INFERENCES FROM A HOLISTIC VALUATION OF INTEGRATED WATERSHED MANAGEMENT BENEFITS

A Dissertation

by

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ABSTRACT

Recognizing that landscapes provide a variety of water and climate regulation, energy, and food production functions, whose sustainability is threatened by several anthropogenic activities, this study (i) identified and comparatively evaluated tools that can be used to quantify the different functions provided by nature, (ii) proposed and evaluated the effectiveness of alternative management options that reconcile needs of food, feed, fuel and healthy ecosystems on enhancing benefits accrued from nature, and (iii) proposed and tested an ecosystem service quantification and valuation framework that can be used to guide decision making and priority setting in integrated watershed management programs.

The performance of the evaluated tools was different before calibration but all had near-equal performance after calibration. When calibrated, all the tools satisfactorily predicted water quantity and quality variables with exceptionally high indices. The evaluation of the effectiveness of different cropping systems revealed that selectively adopting cropping systems associated with high environmental benefits can go a long way in guaranteeing food and energy security, and still ensure environmental sustainability. Lastly, the study showed that an approach that takes advantage of the synergism and complementary nature of concepts used in integrated watershed management and ecosystem services valuation can easily and clearly show the location, quantity, distribution and value of ecosystem services in their production areas, and highlight the impact of anthropogenic activities on the different functions provided by nature.

DEDICATION

My Daughters: - Abigail, Kathryn & Elizabeth -You are my world.

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To my Advisory committee: - Dr. Paul Schwab, Dr. Clyde Munster, Dr. Patricia Smith, and Dr. Srinivasulu Ale: - For the support and guidance you provided, and the time you put in, I will forever be grateful.

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1. INTRODUCTION

1.1. Rationale and Study Objectives

Landscapes provide a variety of water and climate regulation functions that are vital to humanity. They regulate water flow through canopy interception, litter absorption, storage in soils and under the ground. This, in turn, determines the timing and magnitude of runoff, flooding, and groundwater recharge. With runoff as the main driver of water-induced erosion (Blanco-Canqui and Lal, 2010), landscapes provide an important function of minimizing rates of soil loss by regulating water flow. Landscapes also regulate climate by sequestrating carbon from the atmosphere and storing it underground (Lal, 2008), thereby decreasing greenhouse gases in the atmosphere. The delivery of these services is influenced by the landscape's landcover-soil-terrain characteristics (Chapin et al., 2011). Because of the landscape's spatial heterogeneity, the supply of these services, therefore, varies across space. These services are also intangible, do not have market values and are difficult to quantify and value economically (Coates et al., 2013). In many cases, people are not even aware that the surrounding landscape provides these services and so, do not put emphasis on conservation and protection of the landscape. Moreover, the supply of these services is also threatened by unsustainable anthropogenic activities (Reid et al., 2005).

Reyers et al. (2013) asserted that it remains unclear how landscape functions, and particularly changes in those functions, should be measured. Also, Guswa et al. (2014), and Tomer and Locke (2011) noted that even though watershed management programs are implemented world over, measuring and valuing the benefits of implementing such programs remains a challenge. Sklenar et al. (2012) urged that the valuation of benefits accrued from the implementation of management programs is needed to spur investments in these measures, particularly by private entities.

This study's goal was to address the above challenges. First, the performance of different tools in simulating the landscape water quantity and quality processes was evaluated. The objective of this evaluation was to identify tools that simulate landscape processes closest to reality so that they can be used in the assessment of the services provided by the landscape and how such services vary across space. Secondly, the benefits of adopting selective cropping practices as a soil conservation measure were assessed using tools that performed highly. The purpose of this investigation was two-fold. One was to methodologically highlight the application of hydrological models in quantifying services provided by the landscape and the other was to evaluate the effectiveness of alternative management options that reconcile the needs of food, feed, fuel and healthy ecosystems on enhancing the functioning of nature and the benefits provided thereof. Lastly, the study proposed and tested an ecosystem service quantification and valuation framework that could be used to guide decision making and priority setting in integrated watershed management programs. The non-monetary valuation approach proposed in this study presents a simple, yet robust framework for quantifying and establishing baseline values of water-related ecosystem services, so that the benefits of implementing management measures can easily be valued by observing the change in ecosystem value pre and post-implementation.

1.2. Water-Related Ecosystem Services

The Millennium Ecosystem Assessment (MEA) describes the many kinds of benefits that humans derive from ecosystems and promotes the term ‘Ecosystem Services’ (ES) to describe them (Reid et al., 2005). The MEA classified ES and lists them into four categories: provisioning, regulatory, cultural and supporting services. Provisioning services refer to products obtained from ecosystems such as food, freshwater, fiber, biofuel, biochemicals, and ornamentals. Regulatory services are benefits obtained from the regulation of ecosystem processes including flow regulation, water purification, climate regulation, erosion control, control of pests and pathogens, natural hazards mitigation, and air quality regulation. Non-material benefits obtained from ecosystems are cultural ES and include educational, recreational, aesthetic, eco-tourism, heritage, and spiritual benefits. Lastly, supporting ES are services necessary for the production of other ecosystem services and include soil formation, pollination, photosynthesis, and habitat provision.

Water-related Ecosystem Services (WrES) are a subset of ES that affect and regulate the natural functioning of the hydrological cycle (Kandziora et al., 2013). These services described in Table 1.1 include; water flow regulation and purification functions provided by landscapes, below and above surface water storage, soil retention, and climate regulation (Brauman, 2015; Dodds et al., 2013; Guswa et al., 2014; Kandziora et al., 2013). Quantities, distribution, and locations of WrES are influenced by the landscape’s soil–plant-terrain characteristics. Therefore, anthropogenic factors such as agricultural activities that alter the natural state of soil–plant-terrain system also affect the functioning of the landscape, thus the benefits provided by nature. Without proactive, integrated management of landscapes, the value of benefits provided by the landscape can, therefore be negatively be affected.

Table 1.1 Description of water-related ecosystem services

Ecosystem service	**How landscapes provide the service**
Climate regulation	Climate regulation is one of the most important ES provided by terrestrial ecosystems. Annually, plants remove approximately one-fifth of the carbon present in the atmosphere (Keenan and Williams, 2018) through photosynthesis, converting it into short-lived pools such as leaves and humus, to long-lived pools in soils. Carbon dioxide (CO_2) in the atmosphere absorbs thermal radiation emitted by the earth ‘s surface (Fuglestvedt et al., 2008). This leads to the warming of the atmosphere, which, in turn, can lead to a change in the world ‘s climate (Pachauri et al., 2014). Therefore, measures that reduce the buildup of CO_2 in the atmosphere play an important role in regulating the global climate.
Water flow regulation	Landscapes play a central role in the hydrologic cycle, intercepting, filtering, storing and regulating surface and groundwater flows. This, in turn, helps in protecting human populations against the impacts of flooding events. Well-functioning landscapes buffer flows by improving infiltration. This improves, among others, subsurface flow and groundwater recharge which in turn ensures that flows are maintained even during dry seasons and more water percolates to underground aquifers, thereby reducing water supply shortages.

Table 1.1 Continued

Ecosystem service	**How landscapes provide the service**
Water quality improvement	Landscapes regulate water quality in many ways. They purify water by removing pollutants through chemical, physical and biological processes. They retain nutrients through plant uptake (Hopmans and Bristow, 2002), and assimilate, adsorb and mineralize organic pollutants and pathogens (Dodds and Whiles, 2020). Healthy landscapes also filter water by trapping nutrients and soil particles which would otherwise flow into water bodies.
Soil erosion control	Soil loss from the watershed is mainly determined by rain intensity and the landscape's soil-terrain-vegetation characteristics. Landscapes with sufficient plant cover (either growing plants or residue left in the field), protect soil from the erosive power of raindrop impact and flowing water. Belowground biomass also plays a role in reducing soil erosion. Roots reinforce the shear strength of the soil which improves the resistance of soil to erosion (Shinohara et al., 2016). By reducing soil loss, both the onsite impacts of erosion such as loss of soil-crop productivity and offsite impacts like sedimentation are minimized.

1.3. Performance of Hydro-Ecological Models in Simulating Landscape Processes

Several studies recommend the use of hydro-ecological modeling approaches for quantification of WrES (Hein et al., 2006; Maes et al., 2012; Vigerstol and Aukema, 2011) and simulation of landscape processes (Moriasi et al., 2007; Vigerstol and Aukema, 2011). They argue that at both large and small spatial scales, ES assessments can benefit from landscape-scale process-based modeling approaches, mostly applied in watershed hydrological assessments, that consider the landscape's land-soil-water interactions. Many models exist for the consideration of these assessments. However, they differ in terms of complexity, requirements, underlying equations and assumptions (Merritt et al., 2003) and, as such, their performance in simulating hydrological processes and quantifying ES varies. Because of this, Maes et al. (2012) contended that it is illogical to select models on an ad-hoc basis for simulating landscape processes. It is therefore vital that models be appraised to identify those that simulate hydrological processes accurately and provide results closest to reality.

In chapter 2 of this study, some of the most popular hydrological tools, used in simulating landscape processes at both small and large spatial scales are described and their performance comparatively evaluated. The performance of the basin-wide Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998) is compared with that of the small watershed Agricultural Policy Environmental eXtender (APEX) model (Steglich and Williams, 2008) to assess the performance of both models at a field scale level. The new restructured version of SWAT (SWAT+) described in Beiger et al.

(2017) is also compared with the older version to determine whether the new changes incorporated in SWAT+ have improved model performance.

1.4. Impacts of Watershed Management Measures on Landscape Processes

Whereas conventional technologies such as dredging, and other structural measures have long been used in the management of water resources, and for provision of good quality water for the many competing uses, within literature and government white papers, it is acknowledged that the first barrier to contamination of water and protection of water resources should be at the source (Ivey et al., 2006). Collectively known as watershed management practices/measures (Russo et al., 2008), such management practices protect and improve the quality of water and other natural resources within a watershed by managing the use of land and water resources in an integrated and holistic manner (Steinemann, 2000). These management approaches promote coordinated development and management of water, land and related resources, to maximize benefits while ensuring the sustainability of vital ecosystems (GWP, 2000). Accordingly, a watershed management approach can lead to multifaced benefits. For instance, in addition to preventing contaminants from entering water bodies, upstream watershed management measures aimed at controlling soil erosion have an added advantage of maintaining or enhancing farm productivity. Conventional downstream mitigation measures do not have this added benefit as is the case with dredging activities – which can only remove sediments from water bodies and waterways.

During the last decades, policy development at different administrative levels has aimed at advancing watershed management-based frameworks for protecting upstream landscapes and ensuring sustainable availability of good quality water (Mander, 2008; Thorud et al., 2000). Challenges, however, continue to derail the implementation of watershed management measures. Key among many is the inability to quantify the benefits accrued from the implementation of these measures (Sklenar et al., 2012). A review by the US Environmental Protection Agency (USEPA) determined that the most significant weakness of the formulated watershed protection plans in the USA was the inability to estimate load reductions, to quantify and provide a basis for monitoring impacts of implemented measures (USEPA, 2011). More research is needed to develop mechanisms for evaluating watershed policies and programs if adaptive management principles are to be properly implemented (Thorud et al., 2000; Wang et al., 2016).

This research contributes useful suggestions to the field of watershed management by proposing and testing robust but simple approaches that can easily be incorporated in watershed management to quantify the benefits of implementing watershed management measures. Chapter 3 and part of Chapter 4 covers the evaluation of the impact of implementing several management measures and quantification of various ES in their areas of production. Specifically, in chapter 3, the effectiveness of a watershed management policy that prioritizes the implementation of cropping systems with higher environmental benefits is evaluated. Policies like the conservation reserve programs that take land out of production are known to provide a quick fix to watershed management challenges (Morris and Potter, 1995; Ribaudo, 1989; Wallander et al., 2017), but because of the increasing demand for arable land for the production of food, feeds and fuel (Lute et al., 2018), these policies are unsustainable (Lute et al., 2018;

Morefield et al., 2016; Smith and Goodwin, 2003). The policy evaluated in this study is fronted as a novel alternative to such policies that take land out of production. The proposed policy does not take land out of production but rather promotes cropping practices with minimal negative impacts on the environment.

1.5. Ecosystem Service Valuation

Even when quantified, the process of valuing and compounding benefits provided by landscapes is challenging. Different ES are quantified in different units and thus cannot be compared or aggregated. They need to be scaled to a unitary value such as a dollar value or a normalized index. Valuation of these services can raise awareness on the importance of the landscape and consequently spur more investments in the implementation of watershed conservation and management measures. ES valuation can also guide the land use and investment decision-making process by highlighting the most valuable landcover – soil – topographic combinations and alternative management options that could significantly enhance the benefits provided by the landscape.

Several methods can be used to value ES. Most of the approaches attach a monetary value to an ES (Alam et al., 2016; Francesconi et al., 2016; Liekens et al., 2013). The simplest monetary valuation approaches draw on existing prices of goods or services in the marketplace (market price methods) or the contribution of ecosystem products in the production process of goods (productivity methods). However, most ES, notably WrES, lack a market price and are not inputs into a production process (Ezebilo, 2016). Therefore, other approaches such as contingent valuation methods that involve asking people what they would pay for a particular service and hedonic pricing methods that draw from the extra value in property price due to its proximity to an ambient environment have been used to value ES (Boyle, 2017). Other monetary methods do not directly value ES but are instead based on estimations of the costs that would be incurred if ES benefits needed to be recreated through artificial means (Pascual et al., 2010). All these monetary valuation approaches provide hypothetical monetary values of ecosystem services that are not traded in markets (Butterfield et al., 2016; Markandya et al., 2019). Therefore, monetary valuation approaches are associated with high uncertainties due to the non-market nature of WrES, and because of the influence of societal perceptions on the monetary value of ES (Liekens et al., 2013; Small et al., 2017). These approaches also often involve multiple technical teams, with one team undertaking the quantification of ES and the other team(s) later attaching monetary values (Birkhofer et al., 2015; Schmidt et al., 2016).

The above challenges associated with monetary valuation approaches render the use of non-monetary valuation techniques worthy of consideration. Non-monetary techniques do not express the value of ES in monetary terms and do not reflect preferences defined under budget constraints. Non-monetary valuation may be as simple as expressing the state of ES in qualitative terms (e.g., ‘‘poor,” ‘‘good,” ‘‘excellent”) (Martin and Mazzotta, 2018). Chapter 4 describes methodologically a non-monetary approach for evaluating ecosystem services. The approach takes advantage of the synergism between integrated watershed management, ecosystem service, and multi-criteria assessment concepts to develop a robust yet simple framework for identifying priority areas for resource management. In a typical watershed management setting, the identification of priority areas for conservation and/or protection is critical. In addition to identifying priority areas, the framework proposed in this study establishes baseline values for services provided by landscapes. The benefit of implementing a specific watershed management practice can easily be determined by comparing the value of the services provided by the landscape before and after implementation, thus providing a monitoring benefits of watershed management programs.

1.6. Report Structure

The structure of this dissertation is based on TAMU's recommended journal article document format. All sections of the dissertation after the first introductory section of the document are manuscript papers that have been forwarded to different journals to be considered for publishing. Only the manuscript that covers "model evaluation" (Chapter II) is yet to be submitted for publishing. The manuscripts have not been re-edited for inclusion in this dissertation compilation. They appear under each chapter, exactly the way they are in their standalone versions. Only minor changes were made to reflect the change in caption formatting for both figures and tables, adopted in this dissertation report. In Chapter III, the effectiveness of three field cropping systems and three grassland systems in reducing soil erosion is examined. Lastly, chapter IV describes a framework for quantifying landscape functions, their distribution across space and how they are influenced by landscape properties. The research summary and conclusions are presented in Chapter V.

Because of the different modeling undertakings carried out in this study, a great deal of data was used. More data was also generated. Appendices I and II describe the data and steps followed when processing input data in Chapters II, III and IV. Also, the methods used are described in the metadata files appended.

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2. COMPARATIVE EVALUATION OF THE PERFORMANCE OF SWAT, SWAT+ AND APEX MODELS IN SIMULATING HYDROLOGICAL PROCESSES IN MICROWATERSHEDS

2.1. Introduction

Hydrological models are widely used in the understanding and management of both surface and below-surface water flow processes, water-induced soil erosion and pollutant transport processes. Models are also integral to watershed management planning processes and are often used to estimate load reductions due to the implementation of water source protection measures. Many models exist for the consideration of these assessments; however, they differ in terms of complexity, requirements, underlying equations and assumptions (Merritt et al., 2003). As such, model performance in simulating hydrological processes varies. Indeed, prior studies like those by Das et al. (2007), Golmohammadi et al. (2014), Parajuli et al. (2009), Paul et al. (2019), and Shen et al. (2009) that evaluated the performance of several popular hydrological models determined that simulation results by different models for the same study area can differ significantly. It is, therefore vital that models be appraised to identify those that simulate hydrological processes accurately and provide results closest to reality before they can be used in the study of environmental processes.

A review of past studies shows that there is limited research on the performance and application of commonly used models at the field scale level, despite land use and planning activities being undertaken on small-sized areas such as on-farm, mining and construction plots. Globally, 94% of farmlands are smaller than 5 ha (Lowder et al., 2016). The majority of comparison studies have been undertaken on relatively larger spatial scales. For instance, Das et al. (2007) compared the performance of the Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998) and the Annualized Agricultural Non-Point Source (AnnAGNPS) model (Young et al., 1995), in the 143 km^2 Canagagigue Creek Watershed, in the Grand River Basin, Ontario, Canada. Also, Golmohammadi et al. (2014) evaluated the performance of MIKE-SHE (Refsgaard and Storm, 1995), the Agricultural Policy Environmental eXtender (APEX) model (Steglich and Williams, 2008) and SWAT in the Canagagigue Creek Watershed. Parajuli et al. (2009) undertook a comparison of AnnAGNPS and SWAT models in the 136 km^2 Red Rock Creek watershed in South-Central Kansas. El-Nasr et al. (2005) compared the performance of MIKE SHE and SWAT in the 465 km^2 Jeker River Basin, in Belgium. Lastly, Borah et al. (2007) evaluated and compared SWAT and the Dynamic Watershed Simulation (DWSM) model (Borah et al., 2002) for a 620 km^2 Upper Little Wabash River watershed, in IL, USA. A comparison of the Water Erosion Prediction Project (WEPP) model (Flanagan et al., 2001) and SWAT by Shen et al. (2009) in modeling soil erosion in the relatively smaller, 1.62 km^2 Zhangjiachong Watershed in China showed that the performance of models can, indeed be different in micro watersheds. This study compares the performance of hydrological models at even a smaller spatial scale, in a 0.066 km^2 (6.6 ha) micro watershed which realistically represents the size of farmlands in the agricultural sector.

Models are also often subject to revisions aimed at addressing the shortcomings of older versions. Comparing the performance of the different versions of a model can show whether introduced changes in a newer version lead to improved performance. One such model that has gone through many revisions over time and has largely been used to simulate hydrology and water quality processes at large spatial scales is the SWAT model. The model developers recently released a revised version, SWAT+ described in Bieger et al. (2017) that provides a more flexible spatial representation of interactions and processes within a watershed. The performance of SWAT and SWAT+ are compared in this study to determine if the modifications incorporated in SWAT+ improve model performance, specifically at field scale level. The outputs of the two versions are also compared with those simulated by the APEX model, which has widely been used to simulate satisfactorily landscape processes in small watersheds.

2.1.1. An Overview of SWAT, SWAT+, AND APEX Models

Whereas SWAT was developed as a river basin scale model suited for large complex watersheds (Arnold et al., 1998), APEX is better suited for small watersheds (Williams and Izaurralde, 2006). SWAT+ adopts most of the theoretical and empirical equations, and assumptions in SWAT albeit a few but significant changes incorporated to address the limitations of the older version (Bieger et al., 2017). Descriptions of model capabilities, underlying equations and assumptions are detailed in Arnold et al. (1998) and Gassman et al. (2007) for SWAT and, in Williams et al. (2006) and Gassman et al. (2010) for APEX. The new structural changes and improvements incorporated in

SWAT+ are described in Bieger et al., (2017). The models are therefore not described further in detail but a review of the limitations and strengths of the models is presented.

SWAT is a comprehensive, physically-based, hydrological model, that operates on a daily time step at a basin-scale (Arnold et al., 1998). The model is considered one of the most suitable models for predicting the long-term impacts of land management measures on water, sediment and soil nutrient loss in large complex ungauged watersheds with varying soils, land-use, and management conditions (Arnold and Fohrer, 2005; Gassman et al., 2007; Shukla, 2011). SWAT uses a two-level disaggregation scheme; a preliminary sub-basin and stream network delineation based on the watershed's topography, and further discretization based on land use, slope and soil type heterogeneity. Areas with the same topographic characteristics, soil type, land use and management form a Hydrologic Response Unit (HRU), a basic computational unit assumed to be homogeneous in hydrologic response to land cover change. SWAT performance is assessed in this study particularly because of the strengths it has over the other two models. Notably, the model enjoys strong technical support with detailed documentation, several interfaces, tools, and other software supporting the pre- and post-processing of data. The popularity and usage of the model for varying applications, a vibrant user community, and worldwide expertise is a bonus. The main weakness of the SWAT model is the lack of connectivity and interaction of hydrological processes amongst HRUs (Her and Jeong, 2018; Volk et al., 2007). The modeling framework ignores flow and pollutant routing between HRUs (Fig 2.1a). Instead, individual processes are simulated for each HRU, and then flow/pollutants are aggregated for the entire sub-basin. Additionally, SWAT does not allow simulations of multicultural plant communities and its simulation of groundwater processes is limited (Glavan and Pintar, 2012). Finally, numerous additions and modifications to the model over the years have increasingly made the code complicated, bulky and hard to manage (Bieger et al., 2017).

SWAT+ is a new revised version of the SWAT model whose development was aimed at addressing the weaknesses and limitations of older versions of the model. Even though the basic algorithms used to calculate the processes in the model have not changed, the structure and organization of both the code (object-based) and the input files (relational-based) have undergone considerable modification (Bieger et al., 2017). The structure of SWAT+ improves the connectivity and interaction of elements and processes within the watershed allowing for flow and pollutant outputs from one spatial area to be routed through another area (Fig 2.1c). This is accomplished by the delineation of the watershed into LandScape Units (LSUs). The SWAT+ model structure allows for the configuration of two or more plants or crops growing at the same time in the same plant community. Currently, the delineation and discretization of the watershed can be undertaken using QSWAT+, a plugin into the open-source QGIS software interface used to analyze and edit spatial information. The setup, editing of the input files and the running of the model can be undertaken using the SWAT+ editor program, which uses an SQLite database. The older versions of SWAT use a Microsoft Access database to hold model input data.

Like SWAT and SWAT+, the APEX model is a continuous, daily time-step model. The individual field simulation component of APEX is generally a field-size sub-area. The sub-area in APEX behaves functionally the same as an HRU in SWAT. In both spatial units, the weather, soils, and management systems are assumed to be homogeneous (Neitsch et al., 2011; Williams et al., 2008). While simulating complex watersheds, the watershed needs to be subdivided into as many sub-areas as necessary to ensure that each sub-area is relatively homogeneous in terms of soil, land use, management, and weather. The sub-areas can be interconnected allowing runoff, sediment, nutrients, and pesticides to route from one sub-area to another (Fig. 2.1b), just like landscape units in SWAT+. APEX is supported by an ArcGIS based user interface (ArcAPEX) (Tuppad et al., 2009) that can be used for watershed definition and discretization. The user may also manually set up the project and run the model using the stand-alone APEX editor following procedures described in Steglich and Williams (2008). This flexibility is particularly helpful considering that subarea boundaries at the field scale level cannot be accurately determined using coarse resolution Digital Elevation Models (DEMs). Model calibration and sensitivity analysis can be undertaken using the standalone APEX-auto-Calibration and UncerTainty Estimator (APEX-CUTE) program (Wang et al., 2014).

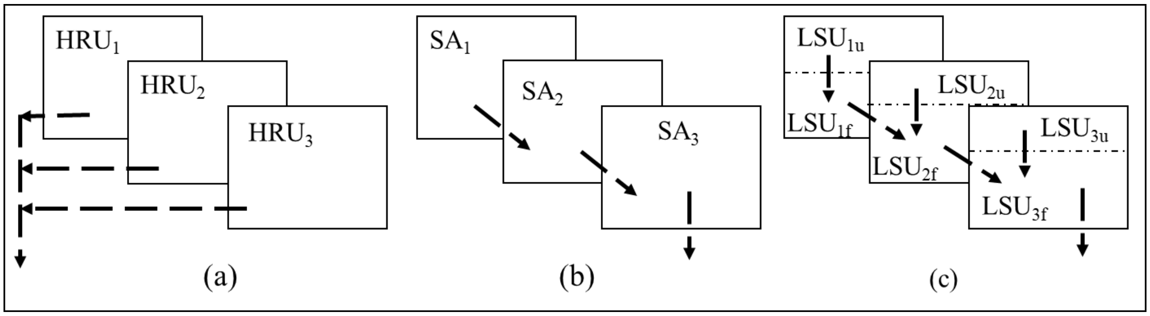

Figure 2.1 Schematic representation of flow and pollutants routing amongst computational units in (a) SWAT (b) APEX and (c) SWAT+ models. Unit 1 is conceptually upstream and unit 3 is the most downstream.

2.2. Methods and Materials

2.2.1. Model Set-up and Parameterization

The study area used for all three models was the 6.6 ha Y6 watershed (31.47N, 96.8W, ~168masl), located within the USDA-ARS Grassland, Soil and Water Research Laboratory Watershed Network near Riesel, TX. Located in the Texas Blacklands Prairie ecoregion (Fig. 2.2), the Riesel experimental watersheds consist of small, single land use watersheds (1.2 - 8.4 ha) with hydrologic, sediment and nutrient monitoring stations at the outlet to measure edge of field processes and other relatively larger micro-watersheds (17.1-125.1 ha) with mixed land uses to evaluate integrated processes (Harmel et al., 2014). Management, precipitation, runoff, air temperature, and sediment data have been collected continuously on these plots since the 1930s and runoff nutrients since the early 2000s. The configuration, layout, and description of the experimental plots, geophysical characteristics and the installed hydrological monitoring instrumentation are detailed in Harmel et al., (2014).

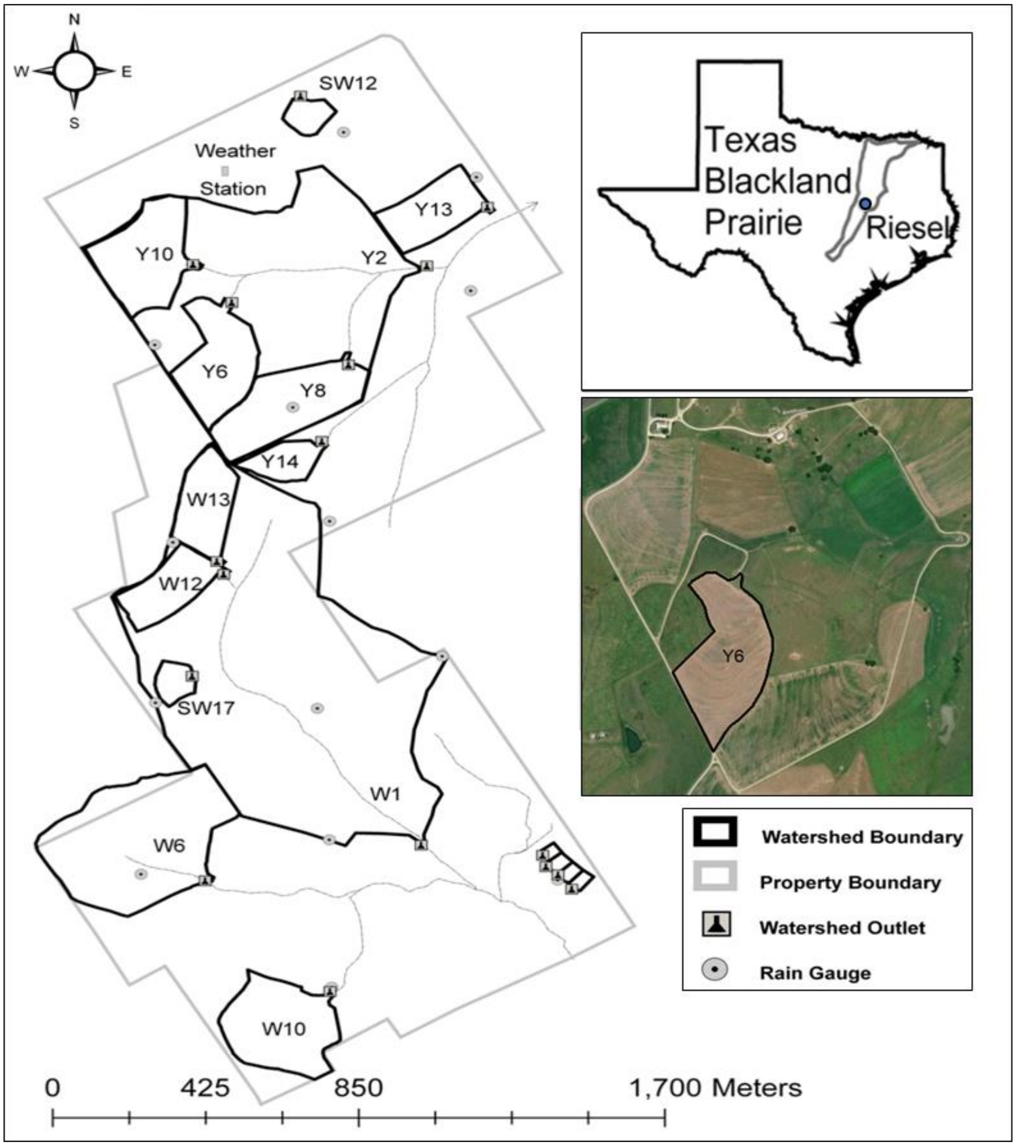

Figure 2.2 Map of the USDA-ARS experimental watersheds near Riesel, Texas.

The SWAT, APEX, and SWAT+ models were set up using the ArcSWAT-2012, the ArcAPEX v.1501 and QSWAT+ v.1.9 interfaces respectively using a 10m x 10m DEM for watershed delineation. The traditional DEM-based watershed delineation approach did not generate flowlines consistent with the drainage network observed in the plots for both the three models. Fittingly, the “burn-in” approach was used to improve stream network and sub-basin delineations. The built-in STATSGO soil database in both models and land cover data from the US National Land Cover Database 2011 were used for watershed discretization. Local weather data and field management data were downloaded from https://www.ars.usda.gov. Flow, soil loss and nutrient data used for model calibration were downloaded from the STEWARDS database - a data delivery application that provides web-based access to soil, water, climate, land management, and geospatial data (Harmel et al., 2014). The models were run using their respective editors (SWAT editor, APEX editor, and SWAT+ editor) to generate the initial set of average monthly predictions.

All the three models use relatively similar equations, assumptions, and parameters when simulating water budget components, soil and nutrient losses. Potential evapotranspiration (ET) was estimated using the Penman-Monteith equation in both models. Though more complex and data-intensive than its alternatives, the Penman-Monteith equation is recommended because of its detailed theoretical basis and accuracy in estimating ET (Batchelor, 1984). The modified rational equation was used to estimate peak runoff rates and the curve number method to estimate the runoff depths. The rational method is recommended for use in small drainage areas up to 250km^2 (Young et al., 2009) and is thus appropriate for this micro-watershed. The curve number method uses the total rainfall volume to predict runoff and is suitable for studies like this where rainfall intensity and duration are not accurately known. For both SWAT and SWAT+, the Modified Universal Soil Loss Equation (MUSLE) was selected for simulating soil dislodgment, transportation, and sedimentation processes. For APEX, a variation of MUSLE, MUSS, adapted for small watersheds with no erosion in channels or streams (Williams and Izaurralde, 2005), was used. In both models, the EPIC enrichment ratio method was used for estimating sediment-bound phosphorus losses in the runoff, and the groundwater loading effects of agricultural management systems equation for estimating soluble P in runoff. Uncalibrated runs were performed using the default values for the different model parameters included in the respective model editor packages to simulate the edge of field water yield (Yield), soil loss (Sed) and mineral phosphorus (MinP) from the plot.

2.2.2. Sensitivity Analysis

APEX, SWAT, and SWAT+ are comprehensive process-based models that employ a large set of parameters during simulation of landscape processes. Sensitivity analysis helps to identify parameters that have significant impacts on model outputs in complex simulation models such as these by determining how model outputs react to changes in particular input parameter values (Pianosi et al., 2016). The sensitivity of Yield, Sed, and MinP to a long list of parameters listed in table 2.1 was evaluated by undertaking global sensitivity analyses for APEX and SWAT models and local sensitivity analysis for SWAT+. In global sensitivity analysis methods, all parameters are simultaneously varied; whereas, parameters are adjusted singularly, one at a time in local sensitivity analyses. The algorithms included in the standalone APEX-CUTE (Wang et al., 2014) and SWAT-CUP (Abbaspour et al., 2007) programs allow for global sensitivity analysis. Currently, no well documented and supported standalone automatic sensitivity analysis and calibration tools exist for use with the SWAT+ model. To screen and identify the most sensitive parameters in SWAT+, the values of each parameter were changed manually one at a time within the SWAT+ editor interface, while keeping all other parameters constant. The parameters considered during sensitivity analysis include those recommended in Wang et al. (2014) for APEX, in Arnold et al. (2012) and Abbaspour et al. (2007) for SWAT and SWAT+, and those identified as affecting the water balance, soil loss, and phosphorous cycle.

2.2.3. Calibration and Validation.

Models are an interpretation of reality and are valid only if they represent the "real world" correctly. Abbott and Refsgaard (2012) characterize the calibration and validation of watershed models as necessary steps required to ensure models are capable of making sufficiently accurate predictions of reality. As parametric models, calibration of SWAT, SWAT+, and APEX requires the estimation of process parameter values based on the user's knowledge of the study area and or using optimizing procedures (Arnold et al., 1998; Bieger et al., 2017; Williams et al., 2008). Optimization techniques involve either interactive trial and error adjustment of parameters or using search algorithms to evaluate the goodness of the model using an objective function (Balascio et al., 1998). Automatic calibration is particularly beneficial for complex models with several parameters like SWAT, SWAT+, and APEX, where manual calibration would otherwise require substantial time and computational efforts to calibrate.

Automatic calibration of APEX and SWAT was done using APEX-CUTE and SWAT-CUP respectively. During calibration, both programs follow an optimization procedure involving the modification of input files with candidate solutions, calculating and evaluating model outputs, iteratively repeating the process until the user stipulated evaluations are completed. SWAT+ was calibrated manually. Well documented standalone automatic calibration tools for SWAT+ do not exist at this time. The model can however easily be calibrated manually, either by adjusting values of candidate parameters within SWAT+ editor, by undertaking a “soft” or “hard” calibration within SWAT+ or, automatically, by using the Integrated Parameter Estimation and Uncertainty Analysis Tool Plus (IPEAT+) (Yen et al., 2019). The automatic approach is still under development and has been previously used to calibrate only flow (Yen et al., 2019). Soft calibration involves calibrating model outputs based on soft data such as water balance component ratios. It is particularly useful when actual time series of observed data are not available but generic watershed ratios such as runoff ratios are known. For this reason, soft calibration was not used since a relatively long time series of data was available for the case study. The calibration by stages described in Nair et al. (2011) and recommended in several studies like Abbaspour et al. (2007), Arnold et al. (2012), Teshager et al. (2016) was adopted. Only the top five most influential parameters for each variable identified by the sensitivity analyses were used for model calibration. For all three models, the first 4 years (1998–2001) were excluded from the results since they were used as a warm-up period. A calibration period of five years (2002-2006), when reliable values of water yield, soil loss, and mineral phosphorus loss were recorded was used for calibration at monthly time steps. The set of parameter solutions that generated the best objective functions were then used during a validation period of three years (2007-2009).

Table 2.1 Parameters used in sensitivity Analysis

Process	APEX	SWAT	SWAT+
Runoff	Runoff CN initial abstraction (PARM20)	Initial SCS curve number II (CN2)	Initial SCS curve number II (CN2)
	CN retention coefficient (PARM92)	Runoff lag coefficient (SURLAG)	Runoff lag coefficient (SURLAG)
ET	Soil evaporation coefficient (PARM12)	Soil evaporation factor (ESCO)	Plant uptake factor (EPCO)
	Evaporation plant cover factor (PARM17)	Plant uptake factor (EPCO)	Plant uptake factor (EPCO)
Baseflow / Drainage	Return flow ratio (RFPO)	Baseflow alpha-factor (ALPHA_BF)	Baseflow alpha-factor (ALPHA_BF)
	Subsurface flow factor (PARM90)	Groundwater “revap” coefficient (REVAP)	Groundwater “revap” coefficient (REVAP)
	GW storage threshold for return flow to occur (PARM40	GW storage threshold for return flow to occur (GWQMN)	GW storage threshold for return flow to occur (FLOMIN)
	Saturated conductivity factor (SATO)	Hydraulic conductivity (SOL_K)	Hydraulic conductivity (SOL_K)
	Groundwater residence time (RFTO)	GW delay (GW DELAY)	Percolation coefficient (PERCO)
Erosion / Sediment	Peak runoff rate-rainfall energy factor (APM)	Peak rate adjustment factor for sediment routing (AJ_PKR)	Peak rate adjustment factor for sediment routing (AJ_PKR)
	Support practice factor (PEC)	Support practice factor (USLE P)	Support practice factor (USLE P)
	Sediment routing exponent (PARM18)	Soil erodibility factor (USLE K)	Soil erodibility factor (USLE K)
Phosphorous loss	Soluble P runoff coefficient (PARM8)	P percolation factor (PPERCO)	P percolation factor (PPERCO)
	P upward movement factor (PARM59)	P soil partitioning factor (PHOSKD)	P soil partitioning factor (PHOSKD)
		Phosphorous availability index (PSP)	Phosphorous availability index (PSP)

2.2.4. Performance Evaluation

To calibrate and validate models and for comparison purposes, quantitative information is required to measure model performance. To achieve this, statistical indices are often used as objective functions to determine the quality and reliability of the predictions when compared to observed values. Moriasi et al., (2007) reviewed several statistical evaluation techniques and highly recommended the use of the Nash-Sutcliffe efficiency (NSE), and percent bias (PBIAS) as indicators of model performance. In addition to the above indices, the Coefficient of Determination (R^2) has been used in several model evaluation studies like Chung et al. (2002; 1999) and Green et al., (2006, 2007). This study uses the above three numeric indices for performance evaluation.

