0.43
650	7,860	20,502	2,383	24,164	169	3.64	36.89	0.26
652	8,127	22,474	2,734	26,371	256	4.04	38.94	0.38
654	3,235	9,005	884	10,192	100	3.28	37.81	0.37
656	548	1,522	572	2,542	32	12.45	55.67	0.70
658	3,792	10,552	2,551	14,771	267	8.07	46.74	0.84
660	3,922	10,919	1,118	12,394	128	3.42	37.92	0.39

Table 9.15 (Cont.)

Watershed	Area (acres)	Rainfall (acre-feet)	Watershed Totals (acre-feet) GW-Use	ET	Runoff	Per-Acre (inches) GW-Use	ET	Runoff
662	2,561	7,130	940	8,484	219	4.40	39.75	1.03
664	3,194	8,835	1,122	10,430	123	4.22	39.19	0.46
666	448	1,246	266	1,689	45	7.13	45.24	1.20
668	2,771	7,714	656	8,424	111	2.84	36.48	0.48
670	4,449	12,385	1,936	15,180	303	5.22	40.94	0.82
SUM	109,781	291,278	36,520	346,287	3,884	3.99	37.85	0.42
Central Sector								
672	8,866	24,681	3,389	29,133	627	4.59	39.43	0.84
674	5,916	16,470	997	16,973	265	2.01	34.43	0.54
676	1,709	4,758	875	6,081	147	6.14	42.70	1.03
686	3,546	9,249	587	9,817	90	1.99	33.22	0.30
688	2,327	6,071	362	6,361	59	1.87	32.80	0.30
690	5,852	15,265	960	16,173	141	1.97	33.16	0.29
692	2,598	6,778	441	7,228	65	2.04	33.38	0.30
694	3,105	8,413	435	8,650	94	1.68	33.43	0.36
696	4,316	11,898	1,336	13,826	148	3.71	36.12	0.41
698	254	706	45	750	35	2.13	35.43	1.65
700	6,717	18,071	1,429	19,714	192	2.55	35.22	0.34
702	6,518	18,147	1,572	20,025	207	2.89	36.87	0.38
704	4,420	12,304	887	13,093	162	2.39	35.55	0.44
706	2,007	5,587	383	5,844	90	2.24	34.94	0.54
708	1,997	5,560	773	6,603	74	4.64	39.78	0.48
710	3,423	9,530	723	10,196	129	2.53	35.74	0.45
712	787	2,190	205	2,408	35	3.13	36.72	0.53
714	2,870	7,990	860	9,110	117	3.60	38.09	0.49
716	128	355	59	438	10	5.53	40.28	0.86
718	2,056	5,724	420	6,075	94	2.45	35.46	0.55
720	3,563	9,919	1,380	11,726	206	4.65	39.49	0.69
722	11,834	32,945	5,957	41,622	851	6.04	42.04	0.86
724	8,813	24,534	1,538	25,449	362	2.09	34.65	0.49
726	2,747	7,648	1,115	9,143	179	4.87	39.94	0.78
728	5,131	14,285	6,738	26,442	289	15.76	61.86	0.68
730	3,322	9,246	1,899	12,327	247	6.86	44.53	0.89
732	699	1,943	700	3,183	201	12.02	54.64	3.45
734	2	4	2	9	0	12.00	54.00	0.00
SUM	105,523	290,271	36,067	338,399	5,116	4.10	38.48	0.58
South Sector								
1124	9,166	25,397	5,794	35,328	457	7.59	46.25	0.60
1125	15,479	40,161	4,976	48,298	503	3.85	37.45	0.39
1126	23,007	59,692	4,634	66,168	405	2.42	34.51	0.21
1127	38,674	100,340	7,308	109,605	602	2.27	34.01	0.19
1128	6,165	15,996	1,036	17,258	237	2.05	33.59	0.40
1129	12,817	33,458	2,325	35,691	176	2.18	33.42	0.17
1130	6,277	17,304	2,739	21,437	122	5.24	40.98	0.23
1131	32,660	89,311	8,299	98,361	973	3.05	36.14	0.36
1132	22,357	61,283	9,975	77,177	365	5.40	41.42	0.19
1133	12,795	35,273	2,429	38,025	320	2.28	35.68	0.30
1134	12,322	33,981	6,357	44,699	391	4.57	43.53	0.38
1135	20,021	55,474	11,095	73,624	760	6.65	44.13	0.45
SUM	211,740	567,670	66,967	665,671	5,311	3.32	37.73	0.30
County Totals								
	551,137	1,487,221	172,228	1,726,255	19,094	3.75	37.54	0.42

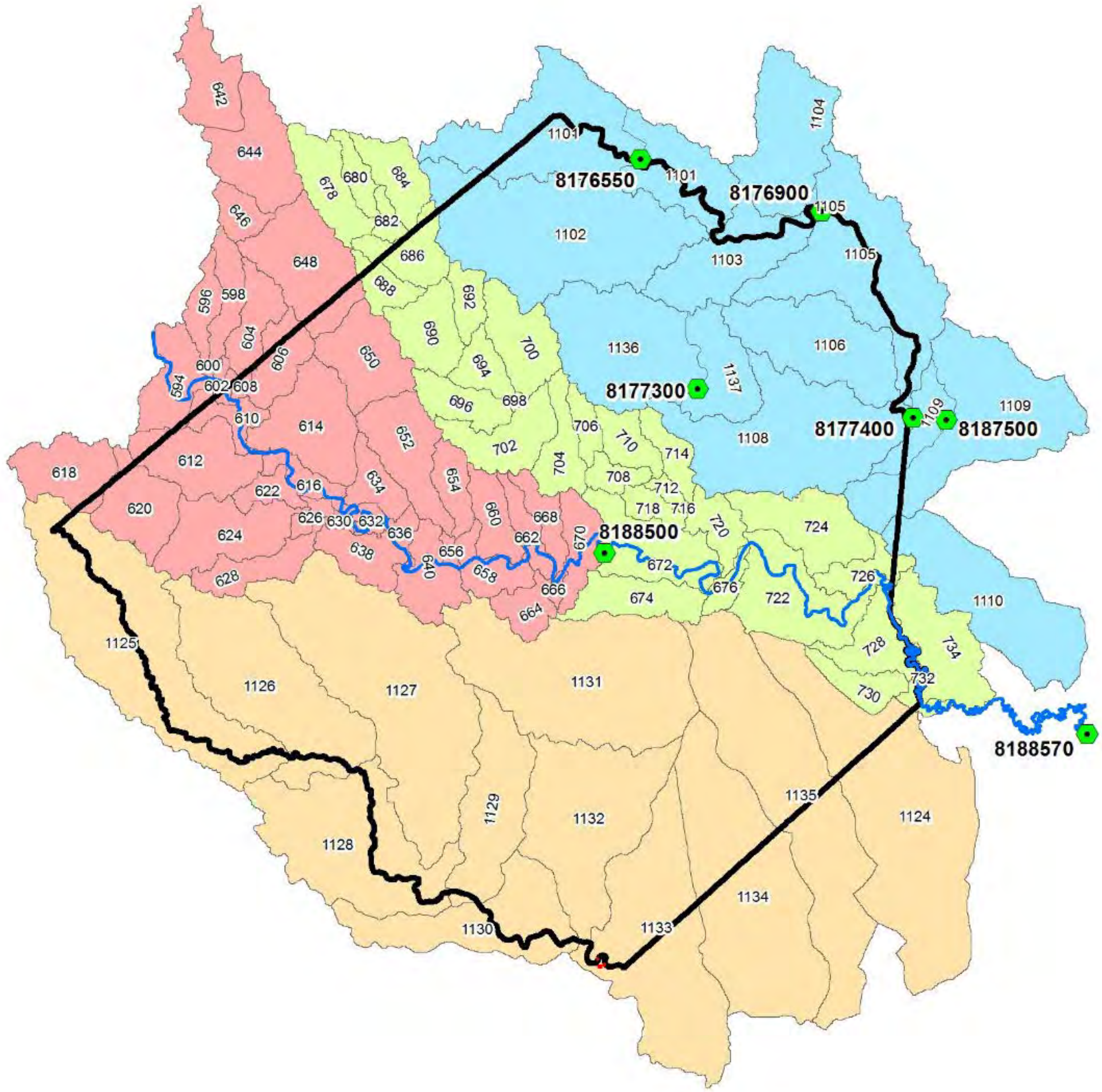

Figure 9.2 Locations of the 81 watersheds delineated in Goliad County, along with the locations of the gauge stations (circles with 7-digit numbers) for each sector of watersheds.

Per-acre annual ET averaged 37.54 inches county-wide (Table 9.15), but ranged between 31.25 inches per acre on Watershed 628 about mid-way between Charco and Berclair in the west-central part of the county and 55.67 inches per acre on Watershed 656 on the San Antonio River about 6 miles west of Goliad. The lower ET rates occurred in watersheds with shallower soils and therefore less dense vegetation. Higher ET rates occurred in watersheds along the river, where vegetation was dense and with high water tables, which resulted in high groundwater useage. Runoff averaged 0.42 inch county-wide (Table 9.15), and averaged less than one inch per year in all but six watersheds.

The simulations indicated that groundwater was utilized by vegetation in all watersheds in the county, however the amounts varied substantially (Table 9.15). Most watersheds (61 = 75%) had average annual groundwater use by vegetation of 2-6 inches (Fig. 9.3). Average annual groundwater use was less than 2 inches in six watersheds (8%), 6-10 inches per year in ten (12%), and more than 10 inches per year in four watersheds (5%). Groundwater use by vegetation was highest in watersheds along the river, especially on the eastern edge of the county, and least in the northwest part of the county.

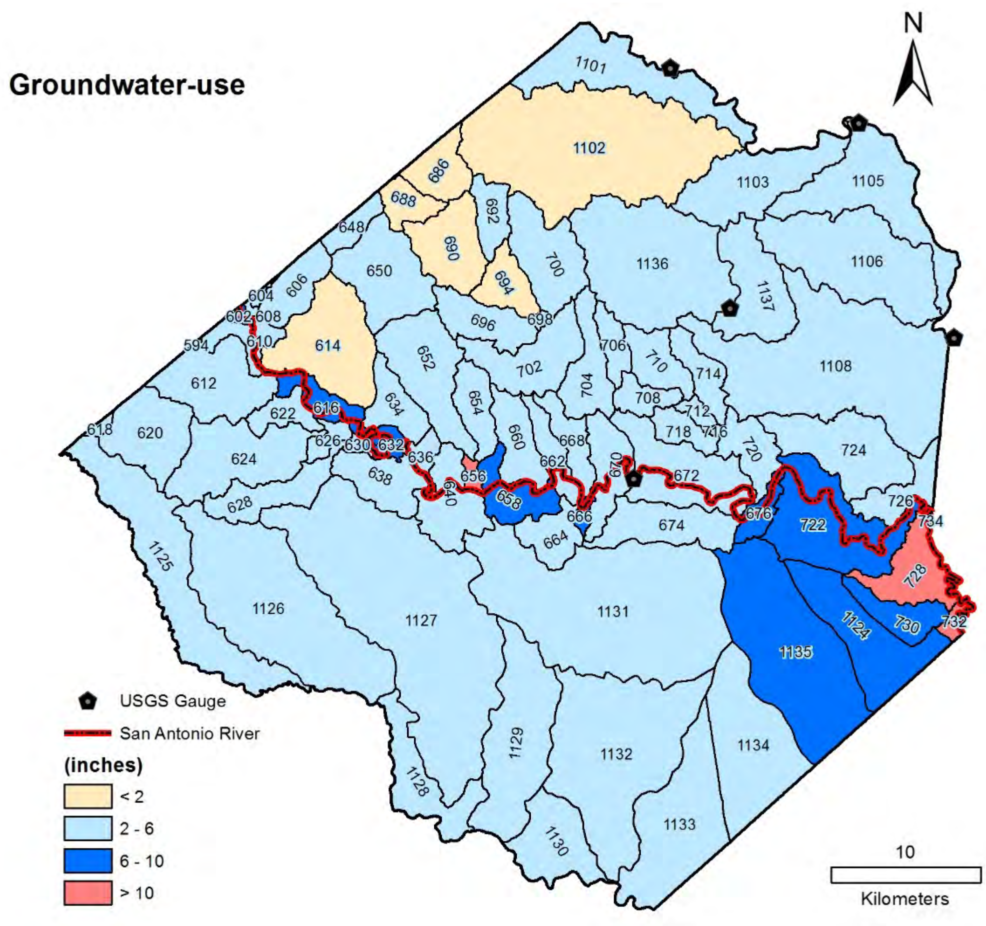

Figure 9.3 Average annual groundwater-use by vegetation (inches/acre) based on 25-year baseline simulations of the Goliad County EDYS model.

The ET values (Table 9.15) include groundwater used by vegetation (GW-Use) because the vegetation uses that water as part of plant transpiration. Net water yield from a specific watershed can be estimated by:

$$\text{Net yield} = \text{Rainfall} - \text{ET} + \text{Runoff} + \text{Recharge}.$$

However, the net yield value provided by this equation does not account for change in soil storage. Therefore, only a portion of this estimated net yield would likely leave the watershed in a particular year. Characteristics of the lower soil profile are not well known for most, if not all, the locations. Those edaphic characteristics have a substantial effect on how much water is stored in lower zones and how much is transferred as groundwater recharge or lateral flow into streams and the river, either in the particular watershed or subsurface lateral transfer to adjacent watersheds. Because of this lack of information on deep vadose zone characteristics, net yield cannot be assigned to a specific spatial location. Better understanding this linkage between soil moisture storage, groundwater usage, and transpiration by vegetation is a major need in ecohydrologic modeling (Maxwell and Condon 2016).

9.2.7 Maximum Effect of Brush Control on Water Balance

Vegetation is a major factor affecting the water balance and a vegetation component of primary importance influencing this is the amount of woody plants, particularly deep-rooted species. Vegetation dynamics strongly affect both ET and groundwater use. Vegetation dynamics are controlled by both natural and anthropogenic factors. Brush control and cultivation are two management factors that have substantial impacts on vegetation and therefore on water balance.

The maximum impact of change in woody vegetation, whether from natural (e.g., drought, succession) or anthropogenic causes, on water balance was simulated by applying the brush control option to all non-urban sites throughout the county. In this scenario, all woody species (except pecan and 50% of live oak) were removed in the first year of the simulation and allowed to regrow over the 25 years. This is not a practical scenario from the standpoint of actual landuse because it is unlikely that all areas would be treated, especially in the same year. However, it is a scenario that estimates the maximum potential effect of brush control on water balance and is useful to determine which areas have the highest potential for increased water yield from brush control. The moderate 25-year rainfall regime (baseline) was used and results would likely be somewhat different under other rainfall regimes.

Maximum potential increased yield was determined by comparing the water balance values from this maximum brush control scenario to those from the baseline scenario. Three water balance variables (GW-use, ET, runoff) were compared. Decreases in GW-use and ET were considered to be net increases in water yield although there would likely be a lag-time before decreased ET might result in increases in groundwater or subsurface flows into streams and the river.

Maximum potential enhanced water yield from brush control was simulated to be 287,188 acre-feet per year county-wide (Table 9.16). This was calculated from decreased ET (287,249 acre-feet) minus 61 acre-feet reduced runoff. Of the 287,188 acre-feet, 47% was from reduced groundwater-use by vegetation (135,906 acre-feet; Table 9.16). The remaining 53% was from reduced transpiration of soil moisture and reduced evaporation from rainfall intercepted by the plant canopy. Under this maximum brush control scenario, average annual total ET (including groundwater use) was simulated to be 1,439,006 acre-feet (Table 9.16), or 97% of average annual rainfall (1,487,221 acre-feet; Table 9.15). Averaged over three years, ET/rainfall ratios at a South Texas site were 99% for a mesquite shrubland and 94% for a shortgrass community (Weltz and Blackburn 1995). Similar values have been reported for mesquite-grasslands in the Rolling Plains of Texas (97%; Carlson et al. 1990), oak-grasslands in the Edwards Plateau (95%; Thurow et al. 1988), and bluestem prairie in Kansas (94%; Bremer et al. 2001). The simulated maximum brush control scenario resulted in a relatively sparse grassland in the early part of the 25-year simulation, followed by a mixed shrub-grassland as the shrubs re-established on some sites. Therefore, the 97% ratio from the maximum brush control scenario seems reasonable.

Table 9.16 Differences in average annual water balance components (acre-feet) between 25-year simulations of baseline and maximum brush control, by watershed, under moderate rainfall regime using the Goliad County EDYS model.

Watershed	Area	Baseline Scenario			Maximum Brush Control			Difference		
	(acres)	GW-Use	ET	Runoff	GW-Use	ET	Runoff	GW-Use	ET	Runoff
Northeast Sector										
1101	10,392	2,365	29,710	340	691	26,351	337	1,674	3,359	3
1102	28,956	4,690	79,890	632	1,118	72,608	628	3,572	7,282	4
1103	9,076	3,139	29,263	381	985	24,903	382	2,154	4,360	- 1
1105	11,398	3,517	36,043	535	1,387	31,543	536	2,130	4,500	- 1
1106	14,382	3,696	43,932	418	1,368	38,887	416	2,328	5,045	2
1108	24,500	8,584	78,853	1,488	3,196	66,941	1,498	5,388	11,912	- 10
1136	18,068	4,893	56,046	690	1,517	49,125	686	3,376	6,921	4
1137	7,321	1,790	22,161	299	625	19,729	296	1,165	2,432	3
SUM	124,093	32,674	375,898	4,783	10,887	330,087	4,779	21,787	45,811	4
West Sector										
594	62	20	195	1	3	160	1	17	35	0
602	295	153	1,019	27	36	782	27	117	237	0
604	277	136	956	9	23	724	9	113	232	0
606	3,567	755	10,268	80	138	8,993	79	617	1,275	1
608	224	88	728	7	5	554	7	83	174	0
610	2,452	887	7,725	140	201	6,319	142	686	1,406	- 2
612	7,502	2,649	23,624	190	487	19,187	192	2,162	4,437	- 2
614	9,962	1,646	27,625	239	304	24,868	238	1,342	2,757	1
616	2,930	1,652	10,475	139	565	8,260	141	1,087	2,215	- 2
618	358	65	1,023	9	8	905	9	57	118	0
620	6,606	2,127	20,441	135	178	16,471	136	1,949	3,970	- 1
622	2,089	849	6,853	57	168	5,435	58	681	1,418	- 1
624	9,236	3,258	29,328	200	314	23,255	200	2,944	6,073	0
626	1,188	235	3,398	63	78	3,061	63	157	337	0
628	4,600	1,534	14,480	99	65	11,429	99	1,469	3,051	0
630	366	173	1,257	11	57	1,015	11	116	242	0
632	982	718	3,828	72	206	2,789	75	512	1,039	- 3
634	3,298	604	9,186	208	189	8,351	208	415	835	0
636	1,262	478	3,982	98	97	3,213	99	381	769	- 1
638	4,362	1,252	13,202	109	149	10,921	110	1,103	2,281	- 1
640	5,490	1,657	16,918	175	321	14,181	176	1,336	2,737	- 1
648	1,766	422	5,135	63	53	4,378	63	369	757	0
650	7,860	2,383	24,164	169	160	19,509	170	2,223	4,655	- 1
652	8,127	2,734	26,371	256	412	21,548	256	2,322	4,823	0
654	3,235	884	10,192	100	121	8,593	100	763	1,599	0
656	548	572	2,542	32	158	1,704	33	414	838	- 1
658	3,792	2,551	14,771	267	378	10,278	272	2,173	4,495	- 5

Table 9.16 (Cont.)

Watershed	Area	Baseline Scenario			Maximum Brush Control			Difference		
	(acres)	GW-Use	ET	Runoff	GW-Use	ET	Runoff	GW-Use	ET	Runoff
660	3,922	1,118	12,394	128	190	10,438	129	928	1,956	- 1
662	2,561	940	8,484	219	203	6,950	222	737	1,534	- 3
664	3,194	1,122	10,430	123	186	8,439	124	936	1,991	- 1
666	448	266	1,689	45	67	1,273	46	199	416	- 1
668	2,771	656	8,424	111	44	7,170	110	612	1,254	1
670	4,449	1,936	15,180	303	439	12,000	306	1,497	3,180	- 3
SUM	109,781	36,520	346,287	3,884	6,003	283,151	3,911	30,517	63,136	- 27
Central Sector										
672	8,866	3,389	29,133	627	883	23,959	625	2,506	5,174	2
674	5,916	997	16,973	265	263	15,364	263	734	1,609	2
676	1,709	875	6,081	147	255	4,796	147	620	1,285	0
686	3,546	587	9,817	90	85	8,789	90	502	1,028	0
688	2,327	362	6,361	59	78	5,801	58	284	560	1
690	5,852	960	16,173	141	131	14,498	140	829	1,675	1
692	2,598	441	7,228	65	73	6,474	65	368	754	0
694	3,105	435	8,650	94	111	8,028	93	324	622	1
696	4,316	1,336	13,826	148	100	11,215	148	1,236	2,611	0
698	254	45	750	35	15	689	35	30	61	0
700	6,717	1,429	19,714	192	288	17,353	191	1,141	2,361	1
702	6,518	1,572	20,025	207	220	17,208	207	1,352	2,817	0
704	4,420	887	13,093	162	194	11,677	161	693	1,416	1
706	2,007	383	5,844	90	118	5,311	90	265	533	0
708	1,997	773	6,603	74	178	5,381	73	595	1,222	1
710	3,423	723	10,196	129	242	9,212	129	481	984	0
712	787	205	2,408	35	63	2,111	35	142	297	0
714	2,870	860	9,110	117	206	7,743	117	654	1,367	0
716	128	59	438	10	7	332	10	52	106	0
718	2,056	420	6,075	94	137	5,492	93	283	583	1
720	3,563	1,380	11,726	206	284	9,465	204	1,096	2,261	2
722	11,834	5,957	41,622	851	1,556	32,559	854	4,401	9,063	- 3
724	8,813	1,538	25,449	362	560	23,310	361	978	2,139	1
726	2,747	1,115	9,143	179	201	7,267	179	914	1,876	0
728	5,131	6,738	26,442	289	1,802	16,270	299	4,936	10,172	- 10
730	3,322	1,899	12,327	247	93	8,425	255	1,806	3,902	- 8
732	699	700	3,183	201	221	2,214	205	479	969	- 4
734	2	2	9	0	1	6	0	1	3	0
SUM	105,523	36,067	338,399	5,116	8,365	280,949	5,127	27,702	57,450	- 11
South Sector										
1124	9,166	5,794	35,328	457	280	23,465	476	5,514	11,863	- 19
1125	15,479	4,976	48,298	503	519	39,156	503	4,457	9,142	0
1126	23,007	4,634	66,168	405	691	58,061	401	3,943	8,107	4
1127	38,674	7,308	109,605	602	1,712	97,579	597	5,596	12,026	5
1128	6,165	1,036	17,258	237	212	15,394	238	824	1,864	- 1
1129	12,817	2,325	35,691	176	452	31,205	176	1,873	4,486	0
1130	6,277	2,739	21,437	122	1,448	18,476	120	1,291	2,961	2
1131	32,660	8,299	98,361	973	1,168	82,481	976	7,131	15,880	- 3
1132	22,357	9,975	77,177	365	2,587	61,523	360	7,388	15,654	5
1133	12,795	2,429	38,025	320	812	34,566	312	1,617	3,459	8
1134	12,322	6,357	44,699	391	668	32,607	392	5,689	12,092	- 1
1135	20,021	11,095	73,624	760	518	50,306	787	10,577	23,318	- 27
SUM	211,740	66,967	665,671	5,311	11,067	544,819	5,338	55,900	120,852	- 27
County Totals										
	551,137	172,228	1,726,255	19,094	36,322	1,439,006	19,155	135,906	287,249	- 61

The maximum brush control scenario resulted in a simulated vegetation consisting of mostly grassland throughout Goliad County, with scattered large live oak trees and low to medium density pecan-oak woodlands along drainages. Under these conditions and with a moderate rainfall regime, there would be a positive net water yield county-wide. A 97% ET/rainfall ratio indicates that the net annual yield would be 3% of annual rainfall, on average, or about 45,000 acre-feet per year (0.3 inch per acre). Once the soil profile was recharged to field capacity, this amount of water would recharge into groundwater or move laterally into creeks and the river. Eventually, the water table would increase (by about 3 inches per year, assuming 50% average pore space) until it reached an approximate elevation equal to the elevation of the waterways, at which point the annual surplus would move into the creeks and rivers as lateral flow.

This 0.3-inch average annual recharge under the maximum brush control scenario compares to a simulated 5.2-inch annual deficit under conditions of current vegetation. Both of these values are based on the county receiving moderate rainfall regime for 25 years. Above average rainfall would produce more recharge under the maximum brush control scenario and less of a deficit under current conditions. Similarly, a dry regime would produce less recharge and a higher deficit. Regardless of which rainfall regime would occur, there would be major fluctuations in recharge or deficit from year to year.

Enhancement of water yield from the maximum brush control scenario would not be uniform across the county. It would be higher in areas with heavier stands of woody species and lower in areas with lighter stands. Enhancement also varies in response to difference in soils (e.g., texture and depth) and species of woody species present in the vegetation (e.g., mesquite and live oak are deep-rooted species, whereas hackberry and blackbrush have shallower root systems; Appendix Table D.9).

Simulated maximum potential water yield enhancement was calculated for each watershed (Table 9.17) as the difference in ET between baseline and maximum brush control scenarios minus difference in runoff between the two scenarios (Table 9.16). It is unlikely that brush control treatments (with or without conversion to improved pasture or cultivated land) would, in practice, be applied to an entire watershed. Instead, applications are likely to be applied to only parts of a particular watershed. Although the enhanced water yield that would occur from a brush control operation will vary even within a watershed because of differences in vegetation, soils, and topography within the watershed, expressing potential water yield enhancement on a per acre basis provides a useful metric to compare potential benefits among watersheds.

Table 9.17 Maximum potential annual water yield enhancement and decrease in groundwater use by vegetation (GW-Use) resulting from the maximum brush control scenario using the Goliad County EDYS model. ET values are average annual decreases and runoff values are average annual increases (net yield = decreased ET + increased runoff).

Watershed	Area (acres)	Watershed Total (acre-feet) ET	Runoff	Net Yield	Per Acre Basis (inches/acre)	Decrease in GW-Use[1] (acre-feet)	(inches/acre)
Northeast Sector							
1101	10,392	3,359	3	3,362	3.88	1,674	1.93
1102	28,956	7,282	4	7,286	3.02	3,572	1.14
1103	9,076	4,360	- 1	4,359	5.76	2,154	2.85
1105	11,398	4,500	- 1	4,499	4.74	2,130	2.24
1106	14,382	5,045	2	5,047	4.21	2,328	1.94
1108	24,500	11,912	- 10	11,902	5.83	5,388	2.55
1136	18,068	6,921	4	6,925	4.60	3,376	2.24
1137	7,321	2,432	3	2,435	3.99	1,165	1.91
SUM	124,093	45,811	4	45,815	4.43	21,787	2.11
West Sector							
594	62	35	0	35	6.77	17	3.29
602	295	237	0	237	9.64	117	4.76
604	277	232	0	232	10.05	113	4.90
606	3,567	1,275	1	1,276	4.29	617	2.08
608	224	174	0	174	9.32	83	4.45
610	2,452	1,406	- 2	1,404	6.87	686	3.36
612	7,502	4,437	- 2	4,435	7.09	2,162	3.46
614	9,962	2,757	1	2,758	3.32	1,342	1.62
616	2,930	2,215	- 2	2,213	9.06	1,087	4.45
618	358	118	0	118	3.96	57	1.91
620	6,606	3,970	- 1	3,969	7.06	1,949	3.54
622	2,089	1,418	- 1	1,417	8.14	681	3.91
624	9,236	6,073	0	6,073	7.89	2,944	3.83
626	1,188	337	0	337	3.40	157	1.59
628	4,600	3,051	0	3,051	7.96	1,469	3.83
630	366	242	0	242	7.93	116	3.80
632	982	1,039	- 3	1,036	12.66	512	6.26
634	3,298	835	0	835	3.04	415	1.51
636	1,262	769	- 1	768	7.30	381	3.62
638	4,362	2,281	- 1	2,280	6.27	1,103	3.03
640	5,490	2,737	- 1	2,736	5.98	1,336	2.92
648	1,766	757	0	757	5.14	369	2.51
650	7,860	4,655	- 1	4,654	7.11	2,223	3.39
652	8,127	4,823	0	4,823	7.12	2,322	3.43
654	3,235	1,599	0	1,599	5.93	763	2.83
656	548	838	- 1	837	18.33	414	9.07
658	3,792	4,495	- 5	4,490	14.21	2,173	6.88
660	3,922	1,956	- 1	1,955	5.98	928	2.84
662	2,561	1,534	- 3	1,531	7.17	737	3.45
664	3,194	1,991	- 1	1,990	7.48	936	3.52
666	448	416	- 1	415	11.12	199	5.31
668	2,771	1,254	1	1,255	5.44	612	2.65
670	4,449	3,180	- 3	3,177	8.57	1,497	4.04
SUM	109,781	63,136	- 27	63,109	6.90	30,517	3.34
Central Sector							
672	8,866	5,174	2	5,176	7.01	2,506	3.39
674	5,916	1,609	2	1,611	3.27	734	1.49
676	1,709	1,285	0	1,285	9.02	620	4.35
686	3,546	1,028	0	1,028	3.48	502	1.70
688	2,327	560	1	561	2.89	284	1.46
690	5,852	1,675	1	1,676	3.44	829	1.70
692	2,598	754	0	754	3.10	368	1.70

Table 9.17 (Cont.)

Watershed	Area (acres)	Watershed Total (acre-feet) ET	Runoff	Net Yield	Per Acre Basis (inches/acre)	Decrease in GW-Use[1] (acre-feet)	(inches/acre)
694	3,105	622	1	623	2.41	324	1.25
696	4,316	2,611	0	2,611	7.26	1,611	4.48
698	254	61	0	61	2.88	30	1.42
700	6,717	2,361	1	2,362	4.22	1,141	2.04
702	6,518	2,817	0	2,817	5.19	1,352	2.50
704	4,420	1,416	1	1,417	3.85	693	1.88
706	2,007	533	0	533	3.19	265	1.58
708	1,997	1,222	1	1,223	7.35	595	3.58
710	3,423	984	0	984	3.45	481	1.69
712	787	297	0	297	4.53	142	2.17
714	2,870	1,367	0	1,367	5.72	654	3.08
716	128	106	0	106	9.93	52	4.88
718	2,056	583	1	584	3.40	283	1.65
720	3,563	2,261	2	2,263	7.62	1,096	3.69
722	11,834	9,063	- 3	9,060	9.19	4,401	4.46
724	8,813	2,139	1	2,140	2.91	978	1.33
726	2,747	1,876	0	1,876	8.20	914	3.99
728	5,131	10,172	- 10	10,162	23.74	4,936	11.54
730	3,322	3,902	- 8	3,894	14.07	1,806	6.52
732	699	969	- 4	965	16.58	479	8.22
734	2	3	0	3	16.50	1	5.50
SUM	105,523	57,450	- 11	57,439	6.53	27,702	3.15
South Sector							
1124	9,166	11,863	- 19	11,844	15.51	5,514	7.22
1125	15,479	9,142	0	9,142	7.09	4,457	3.46
1126	23,007	8,107	4	8,111	4.23	3,943	2.06
1127	38,674	12,026	5	12,031	3.73	5,596	1.74
1128	6,165	1,864	- 1	1,863	3.63	824	1.60
1129	12,817	4,486	0	4,486	4.20	1,873	1.75
1130	6,277	2,961	2	2,963	5.66	1,291	2.47
1131	32,660	15,880	- 3	15,877	5.83	7,131	2.62
1132	22,357	15,654	5	15,659	8.40	7,388	3.97
1133	12,795	3,459	8	3,467	3.25	1,617	1.52
1134	12,322	12,092	- 1	12,091	11.78	5,689	5.54
1135	20,021	23,318	- 27	23,291	13.96	10,577	6.34
SUM	211,740	120,852	- 27	120,825	6.85	55,900	3.17
County Totals							
	551,137	287,249	- 61	287,188	6.62	135,906	2.96

[1] Groundwater use amounts are included in the ET amounts (i.e., groundwater-use is part of the plant transpiration).

Maximum potential enhancement of water yield from brush control was 6.62 inches per acre annually when averaged over the entire county, with a low of 2.41 inches in Watershed 694 in the north-central part of the county and high of 23.74 inches in Watershed 728 along the river in the eastern part of the county (Table 9.17). Potential yields tended to be higher in watersheds located along the river and lower in watersheds located in more upland areas (Fig. 9.4).

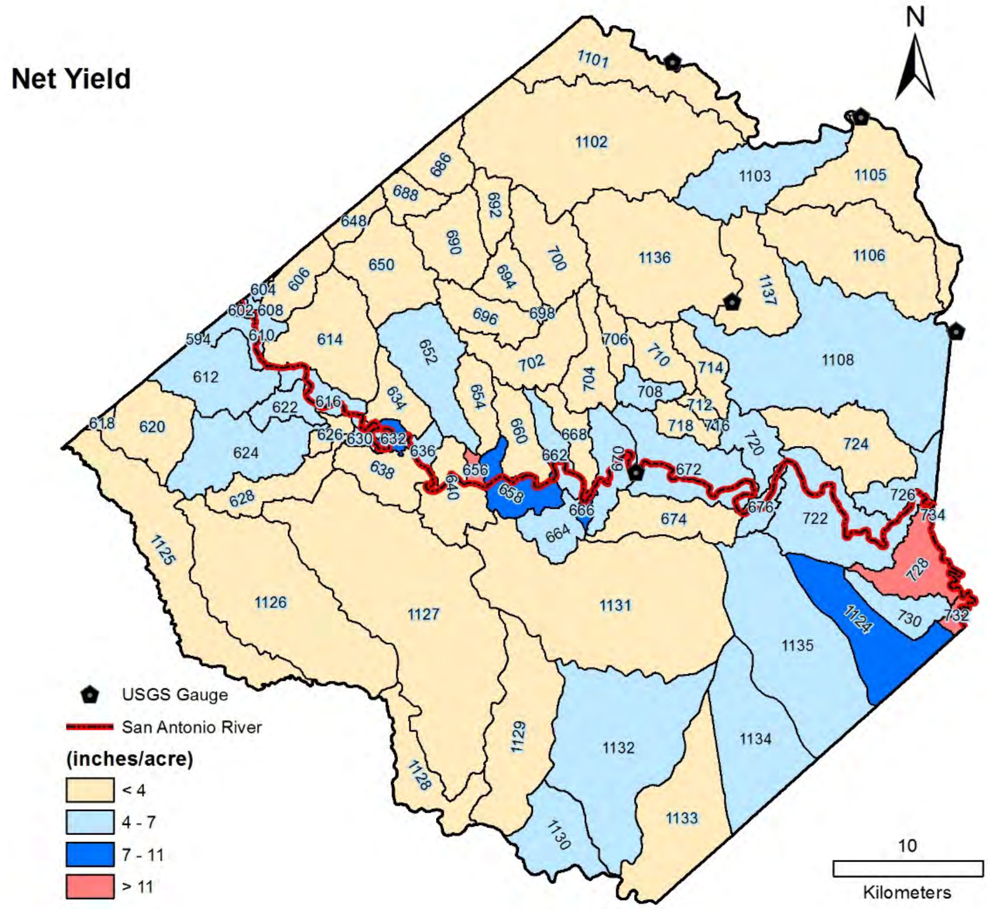

Figure 9.4 Maximum potential increased annual water yield (inches/acre) from brush control based on 25-year simulations of the Goliad EDYS model using the moderate rainfall regime.

Potential increase in water yield from brush control is the result of two primary factors: 1) decreased ET because of less, and different types of, vegetation and 2) lower groundwater use because of a reduction in amount of deep-rooted woody species. Overall, about 45% of the potential increase in water yield in the simulations occurred from lower groundwater use (Table 9.17). Although the proportion of potential increased water yield contributed by reduction in use of groundwater remained fairly constant among the watersheds, the amount of groundwater reduction varied substantially among watersheds (Fig. 9.5).

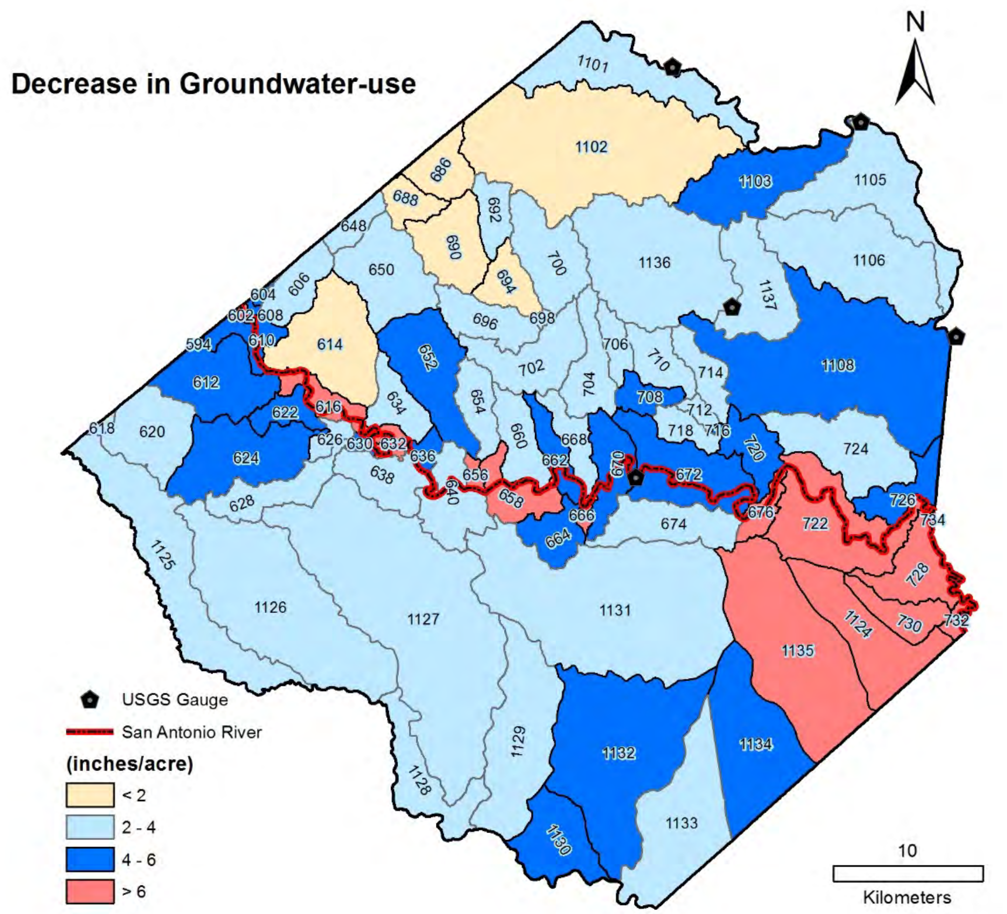

Figure 9.5 Decrease in annual groundwater use by vegetation (inches/acre) from maximum brush control based on 25-year simulations of the Goliad EDYS model using the moderate rainfall regime.

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APPENDIX A PRECIPITATION DATA

Appendix Table A.1 Annual precipitation (PPT; inches) data for Goliad, Texas, 1912-2015.

Year	PPT	Year	PPT	Year	PPT	Year	PPT	Year	PPT	Year	PPT
				1920	24.30	1930	25.94	1940	38.30	1950	18.69
				1921	31.23	1931	40.06	1941	38.05	1951	37.52
				1922	26.34	1932	35.17	1942	41.08	1952	37.22
		1913	34.21	1923	45.35	1933	31.67	1943	33.49	1953	28.50
		1914	42.19	1924	22.38	1934	41.93	1944	32.05	1954	16.14
		1915	21.47	1925	28.78	1935	38.32	1945	29.43	1955	25.27
		1916	19.99	1926	32.86	1936	36.55	1946	45.98	1956	19.49
		1917	9.73	1927	22.47	1937	26.78	1947	30.91	1957	51.52
		1918	32.34	1928	29.59	1938	27.30	1948	26.74	1958	43.05
		1919	47.25	1929	44.62	1939	21.66	1949	35.44	1959	32.35
		SUM	207.18	SUM	307.92	SUM	325.38	SUM	351.47	SUM	309.75
		MEAN	**29.60**	**MEAN**	**30.79**	**MEAN**	**32.54**	**MEAN**	**35.15**	**MEAN**	**30.98**
1960	48.23	1970	30.17	1980	35.59	1990	32.81	2000	37.11	2010	41.38
1961	29.01	1971	39.61	1981	59.48	1991	47.41	2001	45.91	2011	17.24
1962	31.68	1972	52.87	1982	26.22	1992	40.94	2002	42.40	2012	28.99
1963	23.59	1973	51.12	1983	36.56	1993	37.95	2003	34.47	2013	27.76
1964	25.16	1974	38.25	1984	28.39	1994	43.26	2004	47.94	2014	25.63
1965	44.00	1975	39.36	1985	38.08	1995	33.58	2005	28.92	2015	49.63
1966	37.63	1976	55.35	1986	-----	1996	23.93	2006	32.75		
1967	44.08	1977	38.56	1987	-----	1997	53.82	2007	51.84		
1968	42.10	1978	29.48	1988	-----	1998	51.52	2008	22.55		
1969	35.44	1979	40.77	1989	22.66	1999	22.96	2009	35.98		
SUM	360.92	SUM	415.54	SUM	246.98	SUM	388.18	SUM	379.87	SUM	190.63
MEAN	**36.09**	**MEAN**	**41.55**	**MEAN**	**35.28**	**MEAN**	**38.82**	**MEAN**	**37.99**	**MEAN**	**31.77**

Overall mean (1913-2015, excluding incomplete years) = 34.84

APPENDIX B SOILS

Appendix Table B.1 Soil units occurring in Goliad County (Wiedenfeld 2010) and corresponding composite units used in the Goliad County EDYS model.

Symbol	NRCS Soil Unit	EDYS Soil Unit
AnA	Ander fine sandy loam, 0-1% slopes	Ander fine sandy loam
AnB	Ander fine sandy loam, 1-3% slopes	Ander fine sandy loam
BnB	Blanconia lomay fine sand, 0-2% slopes	Ander fine sandy loam
BsA	Buchel clay, 0-1% slopes, occasionally flooded	Buchel clay
BuA	Buchel clay, 0-1% slopes, frequently flooded	Buchel clay
CnA	Cieno loam, 0-1% slopes	Cieno loam
CrA	Clareville sandy clay loam, 0-1% slopes, rarely flooded	Weesatche sandy clay loam
CrB	Clareville sandy clay loam, 1-3% slopes, rarely flooded	Weesatche sandy clay loam
CsC	Colibro sandy clay loam, 3-5% slopes	Pernitas sandy clay loam
CsD	Colibro loam, 5-12% slopes	Pernitas sandy clay loam
CyB	Coy clay loam, 1-3% slopes	Coy clay loam
CyC	Coy clay loam, 3-5% slopes	Coy clay loam
DaA	Dacosta sandy clay loam, 0-1% slopes	Laewest clay
DcA	Dacosta-Contee complex, 0-1% slopes	Laewest clay
DeC	Devine very gravelly fine sandy loam, 1-5% slopes	Pettus loam
EbA	Edna fine sandy loam, 0-1% slopes	Wyick fine sandy loam
EdA	Edroy clay, 0-1% slopes	Edroy clay
EnB	Elmendorf-Denhawken complex, 1-3% slopes	Monteola clay
FdA	Faddin fine sandy loam, 0-1% slopes	Telferner fine sandy loam
GdB	Goliad fine sandy loam, 1-3% slopes	Weesatche fine sandy loam
GoB	Goliad sandy clay loam, 1-3% slopes	Weesatche sandy clay loam
GrA	Greta fine sandy loam, 0-1% slopes	Greta fine sandy loam
ImA	Imogene fine sandy loam, 0-1% slopes	Ander fine sandy loam
InA	Inari fine sandy loam, 0-1% slopes	Telferner fine sandy loam
InB	Inari fine sandy loam, 1-3% slopes	Telferner fine sandy loam
KyB	Kuy fine sand, 1-3% slopes	Kuy fine sand
LaA	Laewest clay, 0-1% slopes	Laewest clay
LaB	Laewest clay, 1-3% slopes	Laewest clay
LaD	Laewest clay, 3-8% slopes	Laewest clay
LmB	Leming loamy fine sand, 0-3% slopes	Raisin loamy fine sand
MbB	Milby fine sand, 0-2% slopes	Nusil fine sand
MeA	Meguin silty clay loam, 0-1% slopes, occasionally flooded	Sinton sandy clay loam
MgA	Meguin silty clay loam, 0-1% slopes, frequently flooded	Sinton sandy clay loam
MoA	Monteola clay, 0-1% slopes	Monteola clay
MoB	Monteola clay, 1-3% slopes	Coy clay loam
MoC	Monteola clay, 3-5% slopes	Coy clay loam
NuC	Nusil fine sand, 1-5% slopes	Nusil fine sand
OdA	Odem-Riverwash complex, 0-1% slopes, frequently flooded	Sinton sandy clay loam
OmD	Olmedo very gravelly loam, 1-8% slopes	Olmedo very gravelly loam
OrA	Orelia fine sandy loam, 0-1% slopes	Telferner fine sandy loam
PaB	Papalote loamy sand, 0-3% slopes	Raisin loamy fine sand
PbA	Papalote fine sandy loam, 0-1% slopes	Ander fine sandy loam
PbB	Papalote fine sandy loam, 1-3% slopes	Ander fine sandy loam
PrB	Parrita sandy clay loam, 0-3% slopes	Parrita sandy clay loam
PtC	Pernitas sandy clay loam, 2-5% slopes	Pernitas sandy clay loam
PuC	Pettus loam, 2-5% slopes	Pettus loam
RaB	Raisin loamy fine sand, 0-3% slopes	Raisin loamy fine sand
RaC	Raisin loamy fine sand, 3-5% slopes	Raisin loamy fine sand
RaC2	Raisin loamy fine sand, 2-5% slopes, moderately eroded	Raisin loamy fine sand
RnB	Raisin fine sandy loam, 1-3% slopes	Weesatche fine sandy loam
RoA	Realitos clay, 0-1% slopes	Realitos clay
RsC	Rhymes fine sand, 1-5% slopes	Nusil fine sand
RuB	Runge fine sandy loam, 1-3% slopes	Weesatche fine sandy loam
RyA	Rydolph silty clay, 0-1% slopes, frequently flooded	Sinton sandy clay loam
ScB	Sarco coarse sand, 0-2% slopes	Sarco coarse sand
SnC	Sarnosa fine sandy loam, 1-5% slopes	Pernitas sandy clay loam
SnD	Sarnosa fine sandy loam, 5-8% slopes	Pernitas sandy clay loam
StC	Schattel sandy clay loam, 1-5% slopes	Schattel sandy clay loam
SwA	Sinton sandy clay loam, 0-1% slopes, occasionally flooded	Sinton sandy clay loam
TeA	Telferner fine sandy loam, 0-1% slopes	Telferner fine sandy loam
TeB	Telferner fine sandy loam, 1-3% slopes	Telferner fine sandy loam
ToA	Tiocano clay, 0-1% slopes	Realitos clay
UsB	Ustarents, loamy, 0-3% slopes	Olmedo very gravelly loam

Appendix Table B.1 (Cont.)

Symbol	NRCS Soil Unit	EDYS Soil Unit
VdA	Vidauri fine sandy loam, 0-1% slopes	Wyick fine sandy loam
VwA	Vidauri-Wyick complex, 0-1% slopes	Wyick fine sandy loam
WcC	Weesatche fine sandy loam, 2-5% slopes	Weesatche fine sandy loam
WeA	Weesatche sandy clay loam, 0-1% slopes	Weesatche sandy clay loam
WeB	Weesatche sandy clay loam, 1-3% slopes	Weesatche sandy clay loam
WeB2	Weesatche sandy clay loam, 1-3% slopes, moderately eroded	Weesatche sandy clay loam
WeC	Weesatche sandy clay loam, 3-5% slopes	Weesatche sandy clay loam
WoA	Woodsboro loam, 0-1% slopes, rarely flooded	Greta fine sandy loam
WyA	Wyick fine sandy loam, 0-1% slopes	Wyick fine sandy loam
ZaA	Zalco sand, 0-1% slopes, occasionally flooded	Zalco sand
ZcA	Zalco sand, 0-1% slopes, frequently flooded	Zalco sand
ZkA	Zunker fine sandy loam, 0-1% slopes, occasionally flooded	Sinton sandy clay loam
ZnA	Zunker fine sandy loam, 0-1% slopes, frequently flooded	Sinton sandy clay loam

APPENDIX C VEGETATION

Appendix Table C.1 NRCS range sites, associated soils, and corresponding EDYS plant communities (mid-seral) used in the Goliad County EDYS model.

Range Site	Soils	EDYS Plant Community
Blackland, RG Plains	EnB MoA	huisache-mesquite-purple threeawn
Blackland, Coastal	DaA DcA LaA LaB LaD	huisache-mesquite-buffalograss
Clayey bottomland	BsA BuA	mesquite-hackberry-ragweed
Clay loam	CrA CrB GoB WeA WeB WeB2 WeC	mesquite-huisache-silver bluestem
Claypan prairie	EbA VdA VwA WyA	huisache-little bluestem-knotroot bristle
Claypan savannah	ScB	post oak-mesquite-little bluestem
Deep sand	KyB	live oak-little bluestem-ragweed
Gravelly ridge	DeC PuC	blackbrush-purple threeawn-buffalograss
Gray sandy loam	CsC CsD PtC SnC SnD	mesquite-huisache-hooded windmillgrass
Lakebed, RG Plains	RoA ToA	huisache-longtom-knotroot bristlegrass
Lakebed, Coastal	EdA	huisache-longtom-flatsedge
Loamy bottomland	MeA MgA OdA RyA SwA ZkA ZnA	live oak-little bluestem-trichloris
Loamy prairie	FdA InA InB OrA TeA TeB	huisache-mesquite-little bluestem
Loamy sand	LmB PaB RaB RaC RaC2	live oak-mesquite-little bluestem
Lowland, Coastal	CnA	huisache-seacoast bluestem-longtom
Rolling blackland	CyB CyC MoB MoC	mesquite-silver bluestem-buffalograss
Salty prairie	GrA WoA	huisache-gulf cordgrass-sea oxeye
Sandy	MbB NuC RsC	mesquite-live oak-little bluestem
Sandy bottomland	ZaA ZcA	live oak-little bluestem-Virginia wildrye
Sandy loam	GdB RnB RuB WcC	mesquite-live oak-silver bluestem
Shallow ridge	OmD	blackbrush-ragweed-Texas wintergrass
Shallow sandy loam	PrB	mesquite-silver bluestem-little bluestem
Sloping clay loam	StC	mesquite-huisache-little bluestem
Tight sandy loam	AnA AnB BnB ImA PbA PbB	mesquite-silver bluestem-trichloris

Determination of species composition and initial biomass (Appendix Table C.2)

In Appendix Table C.2, species composition under light grazing (late-seral conditions) was taken from data in Appendix Tables C.3-C.6. Species composition under moderate (mid-seral) grazing was based on data from Appendix Tables C.7-C.18.

Total grass aboveground biomass under mid-seral conditions was estimated at 70% of late-seral levels (Appendix Table C.22) and total forb aboveground biomass was estimated at 38% of grass levels (Box 1961, Powell and Box 1967, Box and White 1969, Smeins and Diamond 1983, McLendon and Finch unpublished data, McLendon 2015a, 2015b; Appendix Tables C.7-C.11).

For woody species, the values are relative composition (%) of woody plant cover. Herbaceous standing crop biomass is decreased as woody plant cover increases, using the relationship:

amount = (amount at 0% woody cover)[(1.00 – 0.008(% woody cover)]

based on data from Appendix Table C.23.

Appendix Table C.2 Adjustment of plant species composition to account for level of livestock grazing in plant communities in Goliad County. Amounts are clippable biomass (g/m^2) for herbaceous species and relative cover for woody species. Mid-seral herbaceous biomass = 70% of late-seral (Appendix Table C.21).

Range Type	Woody Species	Relative Cover (%)	Grasses	Biomass Late	Biomass Mid	Forbs	Biomass Late	Biomass Mid
Blackland, RG Plains								
	huisache	40	purple threeawn	--	45	ragweed	3	55
	hackberry	1	silver bluestem	28	30	wild indigo	7	15
	mesquite	25	sideoats grama	28	2	old-mans beard	--	5
	live oak	1	hairy grama	--	3	bundleflower	3	2
	whitebrush	6	buffalograss	--	80	sunflower	--	15
	blackbrush	6	hooded windmill	--	25	coneflower	3	3
	granjeno	10	trichloris	73	4	ruellia	3	4
	agarito	2	Arizona cottontop	22	1			
	prickly pear	9	Texas cupgrass	20	2			
			vine-mesquite	20	3			
			little bluestem	73	4			
			plains bristle	22	36			
			indiangrass	45	1			
			Johnsongrass	--	5			
			tall dropseed	22	5			
			Texas wintergrass	20	15			
			Total grasses	373	261	Total forbs	19	99
Blackland, Coastal								
	huisache	41	big bluestem	93	3	ragweed	13	50
	hackberry	1	purple threeawn	--	52	wild indigo	13	44
	mesquite	26	silver bluestem	--	36	old-mans beard	--	50
	live oak	1	sideoats grama	75	4	bundleflower	13	6
	whitebrush	5	hairy grama	--	10	sunflower	--	40
	blackbrush	6	buffalograss	--	151	ruellia	--	8
	granjeno	9	hooded windmill	--	42			
	agarito	1	trichloris	--	5			
	prickly pear	10	vine-mesquite	73	7			
			switchgrass	93	10			
			brownseed paspalum	93	30			
			little bluestem	76	30			
			knotroot bristle	--	16			
			plains bristle	74	47			
			indiangrass	93	7			
			Johnsongrass	--	26			
			tall dropseed	75	18			
			Texas wintergrass	--	28			
			Total grasses	745	522	Total forbs	39	198
Clayey Bottomland								
	huisache	5	bushy bluestem	--	30	ragweed	--	15
	pecan	5	silver bluestem	--	20	giant ragweed	--	40
	hackberry	15	sideoats grama	--	4	spiny aster	--	5
	mesquite	30	buffalograss	22	44	wild indigo	20	8
	live oak	10	hooded windmill	--	10	old-mans beard	--	15
	whitebrush	5	trichloris	34	17	bundleflower	9	5
	baccharis	5	Virginia wildrye	67	20	frogfruit	--	6
	granjeno	10	vine-mesquite	22	10	snoutbean	10	4
	prickly pear	5	switchgrass	39	2	ruellia	--	3
	mustang grape	10	brownseed paspalum	62	30	bush sunflower	--	8
			little bluestem	45	15			
			knotroot bristle	22	30			
			plains bristle	62	25			
			indiangrass	34	1			
			Johnsongrass	--	28			
			Total grasses	409	286	Total forbs	39	109

Appendix Table C.2 (Cont.)

Range Type	Woody Species	Relative Cover (%)	Grasses	Biomass Late	Biomass Mid	Forbs	Biomass Late	Biomass Mid
Clay Loam								
	huisache	15	purple threeawn	--	26	ragweed	--	24
	mesquite	30	silver bluestem	90	45	broomweed	--	20
	blackbrush	10	sideoats grama	22	5	wild indigo	5	4
	whitebrush	10	hairy grama	--	3	old-mans beard	--	10
	baccharis	5	buffalograss	22	45	bundleflower	4	3
	granjeno	15	hooded windmill	--	72	sunflower	--	10
	wolfberry	3	trichloris	67	7	frogfruit	--	8
	agarito	2	Arizona cottontop	28	4	coneflower	--	4
	prickly pear	10	vine-mesquite	--	2	snoutbean	4	4
			brownseed paspalum	11	5	ruellia	--	4
			little bluestem	67	7	bush sunflower	5	10
			knotroot bristle	--	3	orange zexmenia	5	8
			plains bristle	90	43			
			indiangrass	11	1			
			Johnsongrass	--	10			
			tall dropseed	--	5			
			Texas wintergrass	--	3			
			Total grasses	408	286	Total forbs	23	109
Claypan Prairie								
	huisache	30	big bluestem	56	3	ragweed	7	80
	live oak	10	bushy bluestem	--	26	wild indigo	8	30
	baccharis	10	bermudagrass	--	36	Texas doveweed	7	18
	McCartn rose	45	switchgrass	95	4	bundleflower	7	6
	rattlepod	5	longtom	56	55	frogfruit	--	10
			brownseed paspalum	56	35			
			little bluestem	95	85			
			knotroot bristle	56	50			
			indiangrass	78	15			
			smutgrass	--	30			
			littletooth sedge	50	20			
			flatsedge	--	20			
			Total grasses	542	379	Total forbs	29	144
Claypan Savanna								
	mesquite	30	purple threeawn	--	30	ragweed	--	40
	post oak	50	silver bluestem	46	50	broomweed	--	28
	granjeno	15	sideoats grama	46	23	Texas doveweed	--	12
	prickly pear	5	hairy grama	--	20	sunflower	--	20
			red grama	--	5	snoutbean	--	6
			hooded windmill	22	44	bush sunflower	--	10
			trichloris	46	23			
			Arizona cottontop	46	12			
			little bluestem	106	71			
			plains bristle	24	18			
			indiangrass	101	10			
			Total grasses	437	306	Total forbs	--	116
Deep Sand								
	mesquite	5	purple threeawn	--	36	ragweed	--	55
	post oak	25	silver bluestem	--	2	partridge pea	--	2
	live oak	50	hairy grama	--	2	Texas doveweed	4	10
	mustang grape	20	sandbur	--	18	bundleflower	3	3
			hooded windmill	--	5	sunflower	--	10
			brownseed paspalum	62	29	coneflower	3	2
			thin paspalum	57	60	snoutbean	3	1
			little bluestem	83	56	bush sunflower	4	9
			plains bristle	67	22			
			indiangrass	78	8			
			tall dropseed	--	5			
			Total grasses	347	243	Total forbs	17	92

Appendix Table C.2 (Cont.)

Range Type	Woody Species	Relative Cover (%)	Grasses	Biomass Late	Biomass Mid	Forbs	Biomass Late	Biomass Mid
Gravelly Ridge								
	mesquite	15	purple threeawn	39	46	ragweed	8	30
	guajillo	25	silver bluestem	52	26	broomweed	3	17
	blackbrush	40	sideoats	52	4	lazydaisy	4	6
	granjeno	10	red grama	6	8	dogweed	5	15
	agarito	5	buffalograss	34	42			
	prickly pear	5	hooded windmill	22	28			
			Arizona cottontop	27	2			
			green sprangletop	16	2			
			Texas bristlegrass	6	10			
			Texas wintergrass	--	10			
			Total grasses	254	178	Total forbs	20	68
Gray Sandy Loam								
	huisache	25	purple threeawn	--	24	ragweed	--	30
	mesquite	35	sideoats grama	38	10	broomweed	--	15
	whitebrush	5	hairy grama	11	15	partridge pea	4	4
	blackbrush	10	buffalograss	38	50	Texas doveweed	--	17
	granjeno	15	sandbur	--	10	bundleflower	3	3
	prickly pear	10	hooded windmill	36	50	sunflower	--	15
			trichloris	91	30	coneflower	3	4
			Arizona cottontop	28	4	snoutbean	4	5
			green sprangletop	17	2	bush sunflower	6	12
			thin paspalum	--	10			
			plains bristle	91	35			
			Texas bristlegrass	--	5			
			sand dropseed	22	15			
			Total grasses	372	260	Total forbs	20	105
Lakebed, RG Plains								
	huisache	60	bushy bluestem	34	40	ragweed	4	44
	mesquite	30	buffalograss	8	16	spiny aster	--	5
	rattlepod	10	bermudagrass	--	12	wild indigo	3	5
			vine-mesquite	34	15	bundleflower	1	1
			switchgrass	101	10	sunflower	--	20
			longtom	49	75	frogfruit	2	8
			brownseed paspalum	90	70	ruellia	1	2
			knotroot bristle	34	53	curly dock	2	15
			Johnsongrass	--	30	bulltongue	2	5
			littletooth sedge	11	15			
			flatsedge	22	30			
			cattail	11	10			
			Total grasses	394	276	total forbs	15	105
Lakebed, Coastal								
	huisache	80	bushy bluestem	--	40	ragweed	3	52
	mesquite	10	buffalograss	--	5	broomweed	2	10
	rattlepod	10	bermudagrass	--	15	spiny aster	--	10
			switchgrass	90	2	wild indigo	2	5
			longtom	92	80	bundleflower	2	3
			brownseed paspalum	90	40	sunflower	--	10
			knotroot bristle	67	50	frogfruit	2	5
			Johnsongrass	--	40	ruellia	2	5
			flatsedge	67	60	curly dock	2	10
			spikerush	22	15	bulltongue	2	5
			cattail	3	3			
			Total grasses	431	350	Total forbs	17	115

Appendix Table C.2 (Cont.)

Range Type	Woody Species	Relative Cover (%)	Grasses	Biomass Late	Biomass Mid	Forbs	Biomass Late	Biomass Mid
Loamy Bottomland								
	huisache	15	big bluestem	78	10	ragweed	6	36
	pecan	5	bushy bluestem	--	15	giant ragweed	--	30
	hackberry	15	silver bluestem	11	18	spiny aster	--	10
	mesquite	10	sideoats grama	45	25	partridge pea	6	6
	live oak	20	buffalograss	24	30	old-mans beard	6	30
	whitebrush	5	trichloris	78	45	bundleflower	5	4
	baccharis	5	bermudagrass	--	10	sunflower	--	15
	granjeno	5	Virginia wildrye	34	15	frogfruit	--	6
	mustang grape	20	Texas cupgrass	6	3	snoutbean	6	6
			vine-mesquite	22	15	ruellia	5	6
			switchgrass	78	25	greenbriar	10	15
			brownseed paspalum	22	25			
			little bluestem	90	55			
			knotroot bristle	11	15			
			plains bristle	45	25			
			Johnsongrass	--	30			
			Texas wintergrass	22	20			
			littletooth sedge	22	20			
			flatsedge	28	30			
			Total grasses	616	431	Total forbs	44	164
Loamy Prairie								
	huisache	30	big bluestem	34	4	ragweed	--	80
	mesquite	30	bushy bluestem	--	16	wild indigo	10	20
	live oak	10	purple threeawn	--	15	bundleflower	10	12
	McCartn rose	30	bermudagrass	--	4	sunflower	--	20
			Virginia wildrye	21	8	bush sunflower	11	24
			switchgrass	28	4			
			longtom	22	28			
			brownseed paspalum	22	22			
			thin paspalum	23	28			
			little bluestem	370	220			
			knotroot bristle	20	24			
			indiangrass	28	5			
			smutgrass	--	20			
			littletooth sedge	17	12			
			Total grasses	585	410	Total forbs	31	156
Loamy Sand								
	mesquite	35	purple threeawn	--	20	ragweed	2	51
	live oak	40	silver bluestem	17	24	partridge pea	5	6
	granjeno	10	sideoats grama	78	30	Texas doveweed	--	24
	prickly pear	5	hairy grama	--	8	bundleflower	3	4
	mustang grape	10	sandbur	--	12	coneflower	2	3
			hooded windmill	17	20	snoutbean	3	6
			Arizona cottontop	17	4	bush sunflower	6	18
			switchgrass	90	8			
			brownseed paspalum	78	58			
			thin paspalum	17	25			
			little bluestem	90	78			
			plains bristle	17	8			
			Total grasses	421	295	Total forbs	21	112

Appendix Table C.2 (Cont.)

Range Type	Woody Species	Relative Cover (%)	Grasses	Biomass Late	Biomass Mid	Forbs	Biomass Late	Biomass Mid
Lowland Coastal								
	huisache	80	big bluestem	126	8	ragweed	--	40
	baccharis	15	bushy bluestem	28	40	wild indigo	13	68
	rattlepod	5	bermudagrass	--	60	bundleflower	7	10
			switchgrass	127	8	frogfruit	--	18
			longtom	28	62	bush sunflower	13	34
			brownseed paspalum	26	42			
			little bluestem	127	102			
			knotroot bristle	26	34			
			indiangrass	126	27			
			smutgrass	--	36			
			littletooth sedge	25	20			
			flatsedge	--	8			
			Total grasses	639	447	Total forbs	33	170
Rolling Blackland								
	huisache	20	purple threeawn	--	24	ragweed	4	33
	mesquite	45	silver bluestem	40	42	broomweed	--	20
	whitebrush	10	sideoats grama	51	6	wild indigo	8	12
	granjeno	20	hairy grama	--	8	bundleflower	3	4
	agarito	5	buffalograss	29	52	sunflower	--	12
			hooded windmill	--	10	frogfruit	--	8
			trichloris	46	37	coneflower	3	4
			Arizona cottontop	43	4	ruellia	3	6
			Texas cupgrass	35	2			
			vine-mesquite	46	20			
			plains bristle	46	15			
			Texas wintergrass	35	40			
			Total grasses	371	260	Total forbs	21	99
Salty Prairie								
	huisache	90	bermudagrass	--	10	spiny aster	--	6
	mesquite	10	saltgrass	11	18	sea oxeye	39	53
			switchgrass	8	1	frogfruit	--	10
			longtom	11	12	glasswort	--	4
			common reed	6	4			
			little bluestem	7	4			
			knotroot bristle	12	20			
			indiangrass	7	2			
			gulf cordgrass	683	520			
			Total grasses	745	591	Total forbs	39	73
Sandy								
	mesquite	30	purple threeawn	--	25	ragweed	6	48
	live oak	30	sandbur	--	15	wild indigo	6	12
	baccharis	5	hooded windmill	17	25	partridge pea	6	12
	granjeno	10	switchgrass	53	4	Texas doveweed	--	29
	prickly pear	5	brownseed paspalum	53	25	snoutbean	6	12
	mustang grape	20	thin paspalum	18	27			
			little bluestem	210	160			
			indiangrass	53	4			
			tall dropseed	20	12			
			Total grasses	424	297	Total forbs	24	113

Appendix Table C.2 (Cont.)

