HSPF Recharge Models for the San Antonio Segment of the Balcones Fault Zone Edwards Aquifer

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in association with
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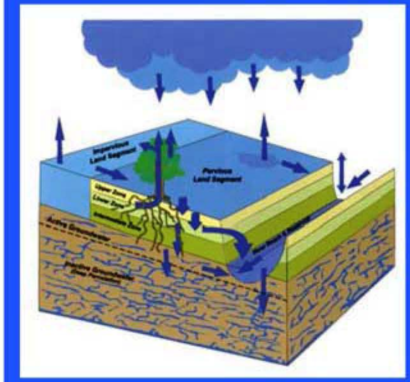
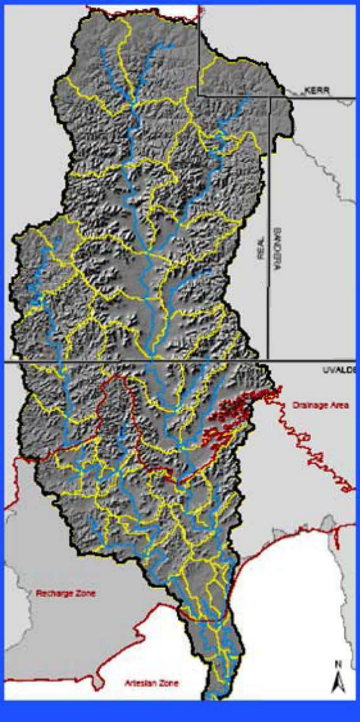
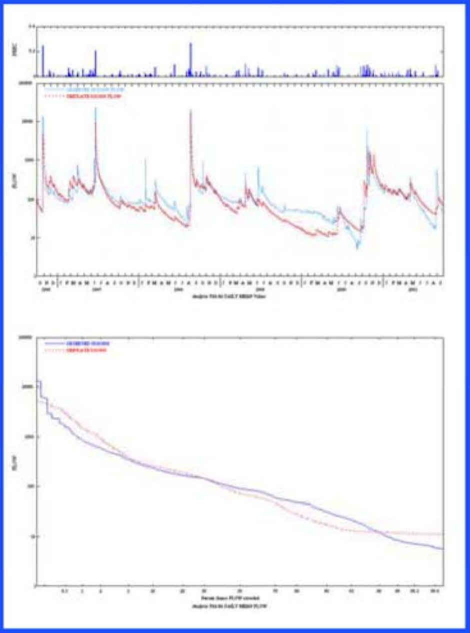
Part 1







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Executive Summary

ES.1 Introduction

Hydrologic models have been developed for the nine basins that recharge the San Antonio section of the Edwards Aquifer and recharge estimates from these models have been implemented into recharge data for the Edwards Aquifer MODFLOW model. The models have been calibrated for the basins of the (1) Nueces/West Nueces Rivers, (2) Frio/Dry Frio Rivers, (3) Sabinal River, (4) area between Sabinal and Medina River (Seco and Hondo Creeks), (5) Medina River, (6) area between Medina and Cibolo (San Geronimo, Helotes, and Salado Creeks), (7) Cibolo/Dry Comal Creeks, (8) Guadalupe River, and (9) Blanco River.

The main objective of the project was to develop hydrologic simulation models for the entire contributing and recharge zone of the Edwards Aquifer with the main focus being to estimate historical recharge to the Edwards Aquifer from 1950 through 2000. In addition to estimating recharge, secondary objectives of the project were to ensure that the models were compatible with the future goals of assessing issues important to the Authority and other stakeholders, including water quality, land use changes, weather modification, brush control, recharge dams, and flood control. To achieve these goals, the entire contributing zone (above the Edwards aquifer recharge zone) of each of the nine basins was incorporated into the models.

ES.2 Data Collection and Model Construction and Calibration

The major components of the models' water budget fall into four categories: precipitation, streamflow, evapotranspiration and recharge. Database development was a major portion of the total modeling effort, requiring acquisition of data from a variety of sources, developing estimation procedures when required data are not available, applying available techniques to fill-in missing data, and ensuring consistency and accuracy of the information obtained.

The hydrologic models were developed using the Hydrologic Simulation Program-Fortran (HSPF) computer model. HSPF incorporates rainfall, evaporation, topography, channel loss information, land use and vegetation data, geologic and soil characteristics, water diversions, and other information to simulate the hydrologic processes that occur in each watershed on an hourly basis. The models are calibrated to observed streamflow data from stream gages in the basins and honor measured channel loss information in the Edwards aquifer recharge zone. The HSPF models provide a historical water budget, and hourly estimates of each component of hydrologic process in the basin, including stormwater runoff, evaporation, quantity of water transported over the land surface and through various soil zones, and recharge to the Edwards aquifer. The models can produce a time history of the hydrologic process along any stream or in any sub-watershed within each basin.

In developing the models for the nine basins, subwatersheds were delineated that were appropriate for completing recharge calculations as well as any type of simulations that the HSPF models might be used for in the future. The resulting models are detailed enough to capture significant topographic, vegetation, and geologic variability within the watershed.

For HSPF, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of streamflow. This approach is required for parameters that cannot be deterministically, and uniquely, evaluated from topographic, climatic, or physical characteristics of the watershed. For the nine-basins models, the calibration period was five years long and included water years 1997 through 2001 because a variety of hydrologic conditions occur during this period. A consistent methodology was used to estimate model parameters in each basin and for the most part, hydrologic parameters did not vary significantly across the basins except for the Nueces basin. Model calibration resulted in parameter values that produce the best overall agreement between simulated and observed values throughout the calibration period based on standard statistical measures of error such as variance.

The calibration process included comparison of daily, monthly, and annual values as well as individual storm events. All of these comparisons were performed to ensure the best possible calibration of hydrologic parameters. In addition, continuous observed streamflow data (simulated and observed values) were analyzed on a frequency basis and their resulting cumulative distributions (e.g., flow duration curves) compared to assess the model behavior and agreement over the full range of observations.

Sensitivity analysis indicates that streamflow and recharge estimates are both sensitive to changes in the key model input parameters that affect the infiltration-runoff dynamics in the watersheds. One of the most sensitive parameters is the channel loss in streambeds over the recharge zone. Estimates of channel loss were based on 115 individual gain-loss studies in the nine basins.

ES.3 Model Results and Recharge Estimates

Calibrated streamflow results from the model indicate that the “contributing zone” models (that portion of the model contributing flow to the stream gage above the recharge zone) are useful and appropriate for simulating hydrologic conditions in the upper part of each basin and simulating flow at the upstream flow gage. When estimating recharge, the models took advantage of all available measured streamflow from upstream gages, resulting in the elimination of simulation errors from the contributing zone streamflow estimates.

Model results indicate that the recharge estimates from the HSPF models are generally comparable to traditional methods used by the USGS and HDR (Figure ES.1). However, the recharge estimates for some basins are higher than previous estimates and others are lower. For the western four basins that are a part of the Nueces River Basin (Nueces, Frio, Sabinal, and Sabinal-Medina), the cumulative recharge for the period between 1950-1996 falls between the USGS and HDR traditional estimates. For the three basins that are a part of the San Antonio River Basin (Medina, Medina-Cibolo, and Cibolo) the cumulative recharge estimates for the same time period are slightly lower than historically estimated by the USGS and HDR methods. In the Guadalupe River Basin (Guadalupe and Blanco), the HSPF recharge estimates are higher than traditional estimates.

Model results indicate that the source of recharge varies dramatically among the basins depending on the channel loss characteristics, areal extent of recharge zone, and upstream flow from the contributing zone. In some basins, the land recharge is a major component of the overall recharge and in other basins (e.g., Sabinal) the recharge is dominated by channel loss.

The average annual estimate of recharge from the HSPF, HDR, and USGS methods for all nine basins are 679,346; 661,703; and 719,217 ac-ft/yr, respectively. The median recharge estimates are 694,445; 621,898; and 615,231 ac-ft/yr, respectively.

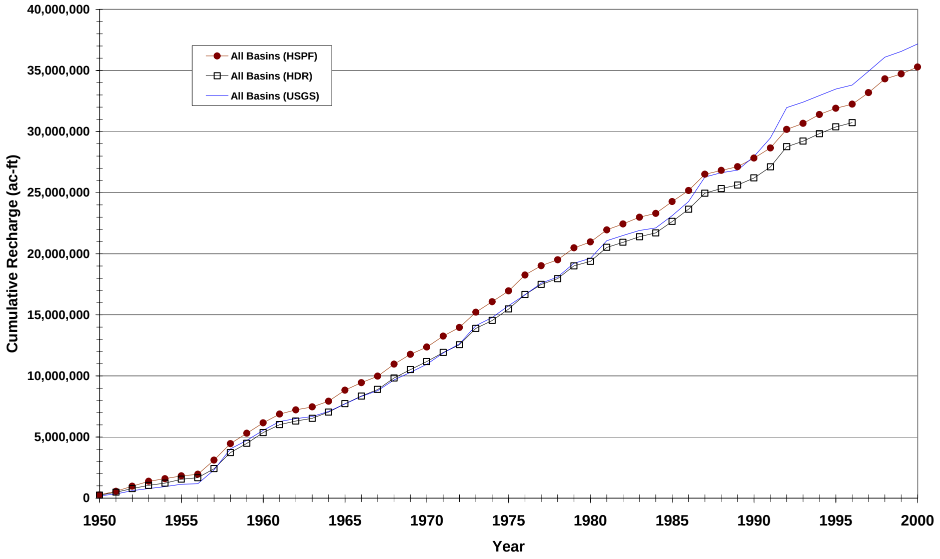

Figure ES.1 Cumulative Recharge Comparison – All Nine Basins

Figure ES.2 illustrates the volumetric contribution of each basin to the total land segment recharge for the Edwards aquifer as estimated by the HSPF models between 1950 and 2000. According to HSPF models, the Nueces and Blanco basins contribute the largest amount of land segment recharge to the aquifer on a volumetric basis.

Figure ES.3 illustrates the volumetric contribution of each basin to the total recharge for the Edwards aquifer as estimated by the HSPF models between 1950 and 2000. According to HSPF models, the Frio, Nueces, and Medina-Cibolo basins contribute the largest amount of total recharge (land and stream) to the aquifer on a volumetric basis.

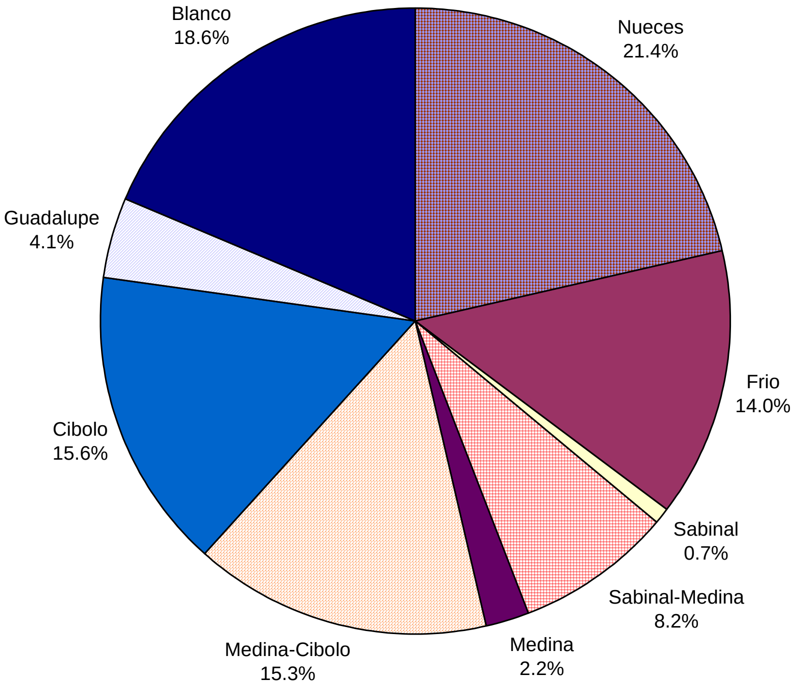

Figure ES.2 Volumetric Contribution of Each Basin to the Total Land Recharge (1950-2000) Estimated by HSPF Models

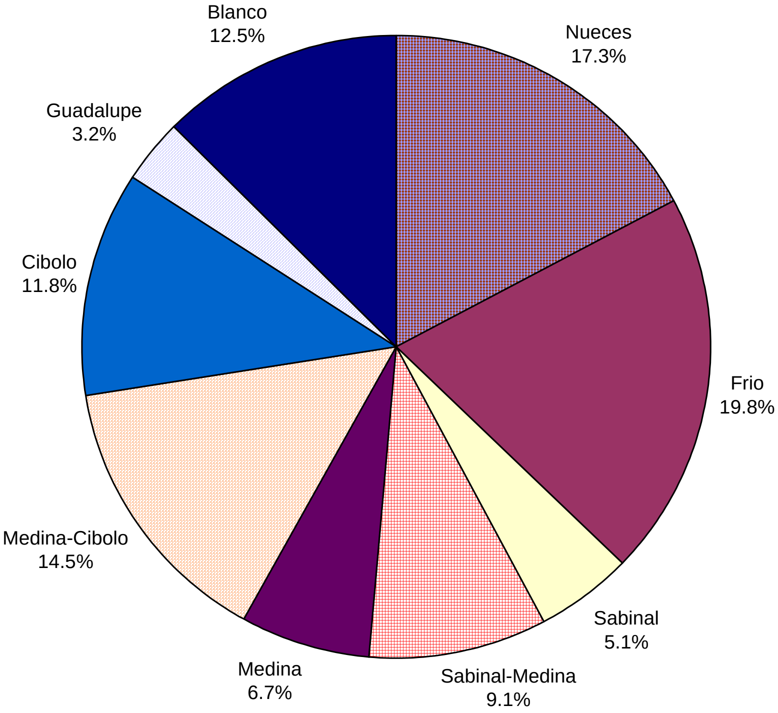

Figure ES.3 Volumetric Contribution of Each Basin to the Total Recharge (1950-2000) Estimated by HSPF Models

ES.4 Conclusions and Recommendations

The HSPF models are valuable tools for simulating the hydrology of the nine basins and assessing recharge under various hydrologic conditions. The models provide a new tool for assessing hourly hydrology, which could not be done with the traditional methods. They simulate each basin more discretely than the traditional methods do; which makes the models more appropriate for evaluating recharge enhancement, water quality and many other technical and regulatory issues.

To improve the accuracy of the models, more detailed field studies should be completed in selected areas of the recharge zone. These assessments should include field-scale rainfall-runoff and evaporation studies, tracer studies, channel loss studies, and other evaluations. Suggested model improvements include incorporating more detailed precipitation data from Authority rain gages that has been collected since this study was initiated; estimating model parameters by developing models for smaller watersheds; and enhancing the existing models to simulate water quality.

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1. Introduction

In October 2002 the Edwards Aquifer Authority (the Authority) contracted with LBG-Guyton Associates to develop HSPF models for seven of the nine major drainage basins that provide recharge to the Edwards Aquifer. The seven basins were the (1) Frio, (2) Sabinal, (3) area between Sabinal and Medina River, (4) Medina, (5) area between Medina River and Cibolo Creek, (6) Cibolo, and the (7) Guadalupe. Pilot recharge zone models were completed for the Nueces and Blanco basins in 2002. In March 2004, the original contract was amended so that pilot study models for Nueces and Blanco basins could be refined and expanded to ensure consistency among the methodology used in all nine basins. This report documents the development, calibration, and results of the models that have been developed for the nine basins that recharge the San Antonio section of the Edwards Aquifer, which are the basins of the (1) Nueces/West Nueces Rivers, (2) Frio/Dry Frio Rivers, (3) Sabinal River, (4) area between Sabinal and Medina River, (5) Medina River, (6) area between Medina River and Cibolo/Dry Comal Creeks, (7) Cibolo/Dry Comal Creeks, (8) Guadalupe River, and (9) Blanco River.

1.1 Purpose and Scope

Hydrologic models for each of the nine basins were developed using the Hydrologic Simulation Program-Fortran (HSPF) computer model. The models simulate the hydrology of each basin using an hourly time step. The main objective of the project was to develop hydrologic simulation models for the entire contributing and recharge zone of the Edwards Aquifer with the main focus being to estimate historical recharge to the Edwards Aquifer from 1950 through 2000. In addition to estimating recharge, secondary objectives of the project were to ensure that the models were compatible with the future goals of assessing issues important to the Authority and other stakeholders, including water quality, land use changes, weather modification, brush control, recharge dams, and flood control.

The models incorporate basin specific information including measured streamflow, precipitation, evaporation, channel losses, and diversions. In addition, the models incorporate characteristics of the geology and soil, land cover and vegetation, infiltration and leakage. The models were calibrated with measured stream flow data collected in each basin where these data were available and to the degree possible, the model parameters selected for each basin were physically based.

1.2 Study Area

Figure 1.2.1 shows the location of the study area. The figure illustrates the nine basins that recharge the Edwards aquifer. The westernmost basin is the Nueces and the easternmost basin is the Blanco. Figure 1.2.1 shows the location of the Edwards Aquifer recharge and artesian zones in relation to the contributing zones for the nine basins. The study area covers all or part of 13 counties and stretches over 162 miles from east to west, encompassing about 6576 square miles in total. It should be noted that the terms drainage area and contributing zone are used in this report to describe the area upstream of the recharge zone of the Edwards aquifer. The term "contributing zone" in this report is not the same Contributing Zone referenced in 30 TAC Chapter 213.

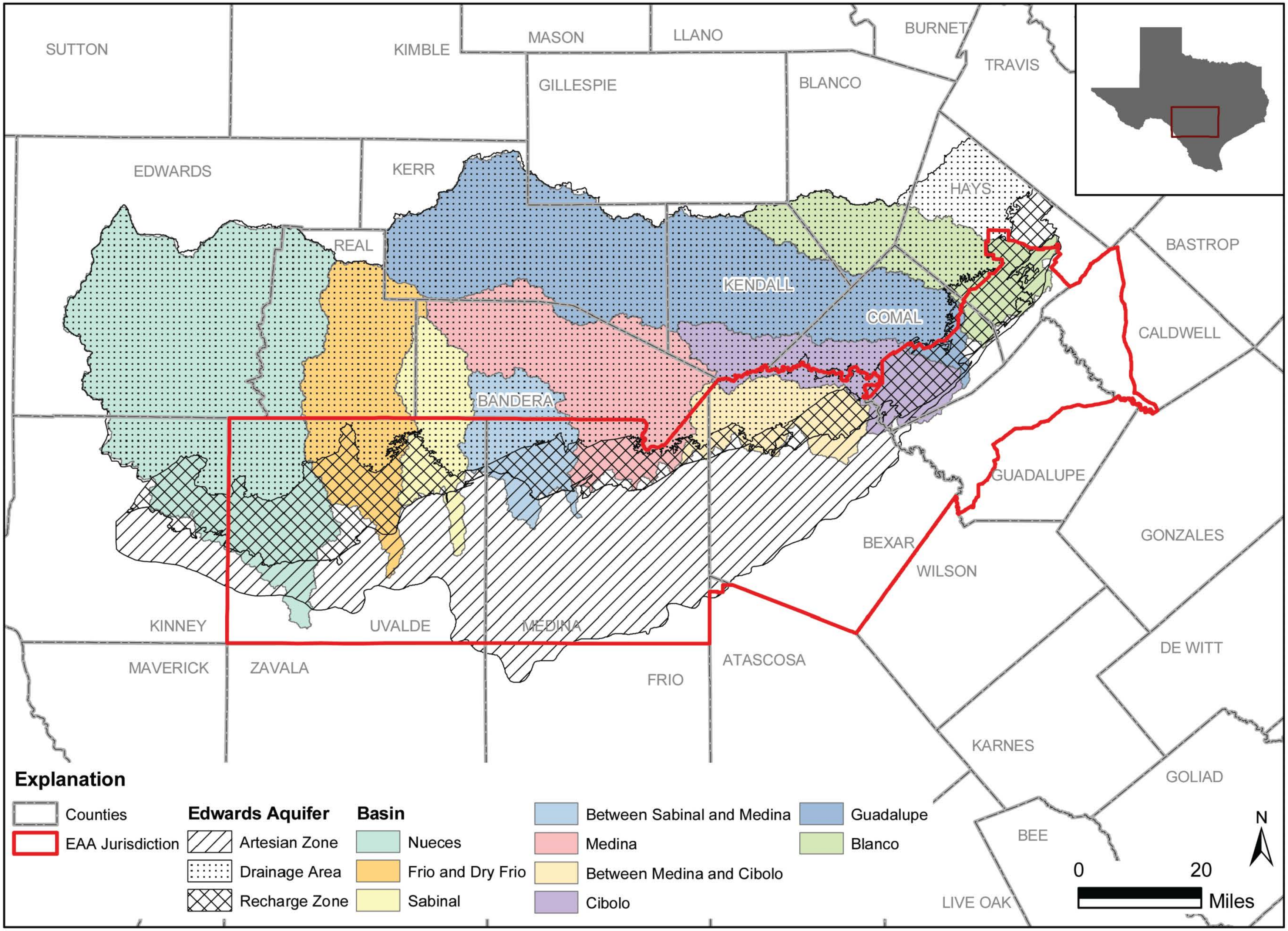


Figure 1.2.1 - Location of the Study Area

1.3 Traditional Recharge Estimates for the Edwards Aquifer

Historically, the United States Geological Survey (USGS) has used a water balance method to calculate recharge to the Edwards aquifer (Puente, 1978). As a part of the Trans-Texas project, HDR Engineering, Inc. (HDR, 1991, 1993) used slightly different methods to calculate recharge to the Edwards Aquifer. Both approaches are water balance methods that rely on total monthly flows in gauges upstream and downstream of the recharge zone. The basic approach is the same, but minor modifications in the HDR methodology are designed to overcome some of the simplifying assumptions of the USGS method. The traditional methods offer a relatively straightforward approach that uses readily available streamflow, precipitation, and curve number data.

In general, the USGS recharge estimates during “wet” years are usually significantly higher than the HDR estimates. In some cases, the USGS estimates are two to three times higher than the HDR estimate in wet years. HDR estimates are consistently higher in two basins (the area between Medina and Cibolo and the Cibolo) except for the years exhibiting the largest recharge. Years exhibiting low recharge for the area between Medina and Cibolo are substantially higher than USGS estimates. Finally, the total estimated recharge from the HDR method is consistently higher in the low-recharge years, and consistently lower in the high-recharge years. A detailed description and comparison of the two methods and their resulting recharge estimates is included in Appendix A.

The HSPF contributing zone models were designed to overcome the weaknesses of the traditional methods. Table 1.3.1 summarizes the difference between the traditional and HSPF methods.

Table 1.3.1 Comparison of Traditional Methods and HSPF Contributing Zone Models

Difference	Traditional Methods	HSPF Contributing Zone Models
Time Discretization	Monthly, discontinuous	Hourly, continuous
Spatial Discretization	1. Contributing zone not considered explicitly 2. Recharge zone is “lumped” together	1. Hydrology in the contributing zone is explicitly simulated 2. Recharge and contributing zone is discretized into smaller watersheds and stream reaches
Hydrologic Parameterization	Recharge zone is considered homogeneous - Limited use of data that varies in space (topography, vegetation, geology, soils, and landuse)	Recharge and contributing zone hydrologic parameterization allow for variation in each watershed based on topography, vegetation, geology, soils, and landuse
Use of Available Data	Limited use of prior information	More appropriate incorporation of prior data due to continuous time discretization Can incorporate more detailed precipitation and evaporation data as available

Table 1.3.1 Comparison of Traditional Methods and HSPF Contributing Zone Models

Difference	Traditional Methods	HSPF Contributing Zone Models
Diversions/Return Flow	USGS: does not consider HDR: does incorporate	Incorporates in the correct stream reach
Predictive Capacity	Limited use as an assessment tool	More applicable in assessing water quality, land use changes, weather modification, brush control, recharge dams, and flood control

1.4 Assessment of Pilot Models for the Nueces and Blanco River Basins

HDR (2002) developed pilot models for the recharge zone of the Nueces and Blanco basins. These pilot models were reviewed in terms of appropriateness for simulating the hydrologic processes of the Edwards aquifer and parameters incorporated in the HSPF model. The review focused on differences between the pilot and full-basin models and assumptions that may impact the accuracy of the recharge calculations or the predictive capability of the models. A full discussion of the comparison is included in Appendix B, but a summary is provided below.

The pilot models provide good tools for estimating daily recharge for the Nueces and Blanco River basins. One reason the models simulate observed flows relatively well at the lower stream gage is because the models only simulate the hydrology of the recharge zone of the Edwards aquifer. The model “boundary condition” for the upstream inflow into the model is the measured flow at the upstream gage (the stream gage located at the upstream boundary of the recharge zone). Thus, the major uncertainties and limitations of the models are associated with (1) estimates of diffuse recharge between streams and (2) gain-loss estimates in the channels. Two factors that affect these recharge components are estimates of precipitation and evaporation on the recharge zone, and measurement error in streamflow. The pilot models and contributing zone HSPF models are both limited by the accuracy of channel losses estimates and estimates of precipitation and evaporation as related to diffuse recharge. The Nueces and Blanco basin pilot models were used as a basis for the contributing zone models in those basins and were modified to incorporate an hourly time step.

2. Conceptual and Simulation Models

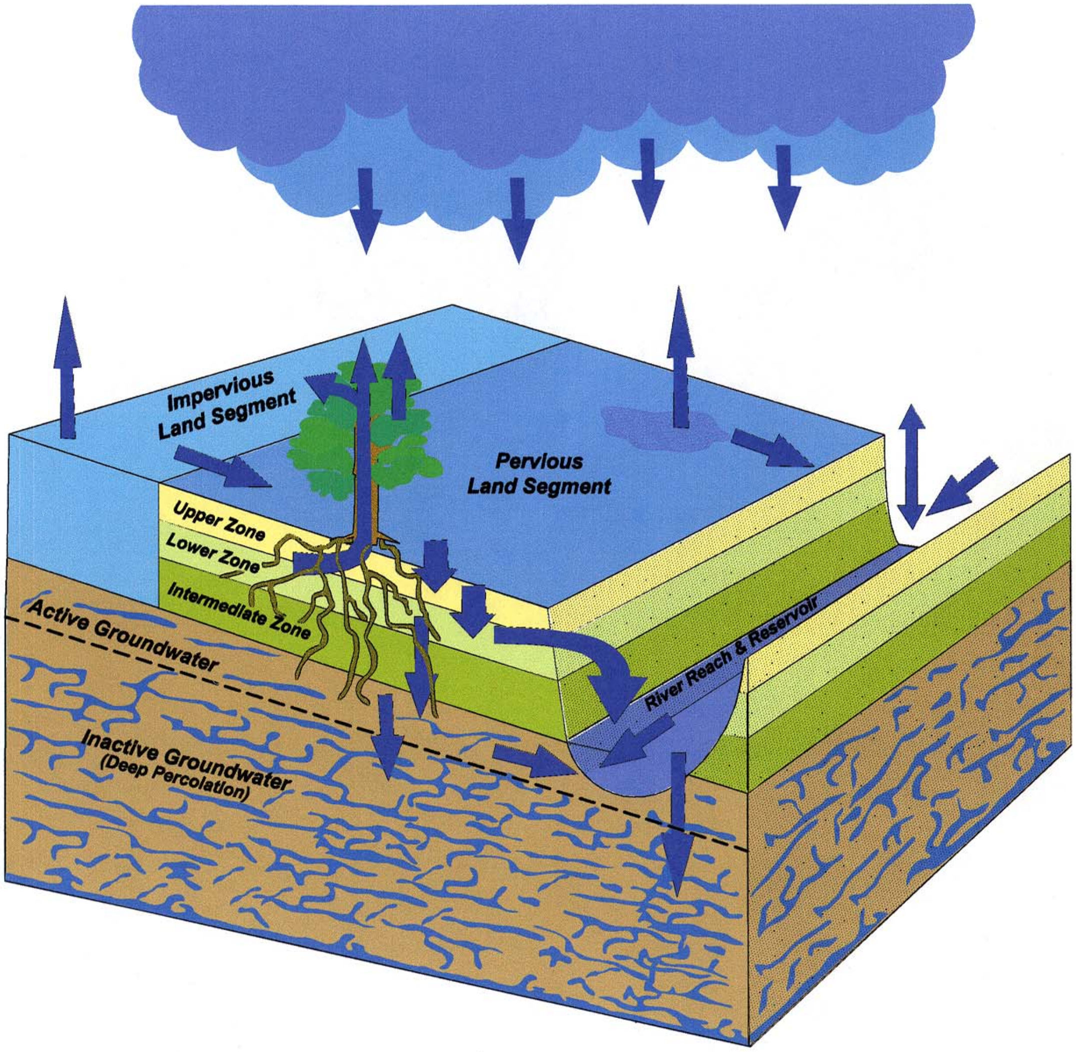
2.1 Conceptual Model of Hydrologic Cycle in the Study Area

Within the HSPF modeling environment the movement and storage of water is conceptualized as presented in Figure 2.1.1. This is a simplification of the complexities of how water moves across the Edwards Plateau, but it does allow the model to simulate these fluxes in a reasonably realistic fashion.

The major components or characteristics are the surface, vegetation, soil, groundwater and the river reach. Land segments may be either pervious or impervious. Pervious segments provide the opportunity for water to infiltrate into the soil while impervious segments do not. Impervious segments would obviously be appropriate for the urban landscape. Pervious segments can be parameterized to represent a variety of land cover types. The soil environment or zone is divided into three major segments: upper zone, lower zone, and intermediate zone. Surface runoff is generated either as overland flow or interflow. Interflow always is generated from the lower soil zone. Water can be extracted from the soils zone via plant transpiration. Plants also influence input into the soil through interception. Finally, the groundwater zone is divided into two zones: an active groundwater zone that may discharge to streams and an inactive groundwater zone that recharges the aquifer.

Major components of the water budget include precipitation, streamflow, evapotranspiration and recharge. For the purposes of this study, the major concern regarding precipitation was assimilating the data, filling in missing data records, and estimating hourly precipitation at locations that contained only daily records. More details of this process are provided in Section 3. The other three components are discussed below.

Streamflow: Within the HSPF environment water can move to the stream channel either as overland flow or interflow. Overland flow is a function of the infiltration characteristics of the landscape. Most of the soil infiltration studies on the Plateau have been conducted at the Sonora Research Station at the western side of the Plateau (Knight et al. 1983, Knight et al. 1984, Thurow et al. 1988, Hester et al. 1997). Infiltration characteristics are largely dictated by vegetation cover which is consistent across the Plateau. The other way that water is conducted to stream channels is through interflow. Recent work is just now highlighting the importance of interflow as a mechanism for runoff production (Wilcox 2005). For calibration purposes, data from the USGS gaging stations are the most useful. However additional studies are also available for smaller catchments. These include current work at Honey Creek (not yet published) but other work as well including work at Seco Creek (Dugas et al. 1998), Sonora (Richardson et al. 1979) and Annandale (Wilcox et al. submitted). These smaller scale studies provide some insight into the influence of land management as well as runoff processes.



after HDR (2002)

Figure 2.1.1 Conceptual Model of Hydrologic Cycle in Study Area

Evapotranspiration: Evapotranspiration studies on the plateau basically consist of studies at the individual tree scale as well as at a larger level. At the tree scale work by Owens on both transpiration and interception are the most complete (Owens and Ansley 1997, Owens et al. 2001). Owens work on interception by Ashe juniper are especially impressive. Dugas et al. (1998) have measured evapotranspiration on a 250 X 600 m area for a five year period on the Seco Creek watershed with some surprising results. There work suggested that evapotranspiration comprises between 65 and 85 % of the water budget which is significantly more than what has been estimated using the traditional water balance method (Maclay 1995). The current conventional wisdom is the numbers estimated by the Dugas et al. study are not applicable across the Plateau. More field studies need to be completed better assess evapotranspiration.

Recharge: There has been extensive research evaluating recharge into the Edwards Aquifer. Most of this work is relies on water budget studies using streamflow records. On that basis recharge has been estimated to be around 10-15% (Puente 1978, Maclay 1995, Khorzad 2003). As noted above, community level evapotranspiration studies using Bowen Ratio (Dugas et al. 1998) towers suggests that recharge may be higher than previously estimated. Given that the Dugas et al. (1998) estimate of recharge is so radically different than what has been accepted collectively before and that so far only one evapotranspiration study has been completed, it is not prudent to incorporate these assumptions in to the HSPF conceptual model at this time.

2.2 Simulation Model – HSPF

2.2.1 Description of HSPF

The Hydrological Simulation Program-FORTRAN, known as HSPF, is a mathematical model developed under EPA sponsorship for use on digital computers to simulate hydrologic and water quality processes in natural and man-made water systems. It is an analytical tool that has application in the planning, design, and operation of water resources systems. The model enables the use of probabilistic analysis in the fields of hydrology and water quality management. HSPF uses such information as the time history of rainfall, temperature, evaporation, and parameters related to land use patterns, soil characteristics, and agricultural practices to simulate the processes that occur in a watershed. The initial result of an HSPF simulation is a time history of the quantity and quality of water transported over the land surface and through various soil zones down to the groundwater aquifers. Runoff flow rate, sediment loads, nutrients, pesticides, toxic chemicals, and other water quality constituent concentrations can be predicted. The model uses these results and stream channel information to simulate instream processes. From this information, HSPF produces a time history of water quantity and quality at any point in the watershed. A detailed description of HSPF capabilities is provided in Appendix C.

HSPF is currently one of the most comprehensive and flexible models of watershed hydrology and water quality available. It is one of a small number of available models that can simulate the continuous, dynamic event, or steady-state behavior of both hydrologic/hydraulic and water quality processes in a watershed, with an integrated linkage of surface, soil, and stream processes. The model is also unusual in its ability to represent the hydrologic regimes of a wide variety of streams and rivers with reasonable accuracy. It has been applied to such diverse climatic regimes as the tropical rain forests of the Caribbean, the arid conditions of Saudi Arabia and the

Canada. The potential applications and uses of the model are comparatively large and include the following:

- Flood control planning and operations,
- Hydropower studies,
- River basin and watershed planning,
- Storm drainage analyses,
- Water quality planning and management,
- Point and nonpoint source pollution analyses,
- Soil erosion and sediment transport studies,
- Evaluation of urban and agricultural best management practices,
- Fate, transport, exposure assessment, and control of pesticides, nutrients, and toxic substances, and
- Time-series data storage, analysis, and display.

HSPF is designed so that it can be applied to most watersheds using existing meteorologic and hydrologic data; soils and topographic information; and land use, drainage, and system (physical and man-made) characteristics. The inputs required by HSPF are not different from those needed by most other simpler models. The primary difference in data needs is that long, rather than short time-series records are preferred. Typical long time-series records include precipitation, waste discharges, and calibration data such as streamflow and constituent concentrations.

2.2.2 Overview of HSPF Capabilities and Components

HSPF contains three application modules and eight utility modules. The three application modules simulate the hydrologic/hydraulic and water quality components of the watershed. The utility modules are used to manipulate, analyze, and report time-series data, as well as compute pollutant removal via control measures. Table 2.2.1 summarizes the constituents and capabilities of the HSPF modules.

Table 2.2.1 HSPF Application and Utility Modules

Application Modules		
PERLND	**IMPLND**	**RCHRES**
Snow Water Sediment Soil temperature Water Quality* Pesticide Nitrogen Phosphorus Tracer	Snow Water Solids Water Quality*	Hydraulics Conservative Temperature Sediment Nonconservatives BOD/DO Nitrogen Phosphorus Carbon/pH Plankton
Utility Modules		
COPY	**PLTGEN**	**DISPLAY**
Data transfer	Plot data	Tabulate, summarize
DURANL	**GENER**	**MUSTIN**
Duration	Transform or combine time series data	Time-series data
BMP	**REPORT**	
Compute pollutant removal via control measures	Customize and view model output	

* Up to 10 user–specified water quality parameters.

Although much of the capability of HSPF is not required for the current project, the future applications of the model could use more of these modules to assess water quality and mitigation alternatives. A brief description of the three modules follows:

1) PERLND - Simulates runoff and water quality constituents from pervious land areas in the watershed.

2) IMPLND - Simulates impervious land area runoff and water quality.

3) RCHRES - Simulates the movement of runoff water and its associated water quality constituents in stream channels and mixed reservoirs.

Typically the results of PERLND or IMPLND simulations are either evaluated as endpoints or are input to a RCHRES network to enable simulation of instream phenomena. To support simulation of a broader range of hydrological phenomena and settings at a watershed scale, HSPF also allows linkage of a PERLND land surface to another PERLND or to an IMPLND land surface. A more detailed description of each of the three main modules is provided in the following sections. In addition, the special actions allowed by HSPF are also summarized. Figure 2.2.1 schematically illustrates the operational protocol of HSPF and the interrelationships between the modules.

2.2.2.1 PERLND Module

Because PERLND simulates the water quality and quantity processes that occur on pervious land areas, it is the most frequently used part of HSPF. To simulate these processes, PERLND models the movement of water along three paths: overland flow, interflow, and groundwater flow. Each of these three paths experiences differences in time delay and differences in interactions between water and its various dissolved constituents. A variety of storage zones are used to represent the processes that occur on the land surface and in the soil horizons. Snow accumulation and melt are also included in the PERLND module so that the complete range of physical processes affecting the generation of water and associated water quality constituents can be represented. Some of the many capabilities available in the PERLND module include the simulation of:

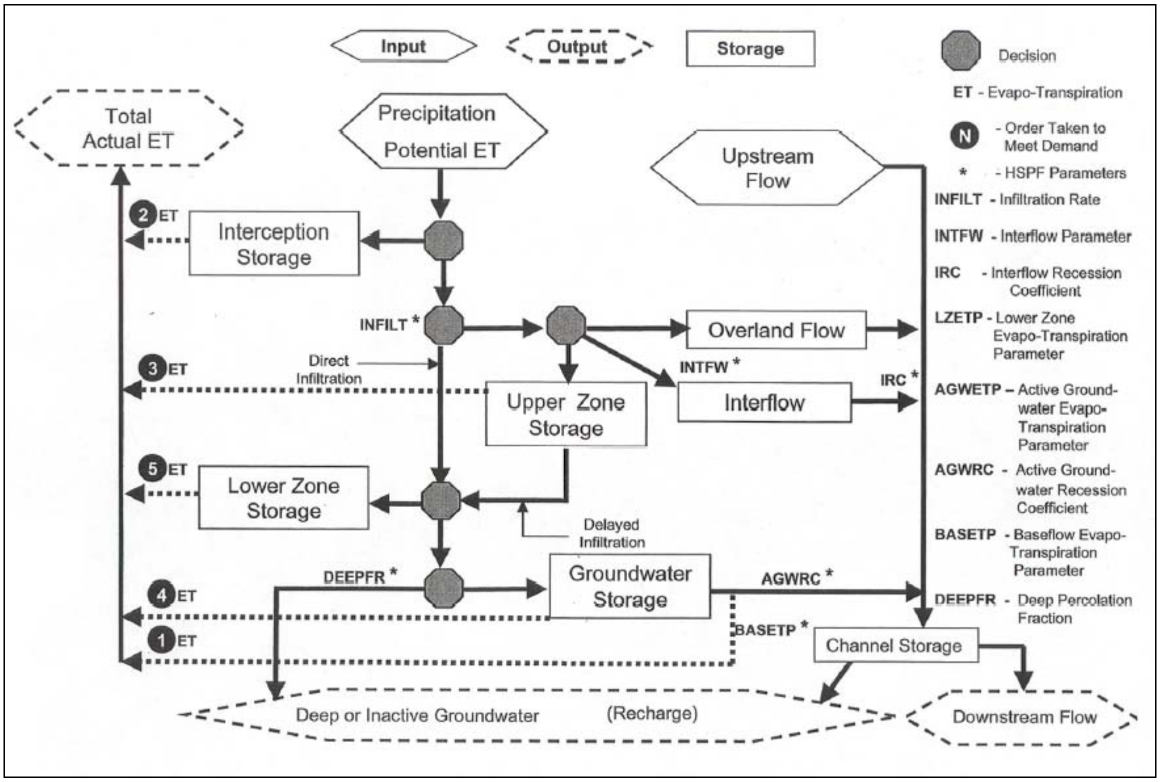
- Water budget and runoff components,
- Snow accumulation and melt,
- Sediment production and removal,
- Accumulation and washoff of user-defined nonpoint pollutants,
- Nitrogen and phosphorus fate and runoff,
- Pesticide fate and runoff, and
- Movement of a tracer chemical.

The PERLND module features individual compartments (i.e., subroutine groups) for specific modeling capabilities, including: air temperature as a function of elevation, snow accumulation and melting, hydrologic water budget, sediment production and removal, soil temperature, surface runoff water temperature and gas concentrations, generalized water quality constituents, solute transport, pesticides, nitrogen, phosphorus, and conservatives.

PWATER is used to calculate the water budget components resulting from precipitation on pervious land areas; as a result, it is the key component of the PERLND module. The basis of the water budget computations contained in HSPF is the Stanford Watershed Model (Crawford and Linsley, 1966). Like the SNOW code, the PWATER code uses both physical and empirical formulations to model the movement of water through the hydrologic cycle. PWATER considers such processes as evapotranspiration; surface detention; surface runoff; infiltration; shallow subsurface flow (interflow); baseflow; and percolation to deep groundwater. Lateral inflows to surface and shallow subsurface storages can be modeled, and a wetland module is included that allows a smooth computational transition between ‘normal’ hydrological conditions and high water table conditions. PWATER also allows representation of irrigation waters applied to pervious land segments.

2.2.2.2 IMPLND Module

IMPLND is used for impervious land surfaces, primarily for urban land categories, where little or no infiltration occurs. However, some land processes do occur, and water, solids, and various pollutants are removed from the land surface by moving laterally downslope to a pervious area, stream channel, or reservoir. IMPLND includes most of the pollutant washoff capabilities of the commonly used urban runoff models, such as the STORM, SWMM, and NPS models. The module shares much of its code with PERLND, but is simplified since infiltration and other interactions with the subsurface cannot occur. The module features individual compartments for modeling air temperature as a function of elevation, snow accumulation and melting, hydrologic water budget, solids accumulation and removal, surface runoff water temperature and gas concentrations, and generalized water quality constituents.



After HDR (2002)

Figure 2.2.1 Schematic of HSPF Hydrologic Functions

2.2.2.3 RCHRES Module

RCHRES is used to route runoff and water quality constituents simulated by PERLND and IMPLND through stream channel networks and reservoirs. The module simulates the processes that occur in a series of open or closed channel reaches or a completely mixed lake. Flow is modeled as unidirectional. A number of processes can be modeled, including the following:

- Hydraulic behavior,
- Heat balance processes that determine water temperature,
- Inorganic sediment deposition, scour, and transport by particle size,
- Chemical partitioning, hydrolysis, volatilization, oxidation, biodegradation, and generalized first-order (e.g., radionuclides) decay, parent chemical/metabolite transformations,
- DO and BOD balances,
- Inorganic nitrogen and phosphorus balances,
- Plankton populations,
- pH, carbon dioxide, total inorganic carbon, and alkalinity,

The RCHRES module features individual compartments for modeling hydraulics (HYDR), constituent advection (ADCALC), conservatives (CONS), water temperature (HTRCH), inorganic sediment (SEDTRN), generalized quality constituents (GQUAL), specific constituents involved in biochemical transformations (RQUAL), and acid mine drainage phenomena (ACIDPH).

1) HYDR simulates the processes that occur in a single reach of an open channel or a completely mixed lake. Hydraulic behavior is modeled using the kinematic wave assumption. All inflows to a reach are assumed to enter at a single upstream point. The outflow of a reach may be distributed across several targets that might represent normal outflows, diversions, and multiple gates of a reservoir. In HSPF, outflows can be represented by either, or both, of two methods: Outflow can be modeled as a function of reach volume for situations where there is no control of flows, or gate settings are only a function of water level.

2) Outflow can be modeled as a function of time to represent demands for municipal, industrial, or agricultural use. To do so, the modeler must provide a time series of outflow values for the outflow target that is time-dependent and independent of reach volume.

If an outflow demand has both volume-dependent and time-dependent components, the modeler can, and must, specify how the components are combined to define the resulting outflow demand. HSPF allows the modeler to define the resulting demand in one of three manners: (1) as the minimum of the two components, (2) as the maximum of the two components, or (3) as the sum of the two components.

HSPF makes no assumptions regarding the shape of a reach; however, the following assumptions are made:

1) There is a fixed, user-defined relation between water depth, surface area, volume, and discharge. This is specified in a Function Table (FTABLE) defined for each reach by the user.

2) For any outflow demand with a volume-dependent component, the relation between the above variables is usually constant in time; however, predetermined seasonal or daily variations in discharge values can be represented by the user.

These assumptions rule out cases where flow reverses direction (e.g., estuaries) or where one stream reach influences another upstream of it in a time-dependent manner. Momentum is not considered, and the routing technique falls in the class known as “storage routing” or “kinematic wave” methods.

In addition to calculating outflow rates and reach water volumes, HYDR computes the values for additional hydraulic parameters that are used in the other code sections of RCHRES including depth, stage, surface area, average depth, top width, hydraulic radius, bed shear stress and shear velocity. A user can also assign the ownership of water inflows and outflows to each reach, with the ownership of outflowing water defined in terms of specified priorities or percentages, or in proportion to the current mixture in the stream segment.

2.2.2.4 Special Actions

Increasingly complex modeling requirements have led to the development of a suite of Special Actions capabilities within HSPF. Special Actions enable the user to alter the value of variables in PERLND, IMPLND and RCHRES in the following manners:

Reset – A variable can be reset at any specified time in the simulation to a specified value.

- Increment – A variable can be incremented at any specified time in the simulation by a specified value.

- Repeat - Each SPECIAL ACTION can be "repeated" at regular time intervals. This facilitates application of chemicals several times per year and each year of the simulation.

- Distribution - A SPECIAL ACTION can be "distributed" over time (equal time increments) with a user-defined pattern that is based on fractions of the total amount. This is useful in representing the activities of multiple farmers applying chemicals on different days when all of the farms are represented by a single PERLND.

- User-defined - Several SPECIAL ACTIONS can be combined as a single "user-defined" action which can be invoked multiple times for different PERLNDS and at different times. This reduces the number of actions required to represent incorporation of chemicals in two or more soil layers as a result of plowing, and application of multiple chemical species.

- Conditional - In addition to the enhancements designed to reduce the user-input requirements of SPECIAL ACTIONS, conditional SPECIAL ACTIONS are possible in which an action can be dependent on the value of some other variable in the model. This can be useful for deferring agricultural operations that are dependent on rainfall or soil moisture, and for reservoir operations that are dependent on river flow or reservoir volume.

2.2.3 Modeling Approach

The selection of the calibration and simulation periods for the HSPF requires an evaluation of available field data. One objective in developing the HSPF models was to estimate historical recharge from 1950 through 2000. Prior to simulating the 50-year period, a 5-year calibration period (1997-2001) was used to adjust model parameters. This period was selected because it contained a wide variety of hydrologic conditions, including very wet (flood during water year 1998), dry (drought during 2000), and average conditions. In addition, this period had a relatively small amount of missing precipitation or evaporation data. Table 2.2.2 compares the distribution of monthly streamflow at the Frio River at Concan (USGS#8195000) during the period from 1951-2000 (50 years) with that of the selected calibration period, 1997-2001 (5-years). The tabulation indicates that the percent occurrence is very similar for each period.

Table 2.2.2 Comparison of flow records for 5-year calibration period to 50-year period in the Frio Basin

Flow Range	1951-2000 (50-year)		1997-2000 (5-year)	
(cfs)	Number of months	% Occurrence	Number of months	% Occurrence
0-200	510	85.00	50	83.33
201-400	60	10.00	6	10.00
401-600	12	2.00	2	3.33
601-800	11	1.83	0	0.00
801-1000	3	0.50	1	1.67
1001-1200	2	0.33	1	1.67
1201-1400	1	0.17	0	0.00
1401-1600	0	0.00	0	0.00
1601-1800	1	0.17	0	0.00
Total	600	100.00	60	100.00

The models were run for one year prior to 1997 so that initial conditions would not affect calibration results. A sensitivity analysis indicated that it was more appropriate to use an hourly timestep to simulate the hydrologic processes than a daily timestep. Appendix E contains a full description of the sensitivity analysis used to draw this conclusion.

The calibration of HSPF to the nine basins followed the standard model calibration procedures as described in the HSPF Application Guide (Donigian et al., 1984), in numerous watershed studies over the past 20 years (see HSPF Bibliography [Donigian, 2002a]), and as recently summarized by Donigian (2002b). The following model calibration discussion focuses solely on the HSPF hydrologic parameters; water quality parameters are not discussed.

2.2.3.1 Parameter Estimation for HSPF Models

For HSPF, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of interest. This approach is required for parameters that cannot be deterministically, and uniquely, evaluated from topographic, climatic, edaphic, or physical characteristics of the watershed. Fortunately, the large majority of HSPF parameters do not fall in this category. Calibration is based on several years of simulation to evaluate parameters under a variety of climatic and soil moisture conditions. Model calibration results in parameter values that produce the best overall agreement between simulated and observed values throughout the calibration period based on standard statistical measures of error such as variance. Any temporal biases in the calibration data may affect the quality of the calibration and will be noted.

Calibration includes the comparison of both monthly and annual time periods, and individual storm events, whenever sufficient data are available for these comparisons. All of these comparisons are performed to ensure a proper calibration of hydrology parameters. In addition, when a continuous observed record is available, such as for streamflow, simulated and observed values are analyzed on a frequency basis and their resulting cumulative distributions (e.g., flow duration curves) compared to assess the model behavior and agreement over the full range of observations.

A weight of evidence approach, as described above, is most widely used and accepted because no single procedure or statistic is widely accepted as measuring, nor capable of establishing, acceptable model performance. Therefore, the calibration will rely on numerous statistical tests (e.g., correlation tests, Model Fit Efficiency) and graphical plots (e.g., scatter, time series, frequency) to determine the model's ability to mimic the hydrologic system.

Calibration is a hierarchical process beginning with the hydrology calibration of both runoff and streamflow. Hydrologic simulation combines the physical characteristics of the watershed and the observed meteorological data series to produce the simulated hydrologic response. All watersheds have similar hydrologic components, but they are generally present in different combinations; thus different hydrologic responses occur on individual watersheds. HSPF simulates runoff from four components: surface runoff from impervious areas directly connected to the channel network, surface runoff from pervious areas, interflow from pervious areas, and groundwater flow. Because the historic streamflow is not divided into these four units, the relative relationship among these components must be inferred from the examination of many events over several years of continuous simulation.

A complete hydrologic calibration involves a successive examination of the following four characteristics of the watershed hydrology, in the order shown: (1) annual water balance, (2) seasonal and monthly flow volumes, (3) baseflow, and (4) storm events. Simulated and observed values for reach characteristic are examined and critical parameters are adjusted to attain acceptable levels of agreement (discussed further below).

The annual water balance specifies the ultimate destination of incoming precipitation and is indicated as:

$$\text{Runoff} = \text{Precipitation} - \text{Actual Evapotranspiration} - \text{Deep Percolation} - \Delta\text{Soil Moisture}$$

HSPF requires input precipitation and potential evapotranspiration (PET), which effectively drive the hydrology of the watershed; actual evapotranspiration (calculated by the model from the input potential); and ambient soil moisture conditions. Thus, both precipitation and evaporation inputs must be accurate and representative of the watershed conditions. It is often necessary to adjust the input data derived from neighboring stations that may be some distance away in order to reflect conditions on the watershed. HSPF allows the use of factors (referred to as MFACT) that uniformly adjust the input data to watershed conditions, based on local isohyetal and evaporation patterns. In addition to the input meteorological data series, there are many critical parameters that govern the annual water balance. A listing and description of these parameters is provided in Appendix F. Appendix F also provides the typical range of values for each parameter and how that parameter is related to the physical system. Some of the more critical parameters are discussed below:

LZSN - lower zone soil moisture storage (inches).
LZETP - vegetation evapotranspiration index (dimensionless).
INFILT - infiltration index for division of surface and subsurface flow (inches/hour).
UZSN - upper zone soil moisture storage (inches).
DEEPFR - fraction of groundwater inflow to deep recharge (dimensionless).

Thus, from the water balance equation, if precipitation is measured on the watershed, and if deep percolation to groundwater is small or negligible, actual evapotranspiration must be adjusted to cause a change in the long-term runoff component of the water balance. Changes in LZSN and LZETP affect the actual evapotranspiration by making more or less moisture available to evaporate or transpire. Both LZSN and INFILT also have a major impact on percolation and are important in obtaining an annual water balance. In addition, on extremely small watersheds (less than 200 to 500 acres) that contribute runoff only during and immediately following storm events, the UZSN parameter can also affect annual runoff volumes because of its impact on individual storm events (described below). Whenever there are losses to deep groundwater, such as recharge, or subsurface flow not measured at the flow gauge, DEEPFR is used to represent this loss from the annual water balance.

In the next step in hydrologic calibration, after an annual water balance is obtained, the seasonal or monthly distribution of runoff is adjusted with use of INFILT, the infiltration parameter defined above. This seasonal distribution is accomplished by INFILT by dividing the incoming moisture among surface runoff, interflow, upper zone soil moisture storage, and percolation to lower zone soil moisture and groundwater storage. Increasing INFILT reduced immediate surface runoff (including interflow) and increases the groundwater component; decreasing INFILT produced the opposite result.

The focus of the next stage in calibration is the baseflow component. This portion of the flow is adjusted in conjunction with the seasonal/monthly flow calibration (previous step) because moving runoff volume between seasons often means transferring the surface runoff from storm events in wet seasons to low-flow periods during dry seasons. By increasing INFILT, runoff is delayed and occurs later in the year as an increased groundwater or baseflow. The shape of the groundwater recession; i.e., the change in baseflow discharge, is controlled by the following parameters:

AGWRC - groundwater recession rate (per day).

KVARY - index for nonlinear groundwater recession.

AGWRC is calculated as the rate of baseflow (i.e., groundwater discharge to the stream) on one day divided by the baseflow on the previous day; thus AGWRC is the parameter that controls the rate of outflow from the groundwater storage. Using hydrograph separation techniques, values of AGWRC are often calculated as the slope of the receding baseflow portion of the hydrograph; these initial values are then adjusted as needed through calibration. The KVARY index allows users to impose a nonlinear recession so that the slope can be adjusted as a function of the groundwater gradient. KVARY is usually set to zero unless the observed flow record shows a definite change in the recession rate (i.e., slope) as a function of wet and dry seasons.

In the final stage of hydrologic calibration, after an acceptable agreement was attained for annual/monthly volumes and baseflow conditions, simulated hydrographs for selected storm events were effectively altered with UZSN and the following parameters:

INTFW - Interflow inflow parameter (dimensionless).

IRC - Interflow recession rate (per day).

Both INTFW and IRC are used to adjust the shape of the hydrograph to better agree with observed values; both parameters are evaluated primarily from past experience and modeling studies, and then adjusted in calibration. Also, minor adjustments to the INFILT parameter are used to improve simulated hydrographs; however, adjustments to INFILT are minimal to prevent disruption of the established annual and monthly water balance. Examination of both daily and short time interval (e.g., hourly) flows are made.

Calibration procedures have been discussed in general terms, above. Specific procedures and rules are listed below:

1. The major PERLND calibration parameters are infiltration (INFILT) and lower zone storage nominal (LZSN).

2. Minor PERLND calibration parameters are upper zone storage nominal (UZSN), interflow index (INTFW), lower zone evapotranspiration (LZETP).

3. PERLND parameters infiltration exponent (INFEXP) and infiltration max to mean ratio (INFILD) will be set to 2.0.

4. PERLND parameters interflow recession constant (IRC), active groundwater recession constant (AGWRC), and variable groundwater modifier (KVARY) will be based on calculated observed streamflow recessions.

5. PERLND parameters length of surface runoff (LSUR), slope of surface runoff (SLSUR), Manning's roughness for the surface runoff (NSUR) will be based on physical basin characteristics.

6. PERLND parameters inception storage (CEPSC) and lower zone evapotranspiration (LZETP) will be based on the type and density of vegetation.

7. PERLND parameters base evapotranspiration and active groundwater evapotranspiration will be initially set to zero.

8. PERLND parameter deep fraction of groundwater (DEEPFR) will be initially set to zero. DEEPFR will be increased to achieve a good water balance once the values of the calibration parameters have been set.

9. The first priority in the calibration process is accurate simulation of annual flow volumes to within 10 percent of observed volumes.

10. Once volumes are correct, low flows and peak events will be adjusted, as needed.

Some of the calibration parameter values may differ from the pilot model studies, based on experience in calibrating HSPF models throughout the United States. Our initial assessment of the pilot models has identified the following calibration parameters to have different values than used in the pilot models. Other parameter values are expected to change as a result of the calibration process, as described above.

1. Interflow recession constant (IRC) values will be in the expected range of 0.30 to 0.70. A value of 0.90 for a recession constant means that the contributing flows on day 2 is 90% of the flow on day 1. This high value is more appropriate for the active groundwater recession constant (AGWRC) than the interflow recession constant (IRC). IRC values are typically in the range of 0.30 to 0.70. The steep receding limb of the Nueces hydrographs supports a low IRC value.

2. Manning’s roughness for overland flow (NSUR) values will be in the expected range of 0.25 to 0.35.

3. Active groundwater evapotranspiration (AGWETP) will be assumed to be zero unless there is evidence that vegetation is transpiring water from the active groundwater storage. The Nueces and Blanco pilot models have AGWETP values of 0.10 and 0.20, respectively.

The hydrologic calibration was performed for the time period of 1997 through 2001. The available flow data was used the daily flow records at the stream gauges identified in Table B4.

2.2.3.2 Calibration Targets

The following specific comparisons of simulated and observed values were performed:

Annual and monthly runoff volumes (inches)
Daily time series of flow (cfs)
Flow duration values (cfs)

The comparisons will use HSPF Expert System statistics to evaluate the accuracy of the calibration. The simulated and observed flow values are divided into a number of categories and then evaluated according to defined criteria that allow the user to target specific flow ranges and events, such as the highest 10% of the flows, 50% low flows, summer storm volumes, etc. The criteria values range from 10 percent error to 20 percent error, depending on the type of flow range. The 12 criteria are shown in Table 2.2.3. Most, but not all, of the criteria have to be met to produce a successful calibration, as this is just one tool used together with the other calibration information to produce an overall view of the calibration to determine whether or not it is sufficiently accurate for the purposes of this study.

Table 2.2.3 HSPF Calibration Statistics and Criteria

	Simulated	**Observed**	**Difference**	**Criteria**	**Meets**
Calibration Target	**(-)**	**(-)**	**(%)**	**(%)**	**Criteria**
Total (in)				10%	Excellent - Poor
10% high (in)				10%	Excellent - Poor
25% high (in)				15%	Excellent - Poor
50% low (in)				15%	Excellent - Poor
25% low (in)				15%	Excellent - Poor
10% low (in)				15%	Excellent - Poor
Storm volume (in)				20%	Excellent - Poor
Average storm peak (cfs)				15%	Excellent - Poor
Summer volume (in)				15%	Excellent - Poor
Winter volume (in)				10%	Excellent - Poor
Summer storms (in)				10%	Excellent - Poor
Winter storms (in)				15%	Excellent - Poor

The calibration process will also produce graphical plots (hydrographs and other graphs) for each stream gauge location for which simulated and observed streamflow data are compared. The graphs produced include:

1. daily simulated and observed streamflow for the calibration period
2. flow duration
3. representative individual flow events
4. monthly simulated and observed flow volumes
5. scatter plot of the simulated and observed daily values

In addition to the above comparisons, the water balance components (input and simulated) will be reviewed for consistency with expected literature values for the Texas Hill Country. This effort includes displaying model results for individual land uses for the following water balance components:

- Precipitation
- Total Runoff (sum of following components)
    - Surface Runoff/Overland Flow
    - Interflow
    - Groundwater/Baseflow

- Total Actual Evapotranspiration (ET) (sum of following components)
  - Interception ET
  - Upper zone ET
  - Lower zone ET
  - Baseflow ET
  - Active groundwater ET

- Deep Groundwater Recharge/Losses

Although observed values will not be available for each of the water balance components listed above, the average annual values must be consistent with expected values for the region, as impacted by the individual land use categories. This is a separate consistency, or reality, check with data independent of the modeling (except for precipitation) to insure that land use categories and overall water balance reflect local conditions in the nine basins.

2.2.4 Key Modeling Assumptions

The following key assumptions will be used in the construction and calibration of the nine basins:

1. The following PERLND parameters were based on physical/hydrologic values: interception storage (CEPSC), length of overland flow (LSUR), active groundwater recession constant (AGWRC), Manning’s roughness for overland flow (NSUR), and interflow recession constant (IRC).

2. No evapotranspiration is assumed to occur from groundwater storage unless there is evidence that vegetation has access to the groundwater.

3. RCHRES channel flow times and lengths (upstream and downstream boundaries) are generally within the range of one to four miles in length.

4. Precipitation and evaporation was applied only on PERLNDs, IMPLNDs, and RCHRES lakes and reservoirs where the surface area is not part of a PERLND.

5. Active groundwater drains to the stream channel system; deep or inactive groundwater drains directly to the aquifer below.

6. Initial HSPF parameters in ungauged areas will be based on calibrated parameters from neighboring gauged basins and will not be modified significantly without scientific justification.

7. When there were two or more channel loss tests in the same segment, an attempt was made to develop a relationship between stream losses at various streamflows. If that was impossible or unsuccessful for model calibration, the test with the higher (the highest) loss was chosen to represent the channel loss.

2.2.5 Potential Application of the HSPF Models

There are many potential applications for the HSPF models. Some of these include:

1) performing recharge calculations,
2) assessing the impact of precipitation enhancement programs,
3) evaluating the effectiveness of brush control,
4) assessing technical and regulatory issues associated with recharge structures,
5) land management studies,
6) water quality assessments,
7) real-time assessment of floods and recharge, and
8) integration with the MODFLOW groundwater model for the Edwards aquifer to simulate surface water and groundwater interaction.

The first five applications could be completed with the current models. Water quality assessments would require data and calibration enhancements. The last two applications would require modifications to the operation and data integration components of the model. More details of HSPF capabilities and potential applications such as simulating water quality are discussed in Appendix C.

