Estimates of Recharge and Surface Water – Groundwater Interactions for Aquifers in Central and West Texas

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1. Introduction

The Texas Water Development Board (TWDB) develops regional-scale groundwater availability models for all the major and minor aquifers of Texas. New groundwater availability models are under development at TWDB and cover four major aquifers namely, going from East to West, Trinity (Hill Country), Edwards Balcones Fault Zone, Edwards-Trinity (Plateau), and Pecos Valley Alluvium. The new models require estimates of recharge and stream baseflow conditions (or groundwater-surface water interactions). The study area covering the identified portions of these aquifers is shown below in Figure 1-1 through Figure 1-4 along with the various administrative boundaries.

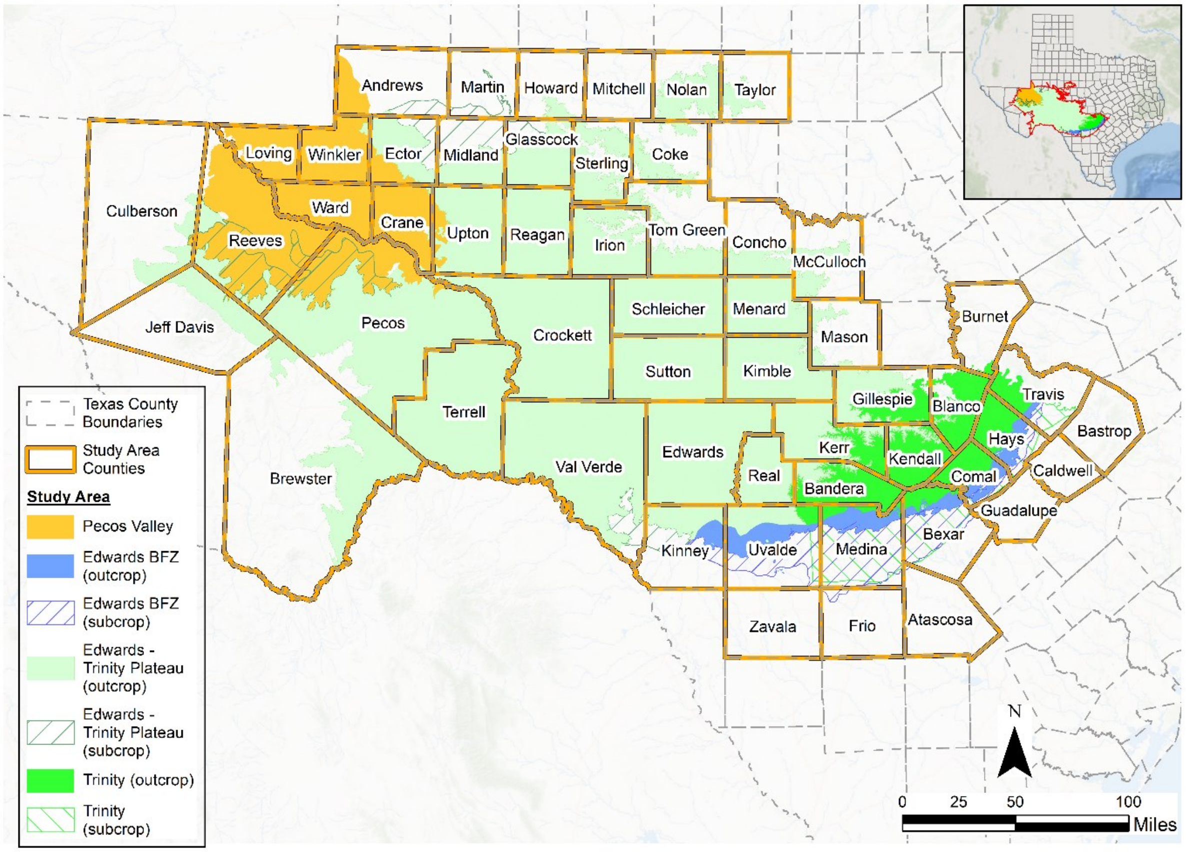


Figure 1-1: Project Study Area and Aquifers and the Included Counties

The TWDB contracted with WSP USA in 2020 to conduct a study for estimating recharge and groundwater-surface water interactions for the identified aquifers in Central and West Texas. This report documents the methodology and results of the study to provide these estimates. The current project has two objectives to estimate: 1) groundwater recharge, and 2) stream baseflow conditions (or groundwater-surface water interactions) in the study area.

In the Texas Aquifer Study, Anaya and others (2016), identified three aquifers in the study area-Edwards Balcones Fault Zone, Edwards-Trinity (Plateau), and Pecos Valley- as contributing more than 50 percent of the stream baseflow on an average annual basis. The fourth aquifer in the study area, Trinity (Hill Country) was found to contribute between 20 and 50 percent of stream baseflow on an average annual basis. The values presented in the Texas Aquifer Study were based on numerical simulations conducted using the appropriate groundwater availability models for the study area, and on analyses of the available monitored streamflow data (Anaya and others, 2016). Previous investigations conducted in the study area have described various conceptual models and quantified both recharge as well as groundwater-surface water interactions (Muller and Price, 1979; Kuniansky, 1989; LBG-Guyton, 1994, 1995; Parsons, 1999; Scanlon and others, 2000; Karst Conservation Initiative, 2011; Anaya and others, 2016). The techniques suggested and used for quantifying recharge, as well as groundwater-surface water interactions in these previous studies, varied from physical methods (field-measurements, isotopic, hydrogeochemical) to those utilizing numerical simulations such as in the groundwater availability models for the study area (Mace and others, 2000; Anaya and Jones, 2009; Jones and others, 2009; LBG-Guyton, 2013). Data and effort required for employing field measurements are cumbersome, and the long-term recharge estimates employed from such techniques are available for the study area in the literature as cited above.

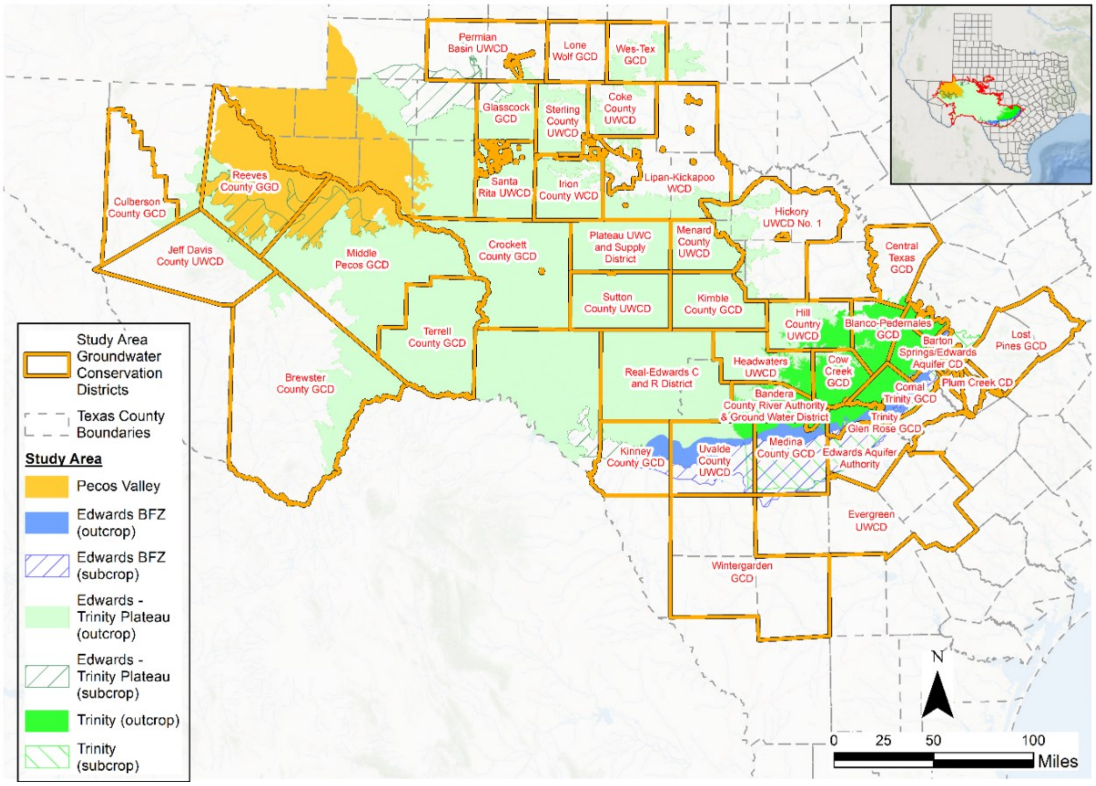


Figure 1-2: Project Study Area and the Included Groundwater Conservation Districts

Another important finding from the Texas Aquifers Study by Anaya and others (2016) was the identification of significant flows between aquifers in the study area, particularly in the Hill Country and Pecos Valley regions. For example, the Edwards Trinity (Plateau) and Pecos Valley aquifers are in direct physical contact and potentially have significant inter-aquifer flow. Cross-formational flow from the Edwards Trinity (Plateau) Aquifer and Trinity Aquifer to the Edwards (Balcones Fault Zone) Aquifer has also been evaluated in previous studies (Clark and Journey, 2006; Wong and others, 2014). Inter-aquifer or cross-formational flow may sometimes be considered a recharge process for an aquifer. In the past, the project team has conducted investigations of cross-formational flow in the study area (LBG-Guyton, 1995). However, it is important to note that recharge is considered separately from cross-formational flow as defined by Mace and others (2001). Therefore, for the purpose of this study, we assumed recharge as the water percolating into the aquifer from precipitation and streamflow only and separate from cross-formational flow.

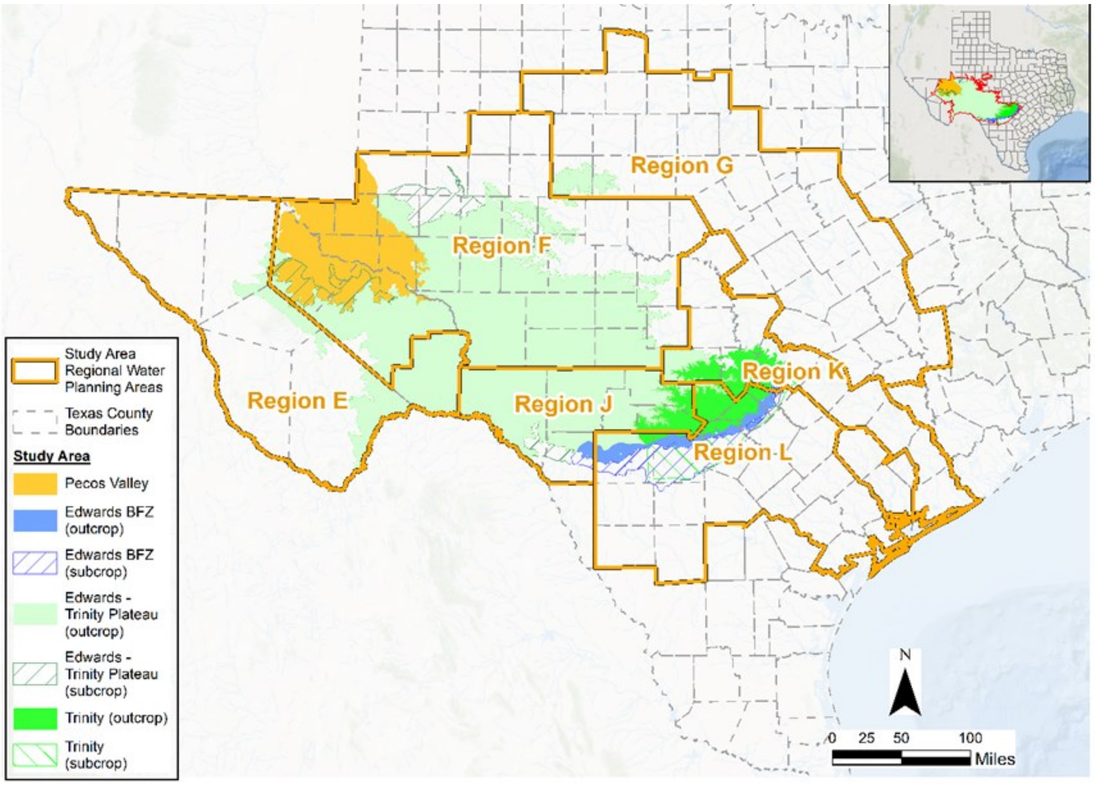


Figure 1-3: Project Study Area and the Overlapping Regional Water Planning Area

Recharge is often estimated as a parameter during model calibration such as in groundwater availability models. Such an approach may result in misleading results, as shown by Ehtiat and others (2016). These findings present a unique challenge to the study's objective, especially in aquifers with a high degree of connectivity to surface waters, such as those in the study area. Recent studies also showed that distributed hydrological modeling provides better recharge estimates (LBG-Guyton, 2005; Dietsch and Wehmeyer, 2012; Ehtiat and others 2016). In addition, streamflow analysis (hydrograph separation and recession-curve displacement) methods are time-tested tools for conducting baseflow analysis and estimating groundwater-surface water interactions. The technical approach developed by the project team is based on the premise that distributed hydrological modeling conducted along with streamflow analyses would provide the most appropriate results for this project.

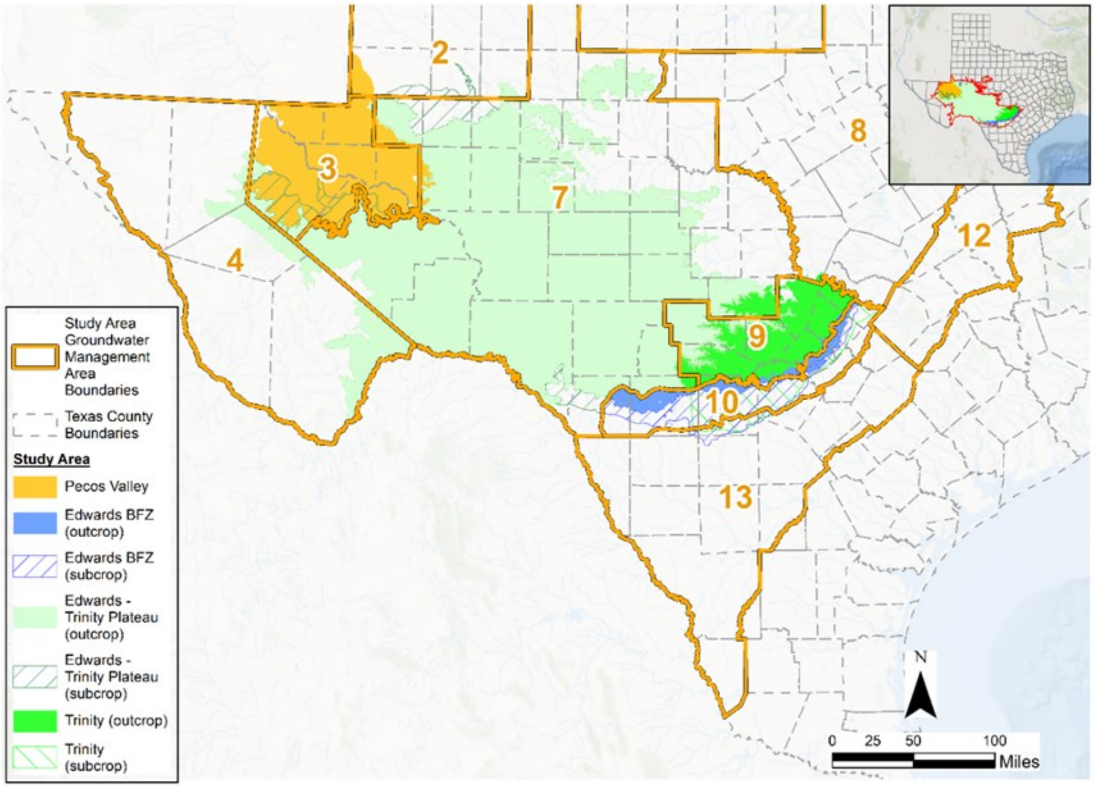


Figure 1-4: Project Study Area and the Overlapping Groundwater Management Areas

2. Identification of the Modeling Tools

The project team's initial research identified three modeling tools to be applied for this study. The United States Geological Survey Soil Water Balance model (Westenbroek and others, 2010; Westenbroek and others, 2018) and the Soil & Water Assessment Tool model (Arnold and others, 2012) are two of these codes that are distributed water-balance models. The third tool is the United States Geological Survey Groundwater Toolbox (Barlow and others, 2014; Barlow and others, 2017), which amalgamates six hydrograph-separation methods to estimate groundwater-discharge or baseflow analysis and groundwater recharge components of the streamflow data. Furthermore, the project team also developed a rainfall-runoff method based on curve number analysis to estimate recharge as well as a machine learning application that emulates the results from the Soil & Water Assessment Tool model. Remote-sensing data was also analyzed for use in comparative analysis of the model results. More details on the three identified codes, numerical basis, and capabilities are presented below, along with a discussion of the identified remote-sensing data.

2.1 Soil Water Balance Model

As described by Westenbroek and others (2010; 2018), the United States Geological Survey Soil Water Balance model code uses a modified Thornthwaite-Mather soil water balance approach (Thornthwaite and Mather, 1957) to calculate components of the water balance equation at a daily timestep. The code allows users to quickly and easily calculate spatial and temporal estimates of net infiltration out of the root zone based on climate, topography, land use, and soil data. In a groundwater flow model, modelers may simulate recharge using MODFLOW's Unsaturated Zone Flow Package (Niswonger and others, 2006; Langevin and others, 2017) or calibrate recharge as a multiplier on the net infiltration.

The Soil Water Balance model uses a combination of gridded and tabular data to calculate potential groundwater recharge separately for each grid cell within a model domain. The Soil Water Balance model evaluates the sources and sinks of water within each grid cell at and near land surface and then calculates infiltration as the difference between the change in soil moisture and the sources and sinks. Sources for infiltration include precipitation and inflow (surface runoff from an adjacent grid cell), while sinks include evapotranspiration, outflow (surface runoff to an adjacent grid cell), and interception (rainfall trapped and used by vegetation and evaporated or transpired from plant surfaces).

There are currently two versions of the United States Geological Survey Soil Water Balance model. Both versions of the model code use essentially the same approach to calculate net infiltration. In Version 1 of the code, Westenbroek and others (2010) describe the calculation as:

$$\boldsymbol{R = (P + melt + in) - (int + out + ET_{act}) - \Delta SM} \qquad \textbf{(Equation 1)}$$

where (all units in inches):

R = recharge
P = precipitation
$melt$ = snowmelt
in = inflow
int = interception
out = outflow
ET_{act} = actual evapotranspiration
ΔSM = change in soil moisture

In Version 2 of the code, Westenbroek and others (2018) expand Equation 1 to include “fog interception” and “irrigation” as other sources of water in the soil moisture calculation. For some parts of our study area, irrigation could be a significant water source in the balance equation. Westenbroek and others (2018) provide a means for calculating irrigation water demand as a water balance input; however, one can also use the irrigation estimates from the TWDB Water Use Survey to account for the irrigation water input by including the TWDB Water Use Survey amount with the gridded precipitation data.

Version 2 (Westenbroek and others, 2018) of the code extends the capabilities of Version 1 (Westenbroek and others, 2010) by including the option to represent additional water budget components (such as, fog, septic, and storm-sewer leakage) along with additional input and output options. For a local model, these additional capabilities may be beneficial. However, due to the regional scale of this project, these local-scale components are not likely to be of significance compared to other water budget components. Through testing of the Version 2 code, we identified some potential issues with the code that resulted in questionable simulation results. Considering each of these factors, we settled on Version 1 of the code for estimating recharge in the study area. Please note that the Soil Water Balance model does not account for baseflow conditions; therefore, it is not helpful in assessing groundwater-surface water interactions.

2.2 Soil & Water Assessment Tool

The Soil & Water Assessment Tool model is a physically based continuous-time model that predicts the impact of management and climate on water, sediment and agricultural chemical yields in watersheds with varying soil, land use and management conditions over a long period of time (Arnold and others, 1998, 2012). Major components of the Soil & Water Assessment Tool model simulation include weather, hydrology, soil temperature, soil properties, plant growth, nutrients, pesticides, pathogens and land management. Climate inputs include daily precipitation, maximum and minimum temperature, solar radiation, humidity and wind speed (Figure 2-1). The Soil & Water Assessment Tool model simulates canopy interception of precipitation, partitioning of precipitation, evapotranspiration, subsurface flow, return flow from shallow aquifers and water distribution between soil layers. The Soil & Water Assessment Tool model has been used to estimate availability of water resources in watersheds (Faramarzi and others, 2009; Schuol and others, 2008b, 2008a; White and others, 2011). The Soil & Water Assessment Tool model helps to understand sources of point and nonpoint source water pollution (Santhi and others, 2002) and techniques for improving water quality (Lee and others, 2010). It also estimates yields for crops, grasslands, and trees (Dile and others, 2016; Luo and others, 2008). The Soil & Water Assessment Tool model has been used to examine the impact of climate change across scales (Abbaspour and others, 2015, 2009; Dile and others, 2013; Faramarzi and others, 2013; Setegn and others, 2010). The Soil & Water Assessment Tool model can also be used to estimate the impacts of best management practices (Arabi and others and others, 2008), land use change (Chiang and others and others, 2010), irrigation demand management (Santhi and others and others, 2005), and construction of ponds and reservoirs (Dile and others and others, 2016) on water quantity and quality.

Simulation of a watershed's hydrology can be separated into two major parts. The first is the land phase of the hydrologic cycle, depicted in Figure 2-1 below. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrients, and pesticide loadings to the main channel from each sub-basin. The second part is the water or routing phase of the hydrologic cycle which can be defined as the movement of water, sediments, nutrients, etc., through the channel network of the watershed to the outlet.

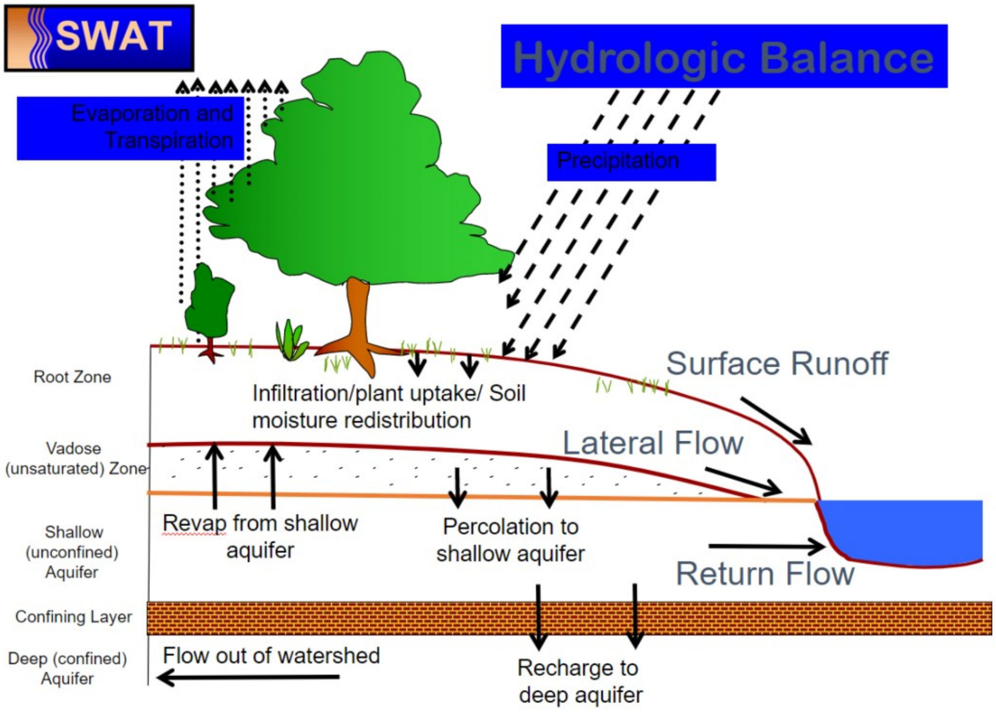


Figure 2-1: Soil & Water Assessment Tool Model Schematic Representation

The hydrologic cycle as simulated by the Soil & Water Assessment Tool model is based on the water balance equation:

$$\boldsymbol{SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}\right)} \qquad \textbf{(Equation 2)}$$

Where SW_t is the final soil water content (millimeters of water), SW_0 is the initial soil water content on day i (millimeters of water), t is the time (days), R_{day} is the amount of precipitation on day i (millimeters of water), Q_{surf} is the amount of surface runoff on day i (millimeters of water), E_a is the amount of evapotranspiration on day i (millimeters of water), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (millimeters of water), and Q_{gw} is the amount of return flow on day i (millimeters of water). The Soil & Water Assessment Tool model simulates canopy interception of precipitation, partitioning of precipitation, evapotranspiration, subsurface flow, return flow from shallow aquifers, and water distribution between soil layers.

The Soil & Water Assessment Tool model can also be used for simulating a wide range of management practices without excessive computation time and resources for large basins. It enables the study of continuous long-term daily simulation (up to 100 years) to predict discharge, sediment, nutrient, and pesticide yields from agricultural watersheds. The Soil & Water Assessment Tool model uses a geographic information system-based interface and geographic information system coverage of digital elevation models to divide a drainage basin into sub-basins. These sub-basins are further divided based on soil type and land cover into areas of similar hydrologic characteristics called hydrologic response units. Hydrologic response units are portions of a sub-basin with unique combinations of land use, slope, and soil attributes. The geographic information system module also estimates the stream length, stream slope and geometrical dimensions, accumulation area, and aspect. This process is depicted in Figure 2-2.

The subdivision of the watershed enables the model to reflect differences in evapotranspiration for various vegetations and soils using local weather assigned to each sub-basin. Runoff is predicted separately for each hydrologic response unit and routed to obtain the total runoff for the watershed. Capturing the spatial heterogeneity through hydrologic response units increases accuracy and gives a spatially explicit calculation of water balance. In addition, the Soil & Water Assessment Tool model estimates crop yield and biomass for grasslands and trees (Luo and others, 2008, Faramarzi and others, 2008, Schuol and others, 2008). The Soil & Water Assessment Tool model has been used to examine the impact of climate change regionally (Rosenberg and others, 1999, Jha and others, 2004) and nationally (Thompson and others, 2005, Rosenberg and others, 2003). The Soil & Water Assessment Tool model can also be used to estimate the impacts of best management practices (Arabi and others, 2008), land-use change (Chiang and others, 2010), irrigation demand management (Santhi and others, 2005), and construction of ponds and reservoirs (Dile and others, 2016b) on water quantity and quality.

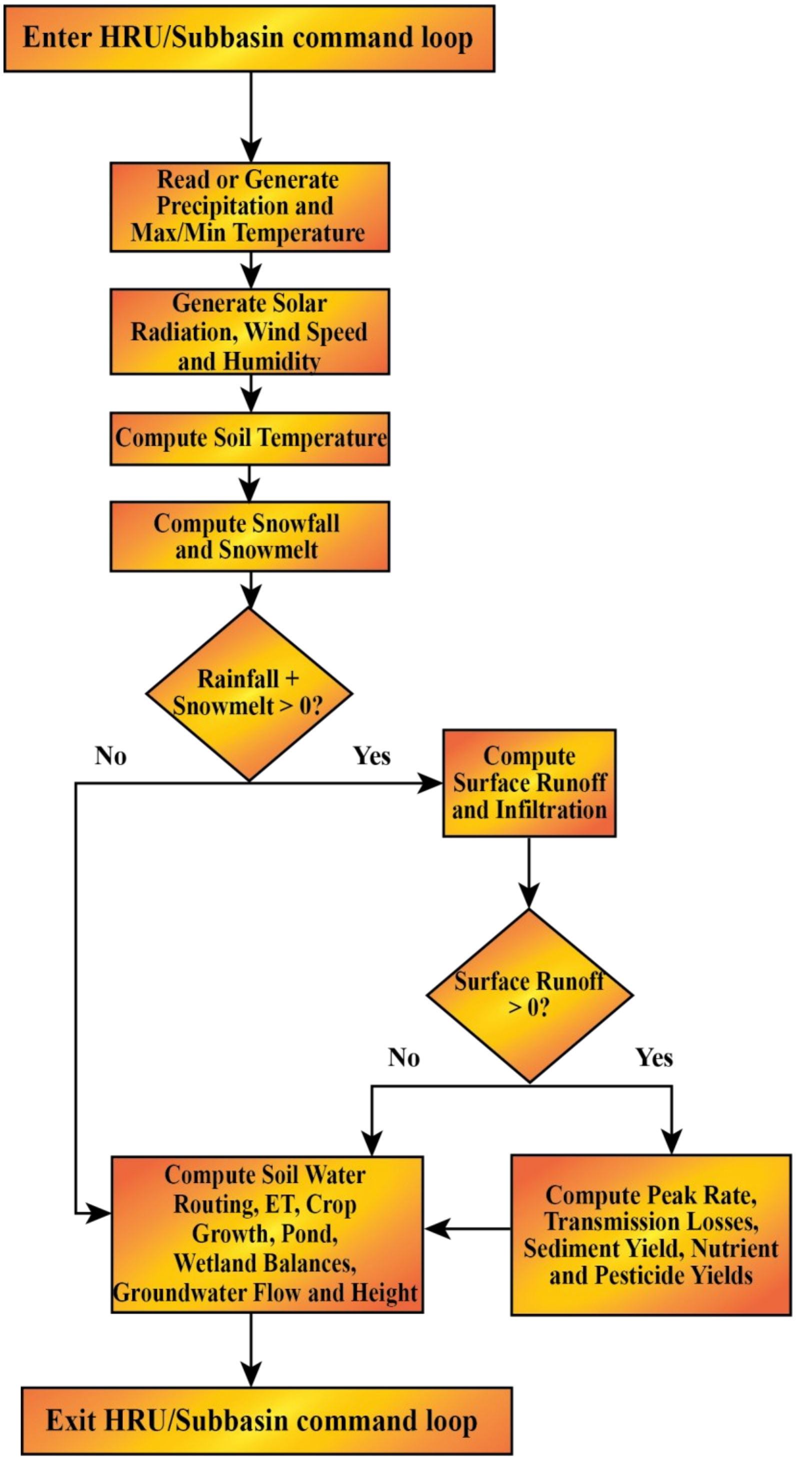


Figure 2-2**: HRU/Subbasin Command Loop**

The Soil & Water Assessment Tool model can simulate hydrological cycles, vegetation growth, and nutrient cycling daily by disaggregating a river basin into sub-basins and hydrologic response units. Hydrologic response units are lumped land areas within sub-basins and comprise a unique land cover, soil, and management combinations. This separation into smaller units allows the model to reflect differences in evapotranspiration and other hydrologic conditions for different land cover and soil (Neitsch and others, 2012). The Soil & Water Assessment Tool model has been applied in thousands of watersheds across the world with more than 4,000 peer-reviewed publications to date. The publications can be accessed from https://www.card.iastate.edu/swat_articles/. Figure 2-3 shows the general sequence of processes used by the Soil & Water Assessment Tool model to model the land phase of the hydrologic cycle.

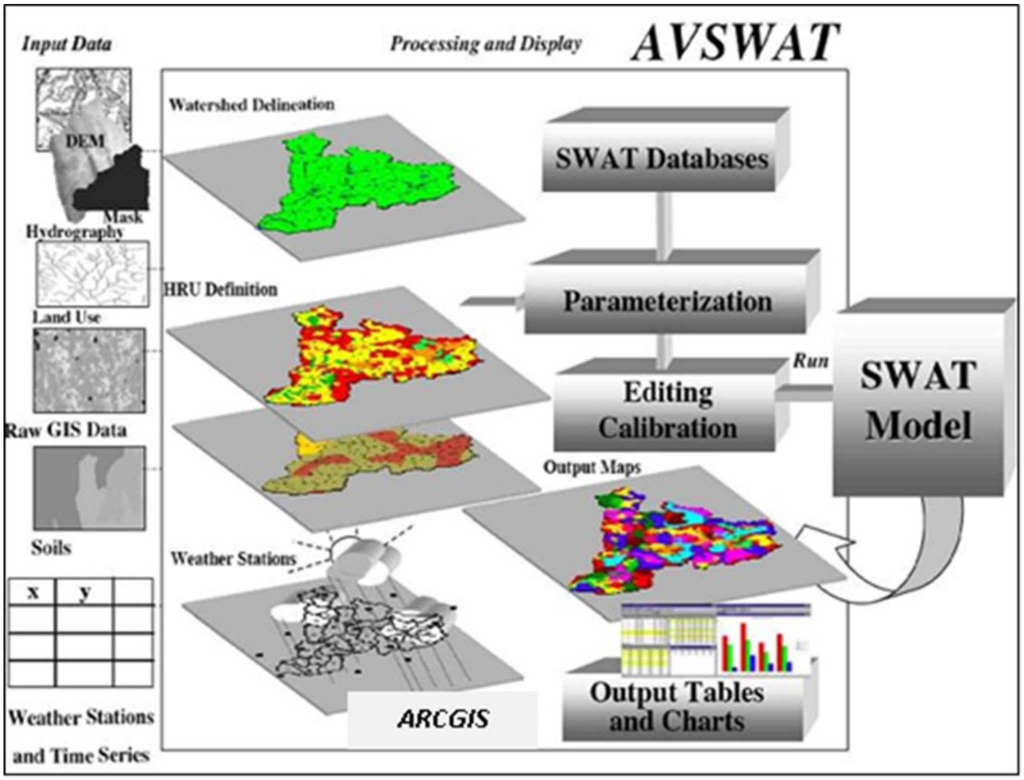


Figure 2-3: Watershed and ArcGIS Simulation with the Soil & Water Assessment Tool Model

2.3 Groundwater Toolbox

The United States Geological Survey developed and published the first version of the Groundwater Toolbox in 2014. The software was designed as a graphical and mapping interface for the analysis of hydrologic data, with customized functions to assess the interplay between surface water sources and groundwater supplies within a given region. The Groundwater Toolbox utilizes open-source software and the MapWindow geographic information system, thereby allowing the user to visually select mapped data for analysis. The Groundwater Toolbox program is downloadable from the United States Geological Survey at the website: https://www.usgs.gov/software/groundwater-toolbox-graphical-and-mapping-interface-analysis-hydrologic-data%20 (as of May 24, 2022), and the model source code is freely distributed from this same weblink. The software may be installed, run, and operated on computers running Microsoft Windows, including both Windows 7 and Windows 10. During this project, we tested the Groundwater Toolbox functionalities and found the software to be generally reliable, yet prone to "unknown error" generation and occasional crashing. We were often unsuccessful at using the Groundwater Toolbox Graphical User Interface to download stream gage data from the United States Geological Survey National Water Information System databases; however, We did succeedat downloading National Water Information System data outside of the Groundwater Toolbox, and then importing the data for analysis using the numerous toolbox functions.

Groundwater Toolbox offers three different modes of baseflow analysis:

1. Interactive mode: The user manually selects each station data, input parameters, and output files. This mode offers tools for exploratory visualization of the input and output. This mode runs on one station at a time; however, multiple baseflow separation methods can be run in parallel.
2. Batch file mode: The user runs an existing batch file with pre-selected stations and input parameters. Stations can be grouped within the batch file with parameters assigned to each group.
3. Batch map mode: The user selects a set of stations for batch analysis. This mode can also be used to create a batch file.

Groundwater Toolbox also offers postprocessing and plotting tools in interactive and batch map modes.

The remainder of this section contains a summary of the various Groundwater Toolbox tools used to assess and quantify groundwater recharge resulting from streamflow, as well as to present our findings and assessments regarding the uncertainty within the recharge calculation results.

2.3.1 Recharge Calculation - Theory

Within the Groundwater Toolbox, groundwater recharge is calculated from daily-averaged stream gage data using two programs in succession: RECESS and RORA. These programs are discussed and documented within the Groundwater Toolbox manuals and documentation, which are accessible from the Help menus within the software. The following discussion of each program is based on the documentation provided within the software, as well as on our experience with using the software during this project.

2.3.1.1 Recession Program (RECESS)

The RECESS program is used for describing the recession of groundwater discharge and for estimating groundwater recharge and discharge from streamflow records. For this analysis, recession is considered to decrease in streamflow after the passage of a storm-induced pulse of surface water runoff. Essentially, "recession" is the rate at which the stream returns to a "normal" condition with all streamflow resulting from groundwater discharges to the streambed. The RECESS program, as documented within the Groundwater Toolbox, was last updated in 1998 by A.T. Rutledge and further documented in the United States Geological Survey Water-Resources Investigations Report 98-4148.

Within RECESS, daily streamflow data is analyzed to compute a "Master Recession Curve" representing the rate at which groundwater fluxes contribute to streamflow after passage of a high streamflow pulse. Such pulses are typically the result of a precipitation event within a drainage area, where the event results in surface runoff to the stream, surface infiltration to the groundwater system, and groundwater recharge through the stream banks. The Master Recession Curve describes the rate of streamflow depletion ("recession") during times when each of the three following conditions are met:

- all streamflow is from groundwater discharge,
- no groundwater recharge is occurring; and
- when the profile of the groundwater head distribution is nearly stable.

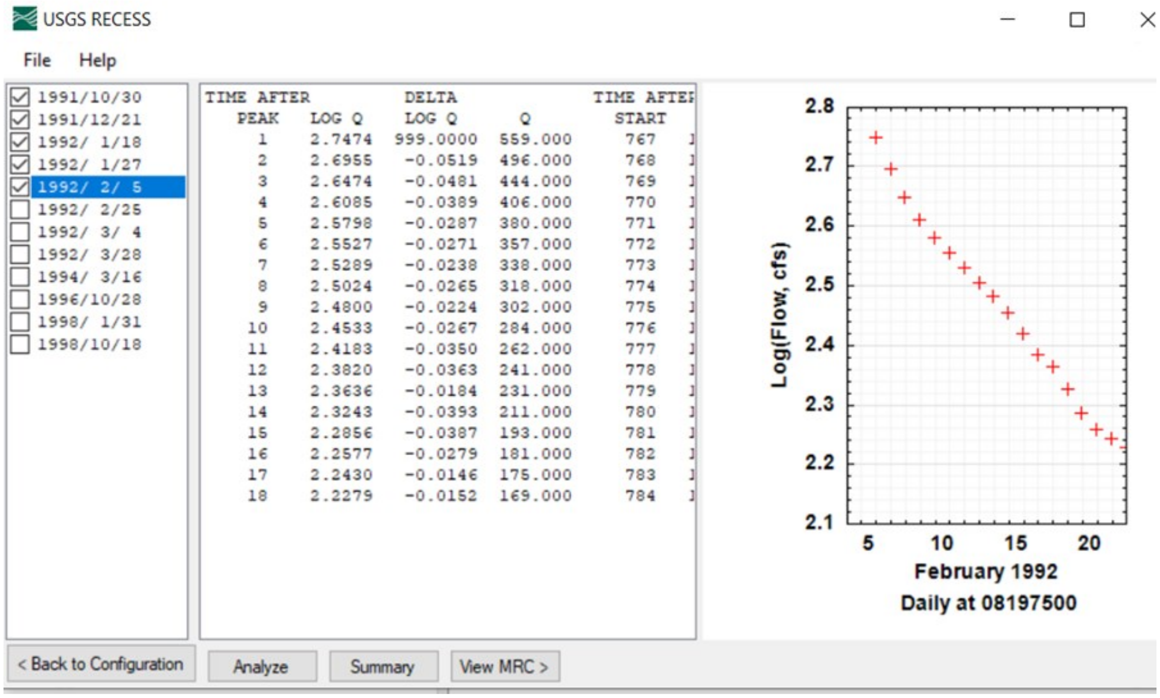
Users of RECESS must assess the likelihood that each of these conditions are met for the given time period of interest and must decide whether to include any specific recession period within the RECESS analysis.

RECESS calculations are based on the assumption of a linear relationship between the logarithm of streamflow and the time passed since the passage of the last peak in streamflow (the time when recession commences). This relationship assumption is given mathematically as:

$$\boldsymbol{T = K[log(Q)] + D} \qquad \textbf{(Equation 3)}$$

Where "*Q*" is the daily averaged streamflow, "*T*" is the time since the last streamflow peak, and "*D*" is a constant value that does not factor into the RECESS calculation process. The value "*K*" is the linear slope of the line relating *T* and *log(Q)* and is referred to as the "recession index." This recession index is also conceptualized as the time per log cycle of streamflow recession.

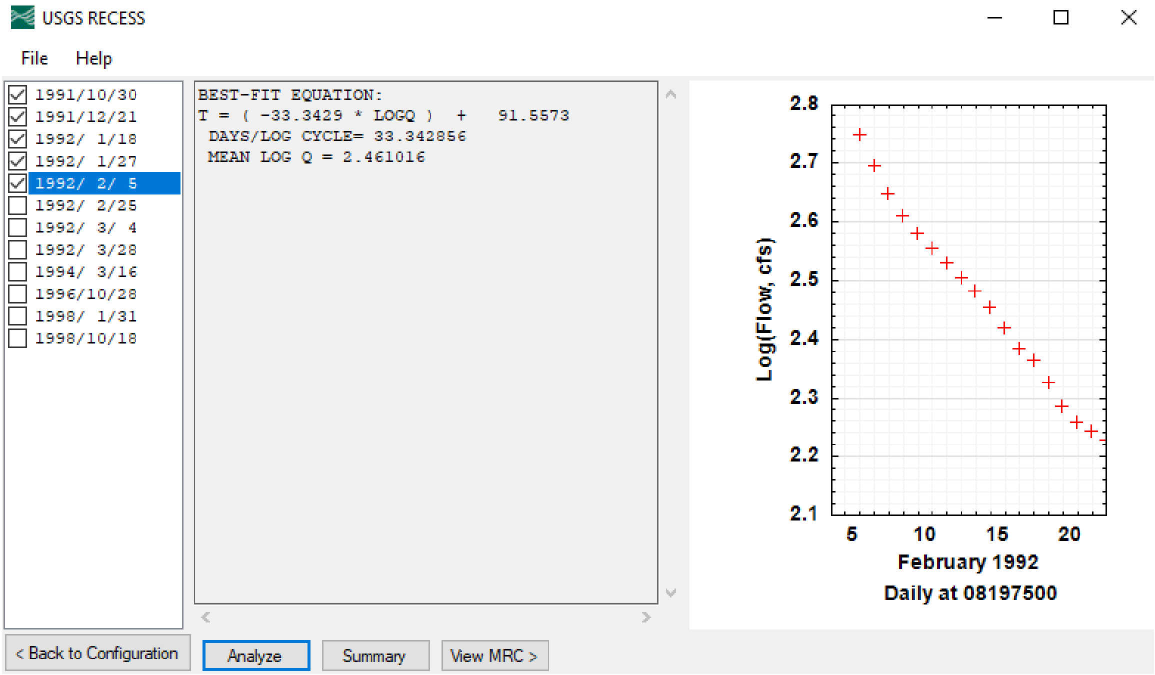
Within RECESS, daily averaged streamflow data is analyzed, and recession periods are identified based on the change in streamflow from one day to the next. This process results in potentially numerous "recession segments," or short periods of time over which recession is occurring, and Equation 3 may be approximated. RECESS will plot each of these recession segments (Figure 2-4), and the program user will indicate which segments best suggest the linear trend between time and *log(Q)*. As shown in Figure 2-4, streamflow data from 2/5/1992 onward does suggest a linear trend between elapsed time and *log(Q)*. Information regarding this trend is computed and provided with the "Analysis" button on the RECESS program Graphical User Interface (Figure 2-5). As shown below in Figure 2-5, the best fit linear equation for the selected recession segment indicates that the segment's recession index value (shown as "DAYS/LOG CYCLE") is 33.343856 with a mean *log(Q)* value of 2.461016.



- ☑ 1991/10/30
- ☑ 1991/12/21
- ☑ 1992/ 1/18
- ☑ 1992/ 1/27
- ☑ 1992/ 2/ 5
- ☐ 1992/ 2/25
- ☐ 1992/ 3/ 4
- ☐ 1992/ 3/28
- ☐ 1994/ 3/16
- ☐ 1996/10/28
- ☐ 1998/ 1/31
- ☐ 1998/10/18

```
TIME AFTER         DELTA                TIME AFTE
   PEAK    LOG Q    LOG Q       Q        START
     1    2.7474  999.0000  559.000       767
     2    2.6955   -0.0519  496.000       768
     3    2.6474   -0.0481  444.000       769
     4    2.6085   -0.0389  406.000       770
     5    2.5798   -0.0287  380.000       771
     6    2.5527   -0.0271  357.000       772
     7    2.5289   -0.0238  338.000       773
     8    2.5024   -0.0265  318.000       774
     9    2.4800   -0.0224  302.000       775
    10    2.4533   -0.0267  284.000       776
    11    2.4183   -0.0350  262.000       777
    12    2.3820   -0.0363  241.000       778
    13    2.3636   -0.0184  231.000       779
    14    2.3243   -0.0393  211.000       780
    15    2.2856   -0.0387  193.000       781
    16    2.2577   -0.0279  181.000       782
    17    2.2430   -0.0146  175.000       783
    18    2.2279   -0.0152  169.000       784
```

Figure 2-4: RECESS Processes for Computing the Recession Index (K)

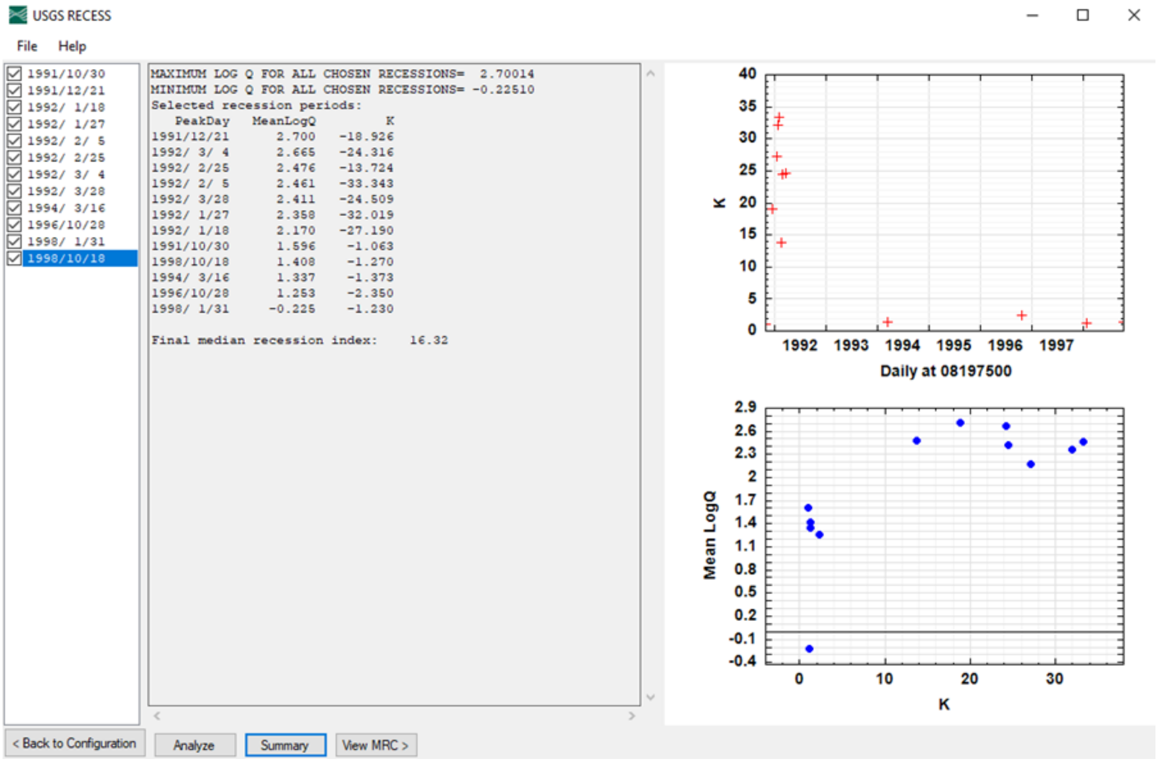


- ☑ 1991/10/30
- ☑ 1991/12/21
- ☑ 1992/ 1/18
- ☑ 1992/ 1/27
- ☑ 1992/ 2/ 5
- ☐ 1992/ 2/25
- ☐ 1992/ 3/ 4
- ☐ 1992/ 3/28
- ☐ 1994/ 3/16
- ☐ 1996/10/28
- ☐ 1998/ 1/31
- ☐ 1998/10/18

```
BEST-FIT EQUATION:
T = ( -33.3429 * LOGQ )  +    91.5573
 DAYS/LOG CYCLE= 33.342856
 MEAN LOG Q = 2.461016
```

Figure 2-5: RECESS Analysis of a Selected Recession Segment Computation of the Recession Index (K)

Once all segments have been reviewed, RECESS will generate a summary analysis for the stream gage data shown below in Figure 2-6. This summary lists all the identified recession segments and their computed recession indices. A median recession index is then computed from the complete set of recession indices. This median recession index is used within the RORA program to calculate recharge.



```
MAXIMUM LOG Q FOR ALL CHOSEN RECESSIONS=  2.70014
MINIMUM LOG Q FOR ALL CHOSEN RECESSIONS= -0.22510
Selected recession periods:
   PeakDay   MeanLogQ         K
1991/12/21      2.700   -18.926
1992/ 3/ 4      2.665   -24.316
1992/ 2/25      2.476   -13.724
1992/ 2/ 5      2.461   -33.343
1992/ 3/28      2.411   -24.509
1992/ 1/27      2.358   -32.019
1992/ 1/18      2.170   -27.190
1991/10/30      1.596    -1.063
1998/10/18      1.408    -1.270
1994/ 3/16      1.337    -1.373
1996/10/28      1.253    -2.350
1998/ 1/31     -0.225    -1.230

Final median recession index:    16.32
```

Figure 2-6: RECESS Summary Analysis of all Selected Recession Segments and Their Resulting Recession Indices

2.3.1.2 RORA

The program RORA was created by the United States Geological Survey, and it implements the recession-curve-displacement method for computing recharge from daily streamflow data. The program executes many of the same analysis steps included within the RECESS program, and we determined that RORA is most efficiently run immediately after RECESS applications on the same stream gage dataset.

The recession-curve displacement method for computing groundwater recharge is based on formulations by Glover (1964) and Rorabaugh (1964), indicating that potential groundwater discharges to streams at a "critical time" (defined below) after a peak discharge are approximately equal to 50 percent of the total volume of water that recharged the groundwater system during the discharge. This "critical time" (T_c) is an empirically derived formula based the recession index (K) and data from Rorabaugh and Simons (1966):

$$\boldsymbol{T_C = 0.2144 \cdot K} \qquad \textbf{(Equation 4)}$$

To compute the volume of recharge resulting from each peak, it is necessary to quantify the amount of additional groundwater entering the stream after the passage of the peak. This analysis is readily discernible from stream hydrographs. Figure 2-7 presents a schematic view of the RORA method for computing groundwater recharge from a streamflow hydrograph.

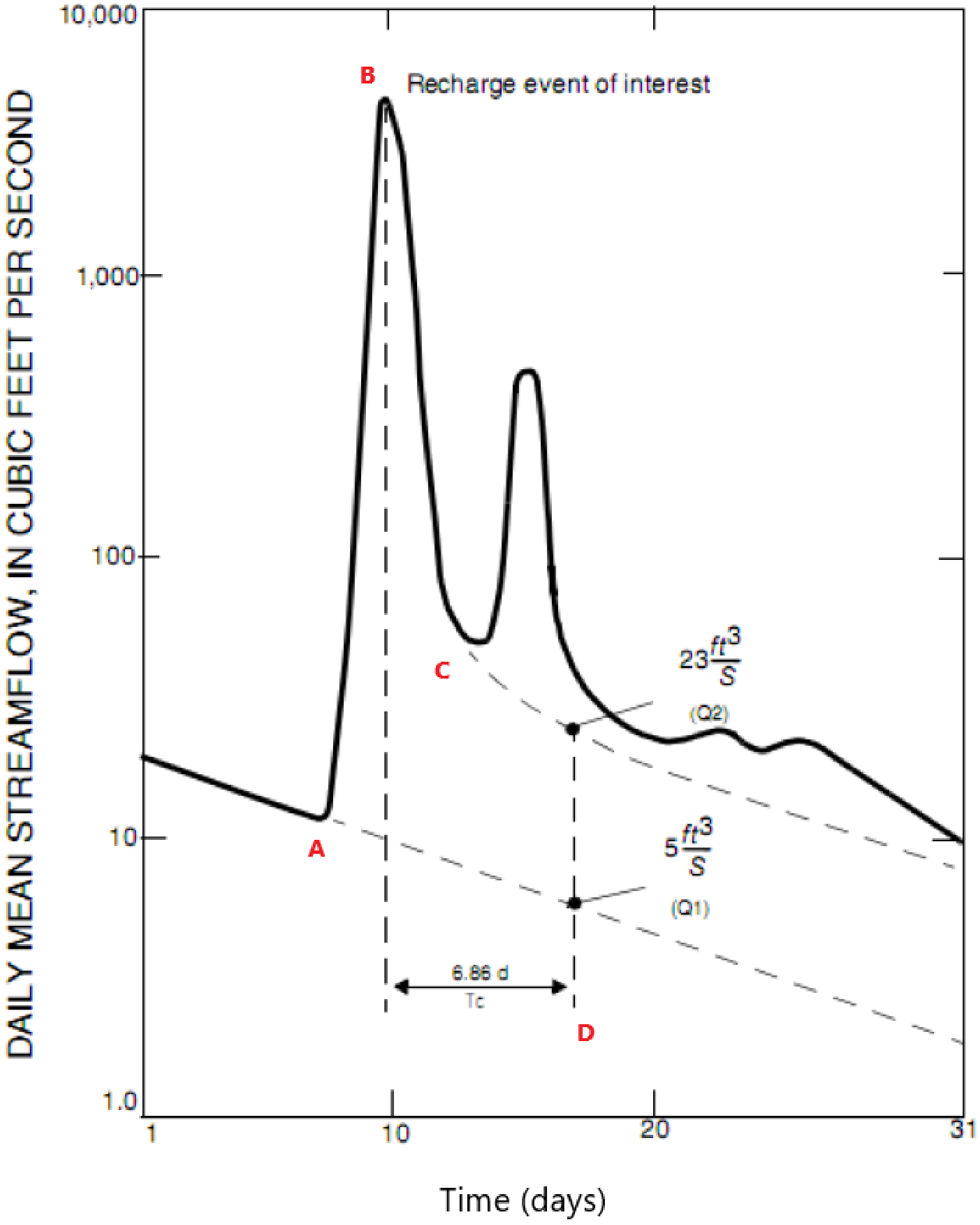


Figure 2-7: RORA Calculation Methods for Determining Recharge (Rutledge, 1998). Note: Red letters were added

On Figure 2-7, there is a streamflow increase that starts at time "A" and peaks at time "B", followed by a period of streamflow recession until time "C" when a smaller streamflow increase occurs. Under the RORA method, the recession index ("*K*" from the RECESS program computations) is used to extend in time the streamflow from time "A" as if the streamflow increase had not occurred. The recession curve is also carried forward in time from time "C" as if the second smaller flow increase had not occurred. Within RORA, the critical time is calculated and added to the time of the initial streamflow peak ("B"), yielding the time "D" at which recharge is calculated. The computed recharge at time D is computed as:

$$\boldsymbol{R = \frac{2(Q_2 - Q_1)K}{2.3026}} \qquad \textbf{(Equation 5)}$$

Where *R* is the total volume of recharge, *K* is the recession index (calculated by RECESS), Q_1 is what the flow would have been at time D if the streamflow increase had not occurred, and Q_2 is what the flow would have been at time D if the recession from the first streamflow increase had been allowed to continue over time (without the second, smaller streamflow increase).

RORA performs these recharge calculations for each peak in the streamflow hydrographic record, and outputs computed recharge results in monthly, quarterly, and annual time increments (based on calendar years/dates). For data from each gaging station, RORA uses a single recession index value (*K*) for its computations, which is the median recession index value determined from the RECESS analysis of the data from that station (see Figure 2-6).

2.3.2 Baseflow Calculation Theory

Groundwater Toolbox offers six different hydrograph separation methods to calculate baseflow, including two methods based on the Base-Flow Index (Wahl and Wahl, 1995), three methods contained within the HySEP program (Sloto and Crouse, 1996), and the PART method (Rutledge, 1998). Each method partitions daily average stream flow into baseflow and runoff components by evaluating the discharge timeseries and identifying minimum stream flows. Each method differs in how minimum stream flows are identified as baseflow and whether baseflow values are interpolated or not. These programs are discussed and documented within the Groundwater Toolbox manuals and the application papers cited above. Each method is described below.

2.3.2.1 HySEP Methods

The three HySEP methods include the HySEP Fixed method, the HySEP Local Minimum method, and the HySEP Slide method. The HySEP methods initially calculate the duration of runoff (N, days) from the drainage area (A, square miles), where $N = A^{0.2}$. The duration of runoff is used to find a calculation window (2N*), which represents the nearest odd integer to the calculation window, between 3 and 11. Functionally, this results in a maximum calculation window of 11 days for any drainage basin larger than 3,125 square miles.

The HySEP methods differ in how they use this search window. The HySEP Fixed method identifies the minimum stream flow within each 2N* interval of the timeseries as baseflow and assigns it to the entire interval. The HySEP Slide method compares the streamflow values for each day against the stream flow values within a sliding calculation window (2N*-1) and assigns the minimum streamflow as baseflow to that day. The HySEP Local Minimum method checks each day to determine if it is a minimum streamflow within the calculation window minus one day (2N*-1). If it is, then this is a local minimum identified as baseflow. The local minima are interpolated to solve for baseflow over the timeseries.

2.3.2.2 PART Method

The PART method designates baseflow to be equal to streamflow on days that fit a requirement of antecedent recession, and then linearly interpolates baseflow for other days. PART uses the same equation as HySEP to solve for runoff duration (N) where, $N=A^{0.2}$. Unlike the HySEP method, the PART method does not round the result. Instead, the PART method is executed for three different values of antecedent recession length: once for the largest integer that is less than N, and once for each of the next two larger integers. The PART method then derives a polynomial equation to solve for baseflow at the exact value of runoff duration (N).

2.3.2.3 Base-Flow Index

The Base-Flow Index Standard method calculates baseflow by dividing the streamflow into segments of constant length (N days) in which the minimum streamflow is identified. Adjacent minima are compared to each other. A value that is less than the turning point test factor input parameter (f) relative to both neighbors is considered baseflow. Baseflow values are then interpolated to form a baseflow timeseries.

The Base-Flow Index Modified method is similar to the Base-Flow Index Standard method, but the turning point test factor parameter is replaced by the recession coefficient (K'). The recession coefficient can be estimated from the Base-Flow Index Standard parameters, where $K' = f^{1/N}$, in which case the Base-Flow Index Modified baseflow results should be approximately the same as the Base-Flow Index Standard program (Barlow and others, 2017).

The groundwater toolbox baseflow calculation methods perform best for perennial, gaining streams that drain homogenous basins with long-term, continuous streamflow data. The analyses perform poorly in streams that are intensively regulated or losing streams, and for analysis intervals less than one month. Confidence in the calculated baseflow results should be evaluated holistically within the context of these constraints and assumptions, which are summarized in Table 2-1.

Table 2-1: Estimated Baseflow Confidence Rating

	High	Medium	Low
Streamflow conditions	Gaining, Perennial	Intermittent	Losing
Hydrogeologic Units	Single	Multiple	--
Size of Watershed (mi^2)	>1 to <500	>500	<1
Time scale of analysis	Annual	Monthly	Daily
Basin slope	<1	>1	--
Water resources development	None	Minor	Substantial
Streamflow record	Complete and > 1 year	Complete < 1 year	Incomplete

2.4 Remote-Sensing Data

Two main remote-sensing datasets have been identified to be useful for this study. The first dataset is the Moderate Resolution Imaging Spectroradiometer data for evapotranspiration and potential evapotranspiration values across the study area. The second dataset is the Soil Moisture Active Passive (SMAP) soil moisture data available for the study area. The details on how these datasets were identified, downloaded, and processed are provided below.

2.4.1 Evapotranspiration Via Remote Sensing

Publicly available and documented remote sensing evapotranspiration dataset such as those available from the Gravity Recovery and Climate Experiment, OpenET project, and others were considered for the study. Two of the three modeling tools, the Soil Water Balance model and Soil & Water Assessment Tool models, internally develop estimates of evapotranspiration for their control volume water balance from which the recharge is computed as a residual. Evapotranspiration is the largest outflow component of overall water balance across the study area, therefore, accurately capturing evapotranspiration is critically important for developing robust recharge estimates.

The various available datasets (including METRIC, pySEBAL, ETFlux, ECOSTRESS, Moderate Resolution Imaging Spectroradiometer 'MODIS') were assessed by several characteristics including pixel size, time step intervals, available period of record, and level of processing required at the user end. Given the intermediate, pixel size (approximately 500 m).[1] ,and the large overlap with our study period of record, and the relatively limited data processing needed, we selected the Moderate Resolution Imaging Spectroradiometer as the preferred

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[1] resulting in nominally four pixels within each 1,000 ft x 1,000 ft raster of the soil water balance model, and numerous pixels within each Hydrologic Unit Code-12 basin

evapotranspiration dataset to employ in this study. The project team downloaded the "gap-filled" (GF) version of the MYD16A2 (Aqua Moderate Resolution Imaging Spectroradiometer evapotranspiration) dataset[2]. As part of utilizing this data, the team evaluated the data quality and usability based on the quality control identifiers downloaded with the Moderate Resolution Imaging Spectroradiometer data.

The purpose of this section is to:

1. Describe the Moderate Resolution Imaging Spectroradiometer data
2. Define Moderate Resolution Imaging Spectroradiometer data quality assessment/quality control codes and their significance
3. Identify potentially problematic dates that should not be used for the study

2.4.1.1 Moderate Resolution Imaging Spectroradiometer Mission Characteristics & Data

National Aeronautics and Space Administration's Moderate Resolution Imaging Spectroradiometer platform is a key component aboard National Aeronautics and Space Administration's Earth Observing System (EOS) Terra (EOS AM-1) and Aqua (EOS PM-1) satellites, launched in 2000 and 2002, respectively, continue to generate data to this day. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. The two view the entire Earth's surface every one to two days, acquiring data in 36 spectral bands.

Based on the logic of the Penman-Monteith (Allen and others, 1998) equation which uses daily meteorological reanalysis data and eight-day remotely sensed vegetation property dynamics from the platform as inputs. National Aeronautics and Space Administration's Moderate Resolution Imaging Spectroradiometer Land Process Team processes the data to develop maps of actual and potential evapotranspiration at a 500-meter pixel scale at eight-day time steps. The Moderate Resolution Imaging Spectroradiometer Global Evapotranspiration User's Guide (Running and others, 2019) provide background on underlying theory, algorithm logic for processing Moderate Resolution Imaging Spectroradiometer data, platform operational details and key uncertainties in the underlying datasets. Figure 2-8 illustrates the data processing steps from the Moderate Resolution Imaging Spectroradiometer platform remote sensing data combined with meteorological data as inputs to Penman-Monteith calculation steps to arrive at the evapotranspiration estimates.

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[2] https://lpdaac.usgs.gov/products/myd16a2gfv006/

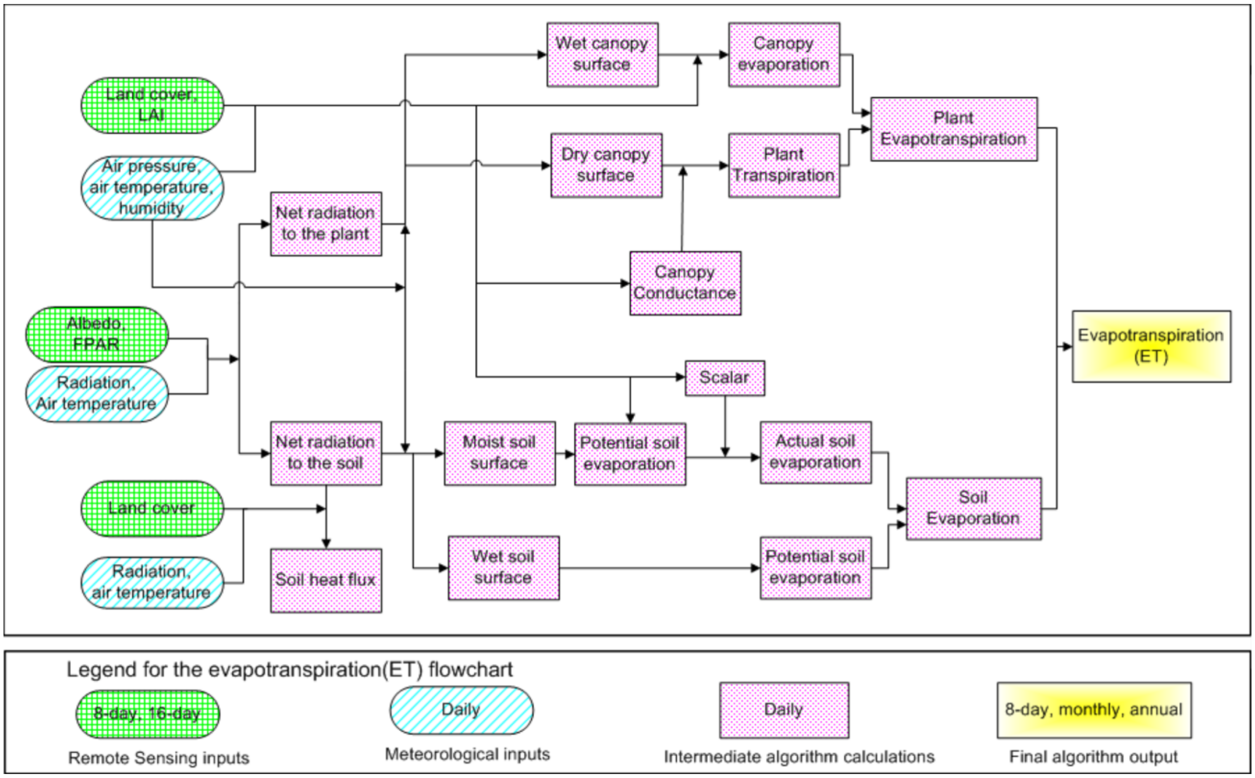


Figure 2-8: Data Sources and Steps in Moderate Resolution Imaging Spectroradiometer Evapotranspiration Calculation Algorithm (Running and others, 2019)

Several issues (components)are important in implementing this algorithm, including some of the assumptions and special issues involved in processing the remotely sensed data used as evapotranspiration model input variables and their influence on the final evapotranspiration estimates. These issues (components) include:

- dependence on Moderate Resolution Imaging Spectroradiometer land cover classification,
- leaf area index (LAI), Fraction of absorbed photosynthetically active radiation (FPAR), and albedo; and
- spatial resolution inconsistency between the 0.5-kilometer Moderate Resolution Imaging Spectroradiometer data and the meteorological data obtained from National Aeronautics and Space Administration’s Global Modeling and Assimilation Office.

2.4.1.2 Dependence of Moderate Resolution Imaging Spectroradiometer Evapotranspiration on Land Classification

One of the first Moderate Resolution Imaging Spectroradiometer products used in the MOD16 algorithm is the Land Cover Product. The MOD16 data downloaded for this project utilizes a three-year smoothed land cover data set. As noted by National Aeronautics and Space Administration (Running and others, 2019), the MOD16 algorithm relies heavily on land cover type through use of the Biome Properties Look-Up Table (BPLUT).

Figure 2-9 shows the global distribution of land cover types used in MOD16. Land cover types employed in Biome Properties Look-Up Table of MOD16 evapotranspiration calculation present the Land Cover Biomes represented in the Biome Properties Look-Up Table (Table 2-2).

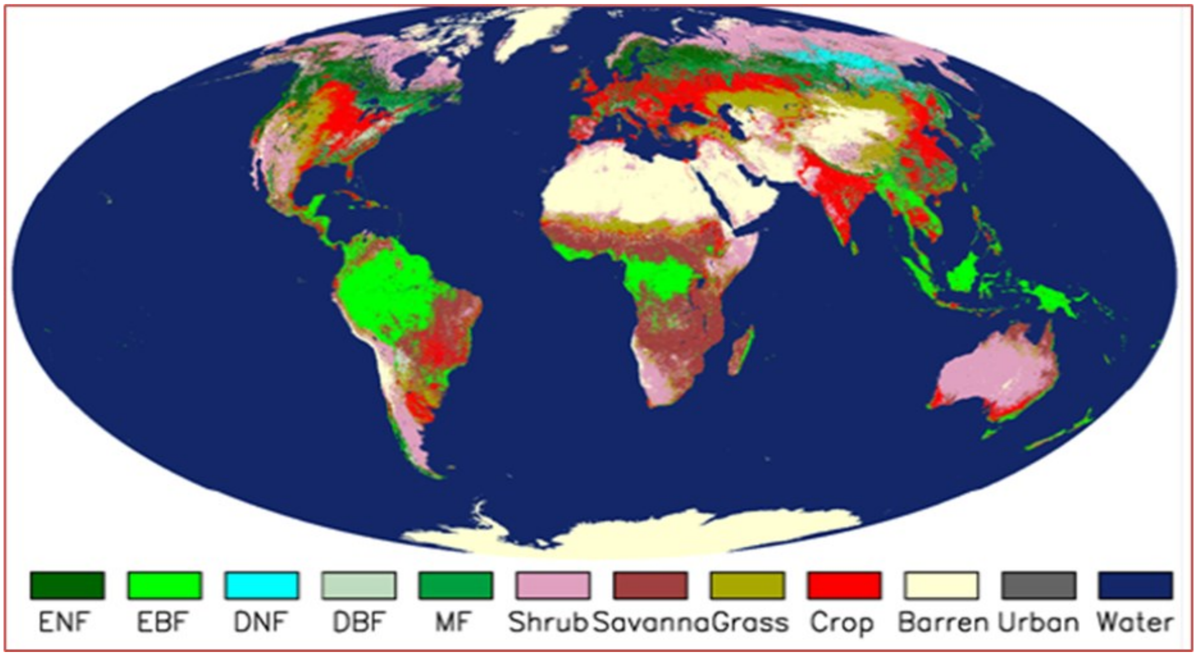
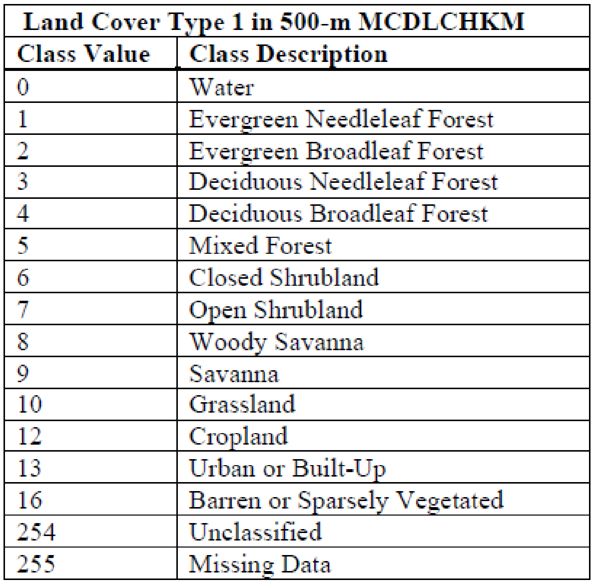


Figure 2-9: Moderate Resolution Imaging Spectroradiometer Evapotranspiration Land Cover Type Used in Evapotranspiration Calculation

Table 2-2: Land Cover Types Employed in Biome Properties Look Up Table of MOD 16 Evapotranspiration Calculation



Land Cover Type 1 in 500-m MCDLCHKM	
Class Value	**Class Description**
0	Water
1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest
5	Mixed Forest
6	Closed Shrubland
7	Open Shrubland
8	Woody Savanna
9	Savanna
10	Grassland
12	Cropland
13	Urban or Built-Up
16	Barren or Sparsely Vegetated
254	Unclassified
255	Missing Data

The end user should recognize the assumptions underlying the application of the Biome Properties Look-Up Table on the estimated evapotranspiration. Specifically, the National Aeronautics and Space Administration team (Running and others, 2019) states:

> "Arguably, the most significant assumption made in the MOD16 logic is that biome-specific physiological parameters do not vary with space or time. These parameters are outlined in the Biome Properties Look-Up Table [Table 2-2] within the MOD16 algorithm. The Biome Properties Look-Up Table constitutes the physiological framework for controlling simulated evapotranspiration. These biome-specific properties are not differentiated for different expressions of a given biome, nor are they varied at any time during the year. These assumptions imply that a semi-desert grassland in Mongolia is treated the same as a tallgrass prairie in the Midwestern United States. Likewise, a sparsely vegetated boreal evergreen needleleaf forest in Canada is treated as functionally equivalent to its coastal temperate evergreen needleleaf forest counterpart."

For this reason, it is essential for this study that land cover types employed by the Soil Water Balance model and the Soil & Water Assessment Tool models are appropriately translated to relevant counterparts in the Moderate Resolution Imaging Spectroradiometer Biome Properties Look-Up Table. This underlines the importance of the potential application of local ground-based data (for example, TexMesonet) for "dialing in" the Moderate Resolution Imaging Spectroradiometer evapotranspiration to the actual on-the-ground conditions in the study area.

2.4.1.3 The Leaf Area Index, Fraction of Absorbed Photosynthetically Active Radiation and Albedo Data

The Leaf Area Index and Fraction of Absorbed Photosynthetically Active Radiation products are an 8-day composite of pixels based on nominally daily observations over that 8-day period. The MOD16 compositing algorithm uses the maximum Fraction of Absorbed Photosynthetically Active Radiation (for each pixel across the eight days) to represent the actual value for that pixel for the entire period; the same day is used for the composite Leaf Area Index value. This temporal discretization implies that, although evapotranspiration is estimated daily, the MOD16 evapotranspiration algorithm assumes that leaf area and Fraction of Absorbed Photosynthetically Active Radiation do not vary during a given eight-day period. This approach largely overcomes issues with aerosols and cloudiness, which is particularly an issue in the tropics.

The Moderate Resolution Imaging Spectroradiometer MCD43A2/A33 albedo products are 16-day moving daily products[3]. Data from both the Terra and Aqua platforms are used in the generation of this product, providing the highest probability for quality input data. This version-6 Moderate Resolution Imaging Spectroradiometer albedo products have been subject of Stage 1 Validation process, indicating that accuracy has been checked using a small number of independent measurements obtained from selected locations and time periods and ground-truth/field program efforts. Running and others (2019) state there may be later improved versions, but the currently available data is considered ready for use in scientific studies such as this one.

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[3] "MCD" in the designation means "Combined" data from the Agua and Terra Moderate Resolution Imaging Spectroradiometer platforms

Notably, the eight-day and daily Moderate Resolution Imaging Spectroradiometer albedo products can still be contaminated by clouds and/or aerosols in certain regions and times of year. As a result, in regions with higher frequencies of cloud cover (for example, tropical rain forests), values of Fraction of Absorbed Photosynthetically Active Radiation/Leaf Area Index will be greatly reduced and the albedo signal dramatically increased. To overcome resulting problems, National Aeronautics and Space Administration researchers and collaborators have developed "gap-filling" methodologies which are applied after the fact to yield gap-filled complete annual data sets. These gap-filled datasets have been used for this project. Running and others (2019) describe the Gap-Filling methodologies and their application to the Moderate Resolution Imaging Spectroradiometer evapotranspiration dataset.

As part of the year-end gap-filling process, the National Aeronautics and Space Administration team provides data quality evaluations for each published image with a pixel-by-pixel evaluation of data quality / usability. The data quality codes and application to the MOD16 dataset employed for this project are provided in the next section.

2.4.1.4 Spatial Resolution Inconsistency Between the Moderate Resolution Imaging Spectroradiometer Data and Meteorological Data

The daily time step computation of evapotranspiration is made possible by the daily meteorological data[4] provided by National Aeronautics and Space Administration's Global Modeling and Assimilation Office (Schubert and others. 1993). These data, produced every six hours, are derived using a Global Circulation Model, which incorporates both ground and satellite-based observations. These data are distributed at a resolution of 0.5° x 0.6° (approximate 50-kilometer pixel) or 1.00° x 1.25° (note that resolution may become finer with updates of Global Modeling and Assimilation Office system at National Aeronautics and Space Administration) in contrast to the 0.5-kilometer gridded MOD16 outputs. The inconsistency in spatial resolution between the two datasets is addressed by spatially smoothing and re-gridding the meteorological data to 0.5-kilometer Moderate Resolution Imaging Spectroradiometer pixel level. The four Global Modeling and Assimilation Office cells nearest to a given 0.5-kilometer Moderate Resolution Imaging Spectroradiometer pixel are used in a non-linear interpolation algorithm, to avoid abrupt changes in meteorological data when passing from one Global Modeling and Assimilation Office image to the next adjacent image. Comparing the daily Global Modeling and Assimilation Office data to daily weather data from over 5,000 stations in the World Meteorological Organization surface network, the Root-Mean-Squared Error and correlation were improved for 73 percent and 84 percent of stations, respectively.

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[4] including average and minimum air temperature, incident PAR and specific humidity

2.4.1.5 Moderate Resolution Imaging Spectroradiometer Data Downloads and Quality Evolution

For this project, the project team downloaded the following datasets for January 1, 1981, through December 31, 2018:

- ET_500m (MYD16A2GF.006), contains actual evapotranspiration estimates,
- PET_500m (MYD16A2GF.006), contains estimates of potential evapotranspiration, and
- ET_QC_500m (MYD16A2GF.006), provides data quality codes for each pixel for each image

The data output is in raster format in GeoTiff files. The total size of the extracted files was 1,831.56 megabytes. The number of the original files (8-day) for evapotranspiration should be 776, however, only 676 data files were provided in the data download. Those 100 files are missing for years 2006 to 2008, as well as February and March 2016. The same is true for the potential evapotranspiration files. Subsequent investigation on the National Aeronautics and Space Administration's Distributed Active Archives Center website revealed that the missing dates were removed from public availability by National Aeronautics and Space Administration due to a recent finding of systematic errors that occurred when the data were processed (National Aeronautics and Space Administration, Land Process Distributed Active Archives Center site[5], March 14, 2018). According to National Aeronautics and Space Administration, these data will be made available again once the reprocessing occurs. In addition, supporting files were downloaded, including:

- Three text files that provide metadata on our data request, and on the data itself,
- Comma Separated Values files that provided summary statistics for computed parameter (for example, evapotranspiration) for each image requested. To verify the data, the team randomly selected two images and performed a statistical analysis on the raster data to reproduce the summary statics reported in the Comma Separated Values file, (minimum, maximum, mean, standard deviation, median, upper and lower quartiles, and upper and lower 1.5* quartile). Per Moderate Resolution Imaging Spectroradiometer User Manual (Running and others, 2019; Table 6.2) a 0.1 scale factor was applied to match statistics reported in the Comma Separated Values file; and
- a Comma Separated Values file that provides pixel statistics for quality assessment/quality control data codes.

Related to the last point and as noted previously, each pixel in each image is assigned a quality assessment/quality control code. Table 2-3 presents code definitions. If desired, even more detailed codes related to precise datasets (for example, albedo or reflectance) and algorithms can be accessed via National Aeronautics and Space Administration's Application for the Extracting and Exploring Analysis Ready Samples (AppEARS) system. Via the Application for Extracting and Exploring Analysis Ready Samples, Python scripts can be used to query detailed quality control codes on a pixel-by-pixel basis.

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[5] https://earthdata.nasa.gov/eosdis/daacs , National Aeronautics and Space Administration's Distributed Active Archive Centers (DAACs); located throughout the United States. All are affiliated through National Aeronautics and Space Administration's Earth Observing System Data and Information System (EOSDIS) is designed as a distributed system

Table 2-3: MOD16GFY Quality Control Codes

Value	MODIS LAND	SCF_QC	Sensor	Detector Status	Cloud State
2	Good quality	Main (RT) method used, best result possible	Aqua	Detectors fine for up to 50% of channels 1, 2	Significant clouds NOT present (clear)
10	Good quality	Main (RT) method used, best result possible	Aqua	Detectors fine for up to 50% of channels 1, 2	Significant clouds WERE present
18	Good quality	Main (RT) method used, best result possible	Aqua	Detectors fine for up to 50% of channels 1, 2	Mixed cloud present on pixel
34	Good quality	Main (RT) method used with saturation. Good, very usable	Aqua	Detectors fine for up to 50% of channels 1, 2	Significant clouds NOT present (clear)
42	Good quality	Main (RT) method used with saturation. Good, very usable	Aqua	Detectors fine for up to 50% of channels 1, 2	Significant clouds WERE present
50	Good quality	Main (RT) method used with saturation. Good, very usable	Aqua	Detectors fine for up to 50% of channels 1, 2	Mixed cloud present on pixel
99	Other Quality (back-up algorithm or fill values)	Main (RT) method failed, empirical algorithm used	Aqua	Detectors fine for up to 50% of channels 1, 2	Significant clouds NOT present (clear)
107	Other Quality (back-up algorithm or fill values)	Main (RT) method failed, empirical algorithm used	Aqua	Detectors fine for up to 50% of channels 1, 2	Significant clouds WERE present
115	Other Quality (back-up algorithm or fill values)	Main (RT) method failed, empirical algorithm used	Aqua	Detectors fine for up to 50% of channels 1, 2	Mixed cloud present on pixel
157	Other Quality (back-up algorithm or fill values)	Pixel not produced at all, value couldn't be retrieved	Terra	Dead detectors caused >50% adjacent detector retrieval	Cloud state not defined, assumed clear

As part of the quality control evaluation of the data downloaded by WSP, statistics have been developed for each of the data codes for every date downloaded. According to the MODIS LAND and SCF_QC columns in Table 2.3, data associated with codes 2 through 50 is considered very useable. Data tagged with codes 99 through 115 is useable recognizing that they have been filled with empirical algorithms. Using the filter “Very Useable” as classified by National Aeronautics and Space Administration, a statistical analysis of the downloaded data indicates that:

- over 95 percent of the downloaded images have more than 98 percent very useable pixels,
- over 98.4 percent of the images have more than 95 percent very useable pixels; and
- nearly 99 percent of the images have over 90 percent very useable pixels.

Figure 2-10 shows the probability exceedance curve for number of useable pixels (having quality control codes 2 through 50). Using a criterion of at least of 95 percent of pixels to be considered very useable, we identified 13 images / dates that should be double-checked before utilization in the comparative analysis. As demonstrated in Table 2-4, most of the pixels (but less than 95 percent) of those particular images are still labeled as Very Useable. For those portions of the study area, even those images can be utilized.

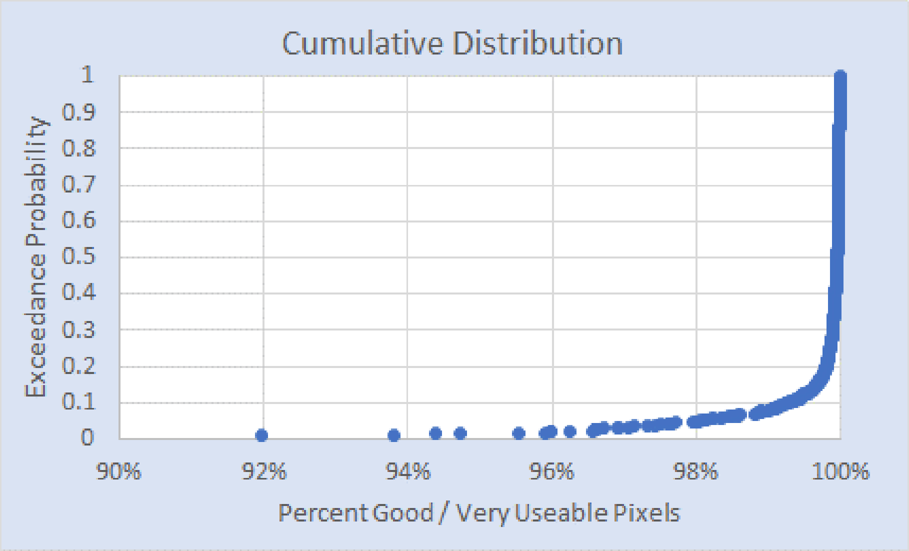
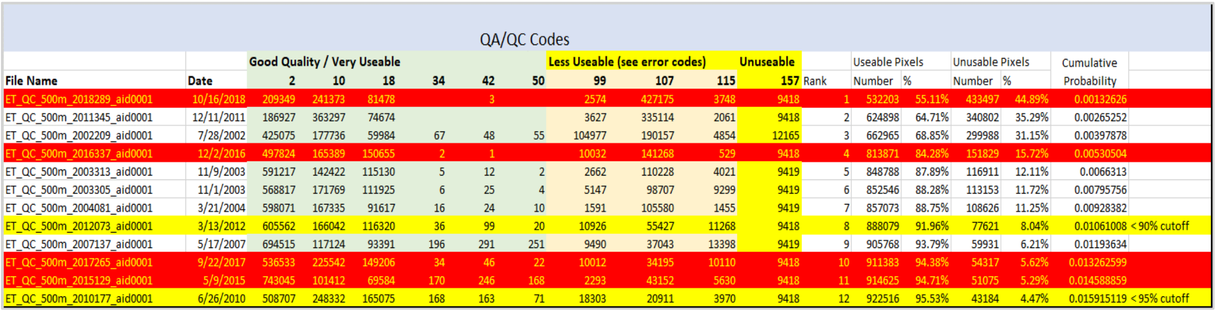


Figure 2-10:Upper Tail of Cumulative Probability Distribution of "Very Useable" Moderate Resolution Imaging Spectroradiometer Pixels in Downloaded Images

Table 2-4 below presents the images/dates with more than five percent less useable pixels. The yellow highlighted rows indicate the images at the 95 percent and 90 percent exceedance probability of very useable pixels. The rows highlighted in red indicate images in our period of record for the TWDB recharge project.

Table 2-4: Identification of Images / Dates with More Than 5 percent Less Useable Pixels



		QA/QC Codes																
		Good Quality / Very Useable						Less Useable (see error codes)			Unuseable		Useable Pixels		Unusable Pixels		Cumulative	
File Name	Date	2	10	18	34	42	50	99	107	115	157	Rank	Number	%	Number	%	Probability	
ET_QC_500m_2018289_aid0001	10/16/2018	209349	241373	81478		3		2574	427175	3748	9418	1	532203	55.11%	433497	44.89%	0.00132626	
ET_QC_500m_2011345_aid0001	12/11/2011	186927	363297	74674				3627	335114	2061	9418	2	624898	64.71%	340802	35.29%	0.00265252	
ET_QC_500m_2002209_aid0001	7/28/2002	425075	177736	59984	67	48	55	104977	190157	4854	12165	3	662965	68.85%	299988	31.15%	0.00397878	
ET_QC_500m_2016337_aid0001	12/2/2016	497824	165389	150655	2	1		10032	141268	529	9418	4	813871	84.28%	151829	15.72%	0.00530504	
ET_QC_500m_2003313_aid0001	11/9/2003	591217	142422	115130	5	12	2	2662	110228	4021	9419	5	848788	87.89%	116911	12.11%	0.0066313	
ET_QC_500m_2003305_aid0001	11/1/2003	568817	171769	111925	6	25	4	5147	98707	9299	9419	6	852546	88.28%	113153	11.72%	0.00795756	
ET_QC_500m_2004081_aid0001	3/21/2004	598071	167335	91617	16	24	10	1591	105580	1455	9419	7	857073	88.75%	108626	11.25%	0.00928382	
ET_QC_500m_2012073_aid0001	3/13/2012	605562	166042	116320	36	99	20	10926	55427	11268	9418	8	888079	91.96%	77621	8.04%	0.01061008	< 90% cutoff
ET_QC_500m_2007137_aid0001	5/17/2007	694515	117124	93391	196	291	251	9490	37043	13398	9419	9	905768	93.79%	59931	6.21%	0.01193634	
ET_QC_500m_2017265_aid0001	9/22/2017	536533	225542	149206	34	46	22	10012	34195	10110	9418	10	911383	94.38%	54317	5.62%	0.013262599	
ET_QC_500m_2015129_aid0001	5/9/2015	743045	101412	69584	170	246	168	2293	43152	5630	9418	11	914625	94.71%	51075	5.29%	0.014588859	
ET_QC_500m_2010177_aid0001	6/26/2010	508707	248332	165075	168	163	71	18303	20911	3970	9418	12	922516	95.53%	43184	4.47%	0.015915119	< 95% cutoff

2.4.2 Soil Moisture by Soil Moisture Active Passive

Soil moisture has been monitored via remote sensing between 2002 and 2011 as part of the Advanced Microwave Scanning Radiometer for Earth Observing Satellite. This data was processed by National Aeronautics and Space Administration scientists to a Level-3 land surface gridded product that includes daily measurements of surface soil moisture and vegetation/roughness water content interpretive information, as well as brightness temperatures and quality control variables (Njoku, 2004). The data's spatial resolution is 25-kilometer x 25 kilometer, which is not ideal for comparison to the Soil Water Balance model data.

More recently, remotely sensed soil moisture data has become available from the Soil Moisture Active Passive mission, which provides data from 2015 to the present with a nine- kilometer spatial resolution. Zhang and others (2017) provided a comparative analysis of the Soil Moisture

Active Passive and the Advanced Microwave Scanning Radiometer for Earth Observing Satellite soil moisture products against in-situ measurements collected from American soil moisture monitoring networks. The monthly average and daily Advanced Microwave Scanning Radiometer for Earth Observing Satellite and Soil Moisture Active Passive soil moisture data were analyzed. Different spatial series, temporal series, and combined spatial-temporal analysis were also completed. The results revealed that Soil Moisture Active Passive soil moisture retrievals are generally better than Advanced Microwave Scanning Radiometer for Earth Observing Satellite soil moisture data. Several agencies across the United States have begun utilizing the Soil Moisture Active Passive soil moisture data for applied research and practical application, including the Texas Bureau of Economic Geology.

The purpose of this section is to:

1. provide background on Soil Moisture Active Passive soil moisture dataset, and processed soil moisture data downloaded for this project,
2. describe the quality assessment/quality control check on Soil Moisture Active Passive data and significance of quality control data codes; and
3. describe data processing method to prepare Soil Moisture Active Passive data for comparative analysis to Soil Water Balance model and the Soil & Water Assessment Tool model data and results.

2.4.2.1 Soil Moisture Active Passive Mission and Data Characteristics

National Aeronautics and Space Administration's Soil Moisture Active Passive mission was launched in early 2015 with two complementary instruments aboard:

- Active Radar instrument, which measures in high detail a radar backscatter (at 1.26 gigahertz and 1.29 gigahertz) of the ground surface; and
- Passive Radiometer that measures land surface microwave emission (or brightness temperature; at 1.41 gigahertz).

Both the radar backscatter and the surface microwave emission are highly affected by the amount of moisture in the soil. This data is readily processed to provide information on surface soil moisture (top five centimeters of the soil column) and on the freeze/thaw state of the land surface with the radar data. The radar data exhibited a spatial resolution of three kilometers by three kilometers, whereas the radiometer data has nine- kilometers by nine- kilometers spatial resolution. Unfortunately, the power supply for the active radar source failed on July 7, 2015; therefore,results from the combined dataset are available only for the period from April 13, 2015 to July 7, 2015. As a backup to the failed onboard Active Radar, complementary radar data is available from the European Union Sentinel satellite which follows the Soil Moisture Active Passive platform orbit closely enough to generally permit data assimilation. The Soil Moisture Active Passive platform radiometer instrument continues to generate high-quality microwave emission data for soil moisture sensing.

There are four "Levels" of Soil Moisture Active Passive data available online:

- Level 1B and 1C data products are calibrated and geolocated instrument measurements of surface radar backscatter cross-section and brightness temperatures. L1B_TB_E data product is calibrated brightness temperatures interpolated onto a global EASE-2 grid. (Equal-Area Scalable Earth grid).
- Level 2 products are geophysical retrievals of soil moisture on a fixed Earth grid based on Level 1 products and ancillary information.
- Level 3 products are daily composites of the Level 2 surface soil moisture and freeze/thaw state data.
- Level 4 products are model-derived value-added data products of surface and root zone soil moisture and carbon net ecosystem exchange that support key Soil Moisture Active Passive applications and more directly address the driving science questions.

Data assimilation is the process of integrating the Soil Moisture Active Passive data with land surface modeling. Through data assimilation, National Aeronautics and Space Administration scientists generated a Level 4 data product that provides estimates of both root zone soil moisture (defined here nominally as soil moisture in the top 1 meter of the soil column) as well as the top five-centimeter data (Reichle and others., 2014). The Level 4 algorithm uses an ensemble Kalman filter to merge Soil Moisture Active Passive observations with soil moisture estimates from the National Aeronautics and Space Administration Catchment land surface model. The Catchment model describes the vertical transfer of soil moisture between the surface and root zone reservoirs and will be driven with observation-based surface meteorological forcing data, including precipitation, on a global nine- kilometer, Earth-fixed grid with a 7.5-minute model time step. If provided with properly calibrated uncertainty inputs, this data assimilation process yields a product that is superior to satellite data or land model data alone. This Level 4 shallow and root-zone soil moisture data is available from April 2015 to present with a nine- kilometer spatial resolution on a three-hour time step size.

The Soil Moisture Active Passive soil moisture data is archived for public retrieval at the National Snow and Ice Data Center[6], part of National Aeronautics and Space Administration's Distributed Active Archives Center data archiving network. The project team downloaded two soil moisture datasets for the period from March 31, 2015 (earliest available) to December 31, 2018 (end of model simulation period for this recharge study), specifically:

1. the Level 4 Geophysical-Data_sm_rootzone_v5 for soil moisture in top one meter of profile,
2. the Level 4 Geophysical-Data_sm _surface for the top five-centimeter soil moisture; and
3. in addition to the two soil moisture datasets, the associated Land Model dataset that includes Soil Classification, Soil Depth, Soil Porosity, Soil Texture, and Terrain Elevation was downloaded.

The data output is in raster format in GeoTiff files. For the above two soil moisture data layers, a total of 21,968 files were downloaded: 10,984 each for the shallow and root-zone soil moisture. While the Distributed Active Archives Center data server selection page indicates the data are available on a daily timestep, the actual downloaded data are on a three-hour time step. The soil

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[6] https://nsidc.org/data/smap/smap-data.html

moisture (θ) is reported in dimensionless volumetric units, which are the units most commonly employed in modeling of soil moisture movement in the vadose zone.

$$\boldsymbol{\theta} = \frac{\boldsymbol{Vol_{water}}}{\boldsymbol{Vol_{soil}}} \qquad \textbf{(Equation 6)}$$

In addition, supporting files were downloaded, including:

- Text files that provide metadata on our data request, and on the data itself,
- Comma Separated Values files that provided summary statistics for computed parameter (volumetric water content in this case) for each image requested. Again, two randomly selected datasets we processed to generate cumulative probability distributions of moisture content over all pixels, to verify the statistical quantiles matched those reported in the Comma Separated Values file; and
- a Comma Separated Values file that provides pixel statistics for quality assessment/quality control data codes.

Like with the Moderate Resolution Imaging Spectroradiometer evapotranspiration data, for each pixel in each Soil Moisture Active Passive image there is an associated set of Quality Control codes. Quality control is an integral part of the Level 3 and Level 4 soil moisture assimilation system, therefore quality control codes are provided with the instrument observations. For the Level 4 processing with the Ensemble Kalman Filter, the model will assimilate only Soil Moisture Active Passive brightness temperature data that have favorable flags for soil moisture estimation (for example, acceptable vegetation density, no rain, no snow cover, no frozen ground, no radio-frequency interference, sufficient distance from open water). The quality control codes indicate if: (i) rain is falling, (ii) the soil is frozen, or (iii) the ground is fully or partly covered with snow. In other words, all pixels with one of those three quality control codes have been excluded from assimilation in the Ensemble Kalman Filter (soil moisture) update whenever the land surface model indicates this. Also, the assimilation system provides some weight to the model's preceding timesteps and buffers the impact of anomalous observations that may slip through the flagging process.

2.4.2.2 Soil Moisture Active Passive Data Processing

Soil Moisture Active Passive data has been processed using the following steps:

1. Rather than attempting to process all three-hour data, it was noted that the daily data is comprised of eight, three-hourly data images. There are eight files each day, sequentially labeled from 0 to 7, and the team arbitrarily extracted label=4 which is equivalent to 12:00 (noon) as the representative daily data. Through this process, a total of 1,373 daily moisture content files were compiled.
2. The daily data processed into monthly average data, and the native nine- kilometer resolution of the Soil Moisture Active Passive root-zone soil moisture data. This monthly data was then resampled to the Soil Water Balance model grid. The Soil Water Balance model grid cell size is 1,000 feet by 1,000 feet, with bilinear interpolation used in the resampling. The resampled monthly data was thus compiled into a total of 45 raster data sets.
3. For comparison to the Soil & Water Assessment Tool model, the re-gridded monthly data also was aggregated into subbasin (Hydrologic Unit Code-12) level, into a shapefile with 45 monthly average values for each Hydrologic Unit Code-12 catchment.

2.5 Rapid Recharge Assessment Tool (Based on Soil Conservation Services Curve Number Method)

As a third alternative method for estimating groundwater recharge, we investigated an application of the standard "Curve Number Method" developed by the Soil Conservation Service. This method essentially involves performing a water balance over an area of interest and is similar to the Soil Water Balance model and the Soil & Water Assessment Tool models described earlier. The main difference between the numerical codes and this Curve Number method is that the latter does not explicitly consider the effects of soil moisture on groundwater recharge. It does, however, include antecedent moisture conditions within its solution algorithms and therefore incorporates some influences of soil moisture on recharge capabilities for an area.

We investigated using the Curve Number method mainly because it is a commonly understood and implementable method that can be quickly applied to any area of interest without time-consuming model development, setup, and calibration. The standard "Curve Number Method" was originally developed by the Soil Conservation Service and is now commonly described in all basic hydrology textbooks. The curve number method calculates surface runoff generated by rainfall events according to the following series of equations:

$$\boldsymbol{q = \frac{(P-I_a)^2}{(P-I_a)+S}} \qquad \textbf{(Equation 7)}$$

$$\boldsymbol{I_a = 0.2S} \qquad \textbf{(Equation 8)}$$

$$\boldsymbol{S = \frac{1000}{CN} - 10} \qquad \textbf{(Equation 9)}$$

Where "q" is the resulting runoff (Units = inches), "P" is the depth of rainfall (inches), "I_a" is the initial abstractions representing the amount of rainfall lost to the land surface or canopy, and "S" is the potential maximum retention of water by the land surface. The value "CN" is the curve number describing the land use/land cover of the watershed (which is also dependent upon the watershed's hydrologic soil group).

Through a revision of the Soil Conservation Services Curve Number method, it is possible to estimate groundwater recharge. We defined recharge – "R" as:

$$\boldsymbol{R = max(0, P - q - I_a - S - ET)} \qquad \textbf{(Equation 10)}$$

Where all terms are as previously defined, and "ET" is the estimated evapotranspiration at a given location. According to the Equation 10, recharge is calculated only if there is sufficient rainfall such that runoff, initial abstractions, surface retention, and evapotranspiration sum to be less than the precipitation amount.

To implement the Equation 10, we utilized data already available from other parts of the project: Land Use/Land Cover grids for the study area, hydrologic soil group grids for the study area, and a Land Use/Land Cover lookup table to develop curve numbers. The PRISM precipitation data developed for the Soil Water Balance model grid cells was used to determine antecedent moisture conditions. Based on the antecedent moisture conditions, we adjusted the curve number "CN" values according to Table 2-5 below:

Table 2-5: Adjustments to Curve Numbers Based on Antecedent Moisture Conditions

		5-Day Antecedent Rainfall Criteria	
Condition	Formula	Growing Season March 15-October 15	Dormant Season October 16-March 14
I – Dry	$CN_I = \frac{4.2CN}{10 - 0.058CN}$	RT < 1.4 in	RT < 0.5 in
II - Average	$CN_{II} = CN$	1.4 in ≤ RT ≤ 2.0 in	0.5 in ≤ RT ≤ 1.0 in
III - Wet	$CN_{III} = \frac{23CN}{10 + 0.13CN}$	RT > 2.0 in	RT > 1.0 in

Note: RT = Total rainfall for the previous 5-days

After computing the adjusted curve number values, we computed values for "S" and "I_a" using Equations 8 and 9. We then computed runoff ("q") using Equation 7 if the rainfall amount ("P") exceeded the computed initial abstractions ("I_a"). In this way, runoff is only computed when there is sufficient precipitation ("P") to reach the ground after accounting for canopy losses.

Values for evapotranspiration ("ET") were derived using one of two methods:

- Method #1 – Using the Hargreaves-Samani (1985) method as in the Soil Water Balance model; and
- Method #2 – Using data from the Moderate Resolution Imaging Spectroradiometer database.

Evapotranspiration values derived from the Moderate Resolution Imaging Spectroradiometer database are available as monthly datasets from 2003 through 2018, with data unavailable for May 2006 through July 2008 and from February 2016 through March 2016. For periods prior to 2003 and when Moderate Resolution Imaging Spectroradiometer data are unavailable, evapotranspiration values were estimated using the Hargreaves-Samani (1985) method.

The Moderate Resolution Imaging Spectroradiometer evapotranspiration data is available as grids of monthly totals and all other terms in Equation 10 are computed daily. Therefore, it is necessary to divide Moderate Resolution Imaging Spectroradiometer data by the number of days in a subject month to obtain appropriate estimates of daily recharge quantities.

The Soil Conservation Services curve number method, as developed here, requires approximately 10-15 minutes of computer processing time to estimate recharge for a month for a total run time of about 3.5 days. This run time is comparable to the model run times for Soil Water Balance model and Soil & Water Assessment Tool model.