Range Type	Woody Species	Relative Cover (%)	Grasses	Biomass Late	Biomass Mid	Forbs	Biomass Late	Biomass Mid
Sandy Bottomland								
	huisache	5	big bluestem	90	4	ragweed	--	48
	hackberry	15	hairy grama	--	6	giant ragweed	--	30
	mesquite	5	sandbur	--	12	partridge pea	22	20
	live oak	55	bermudagrass	--	20	sunflower	--	30
	mustang grape	20	trichloris	--	10	snoutbean	11	12
			Virginia wildrye	78	53			
			guineagrass	--	40			
			switchgrass	95	8			
			thin paspalum	--	20			
			little bluestem	96	80			
			knotroot bristle	78	72			
			plains bristle	--	8			
			indiangrass	90	6			
			Johnsongrass	--	25			
			tall dropseed	--	5			
			Total grasses	527	369	Total forbs	33	140
Sandy Loam								
	mesquite	35	purple threeawn	--	22	ragweed	7	37
	live oak	30	silver bluestem	67	90	broomweed	--	62
	whitebrush	10	red grama	--	4	partridge pea	6	4
	blackbrush	5	sandbur	--	12	Texas doveweed	--	2
	granjeno	15	hooded windmill	54	60	bundleflower	1	2
	prickly pear	5	trichloris	119	40	coneflower	2	3
			Arizona cottontop	66	4	snoutbean	4	6
			brownseed paspalum	--	18	bush sunflower	7	12
			little bluestem	120	70			
			plains bristle	62	22			
			Total grasses	488	342	Total forbs	27	128
Shallow Ridge								
	mesquite	15	purple threeawn	--	14	ragweed	5	23
	guajillo	30	sideoats grama	42	12	broomweed	4	22
	blackbrush	50	hairy grama	--	12	dogweed	2	6
	prickly pear	5	red grama	--	6			
			hooded windmill	--	14			
			trichloris	13	6			
			Arizona cottontop	38	4			
			green sprangletop	34	4			
			little bluestem	40	18			
			Texas bristlegrass	12	16			
			sand dropseed	12	10			
			Texas wintergrass	--	18			
			Total grasses	191	134	Total forbs	11	51
Shallow Sandy Loam								
	huisache	40	purple threeawn	--	15	ragweed	10	24
	mesquite	50	silver bluestem	68	43	broomweed	3	20
	prickly pear	10	hairy grama	--	4	bundleflower	2	3
			buffalograss	--	12	sunflower	3	8
			hooded windmill	29	32	coneflower	2	3
			trichloris	--	15	snoutbean	4	6
			Arizona cottontop	50	5	bush sunflower	12	16
			little bluestem	67	32			
			plains bristle	56	20			
			sand dropseed	30	20			
			Texas wintergrass	--	12			
			Total grasses	300	210	Total forbs	36	80

Appendix Table C.2 (Cont.)

Range Type	Woody Species	Relative Cover (%)	Grasses	Biomass Late	Biomass Mid	Forbs	Biomass Late	Biomass Mid
Sloping Clay Loam								
	huisache	20	purple threeawn	--	23	ragweed	5	24
	mesquite	40	silver bluestem	--	18	broomweed	--	17
	blackbrush	20	sideoats grama	54	12	bundleflower	2	3
	granjeno	15	hairy grama	--	10	sunflower	--	8
	prickly pear	5	red grama	--	4	coneflower	2	3
			buffalograss	28	40	snoutbean	2	4
			hooded windmill	--	12	ruellia	2	4
			trichloris	54	18	bush sunflower	2	8
			Arizona cottontop	50	5			
			plains bristle	52	14			
			Texas wintergrass	27	30			
			Total grasses	265	186	Total forbs	15	71
Tight Sandy Loam								
	mesquite	45	purple threeawn	--	31	ragweed	6	30
	live oak	20	silver bluestem	82	90	broomweed	--	24
	blackbrush	15	sideoats grama	82	16	partridge pea	6	6
	granjeno	15	hairy grama	--	10	Texas doveweed	--	15
	prickly pear	5	red grama	--	5	bundleflower	1	2
			sandbur	--	15	coneflower	1	2
			hooded windmill	36	40	snoutbean	3	6
			trichloris	82	60	bush sunflower	6	23
			Arizona cottontop	80	4			
			plains bristle	45	14			
			Total grasses	407	285	Total forbs	23	108

Appendix Table C.3 Species composition (% cover for woody species, g/m^2 annual aboveground production for herbaceous species, average rainfall) on **clay and clay loam** NRCS range sites under late-seral (excellent range condition) conditions in Goliad County (x = species occurs in early- or mid-seral).

Species	Blackland RG Plains	Blackland Coastal	Clayey Bottomland	Clay Loam	Loamy Bottomland	Rolling Blackland
Huisache	x	x	x	x	---	---
Pecan	---	---	5	---	5	---
Hackberry	2	1	10	---	5	---
Mesquite	x	1	x	2	x	x
Post oak	---	---	---	---	---	---
Live oak	3	2	10	---	10	---
Whitebrush	---	---	---	---	---	x
Baccharis	---	---	x	x	---	---
Granjeno	x	x	---	1	---	x
Wolfberry	---	---	---	1	---	---
Agarito	x	x	---	---	---	x
Greenbriar	---	---	---	---	5	x
Mustang grape	---	---	---	---	10	---
Big bluestem	---	93	---	---	78	---
Bushy bluestem	---	---	x	---	x	---
Purple threeawn	x	x	---	x	---	x
Silver bluestem	28	---	---	90	11	40
Sideoats grama	28	75	---	22	45	51
Hairy grama	x	x	---	x	---	x
Red grama	---	x	---	---	---	x
Buffalograss	x	x	22	22	24	29
Hooded windmillgrass	x	---	---	---	---	x
Trichloris	73	---	34	67	78	46
Arizona cottontop	22	---	---	28	---	43
Virginia wildrye	---	---	67	---	34	---
Texas cupgrass	20	---	---	---	6	35
Vine-mesquite	20	73	22	---	22	46
Switchgrass	---	93	39	---	78	---
Brownseed paspalum	---	93	62	11	22	---
Little bluestem	73	76	45	67	90	---
Knotroot bristlegrass	---	---	22	---	11	---
Plains bristlegrass	22	74	62	90	45	46
Indiangrass	45	93	34	11	---	---
Tall dropseed	22	75	---	x	---	---
Texas wintergrass	20	---	---	x	22	35
Littletooth sedge	---	---	---	---	22	---
Flatsedge	---	---	---	---	28	---
Ragweed	3	13	x	x	6	4
Annual broomweed	---	---	---	x	---	---
Spiny aster	---	---	x	---	x	---
Wild indigo	7	13	20	5	---	8
Partridge pea	---	---	---	---	6	---
Old-mans beard	---	---	---	---	6	---
Bundleflower	3	13	9	4	5	3
Sumpweed	---	---	x	---	---	---
Prairie coneflower	3	---	---	x	---	3
Snoutbean	---	---	10	4	6	---
Ruellia	3	---	---	---	5	3
Bush sunflower	---	---	---	5	---	---
Orange zexmenia	---	---	---	5	---	---
Total herbaceous	392	784	448	431	650	392

Appendix Table C.4 Species composition (% cover for woody species, g/m^2 annual aboveground production for herbaceous species, average rainfall) on **sandy and sandy loam** NRCS range sites under late-seral (excellent range condition) conditions in Goliad County (x = species occurs in early- or mid-seral).

Species	Gray Sandy Loam	Loamy Sand	Sandy	Sandy Loam	Tight Sandy Loam	Claypan Savannah	Claypan Prairie	Deep Sand	Loamy Prairie	Sandy Bottomland
Huisache	x	---	---	---	---	---	x	---	x	x
Sugar hackberry	---	---	---	---	---	---	---	---	---	5
Mesquite	5	2	2	x	3	x	---	---	---	x
Post oak	---	---	---	---	---	60	---	5	---	---
Live oak	---	2	2	---	---	---	x	10	x	15
Whitebrush	1	---	---	x	---	---	---	---	---	---
Blackbrush	1	---	---	5	---	---	---	---	---	---
Baccharis	---	---	x	---	---	---	x	---	---	---
Granjeno	3	x	---	x	2	x	---	---	---	---
McCartney rose	---	---	---	---	---	---	x	---	x	---
Rattlepod	---	---	---	---	---	---	x	---	---	---
Mustang grape	---	---	---	---	---	---	---	10	---	---
Prickly pear	1	x	x	---	---	x	---	---	---	---
Big bluestem	---	---	---	---	---	---	56	---	34	90
Bushy bluestem	---	---	---	---	---	---	x	---	x	---
Purple threeawn	x	x	---	x	---	---	---	x	---	---
Silver bluestem	---	17	---	67	82	46	---	---	---	---
Sideoats grama	38	78	---	---	82	46	---	---	---	---
Hairy grama	11	x	---	---	x	x	---	---	---	x
Red grama	---	---	---	x	x	x	---	---	---	---
Buffalograss	38	---	---	---	---	---	---	---	---	---
Sandbur	x	x	x	x	x	---	---	---	---	x
Hooded windmill	36	17	17	54	36	22	---	x	---	---
Trichloris	91	---	---	119	82	46	---	---	---	---
Bermudagrass	---	---	---	---	---	---	x	---	x	---
Arizona cottontop	28	17	---	66	80	46	---	---	---	---
Virginia wildrye	---	---	---	---	---	---	---	---	21	78
Green sprangletop	17	---	---	---	---	---	---	---	---	---
Switchgrass	---	90	53	---	---	---	95	---	28	95
Longtom	---	---	---	---	---	---	56	---	22	---
Brownseed paspalum	---	78	53	x	---	---	56	62	22	---
Thin paspalum	---	17	18	---	---	---	---	57	23	x
Little bluestem	---	90	210	120	---	106	95	83	370	96
Knotroot bristle	---	---	---	---	---	---	56	---	20	78
Plains bristlegrass	91	17	---	62	45	24	---	67	---	---
Indiangrass	---	---	53	---	---	101	78	78	28	90
Tall dropseed	---	---	20	---	---	---	---	---	---	---
Smutgrass	---	---	---	---	---	---	x	---	x	---
Sand dropseed	22	---	---	---	---	---	---	---	---	---
Littletooth sedge	---	---	---	---	---	---	50	---	17	---
Ragweed	x	2	6	7	6	---	7	---	---	---
Annual broomweed	x	---	---	x	x	x	---	---	---	---
Wild indigo	---	---	6	---	---	---	8	---	10	---
Partridge pea	4	5	6	6	6	---	---	---	---	22
Texas doveweed	x	x	x	x	x	x	7	4	---	---
Bundleflower	3	3	---	1	1	---	7	3	10	---
Prairie coneflower	3	2	---	2	1	---	---	3	---	---
Snoutbean	4	3	6	4	3	---	---	3	---	11
Bush sunflower	6	6	---	7	6	---	---	4	11	---
Total herbaceous	392	442	448	515	430	437	571	364	616	560

Appendix Table C.5 Species composition (% cover for woody species, g/m^2 annual aboveground production for herbaceous species, average rainfall) on **shallow** NRCS range sites under late-seral (excellent range condition) conditions in Goliad County (x = species occurs in early- or mid-seral).

Species	Gravelly Ridge	Shallow Ridge	Shallow Sandy Loam	Sloping Clay Loam
Mesquite	x	---	---	x
Guajillo	10	5	---	---
Blackbrush	15	5	---	5
Granjeno	x	---	---	---
Agarito	x	---	---	---
Prickly pear	x	---	---	x
Purple threeawn	39	x	---	x
Silver bluestem	52	---	68	---
Sideoats grama	52	42	---	54
Hairy grama	---	x	---	x
Red grama	6	x	---	x
Buffalograss	34	---	---	28
Hooded windmill	22	x	29	---
Trichloris	---	13	---	54
Arizona cottontop	27	38	50	50
Green sprangletop	16	34	---	---
Little bluestem	---	40	67	---
Plains bristlegrass	---	---	56	52
Texas bristlegrass	6	12	---	---
Sand dropseed	---	12	30	---
Texas wintergrass	---	---	---	27
Forbs	20	11	36	15
Total herbaceous	274	202	336	280

Appendix Table C.6 Species composition (% cover for woody species, g/m^2 annual aboveground production for herbaceous species) on **wetland** NRCS range sites under late-seral (excellent range condition) conditions in Goliad County (x = species occurs in early- or mid-seral).

Species	Lakebed RG Plains	Lakebed Coastal	Lowland Coastal	Salty Prairie
Huisache	x	x	x	x
Mesquite	x	---	---	---
Baccharis	---	---	x	---
Sea oxeye	---	---	---	39
Rattlepod	x	---	x	---
Big bluestem	---	---	126	---
Bushy bluestem	34	---	28	---
Buffalograss	8	---	---	---
Bermudagrass	x	---	---	x
Saltgrass	---	---	---	11
Vine-mesquite	34	---	---	---
Switchgrass	101	90	127	8
Longtom	49	92	28	11
Brownseed paspalum	90	90	26	
Common reed	---	---	---	6
Little bluestem	---	---	127	7
Knotroot bristlegrass	34	67	26	12
Indiangrass	---	---	126	7
Gulf cordgrass	---	---	---	683
Smutgrass	---	---	x	---
Littletooth sedge	11	---	25	---
Flatsedge	22	67	---	---
Spikerush	---	22	---	---
Cattail	11	3	---	---
Ragweed	4	3	---	---
Annual broomweed	---	2	---	---
Spiny aster	x	---	---	---
Wild indigo	3	2	13	---
Bundleflower	1	2	7	---
Frogfruit	2	2	---	---
Ruellia	1	2	---	---
Curly dock	2	2	---	---
Bulltongue	2	2	---	---
Glasswort	---	---	---	x
Bush sunflower	---	---	13	---
Total herbaceous	409	448	672	784

Appendix Table C.7 Comparison of vegetation data from literature sources for clay and clay loam sites in South Texas.

Species	Box & White (1969) Relative	Box & White (1969) Absolute	Box (1961) Victoria	Box (1961) Orelia	Powell & Box 1967 Victoria	Buckley & Dodd 1969 clay	Dodd & Holtz (1972)	Johnston (1963)
	Welder Wildlife Refuge					**Webb**	**Goliad**	**Kleberg**
Acacia farnesiana	10.0	4.7	5.5	1.3	x			
Acacia rigidula	9.0	4.2	18.4	0.5	x			
Acacia tortuosa	t	t	2.9	1.3				
Berberis trifoliolata	4.1	1.9	6.4	t	x			
Celtis pallida	5.0	2.4	1.2	---	x			
Condalia obovata	2.0	0.9	0.9	---	x			
Diospyros texana	1.0	0.5	---	---				
Lycium berlandieri	1.0	0.5	---	---				
Opuntia leptocaulis	4.7	2.2	---	---				
Opuntia linheimeri	8.4	3.7	t	52.3		x		
Parkinsonia aculeata						x		
Prosopis glandulosa	43.2	20.3	53.0	38.2	x	x		
Prosopis reptans	4.6	2.2	---	---				
Varilla texana						x		
Zanthoxylum fagara	3.8	1.8	3.9	1.3	x			
Zizyphus obtusifolia	2.5	1.2	7.8	5.1				
Total woody (abs cover)		46.5	19.6	39.4	48.6			
Aristida roemeriana	3.3	5.4	14.3	7.6	2.3			2%
Aristida spp.							6.4	
Bothriochloa saccharoides	8.7	14.1	0.6	0.5	4.5			
Bouteloua curtipendula							1.7	
Bouteloua rigidiseta					0.3		8.3	
Bouteloua trifida						2.3		
Buchloe dactyloides	24.4	39.8	27.6	11.3	28.6			30%
Cenchrus ciliaris						4.0		
Cenchrus incertus	---	---	0.1	7.3		1.9		2%
Chloris cucullata							1.2	
Chloris verticillata	1.4	2.2	2.5	25.0	1.6			15%
Cynodon dactylon					0.6			
Digitaria californica	---	---	0.3	0.1				
Eragrostis lugens					3.9			
Eriochloa contracta	---	---	0.4	t	3.9	0.3		
Hilaria belangeri	t	t	16.9	20.9	1.0	27.8		20%
Leptochloa dubia						6.6		
Leptochloa nealleyi					2.2			
Leptoloma cognatum	---	---	0.1	0.1			0.6	
Panicum filipes	3.0	4.8	10.6	2.3	6.9			5%
Panicum hallii						78.2		
Panicum obtusum	1.4	2.2	2.0	t	2.2			
Paspalum pubiflorum	3.9	6.4	0.4	0.6	6.0			
Schedonnardus paniculatus	0.3	0.4	---	---				2%
Schizachyrium scoparium							1.2	
Setaria geniculata	0.9	1.5	0.4	0.5	5.3			
Setaria leucopila	0.8	1.3	17.8	15.0	20.2		1.2	
Sporobolus asper	2.5	4.0	---	---	1.4			
Sporobolus cryptandrus							0.6	
Sporobolus pyramidatus	0.4	0.7	0.2	4.5	1.7	14.4		
Stipa leucotricha	5.3	8.6	0.9	0.9	5.8		1.7	
Tridens albescens	2.1	3.5	0.7	t	1.4			
Tridens congestus	1.5	2.5	---	---				
Tridens eragrostoides	---	---	t	0.5				
Tridens texensis							2.3	
Other grasses (4)	0.2	0.3	0.2	0.2			6.4	
Carex spp.							9.9	
Total grasses (g/m^2)	60.1	97.7			99.8	135.5	41.5	
Total grasses (% cover)			96.0	97.3				
Ambrosia psilostachya	4.9	8.6	---	---	20.4			
Cienfuegosa sulphurea	0.3	0.4	---	---				

Appendix Table C.7 (Cont.)

Species	Box & White (1969) Relative	Box & White (1969) Absolute	Box (1961) Victoria	Box (1961) Orelia	Powell & Box 1967 Victoria	Buckley & Dodd 1969 clay	Dodd & Holtz (1972)	Johnston (1963)
Commelina erecta	1.6	2.7	0.1	t				
Croton monanthogynus	2.8	4.5	0.9	t				
Desmanthus virgatus	2.1	3.5	---	---				5%
Euphorbia albomarginata								2%
Evolvulus sericeus								2%
Lythrum californicum	0.1	0.2	---	---				
Malvastrum aurantiacum	0.2	0.3	---	---				
Phyla incisa	0.5	0.9	t	t				
Portulaca pilosa	0.5	0.9	---	---				
Ratibida columnaris	0.1	0.2	0.6	t				
Ruellia sp.	7.6	12.3	0.8	t				
Solanum eleagnifolium	1.6	2.6	---	---				
Verbesina microptera	2.1	3.5	---	---				
Xanthocephalum texanum	15.0	24.5	0.1	0.5	20.4			
Other forbs (11)	0.5	0.8	1.0	t				
Total forbs	39.9	65.9	3.5	0.5	40.8		104.2	
Total herbaceous (g/m^2)	100.0	163.6			140.6		145.7	
Total herbaceous (% cover)			99.5	97.8				

Box and White (1969) was a chaparral community on Victoria clay. Box (1961) is % relative basal cover. Victoria communities are an average of mesquite and chaparral communities and Orelia community is a prickly pear site.

Appendix Table C.8 Basal cover (%) and composition (% relative basal cover) on late-successional Fayette Prairie clay and clay loam sites (Smeins and Diamond 1983).

Species	Basal Cover		Composition	
	Upland	Lowland	Upland	Lowland
Andropogon gerardii	3	t	2.0	t
Bouteloua curtipendula	6	0	3.7	0.0
Coelorachis cylindrica	3	0	2.0	0.0
Dichanthelium sphaerocarpon	2	0	1.0	0.0
Eragrostis intermedia	1	0	0.3	0.0
Eriochloa sericea	2	0	1.0	0.0
Muhlenbergia capillaris	3	0	1.7	0.0
Panicum virgatum	0	18	0.0	22.0
Paspalum floridanum	4	5	2.7	6.1
Paspalum plicatulum	7	0	4.3	0.0
Paspalum setaceum	3	0	1.7	0.0
Schizachyrium scoparium	59	t	39.0	t
Sorghastrum nutans	11	10	7.3	12.2
Sporobolus asper	4	2	2.7	2.4
Stipa leucotricha	3	0	2.0	0.0
Tripsacum dactyloides	12	41	7.7	50.0
Carex microdonta	4	t	2.7	t
Eleocharis montevidensis	2	3	1.0	3.7
Fimbristylis puberula	2	0	1.3	0.0
Scleria ciliata	2	0	1.3	0.0
Argythamnia humilis	2	0	1.0	0.0
Biforia americana	1	0	0.7	0.0
Cacalia plantaginea	3	0	1.7	0.0
Desmanthus illinoensis	0	2	0.0	2.4
Dyschoriste linearis	2	0	1.3	0.0
Echinacea angustifolia	1	0	0.7	0.0
Krigia occidentalis	2	0	1.3	0.0
Marshallia caespitosa	4	0	2.7	0.0
Physotegia intermedia	3	1	1.7	1.2
Rudbeckia hirta	2	0	1.3	0.0
Ruellia nudiflora	2	0	1.3	0.0
Grasses			79.1	92.7
Grass-likes			6.3	3.7
Forbs			13.7	3.6

Appendix Table C.9 Comparison of vegetation data from literature sources for sandy and sandy loam sites in South Texas. Values are percent composition unless otherwise noted.

Species	Box (1961) Nueces fs	Drawe & Box (1969) Zavala fsl (g/m²)	(%)	Diamond & Smeins (1984) Alfisols	Bovey et al. (1972) Katy sl	McLendon & DeYoung (1976)	McLendon (2014) Aransas (g/m²)	McLendon (2015) Goliad (g/m²)	McLendon (2015) Karnes (g/m²)
Ampelopsis arborea	----	----	----	---	----	----	----	22.7	----
Baccharis glutinosa	----	----	----	---	----	2.7	----	----	----
Quercus virginiana	----	----	----	---	114.2	8.6	----	----	----
Vitis mustangensis	----	----	----	---	----		27.0	----	----
Andropogon glomeratus	----	----	----	---	----	4.3	----	----	----
Aristida purpurescens	1.2	----	----	6	x	----	----	----	----
Bothriochloa ischaemum	----	----	----	---	----	----	----	34.7	----
Bothriochloa saccharoides	----	----	----	---	----	----	----	----	96.0
Bouteloua curtipendula	----	----	----	---	----	----	----	----	1.1
Bouteloua hirsuta	1.8	----	----	---	----	----	----	----	----
Brachiaria ciliatissima	3.2	22.0	9.3	---	----	----	----	----	----
Cenchrus incertus	13.7	23.1	9.7	---	----	2.0	1.1	----	----
Chloris cucullata	4.2	----	----	---	----	----	----	----	17.1
Cynodon dactylon	----	----	----	---	----	3.0	----	----	17.2
Dichanthelium acuminatum	----	----	----	---	----	----	6.1	----	8.0
Dichanthelium langinosum	----	----	----	---	----	3.0	----	----	----
Dichanthelium oligosanthes	----	----	----	4	----	4.0	----	----	----
Dichanthelium sphaerocarpon	---	----	----	---	----	3.7	----	----	----
Digitaria texana	----	----	----	---	----	2.7	----	----	----
Elyonurus tripsacoides	3.1	30.0	12.3	---	----	----	57.4	----	----
Eragrostis secundiflora	1.2	----	----	x	----	----	----	----	----
Eragrostis trichodes	----	----	----	---	----	----	----	----	29.0
Eustachys petraea	----	----	----	---	----	1.6	----	----	----
Leptoloma cognatum	2.1	----	----	---	----	----	----	----	----
Panicum capillare	----	----	----	---	----	----	----	0.8	----
Panicum hallii	----	----	----	---	----	----	----	----	0.4
Panicum maximum	----	----	----	---	----	----	----	67.1	----
Paspalum floridanum	----	----	----	3	----	----	5.0	----	----
Paspalum monostachyum	----	----	----	---	----	11.5	----	----	----
Paspalum plicatulum	0.4	----	----	10	x	5.8	----	----	----
Paspalum setaceum	4.4	----	----	3	----	3.6	3.6	----	18.2
Schizachyrium scoparium	----	----	----	41	x	----	----	33.5	3.7
Schizachyrium littoralis	20.7	13.8	5.7	---	----	3.4	388.6	----	----
Setaria firmula	19.8	33.4	14.0	---	x	----	----	----	----
Setaria leucopila	----	----	----	---	----	----	----	----	22.4
Sorghastrum nutans	----	----	----	7	x	----	----	----	----
Sporobolus asper	----	----	----	3	----	----	----	1.1	1.2
Stipa leucotricha	----	----	----	---	----	----	----	28.5	21.5
Tridens strictus	----	----	----	1	----	----	----	----	----
Other grasses	----	40.4	16.9	---	----	----	----	----	----
Grasses (% cover)				78					
Grasses (relative cover)	75.8		67.9			48.6			
Grasses (g/m²)		162.7			184.7		488.8	165.7	235.8
Carex spp.	----	----	----	---	----	7.0	----	----	----
Fimbristyis puberula	----	----	----	3	----	----	----	----	----
Rhynchospora spp.	----	----	----	1	----	----	----	----	----
Acacia hirta	----	----	----	1	----	----	----	----	----
Acalypha radians	----	----	----	---	----	----	0.4	----	----
Allium sp.	----	----	----	---	----	----	----	0.3	----
Ambrosia psilostachya	----	----	----	3	----	----	12.7	----	4.4
Aster pratensis	----	----	----	1	----	----	----	----	----
Baptisia leucophaea	---	----	----	---	----	3.6	----	----	----
Commelina erecta	0.8	----	----	---	----	3.4	2.5	----	----
Croton capitatus	1.5	9.1	3.7	---	----	----	----	----	----
Croton dioicus	----	----	----	---	----	----	----	----	1.2
Croton punctatus	----	----	----	---	----	5.0	----	----	----
Croton texensis	----	1.7	0.7	---	----	----	----	1.5	----
Erigeron myrionactis	----	----	----	---	----	4.4	----	----	----
Eriogonum multiflorum	1.4	----	----	---	----	----	----	----	----

Appendix Table C.9 (Cont.)

Species	Box (1961) Nueces fsl	Drawe & Box (1969) Zavala fsl (g/m²)	(%)	Diamond & Smeins (1984) Alfisols	Bovey et al. (1972) Katy sl	McLendon & DeYoung (1976)	McLendon (2014) Aransas (g/m²)	(2015) Goliad (g/m²)	(2015) Karnes (g/m²)
Eustoma exaltatum	----	----	----	---	----	3.9	----	----	----
Gnaphalium obtusifolium	----	----	----	---	----	----	1.7	----	----
Gutierrezia texana	----	----	----	---	----	----	----	----	69.8
Heterotheca subaxillaris	----	49.8	21.3	---	----	2.3	----	----	----
Ibervillea lindheimeri	----	----	----	---	----	----	----	0.5	----
Iva angustifolia	----	----	----	---	----	----	22.9	----	----
Liatris spp.	----	----	----	3	----	----	----	----	----
Monarda citriodora	----	----	----	---	----	----	2.4	----	----
Nama hispidum	6.6	----	----	---	----	----	----	----	----
Parthenium hysterophorus	----	----	----	---	----	3.5	----	----	----
Phyla incisa	0.3	----	----	---	----	----	0.7	----	----
Physalis viscosa	----	----	----	---	----	----	1.9	----	----
Ratibida columnaris	----	----	----	1	----	----	6.3	----	----
Rhynchosia americana	----	----	----	---	----	2.9	----	----	----
Rhynchosia texana	----	----	----	---	----	4.3	----	----	----
Sarcostemma cynanchoides	----	----	----	---	----	----	1.1	----	----
Schrankia uncinata	----	----	----	3	----	----	----	----	----
Sida abutifolia	----	----	----	---	----	----	----	----	1.3
Solanum eleagnifolium	----	----	----	---	----	----	----	----	0.5
Tragia urticifolia	----	----	----	1	----	----	----	----	----
Verbesina enceloides	7.8	10.0	4.0	---	----	----	----	----	----
Verbena halei	----	----	----	---	----	----	0.7	----	----
Other forbs	----	5.4	2.3	---	----	----	----	----	3.5
Forbs (% cover)	----	----	----	17	----	----	----	----	----
Forbs (relative cover)	18.4		32.0	---	----	33.3	----	----	----
Forbs (g/m²)		76.0		---	18.5	----	53.3	2.3	80.7
Other species	5.8	----	----	---	----	----	----	----	----

Trace species from Diamond and Smeins (1984): *Andropogon gerardii, Aster ericoides, Buchloe dactyloides, Cacalia plantaginea, Carex microdonta, Cirsium undulatum, Eryngium yuccifolium, Hedyotis nigricans, Linum medium, Muhlenbergia capillaris, Oxalis dillenii, Panicum virgatum, Ruellia nudiflora, Sabatia campestris, Scleria ciliata, Silphium laciniatum, Sisyrinchium pruinosum.*

Appendix Table C.10 Mean frequency (%) of plant communities on Pat Welder Ranch, San Patricio County (McLendon and Dahl 1983).

Species	Mesquite-blackbrush-ragweed	Mesquite-blackbrush-knotroot bristlegrass	Mesquite-blackbrush-huisache	Mesquite-huisache-blackbrush	Mesquite-huisache-buffalograss	MEAN
Prosopis glandulosa	41	53	37	59	46	47
Acacia farnesiana			13	15	13	8
Acacia rigidula	20	17	33	18	12	20
Celtis pallida				12		2
Agrostis hiemalis					11	2
Bothriochloa saccharoides		10		11		4
Buchloe dactyloides	10		14	15	33	14
Chloris verticillata				11		2
Paspalum plicatulum				11		2
Setaria geniculata	19	61	49	12	10	30
Stipa leucotricha		10		17		3
Ambrosia psilostachya	65	79	30	86	23	57
Chamaecrista fasciculata				14	16	6
Gutierrezia texana	25	13	34	29	27	46
Sida ciliaris	23		18	17	27	17
Oxalis dillenii	10			35	20	13

Appendix Table C.11 Species composition of available forage (g/m^2) on a grazed coastal prairie site (Lake Charles clay), Green Lake Ranch, Calhoun County, Texas, December 1973-April 1974 (Durham and Kothmann 1977).

Species	23 Dec	16 Jan	13 Feb	10 Mar	27 Mar	10 Apr	Mean
Cynodon dactylon	38	22	33	58	85	58	49
Paspalum lividum	19	37	63	91	54	60	54
Paspalum plicatulum	15	37	31	46	54	36	37
Schizachyrium littoralis	105	53	75	73	146	83	89
Setaria geniculata	83	31	15	8	8	6	25
Sorghastrum nutans	31	30	15	31	34	21	27
Sporobolus indicus	45	43	24	22	11	14	27
Other species	42	30	15	24	33	13	26
Total Grasses	378	283	271	353	425	291	334

Other grasses: *Bouteloua rigidiseta, Dichanthelium oligosanthes, Panicum virgatum, Paspalum dilatatum.*
The site was dominated by seacoast bluestem and McCartney rose (*Rosa bracteata*).

Appendix Table C.12 Mean aboveground biomass (g/m^2) in grazed plots and exclusion plots on a heavily-grazed sandy rangeland in Brooks County, Texas, February-November 1980 (McLendon and Finch, unpublished data). Values are means of 8 plots per treatment per month for 8 months.

Species	Excluded Animals					Overall
	None	Cattle	Cattle & Deer	Cattle, Deer, & Rabbits	Cattle, Deer, Rabbits, Gophers	Mean
Acacia greggii	0.9	----	----	----	----	0.2
Colubrina texensis	0.3	*	----	----	*	0.1
Opuntia leptocaulis	----	----	0.6	----	1.7	0.5
Opuntia lindheimeri	1.5	12.5	----	17.8	1.4	6.6
Prosopis glandulosa	----	*	----	----	----	*
Aristida purpurea	10.3	18.3	12.2	21.0	23.1	17.0
Aristida purpurescens	25.8	31.8	38.9	31.8	26.1	30.9
Bothriochloa saccharoides	----	----	----	----	0.5	0.1
Bouteloua hirsuta	1.5	1.2	0.9	1.2	1.4	1.2
Bracharia ciliatissima	2.1	2.4	4.5	4.0	5.2	3.6
Cenchrus incertus	2.4	2.3	3.2	3.0	2.4	2.7
Dichanthelium oligosanthes	----	0.3	0.5	0.1	1.9	0.6
Digitaria patens	----	----	0.1	*	----	*
Eragrostis secundiflora	0.1	0.2	0.7	0.4	1.2	0.5
Eragrostis sessilspica	----	----	0.1	*	----	*
Paspalum setaceum	11.1	10.6	16.9	13.0	10.0	12.2
Setaria firmula	4.7	7.6	5.5	2.0	5.3	5.0
Sporobolus cryptandrus	0.1	0.3	0.6	0.3	1.0	0.5
Acalypha radians	0.8	1.2	0.9	1.0	1.4	1.1
Allium runyoni	----	----	----	*	*	*
Ambrosia confertifolia	2.6	7.1	6.1	5.7	3.8	5.1
Aphanostephus kidder	0.1	0.1	0.3	*	----	0.1
Callirhoe involucrate	0.1	0.3	----	0.1	0.3	0.2
Carex sp.	----	----	----	*	----	*
Centaurium texense	----	*	----	----	----	*
Chamaecrista texana	0.5	0.2	0.2	0.5	1.5	0.6
Cnidoscolus texanus	----	----	----	*	----	*
Commelina erecta	0.7	0.3	0.2	0.4	0.4	0.4
Croton argyranthemus	1.5	1.8	3.3	2.4	1.8	2.2
Croton capitatus	7.5	3.3	2.8	3.4	3.3	4.1
Eriogonum multiflorum	*	1.2	0.9	0.6	0.1	0.6
Evolvulus sericeus	0.8	0.4	0.2	*	1.1	0.5
Gaillardia pulchella	2.0	1.8	1.2	0.9	2.4	1.7
Gaura mckelveyae	1.3	2.2	2.5	3.2	1.4	2.1
Heterotheca subaxillaris	16.2	19.6	21.4	24.1	22.2	20.7
Lantana horrida	0.1	0.2	0.6	----	----	0.2
Lepidium lasiocarpum	0.1	0.1	0.2	0.2	0.1	0.1
Linum rigidum	*	*	----	----	*	*
Monarda punctata	19.3	26.9	28.8	25.8	37.4	27.6
Oenothera sp.	----	*	----	----	----	*
Oxalis dillenii	2.5	1.0	1.8	1.4	0.7	1.5
Palafoxia texana	7.4	9.0	7.3	3.7	8.2	7.1
Phlox drummondii	0.5	----	----	*	----	0.1
Physalis cinerascens	0.4	0.4	0.8	1.3	0.3	0.6
Plantago rhodosperma	0.1	----	----	----	----	*
Polygala alba	----	0.1	*	----	*	*
Ratibida peduncularis	2.2	2.3	2.0	1.7	2.5	2.1
Rhynchosia americana	1.8	1.8	2.2	2.3	2.3	2.1
Sida lindheimeri	0.2	0.2	0.3	0.2	0.2	0.2
Tephrosia lindheimeri	6.3	7.1	2.5	8.3	4.3	5.7
Total Aboveground Biomass	135.8	175.5	171.2	181.8	176.9	168.4
Litter	89.9	101.1	150.8	110.2	133.4	117.1
Total Shrubs and Cacti	2.7	12.5	0.6	17.8	3.1	7.4
Total Grasses	58.1	74.4	84.1	76.8	78.1	74.3
Total Forbs	75.0	88.6	86.5	87.2	95.7	86.7

Dashed lines (----) indicate zero values. Astericks (*) indicate trace (< 0.05 g/m^2) amounts.

Appendix Table C.13 Woody plant density (plants/ha) and basal cover (m^2/ha) on Miguel and Papalote fine sandy loam soils on La Copita, Jim Wells County (Archer et al. 1988).

Species	Density: Clusters	Density: Openings	Density: Drainages	Cover Openings	Density of Plants > 2 m in Drainages
Acacia farnesiana		70	44	0.027	37
Aloysia lycioides		0	2189	0.000	0
Bumelia spp.	x	0	35	0.000	9
Celtis pallida	x	0	775	0.000	283
Colubrina texensis		30	582	0.001	0
Condalia hookeri	x	0	462	0.000	97
Diospyros texana	x	16	1101	0.001	106
Lantana macropoda	x	0	---	0.000	0
Lycium berlandieri	x	0	197	0.000	0
Mahonia trifoliolata	x	0	39	0.000	0
Opuntia lindheimeri	x	100	982	-----	0
Opuntia leptocaulis	x	30	---	-----	0
Prosopis glandulosa	x	350	764	0.022	295
Salvia ballotaeflora	x	0	339	0.000	0
Schaefferia cuneifolia	x	0	314	0.000	0
Yucca treculeana		0	---	0.000	---
Zanthoxylum fagara	x	30	3229	0.003	318
Zizyphus obtusifolia	x	0	218	0.000	0
TOTALS		626	11270	0.054	1145

Archer et al. (1988) sites were on Miguel and Papalote fine sandy loams on the La Copita, Jim Wells County. #/ha = number of woody plants per hectare, BC = basal cover (%).
Density of plants > 2 m in drainages included in the values for drainages overall.
Average cluster was 18 m^2.
Woody plant coverage averaged 13.0% in 1940 and 36.4% in 1983. This is an annual increase of 0.55 percentage points per year. At that rate, cover in 2013 would be 52.9% (36.4% + 16.5%).

Appendix Table C.14 Woody plant density (plants/ha) and canopy cover (m^2/plant) in three plant communities on the Welder Wildlife Refuge, San Patricio County, Texas (Box 1961).

Species	Density: Mesquite	Density: Chaparral	Density: Prickly pear	Cover: Mesquite	Cover: Chaparral	Cover: Prickly pear
Acacia farnesiana	50	39	13	----	----	----
Acacia rigidula	3	193	56	11.75	3.69	0.87
Acacia tortuosa	13	34	13	----	----	----
Celtis pallida	t	19	t	----	----	----
Condalia hookeri	t	15	t	----	----	----
Mahonia trifoliolata	t	106	t	----	----	----
Opuntia lindheimeri	t	t	426	----	----	4.84
Prosopis glandulosa	364	174	2046	4.84	1.28	0.74
Zanthoxylum fagara	3	39	13	----	----	----
Zizyphus obtusifolia	14	116	56	----	----	----
TOTAL	447	735	2623			

Appendix Table C.15 Vegetation of the Welder Wildlife Refuge, San Patricio County (Drawe et al. 1978).

Mesquite-mixed grass community: Victoria clay

Moderate stands of mesquite (12-27% cover), with mottes of mixed brush; huisache is increasing (200-500 trees/ha).
Interspaces with dense stands of grass: 17% Texas wintergrass, 8% meadow dropseed, 2% silver bluestem; little bluestem, plains bristlegrass, Texas cupgrass, lovegrass tridens, sourgrass (*Digitaria insularis*).
Forbs (20%): prairie coneflower, western ragweed, ruellia, horsemint, one-seeded doveweed (*Croton monanthogynus*), bladderpod (*Lesquerella lindheimeri*), Texas broomweed.
Depressions: vine-mesquite, pink tridens, white tridens, frogfruit, water clover (*Marsilea mucronata*).
Swales: hackberry, longtom, sumpweed.

Chaparral-mixed grass community: drier clay and clay loam sites

Woody plant cover (34-55%): blackbrush (11%), mesquite, huisache, twisted acacia, agarito, creeping mesquite, granjeno, lotebush, brasil, Texas persimmon, colima. Areas root-plowed 30-35 years ago have brush 2-3 m tall. Mesquite and huisache have increased in height 1.0-1.5 m in 20-25 years and shrubs have increased 0.3-0.5 m.
Understory in mottes: some plains bristlegrass and bunch cutgrass (*Leersia monandra*).
Openings between mottes: similar to mesquite-mixed grass except more silver bluestem and little bluestem.

Chaparral-mixed grass community: sandy loam sites

Woody plant cover (25.7%): granjeno, colima, mesquite, huisache, blackbrush, agarito, lotebush, Texas persimmon, prickly pear (0.3%).
Major grasses: silver bluestem, knotroot bristlegrass, plains bristlegrass, Texas cottontop.

Halophyte-shortgrass community: saline sites adjacent to temporary lakes or swales

Few, scattered mesquite.
Padre Island dropseed, whorled dropseed, saltgrass, Texas willkommia (*Willkommia texana*), gulf cordgrass, shoregrass; sea oxeye, glasswort (*Salicornia virginica*), purslane, saltbush.

Paspalum-aquatic plant community: swales on clay soils

Sesbania and some scattered huisache.
Almost pure stands of hairyseed paspalum (*Paspalum publiflorum*). Some canarygrass (*Phlaris canariensis*), arrowhead, and water clover.
During dry periods, buffalograss and creeping lovegrass (*Neeragrostis reptans*) become abundant.

Gulf cordgrass community: frequently flooded clay swales

Upper clay loam sites: mesquite, granjeno, blackbrush, sea oxeye; bermudagrass, little barley
Upper sandy loam sites: huisache; bermudagrass, rescue grass, geranium
Mid-elevation sites: closed canopy of gulf cordgrass
Lower elevation sites: clubhead cutgrass (*Leersia hexandra*), cattail, and spikerush.

Huisache-mixed grass community: low swale areas

Dense stands of huisache.
Understory under closed canopy: Texas wintergrass, canarygrass, Ozarkgrass, sixweeks fescue
Understory under open canopy: hairyseed paspalum, knotroot bristlegrass, vine-mesquite
Wetter areas: spiny aster and longtom; drier areas: more silver bluestem, lovegrass tridens, plains bristlegrass.

Bunchgrass-annual forb community: sandy and sandy loam soils

Open grassland with 25-40% grass cover. Relative cover = 75% grasses, 19% forbs, 6% shrubs.
Under light grazing: seacoast bluestem, big bluestem, Pan American balsamscale, tanglehead, switchgrass, Texasgrass (*Vaseochloa multinervosa*), trichloris, big sandbur, crinkleawn.
Under moderate grazing: increase in balsamscale and thin paspalum.
Under heavy grazing: sandbur and knotgrass (*Setaria formula*) are common.
Major forbs: skunk daisy (*Ximenesia encelioides*), Texas doveweed, woolly doveweed, wild buckwheat.
On sandy loam sites: increase in sideoats grama, brownseed paspalum, hooded windmillgrass, old-man's beard, and prickly pear.

Hogplum-bunchgrass community: sandy loam soils on river terraces

Stands of hogplum and old-man's beard, with scattered huisache and Texas kidneywood.
Hogplum dense on terraces, huisache dense in swales.
Understory: sideoats grama, brownseed paspalum, hooded windmillgrass, prickly pear.

Huisache-bunchgrass community: lower areas of Odem sandy loam soils

Moderate to dense stands of huisache and dense stands of old-man's beard.
Understory similar to bunchgrass-annual forb community, but with southwestern bristlegrass (*Setaria scheelei*), Texas wintergrass, Virginia wildrye, snoutbean, and ruellia.

Chittimwood-hackberry community: sandy loam soils

Dense stands of chittimwood (*Bumelia lanuginose*) and hackberry. Small trees (3-7 m tall), with canopies extending to near the ground.
Sparse understory: southwestern bristlegrass and Turk's cap (*Malvavicus drummondii*).

Live oak-chaparral community: sandy and sandy loam soils

Overstory: scattered stands of old live oak, 2% canopy cover.
Mid-level: mesquite (30%; 3-5 m tall), colima (14%), Texas persimmon (6%), blackbrush (6%), granjeno (5%), agarito (5%), chittimwood, hackberry, anacua, chapatillo (*Amyris texana*), tickle-tongue.
Understory: seacoast bluestem, brownseed paspalum, tanglehead; some big bluestem, switchgrass, indiangrass, trichloris, southwestern bristlegrass.
Heavier grazing: windmillgrasses, brownseed paspalum, thin paspalum, sandbur.
Turk's cap, pigeon berry (*Rivina humilis*), mistflower, skunk daisy, doveweed.

Mesquite-bristlegrass community: poorly-drained sands and sandy loams

Open stands of mesquite, with granjeno, colima, lotebush, agarito.
Understory: knotroot bristlegrass, brownseed paspalum, Hall panicum, silver bluestem, gummy lovegrass; western ragweed

Riparian woodland community: riparian bottomlands

Stands of large trees: hackberry, anacua, cedar elm, pecan, with mustang grape.
Shrub understory: similar to that of live oak-chaparral community.
Herbaceous understory: southwestern bristlegrass, broadleaf uniola (*Chasmanthium latifolium*), Virginia wildrye, Turk's cap, velvet mallow (*Wissadula amplissima*).

Woodland-spiny aster community: mixed alluvial soils

Mixture of chaparral, western soapberry (*Sapindus saponaria*), and spiny aster.

Spiny aster-longtom community: low-lying areas where water stands for long periods following rains

Dense stands of spiny aster, with some longtom and little snoutbean (*Shynchosia minima*).

Lakes and Ponds

Submersed community: coontail (*Ceratophyllum demersum*), water nymph (*Najas quadalupensis*), water stargrass (*Heteranthera liebmanni*), wigeongrass (*Ruppia maritima*), sago pondweed (*Potamogeton pectinatus*), and muskgrass (*Chara* spp.).
Floating community: mostly lotus (*Nelumbo lutea*).
Lower marsh edges: bulrushes (*Scirpus* spp.), cattails, and sedges.
Upper marsh edges: clubhead cutgrass, longtom, sesbania.
As ponds dry: buffalograss, knotroot bristlegrass, creeping lovegrass.

Appendix Table C.16 Woody plants reported on other study sites in South Texas.

Species	Campbellton Bovey et al. 1970	Webb Co. Buckley & Dodd 1969	Goliad Co. Dodd & Holtz 1972
Acacia farnesiana	major		
Acacia greggii	scattered		
Acacia rigidula	major		308/ha
Celtis pallida	scattered		
Colubrina texensis	scattered		185/ha
Diospyros texana	scattered		124/ha
Eysenhardtia texana	scattered		
Lycium berlandieri	scattered		
Mahonia trifoliolata	scattered		62/ha
Opuntia leptocaulis	scattered		
Opuntia linheimeri	scattered	density = 1	
Parkinsonia aculeata		density = 4	
Prosopis glandulosa	scattered	density = 3	
Varilla texana		density = 2	
Yucca treculeana	scattered		
Zizyphus obtusifolia	scattered		62/ha
Other woody species			333/ha

Appendix Table C.17 Woody plant cover (%) at sites in South Texas.

Community	Woody Cover	Location	Reference
Blackbrush-mesquite	20.4	Welder WR, San Patricio Co.	Box (1961)
Blackbrush-mesquite	38.4	Welder WR, San Patricio Co.	Drawe et al. (1978)
Blackbrush-mesquite	48.6	Welder WR, San Patricio Co.	Powell & Box (1967)
Granjeno-colima	25.7	Welder WR, San Patricio Co.	Drawe et al. (1978)
Mesquite-buffalograss	18.6	Welder WR, San Patricio Co.	Box (1961)
Mesquite-huisache	47	Welder WR, San Patricio Co.	Box & White (1969)
Mesquite-mixed grass	20	Welder WR, San Patricio Co.	Drawe et al. (1978)
Mesquite-prickly pear	36.4	La Copita, Jim Wells Co.	Archer et al. (1988)
Prickly pear-mesquite	39.4	Welder WR, San Patricio Co.	Box (1961)

Appendix Table C.18 Species composition (%) in wetland communities on the Welder Wildlife Refuge, San Patricio County (Scifres et al. 1980).

Species	Clubhead cutgrass	Cattail-cutgrass	Cutgrass-spikerush	Cutgrass-longtom	Wetland Mean	Gulf cordgrass
Borrichia frutescens	0	1	t	0	t	2
Cynodon dactylon	2	5	t	5	3	t
Leersia hexandra	29	19	28	20	24	3
Paspalum lividum	20	14	14	29	19	4
Setaria geniculata	0	0	7	t	2	3
Spartina spartinae	0	0	t	t	t	65
Echinodorus cordifolius	9	4	6	7	6	2
Eleocharis spp	16	10	19	11	14	6
Fimbristylis castanea	6	5	8	3	5	5
Typha domingensis	t	32	t	0	8	0
Iva annua	0	0	0	6	2	0
Phyla incisa	t	t	6	t	2	t
Polygonum ramosissimum	0	0	2	7	2	1
Rumex crispus	4	1	2	9	2	4
Sagittaria latifolia	4	3	3	1	3	4

Appendix Table C.19 Non-quantified species lists for South Texas plant communities.

Species	Drawe (1994) Bluestem-cordgrass	McLendon (1994) Mesquite-granjeno-acacia	Smeins (1994a) Little bluestem-indiangrass	Smeins (1994b) Little bluestem-post oak	Archer (1990) La Copita Jim Wells Co.
Acacia farnesiana		common			
Acacia rigidula		common			
Acacia tortuosa		common			
Aloysia lycioides		common			
Celtis laevigata				common	
Celtis pallida		sub-dominant			common
Condalia hookeri		common			common
Diospyros texana		common			common
Mahonia trifoliolata		common			common
Opuntia linheimeri		common			
Porlieria angustifolia		common			
Prosopis glandulosa		dominant			dominant
Quercus buckleyi				common	
Quercus marilandica				common	
Quercus stellata				dominant	
Quercus virginiana				common	
Rhus aromatic				common	
Schaefferia cuneifolia					common
Smilax bona-nox				common	
Symphoricarpos orbiculatus				common	
Zanthoxylum fagara		common			common
Zizyphus obtusifolia		common			common
Andropogon gerardii				common	
Andropogon glomeratus	common				
Andropogon tenarius	common				
Andropogon virginicus	common				
Aristida purpurea	common	common	common	common	common
Bothriochloa saccharoides	common	common			
Bouteloua curtipendula		common	common	common	
Bouteloua hirsuta		common	common	common	
Bouteloua rigidiseta		common	common		common
Bouteloua trifida		common			common
Buchloe dactyloides	common	common	common	common	
Cenchrus ciliaris		common			
Cenchrus incertus		common			common
Chloris cucullata		common			common
Chloris pluriflora		common			
Dichanthium annulatum		common			
Distichlis spicata	common				
Elyonurus tripsacoides	common				
Hilaria belangeri		common			
Panicum obtusum		common			
Pappophorum bicolor		common			
Paspalum plicatulum	common				
Paspalum lividum	common				
Paspalum setaceum					common
Schizachyrium littoralis	dominant				
Schizachyrium scoparium	dominant		dominant	sub-dominant	
Setaria leucopila		common			
Setaria texana		common			
Sorghastrum nutans			sub-dominant	common	
Spartina spartinae	dominant				
Sporobolus asper	common		common	common	
Sporobolus indicus	common				
Sporobolus tharpii	common				
Stipa leucotricha	common		common	common	
Tridens congestus	common				
Carex spp.	common				
Eleocharis spp.	common				
Fimbristylis spp.	common				
Scirpus spp.	common				

Appendix Table C.19 (Cont.)

Species	Drawe (1994) Bluestem-Cordgrass	McLendon (1994) Mesquite-granjeno-acacia	Smeins (1994a) Little bluestem-indiangrass	Smeins (1994b) Little bluestem-post oak	Archer (1990) La Copita Jim Wells Co.
Ambrosia psilostachya	common				
Amphiachyris dracunculoides		common			
Clematis drummondii		common			
Croton spp.	common	common			
Cynanchum leave		common			
Desmanthus virgatus		common			
Dichondra micrantha	common				
Ericameria texana		common			
Eriogonum multiflorum	common				
Eupatorium odoratum		common			common
Eupatorium incarnatum		common			common
Evolvulus spp.					common
Gnaphalium obtusifolium		common			
Iva annua	common				
Lantana horrida		common			
Parietaria texana		common			
Parthenium incanatum		common			
Ratibida columnaris	common				
Rhynchosia spp.	common				
Sagittaria latifolia	common				
Sarcostemma cynanchoides		common			
Verbesina spp.					common
Zexmenia hispida		common			common

Remnants of the bluestem-cordgrass prairie remain as the Goliad Prairie, McFaddin Prairie (near Victoria), and east of Tivoli (Drawe 1994).

Appendix Table C.20 Effect of range condition or seral stage on forage production.

Type	Location	Units	Exellent	Good	Fair	Poor	Reference
Bluestem prairie	LA	lbs/ac	2828	3239	3351		Duvall & Linnartz (1967)
Bluestem prairie	OK	lbs/ac	3767			3172	Hazell (1967)
Bluestem prairie	NE	% comp	83	46	11		Jensen & Schumacher (1969)
Bluestem prairie	TX	g/m^2	489				McLendon (2014): Aransas NWR
Bluestem prairie	TX	g/m^2			236		McLendon (2015a): Stieren Ranch
Bluestem prairie	TX	g/m^2			208		McLendon et al. (2001): Fort Hood
Bluestem prairie	TX	g/m^2				176	McLendon (2015b): Brooks County
Bluestem prairie	TX	g/m^2				163	Drawe & Box (1969): Welder WR
Bluestem prairie	TX	g/m^2				172	McLendon (1977): Dimmit County

Appendix Table C.21 Effect of grazing intensity on forage production.

Type	Location	Units	Ungrazed	Light	Medium	Heavy	Reference
Black grama grassland	NM	basal	0.73	1.00	0.69	0.57	Paulsen & Ares 1962
Tobosa grassland	NM	basal	0.51	1.00	1.09	0.94	Paulsen & Ares 1962
Blue grama stony hills	NM	g/m^2	62.7		52.6		Pieper 1968
Blue grama loam upland	NM	g/m^2	72.8		61.6		Pieper 1968
Blue grama bottomland	NM	g/m^2	68.3		18.0		Pieper 1968

Appendix Table C.22 Calculation of change in aboveground grass biomass with change in range condition, seral stage, or grazing intensity. Ratios based on data in Appendix Tables C.20 and C.22.

Bluestem prairie	LA	Good = 1.15(Excellent)	Fair = 1.18(Excellent)	
Bluestem prairie	OK			Poor = 0.84(Excellent)
Bluestem prairie	NE	Good = 0.55(Excellent)	Fair = 0.13(Excellent)	
Bluestem prairie	TX		Fair = 0.45(Excellent)	Poor = 0.35(Excellent)
Tobosa grassland	NM	Light = 1.96(Ungrazed)	Medium = 2.14(Ungrazed)	Heavy = 1.84(Ungrazed)
Black grama	NM	Light = 1.37(Ungrazed)	Medium = 0.95(Ungrazed)	Heavy = 0.78(Ungrazed)
Blue grama	NM		Medium = 0.64(Ungrazed)	

Means:	Good = 0.85(Excellent)	Fair = 0.59(Excellent)	Poor = 0.60(Excellent)
	Light = 1.67(Ungrazed)	Medium = 1.25(Ungrazed)	Heavy = 1.31(Ungrazed)
		Medium = 0.75(Light)	Heavy = 0.78(Light)

Summary: 1.00 ----> 0.85 ----> 0.75 ----> 0.59 ----> 0.69

Range Condition:	Excellent	Good	High-Fair	Low-Fair	Poor
Seral Stage:	Late		Mid		Early
Grazing Intensity:	Light		Moderate	Heavy	

Appendix Table C.23 Aboveground biomass (g/m^2) for woody species in the Goliad County EDYS model (values based on 100% canopy cover of the respective woody species).

Species	Common Name	Trunk	Stems	Leaves	Total
Acacia farnesiana	huisache	5,000	1,460	260	6,720
Carya illinioensis	pecan	23,650	3,890	330	27,870
Celtis laevigata	sugar hackberry	11,820	1,950	330	14,100
Prosopis glandulosa	mesquite	7,240	1,000	300	8,540
Quercus stellata	post oak	12,240	1,920	190	14,350
Quercus virginiana	live oak	24,270	3,830	380	28,480
Acacia berlandieri	guajillo	500	1,100	500	2,100
Acacia rigidula	blackbrush	630	1,300	440	2,370
Aloysia lycioides	whitebrush	700	1,500	400	2,600
Baccharis texana	prairie baccharis	1,240	1,240	260	2,740
Borrichia frutescens	sea oxeye	150	100	250	500
Celtis pallida	granjeno	1,060	1,070	350	2,480
Lycium berlandieri	wolfberry	810	810	250	1,870
Mahonia trifoliolata	agarito	70	120	70	260
Rosa bracteata	McCartney rose	1,200	3,600	900	5,700
Sesbania drummondii	rattlepod	250	1,000	100	1,350
Vitis mustangensis	mustang grape	1,200	200	400	1,800
Opuntia lindheimeri	prickly pear	350	2,000	10	2,360

Appendix Table C.24 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 lowest:	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 (Scrifes et al. 1982).
Approximate grass production = (amount at 0% cover)[1.00 – (0.8)(woody plant cover)].

Appendix Table C.25. Species composition and initial biomass values for land-use types in the Goliad County EDYS model. Values for woody species are in % of total woody cover and impervious surfaces are % of total area. Values for herbaceous species are g/m^2.

Species	Urban Houses	Buildings Industrial	Disturbed Areas	Caliche Pits	Tilled Fields	Orchard	Oil Pads
Huisache	---	30	30	10	---	---	---
Pecan	5	---	---	---	---	100	---
Hackberry	---	30	20	---	---	---	---
Mesquite	40	20	30	20	---	---	---
Live oak	55	---	---	---	---	---	---
Blackbrush	---	---	---	30	---	---	---
Whitebrush	---	---	---	10	---	---	---
Baccharis	---	20	10	10	---	---	---
Granjeno	---	---	10	20	---	---	---
Purple threeawn	---	20	25	20	---	---	---
King Ranch bluestem	---	50	20	10	---	---	---
Silver bluestem	---	10	5	20	---	---	---
Sandbur	---	10	10	10	---	---	---
Hooded windmillgrass	---	10	10	20	---	---	---
Bermudagrass	500	100	10	10	---	50	---
Johnsongrass	---	150	20	10	---	20	---
Milo	---	---	---	---	20	---	---
Ragweed	---	50	20	20	---	10	---
Sunflower	---	50	20	10	10	10	---
Impervious surface	50%	90%	0%	10%	0%	0%	100%

Appendix Table C.26 Species composition and aboveground herbaceous production (clippable biomass) in improved pasture by soil series in Goliad County.

NRCS Range Site	Woody Species Relative Composition (%)	Herbaceous Species Initial Aboveground Biomass (g/m^2) BOIS	CYDA	PACO	SOHA	AMPS
Clay Soils						
Blackland RG Plains	huisache 50; mesquite 40; baccharis 10	30	0	544	30	19
Blackland Coastal	huisache 50; McCart rose (40); bacchrs 10	60	0	1089	60	39
Clayey Bottomland	huisache 60; mesquite 30; hackberry 10	33	0	597	33	39
Rolling Blackland	huisache 20; mesquite 60; baccharis 20	30	0	541	30	21
Clay Loam Soils						
Clay Loam	huisache 50; mesquite 40; baccharis 10	33	0	596	33	23
Loamy Bottomland	huisache 60; mesquite 30; hackberry 10	50	0	898	50	44
Sandy Loam Soils						
Claypan Prairie	huisache 50; McCartney rose 50	32	576	0	32	29
Claypan Savanna	huisache 30; mesquite 70	26	464	0	26	15
Gray Sandy Loam	huisache 50; mesquite 40; whitebrush 10	22	395	0	22	20
Loamy Prairie	huisache 50; McCart rose 40; mesquite 10	34	621	0	35	31
Sandy Loam	huisache 50; mesquite 50	29	518	0	29	27
Tight Sandy Loam	huisache 50; mesquite 50	24	432	0	24	23
Sandy Soils						
Deep Sand	huisache 30; mesquite 40; live oak 30	20	369	0	20	17
Loamy Sand	huisache 30; mesquite 50; live oak 20	25	447	0	25	21
Sandy	huisache 40; mesquite 40; baccharis 20	25	450	0	25	24
Sandy Bottomland	huisache 40; mesquite 40; hackberry 20	31	560	0	31	33
Shallow Soils						
Gravelly Ridge	mesquite 20; blackbrush 60; granjeno 20	15	270	0	15	20
Shallow Ridge	mesquite 30; blackbrush 70	11	203	0	11	11
Shallow Sandy Loam	huisache 50; mesquite 50	18	319	0	17	36
Sloping Clay Loam	huisache 30; mesquite 50; blackbrush 20	16	282	0	15	15
Wetland Soils						
Lakebed RG Plains	huisache 70; mesquite 20; baccharis 10	11	418	0	36	15
Lakebed Coastal	huisache 80; mesquite 10; rattlepod 10	13	458	0	38	17
Lowland Coastal	huisache 80; baccharis 10; rattlepod 10	19	629	0	56	33
Salty Prairie	huisache 90; mesquite 10	44	791	0	44	39

BOIS = King Ranch bluestem; CYDA = bermudagrass; PACO = kleingrass; SOHA = Johnsongrass; AMPS = ragweed.
Annual aboveground production (g/m^2) of three forage species, adjusted to mean annual precipitation for Goliad County (34.8 inches), are 576 for bermudagrass, 794 for kleingrass, and 866 for King Ranch bluestem (McCawley 1978, Kapinga 1982) on Orelia fine sandy loam soils. Compared to production from native species (sandy loam = 488 g/m^2), there are 1.18 for bermudagrass, 1.62 for kleingrass, and 1.77 for King Ranch bluestem. Total forage biomass of improved pastures was estimated by multiplying these respective factors by total grass production under excellent range condition (Table C.2).
Major improved pasture species are assumed to be determined by soil texture and soil depth: clays and clay loams = kleingrass; sands, sandy loams, shallow soils, and wetlands = bermudagrass. King Ranch bluestem and Johnsongrass are each considered to constitute 5% of the forage biomass on all improved pastures.

Appendix Table C.27 Initial vegetation plot types, including separation by woody plant coverage (%), used in the Goliad County EDYS model.