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3. Data Collection, Assimilation and Refinement

Database development is a major portion of the total modeling effort, requiring acquisition of data from a variety of sources, developing estimation procedures when required data are not available, applying available techniques to fill-in missing data, and ensuring consistency and accuracy of the information obtained.

The data requirements for HSPF are extensive, in both spatial and temporal detail, especially for an application that includes the contributing and recharge zones. In addition, developing the model to be capable of assessing the potential impact of such activities as brush management in the watershed requires even more sophisticated methods. Typical data requirements for an HSPF application can be categorized as input/execution data, watershed/channel characterization data, and calibration/validation data. The purpose of this section is to summarize the data that was used in the models. A more detailed discussion of data sources is included in Appendix D.

3.1 Precipitation and Evaporation

Precipitation

For the nine-basins study area, a search of precipitation stations was conducted for an area between 30.50 degrees North and 29.00 degrees North, and 98.00 and 100.30 degrees West. Figure 3.1.1 shows the National Weather Service stations that were selected for use during this study. Only a few of the precipitation stations have hourly data. Therefore, daily precipitation data was distributed to hourly intervals so that hourly timesteps could be used in the HSPF model.

The WDMUtil program was used to perform the precipitation data disaggregation. WDMUtil may be obtained through the Internet by accessing the Environmental Protection Agency (EPA) Internet home page at: http://www.epa.gov/ost/basins. The following procedure outlines how daily precipitation time series was distributed to hourly values based on hourly time series from nearby stations. The daily precipitation time series must not contain any missing periods. The WDMUtil program distributes the data according to one of several secondary hourly stations (up to 5 hourly precipitation time series from nearby stations), using the one whose daily total is closest to the daily value. If the daily total for the hourly stations being used are not within a user-specified tolerance of the daily value, the daily value is distributed using a standard triangular distribution centered on the middle of the day. A distribution algorithm is used in sizing the base of the triangle (number of hours) and it is in proportion with the rainfall volume. An illustration of the standard triangular distribution algorithm is presented below.

A data tolerance value represents the allowable range of daily totals from the hourly stations, expressed as a ratio of the total to the daily value being disaggregated. One hundred percent means that any daily total (from the hourly stations) is acceptable. Zero percent means that the daily total must match the daily value exactly. Fifty percent means that the daily total must be between one half and double the daily value. The program provides a summary output file reporting what hourly station was used to disaggregate each daily value or that no hourly station was found to use for disaggregation.

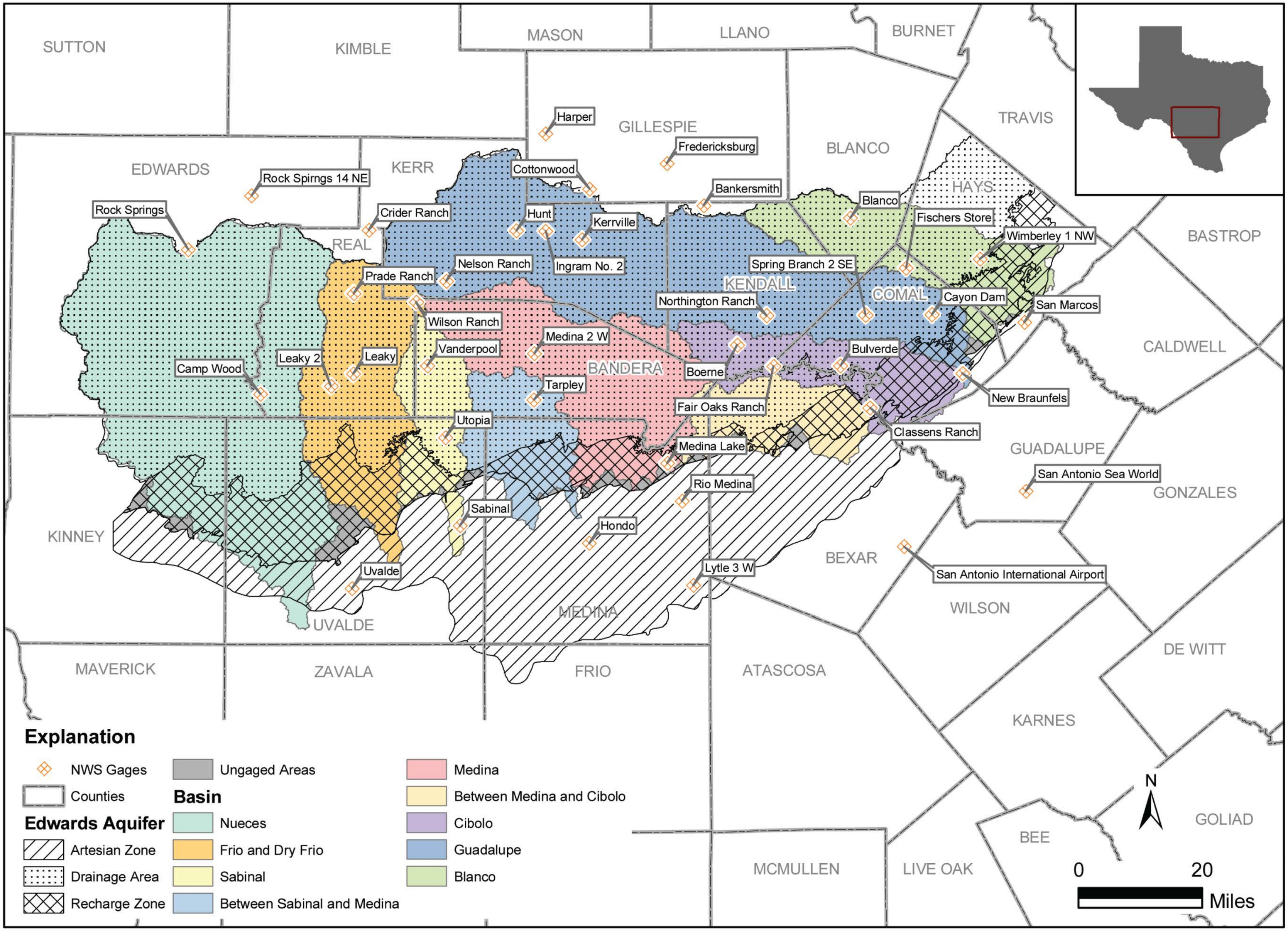


Figure 3.1.1 - Weather Stations in the Area

Before disaggregating the daily precipitation data, missing data was filled in. The fill-in procedure finds all missing values in a primary data set, and fills them in, using user-specified secondary data sets having the same time step. These stations may be adjusted by volume ratio (not counting time periods where one or both of the stations are bad). If more than on secondary station is used, the fill-in value is computed as a weighted average by one of the following methods: 1) by the reciprocal of the distance to the primary station; 2) by the reciprocal of the squares of these distances; 3) by equal weights; or 4) by user-defined weights.

Missing values are filled in by the weighted, adjusted sum of the secondary stations. Any secondary with bad values are ignored, and their weight distributed proportionally among the other stations. If no stations have good values, the corrected station is left with a missing value code. The use of the standard triangular distribution in illustrated below. Two tables SUM (12) and TRIANG (12,24) are defined in Table 3.1.1.

Table 3.1.1 Triangular distribution used in precipitation distribution

Row	SUM	TRIANG (in hundredths of an inch of rainfall)																							
1	1											1													
2	2										1	1													
3	4										1	2	1												
4	8									1	3	3	1												
5	16									1	4	6	4	1											
6	32								1	5	10	10	5	1											
7	64								1	6	15	20	15	6	1										
8	128							1	7	21	35	35	21	7	1										
9	256							1	8	28	56	70	56	28	8	1									
10	512						1	9	36	84	126	126	84	36	9	1									
11	1024						1	10	45	120	210	252	210	120	45	10	1								
12	2048	0	0	0	0	0	0	1	11	55	165	330	462	462	330	165	55	11	1	0	0	0	0	0	0
	Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

SUM(i) (where i=1 to 12) is equal to the sum of the value contained in the row TRIANG (i,j) (j=1 to 24). Example: SUM(6) = 32 = 1 + 5 + 10 + 10 + 5 + 1

SUM(i) (i=1 to 12) contains values supposed to be in hundredths of an inch and has the following property: SUM(i) = $2^{(i-1)}$. i=6, SUM(6)=$2^{(6-1)}$=2^5=32.

For example, a daily value rainfall value is 40 hundredths of an inch, and it is between SUM(6)=32 and SUM(7)=64. A weighting factor, the ratio of 40/64 = 0.625, is used to scale the TRIANG (6,24) and the hourly distribution is centered on the hour, which is the observation time minus 12. If the observation time is 24, the corresponding hourly distribution is shown in Table 3.1.2.

Table 3.1.2 Example of an hourly distribution for precipitation

Hours	Values in hundredths of an inch
1 to 8	0.000
9	0.625
10	3.750
11	9.375
12	12.500
13	9.375
14	3.750
15	0.625
16 to 24	0.000
	Total = 40.000

Figure 3.1.2 shows the location of Authority precipitation gages that collect data at 1-hour intervals. Data is available for most of these gages since 2001. Because consistent data are not available prior to 2001, this information was not used to develop the hourly precipitation data required for model development. In the future, hourly data from these gages may be helpful to refine the models by improving calibration and accuracy of predictions.

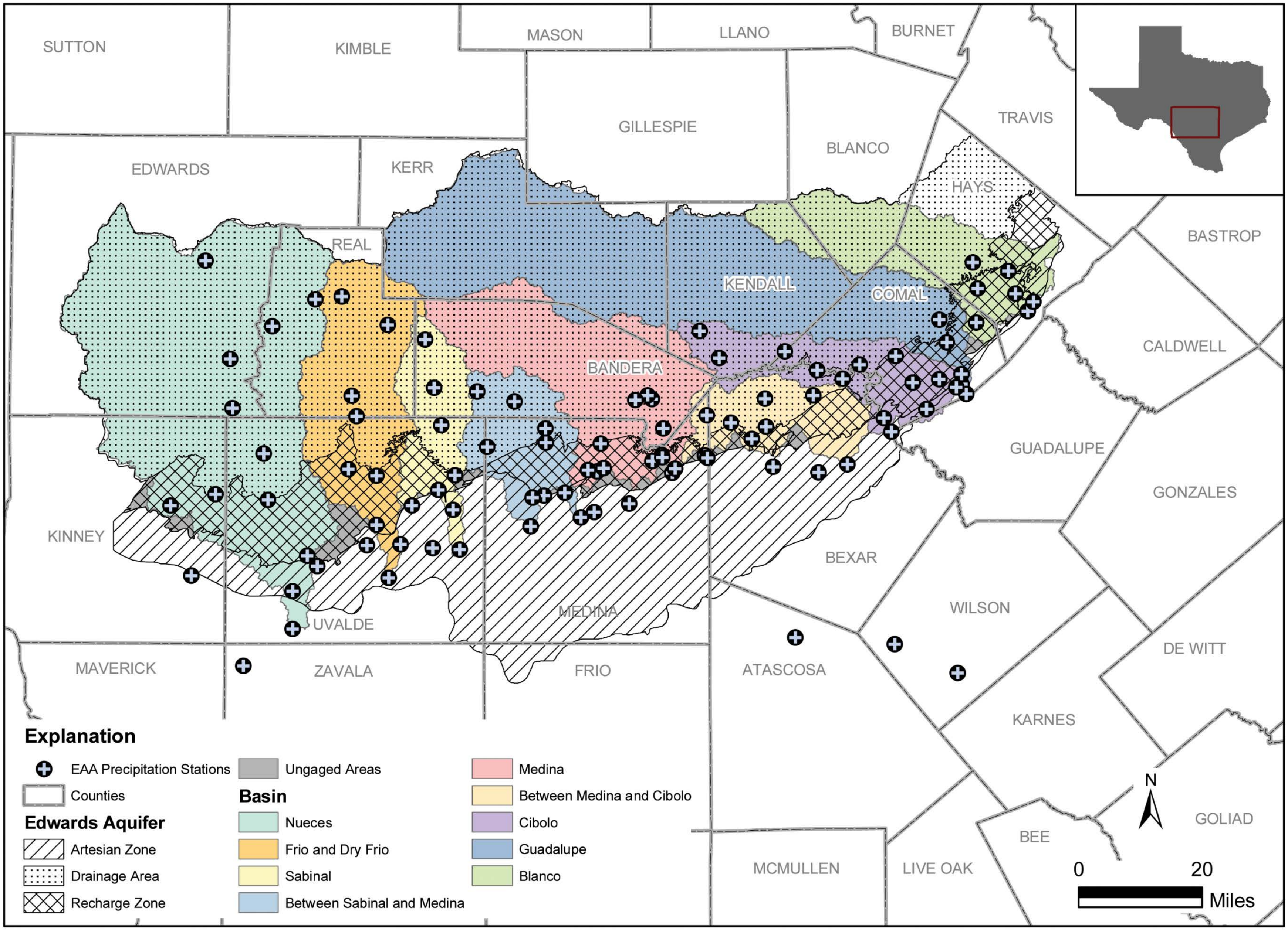


Figure 3.1.2 - EAA Precipitation Stations in the Area

Evaporation

For the nine-basins study area, a search of evaporation stations was conducted for an area between 30.50 degrees North and 29.00 degrees North, and 98.00 and 100.30 degrees West. The hourly potential evapotranspiration (PET) data observed at San Antonio WSFO Airport (SAA) station was the primary data source for the 9-Basins Recharge Models. Missing data in the SAA data time series were filled-in with the daily pan evaporation data recorded at Canyon Lake station using the same technique as discussed for the missing rainfall data. Monthly evaporation data for each 1-degree quadrangle in Texas (available from the TWDB website) was disaggregated into an hourly data set by scaling the hourly SAA data and using a ratio of the respective monthly sum as the scaling factor. Appendix D contains more details about the evaporation data that was assimilated for the models.

3.2 Streamflow

The streamflow data used to calibrate the models for each of the nine basins is listed by basin in Table 3.2.1.

Table 3.2.1 Streamflow Stations for each Basin

Basin No.	Basin Name	Streamflow Station			
		Name	Station Number	Period of Record*	Location
1	Nueces	West Nueces River near Brackettville	8190500	1939-current	contributing
		Nueces River at Laguna	8190000	1923-current	contributing
		Nueces River below Uvalde	8192000	1939-current	recharge zone
2	Frio-Dry Frio	Frio R. at Concan	8195000	1923-current	contributing
		Dry Frio R. nr Reagan Wells	8196000	1952-current	contributing
		Frio R. below Dry Frio R. nr Uvalde	8197500	1952-current	recharge zone
3	Sabinal	Sabinal R. nr Sabinal	8198000	1942-current	contributing
		Sabinal R. at Sabinal	8198500	1952-current	recharge zone
4	Area between Sabinal and Medina	Hondo C. nr Tarpley	8200000	1952-current	contributing
		Hondo C. at King Waterhole nr Hondo	8200700	1960-current	recharge zone
		Seco C. at Miller Ranch nr Utopia	8201500	1961-current	contributing
		Seco C. at Rowe Ranch nr D'Hanis	8202700	1960-current	recharge zone
5	Medina	Medina R. at Bandera	8178880	1982-current	contributing
		Medina Canal nr Riomedina	8180000	1922-current	contributing

Table 3.2.1 Streamflow Stations for each Basin

Basin No.	Basin Name	Streamflow Station			
		Name	Station Number	Period of Record*	Location
		USGS Medina R. nr Riomedina	8180500	1923-current	recharge zone
6	Area between Medina and Cibolo-Dry Comal	Salado C. at Wilderness Rd at San Antonio	8178585	1997-current	contributing
		Salado C. at Loop 410 at San Antonio	8178700	1960-current	contributing
		Salado C. at Loop 13 at San Antonio	8178800	1960-current	recharge zone
7	Cibolo-Dry Comal	Cibolo C. at IH10 above Boerne	8183850	1996-current	contributing
		Cibolo C. at Selma	8185000	1946-current	recharge zone
8	Guadalupe	Guadalupe R. above Comal R. at New Braunfels	8168500	1927-current	contributing
		Comal R. at New Braunfels	8169000	1927-current	contributing
		Guadalupe R. at New Braunfels	8169500	1915-1927	recharge zone
9	Blanco	Blanco River at Wimberley	8171000	1924-current	contributing
		Blanco River near Kyle	8171300	1956-current	contributing

* Daily data

3.3 Topography

The National Elevation Database (NED) 30-meter topographic data were used to delineate watersheds and determine average watershed and stream slope. The NED was selected because it has several advantages over the previous generation 7.5-min Quadrangle digital elevation model (DEM) data, including seamless and corrected boundary information. Figure 3.3.1 illustrates the land surface elevation for the nine-basin area. Figures 3.3.2 and 3.3.3 show the hillshade perspective and slope of the nine-basin area, respectively.

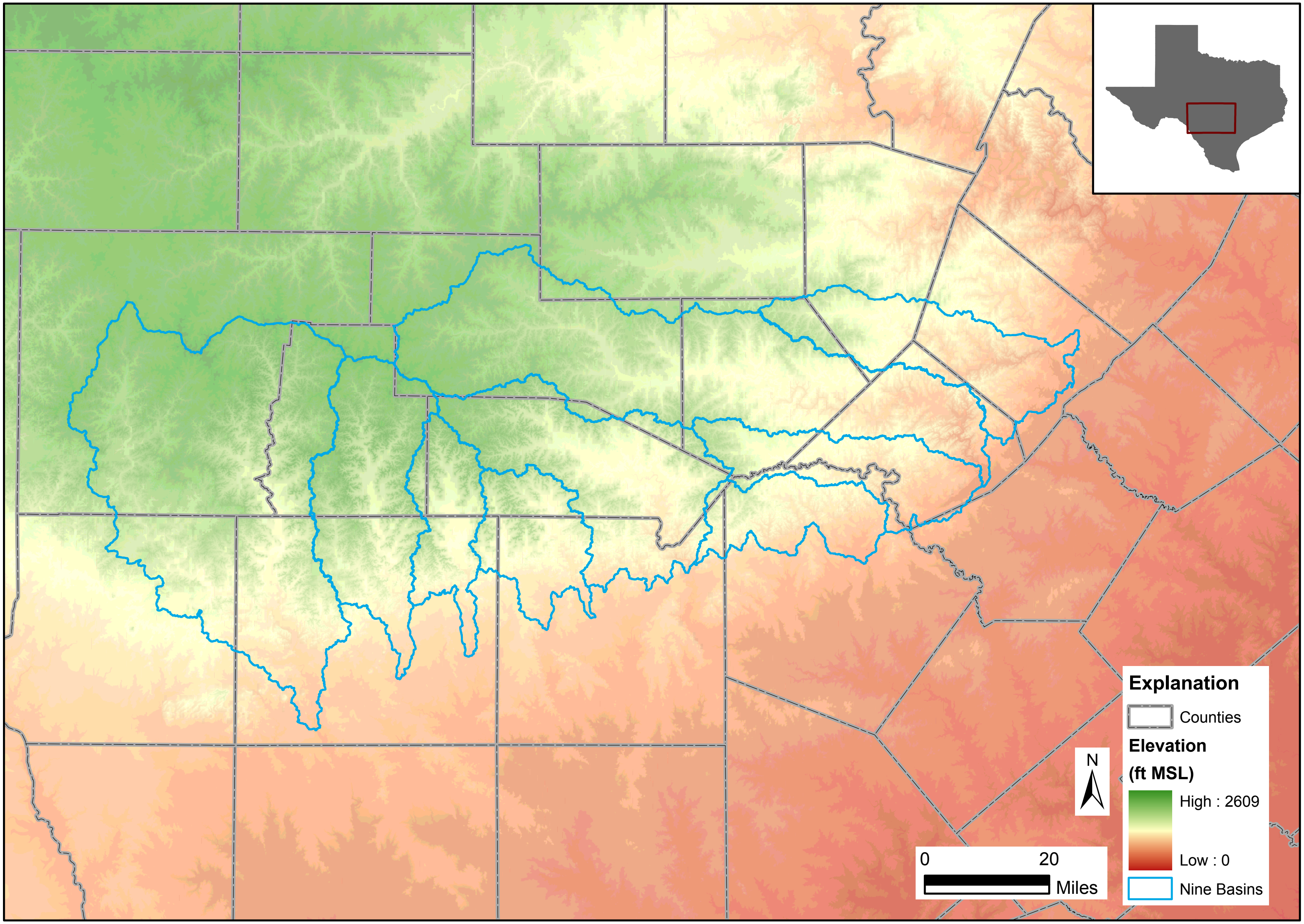


Figure 3.3.1 - Elevation in the Nine Basins

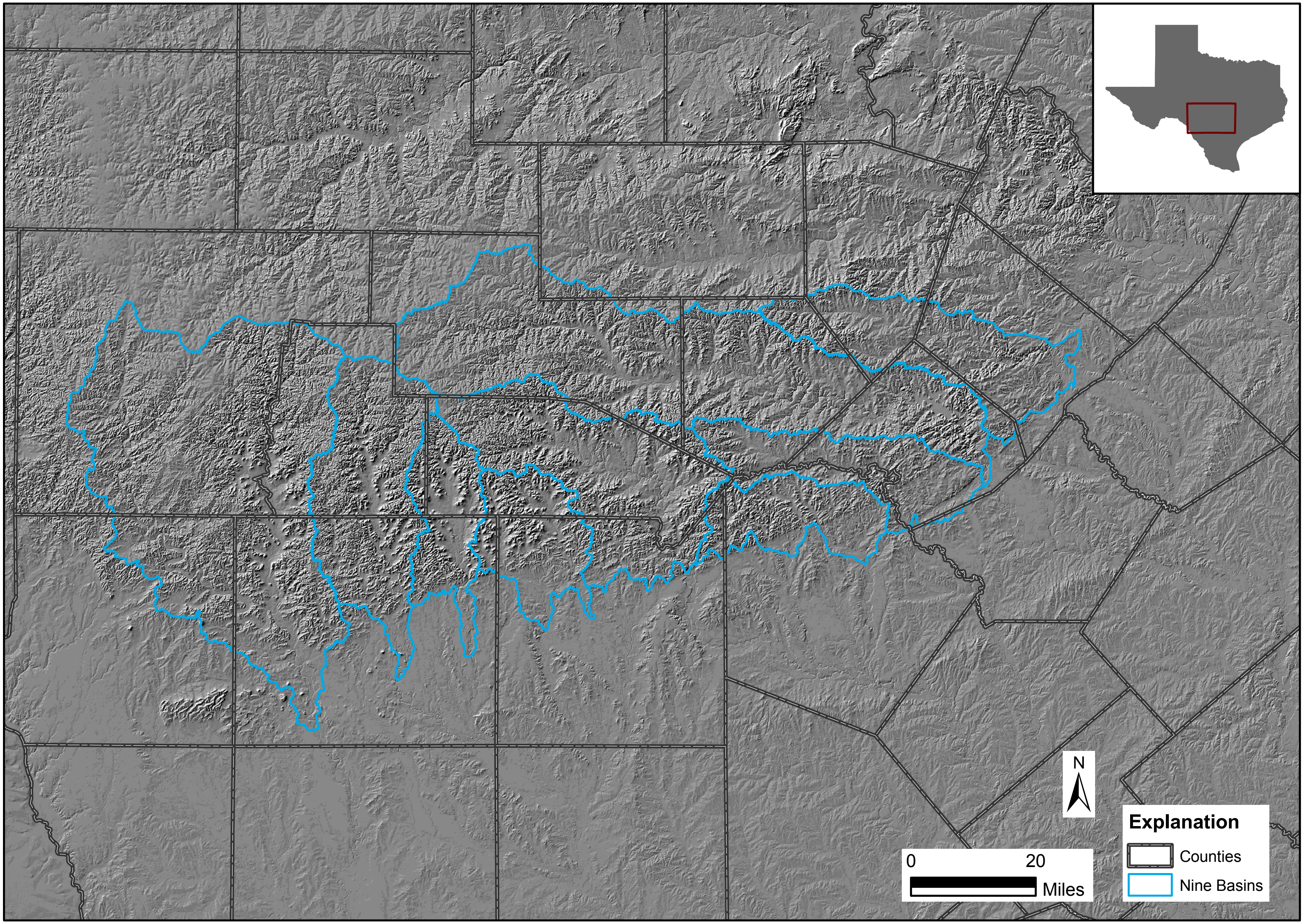


Figure 3.3.2 - Hillshade in the Nine Basins

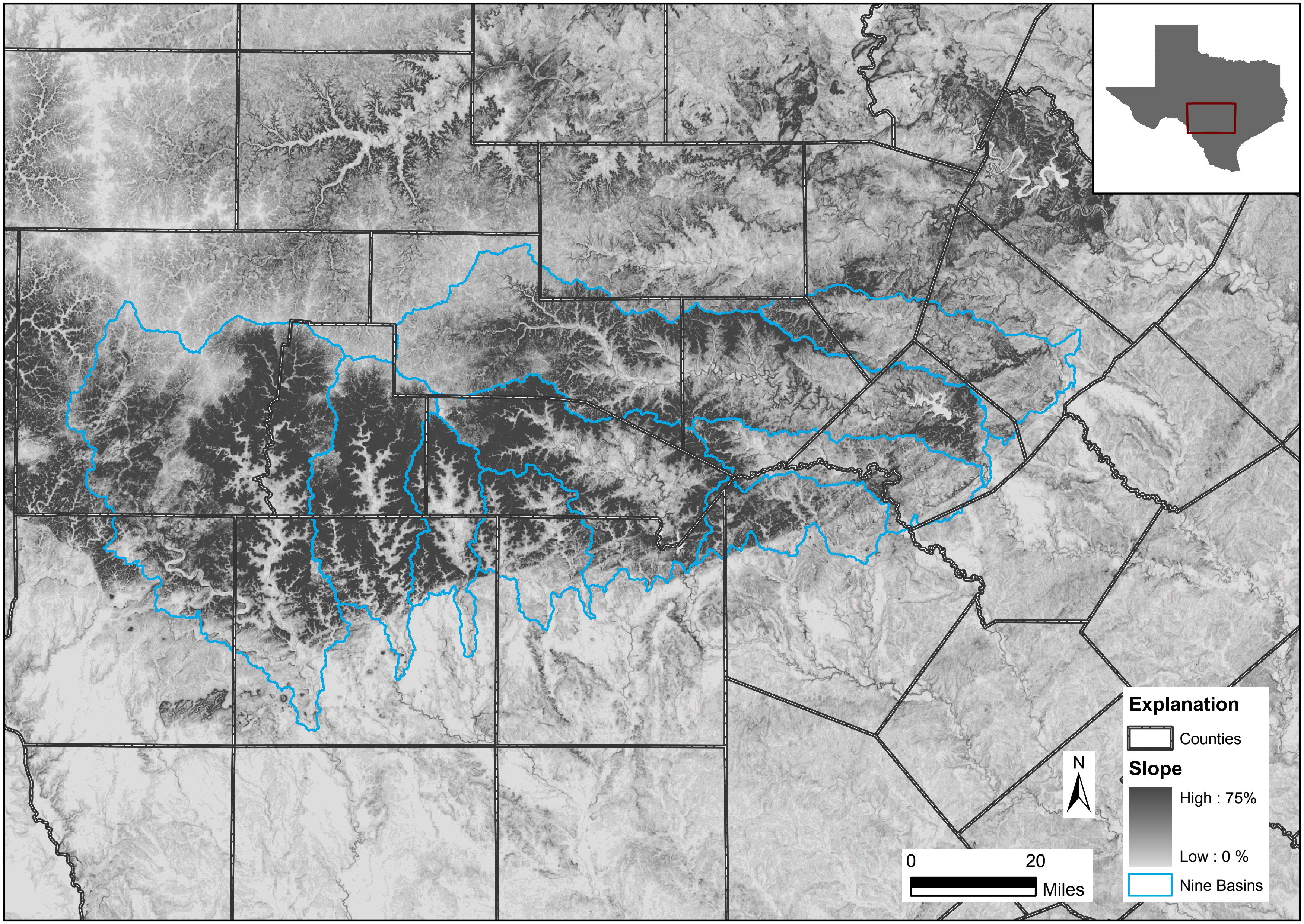


Figure 3.3.3 - Slope in the Nine Basins

3.4 Geology and Soils

Figure 3.4.1 shows the 1:250,000 scale surface geology of the study area (GIS coverages based on Geologic Atlas of Texas). The combination of soils (permeability and thickness) and the geology (permeability and stratigraphic characteristics) determine the difference in the hydrologic response between the contributing zone and the recharge zone.

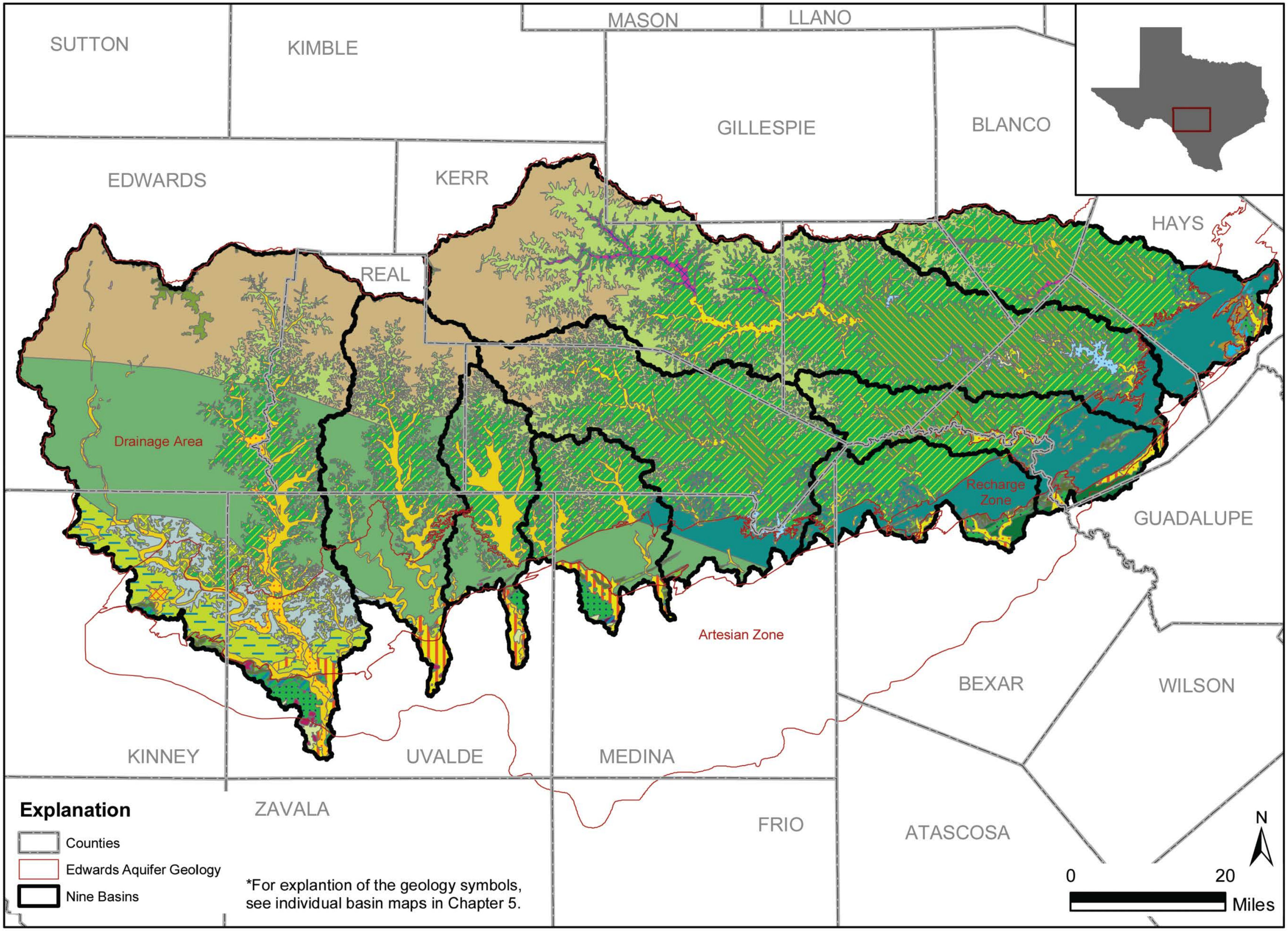
Detailed and reliable soil information is an asset for hydrologic modeling on large scales. In the United States there are several databases available including the SSURGO and STATSGO. The STATSGO database was developed from 1:250,000 scale soil maps and the SSURGO information was developed from 1:24,000 scale soil maps. Figure 3.4.2 shows the STATSGO coverage for the Hydrologic Soil Groups (A, B, C and D). Descriptions of the hydrologic soil groups are summarized in Table 3.4.1. Information in these databases is taken from the NRCS county soil surveys. Previous hydrologic modeling studies for the Edwards Plateau have relied on these databases for soils information.

Table 3.4.1 Hydrologic Soil Groups

Hydrologic Group	Description
A	High infiltration rates. Soils are deep, well drained to excessively drained sands and gravels.
B	Moderate infiltration rates. Deep and moderately deep, moderately well and well-drained soils with moderately coarse textures.
C	Slow infiltration rates. Soils with layers impeding downward movement of water, or soils with moderately fine or fine textures.
D	Very slow infiltration rates. Soils are clayey, have a high water table.

We have elected not to use the STATSGO and SSURGO data based on the advise of Dr. Larry Wilding—Professor Emeritus of Soils, Texas A&M University. Although Dr. Wilding was personally involved in assembling some of the original soils data for counties of the Plateau, he is now convinced that the early mapping does not reflect the true nature of these soils. Dr. Wilding has stated, "Our recent investigations of Hill Country terrain within Barton Creek watershed in western Travis County have disclosed soils of previously unrecognized diversity. The discrepancy between our results and those published previously for the Brackett soils in the Travis County Soil Survey are due to scale of observations, trench sampling technique and intensity of on-site investigations which are outside the purview of a generalized soil survey report. Soil thickness, texture and hydrologic properties are largely controlled by the stair-step microtopography, but in a way contrary to expectations", and "…these maps show neither the details of spatial diversity nor the true thicknesses of soil bodies, especially as relate to the tread and riser microtopography".

Appendix G contains a detailed description of how the soils and geology were incorporated into the land segment (PERLND) development.



*For explantion of the geology symbols, see individual basin maps in Chapter 5.

Figure 3.4.1 - Surface Geology of the Study Area

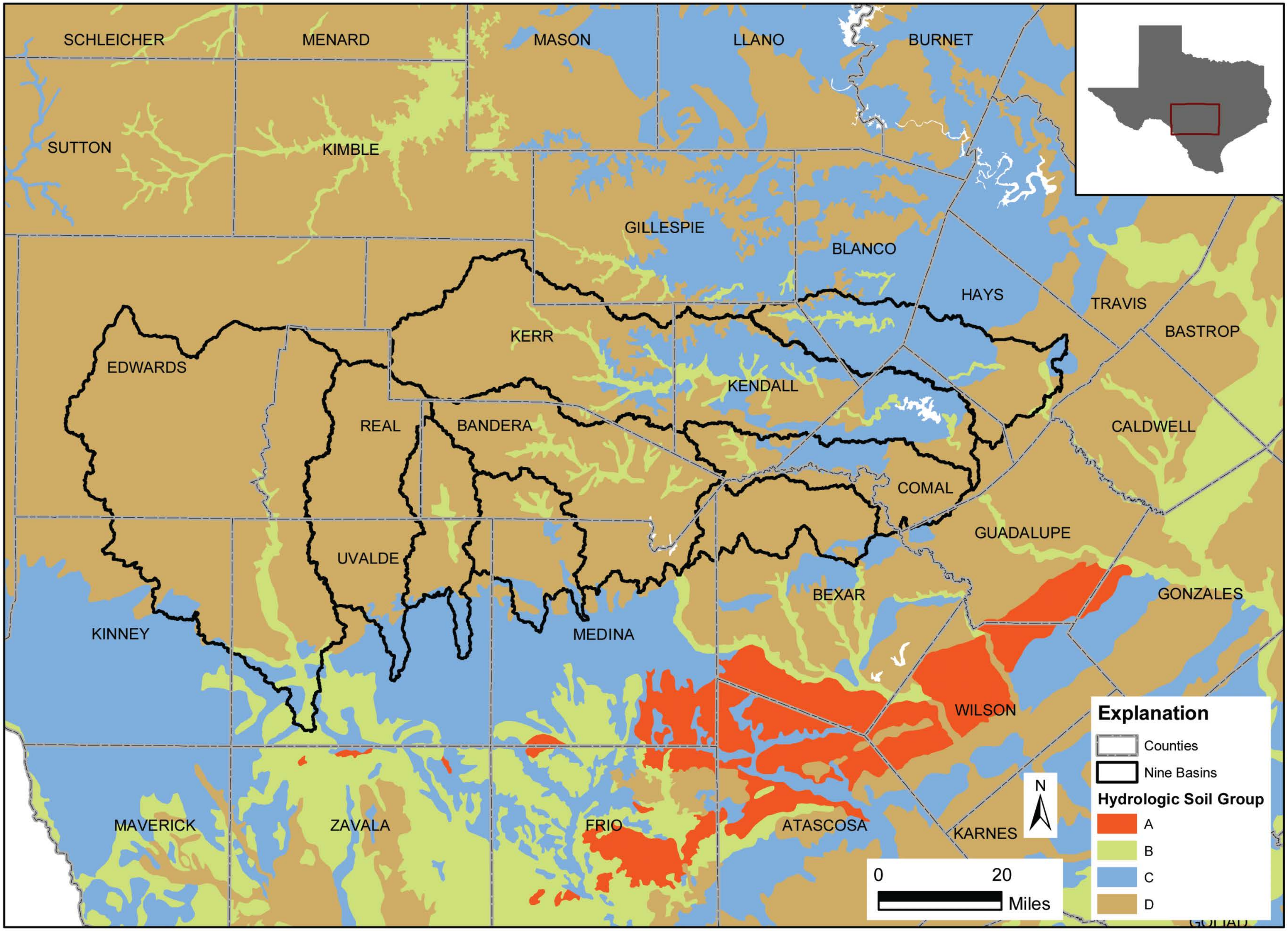


Figure 3.4.2 - STATSGO Hydrologic Soil Groups in the Nine Basin Area

3.5 Landuse – Vegetation

Digital coverages of the landuse and land cover were downloaded from the USGS. The basic sources of land use compilation data are NASA high-altitude aerial photographs and National High-Altitude Photography (NHAP) program photographs, usually at scales smaller than l:60,000. The landuse and land cover data for each of the basins is shown in Section 5.

3.6 Diversions and WAM Assessment

As part of the nine-basin recharge study, historical water use data was incorporated into the recharge models in those recharge basins that have significant historical water use. Available monthly data for each water right in the Nueces, Guadalupe and San Antonio River Basin Water Availability Models (WAMs) were obtained from the Texas Commission on Environmental Quality (TCEQ). This data included the location of each water right diversion, maximum authorized diversion and maximum reported use in the last ten years. Each of the nine-recharge basins was analyzed to determine the number, location; maximum authorized diversion and historical reported water use for the water rights in each basin. Although there are some data limitations, each diversion location, as well authorized maximum diversion, the maximum annual reported use, and the average annual reported use has been developed for each water right to the degree possible. These data have been incorporated into the GIS database so diversions can be assigned to the appropriate stream reach in the HSPF models. All diversions over 1 cubic foot per second where incorporated into the HSPF models. Table 3.6.1 summarizes the historical diversions from each basin, including the authorized maximum diversion, the maximum annual reported use, and the average annual reported use during the recent 10 to 15 years.

Table 3.6.1. Summary of Diversions in Nine Basins

Basin	Number of Active Water Rights	Maximum Authorized Diversion (ac-ft/yr)	Maximum Annual Reported Use (ac-ft/yr)	Recent Average Annual Use (ac-ft/yr)
Nueces	-	-	-	930
Frio-Dry Frio	41	10,573	2,299	590
Sabinal	13	1,317	249	130
Area Between Sabinal and Medina	7	1,607	98	80
Medina	35	121,118	62,742	39,368
Area Between Medina Basin and Cibolo	3	54	0	0
Cibolo Creek and Dry-Comal Creek	8	892	754	585
Guadalupe	190	115,990	21,621	11,000
Blanco	-	-	-	-

3.7 Channel Losses

Accurate channel loss information is critical for determining recharge to the Edwards aquifer because a large portion of the recharge occurs through this mechanism. One hundred and fifteen (115) gain-loss studies have been documented in the nine basins. Appendix I contains maps of the summarized information for each study completed in each basin. Some of the studies are completed in the contributing zone, the recharge zone, or both zones. For streambeds that loose significant volumes of water over the recharge zone, channel loss studies have sometimes been performed after storm event which result in enough flow to traverse the entire recharge zone. Detailed assessment of the gain-loss information indicates that gain-loss studies performed on the same reach can yield different results at different times or under different hydrologic conditions. Therefore, there is some uncertainty regarding the selection of channel-loss values that are representative of a channel reach.

Channel gain-loss information has been summarized by USGS (2002) for approximately ten different streams in the nine-basin study area. Appendix I contains maps of the 115 gain-loss studies completed in the study area. This information was used to estimate loss rates in channels. The USGS (2002b) documents streamflow losses at various streamflows in the Salado Creek Basin in Bexar County after the storm during October 17-19, 1998. These data were used to estimate streamflow losses in that basin as well as other nearby basins. In areas where data are limited, channel loss data were extrapolated.

3.8 Flood Retardation Structures (FRS)

FRS data have been assimilated from the TCEQ documentation of dam safety inspections and related data as per the National Dam Inventory (NDI) program. Most of these structures are primarily for flood control, hold minimal amounts of water, and do not stay full between flood events. Section 5 contains figures for each basin that show the location of FRSs that were considered for inclusion in the HSPF models.

3.9 Recharge Structures

The four recharge structures located throughout the nine-basin study area (Parker, Verde, San Geronimo, and Seco Creeks) have been incorporated into the models to the degree possible based on the available data. Information from Seco and Parkers Creek reservoirs were taken from Brown and Raines (2002). Historical recharge estimates from the structures were used to develop a flow-discharge relationship for each structure. These recharge structures were included in the model by utilizing the RCHRES block in HSPF and estimating FTABLE discharge parameters from existing data. The location of recharge structures are shown on basin maps in Section 5.

3.10 Cross-formational Flow from the Trinity Aquifer

Hydrologic communication between the Trinity and Edwards Aquifers is a complex issue. Several studies have estimated or attempted to quantify the flow between these two aquifers. The estimates of the volume of flow vary widely. In this section, results from each of the studies are summarized. However, because the current MODFLOW model implements injection wells to incorporate cross-formational flow between the Trinity and Edwards aquifers, cross-formational flow has not been assessed in this study. Because the HSPF models assess groundwater flow in a fairly simplistic fashion, they do not yield any new insights into cross-formational flow issues.

Several estimates of flow between the Trinity and Edwards have been made using groundwater models. The Authority's new Edwards model incorporates flow from the Trinity to the Edwards using a general head boundary (GHB) (Lindgren and others, 2004). Flow across this boundary during the steady-state simulation was 40,265 acre-feet/year, which is approximately 6.4 percent of the total inflow to the groundwater model. Flow during transient calibration ranged from 39,457 acre-feet/year during drought years to 37,463 during wet years. This total ranged from 39 percent of the total inflow during drought years to less than 3 percent during wet years. The percent contributions are higher during drought years because of the overall reduced amount of recharge entering the model during droughts, and vice versa for wet years.

Movement out of the southern edge of the Hill Country groundwater availability model (GAM), representing Trinity to Edwards flow, was also done using a GHB (Mace and others, 2000). In the steady-state calibration, a total of 64,000 acre-feet exited the model to this GHB boundary; 8,000 acre-feet (310 acre-feet/mile) went out the GHB boundary in Travis and Hays Counties, 36,000 acre-feet (660 acre-feet/mile) through the GHB boundary in Comal and Bexar Counties, and 20,000 acre-feet (500 acre-feet/mile) to the GHB boundary in Medina County. This accounted for 21% of the water flowing through the aquifer. Mace and others (2000) assumed that some of the water may continue to flow downdip in the Trinity beneath the Edwards, but that all of this water eventually discharges to the Edwards.

Movement from the Trinity to the Edwards was also simulated with a GHB in the Edwards-Trinity (Plateau) GAM (Anaya and Jones, 2004). Net outflow through this boundary was 91,000 acre-feet/year, which included the entire boundary incorporated into the Hill Country GAM discussed above, as well as all of Uvalde County. Anaya and Jones (2004) noted that the net outflow determined in the calibrated Edwards-Trinity (Plateau) GAM was within the range estimated by the Hill Country GAM.

Trinity to Edwards flow was also modeled by Kuniansky and Holligan (1994). This model estimated 2.5 cfs/mile along the simulated 221-mile long boundary between the two aquifers, or more than 500 cfs, which is equivalent to more than 362,000 acre-feet/year. However, this is more than half of the average annual estimated recharge to the Edwards aquifer, and therefore is probably too high.

Several estimates of flow between the Trinity and Edwards have been made in non-modeling studies over the past twenty years. LBG-Guyton (1995) conducted a study to estimate the amount of water moving from the Glen Rose into the Edwards in the San Antonio region, using geologic evidence, hydrologic evidence, and hydrochemical evidence. Based on water-level and pumping-test data, they estimated that 360 acre-feet/year of inflow from the Glen Rose could be transmitted along the 14-mile Haby Crossing fault under 1994 water level conditions. Geochemical modeling confirmed that only small amounts of Glen Rose water are entering the Edwards here, as compared to other sources, probably <5% of the total water immediately downgradient of this fault. Using the same methods regionally, excluding the Cibolo Creek area (where much discharge goes to the Guadalupe River), a range of 2,700 to 11,400 acre-feet/year of underflow from the Glen Rose to the Edwards was estimated. These estimates are based on high and low transmissivities and a positive gradient from the Glen Rose to the Edwards. Regionally, this estimate is less than 2% of the overall water recharged to the Edwards is contributed by the Glen Rose during average recharge conditions.

Other studies including flow between the Trinity and Edwards have produced varying estimates. These include:

- Barker and Ardis (1996) reviewed previous estimates of recharge to the Edwards and indicated that the amount of water entering laterally from the Hill Country is unknown but estimated that the inflow probably exceeds 100,000 acre-ft/yr.

- Maclay (1995) indicated that the inflow from the Glen Rose is “unmeasured; probably minor”.

- Veni (1994) estimated based on a water balance analysis of the Lower Glen Rose in the Cibolo Creek basin that approximately 47,500 acre-feet/year is probably discharged into the Edwards from the Lower Glen Rose. Veni (1994) indicated that this is supported by geochemical evidence, although no quantification is done using geochemical techniques.

Maclay and Land (1988) indicated “a significant amount of flow may move across the Haby Crossing fault from the Lower Glen Rose Limestone to the Edwards aquifer.” In addition, they state “flow from the lower Glen Rose aquifer to the Edwards aquifer also may occur in the vicinity of Cibolo Creek and along northeasterly trending faults in the outcrop area in Comal and Hays Counties.”

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4. Model Construction and Calibration

Whenever HSPF, or any watershed model, is applied to an area of any significant size, the area must be appropriately discretized or “segmented”. The purpose of watershed discretization is to divide the study area into individual land and channel segments, or pieces, which are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior. This segmentation then provides the basis for assigning similar or identical parameter values or functions to where they can be applied logically to all portions of a land area or channel length contained within a segment. Since HSPF and most watershed models differentiate between land and channel portions of a watershed, and each is modeled separately, each undergoes a segmentation process to produce separate land and channel segments that are linked together to represent the entire watershed area.

4.1 Watershed Delineation

The subwatershed discretization divides the watershed into subbasins based on topographic features of the watershed. This technique preserves the natural flow paths, boundaries, and channels required for realistic routing of water, sediment and chemicals. The number of subbasins chosen to model the watershed depends on the size of the watershed, the spatial detail of available input data and the amount of detail required to meet the goals of the project.

In developing the models for the nine basins, the goal was to delineate subwatersheds that were appropriate for completing recharge calculations as well as any type of simulations that the HSPF models might be used for in the future. The resulting models are detailed enough to capture significant topographic, vegetation, and geologic variability within the watershed.

Once the subbasin delineation was completed, each subbasin was further partitioned according to slope, soil/geology, and vegetation to create multiple hydrologic response units (HRUs). Hydrologic response units are unique soil/land use/management combinations within the subbasin that are modeled without regard to spatial positioning. When multiple HRUs are modeled within a subbasin, the hydrologic cycle is modeled for each HRU and then the loadings from all HRUs within the subbasin are summed. The net loadings for the subbasin are then routed through the watershed channel network. Delineated basins are shown on basin maps in Section 5.

4.2 River Reaches (RCHRES)

The definition of land segments (subbasins) was based on the upstream and downstream end of the river reaches and the corresponding drainage area for each river reach. A single subbasin may contain multiple land segments. All of the runoff in a single subbasin is assumed to travel to the river reach that flows through that subbasin. Each subbasin was assigned a precipitation record and an evaporation record.

Upstream and downstream river reach boundaries were based in part on the location of stream gauges, gaining and losing reaches, diversions, flood retardation structures, and recharge dams, major confluences, and river reach length. Major confluences are where two rivers join together. In the model, the flow from two reaches is added together to provide the inflow at the upstream end of the adjacent downstream reach. Reach boundaries at the confluence add the flows together at the correct location. A general rule of thumb is that the travel time should not be less than half of the time step nor greater than twice the time step. This is not a hard and fast rule, but the greater the deviations in reach length from this rule, the greater the error in the model's routing of streamflow through the reach. Section 5 contains a summary table for each basin that provides basic information regarding the length of river reaches and subwatersheds.

The recharge zone FTABLE has two discharge columns: surface and subsurface (channel loss) discharge. Channel loss is satisfied first during each time step, and then remaining water is available for surface flow while subsurface flow remains at a maximum discharge. Gain-loss studies were used to develop the channel loss rate in each reach. If channel loss data were not available for a reach, data from nearby reaches was used to approximate the channel loss.

4.3 Land Segments (PERLND)

The best approach for developing consistent models across the entire recharge zone for the nine basins is to have consistent PERLNDs based on geology, soils, vegetation, and precipitation and evaporation. The initial segmentation typically involves delineating areas (catchments) that have similar meteorological conditions, topographical features, or use practices for a given land. Once the catchments and channel segments have been defined, these catchments must then be further characterized to: 1) develop the model categories (PERLNDs) to represent; 2) define the physical parameters (e.g., elevation, slopes, channel length) for HSPF using available data; and 3) establish initial calibration parameters for HSPF based on past applications within the region and past experience with the model.

Information describing the characteristics of the watershed, including topography, drainage patterns, meteorological variability, soils conditions, and the land use distribution are required for segmenting the watershed into individual land segments that demonstrate a similar hydrologic and water quality response. In an analogous fashion, information describing the channels, floodplain morphology, and other hydraulic features within the watershed allows for the segmentation of the conveyance system (both natural and artificial) into discrete sections with similar hydraulic and water quality behavior. Locations of dams/reservoirs, gages/data collectors, and diversions provide information to develop a segmentation scheme that supports modeling localized conditions within the study area. Appendix H contains a detailed description of the process used to develop PERLNDs for the nine basin models.

4.4 General Approach to Model Calibration

The calibration of HSPF models followed the standard model calibration procedures as described in the HSPF Application Guide (Donigian et al., 1984), in numerous watershed studies over the past 20 years (see HSPF Bibliography [Donigian, 2002a]), and as recently summarized by Donigian (2002b). The following model calibration discussion focuses solely on the HSPF hydrologic parameters; water quality parameters are not discussed.

For HSPF, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of interest. This approach is required for parameters that cannot be deterministically, and uniquely, evaluated from topographic, climatic, edaphic, or physical characteristics of the watershed. Fortunately, the large majority of HSPF parameters do not fall in this category. Appendix G contains a list of HSPF parameters that can be varied during model calibration and also lists the typical ranges for each parameter.

For the nine-basins models, the calibration period was five years long and included water years from 1997-2001 because a variety of climatic and soil moisture conditions occur during this period. For the most part, with the exception of Nueces basin, hydrologic parameters were not varied significantly across the basins. Model calibration resulted in parameter values that produce the best overall agreement between simulated and observed values throughout the calibration period based on standard statistical measures of error such as variance.

The calibration process included comparison of both monthly and annual values and individual storm events. All of these comparisons were performed to ensure a proper calibration of hydrologic parameters. In addition, continuous observed streamflow data (simulated and observed values) were analyzed on a frequency basis and their resulting cumulative distributions (e.g., flow duration curves) compared to assess the model behavior and agreement over the full range of observations.

A weight of evidence approach, as described above, is most widely used and accepted because no single procedure or statistic is widely accepted as measuring, nor capable of establishing, acceptable model performance. Therefore, the calibration relied on numerous statistical tests (e.g., correlation tests, Model Fit Efficiency) and graphical plots (e.g., scatter, time series, frequency) to determine the model’s ability to mimic the hydrologic system of the nine basins.

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5. Model Calibration Results for each Basin

The hydrologic models for each basin include both the recharge zone and the contributing zone. The contributing zone models are very useful for simulating all the hydrology that affects the streamflow over the recharge zone. However, as discussed in Section 2, the contributing zone portion of the model is not required to simulate recharge to the Edwards aquifer unless an upstream gage does not exist. In that case, the contributing zone model would be used to simulate channel flow across the recharge zone.

In this Section, results of the model calibration are presented for the upstream gages to show the model's ability to simulate streamflow from the contributing zone. In addition, results of the model calibration are presented for the downstream gages to show the model's ability to simulate streamflow at the downstream gage. Because there are no direct measurements of recharge in the basins, the primary method of assessing model calibration is by comparing observed and simulated streamflow. The model used for the downstream gage calibration incorporates the measured flow from the upstream gage where possible to reduce the uncertainty in the recharge prediction.

Model sensitivity was assessed by performing a sensitivity analysis on the Frio-Dry Frio basin model to understand how uncertainty in input parameters affect the outcome of the model calibration (by assessing changes in streamflow) and the model predictions (by assessing changes in recharge estimates). The results of this sensitivity analysis are discussed in Section 5.2.

5.1 Nueces - West Nueces

5.1.1 Basin Hydrology and Features

The Nueces basin is the westernmost and the biggest basin that recharges the San Antonio section of the Edwards aquifer. Figure 5.1.1 shows the map of rivers and streams, major roads, cities, county boundaries, NWS and EAA precipitation gages, USGS stream gages, Edwards aquifer contributing, recharge, and artesian zones, FRSs, and ungaged areas in the Nueces Basin. Table 5.1.1 summarizes basic hydrologic and modeling information about the basin. Figure 5.1.2 shows the surface geology and mapped geologic faults in the basin. Figures 5.1.3 and 5.1.4 show the hillshade and land cover/vegetation maps for the Nueces Basin. Figure 5.1.5 shows the portions of different PERLND groups in the basin. Figure 5.1.6 illustrates the delineated subwatersheds within the basin. The numbers in each subwatershed represent a watershed ID and the associated reach number required for HSPF.

The Nueces basin has stream gages at the upstream side of the recharge zone on both the West Nueces (USGS# 08190500) and the Nueces River (USGS# 08190000). A stream gage also exists below the recharge zone southwest of Uvalde on the Nueces River (USGS# 08192000). HDR (2002) developed a pilot model for the recharge zone of the Nueces Basin. The river reaches and pervious land segments are smaller in the recharge zone than in the upper reaches of the contributing zone to simplify the model and yet allow for flexibility in hydrologic properties and HSPF parameterization.

There are three NWS precipitation stations in or near the basin that have daily precipitation records dating back to at least 1950. They are located at the upper end of the basin at Rock Springs, the middle of the basin (Camp Wood), and at the lower end of the basin in Uvalde. Daily data from these three stations was combined with hourly data from Leaky to estimate hourly precipitation throughout the basin. Because the Nueces Basin is the westernmost basin, it has the lowest yearly precipitation of the nine basins.

The geology and hydrogeology of the Edwards aquifer in the Nueces basin are relatively complex and not completely understood. As shown in Figure 5.1.2, the geology of the Nueces River basin is somewhat different than that of the West Nueces River basin. First, there is a larger volume of alluvium present in the channel of the Nueces River basin above the Edwards aquifer recharge zone than there is in the West Nueces River basin. In addition, in the Nueces River basin, the alluvium is underlain by the Lower Glen Rose Formation, which in general, has a relatively low permeability. Therefore, downward movement of infiltration into the alluvium is likely impeded, and may provide for higher baseflow to the upper portion of the Nueces River Basin. These factors, and possibly others, contribute to the relatively high baseflow at the stream gage at Laguna. The hillshade map shown in Figure 5.1.3 shows that the alluvium deposits in the Nueces River basin in the contributing zone is much flatter and wider than that of West Nueces River basin, which may further contribute to increased baseflow. Bush and others (1992) indicate that shallow groundwater flow in the West Nueces basin moves to the southwest.

HDR (2002) discusses the impact of the Leona gravels and the surface water and groundwater interaction near Uvalde. The correlation described by HDR was used in this study to estimate the contribution of water from the Leona gravels to the downstream gage at Uvalde for model calibration purposes. More recently, Green and others (2004) estimate that as much as 100,000 acre-ft of groundwater per year discharges the Edwards aquifer through the Leona River floodplain. This study indicates that a significant volume of groundwater exists through the Leona gravels. However, for this study, we were only interested in that portion of flow that impacts the streamflow measurements at the downstream gage, so the method developed by HDR (2002) was sufficient.

The land cover map shown in Figure 5.1.4 indicates that there is a difference in vegetation between the West Nueces and Nueces River basins. The Nueces River basin contains more evergreen juniper trees whereas the West Nueces contains more shrubland.