The NSE shows the relative magnitude of the variance between the simulated and measured data whereas R^2 indicates the degree of collinearity between simulated and measured data. NSE ranges from $-\infty$ to 1 and R^2 from 0 to 1. For both statistics, the desired optimal value is 1.0. The PBIAS indicates the average tendency of the simulated data to be larger or smaller than the measured data. The optimal value of PBIAS is 0.0, with low magnitude values indicating an accurate model simulation. A good reference for these indices, detailing the steps for calculating these indices and the equations used is Moriasi et al. (2007). The rating criterion for satisfactory performance evaluation varies amongst different studies. Chung et al., (2002; 1999) used NSE > 0.3 and $R^2 > 0.5$ to assess satisfactory performance for discharge and nutrient loss while Green et al., (2006, 2007) used an $R^2 > 0.5$ and NSE >0.4. Moriasi et al. (2007)

recommended an NSE > 0.50 for all variables, a PBIAS ± 25% for streamflow, ± 55% for sediment and ± 70% for MinP on a monthly time step. This study adopts the criterion recommended by Moriasi et al. (2007) and an $R^2 > 0.5$ for satisfactory performance assessment. Better performance amongst the models was assessed based on which model's performance statistics were closest to the optimal value. Additionally, model calibration and performance assessment considered the visual comparison of the overall shape of the time series of simulated data vs the observed data.

2.3. Results

2.3.1. Sensitivity Analysis

Table 2.2 lists the top five parameters that influence water yield, soil and mineral phosphorus loss prediction by APEX, SWAT and SWAT+ models. The parameters are categorized based on the processes they influence most. Results of the sensitivity analysis showed that, in all the three models, water yield prediction is more influenced by parameters that influence the generation of runoff. In APEX, the peak runoff rate – rainfall energy adjustment factor (APM) was the most influential parameter whereas water yield prediction was most sensitive to the curve number value (CN2) in SWAT and SWAT+. The CN2 parameter indicates the runoff potential of a hydrologic soil cover complex (Arnold et al., 2012) whereas the APM parameter is used to fine-tune the energy factor associated with runoff-rainfall events (Neitsch et al., 2011). In APEX, the erosion-control-practice factor (PEC) and the soluble phosphorus runoff exponent (PARM30) were the most influential parameters driving soil and phosphorous loss, respectively. These parameters do not impact water yield, at least significantly. The PEC factor is used in representing the effectiveness of erosion control measures in the APEX model (Neitsch et al., 2011). However, for SWAT and SWAT+, most of the parameters that drive water yield estimation were also the same factors that significantly influenced soil and nutrient loss prediction.

2.3.2. Performance of the APEX Model

Predicted edge of field water yield, soil and mineral phosphorus loss quantities for the 2002-2006 period by the uncalibrated APEX model were all significantly higher than observed values. The percent prediction error was exceeded -100% (Table 2.3) for all variables, thus the model significantly overpredicted all variables. Calculated NSE values were also unsatisfactory for all variables. Though relatively high, the NSE value attained for water yield prediction was below the threshold considered in this study for satisfactory performance. Simulated values, particularly for soil loss, contained large outliers (Fig. 2.3), making the NSE value particularly high. NSE is highly sensitive to extreme values (Moriasi et al., 2007). APEX overestimated soil loss more than any other variable and its performance in predicting soil loss was worse than the predictions by SWAT and SWAT+.

Calibration improved model performance tremendously, delivering near-optimal performance indices for the three variables, particularly water yield and soil loss. Indices of model efficiency (NSE) and collinearity (R^2) of simulated data with the observed values for all variables were close to the optimal values (Table 2.3) for the calibration period. Performance indices were also satisfactory during the validation period. The predicted values also tended to match the observed values for all the variables during both low and peak events (Fig 2.3).

The results agree with those by Baffaut et al. (2017) on all accounts. In both studies, the uncalibrated model significantly over predicted soil and phosphorus loss from small watersheds and the calibrated model performed satisfactorily in predicting the three variables. Other studies (Mudgal et al., 2010; Saleh et al., 2004; Wang et al., 2007; Yin et al., 2009) also determined that the calibrated APEX model simulates flow, soil and nutrient loss satisfactorily. The APEX model was designed for field-scale simulation of edge-of-field runoff volume, soil loss and nutrient loadings (Williams et al., 2008) and is thus expected to perform well at small scales. However, just as Baffaut et al. (2017) argue, the use of the APEX model when uncalibrated is not recommended since it generates unrealistic estimates of water quality parameters.

Table 2.2 The top five most sensitive parameters used for calibration of SWAT, SWAT+, and APEX models.

Processes	Parameters	APEX			Parameters	SWAT			Parameters	SWA+		
		FLOW	SED	MINP		FLOW	SED	MINP		FLOW	SED	MINP
Runoff	APM	*****	****	*****	CN2	*****	***	*****	CN2	****	**	**
	PARM16	**			SLSUBBSN		**		SURLAG		*****	*****
	PARM42	***	*									
Evapotranspiration	PARM17	*			ESCO	****			ESCO	*****	***	****
					EPCO			**	EPCO			
Base flow / Drainage	PARM90	****			ALPHA_BF	***			ALPHA_BF			
					SLSOIL	**	*****		K	***		
					GWQMN	*			PERCO	**		
					LAT_TTIME		*	*	USLE_K	*		
Erosion / Sediment	PEC		*****		LAT_SED		****		LAT_SED			
	PARM19		***						USLE_P		****	***
	PARM18		**									
Phosphorous (P) loss	PARM30			****	SOL_SOLP			****	SOL_SOLP			
	PARM8			***	PHOSKD			***	PHOSKD			
	PARM59			**					BIOMIX			*
	PARM84			*					ADJ_PKR		*	

Table 2.3 Performance of SWAT, SWAT+ and APEX models in simulating water yield, soil, and mineral phosphorus losses.

	Index	Uncalibrated			Calibrated			Validation		
		Yield	Sed	MinP	Yield	Sed	MinP	Yield	Sed	MinP
APEX	PBIAS	-116	-370	-106	8	5	-24	-11	-23	-22
	R^2	0.77	0.67	0.15	0.90	0.80	0.66	0.93	0.76	0.86
	NSE	0.43	-4.02	-0.49	0.89	0.78	0.64	0.92	0.72	0.85
SWAT	PBIAS	25	49	21	21	3	5	-2	-50	-43
	R^2	0.86	0.72	0.39	0.94	0.75	0.63	0.92	0.76	0.74
	NSE	0.69	0.50	0.37	0.87	0.73	0.63	0.92	0.57	0.71
SWAT+	PBIAS	-12	-63	-72	6	18	-24	-2	-30	-1
	R^2	0.63	0.25	0.37	0.91	0.68	0.64	0.93	0.65	0.62
	NSE	0.62	0.09	0.23	0.89	0.64	0.56	0.92	0.51	0.61

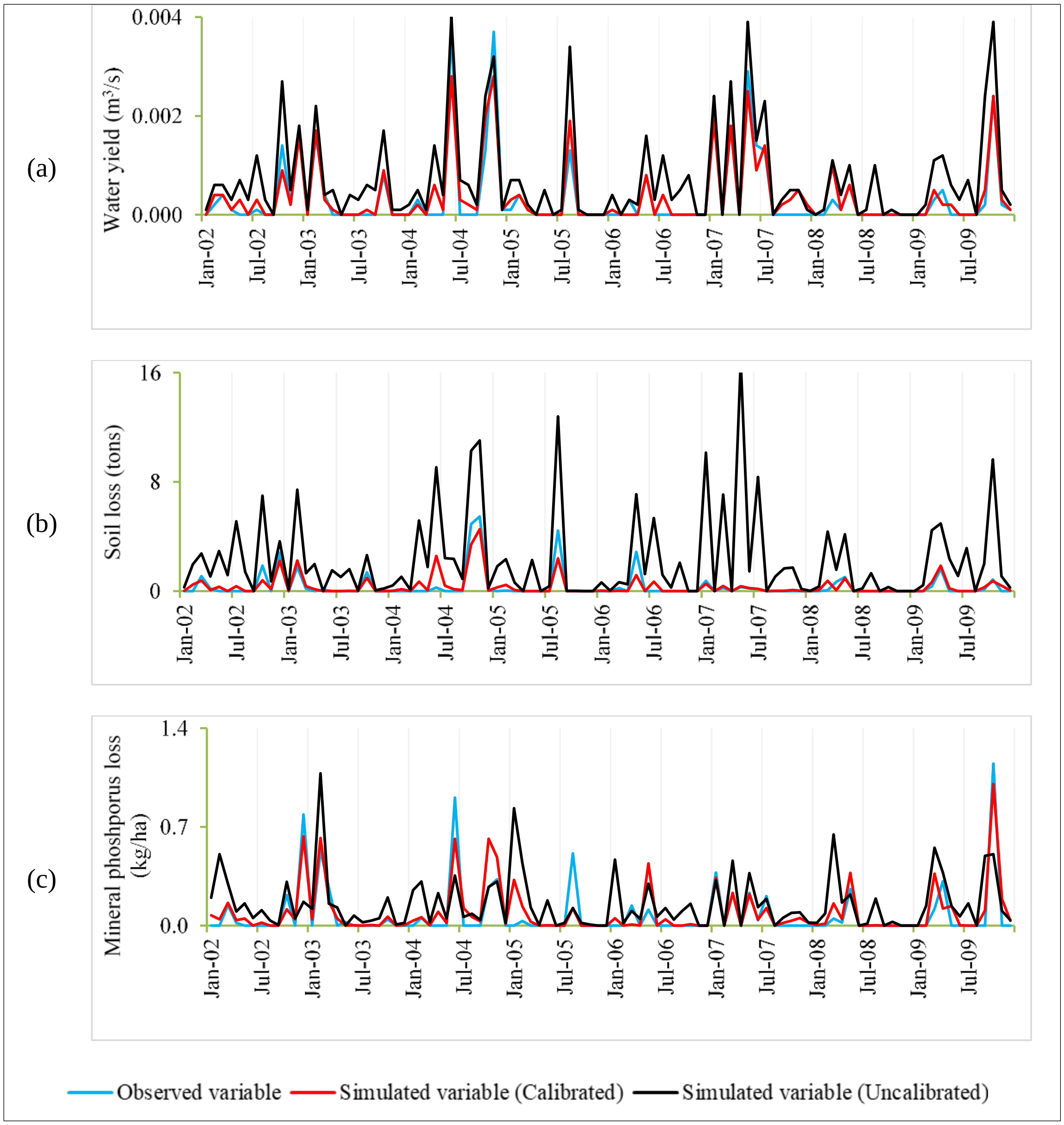

Figure 2.3 Monthly variation of observed and simulated (a) water yield, (b) soil loss (c) mineral phosphorous loss by the uncalibrated and calibrated APEX model for the Y6 plot, at USDA ARS Riesel, TX.

2.3.3. SWAT Performance

The uncalibrated SWAT model performed better than the rest of the models in predicting all variables. Correlation and model efficiency were unexpectedly high especially for water yield and soil loss prediction (Table 2.3). Despite the high indices, the model failed to simulate accurately very low and peak flow events (Fig. 2.4). However, both the long-term simulated and observed average flows were virtually the same, differing only by 0.0001 m^3/s. The uncalibrated model predicted soil loss satisfactorily. The predicted soil loss values were consistently lower than the observed values but the PBIAS value was below the 55% threshold. All other indices save for NSE were within the acceptable range for phosphorus loss estimation. Based on the NSE threshold used in this study, the performance of the SWAT in simulating phosphorous loss was unacceptable, although it would have been acceptable if thresholds used in Baffaut et al. (2017), Green et al., (2006, 2007), and Chung et al., (2002; 1999) were adopted.

After calibration, SWAT predicted all variables satisfactorily (Table 2.3). Its performance matched that of the APEX model. Both models performed well in simulating flow, although the CN method was used in SWAT and the Green and Ampt (GA) equation in APEX. Performance indices when the CN method was in APEX were not as good as those generated when the GA method was used. This improved performance of the CN method in SWAT but not in APEX was also observed in Golmohammadi et al. (2014). The difference in performance may have to do with the calibration processes rather than the models themselves. In SWAT, the CN2 value can readily be adjusted during calibration. However, in the APEX model, the CN value is not directly adjusted, rather other parameters that influence the CN value are adjusted. Soil loss prediction was more accurate with the APEX model, but again the differences in performance were not very pronounced. Predicted soil loss by SWAT was higher than that predicted by APEX, although water yield values were higher for APEX. The higher simulated soil loss values could be due to the potentially low deposition of sediments when the SWAT model is used. In SWAT, pollutant yields are merely summed and added directly to the stream whereas, in APEX, pollutants are routed across the landscape, from high elevation subareas through other subareas to the stream or outlet point. The SWAT model also matched the performance of the APEX model in predicting phosphorus loss, as evidenced by the nearly equal values of R^2 and NSE (Table 2.3).

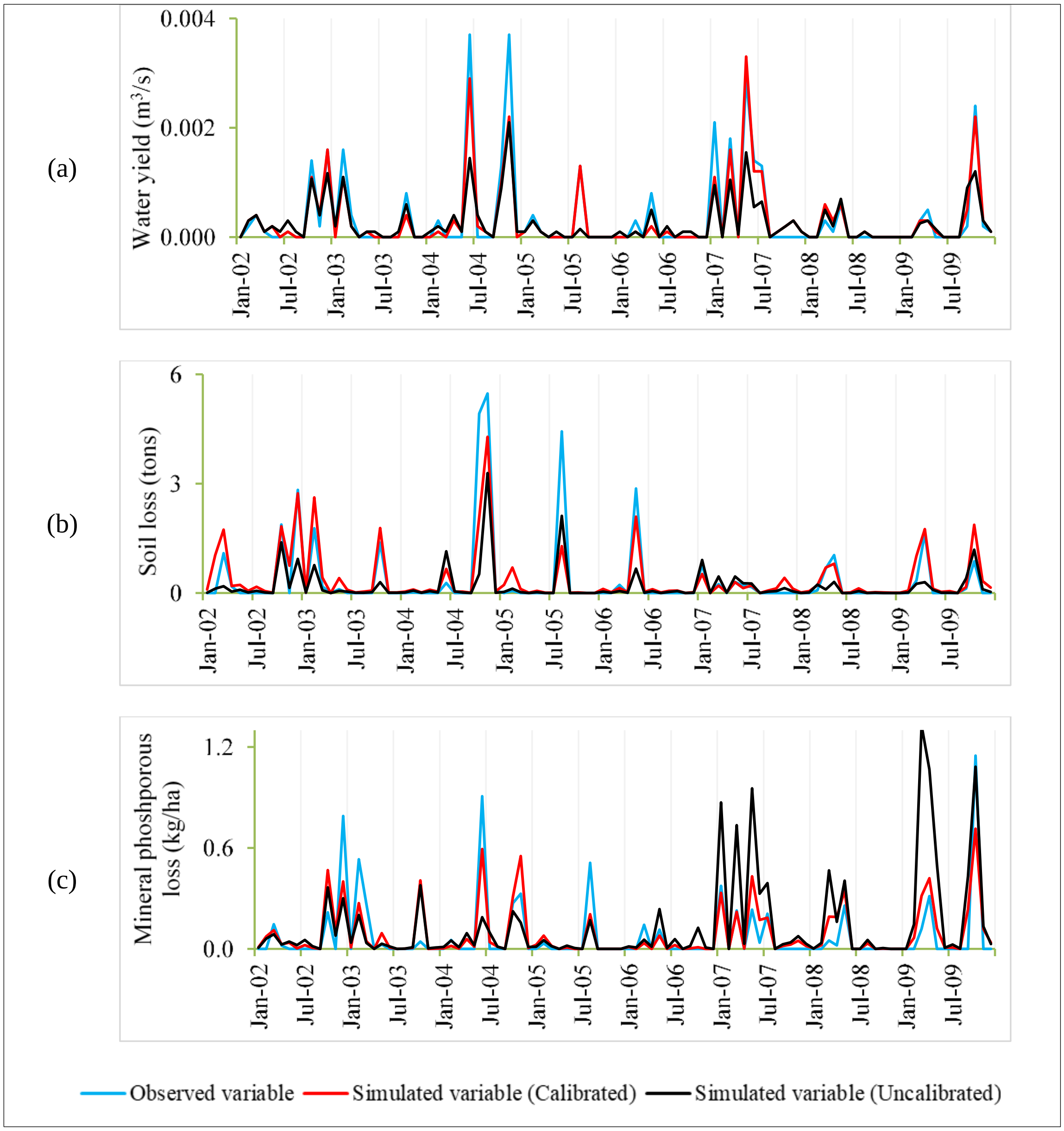

Figure 2.4 Monthly variation of observed and simulated (a) water yield, (b) soil loss (c) mineral phosphorous loss by the uncalibrated and calibrated SWAT model.

2.3.4. Performance of SWAT+.

The uncalibrated SWAT+ model, just like SWAT predicted water yield satisfactory, but unsatisfactorily predicted soil and mineral phosphorous loss. The model overpredicted all the three variables (Table 2.3), although the overprediction was lower than that of the uncalibrated APEX model. The major cause for these over predictions was determined (during calibration) to be due to default values for land cover and SUurface Runoff LAG coefficient (SURLAG). By default, the land cover practice was set to a straight row crop providing a good cover condition grown across the slope. Changing this categorization to a straight row crop providing a good cover grown in a terraced and contoured improved performance significantly. This change affects the curve number and manning value which all influence the amount of runoff generated. Also, values of SURLAG, by default, are set to 4.0 in the model. Lower values for this parameter ensure that more potential runoff is retained within the field per day (Arnold et al., 1998), thus reducing runoff, water-induced soil and mineral phosphorus loss from the watershed.

Even though calibration was done manually, the performance of the SWAT+ model matched that by APEX and SWAT models which were subjected to a rigorous automatic calibration. In APEX and SWAT, 2000 simulations were carried out automatically whereas, in SWAT+, only 20 runs were carried out. Still, running fewer runs and calibrating manually was able to produce a performance that matched that of the other two models.

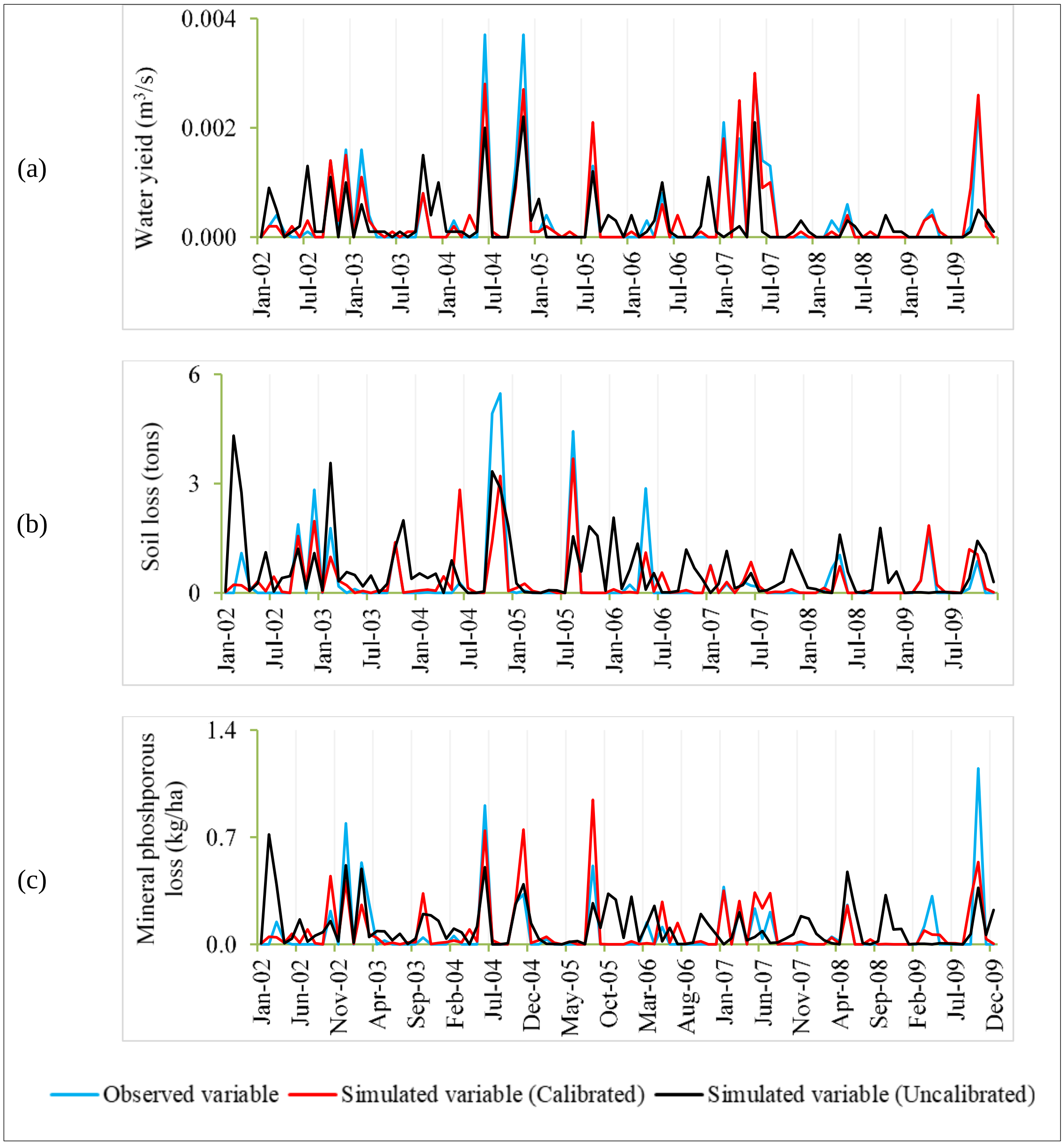

Figure 2.5 Monthly variation of observed and simulated (a) water yield, (b) soil loss (c) mineral phosphorous loss by the uncalibrated and calibrated SWAT+ model.

2.4. Discussion

Mean monthly water yields simulated by the SWAT and SWAT+ model were 0.00028 m^3/s and 0.00034 m^3/s when rounded-down to the nearest ten-thousandths value for SWAT and SWAT respectively. Despite the small difference between the simulated values, the difference in the calculated PBIAS values was substantial (21% and 6% for SWAT and SWAT+ respectively). Computing PBIAS based on values rounded down to the thousandth decimal would show zero PBIAS for both models, which would be misleading. Similarly, processing and recording of measured variables, when the measured values are small can introduce errors since computation errors such as those due to rounding down can be carried forward. For instance, when one records measurements and rounds down to the value of a hundredth, a discharge of 0.0003 m^3/s would be recorded as a zero flow. However, a difference of even say 100 m^3/s may be insignificant when dealing with discharges in very large rivers. PBIAS calculation when quantities of variables being analyzed are infinitesimal is subject to computational errors, and in such case, the PBIAS index can be misleading.

Uncalibrated runs using the default settings were unsatisfactory for all variables by all models, save for yield and soil loss prediction by SWAT, and yield prediction for the SWAT+ model. Whereas some studies have been undertaken using uncalibrated models (Ramirez-Avila et al. 2017; Wintchell et al., 2018), the results of this study showed that such a practice should not be encouraged except when the uncalibrated model has been tested and found to predict variables of interest satisfactorily. As shown in the study, although a calibrated SWAT model performs better than an uncalibrated model, the performance of the uncalibrated model was satisfactory when predicting yield and soil loss. This makes the SWAT model the most appropriate model for simulating water yield and soil loss in data-scarce regions where recorded data may not be available.

2.5. Conclusion

The basin-wide older version of SWAT, the small watershed APEX and the new restructured version of SWAT (SWAT+) models use relatively similar equations, assumptions, and parameters when simulating water budget components, soil and nutrient losses but also have a few but significant differences, for instance, how they spatially conceptualize the routing and flow of runoff and water quality loadings through watersheds. The performance of the three models in simulating the edge of field water quantity and quality processes for a 6.6 ha agricultural plot was evaluated to determine how the differences amongst the models affect performance at field scale levels. The uncalibrated version of SWAT was able to simulate hydrology and soil loss satisfactorily. The uncalibrated APEX model failed to predict any of the variables satisfactorily whereas the SWAT+ model simulated the hydrology but failed to predict water quality variables.

Model calibration significantly improved the performance of the three models, delivering near-optimal performance indicators for hydrology, during both calibration and validation periods. Performance in simulating soil and mineral phosphorus loss by the calibrated models was also relatively high. Notwithstanding the near-equal performance by all the models, the APEX model performed slightly better in simulating water quality variables than other models. Performance indicators for water yield, soil and phosphorous loss were generally better than those reported in literature when the models were used at larger spatial scales. It was also determined that some of the performance indicators particularly PBIAS may not accurately depict the performance of models at the field scale level since this index was found to be highly susceptible to computational errors when evaluating variables with generally small values, like those expected from micro- watersheds.

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3. SELECTIVE CROPPING AS A SOIL CONSERVATION PRACTICE: A BENEFITS EVALUATION

3.1. Introduction

Soil is being lost due to land use activities at a faster rate than the rate of soil renewal. Estimated rates of soil erosion are 10-40 times higher than known soil formation rates (Pimentel, 2006). One land use that is particularly associated with the highest rates of erosion in agriculture, which accounts for about 50% of soil lost globally (Borrelli et al., 2017). Erosion not only affects the site on which it occurs but also has undesirable effects off-site in the larger environment. Onsite agricultural soil loss affects land productivity which in turn imperils human food security (Pimentel, 2006). Offsite impacts such as sedimentation of water bodies occur away from the source, negatively affecting the ability of water resources to provide services to water users. With an estimated 10 million hectares of arable land lost per year to erosion (Pimentel and Burgess, 2013) and with the increased demand for farmlands to meet food demands for the rising population (Hertel, 2011), erosion will continue to pose global human food security and environmental threat in the foreseeable future. Long-term mitigation of the impacts of erosion and sustainability of soil resources do require that erosion rates on agricultural lands be reduced to near-zero levels.

Whereas conventional technologies such as water treatment and dredging have long been used to mitigate the offsite impacts of erosion, within literature and government white papers, it is acknowledged that the first barrier to contamination of water and protection of water infrastructure should be at the source (Ivey et al., 2006). In addition to preventing contaminants from entering water bodies, source protection measures have an added advantage of maintaining or enhancing farm productivity. Consequently, during the last decades, policy development at different administrative levels has aimed at advancing source protection-based frameworks for protecting upstream landscapes and ensuring sustainable availability of good quality water. Several studies that have quantified the impacts of source protection measures have determined that the benefits of these measures are significant (Stuart and Gillon, 2013; Uri, 2001).

Despite the benefits, barriers to implementing erosion control practices on farmlands exist. Several researchers concur that farmers' adoption of conservation programs (CPs) for soil erosion control is primarily influenced by the costs of the investment versus the costs of losing soil to erosion (Cary and Wilkinson, 1997; Lambert et al., 2007; Traore et al., 1998). Lambert et al. (2007) argue that low-cost CPs with significant benefits are likely to be implemented by farmers with minimal or no support. While conservation reserve programs (CRPs) that take land out of production have reduced erosion, (Lute et al., 2018; Ribaudo, 1989; Smith and Goodwin, 2003; Wallander et al., 2017), there are concerns that they are not sustainable (Morefield et al., 2016; Morris and Potter, 1995). Such programs have had limited success in promoting cropland conversion to more permanent uses (Schatzki, 2003). Any alternative erosion control programs should be able to reconcile needs for food, feed, fuel, and healthy ecosystems if they are to be sustainable.

This study proposes and assesses an alternative no-cost management measure – selective cropping as a soil loss mitigation practice. Selective cropping in this particular case involves growing specific crops that provide a relatively higher sediment retention service at the expense of other crops. The effect of each cropping system, which is a combination of type and sequence of crops grown and practices used for growing them (Blanco and Lal, 2008) is looked at holistically. Compared to conservation reserve programs that are financially incentive-driven, the selective cropping approach does not take land out of production. Farmers continue to grow crops on their lands although the growing season, crops grown, or the purpose for which the crops are grown could change. With this approach, we argue that whereas structuring and selection of cropping systems for adoption by farmers are often driven by yield maximization, (Blanco and Lal, 2008), it is also vital that the relative importance of specific cropping systems in ensuring environmental sustainability be considered during on-farm and policy decision making.

3.1.1. Selective Cropping as a Soil Loss Mitigation Practice

The importance of plant cover in controlling water erosion is widely accepted (Harmel et al., 2006; Zuazo and Pleguezuelo, 2009). Plant cover - either growing plants or crop residue left in the field - protect soil from the erosive power of raindrop impact and flowing water. In addition to aboveground vegetation, belowground vegetation plays a role in reducing soil erosion. Roots reinforce the shear strength of the soil which improves the resistance of soil to erosion (Shinohara et al., 2016). Also, on-farm operation and management practices such as the type and frequency of tillage operations, time of planting and harvesting, crop growth duration, amount of residue left after harvesting vary within different cropping systems. These operations have a bearing on the capacity of the landscape to retain soil. As an example, tillage operations affect the amount of crop residue on the soil surface, its distribution and anchorage to the soil and the size of soil aggregates (Guérif et al., 2001). Depending on the type and intensity of tillage activities, such operations may give rise to fine-grain soils with little or no soil cover which are highly susceptible to soil erosion. Therefore, cropping systems that involve fewer tillage practices such as perennial systems are likely to retain more soil compared to annual systems that use frequent tillage operations. Since different cropping systems have plant communities with unique above ground and below-ground biomass forms and involve different on-farm operations, they are bound to have different abilities to check soil erosion.

Driven by the need to mitigate both the onsite and offsite impacts of soil erosion, researchers have become increasingly interested in investigating the benefits of source protection measures. The majority of the investigations have focused on assessing impacts of CRPs that take agriculturally used croplands out of production, converting them to grass or forestlands (Dunn et al., 1993; Osborn, 1993; Reimer et al., 2018; Ribaudo, 1989) and the role of vegetation when grown to check water flow and soil movement such as in buffer strips (Gassman et al., 2006; Osborne and Kovacic, 1993). Little information exists on the environmental benefits of maintaining croplands but altering cropping systems such as replacing (i) a corn cropping system with a wheat system, (ii) a winter wheat cropping system with a spring wheat system, and (iii) a food crop system with a grassland system producing forage for feed or energy generation. This study focuses on evaluating soil loss under such different cropping systems and determines the environmental benefit tradeoff associated with transforming from one system to the other.

3.1.2. Soil Loss Measurement and Prediction

Soil loss measurement around the world commonly uses hydrologically defined runoff plots with runoff and eroded soil collected and measured at the plot outlet in a tank system (Gilley and Flanagan, 2007). Though providing a detailed understanding of the erosion processes, field studies have limitations. Farrell and Neff (1982) opined that if erosion plots are used and acceptable estimates of average annual soil loss are to be obtained, 15 or more years of data are necessary. Such long monitoring periods on the same plot of land, as well as the high cost of experimentation research, make the plot approach unattractive for many researchers (Roels, 1985). To circumvent this long-term absence of continuous data, several studies have used predictive models, calibrated using observed data to simulate water-driven soil erosion processes.

A wide range of predictive models with varying capabilities exists in the literature for soil loss prediction. These models are either empirical, conceptual or physically based (Merritt et al., 2003). Physically-based models provide an understanding of the soil erosion process and are preferred when assessing the spatial and temporal variations of sediment entrainment, transport and deposition processes (Merritt et al., 2003). Some of the popular models that simulate physical processes driving erosion include; the Agricultural Non-point Source Pollution tool (AGNPS)

(Young et al., 1989), the Water Erosion Prediction Project (WEPP) (Flanagan et al., 2001), the Soil Water Assessment Tool (SWAT) (Arnold et al., 1998), and the Agricultural Policy/Environmental eXtender (APEX) model (Williams and Izaurralde, 2006). These models have been used widely in different regions in the US under different management conditions to assess soil loss (Ramirez-Avila et al., 2017). The APEX model, used in this study, was particularly developed to simulate hydrological processes in agricultural farmlands at field scale (Steglich and Williams, 2008) and it is thus suited for studies like this that investigate the impact of cropping practices at the field scale.

The APEX model can simulate and evaluate the impact of different cropping systems over a range of management and climatic conditions on soil erosion. Modeling of cropping scenarios using APEX requires a compilation of management files for each cropping system and running APEX with a particular cropping system one at a time. During scenario compilation and simulation, climatic variables and biophysical descriptors such as soil properties are not altered. Only on farm-management operations and unique crop parameters that describe a specific plant's phenological development are updated. This ensures that the effect of different cropping systems is assessed under similar climatic and biophysical conditions. APEX calculates water-induced erosion in response to rainfall, snowmelt, and irrigation runoff events using several forms of the Universal Soil Loss Equation (Gassman et al., 2010). Runoff provides the erosive energy for detachment and transport of soil. The model encompasses key processes that occur in the hydrologic cycle and determines runoff by partitioning the incoming precipitation into the surface runoff, subsurface flow, percolation, and potential evaporation. The routing of water and sediment capabilities by the APEX model are some of the most comprehensive available in current landscape-scale models (Gassman et al., 2010).

APEX is used in this study to evaluate the environmental benefit tradeoff associated with several alternative cropping systems. Specifically, we investigate (i) whether undertaking spring cropping leads to more soil loss compared to winter cropping, (ii) if cropping systems that grow small grain crops retain more soil than those that grow row crops (iii) whether replacing food cropping systems with grassland systems as sources of feedstock for bioenergy or forage for livestock lead to more soil retention, and (iv) the impact of restoration CPs on soil erosion. This comparative evaluation approach highlights the benefits associated with different cropping systems and provides a basis for on-farm and policy decision making particularly for erosion-prone areas.

3.2. Materials and Methods

The potential impacts of implementing several cropping systems on the hydro-sedimentologic dynamic were investigated for the Y6 experimental watershed (6.6 ha) located at USDA-Agricultural Research Station in Riesel, Texas (Fig. 3.1). The research station has small, single land use watersheds with hydrologic, sediment and nutrient monitoring stations at the outlet to measure the edge of field processes and other relatively larger micro-watersheds with mixed land uses to evaluate integrated processes (Harmel et al., 2007). The detailed description of these watersheds, their geophysical characteristics and installed hydrological monitoring instrumentation can be found in

Harmel et al., (2003). This case study area was selected for a variety of reasons, including its data richness and the fact that many of the cropping systems being simulated have been implemented in the study area.

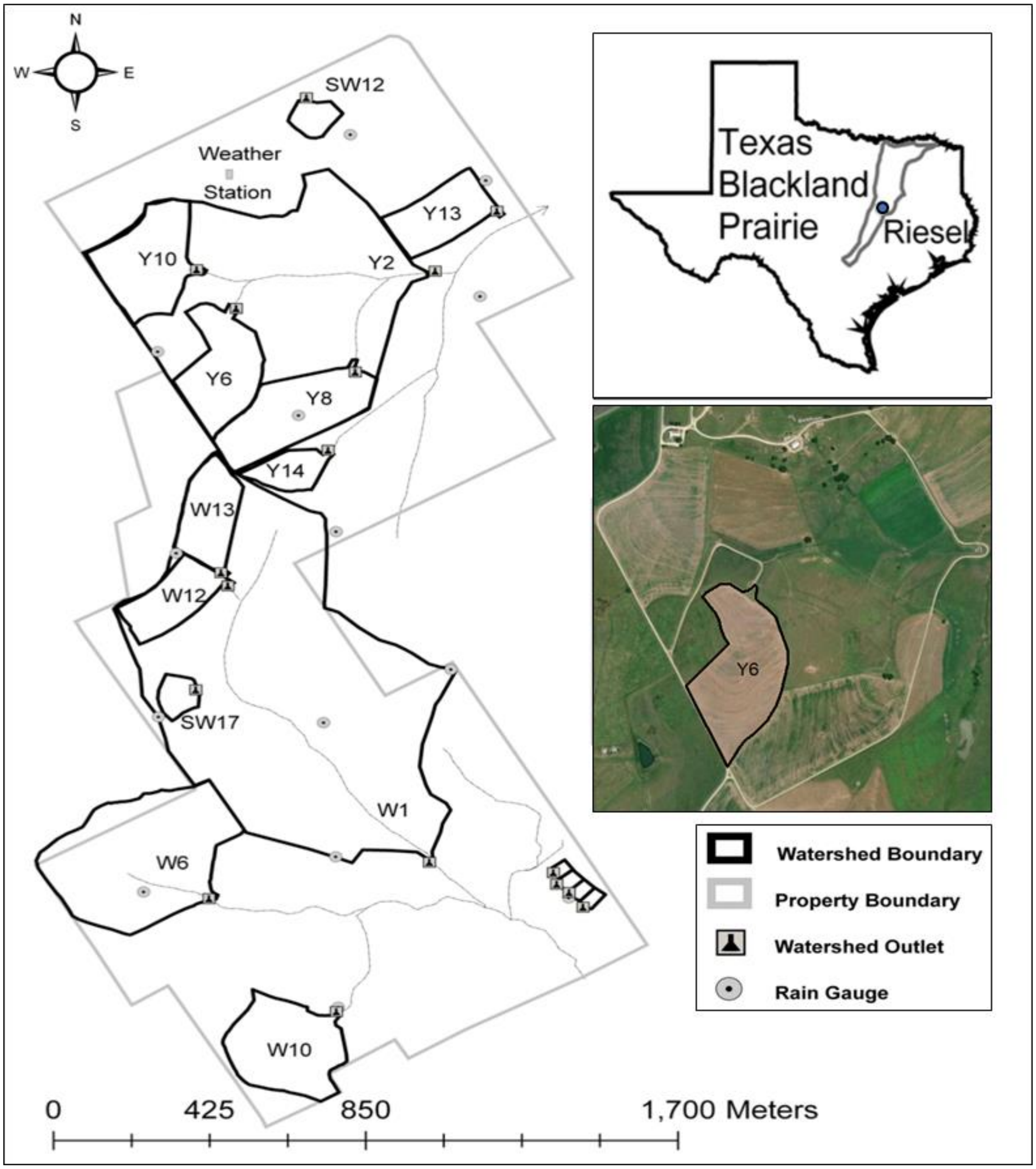

Figure 3.1 Map of the USDA-ARS experimental watersheds near Riesel, Texas

3.2.1. Model Setup and Calibration

The APEX model was set up for a period of 20 years (1995 – 2014) for the Y6 plot. Model setup requires the input of site-specific conditions such as topography, soil parameters, weather, and field management operations. For the simulation period, the required weather data, detailed field management data, continuous runoff, and soil loss observed data are available at http://www.ars.usda.gov/spa/hydro-data. The model was calibrated for 9 years (1998-2006) after a warm-up period of 3-years (1995-1997) and validated for 8-years (2007-2014).