3. Model Input Data

Model results can only be as good as the model input data. Also, to compare the model results, it is important that the input data has the same or similar source. Considerable effort was spent in streamlining the model input data and to make sure that the same data source is employed for developing the input for each model. The discussion provided below presents the data type, source and how it was used in each model along with a general description of the input data requirements for each model.

3.1 Soil Water Balance

The Soil Water Balance model code requires gridded input data for daily climate conditions, soil properties, land use, and topography. For the gridded input data, we used the ESRI ASCII raster format. The code does allow for other gridded data formats (such as, Surfer ASCII grid or netCDF).

In addition to the gridded data, the code requires a lookup table with variables for each possible land use code and hydrologic soil group combination. For each land use and hydrologic soil group combination we must provide the Natural Resources Conservation Service runoff curve number (NRCS, 1986), maximum infiltration rate, and depth of the root zone. In addition, the code requires an interception storage value (the amount of precipitation capture by leaves before reaching the soil) for the growing and dormant season.

We prepared the gridded input data for the model domain shown in Figure 3-1. For this project, all input grid data are in the TWDB Groundwater Availability Modeling projection system (Table 3-1). Each input grid contains 2,810,150 cells with each cell representing 1,000,000 square feet (approximately 23 acres, 1,000 feet by 1,000 feet squares). Table 3-2 provides the grid dimensions for the Soil Water Balance model constructed for this project.

For each gridded dataset we used geoprocessing tools within ArcGIS to prepare the data for the Soil Water Balance model. We began by clipping the dataset to the model domain. We then resampled the dataset from its native resolution to the grid cell dimensions. Next, the team converted the units, if necessary, of the grid cell values. Finally, we verified the grid dimensions to ensure they were consistent with the defined grid and filled in the area covering Mexico with the average value for grid cells within the United States.

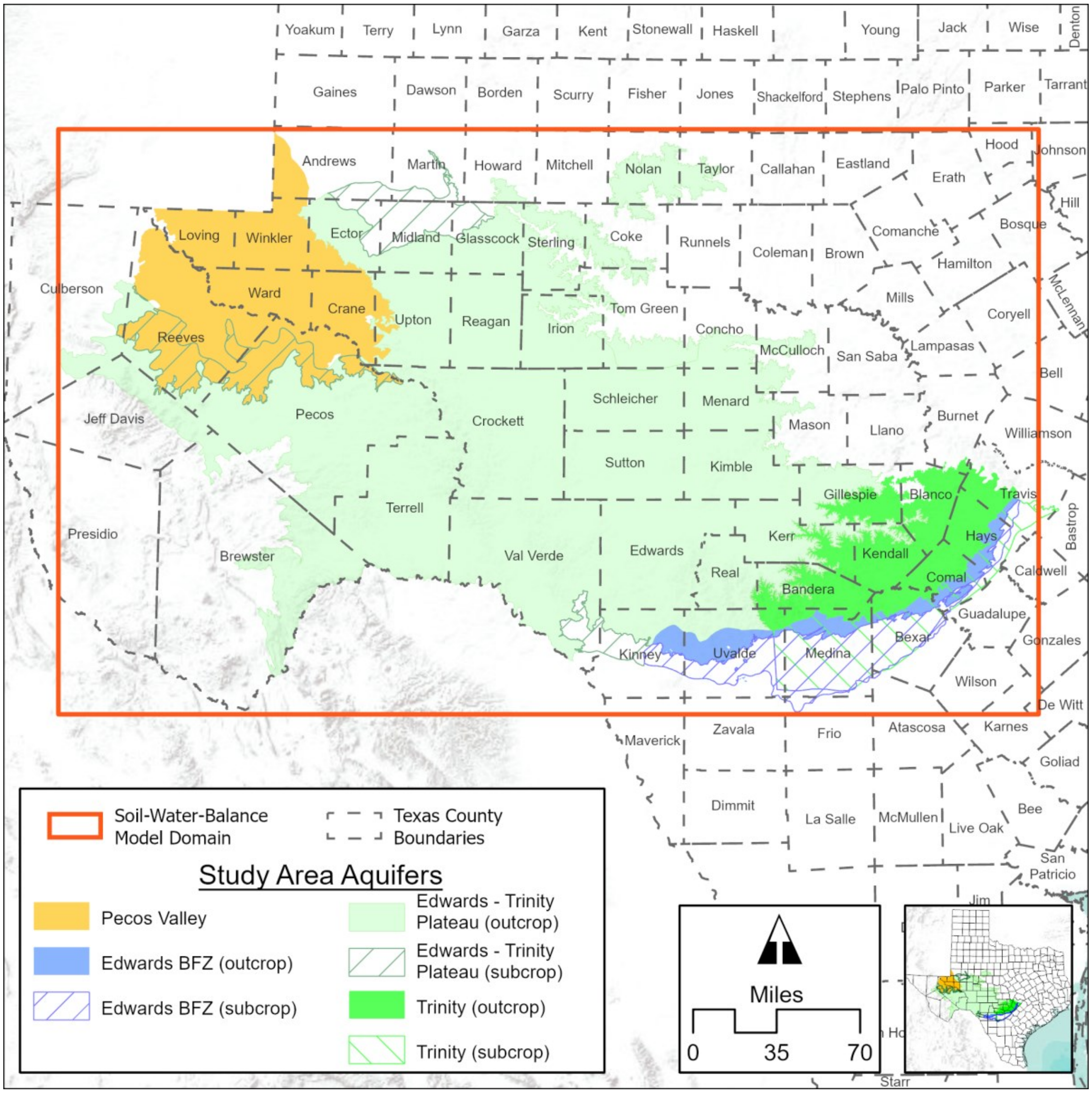


Figure 3-1: Soil Water Balance Model Domain

Table 3-1: Description of the TWDB Groundwater Availability Modeling Projection System

Parameter	Value
Geographic Coordinate System	North American 1983
Angular Unit	Degree (0.0174532925199433)
Prime Meridian	Greenwich (0.0)
Datum	North American 1983
Spheroid	GRS 1980
Semimajor Axis	6378137.0
Semiminor Axis	6356752.314140356
Inverse Flattening	298.257222101
Projection	Albers
False Easting	4921250.0
False Northing	19685000.0
Central Meridian	-100.0
Standard Parallel 1	27.5
Standard Parallel 2	35.0
Latitude of Origin	31.25
Linear Unit	Foot (0.3048006096012192)

Table 3-2: Soil Water Balance Model Grid Dimensions

Parameter	Value
Columns	2,170
Rows	1,295
Lower-Left Corner Easting	3,500,000 Feet
Lower-Left Corner Northing	18,860,000 Feet
Cell Size	1,000 Feet

3.2 Soil & Water Assessment Tool

The Soil & Water Assessment Tool requires model input for weather, hydrology, and soil properties. The weather inputs include daily precipitation, maximum and minimum temperature, solar radiation, humidity, and wind speed. Hydrology is input using the digital elevation models, stream channel delineation, and land use/land cover data. While there are many overlaps on data requirements for the Soil Water Balance model, there is a distinct difference in the data input format. While Soil Water Balance model employs gridded input data for many of the inputs, the Soil & Water Assessment Tool models require the same data on a sub-basin level as defined by the appropriate hydrologic unit code delineation. For this project, the Hydrologic Unit Code-12 level delineation was selected for obtaining the recharge results on an appropriate resolution.

Akin to the Soil Water Balance model, the Soil & Water Assessment Tool also requires a lookup table with variables for each possible land use code and hydrologic soil group combination, and some of these options are built-in to the Soil & Water Assessment Tool's ArcGIS® interface for user convenience.

3.3 Groundwater Toolbox

Groundwater Toolbox reads and writes streamflow and site attribute data from files in the United States Geological Survey relational database file format. The streamflow and site attribute data were downloaded externally from the National Water Information Systems website and reformatted using Python, because the Groundwater Toolbox interface for downloading data was error prone.

Data for 336 stream gage stations were downloaded from the National Water Information System website. Of the 336 stations, 88 stations were removed due to having no complete months of streamflow data in the study time-period, 1981 through 2018, and 11 stations were removed due to data corruption or runtime errors in Groundwater Toolbox. Baseflow was calculated for the remaining 237 stations with acceptable data for Groundwater Toolbox.

Figure 3-2 summarizes the number of stations with complete monthly records, which includes the pre-development period (prior to 1981) and the post-development period (1981 through 2018). Figure 3-3 summarizes the number of stations with continuous data through 2018 for different starting years. For example, there are three stations with continuous data from 1919 through 2018, while 199 stations had continuous data in the year 2018.

Summary statistics were calculated for the station contributing regions (Table 3-3). Gage station drainage area statistics were calculated from the National Water Information System drainage area attribute. There were 27 stations with no drainage area value that are omitted from the statistics. Geographic information system tools were used to create summary statistics of the stream gage Hydrologic Unit Code-8 slope, well density, and geologic unit count. The analysis included stream gages from 60 counties and 45 Hydrologic Unit Code-8 boundaries, as shown in Table 3-4.

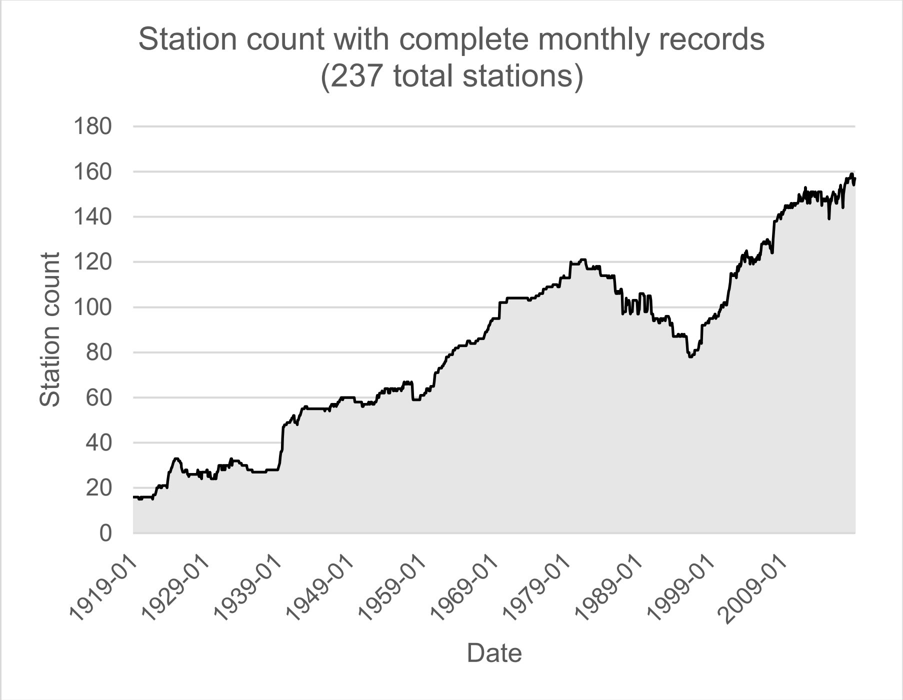


Figure 3-2: Time Series of Station Monthly Data Availability

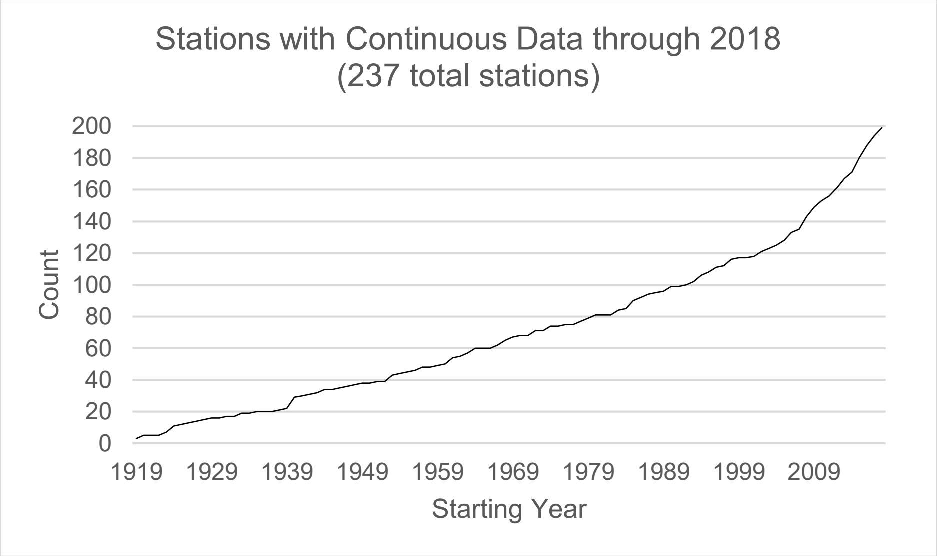


Figure 3-3: Count of Stations with Continuous Data by Starting Year

Table 3-3: Summary Statistics of the Gage Stations Contributing Area

	Mean	Median	Min	Max
Drainage Area* (mi^2)	3,235.9	227.0	0.2	44,015.0
Slope# (percent)	2.1	1.8	0.9	5.4
Well Density# (well/mi^2)	0.3	0.2	0.0	1.0
Geologic Units# (count)	19	18	13	32
*Calculated from the National Water Information System drainage area attribute #Summarized by Hydrologic Unit Code-8 subbasin				

Table 3-4: Counties and Hydrologic Unit Code-8 Boundaries with Streamflow Gage Stations

Unique Counties **60**	Atascosa	Bandera	Bastrop	Bexar	Blanco	Borden	Brewster	Brown
	Burnet	Caldwell	Coke	Coleman	Colorado	Comal	Concho	De Witt
	Dimmit	Edwards	Fisher	Frio	Gillespie	Gonzales	Guadalupe	Hays
	Howard	Irion	Jeff Davis	Jones	Karnes	Kendall	Kerr	Kimble
	Kinney	Lampasas	Live Oak	Llano	Loving	Mason	McCulloch	McMullen
	Medina	Menard	Mitchell	Pecos	Real	Reeves	Runnels	San Saba
	Scurry	Shackelford	Sterling	Taylor	Terrell	Tom Green	Travis	Uvalde
	Val Verde	Ward	Wilson	Zavala				
Hydrologic Unit Code-8 Subbasins **45**	12060102	12080002	12080007	12080008	12090101	12090102	12090103	12090104
	12090105	12090106	12090108	12090109	12090110	12090201	12090202	12090203
	12090204	12090205	12090206	12090301	12100201	12100202	12100203	12100301
	12100302	12100304	12110101	12110102	12110103	12110106	12110107	12110109
	12110110	13040205	13040208	13040302	13070001	13070003	13070005	13070007
	13070008	13070010	13070012	13080001				

3.4 Climate

PRISM Climate Group (PRISM, 2020) data was utilized for the climate data requirements. Specifically, we obtained gridded datasets for precipitation, minimum temperature, and maximum temperature for each day from January 1, 1981, through December 31, 2019. Each gridded PRISM dataset covers the conterminous United States with a resolution of approximately four kilometers. For the Soil Water Balance model, bilinear interpolation was used, after clipping each grid to the model domain, to resample the grid to the model grid resolution. For the Soil & Water Assessment Tool model, the PRISM data was resampled to Hydrologic Unit Code-12 sub-basin level and the input files were generated on a monthly averaged basis. Appropriate conversions were also conducted on the units of precipitation (millimeters to inches) and temperature (Celsius to Fahrenheit) as required by the Soil Water Balance model.

3.5 Land Use

For the Soil Water Balance model, we began by obtaining land use data for the conterminous United States for each year from 1930 through 2100 (Sohl and others, 2014; Sohl and others, 2016). The datasets provide 14 different land use classifications within our study area. To expand upon those 14 classifications, we used more recent gridded "Crop Data Layer" data for the years 2008 through 2019 developed by the United States Department of Agriculture National Agricultural Statistics Service (USDA-NASS, 2008-2019). The Crop Data Layer (also known as CropScape) provides a reasonable estimate of crop areas based on remote sensing methods along with the other land use classifications.

To use the Crop Data Layer grids for our study area, rather than using the grid for each year to define the crops and land use, we calculated the mode (that is, the value that occurs most often) at each pixel location from the twelve-year period available. By calculating the mode for each pixel location, we essentially determined the most common crop or other land type at that location over the last twelve years based on remote sensing analysis. While land use in some areas has certainly changed between 1981 and 2019, for the regional scale of the model a static representation of land use was sufficient for obtaining recharge estimates using the Soil Water Balance model. Figure 3-4 below illustrates the land use classification grid used for the Soil Water Balance model. A similar amalgamation method was used to create the Land Use grid for the Soil & Water Assessment Tool model which also stays constant through the simulation time period of January 1, 1981, through December 31, 2018.

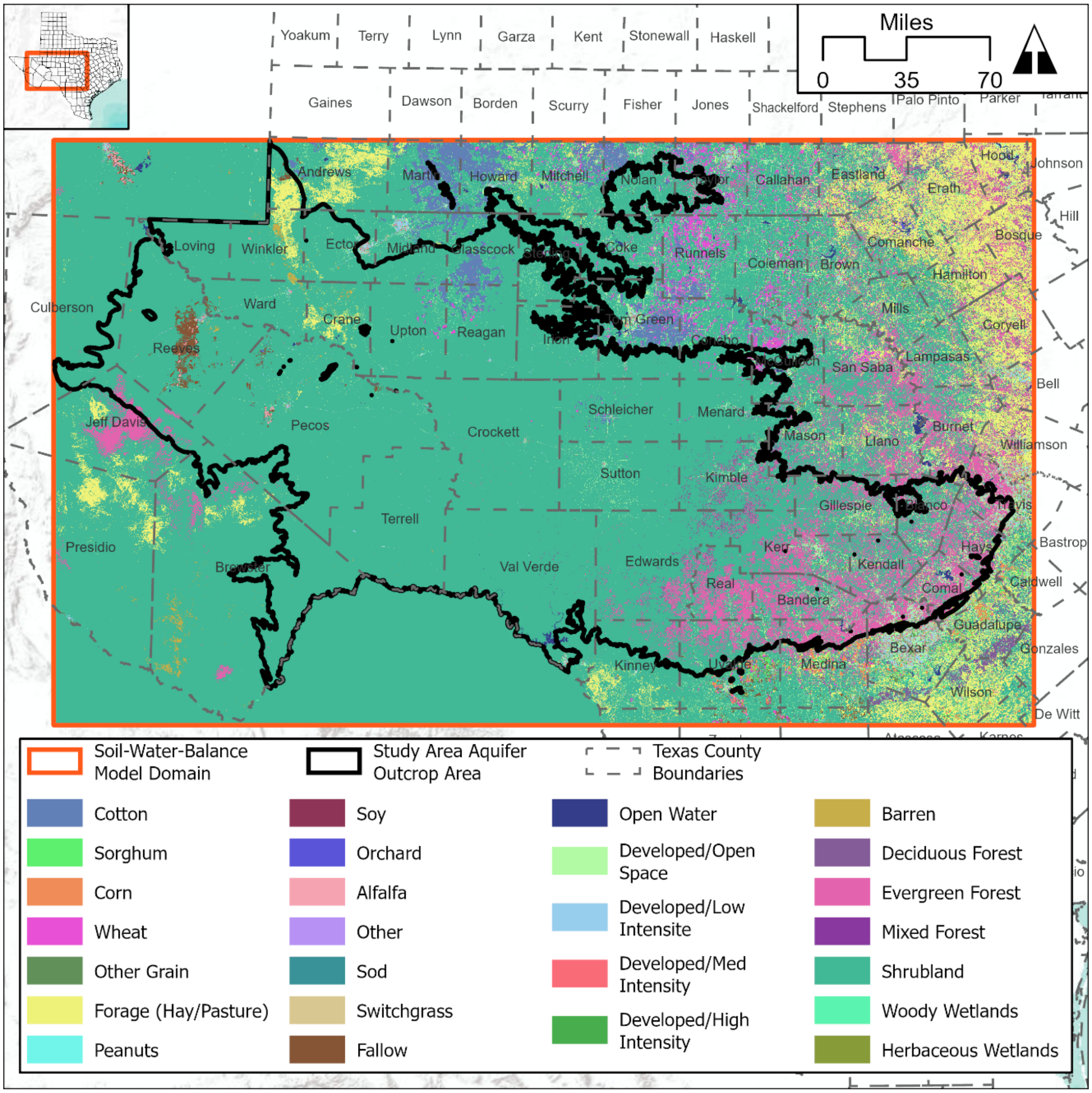


Figure 3-4: Land Use Classification Grid for the Soil Water Balance Model

3.6 Soils

For the Soil Water Balance model, the hydrogeologic soil group and soil available water capacity data from datasets available from the Natural Resources Conservation Service (USDA-NRCS, 2020) were utilized. We used the model grid dimensions to calculate the area of each cell that intersected a defined hydrogeologic soil group and assigned the group covering the most area of the cell as the single cell integer value. We used the same process to assign the soil available water capacity values as a real number to create a gridded dataset. Figure 3-5 illustrates the hydrologic soil group designations in the study area and Figure 3-6 illustrates the available water capacity for each Soil Water Balance model cell.

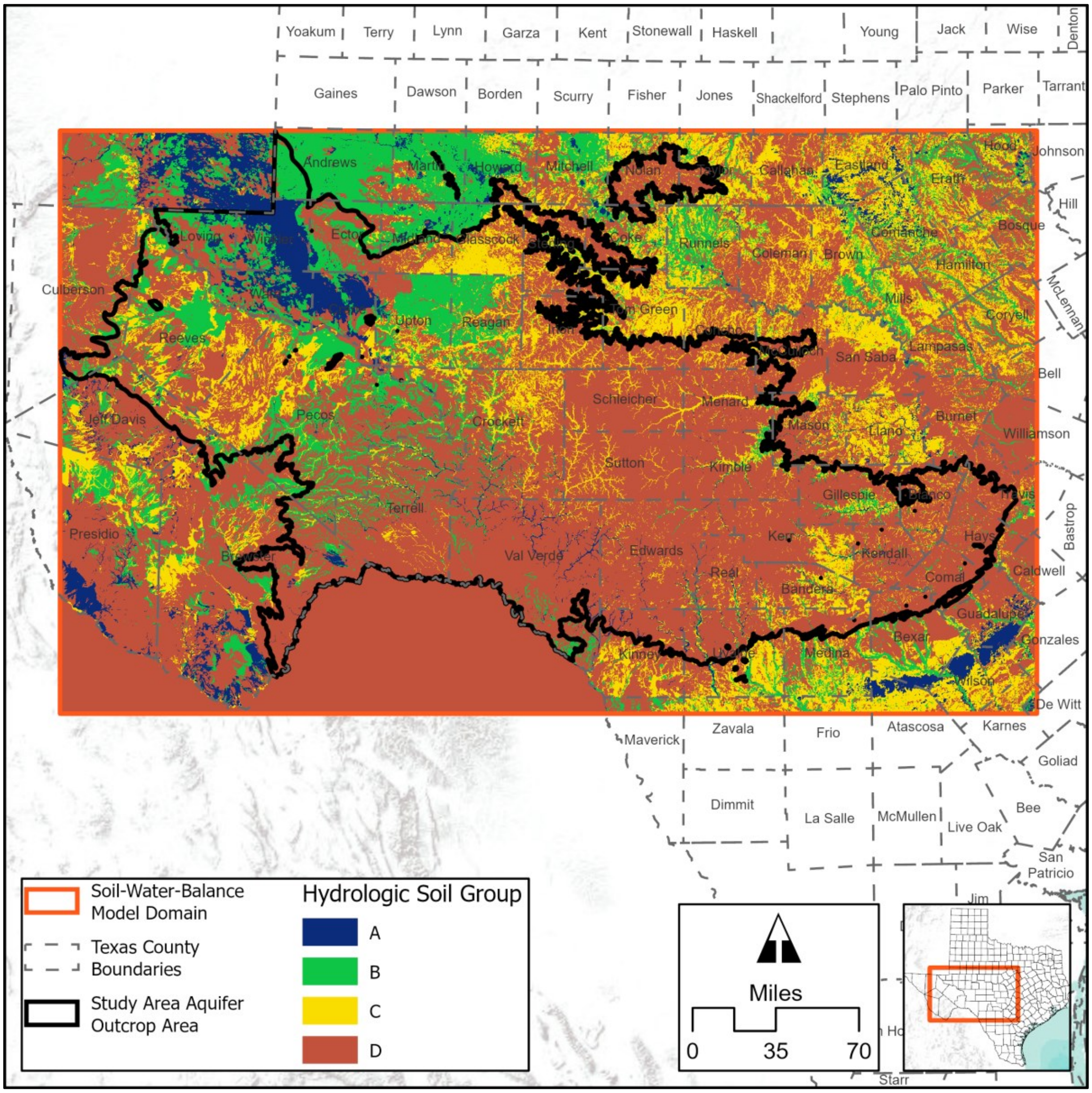


Figure 3-5: Hydrologic Soil Group (USDA-NRCS, 2020)

For both the hydrologic soil group and the available water capacity there are some areas with abrupt changes in the value along a county line. For example, as shown in Figure 3-5, the hydrologic soil group changes from B to C along the boundaries of Upton, Midland, Glasscock and Reagan counties. The available water capacity values appear to be more consistent though we do observe an abrupt change between McCulloch and San Saba counties. These changes along county lines appear to be a relic of the county-specific soil surveys.

For the Soil & Water Assessment Tool model, we used the built-in hydrogeological soil values that are sourced from the same dataset as the Soil Water Balance model (USDA-NRCS, 2020).

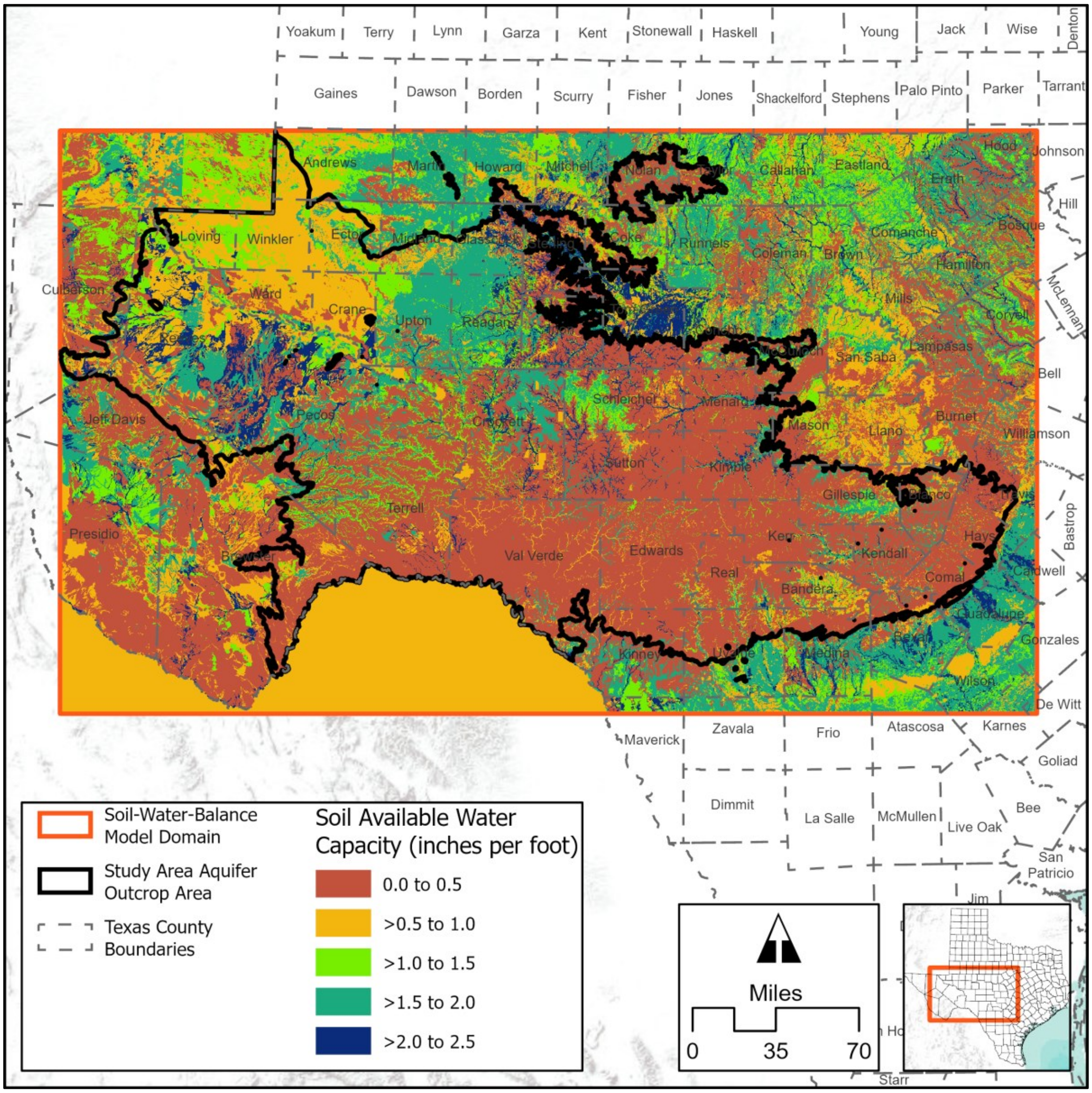


Figure 3-6: Soil Available Water Capacity (USDA-NRCS, 2020)

3.7 Topography

The physics of overland flow are determined by topography. To account for overland flow, the Soil & Water Assessment Tool uses the Digital Elevation Model, clipped to the watershed level, as a model input. However, the Soil Water Balance model uses the overland flow direction at each grid cell as a model input. The overland flow direction at each grid cell is derived from the Digital Elevation Model.

For the Soil Water Balance model, flow direction from one grid cell to another was derived by clipping a Digital Elevation Model for the study area and then resampling the land surface elevation values using bilinear interpolation to create a topography grid for the model domain.

To fill any sinks in the gridded topography input, geoprocessing tools available within ArcGIS® were used. The flow direction was finally calculated using the flow direction geoprocessing tool in ArcGIS®.

The flow direction grid uses integer values to define which direction flow would occur from a cell. These integer values allow the Soil Water Balance model code to route flow across the land surface. If precipitation is greater than the amount that the soil can absorb or is captured by evapotranspiration, then the flow direction value designates the direction in which outflow or runoff from the cell will occur. This runoff becomes a source of potential infiltration for the cell to which it flows.

3.8 Tabular Input

These model inputs are applicable only to the Soil Water Balance model. This is because the Soil & Water Assessment Tool simulates the processes for which these inputs are required by Soil Water Balance model. The tabular input includes information regarding the Natural Resources Conservation Service curve number, rooting depth, and maximum daily recharge specific to a land use classification and hydrologic soil group. Interception values during the growing and non-growing season are also included in the lookup table. In addition, the Soil Water Balance model code can use a soil moisture retention table for the calculations which does not require any user modification.

Table 3-5 lists the initial curve number values we assigned based on the Natural Resources Conservation Service publication "Urban Hydrology for Small Watersheds" (1986). For initial interception values during the growing season (Table 3-5), we used estimates developed by Horton (1919) and a value of zero for the non-growing season. We set initial maximum daily recharge values in Table 3-6 based on example Soil Water Balance model code input values. We defined initial rooting depth values, listed in Table 3-7 based on Foxx and others (1984) and Fan and others (2016).

Table 3-5: Soil Water Balance Model Land Use Runoff Curve Number Look Up Table

Land Use Code	Land Use Description	Runoff Curve Number per Soil Group				Interception	
		A	B	C	D	Growing Season	Non-Growing Season
1	Cotton	61	73	81	84	0.03	0
2	Sorghum	30	58	71	78	0.03	0
3	Corn	65	75	82	86	0.03	0
5	Wheat	30	58	71	78	0.03	0
6	Other Grain	30	58	71	78	0.03	0
7	Forage (Hay/Pasture)	30	58	71	78	0.03	0
8	Peanuts	67	78	85	89	0.03	0
9	Soy	67	78	85	89	0.03	0
11	Orchard	30	55	70	77	0.03	0
12	Alfalfa	30	58	71	78	0.03	0
15	Other	65	75	82	86	0.03	0
59	Sod/Grass Seed	30	58	71	78	0.03	0
60	Switchgrass	30	58	71	78	0.03	0
61	Fallow/Idle Cropland	77	86	91	93	0	0
111	Open Water	100	100	100	100	0	0
121	Developed/Open Space	49	69	79	84	0	0
122	Developed/Low Intensity	67	78	85	89	0	0
123	Developed/Med Intensity	77	85	90	92	0	0
124	Developed/High Intensity	89	92	94	95	0	0
131	Barren	74	83	88	90	0	0
141	Deciduous Forest	30	55	70	77	0.08	0
142	Evergreen Forest	30	55	70	77	0.08	0
143	Mixed Forest	30	55	70	77	0.08	0
152	Shrubland	35	56	70	77	0.05	0
190	Woody Wetlands	30	48	65	73	0	0
195	Herbaceous Wetlands	30	58	71	78	0	0

Table 3-6: Soil Water Balance Model Maximum Recharge Look Up Table

Land Use Code	Land Use Description	Maximum Recharge per Soil Group, Inches per Day			
		A	B	C	D
1	Cotton	4	0.6	0.24	0.12
2	Sorghum	4	0.6	0.24	0.12
3	Corn	4	0.6	0.24	0.12
5	Wheat	4	0.6	0.24	0.12
6	Other Grain	4	0.6	0.24	0.12
7	Forage (Hay/Pasture)	4	0.6	0.24	0.12
8	Peanuts	4	0.6	0.24	0.12
9	Soy	4	0.6	0.24	0.12
11	Orchard	4	0.6	0.24	0.12
12	Alfalfa	4	0.6	0.24	0.12
15	Other	4	0.6	0.24	0.12
59	Sod/Grass Seed	4	0.6	0.24	0.12
60	Switchgrass	4	0.6	0.24	0.12
61	Fallow/Idle Cropland	4	0.6	0.24	0.12
111	Open Water	4	0.6	0.24	0.12
121	Developed/Open Space	4	0.6	0.24	0.12
122	Developed/Low Intensity	4	0.6	0.24	0.12
123	Developed/Med Intensity	4	0.6	0.24	0.12
124	Developed/High Intensity	4	0.6	0.24	0.12
131	Barren	4	0.6	0.24	0.12
141	Deciduous Forest	4	0.6	0.24	0.12
142	Evergreen Forest	4	0.6	0.24	0.12
143	Mixed Forest	4	0.6	0.24	0.12
152	Shrubland	4	0.6	0.24	0.12
190	Woody Wetlands	4	0.6	0.24	0.12
195	Herbaceous Wetlands	4	0.6	0.24	0.12

Table 3-7: Soil Water Balance Model Rooting Depth Look Up Table

Land Use Code	Land Use Description	Rooting Depth per Soil Group, Feet			
		A	B	C	D
1	Cotton	3.05	3.05	3.05	3.05
2	Sorghum	3.05	3.05	3.05	3.05
3	Corn	3.05	3.05	3.05	3.05
5	Wheat	3.41	3.41	3.41	3.41
6	Other Grain	3.05	3.05	3.05	3.05
7	Forage (Hay/Pasture)	2.09	2.09	2.09	2.09
8	Peanuts	2.79	2.79	2.79	2.79
9	Soy	4.53	4.53	4.53	4.53
11	Orchard	30	30	30	30
12	Alfalfa	4.45	4.45	4.45	4.45
15	Other	3.05	3.05	3.05	3.05
59	Sod/Grass Seed	2.09	2.09	2.09	2.09
60	Switchgrass	2.09	2.09	2.09	2.09
61	Fallow/Idle Cropland	1.13	1.13	1.13	1.13
111	Open Water	0	0	0	0
121	Developed/Open Space	2.5	2.5	2.5	2.5
122	Developed/Low Intensity	1.5	1.5	1.5	1.5
123	Developed/Med Intensity	1.5	1.5	1.5	1.5
124	Developed/High Intensity	1.5	1.5	1.5	1.5
131	Barren	1.5	1.5	1.5	1.5
141	Deciduous Forest	30	30	30	30
142	Evergreen Forest	30	30	30	30
143	Mixed Forest	30	30	30	30
152	Shrubland	2.50	2.50	2.50	1.67
190	Woody Wetlands	3.38	3.38	3.38	3.38
195	Herbaceous Wetlands	3.38	3.38	3.38	3.38

3.9 TexMesnoet/MesoWest Data

As Equation 1 indicates, change in soil moisture is a key parameter for the estimation of recharge. TexMesonet began collecting data in May 2016 (TWDB, 2021) and currently operates several stations that collect soil moisture measurements within the study area. In addition, there are hundreds of stations operated by other entities collecting climate parameter measurements across the study area and these data are available through MesoWest (University of Utah, 2021). Figure 3-7 illustrates the location of the MesoWest stations, which includes those stations operated by the TWDB.

In the study area, 59 stations were identified to have measurements of air temperature, relative humidity, solar radiation, and wind speed which can be used to calculate reference evapotranspiration. Thirty-two of the 59 stations are also collecting soil moisture measurements. During further calibration simulations of the Soil Water Balance model, measurements from these stations were used, as appropriate, to guide modification of input parameters such as the root-zone depth and parameters of the Hargreaves-Samani reference evapotranspiration equation (Hargreaves and Samani, 1985). The TexMesonet data were also used for comparative analysis of the Soil & Water Assessment Tool model results.

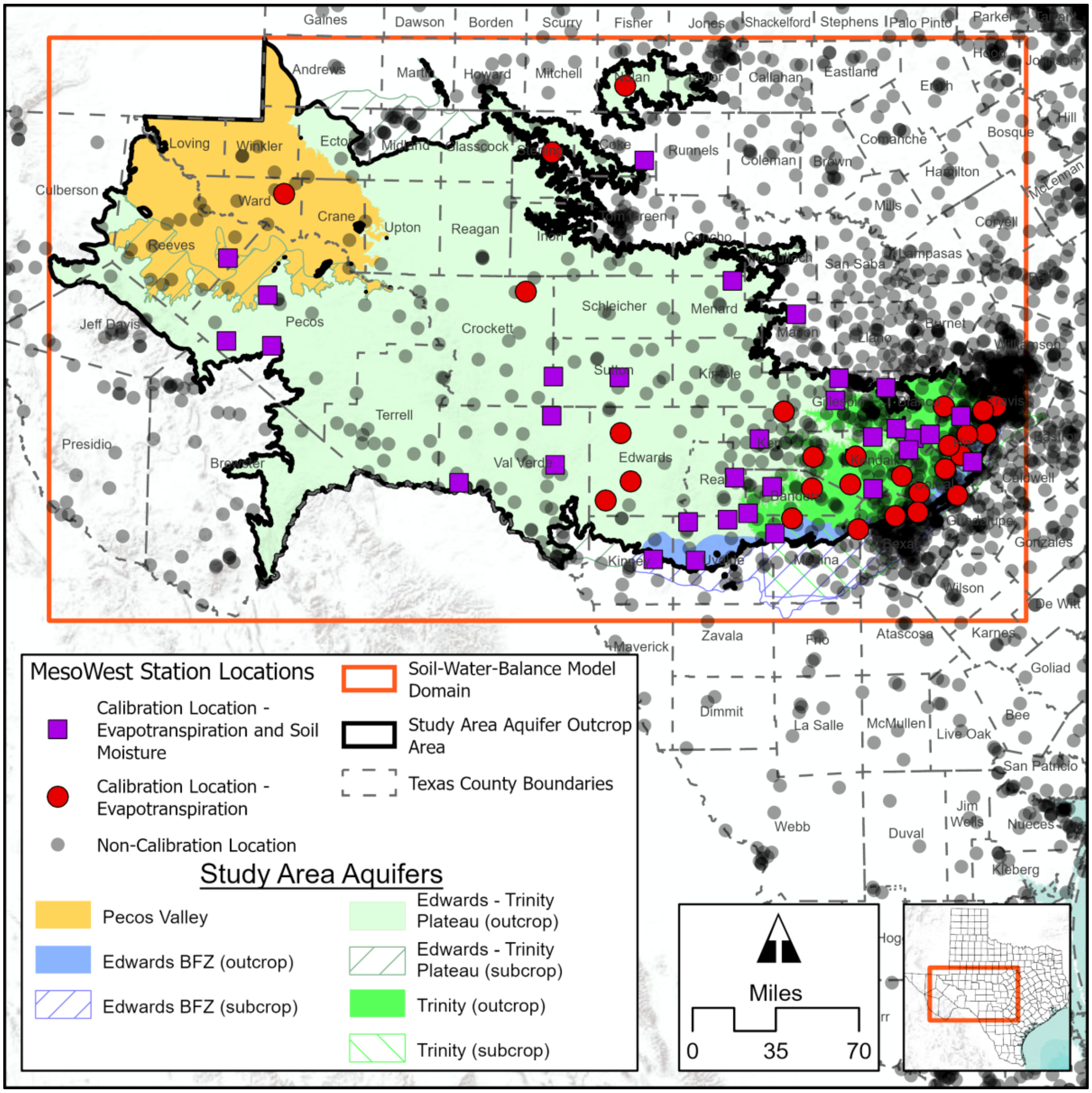


Figure 3-7: MesoWest Station Locations (University of Utah, 2021) and Identification of Sites Used for Soil Water Balance Model Calibration.

3.10 Surface Water Losses and Diversions

Surface water losses and diversions were primarily assumed to be due to a) surface water takings through permitted water rights, and through b) streamflow losses due to shallow groundwater pumping close to major and minor river channels. The background, data sources, methodology and results for both a) and b) are provided in this section.

3.10.1 Surface Water Takings

The use of surface water in Texas is regulated through a system of water rights (Water Rights, Texas Commission on Environmental Quality). The Texas Commission on Environmental Quality maintains a water use database which contains information on water rights, amount of water appropriated, ownership, and annual water use. The data is available from early 1925 to 2014. The water-use water rights data shows the amount of water used by water right holders in non-water master areas of the state. This information is updated each year but publicly available only through the year 2014. The data is segregated on the basis of river basins. Figure 3-8 shows the river basins within the project study area boundary.

The objective of this task is to estimate surface water diversions from the various streams within the project study area. These estimated results will be provided as water loss inputs to the Soil & Water Assessment Tool models to capture the impact of these diversions on the physical system.

The project team used the Water use Water rights data from The Texas Commission on Environmental Quality. The data has information about the volume of water used by water-right holders in non-water master areas of the state. The data also provides information about the water use number, water use type, appropriated use of the water-rights and the river basin where the water-right is located. For each year, water-use data such as monthly diverted flow and return flow is reported in acre-feet. Figure 3-9 presents the water rights river basin control points within our study boundary.

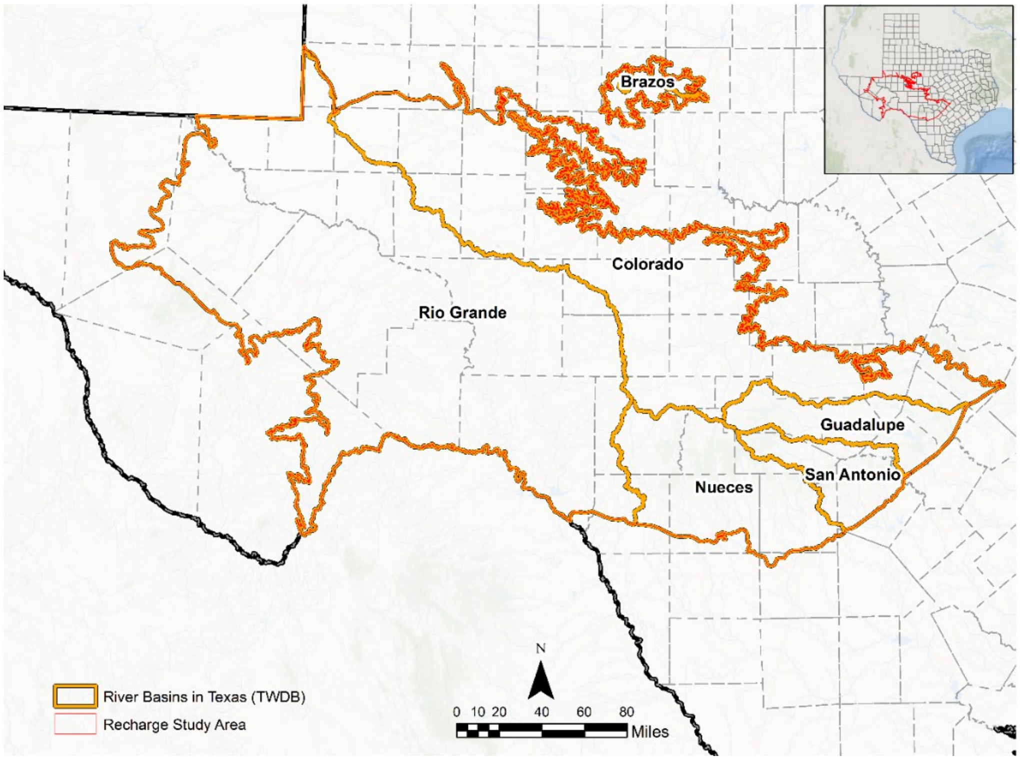


Figure 3-8: River Basins Within the Study Area

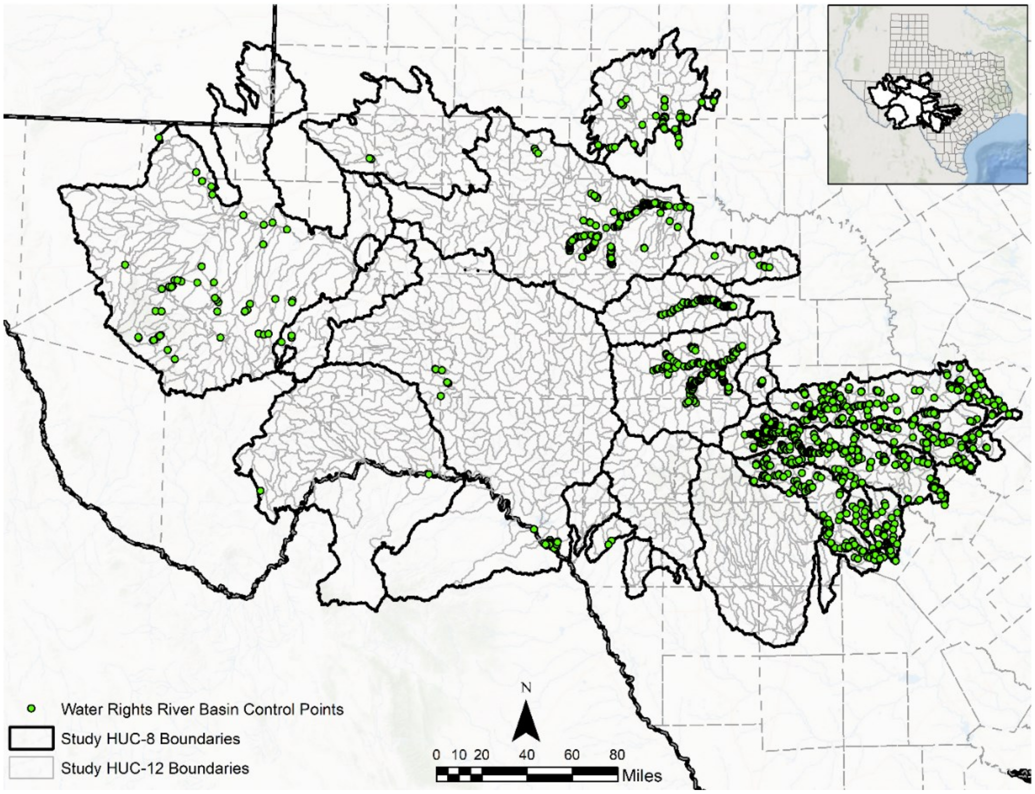
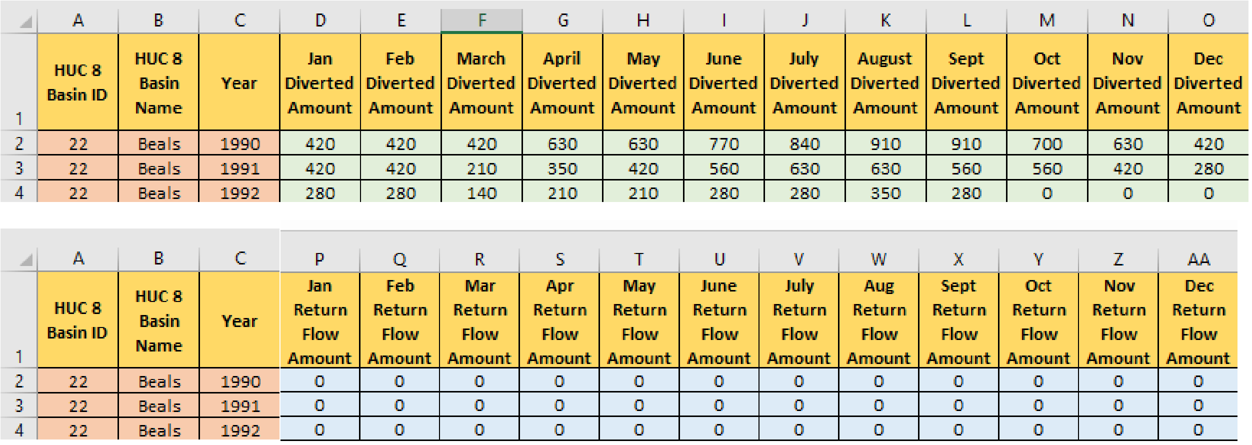


Figure 3-9: Water Rights River Basin Control Points Within the Study Area

Table 3-8 is a snippet from the final output worksheet "Processed_AggregatedData_BasinSum_MonthlyforEachYear.xlsx". Column A represents the Hydrologic Unit Code- 8 Basin ID, Column B represents the Hydrologic Unit Code- 8 Basin name, Column D to O shows the monthly diverted amount in Acre-feet for each basin and Column P to AA shows the monthly return flow in acre-feet for each basin. The zero value could indicate either a no-diversion flow or a non-reported value. The complete table is available as part of the data deliverables and summarizes the surface water takings for each month of the year where data is available.

Table 3-8: Example of Surface Water Takings Each Year for Each Study Hydrologic Unit Code-8 Basins



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	HUC 8 Basin ID	HUC 8 Basin Name	Year	Jan Diverted Amount	Feb Diverted Amount	March Diverted Amount	April Diverted Amount	May Diverted Amount	June Diverted Amount	July Diverted Amount	August Diverted Amount	Sept Diverted Amount	Oct Diverted Amount	Nov Diverted Amount	Dec Diverted Amount
2	22	Beals	1990	420	420	420	630	630	770	840	910	910	700	630	420
3	22	Beals	1991	420	420	210	350	420	560	630	630	560	560	420	280
4	22	Beals	1992	280	280	140	210	210	280	280	350	280	0	0	0

	A	B	C	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1	HUC 8 Basin ID	HUC 8 Basin Name	Year	Jan Return Flow Amount	Feb Return Flow Amount	Mar Return Flow Amount	Apr Return Flow Amount	May Return Flow Amount	June Return Flow Amount	July Return Flow Amount	Aug Return Flow Amount	Sept Return Flow Amount	Oct Return Flow Amount	Nov Return Flow Amount	Dec Return Flow Amount
2	22	Beals	1990	0	0	0	0	0	0	0	0	0	0	0	0
3	22	Beals	1991	0	0	0	0	0	0	0	0	0	0	0	0
4	22	Beals	1992	0	0	0	0	0	0	0	0	0	0	0	0

3.10.2 Streamflow Depletion Due to Shallow Groundwater Pumping

Shallow groundwater pumping near major and minor river channels might cause reduction in streamflow. In this section, we estimate the streamflow depletion occurring from shallow pumping wells that are located close to major and minor rivers. The team is mainly considering the major and minor rivers because these are the channels most likely to be impacted on a daily basis from shallow pumping throughout the year. Other ephemeral channels may also get impacted by shallow pumping but not throughout the year and moreover they do not contribute daily to the flow in major and minor rivers where most of the stream gages exist from which we obtained the calibration data we aim to correct for surface water losses.

For this study, we identified pumping wells with a depth to the top of the screen of up to 200 feet below ground surface that are no more than 0.5 miles from the stream channels within the recharge study area sub watersheds. Using these wells, we may determine if these wells are potentially impacting the stream flow. This analysis is done with varying distances from these stream channels for a more elaborate understanding. A key step in this study includes identifying these shallow pumping wells and categorizing them based on two important factors - distance from the closest stream and depth from ground surface.

Following the identification and categorization (by distance from stream channel and depth of the well) of shallow pumping wells, the next step is to identify the estimated pumpage volumes of these shallow wells. To estimate the pumpage volumes, pumping capacity values associated with the wells were obtained from the Groundwater Database and from Submitted Drillers Reports database. By performing this analysis, we can determine the impact of pumping on the stream channel flow. There are various analytical and numerical modeling methods for estimating the effects of groundwater pumping on streamflow. For our analysis, we used Glover's analytical approach to estimate streamflow depletion as described by Barlow and Leake (2012). The data collection and computations are explained briefly in the following sections.

3.10.2.1 Data Sources for Streamflow Depletion

The project team used TWDB well databases to obtain information on the shallow wells. We used the data from Groundwater Database and the Submitted Drillers Reports Database. Our objective of the study is to find the number of shallow wells near the major and minor streams within the study area's twenty-six sub watersheds. For this purpose, we identified wells with screens within the upper 200 feet from ground level. These are considered shallow wells. Table 3-9 shows the total shallow well counts within the study area from Groundwater Database and from the Submitted Drillers Reports Database. As shown in the table, we filtered out 3,924 pumping shallow wells within the study boundary.

Table 3-9: Total Well Counts Within Our Study Area from Groundwater Databases and From Submitted Drillers Reports Database

Well Counts	Total number of Groundwater Database Wells within the Recharge Study	Total number of Submitted Drillers Report Wells within the Recharge Study	Total Wells within Recharge Study
Wells Within One-Half Mile Radius	**1,349**	**2,575**	**3,924**

3.10.2.2 Methodology

After extracting the wells from Groundwater Database and from Submitted Drillers Reports database within our study area, the next step was to identify the wells within one-half mile from the streams within the study area boundaries. We obtained the wells from three different distances from the streams within one-eighth mile, one-eighth mile to one-quarter mile, and one-quarter mile to one-half mile. This was done to understand the well distributions at various distances. Spatial analysis was performed in ArcGIS software to accomplish the task and as a result, the shallow well counts were obtained. The streams data from each of the twenty-six major sub watersheds were merged together to obtain the complete streams data for the entire TWDB recharge area.

3.10.2.3 Glover's Method

We used Glover's analytical approach (Glover and Balmer, 1954; Glover, 1974) to estimate streamflow depletion as described by Barlow and Leake (2012).

$$\boldsymbol{Q_s = Q_w\, erfc(Z)} \qquad \textbf{(Equation 11)}$$

Glover's method provides an expression for the total rate of streamflow depletion as a function of time (defined mathematically as Q_s) and is equal to the product of the pumping rate of the well, Q_w, and a mathematical function referred to as the complementary error function, *erfc(Z)*.

Variable Z in this equation is equal to:

$$\boldsymbol{Z} = \sqrt{d^2 \frac{S}{4Tt}} \qquad \textbf{(Equation 12)}$$

where, d is the shortest distance between the well to the stream, S is the storage coefficient of the aquifer (or specific yield, for water-table aquifers), T is the transmissivity of the aquifer, and t is the time.

The groundwater well information was obtained from the TWDB Groundwater Database and the Submitted Drillers Reports database. The pumpage values and the year on which the wells went active were obtained from TWDB groundwater database. For the distance between the well and the stream (d), the horizonal distance based on the depth of the well and lateral distance between the well and the stream has been used.

We estimated streamflow depletion for pumping associated with various water use case scenarios such as low, medium, and high. Pumping assumptions are applied based on water use type. Figure 3-10 shows the distribution of the wells within the study based on water use type associated with the wells. The domestic supply wells contribute to around 54 percent of total wells used in the analysis. Appendix A shows the total well counts by water use within each watershed. Appendix B shows the well counts by water use within each county.

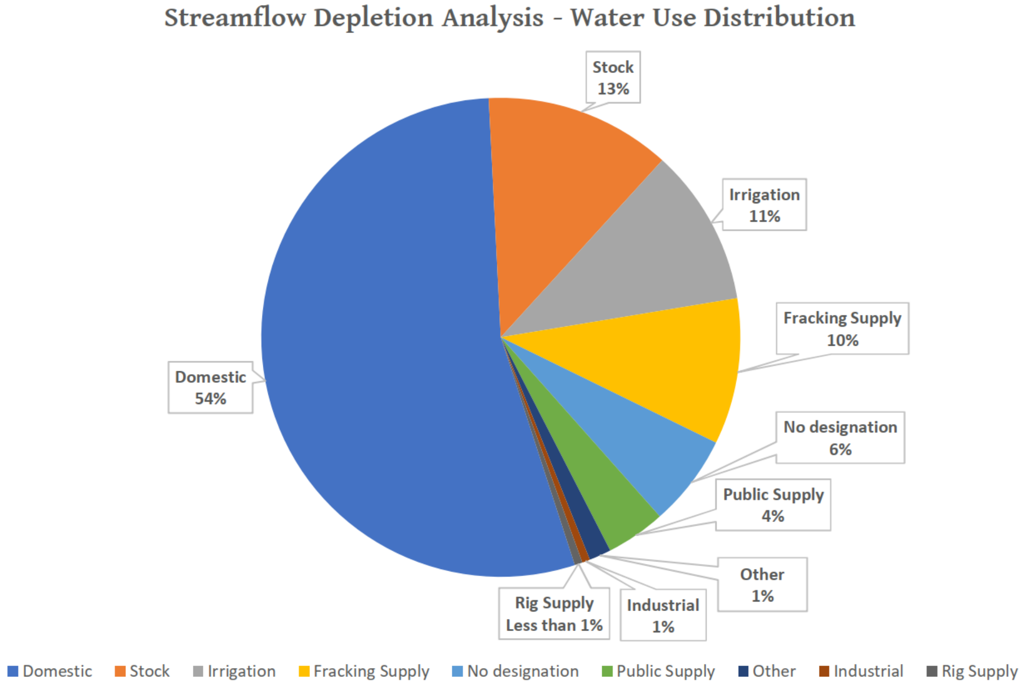


Figure 3-10: Pie Chart Showing the Water Use Distribution of the Wells Within the Study Area

For computing the streamflow depletion volumes, we used three different water use scenarios to understand how much pumping occurred from the wells. We assumed three different water use scenarios as Low, Medium, and High pumping estimates as shown in the below Table 3-10.

Table 3-10: Water Use Scenarios for Different Water Use Type with Pumping Time

Well Use	Pumpage	Low	Med	High	Median selection	Low Selection	High Selection
Other - treat same as no designation	2 AFY	33%	50%	75%	1 AFY avg	50% less	50% more
Domestic - 2 Acre feet fixed	2 AFY	33%	50%	75%	1 AFY avg	50% less	50% more
Stock	2 AFY	33%	50%	75%	1 AFY avg	50% less	50% more
no designation- 2 Acre feet fixed	2 AFY	33%	50%	75%	1 AFY avg	50% less	50% more
Fracking Supply	Avg yield in aquifer+watershed	22%	33%	50%	8 hrs a day	50% less	50% more
Industrial	Avg yield in aquifer+watershed	22%	33%	50%	8 hrs a day	50% less	50% more
Irrigation	Avg yield in aquifer+watershed	7%	10%	15%	4 months a year, 8 hrs a day	50% less	50% more
Rig Supply	Avg yield in aquifer+watershed	22%	33%	50%	8 hrs a day	50% less	50% more
Public Supply	Avg yield in aquifer+watershed	44%	66%	99%	16 hrs a day	50% less	50% more

The streamflow depletion computation was performed in a spreadsheet and the following assumptions were used to fill in the data gaps.

- Within the recharge study area for the wells with available pumping data in the TWDB database, the average well production for each well designation was obtained based on average yield value within the aquifer and watershed.
- For *S* (storage coefficient) and *T* (transmissivity) values, the team used values from various groundwater availability models. Table 3-11 shows the specific yield and transmissivity values used for the streamflow computations for various study aquifers.

Table 3-11: Specific Yield and Transmissivity Values Used for the Streamflow Computations for Various Study Aquifers

Aquifer	Specific Yield (-)	Transmissivity (ft^2/day)
Carrizo	0.2	8,850
Cross Timbers	0.1	4,425
Edwards	0.2	100,000
Edwards-Trinity	0.08	2,195
Lipan	0.05	207
Pecos Valley	0.12	2,358
Trinity	0.1	132

3.10.2.4 Streamflow Depletion Results

Figure 3-11 presents the streamflow depletion rate in acre-feet per year (AFY) for each study well estimated by Glover's method within the study considering medium pumping scenario. Table 3-12 provides a snippet of the results showing streamflow depletion from wells for each sub-basin within each major watershed within the study area. The streamflow depletion is aggregated for three different water use scenarios for input into the Soil & Water Assessment Tool model. The complete table has been provided as part of the data deliverables.

3.11 Rapid Recharge Assessment Tool (Based on Soil Conservation Services Curve Number Method)

Datasets developed for the Soil Water Balance model were used as model inputs for the Soil Conservation Services method. In particular, the ESRI ASCII raster files for minimum and maximum temperature were used to calculate the evapotranspiration while the precipitation grids were used for rainfall. Base curve numbers associated with land use and soil type were from the Soil Conservation Service and modified per Table 2-5.

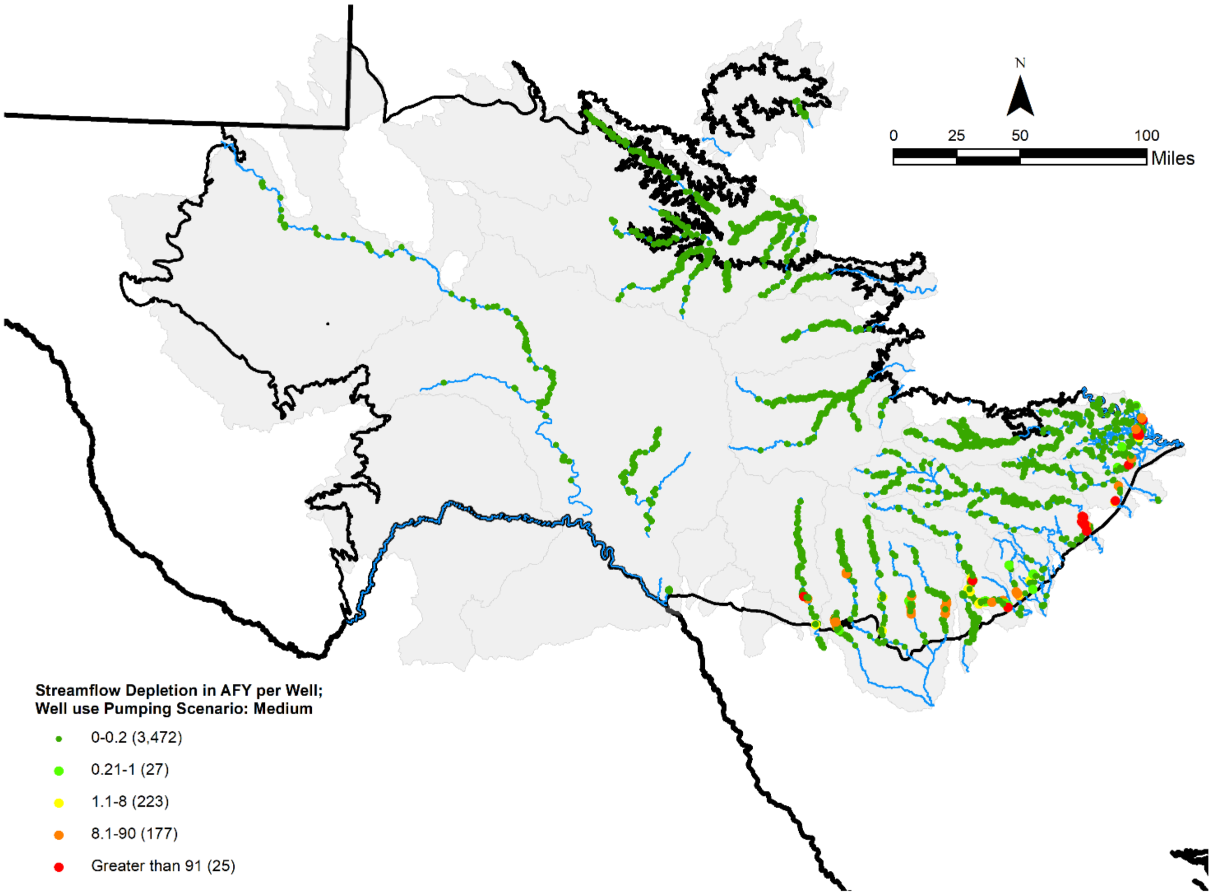
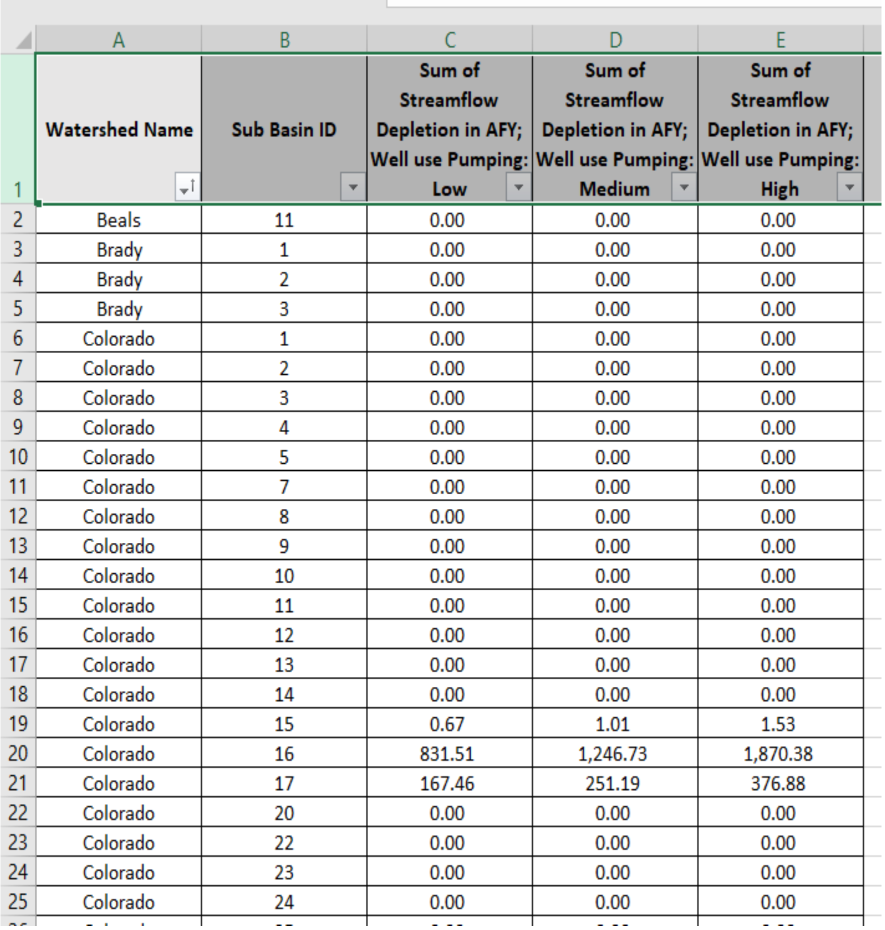


Figure 3-11: Streamflow Depletion Rate in Acre-Feet per Year per Well Estimated by Glover's Analytical Solution within the Study Area

Table 3-12: Example Summary of the Streamflow Depletion Analysis Due to Pumping for Each Sub-Basins Within the Study Area



	A	B	C	D	E
1	**Watershed Name**	**Sub Basin ID**	**Sum of Streamflow Depletion in AFY; Well use Pumping: Low**	**Sum of Streamflow Depletion in AFY; Well use Pumping: Medium**	**Sum of Streamflow Depletion in AFY; Well use Pumping: High**
2	Beals	11	0.00	0.00	0.00
3	Brady	1	0.00	0.00	0.00
4	Brady	2	0.00	0.00	0.00
5	Brady	3	0.00	0.00	0.00
6	Colorado	1	0.00	0.00	0.00
7	Colorado	2	0.00	0.00	0.00
8	Colorado	3	0.00	0.00	0.00
9	Colorado	4	0.00	0.00	0.00
10	Colorado	5	0.00	0.00	0.00
11	Colorado	7	0.00	0.00	0.00
12	Colorado	8	0.00	0.00	0.00
13	Colorado	9	0.00	0.00	0.00
14	Colorado	10	0.00	0.00	0.00
15	Colorado	11	0.00	0.00	0.00
16	Colorado	12	0.00	0.00	0.00
17	Colorado	13	0.00	0.00	0.00
18	Colorado	14	0.00	0.00	0.00
19	Colorado	15	0.67	1.01	1.53
20	Colorado	16	831.51	1,246.73	1,870.38
21	Colorado	17	167.46	251.19	376.88
22	Colorado	20	0.00	0.00	0.00
23	Colorado	22	0.00	0.00	0.00
24	Colorado	23	0.00	0.00	0.00
25	Colorado	24	0.00	0.00	0.00

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4. Groundwater Recharge Estimates

The three identified models were set-up with the input data as discussed in Chapter 3. However, the model application process differed in each case. The key nuances for each model's setup are described below along with representative results.

4.1 Soil Water Balance Model

The extent of the Soil Water Balance model is shown in Figure 3-1. The following provides the details related to the Soil Water Balance model developed to estimate potential infiltration below the soil zone in the study area.

4.1.1 Soil Water Balance Model Set Up

To execute the Soil Water Balance model for the study area, a control file was prepared identifying the required input data discussed in Chapter 3 along with the optional input parameters and output options. Figure 4-1 is a diagram illustrating the input parameters and general calculations of the Soil Water Balance model.

March 15 through October 15 of each year was used as the growing season. The growing season defines whether the code will apply growing season or non-growing season interception amounts to a grid cell. Precipitation amounts must exceed the interception amount before the code will use the precipitation as an input to the soil moisture calculation.

The Hargreaves-Samani (1985) equation was used for estimating evapotranspiration with the southern latitude of 28.908783°N and a northern latitude of 32.5379028°N. These bounding latitude values are used within the code to calculate extraterrestrial radiation. Equation 13 is the Hargreaves-Samani (1985) equation as implemented in the Soil Water Balance model code.

$$\boldsymbol{ET_0} = \frac{\boldsymbol{a \times R_a \times (T_{avg} + b) \times (T_{max} - T_{min})^c}}{\mathbf{25.4}} \qquad \textbf{(Equation 13)}$$

Where:

$ET_0 = reference\ evapotranspiration, inches$

$R_a = extraterrestrial\ radiation, millimeters\ per\ day$

$T_{avg} = average\ air\ temperature, °C$

$T_{max} = maximum\ air\ temperature, °C$

$T_{min} = minimum\ air\ temperature, °C$

$a, b, \&\ c = empirical\ coefficients\ (default =\ 0.0023, 17.8, and\ 0.5, respectively)$

The initial soil moisture was set at a constant value of 50 percent to use the first year of the simulation as a "warm up" period for the model. Subsequent years of the model simulation provide more reliable results. The total simulation time was from January 1, 1981, through December 31, 2019.

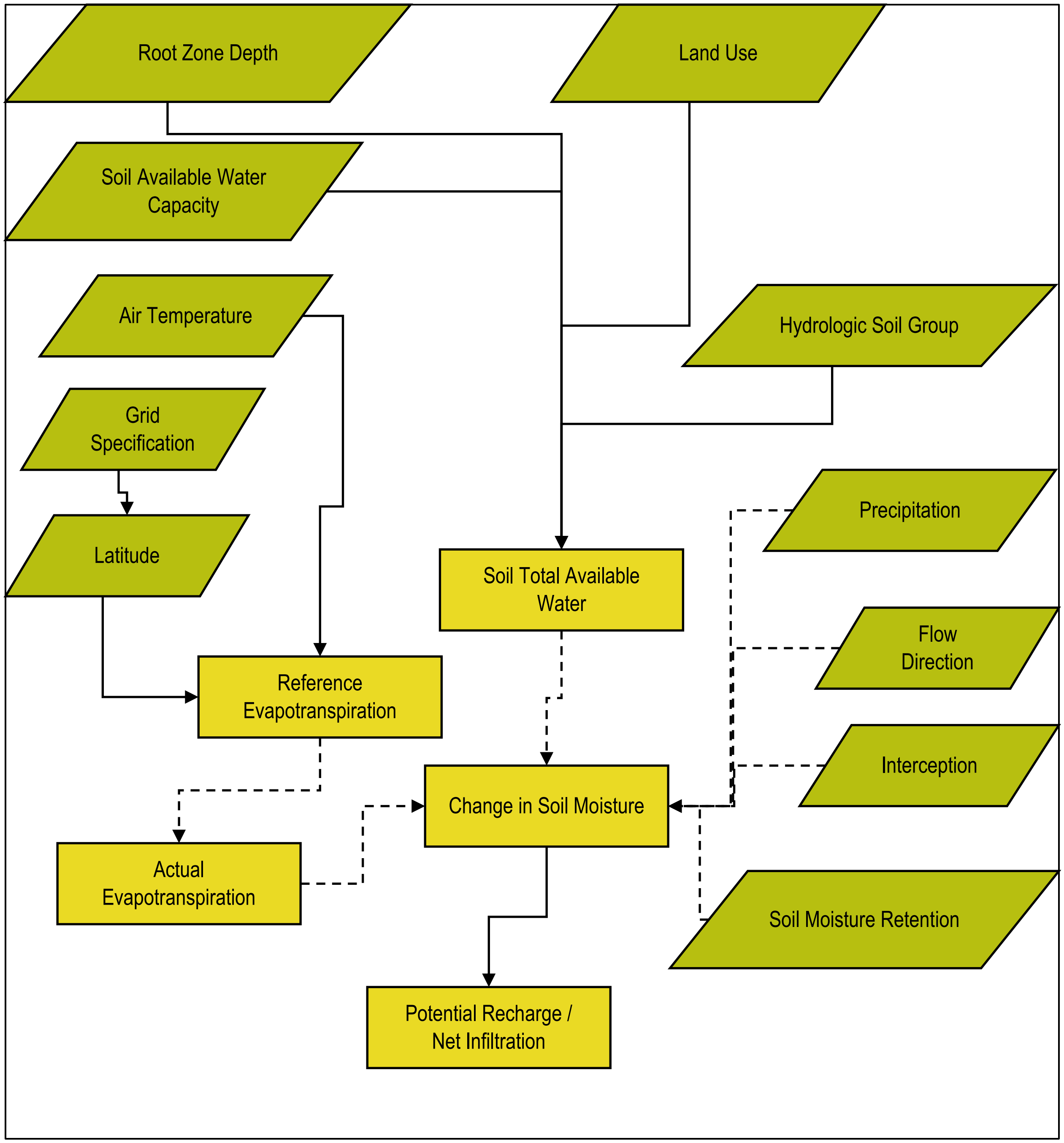


Figure 4-1: Diagram of input data and calculations for the Soil Water Balance model

The simulations were conducted using a computer system running the Windows 10 Pro operating system, with 3.79 gigahertz AMD Ryzen 9 3900X 12-Core Processor and 32.0 gigabytes of random-access memory in the system. Total simulation time for the model was 7,819 minutes (more than 130 hours) using approximately 1.3 gigabytes of random-access memory.

4.1.2 Soil Water Balance Model Calibration

To calibrate the Soil Water Balance model, we adjusted the root zone depths and runoff curve numbers associated with each land use type and hydrologic soil group along with parameters of the Hargreaves-Samani equation for calculating reference evapotranspiration. We focused calibration on the years 2017 through 2019 due to the availability of soil moisture data from discreet measurements at MesoWest station locations (see Figure 3-7). While data from remote sensing are available for earlier years (for example, Soil Moisture Active Passive), these data are available at a coarser scale than the Soil Water Balance model and may not capture the variability in the ground-based measurements (Zhang and others, 2017).

4.1.2.1 Measured Data Processing

There are multiple soil moisture measurements per day available for each station. The measurements are provided as the percent soil moisture at a specified depth. To develop a calibration dataset, we calculated the average percent soil moisture for each day at the deepest interval (typically 50 centimeters or about 20 inches). For days with no data,the team did not include the day within the calibration dataset.

From the daily soil moisture value, we also calculated the absolute value of the daily change in soil moisture, the absolute value of the change in soil moisture relative to first available measurement, and the absolute value of the change between extrema (that is, between the highs and lows in the measured data). We used these calculated values as additional soil moisture calibration targets for the Soil Water Balance model.

We also calculated the daily reference evapotranspiration using the Penman-Monteith equation (Allen and others, 1998). The team performed these calculations using data collected at the MesoWest stations and the evapotranspiration Python package (Roehrig and Villegas, 2021). Data necessary to calculate the reference evapotranspiration are the station elevation and latitude, measurement date, and daily minimum and maximum temperature, average wind speed, minimum and maximum relative humidity, and solar radiation. For days without measurements, the team did not include that day in the calibration dataset. However, if only the solar radiation data were missing, or those data were not collected at a station, we used the Astral Python package to estimate the solar radiation at the station location.

4.1.2.2 Calibration Parameters

Using the daily soil moisture and reference evapotranspiration datasets, our calibration focus was on improving estimates of root zone depth associated with the land use and hydrologic soil groups. The Soil Water Balance model provides soil moisture results in inches based on the depth of the root zone for the land use and hydrologic soil group. By dividing the model results for daily soil moisture by the root zone depth associated with the station location, the match between soil moisture model results and measured values of percent soil moisture can be improved. While there is only a relatively short period during which soil moisture data are available, the calibrated root zone depth values may be used throughout the study period.

During initial testing, in addition to the root zone depth values, we also calibrated the parameters of the Hargreaves-Samani reference evapotranspiration equation (Hargreaves and Samani, 1985).

Specifically, we tested refining the a, b, and c coefficients in the Hargreaves-Samani evapotranspiration equation. For the initial Hargreaves-Samani equation coefficient estimates, we began with values of 0.00138, 24.49, and 0.685 for the a, b, and c coefficients in Equation 14 which Awal and others (2020) have shown to improve the estimate of reference evapotranspiration in West Texas. We applied these initial coefficient values using undocumented features of the Soil Water Balance model (Westenbroek, 2021) and then tested calibrating the values through comparison of the simulation results with calculated reference evapotranspiration. However, we found the parameter coefficients from Awal and others (2020) provided a reasonable estimate of reference evapotranspiration and we therefore removed the coefficients from the calibration parameter set.

The MesoWest stations with soil moisture data represent only a few of the land use types and hydrologic soil groups. During calibration, only the root-zones and runoff curve numbers associated with locations for which calibration data were available were modified. For land use types and hydrologic soil groups for which there are no measured data associated, we tied changes to the root-zone depth and runoff curve numbers to the parameters for which there are measured data available. Table 4-1 summarizes the modified and tied parameters for each land use and hydrologic soil group. "M" indicates a modified parameter. "F" indicates a fixed parameter. "T" indicates a tied parameter with the land use code and soil group identified. For example, "T-122, D" indicates the parameter value is tied to the estimated parameter for land use 122, soil group D.

4.1.2.3 Calibration Methodology

To efficiently calibrate the Soil Water Balance model, we applied PEST++ (White and others, 2020) to aid in estimating the parameters. In particular, we used the iterative ensemble smoother methodology of PEST++ to develop an ensemble of parameters that resulted in a model meeting the calibration criteria. For the model, we set a target of 51 different parameter ensembles which we would later use to create realizations of the simulated recharge.

When setting up the PEST++ files for estimating the parameters, we set the initial values for each parameter with upper and lower bounds based on literature values. For the reference evapotranspiration, we fixed the values 0.00138, 24.49, and 0.685 for the a, b, and c coefficients in Equation 14, which Awal and others (2020) have shown to improve the estimate of reference evapotranspiration in West Texas. Initial values for the runoff curve number were selected based on Natural Resources Conservation Service (210-VI-TR-55, Second Edition, June 1986) data (Table 3-5) with the upper bound being five units higher than the initial value and the lower bound being five units lower than the initial value. Initial values for the root-zone depth were based on available literature (Foxx and others, 1984; Fan and others, 2016).

Table 4-1: Summary of Modified and Tied Parameters

Land Use Code	Runoff Curve Number per Soil Group				Rooting Depth per Soil Group			
	A	B	C	D	A	B	C	D
1	T - 122, D	T - 122, D	T - 122, D	T - 122, D	T - 152, D	T - 152, D	T - 152, D	T - 152, D
2	T - 7, D	T - 7, D	T - 7, D	T - 122, D	T - 152, D	T - 152, D	T - 152, D	T - 152, D
3	T - 122, D	T - 122, D	T - 122, D	T - 7, D	T - 152, D	T - 152, D	T - 152, D	T - 152, D
5	T - 7, D	T - 7, D	T - 7, D	T - 7, D	T - 152, D	T - 152, D	T - 152, D	T - 152, D
6	T - 7, D	T - 7, D	T - 7, D	T - 7, D	T - 152, D	T - 152, D	T - 152, D	T - 152, D
7	T - 7, D	T - 7, D	T - 7, D	M	T - 7, D	M	T - 7, D	M
8	T - 122, D	T - 122, D	T - 122, D	T - 122, D	T - 152, D	T - 152, D	T - 152, D	T - 152, D
9	T - 122, D	T - 122, D	T - 122, D	T - 122, D	T - 152, D	T - 152, D	T - 152, D	T - 152, D
11	T - 142, D	T - 142, D	T - 142, D	T - 142, D	T - 7, B	T - 7, B	T - 7, B	T - 7, B
12	T - 7, D	T - 7, D	T - 7, D	T - 123, C	T - 152, D	T - 152, D	T - 152, D	T - 152, D
15	T - 122, D	T - 122, D	T - 122, D	T - 122, D	T - 152, D	T - 152, D	T - 152, D	T - 152, D
59	T - 7, D	T - 7, D	T - 7, D	T - 7, D	T - 7, D	T - 7, D	T - 7, D	T - 7, D
60	T - 7, D	T - 7, D	T - 7, D	T - 123, C	T - 7, D	T - 7, D	T - 7, D	T - 7, D
61	T - 123, C	T - 123, C	T - 123, C	T - 7, D	T - 7, D	T - 7, D	T - 7, D	T - 7, D
111	F	F	F	F	F	F	F	F
121	T - 121, D	T - 121, D	T - 121, D	M	T - 121, D	T - 121, D	T - 121, D	M
122	T - 122, D	T - 122, D	T - 122, D	M	T - 122, B	M	T - 122, B	T - 122, B
123	T - 123, C	T - 123, C	M	T - 123, C	T - 122, B	T - 122, B	T - 122, B	T - 122, B
124	T - 123, C	T - 123, C	T - 123, C	T - 122, D	T - 122, B	T - 122, B	T - 122, B	T - 122, B
131	T - 123, C	T - 123, C	T - 122, D	T - 122, D	T - 122, B	T - 122, B	T - 122, B	T - 122, B
141	T - 142, D	T - 142, D	T - 142, D	T - 142, D	T - 7, B	T - 7, B	T - 7, B	T - 7, B
142	T - 142, D	T - 142, D	T - 142, D	M	T - 7, B	T - 7, B	T - 7, B	T - 7, B
143	T - 142, D	T - 142, D	T - 142, D	T - 142, D	T - 7, B	T - 7, B	T - 7, B	T - 7, B
152	T - 152, D	T - 152, D	T - 152, D	M	T - 152, D	T - 152, D	T - 152, D	M
190	T - 142, D	T - 142, D	T - 142, D	T - 7, D	T - 152, D	T - 152, D	T - 152, D	T - 152, D
195	T - 7, D	T - 7, D	T - 7, D	T - 7, D	T - 152, D	T - 152, D	T - 152, D	T - 152, D

4.1.2.4 Calibration Results

Review of the calibration results revealed that the model could not replicate the variation in soil moisture well. Measured soil moisture values were generally higher than the modeled values (Figure 4-2). However, the Soil Water Balance model results for the changes in soil moisture were more evenly spread between values that were either too high or too low. Figure 4-3, Figure 4-4, and Figure 4-5 illustrate the measured versus modeled soil moisture daily change, change from initial measurement, and change between extrema, respectively. Table 4-2 provides the calibration statistics for the Soil Water Balance model.

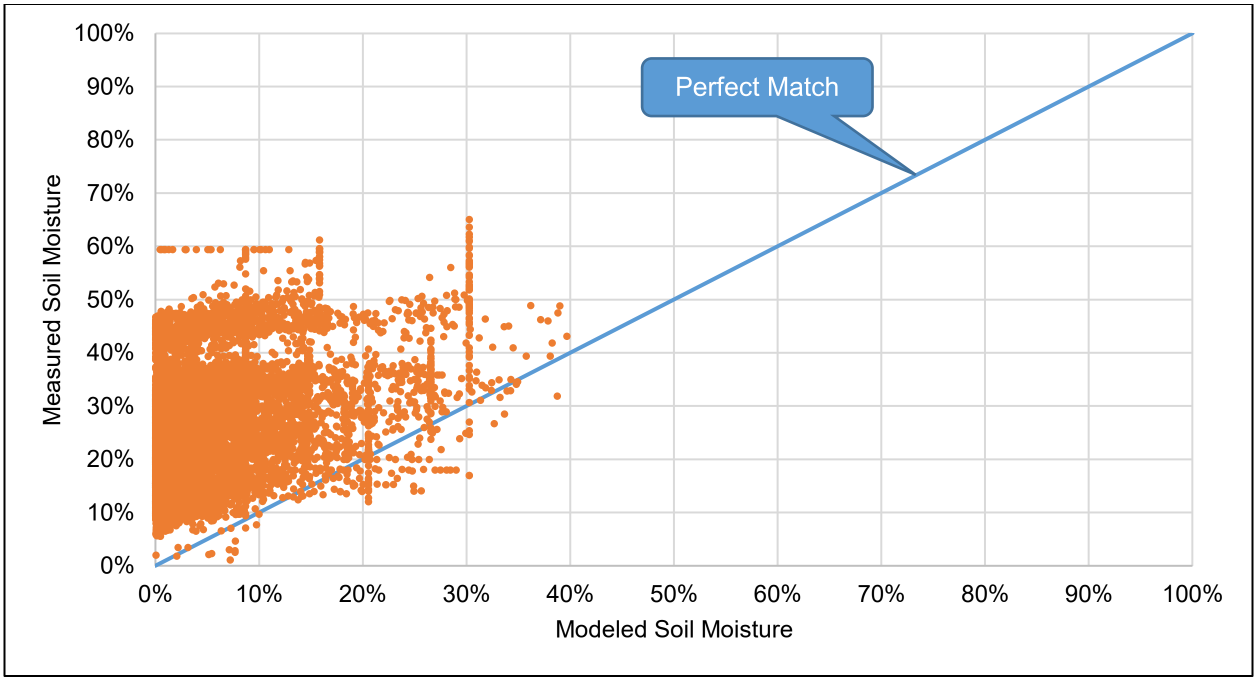


Figure 4-2: Measured Versus Modeled Soil Moisture from the Soil Water Balance Model

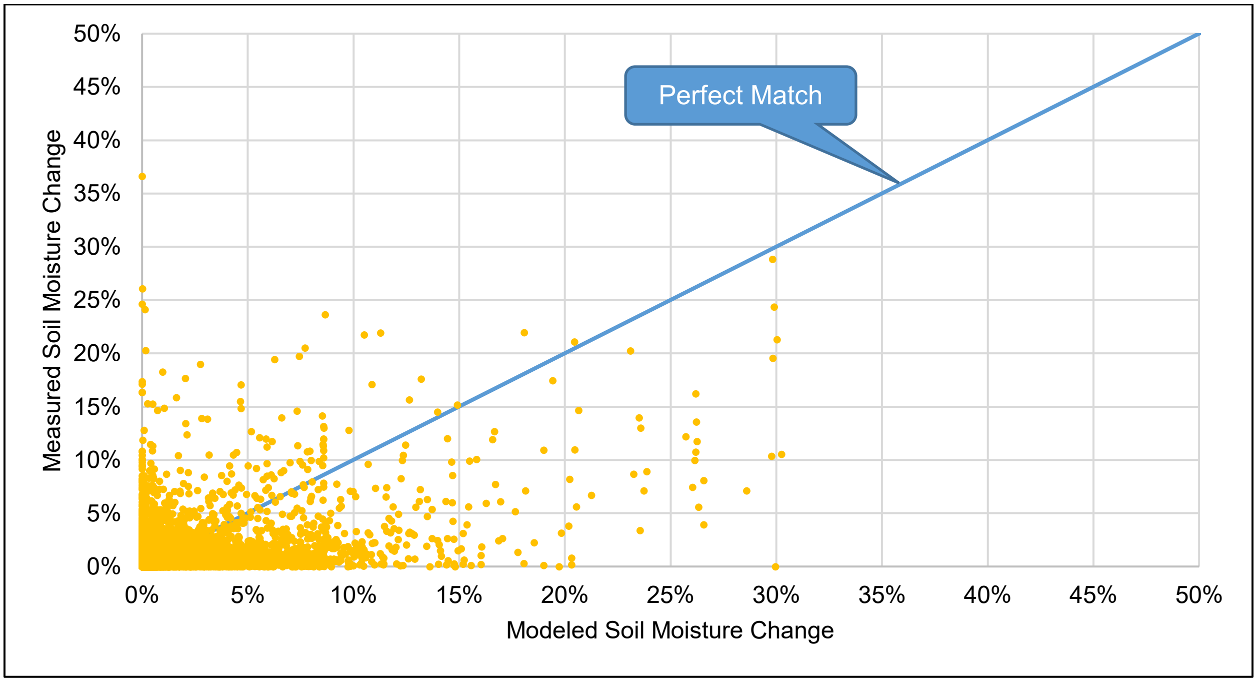


Figure 4-3: Measured versus modeled absolute value of the daily soil moisture change from the Soil Water Balance model.

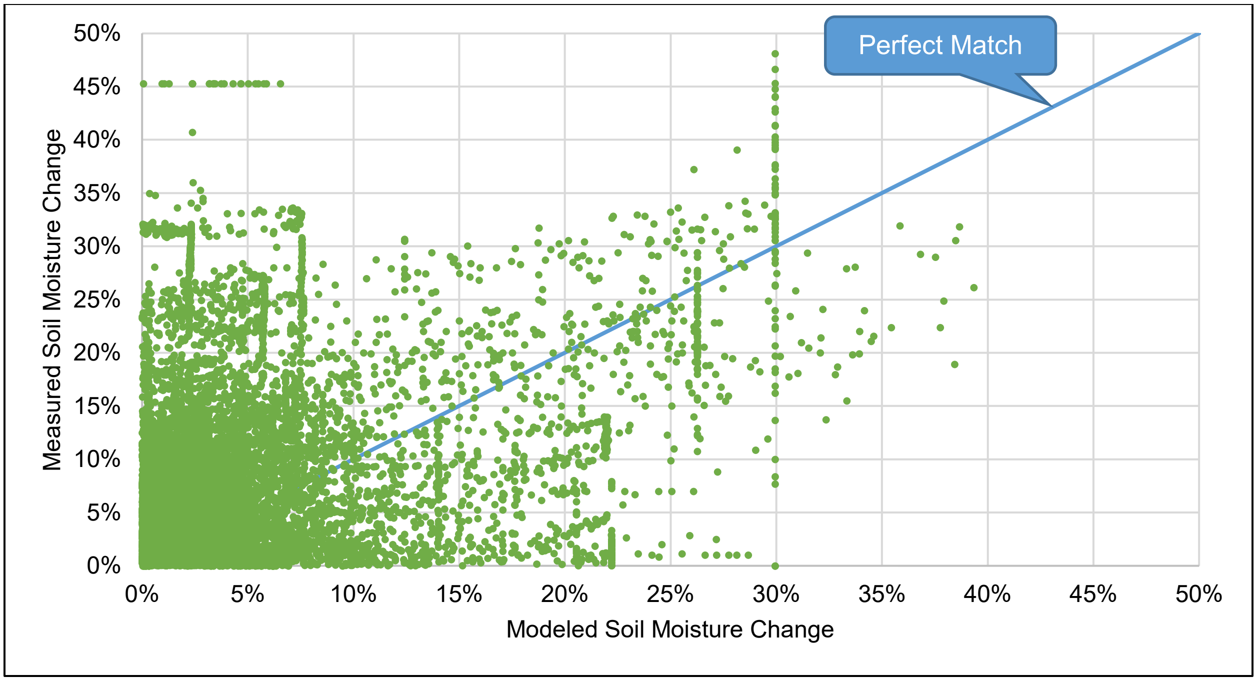


Figure 4-4: Measured versus modeled absolute value of the soil moisture change relative to the first measurement from the Soil Water Balance model.

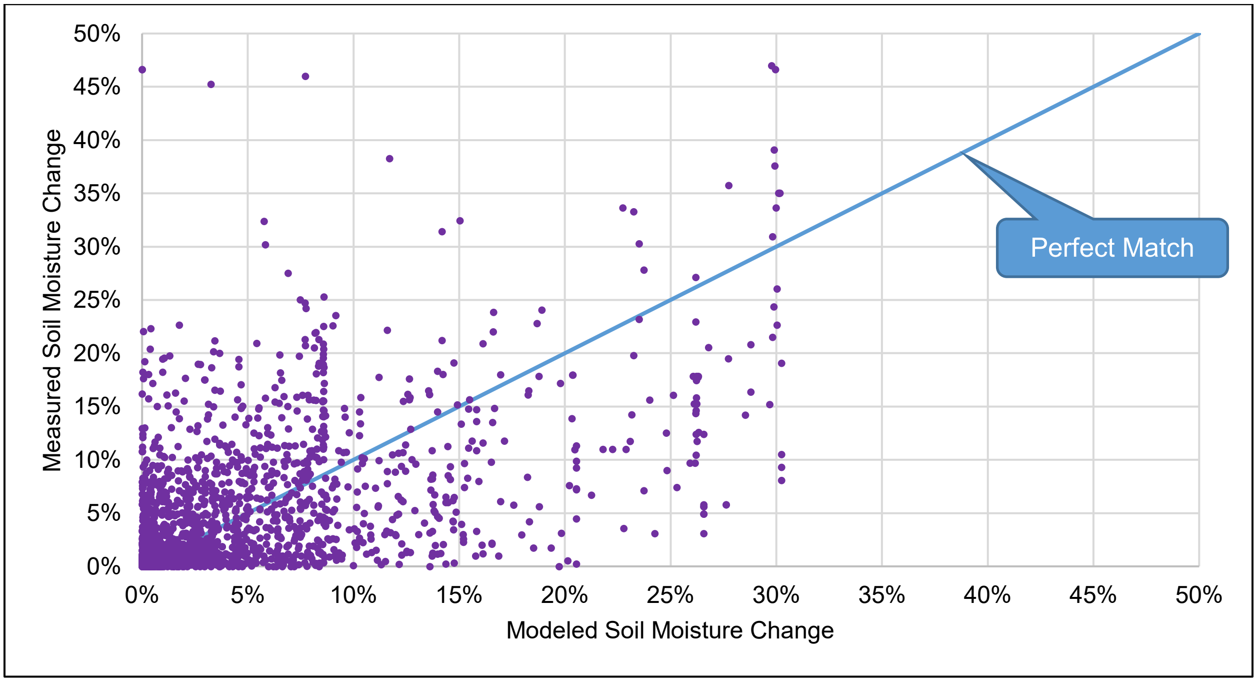


Figure 4-5: Measured Versus Modeled Absolute Value of the Soil Moisture Change Between Extrema from the Soil Water Balance Model

Table 4-2: Soil Water Balance Model Calibration Statistics

Statistical Measure	Target Value	Soil Moisture	Soil Moisture, Daily Change	Soil Moisture, Change from Initial	Soil Moisture, Extrema Change
Measurements	N/A	12,431	12,335	12,404	1,857
Measurement Minimum	N/A	0.01	0.00	0.00	0.00
Measurement Maximum	N/A	0.65	0.37	0.48	0.47
Measurement Average	N/A	0.25	0.01	0.08	0.05
Measurement Range	N/A	0.64	0.37	0.48	0.47
Mean Error	0	0.20	0.00	0.04	0.00
Mean Absolute Error	0	0.20	0.01	0.06	0.04
Root Mean Square Error	0	0.23	0.02	0.09	0.06
Relative Root Mean Square Error	0	0.92	3.11	1.09	1.23
Normalized Root Mean Square Error	0 (<0.1)	0.35	0.06	0.18	0.13

4.1.3 Simulation Results

The results discussed herein reflect the combined results of the 51 realizations of the Soil Water Balance model for the study area. Within this summary, the average values reflect the average from the ensemble of model results rather than a single model. We used the digital files provided with this report to develop the estimates discussed and presented within this section.

Figure 4-6 illustrates the average annual recharge from January 1, 1981, through December 31, 2019, as calculated by the Soil Water Balance model. Figure 4-7 summarizes the gridded values shown in Figure 4-6 by the 12-digit hydrologic unit code. We observed generally increasing recharge rates from the west to east across the study area. The highest recharge rates are in an area south of the outcrop areas for the study area aquifers. More discussions on the results from the Soil Water Balance model are presented in Chapter 6 on comparative analysis.

Review of the calculated recharge from January 1, 1981, through December 31, 2019 for the aquifer outcrop areas (see Figure 4-6) indicated the average recharge is 1.29 inches per year. As Figure 4-6 suggests, the highest average recharge rates are associated with the Trinity (Hill Country) Aquifer and the Edwards (Balcones Fault Zone) Aquifer at 1.88 inches per year and 1.90 inches per year, respectively. The Pecos Valley Aquifer has the lowest average recharge rate of 0.52 inches per year.

Annual calculated recharge rates can vary significantly. For example, as shown in Figure 4-8, the annual recharge to the Pecos Valley Aquifer ranges from 0 to 3.69 inches per year. The Trinity (Hill Country) Aquifer has the greatest range of more than 3.5 inches per year between 1981 and 2019. Figure 4-9 through Figure 4-12 are bar plots illustrating the calculated annual recharge to each of the study area aquifers.

The annual gridded recharge results follow the same spatial pattern of recharge as the average annual distribution shown on Figure 4-6 and a temporal distribution similar to Figure 4-9 through Figure 4-12. Calculated recharge for 2004 was high for each aquifer, while the total was low for 2011, but the spatial distribution remains similar due to the land use and soil characteristics. Figure 4-13 illustrates the similarity in spatial distribution of recharge despite a difference in the total amount with a side-by-side comparison of the calculated recharge for 2004 and 2011.

We reviewed the soil moisture results at the TexMesonet stations to compare the Soil Water Balance model results with the measured values. Figure 4-14 identifies three MesoWest station locations in the “Barren” land use classification but each with a different hydrologic soil group. Figure 4-15 through Figure 4-17 show how the model reasonably reflects the increases and decreases in soil moisture at these MesoWest stations, but the modeled soil moisture magnitudes are greater than measured values.

Digital files provided with this report include the annual and monthly gridded results for the study area. The gridded results include the modeled recharge and reference evapotranspiration for each of the 51 realizations along with summaries of the results. Overall, the results appear to provide a reasonable spatial and temporal distribution of recharge for the study area. These gridded values may be easily incorporated into a numerical groundwater flow model with additional calibration being addressed through an array multiplier.