Table 5.1.1 Summary Information for Nueces Basin

Feature or Statistic	Measure	Details
Total area (sq. miles)	1847	
No. of subwatersheds in model	123	
No. of stream reaches in model	123	
No. of EAA rain gages in basin	11	
Contributing Zone		
Area (sq. miles)	1477	
Stream length (miles)	517	
No. of stream gages above recharge zone	2	USGS# 08190500, 08190000
Average subwatershed area (sq. miles)	15.9	Range: 0.0006 to 58.18
Average stream reach length (miles)	5.2	Range: 0.093 to 14.84
Recharge Zone		
Area (sq. miles)	293	
Stream length (miles) [1]	147.9	
No. stream gages below recharge zone	1	USGS# 08192000
Average subwatershed area (sq. miles)	6.8	Range: 0.000048 to 21.56
Average stream reach length (miles)	2.5	Range: 0.017 to 7.53

[1] Stream length includes only those streams included in the EPA RF1 files

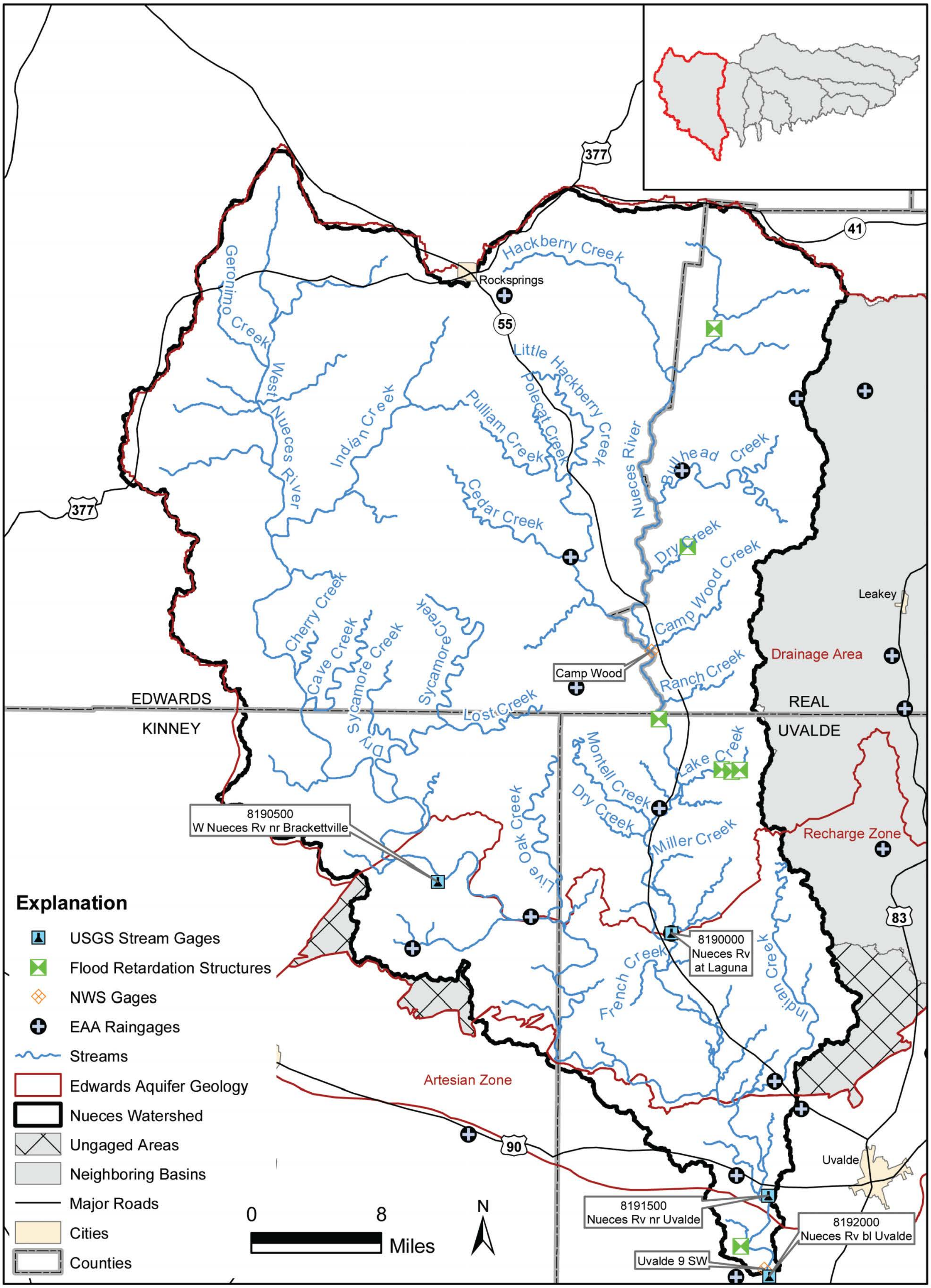


Figure 5.1.1 - Nueces and West Nueces Basin

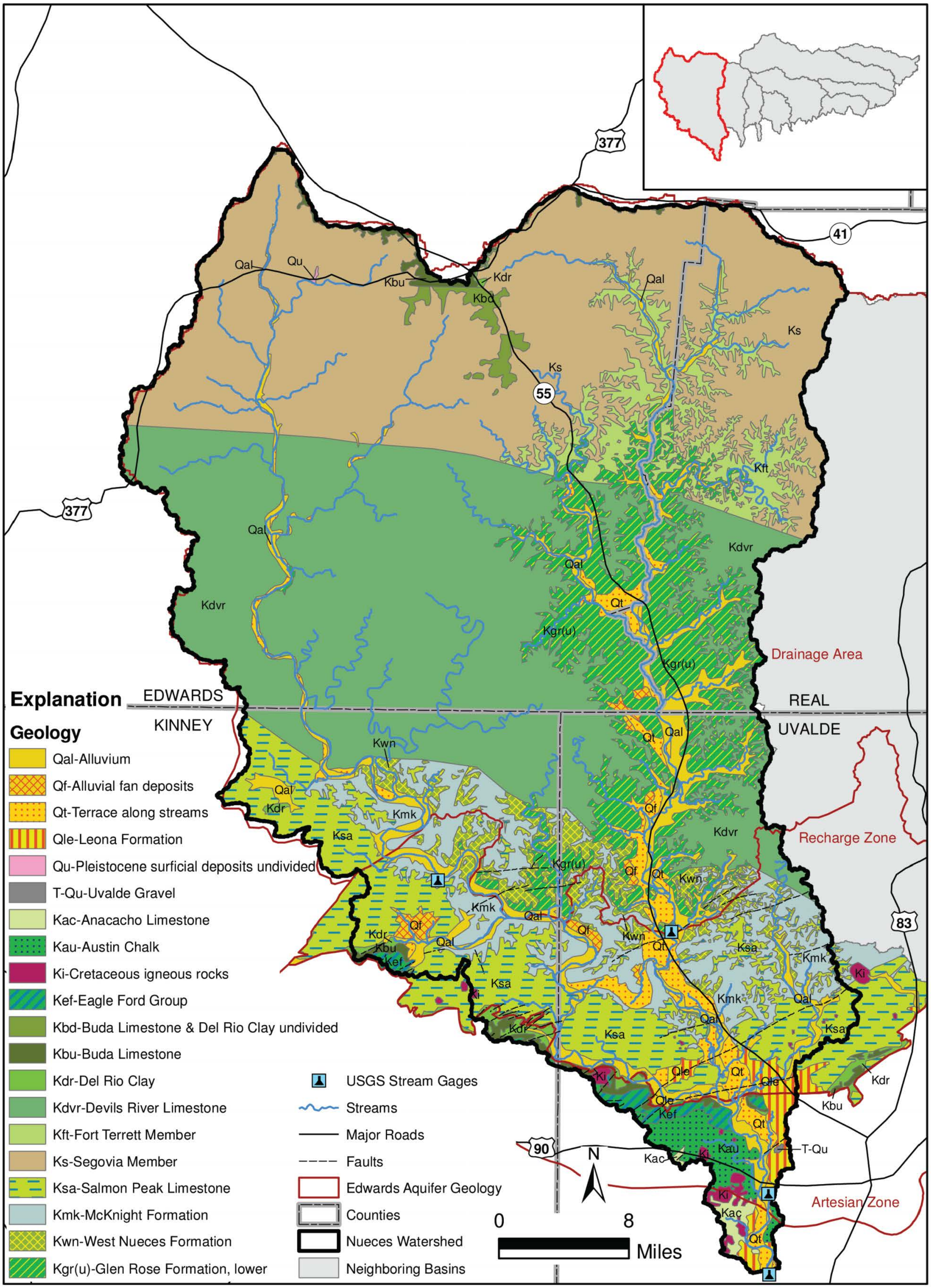


Figure 5.1.2 - Surface Geology in the Nueces Basin

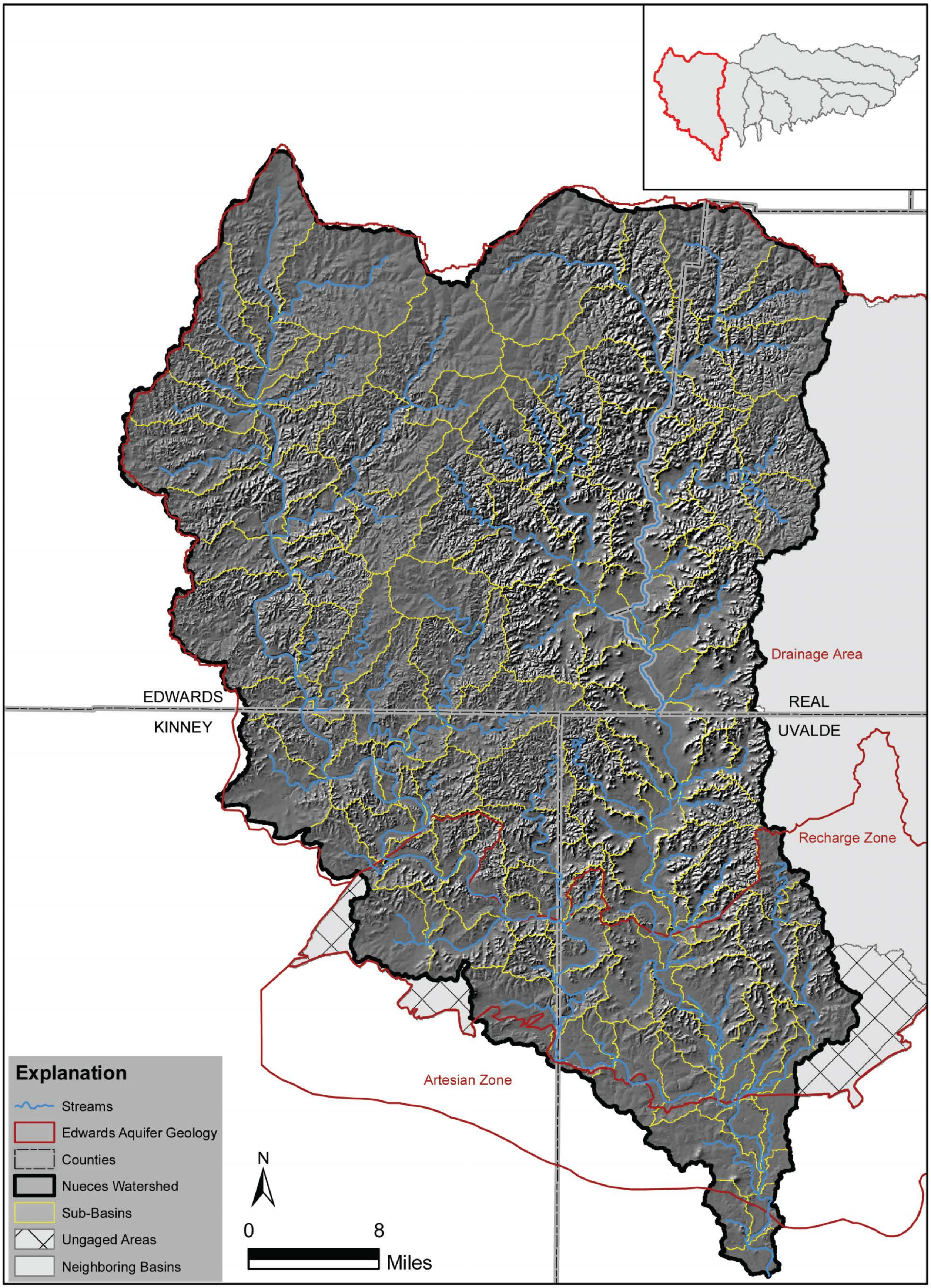


Figure 5.1.3 - Hillshade View in the Nueces Basin

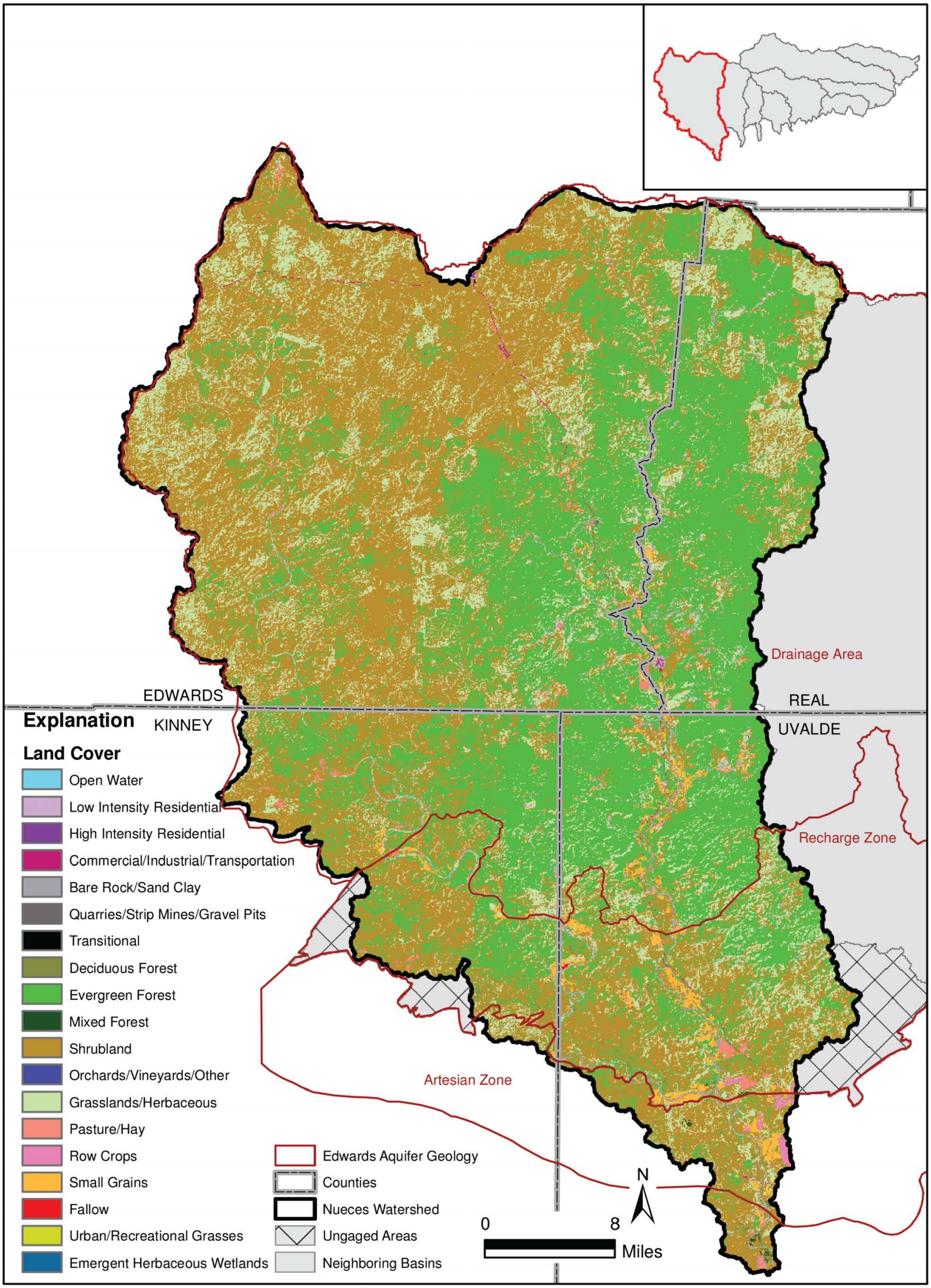


Figure 5.1.4 - Land Cover and Vegetation in the Nueces Basin

Figure 5.1.5 summarizes the proportions of each PERLND group in the basin. It indicates that the largest PERLND components in the contributing zone are steep shallow soil areas and flat shallow soil areas. In addition, approximately 29% of the entire basin is categorized flat with deep soils.

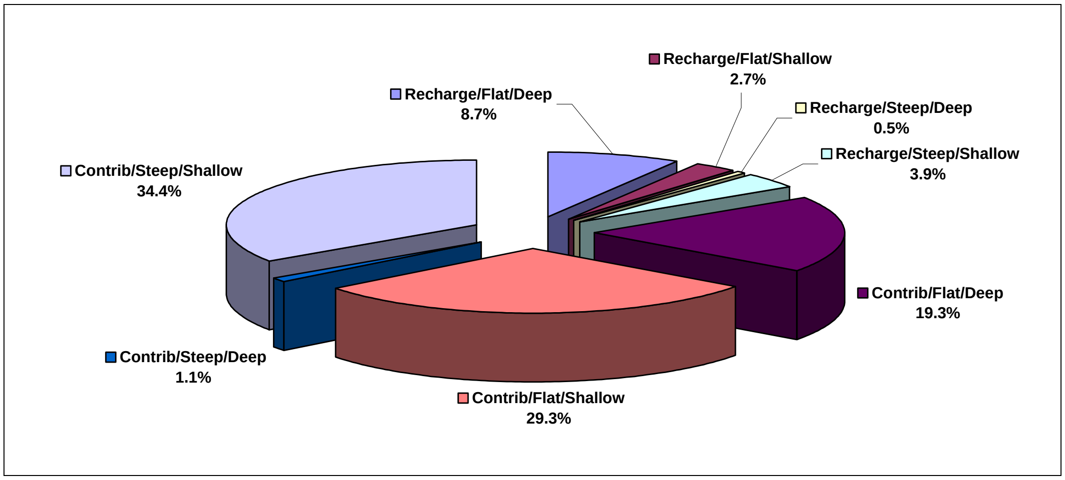


Figure 5.1.5 PERLND Distribution in the Nueces Basin

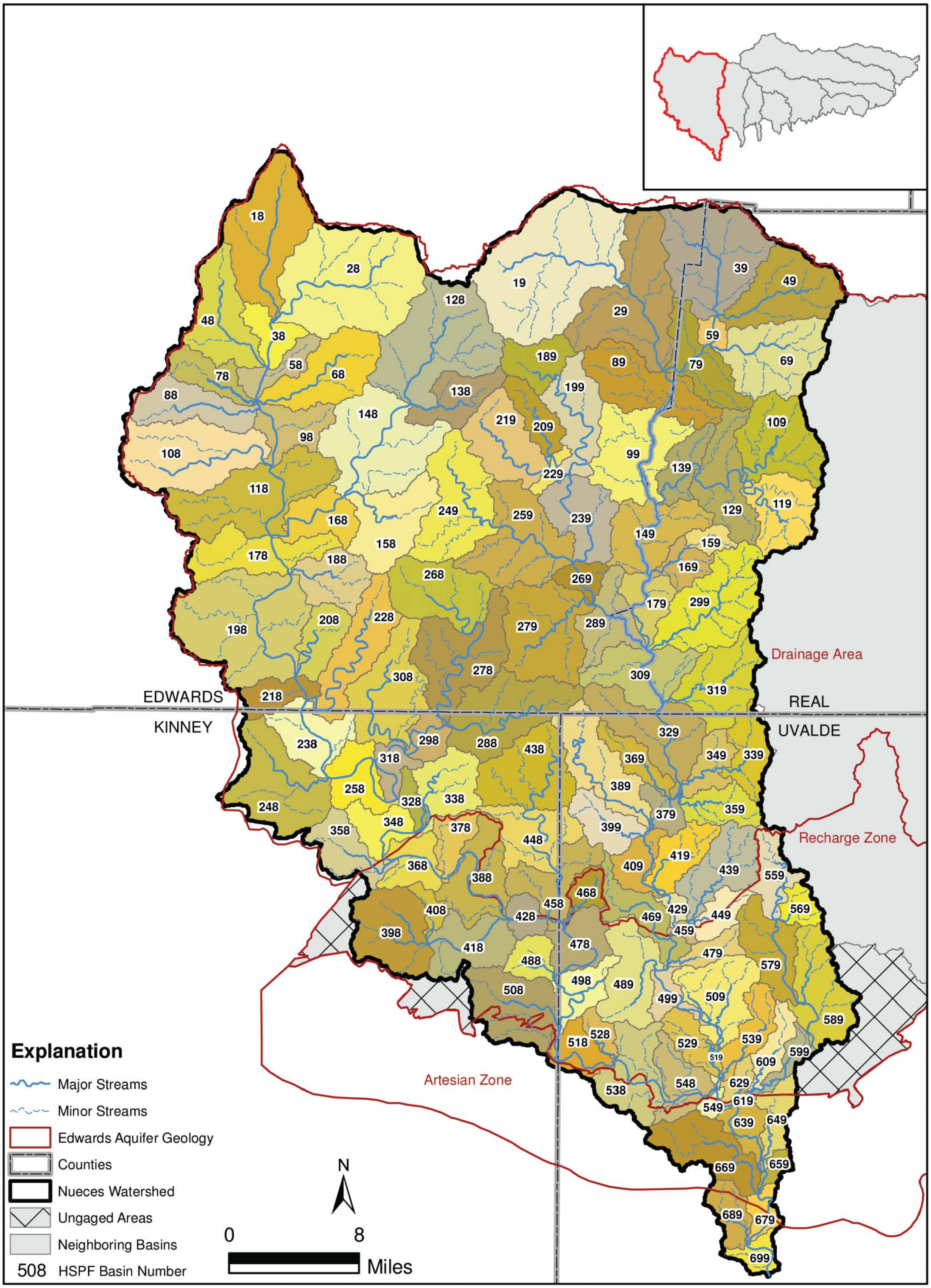


Figure 5.1.6 - Delineated Basins in the Nueces Basin

5.1.2 Model Calibration

After selecting initial hydrologic properties and model parameters for the Nueces contributing zone model, parameters were adjusted within reasonable limits to achieve the best agreement between the observed and simulated streamflow in the river. As discussed in Sections 2 and 4, the calibration of the models was judged by calculating comparative statistics and producing illustrative graphics. The final parameters used in the HSPF models are provided in Appendix J.

5.1.2.1 Streamflow Comparison

5.1.2.1.1 Contributing Zone (Upstream Gages)

Table 5.1.2 shows the estimated precipitation as well as the observed and simulated annual runoff (shown as equivalent depth in inches) in the West Nueces River near Brackettville, for the five water years 1997 through 2001. In addition, the percent error between the observed and simulated runoff is shown in the rightmost column. To this point, calibration of the contributing zone of the Nueces River Basin has not been extremely successful, as shown by the errors in the simulated runoff. We continue to try all reasonable parameter changes and conceptual model adjustment to calibrate the model.

Table 5.1.2 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: West Nueces River near Brackettville, USGS #8190500)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	37.55	4.95	3.72	33.02
1998	33.53	5.14	2.01	156.01
1999	21.29	2.00	0.11	1639.07
2000	20.08	0.14	0.01	2101.12
2001	33.97	3.91	0.81	382.54
Average	29.28	3.23	1.33	-142.23

Table 5.1.3 provides the daily and monthly statistics for the same time period. The simulated flow is significantly and consistently higher than observed flow. Figure 5.1.7 shows the plot of the simulated and observed flows at the gage. While the trends are very similar, the model consistently over predicts streamflow. The daily streamflow frequency (or flow duration curve) shown in Figure 5.1.8 indicates the same trend. Table 5.1.4 shows the results of a very rigorous statistical evaluation of the flows under different hydrologic conditions. Again, the results for the West Nueces are not good.

Table 5.1.5 shows equivalent depth of streamflow in the Nueces River at Laguna, for the five water years 1997 through 2001. Interestingly, calibration of the contributing zone of the Nueces River is not satisfactory either based on reasonable changes to hydrologic parameters, as shown by the errors in the simulated runoff. However, as shown in Figure 5.1.9 and 5.1.10, as well as Table 5.1.7, the difference is that the simulated streamflow in the Nueces River portion of the model is significantly lower than what has been observed, which is the opposite of the West Nueces model result. We continue to try all reasonable parameter changes and conceptual model changes to calibrate the model. These changes include consideration of shifting infiltrated groundwater from one basin to the other if there is a justification to do so.

Table 5.1.3 Daily and Monthly Statistics (Water Years 1997-2001: West Nueces River near Brackettville, USGS #8190500)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	68.10	164.95
Geometric Mean (cfs)	1.39	29.06
Standard Deviation (cfs)	1085.31	691.36
Correlation Coefficient	0.43	
Coefficient of Determination	0.18	
Mean Error (cfs)	96.85	
Mean Absolute Error (cfs)	172.84	
Monthly Statistics		
Count	60	60
Mean (cfs)	67.61	164.43
Geometric Mean (cfs)	2.61	36.40
Standard Deviation (cfs)	236.74	344.74
Correlation Coefficient	0.70	
Coefficient of Determination	0.49	
Mean Error (cfs)	96.82	
Mean Absolute Error (cfs)	129.42	

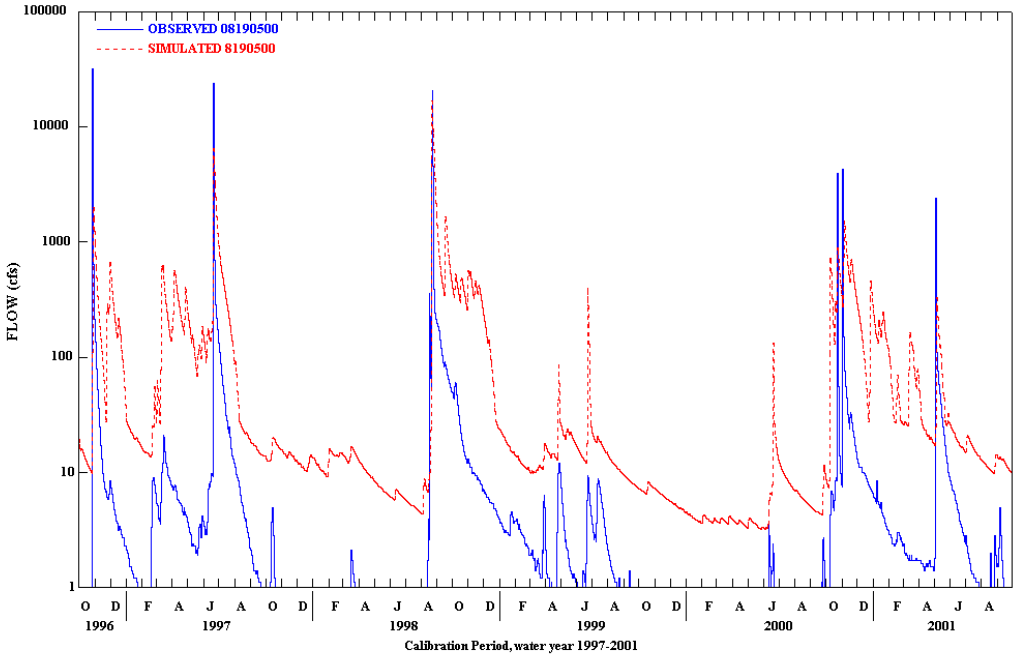


Figure 5.1.7 Daily Streamflow Comparison (Water Years 1997-2001: West Nueces River near Brackettville, USGS #8190500)

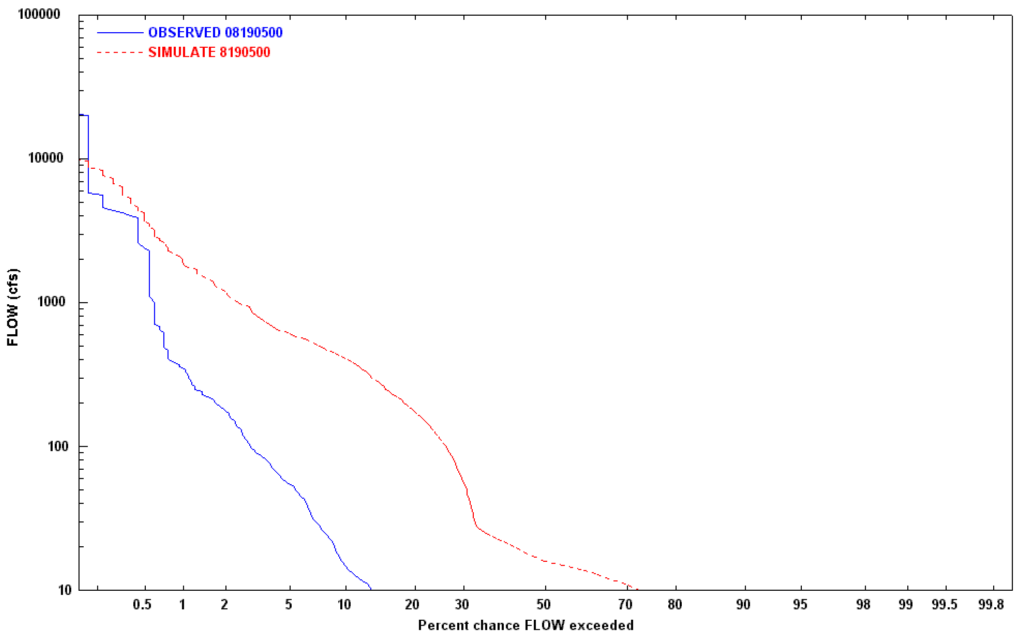


Figure 5.1.8 Daily Streamflow Frequency (Water Years 1997-2001: West Nueces River near Brackettville, USGS #8190500)

Table 5.1.4 Calibration Statistics and Criteria (Water Years 1997-2001: West Nueces River near Brackettville, USGS #8190500)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	1.33	3.23	142%	10%	Poor
10% high (inches)	0.95	2.30	143%	10%	Poor
25% high (inches)	1.23	2.97	141%	15%	Poor
50% Low (inches)	0.01	0.09	1624%	15%	Poor
25% Low (inches)	0.00	0.03	2548%	15%	Poor
10% Low (inches)	0.00	0.01	7935%	15%	Poor
storm volume (inches)	1.23	1.72	40%	20%	Poor
average storm peak (cfs)	20290.00	12975.19	36%	15%	Poor
summer volume (inches)	0.74	1.49	101%	15%	Poor
winter volume (inches)	0.01	0.29	2457%	10%	Poor
summer storms (inches)	0.73	1.28	76%	10%	Poor
winter storms (inches)	0.00	0.00	0%	15%	OK

Table 5.1.5 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Nueces River at Laguna, USGS #8190000)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	37.55	1.17	9.40	-87.55
1998	33.53	1.01	4.87	-79.18
1999	21.29	0.63	4.35	-85.50
2000	20.08	0.10	1.13	-90.98
2001	33.97	1.03	5.55	-81.40
Average	29.28	0.79	5.06	84.39

Table 5.1.6 Daily and Monthly Statistics (Water Years 1997-2001: Nueces River at Laguna, USGS #8190000)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	274.57	42.86
Geometric Mean (cfs)	132.29	19.81
Standard Deviation (cfs)	1399.41	119.93
Correlation Coefficient	0.57	
Coefficient of Determination	0.32	
Mean Error (cfs)	-231.71	
Mean Absolute Error (cfs)	231.85	
Monthly Statistics		
Count	60	60
Mean (cfs)	274.23	42.78
Geometric Mean (cfs)	154.65	21.93
Standard Deviation (cfs)	409.01	60.18
Correlation Coefficient	0.79	
Coefficient of Determination	0.63	
Mean Error (cfs)	-231.46	
Mean Absolute Error (cfs)	231.46	

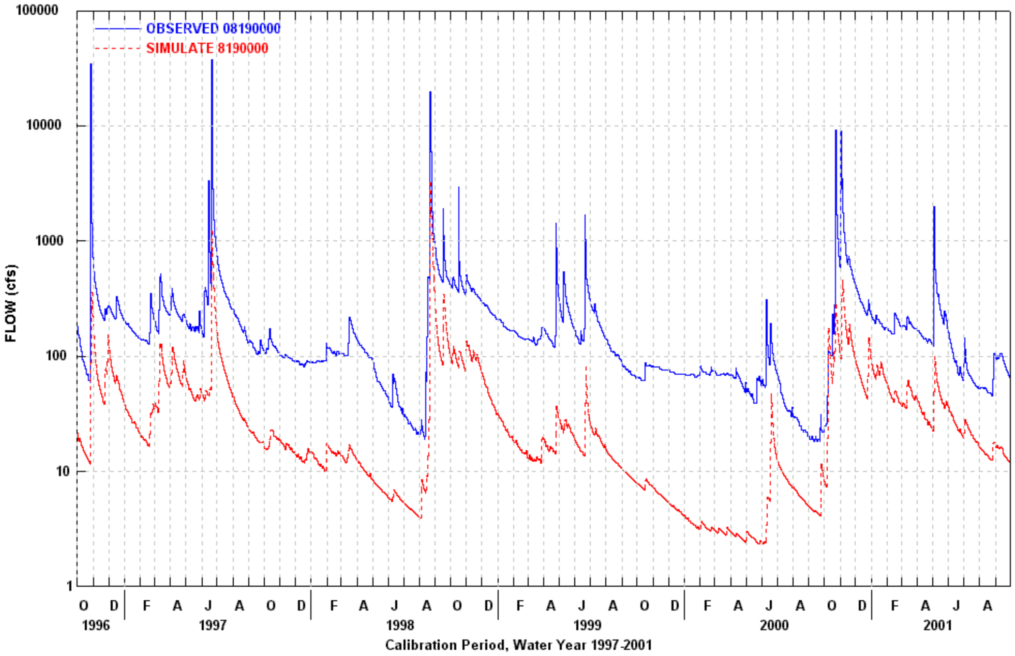


Figure 5.1.9   Daily Streamflow Comparison (Water Years 1997-2001: Nueces River at Laguna, USGS #8190000)

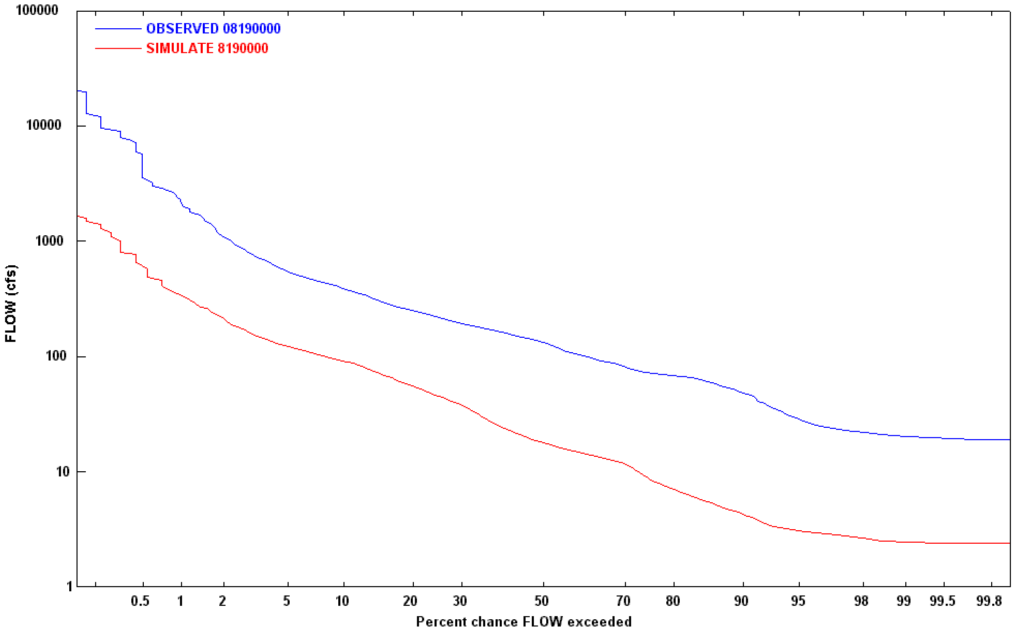


Figure 5.1.10   Daily Streamflow Frequency (Water Years 1997-2001: Nueces River at Laguna, USGS #8190000)

Table 5.1.7 Calibration Statistics and Criteria (Water Years 1997-2001: Nueces River at Laguna, USGS #8190000)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	5.06	0.79	-84%	10%	Poor
10% high (inches)	2.45	0.40	-84%	10%	Poor
25% high (inches)	3.38	0.57	-83%	15%	Poor
50% Low (inches)	0.68	0.09	-87%	15%	Poor
25% Low (inches)	0.23	0.02	-90%	15%	Poor
10% Low (inches)	0.05	0.01	-90%	15%	Poor
storm volume (inches)	2.31	0.28	-88%	20%	Poor
average storm peak (cfs)	25467.50	3405.19	87%	15%	Poor
summer volume (inches)	1.76	0.29	-84%	15%	Poor
winter volume (inches)	0.69	0.13	-82%	10%	Poor
summer storms (inches)	0.60	0.14	-77%	10%	Poor
winter storms (inches)	0.00	0.00	0%	15%	OK

5.1.2.1.2 Recharge Zone (Downstream Gages)

Because the recharge to the Edwards aquifer is calculated based on the observed streamflow in the upper gage and not the simulated streamflow at the upstream gage, the inaccuracy of the contributing zone model does not affect the accuracy of the recharge estimates. This would not be that case if data from the upstream gage was not available. In that case, the contributing zone model would have to be used to estimate the streamflow in the channel that recharges the Edwards aquifer.

In the following graphs and tables, the “recharge” model for the Nueces basin is evaluated. Table 5.1.8 shows the estimated precipitation and the observed and simulated annual streamflow for the Nueces River below Uvalde, for the five water years 1997 through 2001. The data indicates that the average error during the five-year calibration period is about 10% streamflow estimate on an annual basis. Table 5.1.9 indicates that the correlation coefficient for the daily and monthly-simulated streamflow is also very good. Figures 5.1.11 and 5.1.12 shows the 5-year daily hydrograph for the downstream gage, which shows good agreement with the observed values.

Table 5.1.8 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Nueces River below Uvalde, USGS #8192000)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	37.55	5.06	4.94	2.29
1998	33.53	2.77	3.18	-12.94
1999	21.29	1.77	1.63	8.16
2000	20.08	0.25	0.16	55.59
2001	33.97	2.48	1.29	92.10
Average	29.28	2.46	2.24	-9.95

Table 5.1.9 Daily and Monthly Statistics (Water Years 1997-2001: Nueces River below Uvalde, USGS #8192000)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	307.11	337.67
Geometric Mean (cfs)	72.09	98.89
Standard Deviation (cfs)	2347.17	2052.69
Correlation Coefficient	0.88	
Coefficient of Determination	0.77	
Mean Error (cfs)	30.56	
Mean Absolute Error (cfs)	133.08	
Monthly Statistics		
Count	60	60
Mean (cfs)	305.66	336.75
Geometric Mean (cfs)	91.47	123.73
Standard Deviation (cfs)	751.59	658.68
Correlation Coefficient	0.97	
Coefficient of Determination	0.95	
Mean Error (cfs)	31.09	
Mean Absolute Error (cfs)	83.43	

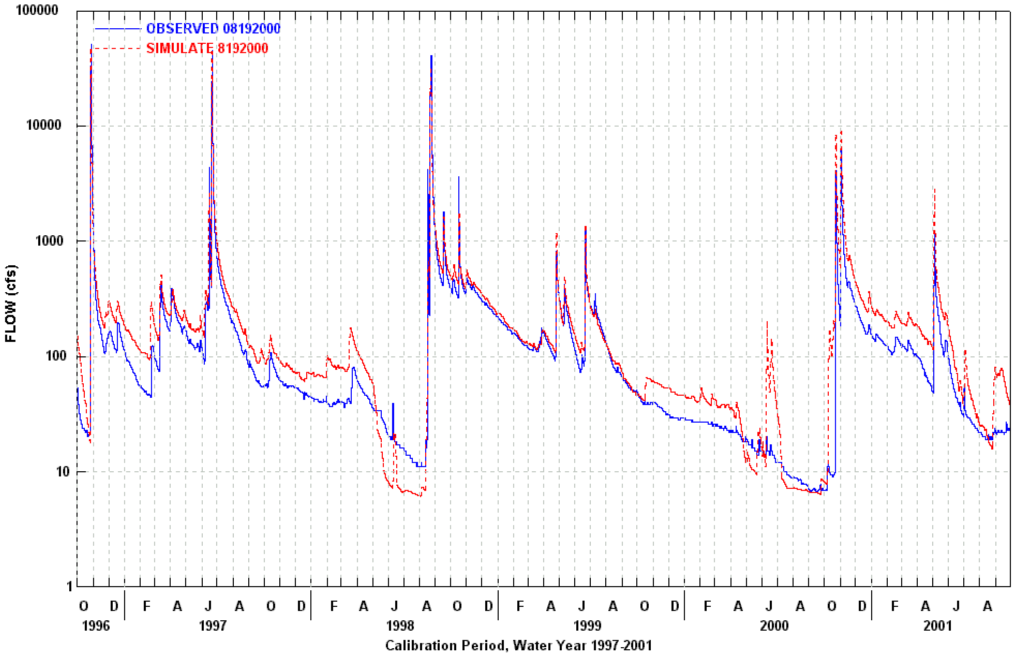


Figure 5.1.11 Daily Streamflow Comparison (Water Years 1997-2001: Nueces River below Uvalde, USGS #8192000)

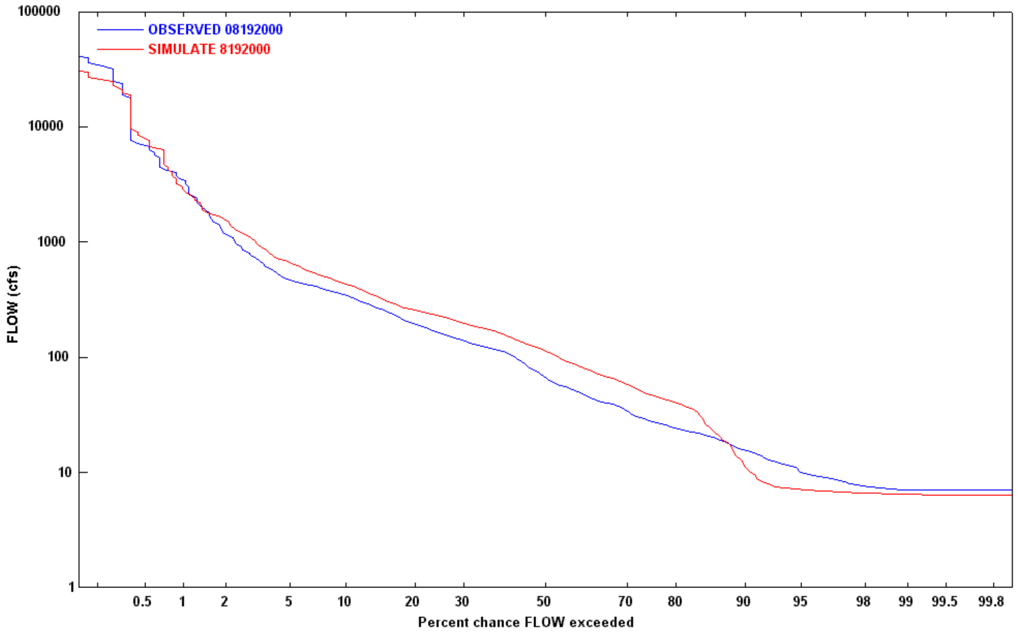


Figure 5.1.12 Daily Streamflow Frequency (Water Years 1997-2001: Nueces River below Uvalde, USGS #8192000)

Table 5.1.10 Calibration Statistics and Criteria (Water Years 1997-2001: Nueces River below Uvalde, USGS #8192000)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	2.24	2.46	10%	10%	Good
10% high (inches)	1.47	1.66	13%	10%	Good
25% high (inches)	1.85	1.98	7%	15%	Excellent
50% Low (inches)	0.11	0.18	61%	15%	Poor
25% Low (inches)	0.03	0.04	30%	15%	Poor
10% Low (inches)	0.01	0.01	-27%	15%	Poor
storm volume (inches)	1.51	1.48	-2%	20%	Excellent
average storm peak (cfs)	36107.50	44542.03	23%	15%	Poor
summer volume (inches)	1.07	1.00	-7%	15%	Excellent
winter volume (inches)	0.17	0.26	49%	10%	Poor
summer storms (inches)	0.54	0.43	-21%	10%	Poor
winter storms (inches)	0.00	0.00	0%	15%	Excellent

5.1.2.2 Water Balance

A detailed water balance summary can be very helpful for gaining insight into the hydrologic components of the system. Table 5.1.11 is provided for that purpose. The water balance components (rainfall, runoff, groundwater flow, and evaporation) were reviewed for consistency with expected literature values for the South-Central Texas region. This effort included displaying model results for a broad group of land segments, such as deep and shallow soils in the contributing and recharge zone, respectively. Although observed values are not available for each of the water balance components listed in the table, the average annual values should be consistent with expected values for the region. For an example, the simulated watershed average total evaporation is 20.99 inches per year and is about 80% of the annual rainfall (26.28 inches).

The table also provides a check on the modeling results with respect to the overall basin water balance. The fate of rainfall is distributed into evaporation, groundwater inflow, and runoff. For an annual water balance, it is reasonable to assume that almost all active groundwater inflow (3.41 inches) contributes to the baseflow. The deep groundwater inflow (0.53 inches) contributes to recharge to either Edwards Aquifer or other formations.

It should be noted that the rainfall total in this table will not be equal to the sum of the other totals from groundwater, surface water, and evapotranspiration because there is a "double counting" that occurs in that baseflow (in the groundwater group) eventually becomes surface water.

Table 5.1.11 Mean Annual Simulated Water Balance in the Nueces Basin (Water Years 1997-2001)

		Contributing Zone		**Recharge Zone**		
Component	**Unit**	**Deep Soil**	**Shallow Soil**	**Deep Soil**	**Shallow Soil**	**Watershed Average**
Rainfall	inch	27.13	27.13	21.80	21.80	**26.28**
Runoff						
Surface	inch	0.02	0.24	0.00	0.06	**0.16**
Interflow	inch	0.14	1.08	0.00	0.31	**0.74**
Baseflow	inch	2.78	4.42	0.02	0.17	**3.41**
Total	inch	2.94	5.74	0.03	0.54	**4.32**
Groundwater Inflow						
Deep	inch	0.00	0.00	3.37	3.27	**0.53**
Active	inch	2.78	4.42	0.02	0.17	**3.41**
Total	inch	2.78	4.42	3.40	3.43	**3.94**
Evaporation						
Potential	inch	67.30	67.30	67.30	67.30	**67.30**
Intercept Stor.	inch	6.70	7.05	6.08	6.37	**6.85**
Upper Zone	inch	2.75	4.01	0.96	1.75	**3.34**
Lower Zone	inch	10.97	9.99	10.56	9.63	**10.21**
Ground Water	inch	2.25	0.00	0.13	0.00	**0.45**
Baseflow	inch	0.69	0.00	0.01	0.00	**0.14**
Total	inch	23.36	21.06	17.74	17.75	**20.99**
Area	acres	231176	763955	104386	82762	**1182279**
Area	%	19.55	64.62	8.83	7.00	**100.00**

5.2 Frio - Dry Frio

5.2.1 Basin Hydrology and Features

The Frio basin has historically provided a significant portion of the recharge to the San Antonio section of the Edwards aquifer. Figure 5.2.1 shows the map of rivers and streams, major roads, cities, county boundaries, NWS and EAA precipitation gages, USGS stream gages, Edwards aquifer contributing, recharge, and artesian zones, FRSs, and ungaged areas in the Frio Basin. Table 5.2.1 summarizes basic hydrologic and modeling information about the basin. Figure 5.2.2 shows the surface geology and mapped geologic faults in the basin. Figures 5.2.3 and 5.2.4 show the hillshade and land cover/vegetation maps for the basin. Figure 5.2.5 shows the portions of different PERLND groups in the basin. Figure 5.2.6 illustrates the outline of alluvium deposits and the outline of what has been characterized as deep soils in the PERLND classification methodology. Figure 5.2.7 illustrates the delineated subwatersheds within the basin.

The Frio basin has stream gages at the upstream side of the recharge zone on both the Dry Frio River (USGS# 08196000) and the Frio River (USGS# 08195000). A stream gage also exists below the recharge zone northeast of Uvalde on the Frio River (USGS# 08197500). There are three NWS precipitation stations in or near the basin that have daily precipitation records that date back to at least 1950. One is located at the upper end of the basin at Prade Ranch and two others are located in the middle of the basin near Leakey. Daily data from these three stations were combined with hourly data from Leakey to estimate hourly precipitation throughout the basin.

As discussed in Section 3 and Appendix H, the STATSGO and SURGO soil coverages were not used directly in this study. Therefore, in order to distinguish probable areas of thicker and thinner soils, topographic slope was used as a surrogate. The topographic slope was smoothed by averaging the slope over a quarter mile radius and categorizing it as flat (deep soils) or steep (shallow soils). In addition, the high elevation plateaus were always categorized as shallow soils. Figure 5.2.6 shows the comparison of the surrogate soil thickness categorization (deep or shallow) and the outline of the alluvium from the surface geology map. The comparison of the deep soils and the alluvium shows good correlation. Therefore, the deep soil category (as defined by topographic slope) was deemed a reasonable surrogate for soil thickness. As necessary, the PERLNDs parameters that characterize the soil permeability, storage capacity, and evapotranspiration were adjusted accordingly during calibration.

Table 5.2.1 Summary Information for Frio Basin

Feature or Statistic	Measure	Details
Total area (sq. miles)	633.3	
No. of subwatersheds in model	48	
No. of stream reaches in model	48	
No. of EAA rain gages in basin	9	
Contributing Zone		
Area (sq. miles)	475.7	
Stream length (miles)	129.2	
No. of stream gages above recharge zone	2	Both gages are actually located at the upper end of the recharge zone
Average subwatershed area (sq. miles)	16.4	Range: 0.015 to 42.39
Average stream reach length (miles)	5.9	Range: 1.535 to 9.06
Recharge Zone		
Area (sq. miles)	139.3	
Stream length (miles) [1]	65.0	
No. stream gages below recharge zone	1	
Average subwatershed area (sq. miles)	5.2	Range: 0.00002 to 15.46
Average stream reach length (miles)	2.9	Range: 0.012 to 5.69

[1] Stream length includes only those streams included in the EPA RF1 files

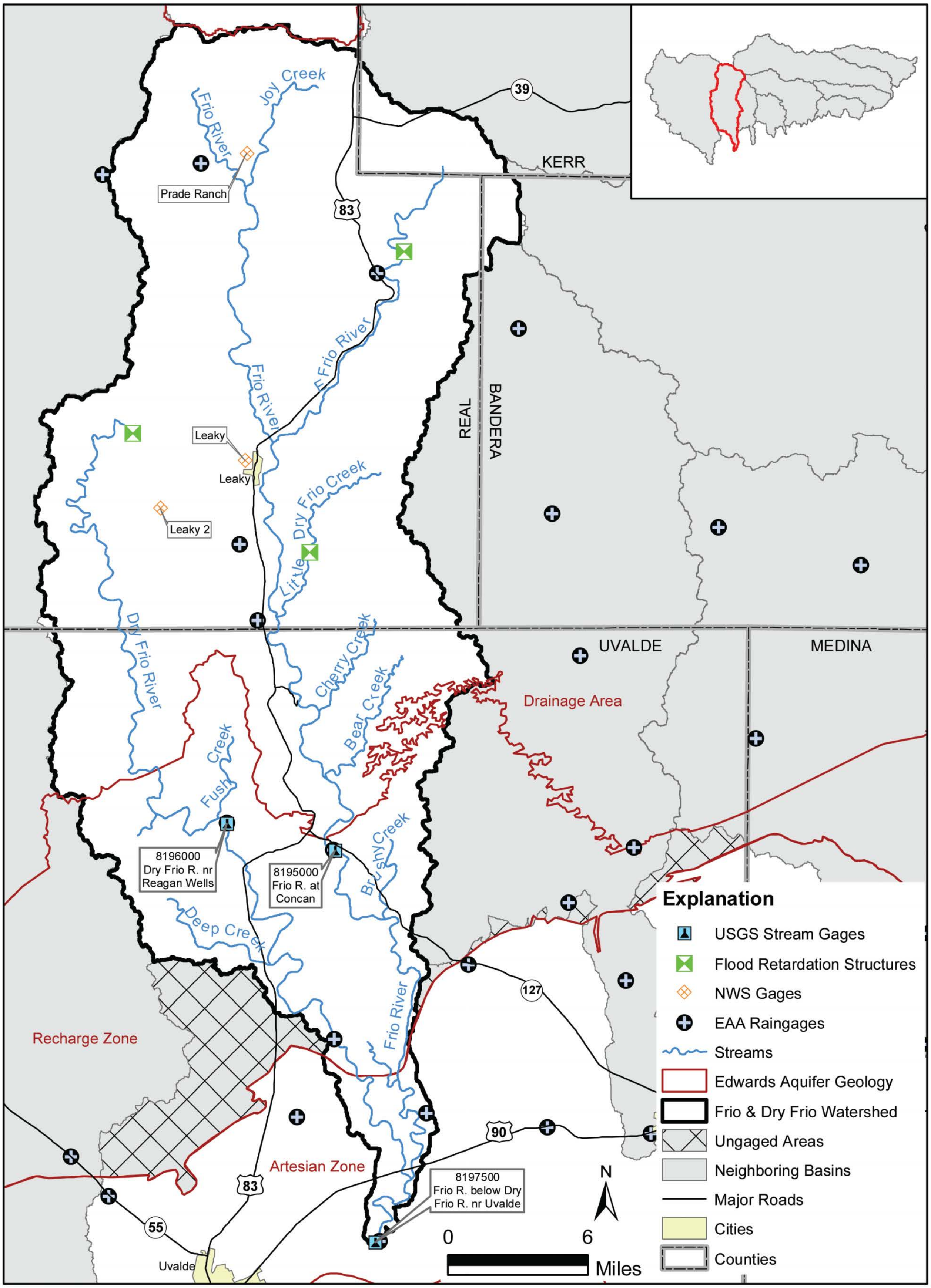


Figure 5.2.1 - Frio Basin

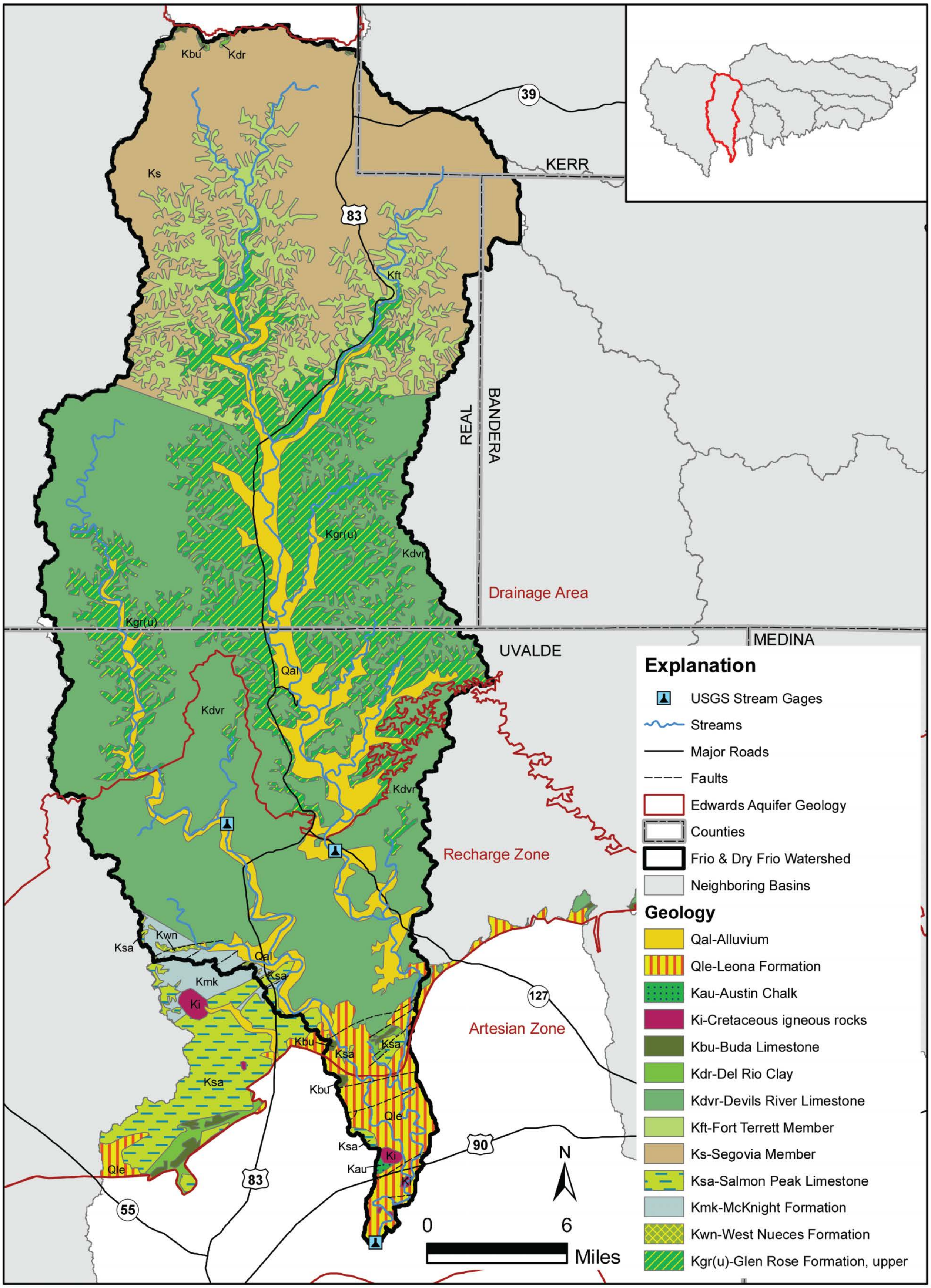


Figure 5.2.2 - Surface Geology in the Frio Basin

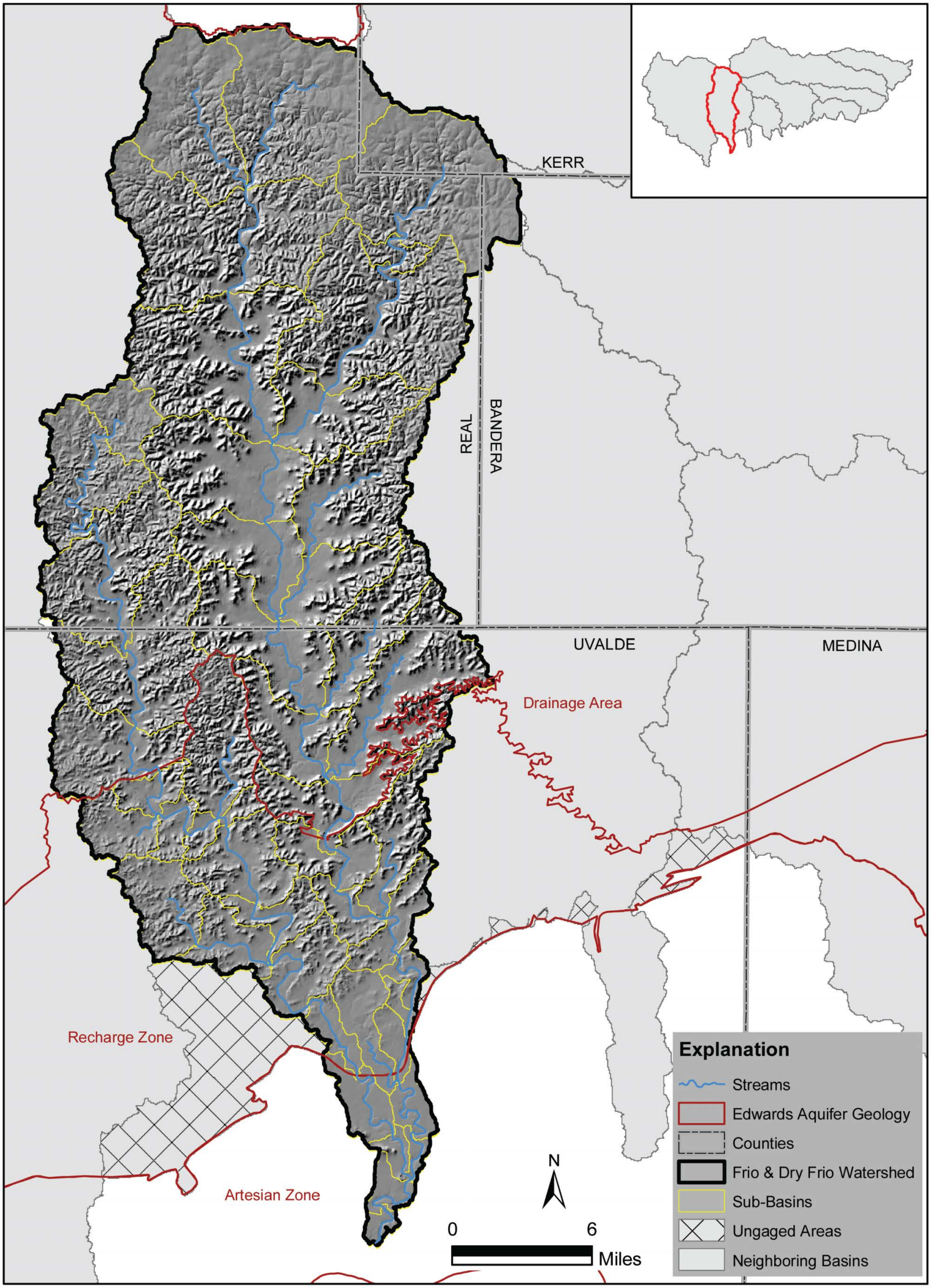


Figure5.2.3 - Hillshade View in the Frio Basin

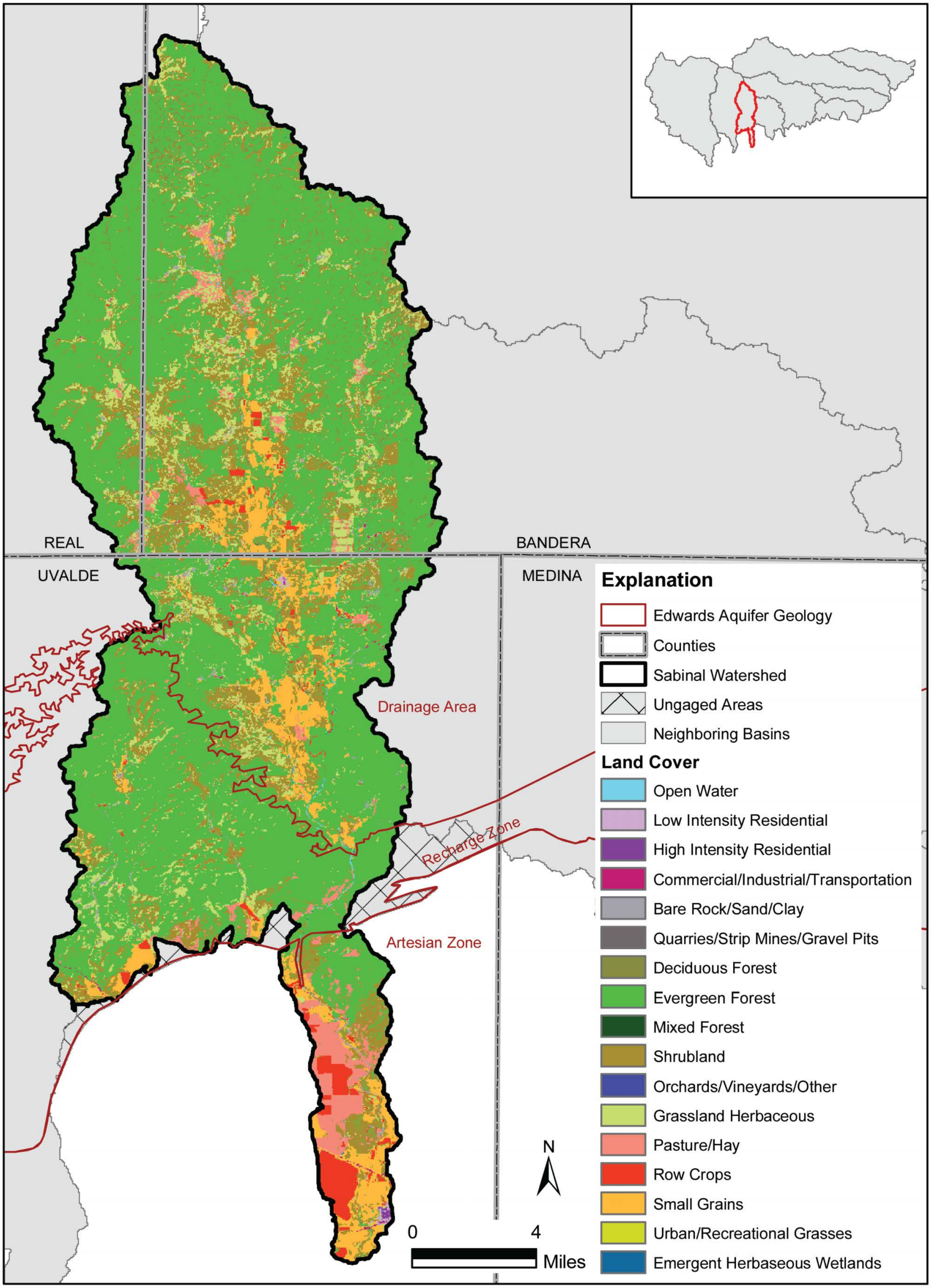


Figure 5.3.4 - Land Cover and Vegetation in the Sabinal Basin

Figure 5.2.5 summarizes the proportions of each PERLND group in the basin. It indicates that the largest PERLND components in the contributing zone are steep shallow soil areas followed by flat shallow soils. In the recharge zone, the dominant land segment is steep shallow soils, followed by flat and deep soils.

