ESTIMATION OF GROUNDWATER RECHARGE IN TEXAS RELATED TO AQUIFER VULNERABILITY TO CONTAMINATION

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August 2003

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ABSTRACT

Quantification of groundwater recharge is important for assessing aquifer vulnerability to contamination because most contaminant sources occur at or near the land surface and recharge rate, among other factors, determines the rate that contaminants can be transported to an aquifer. The purpose of this study was to estimate recharge rates for major aquifers characterized by porous media in Texas. Recharge was estimated using one-dimensional unsaturated flow modeling for the major aquifers and using limited field studies in the Southern High Plains and Seymour aquifers. Field studies included measurement of soil physics (water content, matric potential head) and environmental tracers (chloride) in soil samples from boreholes installed in different land use settings, including natural, dryland farming, and irrigated farming.

Numerical modeling of unsaturated flow was used to estimate recharge using long-term (30 yr) climatic forcing, soils data from STATSGO and SSURGO, and vegetation data. Hydraulic properties were estimated using pedotransfer functions. Simulated recharge using bare sand ranged from 54 mm/yr in west Texas to 720 mm/yr in east Texas and was positively correlated with precipitation. These high recharge rates indicate that climate is not the limiting factor for recharge and that soil texture and vegetation are important in reducing recharge. Recharge estimates based on layered soil profiles were quite variable locally depending on sediment texture and sequence of layers. However, areally weighted average recharge rates were much less variable for the counties analyzed in this study and were positively correlated with precipitation. Layering reduced recharge rates in most cases relative to recharge rates based on monolithic sand profiles. Vegetation also played an important role in controlling recharge and greatly reduced recharge rates in all cases. Addition of vegetation to the monolithic sand profiles reduced recharge rates for most cases by factors ranging from 2 to 11. The final simulations included vegetation and layered soil profiles and resulted in recharge rates ranging from 0.2 to 114 mm/yr. The 30 yr average recharge rate for the large number of stations simulated in the state were positively correlated with precipitation, indicating that long-term precipitation could be used as a predictor of long-term recharge.

Recharge rates based on the chloride mass balance approach ranged from 0.5 to 26 mm/yr in the Southern High Plains and from 6 to 34 mm/yr in the Seymour aquifer. The variation in recharge rates in the Southern High Plains correlated with land use: low recharge rates in the natural settings (0.5 to 0.8 mm/yr) and much higher recharge rates in the dryland farming settings (6 to 26 mm/yr). The variation in recharge rates is consistent with the soil physics measurements: low matric potential heads in the natural setting (-208 to -270 m) indicating dry

conditions and much higher matric potential heads in the dryland and irrigated settings (-2 to -2.8 m) indicating wet conditions. Estimated recharge fluxes were uniformly high (15 to 34 mm/yr) in the sand dune setting overlying the Seymour aquifer whereas recharge rates were lower (6 mm/yr) in a profile in finer grained sediments to the east. The lack of variability in estimated recharge rates with land use in the Seymour aquifer may be attributed to generally coarser textured sediments in the Seymour, which reduces the impact of cultivation on recharge. Recharge estimates based on numerical modeling were generally lower than those based on field studies. The difference in recharge rates may reflect the areally weighted average represented in the modeling analysis versus the point estimates from sandy regions represented by the field studies.

Unsaturated flow modeling proved to be a useful tool in estimating recharge for the major porous media aquifers in the state. The modeling analysis allowed evaluation of different factors controlling recharge including climate, vegetation, and soils. Modeling results indicate that long-term average precipitation can be used as a predictor of recharge. The results of this study have important implications for assessing aquifer vulnerability to contamination and indicate that vegetation, soil texture, and land use are important factors in controlling recharge and aquifer susceptibility to contamination.

INTRODUCTION

Quantification of recharge and understanding of controls on recharge are important for developing strategies to protect groundwater resources from contamination. Areas with high recharge rates are inherently most susceptible to contamination. This premise serves as the foundation for statewide sampling of public water supply wells in California for tritium/helium age dating of the groundwater (Moran et al. 2002). Higher recharge rates are associated with young water and should be more vulnerable to contamination. In addition to age dating the groundwater, samples are also analyzed for low levels of volatile organic compounds to assess the potential for preferential flow of water to these wells. A similar approach is being used in Minnesota that includes evaluation of groundwater chemistry combined with age dating.

A wide variety of approaches can be used to estimate groundwater recharge (Scanlon et al., 2002). Techniques for estimating recharge can generally be subdivided into those based on physical and chemical data and numerical modeling using surface-water, unsaturated-zone, and/or groundwater data. Recharge estimates for the major aquifers in Texas based on previous studies have been summarized in Scanlon et al. (2000). The main techniques that have been used for estimating recharge in Texas are Darcy’s Law, groundwater modeling, base-flow discharge, and stream loss. This compilation of data indicated that the range of recharge rates estimated for the various aquifers is quite large.

The climate in Texas ranges from semiarid to arid in the west to humid in the east. Semiarid and humid settings generally differ in the source of recharge: primarily surface water in semiarid regions and precipitation in humid regions. Semiarid regions are generally characterized by ephemeral (losing) streams and have thick unsaturated zones in basin floor settings. Monitoring and modeling analyses of water potential and chloride profiles in these settings indicate that there is no recharge in natural settings in interdrainage basin floor regions (Scanlon et al., 2003; Walvoord et al., 2003). Recharge is focused beneath surface water bodies such as ephemeral streams (Constantz et al., 2003) and playas (Scanlon et al., 1997, 1997a). Recharge also occurs in mountain block and mountain front settings, as evidenced by bomb pulse tritium in groundwater indicating young (< 50 yr) water (Darling et al., 2003; Mullican et al., 2003; Scanlon et al., 2003). In contrast to semiarid regions where surface water bodies are focal points of recharge, surface water bodies in humid regions serve as discharge points for groundwater. Most streams in humid regions are predominantly gaining streams (Slade et al., 2002). Recharge in humid regions is generally areally distributed in interstream settings. These distinctions in the source of recharge between semiarid and humid regions are important for contaminant transport. It is important not to discharge waste into surface water bodies in semiarid regions because these serve as focal points of recharge. In contrast, contamination of surface water in humid regions will generally not impact the regional aquifer because streams serve as discharge points of groundwater.

Although spatial variability in recharge may not be very important for water resources, it is critical for contaminant transport. Groundwater modeling studies conducted by Mullican et al. (1997) showed that regional water levels in the Southern High Plains aquifer were similar whether recharge was focused beneath playas or areally distributed. Spatial focusing of recharge beneath playas, however, would result in much higher velocities of contaminants moving through the unsaturated zone and would bypass the buffering capacity of unsaturated systems in interplaya settings. The approximately 25,000 playas distributed throughout the Southern High Plains represent ~ 10% of the surface area. Regional estimates of recharge for the Southern High Plains aquifer based on groundwater chloride are about 10 mm/yr (Wood and Sanford, 1995; Scanlon et al., 2002). Recharge estimates beneath playas range from 60 – 120 mm/yr (Wood and Sanford, 1995; Scanlon and Goldsmith, 1997). Spatial focusing of recharge beneath playas results in much higher recharge rates beneath playas relative to the areally averaged value and would allow contaminants to migrate rapidly through the unsaturated zone beneath playas. The corresponding water velocities range from 600 to 1200 mm/yr.

Land use may also play an important role in controlling groundwater recharge. In addition to surface water sourcing recharge in semiarid regions, irrigation may provide an important source of recharge. Irrigation practices have varied significantly over the past 50 yr. Furrow irrigation was dominant in the 1940s through the 1960s (Blandford et al., 2003). Irrigation efficiency was low (40%) with large losses due to unlined ditches and return flow. Irrigation efficiency increased 10 to 20% in the 1960s and 1970s with the use of underground pipes and sprinkler systems. Much more efficient systems were developed and deployed in the 1980s, including low energy precision application (LEPA) systems and drip irrigation. LEPA systems are considered to be 95 – 98% efficient with only 2 to 5% of the water returning to the aquifer. The increasing efficiency of irrigation systems has greatly reduced recharge from irrigation return flow. The increased efficiency should be beneficial to aquifers because groundwater pumping should be reduced; however, studies in Kansas indicated that increased efficiency has resulted in increased irrigated acreages (McMahon et al., 2003). Recharge estimates in irrigated settings in Nevada based on penetration of liquid nitrogen and chloride concentration data ranged from 100 to 500 mm/yr (Stonestrom et al., 2003). Recharge may also be enhanced in agricultural areas that are not irrigated (dryland agriculture) because the process of cultivation loosens the soil and creates rills and furrows. In a regional groundwater modeling study of the High Plains aquifer, Luckey et al. (1986) increased recharge by 53 mm/yr in areas of dryland crops based on the premise that recharge is greater in these regions as a result of plowing and disturbance of the land surface.

Purpose and Scope

The primary objective of this study was to estimate recharge rates for major aquifers characterized by porous media in Texas using unsaturated flow modeling and limited field studies. A modeling approach was chosen because it serves as a reconnaissance tool for estimating recharge and should provide guidance for future field studies. Modeling also has the advantage of allowing the impact of different controls on groundwater recharge, such as climate, vegetation, and soils, to be assessed and can be used to predict groundwater recharge for future conditions. The ready availability of online data on meteorological forcing, vegetation coverage (McMahan et al., 1984), detailed soils data (STATSGO, SSURGO; USDA 1994; 1995), and pedotransfer functions to translate soils data to hydraulic parameters (Schaap and Leij, 1998) greatly enhances our ability to model recharge. Comparisons of simulated and measured water balance parameters at sites in west Texas and Idaho indicated that models could reasonably simulate measured water balance parameters (Scanlon et al., 2002). Limited field studies were conducted in the Southern High Plains and the Seymour aquifer to estimate recharge in these settings and to evaluate the impact of land use on groundwater recharge. Sites in the Southern High Plains were chosen in Dawson County in an attempt to explain groundwater level rises ranging from 10 to 20 m in some wells recorded over the past several decades. Sites in the Seymour aquifer were chosen to represent the recharge zone that is characterized by a large region of sand dunes in Haskell County. Multiple profiles were sampled in the sand dunes and also one profile was drilled to the east of the dunes for comparison with the dune setting. Individual profiles in each region represented natural settings, dryland farming, and irrigated farming. Results from these field studies should provide valuable information on the effect of land use on groundwater recharge.

Texas Climate, Vegetation, and Soils

The climate in Texas has been subdivided into Continental Steppe in the Texas High Plains, and subtropical climate throughout the rest of Texas, which represents a modified marine climate dominated by effect of onshore flow of tropical air from the Gulf of Mexico. Subheadings Subtropical - Humid, Subhumid, Semi-arid, and Arid reflect the changes in moisture content as Gulf air flows across the state. The climate in the Trans Pecos region is dominated by the influence of the southwest monsoon. The High Plains region is influenced by moisture from the Gulf of Mexico, the Gulf of California, and from the southern Rocky Mountains. Tropical storms influence precipitation in the summer in the eastern two thirds of the State. Precipitation in the fall and winter is influenced by the jet stream. Wet winters result from a southerly jet stream whereas dry winters result from a northerly shift of the jet stream. Precipitation in the spring is dominated by mesoscale convection in west Texas.

Analysis of precipitation data from 1961–1990 for 10 meteorological stations throughout the state indicates that 30-yr average annual precipitation ranges from 224 mm/yr in west Texas to 1184 mm/yr in east Texas (Table 1). Annual precipitation at individual stations ranged from 110 mm (El Paso, 1969) to 1783 mm (Houston, 1973). Summer precipitation (Jun-Aug) is dominant throughout much of the state, particularly in the trans-Pecos (43%) and the High Plains (33 to 48%) regions (Table 1). Spring precipitation is dominant in the Austin/Fort Worth region (29 to 33%) whereas fall precipitation is dominant in the Gulf Coast region (28 to 39%). Precipitation is fairly uniformly distributed in the more humid regions in east Texas. Winter precipitation is generally low throughout most of the state (8 to 16%) with the exception of the humid east

Table 1: 1961 to 1990 average precipitation values (mm) for selected locations

Precipitation (mm)	*Annual*		*Winter Dec-Feb*			*Spring Mar-May*			*Summer Jun-Aug*			*Fall Sep-Nov*			*Winter Oct-Mar*	*Summer Apr-Sep*
Station	*Ave*	*CV*	*Ave*	*CV*	*%*	*Ave*	*CV*	*%*	*Ave*	*CV*	*%*	*Ave*	*CV*	*%*	*%*	*%*
El Paso	224	0.35	35	0.56	16	19	0.63	8	96	0.58	43	74	0.66	33	33	67
Midland	380	0.35	40	0.52	11	86	0.47	23	125	0.53	33	128	0.70	34	31	69
Lubbock	474	0.23	41	0.60	9	107	0.46	23	194	0.40	41	132	0.65	28	27	73
Amarillo	499	0.21	42	0.70	8	113	0.41	23	242	0.37	49	103	0.49	21	24	76
Abilene	619	0.23	82	0.60	13	159	0.40	26	197	0.40	32	183	0.51	30	35	65
Brownsville	676	0.23	99	0.40	15	126	0.62	19	187	0.49	28	259	0.41	39	33	67
Austin	809	0.21	146	0.40	18	234	0.37	29	198	0.60	25	231	0.44	29	42	58
Fort Worth	855	0.22	148	0.41	17	283	0.32	33	190	0.52	22	234	0.43	27	43	57
Victoria	932	0.23	154	0.38	16	208	0.55	22	286	0.43	31	290	0.39	31	37	63
Houston	1184	0.22	249	0.27	21	294	0.45	25	315	0.47	27	326	0.36	28	45	56

CV: coefficient of variance, %: percent of annual average

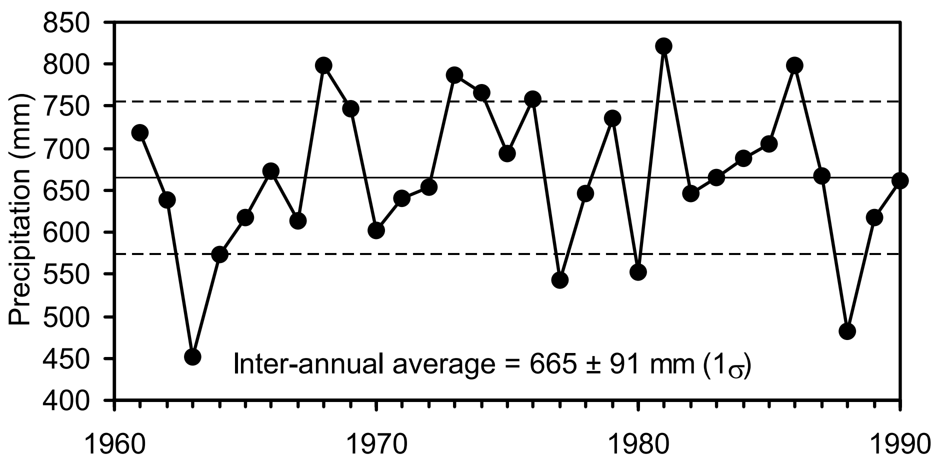


Figure 1: 1961 to1990 average annual precipitation for the stations listed in Table 1. Solid line represents the 30-yr average, dashed lines represent standard deviation (± 1σ)

(21%). Precipitation was generally low (< 1σ) throughout much of the state in 1963-64, 1977, 1980, and 1988 and high (> 1σ) in 1968, 1973-74, 1976, 1981, and 1986 (Fig 1).

Vegetation in Texas is influenced by climate, soils, and topography. A total of 10 different vegetation areas have been identified including Pineywoods (pine-hardwood forest); Gulf Prairies and Marshes (grassland and post oak savannah), Post Oak Savannah (post oak overstory and tall grasses), Blackland Prairies (prairie with bluestem grasses), Cross Timbers and Prairies (bluestem grasses), South Texas Plains (grassland or savannah), Edwards Plateau (range land), Rolling Plains (range land), High Plains (crops), Trans-Pecos (range land, desert shrub) (McMahan et al., 1984). The vegetation types of Texas have been mapped using LANDSAT data and computer classification in the eastern two thirds of the state and land resource mapping by Kier et al., 1977 (McMahan et al., 1984). Vegetation ranges from shrubs

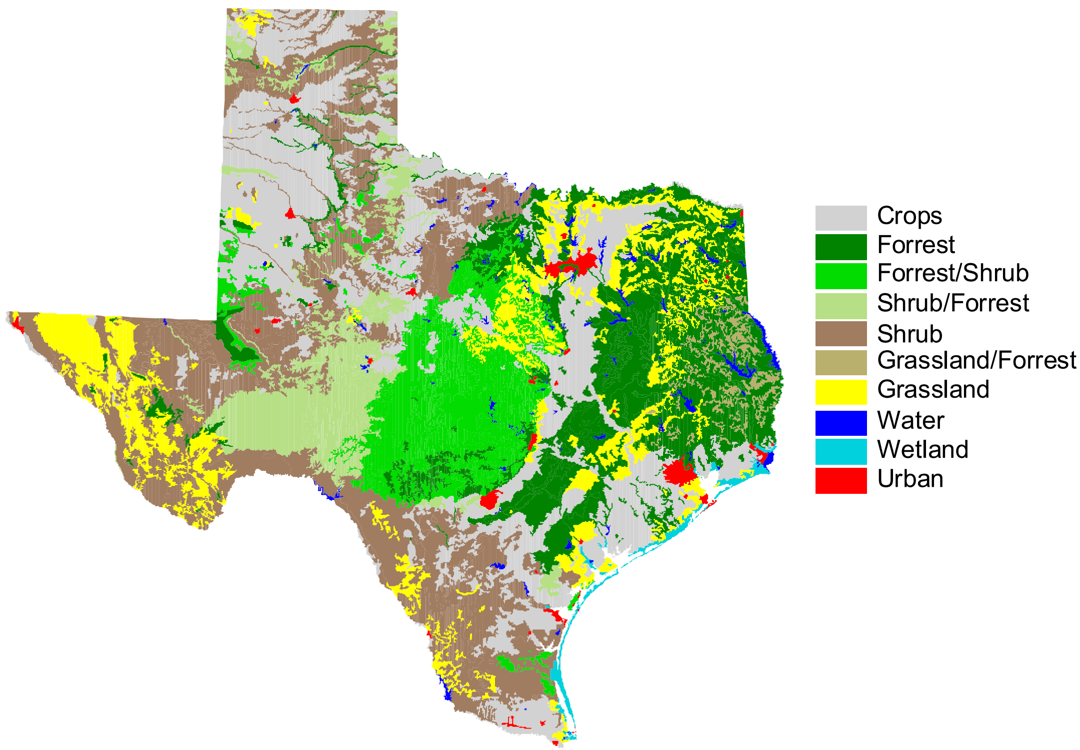


Figure 2: Distribution of dominant vegetation types in Texas.

and grasses in the Trans Pecos region, shrub/forest to forest/shrub in the Edwards Trinity Plateau, and forest and forest/shrub in east Texas (Fig. 2). Cropland areas dominate much of the High Plains, Rolling Plains, Blackland Prairie, and Gulf Coast.

There are various sources of soil databases available for Texas. The most widely used sources of soils data include State Soil Geographic (STATSGO) database that is at a 1:250,000 scale and Soil Survey Geographic (SSURGO) database at a scale of 1:24,000. The STATSGO database includes the following attributes: clay content, organic material, soil water capacity, permeability, infiltration, drainage, and slope. STATSGO mapped units consist of from 2 to 21 soil series in Texas. SSURGO is the most detailed level of soil mapping done by the Natural Resources Conservation Service (NRCS). Mapping scales generally range from 1:12,000 to 1:63,360. This dataset is tiled by 1:24,000 USGS Quadrangle; surveyed by county/multiple counties. The attribute database gives the proportionate extent of the component soils and their properties for each map unit. The map data are in both a 7.5-minute quadrangle format and a county format. Basic mapped units in the SSURGO database consist of a single soil series. There are two versions of the SSURGO database. The SSURGO version 2 database provides more detailed soil texture data than either the SSURGO version 1 or the STATSGO database. In addition to the basic soil data, the SSURGO version 2 database provides soil water retention

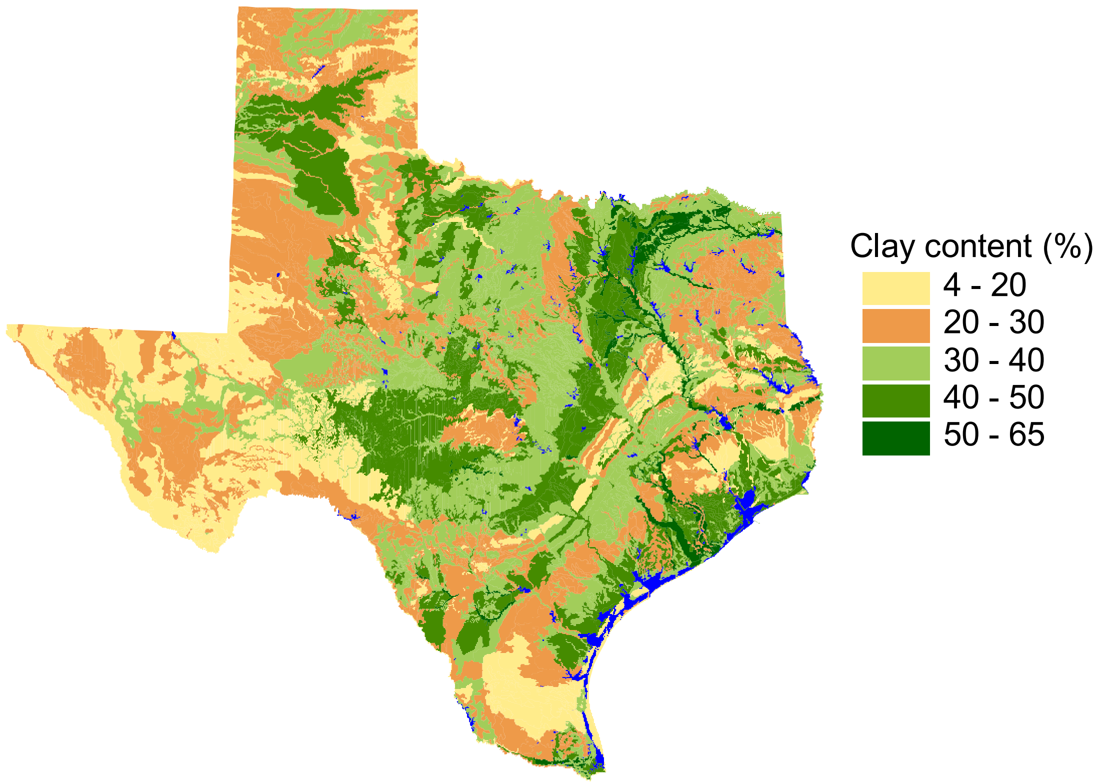


Figure 3: Average soil profile clay content derived from STATSGO database. Water covered areas shown in blue.

data at -3.3 and –150 m matric potential head, which neither the SSURGO version 1 nor the STATSGO database provide. A map of average clay content in the upper 1.5 to 2.0 m based on STATSGO data (Fig. 3) shows some general trends: low clay content in west Texas (Trans Pecos and Cenozoic Pecos Alluvium regions), high clay content in the central High Plains decreasing in the southern High Plains, generally high clay content in central Texas, low clay content in east Texas, high clay content in the central and northern portions of the Gulf Coast and low clay content in the southwestern Gulf Coast. The trends in clay content generally follow the underlying geology.

Field Site Descriptions

Field studies were conducted in Dawson County in the Southern High Plains Aquifer (Fig. 4) and in Haskell County in the Seymour Aquifer (Fig. 5). Dawson County was chosen because groundwater level rises ranging from 10 to 20 m have been observed in several wells over the last few decades, with the greatest rises occurring in the western portion of the county. Groundwater level rises cannot be attributed to rebound after reduction or cessation of irrigation as the irrigated areas lie predominantly in the northern and central portions of the county.

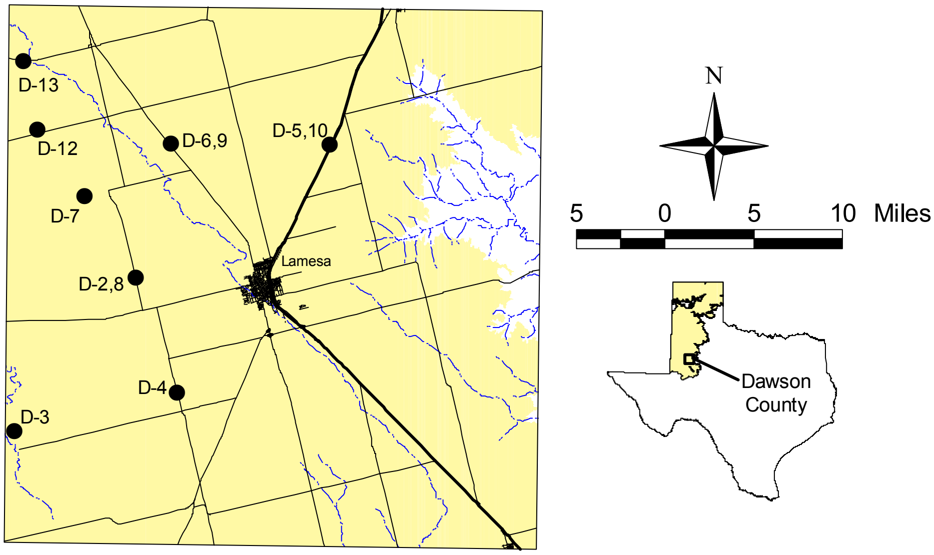


Figure 4: Southern High Plains sampling locations.

Haskell County was chosen because of the shallow and dynamic nature of the Seymour Aquifer. Fairly high recharge rates should occur in the northwest portion of the county in areas with deep sand dunes. Groundwater nitrate concentrations in the Seymour aquifer are high. Concentrations of NO_3-N in Haskell County wells have a median value of 15.9 mg/L, ranging from 6.9 to 44.4 mg/L (TWDB database, most recent analysis in 46 wells over the 1982–2001 time period). Groundwater is the sole source of water for municipal, rural, and agricultural irrigation water in both locations.

The borehole locations in the Southern High Plains were located in four soil series (Sanders et al., 1960). Boreholes D2, D4, D5, and D6 were in Amarillo fine sandy loams and loamy fine sands, where native vegetation species are primarily grasses (bluegrama, side-oats grama, buffalograss, sand dropseed, and three-awn) along with sparse shrubs (catclaw and brushy mesquite). Boreholes D3, D12, and D13 were in Brownfield fine sand where native vegetation consists of bunchgrasses and sparse shrubs (shin oak, sand sage, and brushy mesquite). Borehole D7 was located in Tivoli fine sand with native vegetation consisting of sparse grasses and shin oak shrubs. The borehole locations in the Seymour were located in two soil series (Mowery et al., 1961). Boreholes H1, H3, and H4 were in Miles loamy fine sand and boreholes H5, H6, and H7 were in Springer loamy fine sand. Native vegetation in both soil series consists of bunch grasses.

A range of land use settings was sampled in each county, included natural settings, and cultivated areas where both dryland and irrigated agricultural practices are employed. There

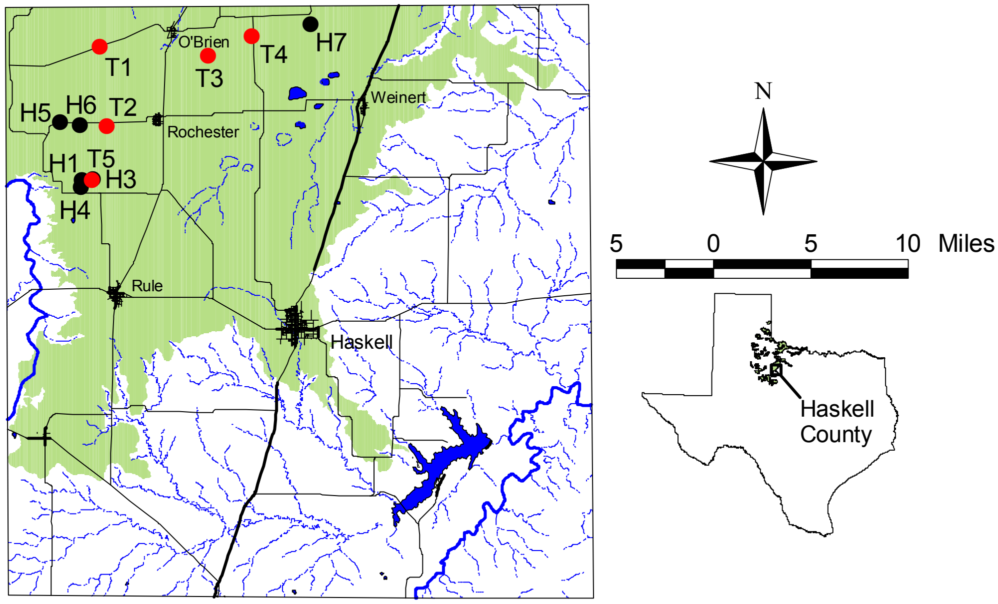


Figure 5: Seymour sampling locations. H: borehole location, T: $^3H/^3He$ well sample location.

were three natural setting boreholes in the Southern High Plains (D7, D12, and D13) and one in the Seymour (D5).

Cultivated sampling locations in the Southern High Plains consisted of one irrigated and four dryland sites. Initial development occurred circa 1900 at one of the dryland sites (D5) and at the irrigated site (D6), and during the mid-1930's at the remaining dryland sites. Cotton remained essentially the only crop grown in the area until 1993, when rotations with peanuts, a nitrogen-fixing plant, began. One crop per year is planted, with a 5-month growing season from approximately mid-May through mid-October. Fields lie fallow for the remaining 7 months of the year. Irrigation at site D6 began about 1955 with a side role (sprinkler) system, changing to a more efficient center pivot sprinkler system in the late 1980's. Annual irrigation applications average approximately 450 mm and range from 300 mm during wet years to as much as 600 to 800 mm during dry years. Nitrogen fertilizers are applied to irrigated crops annually at a rate of approximately 225 kg/ha, whereas application rates to dryland crops are much lower at approximately 55 kg/ha every 2 or 3 years as needed.

Sampling locations in cultivated areas of the Seymour also consisted of one irrigated and 4 dryland sites. Initial cultivation occurred by 1920 at three of the sites (H1, H3, and H4) and during the early 1960's at the remaining sites (H6 and H7). Sites H1 and H3 were taken out of production (i.e., in the Conservation Reserve Program, CRP) in 1990. Site H1 was put back into production in 1999 while site H3 is still currently out of production. Dominant crops in the area include cotton, winter wheat, peanuts, corn, and sorghum. Similar to the Southern High Plains, one crop is planted per year with generally the same growing season, with the exception of winter wheat, which is planted in December and harvested in May or June. Fields generally lie fallow for 7 months of the year. At the sampled irrigated site (H6), coastal bermudagrass is grown as forage for cattle. Irrigation with a side role system began in the early 1960's when the land was first cultivated. Annual irrigation applications in the area are substantially less than in the Southern High Plains, averaging 250 to 300 mm and ranging from 150 mm in wet years to 380 mm during dry years. Nitrogen fertilizer in the form of urea, $CO(NH_2)_2$, is applied to the irrigated site at a rate of approximately 112 kg/ha each month during the 5-month growing season (May-Sep). Nitrogen fertilizers are generally not applied to dryland fields in the Seymour area.

METHODS

Theory

Four basic approaches were used to evaluate unsaturated flow in the study area: numerical modeling, physical measurements, chemical measurements, and electromagnetic induction. Numerical modeling is a tool to simulate groundwater recharge based on meteorological forcing, vegetation cover, and soil profile data. Physical data include field sampling and laboratory measurement of water content and matric potential and/or installation of field instrumentation to monitor water content (time domain reflectometry [TDR] probes)) or to monitor matric potential (heat dissipation sensors). Physical data provide information on flow processes, whereas chemical tracers provide information on net water fluxes on time scales from years to thousands of years. Electromagnetic induction was used to obtain information on large-scale spatial variability in unsaturated zone characteristics and to interpolate and extrapolate data from point estimates provided by boreholes.

Unsaturated Flow Modeling

Unsaturated flow modeling is used to simulate drainage below the root zone, which is equated to groundwater recharge. The code UNSAT-H (Version 3.0; Fayer, 2000) is a one-dimensional, finite difference code that was used for the simulations. The simulations focus on the water balance:

$$P + Irr - \left[E \; or \; ET\right] - R_0 - D = \Delta S \qquad (1)$$

where P is precipitation, Irr is irrigation, E is evaporation, ET is evapotranspiration, R_0 is surface runoff, D is drainage, and ΔS is change in water storage. Precipitation and irrigation are input parameters for the simulations; all other parameters in the water balance are simulated. Runoff is not simulated explicitly but occurs when the near surface soil profile becomes saturated or when precipitation intensity exceeds infiltration capacity of the soils. Water that has infiltrated can move up by evaporation in nonvegetated systems or evapotranspiration in vegetated systems or down as a result of gravity and/or matric-potential gradients. The upper boundary condition is specified using meteorological data and UNSAT-H calculates potential evapotranspiration (*PET*) internally using the Penman-Monteith equation (Penman, 1948). Potential evapotranspiration is controlled by atmospheric conditions whereas actual evapotranspiration is limited by the rate at which soil can transmit water upward to the land surface. UNSAT-H allows evaporation to occur at the potential rate when the head at the surface node is between 0 and a pre-specified lower value. When the head reaches the lower bounding value, the boundary condition changes from a constant flux (*PET*) to a constant head, and evaporation is controlled by the rate at which water can be transmitted to the soil surface. The lower boundary condition used to simulate drainage or recharge is a unit gradient option, which allows water to drain when it reaches the boundary. UNSAT-H simulates subsurface water flow using Richards' equation:

$$\frac{\partial \theta}{\partial t} = -\frac{\partial q}{\partial z} = \frac{\partial}{\partial z}\left(\left(K(\theta)\frac{\partial H}{\partial z}\right) - S = \frac{\partial}{\partial z}\left(\left(K(\theta)\frac{\partial h}{\partial z} - K(\theta)\right) - S(z,t) \qquad (2)$$

where θ is volumetric water content, *q* is water flux, *K* is hydraulic conductivity, *H* is hydraulic head (matric potential head + gravitational potential head), *h* is matric potential head, and *S* is a sink term used to describe the removal of water by plants. Initial conditions may be represented using water content or matric potential head.

The approach proposed by Feddes et al. (1978) is used to simulate water uptake by plants: potential evapotranspiration (*PET*) is partitioned into potential evaporation (*PE*) and potential transpiration (*PT*) components (Fig. 6). *PT* is distributed over the root zone based on depth variations in root density and is reduced to actual transpiration based on matric potential head. Potential transpiration is estimated from *PET* using an equation developed by Ritchie and Burnet (1972) for cotton and grain sorghum (Fayer, 2000):

$$PT = PET(0.5(LAI)^{0.5} \qquad 0.0 \le LAI \le 3.7 \qquad (3)$$

where *LAI* is the leaf area index, defined as the ratio of leaf surface area to the shaded ground surface area. *PT* is applied to the root zone using the volumetric sink term (equation 2). The sink at each node is assigned a fraction of *PT* based on the root length density of each node divided by the total root length in the soil profile. Actual transpiration or the actual sink, *S*(*h*), is simulated by decreasing the potential sink term (S_p) by a reduction factor (α) which ranges from 0 to 1 and relates transpiration rate to the available water (matric potential head) in the root zone (Fig. 6):

$$S(h) = \alpha(h)S_p \qquad (4)$$

Transpiration is zero when the matric potential is greater than a prescribed value close to saturation (h_n) because the soil is anaerobic. Transpiration occurs at the potential rate between prescribed h_n and h_d values. Below h_d, transpiration decreases linearly to 0 at the wilting point (h_w).

To solve Richards' equation, information on constitutive functions relating matric potential head, water content, and unsaturated hydraulic conductivity is required. UNSAT-H includes

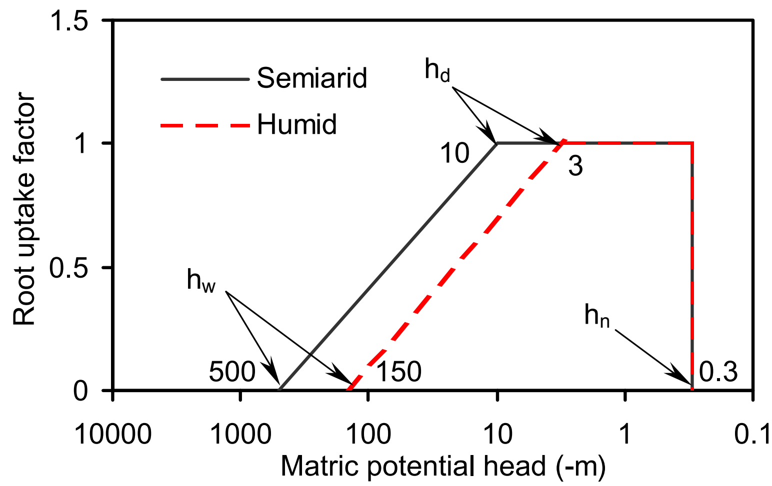


Figure 6: Root uptake factor as a function of matric potential head.

multiple analytical functions for water retention and unsaturated hydraulic conductivity. The most widely used functions are the van Genuchten water retention function (van Genuchten, 1980) and the Mualem hydraulic conductivity function (Mualem, 1976).

Application of process-based water flow models is often hampered by insufficient knowledge of soil hydraulic properties. Direct measurement of water retention and unsaturated hydraulic conductivity relationships at all sites being simulated is infeasible. Soils data from the STATSGO and SSURGO databases were used with pedotransfer functions, which transform available soil data into hydraulic parameters including water retention and hydraulic conductivity that are difficult or expensive to measure directly. Water retention functions and hydraulic conductivity were estimated using soils data from the STATSGO and SSURGO databases (USDA, 1994, 1995) and the Rosetta pedotransfer function software (Schaap et al., 2001) (Appendix A). The Rosetta software uses neural network programming and a database of measured texture, water retention, and saturated hydraulic conductivity samples to provide estimates of the van Genuchten water retention functions and saturated hydraulic conductivity for input to unsaturated flow models. A hierarchical approach is used to estimate hydraulic parameters based on varying levels of soil data from STATSGO or SSURGO:

(a) Soil texture classification
(b) Sand, silt, and clay percentages
(c) Values in (b) plus bulk density
(d) Values in (c) plus water retention at -3 m head
(e) Values in (d) plus water retention at -150 m head

Increased knowledge of soils data (i.e., (e) vs. (a)), results in greater accuracy in the estimated retention function parameters and saturated hydraulic conductivity values.

Physical Approach

Although measurements of physical parameters such as water content and matric potential head may not provide accurate estimates of water flux or recharge, they do provide invaluable information on unsaturated flow processes. Water content varies with sediment texture; therefore, in heterogeneous sediments, water content cannot be used to determine the direction of water movement. However, monitoring water content is generally useful in evaluating movement of water pulses in areas of moderate to high water flux.

Direction of water movement can be determined using potential energy gradients in isothermal systems because water moves from regions of high energy to regions of low energy [Jury et al., 1991]. Gravitational potential is equal to the elevation above a datum, such as the water table. Matric potential describes the forces related to the soil matrix and is dominated by capillary forces under wet conditions and adsorptive forces under dry conditions. Heat dissipation sensors can be used to measure matric potential head over a wide range (-1 to –50 m) whereas tensiometers are restricted to the wet range (0 to -8 m) (Scanlon and Andraski, 2002; Young and Sisson, 2002). Osmotic potential results from the reduction of energy from the addition of solutes to the pore water. Water potential includes matric and osmotic potential and can be measured by thermocouple psychrometers in the laboratory or in the field. Matric or water potentials can be measured in the laboratory on soil samples collected in the field to determine the vertical gradient in matric potentials at the sampling time. In addition, tensiometers, heat dissipation sensors, or thermocouple psychrometer can be installed in the field to continuously monitor matric or water potentials. These data can be used to determine penetration depths of wetting fronts and directions of water movement. Typical water potentials in many semiarid settings are lowest near the surface (-400 to -1000 m) indicating dry conditions and increase exponentially with depth. The upward decrease in water potential indicates an upward driving force for water movement [Scanlon, 1994; Andraski, 1997; Izbicki et al., 2000; Walvoord et al., 2002].

Environmental Tracers

Meteoric Chloride

Chloride concentrations in pore water in the unsaturated zone or in groundwater have been widely used to estimate recharge (Allison and Hughes, 1978; Scanlon, 1991; 2000; Phillips, 1994). Precipitation contains low concentrations of Cl. Chloride in precipitation and dry fallout is transported into the unsaturated zone with infiltrating water. Chloride concentrations increase through the root zone as a result of evapotranspiration because chloride is nonvolatile and is not removed by evaporation or by plant transpiration. Below the root zone, chloride concentrations should remain constant if recharge rates have not varied over time. Qualitative estimates of relative recharge rates can be determined using chloride concentrations in the unsaturated zone pore water or groundwater if precipitation and dry fallout are the only sources of chloride to the subsurface. Chloride concentrations are inversely related to recharge rates: low chloride concentrations indicate high recharge rates because chloride is flushed out of the system whereas high chloride concentrations indicate low recharge rates because chloride accumulates as a result of evapotranspiration. For example, low chloride concentrations beneath playas in the Southern High Plains indicate high recharge whereas high chloride concentrations in natural interplaya settings indicate low recharge (Scanlon and Goldsmith, 1997; Scanlon et al., 1997). Quantitative estimates of recharge can also be calculated using the chloride mass balance approach which balances chloride input (precipitation and dry fallout, *P*, and irrigation, *I*) times the chloride concentration in precipitation (C_P) and in irrigation (C_I) with chloride output (recharge rate, *R*, times chloride concentration in the unsaturated zone pore water or groundwater (C_{uz} or C_{gw}):

$$PC_p + IC_I = RC_{uz} = RC_{gw}, \qquad R = \frac{PC_p + IC_I}{C_{uz}} = \frac{PC_p + IC_I}{C_{gw}} \tag{5}$$

The age of the pore water at any depth in the unsaturated zone can also be estimated by dividing the cumulative total mass of chloride from the surface to that depth by the chloride input.

The chloride input to a system was estimated from chloride deposition in precipitation from the National Atmospheric Deposition Program (NADP, http://nadp.sws.uiuc.edu/). Average Cl inputs based on data from 1980 to 2002 from about 40 stations in Texas and surrounding states were contoured using splines to estimate Cl input at the field sampling sites in the Southern High Plains and Seymour aquifers (Fig. 7). An average value of 0.17 mg/L was determined for the Southern High Plains sampling locations and an average value of 0.16 mg/L was

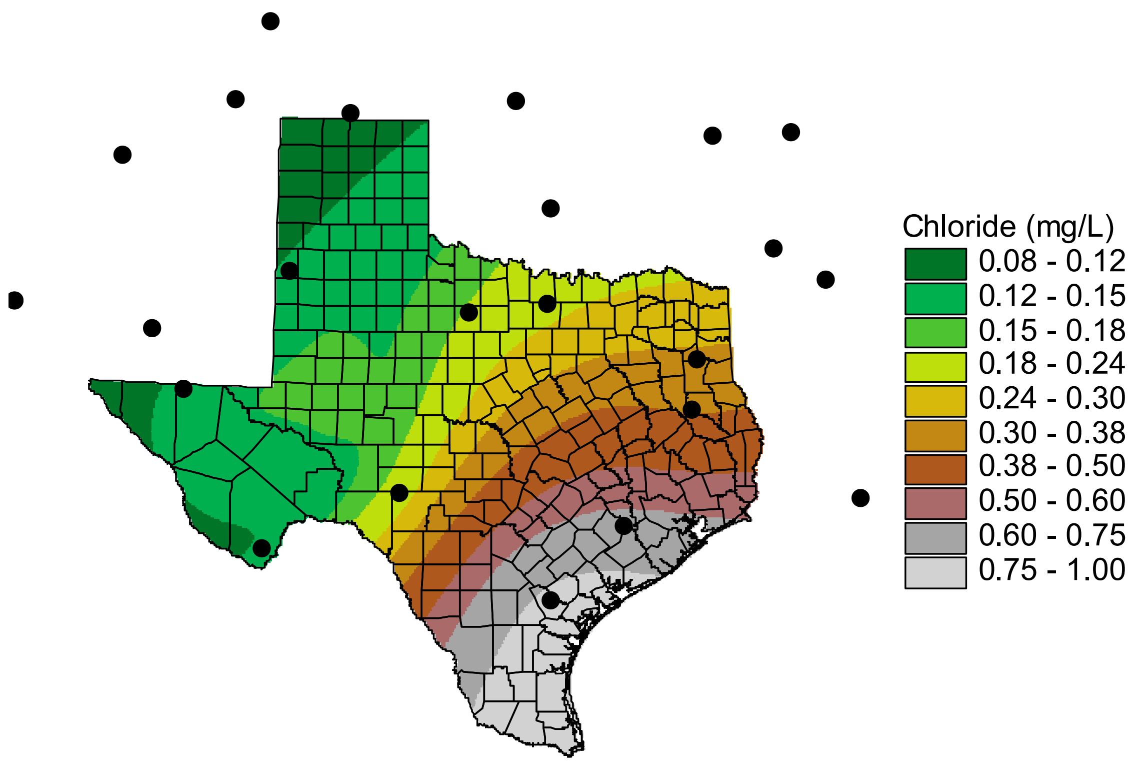


Figure 7: Chloride concentration in precipitation. Points indicate NADP monitoring locations

determined for the Seymour sampling locations. Chloride concentrations reported by the NADP represent wet precipitation and do not include any dry deposition. To account for dry deposition, chloride concentrations from the NADP database were increased by a factor of two, which was suggested by Izbicki (per. comm., 2001). Average precipitation values were calculated for the field sites in the Southern High Plains (457 mm) and Seymour (635 mm) aquifers using 30 yr (1961 to 1990) precipitation records.