Three statistical indices that are commonly used for evaluating the quality and reliability of simulated predictions were used in this study to assess the performance of the model. Specifically, the; (i) Nash-Sutcliffe efficiency (NSE), (ii) percent bias (PBIAS), and (iii) the coefficient of determination (R^2) were used as objective functions for model calibration and performance assessment. These indices are described and evaluated in Moriasi et al., (2007). The NSE shows the relative magnitude of the variance between the simulated and measured data whereas R^2 indicates the degree of collinearity between simulated and measured data. NSE ranges from $-\infty$ to 1 and R^2 from 0 to 1. The desired optimal value for NSE and R^2 is 1.0. PBIAS indicates the average tendency of the simulated data to be larger or smaller than the measured data. The optimal value of PBIAS is 0.0, with low magnitude values indicating more accurate model simulations. Positive values indicate under-estimation bias, and negative values indicate over-estimation bias. NSE and R^2 values greater than 0.5 and PBIAS values within ± 25% are used in several studies as satisfactory performance benchmarks (Green et al., 2007; Moriasi et al., 2007).

The calibrated model simulated both water yield and soil loss with a high degree of accuracy with near-optimal values for the NSE, $R^{2,}$ and PBIAS (Table 3.1). The simulated water yield and soil loss time series are also consonant with the plotted trends of recorded water yield and soil loss values (Fig. 3.2). Validation results were satisfactory indicating that the calibrated model simulates system behavior with enough fidelity and can be used in scenarios with independent inputs.

Table 3.1 Performance metrics for the APEX model for the Y6 plot

Land use	**Index**	**Calibration**	**Validation**
Water yield	R^2	0.85	0.87
	NSE	0.83	0.87
	PBIAS	10.1%	-10.8%
Soil loss	R^2	0.91	0.70
	NSE	0.90	0.67
	PBIAS	-11.8	-2.9%

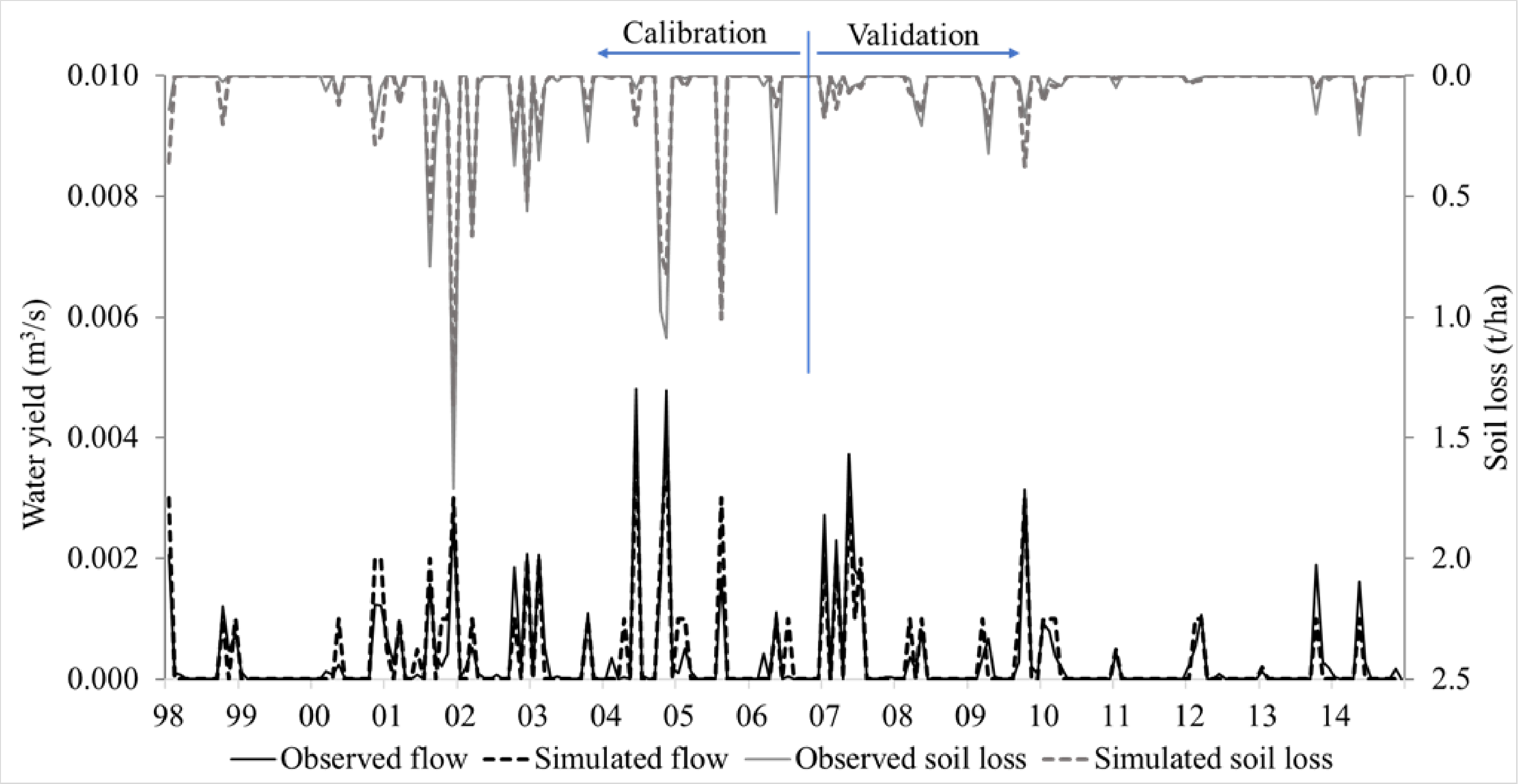

Figure 3.2 Observed and simulated monthly water yield and soil loss for the Y6 plot: 1998 – 2014

3.2.2. Scenario Analysis

The calibrated model was used to investigate the effect of several different cropping systems in table 2 on sediment export from the study area. The scenarios reflect common crops grown in the Blacklands Prairie ecoregion and on experimental plots in the study area. This scenario-based assessment offers a relational comparison of the effects of different cropping systems on the hydro-sedimentological processes, enabling the identification, selection, and implementation of cropping systems that provide higher ecosystem services. All cropping scenarios were simulated for 17 years (1998-2014). The average monthly and annual soil loss for the 2000-2014 period from the field was then determined under each scenario and compared with alternative scenarios.

Table 3.2 Description of Cropping Systems Investigated During the Study

Scenario	**Calibration**	**Validation**
CORN	Corn for grain	Continuous Corn, conventional tillage, fertilize in March, harvest grain in August.
WWHT	Winter wheat for grain	Continuous wheat, conventional till, fertilize in October, plant in November, harvest grain in June.
SWHT	Spring wheat for grain	Continuous wheat, conventional tillage, fertilize and plant in rows in March, harvest grain in August.

Table 3.2 Continued

Scenario	Calibration	Validation
SWCB	Switchgrass for bio-energy	Plant in March in the first year, fertilize in May, bale in November for the next 16 years.
SWCH	Switchgrass for hay	Plant in March in the first year, fertilize in May, bale in May, July, September for the next 16 years.
RNGE	Native prairie harvested for hay	Plant in March during the first year, fertilize in March, bale in July for next 16 years

We compared simulated quantities of water balance components and soil loss from winter wheat (Triticum aestivum) and corn (Zea mays) cropping systems to related quantities from the study area when restored to rangeland to determine the impact of restoration activities. We used the Little bluestem plant (Schizachyrium scoparium) to simulate a meadow of native prairie. The Little bluestem is the dominant plant community in the Mollisol tall Blackland Prairie that is native to the study area (Wayne et al., 2007). The impacts of row cropping vs. small grain systems on sediment retention were investigated by comparing model outputs under a winter wheat system and corn cropping system. Wheat and corn are the most grown field crops by acreage in the US (USDA-NASS, 2018). We assessed the benefits of spring cropping vs winter cropping by evaluating soil loss under winter wheat and spring wheat cropping systems. Winter wheat is planted in the fall and harvested in the late spring/early summer. Spring wheat is planted in the spring and harvested in late summer or early fall. This comparison is necessary to investigate the environmental ramifications of systems with tilling and planting activities in the fall (winter wheat) relative to systems with similar operations in late winter/early spring (spring wheat). Lastly, to determine the benefit associated with growing tall grass forage for bio-energy or pasture, we simulated soil loss from two switchgrass (Panicum virgatum) systems. A switchgrass system where the plant is grown for bioenergy production and a system where switchgrass is grown and baled for hay. Traditionally switchgrass has been grown for use as a forage crop (Keshwani and Cheng, 2009). Recent research has however emphasized the growing of switchgrass for bioethanol production due to its high cellulose content (Wright and Turhollow, 2010). When grown for hay, switchgrass is traditionally harvested two to three times, in spring and during late summer (Douglas et al., 2009). However, when grown for biofuel, several studies (Cassida et al., 2005; Mitchell and Schmer, 2012) recommend only one harvesting operation during the fall season after a killing frost. We adopted one harvesting operation for switchgrass when used for biofuel and three operations when harvested for hay (Table 2.2).

The above cropping systems have previously been practiced on different field plots across the globe, often using conventional tillage for seedbed preparation. In traditional conventional mechanized crop production systems, seedbed preparation consists of two or more field operations aimed at turning, breaking, cutting and mixing the soil, sods, and crop residues and smoothening the surface of the land for subsequent field operations. Tillage practices at the study area often include two primary tillage operations with a chisel plow and tandem disk after harvest and secondary tillage using a field cultivator usually a few days before planting of crops. During model set-up, we adopted this conventional tillage practice and field operations previously used within or near the study area during the simulation of cropping scenarios. All cropping systems are rain-fed with no supplemental irrigation practiced.

3.3. Results

3.3.1. Soil Loss Under Field Cropping Systems

A comparison of corn, spring wheat, and winter wheat systems showed that the spring wheat system retained more soil than the other two crop systems. Growing spring wheat instead of winter wheat or corn improved soil retention annually by about 26% and 20%, respectively (Table 3). Erosion under a winter wheat system is distinctively high from August to January compared to other systems (Fig. 3). Arguably, this could be due to the occurrence of seedbed preparation activities in fall and the fact that the soil cover is minimal during the early winter season for the winter wheat system when the plants are in their early growth stage. The high soil loss rates in August under both cropping systems was due to the occurrence of extreme rainfall events in 2001 and 2005. In both years, abnormally high rainfall amounts were recorded at the study area during a usually dry period. High erosion rates are justified considering there is minimal or no soil cover during this period after harvesting the field crops. As shown in Figure 4, runoff from the winter wheat system is not considerably higher than that from the other systems during the August-January period, implying that the increased soil loss in the winter wheat system was not due to higher runoff alone, but rather the state of the landcover and soil properties.

Table 3.3 Mean Annual Simulated Water Budget and Soil Loss Quantities for Cropping Scenarios From the 6.6 ha Y6 plot, Riesel, TX.

	Scenarios	**Evapo-transpiration (mm)**	**Runoff (mm)**	**Percolation (mm)**	**Soil loss (kg/ha)**
Cropping systems	WWHT	587	160	190	764
	CORN	704 (+20)	186 (+16)	46 (-76)	710 (-7)
	SWHT	599 (+2)	168 (+5)	169 (-11)	572 (-25)
Grass systems	SWCH	794 (+35)	73 (-54)	67 (-65)	166 (-78)
	SWCB	765 (+30)	76 (-53)	94 (-50)	99 (-87)
	RNGE	774 (+32)	77 (-52)	87 (-55)	212 (-72)

Figures in parenthesis are calculated percentage changes relative to simulated quantities under the winter wheat cropping system

From figure 3.3, it can also be seen that soil loss under the spring wheat system is consistently lower than that under a corn system. The difference between the two systems is particularly high in late summer (July, August) when all the crops are mature. A mature wheat plant community is expected to lead to less runoff and soil loss compared to the corn plant community. Corn is planted in rows far enough apart that most of the soil surface is exposed to rainfall impact, compared to wheat.

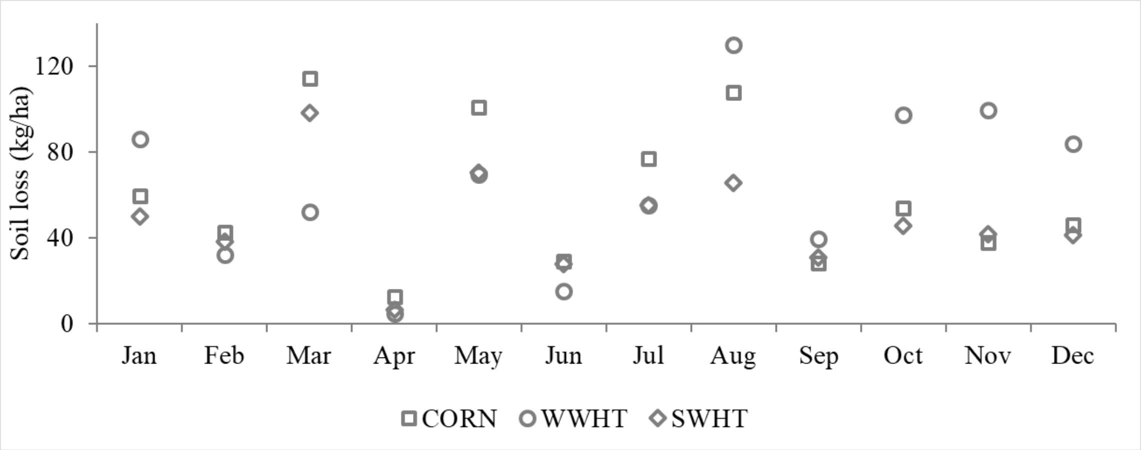

Figure 3.3 Monthly mean soil loss for wheat, corn, and wheat-corn cropping systems

Harmel et al., (2006) analyzed the measured soil loss at the study area and determined that the corn system leads to less soil loss than the wheat system. The results of this study show that not all wheat systems lead to more soil loss. When grown on the same piece of land under similar climatic conditions and field practices, a wheat system retains more soil than a corn system as exemplified by the lower soil loss rates under the spring wheat system (Table 3.3). Like in Harmel et al., (2006) though, this study showed that annual soil loss under a corn system is lower than that from a winter wheat system (Table 3.3).

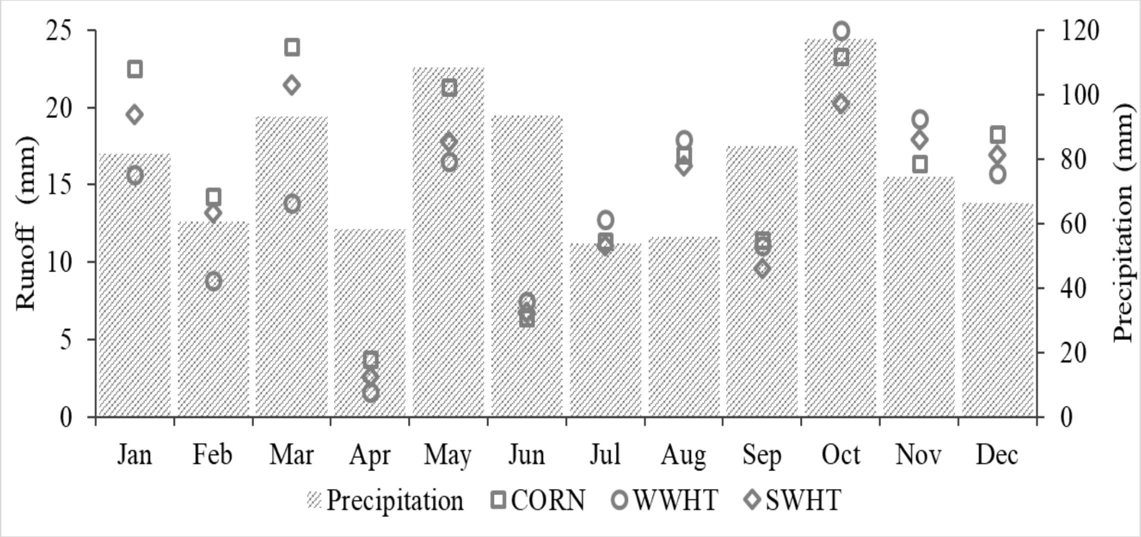

Figure 3.4 Mean monthly precipitation and edge of field runoff under corn, winter wheat, and spring wheat cropping systems.

3.3.2. Soil Loss Under Grass Systems

The simulated soil loss and water budget components for the study area under the two switchgrass systems show that the use of switchgrass as a forage feedstock leads to higher soil losses and less groundwater recharge. The decrease in water yield when a hay system is replaced by a biofuel system is minimal (-3% change) although the increases in soil loss and the water that percolates are significant (38% and 39% respectively) (Table 3.3). The results imply that extra harvesting operations have a bearing on the landscape's hydro-sedimentological processes, particularly on erosion and groundwater recharge, since the distinguishing feature amongst the cropping systems was the difference in the number and scheduling of harvesting operations.

Soil loss under a simulated restored native prairie grassland system is higher than soil loss under either switchgrass system (Table 3.3). This is despite the prairie system being harvested once, like the switchgrass for biofuel system. During scenario compilation and model set-up, the Little bluestem plant was used in the crop module for the prairie grasslands system compared to the switchgrass plant in the crop module for the switchgrass system. The Little bluestem plant community, however, does not establish a soil cover that is tall and dense as that for switchgrass (Steinberg, 2002; Uchytil, 1993). The high soil cover under the switchgrass systems may likely be the main factor leading to more soil retention relative to the prairie system.

Generally, evapotranspiration rates are high for all the grassland systems compared to field cropping systems (Table 3) and account for about 80% of the total precipitation in grassland systems. Both annual evapotranspiration and runoff rates do not differ considerably amongst the different grassland systems. Therefore, irrespective of the grassland system adopted, programs that replace field cropping systems with grass systems lead to reduced runoff. The differences in soil lost under different grassland systems are considerable. As seen in Table 3, growing switchgrass instead of restoring farmlands into a native prairie land cover leads to more soil retention. Better still, when switchgrass is grown for biofuel production, the landscape's soil retention services are further enhanced. This may mean whereas all grassland systems may be used to mitigate high runoff impacts such as flooding, there is a need for selective consideration of which grasslands to use for soil erosion control.

3.3.3. General Discussion, Implications and Conclusion

The study demonstrates that irrespective of the grassland system adopted (restoration to native prairie or growing switchgrass), environmental benefits are significant when the food cropping systems are replaced by grass systems. In both cases, soil retention is enhanced by more than 70%. As shown in Figure 5.5, monthly soil loss increases exponentially with an increase in precipitation for corn and wheat cropping systems although the relationship is linear for the grass system. In croplands with relatively less plant cover, high rainfall events translate to high runoff events, which lead to high erosion rates. However, for grasslands, the dense grass cushion reduces the erosive power of high rainfall events. The grasslands also provide year-round soil cover which helps improve soil retention compared to annual cropping systems that leave the farmland bare after harvesting and during the early growing seasons.

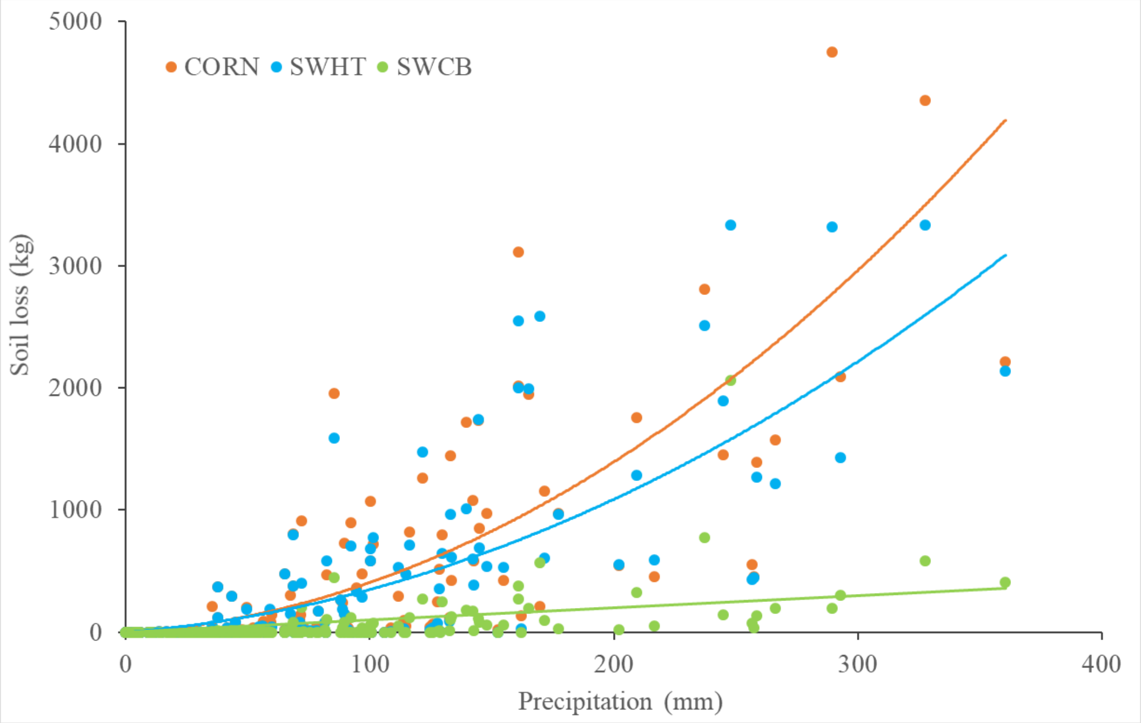

Figure 3.5 Relationship of monthly soil loss to precipitation for wheat, corn, and switchgrass cropping systems.

The global production and use of bioethanol from agricultural feedstocks have increased dramatically in recent years, from 17 billion liters in 2000 (Balat and Balat, 2009) to 100 billion litters in 2016 (Mohanty and Swain, 2018). In the US., approximately 40.5% of the 2011 corn croplands were used for ethanol production (Mumm et al., 2014). There are multiple concerns about the use of food crops for energy production (Hertel, 2011). The most compelling argument against using food crops as energy crops is that such crops would otherwise provide nutrition to the hungry (Hertel, 2011; Mohanty and Swain, 2018). The increased usage of fertilizers associated with ethanol production brings with it environmental consequences such as eutrophication of waterways (Vitousek et al., 2009). Also, the use of croplands for biofuels has been determined to accelerate greenhouse gas emissions to the environment (Searchinger et al., 2008). Because plants like switchgrass have been determined to be viable alternatives to corn as sources of energy, their use could alleviate these concerns. Contrary to corn cropping systems, in addition to retaining more soil, grassland systems require fewer fertilizer inputs and ensure that much of the arable land is left for food growing. The adoption of grassland systems as alternative sources of feedstocks for energy production would, therefore, enhance food security.

In addition to soil erosion mitigation, grassland systems, whether switchgrass for hay or bio-energy or restoring agricultural croplands to the native prairie have added ecological and environmental benefits. Globally, terrestrial grasslands store more carbon than the amount stored in forests or any other ecosystem (O'Mara, 2012). Werling et al. (2014) reported that grasslands harbor significantly greater biodiversity of multiple taxa than annual crops and sustain a variety of ecosystem functions like pollination. Also, Karlen et al. (1999) and Zaibon et al. (2016) found out that soil quality indicators are improved by placing highly erodible cropland into perennial grasslands. The ability of grassland plants to grow on marginal lands (Blanco-Canqui, 2016) in addition to providing the above highlighted environmental and ecological benefits, accentuates the need to adopt grassland cropping systems into agricultural farming.

Results also show that spring wheat cropping leads to more soil retention compared to the winter wheat cropping system. Spring wheat improves soil retention by 26%, implying a policy emphasizing growing spring wheat could lead to retention of over a quarter of soil lost from wheat farms. Winter wheat represents 70-80 percent of total U.S. wheat production (Vocke and Ali, 2013), although, recently the acreage of spring wheat has been steadily increasing. The area of planted spring wheat increased by about 20% in 2018 from the previous year (USDA-NASS, 2018). Though the shift to the spring wheat systems is more of a coping mechanism due to the increased occurrence of mild winters unsuitable for winter wheat growing (Manley, 2000), such transitions could lead to more soil retention, spring wheat is replacing corn or winter wheat systems.

Lastly, we noted that evapotranspiration rates were consistently higher in grassland systems (80-85% of precipitation) than in field cropping systems (60-70% of precipitation). Evapotranspiration was particularly lowest in winter wheat cropping systems. Lower evapotranspiration rates guarantee that more water is available for other water budget components such as runoff in cropland systems. This could be responsible for the increased flows in the streams flowing through this region and the greater midwestern part of the US, which have undergone extensive landcover change from native tall prairies to farmlands (Schilling et al., 2008). Whereas the main reason for the cause of increased flows in this region varies amongst different scholars, with some attributing it to climate change (Frans et al., 2013; Qian et al., 2007; Tomer and Schilling, 2009), those that contend that it is landcover change (Schilling et al., 2008, 2010) highlight the reduced evapotranspiration rates associated with agricultural cropping systems. Irrespective of the cause for increased flows, landcover change could, without doubt, be the main cause of increased soil loss, since, from the discussion above, soil loss rates are relatively low in grassland land covers even during high rain events.

Overarchingly, the results of this study show that there is an opportunity to significantly reduce soil erosion by implementing specific cropping systems that have higher environmental benefits. Specifically, where practical, soil retention could be enhanced by adopting spring wheat cropping instead of the more prevalent winter wheat and corn cropping systems. Use of grassland systems as sources of fuel and feeds, in addition to warranting that most of the arable land is left for food production, significantly reduces soil erosion. The future and sustainability of the water-food-energy-environment nexus require us to meet human needs without harming the environment. Incorporating the merits and demerits of cropping systems and why one system should be preferred over the other during on-farm and policy decision making may go a long way in ensuring food and energy security, and environmental sustainability.

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4. A COMPOSITE INDEX-BASED APPROACH FOR MAPPING OF ECOSYSTEM SERVICES' HOTSPOTS AND COLDSPOTS FOR PRIORITY SETTING IN INTEGRATED WATERSHED MANAGEMENT PROGRAMS

4.1. Introduction

Landscapes provide a variety of water and climate regulation functions that are vital to humanity. They regulate water flow through canopy interception, litter absorption, storage in soils and under the ground. This, in turn, determines the timing and magnitude of runoff, flooding, and groundwater recharge. With runoff as the main driver of water-induced erosion (Blanco-Canqui and Lal, 2010), landscapes provide an important function of minimizing rates of soil loss by regulating water flow. Landscapes also regulate climate by sequestrating carbon from the atmosphere and storing it underground (Lal, 2008), thereby decreasing greenhouse gases in the atmosphere. The delivery of these water-related Ecosystem Services (ES) is influenced by the landscape's landcover-soil-terrain characteristics (Chapin et al., 2011). Because of the landscape's spatial heterogeneity, these services vary across space. Water-related ESs are also intangible, do not have market values and are difficult to quantify and value economically (Coates et al., 2013). In many cases, people are not even aware that the surrounding landscape provides these services and so, do not put emphasis on conservation and protection of the landscape. Moreover, the supply of these services is also threatened by unsustainable anthropogenic activities (Reid et al., 2005). Quantification, valuation, and mapping of these services can show high-value ecosystem service production areas (hotspots) that need to be protected or low-value areas (coldspots) that need to be restored to ensure adequate ES levels. Threats to ES can also be identified by comparing the spatial distribution of ES to maps of activities that affect the landscape's ability to provide ES such as land use activities. Assessments can also highlight the multi-functionality of landscapes (Grizzetti et al., 2016), justifying the need for investments in integrated watershed management (IWM) programs while at the same time fostering human well-being (Daily et al., 2009).

The incorporation of the concept of ES into policy-making has been derailed due to several factors. At local small scales, ES assessments have traditionally relied on site-specific quantification of benefits accrued from the landscape, despite this being a tedious and expensive process (Schägner et al., 2013). These small-scale assessments are hard to scale up to levels relevant to the management of ES (Birkhofer et al., 2015). On the other end of the spectrum, ES valuations at large scales are often based on extrapolated data from site-specific values (Liekens and De Nocker, 2013; Naidoo et al., 2008). Scaling up does not accurately represent the heterogeneity of complex landscapes since this does not account for the nonconstancy of marginal values (Liekens and De Nocker, 2013). This can, in turn, lead to over or underestimation of ES.

Even when quantified, the process of valuing and compounding benefits provided by landscapes is challenging. Different ES are quantified in different units and thus cannot be compared or aggregated. They need to be scaled to a unitary value such as a dollar value or a normalized index. Monetary approaches that assign dollar values to ES are widely used in their economic valuation (Alam et al., 2016; Francesconi et al., 2016). Although these approaches deliver robust estimates of ES values useful for policy decision making (Liekens et al., 2013), they are associated with high uncertainties due to the non-market nature of ES, the influence of societal perceptions of the monetary value of ES, and because quantification and valuation studies are often carried out separately (Schmidt et al., 2016).

Several studies recommend the use of hydro-ecological modeling approaches for quantification of ES (Maes et al., 2012; Vigerstol and Aukema, 2011; Volk, 2013). They argue that at both large and small spatial scales, ES assessments can benefit from landscape-scale process-based modeling approaches, mostly applied in watershed hydrological assessments, that consider the landscape's land-soil-water interactions. Fittingly, several studies emphasize the need to incorporate these land-soil-water interactions when quantifying ES (Bennett et al., 2009; Carpenter et al., 2009; Grizzetti et al., 2016) since the functioning of ecosystems depends upon earth system processes that take place over a range of spatial and temporal scales (Hein et al., 2006). IWM programs also stand to benefit from the incorporation of ecosystem service concepts. Despite the potential synergism, IWM and ES concepts are rarely used conjointly (Liu et al., 2013). IWM frameworks promote coordinated development and management of water, land and related resources, to maximize benefits while ensuring the sustainability of vital ecosystems (GWP, 2000). The concept of Es is appealing to help the implementation of IWM since it describes benefits people obtain from nature while accentuating the need for managing ecosystems in a way that ensures a sustainable supply of ES. IWM programs require determination of baseline conditions, identification of critical areas, and development of criteria to measure the impact of proposed measures. In fact, one of the key bottlenecks of implementing watershed management plans has been the lack of established criteria to measure benefits accrued from implementation of management measure—a case that has led to less interest from private entities to invest in watershed protection measures (Sklenar, et al., 2012a). A review by the US Environmental Protection Agency (USEPA) determined that the most significant weakness of the formulated watershed protection plans was the inability to simulate load reductions and provide a basis for monitoring the impact of measures implemented (USEPA, 2011). The integration of ES valuation addresses these bottlenecks. The consideration of multiple ES could also highlight the beneficial multiplicity of such programs thus attracting resource investment.

Despite the benefits of monetization when valuing ES, the uncertainty and complexity associated with monetary valuation approaches render the use of non-monetary valuation techniques worthy of consideration. Non-monetary techniques do not express the value of ES in monetary terms and do not reflect preferences defined under budget constraints. Valuation may be as simple as expressing the state of ES in qualitative terms (e.g., ‘‘poor,” ‘‘good,” ‘‘excellent”) (Martin and Mazzotta, 2018). For cases where the value of ES needs to be aggregated, the quantities of respective ES can be normalized into a single norm using mathematical concepts that are popular within the field of Multi-Criteria Analysis (MCA) (Langemeyer et al., 2016; Martin and Mazzotta, 2018). Normalized quantities can then easily be aggregated and mapped to show ES production areas associated with high ES value, for instance. Burkhard et al.

(2013) held the view that approaches that aid in aggregating output data, generate indicator maps and use modeling techniques without losing relevant information are needed to improve ES assessments.

This paper describes the development of a Composite ES Index (CESI), proposed for priority setting in watershed management programs. The composite index is derived by aggregating weighted normalized values of inferred carbon storage, groundwater recharge, surface water supply, and soil retention potential in a heterogeneous landscape of Texas, USA. Two hydro-ecological models, the Hydrologic and Water Quality System (HAWQS) (USEPA, 2017) and the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) (Sharp et al., 2018), were used to predict proxies of ES, which were then normalized, weighted and aggregated following a multi-criterion based non-monetary valuation approach to derive spatially explicit ES indices. Index values of individual services and the aggregated service were spatially mapped in their areas of production to highlight the distribution of these services and to show how they vary with land use, climate, and landscape physiography.

4.1.1. HAWQS and InVEST Modelling Frameworks

HAWQS is a web-based water quantity and quality modeling framework that uses the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998; Neitsch et al., 2011) as its modeling platform. SWAT is a comprehensive physically-based hydrological model (Arnold et al., 1998), which is considered one of the most suitable models for predicting the impacts of land management measures on water, sediment and nutrient loss in large complex watersheds (Arnold and Fohrer, 2005; Gassman et al., 2007; Shukla, 2011). As a hydrologic model, SWAT has been widely used to simulate watershed processes at different spatial scales (Bieger et al., 2017; Francesconi et al., 2016; Radcliffe et al., 2015). Although SWAT as a standalone model is recommended for quantifying ES (Vigerstol and Aukema, 2011), SWAT's watershed initialization and characterization processes require a lot of time and computing resources, especially when simulating large geographical areas. HAWQS advances the functionality and ease of application of SWAT by minimizing the necessary initialization time. Also, as HAWQS runs entirely on a web server, computing requirements are minimal.

The InVEST suite of models is a set of distinct modeling tools designed for mapping and valuing multiple ES provided by nature (Sharp et al., 2018). InVEST tools can be used to generate maps of services supplied by ecosystems, including carbon storage, water flow regulation, water purification, among others. They use production functions to convert maps of land use and land cover (LULC), land management, and biophysical conditions into maps of ES supply (Sharp et al., 2018). The tools used to simulate hydrological processes do not differentiate between surface, subsurface, and baseflow (Sharp et al., 2014) and are rather simplistic and inferior to comprehensive models such as SWAT in predicting hydrological components. For this reason, InVEST was only used to estimate the carbon storage potential. InVEST's carbon storage module has been used widely in several studies under different land-use scenarios (Guerry et al., 2015; Jiang et al., 2017; Polasky et al., 2011) and found to reliably estimate terrestrial carbon storage across space.

4.1.2. Multi-criteria Analysis and Ecosystem Service Valuation

Multi-criteria Analysis (MCA) is used as a decision analysis tool to determine preferences among alternative objectives, based on the analysis of a set of attributes. The actual measurements of the attributes need not be in monetary terms. With MCA, multi-dimensional or qualitative measurements of attributes can be converted into quantitative comparable unitary values. This approach is particularly suitable for valuing proxies of ES quantified by hydro-ecological models since the simulated variables are in different units, and the monetary valuation of such non-market services, like functions provided by the landscape in recharging groundwater resources, soil retention and carbon storage are complicated. Normalization techniques used in MCA can be used to scale the simulated multi-dimensional model outputs into a unitary system. Several normalization approaches exist. Commonly used techniques include those that assign zero to the worst value and 1 (or 100%) to the best value or compare each value with the best value using linear extrapolation equations (Podviezko, 2014). The normalized values can then be weighted based on a set of defined criteria to account for the relative importance of different ES across space and aggregated to determine the composite index corresponding to a particular ES production area. The areas can be ranked and characterized based on a rank score or based on a specific threshold to determine the high and low-value ES production areas. When spatially mapped, the individual and composite indices can show how the ES vary across space.

4.2. Materials and Methods

The study identified ES production hotspots and coldspots based on an MCA-derived composite ES index from imputed spatial maps of carbon storage, soil retention, aquifer recharge, and surface water supply indices for 1081 sub-watersheds, which form the major river basins of Texas (Fig 1a). The huge expanse of Texas encompasses several regions with distinctly different climates, soils, land cover, and terrain. Climatic conditions range from arid in the west to humid and subtropical in the east (Fig 1b). Piney woods cover the east-coastal high rainfall regions, bare desert in the west and undulating plains, hills, and mountains in the central part of the State (Fig. 1c). The diversity of the physiographic, climatic and topographic features of the State makes it an ideal candidate for evaluating how those features influence the locale, quantity, and distribution of ES.

Texas provides a wide range of ES whose spatial distribution and extent are largely unquantified, limiting the understanding of ES co-occurrence, the magnitude of supply, and the incorporation of ES into environmental management and planning. First, groundwater resources account for about 60 percent of the State's water needs (TWDB, 2012), yet groundwater supplies are declining (Wurbs, 2014). It is, therefore, necessary to identify areas in the State that replenish these resources so that they can be protected. Soil erosion affects the amount of good quality water available for consumptive and non-consumptive uses in Texas, particularly, surface waters. Sedimentation is notably responsible for the reduction of reservoir storage capacity across the state (Ward et al., 2007). Lastly, Texas is the largest contributor to greenhouse gas emissions in the US (Han et al., 2007), making the protection of high carbon sinks a necessity.

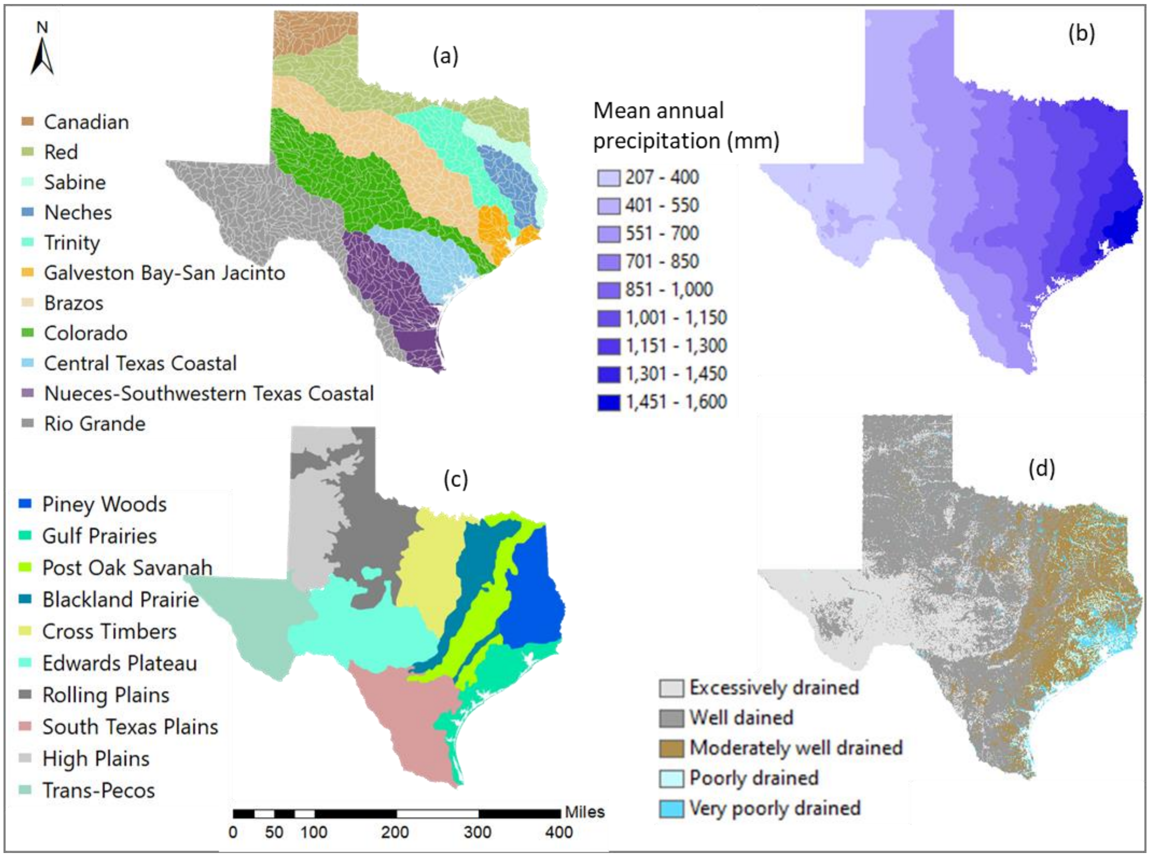

Figure 4.1 (a) Major river basins in Texas, (b) Isohyet map of Texas illustrating decreasing precipitation averages, East to West. (c) Ecological regions, and (d) Soil drainage characteristics.