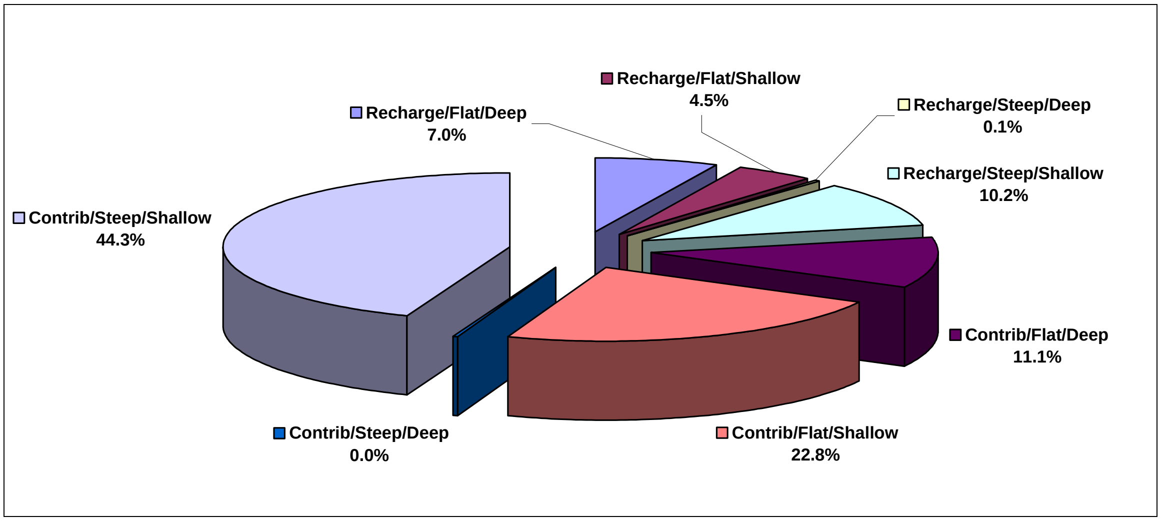


Figure 5.2.5 PERLND Distribution in the Frio Basin

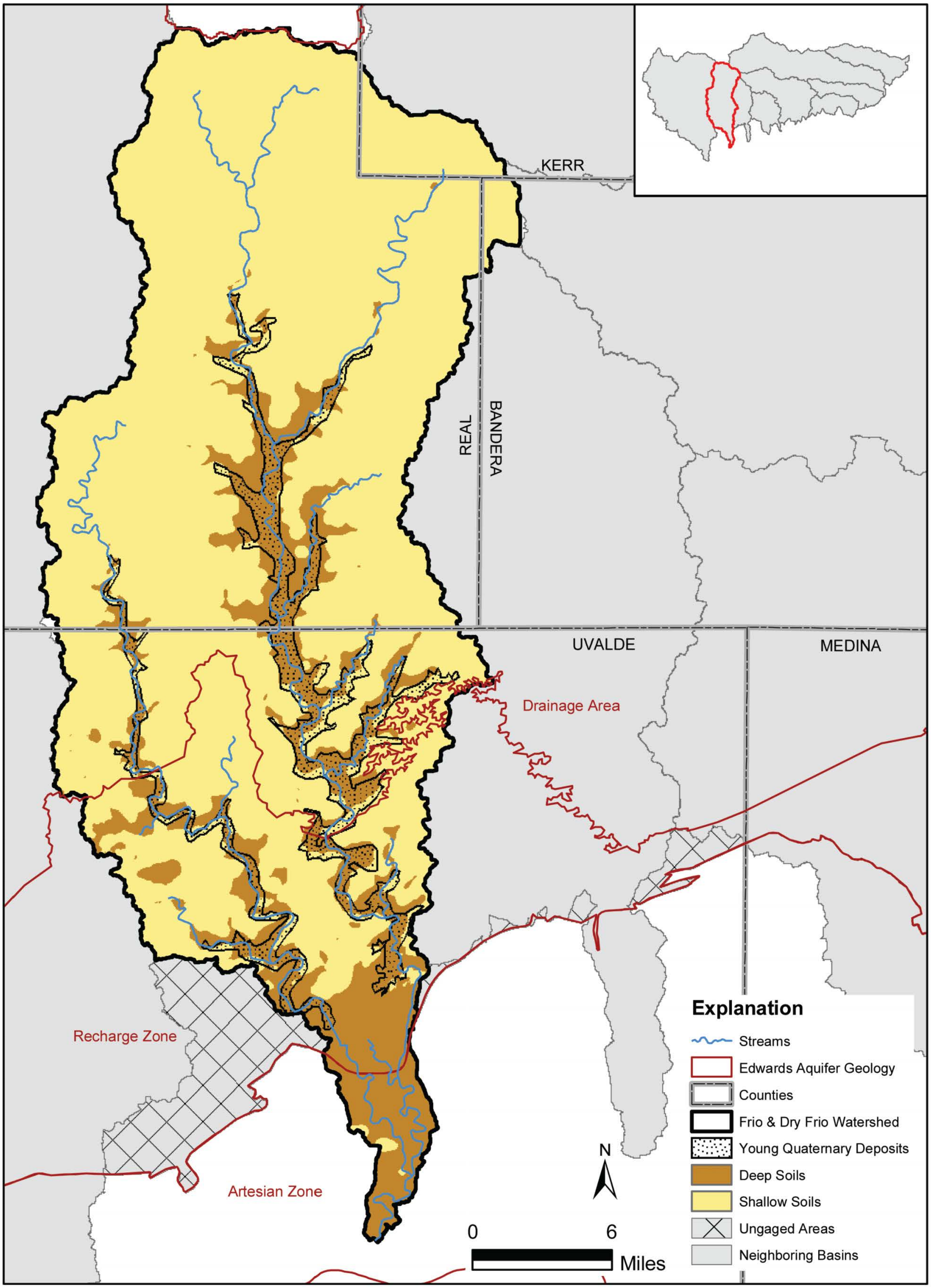


Figure 5.2.6 - Soil Thickness and Alluvium Deposits in the Frio Basin

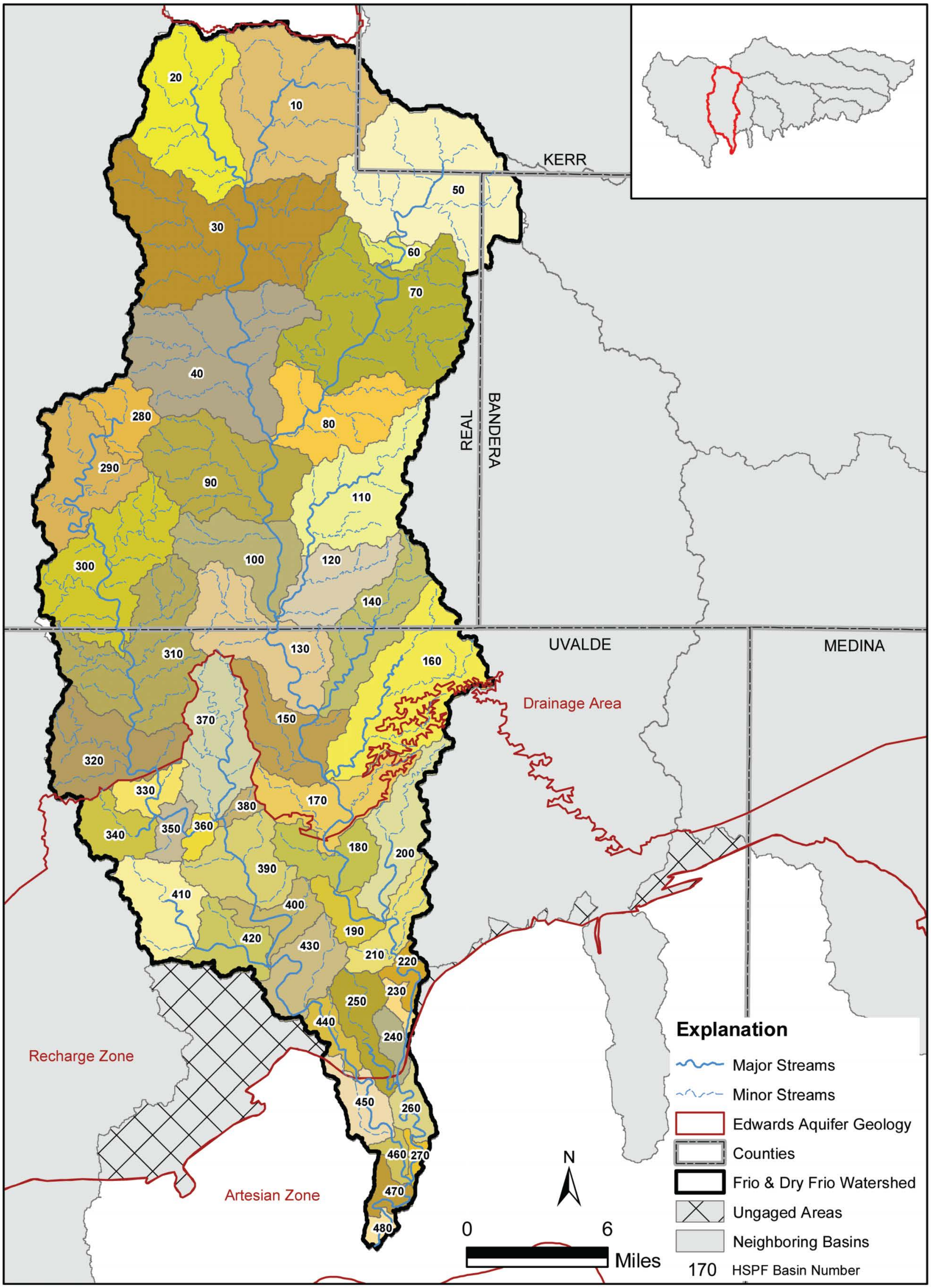


Figure 5.2.7 - Delineated Basins in the Frio Basin

5.2.2 Model Calibration

5.2.2.1 Streamflow Comparison

5.2.2.1.1 Contributing Zone (Upstream Gages)

Table 5.2.2 indicates that the average error in streamflow prediction during the 5-year simulation period is 1.5% for the Frio River at Concan. The percent error is larger in relatively dry years. Daily and monthly correlation coefficients calculated in Table 5.2.3 also indicate a good model fit to the observed flow at the gage.

Figure 5.2.8 compares daily simulated and observed flow at stream gage 8195000 (Frio River at Concan) for the 5-year period between 1997 and 2001. The graph shows the simulated daily streamflow versus the observed daily streamflow. Contrary to the Nueces Basin contributing zone model, the agreement between the observed and simulated flow is relatively good for the Frio basin contributing zone model. One notable difference is the higher frequency of observed stream flow peaks than simulated. This may be an indication that the precipitation data used in the watershed is not geographically detailed enough to simulate each storm and associated runoff event. The flow duration curve, shown in the Figure 5.2.9, indicates that the model simulates the overall hydrology of the contributing zone quite well with the exception of relatively low flow periods as indicated by the tail-end of the streamflow frequency curve.

Table 5.2.2 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Frio River at Concan, USGS #8195000)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	41.29	10.64	10.52	1.21
1998	34.29	5.89	6.08	-3.10
1999	23.26	3.70	4.58	-19.24
2000	19.02	0.70	1.29	-45.49
2001	39.05	7.49	6.39	17.31
Average	31.38	5.69	5.77	-1.47

Table 5.2.3 Daily and Monthly Statistics (Water Years 1997-2001: Frio River at Concan, USGS #8195000)

	Simulated	**Observed**
Daily Statistics		
Count	1826	1826
Mean (cfs)	165.47	163.04
Geometric Mean (cfs)	90.44	76.93
Standard Deviation (cfs)	820.56	546.47
Correlation Coefficient	0.84	
Coefficient of Determination	0.71	
Mean Error (cfs)	-2.43	
Mean Absolute Error (cfs)	79.78	
Monthly Statistics		
Count	60	60
Mean (cfs)	165.35	162.80
Geometric Mean (cfs)	105.71	86.70
Standard Deviation (cfs)	211.09	220.86
Correlation Coefficient	0.94	
Coefficient of Determination	0.89	
Mean Error (cfs)	-2.55	
Mean Absolute Error (cfs)	45.55	

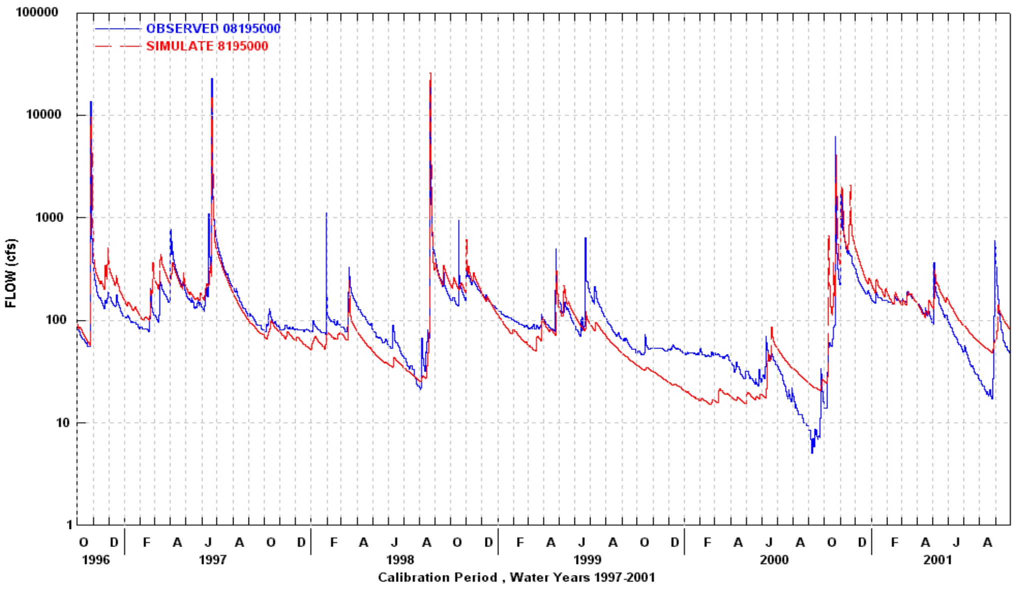


Figure 5.2.8 Daily Streamflow Comparison (Water Years 1997-2001: Frio River at Concan, USGS #8195000)

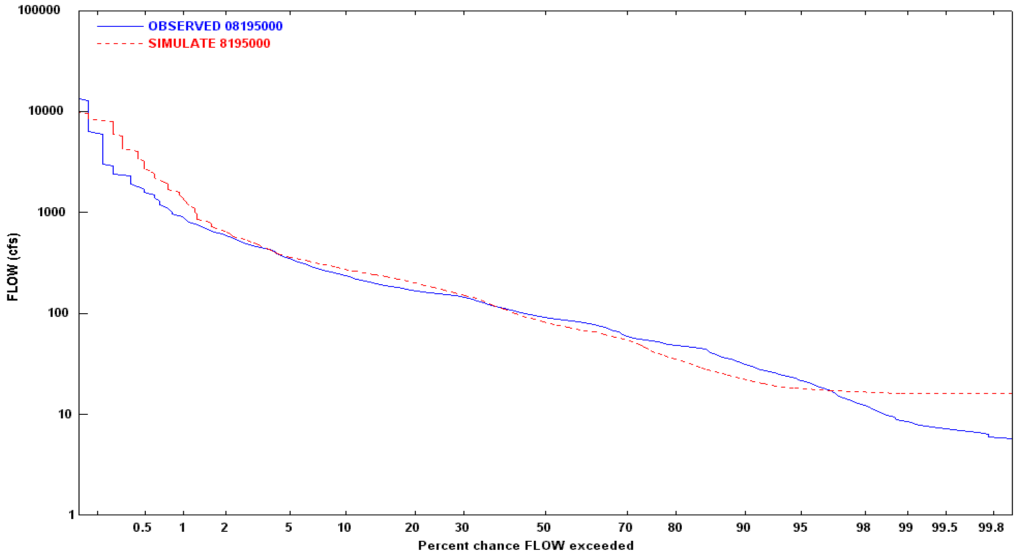


Figure 5.2.9 Daily Streamflow Frequency (Water Years 1997-2001: Frio River at Concan, USGS #8195000)

Table 5.2.4 Calibration Statistics and Criteria (Water Years 1997-2001: Frio River at Concan, USGS #8195000)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	5.77	5.69	-1%	10%	Excellent
10% high (inches)	2.40	2.96	23%	10%	Poor
25% high (inches)	3.57	4.04	13%	15%	Good
50% Low (inches)	0.94	0.67	-28%	15%	Poor
25% Low (inches)	0.30	0.18	-40%	15%	Poor
10% Low (inches)	0.07	0.05	-31%	15%	Poor
storm volume (inches)	2.71	2.68	-1%	20%	Excellent
average storm peak (cfs)	8,400.50	8,000.54	5%	15%	Excellent
summer volume (inches)	2.06	1.90	-8%	15%	Good
winter volume (inches)	0.94	0.87	-7%	10%	Good
summer storms (inches)	0.78	0.91	17%	10%	Good
winter storms (inches)	0.00	0.03	937%	15%	N/A

Figure 5.2.10 compares daily simulated and observed flow at stream gage 8196000 (Dry Frio near Reagan Wells) for the 5-year period between 1997 and 2001. The graph shows the simulated daily streamflow versus the observed daily streamflow. As with the Concan gage, there is a higher frequency of observed stream flow peaks than simulated, indicating that the precipitation

data used in the watershed is not geographically detailed enough to simulate each storm and associated runoff event. The flow duration curve, shown in the bottom graph, indicates that the model simulates the overall hydrology of the contributing zone of the Frio River above the gage relatively well. From Figures 5.2.10 and 5.2.11, it is evident that the low flow events in the Frio basin are not simulated with great accuracy. Table 5.2.7 confirms this visual observation with a "poor" assessment for the low flow statistical assessment. However, in the context of estimating recharge to the aquifer from contributing zone flow, the very low flow estimates are less critical.

Table 5.2.5 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Dry Frio River near Reagan Wells, USGS #8196000)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	41.29	8.06	9.24	-12.72
1998	34.29	4.88	4.84	0.80
1999	23.26	2.64	4.61	-42.86
2000	19.02	0.50	0.75	-33.48
2001	39.05	5.64	3.81	48.26
Average	31.38	4.34	4.65	-6.57

Table 5.2.6 Daily and Monthly Statistics (Water Years 1997-2001: Dry Frio River near Reagan Wells, USGS #8196000)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	43.18	40.34
Geometric Mean (cfs)	14.59	17.68
Standard Deviation (cfs)	263.99	156.56
Correlation Coefficient	0.77	
Coefficient of Determination	0.60	
Mean Error (cfs)	-2.84	
Mean Absolute Error (cfs)	26.65	
Monthly Statistics		
Count	60	60
Mean (cfs)	43.13	40.26
Geometric Mean (cfs)	19.10	20.06
Standard Deviation (cfs)	68.16	60.49
Correlation Coefficient	0.87	
Coefficient of Determination	0.76	
Mean Error (cfs)	-2.87	
Mean Absolute Error (cfs)	19.41	

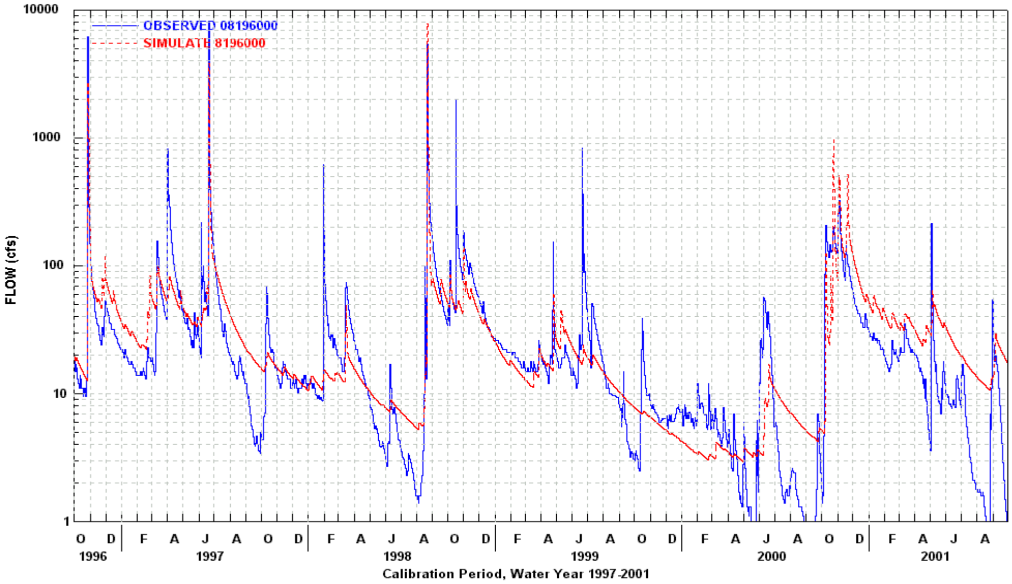


Figure 5.2.10 Daily Streamflow Comparison (Water Years 1997-2001: Dry Frio River near Reagan Wells, USGS #8196000)

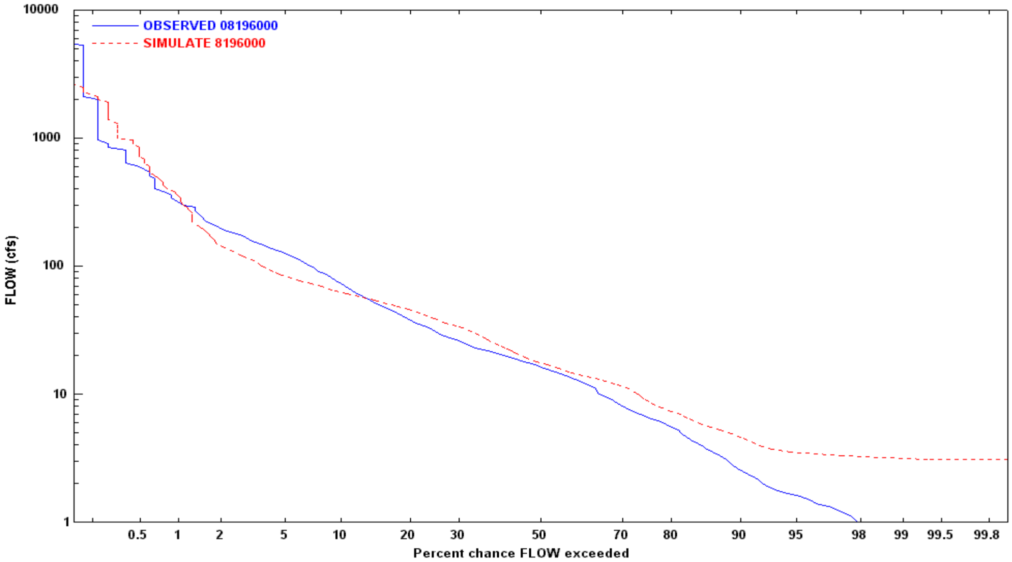


Figure 5.2.11 Daily Streamflow Frequency (Water Years 1997-2001: Dry Frio River near Reagan Wells, USGS #8196000)

Table 5.2.7 Calibration Statistics and Criteria (Water Years 1997-2001: Dry Frio River near Reagan Wells, USGS #8196000)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	4.65	4.34	-7%	10%	Good
10% high (inches)	2.54	2.41	-5%	10%	Good
25% high (inches)	3.56	3.19	-10%	15%	Good
50% Low (inches)	0.39	0.47	21%	15%	Poor
25% Low (inches)	0.09	0.13	39%	15%	Poor
10% Low (inches)	0.02	0.03	101%	15%	Poor
storm volume (inches)	2.87	2.21	-23%	20%	OK
average storm peak (cfs)	2,611.11	3,166.07	21%	15%	Poor
summer volume (inches)	1.60	1.54	-3%	15%	Excellent
winter volume (inches)	0.60	0.62	4%	10%	Excellent
summer storms (inches)	0.64	0.76	20%	10%	Poor
winter storms (inches)	0.00	0.02	351%	15%	N/A

5.2.2.1.2 Recharge Zone (Downstream Gages)

Table 5.2.8 and 5.2.9 indicate that relatively good calibration for stream gage 8197500 (Frio River near Uvalde) during the 5-year period between 1997 and 2001. Figure 5.2.12 compares simulated and observed flow at the gage. Overall, the agreement is good. However, the same difference is noted here in that there is a higher frequency of observed stream flow peaks than simulated. In addition, the simulated flows from storm events last longer. The flow duration curve, shown in Figure 5.2.13, indicates that the model generally overestimates flow below the recharge zone. Figure 5.2.12 also shows the impact of the high channel loss that occurs in the recharge zone as indicated by the quick drop in stream flow after high flow events.

Table 5.2.8 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Frio River below Dry Frio River near Uvalde, USGS #8197500)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	26.36	3.48	4.64	-25.06
1998	28.66	2.46	2.31	6.65
1999	25.96	0.20	0.38	-46.43
2000	12.24	0.00	0.00	0.00
2001	26.28	0.80	0.97	-16.80
Average	23.90	1.39	1.66	16.23

Table 5.2.9 Daily and Monthly Statistics (Water Years 1997-2001: Frio River below Dry Frio River near Uvalde, USGS #8197500)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	77.362	64.804
Geometric Mean (cfs)	0.003	0.045
Standard Deviation (cfs)	1175.514	924.021
Correlation Coefficient	0.711	
Coefficient of Determination	0.506	
Mean Error (cfs)	-12.558	
Mean Absolute Error (cfs)	58.004	
Monthly Statistics		
Count	60	60
Mean (cfs)	77.026	64.41
Geometric Mean (cfs)	0.019	0.193
Standard Deviation (cfs)	275.61	245.298
Correlation Coefficient	0.985	
Coefficient of Determination	0.97	
Mean Error (cfs)	-12.616	
Mean Absolute Error (cfs)	17.159	

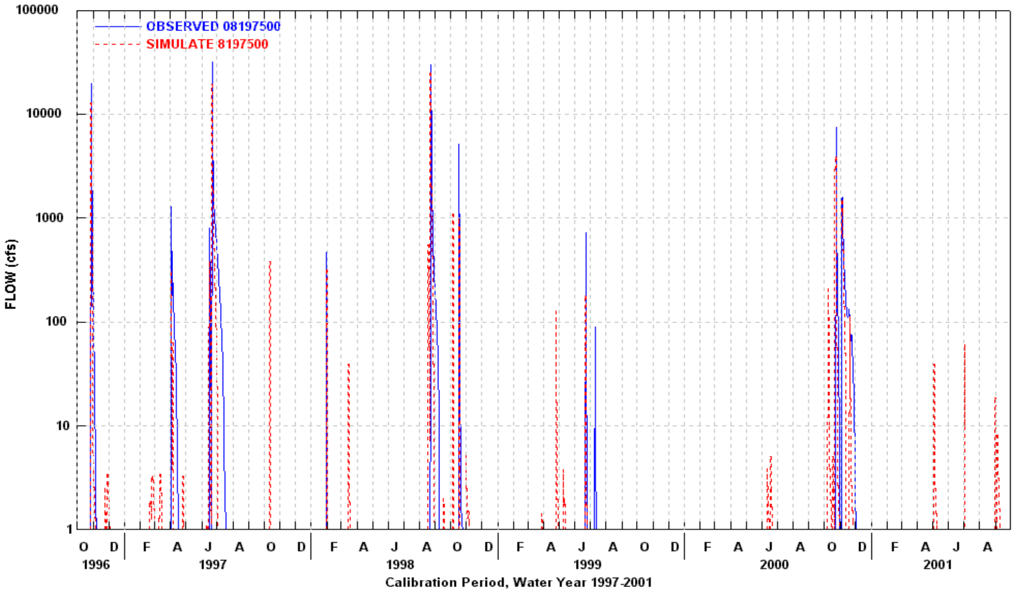


Figure 5.2.12 Daily Streamflow Comparison (Water Years 1997-2001: Frio River below Dry Frio River near Uvalde, USGS #8197500)

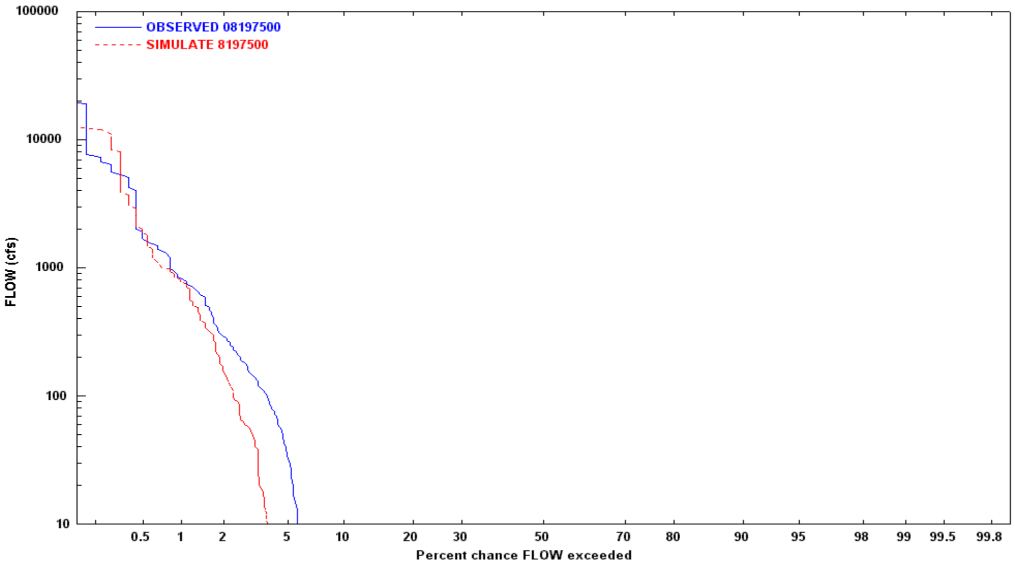


Figure 5.2.13 Daily Streamflow Frequency (Water Years 1997-2001: Frio River below Dry Frio River near Uvalde, USGS #8197500)

Table 5.2.10 Calibration Statistics and Criteria (Water Years 1997-2001: Frio River below Dry Frio River near Uvalde, USGS #8197500)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	1.66	1.39	-16%	10%	OK
10% high (inches)	1.28	1.39	8%	10%	Good
25% high (inches)	1.49	1.39	-7%	15%	Excellent
50% Low (inches)	0	0	0%	15%	Excellent
25% Low (inches)	0	0	0%	15%	Excellent
10% Low (inches)	0	0	0%	15%	Excellent
storm volume (inches)	1.7	1.38	-19%	20%	Good
average storm peak (cfs)	13879	13680.62	1%	15%	Excellent
summer volume (inches)	1.04	0.91	-13%	15%	Good
winter volume (inches)	0.01	0.01	-19%	10%	Poor
summer storms (inches)	0.53	0.51	-3%	10%	Excellent
winter storms (inches)	0	0	0%	15%	Excellent

5.2.2.2 Water Balance

The water balance in the Frio Basin is very similar to the Nueces in terms of the percentage of water that moves through each component.

Table 5.2.11 Mean Annual Simulated Water Balance in the Frio Basin (Water Years 1997-2001)

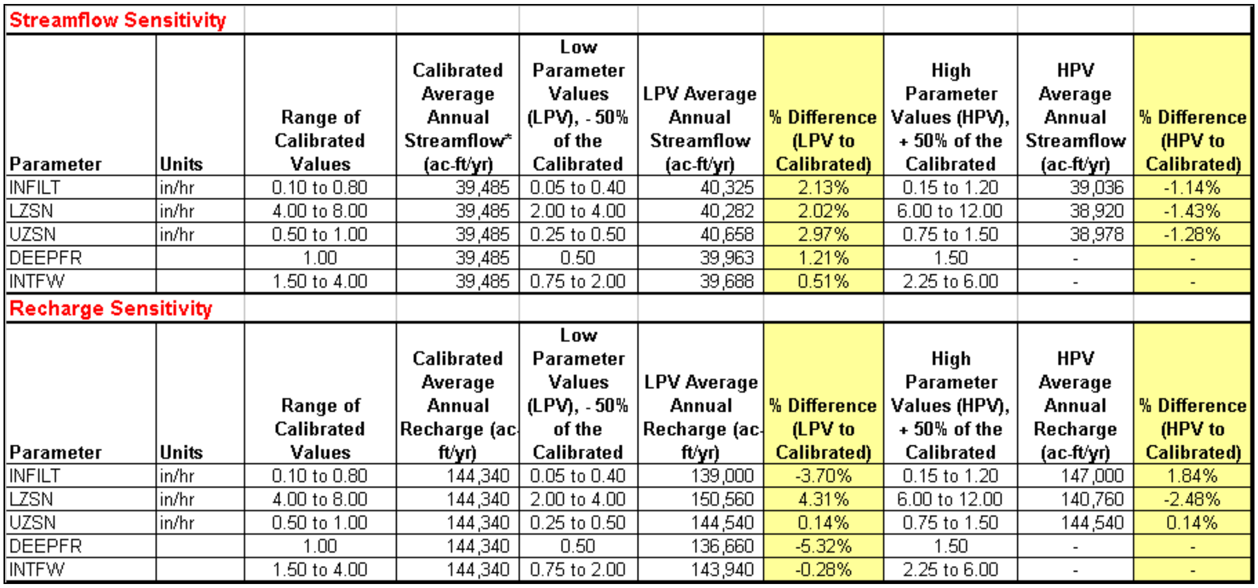
		Contributing Zone		Recharge Zone		
Component	**Unit**	**Deep Soil**	**Shallow Soil**	**Deep Soil**	**Shallow Soil**	**Watershed Average**
Rainfall	inch	29.56	29.56	22.92	22.92	**28.12**
			Runoff			
Surface	inch	0.05	0.64	0.00	0.11	**0.45**
Interflow	inch	0.22	1.74	0.01	0.53	**1.27**
Baseflow	inch	2.69	4.11	0.02	0.17	**3.08**
Total	inch	2.96	6.49	0.03	0.81	**4.81**
			Groundwater Inflow			
Deep	inch	1.37	1.03	3.67	3.91	**1.68**
Active	inch	2.69	4.11	0.02	0.17	**3.08**
Total	inch	4.06	5.14	3.70	4.08	**4.76**
			Evaporation			
Potential	inch	59.56	59.56	59.56	59.56	**59.56**
Intercept Stor.	inch	7.53	8.26	6.25	6.97	**7.84**
Upper Zone	inch	2.76	3.91	1.11	2.19	**3.33**
Lower Zone	inch	11.21	9.54	10.99	8.99	**9.74**
Ground Water	inch	1.98	0.00	0.13	0.00	**0.23**
Baseflow	inch	0.65	0.00	0.01	0.00	**0.07**
Total	inch	24.13	21.70	18.49	18.15	**21.22**
Area	acres	45079	272169	28558	59495	**405301**
Area	%	11.12	67.15	7.05	14.68	**100.00**

5.2.2.3 Sensitivity Analyses

A sensitivity analysis was performed on the Frio Basin model by individually varying five important parameters from their calibrated values. By assessing the change in streamflow and recharge based on the change in the input parameters, one can better understand the uniqueness and robustness of the model.

Table 5.2.12 summarizes the changes in streamflow and recharge based on changes in the HSPF parameters INFILT, LZSN, UZSN, DEEPFR, INTFW. Appendix C and G, as well as Section 2.2 contain a description of these parameters. Review of the Frio model sensitivity analysis indicates that the streamflow is somewhat sensitive to several parameters, but is most sensitive to the upper zone storage (UZSN). In this case, recharge was most sensitive to DEEPFR and LZSN.

Table 5.2.12 Summary of Sensitivity Analyses for Frio Basin Model



Streamflow Sensitivity

Parameter	Units	Range of Calibrated Values	Calibrated Average Annual Streamflow* (ac-ft/yr)	Low Parameter Values (LPV), - 50% of the Calibrated	LPV Average Annual Streamflow (ac-ft/yr)	% Difference (LPV to Calibrated)	High Parameter Values (HPV), + 50% of the Calibrated	HPV Average Annual Streamflow (ac-ft/yr)	% Difference (HPV to Calibrated)
INFILT	in/hr	0.10 to 0.80	39,485	0.05 to 0.40	40,325	2.13%	0.15 to 1.20	39,036	-1.14%
LZSN	in/hr	4.00 to 8.00	39,485	2.00 to 4.00	40,282	2.02%	6.00 to 12.00	38,920	-1.43%
UZSN	in/hr	0.50 to 1.00	39,485	0.25 to 0.50	40,658	2.97%	0.75 to 1.50	38,978	-1.28%
DEEPFR		1.00	39,485	0.50	39,963	1.21%	1.50	-	-
INTFW		1.50 to 4.00	39,485	0.75 to 2.00	39,688	0.51%	2.25 to 6.00	-	-

Recharge Sensitivity

Parameter	Units	Range of Calibrated Values	Calibrated Average Annual Recharge (ac-ft/yr)	Low Parameter Values (LPV), - 50% of the Calibrated	LPV Average Annual Recharge (ac-ft/yr)	% Difference (LPV to Calibrated)	High Parameter Values (HPV), + 50% of the Calibrated	HPV Average Annual Recharge (ac-ft/yr)	% Difference (HPV to Calibrated)
INFILT	in/hr	0.10 to 0.80	144,340	0.05 to 0.40	139,000	-3.70%	0.15 to 1.20	147,000	1.84%
LZSN	in/hr	4.00 to 8.00	144,340	2.00 to 4.00	150,560	4.31%	6.00 to 12.00	140,760	-2.48%
UZSN	in/hr	0.50 to 1.00	144,340	0.25 to 0.50	144,540	0.14%	0.75 to 1.50	144,540	0.14%
DEEPFR		1.00	144,340	0.50	136,660	-5.32%	1.50	-	-
INTFW		1.50 to 4.00	144,340	0.75 to 2.00	143,940	-0.28%	2.25 to 6.00	-	-

5.3 Sabinal

Figure 5.3.1 shows the map of rivers and streams, major roads, cities, county boundaries, NWS and EAA precipitation gages, USGS stream gages, Edwards aquifer contributing, recharge, and artesian zones, FRSs, and ungaged areas in the Sabinal Basin. Table 5.3.1 summarizes basic hydrologic and modeling information about the basin. Figure 5.3.2 shows the surface geology and mapped geologic faults in the basin. Figures 5.3.3 and 5.3.4 show the hillshade and land cover/vegetation maps. Figure 5.3.5 shows the proportions of different PERLND groups in the basin. Figure 5.3.6 illustrates the delineated subwatersheds within the basin and watershed ID number required for HSPF.

5.3.1 Basin Hydrology and Features

Table 5.3.1 Summary Information for Sabinal Basin

Feature or Statistic	Measure	Details
Total area (sq. miles)	295.1	
No. of subwatersheds in model	36	
No. of stream reaches in model	36	
No. of EAA rain gages in basin	7	
Contributing Zone		
Area (sq. miles)	206.5	
Stream length (miles)	74.3	
No. of stream gages above recharge zone	1	
Average subwatershed area (sq. miles)	10.9	Range: 0.00022 to 20.36
Average stream reach length (miles)	4.6	Range: 0.336 to 8.12
Recharge Zone		
Area (sq. miles)	36.8	
Stream length (miles) [1]	39.5	
No. stream gages below recharge zone	1	
Average subwatershed area (sq. miles)	3.5	Range: 0.307 to 10.71
Average stream reach length (miles)	2.8	Range: 0.951 to 4.69

[1] Stream length includes only those streams included in the EPA RF1 files

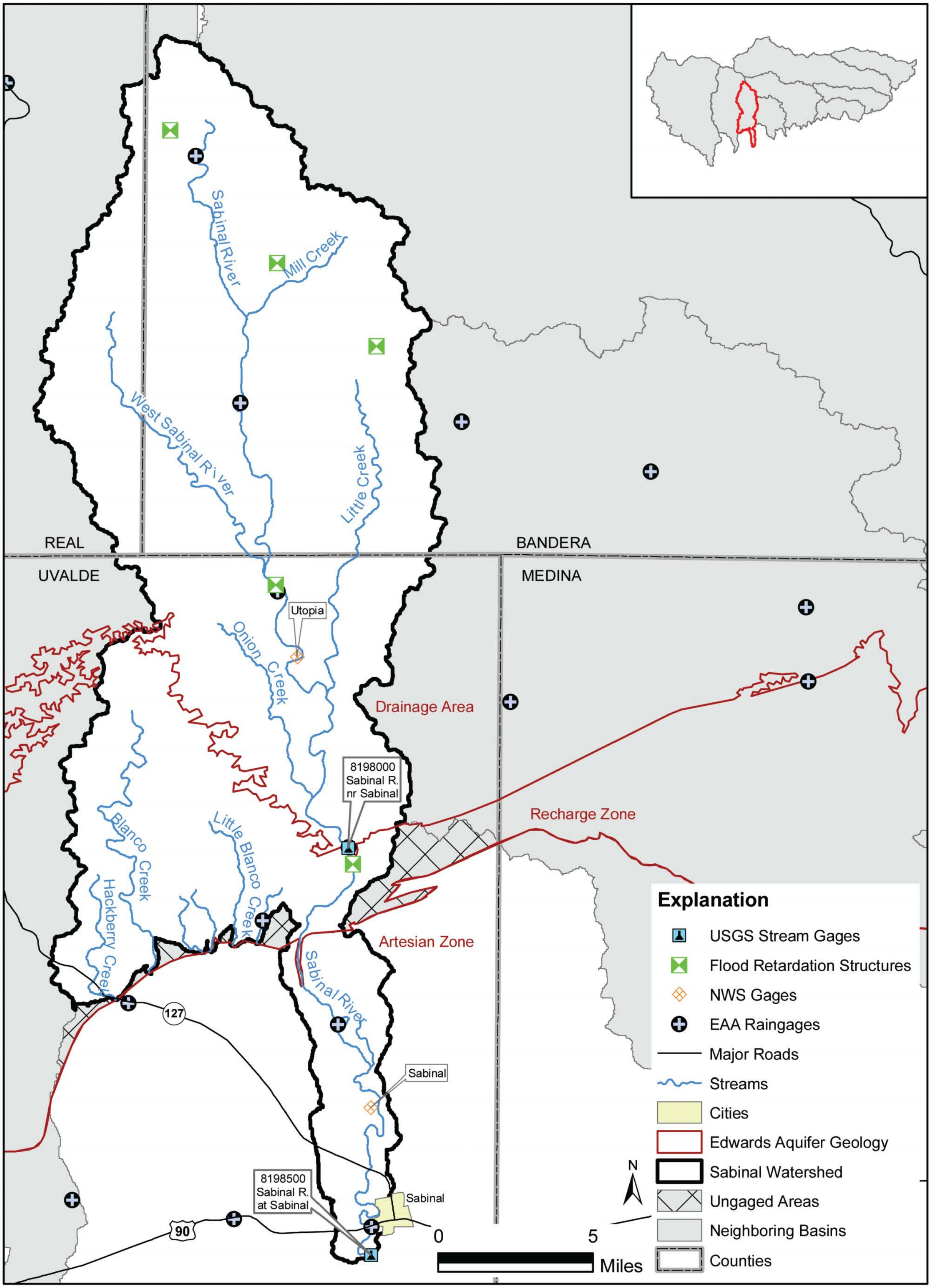


Figure 5.3.1 - Sabinal Basin

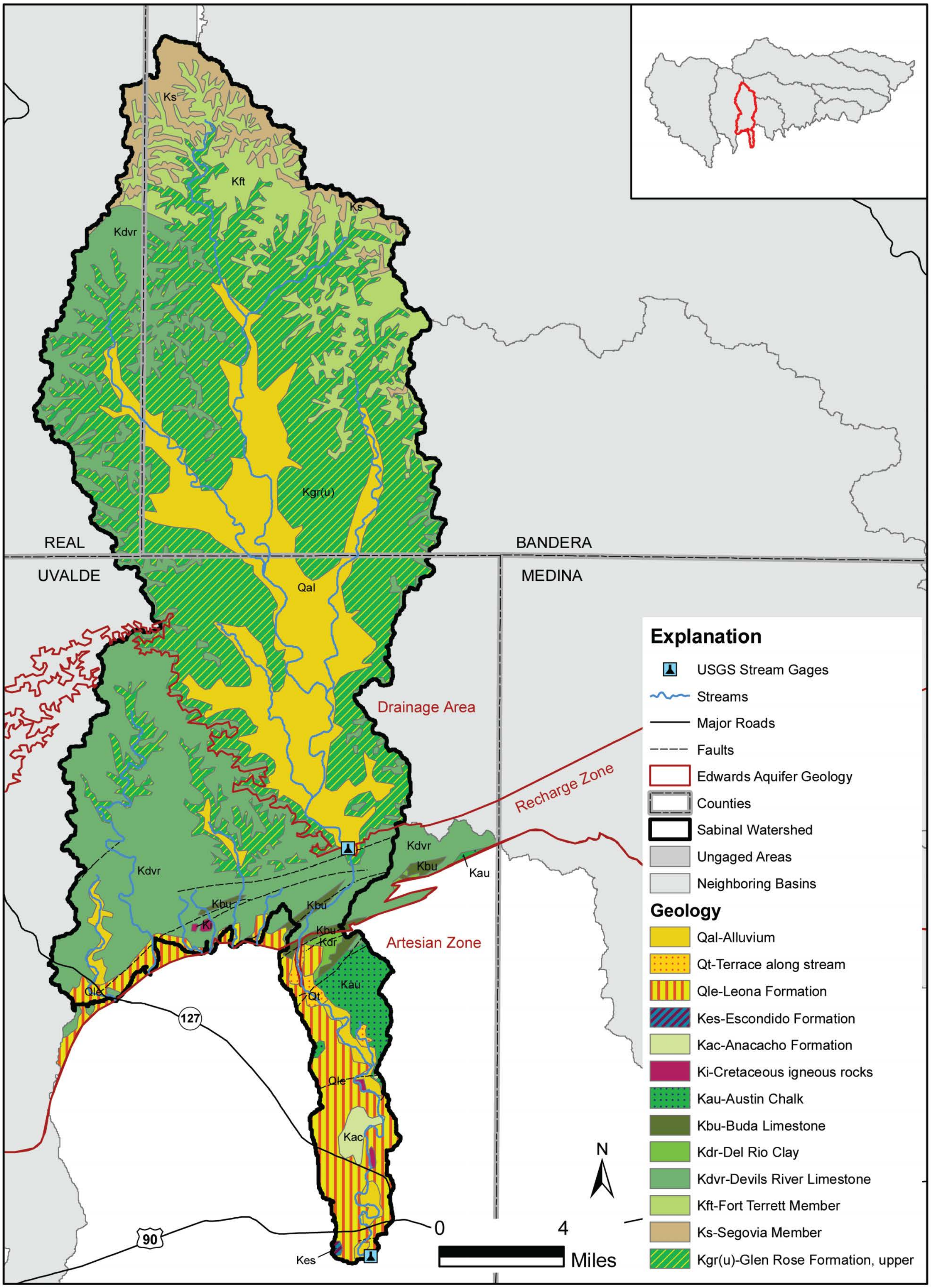


Figure 5.3.2 - Surface Geology in the Sabinal Basin

Figure 5.3.3 - Hillshade View in the Sabinal Basin

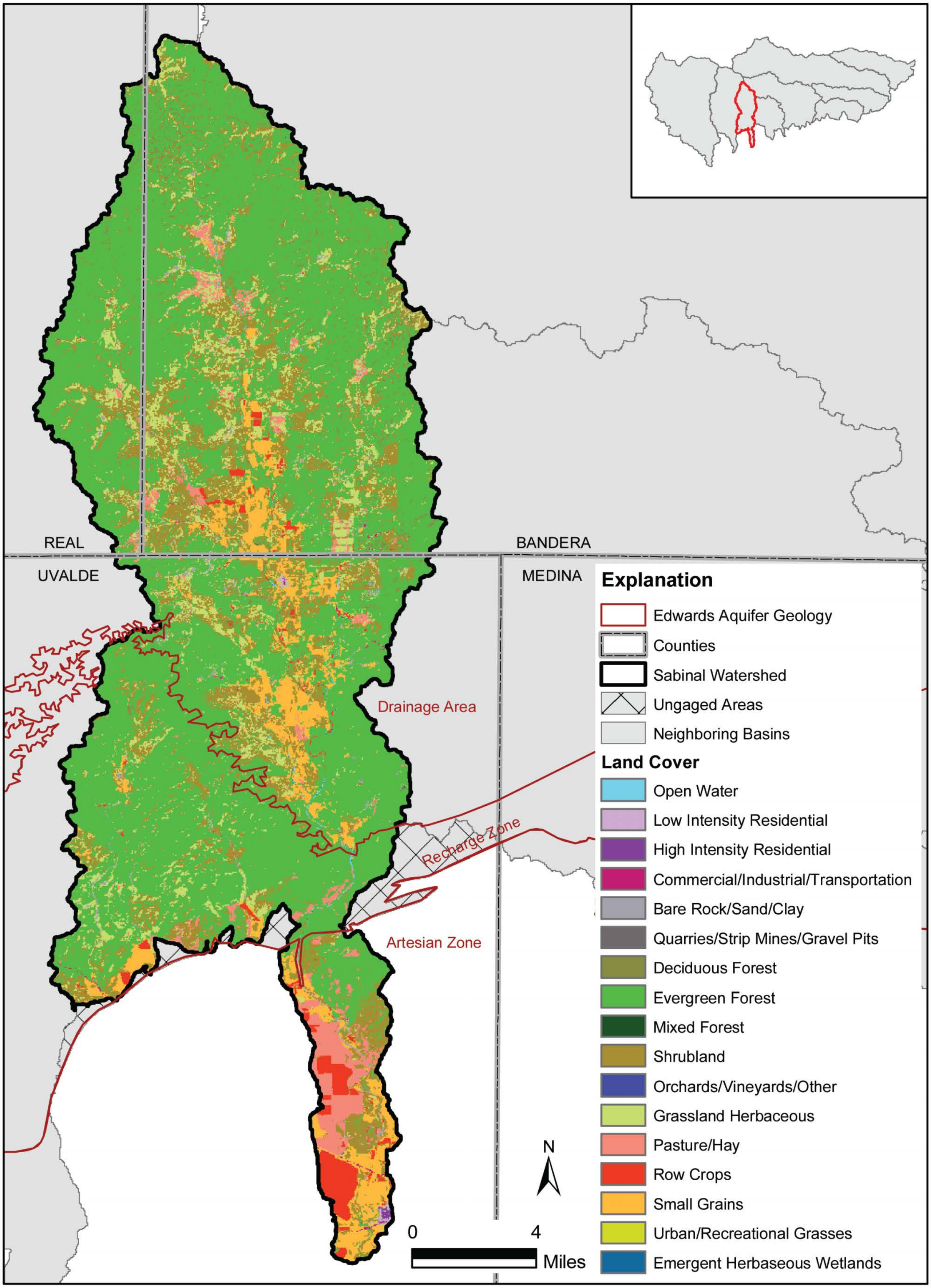


Figure 5.3.4 - Land Cover and Vegetation in the Sabinal Basin

Figure 5.3.5 summarizes the proportions of each PERLND group in the basin. It indicates that the largest PERLND components in the contributing zone are equally divided between the steep shallow soil areas and flat deep soils. In the recharge zone, the dominant land segment is steep shallow soils, followed by flat and deep soils.

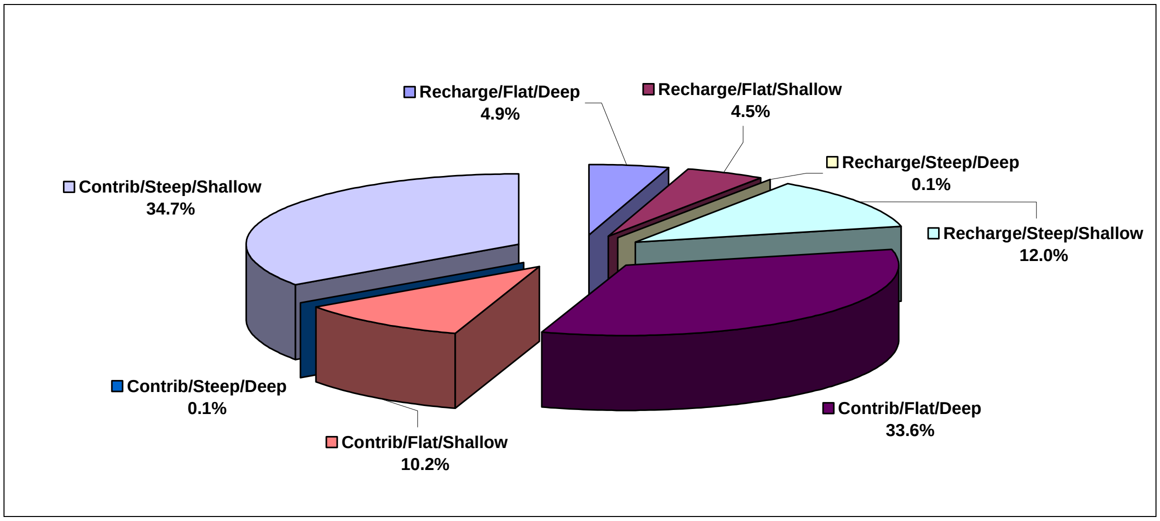


Figure 5.3.5 PERLND Distribution in the Sabinal Basin

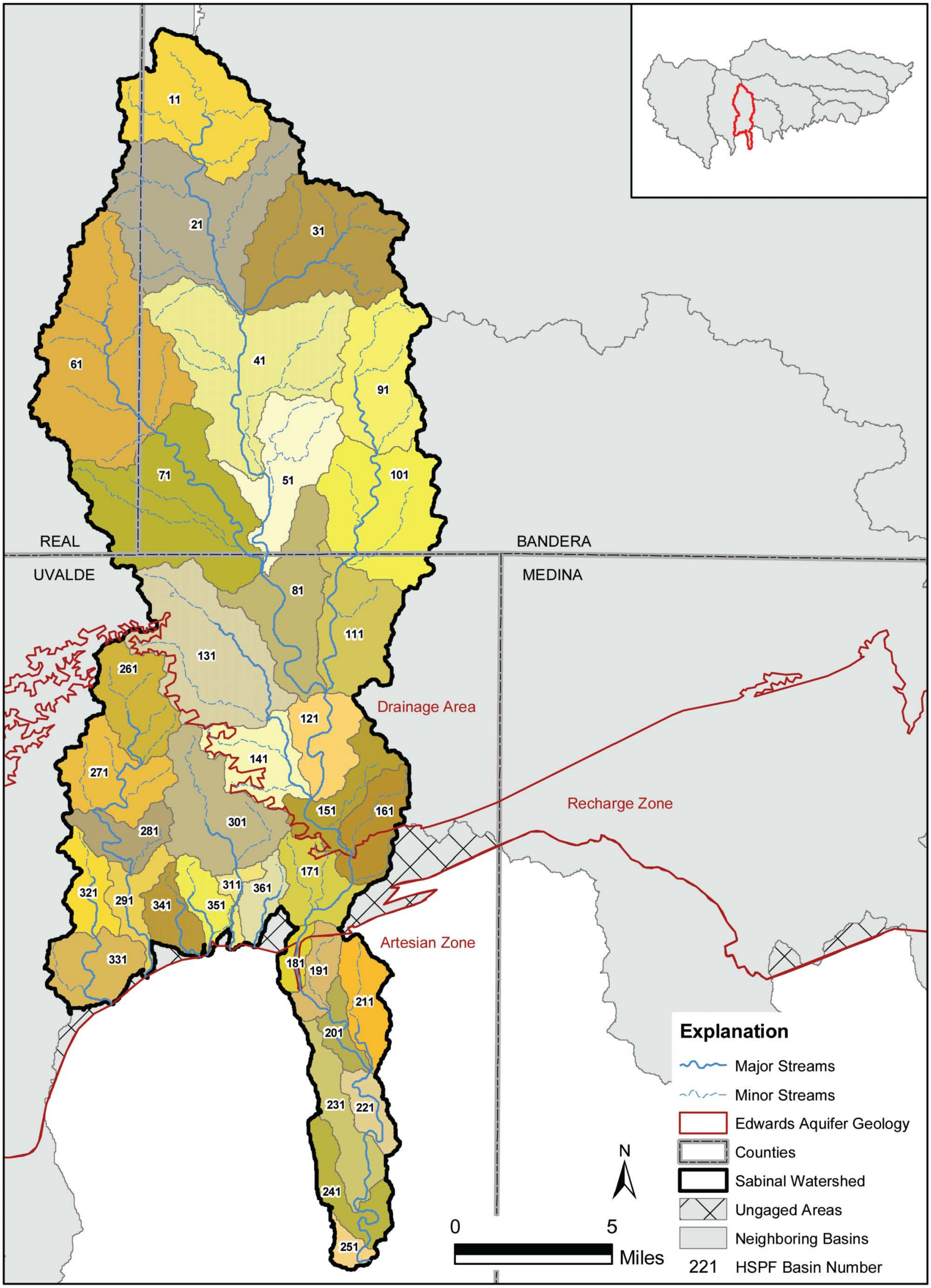


Figure 5.3.6 - Delineated Basins in the Sabinal Basin

5.3.2 Model Calibration

5.3.2.1 Streamflow Comparison

5.3.2.1.1 Contributing Zone (Upstream Gages)

Figure 5.3.7 compares daily simulated and observed flow at stream gage 8198000 (Sabinal near Sabinal) for the 5-year period between 1997 and 2001. Overall, the agreement between the observed and simulated flow is good. However, the flow duration curve, shown in Figure 5.3.8, indicates that the model generally simulates too much flow in river from the contributing zone. This assertion is confirmed after reviewing the percent error in the annual runoff tabulated in Table 5.3.2. The calibration statistics calculated in Table 5.3.4 show that the model might need some refinement.

Table 5.3.2 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Sabinal River near Sabinal, USGS #8198000)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	38.90	5.98	8.92	-32.97
1998	37.35	6.25	4.37	43.14
1999	30.27	4.86	5.29	-8.04
2000	19.08	0.64	0.40	59.40
2001	48.61	11.32	7.45	52.09
Average	34.84	5.81	5.28	9.98

Table 5.3.3 Daily and Monthly Statistics (Water Years 1997-2001: Sabinal River near Sabinal, USGS #8198000)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	80.11	88.10
Geometric Mean (cfs)	28.01	41.84
Standard Deviation (cfs)	367.17	295.44
Correlation Coefficient	0.54	
Coefficient of Determination	0.30	
Mean Error (cfs)	7.99	
Mean Absolute Error (cfs)	48.23	
Monthly Statistics		
Count	60	60
Mean (cfs)	80.22	88.04
Geometric Mean (cfs)	36.72	46.27
Standard Deviation (cfs)	116.82	133.56
Correlation Coefficient	0.68	
Coefficient of Determination	0.46	
Mean Error (cfs)	7.82	
Mean Absolute Error (cfs)	40.70	

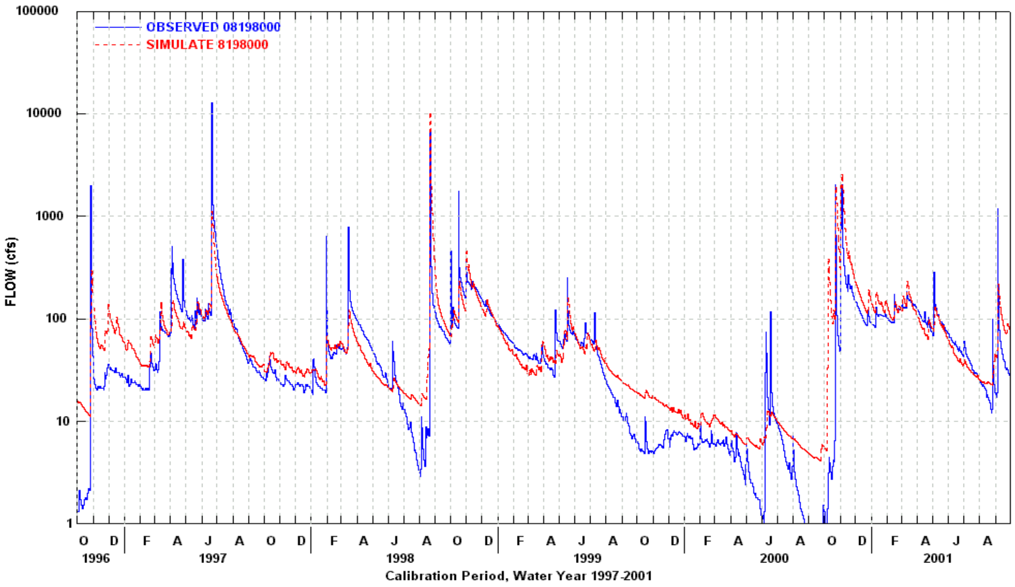


Figure 5.3.7 Daily Streamflow Comparison (Water Years 1997-2001: Sabinal River near Sabinal, USGS #8198000)

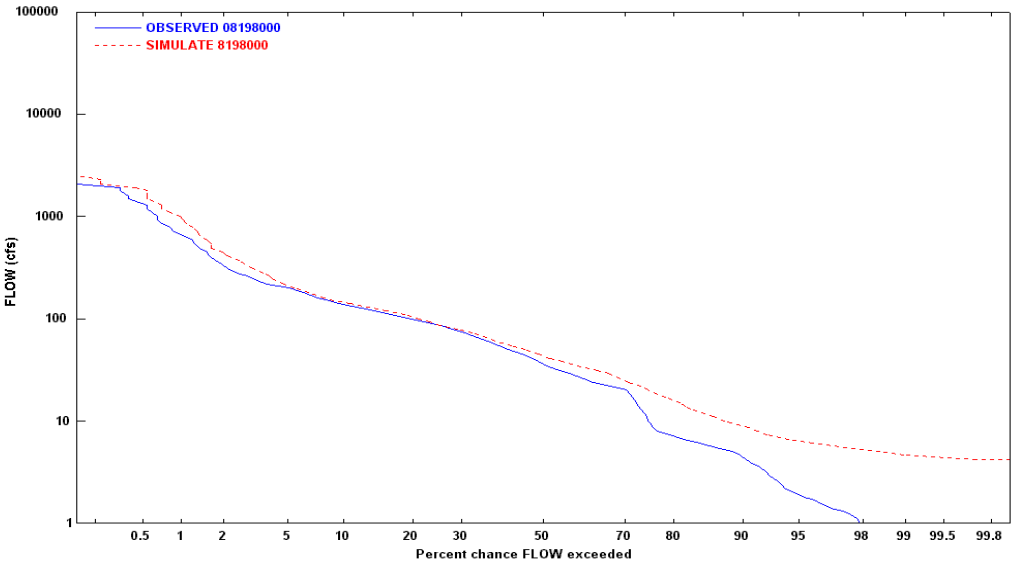


Figure 5.3.8 Daily Streamflow Frequency (Water Years 1997-2001: Sabinal River near Sabinal, USGS #8198000)

Table 5.3.4 Calibration Statistics and Criteria (Water Years 1997-2001: Sabinal River near Sabinal, USGS #8198000)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	5.30	5.83	10%	10%	Good
10% high (inches)	2.34	2.96	27%	10%	Poor
25% high (inches)	3.66	4.09	12%	15%	Good
50% Low (inches)	0.47	0.70	47%	15%	Poor
25% Low (inches)	0.08	0.18	130%	15%	Poor
10% Low (inches)	0.01	0.04	223%	15%	Poor
storm volume (inches)	2.49	2.67	7%	20%	Excellent
average storm peak (cfs)	3,446	4,962	44%	15%	Poor
summer volume (inches)	1.80	1.65	-8%	15%	Excellent
winter volume (inches)	0.91	1.00	10%	10%	Good
summer storms (inches)	0.50	0.95	88%	10%	Poor
winter storms (inches)	0.20	0.11	-44%	15%	Poor

5.3.2.1.2 Recharge Zone (Downstream Gages)

Figure 5.3.9 compares daily simulated and observed flow at stream gage 8198500 (Sabinal River at Sabinal) for the 5-year period between 1997 and 2001. The graph shows the simulated daily streamflow versus the observed daily streamflow. The flow duration curve, shown in Figure 5.3.10, indicates that the model over predicts the flow in the stream under most flow conditions.