Tritium/Helium

Historical tracers or event markers such as bomb-pulse tritium (^{3}H) are used in both unsaturated and saturated zones to estimate recharge. Tritium is part of the water molecule and can also be used to trace water movement. Tritium (half life of 12.32; Lucas and Unterweger, 2000) is produced naturally by cosmic ray neutrons interacting with nitrogen in the upper atmosphere and results in 5 to 10 TU in precipitation in the northern hemisphere. Tritium concentrations increased from 10 to ≥ 2000 TU in the northern hemisphere during atmospheric nuclear testing (IAEA, 1983) that initiated in 1952 and peaked in 1963 to 1964. Tritium has been used widely in the past to estimate recharge (Egboka et al., 1983; Robertson and Cherry, 1989); however, bomb-pulse ^{3}H concentrations have been greatly reduced as a result of radioactive decay. The use of ^3H to date groundwater is generally being replaced by the use of tracers such as tritium/helium-3 ($^3H/^3He$). Tritium decays to the noble gas helium-3. These gas tracers can be used only as water tracers in the saturated zone, where they can no longer exchange with the atmosphere. The first appearance of tracers such $^3H/^3He$ can be used to estimate recharge rates where flow is primarily vertical, as in recharge areas near groundwater divides. Tritium and tritiogenic helium-3 combined behave as a non-decaying tracer and the ratio of ^3He to ^3H can be used to estimate the age of the groundwater (t; age being defined as the time since water entered the saturated zone).

$$t = -\frac{1}{\lambda}\ln\left[1 + \frac{^3He_{trit}}{^3H}\right] \tag{6}$$

where λ is the decay constant (ln $2/t^{1/2}$), $t^{1/2}$ is the ^3H half-life (12.32 yr), and $^3He_{trit}$ is tritiogenic ^3He. Use of this equation assumes that the system is closed (does not allow ^3He to escape) and is characterized by piston flow (no hydrodynamic dispersion).

The range of recharge rates that can be estimated by using groundwater dating depends on the ranges of ages that can be determined. $^3H/^3He$ is used to determine groundwater ages up to approximately 50 yr, with a precision of 2 to 3 yr (Cook and Solomon 1997). The estimated recharge rates are average rates over the time period represented by the groundwater age. Dispersive mixing can result in ±50% uncertainty in $^3H/^3He$ ages prior to 1970, when ^3H input varied markedly during the bomb pulse (Solomon and Sudicky, 1991). The method is most accurate where piezometers have been completed with relatively short well screens. Recharge rates calculated using groundwater dating spatially integrate recharge over an area up gradient from the measurement point. Therefore, spatial scales can range from local (decameter scale) if samples are collected near a groundwater divide (Szabo et al., 1996) to regional (kilometer scale; Pearson and White, 1967).

Electromagnetic Induction

Electromagnetic induction is a noninvasive technique that measures a depth weighted average of the electrical conductivity of the ground termed the apparent electrical conductivity (EC_a). Apparent electrical conductivity of the subsurface varies with clay content, water content, salinity, and temperature. The theoretical basis for EM induction measurements is described in McNeill (1992). Rhoades et al. (1989) developed a linear model to describe subsurface variations in EC_a that generally applies for solution conductivities ≤ 400 mS/m:

$$EC_a = EC_w \theta \tau + EC_s \tag{7}$$

where EC_w is the pore water conductivity, θ is the volumetric water content, τ is the tortuosity, and EC_s is the surface conductance of the sediment (Rhoades et al., 1976). This model applies when the water content is above a certain threshold value. Laboratory studies show that threshold water contents range from 0.05 m^3/m^3 for sand to 0.12 m^3/m^3 for clay (Rhoades et al., 1976). Below this threshold water content, EC_w is 0 and EC_a is controlled by the surface conductance (EC_s), which is primarily determined by the cation exchange capacity of the clays.

The various frequency domain conductivity meters manufactured by Geonics Ltd. (Mississauga, Ontario) differ in the distances between the transmitter and receiver coils, the frequency at which they operate, and their effective exploration depths. The exploration depth of the instruments increases with increased inter-coil spacing and decreased current frequency and varies with the orientation of coils relative to land surface. The characteristics of the instruments are described in Table 2. The EM38 meter senses the upper 0.75 m in the horizontal dipole (HD) mode and 1.5 m in the vertical dipole (VD) mode whereas the EM31 meter senses the upper 3 m in the HD mode and 6 m in the VD mode. The instruments average the conductivity in the horizontal plane over a distance approximately equal to the length of each probe (~1 m for EM38; ~4 m for EM31). The instruments can be operated with transmitter and receiver coils oriented horizontally (vertical dipole mode) or vertically (horizontal dipole mode). Under low values of induction number the meter measures a depth-weighted average:

$$EC_a = \int_0^\infty \phi(z) EC(z) dz \tag{8}$$

where $EC(z)$ is the electrical conductivity of the soil as a function of depth and $\phi(z)$ is a weighting function that represents the depth-response function of the EM31 meter. At low induction numbers, the secondary magnetic field is a linear function of EC_a and the weighting function is independent of the electrical conductivity of the soil (Wait, 1982; McNeill, 1980). EM surveys conducted in west Texas were related to variations in soil texture, salinity, and water flux in different regions and were useful in interpolating between borehole measurements

Table 2: EM instrument characteristics

Instrument	*Inter-coil Spacing (m)*	*Frequency (Hz)*	*Exploration depth (m)*	
			Horizontal Dipole Mode	*Vertical Dipole Mode*
EM38	1.0	14,600	0.75	1.5
EM31	3.7	9,800	3	6

(Scanlon et al., 1999). Temporal variability in water content was monitored using EM induction calibrated with neutron probe monitoring at another site in west Texas (Reedy and Scanlon, 2003).

Numerical Modeling Methods

Data from 10 meteorological stations throughout the state (Fig. 8) were used to simulate recharge in 14 study areas (Fig. 9). For this investigation, a study area is defined as the aquifer outcrop area within a single or multi-county area exclusive of urbanized or water-covered areas. The time period simulated was 1961 through 1990 because of availability of solar radiation for the meteorological stations for this time. The upper boundary condition included meteorological forcing obtained from the database in the GEM code (Hanson et al., 1994). Meteorological input requirements included daily values of precipitation, minimum and maximum air temperature, dew point temperature, average wind speed, and solar radiation.

Irrigation applications were also included along with actual precipitation in areas where crops are irrigated. Irrigation amounts were estimated from crop water use. Water requirements were calculated based on *PET* and crop coefficients and adjusted for initial soil water storage and precipitation. *PET* was calculated using the Penman-Monteith method with meteorological data closest to the modeled site (Doorenbos and Pruitt, 1977). The crop coefficient varied with the crop type and stage of growth. Crop coefficients for sorghum and cotton are based upon

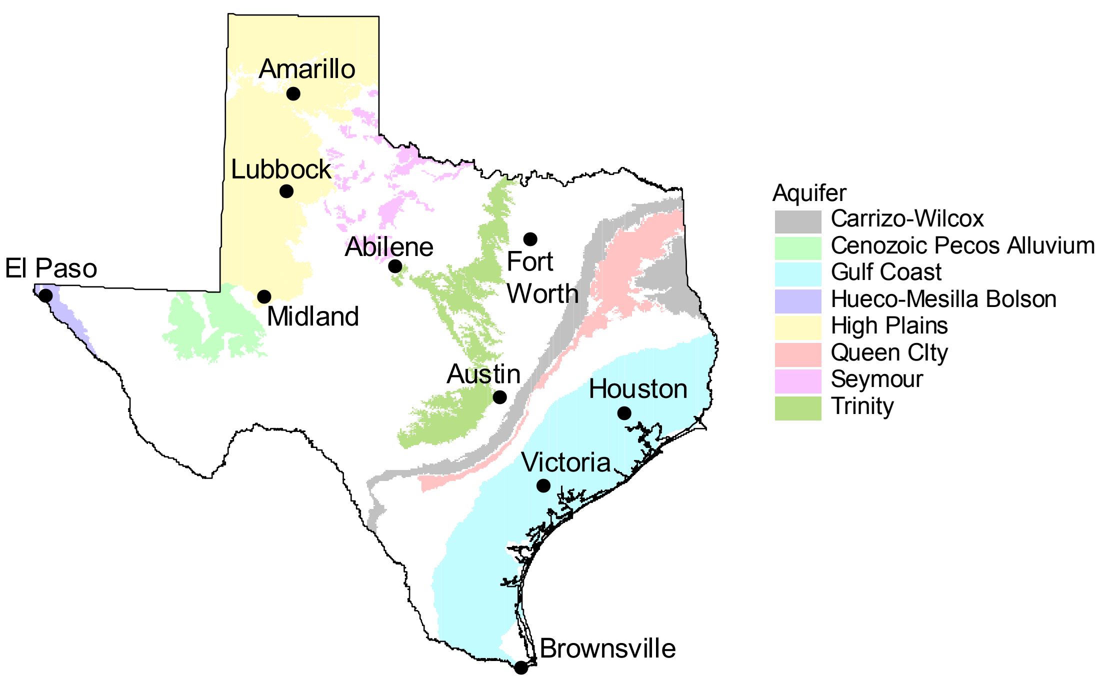


Figure 8: Locations of weather stations used in modeling in relation to aquifer outcrop areas.

Table 3: Average annual crop water requirements. Water use, precipitation, and precipitation plus irrigation values are in mm/yr.

County	*Crop*	*Day of Year* Seed	Harvest	σ	*Water Use* Ave	σ	CV	*Precip.*	*Precip. + Irrigation*
Carson	Sorghum	135	252	7	766	41	0.05	602	869
Midland	Cotton	140	269	21	644	45	0.07	544	790
Lubbock	Sorghum	135	256	7	749	41	0.05	622	892
	Cotton	135	292	21	685	51	0.07	584	874
Fisher, Jones	Cotton	140	260	13	557	28	0.05	455	935

σ, standard deviation, CV: coefficient of variance

lysimeter data of the North Plains PET Network Project Team and are estimated to be within 10% for other parts of the state. The average water use calculated with this method is listed in Table 3.

Seeding and harvesting dates are highly variable and variety-dependent. Seeding dates were chosen to represent the mid range of values provided in the literature. The total crop growth period was determined by the length of time required to accumulate a predetermined total sum of daily heat units. A daily heat unit is calculated as the difference between the average daily temperature and a specified base temperature. The average harvest date was used (Table 3). Daily water requirements and precipitation were summed for each week of the

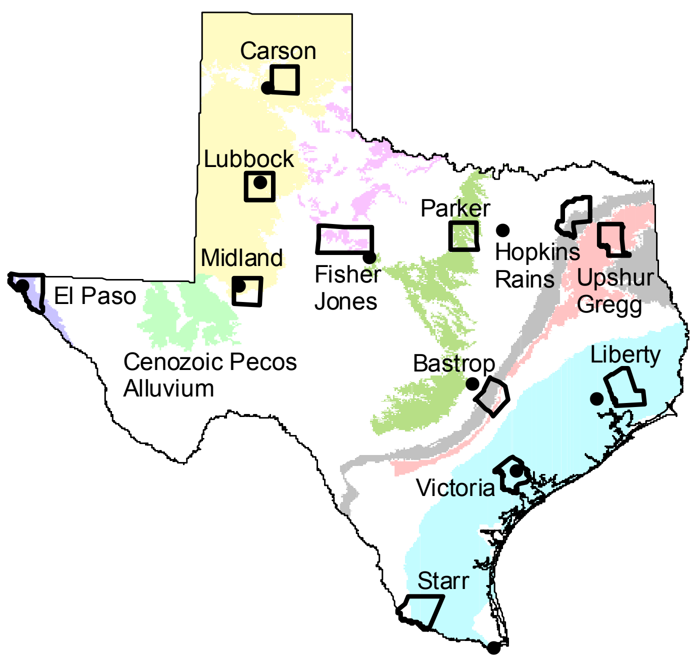


Figure 9: Modeled study areas. The entire Cenozoic Pecos Alluvium Aquifer was simulated whereas all other study areas included 1- to 2-county areas.

Table 4: Percentage of major crops that are irrigated

County	*Crop*	*Total Hectares Harvested (1968-1990)*	*% of County Total*	*% Irrigated (1972-1990)*
Carson	winter wheat	996,200	60	35
	sorghum	590,300	36	60
Midland	cotton	251,650	86	34
	sorghum	31,300	11	9
Lubbock	cotton	2,255,600	75	68
	sorghum	577,100	19	55
Fisher, Jones	cotton	1,306,550	53	1
	winter wheat	798,450	32	2
	sorghum	374,150	15	3

growing season. Precipitation was subtracted from the water requirement and the difference was added at the end of the week. If precipitation exceeded the amount of water required for the week, the balance was carried forward to the following.

Total number of harvested hectares per crop and county, irrigated and non-irrigated, were obtained from the National Agricultural Statistics Service (www.nass.usda.gov/tx). Crop areas were available from 1968 to present. The general crop distribution for modeling purposes was estimated from averages calculated based on data from 1968 to 1990. Areas of irrigated/non-irrigated land were available from 1972 onward. Information on crop distributions and irrigation status is listed in Table 4.

The lower boundary condition for the simulations was specified as a unit gradient that allows water to drain when it reaches the boundary. Matric potential head initial conditions were arbitrarily set at -3 m in humid regions (Fisher-Jones, Parker, Hopkins-Rains, Upshur-Gregg, Liberty, Bastrop, and Victoria) to -10 m for all other counties. The impact of initial conditions on simulation results was evaluated by rerunning the simulations multiple times; however, rerunning simulations once was found to be sufficient to minimize the impact of initial conditions.

Some of the simulations were based on monolithic sand or silt loam soil. Hydraulic properties for the sand were obtained from the UNSODA database (UNSODA 4650, Leij et al., 1996) and those for the silt loam were based on data from Scanlon et al. (2002) (Table 5). Information for layered soil profiles were obtained from STATSGO and SSURGO databases (USDA, 1994; 1995), geographic information system (GIS) software, and Rosetta pedotransfer

Table 5: Monolithic profile hydraulic conductivity and retention parameters.

Texture	K_s (mm/day)	θ_s	θ_r	α (1/m)	*n*
Sand	5870	0.38	0	0.0503	1.7736
Silt loam	430	0.47	0	0.0266	1.1689

function software and database (Schaap et al., 2001). GIS software was used to create study area polygon files for the selected counties or aquifers in the case of the Cenozoic Pecos Alluvium aquifer. These polygon files were then used to clip the study areas out of the original soil map polygon files. Areas for each of the resulting soil map polygons within a study area were calculated and totaled over each unique mapped unit. The resulting master list of mapped soil unit areas was sorted and the dominant units that represented at least 80% of the study area were selected for modeling analysis.

Soil layer physical characteristics for most of the study areas were obtained from the SSURGO version 2 database. The Cenozoic-Pecos Alluvium aquifer had limited SSURGO data available for analysis. For the Cenozoic-Pecos Alluvium, data for the entire (multi-county) outcrop area were obtained from the STATSGO database. Only textural and bulk density information was available from the STATSGO database for input to the Rosetta program. Clay fraction values used for this study were calculated as averages of high and low percentage clay values provided in the database. Silt percentages were then calculated as the differences between the resulting clay percentage values and averages of the high and low percent values passing the standard number 200 sieve, the next smallest particle size information provided in the STATSGO database. Openings in a 200 sieve are slightly larger than the division between silt and sand, with the result that the calculated silt values contained portions of very fine sand fractions. Finally, percent sand was calculated as the residual difference by subtracting the sum of the calculated average clay and silt values from 100.

In study areas included in the SSURGO version 2 database, soil layer texture, bulk density, and volumetric water content at –3 and –150 m head were available for input to Rosetta. Unlike the STATSGO database, representative textural values for percents sand, silt, and clay that sum to 100 are provided in the SSURGO database

The Rosetta model does not take into account coarse sediments (> 2 mm fraction); therefore, the residual (θ_r) and saturated (θ_s) water contents were adjusted to compensate for the percentage of soil composed of material > 2 mm in diameter using the relation provided in Bouwer and Rice (1984):

$$\theta_{r,s} = \theta_{r,s}^{R}(1 - V_f) \tag{9}$$

where superscript R represents the water content from the Rosetta neural network. The volume fraction, V_f, of sediments > 2 mm was calculated as follows:

$$V_f = W_f\left(\frac{\rho_b}{\rho_{>2mm}}\right) \tag{10}$$

where W_f is the weight fraction of sediments > 2 mm in diameter, ρ_b is bulk density of the soil including particles > 2 mm in diameter, and $\rho_{>2mm}$ is bulk density of the coarse fraction (assuming a particle density of 2.65 g/cm^3). The saturated hydraulic conductivity, K_s, was also corrected for the coarse fraction (Bouwer and Rice, 1984):

$$K_s = K_s^R \left(\frac{2(1-V_f)}{2+V_f} \right) \tag{11}$$

Vegetation parameters required for UNSATH include a time series of rooting depth, a root length density function, leaf area index (LAI), percent bare area, and time of seeding and harvesting for crops. The Texas vegetation map (McMahan et al, 1984), which indicates the spatial distribution of dominant vegetation associations, was used to assign vegetation parameters (Fig. 2). Values for parameters were obtained from the literature (Appendix B). Estimates of parameters for the root water uptake reduction factor were -0.3 m head for the head at which plants cease transpiring because of anaerobic conditions, -3 m head for humid regions and -10 m head for semiarid regions for the point at which the *ET* decreases from *PET* to the wilting point which ranged from -150 m head for humid regions to -500 m head for semiarid regions (Fig. 6). A value of 0.3 was used for albedo (Tindall et al., 1999).

The vegetation map, available as a GIS polygon file, was intersected with the study area soil unit polygon files. This resulted in a very large number of soil unit/vegetation type combinations and exhaustive simulations were not performed for each combination. Rather, the drainage results for the layered nonvegetated models within a given study area were examined. Soil profiles having similar magnitude drainage values were grouped together and a representative profile from each group was selected for simulation with the various vegetation types that intersected all of the soil units in that group. Similar to the nonvegetated modeling procedure, the resulting polygon areas were totaled for each group/vegetation type combination and the dominant combinations that summed to 80% of the area were modeled.

A soil profile depth of 5 m was chosen for the simulations because root zone depths for all sites were less than this depth. In monolithic profiles, nodal spacing was increased by a factor of ~ 1.2 to a maximum value of 230 mm and then reduced by a factor of 1.2 to a value of 2 mm at the base of the profile. In layered profiles nodal spacing was also reduced near textural interfaces to a value of 20 mm by gradually increasing and decreasing nodal spacing away from these interfaces.

Field and Laboratory Methods

Soil Texture, Water Content, Chloride, and Nitrate

Boreholes were drilled with a trailer mounted hollow stem auger rig (Giddings Machine Co., Ft. Collins, CO) without any drilling fluid in the Southern High Plains (Dawson County; 8 locations) and in the Seymour aquifer (Haskell County; 6 locations) (Figs. 4 and 5, Table 6). Continuous cores were obtained using a core tube (0.61 m long, 44 mm inside diameter) from the ground surface to depths ranging from approximately 3 to 6 m. Core sample tubes were cut into various length sections and capped and sealed to prevent evaporative loss. Core samples for nitrate analysis were stored on ice in the field and then in a refrigerator at the laboratory to minimize possible denitrification. Core samples for matric potential analysis were separated and placed in sealed containers in the field. Portions of the soil core samples were analyzed for particle size distribution using standard soil hydrometer techniques (Gee and Bauder, 1986). Samples from selected boreholes and depths were analyzed for percents sand, silt, and clay at the Soil, Water, and Plant Analysis Laboratory, Univ. of Arizona (Tucson, AZ).

Core samples were used for laboratory measurement of water content, chloride, and nitrate

Table 6: Borehole sampling summary

Setting	*Borehole*[1]	*Date Drilled*	*Latitude*[2]	*Longitude*[2]	*Elevation*[2] *(m)*	*Depth (m)*	*Analysis*[3]
Natural	D7	6-23	32.8047	-102.1310	933.6	3.35	Cl, N, Txt, MP
	D12	6-26	32.8575	-102.1784	954.0	4.72	Cl, N, MP, Txt
	D13	6-26	32.9129	-102.1930	953.1	5.49	Cl, N, MP, Txt
Dryland	D2	4-8	32.7394	-102.0805	917.4	5.03	Cl, N, Txt
	D8	6-24				4.57	MP
	D3	4-9	32.6134	-102.1943	905.3	4.42	Cl, N
	D4	4-9	32.6463	-102.0378	907.1	3.05	Cl, N
	D5	4-10	32.8498	-101.8952	917.4	4.57	Cl, N, Txt
	D10	6-24				4.27	MP
Irrigated	D6	4-8	32.8484	-102.0482	940.6	6.10	Cl, N, Txt
	D9	6-25				5.49	MP
Natural	H5	4-26	33.3119	-99.9421	486.5	5.79	Cl, N, Txt
	H8	5-16				5.18	MP
Dryland	H1	4-24	33.2688	-99.9229	493.8	6.10	Cl, N, MP, Txt
	H3	4-25	33.2698	-99.9132	493.5	6.10	Cl, N, Txt
	H4	4-25	33.2636	-99.9238	492.6	3.51	Cl, N
	H7	4-26	33.3849	-99.7195	468.5	4.72	Cl, N, Txt
Irrigated	H6	4-26	33.3091	-99.9245	494.4	6.10	Cl, N, Txt
	H9	5-17				6.10	MP

[1]D: Dawson County (Southern High Plains), H: Haskell County (Seymour Aquifer)
[2]Determined by hand-held GPS, horizontal accuracy: ±1.5 m, vertical accuracy: ±3.0 m
[3]Cl: chloride, N: nitrate, MP: matric potential, Txt: texture

concentrations. Gravimetric water content was measured in the laboratory by oven drying samples at 105°C for 24 to 72 hr. To determine chloride and nitrate content, double-deionized water was added to the dried sediment sample in a 1:1 ratio by weight. Samples were agitated on a reciprocal shaker for 4 hours. The supernatant was centrifuged and filtered through 0.45 μm filters. Chloride and nitrate concentrations were analyzed by ion chromatography (detection limit 0.01 mg/L) at the New Mexico Bureau of Mines. Chloride and nitrate concentrations in the supernatant were converted to pore water concentrations by dividing by the gravimetric water content and multiplying by the density of pore water, assumed to be 1.00 Mg/m^3. Chloride and nitrate concentrations are expressed as mg Cl and mg NO_3-N per L of pore water.

Water content was monitored in the field using time domain reflectometry (TDR) in the Seymour aquifer at the H1 borehole location at the edge of a cultivated field that was never irrigated. A total of 14 TDR probes (model 610, Campbell Scientific Inc., Logan, UT) were installed in the walls of a 0.6 m wide trench. The TDR probes consisted of 3 rods (300 mm long) and 5 m cable lengths. Seven TDR probes were installed horizontally into one trench wall at depths of 0.10, 0.20, 0.30, 0.50, 0.80, 1.10, and 1.50 m below the ground surface. The horizontal TDR probes are used to monitor movement of wetting fronts. The remaining seven TDR probes were installed at ~ 60-degree angle into the opposite trench wall to monitor average water contents over 0.25 m depth intervals from the ground surface to a depth of 1.75 m. The data logging system for the TDR consists of an above ground metal enclosure mounted on a concrete pad that houses five secondary enclosures that include the data logging electronics, communications, and power supply equipment. A tipping bucket rain gauge (model 525mm, Texas Electronics, Dallas, TX) that measures liquid precipitation in 0.1 mm depth increments was installed at a height of approximately 2.4 m above the ground surface. The data logging software checks the rain gauge and records any tips each second when other instruments are not being monitored. The data logger software includes several data collection options for monitoring water content with the TDR probes. The most efficient option for data storage uses an internal algorithm to interpret the waveform and calculate the water content. However, it has been our experience at other sites that this algorithm occasionally fails. Accordingly, we developed a more robust algorithm to analyze TDR waveforms. Water content at this site is monitored every three hours using the internal algorithm and every 12 hours the waveforms are also stored. This approach allows us to correlate the results between both algorithms and to maintain a detailed temporal record of soil water content at the site while using less data storage. Soil bulk conductivity is monitored every 3 hours. Soil samples were obtained during excavation of the trench for TDR probe calibration. Composite samples were obtained over 0.3-m intervals to a depth of 1.8 m. Calibrations were performed using a modification of the method described by Young et al. (2002).

Pressure Head Measurements

Matric potential was measured in the laboratory on soil samples collected in the field using tensiometers and a thermocouple psychrometer sample changer. Tensiometers consist of a porous ceramic cup (1.8 cm long, 1 cm diameter) attached to a PVC tube (15.3 cm long) and measure matric potential in the range from 0 to –8 m. A hole slightly smaller than the diameter of the tensiometer was drilled through the sample cup lid and a tensiometer was inserted into the center of the soil sample and allowed to equilibrate for 24 hours. The (negative) pressure of the air above the water column inside the tensiometer was measured with a Tensimeter (Soil Measurement Systems, Tucson, AZ). A thermocouple psychrometer sample changer (model SC-10X, Decagon Devices, Pullman, WA) was used to measure water potential in dry samples (water potentials ~ –5 to –550 m). A Peltier psychrometer was installed in the sample changer and calibrated using salt solutions over a range from –6 to –740 m.

Matric potentials and temperature were monitored in the field at a site adjacent to the TDR probes at the H1 borehole location in the Seymour aquifer. A total of 12 heat dissipation sensor (HDS) instruments (model 229, Campbell Scientific Inc., Logan, UT) were installed in boreholes H1 at depths of 0.2, 0.3, 0.5, 0.8, 1.1, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, and 6.0 m below the ground surface. The boreholes were backfilled with sand (0.15 m) and bentonite. The HDS instruments were calibrated in the laboratory using methods described by Flint et al. (2002). Fourteen calibration points were obtained for each sensor from saturation to dry conditions. One point was obtained at total saturation by placing the sensors submerged in water inside a vacuum chamber. A second saturation point was obtained by submerging each sensor in water without applying a vacuum. This point represents the field saturation. An additional 10 calibration points were obtained at matric potential head values ranging from approximately –1 to –50 m using pressure plate extractors. Finally, two calibration points under dry conditions were obtained by equilibration over a saturated NaCl solution (~ –400 m) and by packing the instruments in silica gel desiccant (~ -1300 m). Calibration equations resulted in mean absolute errors less averaging 10% over the range from –1 to –50 m. Deviations occur at about the –1 m value and at the dry end. Measurements below about –70 m are not well constrained and may not be accurate. The HDS instruments are monitored every 12 hr for matric potential and every 3 hr for soil temperature.

Electromagnetic Induction Surveys

Noninvasive measurements of near-surface apparent electrical conductivity (EC_a) were performed at 10 borehole locations using EM38 and EM31 instruments (Geonics, Mississaugua, ON). The EM38 has nominal depths of investigation of 0.75 m and 1.5 m when operated in the horizontal and vertical dipole modes, respectively, while the EM31 has nominal depths of investigation of 3.0 and 6.0 m (Table 2). The instrument signal response is a function of several soil parameters, including temperature, texture (clay content), water content, and salinity. The effects of soil temperature differences between locations should be minimal as the surveys were conducted over a 6-week interval in mid-May and late June 2003.

Both EM instruments were operated with the instrument lying on the ground surface. Survey measurements were obtained at 3-m intervals along transect lines at various orientations depending upon site characteristics. At four borehole locations, four transect lines 30 m in length and oriented at 90-degree intervals were centered on the borehole location. At the other locations, overhead power lines (which significantly affect the EM instrument response) or other factors (irrigation equipment, roads, fences, pipelines) prevented this geometry and resulted in fewer survey points. The number of measurement points ranged from 10 to 42 at different borehole locations, with four instrument readings (EM38 VD, HD, EM31 VD, HD) obtained at each point.

Groundwater Sampling for Chloride, Nitrate, Tritium, and Helium Analyses

Groundwater samples were collected from five wells in Haskell County in the Seymour Aquifer for tritium and helium analysis (Fig. 5). A sampling pump (Redi-Flo2, Grundfos Pumps Corp., Olathe, KS) connected to a 25 mm ID garden hose was lowered to the mid-depth of the water column in each well. Approximately five well volumes were purged from each well prior to sample collection. Water samples were collected for He analysis in copper tubes (9.5-mm ID, 800-mm long). Water was allowed to flow through the sample tubes until there was no evidence of entrapped air. Samples were collected under pressure from the sample flow stream by applying backpressure to the pump with a valve downstream of the copper sample tube to ensure that dissolved gases remained under pressure in the sample. The sample tubes were then tightly sealed at both ends using refrigeration-tubing clamps and the protruding tube ends were filled with sample water, capped, and sealed with electrical tape. Each sample contained approximately 18 mL. Two 500 ml water samples were then collected from each well for tritium analysis

The samples were sent to the University of Utah Noble Gas Laboratory for tritium and helium analysis. Tritium was analyzed by the He ingrowth method by placing a 250 ml water sample in a container, removing any He, allowing tritium to decay to He for 2 months, and then measuring the He concentration. Helium concentrations were measured in the samples by initially removing water vapor and CO_2 at –95°C and –195°C, respectively. Then N_2 and O_2 were removed by reaction with a Zr-Al alloy. Ar and Ne were adsorbed onto activated charcoal at –195°C and at –233°C, respectively. Helium isotope ratios ($^3He/^4He$) and concentrations were analyzed on a VG 5400 rare-gas mass spectrometer. $^3He/^4He$ ratios are reported relative to the atmospheric ratio (R_{air}) using air helium as the absolute standard.

RESULTS AND DISCUSSION

Unsaturated Flow Modeling

Unsaturated flow modeling was conducted for 13 different study areas adjacent to 10 meteorological stations are located (Figs. 1 and 2). Mean annual precipitation at the different sites varied from 224 to 1184 mm/yr (Table 7). Variability in annual precipitation was greatest in semiarid regions in West Texas (coefficient of variation, CV: 0.35) whereas variability was fairly uniform throughout the rest of Texas (CV: 0.21 – 0.23) (Table 7). Summer precipitation (June – August) is dominant throughout Texas; percentages of summer precipitation range from 23 - 49 (Table 1). Potential ET was calculated using the Penman-Monteith equation in the UNSAT-H code and ranged from 2169 mm in west Texas to 1362 mm in east Texas (Table 7).

Table 7: Average results for the monolithic sand profile models including simulated average annual and seasonal recharge, simulated actual evaporation (*AET*), measured 30-yr average annual precipitation (1961-1990), calculated potential evapotranspiration (*PET*), and the ratio of *PET* to *AET*.

units: mm	*Annual Precip.*		*Annual Recharge*			*Winter Recharge Dec-Feb*			*Spring Recharge Mar-May*			*Summer Recharge Jun-Aug*			*Fall Recharge Sep-Nov*			*AET*		*PET*		*PET/AET*
Station	Ave	CV	Ave	CV	% Prec	Ave	CV	% Tot	Ave	CV	% Tot	Ave	CV	% Tot	Ave	CV	% Tot	Ave	CV	Ave	CV	
El Paso	224	0.35	54	0.22	24	15	0.63	28	15	0.65	28	13	0.50	24	11	0.38	20	180	0.20	2087	0.07	11.6
Midland	380	0.35	131	0.20	35	44	0.54	31	28	0.42	20	25	0.52	17	46	1.12	32	250	0.10	2169	0.06	8.7
Lubbock	474	0.23	175	0.24	37	56	0.30	30	33	0.22	17	30	0.64	16	67	0.68	36	301	0.10	2034	0.06	6.8
Amarillo	499	0.21	180	0.16	36	52	0.20	29	32	0.21	18	35	0.82	19	63	0.54	35	331	0.10	2096	0.06	6.3
Abilene	619	0.23	277	0.19	45	70	0.29	25	49	0.42	18	64	0.68	23	95	0.63	34	358	0.10	2132	0.06	6.0
Brownsville	676	0.24	345	0.19	51	82	0.33	24	54	0.41	16	73	0.81	21	136	0.77	39	340	0.10	1788	0.06	5.3
Austin	809	0.21	416	0.20	51	100	0.40	24	74	0.50	18	143	0.68	34	99	0.55	24	411	0.10	1732	0.05	4.2
Fort Worth	855	0.22	442	0.18	52	99	0.39	22	98	0.65	22	140	0.55	32	106	0.55	24	430	0.10	1819	0.07	4.2
Victoria	932	0.23	516	0.22	55	111	0.33	21	97	0.61	18	160	0.62	30	157	0.59	30	434	0.10	1651	0.08	3.8
Houston	1184	0.22	720	0.18	61	181	0.32	25	154	0.43	21	210	0.62	29	175	0.52	24	482	0.10	1362	0.06	2.8

CV: coefficient of variation, %Tot: percentage of total annual simulated recharge

Monolithic Sand and Silt Loam Profile Simulations

Recharge estimated using monolithic sand profiles without vegetation provides an upper bound on actual recharge because vegetation and layering in soils would generally reduce recharge. These simulations were used to assess the impact of climate alone on recharge. Potential recharge ranged from 54 mm/yr in west Texas to 720 mm/yr in east Texas (Table 8, Appendix C) that represented 24 to 61% of long-term average annual precipitation in these

Table 8: Simulated average annual recharge and actual evapotranspiration (*AET*) for the monolithic sand and silt loam profiles and measured 30-yr average annual precipitation.

Units: mm/yr	*Precip.*	*Sand*			*Silt Loam*		
		Recharge		*AET*	*Recharge*		*AET*
		Total	*% Precip*		*Total*	*% Precip*	
El Paso	224	54	24	180	32	14	200
Midland	380	142	37	250	143	38	242
Lubbock	474	186	39	302	127	27	356
Amarillo	499	180	36	331	119	24	388
Abilene	620	277	45	358	198	32	433
Brownsville	671	345	51	340	261	39	420
Austin	810	416	51	411	315	39	505
Fort Worth	855	442	52	430	335	39	531
Victoria	937	516	55	434	406	43	538
Houston	1184	720	61	482	594	50	600

regions. The lack of runoff in the simulated results was attributed to the high saturated hydraulic conductivity of the sand (5.87 m/d) relative to the applied precipitation intensity.

Mean annual potential recharge increased with precipitation (Fig. 10). The relationships between simulated recharge and precipitation can be described by either linear or power law

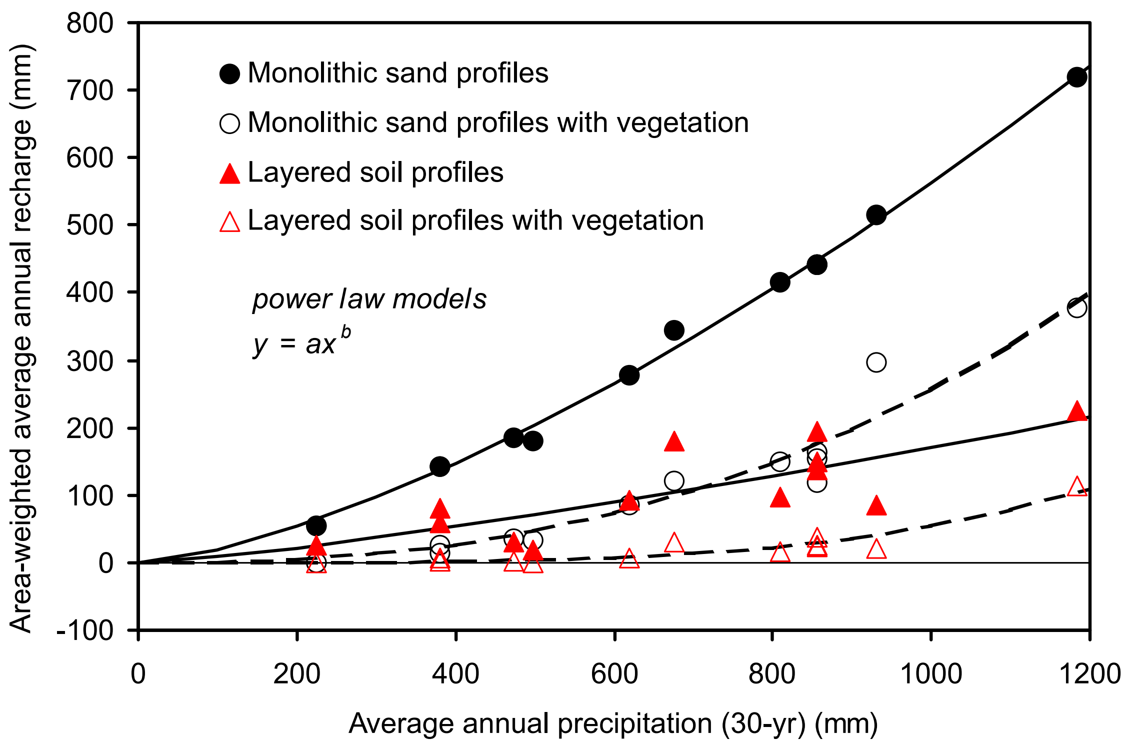


Figure 10: Relationships between precipitation and simulated area-weighted average annual recharge. Solid lines are models fit to the results for profiles without vegetation. Dashed lines are models fit to the results for profiles with vegetation.

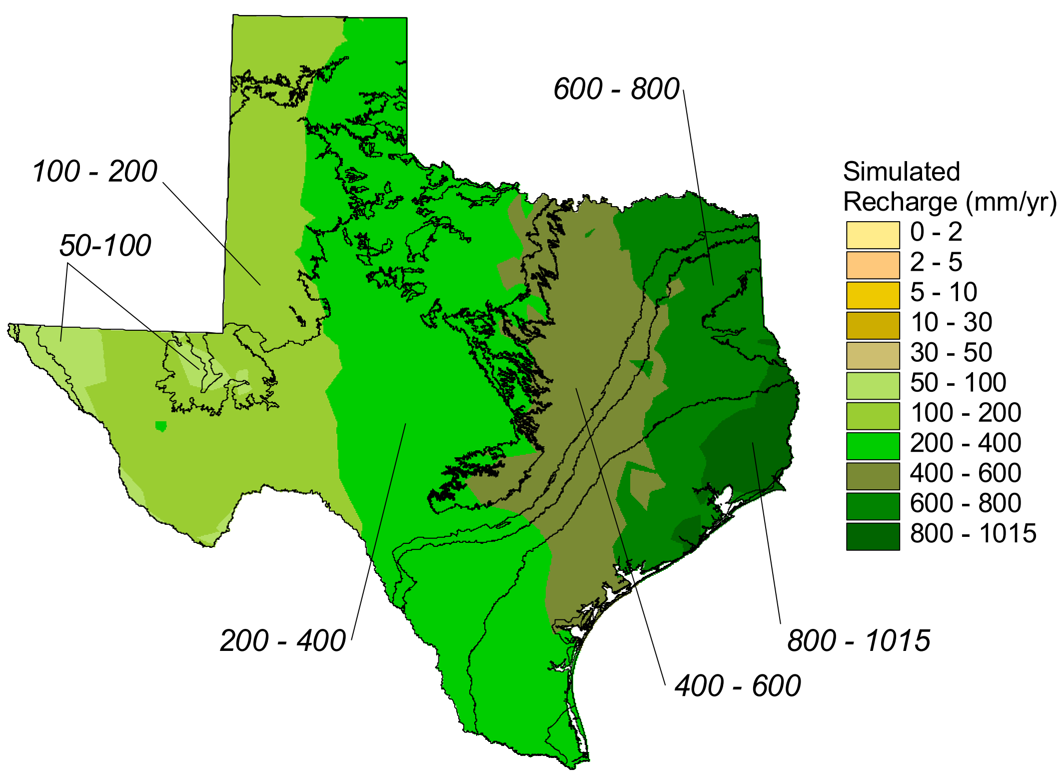
Table 9: Model coefficients and residual statistics for estimating recharge (*y, mm/yr*) from precipitation (*x, mm/yr*). The power law models are shown in Figure 10.

Model	*Modeling Scenario*	*Coefficients*		*R*	*Residual*	
		a	*b*		*σ*	$\lvert y_r \rvert$
Power Law ($y = ax^b$)	Monolithic sand profiles	2.266×10^{-02}	1.465	0.998	8.1	7.9
	Monolithic sand profiles with vegetation	9.855×10^{-06}	2.471	0.962	23.5	30.2
	Layered soil profiles	2.560×10^{-02}	1.275	0.788	26.7	18.9
	Layered soil profiles with vegetation	6.830×10^{-11}	3.964	0.949	6.7	6.4
Linear ($y = ax + b$)	Monolithic sand profiles	6.854×10^{-01}	-129.5	0.994	9.7	16.8
	Monolithic sand profiles with vegetation	3.823×10^{-01}	-135.9	0.928	25.3	31.5
	Layered soil profiles	1.927×10^{-01}	-23.5	0.786	25.3	32.1
	Layered soil profiles with vegetation	8.847×10^{-02}	-37.4	0.793	11.9	13.7

R: correlation coefficient, *σ:* standard deviation (mm/yr), $\lvert y_r \rvert$*:* average absolute deviation (mm/yr).

models; both result in high R values (Table 9). A linear model results in a threshold precipitation of 190 mm/yr before recharge occurs whereas the power law model suggests that recharge decreases to low levels as precipitation decreases.

Predictions from precipitation using the power law model resulted in recharge rates varying from 60 to 1015 mm/yr across Texas (Fig. 11). Simulated recharge was more highly correlated



with winter precipitation (R = 0.97) and fall precipitation (R = 0.97) than with spring (R = 0.93) or winter precipitation (R = 0.76). Runoff estimates from previous statewide water balance simulations ranged from zero in west Texas to 415 mm/yr in east Texas (Reed et al., 1997); therefore, these simulated recharge values are expected to overestimate actual recharge, particularly in east Texas where much of the water runs off. Variability in annual recharge is similar throughout the state and is similar to variability in precipitation (Table 8). Potential *ET* is much greater than simulated actual *ET*; the *PET/AET* ratio decreased from west to east and ranged from 11.6 in El Paso to 2.8 in Houston. The negative correlation between *PET* and *AET* is attributed to *AET* being controlled by water availability throughout much of the state and not energy availability as represented by *PET*.

Simulated recharge for a monolithic silt loam soil was less than that of the monolithic sand profile by up to a factor of 1.7. Simulated recharge ranged from 32 mm/yr in west Texas to 594 mm/yr in east Texas (Table 8), which represented 14 to 50% of long-term average annual precipitation in these regions. No runoff was simulated probably because precipitation intensity was less than the saturated hydraulic conductivity (0.43 m/d). Mean annual recharge was positively correlated with mean annual precipitation (R 0.99).

Layered Soil Profile Without Vegetation Simulations

Soil profiles in most regions are generally layered; therefore, simulations using layered profiles are more realistic than those based on monolithic profiles. Layering of soil profiles should generally reduce recharge relative to monolithic sand profiles. Layering of coarse-

Table 10: Simulation results for the layered soil profiles without vegetation.