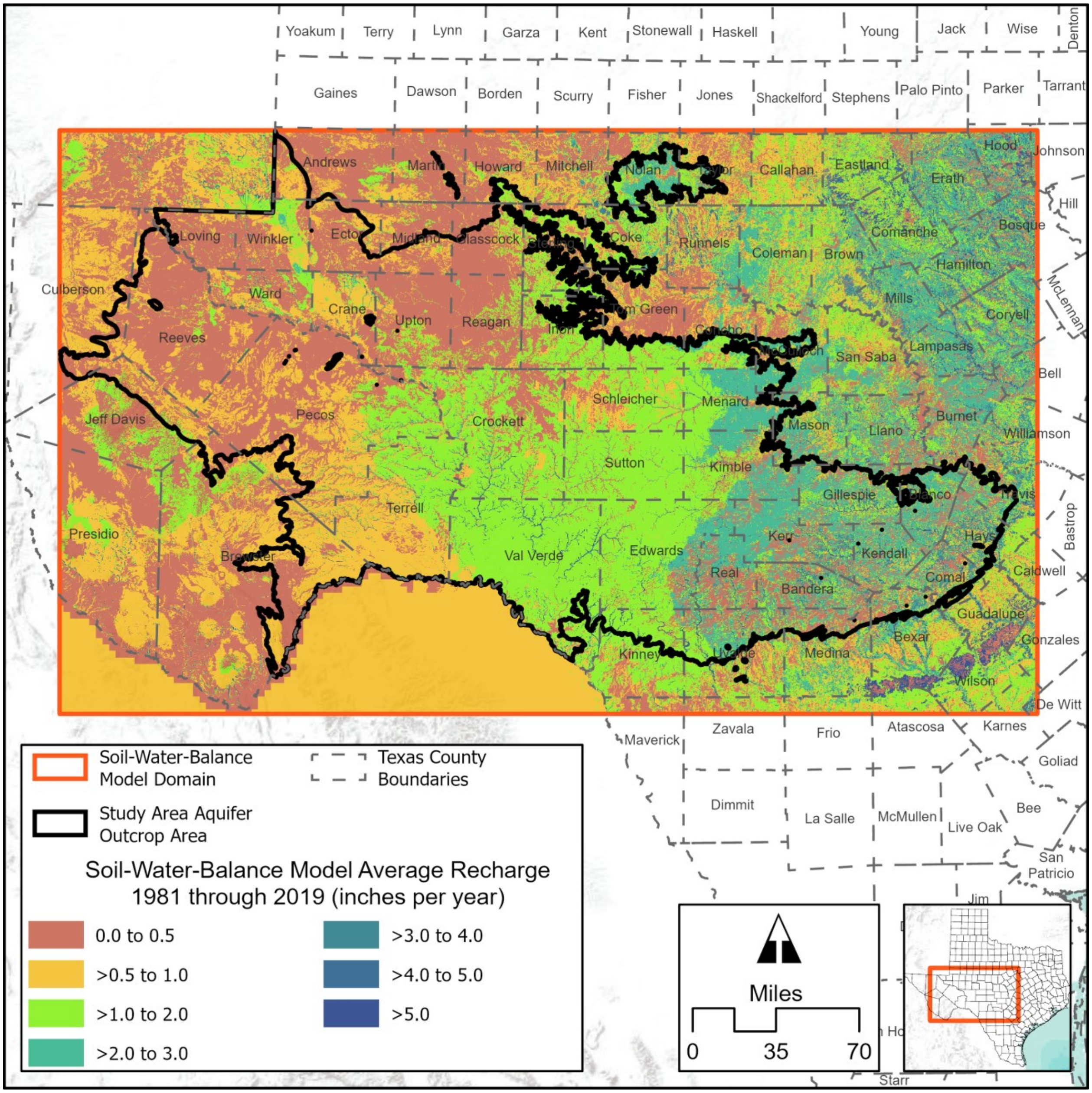


Figure 4-6: Soil Water Balance Model Calculated Average Recharge from January 1, 1981, through December 31, 2019

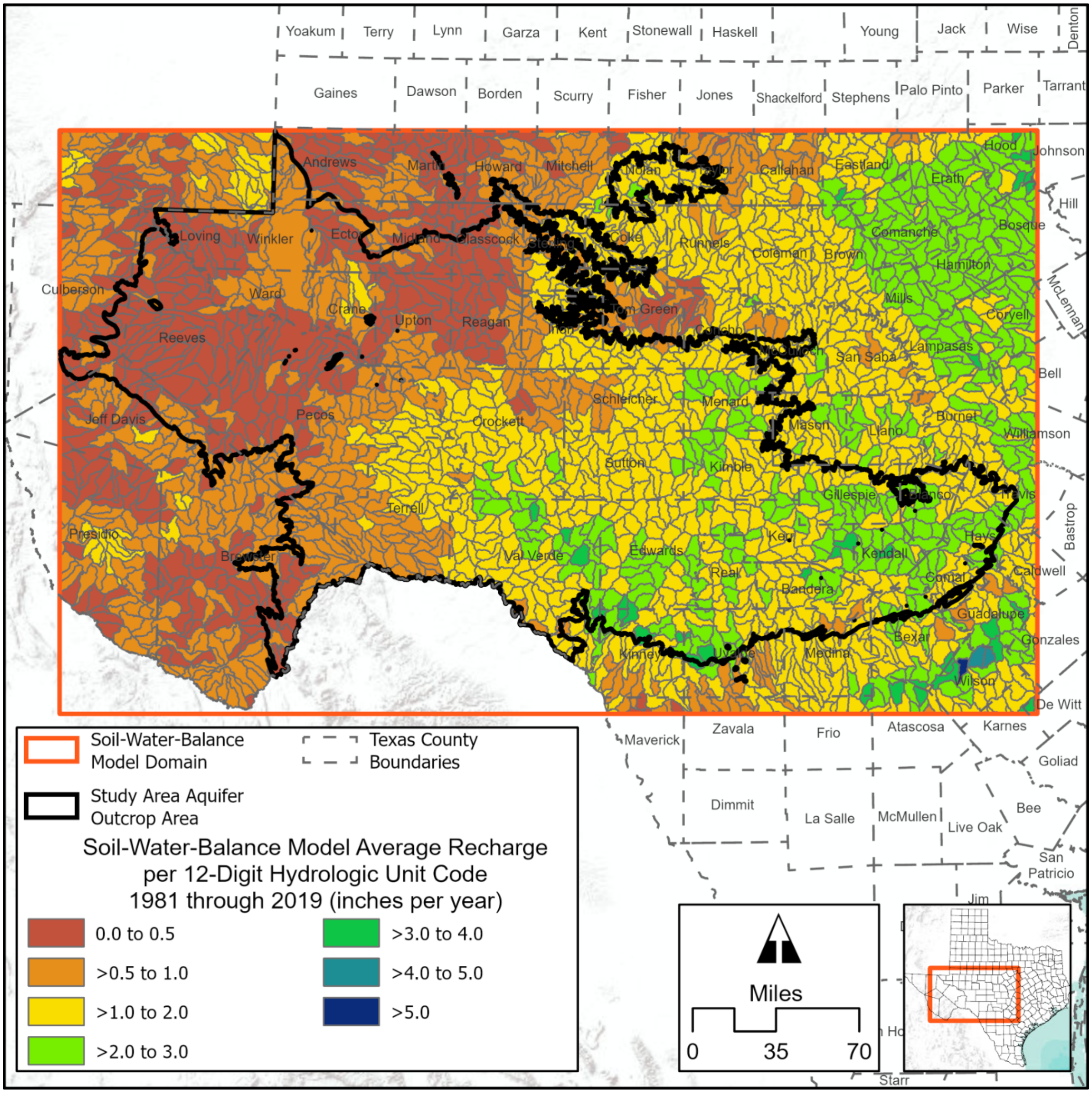


Figure 4-7: Soil Water Balance Model Calculated Average Recharge from January 1, 1981, through December 31, 2019, per 12-Digit Hydrologic Unit Code

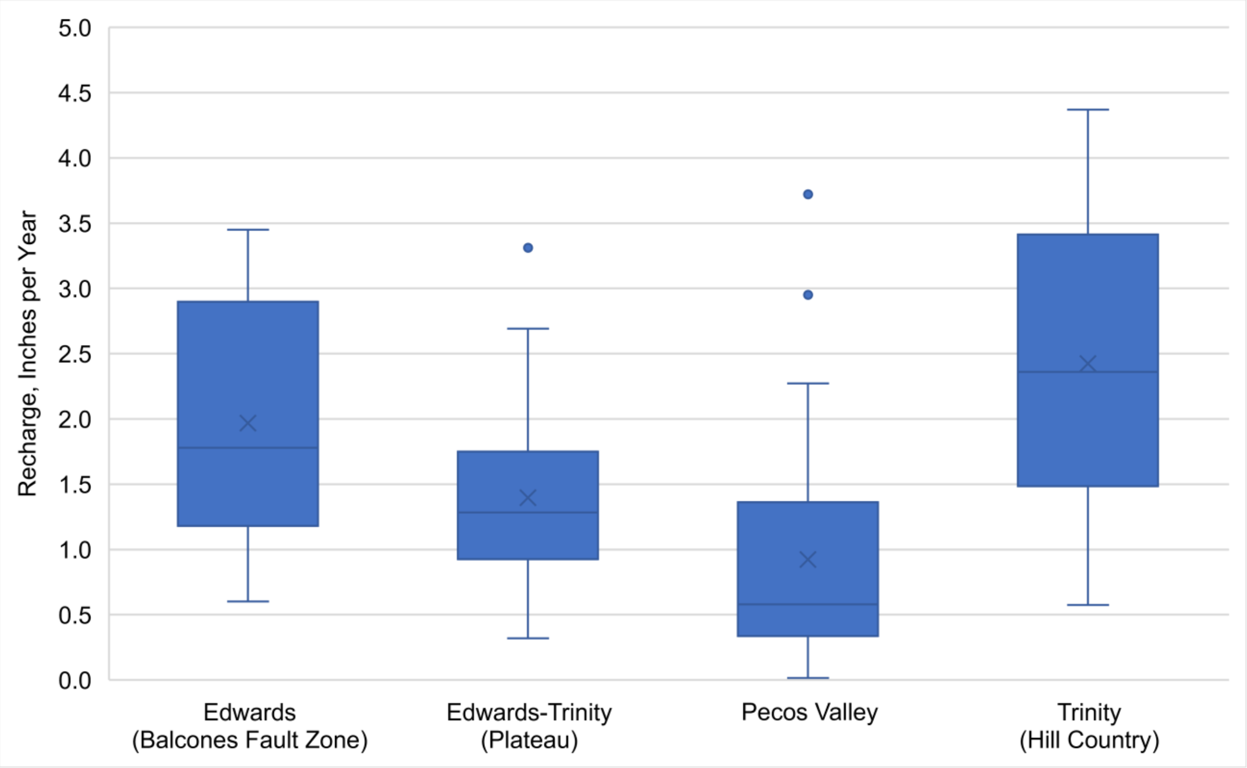


Figure 4-8: Box Plot of the Soil Water Balance Model Calculated Annual Recharge to Each of the Study Area Aquifers

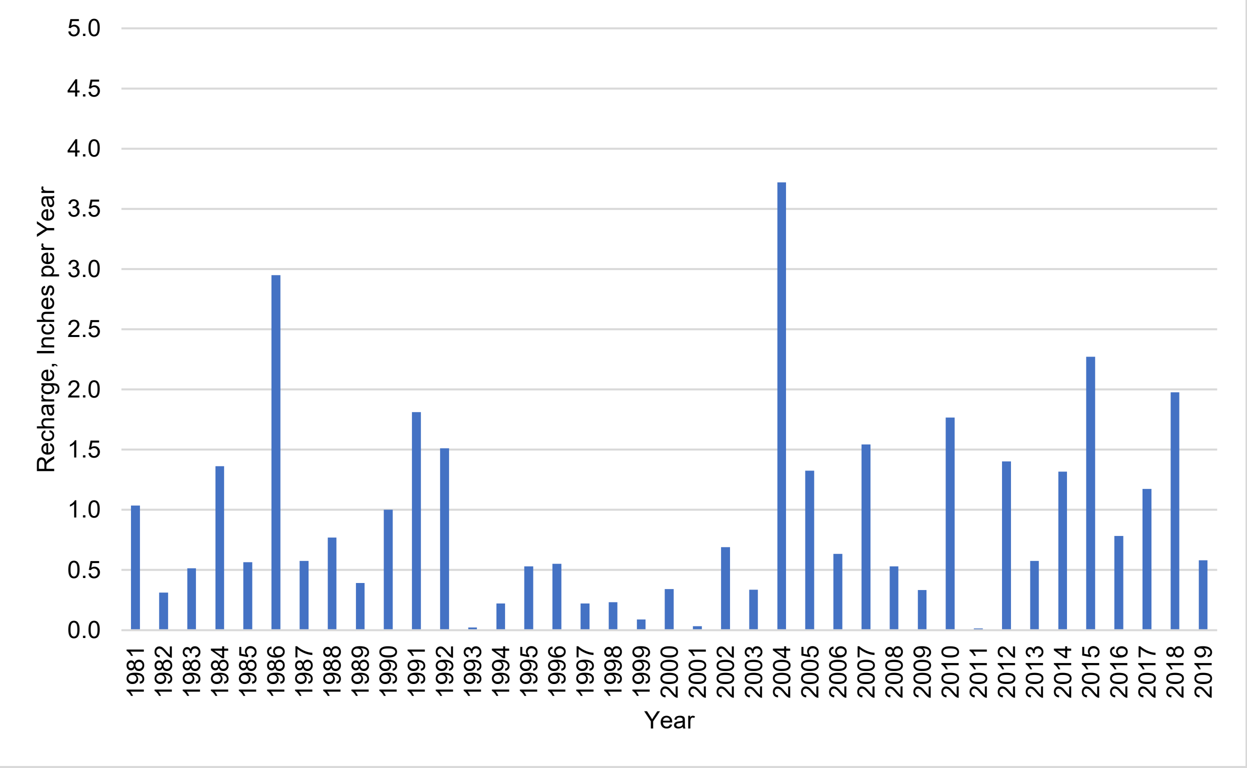


Figure 4-9: Soil Water Balance Model Calculated Annual Recharge to the Pecos Valley Aquifer

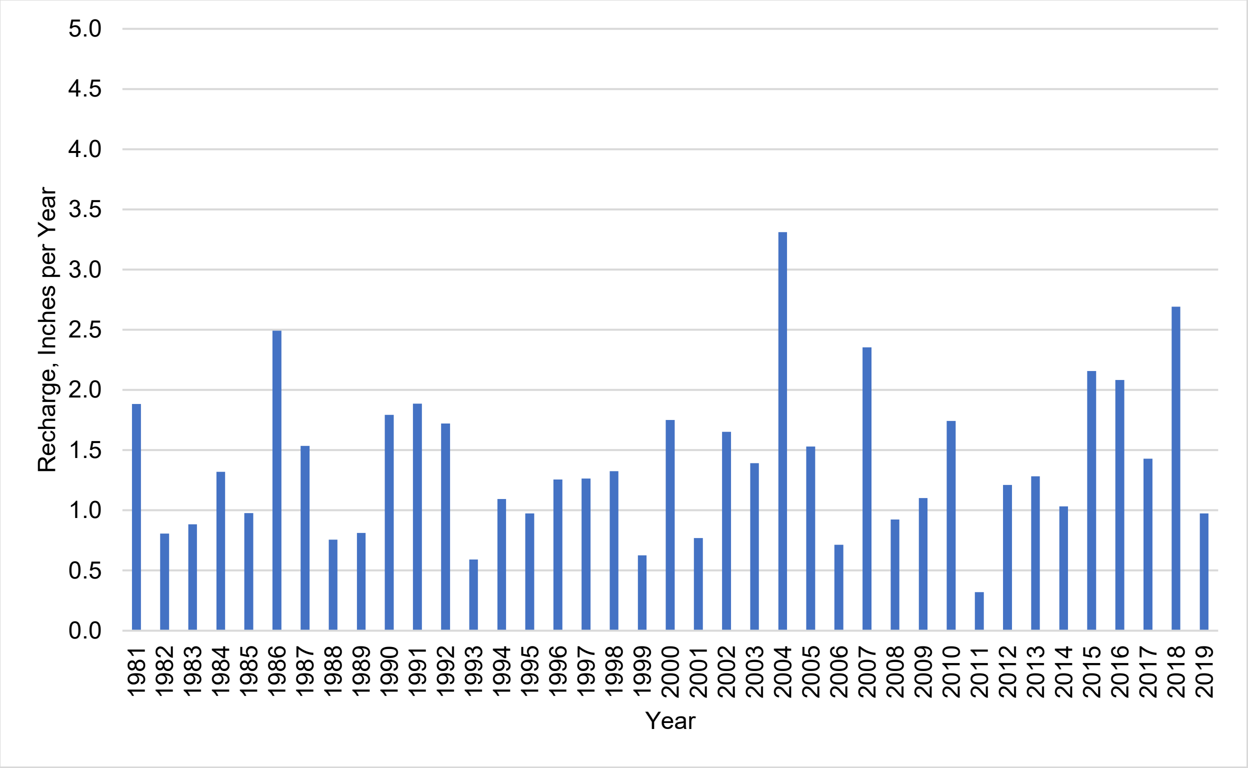


Figure 4-10: Soil Water Balance Model Calculated Annual Recharge to the Edwards-Trinity (Plateau) Aquifer

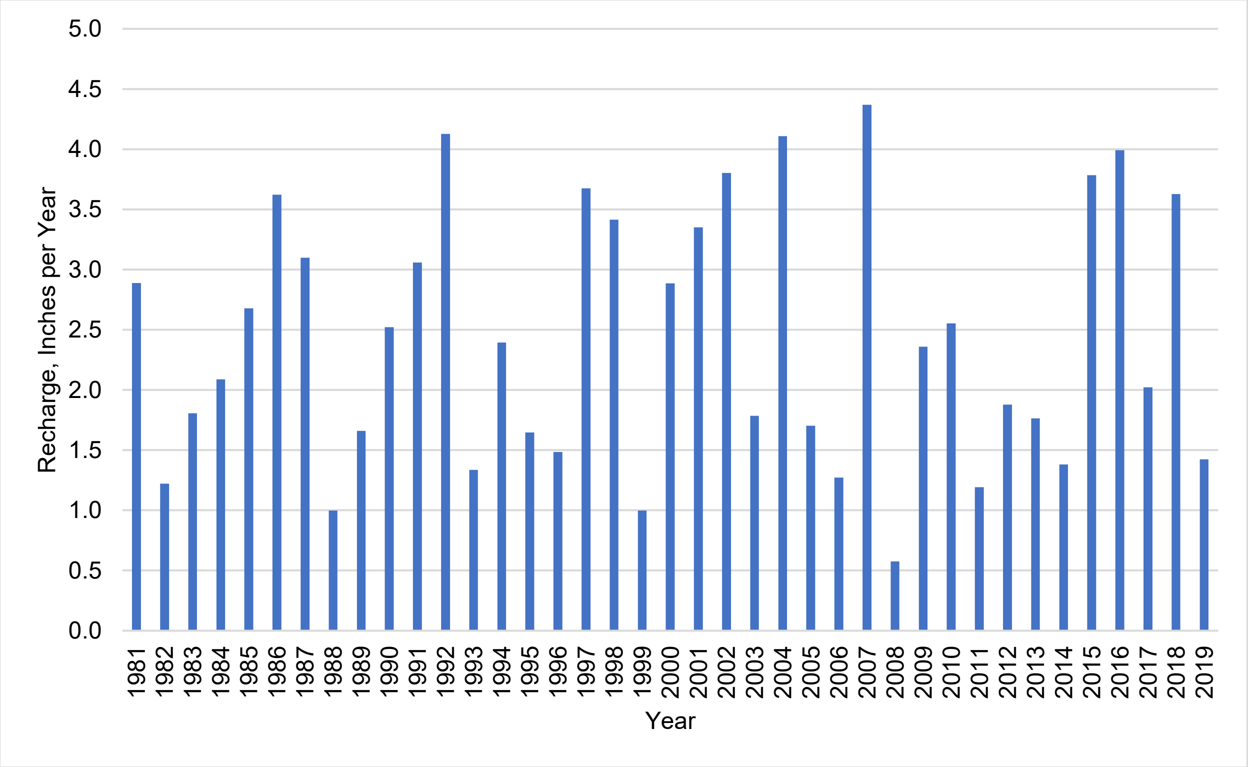


Figure 4-11: Soil Water Balance Model Calculated Annual Recharge to the Trinity (Hill Country) Aquifer

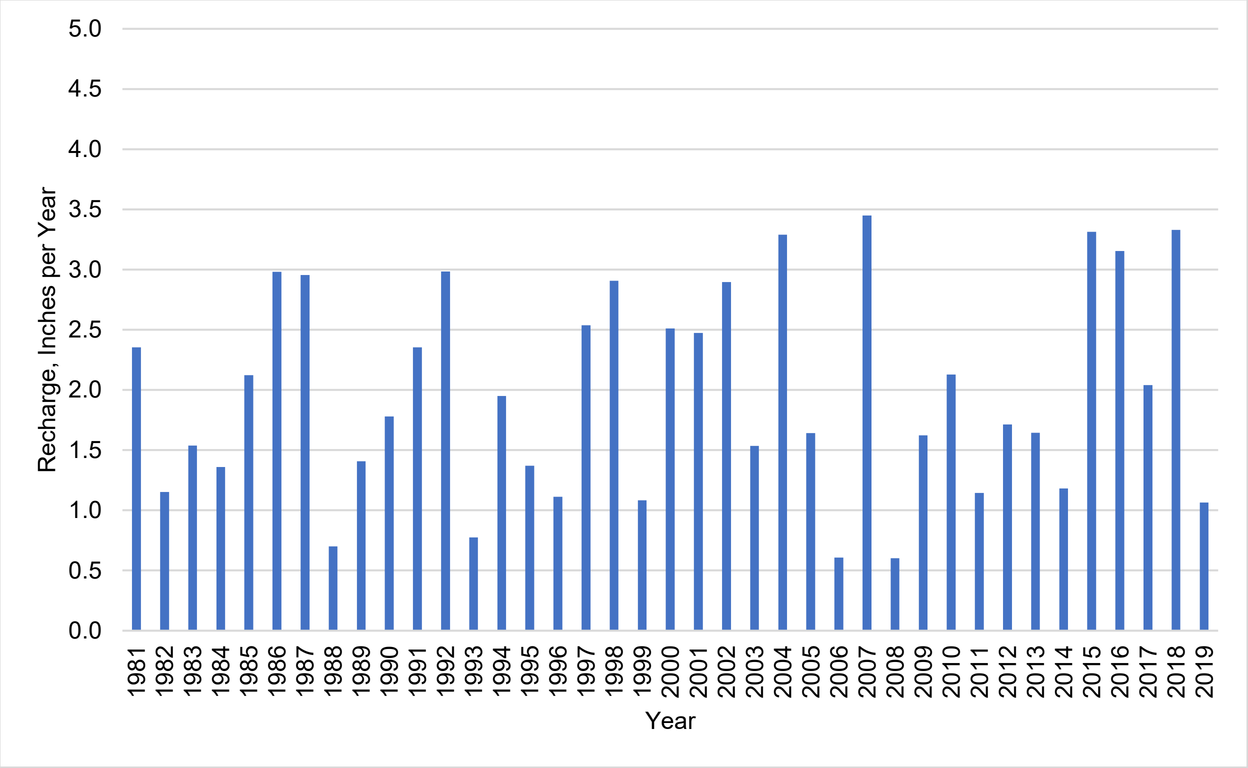


Figure 4-12: Soil Water Balance Model Calculated Annual Recharge to the Edwards (Balcones Fault Zone) Aquifer

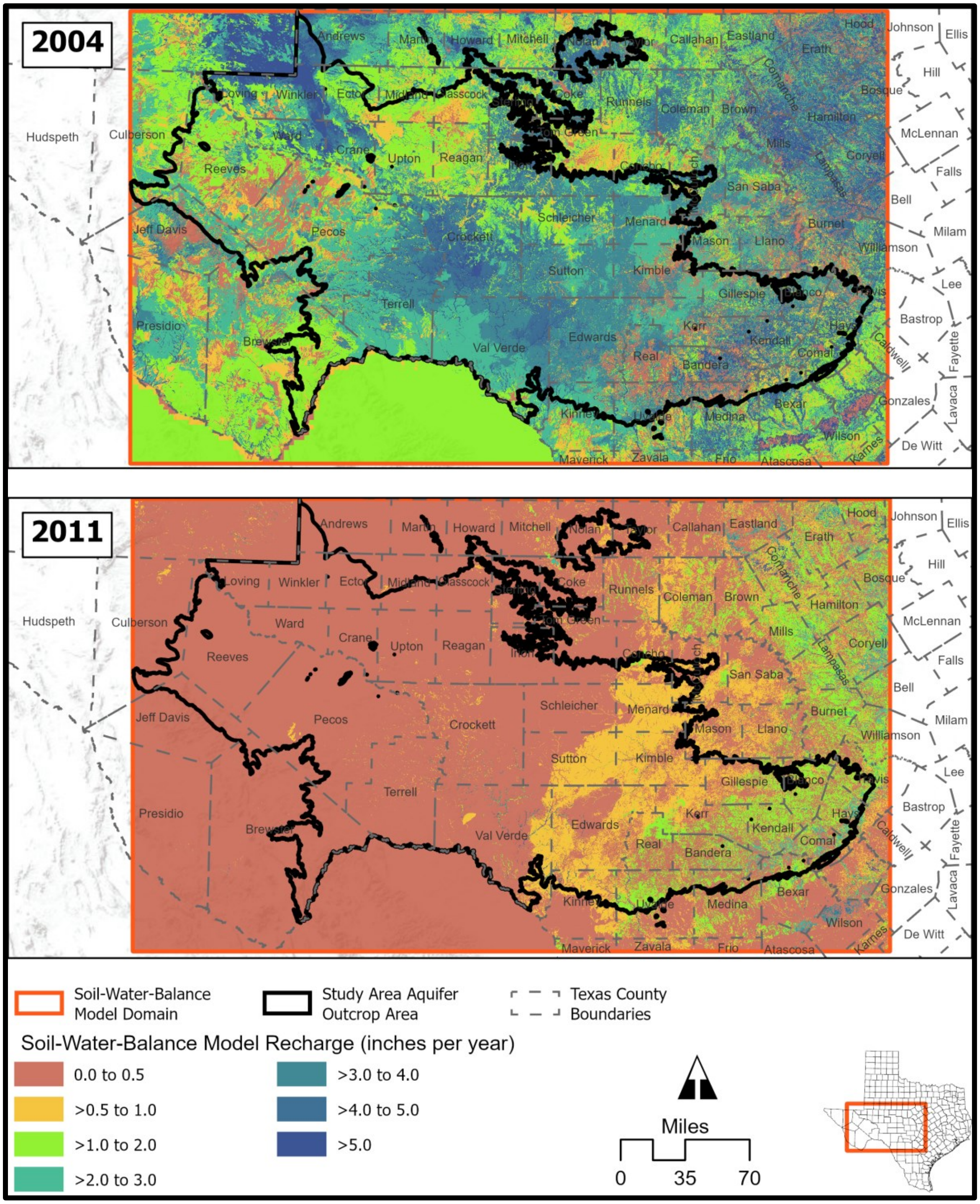


Figure 4-13: Soil Water Balance Model Calculated Annual Recharge for 2004 and 2011

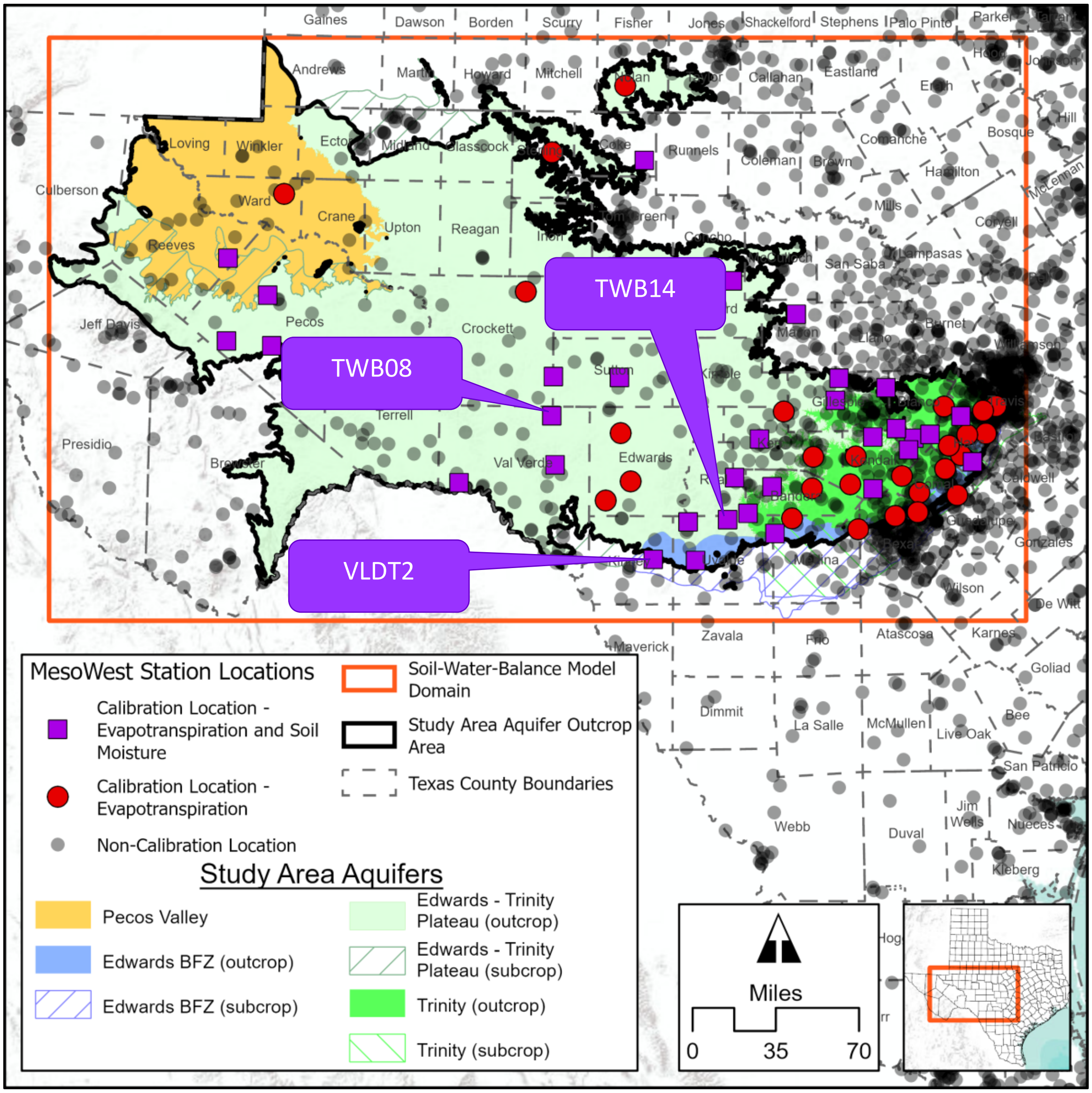


Figure 4-14: Location of Sites for Comparison of Measured Soil Moisture with Soil Water Balance Model Results

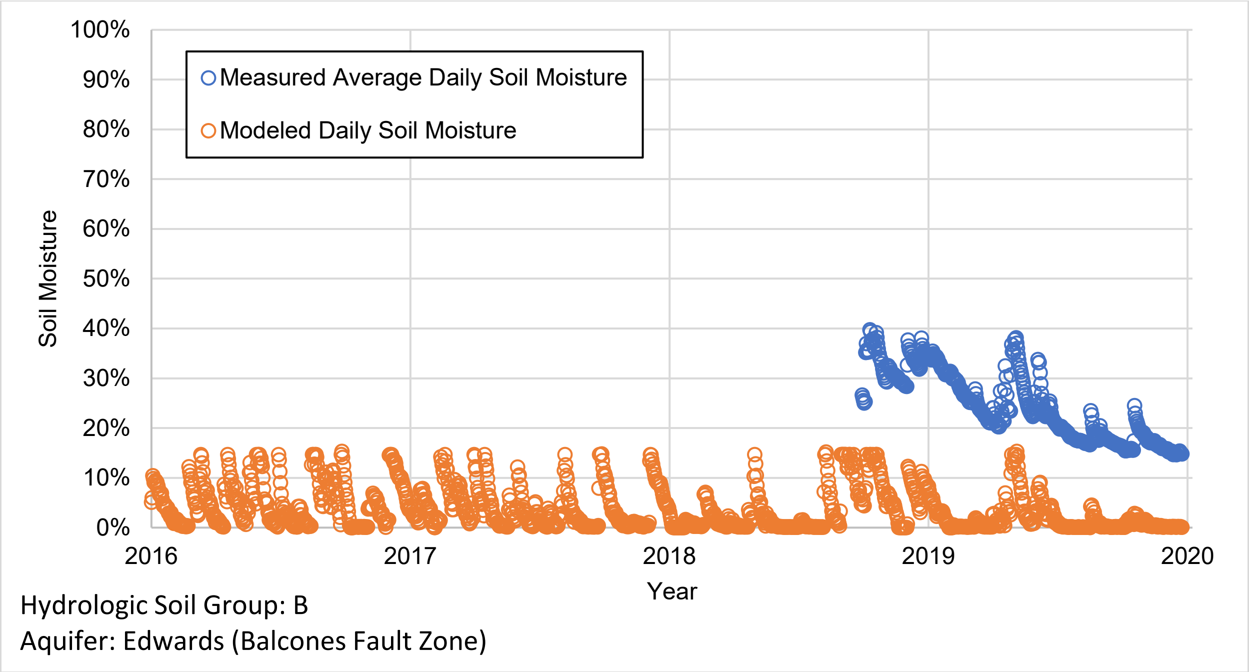


Figure 4-15: Comparison of Soil Water Balance Model Calculated Soil Moisture at TexMesonet Station TWB14

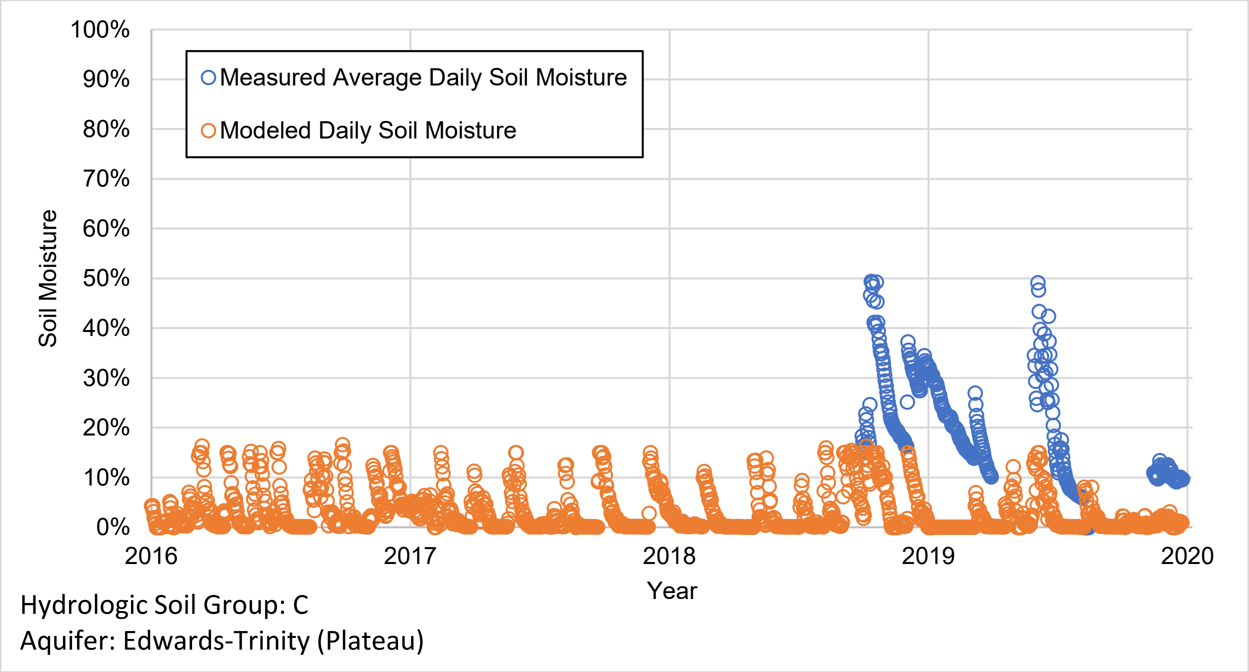


Figure 4-16: Comparison of Soil Water Balance Model Calculated Soil Moisture at TexMesonet Station TWB08

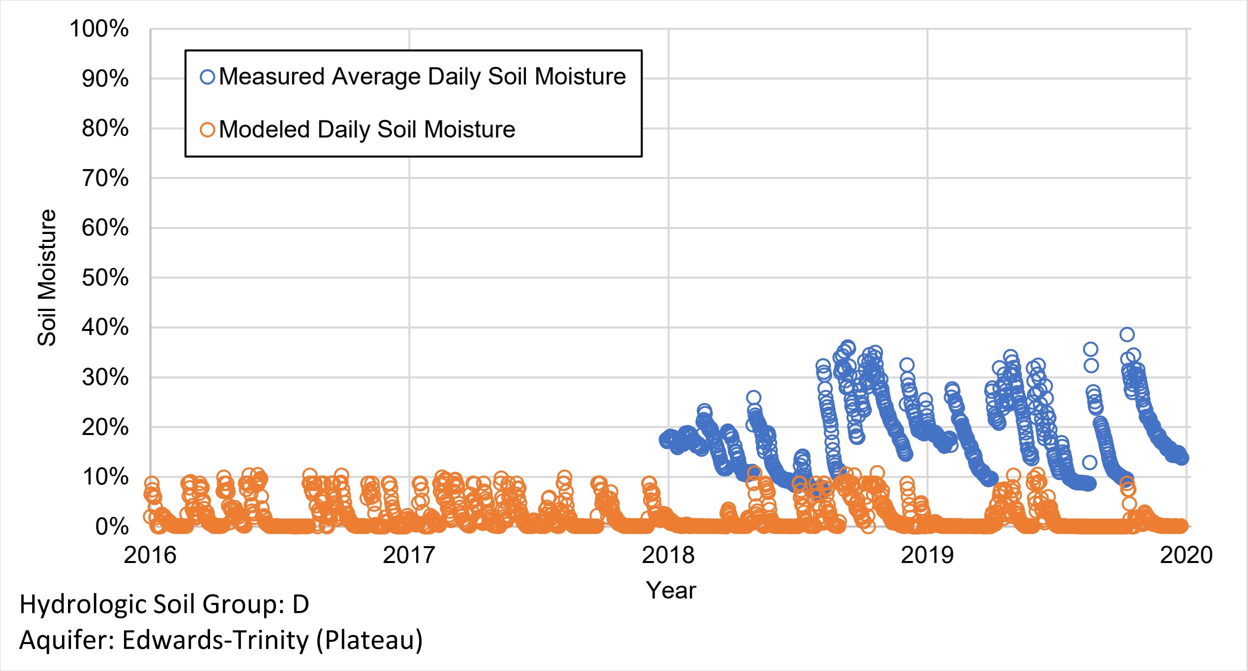
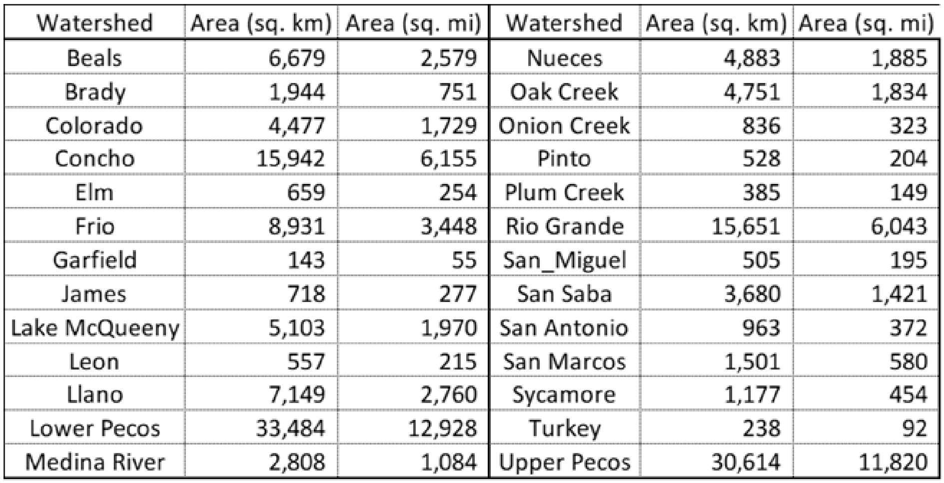


Figure 4-17: Comparison of Soil Water Balance Model Calculated Soil Moisture at TexMesonet Station VLDT2

4.2 Soil & Water Assessment Tool Model

Figure 4-18 shows the study area along with the watersheds identified for development of the Soil & Water Assessment Tool models and Table 4-3 presents the area covered by those watersheds. While a single Soil Water Balance model was constructed for the entire study area, multiple models were created for the Soil & Water Assessment Tool simulations, one for each identified watershed. As described earlier, the watersheds were delineated on the sub-basin level using Hydrologic Unit Code-12 boundaries to obtain recharge results at an appropriate resolution for the project.

Table 4-3: Watersheds Identified for the Soil & Water Assessment Tool Modeling and Their Areas



Watershed	Area (sq. km)	Area (sq. mi)	Watershed	Area (sq. km)	Area (sq. mi)
Beals	6,679	2,579	Nueces	4,883	1,885
Brady	1,944	751	Oak Creek	4,751	1,834
Colorado	4,477	1,729	Onion Creek	836	323
Concho	15,942	6,155	Pinto	528	204
Elm	659	254	Plum Creek	385	149
Frio	8,931	3,448	Rio Grande	15,651	6,043
Garfield	143	55	San_Miguel	505	195
James	718	277	San Saba	3,680	1,421
Lake McQueeny	5,103	1,970	San Antonio	963	372
Leon	557	215	San Marcos	1,501	580
Llano	7,149	2,760	Sycamore	1,177	454
Lower Pecos	33,484	12,928	Turkey	238	92
Medina River	2,808	1,084	Upper Pecos	30,614	11,820

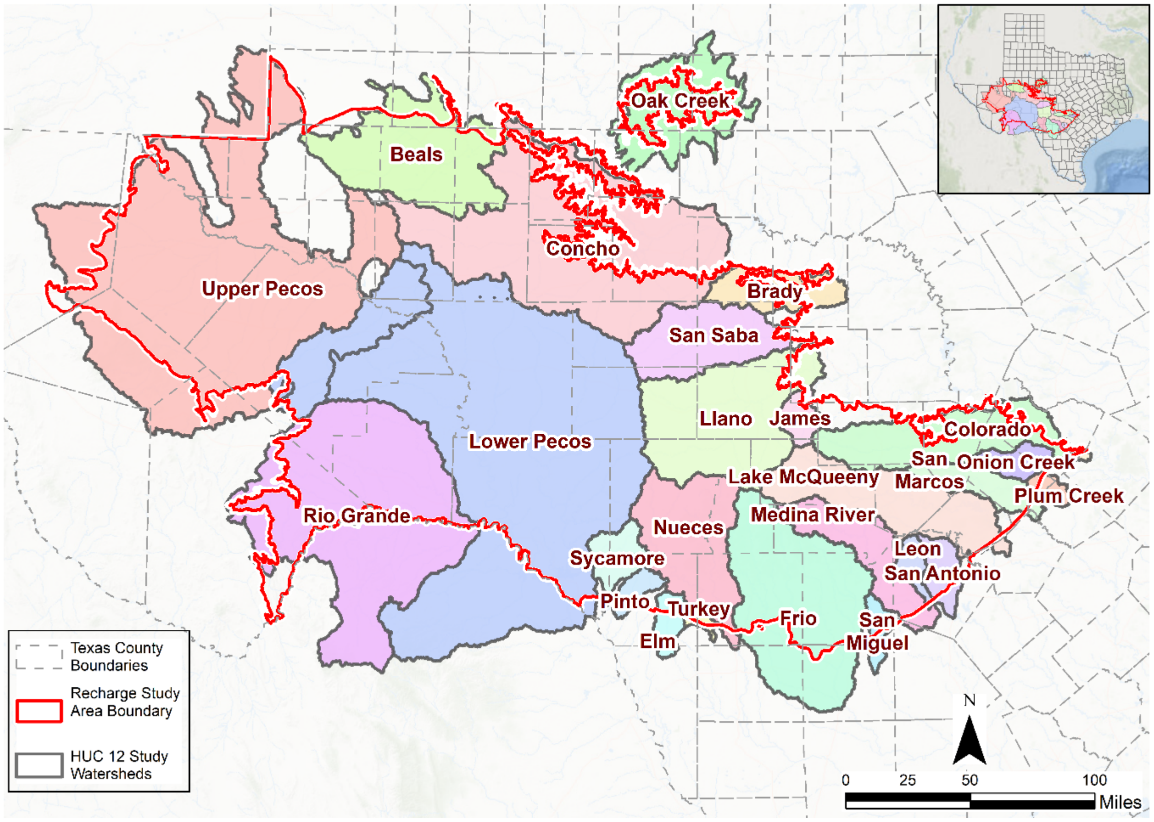


Figure 4-18: Project Study Area and the Identified Watersheds for the Soil & Water Assessment Tool Modeling

4.2.1 The Soil & Water Assessment Tool Model Setup

The Soil & Water Assessment Tool models were set up by importing the model data described in Chapter 3. The model data is imported and processed in a certain stepwise manner from within the Soil & Water Assessment Tool add-in for ArcGIS®. Each step leads to the next one and any errors on one step may lead to model set up failure and the requirement to start over. The steps for developing each individual model are:

1. Unique project setup.
2. watershed delineation: which includes importing the Digital Elevation Model, pre-defined streams, and watersheds; creating a stream network; adding point sources (for later use during calibration); calculating sub-basin parameters (the Soil & Water Assessment Tool does this internally), adding lakes, if present.
3. Hydrologic Response Unit (HRU) Analysis: Land-use, soil data, and slope, all the parameters have to be loaded and processed in a single session or this step may not be completed. Land use grid is selected and clipped to the watershed; master land use table akin to the one used for Soil Water Balance is used to link the land use values to uses. Pre-processed soil data (from SSURGO) is loaded and linked to the built-in soil classification table. Soil slope classifications are created. In our case, we used a default value of two classifications going from 0 to 2 percent, and 2 percent -

maximum. In the end, hydrologic response units are created using the overlay functionality available from within the tool.

4. Filter out small hydrologic response units: In our experience, the road networks or smaller land use classifications cause the creation of these small hydrologic response units. Since small hydrologic response units cause computational burden during simulation, it is prudent to filter out certain hydrologic response units with coverage of a certain area or less. Filtering out of small hydrologic response units was conducted based on the modeler's judgement. For larger watersheds, the filter was set up to 5 hectares, and for smaller watersheds, it was set between 1-5 hectares.
5. Climate data/Weather Stations: PRISM data pre-processed and linked to Hydrologic Unit Code-12 sub-basin level is imported into the model for precipitation and temperature. Other weather data are input through the built-in weather generator from within the Soil & Water Assessment Tool which corresponds to data from over 18,000 weather stations from all over the United States and selects the nearest weather station to the simulated area.
6. Develop the Soil & Water Assessment Tool database: Create model input files.
7. Start Model simulation.

4.2.2 The Soil & Water Assessment Tool Model Calibration

The Soil & Water Assessment Tool model parameters are often calibrated using the Soil & Water Assessment Tool-Calibration Uncertainty Prediction (SWAT-CUP) tool (Abbaspour and others, 2004a; Abbaspour, 2015). Calibration and validation are fundamental processes used to evaluate whether models can reproduce actual biophysical situations. During model calibration, model simulated outputs will be compared with observed data by adjusting parameters in an effort to reproduce actual biophysical situations and reduce model prediction uncertainty (Daggupati and others, 2015). During the validation process, the performance of the calibrated model is evaluated using an independent observed data (for example, streamflow) that is not used for the model calibration. In a process similar to that adopted in the Soil Water Balance model, it is recommended to use model warm up period to initiate and balance different components of the biophysical processes before model calibration and validation (Figure 4-19). It is recommended to use three to five years of initial model simulation to be used for model warm (Daggupati and others, 2015); therefore, the team used the initial three years of the model simulations (January 1, 1981 – December 31, 1983) as the warm-up period.

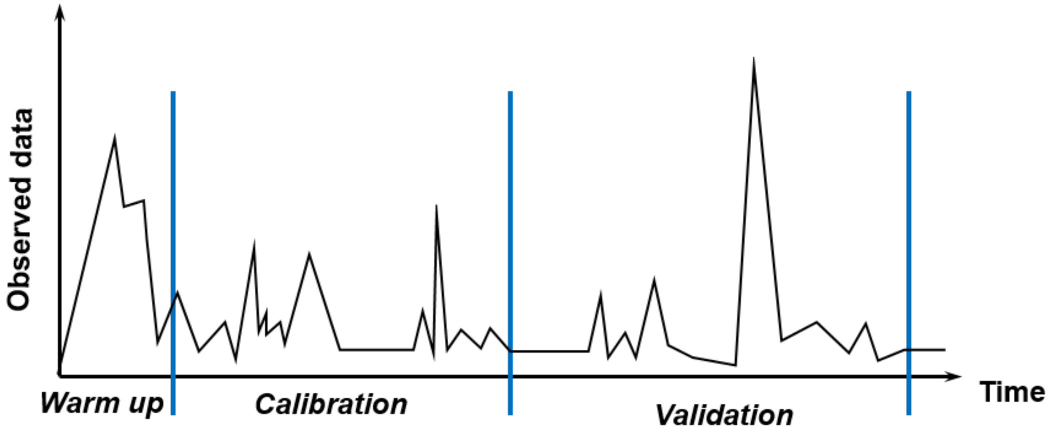


Figure 4-19: Splitting Observed Data for Model Calibration and Validation

4.2.3 Auto-Calibration Tool: The Soil & Water Assessment Tool – Calibration Uncertainty Prediction

Automated model calibration requires that the uncertain model parameters are systematically changed, the model is run, and the required outputs (corresponding to measured data) are extracted from the model output files. The primary function is to provide a link between the input/output of a calibration program and the model. The simplest way of handling the file exchange is through text file formats. The Soil & Water Assessment Tool-Calibration Uncertainty Prediction is an interface that was developed for the calibration of the Soil & Water Assessment Tool. Using this generic interface, any calibration/uncertainty or sensitivity program can easily be linked to the Soil & Water Assessment Tool. The Soil & Water Assessment Tool-Calibration Uncertainty Prediction4 is a public domain program, and as such, may be used and copied freely.

Calibration and uncertainty analysis of the hydrological parameters is often performed using the Sequential Uncertainty Fitting version 2 (SUFI-2) algorithm in the Soil & Water Assessment Tool-Calibration Uncertainty Prediction due to its efficient performance (Yang and others, 2008). SUFI-2 accounts all sources of uncertainties such as uncertainty in conceptual model, model parameters, driving variables, and observed data as parameter uncertainty (Abbaspour and others, 2007, 2004b). The degree of the uncertainties are quantified using p-factor and r-factor in which p-factor is the percentage of measured data bracketed by the 95 percent prediction uncertainty and the r-factor is the average thickness of the 95 percent prediction uncertainty band divided by the standard deviation of the measured data. The 95 percent prediction uncertainty is calculated at the 2.5 percent and 97.5 percent levels of the cumulative distribution of an output variable obtained through Latin-hypercube sampling. A p-factor close to 1 and an r-factor close to zero represents strong model performance (Abbaspour and others, 2007, 2004b). When acceptable values of r-factor and p-factor are reached, the parameter uncertainties are the desired parameter ranges. Further goodness of fit can be quantified by the coefficient of determination and/or Nash-Sutcliffe coefficient between the observations and the final “best” simulation.

Particle swarm optimization is a population-based stochastic optimization technique developed by Eberhart and Kennedy (1995). This algorithm is inspired by the social behavior of bird flocking or fish schooling. Particle swarm optimization simulates the scenario such as a group of birds (called particles) are randomly searching food in an area. Particle swarm optimization is initialized with a group of random particles (solutions) and then searches for optima by updating generations.

The Generalized Likelihood Uncertainty Estimation (Beven and Binley, 1992) was introduced partly to allow for the possible non-uniqueness (or equifinality) of parameter sets during the estimation of model parameters in over-parameterized models. In large over-parameterized models, there is no unique set of parameters, which optimizes goodness-of fit-criteria. A number of possible model performance measures can be used in this kind of analysis. The only formal requirements for use in a Generalized Likelihood Uncertainty Estimation analysis are that the likelihood measure should increase monotonously with increasing performance and zero for models considered unacceptable or non-behavioral.

The ParaSol method aggregates objective functions into a global optimization criterion, minimizes these objective functions or a global optimization criterion using the Shuffle Complex algorithm, and performs uncertainty analysis with a choice between two statistical concepts. Shuffle Complex has been widely used in watershed model calibration and other areas of hydrology such as soil erosion, subsurface hydrology, remote sensing, and land surface modelling (Duan, 2003).

Markov Chain Monte Carlo generates samples from a random walk which adapts to the posterior distribution (Kuczera and Parent, 1998). A sequence (Markov Chain) of parameter sets representing the posterior distribution is constructed as follows: an initial starting point in the parameter space is chosen, and a candidate for the next point is proposed by adding a random realization from a symmetrical jump distribution.

Depending on our requirement and the available planning tool, this project used the Sequential Uncertainty Fitting algorithm, linked with the Soil & Water Assessment Tool, to calibrate the selected calibration gages where data are available in each watershed.

The Soil & Water Assessment Tool model run times depend on the number of hydrologic response units, computer hardware and architecture, simulation period, and the simulated processes. In our experience, model runs times varied depending on the size of the watersheds and on computer architecture. We observed run times from three hours to two days.

4.2.4 Model Performance Analysis

The models were calibrated from 1981 to 2018 based on the availability of gages. Model performance has been evaluated by performing calibration and validation. In calibration and validation, model evaluation is done statistically and graphically. Mainly four objective functions are assessed in model simulations:

- Nash–Sutcliffe efficiency; (NSE)
- Coefficient of determination; (R^2)
- Mean relative bias (PBIAS); and
- Kling Gupta Efficiency (KGE).

The Nash-Sutcliffe efficiency is a normalized statistic. The comparison of the relative magnitude of the residual variance (noise) and the measured data variance (information) is determined by the Nash-Sutcliffe efficiency (Nash and Sutcliffe, 1970). Nash-Sutcliffe efficiency indicates how well the observed versus simulated data plot fits the 1:1 line (Moriasi, 2007). The Nash-Sutcliffe efficiency value of 1 indicates a perfect fit.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(x_{obs}(i) - y_{model}(i))^2}{\sum_{i=1}^{n}(x_{obs}(i) - \overline{x_{obs}})^2}\right] \quad \textbf{Equation 15}$$

Where

$x_{obs}(i)$ = observed variable (flow in m3/s or sediment concentration in mg/L−1)

$y_{model}(i)$ = simulated variable (flow in m3/s or sediment concentration in mg/L−1)

x_{obs} = mean of n values
n = number of observations.

The coefficient of determination describes the proportion of the variance in the observations explained by the model. The range of the coefficient of determination is from 0 to 1 where a higher value (1) gives less error variance and the values greater than 0.5 are considered acceptable (Santhi and others, 2001, Van Liew and others, 2003). It only measures the deviation from the best fit line.

The percentage difference is mainly the percentage of bias. The percent bias measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. Positive values of percent bias indicate model underestimation bias, and negative values indicate model overestimation bias of total volume (Gupta and others, 1999). Table 4-4 below provides a performance rating associated with various objective function results.

Table 4-4: General Performance Ratings for Nash-Sutcliffe Efficiency, Mean Relative Bias, and Coefficient of Determination for a Monthly Time Step (Moriasi and others, 2007)

Formulae	Value	Performance Rating
$\mathrm{NSE} = 1 - \left[\dfrac{\sum_{i=1}^{n} (x_{obs}(i) - y_{model}(i))^2}{\sum_{i=1}^{n} (x_{obs}(i) - \overline{x_{obs}})^2} \right]$	0.75 < NSE < 1.00 0.65 < NSE < 0.75 0.50 < NSE < 0.65 NSE < 0.50	Very good Good Satisfactory Unsatisfactory
$\mathrm{PBIAS} = \left[\dfrac{\sum_{i=1}^{n} (x_{obs}(i) - y_{model}(i))}{\sum_{i=1}^{n} (x_{obs}(i))} \cdot 100 \right]$	PBIAS < ±10% ±10%<PBIAS<±15% ±15%<PBIAS<±25% PBIAS>±25%	Very good Good Satisfactory Unsatisfactory
$R^2 = \dfrac{\left[\sum_{i}^{n} (x_{obs}(i) - \overline{x}_{obs})\,(y_{model}(i) - \overline{y}_{model}) \right]^2}{\sum_{i}^{n} (x_{obs}(i) - \overline{x}_{obs})^2 \sum_{i}^{n} (y_{model}(i) - \overline{y}_{model})^2}$	$R^2 > 0.5$	Satisfactory

4.2.5 The Soil & Water Assessment Tool Calibration Results: Performance Analysis

The various calibration performance indicators from the calibrated models for the simulated watersheds are provided below in Table 4-5. Based on the performance rating table presented in the previous section, while Nash-Sutcliffe Efficiency was unsatisfactory for 18 out of 32 watersheds, the calibration for most watersheds resulted in satisfactory (or better) ratings per the coefficient of determination and percent bias criteria (each with 21 out of 32 sites ranking satisfactory or better).

Table 4-5: The Soil & Water Assessment Tool Calibration Results from the Calibrated Models Tabulated per the Calibration Performance Indicators

Watershed	Sub-basin ID	Gage ID	R^2	NSE	bR2	PBIAS	KGE	Mean_sim (Mean_obs)	StdDev_sim (StdDev_obs)
Beals	6	08123800	0.35	0.19	0.20	-6.3	0.58	0.82(0.77)	2.26(2.30)
Brady	3	08144800	0.16	0.06	0.05	9.8	0.33	0.01(0.01)	0.01(0.01)
Conchos	75	08128400	0.13	0.11	0.01	40.7	-0.04	0.17(0.29)	0.27(0.94)
Conchos	08	08129300	0.54	0.51	0.23	-18	0.48	0.28(0.24)	0.52(0.89)
Conchos	12	08130500	0.34	0.23	0.18	-33.7	0.45	0.23(0.17)	0.68(0.75)
Lake Mcqueeny	10	08165500	0.52	0.09	0.52	0.6	0.53	1.94(1.95)	3.72(2.69)
Lake Mcqueeny	14	08166200	0.54	0.22	0.52	15.8	0.57	3.00(3.57)	5.94(4.58)
Lake Mcqueeny	25	08167000	0.79	0.74	0.75	21.1	0.75	5.79(7.34)	13.70(12.81)
Lake Mcqueeny	35	08167500	0.77	0.74	0.69	18.9	0.77	10.33(12.74)	25.00(24.42)
Lake Mcqueeny	40	08168500	0.32	0.00	0.20	23.9	0.49	12.37(16.25)	28.24(25.50)
Leon	5	08181480	0.83	0.77	0.51	-25.7	0.58	1.55(1.24)	2.59(3.79)
Llano	3	08150000	0.72	0.68	0.52	36.5	0.58	3.36(5.30)	8.62(10.00)
Llano	26	08148500	0.72	0.71	0.46	-1.3	0.72	1.12(1.11)	2.13(2.80)
Llano	48	08149900	0.98	0.95	0.86	33.7	0.65	1.83(2.76)	5.77(6.48)
Lower Pecos	88	08447000	0.67	0.36	0.60	15.4	0.56	0.75(0.89)	1.80(1.31)
Medina	10	08178880	0.73	0.71	0.44	2.3	0.66	4.03(4.13)	8.58(12.31)
Medina	24	08180700	0.48	0.06	0.44	-18.3	0.51	6.11(5.16)	19.24(14.45)
Medina	29	08181500	0.62	0.51	0.53	17.3	0.71	7.29(8.81)	21.06(19.20)
Onion Creek	4	08158700	0.54	0.44	0.41	2.1	0.73	1.49(1.53)	2.94(2.81)
Onion Creek	5	08158827	0.63	0.12	0.58	-116.4	-0.24	2.43(1.12)	4.30(3.13)
Pecos Head	70	08424500	0.13	-0.33	0.05	27.5	0.31	0.41(0.56)	0.85(0.83)
Pecos Head	25	08431700	0.04	-0.82	0.01	-2.3	0.20	0.92(0.90)	1.66(1.46)
Plum Creek	3	08172400	0.77	0.77	0.61	-11.4	0.81	1.77(1.58)	3.54(3.93)
Rio Grande	20	08376300	0.15	0.14	0.02	-14.8	0.14	0.02(0.02)	0.06(0.15)
San Antonio	5	08178800	0.70	0.35	0.61	-46.5	0.39	2.13(1.46)	3.47(2.55)
San Antonio	9	08178565	0.63	0.50	0.42	39.5	0.52	2.34(3.86)	3.47(4.21)
San Marcos	9	08171000	0.69	0.66	0.57	-0.4	0.83	4.85(4.83)	9.35(9.34)
San Marcos	13	08171400	0.56	-0.42	0.43	-5.3	0.22	9.44(8.97)	13.38(7.69)
San Saba	30	08144500	0.43	0.42	0.17	22.6	0.43	0.99(1.28)	2.02(3.34)
Nueces	19	08190000	0.68	0.60	0.46	53	0.41	2.49(5.29)	7.85(9.59)
Nueces	38	08190500	0.48	0.26	0.38	-62.1	0.29	1.35(0.83)	4.01(3.49)
Nueces	46	08192000	0.60	0.55	0.46	0.5	0.77	4.56(4.58)	13.14(13.21)

4.2.6 The Soil & Water Assessment Tool Model Results

Recharge results from all the watersheds have been compiled and presented together in Figure 4-20 as an average over the period January 1, 1984, to December 31, 2018. Detailed model results on a monthly and annual basis are provided in the geodatabase deliverable for the Soil & Water Assessment Tool modeling task. Please note that the native units of recharge for the Soil & Water Assessment Tool model are millimeters. However, we converted those units to inches for presentation in this report. Chapter 6 contains a detailed discussion of the recharge results.

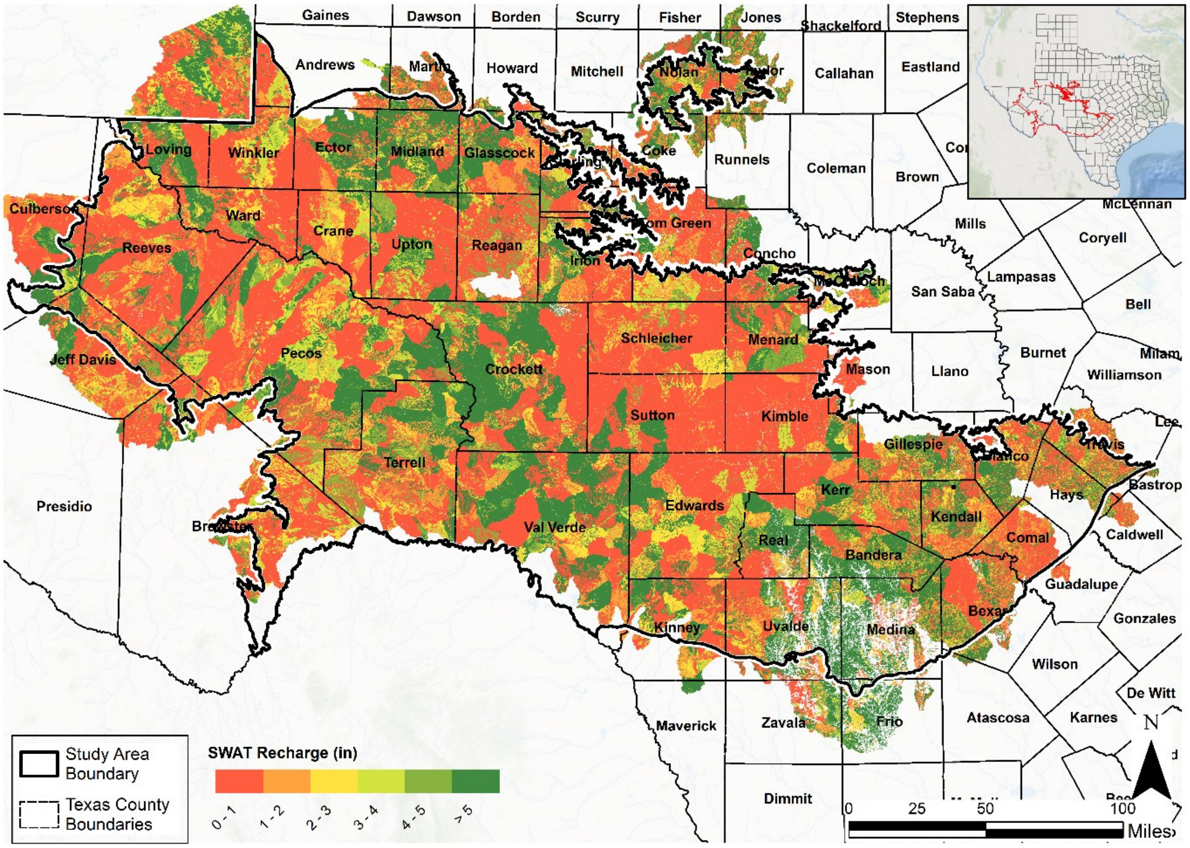


Figure 4-20: Soil & Water Assessment Tool Recharge Values for the Study Area Calculated for the Model Simulation Period

4.3 Groundwater Toolbox: Recharge Estimates

Figure 4-21 presents the location of United States Geological Survey stream gages from which data was used within the Groundwater Toolbox in order to compute estimated monthly, quarterly, and annual recharge values. Gages were selected that had a sufficiently long period of record. Certain gages did not have 100 percent complete data availability for all months and/or years of this period of record. In instances where RECESS or RORA was unable to perform computations due to incomplete records, simulations were setup manually to exclude the periods missing data. We downloaded available data from 794 stream gages located within and around the study area and accessible from the United States Geological Survey National Water Information System website. Of these 794 stream gages, 237 were found to contain valid and sufficient data for the project.

4.3.1 Groundwater Toolbox Model Setup

In applying the RECESS and RORA programs toward calculating recharge from the Groundwater Toolbox, we applied the following procedures for each stream gage dataset. These procedures were developed based on our review of the RECESS and RORA manuals, as well as our experience in applying the methods during this project effort.

First, a relatively short range of analysis for the RECESS recession coefficient calculations was selected. W chose to perform separate analyses for each decade of data within the period of record (POR), thereby allowing for possible changes in the appropriate streamflow recession index to occur over time. The team also found that performing analyses on 10-years of data was more manageable than performing analyses on an entire longer period of record.

Second, the RECESS analysis period the months outside of the normal irrigation season was further refined in an effort to minimize the impact that irrigation diversions and riparian evapotranspiration may have on the streamflow recession rates.

Third, the team specified a minimum flow recession length of five days. This instructed the RECESS program to analyze the daily streamflow data and only identify recession segments lasting at least five days. Our selection of the five-day minimum was subjective; it yielded a large number of identified peaks for our temporally limited datasets, while filtering out one or two extreme recession index values present within a dataset.

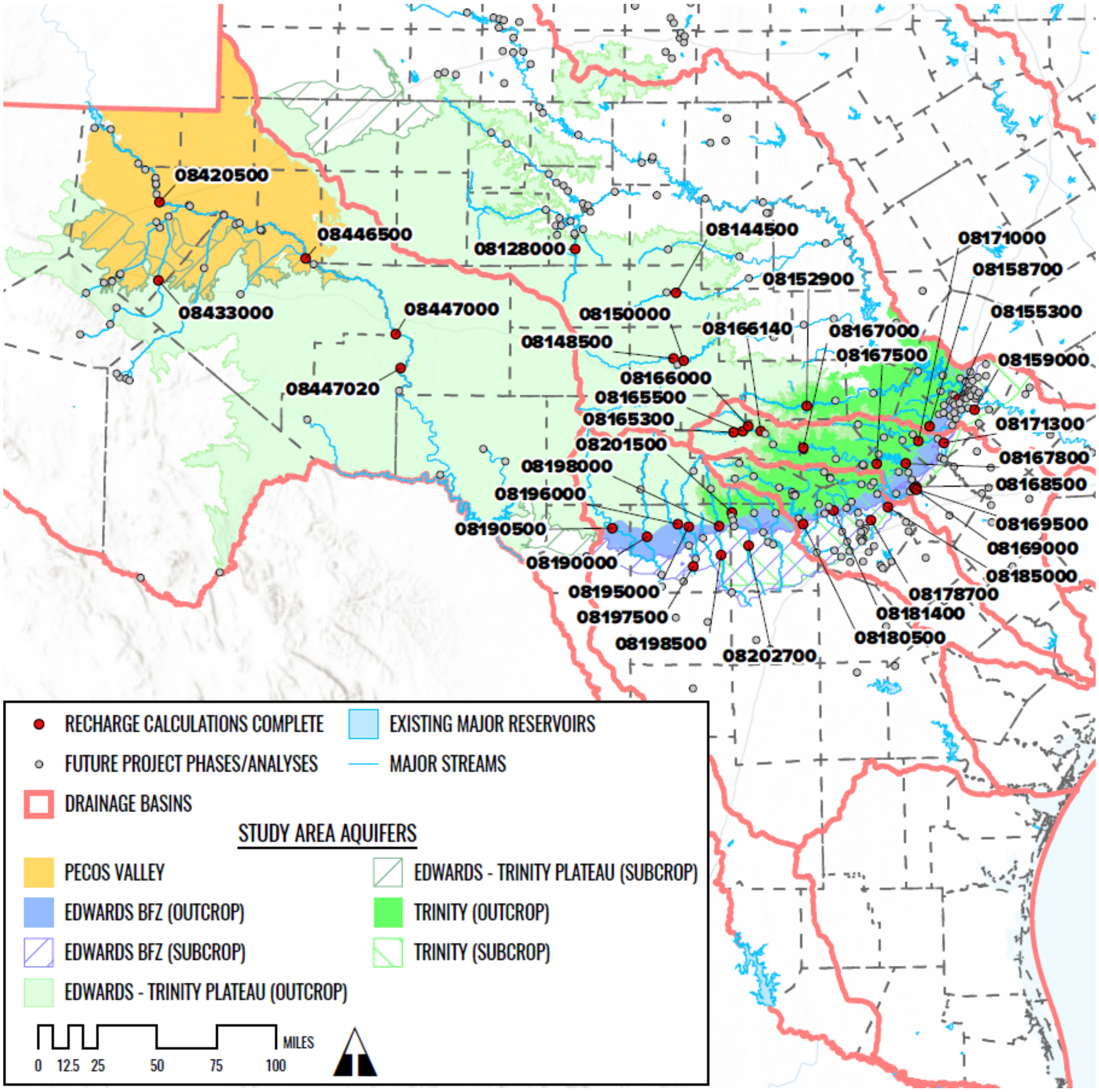


Figure 4-21: Study Area Map Showing United States Geological Survey Stream Gages Used in Groundwater Toolbox Recharge Analyses

Next, we manually reviewed and selected recession segments to include when calculating the median recession index and can select which portion of the identified recession time series will produce the best result. Typically, this is achieved by selecting portions of the dataset which best fits a linear relationship between log discharge (Q) and time (T).

The RORA program then uses the RECESS median recession index to calculate a time-series of recharge over the specified analysis period. RORA does not exclude peaks occurring within the irrigation season months, as was specified within the RECESS simulations. RORA has the additional input of Drainage Area and Requirement of Antecedent Recession. RORA uses to convert the total recharge volume to a height of water for the contributing area, assuming that groundwater divides coincide with surface topography. Because this assumption may not hold true in this study area, a dummy value of one square mile was input to RORA and the results are reported here as volume. The RORA recharge height output should be disregarded. The specified a value of two days for the “Requirement of Antecedent Recession” to increase the number of separate peaks included within the RORA recharge calculation process. Groundwater Toolbox writes the computed recharge to annual, monthly, and quarterly results files.

4.3.2 Recharge Calculation: Results Variation Due to Processing Procedures

As the process for computing recharge with RECESS and RORA involves individual interpretations of streamflow data, it is possible that results will vary as different users make different decisions regarding data inclusion. To quantify this uncertainty, we performed a series of tests regarding data processing methods. These tests are described below and were instrumental in developing the calculation procedures discussed in the previous section. For each test below, we utilized data from the United States Geological Survey gage #08446500 describing streamflow in the Pecos River near Girvin, Texas.

4.3.2.1 Time Period Selection Impacts

In this section, we present the results of our investigation into the impact of the Analysis Dates on the computed recharge results. The Analysis Dates are specified, and they dictate the time period over which streamflow recession is to be considered in computing a median recession index. The Analysis Dates are then carried over from RECESS into RORA and the computation of recharge. As described in the previous section, our adopted procedure is to specify decadal Analysis Dates when computing median recession indices and recharge. This decision allowed for the use of different median recession indices over the period of record for a given gage. An alternative approach would be to use the entire period of record for computing a single median recession index (which is then applicable to the entire streamflow dataset).

Table 4-6 presents the RECESS-computed median recession indices for gage #08446500 based on different specified analysis dates. As shown, values specified by decade ranged from 43.6 to 89.4, whereas the value computed for the entire period of record (1940-2020) was 143.6. This does suggest that the applicable recession index may change overtime for a given stream system. Such changes are likely reflective of geomorphological changes in the riparian system, but could also reflect increased water diversions, rainfall/runoff changes, and changes in aquifer water content.

RORA-calculated annual recharge results are presented for gage #08446500 in Figure 4-22(A). The results shown in GREEN were computed using median recession indices computed by decade. Results shown in BLACK were computed using a single median recession index based on the entire gaged period of record (1940-2020). The difference in computed annual recharge (defined as the GREEN results minus the BLACK results) ranged between -3,000 and 6,000 acre-feet per year., with an apparent transition around 1999 (Figure 4-22(B)).

Prior to 1999, results obtained with decadal median recession curves suggested greater recharge, whereas after 1999 greater recharge was indicated when using the full period of record median recession curve. The percentage difference in recharge was also greater prior to 1999, approaching 20 percent in 1984 (Figure 4-22(C)).

Based on the variation in median recession indices by decade (Table 4-6), we determined improved results were likely obtained by limiting analysis periods by decade and computing separate median recession indices for each decade.

Table 4-6: RECESS-Computed Median Recession Indices by Analysis Dates - Gage #08446500

Time Period	Median Recession Index
1980-1989	43.6
1990-1999	89.4
2000-2009	85.3
2010-2020	64.75
1940-2020	143.6

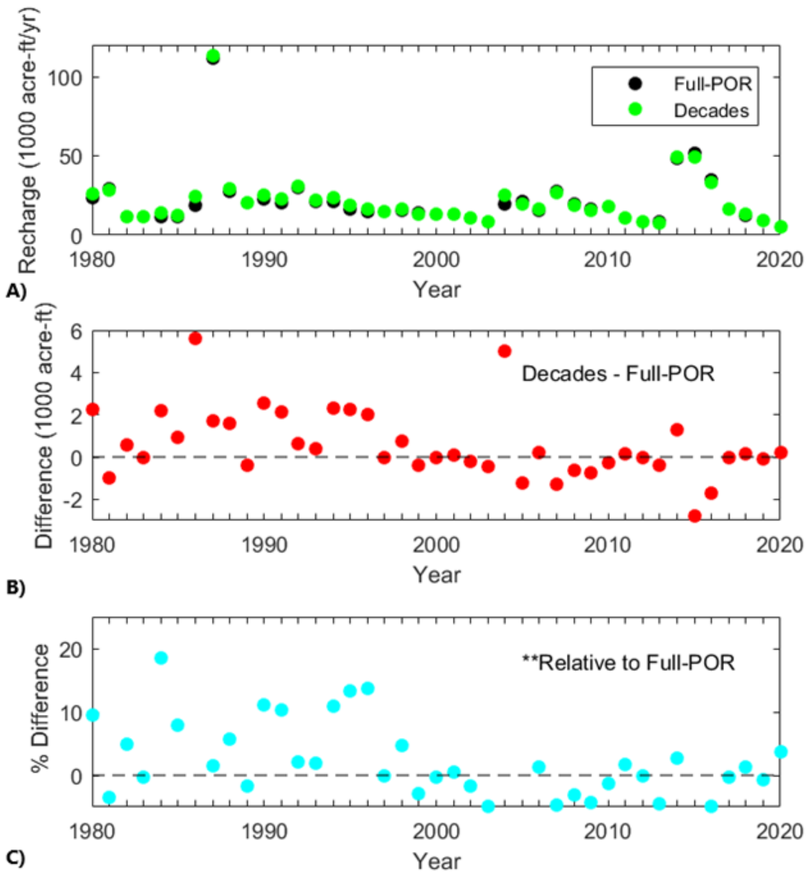


Figure 4-22: RORA Results for Gage #08446500 When Derived from Different Analysis Periods. A) Computed Recharge; B) Recharge Differences, and C) Percentage Differences Relative to Recharge Computed Based on the Full Period of Record Recession Index

4.3.2.2 Seasons & Selections Impact

To assess the relative importance of peak identification and definition, recharge results were calculated following various procedures within RECESS. Specifically, results were obtained under the following four sets of procedures:

- "All" - Accepting all identified peaks, irrespective of the month of year or the datapoints included in each recession sequence
- "Winter Only" – Accepting all identified peaks within the non-irrigation season months (October-March), and including all datapoints within each recession sequence
- "Winter Selected" - Accepting all identified peaks within the non-irrigation season months (October-March) yet limiting each recession sequence to contain only data suggesting a strong linear relationship between log(discharge) and time.
- "Winter Selected by Decade" - Accepting all identified peaks within the non-irrigation season months (October-March), limiting each recession sequence to contain only data suggesting a strong linear relationship between log(discharge) and time, and limiting analysis periods to decades.

The resulting monthly recharge values for year 2011 are shown in Figure 4-23, with recharge reported in acre-feet per month. Results are generally comparable between the "All," "Winter Only," and "Winter Selected" datasets, with greater differences determined for the "Winter selected by Decade" dataset.

As the comparative results shown in Figure 4-22 were also representative of results obtained for other years in the period of record for gage 08446500, we determined that defining median recession indices by decade was more influential to the computed recharge than was limiting the peak identification and recession sequence datapoints. We chose to limit the analyses to non-irrigation season months (the "Winter") based options shown in Figure 4-23 more based on the recommendations in the RECESS documentation than on our observations of the impact on the computed recharge results. We also chose to limit the recession sequences to periods which best generated linear relationships between log(discharge) and time as doing so is consistent with the theory behind the RECESS and RORA calculation processes.

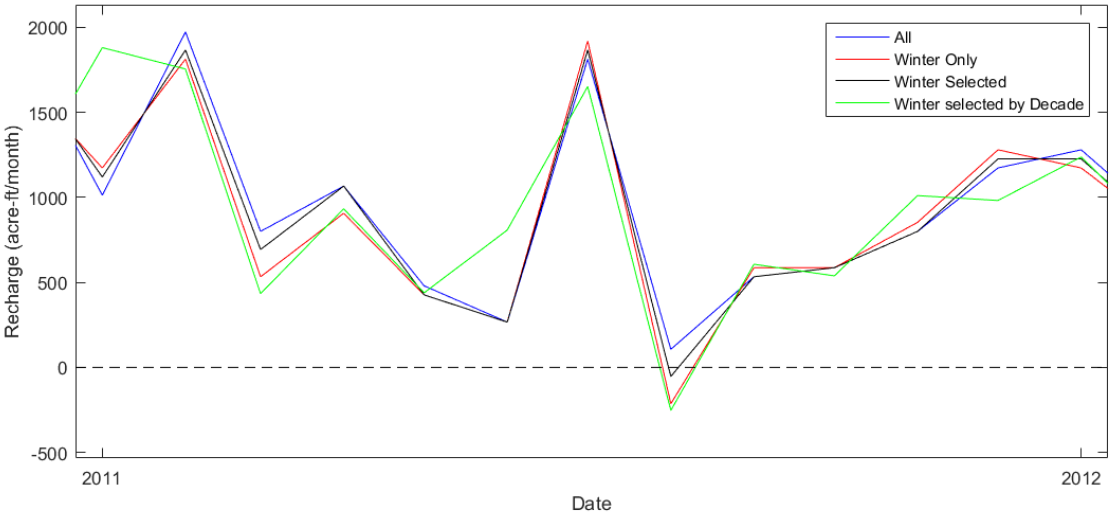


Figure 4-23: Computed Monthly Recharge for 2011 for Gage #08446500, Using Variations in Selection Criteria for Peak Identification and Duration

4.3.3 Groundwater Toolbox: RORA RECESS Results

Appendix C presents the computed annual recharge for each of the 33 stream gage datasets for the period 1981 through 2020. Data is presented as the total acre-feet of water recharged by year at the gage location. Missing data are shown as "0" acre-feet. If data are missing for any entire calendar year, then the value "NA" is presented within Appendix C. The greatest amount of annual recharge (1,619,955 acre-feet) was computed for 1998 at gage #08167800 for the Guadalupe River at Sattler, Texas.

Figure 4-24 presents a graphical representation of the computed recharge at the United States Geological Survey gage #08446500, Pecos River near Girvin, Texas. This gage has a period of record from 1939 through 2019, and RECESS and RORA were executed for each decade over this period. Results indicate that the greatest amount of recharge occurred in 1941 and 1942, when stream flows were high. The reduction in recharge after this period is not reflective of any reservoir construction within the watershed, as Red Bluff Reservoir (located upstream on the Pecos River) was completed in 1935 prior to the available stream gage data. Data for the period of record for this project shows recharge ranging from 5,160 acre-feet in 2020 to 1,169,396 acre-feet in 1941 (Figure 4-24). The median recharge over this time period is 19,245 acre-feet per year.

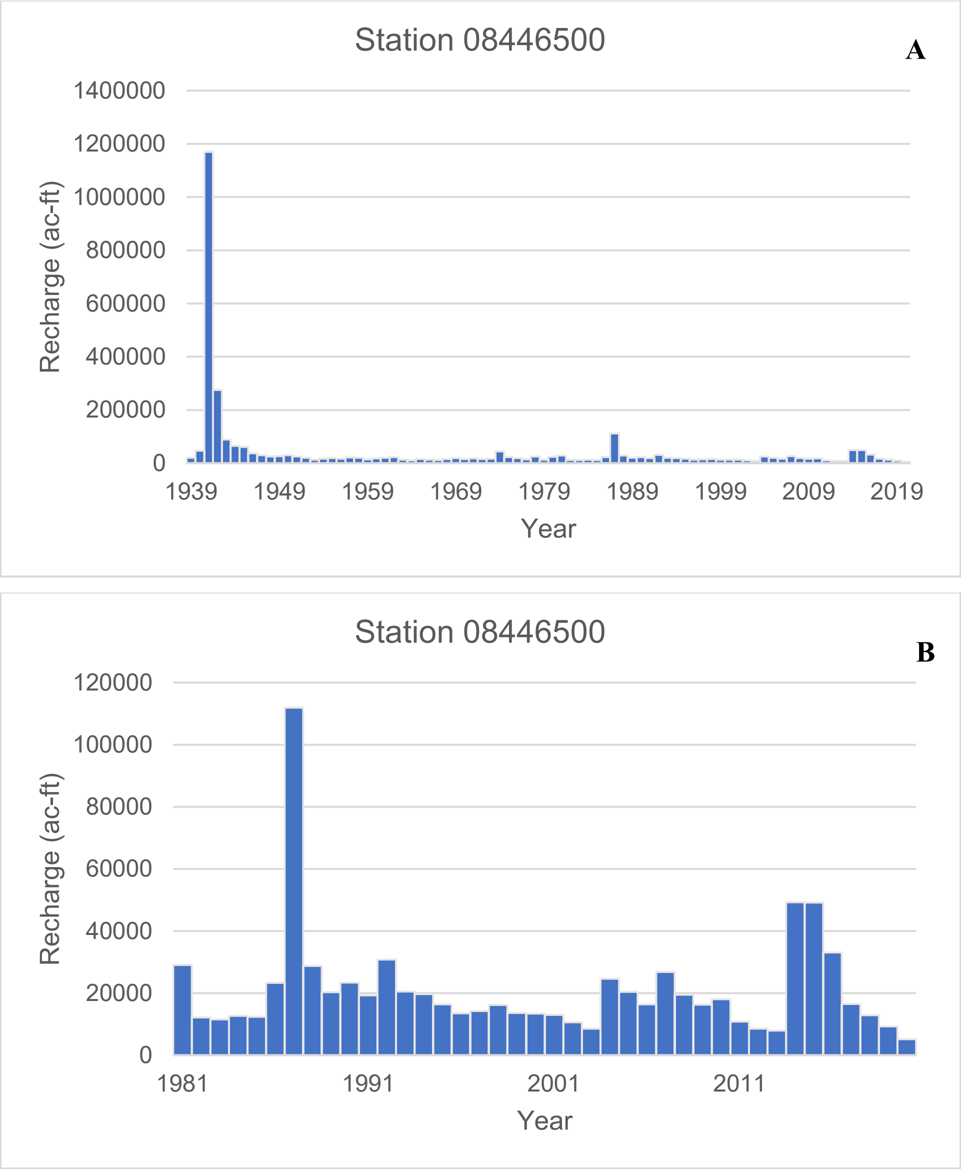


Figure 4-24: Station #08446500 RORA Recharge Results for A) the Period of Record and B) the Time Period of Interest

4.4 Rapid Recharge Assessment Tool (Based on Soil Conservation Services Curve Number Method)

The rapid recharge assessment method described in Chapter 2 was employed to obtain monthly estimates of recharge for the period January 1, 1984, through December 31, 2018. The average recharge over that period is presented in the Figure 4-25 below, monthly, and annual averaged datasets are provided in the geodatabase deliverables submitted with this report. A more detailed discussion on the recharge results is provided in Chapter 6 (comparative analysis).

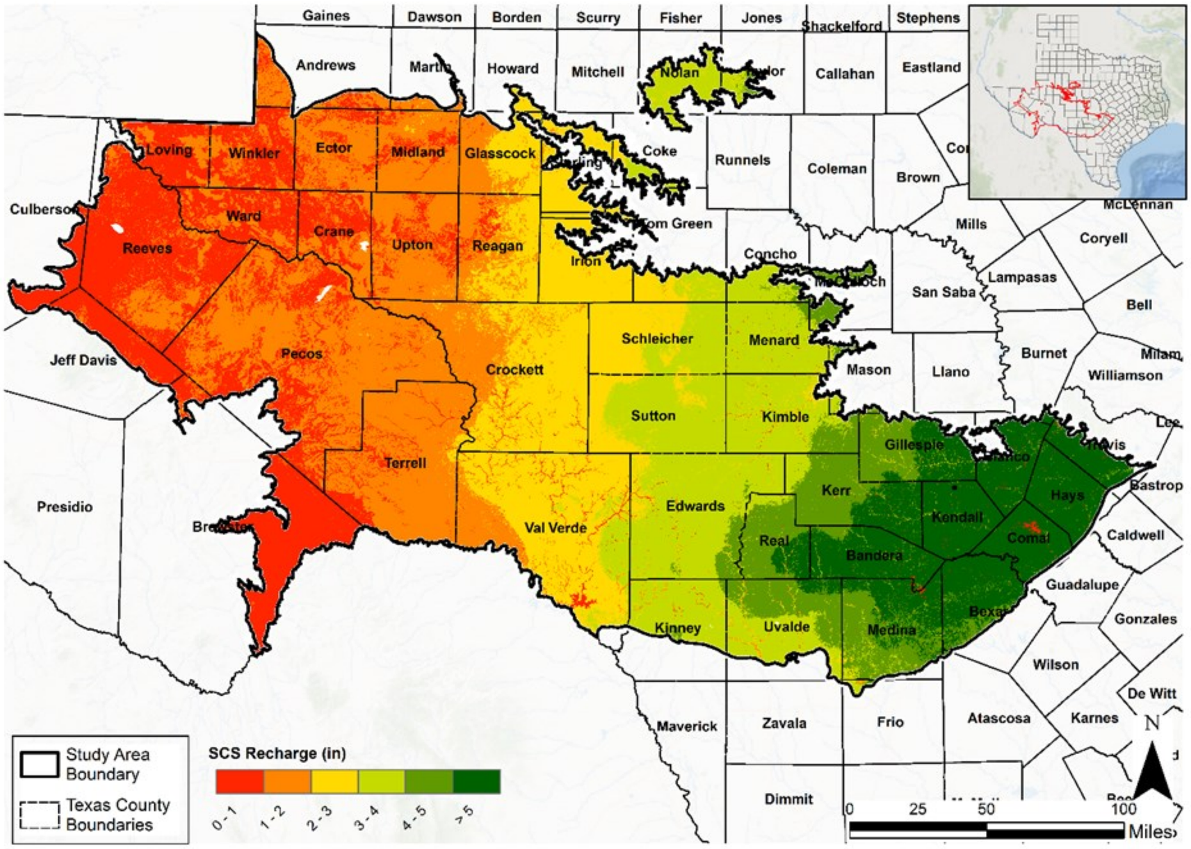


Figure 4-25: Average Recharge Estimates from the Rapid Recharge Assessment Tool (Based on the Soil Conservation Services Curve Number Method) for the Period January 1, 1984 - December 31, 2018

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5. Groundwater – Surface Water Interactions

This chapter provides results from the baseflow separation analysis discussed in Chapter 2. Additional groundwater-surface water interaction data is available within the Soil & Water Assessment Tool modeling task deliverables.

5.1 Baseflow Model Setup

The Base-Flow Index methods tuning parameters, runoff duration (N) and recession coefficient (K'), were assessed following the method outlined in Wahl and Wahl (1995) and the Groundwater Toolbox User Manual (Barlow and others, 2017), for two representative stations in the east and west of the domain Table 5-1. Average streamflow, in cubic feet per second, hydrographs for these stations are shown on Figure 5-1 and Figure 5-2.

Baseflow was calculated for the calendar years 2003 through 2008, which includes two dry years (2006 and 2008), two wet years (2004 and 2007), and two average years (2003, and 2005), as determined by average precipitation recorded by the National Weather Service in 34 counties from 1980 through 2020. Calculations were performed ten times, with the runoff duration parameter (N) set to integer values 1 through 10. The turning point test factor parameter (f) was held constant at the default value of 90 percent as recommended in Wahl and Wahl (1995). The results are shown on Figure 5-3 and Figure 5-4. As expected, the baseflow index decreases with increasing values of runoff duration. There is no clear grouping of the wet and dry years. Neither station shows a consistent relationship between baseflow index and runoff duration, though the curves from several individual years appear to pivot around N=2 or N=3. Accordingly, runoff duration was set to 2 for all stations in the analysis.

The recession parameter in the Base-Flow Index Modified method was calculated directly from the established runoff duration and factor parameters, where $K' = f^{1/N}$, leading to a recession index of K'= 0.94868 days. Default parameters were used for the HySEP and PART methods.

Batch files were created for each of the stations used in the analysis which provided a reproducibility and ease of parameter verification advantage over interactive mode. The HySEP and PART methods could not be run on the stations without drainage area parameter values because area is a required input. However, Base-Flow Index methods do not require area input in the baseflow calculations, and we were able to calculate baseflow for the stations without a defined drainage area. A dummy area of one square-mile was assigned to these stations because Groundwater Toolbox uses the drainage area to convert volumetric baseflow results to a height for all baseflow methods. The baseflow height output is not reported here and should be disregarded for these analyses.

Table 5-1: Representative Station Characteristics

	West Station	East Station
Station ID	8433000	08152000
Station Name	Barrilla Draw nr Saragosa, Texas	Sandy Ck nr Kingsland, Texas
County	Reeves	Llano
Hydrologic Unit Code-8	13070005	12090201
Contributing Area (mi^2)	612	346
Geologic Units (number)	17	32
Slope (percent)	5.32	2.74
Well Density (number/mi^2)	0.0212	0.0015
Stream Condition	Intermittent	Intermittent

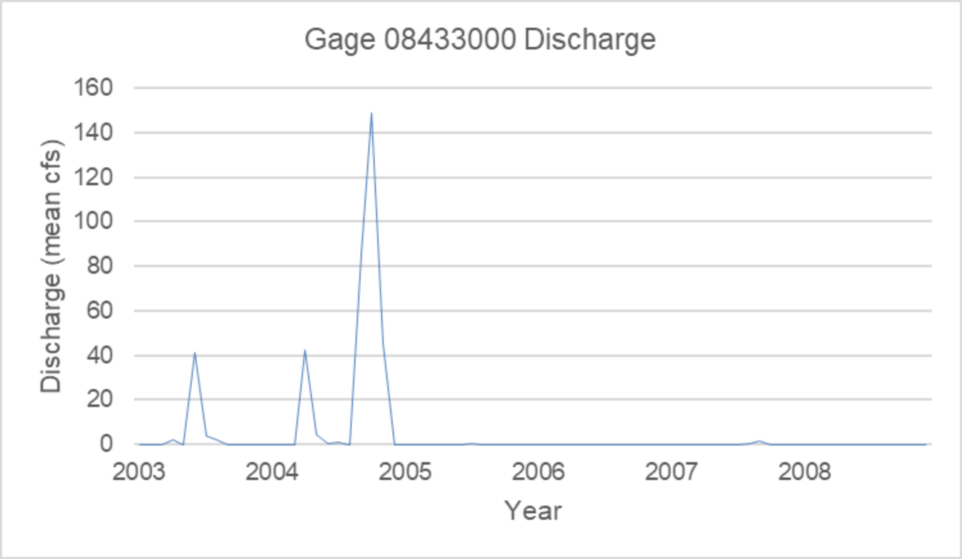

Figure 5-1: Monthly Average Discharge in cubic feet per second (cfs) for Station #08433000

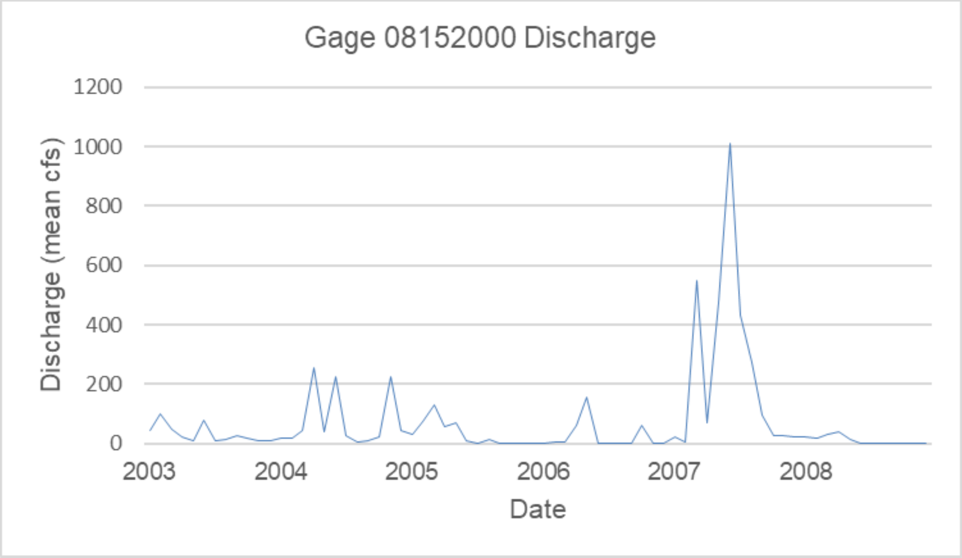

Figure 5-2: Monthly Average Discharge in cubic feet per second (cfs) for Station #08152000

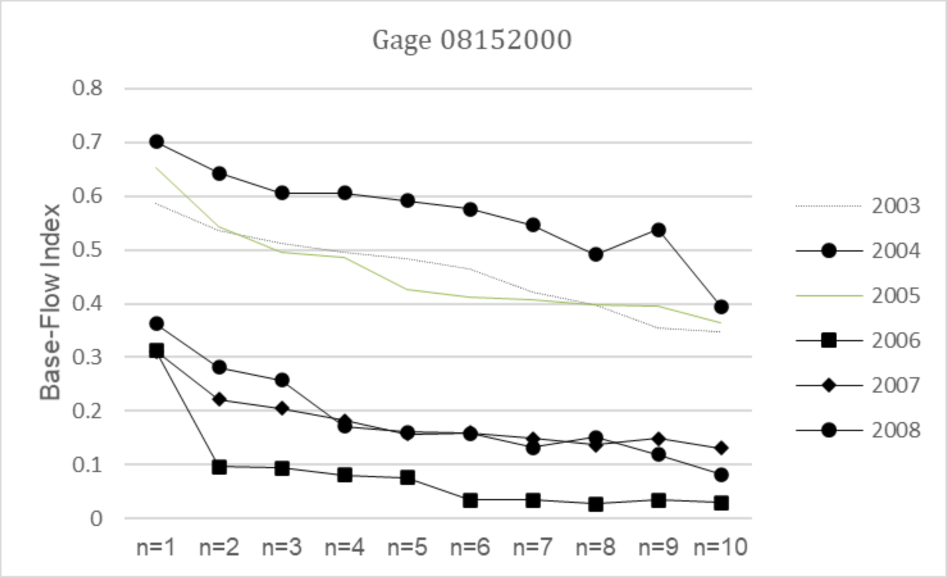

Figure 5-3: Station #08152000, Baseflow Index versus Baseflow Index N Parameter

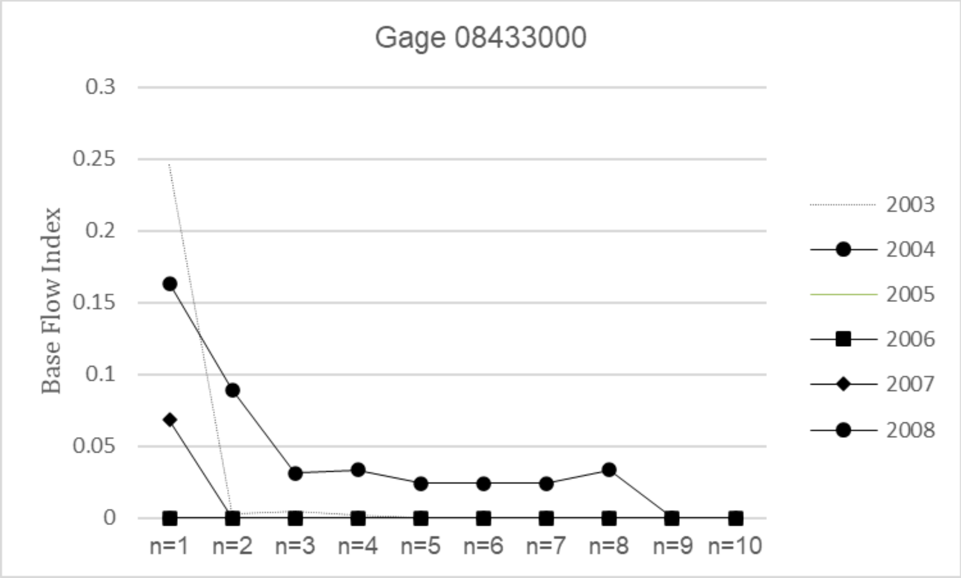

Figure 5-4: Station #08433000, Baseflow Index versus Baseflow Index N Parameter

5.2 Baseflow Calculation Results

Results from the 237 stations are summarized in the section below. Results are assessed in terms of completeness, consistency, and historical trends.

5.2.1 Completeness

Groundwater Toolbox calculates baseflow using each method and outputs an average monthly result reported in cubic feet per second. Groundwater Toolbox will only provide a result for input datasets with a complete month of data. For example, if there is one missing daily stream gage measurement, Groundwater Toolbox will not calculate a baseflow for that month. Since each station has its own period of record within the time-period 1981 through 2018, the number of baseflow records varies for each station. Across the 237 stations, there were 53,705 total complete monthly stream gage records. Figure 5-5 compares the total quantity of baseflow records for each method within the time-period 1981 through 2018. The Base-Flow Index methods produced the greatest number of output because they do not rely on drainage area, which was missing in 27 of the analyzed stations.

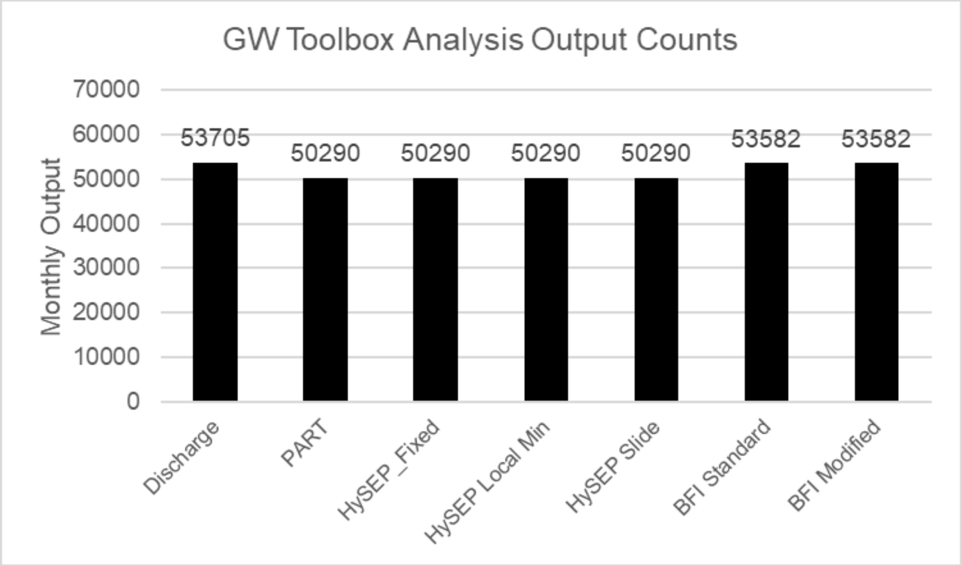

Figure 5-5: Number of Baseflow Records

5.2.2 Consistency

The calculated baseflow results for four stations (08433000, 08152000, 08181800, and 08447020) across the study area were compared to better understand the Groundwater Toolbox methods. The four stations were selected to represent a variety of streamflow and contributing region conditions. Table 5-2 summarizes attributes for the four stations. The calculated baseflow results for these four stations were assessed for the time-period from 2003 through 2008, which includes two dry years (2006 and 2008), two wet years (2004 and 2007), and two average years (2003, and 2005).

Summary statistics were computed for the calculated baseflow results. This includes mean values as well as the 10th, 50th, and 90th percentiles of baseflow values, reported in cubic feet per second. In addition, the coefficient of variation (computed as the standard deviation divided by the mean) was computed across the method summary statistics to assess the relative difference between the baseflow results at each station.

Table 5-2: Station Descriptions and Summary Statistics

	08433000	**08152000**	**08181800**	**08447020**
Station Name	Barrilla Draw near Saragosa	Sandy Creek near Kingsland	San Antonio River near Elmendorf	Independence Creek near Sheffield
Region	Rio Grande	Texas Gulf	Texas Gulf	Rio Grande
County	Reeves	Llano	Bexar	Terrel
Hydrologic Unit Code-8	13070005	12090201	12100301	13070010
Drainage Area (mi^2)	612	346	1743	763
Geologic Units (number)	17	32	23	18
Slope (percent)	5.32	2.74	1.74	2.09
Well Density (number/mi^2)	0.0212	0.0015	1.04	0.07
Stream Condition	Intermittent	Intermittent	Perennial	Perennial

Station 08433000 is on Barrilla Draw in Reeves County. It has a drainage area of 612 square miles. Table 5-3 summarizes the baseflow statistics for the Groundwater Toolbox methods. Discharge and Baseflow timeseries are shown of Figure 5-6. In all methods, baseflow is zero more than 90 percent of the time. Although in absolute terms the difference between the average baseflow from each method is low and the coefficient of variation indicates relatively poor agreement between the methods.