Table 5.3.5 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Sabinal River at Sabinal, USGS #8198500)

Water Year	Precipitation	Simulated Flow	Observed Flow	Percent Error
1997	34.09	4.73	4.88	-3.17
1998	29.85	2.09	1.43	46.12
1999	27.72	1.47	1.04	41.24
2000	16.96	0.04	0.08	-54.50
2001	31.06	3.14	1.96	59.99
Average	27.93	2.29	1.88	-22.00

Table 5.3.6 Daily and Monthly Statistics (Water Years 1997-2001: Sabinal River at Sabinal, USGS #8198500)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	33.51	40.88
Geometric Mean (cfs)	3.10	3.78
Standard Deviation (cfs)	420.38	327.06
Correlation Coefficient	0.95	
Coefficient of Determination	0.90	
Mean Error (cfs)	7.37	
Mean Absolute Error (cfs)	16.20	
Monthly Statistics		
Count	60	60
Mean (cfs)	33.63	40.95
Geometric Mean (cfs)	4.84	6.31
Standard Deviation (cfs)	112.31	109.34
Correlation Coefficient	0.97	
Coefficient of Determination	0.95	
Mean Error (cfs)	7.32	
Mean Absolute Error (cfs)	12.06	

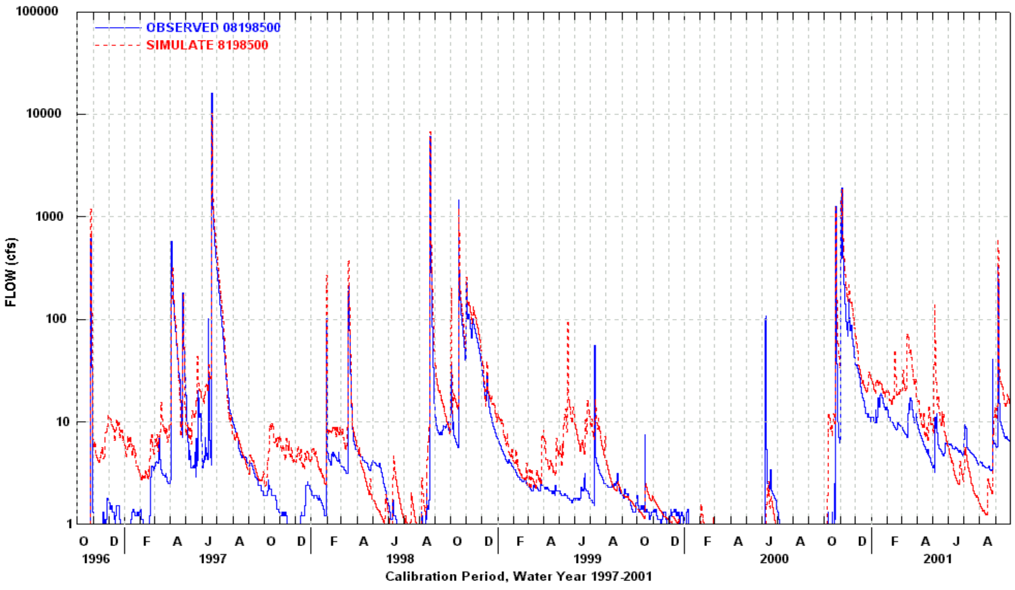


Figure 5.3.9 Daily Streamflow Comparison (Water Years 1997-2001: Sabinal River at Sabinal, USGS #8198500)

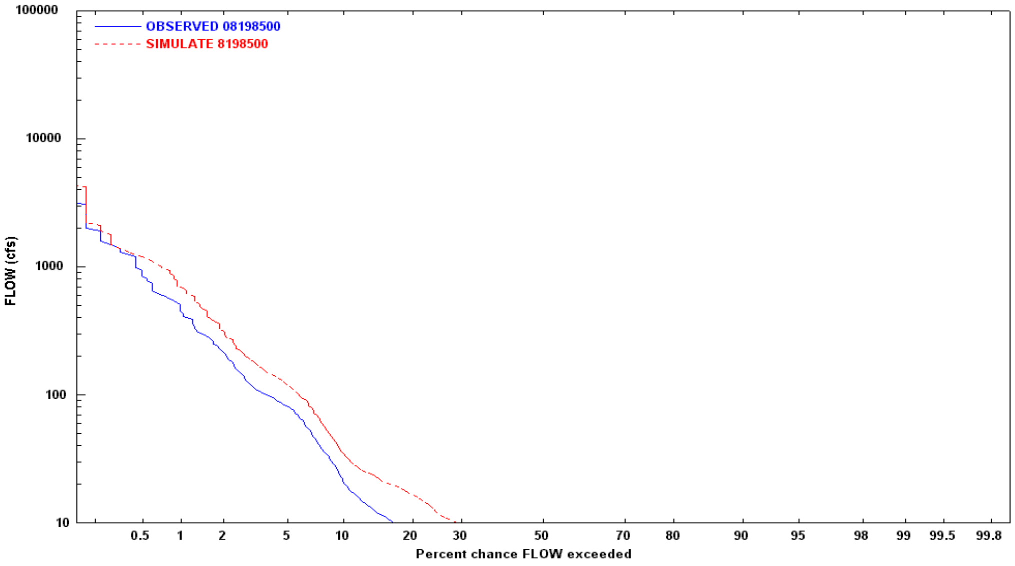


Figure 5.3.10 Daily Streamflow Frequency (Water Years 1997-2001: Sabinal River at Sabinal, USGS #8198500)

Table 5.3.7 Calibration Statistics and Criteria (Water Years 1997-2001: Sabinal River at Sabinal, USGS #8198500)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	1.88	2.29	22%	10%	Poor
10% high (inches)	1.21	1.97	63%	10%	Poor
25% high (inches)	1.66	2.13	28%	15%	Poor
50% Low (inches)	0.03	0.05	51%	15%	Poor
25% Low (inches)	0.01	0.01	-4%	15%	Excellent
10% Low (inches)	0	0	-65%	15%	Poor
storm volume (inches)	1.69	1.98	17%	20%	Good
average storm peak (cfs)	4570.17	5154.9	13%	15%	Good
summer volume (inches)	1.12	1.16	3%	15%	Excellent
winter volume (inches)	0.08	0.17	103%	10%	Poor
summer storms (inches)	0.45	0.62	40%	10%	Poor
winter storms (inches)	0	0	0%	15%	Excellent

5.3.2.2 Water Balance

Table 5.3.8 provides a detailed water balance summary for the Sabinal basin as simulated by the HSPF model. The table indicates that on average, 77% of the precipitation evaporates, and about 4% moves to deep groundwater.

Table 5.3.8 Mean Annual Simulated Water Balance in the Sabinal Basin (Water Years 1997-2001)

		Contributing Zone		Recharge Zone		
Component	**Unit**	**Deep Soil**	**Shallow Soil**	**Deep Soil**	**Shallow Soil**	**Watershed Average**
Rainfall	inch	32.71	32.71	25.94	25.94	**32.41**
Runoff						
Surface	inch	0.12	0.52	0.00	0.16	**0.34**
Interflow	inch	0.34	1.64	0.04	0.98	**1.06**
Baseflow	inch	3.18	3.86	0.02	0.17	**3.42**
Total	inch	3.65	6.03	0.07	1.31	**4.82**
Groundwater Inflow						
Deep	inch	1.56	0.97	4.24	4.05	**1.35**
Active	inch	3.18	3.86	0.02	0.17	**3.42**
Total	inch	4.74	4.83	4.26	4.22	**4.77**
Evaporation						
Potential	inch	59.56	59.56	59.56	59.56	**59.56**
Intercept Stor.	inch	8.18	9.49	7.20	7.44	**8.86**
Upper Zone	inch	3.42	4.52	1.43	2.12	**3.95**
Lower Zone	inch	11.64	10.95	12.19	10.75	**11.25**
Ground Water	inch	2.02	0.00	0.13	0.00	**0.83**
Baseflow	inch	0.72	0.00	0.02	0.00	**0.29**
Total	inch	25.97	24.96	20.96	20.31	**25.19**
Area	acres	63,757	84,480	2,844	3,938	**155,019**
Area	%	41.13	54.50	1.83	2.54	**100.00**

5.4 Area Between Sabinal and Medina

5.4.1 Basin Hydrology and Features

5.4.1.1 Available Data

Figure 5.4.1 shows the map of rivers and streams, major roads, cities, county boundaries, NWS and EAA precipitation gages, USGS stream gages, Edwards aquifer contributing, recharge, and artesian zones, FRSs, and ungaged areas in the area between the Sabinal and Medina basins. Also shown on Figure 5.4.1 are two recharge structures, Seco Creek Dam and Parkers Creek Dam.

Table 5.4.1 summarizes basic hydrologic and modeling information about the basin. Figure 5.4.2 shows the surface geology and mapped geologic faults in the basin. Figures 5.4.3 and 5.4.4 show the hillshade and land cover/vegetation maps. Figure 5.4.5 shows the proportions of different PERLND groups in the basin. Figure 5.4.6 illustrates the delineated subwatersheds within the basin and watershed ID number required for HSPF.

Table 5.4.1 Summary Information for Area Between Sabinal and Medina Basins

Feature or Statistic	Measure	Details
Total area (sq. miles)	325.7	
No. of subwatersheds in model	50	
No. of stream reaches in model	50	
No. of EAA rain gages in basin	9	
Contributing Zone		
Area (sq. miles)	198.6	
Stream length (miles)	68.6	
No. of stream gages above recharge zone	2	
Average subwatershed area (sq. miles)	7.9	Range: 0.035 to 21.25
Average stream reach length (miles)	3.6	Range: 0.017 to 7.55
Recharge Zone		
Area (sq. miles)	86.4	
Stream length (miles) [1]	50.5	
No. stream gages below recharge zone	2	
Average subwatershed area (sq. miles)	2.5	Range: 0.003 to 9.27
Average stream reach length (miles)	1.8	Range: 0.039 to 4.49

[1] Stream length includes only those streams included in the EPA RF1 files

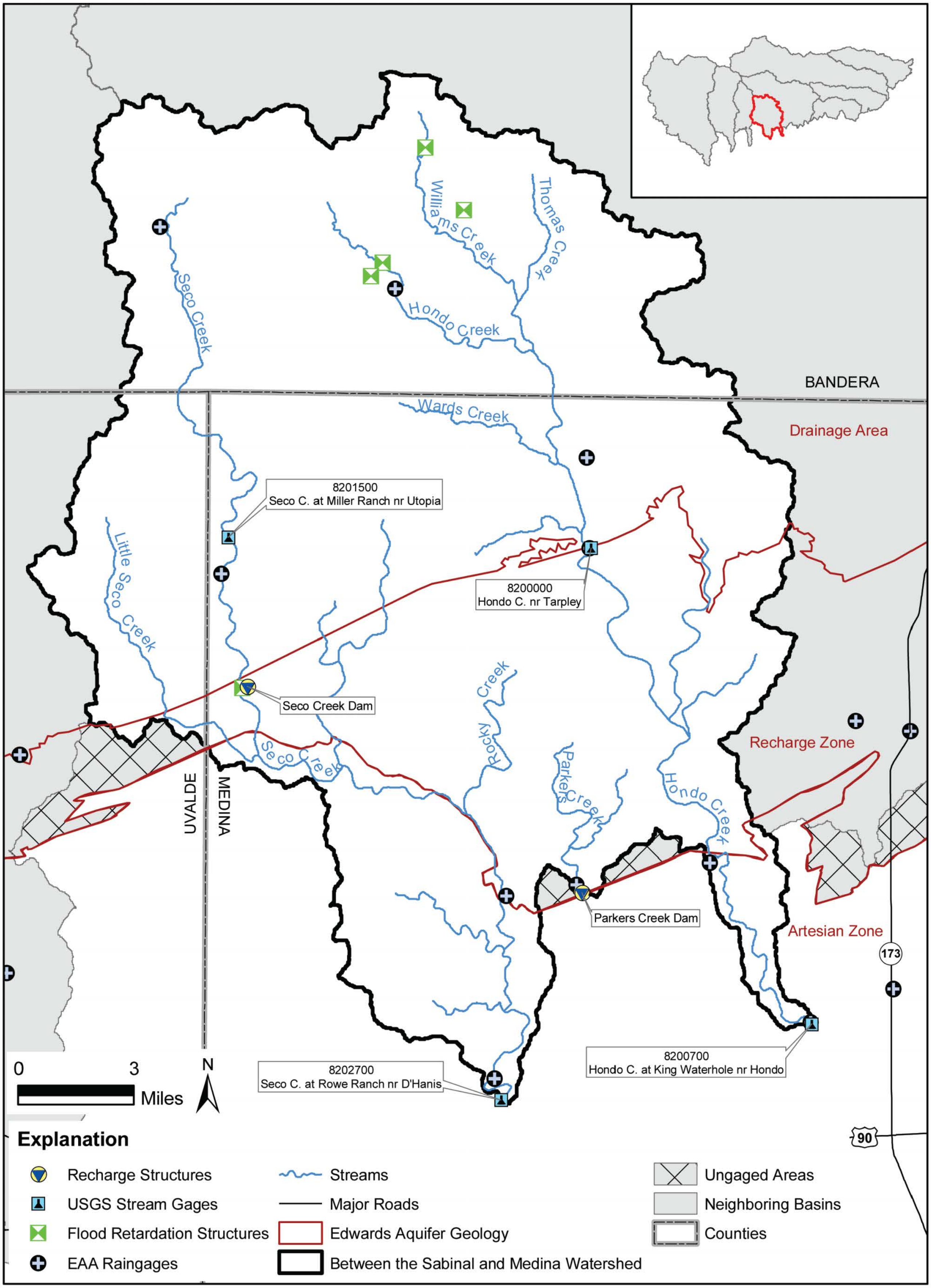


Figure 5.4.1 - Area Between Sabinal and Medina Basins

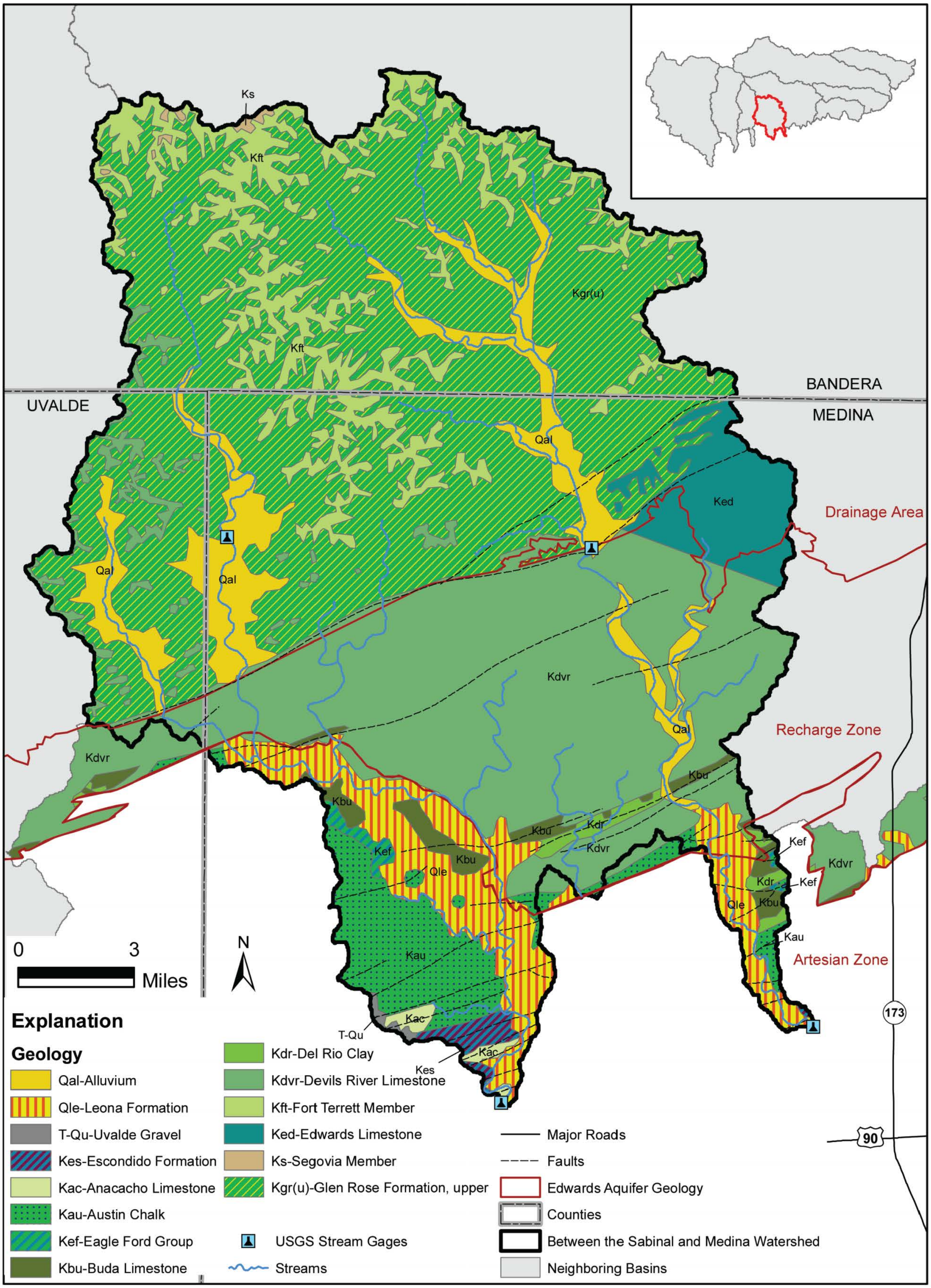


Figure 5.4.2 - Surface Geology in the Area Between Sabinal and Medina Basins

Figure 5.4.3 - Hillshade View in the Area Between Sabinal and Medina Basins

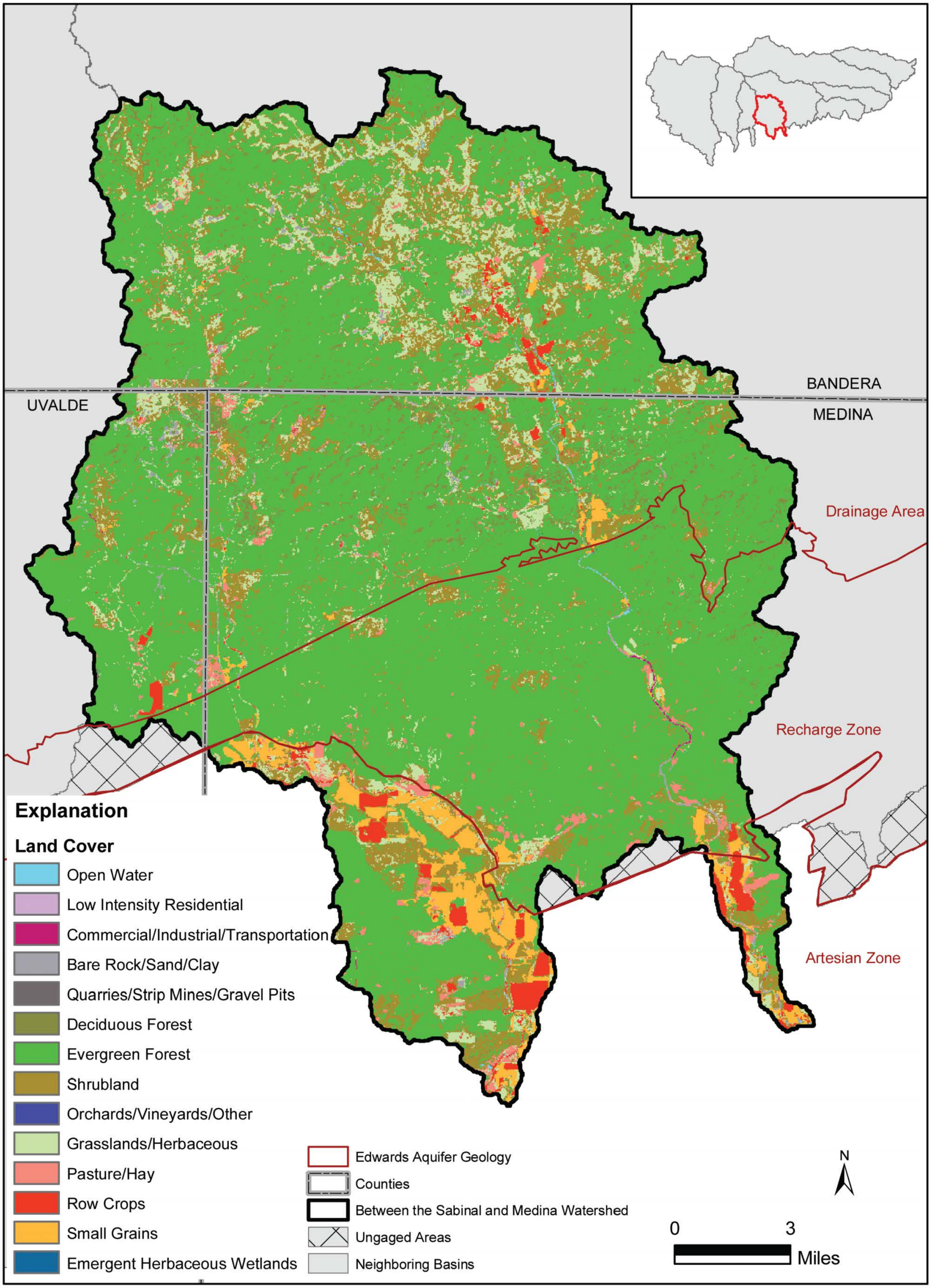


Figure 5.4.4 - Land Cover and Vegetation in the Area Between Sabinal and Medina Basins

Figure 5.4.5 summarizes the proportions of each PERLND group in the basin. It indicates that the largest PERLND components in the contributing zone are flat deep soil areas followed by steep shallow soils. In the recharge zone, by far the dominant land segment are flat and deep soils.

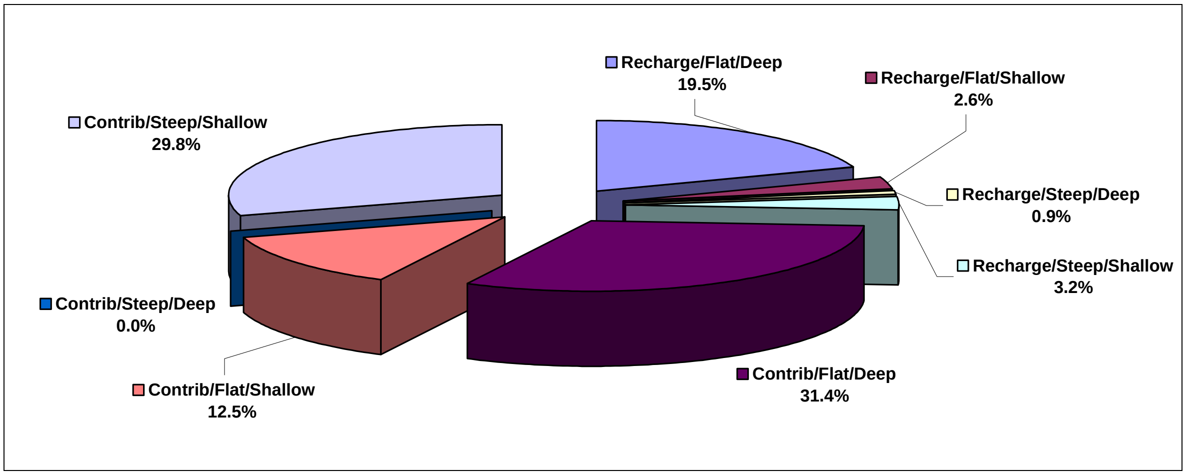


Figure 5.4.5 PERLND Distribution in the Area Between Sabinal and Medina Basins

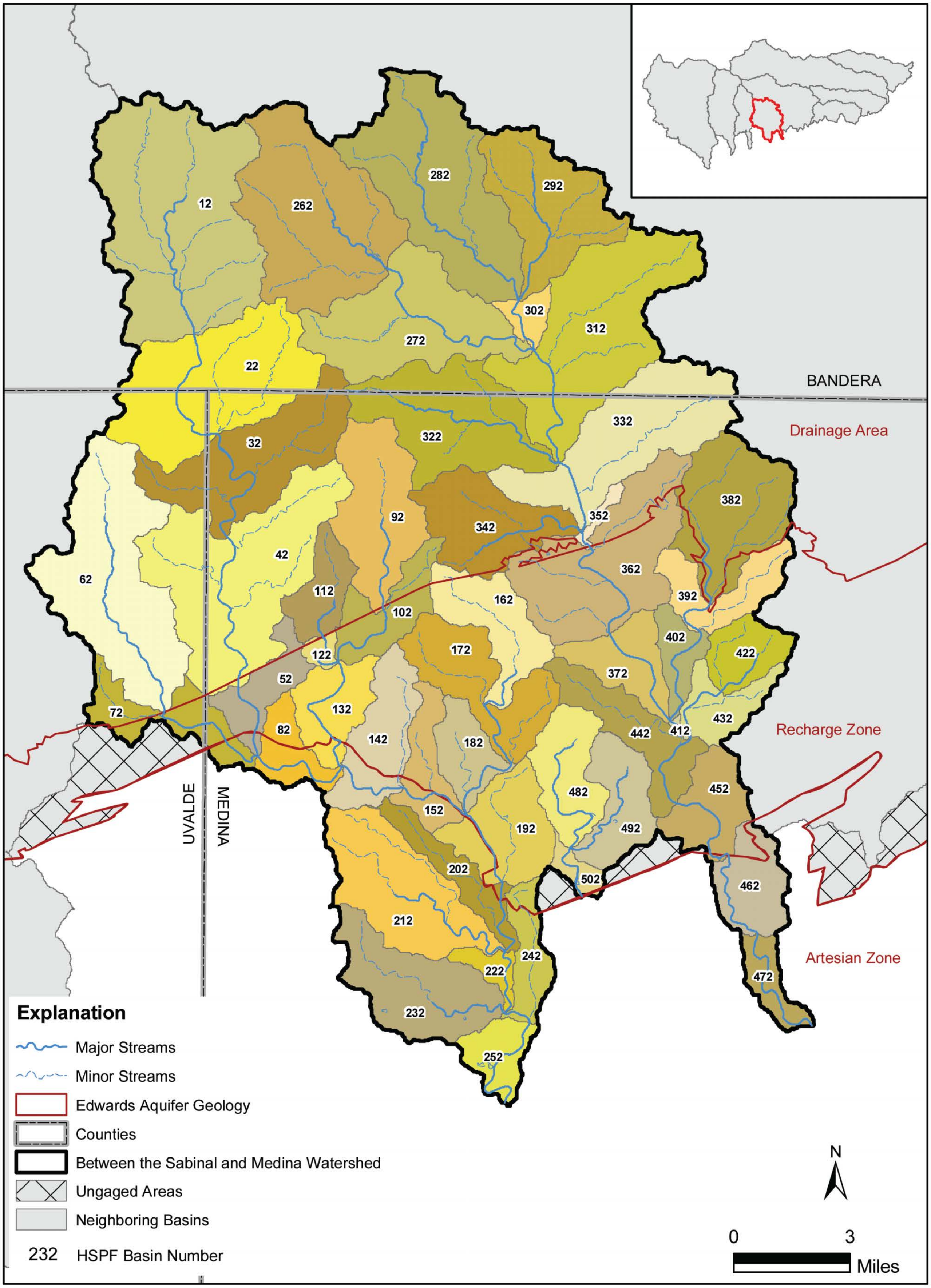


Figure 5.4.6 - Delineated Basins in the Area Between Sabinal and Medina Basins

5.4.2 Model Calibration

5.4.2.1 Streamflow Comparison

5.4.2.1.1 Contributing Zone (Upstream Gages)

Figure 5.4.7 compares daily simulated and observed flow at stream gage 8201500 (Seco Creek at Miller Ranch near Utopia) for the 5-year period between 1997 and 2001. Overall, the agreement between the observed and simulated flow is very good although at very low flows, the model over predicts streamflow. The flow duration curve, shown in Figure 5.4.8, indicates that the model generally simulates flow from the contributing zone relatively well. Tables 5.4.2, 5.4.3, and 5.4.4 provide further statistical information regarding the calibration results for the contributing zone model for Seco Creek.

Figure 5.4.9 compares daily simulated and observed flow at stream gage 8200000 (Hondo Creek near Tarpley) for the 5-year period between 1997 and 2001. Overall, the agreement between the observed and simulated flow is very good. The flow duration curve, shown in Figure 5.4.10, indicates that the model generally simulates flow from the contributing zone relatively well. Tables 5.4.5, 5.4.6, and 5.4.7 provide further statistical information regarding the calibration results for the contributing zone model for Hondo Creek.

Table 5.4.2 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Seco Creek at Miller Ranch near Utopia, USGS # 8201500)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	35.77	6.49	11.40	-43.04
1998	35.46	7.89	5.12	53.99
1999	29.74	7.69	7.57	1.52
2000	22.13	1.50	0.39	286.91
2001	36.68	5.87	5.66	3.73
Average	31.96	5.89	6.03	2.33

Table 5.4.3 Daily and Monthly Statistics (Water Years 1997-2001: Seco Creek at Miller Ranch near Utopia, USGS # 8201500)

	Simulated	**Observed**
Daily Statistics		
Count	1826	1826
Mean (cfs)	20.09	19.62
Geometric Mean (cfs)	5.79	8.14
Standard Deviation (cfs)	126.32	103.12
Correlation Coefficient	0.63	
Coefficient of Determination	0.40	
Mean Error (cfs)	-0.47	
Mean Absolute Error (cfs)	12.92	
Monthly Statistics		
Count	60	60
Mean (cfs)	20.10	19.54
Geometric Mean (cfs)	7.37	9.44
Standard Deviation (cfs)	37.14	35.32
Correlation Coefficient	0.79	
Coefficient of Determination	0.62	
Mean Error (cfs)	-0.56	
Mean Absolute Error (cfs)	10.48	

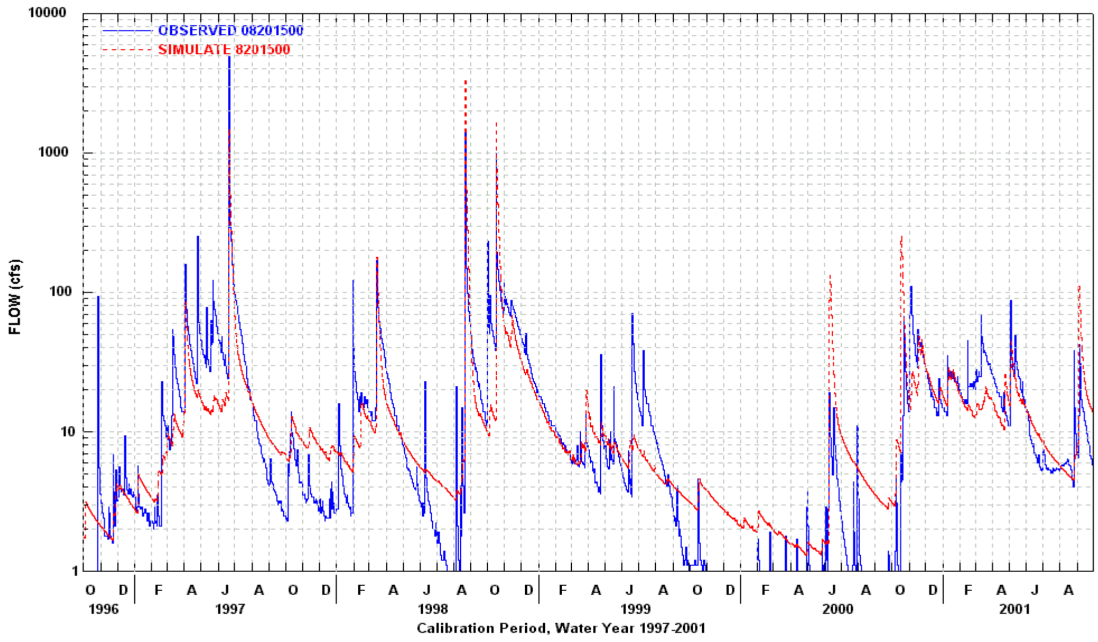


Figure 5.4.7 Daily Streamflow Comparison (Water Years 1997-2001: Seco Creek at Miller Ranch near Utopia, USGS # 8201500)

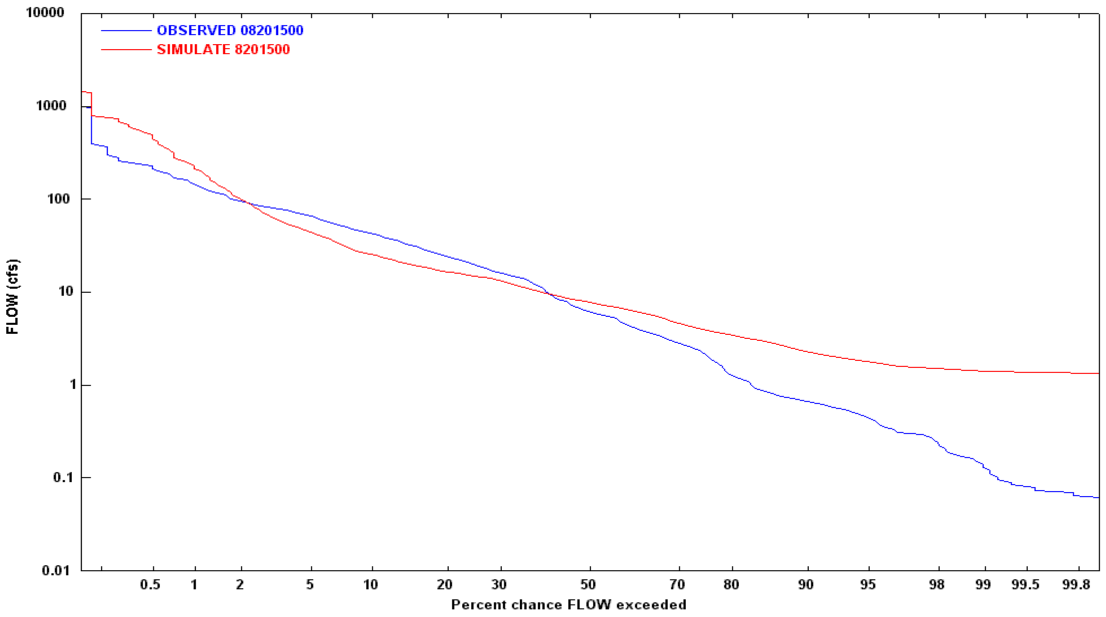


Figure 5.4.8 Daily Streamflow Frequency (Water Years 1997-2001: Seco Creek at Miller Ranch near Utopia, USGS # 8201500)

Table 5.4.4 Calibration Statistics and Criteria (Water Years 1997-2001: Seco Creek at Miller Ranch near Utopia, USGS # 8201500)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	6.03	5.89	-2%	10%	Excellent
10% high (inches)	2.73	3.62	32%	10%	Poor
25% high (inches)	4.69	4.45	-5%	15%	Excellent
50% Low (inches)	0.36	0.63	77%	15%	Poor
25% Low (inches)	0.06	0.19	210%	15%	Poor
10% Low (inches)	0.01	0.05	340%	15%	Poor
storm volume (inches)	2.69	3.08	14%	20%	Good
average storm peak (cfs)	1530.40	6271.04	310%	15%	Poor
summer volume (inches)	2.25	2.35	5%	15%	Excellent
winter volume (inches)	0.92	0.77	-17%	10%	OK
summer storms (inches)	0.48	1.03	114%	10%	Poor
winter storms (inches)	0.00	0.04	886%	15%	N/A

Table 5.4.5 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Hondo Creek near Tarpley, USGS #8200000)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	36.77	6.73	11.20	-39.91
1998	36.45	7.99	4.84	65.17
1999	30.58	7.92	7.05	12.33
2000	22.75	1.61	0.15	974.33
2001	37.71	6.10	7.92	-23.00
Average	32.85	6.07	6.23	2.61

Table 5.4.6 Daily and Monthly Statistics (Water Years 1997-2001: Hondo Creek near Tarpley, USGS #8200000)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	44.05	42.90
Geometric Mean (cfs)	7.82	18.21
Standard Deviation (cfs)	282.11	218.00
Correlation Coefficient	0.61	
Coefficient of Determination	0.37	
Mean Error (cfs)	-1.15	
Mean Absolute Error (cfs)	25.23	
Monthly Statistics		
Count	60	60
Mean (cfs)	44.10	42.76
Geometric Mean (cfs)	10.63	21.10
Standard Deviation (cfs)	80.88	74.87
Correlation Coefficient	0.76	
Coefficient of Determination	0.58	
Mean Error (cfs)	-1.34	
Mean Absolute Error (cfs)	23.26	

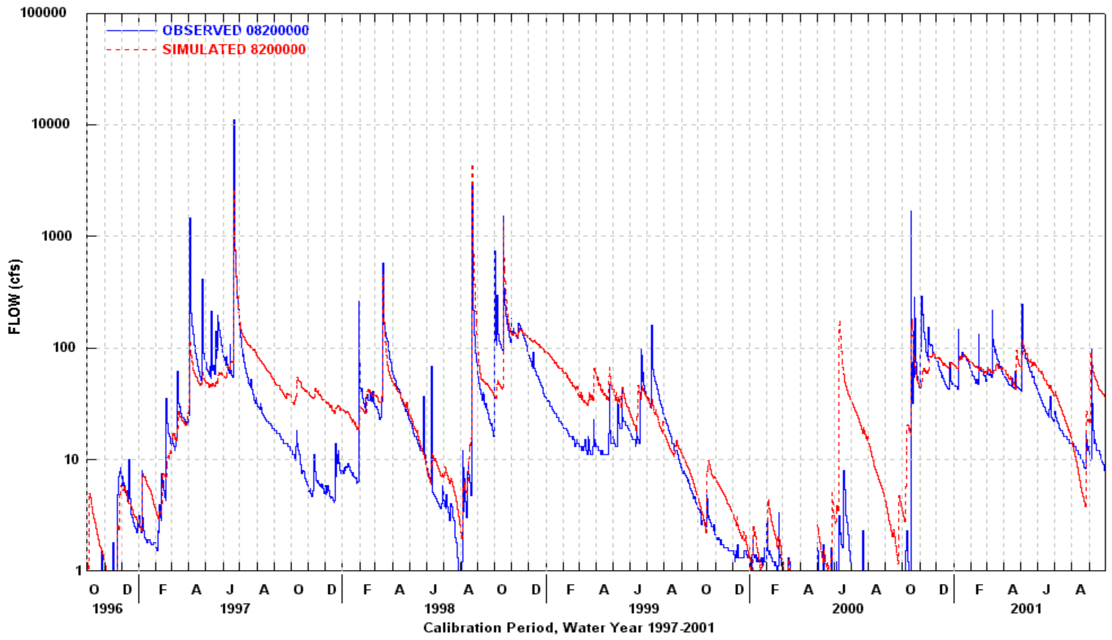


Figure 5.4.9 Daily Streamflow Comparison (Water Years 1997-2001: Hondo Creek near Tarpley, USGS #8200000)

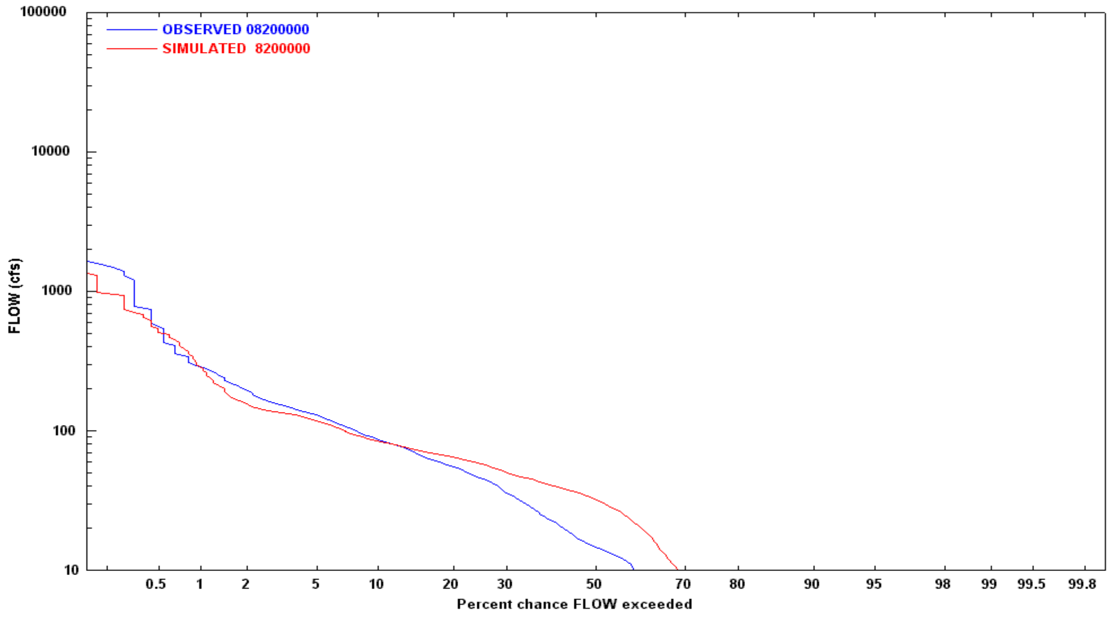


Figure 5.4.10 Daily Streamflow Frequency (Water Years 1997-2001: Hondo Creek near Tarpley, USGS #8200000)

Table 5.4.7 Calibration Statistics and Criteria (Water Years 1997-2001: Hondo Creek near Tarpley, USGS #8200000)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	6.23	6.07	-3%	10%	Excellent
10% high (inches)	2.83	3.67	30%	10%	Poor
25% high (inches)	4.80	4.55	-5%	15%	Excellent
50% Low (inches)	0.31	0.66	110%	15%	Poor
25% Low (inches)	0.03	0.20	583%	15%	Poor
10% Low (inches)	0.00	0.06	4740%	15%	N/A
storm volume (inches)	3.08	3.28	6%	20%	Excellent
average storm peak (cfs)	3234.17	10561.56	227%	15%	Poor
summer volume (inches)	2.20	2.38	8%	15%	Excellent
winter volume (inches)	0.99	0.81	-18%	10%	OK
summer storms (inches)	0.42	1.04	148%	10%	Poor
winter storms (inches)	0.29	0.22	-25%	15%	OK

5.4.2.1.2 Recharge Zone (Downstream Gages)

Figure 5.4.11 compares daily simulated and observed flow at stream gage 8202700 (Seco Creek at Rowe Ranch near D'Hanis) for the 5-year period between 1997 and 2001. The graph shows the simulated daily streamflow versus the observed daily streamflow. As shown on the graph, there is no flow in Seco creek for much of the year and baseflow is virtually nonexistent. The flow duration curve, shown in Figure 5.4.12, indicates that the model generally over estimates the streamflow. Tables 5.4.8, 5.4.9, and 5.4.10 provide further statistical information regarding the calibration results. Observed flow in Seco Creek at Rowe Ranch tends to be flashier than the model is currently simulating.

Figure 5.4.13 compares daily simulated and observed flow at stream gage 8200700 (Hondo Creek at King Waterhole near Hondo) for the 5-year period between 1997 and 2001. The graph shows the simulated daily streamflow versus the observed daily streamflow. The flow duration curve, shown in Figure 5.4.14, indicates that the model over predicts the flow in the stream under most flow conditions. Tables 5.4.11, 5.4.12, and 5.4.13 provide further statistical information regarding the calibration results for the contributing zone model for Hondo Creek. The flow duration curve, shown in the bottom graph This could be an indication that channel losses are greater than currently estimated.

Table 5.4.8 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Seco Creek at Rowe Ranch near D'Hanis, USGS #8202700)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	35.77	2.08	2.84	-26.77
1998	35.46	2.01	1.09	83.77
1999	29.74	1.55	0.86	80.24
2000	22.13	0.00	0.00	0.00
2001	36.68	0.07	0.20	-64.41
Average	31.96	1.14	1.00	-14.44

Table 5.4.9 Daily and Monthly Statistics (Water Years 1997-2001: Seco Creek at Rowe Ranch near D'Hanis, USGS #8202700)

	Simulated	**Observed**
Daily Statistics		
Count	1826	1826
Mean (cfs)	12.18	13.94
Geometric Mean (cfs)	0.00	0.00
Standard Deviation (cfs)	306.62	189.41
Correlation Coefficient	0.81	
Coefficient of Determination	0.66	
Mean Error (cfs)	1.76	
Mean Absolute Error (cfs)	12.40	
Monthly Statistics		
Count	60	60
Mean (cfs)	12.18	13.86
Geometric Mean (cfs)	0.00	0.01
Standard Deviation (cfs)	57.59	58.55
Correlation Coefficient	0.91	
Coefficient of Determination	0.83	
Mean Error (cfs)	1.67	
Mean Absolute Error (cfs)	6.28	

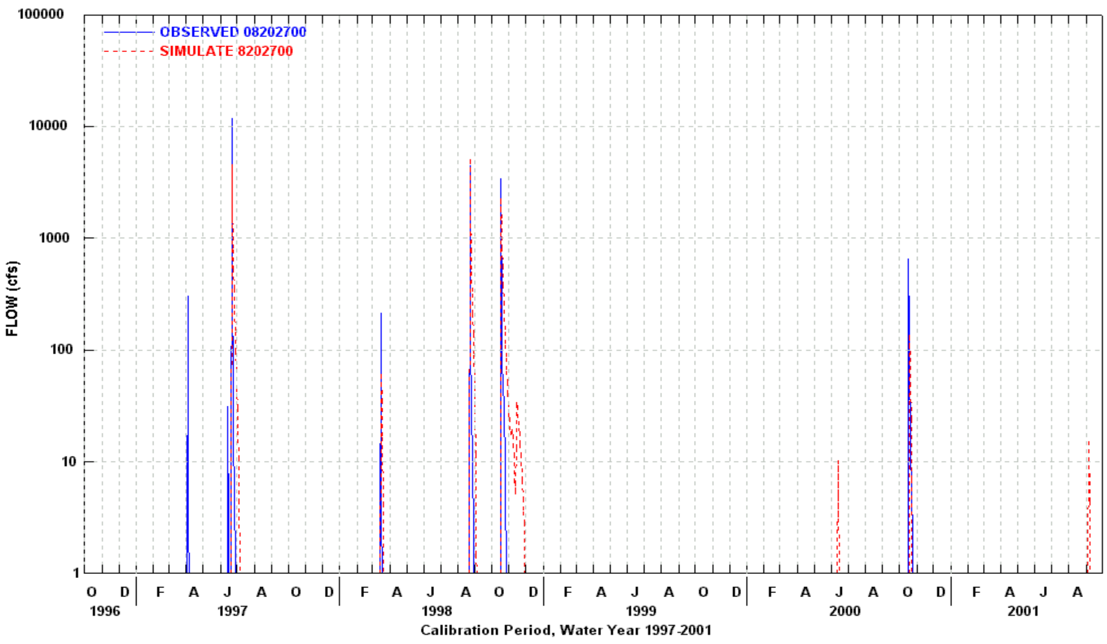


Figure 5.4.11 Daily Streamflow Comparison (Water Years 1997-2001: Seco Creek at Rowe Ranch near D'Hanis, USGS #8202700)

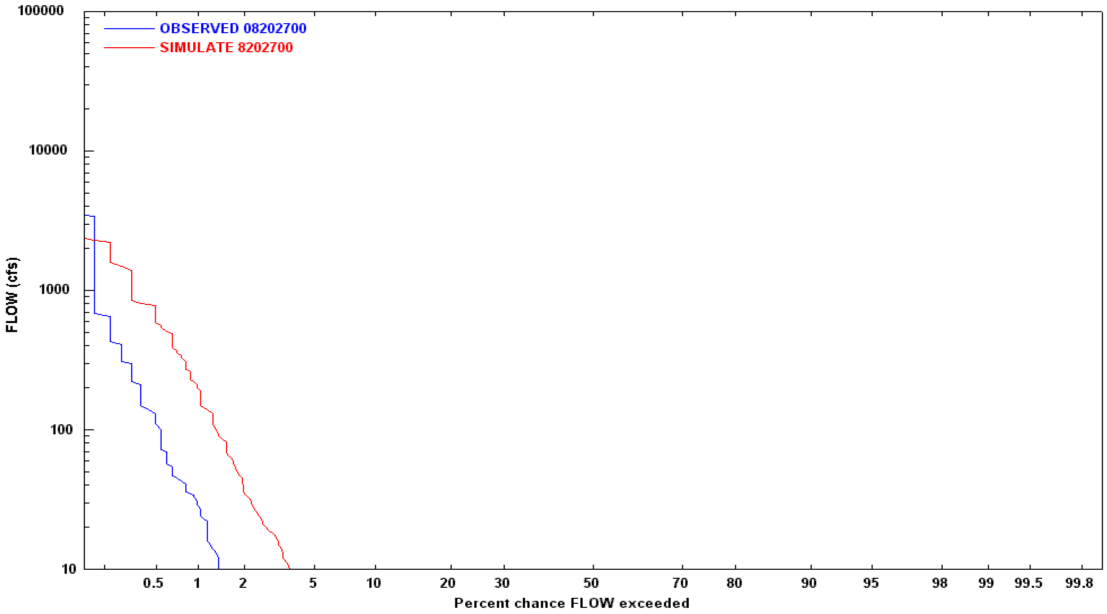


Figure 5.4.12 Daily Streamflow Frequency (Water Years 1997-2001: Seco Creek at Rowe Ranch near D'Hanis, USGS #8202700)

Table 5.4.10 Calibration Statistics and Criteria (Water Years 1997-2001: Seco Creek at Rowe Ranch near D'Hanis, USGS #8202700)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	1.00	1.14	14%	10%	OK
10% high (inches)	0.47	1.14	144%	10%	Poor
25% high (inches)	0.94	1.14	22%	15%	OK
50% Low (inches)	0.00	0.00	0%	15%	Excellent
25% Low (inches)	0.00	0.00	0%	15%	Excellent
10% Low (inches)	0.00	0.00	0%	15%	Excellent
storm volume (inches)	0.99	1.10	12%	20%	Excellent
average storm peak (cfs)	4135.40	6326.20	53%	15%	Poor
summer volume (inches)	0.76	0.81	7%	15%	Excellent
winter volume (inches)	0.01	0.01	-37%	10%	Poor
summer storms (inches)	0.76	0.81	6%	10%	Good
winter storms (inches)	0.00	0.00	0%	15%	Excellent

Table 5.4.11 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Hondo Creek at King Waterhole near Hondo, USGS #8200700)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	36.77	4.23	4.24	-0.36
1998	36.45	1.71	1.06	61.06
1999	30.58	1.18	0.66	78.33
2000	22.75	0.01	0.00	0.00
2001	37.71	0.44	0.80	-45.05
Average	32.85	1.51	1.35	-11.81

Table 5.4.12 Daily and Monthly Statistics (Water Years 1997-2001: Hondo Creek at King Waterhole near Hondo, USGS #8200700)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	14.91	16.67
Geometric Mean (cfs)	0.00	0.24
Standard Deviation (cfs)	347.99	263.11
Correlation Coefficient	0.94	
Coefficient of Determination	0.88	
Mean Error (cfs)	1.76	
Mean Absolute Error (cfs)	10.97	
Monthly Statistics		
Count	60	60
Mean (cfs)	14.94	16.68
Geometric Mean (cfs)	0.00	0.40
Standard Deviation (cfs)	71.38	72.54
Correlation Coefficient	0.97	
Coefficient of Determination	0.94	
Mean Error (cfs)	1.73	
Mean Absolute Error (cfs)	4.95	

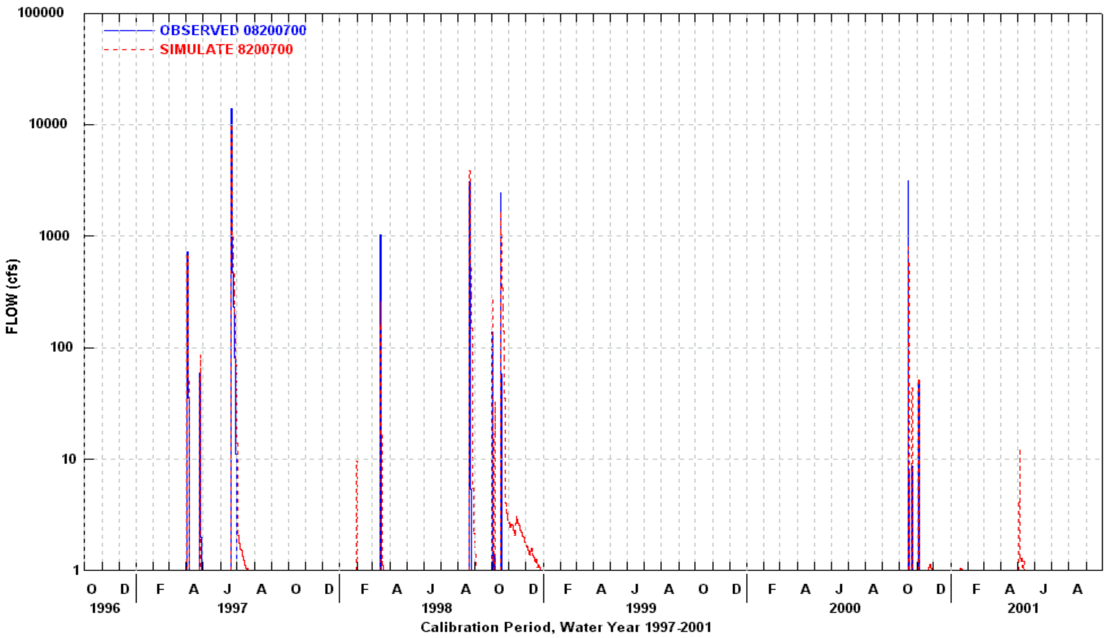


Figure 5.4.13 Daily Streamflow Comparison (Water Years 1997-2001: Hondo Creek at King Waterhole near Hondo, USGS #8200700)

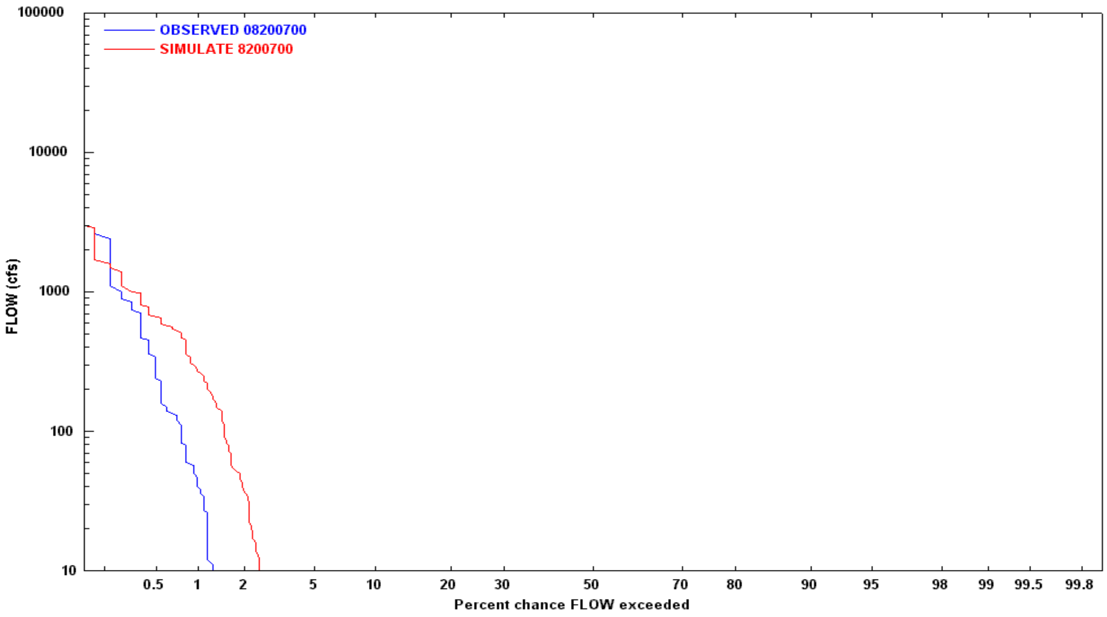


Figure 5.4.14 Daily Streamflow Frequency (Water Years 1997-2001: Hondo Creek at King Waterhole near Hondo, USGS #8200700)

Table 5.4.13 Calibration Statistics and Criteria (Water Years 1997-2001: Hondo Creek at King Waterhole near Hondo, USGS #8200700)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	1.35	1.51	12%	10%	Good
10% high (inches)	0.66	1.49	125%	10%	Poor
25% high (inches)	1.26	1.50	19%	15%	Good
50% Low (inches)	0.00	0.00	0%	15%	Excellent
25% Low (inches)	0.00	0.00	0%	15%	Excellent
10% Low (inches)	0.00	0.00	0%	15%	Excellent
storm volume (inches)	1.34	1.40	5%	20%	Excellent
average storm peak (cfs)	4059.17	4676.96	15%	15%	Good
summer volume (inches)	0.96	1.09	13%	15%	Good
winter volume (inches)	0.05	0.03	-41%	10%	Poor
summer storms (inches)	0.96	1.07	12%	10%	Good
winter storms (inches)	0.05	0.02	-59%	15%	Poor

5.4.2.2 Water Balance

Table 5.4.14 provides a detailed water balance summary for the Area between Sabinal and Medina basins as simulated by the HSPF model.

Table 5.4.14 Mean Annual Simulated Water Balance in the Area Between Sabinal and Medina Basins (Water Years 1997-2001)

		Contributing Zone		Recharge Zone		
Component	**unit**	**Deep Soil**	**Shallow Soil**	**Deep Soil**	**Shallow Soil**	**Watershed Average**
Rainfall	inch	29.58	29.72	29.68	29.67	**29.67**
Runoff						
Surface	inch	0.24	0.79	0.04	0.43	**0.46**
Interflow	inch	0.55	1.95	0.23	1.73	**1.18**
Baseflow	inch	1.93	3.16	0.02	0.17	**2.02**
Total	inch	2.72	5.90	0.29	2.33	**3.66**
Groundwater Inflow						
Deep	inch	1.17	0.80	5.53	4.86	**2.00**
Active	inch	1.93	3.16	0.02	0.17	**2.02**
Total	inch	3.10	3.96	5.55	5.02	**4.02**
Evaporation						
Potential	inch	59.56	59.56	59.56	59.56	**59.56**
Intercept Stor.	inch	7.57	8.21	8.44	8.72	**8.08**
Upper Zone	inch	2.67	3.51	1.80	2.36	**2.86**
Lower Zone	inch	11.61	10.62	12.62	11.01	**11.32**
Ground Water	inch	2.02	0.00	0.13	0.00	**0.68**
Baseflow	inch	0.59	0.00	0.01	0.00	**0.20**
Total	inch	24.46	22.34	23.01	22.10	**23.13**
Area	acres	65,612	88,183	35,897	12,044	**201,736**
Area	%	32.52	43.71	17.79	5.97	**100.00**

5.5 Medina

5.5.1 Basin Hydrology and Features

Figure 5.5.1 shows the map of rivers and streams, major roads, cities, county boundaries, NWS and EAA precipitation gages, USGS stream gages, Edwards aquifer contributing, recharge, and artesian zones, FRSs, and ungaged areas in the Medina Basin. Also shown on Figure 5.5.1 is the Verde Creek Dam, a recharge structure located on Verde Creek in the southwest corner of the Medina basin. Medina Lake is also located in the southern portion of the basin and partially overlies the northern part of the Edwards aquifer recharge zone.

Table 5.5.1 summarizes basic hydrologic and modeling information about the basin. Figure 5.5.2 shows the surface geology and mapped geologic faults in the basin. Figures 5.5.3 and 5.5.4 show the hillshade and land cover/vegetation maps. Figure 5.5.5 shows the proportions of different PERLND groups in the basin. Figure 5.5.6 illustrates the delineated subwatersheds within the basin and watershed ID number required for HSPF.