Units: mm/yr Study Area	*Precip*	*Recharge* Total	% Precip	*Runoff*	*Evap*
El Paso County	224	27	12	0.1	190
Midland County	380	59	16	8	329
Cenozoic Pecos Alluvium	380	81	21	15	276
Lubbock County	474	31	7	59	288
Carson County	497	18	4	259	241
Fisher/Jones Counties	619	93	15	169	380
Starr County	676	179	26	30	466
Bastrop County	809	96	12	147	625
Parker County	855	150	18	146	606
Hopkins/Rains Counties	855	138	16	49	672
Upshur/Gregg Counties	855	195	23	26	653
Victoria County	932	84	9	431	439
Liberty County	1184	226	19	316	687

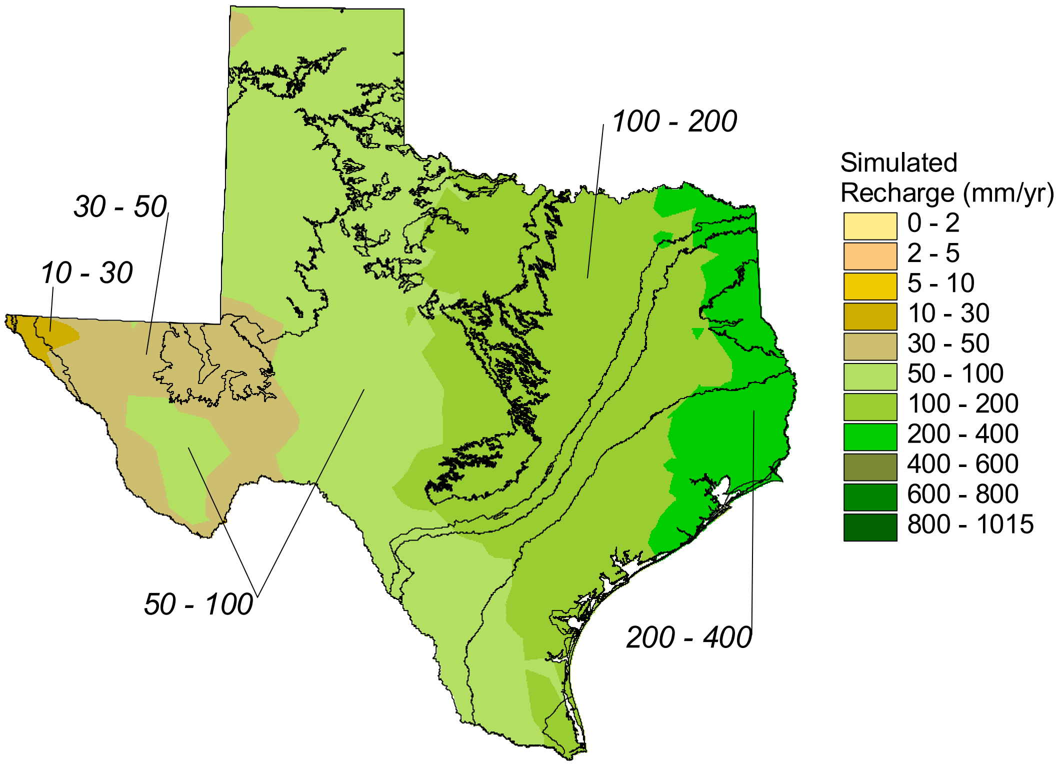


Figure 12: Predicted recharge using the power law relationship between precipitation and simulated recharge for the layered soil profiles modeling results.

grained material over fine-grained material should reduce recharge because of perching on fine-grained material. Layering of fine-grained material over coarse-grained material should also reduce recharge because of capillary barrier effects; matric potential at the fine/coarse interface has to reach the water entry pressure of the underlying coarse material before it can move into the underlying coarse material. Soil texture profiles were obtained from SSURGO for most sites, with the exception of the Cenozoic Pecos Alluvium aquifer where only STATSGO data were available. The number of soil profiles representing ~ 80% of the area of each county ranged from 6 to 29. Profiles with similar recharge results from the base soil simulations were grouped into categories, which resulted in 3 to 7 representative profiles for each site. Simulated recharge from different groups in a single study area varied over 1 to 2 orders of magnitude (Appendix C). The simulated recharge from each group was area-weighted resulting in an average recharge for each study area. Recharge ranged from 18 to 226 mm/yr and correlated with precipitation (R = 0.79; Fig. 10). Simulated recharge for the layered profiles ranged from 4 to 26% of precipitation for the various sites. Simulated recharge was reduced in the layered profiles relative to those for monolithic sand by factors ranging from 2 to 10. Predictions from precipitation using the power law model (Table 9) resulted in recharge rates varying from 24 to 285 mm/yr across Texas (Fig. 12).

Simulated runoff in the various sites generally reflects differences in climate and texture in the state. Simulated runoff was low in El Paso County (0.1 mm/yr) and the Cenozoic Pecos Alluvium (15 mm/yr) where soils have low clay content and are fairly coarse grained (Fig. 3, Table 10). Higher runoff was simulated in the central portion of the High Plains in Carson County (259 mm/yr) where soils are fine grained and corresponds to the distribution of the Blackwater Draw Formation. Simulated runoff decreased to the south as the soils become coarser grained (Lubbock, 59 mm/yr; Midland, 8 mm/yr). Simulated runoff in central Texas was moderately high and variable (Fisher/Jones Counties, 169 mm/yr; Parker County, 146 mm/yr; Bastrop County, 147 mm/yr). Simulated runoff was moderately low in east Texas (Hopkins/Rains Counties, 49 mm/yr; Upshur/Gregg, 26 mm/yr). Variability in simulated runoff in the Gulf Coast sites is related to soil texture; low runoff in the southern Gulf Coast (Starr County, 30 mm/yr) where soils are coarse grained and higher runoff in central (Victoria County, 431 mm/yr) and northern (Liberty County, 316 mm/yr) Gulf Coast where the soils are finer grained and correspond to the distribution of the Beaumont Formation.

Monolithic Sand Profile with Vegetation Simulations

To assess the impact of vegetation without the influence of soil layering, simulations were conducted of recharge in the vegetated monolithic sand profile. Vegetation types were separately simulated and the results were combined in areas having multiple vegetation types, such as trees and grasses. Vegetation greatly reduced simulated recharge at each site relative to simulated recharge for the bare sandy soil by factors ranging from 2 to 11, with the exception

Table 11: Simulation results for monolithic sand profiles with vegetation. All runoff was zero. *R/P* represents the ratio of recharge to precipitation expressed as percentage.

Units: mm/yr	*P*	*Dryland*				*Irrigated*		
Study Area		*R*	*R/P*	*E*	*T*	*R*	*E*	*T*
El Paso County	224	0	0	133	103			
Midland County	380	14	4	166	221	20	172	247
Cenozoic Pecos Alluvium	380	27	7	198	271			
Lubbock County	474	36	8	189	270	77	234	449
Carson County	497	33	7	203	287	61	228	391
Fisher/Jones Counties	619	86	14	260	297	89	260	299
Starr County	676	120	18	229	344			
Bastrop County	809	150	19	203	501			
Parker County	855	153	18	246	480			
Hopkins/Rains Counties	855	164	19	263	453			
Upshur/Gregg Counties	855	118	14	229	534			
Victoria County	932	296	32	304	358			
Liberty County	1184	377	32	247	382			

P: precipitation, *R*: recharge, *E*: evaporation, *T*: transpiration of El Paso where recharge changed from 54 mm/yr to zero (Table 11). The reduction in recharge results from increased ET; no runoff was simulated in these sandy profiles. The relative amounts of evaporation and transpiration also varied with vegetation type. Transpiration was much greater than evaporation for trees.

These data show that the presence or absence of vegetation has a large impact on the simulated recharge; however, the type of vegetation also greatly affected simulated recharge as shown by the range in simulated recharge by 1 to 2 orders of magnitude for different types of vegetation between each site (Appendix C). Shrubs were very effective in reducing recharge because of the length of the growing season relative to crops. Different crop types also varied in their effectiveness in reducing recharge: sorghum resulted in more recharge relative to cotton (factor of 3 difference in Lubbock) which is attributed to the shallower depth of the root zone in sorghum (1.5 m) relative to that in cotton (2.1 m). Grasses generally resulted in large recharge amounts because of their shallow root zone (≤ 1 m) whereas simulated recharge for areas with trees was generally low because of deeper roots (≤ 4.3 m). Simulated recharge for vegetated sand profiles at each site ranged from 0 to 32% of precipitation. Predictions from precipitation using the power law model (Table 9) resulted in recharge rates varying from 5 to 692 mm/yr across Texas (Fig. 13).

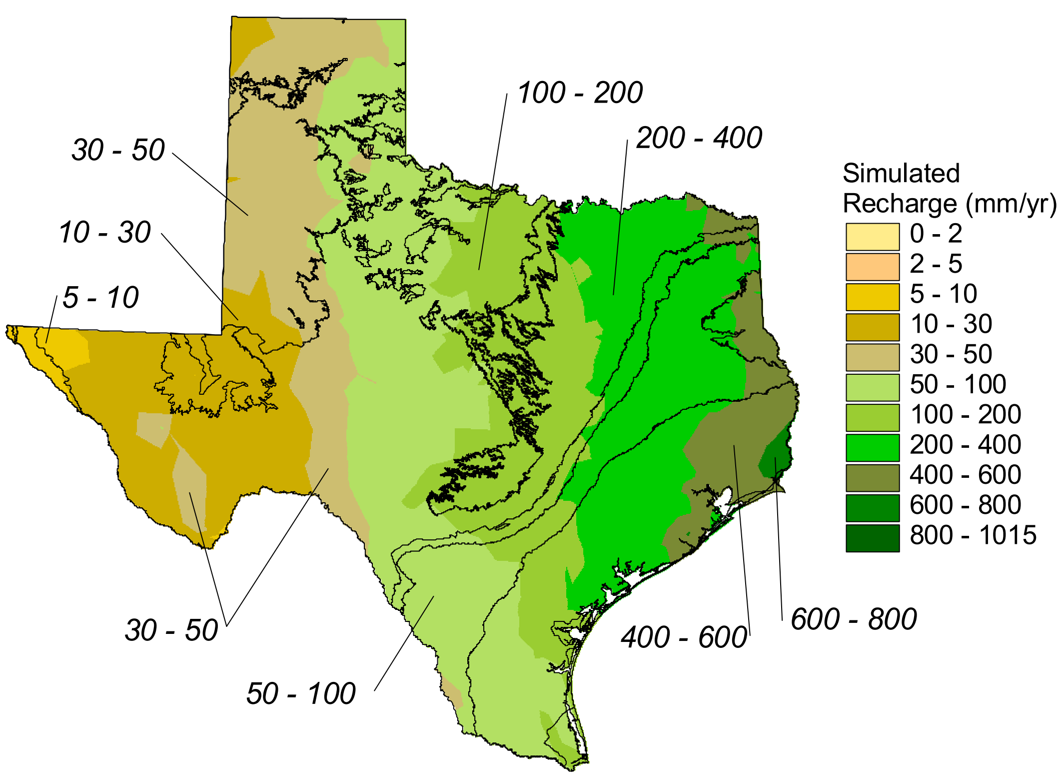


Figure 13: Predicted recharge using the power law relationship between precipitation and simulated recharge for the monolithic sand profiles with vegetation modeling results.

Layered Soil Profiles with Vegetation Simulations

The layered profiles with vegetation are the most realistic representations of the actual conditions and should provide the most reliable recharge estimates for the different regions. Soil profiles with similar recharge were grouped into categories. Vegetation associated with these soil profiles was estimated using GIS overlay analysis. Recharge rates range from a minimum of 0.2 mm/yr in El Paso to a maximum of 114 mm/yr in east Texas (Liberty County) (Table 12). Simulated recharge was generally low in semiarid regions (0.2 to 7 mm/yr) and higher in more humid regions (16 to 114 mm/yr) (Table 12). Simulated recharge rates for the layered soil profiles with vegetation were correlated with precipitation (Fig. 10; R = 0.95). Predictions from precipitation using the power law model (Table 9) resulted in recharge rates varying from 0 to 262 mm/yr across Texas (Fig. 14).

Simulated average recharge rates for the 30-yr period represented 0.1 to 9.6% of the applied precipitation. The addition of vegetation greatly reduced the simulated recharge relative to the layered profiles without vegetation (Fig. 10; Table 10). Reduction factors ranged from 2 to 7 in the more humid settings (Gulf Coast, Carrizo Wilcox, Trinity aquifers) and ranged from 11 to 109 in the more arid regions (Ogallala, Seymour, Cenozoic Pecos Alluvium, and Hueco Bolson aquifers).

Variability in recharge simulated for different vegetation types averaged for the various soil profiles was generally within an order of magnitude. Different vegetation types varied in their effectiveness in reducing recharge (Appendix C). Semiarid regions with shrubs resulted in

Table 12: Simulation results for layered profiles with vegetation. *R/P* represents the ratio of recharge to precipitation expressed as percentage.

Units: mm/yr	*P*	*Dryland*					*Irrigated*			
Study Area		*R*	*R/P*	*RO*	*E*	*T*	*R*	*RO*	*E*	*T*
El Paso County	224	0.2	0.1	0	119	89				
Midland County	380	2	0.5	5	192	201	4	5	199	216
Cenozoic Pecos Alluvium	380	7	1.8	13	179	186				
Lubbock County	474	1	0.2	55	164	148	6	116	208	235
Carson County	497	0.5	0.0	244	148	125	0.5	367	158	148
Fisher/Jones Counties	619	7	1.1	179	262	197	7	180	262	199
Starr County	676	31	4.6	31	303	221				
Bastrop County	809	16	2.0	192	307	327				
Parker County	855	27	3.2	162	352	361				
Hopkins/Rains Counties	855	24	2.8	59	403	386				
Upshur/Gregg Counties	855	38	4.4	27	325	491				
Victoria County	932	21	2.3	401	310	227				
Liberty County	1184	114	9.6	325	318	432				

P: precipitation, *R*: recharge, *RO*: runoff, *E*: evaporation, *T*: transpiration

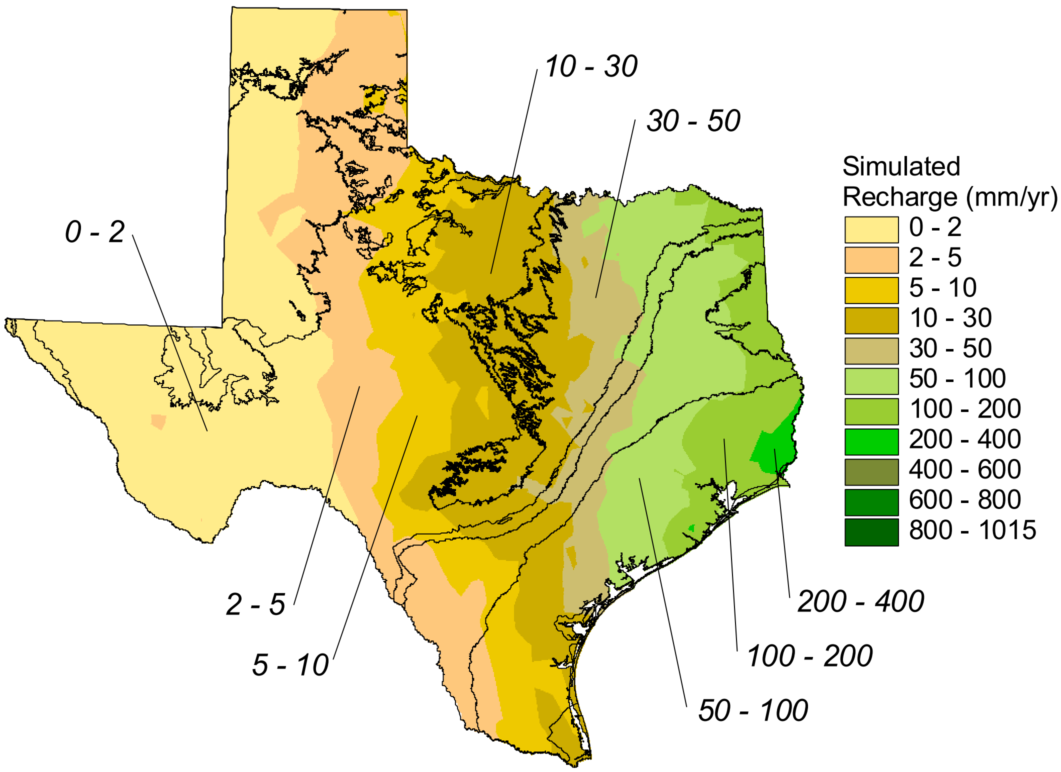


Figure 14: Predicted recharge using the power law relationship between precipitation and simulated recharge for the layered soil profiles with vegetation modeling results.

negligible recharge (< 1 mm/yr). Sorghum resulted in slightly higher recharge than cotton (factor of 2 in Lubbock), which is attributed to shallower rooting depth in sorghum (1.5 m) relative to cotton (2.1 m). Grasses resulted in much higher recharge than trees in more humid settings. For example, in Parker County in the Trinity aquifer simulated recharge in grasses ranged from 1 to 197 mm/yr for different soil profiles whereas simulated recharge for Oak/Mesquite/Juniper and Post-Oak woodland forest was zero.

Sensitivity Analyses Based on Vegetation Parameters

Previous analyses evaluated the impact of precipitation, soils, and vegetation on simulated recharge by isolating the effect of each of these parameters in successive simulations. Sensitivity analyses were conducted to evaluate the impact of varying vegetation parameters such as leaf area index, root depth, root length density, and percent bare area on simulated recharge. These analyses were conducted on four soil profiles representing the range of simulated recharge rates in the Fisher/Jones counties area of the Seymour aquifer using brush vegetation typical of the region. Parameters were decreased by 50 percent and increased by 150 percent, with the exception of percent bare area which is zero for the base case and was increased by 25% and 50% in the sensitivity analyses (Table 13, Fig. 15).

Table 13: Sensitivity of recharge to variations in LAI, RD, RLD, and BA for four soil profiles. Factor refers to the ratio of annual recharge including the effect (e.g., LAI × 50%) to the base case annual recharge. Variable/constant indicates that a parameter changes or is held constant with time or depth during the simulated period.

Units: mm/yr	*Base Case Recharge*	*Effect* *Recharge*	*Factor*	*Effect* *Recharge*	*Factor*
		50% LAI		150% LAI	
Leaf Area Index (LAI) time variable	0.9	1.6	1.9	0.7	0.8
	4.0	9.0	2.3	2.8	0.7
	17.4	30.1	1.7	13.1	0.8
	26.9	42.9	1.6	21.0	0.8
		50% RD		150% RD	
Root Depth (RD) time constant	0.9	12.6	14.6	0.1	0.1
	4.0	17.4	4.4	1.0	0.2
	17.4	39.9	2.3	6.8	0.4
	26.9	55.3	2.1	13.3	0.5
		50% RLD		150% RLD	
Root Length Density (RLD) time constant depth variable	0.9	1.0	1.1	0.8	0.9
	4.0	4.2	1.1	3.7	0.9
	17.4	18.0	1.0	17.1	1.0
	26.9	30.2	1.1	25.7	1.0
		25% BA		50% BA	
% Bare Area (BA) time constant	0.9	1.4	1.6	7.9	9.2
	4.0	7.5	1.9	26.2	6.6
	17.4	27.4	1.6	51.6	3.0
	26.9	39.6	1.5	65.6	2.4

Simulated recharge was more sensitive to decreasing LAI than increasing LAI. Decreasing LAI by 50% resulted in an average doubling of recharge whereas increasing LAI resulted in an average decrease in recharge by 0.8. Simulated recharge was most sensitive to variations in root depth. Decreasing root depth by 50% resulted in an average increase in recharge of a factor of 6 whereas increasing root depth by 150% decreased recharge by a factor of 0.3. The inverse relationship between root depth and simulated recharge is expected because decreasing root depth allows water to drain more readily below the root zone. Simulated recharge was fairly insensitive to variations in root length density. Percent bare area had a large impact on simulated recharge. Increasing percent bare area by 25% increased recharge by an average factor of 1.6 whereas increasing bare area by 50% increased recharge by an average factor of 5.

This analysis indicates that accurate estimates of root depth and percent bare area are critical for reliable simulations of recharge. Percent bare area can be estimated from fractional vegetation coverage using satellite data such as AVHRR or MODIS. However, accurate

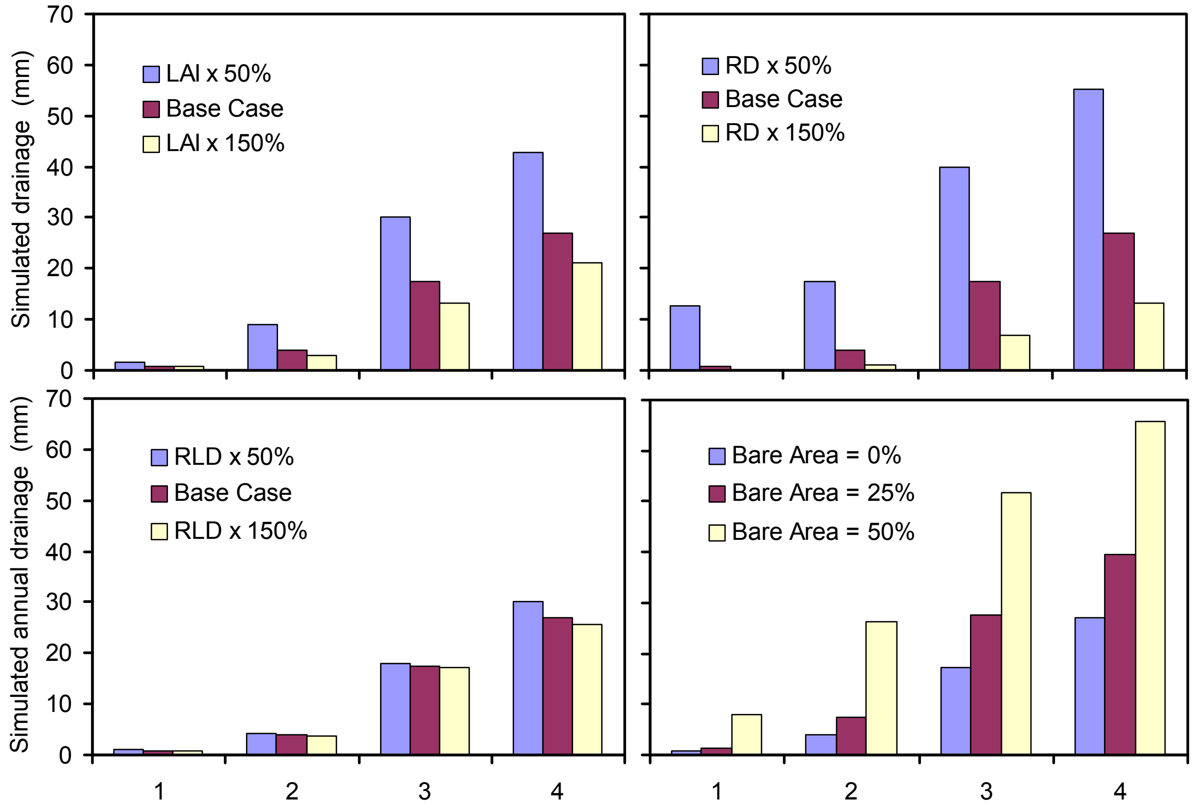


Figure 15: Recharge sensitivity analysis results

estimates of rooting depth are very difficult to obtain. There are very few techniques available to estimate rooting depth. The traditional approach requires manual measurement of roots in soils and is labor intensive and time consuming. Minirhizotrons can be installed in the subsurface to estimate root distribution using cameras; however, some have suggested that these instruments induce root growth suggesting that the measurements may be an artifact of the instrumentation.

Recharge Estimates Based on Field Studies in the Southern High Plains and Seymour Aquifers

Field studies were conducted in the Southern High Plains and Seymour settings to estimate groundwater recharge. The studies included unsaturated zone sampling for texture, water content, matric potential, chloride, and nitrate (Appendix D), and electromagnetic induction surveys (Appendix E) at both sites. Unsaturated zone monitoring of water content and matric potential and groundwater sampling was also performed in the Seymour setting.

Sediments at both sites were generally coarse grained and ranged from sandy loam to sand in the Seymour setting and sandy clay loam to sandy loam at the Southern High Plains site. Sediments in the Seymour setting were slightly coarser grained (mean sand content 80%) than those in the Southern High Plains setting (mean sand content 70%). In the Seymour setting all profiles with the exception of H7 were located on sand dunes. Profile H7 is located east of the sand dunes (Fig. 5) and had lower sand content and higher clay content than the other profiles (Table 14). One of the profiles in the Southern High Plains setting was also located in hummocky dune settings (D7) and had high sand content. Vertical profiles in soil texture were fairly uniform in both the Southern High Plains and Seymour regions with limited layering in some profiles.

Table 14: Borehole sampling results summary: measured average values for soil texture, water content, matric potential head, and chloride and nitrate-nitrogen concentrations in soil water. Calculated recharge based on chloride concentrations below the root zone (≥1.5m depth). Borehole designation D: Dawson County, Southern High Plains; H: Haskell County, Seymour.

Setting	*Borehole*	*Texture (%)*			*Water Content (g/g)*			*Matric Potential Head (m)*			*Chloride (mg/L)*			*Nitrate-N (mg/L)*			*Recharge (mm/yr)*
		Sand	*Silt*	*Clay*	*Ave*	*Min*	*Max*	*Ave*	*Min*	*Max*	*Ave*	*Min*	*Max*	*Ave*	*Min*	*Max*	
Natural	D7	74	12	14	0.07	0.02	0.12	-208	-305	-154	53	13	194	7.6	0.6	68	4.1
	D12	77	7	16	0.06	0.02	0.09	-270	-552	-52	909	35	2344	10	2.3	34	0.1
	D13	69	15	16	0.08	0.03	0.12	-269	-475	-146	159	36	307	33	1.5	74	0.8
Dryland	D2	69	13	18	0.13	0.03	0.21	-2.0	-3.5	-0.1	9.7	3.8	49	36	7.9	151	28
	D3				0.08	0.02	0.15				39	5.4	237	12	0.7	140	9.2
	D4				0.08	0.03	0.10				39	14	61	12	1.3	40	4.4
	D5	57	20	23	0.13	0.09	0.19	-2.3	-4.5	-0.1	8.4	3.6	15	2.3	0.3	4.7	24
Irrigated	D6	73	9	18	0.08	0.01	0.13	-2.8	-4.6	-1.5	316	11	1550	90	5.9	313	
Natural	H5	90	3	7	0.06	0.01	0.15	-0.8	-1.0	-0.2	13	5.6	38	1.6	0.6	8.0	30
Dryland	H1	81	6	13	0.07	0.02	0.12	-1.8	-4.4	-0.7	30	3.1	286	3.3	0.7	9.9	20
	H3	78	7	15	0.08	0.02	0.15				27	5.9	125	2.8	0.2	23	14
	H4				0.09	0.02	0.16				23	3.4	55	9.8	3.4	33	26
	H7	72	11	17	0.08	0.02	0.17				52	14	250	47	0.2	219	5.2
Irrigated	H6	77	8	15	0.10	0.05	0.15	-1.2	-2.1	-0.4	80	30	202	33	2.1	106	

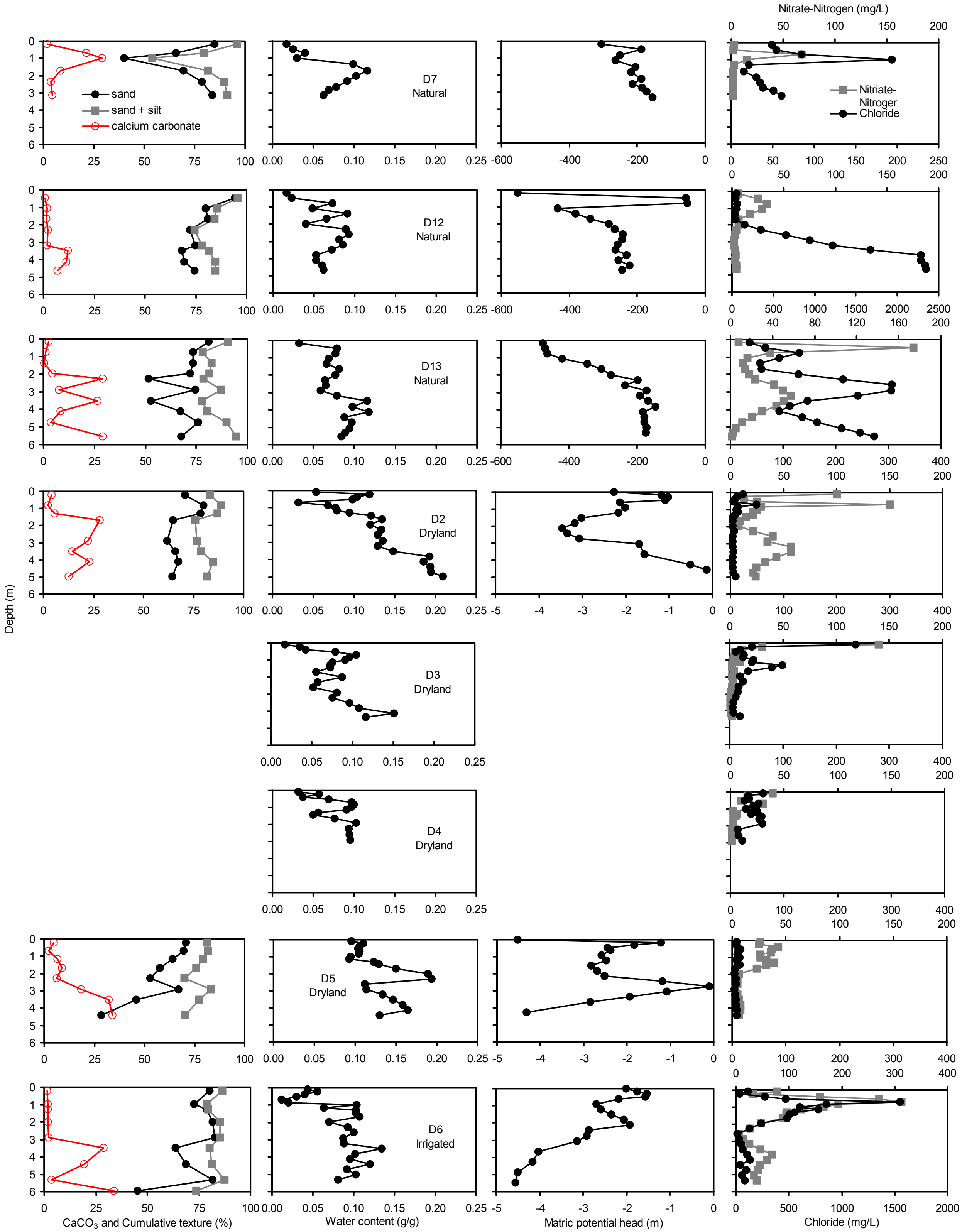


Figure 16: Southern High Plains borehole sample analysis results.

The range in measured average water contents in both the Seymour and Southern High Plains settings was low (0.06 – 0.13 g/g) and was similar in both settings. The lowest average water contents were in the natural sites at both locations (0.06 to 0.08 g/g). Average water contents in the Southern High Plains dryland settings ranged from 0.08 to 0.13 g/g and the irrigated setting average water content was 0.08 g/g. In the Seymour dryland settings, average water content ranged from 0.07 to 0.09 g/g and in the irrigated setting average water content was 0.10 g/g and the highest water contents were in the irrigated sites. Water content profiles in both the Southern High Plains and Seymour settings were quite variable with depth; some

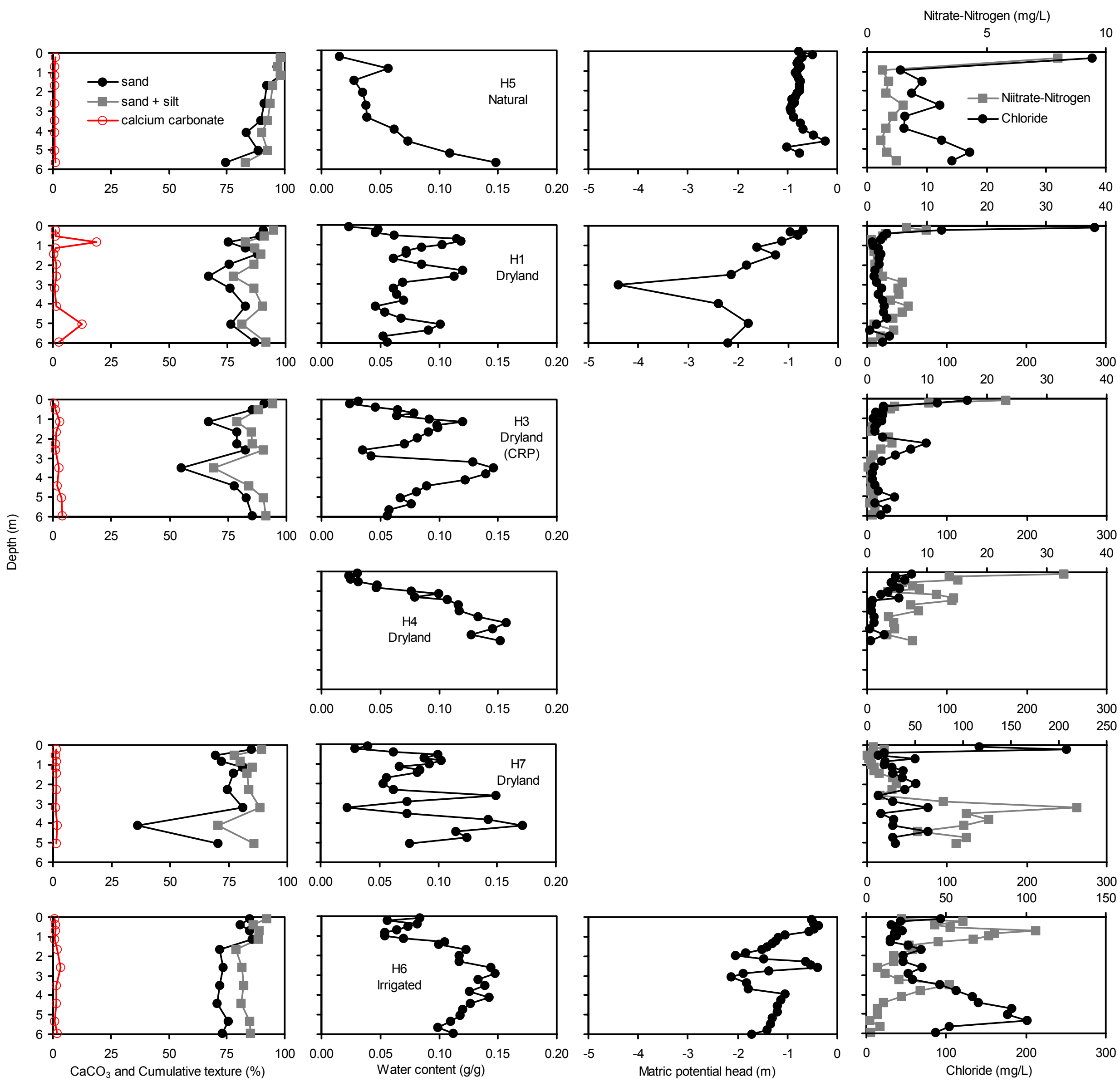


Figure 17: Seymour borehole sample analysis results.

profiles showed increasing water content with depth whereas others were multi-peaked (Figs. 16 and 17).

In the Southern High Plains, matric potentials were high in dryland and irrigated sites (–2 to –2.8 m) and low in natural sites (–208 to –270 m) (Table 14, Figs. 16 and 17). The difference in matric potentials among different land use sites in the Southern High Plains is consistent with water content variations between land use sites. Vertical matric potential profiles in the natural sites in the Southern High Plains generally showed increasing matric potentials with depth which represents an upward driving force for water movement. In contrast, vertical profiles in the dryland and irrigated sites showed decreasing matric potentials with depth that indicate a downward driving force for water movement. Average matric potentials were uniformly high in all measured profiles in the Seymour setting (–0.8 to –1.8 m). There was no consistent trend in vertical matric potential profiles in the Seymour setting.

Spatial variability in water content in the Southern High Plains setting was controlled primarily by land use (Fig. 18). While statistically significant ($p \leq 0.02$), the correlations between water content and clay content ($R = 0.35$) and sand content ($R = -0.46$) were not high and tended to be grouped in relation to land use. Spatial variability in water content in the Seymour setting was controlled primarily by differences in sediment texture. Variations in water content in

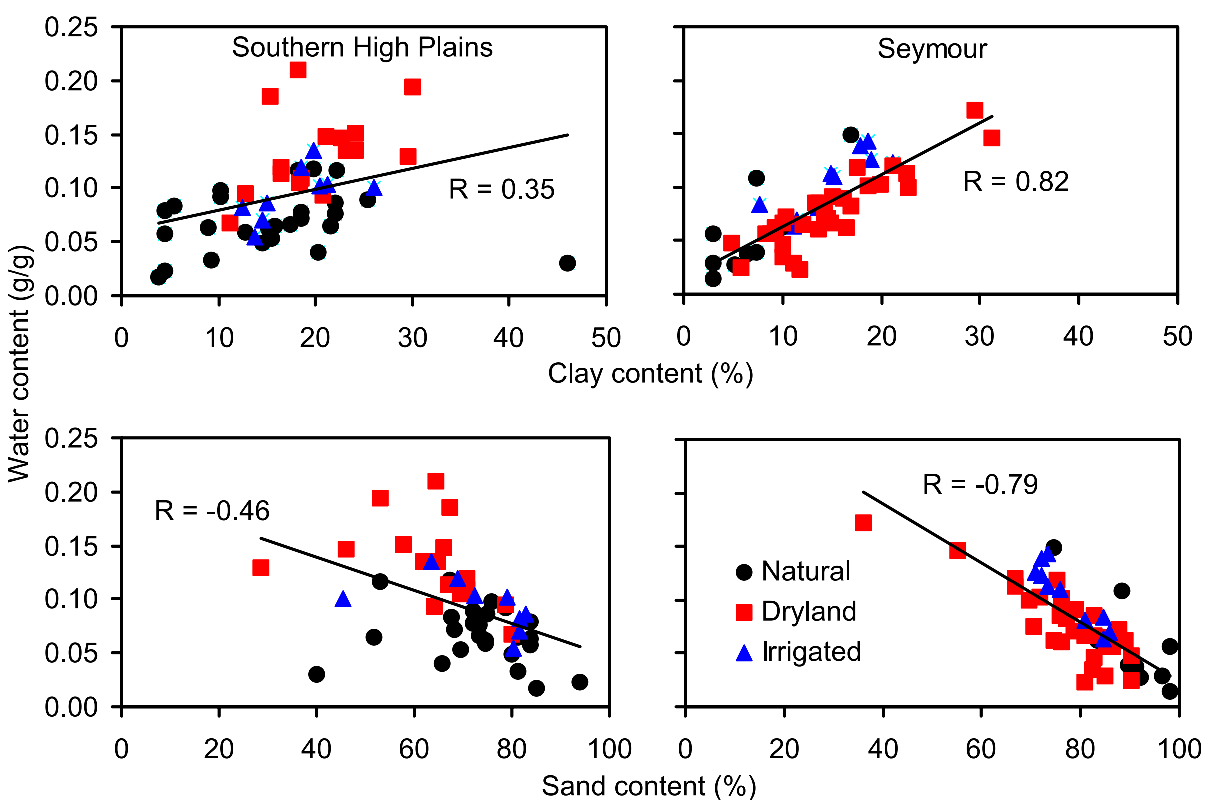


Figure 18: Relationship between texture and water content.

the Seymour setting were negatively correlated with percent sand (R = -0.79) and positively correlated with percent clay (R = 0.82), with both correlations significant to $p < 0.001$.

Average chloride concentrations in the Southern High Plains were highest in the natural sites (53 to 909 mg/L) and in the irrigated site (316 mg/L) with lower chloride concentrations in the dryland sites (8.4 to 39 mg/L). Average chloride concentrations in the Seymour setting were generally low in the non-irrigated sand dune sites (13 to 30 mg/L), slightly higher to the east of the sand dune (52 mg/L), and highest in the irrigated site (80 mg/L). Vertical chloride profiles were quite variable. The irrigated sites in both settings and the natural sites in the Southern High Plains setting showed bulge-shaped profiles while the natural site in the Seymour setting and all of the dryland sites of both settings showed less variability of chloride concentration with depth.

The chloride results are consistent with the soil physics data in the Southern High Plains and indicate that land use is the primary control on water content, matric potential heads, and chloride concentrations (Fig. 19). The dryland sites (D2, D5) have high matric potential heads and low chloride indicating high water flux. The irrigated site (D6) has high matric potential head and higher chloride attributed to evapoconcentration and to fertilizers. The natural sites (D7, D12, D13) have low matric potential head and generally high chloride indicating low water flux. In the Seymour aquifer, low chloride concentrations in the dryland site (H1) are also consistent with the uniformly high matric potentials heads in these sites. High matric potential head and low chloride in the irrigated site (H6) is also attributed to evapoconcentration and to

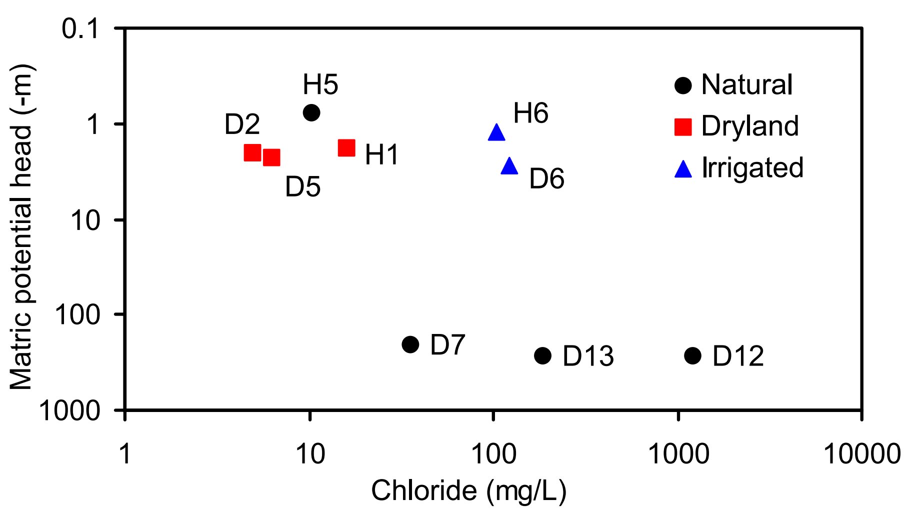


Figure 19: Average chloride concentrations below 1.5 m depth versus average water potential for the Southern High Plains (Dawson County, D) and Seymour (Haskell County, H) settings.

fertilizers. The single natural site in the Seymour setting (H5) differs from those in the Southern High Plains and has high matric potential head and low chloride indicating high water flux.