Table 5-3: Station #08433000 Baseflow Summary Statistics in cubic feet per second (cfs)

Method	**Mean**	**10th Percentile**	**50th Percentile**	**90th Percentile**
PART	0.10	0.00	0.00	0.00
HySEP Fixed	0.16	0.00	0.00	0.00
HySEP Local Minimum	0.03	0.00	0.00	0.00
HySEP Slide	0.15	0.00	0.00	0.00
Base-Flow Index Standard	0.41	0.00	0.00	0.00
Base-Flow Index Modified	0.41	0.00	0.00	0.00
Coefficient of Variation	0.70	--	--	--

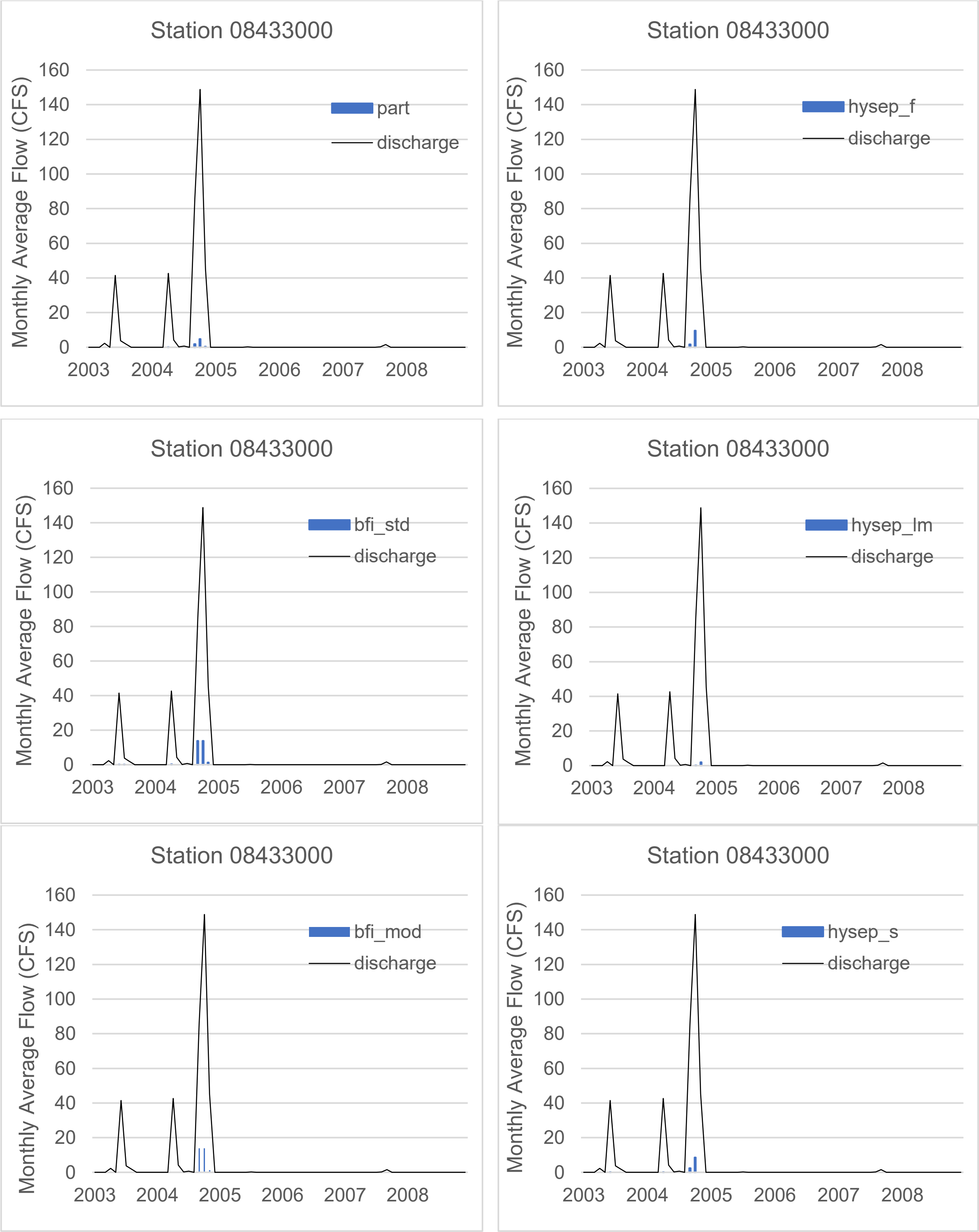

Figure 5-6: Baseflow Separation methods Applied to Station #08433000 in cubic feet per second (cfs)

Gage station 08152000 is in the Llano County with a drainage area of 346 square miles. Table 5.4 summarizes the baseflow statistics for the Groundwater Toolbox methods. Discharge and Baseflow timeseries are shown of Figure 5.7. Baseflow is zero greater than ten percent of the time in all methods. The HySEP local Minimum method yields the lowest baseflows at all percentiles. The coefficient of variation indicates relatively good agreement between the methods.

Table 5-4: Station #08152000 Baseflow Summary Statistics in cubic feet per second (cfs)

Method	Mean	10th Percentile	50th Percentile	90th Percentile
PART	22.56	0.01	8.68	52.97
HySEP Fixed	20.58	0.03	7.64	48.84
HySEP Local Minimum	18.83	0.01	5.79	45.77
HySEP Slide	20.50	0.01	7.74	47.55
Base-Flow Index Standard	20.32	0.01	6.98	50.05
Base-Flow Index Modified	20.23	0.01	6.98	50.02
Coefficient of Variation	0.05	--	0.12	0.05

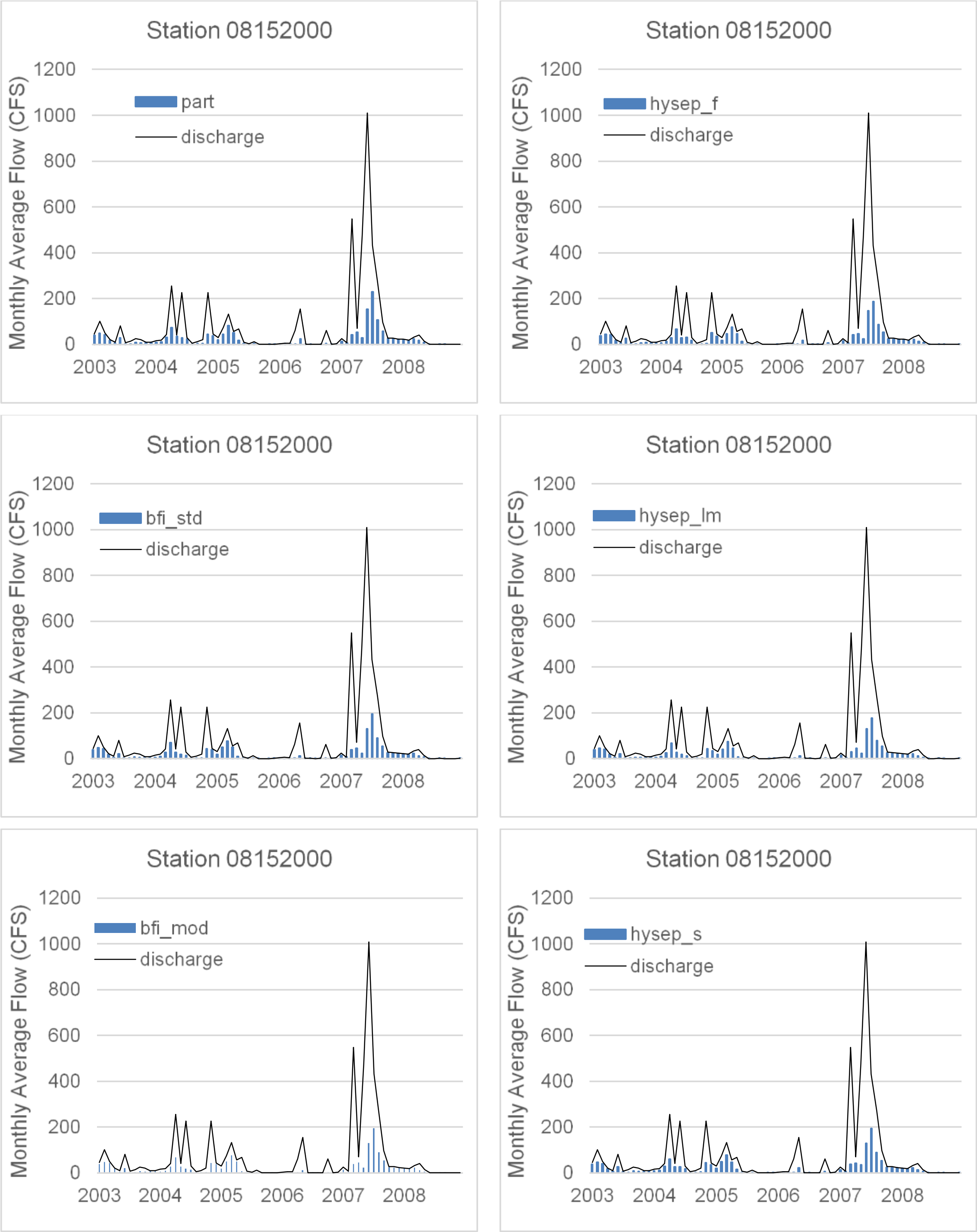

Figure 5-7: Baseflow Separation Methods Applied to Station #08152000

Station 08181800 is on the San Antonio River in Bexar County. It has a drainage area of 1,743 square-miles. A well density of more than one well per square mile in the 12100301 Hydrologic Unit Code-8 sub-basin suggests that the baseflow analysis results may be impacted by well pumping. Table 5-5 summarizes the baseflow statistics for the Groundwater Toolbox methods. Discharge and Baseflow timeseries are shown of Figure 5-8. The Base-Flow Index methods resulted in the greatest baseflow results, at the mean and 10th, 50th, and 90th percentiles. Although in absolute terms the difference between the average flow is low and the coefficient of variation indicates relatively good agreement at all quantiles.

Table 5-5: Station #08181800 Baseflow Summary Statistics in cubic feet per second (cfs)

Method	Mean	10th Percentile	50th Percentile	90th Percentile
PART	488.12	147.00	364.83	1027.28
HySEP Fixed	466.79	135.84	358.79	992.76
HySEP Local Minimum	447.55	124.50	327.76	924.37
HySEP Slide	468.95	132.54	360.63	985.27
Base-Flow Index Standard	499.28	152.78	388.89	1055.19
Base-Flow Index Modified	498.34	151.53	388.10	1069.89
Coefficient of Variation	**0.04**	**0.07**	**0.06**	**0.05**

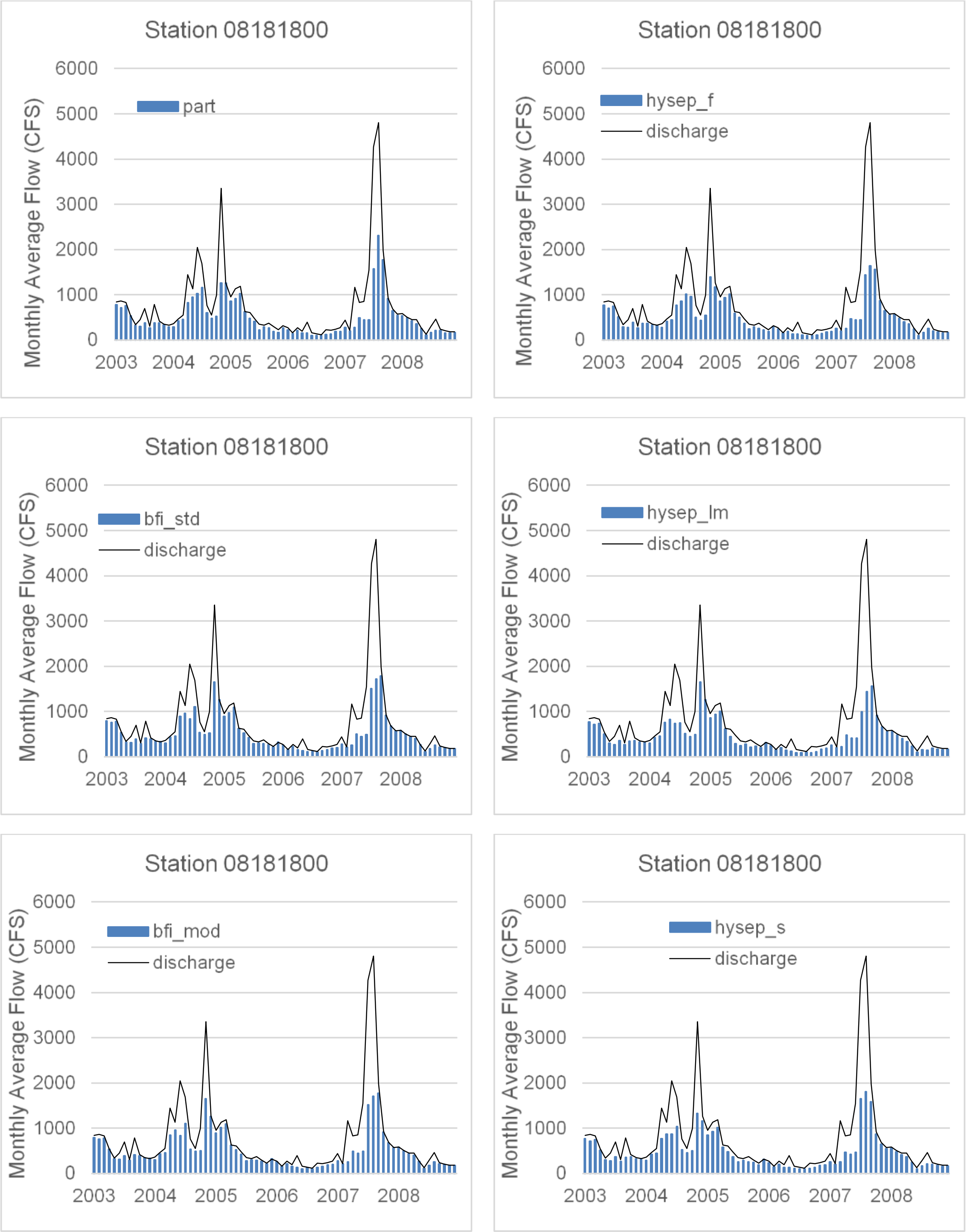

Figure 5-8: Baseflow separation Methods Applied to Station #08181800

Station 08447020 is on Independence Creek in Terrel County. It has a contributing area of 763 square miles. Table 5-6 summarizes the baseflow statistics for the Groundwater Toolbox methods. Discharge and Baseflow timeseries are shown of Figure 5-9. The Base-Flow Index methods resulted in the greatest baseflow results, at the mean and 10th, 50th, and 90th percentiles. The coefficient of variation indicates relatively good agreement at all quantiles.

Table 5-6: Station #08447020 Baseflow Summary Statistics in cubic feet per second (cfs)

Method	**Mean**	**10th Percentile**	**50th Percentile**	**90th Percentile**
PART	28.24	17.12	27.15	41.16
HySEP Fixed	28.18	16.97	27.35	41.15
HySEP Local Minimum	27.43	17.02	27.09	38.34
HySEP Slide	28.13	17.00	27.40	40.75
Base-Flow Index Standard	28.76	17.31	27.82	42.12
Base-Flow Index Modified	28.75	17.35	27.74	42.12
Coefficient of Variation	**0.02**	**0.01**	**0.01**	**0.03**

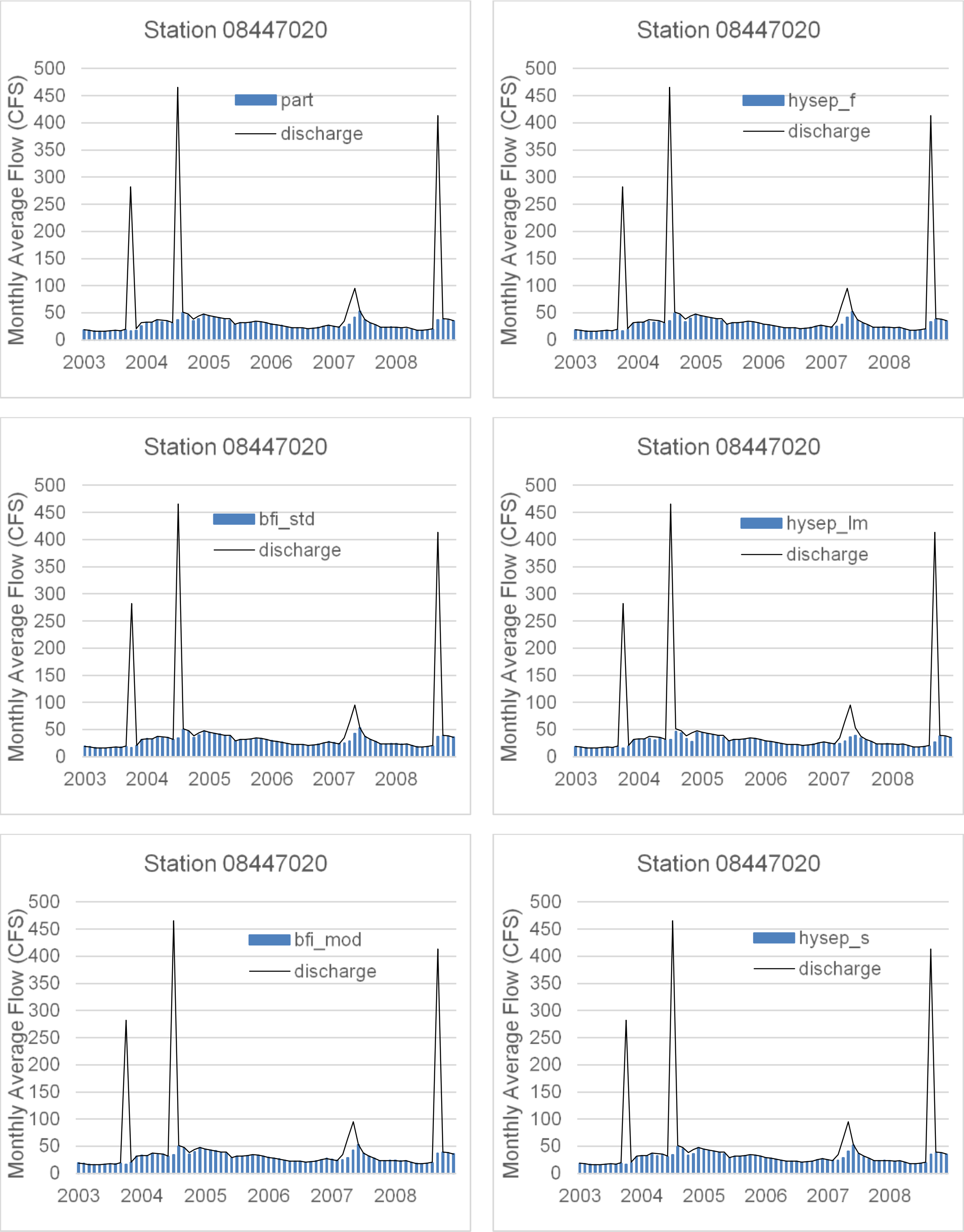

Figure 5-9: Baseflow Separation Methods Applied to Station #08447020

Statistics for the entire dataset were generated for stations that had baseflow estimates for all 6 baseflow methods (Table 5-7). The results show the PART method and HySEP Local Minimum methods are lowest across all quantiles, while the Base-Flow Index methods are the highest. The set of baseflow calculations has a low coefficient of variance across all flow quantiles, indicating that they are generally in agreement with each other.

Table 5-7: All Station Summary in cubic feet per second (cfs) (N=206 stations)

Method	Mean	10th Percentile	50th Percentile	90th Percentile
PART	98.23	0.00	10.79	226.93
HySEP Fixed	117.70	0.00	11.03	233.90
HySEP Local Minimum	105.76	0.00	9.71	213.12
HySEP Slide	117.40	0.00	11.07	234.73
Base-Flow Index Standard	132.29	0.00	11.12	249.71
Base-Flow Index Modified	132.15	0.00	11.08	249.00
Coefficient of Variation	0.11	0.00	0.05	0.05

5.2.3 Historical Trends

A subset of stream gage stations was chosen to compare trends in the Groundwater Toolbox baseflow calculation methods. Twenty stations with continuous data from 1941 through 2018 were selected. The annual stream discharge data for the 20 stations were averaged along with the calculated baseflow for each of the six methods (shown on Figure 5-10). The results show no apparent trend in baseflow or discharge, though interannual variability was high and correlates strongly with streamflow.

Average annual streamflow varies between less than 100 cubic feet per second to nearly 700 cubic feet per second across this set of 20 gages. The calculated baseflow reflects the portion of the streamflow to which groundwater contributes. As such, the baseflow calculations are always less than the streamflow.

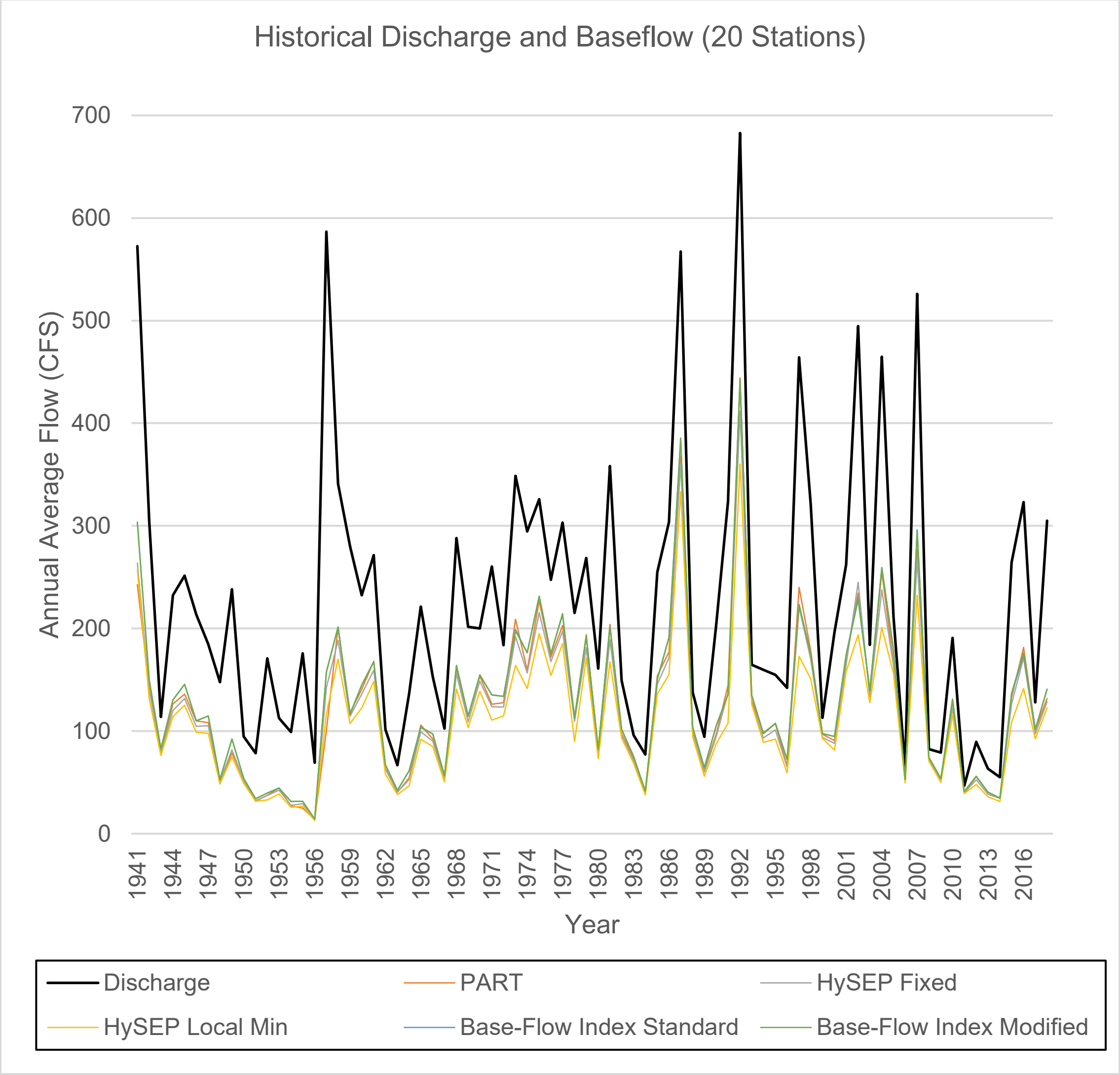

Figure 5-10: Annual Average Discharge and Baseflow by Year Measured in cubic feet per second (cfs)

6. Model Comparative Analysis

Results from all the models and techniques – Soil Water Balance model, the Soil & Water Assessment Tool, Groundwater Toolbox, and remote-sensing have been presented in Chapters 3, 4, and 5. Taken independently, these results provide a reasonable range of recharge estimates for the study area. However, a comparative analysis is required to understand the applicability of these models and the obtained results. This chapter provides results of such a comparative analysis of the different models.

Field-measured estimates of recharge are not available on a regional-scale. Therefore, it is difficult to verify the model results against actual recharge estimates. However, inter-model comparison can also yield interesting insights on model performance. We conducted a thorough inter-model comparison of the results obtained during the study.

A regional-scale recharge estimation is available in literature from the United States Geological Survey (Reitz and others, 2017). This recharge estimation study conducted by the United States Geological Survey is available for the years 2000 through 2013. We have used results from this United States Geological Survey study as base results to conduct our inter-model comparisons.

6.1 Water Budget Estimates from United States Geological Survey (Reitz and Others, 2017)

The United States Geological Survey dataset provided by Reitz and others (2017) was developed using new empirical regressions for estimating: a) runoff, and b) evapotranspiration. Runoff was estimated using the hydrograph separation program (PART). The hydrograph separation program was employed using streamflow data in conjunction with surficial geology, precipitation (from PRISM), and soil hydraulic conductivity (from STATSGO). Evapotranspiration was estimated from water balance estimates at United States Geological Survey gages in conjunction with land cover data (from NLCD), precipitation (from PRISM), and maximum, minimum, and mean daily temperature (from PRISM). Evapotranspiration over open water was estimated separately.

A closed water budget for the various estimated components was ensured by obtaining the total precipitation. United States Geological Survey Water Use datasets were used to estimate the irrigation water use and used as return flow in the calculations to provide additional effective precipitation. The recharge estimates presented by Reitz and others (2017) reflect the effective recharge value which closely approximates the base flow. Effective recharge is the total quantity of water available to replenish the groundwater table. This effective recharge is similar to the net infiltration estimates calculated by the Soil Water Balance model. Total recharge includes the estimated recharge that is intercepted and eventually lost to evapotranspiration. This total recharge is similar to the recharge estimates produced by the Soil & Water Assessment Tool models.

Runoff estimates do not include surficial flow of water from one grid cell to the other. This assumption for runoff calculation is similar to that used for the Soil Conservation Services method model. The United States Geological Survey dataset provided by Reitz and others (2017) contains monthly averaged estimates of evapotranspiration, runoff, and recharge for the period 2000 through 2013.

Overall, the recharge estimates provided by Reitz and others (2017) have a similar underlying input data and methodology to the data and methods used in our study. Therefore, we have confidence in using the results from Reitz and others (2017) as base results for conducting the inter-model comparative analysis of results from our study.

6.2 Annual Averaged Model Results from 1984 through 2018: Qualitative Comparison

We present the results from the three main models used for recharge estimation in our study on the same temporal scale from January 1, 1984, through December 31, 2018. As discussed before, complete PRISM data is available from 1981 onwards. Any historical data before that time has been modeled. Therefore, our models employed the most reliable data from PRISM starting in 1981. Most numerical models require a warm-up period to allow system conditions to stabilize. We have assumed the first three years (1981 through 1983) of the model simulation period to be this warm-up period. The team did not use those results for comparative purposes. The years 1984 through 2018 have been employed as those usable for objectives of this project as referred to as model simulation period, henceforth. Figure 6-1 through Figure 6-9 present the average recharge results over the model simulation years (1984 through 2018) from the three main models employed for spatial estimation of recharge. The results have been overlain on three different base maps (county, aquifer, groundwater conservation district) for a better visualization of model results.

The Figure 6-1 through Figure 6-9 provide for a screening-level comparison of the annual averaged model results obtained from the Soil Water Balance model, Soil & Water Assessment Tool, and the Soil Conservation Services method. Overall, the results show similar trends spatially, with recharge increasing as we move from the western to eastern parts of the study area. Visual observation indicates that Soil Conservation Services method model provides a higher estimate or recharge compared to the Soil Water Balance model or the combined Soil & Water Assessment Tool models. However, the spatial correlation between the results appears to be higher between the Soil Conservation Services method model and the Soil Water Balance model. A primary reason for this higher correlation between the results from the Soil Water Balance model and the Soil Conservation Services method model might be that the same underlying method has been used to estimate evapotranspiration for both these models, namely, the Hargreaves-Samani (1985) method. More details on the input data are provided in Chapter 2.

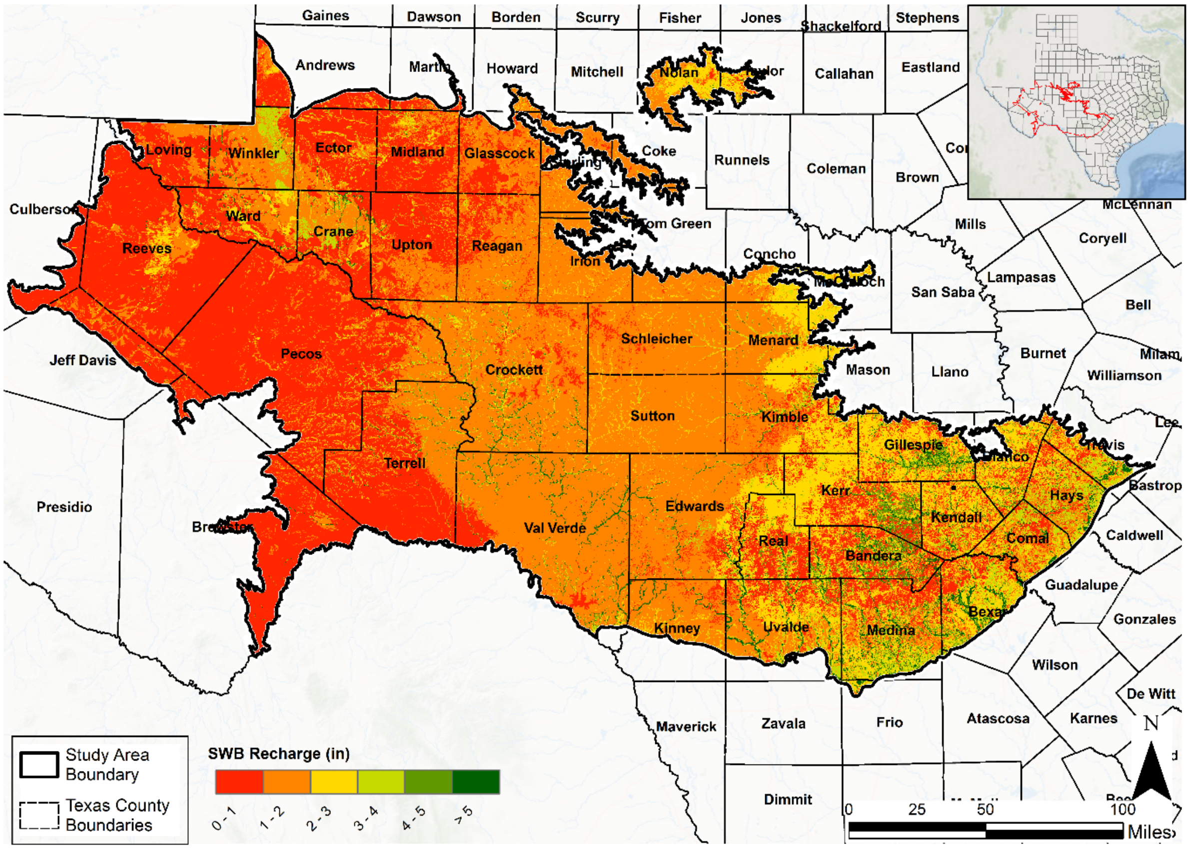

Figure 6-1: Annual Averaged Recharge from the Soil Water Balance Model for the Years 1984 through 2018 for Counties in the Study Area

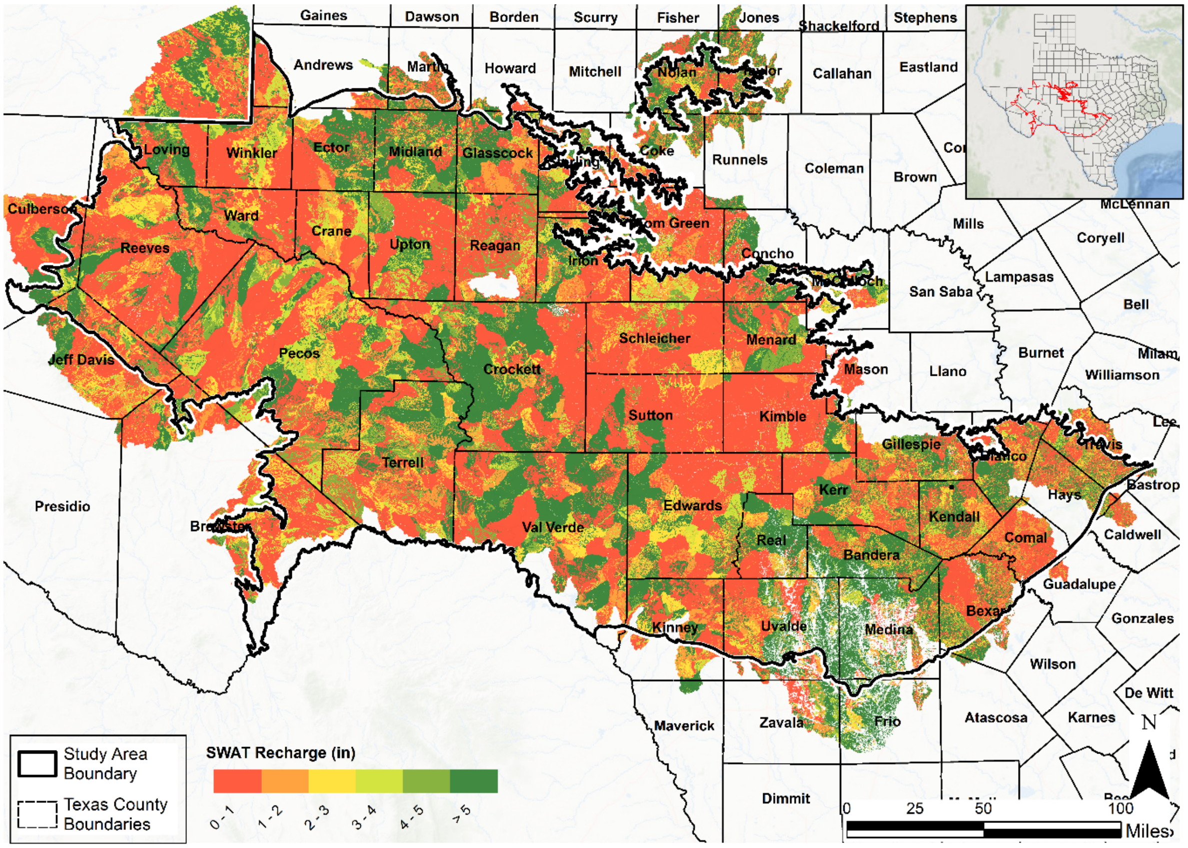

Figure 6-2: Annual Averaged Recharge from the Soil & Water Assessment Tool Models for the Years 1984 through 2018 for Counties in the Study Area

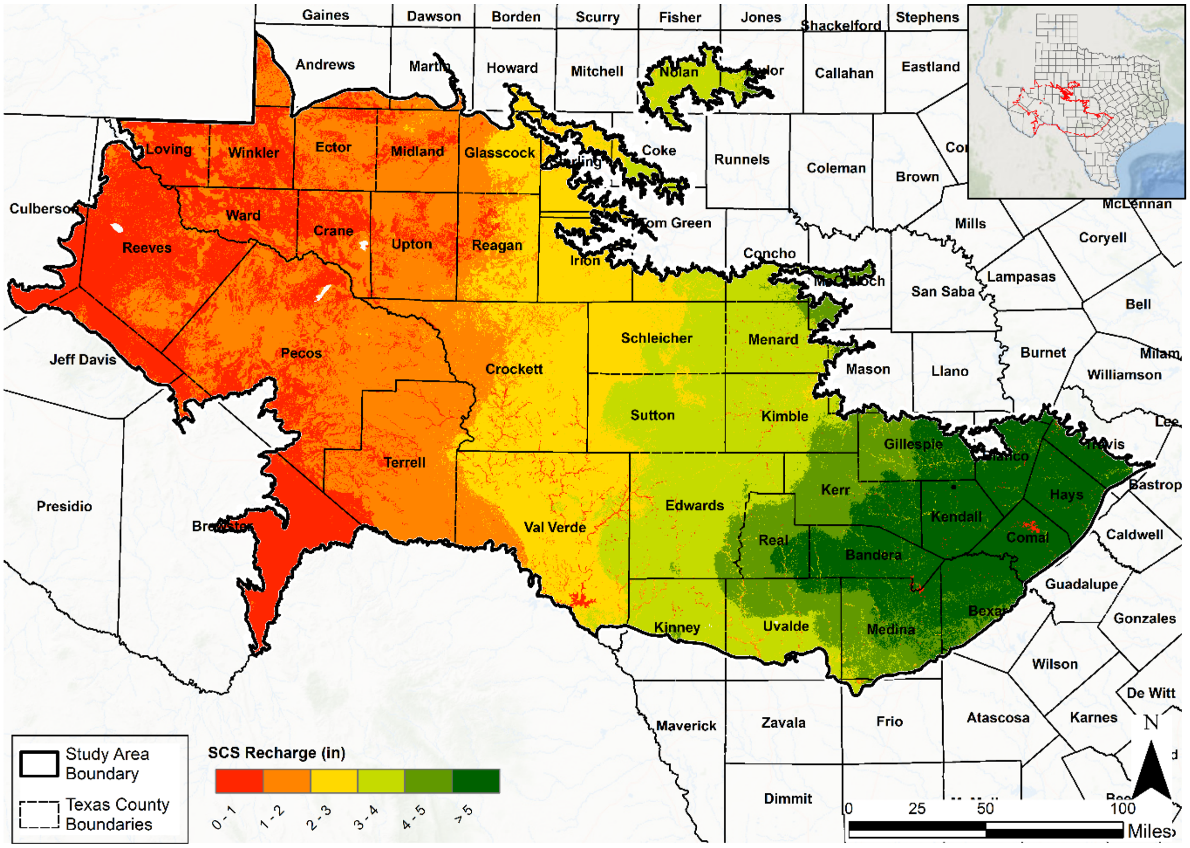

Figure 6-3: Annual Averaged Recharge from the Soil Conservation Services Method Model for the Years 1984 through 2018 for Counties in the Study Area

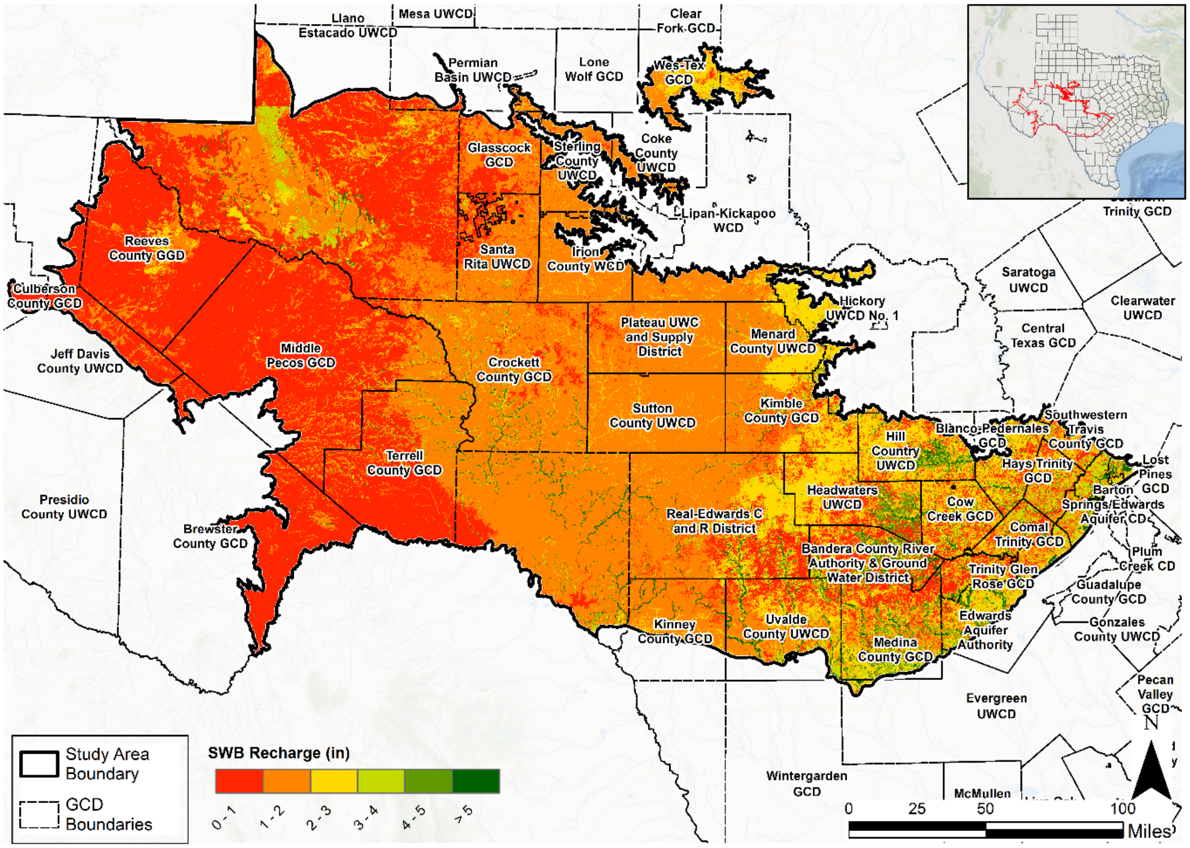

Figure 6-4: Annual Averaged Recharge from the Soil Water Balance Model for Years 1984 through 2018 for Groundwater Conservation Districts in the Study Area

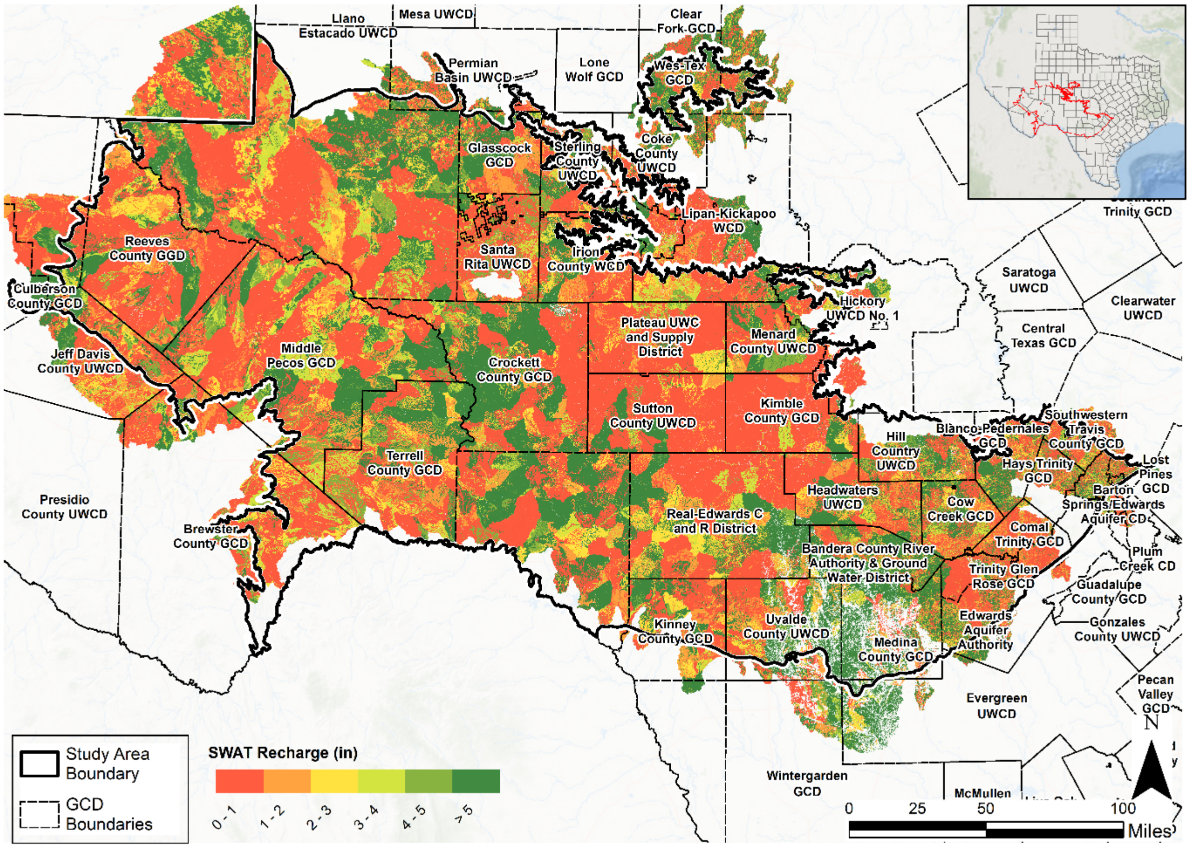

Figure 6-5: Annual Averaged Recharge from the Soil & Water Assessment Tool Models for the Years 1984 through 2018 for Groundwater Conservation Districts in the Study Area

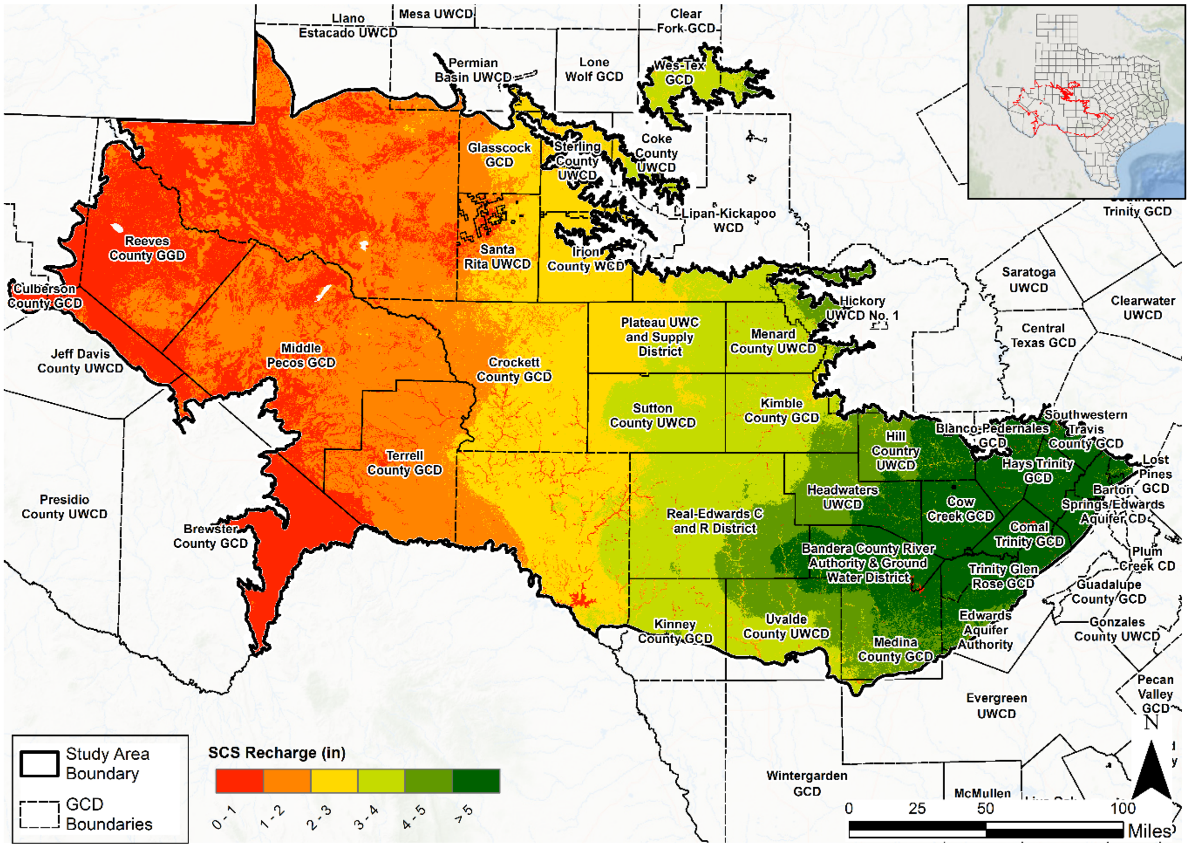

Figure 6-6: Annual Averaged Recharge from the Soil Conservation Services Method Model for the Years 1984 through 2018 for Groundwater Conservation Districts in the Study Area

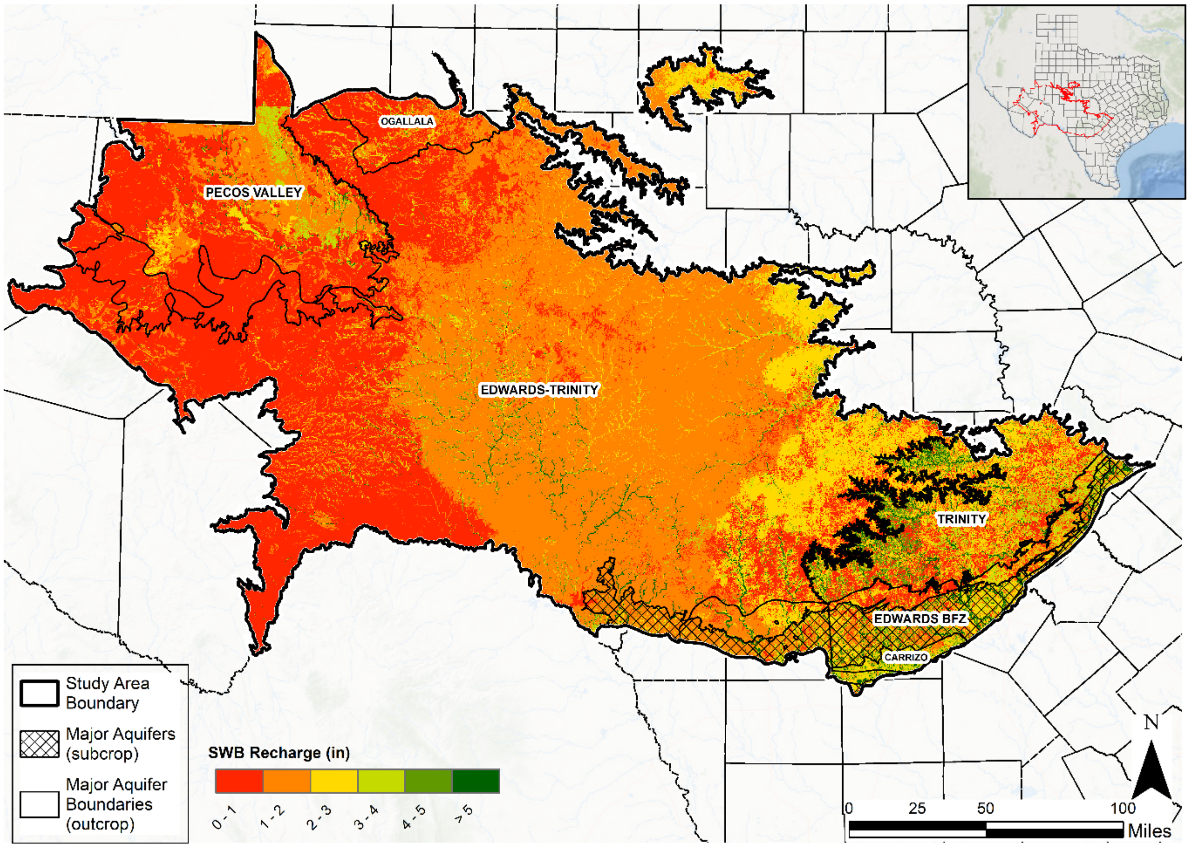

Figure 6-7: Annual Averaged Recharge from the Soil Water Balance Model for the Years 1984 through 2018 for the Aquifers in the Study Area

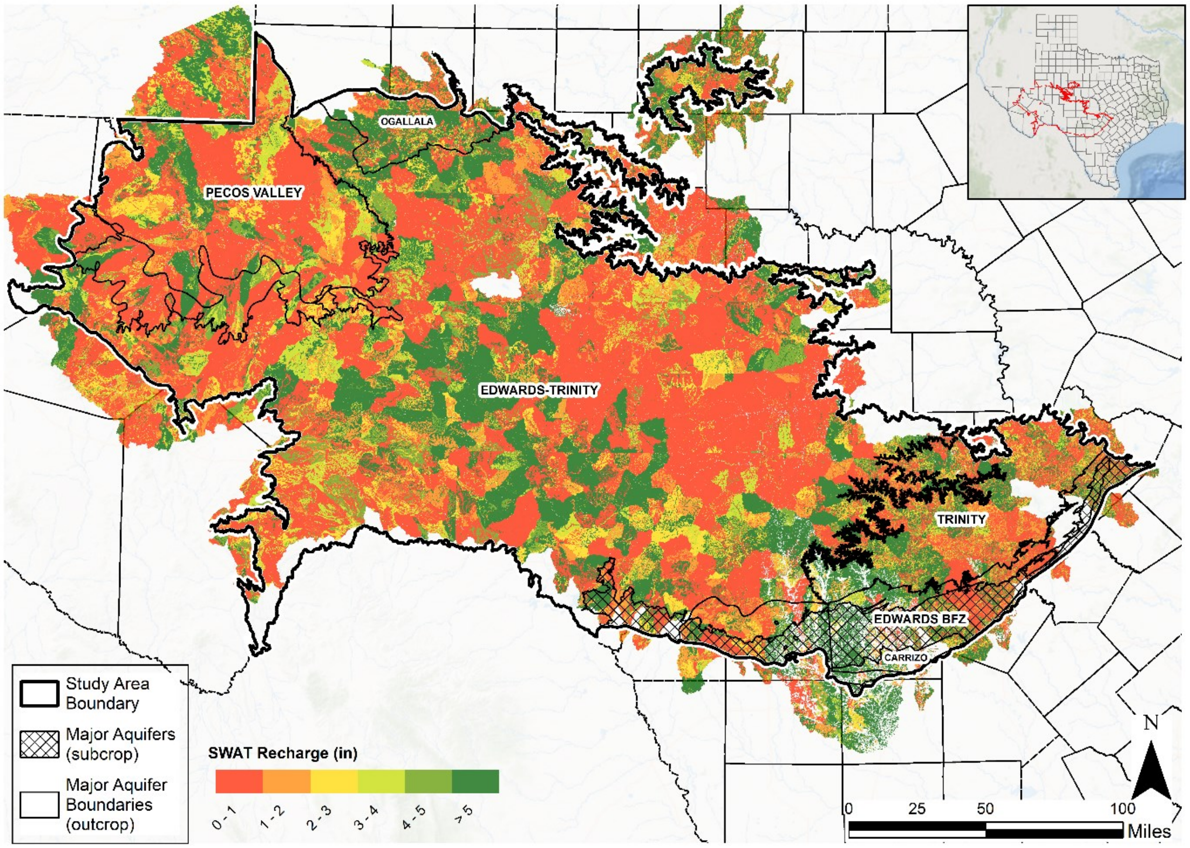

Figure 6-8: Annual Averaged Recharge from the Soil & Water Assessment Tool Models for the Years 1984 through 2018 for the Aquifers in the Study Area

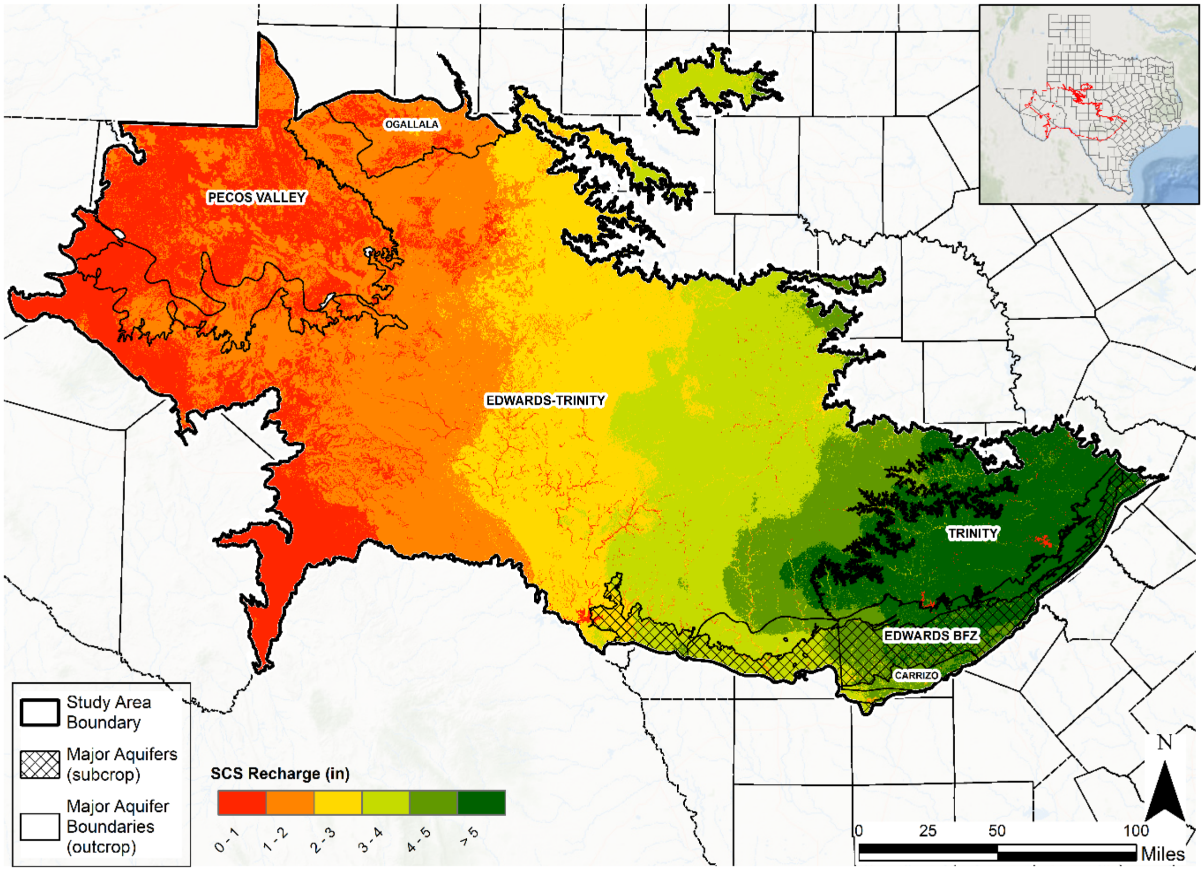

Figure 6-9: Annual Averaged Recharge from the Soil Conservation Services Method Model for the Years 1984 through 2018 for the Aquifers in the Study Area

6.2.1 Annual Averaged Results for Evapotranspiration and Runoff

As discussed earlier, evapotranspiration and runoff are the two largest components of water budget in any basin. Input precipitation values (from PRISM) were plotted along with the estimated evapotranspiration and runoff values from all the models for each of the study aquifers. Figure 6-10 through Figure 6-13 present the average annual estimated evapotranspiration by the Soil Water Balance, Soil & Water Assessment Tool, and United States Geological Survey models for the model simulation period. Average annual estimated runoff from the Soil & Water Assessment Tool, and the United States Geological Survey models are also plotted in these Figures. Please note that the Soil Conservation Services method does not account for runoff routing between model grid cells; therefore, those results are not applicable. The Soil Water Balance accounts for runoff between grid cells during each daily time step but does not provide a robust long-term accounting of overland flow. The United States Geological Survey model also does not account for runoff routing between grid cells and therefore, potentially underestimates the runoff. However, since these runoff estimates have been published and made publicly available by United States Geological Survey, we have included these estimates in our inter-model comparison.

A visual observation of Figure 6-10 through Figure 6-13 shows that evapotranspiration and runoff largely follow the same trend as the precipitation. This is confirming the intuitive understanding that precipitation is the main driver of the water budget. It can also be observed that the estimated evapotranspiration from both the Soil Water Balance model and Soil & Water Assessment Tool models are generally correlated with the evapotranspiration estimated by the United States Geological Survey model. Visual observation also indicates that estimated evapotranspiration from the Soil & Water Assessment Tool model tends to be slightly higher than those estimated from the United States Geological Survey model, with Soil Water Balance model estimating the lowest values of evapotranspiration across the different aquifers and over the model simulation period. The only exception appears to be the Trinity Aquifer, where results from the United States Geological Survey models are generally larger than the other models.

Estimated runoff trends also appear to be correlated between the Soil & Water Assessment Tool models and the United States Geological Survey model. However, as before, the estimated runoff appears to be higher for the Soil & Water Assessment Tool models as compared to the United States Geological Survey model results. However, as with the evapotranspiration comparison, results from the Trinity Aquifer provide the exception. Runoff estimated by the United States Geological Survey model appears to be higher in the Trinity Aquifer region as compared to those estimated by the Soil & Water Assessment Tool models.

The evapotranspiration and runoff estimates were similarly plotted for the identified watersheds covering the study area and presented in Appendix D. The general trends indicate reasonable correlation between the results from the different models and with precipitation. However, no general conclusions can be derived in terms of which model provides a consistently higher or lower estimation of evapotranspiration or runoff values. This is an important insight since it indicates that these water budget components have a higher variability in the trends on watershed-wide scale as compared to the aquifer-wide scale.

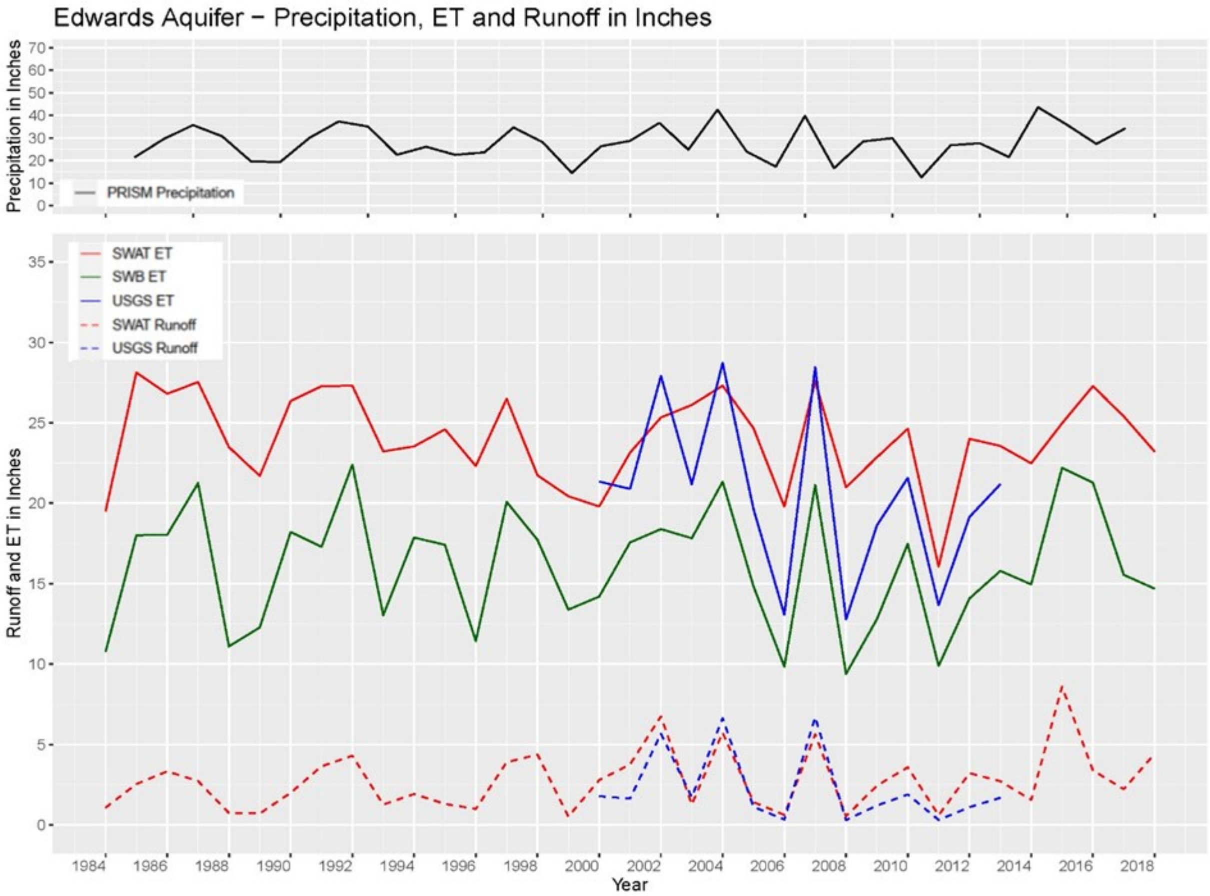

Figure 6-10: Edwards (Balcones Fault Zone) Aquifer - Precipitation, Evapotranspiration and Runoff in Inches

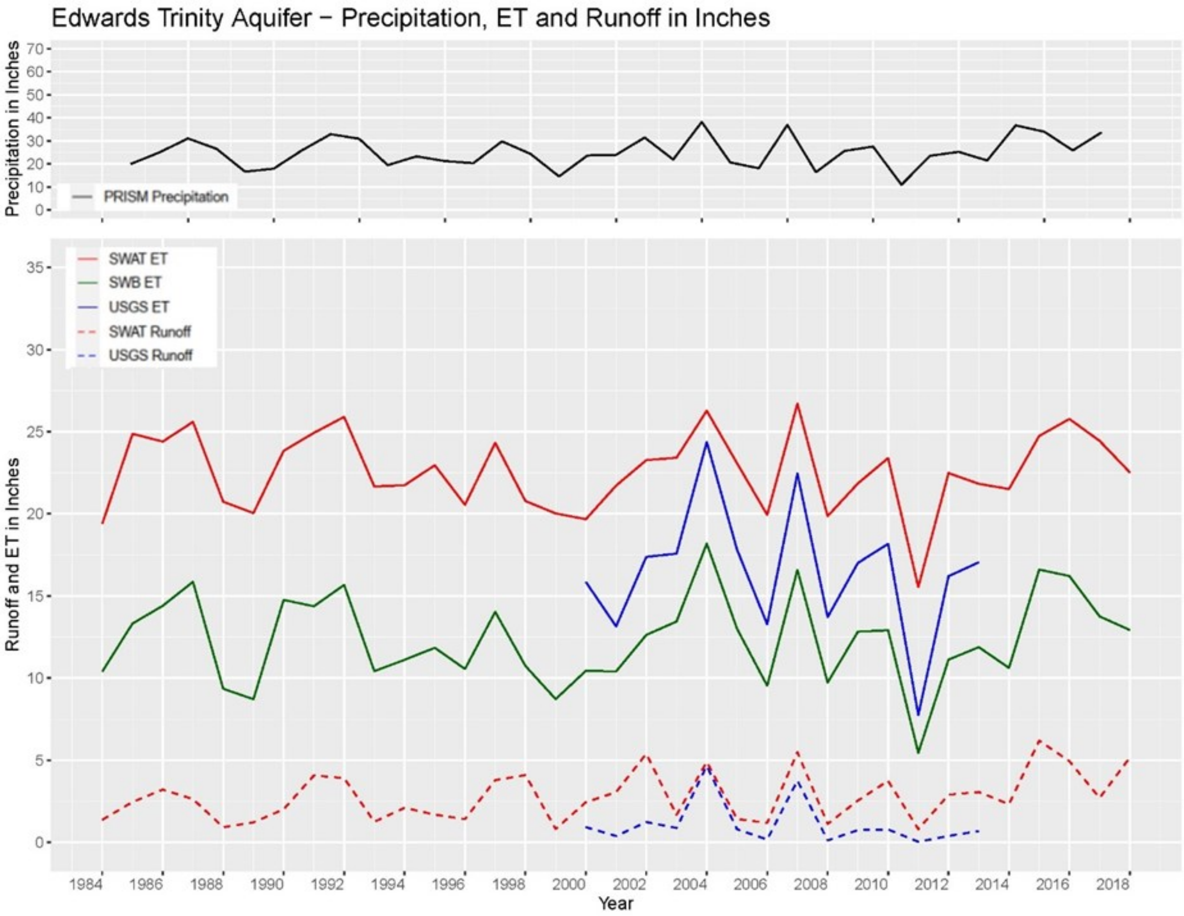

Figure 6-11: Edwards Trinity Aquifer - Precipitation, Evapotranspiration and Runoff in Inches

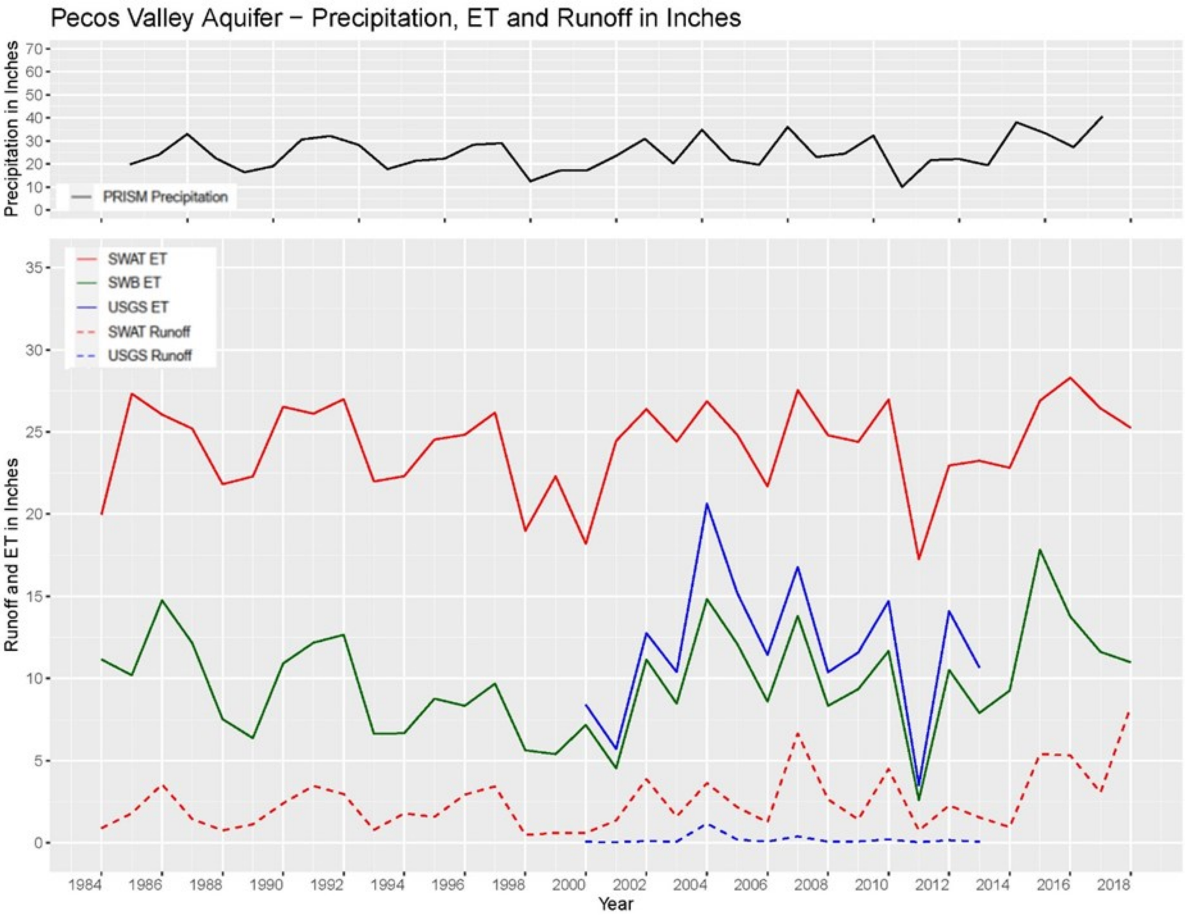

Figure 6-12: Pecos Valley Aquifer - Precipitation, Evapotranspiration and Runoff in Inches

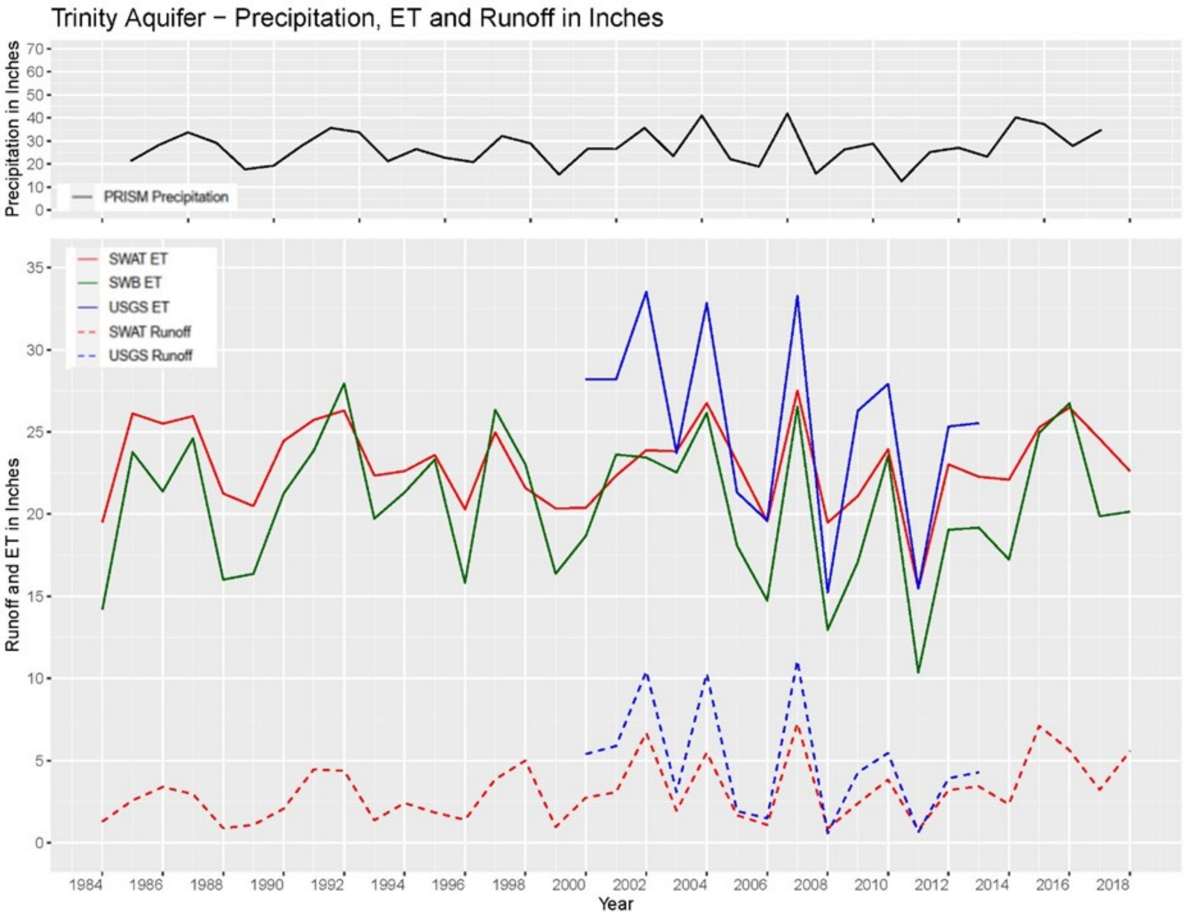

Figure 6-13: Trinity Aquifer - Precipitation, Evapotranspiration and Runoff in Inches

6.2.2 Annual Averaged Results for Recharge

One of the primary goals of this project was the estimation of recharge in the study area. Therefore, it is important to compare the estimated recharge values from the different models employed in the study with the United States Geological Survey base results. Input precipitation values (from PRISM) were plotted along with the estimated annual averaged recharge values from all the models for each of the study aquifers and are presented in Figure 6.14 through Figure 6.17.

Visual observation of Figure 6.14 through Figure 6.17 indicates that all models are generally correlated with precipitation which is similar to the visual comparative results from estimated evapotranspiration and runoff results. Figure 6.14 through Figure 6.17 also indicate the following trend in the recharge values estimated across the aquifers:

> Soil & Water Assessment Tool models > Soil Conservation Service model > United States Geological Survey model > Soil Water Balance model

The only exception to this trend is for the Trinity Aquifer, where the estimated recharge values are highest for the Soil Conservation Services model followed by those from the United States Geological Survey model, then Soil & Water Assessment Tool with Soil Water Balance model providing the lowest estimates.

The annual averaged recharge estimates were similarly plotted for the identified watersheds covering the study area and are presented in Appendix E. The general trends indicate reasonable correlation between the recharge estimates from the different models with precipitation. However, no general conclusions can be derived in terms of which model provides a consistently higher or lower estimation of evapotranspiration or runoff values on the watershed-scale. This insight is the same as the one gained while comparing the results from evapotranspiration and runoff values on the watershed-scale.

Comparing the results of the main components of the water budgets indicates they have a much higher variability on the watershed-wide scale as compared to the aquifer-wide scale. A statistical comparison was conducted to further our inter-model comparison.

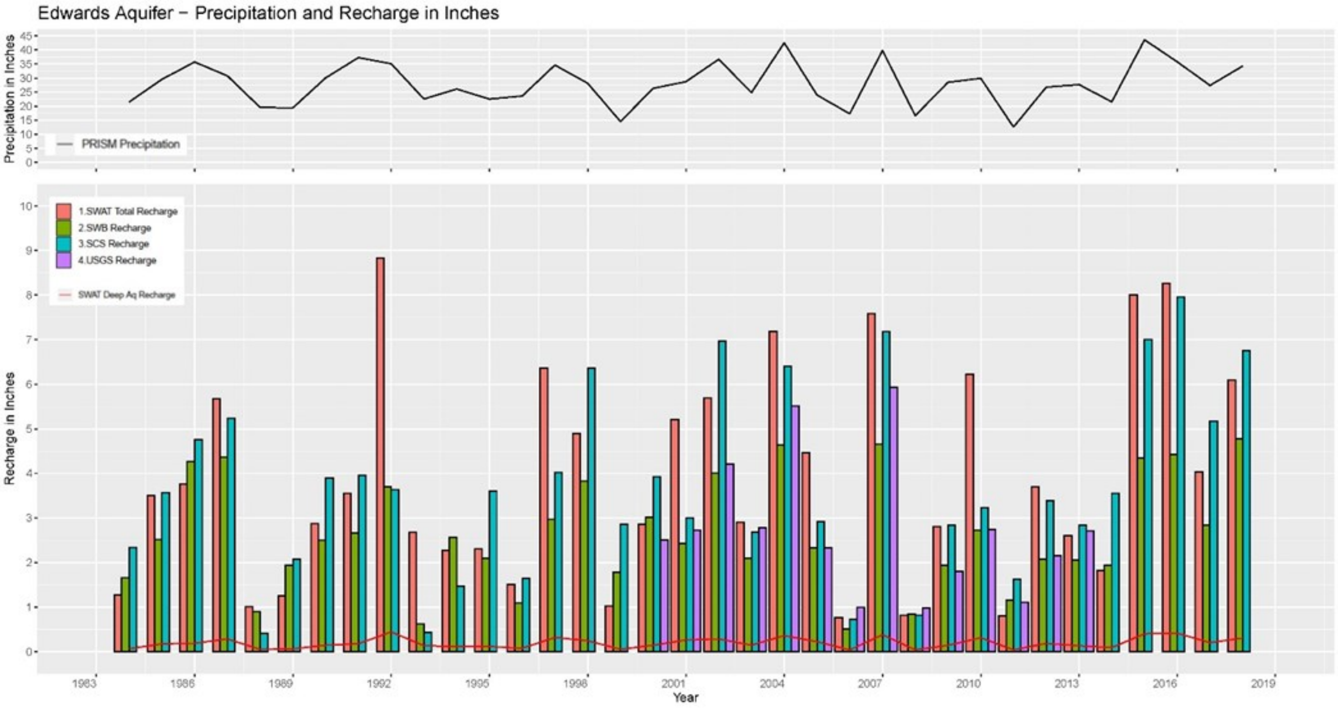

Figure 6-14: Edwards (Balcones Fault Zone) Aquifer - Precipitation and Recharge in Inches

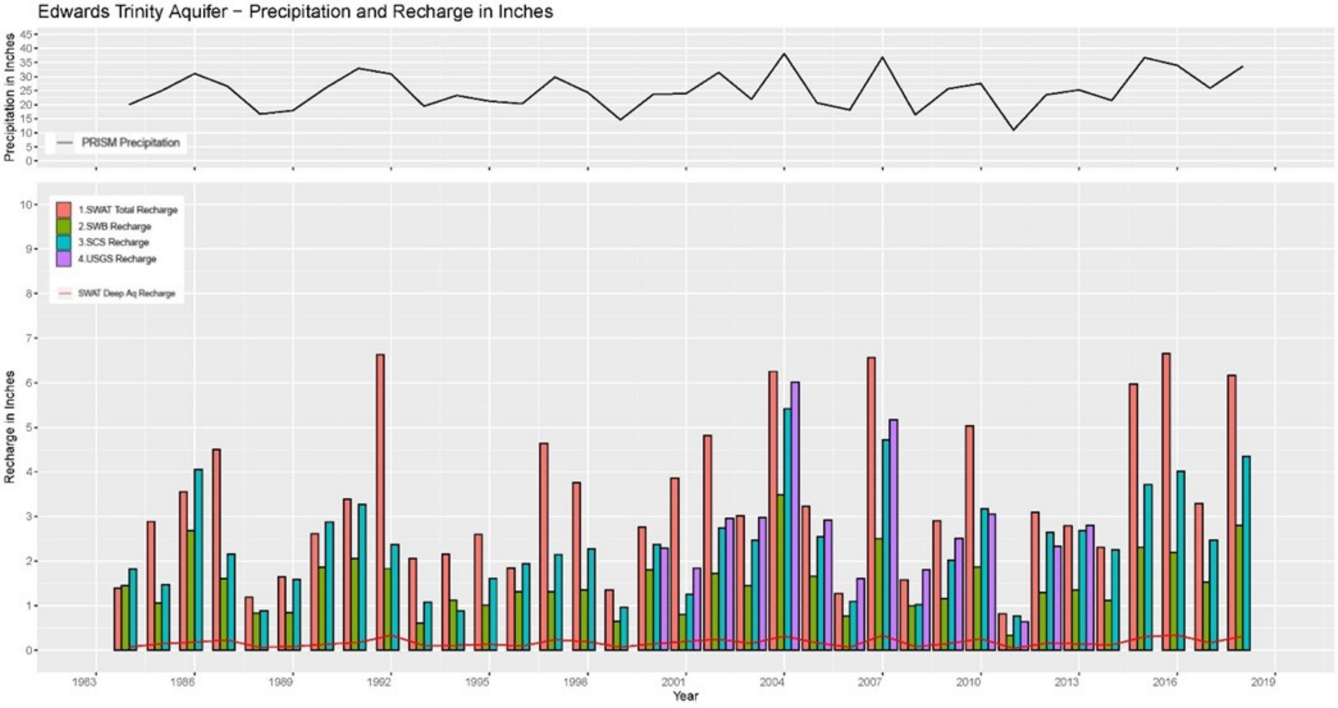

Figure 6-15: Edwards Trinity Aquifer - Precipitation and Recharge in Inches

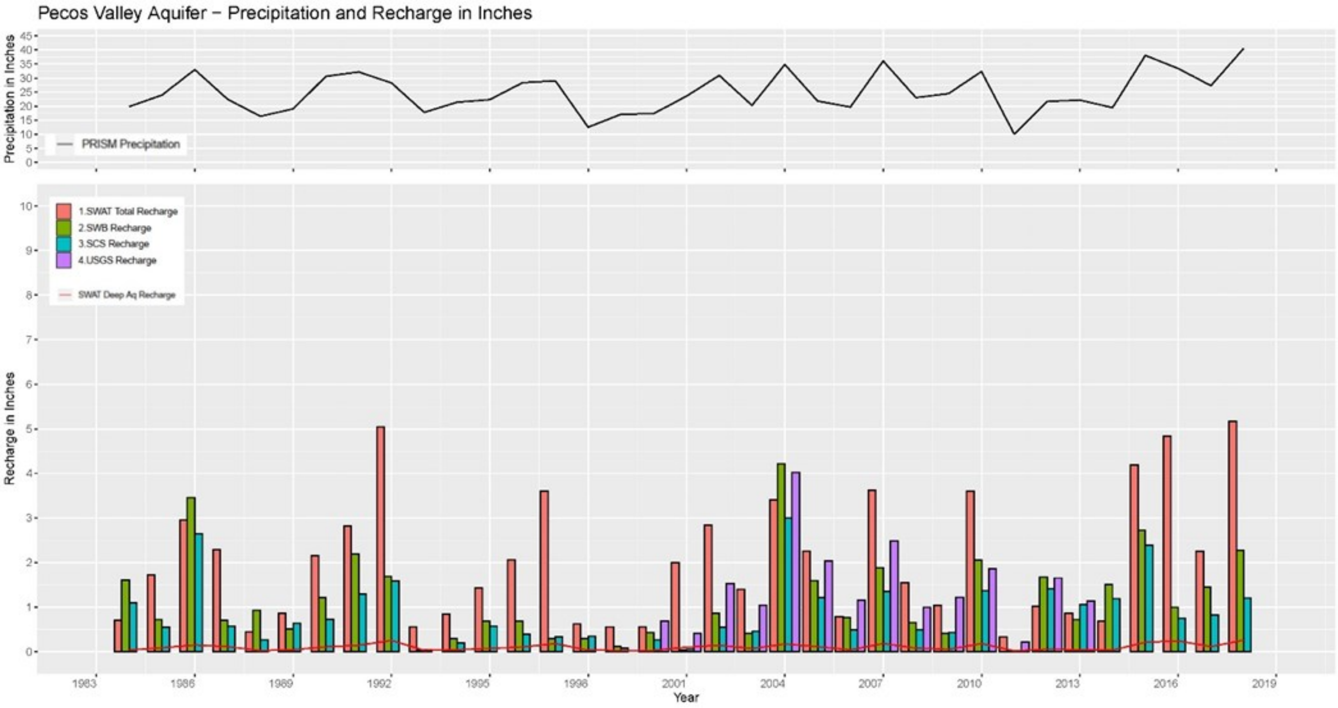

Figure 6-16: Pecos Valley Aquifer - Precipitation and Recharge in Inches

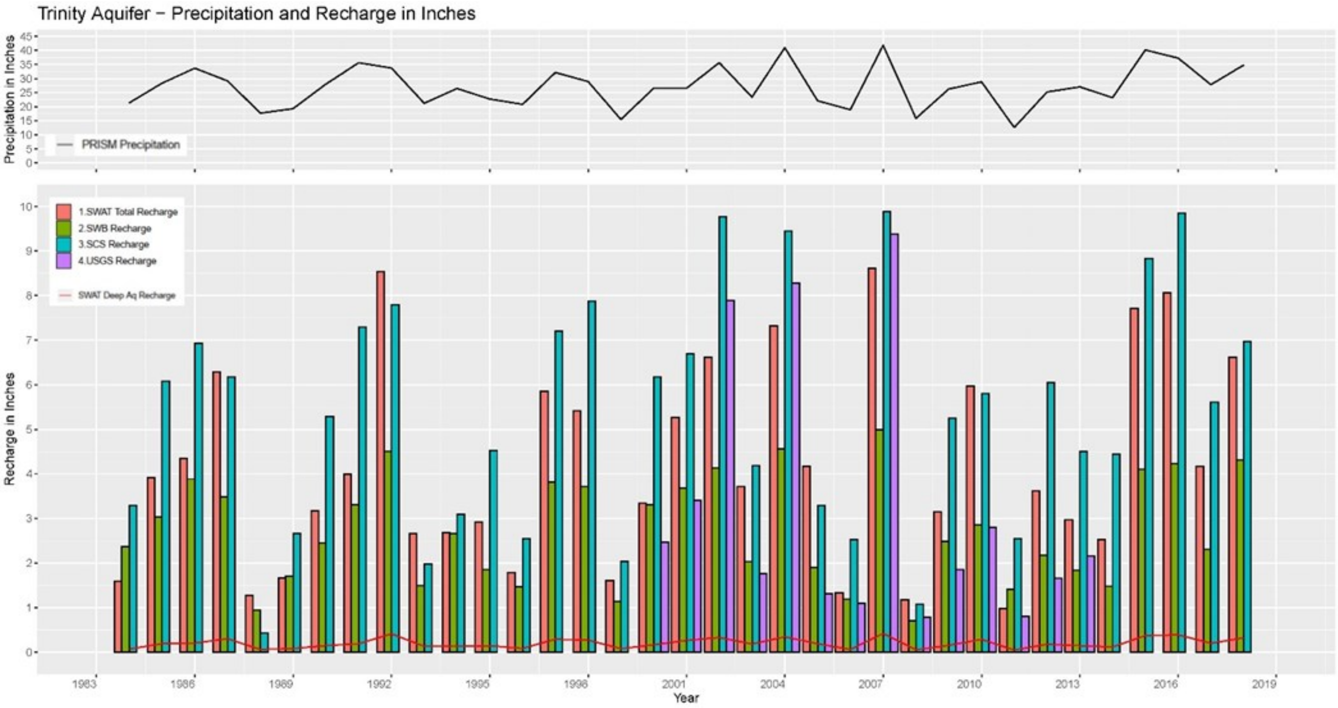

Figure 6-17: Trinity Aquifer - Precipitation and Recharge in Inches

6.3 Annual Averaged Model Results from 1984 through 2018: Statistical Comparison

Visual comparison of the estimated water budget components indicated a general correlation of model results with each other and with precipitation. However, to gain a better understanding of the model results, a statistical comparison is presented here. Two statistical measures were used in conducting this analysis:

1. Coefficient of determination (R^2) [unitless]: quantifies the measure of correlation or closeness in relative movement in results between two sets of values. This was employed to find the quantitative measure of how closely results from one model match the trend from the other.
2. Root mean square error (RMSE) [inches]: is the standard deviation of the residuals and provides a measure of the spread in difference between the model results. In groundwater modeling, it is commonly used to indicate the spread in residuals between observed and modeled values. Since we are assuming the United States Geological Survey model results to be the base results, those results were also assumed to be the ‘observed’ values for estimating Root Mean Square Error for the results from the other models. For inter-model comparisons excluding United States Geological Survey results (such as comparing Soil Conservation Services method with Soil Water Balance), results from one model were considered as observed values.

Table 6-1 through Table 6-3 provide the coefficient of correlation values for the estimated annual averaged recharge, evapotranspiration, and runoff obtained from the different models, respectively. For both evapotranspiration and recharge estimates, the calculated correlation coefficient values indicate that the results from the Soil Water Balance model are more closely correlated with results from the United States Geological Survey models as compared to results from the other models. As discussed earlier, since the Soil Conservation Services method uses a similar approach to calculation of evapotranspiration, the recharge results from the Soil Conservation Services method are also very highly correlated to those from the United States Geological Survey model. The recharge results from the Soil & Water Assessment Tool model also appear to have a moderate to high correlation with results from the Soil Water Balance model and the Soil Conservation Services method.

Evapotranspiration, runoff, and recharge results from the Soil & Water Assessment Tool models also appear to have moderate to high correlation with the United States Geological Survey models except for the Pecos Valley Aquifer. This is a different result from that observed during the qualitative assessment where Trinity Aquifer appeared to be the exception from visual observations.

Root mean square error values are provided for runoff, recharge, and precipitation values obtained from different models in Table 6-3 through Table 6-5 respectively. The Root Mean Square Error values are comparable for all the models when compared with the recharge results from the United States Geological Survey model or between the model themselves. Since the Soil Conservation Services model and Soil Water Balance model appeared to be very highly correlated as described earlier, we would expect the models to have a low Root Mean Square Error values on the same spatial and temporal scales. However, there is, at least, as much difference in Root Mean Square Error values between the Soil Conservation Services method and the Soil Water Balance model as between any other model combination. This is an important observation suggesting that higher correlation does not indicate close match in the numerical values from the models but only similar relative trends in those numerical values.

Table 6-1: Coefficient of Correlation Between Different Model Combinations for the Estimated Recharge Values for All the Study Aquifers

Aquifer	Recharge (R^2)					
	USGS vs SWAT	USGS vs SWB	USGS vs SCS	SWAT vs SWB	SWAT vs SCS	SWB vs SCS
Edwards-Trinity	0.78	0.96	0.95	0.62	0.63	0.91
Edwards	0.79	0.92	0.89	0.71	0.61	0.85
Trinity	0.79	0.87	0.85	0.85	0.8	0.87
Pecos Valley	0.53	0.93	0.91	0.32	0.3	0.92

Note: United States Geological Survey = USGS; Soil & Water Assessment Tool model = SWAT; Soil Water Balance model = SWB; and Soil Conservation Services method = SCS.

Table 6-2: Coefficient of Correlation Between Different Model Combinations for the Estimated Evapotranspiration Values for the Study Aquifers

Aquifer	Evapotranspiration (R^2)		
	USGS vs SWAT	USGS vs SWB	SWAT vs SWB
Edwards-Trinity	0.92	0.98	0.91
Edwards	0.64	0.9	0.66
Trinity	0.72	0.84	0.81
Pecos Valley	0.52	0.97	0.54

Note: United States Geological Survey = USGS; Soil & Water Assessment Tool model = SWAT; and Soil Water Balance model = SWB.

Table 6-3: Coefficient of Correlation and Root Mean Square Error Values Between the United States Geological Survey Model and the Soil & Water Assessment Tool Models for the Estimated Runoff Values for all the Study Aquifers

Aquifer	Estimated Runoff	
	USGS vs SWAT (R^2) [-]	USGS vs SWAT (RMSE) [in]
Edwards-Trinity	0.53	2.06
Edwards	0.80	1.17
Trinity	0.95	2.30
Pecos Valley	0.21	2.72

Note: United States Geological Survey model = USGS; Soil & Water Assessment Tool model = SWAT; R^2 = Coefficient of Determination; and RMSE = Root Mean Square Error

Table 6-4: Root Mean Square Error Values for the Different Models for Estimated Annual Averaged Recharge Values for all the Study Aquifers

Aquifer	Recharge (Root Mean Square Error) [inches]					
	USGS vs SWAT	USGS vs SWB	USGS vs SCS	SWAT vs SWB	SWAT vs SCS	SWB vs SCS
Edwards-Trinity	1.06	1.46	0.45	2.26	1.47	1.03
Edwards	1.57	0.53	1.06	1.91	1.48	1.46
Trinity	1.64	1.94	2.42	1.89	1.67	3.06
Pecos Valley	0.85	0.45	0.67	1.47	1.67	0.45

Note: United States Geological Survey model = USGS; Soil & Water Assessment Tool model = SWAT; Soil Water Balance model = SWB; and Soil Conservation Services method = SCS.

Table 6-5: Root Mean Square Error Values for the Different Models for Estimated Annual Averaged Evapotranspiration Values for all the Study Aquifers

Aquifer	Evapotranspiration (RMSE) [inches]		
	USGS vs SWAT	USGS vs SWB	SWAT vs SWB
Edwards-Trinity	5.87	4.61	10.24
Edwards	4.15	5.59	8.19
Trinity	4.62	5.97	3.3
Pecos Valley	12.34	2.79	14.56

Note: United States Geological Survey model = USGS; Soil & Water Assessment Tool model = SWAT; and Soil Water Balance model = SWB.

A similar statistical analysis was conducted for the model results aggregated at the watershed-scale. Table 6-6 through Table 6-8 present the calculated coefficient of correlation between the different models for estimated annual averaged recharge, evapotranspiration, and runoff respectively. As observed in the case of the aquifer-wide coefficient of correlation values, the Soil Water Balance model results are more closely correlated with the results from the United States Geological Survey model for both recharge and evapotranspiration. The Soil Water Balance model and the Soil Conservation Services method appear to have a very high correlation between each other and with the results from the United States Geological Survey model. This observation is similar to the one gained from aquifer-wide analysis.

Results from the Soil & Water Assessment Tool models have a moderate to high correlation with results from the United States Geological Survey model, and only moderate correlation with the results from the other models. This is a slightly different result as compared to the aquifer-wide analysis. Coefficient of correlation values corresponded more closely between the different models on an aquifer-wide scale rather than on the watershed scale. Qualitative analysis indicated that there are notable differences between the inter-model trend comparison when analyzed on the different spatial-scales (watershed vs aquifer-wide).

Root mean square error values are provided for runoff, recharge, and precipitation values obtained from different models in Table 6-8 through Table 6-10 respectively. The Root Mean Square Error values are comparable for all the models when compared with the recharge results from the United States Geological Survey model or between the model themselves. This result is similar to that obtained from the aquifer-wide scale indicating that the strength of model correlation does not correspond to the matching of numerical results.

Our analysis indicates that on an aquifer-wide scale, on average, the different models perform comparably in estimating recharge values. However, on a watershed-level scale, the relative model performance is inconclusive from the statistical analysis.

A major cause of the differences in the model results might be the different spatial scales at which these models have been set up. The Soil Water Balance model, the Soil Conservation Services method, and the United States Geological Survey method were all applied on a similar regional-scale grid-based structure with simplified assumptions to account for runoff. However, the Soil & Water Assessment Tool was set up on a watershed-level hydrologic response unit-based structure and accounting for the surface routing of runoff. Additionally, the Soil & Water Assessment Tool also accounts for the subsurface hydrologic processes such as baseflow and return flow available for evapotranspiration in drier periods. This allows the Soil & Water Assessment Tool to provide a more detailed breakdown of the water budget components. To achieve a better understanding of the relative model performance on watershed-level scale, we conducted a deeper comparative analysis of the various water budget components available from the model results.