4.2.1. Carbon Storage Estimation Using the InVEST Model

Given the pace of global greenhouse gas emissions, there has been a flurry of recent efforts to assess the carbon sequestration benefits provided by terrestrial ecosystems (Thomson et al., 2008). Annually, plants remove approximately one-fifth of the carbon present in the atmosphere (Keenan and Williams, 2018) through photosynthesis, converting it into short-lived pools such as leaves and humus, to long-lived pools in soils. The InVEST's Carbon Sequestration and Storage (CCS) module can be used to estimate the total carbon stored in terrestrial landscapes by aggregating carbon stored in both aboveground and belowground live biomass, dead aboveground litter and in the soil. The module requires the input of classified land cover raster data and estimates of carbon stored in each carbon pool for a particular land use category.

To estimate the carbon stored per hectare per watershed, we used the USGS 2016 National landcover geospatial dataset for Texas available at https://data.tnris.org/ and determined quantities of carbon stored in each pool. Carbon storage on a land parcel largely depends on the sizes of four carbon pools: aboveground biomass (living plant material above the soil), belowground biomass (living root systems of aboveground biomass), soil organic matter, and dead organic matter (litter, lying and standing deadwood) (Sharp et al., 2018). Landuse data were reclassified into landcover major categories (Table 1) following the classification scheme described by Anderson et al. (1976). Soil carbon pool estimates for Texas were processed from the 2019 gridded nationwide Soil Survey Geographic Database (gSSURGO) database which contains weighted average soil organic carbon (g C/m2) values for the conterminous US. Above and below ground carbon pool estimates used for forested areas were obtained from the national carbon density stock estimates prepared by the Forest Inventory and Analysis (FIA) program, available at www.fia.fs.fed.us/. Estimates of carbon stored in either pool for the remainder of the land-use categories were sourced from Sharp et al. (2014), Qiu and Turner (2013) and Smith et al. (1997) for water, developed area, rangeland, agriculture, and wetlands.

The model outputs a raster map of carbon stored per pixel. Using the zonal analysis tool in ArcGIS, the amount of carbon stored per hectare for each watershed was determined and a reclassified map showing the distribution of carbon stored in each sub-watershed for the entire state generated.

Table 4.1 Land use and average carbon pool estimates used for modeling carbon storage in Texas (Mg C/ha)

Land use	C above	C below	C soil	C dead
Water	0	0	0	0
Built-up area	5	3	20	0
Forest land	90	60	110	30
Rangeland	6	6	20	2
Cropland	3	2	8	1
Wetland	10	5	25	0

4.2.2. Estimation of Water Percolation, Surface Runoff and Soil Loss Using HAWQS

The HAWQS model was used to simulate hydrological processes for all 1081 sub-watersheds for the entire state of Texas at an annual timescale using the SWAT 2012 rev. 670 model version (USEPA, 2017). Annual estimates were appropriate since the long-term mean ecosystem condition of the watersheds were being studied. SWAT model setup required specifying watershed characteristics such as land use, topography, soil parameters, weather, and field management operations. A key advantage of the HAWQS model is that it includes these land use, soil, and topography databases and climatic data sources that can be used without further reprocessing. The simulation period covered 30 years (1986-2015) after a 3-year warm-up period (1983-1985). During watershed definition, the threshold for HRU discretization was set at zero so that the contribution of all land use categories, soil and slope properties were considered.

4.2.3. Valuation of Ecosystem Services Using a Multi-criteria Analysis Approach

Percolation of water through the porous spaces of the soil and rocks is the primary method through which water enters an aquifer (Alley, 2009; Seiler and Gat, 2007). For this reason, measurement of percolation rates is increasingly used in ES assessments to quantify the impact of land-soil-terrain characteristics on groundwater recharge as an ecosystem service. By comparing rates of percolation across spatial scales, it is possible to establish which combination of landscape characteristics influence groundwater recharge, thus, providing a basis for determining the relative groundwater ES provided across space. The same argument applies to runoff and soil loss. Areas associated with high runoff rates are likely to contribute more water into reservoirs used for water supply than those with low or no discharge. Note that the same areas can be sources of floodwaters, and may be associated with high sediment losses. In the above two aspects, areas susceptible to high runoff rates would have low ES values, despite providing more water for reservoir recharge. Clearly, the surface water generation and flow regulation function provided by landscapes can lead to multiple benefits, some obverse to the others. This study, as regards to the surface water generation and flow regulation function, explores only the role of landscapes in providing surface water for consumptive uses. Therefore, high runoff areas that relatively contribute more water to downstream reservoirs provide a higher surface water supply service compared to those with low runoff rates. Similarly, areas with high erosion rates retain less soil and will provide a low soil retention ES function. The same argument holds for carbon storage since areas that store more carbon such as forested areas will provide a higher sink than those with low carbon storage potential. In this study, we used an MCA approach to attach values to the above ES in their production areas so that we can compare how the services vary across space.

Long-term (30 years) mean annual percolation (mm), runoff (mm) and carbon storage densities (Mg C/ha) for all sub-watersheds in Texas were normalized using a maximization function (eq. 1) and a minimization function (eq. 2) was applied for soil loss. This was because the objective of natural resource management programs is to minimize soil erosion rates, maximize percolation for groundwater recharge, augment water yield for reservoir recharge, and enhance carbon storage. The two transformations compare each value to the highest value. Equation 1 assigns high norms to variables with high values whereas equation 2 assigns high norms to variables with low values.

$$y_{ij}^{*} = \frac{y_{ij}}{y_j^{max}} \qquad (1)$$

$$y_{ij}^{*} = 1 - \frac{y_{ij}}{y_j^{max}} \qquad (2)$$

y_{ij}^{*} is the normalized value for the i-th alternative and j-th attribute, y_{ij} is the original value for the i-th alternative and j-th attribute, and y_j^{max} is the maximum value for the j-th attribute

The relative importance of each ecosystem service in its area of production was considered by assigning weights that highlight the benefit of a service being produced in one area versus another. This is important because, for instance, a downstream watershed with high runoff rates but which drains directly into the ocean may not benefit more people than an upstream watershed with similar or low runoff rates. We considered whether a watershed was underlain by a minor, major or no aquifer in assigning weights to watersheds for the groundwater recharge (GWR) ecosystem service. Major aquifers are those that supply large quantities of water in large areas, whereas minor aquifers typically supply large quantities of water in small areas or relatively small quantities in large areas (Ashworth and Hopkins, 1995). For surface water supply, watersheds that drain into more reservoirs are likely to benefit more people than those with no downstream reservoirs. Consequently, watersheds with many downstream reservoirs were assigned higher weights than those draining into few or no reservoirs. For soil loss, watersheds with soils deemed more productive were assigned higher weights. Schaetzl et al. (2012) generated a soil productivity index dataset for the entire conterminous USA based on taxonomic features that tend to be associated with soil productivity (organic matter content, clay mineralogy, and cation exchange capacity). The soil productivity map for Texas (Fig. 2b) was processed from the above dataset and reclassified to show the location of low and high productive soils in Texas. Lastly, the social benefit of sequestrating carbon was assumed to be higher in areas associated with high carbon emissions. For all criteria, the weighting was based on a 3-point Likert scale (Table 2).

Quantile ranges were used to determine thresholds for the quantitative criteria. Values within the first quantile were assigned a weight of 1, and 3 for those values above the third quantile value. Reservoir and aquifer data were obtained from the Texas Water Development Board (TWDB, 2014, 2017). Carbon emissions and land use data were obtained from the USEPA greenhouse Gas inventory database (USEPA, 2020) and the Multi-Resolution Land Characteristics (MRLC) consortium – National Land Cover Database (NLCD, 2016) respectively. Both data sets were re-processed into the three Likert scales (Fig. 2) using zonal analysis and processing tools in ArcGIS.

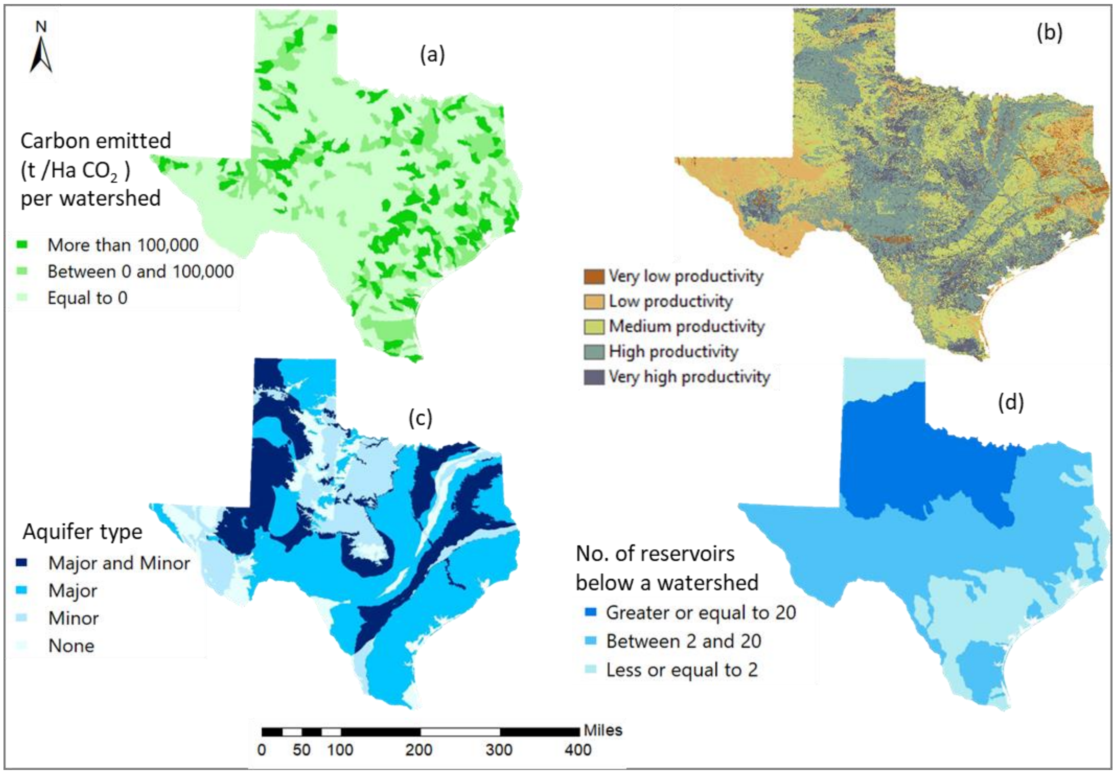

Figure 4.2 (a) 2018 CO2 gas emissions, (b) Soil productivity, (c) Major and Minor aquifers, and (d) Reservoir density map for Texas.

Table 4.2 Criteria for assigning weights to reflect the relative importance of ecosystem services across space

Service	Weighting criteria	Likert scores / multipliers (w=1,2,3)
Groundwater recharge (G)	Does an underlying aquifer exist to store the water that percolates?	[1]$G_{nw} = \begin{bmatrix} [2]G_n\ x\ 3, & for\ major\ aquifer \\ G_n\ x\ 2, & for\ minor\ aquifer \\ G_n\ x\ 1, & for\ no\ aquifer \end{bmatrix}$ (3)
Surface water supply (R)	How many reservoirs (r) are located below the watershed to runoff?	$R_{nw} = \begin{bmatrix} R_n\ x\ 3, & r > 5 \\ R_n\ x\ 2, & 5 \geq r > 1 \\ R_n\ x\ 1, & r \leq 1 \end{bmatrix}$ (4)
Soil retention (S)	The productivity of the soils within the watershed	$S_{nw} = \begin{bmatrix} S_n\ x\ 3, & for\ highly\ productive\ soils \\ S_n\ x\ 2, & for\ moderately\ productive\ soils \\ S_n\ x\ 1, & for\ low\ productive\ soils \end{bmatrix}$ (5)
Carbon storage (C)	How much carbon (t/ha CO2) is emitted (e) from the watershed?	$C_{nw} = \begin{bmatrix} C_n\ x\ 3, & e \geq 100{,}000 \\ C_n\ x\ 2 & 100{,}000 > e > 0 \\ C_n\ x\ 1, & e = 0 \end{bmatrix}$ (6)

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[1] G_{nw} is the normalized and weighted groundwater recharge index

[2] G_n is the normalized ground water recharge value

Simillary, R_{nw}, S_{nw}, and C_{nw} are surface water supply, soil retention, and carbon storage indices respectively.

Spatial maps of values for individual ES and the combined composite ES were processed using ArcGIS tools. To spatialize the ES hotspots and coldspots, we classified the resulting ES values into four percentiles. Watersheds with values in the upper percentile (75th percentile and above) were categorized as hotspots. Coldspots were those in the lowest percentile. Similar criteria based on percentiles were used in several previous studies (Egoh et al., 2011; Mokondoko et al., 2018; Muradian et al., 2013). We quantified relationships between individual services to determine whether the supply of services in their areas of production was interrelated. We also identified relationships between the spatial distribution of the values of ecosystem services with climatic, soil and land-use patterns to determine how these factors influenced the production of ES.

4.3. Results

4.3.1. Provision and Spatial Distribution of ES

Groundwater recharge ES values were markedly high for areas East of the 96o longitude (Fig. 3a). Downstream watersheds in the Sabine, Neches and Red River basins in East Texas had the highest ecosystem service values. Specifically, the (i) Jim Bayou-Frazer Creek in the Red-Sulphur Basin, (ii) Little Cow Creek in the Sabine Basin, and (iii) Turkey Creek-Village Creek in the Neches Basin provided the highest GWR ecosystem service. These areas are underlain by the Gulf Coast and Carrizo-Wilcox major aquifers (Fig 2c) which run from northeast to the southern part of the State. Indices gradually decrease westwards (Fig. 3a) and were lowest in the City of Socorro Watershed in the Rio-Grande Basin, in the headwaters of Blackwater Draw Watershed of the Brazos Basin, and in the North Big Blue Creek Watershed of the Canadian River Basin.

Like groundwater recharge, values of the carbon storage ES were highest in the humid subtropics of the eastern part of the State covered with piney woods and lowest in the arid west and in the high plains of northern Texas (Fig. 3b). Carbon storage potential was highest in West Fork San Jacinto River (San Jacinto), Big Sandy Creek (Neches), Little Cypress Creek (Sabine), Long King Creek (Trinity) watersheds and lowest in the Miller Airfield-Elephant lake and East Rita Blanca Creek watersheds in the Canadian, and Frio Draw in the Red River basin. Substantial high-value carbon storage hotspots were scattered across the central part of the state (Fig 3b), particularly in the Edwards Plateau region (Fig 1c) and in coastal areas. In these regions, most of the carbon storage potential was in the below-ground pool whereas high above ground carbon storage densities were concentrated in the northeastern part of the state (Fig. 4).

The production of the Surface Water Supply (SWS) service was highest in the coastal watersheds of the Galveston-San Jacinto Bay area, in the downstream watersheds of Trinity and Neches Basins, and in several watersheds located in the Middle Brazos and Upper Trinity Basins (Figs. 3c, 1a). In the Galveston-San Jacinto Bay area, indices were highest in the Brays Bayou and White Oak Bayou-Buffalo Bayou watersheds which are part of the urban greater Houston metropolitan area. Relatedly, in the upper Trinity Basin areas, surface water supply indices were highest in the Timber Creek and Big Fossil Creek watersheds which drain the Dallas-Fort Worth urban areas. Like groundwater recharge, indices were low both in the western and northern arid lands majorly due to low rainfall received in these areas. In both Upper Brazos and Trinity Basins, indices were also noticeably high in watersheds draining the Black Prairie ecoregion – typified by a high percentage of land under the cropland land-use system.

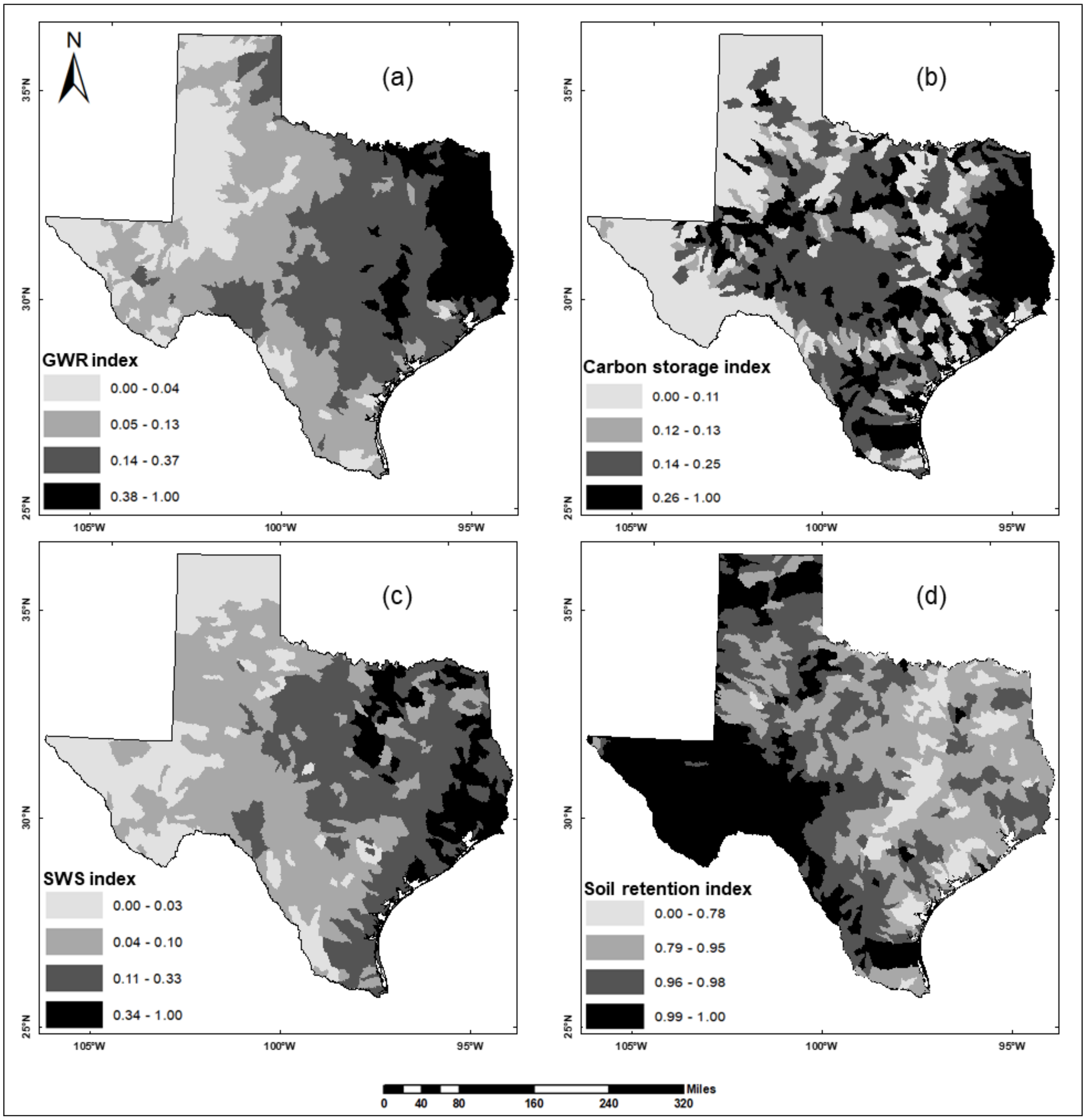

Figure 4.3 Modelled spatial distribution of index values of (a) groundwater recharge (GWR), (b) carbon storage, (c) surface water supply (SWS), and (d) soil retention ecosystem services in Texas.

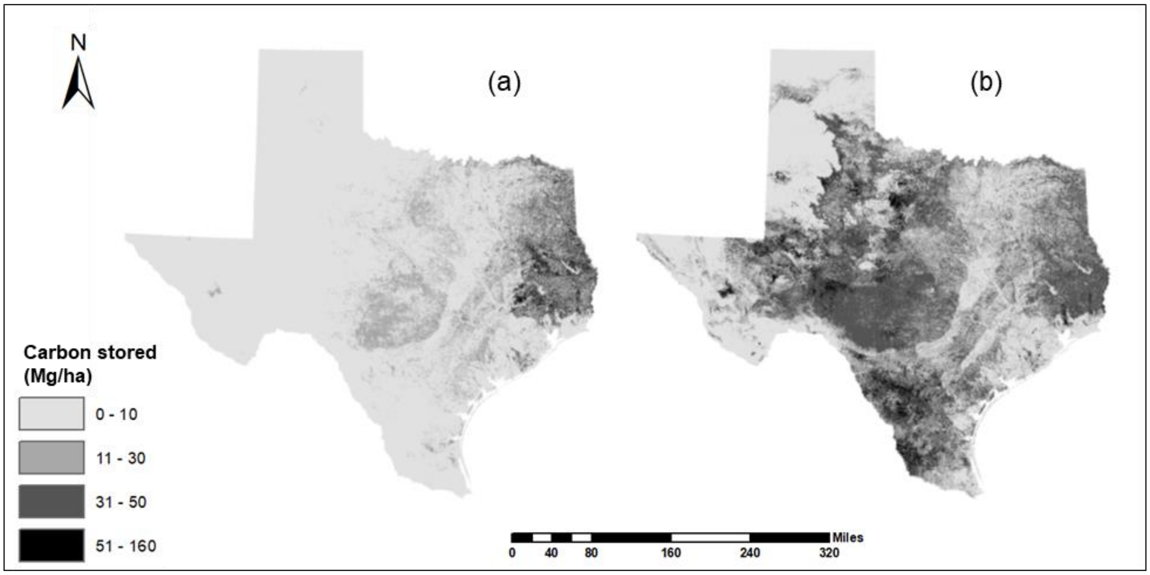

Figure 4.4 Carbon storage densities for (a) above ground and (b) soil carbon pools across Texas.

Soil erosion rates were generally high in the Blacklands Prairie ecoregion and in several parts of the coastal gulf prairies, all of which have relatively high percentages of land under the cropland system. Consequently, the soil retention ES was lowest in these highly agricultural watersheds (Fig 3d). A majority of the watersheds in the Trans Pecos ecoregion receive less than 500 mm of rainfall annually (Fig. 1c) and have very well-drained clay-sandy soils (Fig 1d). Consequently, water-induced soil loss is very low. Therefore, the modeled soil retention values in this region were high (Fig 3d). Lack of soil moisture and high wind erosion are the major soil-management problems in these areas (Gillette and Hanson, 1989; Webb et al., 2017). Patches of high-value soil retention ecosystem value areas also exist in the well-drained central Rio-Grande plains and northern Canadian valleys.

Despite a general trend showing the co-location of high-value ecosystem services mostly in the eastern part of the state (Fig 3), the delivery of most of the ecosystem services was not related. Correlations between values of the simulated ecosystem services were unexpectedly low (Fig 5). Of all the paired ES, SWS and GWR services had the highest correlation (0.34). This is expected since as hydrological processes, they both depend largely on the amount of rainfall received. Among the remaining paired combinations, the correlation was highest for GWR and carbon storage ES, possibly due to the impact of biomass cover on the infiltration process. Because water-induced soil erosion was lowest in arid areas which generally had lower values of GWR, SWS and carbon storage ES, a negative correlation between soil retention and other ES were realized (Fig. 4.5). The correlation with soil retention was however high for SWS and lowest for carbon storage.

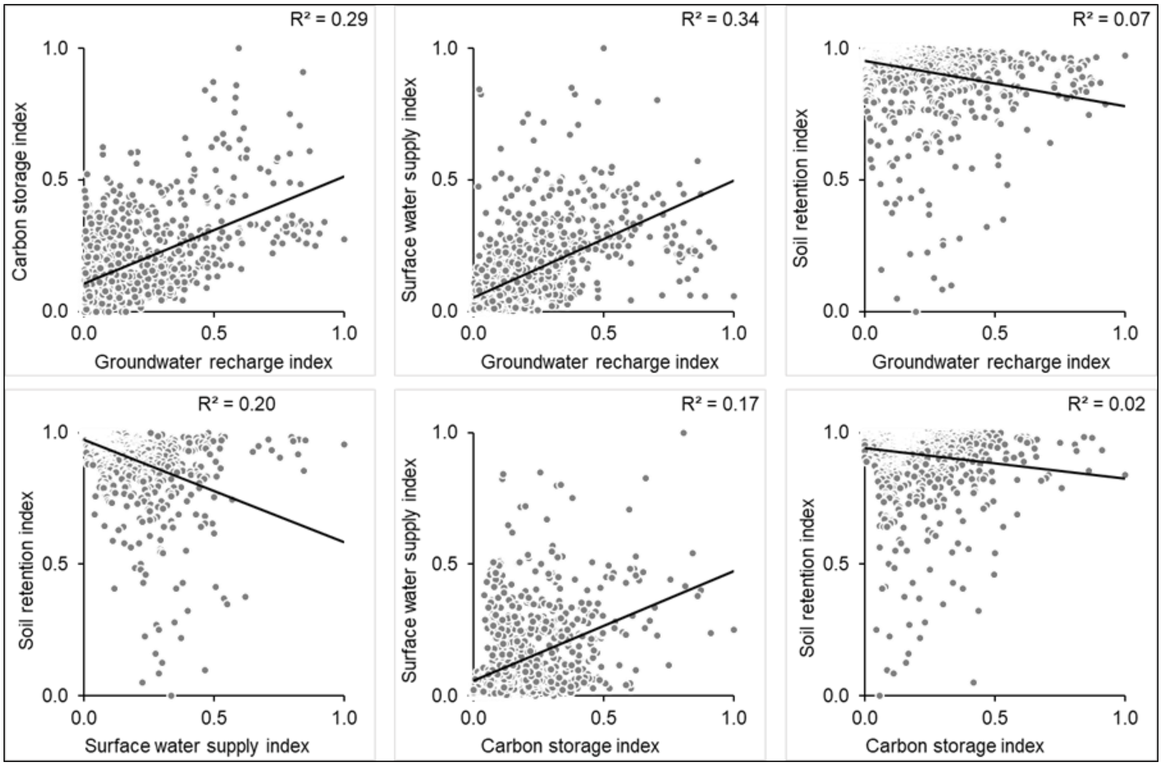

Figure 4.5 Pairwise correlation analysis of values of simulated ecosystem services.

4.3.2. Spatial Distribution of Coldspots and Hotspots Based on Total Ecosystem Service Value

Figure 6 shows the values of total ES values categorized into pentiles. The first pentile with ES values below 1.1 shows the direst coldspots. Conversely, those in the fifth pentile, with ES values greater than 2 are the State's most healthy hotspots. In totality, most of the watersheds in Texas were coldspots (60%) although only 18% (196 watersheds) of the total watersheds are in a dire state. Healthy ecosystems providing multiple ecosystem services were limited in Texas, accounting for only 16% (ES value > 1.7) of the total watersheds. The low percentage (8%) of watersheds with ES values >2 out of a potential maximum of 4 highlights the scarcity of hotspots in Texas. Also, the fact that hotspots generally had low scores, shows that there is potential to improve the amount of ES provided even by the hotspots.

Most of the State’s total ES hotspots were located in the east, with several patches of hotspots scattered in the central part of the State (Fig. 6a). All four ES were considerably high in the humid areas of East Texas. Therefore, it comes as no surprise that most of the hotspots were located in this region. Unexpectedly, the lowest value cold spots were in the central parts of the state. The Pond Creek, Big Elm Creek, Turkey Creek watersheds, all in the Middle Brazos River Basin and the headwaters of San Antonio River watershed in the Central Texas Coastal basin had the lowest aggregated ES value. On the other end of the spectrum, the Tenmile Creek and Big Sandy Creek watersheds in the Neches, the Old River watershed in the Trinity and the Adams Bayou in the Sabine watersheds had the highest ES values. Coldspots, particularly in the center of the State are potential areas for restoration programs since climate is not the limiting factor for the low total ES value.

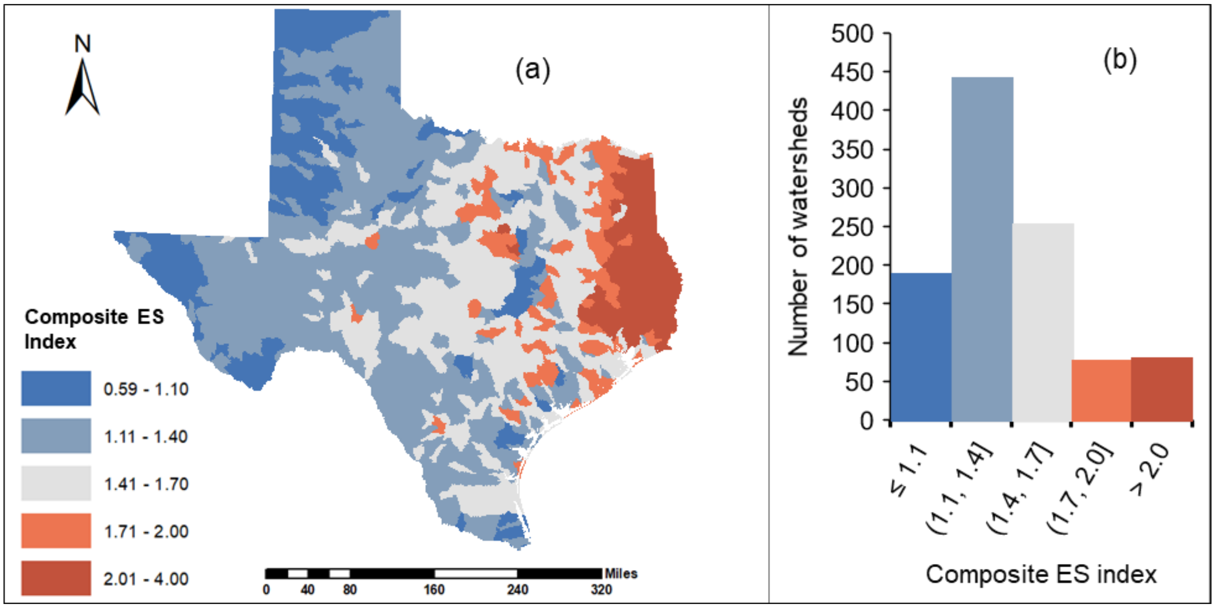

Figure 4.6 (a) Spatial and (b) frequency distributions of total ecosystem service values across Texas

4.4. Discussion

4.4.1. Factors Influencing the Location and Values of Ecosystem Services

In concordance with climatic, land use and physiographic heterogeneity of landscapes in Texas, the supply of individual and total ES varied significantly across space. Generally, though, high-value ES provision areas for groundwater recharge, surface water supply, and carbon storage were co-located in the eastern part of the State and low values in the west, in harmony with the distribution of rainfall in the state. Conversely, soil retention values were higher in areas that received low amounts of rainfall. This is so because, with minimal or no rainfall, rainfall-runoff induced soil loss is also minimal. This, however, does not mean that other types of soil erosion do not exist. Prior studies by Gillette and Hanson (1989) and Webb et al. (2017) established that soil loss is majorly by wind erosion in the arid regions of the western part of the State. Per several studies (e.g., Roces-Díaz et al., 2018), rainfall was the main driver of the spatial variability of ES. Pairwise correlations were particularly high for precipitation with groundwater recharge and surface water supply ES values compared to correlations of precipitation with the rest of the ES (Fig 7).

Unlike the supply of the groundwater recharge ES that gradually decreased westwards congruently with decreasing precipitation, pockets of high- and low-value carbon storage, surface water supply, and soil retention ES were clustered across the state (Fig. 3). The influence of land use on the location of surface water supply and soil retention services was discernible considering that low-value soil retention production areas were in highly agricultural areas, whereas both urbanized and highly agricultural areas consistently had high surface water supply indices. Despite the obvious impact of climate variability on soil loss and runoff, several studies concur that human activity and related land use change are the primary causes of accelerated soil erosion (Borrelli et al., 2017). The high scatter of the carbon storage ES was swayed by the high below-ground carbon storage potential. This pool, as shown by the results of this study, stored more carbon than the above-ground phytomass. This agrees with global estimates that show that carbon stored in soils far exceeds the amount of carbon stored in phytomass and the atmosphere (Scharlemann et al., 2014).

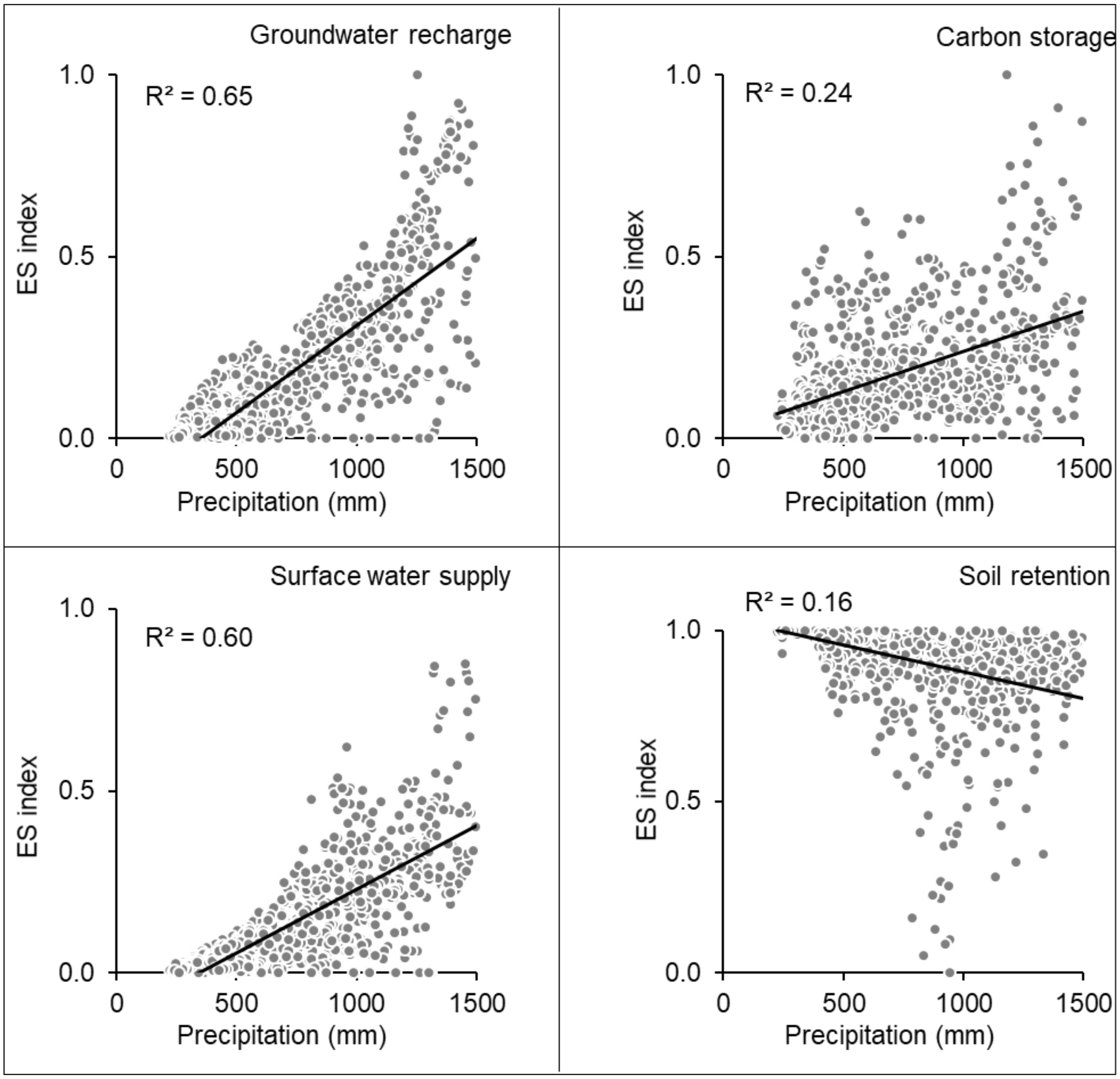

Figure 4.7 Relationship between precipitation and simulated ecosystem service values.

4.4.2. Water Resources Management Implications

The concept of ES was developed to describe the benefits people obtain from ecosystems (Reid et al., 2005). It is therefore important that ES services be located in areas where they can readily be delivered to people. The results of this study showed a clear spatial unevenness in the distribution of ES across the state, implying that access to these services will also, likely not be balanced. The concentration of SWS hotspots in coastal and agricultural areas may also pose a challenge. As evidenced above, the same agricultural areas have low soil retention values implying that the quality of surface water will likely be affected. Siting of reservoirs to collect waters from coastal hotspots could also pose a challenge for management. Similarly, for a region highly dependent on groundwater sources, the GWR service is concentrated in a small portion of the state, implying accessibility will pose a challenge for over 80% of Texas with GWR ES values below the mean value. Also, this service is highly reliant on precipitation, making it susceptible to the negative impacts of climate change such as adverse drought conditions.

Lumbering rates across Texas are highest in high carbon storage ES value areas. The Piney woods ecoregion accounts for 73% of the State's wood-product production (Hung et al., 2016). Historically, this ecoregion was well-stocked with extensive longleaf pine (Pinus palustris), but approximately only 3% of the Pinewoods habitat is still considered intact (Wall et al., 2019). Therefore, in addition to implementing measures that increase the acreage of high carbon storage areas, it is paramount that the existing hotspots be conserved.