Recharge rates calculated using the chloride mass balance approach (equation 5) indicate that water fluxes in the Southern High Plains setting varied with land use: low recharge rates in the natural sites (0.1 to 4 mm/yr) and higher recharge rates in the dryland sites (4 to 28 mm/yr). Water fluxes were highly (positively) correlated with average water content in the Southern High Plains ($p < 0.01$) (Fig. 20). Plots of recharge rates versus soil texture for the Southern High Plains setting showed that the sites were segregated by land use and correlations between water flux and average texture were low and not significant (sand content: $p = 0.23$, clay

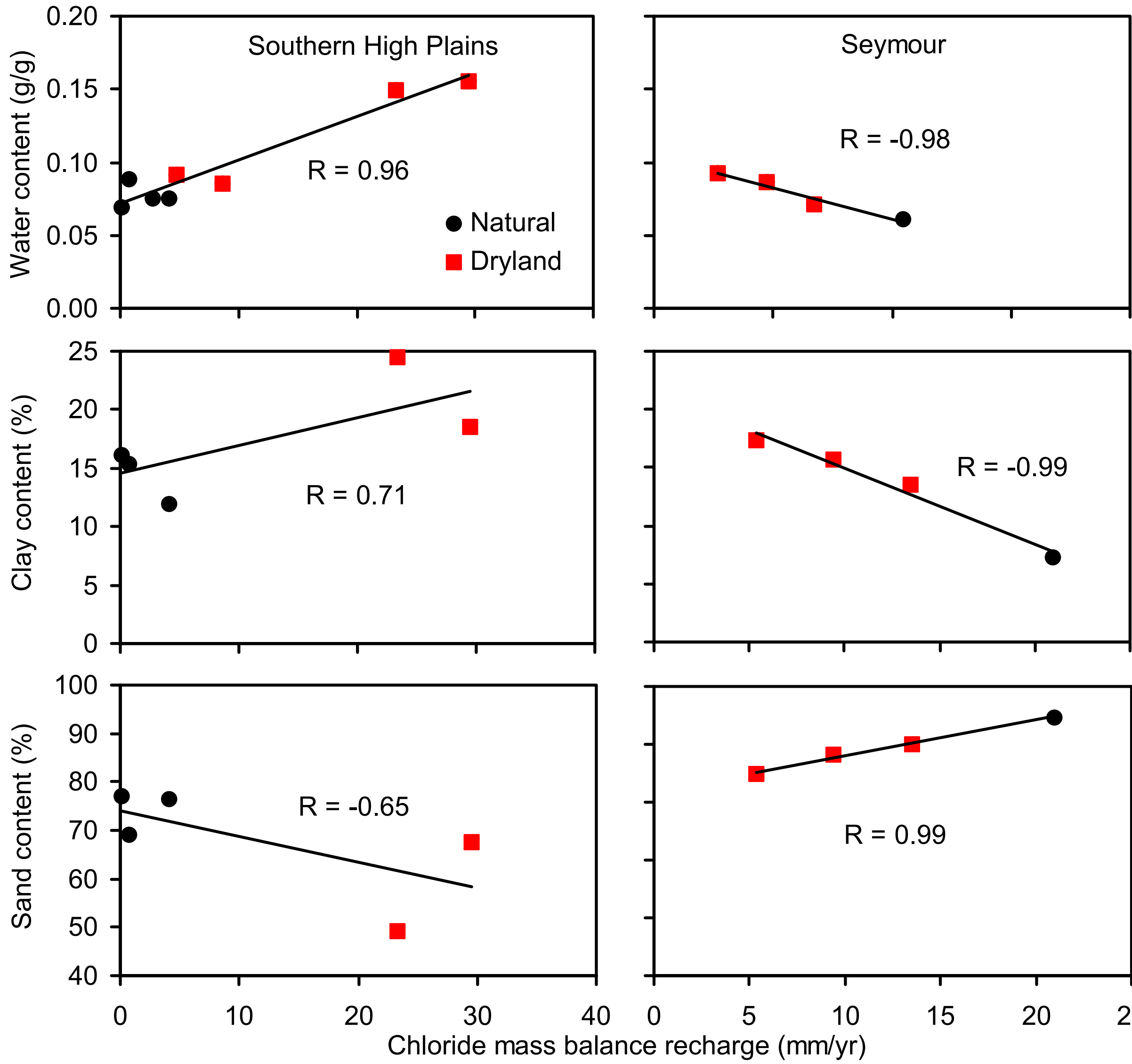


Figure 20: Relationship between estimated recharge and water content and soil textures at the Southern High Plains and Seymour locations.

content: $p = 0.18$). Recharge rates were generally high (5 to 30 mm/yr) throughout the Seymour setting and were highly (negatively) correlated with average water content and with soil texture (negatively correlated with clay content and positively correlated with sand content) and the correlations were significant to $p \leq 0.02$. Recharge could not be estimated accurately for the irrigated sites due to the unknown input of chloride included in fertilizers (potash, KCl).

The contrast between the slopes of the water content versus recharge rate relationships of the Southern High Plains and the Seymour settings indicates that different mechanisms control recharge at each location. In the Southern High Plains, the availability of water below the root zone is the controlling factor. Cultivation has increased the permeability of the soils and caused water contents below the root zone to increase resulting in higher recharge rates relative to the natural (uncultivated) settings. In the Seymour, texture is the controlling factor. Increased water contents below the root zone are related to increased clay contents and decreased sand contents resulting in lower permeability and lower recharge rates.

The time required to accumulate chloride in each of the profiles to the bottom of the profile was also calculated. Low water fluxes generally correspond to large accumulation times or chloride mass balance ages. Ages for the Southern High Plains varied with land use with lower ages for the dryland sites (47 to 96 yr) and greater ages for the natural sites (164 to 2767 yr). Ages for the dryland Seymour sites (35 to 132 yr) were greater than for the natural site (33 yr).

There is no clear pattern in nitrate profiles among the different land use settings. Mean nitrate concentrations expressed as elemental nitrogen were generally higher in the Southern High Plains setting: 7.6 to 33 mg/L in the natural sites, 2.3 to 36 mg/L in the dryland sites, and 90 mg/L in the irrigated site. Nitrate concentrations were generally lower (1.6 to 9.8 mg/L) in the Seymour setting with the exception of one of the dryland sites (47 mg/L) and the irrigated site (33 mg/L). The irrigated sites in both settings had high nitrate concentrations. Relationships between nitrate and chloride concentrations were variable. Some profiles had highly correlated nitrate and chloride profiles (D6, D7, D13, H5, H3) whereas profiles at other sites were either offset in depth or not related. Spatial variability in nitrate concentrations may be related to variations in nitrogen loading and flushing/evapoconcentration.

Apparent electrical conductivity measured with the EM38 and EM31 instruments varied with the penetration depth of the instruments and showed increasing conductivity with depth at all sites (Fig. 21, Appendix E). Apparent electrical conductivity was generally higher in the Southern High Plains setting than in the Seymour setting. The natural site in the Seymour setting had the lowest apparent conductivity whereas conductivity at the other sites was higher

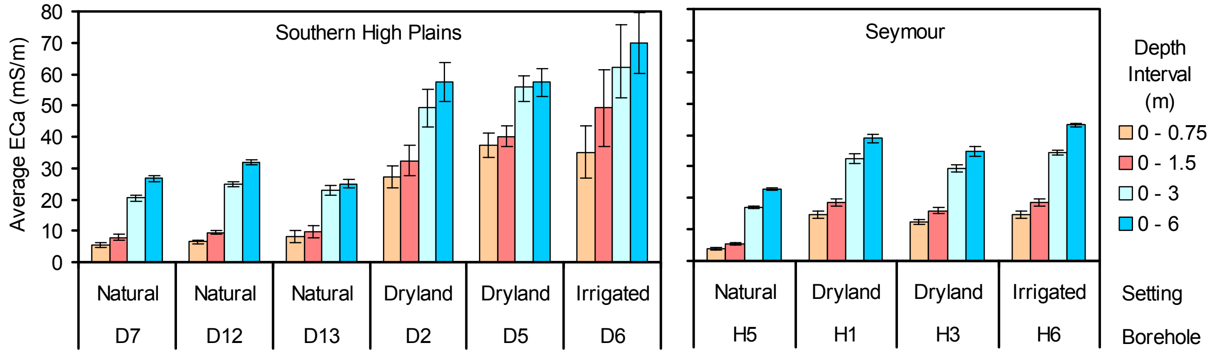


Figure 21: EM Survey results. Column heights represent average survey values. Error bars represent standard deviation (± 1σ)

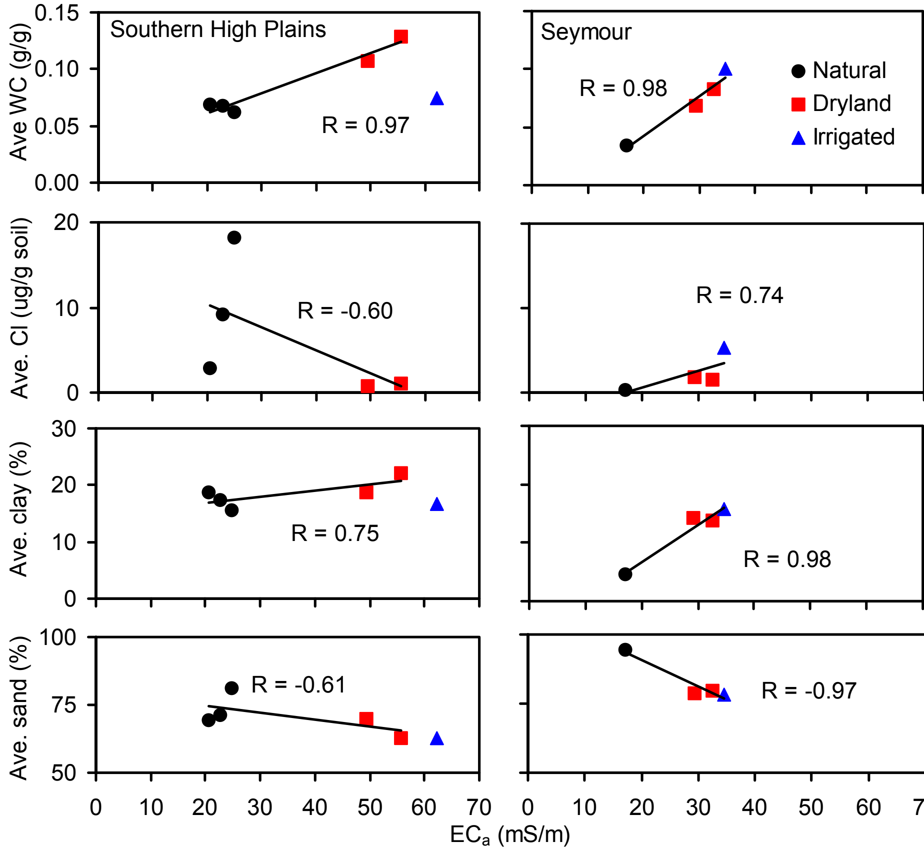


Figure 22: Correlation between apparent electrical conductivity (EC_a, EM31 horizontal dipole mode reading) and average water content, salinity (chloride), and texture in the upper 3 m. The irrigated site in the Southern High Plains was not included in the regression calculations.

and fairly uniform. Variability in EC_a at a particular site was extremely low in the Seymour as shown by the low error bars associated with each measurement interval (Fig. 21).

The primary control on variations in apparent conductivity among sites in the Seymour setting is variations in texture and associated water content variations (Fig. 22). Apparent conductivity (EM31 reading, HD mode, 3-m penetration depth) is positively correlated with clay content and water content and negatively correlated with sand content, with each correlation significant to $p \leq 0.03$. The correlation between apparent conductivity and chloride content is much lower and not significant ($p=0.26$), indicating that salinity is not a dominant component of the EM instrument response in the Seymour settings.

In the Southern High Plains setting, the only significant EC_a correlation is with water content in the absence of data from the irrigated site ($R=0.97$, $p<0.01$). The irrigated site had high chloride content combined with high water content, indicating that salinity may dominate the signal in irrigated settings. While the natural sites also displayed high chloride concentrations, the low water contents at those sites result in a clay content component of the instrument response, EC_s (equation 7). The high correlations between apparent conductivity and water content indicates that EM induction may be useful in reconnaissance mapping of water flux in both the Southern High Plains and the Seymour aquifer settings (excluding irrigated sites in the Southern High Plains). Though the correlations between EC_a and chloride mass balance recharge flux were statistically significant for both settings, the number of data points within different land use areas was small and further investigations should be conducted.

Monitoring of water content and matric potential at the Seymour monitoring location (H1, Fig. 5) began in mid-May, 2003. Water content to a depth of 1.75 m was initially high due to spring precipitation (Fig. 23). Monitored precipitation events in May and June resulted in

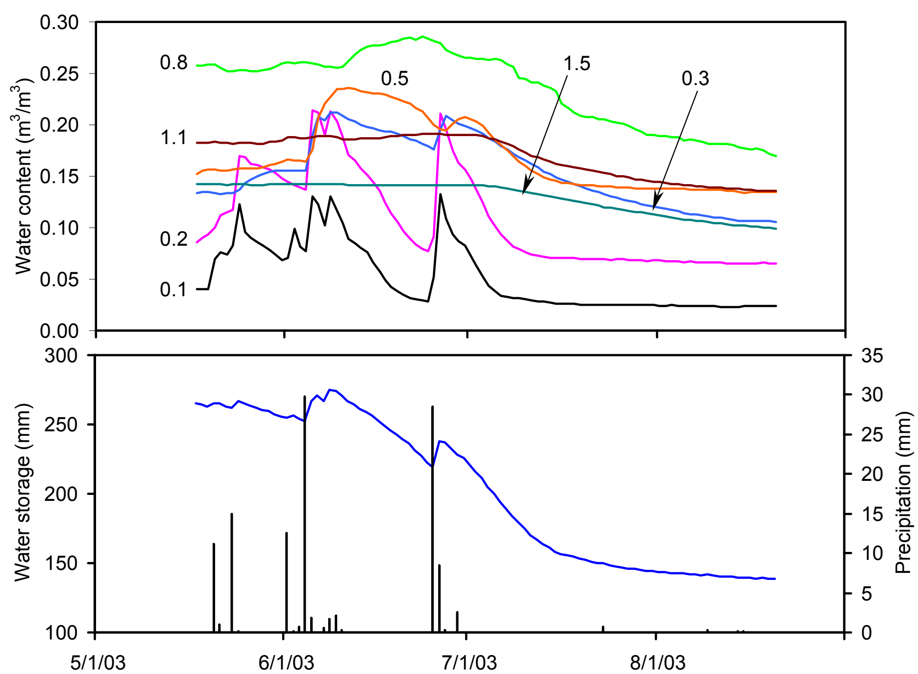


Figure 23: Time series of water content at discrete depths (m) and water storage over the 0 to 1.75 m depth interval monitored with TDR probes at the Seymour monitoring location.

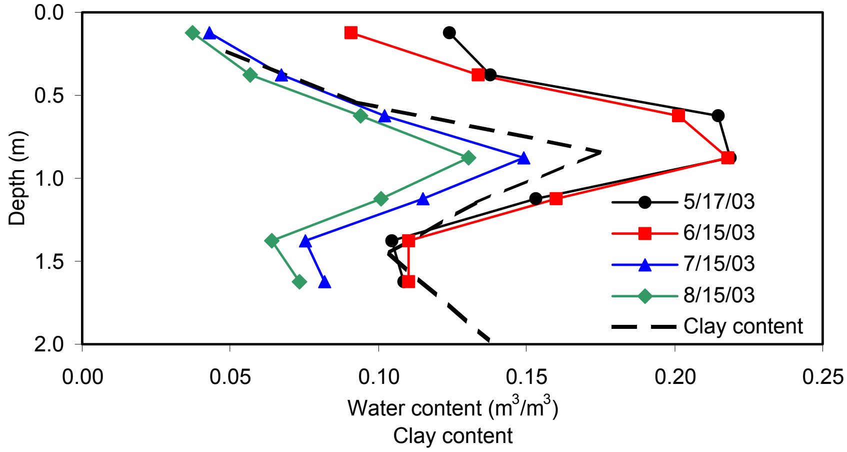
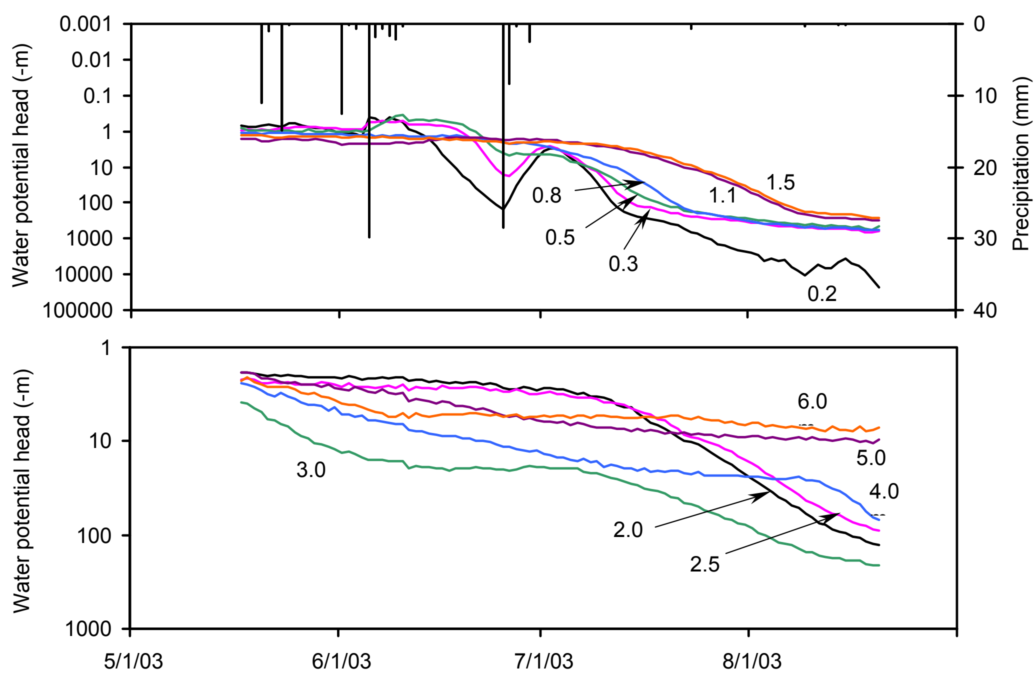


Figure 24: Vertical water content profiles and clay content.

infiltration to depths ranging from 0.2 to 0.5 m followed by redistribution to depths ranging from 0.5 to 1.1 m. Drying occurred successively to all depths beginning in July. Total water storage to 1.75 m depth was initially 265 mm and was reduced to 139 mm by mid-August. Water content with depth was consistently correlated with texture during the monitored time interval (Fig. 24).

Matric potential head was initially high at all monitored depths with values ranging from -0.7 to -4 m. Head values displayed responses with depth to infiltration and redistribution following precipitation consistent with the monitored water content (Fig. 25). Matric potential head at



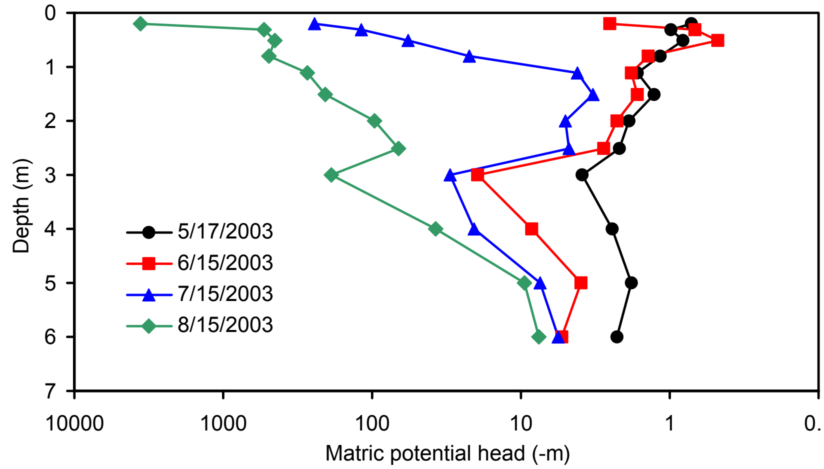


Figure 26: Matric potential head profiles at different times at the Seymour monitoring location.

almost all depths below the time domain reflectometry installation depths indicated continuous drying since the beginning of monitoring. The drying trend indicated by the instruments installed below the 1.5-m depth is attributed to drainage, as there is very little vegetation located at the installation and no roots were observed in any of the core sample below 0.5 m depth.

Vertical gradients in the monitored matric potential head were variable with time (Fig. 26), and were not internally consistent. A contrast developed between the instruments installed above and below the 3-m depth. Initially, a generally downward gradient was indicated across all depths. As drying occurred to successive depths, the instruments at and below 3 m appeared to dry at a faster rate and an apparent upward gradient was established. The instruments above 3 m initially indicated a downward gradient that gradually transitioned to an upward gradient as drying occurred to successive depths. The discontinuity may be an artifact of the installation resulting from inadequate hydraulic contact between the 3-m depth instrument and the soil.

Results of the Seymour water sample $^3H/^3He$ analyses are presented in Table 15. The calculated water sample ages are consistent with the conceptual model that recharge is greatest in the sand dune areas where permeability is highest and decreases in other areas where soil permeability is lower. The results indicate that the groundwater in the sand dune area is approximately 3 years old and increases with distance down gradient toward the north (8 years old) and becomes older toward the northeast with greater distance from the sand dunes (14 and 23 years old) (Fig. 27). This pattern is consistent with water table gradients and flow paths published in previous studies of the Seymour Aquifer (Harden et al., 1978)

Table 15: Measured ^3He, ^4He, ^{20}Ne, ^{40}Ar, and N_2, and calculated tritogenic helium-3 ($^3He_{trit}$) and $^3H/^3He$ ages for groundwater wells sampled in the Seymour aquifer.

Location	*^3H (TU)*	*^3H error (2σ TU)*	*R/Ra*†	*^4He*‡ *(cc STP/g)*	*^{20}Ne (cc STP/g)*	*^{40}Ar (cc STP/g)*	*N_2 (cc STP/g)*	*$^3He_{trit}$ (TU)*	*Age using Ne (yr)*
T1	7.82	0.39	1.068	5.18E-08	1.74E-07	2.75E-04	1.23E-02	4.6	8.2
T2	8.92	0.45	0.998	9.21E-08	3.08E-07	3.61E-04	1.83E-02	1.4	2.6
T3	5.76	0.29	1.150	5.28E-08	1.82E-07	2.73E-04	1.23E-02	7.12	14.3
T4	5.52	0.28	1.258	5.97E-08	2.00E-07	3.34E-04	1.42E-02	14.15	22.6
T5	8.61	0.43	0.880	1.06E-07	3.19E-07	4.16E-04	2.01E-02	1.76	3.3

† R is the $^3He/^4He$ ratio of the sample; Ra is the $^3He/^4He$ ratio of the air standard

‡ STP standard temperature and pressure

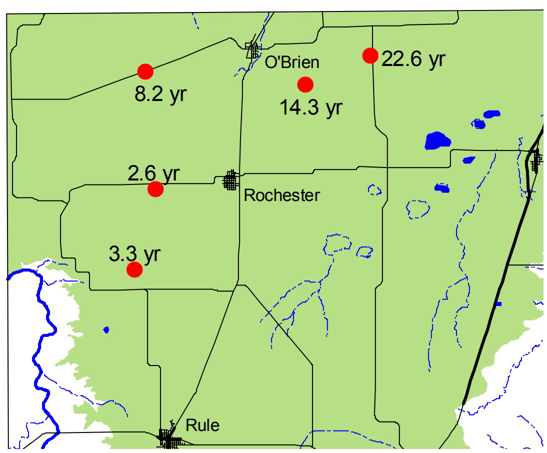


Figure 27: Spatial distribution of $^3H/^3He$ ages calculated for the Seymour water samples.

Comparison of Recharge Estimates Based on Modeling with those Based on Other Techniques

Recharge estimates based on modeling in this study were generally compared with those based on field measurements in this study and previous studies and with existing recharge estimates for the different regions. The closest modeled site to the Southern High Plains field site was located in Lubbock. The areally averaged simulated recharge rate for the Lubbock site (6 mm/yr) is within the range of field estimated recharge rates (0.1 to 28 mm/yr). Simulated recharge rates in areas of dryland farming of cotton and sorghum ranged from 0.0 to 0.5 mm/yr, which are much lower than those estimated from chloride data in the field sites (4.4 to 28 mm/yr). Simulated fluxes were also fairly low in areas of irrigated agriculture (1.9 to 6 mm/yr). These differences between simulated and field estimated recharge rates may be attributed to the inability of the pedotransfer functions to capture the effect of cultivation on the hydraulic properties of the near surface soils.

Simulated areally averaged recharge for the Seymour aquifer in Fisher/Jones Counties (7 mm/yr) is within the range of field based recharge estimates (5 to 30 mm/yr). The higher recharge rates from the field data may reflect the sampling bias in the field studies which focused on the sand dune region and only one profile to the east of the sand dune region.

Modeled recharge rates were also compared with those based on groundwater availability modeling (GAM). Recharge estimates are available for GAM models of the High Plains and the Carrizo Wilcox aquifers. GAM recharge estimates for the High Plains are not directly comparable to recharge estimates based on unsaturated flow modeling and field measurements conducted in this study because recharge in the GAM models includes areally averaged recharge with playa and interplaya settings whereas this study focused on interplaya recharge in different land use settings and based on different soil and vegetation types. As indicated in the introductory section, playa recharge is about an order of magnitude higher than interplaya recharge in many areas (Wood and Sanford, 1995; Scanlon and Goldsmith, 1997). GAM recharge rates in the Central High Plains aquifer ranged from 4 to 38 mm/yr and increased from west to east to reflect sandy soils near the escarpment (Dutton et al., 2001). Simulated recharge in Carson County in natural interplaya settings was 0.5 mm/yr and is similar to that in previous field studies conducted in that region (Scanlon and Goldsmith, 1997; Scanlon et al., 1997). GAM recharge rates for the Southern High Plains ranged from 0.2 to 2.2 mm/yr during predevelopment and ranged from 0.2 to 0.7 mm/yr in Dawson County (Blandford et al., 2003). Post-development recharge rates ranged from 0 to 50 mm/yr and much of Dawson County was in the 38 to 50 mm/yr range. The simulated areally averaged recharge rate for interplaya settings in Lubbock County was 6 mm/yr in this study, whereas GAM recharge rates ranged from 0 to 50 mm/yr to include the effects of playa recharge.

Recharge rates in the Carrizo Wilcox GAM model are consistent with recharge estimates in this study and show an increase in recharge rates from the southwest (0 mm/yr) to the northeast (≤ 64 mm/yr). Recharge rates in the Central Carrizo Wilcox GAM model were based on field studies using chloride data and an average value of 25 mm/yr was used for Bastrop County. The field studies focused on the high permeability Simsboro Formation and resulted in recharge estimates based on unsaturated zone chloride data ranging from 20 to 36 mm/yr. An areally averaged simulated recharge rate for Bastrop County in this study was 16 mm/yr, which includes low and high permeability zones and is consistent with the recharge used in the GAM model. Recharge rates in the northern section of the Carrizo-Wilcox aquifer were compared with county estimates in this study for Hopkins/Rains and Upshur/Gregg Counties. The simulated recharge in this study for Hopkins/Rains Counties was 24 mm/yr which is slightly higher than the GAM estimates for these counties; mostly 0 to 12.5 mm/yr with small areas of 12.5 to 25.4 mm/yr. The Upshur/Gregg recharge estimate based on unsaturated zone modeling of 38 mm/yr is higher than recharge estimates for other regions and within the range of the GAM model estimates of predominantly 25 to 50 mm/yr. Recharge was also estimated for these counties using the median groundwater chloride concentration and the chloride mass balance approach. This resulted in an estimated recharge rate of 45 mm/yr, which is also consistent with the GAM model estimates and the unsaturated zone modeling estimate.

Implications for Aquifer Vulnerability to Contamination

The results of this study have important implications for assessing aquifer vulnerability to contamination. The controls on recharge were elucidated through the modeling analysis in this study. The modeling analysis showed that recharge in bare soil is high, particularly in humid settings and that vegetation and soil profile layering play critical roles in reducing recharge. These results indicate that bare sandy soil should have high recharge in humid settings. Salinization of soils that destroys vegetation should increase recharge. For example, oil field contamination in northeast Texas (Montague Co.) resulted in a large barren area (Paine, 2003). The modeling analysis can be used to predict recharge in different types of soils based on long-term precipitation values.

There is a lot of interest in engineered covers for waste containment. In the last several years, the emphasis has shifted from traditional, multi-layered, engineered covers to vegetated monolithic covers termed evapotranspirative (*ET*) covers (Hauser et al., 2001). The importance of vegetation in reducing recharge underscores the need for maintaining vegetation in these ET to minimize water movement into underlying waste. Application of waste water or sludge for beneficial use should be minimized in areas of fallow ground because of higher recharge rates at these times. Also application should be minimized during winter periods when vegetation is dormant.

Soil layering greatly reduces recharge relative to monolithic profiles. Therefore, disturbance of native soils that destroys the original sediment layering could greatly increase recharge rates. In addition, calcic soils or caliche layers and hard pans may play an important role in reducing recharge in natural settings. Destroying such layering through development or land use could greatly enhance recharge.

Previous studies have shown that recharge in semiarid regions is focused beneath surface water bodies, such as ephemeral streams and playas (Scanlon and Goldsmith, 1997). This has important implications for discharges to surface water bodies, because these water bodies ultimately recharge underlying aquifers and may provide a source of contaminants to aquifers. Past discharge practices to playas have resulted in contamination of underlying perched aquifers beneath the Department of Energy Pantex Plant. Maintaining high quality water in playas is critical for preserving groundwater quality in underlying aquifers.

Recharge in interdrainage natural settings in semiarid regions is negligible as shown by data from Trans Pecos, Texas (Scanlon, 1991; Scanlon and Goldsmith, 1999). This finding is consistent with field studies in the Southern High Plains in this study where high chloride concentrations and low matric potentials indicate low recharge in natural settings. A recently completed project in the Southern High Plains conducted by the Bureau of Economic Geology and the US Geological Survey evaluated recharge beneath irrigated sites based on the distribution of tritium in the unsaturated zone. Recharge estimates ranged from 18 to 33 mm/yr based on the center of mass of tritium in the profile. This estimate represents an average recharge rate over the past 40 to 50 yr but does not indicate temporal variability in recharge during that time. Recharge is expected to be much greater during the 1950s and 1960s when furrow irrigation was used at these sites and was highly inefficient. None of the previous studies examined recharge beneath dryland farming. Field measurements conducted in this study showed that recharge in dryland farming areas is also high (4 to 28 mm/yr), which may be attributed to disturbance of surface soils resulting from tillage. These recharge rates can be used to estimate travel time for contaminants to underlying aquifers. A recharge rate of 20 mm/yr is equivalent to a velocity of 200 mm/yr if the average water content in the profile is 0.2

m^3/m^3. The corresponding travel time will then depend on the water table depth; e.g. a depth of 10 m would result in a travel time of 50 yr. This information is important for assessing transport of contaminants from the land surface to underlying aquifers. Land use plays an important role in controlling recharge. Future land use changes may alter recharge rates and mobilize contaminants stored in the soil profile.

Aquifers with shallow water tables and coarse-grained soils are highly susceptible to contamination. Previous estimates of recharge for the Seymour aquifer including irrigated and nonirrigated sites were about 50 mm/yr. Recharge estimates based on chloride measurements in this study in nonirrigated sites in the sand dunes ranged form 6 to 34 mm/yr. Water tables are very shallow in this aquifer. Therefore, the combination of highly permeable soils and shallow water tables makes this system very vulnerable to contamination.

CONCLUSIONS

The main conclusions of this study are as follows:

- Climate is not a limiting factor for recharge as shown by unsaturated flow modeling using a nonvegetated monolithic sand profile.
- Potential recharge simulated using bare, sandy soil and a 30-yr climate forcing record (1961 to 1990) was highly correlated with precipitation throughout the state (R = 0.99) and increased with precipitation from 54 mm/yr in west Texas to 720 mm/yr in east Texas.
- The presence and type of vegetation greatly reduced recharge in the sandy profile.
- Layered soil profiles based on SSURGO soils data and pedotransfer functions generally resulted in much lower simulated recharge rates relative to monolithic soil profiles.
- Layered soil profiles combined with vegetation resulted in reasonable areally averaged recharge rates for the 13 sites simulated in the state.
- Simulated recharge in vegetated layered systems was positively correlated with precipitation (R = 0.95).
- Field studies in the Southern High Plains and Seymour aquifers yielded recharge rates ranging from 0.1 to 30 mm/yr based on the chloride mass balance approach.
- Recharge in the Southern High Plains was primarily controlled by land use: low recharge rates in natural sites, higher recharge rates in dryland farming sites.
- Recharge in the Seymour aquifer was primarily controlled by soil texture and increased with increased sand content.
- Soil physics (texture, water content, matric potential), chloride concentration, and EM induction provided complimentary data and resulted in a consistent conceptual model for recharge in these settings.
- Simulated recharge was generally lower than chloride mass balance estimated recharge rates. The differences were attributed to the inability of pedotransfer functions to capture the impact of land use in the Southern High Plains and the discrepancy between the areally averaged recharge estimates based on modeling relative to the biased estimates of recharge based on sampling primarily the sand dune area in the Seymour setting.
- The modeling analysis proved useful in estimating areally averaged recharge rates for different settings within the state and indicates that long-term (30-yr) precipitation may be used as a predictor of recharge rates in a reconnaissance mode. Field data are required for detailed estimation of recharge.

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APPENDIX A – MODELING SOIL PHYSICAL DATA AND PARAMETERS

Appendix A. SSURGO and STATSGO texture and water retention data that were input to Rosetta pedotransfer functions to determine water retention and hydraulic conductivity output.

					Input							Output					
Drainage Category	**MUSYM**	**% Area Covered**	**Layer**	**Thick (cm)**	**Gravel %**	**Sand %**	**Silt %**	**Clay %**	**rho (g/cm^3)**	**Theta 0.33 bar**	**Theta 15 bar**	**θ_s**	**θ_r**	**α (1/cm)**	**n**	**K_s (cm/hr)**	**Texture**
Hueco Bolson																	
El Paso County																	
1	DCD2	0.9%	1	28	57.7	67.4	19.6	13.0	1.66	0.088	0.040	0.140	0.013	0.055	1.583	1.728	GRV-SL
			2	86	69.5	67.4	19.6	13.0	1.71	0.066	0.030	0.096	0.010	0.056	1.736	1.492	GR-SL
1	DCB2	0.4%	1	28	57.7	67.4	19.6	13.0	1.66	0.088	0.040	0.140	0.013	0.055	1.583	1.728	GRV-SL
			2	86	69.5	67.4	19.6	13.0	1.71	0.066	0.030	0.096	0.010	0.056	1.736	1.492	GR-SL
1	**BPC**	**12.1%**	**1**	**15**	**0.0**	**79.4**	**16.6**	**4.0**	**1.62**	**0.082**	**0.029**	**0.339**	**0.024**	**0.057**	**1.568**	**5.623**	**LFS**
			2	**15**	**17.4**	**95.4**	**0.6**	**4.0**	**1.67**	**0.072**	**0.024**	**0.287**	**0.020**	**0.058**	**1.619**	**11.676**	**SR FS GR-LFS**
			3	**122**	**0.0**	**89.0**	**5.0**	**6.0**	**1.65**	**0.133**	**0.042**	**0.349**	**0.022**	**0.037**	**1.373**	**3.566**	**SR- S LFS VFSL**
2	**221**	**6.9%**	**1**	**203**	**0.0**	**78.6**	**16.4**	**5.0**	**1.59**	**0.122**	**0.023**	**0.345**	**0.017**	**0.036**	**1.376**	**3.042**	**LFS**
2	DU	2.1%	1	152	1.3	94.4	0.6	5.0	1.67	0.111	0.043	0.347	0.025	0.050	1.443	6.641	FS
2	TBB1	2.9%	1	25	3.0	67.3	20.2	12.5	1.57	0.174	0.080	0.352	0.032	0.033	1.353	1.713	FSL
			2	178	3.3	35.2	36.8	28.0	1.72	0.305	0.170	0.347	0.048	0.008	1.297	0.074	SCL
2	402	1.4%	1	203	0.0	78.6	16.4	5.0	1.59	0.122	0.023	0.345	0.017	0.036	1.376	3.042	LFS
2	171	1.4%	1	203	0.0	78.6	16.4	5.0	1.59	0.121	0.023	0.345	0.017	0.036	1.377	3.097	LFS
3	403	0.9%	1	3	3.0	94.6	1.4	4.0	1.59	0.091	0.018	0.356	0.018	0.053	1.443	10.873	S
			2	71	3.0	57.0	18.0	25.0	1.51	0.218	0.098	0.379	0.040	0.020	1.349	1.716	SCL
			3	61	3.0	57.0	18.0	25.0	1.51	0.218	0.095	0.379	0.065	0.025	1.326	0.516	SCL
			4	68	3.0	57.0	18.0	25.0	1.51	0.218	0.098	0.379	0.040	0.020	1.349	1.716	SCL
3	**HW2**	**15.0%**	**1**	**61**	**6.2**	**66.9**	**20.1**	**13.0**	**1.52**	**0.166**	**0.075**	**0.352**	**0.031**	**0.037**	**1.365**	**2.312**	**FSL**
			2	**124**	**19.6**	**66.9**	**20.1**	**13.0**	**1.52**	**0.166**	**0.075**	**0.261**	**0.027**	**0.039**	**1.362**	**1.017**	**VAR**
			3	**18**	**40.5**	**67.0**	**20.0**	**13.0**	**1.72**	**0.151**	**0.073**	**0.180**	**0.018**	**0.049**	**1.441**	**0.590**	**GR-LFS**
3	TBB2	0.8%	1	20	1.4	63.1	19.4	17.5	1.46	0.199	0.104	0.395	0.044	0.035	1.346	2.385	FSL
			2	13	1.4	35.2	36.8	28.0	1.72	0.305	0.170	0.354	0.049	0.008	1.297	0.076	SCL
			3	61	1.4	35.2	36.8	28.0	1.49	0.294	0.149	0.397	0.054	0.010	1.364	0.367	SCL
			4	109	1.4	60.0	34.0	6.0	1.52	0.126	0.039	0.340	0.020	0.042	1.395	2.287	LS
3	172	1.1%	1	8	3.0	67.4	19.6	13.0	1.49	0.170	0.053	0.365	0.023	0.025	1.362	2.434	SL
			2	106	3.0	57.0	18.0	25.0	1.51	0.218	0.098	0.379	0.040	0.020	1.349	1.716	SCL
			3	89	3.0	67.4	19.6	13.0	1.49	0.170	0.053	0.365	0.023	0.025	1.362	2.434	SL
3	401	1.7%	1	8	3.0	67.4	19.6	13.0	1.47	0.170	0.053	0.370	0.023	0.026	1.360	2.648	SL
			2	106	3.0	57.0	18.0	25.0	1.49	0.218	0.098	0.384	0.040	0.020	1.348	1.868	SCL
			3	89	3.0	67.4	19.6	13.0	1.47	0.170	0.053	0.370	0.023	0.026	1.360	2.648	SL
4	Ha	2.0%	1	30	0.0	36.9	42.1	21.0	1.52	0.285	0.133	0.385	0.048	0.008	1.399	0.392	L

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

					Input							Output					
Drainage Category	**MUSYM**	**% Area Covered**	**Layer**	**Thick (cm)**	**Gravel %**	**Sand %**	**Silt %**	**Clay %**	**rho (g/cm^3)**	**Theta 0.33 bar**	**Theta 15 bar**	θ_s	θ_r	α (1/cm)	**n**	**K_s (cm/hr)**	**Texture**
			2	122	0.0	42.7	43.3	14.0	1.52	0.250	0.091	0.362	0.034	0.008	1.448	0.663	VFSL
4	Hk	2.5%	1	30	0.0	6.7	60.3	33.0	1.71	0.335	0.210	0.387	0.061	0.011	1.220	0.062	SICL
			2	122	0.0	14.2	71.8	14.0	1.52	0.250	0.091	0.363	0.034	0.008	1.445	1.062	VFSL
4	**HW1**	**19.2%**	**1**	**10**	**0.6**	**79.0**	**16.5**	**4.5**	**1.60**	**0.103**	**0.039**	**0.345**	**0.024**	**0.053**	**1.476**	**4.351**	**LFS**
			2	**56**	**0.6**	**66.9**	**20.1**	**13.0**	**1.55**	**0.178**	**0.081**	**0.366**	**0.033**	**0.032**	**1.352**	**1.856**	**FSL**
			3	**81**	**0.8**	**53.9**	**20.1**	**26.0**	**2.00**			**0.278**	**0.046**	**0.040**	**1.144**	**0.057**	**PC**
			4	**56**	**0.6**	**66.9**	**20.1**	**13.0**	**1.55**			**0.374**	**0.046**	**0.031**	**1.431**	**1.328**	**VAR**
4	222	4.8%	1	13	0.0	78.6	16.4	5.0	1.59	0.121	0.023	0.345	0.017	0.036	1.377	3.097	LFS
			2	51	0.0	66.9	20.1	13.0	1.49	0.174	0.055	0.376	0.024	0.024	1.362	2.370	FSL
			3	27	0.0	55.1	18.0	27.0	2.00			0.271	0.041	0.045	1.192	0.120	PC
			4	112	0.0	79.2	15.8	5.0	1.59	0.121	0.023	0.346	0.017	0.036	1.377	3.172	LS
4	DCB1	1.3%	1	15	30.6	45.3	43.2	11.5	1.58	0.168	0.056	0.230	0.016	0.023	1.367	0.630	GRV-L
			2	10	49.4	44.3	40.7	15.0	1.66	0.108	0.052	0.158	0.016	0.051	1.497	0.551	GRX-L
			3	51	57.7	32.8	40.7	26.5	2.00			0.118	0.020	0.027	1.179	0.011	PC
			4	127	57.3	68.9	19.6	11.5	1.69	0.094	0.035	0.138	0.011	0.052	1.486	1.339	GRV-SL
4	DCD1	2.7%	1	15	30.6	45.3	43.2	11.5	1.58	0.168	0.056	0.230	0.016	0.023	1.367	0.630	GRV-L
			2	10	49.4	44.3	40.7	15.0	1.66	0.136	0.052	0.160	0.013	0.037	1.378	0.427	GRX-L
			3	51	57.7	32.8	40.7	26.5	2.00			0.118	0.020	0.027	1.179	0.011	PC
			4	127	57.3	68.9	19.6	11.5	1.69	0.094	0.035	0.138	0.011	0.052	1.486	1.339	GRV-SL
	sum	**80.2%**															
Cenezoic-Pecos																	
Statsgo Data																	
1	KERMIT	3.4%	1	30	0.0	90.0	5.0	5.0	1.45			0.406	0.052	0.034	2.562	16.642	FS
			2	183	7.3	95.0	0.0	5.0	1.45			0.378	0.054	0.029	3.269	24.858	FS
1	**PENWELL**	**5.8%**	**1**	**33**	**0.6**	**86.5**	**7.0**	**6.5**	**1.58**			**0.367**	**0.049**	**0.035**	**2.149**	**7.213**	**FS**
			2	**170**	**0.6**	**84.0**	**8.5**	**7.5**	**1.58**			**0.368**	**0.048**	**0.036**	**1.939**	**5.151**	**FS**
1	DUNELAND	2.2%	1	152	1.2	85.0	10.0	5.0	1.60			0.354	0.044	0.039	2.072	5.931	FS
2	**PYOTE**	**5.6%**	**1**	**91**	**0.0**	**85.0**	**7.5**	**7.5**	**1.50**			**0.393**	**0.051**	**0.034**	**2.033**	**7.338**	**LFS**
			2	**97**	**0.0**	**80.0**	**7.0**	**13.0**	**1.45**			**0.414**	**0.058**	**0.030**	**1.688**	**4.155**	**FSL**
			3	**15**	**17.4**	**80.0**	**9.5**	**10.5**	**1.48**			**0.332**	**0.043**	**0.033**	**1.719**	**2.749**	**LFS**
2	NICKEL	5.1%	1	18	46.9	77.5	11.5	11.0	1.35			0.231	0.028	0.032	1.608	1.422	GRV-L

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Input: Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	Output: θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	Texture
			2	135	50.6	85.0	7.5	7.5	1.50			0.194	0.025	0.034	2.033	1.978	GRV-SL
2	JALMAR	4.3%	1	30	0.6	77.5	16.0	6.5	1.63			0.349	0.040	0.043	1.629	2.495	FS
			2	46	0.6	77.5	16.0	6.5	1.60			0.355	0.040	0.042	1.644	2.743	FS
			3	127	0.6	65.0	8.5	26.5	1.60			0.380	0.065	0.026	1.282	0.643	FSL
3	ORLA	2.0%	1	13	1.1	34.5	43.0	22.5	1.40			0.405	0.067	0.008	1.546	0.494	L
			2	140	11.7	47.5	28.5	24.0	1.40			0.373	0.060	0.014	1.446	0.490	GYP
3	WICKETT	4.8%	1	36	0.6	82.5	9.0	8.5	1.50			0.391	0.050	0.034	1.859	5.362	LFS
			2	41	0.6	73.5	13.5	13.0	1.50			0.393	0.051	0.031	1.526	2.252	FSL
			3	20	0.8	25.0	25.0	50.0	2.00			0.304	0.072	0.026	1.143	0.032	CEM
			4	107	18.2	50.0	38.5	11.5	1.60			0.279	0.032	0.020	1.395	0.413	LFS
3	DALBY	1.6%	1	46	1.3	17.0	30.5	52.5	1.33			0.489	0.099	0.017	1.312	0.617	C
			2	46	1.2	17.0	30.5	52.5	1.30			0.497	0.100	0.017	1.314	0.700	C
			3	61	1.3	17.0	35.5	47.5	1.38			0.470	0.095	0.015	1.345	0.465	C
3	**REAGAN**	**2.4%**	**1**	**191**	**2.1**	**15.0**	**54.0**	**31.0**	**1.43**			**0.432**	**0.083**	**0.008**	**1.502**	**0.329**	**SICL**
3	VERHALEN	3.4%	1	25	1.3	15.0	35.0	50.0	1.35			0.481	0.097	0.015	1.331	0.520	C
			2	127	1.3	17.5	35.0	47.5	1.35			0.477	0.096	0.015	1.346	0.540	C
3	HOLLOMAN	2.3%	1	23	1.2	37.5	39.0	23.5	1.25			0.444	0.072	0.009	1.542	0.993	L
			2	130	0.0	37.5	39.0	23.5	1.45			0.402	0.067	0.010	1.499	0.381	GYP
3	HODGINS	1.3%	1	20	2.5	15.0	51.5	33.5	1.28			0.470	0.088	0.009	1.503	0.740	SICL
			2	183	1.3	15.0	45.0	40.0	1.40			0.455	0.091	0.011	1.420	0.361	CL
3	DELNORTE	13.1%	1	20	28.9	70.0	18.5	11.5	1.48			0.281	0.033	0.031	1.491	1.057	GRV-L
			2	10	47.0	75.0	10.0	15.0	1.53			0.208	0.029	0.029	1.522	0.629	GRX-L
			3	20	57.5	25.0	25.0	50.0	2.00			0.130	0.031	0.026	1.143	0.009	IND
			4	102	54.6	87.5	1.0	11.5	1.53			0.178	0.028	0.027	2.074	1.752	GRV-SL
4	REEVES	3.4%	1	18	0.0	22.5	49.0	28.5	1.40			0.431	0.079	0.008	1.540	0.428	CL
			2	61	0.0	27.5	48.5	24.0	1.45			0.403	0.070	0.007	1.558	0.376	L
			3	74	0.0	27.5	48.5	25.0	1.65			0.357	0.063	0.010	1.452	0.146	GYP
4	HOBAN	2.7%	1	46	2.7	17.5	48.5	34.0	1.38			0.442	0.085	0.009	1.488	0.415	SICL
			2	71	1.4	17.5	41.0	41.5	1.43			0.448	0.090	0.012	1.393	0.325	SICL
			3	66	4.3	30.0	28.5	41.5	1.48			0.416	0.084	0.015	1.333	0.290	SICL
4	**SHARVANA**	**2.9%**	**1**	**15**	**1.4**	**57.5**	**27.5**	**15.0**	**1.45**			**0.389**	**0.050**	**0.020**	**1.441**	**1.168**	**FSL**
			2	**20**	**2.8**	**49.5**	**28.0**	**22.5**	**1.45**			**0.396**	**0.062**	**0.015**	**1.432**	**0.583**	**SCL**
			3	**25**	**16.5**	**25.0**	**25.0**	**50.0**	**2.00**			**0.256**	**0.061**	**0.026**	**1.143**	**0.024**	**IND**

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Input: Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	Output: θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	Texture
			4	**142**	**16.3**	**50.0**	**27.5**	**22.5**	**1.40**			**0.351**	**0.055**	**0.015**	**1.445**	**0.511**	**VAR**
4	REAKOR	8.3%	1	18	0.0	22.5	56.5	21.0	1.25			0.446	0.072	0.005	1.656	1.330	L
			2	147	0.0	15.0	54.5	30.5	1.45			0.430	0.082	0.008	1.527	0.321	CL
4	SIMONA	2.5%	1	20	0.0	57.5	25.0	17.5	1.50			0.390	0.054	0.021	1.414	0.897	FSL
			2	20	20.4	57.5	25.0	17.5	1.50			0.310	0.043	0.021	1.414	0.534	FSL
			3	10	19.2	25.0	25.0	50.0	2.00			0.247	0.059	0.026	1.143	0.022	IND
4	UPTON	3.2%	1	13	23.3	54.5	23.0	22.5	1.40			0.325	0.050	0.017	1.426	0.542	GR-L
			2	20	18.1	44.0	33.5	22.5	1.40			0.339	0.054	0.012	1.480	0.360	GR-L
			3	20	39.1	25.0	25.0	50.0	2.00			0.187	0.044	0.026	1.143	0.014	CEM
			4	124	44.7	75.0	2.5	22.5	1.45			0.235	0.040	0.024	1.463	0.692	GR-L
	sum	**80.3%**															
Ogallalla Aquifer																	
Carson County																	
1	**Mobeetie**	**7.7%**	**1**	**103**	**4.0**	**66.1**	**19.9**	**14.0**	**1.50**	**0.177**	**0.083**	**0.367**	**0.034**	**0.036**	**1.358**	**2.332**	**FSL**
			2	**100**	**5.4**	**66.1**	**19.9**	**14.0**	**1.55**	**0.175**	**0.083**	**0.350**	**0.034**	**0.035**	**1.356**	**1.877**	**FSL**
1	Veal	4.1%	1	20	2.9	56.4	27.6	16.0	1.50	0.192	0.099	0.368	0.040	0.034	1.352	1.564	FSL
			2	23	3.6	55.1	17.4	27.5	1.55	0.239	0.161	0.380	0.071	0.038	1.307	1.269	SCL
			3	160	6.9	55.1	17.4	27.5	1.60	0.234	0.161	0.354	0.068	0.040	1.306	1.018	L
2	**Paloduro**	**5.2%**	**1**	**31**	**2.8**	**35.4**	**33.6**	**31.0**	**1.44**	**0.318**	**0.190**	**0.417**	**0.065**	**0.015**	**1.290**	**0.405**	**CL**
			2	**172**	**3.1**	**34.2**	**38.3**	**27.5**	**1.60**	**0.303**	**0.167**	**0.371**	**0.053**	**0.010**	**1.316**	**0.174**	**CL**
3	**EcB**	**4.6%**	**1**	**48**	**1.3**	**33.2**	**31.9**	**35.0**	**1.66**	**0.337**	**0.218**	**0.383**	**0.059**	**0.012**	**1.226**	**0.078**	**CL**
			2	**49**	**1.3**	**33.3**	**31.7**	**35.0**	**1.66**	**0.329**	**0.204**	**0.379**	**0.057**	**0.010**	**1.249**	**0.090**	**CL**
			3	**106**	**3.3**	**33.6**	**31.9**	**34.5**	**1.72**	**0.326**	**0.205**	**0.357**	**0.053**	**0.010**	**1.232**	**0.057**	**CL**
3	AtB	2.5%	1	13	0.0	34.6	41.8	23.6	1.29	0.282	0.129	0.435	0.050	0.012	1.389	1.052	L
			2	20	0.0	33.3	33.9	32.8	1.67	0.334	0.209	0.382	0.057	0.010	1.242	0.069	CL
			3	29	0.0	30.3	37.4	32.3	1.69	0.326	0.195	0.376	0.055	0.009	1.265	0.068	SCL
			4	41	0.0	41.2	34.0	24.8	1.56	0.292	0.142	0.384	0.050	0.008	1.383	0.277	L
			5	31	0.0	21.2	44.8	34.0	1.65	0.338	0.215	0.392	0.062	0.011	1.230	0.079	L
			6	69	0.0	19.5	46.9	33.6	1.68	0.334	0.208	0.385	0.060	0.010	1.237	0.068	L
4	PuB	9.4%	1	10	0.0	34.2	32.3	33.5	1.54	0.330	0.201	0.411	0.064	0.012	1.272	0.203	CL
			2	33	0.0	23.3	29.2	47.5	1.79	0.341	0.286	0.361	0.085	0.043	1.145	0.037	C

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Appendix A. Continued.

Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Input: Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	Output: θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	Texture
			3	38	0.0	26.0	30.5	43.5	1.71	0.321	0.247	0.375	0.076	0.032	1.171	0.105	C
			4	49	3.2	28.1	29.4	42.5	1.66	0.312	0.240	0.372	0.081	0.035	1.192	0.179	CL
			5	35	3.0	28.1	29.4	42.5	1.57	0.312	0.240	0.395	0.093	0.039	1.214	0.338	CL
			6	38	3.0	27.8	33.7	38.5	1.58	0.333	0.218	0.395	0.065	0.015	1.229	0.161	SICL
4	PuA	14.7%	1	13	0.0	34.2	32.3	33.5	1.54	0.330	0.201	0.411	0.064	0.012	1.272	0.203	CL
			2	33	0.0	23.3	29.2	47.5	1.79	0.341	0.286	0.361	0.085	0.043	1.145	0.037	C
			3	38	0.0	26.0	30.5	43.5	1.71	0.321	0.247	0.375	0.076	0.032	1.171	0.105	C
			4	48	3.2	28.1	29.4	42.5	1.66	0.312	0.240	0.372	0.081	0.035	1.192	0.179	CL
			5	36	3.0	28.1	29.4	42.5	1.57	0.312	0.240	0.395	0.093	0.039	1.214	0.338	CL
			6	35	3.0	27.8	33.7	38.5	1.58	0.333	0.218	0.395	0.065	0.015	1.229	0.161	SICL
4	**PxA**	**22.7%**	**1**	**18**	**0.0**	**12.3**	**53.8**	**33.9**	**1.70**	**0.340**	**0.219**	**0.387**	**0.062**	**0.012**	**1.210**	**0.057**	**SICL**
			2	**33**	**0.0**	**9.9**	**48.0**	**42.1**	**1.78**	**0.323**	**0.250**	**0.362**	**0.073**	**0.034**	**1.147**	**0.033**	**C**
			3	**38**	**0.0**	**13.0**	**47.6**	**39.4**	**1.72**	**0.341**	**0.221**	**0.384**	**0.060**	**0.011**	**1.209**	**0.045**	**C**
			4	**56**	**0.0**	**17.2**	**45.0**	**37.8**	**1.66**	**0.335**	**0.211**	**0.393**	**0.062**	**0.011**	**1.235**	**0.080**	**C**
			5	**23**	**0.7**	**13.8**	**47.1**	**39.1**	**1.76**	**0.344**	**0.229**	**0.374**	**0.058**	**0.012**	**1.189**	**0.029**	**CL**
4	LoA	3.0%	1	23	0.0	33.3	31.7	35.0	1.48	0.332	0.204	0.427	0.068	0.013	1.273	0.311	CL
			2	74	0.0	26.1	28.9	45.0	1.68	0.324	0.251	0.383	0.080	0.033	1.175	0.144	C
			3	35	0.0	27.6	29.4	43.0	1.60	0.316	0.242	0.396	0.088	0.036	1.202	0.269	C
			4	71	0.0	14.0	43.0	43.0	1.60	0.316	0.242	0.397	0.093	0.039	1.197	0.179	C
4	Manson	5.9%	1	13	0.0	31.2	45.3	23.5	1.48	0.291	0.141	0.398	0.052	0.009	1.387	0.450	L
			2	23	0.0	31.1	38.0	30.9	1.72	0.323	0.190	0.368	0.053	0.008	1.271	0.056	L
			3	63	0.7	17.7	45.4	36.9	1.78	0.344	0.228	0.367	0.056	0.011	1.190	0.023	CL
			4	61	1.3	22.7	42.7	34.6	1.68	0.328	0.203	0.377	0.058	0.010	1.243	0.072	CL
			5	33	3.8	29.2	33.4	37.4	1.66	0.327	0.209	0.371	0.058	0.012	1.232	0.095	CL
			6	10	1.3	28.6	26.7	44.7	1.69	0.327	0.262	0.375	0.084	0.038	1.173	0.126	C
	sum	**79.7%**															
Ogallalla Aquifer																	
Lubbock County																	
1	**30**	**20.2%**	**1**	**25**	**1.5**	**34.2**	**37.3**	**28.5**	**1.54**	**0.308**	**0.170**	**0.353**	**0.048**	**0.008**	**1.308**	**0.242**	**FSL**
			2	**82**	**3.1**	**29.9**	**32.1**	**38.0**	**1.60**	**0.331**	**0.213**	**0.347**	**0.048**	**0.008**	**1.308**	**0.146**	**CL**
			3	**96**	**5.0**	**34.7**	**32.8**	**32.5**	**1.72**	**0.314**	**0.190**	**0.340**	**0.047**	**0.008**	**1.308**	**0.067**	**CL**

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

					Input							Output					
Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	Texture
2	42	2.7%	1	18	0.0	17.1	27.9	55.0	2.08	0.347	0.299	0.317	0.076	0.052	1.106	0.005	C
			2	33	0.8	17.1	27.9	55.0	2.13	0.347	0.298	0.311	0.073	0.052	1.103	0.004	C
			3	106	0.8	17.1	27.9	55.0	2.22	0.350	0.308	0.299	0.078	0.062	1.107	0.002	C
2	**41**	**10.5%**	**1**	**30**	**0.0**	**34.2**	**32.3**	**33.5**	**1.52**	**0.330**	**0.201**	**0.416**	**0.065**	**0.012**	**1.274**	**0.233**	**L**
			2	**87**	**0.0**	**23.3**	**29.2**	**47.5**	**1.78**	**0.341**	**0.286**	**0.364**	**0.086**	**0.043**	**1.147**	**0.040**	**C**
			3	**51**	**0.0**	**30.2**	**32.3**	**37.5**	**1.60**	**0.337**	**0.214**	**0.402**	**0.063**	**0.012**	**1.243**	**0.134**	**CL**
			4	**35**	**3.2**	**28.1**	**29.4**	**42.5**	**1.64**	**0.312**	**0.240**	**0.377**	**0.083**	**0.036**	**1.197**	**0.207**	**CL**
3	**1**	**20.0%**	**1**	**97**	**1.5**	**41.4**	**37.1**	**21.5**	**1.50**	**0.288**	**0.141**	**0.352**	**0.048**	**0.008**	**1.308**	**0.617**	**CL**
			2	**106**	**3.0**	**55.5**	**14.5**	**30.0**	**1.60**	**0.261**	**0.191**	**0.347**	**0.048**	**0.008**	**1.308**	**1.039**	**CL**
3	6	4.6%	1	36	0.0	66.1	19.9	14.0	1.55	0.190	0.093	0.372	0.038	0.031	1.343	1.642	FSL
			2	81	0.0	55.1	17.4	27.5	1.55	0.247	0.167	0.395	0.073	0.037	1.296	1.164	FSL
			3	86	3.2	55.1	17.4	27.5	1.68	0.248	0.175	0.350	0.067	0.037	1.265	0.498	SL
4	**5**	**14.2%**	**1**	**36**	**1.4**	**66.1**	**19.9**	**14.0**	**1.55**	**0.190**	**0.093**	**0.372**	**0.038**	**0.031**	**1.343**	**1.642**	**FSL**
			2	**81**	**1.5**	**55.1**	**17.4**	**27.5**	**1.55**	**0.247**	**0.167**	**0.395**	**0.073**	**0.037**	**1.296**	**1.164**	**SCL**
			3	**86**	**3.0**	**55.1**	**17.4**	**27.5**	**1.68**	**0.248**	**0.175**	**0.350**	**0.067**	**0.037**	**1.265**	**0.498**	**SCL**
4	18	7.5%	1	41	1.1	34.2	37.3	28.5	1.44	0.315	0.180	0.424	0.064	0.013	1.313	0.413	CL
			2	30	1.3	34.7	37.8	27.5	1.66	0.307	0.167	0.372	0.052	0.008	1.321	0.113	CL
			3	97	1.3	34.7	37.8	27.5	1.66	0.303	0.162	0.366	0.051	0.008	1.329	0.121	CL
			4	35	3.3	34.7	37.8	27.5	1.72	0.301	0.164	0.346	0.048	0.008	1.308	0.080	CL
	sum	**79.8%**															
Ogallalla Aquifer																	
Midland County																	
1	**SpB**	**5.2%**	**1**	**38**	**1.5**	**83.5**	**6.5**	**10.0**	**1.53**			**0.381**	**0.052**	**0.032**	**1.870**	**4.946**	**LFS**
			2	**76**	**1.4**	**66.1**	**19.9**	**14.0**	**1.50**			**0.385**	**0.049**	**0.028**	**1.443**	**1.477**	**FSL**
			3	**38**	**1.5**	**63.1**	**19.4**	**17.5**	**1.53**			**0.382**	**0.054**	**0.025**	**1.402**	**0.995**	**FSL**
2	MmB	8.6%	1	36	0.0	83.5	6.5	10.0	1.50			0.396	0.054	0.032	1.881	5.551	LFS
			2	15	0.0	38.0	36.0	26.0	1.48			0.402	0.070	0.011	1.457	0.307	SCL
			3	106	3.1	55.1	17.4	27.5	1.60			0.370	0.063	0.023	1.285	0.384	SCL
2	**MdA**	**6.5%**	**1**	**20**	**1.4**	**65.4**	**19.6**	**15.0**	**1.45**			**0.399**	**0.052**	**0.025**	**1.450**	**1.675**	**FSL**
			2	**61**	**1.3**	**55.1**	**17.4**	**27.5**	**1.40**			**0.431**	**0.073**	**0.019**	**1.384**	**0.999**	**SCL**
			3	**76**	**4.2**	**38.0**	**36.0**	**26.0**	**1.45**			**0.392**	**0.068**	**0.011**	**1.469**	**0.331**	**SCL**

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

					Input							Output					
Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	Texture
2	MdB	2.7%	1	20	1.4	65.4	19.6	15.0	1.45			0.399	0.052	0.025	1.450	1.675	FSL
			2	61	1.3	55.1	17.4	27.5	1.40			0.431	0.073	0.019	1.384	0.999	SCL
			3	76	4.2	38.0	36.0	26.0	1.45			0.392	0.068	0.011	1.469	0.331	SCL
3	**AfB**	**22.1%**	**1**	**25**	**0.0**	**66.1**	**19.9**	**14.0**	**1.48**			**0.390**	**0.050**	**0.028**	**1.443**	**1.509**	**FSL**
			2	**87**	**0.0**	**55.1**	**17.4**	**27.5**	**1.48**			**0.415**	**0.071**	**0.020**	**1.354**	**0.714**	**SCL**
			3	**51**	**3.1**	**55.1**	**17.4**	**27.5**	**1.60**			**0.370**	**0.063**	**0.023**	**1.285**	**0.384**	**SCL**
3	AfA	17.9%	1	25	0.0	66.1	19.9	14.0	1.48			0.395	0.050	0.027	1.449	1.632	FSL
			2	87	0.0	55.1	17.4	27.5	1.48			0.415	0.071	0.020	1.354	0.714	SCL
			3	51	3.1	55.1	17.4	27.5	1.60			0.370	0.063	0.023	1.285	0.384	SCL
4	SaB	3.2%	1	15	1.4	65.4	19.6	15.0	1.45			0.399	0.052	0.025	1.450	1.675	FSL
			2	21	2.8	59.6	17.9	22.5	1.45			0.405	0.063	0.021	1.401	1.022	SCL
			3	25	22.0	37.1	17.9	45.0	2.00			0.235	0.053	0.033	1.126	0.026	PC
			4	142	16.5	59.6	17.9	22.5	1.40			0.358	0.055	0.020	1.415	1.015	VAR
4	Ks2	1.2%	1	13	0.0	39.2	37.3	23.5	1.40			0.414	0.068	0.010	1.504	0.485	L
			2	25	1.3	29.5	31.5	39.0	1.40			0.445	0.088	0.014	1.382	0.437	CL
			3	23	1.9	10.0	31.5	58.5	2.00			0.310	0.076	0.021	1.162	0.028	PC
			4	91	1.3	29.5	31.5	39.0	1.40			0.445	0.088	0.014	1.382	0.437	VAR
4	**SlA**	**3.3%**	**1**	**13**	**0.0**	**39.2**	**37.3**	**23.5**	**1.40**			**0.414**	**0.068**	**0.010**	**1.504**	**0.485**	**L**
			2	**25**	**1.3**	**29.5**	**31.5**	**39.0**	**1.40**			**0.445**	**0.088**	**0.014**	**1.382**	**0.437**	**CL**
			3	**23**	**1.9**	**10.0**	**31.5**	**58.5**	**2.00**			**0.310**	**0.076**	**0.021**	**1.162**	**0.028**	**PC**
			4	**91**	**1.3**	**10.0**	**31.5**	**58.5**	**2.00**			**0.445**	**0.088**	**0.014**	**1.382**	**0.437**	**VAR**
5	**Kb**	**6.8%**	**1**	**20**	**11.7**	**43.0**	**39.5**	**17.5**	**1.40**			**0.350**	**0.050**	**0.010**	**1.524**	**0.585**	**L**
			2	**31**	**15.9**	**25.5**	**39.5**	**35.0**	**2.00**			**0.246**	**0.048**	**0.023**	**1.178**	**0.018**	**PC**
5	Ks1	2.2%	1	20	11.7	43.0	39.5	17.5	1.40			0.350	0.050	0.010	1.524	0.585	L
			2	31	15.9	25.5	39.5	35.0	2.00			0.246	0.048	0.023	1.178	0.018	PC
	sum	**79.6%**															
Seymour Aquifer																	
Fisher and Jones Counties																	
1	**Ts**	**1.2%**	**1**	**25**	0.6	**93.2**	**1.3**	**5.5**	**1.50**	**0.084**	**0.042**	**0.392**	**0.031**	**0.061**	**1.725**	**22.372**	**FS**
			2	**132**	0.6	**93.2**	**1.3**	**5.5**	**1.67**	**0.074**	**0.039**	**0.344**	**0.033**	**0.057**	**1.799**	**16.472**	**FS**
2	No	3.3%	1	91	1.1	94.4	0.6	5.0	1.50	0.090	0.039	0.393	0.028	0.062	1.602	19.454	FS

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Input							Output					Texture
					Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	
			2	41	1.3	67.5	21.0	11.5	1.67	0.172	0.076	0.332	0.030	0.029	1.343	1.057	SL
			3	46	3.3	83.5	9.5	7.0	1.73	0.116	0.049	0.315	0.026	0.047	1.426	2.992	FS
			4	25	1.3	77.9	16.1	6.0	1.73	0.101	0.043	0.312	0.026	0.052	1.480	2.972	FS
2	Ne2	1.9%	1	15	1.3	94.4	0.6	5.0	1.65	0.101	0.043	0.352	0.027	0.055	1.508	9.081	FS
			2	97	1.2	92.7	1.3	6.0	1.62	0.096	0.041	0.359	0.028	0.057	1.537	11.313	LFS
			3	91	3.2	91.7	1.3	7.0	1.65	0.113	0.048	0.346	0.028	0.052	1.454	6.950	LFS
2	**Eu**	**7.4%**	**1**	**15**	**0.6**	**94.4**	**0.6**	**5.0**	**1.65**	**0.101**	**0.043**	**0.354**	**0.028**	**0.055**	**1.508**	**9.220**	**FS**
			2	**97**	**0.6**	**92.7**	**1.3**	**6.0**	**1.62**	**0.096**	**0.041**	**0.361**	**0.028**	**0.057**	**1.537**	**11.486**	**LFS**
			3	**91**	**0.6**	**91.7**	**1.3**	**7.0**	**1.65**	**0.113**	**0.048**	**0.355**	**0.028**	**0.052**	**1.454**	**7.386**	**LFS**
2	Br	4.2%	1	76	0.6	92.2	1.3	6.5	1.65	0.105	0.049	0.353	0.030	0.055	1.516	8.874	FS
			2	26	0.6	62.6	18.9	18.5	1.65	0.213	0.121	0.352	0.046	0.029	1.309	0.792	SL
			3	55	0.6	55.4	17.6	27.0	1.65	0.251	0.174	0.365	0.068	0.035	1.267	0.568	SCL
3	**Ne1**	**2.9%**	**1**	**10**	**2.8**	**96.3**	**0.7**	**3.0**	**1.46**	**0.090**	**0.024**	**0.394**	**0.020**	**0.063**	**1.483**	**17.831**	**FS**
			2	**51**	**3.4**	**93.2**	**1.3**	**5.5**	**1.46**	**0.090**	**0.038**	**0.394**	**0.026**	**0.064**	**1.595**	**20.143**	**FS**
			3	**96**	**6.6**	**55.1**	**17.4**	**27.5**	**1.52**	**0.242**	**0.161**	**0.376**	**0.068**	**0.037**	**1.308**	**1.250**	**SCL**
			4	**26**	**1.2**	**61.4**	**18.6**	**20.0**	**1.60**	**0.215**	**0.125**	**0.366**	**0.050**	**0.032**	**1.316**	**1.056**	**SL**
3	MmB2	1.8%	1	41	1.2	77.4	16.1	6.5	1.62	0.120	0.051	0.343	0.027	0.049	1.435	3.319	LFS
			2	132	1.3	55.1	17.4	27.5	1.65	0.251	0.175	0.367	0.069	0.036	1.267	0.587	SCL
			3	25	1.3	34.7	37.8	27.5	1.65	0.306	0.172	0.372	0.053	0.009	1.300	0.124	SCL
3	MmB1	2.5%	1	20	1.2	77.4	16.1	6.5	1.62	0.111	0.051	0.338	0.029	0.053	1.488	3.889	LFS
			2	158	1.3	55.1	17.4	27.5	1.65	0.251	0.175	0.362	0.068	0.036	1.267	0.578	SCL
			3	25	1.3	59.8	12.7	27.5	1.65	0.246	0.172	0.353	0.066	0.037	1.275	0.734	SCL
3	La	1.3%	1	25	1.4	60.0	26.0	14.0	1.52	0.186	0.090	0.363	0.036	0.032	1.351	1.597	SR- FSL
			2	77	1.5	60.0	28.5	11.5	1.62	0.175	0.074	0.332	0.028	0.028	1.348	1.076	SR- FSL
			3	50	1.6	60.0	28.5	11.5	1.67	0.174	0.076	0.321	0.029	0.028	1.341	0.880	SR- LFS L
4	**MfB**	**3.3%**	**1**	**25**	1.2	**70.9**	**16.6**	**12.5**	**1.57**	**0.181**	**0.085**	**0.360**	**0.034**	**0.032**	**1.347**	**1.760**	**FSL**
			2	**153**	1.3	**55.1**	**17.4**	**27.5**	**1.65**	**0.251**	**0.175**	**0.364**	**0.068**	**0.036**	**1.267**	**0.634**	**SCL**
			3	**25**	3.2	**59.8**	**12.7**	**27.5**	**1.65**	**0.251**	**0.175**	**0.353**	**0.066**	**0.037**	**1.275**	**0.734**	**SCL**
4	MfA	1.1%	1	25	1.2	70.9	16.6	12.5	1.57	0.181	0.085	0.360	0.034	0.032	1.347	1.760	FSL
			2	153	1.3	55.1	17.4	27.5	1.65	0.251	0.175	0.364	0.068	0.036	1.267	0.634	SCL
			3	25	3.2	59.8	12.7	27.5	1.65	0.251	0.175	0.353	0.066	0.037	1.275	0.734	SCL
4	MnA	2.6%	1	28	0.6	70.9	16.6	12.5	1.57	0.181	0.085	0.366	0.034	0.032	1.347	1.787	FSL
			2	145	0.6	55.1	17.4	27.5	1.65	0.251	0.175	0.367	0.069	0.036	1.267	0.587	SCL

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

					Input							Output					
Drainage Category	**MUSYM**	**% Area Covered**	**Layer**	**Thick (cm)**	**Gravel %**	**Sand %**	**Silt %**	**Clay %**	**rho (g/cm^3)**	**Theta 0.33 bar**	**Theta 15 bar**	**θ_s**	**θ_r**	**α (1/cm)**	**n**	**K_s (cm/hr)**	**Texture**
			3	25	0.6	34.7	37.8	27.5	1.65	0.306	0.172	0.372	0.053	0.009	1.300	0.124	SCL
5	**MnB**	**3.5%**	**1**	**28**	**0.6**	**70.9**	**16.6**	**12.5**	**1.57**	**0.181**	**0.085**	**0.366**	**0.034**	**0.032**	**1.347**	**1.787**	**FSL**
			2	**69**	**47.0**	**55.1**	**17.4**	**27.5**	**1.65**	**0.251**	**0.175**	**0.196**	**0.037**	**0.036**	**1.267**	**0.190**	**SCL**
			3	**76**	**51.3**	**55.1**	**17.4**	**27.5**	**1.65**	**0.251**	**0.175**	**0.180**	**0.034**	**0.036**	**1.267**	**0.168**	**SCL**
			4	**25**	**1.6**	**34.7**	**37.8**	**27.5**	**1.65**	**0.306**	**0.172**	**0.368**	**0.053**	**0.009**	**1.300**	**0.121**	**SCL**
5	Ac	1.2%	1	38	2.7	35.4	33.6	31.0	1.41	0.316	0.186	0.413	0.064	0.015	1.299	0.473	CL
6	CaC	1.5%	1	15	0.5	41.0	41.5	17.5	1.44	0.262	0.106	0.384	0.039	0.009	1.425	0.727	L
			2	132	0.5	53.8	19.7	26.5	1.44	0.234	0.149	0.415	0.070	0.038	1.330	2.047	L
			3	44	3.1	58.6	22.9	18.5	1.60	0.205	0.114	0.345	0.044	0.031	1.326	0.987	VFSL
6	Sp	1.6%	1	15	1.1	22.4	55.1	22.5	1.44	0.283	0.132	0.394	0.049	0.009	1.397	0.666	SIL
			2	168	1.1	35.2	38.3	26.5	1.50	0.298	0.154	0.393	0.054	0.010	1.356	0.332	L
6	WfB	1.1%	1	15	1.4	68.8	16.2	15.0	1.50	0.190	0.095	0.381	0.039	0.035	1.347	2.350	FSL
			2	76	3.4	30.0	30.0	40.0	1.75	0.316	0.247	0.343	0.071	0.034	1.168	0.064	SC
			3	72	3.5	33.3	31.7	35.0	1.81	0.336	0.224	0.335	0.048	0.010	1.190	0.020	CL
6	**CaB**	**7.1%**	**1**	**25**	0.5	**41.0**	**41.5**	**17.5**	**1.44**	**0.262**	**0.106**	**0.384**	**0.039**	**0.009**	**1.425**	**0.727**	**L**
			2	**122**	0.5	**53.8**	**19.7**	**26.5**	**1.44**	**0.234**	**0.149**	**0.415**	**0.070**	**0.038**	**1.330**	**2.047**	**L**
			3	**44**	3.1	**58.6**	**22.9**	**18.5**	**1.60**	**0.205**	**0.114**	**0.345**	**0.044**	**0.031**	**1.326**	**0.987**	**VFSL**
7	Sc	1.5%	1	86	0.6	35.4	33.6	31.0	1.66	0.330	0.204	0.378	0.056	0.010	1.250	0.078	CL
			2	97	0.7	34.7	37.8	27.5	1.75	0.314	0.177	0.352	0.049	0.007	1.291	0.052	L
7	**WmA**	**2.0%**	**1**	**15**	**1.2**	**35.3**	**33.2**	**31.5**	**1.58**	**0.316**	**0.181**	**0.387**	**0.057**	**0.010**	**1.302**	**0.178**	**CL**
			2	**76**	**1.2**	**30.0**	**30.0**	**40.0**	**1.58**	**0.309**	**0.227**	**0.394**	**0.082**	**0.032**	**1.214**	**0.293**	**CL**
			3	**61**	**3.2**	**29.6**	**30.4**	**40.0**	**1.64**	**0.340**	**0.231**	**0.376**	**0.061**	**0.015**	**1.203**	**0.099**	**CL**
7	WmB	1.5%	1	15	1.2	35.3	33.2	31.5	1.58	0.316	0.181	0.387	0.057	0.010	1.302	0.178	CL
			2	76	1.2	30.0	30.0	40.0	1.58	0.309	0.227	0.394	0.082	0.032	1.214	0.293	CL
			3	61	3.2	29.6	30.4	40.0	1.64	0.340	0.231	0.376	0.061	0.015	1.203	0.099	CL
8	OtA	5.3%	1	30	1.2	33.2	37.8	29.0	1.54	0.309	0.170	0.394	0.058	0.010	1.326	0.237	CL
			2	41	3.2	29.6	30.4	40.0	1.66	0.350	0.244	0.381	0.061	0.015	1.186	0.066	CL
			3	92	1.3	27.6	29.9	42.5	1.70	0.350	0.250	0.380	0.062	0.016	1.171	0.056	CL
8	AbA2	4.8%	1	18	1.3	35.3	33.2	31.5	1.69	0.333	0.210	0.371	0.055	0.010	1.235	0.057	CL
			2	73	1.3	30.0	30.0	40.0	1.66	0.319	0.248	0.379	0.082	0.036	1.185	0.130	CL
			3	72	4.0	34.2	32.3	33.5	1.72	0.322	0.201	0.353	0.052	0.010	1.237	0.057	CL
8	AbA1	4.6%	1	20	1.3	35.3	33.2	31.5	1.69	0.333	0.210	0.369	0.054	0.010	1.235	0.057	CL
			2	107	1.3	29.6	30.4	40.0	1.66	0.352	0.248	0.386	0.063	0.016	1.181	0.066	CL

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Input							Output					Texture
					Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	
			3	64	4.0	35.1	31.4	33.5	1.72	0.289	0.201	0.337	0.059	0.025	1.207	0.116	CL
8	**RwA**	**10.3%**	**1**	**25**	**0.6**	**31.5**	**31.0**	**37.5**	**1.63**	**0.355**	**0.250**	**0.397**	**0.065**	**0.016**	**1.184**	**0.071**	**CL**
			2	**66**	**0.7**	**28.1**	**29.4**	**42.5**	**1.78**	**0.325**	**0.258**	**0.355**	**0.073**	**0.034**	**1.154**	**0.048**	**C**
			3	**112**	**1.4**	**28.1**	**29.4**	**42.5**	**1.80**	**0.306**	**0.238**	**0.344**	**0.070**	**0.033**	**1.166**	**0.069**	**C**
8	TcA	1.1%	1	13	0.0	35.4	33.6	31.0	1.57	0.327	0.195	0.401	0.061	0.010	1.282	0.162	CL
			2	23	2.6	28.1	29.4	42.5	1.93	0.332	0.277	0.317	0.068	0.041	1.126	0.009	C
			3	104	2.6	28.1	29.4	42.5	1.93	0.325	0.262	0.316	0.061	0.034	1.128	0.012	C
			4	51	6.0	28.1	29.4	42.5	1.98	0.318	0.259	0.291	0.058	0.037	1.125	0.009	C
			5	12	6.4	30.0	30.0	40.0	2.11	0.293	0.259	0.260	0.071	0.055	1.149	0.005	C
	sum	**80.2%**															
Trinity																	
Parker County																	
1	**NdC**	**3.6%**	**1**	**20**	**1.4**	**96.3**	**0.7**	**3.0**	**1.46**	**0.062**	**0.024**	**0.397**	**0.025**	**0.063**	**1.836**	**33.126**	**FS**
			2	**51**	**1.4**	**93.2**	**1.3**	**5.5**	**1.46**	**0.104**	**0.038**	**0.403**	**0.024**	**0.061**	**1.473**	**16.328**	**FS**
			3	**43**	**1.4**	**55.1**	**17.4**	**27.5**	**1.52**	**0.242**	**0.161**	**0.396**	**0.072**	**0.037**	**1.308**	**1.447**	**SCL**
			4	**89**	**3.5**	**56.9**	**13.1**	**30.0**	**1.82**	**0.282**	**0.188**	**0.323**	**0.047**	**0.018**	**1.207**	**0.099**	**SCL**
2	Yb1	2.6%	1	20	**1.2**	87.0	1.5	11.5	1.57	0.169	0.076	0.369	0.039	0.032	1.341	1.541	FSL
			2	10	**1.2**	62.5	26.0	11.5	1.57	0.172	0.076	0.380	0.033	0.037	1.351	3.937	FSL
			3	173	**1.2**	62.5	26.0	11.5	1.57	0.172	0.076	0.351	0.031	0.032	1.355	1.508	FSL
2	**DwD21**	**5.1%**	**1**	**15**	**1.4**	**62.5**	**26.0**	**11.5**	**1.46**	**0.169**	**0.073**	**0.377**	**0.030**	**0.036**	**1.364**	**2.426**	**FSL**
			2	**158**	**1.5**	**55.1**	**17.4**	**27.5**	**1.55**	**0.243**	**0.164**	**0.389**	**0.072**	**0.038**	**1.301**	**1.222**	**SCL**
			3	**30**	**1.5**	**57.4**	**17.6**	**25.0**	**1.62**	**0.238**	**0.156**	**0.368**	**0.063**	**0.034**	**1.288**	**0.801**	**SCL**
2	Yb2	1.6%	1	15	1.5	66.1	19.9	14.0	1.57	0.189	0.093	0.361	0.037	0.031	1.342	1.481	FSL
			2	23	1.4	55.8	17.7	26.5	1.46	0.236	0.153	0.411	0.071	0.039	1.325	2.010	SCL
			3	165	1.5	55.8	17.7	26.5	1.57	0.243	0.164	0.383	0.070	0.037	1.296	1.039	SCL
2	DyD31	2.0%	1	15	1.4	62.5	26.0	11.5	1.46	0.169	0.073	0.377	0.030	0.036	1.364	2.426	FSL
			2	153	1.5	55.1	17.4	27.5	1.55	0.243	0.164	0.389	0.072	0.038	1.301	1.222	SCL
			3	35	1.5	57.4	17.6	25.0	1.62	0.238	0.156	0.368	0.063	0.034	1.288	0.801	SCL
2	DwC21	4.5%	1	15	1.4	62.5	26.0	11.5	1.46	0.169	0.073	0.377	0.030	0.036	1.364	2.426	FSL
			2	137	1.5	55.1	17.4	27.5	1.55	0.243	0.164	0.389	0.072	0.038	1.301	1.222	SCL
			3	51	1.5	57.0	18.0	25.0	1.62	0.238	0.156	0.367	0.063	0.034	1.288	0.790	SCL

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Input							Output					Texture
					Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	
2	DgD3	1.3%	1	15	1.4	62.5	26.0	11.5	1.46	0.169	0.073	0.377	0.030	0.036	1.364	2.426	FSL
			2	163	1.5	55.1	17.4	27.5	1.55	0.243	0.164	0.389	0.072	0.038	1.301	1.222	SCL
			3	25	1.5	57.4	17.6	25.0	1.62	0.238	0.156	0.368	0.063	0.034	1.288	0.801	SCL
3	DmC1	1.7%	1	23	1.4	85.9	6.6	7.5	1.44	0.132	0.051	0.403	0.026	0.052	1.397	9.072	LFS
			2	168	1.5	55.1	17.4	27.5	1.55	0.243	0.164	0.389	0.072	0.038	1.301	1.222	SCL
			3	12	1.5	57.4	17.6	25.0	1.62	0.238	0.156	0.368	0.063	0.034	1.288	0.801	SCL
3	SdC	2.7%	1	46	1.3	84.5	6.5	9.0	1.40	0.142	0.057	0.417	0.027	0.052	1.381	9.632	SCL
			2	157	1.5	55.8	17.7	26.5	1.57	0.241	0.160	0.382	0.068	0.036	1.297	1.073	SCL
3	DyD32	0.8%	1	10	1.5	66.1	19.9	14.0	1.55	0.197	0.102	0.368	0.040	0.032	1.338	1.475	FSL
			2	104	1.6	55.5	17.6	27.0	1.65	0.253	0.178	0.364	0.070	0.037	1.267	0.547	SCL
			3	89	1.6	66.1	19.9	14.0	1.71	0.190	0.094	0.328	0.035	0.027	1.321	0.712	FSL
3	**DwC22**	**3.2%**	**1**	**15**	**1.5**	**66.1**	**19.9**	**14.0**	**1.55**	**0.197**	**0.102**	**0.368**	**0.040**	**0.032**	**1.338**	**1.475**	
			2	**97**	**1.6**	**55.5**	**17.6**	**27.0**	**1.65**	**0.253**	**0.178**	**0.364**	**0.070**	**0.037**	**1.267**	**0.547**	**SCL**
			3	**91**	**1.6**	**66.1**	**19.9**	**14.0**	**1.71**	**0.190**	**0.094**	**0.328**	**0.035**	**0.027**	**1.321**	**0.712**	**FSL**
3	DwD22	2.2%	1	25	1.5	66.1	19.9	14.0	1.55	0.197	0.102	0.368	0.040	0.032	1.338	1.475	FSL
			2	89	1.6	55.5	17.6	27.0	1.65	0.253	0.178	0.364	0.070	0.037	1.267	0.547	SCL
			3	89	1.6	66.1	19.9	14.0	1.71	0.190	0.094	0.328	0.035	0.027	1.321	0.712	FSL
3	DmC2	1.2%	1	25	1.5	83.5	6.5	10.0	1.57	0.173	0.080	0.372	0.033	0.036	1.350	2.793	LFS
			2	92	1.6	55.5	17.6	27.0	1.65	0.253	0.178	0.364	0.070	0.037	1.267	0.547	SCL
			3	86	1.6	66.1	19.9	14.0	1.71	0.190	0.094	0.328	0.035	0.027	1.321	0.712	FSL
3	MfB	1.4%	1	30	1.5	66.9	20.1	13.0	1.55	0.189	0.093	0.366	0.037	0.032	1.344	1.595	FSL
			2	72	1.7	57.0	18.0	25.0	1.75	0.237	0.155	0.335	0.054	0.030	1.257	0.351	SCL
			3	101	1.7	35.8	39.2	25.0	1.75	0.298	0.155	0.343	0.046	0.007	1.332	0.071	SCL
4	BsE2	0.9%	1	20	20.7	30.2	32.3	37.5	1.48	0.273	0.176	0.330	0.061	0.028	1.282	0.522	GR-CL
4	BsE1	1.9%	1	10	5.4	37.1	40.4	22.5	1.47	0.283	0.144	0.377	0.049	0.012	1.354	0.454	CL
			2	26	6.1	37.9	35.6	26.5	1.50	0.291	0.158	0.376	0.053	0.012	1.327	0.340	L
4	VeC	3.0%	1	41	1.3	36.5	39.5	24.0	1.41	0.292	0.146	0.410	0.053	0.011	1.369	0.577	CL
			2	86	1.3	35.2	38.3	26.5	1.41	0.299	0.156	0.416	0.057	0.011	1.353	0.538	L
			3	76	2.9	33.5	36.5	30.0	1.52	0.311	0.178	0.394	0.059	0.012	1.305	0.261	CL
4	**WoD**	**4.6%**	**1**	**20**	**1.5**	**62.5**	**26.0**	**11.5**	**1.60**	**0.176**	**0.080**	**0.343**	**0.031**	**0.031**	**1.349**	**1.258**	**FSL**
			2	**77**	**1.7**	**49.8**	**7.7**	**42.5**	**1.77**	**0.327**	**0.263**	**0.353**	**0.069**	**0.032**	**1.163**	**0.109**	**C**
			3	**55**	**3.5**	**47.4**	**22.6**	**30.0**	**1.83**	**0.283**	**0.189**	**0.321**	**0.048**	**0.019**	**1.202**	**0.076**	**SCL**
4	VeD	2.6%	1	41	2.5	36.5	39.5	24.0	1.41	0.292	0.146	0.410	0.053	0.011	1.369	0.577	CL

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

					Input							Output					
Drainage Category	**MUSYM**	**% Area Covered**	**Layer**	**Thick (cm)**	**Gravel %**	**Sand %**	**Silt %**	**Clay %**	**rho (g/cm^3)**	**Theta 0.33 bar**	**Theta 15 bar**	θ_s	θ_r	α (1/cm)	**n**	K_s (cm/hr)	**Texture**
			2	73	2.5	35.2	38.3	26.5	1.41	0.299	0.156	0.416	0.057	0.011	1.353	0.538	L
			3	89	5.0	33.5	36.5	30.0	1.52	0.311	0.178	0.394	0.059	0.012	1.305	0.261	CL
4	ALE	8.1%	1	10	6.0	34.7	37.8	27.5	1.49	0.292	0.157	0.379	0.054	0.012	1.333	0.354	CL
			2	31	52.5	34.7	37.8	27.5	1.48	0.138	0.078	0.177	0.024	0.049	1.502	0.523	GRV-CL
4	WnC	2.0%	1	38	1.5	86.4	6.6	7.0	1.57	0.133	0.052	0.366	0.026	0.046	1.393	5.004	LFS
			2	89	1.7	28.1	29.4	42.5	1.77	0.327	0.263	0.354	0.075	0.036	1.155	0.049	C
			3	25	3.5	37.9	32.1	30.0	1.83	0.283	0.189	0.319	0.049	0.019	1.197	0.053	SCL
5	ChC	3.7%	1	41	7.5	83.5	6.5	10.0	1.92	0.170	0.077	0.269	0.025	0.025	1.306	0.467	LFS
			2	40	3.4	49.8	7.7	42.5	1.75	0.322	0.259	0.351	0.070	0.033	1.172	0.149	C
			3	26	3.7	54.9	12.6	32.5	1.93	0.300	0.219	0.303	0.045	0.020	1.159	0.025	SC
			4	45	3.9	54.9	12.6	32.5	2.06	0.262	0.234	0.263	0.074	0.047	1.220	0.020	C
5	WvD3	3.2%	1	15	1.5	62.5	26.0	11.5	1.60	0.176	0.080	0.343	0.031	0.031	1.349	1.258	FSL
			2	82	1.7	28.1	29.4	42.5	1.77	0.327	0.263	0.354	0.075	0.036	1.155	0.049	C
			3	30	3.5	56.9	13.1	30.0	1.82	0.282	0.188	0.323	0.047	0.018	1.207	0.099	SCL
			4	51	3.5	55.5	14.5	30.0	1.83	0.258	0.189	0.316	0.057	0.033	1.213	0.158	SCL
5	**WoC2**	**11.6%**	**1**	**15**	**1.5**	**62.5**	**26.0**	**11.5**	**1.60**	**0.176**	**0.080**	**0.343**	**0.031**	**0.031**	**1.349**	**1.258**	**FSL**
			2	**97**	**1.7**	**28.1**	**29.4**	**42.5**	**1.77**	**0.327**	**0.263**	**0.354**	**0.075**	**0.036**	**1.155**	**0.049**	**C**
			3	**40**	**3.5**	**53.6**	**16.4**	**30.0**	**1.83**	**0.258**	**0.189**	**0.316**	**0.057**	**0.033**	**1.212**	**0.148**	**SCL**
5	TrC2	1.4%	1	10	3.1	66.1	19.9	14.0	1.61	0.203	0.112	0.350	0.042	0.032	1.325	0.982	FSL
			2	112	3.5	26.1	28.9	45.0	1.81	0.334	0.285	0.340	0.086	0.047	1.153	0.029	C
			3	30	5.6	26.1	28.9	45.0	1.95	0.311	0.301	0.291	0.140	0.057	1.310	0.013	C
6	**Fc**	**1.8%**	**1**	**30**	**5.1**	**29.0**	**31.0**	**40.0**	**1.55**	**0.338**	**0.233**	**0.396**	**0.070**	**0.020**	**1.211**	**0.199**	**CL**
			2	**72**	**5.1**	**8.0**	**52.0**	**40.0**	**1.55**	**0.303**	**0.228**	**0.389**	**0.097**	**0.042**	**1.222**	**0.224**	**SIC**
			3	**101**	**5.0**	**7.7**	**49.8**	**42.5**	**1.64**	**0.309**	**0.239**	**0.372**	**0.091**	**0.042**	**1.193**	**0.120**	**SIC**
6	KcB	1.2%	1	61	5.3	26.1	28.9	45.0	1.82	0.326	0.273	0.331	0.078	0.043	1.153	0.034	C
			2	51	5.0	22.1	27.9	50.0	1.73	0.329	0.278	0.354	0.093	0.047	1.174	0.101	SIC
			3	91	8.9	23.3	29.2	47.5	1.81	0.313	0.258	0.319	0.075	0.042	1.164	0.061	SICL
	sum	**79.8%**															
Queen City- Sparta																	
Upsur and Greg Counties																	
1	KgC	6.0%	1	25	24.5	69.7	21.8	8.5	1.38	0.119	0.046	0.304	0.019	0.056	1.444	4.197	GR-FSL