Table 6-6: Coefficient of Correlation Between Different Model Combinations for the Estimated Recharge Values on Watershed-Scale

Watershed	Recharge (R^2)					
	USGS vs SWAT	USGS vs SWB	USGS vs SCS	SWAT vs SWB	SWAT vs SCS	SWB vs SCS
Beals	0.51	0.9	0.78	0.21	0.24	0.87
Brady	0.52	0.78	0.54	0.6	0.51	0.83
Colorado	0.67	0.84	0.82	0.64	0.6	0.86
Concho	0.62	0.79	0.77	0.43	0.39	0.88
Elm	0.6	0.77	0.77	0.44	0.34	0.84
Frio	0.65	0.86	0.87	0.69	0.7	0.87
Garfield	0.67	0.86	0.89	0.73	0.66	0.84
James	0.5	0.74	0.77	0.52	0.49	0.82
Lake McQueeny	0.71	0.8	0.84	0.68	0.67	0.86
Leon	0.48	0.81	0.81	0.45	0.38	0.87
Llano	0.6	0.85	0.86	0.35	0.3	0.86
Lower Pecos	0.58	0.94	0.96	0.45	0.37	0.87
Medina River	0.7	0.78	0.81	0.79	0.77	0.87
Nueces	0.64	0.89	0.88	0.54	0.46	0.85
Oak Creek	0.63	0.77	0.79	0.35	0.34	0.84
Onion Creek	0.75	0.75	0.69	0.61	0.51	0.86
Pinto	0.75	0.84	0.94	0.48	0.59	0.83
Plum Creek	0.41	0.76	0.82	0.15	0.25	0.74
Rio Grande	0.93	0.85	0.83	0.76	0.67	0.65
San Antonio	0.84	0.76	0.72	0.63	0.64	0.84
San Marcos	0.8	0.8	0.78	0.57	0.54	0.88
San Miguel	0.84	0.84	0.81	0.79	0.71	0.9
San Saba	0.64	0.85	0.78	0.61	0.5	0.83
Sycamore	0.53	0.92	0.93	0.51	0.42	0.88
Turkey	0.71	0.76	0.72	0.41	0.34	0.7
Upper Pecos	0.53	0.94	0.92	0.25	0.3	0.91

Note: United States Geological Survey model = USGS; Soil & Water Assessment Tool model = SWAT; Soil Water Balance model = SWB; Soil Conservation Services Method = SCS, and R^2 = Coefficient of Determination

Table 6-7: Coefficient of Correlation Between Different Model Combinations for the Estimated Evapotranspiration Values on Watershed-Scale

Watershed	Evapotranspiration (R^2)		
	USGS vs SWAT	USGS vs SWB	SWAT vs SWB
Beals	0.66	0.93	0.51
Brady	0.34	0.76	0.46
Colorado	0.44	0.81	0.66
Concho	0.77	0.9	0.75
Elm	0.82	0.87	0.64
Frio	0.82	0.87	0.64
Garfield	0.67	0.76	0.81
James	0.66	0.89	0.71
Lake McQueeny	0.58	0.81	0.74
Leon	0.25	0.75	0.35
Llano	0.39	0.87	0.32
Lower Pecos	0.8	0.95	0.76
Medina River	0.72	0.81	0.75
Nueces	0.33	0.9	0.6
Oak Creek	0.66	0.9	0.52
Onion Creek	0.41	0.73	0.71
Pinto	0.45	0.86	0.56
Plum Creek	0.17	0.65	0.34
Rio Grande	0.77	0.88	0.81
San Antonio	0.65	0.64	0.76
San Marcos	0.51	0.78	0.68
San Miguel	0.75	0.83	0.86
San Saba	0.61	0.88	0.7
Sycamore	0.26	0.89	0.37
Turkey	0.36	0.89	0.39
Upper Pecos	0.61	0.98	0.58

Note: United States Geological Survey model = USGS; Soil & Water Assessment Tool model = SWAT; Soil Water Balance model = SWB; and R^2 = Coefficient of Determination

Table 6-8: Coefficient of Correlation and Root Mean Square Error Values Between the Results from Soil and Water Assessment Tool Model and the United States Geological Survey Model for the Estimated Runoff Values on Watershed-Scale

Watershed	Runoff	
	USGS vs SWAT (R^2) [-]	USGS vs SWAT (RMSE) [in]
Beals	0.33	4.98
Brady	0.32	1.96
Colorado	0.64	2.02
Concho	0.19	2.67
Elm	0.52	5.36
Frio	0.75	2.09
Garfield	0.69	4.6
James	0.44	3.34
Lake McQueeny	0.89	3.35
Leon	0.38	7.8
Llano	0.59	2.4
Lower Pecos	0.26	3.08
Medina River	0.87	1.83
Nueces	0.66	1.91
Oak Creek	0.49	3.36
Onion Creek	0.66	3.19
Pinto	0.86	1.22
Plum Creek	0.25	8.58
Rio Grande	0.51	0.69
San Antonio	0.7	6.43
San Marcos	0.78	3.7
San Miguel	0.9	1.69
San Saba	0.69	1.45
Sycamore	0.5	2.56
Turkey	0.46	1.71
Upper Pecos	0.28	3.27

Note: United States Geological Survey model = USGS; Soil & Water Assessment Tool model = SWAT; Root Mean Square Error = RMSE; and R^2 = Coefficient of Determination

Table 6-9: Root Mean Square Error Values Between the Different Model Results for the Estimated Recharge Values on Watershed-Scale

Watershed	Recharge (Root Mean Square Error) [inches]					
	USGS vs SWAT	USGS vs SWB	USGS vs SCS	SWAT vs SWB	SWAT vs SCS	SWB vs SCS
Beals	5.65	0.52	0.48	5.9	5.6	0.51
Brady	1.41	1.29	1.37	1.77	1.86	2.01
Colorado	1.56	1.85	2.24	1.44	2.39	2.96
Concho	0.85	1.39	0.63	1.27	1.16	1.23
Elm	3.1	0.58	1.33	3.01	2.31	1.85
Frio	5.2	0.7	2.35	5.17	3.11	2.48
Garfield	5.1	1.27	5.23	4	1.86	3.8
James	2.35	1.4	1.36	3.42	2.05	2.21
Lake McQueeny	2.21	2.46	2.24	0.91	3.15	3.34
Leon	4.82	2.37	2.68	3.2	5.93	2.84
Llano	3.27	1.62	0.79	1.77	3.46	1.75
Lower Pecos	2.02	1.73	0.68	3.55	2.93	0.93
Medina River	2.87	2.15	2.55	3.38	1.42	3.11
Nueces	1.4	1.49	0.89	1.28	2.08	1.95
Oak Creek	3.49	0.78	1.16	3.92	3.16	1.49
Onion Creek	1.39	1.52	3.25	1.72	3.03	3.58
Pinto	1.51	1.4	0.83	1.64	1.68	1.81
Plum Creek	2.5	1.34	5.03	1.58	3.9	3.55
Rio Grande	0.82	0.94	0.83	1.25	1.26	0.4
San Antonio	1.1	1.57	3.04	1.84	2.87	2.48
San Marcos	1.59	2.19	2.98	3.01	2.4	3.7
San Miguel	2.15	1.4	3.19	1.58	2.13	1.86
San Saba	1.8	1.88	0.86	1.04	1.69	1.67
Sycamore	1.72	1.9	0.87	1.86	1.83	1.27
Turkey	1.76	1.12	1.11	0.98	2.55	1.92
Upper Pecos	1.13	0.79	0.71	2.07	2.03	0.23

Note: United States Geological Survey model = USGS; Soil & Water Assessment Tool model = SWAT; Soil Water Balance model = SWB; and Soil Conservation Services Method = SCS,

Table 6-10: Root Mean Square Error Values Between the Different Model Results for the Estimated Evapotranspiration Values on Watershed-Scale

Watershed	Evapotranspiration (Root Mean Square Error) [inches]		
	USGS vs SWAT	USGS vs SWB	SWAT vs SWB
Beals	9.51	3.24	12.65
Brady	3.22	6.16	5.95
Colorado	4.1	6.89	6.01
Concho	3.76	3.84	7.25
Elm	9	5.22	13.46
Frio	3.23	5.11	6.73
Garfield	5.63	6.49	9.75
James	4.88	6.2	10.78
Lake McQueeny	5.27	6.92	3.39
Leon	5.41	4.5	6.48
Llano	3.38	6.04	7.16
Lower Pecos	7.48	5.07	12.19
Medina River	6.02	6.3	3.5
Nueces	4.19	5.98	7.74
Oak Creek	3.89	4.36	8.13
Onion Creek	5.19	6.72	3.31
Pinto	3.77	6.09	5.58
Plum Creek	7.83	5.79	4.13
Rio Grande	7.09	2.2	8.04
San Antonio	4.5	4.1	5.81
San Marcos	9.89	7.07	3.89
San Miguel	3.35	7.41	7.33
San Saba	5.12	5.99	10.55
Sycamore	4.17	6.53	6.9
Turkey	4.47	5.38	6.91
Upper Pecos	10.49	2.92	12.92

Note: United States Geological Survey model = USGS; Soil & Water Assessment Tool model = SWAT; and Soil Water Balance model = SWB.

6.4 Comparative Analysis: Water Budget Components

While the qualitative and quantitative comparative analyses indicated comparable values on the major water budget components, it was inconclusive in identifying systematically higher or lower parameter values from specific models. One of the goals of the project is to provide recommendations on future use of the model results as well as identifying the appropriate models for future applications in other regions of the State. Therefore, we need to conduct a more detailed comparative analyses to provide these recommendations. United States Geological Survey estimates provided the main components of the water budget in precipitation, evapotranspiration, recharge, and runoff results for our comparative analyses described earlier. We will delve deeper into the assumptions and underlying methodologies for estimating these main water budget components and how they compare with the methodologies used for the other models.

Evapotranspiration is the largest component of the water budget, and is estimated using similar assumptions and input data by all the models. However, the specific equations used for estimating evapotranspiration are different with the Soil Water Balance and the Soil Conservation Services method using the Samani-Hargreaves formulation, and the Soil & Water Assessment Tool using the Penman-Monteith formulation. The differences in these formulations might account for some of the differences in the estimated evapotranspiration values between Soil & Water Assessment Tool and the other models.

The United States Geological Survey method and the Soil Conservation Services method do not account for surficial inter-grid cell runoff processes. The Soil Water Balance model only considers the runoff that occurs during each daily time step. However, the runoff values estimated by the Soil & Water Assessment Tool do consider the surficial routing of runoff. The differences in underlying assumptions and methodologies are hypothesized to be the reason for the larger differences between the runoff values estimated by the Soil & Water Assessment Tool models and the other models.

As mentioned earlier, the recharge component estimated by the United States Geological Survey method provides total recharge based on application of baseflow separation techniques and does not account for other subsurface components including the lag time in deeper aquifer recharge which might be important for areas with deeper water tables. The Soil & Water Assessment Tool models do provide the sub-component level details on the total recharge components.

The four major sub-components of recharge and associated sub-components estimated by Soil & Water Assessment Tool models are:

1. Total Recharge: simulates the amount of water entering both the shallow and deeper aquifer zones in the simulated time.
2. Deeper Aquifer Recharge: provides an estimate of the water entering the deeper aquifer zone in the simulated time.
3. Revap: simulates the amount of water in the shallow aquifer that returns to the root zone in the simulated time. This happens in periods of low precipitation and/or high evapotranspiration demand. Revap is an important component since it creates a volumetric and temporal buffer between the total and deeper aquifer recharge.
4. Baseflow: is the summation of the lateral and groundwater contribution to the reach.

Appendix F provides a table of annual averaged values of these sub-components of recharge estimated by the Soil & Water Assessment Tool models as well as other major water budget components estimated by the other models on a watershed-level scale for the model simulation period (1984 through 2018). Analyzing the table carefully shows that the estimated recharge values from the Soil & Water Assessment Tool are comparable to those estimated from the other models when the Revap contributions are accounted for. It is important to note that since these values are averaged on annual time period, some of this water might be lost to other components of the water budget such as evapotranspiration and baseflow within the averaging period or over the next averaging period since that volume might still be available within the shallow aquifer zone. The availability of estimates for these additional components of the water budget can be useful for providing additional calibration targets when the results of this study are used for development of groundwater availability models.

The water budget component analysis showed that results from the Soil & Water Assessment Tool models are comparable to the results from the Soil Water Balance and Soil Conservation Services method used during this study as well as to the results from the United States Geological Survey method. Therefore, the project team's recommendations would include application of results from all the identified models for the project area. In our opinion, the effort required to set-up and calibrate all the models for this study was similar, however, the effort required to set up and conduct future predictive runs with these models might not be. It is relatively more complex to run and post-process the Soil & Water Assessment Tool models than the Soil Water Balance model and the Soil Conservation Services method. This is, in part, due to the sheer number of watershed models (26) as compared to the single model runs with the Soil Water Balance model or the Soil Conservation Services method. Therefore, the project team developed a machine learning tool to emulate the results from the Soil & Water Assessment Tool for future applications of those watershed-scale models.

6.5 Development of Machine Learning Tool for Estimating Recharge Based on Soil & Water Assessment Tool Results

In recent decades, advancements in computer science have improved the efficiency of machines to run computationally intensive programs for a variety of applications, greatly accelerating productivity in commercial and research settings. However, the implementation of computationally demanding physics-based models such as Soil & Water Assessment Tool and Soil Water Balance model can be time consuming. Improved sensor technology, online connectivity, and computing power have accelerated our ability to collect, store and access large volumes of data, paving the way to success for a new field of modeling: theory guided data science enables experts to apply domain knowledge and create data-driven models consistent with physics-based simulations. Data-driven models are capable of simulating of complex, non-linear systems and, in most cases, can be developed in less than a day. This section will discuss our approach to applying a data-driven machine learning algorithm to Soil & Water Assessment Tool estimates of recharge in the study area.

6.5.1 Previous Studies – Hydrologic Applications of Machine Learning

The application of machine learning to groundwater-related issues is novel and unprecedented until recently. As demand for reliable freshwater sources is increasing with population growth, the importance of groundwater forecast modeling is being realized. Researchers have applied a variety of machine learning techniques to hydrologic problems as groundwater and climate datasets have become more abundant in recent years.

Razavi-Termeh and others. (2019) used frequency ratio, certainty factor, evidential belief function models in conjunction with a random forest and a logistic model tree to predict hourly volumetric groundwater yields in the Booshehr plain, Iran. Woo and others. (2019) evaluated the aquatic ecosystem health of the Han River watershed, South Korea, by training a random forest classifier on Soil & Water Assessment Tool results. Liang and others (2018) developed a hybrid model in which a random forest was used to forecast precipitation in the Danjiangkou watershed in China for input into to a Soil & Water Assessment Tool model. Golkarian and others (2018) mapped groundwater potential of a 1,513 square kilometer watershed in northeastern Iran using C5.0, random forest, and multivariate adaptive regression splines algorithms. Huang and others (2019) compared the performance of linear regression, multi-layer perception and long short-term memory models in predicting groundwater recharge timeseries in south-eastern South Australia.

6.5.2 Input Dataset Collation

To reduce training duration and model size, we have chosen to incorporate a subset of Soil & Water Assessment Tool's parameters into the machine learning model, including precipitation, potential evapotranspiration (PET), actual evapotranspiration (ET), and recharge (Figure 6-18). Data were obtained directly from annual averaged Soil & Water Assessment Tool output tables for the model simulation period (1984 through 2018). Each year's data is stored as an individual comma separated file with rows corresponding to individual hydrologic response units across the study area. In addition, each hydrologic response unit contains data for every month of the year. Monthly data were summed for all years to yield each input variable's annual contribution to study area hydrologic response units with units of millimeters per year. Annual summations were then consolidated into a single table containing approximately five million rows for the 35 simulated years.

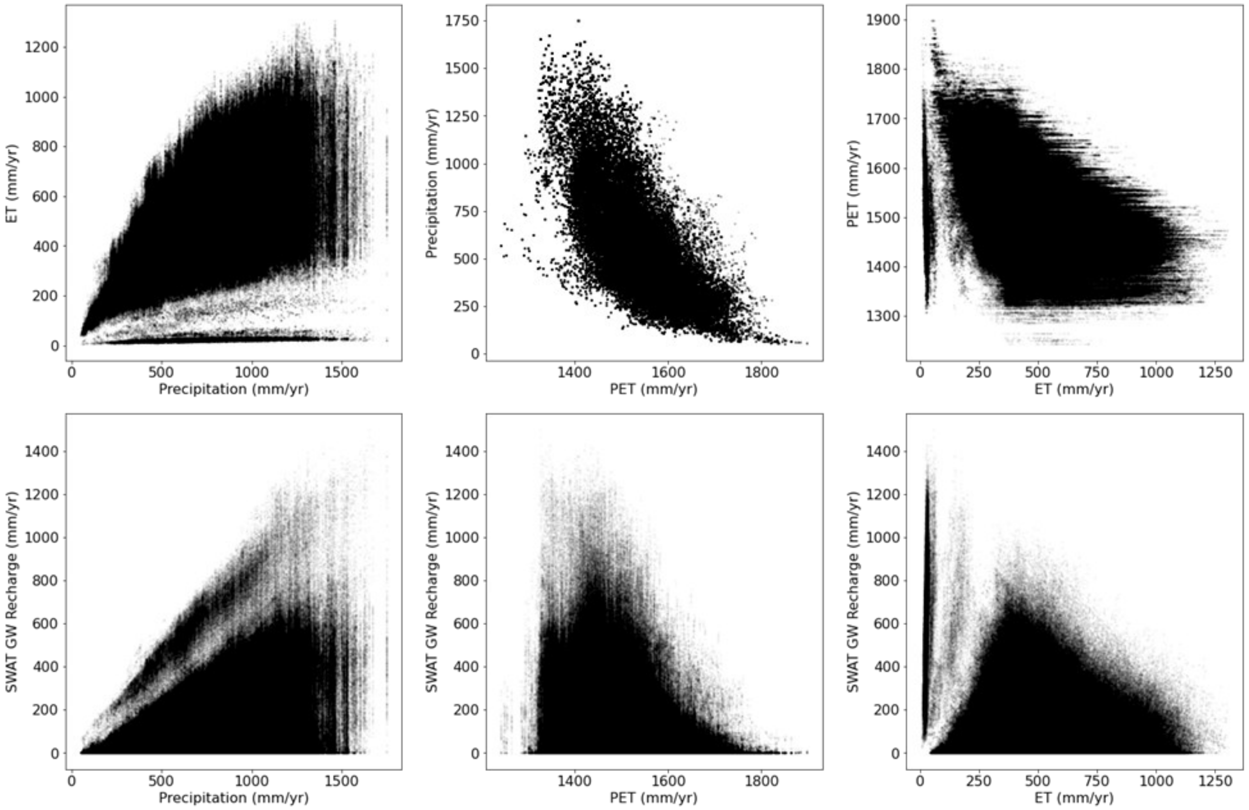

Figure 6-18: Scatter Comparison of Soil & Water Assessment Tool Climate Variables and Recharge Estimates

6.5.3 Model Choice – Random Forest Regressor

Random forest is a widely used machine learning algorithm capable of efficiently discerning complex, non-linear relationships between the predictor (precipitation, potential evapotranspiration, and evapotranspiration) and response variables (recharge) (Breiman, 2001). Random forests are composed of a series of decision trees built from a bootstrapped dataset, with a random subset of the input variables selected when splitting each node. Bootstrapped datasets are samples of the original dataset randomly selected with replacement. During model training, a different bootstrapped sample is constructed for each tree, typically leaving about one-third of cases unused. This unused data, known as the "out-of-bag" dataset can be employed to estimate error and variable importance after model training. Random forests can be applied to both classification and regression problems. Due to the multivariate nature of the input datasets, the Random Forest Regressor from Python's Scikit-Learn library (Pedregosa and others, 2011) was chosen to simulate the recharge response for Soil & Water Assessment Tool.

6.5.4 Feature Engineering

Feature engineering is the process of using domain knowledge to select input variables (features). This involves compiling a comprehensive list of features and their data, iteratively training an estimator (in our case, random forest), and evaluating its performance before removing redundant features and weak predictor variables. In our workflow, predictor variables were filtered to exclude rows containing blank and null values to avoid errors due to incompatibility with the random forest. Feature values were correlated using the Pearson correlation coefficient (Figure 6-19) where a values of zero mean no correlation, one means perfect positive correlation, and negative one means perfect negative correlation. Features with a high degree of correlation (closer to one or negative one) are removed from the input dataset as redundant features do not improve predictive accuracy (Breiman, 2001). For example, the land use and land cover data were originally included in the feature dataset but were ultimately removed due to a high degree of correlation between the underlying classes, and because the random forest accuracy was higher with their exclusion. Additionally, it is computationally less expensive to train a model and generate a prediction with fewer inputs.

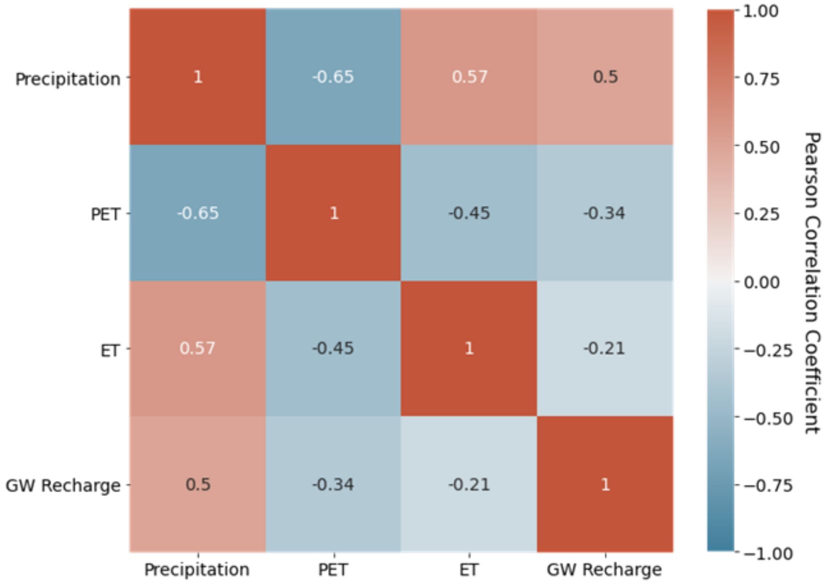

Figure 6-19: Correlation Heatmap of Random Forest Input Variables

6.5.5 Model Training – Cross Validation

Cross-validation techniques were employed to prevent overfitting during random forest training. The row order of the input dataset is spatially and temporally stratified, thus, shuffling the dataset was necessary to ensure the model was trained on a representative subset of data. The Scikit-Learn StratifiedShuffleSplit cross-validator (Pedregosa and others, 2011) shuffles the input dataset and splits samples into pairs of train and test data for each hydrologic response unit. This ensures data from the entire study area is utilized across all simulated years. Without a cross-validator, the model may only train on the hydrologic response units in the eastern part of the study area for earlier simulated years (for example, pre-2000) and fail to predict anything useful in the western part of the study area for later simulated years where climate change may affect recharge response. StratifiedShuffleSplit can be used iteratively, where the number of splits (iterations) is specified in the function, and each split trains a new model on a unique shuffle of the dataset. Model performance is scored after each iteration, and the best performer is typically selected as the final model.

The random forest was initialized and trained from 80 percent of the shuffled input data with the remaining 20 percent used to generate a prediction to score against the Soil & Water Assessment Tool values of groundwater recharge. Model performance was evaluated using the coefficient of correlation and root mean squared error.

6.5.6 Feature Importance – Mean Decrease in Impurity and Permutation Importance

Each feature in the training dataset is evaluated by how well it can predict the target value. There are two methods that can be used to calculate the feature importance for random forests. The first method is known as Mean Decrease in Impurity or Gini Importance, and is calculated from the Gini impurity values at each root node in a decision tree:

$$\boldsymbol{Gini\ Impurity = 1 - (probability\ of\ True)^2 - (probability\ of\ False)^2} \quad \textbf{(Equation 14)}$$

where larger values are considered more impure. Gini impurity decreases as the model is fit to the training dataset; thus, the terminal nodes of each decision tree will have the lowest impurity values. The decrease in Gini impurity is summed for each decision tree and is averaged across all trees in the forest to produce a normalized value of mean decrease in impurity for each predictor feature. Features with the highest reduction in Gini impurity are considered more important. Mean decrease in impurity can be employed to generate a quick estimate of feature importance, however, this method is limited as impurity-based estimates of importance are biased towards high cardinality features. Further, Mean Decrease in Impurity is computed on training set statistics and thus does not reflect the ability of a feature to make useful predictions that generalize to the test set.

The alternative approach is to use the method known as permutation importance which computes feature importance on a held-out test set (Pedregosa and others, 2011). As a result, permutation importance captures the relationship between feature values and model error by measuring the increase in prediction error (the decrease in model accuracy) after an input feature's values are randomly permuted. This algorithm permutes the values for a single predictor feature, after which the test set is passed through the random forests and the accuracy (that is, coefficient of determination) is recalculated. Importance is measured as the difference between the baseline accuracy and the drop in overall accuracy caused by permuting the predictor feature. Due to the random nature of the algorithm, each feature was permuted ten times to capture the spread in prediction error.

6.5.7 Model Validation

The final random forest model selected from the StratifiedShuffleSplit results has a coefficient of determination score of 0.853 and a Root Mean Square Error of 57 millimeters per year (2.24 inches per year). A scatter plot of the recharge estimated from the random forest model against the test dataset from the Soil & Water Assessment Tool model results is displayed in Figure 6-20. In general, the random forest model produces conservative estimates of recharge as shown with a best fit line (Figure 6-20a). However, an average taken every ten observations of SWAT recharge (moving average) reveals that watersheds with Soil & Water Assessment Tool recharge less than approximately 120 millimeters per year (4.7 inches per year) tend to be overpredicted by the random forest model with the highest overpredictions associated with low values of recharge (Figure 6-20b).

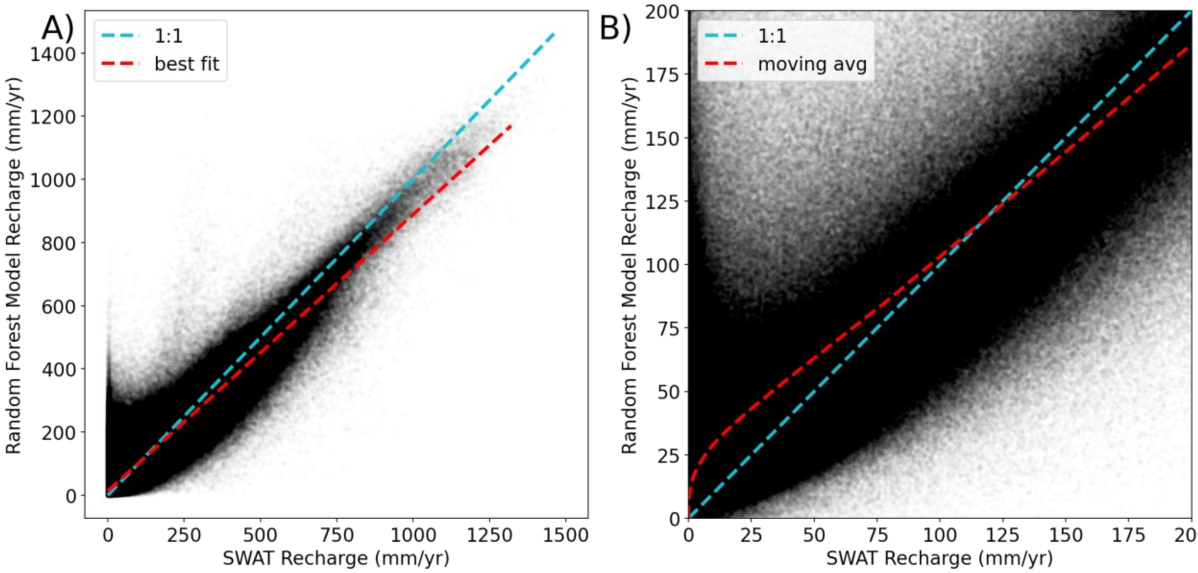

Figure 6-20: Soil & Water Assessment Tool Recharge v*ersus* *Random Forest Model* Recharge *for the Test Dataset*

6.5.8 Full Prediction of Recharge in the Study Area

A prediction was generated from the entire dataset available from the Soil & Water Assessment Tool models for the simulated period (1984 through 2018). Figure 6-21 presents a scatter comparison between Soil & Water Assessment Tool modeled recharge values and the recharge values estimated by the random forest model for the entire study area. A best fit line suggests that, in general, the random forest model yields a conservative estimate of recharge with respect to the recharge estimated by the Soil & Water Assessment Tool (Figure 6-21a). Furthermore, an average taken every ten observations of SWAT recharge (i.e., moving average) shows the same conservative estimate of recharge for hydrologic response units with more than approximately 120 millimeters per year (4.7 inches per year) of estimated recharges as obtained during the model validation exercise. That is, hydrologic response units with less than 120 millimeters per year (4.7 inches per year) of Soil & Water Assessment Tool predicted recharge are overpredicted by the random forest model (Figure 6-21b).

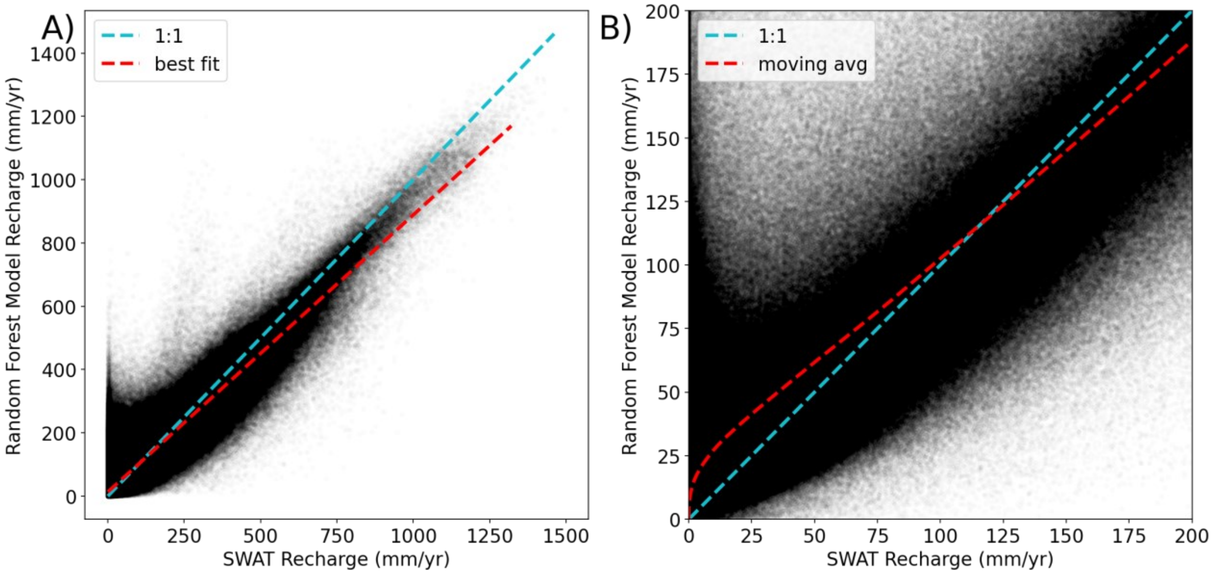

Figure 6-21: Observed Recharge vs. Predicted Recharge for the Entire Study Area

Results for the Root Mean Square Error in prediction for each hydrologic response units were plotted against the longitude across the study area (Figure 6-22). Lower longitude values represent the western portion of the study area while higher longitude values represent the eastern portion of the study area. In general, random forest model recharge is estimated to be higher in the eastern part of the study area (Figure 6-22a) where Root Mean Square Error between the random forest model results and Soil & Water Assessment Tool results is similarly higher (Figure 6-22b). This trend is maintained when the Root Mean Square Error is considered as a percentage of the Soil & Water Assessment Tool predicted recharge (Figure 6-22c), suggesting that the random forest model yields higher error in hydrologic response units where the Soil & Water Assessment Tool predicted recharge is high.

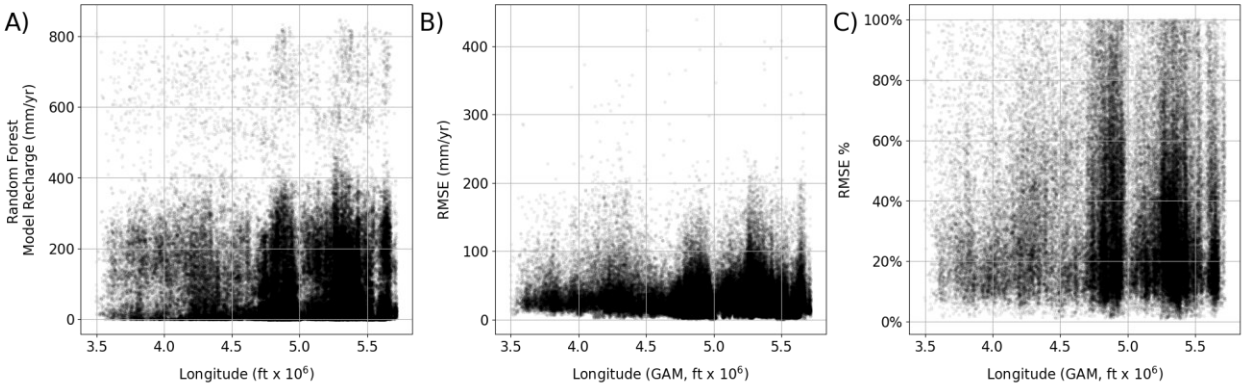

Figure 6-22: Average Hydrologic Unit Code-12 Recharge Prediction Error for the Study Area

6.5.9 Relative Importance of Predictor Features

The relative importance of each feature was extracted using the mean decrease in impurity and the permutation importance algorithms. The mean decrease in impurity results and permutation importance of each input feature is shown in Table 6-11. It is important to note that the permutation importance of all features will not sum to one as is the case for mean decrease in impurity, and that the raw values of permutation importance are not as significant as the relative ranking of all the features. Despite the differences between the mean decrease in impurity and permutation importance algorithms, both methods suggest the two most important predictor variables are precipitation and actual evapotranspiration. This is consistent with the physical system where precipitation controls the total volume of water available for recharge while actual evapotranspiration determines a majority of the amount of water removed from the system. Actual evapotranspiration captures some of the same trends as shown by runoff since estimated actual evapotranspiration takes into account the land use/land cover and soils data that also impacts runoff. Therefore, the impact of runoff is indirectly captured by the system through the trends captured by actual evapotranspiration. Through the feature importance analysis, the random forest model has been able to largely capture and emulate, the behavior of the physical system as simulated by the Soil & Water Assessment Tool models within the study area.

Table 6-11: Calculated Importance of Predictor Features

Feature	Mean Decrease in Impurity	Permutation Importance
Precipitation	33.4%	1.306 ± 0.001
Potential Evapotranspiration	15.8%	0.262 ± 0.0001
Actual Evapotranspiration	50.8%	1.220 ± 0.001

6.5.10 Recharge Prediction Response to Predictor Feature Values

Partial dependence plots are a first order estimate of the quantitative relationship between predictor feature values and the response variable (Molnar, 2020). To compute partial dependence values, a grid sequence is initialized to contain a specified number of evenly distributed values between the minimum and maximum values of the target feature. All feature values in the input dataset are then permuted to a value in the grid sequence. A new prediction of recharge is generated from the permuted dataset and the result of the prediction is averaged. This process is repeated for each value in the grid sequence. The result is a curve representing the recharge estimated by the random forest model as a function of the target feature's values.

It is important to highlight some of the limitations that arise from employing the partial dependence plot analysis. The useful application of partial dependence plot is dependent on correlation within the input dataset. When features are highly correlated, unrealistic scenarios may result from areas of the feature distribution where the probability is very low (Molnar, 2020). For example, it is possible that the partial dependence plot algorithm will yield a prediction of recharge where actual evapotranspiration rates are higher than potential evapotranspiration which is physically impossible. Therefore, unrealistic predictions can be generated from a multitude of physically impossible scenarios.

A partial dependence plot is also limited by the distribution of the datasets on which they were trained. For example, if a model is trained on a dataset that only contains low to moderate values of precipitation, estimates of recharge from the few datapoints containing high precipitation will be less reliable. Moreover, if only high rates of potential evapotranspiration are observed in the study area, the partial dependence grid will fail to effectively interpolate recharge rates resulting from lower potential evapotranspiration rates. Despite these limitations, partial dependence plots provide an insight into the physical system in areas where the feature distribution is well defined.

Partial dependence values were calculated for each predictor feature in the input dataset (that is, the Soil & Water Assessment Tool results). Soil & Water Assessment Tool predicted recharge rates initially increase slowly as precipitation approaches 400 millimeters per year (15.74 inches per year), and then increases rapidly before leveling off above precipitation values over 1,600 millimeters per year (63 inches per year) as presented in Figure 6-23a. The partial dependence plot for potential evapotranspiration (Figure 6-23b) shows that higher Soil & Water Assessment Tool recharge rates are predicted for hydrologic response units where potential evapotranspiration (PET) is less than 1,400 millimeters per year (55.1 inches per year). Estimated Soil & Water Assessment Tool recharge rates decrease rapidly below the value of 55.1 inches per year. Please note that Soil & Water Assessment Tool still predicts recharge to occur at the higher potential evapotranspiration values but at a much lower rate. Lastly, the partial dependence plot for actual evapotranspiration (Figure 6-23c) shows Soil & Water Assessment Tool predicted recharge decreases rapidly as actual evapotranspiration (ET) rates approach 250 millimeters per year (9.8 inches per year) before a slight increase occurs around 350 millimeters per year (13.7 inches per year), and above that value, recharge is predicted to decrease again. The threshold value of 350 millimeters per year (13.7 inches per year) may suggest that more water is available for actual evapotranspiration to occur and for the recharge rates to increase.

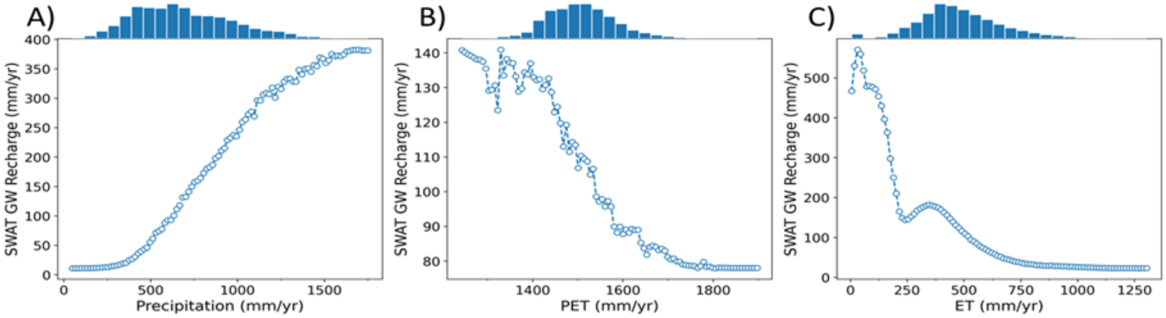

Figure 6-23: Partial Dependence Plots for Predictor Features and their Frequency Distribution in the Input Dataset *(*Soil & Water Assessment Tool *Results)*

Figure 6-24 presents a two-way partial dependence plot that provides insight into Soil & Water Assessment Tool predicted recharge occurring between the interactions of multiple predictor features. The two-way partial dependence plot suggests the more favorable (above average) climate conditions for Soil & Water Assessment Tool predicted recharge to be with:

5. Precipitation rates greater than 1,600 millimeters per year (63 inches per year), and any potential evapotranspiration (PET) rates (Figure 6-24a),
6. Precipitation rates greater than 1,100 millimeters per year (43.3 inches per year), and actual evapotranspiration (ET) rates less than approximately 250 millimeters per year (9.8 inches per year) (Figure 6-24b), and
7. Actual evapotranspiration (ET) rates less than 200 millimeters per year (7.9 inches per year) for any value of potential evapotranspiration (PET) (Figure 6-24c).

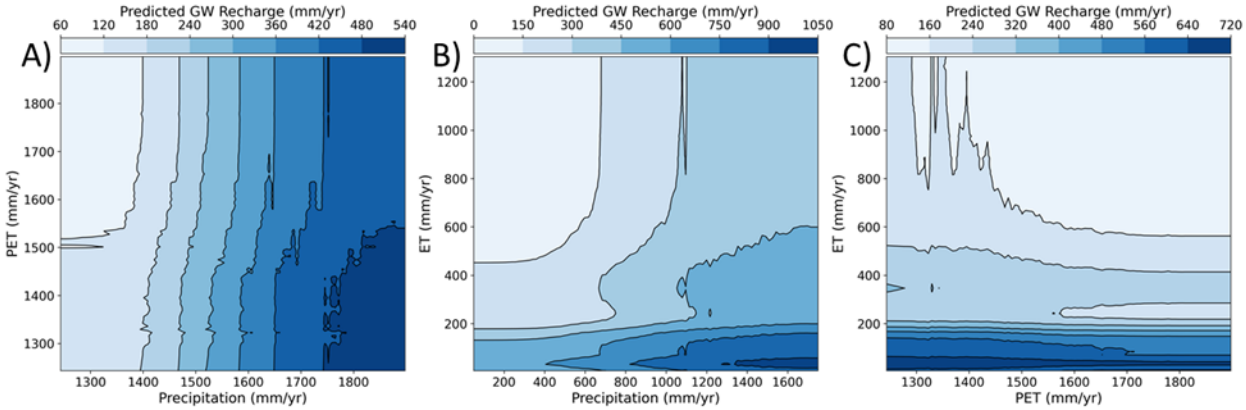

Figure 6-24: Two-Way Partial Dependence Plots for Climate Predictor Features

6.5.11 Application of Machine Learning Tool

Our results suggest that machine learning is a suitable tool for emulating the Soil & Water Assessment Tool to predict recharge estimates in the study area. Random forests are fast, efficient algorithms that can generate a prediction from millions of rows of data in a matter in minutes, eliminating the time constraints that arise when calibrating and applying computationally intensive, physics-based programs. Furthermore, random forests trained from input datasets that represent a large variety of climatic and estimated recharge scenarios will yield a prediction that closely reflects the output of the models they are designed to simulate. The random forest model presented here performs well compared to the recharge estimated from Soil & Water Assessment Tool models, with a coefficient of determination score of 0.853 and a Root Mean Square Error of 57 millimeters per year (2.27 inches per year) through all the hydrologic response units in the study area.

In addition to the high accuracy, random forests are interrogable when applying mean decrease in impurity, permutation importance, and partial dependence algorithms. Application of these techniques has provided additional insight into the processes impacting Soil & Water Assessment Tool predicted recharge in the study area. Our analyses suggest that precipitation and actual evapotranspiration are the most important parameters controlling Soil & Water Assessment Tool predicted recharge in the study area. This insight is further supported by results from the partial dependence plots where the higher-than-average Soil & Water Assessment Tool predicted recharge occurs only in a narrow range of actual evapotranspiration rates.

7. Conclusions and Recommendations on Application of Model Results

The project team has the following key insights and recommendations on using the results from this study:

1. Total precipitation and evapotranspiration values have the largest impact on estimating recharge. PRISM was identified as the best available dataset for estimated precipitation values. Moderate Resolution Imaging Spectroradiometer data were identified as a possible source for evapotranspiration; however, calculated estimates using the Hargreaves-Samani (1985) and Penman-Monteith (Allen and others, 1998) equations were more reliable and applicable for this project. Efforts should be made in improving the spatial and temporal discretization of these datasets along with their data processing/filtration algorithms to obtain better estimates for future applications within the State
2. Certain models provided similar trends in estimates of recharge, in particular, and other components of water budgets, in general, when averaged over aquifer-wide spatial scales. However, no such trends could be discerned over watershed-level spatial scales. Also, the statistical analyses were inconclusive in providing a clear frontrunner in terms of relative inter-model comparison. Similar values of Root Mean Square Error were obtained with all possible combinations of comparative model results. This leads the project team to suggest that recharge results from all the models should be used in future developments of the groundwater availability models.
3. If precipitation and evapotranspiration estimates are available for a study area, then application of the Soil Conservation Services method might provide a reasonable estimate of recharge for another region in the State. Such an estimate can be used as an initial input for recharge into future groundwater availability models. However, it should be noted that it is hard to ascertain the variability of recharge from the application of only one model, and it is recommended that a second model also be used to constrain the recharge values.
4. Results from our study indicate that the Soil Conservation Services method has a high correlation with the Soil Water Balance model, mainly because of similar approaches for calculated the water balance. Therefore, we recommend the use of Soil & Water Assessment Tool on a watershed-level scale to obtain an estimate of recharge that an alternative approach. An added advantage of using the Soil & Water Assessment Tool model are the estimates obtained for additional parameters including baseflow.
5. All estimated values of recharge should be aggregated on grid level (used for the Soil Water Balance model) or at the level of the hydrologic response units (used for the Soil & Water Assessment Tool models) to a monthly or average annual basis. Both monthly and average annual datasets are provided in the geodatabase deliverables and can be used for this purpose. The lowest and highest value of recharge from each of the grid cells (or the hydrologic response unit) should be used as target range for calibrating recharge for groundwater availability models.
6. Baseflow estimates available from Soil & Water Assessment Tool model can be used as soft targets for calibrating the stream or other comparable surface water module within the groundwater availability models.

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APPENDIX A

TOTAL WELL COUNTS BY AQUIFER IN EACH WATERSHED

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Appendix A: Total Well Counts by Aquifer in Each Watershed

AQUIFER	CARRIZO			CROSS TIMBERS			EDWARDS			EDWARDS-TRINITY			LIPAN			PECOS VALLEY			TRINITY			GRAND TOTAL
Watershed Name	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	
Beals												1										1
Brady										4	5	10										19
Colorado							31	33	22	6	7	27							134	149	215	624
Conco				13	6	2				42	37	105	209	209	351							974
Frio	21	10	13				63	31	77	60	20	48							35	10	10	398
James										6	2	2										10
Leon							47	46	8													101
Liano										108	93	64										265
Lower Pecos										39	49	52										140
McQueeny							39	17	14	15	8	21							79	90	122	405
Medina	2	3	4				42	25	31	1									10	3	6	127
Nueces	8	6	1				12	14	15	25	24	16										121
Oakcreek				4		2						5										11
Onion Creek							12	10	19										10	3	17	71
Plum	1	1	1																			3
San Antonio	3	2	5				104	102	48													264
San Marcos							10	43	2		1								43	24	14	137
San Muguel	7	19	35				3	3	3													70
San Saba										52	40	60										152
Upper Pecos										3	2	2				11	3	10				31
Grand Total	**42**	**41**	**59**	**17**	**6**	**4**	**363**	**324**	**239**	**361**	**288**	**413**	**209**	**209**	**351**	**11**	**3**	**10**	**311**	**279**	**384**	**3,924**

APPENDIX B

TOTAL WELL COUNTS BY WATER USE IN EACH COUNTY

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Appendix B: Total Well Counts by Water use in Each County

	DOMESTIC			FRACKING SUPPLY			INDUSTRIAL			IRRIGATION			NO DESIGNATION			OTHER			PUBLIC SUPPLY			RIG SUPPLY			STOCK			GRAND TOTAL
County	Wells within 0.125 Mile	Wells between 0.125 to 0.25 Miles	Wells between 0.25 to 0.5 Miles	Wells within 0.125 Mile	Wells between 0.125 to 0.25 Miles	Wells between 0.25 to 0.5 Miles	Wells within 0.125 Mile	Wells between 0.125 to 0.25 Miles	Wells between 0.25 to 0.5 Miles	Wells within 0.125 Mile	Wells between 0.125 to 0.25 Miles	Wells between 0.25 to 0.5 Miles	Wells within 0.125 Mile	Wells between 0.125 to 0.25 Miles	Wells between 0.25 to 0.5 Miles	Wells within 0.125 Mile	Wells between 0.125 to 0.25 Miles	Wells between 0.25 to 0.5 Miles	Wells within 0.125 Mile	Wells between 0.125 to 0.25 Miles	Wells between 0.25 to 0.5 Miles	Wells within 0.125 Mile	Wells between 0.125 to 0.25 Miles	Wells between 0.25 to 0.5 Miles	Wells within 0.125 Mile	Wells between 0.125 to 0.25 Miles	Wells between 0.25 to 0.5 Miles	
Bandera	20	6	6								1	1	3		1					1	1				2	1	1	44
Bexar	8	5	13	142	140	25			4	6	8	9	2	2		5	6	15	1	3	2						3	399
Blanco	36	22	23							1			4	1	2	1		1	1						6	7	8	113
Caldwell	1	1	1																									3
Comal	26	17	15	1						1		4	12	3	7	1			11	2	3							103
Concho	9	7	3							16	7	10		2	1							1			10	9	14	89
Crane	1																											1
Crockett	2	3	1								2	1	6	1	2							2	1	2	2	6	12	43
Edwards	8	11	3								1										2				3		1	29
Frio	2																										1	3
Gillespie	50	75	132		15				2	4	4	9	3	1	3		6		1	4	9				3	5	15	341
Glasscock	1	2	2							1	2	1	1		2					2					1	1	5	21
Hays	27	11	17		39					2			18	4	8	4			4		3					3	4	144
Howard			1										2															3
Irion	15	29	50						3	6	1	5	1		1				3	1	5			1	10	21	30	182
Kendall	26	79	89			1				1	2	1	4	1	5				7		2				6	5	1	230
Kerr	29	11	16							1		2	6	2	6						1				3	2	5	84
Kimble	81	55	40							6	5	2	1	3	2				1	5	2				8	10	19	240
Loving												1												1				2
Lynn																									1			1

Appendix B: (continued) Total Well Counts by Water use in Each County

	DOMESTIC			FRACKING SUPPLY			INDUSTRIAL			IRRIGATION			NO DESIGNATION			OTHER			PUBLIC SUPPLY			RIG SUPPLY			STOCK			GRAND TOTAL
County	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	**Wells within 0.125 Mile**	**Wells between 0.125 to 0.25 Miles**	**Wells between 0.25 to 0.5 Miles**	
Medina	42	32	46						1	31	9	26	6	2	3				1	1				3	13	9	15	240
Menard	38	22	40							3	4	7	2	1	1				1	5	1				7	8	11	151
Pecos		1	1				1	1				1	3							1						1	2	12
Reagan			1																									1
Real	31	10	15									1	1				2			2	5							67
Reeves			1										3									2						6
Runnels	3		5							6	2	8	5	4	9										1		2	45
Schleicher	1	1																								1	2	5
Sterling	1	7	16						3	6	5	7	3		3						1	2	1		1	8	15	79
Sutton	7	10	2							1	1														3	2	2	28
Taylor	2		2										1											1	1		4	11
Terrell		3								1	1			1												2	3	11
Tom Green	99	89	156						1	30	30	47	2	3	2				11	7	9				21	15	47	569
Travis	36	25	41		22	2		1	1	9	6	6	18	2	10	4	3	10	9	3	2				3	2	3	218
Uvalde	80	44	75				1			11	6	17	7	4	14			1	13	3	5				6	9	7	303
Val Verde	18	14	15								2	1	4		3								1		4	8	10	80
Ward	1		1					1	1			3	1	2								1		1			1	13
Zavala	3	1								1	4															1		10
Grand Total	**704**	**593**	**829**	**143**	**216**	**28**	**2**	**3**	**16**	**144**	**103**	**170**	**119**	**39**	**85**	**15**	**17**	**27**	**64**	**40**	**53**	**8**	**3**	**9**	**115**	**136**	**243**	**3,924**

APPENDIX C

GROUNDWATER TOOLBOX RECHARGE ESTIMATE RESULTS

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Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020

	Recharge Estimates (acre-feet/year) by United States Geological Survey Gage							
Year	**8083100**	**8083230**	**8083240**	**8083245**	**8083300**	**8083400**	**8083420**	**8083430**
1981	4420.27	0.00	39716.80	1549.33	0.00	0.00	0.00	8863.47
1982	10324.80	0.00	43186.67	795.73	0.00	0.00	0.00	5235.20
1983	2720.53	0.00	10075.20	253.87	0.00	0.00	0.00	430.93
1984	1013.33	0.00	5080.00	1770.13	0.00	0.00	0.00	0.00
1985	2138.67	0.00	24388.27	2171.73	0.00	0.00	0.00	0.00
1986	8939.73	0.00	63067.20	4629.33	0.00	0.00	0.00	0.00
1987	5821.33	0.00	43302.40	5616.00	0.00	0.00	0.00	0.00
1988	1606.40	0.00	15035.20	2661.33	0.00	0.00	0.00	0.00
1989	693.87	0.00	5421.87	1066.13	0.00	0.00	0.00	0.00
1990	696.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	2754.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	4819.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	2050.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	676.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1995	745.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	247.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	652.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	182.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	163.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	1350.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	118.40	127.47	0.00	0.00	0.00	0.00	5.87	0.00
2002	88.53	976.53	0.00	0.00	0.00	0.00	214.93	0.00
2003	161.60	2835.73	0.00	0.00	0.00	0.00	44.80	0.00
2004	54.93	692.27	0.00	0.00	0.00	0.00	660.27	0.00
2005	6808.53	3053.87	0.00	0.00	0.00	0.00	51.73	0.00
2006	86.93	3971.73	0.00	0.00	0.00	0.00	20.27	0.00
2007	920.53	21818.13	0.00	0.00	0.00	0.00	140.27	0.00
2008	412.80	6926.93	0.00	0.00	0.00	0.00	552.53	0.00
2009	386.67	1832.00	0.00	0.00	0.00	0.00	43.73	0.00
2010	2022.93	9683.20	0.00	0.00	0.00	0.00	320.00	0.00
2011	291.20	1591.47	0.00	0.00	0.00	0.00	103.47	0.00
2012	92.80	367.47	0.00	0.00	0.00	0.00	160.53	0.00
2013	235.73	160.53	0.00	0.00	0.00	0.00	518.93	0.00
2014	311.47	145.07	0.00	0.00	0.00	0.00	98.67	0.00
2015	429.87	5890.67	0.00	0.00	0.00	0.00	706.13	0.00
2016	1248.00	13390.40	2701.87	0.00	0.00	0.00	1276.80	0.00
2017	441.60	5658.13	8456.53	0.00	0.00	0.00	268.27	0.00
2018	1107.73	23273.60	48191.47	0.00	0.00	0.00	691.20	0.00
2019	3425.07	31284.80	45354.67	0.00	0.00	0.00	129.60	0.00
2020	1405.87	46.93	10313.60	0.00	0.00	0.00	213.33	0.00

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

	Recharge Estimates (acre-feet/year) by United States Geological Survey Gage							
Year	**8083470**	**8083480**	**8084000**	**8084200**	**8103900**	**8117995**	**8118500**	**8119000**
1981	3946.13	0.00	48178.13	0.00	6357.33	0.00	0.00	0.00
1982	1461.87	0.00	51537.60	0.00	2064.00	0.00	0.00	0.00
1983	715.20	0.00	12452.80	0.00	3703.47	0.00	0.00	0.00
1984	140.27	0.00	8141.87	0.00	973.87	0.00	0.00	0.00
1985	0.00	0.00	18679.47	0.00	4314.67	0.00	0.00	0.00
1986	0.00	0.00	103712.00	0.00	7832.53	0.00	0.00	0.00
1987	0.00	0.00	94292.27	0.00	8878.40	0.00	0.00	0.00
1988	0.00	0.00	17269.33	0.00	259.20	1761.07	0.00	0.00
1989	0.00	0.00	9554.13	0.00	1093.87	525.33	0.00	0.00
1990	0.00	0.00	50401.07	0.00	74.13	868.27	0.00	0.00
1991	0.00	0.00	106797.87	0.00	8251.73	3622.40	0.00	0.00
1992	0.00	0.00	130298.13	0.00	20424.00	16388.27	0.00	0.00
1993	0.00	0.00	19182.40	0.00	4643.73	820.80	0.00	0.00
1994	0.00	0.00	28361.60	0.00	1676.27	563.73	0.00	0.00
1995	0.00	0.00	16087.47	0.00	2481.07	1397.33	0.00	0.00
1996	0.00	0.00	11122.13	0.00	1477.33	426.13	0.00	0.00
1997	0.00	0.00	36023.47	0.00	16227.20	2382.40	0.00	0.00
1998	0.00	0.00	2411.20	0.00	12753.60	86.40	0.00	0.00
1999	0.00	0.00	3028.27	0.00	1839.47	3895.47	0.00	0.00
2000	0.00	0.00	6677.33	0.00	1697.60	1977.60	0.00	0.00
2001	0.00	274.13	6704.53	0.00	6988.80	332.27	0.00	0.00
2002	0.00	3330.13	5724.80	0.00	3727.47	4511.47	0.00	0.00
2003	0.00	514.13	5204.80	0.00	3324.27	1774.93	0.00	0.00
2004	0.00	4829.87	7923.20	0.00	6547.20	6828.80	0.00	0.00
2005	0.00	1142.40	5384.53	0.00	4112.00	3602.13	0.00	0.00
2006	0.00	266.67	4438.40	0.00	370.67	339.73	0.00	0.00
2007	0.00	5640.00	102866.13	0.00	15825.60	4165.87	0.00	0.00
2008	0.00	1149.33	11677.87	0.00	159.47	3770.67	0.00	0.00
2009	0.00	361.60	5451.20	0.00	5268.80	482.13	0.00	0.00
2010	0.00	4527.47	16282.13	4639.47	8214.93	0.00	0.00	0.00
2011	0.00	321.07	3547.20	9579.73	109.33	0.00	0.00	0.00
2012	0.00	727.47	2133.87	6814.93	829.87	0.00	0.00	0.00
2013	0.00	70.93	1217.60	9156.80	40.00	0.00	0.00	0.00
2014	0.00	595.20	705.07	8259.73	20.27	0.00	0.00	0.00
2015	0.00	3504.53	12742.40	27276.27	5540.27	0.00	0.00	0.00
2016	0.00	13446.93	87009.07	150090.67	11905.07	0.00	0.00	0.00
2017	0.00	1026.13	12991.47	24600.00	3217.60	17.07	0.00	0.00
2018	0.00	4667.20	109019.73	108980.27	6224.53	306.67	0.00	0.00
2019	0.00	7651.73	123364.80	182510.93	6669.87	428.27	0.00	0.00
2020	0.00	1283.73	14877.33	43001.07	241.60	108.80	0.00	0.00

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

	Recharge Estimates (acre-feet/year) by United States Geological Survey Gage							
Year	**8119500**	**8120500**	**8120700**	**8121000**	**8121500**	**8122000**	**8122500**	**8123500**
1981	388.27	2434.13	8347.73	13272.00	0.00	0.00	0.00	0.00
1982	1441.07	3763.73	29039.47	23837.87	0.00	0.00	0.00	0.00
1983	330.13	1172.27	3914.13	2662.40	0.00	0.00	0.00	0.00
1984	536.00	1098.67	3352.53	5035.73	0.00	0.00	0.00	0.00
1985	902.40	2821.33	11533.87	8072.00	0.00	0.00	0.00	0.00
1986	5350.40	4069.33	29032.00	41234.13	0.00	0.00	0.00	0.00
1987	1888.00	0.00	26038.40	25316.27	0.00	0.00	0.00	0.00
1988	864.00	0.00	7608.53	8925.33	0.00	0.00	0.00	0.00
1989	272.00	0.00	5200.53	3208.53	0.00	0.00	0.00	0.00
1990	0.00	0.00	9400.53	6739.20	0.00	0.00	0.00	0.00
1991	0.00	0.00	11861.33	8578.67	0.00	0.00	0.00	0.00
1992	0.00	0.00	32880.00	30965.33	0.00	0.00	0.00	0.00
1993	0.00	0.00	7493.33	3602.67	0.00	0.00	0.00	0.00
1994	0.00	0.00	2712.00	532.27	0.00	0.00	0.00	0.00
1995	0.00	0.00	3605.33	3798.40	0.00	0.00	0.00	0.00
1996	0.00	0.00	3229.87	4177.60	0.00	0.00	0.00	0.00
1997	0.00	0.00	12264.00	18250.13	0.00	0.00	0.00	0.00
1998	0.00	0.00	1296.00	106.67	0.00	0.00	0.00	0.00
1999	0.00	0.00	5145.60	12107.73	0.00	0.00	0.00	0.00
2000	0.00	0.00	9362.67	3885.87	0.00	0.00	0.00	0.00
2001	0.00	188.80	2025.60	976.00	0.00	0.00	0.00	0.00
2002	0.00	1926.40	2881.60	2726.40	0.00	0.00	0.00	0.00
2003	0.00	576.00	0.00	4390.40	0.00	0.00	0.00	0.00
2004	0.00	2880.53	0.00	10610.67	0.00	0.00	0.00	0.00
2005	0.00	1882.13	0.00	3555.20	0.00	0.00	0.00	0.00
2006	0.00	859.20	0.00	355.73	0.00	0.00	0.00	0.00
2007	0.00	1306.13	0.00	3914.13	0.00	0.00	0.00	0.00
2008	0.00	1825.07	0.00	3101.87	0.00	0.00	0.00	0.00
2009	0.00	421.33	0.00	519.47	0.00	0.00	0.00	0.00
2010	0.00	1931.20	0.00	1564.27	0.00	0.00	0.00	0.00
2011	0.00	286.93	0.00	193.60	0.00	0.00	0.00	0.00
2012	0.00	688.00	0.00	2894.93	0.00	0.00	0.00	0.00
2013	0.00	201.07	0.00	1404.80	0.00	0.00	0.00	0.00
2014	0.00	2257.07	0.00	9195.20	0.00	0.00	0.00	0.00
2015	0.00	4025.60	0.00	9706.67	0.00	0.00	0.00	0.00
2016	0.00	2717.33	0.00	5158.40	0.00	0.00	0.00	0.00
2017	0.00	752.53	0.00	1555.20	0.00	0.00	0.00	0.00
2018	0.00	397.33	0.00	2420.27	0.00	0.00	0.00	0.00
2019	0.00	841.60	0.00	2862.93	0.00	0.00	0.00	0.00
2020	0.00	748.80	0.00	444.27	0.00	0.00	0.00	0.00

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

	Recharge Estimates (acre-feet/year) by United States Geological Survey Gage							
Year	**8123650**	**8123700**	**8123720**	**8123800**	**8123850**	**8123900**	**8124000**	**8126380**
1981	0.00	0.00	0.00	6492.27	34641.07	0.00	523.20	39521.60
1982	0.00	0.00	0.00	6579.73	77363.20	0.00	458.13	53034.67
1983	0.00	0.00	1846.93	2930.67	10989.33	0.00	260.27	6404.27
1984	0.00	0.00	3684.80	3478.93	11548.80	0.00	76.80	6043.73
1985	0.00	0.00	2009.07	3632.53	41101.33	0.00	83.20	5985.07
1986	0.00	0.00	30546.67	45218.13	139715.20	0.00	75690.13	137864.00
1987	0.00	0.00	21963.20	33259.20	78860.80	0.00	64752.00	162244.27
1988	0.00	0.00	267.20	15571.73	28585.60	0.00	35578.67	51444.27
1989	0.00	0.00	0.00	1585.60	15092.27	0.00	45221.87	35932.27
1990	0.00	0.00	0.00	2086.40	33331.73	0.00	7686.40	43443.73
1991	0.00	0.00	0.00	3477.33	31019.73	0.00	4692.80	53344.00
1992	0.00	0.00	0.00	18089.07	97150.93	0.00	1833.07	80172.27
1993	0.00	0.00	0.00	2403.73	15737.60	0.00	2782.40	11120.00
1994	0.00	0.00	0.00	7533.33	24250.67	0.00	3260.27	16836.80
1995	0.00	0.00	0.00	1913.60	11584.00	0.00	4038.93	30037.87
1996	0.00	0.00	0.00	2261.87	8292.27	0.00	53091.73	93393.60
1997	0.00	0.00	0.00	2638.40	21106.67	0.00	9564.80	59778.67
1998	0.00	0.00	0.00	969.60	1705.60	0.00	24466.13	30143.47
1999	0.00	0.00	0.00	442.67	7874.13	0.00	7837.87	8630.93
2000	0.00	0.00	0.00	14627.20	33529.07	0.00	5666.13	7114.13
2001	0.00	0.00	0.00	507.73	7009.07	0.00	6291.20	6882.67
2002	0.00	0.00	0.00	145.07	5798.93	0.00	8105.07	6074.13
2003	0.00	0.00	0.00	3035.73	19998.40	0.00	7316.27	16158.93
2004	0.00	0.00	0.00	6028.27	83173.33	0.00	5462.93	11388.80
2005	0.00	0.00	0.00	1963.20	14373.87	0.00	1591.47	10688.00
2006	0.00	0.00	0.00	1047.47	5300.80	0.00	1670.93	2350.93
2007	0.00	0.00	0.00	3518.40	19386.67	0.00	2538.13	55029.33
2008	0.00	0.00	0.00	918.40	4729.60	0.00	1429.87	7542.40
2009	0.00	0.00	0.00	518.40	1890.67	0.00	240.00	960.00
2010	0.00	0.00	0.00	2529.60	9568.00	0.00	104.00	2425.60
2011	0.00	0.00	0.00	58.13	297.07	0.00	12.80	121.07
2012	0.00	0.00	0.00	10694.40	51789.33	0.00	20.80	5820.80
2013	0.00	0.00	0.00	1065.07	7748.27	0.00	5.33	3310.40
2014	0.00	0.00	0.00	1159.47	12280.53	0.00	10.67	3033.07
2015	0.00	0.00	0.00	1798.40	28173.87	0.00	26.13	3498.13
2016	0.00	0.00	0.00	2860.80	26082.13	0.00	56.53	8549.33
2017	0.00	0.00	0.00	1668.80	10157.33	0.00	511.47	5371.73
2018	0.00	0.00	0.00	7443.20	36102.93	0.00	256.00	87014.93
2019	0.00	0.00	0.00	2350.40	23350.40	0.00	342.40	69020.80
2020	0.00	0.00	0.00	841.60	6896.53	0.00	203.73	6937.07

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

	Recharge Estimates (acre-feet/year) by United States Geological Survey Gage							
Year	**8126500**	**8127000**	**8127500**	**8128000**	**8128030**	**8128400**	**8128500**	**8129300**
1981	0.00	15270.40	4626.13	20382.40	0.00	4995.73	0.00	7378.13
1982	0.00	17114.13	5758.93	12021.33	0.00	2761.60	0.00	6786.67
1983	0.00	2290.67	4299.73	6096.53	0.00	2210.13	0.00	3131.20
1984	0.00	2068.27	0.00	4422.40	0.00	697.07	0.00	2006.93
1985	0.00	5527.47	0.00	7097.60	0.00	1259.73	0.00	2643.20
1986	0.00	23368.00	0.00	19640.53	0.00	16235.73	0.00	7300.80
1987	0.00	46026.13	0.00	36738.13	0.00	26091.20	0.00	21692.27
1988	0.00	2877.87	0.00	15826.67	0.00	5907.73	0.00	9522.67
1989	0.00	7049.60	0.00	9808.00	0.00	2915.73	0.00	4963.73
1990	0.00	21678.93	0.00	14691.20	0.00	2084.80	0.00	7741.87
1991	0.00	51160.53	0.00	21711.47	0.00	5268.80	0.00	8662.93
1992	0.00	75894.40	0.00	38109.33	0.00	31884.80	0.00	13509.87
1993	0.00	2917.87	0.00	16712.53	0.00	4632.53	0.00	6352.53
1994	0.00	23977.60	0.00	11829.33	0.00	1517.87	0.00	4252.80
1995	0.00	10826.67	0.00	7664.53	0.00	343.47	0.00	2543.47
1996	0.00	35616.53	0.00	0.00	0.00	0.00	0.00	0.00
1997	0.00	46158.93	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	3571.20	0.00	0.00	0.00	0.00	0.00	0.00
1999	0.00	1043.73	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	2555.73	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	989.33	0.00	2949.87	0.00	434.13	0.00	0.00
2002	0.00	7365.33	0.00	6390.40	0.00	0.53	0.00	0.00
2003	0.00	9392.00	0.00	5387.20	0.00	0.53	0.00	0.00
2004	0.00	33357.33	0.00	13274.67	0.00	2103.47	0.00	0.00
2005	0.00	30142.93	0.00	19828.27	0.00	2148.27	0.00	0.00
2006	0.00	2430.40	0.00	11400.00	0.00	1009.07	0.00	0.00
2007	0.00	46175.47	0.00	15991.47	0.00	1060.80	0.00	0.00
2008	0.00	2293.33	0.00	8401.60	0.00	661.33	0.00	0.00
2009	0.00	373.33	0.00	4037.87	0.00	4.27	0.00	0.00
2010	0.00	8985.07	0.00	5345.60	0.00	0.00	0.00	0.00
2011	0.00	648.53	0.00	3146.13	0.00	2.13	0.00	0.00
2012	0.00	4910.93	0.00	5893.33	0.00	11.20	0.00	0.00
2013	0.00	95.47	0.00	4821.87	0.00	0.53	0.00	0.00
2014	0.00	2681.60	0.00	7613.87	0.00	108.80	0.00	0.00
2015	0.00	12325.33	0.00	7792.53	0.00	298.13	0.00	0.00
2016	0.00	33779.20	0.00	18300.27	4115.20	0.00	0.00	0.00
2017	0.00	4535.47	0.00	10498.67	15014.40	0.00	0.00	0.00
2018	0.00	29865.07	0.00	33527.47	3663.47	6147.73	0.00	0.00
2019	0.00	44884.80	0.00	24202.13	0.00	1872.00	0.00	0.00
2020	0.00	6198.40	0.00	14034.13	0.00	112.00	0.00	0.00

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

	Recharge Estimates (acre-feet/year) by United States Geological Survey Gage							
Year	**8130500**	**8130700**	**8131000**	**8131190**	**8131400**	**8131600**	**8132450**	**8132500**
1981	12965.87	0.00	0.00	0.00	1458.13	9528.53	0.00	0.00
1982	7946.13	0.00	0.00	0.00	240.53	0.00	0.00	0.00
1983	4295.47	0.00	0.00	0.00	220.80	0.00	0.00	0.00
1984	4742.40	0.00	0.00	0.00	79.47	0.00	0.00	0.00
1985	6344.00	0.00	0.00	0.00	279.47	0.00	0.00	0.00
1986	7093.87	0.00	0.00	0.00	136.00	0.00	0.00	0.00
1987	18470.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988	10928.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1989	8878.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990	6582.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1991	8425.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	16141.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1993	9313.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	5682.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1995	3189.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.00	2370.67	0.00	0.00	0.00	0.00
2004	0.00	0.00	0.00	-21.33	208.53	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	588.27	0.00	0.00	0.00
2006	0.00	2892.27	0.00	0.00	21.87	0.00	0.00	0.00
2007	0.00	14894.40	0.00	0.00	1283.73	0.00	0.00	0.00
2008	0.00	6070.93	0.00	0.00	289.07	0.00	0.00	0.00
2009	0.00	4212.27	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	3144.00	0.00	0.00	134.93	0.00	0.00	0.00
2011	0.00	1118.93	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.00	851.73	0.00	0.00	4.27	0.00	0.00	0.00
2013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	0.00	0.00	0.00	0.00	70.40	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	18.67	0.00	32.53	0.00
2016	0.00	0.00	0.00	0.00	671.47	0.00	133.87	0.00
2017	0.00	0.00	0.00	0.00	169.07	0.00	52.27	0.00
2018	0.00	0.00	0.00	0.00	3849.60	0.00	96.53	0.00
2019	0.00	0.00	0.00	0.00	2836.80	0.00	257.07	0.00
2020	0.00	0.00	0.00	0.00	480.53	0.00	272.53	0.00

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

	Recharge Estimates (acre-feet/year) by United States Geological Survey Gage							
Year	**8133500**	**8133900**	**8134000**	**8134250**	**8135000**	**8136000**	**8136500**	**8136700**
1981	425.60	425.60	3646.93	0.00	943.47	12679.47	40675.20	107301.33
1982	456.00	456.00	3251.20	0.00	1473.07	9994.13	31078.40	114198.40
1983	147.20	147.20	1996.27	0.00	1202.13	3687.47	17376.53	25230.93
1984	0.53	0.53	893.33	0.00	3528.00	3802.13	8577.07	19631.47
1985	1.07	1.07	731.73	0.00	4360.53	2043.20	14682.67	33803.73
1986	0.00	0.00	10280.00	0.00	3544.00	5366.93	26638.93	205916.27
1987	0.00	0.00	6781.87	0.00	2368.00	14032.53	73016.53	357630.40
1988	0.00	0.00	3789.87	0.00	1125.87	5002.13	32826.67	102971.73
1989	0.00	0.00	2043.20	0.00	894.40	3124.27	20803.20	93381.87
1990	0.00	0.00	1942.93	0.00	882.13	4994.67	48651.73	31136.53
1991	0.00	0.00	3380.27	0.00	0.00	5833.60	51035.20	23224.00
1992	0.00	0.00	10475.20	0.00	0.00	15548.27	152747.73	183504.53
1993	0.00	0.00	2481.60	0.00	0.00	5802.13	41088.53	55750.93
1994	0.00	0.00	1897.60	0.00	0.00	5234.13	26711.47	77030.40
1995	0.00	0.00	697.07	0.00	0.00	6699.73	28877.87	9851.73
1996	0.00	0.00	3800.53	0.00	0.00	3420.80	14909.87	191250.13
1997	0.00	0.00	2577.60	0.00	0.00	14858.13	29513.60	57482.67
1998	0.00	0.00	1256.00	0.00	0.00	845.33	6942.40	40238.40
1999	0.00	0.00	579.73	0.00	0.00	641.60	3118.40	7194.67
2000	0.00	0.00	2053.33	2417.60	0.00	1034.67	6877.87	6885.33
2001	0.00	0.00	573.33	261.33	0.00	1990.40	5342.93	6245.87
2002	0.00	0.00	564.80	222.40	0.00	933.33	7712.53	8508.27
2003	0.00	0.00	480.00	1141.87	0.00	1567.47	9262.40	6939.20
2004	0.00	0.00	2488.53	3682.67	0.00	2123.20	12774.93	7420.80
2005	0.00	0.00	13834.13	15888.53	0.00	2347.20	25094.93	4795.20
2006	0.00	0.00	597.87	319.47	0.00	1382.40	8870.40	3876.80
2007	0.00	0.00	1051.73	1232.00	0.00	3955.20	32145.60	5314.67
2008	0.00	0.00	930.67	586.67	0.00	4870.40	17696.53	3899.73
2009	0.00	0.00	441.60	323.73	0.00	5154.13	10652.80	3981.87
2010	0.00	0.00	1271.47	519.47	0.00	6014.40	15105.60	3910.40
2011	0.00	0.00	246.40	14.40	0.00	5077.87	7977.60	3172.80
2012	0.00	0.00	1134.40	534.93	0.00	4916.27	17227.20	8190.93
2013	0.00	0.00	525.33	468.80	0.00	4021.87	8114.13	3966.93
2014	0.00	0.00	233.60	761.07	0.00	4588.27	117554.13	2684.80
2015	0.00	0.00	5812.80	5357.87	0.00	6593.60	14679.47	4020.27
2016	0.00	0.00	74.13	75.73	0.00	4566.40	21780.27	5167.47
2017	0.00	0.00	1.07	13.87	0.00	5286.93	16944.53	5706.67
2018	0.00	0.00	2916.80	0.00	0.00	9937.60	49291.20	5427.73
2019	0.00	0.00	234.13	0.00	0.00	14138.67	75136.53	5996.80
2020	0.00	0.00	0.00	0.00	0.00	10121.07	25421.87	4682.67

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

	Recharge Estimates (acre-feet/year) by United States Geological Survey Gage							
Year	**8138000**	**8141500**	**8142000**	**8144000**	**8144500**	**8144600**	**8144800**	**8145000**
1981	NaN	277.33	0.00	14201.07	44038.40	49278.40	161.60	184.00
1982	NaN	76.27	0.00	14980.27	33701.33	25384.53	212.80	64.00
1983	NaN	29.33	0.00	9780.80	22515.20	20758.93	108.27	45.33
1984	NaN	57.07	0.00	0.00	22217.07	25180.80	62.40	166.40
1985	NaN	37.33	0.00	0.00	23848.53	19752.00	30.40	100.80
1986	NaN	113.07	0.00	0.00	32087.47	24355.73	0.00	2820.80
1987	NaN	476.80	0.00	0.00	51772.80	66996.80	0.00	0.00
1988	NaN	27.73	0.00	0.00	36420.27	24544.00	0.00	0.00
1989	NaN	56.00	0.00	0.00	14203.73	21449.60	0.00	0.00
1990	NaN	296.53	0.00	0.00	48062.40	57750.93	0.00	0.00
1991	NaN	0.00	0.00	0.00	34896.00	56393.07	0.00	0.00
1992	NaN	0.00	0.00	0.00	43214.93	80277.87	0.00	0.00
1993	NaN	0.00	0.00	0.00	0.00	31716.80	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	NaN	0.00	0.00	0.00	4314.13	NaN	0.00	0.00
1998	NaN	0.00	0.00	0.00	13353.07	NaN	0.00	0.00
1999	NaN	0.00	0.00	0.00	11396.80	NaN	0.00	0.00
2000	NaN	0.00	0.00	0.00	18751.47	NaN	0.00	0.00
2001	NaN	0.00	0.00	0.00	19425.60	NaN	0.00	164.80
2002	NaN	0.00	0.00	0.00	16737.60	NaN	0.00	127.47
2003	NaN	0.00	0.00	0.00	15645.87	NaN	0.00	237.33
2004	NaN	0.00	0.00	0.00	21599.47	NaN	0.00	175.47
2005	NaN	0.00	0.00	0.00	25451.20	NaN	0.00	262.40
2006	NaN	0.00	0.00	0.00	18411.73	NaN	0.00	17.60
2007	NaN	0.00	0.00	0.00	29965.33	NaN	0.00	1585.60
2008	NaN	0.00	0.00	0.00	21656.53	NaN	0.00	862.40
2009	NaN	0.00	0.00	0.00	19893.33	NaN	0.00	221.33
2010	NaN	0.00	0.00	0.00	18459.20	NaN	0.00	1768.00
2011	NaN	0.00	0.00	0.00	9161.60	NaN	0.00	7.47
2012	0.00	0.00	0.00	0.00	10539.20	NaN	0.00	521.60
2013	0.00	0.00	0.00	0.00	14475.73	0.00	0.00	446.40
2014	0.00	0.00	0.00	0.00	12488.00	0.00	0.00	649.60
2015	0.00	0.00	1705.60	0.00	12766.40	0.00	0.00	3278.93
2016	0.00	0.00	6331.73	0.00	21237.33	0.00	0.00	885.87
2017	0.00	0.00	993.60	0.00	18728.53	0.00	0.00	130.13
2018	0.00	0.00	482.13	0.00	37322.13	0.00	0.00	17642.13
2019	0.00	0.00	3947.73	0.00	51306.67	0.00	0.00	13828.80
2020	0.00	0.00	231.47	0.00	26846.40	0.00	0.00	208.00

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

	Recharge Estimates (acre-feet/year) by United States Geological Survey Gage							
Year	**8146000**	**8147000**	**8148500**	**8149900**	**8150000**	**8150700**	**8150800**	**8151500**
1981	79940.27	264503.47	264503.47	0.00	0.00	NaN	9406.40	280161.07
1982	49817.07	365657.07	365657.07	0.00	0.00	NaN	1956.27	122756.80
1983	40163.73	90018.13	90018.13	0.00	0.00	NaN	3454.93	89870.40
1984	25089.60	101021.87	101021.87	0.00	0.00	NaN	3826.67	124237.87
1985	75394.67	213624.00	213624.00	0.00	0.00	NaN	5320.53	133933.33
1986	70176.00	576384.00	576384.00	0.00	0.00	NaN	6337.07	240404.27
1987	112735.47	760230.40	760230.40	0.00	0.00	NaN	16075.20	376485.33
1988	40573.33	224608.53	224608.53	0.00	0.00	NaN	1420.27	173473.07
1989	38251.73	248472.00	248472.00	0.00	0.00	NaN	2490.13	134214.40
1990	99570.67	420702.40	420702.40	0.00	0.00	NaN	3386.13	0.00
1991	92841.60	1346901.33	1346901.33	0.00	0.00	NaN	5928.00	215844.27
1992	264743.47	1414365.87	1414365.87	0.00	0.00	NaN	23078.40	413480.53
1993	81722.67	215465.07	215465.07	0.00	0.00	NaN	4531.73	152997.87
1994	0.00	420172.80	420172.80	0.00	0.00	0.00	2835.73	154847.47
1995	0.00	280522.67	280522.67	0.00	0.00	0.00	3390.40	126762.67
1996	0.00	318491.20	318491.20	0.00	0.00	0.00	4338.67	176642.67
1997	22032.53	1123197.87	1123197.87	0.00	25520.53	39909.87	23650.67	379451.20
1998	77929.07	243058.67	243058.67	0.00	118939.73	170233.60	4213.87	219993.60
1999	47534.93	73117.87	73117.87	0.00	94887.47	103740.27	3762.13	119703.47
2000	84079.47	267608.53	267608.53	0.00	167477.87	236208.00	7413.87	315876.27
2001	78552.00	155416.53	155416.53	0.00	97734.93	185798.93	10029.87	237473.60
2002	77026.13	344411.73	349876.27	0.00	90985.60	114413.33	4504.00	152275.20
2003	62520.00	221304.53	233340.80	0.00	77551.47	109539.73	3903.47	123824.00
2004	107980.80	650379.73	683843.20	0.00	123656.53	191113.07	9227.73	257945.07
2005	96683.73	429585.07	455544.00	0.00	89596.27	130026.13	6278.93	159731.20
2006	38912.53	52840.53	60450.67	0.00	58101.87	72501.87	2536.00	77328.53
2007	166809.07	807858.13	866426.13	0.00	221058.13	328184.00	29285.33	479152.53
2008	55667.20	80200.00	90288.53	0.00	73491.20	86560.00	4150.40	95170.13
2009	46512.00	81134.40	96711.47	0.00	75892.80	89869.87	8241.60	108914.13
2010	89649.60	154806.93	178342.40	0.00	83266.67	162546.67	17243.20	208424.00
2011	24291.73	34848.53	39952.53	0.00	43796.80	42918.40	1547.73	46481.07
2012	48190.93	86644.80	94949.87	8176.53	52811.20	64194.13	5097.60	75178.13
2013	41102.93	67868.80	78256.00	35192.53	91937.60	63712.53	4861.87	64473.07
2014	31834.13	50701.87	54840.00	29120.00	66404.80	53059.20	3233.60	47622.40
2015	53492.80	309085.33	326755.73	61368.53	143428.27	114089.07	6440.53	126904.53

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

	Recharge Estimates (acre-feet/year) by United States Geological Survey Gage							
Year	**8146000**	**8147000**	**8148500**	**8149900**	**8150000**	**8150700**	**8150800**	**8151500**
2016	124135.47	609661.87	646486.93	73609.07	172117.33	180829.33	9588.80	210684.80
2017	50279.47	123224.00	133692.80	48202.67	101505.07	76994.67	6086.93	93598.93
2018	169956.80	402313.07	442410.67	96380.80	234399.47	227698.13	8261.33	305933.33
2019	136926.93	345075.20	365404.27	62154.67	141923.73	119037.33	6272.00	137124.80
2020	44051.73	61078.93	73770.13	53340.27	120725.33	89289.60	3570.13	104652.80

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

	Recharge Estimates (acre-feet/year) by United States Geological Survey Gage							
Year	**8152000**	**8152710**	**8152900**	**8153500**	**8154510**	**8154700**	**8155200**	**8155240**
1981	34352.53	0.00	38484.80	121879.47	1309874.13	8837.87	0.00	0.00
1982	6078.93	0.00	11133.87	37257.60	934976.53	2721.07	0.00	0.00
1983	15334.40	0.00	11181.33	35280.00	403203.20	4064.00	0.00	0.00
1984	21662.40	0.00	15537.60	46137.60	744571.73	5217.60	0.00	0.00
1985	31149.87	0.00	26559.47	93257.07	609910.93	7993.07	0.00	0.00
1986	33248.00	0.00	30318.40	154241.07	1215707.73	10625.07	0.00	0.00
1987	56922.13	0.00	67148.27	264638.40	1586443.73	12030.40	0.00	0.00
1988	11250.13	0.00	18636.80	48562.13	720267.73	1665.07	0.00	0.00
1989	17712.53	0.00	12058.67	50315.20	566299.20	2064.53	6226.67	12633.07
1990	0.00	0.00	16481.07	49240.00	525122.67	0.00	2897.07	5194.67
1991	0.00	0.00	34492.80	86928.53	0.00	0.00	51011.73	60858.67
1992	0.00	0.00	87786.67	263724.80	0.00	0.00	79413.87	93542.93
1993	0.00	0.00	9136.53	64433.07	0.00	0.00	18836.80	25294.93
1994	0.00	0.00	0.00	90609.60	0.00	0.00	11045.33	11642.67
1995	0.00	0.00	0.00	92761.60	0.00	0.00	15573.87	22678.40
1996	0.00	0.00	0.00	33319.47	0.00	0.00	485.87	1322.13
1997	0.00	0.00	0.00	264561.60	0.00	0.00	47414.93	72657.60
1998	0.00	0.00	15256.00	119904.53	0.00	0.00	47204.27	62622.93
1999	0.00	0.00	14973.87	43939.20	0.00	0.00	4934.40	5821.87
2000	0.00	0.00	15155.73	27309.87	0.00	0.00	NaN	18322.13
2001	0.00	0.00	33404.80	94005.87	0.00	0.00	NaN	48509.33
2002	0.00	0.00	44409.60	191045.87	0.00	0.00	NaN	51349.33
2003	0.00	0.00	25110.40	93962.13	0.00	0.00	NaN	24600.53
2004	0.00	0.00	51768.53	177727.47	0.00	0.00	NaN	52100.27
2005	0.00	0.00	41908.27	118677.33	0.00	0.00	NaN	17060.80

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

	Recharge Estimates (acre-feet/year) by United States Geological Survey Gage							
Year	**8152000**	**8152710**	**8152900**	**8153500**	**81545410**	**8154700**	**8155200**	**8155240**
2006	0.00	0.00	12342.93	29473.07	0.00	0.00	NaN	2848.53
2007	0.00	0.00	97011.73	282155.73	0.00	0.00	NaN	63424.00
2008	0.00	0.00	13949.33	37978.13	0.00	0.00	NaN	2310.40
2009	0.00	0.00	11592.00	32733.33	0.00	0.00	NaN	23084.27
2010	107001.60	0.00	41726.40	113082.13	0.00	0.00	NaN	49809.07
2011	4982.40	0.00	4957.87	10494.40	0.00	0.00	NaN	2299.73
2012	27607.47	0.00	6281.07	27179.73	0.00	0.00	NaN	16078.40
2013	7175.47	0.00	4227.20	14001.60	0.00	0.00	NaN	17232.00
2014	8898.13	0.00	2276.80	15349.33	0.00	0.00	NaN	12516.27
2015	83985.07	0.00	15646.93	84133.87	0.00	0.00	NaN	84901.87
2016	118396.80	0.00	32139.20	86118.93	0.00	0.00	NaN	74629.87
2017	39442.13	241.07	18453.33	46654.93	0.00	0.00	NaN	25257.60
2018	65253.33	554.13	23213.87	54489.07	0.00	0.00	NaN	39995.73
2019	40387.20	748.80	38808.53	81933.87	0.00	0.00	NaN	42805.33
2020	24914.13	252.80	0.00	30700.27	0.00	0.00	NaN	6857.60

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

Gage	**08166000**		**08166140**		**08167000**		**08167500**		**08167800**	
Year		**Inches**	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**
1981		0.063	NA	NA	285,560	1.317	133,752	0.390	124,518	0.449
1982		0.034	NA	NA	99,521	0.459	419,286	1.221	571,603	2.059
1983		0.028	NA	NA	69,130	0.319	134,062	0.390	133,105	0.479
1984		0.027	NA	NA	57,574	0.265	104,083	0.303	142,690	0.514
1985		0.054	NA	NA	169,237	0.780	66,176	0.193	90,449	0.326
1986		0.058	NA	NA	227,009	1.047	349,072	1.017	497,916	1.794
1987		0.126	NA	NA	409,349	1.887	475,686	1.385	569,836	2.053
1988		0.057	NA	NA	146,579	0.676	697,767	2.032	985,145	3.549
1989		0.041	NA	NA	76,702	0.354	162,092	0.472	173,562	0.625
1990		0.048	NA	NA	109,269	0.504	84,134	0.245	102,190	0.368
1991		0.044	NA	NA	218,244	1.006	162,292	0.473	223,514	0.805
1992		0.121	NA	NA	435,668	2.009	438,377	1.277	1,301,663	4.689
1993		0.040	NA	NA	108,119	0.498	788,228	2.295	1,204,922	4.341
1994		NA	NA	NA	117,621	0.542	195,538	0.569	175,742	0.633
1995		NA	NA	NA	116,027	0.535	191,201	0.557	198,785	0.716
1996		NA	NA	NA	79,663	0.367	162,078	0.472	218,564	0.787
1997		NA	NA	NA	345,707	1.594	87,911	0.256	78,546	0.283
1998		NA	NA	NA	158,865	0.732	586,087	1.707	1,619,955	5.836
1999		0.037	38,325	0.103	88,678	0.409	294,294	0.857	858,482	3.093
2000		0.092	85,140	0.229	120,789	0.557	111,184	0.324	54,632	0.197
2001		0.081	105,416	0.284	199,788	0.921	177,651	0.517	257,363	0.927
2002		0.058	92,714	0.250	285,670	1.317	381,300	1.110	493,869	1.779
2003		0.039	45,408	0.122	131,401	0.606	536,558	1.563	789,423	2.844
2004		0.086	40,631	0.109	311,151	1.435	223,099	0.650	243,589	0.878
2005		0.064	75,291	0.203	152,008	0.701	636,778	1.854	825,318	2.973
2006		0.039	42,890	0.115	50,089	0.231	282,230	0.822	224,280	0.808
2007		0.072	38,602	0.104	344,210	1.587	50,246	0.146	65,653	0.237
2008		0.040	41,697	0.112	54,570	0.252	656,584	1.912	918,747	3.310
2009		0.030	39,463	0.106	42,077	0.194	62,849	0.183	111,893	0.403
2010		0.057	14,281	0.038	137,959	0.636	56,867	0.166	58,633	0.211
2011		0.026	25,463	0.069	28,075	0.129	246,460	0.718	190,180	0.685
2012		0.031	17,516	0.047	43,252	0.199	26,077	0.076	54,726	0.197
2013		0.025	23,189	0.062	28,599	0.132	59,698	0.174	53,377	0.192
2014		0.024	17,317	0.047	25,540	0.118	33,266	0.097	51,441	0.185
2015		0.034	30,410	0.082	112,157	0.517	24,269	0.071	46,677	0.168
2016		0.073	18,748	0.050	212,844	0.981	288,206	0.839	473,463	1.706
2017		0.030	29,891	0.080	89,130	0.411	366,001	1.066	372,149	1.341
2018		0.064	18,648	0.050	102,280	0.472	136,020	0.396	135,055	0.487
2019		0.050	NA	NA	117,456	0.542	184,896	0.538	233,019	0.839
2020		0.027	NA	NA	47,286	0.218	193,147	0.562	171,581	0.618

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

Gage	**08168500**		**08169000**		**08171000**		**08171300**		**08178700**	
Year	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**
1981	834,259	3.111	250,690	0.535	100,201	0.258	117,503	0.500	1,335	0.006
1982	150,669	0.562	195,504	0.417	45,001	0.116	29,295	0.125	610	0.003
1983	188,936	0.705	176,074	0.376	60,263	0.155	47,805	0.204	465	0.002
1984	103,484	0.386	84,834	0.181	38,925	0.100	13,241	0.056	182	0.001
1985	684,102	2.551	229,561	0.490	142,409	0.366	157,515	0.671	2,902	0.013
1986	735,579	2.743	230,778	0.493	182,160	0.469	183,256	0.780	2,253	0.010
1987	1,129,688	4.213	280,903	0.600	173,917	0.447	198,991	0.847	8,457	0.039
1988	184,985	0.690	188,872	0.403	39,030	0.100	21,865	0.093	444	0.002
1989	115,016	0.429	106,052	0.226	25,717	0.066	13,839	0.059	83	0.000
1990	243,940	0.910	151,936	0.324	43,349	0.112	26,817	0.114	593	0.003
1991	738,404	2.754	211,590	0.452	167,998	0.432	175,517	0.747	5,474	0.025
1992	1,413,044	5.269	387,164	0.827	270,982	0.697	288,437	1.228	6,516	0.030
1993	234,830	0.876	284,766	0.608	91,000	0.234	78,188	0.333	6,300	0.029
1994	239,545	0.893	233,045	0.498	79,330	0.204	61,795	0.263	1,147	0.005
1995	210,407	0.785	197,250	0.421	73,140	0.188	73,638	0.314	397	0.002
1996	89,306	0.333	111,352	0.238	15,791	0.041	4,907	0.021	8	0.000
1997	1,208,587	4.507	238,101	0.508	203,908	0.525	210,095	0.895	1,639	0.007
1998	686,186	2.559	283,622	0.606	211,366	0.544	233,350	0.994	15,091	0.069
1999	86,047	0.321	227,599	0.486	34,349	0.088	16,866	0.072	45	0.000
2000	302,895	1.130	195,687	0.418	50,998	0.131	37,650	0.160	674	0.003
2001	566,328	2.112	300,100	0.641	165,265	0.425	161,549	0.688	1,653	0.008
2002	970,338	3.618	332,894	0.711	196,512	0.506	183,045	0.779	15,403	0.070
2003	300,795	1.122	270,015	0.576	96,566	0.248	74,835	0.319	450	0.002
2004	945,994	3.528	337,292	0.720	239,951	0.617	229,497	0.977	7,012	0.032
2005	317,885	1.185	278,394	0.594	105,800	0.272	87,159	0.371	397	0.002
2006	76,797	0.286	179,066	0.382	16,475	0.042	3,934	0.017	45	0.000
2007	1,083,697	4.041	347,210	0.741	193,686	0.498	208,518	0.888	NA	NA
2008	139,081	0.519	202,954	0.433	20,394	0.052	7,022	0.030	NA	NA
2009	92,956	0.347	196,614	0.420	35,908	0.092	24,114	0.103	NA	NA
2010	312,917	1.167	259,499	0.554	126,082	0.324	124,420	0.530	NA	NA
2011	71,887	0.268	153,121	0.327	15,360	0.040	3,742	0.016	115	0.001
2012	91,012	0.339	163,523	0.349	47,949	0.123	27,786	0.118	702	0.003
2013	72,651	0.271	129,169	0.276	27,879	0.072	15,677	0.067	3,422	0.016
2014	61,754	0.230	91,590	0.196	12,913	0.033	2,214	0.009	116	0.001
2015	610,071	2.275	236,021	0.504	171,466	0.441	198,562	0.845	5,482	0.025
2016	622,638	2.322	298,929	0.638	130,257	0.335	123,814	0.527	2,815	0.013
2017	223,442	0.833	244,070	0.521	58,498	0.151	40,752	0.174	170	0.001
2018	261,802	0.976	219,070	0.468	52,937	0.136	39,372	0.168	5,750	0.026
2019	282,716	1.054	262,341	0.560	77,297	0.199	78,226	0.333	2,366	0.011
2020	71,657	0.267	207,395	0.443	24,972	0.064	13,458	0.057	NA	NA

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

Gage	08181400		08185000		08190000		08190500		08195000	
Year	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**
1981	3,304	0.015	4,951	0.015	202,011	0.711	44,451	0.169	191,892	0.658
1982	442	0.002	45	0.000	63,621	0.224	1,374	0.005	60,873	0.209
1983	NA	NA	36	0.000	57,490	0.202	7,926	0.030	54,051	0.185
1984	1	0.000	1	0.000	80,815	0.284	3,882	0.015	73,340	0.251
1985	3,214	0.015	1,860	0.005	77,889	0.274	717	0.003	81,278	0.279
1986	2,241	0.010	2,252	0.007	137,677	0.484	5,079	0.019	115,780	0.397
1987	5,996	0.027	12,006	0.035	245,701	0.864	16,230	0.062	230,079	0.789
1988	NA	NA	NA	NA	64,701	0.228	431	0.002	70,764	0.243
1989	2	0.000	NA	NA	37,621	0.132	218	0.001	36,673	0.126
1990	647	0.003	NA	NA	140,739	0.495	17,977	0.068	98,318	0.337
1991	5,761	0.026	25,843	0.076	218,639	0.769	13,086	0.050	158,645	0.544
1992	12,761	0.058	56,705	0.167	179,350	0.631	12,139	0.046	206,327	0.707
1993	680	0.003	677	0.002	43,077	0.152	333	0.001	54,460	0.187
1994	214	0.001	NA	NA	75,069	0.264	5,985	0.023	82,723	0.284
1995	272	0.001	NA	NA	61,040	0.215	336	0.001	70,619	0.242
1996	2	0.000	NA	NA	96,502	0.339	11,486	0.044	60,551	0.208
1997	5,400	0.025	33,467	0.098	165,874	0.583	14,160	0.054	132,505	0.454
1998	5,351	0.024	23,611	0.069	191,847	0.675	18,982	0.072	110,013	0.377
1999	79	0.000	NA	NA	88,837	0.313	1,445	0.005	63,298	0.217
2000	2,811	0.013	1,705	0.005	142,892	0.503	4,000	0.015	85,671	0.294
2001	2,284	0.010	2,337	0.007	179,080	0.630	4,278	0.016	70,654	0.242
2002	2,311	0.011	102,204	0.300	93,089	0.327	1,190	0.005	120,515	0.413
2003	568	0.003	NA	NA	96,381	0.339	4,295	0.016	58,683	0.201
2004	2,756	0.013	17,627	0.052	237,710	0.836	24,462	0.093	165,570	0.567
2005	NA	NA	291	0.001	94,337	0.332	1,611	0.006	68,375	0.234
2006	NA	NA	NA	NA	42,660	0.150	145	0.001	35,821	0.123
2007	7,317	0.033	23,557	0.069	281,614	0.991	52,502	0.199	178,201	0.611
2008	1	0.000	NA	NA	39,621	0.139	232	0.001	27,681	0.095
2009	253	0.001	258	0.001	33,852	0.119	34	0.000	20,571	0.071
2010	3,738	0.017	1,693	0.005	62,750	0.221	806	0.003	44,045	0.151
2011	1	0.000	NA	NA	13,434	0.047	18	0.000	11,946	0.041
2012	213	0.001	14	0.000	33,488	0.118	153	0.001	33,913	0.116
2013	64	0.000	117	0.000	28,012	0.099	533	0.002	19,443	0.067
2014	4	0.000	NA	NA	18,747	0.066	1	0.000	16,258	0.056
2015	3,700	0.017	13,602	0.040	154,917	0.545	10,869	0.041	104,340	0.358
2016	2,805	0.013	9,046	0.027	148,676	0.523	19,453	0.074	96,178	0.330
2017	22	0.000	10	0.000	70,530	0.248	5,267	0.020	49,804	0.171
2018	5,620	0.026	4,204	0.012	307,448	1.082	36,543	0.139	174,110	0.597
2019	1,211	0.006	3	0.000	85,991	0.302	14,144	0.054	40,760	0.140
2020	2	0.000	4,951	0.015	41,872	0.147	95	0.000	19,779	0.068

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

Gage	**08196000**		**08197500**		**08198000**		**08198500**		**08201500**	
Year	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**
1981	38,560	0.090	45,549	0.235	131,225	0.310	66,529	0.157	27,137	0.071
1982	13,116	0.030	2,668	0.014	19,258	0.046	2,046	0.005	4,085	0.011
1983	9,547	0.022	NA	NA	23,033	0.054	669	0.002	3,075	0.008
1984	12,549	0.029	8,241	0.042	24,092	0.057	6,794	0.016	4,903	0.013
1985	25,726	0.060	3,809	0.020	50,174	0.119	7,309	0.017	15,867	0.042
1986	25,701	0.060	2,001	0.010	59,441	0.141	14,942	0.035	20,004	0.052
1987	65,337	0.152	49,970	0.257	163,188	0.386	124,368	0.294	36,822	0.097
1988	7,857	0.018	1,113	0.006	13,245	0.031	1,926	0.005	1,288	0.003
1989	3,855	0.009	NA	NA	7,655	0.018	627	0.001	936	0.002
1990	17,364	0.040	3,825	0.020	34,511	0.082	4,944	0.012	11,025	0.029
1991	28,825	0.067	40,719	0.210	85,821	0.203	50,375	0.119	24,862	0.065
1992	48,075	0.112	69,159	0.356	177,487	0.420	133,778	0.316	40,163	0.105
1993	10,847	0.025	NA	NA	27,457	0.065	2,477	0.006	7,055	0.019
1994	23,629	0.055	744	0.004	25,466	0.060	812	0.002	4,290	0.011
1995	15,210	0.035	1,953	0.010	26,044	0.062	893	0.002	5,637	0.015
1996	12,068	0.028	9,033	0.047	9,235	0.022	561	0.001	1,007	0.003
1997	32,453	0.075	45,059	0.232	77,817	0.184	38,772	0.092	18,562	0.049
1998	33,780	0.078	27,402	0.141	58,428	0.138	13,845	0.033	20,839	0.055
1999	11,364	0.026	353	0.002	21,857	0.052	1,296	0.003	3,854	0.010
2000	21,094	0.049	19,306	0.099	36,893	0.087	9,221	0.022	5,569	0.015
2001	8,734	0.020	11,468	0.059	55,605	0.132	5,955	0.014	11,548	0.030
2002	26,130	0.061	80,657	0.415	85,790	0.203	43,941	0.104	11,714	0.031
2003	17,415	0.040	NA	NA	23,258	0.055	1,793	0.004	5,669	0.015
2004	47,277	0.110	47,794	0.246	96,809	0.229	34,119	0.081	29,170	0.077
2005	14,259	0.033	NA	NA	36,116	0.085	3,519	0.008	7,155	0.019
2006	5,546	0.013	NA	NA	6,813	0.016	587	0.001	251	0.001
2007	35,661	0.083	44,479	0.229	92,206	0.218	41,504	0.098	28,681	0.075
2008	3,318	0.008	NA	NA	5,632	0.013	993	0.002	811	0.002
2009	2,917	0.007	NA	NA	1,765	0.004	387	0.001	892	0.002
2010	15,561	0.036	NA	NA	27,117	0.064	7,069	0.017	13,107	0.034
2011	1,965	0.005	NA	NA	970	0.002	246	0.001	1	0.000
2012	14,376	0.033	98	0.001	4,765	0.011	972	0.002	17	0.000
2013	2,875	0.007	NA	NA	607	0.001	166	0.000	152	0.000
2014	4,721	0.011	2	0.000	1,794	0.004	630	0.001	1,246	0.003
2015	52,818	0.123	11,810	0.061	40,028	0.095	15,259	0.036	13,153	0.035
2016	38,363	0.089	852	0.004	51,899	0.123	17,143	0.041	14,723	0.039
2017	13,362	0.031	NA	NA	14,639	0.035	412	0.001	3,278	0.009
2018	68,395	0.159	58,283	0.300	85,299	0.202	46,031	0.109	21,770	0.057
2019	12,770	0.030	NA	NA	21,731	0.051	1,803	0.004	4,460	0.012
2020	3,128	0.007	NA	NA	3,337	0.008	204	0.000	640	0.002

Groundwater Toolbox Recharge Estimate Results by Gage, 1981 through 2020 (continued)

Gage	08202700		08446500		08447020	
Year	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**	**Acre-ft**	**Inches**
1981	2,461	0.005	29,035	0.058	21,468	0.070
1982	NA	NA	12,182	0.024	16,638	0.054
1983	NA	NA	11,586	0.023	16,043	0.052
1984	12	0.000	12,707	0.025	16,778	0.054
1985	82	0.000	12,324	0.025	9,279	0.030
1986	6	0.000	23,251	0.047	NA	NA
1987	5,969	0.013	111,974	0.224	NA	NA
1988	NA	NA	28,772	0.058	NA	NA
1989	NA	NA	20,278	0.041	NA	NA
1990	27	0.000	23,422	0.047	NA	NA
1991	373	0.001	19,235	0.039	NA	NA
1992	189	0.000	30,846	0.062	NA	NA
1993	2	0.000	20,552	0.041	NA	NA
1994	NA	NA	19,676	0.039	NA	NA
1995	NA	NA	16,436	0.033	NA	NA
1996	NA	NA	13,454	0.027	NA	NA
1997	277	0.001	14,253	0.029	NA	NA
1998	677	0.001	16,216	0.032	NA	NA
1999	NA	NA	13,614	0.027	NA	NA
2000	296	0.001	13,419	0.027	NA	NA
2001	NA	NA	12,964	0.026	NA	NA
2002	5,343	0.011	10,654	0.021	5,890	0.019
2003	5	0.000	8,603	0.017	14,682	0.048
2004	189	0.000	24,660	0.049	31,394	0.102
2005	1	0.000	20,417	0.041	26,888	0.087
2006	NA	NA	16,403	0.033	18,633	0.061
2007	276	0.001	26,823	0.054	24,206	0.079
2008	NA	NA	19,481	0.039	20,398	0.066
2009	NA	NA	16,257	0.033	20,680	0.067
2010	34	0.000	18,085	0.036	23,063	0.075
2011	NA	NA	10,846	0.022	16,632	0.054
2012	NA	NA	8,597	0.017	15,247	0.050
2013	NA	NA	7,912	0.016	13,331	0.043
2014	4	0.000	49,222	0.099	15,331	0.050
2015	52	0.000	49,118	0.098	15,263	0.050
2016	113	0.000	33,037	0.066	14,727	0.048
2017	NA	NA	16,525	0.033	11,837	0.038
2018	154	0.000	12,900	0.026	13,987	0.045
2019	NA	NA	9,259	0.019	15,538	0.050
2020	NA	NA	5,160	0.010	1,131	0.004