Plot Type	Range Type	Woody Coverage	Number of Cells	Plot Type	Range Type	Woody Coverage	Number of Cells
4501	Blackland Coastal	0-1	507	12101	Loamy Prairie	0-1	105
4601	Blackland Coastal	1-10	1389	12201	Loamy Prairie	1-10	354
4701	Blackland Coastal	10-25	67	12301	Loamy Prairie	10-25	657
4801	Blackland Coastal	25-50	240	12401	Loamy Prairie	25-50	702
4901	Blackland Coastal	50-75	310	12501	Loamy Prairie	50-75	7
5001	Blackland Coastal	75-90	174	12601	Loamy Prairie	75-90	1783
5101	Blackland Coastal	90-100	15				
				8701	Loamy Sand	0-1	2052
4201	Blackland RG Plains	25-50	1639	8801	Loamy Sand	1-10	8600
4301	Blackland RG Plains	50-75	2770	8901	Loamy Sand	10-25	3482
4401	Blackland RG Plains	75-90	1348	9001	Loamy Sand	25-50	5942
				9101	Loamy Sand	50-75	7509
13401	Clay Loam	0-1	22332	9201	Loamy Sand	75-90	1248
13501	Clay Loam	1-10	6905	9301	Loamy Sand	90-100	15
13601	Clay Loam	10-25	9175				
13701	Clay Loam	25-50	14636	1301	Lowland Coastal	0-1	287
13801	Clay Loam	50-75	2546	1401	Lowland Coastal	1-10	466
13901	Clay Loam	75-90	22	1501	Lowland Coastal	10-25	235
14001	Clay Loam	90-100	211	1601	Lowland Coastal	25-50	144
				1701	Lowland Coastal	50-75	458
801	Clayey Bottomland	1-10	3	1801	Lowland Coastal	75-90	80
901	Clayey Bottomland	25-50	135				
1001	Clayey Bottomland	50-75	712	1901	Rolling Blackland	1-10	25
1101	Clayey Bottomland	75-90	19	2001	Rolling Blackland	10-25	66
1201	Clayey Bottomland	90-100	135	2101	Rolling Blackland	25-50	338
				2201	Rolling Blackland	50-75	575
14101	Claypan Prairie	0-1	514	2301	Rolling Blackland	75-90	21
14201	Claypan Prairie	1-10	1524	2401	Rolling Blackland	90-100	45
14301	Claypan Prairie	10-25	3368				
14401	Claypan Prairie	25-50	1033	3001	Salty Prairie	0-1	114
14501	Claypan Prairie	50-75	6	3101	Salty Prairie	1-10	589
14601	Claypan Prairie	75-90	43	3201	Salty Prairie	10-25	507
14701	Claypan Prairie	90-100	306	3301	Salty Prairie	25-50	61
				3401	Salty Prairie	50-75	1529
10101	Claypan Savannah	0-1	1	3501	Salty Prairie	75-90	18
10201	Claypan Savannah	1-10	331				
10301	Claypan Savannah	10-25	133	5201	Sandy	0-1	343
10401	Claypan Savannah	25-50	210	5301	Sandy	1-10	415
10501	Claypan Savannah	50-75	543	5401	Sandy	10-25	578
10601	Claypan Savannah	75-90	833	5501	Sandy	25-50	633
				5601	Sandy	50-75	846
3601	Deep Sand	0-1	199	5701	Sandy	75-90	209
3701	Deep Sand	1-10	141	5801	Sandy	90-100	6
3801	Deep Sand	10-25	101				
3901	Deep Sand	25-50	41	14801	Sandy Bottomland	0-1	597
4001	Deep Sand	50-75	723	14901	Sandy Bottomland	1-10	1211
4101	Deep Sand	75-90	495	15001	Sandy Bottomland	10-25	1732
				15101	Sandy Bottomland	25-50	1221
8001	Gravelly Ridge	0-1	13	15201	Sandy Bottomland	50-75	342
8101	Gravelly Ridge	1-10	117	15301	Sandy Bottomland	75-90	525
8201	Gravelly Ridge	10-25	185	15401	Sandy Bottomland	90-100	43
8301	Gravelly Ridge	25-50	84				
8401	Gravelly Ridge	50-75	141	12701	Sandy Loam	0-1	5836
8501	Gravelly Ridge	75-90	89	12801	Sandy Loam	1-10	2174
8601	Gravelly Ridge	90-100	10	12901	Sandy Loam	10-25	2125
				13001	Sandy Loam	25-50	2737
7301	Gray Sandy Loam	0-1	41	13101	Sandy Loam	50-75	640
7401	Gray Sandy Loam	1-10	144	13201	Sandy Loam	75-90	99
7501	Gray Sandy Loam	10-25	246	13301	Sandy Loam	90-100	36
7601	Gray Sandy Loam	25-50	4337				
7701	Gray Sandy Loam	50-75	3713	5901	Shallow Ridge	0-1	649
7801	Gray Sandy Loam	75-90	505	6001	Shallow Ridge	1-10	1086
7901	Gray Sandy Loam	90-100	151	6101	Shallow Ridge	10-25	824
				6201	Shallow Ridge	25-50	1375

Appendix Table C.27 (Cont.)

Plot Type	Range Type	Woody Coverage	Number of Cells	Plot Type	Range Type	Woody Coverage	Number of Cells
2501	Lakebed Coastal	0-1	178	6301	Shallow Ridge	50-75	1387
2601	Lakebed Coastal	1-10	9	6401	Shallow Ridge	75-90	21
2701	Lakebed Coastal	10-25	129	6501	Shallow Ridge	90-100	30
2801	Lakebed Coastal	25-50	247				
2901	Lakebed Coastal	50-75	8	6601	Shallow Sandy Loam	0-1	602
				6701	Shallow Sandy Loam	1-10	1219
9401	Lakebed RG Plains	0-1	23	6801	Shallow Sandy Loam	10-25	851
9501	Lakebed RG Plains	1-10	212	6901	Shallow Sandy Loam	25-50	921
9601	Lakebed RG Plains	10-25	11	7001	Shallow Sandy Loam	50-75	1133
9701	Lakebed RG Plains	25-50	11	7101	Shallow Sandy Loam	75-90	88
9801	Lakebed RG Plains	50-75	10	7201	Shallow Sandy Loam	90-100	62
9901	Lakebed RG Plains	75-90	175				
10001	Lakebed RG Plains	90-100	20	10701	Sloping Clay Loam	0-1	70
				10801	Sloping Clay Loam	1-10	166
11401	Loamy Bottomland	0-1	107	10901	Sloping Clay Loam	10-25	24
11501	Loamy Bottomland	1-10	34	11001	Sloping Clay Loam	25-50	104
11601	Loamy Bottomland	10-25	320	11101	Sloping Clay Loam	50-75	30
11701	Loamy Bottomland	25-50	1598	11201	Sloping Clay Loam	75-90	259
11801	Loamy Bottomland	50-75	159	11301	Sloping Clay Loam	90-100	3
11901	Loamy Bottomland	75-90	503				
12001	Loamy Bottomland	90-100	64	101	Tight Sandy Loam	0-1	1564
				201	Tight Sandy Loam	1-10	9342
				301	Tight Sandy Loam	10-25	3337
				401	Tight Sandy Loam	25-50	4501
				501	Tight Sandy Loam	50-75	7014
				601	Tight Sandy Loam	75-90	1304
				701	Tight Sandy Loam	90-100	216

Appendix Table C.28 Weighted mean woody plant cover (%) by plot type and overall used as initial input values into the Goliad County EDYS model. Means are weighted by area (number of cells) in each woody coverage category.

Range Type	Number of Cells	(Number of Cells)(Woody Coverage)	Mean Woody Cover
Blackland Coastal	13,321	3,063.23	23.00
Blackland RG Plains	5,875	3,532.60	60.13
Clay Loam	308,678	129,654.43	42.00
Clayey Bottomland	15,355	10,177.73	66.28
Claypan Prairie	90,749	10,258.11	11.30
Claypan Savanna	67,511	31,659.33	46.90
Deep Sand	4,750	1,966.86	41.41
Gravelly Ridge	4,593	2,004.61	43.64
Gray Sandy Loam	44,025	24,683.23	56.07
Lakebed Coastal	833	193.65	23.25
Lakebed RG Plains	2,171	872.34	40.18
Loamy Bottomland	48,961	27,599.67	56.37
Loamy Prairie	35,503	9,443.67	26.60
Loamy Sand	165,968	53,239.76	32.08
Lowland Coastal	1,678	479.74	28.59
Rolling Blackland	11,634	6,475.47	55.66
Salty Prairie	36,184	2,638.58	10.06
Sandy	26,558	9,932.44	37.40
Sandy Bottomland	24,786	13,898.80	56.08
Sandy Loam	55,761	10,550.01	18.92
Shallow Ridge	40,668	14,410.55	35.42
Shallow Sandy Loam	46,612	30,670.13	65.80
Sloping Clay Loam	2,790	867.24	31.08
Tight Sandy Loam	207,904	73,877.55	35.53
Improved Pasture	25,794	350.92	1.36
Total	1,288,662	471,500.65	
Overall Weighted Mean			36.59

Appendix Table C.29 Forage consumption (C; g/m^2) by cattle on a seacoast bluestem-McCartney rose pasture in Calhoun County, Texas. Values are from utilization (U; %) x available forage (F; g/m^2). Data taken from Durham and Kothmann (1977).

Species	Dec 22			Jan 14			Feb 11			Mar 08			Mar 25			Apr 08		
	U	F	C	U	F	C	U	F	C	U	F	C	U	F	C	U	F	C
McCartney rose	6	101	6.1	9	44	4.0	6	94	5.8	5	36	1.8	2	90	1.8	0	--	1.3
Bermudagrass	35	38	13.3	31	22	6.8	40	33	13.2	27	58	15.7	20	85	17.0	31	58	18.0
Longtom	15	19	2.9	33	37	12.2	32	63	20.2	25	91	22.8	22	54	11.9	11	60	6.6
Brownseed paspalum	28	15	4.2	26	37	9.6	38	31	11.8	25	46	11.5	17	54	9.2	14	36	5.0
Seacoast bluestem	10	105	10.5	16	53	8.5	29	75	21.8	22	73	16.1	22	146	32.1	24	83	19.9
Knotroot bristle	12	83	10.0	3	31	0.9	30	15	4.5	24	8	1.9	27	8	2.2	40	6	2.4
Indiangrass	7	31	2.2	4	30	1.2	25	15	3.8	18	31	5.6	14	34	4.8	33	21	7.0
Smutgrass	37	45	16.7	44	43	18.9	55	24	13.2	46	22	10.1	36	11	4.0	14	14	2.0
Other grasses	5	42	2.1	14	30	4.2	15	15	2.3	14	24	3.4	24	33	8.0	20	13	2.6
Total			68.0			66.3			96.6			88.9			91.0			64.8

Consumption of McCartney rose was calculated from botanical composition of diet data.

Appendix Table C.30 Calculation of forage disappearance, animal unit basis, by cattle on a seacoast bluestem-McCartney rose pasture in Calhoun County, Texas. Data taken from Durham and Kothmann (1977).

Total forage utilization over 110 days (22 Dec-10 Apr) = 475.6 g/m^2 (Appendix Table C.27) = 4.32 g/m^2 per day.
Total area grazed = 7.2 ha = 72,000 m^2 = 17.8 acres.
Area was grazed by four cows. Assume cows were 1000 lbs = 4 AU.
Average daily consumption = (72,000 m^2)(4.32 g/m^2/d)/4 AU = 77,760 g/AUD = 171.28 lbs/AUD

Total forage production = forage utilized + forage remaining = (475.6 – 20.8) + 291 = 746 g/m^2
Utilization rate = 455/746 = 0.610

ADDITIONAL PLANT AND VEGETATION DATA

Bovey, R.W., R.E. Meyer, and H.L. Morton. 1972. Herbage production following brush control with herbicides in Texas. Journal of Range Management 25:136-142.

Victoria County, Katy gravelly sandy loam.
Live oak-little bluestem community (shrub live oak = 2 m tall): live oak, little bluestem, brownseed paspalum, indiangrass, threeawns, lovegrasses, knotroot bristlegrass, bitter sneezeweed, Lindheimer doveweed.
Oct 1967 herbaceous biomass = 185 g/m^2 grasses + 18 g/m^2 forbs
Area bulldozed in Jul 1963 and harvested in Apr 1970 = 114 g/m^2 live oak regrowth + 2 g/m^2 grasses + 2 g/m^2 forbs
Victoria 1967 PPT = 33.90 inches = 86.1 cm Oct 1966-Sep 1967 = 28.18 inches = 71.6 cm

PUE = 203 g/m^2/71.6 cm = 2.84 g/m^2/cm + live oak production

Box, Thadis W. and Richard S. White. 1969. Fall and winter burning of South Texas brush ranges. Journal of Range Management 22:373-376.

Chaparral community, Welder Wildlife Refuge. Mesquite-huisache-blackbrush community

Sampled Aug 1967
Herbaceous production (24% buffalograss, 9% silver bluestem, 8% ruellia, 15% Texas broomweed):
163.6 g/m^2 = 97.7 g/m^2 grasses + 65.9 g/m^2 forbs

Buckley, P.E. and J.D. Dodd. 1969. Heavy precipitation influences saline clay flat vegetation. Journal of Range Management 22:405-407.

18 mi NNE of Zapata. Prickly pear-saladillo-mesquite community. Root plowed in 1962.
Sampled in Nov 1967 following Beulah.
Herbaceous production (56% Hall panicum, 20% curly mesquite, 10% whorled dropseed): 136 g/m^2
1967 PPT at study site = 26.39 inches = 67.0 cm

PUE = 136 g/m^2/67.0 cm = 2.03 g/m^2/cm + shrub production

Dodd, J.D. and S.T. Holtz. 1972. Integration of burning with mechanical manipulation of South Texas grassland. Journal of Range Management 25:130-136.

Cartwright Ranch, Goliad County. Blackbrush-Texas persimmon-hogplum community.
Sampled Jun 1968.
Herbaceous production = 145 g/m^2 = 41 g/m^2 grass (24% sedge, 20% Texas grama, 16% threeawns) + 104 g/m^2 forbs (8% orange zexmenia, 4% Texas broomweed)
Jun 1967-May 1968 PPT at Goliad = 54.45 inches = 138.3 cm

PUE = 145 g/m^2/138.3 cm = 1.05 g/m^2/cm + shrub production

Drawe, D. Lynn and Thadis W. Box. 1969. High rates of nitrogen fertilization influence coastal prairie range. Journal of Range Management 22:32-36.

Bunchgrass-annual forb community on Zavala fine sandy loam, Welder Wildlife Refuge.
21% camphorweed, 14% knotgrass, 12% balsamscale, 10% sandbur, 9% signalgrass, 6% seacoast
Sampled in August of each year.

	1965	1966	1967	
Herbaceous production (g/m^2):	237	228	252	
Grasses (g/m^2):	159	137	192	
Forbs (g/m^2):	78	91	60	
Sep-Aug PPT (cm):	68.5	101.3	65.2	Refugio PPT(0.904)
PUE ($g/m^2/cm$):	3.46	2.25	3.87	Mean = 3.20

Jan 1964-Sep 1965 PPT Refugio = 50.59 inches
Jan 1964-Sep 1965 PPT WWR = 45.74 inches 45.74/50.59 = 0.904

Powell, Jeff and Thadis W. Box. 1967. Mechanical control and fertilization as brush management practices affect forage production in South Texas. Journal of Range Management 20:227-236.

Chaparral-bristlegrass community, Victoria clay, Welder Wildlife Refuge.
Blackbrush-huisache-mesquite (49% brush cover).
Herbaceous: plains bristlegrass (15%), buffalograss (11%), ragweed, Texas broomweed (31% forbs)
Forage production: 101 g/m^2 in 1964; 162 g/m^2 in 1965

Oct 1963-Sep 1964 PPT = 0.904(Refugio) = 0.904(33.37) = 30.17 inches = 76.6 cm
Oct 1964-Sep 1965 PPT = 0.904(Refugio Oct-Dec) + 17.44 inches = 0.904(7.03) + 17.44 = 60.5 cm

1964 PUE = 101 g/m^2/76.6 cm = 1.32 $g/m^2/cm$ 1965 PUE = 162 g/m^2/60.5 cm = 2.68 $g/m^2/cm$

APPENDIX D ANIMALS

Appendix Table D.1 Estimation of cattle stocking rates (moderate level) for vegetation plot types in the Goliad County EDYS model. Values assume fair range condition and no woody plant cover.

Range Type	Annual Forage (g/m^2)	Available Forage (g/m^2)	AU Forage Requirement (g/AUD)(365 d)	Stocking Rate (m^2/AU)	Stocking Rate (ac/AU)
Blackland RG Plains	261	131	5,634,870	43,014	10.63
Blackland Coastal	522	261	5,634,870	21,580	5.33
Clayey Bottomland	286	143	5,634,870	39,405	9.73
Clay Loam	286	143	5,634,870	39,405	9.73
Claypan Prairie	379	190	5,634,870	29,657	7.33
Claypan Savanna	306	153	5,634,870	36,829	9.10
Deep Sand	243	122	5,634,870	46,188	11.41
Gravelly Ridge	178	89	5,634,870	63,313	15.64
Gray Sandy Loam	260	130	5,634,870	43,345	10.71
Lakebed RG Plains	276	138	5,634,870	40,832	10.09
Lakebed Coastal	350	175	5,634,870	32,199	7.95
Loamy Bottomland	431	216	5,634,870	26,087	6.94
Loamy Prairie	410	205	5,634,870	27,487	6.79
Loamy Sand	295	148	5,634,870	38,074	9.41
Lowland Coastal	447	224	5,634,870	25,156	6.21
Rolling Blackland	260	130	5,634,870	43,345	10.71
Salty Prairie	520	260	5,634,870	21,673	5.35
Sandy	297	149	5,634,870	37,818	9.34
Sandy Bottomland	369	185	5,634,870	30,459	7.52
Sandy Loam	342	171	5,634,870	32,952	8.14
Shallow Ridge	134	67	5,634,870	84,103	20.78
Shallow Sandy Loam	210	105	5,634,870	53,665	13.26
Sloping Clay Loam	186	93	5,634,870	60,590	14.97
Tight Sandy Loam	285	143	5,634,870	39,405	9.73
Improved Pasture	566	283	5,634,870	19,911	4.92
Mean					9.67

Annual forage = fair range condition (Appendix Table C.2).
Available forage = (Annual Forage)(0.5), whre 0.5 is proper management harvest rate.
AU Forage Requirement = 15,438 g/AUD = (Table 6.1). Stocking Rate = (AU Forage Requirement)/(Available Forage).

Appendix Table D.2 Estimation of cattle stocking rates (moderate level) for vegetation plot types, adusted for woody plant cover, in the Goliad County EDYS model. Values assume fair range condition.

Range Type	Woody Cover (%)	Annual Forage (g/m^2)	Available Forage (g/m^2)	Forage Requirement (g/AU)	Stocking Rate (m^2/AU)	Stocking Rate (ac/AU)
Blackland RG Plains	0	261	131	5,634,870	43,104	10.63
Blackland RG Plains	38	182	91	5,634,870	61,922	15.30
Blackland RG Plains	63	130	65	5,634,870	86,690	21.42
Blackland RG Plains	83	87	44	5,634,870	128,065	31.64
Blackland Coastal	0	522	261	5,634,870	21,580	5.33
Blackland Coastal	5	501	250	5,634,870	22,539	5.57
Blackland Coastal	18	447	223	5,634,870	25,268	6.24
Blackland Coastal	38	364	182	5,634,870	30,961	7.65
Blackland Coastal	63	261	130	5,634,870	43,345	10.71
Blackland Coastal	83	174	87	5,634,870	64,769	16.00
Blackland Coastal	95	63	31	5,634,870	181,770	44.90
Clayey Bottomland	0	286	143	5,634,870	39,405	9.73
Clayey Bottomland	5	275	137	5,634,870	41,130	10.16
Clayey Bottomland	38	200	100	5,634,870	56,349	13.92
Clayey Bottomland	63	143	71	5,634,870	79,364	19.61
Clayey Bottomland	83	95	47	5,634,870	119,891	29.62
Clay Loam	0	286	143	5,634,870	39,405	9.73
Clay Loam	5	275	137	5,634,870	41,130	10.16
Clay Loam	18	245	122	5,634,870	46,187	11.41
Clay Loam	38	200	100	5,634,870	56,349	13.92
Clay Loam	63	143	71	5,634,870	79,364	19.61
Clay Loam	83	95	47	5,634,870	119,891	29.62
Clay Loam	95	69	34	5,634,870	165,731	40.94
Claypan Prairie	0	379	190	5,634,870	29,657	7.33
Claypan Prairie	5	364	182	5,634,870	30,961	7.65
Claypan Prairie	18	324	162	5,634,870	34,783	8.59
Claypan Prairie	38	265	132	5,634,870	42,688	10.55
Claypan Prairie	63	189	94	5,634,870	59,945	14.81
Claypan Prairie	83	129	64	5,634,870	88,045	21.75
Claypan Prairie	95	91	45	5,634,870	125,217	30.93
Claypan Savanna	0	306	153	5,634,870	36,829	9.10
Claypan Savanna	5	294	147	5,634,870	38,333	9.47
Claypan Savanna	18	262	131	5,634,870	43,014	10.63
Claypan Savanna	38	214	107	5,634,870	52,662	13.01
Claypan Savanna	63	153	76	5,634,870	74,143	18.32
Claypan Savanna	83	102	51	5,634,870	110,488	27.29
Deep Sand	0	243	122	5,634,870	46,187	11.41
Deep Sand	5	233	116	5,634,870	48,577	12.00
Deep Sand	18	208	104	5,634,870	54,181	13.38
Deep Sand	38	170	85	5,634,870	66,293	16.38
Deep Sand	63	121	60	5,634,870	93,915	23.20
Deep Sand	83	81	40	5,634,870	140,872	34.80
Gravelly Ridge	0	178	89	5,634,870	63,313	15.64
Gravelly Ridge	5	171	85	5,634,870	66,293	16.38
Gravelly Ridge	18	152	76	5,634,870	74,143	18.32
Gravelly Ridge	38	124	62	5,634,870	90,885	21.45
Gravelly Ridge	63	89	45	5,634,870	125,217	30.93
Gravelly Ridge	83	59	29	5,634,870	194,306	48.00
Gravelly Ridge	95	43	21	5,634,870	268,327	66.29
Gray Sandy Loam	0	260	130	5,634,870	43,345	10.71
Gray Sandy Loam	5	250	125	5,634,870	45,079	11.14
Gray Sandy Loam	18	223	111	5,634,870	50,765	12.54
Gray Sandy Loam	38	182	91	5,634,870	61,922	15.30
Gray Sandy Loam	63	130	65	5,634,870	86,690	21.42
Gray Sandy Loam	83	86	43	5,634,870	131,043	32.37
Gray Sandy Loam	95	62	31	5,634,870	181,770	44.90
Lakebed RG Plains	0	276	138	5,634,870	40,832	10.09
Lakebed RG Plains	5	265	132	5,634,870	42,688	10.55
Lakebed RG Plains	18	236	118	5,634,870	47,753	11.80
Lakebed RG Plains	38	193	96	5,634,870	58,697	14.50
Lakebed RG Plains	63	138	69	5,634,870	81,665	20.17
Lakebed RG Plains	83	92	46	5,634,870	122,497	30.26
Lakebed RG Plains	95	74	37	5,634,870	152,294	37.62
Lakebed Coastal	0	350	175	5,634,870	32,199	7.95

Appendix Table D.2 (Cont.)

Range Type	Woody Cover (%)	Annual Forage (g/m^2)	Available Forage (g/m^2)	Forage Requirement (g/AU)	Stocking Rate (m^2/AU)	Stocking Rate (ac/AU)
Lakebed Coastal	5	336	168	5,634,870	33,451	8.26
Lakebed Coastal	18	300	150	5,634,870	37,566	9.28
Lakebed Coastal	38	245	122	5,634,870	46,187	11.41
Lakebed Coastal	63	168	84	5,634,870	67,082	16.57
Loamy Bottomland	0	431	216	5,634,870	26,087	6.94
Loamy Bottomland	5	414	207	5,634,870	27,222	6.72
Loamy Bottomland	18	369	184	5,634,870	30,624	7.57
Loamy Bottomland	38	300	150	5,634,870	37,566	9.28
Loamy Bottomland	63	215	107	5,634,870	52,662	13.01
Loamy Bottomland	83	143	71	5,634,870	79,364	19.61
Loamy Bottomland	95	103	51	5,634,870	110,488	27.29
Loamy Prairie	0	410	205	5,634,870	27,487	6.79
Loamy Prairie	5	394	197	5,634,870	28,603	7.07
Loamy Prairie	18	351	175	5,634,870	32,199	7.95
Loamy Prairie	38	286	143	5,634,870	39,405	9.73
Loamy Prairie	63	205	102	5,634,870	55,244	13.65
Loamy Prairie	83	136	68	5,634,870	82,866	20.47
Loamy Sand	0	295	148	5,634,870	38,074	9.41
Loamy Sand	5	283	141	5,634,870	39,964	9.87
Loamy Sand	18	253	126	5,634,870	44,721	11.05
Loamy Sand	38	206	103	5,634,870	54,707	13.51
Loamy Sand	63	147	73	5,634,870	77,190	19.07
Loamy Sand	83	98	49	5,634,870	114,997	28.41
Loamy Sand	95	71	35	5,634,870	160,996	39.77
Lowland Coastal	0	447	224	5,634,870	25,156	6.21
Lowland Coastal	5	429	214	5,634,870	26,331	6.50
Lowland Coastal	18	383	191	5,634,870	29,502	7.29
Lowland Coastal	38	312	156	5,634,870	36,121	8.92
Lowland Coastal	63	223	111	5,634,870	50,765	12.54
Lowland Coastal	83	149	74	5,634,870	76,147	18.81
Rolling Blackland	0	260	130	5,634,870	43,345	10.71
Rolling Blackland	5	250	125	5,634,870	45,079	11.14
Rolling Blackland	18	223	111	5,634,870	50,765	12.54
Rolling Blackland	38	182	91	5,634,870	61,922	15.30
Rolling Blackland	63	130	65	5,634,870	86,690	21.42
Rolling Blackland	83	86	43	5,634,870	131,043	32.37
Rolling Blackland	95	62	31	5,634,870	181,770	44.90
Salty Prairie	0	520	260	5,634,870	21,673	5.35
Salty Prairie	5	499	249	5,634,870	22,630	5.59
Salty Prairie	18	445	222	5,634,870	25,382	6.27
Salty Prairie	38	364	182	5,634,870	30,961	7.65
Salty Prairie	63	260	130	5,634,870	43,345	10.71
Salty Prairie	83	172	86	5,634,870	65,522	16.19
Sandy	0	297	149	5,634,870	37,818	9.34
Sandy	5	285	142	5,634,870	39,682	9.80
Sandy	18	254	127	5,634,870	44,369	10.96
Sandy	38	207	103	5,634,870	54,707	13.51
Sandy	63	148	74	5,634,870	76,147	18.81
Sandy	83	99	49	5,634,870	114,997	28.41
Sandy	95	71	35	5,634,870	160,996	39.77
Sandy Bottomland	0	369	185	5,634,870	30,459	7.52
Sandy Bottomland	5	354	177	5,634,870	31,835	7.86
Sandy Bottomland	18	316	158	5,634,870	35,664	8.81
Sandy Bottomland	38	258	129	5,634,870	43,666	10.79
Sandy Bottomland	63	184	92	5,634,870	61,249	15.13
Sandy Bottomland	83	123	61	5,634,870	92,375	22.82
Sandy Bottomland	95	89	44	5,634,870	128,065	31.64
Sandy Loam	0	342	171	5,634,870	32,952	8.14
Sandy Loam	5	328	164	5,634,870	34,359	8.49
Sandy Loam	18	293	146	5,634,870	38,595	9.56
Sandy Loam	38	238	119	5,634,870	47,352	11.70
Sandy Loam	63	171	85	5,634,870	66,293	16.38
Sandy Loam	83	114	57	5,634,870	98,857	24.42
Sandy Loam	95	82	41	5,634,870	137,436	33.95
Shallow Ridge	0	134	67	5,634,870	84,103	20.78
Shallow Ridge	5	129	64	5,634,870	88,045	21.75

Appendix Table D.2 (Cont.)

Range Type	Woody Cover (%)	Annual Forage (g/m^2)	Available Forage (g/m^2)	Forage Requirement (g/AU)	Stocking Rate (m^2/AU)	Stocking Rate (ac/AU)
Shallow Ridge	18	115	57	5,634,870	98,857	24.42
Shallow Ridge	38	93	46	5,634,870	122,497	30.26
Shallow Ridge	63	67	33	5,634,870	170,754	42.18
Shallow Ridge	83	44	22	5,634,870	256,130	63.27
Shallow Ridge	95	32	16	5,634,870	352,179	87.00
Shallow Sandy Loam	0	210	105	5,634,870	53,665	13.26
Shallow Sandy Loam	5	202	101	5,634,870	55,791	13.78
Shallow Sandy Loam	18	180	90	5,634,870	62,610	15.47
Shallow Sandy Loam	38	147	73	5,634,870	77,190	19.07
Shallow Sandy Loam	63	105	52	5,634,870	108,363	26.77
Shallow Sandy Loam	83	70	35	5,634,870	160,996	39.77
Shallow Sandy Loam	95	50	25	5,634,870	225,395	55.68
Sloping Clay Loam	0	186	93	5,634,870	60,590	14.97
Sloping Clay Loam	5	179	89	5,934,870	63,313	15.63
Sloping Clay Loam	18	159	79	5,934,870	71,327	17.62
Sloping Clay Loam	38	130	65	5,634,870	86,690	21.42
Sloping Clay Loam	63	93	46	5,634,870	122,497	30.26
Sloping Clay Loam	83	62	31	5,634,870	181,770	44.90
Sloping Clay Loam	95	45	22	5,634,870	256,130	63.27
Tight Sandy Loam	0	285	143	5,634,870	39,405	9.73
Tight Sandy Loam	5	274	137	5,634,870	41,130	10.16
Tight Sandy Loam	18	244	122	5,634,870	46,187	11.41
Tight Sandy Loam	38	199	99	5,634,870	56,918	14.06
Tight Sandy Loam	63	142	71	5,634,870	79,364	19.61
Tight Sandy Loam	83	95	47	5,634,870	119,891	29.62
Tight Sandy Loam	95	68	34	5,634,870	165,731	40.94
Improved Pasture	0	566	283	5,634,870	19,911	4.92
Improved Pasture	5	543	271	5,634,870	20,793	5.14
Improved Pasture	18	484	242	5,634,870	23,285	5.75
Caliche Pit	0	100	50	5,634,870	112,697	27.84
Caliche Pit	5	96	48	5,634,870	117,393	29.00
Caliche Pit	18	86	43	5,634,870	131,043	32.37
Caliche Pit	38	70	35	5,634,870	160,996	39.77
Disturbed Site	0	100	50	5,634,870	112,697	27.84
Disturbed Site	5	96	48	5,634,870	117,393	29.00
Disturbed Site	18	86	43	5,634,870	131,043	32.37
Disturbed Site	38	70	35	5,634,870	160,996	39.37
Orchard	0	70	35	5,634,870	160,996	39.37
Orchard	5	67	33	5,634,870	170,754	42.18
Orchard	18	60	30	5,634,870	187,829	46.40
Orchard	38	49	24	5,634,870	234,786	58.00
Urban/Housing	0	500	250	5,634,870	22,539	5.57
Urban/Housing	5	480	240	5,634,870	23,479	5.80
Urban/Housing	18	428	214	5,634,870	26,331	6.50
Urban/Housing	38	348	174	5,634,870	32,384	8.00
Urban/Housing	63	250	125	5,634,870	45,079	11.14
Industrial	0	350	175	5,634,870	32,199	7.95
Industrial	5	336	168	5,634,870	33,541	8.26
Industrial	18	300	150	5,634,870	37,566	9.28
Industrial	38	245	122	5,634,870	46,187	11.41
Oil Pad	0	0	0	5,634,870	-------	-----
Oil Pad	5	0	0	5,634,870	-------	-----
Oil Pad	18	0	0	5,634,870	-------	-----

Annual forage = fair range condition (Appendix Table C.2).
Available forage = (Annual Forage)(0.5), where 0.5 is proper management harvest rate.
AU Forage Requirement = 15,438 g/AUD (Table 6.1).
Stocking rate = (AU Forage Requirement)(Available Forage)[1.00 – 0.8(percent woody plant cover/100)]; Appendix Table C.24.

APPENDIX E PLANT PARAMETERS

Appendix Table E.1 General species characteristics for species used in the Goliad County EDYS model.

Common Name	Growth Form	Legume	Biennial
Huisache	Deciduous Tree	1	No
Pecan	Deciduous Tree	0	No
Sugar hackberry	Deciduous Tree	0	No
Mesquite	Deciduous Tree	1	No
Post oak	Deciduous Tree	0	No
Live oak	Evergreen Tree	0	No
Guajillo	Evergreen Shrub	1	No
Blackbrush	Deciduous Shrub	1	No
Whitebrush	Deciduous Shrub	0	No
Prairie baccharis	Deciduous Shrub	0	No
Sea oxeye	Deciduous Shrub	0	No
Granjeno	Deciduous Shrub	0	No
Carolina wolfberry	Deciduous Shrub	0	No
Agarito	evergreen shrub	0	No
McCartney rose	Deciduous Shrub	0	No
Rattlepod	Deciduous Shrub	1	No
Mustang grape	Deciduous Vine	0	No
Texas prickly pear	Cacti	0	No
Big bluestem	Perennial Grass	0	No
Bushy bluestem	Perennial Grass	0	No
Purple threeawn	Perennial Grass	0	No
King Ranch bluestem	Perennial Grass	0	No
Silver bluestem	Perennial Grass	0	No
Sideoats grama	Perennial Grass	0	No
Hairy grama	Perennial Grass	0	No
Red grama	Perennial Grass	0	No
Buffalograss	Perennial Grass	0	No
Sandbur	Perennial Grass	0	No
Hooded windmillgrass	Perennial Grass	0	No
Trichloris	Perennial Grass	0	No
Bermudagrass	Perennial Grass	0	No
Arizona cottontop	Perennial Grass	0	No
Saltgrass	Perennial Grass	0	No
Virginia wildrye	Perennial Grass	0	No
Texas cupgrass	Perennial Grass	0	No
Green sprangletop	Perennial Grass	0	No
Kleingrass	Perennial Grass	0	No
Guineagrass	Perennial Grass	0	No
Vine-mesquite	Perennial Grass	0	No
Switchgrass	Perennial Grass	0	No
Longtom	Perennial Grass	0	No
Brownseed paspalum	Perennial Grass	0	No

Appendix Table E.1 (Cont.)

Common Name	Growth Form	Legume	Biennial
Thin paspalum	Perennial Grass	0	No
Common reed	Perennial Grass	0	No
Little bluestem	Perennial Grass	0	No
Knotroot bristlegrass	Perennial Grass	0	No
Plains bristlegrass	Perennial Grass	0	No
Texas bristlegrass	Perennial Grass	0	No
Indiangrass	Perennial Grass	0	No
Johnsongrass	Perennial Grass	0	No
Gulf cordgrass	Perennial Grass	0	No
Tall dropseed	Perennial Grass	0	No
Sand dropseed	Perennial Grass	0	No
Smutgrass	Perennial Grass	0	No
Texas wintergrass	Perennial Grass	0	No
Milo	Annual Grass	0	No
Wheat	Annual Grass	0	No
Corn	Annual Grass	0	No
Littletooth sedge	Perennial Grasslike	0	No
Flatsedge	Perennial Grasslike	0	No
Cattail	Perennial Grasslike	0	No
Ragweed	Perennial Forb	0	No
Lazydaisy	Perennial Forb	0	No
Spiny aster	Perennial Forb	0	No
Whitestem wild indigo	Perennial Forb	0	No
Old-mans beard	Perennial Forb	0	No
Bundleflower	Perennial Forb	1	No
Frogfruit	Perennial Forb	0	No
Prairie coneflower	Perennial Forb	0	No
Snoutbean	Perennial Forb	1	No
Ruellia	Perennial Forb	0	No
Curly dock	Perennial Forb	1	No
Bulltongue	Perennial Forb	1	No
Glasswort	Perennial Forb	0	No
Bush sunflower	Perennial Forb	0	No
Green briar	Perennial Forb	0	No
Texas verbena	Perennial Forb	0	No
Orange zexmenia	Perennial Forb	0	No
Giant ragweed	Annual Forb	0	No
Annual broomweed	Annual Forb	0	No
Partridge pea	Annual Forb	1	No
Texas doveweed	Annual Forb	0	No
Sunflower	Annual Forb	0	No
Dogweed	Annual Forb	0	No

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

Common Name	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Huisache	0.34	0.12	0.38	0.11	0.05	0.00
Pecan	0.32	0.11	0.40	0.12	0.05	0.00
Sugar hackberry	0.16	0.06	0.55	0.17	0.06	0.00
Mesquite	0.14	0.10	0.39	0.28	0.09	0.00
Post oak	0.20	0.07	0.51	0.16	0.06	0.00
Live oak	0.24	0.08	0.48	0.15	0.05	0.00
Guajillo	0.27	0.12	0.34	0.18	0.09	0.00
Blackbrush	0.27	0.12	0.34	0.18	0.09	0.00
Whitebrush	0.26	0.12	0.34	0.19	0.09	0.00
Prairie baccharis	0.26	0.12	0.34	0.19	0.09	0.00
Sea oxeye	0.32	0.15	0.28	0.19	0.06	0.00
Granjeno	0.28	0.12	0.33	0.18	0.09	0.00
Carolina wolfberry	0.25	0.10	0.21	0.23	0.21	0.00
Agarito	0.35	0.14	0.28	0.15	0.08	0.00
McCartney rose	0.32	0.15	0.28	0.19	0.06	0.00
Rattlepod	0.27	0.11	0.34	0.19	0.09	0.00
Mustang grape	0.23	0.10	0.35	0.17	0.15	0.00
Texas prickly pear	0.16	0.08	0.37	0.38	0.01	0.00
Big bluestem	0.24	0.24	0.10	0.21	0.21	0.00
Bushy bluestem	0.23	0.36	0.13	0.16	0.12	0.00
Purple threeawn	0.33	0.32	0.07	0.14	0.14	0.00
King Ranch bluestem	0.31	0.30	0.08	0.16	0.15	0.00
Silver bluestem	0.25	0.25	0.10	0.20	0.20	0.00
Sideoats grama	0.31	0.31	0.08	0.15	0.15	0.00
Hairy grama	0.18	0.18	0.21	0.06	0.37	0.00
Red grama	0.18	0.18	0.21	0.06	0.37	0.00
Buffalograss	0.28	0.27	0.12	0.05	0.28	0.00
Sandbur	0.26	0.39	0.12	0.08	0.15	0.00
Hooded windmillgrass	0.23	0.24	0.14	0.05	0.34	0.00
Trichloris	0.25	0.25	0.10	0.20	0.20	0.00
Bermudagrass	0.28	0.27	0.15	0.05	0.25	0.00
Arizona cottontop	0.23	0.24	0.11	0.21	0.21	0.00
Saltgrass	0.23	0.36	0.13	0.16	0.12	0.00
Virginia wildrye	0.23	0.23	0.11	0.22	0.21	0.00
Texas cupgrass	0.26	0.26	0.10	0.19	0.19	0.00
Green sprangletop	0.23	0.23	0.11	0.22	0.21	0.00
Kleingrass	0.23	0.24	0.11	0.21	0.21	0.00
Guineagrass	0.23	0.24	0.11	0.21	0.21	0.00
Vine-mesquite	0.23	0.23	0.11	0.22	0.21	0.00
Switchgrass	0.25	0.25	0.10	0.20	0.20	0.00
Longtom	0.36	0.35	0.08	0.03	0.18	0.00
Brownseed paspalum	0.22	0.33	0.10	0.16	0.19	0.00

Appendix Table E.2 (Cont.)

Common Name	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Thin paspalum	0.22	0.21	0.17	0.06	0.34	0.00
Common reed	0.18	0.18	0.18	0.26	0.20	0.00
Little bluestem	0.31	0.31	0.08	0.15	0.15	0.00
Knotroot bristlegrass	0.26	0.26	0.14	0.05	0.29	0.00
Plains bristlegrass	0.31	0.46	0.03	0.12	0.08	0.00
Texas bristlegrass	0.19	0.19	0.19	0.06	0.37	0.00
Indiangrass	0.37	0.36	0.05	0.11	0.11	0.00
Johnsongrass	0.35	0.34	0.06	0.13	0.12	0.00
Gulf cordgrass	0.31	0.46	0.03	0.12	0.08	0.00
Tall dropseed	0.26	0.26	0.10	0.19	0.19	0.00
Sand dropseed	0.24	0.23	0.11	0.21	0.21	0.00
Smutgrass	0.31	0.46	0.03	0.12	0.08	0.00
Texas wintergrass	0.28	0.28	0.13	0.04	0.27	0.00
Milo	0.25	0.25	0.10	0.20	0.20	0.00
Wheat	0.23	0.24	0.11	0.21	0.21	0.00
Corn	0.25	0.25	0.10	0.20	0.20	0.00
Littletooth sedge	0.28	0.27	0.13	0.05	0.27	0.00
Flatsedge	0.39	0.38	0.05	0.09	0.09	0.00
Cattail	0.39	0.38	0.05	0.09	0.09	0.00
Ragweed	0.28	0.28	0.09	0.18	0.17	0.00
Lazydaisy	0.29	0.29	0.08	0.17	0.17	0.00
Spiny aster	0.49	0.20	0.05	0.17	0.09	0.00
Whitestem wild indigo	0.24	0.25	0.09	0.15	0.27	0.00
Old-mans beard	0.29	0.28	0.08	0.09	0.26	0.00
Bundleflower	0.29	0.30	0.08	0.16	0.17	0.00
Frogfruit	0.16	0.17	0.20	0.07	0.40	0.00
Prairie coneflower	0.29	0.29	0.08	0.18	0.17	0.00
Snoutbean	0.21	0.20	0.17	0.06	0.36	0.00
Ruellia	0.19	0.19	0.19	0.06	0.37	0.00
Curly dock	0.20	0.05	0.19	0.09	0.47	0.00
Bulltongue	0.20	0.05	0.19	0.09	0.47	0.00
Glasswort	0.14	0.10	0.25	0.25	0.26	0.00
Bush sunflower	0.28	0.28	0.09	0.18	0.17	0.00
Green briar	0.25	0.25	0.15	0.18	0.16	0.00
Texas verbena	0.21	0.20	0.17	0.06	0.36	0.00
Orange zexmenia	0.28	0.28	0.09	0.18	0.17	0.00
Giant ragweed	0.16	0.17	0.13	0.27	0.27	0.00
Annual broomweed	0.19	0.19	0.12	0.25	0.25	0.00
Partridge pea	0.19	0.19	0.19	0.06	0.37	0.00
Texas doveweed	0.14	0.15	0.14	0.29	0.28	0.00
Sunflower	0.08	0.07	0.17	0.34	0.34	0.00
Dogweed	0.19	0.19	0.16	0.06	0.40	0.00

croot = coarse roots; froot = fine roots

Data Sources

Root:Shoot Ratios

Huisache: huisache seedling = 0.48 (Fulbright et al. 1997); *Leucaena leucocephala* seedling = 0.46 (Jones & Aliyu 1976; Huang et al. 1985); *Leucaena leucocephala* mature = 0.82 (Von Carlowitz & Wolf 1991); huisache mature = 0.82(0.48/0.46) = 0.85
Pecan: Slow-growing hardwoods (Odum 1971:375)
Sugar hackberry: *Fagus* sp. (Garelkov 1973)
Texas persimmon Slow-growing hardwoods (Odum 1971:375)
Mesquite: Twice the value reported by Barth et al. (1982)
Post oak: Mean of *Quercus alba* (Nadelhoffer et al. 1985), *Q. rubra* (Nadelhoffer et al. 1985), *Q. robur* (Andersson 1970, Duvigneaud et al. 1971, Rodin & Bazilevich 1967), *Q. robus* (Duvigneaud et al. 1971), *Q. velutina* (Nadelhoffer et al. 1985)
Live oak: Mean of *Quercus alba* and *Q. velutina* (Nadelhoffer et al. 1985)

Coarse:Fine Root Ratios

Coarse:Fine 75:25 trees; 70:30 shrubs; 50:50 herbaceous

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

Appendix Table E.3 Allocation of new biomass production by plant part (proportion of total) for species included in the Goliad County EDYS model.

Common Name	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Huisache	0.08	0.20	0.09	0.22	0.41	0.00
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
Mesquite	0.08	0.30	0.12	0.19	0.31	0.00
Post 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
Guajillo	0.06	0.20	0.04	0.18	0.52	0.00
Blackbrush	0.05	0.20	0.05	0.20	0.50	0.00
Whitebrush	0.04	0.18	0.04	0.25	0.49	0.00
Prairie baccharis	0.05	0.20	0.05	0.20	0.50	0.00
Sea oxeye	0.14	0.40	0.10	0.15	0.21	0.00
Granjeno	0.04	0.18	0.04	0.22	0.52	0.00
Carolina wolfberry	0.08	0.25	0.20	0.22	0.25	0.00
Agarito	0.07	0.25	0.10	0.10	0.48	0.00
McCartney rose	0.14	0.40	0.10	0.15	0.21	0.00
Rattlepod	0.05	0.20	0.10	0.15	0.50	0.00
Mustang grape	0.03	0.20	0.10	0.15	0.52	0.00
Texas prickly pear	0.10	0.22	0.20	0.46	0.02	0.00
Big bluestem	0.10	0.24	0.05	0.30	0.31	0.00
Bushy bluestem	0.10	0.25	0.10	0.25	0.30	0.00
Purple threeawn	0.12	0.25	0.08	0.10	0.45	0.00
King Ranch bluestem	0.12	0.25	0.10	0.05	0.48	0.00
Silver bluestem	0.12	0.24	0.05	0.25	0.34	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
Buffalograss	0.16	0.27	0.10	0.12	0.35	0.00
Sandbur	0.02	0.40	0.10	0.15	0.33	0.00
Hooded windmillgrass	0.12	0.24	0.07	0.05	0.52	0.00
Trichloris	0.12	0.25	0.04	0.26	0.33	0.00
Bermudagrass	0.12	0.25	0.10	0.05	0.48	0.00
Arizona cottontop	0.12	0.24	0.05	0.30	0.29	0.00
Saltgrass	0.09	0.36	0.19	0.24	0.12	0.00
Virginia wildrye	0.12	0.23	0.05	0.30	0.30	0.00
Texas cupgrass	0.12	0.23	0.10	0.24	0.31	0.00
Green sprangletop	0.12	0.24	0.08	0.25	0.31	0.00
Kleingrass	0.11	0.24	0.05	0.30	0.30	0.00
Guineagrass	0.11	0.24	0.05	0.30	0.30	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
Longtom	0.13	0.25	0.08	0.22	0.32	0.00
Brownseed paspalum	0.10	0.22	0.08	0.30	0.30	0.00

Appendix Table E.3 (Cont.)

Common Name	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Thin paspalum	0.11	0.21	0.09	0.20	0.39	0.00
Common reed	0.15	0.25	0.10	0.20	0.30	0.00
Little bluestem	0.13	0.25	0.05	0.26	0.31	0.00
Knotroot bristlegrass	0.14	0.25	0.10	0.26	0.25	0.00
Plains bristlegrass	0.04	0.17	0.11	0.45	0.23	0.00
Texas bristlegrass	0.09	0.20	0.09	0.10	0.52	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
Gulf cordgrass	0.04	0.17	0.11	0.45	0.23	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
Smutgrass	0.04	0.17	0.11	0.45	0.23	0.00
Texas wintergrass	0.10	0.20	0.05	0.40	0.25	0.00
Milo	0.10	0.20	0.05	0.25	0.40	0.00
Wheat	0.25	0.25	0.10	0.20	0.20	0.00
Corn	0.25	0.25	0.10	0.20	0.20	0.00
Littletooth sedge	0.14	0.27	0.07	0.10	0.42	0.00
Flatsedge	0.18	0.35	0.06	0.12	0.29	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
Spiny aster	0.28	0.12	0.20	0.20	0.20	0.00
Whitestem wild indigo	0.04	0.18	0.26	0.26	0.26	0.00
Old-mans beard	0.15	0.28	0.10	0.24	0.23	0.00
Bundleflower	0.08	0.18	0.10	0.32	0.32	0.00
Frogfruit	0.08	0.17	0.10	0.30	0.35	0.00
Prairie coneflower	0.12	0.24	0.08	0.30	0.26	0.00
Snoutbean	0.10	0.20	0.10	0.30	0.30	0.00
Ruellia	0.15	0.25	0.15	0.05	0.40	0.00
Curly dock	0.05	0.15	0.20	0.10	0.50	0.00
Bulltongue	0.05	0.15	0.20	0.10	0.50	0.00
Glasswort	0.15	0.15	0.24	0.10	0.36	0.00
Bush sunflower	0.12	0.25	0.12	0.26	0.25	0.00
Green briar	0.15	0.15	0.15	0.30	0.25	0.00
Texas verbena	0.10	0.20	0.12	0.29	0.29	0.00
Orange zexmenia	0.13	0.25	0.12	0.25	0.25	0.00
Giant ragweed	0.16	0.17	0.13	0.27	0.27	0.00
Annual broomweed	0.19	0.19	0.12	0.25	0.25	0.00
Partridge pea	0.19	0.19	0.19	0.06	0.37	0.00
Texas doveweed	0.14	0.15	0.14	0.29	0.28	0.00
Sunflower	0.12	0.20	0.10	0.30	0.23	0.05
Dogweed	0.19	0.19	0.16	0.06	0.40	0.00

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

Common Name	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Huisache	0.00	0.23	0.00	0.04	0.73	0.00
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
Mesquite	0.00	0.15	0.00	0.10	0.75	0.00
Post 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
Guajillo	0.00	0.20	0.00	0.20	0.60	0.00
Blackbrush	0.00	0.20	0.00	0.20	0.60	0.00
Whitebrush	0.00	0.19	0.00	0.20	0.61	0.00
Prairie baccharis	0.00	0.19	0.00	0.20	0.61	0.00
Sea oxeye	0.00	0.15	0.00	0.25	0.60	0.00
Granjeno	0.00	0.21	0.00	0.19	0.60	0.00
Carolina wolfberry	0.00	0.25	0.20	0.20	0.35	0.00
Agarito	0.00	0.26	0.00	0.37	0.37	0.00
McCartney rose	0.00	0.15	0.00	0.25	0.60	0.00
Rattlepod	0.00	0.19	0.00	0.30	0.51	0.00
Mustang grape	0.00	0.17	0.00	0.23	0.60	0.00
Texas prickly pear	0.10	0.15	0.05	0.69	0.01	0.00
Big bluestem	0.01	0.18	0.00	0.41	0.40	0.00
Bushy bluestem	0.00	0.00	0.00	0.33	0.67	0.00
Purple threeawn	0.00	0.19	0.00	0.03	0.78	0.00
King Ranch bluestem	0.01	0.19	0.00	0.04	0.76	0.00
Silver bluestem	0.00	0.18	0.00	0.41	0.41	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
Buffalograss	0.00	0.20	0.00	0.09	0.71	0.00
Sandbur	0.00	0.40	0.00	0.25	0.35	0.00
Hooded windmillgrass	0.00	0.18	0.00	0.03	0.79	0.00
Trichloris	0.00	0.19	0.00	0.40	0.41	0.00
Bermudagrass	0.01	0.19	0.00	0.03	0.77	0.00
Arizona cottontop	0.00	0.18	0.00	0.41	0.41	0.00
Saltgrass	0.00	0.35	0.00	0.38	0.27	0.00
Virginia wildrye	0.00	0.17	0.00	0.41	0.42	0.00
Texas cupgrass	0.00	0.17	0.00	0.42	0.41	0.00
Green sprangletop	0.00	0.18	0.00	0.41	0.41	0.00
Kleingrass	0.00	0.18	0.00	0.41	0.41	0.00
Guineagrass	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
Longtom	0.00	0.26	0.00	0.03	0.71	0.00
Brownseed paspalum	0.00	0.15	0.00	0.40	0.45	0.00

Appendix Table E.4 (Cont.)

Common Name	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Thin paspalum	0.00	0.16	0.00	0.05	0.79	0.00
Common reed	0.02	0.19	0.00	0.40	0.41	0.00
Little bluestem	0.01	0.18	0.00	0.40	0.41	0.00
Knotroot bristlegrass	0.01	0.19	0.00	0.05	0.75	0.00
Plains bristlegrass	0.00	0.15	0.00	0.53	0.32	0.00
Texas bristlegrass	0.00	0.15	0.00	0.05	0.80	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
Gulf cordgrass	0.00	0.15	0.00	0.53	0.32	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
Smutgrass	0.00	0.15	0.00	0.53	0.32	0.00
Texas wintergrass	0.00	0.19	0.00	0.03	0.78	0.00
Milo	0.25	0.25	0.10	0.20	0.20	0.00
Wheat	0.25	0.25	0.10	0.20	0.20	0.00
Corn	0.25	0.25	0.10	0.20	0.20	0.00
Littletooth sedge	0.00	0.20	0.00	0.05	0.75	0.00
Flatsedge	0.00	0.26	0.00	0.20	0.54	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
Spiny aster	0.00	0.10	0.00	0.52	0.38	0.00
Whitestem wild indigo	0.00	0.15	0.00	0.85	0.00	0.00
Old-mans beard	0.00	0.21	0.00	0.39	0.40	0.00
Bundleflower	0.00	0.14	0.00	0.43	0.43	0.00
Frogfruit	0.00	0.13	0.00	0.44	0.43	0.00
Prairie coneflower	0.00	0.18	0.00	0.41	0.41	0.00
Snoutbean	0.00	0.15	0.00	0.43	0.42	0.00
Ruellia	0.00	0.14	0.00	0.21	0.65	0.00
Curly dock	0.00	0.05	0.00	0.35	0.60	0.00
Bulltongue	0.00	0.05	0.00	0.35	0.60	0.00
Glasswort	0.00	0.10	0.15	0.05	0.70	0.00
Bush sunflower	0.00	0.19	0.00	0.41	0.40	0.00
Green briar	0.00	0.10	0.00	0.20	0.70	0.00
Texas verbena	0.00	0.15	0.00	0.43	0.42	0.00
Orange zexmenia	0.00	0.19	0.00	0.41	0.40	0.00
Giant ragweed	0.16	0.17	0.13	0.27	0.27	0.00
Annual broomweed	0.19	0.19	0.12	0.25	0.25	0.00
Partridge pea	0.19	0.19	0.19	0.06	0.37	0.00
Texas doveweed	0.14	0.15	0.14	0.29	0.28	0.00
Sunflower	0.16	0.17	0.13	0.27	0.27	0.00
Dogweed	0.19	0.19	0.16	0.06	0.40	0.00

General guidelines for greenout allocation:

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 allocations.

Appendix Table E.9 Root architecture, proportion of roots by maximum rooting depth, and maximum potential rooting depth (mm) for plant species included in the Goliad County EDYS model.

Common Name	0-1	1-5	5-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Max Root Depth (mm)
Huisache	6	11	14	18	15	12	8	6	4	3	2	1	5000
Pecan	4	9	14	20	13	5	6	6	2	6	8	7	6250
Sugar hackberry	2	9	14	20	15	5	6	6	2	6	8	7	6000
Mesquite	15	14	15	14	11	9	7	5	4	3	2	1	53400
Post oak	2	8	9	18	15	11	11	6	5	5	5	5	5700
Live oak	4	14	15	21	12	8	8	7	4	4	2	1	22000
Guajillo	3	10	13	18	13	11	9	8	5	5	3	2	5000
Blackbrush	3	9	13	19	15	12	9	7	4	4	3	2	5250
Whitebrush	2	10	16	19	14	12	9	6	5	4	2	1	2230
Prairie baccharis	1	5	9	12	18	17	11	11	7	6	2	1	1900
Sea oxeye	4	6	15	20	15	12	10	6	5	3	2	2	2000
Granjeno	4	13	14	17	14	12	10	6	4	3	2	1	6680
Carolina wolfberry	10	12	25	20	20	5	3	1	1	1	1	1	1500
Agarito	3	10	12	19	13	12	10	9	5	4	2	1	3000
McCartney rose	2	6	8	15	16	14	8	10	9	7	3	2	3700
Rattlepod	2	5	9	15	17	16	13	8	7	5	2	1	1380
Mustang grape	5	12	15	17	13	11	9	7	5	3	2	1	3660
Texas prickly pear	2	9	12	19	13	20	11	6	4	2	1	1	840
Big bluestem	15	18	20	15	9	7	5	4	3	2	1	1	3050
Bushy bluestem	5	10	20	20	15	12	10	3	2	1	1	1	720
Purple threeawn	4	7	10	15	18	15	14	8	5	2	1	1	1830
King Ranch bluestem	4	16	21	18	14	8	6	4	3	2	2	2	1200
Silver bluestem	12	22	20	20	8	6	3	3	2	2	1	1	2380
Sideoats grama	12	20	23	21	12	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
Buffalograss	8	23	24	20	8	5	4	3	2	1	1	1	2160
Sandbur	10	20	25	12	7	6	5	5	4	3	2	1	350
Hooded windmillgrass	4	12	13	21	12	11	11	4	3	3	3	3	990
Trichloris	10	14	16	17	10	8	8	6	4	4	2	1	2300
Bermudagrass	5	14	17	15	12	10	8	6	5	4	3	1	900
Arizona cottontop	3	12	13	21	12	10	8	6	5	4	3	3	1000
Saltgrass	10	20	22	20	10	6	4	3	2	1	1	1	720
Virginia wildrye	4	12	16	18	14	12	8	6	4	3	2	1	720
Texas cupgrass	4	15	17	19	12	7	7	5	4	4	4	3	1040
Green sprangletop	3	13	15	18	13	11	9	6	4	4	3	1	1150
Kleingrass	3	10	13	18	15	13	13	3	3	3	3	3	2280
Guineagrass	3	10	13	18	15	13	13	3	3	3	3	3	2280
Vine-mesquite	3	11	13	19	14	10	8	6	5	4	4	3	2020
Switchgrass	15	17	20	12	8	8	7	4	4	2	2	1	3350
Longtom	5	19	18	12	9	7	7	6	5	4	4	4	900
Brownseed paspalum	6	20	28	16	12	8	5	1	1	1	1	1	1000

Appendix Table E.9 (Cont.)