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Input Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	Output θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	Texture
			2	82	3.6	23.3	29.2	47.5	1.55	0.319	0.254	0.402	0.105	0.044	1.217	0.436	CL
			3	38	3.9	31.5	31.0	37.5	1.70	0.334	0.221	0.363	0.056	0.012	1.209	0.062	SCL
			4	20	4.0	42.5	25.0	32.5	1.75	0.288	0.199	0.337	0.056	0.023	1.205	0.111	SR-FSL-C
1	TeE	5.1%	1	10	1.6	81.8	9.2	9.0	1.65	0.157	0.067	0.345	0.029	0.035	1.358	2.123	LFS
			2	64	7.2	81.8	9.2	9.0	1.66	0.144	0.057	0.321	0.025	0.037	1.369	2.359	LFS
			3	58	1.6	55.1	17.4	27.5	1.65	0.251	0.175	0.364	0.068	0.036	1.267	0.582	FSL
			4	31	7.1	47.5	22.5	30.0	1.76	0.278	0.192	0.322	0.053	0.025	1.211	0.122	SR-FSL-C
1	**LbC**	**13.0%**	**1**	**15**	**1.5**	**81.8**	**9.2**	**9.0**	**1.62**	**0.165**	**0.073**	**0.354**	**0.030**	**0.035**	**1.353**	**2.136**	**LFS**
			2	**61**	**1.6**	**81.8**	**9.2**	**9.0**	**1.65**	**0.155**	**0.065**	**0.344**	**0.028**	**0.035**	**1.359**	**2.197**	**LFS**
			3	**46**	**1.6**	**56.5**	**18.0**	**25.5**	**1.70**	**0.248**	**0.171**	**0.349**	**0.062**	**0.034**	**1.257**	**0.395**	**FSL**
			4	**61**	**3.4**	**55.4**	**17.6**	**27.0**	**1.76**	**0.254**	**0.184**	**0.330**	**0.062**	**0.036**	**1.236**	**0.233**	**FSL**
2	**Iu**	**6.5%**	**1**	**30**	**0.0**	**68.1**	**21.4**	**10.5**				**0.38**	**0.043**	**0.033**	**1.412**	**1.747**	**FSL**
			2	**26**	**0.0**	**70.5**	**16.5**	**13.0**				**0.38**	**0.048**	**0.033**	**1.413**	**1.640**	**FSL**
			3	**96**	**0.0**	**68.5**	**21.5**	**10.0**				**0.39**	**0.042**	**0.034**	**1.417**	**1.817**	**SL**
3	**CbE**	**21.1%**	**1**	**20**	**6.5**	**69.7**	**21.8**	**8.5**	**1.36**	**0.146**	**0.056**	**0.383**	**0.024**	**0.047**	**1.378**	**4.792**	**FSL**
			2	**71**	**8.3**	**23.3**	**29.2**	**47.5**	**1.56**	**0.305**	**0.243**	**0.376**	**0.102**	**0.046**	**1.235**	**0.482**	**SCL**
			3	**61**	**8.2**	**41.5**	**26.0**	**32.5**	**1.76**	**0.275**	**0.188**	**0.318**	**0.053**	**0.024**	**1.214**	**0.131**	**SR-FSL-C**
3	BoC	18.8%	1	30	1.9	69.3	21.7	9.0	1.62	0.161	0.066	0.337	0.027	0.032	1.356	1.469	FSL
			2	82	4.3	55.8	17.7	26.5	1.73	0.247	0.175	0.333	0.062	0.036	1.252	0.333	SCL
			3	71	10.7	55.8	17.7	26.5	1.79	0.235	0.169	0.296	0.056	0.038	1.253	0.262	SCL
3	KtB	3.4%	1	18	0.0	62.7	23.3	14.0	1.52	0.188	0.091	0.375	0.037	0.032	1.349	1.750	VFSL
			2	106	0.6	34.8	38.2	27.0	1.55	0.305	0.162	0.391	0.055	0.009	1.344	0.238	L
			3	54	0.6	28.1	29.4	42.5	1.71	0.325	0.257	0.372	0.080	0.036	1.169	0.090	SC
4	**Ma**	**7.2%**	**1**	**20**	**4.9**	**44.8**	**41.2**	**14.0**	**1.62**	**0.259**	**0.111**	**0.333**	**0.036**	**0.008**	**1.397**	**0.376**	**L**
			2	**145**	**4.9**	**34.8**	**38.2**	**27.0**	**1.62**	**0.295**	**0.159**	**0.357**	**0.050**	**0.010**	**1.322**	**0.167**	**L**
	sum	**81.1%**															
Carrizo-Wilcox																	
Hopkins and Rains Counties																	
1	**WoC**	**13.0%**	**1**	**15**	**1.4**	**85.9**	**6.6**	**7.5**	**1.52**	**0.147**	**0.060**	**0.381**	**0.027**	**0.044**	**120.5**	**5.023**	**LFS**
			2	**54**	**1.5**	**85.9**	**6.6**	**7.5**	**1.55**	**0.126**	**0.047**	**0.371**	**0.025**	**0.048**	**149.9**	**6.246**	**LFS**

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Input							Output					Texture
					Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	
			3	134	1.5	58.2	17.8	24.0	1.55	0.229	0.143	0.384	0.062	0.035	31.0	1.292	FSL
2	FrB	25.0%	1	41	1.5	63.5	26.5	10.0	1.53	0.171	0.075	0.358	0.030	0.034	42.7	1.779	FSL
			2	56	1.6	55.1	17.4	27.5	1.66	0.244	0.164	0.360	0.063	0.033	15.2	0.632	SCL
			3	86	1.7	30.0	30.0	40.0	1.81	0.312	0.235	0.341	0.062	0.027	1.1	0.047	C
			4	46	0.7	23.3	29.2	47.5	1.80	0.337	0.280	0.356	0.081	0.041	0.9	0.038	C
2	Na	10.0%	1	18	0.0	35.2	38.3	26.5	1.37	0.297	0.149	0.428	0.057	0.011	16.0	0.668	CL
			2	147	0.0	37.9	35.6	26.5	1.54	0.297	0.150	0.391	0.053	0.008	6.6	0.274	L
			3	38	0.0	33.5	40.0	26.5	1.65	0.305	0.161	0.372	0.052	0.007	3.1	0.129	SR L SICL
3	WtC	13.0%	1	20	3.5	45.7	41.8	12.5	1.50	0.242	0.089	0.352	0.031	0.009	18.8	0.783	L
			2	31	3.2	22.1	27.9	50.0	1.66	0.327	0.267	0.378	0.094	0.043	4.8	0.202	C
			3	76	6.8	30.0	30.0	40.0	1.74	0.292	0.211	0.335	0.063	0.028	3.2	0.131	SCL
			4	102	6.8	37.5	30.0	32.5	1.74	0.243	0.172	0.319	0.064	0.036	6.8	0.283	SR SCL C
3	WtD	15.0%	1	23	3.5	45.7	41.8	12.5	1.50	0.242	0.089	0.352	0.031	0.009	18.8	0.783	L
			2	38	3.2	22.1	27.9	50.0	1.66	0.327	0.267	0.378	0.094	0.043	4.8	0.202	C
			3	86	6.8	30.0	30.0	40.0	1.74	0.292	0.211	0.335	0.063	0.028	3.2	0.131	SCL
			4	36	6.8	37.5	30.0	32.5	1.74	0.278	0.172	0.327	0.049	0.016	3.2	0.134	SR SCL C
3	Lr	4.0%	1	23	7.9	45.3	43.2	11.5	1.57	0.227	0.080	0.318	0.027	0.010	15.5	0.644	L
			2	112	4.6	30.0	30.0	40.0	2.43	0.312	0.240	0.249	0.040	0.032	0.0	0.001	C
			3	30	5.6	33.5	36.5	30.0	1.93	0.308	0.180	0.303	0.039	0.006	0.3	0.012	L
	sum	80.0%															
Carrizo-Wilcox																	
Bastrop County																	
1	Sa	2.1%	1	25	8.4	62.8	26.2	11.0	1.67	0.162	0.072	0.302	0.027	0.033	1.350	0.993	FSL
			2	127	8.4	87.3	6.7	6.0	1.68	0.132	0.043	0.311	0.020	0.037	1.374	2.592	LFS
1	Sm	1.7%	1	15	1.5	60.0	18.5	21.5	1.55	0.235	0.152	0.383	0.063	0.036	1.307	1.076	FSL
			2	26	1.5	41.4	37.1	21.5	1.55	0.284	0.135	0.374	0.047	0.008	1.386	0.323	L
			3	86	1.5	57.0	18.0	25.0	1.60	0.232	0.147	0.371	0.060	0.033	1.299	0.986	SCL
			4	30	7.7	61.7	18.8	19.5	1.55	0.201	0.116	0.351	0.047	0.036	1.341	1.539	FSL
1	PaE	12.5%	1	132	1.3	92.7	1.3	6.0	1.41	0.131	0.042	0.416	0.021	0.052	1.373	12.731	FS
			2	46	3.0	92.7	1.3	6.0	1.41	0.125	0.036	0.372	0.060	0.035	1.310	1.179	SCL
1	SkC	3.2%	1	71	5.2	85.9	6.6	7.5	1.57	0.143	0.053	0.352	0.024	0.040	1.371	3.930	FS

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

					Input							Output					
Drainage Category	**MUSYM**	**% Area Covered**	**Layer**	**Thick (cm)**	**Gravel %**	**Sand %**	**Silt %**	**Clay %**	**rho (g/cm^3)**	**Theta 0.33 bar**	**Theta 15 bar**	θ_s	θ_r	α (1/cm)	**n**	**K_s (cm/hr)**	**Texture**
			2	71	5.5	85.9	6.6	7.5	1.57	0.143	0.053	0.338	0.060	0.036	1.278	0.540	SCL
			3	61	7.2	57.0	18.0	25.0	1.68	0.236	0.160	0.331	0.058	0.036	1.286	0.618	SCL
2	DeC	7.6%	1	74	6.2	87.3	6.7	6.0	1.57	0.133	0.044	0.346	0.021	0.042	1.378	4.298	LFS
			2	12	0.7	87.3	6.7	6.0	1.57	0.133	0.044	0.340	0.050	0.019	1.194	0.086	SC
			3	16	0.8	56.1	12.9	31.0	1.80	0.297	0.205	0.288	0.036	0.012	1.180	0.013	SC
			4	101	0.7	58.9	13.6	27.5	2.03	0.286	0.188	0.323	0.068	0.038	1.185	0.076	SCL
2	Bo	3.2%	1	147	1.3	39.2	37.3	23.5	1.36	0.295	0.150	0.425	0.056	0.012	1.360	0.714	L
			2	44	1.3	34.7	37.8	27.5	1.36	0.295	0.150	0.440	0.066	0.014	1.321	0.690	L
2	**TfB**	**6.1%**	**1**	**38**	8.1	**66.1**	**19.9**	**14.0**	**1.63**	**0.179**	**0.090**	**0.323**	**0.034**	**0.034**	**1.344**	**1.181**	**FSL**
			2	**89**	3.5	**23.3**	**29.2**	**47.5**	**1.81**	**0.330**	**0.274**	**0.342**	**0.079**	**0.041**	**1.149**	**0.040**	**C**
			3	**33**	3.7	**33.3**	**31.7**	**35.0**	**1.94**	**0.331**	**0.214**	**0.315**	**0.042**	**0.008**	**1.194**	**0.008**	**SCL**
2	AtD	5.1%	1	13	25.1	64.6	26.9	8.5	1.48	0.127	0.044	0.275	0.017	0.046	1.404	2.159	GR-FSL
			2	28	1.0	49.7	2.8	47.5	1.82	0.338	0.284	0.348	0.073	0.035	1.152	0.081	SC
			3	40	1.3	52.0	12.0	36.0	1.77	0.310	0.230	0.349	0.058	0.024	1.177	0.106	CL
			4	41	3.4	57.0	18.0	25.0	1.78	0.237	0.157	0.322	0.052	0.030	1.249	0.277	FSL
			5	81	3.6	30.0	35.0	35.0	1.87	0.285	0.225	0.312	0.066	0.040	1.171	0.036	SR- FSL CN-C
2	Gs	2.7%	1	66	0.5	40.2	43.8	16.0	1.39	0.265	0.109	0.395	0.039	0.010	1.418	1.009	CL
			2	81	0.6	34.2	37.3	28.5	1.58	0.311	0.172	0.388	0.056	0.009	1.320	0.183	L
			3	56	0.6	34.2	37.3	28.5	1.63	0.315	0.178	0.379	0.055	0.009	1.304	0.123	L
3	CfB	2.4%	1	20	2.5	67.3	20.2	12.5	1.62	0.188	0.094	0.345	0.036	0.031	1.336	1.117	FSL
			2	71	9.2	23.3	29.2	47.5	1.87	0.316	0.264	0.307	0.072	0.043	1.151	0.032	C
			3	61	9.4	26.1	28.9	45.0	1.93	0.312	0.258	0.293	0.064	0.040	1.141	0.018	C
			4	51	6.1	30.0	30.0	40.0	2.01	0.299	0.247	0.284	0.060	0.041	1.137	0.010	SR- L C
3	**AfC**	**7.9%**	**1**	**20**	6.2	**67.3**	**20.2**	**12.5**	**1.57**	**0.172**	**0.081**	**0.341**	**0.032**	**0.035**	**1.357**	**1.694**	**FSL**
			2	**26**	2.5	**26.1**	**28.9**	**45.0**	**1.85**	**0.327**	**0.265**	**0.336**	**0.069**	**0.036**	**1.140**	**0.027**	**CL**
			3	**76**	2.6	**31.2**	**30.3**	**38.5**	**2.00**	**0.316**	**0.245**	**0.302**	**0.051**	**0.028**	**1.125**	**0.007**	**CL**
			4	**71**	2.6	**49.6**	**12.9**	**37.5**	**2.00**	**0.287**	**0.239**	**0.289**	**0.061**	**0.038**	**1.159**	**0.023**	**SCL**
3	AfC2	9.2%	1	20	6.2	67.3	20.2	12.5	1.57	0.172	0.081	0.341	0.032	0.035	1.357	1.694	FSL
			2	26	2.5	26.1	28.9	45.0	1.85	0.327	0.265	0.336	0.069	0.036	1.140	0.027	CL
			3	76	2.6	31.2	30.3	38.5	2.00	0.316	0.245	0.302	0.051	0.028	1.125	0.007	CL
			4	71	2.6	49.6	12.9	37.5	2.00	0.287	0.239	0.289	0.061	0.038	1.159	0.023	SCL
3	CsD3	3.2%	1	10	2.5	67.3	20.2	12.5	1.62	0.188	0.094	0.345	0.036	0.031	1.336	1.117	FSL
			2	20	9.2	23.3	29.2	47.5	1.87	0.316	0.264	0.307	0.072	0.043	1.151	0.032	C

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Input: Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	Output: θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	Texture
			3	97	9.4	26.1	28.9	45.0	1.93	0.312	0.258	0.293	0.064	0.040	1.141	0.018	C
			4	25	7.4	33.3	31.7	35.0	1.84	0.323	0.213	0.318	0.045	0.011	1.193	0.021	CL
			5	51	6.1	25.0	30.0	45.0	2.01	0.327	0.278	0.295	0.067	0.047	1.121	0.006	SR- L C
3	CsC2	10.9%	1	10	2.5	67.3	20.2	12.5	1.62	0.188	0.094	0.345	0.036	0.031	1.336	1.117	FSL
			2	20	9.2	23.3	29.2	47.5	1.87	0.316	0.264	0.307	0.072	0.043	1.151	0.032	C
			3	72	9.4	26.1	28.9	45.0	1.93	0.312	0.258	0.293	0.064	0.040	1.141	0.018	C
			4	25	7.4	33.9	31.1	35.0	1.84	0.291	0.213	0.308	0.054	0.027	1.173	0.044	CL
			5	25	6.1	25.0	30.0	45.0	2.01	0.327	0.278	0.295	0.067	0.047	1.121	0.006	SR- L C
3	BeC2	2.3%	1	20	1.5	26.5	28.5	45.0	1.54	0.359	0.262	0.422	0.077	0.023	1.183	0.211	CL
			2	41	1.7	26.1	28.9	45.0	1.78	0.331	0.271	0.354	0.079	0.039	1.152	0.046	C
			3	86	5.4	26.1	28.9	45.0	1.86	0.321	0.264	0.322	0.070	0.039	1.145	0.028	C
			4	44	7.0	26.1	28.9	45.0	2.18	0.304	0.298	0.253	0.124	0.063	1.275	0.003	CN-C
	sum	**80.0%**															
Gulf Coast																	
Liberty County																	
1	Kr	6.2%	1	38	1.6	63.5	26.5	10.0	1.67	0.170	0.074	0.325	0.029	0.030	1.343	0.962	FSL
			2	165	8.7	36.5	39.5	24.0	1.68	0.278	0.145	0.325	0.043	0.010	1.321	0.145	SCL
1	VaA	3.6%	1	28	4.7	5.3	44.7	50.0	1.60	0.320	0.259	0.388	0.108	0.049	1.201	0.170	SIC
			2	175	1.6	18.2	29.3	52.5	1.66	0.340	0.289	0.388	0.105	0.048	1.181	0.170	C
1	Ka	3.9%	1	152	0.7	22.1	27.9	50.0	1.72	0.345	0.297	0.376	0.100	0.048	1.165	0.078	C
1	**Kf**	**8.8%**	**1**	**152**	**0.7**	**22.1**	**27.9**	**50.0**	**1.72**	**0.345**	**0.297**	**0.376**	**0.100**	**0.048**	**1.165**	**0.078**	**C**
1	SwB1	1.1%	1	30	2.6	63.1	26.4	10.5	1.34	0.162	0.067	0.401	0.027	0.043	1.369	3.885	FSL
			2	54	1.5	23.3	29.2	47.5	1.54	0.324	0.257	0.414	0.106	0.043	1.212	0.441	C
			3	68	2.7	55.8	17.7	26.5	1.41	0.227	0.143	0.417	0.068	0.040	1.341	2.716	SCL
			4	51	2.7	62.6	26.4	11.0	1.41	0.155	0.062	0.381	0.027	0.041	1.375	3.152	SR- S FSL
1	Wk2	2.2%	1	53	1.6	63.5	26.5	10.0	1.67	0.170	0.074	0.325	0.029	0.030	1.343	0.962	FSL
			2	99	8.7	58.2	17.8	24.0	1.68	0.221	0.145	0.324	0.055	0.036	1.296	0.675	SCL
2	Sd2	0.5%	1	15	0.6	63.5	26.5	10.0	1.67	0.172	0.075	0.328	0.029	0.029	1.342	0.949	FSL
			2	56	0.6	65.2	27.3	7.5	1.67	0.147	0.053	0.320	0.023	0.032	1.360	1.252	FSL
			3	61	0.6	66.9	20.1	13.0	1.67	0.184	0.087	0.338	0.034	0.028	1.333	0.948	VFSL
			4	71	0.7	34.7	32.8	32.5	1.83	0.334	0.211	0.345	0.048	0.008	1.219	0.018	CL

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Input: Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	Output: θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	Texture
2	Ve	1.6%	1	8	0.0	34.2	32.3	33.5	1.60	0.339	0.218	0.400	0.062	0.012	1.235	0.112	CL
			2	144	0.0	22.1	27.9	50.0	1.74	0.342	0.288	0.374	0.092	0.044	1.156	0.070	C
2	**Bm1**	**4.1%**	**1**	**13**	**0.6**	**35.8**	**39.2**	**25.0**	**1.52**	**0.316**	**0.180**	**0.401**	**0.059**	**0.011**	**1.309**	**0.271**	**CL**
			2	**78**	**0.6**	**23.3**	**29.2**	**47.5**	**1.65**	**0.330**	**0.265**	**0.391**	**0.092**	**0.040**	**1.179**	**0.177**	**C**
			3	**61**	**2.3**	**26.1**	**28.9**	**45.0**	**1.75**	**0.319**	**0.250**	**0.357**	**0.074**	**0.033**	**1.165**	**0.088**	**C**
2	WvD	1.7%	1	15	1.3	62.5	26.0	11.5	1.36	0.164	0.068	0.402	0.028	0.041	1.367	3.633	FSL
			2	168	1.8	22.1	27.9	50.0	1.87	0.344	0.299	0.340	0.088	0.050	1.138	0.018	C
2	Sd1	1.0%	1	51	1.7	47.9	45.6	6.5	1.78	0.208	0.056	0.292	0.022	0.008	1.438	0.382	L
			2	81	1.7	44.8	41.2	14.0	1.83	0.257	0.102	0.308	0.033	0.006	1.417	0.106	SIL
			3	71	1.7	43.0	39.5	17.5	1.83	0.274	0.123	0.316	0.037	0.006	1.382	0.071	SIL
2	Gy1	1.0%	1	18	0.0	13.9	70.1	16.0	1.57	0.281	0.128	0.375	0.046	0.008	1.392	0.716	SIL
			2	40	0.0	7.1	65.4	27.5	1.60	0.316	0.179	0.399	0.062	0.011	1.291	0.248	SIL
			3	94	0.0	27.3	45.2	27.5	1.60	0.316	0.179	0.389	0.058	0.009	1.303	0.168	C
3	Wk1	3.1%	1	13	0.6	46.0	44.0	10.0	1.65	0.239	0.082	0.330	0.029	0.007	1.447	0.486	L
			2	45	0.6	46.0	44.0	10.0	1.70	0.230	0.073	0.318	0.027	0.007	1.453	0.400	L
			3	94	0.6	36.5	39.5	24.0	1.67	0.304	0.161	0.364	0.050	0.007	1.334	0.117	L
3	Wa	2.4%	1	20	0.6	46.0	44.0	10.0	1.65	0.239	0.082	0.330	0.029	0.007	1.447	0.486	L
			2	36	0.6	46.0	44.0	10.0	1.70	0.230	0.073	0.318	0.027	0.007	1.453	0.400	L
			3	96	0.6	36.5	39.5	24.0	1.67	0.304	0.161	0.364	0.050	0.007	1.334	0.117	L
3	**SwB2**	**0.5%**	**1**	**13**	**0.6**	**46.0**	**44.0**	**10.0**	**1.65**	**0.239**	**0.082**	**0.330**	**0.029**	**0.007**	**1.447**	**0.486**	**L**
			2	**76**	**0.6**	**46.0**	**44.0**	**10.0**	**1.70**	**0.230**	**0.073**	**0.318**	**0.027**	**0.007**	**1.453**	**0.400**	**L**
			3	**63**	**0.6**	**36.5**	**39.5**	**24.0**	**1.67**	**0.304**	**0.161**	**0.364**	**0.050**	**0.007**	**1.334**	**0.117**	**L**
3	Km2	0.9%	1	46	1.4	43.0	39.5	17.5	1.52	0.270	0.117	0.371	0.041	0.008	1.412	0.485	L
			2	106	1.8	28.1	29.4	42.5	1.87	0.322	0.254	0.332	0.063	0.031	1.140	0.023	C
3	My1	2.5%	1	30	1.5	41.6	37.4	21.0	1.57	0.300	0.158	0.377	0.051	0.009	1.342	0.256	L
			2	16	5.5	37.9	35.6	26.5	1.81	0.301	0.169	0.320	0.043	0.007	1.279	0.039	L
			3	122	13.9	36.5	34.5	29.0	1.72	0.285	0.173	0.305	0.045	0.015	1.248	0.095	SIL
			4	35	5.7	29.0	31.0	40.0	1.87	0.298	0.255	0.308	0.083	0.049	1.182	0.032	SIL
4	An2	1.0%	1	51	1.4	29.1	53.4	17.5	1.52	0.270	0.117	0.369	0.042	0.008	1.415	0.618	SIL
			2	10	1.5	17.8	52.2	30.0	1.60	0.311	0.175	0.386	0.059	0.010	1.302	0.186	SCL
			3	96	1.8	28.1	29.4	42.5	1.87	0.322	0.254	0.332	0.063	0.031	1.140	0.023	C
4	Km1	1.2%	1	48	0.0	41.6	37.4	21.0	1.52	0.292	0.142	0.389	0.050	0.008	1.383	0.364	L
			2	59	0.0	23.3	29.2	47.5	1.74	0.340	0.283	0.373	0.089	0.042	1.155	0.061	C

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Input Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	Output θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	Texture
			3	45	0.0	27.8	29.7	42.5	1.86	0.363	0.264	0.355	0.053	0.013	1.141	0.010	C
4	Ae1	5.9%	1	53	0.6	60.7	27.8	11.5	1.52	0.180	0.084	0.365	0.033	0.033	1.355	1.674	VFSL
			2	21	0.6	36.9	42.1	21.0	1.71	0.281	0.129	0.345	0.043	0.006	1.393	0.141	VFSL
			3	78	0.7	22.1	27.9	50.0	1.80	0.342	0.291	0.358	0.088	0.045	1.146	0.039	C
4	**Bm2**	**1.9%**	**1**	**20**	**1.4**	**11.4**	**68.6**	**20.0**	**1.44**	**0.288**	**0.140**	**0.401**	**0.052**	**0.010**	**1.377**	**0.992**	**SIL**
			2	**71**	**1.5**	**7.1**	**65.4**	**27.5**	**1.58**	**0.305**	**0.165**	**0.391**	**0.059**	**0.010**	**1.317**	**0.297**	**SICL**
			3	**61**	**1.8**	**8.4**	**54.1**	**37.5**	**1.91**	**0.309**	**0.230**	**0.330**	**0.058**	**0.031**	**1.136**	**0.015**	**SICL**
4	Gy2	0.8%	1	20	0.6	20.8	67.7	11.5	1.52	0.241	0.084	0.352	0.030	0.009	1.443	1.175	SIL
			2	69	0.6	36.9	42.1	21.0	1.71	0.281	0.129	0.345	0.043	0.006	1.393	0.141	VFSL
			3	63	0.7	5.3	44.7	50.0	1.80	0.342	0.291	0.364	0.096	0.053	1.140	0.022	C
4	An1	1.4%	1	41	1.3	29.1	53.4	17.5	1.39	0.270	0.116	0.393	0.042	0.010	1.414	1.063	SIL
			2	53	1.4	29.1	53.4	17.5	1.50	0.263	0.109	0.369	0.040	0.009	1.424	0.676	SIL
			3	109	1.7	22.1	27.9	50.0	1.84	0.343	0.295	0.346	0.087	0.047	1.141	0.025	SIC
4	My2	0.6%	1	33	0.0	44.3	40.7	15.0	1.57	0.273	0.118	0.365	0.041	0.008	1.417	0.434	L
			2	51	1.8	30.2	32.3	37.5	1.93	0.347	0.239	0.329	0.046	0.010	1.160	0.006	CL
			3	119	7.2	37.9	35.6	26.5	1.84	0.294	0.163	0.307	0.040	0.007	1.278	0.035	SIL
5	**Ba**	**11.8%**	**1**	**71**	**1.9**	**18.2**	**29.3**	**52.5**	**2.01**	**0.335**	**0.279**	**0.316**	**0.067**	**0.041**	**1.113**	**0.008**	**C**
			2	**28**	**2.1**	**18.2**	**29.3**	**52.5**	**2.17**	**0.342**	**0.293**	**0.297**	**0.069**	**0.053**	**1.102**	**0.003**	**C**
			3	**53**	**2.1**	**18.2**	**29.3**	**52.5**	**2.26**	**0.343**	**0.296**	**0.288**	**0.070**	**0.059**	**1.106**	**0.002**	**C**
5	Ae2	2.5%	1	53	1.4	29.1	53.4	17.5	1.52	0.270	0.117	0.369	0.042	0.008	1.415	0.618	SIL
			2	11	1.5	17.8	52.2	30.0	1.60	0.311	0.175	0.386	0.059	0.010	1.302	0.186	SCL
			3	88	1.8	7.7	49.8	42.5	1.87	0.322	0.254	0.341	0.069	0.038	1.131	0.016	C
5	Vd	3.1%	1	8	1.9	2.6	44.9	52.5	2.01	0.335	0.279	0.325	0.072	0.049	1.107	0.006	SIC
			2	144	2.1	18.2	29.3	52.5	2.17	0.343	0.296	0.297	0.069	0.053	1.103	0.003	C
6	**LaA**	**3.1%**	**1**	**15**	**0.0**	**18.2**	**29.3**	**52.5**	**2.00**	**0.344**	**0.292**	**0.327**	**0.074**	**0.046**	**1.111**	**0.007**	**C**
			2	**76**	**2.1**	**18.2**	**29.3**	**52.5**	**2.17**	**0.342**	**0.293**	**0.297**	**0.069**	**0.053**	**1.102**	**0.003**	**C**
			3	**61**	**2.1**	**18.2**	**29.3**	**52.5**	**2.22**	**0.342**	**0.294**	**0.292**	**0.069**	**0.056**	**1.103**	**0.002**	**C**
6	Fa	1.9%	1	13	0.0	9.8	22.7	67.5	1.81	0.442	0.375	0.405	0.086	0.043	1.090	0.008	C
			2	68	0.0	6.6	15.9	77.5	1.97	0.443	0.381	0.384	0.091	0.050	1.100	0.005	C
			3	71	0.0	10.4	24.6	65.0	2.05	0.408	0.333	0.355	0.067	0.033	1.104	0.003	C
	sum	**79.9%**															

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Input Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	Output θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	Texture
Gulf Coast																	
Victoria County																	
1	**GaC**	**3.0%**	**1**	**53**	**41.4**	**87.3**	**6.7**	**6.0**	**1.54**	**0.078**	**0.031**	**0.220**	**0.016**	**0.061**	**1.649**	**7.488**	**GR-LFS**
			2	**64**	**41.7**	**87.3**	**6.7**	**6.0**	**1.56**	**0.076**	**0.027**	**0.215**	**0.015**	**0.060**	**1.622**	**7.108**	**GR-LFS**
			3	**86**	**27.3**	**22.1**	**27.9**	**50.0**	**1.70**	**0.260**	**0.220**	**0.264**	**0.089**	**0.053**	**1.307**	**0.397**	**GR-C**
2	NcA1	6.2%	1	20	1.5	67.8	23.7	8.5	1.57	0.156	0.061	0.347	0.026	0.034	1.364	1.853	SL
			2	44	1.7	57.0	18.0	25.0	1.81	0.245	0.166	0.322	0.052	0.029	1.232	0.185	SCL
			3	139	1.7	59.6	17.9	22.5	1.75	0.231	0.146	0.333	0.050	0.029	1.265	0.360	SCL
2	InB	3.6%	1	36	0.6	67.6	20.4	12.0	1.60	0.191	0.095	0.356	0.036	0.030	1.336	1.197	FSL
			2	88	0.6	26.1	28.9	45.0	1.68	0.322	0.250	0.380	0.081	0.034	1.177	0.149	C
			3	79	0.6	34.7	32.8	32.5	1.60	0.322	0.190	0.391	0.058	0.010	1.284	0.147	SC
2	StB	3.4%	1	33	3.9	84.9	6.6	8.5	1.68	0.104	0.064	0.329	0.041	0.055	1.663	6.805	LFS
			2	84	4.1	28.1	29.4	42.5	1.81	0.315	0.247	0.334	0.067	0.033	1.157	0.047	C
			3	48	4.3	49.8	7.7	42.5	1.88	0.317	0.252	0.318	0.057	0.028	1.151	0.050	C
2	**TeA**	**13.4%**	**1**	**41**	**3.1**	**66.9**	**20.1**	**13.0**	**1.60**	**0.182**	**0.088**	**0.346**	**0.034**	**0.032**	**1.344**	**1.348**	**FSL**
			2	**20**	**3.6**	**49.8**	**7.7**	**42.5**	**1.88**	**0.321**	**0.257**	**0.321**	**0.058**	**0.029**	**1.148**	**0.044**	**SC**
			3	**142**	**3.3**	**55.5**	**14.5**	**30.0**	**1.72**	**0.251**	**0.179**	**0.342**	**0.065**	**0.035**	**1.250**	**0.451**	**SCL**
2	FoB	1.9%	1	30	3.1	84.9	6.6	8.5	1.62	0.103	0.062	0.348	0.040	0.030	1.500	8.688	FSL
			2	26	1.5	84.9	6.6	8.5	1.60	0.103	0.062	0.359	0.041	0.032	1.455	9.564	FSL
			3	96	1.6	28.1	29.4	42.5	1.69	0.321	0.251	0.372	0.080	0.047	1.369	0.116	SL
3	NcA2	1.8%	1	15	1.6	57.0	18.0	25.0	1.71	0.250	0.174	0.347	0.062	0.034	1.252	0.340	SCL
			2	115	1.7	33.6	36.9	29.5	1.75	0.319	0.188	0.353	0.050	0.008	1.265	0.045	SCL
			3	73	1.7	57.0	18.0	25.0	1.75	0.237	0.154	0.335	0.053	0.029	1.257	0.347	SCL
3	**TeB**	**4.0%**	**1**	**30**	**3.1**	**66.9**	**20.1**	**13.0**	**1.60**	**0.182**	**0.088**	**0.346**	**0.034**	**0.032**	**1.344**	**1.348**	**FSL**
			2	**72**	**3.6**	**49.8**	**7.7**	**42.5**	**1.88**	**0.321**	**0.257**	**0.321**	**0.058**	**0.029**	**1.148**	**0.044**	**SC**
			3	**50**	**3.3**	**55.5**	**14.5**	**30.0**	**1.72**	**0.251**	**0.179**	**0.342**	**0.065**	**0.035**	**1.250**	**0.451**	**SCL**
3	FaA	1.6%	1	41	0.6	64.2	26.8	9.0	1.60	0.181	0.084	0.346	0.031	0.030	1.344	0.054	FSL
			2	76	0.7	24.0	30.0	46.0	1.84	0.340	0.286	0.348	0.080	0.043	1.136	0.053	CL
			3	86	4.1	52.2	13.8	34.0	1.81	0.269	0.210	0.321	0.067	0.038	1.213	0.056	SCL
3	EdA	5.9%	1	20	1.5	63.9	26.6	9.5	1.57	0.177	0.081	0.349	0.031	0.032	1.350	1.411	FSL
			2	84	0.7	26.1	28.9	45.0	1.80	0.334	0.274	0.354	0.076	0.037	1.146	0.038	C
			3	99	0.7	26.1	28.9	45.0	1.80	0.331	0.268	0.329	0.043	0.006	1.245	0.012	C

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Input							Output					Texture
					Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	
3	DaA	7.4%	1	30	3.3	57.0	18.0	25.0	1.72	0.236	0.155	0.336	0.055	0.032	1.265	0.430	SCL
			2	72	3.6	44.0	14.0	42.0	1.88	0.319	0.254	0.320	0.059	0.029	1.147	0.036	C
			3	101	3.7	50.0	14.0	36.0	1.91	0.303	0.223	0.309	0.048	0.020	1.159	0.032	SCL
4	Mf1	1.9%	1	25	0.0	7.2	47.8	45.0	1.68	0.331	0.265	0.389	0.094	0.044	1.163	0.071	SIC
			2	127	3.2	6.9	63.1	30.0	1.66	0.314	0.185	0.376	0.059	0.012	1.259	0.136	SICL
4	**Me**	**2.2%**	**1**	**33**	**0.0**	**7.2**	**47.8**	**45.0**	**1.68**	**0.331**	**0.265**	**0.389**	**0.094**	**0.044**	**1.163**	**0.071**	**SIC**
			2	**170**	**3.2**	**6.9**	**63.1**	**30.0**	**1.66**	**0.314**	**0.185**	**0.376**	**0.059**	**0.012**	**1.259**	**0.136**	**SICL**
4	Mf2	0.1%	1	33	0.8	8.9	21.1	70.0	2.17	0.427	0.400	0.344	0.145	0.101	1.130	0.002	C
			2	31	2.1	8.9	21.1	70.0	2.17	0.422	0.392	0.338	0.134	0.096	1.124	0.002	C
			3	88	2.1	8.9	21.1	70.0	2.22	0.420	0.396	0.331	0.147	0.105	1.139	0.002	C
5	DnA1	3.2%	1	28	3.3	34.4	37.6	28.0	1.72	0.307	0.173	0.348	0.049	0.008	1.291	0.071	CL
			2	99	3.6	26.1	28.9	45.0	1.88	0.328	0.271	0.326	0.070	0.039	1.136	0.019	C
			3	76	3.7	52.0	12.0	36.0	1.91	0.303	0.223	0.309	0.047	0.020	1.160	0.034	SCL
5	DnA2	1.6%	1	23	3.5	33.3	31.7	35.0	1.81	0.335	0.222	0.341	0.049	0.010	1.194	0.021	CL
			2	119	5.5	22.1	27.9	50.0	1.92	0.341	0.306	0.315	0.095	0.057	1.149	0.011	C
			3	61	5.7	23.3	29.2	47.5	1.98	0.338	0.300	0.304	0.085	0.057	1.133	0.006	CL
5	Tr	2.4%	1	33	0.8	8.9	21.1	70.0	2.17	0.427	0.400	0.344	0.145	0.101	1.130	0.002	C
			2	31	2.1	8.9	21.1	70.0	2.17	0.422	0.392	0.338	0.134	0.096	1.124	0.002	C
			3	88	2.1	8.9	21.1	70.0	2.22	0.420	0.396	0.331	0.147	0.105	1.139	0.002	C
5	LaD	1.4%	1	25	0.4	22.1	27.9	50.0	2.13	0.351	0.308	0.307	0.079	0.059	1.106	0.003	C
			2	127	0.6	22.1	27.9	50.0	2.13	0.338	0.281	0.303	0.061	0.041	1.103	0.003	C
			3	51	2.6	22.1	27.9	50.0	2.13	0.336	0.278	0.279	0.054	0.042	1.105	0.002	C
5	**LaA**	**16.0%**	**1**	**25**	0.4	**22.1**	**27.9**	**50.0**	**2.13**	**0.351**	**0.308**	**0.307**	**0.079**	**0.059**	**1.106**	**0.003**	**C**
			2	**112**	0.6	**22.1**	**27.9**	**50.0**	**2.13**	**0.338**	**0.281**	**0.303**	**0.061**	**0.041**	**1.103**	**0.003**	**C**
			3	**66**	2.6	**22.1**	**27.9**	**50.0**	**2.13**	**0.336**	**0.278**	**0.279**	**0.054**	**0.042**	**1.105**	**0.002**	**C**
	sum	**64.8%**															
Gulf Coast																	
Starr County																	
1	**Sa**	**4.2%**	**1**	**117**	**0.0**	**76.6**	**16.4**	**7.0**	**1.67**	**0.129**	**0.053**	**0.333**	**0.026**	**0.044**	**1.397**	**2.318**	**FS**
			2	**74**	**0.0**	**63.6**	**13.4**	**23.0**	**1.71**	**0.232**	**0.145**	**0.351**	**0.052**	**0.029**	**1.274**	**0.558**	**FSL**
1	Ra	5.3%	1	28	0.6	64.9	11.6	23.5	1.63	0.307	0.166	0.378	0.047	0.008	1.321	0.245	FSL

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θ_s, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

Appendix A. Continued.

Drainage Category	MUSYM	% Area Covered	Layer	Thick (cm)	Input: Gravel %	Sand %	Silt %	Clay %	rho (g/cm^3)	Theta 0.33 bar	Theta 15 bar	Output: θ_s	θ_r	α (1/cm)	n	K_s (cm/hr)	Texture
			2	175	1.7	60.3	10.2	29.5	1.77	0.264	0.197	0.339	0.064	0.035	1.225	0.258	FSL
2	Cp	9.1%	1	28	2.1	67.3	15.7	17.0	1.55	0.202	0.109	0.373	0.044	0.033	1.334	1.680	FSL
			2	66	2.0	62.2	11.3	26.5	1.50	0.239	0.158	0.404	0.071	0.039	1.312	2.078	SCL
2	Br	10.4%	1	30	0.6	70.6	16.4	13.0	1.62	0.187	0.091	0.355	0.036	0.030	1.337	1.301	FSL
			2	173	2.9	62.6	13.4	24.0	1.52	0.227	0.142	0.390	0.061	0.037	1.319	1.854	SCL
2	**Mc**	**38.1%**	**1**	**43**	**0.0**	**65.2**	**15.3**	**19.5**	**1.55**	**0.218**	**0.126**	**0.386**	**0.052**	**0.032**	**1.320**	**1.488**	**FSL**
			2	**109**	**3.0**	**62.2**	**11.3**	**26.5**	**1.57**	**0.238**	**0.158**	**0.381**	**0.066**	**0.037**	**1.300**	**1.427**	**SCL**
3	**De**	**6.0%**	**1**	**36**	**0.0**	**71.7**	**16.8**	**11.5**	**1.62**	**0.180**	**0.082**	**0.354**	**0.032**	**0.030**	**1.343**	**1.378**	**FSL**
			2	**40**	**0.0**	**62.6**	**13.4**	**24.0**	**1.65**	**0.244**	**0.162**	**0.369**	**0.062**	**0.033**	**1.274**	**0.672**	**SCL**
			3	**76**	**0.0**	**38.6**	**13.4**	**48.0**	**2.00**			**0.305**	**0.072**	**0.034**	**1.123**	**0.045**	**PC**
4	**Zp**	**9.6%**	**1**	**20**	**7.7**	**62.7**	**11.3**	**26.0**	**1.40**	**0.283**	**0.150**	**0.404**	**0.049**	**0.017**	**1.315**	**1.536**	**L**
			2	**56**	**10.6**	**36.7**	**11.3**	**52.0**	**2.00**			**0.276**	**0.068**	**0.033**	**1.124**	**0.043**	**PC**
	sum	**82.8%**															

Drainage category (1, highest – 7 lowest), MUSYM, map unit soil identification; percent of county or aquifer covered by soil unit; soil profile layer (1-6); percent gravel, sand, silt, and clay; rho, bulk density; theta 0.33 bar, water content at field capacity; theta 15 bar, water content at wilting point; pedotransfer output: θs, water content at saturation; θ_r, residual water content, α and n, van Genuchten retention values; K_s, saturated hydraulic conductivity; texture, USDA texture classification.

APPENDIX B – VEGETATION MODELING PARAMETERS

Table B-1: Crop vegetation modeling parameter values and literature references.