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APPENDIX D

COMPARATIVE ANALYSIS OF MODELED PRECIPITATION, EVAPOTRANSPIRATION, AND RUNOFF FOR WATERSHEDS

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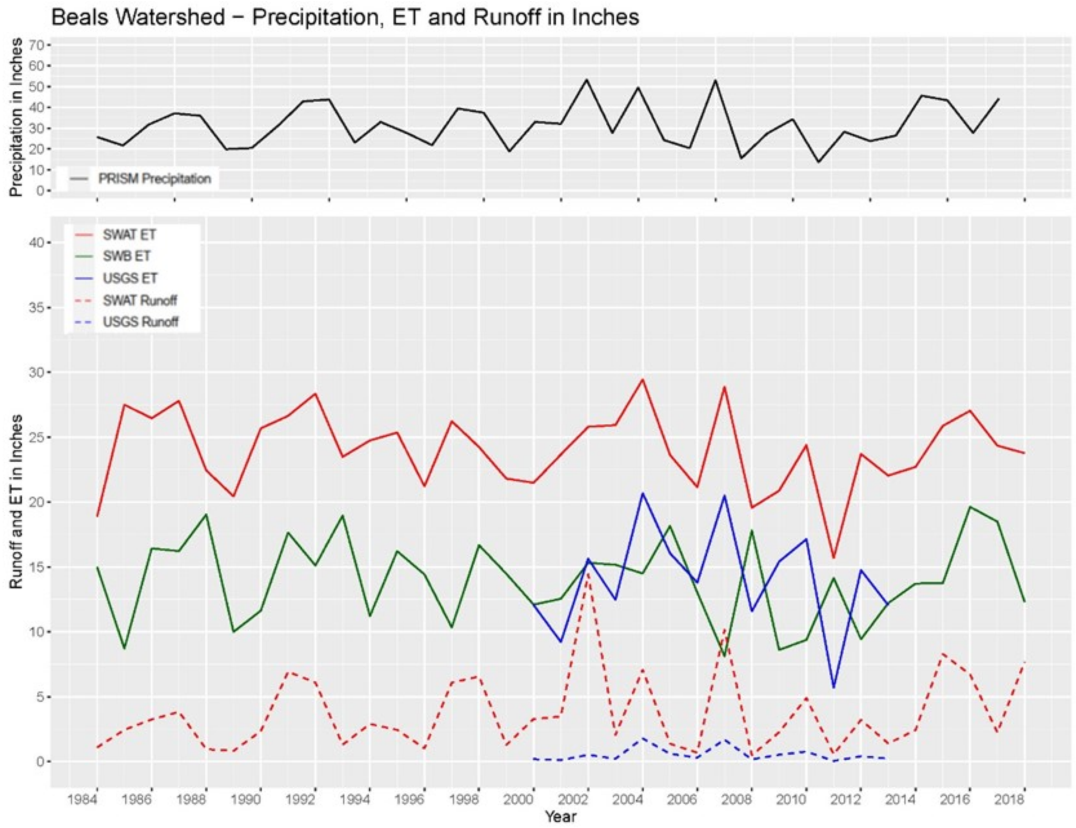
Beals Watershed – Precipitation, ET and Runoff in Inches
Precipitation in Inches
PRISM Precipitation
Runoff and ET in Inches
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
0
5
10
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20
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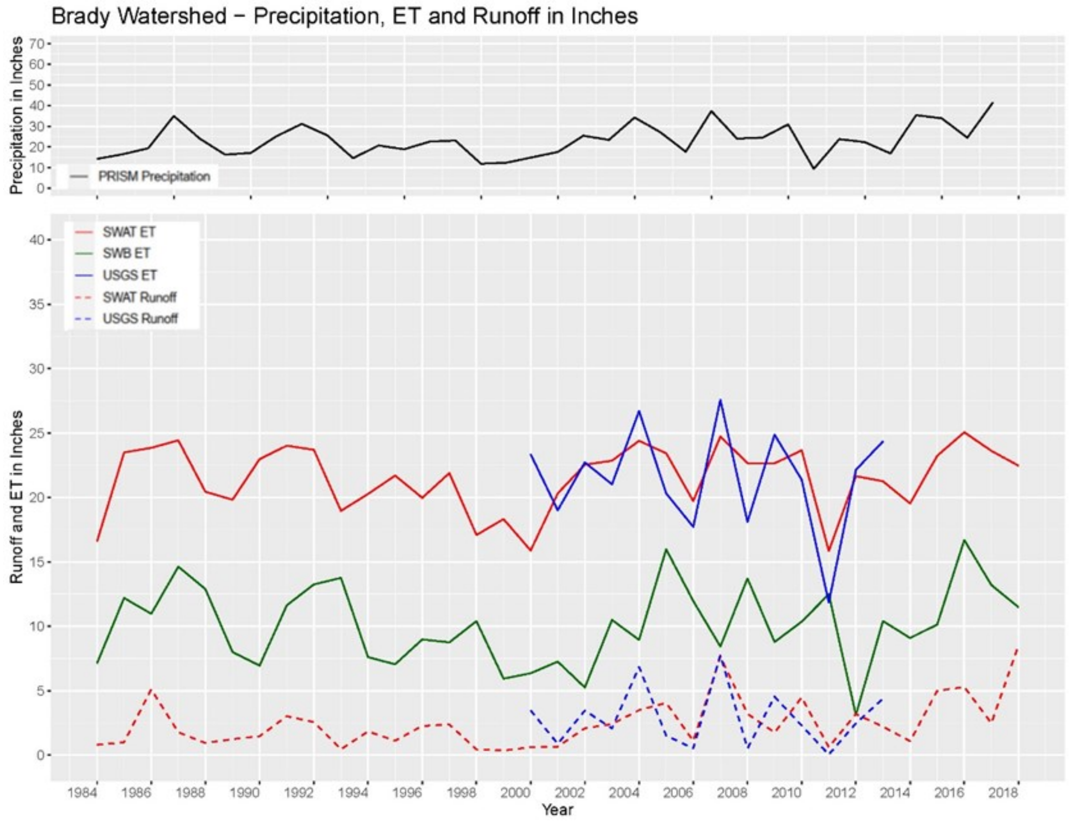
2018
Year


Brady Watershed – Precipitation, ET and Runoff in Inches
Precipitation in Inches
PRISM Precipitation
Runoff and ET in Inches
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
0
5
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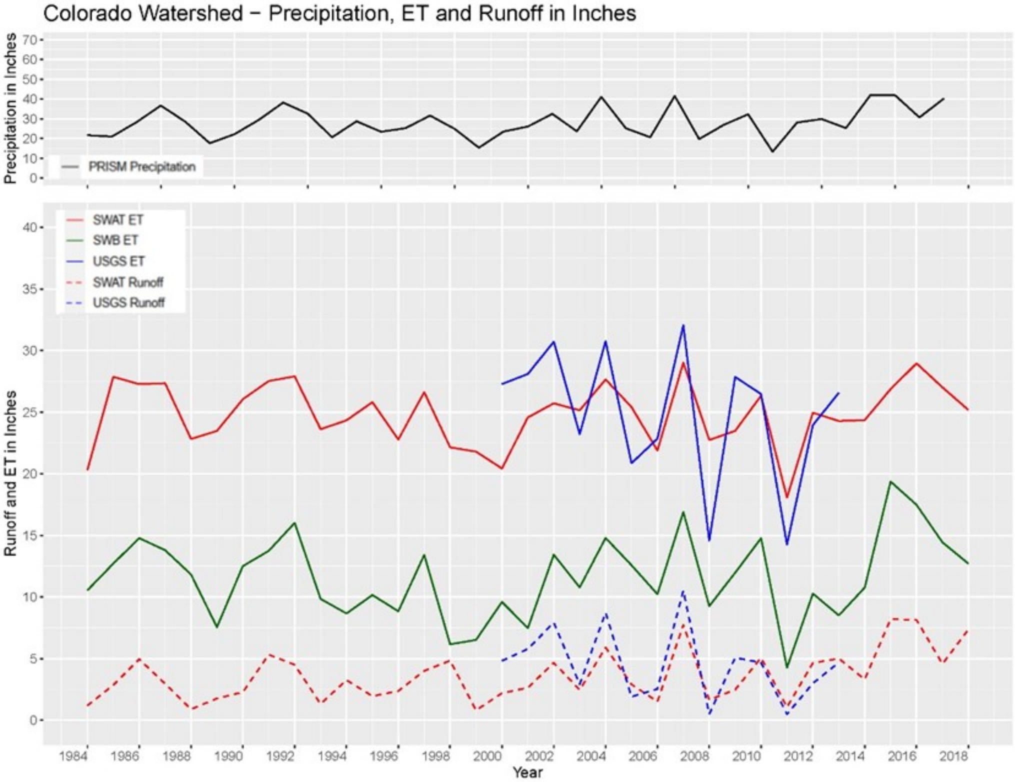
Colorado Watershed – Precipitation, ET and Runoff in Inches
Precipitation in Inches
70
60
50
40
30
20
10
0
PRISM Precipitation
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
Runoff and ET in Inches
40
35
30
25
20
15
10
5
0
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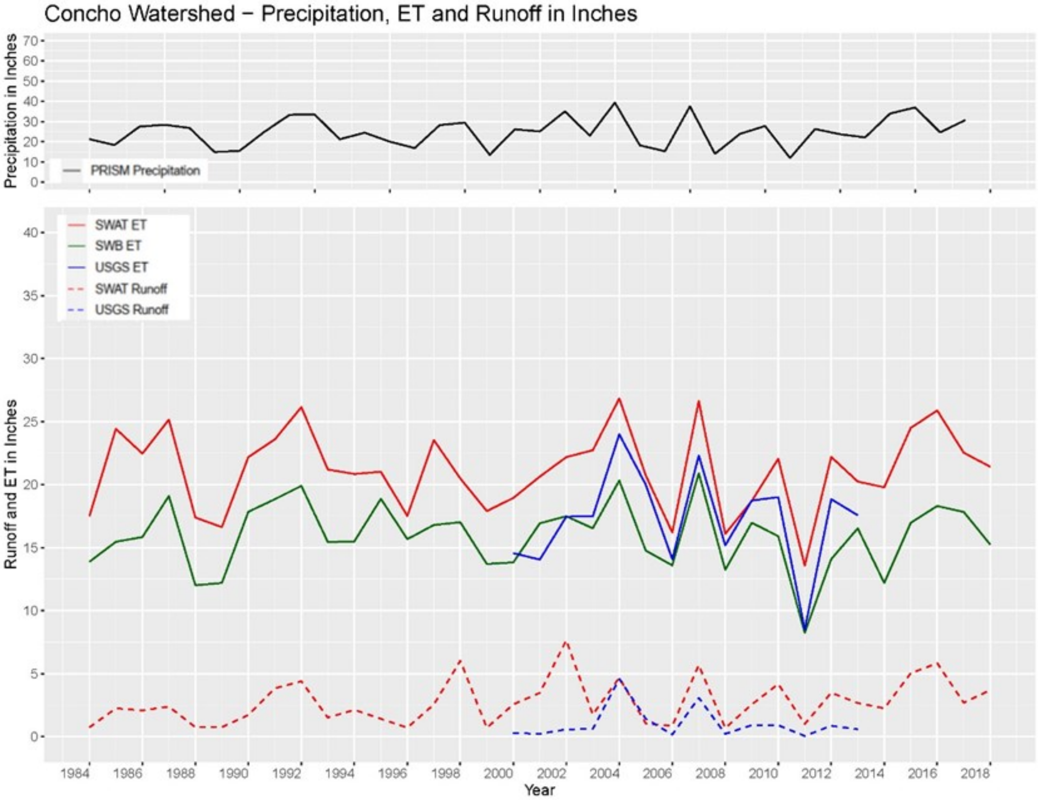
2018
Year


Concho Watershed – Precipitation, ET and Runoff in Inches
Precipitation in Inches
70
60
50
40
30
20
10
0
PRISM Precipitation
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
Runoff and ET in Inches
40
35
30
25
20
15
10
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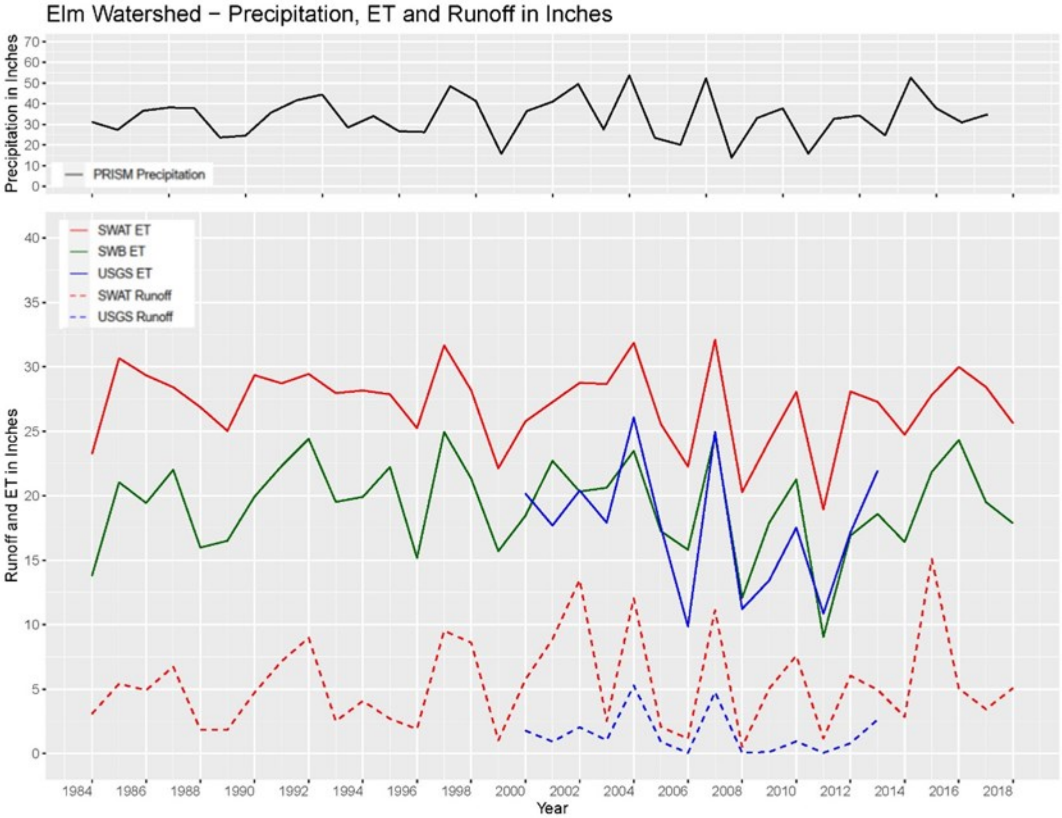
Year


Elm Watershed – Precipitation, ET and Runoff in Inches
Precipitation in Inches
0
10
20
30
40
50
60
70
PRISM Precipitation
Runoff and ET in Inches
0
5
10
15
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25
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35
40
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
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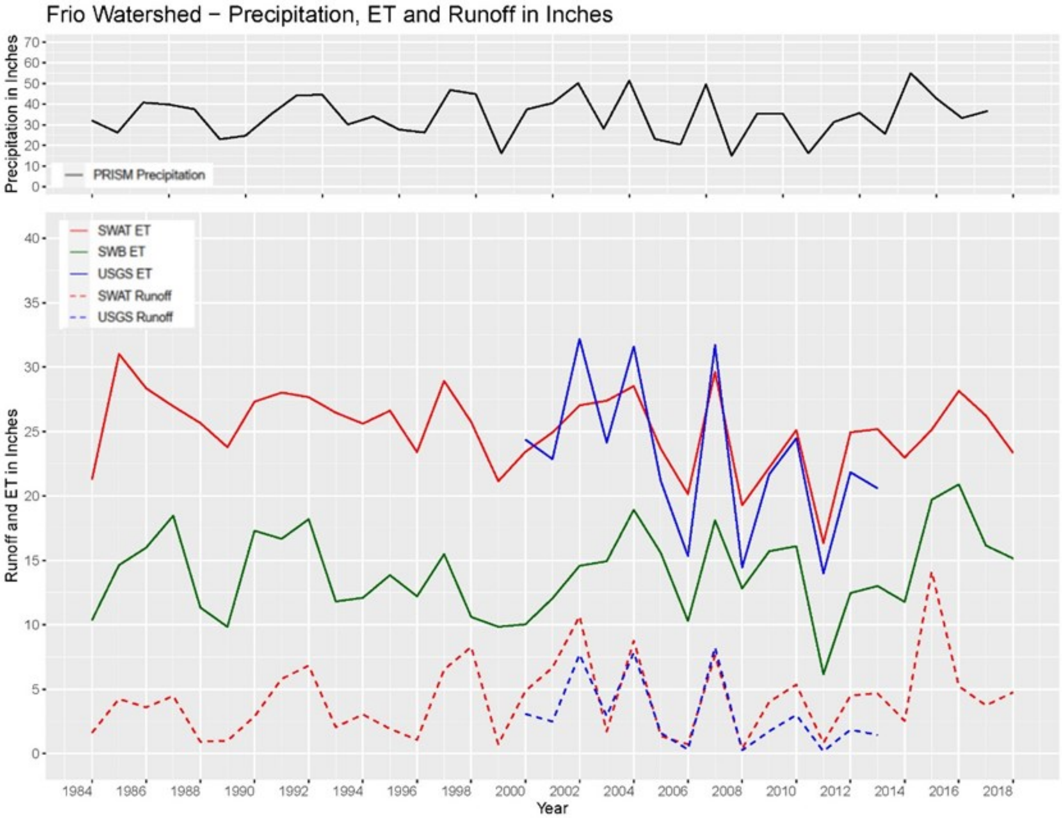
2018
Year


Frio Watershed – Precipitation, ET and Runoff in Inches
Precipitation in Inches
0
10
20
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40
50
60
70
PRISM Precipitation
Runoff and ET in Inches
0
5
10
15
20
25
30
35
40
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
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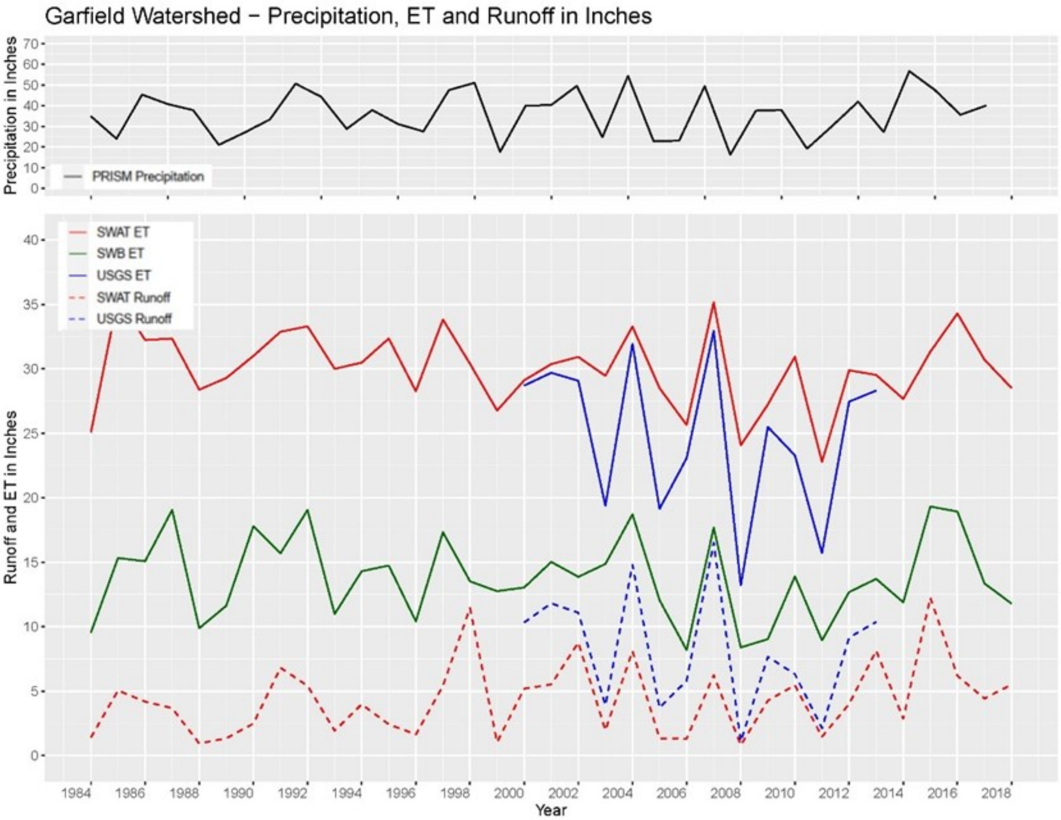
2018
Year


Garfield Watershed – Precipitation, ET and Runoff in Inches
Precipitation in Inches
70
60
50
40
30
20
10
0
PRISM Precipitation
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
Runoff and ET in Inches
40
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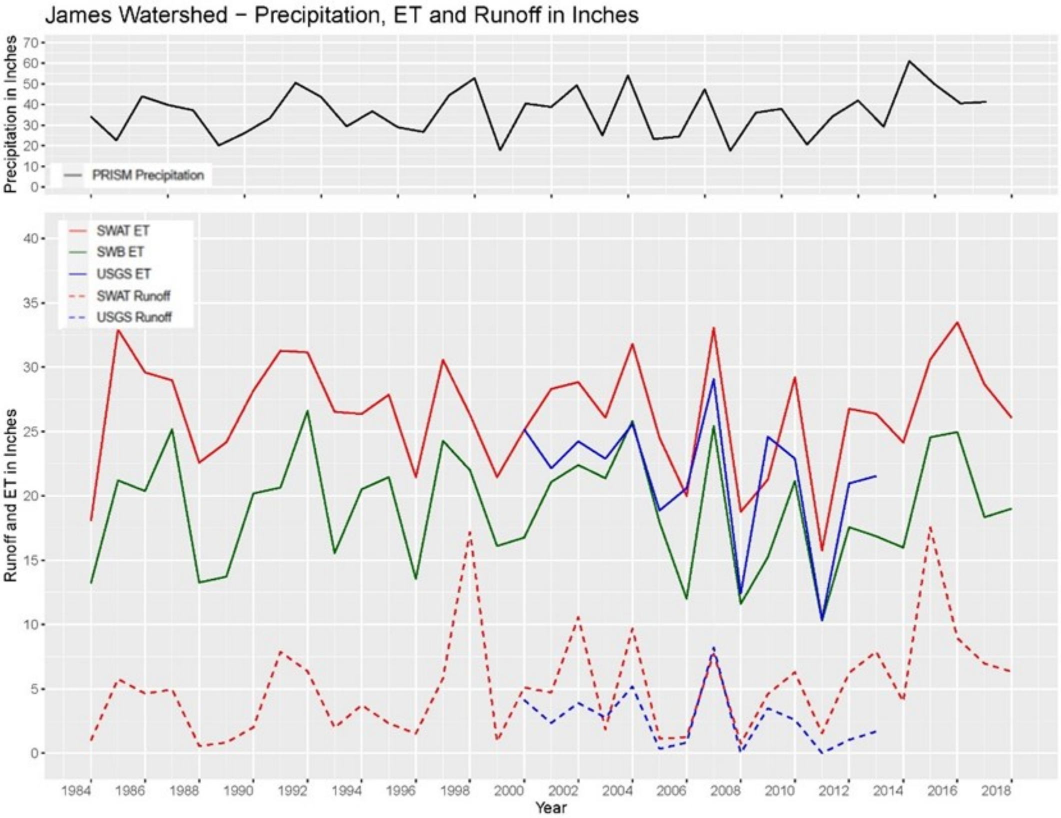
James Watershed – Precipitation, ET and Runoff in Inches
Precipitation in Inches
70
60
50
40
30
20
10
0
PRISM Precipitation
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
Runoff and ET in Inches
40
35
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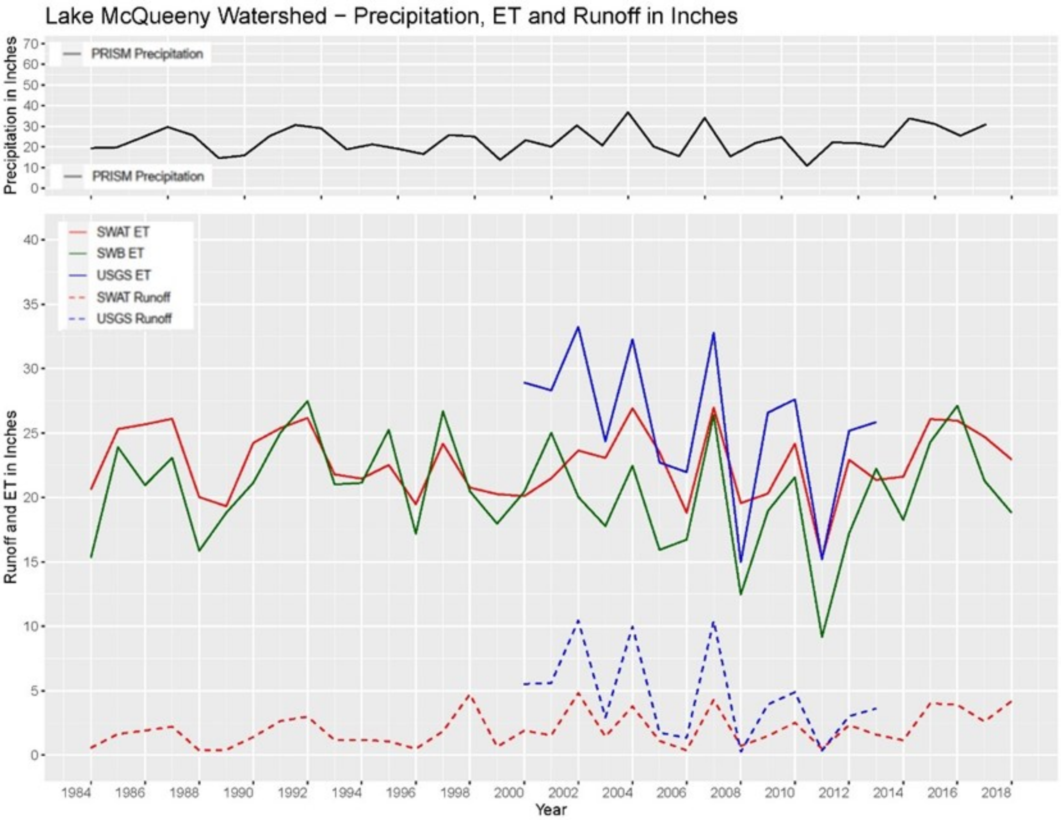
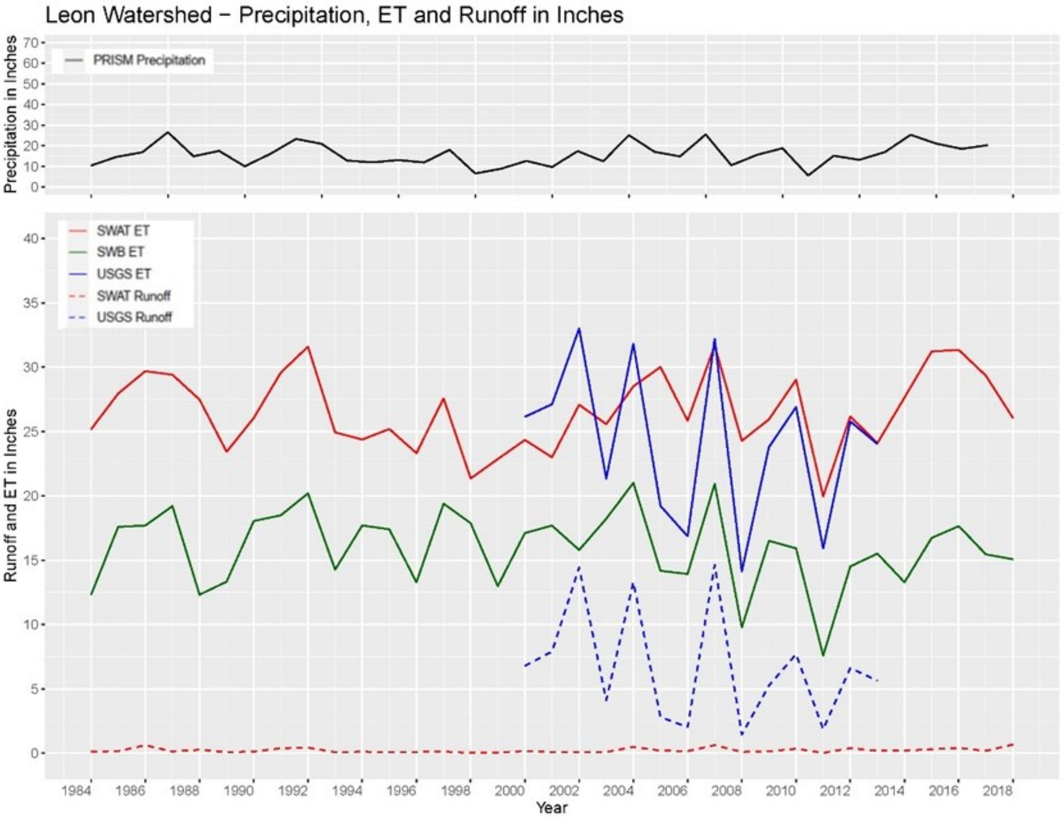
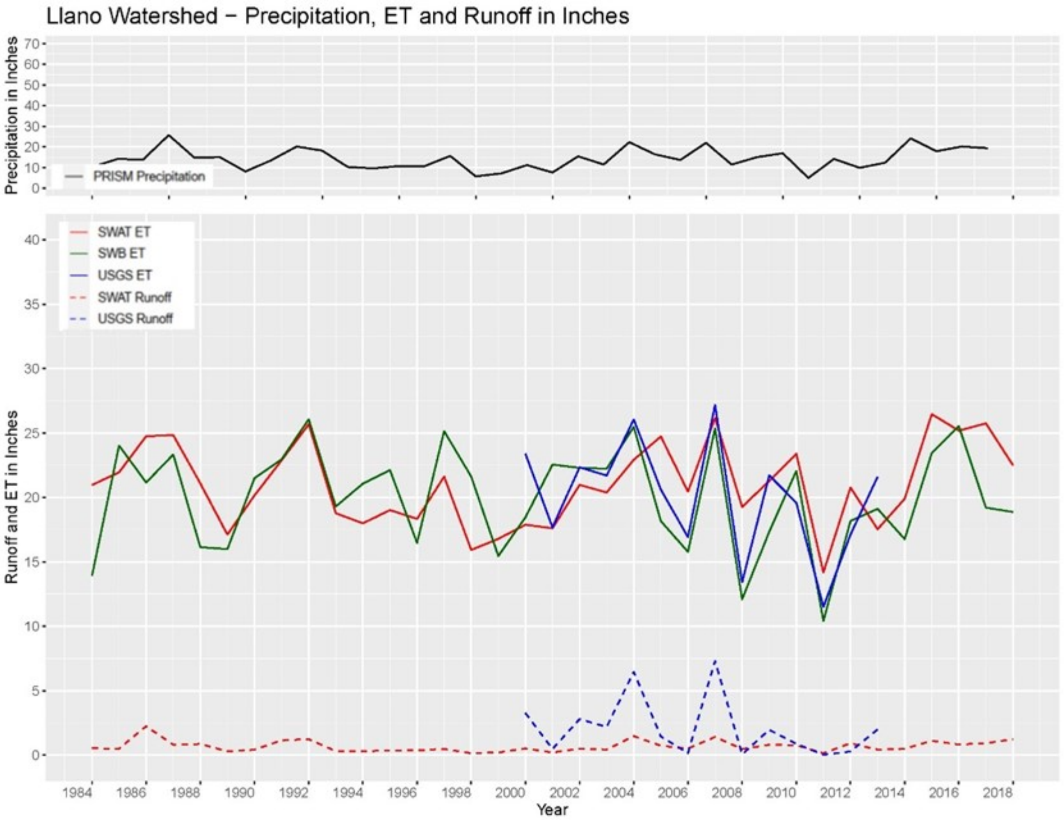

Lake McQueeny Watershed − Precipitation, ET and Runoff in Inches


Leon Watershed − Precipitation, ET and Runoff in Inches


Llano Watershed − Precipitation, ET and Runoff in Inches
Precipitation in Inches
70
60
50
40
30
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10
0
PRISM Precipitation
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
Runoff and ET in Inches
40
35
30
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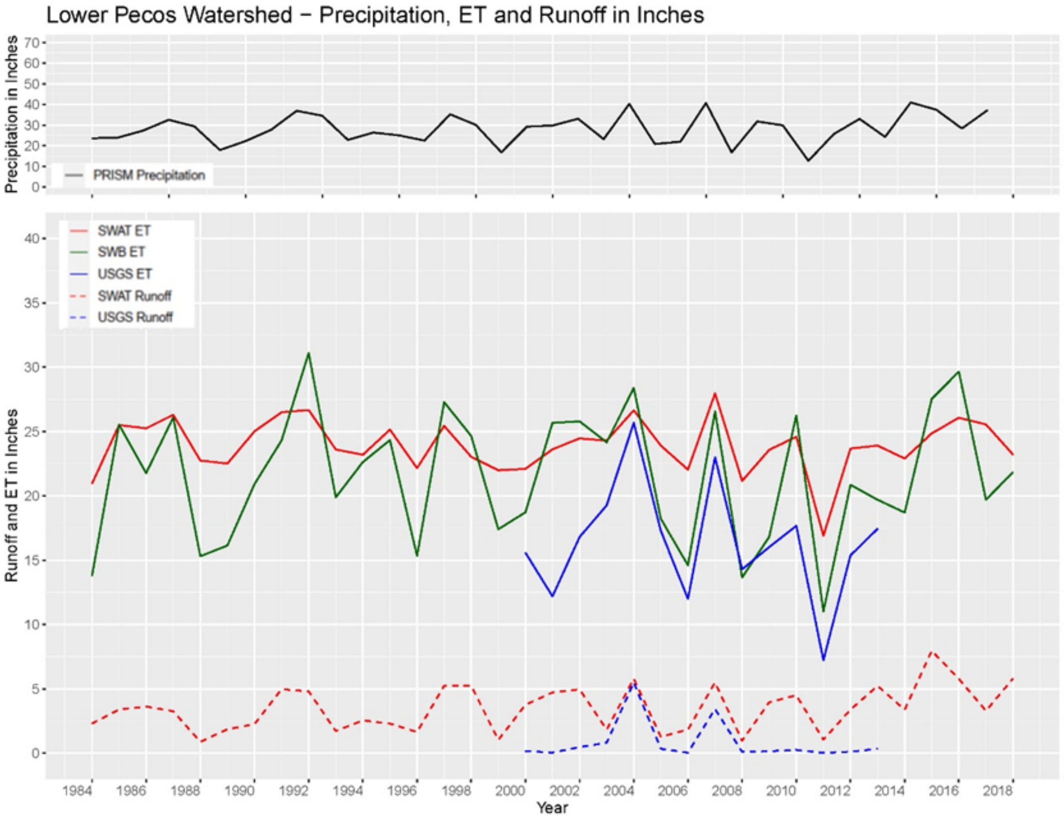
Lower Pecos Watershed − Precipitation, ET and Runoff in Inches
Precipitation in Inches
70
60
50
40
30
20
10
0
PRISM Precipitation
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
Runoff and ET in Inches
40
35
30
25
20
15
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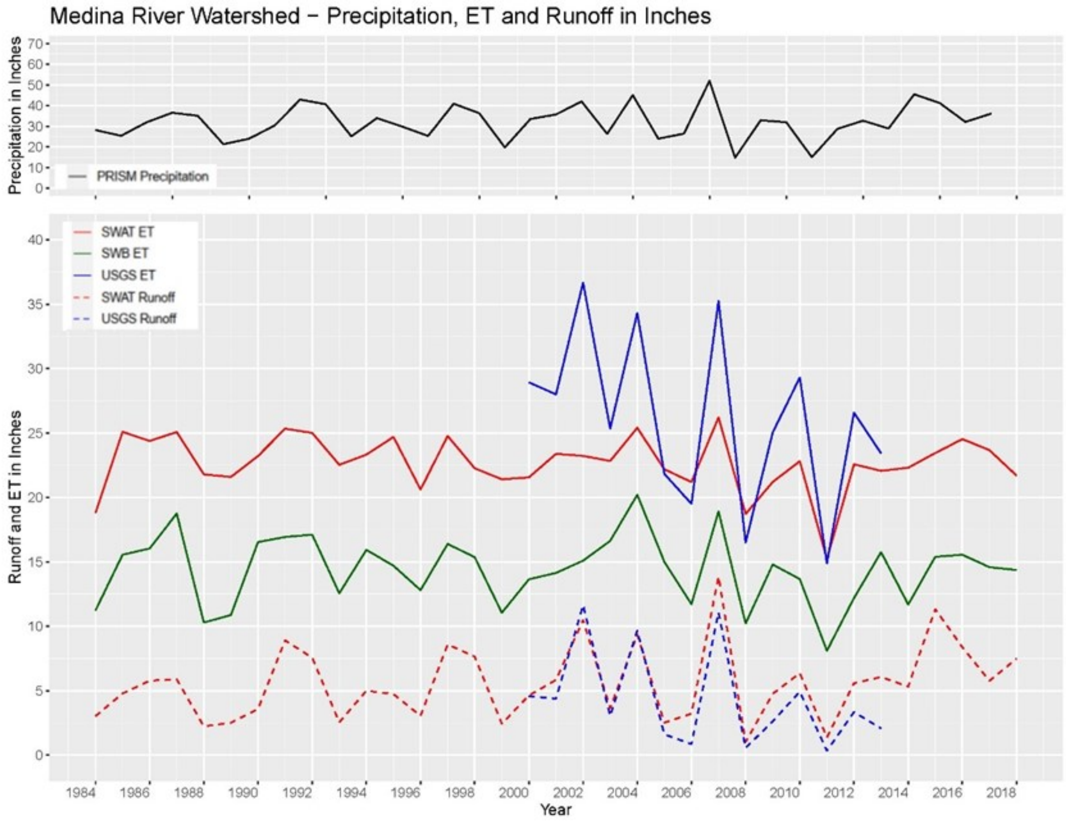
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Runoff and ET in Inches
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40
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
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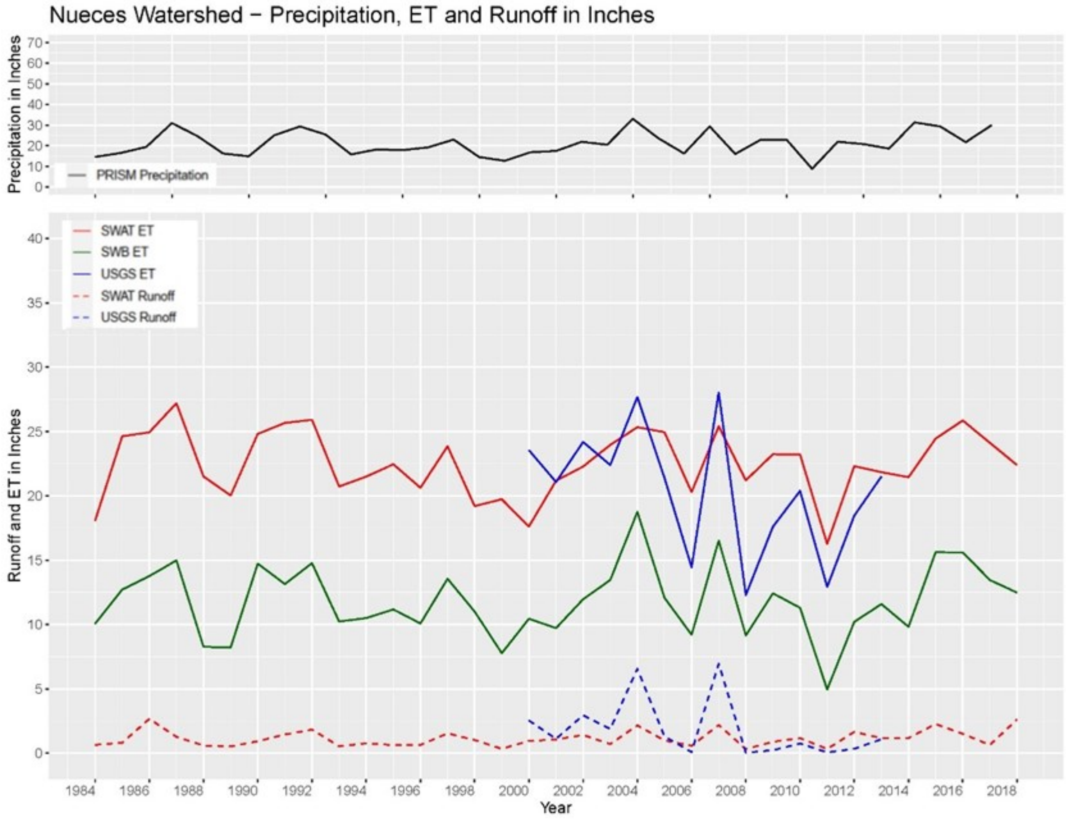
Nueces Watershed – Precipitation, ET and Runoff in Inches
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Runoff and ET in Inches
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SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
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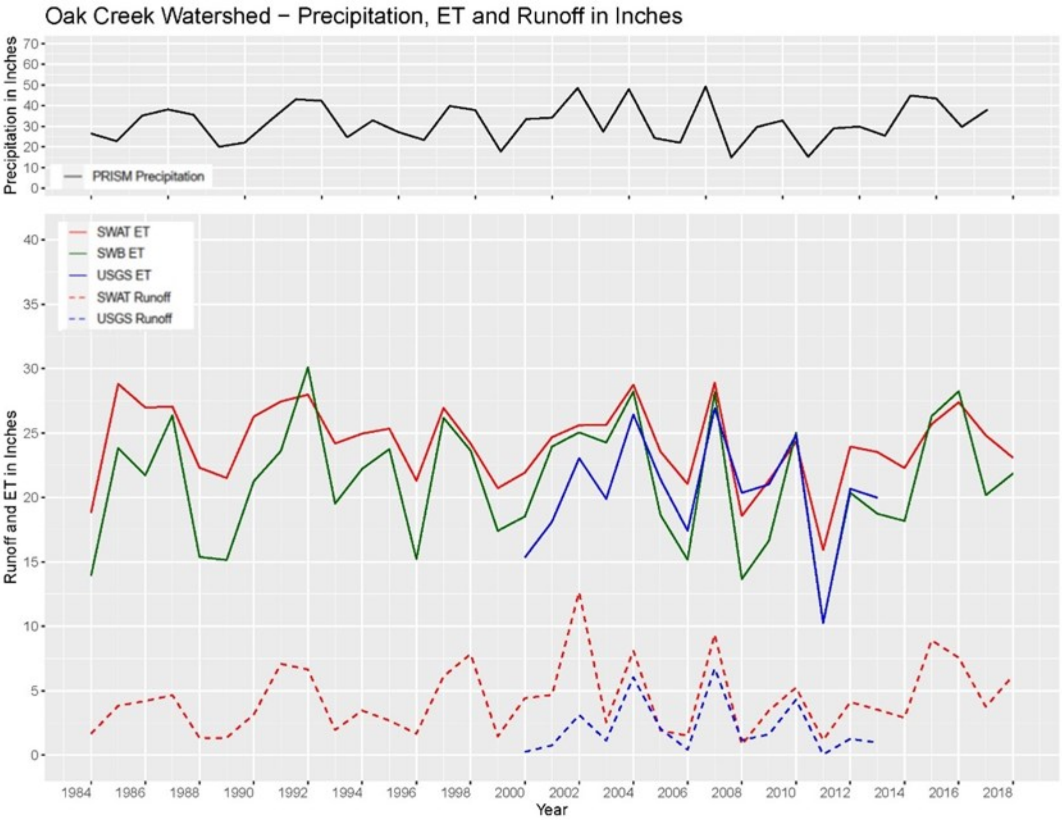
Oak Creek Watershed − Precipitation, ET and Runoff in Inches
Precipitation in Inches
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SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
Runoff and ET in Inches
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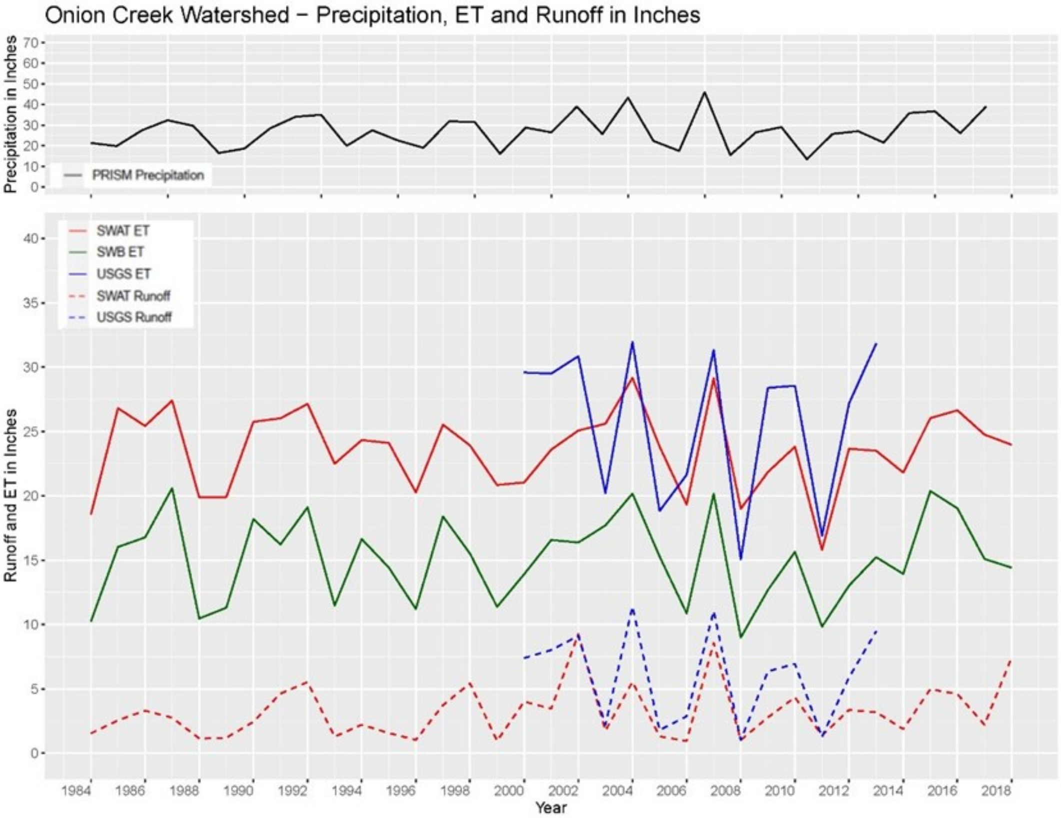
Onion Creek Watershed − Precipitation, ET and Runoff in Inches
Precipitation in Inches
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PRISM Precipitation
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
Runoff and ET in Inches
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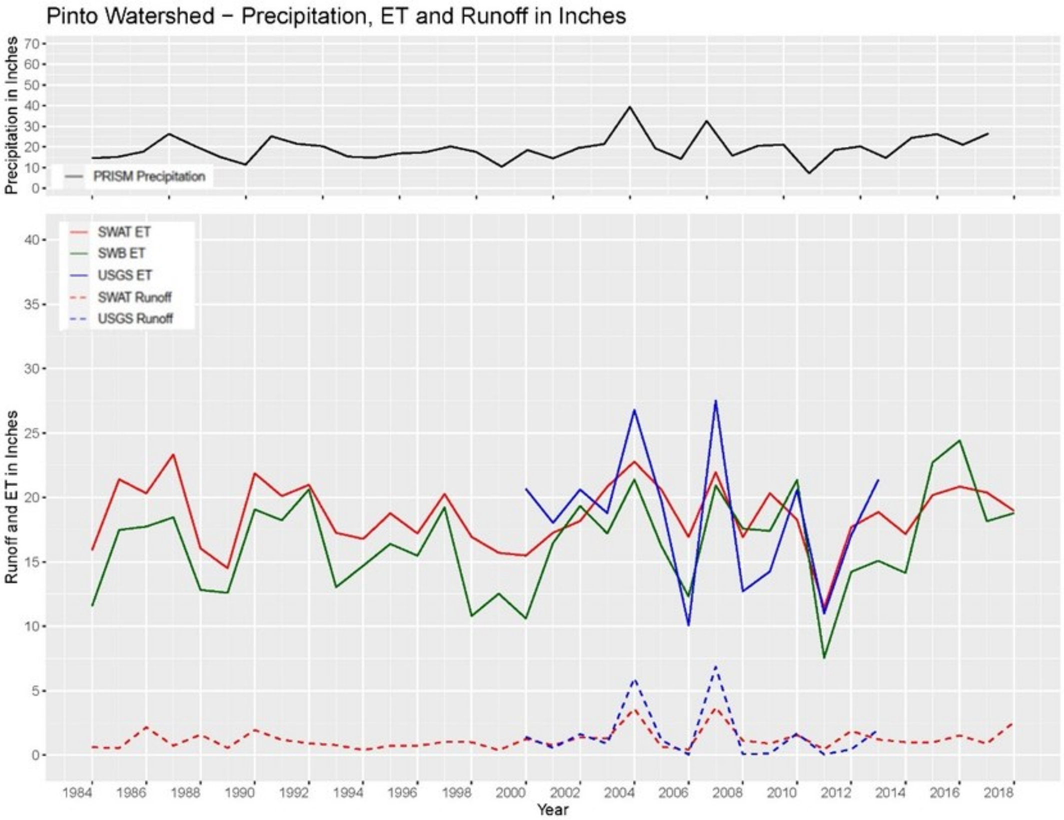
Pinto Watershed – Precipitation, ET and Runoff in Inches
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PRISM Precipitation
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
Runoff and ET in Inches
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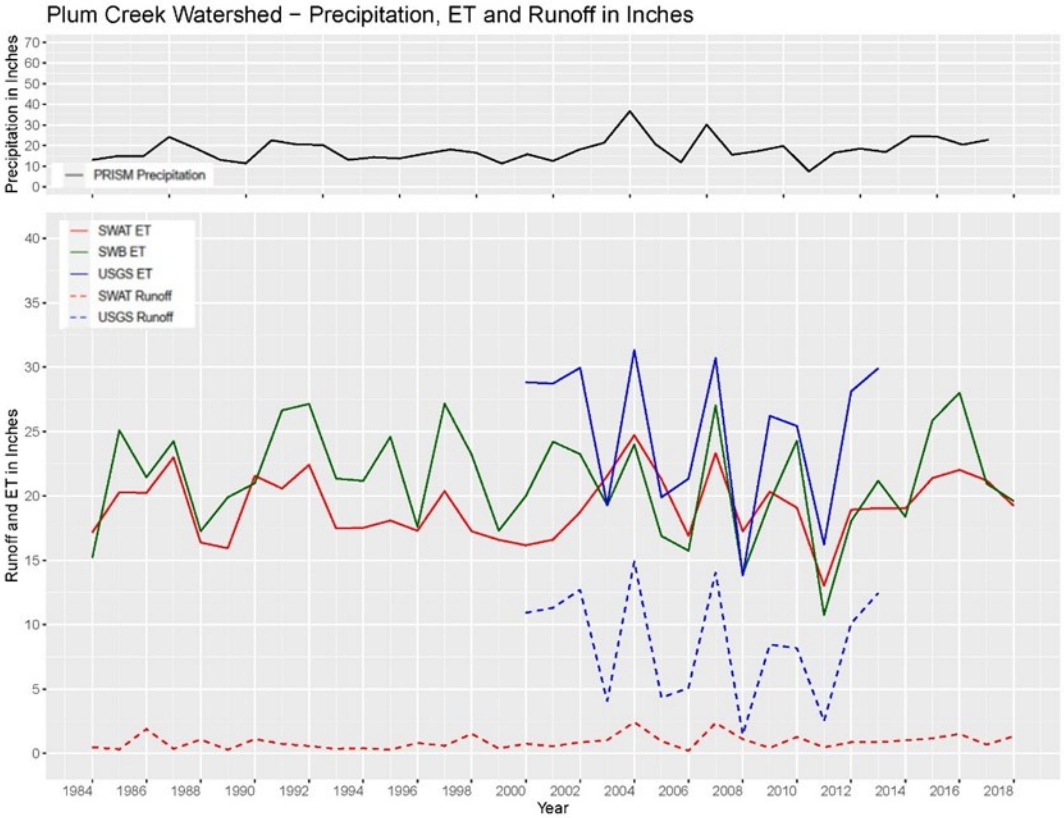
Plum Creek Watershed – Precipitation, ET and Runoff in Inches
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PRISM Precipitation
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
Runoff and ET in Inches
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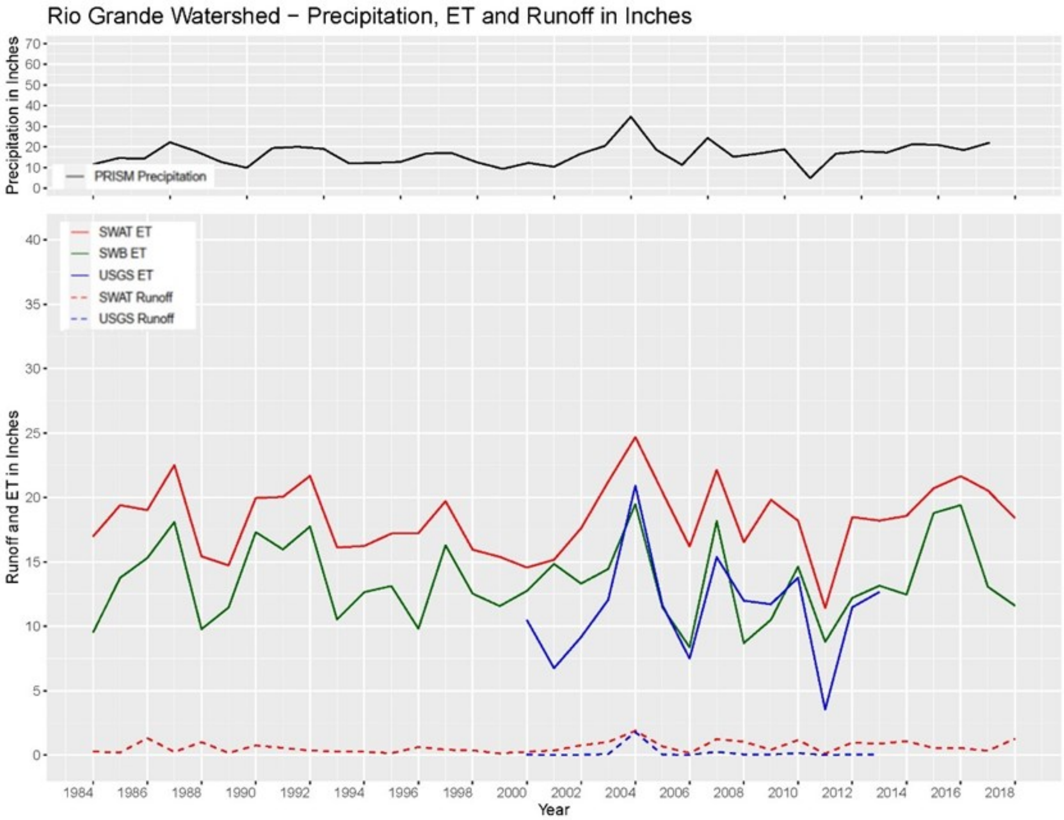
Rio Grande Watershed − Precipitation, ET and Runoff in Inches
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SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
Runoff and ET in Inches
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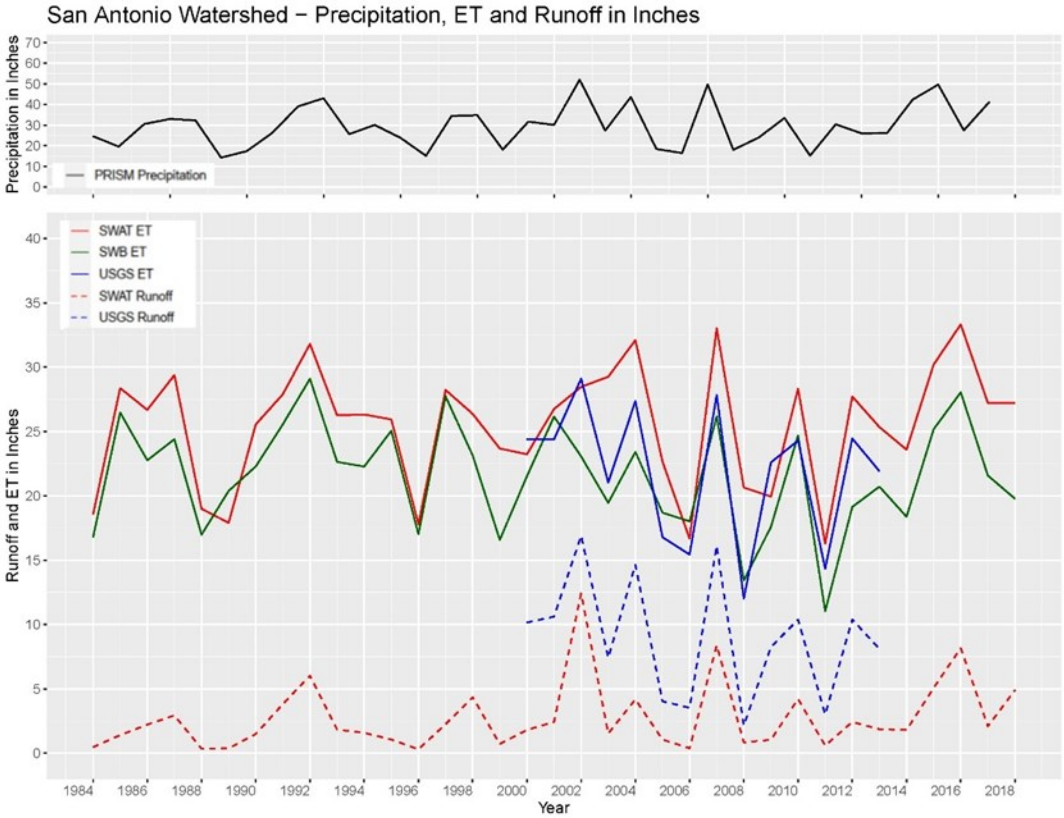
San Antonio Watershed − Precipitation, ET and Runoff in Inches
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PRISM Precipitation
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
Runoff and ET in Inches
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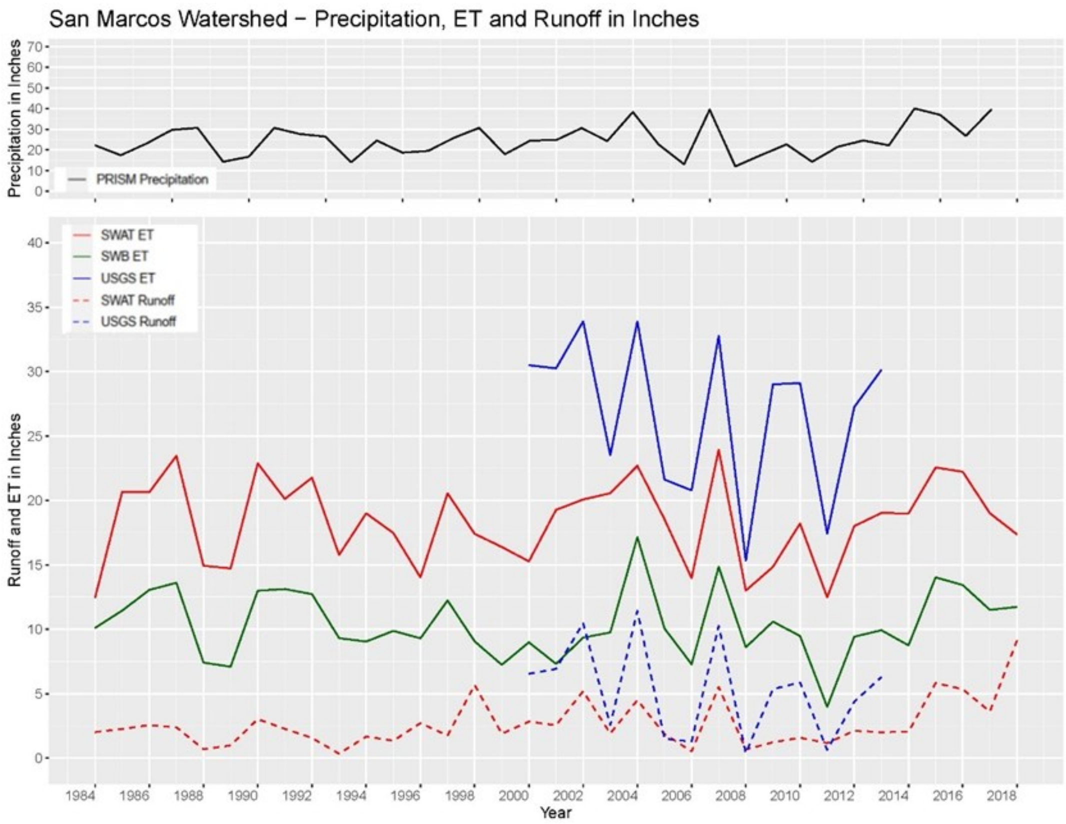
San Marcos Watershed – Precipitation, ET and Runoff in Inches
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PRISM Precipitation
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
Runoff and ET in Inches
0
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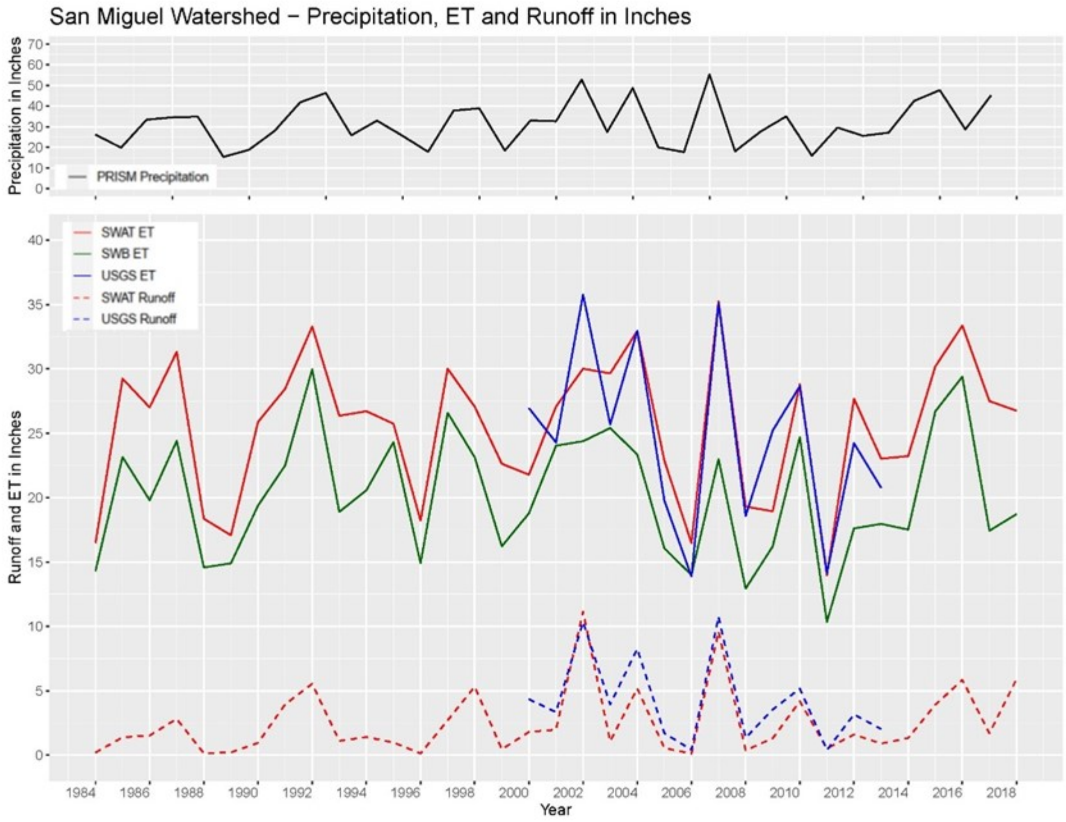
San Miguel Watershed – Precipitation, ET and Runoff in Inches
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0
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PRISM Precipitation
SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
Runoff and ET in Inches
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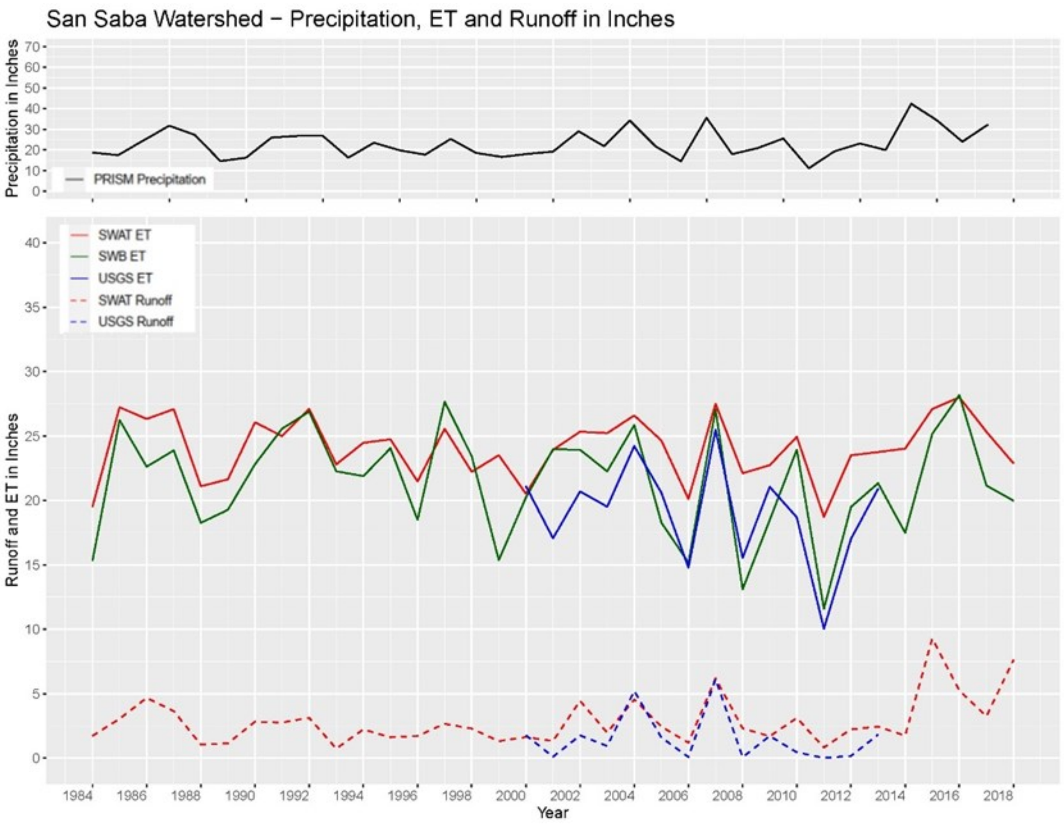
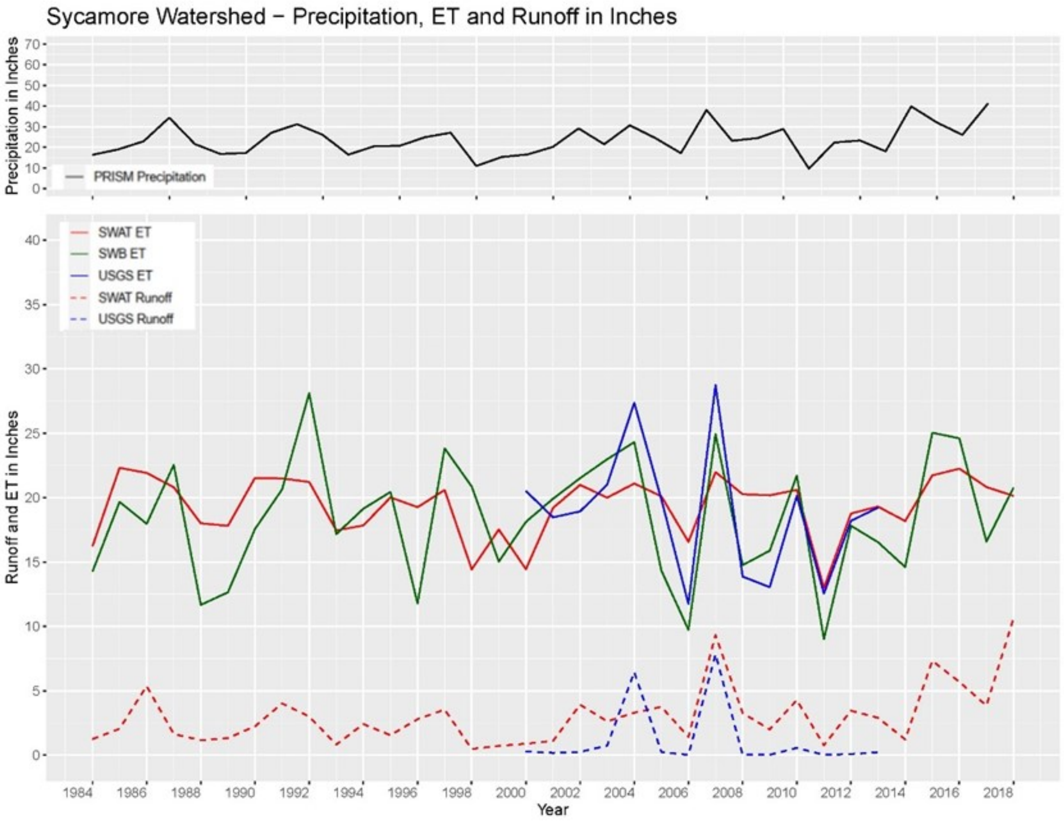
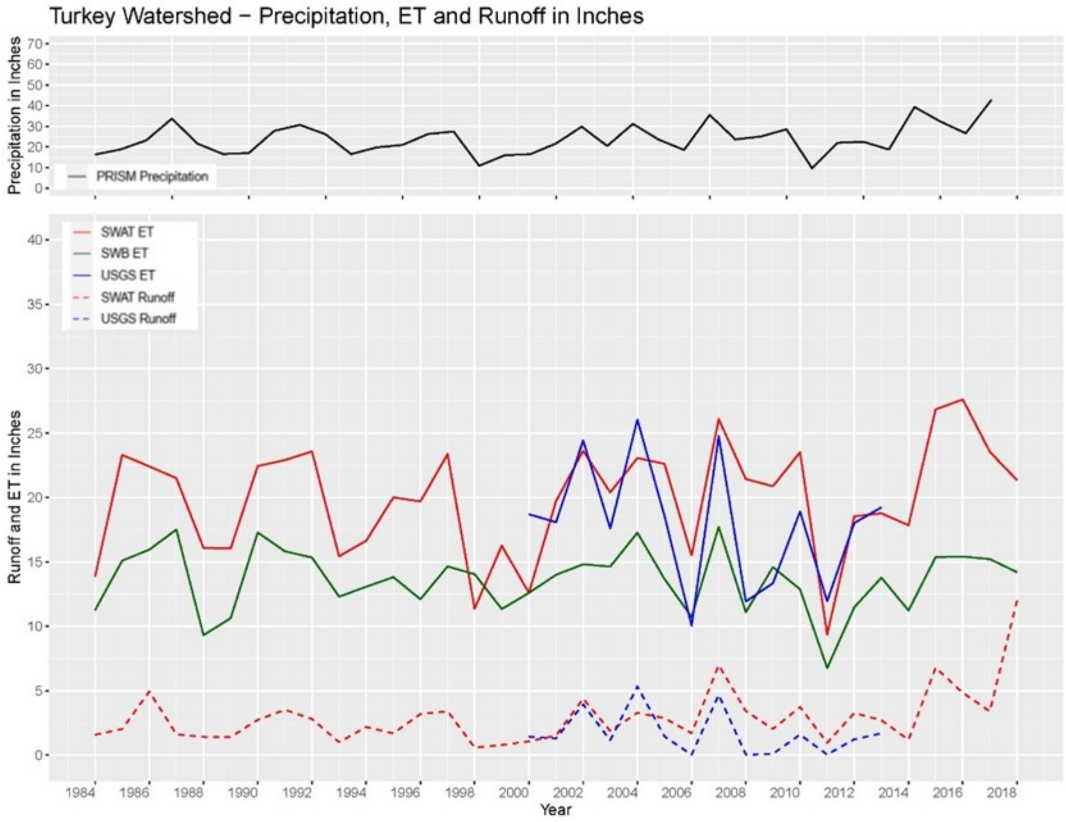
Year


San Saba Watershed − Precipitation, ET and Runoff in Inches


Sycamore Watershed − Precipitation, ET and Runoff in Inches


Turkey Watershed − Precipitation, ET and Runoff in Inches
Precipitation in Inches
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10
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40
50
60
70
PRISM Precipitation
Runoff and ET in Inches
0
5
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35
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SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
1984
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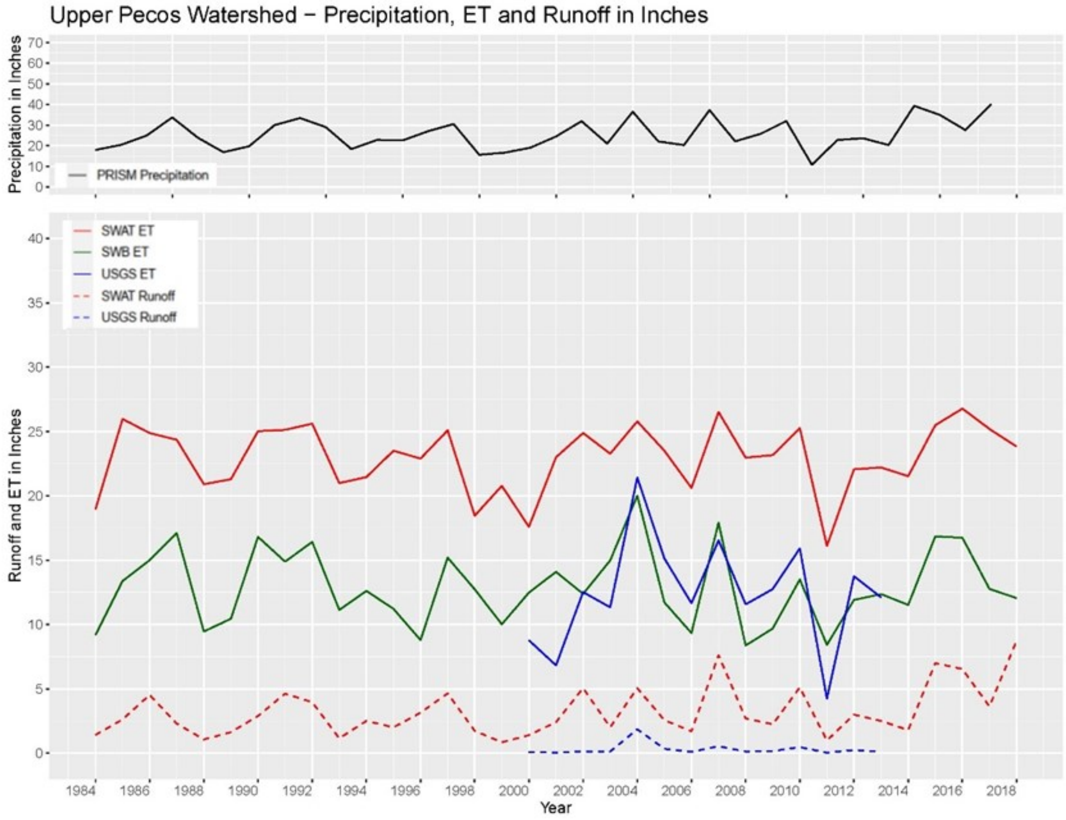
Upper Pecos Watershed − Precipitation, ET and Runoff in Inches
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PRISM Precipitation
Runoff and ET in Inches
0
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35
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SWAT ET
SWB ET
USGS ET
SWAT Runoff
USGS Runoff
1984
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APPENDIX E

COMPARATIVE ANALYSIS OF MODELED PRECIPITATION AND RECHARGE FOR WATERSHEDS

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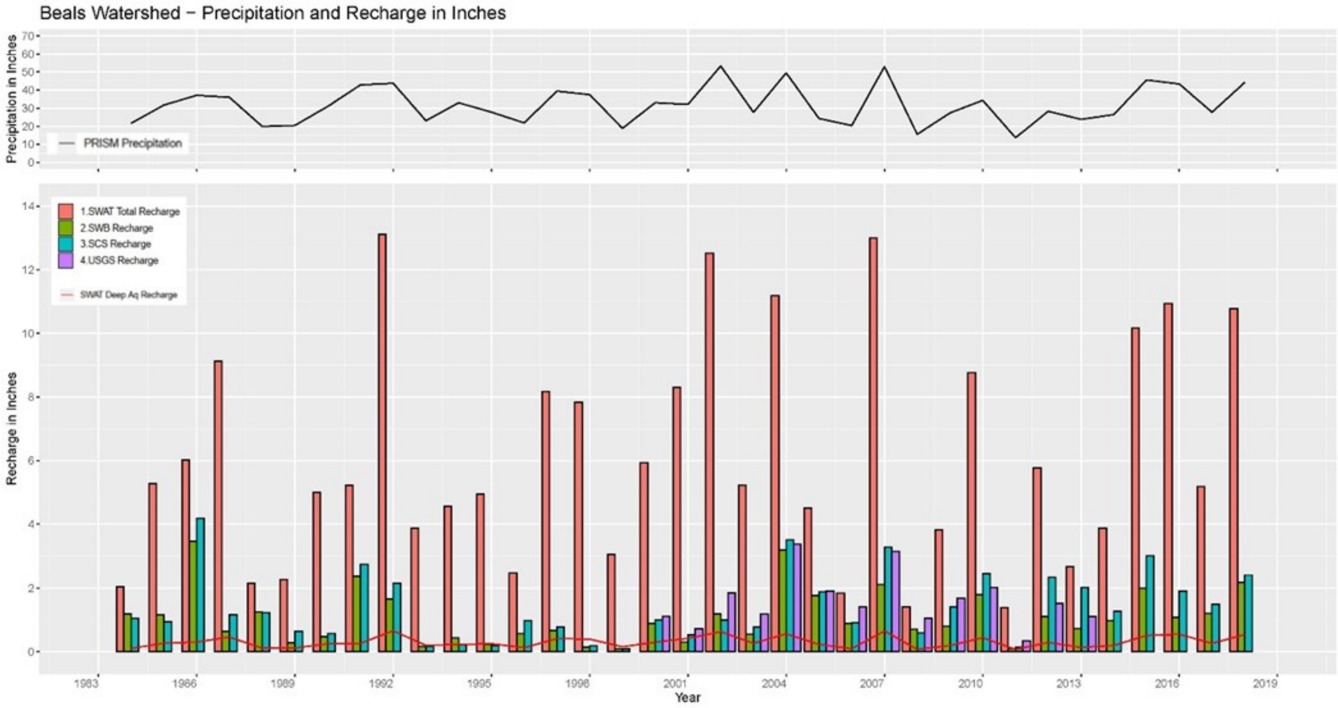
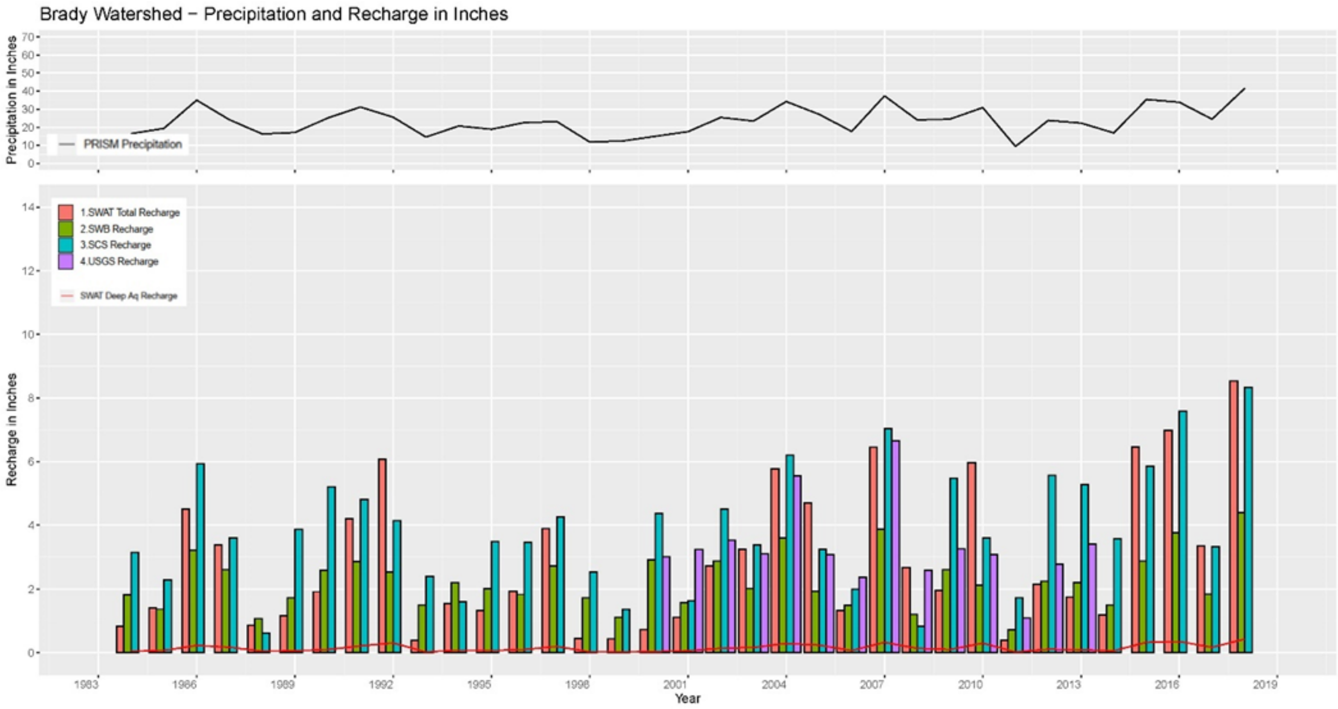
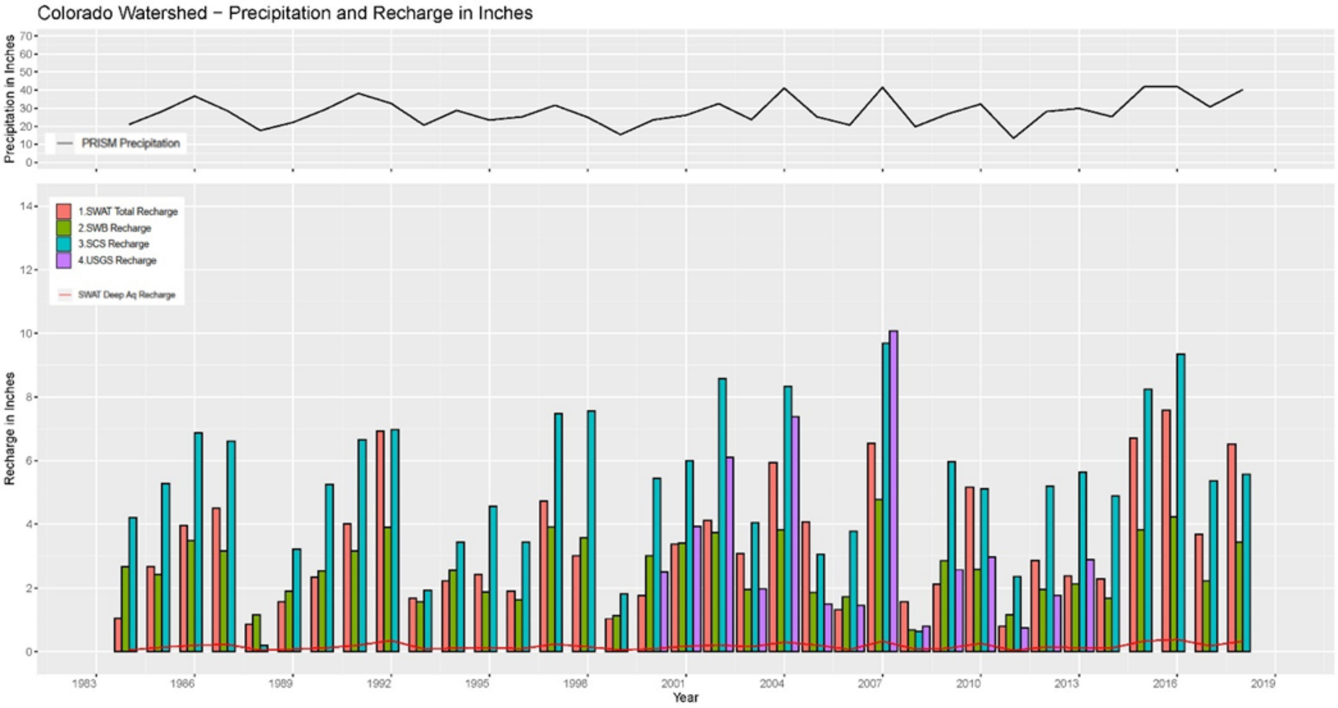
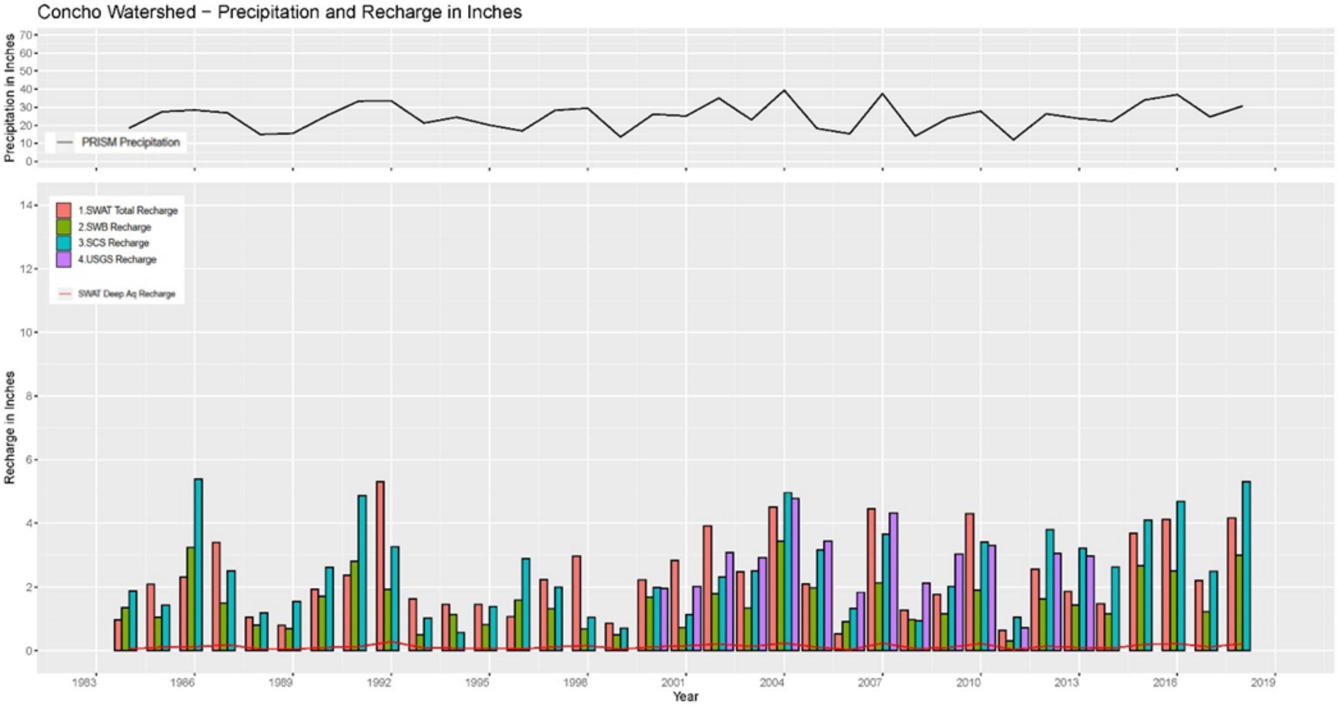

Beals Watershed − Precipitation and Recharge in Inches

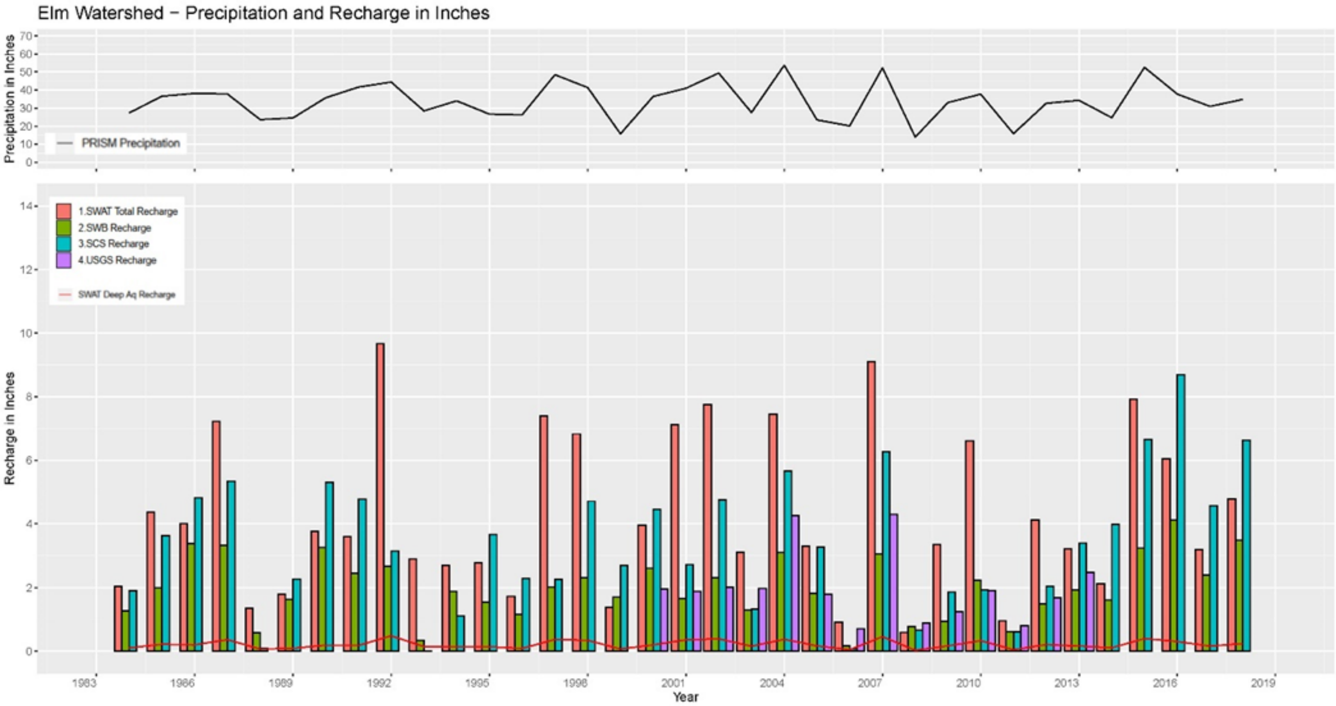

Brady Watershed − Precipitation and Recharge in Inches



Colorado Watershed – Precipitation and Recharge in Inches



Concho Watershed – Precipitation and Recharge in Inches


Elm Watershed − Precipitation and Recharge in Inches
Precipitation in Inches
PRISM Precipitation
Recharge in Inches
1.SWAT Total Recharge
2.SWB Recharge
3.SCS Recharge
4.USGS Recharge
SWAT Deep Aq Recharge
Year
1983
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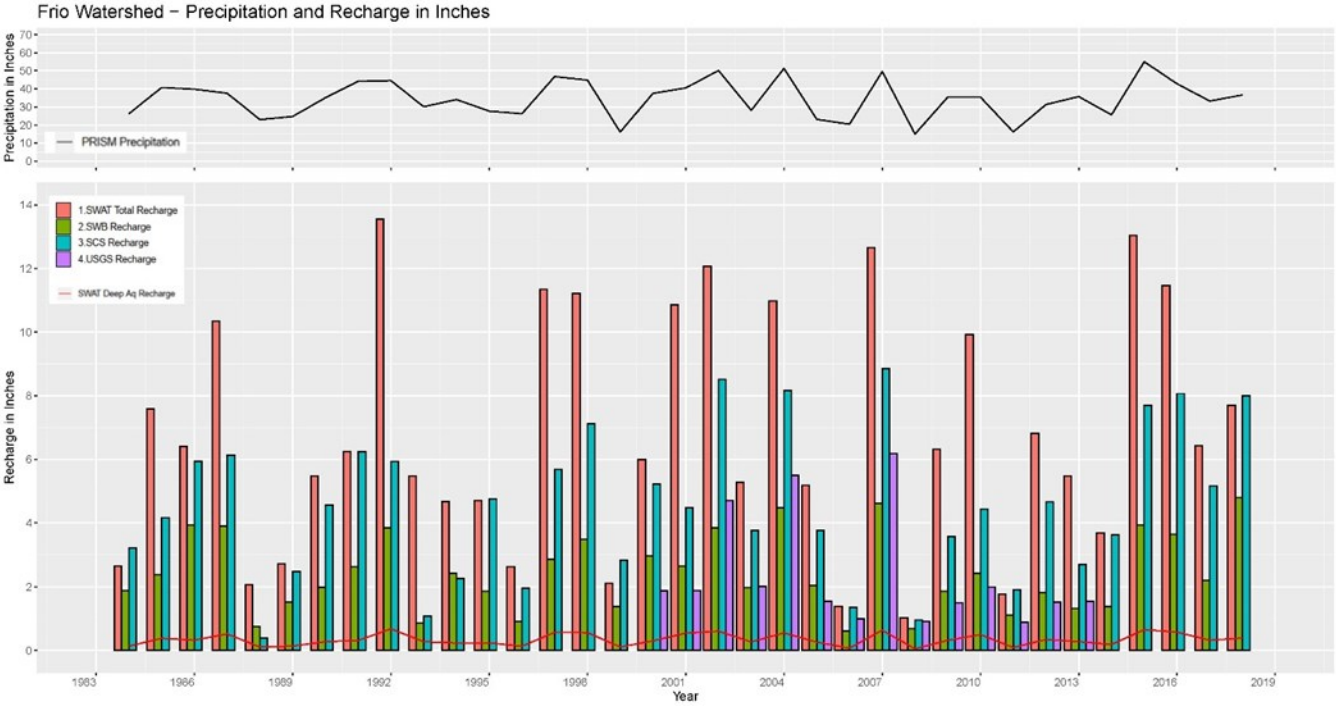
2016
2019


Frio Watershed − Precipitation and Recharge in Inches
Precipitation in Inches
PRISM Precipitation
Recharge in Inches
1.SWAT Total Recharge
2.SWB Recharge
3.SCS Recharge
4.USGS Recharge
SWAT Deep Aq Recharge
Year
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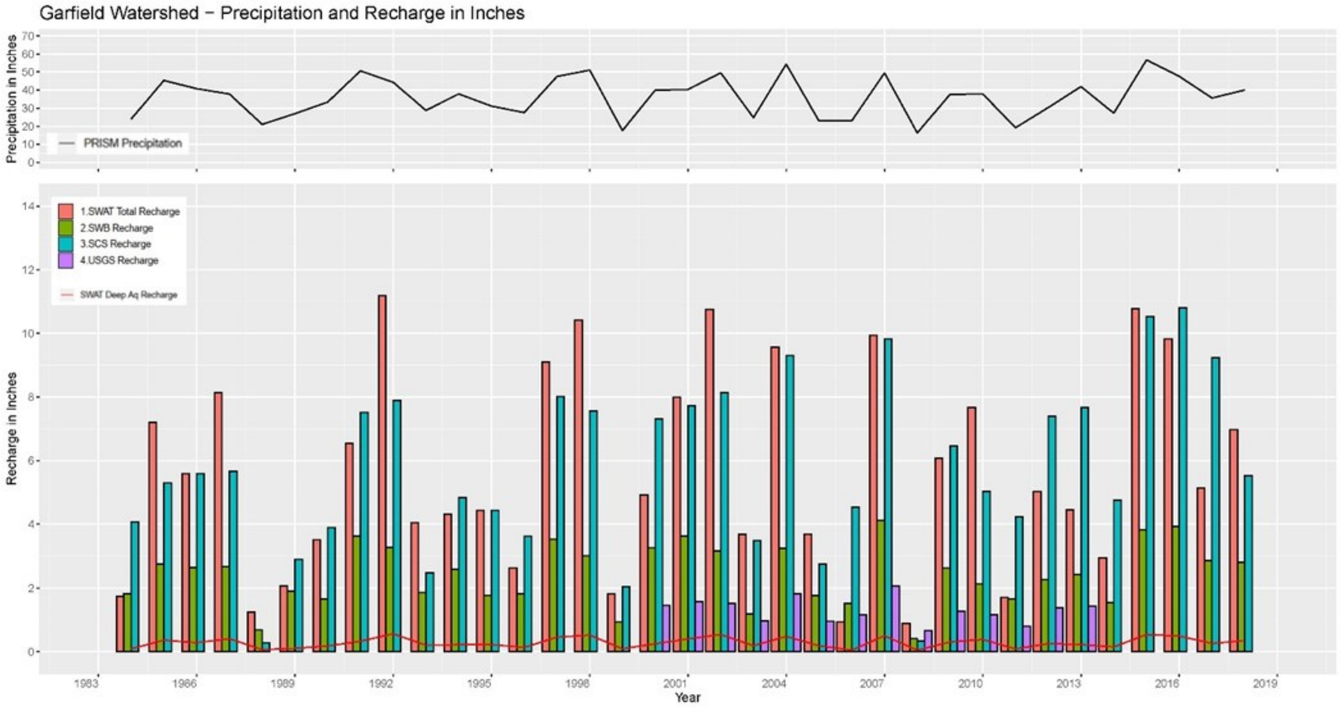
Garfield Watershed − Precipitation and Recharge in Inches
Precipitation in Inches
0
10
20
30
40
50
60
70
PRISM Precipitation
Recharge in Inches
0
2
4
6
8
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12
14
1.SWAT Total Recharge
2.SWB Recharge
3.SCS Recharge
4.USGS Recharge
SWAT Deep Aq Recharge
1983
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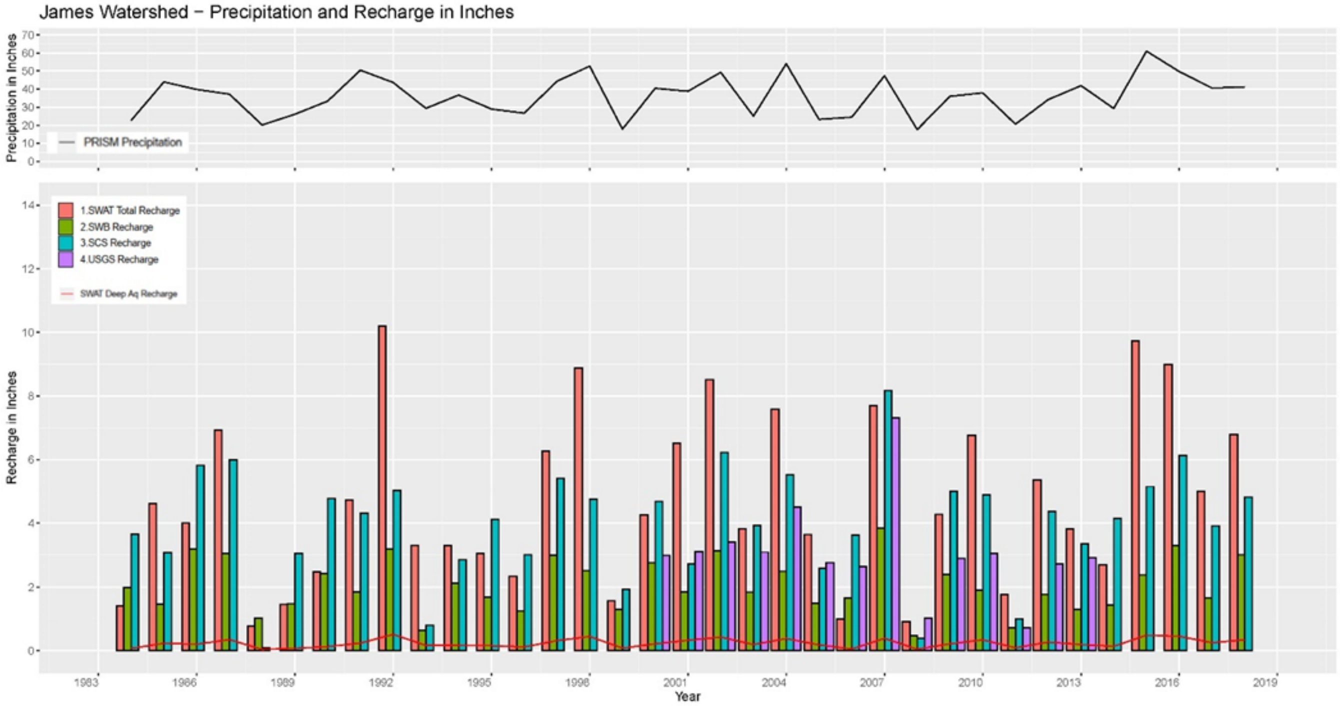
2019
Year