Common Name	0-1	1-5	5-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Max Root Depth (mm)
Thin paspalum	3	12	15	24	13	10	7	6	4	3	2	1	1660
Common reed	2	9	11	23	9	9	8	8	7	6	5	3	3500
Little bluestem	10	22	23	18	8	5	4	3	3	2	1	1	2440
Knotroot bristlegrass	4	14	16	18	14	10	8	6	5	2	2	1	1020
Plains bristlegrass	6	19	19	27	9	4	3	3	3	3	2	2	1600
Texas bristlegrass	3	13	14	21	12	11	9	6	4	3	2	2	930
Indiangrass	12	25	21	10	9	7	5	4	3	2	1	1	2430
Johnsongrass	3	12	17	18	14	10	9	7	5	3	1	1	2410
Gulf cordgrass	10	20	25	12	7	6	5	5	4	3	2	1	3960
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
Smutgrass	3	13	14	20	12	9	5	6	8	5	3	2	2100
Texas wintergrass	3	11	13	18	14	10	8	8	6	4	3	2	1950
Milo	2	6	9	18	17	14	12	9	7	3	2	1	1950
Wheat	2	5	7	15	16	15	13	10	8	5	3	1	3000
Corn	2	7	10	22	17	13	12	8	5	2	1	1	2400
Littletooth sedge	2	9	12	22	16	10	8	6	5	5	4	1	1310
Flatsedge	2	5	8	15	13	12	12	10	9	7	4	3	630
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
Spiny aster	15	20	25	25	5	3	2	1	1	1	1	1	3100
Whitestem wild indigo	10	24	20	24	9	4	3	2	1	1	1	1	1700
Old-mans beard	3	9	13	24	16	9	7	6	4	3	3	3	1280
Bundleflower	3	9	14	23	12	5	4	5	9	7	6	3	2100
Frogfruit	2	6	8	14	12	11	14	11	11	5	4	2	690
Prairie coneflower	4	16	14	23	14	6	6	4	4	4	3	2	1830
Snoutbean	5	12	20	15	8	4	2	3	10	12	6	3	1350
Ruellia	4	4	7	19	20	14	11	7	6	4	3	1	1500
Curly dock	8	30	34	12	5	4	2	1	1	1	1	1	610
Bulltongue	8	30	34	12	5	4	2	1	1	1	1	1	610
Glasswort	8	16	16	24	12	8	6	4	2	2	1	1	457
Bush sunflower	10	14	18	23	11	6	5	4	3	3	2	1	2620
Green briar	4	12	13	25	8	5	5	5	6	6	6	5	1500
Texas verbena	2	8	10	15	14	13	8	8	8	6	5	3	1520
Orange zexmenia	3	8	13	30	11	8	7	7	5	4	3	1	2640
Giant ragweed	2	6	11	23	10	9	9	9	8	7	4	2	1970
Annual broomweed	4	17	9	17	12	14	8	7	4	3	3	2	1050
Partridge pea	2	8	10	15	14	10	8	11	8	6	5	3	850
Texas doveweed	3	13	8	16	13	14	10	7	5	4	4	3	320
Sunflower	6	24	6	9	12	16	10	7	2	3	3	2	3100
Dogweed	3	6	8	15	11	12	12	11	9	6	4	3	760

Data Sources

Root Architecture

Huisache	mean of *Leucaena leucocephala* (Toky & Bisht 1992) and *Prosopis glandulosa*
Pecan, sugar hackberry, Texas persimmon	*Acer saccharum* (Dawson 1993)
Mesquite	mean of Heitschmidt et al. (1988) and Montana et al. (1995)
Post oak	*Quercus havardii* (Sears et al. 1986)
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)
Guajillo	*Larrea tridentata* (Wallace et al. 1980; Moorhead et al. 1989; Montana et al. 1995; Ogle et al. 2004)
Blackbrush	mean of *Flourensia cernua* (Wallace et al. 1980) and *Larrea tridentata* (Wallace et al. 1980; Moorhead et al. 1989; Montana et al. 1995; Ogle et al. 2004)
Whitebrush	mean of *Krameria parvifolia, Lycium andersonii, L. pallidum* (Wallace et al. 1980), and *Tetradymia spinosa* (Branson et al. 1976)
Prairie baccharis	*Pulchea sericea* (Gary 1963)
Granjeno	mean of *Flourensia cernua* (Wallace et al. 1980) and *Prosopis glandulosa*
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)
Rattlepod	mean of *Leucaena leucocephala* (Toky & Bisht 1992) and *Pulchea sericea* (Gary 1963)
Mustang grape	mean of 25 shrubs
Prickly pear	mean of *Opuntia acanthocarpa* (Nobel & Bobich 2002), *O. humifusa* (Sperry 1935), and *O. polyacantha* (Dougherty 1986)
Big bluestem	Sperry (1935), Weaver & Zink (1946), Weaver & Darland (1949), Coupland & Bradshaw (1953); Hopkins (1953), Weaver (1954)
Purple threeawn	modified from Weaver & Clements (1938)
King Ranch bluestem	Coyne & Bradford (1986)
Silver bluestem	mean of *Bouteloua curtipendula* and *Schizachyrium scoparium*
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)
Buffalograss	Weaver & Clements (1938), Weaver & Darland (1949), Hopkins (1953)
Sandbur	mean of *Aristida purpurea* (Weaver & Clements 1938) and *Sporobolus cryptandrus* (Albertson 1937; Weaver & Darland 1949; Hopkins 1953)
Hooded windmill	mean of *Axonopus compressus* (Fiala & Herrera 1988) and *Sporobolus cryptandrus* (Albertson 1937; Weaver & Darland 1949; Hopkins 1953)
Trichloris	*Schizachyrium scoparium*
Bermudagrass	mean of *Axonopus compressus* (Fiala & Herrera 1988), *Distichlis spicata* (Seliskar 1983; Dahlgren et al. 1997; McLendon 2008), *Hilaria mutica* (Montana et al. 1995)
Arizona cottontop	mean of *Cenchrus ciliaris* (Chaieb et al. 1996), *Hilaria jamesii* (Moore & West 1973; Daddy 1985), *Sporobolus cryptandrus* (Albertson 1937; Weaver & Darland 1949; Hopkins 1953)
Virginia wildrye	mean of *Agropyron trachycaulum* and *Poa compressa* (McLendon 2001)
Clubhead cutgrass	mean of *Axonopus compressus* (Fiala & Herrera 1988), *Paspalum notatum* (Hernandez & Fiala 1992)
Kleingrass	Hons et al. (1979)
Vine-mesquite	mean of *Boutleoua 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)
Longtom	mean of *Distichlis spicata* (Seliskar 1983; Dahlgren et al. 1997; McLendon 2008) and *Paspalum notatum* (Hernandez & Fiala 1992)
Thin paspalum	mean of *Andropogon gerardii* var. *paucipilus* (Weaver & Clements 1938), *Cenchrus ciliaris* (Chaieb et al. 1996), *Redfieldia flexuosa* (Weaver & Clements 1938), *Sporobolus cryptandrus* (Albertson 1937; Weaver & Darland 1949; Hopkins 1953), and *Schzachyrium scoparium*
Little bluestem	Sperry (1935), Weaver & Zink (1946), Weaver (1947, 1950, 1954, 1958), Weaver & Darland (1949), Coupland & Bradshaw (1953), Jurena & Archer (2003)
Knotroot bristlegrass	mean of *Bouteloua curtipendula* (Weaver & Darland 1949; Hopkins 1953; Weaver 1954; Pettit & Jayens 1971) and *Sporobolus airoides* (McLendon 2008)
Texas bristlegrass	mean of *Aristida purpurea* (Weaver & Clements 1938), *Axonopus compressus* (Fiala & Herrera 1988), *Digitaria commutata* (Chaieb et al. 1996), *Koeleria pyramidata* (Coupland & Bradshaw 1953), *Sporobolus cryptandrus* (Albertson 1937; Weaver & Darland 1949; Hopkins 1953)
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)
Texas wintergrass	mean of *Stipa comata* (Melgoza & Nowak 1991), *S. lagascae* (Chaieb et al. 1996), *S. spartea* (Sperry 1935; Coupland & Bradshaw 1953)
Milo	mean of *Triticum aestivum* and *Zea mays*
Wheat	Weaver et al. (1924), Weaver & Clements (1938)
Corn	Weaver & Clements (1938)
Littletooth sedge	mean of *Carex douglasii* (Manning et al. 1989) and *C. varia* (Sperry 1935)
Flatsedge	mean of *Carex nebrascensis* (Manning et al. 1989; Svejcar & Trent 1995; Kauffman et al. 2004) and *Scirpus validus* (Weaver & Clements 1938)
Fimbry	mean of *Carex douglasii* (Manning et al. 1989), *C. nebrascensis* (Manning et al. 1989; Svejcar & Trent 1995; Kauffman et al. 2004), *C. lasiocarpa, C. rostrata, C. trichocarpa* (Bernard & Fiala 1986), *C. varia* (Sperry 1935), *Juncus balticus* (Manning et al. 1989), *Scirpus validus* (Weaver & Clements 1938)
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 pectinata* (Sperry 1935)
Ragweed	Sperry (1935)
Old-mans beard	mean of *Achillea millefolium* and *Solidago decumbens* (Holch et al. 1941)
Bundleflower	mean of *Oxytropis lambertii* (Weaver & Clements 1938), *Petalostemum purpureum* (Sperry 1935), and *Potentilla diversifolis* and *P. gracilis* (Holch et al. 1941)
Frogfruit	mean of *Potentilla gracilis* (Holch et al. 1941), *Pycanthemum tenuifolium* (Sperry 1935)
Prairie coneflower	*Ratibida pinnata* (Sperry 1935)
Snoutbean	*Petalostemum purpureum* (Sperry 1935)
Ruellia	*Ruellia humilis* (Sperry 1935)
Bush sunflower	*Helianthus scaberriums* (Sperry 1935)
Texas verbena	mean of *Aster multiflorus* (Sperry 1935), *A. oblongifolius* (Sperry 1935), *Erysimum asperum* (Holch et al. 1941), *Gallardia aristata* (Holch et al. 1941), *Geranium fremontii* (Holch et al. 1941), *Silphium integrifolium* (Sperry 1935)
Orange zexmenia	mean of *Helianthus scaberriums* and *Parthenium hispidum* (Sperry 1935)
Giant ragweed	mean of *Ambrosia psilostachya* and *Parthenium hispidum* (Sperry 1935)

Annual broomweed	mean of *Helianthus annuus* (Stone et al. 2001), *Grindelia squarrosa* (Holch et al. 1941)
Partridge pea	mean of *Erysimum asperum* (Holch et al. 1941), *Euphorbia corollata* (Sperry 1935)
Texas doveweed	mean of *Centaurea maculosa* (Marier et al. 1999), *Grindelia squarrosa* (Holch et al. 1941), *Helianthus annuus* (Stone et al. 2001)
Sunflower	Stone et al. (2001)
Duckweed	*Phacelia glandulosa* (Holch et al. 1941)
Texas bluebonnet	*Oxytropis lambertii* (Weaver & Clements 1938)
Dogweed	mean of *Aster multiflorus* (Sperry 1935), *A. oblongifolius* (Sperry 1935), *Eriogonum alatum* (Holch et al. 1941), and *Grindelia squarrosa* (Holch et al. 1941)

Maximum Potential Rooting Depth

Huisache	mean of *Chilopsis linearis* (Meinzer 1927), *Prosopis velutina* (Snyder & Williams 2003)
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)
Mesquite	Phillips (1963)
Post oak	mean of *Quercus durandii* (Jackson et al. 1999) and *Q. macrocarpa* (Biswell 1935)
Live oak	Jackson et al. (1999)

Guajillo	*Larrea tridentata* (Gile et al. 1998)
Blackbrush	mean of *Koeberlinia spinosa* (Gibbens & Lenz 2001), *Larrea tridentata* (Gile et al. 1998)
Whitebrush	mean of *Corylus americana* (Weaver 1919), *Fallugia paradoxa* (Foxx & Tierney 1986), *Lycium berlandieri* (Gibbens & Lenz 2001), *L. pallidum* (Yoder & Nowak 1999a)
Prairie baccharis	mean of *Baccharis glutinosa* (Gary 1963), *B. pilularis* (Wright 1928)
Granjeno	mean of *Arctostaphylos glandulosa* (Hellmers et al. 1955), *Celtis laevigata* (Jackson et al. 1999), *Flourensia cernua* (Gibbens & Lenz 2001), *Koeberlinia spinosa* (Gibbens & Lenz 2001), *Larrea tridentata* (Gile et al. 1998), *Lycium berlandieri* (Gibbens & Lenz 2001), *Sarcobatus vermiculatus* (Meinzer 1927)
Agarito	*Berberis repens* (Weaver 1919)
Rattlepod	mean of *Baccharis glutinosa* (Gary 1963), *Pulchea sericea* (Gary 1963), *Sesbania sesban* (Sekiya & Yano 2002)
Mustang grape	*Toxicodendron radicans* (Tolstead 1942)
Prickly pear	mean of *Opuntia imbricata* (Dittmer 1959), *O. polyacantha* (Tierney & Foxx 1987)

Big bluestem	Tomanek & Albertson (1957)
Purple threeawn	Albertson (1937)
King Ranch bluestem	Coyne & Bradford (1986)
Silver bluestem	mean of *Bouteloua curtipendula* (Tomanek & Albertson 1957), *Heteropogon contortus* (Cable 1980), *Schizachyrium scoparium* (Weaver & Fitzpatrick 1934), *Sporobolus asper* (Weaver & Albertson 1943)
Sideoats grama	Tomanek & Albertson (1957)
Hairy grama	Weaver (1926)
Buffalograss	Weaver & Clements (1938)
Sandbur	Dittmer (1959)
Hooded windmillgrass	mean of *Bouteloua hirsuta* (Weaver 1926), *Cenchrus incertus* (Dittmer 1959), *Digitaria californica* (Cable 1980), *Hilaria jamesii* (Weaver 1958), *Muhlenbergia torreyi* (Weaver 1958), *Scleropogon brevifolius* (Gibbens & Lenz 2001)
Trichloris	about 5% less than *Schizachyrium scoparium*
Bermudagrass	Garrot & Mancino (1994)
Arizona cottontop	Cable (1980)
Virginia wildrye	*Elymus canadensis* (Weaver 1958)
Clubhead cutgrass	mean of *Holcus lanatus* and *Nardus stricta* (Boggie et al. 1958)
Kleingrass	mean of *Eragrostis lehmanniana* (Gibbens & Lenz 2001) and *Panicum virgatum* (Weaver 1954)

Vine-mesquite	mean of *Distichlis spicata* (Shantz & Piemeisel 1940), *Hilaria mutica* (Cottle 1931), *Panicm virgatum* (Weaver 1954)
Switchgrass	Weaver (1954)
Longtom	mean of *Cynodon dactylon* (Garrot & Mancino 1994), *Distichlis spicata* (Shantz & Piemeisel 1940), and *Holcus lanatus* and *Nardus stricta* (Boggie et al. 1958)
Thin paspalum	mean of *Heteropogon contortus* (Cable 1980), *Muhlenbergia arenacea* (Gibbens & Lenz 2001), *Redfieldia flexuosa* (Weaver 1958), *Schizachyrium scoparium* (Weaver & Fitzpatrick 1934), *Sporobolus asper* (Weaver & Albertson 1943)
Little bluestem	Weaver & Fitzpatrick (1934)
Knotroot bristlegrass	mean of *Agrostis tenuis* (Boggie et al. 1958), *Dichanthelium scribnerianum* (Weaver 1954), *Muhlenbergia torreyi* (Weaver 1958), *Poa pratensis* (Weaver 1954)
Texas bristlegrass	mean of *Aristida purpurea* (Albertson 1937), *Bouteloua hirsuta* (Weaver 1926), *Cenchrus incertus* (Dittmer 1959), *Dichanthelium scribnerianum* (Weaver 1954), *Festuca ovina* (Boggie et al. 1958), *Koeleria pyramidata* (Wyatt et al. 1980), *Muhlenbergia porteri* (Gibbens & Lenz 2001), *Scleropogon brevifolius* (Gibbens & Lenz 2001)
Johnsongrass	mean of *Sorghastrum nutans* (Albertson 1937) and *Zea mays* (Weaver 1926)
Tall dropseed	Weaver & Albertson (1943)
Texas wintergrass	*Stipa comata* (Wyatt et al. 1980)
Milo	mean of *Pennisetum glaucum* (Payne et al. 1990) and *Zea mays* (Weaver 1926)
Wheat	Hamblin & Tennant (1987)
Corn	Weaver (1926)
Littletooth sedge	mean of *Carex filifolia* (Weaver 1920; Tolstead 1942), *C. geyerii* (Spence 1937), *C. varia* (Sperry 1935)
Flatsedge	mean of *Carex nebrascensis* (Chambers et al. 1999), *Juncus balticus* (Manning et al. 1989), *Scirpus validus* (Weaver & Clements 1938)
Fimbry	mean of *Juncus balticus* (Manning et al. 1989), *Scirpus validus* (Weaver & Clements 1938)
Cattail	mean of *Lepidium latifolium* (Renz et al. 1997), *Scirpus validus* (Weaver & Clements 1938), *Spartina pectinata* (Weaver 1958)
Ragweed	Weaver (1958)
Old-mans beard	mean of *Achillea millefolium* (Spence 1937), *Smilax rotundifolia* (Duncan 1935)
Bundleflower	*Desmanthus cooleyi* (Gibbens & Lenz 2001)
Frogfruit	mean of *Euphorbia albomarginata* (Gibbens & Lenz 2001), *Evolvulus nuttallianus* (Albertson 1937), *Hedyotis nigricans* (Albertson 1937)
Prairie coneflower	Hopkins (1951)
Snoutbean	mean of *Cassia bauhinioides* (Gibbens & Lenz 2001), *Desmanthus cooleyi* (Gibbens & Lenz 2001), *Hoffmanseggia drepanocarpa* (Gibbens & Lenz 2001), *Thermopsis rhombifolia* (Coupland & Johnson 1965), *Trifolium pretense* (Keim & Beadle 1927)
Ruellia	*Ruellia caroliniensis* (Sperry 1935)
Bush sunflower	mean of *Arnica pumila* (Holch et al. 1941), *Balsamorhiza sagittata* (Weaver 1958), *Chrysopsis villosa* (Weaver 1958), *Helianthus laetiflorus* (Weaver 1954), *Parthenium integrifolium* (Sperry 1935), *Veronica baldwinii* (Weaver 1919)
Texas verbena	*Verbena stricta* (Weaver 1958)
Orange zexmenia	mean of *Artemisia dracunculus* (Foxx & Tierney 1986), *Chrysopsis villosa* (Weaver 1958), *Helianthus laetiflorus* (Weaver 1954), *Machaeranthera pinnatifida* (Hopkins 1951), *Parthenium integrifolium* (Sperry 1935)
Giant ragweed	mean of *Ambrosia acanthicarpa* (Dittmer 1959), *A. artemisifolia* (Cole & Holch 1941), *Helianthus annuus* (Schwarzbach et al. 2001), *Kochia scoparia* (Foxx & Tierney 1986)
Annual broomweed	mean of *Croton pottsii* (Gibbens & Lenz 2001), *C. texensis* (Dittmer 1959)
Partridge pea	*Cassia bauhinioides* (Gibbens & Lenz 2001)

Texas doveweed	Dittmer (1959)
Sunflower	Schwarzbach et al. (2001)
Duckweed	mean of *Mimulus bigelovii* and *Polygonum aviculare* (Forseth et al. 1984)
Texas bluebonnet	mean of *Cassia bauhinioides* (Gibbens & Lenz 2001), *Hoffmanseggia drepanocarpa* (Gibbens & Lenz 2001), *Medicago lupulina* (Cole & Holch 1941), *Lupinus caudatus* (Foxx & Tierney 1986)
Dogweed	mean of *Aphanostephus ramoissimus* (Gibbens & Lenz 2001), *Centaurea solstitialis* (Sheley & Larson 1994), *Croton texensis* (Dittmer 1959), *Erodium botrys* (McKell et al. 1962), *Lepidium densiflorum* (Allen & Knight 1984), *Linum australe* (Gibbens & Lenz 2001), *Verbena utricifolia* (Cole & Holch 1941)

Appendix Table E.11 Values for months when physiological responses occur in plant species included in the Goliad County EDYS model.

Common Name	Green-out	Seed-sprout		Seed-set		Dormancy
Huisache	2	2	9	4	9	12
Pecan	3	3	9	4	9	10
Sugar hackberry	3	3	9	4	8	10
Mesquite	3	3	9	4	8	11
Post oak	3	3	7	4	8	11
Live oak	3	3	7	4	8	2
Guajillo	1	2	10	6	10	12
Blackbrush	2	2	10	6	10	12
Whitebrush	2	3	10	6	10	11
Prairie baccharis	2	2	10	2	10	11
Sea oxeye	4	3	9	4	8	10
Granjeno	3	2	10	4	8	11
Carolina wolfberry	3	3	9	4	9	11
Agarito	1	2	10	4	8	12
McCartney rose	1	3	9	4	8	1
Rattlepod	3	2	10	6	7	11
Mustang grape	2	3	9	6	10	12
Texas prickly pear	1	2	11	7	8	12
Big bluestem	3	4	8	8	8	11
Bushy bluestem	3	4	4	8	8	11
Purple threeawn	3	4	9	7	11	12
King Ranch bluestem	3	4	10	6	10	11
Silver bluestem	3	3	9	5	7	11
Sideoats grama	3	4	9	6	10	11
Hairy grama	3	4	10	6	10	11
Red grama	3	4	9	5	9	11
Buffalograss	3	3	9	5	10	11
Sandbur	3	4	9	7	8	11
Hooded windmillgrass	3	3	10	7	8	11
Trichloris	3	3	10	7	8	11
Bermudagrass	3	4	10	5	8	11
Arizona cottontop	3	3	9	5	7	11
Saltgrass	3	3	9	5	7	11
Virginia wildrye	10	10	6	5	7	6
Texas cupgrass	3	4	9	6	9	10
Green sprangletop	3	4	9	5	9	11
Kleingrass	3	3	9	5	7	11
Guineagrass	3	3	9	5	7	11
Vine-mesquite	3	4	10	5	10	12
Switchgrass	3	5	9	7	9	11
Longtom	3	3	10	8	10	11
Brownseed paspalum	3	3	8	8	10	10

Appendix Table E.11 (Cont.)

Common Name	Green-out	Seed-sprout		Seed-set		Dormancy
Thin paspalum	3	3	10	8	9	11
Common reed	3	4	10	9	11	11
Little bluestem	3	5	9	7	9	11
Knotroot bristlegrass	3	3	10	5	8	12
Plains bristlegrass	3	3	9	5	8	11
Texas bristlegrass	2	2	11	5	8	12
Indiangrass	3	5	9	7	9	11
Johnsongrass	3	4	9	7	10	11
Gulf cordgrass	3	3	9	5	8	11
Tall dropseed	3	4	9	5	8	11
Sand dropseed	3	4	10	5	9	11
Smutgrass	3	3	9	5	8	11
Texas wintergrass	10	10	5	3	5	6
Milo	3	3	9	5	8	11
Wheat	10	10	4	4	5	5
Corn	4	4	9	5	8	11
Littletooth sedge	3	3	10	5	9	12
Flatsedge	2	3	10	4	9	12
Cattail	3	4	10	6	8	12
Ragweed	3	3	9	5	10	10
Lazydaisy	2	3	9	3	7	10
Spiny aster	3	4	9	6	8	9
Whitestem wild indigo	3	3	9	5	8	11
Old-mans beard	3	3	10	6	10	12
Bundleflower	3	4	9	5	10	11
Frogfruit	3	3	9	3	10	11
Prairie coneflower	2	2	8	4	8	10
Snoutbean	3	3	9	4	8	11
Ruellia	3	3	10	4	8	12
Curly dock	2	3	9	4	8	11
Bulltongue	2	3	9	4	8	11
Glasswort	2	3	8	5	9	10
Bush sunflower	3	3	9	5	9	11
Green briar	3	9	6	2	6	2
Texas verbena	2	2	9	4	8	12
Orange zexmenia	3	4	9	5	9	11
Giant ragweed	3	3	9	7	8	11
Annual broomweed	3	2	9	3	10	11
Partridge pea	3	3	9	6	7	11
Texas doveweed	3	2	9	4	8	11
Sunflower	2	2	10	5	9	11
Dogweed	3	3	9	4	9	11

Appendix Table E.13 Values for water use variables used in the Goliad County EDYS model.

Common Name	Maintenance (mm/g bio/mo)	New biomass maintenance	Water to production	Green-out water use
Huisache	0.0000085	0.04	1.25	0.55
Pecan	0.0000085	0.04	0.88	0.55
Sugar hackberry	0.0000090	0.05	0.90	0.45
Mesquite	0.0000085	0.04	1.10	0.50
Post oak	0.0000080	0.04	0.90	0.45
Live oak	0.0000080	0.03	0.80	0.45
Guajillo	0.0000090	0.05	1.63	0.70
Blackbrush	0.0000090	0.05	1.63	0.70
Whitebrush	0.0000090	0.05	1.20	0.70
Prairie baccharis	0.0000090	0.05	0.81	0.70
Sea oxeye	0.0000100	0.05	1.87	0.50
Granjeno	0.0000100	0.05	1.22	0.50
Carolina wolfberry	0.0000085	0.04	1.25	0.65
Agarito	0.0000080	0.04	1.47	0.60
McCartney rose	0.0000090	0.05	1.00	0.65
Rattlepod	0.0000250	0.07	0.64	0.75
Mustang grape	0.0000090	0.05	0.90	0.70
Texas prickly pear	0.0000080	0.04	0.30	0.80
Big bluestem	0.0000280	0.05	0.83	0.80
Bushy bluestem	0.0000280	0.05	1.30	0.80
Purple threeawn	0.0000150	0.04	0.68	0.65
King Ranch bluestem	0.0000150	0.04	0.70	0.67
Silver bluestem	0.0000160	0.04	0.76	0.70
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
Buffalograss	0.0000150	0.04	0.74	0.64
Sandbur	0.0003910	0.05	0.47	0.80
Hooded windmillgrass	0.0003910	0.05	0.87	0.80
Trichloris	0.0003910	0.05	0.87	0.80
Bermudagrass	0.0000160	0.04	0.91	0.70
Arizona cottontop	0.0000160	0.04	0.63	0.70
Saltgrass	0.0000160	0.04	0.78	0.70
Virginia wildrye	0.0000160	0.04	1.24	0.70
Texas cupgrass	0.0000170	0.05	0.82	0.75
Green sprangletop	0.0000160	0.04	0.76	0.70
Kleingrass	0.0000160	0.04	1.36	0.70
Guineagrass	0.0000160	0.04	1.36	0.70
Vine-mesquite	0.0000150	0.04	0.90	0.65
Switchgrass	0.0000180	0.05	1.00	0.75
Longtom	0.0000017	0.06	0.50	0.65
Brownseed paspalum	0.0000017	0.06	0.95	0.65

Appendix Table E.13 (Cont.)

Common Name	Maintenance (mm/g bio/mo)	New biomass maintenance	Water to production	Green-out water use
Thin paspalum	0.0000017	0.06	0.76	0.65
Common reed	0.0000200	0.06	0.73	0.70
Little bluestem	0.0000170	0.05	0.90	0.65
Knotroot bristlegrass	0.0000120	0.04	0.90	0.70
Plains bristlegrass	0.0000120	0.04	0.80	0.70
Texas bristlegrass	0.0000120	0.04	0.61	0.70
Indiangrass	0.0000175	0.05	0.89	0.75
Johnsongrass	0.0000175	0.06	0.89	0.70
Gulf cordgrass	0.0000120	0.04	0.60	0.70
Tall dropseed	0.0000160	0.04	0.71	0.70
Sand dropseed	0.0000140	0.04	0.85	0.65
Smutgrass	0.0000120	0.04	0.60	0.70
Texas wintergrass	0.0000120	0.03	0.99	0.65
Milo	0.0000120	0.04	0.33	0.70
Wheat	0.0000120	0.04	0.76	0.70
Corn	0.0000120	0.04	0.37	0.70
Littletooth sedge	0.0000200	0.06	0.79	0.67
Flatsedge	0.0000200	0.06	0.73	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
Spiny aster	0.0000100	0.04	0.50	0.78
Whitestem wild indigo	0.0000187	0.05	1.10	0.67
Old-mans beard	0.0000090	0.05	0.80	0.70
Bundleflower	0.0000140	0.03	0.67	0.72
Frogfruit	0.0000070	0.03	0.70	0.72
Prairie coneflower	0.0000160	0.06	0.69	0.67
Snoutbean	0.0000250	0.08	0.83	0.82
Ruellia	0.0000250	0.08	0.60	0.82
Curly dock	0.0000250	0.08	0.87	0.82
Bulltongue	0.0000250	0.08	0.87	0.82
Glasswort	0.0000190	0.06	0.80	0.67
Bush sunflower	0.0000200	0.07	0.85	0.75
Green briar	0.0000180	0.05	1.20	0.61
Texas verbena	0.0000250	0.08	0.79	0.82
Orange zexmenia	0.0000180	0.05	0.70	0.60
Giant ragweed	0.0000070	0.03	0.53	0.72
Annual broomweed	0.0000070	0.03	0.58	0.72
Partridge pea	0.0000250	0.07	0.76	0.75
Texas doveweed	0.0000250	0.08	0.56	0.82
Sunflower	0.0000200	0.06	0.55	0.70
Dogweed	0.0000070	0.03	0.50	0.72

Data Sources

Water to Production

Huisache: mean of *Cercidium microphylum* and *Prosopis velutina* (McGinnes & Arnold 1939)
Pecan, sugar hackberry, Texas persimmon, post oak, live oak: *Populus fremontii* (Anderson 1982)
Mesquite: Dwyer & DeGarmo (1970)

Guajillo and blackbrush: *Acacia greggii, Cercidium microphylum, Prosopis velutina* (McGinnes & Arnold 1939)
Whitebrush: mean of *Atriplex lentiformis* (Watson 1990), *Chrysothamnus nauseosus* (Donovan et al. 1996), *Sarcobatus vermiculatus* (Donovan et al. 1996), *Simmondsia chinensis* (McGinnes & Arnold 1939)
Baccharis: 0.9(*Populus fremontii*) = *Baccharis salicifolia* (Glenn et al. 1998)
Granjeno: mean of *Atriplex canescens* (Watson 1990), *Larrea tridentata* (Dwyer & DeGarmo 1970), *Populus fremontii* (Anderson 1982)
Agarito: *Larrea tridentata* (mean of Dwyer & DeGarmo 1970; Lane et al. 1984)
Rattlepod: mean of *Atriplex lentiformis* (Watson 1990), *Baccharis salicifolia* (Glenn et al. 1998), *Salix goodingii* (Glenn et al. 1998)
Mustang grape: *Populus fremontii* (Anderson 1982)

Prickly pear: *Opuntia basilaris* (Nobel 1976)

Big bluestem: Weaver (1941)
Purple threeawn: McLendon et al. (unpublished)
KR bluestem: Coyne & Bradford (1986)
Silver bluestem: McGinnes & Arnold (1939)
Sideoats grama: McGinnes & Arnold (1939)
Hairy grama: McGinnes & Arnold (1939)
Buffalograss: 90% of blue grama (Shantz & Piemeisel 1927)
Sandbur: *Cenchrus ciliaris,* mean of Khan (1971) and Kapinga (1982)
Hooded windmillgrass and trichloris: *Chloris gayana* (Kapinga 1982)
Bermudagrass: mean of McDonald & Hughes (1968) and Wiedenfeld (1988)
Arizona cottontop: McGinnes & Arnold (1939)
Virginia wildrye: *Leymus junceus*, mean of Hunt (1962), Power (1985), Frank & Berdahl (1999)
Clubhead cutgrass: *Phalaris aquatica* (Morison & Gifford 1984)
Kleingrass: mean of McCawley (1978) and Kapinga (1982)
Vine-mesquite: 90% of *Hilaria mutica* (Dwyer & DeGarmo 1970)
Switchgrass: mean of *Andropogon gerardii* (Weaver 1941), *Panicum antidotale* (Writht & Dobrenz 1970)
Longtom: *Paspalum vaginatum* (Biran et al. 1981)
Thin paspalum: mean of *Aristida purpurea* (McLendon et al., unpublished), *Bouteloua hirsuta* (McGinnes & Arnold), *Cenchrus ciliaris* (Kapinga 1982), *Eragrostis curvula* (Wiedenfield 1988), *Heteropogon contortus* (McGinnes & Arnold 1939), *Schizachyrium scoparium* (Weaver 1941), *Sporobolus airoides* (Benton & Wester 1998), *Sporobolus flexuous* (Dwyer & DeGarmo)
Little bluestem: mean of Weaver (1941) and McLendon et al. (unpublished)
Knotroot bristle: mean of *Spartina alterniflora* (Gallagher et al. 1980) and *Sporobolus wrightii* (Cox 1985)
Texas bristlegrass: mean of *Bothriochloa saccharoides* (McGinnes & Arnold), *Setaria italic* (Briggs & Shantz 1913), *Sporobolus flexuous* (Dwyer & DeGarmo 1970)
Johnsongrass: mean of *Andropogon gerardii* (Weaver 1941), *Chloris gayana* (Kapinga 1982), *Panicum antidotale* (Wright & Dobrenz), *Phragmites australis* (Mueller et al. 2005), *Sorghum bicolor* (Briggs & Shantz 1913)
Tall dropseed: *Sporobolus flexuosus* (Dwyer & DeGarmo 1970)
Texas wintergrass: *Stipa viridula* (Fairbourn 1982)

Milo: Briggs & Shantz (1913), Peng & Krieg (1992)
Wheat: Briggs & Shantz (1913)
Corn: Briggs & Shantz (1913)

Littletooth sedge: *Juncus roemerianus* (Giurgevich & Dunn 1978)
Flatsedge: *Phragmites australis* (Mueller et al. 2005)
Fimbry: *Phalaris arundinacea* (Mueller et al. 2005)
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)
Old-mans beard: mean of *Ambrosia artemisifolia* and *Iva xanthifolia* (Shantz & Piemeisel 1927)
Bundleflower: mean of *Lotus humistrautis* (McGinnes & Arnold 1939), *Melilotus alba* (Shantz & Piemeisel 1927)
Frogfruit: mean of *Amaranthus retroflexus* (Briggs & Shantz 1913), *Plantago insularis* (McGinnes & Arnold 1939), *Polygonum aviculare* (Shantz & Piemeisel 1927)
Priaire coneflower: mean of *Ambrosia artemisifolia, Grindelia squarrosa*, *Helianthus petiolaris*, *Polygonum aviculare* (Shantz & Piemeisel 1927)
Snoutbean: mean of *Glycine max* (Lawn 1982), *Lotus humistrautis* (McGinnes & Arnold 1939), *Pisum sativum* (Briggs & Shantz 1913)
Ruellia: mean of *Fagopyrum fagopyrum* (Briggs & Shantz 1913), *Iva xanthifolia* (Shantz & Piemeisel 1927), *Plantago insularis* (McGinnes & Arnold 1939), *Polygonum aviculare* (Shantz & Piemeisel 1927), *Solanum tuberosum* (Briggs & Shantz 1913)
Bush sunflower: mean of *Helianthus petiolaris* and *Polygonum aviculare* (Shantz & Piemeisel 1927)
Texas verbena: mean of *Chenopodium album* (Shantz & Piemeisel 1927), *Erodium cicutarium* (McGinnes & Arnold 1939)
Orange zexmenia: 0.8(bush sunflower)

Giant ragweed: mean of *Amaranthus retroflexus* (Briggs & Shantz 1913), *Helianthus annuus* (mean of 4 studies), *Iva xanthifolia* (Shantz & Piemeisel 1927), *Polygonum aviculare* (Shantz & Piemeisel 1927)
Annual broomweed: mean of *Fagopyrum fagopyrum* (Briggs & Shantz 1913), *Grindelia squarrosa* (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)
Partridge pea: mean of *Astragalus cicer* (Fairbourn 1982), *Lotus humistrautis* (McGinnes & Arnold 1939), *Pisum sativum* (Briggs & Shantz 1913)
Texas doveweed: mean of *Brassica napus* (Briggs & Shantz 1913), *Chenopodium album* (Shantz & Piemeisel 1927), *Fagopyrum fagopyrum* (Briggs & Shantz 1913),
Texas bluebonnet: mean of *Astragalus cicer* (Fairbourn 1982), *Lotus humistrautis* (McGinnes & Arnold 1939), *Trifolium pretense* (Mueller et al. 2005)
Dogweed: mean of *Boerhaavia torreyana* (McGinnes & Arnold 1939), *Pectocarya linearis* (McGinnes & Arnold 1939), *Salsola iberica* (Briggs & Shantz 1913)

Appendix Table E.14 Growth rate control factor values for plant species included in the Goliad County EDYS model.

Common Name	Max growth rate	Max biomass	Max plant height	Max old biomass drought loss
Huisache	1.10	5000	6000	0.20
Pecan	0.98	28000	42672	0.10
Sugar hackberry	1.10	14000	9144	0.10
Mesquite	0.90	6400	9144	0.05
Post oak	0.25	15000	9144	0.10
Live oak	0.40	29000	9144	0.10
Guajillo	0.28	2100	1500	0.35
Blackbrush	0.28	2400	1500	0.35
Whitebrush	1.00	2600	1500	0.35
Prairie baccharis	1.20	2800	1500	0.40
Sea oxeye	0.80	390	792	0.50
Granjeno	0.90	2500	792	0.50
Carolina wolfberry	0.50	1000	1500	0.25
Agarito	0.25	1200	792	0.10
McCartney rose	0.75	2000	792	0.30
Rattlepod	1.30	1400	792	0.70
Mustang grape	1.00	2000	1500	0.40
Texas prickly pear	0.05	2400	792	0.10
Big bluestem	3.00	800	792	0.80
Bushy bluestem	2.25	390	792	0.80
Purple threeawn	2.75	300	792	0.20
King Ranch bluestem	2.50	800	610	0.20
Silver bluestem	2.75	600	610	0.40
Sideoats grama	2.75	600	610	0.25
Hairy grama	1.75	250	610	0.20
Red grama	1.75	150	850	0.20
Buffalograss	1.71	350	610	0.30
Sandbur	2.20	1020	610	0.80
Hooded windmillgrass	1.75	250	610	0.80
Trichloris	2.25	600	610	0.80
Bermudagrass	2.50	600	396	0.25
Arizona cottontop	2.50	500	351	0.40
Saltgrass	2.30	1020	351	0.40
Virginia wildrye	2.75	600	351	0.40
Texas cupgrass	2.50	600	351	0.30
Green sprangletop	2.50	400	351	0.30
Kleingrass	2.00	800	351	0.40
Guineagrass	2.00	800	351	0.40
Vine-mesquite	2.75	450	351	0.30
Switchgrass	2.75	800	351	0.30
Longtom	2.75	500	610	0.40
Brownseed paspalum	2.40	780	990	0.40

Appendix Table E.14 (Cont.)

Common Name	Max growth rate	Max biomass	Max plant height	Max old biomass drought loss
Thin paspalum	2.25	400	610	0.40
Common reed	3.26	2100	850	0.15
Little bluestem	2.50	600	914	0.30
Knotroot bristlegrass	1.50	250	850	0.30
Plains bristlegrass	1.36	1080	850	0.30
Texas bristlegrass	1.50	100	850	0.30
Indiangrass	2.75	750	792	0.30
Johnsongrass	2.75	800	850	0.35
Gulf cordgrass	1.36	1080	2012	0.30
Tall dropseed	2.75	600	850	0.30
Sand dropseed	2.75	400	850	0.20
Smutgrass	1.36	1080	850	0.30
Texas wintergrass	2.00	300	1200	0.25
Milo	4.00	1000	1200	0.30
Wheat	2.00	350	1200	0.30
Corn	3.00	1200	1200	0.30
Littletooth sedge	1.25	250	1325	0.50
Flatsedge	1.50	500	351	0.30
Cattail	1.00	800	351	0.50
Ragweed	3.12	600	1035	0.20
Lazydaisy	2.00	60	1035	0.25
Spiny aster	3.50	1000	1325	0.30
Whitestem wild indigo	1.75	710	351	0.50
Old-mans beard	1.00	400	1400	0.35
Bundleflower	2.00	80	1035	0.20
Frogfruit	2.40	60	1035	0.10
Prairie coneflower	2.00	60	895	0.30
Snoutbean	2.00	80	1050	0.80
Ruellia	2.00	50	1050	0.80
Curly dock	1.50	450	1050	0.80
Bulltongue	1.50	450	1050	0.80
Glasswort	1.80	450	1050	0.40
Bush sunflower	1.75	300	1050	0.20
Green briar	0.40	800	792	0.40
Texas verbena	2.50	50	1050	0.80
Orange zexmenia	1.35	200	1050	0.15
Giant ragweed	4.00	1000	1035	0.10
Annual broomweed	3.00	300	1035	0.10
Partridge pea	1.50	200	1325	0.70
Texas doveweed	1.50	250	895	0.80
Sunflower	3.00	750	895	0.30
Dogweed	1.00	60	1035	0.10

Data Sources

Maximum Growth Rate

Purple threeawn	*Aristida glabrata* (McGinnies & Arnold 1939)
Silver bluestem	McGinnies & Arnold (1939)
Sideoats grama	McGinnies & Arnold (1939)
Hairy grama	McGinnies & Arnold (1939)
Buffalograss	*Hilaria belangeri* (McGinnies & Arnold 1939)
Arizona cottontop	modified from McGinnies & Arnold (1939)
Thin paspalum	*Heteropogon contortus* (McGinnies & Arnold 1939)

Maximum Aboveground Biomass

King Ranch bluestem	*Dichanthium annualtum* (Kapinga 1982)

Appendix Table E.15 Monthly growth rates (proportion of maximum potential growth rate, Appendix Table E.14) for plant species in the Goliad County EDYS model.

Common Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Huisache	0.10	0.20	0.70	0.90	1.00	1.00	1.00	1.00	0.80	0.50	0.20	0.10
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
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
Post 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
Guajillo	0.05	0.10	0.50	0.90	1.00	1.00	1.00	1.00	0.80	0.50	0.10	0.05
Blackbrush	0.05	0.15	0.50	0.90	1.00	1.00	1.00	1.00	0.80	0.60	0.30	0.10
Whitebrush	0.20	0.40	0.90	1.00	1.00	1.00	1.00	1.00	0.80	0.50	0.30	0.20
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
Sea oxeye	0.00	0.00	0.00	0.50	0.90	1.00	1.00	1.00	0.90	0.50	0.00	0.00
Granjeno	0.05	0.10	0.70	0.90	1.00	1.00	1.00	1.00	0.80	0.50	0.30	0.05
Carolina wolfberry	0.00	0.00	0.50	0.80	1.00	1.00	1.00	1.00	1.00	0.70	0.30	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
McCartney rose	0.20	0.20	0.40	0.80	1.00	1.00	1.00	1.00	0.90	0.60	0.30	0.20
Rattlepod	0.05	0.20	0.40	0.70	1.00	1.00	1.00	1.00	0.90	0.70	0.40	0.05
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
Texas 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
Big bluestem	0.00	0.10	0.50	0.90	1.00	1.00	1.00	1.00	0.90	0.60	0.30	0.05
Bushy bluestem	0.00	0.00	0.30	0.60	0.90	1.00	1.00	1.00	0.75	0.40	0.05	0.00
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
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
Silver bluestem	0.10	0.15	0.50	0.80	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
Buffalograss	0.05	0.10	0.40	0.80	1.00	1.00	1.00	0.90	0.70	0.50	0.30	0.10
Sandbur	0.00	0.00	0.20	0.50	0.80	1.00	1.00	0.90	0.80	0.60	0.30	0.00
Hooded windmillgrass	0.00	0.01	0.40	0.80	0.90	1.00	1.00	0.90	0.70	0.50	0.20	0.00
Trichloris	0.10	0.10	0.50	0.70	1.00	1.00	1.00	0.90	0.70	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
Arizona cottontop	0.20	0.30	0.40	0.50	0.60	0.70	0.90	1.00	0.60	0.50	0.40	0.30
Saltgrass	0.10	0.20	0.60	1.00	1.00	0.90	0.80	0.70	0.80	0.40	0.20	0.10
Virginia wildrye	0.50	0.80	1.00	1.00	0.80	0.40	0.10	0.10	0.30	0.40	0.50	0.50
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
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
Kleingrass	0.10	0.20	0.30	0.50	0.80	1.00	1.00	1.00	0.80	0.60	0.40	0.20
Guineagrass	0.10	0.20	0.30	0.50	0.80	1.00	1.00	1.00	0.80	0.60	0.40	0.20
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
Longtom	0.10	0.30	0.75	0.90	1.00	1.00	1.00	1.00	0.60	0.40	0.20	0.10
Brownseed paspalum	0.00	0.00	0.50	0.90	1.00	1.00	1.00	1.00	0.90	0.50	0.20	0.00

Appendix Table E.15 (Cont.)

Common Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Thin paspalum	0.10	0.20	0.40	0.80	1.00	1.00	1.00	0.80	0.60	0.40	0.20	0.10
Common reed	0.00	0.10	0.50	0.90	1.00	1.00	1.00	1.00	1.00	0.70	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
Knotroot bristlegrass	0.10	0.30	0.60	0.80	1.00	1.00	1.00	0.80	0.60	0.40	0.20	0.10
Plains bristlegrass	0.00	0.10	0.80	1.00	1.00	0.90	0.80	0.70	0.80	0.40	0.20	0.00
Texas bristlegrass	0.20	0.40	0.60	0.80	1.00	1.00	0.80	0.70	0.60	0.50	0.40	0.30
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	0.80	0.40	0.20	0.05
Gulf cordgrass	0.10	0.30	0.80	1.00	1.00	0.90	0.80	0.70	0.80	0.40	0.20	0.10
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
Smutgrass	0.10	0.30	0.80	1.00	1.00	0.90	0.80	0.70	0.80	0.40	0.20	0.10
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
Milo	0.00	0.10	0.90	1.00	1.00	1.00	1.00	0.80	0.50	0.20	0.00	0.00
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
Corn	0.00	0.10	0.90	1.00	1.00	1.00	1.00	0.90	0.60	0.30	0.10	0.00
Littletooth sedge	0.10	0.25	0.50	0.90	1.00	1.00	1.00	0.90	0.70	0.50	0.30	0.10
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
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	0.10
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
Spiny aster	0.00	0.15	0.30	0.60	1.00	1.00	1.00	0.80	0.60	0.30	0.10	0.00
Whitestem wild indigo	0.00	0.10	0.60	1.00	1.00	1.00	1.00	1.00	0.80	0.20	0.10	0.00
Old-mans beard	0.10	0.20	0.40	0.80	1.00	1.00	1.00	0.90	0.70	0.50	0.30	0.20
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
Frogfruit	0.10	0.20	0.50	0.70	1.00	1.00	1.00	0.80	0.60	0.40	0.20	0.10
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
Snoutbean	0.10	0.15	0.60	0.90	1.00	1.00	1.00	1.00	0.80	0.40	0.20	0.10
Ruellia	0.10	0.20	0.70	0.90	1.00	1.00	1.00	1.00	0.80	0.40	0.20	0.10
Curly dock	0.10	0.10	0.40	0.80	1.00	1.00	1.00	1.00	0.90	0.40	0.20	0.10
Bulltongue	0.10	0.10	0.40	0.80	1.00	1.00	1.00	1.00	0.90	0.40	0.20	0.10
Glasswort	0.00	0.00	0.40	0.90	1.00	1.00	1.00	1.00	0.80	0.50	0.20	0.00
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
Green briar	0.10	0.30	0.80	1.00	1.00	1.00	1.00	0.90	0.70	0.50	0.40	0.10
Texas verbena	0.20	0.40	0.80	1.00	1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.30
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
Giant ragweed	0.10	0.20	0.50	0.90	1.00	1.00	1.00	0.80	0.60	0.40	0.20	0.00
Annual broomweed	0.10	0.20	0.40	0.80	1.00	1.00	0.90	0.70	0.50	0.30	0.10	0.00
Partridge pea	0.20	0.40	0.80	1.00	1.00	1.00	0.90	0.70	0.50	0.30	0.10	0.00
Texas doveweed	0.10	0.30	0.60	1.00	1.00	1.00	0.90	0.80	0.60	0.40	0.10	0.00
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
Dogweed	0.10	0.30	0.50	0.80	1.00	1.00	1.00	0.60	0.40	0.20	0.10	0.00

Data Sources

Purple threeawn	Modified from *Aristida divaricata* (McGinnies & Arnold 1939)
Silver bluestem	McGinnies & Arnold 1939
Sideoats grama	McGinnies & Arnold 1939
Hairy grama	McGinnies & Arnold 1939
Arizona cottontop	McGinnies & Arnold 1939

Appendix Table E.16 Plant part productivity rates (proportion of maximum photosynthetic rate) for plant species in the Goliad County EDYS model.

Common Name	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Huisache	0.00	0.00	0.00	0.05	1.00	0.00
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
Mesquite	0.00	0.00	0.00	0.02	1.00	0.00
Post 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
Guajillo	0.00	0.00	0.00	0.02	1.00	0.00
Blackbrush	0.00	0.00	0.00	0.00	1.00	0.00
Whitebrush	0.00	0.00	0.00	0.05	1.00	0.00
Prairie baccharis	0.00	0.00	0.00	0.00	1.00	0.00
Sea oxeye	0.00	0.00	0.00	0.20	1.00	0.10
Granjeno	0.00	0.00	0.00	0.00	1.00	0.00
Carolina wolfberry	0.00	0.00	0.00	0.10	1.00	0.00
Agarito	0.00	0.00	0.00	0.02	1.00	0.00
McCartney rose	0.00	0.00	0.00	0.30	1.00	0.00
Rattlepod	0.00	0.00	0.00	0.05	1.00	0.00
Mustang grape	0.00	0.00	0.00	0.00	1.00	0.00
Texas prickly pear	0.00	0.00	0.02	1.00	0.00	0.00
Big bluestem	0.00	0.00	0.00	0.10	1.00	0.00
Bushy bluestem	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
King Ranch bluestem	0.00	0.00	0.05	0.30	1.00	0.00
Silver bluestem	0.00	0.00	0.00	0.20	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
Buffalograss	0.00	0.00	0.10	0.20	1.00	0.00
Sandbur	0.00	0.00	0.10	0.40	1.00	0.00
Hooded windmillgrass	0.00	0.00	0.10	0.20	1.00	0.00
Trichloris	0.00	0.00	0.01	0.20	1.00	0.00
Bermudagrass	0.00	0.00	0.10	0.20	1.00	0.00
Arizona cottontop	0.00	0.00	0.05	0.20	1.00	0.00
Saltgrass	0.00	0.00	0.00	0.10	1.00	0.00
Virginia wildrye	0.00	0.00	0.00	0.10	1.00	0.00
Texas cupgrass	0.00	0.00	0.05	0.20	1.00	0.00
Green sprangletop	0.00	0.00	0.05	0.20	1.00	0.00
Kleingrass	0.00	0.00	0.00	0.10	1.00	0.00
Guineagrass	0.00	0.00	0.00	0.10	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
Longtom	0.00	0.00	0.03	0.20	1.00	0.00
Brownseed paspalum	0.00	0.00	0.00	0.20	1.00	0.00

Appendix Table E.16 (Cont.)

Common Name	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Thin paspalum	0.00	0.00	0.05	0.20	1.00	0.00
Common reed	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
Knotroot bristlegrass	0.00	0.00	0.10	0.20	1.00	0.00
Plains bristlegrass	0.00	0.00	0.00	0.30	1.00	0.00
Texas bristlegrass	0.00	0.00	0.10	0.20	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
Gulf cordgrass	0.00	0.00	0.00	0.30	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
Smutgrass	0.00	0.00	0.00	0.30	1.00	0.00
Texas wintergrass	0.00	0.00	0.10	0.20	1.00	0.00
Milo	0.00	0.00	0.00	0.20	1.00	0.00
Wheat	0.00	0.00	0.02	0.20	1.00	0.00
Corn	0.00	0.00	0.00	0.20	1.00	0.00
Littletooth sedge	0.00	0.00	0.05	0.20	1.00	0.00
Flatsedge	0.00	0.00	0.00	0.20	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
Spiny aster	0.00	0.00	0.00	0.60	1.00	0.00
Whitestem wild indigo	0.00	0.00	0.10	1.00	0.00	0.00
Old-mans beard	0.00	0.00	0.10	0.20	1.00	0.00
Bundleflower	0.00	0.00	0.10	0.10	1.00	0.00
Frogfruit	0.00	0.00	0.05	0.05	1.00	0.00
Prairie coneflower	0.00	0.00	0.00	0.05	1.00	0.00
Snoutbean	0.00	0.00	0.05	0.10	1.00	0.00
Ruellia	0.00	0.00	0.05	0.10	1.00	0.00
Curly dock	0.00	0.00	0.00	0.10	1.00	0.00
Bulltongue	0.00	0.00	0.00	0.10	1.00	0.00
Glasswort	0.00	0.00	0.10	0.20	1.00	0.00
Bush sunflower	0.00	0.00	0.05	0.10	1.00	0.00
Green briar	0.00	0.00	0.10	0.50	1.00	0.00
Texas verbena	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
Giant ragweed	0.00	0.00	0.00	0.20	1.00	0.00
Annual broomweed	0.00	0.00	0.00	0.10	1.00	0.00
Partridge pea	0.00	0.00	0.00	0.10	1.00	0.00
Texas doveweed	0.00	0.00	0.00	0.05	1.00	0.00
Sunflower	0.00	0.00	0.05	0.20	1.00	0.00
Dogweed	0.00	0.00	0.00	0.20	1.00	0.00

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

Common Name	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Huisache	0.02	0.00	0.01	0.05	1.00	0.00
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
Mesquite	0.02	0.00	0.01	0.05	1.00	0.00
Post 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
Guajillo	0.02	0.00	0.02	0.05	1.00	0.00
Blackbrush	0.02	0.00	0.02	0.05	1.00	0.00
Whitebrush	0.04	0.00	0.04	0.10	1.00	0.00
Prairie baccharis	0.04	0.00	0.04	0.10	1.00	0.00
Sea oxeye	0.10	0.00	0.00	0.10	0.80	0.00
Granjeno	0.02	0.00	0.02	0.05	1.00	0.00
Carolina wolfberry	0.10	0.00	0.10	0.20	1.00	0.00
Agarito	0.02	0.00	0.02	0.05	1.00	0.00
McCartney rose	0.05	0.00	0.05	0.20	1.00	0.00
Rattlepod	0.02	0.00	0.05	0.10	1.00	0.00
Mustang grape	0.01	0.00	0.02	0.10	1.00	0.00
Texas prickly pear	0.01	0.00	0.02	0.00	0.00	0.00
Big bluestem	0.05	0.00	0.10	0.50	1.00	0.00
Bushy bluestem	0.00	0.00	1.00	1.00	1.00	0.00
Purple threeawn	0.05	0.00	0.05	0.50	1.00	0.00
King Ranch bluestem	0.05	0.00	0.10	0.50	1.00	0.00
Silver 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
Buffalograss	0.05	0.00	0.05	0.50	1.00	0.00
Sandbur	0.10	0.00	0.20	0.50	1.00	0.00
Hooded windmillgrass	0.05	0.00	0.05	0.50	1.00	0.00
Trichloris	0.05	0.00	0.10	0.50	1.00	0.00
Bermudagrass	0.10	0.00	0.10	0.50	1.00	0.00
Arizona cottontop	0.05	0.00	0.10	0.50	1.00	0.00
Saltgrass	0.10	0.00	0.10	0.50	1.00	0.00
Virginia wildrye	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
Green sprangletop	0.05	0.00	0.05	0.50	1.00	0.00
Kleingrass	0.05	0.00	0.10	0.50	1.00	0.00
Guineagrass	0.05	0.00	0.10	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
Longtom	0.05	0.00	0.10	0.50	1.00	0.00
Brownseed paspalum	0.10	0.00	0.10	0.50	1.00	0.00

Appendix Table E.17 (Cont.)

Common Name	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Thin paspalum	0.05	0.00	0.05	0.50	1.00	0.00
Common reed	0.10	0.00	0.10	0.25	1.00	0.00
Little bluestem	0.05	0.00	0.10	0.50	1.00	0.00
Knotroot bristlegrass	0.10	0.00	0.10	0.50	1.00	0.00
Plains bristlegrass	0.10	0.00	0.10	0.50	1.00	0.00
Texas bristlegrass	0.05	0.00	0.05	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
Gulf cordgrass	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
Smutgrass	0.10	0.00	0.10	0.50	1.00	0.00
Texas wintergrass	0.05	0.00	0.05	0.50	1.00	0.00
Milo	0.00	0.00	0.10	0.50	1.00	0.00
Wheat	0.00	0.00	0.10	0.50	1.00	0.00
Corn	0.00	0.00	0.10	0.50	1.00	0.00
Littletooth sedge	0.05	0.00	0.05	0.50	1.00	0.00
Flatsedge	0.10	0.00	0.10	0.50	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
Spiny aster	0.00	0.00	0.20	0.50	1.00	0.00
Whitestem wild indigo	0.10	0.00	0.10	1.00	0.00	0.00
Old-mans beard	0.10	0.00	0.10	0.40	1.00	0.00
Bundleflower	0.05	0.00	0.10	0.40	1.00	0.00
Frogfruit	0.05	0.00	0.10	0.30	1.00	0.00
Prairie coneflower	0.10	0.00	0.10	0.30	1.00	0.00
Snoutbean	0.10	0.00	0.20	0.30	1.00	0.00
Ruellia	0.10	0.00	0.10	0.30	1.00	0.00
Curly dock	0.20	0.00	0.40	0.40	1.00	0.00
Bulltongue	0.20	0.00	0.40	0.40	1.00	0.00
Glasswort	0.10	0.00	0.10	0.50	1.00	0.00
Bush sunflower	0.10	0.00	0.20	0.40	1.00	0.00
Green briar	0.10	0.00	0.20	0.50	1.00	0.00
Texas verbena	0.05	0.00	0.10	0.30	1.00	0.00
Orange zexmenia	0.10	0.00	0.10	0.40	1.00	0.00
Giant ragweed	0.00	0.00	0.20	0.50	1.00	0.00
Annual broomweed	0.00	0.00	0.10	0.20	1.00	0.00
Partridge pea	0.00	0.00	0.20	0.40	1.00	0.00
Texas doveweed	0.00	0.00	0.10	0.20	1.00	0.00
Sunflower	0.00	0.00	0.20	0.50	1.00	0.00
Dogweed	0.00	0.00	0.20	0.30	1.00	0.00

Appendix Table E.18 Physiological control constants for plant species in the Goliad County EDYS model.

Common Name	Growing season max root:shoot	Growing season green-out shoot:root	Max 1-mo seed germination	Max 1st-mo seedling growth
Huisache	1.70	0.230	0.730	20.00
Pecan	1.50	0.670	0.730	5.00
Sugar hackberry	0.56	1.780	0.800	10.00
Mesquite	0.64	1.560	0.500	10.00
Post oak	0.72	0.130	0.950	8.00
Live oak	0.92	1.090	0.630	8.00
Guajillo	1.30	0.200	0.960	20.00
Blackbrush	1.30	0.200	0.960	20.00
Whitebrush	1.22	0.190	0.960	20.00
Prairie baccharis	1.22	0.820	0.940	10.00
Sea oxeye	1.80	0.280	0.750	15.00
Granjeno	1.32	0.200	0.750	15.00
Carolina wolfberry	1.10	0.463	0.720	20.00
Agarito	1.94	0.520	0.790	10.00
McCartney rose	5.10	0.097	0.480	20.00
Rattlepod	1.22	0.190	0.260	30.00
Mustang grape	1.00	1.000	0.640	10.00
Texas prickly pear	0.62	1.610	0.700	10.00
Big bluestem	1.72	0.230	0.540	20.00
Bushy bluestem	1.30	0.750	0.540	20.00
Purple threeawn	3.78	0.260	0.160	20.00
King Ranch bluestem	3.18	0.310	0.600	30.00
Silver bluestem	2.00	0.250	0.900	30.00
Sideoats grama	3.20	0.310	0.720	20.00
Hairy grama	1.12	0.890	0.390	20.00
Red grama	1.12	0.890	0.390	20.00
Buffalograss	2.40	0.270	0.618	30.00
Sandbur	2.00	0.249	0.440	15.00
Hooded windmillgrass	1.80	0.240	0.440	15.00
Trichloris	2.00	0.250	0.440	15.00
Bermudagrass	2.42	0.410	0.850	20.00
Arizona cottontop	1.80	0.240	0.900	30.00
Saltgrass	1.40	0.530	0.900	30.00
Virginia wildrye	1.68	0.230	0.900	30.00
Texas cupgrass	2.12	0.470	0.530	20.00
Green sprangletop	1.72	0.580	0.790	20.00
Kleingrass	1.80	0.240	0.900	30.00
Guineagrass	1.80	0.240	0.900	30.00
Vine-mesquite	1.70	0.590	0.370	20.00
Switchgrass	1.96	0.510	0.480	20.00
Longtom	5.00	0.360	0.530	30.00
Brownseed paspalum	2.40	0.210	0.530	30.00

Appendix Table E.18 (Cont.)

Common Name	Growing season max root:shoot	Growing season green-out shoot:root	Max 1-mo seed germination	Max 1st-mo seedling growth
Thin paspalum	1.52	0.220	0.530	30.00
Common reed	0.72	1.250	0.010	10.00
Little bluestem	3.26	0.310	0.480	20.00
Knotroot bristlegrass	2.20	0.260	0.580	25.00
Plains bristlegrass	3.40	0.220	0.580	25.00
Texas bristlegrass	1.20	0.190	0.580	25.00
Indiangrass	1.72	0.580	0.630	20.00
Johnsongrass	4.42	0.230	0.880	20.00
Gulf cordgrass	3.40	0.220	0.580	25.00
Tall dropseed	2.20	0.450	0.800	20.00
Sand dropseed	1.76	0.570	0.800	20.00
Smutgrass	3.40	0.220	0.580	25.00
Texas wintergrass	2.52	0.400	0.130	20.00
Milo	2.00	0.250	0.580	25.00
Wheat	1.76	0.570	0.940	20.00
Corn	2.00	0.250	0.580	25.00
Littletooth sedge	2.40	0.270	0.353	30.00
Flatsedge	6.66	0.170	0.460	20.00
Cattail	6.66	0.170	0.650	20.00
Ragweed	2.52	0.400	0.600	20.00
Lazydaisy	2.76	0.360	0.700	10.00
Spiny aster	2.30	0.350	0.950	40.00
Whitestem wild indigo	1.60	0.300	0.520	15.00
Old-mans beard	2.60	0.280	0.960	20.00
Bundleflower	2.92	0.350	0.420	20.00
Frogfruit	1.00	0.170	0.500	20.00
Prairie coneflower	2.76	0.360	0.500	20.00
Snoutbean	1.40	0.210	0.700	50.00
Ruellia	1.20	0.190	0.700	50.00
Curly dock	0.70	0.270	0.700	50.00
Bulltongue	0.70	0.270	0.700	50.00
Glasswort	3.90	0.129	0.990	30.00
Bush sunflower	2.52	0.400	0.380	20.00
Green briar	2.00	0.250	0.600	30.00
Texas verbena	1.40	0.210	0.700	50.00
Orange zexmenia	2.52	0.400	0.500	20.00
Giant ragweed	1.00	0.170	0.500	20.00
Annual broomweed	1.20	0.190	0.500	20.00
Partridge pea	1.20	0.190	0.260	30.00
Texas doveweed	0.80	0.140	0.700	50.00
Sunflower	0.34	2.940	0.820	30.00
Dogweed	1.20	0.190	0.600	30.00

Growing season max root:shoot ratio = twice the initial root:shoot ratio value (Appendix Table D.2). Examples of field root:shoot ratios include: *Quercus robur* 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. 1979), 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 (Buyanovsky 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).

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

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

Common Name	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Huisache	0.02	0.06	0.010	0.02	0.85	1.00
Pecan	0.01	0.05	0.005	0.01	1.00	1.00
Sugar hackberry	0.01	0.05	0.010	0.02	0.98	1.00
Mesquite	0.01	0.05	0.005	0.02	0.90	1.00
Post oak	0.01	0.05	0.010	0.02	1.00	1.00
Live oak	0.01	0.05	0.005	0.01	0.74	1.00
Guajillo	0.03	0.15	0.030	0.10	0.35	1.00
Blackbrush	0.03	0.15	0.020	0.10	0.40	1.00
Whitebrush	0.04	0.15	0.030	0.25	0.90	1.00
Prairie baccharis	0.04	0.15	0.050	0.15	0.85	1.00
Sea oxeye	0.01	0.05	0.010	0.03	1.00	1.00
Granjeno	0.03	0.15	0.020	0.05	0.80	1.00
Carolina wolfberry	0.05	0.15	0.050	0.20	1.00	1.00
Agarito	0.02	0.10	0.020	0.10	0.35	1.00
McCartney rose	0.03	0.10	0.020	0.20	0.35	1.00
Rattlepod	0.08	0.15	0.100	0.20	0.95	1.00
Mustang grape	0.04	0.15	0.010	0.08	0.95	1.00
Texas prickly pear	0.04	0.10	0.020	0.08	0.05	1.00
Big bluestem	0.03	0.09	0.030	0.90	0.99	1.00
Bushy bluestem	0.06	0.15	0.200	1.00	1.00	1.00
Purple threeawn	0.10	0.20	0.050	0.95	0.95	1.00
King Ranch bluestem	0.10	0.20	0.080	0.95	0.98	1.00
Silver bluestem	0.07	0.15	0.040	0.90	0.95	1.00
Sideoats grama	0.05	0.15	0.030	0.90	0.98	1.00
Hairy grama	0.15	0.30	0.080	0.95	0.90	1.00
Red grama	0.15	0.30	0.150	0.95	0.95	1.00
Buffalograss	0.15	0.30	0.150	0.85	0.90	1.00
Sandbur	0.10	0.20	0.050	1.00	1.00	1.00
Hooded windmillgrass	0.15	0.30	0.080	0.95	0.95	1.00
Trichloris	0.10	0.20	0.040	0.90	0.95	1.00
Bermudagrass	0.10	0.20	0.150	0.70	0.90	1.00
Arizona cottontop	0.10	0.20	0.050	0.95	0.95	1.00
Saltgrass	0.10	0.20	0.050	0.85	1.00	1.00
Virginia wildrye	0.12	0.25	0.100	0.95	0.99	1.00
Texas cupgrass	0.10	0.20	0.100	0.95	0.95	1.00
Green sprangletop	0.15	0.30	0.150	0.95	0.90	1.00
Kleingrass	0.18	0.40	0.150	0.95	0.95	1.00
Guineagrass	0.18	0.40	0.150	0.95	0.95	1.00
Vine-mesquite	0.10	0.20	0.050	0.90	0.95	1.00
Switchgrass	0.05	0.15	0.030	0.90	0.95	1.00
Longtom	0.15	0.30	0.060	0.80	0.95	1.00
Brownseed paspalum	0.10	0.20	0.050	0.90	1.00	1.00

Appendix Table E.19 (Cont.)

Common Name	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Thin paspalum	0.17	0.25	0.120	0.95	0.99	1.00
Common reed	0.03	0.10	0.050	0.80	0.90	1.00
Little bluestem	0.10	0.20	0.030	0.90	0.98	1.00
Knotroot bristlegrass	0.18	0.30	0.150	0.90	0.90	1.00
Plains bristlegrass	0.08	0.20	0.040	0.95	0.90	1.00
Texas bristlegrass	0.25	0.50	0.250	0.98	0.99	1.00
Indiangrass	0.05	0.15	0.030	0.90	0.95	1.00
Johnsongrass	0.10	0.20	0.100	0.90	0.95	1.00
Gulf cordgrass	0.08	0.20	0.040	0.95	0.90	1.00
Tall dropseed	0.10	0.20	0.050	0.95	0.97	1.00
Sand dropseed	0.15	0.30	0.100	0.90	0.95	1.00
Smutgrass	0.08	0.20	0.040	0.95	0.90	1.00
Texas wintergrass	0.15	0.30	0.150	0.95	0.95	1.00
Milo	1.00	1.00	1.000	1.00	1.00	1.00
Wheat	1.00	1.00	1.000	1.00	1.00	1.00
Corn	1.00	1.00	1.000	1.00	1.00	1.00
Littletooth sedge	0.15	0.30	0.200	0.90	0.95	1.00
Flatsedge	0.15	0.30	0.150	0.97	0.95	1.00
Cattail	0.10	0.20	0.050	0.95	0.90	1.00
Ragweed	0.18	0.35	0.200	0.95	0.99	1.00
Lazydaisy	0.20	0.40	0.150	0.80	0.99	1.00
Spiny aster	0.08	0.20	0.100	0.90	1.00	1.00
Whitestem wild indigo	0.10	0.20	0.050	0.95	1.00	1.00
Old-mans beard	0.15	0.30	0.120	0.60	0.90	1.00
Bundleflower	0.10	0.20	0.120	0.60	0.95	1.00
Frogfruit	0.20	0.30	0.200	0.80	0.95	1.00
Prairie coneflower	0.15	0.30	0.200	0.70	0.95	1.00
Snoutbean	0.05	0.15	0.050	0.40	0.95	1.00
Ruellia	0.18	0.30	0.100	0.60	0.80	1.00
Curly dock	0.50	0.60	0.500	0.90	0.90	1.00
Bulltongue	0.50	0.60	0.500	0.90	0.90	1.00
Glasswort	0.20	0.40	0.200	1.00	1.00	1.00
Bush sunflower	0.10	0.20	0.200	0.95	0.99	1.00
Green briar	0.08	0.20	0.100	0.40	1.00	1.00
Texas verbena	0.25	0.50	0.300	0.90	0.90	1.00
Orange zexmenia	0.10	0.20	0.200	0.95	0.98	1.00
Giant ragweed	1.00	1.00	1.000	1.00	1.00	1.00
Annual broomweed	1.00	1.00	1.000	1.00	1.00	1.00
Partridge pea	1.00	1.00	1.000	1.00	1.00	1.00
Texas doveweed	1.00	1.00	1.000	1.00	1.00	1.00
Sunflower	1.00	1.00	1.000	1.00	1.00	1.00
Dogweed	1.00	1.00	1.000	1.00	1.00	1.00

Data Sources

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

Appendix Table E.20 Shading effect on species included in the Goliad County EDYS model. Values are the proportional decreases in maximum potential production of the **shaded species** resulting from 100% cover of the **shading species.**

Common Name	Huisache	Pecan	Sugar hackberry	Mesquite	Post oak	Live oak	Guajillo	Blackbrush	Whitebrush	Prairie baccharis	Sea oxeye
Huisache	0.00	0.03	0.01	0.01	0.01	0.03	0.00	0.00	0.01	0.01	0.00
Pecan	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	0.02	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
Mesquite	0.00	0.06	0.01	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
Post oak	0.00	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Live oak	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guajillo	0.03	0.03	0.02	0.02	0.02	0.03	0.00	0.01	0.02	0.02	0.00
Blackbrush	0.01	0.02	0.02	0.01	0.02	0.04	0.01	0.00	0.01	0.01	0.00
Whitebrush	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00
Prairie baccharis	0.00	0.03	0.02	0.02	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Sea oxeye	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Granjeno	0.01	0.01	0.01	0.01	0.01	0.02	0.00	0.00	0.01	0.01	0.00
Carolina wolfberry	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	0.04	0.03	0.01	0.00	0.03	0.00	0.00	0.00	0.01	0.00
McCartney rose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rattlepod	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.01	0.01	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
Texas prickly pear	0.00	0.04	0.02	0.01	0.00	0.04	0.00	0.00	0.00	0.01	0.00
Big bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bushy bluestem	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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
King Ranch bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver bluestem	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
Hairy grama	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
Buffalograss	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sandbur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hooded windmillgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trichloris	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
Arizona cottontop	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Saltgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Virginia wildrye	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
Green sprangletop	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kleingrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guineagrass	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
Switchgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Longtom	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brownseed paspalum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table E.20 (Cont.)

Common Name	Huisache	Pecan	Sugar hackberry	Mesquite	Post oak	Live oak	Guajillo	Blackbrush	Whitebrush	Prairie baccharis	Sea oxeye
Thin paspalum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Common reed	0.00	0.02	0.01	0.00	0.00	0.02	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
Knotroot bristlegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plains bristlegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas bristlegrass	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
Johnsongrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gulf cordgrass	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
Sand dropseed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Smutgrass	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
Milo	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
Corn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Littletooth sedge	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
Cattail	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
Lazydaisy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spiny aster	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Whitestem wild indigo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Old-mans beard	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
Frogfruit	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
Snoutbean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ruellia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Curly dock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulltongue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glasswort	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
Green briar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas verbena	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
Giant ragweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Annual broomweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Partridge pea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas doveweed	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
Dogweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table E.20 (Cont.)

Common Name	Granjeno	Carolina wolfberry	Agarito	McCartney rose	Rattlepod	Mustang grape	Texas prickly pear	Big bluestem	Bushy bluestem	Purple threeawn	King Ranch bluestem
Huisache	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
Pecan	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
Sugar hackberry	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
Mesquite	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00
Post oak	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
Live oak	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00
Guajillo	0.01	0.00	0.01	0.00	0.00	0.04	0.00	0.06	0.00	0.00	0.00
Blackbrush	0.01	0.00	0.00	0.00	0.00	0.04	0.00	0.04	0.00	0.00	0.00
Whitebrush	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Prairie baccharis	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00
Sea oxeye	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Granjeno	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
Carolina wolfberry	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	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
McCartney rose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rattlepod	0.01	0.00	0.00	0.00	0.00	0.04	0.00	0.05	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
Texas prickly pear	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00
Big bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bushy bluestem	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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
King Ranch bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	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
Hairy grama	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
Buffalograss	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.01	0.01
Sandbur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hooded windmillgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.01	0.01
Trichloris	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	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
Arizona cottontop	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00
Saltgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Virginia wildrye	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	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
Green sprangletop	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kleingrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00
Guineagrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	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
Switchgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Longtom	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00
Brownseed paspalum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table E.20 (Cont.)