Table 5.5.1 Summary Information for Medina Basin

Feature or Statistic	Measure	Details
Total area (sq. miles)	708.9	
No. of subwatersheds in model	67	
No. of stream reaches in model	67	
No. of EAA rain gages in basin	12	
Contributing Zone		
Area (sq. miles)	683.7	
Stream length (miles)	233.7	
No. of stream gages above recharge zone	1	
Average subwatershed area (sq. miles)	13.9	Range: 0.005 to 43.84
Average stream reach length (miles)	2.4	Range: 1.500 to 11.89
Recharge Zone		
Area (sq. miles)	95.2	
Stream length (miles) [1]	53.5	
No. stream gages below recharge zone	2	
Average subwatershed area (sq. miles)	2.8	Range: 0.002 to 13.41
Average stream reach length (miles)	1.8	Range: 0.012 to 4.44

[1] Stream length includes only those streams included in the EPA RF1 files

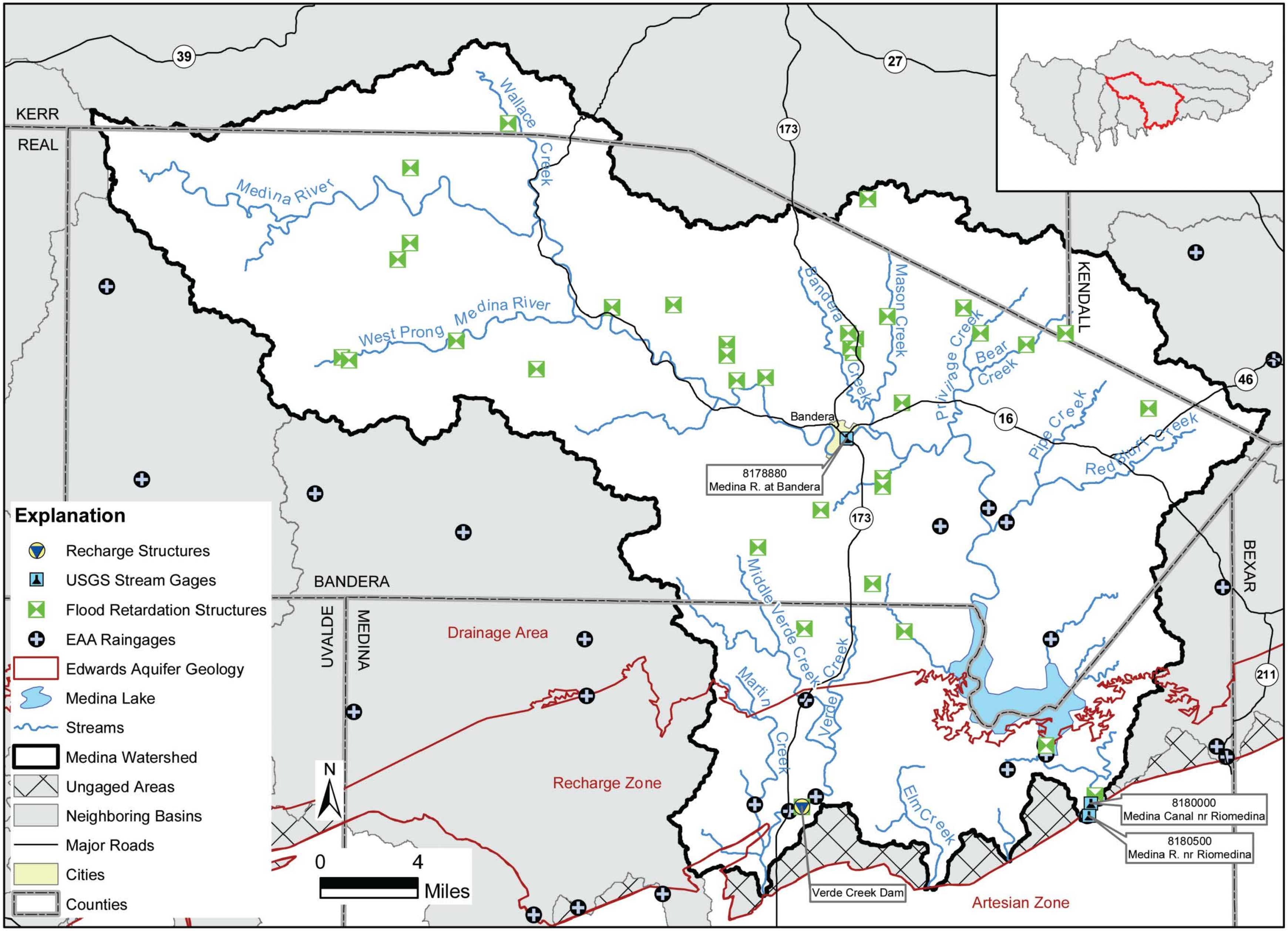


Figure 5.5.1 - Medina Basin

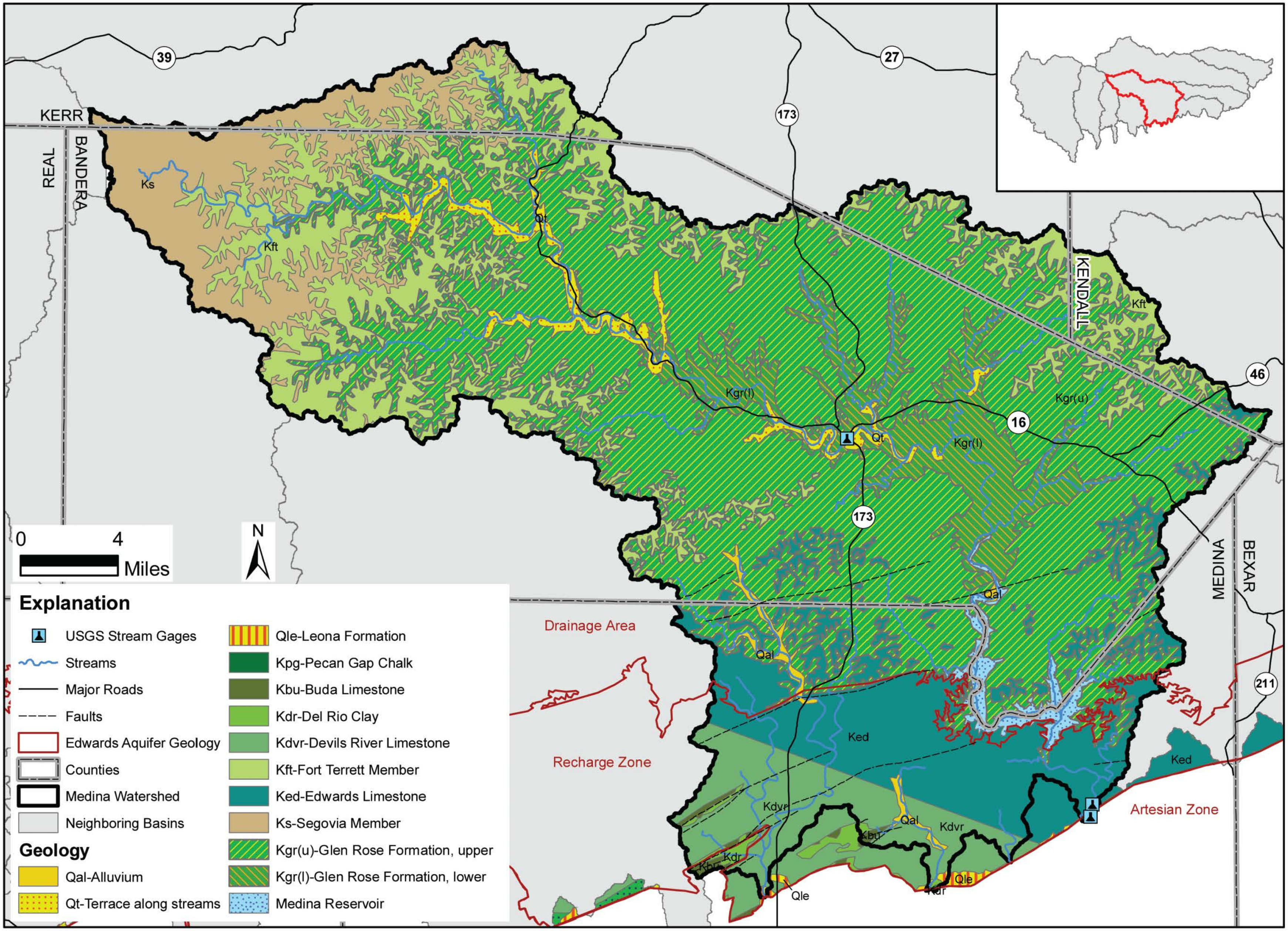


Figure 5.5.2 - Surface Geology in the Medina Basin

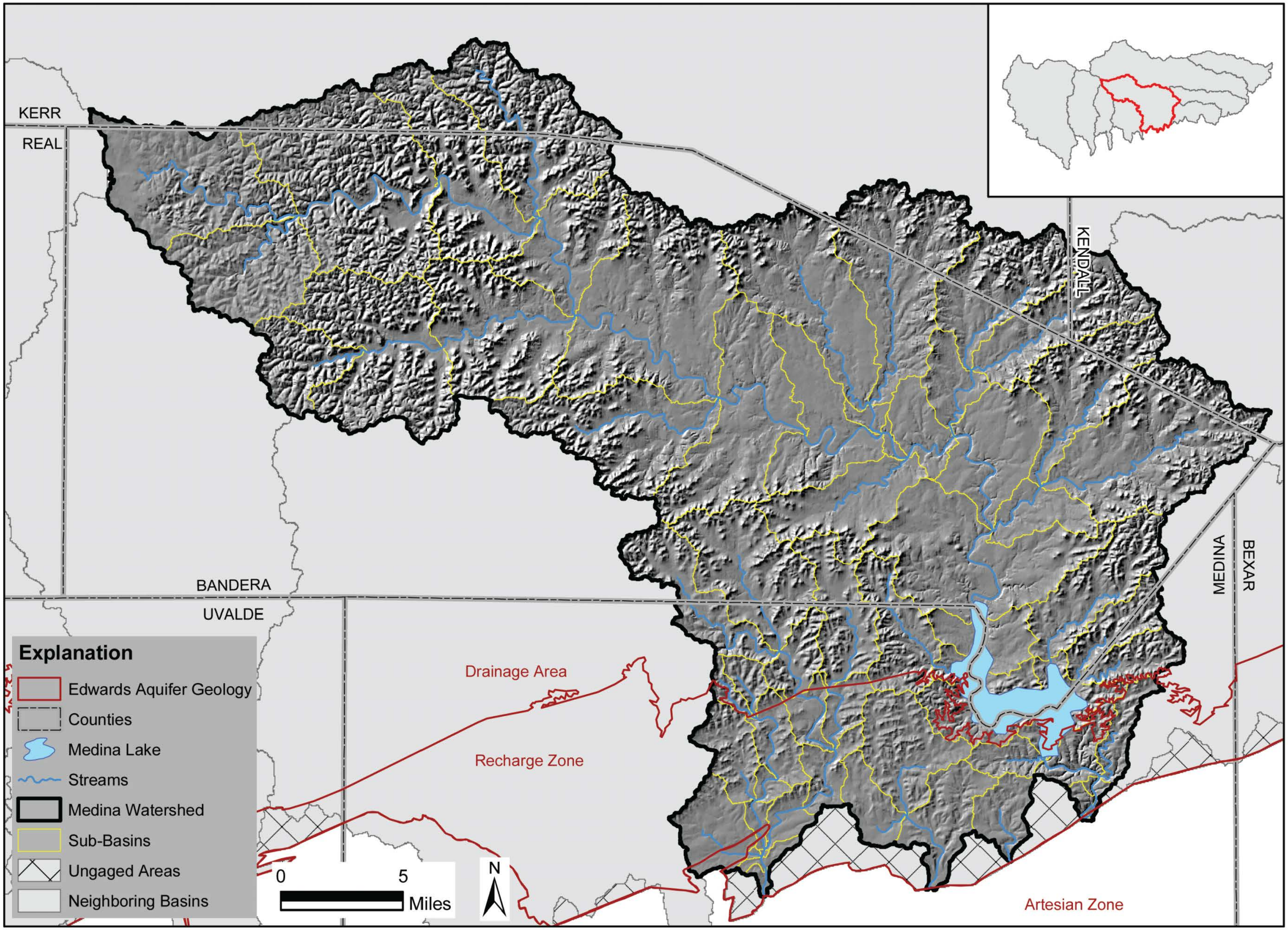


Figure 5.5.3 - Hillshade View in the Medina Basin

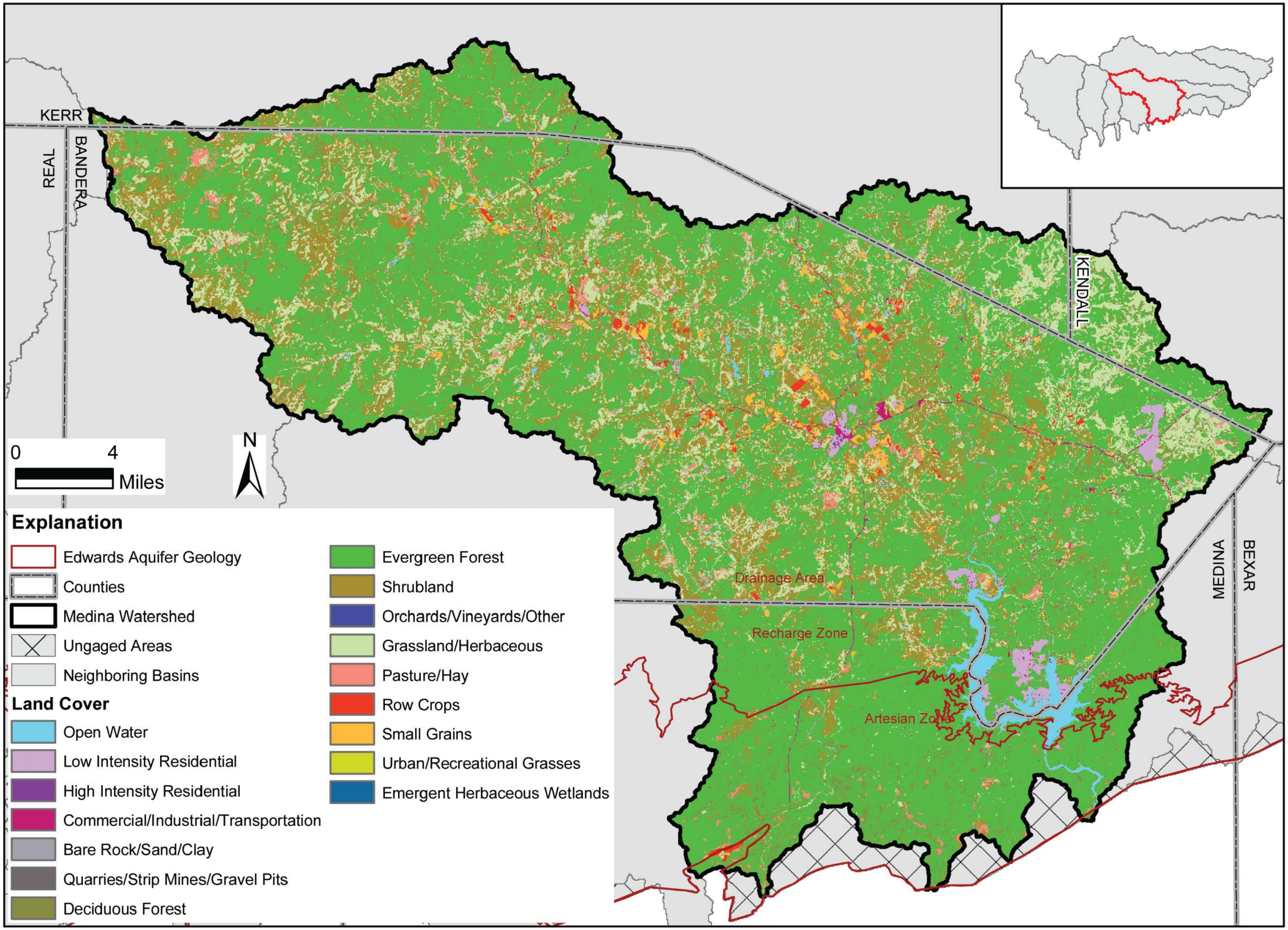


Figure 5.5.4 - Land Cover and Vegetation in the Medina Basin

Figure 5.5.5 summarizes the proportions of each PERLND group in the Medina basin. The pie chart illustrates that the largest PERLND components in the contributing zone are steep shallow soil areas followed by flat shallow soils. In the recharge zone, the dominant land segment is flat and deep soils.

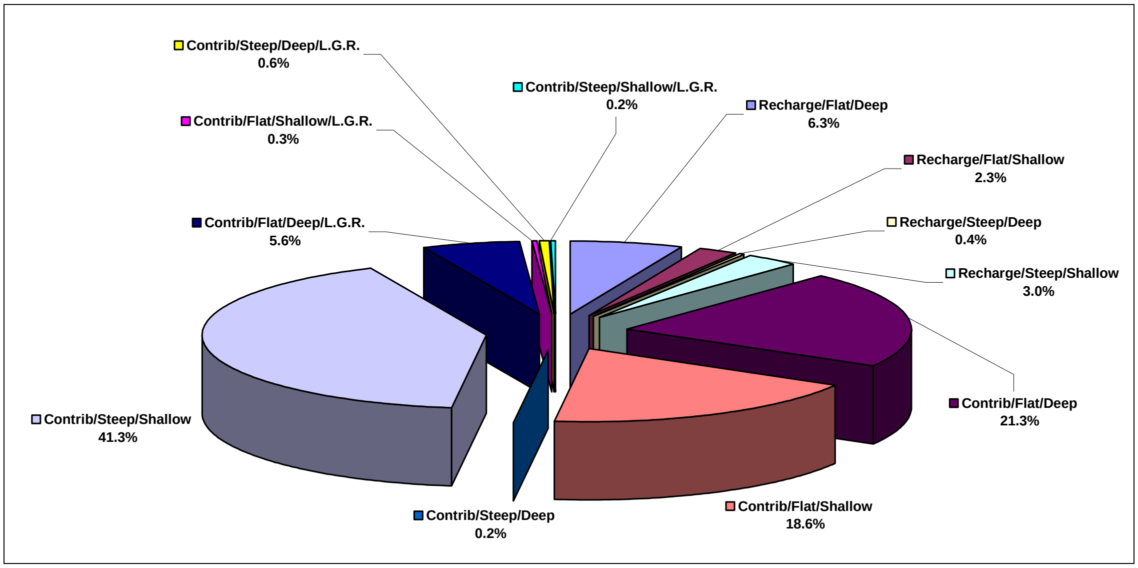


Figure 5.5.5 PERLND Distribution in the Medina Basin

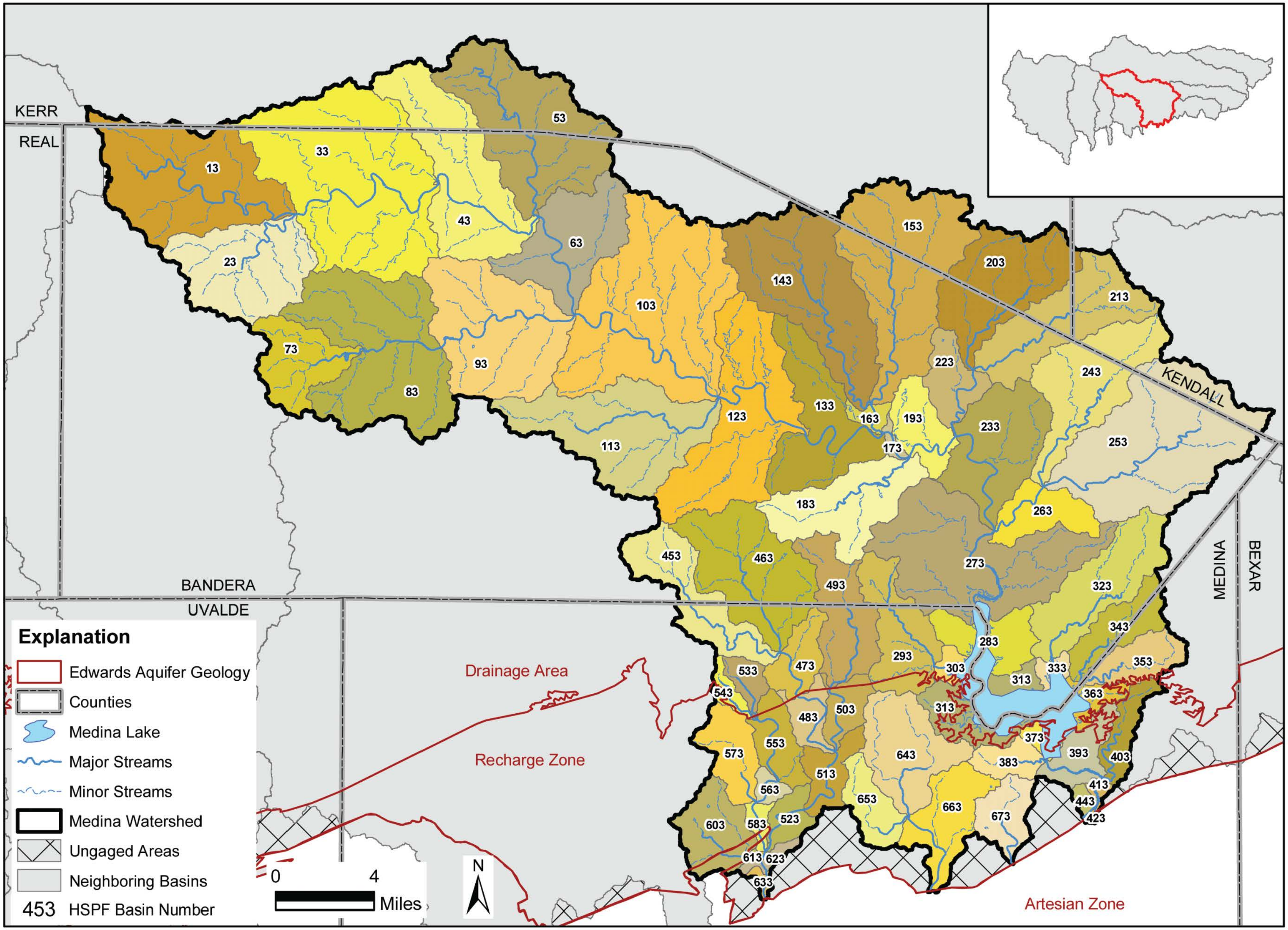


Figure 5.5.6 - Delineated Basins in the Medina Basin

5.5.2 Model Calibration

5.5.2.1 Streamflow Comparison

5.5.2.1.1 Contributing Zone (Upstream Gages)

Figure 5.5.7 compares daily simulated and observed flow at stream gage 8178880 (Medina River at Bandera) for the 5-year period between 1997 and 2001. The agreement between the observed and simulated flow is very good. The flow duration curve, shown in Figure 5.5.8, indicates that the model generally simulates flow from the contributing zone relatively well except for very low flow conditions. Tables 5.5.2, 5.5.3, and 5.5.4 provide further statistical information regarding the calibration results.

Table 5.5.2 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Medina River at Bandera, USGS #8178880)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	38.96	9.08	7.89	15.14
1998	28.31	3.25	3.83	-15.05
1999	25.76	4.18	4.60	-9.21
2000	19.21	0.71	0.71	0.03
2001	37.72	7.02	8.40	-16.35
Average	29.99	4.85	5.08	4.64

Table 5.5.3 Daily and Monthly Statistics (Water Years 1997-2001: Medina River at Bandera, USGS #8178880)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	145.80	139.03
Geometric Mean (cfs)	64.70	80.87
Standard Deviation (cfs)	485.47	248.11
Correlation Coefficient	0.57	
Coefficient of Determination	0.33	
Mean Error (cfs)	-6.77	
Mean Absolute Error (cfs)	73.76	
Monthly Statistics		
Count	60	60
Mean (cfs)	146.18	139.43
Geometric Mean (cfs)	78.63	86.83
Standard Deviation (cfs)	184.55	162.22
Correlation Coefficient	0.89	
Coefficient of Determination	0.79	
Mean Error (cfs)	-6.76	
Mean Absolute Error (cfs)	51.94	

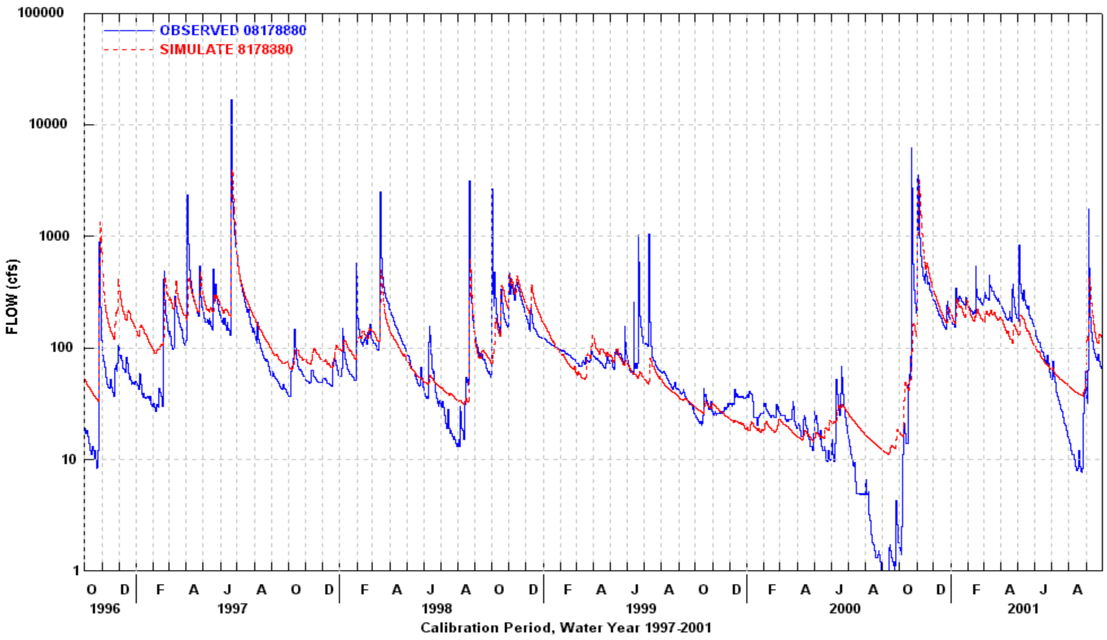


Figure 5.5.7 Daily Streamflow Comparison (Water Years 1997-2001: Medina River at Bandera, USGS #8178880)

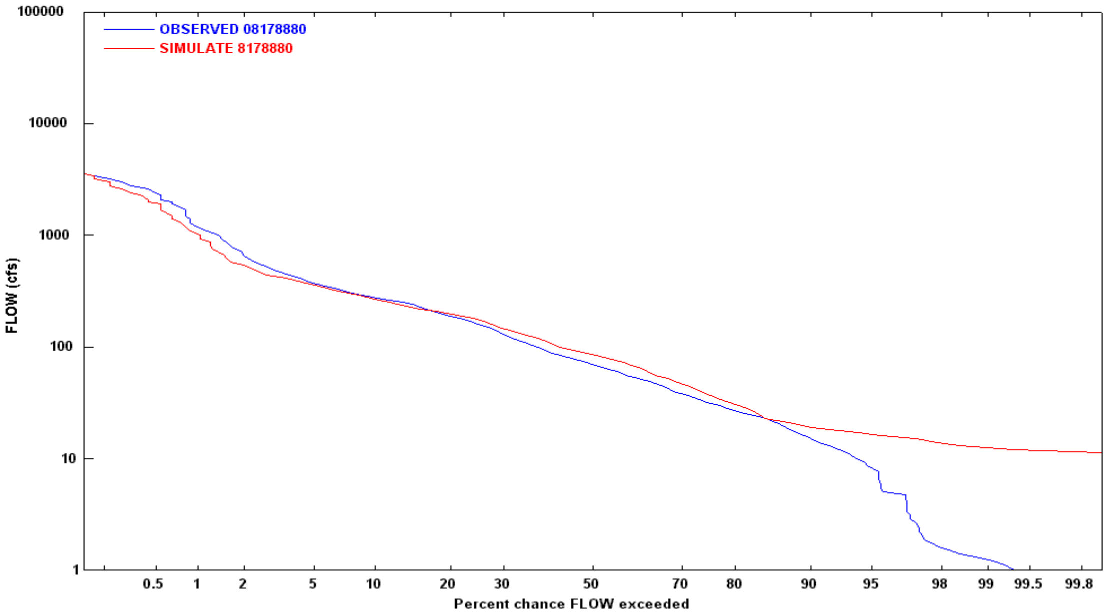


Figure 5.5.8 Daily Streamflow Frequency (Water Years 1997-2001: Medina River at Bandera, USGS #8178880)

Table 5.5.4 Calibration Statistics and Criteria (Water Years 1997-2001: Medina River at Bandera, USGS #8178880)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	4.75	4.53	-5%	10%	Excellent
10% high (inches)	2.04	1.83	-10%	10%	Good
25% high (inches)	3.30	2.87	-13%	15%	Good
50% Low (inches)	0.54	0.68	27%	15%	Poor
25% Low (inches)	0.14	0.18	33%	15%	Poor
10% Low (inches)	0.02	0.05	122%	15%	Poor
storm volume (inches)	2.56	2.08	-18%	20%	Good
average storm peak (cfs)	3315.46	1116.36	66%	15%	Poor
summer volume (inches)	1.28	1.06	-17%	15%	Good
winter volume (inches)	1.03	1.04	1%	10%	Excellent
summer storms (inches)	0.27	0.20	-27%	10%	Poor
winter storms (inches)	0.24	0.27	12%	15%	Good

5.5.2.1.2 Recharge Zone (Downstream Gages)

Figure 5.5.9 compares daily simulated and observed flow at stream gage 8178880 (Medina River near Rio Medina) for the 5-year period between 1997 and 2001. The agreement between the observed and simulated flow is not satisfactory. Apparently, there are operations associated with Medina Lake and the irrigation district that the model does not account for. The flow duration curve, shown in Figure 5.5.10, indicates that the model could be improved. Tables 5.5.5, 5.5.6, and 5.5.7 provide further statistical information regarding the calibration results.

Table 5.5.5 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Medina River near Riomedina, USGS #8180500)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	38.96	0.05	0.00	N/A
1998	28.31	0.37	0.00	N/A
1999	25.76	0.32	0.00	N/A
2000	19.21	0.00	0.00	0.00
2001	37.72	0.44	1.05	-57.51
Average	29.99	0.24	0.21	-13.88

Table 5.5.6 Daily and Monthly Statistics (Water Years 1997-2001: Medina River near Riomedina, USGS #8180500)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	10.01	11.40
Geometric Mean (cfs)	0.01	0.00
Standard Deviation (cfs)	28.65	59.46
Correlation Coefficient	0.15	
Coefficient of Determination	0.02	
Mean Error (cfs)	1.39	
Mean Absolute Error (cfs)	16.69	
Monthly Statistics		
Count	60	60
Mean (cfs)	10.08	11.34
Geometric Mean (cfs)	0.01	0.01
Standard Deviation (cfs)	26.99	36.91
Correlation Coefficient	0.23	
Coefficient of Determination	0.05	
Mean Error (cfs)	1.26	
Mean Absolute Error (cfs)	15.59	

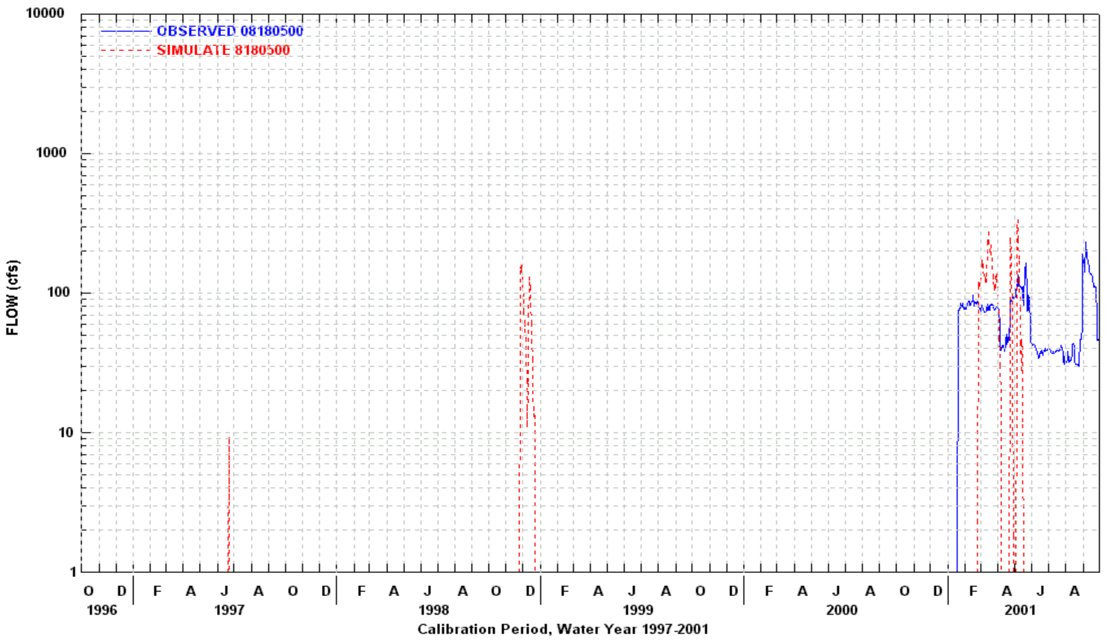


Figure 5.5.9 Daily Streamflow Comparison (Water Years 1997-2001: Medina River near Riomedina, USGS #8180500)

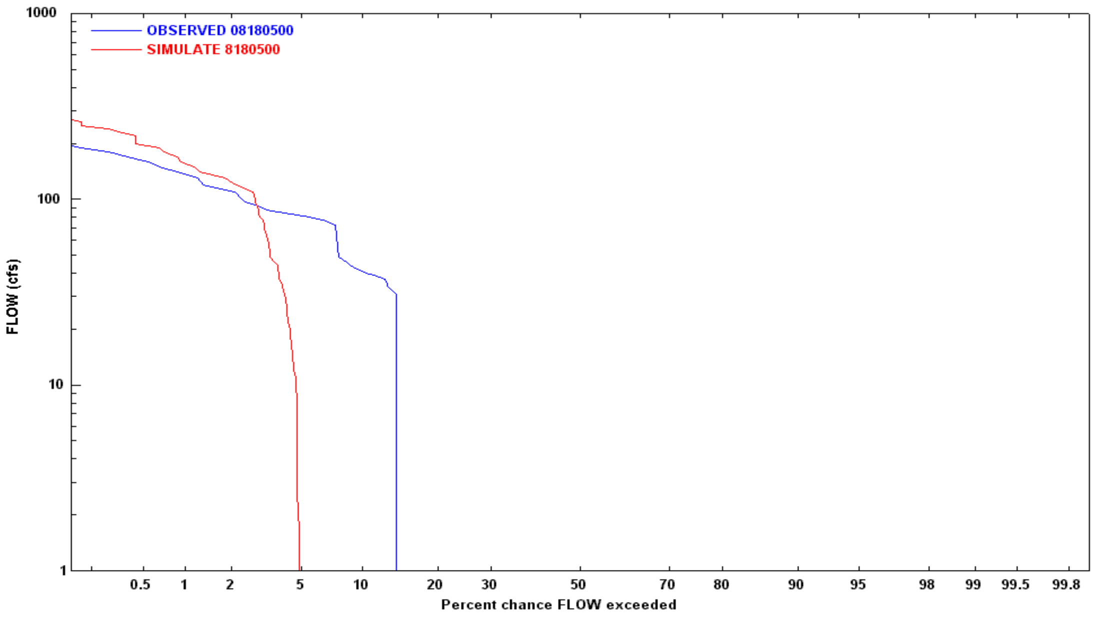


Figure 5.5.10 Daily Streamflow Frequency (Water Years 1997-2001: Medina River near Riomedina, USGS #8180500)

Table 5.5.7 Calibration Statistics and Criteria (Water Years 1997-2001: Medina River near Riomedina, USGS #8180500)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	0.21	0.24	14%	10%	OK
10% high (inches)	0.18	0.24	34%	10%	Poor
25% high (inches)	0.21	0.24	15%	15%	Good
50% Low (inches)	0.00	0.00	0%	15%	Excellent
25% Low (inches)	0.00	0.00	0%	15%	Excellent
10% Low (inches)	0.00	0.00	0%	15%	Excellent
storm volume (inches)	0.01	0.02	29%	20%	OK
average storm peak (cfs)	14.89	54.43	266%	15%	Poor
summer volume (inches)	0.07	0.01	-85%	15%	Poor
winter volume (inches)	0.06	0.11	82%	10%	Poor
summer storms (inches)	0.00	0.00	0%	10%	Excellent
winter storms (inches)	0.00	0.00	0%	15%	Excellent

5.5.2.2 Water Balance

Table 5.5.8 provides a detailed water balance summary for the Medina basin as simulated by the HSPF model.

Table 5.5.8 Mean Annual Simulated Water Balance in the Medina Basin (Water Years 1997-2001)

		Contributing Zone		Recharge Zone		
Component	**unit**	**Deep Soil**	**Shallow Soil**	**Deep Soil**	**Shallow Soil**	**Watershed Average**
Rainfall	inch	28.43	28.43	28.43	28.43	28.43
				Runoff		
Surface	inch	0.01	0.13	0.00	0.04	0.09
Interflow	inch	0.07	0.95	0.01	0.58	0.72
Baseflow	inch	2.25	3.66	0.02	0.17	3.19
Total	inch	2.33	4.74	0.04	0.79	4.00
				Groundwater Inflow		
Deep	inch	1.18	0.92	5.15	5.26	1.12
Active	inch	2.25	3.66	0.02	0.17	3.19
Total	inch	3.43	4.58	5.17	5.42	4.32
				Evaporation		
Potential	inch	53.83	53.83	53.83	53.83	53.83
Intercept Stor.	inch	7.89	8.41	9.01	9.22	8.30
Upper Zone	inch	2.60	3.79	1.50	2.55	3.45
Lower Zone	inch	10.88	9.87	11.76	10.21	10.14
Ground Water	inch	1.71	0.00	0.13	0.00	0.43
Baseflow	inch	0.60	0.00	0.02	0.00	0.15
Total	inch	23.67	22.07	22.42	21.98	22.47
Area	acres	94848	270835	1589	10474	377746
Area	%	25.11	71.70	0.42	2.77	100.00

5.6 Area Between Medina and Cibolo

5.6.1 Basin Hydrology and Features

Figure 5.6.1 shows the map of rivers and streams, major roads, cities, county boundaries, NWS and EAA precipitation gages, USGS stream gages, Edwards aquifer contributing, recharge, and artesian zones, FRSs, and ungaged areas in the Area between the Medina and Cibolo Basin. Also shown in Figure 5.6.1 is the San Geronimo Creek Dam, a recharge structure located very close to the Bexar-Medina county line.

Table 5.6.1 summarizes basic hydrologic and modeling information about the basin. Figure 5.6.2 shows the surface geology and mapped geologic faults in the basin. Figures 5.6.3 and 5.6.4 show the hillshade and land cover/vegetation maps. Figure 5.6.5 shows the proportions of different PERLND groups in the basin. Figure 5.6.6 illustrates the delineated subwatersheds within the basin and watershed ID number required for HSPF.

Table 5.6.1 Summary Information for Area Between Medina and Cibolo Basins

Feature or Statistic	Measure	Details
Total area (sq. miles)	302.3	
No. of subwatersheds in model	67	
No. of stream reaches in model	67	
No. of EAA rain gages in basin	9	
Contributing Zone		
Area (sq. miles)	158.8	
Stream length (miles)	53.9	
No. of stream gages above recharge zone	1	
Average subwatershed area (sq. miles)	5.7	Range: 0.146 to 19.95
Average stream reach length (miles)	2.7	Range: 0.395 to 8.23
Recharge Zone		
Area (sq. miles)	110.8	
Stream length (miles) [1]	80.3	
No. stream gages below recharge zone	1	
Average subwatershed area (sq. miles)	2.3	Range: 0.042 to 7.91
Average stream reach length (miles)	1.8	Range: 0.025 to 6.65

[1] Stream length includes only those streams included in the EPA RF1 files

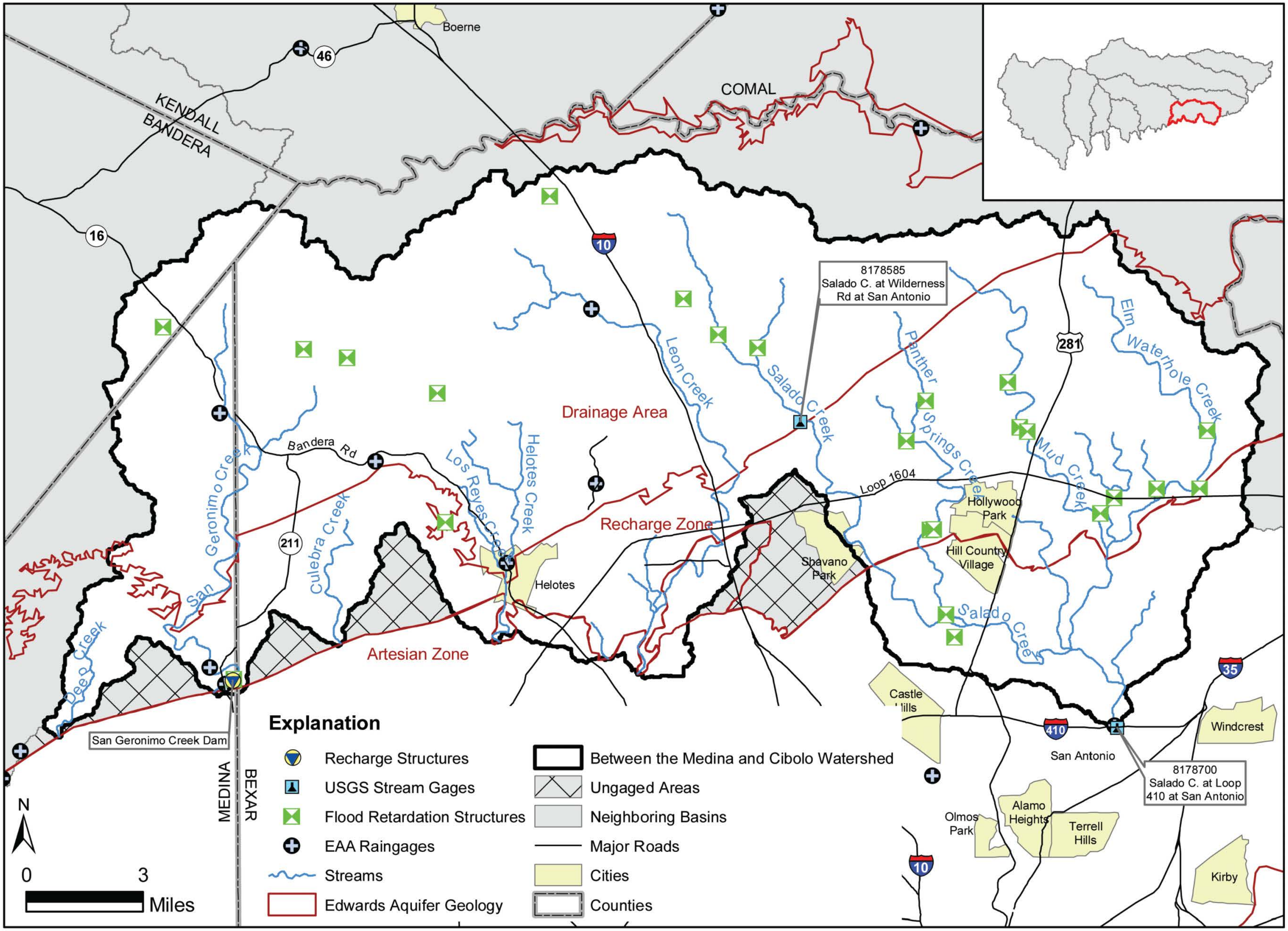


Figure 5.6.1 - Area Between Medina and Cibolo Basins

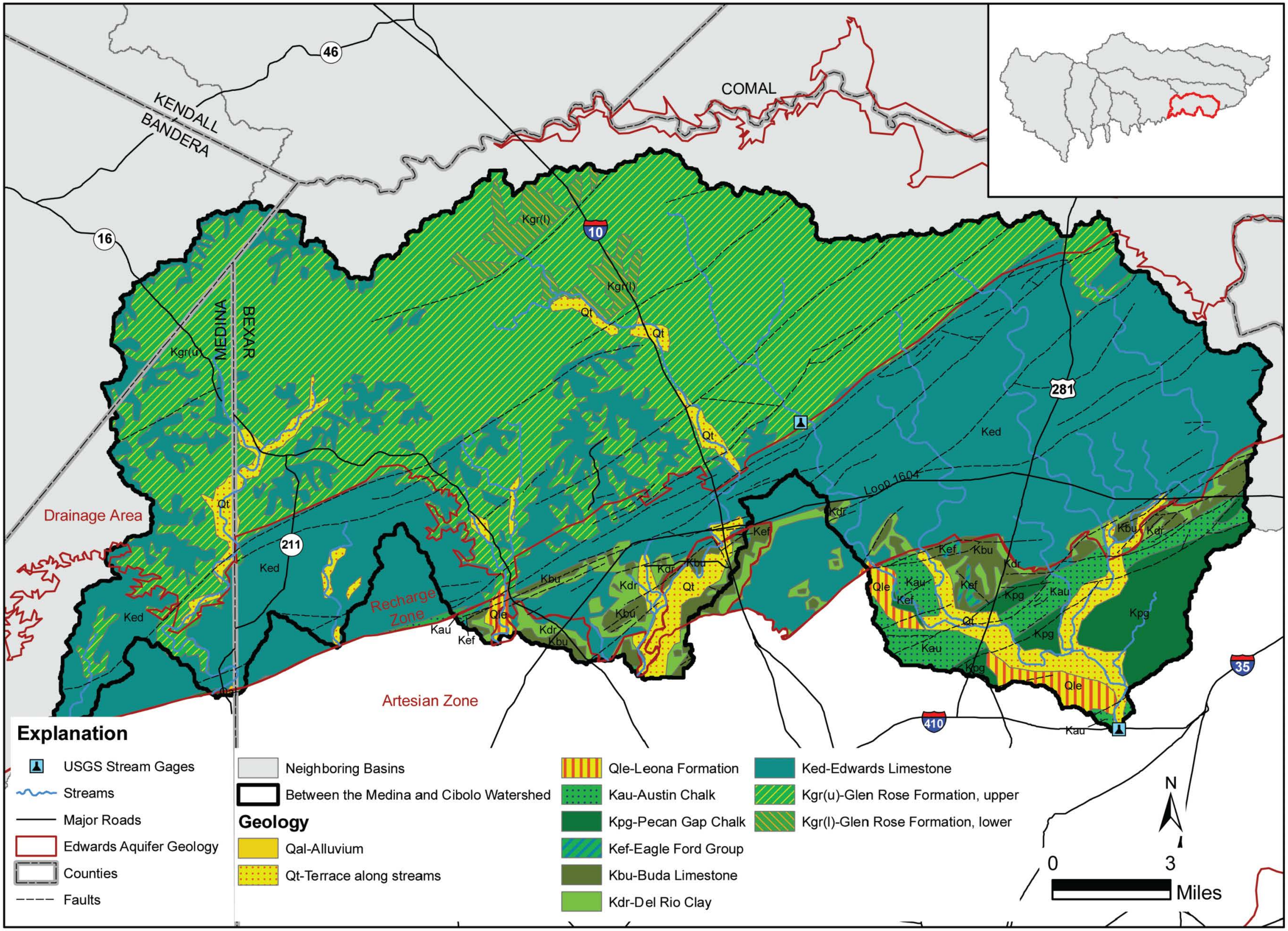


Figure 5.6.2 - Surface Geology in the Area Between Medina and Cibolo Basins

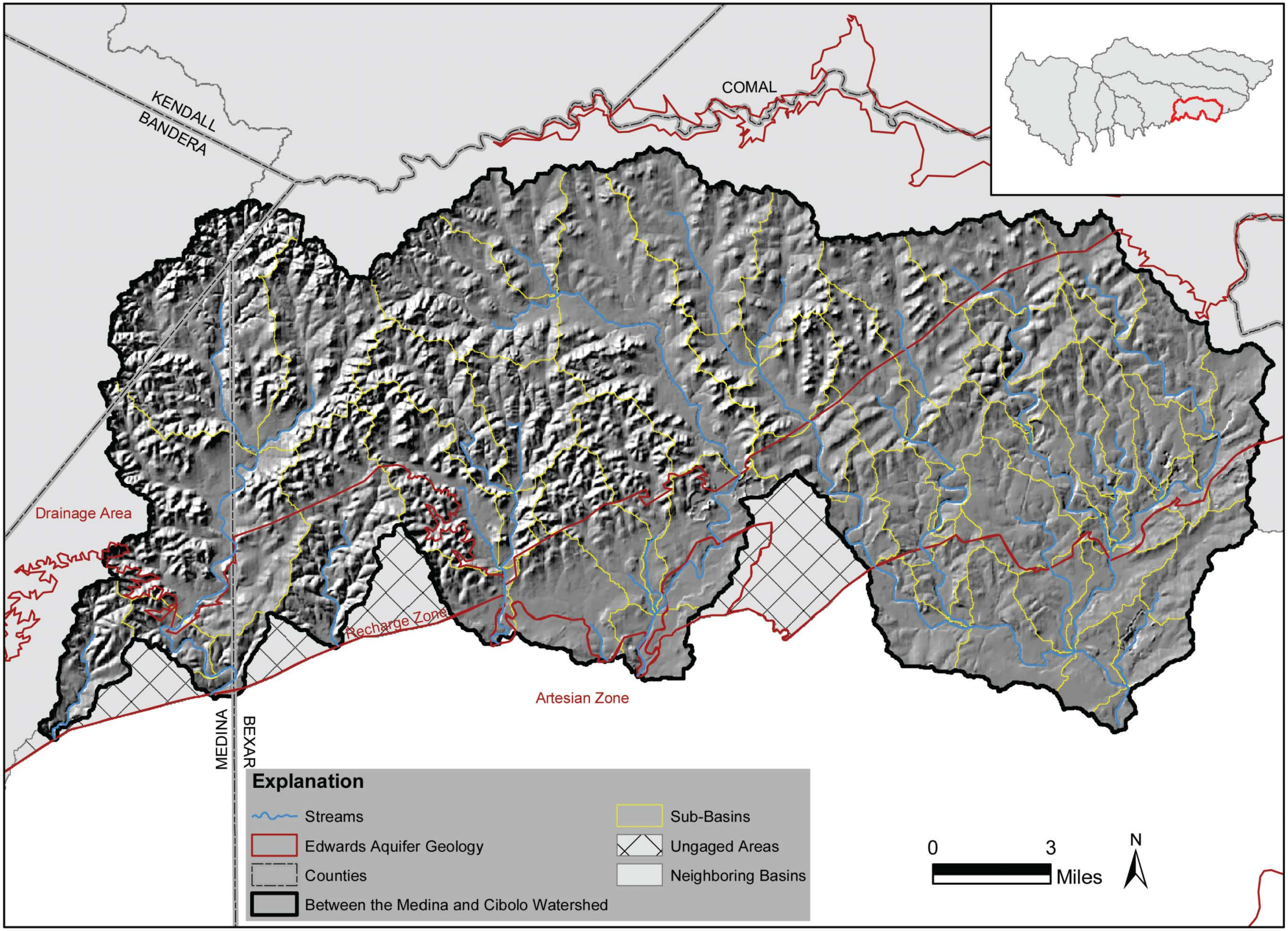


Figure 5.6.3 - Hillshade View in the Area Between Medina and Cibolo Basins

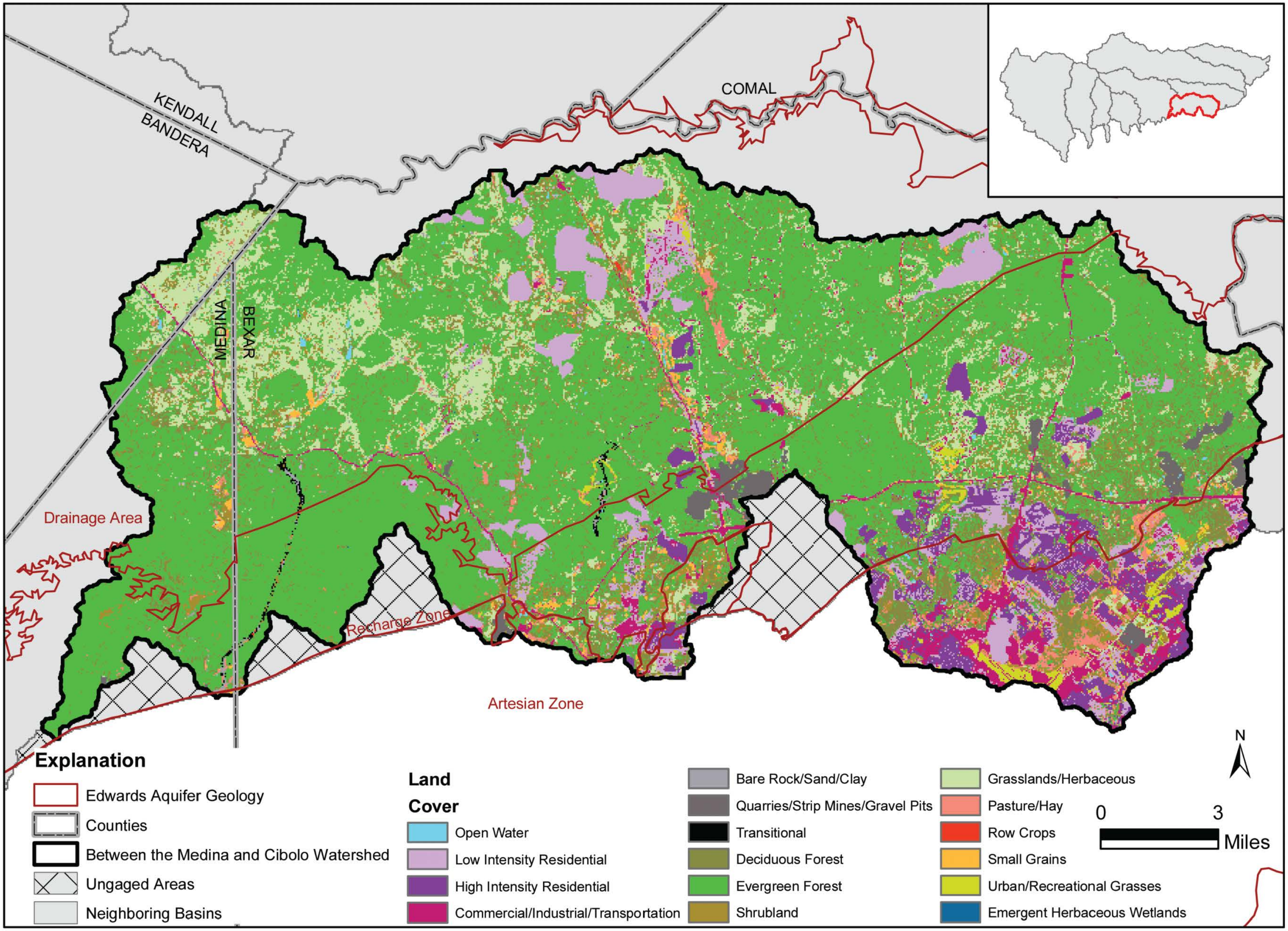


Figure 5.6.4 - Land Cover and Vegetation in the Area Between Medina and Cibolo Basins

Figure 5.6.5 summarizes the proportions of each PERLND group in the basin. The graph shows that the largest PERLND components in the contributing zone are flat deep soils, followed by steep shallow soils. In the recharge zone, the dominant land segment is flat deep soils.

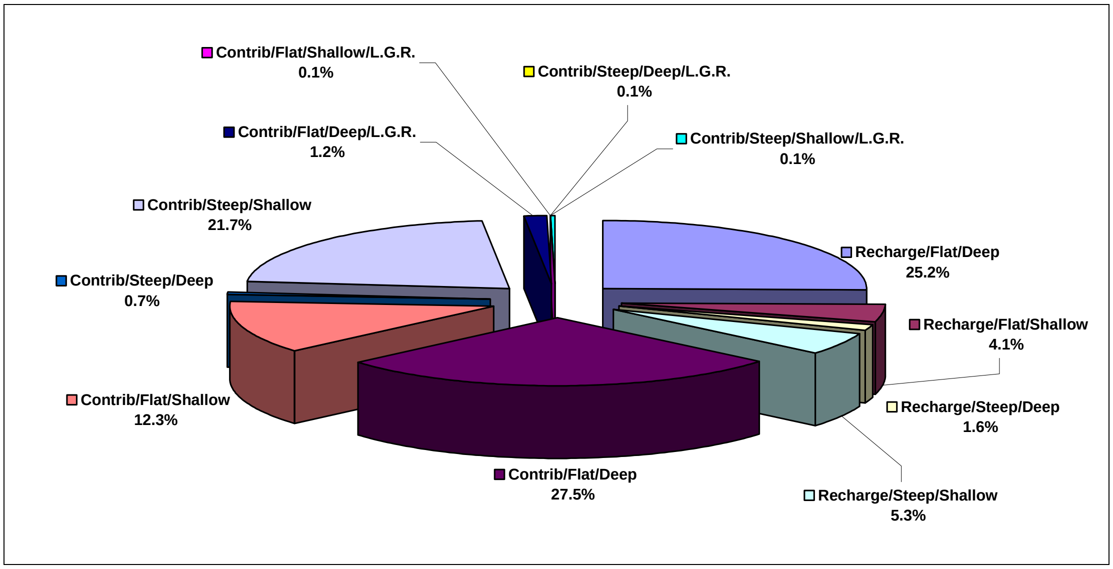


Figure 5.6.5 PERLND Distribution in the Area Between Medina and Cibolo Basins

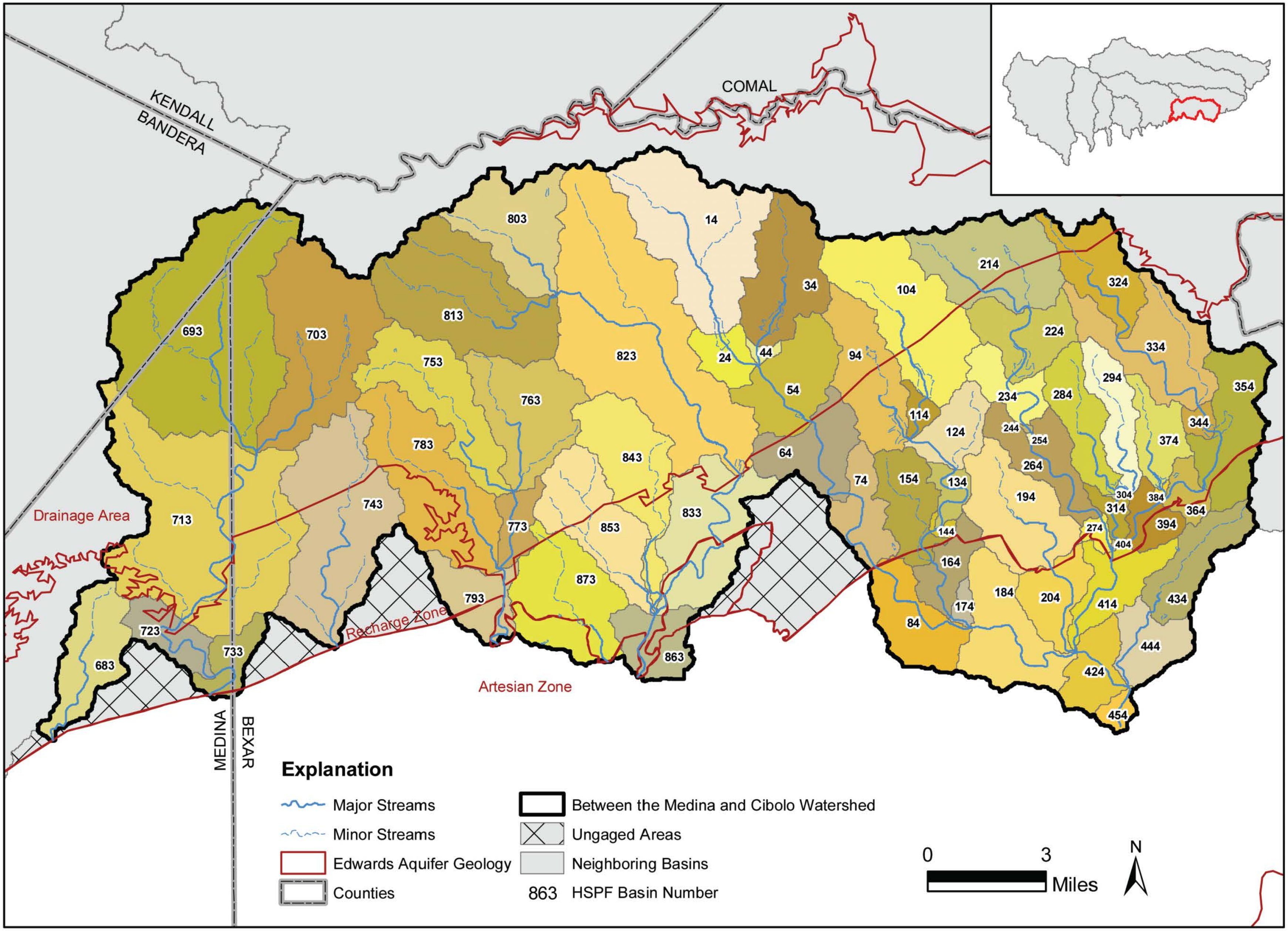


Figure 5.6.6 - Delineated Basins in the Area Between Medina and Cibolo Basins

5.6.2 Model Calibration

5.6.2.1 Streamflow Comparison

5.6.2.1.1 Contributing Zone (Upstream Gages)

Figure 5.6.7 compares daily simulated and observed flow at stream gage 8178585 (Salado Creek at Wilderness Road at San Antonio) for the 5-year period between 1997 and 2001. The agreement between the observed and simulated flow is fair for high flow events but not very good for post-storm events. The simulated peaks from storm events usually recede too slowly. The flow duration curve, shown in Figure 5.6.8, also indicates that the model generally simulates too much flow during low flow conditions. Having storage in the lower zone set too high in the model may cause this problem. Tables 5.6.2, 5.6.3, and 5.6.4 provide further statistical information regarding the calibration results.