James Watershed − Precipitation and Recharge in Inches
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0
10
20
30
40
50
60
70
PRISM Precipitation
Recharge in Inches
0
2
4
6
8
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12
14
1.SWAT Total Recharge
2.SWB Recharge
3.SCS Recharge
4.USGS Recharge
SWAT Deep Aq Recharge
1983
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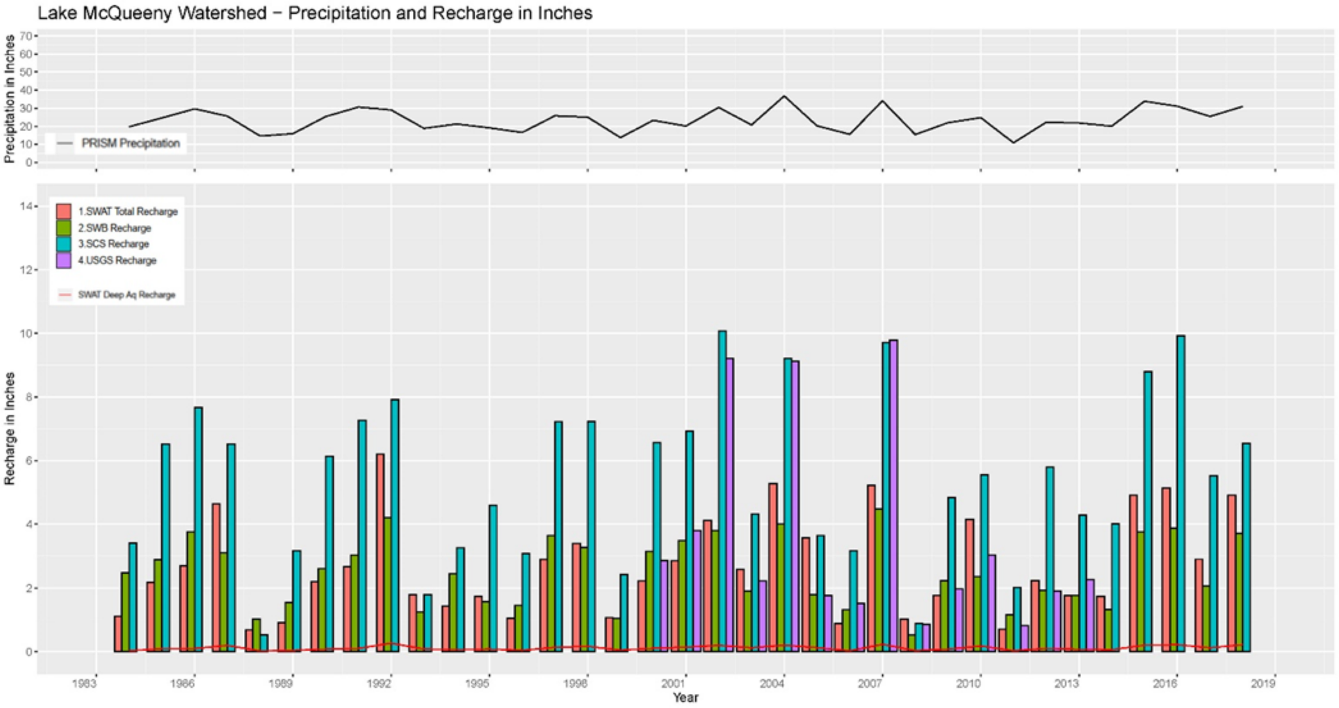
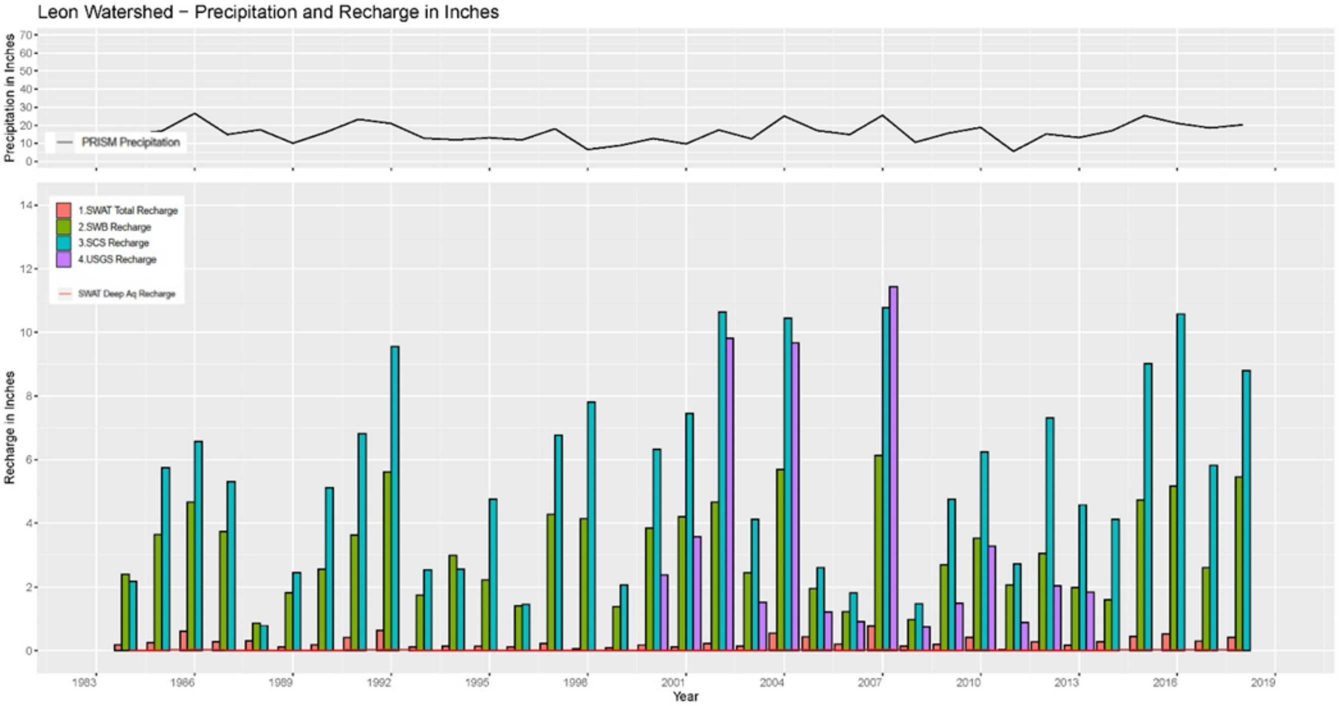
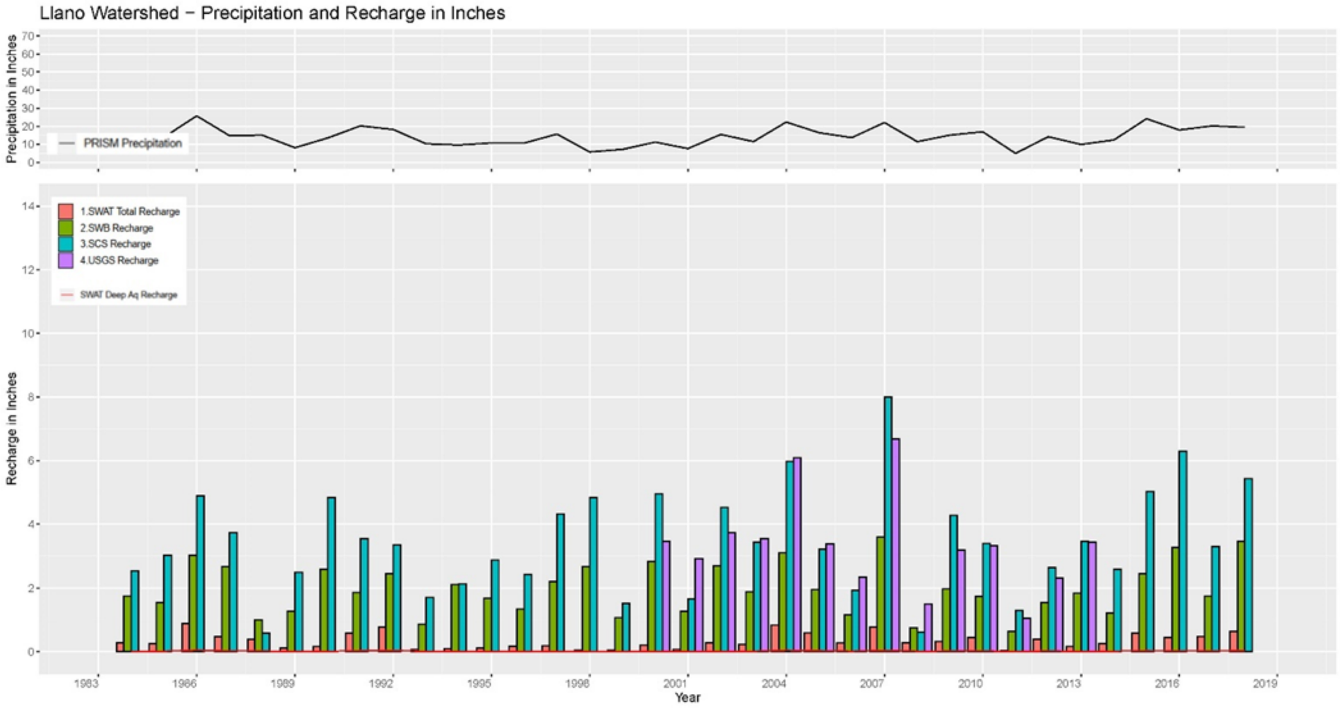
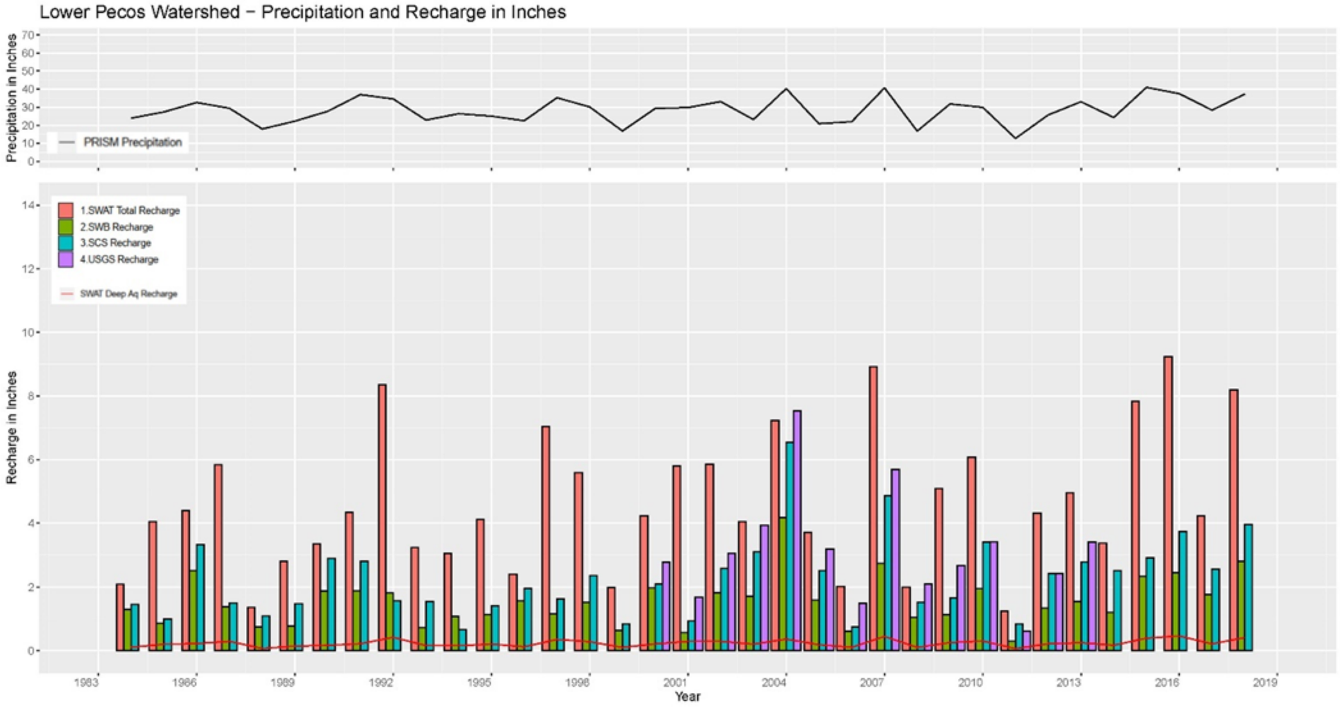
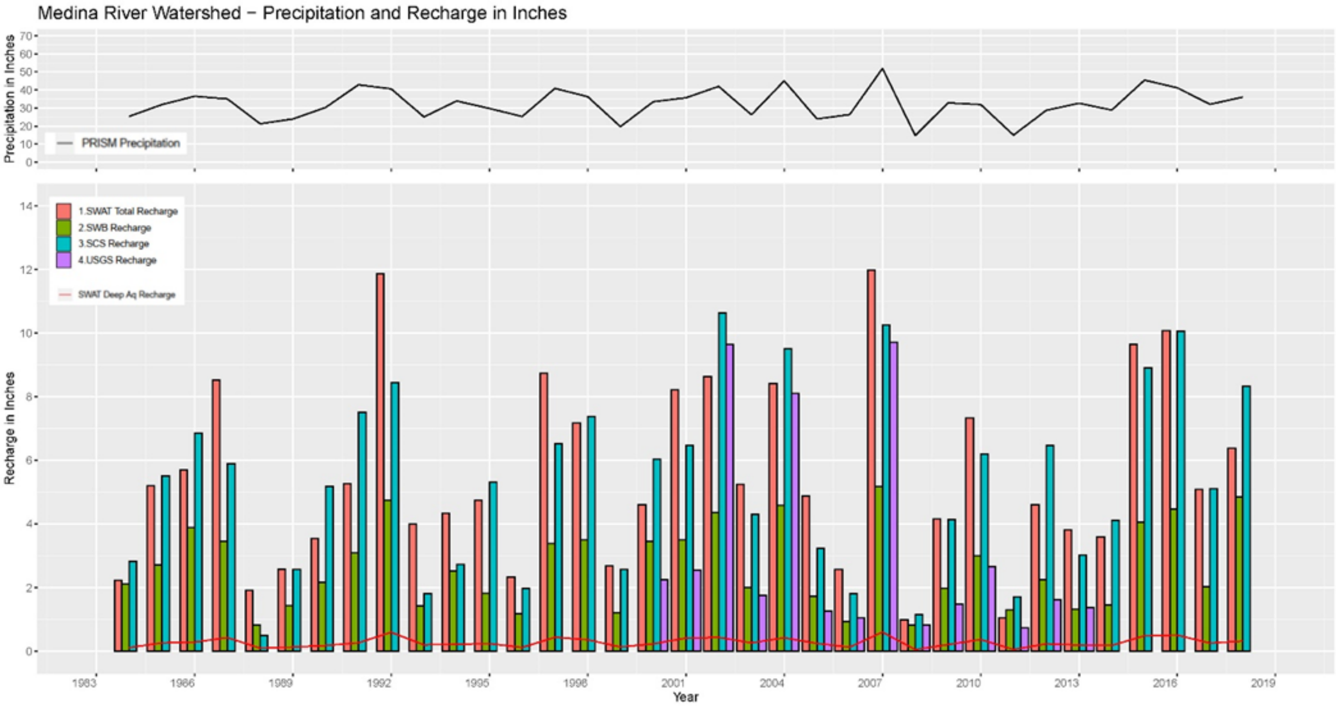
Year


Lake McQueeny Watershed – Precipitation and Recharge in Inches


Leon Watershed – Precipitation and Recharge in Inches


Llano Watershed − Precipitation and Recharge in Inches


Lower Pecos Watershed − Precipitation and Recharge in Inches


Medina River Watershed – Precipitation and Recharge in Inches
Precipitation in Inches
0
10
20
30
40
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PRISM Precipitation
Recharge in Inches
0
2
4
6
8
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14
1.SWAT Total Recharge
2.SWB Recharge
3.SCS Recharge
4.USGS Recharge
SWAT Deep Aq Recharge
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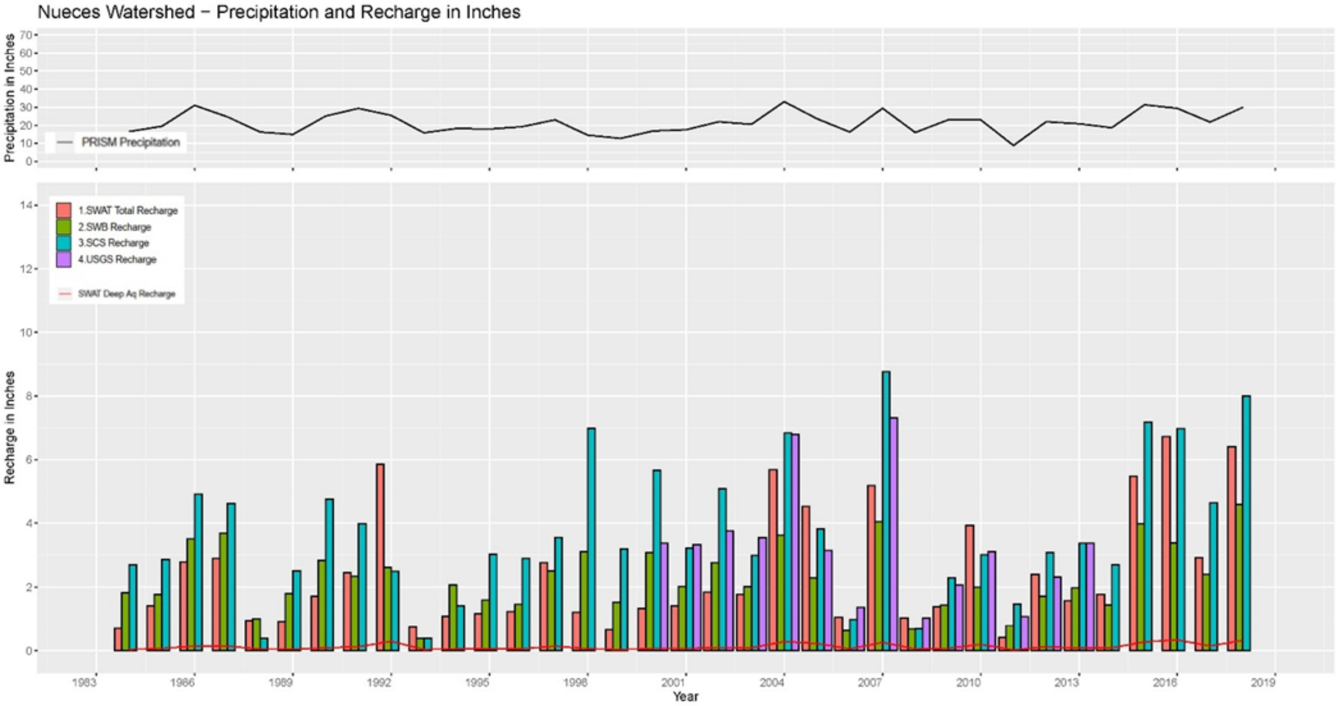
Year


Nueces Watershed – Precipitation and Recharge in Inches
Precipitation in Inches
0
10
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PRISM Precipitation
Recharge in Inches
0
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1.SWAT Total Recharge
2.SWB Recharge
3.SCS Recharge
4.USGS Recharge
SWAT Deep Aq Recharge
1983
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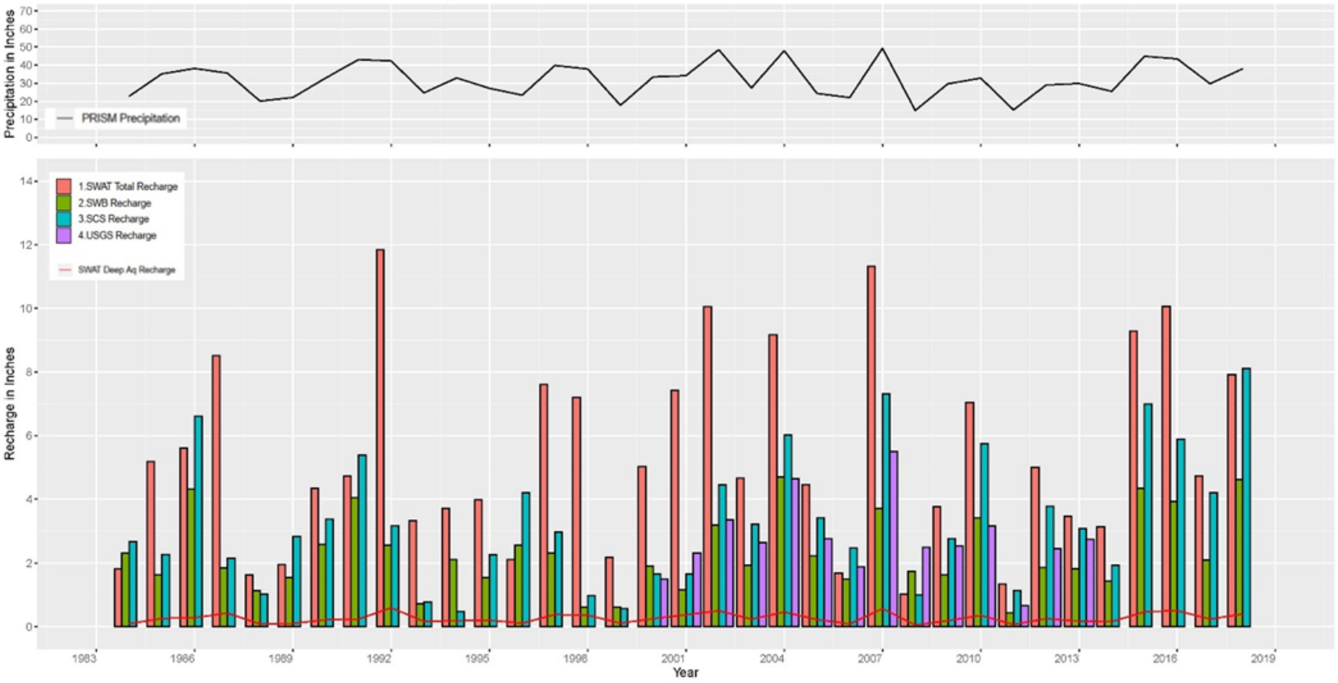
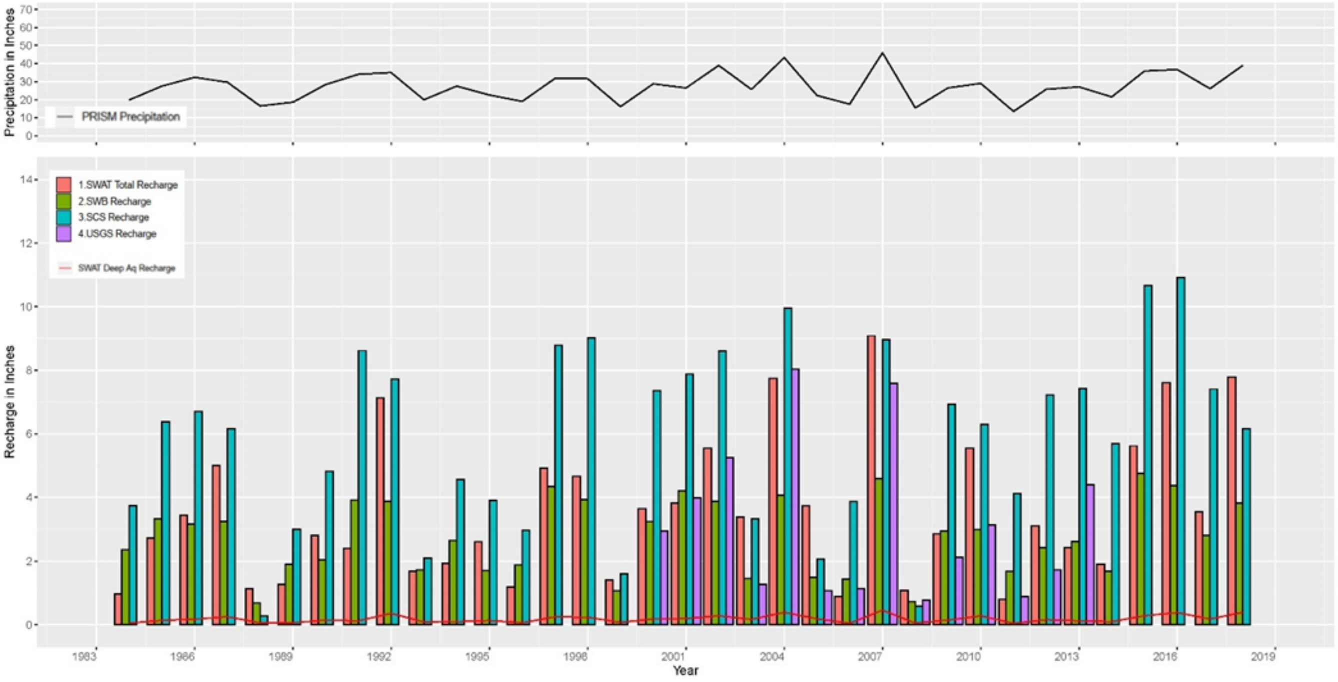
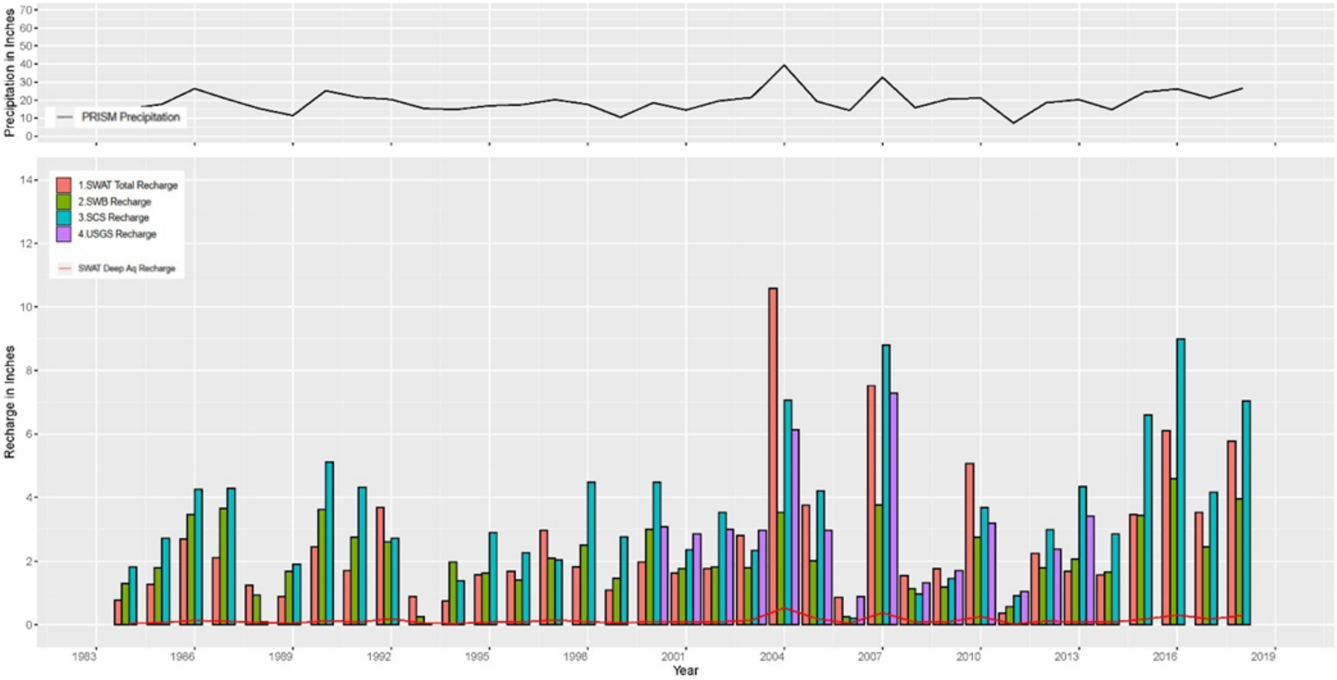
Year

Oak Creek Watershed − Precipitation and Recharge in Inches

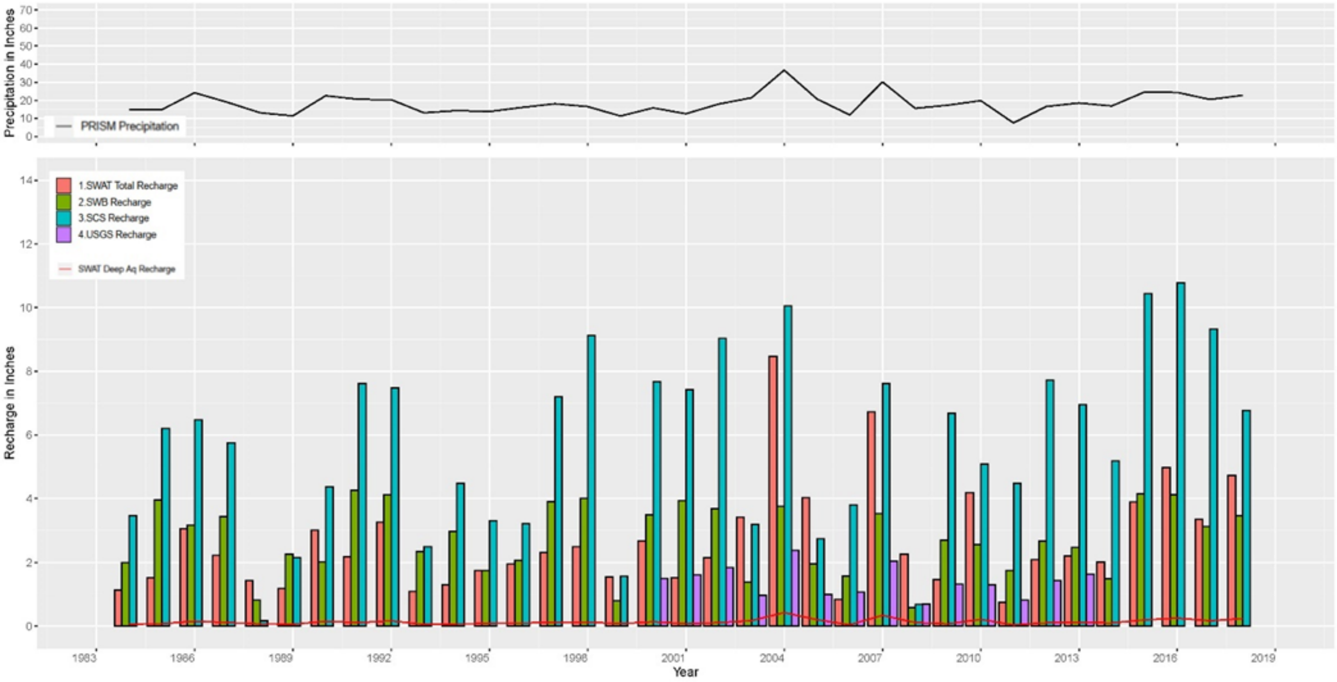


Onion Creek Watershed − Precipitation and Recharge in Inches



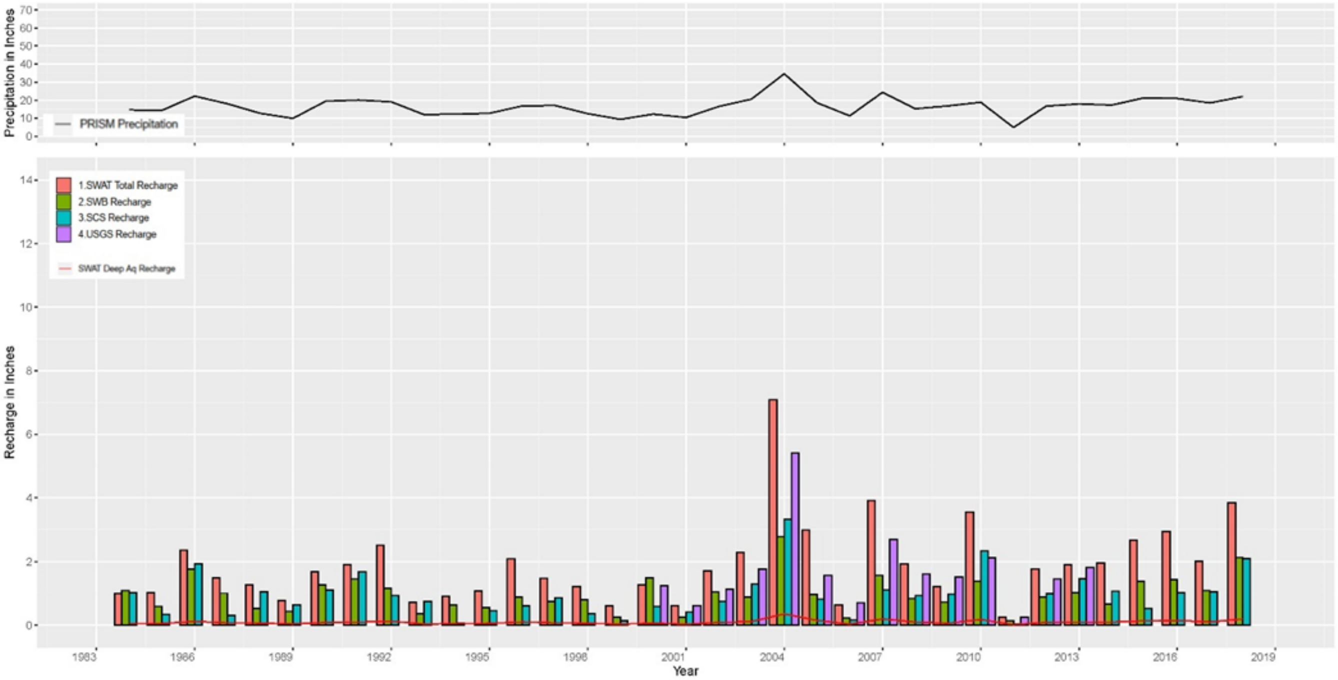


Pinto Watershed − Precipitation and Recharge in Inches

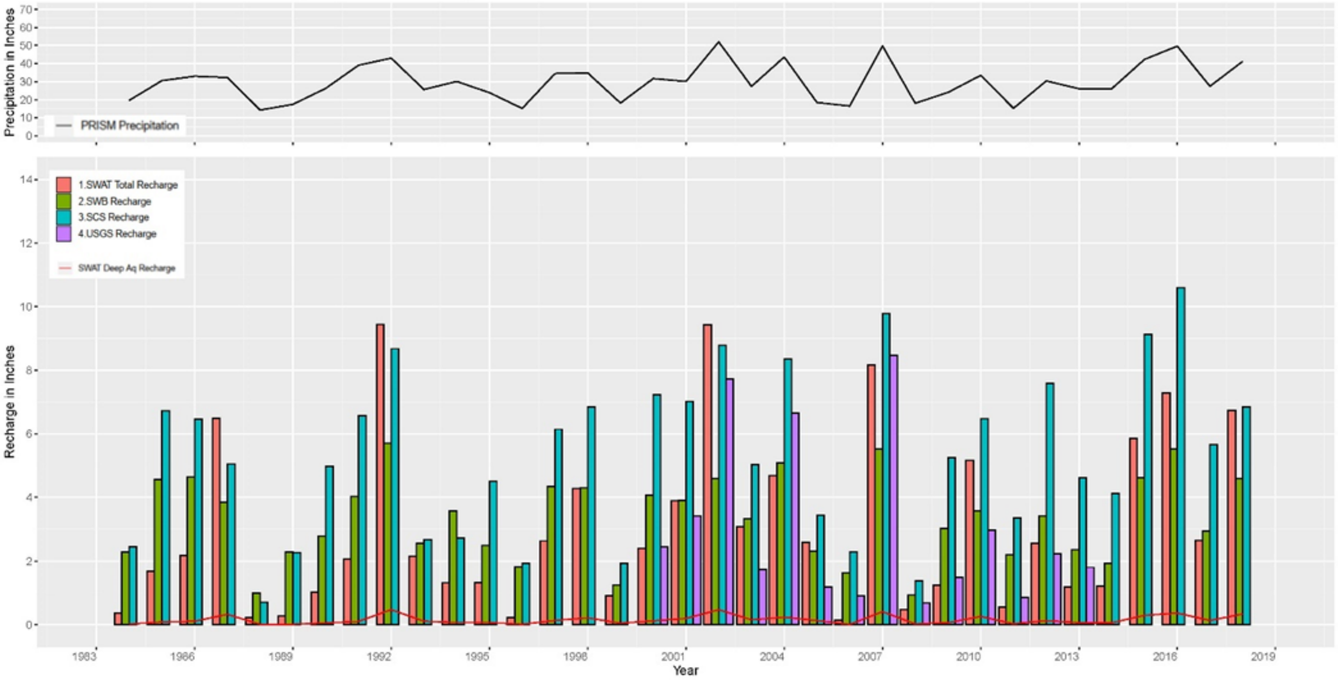


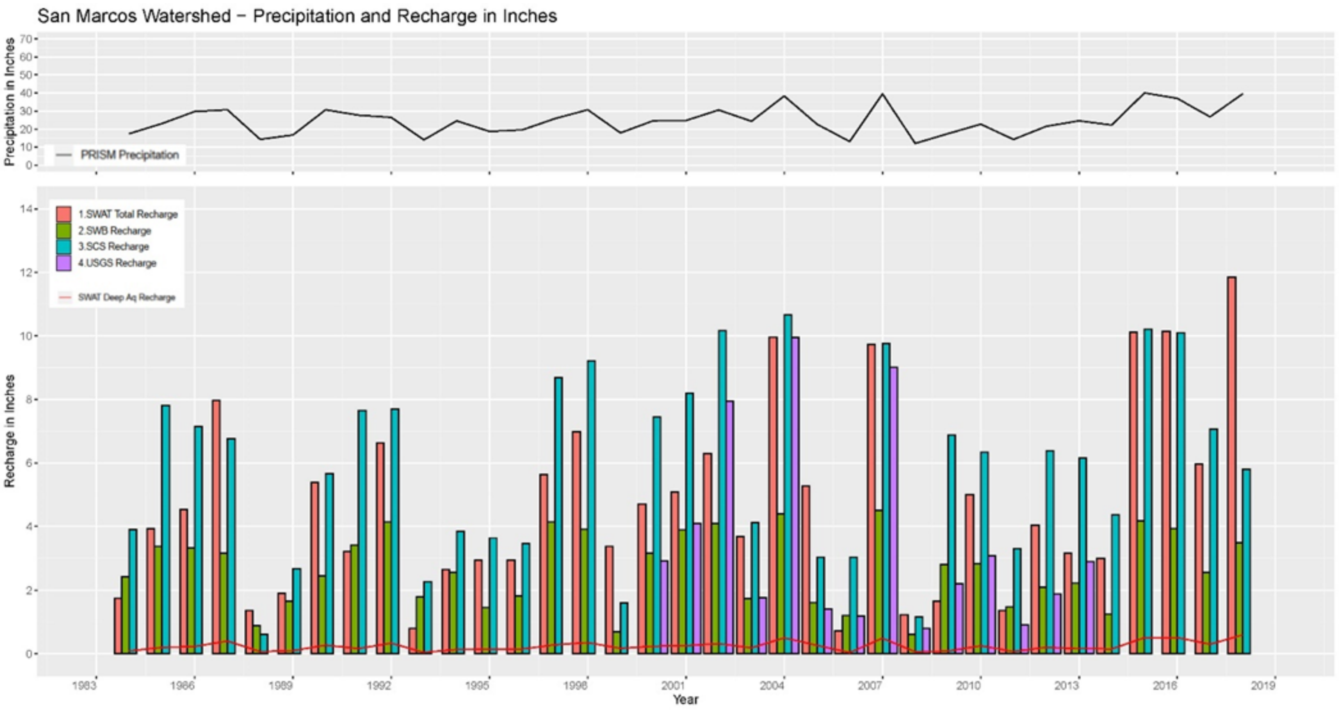
Plum Creek Watershed − Precipitation and Recharge in Inches

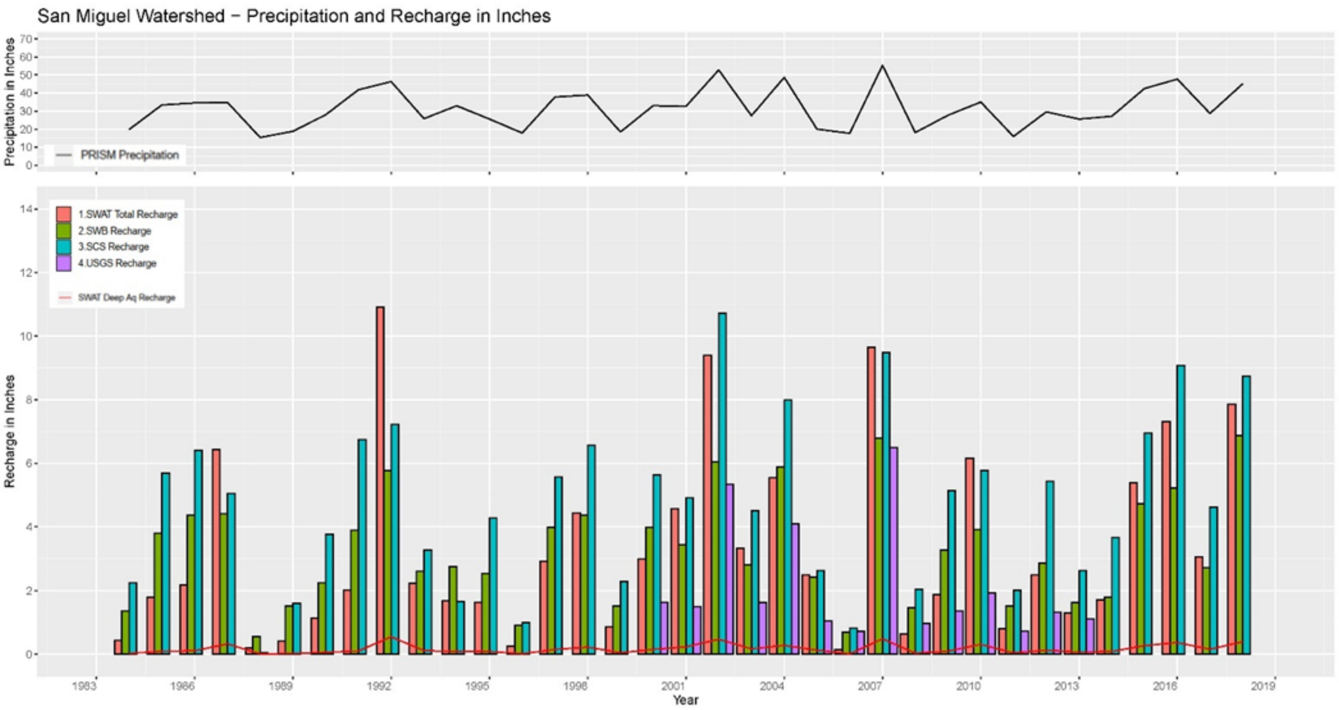
Rio Grande Watershed – Precipitation and Recharge in Inches

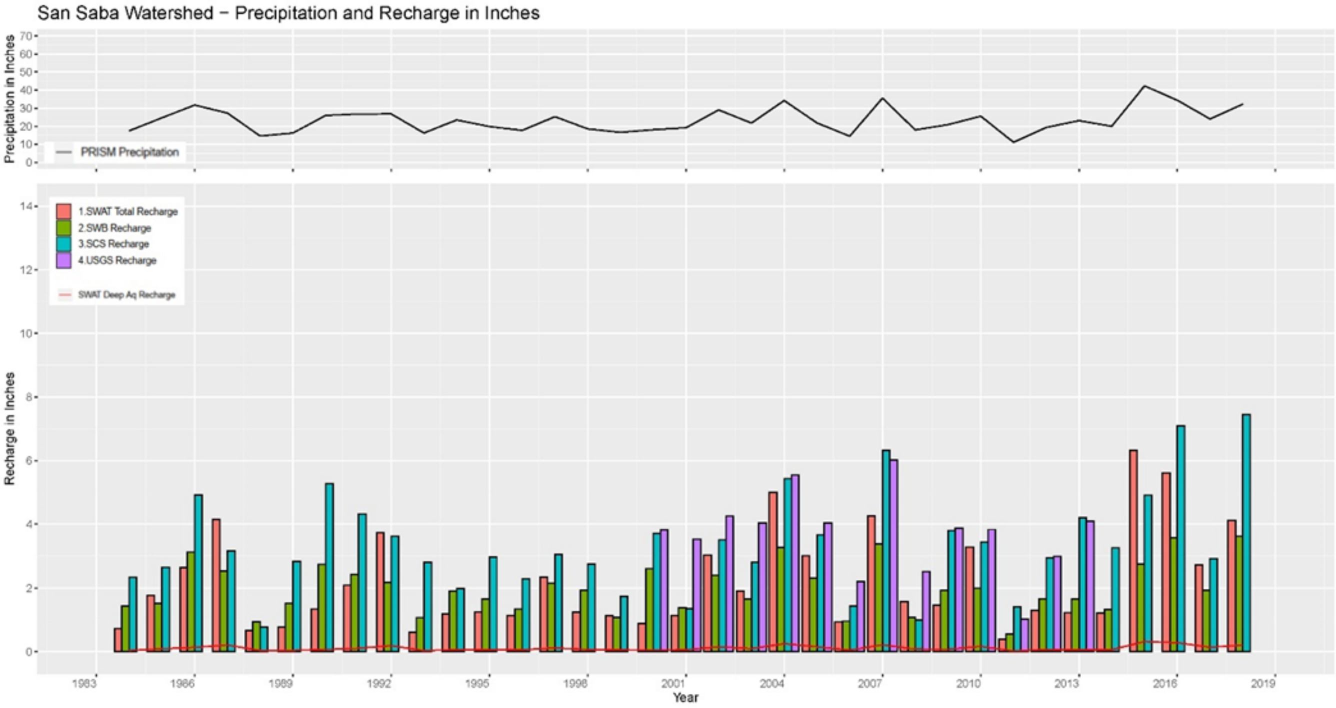


San Antonio Watershed – Precipitation and Recharge in Inches




San Marcos Watershed − Precipitation and Recharge in Inches


San Miguel Watershed − Precipitation and Recharge in Inches


San Saba Watershed – Precipitation and Recharge in Inches
Precipitation in Inches
0
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PRISM Precipitation
Recharge in Inches
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1.SWAT Total Recharge
2.SWB Recharge
3.SCS Recharge
4.USGS Recharge
SWAT Deep Aq Recharge
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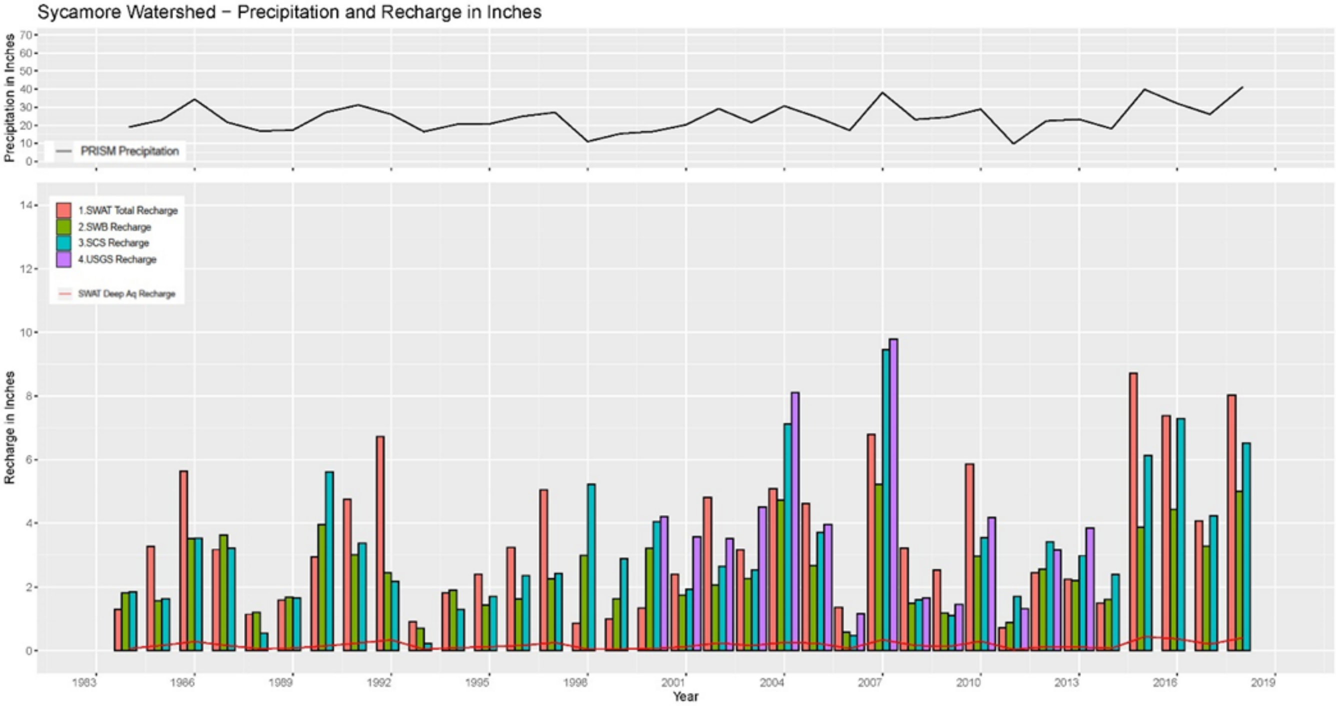
Sycamore Watershed – Precipitation and Recharge in Inches
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PRISM Precipitation
Recharge in Inches
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1.SWAT Total Recharge
2.SWB Recharge
3.SCS Recharge
4.USGS Recharge
SWAT Deep Aq Recharge
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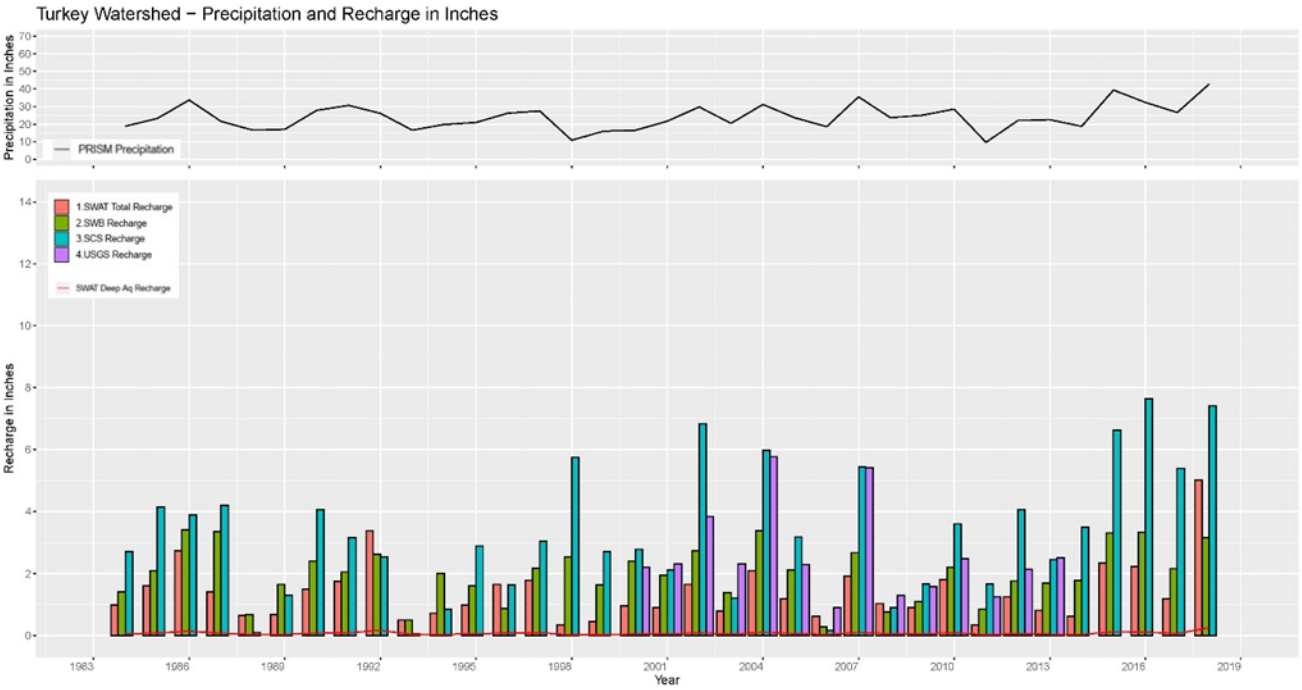
Turkey Watershed – Precipitation and Recharge in Inches
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PRISM Precipitation
Recharge in Inches
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1.SWAT Total Recharge
2.SWB Recharge
3.SCS Recharge
4.USGS Recharge
SWAT Deep Aq Recharge
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2004
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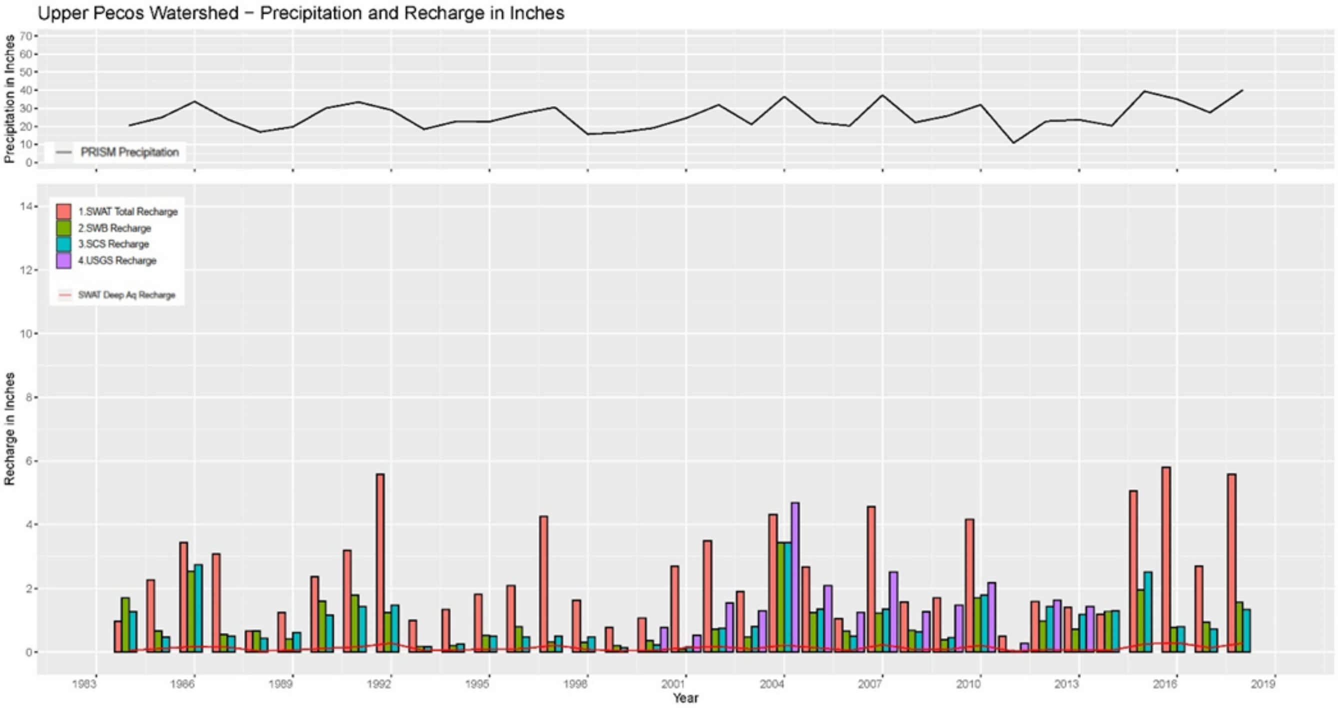
2010
2013
2016
2019
Year


Upper Pecos Watershed – Precipitation and Recharge in Inches
Precipitation in Inches
0
10
20
30
40
50
60
70
PRISM Precipitation
Recharge in Inches
0
2
4
6
8
10
12
14
1.SWAT Total Recharge
2.SWB Recharge
3.SCS Recharge
4.USGS Recharge
SWAT Deep Aq Recharge
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
2019
Year

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APPENDIX F

SUMMARY OF ANNUAL MODEL RESULTS FOR WATERSHEDS

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Watersheds (Parameter Values)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1984	Beals	21.68	0.21	1.69	2.03	0.10	1.18	1.04		18.88	10.54		1.10	
1984	Brady	16.45	0.36	1.06	0.83	0.04	1.83	3.15		16.58	13.87		0.81	
1984	Colorado	21.00	0.53	0.98	1.04	0.05	2.66	4.21		20.30	13.78		1.19	
1984	Concho	18.36	0.14	0.75	0.96	0.05	1.35	1.88		17.49	10.35		0.74	
1984	Elm	27.35	0.30	1.03	2.04	0.10	1.27	1.90		23.24	9.54		3.08	
1984	Frio	26.22	0.26	1.42	2.65	0.13	1.89	3.22		21.27	13.21		1.62	
1984	Garfield	23.98	0.19	1.03	1.74	0.09	1.82	4.08		25.07	15.33		1.41	
1984	James	22.64	0.17	0.87	1.41	0.07	1.98	3.66		18.06	12.30		0.98	
1984	Lake McQueeny	19.72	0.19	1.86	1.12	0.03	2.48	3.41		20.62	13.90		0.56	
1984	Leon	14.63	0.03	0.19	0.19	0.01	2.40	2.17		25.17	13.78		0.11	
1984	Llano	14.17	0.00	0.34	0.28	0.01	1.75	2.54		20.97	11.23		0.52	
1984	Lower Pecos	23.90	1.03	0.90	2.09	0.10	1.30	1.45		20.94	10.06		2.30	
1984	Medina River	25.39	0.99	1.13	2.23	0.11	2.12	2.83		18.78	13.92		3.02	
1984	Nueces	16.50	0.05	0.73	0.71	0.04	1.82	2.69		18.06	10.24		0.65	
1984	Oak Creek	22.79	0.28	1.07	1.81	0.09	2.31	2.66		18.82	11.56		1.66	
1984	Onion Creek	19.83	0.01	0.83	0.96	0.05	2.35	3.75		18.55	15.18		1.54	
1984	Pinto	15.17	0.01	1.04	0.77	0.04	1.30	1.80		15.90	9.52		0.60	
1984	Plum Creek	14.92	0.12	1.43	1.12	0.06	2.00	3.47		17.15	16.78		0.47	
1984	Rio Grande	14.60	0.01	1.35	1.00	0.05	1.09	1.02		16.97	10.10		0.27	
1984	San Antonio	19.59	0.01	0.37	0.37	0.02	2.28	2.45		18.55	14.29		0.47	
1984	San Marcos	17.43	0.04	1.78	1.75	0.09	2.42	3.91		12.45	15.31		2.02	
1984	San Miguel	19.84	0.00	0.44	0.44	0.02	1.36	2.24		16.46	14.26		0.20	
1984	San Saba	17.47	0.27	0.58	0.73	0.04	1.43	2.33		19.51	11.25		1.73	
1984	Sycamore	18.99	0.57	1.10	1.30	0.07	1.81	1.84		16.21	9.19		1.25	
1984	Turkey	18.81	0.35	1.15	0.99	0.05	1.41	2.70		13.85	8.71		1.58	
1984	Upper Pecos	20.43	0.43	1.07	0.96	0.05	1.70	1.27		18.95	12.19		1.41	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1985	Beals	31.72	0.82	3.60	5.29	0.26	1.15	0.95		27.50	12.71		2.45	
1985	Brady	19.36	0.82	1.04	1.40	0.07	1.37	2.28		23.49	15.47		1.00	
1985	Colorado	28.19	1.65	1.02	2.68	0.13	2.42	5.29		27.87	21.04		2.85	
1985	Concho	27.46	0.38	0.97	2.08	0.11	1.05	1.43		24.42	14.64		2.25	
1985	Elm	36.55	0.70	3.51	4.36	0.22	2.00	3.63		30.66	15.32		5.41	
1985	Frio	40.73	0.89	5.38	7.60	0.38	2.38	4.17		31.02	21.20		4.24	
1985	Garfield	45.32	0.87	4.19	7.20	0.36	2.75	5.30		35.53	23.90		5.05	
1985	James	43.95	0.67	3.05	4.63	0.23	1.47	3.08		32.93	17.59		5.76	
1985	Lake McQueeny	24.59	0.56	2.32	2.18	0.09	2.89	6.53		25.31	24.03		1.64	
1985	Leon	16.82	0.06	0.16	0.25	0.01	3.65	5.74		27.95	25.52		0.16	
1985	Llano	13.88	0.00	0.28	0.24	0.01	1.53	3.02		21.95	15.55		0.50	
1985	Lower Pecos	27.35	2.76	0.98	4.05	0.20	0.86	0.99		25.50	12.71		3.39	
1985	Medina River	31.94	3.74	1.05	5.20	0.26	2.72	5.50		25.09	23.82		4.78	
1985	Nueces	19.44	0.52	0.71	1.42	0.07	1.76	2.86		24.63	16.03		0.81	
1985	Oak Creek	35.14	1.09	3.37	5.18	0.26	1.63	2.27		28.81	17.48		3.83	
1985	Onion Creek	27.51	0.05	2.36	2.73	0.14	3.34	6.38		26.81	25.09		2.56	
1985	Pinto	17.71	0.16	0.92	1.27	0.06	1.79	2.71		21.40	13.76		0.55	
1985	Plum Creek	14.89	0.25	1.35	1.52	0.08	3.95	6.20		20.29	26.47		0.32	
1985	Rio Grande	14.35	0.06	1.29	1.03	0.05	0.60	0.35		19.40	11.45		0.20	
1985	San Antonio	30.52	0.08	1.17	1.69	0.08	4.57	6.72		28.37	23.16		1.40	
1985	San Marcos	23.03	0.34	3.25	3.93	0.20	3.37	7.82		20.67	26.24		2.26	
1985	San Miguel	33.39	0.00	1.34	1.78	0.09	3.81	5.69		29.24	19.67		1.38	
1985	San Saba	24.64	0.91	0.75	1.77	0.09	1.52	2.66		27.23	15.09		3.04	
1985	Sycamore	22.95	1.94	1.06	3.28	0.16	1.56	1.63		22.31	13.38		2.05	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1985	Turkey	23.20	0.96	1.11	1.59	0.08	2.09	4.15		23.30	16.43		2.02	
1985	Upper Pecos	24.94	1.38	1.03	2.26	0.11	0.66	0.47		25.97	10.97		2.62	
1986	Beals	37.10	1.14	3.28	6.02	0.30	3.48	4.20		26.46	14.77		3.25	
1986	Brady	34.99	2.41	1.03	4.51	0.23	3.21	5.92		23.85	15.84		5.10	
1986	Colorado	36.67	2.36	1.04	3.97	0.20	3.48	6.87		27.27	19.44		4.95	
1986	Concho	28.39	0.33	0.88	2.31	0.12	3.23	5.38		22.46	15.99		2.08	
1986	Elm	38.12	0.62	2.61	4.00	0.20	3.39	4.83		29.34	15.07		4.92	
1986	Frio	39.80	0.86	4.40	6.41	0.32	3.94	5.94		28.36	20.37		3.59	
1986	Garfield	40.77	0.78	4.05	5.60	0.28	2.64	5.59		32.24	20.95		4.19	
1986	James	39.79	0.54	3.16	4.00	0.20	3.19	5.82		29.59	17.69		4.64	
1986	Lake McQueeny	29.64	0.59	2.44	2.71	0.10	3.75	7.67		25.68	21.16		1.90	
1986	Leon	26.56	0.09	0.28	0.60	0.03	4.66	6.57		29.69	21.77		0.62	
1986	Llano	25.74	0.00	0.43	0.87	0.04	3.03	4.90		24.75	16.04		2.24	
1986	Lower Pecos	32.57	2.71	1.00	4.41	0.22	2.51	3.34		25.25	13.76		3.63	
1986	Medina River	36.53	4.14	1.05	5.70	0.28	3.88	6.86		24.38	21.72		5.78	
1986	Nueces	30.99	1.34	0.84	2.79	0.14	3.51	4.91		24.94	16.77		2.67	
1986	Oak Creek	38.12	1.24	3.06	5.60	0.28	4.32	6.61		26.98	17.74		4.20	
1986	Onion Creek	32.37	0.21	2.08	3.45	0.17	3.17	6.69		25.43	21.45		3.31	
1986	Pinto	26.31	0.78	1.00	2.71	0.14	3.46	4.25		20.32	15.30		2.15	
1986	Plum Creek	24.18	0.74	1.30	3.07	0.15	3.17	6.48		20.23	22.76		1.89	
1986	Rio Grande	22.24	0.25	1.26	2.36	0.12	1.76	1.94		19.02	13.05		1.31	
1986	San Antonio	32.98	0.09	1.44	2.17	0.11	4.63	6.46		26.68	19.79		2.22	
1986	San Marcos	29.71	0.33	2.93	4.54	0.23	3.33	7.15		20.63	22.62		2.56	
1986	San Miguel	34.51	0.02	1.49	2.18	0.11	4.36	6.42		27.01	17.97		1.52	
1986	San Saba	31.72	1.55	0.78	2.64	0.13	3.12	4.93		26.32	15.95		4.68	
1986	Sycamore	34.37	3.74	1.06	5.64	0.28	3.52	3.53		21.92	15.00		5.36	
1986	Turkey	33.69	1.40	1.11	2.74	0.14	3.41	3.90		22.41	16.22		4.93	
1986	Upper Pecos	33.72	1.99	1.03	3.43	0.17	2.55	2.74		24.88	14.62		4.53	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1987	Beals	36.00	1.99	6.09	9.13	0.46	0.64	1.16		27.80	13.80		3.83	
1987	Brady	24.15	1.98	1.02	3.39	0.17	2.61	3.61		24.43	19.10		1.77	
1987	Colorado	28.53	2.91	1.21	4.50	0.22	3.16	6.61		27.35	22.01		2.96	
1987	Concho	26.82	0.50	1.63	3.40	0.18	1.50	2.51		25.16	18.46		2.38	
1987	Elm	37.85	0.78	5.20	7.22	0.36	3.32	5.34		28.42	19.05		6.74	
1987	Frio	37.54	1.88	6.98	10.35	0.52	3.90	6.12		26.96	25.16		4.47	
1987	Garfield	37.82	2.09	5.51	8.14	0.41	2.68	5.67		32.34	23.08		3.68	
1987	James	37.18	0.71	5.84	6.93	0.35	3.05	5.99		28.97	19.20		4.95	
1987	Lake McQueeny	25.58	1.70	3.14	4.64	0.20	3.10	6.52		26.11	23.33		2.22	
1987	Leon	14.90	0.06	0.34	0.28	0.01	3.75	5.31		29.41	26.09		0.13	
1987	Llano	14.82	0.01	0.59	0.47	0.02	2.68	3.73		24.84	18.75		0.81	
1987	Lower Pecos	29.40	4.16	1.30	5.84	0.29	1.37	1.50		26.29	14.98		3.26	
1987	Medina River	35.07	7.27	1.05	8.53	0.43	3.46	5.89		25.08	26.36		5.88	
1987	Nueces	24.66	1.19	1.50	2.90	0.14	3.69	4.62		27.20	20.59		1.27	
1987	Oak Creek	35.56	2.45	5.42	8.51	0.43	1.85	2.14		27.05	18.46		4.65	
1987	Onion Creek	29.64	0.45	4.34	5.01	0.25	3.25	6.17		27.40	24.25		2.75	
1987	Pinto	20.50	0.68	1.51	2.11	0.11	3.66	4.30		23.34	18.09		0.73	
1987	Plum Creek	18.91	0.76	1.48	2.22	0.11	3.44	5.76		23.00	24.40		0.35	
1987	Rio Grande	18.01	0.25	1.35	1.49	0.07	1.01	0.30		22.51	13.61		0.24	
1987	San Antonio	32.28	0.41	5.18	6.49	0.32	3.84	5.05		29.39	24.41		2.94	
1987	San Marcos	30.67	0.51	5.76	7.97	0.40	3.16	6.76		23.46	23.88		2.39	
1987	San Miguel	34.85	0.24	5.45	6.44	0.32	4.42	5.04		31.32	22.54		2.81	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1987	San Saba	27.28	0.97	2.35	4.16	0.21	2.52	3.16		27.08	17.50		3.64	
1987	Sycamore	21.61	2.23	1.05	3.18	0.16	3.63	3.22		20.80	17.11		1.64	
1987	Turkey	21.55	0.66	1.10	1.41	0.07	3.35	4.20		21.50	19.03		1.61	
1987	Upper Pecos	23.92	2.15	1.02	3.07	0.15	0.56	0.51		24.36	12.88		2.30	
1988	Beals	19.90	0.37	3.88	2.14	0.11	1.25	1.22		22.44	11.83		0.95	
1988	Brady	16.29	0.50	1.08	0.87	0.04	1.07	0.61		20.44	12.01		0.93	
1988	Colorado	17.63	0.55	1.10	0.87	0.04	1.15	0.19		22.82	15.98		0.89	
1988	Concho	14.93	0.16	1.29	1.05	0.05	0.80	1.19		17.39	11.34		0.74	
1988	Elm	23.61	0.40	2.80	1.35	0.07	0.59	0.08		26.87	9.87		1.86	
1988	Frio	22.99	0.36	4.82	2.06	0.10	0.75	0.38		25.66	13.26		0.92	
1988	Garfield	21.05	0.22	3.64	1.23	0.06	0.68	0.26		28.38	15.86		0.93	
1988	James	20.16	0.22	1.75	0.76	0.04	1.02	0.08		22.58	12.32		0.57	
1988	Lake McQueeny	14.57	0.19	2.25	0.68	0.02	1.03	0.53		20.03	16.14		0.36	
1988	Leon	17.51	0.06	0.27	0.30	0.02	0.87	0.78		27.48	15.30		0.27	
1988	Llano	15.05	0.00	0.43	0.38	0.02	1.01	0.58		21.08	10.29		0.86	
1988	Lower Pecos	17.92	0.87	1.22	1.37	0.07	0.74	1.09		22.74	8.27		0.88	
1988	Medina River	21.32	1.34	1.11	1.90	0.10	0.83	0.50		21.79	15.38		2.23	
1988	Nueces	16.24	0.28	1.05	0.94	0.05	1.00	0.39		21.51	10.47		0.59	
1988	Oak Creek	20.07	0.41	3.00	1.62	0.08	1.13	1.01		22.31	12.82		1.33	
1988	Onion Creek	16.50	0.03	2.16	1.12	0.06	0.68	0.28		19.88	17.26		1.14	
1988	Pinto	15.15	0.19	1.10	1.23	0.06	0.92	0.08		16.05	9.78		1.58	
1988	Plum Creek	13.09	0.19	1.36	1.42	0.07	0.82	0.17		16.38	16.98		1.08	
1988	Rio Grande	12.72	0.10	1.28	1.27	0.06	0.53	1.06		15.43	7.41		1.01	
1988	San Antonio	14.25	0.01	1.73	0.22	0.01	1.00	0.70		19.00	14.58		0.35	
1988	San Marcos	14.30	0.07	3.81	1.36	0.07	0.88	0.60		14.93	18.26		0.69	
1988	San Miguel	15.38	0.00	1.68	0.19	0.01	0.56	0.04		18.36	11.68		0.14	
1988	San Saba	14.58	0.37	1.51	0.67	0.03	0.93	0.76		21.10	9.31		1.06	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1988	Sycamore	16.78	0.75	1.10	1.14	0.06	1.20	0.55		18.01	9.45		1.16	
1988	Turkey	16.57	0.45	1.14	0.64	0.03	0.67	0.09		16.08	9.99		1.42	
1988	Upper Pecos	16.89	0.41	1.07	0.65	0.03	0.67	0.43		20.90	8.00		1.07	
1989	Beals	20.47	0.31	2.32	2.27	0.11	0.29	0.65		20.44	7.55		0.82	
1989	Brady	17.07	0.62	1.04	1.17	0.06	1.73	3.87		19.82	12.19		1.24	
1989	Colorado	22.14	0.93	0.96	1.57	0.08	1.90	3.23		23.48	16.51		1.76	
1989	Concho	15.49	0.19	0.92	0.79	0.04	0.69	1.55		16.63	9.84		0.76	
1989	Elm	24.54	0.34	1.48	1.79	0.09	1.63	2.27		25.03	11.63		1.84	
1989	Frio	24.69	0.33	2.77	2.71	0.14	1.53	2.48		23.79	13.72		1.00	
1989	Garfield	26.95	0.34	1.94	2.07	0.10	1.90	2.90		29.29	18.81		1.34	
1989	James	26.09	0.32	1.10	1.45	0.07	1.47	3.05		24.16	13.33		0.82	
1989	Lake McQueeny	15.88	0.20	2.05	0.91	0.04	1.55	3.17		19.32	15.99		0.41	
1989	Leon	10.05	0.02	0.16	0.11	0.01	1.83	2.46		23.42	16.14		0.07	
1989	Llano	8.12	0.00	0.29	0.10	0.01	1.27	2.49		17.11	10.87		0.29	
1989	Lower Pecos	22.26	1.72	1.07	2.80	0.14	0.78	1.48		22.51	8.21		1.86	
1989	Medina River	23.97	1.78	1.05	2.58	0.13	1.44	2.57		21.59	15.14		2.51	
1989	Nueces	14.91	0.31	0.79	0.90	0.05	1.79	2.50		20.03	11.30		0.52	
1989	Oak Creek	22.11	0.45	1.67	1.94	0.10	1.55	2.83		21.51	12.59		1.35	
1989	Onion Creek	18.60	0.07	1.31	1.27	0.06	1.89	2.99		19.90	19.89		1.19	
1989	Pinto	11.44	0.23	0.96	0.89	0.04	1.69	1.89		14.51	11.46		0.56	
1989	Plum Creek	11.41	0.20	1.33	1.17	0.06	2.25	2.16		15.93	20.38		0.28	
1989	Rio Grande	9.91	0.10	1.22	0.78	0.04	0.43	0.64		14.73	7.09		0.17	
1989	San Antonio	17.40	0.02	0.25	0.27	0.01	2.28	2.26		17.90	14.90		0.37	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1989	San Marcos	16.71	0.10	1.96	1.90	0.09	1.65	2.68		14.72	19.27		0.98	
1989	San Miguel	18.81	0.00	0.34	0.40	0.02	1.52	1.59		17.08	12.64		0.21	
1989	San Saba	16.24	0.34	0.62	0.76	0.04	1.52	2.83		21.64	10.63		1.15	
1989	Sycamore	17.31	0.91	1.07	1.58	0.08	1.68	1.66		17.81	10.45		1.33	
1989	Turkey	17.02	0.44	1.10	0.68	0.03	1.64	1.30		16.03	11.63		1.40	
1989	Upper Pecos	19.72	0.72	0.98	1.24	0.06	0.41	0.61		21.29	6.95		1.63	
1990	Beals	30.93	0.76	3.59	5.00	0.25	0.46	0.57		25.68	12.50		2.35	
1990	Brady	25.11	1.13	0.86	1.91	0.10	2.59	5.21		22.97	17.85		1.46	
1990	Colorado	29.39	1.46	0.80	2.34	0.12	2.54	5.25		26.05	19.93		2.28	
1990	Concho	24.96	0.30	0.92	1.93	0.10	1.71	2.62		22.19	17.30		1.71	
1990	Elm	35.70	0.61	2.78	3.77	0.19	3.26	5.30		29.35	17.79		4.72	
1990	Frio	35.08	0.61	4.17	5.48	0.27	1.98	4.56		27.32	20.18		2.88	
1990	Garfield	33.34	0.41	2.61	3.52	0.18	1.65	3.89		31.00	21.15		2.48	
1990	James	33.34	0.46	1.78	2.48	0.12	2.42	4.77		28.18	18.04		2.01	
1990	Lake McQueeny	25.33	0.59	2.11	2.20	0.08	2.60	6.14		24.23	21.50		1.41	
1990	Leon	16.09	0.05	0.13	0.18	0.01	2.56	5.12		26.05	20.91		0.12	
1990	Llano	13.51	0.00	0.18	0.16	0.01	2.59	4.84		20.16	16.53		0.42	
1990	Lower Pecos	27.70	2.08	1.00	3.34	0.17	1.87	2.91		25.02	14.73		2.26	
1990	Medina River	30.35	2.55	0.99	3.55	0.18	2.16	5.18		23.21	21.25		3.58	
1990	Nueces	25.07	0.78	0.73	1.71	0.09	2.84	4.77		24.81	18.19		0.93	
1990	Oak Creek	32.84	0.93	2.95	4.34	0.22	2.58	3.37		26.27	19.07		3.14	
1990	Onion Creek	28.36	0.22	2.23	2.80	0.14	2.04	4.83		25.75	20.99		2.44	
1990	Pinto	25.15	0.77	0.99	2.44	0.12	3.62	5.12		21.87	17.31		1.95	
1990	Plum Creek	22.55	1.00	1.30	3.01	0.15	2.02	4.37		21.56	22.28		1.11	
1990	Rio Grande	19.43	0.13	1.01	1.69	0.08	1.27	1.10		19.95	12.99		0.75	
1990	San Antonio	26.25	0.04	0.90	1.03	0.05	2.79	4.97		25.55	19.39		1.49	
1990	San Marcos	30.67	0.37	4.08	5.40	0.27	2.45	5.67		22.87	22.81		3.02	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1990	San Miguel	27.95	0.00	1.10	1.14	0.06	2.25	3.77		25.88	17.57		0.95	
1990	San Saba	25.98	0.65	0.68	1.33	0.07	2.74	5.27		26.06	17.28		2.82	
1990	Sycamore	27.11	1.89	0.95	2.94	0.15	3.96	5.62		21.53	16.81		2.24	
1990	Turkey	27.80	0.74	0.92	1.50	0.08	2.41	4.07		22.44	17.65		2.74	
1990	Upper Pecos	30.00	1.47	0.78	2.36	0.12	1.60	1.17		25.03	11.62		2.89	
1991	Beals	42.85	0.89	3.26	5.23	0.26	2.37	2.74		26.64	13.75		6.92	
1991	Brady	31.15	2.53	0.79	4.21	0.21	2.86	4.81		24.02	18.84		3.02	
1991	Colorado	38.18	2.48	0.84	4.02	0.20	3.16	6.67		27.53	22.31		5.32	
1991	Concho	33.32	0.40	1.49	2.37	0.12	2.80	4.88		23.59	16.67		3.84	
1991	Elm	41.61	0.55	2.53	3.59	0.18	2.45	4.78		28.72	15.69		7.15	
1991	Frio	44.19	0.71	4.35	6.25	0.31	2.62	6.24		28.02	20.64		5.79	
1991	Garfield	50.61	0.80	3.98	6.55	0.33	3.64	7.52		32.87	25.03		6.81	
1991	James	50.45	0.60	3.23	4.73	0.24	1.84	4.31		31.27	18.49		7.87	
1991	Lake McQueeny	30.60	0.62	2.31	2.67	0.10	3.03	7.27		25.38	22.95		2.64	
1991	Leon	23.29	0.07	0.20	0.40	0.02	3.63	6.81		29.58	24.31		0.38	
1991	Llano	20.21	0.00	0.31	0.58	0.03	1.86	3.54		22.88	16.93		1.15	
1991	Lower Pecos	36.94	2.73	1.02	4.35	0.22	1.89	2.80		26.49	13.14		4.97	
1991	Medina River	42.90	3.34	0.94	5.27	0.26	3.09	7.51		25.34	23.60		8.91	
1991	Nueces	29.34	0.99	0.86	2.45	0.12	2.33	3.98		25.67	16.22		1.45	
1991	Oak Creek	43.02	1.05	2.67	4.74	0.24	4.06	5.38		27.45	18.22		7.08	
1991	Onion Creek	34.05	0.10	1.72	2.41	0.12	3.92	8.62		26.03	26.64		4.63	
1991	Pinto	21.50	0.48	1.11	1.70	0.09	2.76	4.33		20.10	15.97		1.19	
1991	Plum Creek	20.54	0.51	1.43	2.19	0.11	4.27	7.62		20.57	25.57		0.74	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1991	Rio Grande	20.04	0.23	1.31	1.91	0.10	1.44	1.68		20.04	13.12		0.56	
1991	San Antonio	39.03	0.07	1.44	2.06	0.10	4.04	6.57		27.90	22.50		3.81	
1991	San Marcos	27.69	0.25	2.53	3.21	0.16	3.43	7.65		20.12	25.57		2.27	
1991	San Miguel	41.78	0.00	1.47	2.02	0.10	3.90	6.75		28.45	20.64		3.95	
1991	San Saba	26.76	1.28	0.50	2.09	0.10	2.43	4.32		24.99	15.82		2.76	
1991	Sycamore	31.20	2.88	0.92	4.75	0.24	3.01	3.37		21.49	14.88		4.01	
1991	Turkey	30.65	0.86	0.73	1.75	0.09	2.05	3.16		22.90	15.11		3.52	
1991	Upper Pecos	33.40	1.98	0.71	3.19	0.16	1.78	1.42		25.13	13.25		4.63	
1992	Beals	43.77	3.63	6.56	13.11	0.66	1.65	2.14		28.35	16.01		6.09	
1992	Brady	25.56	4.59	0.87	6.08	0.30	2.53	4.14		23.70	19.90		2.56	
1992	Colorado	32.60	4.82	1.26	6.93	0.35	3.91	6.97		27.91	24.41		4.50	
1992	Concho	33.50	0.96	2.26	5.31	0.28	1.93	3.26		26.15	18.19		4.39	
1992	Elm	44.39	1.51	5.62	9.67	0.48	2.67	3.14		29.44	19.05		8.98	
1992	Frio	44.53	2.89	7.07	13.55	0.68	3.86	5.93		27.67	26.60		6.83	
1992	Garfield	44.31	2.90	5.89	11.18	0.56	3.27	7.88		33.30	27.47		5.41	
1992	James	43.64	1.11	6.68	10.20	0.51	3.20	5.04		31.15	20.19		6.38	
1992	Lake McQueeny	29.02	2.15	3.27	6.21	0.27	4.22	7.92		26.17	26.07		2.98	
1992	Leon	20.95	0.08	0.48	0.63	0.03	5.62	9.55		31.59	31.10		0.44	
1992	Llano	18.20	0.01	0.69	0.76	0.04	2.45	3.34		25.68	17.11		1.23	
1992	Lower Pecos	34.55	5.92	1.36	8.35	0.42	1.81	1.56		26.67	14.77		4.80	
1992	Medina River	40.62	9.77	1.00	11.86	0.59	4.75	8.44		25.01	30.11		7.56	
1992	Nueces	25.45	2.15	1.98	5.85	0.29	2.62	2.49		25.91	19.10		1.83	
1992	Oak Creek	42.29	3.55	5.77	11.83	0.59	2.56	3.18		27.98	20.62		6.64	
1992	Onion Creek	34.98	1.34	4.70	7.14	0.36	3.89	7.71		27.14	27.14		5.53	
1992	Pinto	20.35	1.31	1.71	3.69	0.18	2.60	2.72		20.98	17.74		0.92	
1992	Plum Creek	20.32	1.24	1.70	3.26	0.16	4.12	7.48		22.41	29.10		0.57	
1992	Rio Grande	19.08	0.60	1.55	2.51	0.13	1.16	0.92		21.67	12.73		0.35	
1992	San Antonio	43.01	1.15	6.06	9.44	0.47	5.70	8.68		31.81	29.97		6.03	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1992	San Marcos	26.46	0.44	5.37	6.64	0.33	4.15	7.69		21.76	26.89		1.57	
1992	San Miguel	46.30	0.92	7.32	10.91	0.55	5.76	7.22		33.29	28.11		5.54	
1992	San Saba	26.81	1.79	1.48	3.73	0.19	2.17	3.62		27.11	15.33		3.12	
1992	Sycamore	26.04	5.12	0.97	6.73	0.34	2.45	2.17		21.21	16.42		3.00	
1992	Turkey	26.11	1.51	0.97	3.38	0.17	2.61	2.53		23.57	18.95		2.80	
1992	Upper Pecos	29.03	3.96	0.88	5.58	0.28	1.24	1.48		25.61	13.76		3.96	
1993	Beals	23.09	0.74	4.75	3.88	0.19	0.16	0.17		23.49	9.84		1.30	
1993	Brady	14.57	0.22	0.84	0.38	0.02	1.50	2.39		18.96	15.44		0.45	
1993	Colorado	20.64	1.22	1.01	1.67	0.08	1.56	1.92		23.62	19.52		1.32	
1993	Concho	21.22	0.44	1.58	1.62	0.08	0.51	1.03		21.19	11.81		1.51	
1993	Elm	28.44	0.55	3.28	2.90	0.15	0.34	0.00		27.96	10.98		2.51	
1993	Frio	30.12	1.30	5.52	5.48	0.27	0.87	1.07		26.46	15.55		2.05	
1993	Garfield	28.76	1.17	4.42	4.06	0.20	1.86	2.47		30.00	21.01		1.93	
1993	James	29.36	0.52	3.74	3.31	0.17	0.64	0.79		26.53	14.26		1.98	
1993	Lake McQueeny	18.82	0.68	1.99	1.78	0.08	1.25	1.79		21.79	19.30		1.16	
1993	Leon	12.81	0.03	0.19	0.10	0.01	1.75	2.54		24.93	19.88		0.07	
1993	Llano	10.31	0.00	0.30	0.07	0.00	0.87	1.70		18.77	12.56		0.30	
1993	Lower Pecos	22.85	2.44	1.15	3.23	0.16	0.73	1.54		23.60	10.23		1.72	
1993	Medina River	25.11	3.31	0.98	3.99	0.20	1.42	1.81		22.53	19.52		2.55	
1993	Nueces	15.80	0.29	1.68	0.75	0.04	0.38	0.39		20.73	11.47		0.54	
1993	Oak Creek	24.61	1.07	3.94	3.32	0.17	0.72	0.76		24.19	13.03		1.95	
1993	Onion Creek	19.95	0.04	2.62	1.69	0.08	1.73	2.09		22.49	21.34		1.28	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1993	Pinto	15.31	0.08	1.41	0.89	0.04	0.26	0.01		17.25	10.52		0.77	
1993	Plum Creek	13.09	0.12	1.40	1.09	0.05	2.34	2.49		17.46	22.64		0.35	
1993	Rio Grande	12.03	0.01	1.36	0.72	0.04	0.36	0.74		16.12	9.31		0.27	
1993	San Antonio	25.62	0.22	2.90	2.16	0.11	2.55	2.68		26.26	18.89		1.83	
1993	San Marcos	14.03	0.10	2.04	0.79	0.04	1.78	2.27		15.77	22.26		0.34	
1993	San Miguel	25.81	0.30	3.01	2.23	0.11	2.60	3.27		26.36	17.16		1.10	
1993	San Saba	16.26	0.27	0.76	0.61	0.03	1.06	2.80		22.80	12.30		0.74	
1993	Sycamore	16.46	0.57	0.96	0.90	0.05	0.70	0.22		17.45	11.13		0.82	
1993	Turkey	16.54	0.34	0.73	0.49	0.02	0.49	0.04		15.43	11.22		1.00	
1993	Upper Pecos	18.40	0.71	0.82	0.98	0.05	0.18	0.17		20.99	7.60		1.15	
1994	Beals	32.97	0.66	4.04	4.56	0.23	0.43	0.21		24.75	8.66		2.90	
1994	Brady	20.69	0.69	0.81	1.53	0.08	2.20	1.59		20.27	15.50		1.84	
1994	Colorado	28.73	1.28	0.85	2.22	0.11	2.56	3.44		24.34	19.91		3.26	
1994	Concho	24.46	0.38	1.22	1.45	0.08	1.14	0.57		20.84	12.09		2.13	
1994	Elm	34.00	0.51	2.73	2.70	0.14	1.88	1.12		28.16	14.30		4.08	
1994	Frio	34.06	0.57	4.33	4.67	0.23	2.42	2.26		25.61	20.51		3.04	
1994	Garfield	37.88	0.59	3.19	4.31	0.22	2.59	4.83		30.48	21.13		3.97	
1994	James	36.71	0.44	2.90	3.30	0.16	2.12	2.86		26.37	17.70		3.73	
1994	Lake McQueeny	21.23	0.32	1.65	1.42	0.07	2.44	3.26		21.46	21.07		1.19	
1994	Leon	11.95	0.03	0.14	0.14	0.01	2.99	2.57		24.38	22.63		0.11	
1994	Llano	9.62	0.00	0.15	0.10	0.01	2.10	2.14		17.99	15.93		0.30	
1994	Lower Pecos	26.38	1.89	1.07	3.05	0.15	1.08	0.65		23.19	10.50		2.55	
1994	Medina River	33.94	3.04	0.97	4.34	0.22	2.52	2.73		23.32	22.22		5.00	
1994	Nueces	18.22	0.28	1.34	1.07	0.05	2.06	1.41		21.50	16.64		0.76	
1994	Oak Creek	32.88	0.85	2.89	3.72	0.19	2.10	0.49		24.96	14.70		3.45	
1994	Onion Creek	27.50	0.01	1.96	1.93	0.10	2.65	4.56		24.33	21.17		2.21	
1994	Pinto	14.79	0.09	1.08	0.75	0.04	1.97	1.38		16.78	12.65		0.40	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1994	Plum Creek	14.33	0.19	1.29	1.30	0.07	2.97	4.48		17.52	22.27		0.40	
1994	Rio Grande	12.30	0.05	1.12	0.90	0.04	0.63	0.06		16.23	9.05		0.25	
1994	San Antonio	30.09	0.07	1.88	1.31	0.07	3.57	2.73		26.32	20.58		1.58	
1994	San Marcos	24.55	0.22	2.23	2.65	0.13	2.56	3.84		19.00	21.89		1.67	
1994	San Miguel	32.93	0.01	2.28	1.67	0.08	2.75	1.66		26.71	19.14		1.40	
1994	San Saba	23.47	0.47	0.67	1.19	0.06	1.91	1.98		24.47	13.07		2.23	
1994	Sycamore	20.49	0.96	0.97	1.81	0.09	1.89	1.28		17.84	12.61		2.41	
1994	Turkey	19.78	0.37	0.70	0.72	0.04	2.00	0.84		16.64	16.21		2.18	
1994	Upper Pecos	22.80	0.74	0.77	1.33	0.07	0.21	0.26		21.45	7.05		2.50	
1995	Beals	27.79	0.96	3.97	4.95	0.25	0.24	0.20		25.35	10.16		2.44	
1995	Brady	18.88	0.74	0.75	1.32	0.07	2.01	3.48		21.70	18.87		1.12	
1995	Colorado	23.43	1.65	0.83	2.43	0.12	1.87	4.56		25.81	22.22		1.96	
1995	Concho	20.06	0.40	1.11	1.45	0.08	0.82	1.38		21.02	13.85		1.42	
1995	Elm	26.64	0.49	2.76	2.78	0.14	1.53	3.67		27.87	14.74		2.70	
1995	Frio	27.67	0.78	4.55	4.71	0.24	1.85	4.75		26.62	21.45		1.93	
1995	Garfield	31.13	0.96	4.12	4.43	0.22	1.77	4.44		32.35	25.26		2.43	
1995	James	28.96	0.45	3.37	3.05	0.15	1.69	4.12		27.86	17.40		2.32	
1995	Lake McQueeny	19.11	0.44	1.78	1.74	0.08	1.57	4.60		22.52	22.12		1.06	
1995	Leon	13.09	0.04	0.09	0.13	0.01	2.21	4.77		25.19	24.33		0.07	
1995	Llano	10.75	0.00	0.12	0.11	0.01	1.67	2.87		19.02	14.70		0.35	
1995	Lower Pecos	25.04	2.94	1.08	4.12	0.21	1.14	1.42		25.14	11.17		2.29	
1995	Medina River	29.79	3.93	0.97	4.74	0.24	1.82	5.31		24.69	23.75		4.73	
1995	Nueces	17.87	0.42	0.88	1.17	0.06	1.59	3.03		22.45	14.43		0.63	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1995	Oak Creek	27.16	1.15	3.02	3.98	0.20	1.53	2.26		25.34	16.39		2.68	
1995	Onion Creek	22.56	0.09	2.44	2.60	0.13	1.70	3.90		24.11	24.59		1.57	
1995	Pinto	16.85	0.24	0.94	1.57	0.08	1.62	2.90		18.77	13.12		0.71	
1995	Plum Creek	13.80	0.39	1.30	1.75	0.09	1.75	3.31		18.08	25.06		0.29	
1995	Rio Grande	12.73	0.08	1.05	1.07	0.05	0.56	0.46		17.20	9.87		0.15	
1995	San Antonio	23.87	0.06	1.39	1.32	0.07	2.49	4.50		25.94	24.31		1.06	
1995	San Marcos	18.70	0.20	2.48	2.93	0.15	1.45	3.64		17.47	24.05		1.35	
1995	San Miguel	25.59	0.03	1.87	1.64	0.08	2.54	4.27		25.74	20.44		0.98	
1995	San Saba	19.84	0.58	0.66	1.25	0.06	1.65	2.97		24.74	13.81		1.61	
1995	Sycamore	20.73	1.58	0.93	2.40	0.12	1.44	1.70		20.02	11.22		1.55	
1995	Turkey	20.95	0.62	0.66	0.98	0.05	1.60	2.89		20.01	14.42		1.68	
1995	Upper Pecos	22.54	1.24	0.69	1.81	0.09	0.52	0.50		23.51	8.98		2.01	
1996	Beals	21.84	0.36	2.55	2.47	0.12	0.57	0.98		21.22	8.84		1.02	
1996	Brady	22.58	1.03	0.75	1.93	0.10	1.83	3.46		19.97	15.67		2.26	
1996	Colorado	25.24	1.12	0.78	1.89	0.09	1.63	3.45		22.78	15.17		2.37	
1996	Concho	16.86	0.16	1.01	1.07	0.06	1.59	2.89		17.51	12.21		0.72	
1996	Elm	26.25	0.34	1.24	1.72	0.09	1.16	2.30		25.24	10.41		1.90	
1996	Frio	26.24	0.33	2.90	2.63	0.13	0.90	1.96		23.40	13.54		1.07	
1996	Garfield	27.55	0.32	2.66	2.62	0.13	1.82	3.62		28.27	17.18		1.64	
1996	James	26.68	0.30	1.70	2.33	0.12	1.24	3.01		21.45	13.28		1.52	
1996	Lake McQueeny	16.54	0.21	1.34	1.05	0.04	1.45	3.09		19.47	16.47		0.49	
1996	Leon	11.91	0.03	0.08	0.12	0.01	1.41	1.45		23.32	15.32		0.10	
1996	Llano	10.70	0.00	0.15	0.17	0.01	1.34	2.43		18.33	12.80		0.37	
1996	Lower Pecos	22.50	1.27	1.05	2.40	0.12	1.55	1.95		22.15	10.08		1.65	
1996	Medina River	25.32	1.24	0.99	2.34	0.12	1.18	1.97		20.62	15.21		3.05	
1996	Nueces	19.21	0.38	0.71	1.23	0.06	1.45	2.91		20.63	11.21		0.64	
1996	Oak Creek	23.38	0.45	1.64	2.11	0.11	2.57	4.20		21.30	15.48		1.66	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1996	Onion Creek	19.03	0.07	0.94	1.19	0.06	1.89	2.96		20.26	17.59		1.03	
1996	Pinto	17.42	0.38	0.99	1.68	0.08	1.40	2.27		17.21	9.81		0.72	
1996	Plum Creek	16.08	0.28	1.28	1.94	0.10	2.06	3.21		17.29	17.02		0.81	
1996	Rio Grande	16.80	0.24	1.01	2.08	0.10	0.88	0.60		17.23	9.30		0.63	
1996	San Antonio	15.14	0.01	0.43	0.23	0.01	1.80	1.93		17.79	14.91		0.30	
1996	San Marcos	19.53	0.11	1.76	2.94	0.15	1.82	3.47		14.03	18.49		2.71	
1996	San Miguel	17.85	0.00	0.57	0.26	0.01	0.90	0.99		18.22	11.79		0.13	
1996	San Saba	17.71	0.61	0.46	1.14	0.06	1.34	2.30		21.48	12.09		1.72	
1996	Sycamore	24.91	1.90	0.93	3.24	0.16	1.63	2.36		19.26	8.79		2.79	
1996	Turkey	26.23	0.76	0.68	1.65	0.08	0.86	1.64		19.69	10.34		3.19	
1996	Upper Pecos	27.06	1.19	0.67	2.08	0.10	0.79	0.48		22.89	8.75		3.15	
1997	Beals	39.44	1.40	4.88	8.17	0.41	0.66	0.78		26.23	13.42		6.08	
1997	Brady	23.09	2.52	0.73	3.89	0.19	2.72	4.27		21.89	16.80		2.38	
1997	Colorado	31.59	3.36	0.76	4.73	0.24	3.91	7.48		26.61	24.95		4.00	
1997	Concho	28.23	0.53	1.39	2.23	0.12	1.32	1.99		23.53	15.48		2.55	
1997	Elm	48.46	1.09	4.22	7.40	0.37	2.02	2.26		31.66	17.33		9.52	
1997	Frio	46.79	1.81	6.03	11.33	0.57	2.87	5.68		28.93	24.28		6.52	
1997	Garfield	47.52	1.95	4.86	9.10	0.45	3.53	8.01		33.82	26.68		5.41	
1997	James	44.34	0.70	4.01	6.27	0.31	3.00	5.41		30.57	19.39		5.82	
1997	Lake McQueeny	25.78	0.74	1.76	2.90	0.14	3.65	7.22		24.17	25.15		1.84	
1997	Leon	18.05	0.05	0.17	0.23	0.01	4.28	6.78		27.57	27.28		0.12	
1997	Llano	15.67	0.00	0.19	0.18	0.01	2.21	4.32		21.62	16.39		0.48	
1997	Lower Pecos	35.22	5.19	1.14	7.04	0.35	1.15	1.62		25.43	13.55		5.24	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1997	Medina River	40.90	7.09	0.91	8.73	0.44	3.39	6.52		24.77	26.18		8.59	
1997	Nueces	22.98	1.07	1.35	2.77	0.14	2.51	3.56		23.85	18.40		1.54	
1997	Oak Creek	39.78	1.86	4.26	7.60	0.38	2.32	2.98		26.94	19.22		6.12	
1997	Onion Creek	31.76	0.17	3.79	4.92	0.25	4.34	8.78		25.53	27.17		3.73	
1997	Pinto	20.23	0.63	1.81	2.96	0.15	2.09	2.04		20.26	16.29		1.03	
1997	Plum Creek	18.10	0.56	1.59	2.30	0.11	3.90	7.19		20.37	27.73		0.58	
1997	Rio Grande	17.05	0.19	1.45	1.48	0.07	0.75	0.87		19.71	12.24		0.42	
1997	San Antonio	34.43	0.09	2.03	2.63	0.13	4.34	6.15		28.23	26.59		2.25	
1997	San Marcos	25.77	0.32	5.08	5.63	0.28	4.15	8.68		20.55	27.67		1.76	
1997	San Miguel	37.80	0.00	2.39	2.92	0.15	3.99	5.57		30.01	23.83		2.69	
1997	San Saba	25.29	1.22	0.93	2.34	0.12	2.16	3.05		25.57	14.65		2.66	
1997	Sycamore	27.09	3.50	0.91	5.05	0.25	2.26	2.43		20.59	15.20		3.53	
1997	Turkey	27.47	0.75	0.83	1.78	0.09	2.17	3.04		23.36	16.68		3.40	
1997	Upper Pecos	30.51	2.99	0.73	4.25	0.21	0.32	0.50		25.09	10.40		4.65	
1998	Beals	37.45	1.79	4.81	7.84	0.39	0.15	0.18		24.24	6.16		6.56	
1998	Brady	11.86	0.22	0.77	0.45	0.02	1.72	2.53		17.09	17.02		0.44	
1998	Colorado	24.96	2.02	0.85	3.02	0.15	3.59	7.55		22.15	21.32		4.84	
1998	Concho	29.43	0.78	1.30	2.97	0.16	0.67	1.04		20.48	10.60		6.02	
1998	Elm	41.36	1.29	4.05	6.83	0.34	2.30	4.72		28.18	13.51		8.59	
1998	Frio	44.81	3.05	6.11	11.21	0.56	3.48	7.12		25.74	21.99		8.29	
1998	Garfield	51.04	3.15	5.01	10.41	0.52	3.01	7.56		30.39	20.47		11.44	
1998	James	52.68	1.21	4.53	8.88	0.44	2.51	4.76		26.30	17.87		17.19	
1998	Lake McQueeny	25.02	1.29	1.60	3.39	0.17	3.28	7.23		20.76	21.61		4.73	
1998	Leon	6.57	0.01	0.06	0.06	0.00	4.14	7.81		21.35	24.64		0.03	
1998	Llano	5.78	0.00	0.06	0.05	0.00	2.67	4.84		15.93	15.36		0.14	
1998	Lower Pecos	30.11	4.13	1.11	5.60	0.28	1.53	2.35		23.03	11.00		5.24	
1998	Medina River	36.31	5.51	0.97	7.17	0.36	3.50	7.38		22.26	23.63		7.64	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1998	Nueces	14.52	0.53	0.87	1.20	0.06	3.11	6.98		19.20	15.51		1.02	
1998	Oak Creek	37.83	1.91	4.03	7.19	0.36	0.62	0.98		24.16	10.80		7.84	
1998	Onion Creek	31.60	0.32	3.34	4.67	0.23	3.93	9.02		23.92	23.19		5.42	
1998	Pinto	17.59	0.38	1.62	1.82	0.09	2.50	4.47		16.93	12.53		1.00	
1998	Plum Creek	16.52	0.61	1.60	2.49	0.12	4.00	9.12		17.24	23.14		1.52	
1998	Rio Grande	12.54	0.12	1.14	1.21	0.06	0.80	0.35		15.94	9.06		0.36	
1998	San Antonio	34.81	0.24	2.73	4.28	0.21	4.31	6.84		26.37	23.13		4.35	
1998	San Marcos	30.70	0.49	3.99	6.98	0.35	3.92	9.22		17.41	23.43		5.66	
1998	San Miguel	38.87	0.16	2.92	4.44	0.22	4.37	6.56		27.06	20.86		5.32	
1998	San Saba	18.54	0.19	0.84	1.23	0.06	1.93	2.76		22.22	14.04		2.29	
1998	Sycamore	10.99	0.48	0.96	0.87	0.04	2.99	5.22		14.43	12.73		0.48	
1998	Turkey	10.87	0.18	0.80	0.34	0.02	2.53	5.74		11.37	14.47		0.59	
1998	Upper Pecos	15.62	1.21	0.73	1.62	0.08	0.31	0.48		18.46	5.93		1.74	
1999	Beals	18.85	0.40	4.29	3.05	0.15	0.10	0.08		21.81	6.52		1.28	
1999	Brady	12.39	0.22	0.74	0.43	0.02	1.11	1.36		18.32	13.70		0.36	
1999	Colorado	15.37	0.72	0.95	1.03	0.05	1.13	1.80		21.79	15.70		0.80	
1999	Concho	13.51	0.20	1.47	0.86	0.04	0.50	0.70		17.90	9.85		0.70	
1999	Elm	15.72	0.20	3.57	1.37	0.07	1.70	2.69		22.13	12.75		1.02	
1999	Frio	16.14	0.27	5.65	2.11	0.11	1.37	2.83		21.14	16.10		0.73	
1999	Garfield	17.61	0.28	4.94	1.81	0.09	0.93	2.04		26.76	17.96		1.04	
1999	James	17.82	0.26	4.94	1.57	0.08	1.29	1.92		21.46	12.98		0.91	
1999	Lake McQueeny	13.72	0.37	1.82	1.06	0.05	1.04	2.42		20.26	15.46		0.64	
1999	Leon	8.84	0.01	0.06	0.08	0.00	1.38	2.05		22.86	17.41		0.05	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
1999	Llano	7.19	0.00	0.04	0.04	0.00	1.06	1.51		16.79	11.05		0.20	
1999	Lower Pecos	16.82	1.46	1.03	1.98	0.10	0.63	0.84		21.98	7.77		1.03	
1999	Medina River	19.75	2.40	0.98	2.68	0.13	1.21	2.57		21.41	17.41		2.44	
1999	Nueces	12.71	0.21	0.66	0.65	0.03	1.53	3.20		19.74	11.38		0.34	
1999	Oak Creek	17.77	0.62	3.50	2.18	0.11	0.62	0.57		20.72	12.53		1.45	
1999	Onion Creek	16.12	0.04	2.88	1.40	0.07	1.06	1.60		20.84	17.30		0.96	
1999	Pinto	10.44	0.17	1.27	1.09	0.05	1.47	2.76		15.70	11.56		0.38	
1999	Plum Creek	11.32	0.33	1.59	1.55	0.08	0.79	1.56		16.59	16.58		0.38	
1999	Rio Grande	9.38	0.01	1.05	0.61	0.03	0.26	0.15		15.39	7.24		0.13	
1999	San Antonio	18.13	0.04	2.08	0.91	0.05	1.25	1.94		23.68	16.22		0.72	
1999	San Marcos	17.89	0.18	5.03	3.37	0.17	0.69	1.59		16.39	15.37		1.89	
1999	San Miguel	18.46	0.01	2.15	0.86	0.04	1.51	2.28		22.63	15.03		0.46	
1999	San Saba	16.62	0.23	1.25	1.12	0.06	1.08	1.74		23.51	11.34		1.32	
1999	Sycamore	15.35	0.59	0.88	1.00	0.05	1.63	2.88		17.52	10.02		0.71	
1999	Turkey	15.98	0.31	0.64	0.44	0.02	1.64	2.70		16.26	12.09		0.78	
1999	Upper Pecos	16.67	0.50	0.65	0.77	0.04	0.20	0.13		20.77	6.36		0.85	
2000	Beals	32.99	0.77	2.94	5.93	0.30	0.89	1.01	1.11	21.48	9.59	12.06	3.28	0.18
2000	Brady	14.98	0.25	0.73	0.73	0.04	2.92	4.38	3.01	15.88	13.83	23.35	0.61	3.47
2000	Colorado	23.52	0.96	0.77	1.76	0.09	3.01	5.44	2.50	20.43	18.44	27.28	2.19	4.82
2000	Concho	26.12	0.40	0.94	2.22	0.12	1.67	1.98	1.96	18.94	10.03	14.56	2.56	0.29
2000	Elm	36.45	0.55	2.00	3.95	0.20	2.60	4.47	1.96	25.77	13.04	20.17	5.74	1.77
2000	Frio	37.47	0.56	3.25	6.00	0.30	2.96	5.22	1.87	23.43	16.76	24.37	4.86	3.08
2000	Garfield	39.95	0.57	2.60	4.92	0.25	3.26	7.31	1.45	29.11	20.43	28.70	5.19	10.32
2000	James	40.44	0.51	2.62	4.27	0.21	2.76	4.69	2.99	25.10	17.11	25.17	5.11	4.14
2000	Lake McQueeny	23.26	0.46	1.27	2.21	0.11	3.15	6.56	2.86	20.10	18.45	28.91	1.90	5.52
2000	Leon	12.66	0.03	0.11	0.18	0.01	3.84	6.33	2.39	24.34	18.72	26.15	0.16	6.78