Common Name	Granjeno	Carolina wolfberry	Agarito	McCartney rose	Rattlepod	Mustang grape	Texas prickly pear	Big bluestem	Bushy bluestem	Purple threeawn	King Ranch bluestem
Thin paspalum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.01	0.00
Common reed	0.00	0.00	0.00	0.00	0.00	0.02	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
Knotroot bristlegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.01	0.01
Plains bristlegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas bristlegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.02	0.02
Indiangrass	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
Gulf cordgrass	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
Sand dropseed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Smutgrass	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
Milo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.06	0.06
Wheat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00
Littletooth sedge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.02	0.01
Flatsedge	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
Ragweed	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
Spiny aster	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Whitestem wild indigo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Old-mans beard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	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
Frogfruit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.01	0.01
Prairie coneflower	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snoutbean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00
Ruellia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00
Curly dock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulltongue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glasswort	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
Green briar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas verbena	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	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
Giant ragweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
Annual broomweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.01	0.00
Partridge pea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00
Texas doveweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.01	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
Dogweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.03	0.01

Appendix Table E.20 (Cont.)

Common Name	Silver bluestem	Sideoats grama	Hairy grama	Red grama	Buffalograss	Sandbur	Hooded windmillgrass	Trichloris	Bermudagrass	Arizona cottontop	Saltgrass
Huisache	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pecan	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
Mesquite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post oak	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
Guajillo	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Blackbrush	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Whitebrush	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
Sea oxeye	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Granjeno	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carolina wolfberry	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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
McCartney rose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rattlepod	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
Texas prickly pear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Big bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bushy bluestem	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	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
King Ranch bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver bluestem	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
Hairy grama	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Red grama	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Buffalograss	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Sandbur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hooded windmillgrass	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00
Trichloris	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	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arizona cottontop	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Saltgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Virginia wildrye	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
Green sprangletop	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kleingrass	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guineagrass	0.01	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
Switchgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Longtom	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Brownseed paspalum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table E.20 (Cont.)

Common Name	Silver bluestem	Sideoats grama	Hairy grama	Red grama	Buffalograss	Sandbur	Hooded windmillgrass	Trichloris	Bermudagrass	Arizona cottontop	Saltgrass
Thin paspalum	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Common reed	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
Knotroot bristlegrass	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
Plains bristlegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas bristlegrass	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.02	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
Johnsongrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gulf cordgrass	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
Sand dropseed	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Smutgrass	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
Milo	0.09	0.08	0.00	0.00	0.00	0.00	0.00	0.02	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
Corn	0.08	0.07	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Littletooth sedge	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.03	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
Cattail	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
Lazydaisy	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spiny aster	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Whitestem wild indigo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Old-mans beard	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Bundleflower	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Frogfruit	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Prairie coneflower	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snoutbean	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Ruellia	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Curly dock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulltongue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glasswort	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
Green briar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas verbena	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	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
Giant ragweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Annual broomweed	0.06	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.02	0.00
Partridge pea	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.00
Texas doveweed	0.05	0.04	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.02	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
Dogweed	0.06	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.05	0.00

Appendix Table E.20 (Cont.)

Common Name	Virginia wildrye	Texas cupgrass	Green sprangletop	Kleingrass	Guineagrass	Vine-mesquite	Switchgrass	Longtom	Brownseed paspalum	Thin paspalum	Common reed
Huisache	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pecan	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
Mesquite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Post oak	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
Guajillo	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Blackbrush	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Whitebrush	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	0.05
Sea oxeye	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Granjeno	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carolina wolfberry	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	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.07
McCartney rose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rattlepod	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
Texas prickly pear	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.08
Big bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bushy bluestem	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	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10
King Ranch bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.05
Silver bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Sideoats grama	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.06
Hairy grama	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10
Red grama	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10
Buffalograss	0.01	0.00	0.00	0.04	0.00	0.00	0.08	0.00	0.00	0.02	0.00
Sandbur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hooded windmillgrass	0.02	0.00	0.00	0.05	0.00	0.00	0.08	0.00	0.00	0.02	0.00
Trichloris	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Bermudagrass	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.02
Arizona cottontop	0.01	0.00	0.00	0.02	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Saltgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Virginia wildrye	0.00	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Texas cupgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.05
Green sprangletop	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.05
Kleingrass	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Guineagrass	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Vine-mesquite	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.02
Switchgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Longtom	0.01	0.00	0.00	0.01	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Brownseed paspalum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table E.20 (Cont.)

Common Name	Virginia wildrye	Texas cupgrass	Green sprangletop	Kleingrass	Guineagrass	Vine-mesquite	Switchgrass	Longtom	Brownseed paspalum	Thin paspalum	Common reed
Thin paspalum	0.01	0.00	0.00	0.03	0.00	0.00	0.06	0.00	0.00	0.00	0.00
Common reed	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	0.02	0.00	0.00	0.00	0.04
Knotroot bristlegrass	0.02	0.00	0.00	0.04	0.00	0.00	0.06	0.03	0.00	0.02	0.00
Plains bristlegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas bristlegrass	0.02	0.00	0.00	0.05	0.00	0.00	0.10	0.01	0.00	0.03	0.00
Indiangrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Johnsongrass	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.02
Gulf cordgrass	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	0.03	0.00	0.00	0.00	0.05
Sand dropseed	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.10
Smutgrass	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	0.05	0.00	0.00	0.00	0.05
Milo	0.00	0.00	0.00	0.04	0.00	0.00	0.10	0.00	0.00	0.00	0.00
Wheat	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10
Corn	0.00	0.00	0.00	0.02	0.00	0.00	0.09	0.00	0.00	0.00	0.00
Littletooth sedge	0.01	0.00	0.00	0.03	0.00	0.00	0.08	0.02	0.00	0.02	0.00
Flatsedge	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.02
Cattail	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	0.10	0.00	0.00	0.00	0.05
Lazydaisy	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10
Spiny aster	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Whitestem wild indigo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Old-mans beard	0.00	0.00	0.00	0.01	0.00	0.00	0.07	0.00	0.00	0.01	0.00
Bundleflower	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10
Frogfruit	0.01	0.00	0.00	0.03	0.00	0.00	0.09	0.02	0.00	0.02	0.00
Prairie coneflower	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10
Snoutbean	0.01	0.00	0.00	0.02	0.00	0.00	0.07	0.00	0.00	0.02	0.00
Ruellia	0.01	0.00	0.00	0.03	0.00	0.00	0.08	0.00	0.00	0.01	0.00
Curly dock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulltongue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glasswort	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	0.05	0.00	0.00	0.00	0.10
Green briar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas verbena	0.01	0.00	0.00	0.02	0.00	0.00	0.07	0.01	0.00	0.02	0.00
Orange zexmenia	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.10
Giant ragweed	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Annual broomweed	0.01	0.00	0.00	0.05	0.00	0.00	0.10	0.00	0.00	0.04	0.00
Partridge pea	0.01	0.00	0.00	0.03	0.00	0.00	0.06	0.00	0.00	0.01	0.00
Texas doveweed	0.01	0.00	0.00	0.04	0.00	0.00	0.10	0.00	0.00	0.04	0.00
Sunflower	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.07
Dogweed	0.04	0.00	0.00	0.05	0.00	0.00	0.10	0.03	0.00	0.04	0.00

Appendix Table E.20 (Cont.)

Common Name	Little bluestem	Knotroot bristlegrass	Plains bristlegrass	Texas bristlegrass	Indiangrass	Johnsongrass	Gulf cordgrass	Tall dropseed	Sand dropseed	Smutgrass	Texas wintergrass
Huisache	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pecan	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
Mesquite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post oak	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
Guajillo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Blackbrush	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Whitebrush	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
Sea oxeye	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Granjeno	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carolina wolfberry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agarito	0.01	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00
McCartney rose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rattlepod	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
Texas prickly pear	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Big bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bushy bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Purple threeawn	0.05	0.00	0.00	0.00	0.10	0.10	0.00	0.03	0.00	0.00	0.00
King Ranch bluestem	0.01	0.00	0.00	0.00	0.05	0.05	0.00	0.00	0.00	0.00	0.00
Silver bluestem	0.01	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	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Hairy grama	0.05	0.00	0.00	0.00	0.10	0.10	0.00	0.03	0.00	0.00	0.00
Red grama	0.05	0.00	0.00	0.00	0.10	0.10	0.00	0.03	0.00	0.00	0.00
Buffalograss	0.02	0.00	0.00	0.00	0.00	0.04	0.00	0.02	0.00	0.00	0.00
Sandbur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hooded windmillgrass	0.05	0.00	0.00	0.00	0.00	0.04	0.00	0.02	0.00	0.00	0.00
Trichloris	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Bermudagrass	0.05	0.00	0.00	0.00	0.05	0.04	0.00	0.00	0.00	0.00	0.00
Arizona cottontop	0.02	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.00	0.00	0.00
Saltgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Virginia wildrye	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Texas cupgrass	0.01	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00
Green sprangletop	0.02	0.00	0.00	0.00	0.05	0.05	0.00	0.00	0.00	0.00	0.00
Kleingrass	0.03	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Guineagrass	0.03	0.00	0.00	0.00	0.00	0.03	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
Switchgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Longtom	0.04	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.00	0.00	0.00
Brownseed paspalum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table E.20 (Cont.)

Common Name	Little bluestem	Knotroot bristlegrass	Plains bristlegrass	Texas bristlegrass	Indiangrass	Johnsongrass	Gulf cordgrass	Tall dropseed	Sand dropseed	Smutgrass	Texas wintergrass
Thin paspalum	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00
Common reed	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
Knotroot bristlegrass	0.04	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.00	0.00
Plains bristlegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas bristlegrass	0.06	0.00	0.00	0.00	0.00	0.06	0.00	0.02	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
Johnsongrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gulf cordgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tall dropseed	0.01	0.00	0.00	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.00
Sand dropseed	0.03	0.00	0.00	0.00	0.05	0.05	0.00	0.03	0.00	0.00	0.00
Smutgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas wintergrass	0.01	0.00	0.00	0.00	0.05	0.05	0.00	0.00	0.00	0.00	0.00
Milo	0.06	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00
Wheat	0.05	0.00	0.00	0.00	0.10	0.10	0.00	0.05	0.00	0.00	0.00
Corn	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
Littletooth sedge	0.05	0.00	0.00	0.00	0.00	0.04	0.00	0.02	0.00	0.00	0.00
Flatsedge	0.05	0.00	0.00	0.00	0.10	0.10	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
Ragweed	0.05	0.00	0.00	0.00	0.10	0.10	0.00	0.00	0.00	0.00	0.00
Lazydaisy	0.07	0.00	0.00	0.00	0.10	0.10	0.00	0.05	0.00	0.00	0.00
Spiny aster	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Whitestem wild indigo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Old-mans beard	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00
Bundleflower	0.07	0.00	0.00	0.00	0.10	0.10	0.00	0.04	0.00	0.00	0.00
Frogfruit	0.03	0.00	0.00	0.00	0.00	0.03	0.00	0.02	0.00	0.00	0.00
Prairie coneflower	0.03	0.00	0.00	0.00	0.10	0.10	0.00	0.02	0.00	0.00	0.00
Snoutbean	0.03	0.00	0.00	0.00	0.00	0.03	0.00	0.02	0.00	0.00	0.00
Ruellia	0.04	0.00	0.00	0.00	0.00	0.04	0.00	0.03	0.00	0.00	0.00
Curly dock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulltongue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glasswort	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bush sunflower	0.01	0.00	0.00	0.00	0.05	0.05	0.00	0.00	0.00	0.00	0.00
Green briar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas verbena	0.03	0.00	0.00	0.00	0.00	0.03	0.00	0.02	0.00	0.00	0.00
Orange zexmenia	0.02	0.00	0.00	0.00	0.05	0.05	0.00	0.00	0.00	0.00	0.00
Giant ragweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Annual broomweed	0.07	0.00	0.00	0.00	0.00	0.08	0.00	0.03	0.00	0.00	0.00
Partridge pea	0.04	0.00	0.00	0.00	0.00	0.04	0.00	0.02	0.00	0.00	0.00
Texas doveweed	0.05	0.00	0.00	0.00	0.00	0.07	0.00	0.04	0.00	0.00	0.00
Sunflower	0.01	0.00	0.00	0.00	0.05	0.05	0.00	0.00	0.00	0.00	0.00
Dogweed	0.08	0.00	0.00	0.00	0.00	0.08	0.00	0.07	0.00	0.00	0.00

Appendix Table E.20 (Cont.)

Common Name	Milo	Wheat	Corn	Littletooth sedge	Flatsedge	Cattail	Ragweed	Lazydaisy	Spiny aster	Whitestem wild indigo	Old-mans beard
Huisache	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pecan	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
Mesquite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post oak	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
Guajillo	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Blackbrush	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Whitebrush	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
Sea oxeye	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Granjeno	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carolina wolfberry	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	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
McCartney rose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rattlepod	0.00	0.00	0.05	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
Texas prickly pear	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
Big bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bushy bluestem	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	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00
King Ranch bluestem	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
Silver bluestem	0.00	0.00	0.02	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	0.06	0.00	0.00	0.00	0.00	0.00
Hairy grama	0.00	0.00	0.00	0.00	0.03	0.10	0.05	0.00	0.00	0.00	0.00
Red grama	0.00	0.00	0.00	0.00	0.05	0.10	0.05	0.00	0.00	0.00	0.00
Buffalograss	0.00	0.00	0.05	0.00	0.01	0.03	0.03	0.00	0.00	0.00	0.03
Sandbur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hooded windmillgrass	0.00	0.00	0.05	0.00	0.03	0.04	0.04	0.00	0.00	0.00	0.04
Trichloris	0.00	0.00	0.05	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	0.05	0.01	0.00	0.00	0.00	0.00
Arizona cottontop	0.00	0.00	0.04	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01
Saltgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Virginia wildrye	0.00	0.00	0.05	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Texas cupgrass	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
Green sprangletop	0.00	0.00	0.00	0.00	0.00	0.05	0.01	0.00	0.00	0.00	0.00
Kleingrass	0.00	0.00	0.04	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.01
Guineagrass	0.00	0.00	0.04	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.01
Vine-mesquite	0.00	0.00	0.00	0.00	0.00	0.02	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
Longtom	0.00	0.00	0.03	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.03
Brownseed paspalum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table E.20 (Cont.)

Common Name	Milo	Wheat	Corn	Littletooth sedge	Flatsedge	Cattail	Ragweed	Lazydaisy	Spiny aster	Whitestem wild indigo	Old-mans beard
Thin paspalum	0.00	0.00	0.04	0.00	0.01	0.01	0.03	0.00	0.00	0.00	0.03
Common reed	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	0.02	0.00	0.00	0.00	0.00	0.00
Knotroot bristlegrass	0.00	0.00	0.04	0.00	0.02	0.02	0.03	0.00	0.00	0.00	0.04
Plains bristlegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas bristlegrass	0.00	0.00	0.04	0.00	0.04	0.04	0.06	0.00	0.00	0.00	0.05
Indiangrass	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Johnsongrass	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Gulf cordgrass	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	0.05	0.01	0.00	0.00	0.00	0.00
Sand dropseed	0.00	0.00	0.00	0.00	0.00	0.10	0.03	0.00	0.00	0.00	0.00
Smutgrass	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	0.05	0.00	0.00	0.00	0.00	0.00
Milo	0.00	0.00	0.06	0.00	0.02	0.03	0.04	0.00	0.00	0.00	0.05
Wheat	0.00	0.00	0.00	0.00	0.03	0.10	0.05	0.00	0.00	0.00	0.00
Corn	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.00	0.05
Littletooth sedge	0.00	0.00	0.04	0.00	0.03	0.03	0.04	0.00	0.00	0.00	0.04
Flatsedge	0.00	0.00	0.00	0.00	0.00	0.03	0.01	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
Ragweed	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00
Lazydaisy	0.00	0.00	0.00	0.00	0.05	0.10	0.10	0.00	0.00	0.00	0.00
Spiny aster	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Whitestem wild indigo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Old-mans beard	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Bundleflower	0.00	0.00	0.00	0.00	0.01	0.08	0.05	0.00	0.00	0.00	0.00
Frogfruit	0.00	0.00	0.01	0.00	0.01	0.01	0.03	0.00	0.00	0.00	0.05
Prairie coneflower	0.00	0.00	0.00	0.00	0.01	0.10	0.10	0.00	0.00	0.00	0.00
Snoutbean	0.00	0.00	0.02	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.05
Ruellia	0.00	0.00	0.02	0.00	0.01	0.02	0.03	0.00	0.00	0.00	0.06
Curly dock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulltongue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glasswort	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	0.05	0.00	0.00	0.00	0.00	0.00
Green briar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas verbena	0.00	0.00	0.03	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.06
Orange zexmenia	0.00	0.00	0.00	0.00	0.00	0.08	0.02	0.00	0.00	0.00	0.00
Giant ragweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Annual broomweed	0.00	0.00	0.04	0.00	0.02	0.02	0.04	0.00	0.00	0.00	0.07
Partridge pea	0.00	0.00	0.02	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.05
Texas doveweed	0.00	0.00	0.04	0.00	0.02	0.02	0.04	0.00	0.00	0.00	0.06
Sunflower	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
Dogweed	0.00	0.00	0.05	0.00	0.02	0.02	0.05	0.00	0.00	0.00	0.06

Appendix Table E.20 (Cont.)

Common Name	Bundleflower	Frogfruit	Prairie coneflower	Snoutbean	Ruellia	Curly dock	Bulltongue	Glasswort	Bush sunflower
Huisache	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pecan	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
Mesquite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post oak	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
Guajillo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Blackbrush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Whitebrush	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
Sea oxeye	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Granjeno	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carolina wolfberry	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	0.00	0.00	0.00	0.00	0.00	0.00
McCartney rose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rattlepod	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
Texas prickly pear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Big bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bushy bluestem	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	0.00	0.00	0.00	0.00	0.00	0.00
King Ranch bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver bluestem	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
Hairy grama	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Red grama	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Buffalograss	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Sandbur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hooded windmillgrass	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02
Trichloris	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
Arizona cottontop	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Saltgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Virginia wildrye	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
Green sprangletop	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kleingrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guineagrass	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
Switchgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Longtom	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Brownseed paspalum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table E.20 (Cont.)

Common Name	Bundleflower	Frogfruit	Prairie coneflower	Snoutbean	Ruellia	Curly dock	Bulltongue	Glasswort	Bush sunflower
Thin paspalum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Common reed	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
Knotroot bristlegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Plains bristlegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas bristlegrass	0.00	0.00	0.00	0.02	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
Johnsongrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gulf cordgrass	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
Sand dropseed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Smutgrass	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
Milo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Wheat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Corn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Littletooth sedge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Flatsedge	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
Ragweed	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	0.05
Spiny aster	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Whitestem wild indigo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Old-mans beard	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	0.03
Frogfruit	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	0.03
Snoutbean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Ruellia	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.03
Curly dock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulltongue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glasswort	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
Green briar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas verbena	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Orange zexmenia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Giant ragweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Annual broomweed	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.04
Partridge pea	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02
Texas doveweed	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02
Sunflower	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dogweed	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.09

Appendix Table E.20 (Cont.)

Common Name	Green briar	Texas verbena	Orange zexmenia	Giant ragweed	Annual broomweed	Partridge pea	Texas doveweed	Sunflower	Dogweed
Huisache	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pecan	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
Mesquite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Post oak	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
Guajillo	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00
Blackbrush	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00
Whitebrush	0.00	0.00	0.00	0.20	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
Sea oxeye	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Granjeno	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00
Carolina wolfberry	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	0.00	0.00	0.00	0.00	0.00	0.00
McCartney rose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rattlepod	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.10	0.00
Mustang grape	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas prickly pear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Big bluestem	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.10	0.00
Bushy bluestem	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	0.00	0.00	0.00	0.00	0.02	0.00
King Ranch bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver bluestem	0.00	0.00	0.00	0.60	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
Hairy grama	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.03	0.00
Red grama	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.04	0.00
Buffalograss	0.00	0.00	0.00	0.90	0.00	0.00	0.05	0.30	0.00
Sandbur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hooded windmillgrass	0.00	0.00	0.00	0.95	0.01	0.00	0.05	0.60	0.00
Trichloris	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.20	0.00
Bermudagrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arizona cottontop	0.00	0.00	0.00	0.80	0.01	0.00	0.04	0.50	0.00
Saltgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Virginia wildrye	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.30	0.00
Texas cupgrass	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
Kleingrass	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.20	0.00
Guineagrass	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.20	0.00
Vine-mesquite	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
Longtom	0.00	0.00	0.00	0.70	0.00	0.00	0.01	0.30	0.00
Brownseed paspalum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table E.20 (Cont.)

Common Name	Green briar	Texas verbena	Orange zexmenia	Giant ragweed	Annual broomweed	Partridge pea	Texas doveweed	Sunflower	Dogweed
Thin paspalum	0.00	0.00	0.01	0.80	0.01	0.00	0.04	0.60	0.00
Common reed	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
Knotroot bristlegrass	0.00	0.00	0.00	0.80	0.02	0.00	0.03	0.50	0.00
Plains bristlegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas bristlegrass	0.00	0.00	0.00	0.90	0.01	0.00	0.02	0.50	0.00
Indiangrass	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
Gulf cordgrass	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
Sand dropseed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Smutgrass	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
Milo	0.00	0.00	0.00	0.90	0.00	0.00	0.01	0.40	0.00
Wheat	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.05	0.00
Corn	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.30	0.00
Littletooth sedge	0.00	0.00	0.00	0.80	0.01	0.00	0.03	0.60	0.00
Flatsedge	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
Ragweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Lazydaisy	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.05	0.00
Spiny aster	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Whitestem wild indigo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Old-mans beard	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.30	0.00
Bundleflower	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.03	0.00
Frogfruit	0.00	0.00	0.00	0.40	0.01	0.00	0.02	0.30	0.00
Prairie coneflower	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.05	0.00
Snoutbean	0.00	0.00	0.00	0.80	0.01	0.00	0.03	0.50	0.00
Ruellia	0.00	0.00	0.00	0.80	0.01	0.00	0.02	0.40	0.00
Curly dock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulltongue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glasswort	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
Green briar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas verbena	0.00	0.00	0.01	0.80	0.02	0.00	0.04	0.50	0.00
Orange zexmenia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Giant ragweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Annual broomweed	0.00	0.00	0.01	0.80	0.00	0.00	0.02	0.50	0.00
Partridge pea	0.00	0.00	0.00	0.70	0.00	0.00	0.01	0.20	0.00
Texas doveweed	0.00	0.00	0.00	0.90	0.01	0.00	0.00	0.50	0.00
Sunflower	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dogweed	0.00	0.01	0.04	0.99	0.04	0.06	0.06	0.80	0.00

Appendix Table E.21 Cattle preference factors for plant parts, by species, in the Goliad County EDYS model. Values are relative rankings (1 = highest, 30 = lowest). High rankings indicate the plant part and species are highly preferred by cattle.

Common Name	Croot	Froot	Trunk	Stems	Leaves	Seeds	SDStems	SDLeaves	SdlgRoot	SdlgShoot	SeedBank
Huisache	35	35	35	35	10	21	36	28	10	10	35
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
Mesquite	20	19	22	17	14	3	19	15	8	7	17
Post oak	35	35	35	35	25	34	35	31	25	25	34
Live oak	20	19	22	17	13	16	19	15	7	6	16
Guajillo	35	35	35	34	6	18	35	20	6	6	35
Blackbrush	35	35	35	35	12	21	35	29	12	12	35
Whitebrush	35	35	35	34	17	18	30	28	17	17	35
Prairie baccharis	29	29	29	26	10	10	31	20	6	6	12
Sea oxeye	29	29	29	26	10	10	31	20	6	6	12
Granjeno	35	35	35	34	16	16	31	29	16	16	36
Carolina wolfberry	29	29	29	26	10	10	31	20	6	6	12
Agarito	19	18	21	16	16	16	18	17	7	6	17
McCartney rose	29	29	29	26	10	10	31	20	6	6	12
Rattlepod	35	35	35	34	26	36	35	30	25	25	36
Mustang grape	19	18	21	16	9	4	18	11	6	5	17
Texas prickly pear	19	18	20	8	8	3	18	18	3	2	17
Big bluestem	11	11	3	1	1	1	11	9	1	1	34
Bushy bluestem	29	29	29	26	10	10	31	20	6	6	12
Purple threeawn	18	17	5	3	3	3	4	4	3	2	17
King Ranch bluestem	18	17	5	2	2	2	5	5	2	1	9
Silver bluestem	10	10	3	2	2	2	9	9	1	1	35
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
Buffalograss	8	8	2	1	1	1	2	2	1	1	35
Sandbur	6	6	6	1	1	1	5	5	1	1	5
Hooded windmillgrass	9	9	5	4	4	4	8	8	3	3	36
Trichloris	10	10	4	2	2	2	9	9	1	1	36
Bermudagrass	18	17	4	1	1	1	3	3	2	1	8
Arizona cottontop	10	10	3	1	1	1	9	9	1	1	36
Saltgrass	6	6	6	1	1	1	5	5	1	1	5
Virginia wildrye	10	10	4	2	2	2	9	9	1	1	35
Texas cupgrass	18	17	4	1	1	1	3	3	2	1	7
Green sprangletop	18	17	4	1	1	1	3	3	2	1	8
Kleingrass	10	10	4	2	2	2	9	9	1	1	35
Guineagrass	10	10	4	2	2	2	9	9	1	1	35
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
Longtom	9	8	3	2	2	2	8	8	1	1	34
Brownseed paspalum	7	7	7	2	2	2	5	5	1	1	5

Appendix Table E.21 (Cont.)

Common Name	Croot	Froot	Trunk	Stems	Leaves	Seeds	SDStems	SDLeaves	SdlgRoot	SdlgShoot	SeedBank
Thin paspalum	10	10	4	3	3	3	9	9	2	2	35
Common reed	7	7	7	2	2	2	5	5	1	1	5
Little bluestem	18	17	5	2	2	2	4	4	2	1	9
Knotroot bristlegrass	10	10	6	4	4	4	9	9	3	3	35
Plains bristlegrass	7	7	7	3	3	3	6	6	2	2	6
Texas bristlegrass	9	9	4	3	3	3	8	8	2	2	35
Indiangrass	18	17	5	1	1	1	4	4	2	1	3
Johnsongrass	7	7	7	3	3	3	6	6	2	2	6
Gulf cordgrass	7	7	7	3	3	3	6	6	2	2	6
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
Smutgrass	7	7	7	3	3	3	6	6	2	2	6
Texas wintergrass	18	17	4	1	1	1	3	3	3	2	9
Milo	10	10	9	3	2	2	11	9	1	1	3
Wheat	18	16	2	1	1	1	5	5	2	1	3
Corn	10	10	9	3	1	1	11	9	1	1	2
Littletooth sedge	9	9	6	5	5	5	9	9	4	4	35
Flatsedge	18	17	6	4	3	3	5	5	3	2	9
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
Spiny aster	0	0	0	5	4	0	7	6	0	0	0
Whitestem wild indigo	7	7	7	3	3	3	6	6	2	2	6
Old-mans beard	16	16	15	14	14	14	16	16	13	13	36
Bundleflower	18	17	4	3	3	3	5	5	2	1	8
Frogfruit	14	14	12	11	11	11	13	13	10	10	35
Prairie coneflower	18	17	5	4	4	4	6	6	2	1	8
Snoutbean	13	13	12	11	11	11	12	12	10	10	34
Ruellia	14	14	13	12	12	12	13	13	11	11	34
Curly dock	20	20	20	12	12	12	20	20	10	10	11
Bulltongue	20	20	20	12	12	12	20	20	10	10	11
Glasswort	20	20	20	12	12	12	20	20	10	10	11
Bush sunflower	18	17	9	9	7	7	17	8	4	3	7
Green briar	29	29	29	26	10	10	31	20	6	6	12
Texas verbena	18	18	17	15	15	15	17	17	14	14	35
Orange zexmenia	18	17	5	3	3	3	4	4	2	1	7
Giant ragweed	30	30	29	27	25	25	33	32	24	24	35
Annual broomweed	31	31	31	30	28	27	32	31	27	27	36
Partridge pea	13	13	10	8	8	8	12	12	7	7	34
Texas doveweed	31	31	32	31	26	26	31	30	25	25	34
Sunflower	18	17	9	9	6	5	19	9	4	3	6
Dogweed	31	30	30	29	29	29	30	30	28	28	34

SDStems = standing dead stems; SDLeaves = standing dead leaves; SdlgRoot = seedling roots; SdlgShoot = seedling shoots

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

Common Name	Croot	Froot	Trunk	Stems	Leaves	Seeds	SDStems	SDLeaves	SdlgRoot	SdlgShoot
Huisache	6	6	6	4	4	4	4	4	6	6
Pecan	6	6	6	5	5	5	5	5	6	6
Sugar hackberry	6	6	6	5	5	5	5	5	6	6
Mesquite	6	6	6	5	5	5	5	5	6	6
Post oak	6	6	6	4	4	4	4	4	6	6
Live oak	6	6	6	5	5	5	5	5	6	6
Guajillo	6	6	6	5	5	5	5	5	6	6
Blackbrush	6	6	6	5	5	5	5	5	6	6
Whitebrush	6	6	6	5	5	5	5	5	6	6
Prairie baccharis	5	5	5	4	4	4	4	4	5	5
Sea oxeye	5	5	5	4	4	4	4	4	5	5
Granjeno	6	6	6	5	5	5	5	5	6	6
Carolina wolfberry	5	5	5	4	4	4	4	4	5	5
Agarito	6	6	6	6	6	6	6	6	6	6
McCartney rose	5	5	5	4	4	4	4	4	5	5
Rattlepod	6	6	6	5	5	5	5	5	6	6
Mustang grape	6	6	6	5	5	5	5	5	6	6
Texas prickly pear	6	6	6	6	6	6	6	6	6	6
Big bluestem	6	6	6	6	6	5	6	6	6	6
Bushy bluestem	5	5	5	4	4	4	4	4	5	5
Purple threeawn	6	6	6	6	6	6	6	6	6	6
King Ranch bluestem	6	6	6	6	6	6	6	6	6	6
Silver bluestem	6	6	6	6	6	5	6	6	6	6
Sideoats grama	6	6	6	6	6	5	6	6	6	6
Hairy grama	6	6	6	6	6	6	6	6	6	6
Red grama	6	6	6	6	6	6	6	6	6	6
Buffalograss	6	6	6	6	6	6	6	6	6	6
Sandbur	5	5	5	5	5	5	5	5	5	5
Hooded windmillgrass	6	6	6	6	6	6	6	6	6	6
Trichloris	6	6	6	6	6	5	6	6	6	6
Bermudagrass	6	6	6	6	6	6	6	6	6	6
Arizona cottontop	6	6	6	6	6	5	6	6	6	6
Saltgrass	5	5	5	5	5	5	5	5	5	5
Virginia wildrye	6	6	6	6	6	5	6	6	6	6
Texas cupgrass	6	6	6	6	6	6	6	6	6	6
Green sprangletop	6	6	6	6	6	6	6	6	6	6
Kleingrass	6	6	6	6	6	5	6	6	6	6
Guineagrass	6	6	6	6	6	5	6	6	6	6
Vine-mesquite	6	6	6	6	6	6	6	6	6	6
Switchgrass	6	6	6	6	6	5	6	6	6	6
Longtom	6	6	5	5	5	5	5	5	5	5
Brownseed paspalum	5	5	5	5	5	5	5	5	5	5

Appendix Table E.22 (Cont.)

Common Name	Croot	Froot	Trunk	Stems	Leaves	Seeds	SDStems	SDLeaves	SdlgRoot	SdlgShoot
Thin paspalum	6	6	6	6	6	6	6	6	6	6
Common reed	5	5	5	5	5	5	5	5	5	5
Little bluestem	6	6	6	6	6	5	6	6	6	6
Knotroot bristlegrass	6	6	6	6	6	6	6	6	6	6
Plains bristlegrass	2	2	2	5	5	5	5	5	5	5
Texas bristlegrass	6	6	6	6	6	6	6	6	6	6
Indiangrass	6	6	6	6	6	5	6	6	6	6
Johnsongrass	2	2	2	5	5	5	5	5	5	5
Gulf cordgrass	2	2	2	5	5	5	5	5	5	5
Tall dropseed	6	6	6	6	6	5	6	6	6	6
Sand dropseed	6	6	6	6	6	6	6	6	6	6
Smutgrass	2	2	2	5	5	5	5	5	5	5
Texas wintergrass	6	6	6	6	6	6	6	6	6	6
Milo	6	6	6	6	6	6	6	6	6	6
Wheat	6	6	6	6	6	6	6	6	6	6
Corn	6	6	6	6	6	5	6	6	6	6
Littletooth sedge	6	6	6	6	6	6	6	6	6	6
Flatsedge	6	6	6	6	6	5	6	6	6	6
Cattail	6	6	5	5	5	5	5	5	5	5
Ragweed	6	6	6	6	6	5	6	6	6	6
Lazydaisy	6	6	6	6	6	6	6	6	6	6
Spiny aster	0	0	0	4	4	0	4	4	0	0
Whitestem wild indigo	2	2	2	5	5	5	5	5	5	5
Old-mans beard	6	6	6	6	5	5	6	5	6	6
Bundleflower	6	6	6	6	6	6	6	6	6	6
Frogfruit	6	6	6	6	6	6	6	6	6	6
Prairie coneflower	6	6	6	6	6	6	6	6	6	6
Snoutbean	6	6	6	6	6	6	6	6	6	6
Ruellia	6	6	6	6	6	6	6	6	6	6
Curly dock	5	5	5	5	5	5	5	5	5	5
Bulltongue	5	5	5	5	5	5	5	5	5	5
Glasswort	5	5	5	5	5	5	5	5	5	5
Bush sunflower	6	6	6	6	6	6	6	6	6	6
Green briar	5	5	5	4	4	4	4	4	5	5
Texas verbena	6	6	6	6	6	6	6	6	6	6
Orange zexmenia	6	6	6	6	6	6	6	6	6	6
Giant ragweed	6	6	6	6	6	5	6	6	6	6
Annual broomweed	6	6	6	6	6	6	6	6	6	6
Partridge pea	6	6	6	6	6	6	6	6	6	6
Texas doveweed	6	6	6	6	6	6	6	6	6	6
Sunflower	6	6	6	6	6	5	6	6	6	6
Dogweed	6	6	6	6	6	6	6	6	6	6

SDStems = standing dead stems; SDLeaves = standing dead leaves; SdlgRoot = seedling roots; SdlgShoot = seedling shoots

Appendix Table E.23 Accessibility of plant parts, by species, for consumption by cattle in the Goliad County EDYS model. Values are the percentage of standing crop biomass that could be accessed by cattle.

Common Name	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SDStems	SDLeaves	SdlgRoot	SdlgShoot	SeedBank
Huisache	0	0	1	10	10	5	10	10	10	40	20
Pecan	0	0	1	1	1	0	1	1	0	80	5
Sugar hackberry	0	0	1	2	2	1	2	2	0	25	0
Mesquite	0	0	1	10	10	10	10	10	0	40	2
Post oak	0	0	1	1	1	0	1	1	10	70	50
Live oak	0	0	1	5	5	4	5	5	0	50	2
Guajillo	1	1	90	99	99	99	99	99	10	60	30
Blackbrush	1	1	90	95	90	90	95	80	10	50	10
Whitebrush	0	0	90	99	95	75	95	80	5	40	0
Prairie baccharis	1	0	99	99	80	90	99	50	20	80	0
Sea oxeye	1	0	99	99	80	90	99	50	20	80	0
Granjeno	0	0	90	95	80	10	90	50	5	40	0
Carolina wolfberr	1	0	99	99	80	90	99	50	20	80	0
Agarito	0	0	80	95	95	95	95	95	0	5	0
McCartney rose	1	0	99	99	80	90	99	50	20	80	0
Rattlepod	0	0	95	99	95	95	95	80	10	70	20
Mustang grape	0	0	5	5	5	4	5	5	0	5	0
Texas prickly pear	0	0	50	95	95	95	95	95	0	5	0
Big bluestem	1	1	40	90	90	95	90	90	10	50	0
Bushy bluestem	1	0	99	99	80	90	99	50	20	80	0
Purple threeawn	0	0	5	95	95	90	95	95	0	5	0
King Ranch bluest	0	0	5	90	90	95	90	90	0	5	0
Silver bluestem	1	1	40	90	90	95	90	85	10	50	0
Sideoats grama	0	0	5	95	95	90	95	95	0	10	0
Hairy grama	0	0	2	90	90	90	90	90	0	2	0
Red grama	0	0	2	80	85	80	80	85	0	1	0
Buffalograss	1	1	20	80	75	40	80	70	5	20	0
Sandbur	10	0	40	70	80	95	70	80	40	50	0
Hooded windmill	1	1	30	90	85	90	90	80	5	30	0
Trichloris	1	1	40	90	90	95	90	85	10	50	0
Bermudagrass	0	0	2	80	80	80	80	80	0	2	0
Arizona cottontop	1	1	30	90	90	95	90	85	10	50	0
Saltgrass	10	0	40	70	80	95	70	80	40	50	0
Virginia wildrye	1	1	40	90	90	95	90	85	10	50	0
Texas cupgrass	0	0	5	95	95	90	95	95	0	10	0
Green sprangleto	0	0	5	95	95	95	95	95	0	10	0
Kleingrass	1	1	30	90	90	95	90	85	10	50	0
Guineagrass	1	1	30	90	90	95	90	85	10	50	0
Vine-mesquite	0	0	5	80	85	90	80	85	0	5	0
Switchgrass	0	0	5	95	95	95	95	95	0	10	0
Longtom	3	2	10	80	75	90	80	70	10	30	0
Brownseed paspa	10	0	40	80	80	95	80	80	40	50	0

Appendix Table E.23 (Cont.)

Common Name	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SDStems	SDLeaves	SdlgRoot	SdlgShoot	SeedBank
Thin paspalum	1	1	20	90	90	95	90	85	10	30	0
Common reed	10	0	40	80	80	95	80	80	40	50	0
Little bluestem	0	0	5	95	95	95	95	95	0	10	0
Knotroot bristlegr	1	1	10	80	75	90	80	70	5	20	0
Plains bristlegrass	5	0	50	80	80	95	80	80	50	50	0
Texas bristlegrass	1	1	10	90	80	90	90	75	5	20	0
Indiangrass	0	0	5	95	95	95	95	95	0	10	0
Johnsongrass	5	0	50	80	80	95	80	80	50	50	0
Gulf cordgrass	5	0	50	80	80	95	80	80	50	50	0
Tall dropseed	0	0	5	95	95	95	95	95	0	10	0
Sand dropseed	0	0	5	95	95	90	95	95	0	5	0
Smutgrass	5	0	50	80	80	95	80	80	50	50	0
Texas wintergrass	0	0	5	90	90	90	90	90	0	5	0
Milo	2	1	20	90	90	95	90	85	20	70	20
Wheat	0	0	5	95	95	95	95	95	0	10	1
Corn	2	1	30	90	90	95	90	85	30	80	70
Littletooth sedge	1	1	10	90	80	90	90	70	5	20	0
Flatsedge	0	0	5	90	85	90	90	85	0	5	0
Cattail	5	5	50	90	90	80	90	90	0	10	0
Ragweed	0	0	5	95	95	95	95	95	0	5	0
Lazydaisy	0	0	1	90	70	80	90	70	0	1	0
Spiny aster	0	0	0	100	100	0	100	100	0	0	0
Whitestem wild ir	5	0	50	80	80	95	80	80	50	50	0
Old-mans beard	1	1	10	70	80	80	70	70	5	20	0
Bundleflower	0	0	5	90	80	80	90	80	0	2	0
Frogfruit	1	1	5	70	50	70	70	40	5	10	0
Prairie coneflowe	0	0	2	90	70	90	90	70	0	5	0
Snoutbean	1	1	10	75	60	80	75	50	5	10	1
Ruellia	1	1	1	60	40	60	60	30	1	5	0
Curly dock	5	0	50	80	80	80	80	70	10	40	0
Bulltongue	5	0	50	80	80	80	80	70	10	40	0
Glasswort	5	0	50	80	80	80	80	70	10	40	0
Bush sunflower	0	0	5	90	85	95	90	85	0	5	0
Green briar	1	0	99	99	80	90	99	50	20	80	0
Texas verbena	1	1	5	80	70	90	80	60	5	10	0
Orange zexmenia	0	0	5	90	85	90	90	85	0	5	0
Giant ragweed	1	1	20	90	90	80	90	80	10	50	0
Annual broomwe	1	1	5	80	80	85	80	70	10	40	0
Partridge pea	1	1	5	80	70	70	80	60	10	30	1
Texas doveweed	1	1	5	85	90	90	85	80	10	20	0
Sunflower	0	0	5	95	95	90	95	95	0	5	0
Dogweed	1	1	1	80	60	90	80	50	1	10	0

SDStems = standing dead stems; SDLeaves = standing dead leaves; SdlgRoot = seedling roots; SdlgShoot = seedling shoots

Appendix D

Estimated Historical Water Use
TWDB Historical Water Use Survey

Estimated Historical Water Use
TWDB Historical Water Use Survey (WUS) Data

Groundwater and surface water historical use estimates are currently unavailable for calendar year 2016. TWDB staff anticipates the calculation and posting of these estimates at a later date.

GOLIAD COUNTY

All values are in acre-feet

Year	Source	Municipal	Manufacturing	Mining	Steam Electric	Irrigation	Livestock	Total
2015	GW	824	0	0	159	3,057	597	4,637
	SW	0	0	0	25	0	150	175
2014	GW	943	0	0	171	2,770	587	4,471
	SW	0	0	0	495	96	147	738
2013	GW	945	0	11	177	2,785	592	4,510
	SW	0	0	2	1,595	158	148	1,903
2012	GW	970	0	1	193	2,884	637	4,685
	SW	0	0	0	1,670	127	160	1,957
2011	GW	1,043	0	30	166	3,436	772	5,447
	SW	0	0	6	1,086	0	193	1,285
2010	GW	912	0	41	189	1,937	775	3,854
	SW	0	1	8	1,069	0	193	1,271
2009	GW	919	0	43	285	2,454	870	4,571
	SW	0	1	8	1,569	0	218	1,796
2008	GW	833	0	46	399	2,257	802	4,337
	SW	0	1	8	1,471	0	201	1,681
2007	GW	731	1	0	174	1,065	911	2,882
	SW	0	0	0	1,481	0	228	1,709
2006	GW	854	1	0	1,197	2,176	1,045	5,273
	SW	0	0	0	1,476	0	261	1,737
2005	GW	804	1	0	134	2,539	885	4,363
	SW	0	0	0	1,570	0	222	1,792
2004	GW	768	0	0	2,154	1,585	40	4,547
	SW	0	0	0	1,540	0	1,100	2,640
2003	GW	801	0	0	127	1,894	40	2,862
	SW	0	0	0	0	31	1,099	1,130
2002	GW	816	2	0	138	251	32	1,239
	SW	0	0	0	0	360	873	1,233
2001	GW	816	0	0	141	103	33	1,093
	SW	0	0	0	0	148	904	1,052
2000	GW	799	0	0	156	147	92	1,194
	SW	0	0	0	1,855	212	828	2,895

Appendix E

2012 – 2016 Goliad County Historic Use Allocations

Appendix E
2008-2016 Goliad County Historic Use Allocations

Year	Source	Municipal	Industrial	Steam Electric	Irrigation	Mining	Livestock	Total
2008	GW	908	33	311	1695	72	920	3939
2009	GW	908	33	311	2295	46	920	4513
2010	GW	1024	33	311	2350	46	920	4684
2011	GW	1024	33	311	2484	47	920	4819
2012	GW	1024	33	311	2484	38	920	4860
2013	GW	611	34	151	3200	70	1128	5194
2014	GW	611	34	311	3200	70	1015	5241
2015	GW	611	34	311	3200	70	1470	5696
2016	GW	611	34	311	3200	70	1470	5696

Appendix F

GCGCD Projected Groundwater Use Numbers from the 2017 State Water Plan Amended

2017 REGION L WATER PLAN

PROJECTIONS: GOLIAD COUNTY

APPENDIX F

Appendix F

Goliad County Projected Groundwater Use Numbers from the Draft 2017 State Water Plan Amended

	2020	2030	2040	2050	2060	2070
IRRIGATION	3200	3200	3200	3200	3200	3200
MANUFACTURING	34	51	68	85	102	122
STEAM ELECTRIC[1]	311	311	311	311	311	311
LIVESTOCK	1128	1128	1128	1128	1128	1128
MINING	1700	1700	1700	700	500	500

[1] Groundwater only from GCGCD Historical Use Numbers documented

Appendix G

GAM Run 12-018 v 2

GAM Run 12-018 (Version 2): Goliad County Groundwater Conservation District Management Plan

by Radu Boghici
Texas Water Development Board
Groundwater Resources Division
Groundwater Availability Modeling Section
(512) 463-5808
January 24, 2013

1/24/2013

The seal appearing on this document was authorized by Radu Boghici, P.G. 482 on January 24, 2013.

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GAM Run 12-018 (Version 2): Goliad County Groundwater Conservation District Management Plan

by Radu Boghici
Texas Water Development Board
Groundwater Resources Division
Groundwater Availability Modeling Section
(512) 463-5808
January 24, 2013

EXECUTIVE SUMMARY:

Texas State Water Code, Section 36.1071, Subsection (h), states that, in developing its groundwater management plan, a groundwater conservation district shall use groundwater availability modeling information provided by the executive administrator of the Texas Water Development Board (TWDB) in conjunction with any available site-specific information provided by the district for review and comment to the executive administrator. Information derived from groundwater availability models that shall be included in the groundwater management plan includes:

- the annual amount of recharge from precipitation to the groundwater resources within the district, if any;
- for each aquifer within the district, the annual volume of water that discharges from the aquifer to springs and any surface water bodies, including lakes, streams, and rivers; and
- the annual volume of flow into and out of the district within each aquifer and between aquifers in the district.

This report is a revision to the GAM Run 12-018 report dated November 30, 2012. We have included an updated water budget to fulfill the requirements noted above (Table 1) and an addendum requested by the district on December 18, 2012. GAM Run 12-018 (Version 2) is Part 2 of a two-part package of information from the TWDB to Goliad County Groundwater Conservation District management plan to fulfill the requirements noted above. The groundwater management plan for the Goliad Groundwater Conservation District is due for approval by the executive administrator of the TWDB before November 14, 2013.

This report discusses the method, assumptions, and results from model runs using the groundwater availability model for the central portion of the Gulf Coast. Table 1 summarizes the groundwater availability model data required by the statute, and Figure 1 shows the area of the model from which the values in the table was extracted. This model run replaces the results of GAM Run 12-018. GAM Run 12-018 (Version 2) meets current standards. If after review of the figure, Goliad County Groundwater Conservation District determines that the district boundaries used in the assessment do not reflect current conditions, please notify the Texas Water Development Board immediately. The TWDB has also approved, for planning purposes, alternative models that can have water budget information extracted for the district. These alternative models include the Groundwater Management Area 16 model and the fully penetrating alternative model for the central portion of the Gulf Coast. Please contact the author of this report if a comparison report using these models is desired.

METHODS:

In accordance with the provisions of the Texas State Water Code, Section 36.1071, Subsection (h), the groundwater availability model for the central portion of the Gulf Coast Aquifer was run for this analysis. Goliad County Water budgets for 1981 through 1999 were extracted using ZONEBUDGET Version 3.01 (Harbaugh, 2009) The average annual water budget values for recharge, surface water outflow, inflow to the district, outflow from the district, net inter-aquifer flow (upper), and net inter-aquifer flow (lower) for the portions of the aquifers located within the district are summarized in this report.

PARAMETERS AND ASSUMPTIONS:

Gulf Coast Aquifer

- Version 1.01 of the groundwater availability model for the central portion of the Gulf Coast Aquifer was used for this analysis. See Chowdhury and others (2004) and Waterstone and others (2003) for assumptions and limitations of the groundwater availability model.
- The model for the central section of the Gulf Coast Aquifer assumes partially penetrating wells in the Evangeline Aquifer due to a lack of data for aquifer properties in the lower section of the aquifer.
- This groundwater availability model includes four layers, which generally correspond to (from top to bottom):

1. the Chicot Aquifer,
2. the Evangeline Aquifer,
3. the Burkeville Confining Unit, and
4. the Jasper Aquifer including parts of the Catahoula Formation.

RESULTS:

A groundwater budget summarizes the amount of water entering and leaving the aquifer according to the groundwater availability model. Selected groundwater budget components listed below were extracted from the model results for the aquifers located within the district and averaged over the duration of the calibration and verification portion of the model runs in the district, as shown in Table 1. The components of the modified budget shown in Table 1 include:

- Precipitation recharge—The areally distributed recharge sourced from precipitation falling on the outcrop areas of the aquifers (where the aquifer is exposed at land surface) within the district.
- Surface water outflow—The total water discharging from the aquifer (outflow) to surface water features such as streams, reservoirs, and drains (springs).
- Flow into and out of district—The lateral flow within the aquifer between the district and adjacent counties.
- Flow between aquifers—The net vertical flow between aquifers or confining units. This flow is controlled by the relative water levels in each aquifer or confining unit and aquifer properties of each aquifer or confining unit that define the amount of leakage that occurs. "Inflow" to an aquifer from an overlying or underlying aquifer will always equal the "Outflow" from the other aquifer.

The information needed for the District's management plan is summarized in Table 1. In addition, we have provided a detailed water budget that averages the Gulf Coast Aquifer inflows and outflows for Goliad County by each model layer from 1981 to 1999 (Addendum, Table 2). It is important to note that sub-regional water budgets are not exact. This is due to the size of the model cells and the approach used to extract data from the model. To avoid double accounting, a model cell that straddles a political boundary, such as a district or county boundary, is assigned to one side of the boundary based on the location of the centroid of the model cell. For example, if a cell contains two counties, the cell is assigned to the county where the centroid of the cell is located (Figure 1).

TABLE 1: SUMMARIZED INFORMATION FOR THE GULF COAST AQUIFER THAT IS NEEDED FOR GOLIAD COUNTY GROUNDWATER CONSERVATION DISTRICT'S GROUNDWATER MANAGEMENT PLAN. ALL VALUES ARE REPORTED IN ACRE-FEET PER YEAR AND ROUNDED TO THE NEAREST 1 ACRE-FOOT. THESE FLOWS MAY INCLUDE BRACKISH WATERS.

Management Plan requirement	*Aquifer or confining unit*	*Results*
Estimated annual amount of recharge from precipitation to the district	Gulf Coast Aquifer	16,603
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Gulf Coast Aquifer	21,645
Estimated annual volume of flow into the district within each aquifer in the district	Gulf Coast Aquifer	4,665
Estimated annual volume of flow out of the district within each aquifer in the district	Gulf Coast Aquifer	14,872
Estimated net annual volume of flow between each aquifer in the district	Not Applicable	Not Applicable

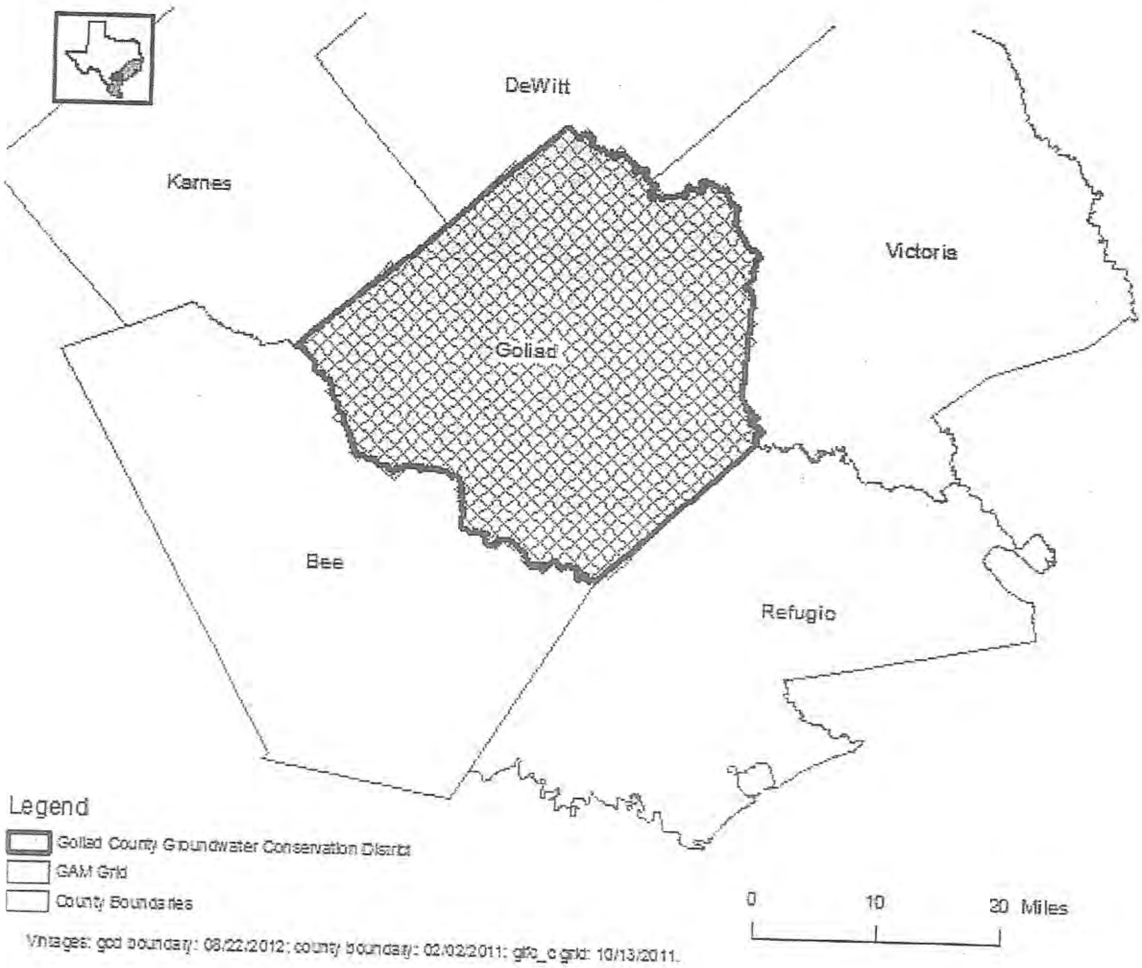

FIGURE 1: AREA OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PORTION OF THE GULF COAST AQUIFER FROM WHICH THE INFORMATION IN TABLE 1 WAS EXTRACTED (THE GULF COAST AQUIFER EXTENT WITHIN THE DISTRICT BOUNDARY).

LIMITATIONS

The groundwater model(s) used in completing this analysis is the best available scientific tool that can be used to meet the stated objective(s). To the extent that this analysis will be used for planning purposes and/or regulatory purposes related to pumping in the past and into the future, it is important to recognize the assumptions and limitations associated with the use of the results. In reviewing the use of models in environmental regulatory decision making, the National Research Council (2007) noted:

> *"Models will always be constrained by computational limitations, assumptions, and knowledge gaps. They can best be viewed as tools to help inform decisions rather than as machines to generate truth or make decisions. Scientific advances will never make it possible to build a perfect model that accounts for every aspect of reality or to prove that a given model is correct in all respects for a particular regulatory application. These characteristics make evaluation of a regulatory model more complex than solely a comparison of measurement data with model results."*

A key aspect of using the groundwater model to evaluate historic groundwater flow conditions includes the assumptions about the location in the aquifer where historic pumping was placed. Understanding the amount and location of historic pumping is as important as evaluating the volume of groundwater flow into and out of the district, between aquifers within the district (as applicable), interactions with surface water (as applicable), recharge to the aquifer system (as applicable), and other metrics that describe the impacts of that pumping. In addition, assumptions regarding precipitation, recharge, and interaction with streams are specific to particular historic time periods.

Because the application of the groundwater model was designed to address regional scale questions, the results are most effective on a regional scale. The TWDB makes no warranties or representations related to the actual conditions of any aquifer at a particular location or at a particular time.

It is important for groundwater conservation districts to monitor groundwater pumping and overall conditions of the aquifer. Because of the limitations of the groundwater model and the assumptions in this analysis, it is important that the groundwater conservation districts work with the TWDB to refine this analysis in the future given the reality of how the aquifer responds to the actual amount and location of pumping now and in the future. Historic precipitation patterns also need to be placed in context as future climatic conditions, such as dry and wet year precipitation patterns, may differ and affect groundwater flow conditions.

REFERENCES:

Chowdhury, Ali. H., Wade, S., Mace, R.E., and Ridgeway, C., 2004, Groundwater Availability Model of the Central Gulf Coast Aquifer System: Numerical Simulations through 1999- Model Report, 114 p., http://www.twdb.texas.gov/groundwater/models/gam/glfc_c/TWDB_Recalibration_Report.pdf.

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National Research Council, 2007, Models in Environmental Regulatory Decision Making Committee on Models in the Regulatory Decision Process, National Academies Press, Washington D.C., 287 p.

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Waterstone Environmental Hydrology and Engineering Inc. and Parsons, 2003, Groundwater availability of the Central Gulf Coast Aquifer: Numerical Simulations to 2050, Central Gulf Coast, Texas Contract report to the Texas Water Development Board, 157 p.

GAM Run 12-018 Addendum

TABLE 2. GROUNDWATER FLOW BUDGET FOR EACH AQUIFER, INTO AND OUT OF, GOLIAD GROUNDWATER CONSERVATION DISTRICT, IN THE GROUNDWATER AVAILABLILITY MODEL OF THE CENTRAL PART OF THE GULF COAST AQUIFER. FLOWS ARE IN ACRE-FEET PER YEAR. VALUES HAVE BEEN ROUNDED TO WHOLE NUMBERS.

	Central Gulf Coast GAM 1981-99				
	Chicot	Evangeline	Burkeville	Jasper	**Total Gulf Coast Aquifer**
Inflow					
Lakes	1,510	0	0	0	**1,510**
Recharge	9,440	7,163	0	0	**16,603**
Streams/Rivers	1,935	11,879	0	0	**13,815**
Vertical Leakage Upper	0	1,430	285	290	**-**
Vertical Leakage Lower	666	575	440	0	**-**
Lateral Flow	684	3,375	39	565	**4,665**
Total Inflow	14,235	24,422	764	855	**36,593**
Outflow					
Wells	122	1,068	0	0	**1,191**
Springs	11	1	0	0	**13**
Evapotranspiration	706	74	0	0	**780**
Streams/Rivers	8,153	13,479	0	0	**21,632**
Vertical Leakage Upper	0	666	575	440	**-**
Vertical Leakage Lower	1,430	285	290	0	**-**
Lateral Flow	4,438	9,722	57	656	**14,872**
Total Outflow	14,860	25,295	922	1,096	**38,488**
Inflow - Outflow	-625	-873	-158	-241	**-1,895**
Storage Change	-626	-873	-155	-241	**-1,896**
Model Error	1	0	-3	0	**1**
Model Error (percent)	0.01%	0.00%	0.31%	0.00%	**0.00%**

Appendix H

2017 State Water Plan Data Sets

Projected Surface Water Supplies
TWDB 2017 State Water Plan Data

Projected Water Demand
TWDB 2017 State Water Plan

Projected Water Supply Needs
TWDB 2017 State Water Plan Data

Projected Water Management Strategies
TWDB 2017 State Water Plan Data

Projected Surface Water Supplies
TWDB 2017 State Water Plan Data

GOLIAD COUNTY

All values are in acre-feet

RWPG	WUG	WUG Basin	Source Name	2020	2030	2040	2050	2060	2070
L	IRRIGATION, GOLIAD	SAN ANTONIO	SAN ANTONIO RUN-OF-RIVER	2,425	2,425	2,425	2,425	2,425	2,425
L	LIVESTOCK, GOLIAD	GUADALUPE	GUADALUPE LIVESTOCK LOCAL SUPPLY	140	140	140	140	140	140
L	LIVESTOCK, GOLIAD	SAN ANTONIO	SAN ANTONIO LIVESTOCK LOCAL SUPPLY	215	215	215	215	215	215
L	LIVESTOCK, GOLIAD	SAN ANTONIO-NUECES	SAN ANTONIO-NUECES LIVESTOCK LOCAL SUPPLY	209	209	209	209	209	209
L	STEAM ELECTRIC POWER, GOLIAD	GUADALUPE	COLETO CREEK LAKE/RESERVOIR	24,160	24,160	24,160	24,160	24,160	24,160
	Sum of Projected Surface Water Supplies (acre-feet)			**27,149**	**27,149**	**27,149**	**27,149**	**27,149**	**27,149**

Projected Water Demands
TWDB 2017 State Water Plan Data

Please note that the demand numbers presented here include the plumbing code savings found in the Regional and State Water Plans.

GOLIAD COUNTY

All values are in acre-feet

RWPG	WUG	WUG Basin	2020	2030	2040	2050	2060	2070
L	COUNTY-OTHER, GOLIAD	GUADALUPE	502	547	575	585	436	441
L	COUNTY-OTHER, GOLIAD	SAN ANTONIO	421	458	482	490	365	370
L	COUNTY-OTHER, GOLIAD	SAN ANTONIO-NUECES	112	123	129	131	99	99
L	GOLIAD	SAN ANTONIO	611	674	713	729	544	551
L	IRRIGATION, GOLIAD	GUADALUPE	575	575	575	575	575	575
L	IRRIGATION, GOLIAD	SAN ANTONIO	2,209	2,209	2,209	2,209	2,209	2,209
L	IRRIGATION, GOLIAD	SAN ANTONIO-NUECES	416	416	416	416	416	416
L	LIVESTOCK, GOLIAD	GUADALUPE	262	262	262	262	262	262
L	LIVESTOCK, GOLIAD	SAN ANTONIO	448	448	448	448	448	448
L	LIVESTOCK, GOLIAD	SAN ANTONIO-NUECES	418	418	418	418	418	418
L	MANUFACTURING, GOLIAD	SAN ANTONIO	34	51	68	85	102	122
L	MINING, GOLIAD	GUADALUPE	126	126	126	126	126	126
L	MINING, GOLIAD	SAN ANTONIO	275	275	275	275	275	275
L	MINING, GOLIAD	SAN ANTONIO-NUECES	49	49	49	49	49	49
L	STEAM ELECTRIC POWER, GOLIAD	GUADALUPE	17,080	17,080	17,080	17,080	17,080	17,080
		Sum of Projected Water Demands (acre-feet)	**23,538**	**23,711**	**23,825**	**23,878**	**23,404**	**23,441**

Projected Water Supply Needs
TWDB 2017 State Water Plan Data

Negative values (in red) reflect a projected water supply need, positive values a surplus.