4.4.3. Methodological Limitations and Opportunities

Technically, the evaluation of ES production areas based on an MCA approach is simple and straightforward. Simply put, the MCA approach used in this study involved quantifying different alternatives, multiplying weights by the scores, and summing the weighted scores to get an aggregate ecosystem value for each production area. Because the services are valued in abstract terms, to ensure the required buy-in for such a structured process (Thokala and Madhavan, 2018), the values that are attributed to the services should reflect the views and needs of stakeholders that benefit from the provision of ES. Stakeholders can have very different perspectives on the values of ES, based, among others, on their dependency upon specific services (Hein et al., 2006). A key strength of the MCA approach is its ability to bring in input by stakeholders at several levels such as when choosing weighting criteria and or setting thresholds for values of coldspots and hotspots. Irrespective of the scale and type of services being evaluated, lack of stakeholder participation in eliciting preferential values of ES can be a fundamental limitation of this methodology.

The study looked at four ES using four criteria to attach values of ES in their areas of production. However, the same areas provide other ES. Also, there are far more types of social, technical, institutional and infrastructure criteria that can be considered. Consideration of more ES would highlight, further, the productive multiplicity of landscapes thus attracting investments in environmental management. Bennett et al. (2009) confirmed the assumed strengths of this approach, arguing that research that quantifies the provision of multiple services leads to a better understanding of the value of nature. Despite the added benefits, the quantification and valuation of multiple services can be complicated. Whereas this can easily be done at large institutional levels, it may be limited by financial and technical resources when initiated by small institutions. Nonetheless, without compromising results, more ES and weighting criteria need to be included during the assessment of ecosystem services.

4.5. Conclusion

Ecosystem service hotspot and coldspot mapping provide a pathway for priority setting in IWM programs. Valuation techniques used in ES assessments provide a mechanism for establishing baselines and measuring progress in watershed management programs. Also, ES assessments stand to benefit from landscape process-based modeling approaches, popular in IWM programs. The approach used in this study highlighted the advantages of this integrated approach. Hydrological tools used in this study quantified proxies of ES at such a large (for the entire State of Texas), yet at a fine-scale (watershed level)- a feat not easily achievable when traditional small-scale field assessments are undertaken. Also, the use of MCA to value ES provided a simpler basis for identifying priority areas for resource management. Monetary valuation of the different non-market intangible services would have been more complicated. This important synergism amongst the two frameworks needs to be espoused as we attempt to address current and future water-related issues.

Approach aside, the results of the study showed a high congruency of the existence and distribution of ES with climatic and land-use characteristics. The supply of individual and total ES varied significantly across space, although a high degree of co-location of high-value ES provision areas was noted in the eastern humid part of Texas. Conversely, total ES were low in the arid west, and in the highly agriculturalized areas in the central part of the State. Therefore, both the distribution of rainfall and land-use activities markedly influenced the distribution of ecosystem service cold and hotspots.

Maintaining sustainable ES levels in this region will require putting at the forefront, management of the impacts of climate variability and land-use changes.

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5. CONCLUSIONS

Both the basin-wide older version of SWAT, the small watershed APEX and the new restructured version of SWAT (SWAT+) models use relatively similar equations, assumptions, and parameters when simulating water budget components, soil and nutrient losses. They also differ significantly on how they spatially conceptualize the routing and flow of runoff and water quality loadings through watersheds. When their performance was evaluated in simulating water quality and quantity variables at a micro spatial scale, the performance of the three models was different before calibration but all had near-equal performance after calibration. When calibrated, all the tools satisfactorily predicted water quantity and quality variables with exceptionally high indices. The uncalibrated SWAT model performed better than other models in simulating water yield and soil loss. It is thus recommended as the better modeling option in data scares regions or in cases where calibration is not of much significance. Because the performance of calibrated models is much better than that for uncalibrated versions as shown in this study, it is recommended that as much as possible, models should be calibrated before they can be used in resource management studies.

The evaluation of the effectiveness of different cropping systems using the APEX model (which was the best performing model amongst the evaluated models) revealed that selectively adopting cropping systems associated with high environmental benefits can go a long way in guaranteeing food and energy security, and still ensure environmental sustainability. It is, therefore, important that while considering which crops or management practices to adopt, the role of a particular practice in improving the health of the ecosystem should be considered. This requires concerted efforts in (i) identifying which cropping systems and practices are associated with more environmental benefits, and (ii) promoting the adoption of these practices.

The study also showed that the supply of individual and total ES can vary significantly across space and determined that, both the distribution of rainfall and land-use activities markedly influenced the distribution of ecosystem service cold and hotspots. The methodology used to determine the values of ES across space was simple but robust. Clearly, an approach that takes advantage of the synergism and complementary nature of concepts used in integrated watershed management and ecosystem services valuation can easily and clearly show the location, quantity, distribution and value of ecosystem services in their production areas, and highlight the impact of anthropogenic activities on the different functions provided by nature. It provides a clear framework for establishing baselines for watershed management programs and provides a basis for monitoring the impacts of such plans. Future studies could use monetary valuation and compare how such an approach compares with this non-monetary valuation. Monetary valuations may spur more investments in water resource management programs, compared to non-monetary valuations since stakeholders are likely to prefer benefits expressed in dollar values than in indices.

APPENDIX A

DESCRIPTION AND DATA PROCESSING STEPS FOR INPUT AND CALIBRATION DATA USED IN CHAPTERS 2 AND 3

Several datasets including but not limited to precipitation, discharge, soil loss, soluble phosphorous and other spatial data were used in the modeling studies undertaken in this study. All the data has not been appended to these reports since the data was voluminous. However, similar steps were followed when downloading and processing such data. For elaboration purposes, a metadata file (Table A.1) which describes how runoff data used in the sensitivity analysis and calibration of models was processed is appended. Though formulas and steps followed when processing respective datasets may be different, the general methodology is the same.

Table A.1 Metadata for 1980-2015 runoff data from the Y6 plot at the USDA-ARS watersheds near Riesel, TX.

Original Data:	*Identification Information:*	*Originator:*	USDA-ARS Grassland, Soil and Water Research Laboratory
		Publication Date:	Unknown.
		Title:	Riesel daily runoff records in inches
		Online Linkage:	https://www.ars.usda.gov/plains-area/temple-tx/grassland-soil-and-water-research-laboratory/docs/hydrologic-data/
		Description:	Recorded USDA-ARS edge-of-field and small watershed flow (discharge) from the Y6 plot at the USDA-ARS Riesel watersheds, TX, USA.
	Units:		inches/day
	Access Constraints:		None
	Resource Description:		Downloadable Data
Data Processing:	*Date first accessed:*		20180816
	Methods:	*Processing tools:*	The downloaded data in a text file was processed using Microsoft excel.
		Process description:	The downloaded data was first visually inspected for the correctness and any missing data gap filled. In the raw data, there were limited data gaps. Any missing discharge values were linearly interpolated from the adjacent data.
			The data was converted to mm by multiplying the recorded discharge in inches by 25.4.
			Monthly discharge (mm) was calculated by aggregating daily recorded runoff data.
			To calculate monthly discharge data (m^3/s), the monthly discharge (mm) was divided by 1000 to convert it into m. The resulting discharge (m) was then multiplied by the area of plot in m^2 (6.6 ha x 10000) to get the total discharge per month in m^3. The volume was then divided by the seconds in each month to get the required discharge.
Metadata Reference Information:	*Metadata Date:*		20200216
	Metadata title:		1980-2015 runoff data from the Y6 plot at the USDA-ARS watersheds near Riesel, TX.
	Metadata contact	*Contact person:*	Duncan Kikoyo
		Organization:	Texas A&M University

APPENDIX B

DETERMINATION OF GROUNDWATER RECHARGE ECOSYSTEM SERVICE HOTSPOTS AND COLDSPOTS

The steps followed when calculating ecosystem service indices in Chapter IV are described in the metadata tabular file below (Table B.1). For all other ecosystem services, similar steps were followed, although sources of data and methods to calculate respective indices were different. Also, for elaborative purposes, input data processed from several spatial datasets, how the data was re-processed following a multi-criteria analysis approach is presented in Table B.2. Datasets for other ecosystem services are not appended because of the voluminous nature of the input and output datasets.

Table B.1 Metadata file describing data used and steps taken in determining groundwater recharge ecosystem service indices

Data: *Watershed ID (Column A)* *HUC10 (Column B)* *Watershed Name (Column C)* *Basin Name (Colum D)*	*Original Data:*	*Identification Information:*	*Originator:*	USGS
			Publication Date:	2018
			Title:	National hydrology dataset plus high resolution – Watershed boundary dataset
			Online Linkage:	https://www.usgs.gov/core-science-systems/ngp/national-hydrography/
			Description:	The Watershed Boundary Dataset (WBD) is a seamless, national hydrologic unit dataset. Hydrologic units represent the area of the landscape that drains to a portion of the stream network. Hydrologic units in the WBD are arranged in a nested, hierarchical system with each HU in the system identified using a unique code. Hydrologic unit codes (HUC) are developed using a progressive two-digit system where each successively smaller areal unit is identified by adding two digits to the identifying code the smaller unit is nested within.
		Resource Description:		Downloadable spatial data
	Data Processing:	*Date first accessed:*		20181012
		Methods:	*Processing tools:*	The downloaded spatial data was processed using tools in ArcGIS, using text editors (WordPad and notepad) and Microsoft excel.
			Process description:	The WBD files that cover the entire State of Texas were downloaded from the online linkage above. The dataset was re-processed in ArcGIS and a file geodatabase was created for the entire State. The database lists and describes all the data in columns A-D of Table B.2
	Metadata Reference Information:	*Metadata Date:*		20200216
		Metadata title:		Watershed boundary dataset for Texas.
		Metadata contact	*Contact person:*	Duncan Kikoyo
			Organization:	Texas A&M University

Table B.1 Continued

Data: *Underlying aquifers (Columns E, F&G)*	*Original Data:*	*Identification Information:*	*Originator:*	Texas Water Development Board (TWDB)
			Publication Date:	2007
			Title:	Aquifers of Texas
			Online Linkage:	https://www.twdb.texas.gov/gis-data/
			Description:	This dataset contains what TWDB considers as major and minor aquifers of Texas. A minor aquifer has large quantities of groundwater in small areas or relatively small quantities of groundwater in large areas. A major aquifer has large quantities of water and supplies large areas. The aquifers were originally delineated in 1990 for the 1991 State Water Plan. They were last updated in 2007.
		Access Constraints:		None
		Resource Description:		Downloadable spatial data
	Data Processing:	*Date first accessed:*		20181012
		Methods:	*Processing tools:*	The downloaded spatial data was processed several tools included in ArcGIS, using text editors (WordPad and notepad) and Microsoft excel.
			Process description:	The two datasets (one for minor and the other for major aquifers) were downloaded from the online linkage above. The datasets were merged in ArcGIS. Using spatial analysis tools, the WBD dataset for Texas was used for zoning the merged aquifer dataset. A geodatabase file with watersheds and the name and category of the underlying aquifer was generated
	Metadata Reference Information:	*Metadata Date:*		20190412
		Metadata title:		Classification of aquifers under each watershed in Texas.
		Metadata contact	*Contact person:*	Duncan Kikoyo
			Organization:	Texas A&M University

Table B.1 Continued

Data: *Weights based on a Linkert scale of 1-3 (Columns H)*	*Original Data:*	*Identification Information:*	*Originator:*	Duncan Kikoyo
			Publication Date:	20190412
			Title:	Classification of aquifers under each watershed in Texas.
		Access Constraints:		None
		Resource Description:		Geodatabase file
	Data Processing:	*Date first accessed:*		20190412
		Methods:	*Processing tools:*	ArcGIS, WordPad and Microsoft excel.
			Process description:	The geodatabase file for the different watersheds with merged aquifers was reclassified into three categories. Watersheds with major aquifers were assigned a weight of 3, those with only minor aquifers were assigned a weight of 2 and those with no aquifer were assigned a weight of 1.
	Metadata Reference Information:	*Metadata Date:*		20190618
		Metadata title:		Weights for GWR based on a Linkert scale of 1-3
		Metadata contact	*Contact person:*	Duncan Kikoyo
Data: *Long-term mean annual percolation rates (Columns I)*	*Original Data:*	*Identification Information:*	*Originator:*	Various
			Title:	Various
		Access Constraints:		None
		Resource Description:		Geodatabase data
	Data Processing:	*Date first accessed:*		20180311
		Methods:	*Processing tools:*	ArcGIS, WordPad and Microsoft excel.
			Process description:	The long-term (30-year period) mean percolation rates for each watershed in Texas were simulated using the HAWQS model following procedures described in Chapter IV.
	Metadata Reference Information:	*Metadata Date:*		20190618
		Metadata title:		Long-term mean annual percolation rates for watersheds in Texas
		Metadata contact	*Contact person:*	Duncan Kikoyo

Table B.1 Continued

Data: *GWR norms (Column J), Weighted norms (Column K), Ecosystem service rank (Column L)*	*Original Data:*	*Identification Information:*	*Originator:*	Duncan Kikoyo
			Publication Date:	20190618, 20180311
			Title:	Long-term mean annual percolation rates for watersheds in Texas, Classification of aquifers under each watershed in Texas
			Online Linkage:	None
			Description:	Geodatabase files with long-term mean annual percolation rates for watersheds in Texas and classified spatial data showing aquifers under each watershed
		Access Constraints:		None
		Resource Description:		Geodatabase data
	Data Processing:	*Date first accessed:*		20191204
		Methods:	*Processing tools:*	ArcGIS and Microsoft excel.
			Process description:	Norms for the different percolation rates and corresponding watersheds were calculated using a maximizing function described in Chapter IV. Column K = Column H * Column J. Column L shows the ranks of the GWR ecosystem service value, determined using excel.
	Metadata Reference Information:	*Metadata Date:*		20200216
		Metadata title:		Determination of values of GWR ecosystem services in their production areas for Texas
		Metadata contact	*Contact person:*	Duncan Kikoyo
			Organization:	Texas A&M University

Table B.2 Criteria for assigning weights to reflect the relative importance of ecosystem services across space

A	B	C	D	E	F	G	H	I	J	K	L
ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
1	1202000401	West Mud Creek-Mud Creek	Neches	None	Carrizo	Major	3	263.002	0.512	1.536	79
2	1307000407	Billingslea Draw	Rio Grande	None	Edwards-Trinity	Major	3	27.819	0.054	0.162	770
3	1206020105	Possom Kingdom Lake-Brazos River	Brazos	Cross Timbers	None	Minor	2	68.647	0.134	0.267	616
4	1304020106	Eagle Canyon-Rio Grande	Rio Grande	West Texas Bolsons	None	Minor	2	13.666	0.027	0.053	946
5	1203010101	Cameron Creek-West Fork Trinity River	Trinity	Cross Timbers	None	Minor	2	76.755	0.149	0.299	582
6	1304020905	Washboard Canyon	Rio Grande	None	Edwards-Trinity	Major	3	41.492	0.081	0.242	652
7	1113010305	Scatterbranch Creek-North Pease River	Red	Blaine	None	Minor	2	22.089	0.043	0.086	880
8	1109010303	Sand Draw	Canadian	Rita Blanca	Ogallala	Major & Minor	3	21.757	0.042	0.127	819
9	1207020110	Belton Lake	Brazos	None	Trinity	Major	3	176.15	0.343	1.029	169
10	1209010604	Cow Creek-Colorado River	Colorado	Cross Timbers	Edwards-Trinity	Major & Minor	3	88.256	0.172	0.515	405
11	1210030305	Cabeza Creek-San Antonio River	Central Texas Coastal	None	Gulf_Coast	Major	3	118.571	0.231	0.693	314
12	1205000602	Crawfish Draw	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	1.851	0.004	0.011	1047
13	1113020902	South Fork Little Wichita River-Little Wichita River	Red	Cross Timbers	None	Minor	2	90.399	0.176	0.352	518
14	1308000214	San Ambrosia Creek	Rio Grande	None	Carrizo	Major	3	32.054	0.062	0.187	725
15	1210020301	Upper Blanco River	Central Texas Coastal	None	Trinity	Major	3	158.761	0.309	0.927	208
16	1208000204	Lake J B Thomas-Colorado River	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	19.55	0.038	0.114	837
17	1206010204	Plum Creek-Clear Fork Brazos River	Brazos	Blaine	Seymour	Major & Minor	3	28.05	0.055	0.164	765
18	1203010309	Elm Fork Trinity River-Little Elm Reservoir	Trinity	Woodbine	Trinity	Major & Minor	3	124.268	0.242	0.726	301

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
19	1304020108	Van Horn Creek-Rio Grande	Rio Grande	Igneous	None	Minor	2	42.551	0.083	0.166	760
20	1208000304	Seminole Draw	Colorado	Dockum	Ogallala	Major & Minor	3	5.249	0.01	0.031	984
21	1206020206	Childress Creek-Brazos River	Brazos	Woodbine	Trinity	Major & Minor	3	191.231	0.372	1.117	149
22	1203020104	Box Creek-Trinity River	Trinity	None	Carrizo	Major	3	171.392	0.334	1.001	177
23	1211010506	Becerra Creek	Southwestern Texas Coastal	Yegua Jackson	Carrizo	Major & Minor	3	24.906	0.048	0.145	790
24	1209040202	Water Hole Creek-Caney Creek	Colorado	None	Gulf_Coast	Major	3	127.658	0.249	0.746	291
25	1211020203	South Jetty-Gulf of Mexico	Southwestern Texas Coastal	None	None	None	1	0	0	0	1069
26	1207010205	Yegua Creek	Brazos	Queen City	Gulf_Coast	Major & Minor	3	140.592	0.274	0.821	265
27	1204020403	Halls Bayou-West Bay	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	168.315	0.328	0.983	189
28	1211010904	Lagunillas Creek	Southwestern Texas Coastal	Sparta	Carrizo	Major & Minor	3	51.068	0.099	0.298	584
29	1308000105	Pinto Creek	Rio Grande	None	Edwards-Trinity	Major	3	72.462	0.141	0.423	465
30	1203010105	Big Sandy Creek	Trinity	None	Trinity	Major	3	135.472	0.264	0.791	277
31	1204020102	Hillebrandt Bayou	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	106.544	0.207	0.622	342
32	1114030602	Black Cypress Creek-Black Cypress Bayou	Red	None	Carrizo	Major	3	456.467	0.889	2.666	4
33	1110020103	Upper Kiowa Creek	Canadian	None	Ogallala	Major	3	19.88	0.039	0.116	834
34	1203010502	Tenmile Creek-Trinity River	Trinity	Woodbine	Trinity	Major & Minor	3	114.711	0.223	0.67	321
35	1206010107	Elm Creek	Brazos	Cross Timbers	None	Minor	2	46.865	0.091	0.182	737
36	1112010303	Gip Creek-Prairie Dog Town Fork Red River	Red	Dockum	Ogallala	Major & Minor	3	37.81	0.074	0.221	683
37	1304010007	Alamo Arroyo-Rio Grande	Rio Grande	None	Hueco_Bolson	Major	3	14.921	0.029	0.087	877
38	1201000402	Flat Fork Creek	Sabine	None	Carrizo	Major	3	380.332	0.74	2.221	32

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
39	1113021002	Horseshoe Bend-Red River	Red	None	Trinity	Major	3	243.467	0.474	1.422	95
40	1210040302	San Antonio Bay-Espiritu Santo Bay	Central Texas Coastal	None	Gulf_Coast	Major	3	121.048	0.236	0.707	309
41	1207010106	Cedar Creek-Brazos River	Brazos	Brazos River Alluvium	Carrizo	Major & Minor	3	191.143	0.372	1.116	150
42	1209010104	Coyote Creek-Colorado River	Colorado	None	Edwards-Trinity	Major	3	35.283	0.069	0.206	703
43	1206010505	Gunsolus Creek	Brazos	Cross Timbers	None	Minor	2	74.982	0.146	0.292	591
44	1307000105	Red Hills Draw	Rio Grande	None	Pecos Valley	Major	3	25.553	0.05	0.149	783
45	1211010303	Soldier Slough-Nueces River	Southwestern Texas Coastal	None	Carrizo	Major	3	13.682	0.027	0.08	889
46	1202000407	Bayou Loco-Angelina River	Neches	Sparta	Carrizo	Major & Minor	3	310.614	0.605	1.814	49
47	1304020524	Heath Creek-Rio Grande	Rio Grande	None	Edwards-Trinity	Major	3	19.474	0.038	0.114	838
48	1307000806	Sheffield Draw-Pecos River	Rio Grande	None	Edwards-Trinity	Major	3	52.06	0.101	0.304	576
49	1202000601	Big Sandy Creek-Village Creek	Neches	None	Gulf_Coast	Major	3	432.157	0.841	2.524	12
50	1307000714	McElroy Ranch-Mayfield Draw	Rio Grande	None	Pecos Valley	Major	3	6.645	0.013	0.039	965
51	1113010101	Groesbect Creek	Red	Blaine	Seymour	Major & Minor	3	31.516	0.061	0.184	731
52	1304030109	Headwaters Johnson Draw	Rio Grande	None	Edwards-Trinity	Major	3	43.616	0.085	0.255	639
53	1201000104	Lake Tawakoni	Sabine	Nacatoch	None	Minor	2	152.308	0.297	0.593	359
54	1303010209	City of El Paso-Rio Grande	Rio Grande	None	Hueco_Bolson	Major	3	4.705	0.009	0.027	993
55	1113010106	Ewell Hollow-Red River	Red	None	Seymour	Major	3	95.339	0.186	0.557	378
56	1211010102	Pulliam Creek	Southwestern Texas Coastal	None	Edwards-Trinity	Major	3	44.17	0.086	0.258	634
57	1203010902	Upper Chambers Creek	Trinity	Woodbine	Trinity	Major & Minor	3	144.288	0.281	0.843	255
58	1203010703	Cedar Creek Reservoir-Cedar Creek	Trinity	None	Carrizo	Major	3	126.22	0.246	0.737	295

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
59	1307001203	Harkett Canyon-Pecos River	Rio Grande	None	Edwards-Trinity	Major	3	93.152	0.181	0.544	381
60	1211010406	Lower Turkey Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	14.987	0.029	0.088	876
61	1201000410	Housen Bayou-Toledo Bend Reservoir	Sabine	None	Carrizo	Major	3	429.544	0.836	2.509	13
62	1211020501	Jaboncillos Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	42.229	0.082	0.247	649
63	1109010503	Tecovas Creek-Canadian River	Canadian	None	Ogallala	Major	3	21.057	0.041	0.123	824
64	1109010602	Bear Creek-Canadian River	Canadian	None	Ogallala	Major	3	62.09	0.121	0.363	511
65	1211020202	Corpus Christi Bay	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	9.597	0.019	0.056	940
66	1209020302	Middle South Llano River	Colorado	None	Edwards-Trinity	Major	3	79.209	0.154	0.463	435
67	1304021103	Lower Big Canyon	Rio Grande	None	Edwards-Trinity	Major	3	61.38	0.12	0.359	515
68	1207020505	Granger Lake-San Gabriel River	Brazos	None	Trinity	Major	3	135.432	0.264	0.791	278
69	1209010907	Tiger Creek-San Saba River	Colorado	Hickory	Edwards-Trinity	Major & Minor	3	96.382	0.188	0.563	373
70	1304020501	Alamo Creek-Rio Grande	Rio Grande	None	None	None	1	31.12	0.061	0.061	932
71	1211010201	Headwaters West Nueces River	Southwestern Texas Coastal	None	Edwards-Trinity	Major	3	52.708	0.103	0.308	571
72	1211010403	Palo Blanco Creek-Comanche Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	7.049	0.014	0.041	960
73	1114010605	Walnut Bayou-Red River	Red	Nacatoch	None	Minor	2	268.468	0.523	1.045	166
74	1211010608	Elm Creek-Frio River	Southwestern Texas Coastal	None	Carrizo	Major	3	57.537	0.112	0.336	543
75	1307000721	Courtney Creek-Pecos River	Rio Grande	None	Pecos Valley	Major	3	14.675	0.029	0.086	882
76	1304020403	Middle Terlingua Creek	Rio Grande	Igneous	None	Minor	2	44.622	0.087	0.174	747
77	1207020305	Stillhouse Hollow Lake-Lampasas River	Brazos	None	Trinity	Major	3	157.575	0.307	0.92	211

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
78	1209020103	Sandy Creek	Colorado	None	Trinity	Major	3	121.849	0.237	0.712	304
79	1304030106	Cauthorn Draw	Rio Grande	None	Edwards-Trinity	Major	3	80.119	0.156	0.468	431
80	1203020205	South Bedias Creek-Bedias Creek	Trinity	Sparta	Gulf_Coast	Major & Minor	3	160.654	0.313	0.938	204
81	1209020603	Pedernales River-Lake Travis	Colorado	None	Trinity	Major	3	144.953	0.282	0.847	254
82	1209010901	North Valley Prong	Colorado	None	Edwards-Trinity	Major	3	47.048	0.092	0.275	610
83	1210040201	Headwaters Garcitas Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	104.819	0.204	0.612	348
84	1307000710	Yarbrough Allen Oil Field-Red Lakes	Rio Grande	Dockum	Pecos Valley	Major & Minor	3	19.057	0.037	0.111	842
85	1208000502	City of Midland-Midland Draw	Colorado	Dockum	Ogallala	Major & Minor	3	2.199	0.004	0.013	1035
86	1304020604	Lower Maravillas Creek	Rio Grande	None	Edwards-Trinity	Major	3	14.885	0.029	0.087	878
87	1206020401	Green Creek-North Bosque River	Brazos	None	Trinity	Major	3	153.705	0.299	0.898	224
88	1211020604	Arroyo Baluarte	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	31.653	0.062	0.185	729
89	1210010104	Keller Branch-Lavaca River	Central Texas Coastal	None	Gulf_Coast	Major	3	114.278	0.222	0.667	324
90	1209010303	Upper Centralia Draw	Colorado	None	Edwards-Trinity	Major	3	6.757	0.013	0.039	963
91	1208000402	Eightmile Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	1.559	0.003	0.009	1055
92	1110010404	Hackberry Creek	Canadian	None	Ogallala	Major	3	19.766	0.038	0.115	836
93	1207010306	Wickson Creek-Navasota River	Brazos	Sparta	Carrizo	Major & Minor	3	147.288	0.287	0.86	248
94	1211011104	Ramirena Creek-Lake Corpus Christi	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	103.916	0.202	0.607	349
95	1204010303	Winters Bayou-East Fork San Jacinto River	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	328.853	0.64	1.921	43

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
96	1204010406	Greens Bayou	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	53.793	0.105	0.314	564
97	1113020602	Lake Diversion-Wichita River	Red	Cross Timbers	Seymour	Major & Minor	3	40.193	0.078	0.235	659
98	1209020501	Lake Marble Falls-Lake Travis	Colorado	Hickory	Trinity	Major & Minor	3	106.139	0.207	0.62	344
99	1210020402	Twelvemile Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	121.289	0.236	0.708	308
100	1112030101	Upper McClellan Creek	Red	Dockum	Ogallala	Major & Minor	3	5.449	0.011	0.032	981
101	1208000604	Foster Cemetery-Sulphur Springs Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	5.029	0.01	0.029	986
102	1202000204	Piney Creek	Neches	None	Gulf_Coast	Major	3	338.062	0.658	1.975	41
103	1307000602	Alpine Creek-Musquiz Creek	Rio Grande	Igneous	Edwards-Trinity	Major & Minor	3	80.964	0.158	0.473	429
104	1307000401	Paint Horse Draw-Cottonwood Creek	Rio Grande	Rustler	Edwards-Trinity	Major & Minor	3	51.933	0.101	0.303	578
105	1112010406	Rock Creek-Tule Creek	Red	Dockum	Ogallala	Major & Minor	3	11.919	0.023	0.07	911
106	1109010205	Syndicate Hills	Canadian	Dockum	Ogallala	Major & Minor	3	5.852	0.011	0.034	976
107	1211010702	Middle Hondo Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	65.795	0.128	0.384	491
108	1211010602	Headwaters Frio River	Southwestern Texas Coastal	None	Edwards	Major	3	56.602	0.11	0.331	546
109	1209010307	Lower Centralia Draw	Colorado	Dockum	Edwards-Trinity	Major & Minor	3	17.606	0.034	0.103	853
110	1205000107	Town of Goodland	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	4.707	0.009	0.027	992
111	1109010101	Horse Creek	Canadian	None	Ogallala	Major	3	11.544	0.022	0.067	915
112	1210040106	1210040106-Gulf of Mexico	Central Texas Coastal	None	None	None	1	0	0	0	1069
113	1209010601	Mustang Creek-Colorado River	Colorado	Cross Timbers	Edwards-Trinity	Major & Minor	3	70.278	0.137	0.41	478

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
114	1205000402	City of Levelland-Tahoka Lake	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	2.062	0.004	0.012	1041
115	1203010202	Upper Clear Fork Trinity River	Trinity	None	Trinity	Major	3	128.476	0.25	0.75	289
116	1113020703	Middle Beaver Creek	Red	None	Seymour	Major	3	41.922	0.082	0.245	651
117	1305000424	Sulphur Creek-Wild Horse Draw	Rio Grande	None	Edwards-Trinity	Major	3	20.412	0.04	0.119	831
118	1309000112	Remadura de Sandia Creek-Canada Honda	Rio Grande	None	Gulf_Coast	Major	3	46.415	0.09	0.271	612
119	1305000411	University Draw-Antelope Draw	Rio Grande	Bone Spring-Victorio Peak	None	Minor	2	15.775	0.031	0.061	931
120	1112010105	City of Hereford-Tierra Blanca Creek	Red	Dockum	Ogallala	Major & Minor	3	6.467	0.013	0.038	967
121	1211020804	La Sal Vieja	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	15.712	0.031	0.092	872
122	1113020102	Belknap Creek-Red River	Red	None	Trinity	Major	3	179.491	0.349	1.048	163
123	1202000103	Flat Creek-Neches River	Neches	None	Carrizo	Major	3	259.241	0.505	1.514	83
124	1114030101	Spring Creek-South Sulphur River	Red	Woodbine	Trinity	Major & Minor	3	200.142	0.39	1.169	132
125	1114010104	Tuklo Creek-Red River	Red	Woodbine	Trinity	Major & Minor	3	223.353	0.435	1.305	111
126	1207010404	Big Creek-Brazos River	Brazos	Brazos River Alluvium	Gulf_Coast	Major & Minor	3	86.034	0.167	0.502	415
127	1201000403	Bayou Grand Cane-Toledo Bend Reservoir	Sabine	None	Carrizo	Major	3	390.971	0.761	2.284	29
128	1114030203	Long Lake Slough-Sulphur River	Red	Nacatoch	Carrizo	Major & Minor	3	255.611	0.498	1.493	85
129	1209010404	Middle North Concho River	Colorado	None	Edwards-Trinity	Major	3	37.178	0.072	0.217	687
130	1205000605	Lower White River	Brazos	Dockum	Ogallala	Major & Minor	3	20.232	0.039	0.118	832
131	1205000408	Gyp Creek-Double Mountain Fork Brazos River	Brazos	Blaine	Seymour	Major & Minor	3	28.167	0.055	0.165	764
132	1203020211	Brushy Creek-Lake Livingston	Trinity	None	Gulf_Coast	Major	3	271.976	0.53	1.589	73

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
133	1209030106	Clear Creek-Cummins Creek	Colorado	Sparta	Gulf_Coast	Major & Minor	3	214.278	0.417	1.252	119
134	1305000418	Perry Draw-Wild Horse Draw	Rio Grande	Igneous	None	Minor	2	26.274	0.051	0.102	855
135	1203020101	Caney Creek-Tehuacana Creek	Trinity	None	Carrizo	Major	3	150.631	0.293	0.88	237
136	1211020807	Lower Arroyo Colorado	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	9.337	0.018	0.055	943
137	1114030404	Paw Bayou	Red	None	Carrizo	Major	3	380.201	0.74	2.221	33
138	1210020205	Upper Sandies Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	165.354	0.322	0.966	193
139	1203010402	Middle Denton Creek	Trinity	None	Trinity	Major	3	170.255	0.331	0.994	182
140	1304020102	Mayfield Canyon-Rio Grande	Rio Grande	None	Hueco_Bolson	Major	3	10.734	0.021	0.063	924
141	1209020401	Johnson Fork	Colorado	Hickory	Edwards-Trinity	Major & Minor	3	84.304	0.164	0.492	417
142	1207020107	Pecan Creek-Leon River	Brazos	None	Trinity	Major	3	170.05	0.331	0.993	184
143	1204020202	Spindletop Bayou	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	71.903	0.14	0.42	469
144	1110020203	Sand Creek-Wolf Creek	Canadian	None	Ogallala	Major	3	57.973	0.113	0.339	539
145	1204010102	West Fork San Jacinto River-Conroe Lake	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	305.359	0.595	1.784	55
146	1307000902	Sixshooter Draw-Monument Draw	Rio Grande	None	Edwards-Trinity	Major	3	47.598	0.093	0.278	606
147	1109010305	Cottonwood Draw-Rita Blanca Creek	Canadian	Dockum	Ogallala	Major & Minor	3	6.635	0.013	0.039	966
148	1109010204	Monia Creek-Punta de Agua Creek	Canadian	Dockum	Ogallala	Major & Minor	3	2.686	0.005	0.016	1024
149	1307000502	Outlet Limpia Creek	Rio Grande	Igneous	Edwards-Trinity	Major & Minor	3	62.764	0.122	0.367	504
150	1202000302	Sandy Creek-Neches River	Neches	None	Gulf_Coast	Major	3	441.993	0.861	2.582	8
151	1206020102	Rock Creek	Brazos	Cross Timbers	None	Minor	2	95.27	0.185	0.371	497
152	1202000404	Shawnee Creek-Angelina River	Neches	None	Carrizo	Major	3	288.343	0.561	1.684	64

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
153	1206010201	Linn Creek-Cottonwood Creek	Brazos	Blaine	Seymour	Major & Minor	3	15.717	0.031	0.092	871
154	1201000502	Little Cow Creek	Sabine	None	Gulf_Coast	Major	3	473.981	0.923	2.768	2
155	1208000207	Willow Creek-Colorado River	Colorado	Dockum	Ogallala	Major & Minor	3	19.251	0.037	0.112	841
156	1201000302	Running Creek-Case Lake	Sabine	None	Carrizo	Major	3	185.893	0.362	1.086	157
157	1112010306	Mulberry Creek-Prarie Dog Town Fork Red River	Red	Dockum	Ogallala	Major & Minor	3	51.29	0.1	0.3	580
158	1112010203	Lower Palo Duro Creek	Red	Dockum	Ogallala	Major & Minor	3	5.552	0.011	0.032	977
159	1210040502	Copano Bay	Central Texas Coastal	None	Gulf_Coast	Major	3	75.538	0.147	0.441	453
160	1304020112	Arroyo Cienega-Rio Grande	Rio Grande	Igneous	None	Minor	2	57.182	0.111	0.223	679
161	1113010203	Rabbit Creek-Red River	Red	None	Seymour	Major	3	76.669	0.149	0.448	447
162	1207020202	Middle Cowhouse Creek	Brazos	None	Trinity	Major	3	166.757	0.325	0.974	191
163	1209010701	Headwaters Pecan Bayou	Colorado	Cross Timbers	Trinity	Major & minor	3	71.524	0.139	0.418	472
164	1211010901	Headwaters San Miguel Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	72.957	0.142	0.426	462
165	1308000118	Elm Creek	Rio Grande	None	Edwards-Trinity	Major	3	17.342	0.034	0.101	858
166	1304030201	Deaton Draw-Devils River	Rio Grande	None	Edwards-Trinity	Major	3	106.411	0.207	0.622	343
167	1309000203	Lake Tropicana-Rio Grande	Rio Grande	None	Gulf_Coast	Major	3	0	0	0	1069
168	1207010303	Sanders Creek-Navasota River	Brazos	None	Carrizo	Major	3	155.755	0.303	0.91	214
169	1304020902	Willow Creek-San Francisco Creek	Rio Grande	None	Edwards-Trinity	Major	3	69.001	0.134	0.403	483
170	1203010104	Lake Bridgeport-West Fork Trinity River	Trinity	None	Trinity	Major	3	134.704	0.262	0.787	279
171	1204020502	Middle Oyster Creek	Galveston Bay-San Jacinto	Brazos River Alluvium	Gulf_Coast	Major & Minor	3	97.878	0.191	0.572	369
172	1203010803	Pin Oak Creek	Trinity	None	Trinity	Major	3	136.527	0.266	0.797	275

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
173	1206020301	Middle Bosque River	Brazos	None	Trinity	Major	3	170.377	0.332	0.995	181
174	1211010503	Caiman Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	23.944	0.047	0.14	798
175	1307001103	Lower Howard Draw	Rio Grande	None	Edwards-Trinity	Major	3	91.331	0.178	0.533	391
176	1210040703	Chiltipin Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	25.322	0.049	0.148	786
177	1208000302	Headwaters Wardswell Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	1.541	0.003	0.009	1056
178	1210020304	Plum Creek	Central Texas Coastal	None	Trinity	Major	3	170.204	0.331	0.994	183
179	1203010505	Rush Creek-Trinity River	Trinity	None	Carrizo	Major	3	102.701	0.2	0.6	354
180	1208000607	Town of Ackerly-Sulphur Springs Draw	Colorado	None	Ogallala	Major	3	3.755	0.007	0.022	1010
181	1304020301	Terneros Creek	Rio Grande	Igneous	None	Minor	2	58.076	0.113	0.226	670
182	1205000109	Ramsey Hill-Yellow House Draw	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	3.115	0.006	0.018	1020
183	1201000101	Caney Creek-Cowleech Fork Sabine River	Sabine	Woodbine	Trinity	Major & Minor	3	192.174	0.374	1.122	146
184	1308000102	San Felipe Creek-Rio Grande	Rio Grande	None	Edwards-Trinity	Major	3	52.734	0.103	0.308	570
185	1114010108	Garretts Bluff-Red River	Red	Woodbine	Trinity	Major & Minor	3	242.979	0.473	1.419	97
186	1211011107	Bayou Creek-Nueces River	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	48.395	0.094	0.283	596
187	1113010302	Quitaque Creek	Red	None	Seymour	Major	3	22.853	0.044	0.133	808
188	1202000701	Pine Island Bayou	Neches	None	Gulf_Coast	Major	3	228.816	0.445	1.336	107
189	1207010103	Little Brazos River-Brazos River	Brazos	None	Carrizo	Major	3	125.039	0.243	0.73	299
190	1210020101	Headwaters Guadalupe River	Central Texas Coastal	None	Trinity	Major	3	82.171	0.16	0.48	423