Watersheds (Parameter Values) (continued)

Year	**Watershed**	**Parameter Values (inches)**												
		Precipitation	**SWAT Baseflow**	**SWAT Revap**	**SWAT Total Recharge**	**SWAT Aquifer Deep Recharge**	**SWB Recharge**	**SCS Recharge**	**USGS Recharge**	**SWAT ET**	**SWB ET**	**USGS ET**	**SWAT Runoff**	**USGS Runoff**
2000	Llano	11.22	0.00	0.11	0.21	0.01	2.83	4.96	3.46	17.89	13.64	23.40	0.52	3.26
2000	Lower Pecos	29.27	2.32	1.01	4.23	0.21	1.97	2.10	2.78	22.10	10.45	15.59	3.75	0.17
2000	Medina River	33.51	2.72	0.96	4.61	0.23	3.45	6.04	2.25	21.56	18.53	28.94	4.62	4.57
2000	Nueces	16.85	0.26	0.67	1.33	0.07	3.08	5.67	3.37	17.61	13.91	23.55	0.95	2.54
2000	Oak Creek	33.48	0.92	1.96	5.02	0.25	1.91	1.66	1.49	21.93	10.61	15.34	4.42	0.25
2000	Onion Creek	28.78	0.10	1.39	3.65	0.18	3.24	7.36	2.94	21.04	20.00	29.58	4.01	7.39
2000	Pinto	18.51	0.43	0.99	1.97	0.10	3.00	4.47	3.09	15.49	12.74	20.66	1.24	1.41
2000	Plum Creek	15.81	0.76	1.28	2.68	0.13	3.49	7.68	1.50	16.16	21.52	28.82	0.75	10.92
2000	Rio Grande	12.27	0.09	0.88	1.27	0.06	1.49	0.60	1.24	14.56	8.99	10.48	0.27	0.03
2000	San Antonio	31.69	0.07	1.01	2.40	0.12	4.07	7.23	2.44	23.23	18.78	24.37	1.81	10.16
2000	San Marcos	24.59	0.21	2.75	4.71	0.24	3.16	7.45	2.93	15.27	20.23	30.50	2.83	6.54
2000	San Miguel	32.98	0.00	1.20	2.99	0.15	3.98	5.63	1.64	21.78	18.12	26.95	1.80	4.34
2000	San Saba	18.06	0.31	0.57	0.88	0.04	2.61	3.71	3.84	20.52	12.59	21.11	1.63	1.78
2000	Sycamore	16.55	0.62	0.88	1.33	0.07	3.22	4.06	4.22	14.45	12.48	20.52	0.89	0.28
2000	Turkey	16.49	0.35	0.47	0.95	0.05	2.41	2.77	2.20	12.60	12.55	18.70	1.06	1.43
2000	Upper Pecos	19.06	0.53	0.61	1.07	0.05	0.36	0.22	0.76	17.60	7.25	8.77	1.40	0.08
2001	Beals	32.08	1.71	5.92	8.30	0.41	0.30	0.53	0.71	23.66	7.48	9.22	3.47	0.11
2001	Brady	17.55	0.52	0.70	1.11	0.06	1.57	1.64	3.24	20.31	16.93	19.00	0.66	0.88
2001	Colorado	26.06	2.09	0.88	3.37	0.17	3.41	6.00	3.93	24.58	22.71	28.10	2.63	5.79
2001	Concho	25.08	0.77	1.71	2.83	0.15	0.72	1.13	2.01	20.64	12.05	14.05	3.47	0.22
2001	Elm	40.94	0.85	5.01	7.12	0.36	1.66	2.71	1.88	27.26	15.02	17.69	8.87	0.92
2001	Frio	40.48	1.90	6.64	10.86	0.54	2.65	4.48	1.89	24.93	21.08	22.86	6.67	2.49
2001	Garfield	40.33	1.53	5.06	7.98	0.40	3.63	7.73	1.57	30.37	25.01	29.69	5.52	11.81
2001	James	38.78	0.67	4.62	6.51	0.33	1.84	2.73	3.12	28.31	17.69	22.14	4.72	2.35

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2001	Lake McQueeny	20.11	0.91	1.97	2.85	0.14	3.49	6.92	3.80	21.48	22.55	28.31	1.54	5.60
2001	Leon	9.70	0.02	0.09	0.11	0.01	4.21	7.45	3.58	23.00	25.67	27.12	0.09	7.90
2001	Llano	7.64	0.00	0.15	0.07	0.00	1.27	1.66	2.93	17.60	14.14	17.68	0.20	0.47
2001	Lower Pecos	29.77	4.37	1.13	5.80	0.29	0.57	0.92	1.67	23.62	9.72	12.19	4.72	0.05
2001	Medina River	35.71	6.60	0.97	8.22	0.41	3.50	6.47	2.54	23.38	23.95	28.00	5.84	4.38
2001	Nueces	17.49	0.66	0.79	1.40	0.07	2.02	3.22	3.32	21.18	16.57	21.08	1.06	1.11
2001	Oak Creek	34.12	1.94	4.78	7.43	0.37	1.15	1.64	2.32	24.68	16.46	18.11	4.66	0.75
2001	Onion Creek	26.48	0.29	4.23	3.82	0.19	4.21	7.88	3.99	23.59	24.21	29.50	3.46	8.01
2001	Pinto	14.47	0.17	1.72	1.62	0.08	1.77	2.35	2.85	17.26	14.84	18.03	0.76	0.57
2001	Plum Creek	12.56	0.24	1.56	1.52	0.08	3.95	7.42	1.61	16.60	26.16	28.72	0.56	11.30
2001	Rio Grande	10.40	0.02	0.93	0.62	0.03	0.25	0.40	0.62	15.16	7.32	6.75	0.36	0.01
2001	San Antonio	30.08	0.21	3.52	3.90	0.19	3.90	7.02	3.42	26.75	24.03	24.40	2.43	10.61
2001	San Marcos	24.72	0.35	5.47	5.08	0.25	3.89	8.20	4.10	19.27	23.97	30.25	2.55	6.92
2001	San Miguel	32.62	0.14	4.05	4.58	0.23	3.45	4.91	1.50	27.07	19.91	24.29	1.98	3.34
2001	San Saba	19.19	0.41	0.79	1.14	0.06	1.38	1.35	3.54	23.93	13.99	17.06	1.32	0.10
2001	Sycamore	20.25	1.34	0.85	2.41	0.12	1.75	1.93	3.58	19.20	14.09	18.47	1.10	0.17
2001	Turkey	21.65	0.53	0.56	0.90	0.04	1.94	2.12	2.32	19.71	15.32	18.08	1.52	1.28
2001	Upper Pecos	24.50	1.66	0.59	2.70	0.13	0.10	0.16	0.53	23.00	5.25	6.83	2.41	0.06
2002	Beals	53.29	4.72	5.73	12.52	0.63	1.19	0.99	1.84	25.80	13.43	15.63	14.43	0.52
2002	Brady	25.42	1.27	0.67	2.73	0.14	2.88	4.51	3.53	22.54	17.49	22.72	2.08	3.46
2002	Colorado	32.47	2.71	0.82	4.12	0.21	3.74	8.58	6.11	25.71	20.33	30.71	4.66	7.93
2002	Concho	35.02	1.24	1.59	3.92	0.21	1.79	2.32	3.08	22.18	14.58	17.46	7.64	0.58
2002	Elm	49.42	2.10	4.80	7.75	0.39	2.31	4.76	2.01	28.76	13.86	20.40	13.47	2.04
2002	Frio	50.11	3.96	6.50	12.07	0.60	3.86	8.51	4.71	27.03	22.39	32.19	10.66	7.70
2002	Garfield	49.54	3.80	5.24	10.75	0.54	3.17	8.14	1.51	30.93	20.03	29.07	8.77	11.08
2002	James	49.28	1.71	4.64	8.51	0.43	3.13	6.23	3.41	28.83	15.79	24.23	10.57	3.90
2002	Lake McQueeny	30.42	1.78	1.65	4.12	0.20	3.81	10.07	9.22	23.64	22.29	33.24	4.82	10.45

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2002	Leon	17.38	0.06	0.13	0.22	0.01	4.66	10.63	9.82	27.08	25.78	33.01	0.09	14.43
2002	Llano	15.46	0.00	0.17	0.28	0.01	2.69	4.53	3.73	20.97	15.09	22.34	0.51	2.79
2002	Lower Pecos	33.09	4.41	1.04	5.85	0.29	1.82	2.58	3.06	24.46	11.96	16.80	4.96	0.47
2002	Medina River	41.98	7.23	0.93	8.64	0.43	4.37	10.63	9.64	23.23	25.05	36.67	10.48	11.64
2002	Nueces	21.91	0.87	0.69	1.83	0.09	2.76	5.09	3.76	22.28	16.37	24.18	1.41	2.94
2002	Oak Creek	48.49	3.48	4.88	10.04	0.50	3.18	4.45	3.36	25.61	19.34	23.04	12.65	3.11
2002	Onion Creek	38.96	1.16	3.38	5.55	0.28	3.89	8.61	5.26	25.08	23.24	30.86	9.26	9.12
2002	Pinto	19.50	0.44	0.99	1.78	0.09	1.81	3.53	3.00	18.17	13.31	20.61	1.37	1.62
2002	Plum Creek	17.94	0.48	1.46	2.14	0.11	3.68	9.04	1.84	18.74	23.06	29.95	0.86	12.71
2002	Rio Grande	16.48	0.07	1.03	1.71	0.09	1.04	0.75	1.13	17.61	9.36	9.17	0.76	0.02
2002	San Antonio	51.99	1.67	4.37	9.43	0.47	4.60	8.79	7.73	28.47	24.38	29.10	12.42	16.90
2002	San Marcos	30.57	0.52	4.62	6.31	0.32	4.09	10.16	7.96	20.07	23.93	33.90	5.18	10.48
2002	San Miguel	52.76	1.58	4.96	9.39	0.47	6.04	10.71	5.35	30.02	21.51	35.77	11.14	10.34
2002	San Saba	29.01	0.94	1.02	3.03	0.15	2.40	3.51	4.26	25.34	14.81	20.70	4.44	1.76
2002	Sycamore	29.16	3.01	0.82	4.81	0.24	2.06	2.65	3.52	20.99	12.38	18.93	3.92	0.25
2002	Turkey	29.78	0.93	0.41	1.64	0.08	2.74	6.84	3.85	23.62	15.17	24.42	4.37	3.94
2002	Upper Pecos	31.89	2.49	0.56	3.50	0.17	0.72	0.76	1.55	24.88	10.49	12.52	5.06	0.14
2003	Beals	27.71	1.38	5.47	5.23	0.26	0.54	0.78	1.18	25.93	10.78	12.47	2.05	0.22
2003	Brady	23.41	2.04	0.71	3.25	0.16	2.02	3.39	3.10	22.85	16.53	21.02	2.41	2.07
2003	Colorado	23.63	2.19	0.92	3.08	0.15	1.96	4.06	1.97	25.15	20.62	23.22	2.46	2.92
2003	Concho	22.99	0.70	1.76	2.48	0.13	1.34	2.50	2.92	22.73	14.93	17.48	1.75	0.61
2003	Elm	27.54	0.97	3.62	3.11	0.16	1.29	1.33	1.97	28.67	14.87	17.91	2.53	1.03
2003	Frio	28.08	1.61	6.22	5.29	0.26	1.97	3.77	2.00	27.39	21.37	24.14	1.71	2.90

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2003	Garfield	24.72	1.30	5.07	3.68	0.18	1.18	3.48	0.97	29.46	17.78	19.38	1.96	3.90
2003	James	25.04	1.15	5.29	3.83	0.19	1.83	3.93	3.09	26.07	18.22	22.89	1.84	2.76
2003	Lake McQueeny	20.70	1.06	2.08	2.58	0.12	1.91	4.32	2.22	23.07	22.23	24.36	1.43	2.91
2003	Leon	12.48	0.04	0.13	0.14	0.01	2.44	4.12	1.52	25.57	24.16	21.33	0.09	4.11
2003	Llano	11.50	0.00	0.31	0.23	0.01	1.88	3.43	3.55	20.39	16.63	21.70	0.43	2.19
2003	Lower Pecos	23.19	3.03	1.12	4.05	0.20	1.71	3.10	3.94	24.29	13.46	19.26	1.82	0.81
2003	Medina River	26.30	4.57	0.96	5.25	0.26	2.01	4.30	1.76	22.83	24.26	25.34	3.63	3.03
2003	Nueces	20.50	0.77	0.94	1.77	0.09	2.01	2.99	3.54	23.96	17.70	22.39	0.71	1.88
2003	Oak Creek	27.38	1.69	4.70	4.67	0.23	1.93	3.22	2.64	25.63	17.20	19.89	2.55	1.13
2003	Onion Creek	25.66	0.42	3.74	3.39	0.17	1.45	3.34	1.26	25.60	19.27	20.21	1.75	2.19
2003	Pinto	21.42	0.87	1.63	2.80	0.14	1.80	2.33	2.96	20.83	14.45	18.79	1.30	0.88
2003	Plum Creek	21.39	1.20	1.56	3.43	0.17	1.39	3.19	0.97	21.55	19.45	19.28	1.02	4.06
2003	Rio Grande	20.57	0.28	1.37	2.29	0.11	0.87	1.29	1.75	21.22	9.75	12.06	1.02	0.08
2003	San Antonio	27.37	0.51	5.03	3.07	0.15	3.33	5.04	1.73	29.25	25.41	21.03	1.53	7.42
2003	San Marcos	24.29	0.28	4.22	3.68	0.18	1.73	4.12	1.76	20.56	22.26	23.52	1.91	2.56
2003	San Miguel	27.43	0.61	4.81	3.34	0.17	2.82	4.51	1.62	29.65	22.98	25.69	1.07	3.94
2003	San Saba	21.76	1.03	1.33	1.90	0.10	1.65	2.81	4.04	25.23	14.63	19.51	1.98	0.94
2003	Sycamore	21.49	2.29	0.87	3.18	0.16	2.27	2.54	4.51	20.00	14.98	21.02	2.62	0.74
2003	Turkey	20.44	0.57	0.46	0.80	0.04	1.38	1.20	2.32	20.39	14.49	17.59	1.88	1.16
2003	Upper Pecos	21.05	1.44	0.63	1.90	0.09	0.48	0.81	1.29	23.28	8.94	11.34	2.02	0.13
2004	Beals	49.49	4.67	4.85	11.18	0.56	3.20	3.50	3.37	29.45	14.79	20.68	7.08	1.78
2004	Brady	34.21	3.87	0.68	5.78	0.29	3.61	6.20	5.56	24.39	20.32	26.70	3.49	6.84
2004	Colorado	41.07	4.08	0.78	5.94	0.30	3.83	8.34	7.38	27.65	23.48	30.75	5.89	8.73
2004	Concho	39.32	1.22	1.96	4.52	0.23	3.43	4.97	4.78	26.84	18.92	23.99	4.69	4.59
2004	Elm	53.67	1.85	3.31	7.46	0.37	3.10	5.67	4.26	31.87	18.71	26.07	12.04	5.28
2004	Frio	51.33	3.07	5.13	10.99	0.55	4.47	8.17	5.49	28.53	25.82	31.60	8.77	7.85
2004	Garfield	54.35	2.79	3.81	9.57	0.48	3.25	9.30	1.82	33.29	22.46	31.95	8.10	14.80

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2004	James	54.02	1.23	3.45	7.58	0.38	2.49	5.52	4.51	31.80	21.01	25.57	9.69	5.19
2004	Lake McQueeny	36.73	1.86	1.82	5.28	0.20	4.01	9.22	9.11	26.92	25.47	32.28	3.79	9.98
2004	Leon	25.13	0.09	0.20	0.54	0.03	5.70	10.44	9.66	28.51	28.38	31.81	0.49	13.29
2004	Llano	22.30	0.00	0.37	0.83	0.04	3.10	5.98	6.09	22.92	20.21	26.05	1.47	6.46
2004	Lower Pecos	40.26	5.01	1.11	7.23	0.36	4.18	6.55	7.53	26.65	18.75	25.68	5.78	5.49
2004	Medina River	45.06	6.50	0.91	8.41	0.42	4.58	9.50	8.10	25.40	28.22	34.32	9.35	9.66
2004	Nueces	33.04	1.70	1.40	5.68	0.28	3.62	6.83	6.80	25.33	20.18	27.68	2.17	6.57
2004	Oak Creek	47.96	3.14	4.01	9.17	0.46	4.70	6.02	4.65	28.74	21.39	26.44	8.10	6.05
2004	Onion Creek	43.27	1.58	3.83	7.75	0.39	4.06	9.95	8.03	29.17	23.99	31.97	5.54	11.40
2004	Pinto	39.36	4.18	2.19	10.58	0.53	3.53	7.06	6.12	22.78	19.49	26.79	3.60	5.98
2004	Plum Creek	36.66	4.37	1.72	8.47	0.42	3.76	10.05	2.38	24.72	23.41	31.33	2.43	14.90
2004	Rio Grande	34.63	2.23	1.75	7.08	0.35	2.78	3.34	5.41	24.68	17.15	20.92	1.89	1.78
2004	San Antonio	43.59	0.95	2.95	4.69	0.23	5.09	8.35	6.65	32.09	23.36	27.36	4.18	14.65
2004	San Marcos	38.32	1.25	5.45	9.97	0.50	4.40	10.66	9.95	22.69	25.85	33.90	4.50	11.43
2004	San Miguel	48.67	1.07	3.21	5.55	0.28	5.89	7.98	4.09	32.94	24.31	32.96	5.18	8.26
2004	San Saba	34.21	2.03	1.69	5.00	0.25	3.27	5.43	5.54	26.60	17.26	24.22	4.55	5.20
2004	Sycamore	30.64	3.40	0.82	5.09	0.25	4.73	7.11	8.10	21.10	20.01	27.37	3.30	6.44
2004	Turkey	31.17	1.00	0.50	2.09	0.10	3.39	5.98	5.77	23.06	18.16	26.04	3.28	5.34
2004	Upper Pecos	36.44	2.85	0.57	4.32	0.22	3.43	3.44	4.69	25.79	15.98	21.42	5.05	1.85
2005	Beals	24.28	1.27	4.87	4.52	0.23	1.75	1.88	1.90	23.63	12.58	16.06	1.38	0.60
2005	Brady	27.17	3.94	0.83	4.71	0.24	1.93	3.25	3.08	23.43	14.76	20.32	4.05	1.51
2005	Colorado	25.21	3.19	1.03	4.08	0.20	1.86	3.07	1.50	25.41	17.25	20.85	2.91	1.91
2005	Concho	18.22	0.61	2.31	2.10	0.11	1.97	3.17	3.44	20.72	15.57	19.99	1.04	1.42

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2005	Elm	23.45	1.11	4.44	3.30	0.16	1.82	3.27	1.78	25.57	12.06	17.55	2.06	0.92
2005	Frio	23.12	1.72	6.60	5.18	0.26	2.04	3.76	1.55	23.65	17.94	21.15	1.35	1.60
2005	Garfield	22.90	1.22	5.35	3.69	0.18	1.75	2.75	0.96	28.50	15.93	19.14	1.34	3.71
2005	James	23.24	1.02	5.40	3.64	0.18	1.48	2.59	2.76	24.51	14.17	18.86	1.13	0.33
2005	Lake McQueeny	20.22	1.16	2.82	3.57	0.12	1.80	3.65	1.76	23.50	18.16	22.71	1.10	1.74
2005	Leon	17.07	0.07	0.38	0.43	0.02	1.95	2.60	1.21	30.01	18.21	19.22	0.20	2.80
2005	Llano	16.42	0.00	0.68	0.59	0.03	1.95	3.23	3.38	24.73	15.00	20.61	0.73	1.44
2005	Lower Pecos	20.85	2.88	1.32	3.70	0.19	1.59	2.52	3.19	23.90	12.08	17.27	1.27	0.34
2005	Medina River	23.97	4.35	1.00	4.88	0.24	1.72	3.24	1.26	22.19	18.64	21.83	2.51	1.61
2005	Nueces	23.61	1.87	2.01	4.53	0.23	2.29	3.81	3.15	24.95	15.29	21.40	0.99	1.30
2005	Oak Creek	24.31	1.72	4.65	4.47	0.22	2.22	3.42	2.76	23.56	16.21	21.40	1.91	2.04
2005	Onion Creek	22.30	0.74	4.30	3.73	0.19	1.48	2.06	1.06	23.84	16.89	18.82	1.31	1.79
2005	Pinto	19.25	1.66	2.64	3.75	0.19	2.01	4.22	2.97	20.60	11.45	19.71	0.64	1.16
2005	Plum Creek	20.74	1.99	2.14	4.03	0.20	1.96	2.74	0.99	21.29	18.69	19.89	0.96	4.32
2005	Rio Grande	18.56	0.88	2.23	2.98	0.15	0.97	0.82	1.56	20.41	10.07	11.63	0.67	0.04
2005	San Antonio	18.42	0.52	3.51	2.59	0.13	2.31	3.45	1.19	22.67	16.06	16.79	1.06	4.04
2005	San Marcos	22.71	0.63	5.89	5.27	0.26	1.61	3.04	1.41	18.54	18.28	21.62	1.86	1.50
2005	San Miguel	20.00	0.61	3.96	2.49	0.12	2.42	2.63	1.04	22.88	14.34	19.78	0.55	1.70
2005	San Saba	21.82	1.73	1.82	3.02	0.15	2.30	3.68	4.05	24.65	13.68	20.60	2.45	1.60
2005	Sycamore	24.46	3.78	0.89	4.63	0.23	2.68	3.72	3.97	20.11	11.72	19.87	3.75	0.24
2005	Turkey	23.61	0.79	0.62	1.19	0.06	2.11	3.17	2.29	22.61	13.03	18.58	2.87	1.45
2005	Upper Pecos	22.11	2.12	0.72	2.68	0.13	1.24	1.35	2.08	23.51	11.96	15.14	2.57	0.34
2006	Beals	20.38	0.24	3.52	1.84	0.09	0.89	0.90	1.41	21.15	10.23	13.79	0.68	0.31
2006	Brady	17.67	0.75	0.82	1.33	0.07	1.48	1.99	2.36	19.72	13.60	17.72	1.10	0.53
2006	Colorado	20.65	0.77	0.91	1.31	0.07	1.72	3.78	1.45	21.89	15.81	22.85	1.51	2.54
2006	Concho	15.29	0.15	1.40	0.53	0.03	0.92	1.32	1.83	16.20	10.29	14.09	0.85	0.16
2006	Elm	20.13	0.17	1.84	0.92	0.05	0.17	0.07	0.71	22.27	8.19	9.86	1.16	0.05

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2006	Frio	20.42	0.15	3.08	1.39	0.07	0.61	1.35	1.00	20.15	12.01	15.33	0.72	0.32
2006	Garfield	23.03	0.19	1.82	0.93	0.05	1.52	4.54	1.15	25.65	16.72	23.07	1.30	5.80
2006	James	24.45	0.21	1.86	0.99	0.05	1.65	3.63	2.63	19.98	13.93	20.59	1.24	0.82
2006	Lake McQueeny	15.53	0.12	1.63	0.87	0.03	1.31	3.17	1.52	18.81	15.78	21.96	0.37	1.33
2006	Leon	14.84	0.04	0.25	0.21	0.01	1.22	1.81	0.92	25.84	14.61	16.85	0.16	2.03
2006	Llano	13.69	0.00	0.38	0.27	0.01	1.15	1.92	2.34	20.45	11.71	16.92	0.51	0.16
2006	Lower Pecos	21.96	1.07	1.18	2.02	0.10	0.60	0.74	1.48	22.04	9.20	12.00	1.84	0.04
2006	Medina River	26.43	1.70	1.02	2.57	0.13	0.93	1.80	1.05	21.19	15.16	19.50	3.21	0.85
2006	Nueces	16.24	0.29	2.01	1.04	0.05	0.64	0.97	1.37	20.30	10.87	14.45	0.57	0.09
2006	Oak Creek	22.04	0.40	2.29	1.69	0.08	1.50	2.47	1.89	21.04	12.31	17.42	1.50	0.42
2006	Onion Creek	17.52	0.02	1.91	0.90	0.04	1.43	3.87	1.14	19.32	15.74	21.64	0.94	2.86
2006	Pinto	14.23	0.05	2.43	0.87	0.04	0.26	0.21	0.88	16.92	8.38	10.06	0.42	0.05
2006	Plum Creek	11.92	0.06	1.99	0.84	0.04	1.57	3.80	1.07	16.91	18.02	21.34	0.20	5.08
2006	Rio Grande	11.32	0.01	1.99	0.63	0.03	0.23	0.16	0.71	16.18	7.29	7.49	0.15	0.01
2006	San Antonio	16.45	0.01	0.88	0.15	0.01	1.64	2.30	0.91	16.67	14.00	15.44	0.38	3.53
2006	San Marcos	13.08	0.01	3.47	0.71	0.04	1.21	3.03	1.19	13.97	15.18	20.78	0.52	1.28
2006	San Miguel	17.70	0.00	1.10	0.14	0.01	0.69	0.81	0.71	16.48	9.73	13.88	0.12	0.41
2006	San Saba	14.50	0.59	0.76	0.93	0.05	0.96	1.43	2.21	20.11	10.72	14.78	1.19	0.08
2006	Sycamore	17.18	0.79	0.91	1.37	0.07	0.58	0.48	1.16	16.56	9.34	11.75	1.42	0.02
2006	Turkey	18.55	0.39	0.40	0.62	0.03	0.28	0.15	0.90	15.49	8.12	10.04	1.69	0.03
2006	Upper Pecos	20.31	0.61	0.69	1.06	0.05	0.65	0.51	1.24	20.61	8.43	11.65	1.70	0.10
2007	Beals	52.98	3.26	5.39	12.99	0.65	2.11	3.28	3.15	28.88	16.90	20.50	10.15	1.68
2007	Brady	37.34	4.92	0.75	6.45	0.32	3.88	7.03	6.67	24.72	20.90	27.58	7.63	7.77

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2007	Colorado	41.54	4.82	0.89	6.55	0.33	4.78	9.69	10.07	29.02	24.69	32.05	7.74	10.52
2007	Concho	37.52	1.17	1.87	4.45	0.23	2.13	3.66	4.33	26.63	18.11	22.31	5.68	3.08
2007	Elm	52.26	1.47	4.46	9.10	0.46	3.06	6.27	4.30	32.10	17.69	24.96	11.12	4.77
2007	Frio	49.56	1.90	5.86	12.66	0.63	4.61	8.85	6.18	29.64	25.43	31.71	7.62	8.25
2007	Garfield	49.43	1.94	4.82	9.94	0.50	4.12	9.83	2.06	35.16	26.41	32.95	6.25	16.52
2007	James	47.32	0.86	4.47	7.69	0.38	3.84	8.18	7.32	33.07	20.94	29.07	7.75	8.21
2007	Lake McQueeny	34.06	1.74	2.16	5.22	0.23	4.49	9.72	9.79	26.97	25.35	32.79	4.29	10.43
2007	Leon	25.47	0.11	0.51	0.77	0.04	6.13	10.77	11.42	31.68	26.57	32.21	0.62	14.64
2007	Llano	22.01	0.02	0.59	0.76	0.04	3.59	8.01	6.68	26.17	18.92	27.17	1.41	7.31
2007	Lower Pecos	40.67	6.60	1.20	8.92	0.45	2.74	4.86	5.69	27.96	16.53	23.01	5.49	3.44
2007	Medina River	51.95	9.88	0.89	11.98	0.60	5.17	10.25	9.72	26.21	28.17	35.26	13.86	11.08
2007	Nueces	29.38	2.13	1.85	5.18	0.26	4.06	8.76	7.30	25.40	20.16	28.04	2.19	6.95
2007	Oak Creek	49.27	3.11	4.75	11.32	0.57	3.71	7.31	5.51	28.91	20.93	26.93	9.37	6.73
2007	Onion Creek	45.99	1.55	4.42	9.09	0.45	4.59	8.96	7.60	29.14	27.02	31.33	8.57	11.07
2007	Pinto	32.60	2.91	2.35	7.52	0.38	3.77	8.79	7.29	21.96	18.17	27.53	3.69	6.86
2007	Plum Creek	30.14	3.41	1.84	6.73	0.34	3.53	7.62	2.04	23.33	26.18	30.71	2.36	14.06
2007	Rio Grande	24.33	0.86	1.86	3.92	0.20	1.56	1.11	2.69	22.14	14.84	15.37	1.24	0.26
2007	San Antonio	49.73	0.86	4.31	8.16	0.41	5.52	9.77	8.47	33.02	23.00	27.84	8.38	16.11
2007	San Marcos	39.48	0.79	5.16	9.73	0.49	4.52	9.76	9.01	23.94	27.07	32.77	5.52	10.26
2007	San Miguel	55.29	0.78	5.38	9.66	0.48	6.79	9.48	6.50	35.26	24.94	35.12	9.61	10.76
2007	San Saba	35.53	2.32	1.27	4.27	0.21	3.39	6.33	6.02	27.50	17.72	25.49	6.20	6.13
2007	Sycamore	38.08	5.06	0.82	6.80	0.34	5.22	9.45	9.79	21.99	17.92	28.75	9.33	7.83
2007	Turkey	35.48	1.09	0.51	1.91	0.10	2.67	5.44	5.42	26.09	17.81	24.76	6.98	4.67
2007	Upper Pecos	37.26	3.39	0.60	4.56	0.23	1.22	1.35	2.51	26.52	13.71	16.54	7.62	0.54
2008	Beals	15.53	0.15	4.66	1.40	0.07	0.71	0.59	1.05	19.56	9.26	11.57	0.49	0.17
2008	Brady	24.05	1.92	0.81	2.67	0.13	1.21	0.83	2.59	22.66	13.24	18.10	3.21	0.51
2008	Colorado	19.72	1.03	0.85	1.56	0.08	0.68	0.62	0.79	22.74	12.07	14.58	1.66	0.49

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2008	Concho	14.02	0.12	1.67	1.28	0.06	0.98	0.94	2.12	16.09	12.82	15.18	0.68	0.22
2008	Elm	13.95	0.07	2.95	0.59	0.03	0.78	0.66	0.88	20.29	8.39	11.21	0.51	0.06
2008	Frio	14.99	0.09	4.68	1.02	0.05	0.68	0.95	0.91	19.28	11.61	14.44	0.38	0.26
2008	Garfield	16.30	0.13	3.07	0.89	0.04	0.40	0.33	0.66	24.07	12.47	13.21	0.80	1.10
2008	James	17.59	0.13	2.70	0.91	0.05	0.47	0.38	1.02	18.76	9.77	12.41	0.74	0.01
2008	Lake McQueeny	15.38	0.20	1.79	1.01	0.03	0.51	0.89	0.86	19.56	12.10	14.97	0.71	0.25
2008	Leon	10.57	0.02	0.24	0.15	0.01	0.98	1.47	0.75	24.27	13.65	14.13	0.09	1.45
2008	Llano	11.48	0.00	0.32	0.28	0.01	0.75	0.62	1.50	19.26	10.21	13.43	0.47	0.06
2008	Lower Pecos	16.76	1.17	1.27	2.00	0.10	1.04	1.52	2.10	21.16	9.15	14.29	0.97	0.10
2008	Medina River	14.82	0.60	1.00	0.98	0.05	0.81	1.16	0.83	18.71	13.66	16.50	1.02	0.56
2008	Nueces	16.00	0.26	1.85	1.02	0.05	0.68	0.70	1.02	21.20	9.00	12.29	0.32	0.03
2008	Oak Creek	14.93	0.21	3.64	1.02	0.05	1.74	1.00	2.49	18.56	17.58	20.36	0.80	1.16
2008	Onion Creek	15.46	0.09	3.34	1.08	0.05	0.73	0.58	0.77	19.00	13.93	15.07	1.02	1.01
2008	Pinto	15.77	0.31	2.33	1.55	0.08	1.14	0.96	1.32	16.92	8.69	12.71	1.13	0.07
2008	Plum Creek	15.56	0.64	1.91	2.25	0.11	0.58	0.68	0.69	17.24	13.43	13.80	1.11	1.44
2008	Rio Grande	15.24	0.29	1.89	1.93	0.10	0.84	0.93	1.61	16.52	8.60	11.98	1.04	0.05
2008	San Antonio	18.03	0.01	2.80	0.48	0.02	0.93	1.38	0.68	20.64	12.94	12.02	0.84	2.16
2008	San Marcos	12.04	0.03	4.26	1.22	0.06	0.60	1.16	0.79	13.00	13.11	15.33	0.67	0.38
2008	San Miguel	18.11	0.00	3.16	0.63	0.03	1.46	2.05	0.96	19.31	14.76	18.57	0.38	1.35
2008	San Saba	17.97	1.12	0.78	1.57	0.08	1.08	0.99	2.51	22.11	11.09	15.54	2.31	0.07
2008	Sycamore	23.17	2.40	0.96	3.22	0.16	1.48	1.60	1.65	20.27	8.37	13.87	3.26	0.03
2008	Turkey	23.63	0.76	0.39	1.02	0.05	0.75	0.90	1.29	21.43	8.61	11.92	3.42	0.04
2008	Upper Pecos	22.15	1.08	0.66	1.57	0.08	0.68	0.63	1.26	22.97	8.77	11.57	2.70	0.13

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2009	Beals	27.37	0.41	2.40	3.83	0.19	0.79	1.40	1.68	20.88	11.97	15.41	2.26	0.52
2009	Brady	24.49	1.27	0.75	1.95	0.10	2.61	5.48	3.27	22.65	16.98	24.87	1.76	4.54
2009	Colorado	26.89	1.19	0.77	2.11	0.11	2.85	5.96	2.57	23.48	17.90	27.86	2.48	5.07
2009	Concho	23.89	0.27	1.54	1.77	0.09	1.17	2.02	3.04	18.70	15.70	18.73	2.55	0.91
2009	Elm	33.06	0.47	1.63	3.35	0.17	0.94	1.86	1.24	24.26	9.03	13.43	5.04	0.12
2009	Frio	35.42	0.51	2.61	6.31	0.32	1.86	3.57	1.50	22.19	15.23	21.68	4.01	1.73
2009	Garfield	37.56	0.58	2.03	6.08	0.30	2.63	6.46	1.27	27.24	18.94	25.49	4.26	7.67
2009	James	36.01	0.43	1.47	4.28	0.21	2.39	5.00	2.90	21.27	16.51	24.60	4.59	3.49
2009	Lake McQueeny	21.95	0.29	1.19	1.77	0.08	2.23	4.84	1.97	20.29	17.33	26.58	1.48	3.93
2009	Leon	15.57	0.05	0.18	0.20	0.01	2.69	4.75	1.48	25.94	16.82	23.78	0.15	5.26
2009	Llano	15.08	0.00	0.35	0.32	0.02	1.97	4.28	3.19	21.28	14.80	21.72	0.80	1.97
2009	Lower Pecos	31.77	3.01	1.18	5.09	0.25	1.12	1.66	2.67	23.57	12.42	16.02	3.95	0.15
2009	Medina River	32.88	2.42	0.98	4.15	0.21	1.99	4.14	1.47	21.20	16.64	25.04	4.76	2.62
2009	Nueces	22.94	0.42	1.51	1.37	0.07	1.43	2.30	2.05	23.24	12.68	17.60	0.89	0.23
2009	Oak Creek	29.64	0.70	1.75	3.77	0.19	1.63	2.77	2.54	21.32	17.40	21.01	3.46	1.61
2009	Onion Creek	26.50	0.08	2.17	2.85	0.14	2.95	6.93	2.11	21.84	19.55	28.40	2.78	6.36
2009	Pinto	20.52	0.34	2.12	1.76	0.09	1.19	1.45	1.69	20.33	10.51	14.26	0.89	0.12
2009	Plum Creek	17.32	0.27	1.89	1.46	0.07	2.70	6.68	1.32	20.31	17.59	26.22	0.43	8.46
2009	Rio Grande	16.82	0.10	1.80	1.22	0.06	0.73	0.97	1.51	19.81	10.59	11.71	0.41	0.04
2009	San Antonio	24.02	0.03	0.69	1.23	0.06	3.03	5.25	1.48	19.94	16.22	22.60	1.05	8.26
2009	San Marcos	17.46	0.07	1.64	1.64	0.08	2.80	6.89	2.20	14.84	18.48	29.01	1.23	5.36
2009	San Miguel	27.68	0.00	1.03	1.88	0.09	3.27	5.15	1.36	18.94	15.88	25.21	1.31	3.54
2009	San Saba	20.89	0.98	0.41	1.46	0.07	1.92	3.81	3.88	22.74	14.59	21.05	1.69	1.72
2009	Sycamore	24.48	1.72	0.88	2.53	0.13	1.17	1.10	1.45	20.18	9.69	13.04	2.00	0.03
2009	Turkey	25.05	0.60	0.37	0.90	0.05	1.08	1.66	1.58	20.87	9.38	13.35	2.02	0.10
2009	Upper Pecos	25.78	1.08	0.59	1.70	0.08	0.39	0.45	1.48	23.17	10.36	12.75	2.25	0.17

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2010	Beals	34.31	1.42	5.32	8.76	0.44	1.79	2.45	2.03	24.39	14.77	17.14	4.89	0.77
2010	Brady	30.88	4.66	0.78	5.96	0.30	2.12	3.61	3.09	23.65	15.90	21.38	4.47	2.29
2010	Colorado	32.27	3.78	0.93	5.16	0.26	2.58	5.11	2.97	26.34	21.26	26.47	5.07	4.68
2010	Concho	27.77	0.78	2.34	4.30	0.22	1.89	3.41	3.31	22.05	16.10	19.01	4.17	0.91
2010	Elm	37.70	0.82	4.56	6.61	0.33	2.23	1.92	1.90	28.06	13.90	17.52	7.59	0.95
2010	Frio	35.39	1.82	6.73	9.93	0.50	2.42	4.44	1.99	25.11	21.15	24.47	5.35	3.00
2010	Garfield	37.88	2.08	5.21	7.67	0.38	2.13	5.04	1.16	30.94	21.56	23.28	5.45	6.31
2010	James	37.88	0.73	5.38	6.77	0.34	1.90	4.89	3.05	29.22	15.91	22.88	6.29	2.59
2010	Lake McQueeny	24.75	1.28	2.39	4.15	0.18	2.36	5.55	3.04	24.17	22.05	27.61	2.51	4.89
2010	Leon	18.79	0.07	0.29	0.42	0.02	3.54	6.24	3.28	29.02	26.25	26.90	0.35	7.69
2010	Llano	16.93	0.01	0.42	0.44	0.02	1.73	3.40	3.32	23.39	13.66	19.59	0.76	0.88
2010	Lower Pecos	29.90	4.81	1.24	6.08	0.30	1.95	3.41	3.43	24.59	11.30	17.66	4.50	0.25
2010	Medina River	31.95	6.05	0.97	7.33	0.37	3.00	6.20	2.65	22.81	25.02	29.31	6.36	4.92
2010	Nueces	23.00	1.33	1.82	3.93	0.20	1.99	3.01	3.11	23.21	15.65	20.38	1.17	0.76
2010	Oak Creek	32.79	1.79	4.52	7.04	0.35	3.43	5.75	3.16	24.33	21.36	24.84	5.24	4.30
2010	Onion Creek	29.02	0.64	4.43	5.55	0.28	2.98	6.30	3.14	23.81	24.28	28.55	4.34	6.93
2010	Pinto	21.12	1.68	2.25	5.07	0.25	2.75	3.68	3.19	18.28	14.63	20.57	1.55	1.67
2010	Plum Creek	19.81	1.61	1.83	4.20	0.21	2.57	5.08	1.30	19.08	24.70	25.43	1.28	8.16
2010	Rio Grande	18.82	0.93	1.88	3.56	0.18	1.38	2.33	2.12	18.19	9.48	13.77	1.16	0.16
2010	San Antonio	33.46	0.43	3.76	5.16	0.26	3.59	6.48	2.97	28.32	24.71	24.30	4.21	10.37
2010	San Marcos	22.69	0.26	4.37	4.99	0.25	2.83	6.34	3.09	18.21	23.95	29.11	1.58	5.87
2010	San Miguel	35.00	0.34	4.61	6.16	0.31	3.92	5.78	1.92	28.82	21.72	28.66	4.18	5.17
2010	San Saba	25.55	2.04	0.97	3.29	0.16	1.99	3.45	3.84	24.94	12.87	18.69	3.12	0.45
2010	Sycamore	28.89	4.39	0.90	5.87	0.29	2.96	3.54	4.18	20.60	13.51	20.14	4.28	0.56

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2010	Turkey	28.52	0.95	0.63	1.80	0.09	2.20	3.59	2.48	23.51	14.15	18.90	3.73	1.59
2010	Upper Pecos	31.95	3.10	0.64	4.17	0.21	1.70	1.80	2.19	25.26	12.49	15.91	5.11	0.47
2011	Beals	13.66	0.05	3.94	1.39	0.07	0.09	0.13	0.35	15.69	4.26	5.70	0.56	0.05
2011	Brady	9.37	0.15	0.82	0.39	0.02	0.72	1.72	1.09	15.84	8.24	11.84	0.62	0.04
2011	Colorado	13.32	0.39	0.86	0.79	0.04	1.17	2.35	0.74	18.06	9.06	14.25	1.06	0.48
2011	Concho	11.93	0.14	1.64	0.64	0.03	0.31	1.05	0.71	13.58	6.16	8.51	1.00	0.05
2011	Elm	15.86	0.07	2.79	0.95	0.05	0.62	0.61	0.81	18.94	8.93	10.87	1.16	0.06
2011	Frio	16.18	0.08	4.96	1.78	0.09	1.11	1.91	0.88	16.34	10.30	13.97	0.83	0.19
2011	Garfield	19.18	0.18	4.04	1.69	0.08	1.66	4.24	0.79	22.79	9.18	15.71	1.46	2.12
2011	James	20.59	0.12	3.36	1.76	0.09	0.71	1.01	0.71	15.75	7.59	10.40	1.53	0.01
2011	Lake McQueeny	10.85	0.16	1.41	0.70	0.03	1.17	2.02	0.82	15.29	10.41	15.21	0.49	0.35
2011	Leon	5.57	0.00	0.09	0.04	0.00	2.06	2.73	0.88	19.96	11.02	15.91	0.02	1.85
2011	Llano	5.00	0.00	0.19	0.04	0.00	0.64	1.29	1.05	14.19	8.10	11.51	0.14	0.03
2011	Lower Pecos	12.71	0.53	1.22	1.24	0.06	0.30	0.84	0.61	16.90	4.95	7.22	1.05	0.03
2011	Medina River	15.03	0.48	1.06	1.05	0.05	1.31	1.71	0.73	15.22	10.32	14.88	1.37	0.34
2011	Nueces	8.80	0.03	1.43	0.42	0.02	0.78	1.46	1.06	16.26	9.83	12.92	0.33	0.06
2011	Oak Creek	15.23	0.15	2.54	1.33	0.07	0.43	1.14	0.65	15.91	7.56	10.24	1.16	0.05
2011	Onion Creek	13.51	0.00	1.95	0.79	0.04	1.67	4.12	0.87	15.79	10.75	16.91	1.37	1.25
2011	Pinto	7.25	0.00	2.06	0.36	0.02	0.57	0.91	1.04	11.43	8.78	10.99	0.44	0.05
2011	Plum Creek	7.50	0.00	1.86	0.75	0.04	1.75	4.47	0.81	13.01	11.04	16.23	0.47	2.50
2011	Rio Grande	4.90	0.00	1.79	0.25	0.01	0.13	0.03	0.25	11.42	3.98	3.53	0.11	0.01
2011	San Antonio	15.20	0.02	1.72	0.56	0.03	2.19	3.36	0.85	16.28	10.35	14.34	0.59	3.01
2011	San Marcos	14.26	0.02	1.43	1.36	0.07	1.47	3.31	0.91	12.49	11.59	17.43	1.17	0.64
2011	San Miguel	15.94	0.03	2.45	0.80	0.04	1.51	2.01	0.73	13.97	9.01	14.15	0.51	0.39
2011	San Saba	11.14	0.11	0.49	0.39	0.02	0.55	1.42	1.02	18.73	6.75	10.04	0.82	0.02
2011	Sycamore	9.72	0.40	0.96	0.72	0.04	0.88	1.69	1.32	12.99	8.42	12.55	0.76	0.03
2011	Turkey	9.66	0.17	0.43	0.34	0.02	0.85	1.66	1.26	9.36	9.43	11.94	0.95	0.04

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2011	Upper Pecos	10.79	0.24	0.66	0.49	0.02	0.04	0.04	0.28	16.10	3.12	4.24	0.99	0.04
2012	Beals	28.26	0.64	4.28	5.77	0.29	1.10	2.33	1.51	23.70	10.28	14.76	3.21	0.40
2012	Brady	23.78	1.18	0.74	2.14	0.11	2.25	5.57	2.77	21.65	14.09	22.14	3.18	2.46
2012	Colorado	28.08	1.78	0.84	2.86	0.14	1.95	5.20	1.77	24.96	16.92	23.96	4.65	3.00
2012	Concho	26.29	0.62	1.53	2.55	0.14	1.62	3.80	3.05	22.19	12.46	18.84	3.48	0.87
2012	Elm	32.64	0.59	3.19	4.13	0.21	1.49	2.05	1.69	28.08	12.68	17.15	6.04	0.80
2012	Frio	31.33	0.58	5.47	6.82	0.34	1.80	4.66	1.51	24.94	17.56	21.84	4.50	1.85
2012	Garfield	30.33	0.53	4.24	5.03	0.25	2.26	7.39	1.37	29.89	17.21	27.45	3.99	9.15
2012	James	34.20	0.51	4.22	5.35	0.27	1.77	4.38	2.73	26.77	14.51	20.96	6.23	1.03
2012	Lake McQueeny	22.21	0.49	1.59	2.23	0.10	1.92	5.79	1.91	22.92	18.17	25.17	2.33	3.01
2012	Leon	15.15	0.04	0.17	0.27	0.01	3.05	7.31	2.03	26.17	20.85	25.78	0.39	6.62
2012	Llano	14.20	0.00	0.29	0.40	0.02	1.54	2.64	2.32	20.77	12.19	17.12	0.92	0.28
2012	Lower Pecos	25.71	2.80	1.15	4.32	0.22	1.34	2.42	2.42	23.67	10.21	15.38	3.39	0.11
2012	Medina River	28.74	3.33	0.98	4.60	0.23	2.25	6.47	1.63	22.57	20.36	26.57	5.58	3.34
2012	Nueces	21.93	0.79	1.30	2.40	0.12	1.71	3.09	2.32	22.31	13.03	18.46	1.65	0.34
2012	Oak Creek	28.98	0.90	3.53	4.99	0.25	1.86	3.78	2.46	23.95	14.24	20.67	4.11	1.26
2012	Onion Creek	25.73	0.02	2.77	3.10	0.16	2.41	7.22	1.72	23.66	18.04	27.19	3.37	5.90
2012	Pinto	18.53	0.11	1.84	2.24	0.11	1.78	2.99	2.38	17.70	12.20	17.08	1.88	0.45
2012	Plum Creek	16.57	0.25	1.76	2.09	0.10	2.67	7.71	1.42	18.92	19.13	28.11	0.87	10.10
2012	Rio Grande	16.71	0.02	1.47	1.78	0.09	0.89	0.99	1.45	18.47	9.42	11.48	0.97	0.04
2012	San Antonio	30.38	0.09	2.09	2.55	0.13	3.42	7.60	2.23	27.71	17.61	24.46	2.43	10.39
2012	San Marcos	21.50	0.22	3.70	4.04	0.20	2.09	6.39	1.88	18.01	19.49	27.25	2.12	4.38
2012	San Miguel	29.58	0.00	2.27	2.49	0.12	2.87	5.44	1.31	27.68	17.81	24.22	1.61	3.17

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2012	San Saba	19.32	0.61	0.67	1.30	0.06	1.66	2.96	2.99	23.50	11.47	17.02	2.24	0.17
2012	Sycamore	22.35	1.52	0.87	2.44	0.12	2.56	3.43	3.16	18.77	11.91	18.20	3.45	0.09
2012	Turkey	22.01	0.72	0.48	1.24	0.06	1.76	4.06	2.13	18.53	12.21	18.02	3.27	1.23
2012	Upper Pecos	22.79	0.96	0.59	1.59	0.08	0.98	1.43	1.63	22.06	10.40	13.75	3.00	0.23
2013	Beals	23.80	0.42	2.55	2.66	0.13	0.73	2.02	1.10	22.04	8.51	12.05	1.40	0.22
2013	Brady	22.30	1.07	0.69	1.75	0.09	2.21	5.28	3.41	21.26	16.53	24.35	2.21	4.39
2013	Colorado	29.86	1.50	0.74	2.38	0.12	2.13	5.63	2.89	24.28	18.58	26.57	5.00	4.68
2013	Concho	23.71	0.41	1.32	1.85	0.10	1.43	3.21	2.98	20.24	13.01	17.57	2.67	0.58
2013	Elm	34.28	0.55	2.33	3.21	0.16	1.92	3.39	2.48	27.28	13.71	21.94	4.94	2.63
2013	Frio	35.71	0.64	3.74	5.48	0.27	1.32	2.70	1.53	25.19	16.86	20.59	4.68	1.45
2013	Garfield	41.92	0.60	2.34	4.46	0.22	2.43	7.66	1.43	29.53	22.22	28.31	8.14	10.37
2013	James	41.89	0.49	2.75	3.82	0.19	1.30	3.37	2.92	26.37	15.51	21.53	7.90	1.68
2013	Lake McQueeny	21.80	0.37	1.22	1.75	0.07	1.78	4.29	2.27	21.36	19.12	25.85	1.59	3.62
2013	Leon	13.18	0.03	0.14	0.17	0.01	1.98	4.58	1.83	24.10	19.70	24.03	0.20	5.63
2013	Llano	9.91	0.00	0.22	0.16	0.01	1.83	3.45	3.43	17.53	15.75	21.60	0.42	1.99
2013	Lower Pecos	33.00	3.24	1.08	4.96	0.25	1.55	2.79	3.41	23.91	11.59	17.44	5.23	0.34
2013	Medina River	32.70	2.61	0.94	3.82	0.19	1.32	3.03	1.38	22.06	18.73	23.42	6.06	2.07
2013	Nueces	20.82	0.67	0.89	1.56	0.08	1.98	3.37	3.37	21.84	15.23	21.50	1.17	1.09
2013	Oak Creek	29.81	0.79	2.43	3.47	0.17	1.82	3.07	2.74	23.52	15.08	19.98	3.53	0.97
2013	Onion Creek	27.06	0.12	2.09	2.43	0.12	2.62	7.43	4.41	23.50	21.17	31.84	3.19	9.48
2013	Pinto	20.24	0.58	1.69	1.69	0.08	2.07	4.34	3.42	18.87	13.15	21.38	1.21	1.96
2013	Plum Creek	18.52	0.50	1.52	2.20	0.11	2.47	6.94	1.64	19.04	20.72	29.91	0.88	12.45
2013	Rio Grande	17.89	0.22	1.31	1.89	0.09	1.03	1.46	1.80	18.20	9.93	12.66	0.89	0.05
2013	San Antonio	26.04	0.06	1.25	1.18	0.06	2.35	4.61	1.80	25.35	17.96	21.92	1.86	8.10
2013	San Marcos	24.57	0.26	2.32	3.16	0.16	2.21	6.16	2.90	19.03	21.34	30.13	2.01	6.29
2013	San Miguel	25.56	0.04	1.35	1.30	0.07	1.63	2.62	1.11	23.03	16.53	20.77	0.89	2.03
2013	San Saba	23.11	0.65	0.50	1.23	0.06	1.65	4.21	4.09	23.76	13.78	20.91	2.45	1.82

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2013	Sycamore	23.31	1.42	0.80	2.24	0.11	2.21	2.98	3.86	19.30	12.36	19.23	2.90	0.22
2013	Turkey	22.48	0.51	0.37	0.80	0.04	1.69	2.45	2.50	18.76	13.72	19.23	2.71	1.69
2013	Upper Pecos	23.63	0.86	0.55	1.40	0.07	0.72	1.17	1.43	22.21	9.09	12.10	2.50	0.12
2014	Beals	26.42	0.53	2.82	3.88	0.19	0.97	1.26		22.70	10.76		2.43	
2014	Brady	16.86	0.62	0.67	1.19	0.06	1.50	3.58		19.54	12.20		1.08	
2014	Colorado	25.28	1.55	0.74	2.28	0.11	1.68	4.89		24.35	16.41		3.32	
2014	Concho	22.14	0.32	1.16	1.47	0.08	1.15	2.63		19.79	11.77		2.25	
2014	Elm	24.68	0.36	2.08	2.12	0.11	1.60	4.00		24.74	11.89		2.85	
2014	Frio	25.63	0.39	4.09	3.70	0.19	1.37	3.63		22.98	15.98		2.54	
2014	Garfield	27.24	0.39	3.55	2.94	0.15	1.54	4.76		27.67	18.26		2.86	
2014	James	29.28	0.34	3.15	2.69	0.13	1.44	4.16		24.15	13.28		4.02	
2014	Lake McQueeny	20.04	0.33	1.46	1.74	0.06	1.32	4.02		21.61	16.76		1.15	
2014	Leon	16.95	0.06	0.20	0.28	0.01	1.60	4.13		27.64	18.70		0.20	
2014	Llano	12.39	0.00	0.24	0.25	0.01	1.21	2.59		19.90	11.69		0.49	
2014	Lower Pecos	24.28	2.39	1.12	3.38	0.17	1.20	2.52		22.90	9.82		3.38	
2014	Medina River	28.89	2.78	0.92	3.59	0.18	1.45	4.12		22.31	18.18		5.32	
2014	Nueces	18.63	0.66	0.99	1.77	0.09	1.43	2.71		21.45	13.93		1.18	
2014	Oak Creek	25.45	0.76	2.37	3.14	0.16	1.43	1.93		22.28	14.14		2.90	
2014	Onion Creek	21.51	0.07	1.98	1.90	0.09	1.68	5.69		21.81	18.38		1.87	
2014	Pinto	14.70	0.40	1.37	1.56	0.08	1.65	2.86		17.17	12.46		1.00	
2014	Plum Creek	16.87	0.47	1.40	2.01	0.10	1.48	5.19		19.03	18.37		1.01	
2014	Rio Grande	17.29	0.37	1.41	1.95	0.10	0.67	1.06		18.57	8.75		1.08	
2014	San Antonio	26.07	0.04	1.04	1.22	0.06	1.93	4.13		23.59	17.52		1.80	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2014	San Marcos	22.22	0.25	2.78	3.00	0.15	1.25	4.37		18.98	17.49		2.05	
2014	San Miguel	27.11	0.04	1.41	1.71	0.09	1.80	3.67		23.23	14.61		1.33	
2014	San Saba	19.96	0.38	0.76	1.22	0.06	1.33	3.26		24.03	11.22		1.74	
2014	Sycamore	18.07	0.94	0.78	1.50	0.07	1.61	2.39		18.18	11.52		1.22	
2014	Turkey	18.76	0.45	0.29	0.62	0.03	1.77	3.49		17.84	13.74		1.19	
2014	Upper Pecos	20.34	0.79	0.54	1.19	0.06	1.28	1.31		21.53	10.13		1.80	
2015	Beals	45.58	2.05	5.13	10.16	0.51	1.99	3.01		25.87	19.36		8.29	
2015	Brady	35.36	4.44	0.70	6.46	0.32	2.88	5.86		23.24	16.97		4.99	
2015	Colorado	42.01	4.81	0.89	6.71	0.34	3.83	8.24		26.88	21.85		8.20	
2015	Concho	33.95	1.28	1.84	3.69	0.20	2.67	4.11		24.50	19.71		5.03	
2015	Elm	52.52	1.00	4.38	7.92	0.40	3.24	6.67		27.82	19.32		15.10	
2015	Frio	54.98	2.64	6.34	13.04	0.65	3.94	7.69		25.14	24.55		14.15	
2015	Garfield	56.68	2.75	4.98	10.77	0.54	3.83	10.52		31.33	24.31		12.24	
2015	James	60.97	1.22	5.29	9.73	0.49	2.38	5.15		30.60	16.73		17.54	
2015	Lake McQueeny	33.81	1.53	2.24	4.91	0.20	3.76	8.79		26.08	23.44		4.02	
2015	Leon	25.30	0.10	0.27	0.44	0.02	4.73	9.02		31.22	27.54		0.30	
2015	Llano	24.15	0.00	0.41	0.58	0.03	2.46	5.02		26.47	15.40		1.11	
2015	Lower Pecos	40.94	5.73	1.11	7.82	0.39	2.32	2.91		24.86	15.61		7.96	
2015	Medina River	45.48	7.39	0.94	9.66	0.48	4.06	8.90		23.44	26.31		11.32	
2015	Nueces	31.31	1.67	1.76	5.48	0.27	3.98	7.18		24.45	20.37		2.26	
2015	Oak Creek	44.86	2.50	4.48	9.28	0.46	4.34	6.99		25.69	22.72		8.92	
2015	Onion Creek	35.84	0.55	3.73	5.62	0.28	4.76	10.65		26.04	25.86		4.98	
2015	Pinto	24.39	0.89	1.74	3.47	0.17	3.44	6.59		20.18	18.78		0.98	
2015	Plum Creek	24.58	1.15	1.77	3.89	0.19	4.16	10.44		21.38	25.17		1.17	
2015	Rio Grande	21.33	0.50	1.71	2.67	0.13	1.38	0.52		20.71	14.03		0.55	
2015	San Antonio	42.32	0.57	3.53	5.85	0.29	4.63	9.13		30.20	26.69		5.07	
2015	San Marcos	40.03	0.65	5.71	10.11	0.51	4.18	10.20		22.56	25.17		5.83	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2015	San Miguel	42.49	0.58	3.17	5.38	0.27	4.72	6.94		30.18	25.04		3.91	
2015	San Saba	42.34	2.45	1.96	6.32	0.32	2.75	4.91		27.10	15.37		9.28	
2015	Sycamore	39.83	5.79	0.86	8.72	0.44	3.88	6.13		21.73	16.84		7.32	
2015	Turkey	39.35	1.22	0.54	2.35	0.12	3.30	6.62		26.83	19.62		6.78	
2015	Upper Pecos	39.34	3.33	0.58	5.06	0.25	1.95	2.52		25.49	16.69		7.00	
2016	Beals	43.39	4.16	5.49	10.93	0.55	1.08	1.89		27.03	17.48		6.72	
2016	Brady	33.85	5.79	0.80	6.99	0.35	3.77	7.58		25.06	18.30		5.29	
2016	Colorado	41.92	6.03	0.96	7.58	0.38	4.24	9.35		28.96	24.32		8.14	
2016	Concho	36.96	1.75	1.76	4.11	0.22	2.50	4.69		25.88	20.89		5.83	
2016	Elm	37.74	1.54	4.04	6.06	0.30	4.11	8.70		29.99	18.93		5.04	
2016	Frio	42.78	4.00	6.49	11.47	0.57	3.65	8.07		28.15	24.96		5.23	
2016	Garfield	47.58	3.65	5.29	9.83	0.49	3.93	10.80		34.29	27.12		6.18	
2016	James	49.70	2.76	5.67	9.00	0.45	3.29	6.12		33.48	17.65		8.93	
2016	Lake McQueeny	31.08	1.96	2.48	5.14	0.22	3.88	9.92		25.96	25.54		3.90	
2016	Leon	21.07	0.09	0.39	0.51	0.03	5.17	10.58		31.34	29.65		0.40	
2016	Llano	17.91	0.00	0.42	0.44	0.02	3.27	6.29		25.18	15.55		0.82	
2016	Lower Pecos	37.45	7.25	1.32	9.23	0.46	2.45	3.75		26.07	15.60		5.77	
2016	Medina River	41.22	8.56	0.93	10.07	0.50	4.47	10.06		24.53	28.24		8.38	
2016	Nueces	29.35	2.99	2.07	6.72	0.34	3.38	6.97		25.86	19.02		1.50	
2016	Oak Creek	43.43	4.01	4.86	10.06	0.50	3.93	5.90		27.38	24.42		7.55	
2016	Onion Creek	36.68	1.24	4.73	7.60	0.38	4.38	10.92		26.65	28.01		4.59	
2016	Pinto	26.16	1.64	2.40	6.10	0.30	4.59	8.98		20.84	19.41		1.52	
2016	Plum Creek	24.36	2.09	1.91	4.98	0.25	4.13	10.78		22.02	28.05		1.50	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2016	Rio Grande	20.93	0.71	1.80	2.95	0.15	1.44	1.01		21.65	13.43		0.54	
2016	San Antonio	49.60	1.66	4.19	7.28	0.36	5.51	10.59		33.32	29.39		8.17	
2016	San Marcos	36.97	2.10	6.04	10.15	0.51	3.94	10.09		22.22	28.18		5.34	
2016	San Miguel	47.69	1.83	4.16	7.30	0.37	5.22	9.09		33.36	24.61		5.84	
2016	San Saba	34.37	3.01	2.22	5.61	0.28	3.58	7.10		28.00	15.41		5.24	
2016	Sycamore	32.05	6.04	0.95	7.38	0.37	4.44	7.29		22.25	16.75		5.69	
2016	Turkey	32.33	1.25	0.74	2.23	0.11	3.33	7.64		27.61	18.49		4.84	
2016	Upper Pecos	34.94	4.41	0.80	5.80	0.29	0.78	0.80		26.78	13.20		6.54	
2017	Beals	27.74	1.45	4.79	5.18	0.26	1.20	1.48		24.35	14.43		2.24	
2017	Brady	24.46	2.66	0.82	3.35	0.17	1.83	3.32		23.62	17.83		2.48	
2017	Colorado	30.68	2.80	0.94	3.69	0.18	2.22	5.37		27.01	19.51		4.57	
2017	Concho	24.64	0.70	1.68	2.21	0.12	1.23	2.49		22.53	16.15		2.69	
2017	Elm	30.95	0.77	3.28	3.20	0.16	2.40	4.58		28.43	13.35		3.44	
2017	Frio	33.24	1.69	5.81	6.42	0.32	2.19	5.15		26.23	18.34		3.74	
2017	Garfield	35.60	1.51	4.75	5.13	0.26	2.87	9.23		30.71	21.30		4.43	
2017	James	40.56	1.21	4.15	5.00	0.25	1.66	3.92		28.66	15.45		6.96	
2017	Lake McQueeny	25.42	1.14	2.06	2.91	0.12	2.05	5.53		24.71	19.20		2.60	
2017	Leon	18.49	0.05	0.25	0.30	0.02	2.61	5.82		29.34	19.70		0.18	
2017	Llano	20.19	0.01	0.39	0.48	0.02	1.75	3.30		25.75	14.59		0.92	
2017	Lower Pecos	28.34	3.18	1.28	4.23	0.21	1.76	2.57		25.55	13.46		3.29	
2017	Medina River	32.10	4.20	0.94	5.08	0.25	2.04	5.11		23.67	20.18		5.76	
2017	Nueces	21.74	1.41	2.10	2.93	0.15	2.41	4.64		24.12	15.10		0.64	
2017	Oak Creek	29.73	1.80	4.06	4.74	0.24	2.10	4.20		24.81	18.16		3.75	
2017	Onion Creek	26.09	0.59	4.01	3.55	0.18	2.81	7.41		24.76	20.95		2.21	
2017	Pinto	21.06	1.10	2.47	3.54	0.18	2.45	4.16		20.38	13.07		0.89	
2017	Plum Creek	20.46	1.42	1.95	3.35	0.17	3.12	9.32		21.20	21.58		0.68	
2017	Rio Grande	18.48	0.44	1.74	2.01	0.10	1.09	1.05		20.53	11.51		0.33	
2017	San Antonio	27.45	0.49	3.63	2.65	0.13	2.94	5.66		27.22	17.43		2.08	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2017	San Marcos	26.76	1.09	6.06	5.97	0.30	2.55	7.07		19.01	21.16		3.62	
2017	San Miguel	28.69	0.42	3.68	3.06	0.15	2.71	4.62		27.50	16.58		1.69	
2017	San Saba	24.02	1.50	1.94	2.73	0.14	1.93	2.93		25.33	15.21		3.25	
2017	Sycamore	26.04	3.21	0.97	4.08	0.20	3.29	4.24		20.82	12.77		3.85	
2017	Turkey	26.60	0.86	0.47	1.19	0.06	2.16	5.39		23.53	12.30		3.39	
2017	Upper Pecos	27.60	2.08	0.76	2.70	0.13	0.94	0.73		25.20	11.48		3.63	
2018	Beals	44.23	3.21	4.60	10.77	0.54	2.18	2.41		23.77	12.71		7.68	
2018	Brady	41.51	5.54	0.79	8.53	0.43	4.40	8.34		22.46	15.25		8.53	
2018	Colorado	40.24	4.23	0.87	6.52	0.33	3.45	5.57		25.18	17.86		7.36	
2018	Concho	30.68	1.16	1.55	4.16	0.22	3.00	5.31		21.42	15.15		3.69	
2018	Elm	34.78	0.65	2.88	4.78	0.24	3.49	6.63		25.64	11.79		5.08	
2018	Frio	36.62	1.44	4.77	7.70	0.38	4.80	8.00		23.35	19.01		4.76	
2018	Garfield	40.02	1.58	3.74	6.97	0.35	2.80	5.54		28.51	18.81		5.51	
2018	James	41.22	1.40	3.85	6.79	0.34	3.01	4.83		26.08	15.07		6.34	
2018	Lake McQueeny	30.93	1.83	1.73	4.92	0.22	3.72	6.53		22.95	18.87		4.19	
2018	Leon	20.26	0.06	0.20	0.42	0.02	5.46	8.80		26.04	21.83		0.67	
2018	Llano	19.40	0.02	0.40	0.63	0.03	3.46	5.43		22.49	14.37		1.23	
2018	Lower Pecos	37.21	5.74	1.20	8.18	0.41	2.80	3.97		23.20	12.48		5.80	
2018	Medina River	36.08	4.66	0.91	6.38	0.32	4.85	8.33		21.69	21.85		7.48	
2018	Nueces	29.89	2.76	2.02	6.40	0.32	4.59	8.00		22.39	14.42		2.61	
2018	Oak Creek	37.96	2.38	3.38	7.91	0.40	4.62	8.11		23.08	18.78		6.17	
2018	Onion Creek	38.94	1.30	3.27	7.79	0.39	3.82	6.16		23.97	19.60		7.41	
2018	Pinto	26.49	2.33	2.03	5.78	0.29	3.95	7.04		18.97	11.60		2.55	
2018	Plum Creek	22.79	2.20	1.78	4.73	0.24	3.46	6.78		19.23	19.78		1.33	
2018	Rio Grande	22.00	1.00	1.53	3.85	0.19	2.13	2.09		18.40	11.73		1.27	
2018	San Antonio	41.23	0.82	3.04	6.73	0.34	4.60	6.84		27.23	18.72		4.90	
2018	San Marcos	39.55	2.90	5.33	11.84	0.59	3.49	5.80		17.36	19.98		9.13	
2018	San Miguel	45.11	1.03	3.31	7.85	0.39	6.87	8.74		26.75	20.78		5.90	

Watersheds (Parameter Values) (continued)

Year	Watershed	Parameter Values (inches)												
		Precipitation	SWAT Baseflow	SWAT Revap	SWAT Total Recharge	SWAT Aquifer Deep Recharge	SWB Recharge	SCS Recharge	USGS Recharge	SWAT ET	SWB ET	USGS ET	SWAT Runoff	USGS Runoff
2018	San Saba	32.23	1.82	1.38	4.12	0.21	3.62	7.44		22.87	14.20		7.63	
2018	Sycamore	41.20	5.36	0.95	8.02	0.40	5.01	6.53		20.14	12.05		10.63	
2018	Turkey	42.74	1.17	0.49	5.01	0.25	3.16	7.40		21.35	11.72		11.99	
2018	Upper Pecos	40.04	3.37	0.71	5.58	0.28	1.57	1.34		23.83	11.14		8.72	

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APPENDIX G

MACHINE LEARNING (RANDOM FOREST) PREDICTION OF SOIL & WATER ASSESSMENT TOOL GROUNDWATER RECHARGE

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Appendix G

Machine Learning (Random Forest) Prediction of Soil & Water Assessment Tool Groundwater Recharge

Software Prerequisites

1. Download the version of Anaconda Individual Edition that is appropriate for you operating system and follow the steps for installation (https://www.anaconda.com/products/individual).
    - Anaconda is a free, open-source distribution of the Python and R programming languages and serves as a package manager with hundreds to thousands of libraries, some of which come pre-installed (e.g., Pandas, NumPy, etc.) with the download.
2. Additional packages will need to be installed on your local machine using conda (recommended) or pip, including:

    a) GeoPandas – read and write vector geospatial data in Python

    - Installation guide: https://geopandas.org/en/stable/getting_started/install.html
    - Note that a new environment may need to be created to avoid dependency conflicts. Follow the steps in the above URL.
    - Documentation: https://geopandas.org/en/stable/docs.html

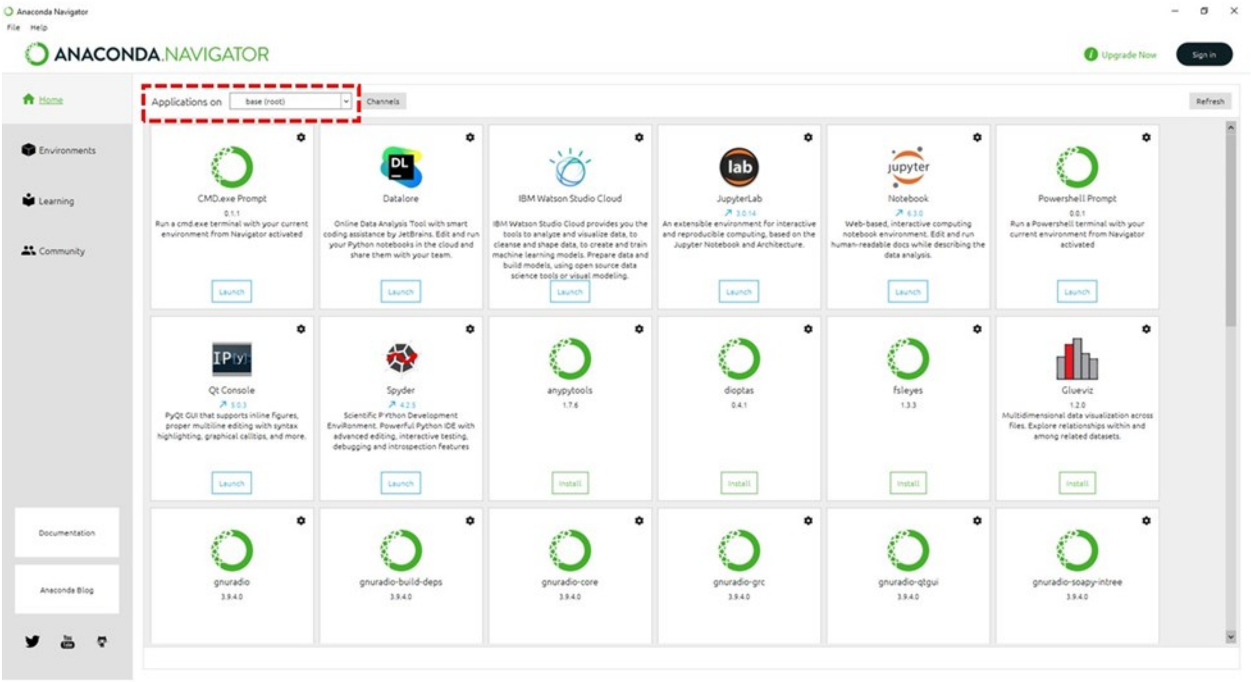
    b) Rasterio – read and write gridded raster geospatial data in Python

    - Installation guide: https://github.com/conda-forge/rasterio-feedstock
    - Documentation: https://rasterio.readthedocs.io/en/latest/

Launching and IPython Notebook using Jupyter

Below are the steps to open the IPython Notebook and run the code contained within.

1. Launch the Anaconda Navigator application on your local machine.
2. To ensure GeoPandas and Rasterio were properly installed in the newly created environment, select the dropdown menu under “Applications on” and select the new environment:



Run a cmd.exe terminal with your current environment from Navigator activated

Online Data Analysis Tool with smart coding assistance by JetBrains. Edit and run your Python notebooks in the cloud and share them with your team.

IBM Watson Studio Cloud provides you the tools to analyze and visualize data, to cleanse and shape data, to create and train machine learning models. Prepare data and build models, using open source data science tools or visual modeling.

An extensible environment for interactive and reproducible computing, based on the Jupyter Notebook and Architecture.

Web-based, interactive computing notebook environment. Edit and run human-readable docs while describing the data analysis.

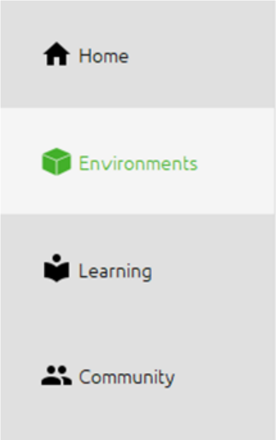
Run a Powershell terminal with your current environment from Navigator activated

PyQt GUI that supports inline figures, proper multiline editing with syntax highlighting, graphical calltips, and more.

Scientific PYthon Development EnviRonment. Powerful Python IDE with advanced editing, interactive testing, debugging and introspection features

Multidimensional data visualization across files. Explore relationships within and among related datasets.

3. While in the new environment, select the “Environments” tab on the left-hand side of the window.



4. Use the search bar or scroll to locate “geopandas” and “rasterio”.

   - If these libraries are visible in this list then they were installed successfully.

5. Proceed to launch JupyterLab or Jupyter Notebook from the Home tab.

   - It is highly recommended that Google Chrome is installed on the local machine, as Jupyter runs on Chrome by default. No internet connection is necessary.

6. After launching the Jupyter application, navigate to the IPython Notebook file path and double-click to open.

7. It is recommended to turn on cell line numbers to better navigate the document.

   - JupyterLab: View > Show Line Numbers

  - Jupyter Notebook: View > Toggle Line Numbers (Shift-L)

8. To shutdown Jupyter, open the “File” tab and select “Shut Down” for JupyterLab or “Close and Halt” for Jupyter Notebook.

Note: This IPython Notebook contains 2 primary cell types – markdown and code. Markdown is simply for annotation and will not execute any process when run. If a markdown cell accidentally gets converted to code, is can be converted back to markdown by clicking outside of the cell to the left (this selects the cell) and typing “M” (not case sensitive). Conversely, a markdown cell can be converted to code by typing “Y” on the keyboard.

Machine Learning with Python Data Pre-Processing (Optional)

The IPython Notebook contains optional code for data pre-processing. More specifically, this code allows zonal statistics to be calculated using the GeoPandas and Rasterio libraries. In some cases, using Python to conduct raster operations (e.g., zonal statistics) will be faster than using geographic information system software. If pre-processing is conducted in Python, the following steps can be taken to extract raster statistics for polygons within a shapefile:

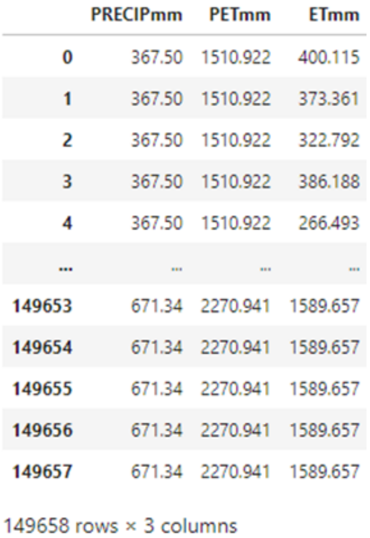
1. Download the raster dataset (e.g., PRISM) and the corresponding shapefile(s) (e.g., Hydrologic Unit Code-12, HRU, etc.) from their respective sources.
2. Ensure that projection information is consistent between datasets, just as you would before performing operations in geographic information system software.
3. Run each cell (Shift+Enter runs one cell at a time) under items 1 (“Import libraries…”) and 2 (“Data Pre-processing…”) within the IPython Notebook.
    - Read the annotations (preceded by “#” in the notebook) carefully as these may contain relevant information for making minor but necessary amendments to the code.

Note: Data extraction may take a considerable amount of time (hours in some cases), depending on the size and complexity of the raster and vector datasets. To check if a cell is actively running, check the browser tab for the hourglass symbol:

Machine Learning Prerequisites

To apply the Random Forest to the processed dataset, the following criteria must be strictly adhered to:

1. Input data must be in a tabular format (e.g., Comma Separated Values, XLS, JSON, etc.).
2. Input table column names must be named exactly as follows and in this precise order:
    - PRECIPmm, PETmm, ETmm
    - These names are case-sensitive and cannot contain spaces
    - Example table:



	PRECIPmm	PETmm	ETmm
0	367.50	1510.922	400.115
1	367.50	1510.922	373.361
2	367.50	1510.922	322.792
3	367.50	1510.922	386.188
4	367.50	1510.922	266.493
...	...	...	...
149653	671.34	2270.941	1589.657
149654	671.34	2270.941	1589.657
149655	671.34	2270.941	1589.657
149656	671.34	2270.941	1589.657
149657	671.34	2270.941	1589.657

149658 rows × 3 columns

8. To ensure model consistency, units for the above 3 variables should be in millimeters. If necessary, make the appropriate unit conversions prior to applying the model to the input dataset.

Generating a Prediction

1. Run cells (Shift+Enter) under item 3 ("Generating a Prediction"), skipping the optional cell if input data were pre-processed in Python.
    - To load the Random Forest model, copy the file location and paste into the appropriate cell ("Load the pre-trained…"). Read annotations in this cell for precise placement of the file path.
    - Note the model file extension will be .SAV and cannot be opened outside of Python.
2. The model is applied by running the cell below markdown cell "Apply Random Forest to the input dataset". The output will be a NumPy array containing groundwater recharge (GW_RCHGmm) in units of millimeters.
    - Note: It may take a considerable amount of time to generate a prediction, depending on the length of the input dataset. However, a dataset containing 3

columns and 150,000 rows can take anywhere between 1 – 10 seconds with more powerful machines able to compute the prediction faster. If the prediction cell is running for much longer than this, you can interrupt the cell by pressing the "i" key on the keyboard twice or opening the "Kernel" tab at the top of the page and selecting "Interrupt". Following an interruption, proceed to rerun the cell (Shift+Enter).

3. Running the final code cell will create a new column in the input data table named "GW_RCHGmm" and will save the final table under the specified file path and file extension. The output table can be merged with the shapefile in geographic information system software to allow the mapping of groundwater recharge.

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APPENDIX H

RESPONSE TO TWDB COMMENTS

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RESPONSE TO TWDB COMMENTS

***General** Comments to be Addressed for the Draft Final Report:*

1. The geodatabase requirements listed in the Contract are complete. Please refer to the "general comments to be addressed for the Draft Final geodatabases and data deliverables" section listed within this appendix (Appendix H).

2. The draft final report has been modified to be in compliance with all of the requirements outlined in the Contract, Exhibit B, Section 3.1, Page 4 of 4, and Exhibit D.

3. The draft final report has been revised to address all acronyms that were abbreviated in prior submittals. This report is in compliance with the Contract, Exhibit B, Section 3.1, Page 4 of 4, which states, "please do not use any acronyms except for TWDB".

4. The draft final report has addressed the issue with figures being less than 300 dpi, and is in compliance with the Contract, Exhibit D, Page 2 of 9 that requires all figures to be saved at least 300 dpi. The report setting has been changed so that the default resolution is "high fidelity", and the box has been ticked to ensure that the images are not being compressed (see screengrab below).

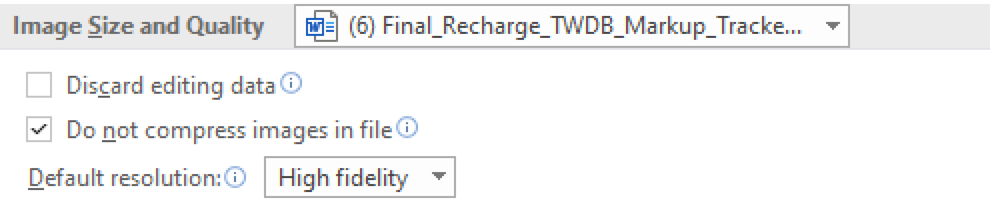

Image Size and Quality (6) Final_Recharge_TWDB_Markup_Tracke...

☐ Discard editing data

☑ Do not compress images in file

Default resolution: High fidelity

5. The draft final report has been updated to include all modifications necessary in addressing all the TWDB comments. A record of these responses has been developed within this appendix (see response to comments below).

***Specific** Comments to be Addressed for the Draft Final Report:*

6. The original comment (Section 2.1, Page 5) regarding the use of a consistent format for Soil Water Balance model, has been resolved (see Section 2.1, Page 18). The consistent format of "Soil Water Balance model" has been used uniformly throughout the Draft Final Report.

7. Figure 2-1 has been replaced with a higher resolution figure that is at least 300 dpi (Section 2.2, Page 20).

8. Figure 2-2 has been replaced with a higher resolution figure that is at least 300 dpi (Section 2.2, Page 22).

9. Section 2.3, Page 24 the link has been corrected and has been verified for being active.

10. Section 2.3.1.1, Page 25, first paragraph – Rutledge, 1998 has been included in the list of references.

11. The figures listed within Section 2.3.1.1 have been updated along with the text to ensure that the correct figures are being listed and referenced. Correct figures to be listed in the text related to this comment are Figure 2-4 and Figure 2-5 (last paragraph on Page 25).

12. The duplication of Figure 2-2 and Figure 2-3 has been resolved by deleting the duplicates found in Section 4.4.2.

13. The duplication of Figure 2-4 has been resolved by deleting the identical figure in Section 4.4.2.

14. Section 2.3.1.2, second paragraph has resolved the comment around needing to explain "critical time" by adding in parenthesis (defined below). The explanation can be found on pages 27 through 29.

15. The citation on Figure 2-7 has been corrected and is listed in the references.

16. Figure 2-7 is the correct figure number for the last paragraph on Page 28 within Section 2.3.1.2. The original figure number was incorrect and has been modified.

17. Section 2.3.1.2., last sentence has been revised for clarity with the following statement, "RORA uses a single recession index value (K) for its computations which is the median recession index value determined from the RECESS analysis of the data from that station".

18. Section 2.3.2., Page 29 – Wahl and Wahl, 1995; Slotto and Crouse, 1996; and Rutledge 1998 has been included in the list of references.

19. Section 2.4.2.1., Page 42, Equation 6 is the correct equation and all other equations mentioned in the report have been reviewed and labeling has been corrected.

20. Section 2.4.2.2., Page 43, label =4 has been explained as equivalent to 12:00 noon.

21. Section 2.5, Table 2-5, Page 44 has been modified to adopt the TWDB suggested changes for the average condition.

22. Section 3.1.1. has been removed from the Draft Final Report. This section was found insignificant and therefore, the comment related to needing to verify if the equation number mentioned is correct is no longer applicable.

23. Section 3.10.2, Page 64 has addressed the comment requesting a rewrite to the sentence for clarity. The sentence now reads, “Following the identification and categorization (by distance from stream channel and depth of the well) of shallow pumping wells, the next step is to identify the estimated pumpage volumes of these shallow wells. To estimate the pumpage volumes, pumping capacity values associated with the wells were obtained from the Groundwater Database and from Submitted Drillers Reports database”.

24. Section 3.10.2.2, Page 65 now includes the count of shallow wells within the three different distances from the streams.

25. Section 3.10.2.3 was revised so that the figure and description have been moved to the results section.

26. Section 3.10.2.3., Page 65 the equation number is question has been modified from Equation 8 to Equation 11. All other equations within the report have been modified and are in sequential order.

27. Section 3.10.2.3, Page 67, Table 3-10 has been modified to be in compliance with Exhibit B and Exhibit D.

28. Section 3.10.2.3, Page 68, Table 3-11 has been modified to be in compliance with Exhibit B and Exhibit D.

29. The comment regarding the original Table 4-1 related to font being in compliance with Exhibit B and Exhibit D has been addressed. The corrected table is now Table 3-1 in the Draft Final Report (Page 48).

30. The comment regarding the original Table 4-2 related to font being in compliance with Exhibit B and Exhibit D has been addressed. The corrected table is now Table 3-2 in the Draft Final Report (Page 48).

31. There was no difference between Figure 4-3 and Figure 4-4. The incorrect chart has been replaced (Page 77).

32. Section 4.3.2.1, Page 102, Table 4-6 table caption has been moved to be on the same page as the table.

33. Section 4.4 should not have been in the deliverable. The text and information in the section appears in various other places in the report. It appears to have been the original draft text, figures, and tables that were copied and pasted to other sections. Section 4.4 has been deleted within the Draft Final Report.

34. Table 4-11 has been deleted. Please see response to comment #33 for further explanation.

35. Table 4-12 has been deleted. Please see response to comment #33 for further explanation.

36. Discussion was added prior to Figure 5-10 to better explain the trend. Please see Section 5.2.3., Page 120.

37. Section 6.2, Page 123 second paragraph was corrected to state that the recharge trend is increasing from west to east.

38. Figure 6-10 has been moved to Section 6.2.1., Page 134 and title "Edwards (Balcones Fault Zone) Aquifer – Precipitation, Evapotranspiration and Runoff in Inches". This is the section where it is first discussed.

39. Consideration to build Figure 6-14 through 6-17 to be in a similar format as Figure 6-10 through Figure 6-13 was taken into advisement. Due to changes within the original project team, and the fact that some members are no longer with WSP, the original data that would allow for WSP to rebuild the figures was not located.

40. Section 6.2.2., Page 138, the second item should have been Soil Conservation Service model. This has been corrected within the text.

41. Table 6-1 through Table 6-10 has been modified so that all tables have a consistent format within the Draft Final Report. See Pages 142-150.

42. Section 6.5.1., Page 153 has been modified. The purpose of this paragraph is to show that machine learning has been used by others. Results originally in this section have been removed as it was found irrelevant and slightly confusing to the average reader.

43. An explanation of the term "moving average" has been added for clarification, with the term added in paratheses. Section 6.5.7., Page 155.

44. Figure y-axis label has corrected to reflect percentage RMSE in subplot C.

45. The reference for Razavai-Termech has been corrected to include all authors instead of using Et. Al (Page 168).

46. It is possible to use the pre-trained Random Forest Model (.SAV file) for regions outside the current study area, however, we do not recommend doing so. The Random Forest is a data-driven model designed to emulate SWAT for this particular location. Additionally, the Random Forest's predictive power is highly sensitive to the distribution of values within the datasets used to train it (e.g., Figure 6-18). Machine learning is an effective tool at generating predictions from conditions that are likely to be encountered again. Thus, the Random Forest can forecast recharge in the study area if the forecasted climate datasets (precipitation, ET, PET) were collected in the same manner (HRU scale, see section 8.5.2) and are within the range of values shown in Figure 6-18. In Appendix G, we have provided the scripts (. IPYNB file, annotated

with detailed instructions) used in the Random Forest model workflow; these include code to collect statistics from geospatial data (i.e., training data) and code for model training and implementation. Example datasets have been provided as requested. These examples can be found on the hard drive deliverable.

General ***Comments to be Addressed for the Draft Final Geodatabases and Data Deliverables:***

47. Due to the geodatabases all being fairly large in size, each model ran was given its own geodatabase to make sure the geodatabases function properly and efficiently.

48. Based on the comments and responses to comments related to the final geodatabases, the previous comments from the TWDB regarding the draft deliverables, WSP is confident that most of these concerns have been addressed with the final submittal and revised geodatabases/hard drive.

49. In correspondence with the TWDB, WSP no longer needs to provide input data into the geodatabase. Rather, WSP will keep the input data in its native form inside the files given to TWDB. On April 22, 2022, we received clarification from Mr. Roberto Anaya that ASCII files for the models would not need to be converted from the native model format for inclusion in the geodatabases as long as appropriate "readme" or "metadata" files were provided to describe the model input files.

50. In correspondence with the TWDB, WSP no longer needs to provide input data into the geodatabase. Rather, WSP will keep the input data in its native form inside the files given to TWDB. On April 22, 2022, we received clarification from Mr. Roberto Anaya that ASCII files for the models would not need to be converted from the native model format for inclusion in the geodatabases as long as appropriate "readme" or "metadata" files were provided to describe the model input files.

51. In correspondence with the TWDB, WSP no longer needs to provide input data into the geodatabase. Rather, WSP will keep the input data in its native form inside the files given to TWDB. On April 22, 2022, we received clarification from Mr. Roberto Anaya that ASCII files for the models would not need to be converted from the native model format for inclusion in the geodatabases as long as appropriate "readme" or "metadata" files were provided to describe the model input files.

52. In correspondence with the TWDB, WSP no longer needs to provide input data into the geodatabase. Rather, WSP will keep the input data in its native form inside the files given to TWDB. On April 22, 2022, we received clarification from Mr. Roberto Anaya that ASCII files for the models would not need to be converted from the native model format for inclusion in the geodatabases as long as appropriate "readme" or "metadata" files were provided to describe the model input files.

53. In correspondence with the TWDB, WSP no longer needs to provide input data into the geodatabase. Rather, WSP will keep the input data in its native form inside the files given to TWDB. On April 22, 2022, we received clarification from Mr. Roberto

Anaya that ASCII files for the models would not need to be converted from the native model format for inclusion in the geodatabases as long as appropriate "readme" or "metadata" files were provided to describe the model input files.

54. In correspondence with the TWDB, WSP no longer needs to provide input data into the geodatabase. Rather, WSP will keep the input data in its native form inside the files given to TWDB. On April 22, 2022, we received clarification from Mr. Roberto Anaya that ASCII files for the models would not need to be converted from the native model format for inclusion in the geodatabases as long as appropriate "readme" or "metadata" files were provided to describe the model input files.

55. For this comment the Land Use Grid that was used for the SWB Model was uploaded. In the SWB and SWB Monthly geodatabases under the raster catalog titled “ConservationLandUseGrids”, there is now a raster file uploaded called “Land_Use_Grid” to satisfy this missing data.

56. To support Section 3.6 the raster dataset titled “twdb_etp_hydrologic_soils” was added into the SWB and SWB Monthly geodatabases to satisfy the missing data.

57. . To support Section 3.7, the raster datasets titled “land_surf_ft” and “LS_FlowDirection” have been provided in SWB and SWB Monthly geodatabases. These two files provide the elevation topography and D8 flow direction data that was initially missing from the geodatabases accordingly.

58. In correspondence with the TWDB, WSP no longer needs to provide input data into the geodatabase. Rather, WSP will keep the input data in its native form inside the files given to TWDB. On April 22, 2022, we received clarification from Mr. Roberto Anaya that ASCII files for the models would not need to be converted from the native model format for inclusion in the geodatabases as long as appropriate "readme" or "metadata" files were provided to describe the model input files. This data is located in the “SWAT_metadata” PDF provided in the deliverable

59. To support Section 3.9, in every geodatabase there is now a shapefile under the Climate feature class labeled TEXMESONET_MESOWEST_Stations. This file contains all the information contained in the 59 stations that were identified in this section.

60. To support this comment there has been a file added to the final deliverable. In the “SWAT metadata” folder this is now a CSV file named “Merge”. This CSV contains all the information listed as needed to adress this comment.

61. To support Section 3.10 the initial data used in a report table has been uploaded to the final deliverable. To find this spreadsheet go to Report -> Report Reference Items -> surfacewater_takings. In this folder will be the Processed_AggregatedData_BasinSum_MonthlyforEachYear.xlsx worksheet data.

62. To support this comment there has been a file added to the final deliverable. Under the "SWAT metadata" folder this is an excel file titled "Streamflow_Depletion_Levelll_6.1".

63. To support this comment there has been a folder titled "SCS_model_input" created inside the final deliverable. In this folder you will find the input data for the rapid recharge assessment.

64. To support Section 4.1, a raster grid with all required value attribute fields has been added to the SWB and SWB monthly geodatabases. This raster grid is titled "SWB_Domain_Snap_Raster".

65. In correspondence with the TWDB, WSP no longer needs to provide input data into the geodatabase. Rather, WSP will keep the input data in its native form inside the files given to TWDB. On April 22, 2022, we received clarification from Mr. Roberto Anaya that ASCII files for the models would not need to be converted from the native model format for inclusion in the geodatabases as long as appropriate "readme" or "metadata" files were provided to describe the model input files. This information can be found in the SWB readme file.

66. In correspondence with the TWDB, WSP no longer needs to provide input data into the geodatabase. Rather, WSP will keep the input data in its native form inside the files given to TWDB. On April 22, 2022, we received clarification from Mr. Roberto Anaya that ASCII files for the models would not need to be converted from the native model format for inclusion in the geodatabases as long as appropriate "readme" or "metadata" files were provided to describe the model input files.

67. In correspondence with the TWDB, WSP no longer needs to provide input data into the geodatabase. Rather, WSP will keep the input data in its native form inside the files given to TWDB. On April 22, 2022, we received clarification from Mr. Roberto Anaya that ASCII files for the models would not need to be converted from the native model format for inclusion in the geodatabases as long as appropriate "readme" or "metadata" files were provided to describe the model input files. Soil moisture data can be found in the SWB database and in its files.

68. To support this comment there has been a file added into the "SWB_model" folder titled "SM_Calibration_Results".

69. To support Section 4.1.2.3 the Pest++ files that were used to calibrate the Soil Water Balance model have been inserted into the deliverable. They can be located under the files named SWB_model -> Calibration -> Manager_v2 -> Pest_control_files.
70. To support this comment there has been a file added into the "SWB_model" folder titled "SM_Calibration_Results".
71. Gridded data for 12-digit HUC was not created however tabulated summaries are in the SWB model output files. The readme file inside of the SWB deliverable covers this information.
72. To support Section 4.3 there is now annual reference evapotranspiration raster data in the "TWDB_Recharge_SWB". The raster catalogue is titled "Reference_ET_SWB".
73. To support this comment there has been three excel files added to the "SWB_model" folder in the final deliverable. The shapefiles that were used in the figure can be found as the "TEXMESONET" shapefile that is uploaded to the SWB geodatabase under the climate feature class.
74. To support this comment there has been a file added to the final deliverable. In the "SWAT metadata" folder there is a folder named "SWAT_inputs". This folder along with the "SWAT_metadata" PDF satisfy this comment.
75. To support Table 4.7 there has been a file added to the final deliverable. In the "SWAT metadata" folder there is an excel file titled "SWAT_Stats_Updated" which is the table used to create Table 4.7.
76. In the "SWAT metadata" folder there is an excel folder titled "Shapefiles" which are the shapefiles used to create Figure 4-21. In the Interim 2 Report, this figure was listed as Figure 4-14.
77. To support Table 5.1 the tables/spreadsheets used to develop the table in the report has been added to the "TWDB_Recharge_GWToolbox" geodatabase. The spreadsheets used to derive the tables in the report were the "Stream_Gauges", "Stream_Gauge_Recharge", and "Steam_Gauge_Discharge_Baseflow".
78. To support Table 5.2 through table 5.7 the tables/spreadsheets used to develop the table in the report has been added to the "TWDB_Recharge_GWToolbox" geodatabase. The spreadsheets used to derive the tables in the report were the

"Stream_Gauges", "Stream_Gauge_Recharge", and
"Steam_Gauge_Discharge_Baseflow".

79. To support Section 5.2.3, the spreadsheet that was used to create Figure 5.10 is provided. This table is located in the "TWDB_Recharge_GWToolbox" geodatabase and the spreadsheet itself is titled "Steam_Gauge_Discharge_Baseflow".

80. The files used to create Appendices A, B, E and D are located in the final deliverable. These files are located under the "Report" folder, and then "Report Reference Items" folder. The rest of the appendices were submitted as the full table and no data is missing from the tables inside of the report.

***General** Comments to be Addressed for the Draft Interim 2 Report:*

In preparing Appendix H to address the comments associated with the Draft Final Report, the Project Team also feels confident that most, if not all, of the Draft Interim 2 Report comments were also resolved. Due to staff changes within the Project Team, which led to the loss of the original project manager and the replacement for the original project manager, Jennifer Herrera stepped in to lead the Team in addressing and resolving project comments to complete the project for the TWDB prior to the extended deadline.