Table 5.6.2 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Salado Creek near Wilderness Road at San Antonio, USGS #8178585)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	38.93	8.05	6.14	31.10
1998	20.15	0.09	0.00	N/A
1999	49.76	1.23	2.11	-41.85
2000	36.28	3.12	2.75	-13.51
2001	38.93	8.05	6.14	31.10
Average	20.15	0.09	0.00	N/A

Table 5.6.3 Daily and Monthly Statistics (Water Years 1997-2001: Salado Creek near Wilderness Road at San Antonio, USGS #8178585)

	Simulated	Observed
Daily Statistics		
Count	1096	1096
Mean (cfs)	4.81	5.46
Geometric Mean (cfs)	0.01	0.49
Standard Deviation (cfs)	35.29	38.41
Correlation Coefficient	0.92	
Coefficient of Determination	0.85	
Mean Error (cfs)	0.65	
Mean Absolute Error (cfs)	2.59	
Monthly Statistics		
Count	36	36
Mean (cfs)	4.77	5.41
Geometric Mean (cfs)	0.02	0.57
Standard Deviation (cfs)	19.45	23.41
Correlation Coefficient	0.98	
Coefficient of Determination	0.96	
Mean Error (cfs)	0.64	
Mean Absolute Error (cfs)	2.12	

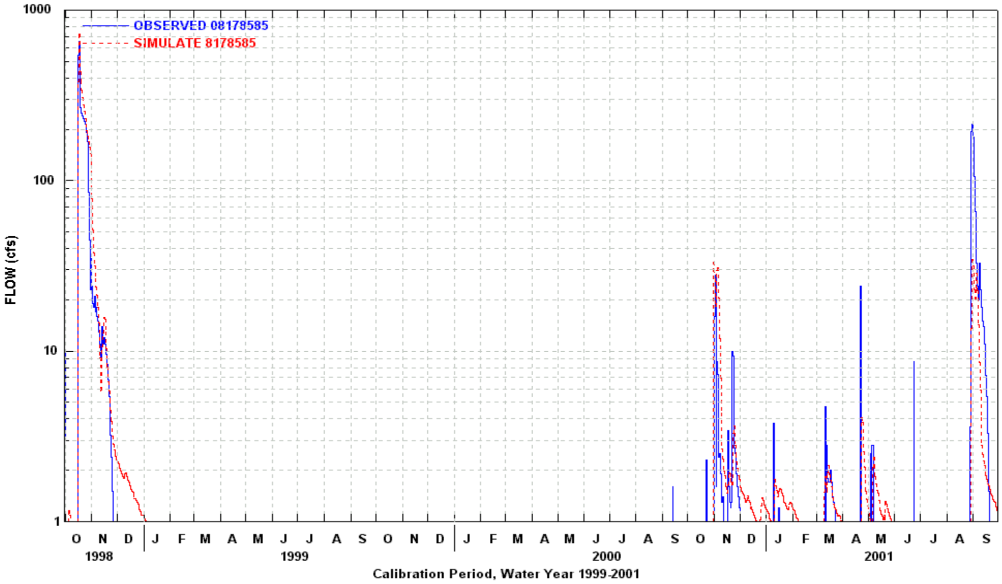


Figure 5.6.7 Daily Streamflow Comparison (Water Years 1997-2001: Salado Creek near Wilderness Road at San Antonio, USGS #8178585)

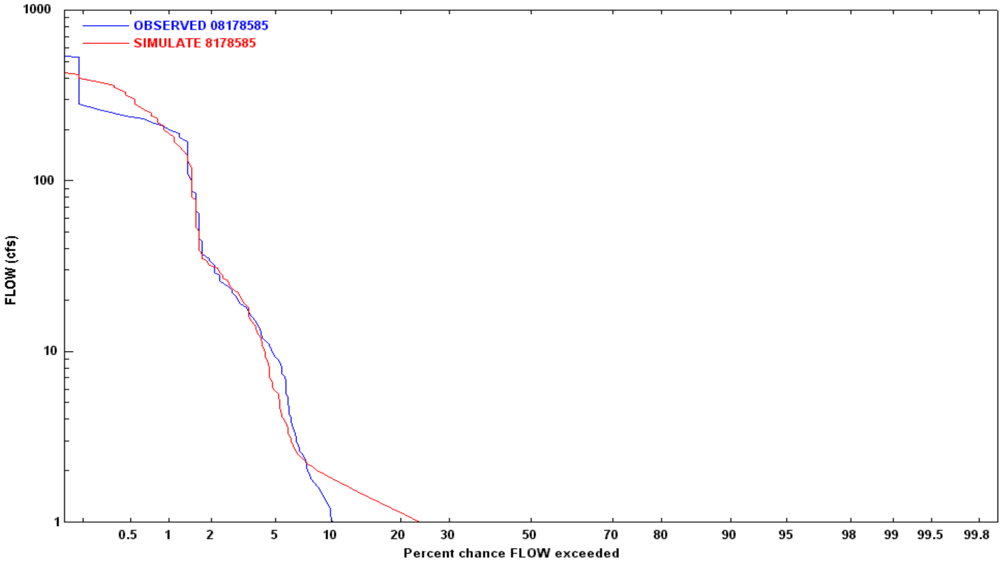


Figure 5.6.8 Daily Streamflow Frequency (Water Years 1997-2001: Salado Creek near Wilderness Road at San Antonio, USGS #8178585)

Table 5.6.4 Calibration Statistics and Criteria (Water Years 1997-2001: Salado Creek near Wilderness Road at San Antonio, USGS #8178585)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	2.75	3.12	14%	10%	Excellent
10% high (inches)	2.36	2.88	22%	10%	Poor
25% high (inches)	2.75	2.98	9%	15%	Excellent
50% Low (inches)	0.00	0.06	0%	15%	Excellent
25% Low (inches)	0.00	0.02	0%	15%	Excellent
10% Low (inches)	0.00	0.01	0%	15%	Excellent
storm volume (inches)	2.55	2.66	4%	20%	Excellent
average storm peak (cfs)	433.50	1589.44	267%	15%	Poor
summer volume (inches)	0.56	0.17	-70%	15%	Poor
winter volume (inches)	0.03	0.09	182%	10%	Poor
summer storms (inches)	0.56	0.13	-76%	10%	Poor
winter storms (inches)	0.00	0.00	0%	15%	Excellent

5.6.2.1.2 Recharge Zone (Downstream Gages)

Figure 5.6.9 compares daily simulated and observed flow at stream gage 8178700 (Salado Creek at Loop 410 at San Antonio) for the 5-year period between 1997 and 2001. As with the gage above the recharge zone, the agreement between the observed and simulated flow is fair for high flow events but not very good during dry periods between storm events or wet periods. The simulated peaks from storm events usually match fairly well, but recede too slow. The flow duration curve, shown in Figure 5.6.10, also indicates that the model generally simulates too much flow during low flow conditions. Tables 5.6.5, 5.6.6, and 5.6.7 provide further statistical information regarding the calibration results.

Table 5.6.5 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Salado Creek at Loop 410 at San Antonio, USGS #8178700)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	48.01	11.06	13.58	-18.53
1998	36.96	5.94	6.21	-4.42
1999	28.88	7.15	9.86	-27.53
2000	21.72	0.67	0.83	-19.06
2001	47.50	8.31	7.50	10.84
Average	**36.61**	**6.63**	**7.60**	**12.77**

Table 5.6.6 Daily and Monthly Statistics (Water Years 1997-2001: Salado Creek at Loop 410 at San Antonio, USGS #8178700)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	19.75	23.26
Geometric Mean (cfs)	0.03	0.28
Standard Deviation (cfs)	324.72	190.07
Correlation Coefficient	0.71	
Coefficient of Determination	0.51	
Mean Error (cfs)	3.52	
Mean Absolute Error (cfs)	21.56	
Monthly Statistics		
Count	60	60
Mean (cfs)	19.55	23.08
Geometric Mean (cfs)	0.52	3.66
Standard Deviation (cfs)	99.17	98.59
Correlation Coefficient	0.99	
Coefficient of Determination	0.99	
Mean Error (cfs)	3.53	
Mean Absolute Error (cfs)	7.25	

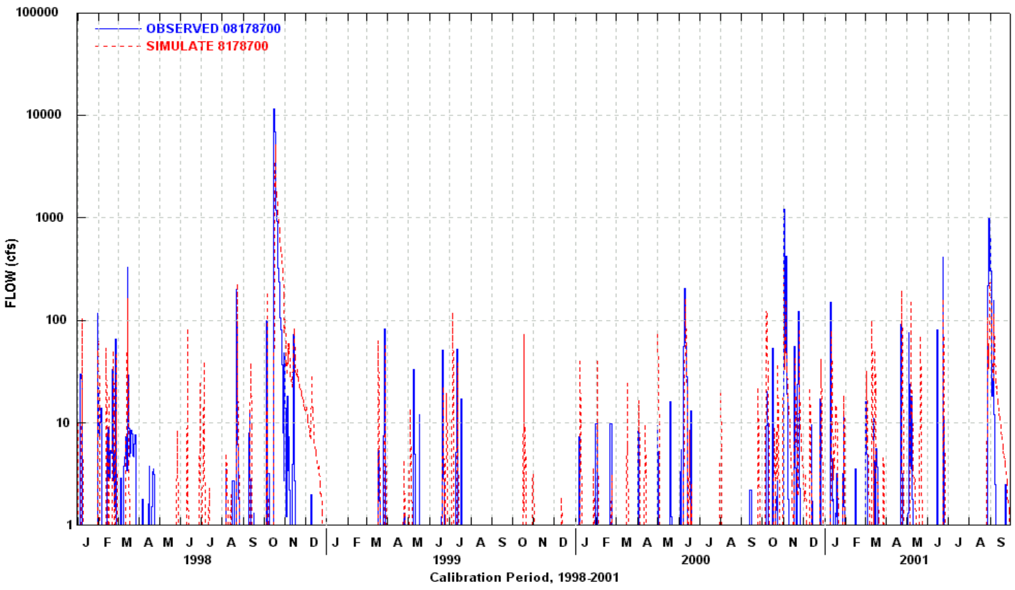


Figure 5.6.9 Daily Streamflow Comparison (Water Years 1997-2001: Salado Creek at Loop 410 at San Antonio, USGS #8178700)

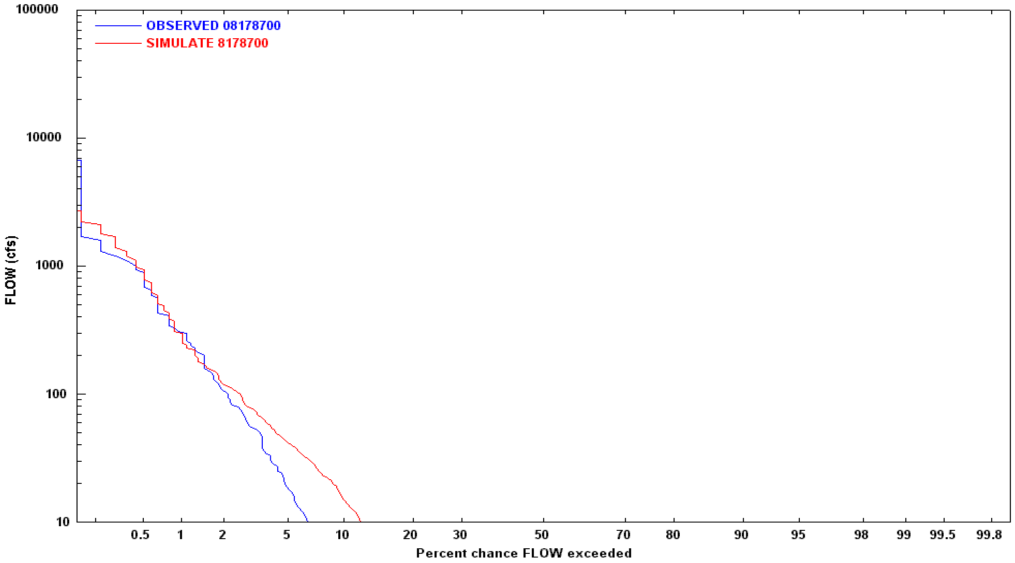


Figure 5.6.10 Daily Streamflow Frequency (Water Years 1997-2001: Salado Creek at Loop 410 at San Antonio, USGS #8178700)

Table 5.6.7 Calibration Statistics and Criteria (Water Years 1997-2001: Salado Creek at Loop 410 at San Antonio, USGS #8178700)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	1.97	2.32	18%	10%	OK
10% high (inches)	1.32	2.09	59%	10%	Poor
25% high (inches)	1.63	2.27	39%	15%	Poor
50% Low (inches)	0.00	0.00	1008%	15%	N/A
25% Low (inches)	0.00	0.00	0%	15%	Excellent
10% Low (inches)	0.00	0.00	0%	15%	Excellent
storm volume (inches)	1.81	1.60	-12%	20%	Excellent
average storm peak (cfs)	1662.00	2666.40	60%	15%	Poor
summer volume (inches)	0.35	0.37	6%	15%	Excellent
winter volume (inches)	0.07	0.15	118%	10%	Poor
summer storms (inches)	1.97	2.32	18%	10%	OK
winter storms (inches)	1.32	2.09	59%	10%	Poor

5.6.2.2 Water Balance

Table 5.6.8 provides a detailed water balance summary for the area between Medina and Cibolo basin as simulated by the HSPF model.

Table 5.6.8 Mean Annual Simulated Water Balance in the Salado Basin within the Area Between Medina and Cibolo Basins (Water Years 1997-2001)

		Contributing Zone		Recharge Zone			
Component	**unit**	**Deep Soil**	**Shallow Soil**	**Deep Soil**	**Shallow Soil**	**Imperme-able Land**	**Watershed Average**
Rainfall	inch	34.10	34.10	34.10	34.10	31.53	**33.98**
Runoff							
Surface	inch	0.53	1.26	0.48	0.73	25.52	**1.73**
Interflow	inch	0.95	3.00	0.93	2.83	0.00	**1.14**
Baseflow	inch	6.21	3.85	0.15	0.15	0.00	**2.79**
Total	inch	7.69	8.11	1.56	3.72	25.52	**5.65**
Groundwater Inflow							
Deep	inch	2.73	1.69	9.11	7.53	0.00	**5.56**
Active	inch	6.21	3.85	0.15	0.15	0.00	**2.79**
Total	inch	8.94	5.54	9.26	7.68	0.00	**8.35**
Evaporation							
Potential	inch	53.83	53.83	53.83	53.83	53.83	**53.83**
Intercept Stor.	inch	6.74	7.88	6.90	7.59	0.00	**6.63**
Upper Zone	inch	2.87	4.29	2.73	3.50	0.00	**2.82**
Lower Zone	inch	12.49	11.24	12.55	11.25	0.00	**11.79**
Ground Water	inch	0.17	0.11	0.01	0.01	0.00	**0.08**
Baseflow	inch	0.16	0.15	0.00	0.00	0.00	**0.08**
Total	inch	22.44	23.67	22.19	22.35	6.00	**21.66**
Area	acres	20536	4174	23526	2280	2445	**52961**
Area	%	39%	8%	44%	4%	5%	**100%**

5.7 Cibolo and Comal

5.7.1 Basin Hydrology and Features

Figure 5.7.1 shows the map of rivers and streams, major roads, cities, county boundaries, NWS and EAA precipitation gages, USGS stream gages, Edwards aquifer contributing, recharge, and artesian zones, FRSs, and ungaged areas in the Cibolo Basin. Table 5.7.1 summarizes basic hydrologic and modeling information about the basin. Figure 5.7.2 shows the surface geology and mapped geologic faults in the basin. Figures 5.7.3 and 5.7.4 show the hillshade and land cover/vegetation maps. Figure 5.7.5 shows the proportions of different PERLND groups in the basin. Figure 5.7.6 illustrates the delineated subwatersheds within the basin and watershed ID number required for HSPF.

Table 5.7.1 Summary Information for Cibolo Basin

Feature or Statistic	Measure	Details
Total area (sq. miles)	403.7	
No. of subwatersheds in model	63	
No. of stream reaches in model	63	
No. of EAA rain gages in basin	14	
Contributing Zone		
Area (sq. miles)	237.5	
Stream length (miles)	72.0	
No. of stream gages above recharge zone	1	
Average subwatershed area (sq. miles)	6.1	Range: 0.0002 to 22.29
Average stream reach length (miles)	2.3	Range: 0.076 to 8.76
Recharge Zone		
Area (sq. miles)	126.2	
Stream length (miles) [1]	103.3	
No. stream gages below recharge zone	2	
Average subwatershed area (sq. miles)	2.5	Range: 0.003 to 11.46
Average stream reach length (miles)	2.4	Range: 0.021 to 8.29

[1] Stream length includes only those streams included in the EPA RF1 files

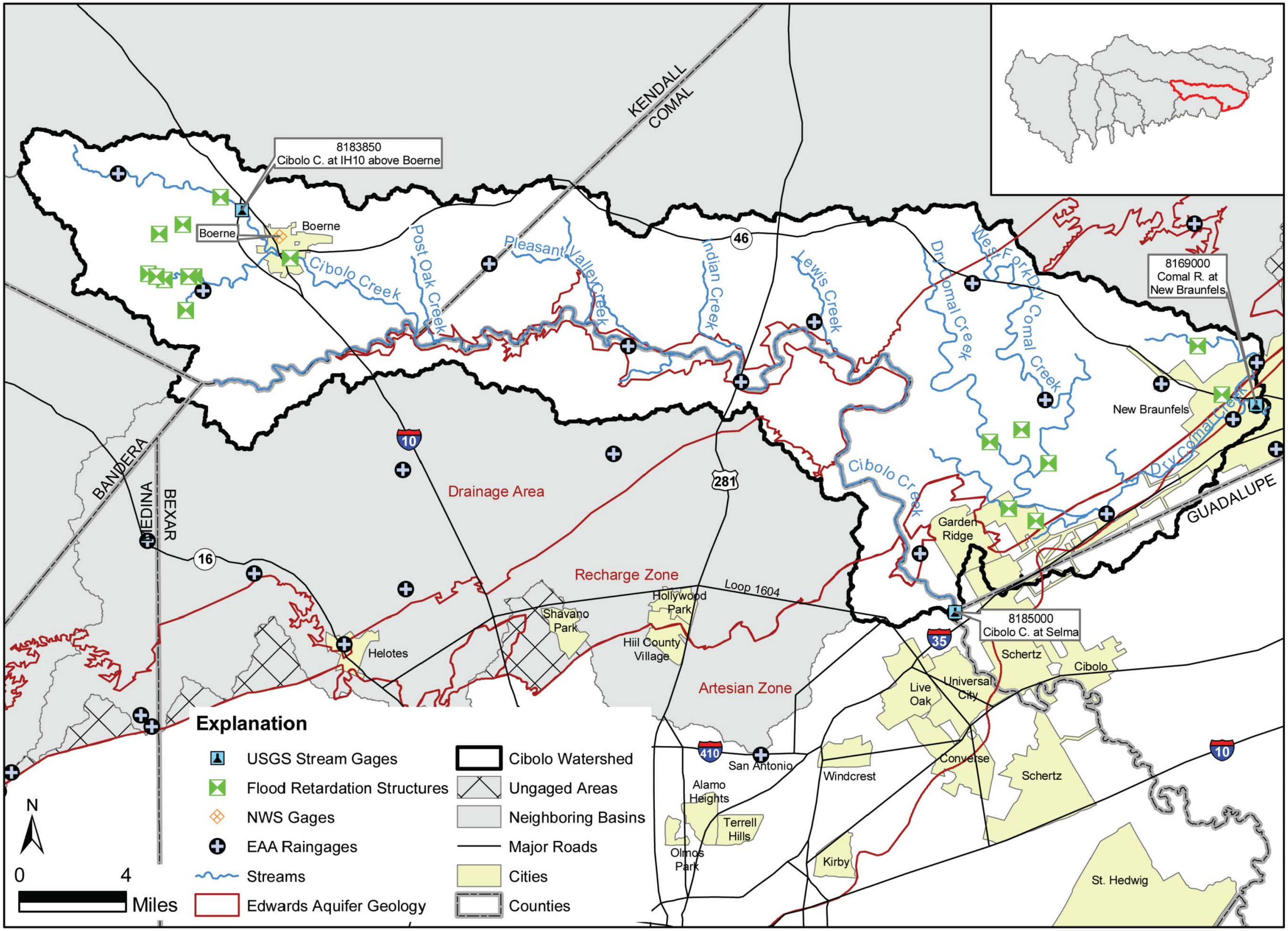


Figure 5.7.1 - Cibolo Basin

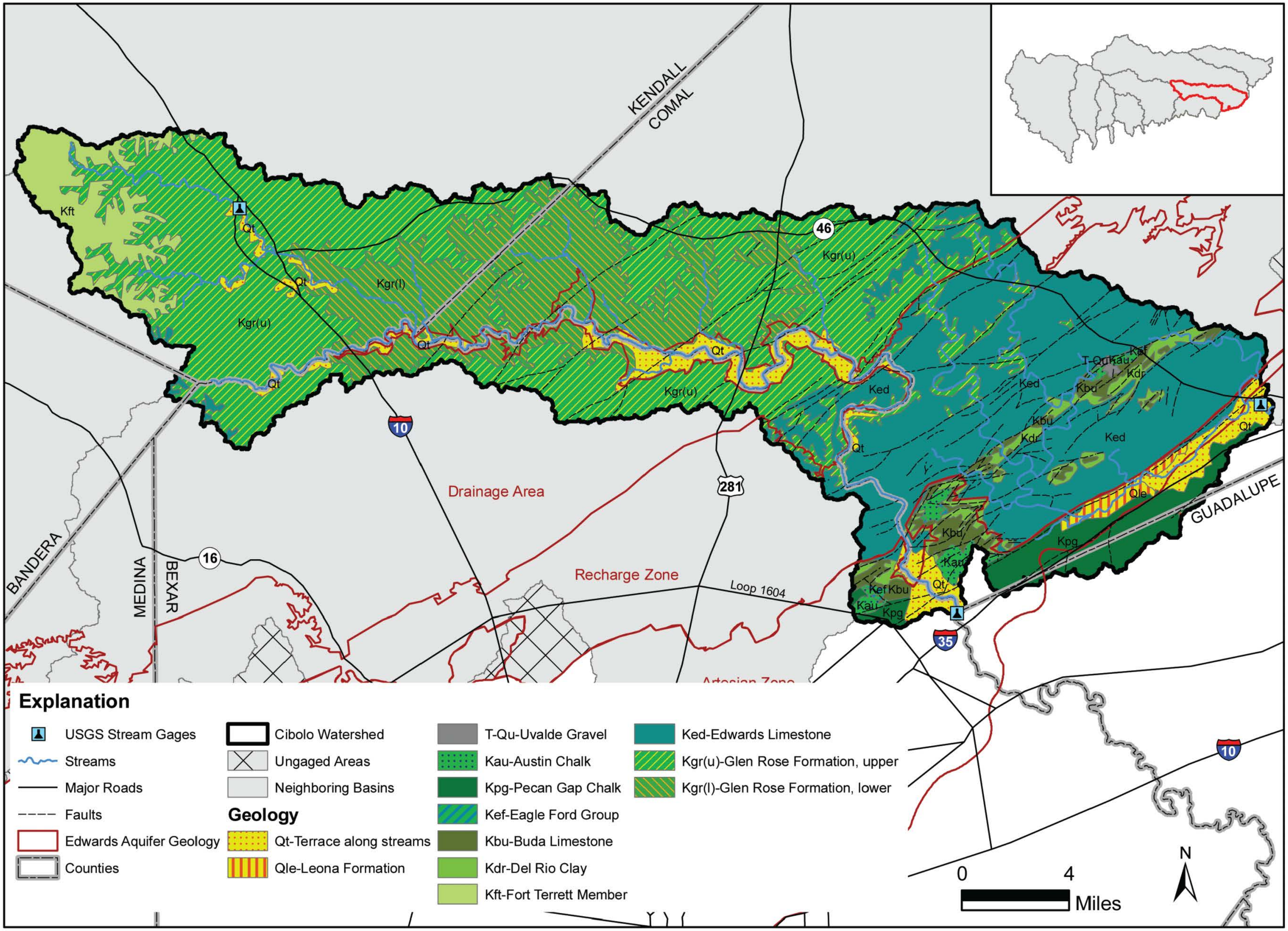


Figure 5.7.2 - Surface Geology in the Cibolo Basin

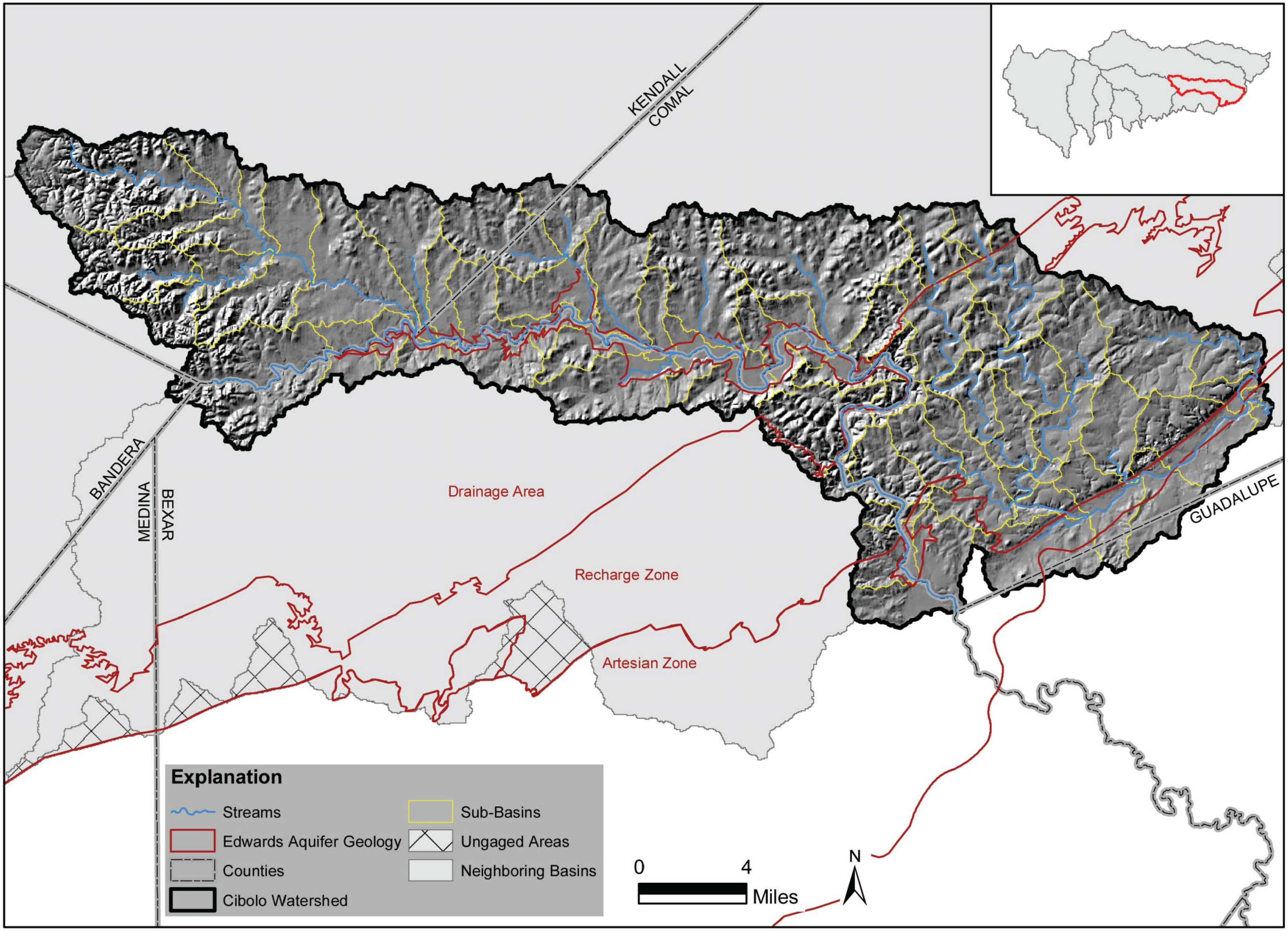


Figure 5.7.3 - Hillshade View in the Cibolo Basin

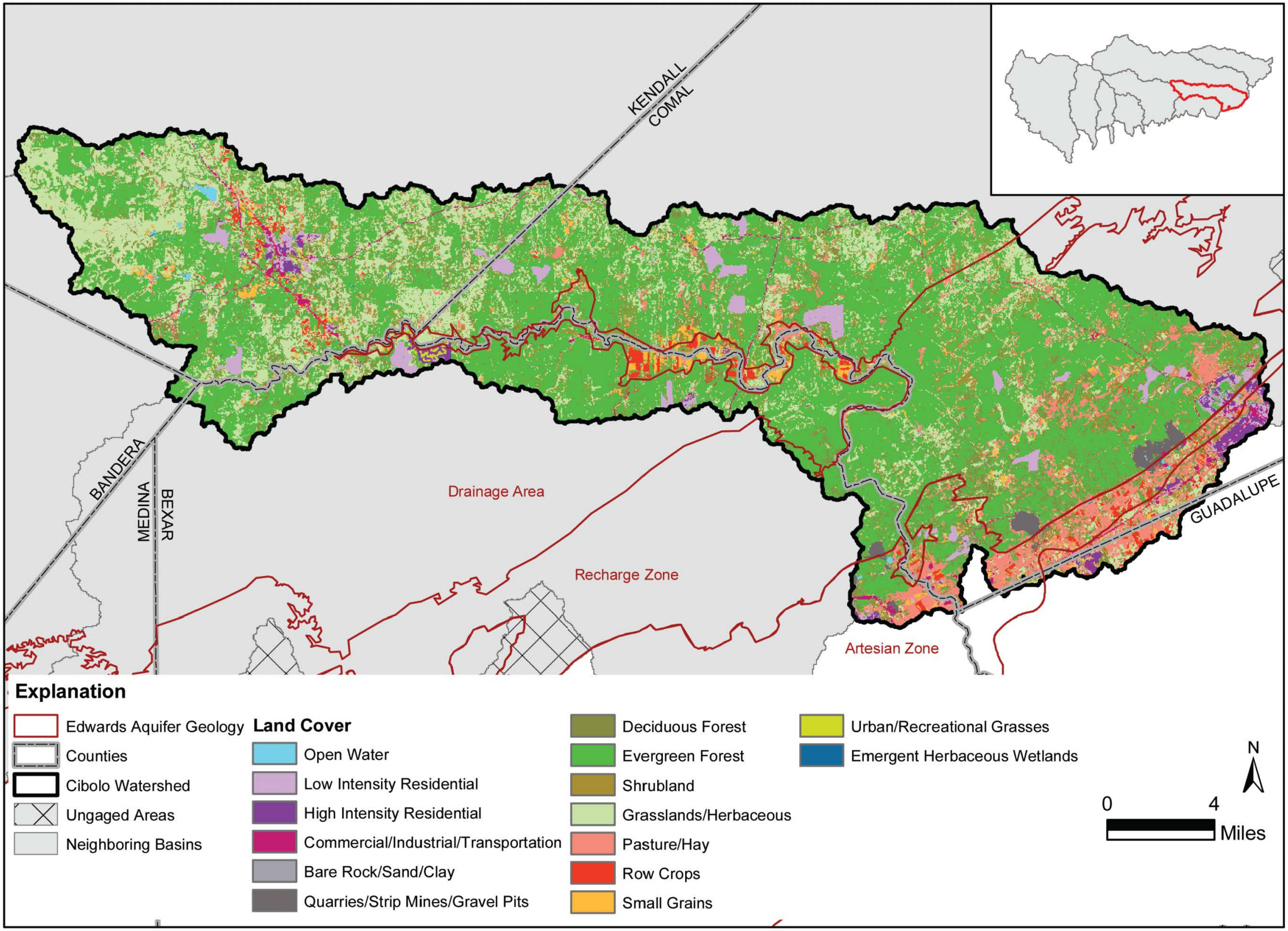


Figure 5.7.4 - Land Cover and Vegetation in the Cibolo Basin

Figure 5.7.5 summarizes the proportions of each PERLND group in the Cibolo basin. It indicates that the largest PERLND components in the contributing zone are flat deep soil areas followed by flat shallow soils. In the recharge zone, the dominant land segment is flat and deep soils.

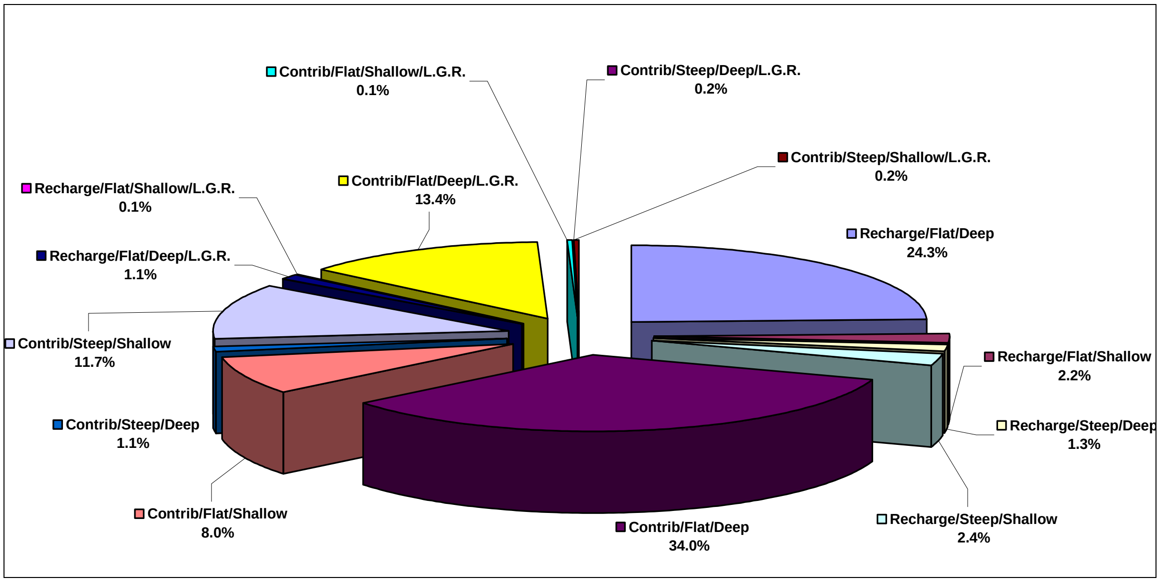


Figure 5.7.5 PERLND Distribution in the Cibolo Basin

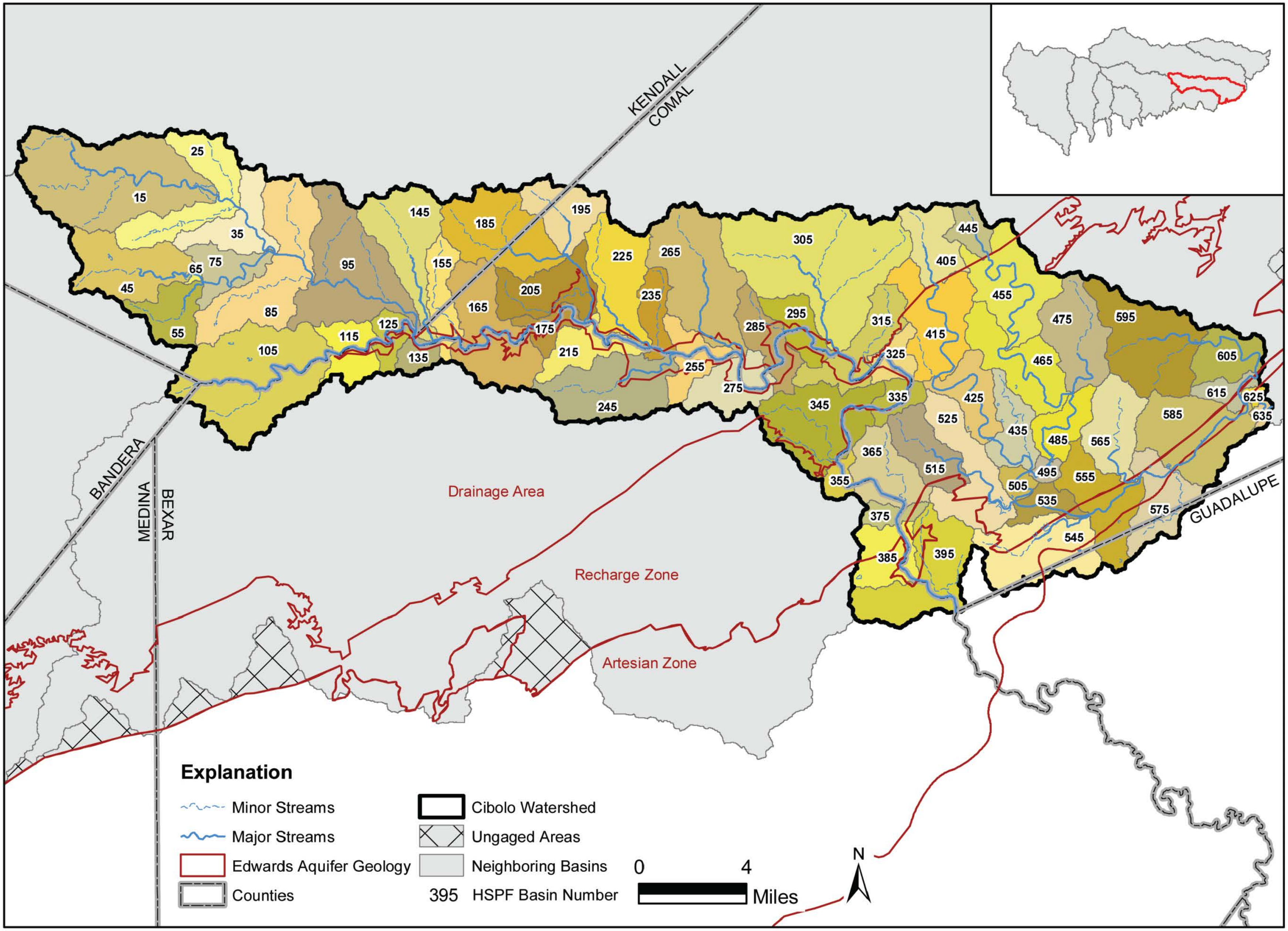


Figure 5.7.6 - Delineated Basins in the Cibolo Basin

5.7.2 Model Calibration

5.7.2.1 Streamflow Comparison

5.7.2.1.1 Contributing Zone (Upstream Gages)

Figure 5.7.7 compares daily simulated and observed flow at stream gage 8183850 (Cibolo Creek at IH10 above Boerne) for the 5-year period between 1997 and 2001. The agreement between the observed and simulated flow is good for flows greater than about 10 cfs but not very good below that flowrate. The flow duration curve, shown in Figure 5.7.8, also indicates that the model generally simulates too much flow during low flow conditions. Tables 5.7.2, 5.7.3, and 5.7.4 provide further statistical information regarding the calibration results.

Table 5.7.2 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Cibolo Creek at IH10 above Boerne, USGS #8183850)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	41.52	9.69	18.32	-47.14
1998	33.44	5.53	6.14	-9.97
1999	40.83	20.11	6.00	235.01
2000	21.14	0.40	0.22	80.07
2001	52.20	11.68	9.11	28.28
Average	37.83	9.48	7.96	-19.12

Table 5.7.3 Daily and Monthly Statistics (Water Years 1997-2001: Cibolo Creek at IH10 above Boerne, USGS #8183850)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	16.30	19.42
Geometric Mean (cfs)	2.51	4.90
Standard Deviation (cfs)	124.34	86.15
Correlation Coefficient	0.17	
Coefficient of Determination	0.03	
Mean Error (cfs)	3.12	
Mean Absolute Error (cfs)	17.23	
Monthly Statistics		
Count	60	60
Mean (cfs)	16.39	19.37
Geometric Mean (cfs)	3.77	5.42
Standard Deviation (cfs)	41.59	49.03
Correlation Coefficient	0.35	
Coefficient of Determination	0.13	
Mean Error (cfs)	2.98	
Mean Absolute Error (cfs)	15.52	

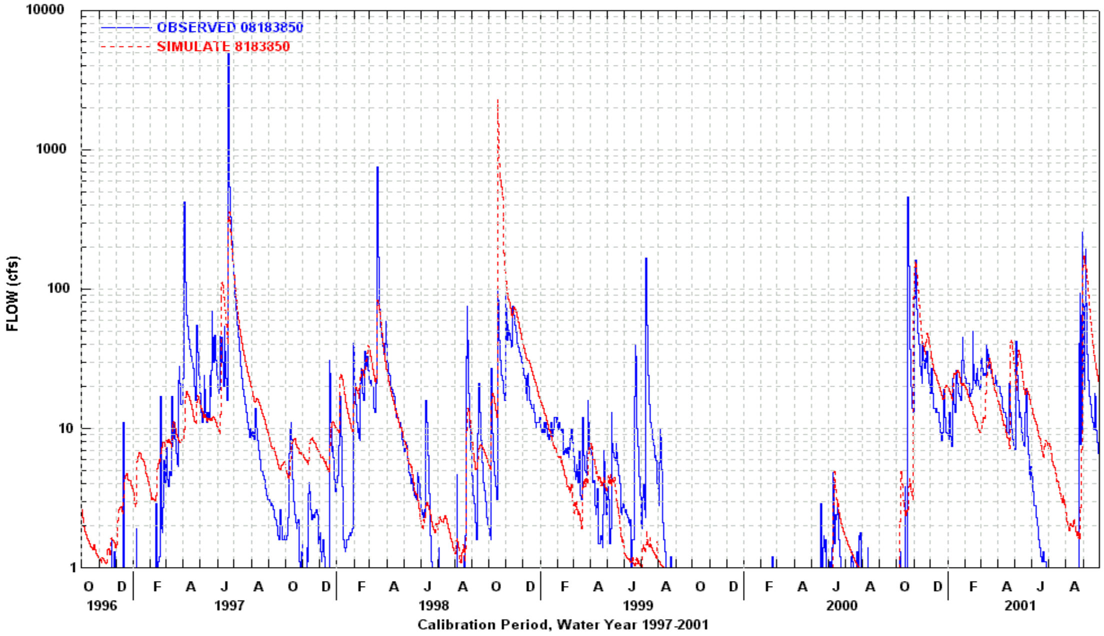


Figure 5.7.7 Daily Streamflow Comparison (Water Years 1997-2001: Cibolo Creek at IH10 above Boerne, USGS #8183850)

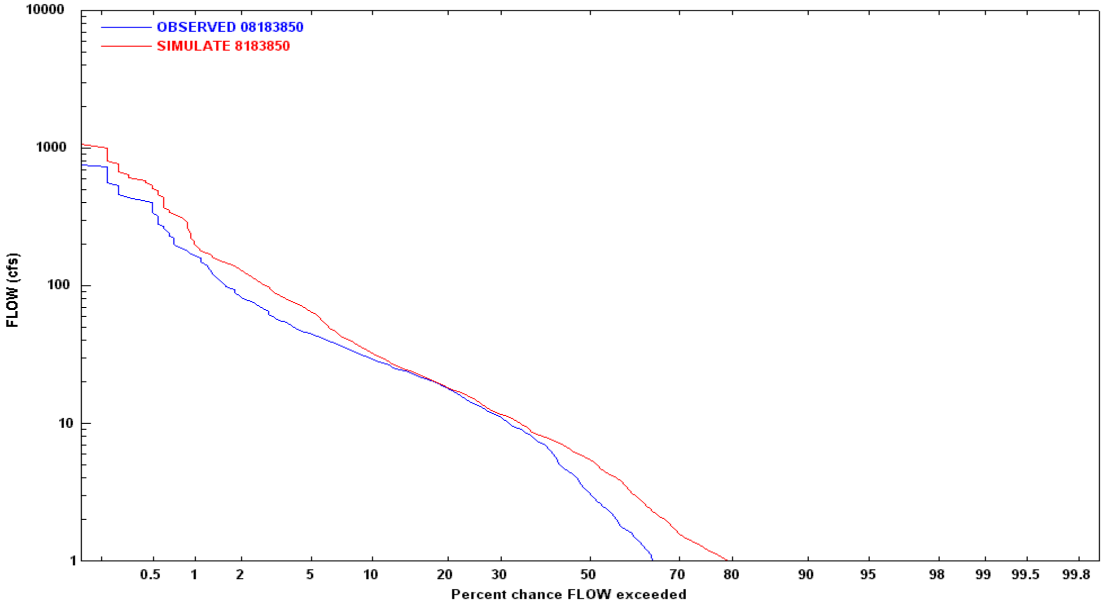


Figure 5.7.8 Daily Streamflow Frequency (Water Years 1997-2001: Cibolo Creek at IH10 above Boerne, USGS #8183850)

Table 5.7.4 Calibration Statistics and Criteria (Water Years 1997-2001: Cibolo Creek at IH10 above Boerne, USGS #8183850)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	7.96	9.48	19%	10%	Poor
10% high (inches)	4.07	6.39	57%	10%	Poor
25% high (inches)	6.66	7.94	19%	15%	Poor
50% Low (inches)	0.20	0.44	124%	15%	Poor
25% Low (inches)	0.03	0.09	220%	15%	Poor
10% Low (inches)	0.00	0.02	430%	15%	N/A
storm volume (inches)	3.84	1.29	-67%	20%	Poor
average storm peak (cfs)	1347.80	750.75	44%	15%	Poor
summer volume (inches)	3.45	2.03	-41%	15%	Poor
winter volume (inches)	1.52	1.38	-9%	10%	Good
summer storms (inches)	0.12	0.00	-97%	10%	Poor
winter storms (inches)	0.53	0.24	-55%	15%	Poor

5.7.2.1.2 Recharge Zone (Downstream Gages)

Figure 5.7.9 compares daily simulated and observed flow at stream gage 8185000 (Cibolo Creek at Selma) for the 5-year period between 1997 and 2001. As with the gage above the recharge zone, the agreement between the observed and simulated flow is fair for high flow events but not very good during dry periods between storm events or wet periods. The simulated peaks from storm events usually match fairly well, but recede too slow. The flow duration curve, shown in Figure 5.7.10, also indicates that the model generally simulates too much flow during low flow conditions, which may be caused by setting channel losses to low. Tables 5.7.5, 5.7.6, and 5.7.7 provide further statistical information regarding the calibration results.

Table 5.7.5 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Cibolo Creek at Selma, USGS #8185000)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	41.52	2.77	6.52	-57.50
1998	33.44	0.20	0.74	-72.86
1999	40.83	10.40	7.27	43.14
2000	21.14	0.00	0.00	-100.00
2001	52.20	0.95	1.43	-33.36
Average	37.83	2.87	3.19	10.24

Table 5.7.6 Daily and Monthly Statistics (Water Years 1997-2001: Cibolo Creek at Selma, USGS #8185000)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	64.35	57.75
Geometric Mean (cfs)	0.00	0.00
Standard Deviation (cfs)	1068.77	810.19
Correlation Coefficient	0.68	
Coefficient of Determination	0.46	
Mean Error (cfs)	-6.59	
Mean Absolute Error (cfs)	59.15	
Monthly Statistics		
Count	60	60
Mean (cfs)	64.16	57.19
Geometric Mean (cfs)	0.01	0.01
Standard Deviation (cfs)	295.78	323.55
Correlation Coefficient	0.88	
Coefficient of Determination	0.78	
Mean Error (cfs)	-6.97	
Mean Absolute Error (cfs)	31.83	

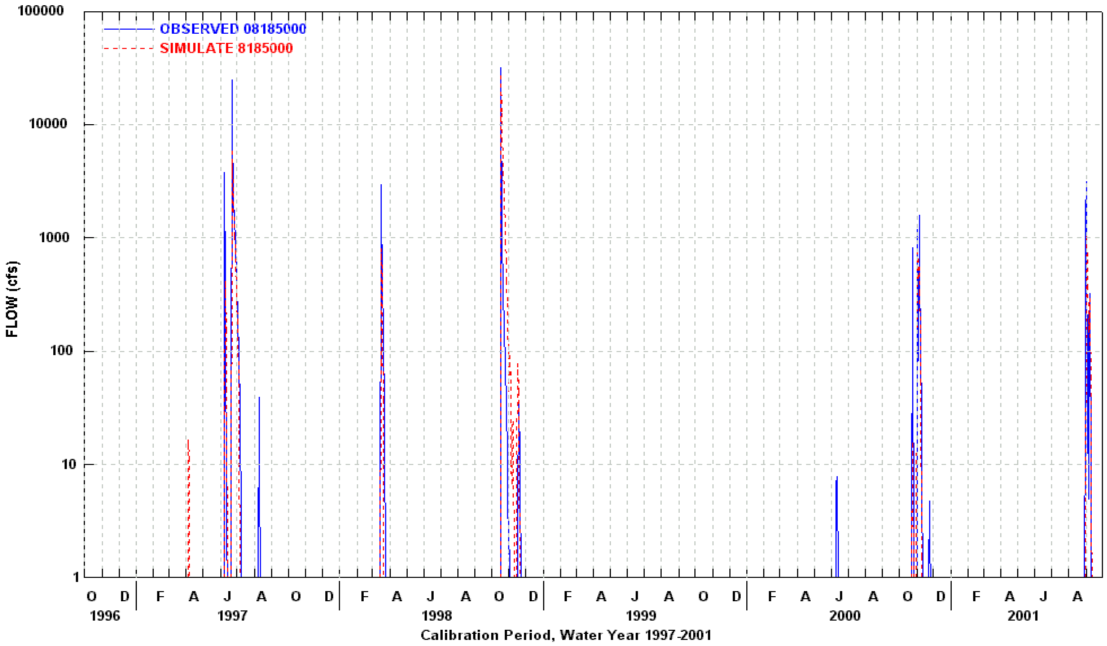


Figure 5.7.9 Daily Streamflow Comparison (Water Years 1997-2001: Cibolo Creek at Selma, USGS #8185000)

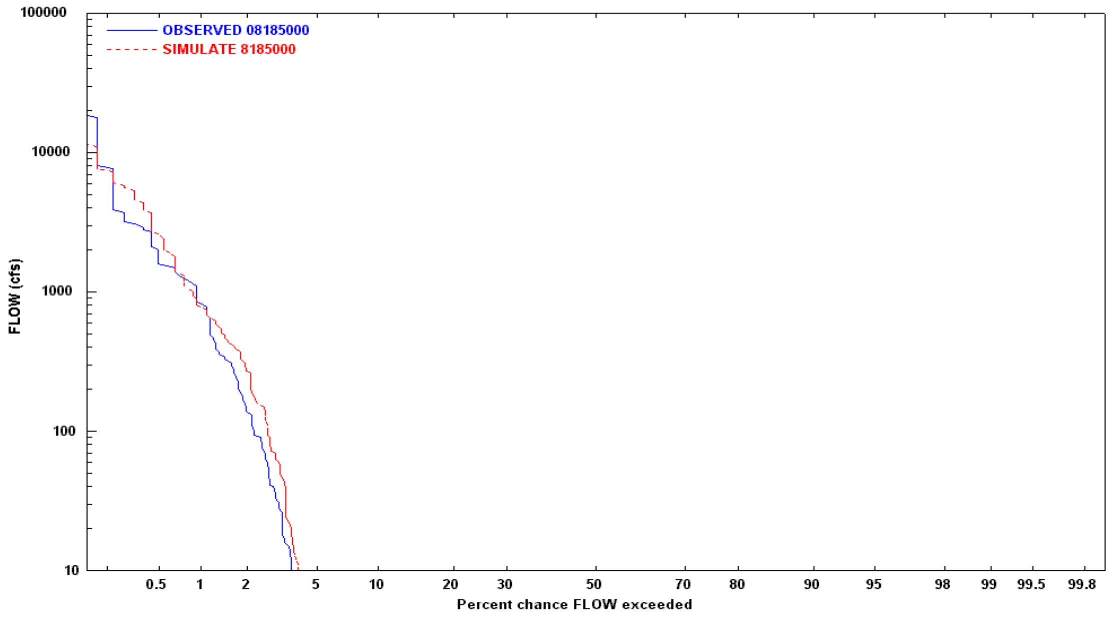


Figure 5.7.10 Daily Streamflow Frequency (Water Years 1997-2001: Cibolo Creek at Selma, USGS #8185000)

Table 5.7.7 Calibration Statistics and Criteria (Water Years 1997-2001: Cibolo Creek at Selma, USGS #8185000)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	3.19	2.87	-10%	10%	Good
10% high (inches)	2.32	2.87	23%	10%	Poor
25% high (inches)	2.85	2.87	1%	15%	Excellent
50% Low (inches)	0.00	0.00	0%	15%	Excellent
25% Low (inches)	0.00	0.00	0%	15%	Excellent
10% Low (inches)	0.00	0.00	0%	15%	Excellent
storm volume (inches)	4.62	4.93	7%	20%	Excellent
average storm peak (cfs)	16236.67	17898.99	10%	15%	Excellent
summer volume (inches)	1.35	0.62	-54%	15%	Poor
winter volume (inches)	0.15	0.04	-73%	10%	Poor
summer storms (inches)	0.16	0.09	-41%	10%	Poor
winter storms (inches)	1.60	2.12	32%	15%	Poor

Figure 5.7.11 compares daily simulated and observed flow at stream gage 8185000 (Comal River at New Bruanfels) for the 5-year period between 1997 and 2001. The hydrograph and the flow duration curve, shown in Figure 5.7.12 both indicate that the model is simulating the flow very well. One reason for the good match is that the measured springflow from Comal springs is used as a direct input into the Comal River, which is significantly larger than contributions from the rest of the basin. Tables 5.7.8, 5.7.9, and 5.7.10 provide further statistical information regarding the calibration results.

Table 5.7.8 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Comal River at New Braunfels, USGS #8169000)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	41.41	26.06	24.96	4.41
1998	33.36	28.83	28.85	-0.08
1999	40.73	46.96	50.37	-6.76
2000	21.08	27.36	27.53	-0.62
2001	52.07	34.18	34.85	-1.93
Average	37.73	32.68	33.31	-1.90

Table 5.7.9 Daily and Monthly Statistics (Water Years 1997-2001: Comal River at New Braunfels, USGS #8169000)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	318.89	312.82
Geometric Mean (cfs)	289.48	290.02
Standard Deviation (cfs)	600.90	306.75
Correlation Coefficient	0.73	
Coefficient of Determination	0.53	
Mean Error (cfs)	-6.07	
Mean Absolute Error (cfs)	23.73	
Monthly Statistics		
Count	60	60
Mean (cfs)	318.69	312.77
Geometric Mean (cfs)	296.29	294.87
Standard Deviation (cfs)	191.47	148.70
Correlation Coefficient	0.98	
Coefficient of Determination	0.97	
Mean Error (cfs)	-5.92	
Mean Absolute Error (cfs)	12.40	

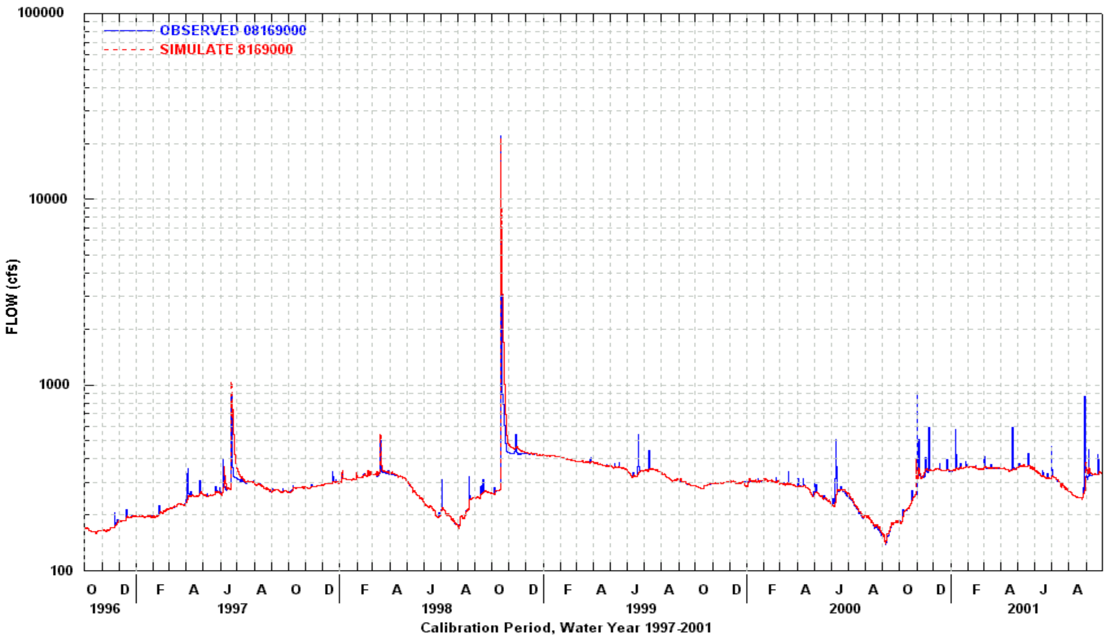


Figure 5.7.11 Daily Streamflow Comparison (Water Years 1997-2001: Comal River at New Braunfels, USGS #8169000)

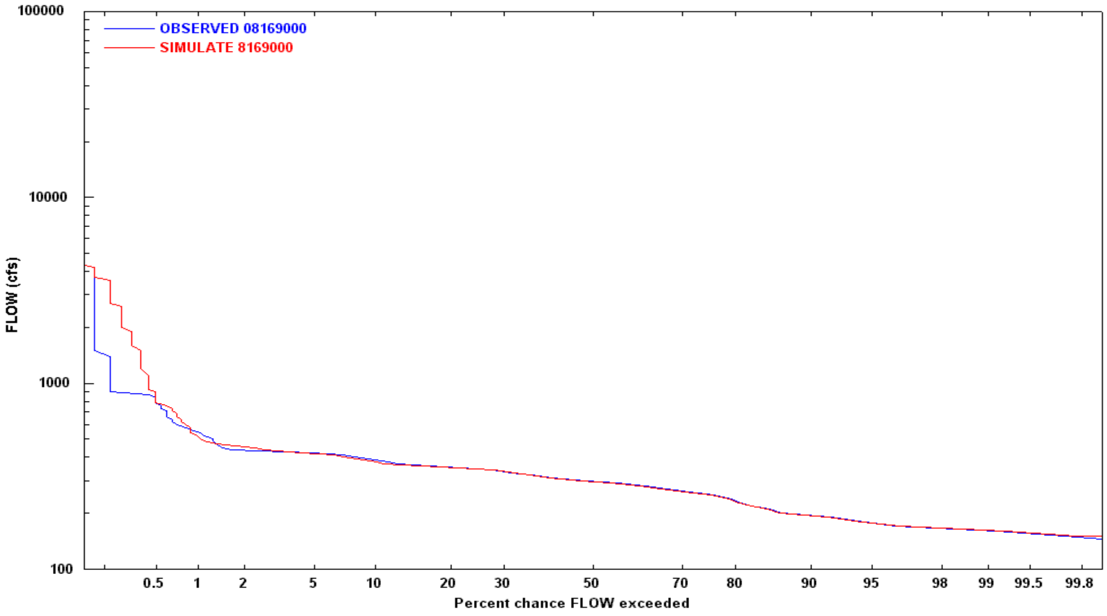


Figure 5.7.12 Daily Streamflow Frequency (Water Years 1997-2001: Comal River at New Braunfels, USGS #8169000)

Table 5.7.10 Calibration Statistics and Criteria (Water Years 1997-2001: Comal River at New Braunfels, USGS #8169000)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches) =	33.31	32.68	-2%	10%	Excellent
10% high (inches) =	5.60	6.23	11%	10%	Good
25% high (inches) =	11.93	11.87	-1%	15%	Excellent
50% Low (inches) =	12.54	12.48	0%	15%	Excellent
25% Low (inches) =	5.30	5.29	0%	15%	Excellent
10% Low (inches) =	1.83	1.84	1%	15%	Excellent
storm volume (inches) =	33.31	32.68	-2%	20%	Excellent
average storm peak (cfs) =	22,000.00	21,124.13	4%	15%	Excellent
summer volume (inches) =	7.37	7.53	2%	15%	Excellent
winter volume (inches) =	8.31	8.29	0%	10%	Excellent
summer storms (inches) =	0.00	0.00	0%	10%	Excellent
winter storms (inches) =	0.00	0.00	0%	15%	Excellent

5.7.2.2 Water Balance

Table 5.7.11 provides a detailed water balance summary for the Cibolo basin as simulated by the HSPF model.

Table 5.7.11 Mean Annual Simulated Water Balance in the Cibolo Basin (Water Years 1997-2001)

	Edwards				Lower Glen Rose			Watershed Average
	Contributing Zone		Recharge Zone		Contributing Zone		Recharge Zone	
	Deep Soil	Shallow Soil	Deep Soil	Shallow Soil	Deep Soil	Shallow Soil	Deep Soil	
Rainfall (in)	33.81	33.81	33.81	33.81	33.81	33.81	33.81	33.81
Runoff								
Surface (in)	0.86	1.45	0.53	0.85	0.84	1.55	0.46	1.00
Interflow (in)	1.16	3.38	1.02	3.15	1.13	3.47	0.99	1.87
Baseflow (in)	4.19	4.95	0.01	0.17	1.90	3.00	0.01	3.44
Total (in)	6.22	9.77	1.56	4.16	3.87	8.01	1.46	6.31
Groundwater Inflow								
Deep (in)	1.79	1.27	9.71	7.80	4.34	3.03	9.33	3.03
Active (in)	4.19	4.95	0.01	0.17	1.90	3.00	0.01	3.44
Total (in)	5.98	6.22	9.72	7.97	6.24	6.03	9.34	6.47
Evaporation								
Potential (in)	48.38	48.38	48.38	48.38	48.38	48.38	48.38	48.38
Intercept St (in)	6.68	7.10	6.69	7.45	6.95	7.17	7.11	6.90
Upper Zone (in)	3.57	4.66	2.84	3.57	3.42	4.76	2.59	3.79
Lower Zone (in)	11.13	10.04	11.57	10.32	11.36	10.00	11.91	10.87
Groundwater (in)	1.78	0.00	0.15	0.00	1.64	0.00	0.15	1.03
Baseflow (in)	0.67	0.00	0.01	0.00	0.53	0.00	0.01	0.37
Total (in)	23.82	21.80	21.26	21.33	23.89	21.93	21.77	22.96
Area (ac)	68404	49637	10350	7970	35182	599	2979	175121
Area (%)	39.06	28.34	5.91	4.55	20.09	0.34	1.70	100.00

Table 5.7.12 provides a detailed water balance summary for the Comal basin as simulated by the HSPF model.