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
191	1209010202	Lower Spring Creek	Colorado	None	Edwards-Trinity	Major	3	34.745	0.068	0.203	709
192	1211010307	Espio Creek-Nueces River	Southwestern Texas Coastal	None	Carrizo	Major	3	32.846	0.064	0.192	721
193	1304020813	Indian Creek-Rio Grande	Rio Grande	None	Edwards-Trinity	Major	3	59.179	0.115	0.346	526
194	1202000503	Naconiche Creek-Attoyac River	Neches	None	Carrizo	Major	3	373.936	0.728	2.184	34
195	1206010207	Elm Creek	Brazos	None	Edwards-Trinity	Major	3	37.012	0.072	0.216	690
196	1208000201	Upper Tobacco Creek	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	4.895	0.01	0.029	988
197	1112010505	Outlet Prairie Dog Town Fork Red River	Red	None	Seymour	Major	3	72.399	0.141	0.423	466
198	1209020202	Middle North Llano River	Colorado	None	Edwards-Trinity	Major	3	66.599	0.13	0.389	488
199	1201000201	Old Sabine River Channel-Sabine River	Sabine	Queen City	Carrizo	Major & Minor	3	244.061	0.475	1.425	94
200	1201000204	Prairie Creek-Sabine River	Sabine	None	Carrizo	Major	3	262.604	0.511	1.534	80
201	1304030103	Taylor Box Draw-Granger Draw	Rio Grande	None	Edwards-Trinity	Major	3	99.846	0.194	0.583	363
202	1211020402	Lower Santa Gertrudis Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	39.232	0.076	0.229	667
203	1307000717	Belding Draw-Leon Lake	Rio Grande	Rustler	Edwards-Trinity	Major & Minor	3	38.593	0.075	0.225	672
204	1113010403	Lower Tongue River	Red	Blaine	None	Minor	2	43.838	0.085	0.171	753
205	1109010506	Big Blue Creek	Canadian	Dockum	Ogallala	Major & Minor	3	23.167	0.045	0.135	806
206	1112030402	Upper Elm Fork Red River	Red	Blaine	None	Minor	2	65.426	0.127	0.255	638
207	1110020105	Town of Rosston-Beaver River	Canadian	None	Ogallala	Major	3	82.061	0.16	0.479	424
208	1209010205	Pecan Creek-South Concho River	Colorado	None	Edwards-Trinity	Major	3	39.447	0.077	0.23	664
209	1206020404	Neils Creek-North Bosque River	Brazos	None	Trinity	Major	3	155.32	0.302	0.907	216

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
210	1211020601	Mesquite Creek-Noriacitas Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	17.397	0.034	0.102	856
211	1210010203	West Sandy Creek-Sandy Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	168.372	0.328	0.983	188
212	1110020301	Bridge Creek-Wolf Creek	Canadian	None	Ogallala	Major	3	91.493	0.178	0.534	389
213	1209010904	Dry Creek-San Saba River	Colorado	None	Edwards-Trinity	Major	3	66.425	0.129	0.388	489
214	1210030101	Headwaters Salado Creek	Central Texas Coastal	None	Carrizo	Major	3	62.606	0.122	0.366	507
215	1304020601	Headwaters Maravillas Creek	Rio Grande	Marathon	None	Minor	2	52.965	0.103	0.206	702
216	1305000421	Camel Draw-Eagle Flat Draw	Rio Grande	West Texas Bolsons	None	Minor	2	28.381	0.055	0.111	845
217	1208000505	Upper Johnson Draw	Colorado	None	Edwards-Trinity	Major	3	4.982	0.01	0.029	987
218	1308000309	Arroyo Veleno-Falcon Reservoir	Rio Grande	Yegua Jackson	None	Minor	2	67.421	0.131	0.263	625
219	1204010403	Whiteoak Bayou-Buffalo Bayou	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	14.138	0.028	0.083	886
220	1209011002	Lower Brady Creek	Colorado	Hickory	Edwards-Trinity	Major & Minor	3	89.969	0.175	0.525	396
221	1113020501	Upper South Wichita River	Red	Blaine	None	Minor	2	41.963	0.082	0.163	767
222	1203010205	Big Fossil Creek-West Fork Trinity River	Trinity	Woodbine	Trinity	Major & Minor	3	42.448	0.083	0.248	647
223	1207010401	Clear Creek-Brazos River	Brazos	Brazos River Alluvium	Gulf_Coast	Major & Minor	3	138.446	0.27	0.809	271
224	1109010605	Indian Creek-Canadian River	Canadian	None	Ogallala	Major	3	71.825	0.14	0.42	470
225	1205000501	Running Water Draw	Brazos	Dockum	Ogallala	Major & Minor	3	1.563	0.003	0.009	1054
226	1211010204	Lower West Nueces River	Southwestern Texas Coastal	None	Edwards	Major	3	38.93	0.076	0.227	668
227	1206010502	Salt Prong Hubbard Creek	Brazos	Cross Timbers	None	Minor	2	55.752	0.109	0.217	688
228	1201000211	Socagee Creek-Sabine River	Sabine	None	Carrizo	Major	3	321.838	0.627	1.88	44
229	1209020504	Onion Creek-Colorado River	Colorado	None	Trinity	Major	3	183.607	0.357	1.072	160

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
230	1206010104	Dutchman Creek-Brazos River	Brazos	None	Seymour	Major	3	17.875	0.035	0.104	852
231	1210040204	Chocolate Bayou-Chocolate Bay	Central Texas Coastal	None	Gulf_Coast	Major	3	30.075	0.059	0.176	744
232	1207020302	Simms Creek-Lampasas River	Brazos	Hickory	Trinity	Major & Minor	3	165.079	0.321	0.964	194
233	1113020605	Wichita River Outlet	Red	None	Seymour	Major	3	78.088	0.152	0.456	441
234	1211011101	Sulphur Creek-Nueces River	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	81.131	0.158	0.474	428
235	1307000803	Lower Fourmile Draw-Fourmile Draw	Rio Grande	None	Edwards-Trinity	Major	3	56.095	0.109	0.328	549
236	1208000210	Wildhorse Creek-Colorado River	Colorado	Dockum	None	Minor	2	20.101	0.039	0.078	894
237	1210010101	Rocky Creek-Lavaca River	Central Texas Coastal	None	Gulf_Coast	Major	3	175.213	0.341	1.023	171
238	1211020801	Upper Arroyo Colorado	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	7.88	0.015	0.046	956
239	1114010603	Whitegrass Creek-Red River	Red	Woodbine	Trinity	Major & Minor	3	280.72	0.547	1.64	67
240	1109010608	Oasis Creek-Canadian River	Canadian	None	Ogallala	Major	3	126.639	0.247	0.74	294
241	1307000103	Lower Salt Creek	Rio Grande	Rustler	Pecos Valley	Major & Minor	3	36.403	0.071	0.213	695
242	1208000410	Upper Mustang Draw	Colorado	Dockum	Ogallala	Major & Minor	3	4.295	0.008	0.025	996
243	1203010306	Duck Creek-Clear Creek	Trinity	None	Trinity	Major	3	140.854	0.274	0.823	264
244	1309000116	Garcias Creek-Rio Grande	Rio Grande	None	Gulf_Coast	Major	3	41.061	0.08	0.24	654
245	1304020703	Calamity Creek-Chalk Draw	Rio Grande	Igneous	None	Minor	2	68.738	0.134	0.268	615
246	1305000414	Antelope Gulch	Rio Grande	None	None	None	1	23.992	0.047	0.047	955
247	1205000304	South Dokegood Creek	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	2.357	0.005	0.014	1030
248	1205000503	Town of Dimmitt-North Fork	Brazos	None	Ogallala	Major	3	2.15	0.004	0.013	1038
249	1308000224	Santa Isabel Creek	Rio Grande	None	Carrizo	Major	3	47.794	0.093	0.279	603

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
250	1211010605	Blanco Creek	Southwestern Texas Coastal	None	Trinity	Major	3	51.881	0.101	0.303	579
251	1114010105	Bois d'Arc Creek	Red	Woodbine	Trinity	Major & Minor	3	190.799	0.371	1.114	152
252	1304020205	Outlet Alamito Creek	Rio Grande	Igneous	None	Minor	2	26.359	0.051	0.103	854
253	1201000510	Cow Bayou	Sabine	None	Gulf_Coast	Major	3	217.303	0.423	1.269	115
254	1114030206	Wright Patman Lake-Sulphur River	Red	Nacatoch	Carrizo	Major & Minor	3	348.214	0.678	2.034	40
255	1204020302	Cedar Bayou-Frontal Galveston Bay	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	271.91	0.529	1.588	74
256	1206020108	Upper Palo Pinto Creek	Brazos	None	Trinity	Major	3	89.449	0.174	0.522	398
257	1307000404	Clayton Draw-Herds Pass Draw	Rio Grande	Rustler	Edwards-Trinity	Major & Minor	3	31.809	0.062	0.186	727
258	1203020208	Nelson Creek-Lake Livingston	Trinity	Sparta	Gulf_Coast	Major & Minor	3	218.013	0.424	1.273	112
259	1209030103	Walnut Creek-Cedar Creek	Colorado	Queen City	Carrizo	Major & Minor	3	194.532	0.379	1.136	142
260	1210040103	Tres Palacios River	Central Texas Coastal	None	Gulf_Coast	Major	3	55.355	0.108	0.323	556
261	1203020302	Whites Bayou-Turtle Bayou	Trinity	None	Gulf_Coast	Major	3	138.305	0.269	0.808	272
262	1209010502	Willow Creek-Concho River	Colorado	None	Edwards-Trinity	Major	3	27.511	0.054	0.161	772
263	1205000405	Grape Creek-Double Mountain Fork Brazos River	Brazos	None	Ogallala	Major	3	19.354	0.038	0.113	840
264	1205000703	Town of Wake	Brazos	Dockum	Ogallala	Major & Minor	3	2.129	0.004	0.012	1039
265	1211010611	Lower Leona River	Southwestern Texas Coastal	None	Carrizo	Major	3	44.348	0.086	0.259	632
266	1114030104	North Sulphur River-South Sulphur River	Red	Blossom	Trinity	Major & Minor	3	187.338	0.365	1.094	155
267	1112010102	Outlet Tierra Blanca Creek	Red	Dockum	Ogallala	Major & Minor	3	8.049	0.016	0.047	954
268	1204020205	1204020205-Gulf of Mexico	Galveston Bay-San Jacinto	None	None	None	1	0	0	0	1069
269	1207010203	Nails Creek-Yegua Creek	Brazos	Sparta	Gulf_Coast	Major & Minor	3	212.598	0.414	1.242	121

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
270	1210020206	Five Mile Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	147.732	0.288	0.863	246
271	1304020103	Red Light Draw	Rio Grande	West Texas Bolsons	None	Minor	2	5.843	0.011	0.023	1007
272	1109010501	Alamosa Creek-Canadian River	Canadian	Dockum	Ogallala	Major & Minor	3	23.186	0.045	0.135	805
273	1206020204	Lake Whitney	Brazos	Woodbine	Trinity	Major & Minor	3	165.652	0.323	0.968	192
274	1307001002	Harral Draw	Rio Grande	None	Edwards-Trinity	Major	3	57.777	0.112	0.337	541
275	1308000119	Quemado Creek-Rio Grande	Rio Grande	None	None	None	1	15.261	0.03	0.03	985
276	1209020404	Little Devils River-James River	Colorado	Hickory	Edwards-Trinity	Major & Minor	3	95.427	0.186	0.557	377
277	1206010202	Headwaters Clear Fork Brazos River	Brazos	Dockum	Seymour	Major & Minor	3	13.625	0.027	0.08	892
278	1208000202	Lower Tobacco Creek	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	21.788	0.042	0.127	818
279	1109010301	East Rita Blanca Creek	Canadian	Rita Blanca	Ogallala	Major & Minor	3	7.515	0.015	0.044	957
280	1207020108	Plum Creek-Leon River	Brazos	None	Trinity	Major	3	154.398	0.301	0.902	221
281	1210040601	Medio Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	121.999	0.238	0.713	303
282	1208000702	Lower Beals Creek	Colorado	Dockum	Edwards-Trinity	Major & Minor	3	28.274	0.055	0.165	761
283	1205000505	Duncan Lake-Running Water Draw	Brazos	Dockum	Ogallala	Major & Minor	3	1.063	0.002	0.006	1060
284	1209040103	Lower San Bernard River	Colorado	None	Gulf_Coast	Major	3	175.569	0.342	1.025	170
285	1211010512	Rex Cabaniss Creek-Nueces River	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	82.37	0.16	0.481	420
286	1202000702	Little Pine Island Bayou-Pine Island Bayou	Neches	None	Gulf_Coast	Major	3	237.91	0.463	1.39	104
287	1204010105	Lake Houston-San Jacinto River	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	96.792	0.188	0.565	370
288	1202000303	Big Walnut Run-Neches River	Neches	None	Gulf_Coast	Major	3	362.21	0.705	2.116	38

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
289	1206020103	Cedar Creek	Brazos	Cross Timbers	None	Minor	2	76.252	0.148	0.297	585
290	1304020111	Arroyo Escondido-Rio Grande	Rio Grande	Igneous	None	Minor	2	18.753	0.037	0.073	903
291	1202000405	East Fork Angelina River-Angelina River	Neches	None	Carrizo	Major	3	312.1	0.608	1.823	48
292	1205000110	Illusion Lake-Yellow Lake	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	4.789	0.009	0.028	990
293	1209010704	Devils River-Pecan Bayou	Colorado	None	Trinity	Major	3	102.06	0.199	0.596	356
294	1201000303	Dry Creek-Lake Fork Creek	Sabine	None	Carrizo	Major	3	225.205	0.438	1.315	109
295	1203010403	Lower Denton Creek	Trinity	Woodbine	Trinity	Major & Minor	3	108.619	0.211	0.634	336
296	1112010301	Headwaters Prairie Dog Town Fork Red River	Red	Dockum	Ogallala	Major & Minor	3	18.88	0.037	0.11	846
297	1304030204	Evans Creek-Amistad Reservoir	Rio Grande	None	Edwards-Trinity	Major	3	114.916	0.224	0.671	319
298	1207020203	Lower Cowhouse Creek	Brazos	None	Trinity	Major	3	154.687	0.301	0.903	220
299	1211010902	Black Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	70.036	0.136	0.409	481
300	1307000108	Rudd Draw-Soda Lake	Rio Grande	None	Pecos Valley	Major	3	17.075	0.033	0.1	863
301	1307000203	Lower Delaware River	Rio Grande	Rustler	None	Minor	2	26.066	0.051	0.101	857
302	1114030504	Alley Creek-Big Cypress Creek	Red	Queen City	Carrizo	Major & Minor	3	405.726	0.79	2.37	24
303	1210020104	Guadalupe River-Canyon Lake	Central Texas Coastal	None	Trinity	Major	3	133.482	0.26	0.78	282
304	1210020305	Lower San Marcos River	Central Texas Coastal	Sparta	Carrizo	Major & Minor	3	151.249	0.294	0.883	234
305	1109010507	Lake Meredith-Canadian River	Canadian	Dockum	Ogallala	Major & Minor	3	50.048	0.097	0.292	590
306	1109010106	Romero Creek-Canadian River	Canadian	Dockum	Ogallala	Major & Minor	3	18.949	0.037	0.111	844
307	1109020101	Town of Arnett-Canadian River	Canadian	None	Ogallala	Major	3	88.825	0.173	0.519	402

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
308	1203010804	Alligator Creek-Richland Creek	Trinity	None	Carrizo	Major	3	107.56	0.209	0.628	340
309	1206020302	Hog Creek-Waco Lake	Brazos	None	Trinity	Major	3	173.328	0.337	1.012	175
310	1308000103	West Fork Sycamore Creek-Sycamore Creek	Rio Grande	None	Edwards-Trinity	Major	3	132.432	0.258	0.773	284
311	1307001201	Geddis Canyon-Pecos River	Rio Grande	None	Edwards-Trinity	Major	3	78.409	0.153	0.458	440
312	1304021101	Upper Big Canyon	Rio Grande	None	Edwards-Trinity	Major	3	39.857	0.078	0.233	660
313	1113010501	Upper Pease River	Red	None	Seymour	Major	3	54.431	0.106	0.318	559
314	1202000604	Cypress Creek-Village Creek	Neches	None	Gulf_Coast	Major	3	276.858	0.539	1.617	68
315	1208000306	Upper Monument Draw	Colorado	Dockum	Ogallala	Major & Minor	3	3.41	0.007	0.02	1014
316	1211020100	Nueces Bay-Corpus Christi Bay	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	31.364	0.061	0.183	735
317	1201000207	Eightmile Creek-Sabine River	Sabine	None	Carrizo	Major	3	296.891	0.578	1.734	59
318	1201000102	West Caddo Creek	Sabine	Woodbine	Trinity	Major & Minor	3	149.469	0.291	0.873	242
319	1112010403	North Tule Draw-Tule Creek	Red	Dockum	Ogallala	Major & Minor	3	9.531	0.019	0.056	941
320	1304020307	Panther Creek-Rio Grande	Rio Grande	Igneous	None	Minor	2	44.146	0.086	0.172	750
321	1307000718	Comanche Creek	Rio Grande	None	Pecos Valley	Major	3	39.749	0.077	0.232	661
322	1202000509	Harvey Creek-Angelina River	Neches	None	Gulf_Coast	Major	3	406.124	0.791	2.372	23
323	1307000712	Running W Oil Field-Sand Hills Oil Field	Rio Grande	None	Pecos Valley	Major	3	20.839	0.041	0.122	828
324	1113010303	Turkey Creek-North Pease River	Red	None	Seymour	Major	3	62.128	0.121	0.363	510
325	1305000407	Big Dog Canyon	Rio Grande	Capitan Reef Complex	None	Minor	2	54.416	0.106	0.212	696
326	1112030201	North Fork Red River	Red	None	Ogallala	Major	3	104.992	0.204	0.613	347
327	1211010401	Elm Creek	Southwestern Texas Coastal	None	Edwards-Trinity	Major	3	21.225	0.041	0.124	821
328	1207020503	Berry Creek	Brazos	None	Trinity	Major	3	186.683	0.363	1.09	156

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
329	1209010905	Elm Creek-San Saba River	Colorado	Hickory	Edwards-Trinity	Major & Minor	3	70.769	0.138	0.413	475
330	1209020203	Lower North Llano River	Colorado	Hickory	Edwards-Trinity	Major & Minor	3	55.772	0.109	0.326	550
331	1209010102	Valley Creek-Colorado River	Colorado	None	Edwards-Trinity	Major	3	48.077	0.094	0.281	600
332	1211010404	Upper Turkey Creek	Southwestern Texas Coastal	None	Edwards	Major	3	24.947	0.049	0.146	789
333	1206010301	Upper California Creek	Brazos	None	Seymour	Major	3	13.03	0.025	0.076	899
334	1210040704	Lower Aransas River	Central Texas Coastal	None	Gulf_Coast	Major	3	62.873	0.122	0.367	502
335	1304020602	Upper Maravillas Creek	Rio Grande	Marathon	Edwards-Trinity	Major & Minor	3	27.895	0.054	0.163	769
336	1202000506	Stanley Creek-Angelina River	Neches	Yegua Jackson	Carrizo	Major & Minor	3	400.602	0.78	2.34	26
337	1307000708	Town of Kermit-Monument Draw	Rio Grande	None	Pecos Valley	Major	3	18.475	0.036	0.108	849
338	1114030201	River Crest Lake-Sulphur River	Red	Blossom	Trinity	Major & Minor	3	211.084	0.411	1.233	123
339	1112020201	Richardson Creek-Salt Fork Red River	Red	None	Seymour	Major	3	74.095	0.144	0.433	458
340	1110020302	Mammoth Creek	Canadian	None	Ogallala	Major	3	76.037	0.148	0.444	451
341	1207010101	Deer Creek-Brazos River	Brazos	Brazos River Alluvium	Trinity	Major & Minor	3	153.314	0.298	0.895	226
342	1304030104	Headwaters Dry Devils River	Rio Grande	None	Edwards-Trinity	Major	3	45.651	0.089	0.267	618
343	1209010301	Upper High Lonesome Draw	Colorado	None	Edwards-Trinity	Major	3	1.449	0.003	0.008	1058
344	1209010402	Lacy Creek	Colorado	None	Edwards-Trinity	Major	3	21.987	0.043	0.128	816
345	1113020502	Lower South Wichita River	Red	None	Seymour	Major	3	43.106	0.084	0.252	643
346	1112030202	Sweetwater Creek	Red	None	Ogallala	Major	3	112.553	0.219	0.657	328
347	1309000111	Arroyo Grande-Rio Grande	Rio Grande	None	Gulf_Coast	Major	3	27.947	0.054	0.163	768
348	1208000307	Middle Monument Draw	Colorado	Dockum	Ogallala	Major & Minor	3	4.843	0.009	0.028	989

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
349	1209020601	Headwaters Pedernales River	Colorado	Hickory	Edwards-Trinity	Major & Minor	3	156.559	0.305	0.914	213
350	1307000719	Livingston Canyon	Rio Grande	None	Edwards-Trinity	Major	3	38.58	0.075	0.225	673
351	1205000706	Croton Creek	Brazos	None	Seymour	Major	3	44.395	0.086	0.259	631
352	1308000310	Arroyo del Tigre Grande-Falcon Reservoir	Rio Grande	None	Gulf_Coast	Major	3	41.234	0.08	0.241	653
353	1210040104	East Branch Mad Island Slough-Matagorda Bay	Central Texas Coastal	None	Gulf_Coast	Major	3	102.661	0.2	0.6	355
354	1114030207	Outlet Sulphur River	Red	Nacatoch	Carrizo	Major & Minor	3	314.519	0.612	1.837	47
355	1210030201	North Prong Medina River	Central Texas Coastal	None	Trinity	Major	3	90.214	0.176	0.527	394
356	1209020101	Cherokee Creek-Colorado River	Colorado	Hickory	Trinity	Major & Minor	3	124.559	0.243	0.728	300
357	1307001204	Dead Mans Canyon-Pecos River	Rio Grande	None	Edwards-Trinity	Major	3	110.43	0.215	0.645	334
358	1203010603	Pilot Grove Creek-Lavon Lake	Trinity	Woodbine	Trinity	Major & Minor	3	217.972	0.424	1.273	113
359	1203020203	Big Creek-Trinity River	Trinity	Sparta	Carrizo	Major & Minor	3	153.01	0.298	0.894	228
360	1304020401	Headwaters Terlingua Creek	Rio Grande	Igneous	None	Minor	2	48.755	0.095	0.19	723
361	1204020105	Sabine Lake	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	204.01	0.397	1.192	129
362	1206010503	Upper Hubbard Creek	Brazos	Cross Timbers	Trinity	Major & Minor	3	62.502	0.122	0.365	508
363	1204010404	Brays Bayou	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	10.649	0.021	0.062	928
364	1208000309	Lower Monument Draw	Colorado	Dockum	Ogallala	Major & Minor	3	2.954	0.006	0.017	1022
365	1110010302	Middle Coldwater Creek	Canadian	Dockum	Ogallala	Major & Minor	3	13.942	0.027	0.081	888
366	1211011102	Spring Creek-Nueces River	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	85.012	0.166	0.497	416
367	1307000804	Simpson Canyon-Pecos River	Rio Grande	None	Edwards-Trinity	Major	3	52.638	0.102	0.307	573
368	1208000506	Lower Johnson Draw	Colorado	None	Edwards-Trinity	Major	3	3.252	0.006	0.019	1018

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
369	1206010105	Millers Creek	Brazos	None	Seymour	Major	3	23.991	0.047	0.14	797
370	1210040205	Powderhorn Lake-Matagorda Bay	Central Texas Coastal	None	Gulf_Coast	Major	3	56.321	0.11	0.329	548
371	1211020602	Laborcitas Creek-Palo Blanco Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	28.374	0.055	0.166	759
372	1210010102	Clarks Creek-Lavaca River	Central Texas Coastal	None	Gulf_Coast	Major	3	190.99	0.372	1.116	151
373	1201000509	Nichols Creek-Sabine River	Sabine	None	Gulf_Coast	Major	3	306.489	0.597	1.79	54
374	1205000204	Soda Lake-Blackwater Draw	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	2.575	0.005	0.015	1025
375	1207010304	Duck Creek-Navasota River	Brazos	None	Carrizo	Major	3	150.984	0.294	0.882	236
376	1206020111	Rock Creek-Brazos River	Brazos	None	Trinity	Major	3	138.007	0.269	0.806	273
377	1304020704	Lower Nine Point Draw	Rio Grande	None	Edwards-Trinity	Major	3	12.428	0.024	0.073	906
378	1304010002	City of Socorro-Rio Grande	Rio Grande	None	Hueco_Bolson	Major	3	0.154	0	0.001	1067
379	1114010107	Pine Creek	Red	Woodbine	Trinity	Major & Minor	3	152.944	0.298	0.893	229
380	1209010503	Kickapoo Creek	Colorado	None	Edwards-Trinity	Major	3	58.143	0.113	0.34	535
381	1113020701	Headwaters Beaver Creek	Red	None	Seymour	Major	3	46.931	0.091	0.274	611
382	1110010304	Frisco Creek	Canadian	Dockum	Ogallala	Major & Minor	3	15.328	0.03	0.09	875
383	1211011001	Headwaters Atascosa River	Southwestern Texas Coastal	None	Carrizo	Major	3	66.35	0.129	0.388	490
384	1208000411	Lower Mustang Draw	Colorado	None	Ogallala	Major	3	10.075	0.02	0.059	935
385	1203010307	Little Elm Creek-Little Elm Reservoir	Trinity	Woodbine	Trinity	Major & Minor	3	154.815	0.301	0.904	218
386	1204020401	Clear Creek-Frontal Galveston Bay	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	80.367	0.156	0.469	430
387	1205000305	Sand Creek-North Fork Double Mountain Fork Brazos River	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	24.667	0.048	0.144	793

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
388	1211020802	Edinburg North Main Canal	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	8.467	0.016	0.049	953
389	1304020107	Sand Creek-Rio Grande	Rio Grande	West Texas Bolsons	None	Minor	2	13.666	0.027	0.053	946
390	1203020209	Kickapoo Creek	Trinity	None	Gulf_Coast	Major	3	244.8	0.477	1.43	93
391	1211010606	Upper Sabinal River	Southwestern Texas Coastal	None	Trinity	Major	3	73.239	0.143	0.428	460
392	1211020810	Lower Laguna Madre	Southwestern Texas Coastal	None	None	None	1	0	0	0	1069
393	1207020105	South Leon River-Leon River	Brazos	None	Trinity	Major	3	152.006	0.296	0.888	233
394	1202000202	Cochino Bayou-Neches River	Neches	Sparta	Carrizo	Major & Minor	3	328.989	0.641	1.922	42
395	1307000303	Cherry Creek	Rio Grande	None	Edwards-Trinity	Major	3	36.769	0.072	0.215	692
396	1307000405	Herds Pass Draw-Salt Draw	Rio Grande	Rustler	Edwards-Trinity	Major & Minor	3	27.069	0.053	0.158	775
397	1205000603	Upper White River	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	2.963	0.006	0.017	1021
398	1308000301	Retama Creek-San Juanito Creek	Rio Grande	None	Gulf_Coast	Major	3	30.107	0.059	0.176	743
399	1210030402	Upper Cibolo Creek	Central Texas Coastal	None	Trinity	Major	3	86.292	0.168	0.504	413
400	1305000415	Eightmile Draw	Rio Grande	Bone Spring-Victorio Peak	None	Minor	2	2.468	0.005	0.01	1052
401	1113020905	Dry Fork Little Wichita River-Little Wichita River	Red	Cross Timbers	None	Minor	2	103.772	0.202	0.404	482
402	1203010301	Headwaters Elm Fork Trinity River	Trinity	None	Trinity	Major	3	150.521	0.293	0.879	238
403	1210040505	Aransas Pass-Gulf of Mexico	Central Texas Coastal	None	None	None	1	0	0	0	1069
404	1210030302	Marcelinas Creek-San Antonio River	Central Texas Coastal	None	Gulf_Coast	Major	3	91.108	0.177	0.532	393
405	1205000406	Cooper Creek-Double Mountain Fork Brazos River	Brazos	Dockum	None	Minor	2	34.646	0.067	0.135	807
406	1109010103	Arroyo Trujillo	Canadian	Dockum	Ogallala	Major & Minor	3	29.367	0.057	0.172	751

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
407	1211010509	Quintania Creek-Nueces River	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	38.56	0.075	0.225	674
408	1203010102	Big Cleveland Creek-West Fork Trinity River	Trinity	Cross Timbers	None	Minor	2	94.023	0.183	0.366	506
409	1208000803	Oak Creek	Colorado	None	Edwards-Trinity	Major	3	59.296	0.115	0.346	524
410	1211010804	Esperanza Creek-Frio River	Southwestern Texas Coastal	Yegua Jackson	Carrizo	Major & Minor	3	44.32	0.086	0.259	633
411	1307000201	Willow Draw-Wild Horse Draw	Rio Grande	None	None	None	1	94.365	0.184	0.184	733
412	1305000321	Tularosa Valley	Rio Grande	None	Hueco_Bolson	Major	3	2.453	0.005	0.014	1026
413	1304030303	Red Bluff Creek	Rio Grande	None	Edwards-Trinity	Major	3	119.023	0.232	0.695	313
414	1208000205	Gavett Creek-Bull Creek	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	23.251	0.045	0.136	804
415	1203010310	Timber Creek-Elm Fork Trinity River	Trinity	Woodbine	Trinity	Major & Minor	3	52.898	0.103	0.309	567
416	1203010903	Waxahachie Creek	Trinity	Woodbine	Trinity	Major & Minor	3	148.318	0.289	0.866	243
417	1304021002	Downie Draw-Meyers Canyon	Rio Grande	None	Edwards-Trinity	Major	3	52.767	0.103	0.308	568
418	1307000408	Salt Draw-Toyah Lake	Rio Grande	None	Edwards-Trinity	Major	3	18.144	0.035	0.106	851
419	1210020302	Lower Blanco River	Central Texas Coastal	None	Trinity	Major	3	140.485	0.274	0.821	266
420	1207010301	Christmas Creek-Navasota River	Brazos	None	Carrizo	Major	3	178.894	0.348	1.045	167
421	1304010008	Arroyo Diablo-Rio Grande	Rio Grande	None	Hueco_Bolson	Major	3	6.108	0.012	0.036	973
422	1109010207	Los Redos Creek-Punta de Agua Creek	Canadian	Dockum	Ogallala	Major & Minor	3	19.045	0.037	0.111	843
423	1207020111	Nolan Creek-Leon River	Brazos	None	Trinity	Major	3	145.128	0.283	0.848	252
424	1114030701	Little Cypress Creek	Red	None	Carrizo	Major	3	371.699	0.724	2.171	36

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
425	1114030501	Glade Branch-Big Cypress Creek	Red	None	Carrizo	Major	3	289.743	0.564	1.692	63
426	1110020201	South Wolf Creek-Wolf Creek	Canadian	None	Ogallala	Major	3	11.257	0.022	0.066	918
427	1209040203	Live Oak Bayou-Frontal East Matagorda Bay	Colorado	None	Gulf_Coast	Major	3	100.929	0.196	0.589	361
428	1204020103	Salt Bayou	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	193.565	0.377	1.131	144
429	1114010102	Sandy Creek-Red River	Red	Woodbine	Trinity	Major & Minor	3	185.246	0.361	1.082	158
430	1209020407	San Fernando Creek-Llano River	Colorado	Hickory	None	Minor	2	116.55	0.227	0.454	444
431	1206010108	Boggy Creek-Brazos River	Brazos	Cross Timbers	Seymour	Major & Minor	3	43.609	0.085	0.255	640
432	1309000117	La Joya Creek-Rio Grande	Rio Grande	None	Gulf_Coast	Major	3	35.469	0.069	0.207	701
433	1201000407	Patroon Bayou	Sabine	None	Carrizo	Major	3	437.003	0.851	2.552	10
434	1204010301	Peach Creek-Caney Creek	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	259.991	0.506	1.519	82
435	1206020207	Tehuacana Creek	Brazos	Woodbine	Trinity	Major & Minor	3	149.838	0.292	0.875	239
436	1202000402	Caney Creek-Mud Creek	Neches	None	Carrizo	Major	3	274.61	0.535	1.604	69
437	1308000112	Tequesquite Creek-Rio Grande	Rio Grande	None	Edwards-Trinity	Major	3	22.83	0.044	0.133	809
438	1206010506	Lower Hubbard Creek	Brazos	Cross Timbers	None	Minor	2	51.166	0.1	0.199	711
439	1304020110	Arroyo Panales-Rio Grande	Rio Grande	Igneous	None	Minor	2	18.753	0.037	0.073	903
440	1202000602	Turkey Creek-Village Creek	Neches	None	Gulf_Coast	Major	3	464.79	0.905	2.715	3
441	1201000505	Quicksand Creek-Sabine River	Sabine	None	Gulf_Coast	Major	3	414.707	0.807	2.422	18
442	1307000715	Mayfield Draw-Landreth Draw	Rio Grande	None	Pecos Valley	Major	3	11.694	0.023	0.068	913
443	1113010104	Wanderers Creek	Red	None	Seymour	Major	3	39.317	0.077	0.23	665
444	1113010201	Suttle Creek-Red River	Red	None	Seymour	Major	3	70.111	0.136	0.409	479

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
445	1209010105	Mustang Creek-Colorado River	Colorado	Cross Timbers	None	Minor	2	65.663	0.128	0.256	636
446	1307000706	Block 12 Oil Field-Monument Draw	Rio Grande	Dockum	Ogallala	Major & Minor	3	15.594	0.03	0.091	874
447	1209010801	Upper Jim Ned Creek	Colorado	Cross Timbers	Edwards-Trinity	Major & Minor	3	75.26	0.147	0.44	454
448	1211011105	Lagarto Creek-Lake Corpus Christi	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	98.962	0.193	0.578	366
449	1201000210	Murvaul Creek-Sabine River	Sabine	None	Carrizo	Major	3	299.032	0.582	1.747	58
450	1211020504	Salado Creek-Los Olmos Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	32.946	0.064	0.192	720
451	1113020402	Middle North Wichita River	Red	None	Seymour	Major	3	34.108	0.066	0.199	712
452	1211010305	Headwaters San Roque Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	17.159	0.033	0.1	860
453	1205000201	Town of Midway	Brazos	None	Ogallala	Major	3	1.904	0.004	0.011	1045
454	1304020527	Horse Canyon-Rio Grande	Rio Grande	None	Edwards-Trinity	Major	3	19.474	0.038	0.114	838
455	1207010109	New Year Creek-Brazos River	Brazos	Brazos River Alluvium	Gulf_Coast	Major & Minor	3	152.308	0.297	0.89	232
456	1210020203	Peach Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	161.349	0.314	0.942	203
457	1109010504	East Amarillo Creek-Canadian River	Canadian	Dockum	Ogallala	Major & Minor	3	33.99	0.066	0.199	713
458	1304020113	Cibolo Creek	Rio Grande	Igneous	None	Minor	2	57.182	0.111	0.223	679
459	1307000704	Rock Lake	Rio Grande	Dockum	Pecos Valley	Major & Minor	3	31.67	0.062	0.185	728
460	1110020101	Clear Creek	Canadian	None	Ogallala	Major	3	49.381	0.096	0.288	593
461	1209020104	Inks Lake-Lake Lyndon B Johnson	Colorado	Hickory	Trinity	Major & Minor	3	103.338	0.201	0.604	353
462	1211010103	Headwaters Nueces River	Southwestern Texas Coastal	None	Edwards-Trinity	Major	3	51.154	0.1	0.299	583
463	1201000105	Mill Creek-Sabine River	Sabine	None	Carrizo	Major	3	156.564	0.305	0.914	212
464	1210040701	Poesta Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	78.865	0.154	0.461	437

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
465	1211010501	Headwaters Las Raices Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	30.132	0.059	0.176	742
466	1206010304	Lower Paint Creek	Brazos	Cross Timbers	None	Minor	2	38.105	0.074	0.148	784
467	1209010908	Richland Springs Creek-San Saba River	Colorado	Hickory	None	Minor	2	89.448	0.174	0.348	522
468	1208000103	Lost Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	4.74	0.009	0.028	991
469	1211020301	Upper Laguna Madre	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	88.426	0.172	0.516	404
470	1203010801	Richland Creek-Navarro Mills Lake	Trinity	Woodbine	Trinity	Major & Minor	3	148.088	0.288	0.865	245
471	1304030101	Headwaters Buckhorn Draw	Rio Grande	None	Edwards-Trinity	Major	3	38.327	0.075	0.224	678
472	1307001101	Upper Howard Draw	Rio Grande	None	Edwards-Trinity	Major	3	56.632	0.11	0.331	545
473	1304010003	Cuadrilla Lateral-Rio Grande	Rio Grande	None	Hueco_Bolson	Major	3	9.039	0.018	0.053	949
474	1203020206	Wright Creek-Trinity River	Trinity	Yegua Jackson	Carrizo	Major & Minor	3	142.502	0.277	0.832	260
475	1211010609	Upper Leona River	Southwestern Texas Coastal	None	Edwards	Major	3	31.006	0.06	0.181	738
476	1304020404	Lower Terlingua Creek	Rio Grande	None	None	None	1	30.096	0.059	0.059	936
477	1114020102	Upper McKinney Bayou	Red	Nacatoch	Carrizo	Major & Minor	3	263.46	0.513	1.539	78
478	1203010701	Kings Creek-Cedar Creek Reservoir	Trinity	Nacatoch	None	Minor	2	94.051	0.183	0.366	505
479	1114030603	Jim Bayou-Frazier Creek	Red	None	Carrizo	Major	3	513.638	1	3	1
480	1207020403	Lower Little River	Brazos	Brazos River Alluvium	Carrizo	Major & Minor	3	183.31	0.357	1.071	161
481	1209030101	Willbarger Creek-Colorado River	Colorado	None	Carrizo	Major	3	149.504	0.291	0.873	241
482	1209010902	Middle Valley Prong	Colorado	None	Edwards-Trinity	Major	3	45.619	0.089	0.266	619
483	1210040202	Garcitas Creek-Frontal Lavaca Bay	Central Texas Coastal	None	Gulf_Coast	Major	3	86.779	0.169	0.507	411