GOLIAD COUNTY

All values are in acre-feet

RWPG	WUG	WUG Basin	2020	2030	2040	2050	2060	2070
L	COUNTY-OTHER, GOLIAD	GUADALUPE	87	42	14	4	153	148
L	COUNTY-OTHER, GOLIAD	SAN ANTONIO	70	33	9	1	126	121
L	COUNTY-OTHER, GOLIAD	SAN ANTONIO-NUECES	20	9	3	1	33	33
L	GOLIAD	SAN ANTONIO	193	130	91	75	260	253
L	IRRIGATION, GOLIAD	GUADALUPE	167	167	167	167	167	167
L	IRRIGATION, GOLIAD	SAN ANTONIO	808	808	808	808	808	808
L	IRRIGATION, GOLIAD	SAN ANTONIO-NUECES	0	0	0	0	0	0
L	LIVESTOCK, GOLIAD	GUADALUPE	0	0	0	0	0	0
L	LIVESTOCK, GOLIAD	SAN ANTONIO	0	0	0	0	0	0
L	LIVESTOCK, GOLIAD	SAN ANTONIO-NUECES	0	0	0	0	0	0
L	MANUFACTURING, GOLIAD	SAN ANTONIO	88	71	54	37	20	0
L	MINING, GOLIAD	GUADALUPE	0	0	0	0	0	0
L	MINING, GOLIAD	SAN ANTONIO	0	0	0	0	0	0
L	MINING, GOLIAD	SAN ANTONIO-NUECES	0	0	0	0	0	0
L	STEAM ELECTRIC POWER, GOLIAD	GUADALUPE	9,880	9,880	9,880	9,880	9,880	9,880
		Sum of Projected Water Supply Needs (acre-feet)	**0**	**0**	**0**	**0**	**0**	**0**

Projected Water Management Strategies
TWDB 2017 State Water Plan Data

GOLIAD COUNTY

WUG, Basin (RWPG) All values are in acre-feet

Water Management Strategy	Source Name [Origin]	2020	2030	2040	2050	2060	2070
COUNTY-OTHER, GOLIAD, GUADALUPE (L)							
MUNICIPAL WATER CONSERVATION (RURAL)	DEMAND REDUCTION [GOLIAD]	107	113	103	79	0	0
		107	**113**	**103**	**79**	**0**	**0**
COUNTY-OTHER, GOLIAD, SAN ANTONIO (L)							
MUNICIPAL WATER CONSERVATION (RURAL)	DEMAND REDUCTION [GOLIAD]	90	94	87	65	0	0
		90	**94**	**87**	**65**	**0**	**0**
COUNTY-OTHER, GOLIAD, SAN ANTONIO-NUECES (L)							
MUNICIPAL WATER CONSERVATION (RURAL)	DEMAND REDUCTION [GOLIAD]	24	25	23	17	0	0
		24	**25**	**23**	**17**	**0**	**0**
GOLIAD, SAN ANTONIO (L)							
MUNICIPAL WATER CONSERVATION (RURAL)	DEMAND REDUCTION [GOLIAD]	174	228	264	254	120	133
		174	**228**	**264**	**254**	**120**	**133**
Sum of Projected Water Management Strategies (acre-feet)		**395**	**460**	**477**	**415**	**120**	**133**

Appendix I

GAM Run16-025 MAG Modeled Available Groundwater for the Gulf Coast Aquifer System in Groundwater Management Area 15

GAM RUN 16-025 MAG:
MODELED AVAILABLE GROUNDWATER FOR THE GULF COAST AQUIFER SYSTEM IN GROUNDWATER MANAGEMENT AREA 15

Rohit Raj Goswami, Ph.D., P.E.
Texas Water Development Board
Groundwater Division
Groundwater Availability Modeling Section
(512) 463-0495

March 22, 2017

3/22/2017

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GAM RUN 16-025 MAG: MODELED AVAILABLE GROUNDWATER FOR THE GULF COAST AQUIFER SYSTEM IN GROUNDWATER MANAGEMENT AREA 15

Rohit Raj Goswami, Ph.D., P.E.
Texas Water Development Board
Groundwater Division
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(512) 463-0495
March 22, 2017

EXECUTIVE SUMMARY:

The modeled available groundwater for Groundwater Management Area 15 for the Gulf Coast Aquifer System is summarized by decade for the groundwater conservation districts (Table 1) and for use in the regional water planning process (Table 2). The modeled available groundwater estimates range from approximately 515,000 acre-feet per year in 2020 to approximately 518,000 acre-feet per year in 2069(Table 1). The estimates were extracted from results of a model run using the groundwater availability model for the central part of the Gulf Coast Aquifer System (version 1.01). The model run files, which meet the desired future conditions adopted by district representatives of Groundwater Management Area 15, were submitted to the Texas Water Development Board (TWDB) on June 28, 2016, as part of the Desired Future Conditions Explanatory Report for Groundwater Management Area 15. The explanatory report and other materials submitted to the Texas Water Development Board (TWDB) were determined to be administratively complete on October 20, 2016.

REQUESTOR:

Mr. Tim Andruss, chair of Groundwater Management Area 15.

DESCRIPTION OF REQUEST:

In a letter dated June 23, 2016, Mr. Tim Andruss provided the TWDB with the desired future conditions of the Gulf Coast Aquifer System adopted by the groundwater conservation districts in Groundwater Management Area 15. The Gulf Coast Aquifer System includes the Chicot Aquifer, Evangeline Aquifer, Burkeville Confining Unit and the Jasper Aquifer (including parts of the Catahoula Formation). TWDB staff worked with INTERA Incorporated, the consultant for Groundwater Management Area 15, in reviewing model files associated with the desired future conditions. We received clarification from INTERA Incorporated, on behalf of Groundwater Management Area 15, on September 18, 2016, concerning assumptions on variances of average drawdown values per county to model results, which was ±3.5 feet for nearly all areas within the Groundwater Management Area 15. The exception is Goliad County which has a variance in drawdown of ±5 feet. The desired future conditions for the Gulf Coast Aquifer System, as described in Resolution No. 2016-01 and adopted April 29, 2016, by the groundwater conservation districts within Groundwater Management Area 15, are described below:

Groundwater Management Area 15 [all counties]

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 13 feet in December 2069 from estimated year 2000 conditions.

Aransas County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 0 feet in December 2069 from estimated year 2000 conditions.

Bee County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 7 feet in December 2069 from estimated year 2000 conditions.

Calhoun County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 5 feet in December 2069 from estimated year 2000 conditions.

Colorado County

Drawdown shall not exceed an average of 17 feet in Chicot and Evangeline Aquifers and 23 feet in in the Jasper Aquifer in December 2069 from estimated year 2000 conditions.

DeWitt County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 17 feet in December 2069 from estimated year 2000 conditions.

Fayette County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 16 feet in December 2069 from estimated year 2000 conditions.

Goliad County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 10 feet in December 2069 from estimated year 2000 conditions.

Jackson County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 15 feet in December 2069 from estimated year 2000 conditions.

Karnes County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 22 feet in December 2069 from estimated year 2000 conditions.

Lavaca County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 18 feet in December 2069 from estimated year 2000 conditions.

Matagorda County

Drawdown shall not exceed an average of 11 feet in Chicot and Evangeline Aquifers in December 2069 from estimated year 2000 conditions.

Refugio County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 5 feet in December 2069 from estimated year 2000 conditions.

Victoria County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 5 feet in December 2069 from estimated year 2000 conditions.

Wharton County

Drawdown shall not exceed an average of 15 feet in Chicot and Evangeline Aquifers in December 2069 from estimated year 2000 conditions.

Based on the adopted desired future conditions, TWDB has estimated the modeled available groundwater for the Gulf Coast Aquifer System in Groundwater Management Area 15.

METHODS:

The groundwater availability model for the central part of the Gulf Coast Aquifer System (Figure 1) was run using the model files submitted with the explanatory report (GMA 15 and others, 2016). Model-calculated water levels were extracted for the year 2000 and the end of the year 2069, and drawdown was calculated as the difference between water levels at the beginning of 2000 and water levels at the end of 2069. Drawdown averages were calculated for each county by aquifer and for the entire Groundwater Management Area 15 by aquifer. As specified in the explanatory report (GMA 15 and others, 2016), drawdown for cells which became dry during the simulation (water level dropped below the base of the cell) were excluded from the averaging. The calculated drawdown averages were compared with the desired future conditions to verify that the pumping scenario achieved the desired future conditions within one foot.

The modeled available groundwater values were determined by extracting pumping rates by decade from the model results using ZONEBUDGET Version 3.01 (Harbaugh, 2009). Annual pumping rates are presented by county and groundwater conservation district, subtotaled by groundwater conservation district, and then summed by Groundwater Management Area 15 (Figure 2 and Table 1). Annual pumping rates are also presented by county, river basin, and regional water planning area within Groundwater Management Area 15 (Figure 2 and Table 2).

Modeled Available Groundwater and Permitting

As defined in Chapter 36 of the Texas Water Code, "modeled available groundwater" is the estimated average amount of water that may be produced annually to achieve a desired future condition. Groundwater conservation districts are required to consider modeled available groundwater, along with several other factors, when issuing permits in order to manage groundwater production to achieve the desired future condition(s). The other factors districts must consider include annual precipitation and production patterns, the estimated amount of pumping exempt from permitting, existing permits, and a reasonable estimate of actual groundwater production under existing permits.

PARAMETERS AND ASSUMPTIONS:

The parameters and assumptions for the groundwater availability are described below:

- Version 1.01 of the groundwater availability model for the central portion of the Gulf Coast Aquifer System was used for this analysis. See Chowdhury and others (2004) and Waterstone and others (2003) for assumptions and limitations of the model.
- The model has four layers which represent the Chicot Aquifer (Layer 1), the Evangeline Aquifer (Layer 2), the Burkeville Confining Unit (Layer 3), and the Jasper Aquifer and parts of the Catahoula Formation in direct hydrologic communication with the Jasper Aquifer (Layer 4).
- The model was run with MODFLOW-96 (Harbaugh and others, 1996).
- Drawdown averages and modeled available groundwater values are based on the extent of the model area rather than official aquifer boundaries (Figures 1 and 2).
- Drawdown for cells with water levels below the base elevation of the cell ("dry" cells) were excluded from the averaging per emails exchanged with INTERA, Inc. dated October 21, 2015.
- Estimates of modeled available groundwater from the model simulation were rounded to whole numbers.
- A model drawdown tolerance of up to 5 feet was assumed for Goliad County and up to 3.5 feet for the rest of Groundwater Management Area 15 when comparing desired future conditions (average drawdown values per county) to model drawdown results.
- Average drawdown by county may include some model cells that represent portions of surface water such as bays, reservoirs, and the Gulf of Mexico.

RESULTS:

The modeled available groundwater for the Gulf Coast Aquifer System that achieves the desired future conditions adopted by Groundwater Management Area 15 increases from approximately 515,000 acre-feet per year in 2020 to approximately 518,000 acre-feet per year in 2069 (Table 1). The modeled available groundwater is summarized by groundwater conservation district and county (Table 1). The modeled available groundwater has also been summarized by county, river basin, and regional water planning area for use in the regional water planning process (Table 2). Small differences of values between table summaries are due to rounding.

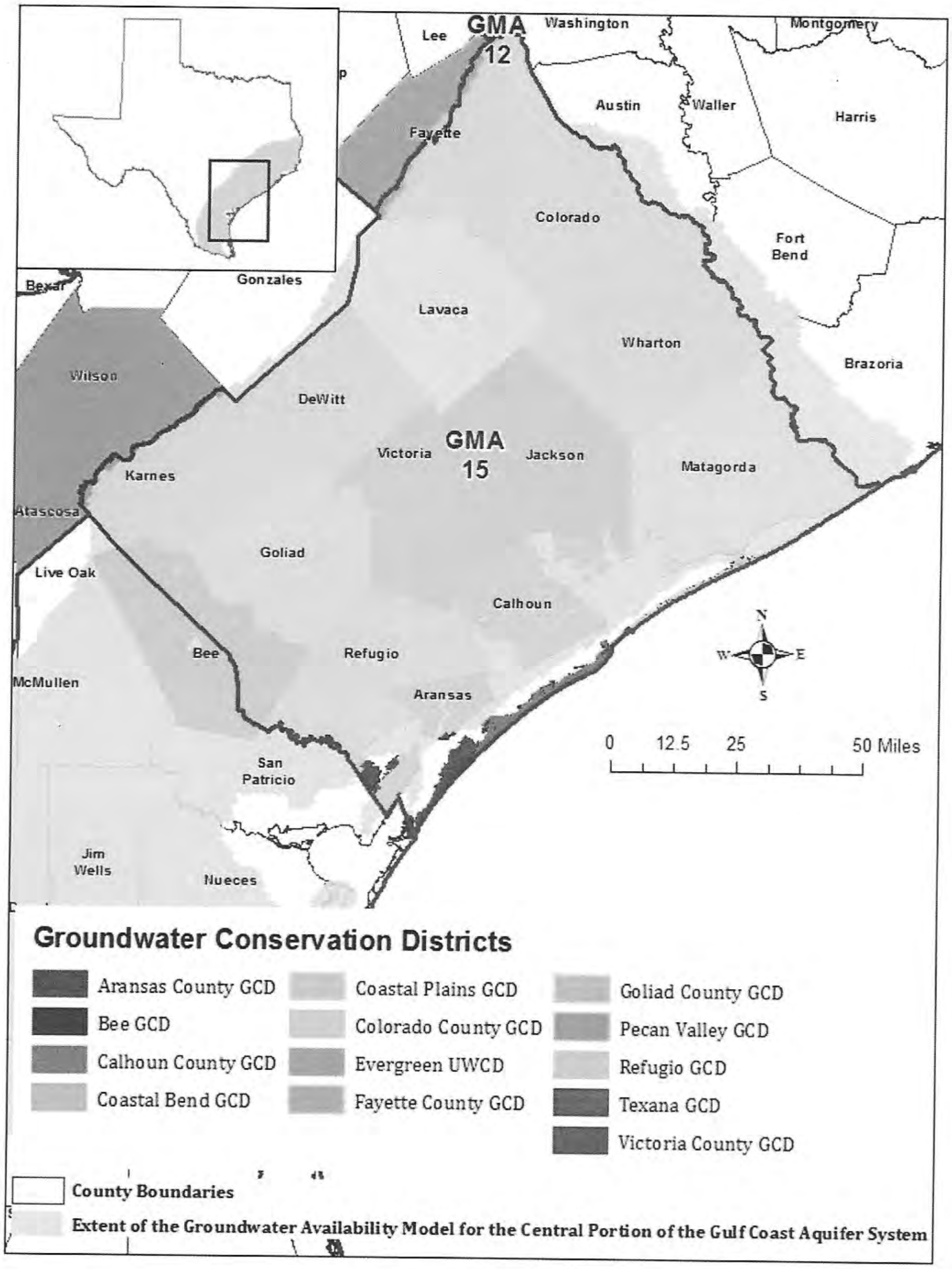

FIGURE 1. MAP SHOWING GROUNDWATER CONSERVATION DISTRICTS (GCDS) AND COUNTIES IN GROUNDWATER MANAGEMENT AREA 15 OVERLAIN ON THE EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PORTION OF THE GULF COAST AQUIFER SYSTEM.

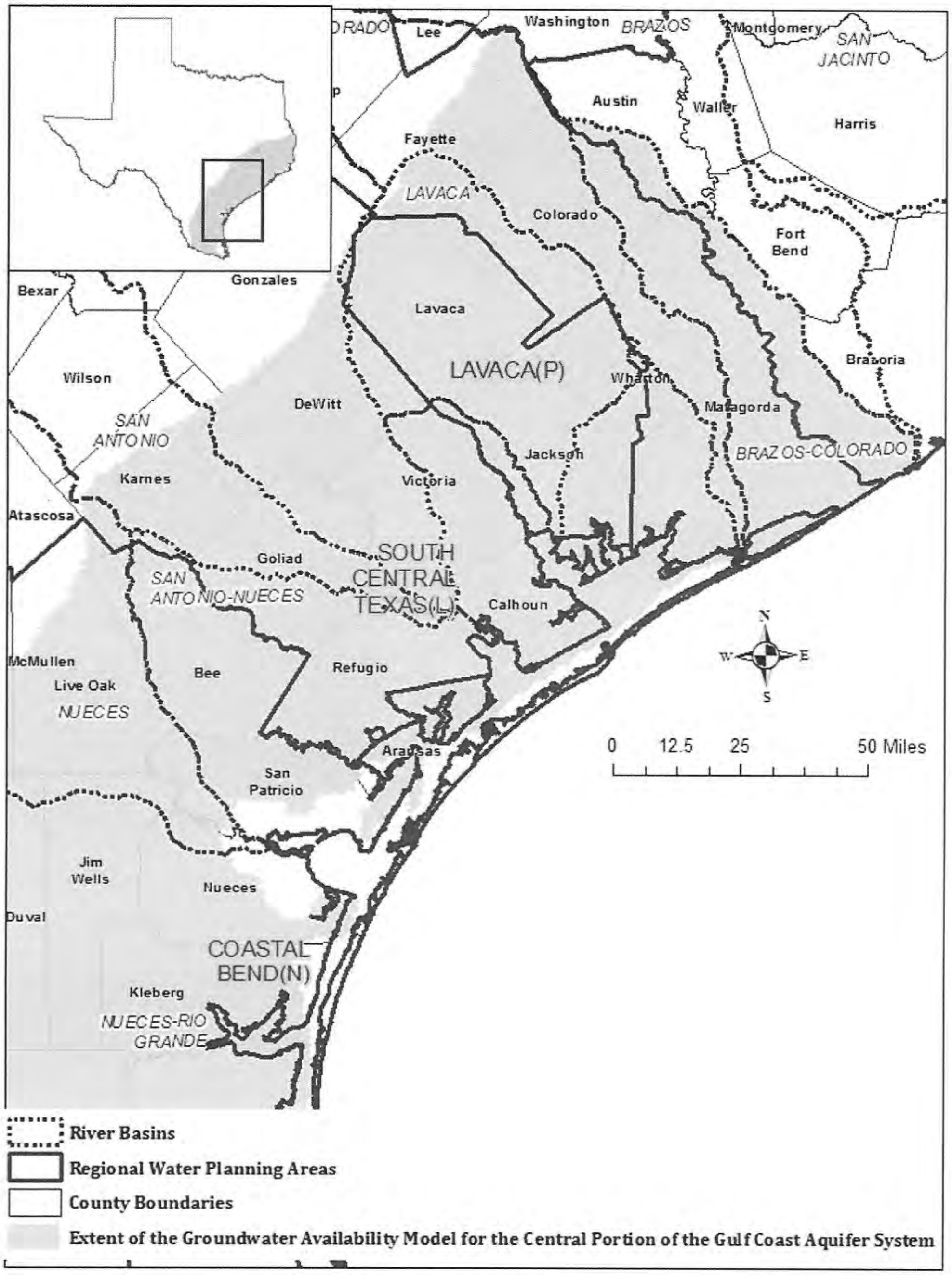

FIGURE 2. MAP SHOWING REGIONAL WATER PLANNING AREAS, GROUNDWATER CONSERVATION DISTRICTS (GCDS), COUNTIES, AND RIVER BASINS IN GROUNDWATER MANAGEMENT AREA 15 OVERLAIN ON THE EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PORTION OF THE GULF COAST AQUIFER SYSTEM.

TABLE 1. MODELED AVAILABLE GROUNDWATER FOR THE GULF COAST AQUIFER SYSTEM IN GROUNDWATER MANAGEMENT AREA 15 SUMMARIZED BY GROUNDWATER CONSERVATION DISTRICT (GCD) AND COUNTY FOR EACH DECADE BETWEEN 2010 AND 2069. VALUES ARE IN ACRE-FEET PER YEAR.

Groundwater Conservation District	County	Aquifer	2010	2020	2030	2040	2050	2060	2069
Aransas County GCD Total	**Aransas**	**Gulf Coast Aquifer System**	**1,542**	**1,542**	**1,542**	**1,542**	**1,542**	**1,542**	**1,542**
Bee County GCD Total	**Bee**	**Gulf Coast Aquifer System**	**9,456**	**9,456**	**9,431**	**9,431**	**9,379**	**9,379**	**9,361**
Calhoun County GCD Total	**Calhoun**	**Gulf Coast Aquifer System**	**2,569**	**7,565**	**7,565**	**7,565**	**7,565**	**7,565**	**7,565**
Coastal Bend GCD Total	**Wharton**	**Gulf Coast Aquifer System (Chicot and Evangeline)**	**181,168**	**181,168**	**181,168**	**181,168**	**181,168**	**181,168**	**181,168**
Coastal Plains GCD Total	**Matagorda**	**Gulf Coast Aquifer System (Chicot and Evangeline)**	**38,828**	**38,828**	**38,828**	**38,828**	**38,828**	**38,828**	**38,828**
Colorado County GCD	Colorado	Gulf Coast Aquifer System (Chicot and Evangeline)	79,780	74,964	74,964	72,765	72,765	71,618	71,618
Colorado County GCD	Colorado	Gulf Coast Aquifer System (Jasper)	918	918	918	918	918	918	918
Colorado County GCD Total	**Colorado**	**Gulf Coast Aquifer System**	**80,698**	**75,882**	**75,882**	**73,683**	**73,683**	**72,536**	**72,536**
Evergreen UWCD Total	**Karnes**	**Gulf Coast Aquifer System**	**10,196**	**10,196**	**10,196**	**3,015**	**2,917**	**2,751**	**2,751**
Fayette County GCD Total	**Fayette**	**Gulf Coast Aquifer System**	**1,977**	**1,853**	**1,853**	**1,853**	**1,853**	**1,853**	**1,703**
Goliad County GCD Total	**Goliad**	**Gulf Coast Aquifer System**	**11,420**	**11,539**	**11,539**	**11,539**	**11,539**	**11,552**	**11,539**

Groundwater Conservation District	County	Aquifer	2010	2020	2030	2040	2050	2060	2069
Pecan Valley GCD Total	**DeWitt**	**Gulf Coast Aquifer System**	**15,471**	**15,476**	**15,476**	**14,485**	**14,485**	**14,485**	**14,485**
Refugio GCD Total	**Refugio**	**Gulf Coast Aquifer System**	**5,847**	**5,847**	**5,847**	**5,847**	**5,847**	**5,847**	**5,847**
Texana GCD Total	**Jackson**	**Gulf Coast Aquifer System**	**76,787**	**90,482**	**90,482**	**90,482**	**90,482**	**90,482**	**90,482**
Victoria County GCD Total	**Victoria**	**Gulf Coast Aquifer System**	**35,640**	**44,974**	**49,970**	**54,966**	**54,966**	**59,963**	**59,963**
Total (GCDs)		**Gulf Coast Aquifer System**	**471,599**	**494,808**	**499,779**	**494,404**	**494,254**	**497,951**	**497,770**
No District-County	Bee	Gulf Coast Aquifer System	10	10	10	10	10	10	10
No District-County	Lavaca	Gulf Coast Aquifer System	20,253	20,253	20,253	20,253	20,253	20,253	20,239
No district-County Total		**Gulf Coast Aquifer System**	**20,263**	**20,263**	**20,263**	**20,263**	**20,263**	**20,263**	**20,249**
Total for GMA 15		**Gulf Coast Aquifer System**	**491,862**	**515,071**	**520,042**	**514,667**	**514,517**	**518,214**	**518,019**

TABLE 2 **MODELED AVAILABLE GROUNDWATER BY DECADE FOR THE GULF COAST AQUIFER SYSTEM IN GROUNDWATER MANAGEMENT AREA 15. RESULTS ARE IN ACRE-FEET PER YEAR AND ARE SUMMARIZED BY COUNTY, REGIONAL WATER PLANNING AREA (RWPA), RIVER BASIN, AND AQUIFER.**

County	RWPA	River Basin	Aquifer	2020	2030	2040	2050	2060
Aransas	N	San Antonio- Nueces	Gulf Coast Aquifer System	1,542	1,542	1,542	1,542	1,542
Bee	N	San Antonio- Nueces	Gulf Coast Aquifer System	9,439	9,414	9,414	9,362	9,362
Bee	N	Nueces	Gulf Coast Aquifer System	27	27	27	27	27
Calhoun	L	Colorado- Lavaca	Gulf Coast Aquifer System	5,210	5,210	5,210	5,210	5,210
Calhoun	L	Guadalupe	Gulf Coast Aquifer System	18	18	18	18	18
Calhoun	L	Lavaca-Guadalupe	Gulf Coast Aquifer System	2,330	2,330	2,330	2,330	2,330
Calhoun	L	San Antonio- Nueces	Gulf Coast Aquifer System	7	7	7	7	7
Colorado	K	Brazos-Colorado	Gulf Coast Aquifer System (Chicot and Evangeline)	15,342	15,342	15,342	15,342	15,342
Colorado	K	Brazos-Colorado	Gulf Coast Aquifer System (Jasper Aquifer)	49	49	49	49	49
Colorado	K	Colorado	Gulf Coast Aquifer System (Chicot and Evangeline)	20,506	20,506	20,066	20,066	20,066
Colorado	K	Colorado	Gulf Coast Aquifer System (Jasper Aquifer)	273	273	273	273	273
Colorado	K	Lavaca	Gulf Coast Aquifer System (Chicot and Evangeline)	39,116	39,116	37,357	37,357	36,210
Colorado	K	Lavaca	Gulf Coast Aquifer System (Jasper Aquifer)	596	596	596	596	596
Dewitt	L	Guadalupe	Gulf Coast Aquifer System	11,358	11,358	10,470	10,470	10,470
Dewitt	L	Lavaca-Guadalupe	Gulf Coast Aquifer System	417	417	417	417	417
Dewitt	L	Lavaca	Gulf Coast Aquifer System	2,935	2,935	2,935	2,874	2,874
Dewitt	L	San Antonio	Gulf Coast Aquifer System	766	766	724	724	724

County	RWPA	River Basin	Aquifer	2020	2030	2040	2050	2060
Fayette	K	Brazos	Gulf Coast Aquifer System	2	2	2	2	2
Fayette	K	Colorado	Gulf Coast Aquifer System	989	989	989	989	989
Fayette	K	Lavaca	Gulf Coast Aquifer System	862	862	862	862	862
Goliad	L	Guadalupe	Gulf Coast Aquifer System	4,377	4,377	4,377	4,377	4,380
Goliad	L	San Antonio- Nueces	Gulf Coast Aquifer System	1,190	1,190	1,190	1,190	1,195
Goliad	L	San Antonio	Gulf Coast Aquifer System	5,972	5,972	5,972	5,972	5,977
Jackson	P	Colorado-Lavaca	Gulf Coast Aquifer System	28,025	28,025	28,025	28,025	28,025
Jackson	P	Lavaca-Guadalupe	Gulf Coast Aquifer System	12,875	12,875	12,875	12,875	12,875
Jackson	P	Lavaca	Gulf Coast Aquifer System	49,582	49,582	49,582	49,582	49,582
Karnes	L	Guadalupe	Gulf Coast Aquifer System	11	11	11	11	11
Karnes	L	Nueces	Gulf Coast Aquifer System	1,057	1,057	78	78	78
Karnes	L	San Antonio	Gulf Coast Aquifer System	9,082	9,082	2,880	2,782	2,616
Karnes	L	San Antonio-Nueces	Gulf Coast Aquifer System	46	46	46	46	46
Lavaca	P	Guadalupe	Gulf Coast Aquifer System	41	41	41	41	41
Lavaca	P	Lavaca-Guadalupe	Gulf Coast Aquifer System	401	401	401	401	401
Lavaca	P	Lavaca	Gulf Coast Aquifer System	19,811	19,811	19,811	19,811	19,811
Matagorda	K	Brazos-Colorado	Gulf Coast Aquifer System (Chicot and Evangeline)	15,282	15,282	15,282	15,282	15,282
Matagorda	K	Colorado-Lavaca	Gulf Coast Aquifer System (Chicot and Evangeline)	20,329	20,329	20,329	20,329	20,329
Matagorda	K	Colorado	Gulf Coast Aquifer System (Chicot and Evangeline)	3,217	3,217	3,217	3,217	3,217
Refugio	L	San Antonio- Nueces	Jasper Aquifer	5,526	5,526	5,526	5,526	5,526
Refugio	L	San Antonio	Gulf Coast Aquifer System	321	321	321	321	321
Victoria	L	Guadalupe	Gulf Coast Aquifer System	17,600	22,596	27,592	27,592	27,592
Victoria	L	Lavaca-Guadalupe	Gulf Coast Aquifer System	25,451	25,451	25,451	25,451	30,448
Victoria	L	Lavaca	Gulf Coast Aquifer System	234	234	234	234	234
Victoria	L	San Antonio	Gulf Coast Aquifer System	1,689	1,689	1,689	1,689	1,689

County	RWPA	River Basin	Aquifer	2020	2030	2040	2050	2060
Wharton	K	Brazos-Colorado	Gulf Coast Aquifer System (Chicot and Evangeline)	50,527	50,527	50,527	50,527	50,527
Wharton	K	Colorado-Lavaca	Gulf Coast Aquifer System (Chicot and Evangeline)	16,196	16,196	16,196	16,196	16,196
Wharton	P	Colorado-Lavaca	Gulf Coast Aquifer System (Chicot and Evangeline)	14,091	14,091	14,091	14,091	14,091
Wharton	K	Colorado	Gulf Coast Aquifer System (Chicot and Evangeline)	35,910	35,910	35,910	35,910	35,910
Wharton	P	Colorado	Gulf Coast Aquifer System (Chicot and Evangeline)	873	873	873	873	873
Wharton	K	Lavaca	Gulf Coast Aquifer System (Chicot and Evangeline)	579	579	579	579	579
Wharton	P	Lavaca	Gulf Coast Aquifer System (Chicot and Evangeline)	62,992	62,992	62,992	62,992	62,992
GMA 15 Total			**Gulf Coast Aquifer System**	**515,071**	**520,042**	**514,667**	**514,517**	**518,214**

LIMITATIONS:

The groundwater model used in completing this analysis is the best available scientific tool that can be used to meet the stated objectives. To the extent that this analysis will be used for planning purposes and/or regulatory purposes related to pumping in the past and into the future, it is important to recognize the assumptions and limitations associated with the use of the results. In reviewing the use of models in environmental regulatory decision making, the National Research Council (2007) noted:

> "Models will always be constrained by computational limitations, assumptions, and knowledge gaps. They can best be viewed as tools to help inform decisions rather than as machines to generate truth or make decisions. Scientific advances will never make it possible to build a perfect model that accounts for every aspect of reality or to prove that a given model is correct in all respects for a particular regulatory application. These characteristics make evaluation of a regulatory model more complex than solely a comparison of measurement data with model results."

A key aspect of using the groundwater model to evaluate historic groundwater flow conditions includes the assumptions about the location in the aquifer where historic pumping was placed. Understanding the amount and location of historic pumping is as important as evaluating the volume of groundwater flow into and out of the district, between aquifers within the district (as applicable), interactions with surface water (as applicable), recharge to the aquifer system (as applicable), and other metrics that describe the impacts of that pumping. In addition, assumptions regarding precipitation, recharge, and streamflow are specific to a particular historic time period.

Because the application of the groundwater model was designed to address regional scale questions, the results are most effective on a regional scale. The TWDB makes no warranties or representations relating to the actual conditions of any aquifer at a particular location or at a particular time.

It is important for groundwater conservation districts to monitor groundwater pumping and groundwater levels in the aquifer. Because of the limitations of the groundwater model and the assumptions in this analysis, it is important that the groundwater conservation districts work with the TWDB to refine this analysis in the future given the reality of how the aquifer responds to the actual amount and location of pumping now and in the future. Historic precipitation patterns also need to be placed in context as future climatic conditions, such as dry and wet year precipitation patterns, may differ and affect groundwater flow conditions.

REFERENCES:

Chowdhury, A., Wade, S., Mace, R.E., and Ridgeway, C. 2004. Groundwater Availability of the Central Gulf Coast Aquifer System: Numerical Simulations through 1999: Texas Water Development Board, unpublished report.

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National Research Council, 2007, Models in Environmental Regulatory Decision Making Committee on Models in the Regulatory Decision Process, National Academies Press, Washington D.C., 287 p., http://www.nap.edu/catalog.php?record_id=11972.

Texas Water Code, 2011, http://www.statutes.legis.state.tx.us/docs/WA/pdf/WA.36.pdf.

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Appendix J

GMA 15 Resolution to Adopt Desire Future Conditions for GMA 15 Aquifers

RESOLUTION TO ADOPT DESIRED FUTURE CONDITIONS

FOR GROUNDWATER MANAGEMENT AREA 15 AQUIFERS

STATE OF TEXAS	§	
	§	**RESOLUTION # 2016-01**
GROUNDWATER	§	
MANAGEMENT AREA 15	§	

WHEREAS, Texas Water Code § 36.108 requires the Groundwater Conversation Districts located whole or in part in a Groundwater Management Area ("GMA") designated by the Texas Water Development Board to adopt desired future conditions for the relevant aquifers located within the management area;

WHEREAS, the Groundwater Conservation Districts located wholly or partially within Groundwater Management Area 15 ("GMA 15"), as designated by the Texas Water Development Board, as of the date of this resolution are as follows:
Aransas County Groundwater Conservation District, Bee Groundwater Conservation District, Calhoun County Groundwater Conservation District, Coastal Bend Groundwater Conservation District, Coastal Plains Groundwater Conservation District, Colorado County Groundwater Conservation District, Corpus Christi Aquifer Storage and Recovery Conservation District, Evergreen Underground Water Conservation District, Fayette County Groundwater Conservation District, Goliad County Groundwater Conservation District, Pecan Valley Groundwater Conservation District, Refugio Groundwater Conservation District, Texana Groundwater Conservation District, and Victoria County Groundwater Conservation District ;

WHEREAS, the Board Presidents or their Designated Representatives of districts in GMA 15 have met at various meetings and conducted joint planning in accordance with Chapter 36.108, Texas Water Code since September 2005 and;

WHEREAS, GMA 15, having given proper and timely notice, held an open meeting of the GMA 15 Member Districts on April 29, 2016 and;

WHEREAS, GMA 15 has solicited and considered public comment at specially called Public Meetings, including the meeting on April 29, 2016 and;

WHEREAS, the GMA 15 Member Districts received and considered technical advice regarding local aquifers, hydrology, geology, recharge characteristics, local groundwater demands and usage, population projections, ground and surface water inter-relationships, and other considerations that affect groundwater conditions and;

WHEREAS, following public discussion and due consideration of the current and future needs and conditions of the aquifers in question, the current and projected groundwater demands, and the potential effects on springs, surface water, habitat, and water-dependent species through the year 2069, GMA 15 Member Districts have analyzed drawdown estimations from numerous pumping scenarios using the Central Gulf Coast Groundwater Availability Model and have voted on a motion made and seconded to adopt a Desired Future Condition (DFC) stated as follows:

Groundwater Management Area 15 adopts Desired Future Conditions (DFCs) as average drawdowns that occur between January 2000 and December 2069 for the following:

Gulf Coast Aquifer System – represents an average drawdown for the Chicot Aquifer, the Evangeline Aquifer, the Burkeville Confining Unit, and the Jasper Aquifer that is weighted by the area of each hydrogeological unit in the Central Gulf Coast Aquifer GAM (Chowdhury and others, 2004).

Chicot and Evangeline Aquifers – represents an average drawdown for the Chicot Aquifer and the Evangeline Aquifer that is weighted by the area of each hydrogeological unit in the Central Gulf Coast Aquifer GAM (Chowdhury and others, 2004).

Jasper Aquifer- represents an average drawdown for the area of the Jasper Aquifer in the Central Gulf Coast Aquifer GAM (Chowdhury and others, 2004).

Groundwater Management Area 15 adopts Desired Future Conditions for each county within the groundwater management area (county-specific DFCs) and adopts a Desired Future Condition for the counties in the groundwater management area (gma-specific DFC). The Desired Future Condition for the counties in the groundwater management area shall not exceed an average drawdown of 13 feet for the Gulf Coast Aquifer System at December 2069. Desired Future Conditions for each county within the groundwater management area (county-specific DFCs) shall not exceed the values specified in Table A-1 at December 2069.

Table A-1. Desired Future Conditions for GMA 15 expressed as an Average Drawdown between January 2000 and December 2069.

Aransas County: 0 feet of drawdown of the Gulf Coast Aquifer System;
Bee County: 7 feet of drawdown of the Gulf Coast Aquifer System;
Calhoun County: 5 feet of drawdown of the Gulf Coast Aquifer System;
Colorado County: 17 feet of drawdown of the Chicot and Evangeline Aquifers and 23 feet of drawdown of the Jasper Aquifer;
Dewitt County: 17 feet of drawdown of the Gulf Coast Aquifer System;
Fayette County: 16 feet of drawdown of the Gulf Coast Aquifer System;
Goliad County: 10 feet of drawdown of the Gulf Coast Aquifer System;
Jackson County: 15 feet of drawdown of the Gulf Coast Aquifer System;
Karnes County: 22 feet of drawdown of the Gulf Coast Aquifer System;
Lavaca County: 18 feet of drawdown of the Gulf Coast Aquifer System;
Matagorda County: 11 feet of drawdown of the Chicot and Evangeline Aquifers;

Refugio County: 5 feet of drawdown of the Gulf Coast Aquifer System;
Victoria County: 5 feet of drawdown of the Gulf Coast Aquifer System;
Wharton County: 15 feet of drawdown of the Chicot and Evangeline Aquifers.

NOW THEREFORE BE IT RESOLVED, that the Groundwater Management Area 15 Member Districts do hereby document, record and confirm a Desired Future Condition stated above was adopted by all member districts present.

AND IT IS SO ORDERED.

PASSED AND ADOPTED on this 29th day of April 2016.

ATTEST:

Tom Callan
Aransas County Groundwater Conservation District

Lonnie Stewart
Bee County Groundwater Conservation District

Tim Andruss
Calhoun County Groundwater Conservation District

Neil Hudgins
Coastal Bend Groundwater Conservation District

Neil Hudgins
Coastal Plains Groundwater Conservation District

James E. Brasher
Colorado County Groundwater Conservation District

Corpus Christi Aquifer Storage and Recovery Conservation District

Russell Labus
Evergreen Underground Water Conservation District

DAVID A. VAN DRESAR

Fayette County Groundwater Conservation District

ART A. DOHMANN

Goliad County Groundwater Conservation District

Charlotte Krause

Pecan Valley Groundwater Conservation District

, TIM ANDRUSS

Refugio Groundwater Conservation District

, TIM ANDRUSS

Texana Groundwater Conservation District

K. ELLER

Victoria County Groundwater Conservation District

Appendix K

GMA 15 Transmittal Letter

Victoria County Groundwater Conservation District

Via: Certified Mail RRR No.: 7014 1200 0001 0183 5355

June 23, 2016

Mr. Jeff Walker, Executive Administrator
Texas Water Development Board
1700 North Congress Avenue
P.O. Box 13231
Austin, Texas 78711-3231

RE: Groundwater Management Area 15 Desired Future Condition Submission Packet

Mr. Walker,

The members of Groundwater Management Area 15 are pleased to submit the adopted Desired Future Conditions for GMA 15, Explanatory Report and Supporting Materials to the Texas Water Development Board for review. The information is stored in digital form in the included USB drive.

Requests for clarifications or supplemental information of a technical or modeling-related nature should be submitted to Mr. Steve Young of Intera, Inc. at 1812 Centre Creek Drive, Suite 300, Austin, Texas 78754.

Request for clarifications or supplemental information of an administrative nature should be submitted to me at 2805 N. Navarro St., Ste 210, Victoria, Texas 77901.

Regards,

Tim Andruss
GMA 15 Chair/Administrator

Cc:
Aransas County Groundwater Conservation District, Bee Groundwater Conservation District, Calhoun County Groundwater Conservation District, Coastal Bend Groundwater Conservation District, Coastal Plains Groundwater Conservation District, Colorado County Groundwater Conservation District, Corpus Christi ASR Conservation District, Evergreen Underground Water Conservation District, Fayette County Groundwater Conservation District, Goliad County Groundwater Conservation District, Pecan Valley Groundwater Conservation District, Refugio Groundwater Conservation District, Texana Groundwater Conservation District, Victoria County Groundwater Conservation District

Appendix L

DFC Explanatory Report for GMA 15

DESIRED FUTURE CONDITION EXPLANATORY REPORT FOR GROUNDWATER MANAGEMENT AREA 15

This report was considered and approved by the member districts of Groundwater Management Area 15 on June 14, 2016.

Member Districts:

1. Aransas County Groundwater Conservation District
2. Bee Groundwater Conservation District
3. Calhoun County Groundwater Conservation District
4. Coastal Bend Groundwater Conservation District
5. Coastal Plains Groundwater Conservation District
6. Colorado County Groundwater Conservation District
7. Corpus Christi ASR Conservation District
8. Evergreen Underground Water Conservation District
9. Fayette County Groundwater Conservation District
10. Goliad County Groundwater Conservation District
11. Pecan Valley Groundwater Conservation District
12. Refugio Groundwater Conservation District
13. Texana Groundwater Conservation District
14. Victoria County Groundwater Conservation District

Technical Consultancy and Support Provided by:

INTERA
GEOSCIENCE & ENGINEERING SOLUTIONS

Steven Young, PhD, PE, PG

INTERA Incorporated
1812 Centre Creek Drive
Suite 300
Austin, TX 78754
512-425-2000

Geoscientist Seal

Steven C. Young, P.G., P.E., Ph.D.

Dr. Young was the technical lead responsible for assembling, interpreting, and documenting the information in the explanatory report. He is also the principal writer of the report.

STATE OF TEXAS
STEVE C YOUNG
GEOLOGY
231
LICENSED
PROFESSIONAL GEOSCIENTIST

Steven C Young — 6/18/2016

Signature — Date

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ACROYNMS AND ABBREVIATIONS

AFY	acre feet per year
ASCRD	Aquifer Storage & Recovery Conservation District
CGC GAM	Central Gulf Coast Aquifers GAM
DFC	Desired Future Condition
GAM	groundwater availability model
GMA	Groundwater Management Area
GW-SW	Groundwater-surface water
HB	House Bill
INTERA	INTERA Incorporated
LCRB	Lower Colorado River Basin
MAG	modeled available groundwater
RFP	request for proposal
RMSE	root mean square error
TERS	total estimated recoverable storage
TWDB	Texas Water Development Board
UWCD	Underground Water Conservation District

1.0 INTRODUCTION

1.1 GMA 15

Groundwater Management Areas (GMAs) were created "in order to provide for the conservation, preservation, protection, recharging, and prevention of waste of the groundwater, and of groundwater reservoirs or their subdivisions, and to control subsidence caused by withdrawal of water from those groundwater reservoirs or their subdivisions, consistent with the objectives of Section 59, Article XVI, Texas Constitution, groundwater management areas may be created..." (Texas Water Code §35.001).

The responsibility for GMA delineation was delegated to the Texas Water Development Board (TWDB). (Section 35.004, Chapter 35, Title 2, Texas Water Code). The initial GMA delineations were adopted on December 15, 2002, and are modified as necessary according to agency rules. There are 16 GMAs in Texas. **Figure 1-1** shows the boundaries of these 16 GMAs, including GMA 15. **Figure 1-2** shows the location of the 14 Groundwater Conservation Districts (GCDs) that are contained wholly or in part within the boundary of GMA 15: These 14 GCDs are Aransas County GCD, Bee GCD, Calhoun County GCD, Coastal Bend GCD, Coastal Plains GCD, Colorado County GCD, Corpus Christi Aquifer Storage & Recovery Conservation District (ASRCD), Evergreen Underground Water Conservation District (UWCD), Fayette County GCD, Goliad County GCD, Pecan Valley GCD, Refugio GCD, Texana GCD, and Victoria County GCD.

In GMA 15, the TWDB recognizes two major aquifers and three minor aquifers. **Figure 1-3** shows the footprints of the two major aquifers, the Gulf Coast and the Carrizo-Wilcox aquifers. The Carrizo-Wilcox occurs only as a subcrop in the four most up-dip counties, DeWitt, Karnes, Lavaca, and Fayette counties. **Figure 1-4** shows the footprints of the minor aquifers, which are the Yegua-Jackson, the Sparta and the Queen City aquifers. These three minor aquifers only occur as subcrops in Fayette County. **Table 1-1** is a stratigraphic column showing relative age and placement of the aquifers.

Table 1-1 A simplified stratigraphic column for GMA 15 (modified from Young and others, 2010)

<table>
<tr><th>EPOCH</th><th colspan="2">Hydrogeologic Unit</th></tr>
<tr><td>Holocene</td><td rowspan="3">Chicot Aquifer</td><td rowspan="7">Gulf Coast Aquifer</td></tr>
<tr><td>Pleistocene</td></tr>
<tr><td>Pliocene</td></tr>
<tr><td rowspan="3">Miocene</td><td>Evangeline Aquifer</td></tr>
<tr><td>Burkeville Confining Unit</td></tr>
<tr><td rowspan="2">Jasper Aquifer</td></tr>
<tr><td rowspan="2">Oligocene</td></tr>
<tr><td colspan="2">aquitard</td></tr>
<tr><td rowspan="5">Eocene</td><td colspan="2">Yegua-Jackson Aquifer</td></tr>
<tr><td colspan="2">Sparta Aquifer</td></tr>
<tr><td colspan="2">Queen City Aquifer</td></tr>
<tr><td colspan="2">aquitard</td></tr>
<tr><td colspan="2" rowspan="2">Carrizo-Wilcox Aquifer</td></tr>
<tr><td>Paleocene</td></tr>
</table>

In this report, the Gulf Coast Aquifer will be divided into four major hydrogeologic units, which are shown in Table 1-1. These four units are, from youngest to oldest, the Chicot Aquifer, the Evangeline Aquifer, the Burkeville Confining Unit, and the Jasper Aquifer.

There are fourteen counties in GMA 15. **Table 1-2** lists the fourteen counties and their area and population projects. In 2010, the fourteen counties had a population of 369,500 people, and the county with the largest population was Victoria County, with 86,800 people. The population of the fourteen counties is expected to grow to 473,000 people in 2070, with Victoria expanding to a population of 116,500 people.

Table 1-2 Population projection from the 2017 State Water Plan by county and the area for the counties

County Name	Area (sq miles)[1]	2010[2]	2020	2030	2040	2050	2060	2070
Aransas	252	23,158	24,463	24,991	24,937	25,102	25,103	25,104
Bee	880	31,861	33,478	34,879	35,487	35,545	35,579	35,590
Calhoun	506	21,381	24,037	26,866	29,622	32,276	34,906	37,454
Colorado	960	20,874	21,884	22,836	23,544	24,582	25,449	26,293
DeWitt	909	20,097	20,855	21,555	21,900	22,216	22,425	22,572
Fayette	950	24,554	28,373	32,384	35,108	37,351	39,119	40,476
Goliad	852	7,210	8,427	9,519	10,239	10,545	10,759	10,884
Jackson	829	14,075	14,606	15,119	15,336	15,515	15,627	15,699
Karnes	747	14,824	15,456	15,938	15,968	15,968	15,968	15,968
Lavaca	970	19,263	19,263	19,263	19,263	19,263	19,263	19,263
Matagorda	1,100	36,702	39,166	41,226	42,548	43,570	44,296	44,815
Refugio	770	7,383	7,687	7,929	7,985	8,119	8,175	8,213
Victoria	882	86,793	93,857	100,260	105,298	109,785	113,470	116,522
Wharton	1,086	41,280	43,804	46,614	48,860	50,804	52,599	54,189
GMA 15 Total		369,455	395,356	419,379	436,095	450,641	462,738	473,042

[1] Source of county areas is http://www.indexmundi.com/facts/united-states/quick-facts/texas/land-area#table

[2] 2010 is based on the United States Census

1.2 Joint Planning Process

The joint-planning process was first adopted by the Texas Legislature with the passage of House Bill (HB) 1763 in 2005. One of the requirements of HB 1763 is that, where two or more districts are located within the same boundaries of GMA, the districts shall establish Desired Future Conditions (DFCs) for all relevant aquifers in the GMA by no later than September 1, 2010 and every five years thereafter.

DFCs are defined in Title 31, Part 10, §356.10 (6) of the Texas Administrative Code as "the desired, quantified condition of groundwater resources (such as water levels, spring flows, or volumes) within a management area at one or more specified future times as defined by participating groundwater conservation districts within a groundwater management area as part of the joint planning process."

The specified future time extends through at least the period that includes the current planning period for the development of regional water plans pursuant to §16.053, Texas Water Code, or in perpetuity, as defined by participating districts within a GMA as part of the joint planning process. DFCs have to be physically possible, individually and collectively, if different DFCs are stated for different geographic areas overlying an aquifer or subdivision of an aquifer.

The joint-planning process was expanded significantly by the passage of Senate Bill 660 in 2011. The more substantive elements of the expanded process include: (1) new requirements that an explanatory report be developed and submitted at the conclusion of the joint-planning process to document that certain required factors for consideration have been addressed; (2) a change from requirements involving estimates of managed available groundwater to modeled available groundwater (MAG) (including the process for addressing exempt use); (3) new requirements for individual districts to provide for a 90-day public comment period, during which the individual district is to a hold public hearing on proposed DFCs before final adoption by at least two thirds of the district representatives in the GMA; and (4) as soon as possible after final adoption of the DFCs by district representatives in the GMA, individual districts are finally then to adopt the DFCs. Solely applicable to the current round of joint-planning, the deadline for adopting proposed DFCs was extended to May 1, 2016, by the passage of Senate Bill 1282 by the Texas Legislature in 2013.

If a GMA includes more than one district, those districts must engage in a joint planning process, including at least an annual meeting. The districts must jointly determine the DFCs for the management area and, in doing so, are required to consider the nine following factors:

1. aquifer uses or conditions within the management area, including conditions that differ substantially from one geographic area to another;
2. the water supply needs and water management strategies included in the state water plan;
3. hydrological conditions, including for each aquifer in the management area the total estimated recoverable storage as provided by the executive administrator, and the average annual recharge, inflows, and discharge;
4. other environmental impacts, including impacts on spring flow and other interactions between groundwater and surface water;
5. the impact on subsidence;
6. socioeconomic impacts reasonably expected to occur;
7. the impact on the interests and rights in private property, including ownership and the rights of management area landowners and their lessees;
8. the feasibility of achieving the DFC; and
9. any other information relevant to the specific DFCs.

After DFCs are adopted by a GMA, the TWDB calculates Modeled Available Groundwater (MAG) based on the DFCs. A MAG is defined in Title 31, Part 10, §356.10 (13) of the Texas Administrative Code as "the amount of water that the executive administrator determines may be produced on an average annual basis to achieve a desired future condition."

1.3 GMA 15 Joint Planning

The joint-planning process established by HB 1763 in 2005 and amended by Senate Bill 660 in 2011 is a public, transparent process, where all planning decisions are made in open, publicly noticed meetings in accordance with provisions contained in Texas Water Code Chapter 36. From 2012 to 2015, GMA 15 convened 18 times within the boundary of the GMA at the dates listed in **Table 1-3**. All of the meetings were open to the public. All meeting notices were posted at least 10 days in advance of the meeting and included an invite to submit comments, questions, and requests for additional information to Tim Andruss of the Victoria County GCD by mail at 2805 N. Navarro St. Suite 210, Victoria, TX 77901, by email at admin@vcgcd.org, or by phone at (361) 579-6883.

Table 1-3 lists the dates and the major discussion topics of the GMA 15 joint planning meetings from 2012 to 2015. **Appendix A** contains the meeting notices and the minutes for the meetings. In June 2013, GMA 15 selected INTERA Incorporated (INTERA) to be their technical consultant. INTERA performed the groundwater availability model (GAM) simulations for GMA 15, provided technical guidance, and supported the preparation of this explanatory report.

Table 1-3 List of meetings that were convened GMA 15 from 2012 to 2016

Meeting Date	Quorum Present	Major Discussion Topic
June 20, 2012	Yes	Discussed joint planning requirements, groundwater monitoring and DFC compliance, regional water planning
October 10, 2012	Yes	GCDs report on recent and on-going hydrogeology projects, methods for estimating groundwater usage, appointed officers, interlocal GCD agreements, discussion of GCD management plans
February 14, 2013	Yes	Aquifer use and measured groundwater levels, RFP for hiring a consultant, possible use of LCRB model as alternative groundwater model
April 11, 2013	Yes	Population estimates, GCD annual reports, responses from RFP for consultant
June 13, 2013	Yes	GCD Management Plans, population estimates, INTERA selected as consultant
October 10, 2013	Yes	Lavaca GCD dissolved, regional water planning, GCD management plans, officer election
January 9, 2014	Yes	Regional water planning, review of GCD management plans, PDFCs, anticipated future pumping scenarios for GAM runs
April 10, 2014	Yes	Pumping scenarios for GAM Runs, assessment of GCD management plans on DFCs, TWDB report on an updated GAM*
July 10, 2014	Yes	Assessment of GCD management plans on DFCs, baseline and high-production pumping scenarios
October 9, 2014	Yes	GCD management plans, regional water planning, submitted INTERA files on water budgets, TERS, historical pumping
January 8, 2015	Yes	Social economic impact of DFCs, aquifer sustainability
April 9, 2015	Yes	Regional water planning issues, future pumping scenarios, impacts of drought on DFCs
July 15, 2015	Yes	Feasibility of DFCs, INTERA presentation, considerations regarding subsidence, social economic, personal property
August 13, 2015	Yes	Review of INTERA DFC pumping runs
October 8, 2015	Yes	Review of DFC pumping runs, review DFC adoption steps
December 9, 2015	Yes	Review of nine factors to consider regarding DFCs
January 16, 2016	Yes	Proposed DFCs
April 29, 2016	Yes	District Summaries of Public Comment Period, Adoption of DFCs

During the GMA 15 meeting on January 14, 2016, GMA 15 designated the draft Groundwater Management Area 15 Desired Future Conditions language, with modification, as the Proposed Desired Future Conditions of Groundwater Management Area 15. As required by Texas Water Code Section

36.108(d-2), the proposed DFCs were subsequently distributed to the individual districts in GMA 15. A period of not less than 90 days was provided to allow for public comments on the proposed DFCs; during this comment period, each district held a public hearing on the proposed DFCs. **Table 1-4** lists the date that each district conducted a public hearing on the proposed DFCs.

Table 1-4 Public hearings conducted by the GCDs regarding the proposed DFCs

GCD	Public Hearing Date
Aransas County GCD	March 23, 2016
Bee GCD	March 23, 2016
Calhoun County GCD	April 18, 2016
Coastal Bend GCD	April 25, 2016
Coastal Plains GCD	April 25, 2016
Colorado County GCD	April 27, 2016
Corpus Christi ASRCD	February 4, 2016
Evergreen UWCD	April 22, 2016
Fayette County GCD	March 7, 2016
Goliad County GCD	April 18, 2016
Pecan Valley GCD	April 19, 2016
Refugio GCD	April 18, 2016
Texana GCD	April 14, 2016
Victoria County GCD	April 15, 2016

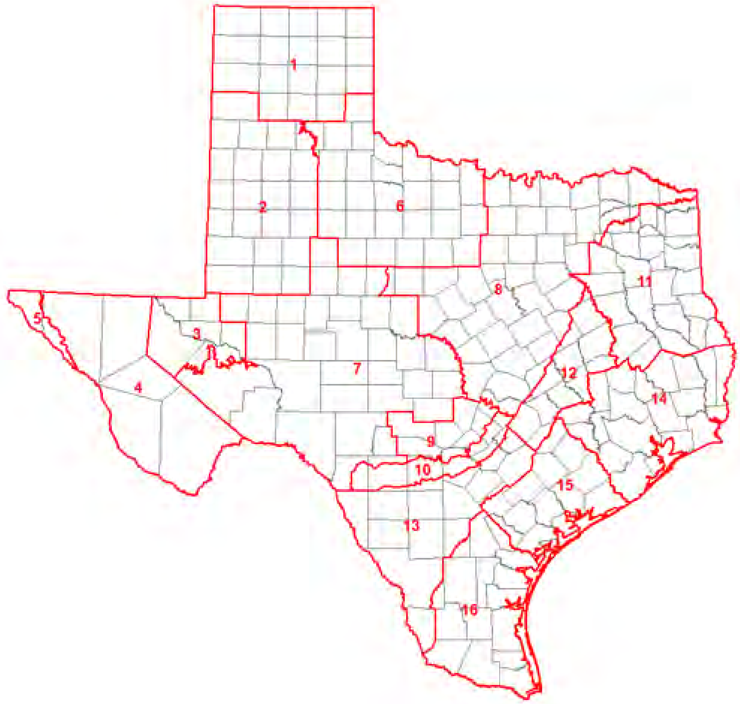


Figure 1-1 Delineation of 16 groundwater management zones in Texas (obtained from http://www.twdb.texas.gov/groundwater/management_areas/index.asp)

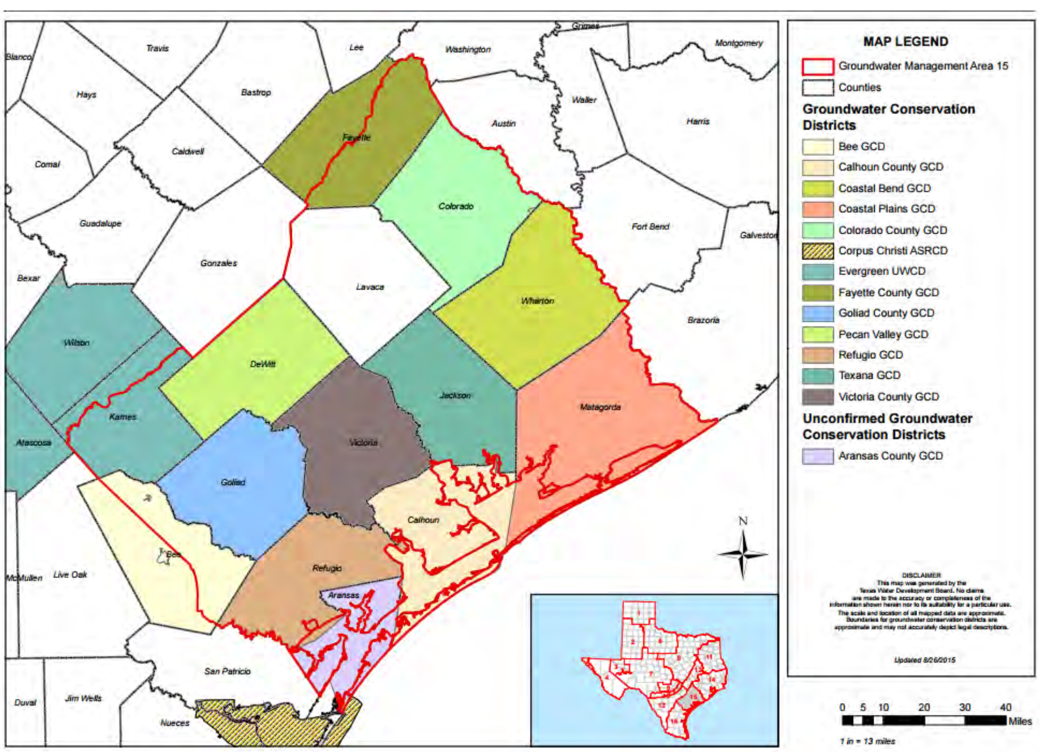


Figure 1-2 Delineation of GMA 15 showing locations of GCDs (obtained from http://www.twdb.texas.gov/groundwater/management_areas/gma15.asp)

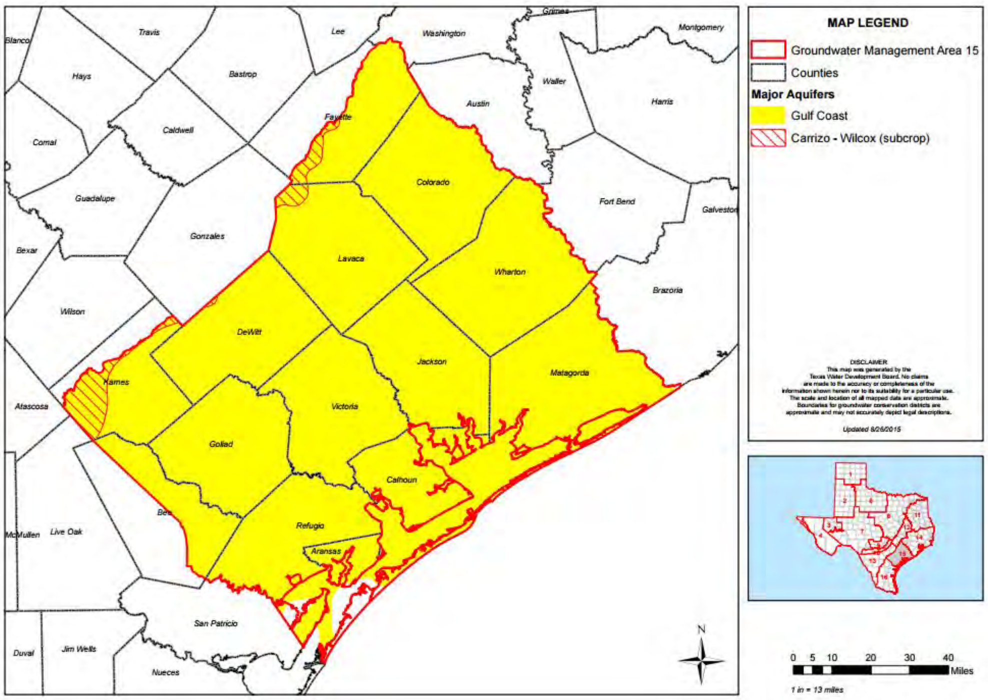


Figure 1-3 Map of GMA 15 major aquifer boundaries (obtained from http://www.twdb.texas.gov/groundwater/management_areas/gma15.asp)

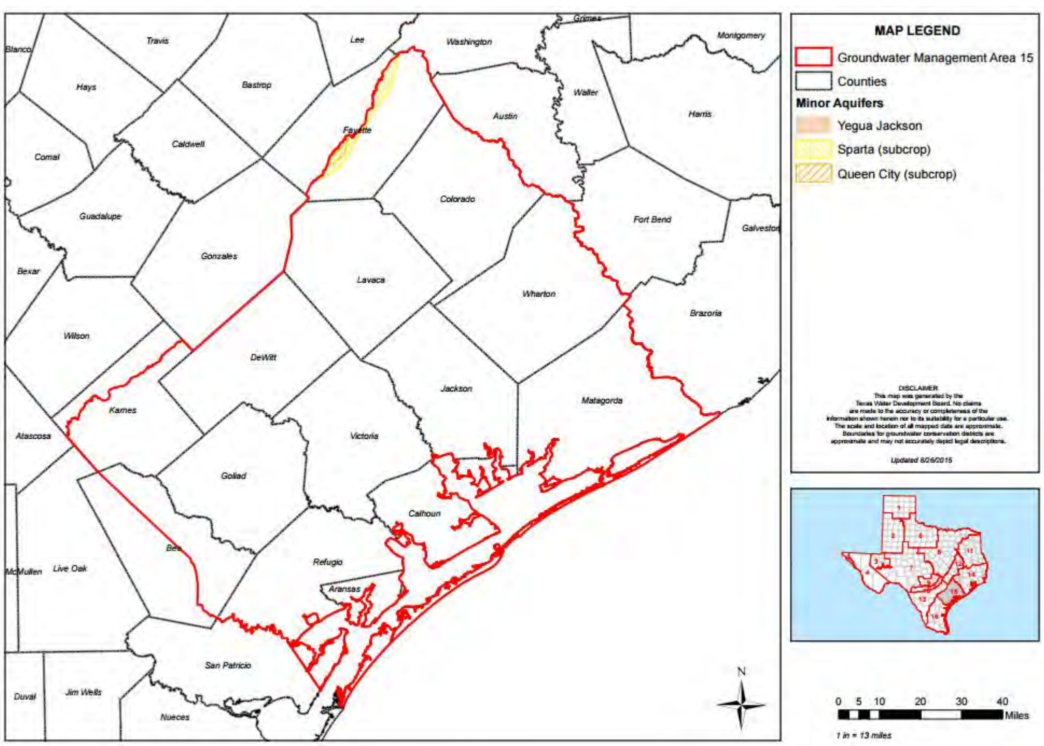


Figure 1-4 Map of GMA 15 minor aquifer boundaries (obtained from http://www.twdb.texas.gov/groundwater/management_areas/gma15.asp)

2.0 GMA 15 DESIRED FUTURE CONDITIONS

2.1 Gulf Coast Aquifers

The three Gulf Coast aquifers of interest are the Chicot Aquifer, the Evangeline Aquifer, and the Jasper Aquifer. As shown in Table 1-1, the Burkeville Confining Unit lies between and separates the Evangeline and the Jasper aquifers. For the purpose of establishing DFCs, GMA 15 has adopted the boundaries in the Central Gulf Coast GAM (CGC GAM) (Chowdhury and others, 2004) to define the areas and volumes associated with the Chicot Aquifer, Evangeline Aquifer, the Jasper Aquifer, and the Burkeville Confining Unit.

On April 29, 2016, GMA 15 Representatives approved resolution 2016-01 titled Resolution to Adopt the Desired Future Conditions for Groundwater Management Area 15. **Appendix B** contains the resolution. The adopted DFCs are based on acceptable levels of drawdown for each county and the entire groundwater management area from 2000 to 2070. Groundwater Management Area 15 adopts Desired Future Conditions (DFCs) as average drawdowns that occur between January 2000 and December 2069 for the following:

Gulf Coast Aquifer System – represents an average drawdown for the Chicot Aquifer, the Evangeline Aquifer, the Burkeville Confining Unit, and the Jasper Aquifer that is weighted by the area of each hydrogeological unit in the Central Gulf Coast Aquifer GAM (Chowdhury and others, 2004).

Chicot and Evangeline Aquifers – represents an average drawdown for the Chicot Aquifer and the Evangeline Aquifer that is weighted by the area of each hydrogeological unit in the Central Gulf Coast Aquifer GAM (Chowdhury and others, 2004).

Jasper Aquifer- represents an average drawdown for the area of the Jasper Aquifer in the Central Gulf Coast Aquifer GAM (Chowdhury and others, 2004).

Groundwater Management Area 15 adopts Desired Future Conditions for each county within the groundwater management area (county-specific DFCs) and adopts a Desired Future Condition for the counties in the groundwater management area (GMA-specific DFC). The Desired Future Condition for the counties in the groundwater management area shall not exceed an average drawdown of 13 feet for the Gulf Coast Aquifer System at December 2069. Desired Future Conditions for each county within the groundwater management area (county-specific DFCs) shall not exceed the values specified in **Table A-1** at December 2069.

Table A-1 Desired Future Conditions for GMA 15 expressed as an Average Drawdown between January 2000 and December 2069.