Crop	*Max LAI*[1]	*Max Root Depth (m)*	*RLD*[2] *Parameters*			*Crop Growing Season*[3]	*References*
			a	*b*	*c*		
Corn	5.7	2	0.85	0.4	0.02	Victoria: 70-210	Howell et al., 1996; Robertson et al., 1980
Cotton	5.75	2.1	0.5	0.013	0.0	Seymour: 140-260 Lubbock: 135-292 Midland: 140-269 El Paso: 121-248	nd and Dugas, 1989
Sorghum	3.31	1.5	0.85	0.4	0.01	Carson: 135-288 Lubbock: 135-274 Starr: 61-191	Weaver, 1926; Woods et al., 2001.
Hay	2.75	1.35	0.8	0.04	0.01	Bastrop: 101-210	Dugas, Heuer, and Mayeux, 1999; Dudeck et al.
Soybeans	5	2	0.85	0.05	0.01	Liberty: 121-233	Holshouser and Jones. 2001; McWilliams et al., 1999

[1]Leaf Area Index

[2]Root Length Density: $\rho_{rL} = a \times \exp(-bz) + c$ (m roots/m soil), where z = depth.

[3]Day of seeding to day of harvest

Table B-2: Natural vegetation modeling parameter values and literature references.

Vegetation Type/Species	*Max LAI*[1]	*Root Depth (m)*	*% Bare Area*[2]	*% Grass*[3]	*RLD*[4] *Parameters*			*References*
					a	*b*	*c*	
Grass	1.2	1			0.5	0.03	0.04	Jackson et al., 1996; Dugas et al., 1999. Ansley et al., 2002.
Creosotebush Shrub	0.4	1	0.5		0.4	0.03	0.05	Wallace, 19XX; Ackerman, et al. 19XX; Gibbens, Hicks, and Dugas, 1996
Shrub	0.5	1.8	0.6-El Paso 0.2		0.6	0.045	0.01	Heitschmidt et al., 1998; Ansley et al., 2002; James Ansley- pers com
Brush/Shrub	1	1.8	0.2		0.64	0.014	0.01	Heitschmidt et al., 1998; Ansley et al., 2002; James Ansley- pers com
Havard Shin Oak-Mesquite Brush	1.65	1.8	0.2		0.64	0.014	0.01	Heitschmidt et al., 1998; Ansley et al., 2002; James Ansley- pers com
Post Oak Woods/Forest/ Grassland	6	4.3		60	0.4	0.014	0.02	Owens, 1996; Heitschmidt et al., 1998; Ansley et al., 2002; James Ansley- pers com; Karlik and McKay, 2002; REMR Technical Note EI-M-1.3
Mesquite Granjeno Parks	2	3.5		60	0.64	0.014	0.0	Heitschmidt et al., 1998; Ansley et al., 2002; James Ansley- pers com
Oak Mesquite Juniper Parks/Woods	7	3.5		50	0.395	0.012	0.02	Owens, 1996; Heitschmidt et al., 1998; Ansley et al., 2002; James Ansley- pers com; Karlik and McKay. 2002; REMR Technical Note EI-M-1.3
Post Oak Woods/Forest; Willow Oak-Water oak-Blackgum Forest	6	4.3		25	0.4	0.014	0.02	Owens, 1996; Heitschmidt et al., 1998; Ansley et al., 2002; James Ansley- pers com; Karlik and McKay. 2002; REMR Technical Note EI-M-1.3
Pine-Hardwood Forest	3.5	4		25	1.0	0.012	0.01	Law et al., 2001; Smialkowski, 1996; Beymer, 2001; Harrington, 2001; Oren, et al., 1994.

[1]LAI - Leaf Area Index
[2]Percentage of area assumed to have no vegetation.
[3]Percentage of grass assumed to be included in the vegetation type.
[4]Root Length Density: $\rho_{rL} = a \times \exp(-bz) + c$ (m roots/ m soil), where z = depth

APPENDIX C – MODEL RESULTS

Appendix C. UNSATH Model Results. (MUSYM, Map Unit Symbol of SSURGO/STATSGO soil profiles; %, normalized percent of simulated area (ie. County, outcrop area); E, evaporation; T, transpiration; RO, run off; R, recharge; weighted values are weighted according to percent of area represented.

Hueco-Bolson Aquifer
El Paso county
El Paso meteorological station - 224 mm annual average precipitation

		Raw Model Results				Weighted Model Results			
MUSYM	%	E	T	RO	R	E	T	RO	R
Bare Soils									
sand		180	-	0	54				
BPC	17%	167	-	0	73	28	-	0	12
221	18%	221	-	0	50	41	-	0	9
HW2	24%	226	-	0	13	55	-	0	3
HW1	41%	233	-	0	6	95	-	0	2
	100%					**190**	**-**	**0**	**27**
Cotton									
sand		117	121	0	1	0	0	0	
BPC	1%	102	144	0	0	1	2	0	0
HW1	6%	111	136	0	0	6	8	0	0
	7%					**8**	**10**	**0**	**0**
Shrub									
sand		134	102	0	0				
BPC	15%	121	124	0	0	19	19	0	0
221	18%	152	91	0	0	28	17	0	0
HW2	25%	150	92	0	0	37	23	0	0
HW1	35%	133	114	0	0	46	40	0	0
	93%					**111**	**79**	**0**	**0**
Total	**100%**					**119**	**89**	**0**	**0**

Cenozoic-Pecos Alluvium
Outcrop area
Midland meteorological station - 380 mm annual average precipitation

		Raw Model Results				Weighted Model Results			
MUSYM	**%**	**E**	**T**	**RO**	**R**	**E**	**T**	**RO**	**R**
Bare Soils									
sand		250	-	0	142				
PENWELL	14%	147	-	0	240	21	-	0	34
PYOTE	19%	194	-	0	194	36	-	0	36
REAGAN	38%	349	-	23	23	134	-	9	9
SHARVANA	29%	367	-	22	8	106	-	6	2
	100%					**276**	**-**	**15**	**81**
Cotton									
sand		144	239	0	16				
REAGAN	4%	176	201	20	0	7	8	1	0
SHARVANA	4%	201	182	19	0	7	7	1	0
	8%					**15**	**15**	**2**	**0**
Creosotebush Shrub									
sand		170	198	0	32				
PYOTE	6%	137	210	0	50	9	14	0	3
REAGAN	26%	221	158	19	1	59	42	5	0
SHARVANA	18%	242	143	18	0	43	25	3	0
	51%					**110**	**81**	**8**	**3**
Brush and Shrub									
sand		149	244	0	9				
PENWELL	4%	94	295	0	12	4	12	0	1
PYOTE	8%	118	276	0	6	9	21	0	0
REAGAN	8%	183	197	19	0	15	17	2	0
SHARVANA	8%	190	198	16	0	14	15	1	0
	28%					**39**	**52**	**3**	**1**
Havard Shin Oak-Mesquite Brush									
sand		154	237	0	10			0	
PENWELL	10%	101	279	0	18	10	27	0	2
PYOTE	4%	130	259	0	10	5	11	0	0
	14%					**15**	**38**	**0**	**2**
Total	**100%**					**179**	**186**	**13**	**7**

Ogallala Aquifer
Carson County
Amarillo Meteorological Station - 479 mm annual average precipitation

MUSYM	%	Raw Model Results E	T	RO	R	Weighted Model Results E	T	RO	R
Bare Soils									
sand		331	-	0	180				
Mobeetie	15%	423	-	0	97	63	-	0	14
Paloduro	7%	393	-	99	23	26	-	6	2
EcB	9%	216	-	292	9	19	-	26	1
PxA	70%	192	-	325	2	134	-	227	1
	100%					**241**	**-**	**259**	**18**
Sorghum									
sand		193	284	0	47				
Mobeetie	0%	221	299	2	3	0	0	0	0
Paloduro	1%	206	233	84	0	1	1	0	0
EcB	2%	128	115	279	0	3	2	6	0
PxA	25%	113	95	312	1	28	24	78	0
	28%					**32**	**28**	**85**	**0**
Sorghum Irrigated		869 mm average precipitation/irrigation							
sand		254	537	0	113				
Mobeetie	0%	315	558	0	29	0	0	0	0
Paloduro	1%	272	414	212	0	2	3	2	0
EcB	3%	157	180	561	0	5	6	18	0
PxA	38%	137	146	612	1	52	55	230	0
	42%					**59**	**64**	**250**	**0**
Shrub									
sand		224	295	0	2				
Mobeetie	15%	265	259	2	0	39	38	0	0
Paloduro	6%	250	182	89	0	14	10		
EcB	3%	151	86	283	0	5	3	10	0
PxA	7%	132	72	316	0	9	5	22	0
	31%					**67**	**56**	**32**	**0**
Total	**100%**					**158**	**148**	**367**	**0**

Lubbock County
Lubbock Meteorological Station - 474 mm annual average precipitation

		Raw Model Results				Weighted Model Results			
MUSYM	%	E	T	RO	R	E	T	RO	R
Bare Soils									
sand		302	-	0	186				
30	27%	419	-	0	68	113	-	0	18
41	35%	431	-	29	33	150	-	10	11
1	25%	374	-	111	5	94	-	28	1
5	13%	335	-	155	1	44	-	20	0
	100%					**288**	**-**	**58**	**31**
Cotton									
sand		187	285	0	21				
30	6%	213	279	3	0	13	17	0	0
2	8%	232	239	27	0	19	19	2	0
3	6%	209	181	104	0	12	11	6	0
4	3%	202	143	148	0	6	5	5	0
	23%					**38**	**35**	**13**	**0**
Cotton Irrigated		874 mm average preciptitation/irrigation							
sand		253	567	0	76				
30	13%	335	535	2	14	43	69	0	2
2	17%	329	479	86	3	57	83	15	0
3	13%	285	324	287	0	36	41	36	0
4	7%	281	231	383	0	19	16	26	0
	50%					**112**	**139**	**77**	**2**
Sorghum									
sand		193	229	0	75				
30	3%	236	251	2	6	7	8	0	0
2	4%	250	221	25	6	11	9	1	0
3	3%	212	188	98	0	7	6	3	0
4	2%	202	154	140	1	3	3	2	0
	12%					**20**	**18**	**6**	**0**
Sorghum Irrigated		892 mm average precipitation/irrigation							
sand		274	483	0	167				
30	4%	376	497	1	42	15	19	0	2
2	5%	390	450	62	22	20	23	3	1
3	4%	301	367	250	1	11	14	9	0
4	2%	281	296	341	1	6	6	7	0
	15%					**37**	**43**	**20**	**3**
Total	**100%**					**208**	**235**	**116**	**6**

Midland County
Midland Meteorological Station - 380 mm annual average precipitation

MUSYM	%	Raw Model Results E	T	RO	R	Weighted Model Results E	T	RO	R
Bare Soils									
sand		250	-	0	142				
SpB	7%	256	-	0	136	17	-	0	9
MdA	22%	318	-	0	79	71	-	0	18
AfB	50%	331	-	1	64	166	-	0	32
SlA	11%	365	-	26	5	41	-	3	1
Kb	10%	348	-	48	1	34	-	5	0
	100%					**329**	**-**	**8**	**59**
Cotton									
sand		172	205	0	21				
MdA	4%	191	210	0	1	8	9	0	0
AfB	13%	192	191	1	0	25	25	0	0
SlA	1%	244	134	22	0	2	1	0	0
	19%					**36**	**36**	**0**	**0**
Cotton Irrigated		790 mm annual average precipitation/irrigation							
sand		237	482	0	91				
MdA	2%	191	498	0	50	4	11	0	1
AfB	7%	298	295	1	12	20	20	0	1
SlA	1%	378	270	157	0	2	1	1	0
	10%					**27**	**33**	**1**	**2**
Shrub									
sand		164	227	0	11				
SpB	6%	153	247	0	1	9	15	0	0
MdA	17%	185	218	0	0	31	37	0	0
AfB	33%	174	224	0	4	58	74	0	1
SlA	7%	239	142	21	0	17	10	2	0
Kb	9%	251	126	29	0	21	11	2	0
	72%					**137**	**147**	**4**	**2**
Total	**100%**					**199**	**216**	**5**	**4**

Seymour Aquifer
Fisher and Jones counties
Abilene Meteorological Station - 619 mm annual average precipitation

		Raw Model Results				Weighted Model Results			
MUSYM	***%***	***E***	***T***	***RO***	***R***	***E***	***T***	***RO***	***R***
Bare Soils									
sand		358	-	0	277				
Ts	1%	350	-	0	289	5	-	0	4
Eu	21%	404	-	0	241	84	-	0	50
Ne1	11%	462	-	0	183	49	-	0	19
MfB	9%	516	-	12	115	45	-	1	10
MnB	6%	532	-	40	68	31	-	2	4
CaB	14%	594	-	16	28	82	-	2	4
WmA	6%	392	-	241	4	24	-	15	0
RwA	32%	181	-	458	1	59	-	148	0
	100%					**380**	**-**	**169**	**92**
Cotton									
sand		269	268	0	104				
Eu	5%	294	292	0	64	16	16	0	4
Ne1	5%	326	304	0	23	18	17	0	1
MfB	9%	367	263	14	1	31	22	1	0
MnB	5%	392	216	38	1	20	11	2	0
CaB	14%	434	192	15	0	60	26	2	0
WmA	6%	297	106	235	0	17	6	14	0
RwA	31%	130	59	451	1	41	18	141	0
	76%					**203**	**117**	**159**	**5**
Cotton Irrigated		934 mm annual average precipitation/irrigation							
sand		310	484	0	164				
Eu	0%	344	504	0	123	0	0	0	0
Ne1	0%	386	511	0	73	0	0	0	0
MfB	0%	442	448	26	44	0	0	0	0
MnB	0%	462	340	96	53	0	0	0	0
CaB	0%	518	392	42	1	1	1	0	0
WmA	0%	344	177	432	0	0	0	0	0
RwA	0%	151	88	719	1	1	0	3	0
	1%					**3**	**2**	**3**	**0**
Brush									
sand		231	390	0	25				
Ts	1%	225	391	0	36	3	6	0	1
Eu	14%	251	399	0	6	36	58	0	1
Ne1	2%	278	382	0	1	6	8	0	0
CaB	1%	389	241	14	0	6	4	0	0
RwA	4%	119	74	447	1	5	3	18	0
	24%					**56**	**78**	**18**	**2**
Total	**100%**					**263**	**198**	**180**	**7**

Trinity Aquifer
Parker County
Fort Worth Meteorological Station - 855 mm annual average precipitation

		Raw Model Results				Weighted Model Results			
MUSYM	**%**	**E**	**T**	**RO**	**R**	**E**	**T**	**RO**	**R**
Bare Soils									
sand		430	-	0	442				
NdC	5%	414	-	0	441	19	-	0	20
DwD21	21%	608	-	1	263	130	-	0	56
DwC22	17%	606	-	55	227	100	-	9	38
WoD	29%	642	-	173	84	186	-	50	24
WoC2	25%	636	-	269	48	158	-	67	12
Fc	4%	343	-	530	6	13	-	20	0
	100%					**606**	**-**	**146**	**150**
Hay									
sand		277	383	0	225				
DwD21	2%	383	412	4	86	8	9	0	2
DwC22	2%	391	383	51	60	9	9	1	1
WoC2	2%	442	383	250	1	9	8	5	0
	6%					**26**	**25**	**6**	**3**
Grass									
sand		304	378	0	201				
NdC	2%	266	422	0	197	4	7	0	3
DwD21	6%	414	388	5	73	25	23	0	4
DwC22	5%	422	359	53	64	21	18	3	3
WoD	13%	458	290	162	1	58	37	21	0
WoC2	10%	468	213	254	1	46	21	25	0
Fc		220	152	510	1	0	0	0	0
	35%					**155**	**106**	**49**	**11**
Oak-Mesquite-Juniper Parks/Woods									
sand		187	590	0	103				
DwD21	2%	255	573	8	37	4	9	0	1
WoD	5%	285	393	220	0	13	18	10	0
WoC2	3%	289	247	370	0	10	8	13	0
	10%					**27**	**36**	**23**	**1**
Post Oak Woods, Forest and Grassland									
sand		214	542	0	121				
NdC	3%	187	576	0	118	5	15	0	3
DwD21	13%	292	529	5	44	37	66	1	6
DwC22	9%	298	492	66	38	26	42	6	3
WoD	12%	324	348	225	0	39	42	27	0
WoC2	11%	329	226	356	0	35	24	38	0
Fc	2%	159	188	529	0	4	4	12	0
	49%					**145**	**194**	**84**	**12**
Total	**100%**					**352**	**361**	**162**	**27**

Queen City-Sparta Aquifer
Upsur and Gregg counties
Fort Worth Meteorological Station - 855 mm annual average precipitation

		Raw Model Results				Weighted Model Results			
MUSYM	***%***	***E***	***T***	***RO***	***R***	***E***	***T***	***RO***	***R***
Bare Soils									
sand		431	-	0	442				
LbC	30%	616	-	2	255	183	-	1	76
Iu	8%	592	-	38	244	47	-	3	20
CbE	53%	678	-	16	179	361	-	9	95
Ma	9%	680	-	150	43	61	-	13	4
	100%					**653**	**-**	**26**	**195**
Grass									
sand		304	378	0	200				
LbC	13%	393	399	1	91	50	51	0	12
Iu	3%	401	367	35	84	13	11	1	3
CbE	24%	453	358	16	58	111	87	4	14
Ma	3%	446	304	130	1	15	10	4	0
	44%					**189**	**160**	**10**	**28**
Pine-Hardwood Forest									
sand		173	654	0	54				
LbC	17%	224	633	2	23	38	107	0	4
Iu	5%	230	588	47	21	11	27	2	1
CbE	28%	259	580	23	14	72	161	6	4
Ma	3%	254	468	151	0	9	16	5	0
	53%					**129**	**312**	**14**	**9**
Willow Oak-Water oak-Blackgum Forest									
sand		131	697	0	50				
CbE	1%	200	634	25	14	3	9	0	0
Ma	2%	196	516	159	0	4	10	3	0
	3%					**7**	**19**	**4**	**0**
Total	**100%**					**325**	**491**	**27**	**38**

Carizzo-Wilcox Aquifer
Hopkins and Rains counties
Fort Worth Meteorological Station - 855 mm annual average precipitation

		Raw Model Results				Weighted Model Results			
MUSYM	***%***	***E***	***T***	***RO***	***R***	***E***	***T***	***RO***	***R***
Bare Soils									
sand		430	-	0	442				
WoC	16%	590	-	0	289	96	-	0	47
FrB	44%	650	-	20	176	284	-	9	77
WtD	40%	730	-	100	36	292	-	40	14
	100%					**672**	**-**	**49**	**138**
Grass									
sand		304	378	0	201				
WoC	11%	390	396	0	104	42	43	0	11
FrB	24%	424	406	13	25	103	99	3	6
WtD	20%	545	230	104	0	109	46	21	0
	55%					**255**	**188**	**24**	**17**
Post Oak Woods, Forest and Grassland									
sand		213	544	0	121				
WoC	6%	274	547	0	62	16	31	0	4
FrB	20%	298	529	19	15	59	105	4	3
WtD	19%	384	323	162	0	74	62	31	0
	45%					**149**	**198**	**35**	**7**
Total	**100%**					**403**	**386**	**59**	**24**

Bastrop county
Austin meteorological *station - 809 mm annual average precipitation*

		Raw Model Results				Weighted Model Results			
MUSYM	***%***	***E***	***T***	***RO***	***R***	***E***	***T***	***RO***	***R***
Bare Soils									
sand		411	-	0	416				
PaE	24%	583	-	0	250	142	-	0	61
TfB	31%	647	-	152	77	199	-	47	24
AfC	45%	632	-	223	26	283	-	100	12
	100%					**625**	**-**	**147**	**96**
Hay									
sand		261	367	0	211				
PaE	4%	347	404	0	88	14	16	0	4
TfB	6%	402	336	118	8	23	19	7	0
AfC	5%	419	240	210	1	19	11	10	0
	14%					**56**	**47**	**16**	**4**
Sorghum									
sand		325	198	0	311				
PaE	3%	439	240	0	158	11	6	0	4
TfB	3%	492	205	135	36	17	7	5	1
AfC	3%	496	161	203	1	14	5	6	0
	9%					**42**	**18**	**10**	**5**
Post Oak Woods/Forest									
sand		129	650	0	49				
PaE	11%	169	639	0	20	18	67	0	2
TfB	6%	204	436	208	3	12	25	12	0
AfC	10%	209	239	395	0	21	24	40	0
	26%					**50**	**116**	**51**	**2**
Post Oak Woods, Forest and Grassland									
sand		204	515	0	112				
PaE	7%	266	519	0	48	19	37	0	3
TfB	16%	317	353	174	8	50	56	28	1
AfC	28%	323	197	311	0	90	55	86	0
	51%					**159**	**147**	**114**	**5**
Total	**100%**					**307**	**327**	**192**	**16**

Gulf Coast Aquifer
Liberty county
Houston meteorological station - 1184 mm annual average precipitation

		Raw Model Results				Weighted Model Results			
MUSYM	***%***	***E***	***T***	***RO***	***R***	***E***	***T***	***RO***	***R***
Bare Soils									
sand		482	-	0	720				
Kr	21%	630	-	0	580	133	-	0	123
Bm1	12%	817	-	0	318	101	-	0	39
SwB2	12%	977	-	0	215	115	-	0	25
Bm2	16%	1035	-	30	139	163	-	5	22
Ba	22%	429	-	698	66	93	-	151	14
LaA	6%	193	-	1008	20	12	-	63	1
Kf	11%	630	-	879	6	69	-	97	1
	100%					**687**	**-**	**316**	**226**
Soybeans									
sand		326	315	0	570				
Kr	2%	416	332	0	468	9	7	0	10
Bm1	6%	552	329	0	258	33	20	0	16
SwB2	4%	655	331	0	207	28	14	0	9
Bm2	9%	686	347	33	140	61	31	3	12
Ba	13%	264	259	682	0	34	34	89	0
LaA	4%	135	95	995	0	5	4	39	0
	38%					**171**	**110**	**131**	**47**
Grass									
sand		350	383	0	477				
Kr	4%	434	369	0	413	16	13	0	15
SwB2	2%	701	297	0	196	12	5	0	3
	4%					**16**	**13**	**0**	**15**
Willow Oak-Water oak-Blackgum Forest									
sand		155	838	0	207				
Kr	4%	187	845	0	174	8	36	0	7
Kf	9%	44	69	1077	0	4	7	102	0
	14%					**12**	**43**	**102**	**7**
Pine-Hardwood Forest									
sand		200	750	0	256				
Kr	13%	239	759	0	214	30	95	0	27
Bm1	6%	320	720	1	82	19	44	0	5
SwB2	6%	352	706	0	132	21	43	0	8
Bm2	8%	368	636	55	60	28	49	4	5
Ba	10%	178	320	702	0	18	33	72	0
LaA	2%	97	130	990	0	2	2	15	0
	44%					**119**	**266**	**92**	**45**
Total	**100%**					**318**	**432**	**325**	**114**

Victoria county
Victoria meteorological station - 932 mm annual average precipitation

		Raw Model Results				Weighted Model Results			
MUSYM	***%***	***E***	***T***	***RO***	***R***	***E***	***T***	***RO***	***R***
Bare Soils									
sand		434	-	0	516				
GaC	4%	321	-	0	632	12	-	0	23
TeA	35%	668	-	149	116	236	-	53	41
TeB	25%	693	-	233	76	176	-	59	19
Me	5%	160	-	775	13	8	-	41	1
LaA	30%	21	-	917	1	6	-	278	0
	100%					**439**	**-**	**431**	**84**
Sorghum									
sand		323	254	0	381				
TeA	2%	488	270	127	54	11	6	3	1
TeB	6%	514	243	215	27	32	15	14	2
Me	1%	119	65	767	0	2	1	11	0
LaA	16%	20	7	916	1	3	1	149	0
	26%					**49**	**23**	**177**	**3**
Corn									
sand		287	343	0	328				
TeA	1%	434	361	130	16	4	3	1	0
TeB	2%	453	314	217	1	11	7	5	0
Me	1%	105	77	769	0	1	0	4	0
LaA	6%	16	8	917	1	1	0	55	0
	10%					**16**	**11**	**65**	**0**
Grass									
sand		304	394	0	262				
GaC	4%	227	355	2	376	8	12	0	13
TeA	31%	450	359	125	11	139	111	39	3
TeB	17%	485	303	212	4	84	53	37	1
Me	1%	113	77	765	4	2	1	10	0
LaA	7%	19	7	915	1	1	1	68	0
	61%					**235**	**178**	**154**	**17**
Post Oak Woods, Forest and Grassland									
sand		213	581	0	160				
TeA	3%	321	437	162	6	11	15	5	0
	3%					**11**	**15**	**5**	**0**
Total	**100%**					**310**	**227**	**401**	**21**

Starr County
Brownsville meteorological station - 676 mm annual average precipitation

		Raw Model Results				***Weighted Model Results***			
MUSYM	***%***	***E***	***T***	***RO***	***R***	***E***	***T***	***RO***	***R***
Bare Soils									
sand		340	-	0	345				
Sa	12%	404	-	5	280	47	-	1	32
Mc	70%	459	-	5	201	319	-	3	140
De	7%	547	-	64	74	40	-	5	5
Zp	12%	522	-	180	15	61	-	21	2
	100%					**467**	**-**	**30**	**180**
Sorghum									
sand		261	186	0	245				
Sa	2%	295	233	12	154	5	4	0	2
Mc	16%	337	217	9	113	54	35	1	18
Zp	2%	421	128	171	0	8	2	3	0
	19%					**67**	**41**	**5**	**20**
Grass									
sand		226	339	0	129				
Sa	3%	256	350	14	74	7	9	0	2
Mc	9%	284	349	12	35	24	30	1	3
De	2%	310	328	35	16	6	7	1	0
	13%					**37**	**46**	**2**	**5**
Brush									
sand		228	383	0	83				
Sa	5%	265	397	14	17	12	18	1	1
Mc	37%	293	372	14	1	109	138	5	0
De	2%	322	329	38	0	5	5	1	0
Zp	8%	407	147	179	6	34	12	15	0
	52%					**160**	**174**	**21**	**2**
Mesquite-Granjeno Parks									
sand		201	410	0	85				
Sa	3%	230	402	17	44	8	14	1	2
Mc	10%	254	392	13	21	25	38	1	2
De	2%	276	367	36	9	6	8	1	0
	16%					**39**	**61**	**3**	**4**
Total	**100%**					**303**	**321**	**31**	**31**

APPENDIX D – BOREHOLE SAMPLES ANALYSES RESULTS

Table D-1: Southern High Plains borehole sample analysis results.

Borehole (setting)	*Depth (m)*	*Water Content (g/g)*	*Chloride (mg/kg)*	*Chloride (mg / L)*	*Nitrate (mg/kg)*	*Nitrate (mg/ L)*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*USDA Texture*
D7 (natural)	0.15	0.02	0.9	48.8	0.2	11.3	85.0	11.1	3.9	loamy sand
	0.46	0.03	1.4	54.2	0.2	9.3				
	0.69	0.04	3.4	85.0	12.0	300.0	65.8	13.9	20.3	sandy clay loam
	0.99	0.03	5.8	193.8	2.0	66.8	40.0	13.9	46.0	clay
	1.33	0.10	2.1	21.2	1.1	11.1				
	1.73	0.12	1.8	15.2	0.6	5.2	69.6	12.2	18.2	sandy loam
	2.04	0.10	3.1	30.2	0.7	6.7				
	2.35	0.09	3.2	34.7	0.5	5.4	78.6	11.2	10.2	sandy loam
	2.68	0.08	3.0	38.4	0.4	5.4				
	2.83	0.07	3.5	50.6	0.4	5.2				
	3.14	0.06	3.8	60.5	0.4	6.5	83.7	7.3	8.9	loamy sand
	3.96	0.06	2.6	45.4	0.3	4.4	83.7	11.8	4.5	loamy sand
	5.87	0.08	1.0	12.7	0.2	2.7	83.7	11.8	4.5	loamy sand
D12 (natural)	0.15	0.02	0.9	56.7	0.4	25.9	94.0	1.6	4.5	sand
	0.46	0.02	0.9	41.2	2.5	112.1				
	0.76	0.07	4.3	58.9	11.0	150.6	79.9	5.6	14.5	sandy loam
	1.07	0.05	2.6	53.5	6.3	129.6				
	1.37	0.09	3.2	35.1	6.8	74.7	81.2	3.1	15.8	sandy loam
	1.68	0.07	2.6	40.6	1.9	29.7				
	1.98	0.04	6.0	151.4	1.1	27.8	72.1	2.5	25.4	sandy clay loam
	2.29	0.09	31.3	350.7	1.6	18.1				
	2.59	0.09	61.1	658.3	1.2	13.0				
	2.90	0.08	76.2	938.6	0.8	10.4	74.8	3.2	22.0	sandy clay loam
	3.20	0.09	104.6	1221.8	0.9	10.4	68.2	13.2	18.5	sandy loam
	3.51	0.07	120.0	1671.5	1.0	13.7				
	3.81	0.05	119.7	2288.3	0.8	15.8	69.5	15.0	15.5	sandy loam
	4.11	0.05	120.0	2285.2	0.7	13.9				
	4.42	0.06	140.0	2341.7	1.1	18.4	74.6	10.1	15.2	sandy loam
	4.65	0.06	144.0	2343.5	1.1	17.9				
	5.52	0.08	23.0	273.8	0.5	6.4	67.5	26.9	5.5	sandy loam

Table D-1: Southern High Plains borehole sample analysis results (continued).

Borehole (setting)	*Depth (m)*	*Water Content (g/g)*	*Chloride (mg/kg)*	*Chloride (mg / L)*	*Nitrate (mg/kg)*	*Nitrate (mg/ L)*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*USDA Texture*
D13 (natural)	0.15	0.03	1.2	36.5	1.1	33.4	81.2	9.5	9.3	loamy sand
	0.46	0.08	5.2	65.8	61.0	771.5				
	0.76	0.08	10.0	130.6	13.0	169.7	73.4	4.6	22.0	sandy clay loam
	1.07	0.07	6.4	93.3	5.0	72.9				
	1.37	0.07	3.7	55.8	3.5	52.8	73.3	9.3	17.4	sandy loam
	1.68	0.08	4.8	58.9	5.0	61.3				
	1.98	0.08	10.0	129.6	6.1	79.1	72.0	9.4	18.6	sandy loam
	2.29	0.06	13.9	214.6	6.6	102.7	51.6	26.8	21.6	sandy clay loam
	2.59	0.07	20.0	307.0	12.0	184.2				
	2.90	0.06	17.9	306.1	13.0	221.1	74.7	12.6	12.7	sandy loam
	3.20	0.08	19.1	241.7	20.1	254.4				
	3.51	0.12	17.0	146.3	26.0	223.7	52.9	24.9	22.2	sandy clay loam
	3.81	0.10	11.0	112.7	19.0	194.6				
	4.11	0.12	11.0	93.3	16.0	135.7	67.2	13.0	19.8	sandy loam
	4.42	0.09	12.0	136.2	8.1	91.9				
	4.72	0.10	16.0	164.8	4.8	49.4	76.0	13.7	10.2	sandy loam
	5.06	0.09	20.0	211.8	2.2	23.3				
	5.33	0.09	22.0	246.8	0.9	10.2				
	5.52	0.08	23.0	273.8	0.5	6.4	67.5	26.9	5.5	sandy loam
D2 (dryland)	0.08	0.05	1.3	24.2	24.0	447.0				
	0.23	0.12	1.5	12.5	5.7	47.6				
	0.38	0.10	0.8	8.2	5.9	56.6	70.9	12.6	16.5	sandy loam
	0.53	0.10	0.6	6.0	11.0	111.1				
	0.69	0.03	1.6	48.5	21.3	667.4				
	0.84	0.07	0.9	13.7	8.7	128.1				
	0.99	0.08	0.9	11.3	8.6	111.5	80.1	8.7	11.2	sandy loam
	1.14	0.08	1.1	13.9	7.4	93.3				
	1.30	0.09	0.8	8.6	8.8	92.7				
	1.45	0.12	0.5	4.1	7.8	64.7	78.6	8.5	12.8	sandy loam
	1.68	0.13	0.5	3.8	5.6	41.4				
	1.98	0.12	0.5	3.9	4.2	35.1	64.8	11.1	24.1	sandy clay loam
	2.29	0.13	0.9	7.1	13.0	97.0				
	2.59	0.13	0.6	4.3	23.0	177.6				
	2.90	0.14	0.6	4.3	20.9	154.6				
	3.20	0.13	0.6	4.7	32.8	254.4	62.0	14.8	23.2	sandy clay loam
	3.51	0.15	0.9	6.2	38.0	255.5				
	3.81	0.19	0.8	4.3	37.0	191.9	65.9	13.0	21.1	sandy clay loam
	4.11	0.19	0.8	4.6	27.0	145.2				
	4.42	0.19	0.8	4.0	21.0	108.6	67.4	17.4	15.3	sandy loam
	4.72	0.19	1.1	5.6	19.0	97.4				
	4.95	0.21	2.1	10.0	22.0	105.0				

Table D-1: Southern High Plains borehole sample analysis results (continued).

Borehole (setting)	*Depth (m)*	*Water Content (g/g)*	*Chloride (mg/kg)*	*Chloride (mg / L)*	*Nitrate (mg/kg)*	*Nitrate (mg/ L)*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*USDA Texture*
D3 (dryland)	0.08	0.02	4.2	237.2	10.9	621.3				
	0.23	0.04	1.5	42.2	4.8	135.2				
	0.38	0.04	0.8	19.7	2.3	53.2				
	0.53	0.08	0.8	10.7	1.6	20.3				
	0.69	0.10	2.7	25.8	3.2	30.6				
	0.84	0.10	2.4	24.8	1.8	18.6				
	0.99	0.09	4.0	44.2	1.3	14.4				
	1.14	0.08	3.2	42.1	3.2	42.1				
	1.30	0.07	7.2	99.2	0.7	9.6				
	1.45	0.07	5.8	79.9	0.7	9.4				
	1.68	0.06	1.9	34.2	1.0	17.8				
	1.98	0.09	1.7	19.5	0.7	8.4				
	2.29	0.06	1.4	24.5	0.6	10.9				
	2.59	0.05	0.8	16.3	0.5	10.2				
	2.90	0.08	1.2	14.8	0.5	6.8				
	3.20	0.08	0.8	11.1	0.3	3.6				
	3.51	0.10	0.7	7.4	0.3	3.5				
	3.81	0.11	0.6	5.4	0.3	3.0				
	4.11	0.15	1.0	6.4	0.8	5.0				
	4.34	0.12	2.2	18.9	1.2	10.3				
D4 (dryland)	0.08	0.03	1.9	60.8	5.5	176.0				
	0.23	0.06	1.9	32.9	4.0	69.3				
	0.38	0.04	1.3	34.7	2.9	77.5				
	0.53	0.07	1.8	26.0	3.0	43.3				
	0.69	0.10	5.1	52.4	13.0	133.6				
	0.84	0.10	4.3	42.7	9.9	98.3				
	0.99	0.10	2.8	29.1	6.7	69.6				
	1.14	0.09	4.6	50.3	0.9	9.4				
	1.30	0.06	2.2	38.9	1.6	28.3				
	1.45	0.05	2.9	57.8	1.1	21.9				
	1.64	0.08	4.2	54.6	0.9	11.4				
	1.91	0.10	6.1	59.6	1.2	11.7				
	2.25	0.09	1.3	13.8	0.6	6.4				
	2.59	0.09	1.4	14.7	0.6	6.1				
	2.90	0.10	2.2	22.8	0.5	5.7				

Table D-1: Southern High Plains borehole sample analysis results (continued).

Borehole (setting)	*Depth (m)*	*Water Content (g/g)*	*Chloride (mg/kg)*	*Chloride (mg / L)*	*Nitrate (mg/kg)*	*Nitrate (mg/ L)*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*USDA Texture*
D5 (dryland)	0.08	0.10	0.9	8.9	11.0	115.6				
	0.23	0.11	0.7	6.8	12.0	109.9	70.7	10.6	18.6	sandy loam
	0.38	0.11	1.0	9.2	19.9	189.6				
	0.53	0.10	1.6	15.4	17.0	164.1				
	0.69	0.11	1.1	10.4	16.9	160.7	69.6	12.2	18.3	sandy loam
	0.84	0.10	1.0	9.5	12.0	114.5				
	0.99	0.09	1.3	13.6	10.9	115.3				
	1.14	0.09	0.8	8.9	13.0	139.6	64.1	15.1	20.8	sandy clay loam
	1.30	0.12	1.2	9.7	21.0	170.2				
	1.45	0.13	1.8	14.0	18.0	139.8				
	1.68	0.15	0.9	5.7	15.0	100.0	57.8	18.1	24.1	sandy clay loam
	1.98	0.19	0.9	4.5	5.5	29.1				
	2.29	0.19	1.3	6.7	4.1	21.1	52.9	17.1	30.0	sandy clay loam
	2.59	0.11	0.7	6.6	2.4	21.4				
	2.90	0.11	0.4	3.6	1.5	13.3	67.0	16.5	16.5	sandy loam
	3.20	0.13	0.7	5.3	2.8	21.0				
	3.51	0.15	1.0	6.5	4.1	27.9	46.0	31.3	22.7	loam
	3.81	0.16	1.0	6.3	5.3	33.6				
	4.11	0.16	1.4	8.3	5.8	35.0				
	4.42	0.13	1.1	8.1	3.7	28.5	28.7	41.7	29.6	clay loam
D6 (irrigated)	0.08	0.04	5.0	114.9	15.0	344.7				
	0.23	0.06	1.9	34.3	7.9	142.8	80.2	6.1	13.7	sandy loam
	0.38	0.04	11.0	275.0	28.0	700.0				
	0.53	0.03	14.0	466.7	36.0	1200.0				
	0.69	0.01	18.6	1549.9	16.7	1386.8				
	0.84	0.02	17.0	857.1	17.0	857.1				
	0.99	0.10	62.9	605.9	75.9	730.9	72.5	6.3	21.2	sandy clay loam
	1.14	0.06	49.8	780.2	34.8	546.1				
	1.30	0.10	56.7	553.8	43.8	427.5	78.9	0.7	20.4	sandy clay loam
	1.45	0.10	52.0	507.9	43.0	420.0				
	1.68	0.11	52.0	483.5	42.0	390.5				
	1.98	0.07	16.9	241.3	14.9	212.9	81.5	3.9	14.6	sandy loam
	2.29	0.09	12.0	129.8	11.0	119.0				
	2.59	0.10	1.1	11.0	2.6	26.1				
	2.90	0.09	2.2	25.1	4.7	53.7	82.8	2.3	15.0	sandy loam
	3.20	0.09	4.2	47.3	9.6	109.2				
	3.51	0.13	8.9	66.1	28.1	207.9	63.5	16.7	19.8	sandy loam
	3.81	0.10	11.0	107.9	31.0	304.2				
	4.11	0.10	12.9	135.8	24.9	261.1				
	4.42	0.12	4.8	40.1	24.0	200.4	68.8	12.6	18.6	sandy loam
	4.72	0.09	8.8	95.7	17.0	185.0				
	5.03	0.10	5.4	52.7	15.0	146.3				
	5.33	0.08	6.6	81.4	14.0	172.6	81.5	6.0	12.5	sandy loam

Table D-2: Seymour borehole sample analysis results.

Borehole (setting)	Depth (m)	Water Content (g/g)	Chloride (mg/kg)	Chloride (mg / L)	Nitrate (mg/kg)	Nitrate (mg/ L)	Sand (%)	Silt (%)	Clay (%)	USDA Texture
H5 (natural)	0.08	0.02	0.6	41.0	1.0	64.0				
	0.23	0.01	0.8	62.7	0.6	46.8	98.0	0.0	3.0	sand
	0.38	0.01	0.4	31.0	0.4	32.5				
	0.53	0.02	0.4	23.1	0.1	5.5				
	0.69	0.01	3.5	294.2	0.5	40.3	96.7	0.3	3.0	sand
	0.84	0.02	0.3	17.7	0.2	12.5				
	0.99	0.02	0.2	11.9	0.2	8.1				
	1.14	0.02	0.5	22.4	0.1	6.3	98.0	0.0	3.0	sand
	1.30	0.02	2.5	111.6	0.2	9.4				
	1.45	0.03	0.2	6.2	0.1	4.4				
	1.68	0.03	0.3	12.0	0.1	3.5	92.2	2.6	5.2	sand
	1.98	0.02	2.4	99.1	0.1	5.4				
	2.29	0.03	0.3	7.5	0.1	3.4				
	2.59	0.03	1.7	56.0	0.1	3.1	91.1	2.5	6.4	sand
	2.90	0.04	0.5	12.3	0.2	6.6				
	3.20	0.03	2.1	83.9	0.2	6.8				
	3.51	0.04	0.2	6.4	0.2	4.8	89.8	2.8	7.4	sand
	3.81	0.03	1.7	52.3	0.2	7.7				
	4.11	0.06	0.4	6.1	0.2	3.5	83.5	6.7	9.9	loamy sand
	4.42	0.03	1.9	60.9	0.2	6.7				
	4.72	0.07	0.9	12.5	0.2	2.5				
	5.03	0.03	1.6	51.7	0.3	10.7	88.4	4.2	7.4	loamy sand
	5.33	0.11	2.2	20.6	0.5	4.5				
	5.64	0.15	2.1	14.2	0.8	5.4	74.5	8.6	16.9	sandy loam
H6 (irrigated)	0.08	0.08	7.8	93.0	8.2	97.4	84.7	7.6	7.7	loamy sand
	0.23	0.06	2.4	42.9	15.0	267.9				
	0.38	0.08	2.5	30.7	15.4	188.8	80.9	5.5	13.6	sandy loam
	0.53	0.07	2.7	36.9	17.0	232.1				
	0.69	0.06	2.9	45.4	29.9	469.2	84.7	4.2	11.1	loamy sand
	0.84	0.05	1.9	35.6	19.1	355.8				
	0.99	0.05	2.0	37.7	18.2	339.5				
	1.14	0.07	2.1	29.7	20.7	297.2	86.0	2.5	11.5	loamy sand
	1.30	0.10	3.1	29.5	20.9	199.9				
	1.45	0.10	5.3	52.7	11.9	119.4				
	1.68	0.12	8.4	68.6	15.7	127.6	72.0	6.8	21.2	sandy clay loam
	1.98	0.12	5.4	45.9	8.8	75.4				
	2.29	0.12	5.4	45.9	8.8	75.4				
	2.59	0.14	10.0	69.6	4.3	29.9	73.3	8.1	18.7	sandy loam
	2.90	0.15	7.8	52.5	7.9	53.1				
	3.20	0.13	7.7	58.0	11.9	89.2				
	3.51	0.14	12.8	92.1	31.9	230.2	72.0	10.3	17.8	sandy loam
	3.81	0.13	14.2	113.0	19.0	150.7				
	4.11	0.14	18.9	132.7	13.9	97.8				
	4.42	0.13	17.8	140.6	6.1	48.1	70.7	10.3	19.0	sandy loam
	4.72	0.12	21.9	182.5	3.8	31.5				
	5.03	0.12	20.9	177.3	3.7	31.2				
	5.33	0.11	22.1	201.6	1.0	9.2	75.8	8.9	15.2	sandy loam
	5.64	0.10	10.3	104.4	3.8	38.0				
	5.94	0.11	9.7	86.4	1.4	12.5	73.2	11.9	14.9	sandy loam

Table D-2: Seymour borehole sample analysis results (continued).