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
484	1208000503	Upper Monahans Draw	Colorado	None	Edwards-Trinity	Major	3	1.696	0.003	0.01	1051
485	1206010102	Little Croton Creek-Brazos River	Brazos	None	Seymour	Major	3	28.464	0.055	0.166	758
486	1204010401	Barker Reservoir	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	72.709	0.142	0.425	463
487	1211010202	Upper West Nueces River	Southwestern Texas Coastal	None	Edwards-Trinity	Major	3	53.87	0.105	0.315	563
488	1209010203	Dove Creek	Colorado	None	Edwards-Trinity	Major	3	35.988	0.07	0.21	698
489	1206020402	Duffau Creek-North Bosque River	Brazos	None	Trinity	Major	3	173.067	0.337	1.011	176
490	1304021203	Eagle Nest Creek-Rio Grande	Rio Grande	None	Edwards-Trinity	Major	3	77.352	0.151	0.452	446
491	1304030107	Sawyer Draw-Dry Devils River	Rio Grande	None	Edwards-Trinity	Major	3	86.513	0.168	0.505	412
492	1208000407	Lower McKenzie Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	3.574	0.007	0.021	1012
493	1206010403	Bufford Creek-Clear Fork Brazos River	Brazos	Cross Timbers	None	Minor	2	71.443	0.139	0.278	605
494	1110010405	Lower Palo Duro Creek	Canadian	None	Ogallala	Major	3	22.627	0.044	0.132	811
495	1207010307	Gibbons Creek-Navasota River	Brazos	Yegua Jackson	Gulf_Coast	Major & Minor	3	157.657	0.307	0.921	210
496	1307000605	Coyanosa Draw	Rio Grande	None	Edwards-Trinity	Major	3	20.99	0.041	0.123	826
497	1112030102	Lower McClellan Creek	Red	None	Ogallala	Major	3	49.677	0.097	0.29	592
498	1304020701	Upper Nine Point Draw	Rio Grande	None	None	None	1	39.595	0.077	0.077	897
499	1112010503	Salt Creek-Prairie Dog Town Fork Red River	Red	None	Seymour	Major	3	46.035	0.09	0.269	614
500	1204010304	East Fork San Jacinto River-Frontal Lake Houston	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	190.602	0.371	1.113	154
501	1211020507	Cayo del Grullo	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	62.161	0.121	0.363	509

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
502	1211020605	Laguna Salada-Palo Blanco Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	55.415	0.108	0.324	554
503	1210010201	Headwaters Navidad River	Central Texas Coastal	Sparta	Gulf_Coast	Major & Minor	3	191.437	0.373	1.118	147
504	1205000302	Harvey Creek-Spring Creek	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	2.235	0.004	0.013	1033
505	1209020502	Cow Creek-Lake Travis	Colorado	None	Trinity	Major	3	81.457	0.159	0.476	427
506	1211011004	La Parita Creek-Atascosa River	Southwestern Texas Coastal	Sparta	Carrizo	Major & Minor	3	70.088	0.136	0.409	480
507	1307000801	Fivemile Creek	Rio Grande	None	Edwards-Trinity	Major	3	40.732	0.079	0.238	655
508	1204010407	Buffalo Bayou-San Jacinto River	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	74.308	0.145	0.434	457
509	1110010402	South Palo Duro Creek	Canadian	Dockum	Ogallala	Major & Minor	3	2.21	0.004	0.013	1034
510	1305000417	Linda Lake	Rio Grande	Bone Spring-Victorio Peak	None	Minor	2	0.129	0	0.001	1068
511	1208000601	Headwaters Sulphur Springs Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	2.363	0.005	0.014	1029
512	1113020603	Holliday Creek	Red	Cross Timbers	Seymour	Major & Minor	3	53.282	0.104	0.311	565
513	1203020212	Menard Creek-Trinity River	Trinity	None	Gulf_Coast	Major	3	285.848	0.557	1.67	66
514	1203020107	Big Elkhart Creek-Trinity River	Trinity	Sparta	Carrizo	Major & Minor	3	125.448	0.244	0.733	298
515	1211010603	Dry Frio River	Southwestern Texas Coastal	None	Edwards	Major	3	53.002	0.103	0.31	566
516	1304020203	Perdiz Creek-Alamito Creek	Rio Grande	Igneous	None	Minor	2	38.036	0.074	0.148	785
517	1210030204	Leon Creek	Central Texas Coastal	None	Carrizo	Major	3	60.551	0.118	0.354	516
518	1109010203	Tramperos Creek-Punta de Agua Creek	Canadian	Dockum	Ogallala	Major & Minor	3	3.408	0.007	0.02	1015
519	1201000506	Big Cow Creek	Sabine	None	Gulf_Coast	Major	3	445.319	0.867	2.601	7

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
520	1112010106	Buffalo Lake-Tierra Blanca Creek	Red	Dockum	Ogallala	Major & Minor	3	11.586	0.023	0.068	914
521	1309000114	Las Blancas Creek-Los Olmos Creek	Rio Grande	None	Gulf_Coast	Major	3	52.364	0.102	0.306	575
522	1305000412	South Well Draw	Rio Grande	None	None	None	1	16.214	0.032	0.032	982
523	1109010102	Minneosa Creek	Canadian	Dockum	Ogallala	Major & Minor	3	10.723	0.021	0.063	926
524	1204020204	Cane Bayou	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	195.205	0.38	1.14	141
525	1209010602	Bull Creek-Colorado River	Colorado	Cross Timbers	Edwards-Trinity	Major & Minor	3	59.149	0.115	0.345	527
526	1211010801	Martin Branch-Frio River	Southwestern Texas Coastal	Yegua Jackson	Carrizo	Major & Minor	3	37.381	0.073	0.218	684
527	1202000205	Shawnee Creek-Neches River	Neches	None	Gulf_Coast	Major	3	406.663	0.792	2.375	22
528	1209010310	Dry Creek-Middle Concho River	Colorado	None	Edwards-Trinity	Major	3	34.86	0.068	0.204	708
529	1206020201	Paluxy River	Brazos	None	Trinity	Major	3	141.142	0.275	0.824	261
530	1114030102	Middle Sulphur River-South Sulphur River	Red	Woodbine	Trinity	Major & Minor	3	197.458	0.384	1.153	138
531	1205000403	Double Lakes-Double Mountain Fork Brazos River	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	4.269	0.008	0.025	997
532	1209030202	Jones Creek-Colorado River	Colorado	None	Gulf_Coast	Major	3	90.091	0.175	0.526	395
533	1210040101	Cox Creek-Frontal Cox Bay	Central Texas Coastal	None	Gulf_Coast	Major	3	52.755	0.103	0.308	569
534	1114010101	Choctaw Creek	Red	Woodbine	Trinity	Major & Minor	3	234.764	0.457	1.371	106
535	1203010304	Culp Branch-Elm Fork Trinity River	Trinity	Woodbine	Trinity	Major & Minor	3	138.455	0.27	0.809	270
536	1308000308	Los Tanques Creek-Villa Creek	Rio Grande	None	Gulf_Coast	Major	3	35.968	0.07	0.21	699
537	1305000419	Ryan Draw	Rio Grande	Igneous	None	Minor	2	22.134	0.043	0.086	879
538	1109010403	Trabajo Creek-Carrizo Creek	Canadian	Rita Blanca	Ogallala	Major & Minor	3	24.648	0.048	0.144	794

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
539	1204020505	Freeport Harbor Channel-Gulf of Mexico	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	0	0	0	1069
540	1209010405	Lower North Concho River	Colorado	None	Edwards-Trinity	Major	3	38.713	0.075	0.226	671
541	1207020102	Armstrong Creek-Leon River	Brazos	None	Trinity	Major	3	98.153	0.191	0.573	368
542	1202000106	Box Creek	Neches	Queen City	Carrizo	Major & Minor	3	268.495	0.523	1.568	75
543	1307000402	Coalson Draw-Cottonwood Creek	Rio Grande	Rustler	Edwards-Trinity	Major & Minor	3	10.347	0.02	0.06	933
544	1114010106	Sanders Creek	Red	Woodbine	Trinity	Major & Minor	3	174.364	0.339	1.018	173
545	1204010103	Caney Creek-Lake Creek	Galveston Bay-San Jacinto	Sparta	Gulf_Coast	Major & Minor	3	260.912	0.508	1.524	81
546	1211010805	San Miguel Creek-Frio River	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	96.638	0.188	0.564	371
547	1203020102	Catfish Creek	Trinity	None	Carrizo	Major	3	190.704	0.371	1.114	153
548	1209040101	Upper San Bernard River	Colorado	None	Gulf_Coast	Major	3	108.628	0.211	0.634	335
549	1307000903	Tunas Creek	Rio Grande	None	Edwards-Trinity	Major	3	45.655	0.089	0.267	617
550	1307000202	Upper Delaware River	Rio Grande	Capitan Reef Complex	None	Minor	2	94.411	0.184	0.368	501
551	1210040503	Saint Charles Bay	Central Texas Coastal	None	Gulf_Coast	Major	3	92.225	0.18	0.539	387
552	1207010201	Middle Yegua Creek	Brazos	None	Carrizo	Major	3	195.225	0.38	1.14	140
553	1304030304	Lower Dry Devils River	Rio Grande	None	Edwards-Trinity	Major	3	120.796	0.235	0.706	310
554	1209020402	Big Saline Creek-Llano River	Colorado	Hickory	Edwards-Trinity	Major & Minor	3	61.424	0.12	0.359	514
555	1204020203	Oyster Bayou-Gulf of Mexico	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	162.1	0.316	0.947	201
556	1112030203	Town of Erick-North Fork Red River	Red	Blaine	None	Minor	2	112.438	0.219	0.438	455
557	1109010304	Rita Blanca Lake-Rita Blanca Creek	Canadian	Dockum	Ogallala	Major & Minor	3	2.337	0.005	0.014	1031

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
558	1209010305	North Creek Draw	Colorado	None	Edwards-Trinity	Major	3	3.705	0.007	0.022	1011
559	1114030502	Brushy Creek-Big Cypress Creek	Red	None	Carrizo	Major	3	310.044	0.604	1.811	51
560	1110020202	Northup Creek-Wolf Creek	Canadian	None	Ogallala	Major	3	50.277	0.098	0.294	588
561	1304020903	Indian Creek-San Francisco Creek	Rio Grande	Marathon	Edwards-Trinity	Major & Minor	3	27.585	0.054	0.161	771
562	1114030702	Little Cypress Bayou	Red	None	Carrizo	Major	3	427.386	0.832	2.496	14
563	1113020101	Whiskey Creek-Red River	Red	None	Seymour	Major	3	144.997	0.282	0.847	253
564	1307000503	Lawrence Draw-Barrilla Draw	Rio Grande	Rustler	Edwards-Trinity	Major & Minor	3	23.732	0.046	0.139	801
565	1201000301	Lake Fork Creek-Case Lake	Sabine	None	Carrizo	Major	3	179.663	0.35	1.049	162
566	1304010009	Arroyo Balluco-Rio Grande	Rio Grande	None	Hueco_Bolson	Major	3	16.836	0.033	0.098	865
567	1304020101	Asebuches Arroyo-Rio Grande	Rio Grande	None	Hueco_Bolson	Major	3	10.734	0.021	0.063	924
568	1110020304	City of Shattuck-Wolf Creek	Canadian	None	Ogallala	Major	3	76.643	0.149	0.448	448
569	1206020208	Castleman Creek-Brazos River	Brazos	Woodbine	Trinity	Major & Minor	3	112.81	0.22	0.659	327
570	1307000106	Horsehead Draw-Pecos River	Rio Grande	Rustler	Pecos Valley	Major & Minor	3	14.367	0.028	0.084	883
571	1208000208	Morgan Creek	Colorado	Dockum	Ogallala	Major & Minor	3	17.245	0.034	0.101	859
572	1209040204	East Matagorda Bay	Colorado	None	Gulf_Coast	Major	3	174.912	0.341	1.022	172
573	1204020503	Austin Bayou	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	91.645	0.178	0.535	388
574	1305000410	Cameleche Tanks-University Draw	Rio Grande	Bone Spring-Victorio Peak	None	Minor	2	20.462	0.04	0.08	890
575	1207010302	Steele Creek	Brazos	None	Carrizo	Major	3	213.553	0.416	1.247	120
576	1209020408	Little Llano River-Llano River	Colorado	Hickory	None	Minor	2	112.234	0.219	0.437	456
577	1209010702	Turkey Creek-Pecan Bayou	Colorado	Cross Timbers	Trinity	Major & Minor	3	87.345	0.17	0.51	410

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
578	1211010510	Old Nueces River Channel-Nueces River	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	44.71	0.087	0.261	629
579	1304030202	Dolan Creek	Rio Grande	None	Edwards-Trinity	Major	3	114.296	0.223	0.668	323
580	1309000205	Outlet Rio Grande	Rio Grande	None	None	None	1	0	0	0	1069
581	1204010302	Tarkington Bayou-Luce Bayou	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	207.046	0.403	1.209	126
582	1211020505	Agua Dulce Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	38.921	0.076	0.227	669
583	1209010201	Upper Spring Creek	Colorado	None	Edwards-Trinity	Major	3	29.878	0.058	0.175	746
584	1208000608	Sulphur Springs Draw-Natural Dam Lake	Colorado	None	Ogallala	Major	3	5.972	0.012	0.035	975
585	1203010601	Indian Creek-Pilot Grove Creek	Trinity	Woodbine	Trinity	Major & Minor	3	241.666	0.47	1.411	100
586	1211010306	Appurceon Creek-Nueces River	Southwestern Texas Coastal	None	Carrizo	Major	3	22.517	0.044	0.132	813
587	1208000301	Wards Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	2.189	0.004	0.013	1036
588	1208000104	Sulphur Draw-Lost Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	5.457	0.011	0.032	980
589	1112010401	Town of Easter	Red	Dockum	Ogallala	Major & Minor	3	5.544	0.011	0.032	978
590	1112010103	Frio Draw	Red	Dockum	Ogallala	Major & Minor	3	4.174	0.008	0.024	1000
591	1209010802	Lower Jim Ned Creek	Colorado	Cross Timbers	None	Minor	2	94.173	0.183	0.367	503
592	1211010504	Carrizitos Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	24.687	0.048	0.144	792
593	1211011106	Penitas Creek-Lake Corpus Christi	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	95.65	0.186	0.559	376
594	1202000603	Theuvenins Creek-Beech Creek	Neches	None	Gulf_Coast	Major	3	393.207	0.766	2.297	28
595	1201000507	Dempsey Creek-Sabine River	Sabine	None	Gulf_Coast	Major	3	354.154	0.69	2.069	39

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
596	1304021003	Buck Creek-Thurston Canyon	Rio Grande	None	Edwards-Trinity	Major	3	55.47	0.108	0.324	553
597	1304030102	Buckhorn Draw-Granger Draw	Rio Grande	None	Edwards-Trinity	Major	3	54.712	0.107	0.32	558
598	1113010404	Middle Pease River	Red	Dockum	Ogallala	Major & Minor	3	34.178	0.067	0.2	710
599	1207020501	North Fork San Gabriel River	Brazos	None	Trinity	Major	3	152.714	0.297	0.892	230
600	1210020102	Turtle Creek-Guadalupe River	Central Texas Coastal	None	Trinity	Major	3	103.834	0.202	0.606	351
601	1210020204	McCoy Creek-Guadalupe River	Central Texas Coastal	None	Gulf_Coast	Major	3	154.782	0.301	0.904	219
602	1208000105	Union Cemetery-Lost Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	1.7	0.003	0.01	1050
603	1304020802	Reagan Canyon-Rio Grande	Rio Grande	None	Edwards-Trinity	Major	3	28.197	0.055	0.165	762
604	1202000504	Big Iron Ore Creek-Attoyac River	Neches	None	Carrizo	Major	3	413.728	0.805	2.416	19
605	1201000205	Rabbit Creek-Sabine River	Sabine	None	Carrizo	Major	3	240.376	0.468	1.404	101
606	1208000804	Kickapoo Creek-Colorado River	Colorado	None	Edwards-Trinity	Major	3	40.7	0.079	0.238	656
607	1206010208	Deadman Creek-Clear Fork Brazos River	Brazos	None	Seymour	Major	3	47.579	0.093	0.278	607
608	1203010802	Post Oak Creek-Richland Creek	Trinity	Woodbine	Trinity	Major & Minor	3	155.719	0.303	0.91	215
609	1211020403	Rosita Creek-San Diego Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	78.525	0.153	0.459	439
610	1307001102	Middle Howard Draw	Rio Grande	None	Edwards-Trinity	Major	3	60.317	0.117	0.352	517
611	1210040702	Upper Aransas River	Central Texas Coastal	None	Gulf_Coast	Major	3	54.357	0.106	0.317	560
612	1207010104	Pond Creek	Brazos	None	Carrizo	Major	3	101.031	0.197	0.59	360
613	1201000202	Lake Winnsboro-Big Sandy Creek	Sabine	None	Carrizo	Major	3	241.809	0.471	1.412	99
614	1202000507	Ayish Bayou	Neches	None	Carrizo	Major	3	446.596	0.869	2.608	6

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
615	1114030405	Cross Bayou	Red	None	Carrizo	Major	3	320.118	0.623	1.87	45
616	1110020104	Lower Kiowa Creek	Canadian	None	Ogallala	Major	3	48.39	0.094	0.283	597
617	1204010402	Addicks Reservoir	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	55.483	0.108	0.324	552
618	1207010402	Mill Creek-Brazos River	Brazos	Brazos River Alluvium	Gulf_Coast	Major & Minor	3	169.526	0.33	0.99	186
619	1210030102	Headwaters San Antonio River	Central Texas Coastal	None	Carrizo	Major	3	31.581	0.061	0.184	730
620	1109010606	Red Deer Creek	Canadian	None	Ogallala	Major	3	55.526	0.108	0.324	551
621	1203020207	White Rock Creek	Trinity	None	Gulf_Coast	Major	3	224.824	0.438	1.313	110
622	1209010903	Rocky Creek-San Saba River	Colorado	None	Edwards-Trinity	Major	3	57.849	0.113	0.338	540
623	1203010206	Mountain Creek-Mountain Creek Lake	Trinity	Woodbine	Trinity	Major & Minor	3	121.313	0.236	0.709	307
624	1308000306	Cavasara Creek-Rio Grande	Rio Grande	Yegua Jackson	None	Minor	2	44.95	0.088	0.175	745
625	1206010501	Deep Creek	Brazos	Cross Timbers	Trinity	Major & Minor	3	59.391	0.116	0.347	523
626	1305000422	Tally Slough-Wild Horse Draw	Rio Grande	Igneous	None	Minor	2	17.978	0.035	0.07	910
627	1307000301	Madera Canyon	Rio Grande	Igneous	Pecos Valley	Major & Minor	3	87.393	0.17	0.51	409
628	1208000101	South Fork Sulphur Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	4.126	0.008	0.024	1003
629	1113020105	Lake Nocona-Red River	Red	None	Trinity	Major	3	184.867	0.36	1.08	159
630	1110020102	North Fork Kiowa Creek	Canadian	None	Ogallala	Major	3	11.14	0.022	0.065	920
631	1210010204	West Mustang Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	67.412	0.131	0.394	485
632	1209011001	Upper Brady Creek	Colorado	None	Edwards-Trinity	Major	3	61.797	0.12	0.361	513
633	1205000303	Plum Creek-North Fork Double Mountain Fork Brazos River	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	4.267	0.008	0.025	998

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
634	1205000112	Smyer Oil Field-Yellow House Draw	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	1.594	0.003	0.009	1053
635	1113020403	Lower North Wichita River	Red	None	Seymour	Major	3	36.053	0.07	0.211	697
636	1304021214	Rio Grande-Amistad Reservoir	Rio Grande	None	Edwards-Trinity	Major	3	111.811	0.218	0.653	331
637	1209020503	City of Austin-Colorado River	Colorado	None	Trinity	Major	3	111.091	0.216	0.649	332
638	1207020303	Lucy Creek-Lampasas River	Brazos	None	Trinity	Major	3	159.848	0.311	0.934	206
639	1211010301	Indian Creek-Nueces River	Southwestern Texas Coastal	None	Carrizo	Major	3	35.167	0.068	0.205	704
640	1307000606	Hackberry Draw	Rio Grande	Rustler	Edwards-Trinity	Major & Minor	3	11.405	0.022	0.067	916
641	1206010103	Lake Creek	Brazos	None	Seymour	Major	3	6.196	0.012	0.036	972
642	1112020101	Greenbelt Reservoir-Salt Fork Red River	Red	Dockum	Ogallala	Major & Minor	3	34.915	0.068	0.204	707
643	1112030103	Headwaters North Fork Red River	Red	None	Ogallala	Major	3	47.657	0.093	0.278	604
644	1307000101	Red Bluff Reservoir	Rio Grande	Rustler	Pecos Valley	Major & Minor	3	44.869	0.087	0.262	626
645	1211020508	Alazan Bay-Baffin Bay	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	63.048	0.123	0.368	499
646	1208000305	City of Seminole-Wardswell Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	7.208	0.014	0.042	958
647	1211011005	Outlet Atascosa River	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	108.19	0.211	0.632	338
648	1207020103	Copperas Creek	Brazos	None	Trinity	Major	3	88.971	0.173	0.52	401
649	1210030205	Lower Medina River	Central Texas Coastal	None	Carrizo	Major	3	67.391	0.131	0.394	486
650	1114030301	Upper White Oak Creek	Red	None	Carrizo	Major	3	198.585	0.387	1.16	136
651	1110010403	Upper Palo Duro Creek	Canadian	None	Ogallala	Major	3	8.995	0.018	0.053	950
652	1203020201	Lower Keechi Creek	Trinity	Sparta	Carrizo	Major & Minor	3	164.194	0.32	0.959	195

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
653	1305000413	Sierra Diablo-Witherspoon Draw	Rio Grande	None	None	None	1	25.481	0.05	0.05	952
654	1208000409	Town of Andrews-Baird Lake	Colorado	Dockum	Ogallala	Major & Minor	3	0.97	0.002	0.006	1062
655	1203010106	West Fork Trinity River-Eagle Mountain Lake	Trinity	None	Trinity	Major	3	147.402	0.287	0.861	247
656	1203010305	Blocker Creek-Clear Creek	Trinity	None	Trinity	Major	3	162.687	0.317	0.95	199
657	1308000226	Espada Creek-Rio Grande	Rio Grande	None	Carrizo	Major	3	47.15	0.092	0.275	609
658	1114010604	Mill Creek-Red River	Red	Nacatoch	None	Minor	2	290.663	0.566	1.132	143
659	1202000101	Black Fork Creek-Neches River	Neches	None	Carrizo	Major	3	211.498	0.412	1.235	122
660	1202000301	Billiams Creek-Neches River	Neches	None	Gulf_Coast	Major	3	448.828	0.874	2.621	5
661	1211010604	Salt Creek-Frio River	Southwestern Texas Coastal	None	Edwards	Major	3	45.52	0.089	0.266	620
662	1205000504	Slaton Draw-Running Water Draw	Brazos	Dockum	Ogallala	Major & Minor	3	1.111	0.002	0.006	1059
663	1304020204	Cienega Creek	Rio Grande	Igneous	None	Minor	2	46.95	0.091	0.183	736
664	1109010104	Trujillo Creek	Canadian	Dockum	Ogallala	Major & Minor	3	24.047	0.047	0.14	796
665	1209010501	Lipan Creek	Colorado	Lipan	Edwards-Trinity	Major & Minor	3	21.162	0.041	0.124	823
666	1209010311	West Rocky Creek-Middle Concho River	Colorado	None	Edwards-Trinity	Major	3	33.188	0.065	0.194	717
667	1211010612	Buck Creek-Frio River	Southwestern Texas Coastal	Sparta	Carrizo	Major & Minor	3	45.473	0.089	0.266	621
668	1203020303	Old River-Trinity River	Trinity	None	Gulf_Coast	Major	3	199.499	0.388	1.165	133
669	1206020109	Lower Palo Pinto Creek	Brazos	None	Trinity	Major	3	92.667	0.18	0.541	384
670	1206020202	Nolan River	Brazos	Woodbine	Trinity	Major & Minor	3	153.765	0.299	0.898	223
671	1210040102	East Carancahua Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	49.262	0.096	0.288	594
672	1210030306	San Antonio River-Guadalupe River	Central Texas Coastal	None	Gulf_Coast	Major	3	117.024	0.228	0.684	316

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
673	1205000704	Duck Creek	Brazos	None	Seymour	Major	3	28.777	0.056	0.168	756
674	1112010404	South Tule Draw	Red	Dockum	Ogallala	Major & Minor	3	4.075	0.008	0.024	1004
675	1209030104	Alum Creek-Colorado River	Colorado	Sparta	Carrizo	Major & Minor	3	162.665	0.317	0.95	200
676	1202000107	San Pedro Creek-Neches River	Neches	Queen City	Carrizo	Major & Minor	3	239.972	0.467	1.402	102
677	1307000403	Kent Draw-Herds Pass Draw	Rio Grande	None	Edwards-Trinity	Major	3	57.992	0.113	0.339	538
678	1112010201	Upper Palo Duro Creek	Red	Dockum	Ogallala	Major & Minor	3	7.131	0.014	0.042	959
679	1110020106	Town of Fort Supply-Beaver River	Canadian	None	Ogallala	Major	3	74.087	0.144	0.433	459
680	1211020808	Laguna Atascosa	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	38.331	0.075	0.224	677
681	1207020109	Coryell Creek-Leon River	Brazos	None	Trinity	Major	3	140.979	0.274	0.823	262
682	1113010401	Upper Middle Pease River	Red	Dockum	Ogallala	Major & Minor	3	34.958	0.068	0.204	706
683	1304020906	Cow Creek-San Francisco Creek	Rio Grande	None	Edwards-Trinity	Major	3	25.735	0.05	0.15	782
684	1113021005	Denison Dam-Red River	Red	None	Trinity	Major	3	245.643	0.478	1.435	91
685	1114030601	French Creek-Big Cypress Bayou	Red	None	Carrizo	Major	3	438.686	0.854	2.562	9
686	1108000609	Rana Arroyo-Canadian River	Canadian	Dockum	None	Minor	2	16.171	0.031	0.063	922
687	1207010204	Davidson Creek	Brazos	None	Carrizo	Major	3	206.797	0.403	1.208	127
688	1304030301	Upper Dry Devils River	Rio Grande	None	Edwards-Trinity	Major	3	114.59	0.223	0.669	322
689	1209010605	Clear Creek-Colorado River	Colorado	Cross Timbers	None	Minor	2	97.702	0.19	0.38	493
690	1113020903	Lake Arrowhead-Little Wichita River	Red	Cross Timbers	None	Minor	2	100.543	0.196	0.391	487
691	1109010502	Sierrita de la Cruz Creek-Canadian River	Canadian	Dockum	Ogallala	Major & Minor	3	28.003	0.055	0.164	766
692	1208000801	Little Silver Creek-Colorado River	Colorado	Dockum	Edwards-Trinity	Major & Minor	3	45.273	0.088	0.264	622

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
693	1206010205	Mulberry Creek	Brazos	None	Edwards-Trinity	Major	3	32.821	0.064	0.192	722
694	1210040602	Blanco Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	134.097	0.261	0.783	281
695	1209040201	Linnville Bayou	Colorado	None	Gulf_Coast	Major	3	143.055	0.279	0.836	258
696	1208000405	Middle McKenzie Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	6.455	0.013	0.038	968
697	1210020207	Lower Sandies Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	162.031	0.315	0.946	202
698	1206020106	Keechi Creek	Brazos	None	Trinity	Major	3	108.276	0.211	0.632	337
699	1308000219	San Lorenzo Creek-Rio Grande	Rio Grande	None	Carrizo	Major	3	38.528	0.075	0.225	675
700	1204010201	Little Cypress Creek-Cypress Creek	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	63.204	0.123	0.369	498
701	1211010802	Snake Creek-Cibolo Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	27.235	0.053	0.159	773
702	1211010903	Raccoon Creek-San Miguel Creek	Southwestern Texas Coastal	Yegua Jackson	Carrizo	Major & Minor	3	65.584	0.128	0.383	492
703	1209020405	Comanche Creek-Llano River	Colorado	Hickory	Edwards-Trinity	Major & Minor	3	95.783	0.186	0.559	374
704	1211010601	West Frio River	Southwestern Texas Coastal	None	Edwards-Trinity	Major	3	76.436	0.149	0.446	449
705	1211010507	Salado Creek-San Casimiro Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	28.97	0.056	0.169	755
706	1112020203	Cave Creek-Salt Fork Red River	Red	None	Seymour	Major	3	70.694	0.138	0.413	476
707	1206020205	Aquilla Creek	Brazos	Woodbine	Trinity	Major & Minor	3	170.555	0.332	0.996	179
708	1203010503	Red Oak Creek	Trinity	Woodbine	Trinity	Major & Minor	3	160.125	0.312	0.935	205
709	1307000109	Mosquito Lake-Pecos River	Rio Grande	None	Pecos Valley	Major	3	9.927	0.019	0.058	937
710	1307000711	Town of Monahans-Ozark Lake	Rio Grande	Dockum	Ogallala	Major & Minor	3	26.964	0.052	0.157	778
711	1112010304	Battle Creek-Prairie Dog Town Fork Red River	Red	Dockum	Ogallala	Major & Minor	3	42.548	0.083	0.249	646

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
712	1204020404	Mustang Bayou-Gulf of Mexico	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	128.244	0.25	0.749	290
713	1304020109	Capote Creek	Rio Grande	Igneous	None	Minor	2	18.753	0.037	0.073	903
714	1210040400	Hynes Bay-San Antonio Bay	Central Texas Coastal	None	Gulf_Coast	Major	3	114.84	0.224	0.671	320
715	1203020105	Buffalo Creek	Trinity	None	Carrizo	Major	3	146.856	0.286	0.858	250
716	1304010004	Borrego Draw-Rio Grande	Rio Grande	None	Hueco_Bolson	Major	3	10.741	0.021	0.063	923
717	1201000401	Tenaha Creek	Sabine	None	Carrizo	Major	3	382.16	0.744	2.232	30
718	1308000104	Sacatosa Creek-Sycamore Creek	Rio Grande	None	Edwards-Trinity	Major	3	96.466	0.188	0.563	372
719	1304021102	Middle Big Canyon	Rio Grande	None	Edwards-Trinity	Major	3	53.966	0.105	0.315	561
720	1113010502	Lower Pease River	Red	None	Seymour	Major	3	58.679	0.114	0.343	531
721	1207010107	Old River-Brazos River	Brazos	Sparta	Carrizo	Major & Minor	3	106.108	0.207	0.62	345
722	1209010705	Blanket Creek	Colorado	None	Trinity	Major	3	134.204	0.261	0.784	280
723	1304030110	Anderson Draw-Johnson Draw	Rio Grande	None	Edwards-Trinity	Major	3	91.216	0.178	0.533	392
724	1109010107	Alamocitos Creek-Canadian River	Canadian	Dockum	Ogallala	Major & Minor	3	24.849	0.048	0.145	791
725	1110010106	Cimarron Feeders Number 1 Reservoir-Beaver River	Canadian	Dockum	Ogallala	Major & Minor	3	22.359	0.044	0.131	815
726	1211020502	Agua Poquita Creek-Los Olmos Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	71.906	0.14	0.42	468
727	1307001202	Big Fielder Draw-Pecos River	Rio Grande	None	Edwards-Trinity	Major	3	88.996	0.173	0.52	400
728	1307000807	Reagan Canyon-Pecos River	Rio Grande	None	Edwards-Trinity	Major	3	60.239	0.117	0.352	519
729	1205000111	Town of Littlefield	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	2.167	0.004	0.013	1037
730	1211020302	1211020302-Gulf of Mexico	Southwestern Texas Coastal	None	None	None	1	0	0	0	1069

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
731	1202000501	Anderson Creek-Angelina River	Neches	Sparta	Carrizo	Major & Minor	3	364.673	0.71	2.13	37
732	1201000208	Martin Creek	Sabine	None	Carrizo	Major	3	318.79	0.621	1.862	46
733	1109010603	Spring Creek-Canadian River	Canadian	None	Ogallala	Major	3	78.047	0.152	0.456	442
734	1304020518	Dominguez Mountains-Rio Grande	Rio Grande	None	None	None	1	20.395	0.04	0.04	961
735	1209020303	Paint Creek	Colorado	None	Edwards-Trinity	Major	3	89.274	0.174	0.521	399
736	1202000510	Indian Creek-Angelina River	Neches	None	Gulf_Coast	Major	3	397.944	0.775	2.324	27
737	1201000411	Sixmile Creek-Toledo Bend Reservoir	Sabine	None	Gulf_Coast	Major	3	411.045	0.8	2.401	20
738	1307000713	Sand Hills Oil Field-Juan Cordona Lake	Rio Grande	None	Pecos Valley	Major	3	13.209	0.026	0.077	895
739	1305000408	Alkali Lakes	Rio Grande	Bone Spring-Victorio Peak	None	Minor	2	27.836	0.054	0.108	848
740	1211010101	East Prong Nueces River	Southwestern Texas Coastal	None	Edwards-Trinity	Major	3	65.033	0.127	0.38	494
741	1209010103	Bluff Creek-Elm Creek	Colorado	Cross Timbers	Edwards-Trinity	Major & Minor	3	46.237	0.09	0.27	613
742	1203010702	Cedar Creek-Cedar Creek Reservoir	Trinity	None	Carrizo	Major	3	107.837	0.21	0.63	339
743	1307001003	Middle Independence Creek	Rio Grande	None	Edwards-Trinity	Major	3	58.269	0.113	0.34	533
744	1206010302	Upper Paint Creek	Brazos	None	Seymour	Major	3	16.412	0.032	0.096	868
745	1211010402	Headwaters Palo Blanco Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	6.437	0.013	0.038	969
746	1207020504	Turkey Creek-Brushy Creek	Brazos	None	Carrizo	Major	3	123.998	0.241	0.724	302
747	1210020201	Comal River-Guadalupe River	Central Texas Coastal	None	Trinity	Major	3	101.882	0.198	0.595	357
748	1209020102	Lake Buchanan-Colorado River	Colorado	Hickory	Trinity	Major & Minor	3	107.457	0.209	0.628	341
749	1304020804	Dry Creek-Sanderson Creek	Rio Grande	None	Edwards-Trinity	Major	3	33.548	0.065	0.196	715

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
750	1209010403	Upper North Concho River	Colorado	None	Edwards-Trinity	Major	3	30.889	0.06	0.18	739
751	1205000205	City of Lubbock-Blackwater Draw	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	3.78	0.007	0.022	1009
752	1113020601	Lake Kemp-Wichita River	Red	None	Seymour	Major	3	44.732	0.087	0.261	628
753	1307000720	Leon Creek	Rio Grande	None	Pecos Valley	Major	3	14.189	0.028	0.083	885
754	1112010504	Buck Creek	Red	None	Seymour	Major	3	55.048	0.107	0.322	557
755	1306001113	Red Bluff Draw	Rio Grande	None	None	None	1	8.431	0.016	0.016	1023
756	1206010401	Foyle Creek-Clear Fork Brazos River	Brazos	Cross Timbers	None	Minor	2	64.253	0.125	0.25	644
757	1203010604	East Fork Trinity River-Lake Ray Hubbard	Trinity	Woodbine	Trinity	Major & Minor	3	110.496	0.215	0.645	333
758	1208000404	Town of Seagraves	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	3.979	0.008	0.023	1005
759	1203020204	Caney Creek-Bedias Creek	Trinity	Yegua Jackson	Carrizo	Major & Minor	3	127.27	0.248	0.743	292
760	1207020401	Upper Little River	Brazos	None	Trinity	Major	3	153.508	0.299	0.897	225
761	1307000709	Monument Draw-Pecos River	Rio Grande	Rustler	Pecos Valley	Major & Minor	3	12.095	0.024	0.071	908
762	1205000707	Lower Salt Fork Brazos River	Brazos	Blaine	Seymour	Major & Minor	3	34.998	0.068	0.204	705
763	1309000113	Las Escobas Creek	Rio Grande	None	Gulf_Coast	Major	3	73.084	0.142	0.427	461
764	1304020603	Middle Maravillas Creek	Rio Grande	Marathon	Edwards-Trinity	Major & Minor	3	13.205	0.026	0.077	896
765	1210040105	Matagorda Bay	Central Texas Coastal	None	Gulf_Coast	Major	3	128.89	0.251	0.753	287
766	1210020403	Headwaters Coleto Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	95.305	0.186	0.557	379
767	1110010303	Miller Airfield-Elephant Lake	Canadian	Dockum	Ogallala	Major & Minor	3	1.055	0.002	0.006	1061
768	1211011103	Nueces River-Lake Corpus Christi	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	100.608	0.196	0.588	362

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
769	1211011002	Galvan Creek-Atascosa River	Southwestern Texas Coastal	Sparta	Carrizo	Major & Minor	3	62.992	0.123	0.368	500
770	1304020402	Upper Terlingua Creek	Rio Grande	Igneous	None	Minor	2	39.484	0.077	0.154	780
771	1206010504	Big Sandy Creek	Brazos	Cross Timbers	Trinity	Major & Minor	3	70.477	0.137	0.412	477
772	1211020603	Cibolo Creek-Palo Blanco Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	21.033	0.041	0.123	825
773	1208000605	City of Lamesa-Sulphur Springs Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	3.463	0.007	0.02	1013
774	1303010208	Avispa Canyon-Rio Grande	Rio Grande	None	Hueco_Bolson	Major	3	4.463	0.009	0.026	994
775	1208000403	Upper McKenzie Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	1.876	0.004	0.011	1046
776	1307000603	Antelope Draw-Coyanosa Draw	Rio Grande	None	Edwards-Trinity	Major	3	57.593	0.112	0.336	542
777	1209010304	Middle Centralia Draw	Colorado	None	Edwards-Trinity	Major	3	12.662	0.025	0.074	902
778	1206010106	Seymour Creek-Brazos River	Brazos	None	Seymour	Major	3	23.414	0.046	0.137	803
779	1112020202	Sand Creek-Salt Fork Red River	Red	Blaine	Seymour	Major & Minor	3	48.297	0.094	0.282	598
780	1211010703	Parkers Creek-Seco Creek	Southwestern Texas Coastal	None	Trinity	Major	3	91.421	0.178	0.534	390
781	1209010308	Headwaters Middle Concho River	Colorado	None	Edwards-Trinity	Major	3	17.11	0.033	0.1	861
782	1205000401	Town of Whiteface-Town of Clauene	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	1.785	0.003	0.01	1048
783	1114010602	Town of Dimple-Pecan Bayou	Red	Woodbine	Trinity	Major & Minor	3	209.367	0.408	1.223	124
784	1205000105	Salt Lake	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	6.407	0.012	0.037	970
785	1202000203	Cedar Creek-Neches River	Neches	Yegua Jackson	Carrizo	Major & Minor	3	306.683	0.597	1.791	53