Aransas County	0 feet of drawdown of the Gulf Coast Aquifer System
Bee County	7 feet of drawdown of the Gulf Coast Aquifer System;
Calhoun County	5 feet of drawdown of the Gulf Coast Aquifer System
Colorado County	17 feet of drawdown of the Chicot and Evangeline Aquifers and 23 feet of drawdown of the Jasper Aquifer
Dewitt County	17 feet of drawdown of the Gulf Coast Aquifer System
Fayette County	16 feet of drawdown of the Gulf Coast Aquifer System
Goliad County	10 feet of drawdown of the Gulf Coast Aquifer System
Jackson County	15 feet of drawdown of the Gulf Coast Aquifer System
Karnes County	22 feet of drawdown of the Gulf Coast Aquifer System
Lavaca County	18 feet of drawdown of the Gulf Coast Aquifer System
Matagorda County	11 feet of drawdown of the Chicot and Evangeline Aquifers
Refugio County	5 feet of drawdown of the Gulf Coast Aquifer System
Victoria County	5 feet of drawdown of the Gulf Coast Aquifer System
Wharton County	15 feet of drawdown of the Chicot and Evangeline Aquifers

2.2 Carrizo-Wilcox Aquifer

GMA 15 considers the portion of the Carrizo-Wilcox Aquifer within boundary of GMA 15 non-relevant for joint planning purposes. The portion of this aquifer system present within GMA 15 is small, downdip, and only present at great depths. Use and projected demands from the Carrizo-Wilcox Aquifer within GMA 15 is negligible to non-existent. The total estimated recoverable storage (TERS) for the Carrizo-Wilcox is 17,475,000 to 52,425,000 acre-feet for all of GMA 15. Approximately 85% of the TERS present within GMA 15 is within the boundaries of Evergreen UWCD and Fayette County GCD. Evergreen UWCD and Fayette County GCD manage their Carrizo-Wilcox resources as part of GMA 13 and GMA 12, respectively. Therefore, GMA 15 concludes that the desired future conditions in adjacent or hydraulically connected relevant aquifers will not be affected.

2.3 Yegua-Jackson, Sparta, and Queen-City aquifers

GMA 15 considers the portions of the Yegua-Jackson, Sparta, and Queen-City Aquifers within the boundary of GMA 15 non-relevant for joint planning purposes. The portions of these aquifers within GMA 15 are small. Use and projected demands from these aquifers within GMA 15 is negligible to non-existent. The TERS for the Queen City Aquifer is 160,000 to 480,000 acre-feet for all of GMA 15 and located only within Fayette County. The TERS for the Sparta Aquifer is 725,000 to 2,175,000 acre-feet for all of GMA 15 and located only within Fayette County. The Fayette County GCD has additional groundwater resources in both the Queen City and Sparta aquifers outside of GMA 15 and manages these resources as part of GMA 12. The TERS for the Yegua-Jackson Aquifer is 202,500 to 607,500 acre-feet for all of GMA 15 and located only within Karnes County and Lavaca County. The boundary of Evergreen UWCD includes Karnes County. Evergreen UWCD manages the Yegua-Jackson Aquifer resources as part of GMA 13. Estimated use from the Yegua-Jackson Aquifer within Lavaca County is less than 10 acre-feet/year. Lavaca County is not located within the boundary of an existing groundwater conservation district and the groundwater resources within are not managed. Therefore, GMA 15 concludes that the desired future conditions in adjacent or hydraulically connected relevant aquifers will not be affected.

3.0 POLICY JUSTIFICATION

The adoption of DFCs by districts, pursuant to the requirements and procedures set forth in Texas Water Code Chapter 36, is an important policy-making function. DFCs are planning goals that state a desired condition of the groundwater resources in the future in order to promote better long-term management of those resources. Districts are authorized to utilize different approaches in developing and adopting DFCs based on local conditions and the consideration of other statutory criteria as set forth in Texas Water Code Section 36.108.

GMA 15 and each of its member districts evaluated DFCs with regard to the nine factors required by Texas Water Code Section 36.108(d), as listed in Section 1.2. In addition to these nine factors, GMA 15 and the individual districts evaluated DFCs with regard to providing a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, and recharging, and prevention of waste of groundwater in GMA 15.

In evaluating the DFCs, GMA 15 and the individual districts recognizes that: 1) the production capability of the aquifer varies significantly across GMA 15, 2) historical groundwater production is significantly different across GMA 15, and 3) the importance of groundwater production to the social-economic livelihood of an area is significantly varied among the districts. As a result of this recognition, a key GMA 15 policy decision was to allow districts to set different DFCs for portion of a specific aquifer within their boundaries, as long as the different DFCs could be shown to be physically possible. The allowance of different DFCs among the districts is justified for several reasons. One reason is that the Texas Water Code Section 36.108(d)(1) authorizes the adoption of different DFCs for different geographic areas over the same aquifer based on the boundaries of political subdivisions. The statute expressly and specifically directs districts “to consider uses or conditions of an aquifer within the management area, including conditions that differ substantially from one geographic area to another” when developing and adopting DFCs for:

1. each aquifer, subdivision of an aquifer, or geologic strata located in whole or in part within the boundaries of the management area; *or*
2. each geographic area overlying an aquifer in whole or in part or subdivision of an aquifer within the boundaries of the management area.

The Legislature’s addition of the phrase “in whole or in part” makes it clear that districts may establish a “different” DFC for a geographic area that does not cover the entire aquifer but only part of that aquifer. Moreover, the plain meaning of the term “geographic area” in this context clearly includes an area defined by political boundaries, such as those of a district or a county.

Each district in GMA 15 submitted a summary of the public comment period and public hearing regarding the proposed DFCs inclusive of all relevant comments received during the 90-day public comment period regarding the proposed DFCs, any suggested revisions to the proposed DFCS, and the basis for the revisions. The summaries are provided in **Appendix C**. GMA 15 Representatives reviewed the summary submittals during a meeting held on April 29, 2016. The DFCs that were considered and proposed for final adoption specify acceptable drawdown levels in the Gulf Coast aquifers on a county-by-county basis and across the entire GMA 15.

4.0 TECHNICAL JUSTIFICATION

The adopted DFCs for the Gulf Coast Aquifer in Section 2.0 were partly developed from simulations of various future pumping scenarios using the CGC GAM (Chowdhury and others, 2004).

4.1 Overview of the Central Gulf Coast GAM (CGC GAM)

The development of the CGC GAM (Chowdhury and others, 2004) began with Waterstone Environmental Hydrology and Engineering, Inc. (Waterstone and Parsons, 2003), and was completed by the TWDB. **Figure 4-1** shows the model domain for the CGC GAM. The model boundary is defined by: (1) the limits of the outcrop area in the west, (2) the Gulf of Mexico, (3) groundwater divide to the north through the Colorado-Fort Bend-Brazoria counties, and (4) groundwater divide to the south through Jim Hogg, Brooks, and Kenedy counties. The model has four layers, which from top to bottom represent the Chicot Aquifer, the Evangeline Aquifer, the Burkeville confining Unit, and the Jasper Aquifer. **Figure 4-2** shows the layering of the model using both three-dimensional and two-dimensional surfaces.

The groundwater code used to model the groundwater flow is MODFLOW-96 (Harbaugh and McDonald, 1996). MODFLOW-96 is code that solves the groundwater flow equation for a finite-difference numerical grid. The numerical grid for the CGC GAM consists of grid cells with dimensions of one mile by one mile. The thickness of each grid cell equals the thickness of the model layer/geologic unit that it represents. The dimension of the grid cell is important because it limits the resolution at which the groundwater system can be described. Among the limitations placed on the model solution by the numerical grid are the following:

- the aquifer properties assigned to a grid cell are assumed to be uniform and constant;
- all the of wells located within the area of a grid cell are represented by a single well at the center of the grid cell;
- all of the wells that pump from a geologic unit are assumed be screened across the entire length of the geologic unit; and
- the water level for the entire grid cell volume is represented by a single value at the center of the grid cell.

The model approach described by the TWDB (Chowdhury and others, 2004) includes: (1) calibrating the model for steady-state conditions from 1910 to 1940 (based on assumptions of no water level change during pre-pumping conditions), and (2) calibrating the model for transient conditions from 1940 to 1999 (based on assumed yearly changes in pumping). The steady-state calibration was performed primarily to investigate the model sensitivity to changes in aquifer properties and boundary conditions. The transient calibration was performed to estimate the final aquifer parameters and boundary conditions for the final model.

The transient calibration by the TWDB primarily focused on adjusting hydraulic parameters to match measured water levels obtained from the TWDB groundwater well database. The vast majority of the water levels used to calibrate the model are from the Chicot and Evangeline aquifers. Only a few water level measurements were associated with the Burkeville Confining Unit and the Jasper aquifer. Both the TWDB and the Waterstone reports provide relatively little information regarding aquifer properties, recharge distributions, and hydraulic boundary conditions. As a result, a reader has little to no information with which to evaluate the reasonableness of many model parameters important to making predictions of pumping impacts.

4.2 Development of the CGC GAM

The primary criteria used by the TWDB to evaluate the model calibration results were comparison between simulated and measured water levels. A standard metric for assessing the goodness in matching historic water levels is the root-mean square error (RMSE). The RMSE is a measure of the average difference between the measured and simulated water levels. The acceptable value of RMSE is both model- and problem-dependent. For regional models that span hundreds of miles, an RMSE of about 10% of the range in head values is generally accepted as a minimum goal during model calibration.

Chowdhury and others (2004) use water levels from 1989 and 1999 to calibrate the CGC GAM. **Figure 4-3** compares the measured and simulated water levels for 1989 and 1999, respectively. The RMSE for the calibration is 46 feet for 1989 and 36 feet for 1999. The RMSE values for the 1989 calibration period and for the 1999 calibration period are about 5% of the total change in water levels across the model area shown in Figure 4-1.

In addition to water levels, Chowdhury and others (2004) show matches for baseflows in streams. **Figure 4-4** shows comparisons between measured and simulated base flows for three river gages in the model domain. The figures show that the simulated base flows are significantly lower than the measured values. Referring to the underestimated stream flows in Figure 4-4, Chowdhury and others (2004) state:

> "In regional groundwater flow models, it is always difficult to reproduce baseflow where the errors in the simulated heads in the aquifers could be potentially large and the state in the river are fixed. A global increase in stream conductance causes too much of a hydraulic interaction between the aquifers and the streams in the central Gulf Coast GAM (Waterstone and Parson, 2003) and would require unreasonable recharge to calibrate the model."

Among the concerns with the calibration of the CGC GAM is that Chowdhury and others (2004) and Waterstone and Parson (2003) provide relatively little documentation and data that can be used to check the reasonableness of the model parameters. With regard to hydraulic properties, Chowdhury and others (2004) do not present any results from specific aquifer tests, geophysical logs, or regional hydrogeological studies to justify their parameterization of the aquifer properties. Chowdhury and others (2004) use three hydraulic conductivity zones (**Figure 4-5**) to model the Evangeline Aquifer but they do not compare these zonation values and results from analysis of field data.

With regard to pumping rates, Chowdhury and others (2004) state that they recalibrated the Waterstone draft GAM based on TWDB estimates of pumpage distribution. However, Chowdhury and others (2004) do not discuss the procedure used to assign TWDB pumping rates to the grid cells among the aquifer layers and the potential sources of error and uncertainty.

Chowdhury and others (2004) present the following three water budgets for the CGC GAM: 1) steady-state for pre-development; 2) transient conditions for 1989; and, 3) transient conditions for 1999. Water budgets provide a breakdown of where the sources and discharges of water occur in the groundwater model. All three of these water budgets are reproduced and shown in **Table 4-1**.

The water budget for the pre-development conditions, which represents the time prior to pumping, is about 600,000 acre feet per year (AFY). The two primary sources of inflow are streams (69%) and recharge from precipitation (29%). The two primary sources of outflows are streams (84%) and the Gulf of Mexico (16%). The average water budget for the 1989 and the 1999 pumping conditions is about 1,000,000 AFY. The increase in the water budget is caused by groundwater pumping, which averages

Table 4-1 Water budgets from the CGC GAM (from Chowdhury and others, 2004)

Steady-state Conditions for Pre-Development				
Parameter	Flow (in) (AFY)	Flow (out) (AFY)	Flow (in) (percent)	Flow (out) (percent)
Drains	0	-4,075	0%	1%
Lake Leakage	9,319	0	2%	0%
Evapo-transpiration	0	0	0%	0%
Gulf of Mexico	0	-97,008	0%	16%
Recharge	180,796	0	29%	0%
Stream Leakage	426,578	-515,610	69%	84%
Total	616,693	-616,693	100%	100%
Transient Conditions for 1989				
Parameter	Flow (in) (AFY)	Flow (out) (AFY)	Flow (in) (percent)	Flow (out) (percent)
Storage	365,155	-237,054	32.53%	21.12%
Pumping	0	-386,932	0%	34%
Drains	0	-1,832	0%	0%
Lake Leakage	21,752	0	2%	0%
Evapo-transpiration	0	-37,920	0%	3%
Gulf of Mexico	2,579	-71,551	0%	6%
Recharge	265,448	0	24%	0%
Stream Leakage	467,671	-387,296	42%	35%
Total	1,122,605	-1,122,585	100%	100%
Transient Conditions for 1999				
Parameter	Flow (in) (AFY)	Flow (out) (AFY)	Flow (in) (percent)	Flow (out) (percent)
Storage	248,228	-22,549	25.53%	2.32%
Pumping	0	-425,020	0%	44%
Drains	0	-2,035	0%	0%
Lake Leakage	21,409	0	2%	0%
Evapo-transpiration	0	-20,958	0%	2%
Gulf of Mexico	1,299	-87,330	0%	9%
Recharge	182,909	0	19%	0%
Stream Leakage	518,498	-414,450	53%	43%
Total	972,343	-972,342	100%	100%

about 400,000 AFY. The three major sources of inflow are leakage from stream (47%), water release from aquifer storage (29%), and recharge (21%). The three major sources of discharge are groundwater flow to streams (39%), pumping from the aquifer (39%), and addition of water into storage (12%).

4.3 Application of CGC GAM

The CGC GAM was used to simulate the impact of pumping for a period from January 1, 2000 to December 31, 2071. The initial water level conditions for the predictive GAM runs from Chowdhury and others (2004) for December 1999 and are shown in **Figure 4-6**. To help establish appropriate benchmarks for districts to evaluate pumping impacts, **Appendix D** presents the water budgets for each county for 1999. These water budgets were presented to the GMA 15 by INTERA on April 10, 2014.

Two scenarios of pumping rates and locations were generated by the GMA 15 for the time period from 2000 to 2070 to represent alternative future pumping scenarios. Each pumping scenario is contained in a single computer file that can be read and used by the CGC GAM. The two scenarios are called “Baseline” and “High-Production.” The “Baseline” scenario represented a district’s current MAG, with updates to account for anticipated district growth and/or permits recently awarded. There was no consensus among the districts for a definition of “High-Production.” The “High-Production” scenario was developed to allow several districts to evaluate the impact of increased pumping on drawdowns.

In order to help represent spatial and temporal trends of interest to the districts adequately, the pumping scenarios were generated using a template that allowed yearly changes in pumping in any grid cell or group of cells in the GAM, so that the districts could represent future pumping rates at the temporal and spatial resolution they deemed appropriate for the joint planning process. Several versions of the Baseline and the High-Production pumping files were generated and run with the CGC GAM in 2014. The final set of pumping files used to help establish the adopted DFCs include the designation “Option 1.” **Table 4-2** presents the pumping by county and by aquifer in 2070 for the Baseline Option 1 pumping scenario. **Table 4-3** presents the pumping by county and by aquifer in 2070 for the High-Production Option 1 pumping scenario. **Figure 4-7** shows the annual variation of total pumping by county for the Baseline Option 1 pumping scenario. **Figure 4-8** shows the annual variation of total pumping by county for the High-Production Option 1 pumping scenario.

Table 4-2 2070 pumping rates associated with the Baseline Pumping Scenario

County	Chicot Aquifer	Evangeline Aquifer	Burkeville Confining Unit	Jasper Aquifer	Total
Aransas	1,863	0	0	0	1,863
Austin	3,180	4,006	5	22	7,214
Bee	3,707	5,505	17	289	9,518
Brazoria	8,901	289	0	0	9,189
Calhoun	7,950	68	0	0	8,018
Colorado	31,602	40,066	0	919	72,587
Dewitt	1,019	7,818	166	6,408	15,411
Fayette	0	264	405	1,878	2,546
Fort Bend	6,248	5,381	0	0	11,629
Goliad	714	10,702	306	102	11,824
Jackson	66,147	24,529	0	0	90,676
Karnes	0	105	627	3,262	3,993
Lavaca	3,095	12,647	151	4,692	20,585
Matagorda	33,898	7,121	0	0	41,020
Refugio	3,383	2,636	0	0	6,019
Victoria	32,170	27,873	0	0	60,043
Wharton	114,878	66,575	0	0	181,452
Total	318,755	215,584	1,676	17,572	553,587

Table 4-3 2070 pumping rates associated with the High-Production Pumping Scenario

County	Chicot Aquifer	Evangeline Aquifer	Burkeville Confining Unit	Jasper Aquifer	Total
Aransas	1,863	0	0	0	1,863
Austin	3,180	4,006	5	22	7,214
Bee	3,707	5,505	17	289	9,518
Brazoria	8,901	289	0	0	9,189
Calhoun	12,456	10,070	0	0	22,526
Colorado	48,419	62,874	0	919	112,211
Dewitt	1,019	7,813	165	19,178	28,176
Fayette	0	914	1,380	6,664	8,958
Fort Bend	6,286	5,381	0	0	11,667
Goliad	724	12,288	311	286	13,609
Jackson	92,308	85,452	0	0	177,760
Karnes	0	105	737	4,485	5,327
Lavaca	3,095	12,647	151	4,692	20,585
Matagorda	42,732	9,063	0	0	51,795
Refugio	6,379	37,951	0	0	44,331
Victoria	104,670	70,373	0	50,000	225,043
Wharton	135,864	78,713	0	0	214,577
Total	471,604	403,442	2,766	86,536	964,348

The CGC GAM was used to simulate future groundwater conditions using the same average conditions for recharge and stream water levels used by the TWDB to generate MAGs from the 2010 DFCs (Hill and Oliver, 2011). The average drawdowns for each county by aquifer are presented in **Table 4-4** for the Baseline Option 1 simulation and in **Table 4-5** for the High-Production Option 1 simulation. To evaluate the sensitivity of predicted drawdown to recharge, the Baseline Option 1 future pumping scenario was also run with 50% of the average recharge rate. Simulated average drawdown results for the "50% recharge" simulation are provided in **Table 4-6**. Prior to considering the results in Tables 4-4, 4-5, and 4-6 for proposing DFCs, GMA 15 had the TWDB verify the values in Table 4-4 by recalculating the average drawdowns using the codes developed by the TWDB.

Table 4-4 Average drawdowns (feet) from 2000 to 2070 for the Baseline Option 1 Pumping Scenario

County	Chicot	Evangeline	Chicot+ Evangeline	Burkeville	Jasper	Gulf Coast Aquifer System	Overall (without Burkeville)
Aransas	-0.1	5.8	0.0	NA	NA	0.0	0.0
Bee	1.3	8.7	6.2	7.7	5.6	6.5	6.0
Calhoun	-0.6	10.7	2.6	2.8	NA	2.6	2.6
Colorado	12.8	26.0	20.1	22.6	24.8	22.0	21.8
Dewitt	1.2	6.1	5.4	17.0	26.1	17.3	17.4
Fayette	NA	5.6	5.6	17.7	18.1	16.1	15.5
Goliad	-3.4	0.7	-0.1	7.2	10.5	5.2	4.2
Jackson	15.2	20.2	17.7	14.4	22.0	17.5	18.5
Karnes	NA	0.3	0.3	18.2	24.0	20.4	21.0
Lavaca	7.2	6.8	6.9	16.1	31.1	17.6	18.2
Matagorda	4.0	17.2	8.0	16.7	NA	8.8	8.0
Refugio	-0.4	7.3	3.2	2.8	NA	3.1	3.2
Victoria	-4.4	6.0	1.0	5.0	9.5	3.5	3.0
Wharton	14.6	12.4	13.5	25.5	28.4	20.0	18.1
Average	5.5	11.4	8.5	15.1	22.0	13.2	12.6

NA – not applicable because model does include this unit in this county

Table 4-5 Average drawdowns (feet) from 2000 to 2070 for the High-Production Option 1 Pumping Scenario

County	Chicot	Evangeline	Chicot+ Evangeline	Burkeville	Jasper	Gulf Coast Aquifer System	Overall (without Burkeville)
Aransas	0.0	46.0	1.1	NA	NA	1.1	1.1
Bee	3.8	15.4	11.5	11.1	6.5	10.1	9.7
Calhoun	4.5	108.4	34.1	7.9	NA	33.9	34.1
Colorado	30.4	54.3	43.6	36.7	36.6	40.0	41.1
Dewitt	4.0	9.5	8.7	27.0	53.3	32.4	34.5
Fayette	NA	15.0	15.0	40.5	50.4	42.6	43.2
Goliad	4.5	13.1	11.3	12.9	19.6	14.2	14.7
Jackson	65.4	143.6	104.4	52.8	42.0	82.2	92.0
Karnes	NA	1.6	1.6	21.3	32.8	27.2	28.7
Lavaca	25.0	19.1	20.9	21.2	35.6	25.9	27.7
Matagorda	8.2	65.2	25.5	27.3	NA	25.7	25.5
Refugio	1.6	67.7	32.0	20.0	NA	30.2	32.0
Victoria	27.0	81.3	55.1	68.3	180.1	79.5	83.8
Wharton	38.4	60.7	49.6	43.6	38.3	45.5	46.1
Average	20.7	56.2	38.7	34.9	46.7	39.6	41.1

Table 4-6 Average drawdowns (feet) from 2000 to 2070 for the Baseline Option 1 Pumping Scenario with 50% pumping

County	Chicot	Evangeline	Chicot+ Evangeline	Burkeville	Jasper	Gulf Coast Aquifer System	Overall (without Burkeville)
Aransas	-0.1	7.0	0.1	NA	NA	0.1	0.1
Bee	14.7	19.8	18.0	13.4	9.6	14.4	14.9
Calhoun	-0.4	12.2	3.2	2.9	NA	3.2	3.2
Colorado	27.4	38.8	33.7	29.8	30.0	31.7	32.4
Dewitt	9.6	8.9	9.0	19.7	28.1	20.1	20.2
Fayette	NA	12.6	12.6	21.7	20.8	19.9	19.1
Goliad	3.0	5.0	4.6	9.9	12.7	8.5	7.9
Jackson	23.8	27.4	25.6	17.2	23.8	23.2	25.2
Karnes	NA	12.2	12.2	22.6	25.6	23.6	23.9
Lavaca	24.0	13.4	16.6	19.4	33.4	23.0	24.4
Matagorda	4.5	19.4	9.0	17.3	NA	9.8	9.0
Refugio	0.6	9.9	4.9	4.2	NA	4.8	4.9
Victoria	-0.3	9.4	4.8	7.0	11.7	6.5	6.4
Wharton	21.4	19.2	20.3	28.4	30.4	24.7	23.4
Average	10.4	17.6	14.1	18.8	24.7	17.6	17.2

4.4 Evidence and Sources of Predictive Uncertainty in CGC GAM Simulations of Pumping Scenarios

During the July 2015 GMA 15 meeting, INTERA discussed sources of error and uncertainty in the predicted water levels in Tables 4-4,4-5, 4-6. A list of these sources is presented in **Figure 4-9**. **Appendix E** contains the slide presentation that INTERA presented to GMA 15 regarding predictive uncertainty associated with the CGC GAM. Several of the documented sources of uncertainty include flaws in the conceptual groundwater flow model, insufficient field data, inaccurate aquifer properties, oversimplified aquifer dynamics, improper aquifer boundaries and stratigraphy, and inadequate numerical spatial resolution. Among the references discussed to illustrate examples of the documented sources of uncertainty and error in the CGC GAM are Chowdhury and others (2004), TWDB (2014), Young (2012; 2014), Young and Kelley (2006), and Young and others (2010; 2012; 2013). A key message in the July discussion was the TWDB statement regarding the CGC GAM simulations by Hill and Oliver (2011):

> "The groundwater model used in developing estimates of modeled available groundwater is the best available scientific tool that can be used to estimate the pumping that will achieve the desired future conditions. Although the groundwater model used in this analysis is the best available scientific tool for this purpose, it, like all models, has limitations. In reviewing the use of models in environmental regulatory decision-making, the National Research Council (2007) noted:
>
> 'Models will always be constrained by computational limitations, assumptions, and knowledge gaps. They can best be viewed as tools to help inform decisions rather than as machines to generate truth or make decisions. Scientific advances will never make it

possible to build a perfect model that accounts for every aspect of reality or to prove that a given model is correct in all respects for a particular regulatory application. These characteristics make evaluation of a regulatory model more complex than solely a comparison of measurement data with model results.'

Given these limitations, users of this information are cautioned that the modeled available groundwater numbers should not be considered a definitive, permanent description of the amount of groundwater that can be pumped to meet the adopted desired future condition. Because the application of the groundwater model was designed to address regional scale questions, the results are most effective on a regional scale. The TWDB makes no warranties or representations relating to the actual conditions of any aquifer at a particular location or at a particular time."

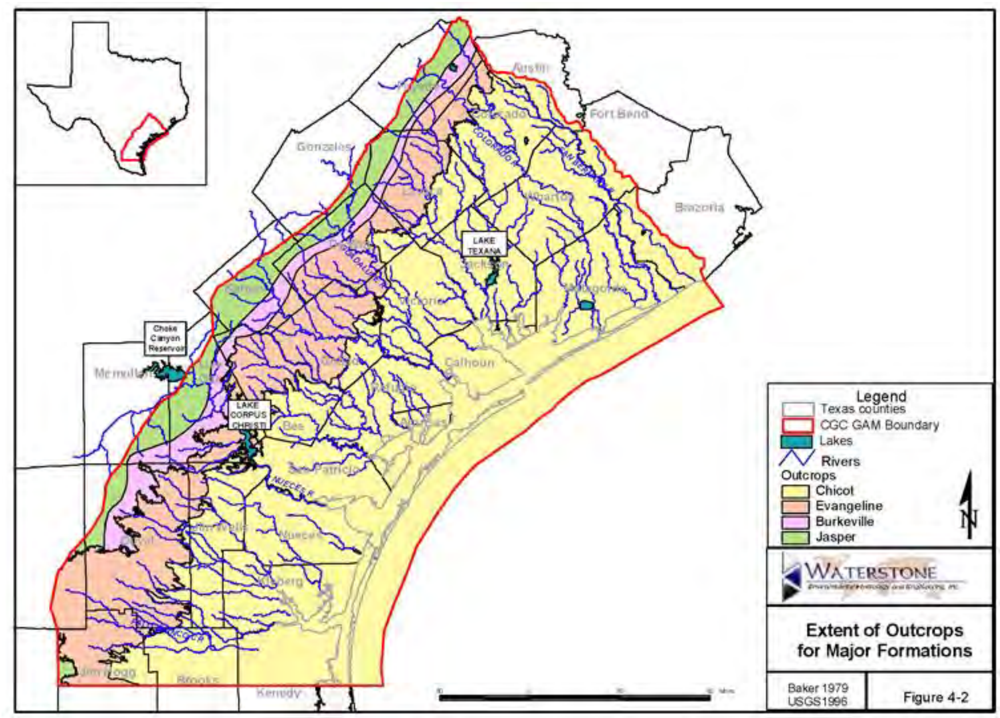


Figure 4-1 Model domain for the Central Gulf Coast GAM (Waterstone and Parson, 2003)

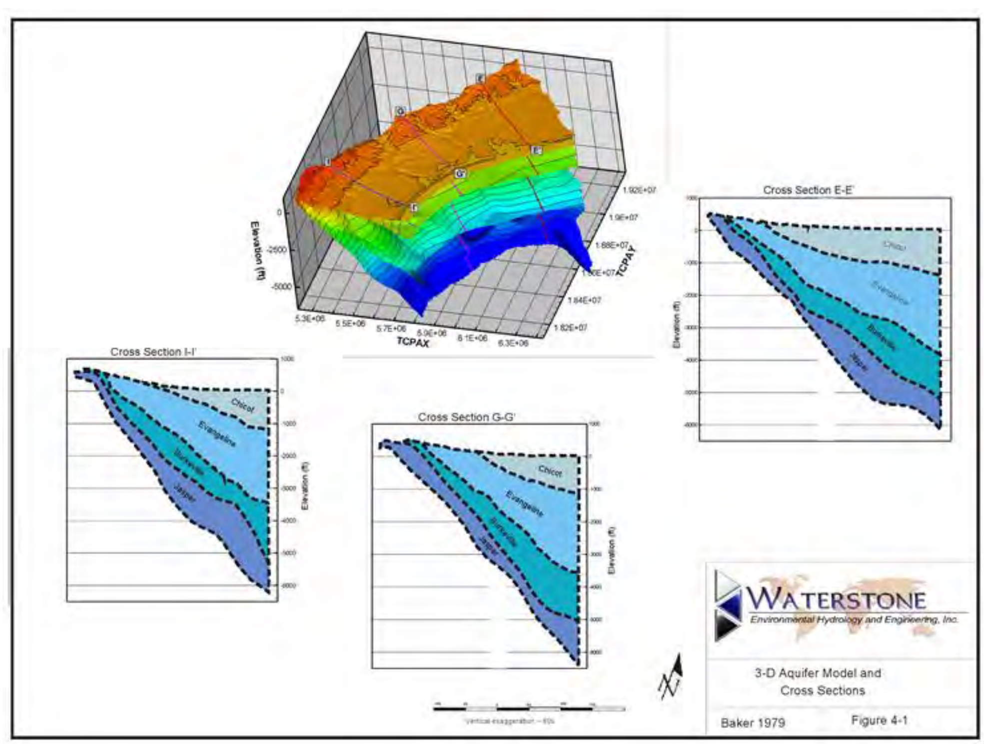
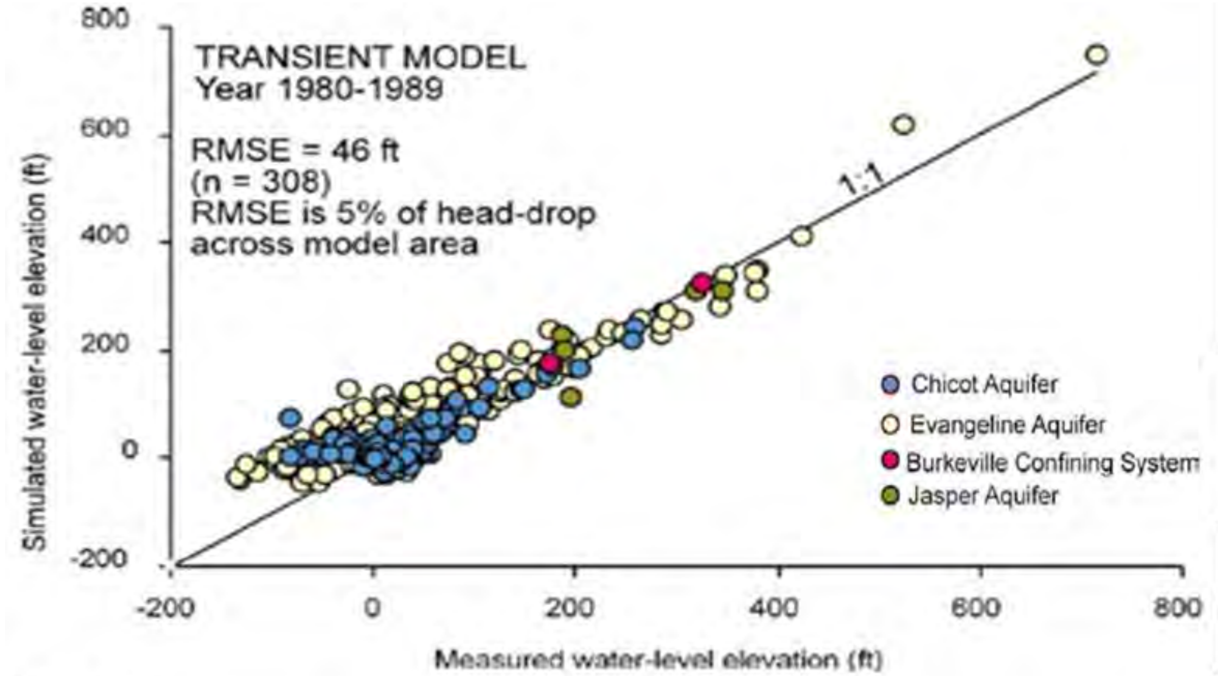


Figure 4-2 Three-dimensional surfaces and two-dimensional cross-sections showing the model layers for the Central Gulf Coast GAM (Waterstone and Parson, 2003)



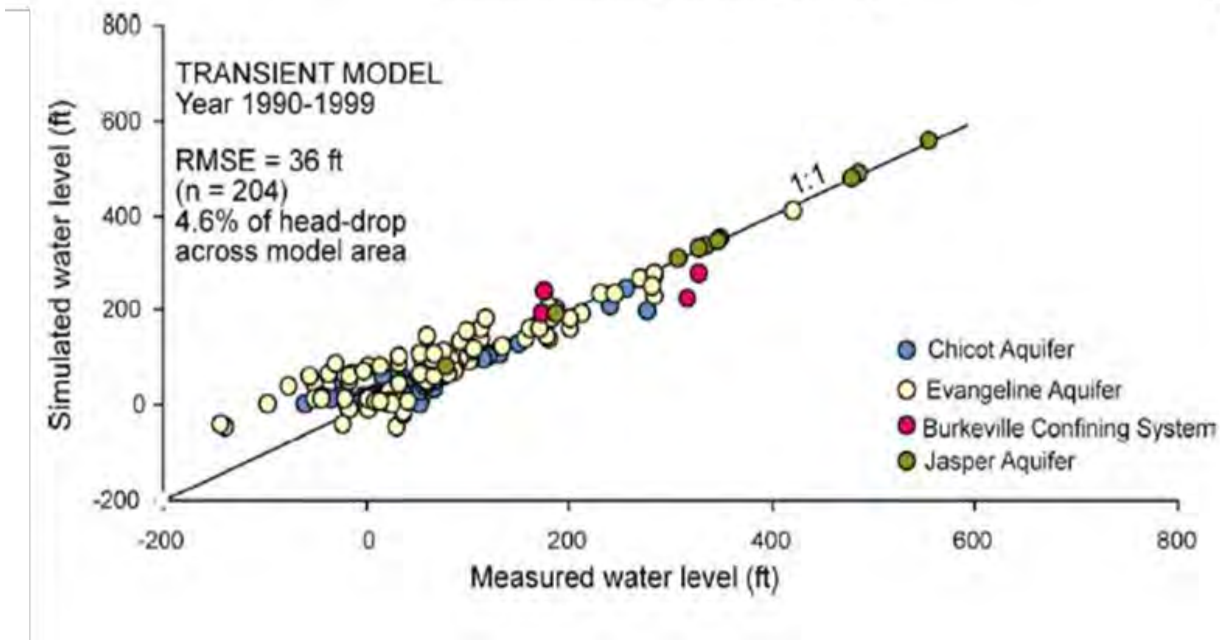


Figure 4-3 Comparison of measured and simulated water levels presented by Chowdhury and others (2004) for the CGC GAM for 1989 (top plot) and 1999 (bottom plot)

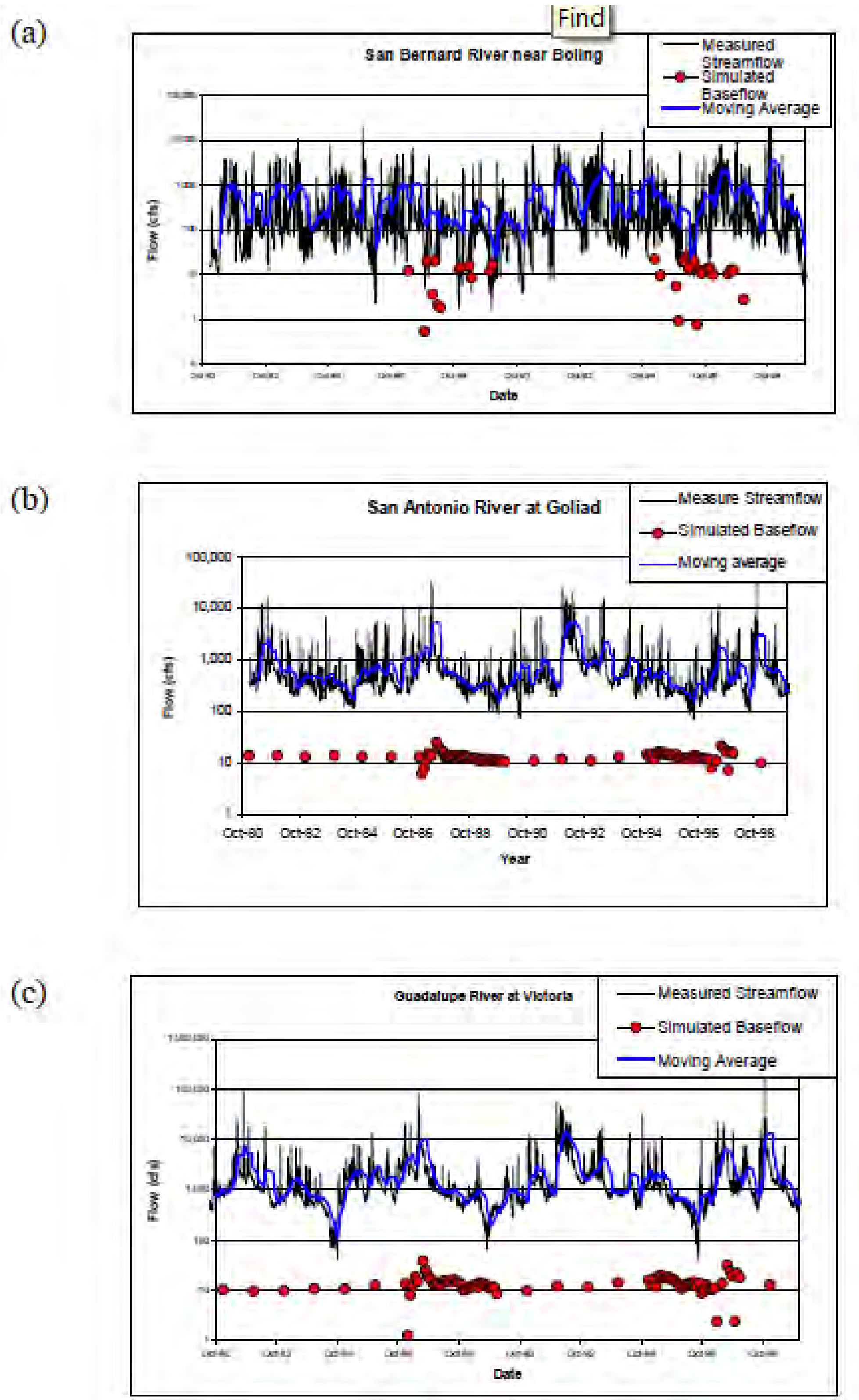


Figure 4-4 Comparison of streamflow hydrographs with simulated baseflow for the (a) San Bernard River near Boling, (b) San Antonio River at Goliad, and (c) Guadalupe River at Victoria (Chowdhury and others, 2004)

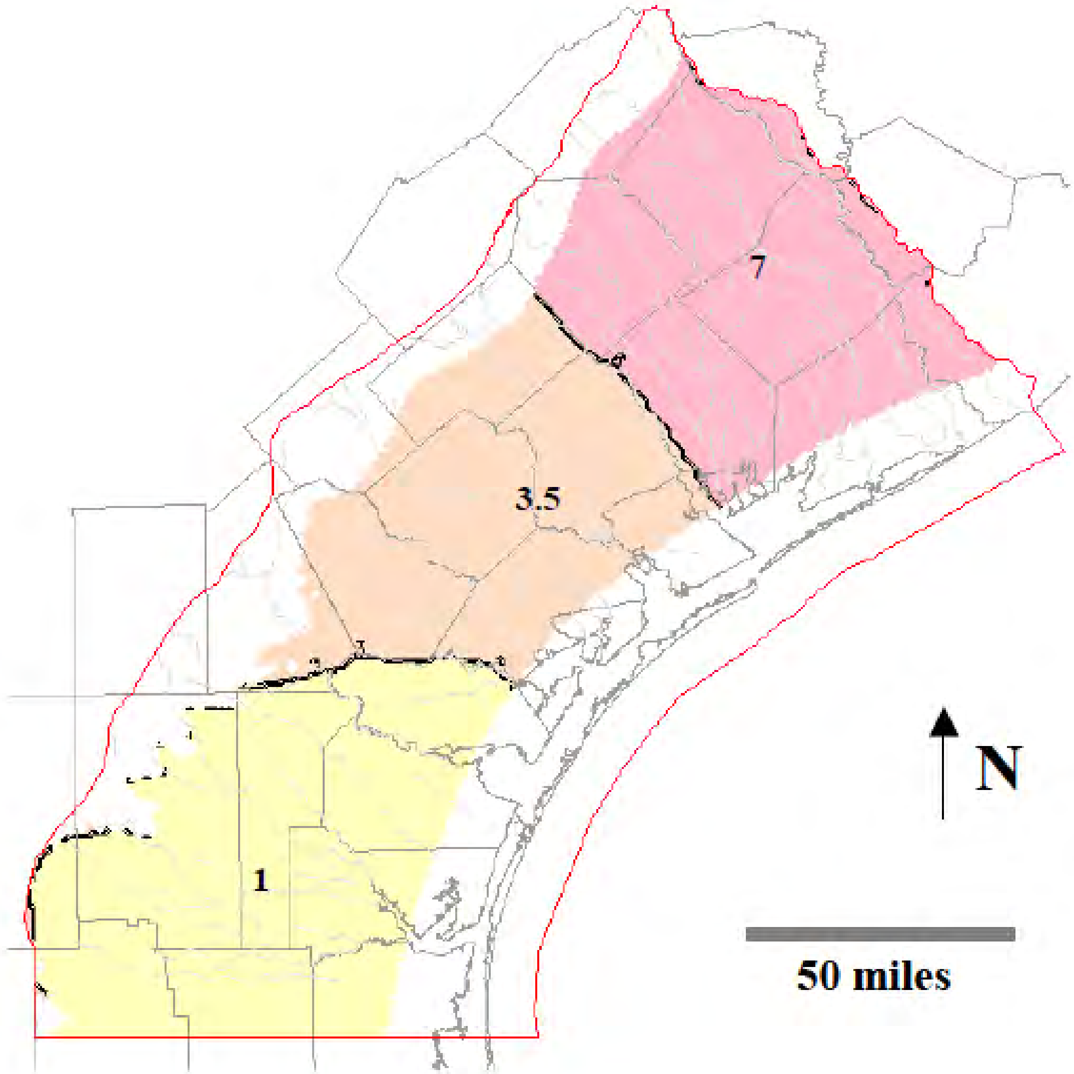


Figure 4-5 Hydraulic conductivity zones in the Evangeline Aquifer used from the calibrated CGC GAM. Hydraulic conductivity values labeled for each zone are in ft/day (from Waterstone and Parsons, 2003)

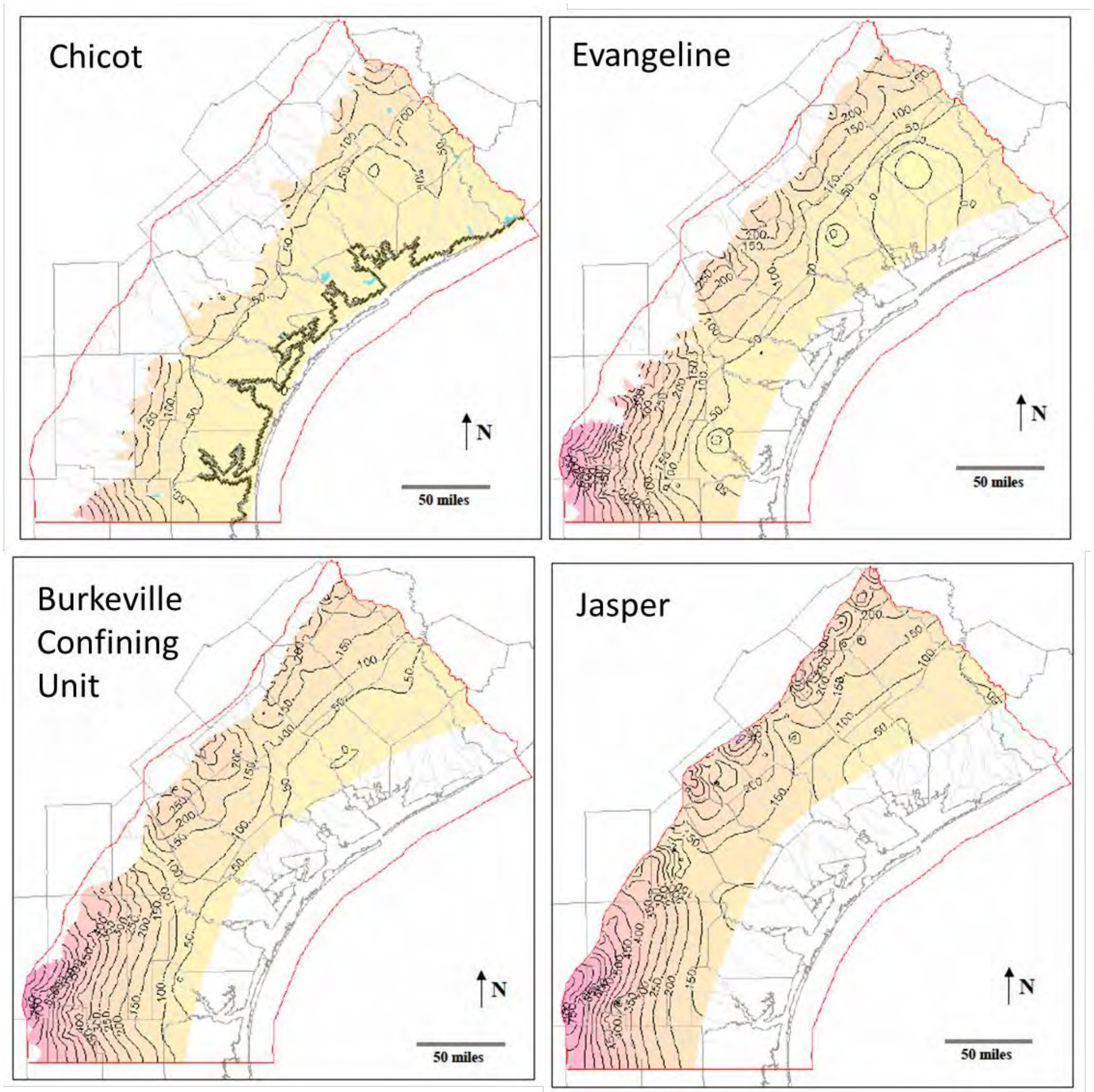


Figure 4-6 1999 Water levels simulated for the Chicot Aquifer, Evangeline Aquifer, the Burkeville Confining Unit, and the Jasper Aquifer by the Central Gulf Coast GAM (Chowdhury and others, 2004).

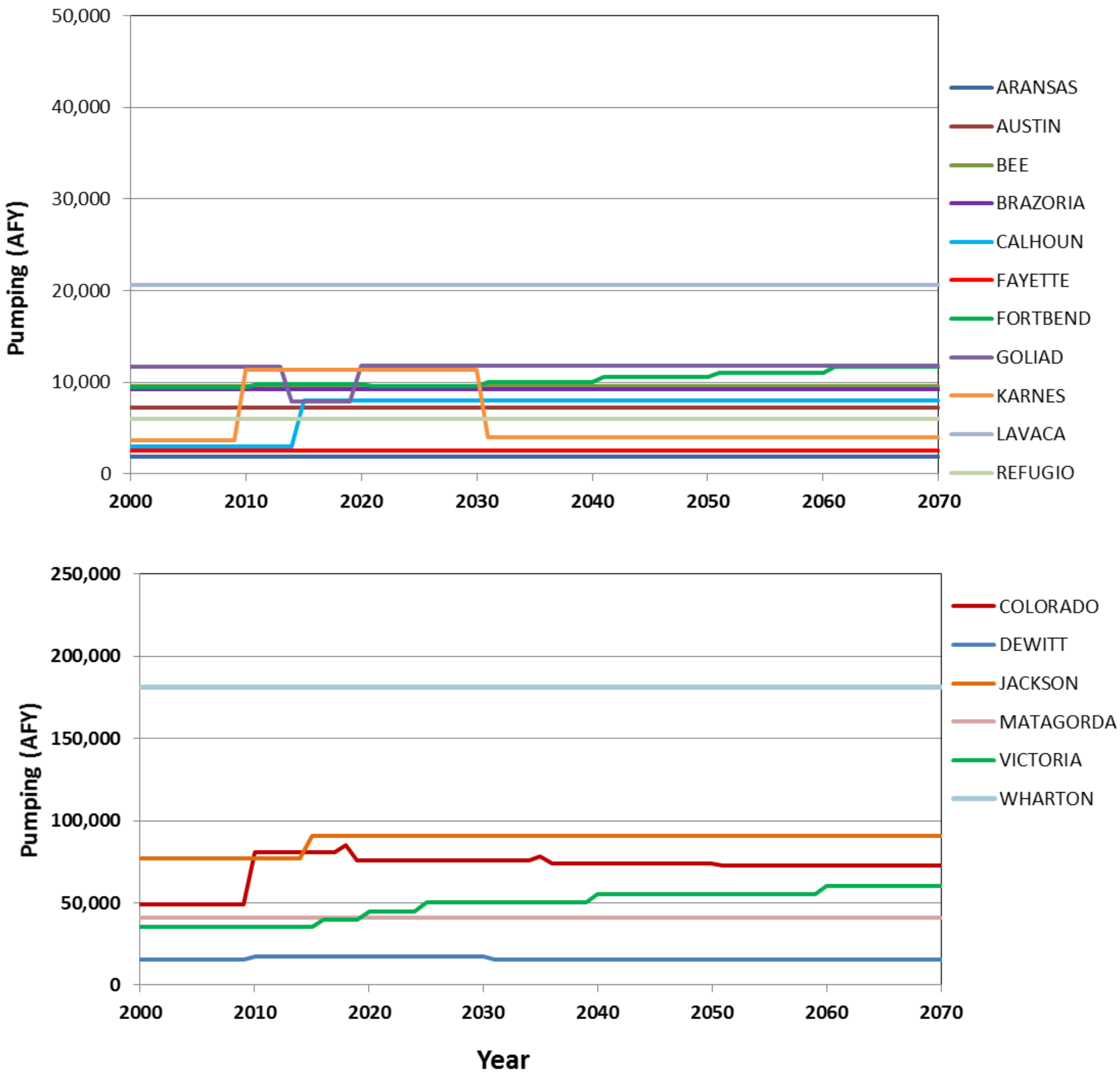


Figure 4-7 Annual changes in pumping by county for the Baseline Future Pumping Scenario

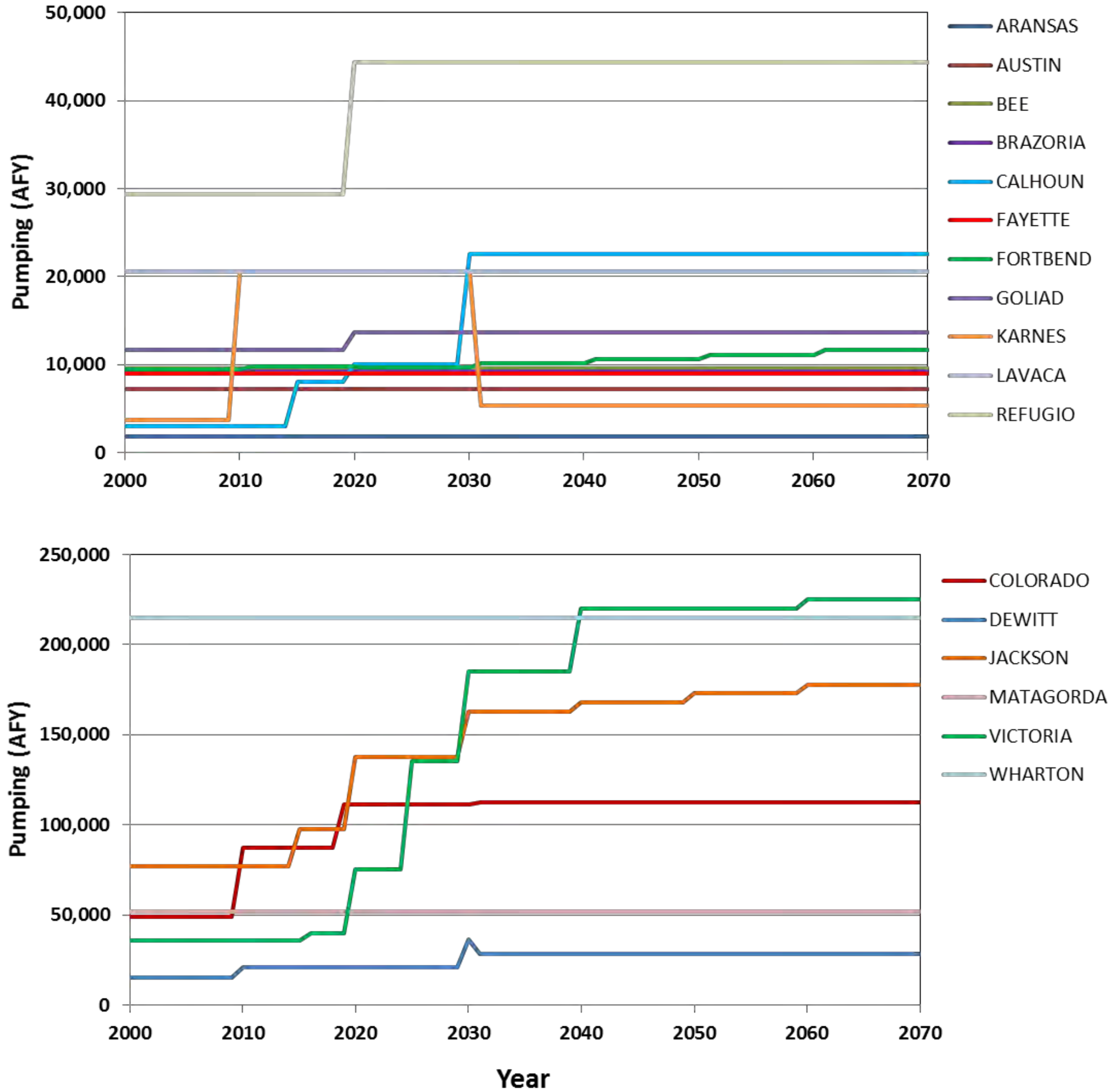


Figure 4-8 Annual changes in pumping by county for the High-Production Future Pumping Scenario

1. **Central Gulf Coast GAM Report (2004)**
    a. **Calibration statistics between measured and model values**
    b. **Plots of residuals for different aquifers**

2. **LCRA-SAWS Water Project (LSWP) Reports (2005 to 2009)**
    a. **Spatial placement of pumping**
    b. **Vertical placement of pumping**
    c. **Temporal and Spatial distribution of recharge**
    d. **Numerical discretization around streams**
    e. **Aquifer boundaries**
    f. **Spatial variability in aquifers**
    g. **Addition of land subsidence (aquifer storage)**

3. **DFC Presentation to GMA 15 on Behalf of CCGCD, CBGCD, CPGCD (2010)**
    a. **Volume-weighted versus area-weighted drawdown averages**
    b. **Difference in pumping by aquifer between GMA model and reported by district**
    c. **Incomplete spatial coverage of aquifers by active model grid cells**

4. **PVGCD Report Regarding the Impacts of Large-scale Pumping (2012)**
    a. **Catahoula is an important Gulf Coast Geologic Unit**
    b. **Burkeville is not a low permeability unit for most of DeWitt County**
    c. **Jasper and Burkeville transmissivity is too low. Non-uniqueness of Central GAM calibration – can be recalibrated with much high recharge and transmissivity values**

5. **VCGCD Report discussing Science Development Program (2012)**
    a. **Aquifer boundaries and hydraulic properties – Burkeville K too low and K distribution for Chicot and Evangeline not consistent with field data**
    b. **Recharge and GW-SW exchange**

6. **VCGCD Report discussing Transmissivity values from Aquifer Tests (2014)/ TWDB Regional ASR & OCS Plan for Golden Crescent Region of Texas (2014)**
    a. **Evangeline modeled transmissivity values are too low in Victoria County**
    b. **Notable differenced between measured and modeled transmissivity in Jackson County**

7. **TWDB Report Evaluation of Hydrogeochemical Data regarding Implication to Developing Gulf Coast GAMs (2013)**
    a. **Implications to Conceptual Model**
    b. **Considerations for Implementing Recharge and GW-SW Interaction**

8. **On-going studies by CBGCD, CPGCD, VCGCD, TGCD, RGCD, EUWCD, and PVGCD to Support Development of GAM 15 & 16 (2015)**
    a. **Groundwater-surface water interaction**
    b. **Aquifer Hydraulic Properties are spatially variable**
    c. **Considerable uncertainty in recharge estimates**
    d. **Land-Subsidence has appear to occurred**

Figure 4-9 Eight different studies that document source of predictive error and uncertainty in the CGC GAM simulations

5.0 FACTORS CONSIDERED FOR THE DESIRED FUTURE CONDITIONS

Section 36.108(d)(1-8) of the Texas Water Code requires districts of a GMA document the consideration of the nine listed factors (provided in Section 1.2) prior to proposing a DFC. This section of the explanatory report summarizes information considered by GMA 15 regarding the factors.

5.1 Aquifer Uses and Conditions

Texas Water Code Section 36.108(d)(1) directs districts to consider, during the joint-planning process, "aquifer uses or conditions within the management area, including conditions that differ substantially from one geographic area to another." Information on aquifer uses and conditions that was discussed in the GMA 15 includes, but is not limited, to the following:

- The TWDB water use surveys
- The TWDB historical groundwater pumping database
- The TWDB groundwater well database
- Documentation of the CGC GAM including Chowdhury and others (2004) and Waterstone and Parson (2003)
- Documentation of the Lower Colorado River Basin Model Report (Young and Kelley, 2006; Young and others, 2009)
- Reponses from the districts regarding GMA 15 Questionnaire #2

As summarized in the GMA 15 December 2015 meeting minutes:

> "The aquifer uses and conditions differ substantially across Groundwater Management Area 15. Groundwater production is generally greater in the northeastern portions of GMA 15 in Colorado, Wharton, Matagorda, and Jackson counties. Groundwater in the northeastern portion of GMA 15 is predominately used for irrigation purposes. Groundwater production in the central portion of GMA 15 in Victoria County is predominately used for irrigation, municipal, and industrial uses. Groundwater production in the north central portion of GMA 15 in DeWitt County and Karnes County is predominately used for domestic and livestock purposes as well as supporting oil and gas production in the Eagle Ford Shale. Groundwater production in the southwestern portions of GMA 15 is predominately used for domestic, livestock, and agricultural uses. The condition of the Gulf Coast Aquifer differs significantly geographically. Generally, the capacity of the Gulf Coast Aquifer to produce groundwater increases to the northeast and decreases to the southwest as well as increase down dip relative to up dip portions of the Gulf Coast Aquifer."

The differences in the groundwater pumped by the counties were discussed in the April 2014 meeting. A planning sheet, provided in **Appendix F**, was distributed to each district that contained the following information for each county:

- TWDB pumping estimates from 2000 to 2011
- Decadal values for current MAGs
- Decadal summary of the 2012 State Water Plan for groundwater supplies, water demands and groundwater supply strategies
- Decadal summary of the 2017 State Water Plan Water Demands

- Total Estimated Recoverable Storage

Table 5-1 summarizes the average and median groundwater pumping from 2000 to 2011 based on the TWDB groundwater database. The average county pumping in the Gulf Coast Aquifer ranges from a low of 483 AFY in Aransas County to a high of 127,475 AFY in Wharton County. Over 80% of the pumping in the 14 counties occurs in four northeast counties: Wharton, Matagorda, Colorado, and Jackson counties. Pumping in these four counties is dominated by irrigation.

Table 5-1 Average groundwater pumping (AFY) from 2000 to 2011 for counties in GMA 15 based on TWDB historical groundwater pumping

County	Aquifer	Average	Median	Minimum	Maximum
Aransas	Gulf Coast Aquifer	483	483	425	589
	Other Aquifer	18	11	1	55
	Unknown	4	3	0	10
	Subtotal	505	497	426	655
Bee	Edwards-BFZ Aquifer	105	91	78	178
	Gulf Coast Aquifer	6,568	5,988	5,545	8,916
	Other Aquifer	279	263	157	491
	Unknown	206	205	195	218
	Subtotal	7,159	6,547	5,975	9,803
Calhoun	Gulf Coast Aquifer	1,000	618	489	1,854
	Other Aquifer	21	14	0	54
	Unknown	13	14	2	23
	Subtotal	1,034	646	491	1,932
Colorado	Gulf Coast Aquifer	30,476	26,925	20,397	54,843
	Other Aquifer	742	742	168	1,315
	Trinity Aquifer*	468	0	0	3,311
	Unknown	196	0	0	725
	Subtotal	31,882	27,667	20,565	60,194
DeWitt	Gulf Coast Aquifer	4,821	4,776	3,889	6,188
	Other Aquifer	42	42	4	97
	Unknown	595	265	43	1,808
	Subtotal	5,458	5,083	3,936	8,093
Fayette	Carrizo-Wilcox Aquifer	19	14	2	44
	Gulf Coast Aquifer	3,082	3,306	1,493	3,911
	Other Aquifer	196	117	77	573
	Queen City Aquifer	5	1	0	14
	Sparta Aquifer	220	138	94	758
	Unknown	34	29	20	57
	Yegua-Jackson Aquifer	236	111	61	1150
	Subtotal	3,792	3,715	1,747	6,506

County	Aquifer	Average	Median	Minimum	Maximum
Goliad	Gulf Coast Aquifer	3,395	3,878	1,093	5,272
	Unknown	40	42	30	46
	Subtotal	3,435	3,920	1,123	5,318
Jackson	Gulf Coast Aquifer	46,373	44,056	36,064	90,186
	Other Aquifer	624	682	6	1,184
	Unknown	40	43	31	43
	Subtotal	47,037	44,781	36,101	9,1413
Karnes	Carrizo-Wilcox Aquifer	167	153	98	276
	Gulf Coast Aquifer	3,457	3,405	2,638	4,408
	Unknown	690	218	0	2,326
	Yegua-Jackson Aquifer	267	326	48	487
	Subtotal	4,581	4,101	2,785	7,497
Lavaca	Gulf Coast Aquifer	9,219	8,573	6,993	13,683
	Other Aquifer	999	999	676	1,322
	Unknown	74	54	54	133
	Yegua-Jackson Aquifer	7	7	6	8
	Subtotal	10,298	9,633	7,729	15,146
Matagorda	Gulf Coast Aquifer	34,945	32,418	21,060	55,044
	Other Aquifer	380	25	14	2,171
	Unknown	45	43	38	55
	Subtotal	35,369	32,486	21,112	57,270
Refugio	Gulf Coast Aquifer	2,269	2,077	1,625	3,930
	Unknown	47	48	30	62
	Subtotal	2,316	2,124	1,655	3,992
Victoria	Gulf Coast Aquifer	13,900	11,253	6,430	32,864
	Unknown	40	42	32	45
	Subtotal	13,941	11,295	6,462	32,909
Wharton	Gulf Coast Aquifer	127,475	13,0978	87,380	185,772
	Other Aquifer	1,976	1,976	1,909	2,042
	Unknown	51	55	38	56
	Subtotal	129,501	133,008	89,327	187,871

*Note: there no pumping from the Trinity Aquifer in Colorado. There values are incorrectly stated in the TWDB historical pumping database

The spatial distribution of the pumping across the counties and among the Chicot Aquifer, Evangeline Aquifer, Burkeville Confining Unit, and Jasper aquifer is provided in **Appendix G**. **Appendix H** illustrates the spatial distribution of pumping by county used to establish the DFC and MAG during the 2010 joint planning. The figures in Appendices G and H show the total pumping across a grid cell. Each grid cell covers one square mile. To help facilitate comparison of pumping among counties and among the four hydrogeological units, the pumping rate per grid cell is color-coded using the same scale for all figures. The scale consists of the following seven intervals:

1. no pumping;
2. < 10 AFY;
3. 10 to 30 AFY;
4. 30 to 100 AFY;
5. 100 to 300 AFY;
6. 300 to 1,000 AFY; and
7. > 1,000 AFY.

The information in Appendices G and H was first presented in the April 2014 GMA 15 meeting and discussed during several later GMA 15 meetings. Based on considerations of information in Section 5.1, GMA 15 anticipates that the adoption of the DFCs will not impact the aquifer use and conditions within GMA 15 significantly during the planning horizon and would provide a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging and prevention of waste of groundwater, and control of subsidence in the management area.

5.2 Water Supply Needs and Water Management Strategies

Texas Water Code Section 36.108 (d)(2) directs districts to consider, during the joint-planning process, the water supply needs and water management strategies included in the state water plan. GMA 15 comprises an area spanning Regional Water Planning Areas K, L, N, and P. District representatives from GMA 15 attended the planning meetings for Regions K, L, N, and P. During the planning period, the representatives provided reports to the GMA 15 regarding the activities of the planning groups. In addition to considering the regional planning reports, the district representatives considered water supply needs and recommended water management strategies included in 2012 State Water Plan and the 2017 State Water Planned Water Demands, which are contained in Appendix F.