Borehole (setting)	*Depth (m)*	*Water Content (g/g)*	*Chloride (mg/kg)*	*Chloride (mg / L)*	*Nitrate (mg/kg)*	*Nitrate (mg/ L)*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*USDA Texture*
H1 (dryland)	0.08	0.02	6.6	286.5	0.7	29.5				
	0.23	0.05	4.5	93.3	2.1	43.7	90.4	4.6	4.9	Sand
	0.38	0.05	1.2	25.1	0.6	13.9				
	0.53	0.06	1.3	20.9	0.7	11.6	89.1	1.7	9.2	loamy sand
	0.69	0.12	2.0	17.4	0.4	3.2				
	0.84	0.12	0.8	6.3	0.4	3.4	75.2	7.4	17.5	sandy loam
	0.99	0.10	0.8	7.7	0.4	4.3				
	1.14	0.09	1.2	14.1	0.5	5.7	82.7	4.0	13.3	sandy loam
	1.30	0.07	1.0	13.7	0.3	4.8				
	1.45	0.07	1.2	16.8	0.5	7.4	87.8	1.7	10.4	loamy sand
	1.68	0.06	0.9	14.6	0.5	7.9				
	1.98	0.08	1.3	15.3	0.5	5.4	75.9	10.4	13.7	sandy loam
	2.29	0.12	1.2	10.0	1.0	8.0				
	2.59	0.11	1.0	8.8	1.3	11.5	66.9	10.6	22.5	sandy clay loam
	2.90	0.07	0.8	11.7	1.8	26.1				
	3.20	0.06	1.1	18.2	1.4	23.1	76.1	10.2	13.7	sandy loam
	3.51	0.06	0.9	14.3	1.5	23.3				
	3.81	0.07	1.4	19.8	1.2	17.0				
	4.11	0.05	1.0	21.3	1.4	30.4	82.7	7.3	10.0	loamy sand
	4.42	0.05	1.1	20.4	1.4	26.0				
	4.72	0.07	1.7	25.0	1.3	19.1				
	5.03	0.10	1.2	11.9	0.5	4.8	76.3	5.0	18.7	sandy loam
	5.33	0.09	0.3	3.1	1.8	19.7				
	5.64	0.05	1.4	27.5	0.5	10.1				
	5.94	0.06	1.1	19.5	0.2	3.9	86.6	5.1	8.3	loamy sand
H3 (dryland)	0.08	0.03	3.9	125.3	3.2	102.8				
	0.23	0.02	2.1	88.2	1.1	45.9	90.4	3.8	5.8	sand
	0.38	0.05	0.9	20.5	0.9	20.1				
	0.53	0.06	1.3	20.1	1.1	17.0	85.3	2.6	12.1	loamy sand
	0.69	0.08	0.8	10.3	0.9	11.7				
	0.84	0.06	1.2	18.9	0.7	10.7				
	0.99	0.09	0.7	8.0	0.7	7.9				
	1.14	0.12	2.2	18.1	0.8	6.8	66.7	12.1	21.2	sandy clay loam
	1.30	0.10	1.1	11.3	0.5	4.9				
	1.45	0.10	0.9	9.1	0.4	3.9				
	1.68	0.09	0.9	9.8	0.3	2.9	78.9	6.2	15.0	sandy loam
	1.98	0.08	1.6	19.5	1.3	15.8				
	2.29	0.07	5.2	74.3	1.3	18.6	78.8	6.6	14.6	sandy loam
	2.59	0.03	1.9	55.1	0.4	10.4	82.6	7.5	10.0	loamy sand
	2.90	0.04	1.5	35.7	0.2	4.3				
	3.20	0.13	2.4	18.6	0.4	2.8				
	3.51	0.15	1.3	8.6	0.1	0.9	55.1	13.6	31.2	sandy clay loam
	3.81	0.14	0.9	6.6	0.5	3.2				
	4.11	0.12	0.7	5.9	0.3	2.7				
	4.42	0.09	0.8	9.5	0.3	2.9	77.7	6.1	16.2	sandy loam
	4.72	0.08	1.1	13.6	0.2	2.7				
	5.03	0.07	2.3	34.1	0.3	4.6	82.7	7.3	10.0	loamy sand
	5.33	0.08	0.7	9.2	0.1	1.7				
	5.64	0.06	1.4	24.3	0.3	5.7				
	5.94	0.06	1.0	17.4	0.2	3.5	85.3	6.0	8.7	loamy sand

Table D-2: Seymour borehole sample analysis results (continued).

Borehole (setting)	*Depth (m)*	*Water Content (g/g)*	*Chloride (mg/kg)*	*Chloride (mg / L)*	*Nitrate (mg/kg)*	*Nitrate (mg/ L)*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*USDA Texture*
H4 (dryland)	0.08	0.03	1.7	55.2	4.5	145.9				
	0.23	0.02	0.8	35.8	1.4	61.0				
	0.38	0.03	1.2	47.5	1.7	67.3				
	0.53	0.03	0.9	30.0	0.8	26.1				
	0.69	0.05	1.6	33.7	1.6	33.7				
	0.84	0.05	1.9	40.6	1.8	38.5				
	0.99	0.08	2.0	25.5	1.2	15.3				
	1.14	0.10	1.7	17.0	5.1	51.0				
	1.30	0.08	3.2	39.8	5.1	63.9				
	1.45	0.11	0.7	6.4	6.7	62.6				
	1.68	0.12	0.7	5.7	3.8	32.5				
	1.98	0.12	0.6	5.1	4.5	38.1				
	2.29	0.13	1.2	9.0	2.1	15.7				
	2.59	0.16	1.4	8.9	3.1	19.7				
	2.90	0.15	0.5	3.4	2.9	20.0				
	3.20	0.13	2.8	21.9	1.9	14.9				
	3.51	0.15	0.7	4.3	5.0	33.3				
H7 (dryland)	0.08	0.04	5.6	140.0	1.1	27.5				
	0.23	0.03	7.2	249.5	2.3	79.7	84.8	4.1	11.1	loamy sand
	0.38	0.06	1.3	21.5	1.5	24.8				
	0.53	0.10	1.4	14.0	0.1	1.0	69.5	7.7	22.8	sandy clay loam
	0.69	0.09	5.3	60.3	0.8	9.6				
	0.84	0.10	2.3	22.5	1.7	16.6	71.9	8.2	19.9	sandy loam
	0.99	0.09	2.0	21.5	2.0	21.5				
	1.14	0.07	2.1	31.5	2.1	31.5	81.0	4.2	14.9	sandy loam
	1.30	0.08	3.8	45.1	2.6	30.8				
	1.45	0.08	2.6	31.9	4.4	54.0	77.1	5.8	17.0	sandy loam
	1.68	0.06	2.4	43.8	6.6	117.3				
	1.98	0.05	3.2	60.6	7.2	134.6				
	2.29	0.06	2.9	47.4	7.1	115.0	74.5	8.9	16.5	sandy loam
	2.59	0.15	2.1	13.8	8.7	58.4				
	2.90	0.07	2.4	32.6	25.9	352.7				
	3.20	0.02	1.7	75.8	21.9	969.1	81.0	7.2	11.8	sandy loam
	3.51	0.07	1.2	16.7	33.7	459.0				
	3.81	0.14	4.8	33.4	80.1	560.7				
	4.11	0.17	5.6	32.3	76.7	446.5	36.1	34.5	29.4	clay loam
	4.42	0.12	8.7	76.0	26.8	233.2				
	4.72	0.12	4.0	32.3	57.2	459.9				
	5.03	0.08	2.7	35.8	31.1	410.5	70.6	15.0	14.3	sandy loam

Table D-2: Seymour borehole sample analysis results (continued).

Borehole (setting)	*Depth (m)*	*Water Content (g/g)*	*Chloride (mg/kg)*	*Chloride (mg / L)*	*Nitrate (mg/kg)*	*Nitrate (mg/ L)*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*USDA Texture*
H4 (dryland)	0.08	0.03	1.7	55.2	4.5	145.9				
	0.23	0.02	0.8	35.8	1.4	61.0				
	0.38	0.03	1.2	47.5	1.7	67.3				
	0.53	0.03	0.9	30.0	0.8	26.1				
	0.69	0.05	1.6	33.7	1.6	33.7				
	0.84	0.05	1.9	40.6	1.8	38.5				
	0.99	0.08	2.0	25.5	1.2	15.3				
	1.14	0.10	1.7	17.0	5.1	51.0				
	1.30	0.08	3.2	39.8	5.1	63.9				
	1.45	0.11	0.7	6.4	6.7	62.6				
	1.68	0.12	0.7	5.7	3.8	32.5				
	1.98	0.12	0.6	5.1	4.5	38.1				
	2.29	0.13	1.2	9.0	2.1	15.7				
	2.59	0.16	1.4	8.9	3.1	19.7				
	2.90	0.15	0.5	3.4	2.9	20.0				
	3.20	0.13	2.8	21.9	1.9	14.9				
	3.51	0.15	0.7	4.3	5.0	33.3				
H7 (dryland)	0.08	0.04	5.6	140.0	1.1	27.5				
	0.23	0.03	7.2	249.5	2.3	79.7	84.8	4.1	11.1	loamy sand
	0.38	0.06	1.3	21.5	1.5	24.8				
	0.53	0.10	1.4	14.0	0.1	1.0	69.5	7.7	22.8	sandy clay loam
	0.69	0.09	5.3	60.3	0.8	9.6				
	0.84	0.10	2.3	22.5	1.7	16.6	71.9	8.2	19.9	sandy loam
	0.99	0.09	2.0	21.5	2.0	21.5				
	1.14	0.07	2.1	31.5	2.1	31.5	81.0	4.2	14.9	sandy loam
	1.30	0.08	3.8	45.1	2.6	30.8				
	1.45	0.08	2.6	31.9	4.4	54.0	77.1	5.8	17.0	sandy loam
	1.68	0.06	2.4	43.8	6.6	117.3				
	1.98	0.05	3.2	60.6	7.2	134.6				
	2.29	0.06	2.9	47.4	7.1	115.0	74.5	8.9	16.5	sandy loam
	2.59	0.15	2.1	13.8	8.7	58.4				
	2.90	0.07	2.4	32.6	25.9	352.7				
	3.20	0.02	1.7	75.8	21.9	969.1	81.0	7.2	11.8	sandy loam
	3.51	0.07	1.2	16.7	33.7	459.0				
	3.81	0.14	4.8	33.4	80.1	560.7				
	4.11	0.17	5.6	32.3	76.7	446.5	36.1	34.5	29.4	clay loam
	4.42	0.12	8.7	76.0	26.8	233.2				
	4.72	0.12	4.0	32.3	57.2	459.9				
	5.03	0.08	2.7	35.8	31.1	410.5	70.6	15.0	14.3	sandy loam

Table D-3: Southern High Plains borehole sample matric potential results. MP: matric potential.

D7 (natural)		*D12 (natural)*		*D13 (natural)*		*D2 (dryland)*		*D5 (dryland)*		*D6 (irrigated)*	
Depth (m)	*MP (m)*	*Depth (m)*	*MP (m)*	*Depth (m)*	*MP (m)*	*Depth (m)*	*MP (m)*	*Depth (m)*	*MP (m)*	*Depth (m)*	*MP (m)*
0.15	-305	0.15	-552	0.15	-475	0	-2.3	0.00	-4.6	0.00	-2.0
0.46	-188	0.46	-57	0.46	-470	0.2	-1.2	0.15	-1.2	0.15	-1.8
0.84	-250	0.76	-52	0.76	-463	0.3	-1.0	0.30	-1.9	0.30	-1.6
1.14	-264	1.07	-435	1.07	-420	0.5	-1.1	0.46	-2.5	0.46	-1.6
1.52	-205	1.37	-381	1.37	-346	0.6	-2.2	0.61	-2.4	0.61	-2.2
1.83	-218	1.68	-338	1.68	-304	0.9	-2.1	0.91	-2.6	0.91	-2.7
2.21	-188	1.98	-283	1.98	-276	1.2	-2.2	1.22	-2.5	1.22	-2.6
2.51	-213	2.29	-267	2.29	-198	1.5	-3.1	1.52	-2.9	1.52	-2.4
2.74	-185	2.59	-242	2.59	-235	1.8	-3.2	1.83	-2.7	1.83	-2.1
2.97	-172	2.90	-244	2.90	-172	2.1	-3.5	2.13	-2.6	2.13	-2.0
3.29	-154	3.20	-258	3.20	-190	2.4	-3.4	2.44	-1.2	2.44	-2.9
4.27	-183	3.51	-265	3.51	-168	2.7	-3.1	2.74	0.0	2.74	-3.0
5.79	-179	3.81	-232	3.81	-146	3	-1.7	3.05	-1.1	3.05	-3.2
		4.11	-255	4.11	-183	3.7	-1.6	3.35	-2.0	3.66	-4.1
		4.42	-223	4.42	-177	4.3	-0.5	3.66	-2.9	4.27	-4.2
		4.65	-245	4.72	-179	4.6	-0.1	4.27	-4.4	4.88	-4.6
				5.03	-171					5.49	-4.6
				5.33	-173						

Table D-4: Seymour borehole sample matric potential results. MP: matric potential.

H5 (natural)		*H1 (dryland)*		*H6 (irrigated)*	
Depth (m)	MP (m)	Depth (m)	MP (m)	Depth (m)	MP (m)
0.00	-0.8	0.20	-0.7	0.15	-0.5
0.20	-0.5	0.30	-1.0	0.30	-0.5
0.30	-0.7	0.50	-0.8	0.46	-0.4
0.50	-0.8	0.80	-1.1	0.61	-0.5
0.60	-0.8	1.10	-1.6	0.76	-0.6
0.80	-0.7	1.50	-1.3	0.91	-1.1
0.90	-0.8	2.00	-1.8	1.07	-1.2
1.10	-0.8	2.50	-2.1	1.22	-1.2
1.20	-0.8	3.00	-4.4	1.37	-1.3
1.40	-0.8	4.00	-2.4	1.52	-1.4
1.50	-0.7	5.00	-1.8	1.68	-1.5
1.70	-0.8	6.00	-2.2	1.83	-1.8
1.80	-0.8			1.98	-2.1
2.00	-0.8			2.13	-1.5
2.10	-0.8			2.29	-0.6
2.30	-0.8			2.44	-0.5
2.40	-0.9			2.59	-0.4
2.60	-0.9			2.74	-1.4
2.70	-0.9			2.90	-1.9
2.90	-1.0			3.05	-2.1
3.00	-0.9			3.35	-1.8
3.40	-0.9			3.66	-1.8
3.70	-0.7			3.96	-1.1
4.00	-0.7			4.27	-1.1
4.30	-0.5			4.57	-1.2
4.60	-0.3			4.88	-1.2
4.90	-1.0			5.18	-1.3
5.20	-0.8			5.49	-1.3
				5.79	-1.4
				6.00	-1.7

APPENDIX E – ELECTROMAGNETIC INDUCTION SURVEY DATA

Table E-1: Southern High Plains electromagnetic induction survey instrument response data for the natural settings. Bold values represent borehole location. H: horizontal dipole mode, V: vertical dipole mode.

Units: mS/m		Natural (D-7)				Natural (D-12)				Natural (D-13)			
Easting	Northing	EM38		EM31		EM38		EM31		EM38		EM31	
(m)	(m)	H	V	H	V	H	V	H	V	H	V	H	V
0	30	4.4	6.6	19.3	25.3	6.3	9.6	24.4	31.9				
0	27	4.6	6.5	19.4	26.0	6.5	9.8	24.3	30.2				
0	24	4.3	6.5	19.8	25.9	5.8	8.6	24.4	32.4				
0	21	4.5	6.2	19.4	25.7	5.9	8.7	24.9	31.4				
0	18	5.2	7.6	19.7	26.4	5.5	8.6	24.2	30.5				
0	15	5.2	8.0	21.1	27.6	6.2	8.9	24.3	30.9				
0	12	5.3	8.0	21.2	27.6	5.2	8.5	24.3	32.0				
0	9	5.0	8.3	20.6	27.9	6.4	8.8	24.3	31.9				
0	6	5.8	8.6	20.7	28.4	6.7	9.7	24.5	31.7				
0	3	4.2	8.6	21.8	27.6	5.9	9.0	24.2	32.6				
0	0	**6.0**	**8.8**	**21.7**	**27.5**	**6.6**	**9.2**	**24.7**	**30.8**				
0	-3	7.0	9.0	21.6	27.6	5.7	9.2	24.3	32.6				
0	-6	6.8	9.2	21.6	27.5	6.3	9.2	24.8	31.4				
0	-9	6.3	8.5	20.6	26.6	6.2	9.4	24.0	32.5				
0	-12	6.1	7.8	19.9	25.5	6.4	9.6	25.0	32.3				
0	-15	5.8	7.6	20.1	25.3	6.5	9.8	25.3	32.6				
0	-18	6.2	8.5	20.2	27.3	6.0	8.9	24.9	32.7				
0	-21	6.3	8.5	20.5	26.7	5.8	9.0	24.3	32.2				
0	-24	6.2	8.3	20.5	27.4	6.1	9.4	24.3	31.7				
0	-27	5.9	7.7	20.2	26.4	6.2	8.7	24.6	32.3				
0	-30	5.9	7.8	20.4	25.8	6.1	8.8	24.3	31.5				
30	0					7.7	11.2	26.1	33.1	7.2	8.5	21.0	22.4
27	0					7.4	10.9	25.0	33.2	11.5	12.2	24.4	23.0
24	0					5.9	9.2	25.3	32.4	11.0	12.3	25.0	25.4
21	0					7.4	9.9	25.7	30.3	10.4	11.8	25.3	23.8
18	0					5.6	8.5	24.7	32.7	9.3	10.4	24.0	23.5
15	0					6.3	9.5	25.3	32.6	7.4	8.1	22.2	25.7
12	0					7.4	10.5	25.6	31.8	5.7	11.0	20.8	26.0
9	0					8.3	10.7	26.0	31.0	5.3	7.4	20.1	26.0
6	0					6.9	9.4	25.7	32.8	8.0	7.8	20.8	24.8
3	0					7.0	9.3	25.0	32.9	7.2	8.6	21.3	25.1
0	0					**6.9**	**9.4**	**25.1**	**30.3**	**6.2**	**7.0**	**21.2**	**25.7**
-3	0					7.1	9.7	25.2	31.5	6.0	7.1	21.2	26.7
-6	0					7.3	10.5	26.5	31.3	7.2	9.0	23.0	26.5
-9	0					6.8	10.3	26.6	32.1	9.5	12.3	25.0	24.0
-12	0					6.2	9.5	25.2	32.3	10.3	12.7	25.4	26.0
-15	0					6.6	9.4	24.5	31.8	10.9	11.6	24.2	22.2
-18	0					5.8	8.8	25.0	30.8	6.3	9.5	23.0	25.5
-21	0					6.1	8.9	24.6	31.3	7.5	8.5	21.6	26.7
-24	0					6.6	9.7	24.6	31.8	8.4	9.6	21.9	34.0
-27	0					6.4	9.3	25.1	32.0	9.8	14.1	26.0	2.0
-30	0					6.6	9.9	25.2	32.6	9.8	14.4	21.5	35.0

Table E-1 (continued): Southern High Plains electromagnetic induction survey instrument response data for the cultivated settings. Bold values represent borehole location. H: horizontal dipole mode, V: vertical dipole mode.

Units: mS/m		*D2 (dryland)*				*D5 (dryland)*				*D6 (dryland)*			
Easting (m)	*Northing (m)*	*EM38*		*EM31*		*EM38*		*EM31*		*EM38*		*EM31*	
		H	*V*	*H*	*V*	*H*	*V*	*H*	*V*	*H*	*V*	*H*	*V*
0	30	19.6	23.8	41.2	48.2	34.0	41.2	56.2	59.5	35.0	45.3	72.5	60.5
0	27	20.8	24.0	41.0	48.5	35.2	41.7	57.3	60.4	32.8	45.8	73.0	61.5
0	24	21.7	27.5	41.1	49.8	34.1	42.0	58.4	59.0	32.7	46.9	66.5	62.3
0	21	20.3	25.9	41.4	51.5	38.4	43.2	58.9	60.5	30.3	46.7	62.4	67.5
0	18	21.5	26.1	41.5	48.5	35.3	43.7	58.3	60.4	32.8	44.1	58.3	66.5
0	15	22.3	26.4	42.5	49.7	36.3	41.9	58.2	59.9	31.2	45.5	55.5	64.9
0	12	21.7	26.1	43.4	51.6	40.0	45.9	58.0	59.4	30.6	44.8	55.0	65.5
0	9	22.5	27.8	44.2	52.2	37.1	42.2	57.6	59.1	29.3	43.8	54.7	65.1
0	6	24.1	28.3	45.7	54.6	38.5	45.0	57.0	53.7	29.5	43.5	52.0	64.2
0	3	26.6	32.4	48.7	56.5	41.4	42.7	57.5	59.0	28.5	40.9	52.0	63.5
0	0	26.8	32.3	51.0	60.4	35.7	41.1	55.2	57.5	**27.0**	**38.7**	**51.2**	**68.3**
0	-3	28.0	33.4	52.3	58.5	38.5	41.9	56.7	56.4	30.7	38.5	52.0	62.5
0	-6	28.4	33.5	53.4	62.6	36.5	40.5	56.0	56.4	28.4	35.2	51.8	65.6
0	-9	28.7	36.6	54.1	63.4	35.7	39.7	53.9	54.5	25.0	33.5	47.7	65.5
0	-12	26.6	35.5	53.8	63.1	35.9	41.4	52.5	50.3	23.0	36.4	49.4	65.8
0	-15	28.2	35.4	54.8	63.9	33.0	36.6	51.4	53.5	31.5	41.5	42.1	65.0
0	-18	29.2	35.8	55.6	65.0	33.2	37.4	50.0	51.3	30.2	42.3	54.0	73.0
0	-21	29.7	38.2	55.9	65.0	33.3	35.5	49.8	50.2	30.0	42.9	54.0	72.0
0	-24	27.7	36.3	56.9	64.4	28.3	33.4	47.0	50.7	31.0	42.1	55.5	69.5
0	-27	28.3	36.7	56.2	66.2	29.8	31.7	44.8	46.1	31.9	41.3	54.4	69.2
0	-30	29.4	37.6	57.0	65.9	27.6	30.4	45.0	44.7	28.9	40.5	51.7	69.8
30	0	25.9	26.4	41.4	46.3					52.0	72.6	86.5	89.1
27	0	24.9	26.7	41.3	48.1					48.9	70.9	88.0	91.4
24	0	24.9	28.0	41.8	49.4					48.8	70.7	85.0	90.0
21	0	26.3	28.3	43.5	49.8					49.0	68.9	85.0	86.7
18	0	26.5	28.8	44.3	51.1	**36.4**	**38.0**	**57.0**	**69.2**	48.0	68.7	83.0	84.5
15	0	26.4	29.8	45.2	53.5	36.8	39.0	56.3	62.0	47.1	67.3	79.0	81.3
12	0	25.4	29.9	45.4	54.1	36.0	37.3	55.0	61.5	46.9	66.0	75.4	74.5
9	0	28.6	31.2	47.9	56.0	38.7	39.2	56.2	59.0	42.3	59.4	72.1	75.5
6	0	29.1	32.5	49.7	57.3	39.9	39.7	57.3	59.0	42.9	59.3	64.5	65.4
3	0	29.9	33.5	50.2	57.3	43.7	42.3	58.2	57.4	35.5	50.2	57.0	55.3
0	0	29.9	34.0	51.4	59.9	41.3	41.0	58.4	58.2	**28.3**	**39.3**	**51.9**	**53.8**
-3	0	28.2	34.3	51.0	60.3	41.7	40.3	58.1	57.0				
-6	0	28.5	34.2	51.9	61.4	39.7	40.3	57.2	57.8				
-9	0	30.1	36.4	52.9	60.9	39.9	42.2	57.3	58.6				
-12	0	30.2	36.9	54.1	61.7	41.0	37.9	57.3	59.3				
-15	0	32.2	37.5	55.5	63.6	41.3	41.0	57.2	58.1				
-18	0	31.9	37.7	56.2	63.4	40.7	41.7	57.5	59.5				
-21	0	33.0	37.8	56.5	62.4	41.0	41.5	58.2	59.5				
-24	0	32.6	38.5	56.2	63.0	40.4	40.5	58.1	59.3				
-27	0	31.5	39.4	55.2	63.5	40.1	41.5	59.3	60.4				
-30	0	**30.2**	**39.4**	**54.9**	**62.0**	40.3	41.7	59.7	60.6				

Table E-2: Seymour electromagnetic induction survey instrument response data for the natural and irrigated settings. Bold values represent borehole location. H: horizontal dipole mode, V: vertical dipole mode.

Units: mS/m		H5 (natural)				H6 (irrigated)			
Easting	Northing	EM38		EM31		EM38		EM31	
(m)	(m)	H	V	H	V	H	V	H	V
0	30					12.0	18.0	32.5	40.7
0	27					12.9	17.5	32.7	41.0
0	24					13.2	17.8	32.8	41.3
0	21					13.2	17.9	33.3	41.3
0	18					14.6	19.1	34.2	41.8
0	15					16.4	20.3	34.9	41.9
0	12					16.1	19.9	35.5	42.7
0	9					15.8	19.3	35.1	43.0
0	6					15.7	19.0	34.8	43.5
0	3					15.4	19.1	34.9	43.3
0	0					**15.3**	**18.6**	**34.9**	**43.0**
0	-3					14.2	18.8	34.2	43.3
0	-6					14.7	18.0	34.3	42.7
0	-9					13.8	18.6	34.5	43.6
0	-12					15.8	17.7	35.8	44.4
0	-15					15.1	19.3	35.3	44.1
0	-18					16.4	19.0	35.9	44.2
0	-21					16.2	20.1	36.3	44.5
0	-24					15.5	20.4	36.3	45.3
0	-27					14.4	19.1	35.6	45.9
0	-30					14.0	19.8	36.0	46.1
30	0								
27	0								
24	0								
21	0								
18	0								
15	0								
12	0	4.5	6.0	17.7	23.4				
9	0	4.0	5.5	17.8	22.9				
6	0	3.0	6.3	16.7	22.5				
3	0	3.5	5.1	16.7	22.8				
0	0	**3.3**	**5.2**	**16.5**	**22.5**	**15.3**	**18.6**	**34.9**	**43.0**
-3	0	4.2	5.4	16.4	22.7	13.2	17.2	33.2	43.6
-6	0	4.0	5.6	16.8	22.9	13.1	17.6	34.2	43.1
-9	0	4.2	5.5	17.5	22.5	14.0	18.2	33.6	42.0
-12	0	4.0	5.2	17.0	23.3	14.0	16.0	34.0	42.7
-15	0	3.8	5.3	17.5	23.2	12.9	16.8	33.3	42.8
-18	0					13.0	19.9	35.5	43.0
-21	0					14.1	17.3	33.4	43.0
-24	0					12.9	17.6	35.5	44.8
-27	0					13.5	18.7	34.5	43.9
-30	0					15.7	20.6	35.0	43.0

Table E-2 (continued): Seymour electromagnetic induction survey instrument response data for the dryland settings. Bold values represent borehole location. H: horizontal dipole mode, V: vertical dipole mode.

Units: mS/m		*H1 (dryland)*				*H3 (dryland*			
Easting (m)	*Northing (m)*	*EM38*		*EM31*		*EM38*		*EM31*	
		H	*V*	*H*	*V*	*H*	*V*	*H*	*V*
0	30	13.1	17.0	31.0	36.2	14.8	17.9	30.3	34.3
0	27	13.0	17.3	30.8	35.8	14.3	17.5	30.4	35.2
0	24	13.3	16.7	30.3	35.5	13.9	17.4	30.1	34.5
0	21	12.5	17.2	30.0	35.7	13.7	16.7	30.2	35.4
0	18	13.0	16.4	31.0	36.5	13.2	16.5	29.9	35.4
0	15	13.2	17.0	31.5	36.2	13.9	17.1	30.6	35.8
0	12	13.8	17.8	31.9	38.2	13.6	17.0	30.0	35.9
0	9	15.2	18.2	33.3	39.1	12.7	16.5	30.1	35.8
0	6	16.1	20.3	35.3	39.8	12.5	16.8	29.4	36.3
0	3	16.1	20.2	34.7	39.9	11.9	16.1	28.8	35.4
0	0	**15.2**	**19.2**	**34.0**	**41.2**	**12.9**	**16.6**	**29.3**	**34.5**
0	-3	15.1	18.4	32.4	40.0	11.7	15.1	28.8	34.0
0	-6	15.6	18.9	32.0	38.1	11.6	15.0	28.2	33.7
0	-9	14.2	18.7	31.4	38.7	10.9	17.9	28.1	33.6
0	-12	14.0	17.5	31.0	38.9	11.9	15.4	28.4	32.8
0	-15	13.2	16.9	30.8	37.2	12.6	15.0	27.9	32.8
0	-18	12.9	16.1	30.5	37.6	12.0	14.4	28.1	33.0
0	-21	12.5	16.0	30.7	37.6	11.0	13.7	27.4	33.1
0	-24	11.9	16.2	31.3	38.9	11.2	14.2	27.5	31.9
0	-27	12.4	16.7	32.0	39.5	11.0	13.9	27.3	31.8
0	-30	13.3	17.8	32.8	40.0	10.2	13.4	26.3	32.2
30	0					13.1	17.2	31.1	37.0
27	0					13.3	16.6	30.5	37.3
24	0					12.8	16.2	30.4	36.6
21	0					12.2	16.3	30.1	36.0
18	0					13.3	15.9	30.4	36.8
15	0					13.5	15.5	31.2	36.7
12	0					13.2	16.5	31.1	37.0
9	0					13.0	16.6	30.7	36.3
6	0					12.7	16.0	30.0	35.8
3	0					12.5	16.2	29.2	35.8
0	0					**12.9**	**16.6**	**29.3**	**34.5**
-3	0					12.0	16.1	29.7	35.1
-6	0					12.9	16.3	29.4	33.1
-9	0					12.0	16.1	29.2	33.2
-12	0					11.2	15.3	28.5	32.5
-15	0					10.1	13.0	26.1	32.6
-18	0					13.1	15.9	28.8	30.5
-21	0					8.8	12.9	25.8	33.0
-24	0					13.8	15.7	27.7	29.3
-27	0					11.3	15.3	27.9	32.3
-30	0					14.0	15.2	27.5	34.8

APPENDIX E – ELECTROMAGNETIC INDUCTION SURVEY DATA

Table E-1: Southern High Plains electromagnetic induction survey instrument response data for the natural settings. Bold values represent borehole location. H: horizontal dipole mode, V: vertical dipole mode.

Units: mS/m		*Natural (D-7)*				*Natural (D-12)*				*Natural (D-13)*			
Easting	*Northing*	*EM38*		*EM31*		*EM38*		*EM31*		*EM38*		*EM31*	
(m)	*(m)*	*H*	*V*	*H*	*V*	*H*	*V*	*H*	*V*	*H*	*V*	*H*	*V*
0	30	4.4	6.6	19.3	25.3	6.3	9.6	24.4	31.9				
0	27	4.6	6.5	19.4	26.0	6.5	9.8	24.3	30.2				
0	24	4.3	6.5	19.8	25.9	5.8	8.6	24.4	32.4				
0	21	4.5	6.2	19.4	25.7	5.9	8.7	24.9	31.4				
0	18	5.2	7.6	19.7	26.4	5.5	8.6	24.2	30.5				
0	15	5.2	8.0	21.1	27.6	6.2	8.9	24.3	30.9				
0	12	5.3	8.0	21.2	27.6	5.2	8.5	24.3	32.0				
0	9	5.0	8.3	20.6	27.9	6.4	8.8	24.3	31.9				
0	6	5.8	8.6	20.7	28.4	6.7	9.7	24.5	31.7				
0	3	4.2	8.6	21.8	27.6	5.9	9.0	24.2	32.6				
0	0	**6.0**	**8.8**	**21.7**	**27.5**	**6.6**	**9.2**	**24.7**	**30.8**				
0	-3	7.0	9.0	21.6	27.6	5.7	9.2	24.3	32.6				
0	-6	6.8	9.2	21.6	27.5	6.3	9.2	24.8	31.4				
0	-9	6.3	8.5	20.6	26.6	6.2	9.4	24.0	32.5				
0	-12	6.1	7.8	19.9	25.5	6.4	9.6	25.0	32.3				
0	-15	5.8	7.6	20.1	25.3	6.5	9.8	25.3	32.6				
0	-18	6.2	8.5	20.2	27.3	6.0	8.9	24.9	32.7				
0	-21	6.3	8.5	20.5	26.7	5.8	9.0	24.3	32.2				
0	-24	6.2	8.3	20.5	27.4	6.1	9.4	24.3	31.7				
0	-27	5.9	7.7	20.2	26.4	6.2	8.7	24.6	32.3				
0	-30	5.9	7.8	20.4	25.8	6.1	8.8	24.3	31.5				
30	0					7.7	11.2	26.1	33.1	7.2	8.5	21.0	22.4
27	0					7.4	10.9	25.0	33.2	11.5	12.2	24.4	23.0
24	0					5.9	9.2	25.3	32.4	11.0	12.3	25.0	25.4
21	0					7.4	9.9	25.7	30.3	10.4	11.8	25.3	23.8
18	0					5.6	8.5	24.7	32.7	9.3	10.4	24.0	23.5
15	0					6.3	9.5	25.3	32.6	7.4	8.1	22.2	25.7
12	0					7.4	10.5	25.6	31.8	5.7	11.0	20.8	26.0
9	0					8.3	10.7	26.0	31.0	5.3	7.4	20.1	26.0
6	0					6.9	9.4	25.7	32.8	8.0	7.8	20.8	24.8
3	0					7.0	9.3	25.0	32.9	7.2	8.6	21.3	25.1
0	0					**6.9**	**9.4**	**25.1**	**30.3**	**6.2**	**7.0**	**21.2**	**25.7**
-3	0					7.1	9.7	25.2	31.5	6.0	7.1	21.2	26.7
-6	0					7.3	10.5	26.5	31.3	7.2	9.0	23.0	26.5
-9	0					6.8	10.3	26.6	32.1	9.5	12.3	25.0	24.0
-12	0					6.2	9.5	25.2	32.3	10.3	12.7	25.4	26.0
-15	0					6.6	9.4	24.5	31.8	10.9	11.6	24.2	22.2
-18	0					5.8	8.8	25.0	30.8	6.3	9.5	23.0	25.5
-21	0					6.1	8.9	24.6	31.3	7.5	8.5	21.6	26.7
-24	0					6.6	9.7	24.6	31.8	8.4	9.6	21.9	34.0
-27	0					6.4	9.3	25.1	32.0	9.8	14.1	26.0	2.0
-30	0					6.6	9.9	25.2	32.6	9.8	14.4	21.5	35.0

Table E-1 (continued): Southern High Plains electromagnetic induction survey instrument response data for the cultivated settings. Bold values represent borehole location. H: horizontal dipole mode, V: vertical dipole mode.

Units: mS/m		*D2 (dryland)*				*D5 (dryland)*				*D6 (dryland)*			
Easting (m)	*Northing (m)*	*EM38*		*EM31*		*EM38*		*EM31*		*EM38*		*EM31*	
		H	*V*	*H*	*V*	*H*	*V*	*H*	*V*	*H*	*V*	*H*	*V*
0	30	19.6	23.8	41.2	48.2	34.0	41.2	56.2	59.5	35.0	45.3	72.5	60.5
0	27	20.8	24.0	41.0	48.5	35.2	41.7	57.3	60.4	32.8	45.8	73.0	61.5
0	24	21.7	27.5	41.1	49.8	34.1	42.0	58.4	59.0	32.7	46.9	66.5	62.3
0	21	20.3	25.9	41.4	51.5	38.4	43.2	58.9	60.5	30.3	46.7	62.4	67.5
0	18	21.5	26.1	41.5	48.5	35.3	43.7	58.3	60.4	32.8	44.1	58.3	66.5
0	15	22.3	26.4	42.5	49.7	36.3	41.9	58.2	59.9	31.2	45.5	55.5	64.9
0	12	21.7	26.1	43.4	51.6	40.0	45.9	58.0	59.4	30.6	44.8	55.0	65.5
0	9	22.5	27.8	44.2	52.2	37.1	42.2	57.6	59.1	29.3	43.8	54.7	65.1
0	6	24.1	28.3	45.7	54.6	38.5	45.0	57.0	53.7	29.5	43.5	52.0	64.2
0	3	26.6	32.4	48.7	56.5	41.4	42.7	57.5	59.0	28.5	40.9	52.0	63.5
0	0	26.8	32.3	51.0	60.4	35.7	41.1	55.2	57.5	**27.0**	**38.7**	**51.2**	**68.3**
0	-3	28.0	33.4	52.3	58.5	38.5	41.9	56.7	56.4	30.7	38.5	52.0	62.5
0	-6	28.4	33.5	53.4	62.6	36.5	40.5	56.0	56.4	28.4	35.2	51.8	65.6
0	-9	28.7	36.6	54.1	63.4	35.7	39.7	53.9	54.5	25.0	33.5	47.7	65.5
0	-12	26.6	35.5	53.8	63.1	35.9	41.4	52.5	50.3	23.0	36.4	49.4	65.8
0	-15	28.2	35.4	54.8	63.9	33.0	36.6	51.4	53.5	31.5	41.5	42.1	65.0
0	-18	29.2	35.8	55.6	65.0	33.2	37.4	50.0	51.3	30.2	42.3	54.0	73.0
0	-21	29.7	38.2	55.9	65.0	33.3	35.5	49.8	50.2	30.0	42.9	54.0	72.0
0	-24	27.7	36.3	56.9	64.4	28.3	33.4	47.0	50.7	31.0	42.1	55.5	69.5
0	-27	28.3	36.7	56.2	66.2	29.8	31.7	44.8	46.1	31.9	41.3	54.4	69.2
0	-30	29.4	37.6	57.0	65.9	27.6	30.4	45.0	44.7	28.9	40.5	51.7	69.8
30	0	25.9	26.4	41.4	46.3					52.0	72.6	86.5	89.1
27	0	24.9	26.7	41.3	48.1					48.9	70.9	88.0	91.4
24	0	24.9	28.0	41.8	49.4					48.8	70.7	85.0	90.0
21	0	26.3	28.3	43.5	49.8					49.0	68.9	85.0	86.7
18	0	26.5	28.8	44.3	51.1	**36.4**	**38.0**	**57.0**	**69.2**	48.0	68.7	83.0	84.5
15	0	26.4	29.8	45.2	53.5	36.8	39.0	56.3	62.0	47.1	67.3	79.0	81.3
12	0	25.4	29.9	45.4	54.1	36.0	37.3	55.0	61.5	46.9	66.0	75.4	74.5
9	0	28.6	31.2	47.9	56.0	38.7	39.2	56.2	59.0	42.3	59.4	72.1	75.5
6	0	29.1	32.5	49.7	57.3	39.9	39.7	57.3	59.0	42.9	59.3	64.5	65.4
3	0	29.9	33.5	50.2	57.3	43.7	42.3	58.2	57.4	35.5	50.2	57.0	55.3
0	0	29.9	34.0	51.4	59.9	41.3	41.0	58.4	58.2	**28.3**	**39.3**	**51.9**	**53.8**
-3	0	28.2	34.3	51.0	60.3	41.7	40.3	58.1	57.0				
-6	0	28.5	34.2	51.9	61.4	39.7	40.3	57.2	57.8				
-9	0	30.1	36.4	52.9	60.9	39.9	42.2	57.3	58.6				
-12	0	30.2	36.9	54.1	61.7	41.0	37.9	57.3	59.3				
-15	0	32.2	37.5	55.5	63.6	41.3	41.0	57.2	58.1				
-18	0	31.9	37.7	56.2	63.4	40.7	41.7	57.5	59.5				
-21	0	33.0	37.8	56.5	62.4	41.0	41.5	58.2	59.5				
-24	0	32.6	38.5	56.2	63.0	40.4	40.5	58.1	59.3				
-27	0	31.5	39.4	55.2	63.5	40.1	41.5	59.3	60.4				
-30	0	**30.2**	**39.4**	**54.9**	**62.0**	40.3	41.7	59.7	60.6				

Table E-2: Seymour electromagnetic induction survey instrument response data for the natural and irrigated settings. Bold values represent borehole location. H: horizontal dipole mode, V: vertical dipole mode.

Units: mS/m		*H5 (natural)*				*H6 (irrigated)*			
Easting	*Northing*	*EM38*		*EM31*		*EM38*		*EM31*	
(m)	*(m)*	*H*	*V*	*H*	*V*	*H*	*V*	*H*	*V*
0	30					12.0	18.0	32.5	40.7
0	27					12.9	17.5	32.7	41.0
0	24					13.2	17.8	32.8	41.3
0	21					13.2	17.9	33.3	41.3
0	18					14.6	19.1	34.2	41.8
0	15					16.4	20.3	34.9	41.9
0	12					16.1	19.9	35.5	42.7
0	9					15.8	19.3	35.1	43.0
0	6					15.7	19.0	34.8	43.5
0	3					15.4	19.1	34.9	43.3
0	0					**15.3**	**18.6**	**34.9**	**43.0**
0	-3					14.2	18.8	34.2	43.3
0	-6					14.7	18.0	34.3	42.7
0	-9					13.8	18.6	34.5	43.6
0	-12					15.8	17.7	35.8	44.4
0	-15					15.1	19.3	35.3	44.1
0	-18					16.4	19.0	35.9	44.2
0	-21					16.2	20.1	36.3	44.5
0	-24					15.5	20.4	36.3	45.3
0	-27					14.4	19.1	35.6	45.9
0	-30					14.0	19.8	36.0	46.1
30	0								
27	0								
24	0								
21	0								
18	0								
15	0								
12	0	4.5	6.0	17.7	23.4				
9	0	4.0	5.5	17.8	22.9				
6	0	3.0	6.3	16.7	22.5				
3	0	3.5	5.1	16.7	22.8				
0	0	**3.3**	**5.2**	**16.5**	**22.5**	**15.3**	**18.6**	**34.9**	**43.0**
-3	0	4.2	5.4	16.4	22.7	13.2	17.2	33.2	43.6
-6	0	4.0	5.6	16.8	22.9	13.1	17.6	34.2	43.1
-9	0	4.2	5.5	17.5	22.5	14.0	18.2	33.6	42.0
-12	0	4.0	5.2	17.0	23.3	14.0	16.0	34.0	42.7
-15	0	3.8	5.3	17.5	23.2	12.9	16.8	33.3	42.8
-18	0					13.0	19.9	35.5	43.0
-21	0					14.1	17.3	33.4	43.0
-24	0					12.9	17.6	35.5	44.8
-27	0					13.5	18.7	34.5	43.9
-30	0					15.7	20.6	35.0	43.0

Table E-2 (continued): Seymour electromagnetic induction survey instrument response data for the dryland settings. Bold values represent borehole location. H: horizontal dipole mode, V: vertical dipole mode.

Units: mS/m		*H1 (dryland)*				*H3 (dryland*			
Easting (m)	*Northing (m)*	*EM38*		*EM31*		*EM38*		*EM31*	
		H	*V*	*H*	*V*	*H*	*V*	*H*	*V*
0	30	13.1	17.0	31.0	36.2	14.8	17.9	30.3	34.3
0	27	13.0	17.3	30.8	35.8	14.3	17.5	30.4	35.2
0	24	13.3	16.7	30.3	35.5	13.9	17.4	30.1	34.5
0	21	12.5	17.2	30.0	35.7	13.7	16.7	30.2	35.4
0	18	13.0	16.4	31.0	36.5	13.2	16.5	29.9	35.4
0	15	13.2	17.0	31.5	36.2	13.9	17.1	30.6	35.8
0	12	13.8	17.8	31.9	38.2	13.6	17.0	30.0	35.9
0	9	15.2	18.2	33.3	39.1	12.7	16.5	30.1	35.8
0	6	16.1	20.3	35.3	39.8	12.5	16.8	29.4	36.3
0	3	16.1	20.2	34.7	39.9	11.9	16.1	28.8	35.4
0	0	**15.2**	**19.2**	**34.0**	**41.2**	**12.9**	**16.6**	**29.3**	**34.5**
0	-3	15.1	18.4	32.4	40.0	11.7	15.1	28.8	34.0
0	-6	15.6	18.9	32.0	38.1	11.6	15.0	28.2	33.7
0	-9	14.2	18.7	31.4	38.7	10.9	17.9	28.1	33.6
0	-12	14.0	17.5	31.0	38.9	11.9	15.4	28.4	32.8
0	-15	13.2	16.9	30.8	37.2	12.6	15.0	27.9	32.8
0	-18	12.9	16.1	30.5	37.6	12.0	14.4	28.1	33.0
0	-21	12.5	16.0	30.7	37.6	11.0	13.7	27.4	33.1
0	-24	11.9	16.2	31.3	38.9	11.2	14.2	27.5	31.9
0	-27	12.4	16.7	32.0	39.5	11.0	13.9	27.3	31.8
0	-30	13.3	17.8	32.8	40.0	10.2	13.4	26.3	32.2
30	0					13.1	17.2	31.1	37.0
27	0					13.3	16.6	30.5	37.3
24	0					12.8	16.2	30.4	36.6
21	0					12.2	16.3	30.1	36.0
18	0					13.3	15.9	30.4	36.8
15	0					13.5	15.5	31.2	36.7
12	0					13.2	16.5	31.1	37.0
9	0					13.0	16.6	30.7	36.3
6	0					12.7	16.0	30.0	35.8
3	0					12.5	16.2	29.2	35.8
0	0					**12.9**	**16.6**	**29.3**	**34.5**
-3	0					12.0	16.1	29.7	35.1
-6	0					12.9	16.3	29.4	33.1
-9	0					12.0	16.1	29.2	33.2
-12	0					11.2	15.3	28.5	32.5
-15	0					10.1	13.0	26.1	32.6
-18	0					13.1	15.9	28.8	30.5
-21	0					8.8	12.9	25.8	33.0
-24	0					13.8	15.7	27.7	29.3
-27	0					11.3	15.3	27.9	32.3
-30	0					14.0	15.2	27.5	34.8