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
786	1305000425	Nester Tank-Diablo Rim	Rio Grande	Capitan Reef Complex	None	Minor	2	17.617	0.034	0.069	912
787	1110010305	Lower Coldwater Creek	Canadian	Dockum	Ogallala	Major & Minor	3	10.084	0.02	0.059	934
788	1205000202	Headwaters Blackwater Draw	Brazos	None	Ogallala	Major	3	0.452	0.001	0.003	1066
789	1203010203	Lower Clear Fork Trinity River	Trinity	Woodbine	Trinity	Major & Minor	3	120.382	0.234	0.703	312
790	1208000501	Whalen Lake-Midland Draw	Colorado	Dockum	Ogallala	Major & Minor	3	2.066	0.004	0.012	1040
791	1203010308	Hickory Creek-Little Elm Reservoir	Trinity	Woodbine	Trinity	Major & Minor	3	116.046	0.226	0.678	317
792	1112010501	Oxbow Creek-Little Red River	Red	None	Seymour	Major	3	58.085	0.113	0.339	536
793	1113020704	Lower Beaver Creek	Red	Cross Timbers	Seymour	Major & Minor	3	42.265	0.082	0.247	648
794	1112010104	Black Lake-Frio Draw	Red	Dockum	Ogallala	Major & Minor	3	4.166	0.008	0.024	1001
795	1210030202	Upper Medina River	Central Texas Coastal	None	Trinity	Major	3	112.896	0.22	0.659	326
796	1207020106	Resley Creek-Leon River	Brazos	None	Trinity	Major	3	178.748	0.348	1.044	168
797	1210030303	Ecleto Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	130.203	0.253	0.76	286
798	1308000207	Rosita Creek-Rio Grande	Rio Grande	None	None	None	1	31.914	0.062	0.062	929
799	1207010405	Dry Bayou-Brazos River	Brazos	None	Gulf_Coast	Major	3	143.96	0.28	0.841	256
800	1114030204	Bassett Creek-Sulphur River	Red	Nacatoch	Carrizo	Major & Minor	3	255.037	0.497	1.49	87
801	1205000409	Tonk Creek-Double Mountain Fork Brazos River	Brazos	None	Seymour	Major	3	29.234	0.057	0.171	752
802	1211020805	East Main Drain-Frontal Laguna Madre	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	20.204	0.039	0.118	833
803	1304020201	Alamito Creek-San Esteban Lake	Rio Grande	Igneous	None	Minor	2	21.287	0.041	0.083	884
804	1113021003	Fobb Bottom-Red River	Red	None	Trinity	Major	3	273.183	0.532	1.596	71
805	1209030107	Buckners Creek-Colorado River	Colorado	Sparta	Gulf_Coast	Major & Minor	3	201.558	0.392	1.177	130

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
806	1202000104	Brushy Creek-Neches River	Neches	Queen City	Carrizo	Major & Minor	3	274.03	0.534	1.601	70
807	1307000304	Lower Toyah Creek	Rio Grande	Rustler	Pecos Valley	Major & Minor	3	16.358	0.032	0.096	869
808	1206020112	Lake Granbury-Brazos River	Brazos	None	Trinity	Major	3	143.588	0.28	0.839	257
809	1308000302	Dolores Creek	Rio Grande	None	Gulf_Coast	Major	3	20.881	0.041	0.122	827
810	1210030403	Middle Cibolo Creek	Central Texas Coastal	Queen City	Carrizo	Major & Minor	3	113.081	0.22	0.66	325
811	1205000701	Headwaters Salt Fork Brazos River	Brazos	Dockum	Ogallala	Major & Minor	3	19.789	0.039	0.116	835
812	1203010302	Buck Creek-Isle du Bois Creek	Trinity	Woodbine	Trinity	Major & Minor	3	168.194	0.327	0.982	190
813	1113021004	Big Mineral Arm	Red	Woodbine	Trinity	Major & Minor	3	214.702	0.418	1.254	116
814	1304030302	Buffalo Draw	Rio Grande	None	Edwards-Trinity	Major	3	121.727	0.237	0.711	306
815	1209010606	San Saba River-Colorado River	Colorado	None	Trinity	Major	3	120.6	0.235	0.704	311
816	1205000407	Rough Creek	Brazos	None	Seymour	Major	3	27.046	0.053	0.158	777
817	1113020904	East Fork Little Wichita River	Red	Cross Timbers	None	Minor	2	155.842	0.303	0.607	350
818	1208000802	Lake E V Spence-Colorado River	Colorado	None	Edwards-Trinity	Major	3	37.237	0.072	0.217	685
819	1307000110	Blake Draw-Pecos River	Rio Grande	Rustler	Edwards-Trinity	Major & Minor	3	27.052	0.053	0.158	776
820	1208000408	Shafter Lake	Colorado	Dockum	Ogallala	Major & Minor	3	2.028	0.004	0.012	1042
821	1203010401	Upper Denton Creek	Trinity	None	Trinity	Major	3	145.259	0.283	0.848	251
822	1113030102	Rush Creek-Washita River	Red	None	Ogallala	Major	3	115.284	0.224	0.673	318
823	1203010904	Lower Chambers Creek	Trinity	Woodbine	Trinity	Major & Minor	3	131.972	0.257	0.771	285
824	1206020107	Ioni Creek-Brazos River	Brazos	Cross Timbers	None	Minor	2	92.794	0.181	0.361	512
825	1307000501	Cienega Creek-Limpia Creek	Rio Grande	Igneous	Edwards-Trinity	Major & Minor	3	87.64	0.171	0.512	408
826	1204010101	West Fork San Jacinto River	Galveston Bay-San Jacinto	Sparta	Gulf_Coast	Major & Minor	3	242.344	0.472	1.415	98

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
827	1304021001	Pyle Draw-Downie Draw	Rio Grande	None	Edwards-Trinity	Major	3	40.48	0.079	0.236	657
828	1307000705	Antelope Draw	Rio Grande	Dockum	Pecos Valley	Major & Minor	3	24.315	0.047	0.142	795
829	1209020406	Hickory Creek-Llano River	Colorado	Hickory	Edwards-Trinity	Major & Minor	3	125.624	0.245	0.734	297
830	1207020201	Upper Cowhouse Creek	Brazos	None	Trinity	Major	3	168.653	0.328	0.985	187
831	1308000113	Las Moras Creek	Rio Grande	None	Edwards-Trinity	Major	3	39.591	0.077	0.231	663
832	1204020201	East Fork Double Bayou-Trinity Bay	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	77.768	0.151	0.454	443
833	1210020303	Upper San Marcos River	Central Texas Coastal	None	Trinity	Major	3	157.81	0.307	0.922	209
834	1211010803	Yeager Creek-Cibolo Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	33.353	0.065	0.195	716
835	1208000206	Deep Creek	Colorado	Dockum	None	Minor	2	19.175	0.037	0.075	901
836	1206010109	Fish Creek-Brazos River	Brazos	Cross Timbers	None	Minor	2	71.921	0.14	0.28	601
837	1112010305	Headwaters Mulberry Creek	Red	Dockum	Ogallala	Major & Minor	3	13.06	0.025	0.076	898
838	1210040501	Copano Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	88.155	0.172	0.515	406
839	1201000409	Palo Gaucho Bayou	Sabine	None	Carrizo	Major	3	433.289	0.844	2.531	11
840	1112010202	North Palo Duro Creek	Red	Dockum	Ogallala	Major & Minor	3	6.045	0.012	0.035	974
841	1202000403	Johnson Creek	Neches	None	Carrizo	Major	3	294.172	0.573	1.718	61
842	1203020106	Upper Keechi Creek	Trinity	None	Carrizo	Major	3	153.778	0.299	0.898	222
843	1211010508	Torres Creek-Black Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	35.955	0.07	0.21	700
844	1206020101	Salt Creek	Brazos	Cross Timbers	None	Minor	2	65.067	0.127	0.253	642
845	1204010202	Walnut Creek-Spring Creek	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	192.605	0.375	1.125	145
846	1304020901	Pena Blanca Creek	Rio Grande	Marathon	None	Minor	2	46.138	0.09	0.18	740

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
847	1203010103	Lost Creek-West Fork Trinity River	Trinity	Cross Timbers	None	Minor	2	95.885	0.187	0.373	496
848	1204020501	Upper Oyster Creek	Galveston Bay-San Jacinto	Brazos River Alluvium	Gulf_Coast	Major & Minor	3	78.616	0.153	0.459	438
849	1209010706	Browns Creek-Pecan Bayou	Colorado	None	Trinity	Major	3	153.012	0.298	0.894	227
850	1304030111	Johnson Draw-Devils River	Rio Grande	None	Edwards-Trinity	Major	3	98.995	0.193	0.578	365
851	1201000209	Irons Bayou	Sabine	None	Carrizo	Major	3	296.374	0.577	1.731	60
852	1203010504	Village Creek-Trinity River	Trinity	Woodbine	Trinity	Major & Minor	3	135.989	0.265	0.794	276
853	1208000606	Alkali Lake-Sulphur Springs Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	4.236	0.008	0.025	999
854	1205000108	Silver Lake-Yellow House Draw	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	3.799	0.007	0.022	1008
855	1113010202	China Creek-Red River	Red	None	Seymour	Major	3	52.047	0.101	0.304	577
856	1207010108	Beason Creek-Brazos River	Brazos	Queen City	Gulf_Coast	Major & Minor	3	159.592	0.311	0.932	207
857	1211010502	Las Raices Creek-Nueces River	Southwestern Texas Coastal	None	Carrizo	Major	3	37.84	0.074	0.221	682
858	1202000502	Bayou Carrizo-Angelina River	Neches	Sparta	Carrizo	Major & Minor	3	373.434	0.727	2.181	35
859	1201000504	Sandy Creek-Sabine River	Sabine	None	Gulf_Coast	Major	3	381.133	0.742	2.226	31
860	1109010206	Sand Well-Punta de Agua Creek	Canadian	Dockum	Ogallala	Major & Minor	3	13.626	0.027	0.08	891
861	1211020503	Santonino Creek-Macho Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	59.692	0.116	0.349	521
862	1307000901	Number Four Draw-Sixshooter Draw	Rio Grande	None	Edwards-Trinity	Major	3	28.759	0.056	0.168	757
863	1113020401	Upper North Wichita River	Red	Blaine	None	Minor	2	48.359	0.094	0.188	724
864	1113010301	Los Lingos Creek	Red	None	Seymour	Major	3	18.598	0.036	0.109	847
865	1211010304	Tortuga Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	22.622	0.044	0.132	812

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
866	1209020201	Upper North Llano River	Colorado	None	Edwards-Trinity	Major	3	47.885	0.093	0.28	602
867	1209020304	Lower South Llano River	Colorado	Hickory	Edwards-Trinity	Major & Minor	3	58.189	0.113	0.34	534
868	1201000106	Grand Saline Creek-Sabine River	Sabine	None	Carrizo	Major	3	196.887	0.383	1.15	139
869	1114010103	Island Bayou	Red	Woodbine	Trinity	Major & Minor	3	245.342	0.478	1.433	92
870	1206010206	Noodle Creek-Clear Fork Brazos River	Brazos	None	Seymour	Major	3	20.768	0.04	0.121	830
871	1206010303	Lower California Creek	Brazos	None	Seymour	Major	3	16.828	0.033	0.098	866
872	1210040603	Mission River	Central Texas Coastal	None	Gulf_Coast	Major	3	89.873	0.175	0.525	397
873	1304020521	Tornillo Creek	Rio Grande	None	Edwards-Trinity	Major	3	21.25	0.041	0.124	820
874	1304020114	Spencer Creek-Rio Grande	Rio Grande	Igneous	None	Minor	2	57.182	0.111	0.223	679
875	1207010102	Brushy Creek-Big Creek	Brazos	None	Trinity	Major	3	127.053	0.247	0.742	293
876	1210020202	Mill Creek-Guadalupe River	Central Texas Coastal	Yegua Jackson	Carrizo	Major & Minor	3	154.951	0.302	0.905	217
877	1110010108	Town of Texhoma-Beaver River	Canadian	Dockum	Ogallala	Major & Minor	3	11.293	0.022	0.066	917
878	1211020401	Upper Santa Gertrudis Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	71.443	0.139	0.417	473
879	1307001004	Lower Independence Creek	Rio Grande	None	Edwards-Trinity	Major	3	71.189	0.139	0.416	474
880	1307000716	Crossett Oil Field-Soda Lake	Rio Grande	None	Edwards-Trinity	Major	3	11.181	0.022	0.065	919
881	1113010402	Upper Tongue River	Red	Dockum	Ogallala	Major & Minor	3	40.313	0.078	0.235	658
882	1109010505	North Big Blue Creek	Canadian	Dockum	Ogallala	Major & Minor	3	0.465	0.001	0.003	1065
883	1207020402	Big Elm Creek	Brazos	None	Carrizo	Major	3	152.492	0.297	0.891	231
884	1206010101	North Croton Creek	Brazos	Blaine	None	Minor	2	39.208	0.076	0.153	781
885	1203010605	Duck Creek-East Fork Trinity River	Trinity	Woodbine	Trinity	Major & Minor	3	121.842	0.237	0.712	305

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
886	1208000504	Lower Monahans Draw	Colorado	None	Edwards-Trinity	Major	3	2.449	0.005	0.014	1027
887	1205000301	Buffalo Springs Lake-North Fork Double Mountain Fork Brazos River	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	1.758	0.003	0.01	1049
888	1305000420	Walnut Draw-Wild Horse Draw	Rio Grande	Igneous	None	Minor	2	47.123	0.092	0.183	734
889	1209010204	Headwaters South Concho River	Colorado	None	Edwards-Trinity	Major	3	38.398	0.075	0.224	676
890	1206020403	Meridian Creek-North Bosque River	Brazos	None	Trinity	Major	3	173.497	0.338	1.013	174
891	1210010202	Ragsdale Creek-Lavaca River	Central Texas Coastal	None	Gulf_Coast	Major	3	191.299	0.372	1.117	148
892	1211010203	Middle West Nueces River	Southwestern Texas Coastal	None	Edwards	Major	3	42.068	0.082	0.246	650
893	1207010308	Rocky Creek-Navasota River	Brazos	Brazos River Alluvium	Gulf_Coast	Major & Minor	3	151.112	0.294	0.883	235
894	1304020811	Shafter Canyon-Rio Grande	Rio Grande	None	Edwards-Trinity	Major	3	28.197	0.055	0.165	762
895	1206010402	Kings Creek-Clear Fork Brazos River	Brazos	Cross Timbers	None	Minor	2	49.564	0.096	0.193	719
896	1109010604	Bent Creek-Canadian River	Canadian	None	Ogallala	Major	3	79.35	0.154	0.463	432
897	1208000406	Cedar Lake Oil Field-Cedar Lake	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	4.304	0.008	0.025	995
898	1304030108	Dry Devils River-Devils River	Rio Grande	None	Edwards-Trinity	Major	3	105.39	0.205	0.616	346
899	1211011003	Borrego Creek-Atascosa River	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	101.791	0.198	0.595	358
900	1113020604	Buffalo Creek-Wichita River	Red	Cross Timbers	Seymour	Major & Minor	3	44.047	0.086	0.257	635
901	1211020506	Petronila Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	10.663	0.021	0.062	927
902	1210040203	Placedo Creek-Lavaca Bay	Central Texas Coastal	None	Gulf_Coast	Major	3	50.464	0.098	0.295	587
903	1210020404	Coleto Creek-Guadalupe River	Central Texas Coastal	None	Gulf_Coast	Major	3	79.265	0.154	0.463	434

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
904	1304020702	Ash Creek-Calamity Creek	Rio Grande	Igneous	None	Minor	2	88.135	0.172	0.343	529
905	1307000604	Burnt House Creek	Rio Grande	None	Edwards-Trinity	Major	3	59.08	0.115	0.345	528
906	1305000322	Old Coe Lake	Rio Grande	None	Hueco_Bolson	Major	3	3.964	0.008	0.023	1006
907	1114030604	Big Cypress Bayou-Frontal Caddo Lake	Red	None	Carrizo	Major	3	422.784	0.823	2.469	17
908	1208000602	Ranger Lake	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	2.422	0.005	0.014	1028
909	1109010105	Mujares Creek-Trujillo Creek	Canadian	Dockum	Ogallala	Major & Minor	3	22.501	0.044	0.131	814
910	1307000802	Southwest Mesa-Pecos River	Rio Grande	None	Edwards-Trinity	Major	3	25.114	0.049	0.147	788
911	1110010401	North Palo Duro Creek	Canadian	Dockum	Ogallala	Major & Minor	3	1.503	0.003	0.009	1057
912	1305000409	North Draw	Rio Grande	Bone Spring-Victorio Peak	None	Minor	2	14.638	0.028	0.057	938
913	1210030404	Lower Cibolo Creek	Central Texas Coastal	None	Gulf_Coast	Major	3	92.677	0.18	0.541	383
914	1205000702	Upper Salt Fork Brazos River	Brazos	None	Seymour	Major	3	37.165	0.072	0.217	689
915	1204020101	Lower Neches Valley Authority Canal-Taylor Bayou	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	118.362	0.23	0.691	315
916	1307000102	Upper Salt Creek	Rio Grande	Rustler	None	Minor	2	34.011	0.066	0.132	810
917	1309000115	Los Olmos Creek-Rio Grande	Rio Grande	None	Gulf_Coast	Major	3	44.49	0.087	0.26	630
918	1203020301	Davis Bayou-Trinity River	Trinity	None	Gulf_Coast	Major	3	245.957	0.479	1.437	90
919	1211020701	Middle Laguna Madre	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	52.608	0.102	0.307	574
920	1112010502	Little Red River-Prairie Dog Town Fork Red River	Red	None	Seymour	Major	3	50.209	0.098	0.293	589
921	1304020202	Savcito Creek-Alamito Creek	Rio Grande	Igneous	None	Minor	2	31.188	0.061	0.121	829
922	1204020301	Adlong Ditch-Cedar Bayou	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	140.963	0.274	0.823	263

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
923	1211010704	Lower Hondo Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	71.976	0.14	0.42	467
924	1209010309	Tepee Draw-Middle Concho River	Colorado	Dockum	Edwards-Trinity	Major & Minor	3	27.171	0.053	0.159	774
925	1201000508	Little Cypress Creek-Cypress Creek	Sabine	None	Gulf_Coast	Major	3	255.556	0.498	1.493	86
926	1114030205	Anderson Creek	Red	Nacatoch	Carrizo	Major & Minor	3	243.032	0.473	1.419	96
927	1205000203	Progress Draw	Brazos	Dockum	Ogallala	Major & Minor	3	0.913	0.002	0.005	1063
928	1203010204	Village Creek	Trinity	Woodbine	Trinity	Major & Minor	3	92.563	0.18	0.541	385
929	1308000307	Salamoneno Creek	Rio Grande	None	Gulf_Coast	Major	3	31.487	0.061	0.184	732
930	1205000404	Salt Creek-Double Mountain Fork Brazos River	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	9.34	0.018	0.055	942
931	1113020901	North Fork Little Wichita River-Lake Kickapoo	Red	Cross Timbers	None	Minor	2	58.941	0.115	0.23	666
932	1203010303	Indian Creek-Isle du Bois Creek	Trinity	Woodbine	Trinity	Major & Minor	3	217.728	0.424	1.272	114
933	1205000502	Town of Sunnyside-Running Water Draw	Brazos	None	Ogallala	Major	3	3.189	0.006	0.019	1019
934	1308000223	Cuchara Creek-Santa Isabel Creek	Rio Grande	None	Carrizo	Major	3	36.939	0.072	0.216	691
935	1113030101	Headwaters Washita River	Red	None	Ogallala	Major	3	79.335	0.154	0.463	433
936	1209030102	Piney Creek-Colorado River	Colorado	None	Carrizo	Major	3	162.995	0.317	0.952	198
937	1210030203	Middle Medina River	Central Texas Coastal	None	Trinity	Major	3	82.929	0.161	0.484	419
938	1209030201	Skull Creek-Colorado River	Colorado	None	Gulf_Coast	Major	3	133.481	0.26	0.78	283
939	1206020113	Fall Creek-Brazos River	Brazos	None	Trinity	Major	3	140.41	0.273	0.82	267
940	1211020806	Middle Arroyo Colorado	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	10.527	0.02	0.061	930
941	1114010601	Big Pine Creek-Red River	Red	Woodbine	Trinity	Major & Minor	3	253.159	0.493	1.479	88
942	1207020101	South Fork Leon River-Leon River	Brazos	Cross Timbers	Trinity	Major & Minor	3	77.598	0.151	0.453	445

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
943	1202000105	Hurricane Creek-Neches River	Neches	Queen City	Carrizo	Major & Minor	3	286.278	0.557	1.672	65
944	1114030103	North Sulphur River	Red	Woodbine	Trinity	Major & Minor	3	209.317	0.408	1.223	125
945	1211010610	Middle Leona River	Southwestern Texas Coastal	None	Carrizo	Major	3	33.868	0.066	0.198	714
946	1109010404	Outlet Carrizo Creek	Canadian	Dockum	Ogallala	Major & Minor	3	13.425	0.026	0.078	893
947	1110010205	Town of Adams-Beaver River	Canadian	None	Ogallala	Major	3	42.731	0.083	0.25	645
948	1204020405	Outer Bar Channel-Gulf of Mexico	Galveston Bay-San Jacinto	None	None	None	1	0	0	0	1069
949	1209020403	Honey Creek-Llano River	Colorado	Hickory	Edwards-Trinity	Major & Minor	3	76.375	0.149	0.446	450
950	1210030304	Hondo Creek-San Antonio River	Central Texas Coastal	None	Gulf_Coast	Major	3	92.443	0.18	0.54	386
951	1205000601	Callahan Draw	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	1.951	0.004	0.011	1044
952	1308000215	Indio Creek-Rio Grande	Rio Grande	None	Carrizo	Major	3	31.914	0.062	0.186	726
953	1204010104	Crystal Creek-West Fork San Jacinto River	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	214.411	0.417	1.252	117
954	1206020203	Camp Creek-Brazos River	Brazos	None	Trinity	Major	3	147.056	0.286	0.859	249
955	1307001001	Upper Independence Creek	Rio Grande	None	Edwards-Trinity	Major	3	53.939	0.105	0.315	562
956	1109010302	Perico Creek	Canadian	Rita Blanca	Ogallala	Major & Minor	3	12.069	0.023	0.07	909
957	1207010202	East Yegua Creek	Brazos	None	Carrizo	Major	3	214.408	0.417	1.252	118
958	1307000406	Broke Tank Draw-Adobe Draw	Rio Grande	Igneous	Edwards-Trinity	Major & Minor	3	64.628	0.126	0.377	495
959	1206020104	Caddo Creek	Brazos	Cross Timbers	None	Minor	2	87.114	0.17	0.339	537
960	1206010203	Bitter Creek-Sweetwater Creek	Brazos	None	Edwards-Trinity	Major	3	39.686	0.077	0.232	662
961	1208000203	Gold Creek-Colorado River	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	6.732	0.013	0.039	964

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
962	1209040102	Middle San Bernard River	Colorado	None	Gulf_Coast	Major	3	98.304	0.191	0.574	367
963	1210040504	Aransas Bay	Central Texas Coastal	None	Gulf_Coast	Major	3	43.701	0.085	0.255	637
964	1209010603	Home Creek	Colorado	Cross Timbers	None	Minor	2	76.037	0.148	0.296	586
965	1209010703	Red River-Pecan Bayou	Colorado	None	Trinity	Major	3	95.75	0.186	0.559	375
966	1304030203	Devils River-Amistad Reservoir	Rio Grande	None	Edwards-Trinity	Major	3	112.029	0.218	0.654	329
967	1309000204	Clark Bend-Rio Grande	Rio Grande	None	Gulf_Coast	Major	3	0	0	0	1069
968	1209010306	Big Lake Draw	Colorado	Dockum	Edwards-Trinity	Major & Minor	3	8.512	0.017	0.05	951
969	1204020504	Lower Oyster Creek	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	149.631	0.291	0.874	240
970	1204020402	Dickinson Bayou-Galveston Bay	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	88.029	0.171	0.514	407
971	1304020904	Maxon Creek	Rio Grande	Marathon	Edwards-Trinity	Major & Minor	3	45.193	0.088	0.264	623
972	1202000703	Boggy Creek-Black Creek	Neches	None	Gulf_Coast	Major	3	251.978	0.491	1.472	89
973	1203020103	Lake Creek-Trinity River	Trinity	None	Carrizo	Major	3	142.565	0.278	0.833	259
974	1211010511	Leopard Creek-Nueces River	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	47.434	0.092	0.277	608
975	1307000601	Paisano Creek-Alpine Creek	Rio Grande	Igneous	None	Minor	2	72.394	0.141	0.282	599
976	1202000304	Tenmile Creek-Neches River	Neches	None	Gulf_Coast	Major	3	257.325	0.501	1.503	84
977	1208000209	Champion Creek	Colorado	Dockum	Edwards-Trinity	Major & Minor	3	23.55	0.046	0.138	802
978	1307000107	Mcllvain Draw-Pecos River	Rio Grande	Rustler	Pecos Valley	Major & Minor	3	12.33	0.024	0.072	907
979	1307000104	Narrow Bow Draw-Pecos River	Rio Grande	Rustler	Pecos Valley	Major & Minor	3	14.72	0.029	0.086	881
980	1203010501	Headwaters Trinity River	Trinity	Woodbine	Trinity	Major & Minor	3	68.339	0.133	0.399	484
981	1114030503	Boggy Creek	Red	None	Carrizo	Major	3	310.379	0.604	1.813	50

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
982	1112010302	Happy Draw-Prairie Dog Town Fork Red River	Red	Dockum	Ogallala	Major & Minor	3	16.97	0.033	0.099	864
983	1113020107	Moss Lake-Red River	Red	None	Trinity	Major	3	226.442	0.441	1.323	108
984	1209020301	Upper South Llano River	Colorado	None	Edwards-Trinity	Major	3	59.972	0.117	0.35	520
985	1207020301	Bennett Creek-Lampasas River	Brazos	None	Trinity	Major	3	163.299	0.318	0.954	197
986	1201000103	Greasy Creek-South Fork Sabine River	Sabine	None	Trinity	Major	3	139.509	0.272	0.815	269
987	1114010202	Lower Blue River	Red	Woodbine	Trinity	Major & Minor	3	179.202	0.349	1.047	164
988	1307000805	Live Oak Creek	Rio Grande	None	Edwards-Trinity	Major	3	55.373	0.108	0.323	555
989	1109010601	Rock Creek-Canadian River	Canadian	Dockum	Ogallala	Major & Minor	3	45.067	0.088	0.263	624
990	1307000702	City of Eunice-Monument Draw	Rio Grande	None	Pecos Valley	Major	3	30.565	0.06	0.179	741
991	1114020601	Wallace Bayou	Red	None	Carrizo	Major	3	272.553	0.531	1.592	72
992	1203010901	North Fork Chambers Creek	Trinity	Woodbine	Trinity	Major & Minor	3	170.955	0.333	0.998	178
993	1202000406	Gibbons Creek-Angelina River	Neches	None	Carrizo	Major	3	304.223	0.592	1.777	56
994	1206020303	Waco Lake	Brazos	Brazos River Alluvium	Trinity	Major & Minor	3	126.118	0.246	0.737	296
995	1211010505	Los Olmos Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	23.934	0.047	0.14	799
996	1304020520	Fresno Creek-Rio Grande	Rio Grande	None	None	None	1	20.395	0.04	0.04	961
997	1201000511	Adams Bayou-Sabine River	Sabine	None	Gulf_Coast	Major	3	238.203	0.464	1.391	103
998	1209040205	1209040205-Gulf of Mexico	Colorado	None	Gulf_Coast	Major	3	0	0	0	1069
999	1208000701	Upper Beals Creek	Colorado	None	Ogallala	Major	3	15.943	0.031	0.093	870
1000	1203010602	East Fork Trinity River-Lavon Lake	Trinity	Woodbine	Trinity	Major & Minor	3	179.121	0.349	1.046	165
1001	1112010402	Middle Tule Draw	Red	Dockum	Ogallala	Major & Minor	3	9.653	0.019	0.056	939

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
1002	1208000303	City of Lovington	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	3.26	0.006	0.019	1017
1003	1113010102	Tepee Creek-Red River	Red	None	Seymour	Major	3	99.788	0.194	0.583	364
1004	1207020502	South Fork San Gabriel River	Brazos	None	Trinity	Major	3	136.966	0.267	0.8	274
1005	1201000206	Cherokee Bayou-Sabine River	Sabine	None	Carrizo	Major	3	293.018	0.57	1.711	62
1006	1211020404	Chiltipin Creek-San Fernando Creek	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	51.237	0.1	0.299	581
1007	1304021004	Lozier Canyon	Rio Grande	None	Edwards-Trinity	Major	3	71.752	0.14	0.419	471
1008	1113010304	Wind River-North Pease River	Red	Blaine	None	Minor	2	39.767	0.077	0.155	779
1009	1113010405	Lower Middle Pease River	Red	Blaine	None	Minor	2	37.71	0.073	0.147	787
1010	1211020201	Oso Creek-Frontal Corpus Christi Bay	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	14.107	0.027	0.082	887
1011	1113010103	Sandy Creek	Red	Blaine	Seymour	Major & Minor	3	36.676	0.071	0.214	694
1012	1207010105	Walnut Creek-Brazos River	Brazos	None	Carrizo	Major	3	198.994	0.387	1.162	134
1013	1210020103	Block Creek-Guadalupe River	Central Texas Coastal	None	Trinity	Major	3	128.495	0.25	0.75	288
1014	1211010405	Chaparrosa Creek	Southwestern Texas Coastal	None	Carrizo	Major	3	18.469	0.036	0.108	850
1015	1202000508	Bear Creek-Ayish Bayou	Neches	None	Gulf_Coast	Major	3	425.598	0.829	2.486	15
1016	1304020805	Sanderson Creek	Rio Grande	None	Edwards-Trinity	Major	3	43.438	0.085	0.254	641
1017	1202000505	Brushy Creek-Attoyac River	Neches	Sparta	Carrizo	Major & Minor	3	410.276	0.799	2.396	21
1018	1201000408	Bayou Siep-Toledo Bend Reservoir	Sabine	None	Carrizo	Major	3	423.205	0.824	2.472	16
1019	1209010906	Calf Creek-San Saba River	Colorado	Hickory	Edwards-Trinity	Major & Minor	3	79.196	0.154	0.463	436
1020	1209010101	Mule Creek-Colorado River	Colorado	None	Edwards-Trinity	Major	3	36.715	0.071	0.214	693

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
1021	1206010209	Chimney Creek-Clear Fork Brazos River	Brazos	None	Seymour	Major	3	57.179	0.111	0.334	544
1022	1304020315	Fresno Creek-Rio Grande	Rio Grande	Igneous	None	Minor	2	44.591	0.087	0.174	748
1023	1304030105	Halbert Draw-Dry Devils River	Rio Grande	None	Edwards-Trinity	Major	3	82.238	0.16	0.48	422
1024	1201000203	Harris Creek	Sabine	Queen City	Carrizo	Major & Minor	3	268.313	0.522	1.567	76
1025	1203010207	Mountain Creek-West Fork Trinity River	Trinity	Woodbine	Trinity	Major & Minor	3	58.421	0.114	0.341	532
1026	1207010403	Bessies Creek-Brazos River	Brazos	Brazos River Alluvium	Gulf_Coast	Major & Minor	3	93.014	0.181	0.543	382
1027	1114030202	Cuthand Creek-Sulphur River	Red	Blossom	Trinity	Major & Minor	3	206.476	0.402	1.206	128
1028	1109010607	Home Ranch Creek-Canadian River	Canadian	None	Ogallala	Major	3	82.35	0.16	0.481	421
1029	1208000102	Sulphur Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	5.267	0.01	0.031	983
1030	1210010205	Mustang Creek-Navidad River	Central Texas Coastal	None	Gulf_Coast	Major	3	58.731	0.114	0.343	530
1031	1211010104	Montell Creek-Nueces River	Southwestern Texas Coastal	None	Edwards-Trinity	Major	3	44.808	0.087	0.262	627
1032	1307000707	China Lake	Rio Grande	None	Pecos Valley	Major	3	21.183	0.041	0.124	822
1033	1306001111	Black River	Rio Grande	Capitan Reef Complex	None	Minor	2	25.663	0.05	0.1	862
1034	1114010606	Bull Creek-Red River	Red	Nacatoch	Carrizo	Major & Minor	3	266.959	0.52	1.559	77
1035	1209020602	North Grape Creek-Pedernales River	Colorado	None	Trinity	Major	3	170.468	0.332	0.996	180
1036	1210030103	Calaveras Creek-San Antonio River	Central Texas Coastal	None	Carrizo	Major	3	83.188	0.162	0.486	418
1037	1305000423	Bunton Draw-Michigan Draw	Rio Grande	Igneous	Edwards-Trinity	Major & Minor	3	33.08	0.064	0.193	718
1038	1207020304	Salado Creek	Brazos	None	Trinity	Major	3	197.838	0.385	1.156	137
1039	1204010405	Sims Bayou	Galveston Bay-San Jacinto	None	Gulf_Coast	Major	3	23.919	0.047	0.14	800

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
1040	1208000308	Town of Seminole-Seminole Draw	Colorado	Dockum	Ogallala	Major & Minor	3	4.129	0.008	0.024	1002
1041	1210010103	Little Brushy Creek-Lavaca River	Central Texas Coastal	None	Gulf_Coast	Major	3	169.884	0.331	0.992	185
1042	1209010302	Lower High Lonesome Draw	Colorado	None	Edwards-Trinity	Major	3	2.292	0.004	0.013	1032
1043	1112020102	Whitefish Creek-Salt Fork Red River	Red	None	Ogallala	Major	3	75.917	0.148	0.443	452
1044	1211010302	Sand Creek-Nueces River	Southwestern Texas Coastal	None	Carrizo	Major	3	15.599	0.03	0.091	873
1045	1304010001	Bowman Lateral-Rio Grande	Rio Grande	None	Hueco_Bolson	Major	3	0.576	0.001	0.003	1064
1046	1114030402	Black Bayou	Red	None	Carrizo	Major	3	405.531	0.79	2.369	25
1047	1210020401	Spring Creek-Guadalupe River	Central Texas Coastal	None	Gulf_Coast	Major	3	103.693	0.202	0.606	352
1048	1205000113	City of Shallowater-Yellow House Draw	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	2.01	0.004	0.012	1043
1049	1210040301	Green Lake	Central Texas Coastal	None	Gulf_Coast	Major	3	86.161	0.168	0.503	414
1050	1208000603	Prentice Oil and Gas Field-Sulphur Springs Draw	Colorado	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	5.529	0.011	0.032	979
1051	1209010504	Little Concho Creek-Concho River	Colorado	None	Edwards-Trinity	Major	3	37.185	0.072	0.217	686
1052	1211010905	La Jarita Creek-San Miguel Creek	Southwestern Texas Coastal	Yegua Jackson	Carrizo	Major & Minor	3	56.338	0.11	0.329	547
1053	1203010201	Lake Worth-West Fork Trinity River	Trinity	None	Trinity	Major	3	88.751	0.173	0.518	403
1054	1113020702	Upper Beaver Creek	Red	None	Seymour	Major	3	52.698	0.103	0.308	572
1055	1308000228	Chacon Creek-Rio Grande	Rio Grande	None	Carrizo	Major	3	21.97	0.043	0.128	817
1056	1207010305	Cedar Creek-Navasota River	Brazos	None	Carrizo	Major	3	163.482	0.318	0.955	196
1057	1207020104	Sabana River	Brazos	None	Trinity	Major	3	82.056	0.16	0.479	425

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
1058	1114030302	Lower White Oak Creek	Red	None	Carrizo	Major	3	235.298	0.458	1.374	105
1059	1205000106	Baker Lake	Brazos	Edwards-Trinity (High Plains)	Ogallala	Major & Minor	3	3.361	0.007	0.02	1016
1060	1210040303	1210040303-Gulf of Mexico	Central Texas Coastal	None	Gulf_Coast	Major	3	0	0	0	1069
1061	1203020202	Boggy Creek	Trinity	Sparta	Carrizo	Major & Minor	3	148.264	0.289	0.866	244
1062	1112010405	MacKenzie Reservoir-Tule Creek	Red	Dockum	Ogallala	Major & Minor	3	9.136	0.018	0.053	945
1063	1211020803	Upper Pilot Channel-Laguna Madre	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	12.993	0.025	0.076	900
1064	1110010301	Upper Coldwater Creek	Canadian	Dockum	Ogallala	Major & Minor	3	10.93	0.021	0.064	921
1065	1304020105	Green River	Rio Grande	West Texas Bolsons	None	Minor	2	13.666	0.027	0.053	946
1066	1210030401	Headwaters Cibolo Creek	Central Texas Coastal	None	Trinity	Major	3	139.806	0.272	0.817	268
1067	1205000705	Middle Salt Fork Brazos River	Brazos	None	Seymour	Major	3	29.512	0.057	0.172	749
1068	1205000604	Middle White River	Brazos	Dockum	Ogallala	Major & Minor	3	9.231	0.018	0.054	944
1069	1202000102	Kickapoo Creek	Neches	None	Carrizo	Major	3	200.845	0.391	1.173	131
1070	1202000201	Hickory Creek-Neches River	Neches	Queen City	Carrizo	Major & Minor	3	306.727	0.597	1.791	52
1071	1211010607	Lower Sabinal River	Southwestern Texas Coastal	None	Trinity	Major	3	59.266	0.115	0.346	525
1072	1211010701	Upper Hondo Creek	Southwestern Texas Coastal	None	Trinity	Major	3	112.02	0.218	0.654	330
1073	1307000302	Upper Toyah Creek	Rio Grande	None	Edwards-Trinity	Major	3	16.657	0.032	0.097	867
1074	1209010401	Headwaters North Concho River	Colorado	None	Edwards-Trinity	Major	3	29.146	0.057	0.17	754
1075	1206020110	Turkey Creek-Brazos River	Brazos	Cross Timbers	Trinity	Major & Minor	3	81.527	0.159	0.476	426
1076	1211020809	Brownsville Ship Channel	Southwestern Texas Coastal	None	Gulf_Coast	Major	3	49.233	0.096	0.288	595

Table B.2 Continued

ID	HUC10	Watershed Name	Basin Name	Minor aquifer	Major aquifer	Classification for weighting purposes	Assigned weight	30yr mean percolation rate (mm/yr.)	Normalized proxy value for GWR	Weighted and Normalized GWR index	GWR ES rank for the watershed
1077	1112030401	Elm Creek	Red	None	Ogallala	Major	3	72.683	0.142	0.425	464
1078	1209030105	Rabbs Creek-Colorado River	Colorado	Sparta	Gulf_Coast	Major & Minor	3	198.668	0.387	1.16	135
1079	1210030301	Kicaster Creek-San Antonio River	Central Texas Coastal	Sparta	Carrizo	Major & Minor	3	94.93	0.185	0.554	380
1080	1203020210	Long King Creek	Trinity	None	Gulf_Coast	Major	3	301.324	0.587	1.76	57
1081	1305000416	Delaware Mountains-Guadalupe Arroyo	Rio Grande	Bone Spring-Victorio Peak	None	Minor	2	9.317	0.018	0.036	971