The overall water needs for a region, as defined within the Texas State Water Plan, are the demands (based on water demand projections developed during the water planning process for six major water use sectors) that cannot be met with existing supplies. These existing supplies may be inadequate to satisfy demands due to natural conditions (e.g., instance, sustainable supply of an aquifer or firm yield of a reservoir) or infrastructure limitations (e.g., inadequate diversion, treatment, or transmission capacity). A review of the future water management strategies within a region gives some insight into the potential future supply for meeting an identified need. Therefore, future groundwater management strategies identified in the 2012 Texas State Water Plan indicate the potential future demand for groundwater in addition to currently utilized supplies. **Table 5-2** provides 2012 State Water Planning Values for 2060 for GMA 15 Counties. The summation of Gulf Coast groundwater strategies for the 14 counties is 142,654 AFY. Over 90% of these strategies are associated with Wharton, Matagorda, Jackson, and Colorado counties. These large numbers indicate a potential future demand for groundwater in these four counties, in addition to currently utilized supplies.

Based on a review of the a summary of the water supply needs and water management strategies of the 2012 Texas State Water Plan, GMA 15 determined that the proposed DFCs are not anticipated to have a significant impact on the water supplies, water supply needs, or water management strategies of the 2012 Texas State Water Plan during the planning horizon and would provide a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging and prevention of waste of groundwater, and control of subsidence in the management area.

Table 5-2 2012 State Water Planning values for 2060 for GMA 15 counties in addition to 2010 MAG values

County	MAG	2012 State Water Plan Amounts for 2060 (AFY)			
		Groundwater Supplies	Water* Demands	Water* Supply Need (-) Surplus (+)	Gulf Coast Strategy
Aransas	1,862	579	4,335	-1,579	200
Bee (GMA 15)	10,660	7,121	11,578	-890	11,016
Calhoun	2,995	2,345	86,370	8,206	0
Colorado	48,953	38,508	188,786	-7,357	15,519
Dewitt	14,616	10,335	4,907	6,394	0
Fayette	18,917	11,742	79,542	-25,054	632
Goliad	11,699	4,566	19,224	6,728	0
Jackson	76,386	57,728	63,531	-3,971	5,053
Karnes (GMA 15)	3,116	5,269	6,167	536	161
Lavaca	20,373	14,445	13,550	895	0
Matagorda	45,896	36,302	319,162	-137,320	29,566
Refugio	29,328	2,952	2,002	1,262	0
Victoria	35,694	30,941	126,617	-65,275	0
Wharton	178,493	171,310	297,503	-60,550	80,507
Total	498,988	394,143	122,3274	-277,975	142,654

*water demands and water supply includes both groundwater and surfwater demands and supplies

5.3 Hydrological Conditions

Texas Water Code Section 36.108 (d)(3) requires that all GCDs, during the joint-planning process, consider hydrological conditions, including for each aquifer in the management area the total estimated recoverable storage (TERS) as provided by the TWDB executive administrator, and the average annual recharge, inflows, and discharge. As part of the joint-planning process, district representatives in GMA 15 reviewed and considered estimates of TERS, inflows, outflows, recharge, and discharge for all relevant aquifers based on results from the most recently adopted GAMs and technical assessments from the TWDB.

5.3.1 Total Estimated Recoverable Storage (TERS)

The Texas Administrative Code Rule §356.10 (Texas Administrative Code, 2011) defines the TERS as the estimated amount of groundwater within an aquifer that accounts for recovery scenarios that range between 25 percent and 75 percent of the porosity-adjusted aquifer volume. TERS values may include a mixture of water quality types, including fresh, brackish, and saline groundwater, because the available data and the existing groundwater availability models do not differentiate between different water quality types.

Wade and Anaya (2014) calculate TERS for the portion of the aquifers within GMA 15 that lies within the official lateral aquifer boundaries as delineated by George and others (2011). **Appendix I** presents the report by Wade and Anaya (2014) in its entirety. **Table 5-3** and **Figure 5-1** present the TERS values calculated for portions Gulf Coast Aquifer in 14 counties of interest. The TERS values do not take into account the effects of land surface subsidence, degradation of water quality, or any changes to surface water-groundwater interaction that may occur as the result of extracting groundwater from the aquifer.

Table 5-3 Total Estimated Recoverable Storage by County for the Gulf Coast Aquifer Provided by Wade and Anaya (2014).

County	25% of Total Storage	75% of Total Storage
Aransas	1,375,000	4,125,000
Bee	3,000,000	9,000,000
Calhoun	4,250,000	12,750,000
Colorado	7,000,000	21,000,000
DeWitt	5,550,000	16,650,000
Fayette	5,860,000	17,580,000
Goliad	6,500,000	19,500,000
Jackson	11,250,000	33,750,000
Karnes	12,397,500	37,192,500
Lavaca	8,080,000	24,240,000
Matagorda	12,000,000	36,000,000
Refugio	5,750,000	17,250,000
Victoria	9,750,000	29,250,000
Wharton	18,000,000	54,000,000

During the GMA 15 April 2015 meeting, INTERA provided a summary of the TERS values per county in the Groundwater Planning Datasheets (Appendix I) and explained the assumptions and methods used to calculate TERS. Several example calculations were demonstrated for the district members. **Appendix J** provides the INTERA entire presentation as provided in April 2015.

5.3.2 Groundwater Water Budgets and Issues of Pumping Sustainability

During the GMA 15 April 2015 meeting, INTERA presented historical water budgets by county for the years 1981, 1990, and 1999 (see Appendix J). The important concepts of aquifer dynamics and their role in determining groundwater availability were explained. In addition, the inflow and outflow water budget were discussed in terms of factors important to establishing sustainable groundwater pumping rates. A modeling example from GMA 15 was presented to illustrate that a major consideration when estimating sustainable pumping rates is how accurately the GAM predicts/represents the processes responsible for captured groundwater flow by pumping. Among the important points regarding the groundwater water budgets and sustainability is tracking the shape of the curve showing average-drawdown changes over time and the curve of storage depletion over time.

The key water budget concepts discussed the April 2015 GMA 15 meeting were reiterated at several other meetings and at all meetings where water budget results were discussed. **Figure 5-2** provides example water budgets for Matagorda and Refugio counties that are in Appendix J and associated with Baseline Option 1. The water budgets have been developed with sufficient detail to understand the exchange of groundwater flow between counties, between aquifers, and between surface water and groundwater. **Figure 5-3** shows plots of average drawdown over time from 2000 to 2070 for Matagorda and Refugio counties that are in Appendix J and are associated with Baseline Option 1. The drawdown curves have sufficient resolution so that annual changes can be visually tracked and evaluated to determine whether or not the pumping rate is sustainable. **Figure 5-4** is a plot of water levels in the Chicot Aquifer in 2070 predicted by the Baseline Option 1 pumping scenario and is included in Appendix J. The contours of the water levels are in sufficient detail so that the general groundwater flow direction can be deduced within and between counties.

5.3.3 Overall Assessment

Based on a review of the TERS and simulated water budgets associated with the Baseline (Option 1) model run, the adoption of the DFCs of GMA 15 are not anticipated to impact the hydrological conditions within GMA 15 significantly during the planning horizon and would provide a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging and prevention of waste of groundwater, and control of subsidence in the management area.

5.4 Environmental Factors

Texas Water Code §36.108 (d)(4) requires that districts, during the joint-planning process, consider environmental impacts, including impacts on spring flow and other interactions between groundwater and surface water. The primary environmental factor of interest in GMA 15 is whether or not groundwater pumping has an adverse impact on baseflows in rivers and streams. During the first, as well as this joint planning session, GMA 15 members have been concerned that the CGC GAM provides inaccurate estimates of groundwater-surface water exchange. These concerns are based on comparison with simulations of GW-SW interactions simulated by the Lower Colorado River Basin (LCRB) model (Young and others, 2010) and the inability of the CGC GAM to reasonably predict river baseflow (Chowdhury and others, 2004). A consensus among GMA 15 members is that the CGC GAM underestimates the contribution of groundwater to stream baseflow during pre-development conditions and overestimates the capture of stream baseflow for pumping conditions. The poor performance of the CGC GAM (see **Figure 4-4**) is believed to be caused by improper and excessively large numerical grid cells around the rivers and near the ground surface, which prevents a proper numerical representation of a shallow groundwater system.

The inability of the CGC GAM to predict GW-SW interactions adequately was discussed in several meetings and include discussions of the following topics: 1) the possible use of the LCRB model in conjunction with the CGC GAM; 2) the update of the CGC GAM by the TWDB; 3) uncertainty and error associated with the CGC GAM predictions; and 4) the concerns expressed by the Goliad County GCD dated August 19, 2015 to Dr. Steve Young (**Appendix L**). With regard to the problems with the CGC GAM with accurately predicting GW-SW interaction, the Goliad County GCD states in their August 19, 2015 letter to Dr. Young:

> "GCGCD has expressed a great interest in working with TWDB in developing the updated model of the Gulf Coast Aquifer for the Central Gulf Coast. In addition to the question of recharge, GCGCD is concerned that the modeled water budget shows a significant inflow

> of streams to the Evangeline and Chicot Aquifers. The USGS gain-loss studies of the Lower San Antonio River Basin and the Coleto Creek Watershed shows in both studies a surface water gain from the Aquifer. This discrepancy needs extensive further evaluation."

In addition, during the joint planning process, GCGCD included the following response to one of the survey questions:

> "Spring flow has declined in Goliad County for many years and continued drawdown of the aquifer will result in a further decline in spring flow."

The general consensus of GMA 15 is that the CGC GAM may not be a reliable predictor of GW-SW interaction for some pumping scenarios. As a result, the flow rates associated with GW-SW interactions in the calculated water budgets in Appendices C & K are considered by some GMA 15 districts as unreliable. In assessing the potential environmental impacts of pumping on GW-SW interaction, each district reviewed other information besides the results predicted by the CGC GAM. Such information included gain-loss studies performed on streams and results from other groundwater models and surface water models. Based on the collective analyses of the districts regarding GW-SW interaction, GMA 15 anticipates that the pumping rates associated with the Baseline (Option 1) will not impact environmental conditions significantly during the planning horizon and would provide a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging and prevention of waste of groundwater, and control of subsidence in the management area.

5.5 Subsidence

Texas Water Code Section 36.108 (d)(5) requires that districts, during the joint-planning process, consider the impacts of proposed DFCs on subsidence. Along the Texas Gulf Coast Aquifer, land subsidence is a potentially important issue associated with the management of groundwater. In Harris County, the pumping of groundwater has caused the land surface to subside more than three feet across most of the county and more than nine feet across the southeast part of the county. To help prevent land subsidence in the Gulf Coast, the Houston-Galveston Subsidence District was created in 1975, and the Fort Bend Subsidence District was created in 1989. Groundwater level decline, subsidence, and faulting are inter-related in the Gulf Coast Aquifer system, all having the potential for an adverse economic impact (Campbell and others, 2013). Jones and Larson (1975) estimated the cost associated with land subsidence in an approximately 900 square mile area, including the small portion of Harris County and some shoreline in Galveston County, to be about $32 million (about $150 million in 2015 terms) annually.

Land subsidence was discussed at several GMA 15 meetings, including April 10, 2015; July 15, 2015; December 9, 2015; and April 29, 2016. In July 15, 2015 (**Appendix M**) INTERA presented results from an ongoing study on land subsidence in GMA 15 funded by districts in GMA 15. **Figure 5-5** (from Appendix M) was discussed to demonstrate that land subsidence has occurred in GMA 15 and will likely continue occurring in the near future. During the discussion, four districts were identified as being interested in setting a DFC for land subsidence. Among the obstacles for setting a DFC for land subsidence is demonstrating compliance because of the inability of the districts to measure subsidence.

On April 29, 2016, INTERA provided a summary of an investigation into modeling and measuring land subsidence in the Texas central Gulf Coast. The presentation is provided in **Appendix N**. During the discussion, INTERA presented a paragraph of the study's Executive Summary that concisely summarizes the estimated historical land subsidence in GMA 15. This paragraph from Young (2016) is reproduced below:

> "The report presents ground surface elevation data from National Geodectic Survey (NGS) benchmarks called Permanent Identifiers (PIDs), old topographic maps, and LIght and raDAR (LIDAR) data from seven counties in GMA 15. The PID data provide ground surface elevations at 1,700 point locations prior to 1950. The topographic maps cover approximately 2,150 square miles and were constructed between 1950 and 1960. To extract point location data from the topographic maps, the maps were digitized and converted to Geographic Information System (GIS) files. The LIDAR data cover approximately 2,500 square miles and were collected after 2006. The joint analysis of these three data sets support the following conclusions:
>
> - The LIDAR and PID data indicate that DeWitt, Jackson, Matagorda, Refugio, Victoria, and Wharton counties have experienced at least 2 ft of land subsidence, and Calhoun County has experienced at least 1.5 ft of land subsidence.
> - The LIDAR and topographic map data indicate that Calhoun, DeWitt, Jackson, Matagorda, Refugio, Victoria, and Wharton counties have experienced at least 2 ft of land subsidence since 1950.
> - An analysis of the PID data, topographic map data, and LIDAR data indicates that more than two feet of average subsidence has occurred across about 100 square miles covering southwest Wharton, southeast Jackson, and northwest Matagorda counties."

During the GMA 15 discussion on April 29, 2016 INTERA presented an approach for performing scoping calculations of land subsidence based on simulated drawdowns from a groundwater model. The approach was demonstrated for the 14 locations shown in **Figure 5-6**. **Table 5-4** presents the calculated land subsidence at the 14 locations based on water levels predicted by the CGC GAM in 1999 and by the DFC GAM Run based on the Baseline Option 1 pumping file. Over the 70-year period, the anticipated increase in land subsidence at the 14 locations ranges between 0.1 and 1.2 feet. INTERA emphasizes that the values in **Table 5-4** have several major assumptions that should to be investigated and vetted fully prior to acting on any predicted land subsidence.

For this joint-planning session, no district proposed a DFC for land subsidence, but several districts are interested in establishing monitoring systems to measure land subsidence and for continuing further research into improving GMA 15's ability to predict land subsidence. As information becomes available, several GCDs may adjust their management plans and groundwater rules to prevent land subsidence, until which time the conditions are appropriate to propose DFCs for land subsidence.

Table 5-4 Prediction of land subsidence at fourteen sites in GMA 15 for the years 2000 and 2070 using drawdown simulated by the Central Gulf Coast GAM (Chowdhury and others, 2004) and clay thickness data from Young and others (2010; 2012)

ID	County	Drawdown (ft)								Clay Thickness (ft)				Land Subsidence (ft)	
		Chicot		Evangeline		Burkeville		Jasper		Chicot	Evangeline	Burkeville	Jasper	1940-2000	1940-2070
		1940-2000	1940-2070	1940-2000	1940-2070	1940-2000	1940-2070	1940-2000	1940-2070						
1	Calhoun	7.4	3.4	12.4	18.9	-	-	-	-	226	1299	418	925	0.4	0.5
2	Calhoun	-0.8	2.2	22.9	40.6	-	-	-	-	369	1442	407	1377	0.7	1.2
3	Dewitt	-	-	0.8	1.0	3.4	9.8	7.9	24.1	-	349	318	516	0.1	0.3
4	Dewitt	-	-	9.5	15.6	51.7	73.0	142.3	185.2	-	116	331	537	1.9	2.5
5	Jackson	18.7	55.7	64.7	88.1	39.2	56.3	22.0	45.4	139	683	224	618	1.4	2.2
6	Jackson	12.1	32.4	55.9	78.4	33.0	52.6	-	-	360	1096	339	966	1.5	2.3
7	Matagorda	-1.7	1.2	39.4	57.4	-	-	-	-	482	1569	652	1220	1.2	1.8
8	Matagorda	2.1	0.8	37.9	49.0	13.1	27.0	-	-	203	1264	415	1400	1.1	1.5
9	Refugio	5.2	1.8	3.4	10.1	-0.1	3.9	-	-	128	835	270	722	0.1	0.2
10	Refugio	0.3	1.2	4.1	15.5	-	-	-	-	264	1141	264	726	0.1	0.4
11	Victoria	5.0	8.0	13.2	40.1	1.7	6.4	-	-	207	757	225	550	0.2	0.7
12	Victoria	27.0	34.9	45.3	52.5	38.0	43.9	26.2	33.0	108	605	190	785	1.2	1.4
13	Wharton	75.4	94.1	156.7	149.8	61.9	90.2	27.9	59.9	84	780	266	610	3.2	3.7
14	Wharton	8.7	27.5	57.4	91.0	44.5	80.9	38.2	72.2	78	599	287	842	1.6	2.8

5.6 Socioeconomics

Texas Water Code Section 36.108 (d)(6) requires that GCDs consider socioeconomic impacts reasonably expected to occur as a result of the proposed DFCs for relevant aquifers as part of the joint-planning process. There is a lack of information available to GCDs regarding socioeconomic impacts that would be considered relevant to the joint-planning process. However, Texas statute requires that regional water plans include a quantitative description of the socioeconomic impacts of not meeting the identified water needs. Historically, this analysis has been performed for regional water planning groups by the TWDB. As a result, this section will rely heavily on the TWDB analyses for planning regions within GMA 15. In addition, GMA 15 Representatives participated in a questionnaire that covered several topics, including potential socioeconomic impacts of the proposed DFC. In addition to a short review of the TWDB regional planning socioeconomic impact analysis, this section will end with a qualitative discussion of socioeconomic impacts of the proposed DFCs based upon the questionnaire and discussion in public meetings held by GMA 15.

5.6.1 Regional Planning Assessment of Socioeconomic Impact

Consideration of socioeconomic impacts as part of water planning in Texas has been a fundamental element of the planning process dating back to the 1990s. Texas Water Code Section 16.051 (a) states that the TWDB "shall prepare, develop, formulate, and adopt a comprehensive state water plan that...

shall provide for... further economic development." Title 31 of the Texas Administrative Code, Section 357.7 (4)(A) states, "The executive administrator shall provide available technical assistance to the regional water planning groups, upon request, on water supply and demand analysis, including methods to evaluate the social and economic impacts of not meeting needs." The socioeconomic analysis provided by the TWDB to support planning groups provides the only available consistent analysis of socioeconomic impacts of unmet water needs available for the state and as such is a valuable analysis for joint planning.

Socioeconomic analysis of unmet water needs is performed by the TWDB at the request of the individual regional water planning groups and is based on water supply needs from the regional water plans. A general description of the methodology and approach is reproduced below from "Socioeconomic Impacts of Projected Water Shortages for the Region P Regional Water Planning Group" (Ellis, Cho and Kluge, 2015a).

> "The analysis was performed using an economic modeling software package, IMPLAN (Impact for Planning Analysis), as well as other economic analysis techniques, and represents a snapshot of socioeconomic impacts that may occur during a single year during a drought of record within each of the planning decades. For each water use category, the evaluation focused on estimating income losses and job losses. The income losses represent an approximation of gross domestic product (GDP) that would be foregone if water needs are not met.
>
> The analysis also provides estimates of financial transfer impacts, which include tax losses (state, local, and utility tax collections); water trucking costs; and utility revenue losses. In addition, social impacts were estimated, encompassing lost consumer surplus (a welfare economics measure of consumer wellbeing); as well as population and school enrollment losses."

At the beginning of this round of joint-planning, GMA 15 Representatives only had access to the 2011 Regional Water Plan socioeconomic analyses (Norvell and Shaw, 2010a, 2010b, 2010c and 2010d). INTERA sent these technical reports to GMA 15 for circulation among district representatives on October 13, 2015. Since that time, the 2016 Regional Water Plans have been approved with updated socioeconomic analyses (Ellis, Cho and Kluge, 2015a, 2015b, 2015c and 2015d). Results presented in this section are taken from the 2016 Regional Water Plans, and all impact estimates are in 2013 dollars.

The socioeconomic impact analysis provided by the TWDB to Region K, Region L, Region N and Region P regional water planning groups for the 2016 regional water plans informed the district representatives' considerations of socioeconomic impacts reasonably expected to occur as a result of the proposed DFCs for relevant aquifers in GMA 15. These technical memoranda are included in their entirety as **Appendix O**, **Appendix P, Appendix Q** and **Appendix R**, respectively. To illustrate the impacts of not meeting water supply needs, examples for specific water user groups for each of the four regional water planning areas (K, L, N and O) along with regional summaries for Region L were presented to GMA 15 Representatives. These details are provided in **Appendix S**, which provides INTERA's presentation made to the GMA 15 Representatives on April 29, 2016.

A consistent method of evaluating losses across regions is to review regional social impacts calculated by the TWDB in their analysis. **Table 5-5** provides a summary of the consumer surplus losses, population losses and school enrollment losses from not meeting water supply needs for Region L in GMA 15. Region

L is presented because impacts to Region L are most significant. One can review all sector impacts as well as social impacts for all regions through review of **Appendices O through R**.

Table 5-5 Region-wide Social Impacts of Water Shortages in Region L (from Ellis, Cho and Kluge, 2015b).

Impact Measures	2020	2030	2040	2050	2060	2070
Consumer surplus losses ($ millions)	$29	$58	$108	$171	$264	$403
Population losses	3,356	3,821	4,324	4,693	5,591	9,199
School enrollment losses	621	707	800	868	1,034	1,702

* Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000

The total economic impacts are significant, with Region L experiencing $1.99 billion in income losses and almost 18,300 job losses in 2020 if no water management strategies are implemented to meet projected shortages. Region K could suffer income losses of $1.557 billion in 2020 and a loss of 9,877 jobs. Region P income losses could be $9 million in 2020, with job losses estimated at 279. In Region N, income losses could be $4.49 billion in 2020, with job losses estimated at 24,000.

5.6.2 Other Considerations of Socioeconomic Impacts

While the information on socioeconomic impacts of not meeting water supply needs as quantified in the adopted 2016 regional water plans is useful for GMA 15 Representatives to consider, the factor to consider in joint-planning is what socioeconomic impacts result from the DFCs.

The challenge in joint-planning relative to regional planning is that no standardized local or regional socioeconomics analytical tool has been developed to support joint-planning. Also, the nature of socioeconomic impacts from proposed DFCs is unique from one GCD to another within a common GMA in that two or more GCDs may share a common DFC, but the method adopted by the individual GCD to achieve the DFC through local regulatory plans will inevitably result in differences in socioeconomic impacts.

Instead, GMA 15 - Representatives, through public meetings and through a questionnaire process, had discussions of qualitative socioeconomic impacts that may result from proposed DFCs. These impacts were both positive and negative, depending on the timing of the consideration. A summary of the results of the GMA 15 discussion and the results from the questionnaire can be found in INTERA's July 15, 2015 GMA 15 presentation provided in **Appendix M** of this report.

Among the concerns expressed by the GCD is the economic impact of water level drawdown. Lower water levels in a well can cause types of costs: deeper well cost and pumping cost. In GMA 15, Goliad County GCD performed a preliminary cost impact analysis, which is provided in **Appendix T**. When an existing water source is no longer productive a replacement well is required or in the case of a new location, the well will need to be drilled deeper. In Goliad County, the depth between productive sands varies from 50-100 feet in most areas. A budget price for a new well, drilled well only, is $6500. Adding 75 feet to the depth adds $1500 to the cost. Goliad County GCD estimates that for each drop of 10 feet of water level to wells that pump a cumulative total of 7000 acre feet per year, the additional annual pumping cost is approximately $1,000,000.

Based on a review of the TWDB socioeconomic impact analysis for Region K, L, N, and P and related factors, GMA 15 members do not anticipate that the adoption of the DFCs of GMA 15 will adversely impact the socioeconomics in GMA 15 during the planning horizon and would provide a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging and prevention of waste of groundwater, and control of subsidence in the management area.

5.7 Private Property Rights

Texas Water Code Section 36.108(d)(7) requires that district representatives consider the impact of proposed DFCs on the interests and rights in private property, including ownership and the rights of management area landowners and their lessees and assigns in groundwater, as recognized under Texas Water Code Section 36.002. GMA 15 recognizes that the primary vehicle in which private property rights are protected in GMA 15 is through each GCD's management plan and groundwater rules. Because the local hydrogeological conditions, environmental, and socioeconomic factors vary across GMA 15, the manner in which GCDs protect private property rights may vary among the GCDs.

GMA 15 members considered property rights when it reviewed other district groundwater management plan, participated in the GMA's survey questions regarding property rights, and it discussed recent court cases involving groundwater. The GMA 15 survey questions asked each GCD to describe the consequences related to private property rights, especially negative impacts, that may occur if the adopted DFCs did not achieve a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging and prevention of waste of groundwater, and control of subsidence in the management area. During the July 2015 meeting, GMA 15 members discussed the potential consequences of too lax or too restrictive DFCs on personal property rights. In short, there are undesirable consequences that affect individual landowners if the DFCs are too lax or too restrictive. Some of the issues addressed by the district representatives are documented in INTERA's presentation (**Appendix M**) that provides GCD responses to the survey's questions regarding personal property rights. To assist GCDs with responding to public comments on the proposed DFCs, INTERA presented the information in **Appendix U** at the GMA 15 meeting on April 29, 2016. A keystone to all discussions regarding personal property rights is the Texas Water Code Section 36.002, which reads as follows:

> "Sec 36.002 Ownership of Groundwater.
> (a) The legislature recognizes that a landowner owns the groundwater below the surface of the landowner's land as real property.
> (b) The groundwater ownership and rights described by this section:
>
> 1) entitle the landowner, including a landowner's lessees, heirs, or assigns, to drill for and produce the groundwater below the surface of real property, subject to Subsection (d), without causing waste or malicious drainage of other property or negligently causing subsidence, but does not entitle a landowner, including a landowner's lessees, heirs, or assigns, to the right to capture a specific amount of groundwater below the surface of that landowner's land; and
> 2) do not affect the existence of common law defenses or other defenses to liability under the rule of capture.
>
> (c)Nothing in this code shall be construed as granting the authority to deprive or divest a landowner, including a landowner's lessees, heirs, or assigns, of the groundwater

ownership and rights described by this section.
(d)This section does not:

1) prohibit a district from limiting or prohibiting the drilling of a well by a landowner for failure or inability to comply with minimum well spacing or tract size requirements adopted by the district;
2) affect the ability of a district to regulate groundwater production as authorized under Section 36.113, 36.116, or 36.122 or otherwise under this chapter or a special law governing a district; or
3) require that a rule adopted by a district allocate to each landowner a proportionate share of available groundwater for production from the aquifer based on the number of acres owned by the landowner.

(e)This section does not affect the ability to regulate groundwater in any manner authorized under:

1) Chapter 626, Acts of the 73rd Legislature, Regular Session, 1993, for the Edwards Aquifer Authority;
2) Chapter 8801, Special District Local Laws Code, for the Harris-Galveston Subsidence District; and
3) Chapter 8834, Special District Local Laws Code, for the Fort Bend Subsidence District."

Based on a review of the districts management plans and related factors, the majority of the GMA 15 members do not anticipate that the adoption of the DFCs of GMA 15 will impact the hydrological conditions within GMA 15 significantly affect personal property rights associated with groundwater during the planning horizon and would provide a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging and prevention of waste of groundwater, and control of subsidence in the management area. Among the GCDs that did not embrace this position was Goliad County GCD. Goliad County GCD's position is that the adoption of the DFC could significantly impact interests and rights in private property within Goliad County.

5.8 Feasibility of Achieving the Proposed Desired Future Condition

Texas Water Code Section 36.108 (d)(8) requires that GCDs, during the joint-planning process, consider the feasibility of achieving the proposed DFC(s). This requirement was added to the joint-planning process with the passage of Senate Bill 660 by the 82nd Texas Legislature in 2011. However, this review concept actually dates back to the rules adopted by the TWDB in 2007 to provide guidance as to what the TWDB would consider during a petition process regarding the reasonableness of an adopted DFC. In these rules, the TWDB required that an adopted DFC must be physically possible from a hydrological perspective.

During the TWDB's review of multiple petitions regarding the reasonableness of adopted DFCs in GMAs from 2010 to 2011, the evaluation of whether or not an adopted DFC was physically possible was based on whether or not the DFC(s) could be reasonably simulated using the TWDB's adopted GAM for the aquifer(s) in question. This was a valid approach because if an adopted DFC was not physically possible, then, under the physical laws of hydrology as incorporated in the mathematical calculations executed during model simulations, the model would not execute the prescribed simulation successfully.

GMA 15 considers a valid evaluation of the feasibility of DFCs as whether or not the proposed DFCs are consistent with the DFCs predicted by the CGC GAM, using appropriate and reasonable environmental conditions and within the confidence limits of the CGC GAM. GMA 15 recognizes the GAMs as representing the best science for understanding the groundwater flow systems in GAM 15, while at the same time recognizing that the GAMs have been demonstrated to contain error and uncertainty. As such, GMA 15 will presume that DFCs are feasible if they can be generated by a GAM within a reasonable tolerance. GMA 15 spent several meetings discussing the potential limitations of the CGC GAM, and what reasonable tolerance limits are for CGC predictions of average drawdown values (see **Appendix M**). Among these reasons for using tolerance criteria for evaluating the feasibility of a DFC are:

- GAM Predictive Uncertainty/Error
- Unknown Errors in Stargin 1999 Water Level Conditions
- Uncertainty in Future Environmental Conditions (for instance recharge and rivers levels)
- Uncertainty in Future Pumping Rates & Locations
- Error/Uncertainty in Measurement of DFCs to Demonstrate Compliance
- Non-uniqueness of model calibration

In light of the issues above and other known limitations and possible errors in the CGC GAM, GMA 15 members agreed that DFCs would be considerable feasible, compatible and physically possible if the difference between the proposed DFCs and the DFC predicted by the CGC GAM are within 3.5 feet, except in the case of Goliad County. For this comparison, the DFCs of interest are average drawdown values from 2000 to 2070 for an aquifer in a county. Factors considered for a determining tolerance criterion of 3.5 feet include:

- Residuals and RMSE between the measured and simulated values for historical water levels produced by the CGC GAM;
- Sensitivity of the simulated drawdown to the recharge rate used in the predictive simulation and estimates of uncertainty in the magnitude and distribution of historical and predicted recharge rates;
- Sensitivity of the simulated drawdown to the hydraulic properties of the aquifer properties in the predicted simulation and observed differences between measured hydraulic aquifer properties and modeled aquifer hydraulic properties in the CGC GAM;
- Uncertainty in the temporal and spatial distribution of historical and future pumping in the GMA 15 counties; and
- The list of evidence and sources of GAM predictive uncertainty in **Appendix M**.

GMA 15 considers the proposed Goliad County DFCs to be compatible and physically possible if the difference between the proposed and predicted DFCs are within 5.0 feet. Factors considered by GMA 15 for determining the tolerance criterion of 5.0 feet have been documented by Goliad County GCD (see **Appendix L** and **Appendix V**) and include:

- an evaluation of water level change in 60 Evangeline Aquifer wells from 2003 to 2015, which indicates that the GAM underpredicts drawdown in the Evangeline Aquifer underlying Goliad County;

- an evaluation of water level change in 15 Chicot Aquifer wells from 2003 to 2015, which indicates that the GAM underpredicts drawdown in the Chicot Aquifer underlying Goliad County;
- an evaluation of gain-loss studies performed by the United States Geological Survey that indicates that the GAM overpredicts leakage from the streams in areas of pumping; and
- evidence suggesting that the GAM's average recharge rate for Goliad County is too high.

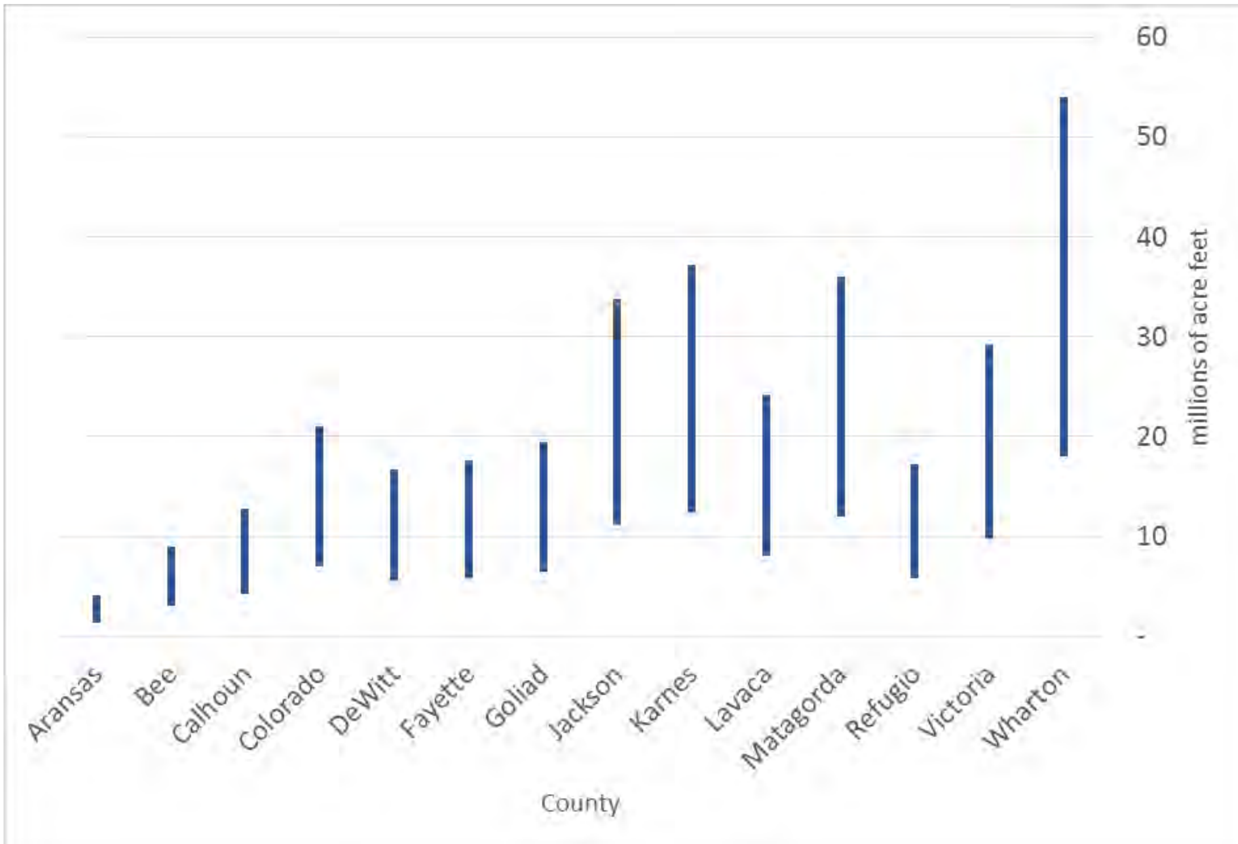


Figure 5-1 Total Estimated Recoverable Storage by County for the Gulf Coast Aquifer Provided by Wade and Anaya (2014).

Matagorda	2030				2050				2070			
	Chicot	Evangeline	Burkeville	Jasper	Chicot	Evangeline	Burkeville	Jasper	Chicot	Evangeline	Burkeville	Jasper
Inflow												
River Leakage	792	0	0	-	792	0	0	-	792	0	0	-
Recharge	22,372	0	0	-	22,372	0	0	-	22,372	0	0	-
Net Stream Leakage	32,163	0	0	-	33,575	0	0	-	34,247	0	0	-
Net Vertical Leakage Upper	-	9,009	-	-	-	9,306	-	-	-	9,533	-	-
Net Vertical Leakage Lower	-	318	0	-	-	291	0	-	-	262	0	-
Net Lateral Flow From Brazoria	-	1,218	-	-	-	1,212	-	-	-	1,180	-	-
Net Lateral Flow From Wharton	2,288	-	3	-	1,731	-	2	-	1,466	-	-	-
Total Inflow	*57,615*	*10,545*	*3*	-	*58,470*	*10,809*	*2*	-	*58,877*	*10,975*	-	-
Outflow												
Wells	31,733	7,121	0	-	31,733	7,121	0	-	31,733	7,121	0	-
Drains	243	0	0	-	241	0	0	-	240	0	0	-
Et	3,023	0	0	-	3,011	0	0	-	3,005	0	0	-
Net Head Dep Bounds	5,277	0	0	-	5,118	0	0	-	5,053	0	0	-
Net Vertical Leakage Upper	-	-	318	-	-	-	291	-	-	-	262	-
Net Vertical Leakage Lower	9,009	-	-	-	9,306	-	-	-	9,533	-	-	-
Net Lateral Flow To Brazoria	2,791	-	6	-	2,807	-	6	-	2,819	-	6	-
Net Lateral Flow To Calhoun	57	-	-	-	56	-	-	-	56	-	-	-
Net Lateral Flow To Jackson	346	595	-	-	579	610	-	-	682	620	-	-
Net Lateral Flow To Wharton	-	2,914	-	-	-	3,122	-	-	-	3,267	-	-
Net Lateral Outflow To Other Areas	6,176	-	-	-	6,014	-	-	-	5,948	-	-	-
Total Outflow	*58,655*	*10,630*	*324*	-	*58,865*	*10,853*	*297*	-	*59,069*	*11,008*	*268*	-
Inflow - Outflow	-1,040	-85	-321	-	-395	-44	-295	-	-192	-33	-268	-
Storage Change	-1,045	-70	-321	-	-395	-38	-295	-	-191	-24	-267	-
Model Error	5	-15	0	-	0	-6	0	-	-1	-9	-1	-
Model Error (percent)	0.01%	0.14%	0.00%	-	0.00%	0.06%	0.00%	-	0.00%	0.08%	0.37%	-

Refugio	2030				2050				2070			
	Chicot	Evangeline	Burkeville	Jasper	Chicot	Evangeline	Burkeville	Jasper	Chicot	Evangeline	Burkeville	Jasper
Inflow												
Recharge	14,562	0	0	-	14,562	0	0	-	14,562	0	0	-
Net Vertical Leakage Lower	397	98	0	-	305	92	0	-	250	85	0	-
Net Lateral Flow From Bee	5,130	2,573	16	-	5,077	2,549	15	-	4,944	2,530	15	-
Net Lateral Flow From Goliad	3,118	2,809	12	-	3,101	2,806	12	-	3,098	2,807	12	-
Net Lateral Flow From Victoria	223	-	-	-	166	-	-	-	163	-	-	-
Total Inflow	*23,430*	*5,480*	*28*	-	*23,211*	*5,447*	*27*	-	*23,017*	*5,422*	*27*	-
Outflow												
Wells	3,226	2,624	0	-	3,226	2,624	0	-	3,226	2,624	0	-
Drains	111	0	0	-	110	0	0	-	110	0	0	-
Et	1,846	0	0	-	1,843	0	0	-	1,842	0	0	-
Head Dep Bounds	4,905	0	0	-	4,888	0	0	-	4,882	0	0	-
Net Stream Leakage	4,419	0	0	-	3,985	0	0	-	3,707	0	0	-
Net Vertical Leakage Upper	-	397	98	-	-	305	92	-	-	250	85	-
Net Lateral Flow To Aransas	2,195	34	-	-	2,193	33	-	-	2,193	33	-	-
Net Lateral Flow To Calhoun	489	108	-	-	494	115	-	-	497	122	-	-
Net Lateral Flow To San Patricio	2,883	789	3	-	3,026	809	3	-	3,108	820	4	-
Net Lateral Flow To Victoria	-	1,520	-	-	-	1,540	-	-	-	1,551	-	-
Net Lateral Outflow To Other Areas	3,477	24	-	-	3,473	25	-	-	3,472	24	-	-
Total Outflow	*23,551*	*5,496*	*101*	-	*23,238*	*5,451*	*95*	-	*23,037*	*5,424*	*89*	-
Inflow - Outflow	-121	-16	-73	-	-27	-4	-68	-	-20	-2	-62	-
Storage Change	-123	-20	-73	-	-30	-4	-68	-	-21	-4	-62	-
Model Error	2	4	0	-	3	0	0	-	1	2	0	-
Model Error (percent)	0.01%	0.07%	0.00%	-	0.01%	0.00%	0.00%	-	0.00%	0.04%	0.00%	-

Figure 5-2 Water budgets calculated for Matagorda and Refugio counties from GMA 15 Baseline Option 1 DFC model simulation

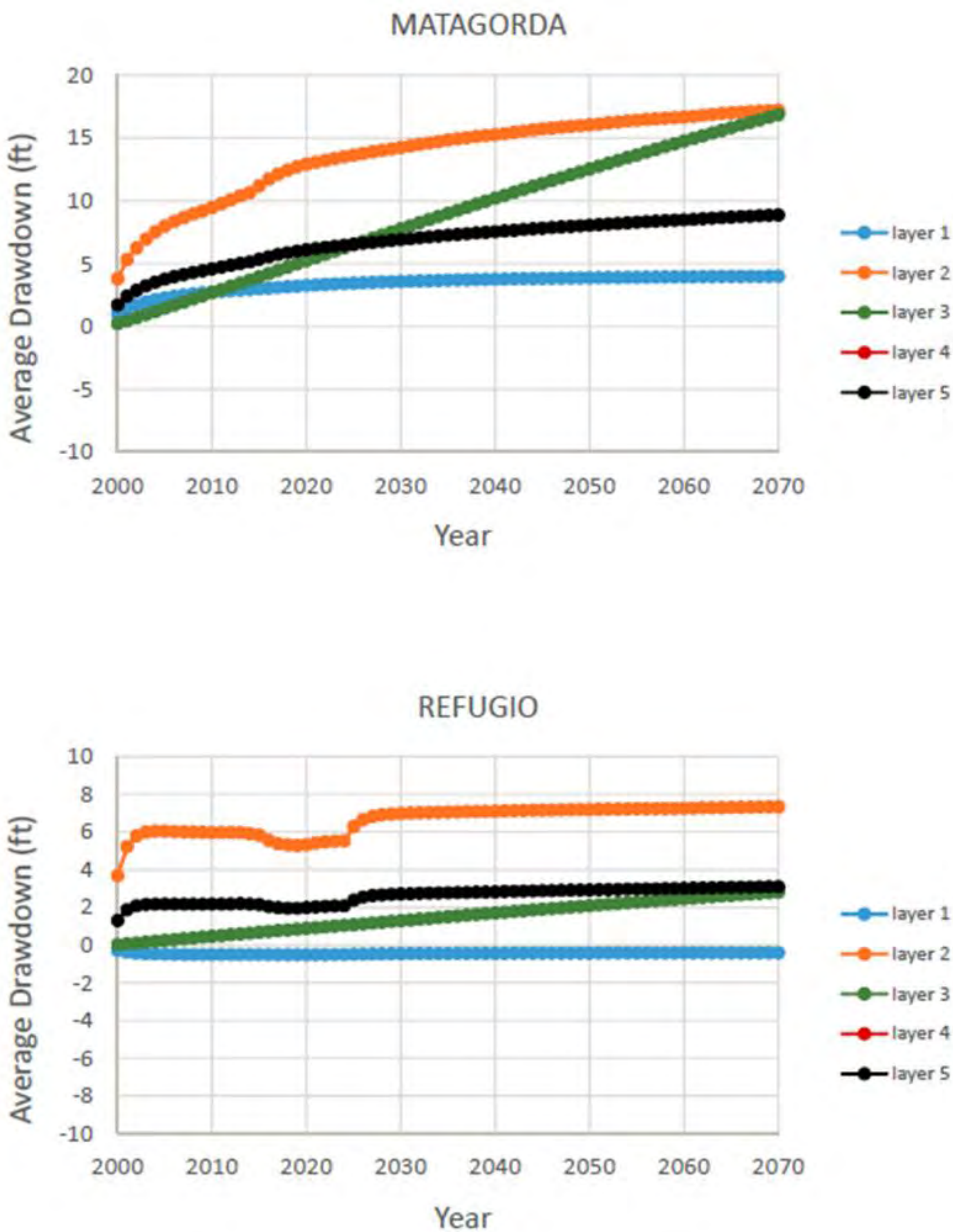


Figure 5-3 Average drawdown curves from 2000 to 2070 calculated for Matagorda and Refugio counties from GMA 15 Baseline Option 1 DFC model simulation (model layer 1 represents the Chicot Aquifer, layer 2 the Evangeline Aquifer, layer 3 the Burkeville confining unit, and layer 4 the Jasper Aquifer)

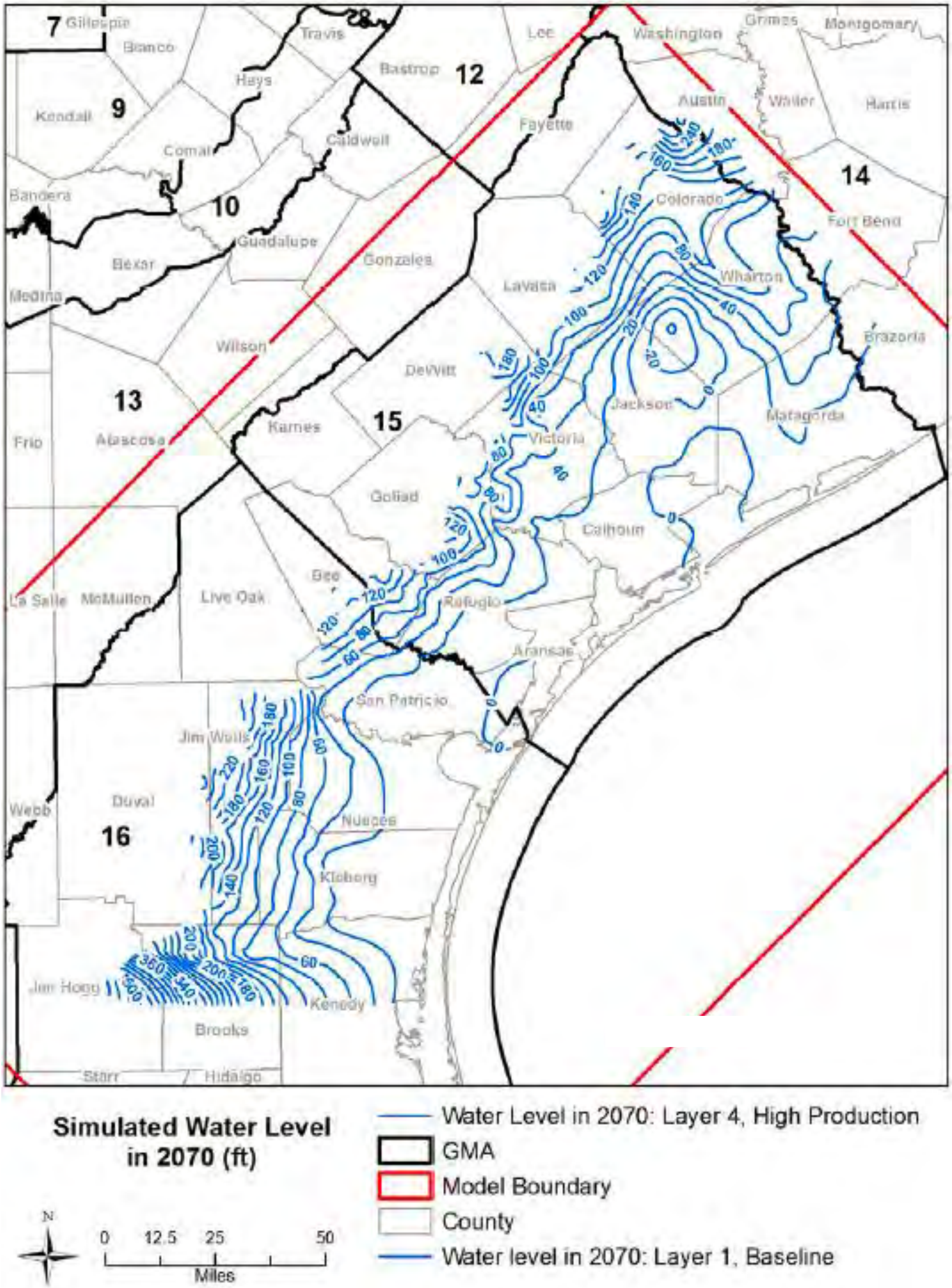


Figure 5-4 Contours of 2070 water levels for the Chicot Aquifer for from GMA 15 Baseline Option 1 DFC model simulation

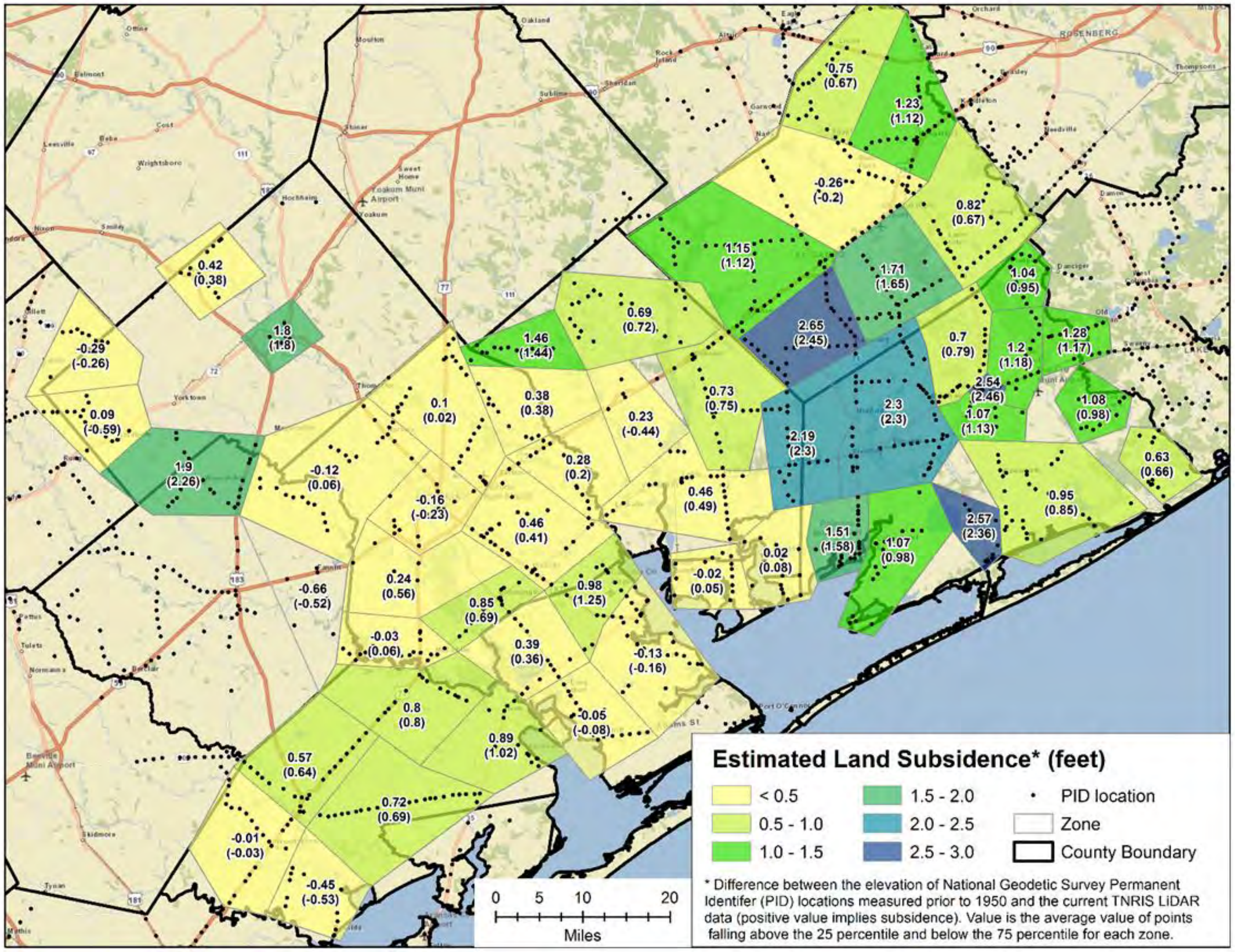


Figure 5-5 Estimated average land subsidence from before 1950 to after 2003 for specific polygons as determined by the difference between ground surface elevation from PIDs surveyed prior to 1950 and from LIDAR surveys after 2006 at the locations of the PIDs. Land Subsidence values are expressed as averages and medians (in parenthesis) of the differences calculated at PIDS located inside the polygons. Positive values indicate lower ground surface elevation at later time. Negative values indicate higher ground surface elevation at later time.

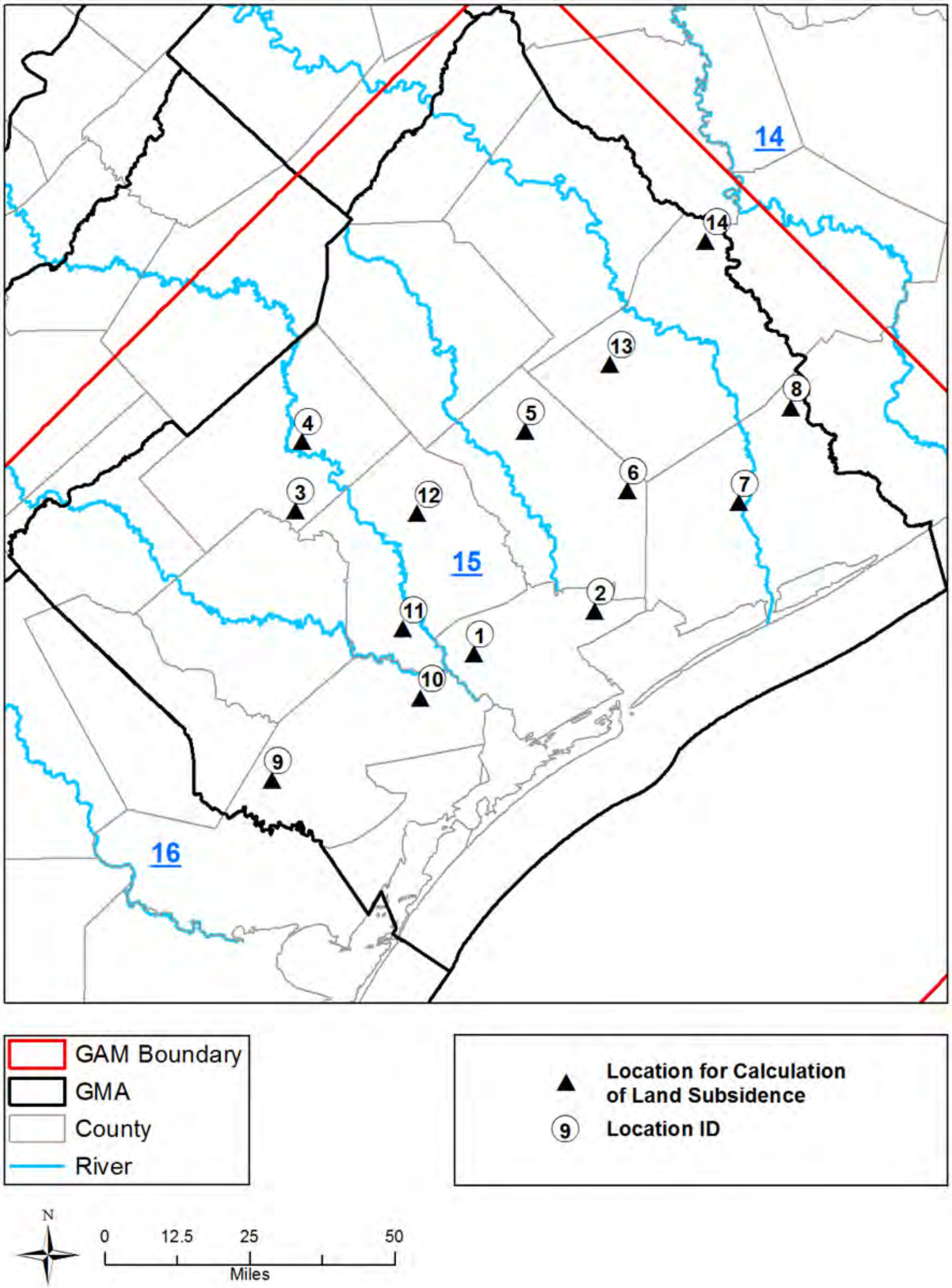


Figure 5-6 Locations in GMA 15 where land subsidence is calculated in Table 5-6.

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Appendix A

Copies of Agenda and Minutes for GMA 15 2012 – Present

Appendix B

GMA 15 Resolution for Proposed DFCs Dated January 15, 2015

Appendix C

GCD Summary Reports of Public Hearings on DFCs

Appendix D

Water Budgets Predicted by the Central Gulf Coast GAM for 1999 by County

Appendix E

INTERA July 10, 2015 Presentation Discussing Evidence and Sources of GAM Predictive Uncertainty

Appendix F

Groundwater Planning Datasheets for Counties in GMA 15 Managed by GCDs

Appendix G

Spatial Distribution of Pumping by County and Geological Unit for 1999 in the CGC GAM (Chowdhury and others, 2014)

Appendix H

Spatial Distribution of Pumping by County and Geological Unit for 2000 to 2060 in the CGC GAM for establishing the MAG (Hill and Oliver, 2014)

Appendix I

GAM Task 13-038: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 15 (Wade and Anaya, 2014)

Appendix J

INTERA's Presentation to GMA 15 on April 10, 2014

Appendix K

Letter from INTERA to Tim Andruss Dated December 2, 2015 Providing GAM Modelling Results from the Baseline Option 1 and the High-Production Option 1 Pumping Files

Appendix L

Letter from Goliad County to Steve Young, INTERA, dated August 19, 2015

Appendix M

INTERA's Presentation to GMA 15 on July 15, 2015

Appendix N

INTERA Presenation to GMA 15 on Land Subsidence on April 29, 2016

Appendix O

TWDB Socioeconomic Impact Assessment for Region K Planning

Appendix P

TWDB Socioeconomic Impact Assessment for Region L Planning

Appendix Q

TWDB Socioeconomic Impact Assessment for Region N Planning

Appendix R

TWDB Socioeconomic Impact Assessment for Region P Planning

Appendix S

INTERA Presentation to GMA 15 on Socioecomonics on April 29, 2016

Appendix T

Goliad County Economic Impact Assessment on Lower Water Levels

Appendix U

INTERA Presentation to GMA 15 on Property Rights on April 29, 2016

Appendix V

Goliad County Supporting Information to Appendix M

Appendix M

GCGCD Proposed Desired Future Conditions

GOLIAD COUNTY GROUNDWATER CONSERVATION DISTRICT

PROPOSED DESIRED FUTURE CONDITION

DATED January 11, 2016

The Goliad County Groundwater Conservation District (GCGCD) Mission Statement and Desired Future Condition (DFC) are to maintain groundwater availability from the Gulf Coast Aquifer on a sustainable basis. A sustainable groundwater supply is critical for the continued viability of the agricultural economy of the county. Without a viable agricultural economy, the county would suffer major economic distress.

Historic water level data gathered by the Texas Water Development Board (TWDB) and by GCGCD since 2003 shows a steady water level decline since 1980. During the drought of the 1950's and periodic recordings to date, the upper aquifer sands are being depleted and some have completely dried up. GCGCD has prepared an economic impact statement that details the additional costs associated with continued declining water levels and is committed to minimize those additional costs by implementation of use, spacing, depth, and drawdown rules. GCGCD projects that some water level decline will continue and there will be an associated economic impact.

GCGCD has compared empirical pumping and water level data with the Modeled Available Groundwater (MAG) run by Intera titled "2014 DFC Baseline Run-2070 Pumping". GCGCD finds that this modeled data using average recharge cannot be used to provide an accurate DFC. The MAG shows an annual overall pumping rate of 12,185 acre feet which far exceeds the 2014 groundwater pumping of 6,115 acre feet documented by GCGCD. Annual pumping continues to increase and the pumping recorded in 2014, which was a drought year, is considered to be the highest annual groundwater use to date. The associated modeled drawdown of 1.0 foot in the Evangeline aquifer and a rise of 3.3 feet in the Chicot Aquifer is contrary to the drawdown being recorded by GCGCD. GCGCD drawdown data will be presented in detail later.

GCGCD asserts that a primary reason that the TWDB Model data does not support the empirical drawdown data compiled by GCGCD is that the Model uses values for annual rainfall and recharge that are too high. Average annual rainfall for Goliad County continues to drop and there are long range projections that continued lower rainfall can be expected. Too much emphasis has been put on the drought of record with the implication that all of the other years are normal. Since the drought of the 1950's there have been several significant droughts and many mini droughts. In fact most years, even those with above average rainfall, have drought periods.

Annual recharge is affected by two components, rainfall and ground surface geology. In addition to the lower annual rainfall comments above, surface use has changed significantly in the last 60 years, especially in north Goliad County. Much of this area is classified as the recharge area for the Evangeline Aquifer. 60 years ago, 40-45 percent of north Goliad County was tilled for crops. This type of a surface provided for greater rainfall capture and allowed rapid and significant percolation by rainfall into the subsurface. Today there is minimum tillage occurring in north Goliad County. The compacted grass and brush covered soil fundamentally and substantially changed recharge rates. In addition, the introduction of brush and hardwoods significantly increased plant use and transevaporation.

The San Antonio River authority has engaged Texas Tech to develop the brush management Ecological Dynamics Simulation Model (EDYS) for Goliad and adjacent counties. This model is basically complete and the final report is being prepared. GCGCD has been provided a preview of the model. This model may be beneficial to determine the change in recharge and the current recharge.

Referring to the graph of the North Goliad County Wells using TWDB data, note that there was a steady increase in water levels recorded after the drought of the 1950's until about 1980. These graphs were prepared by LBG Guyton for Region L using TWDB data from 1954-2000. During this time, farm land was being converted to range land. As previously noted, after 1980, water levels began a steady decline. That decline occurred without a notable change in rainfall. This data should support the thought that a change in land use has significantly reduced the amount of recharge occurring especially to the Evangeline aquifer in north Goliad County. Referring to the rainfall data attached, note that annual rainfall has declined significantly for the years 2008 through 2014 which along with reduced recharge has resulted in a recorded drop of water level of 8.6 feet in the Evangeline Aquifer in the last 12 years.

Intera has recently completed the model run entitled "Baseline DFC Run with 50% Recharge" for GMA-15. The drawdown generated by this run is significantly more than with average recharge but still is much less than what is recorded by TWDB and GCGCD data.

Included as attachments are graphs of water levels recorded by TWDB starting in 1955 and continuing with graphs of water levels recorded by GCGCD starting in 2003 through spring of 2015. Currently most of the groundwater supply comes from the Evangeline Aquifer in north Goliad County and the Chicot Aquifer in south Goliad County. Please note from the attached water level data that water levels have continued to decline in both of these aquifers since 1980. The GCGCD data covers a more dispersed area and includes a greater number of wells. In addition, all of the GCGCD wells are open cased not pumped and therefore are a true representation of static water levels.

The GCGCD data averages five depths of wells in the Evangeline Aquifer and three depths of wells in the Chicot Aquifer. The averages are from data generated since 2003 through spring of 2015. For the years 2003-2014, rainfall was below average for 8 of these 12 years. The average rainfall for these 12 years was below average.

For the Evangeline Aquifer:

_7_ wells above 100 feet depth, water level dropped _6.32_ feet,

_23_ wells 101 to 199 feet depth, water level dropped _8.46_ feet,

_18_ wells 201 to 300 feet depth, water level dropped _8.62_ feet,

_4_ wells 301 to 400 feet depth, water level dropped 14_feet,

_2_ wells below 401 feet depth, water level dropped _7.44_ feet.

The weighted average of sixty (60) wells in the Evangeline Aquifer is _8.59_ feet drawdown.

For the Chicot Aquifer:

_4_ wells above 100 feet depth, water level dropped _5.24_ feet, _6_ wells 101 to 200 feet depth, water level dropped _2.61_ feet,

_5_ wells 201 to 400 feet depth, water level dropped _6.19_ feet.

The weighted average of fifteen (15) wells in the Chicot Aquifer is _4.50 feet drawdown.

GCGCD has expressed a great interest in working with TWDB in developing the updated model of the Gulf Coast Aquifer for the Central Gulf Coast. In addition to the question of recharge, GCGCD is concerned that the modeled water budget shows a significant inflow of streams to the Evangeline and Chicot Aquifers. The USGS gain-loss studies of the Lower San Antonio River Basin and the Coleto Creek Watershed shows in both studies a surface water gain from the Aquifer. This discrepancy needs extensive further evaluation.

The Baseline DFC Run with 50% Recharge provides drawdown data that is more consistent with the empirical data presented. The GMA-15 Members voted to use average drawdown in establishing the DFC and MAG. GCGCD has noted that average drawdown values used vary in different model runs. GCGCD has included in the District's Management Plan the water budget of GAM Run 12-018 (Version 2) provided by TWDB. GAM Run 12-018 (Version 2) uses recharge values of 9,440 acre feet for the Chicot Aquifer and 7,163 acre feet for the Evangeline Aquifer. GCGCD requests that these recharge values be the maximum values used for Goliad County in modeling the new DFC and MAG.

After a thorough evaluation of all factors including model runs and empirical data compiled by TWDB and GCGCD, GCGCD requests that a greater variance be allowed for the District based on evidence provided to support a higher GAM predictive uncertainty.

The Desired Future Condition of the Gulf Coast Aquifer within Goliad County shall not exceed an average of 10 feet of drawdown of the Gulf Coast Aquifer in the year 2070 relative to the water levels of the aquifer at year 1999.