Table 5.7.12 Mean Annual Simulated Water Balance in the Comal Basin (Water Years 1997-2001)

		Contributing Zone		Recharge Zone		
	unit	**Deep Soil**	**Shallow Soil**	**Deep Soil**	**Shallow Soil**	**Watershed Average**
Rainfall	inch	35.68	35.68	35.68	35.68	35.68
Runoff						
Surface	inch	0.98	1.34	0.45	0.96	0.63
Interflow	inch	1.42	3.68	1.05	3.69	1.31
Baseflow	inch	7.50	6.78	10.49	9.08	9.57
Total	inch	9.90	11.81	11.98	13.73	11.50
Groundwater Inflow						
Deep	inch	2.10	1.40	10.46	8.91	8.02
Active	inch	5.40	5.38	0.02	0.17	1.55
Total	inch	7.50	6.78	10.49	9.08	9.57
Evaporation						
Potential	inch	46.96	46.96	46.96	46.96	46.96
Intercept St	inch	6.11	7.74	7.12	7.06	6.86
Upper Zone	inch	4.13	4.20	2.75	3.87	3.20
Lower Zone	inch	11.00	10.88	12.37	10.48	11.89
Ground Water	inch	1.68	0.00	0.13	0.00	0.54
Baseflow	inch	0.67	0.00	0.01	0.00	0.19
Total	inch	23.59	22.81	22.39	21.41	22.67
Area	acres	22241	1243	55837	3882	83203
Area	%	26.73	1.49	67.11	4.67	100.00

5.8 Guadalupe

5.8.1 Basin Hydrology and Features

Figure 5.8.1 shows the map of rivers and streams, major roads, cities, county boundaries, NWS and EAA precipitation gages, USGS stream gages, Edwards aquifer contributing, recharge, and artesian zones, FRSs, and ungaged areas in the Guadalupe Basin. Canyon Dam and Lake are located just upstream of the recharge zone have a big impact on the hydrology of the basin.

Table 5.8.1 summarizes basic hydrologic and modeling information about the basin. Figure 5.8.2 shows the surface geology and mapped geologic faults in the basin. Figures 5.8.3 and 5.8.4 show the hillshade and land cover/vegetation maps. Figure 5.8.5 shows the proportions of different PERLND groups in the basin. Figure 5.8.6 illustrates the delineated subwatersheds within the basin and watershed ID number required for HSPF.

Table 5.8.1 Summary Information for Guadalupe Basin

Feature or Statistic	Measure	Details
Total area (sq. miles)	1518.4	
No. of subwatersheds in model	77	
No. of stream reaches in model	77	
No. of EAA rain gages in basin	2	
Contributing Zone		
Area (sq. miles)	1467.4	
Stream length (miles)	473.9	
No. of stream gages above recharge zone	8	
Average subwatershed area (sq. miles)	20.4	Range: 1.841 to 20.66
Average stream reach length (miles)	6.2	Range: 0.001 to 62.86
Recharge Zone		
Area (sq. miles)	44.9	
Stream length (miles) [1]	14.3	
No. stream gages below recharge zone	2	
Average subwatershed area (sq. miles)	3.8	Range: 0.333 to 7.69
Average stream reach length (miles)	1.8	Range: 0.031 to 3.97

[1] Stream length includes only those streams included in the EPA RF1 files

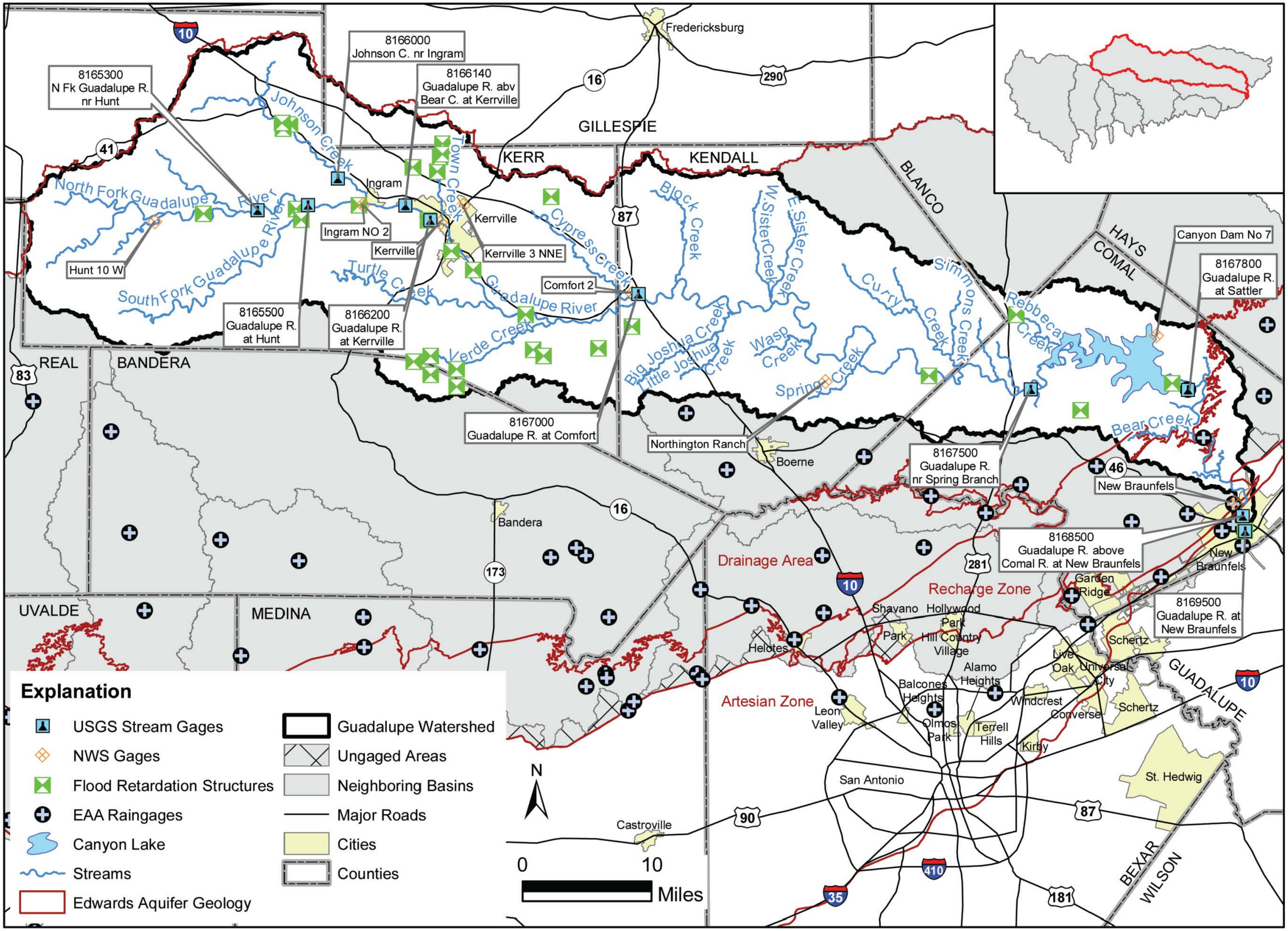


Figure 5.8.1 - Guadalupe Basin

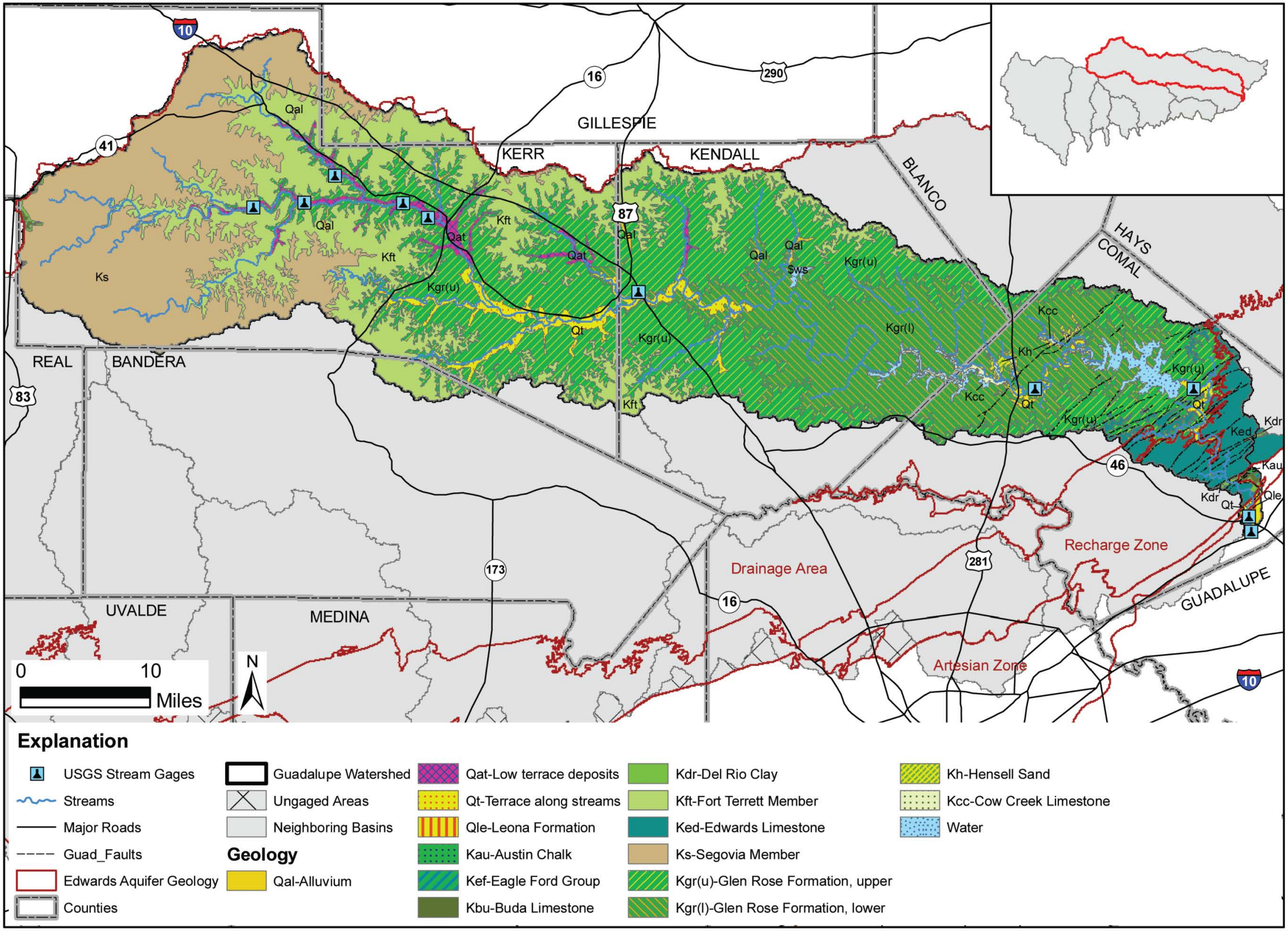


Figure 5.8.2 - Surface Geology in the Guadalupe Basin

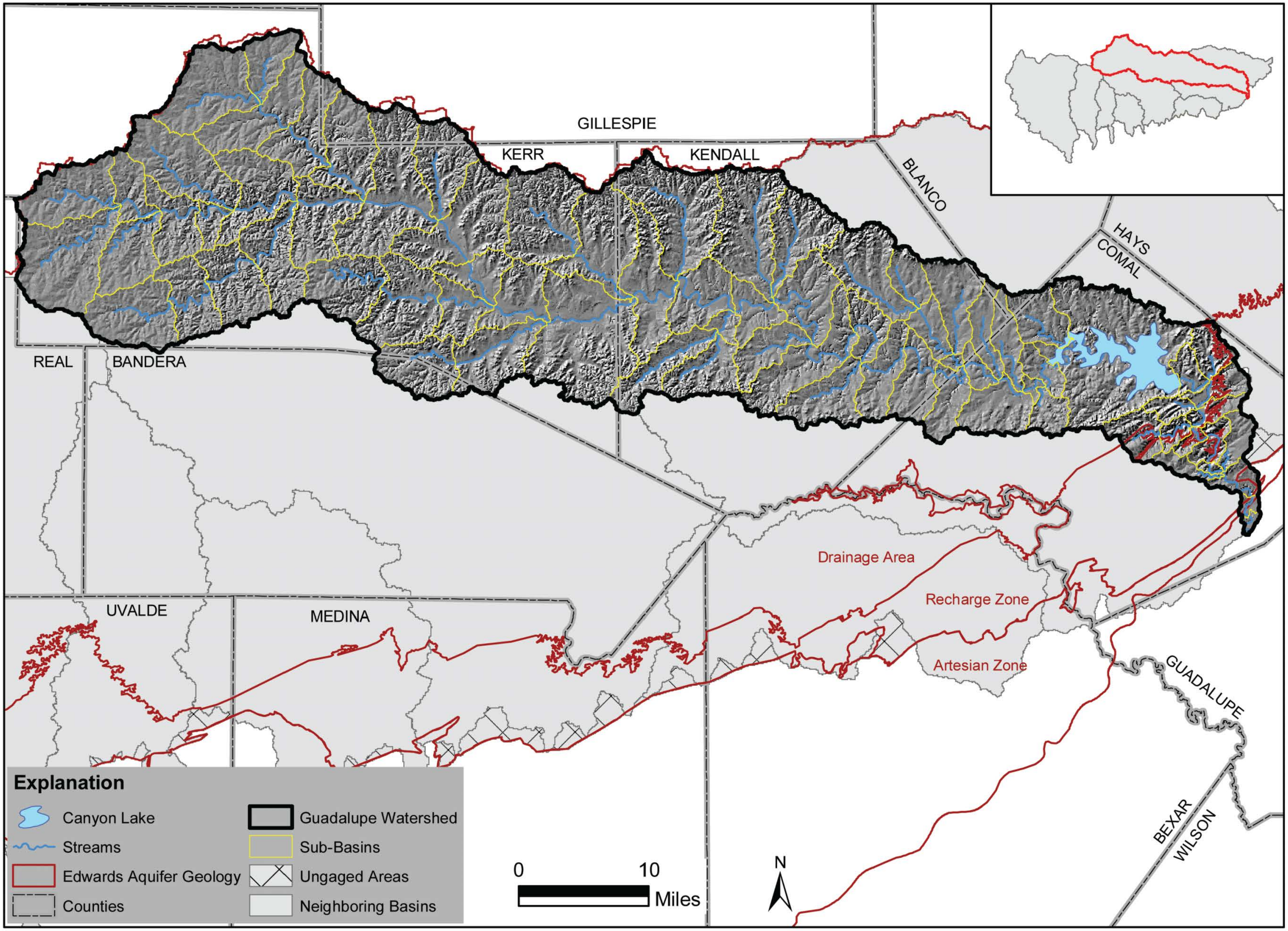


Figure 5.8.3 - Hillshade View in the Guadalupe Basin

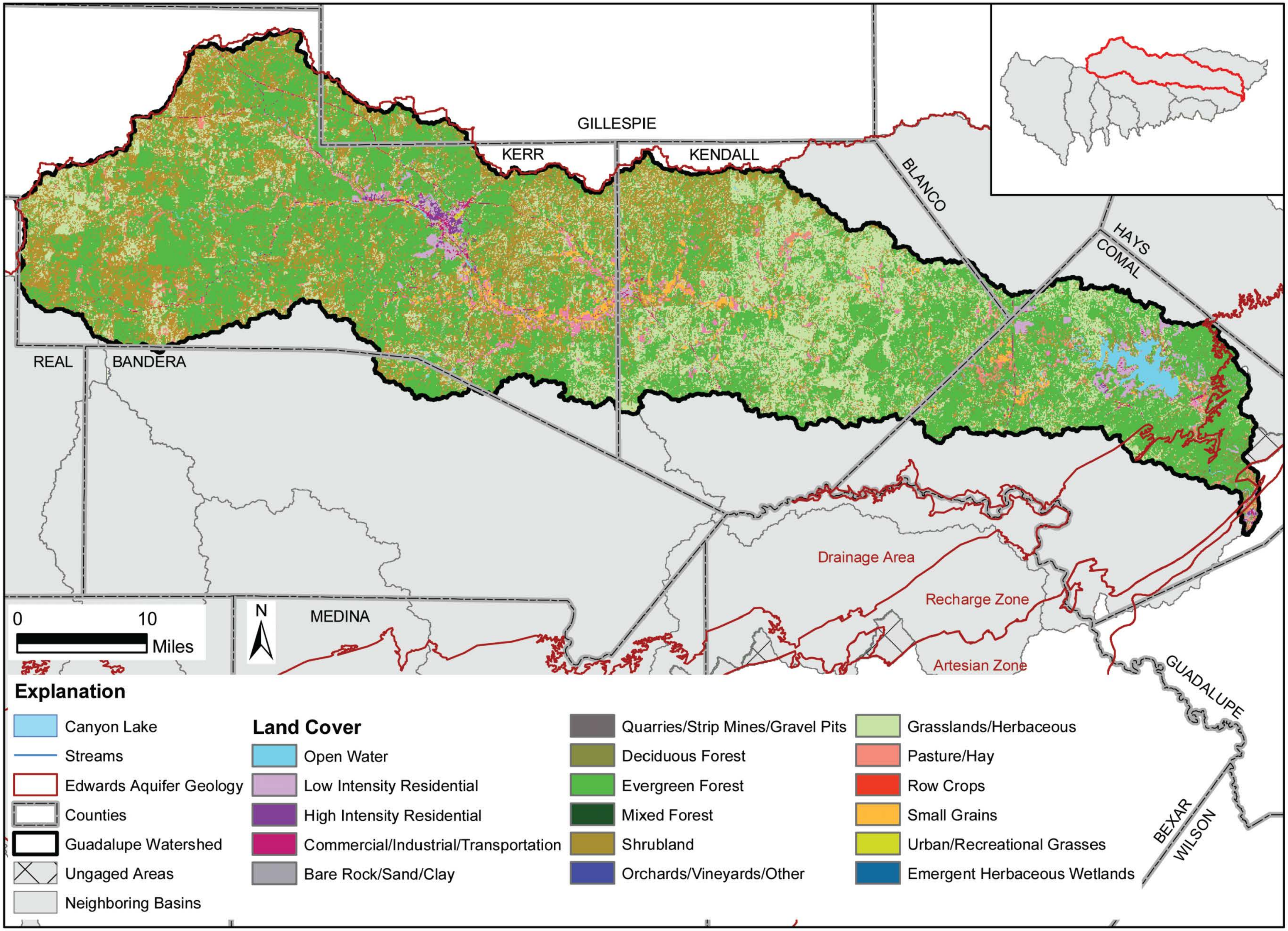


Figure 5.8.4 - Land Cover and Vegetation in the Guadalupe Basin

Figure 5.8.5 summarizes the proportions of each PERLND group in the Guadalupe basin. The pie chart indicates that the largest PERLND components in the contributing zone are flat shallow soil areas followed by steep shallow soils. In the recharge zone, the dominant land segment is steep shallow soils in combination with Lower Glen Rose surface geology.

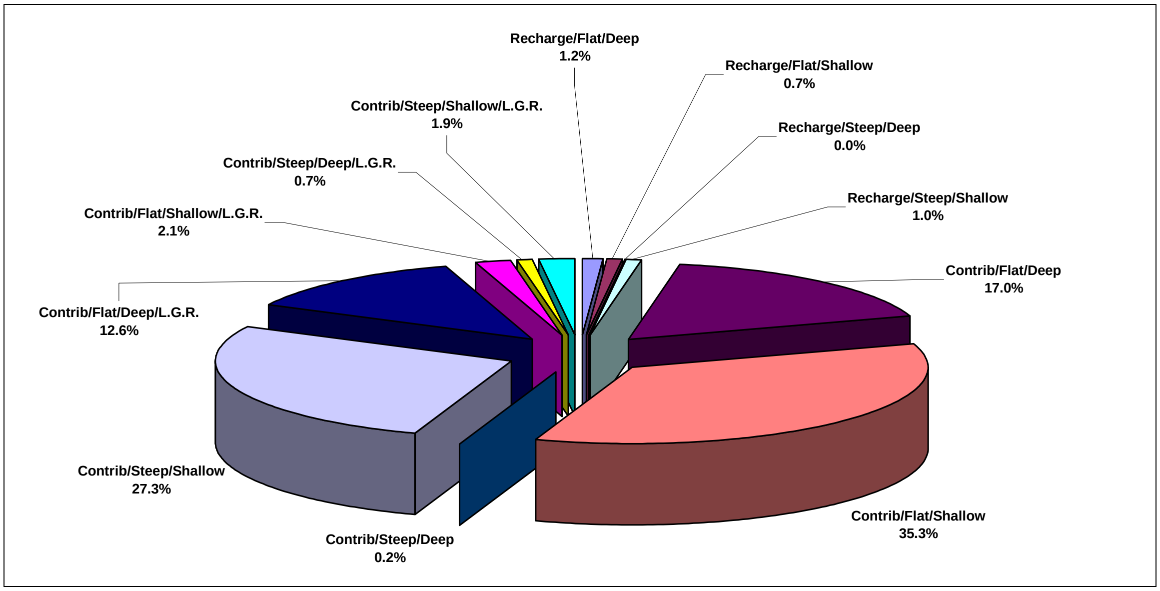


Figure 5.8.5 PERLND Distribution in the Guadalupe Basin

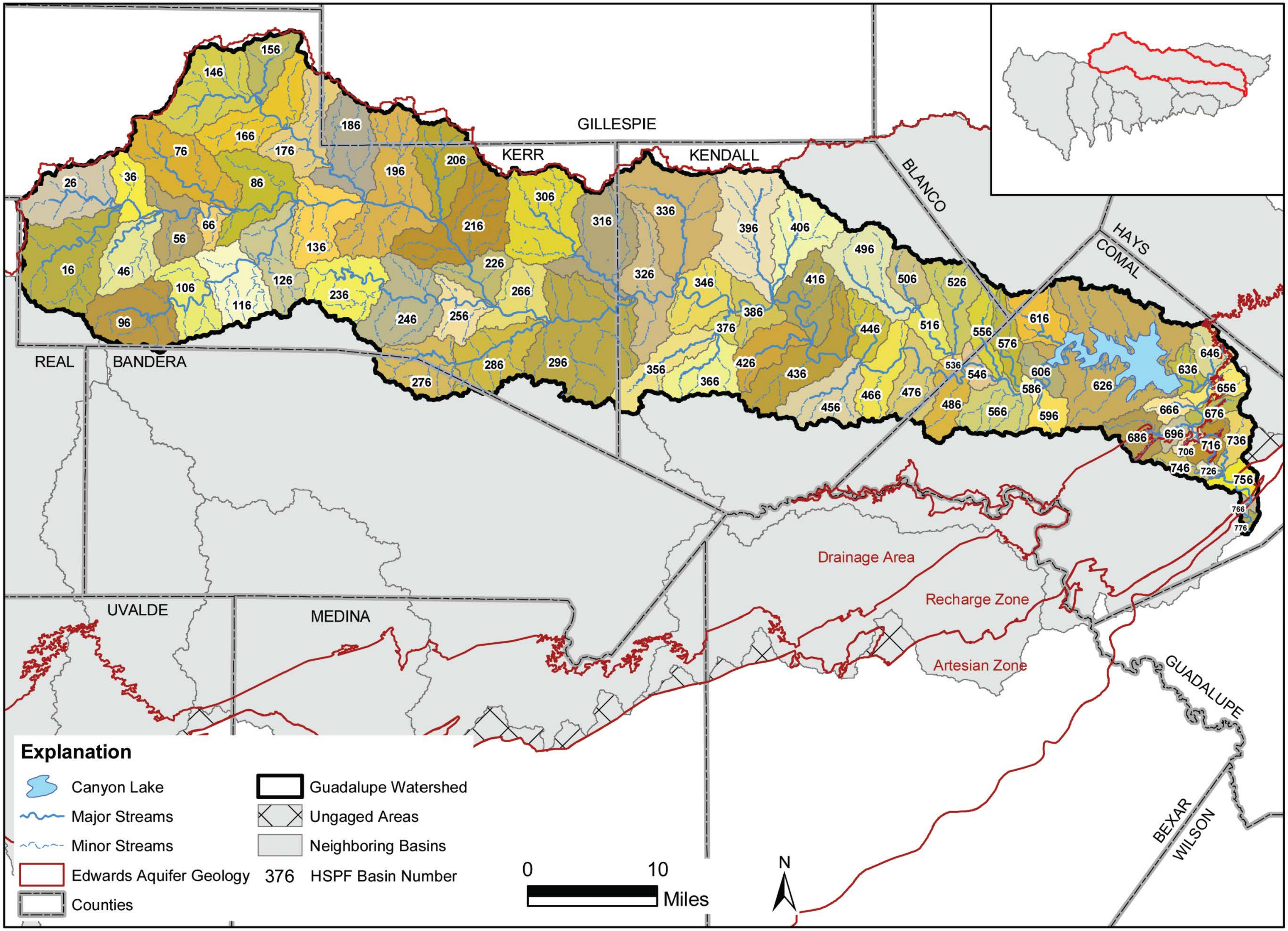


Figure 5.8.6 - Delineated Basins in the Guadalupe Basin

5.8.2 Model Calibration

5.8.2.1 Streamflow Comparison

5.8.2.1.1 Contributing Zone (Upstream Gages)

As shown on Figure 5.8.1, there are eight streamflow gages in the contributing zone of the Guadalupe Basin above Canyon Dam. Because the recharge to the Edwards aquifer is mostly dependent on streamflow below Canyon Dam, only one streamflow gage above Canyon Dam is discussed in regards to calibration. Each of the upstream gages was used to calibrate the contributing zone model and the calibrated results were very good for each gage.

Figure 5.8.7 compares daily simulated and observed flow at stream gage 8167500 (Guadalupe River at Spring Branch) for the 5-year period between 1997 and 2001. The agreement between the observed and simulated flow is excellent. The flow duration curve, shown in Figure 5.8.8, indicates good agreement accept for very low flow events.

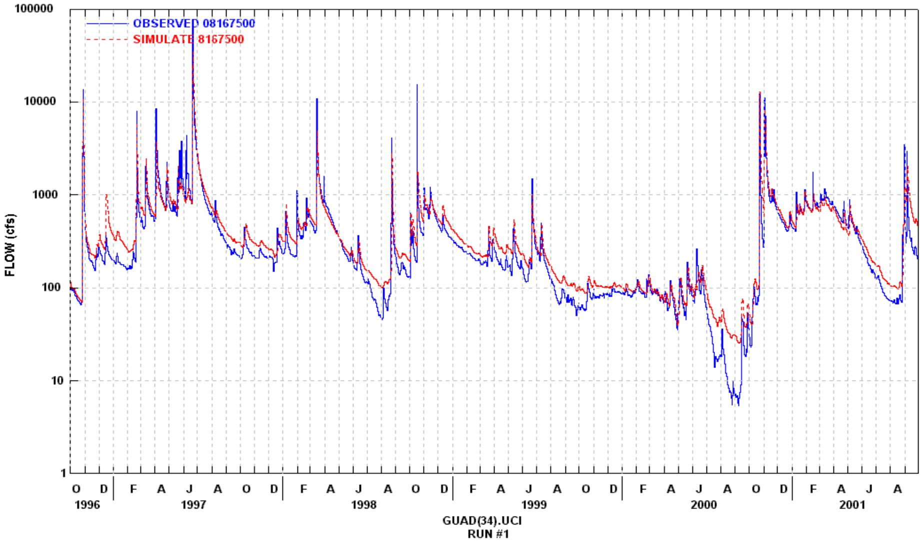


Figure 5.8.7 Daily Streamflow Comparison (Water Years 1997-2001: Guadalupe River at Spring Branch, USGS #8167500)

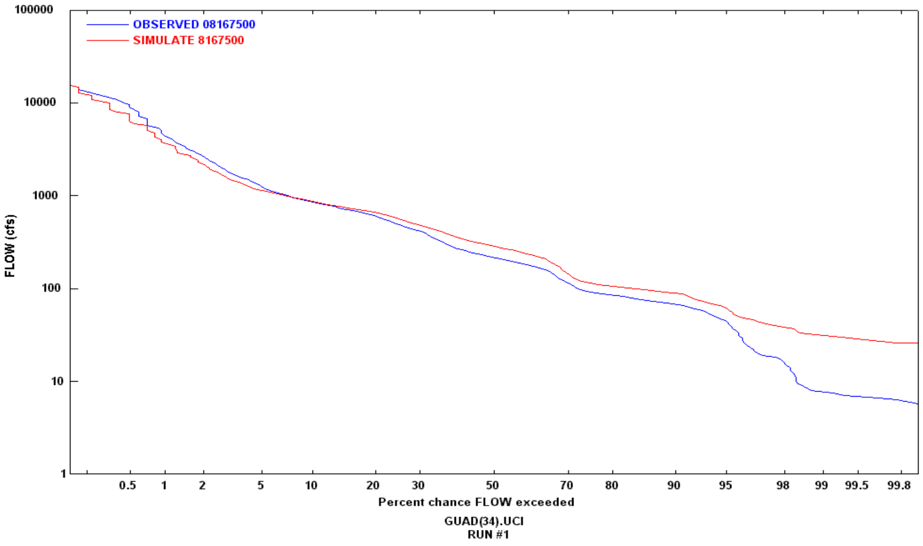


Figure 5.8.8 Daily Streamflow Frequency (Water Years 1997-2001: Guadalupe River at Spring Branch, USGS #8167500)

5.8.2.1.2 Recharge Zone (Downstream Gages)

Figure 5.8.9 compares daily simulated and observed flow at stream gage 8168500 (Guadalupe River above Comal River at New Braunfels) for the 5-year period between 1997 and 2001. The agreement between the observed and simulated flow is excellent. The flow duration curve, shown in Figure 5.8.10, indicates good agreement accept for low probability high flow events. Tables 5.8.2, 5.8.3, and 5.8.4 provide further statistical information regarding the calibration results.

Table 5.8.2 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Guadalupe River at New Braunfels, USGS #8168500)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	38.78	10.75	10.47	-2.72
1998	39.09	4.38	4.24	-3.28
1999	47.07	5.90	6.33	6.76
2000	27.77	1.06	0.86	-23.49
2001	49.72	7.13	7.50	4.95
Average	40.49	5.84	5.88	0.59

Table 5.8.3 Daily and Monthly Statistics (Water Years 1997-2001: Guadalupe River at New Braunfels, USGS #8168500)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	657.30	653.42
Geometric Mean (cfs)	326.54	343.82
Standard Deviation (cfs)	1311.18	1113.63
Correlation Coefficient	0.96	
Coefficient of Determination	0.92	
Mean Error (cfs)	-3.88	
Mean Absolute Error (cfs)	71.66	
Monthly Statistics		
Count	60	60
Mean (cfs)	656.97	652.95
Geometric Mean (cfs)	354.07	371.43
Standard Deviation (cfs)	857.93	860.62
Correlation Coefficient	0.99	
Coefficient of Determination	0.99	
Mean Error (cfs)	-4.02	
Mean Absolute Error (cfs)	50.18	

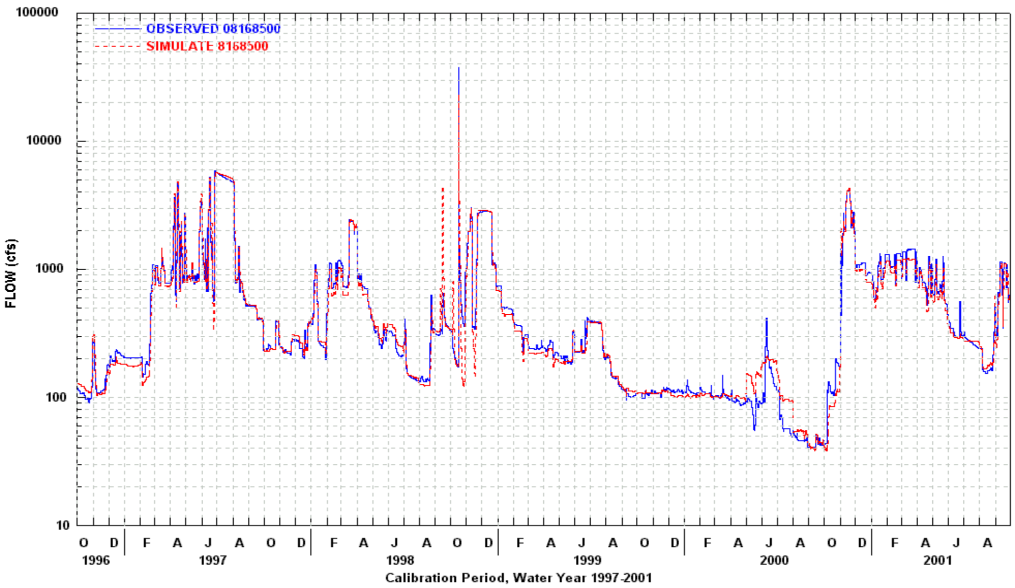


Figure 5.8.9 Daily Streamflow Comparison (Water Years 1997-2001: Guadalupe River at New Braunfels, USGS #8168500)

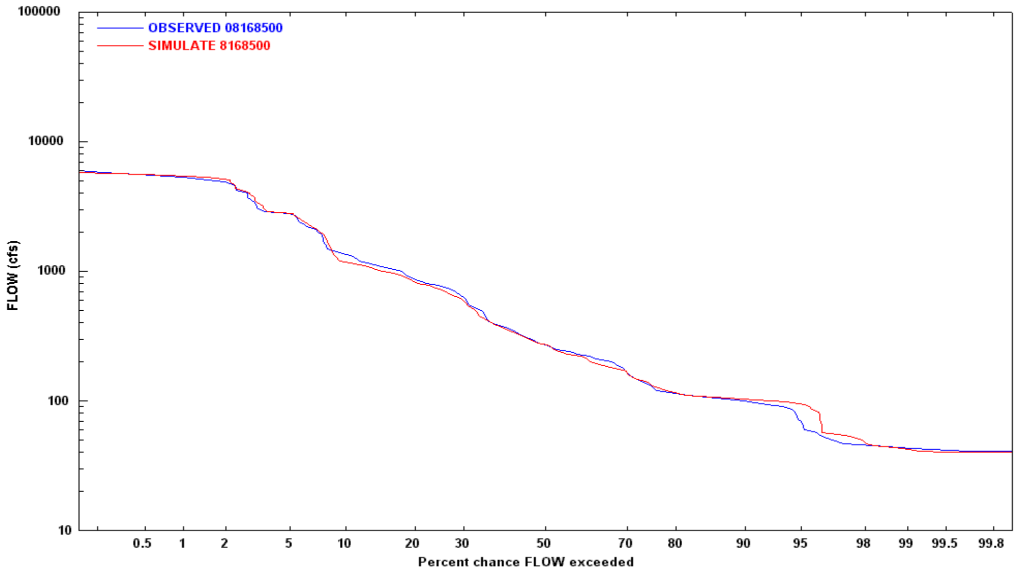


Figure 5.8.10 Daily Streamflow Frequency (Water Years 1997-2001: Guadalupe River at New Braunfels, USGS #8168500)

Table 5.8.4 Calibration Statistics and Criteria (Water Years 1997-2001: Guadalupe River at New Braunfels, USGS #8168500)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	5.88	5.84	-1%	10%	Excellent
10% high (inches)	2.70	2.88	7%	10%	Excellent
25% high (inches)	4.16	4.13	-1%	15%	Excellent
50% Low (inches)	0.67	0.72	8%	15%	Excellent
25% Low (inches)	0.21	0.25	19%	15%	Good
10% Low (inches)	0.06	0.08	32%	15%	Poor
storm volume (inches)	1.96	1.92	-2%	20%	Excellent
average storm peak (cfs)	11448.00	22620.27	98%	15%	Poor
summer volume (inches)	1.59	1.68	6%	15%	Excellent
winter volume (inches)	1.29	1.19	-7%	10%	Excellent
summer storms (inches)	1.00	1.03	3%	10%	Excellent
winter storms (inches)	0.00	0.00	0%	15%	Excellent

5.8.2.2 Water Balance

Table 5.8.11 provides a detailed water balance summary for the Guadalupe basin as simulated by the HSPF model.

Table 5.8.5 Mean Annual Simulated Water Balance in the Guadalupe Basin (Water Years 1997-2001)

		Contributing Zone		Recharge Zone		
Component	**unit**	**Deep Soil**	**Shallow Soil**	**Deep Soil**	**Shallow Soil**	**Watershed Average**
Rainfall	inch	38.42	38.42	38.42	38.42	38.42
Runoff						
Surface	inch	2.82	3.50	2.11	3.36	3.08
Interflow	inch	1.01	2.37	0.73	2.47	1.91
Baseflow	inch	4.21	4.91	0.02	0.17	2.24
Total	inch	8.04	10.78	2.87	6.00	7.24
Groundwater Inflow						
Deep	inch	1.82	1.25	8.92	6.84	4.83
Active	inch	4.21	4.91	0.02	0.17	2.24
Total	inch	6.03	6.16	8.94	7.00	7.08
Evaporation						
Potential	inch	53.83	53.83	53.83	53.83	53.83
Intercept Stor.	inch	7.31	9.03	8.86	9.41	8.99
Upper Zone	inch	5.46	4.51	3.17	3.63	3.98
Lower Zone	inch	11.33	11.96	13.35	12.09	12.29
Ground Water	inch	1.77	0.00	0.13	0.00	0.15
Baseflow	inch	0.84	0.00	0.02	0.00	0.06
Total	inch	26.71	25.50	25.52	25.13	25.48
Area	acres	3580	20017	12423	15813	51833
Area	%	6.91	38.62	23.97	30.51	100.00

5.9 Blanco

5.9.1 Basin Hydrology and Features

Figure 5.9.1 shows the map of rivers and streams, major roads, cities, county boundaries, NWS and EAA precipitation gages, USGS stream gages, Edwards aquifer contributing, recharge, and artesian zones, FRSs, and ungaged areas in the Blanco Basin. Table 5.9.1 summarizes basic hydrologic and modeling information about the basin. Figure 5.9.2 shows the surface geology and mapped geologic faults in the basin. Figures 5.9.3 and 5.9.4 show the hillshade and land cover/vegetation maps. Figure 5.9.5 shows the proportions of different PERLND groups in the basin. Figure 5.9.6 illustrates the delineated subwatersheds within the basin and watershed ID number required for HSPF.

Table 5.9.1 Summary Information for Blanco Basin

Feature or Statistic	Measure	Details
Total area (sq. miles)	541.3	
No. of subwatersheds in model	70	
No. of stream reaches in model	70	
No. of EAA rain gages in basin	7	
Contributing Zone		
Area (sq. miles)	377.5	
Stream length (miles)	137.9	
No. of stream gages above recharge zone	1	
Average subwatershed area (sq. miles)	9.0	Range: 0.026 to 22.85
Average stream reach length (miles)	3.7	Range: 0.374 to 7.46
Recharge Zone		
Area (sq. miles)	124.0	
Stream length (miles) [1]	77.8	
No. stream gages below recharge zone	2	
Average subwatershed area (sq. miles)	3.3	Range: 0061 to 14.60
Average stream reach length (miles)	2.7	Range: 0.305 to 7.41

[1] Stream length includes only those streams included in the EPA RF1 files

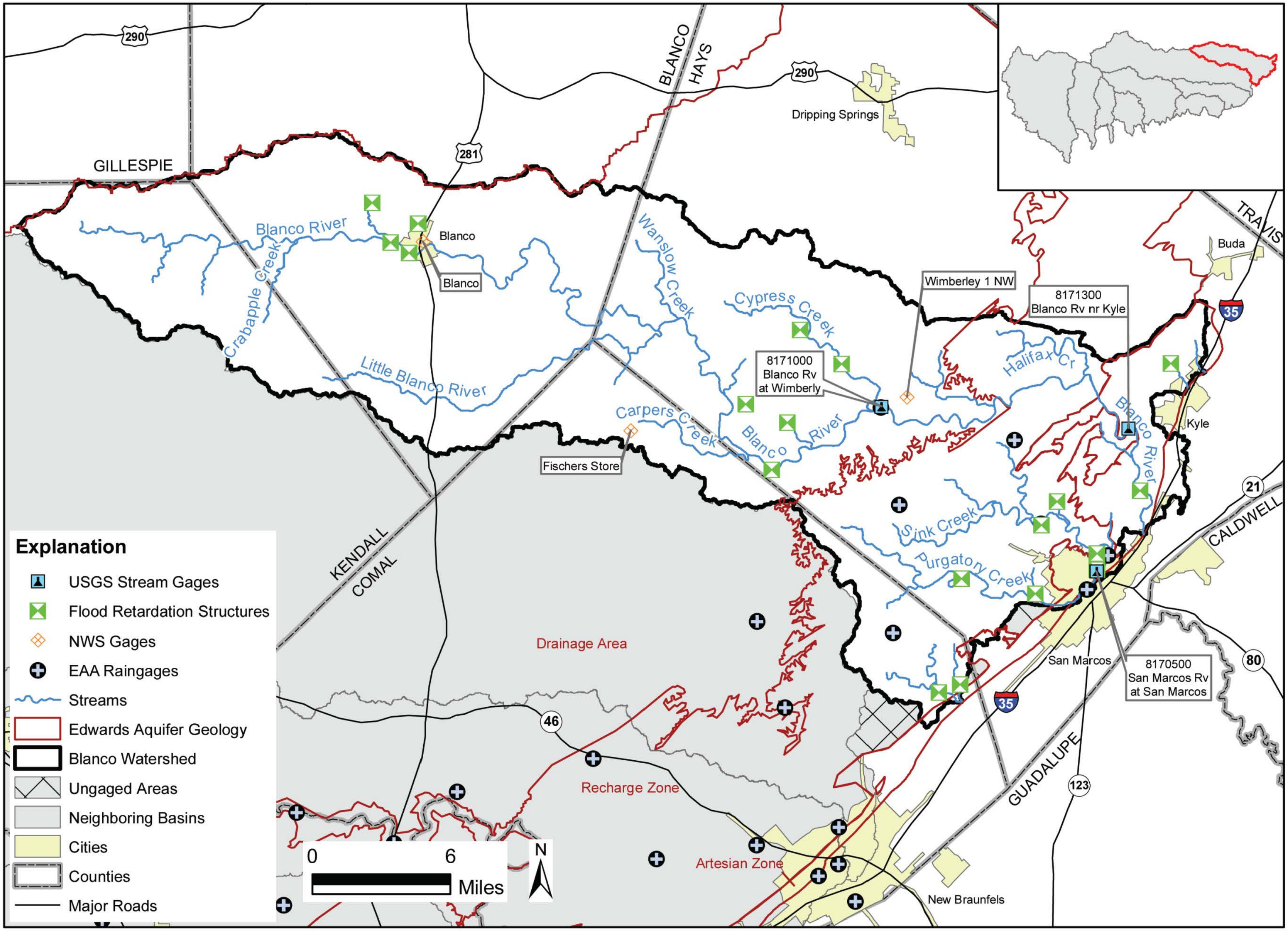


Figure 5.9.1 - Blanco Basin

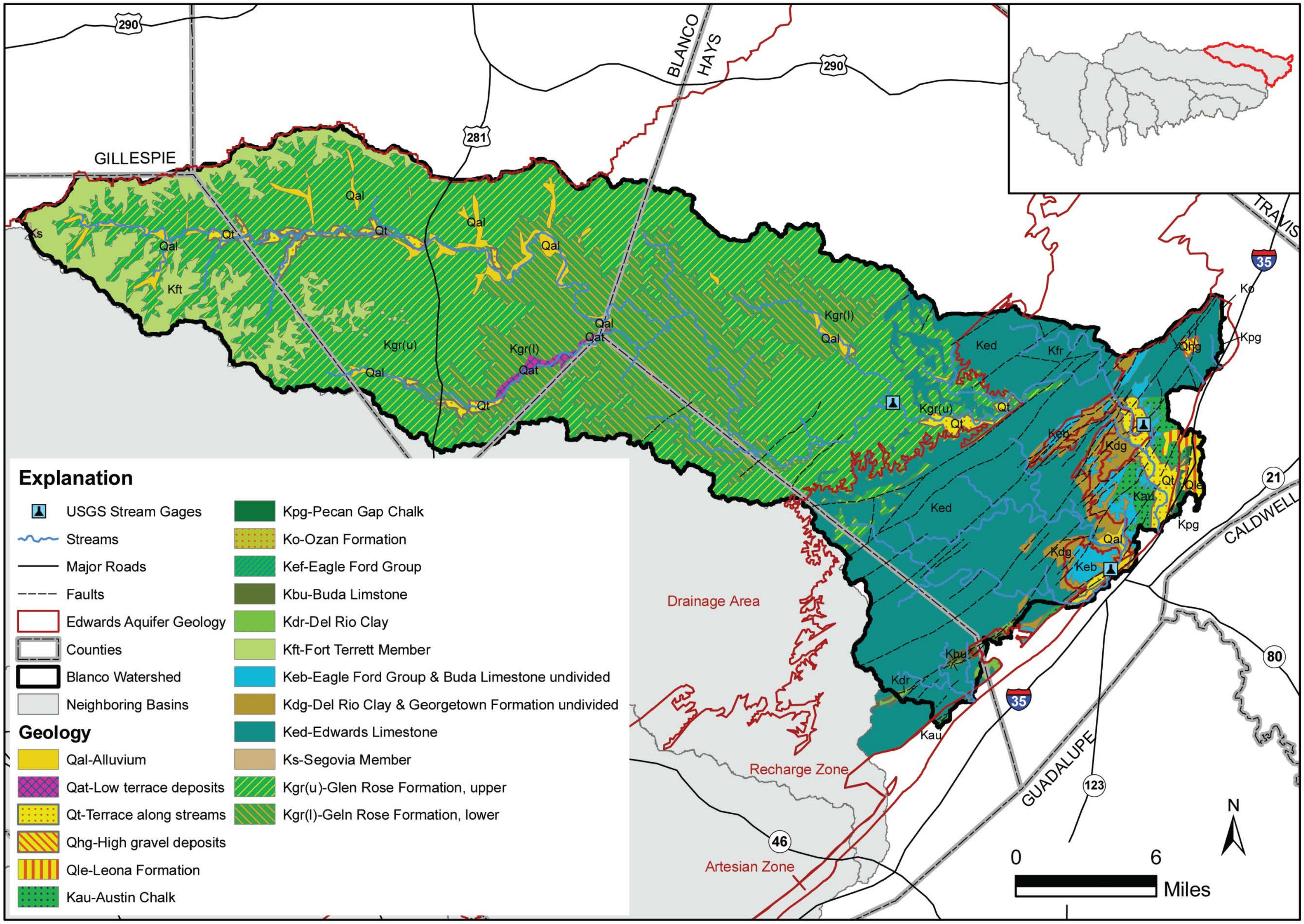


Figure 5.9.2 - Surface Geology in the Blanco Basin

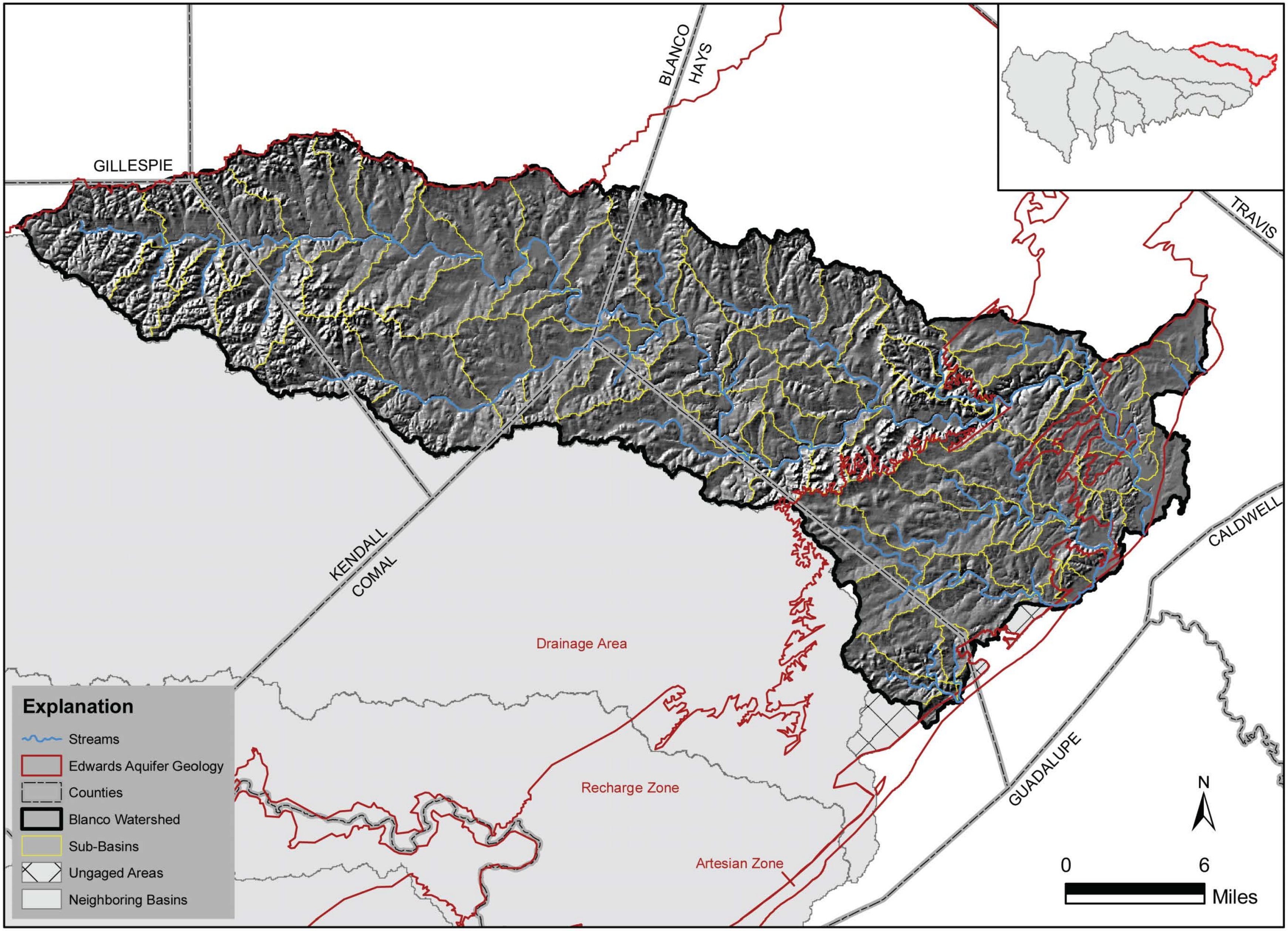


Figure 5.9.3 - Hillshade View in the Blanco Basin

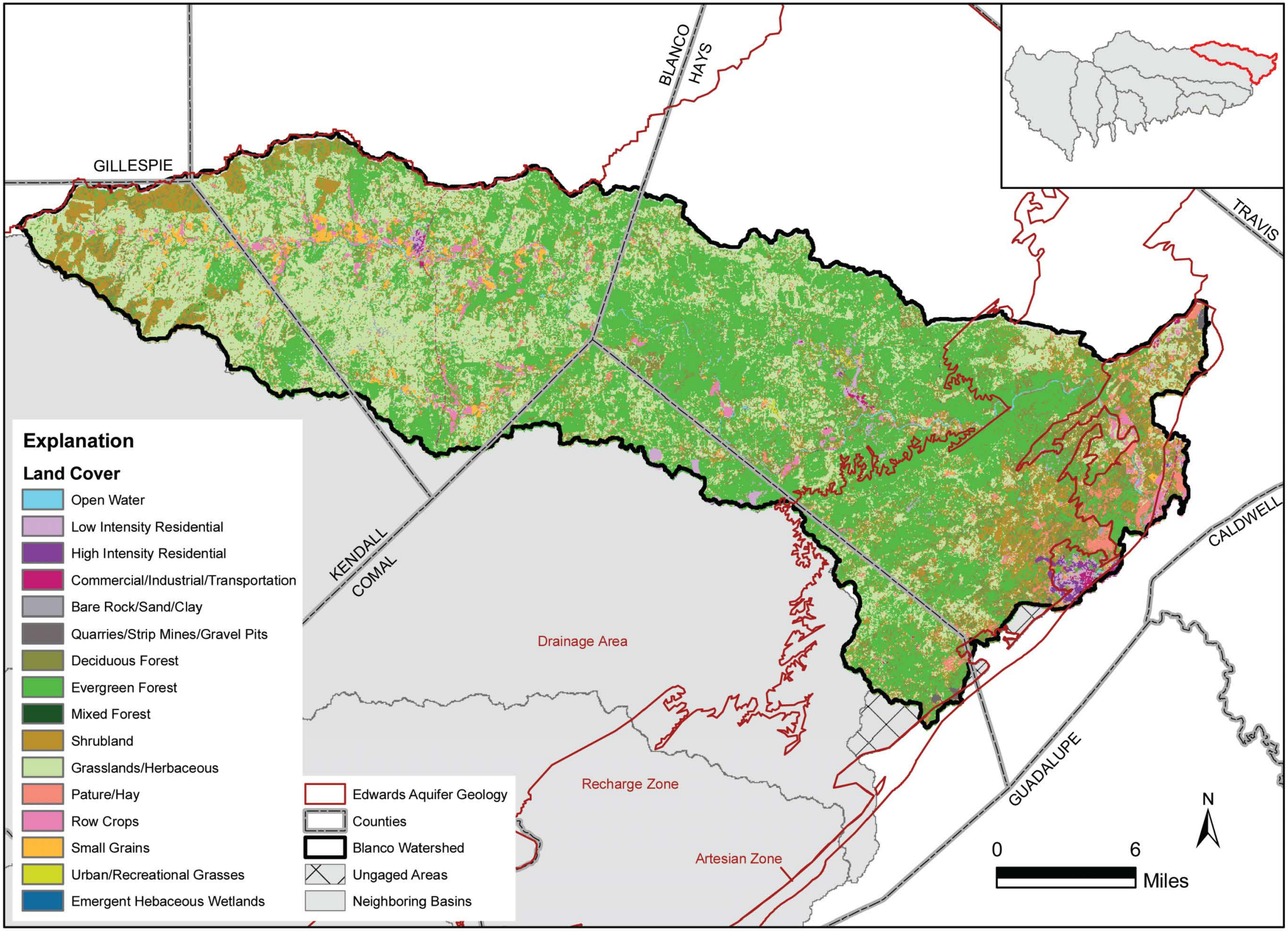


Figure 5.9.4 - Land Cover in the Blanco Basin

Figure 5.9.5 summarizes the proportions of each PERLND group in the Blanco basin. The chart indicates that the largest PERLND components in the contributing zone are flat deep soil areas followed by steep shallow soils. In the recharge zone, the dominant land segment is flat and deep soils.

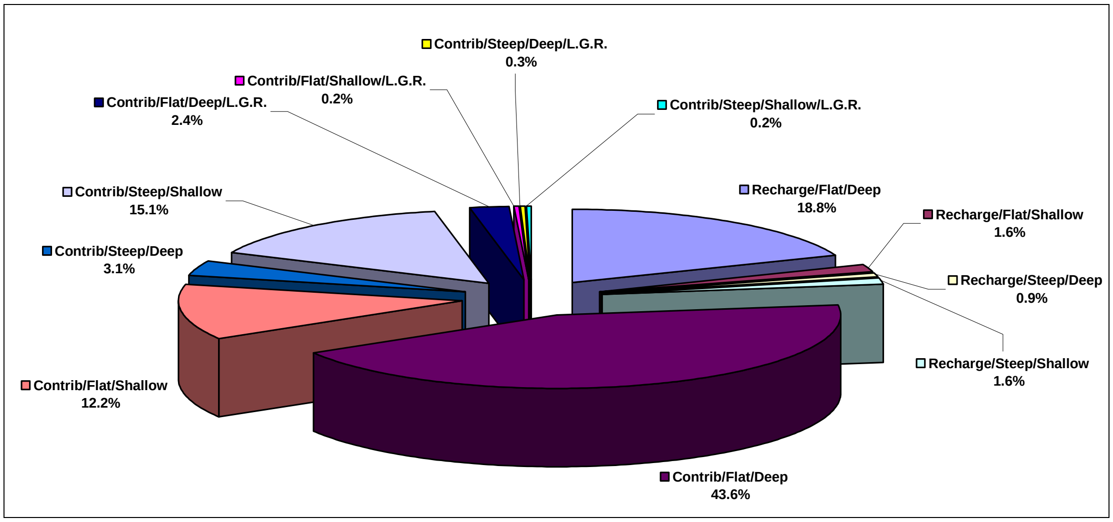


Figure 5.9.5 PERLND Distribution in the Blanco Basin

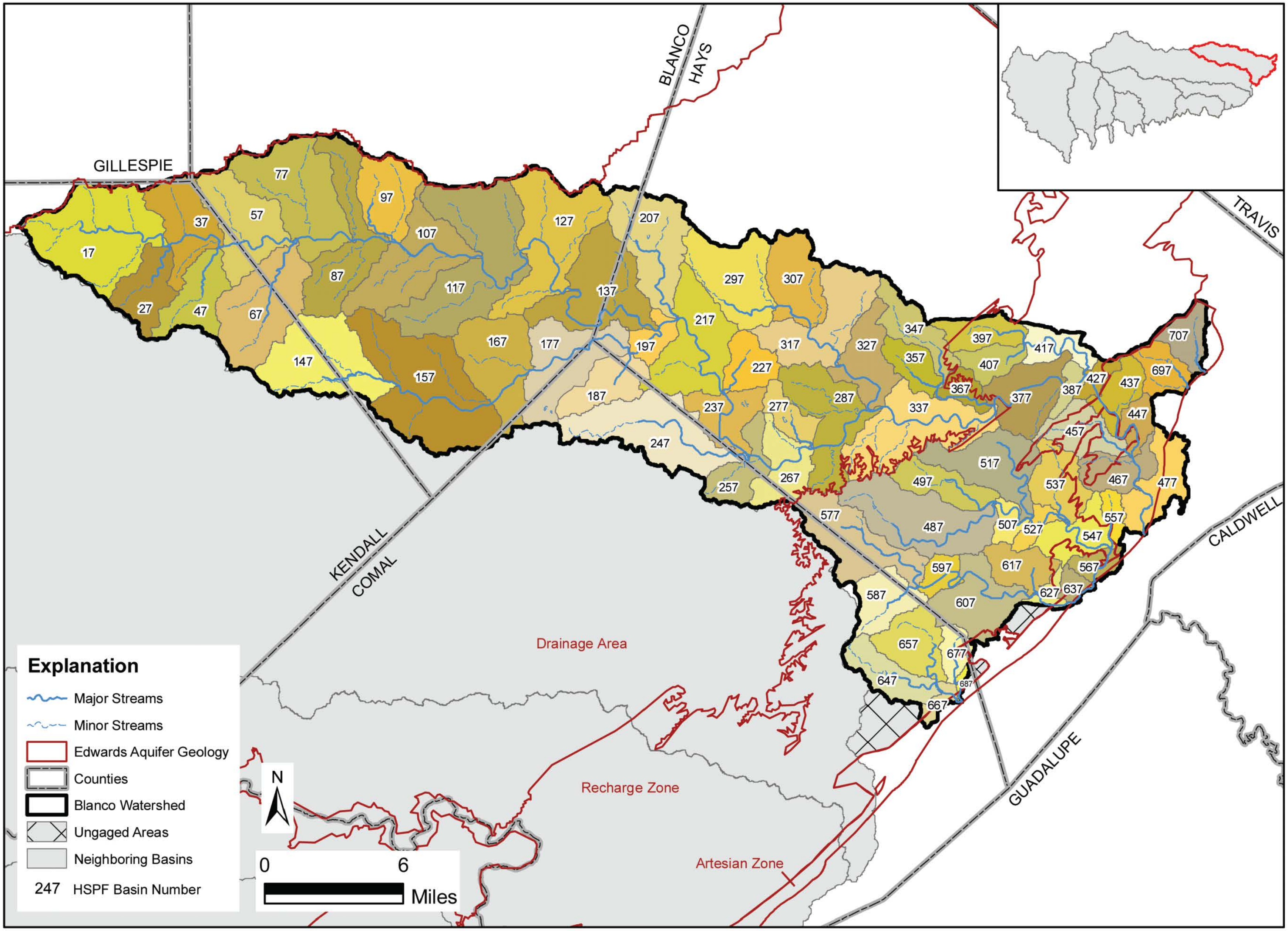


Figure 5.9.6 - Delineated Basins in the Blanco Basin

5.9.2 Model Calibration

5.9.2.1 Streamflow Comparison

5.9.2.1.1 Contributing Zone (Upstream Gages)

Figure 5.9.7 compares daily simulated and observed flow at stream gage #8171000, Blanco River at Wimberley) for the 5-year period between 1997 and 2001. Overall, the agreement between the observed and simulated flow is good. The flow duration curve, shown in Figure 5.9.8, indicates that the model generally simulates flow from the contributing zone relatively well. Tables 5.9.2, 5.9.3, and 5.9.4 provide further statistical information regarding the calibration.

Table 5.9.2 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Blanco River at Wimberley, USGS #8171000)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	48.01	11.06	13.58	-18.53
1998	36.96	5.94	6.21	-4.42
1999	28.88	7.15	9.86	-27.53
2000	21.72	0.67	0.83	-19.06
2001	47.50	8.31	7.50	10.84
Average	36.61	6.63	7.60	12.77

Table 5.9.3 Daily and Monthly Statistics (Water Years 1997-2001: Blanco River at Wimberley, USGS #8171000)

	Simulated	Observed
Daily Statistics		
Count	1826	1826
Mean (cfs)	198.60	173.24
Geometric Mean (cfs)	74.20	87.45
Standard Deviation (cfs)	825.65	291.23
Correlation Coefficient	0.59	
Coefficient of Determination	0.35	
Mean Error (cfs)	-25.36	
Mean Absolute Error (cfs)	99.00	
Monthly Statistics		
Count	60	60
Mean (cfs)	199.33	173.82
Geometric Mean (cfs)	82.80	93.41
Standard Deviation (cfs)	360.76	210.66
Correlation Coefficient	0.92	
Coefficient of Determination	0.85	
Mean Error (cfs)	-25.51	
Mean Absolute Error (cfs)	76.64	

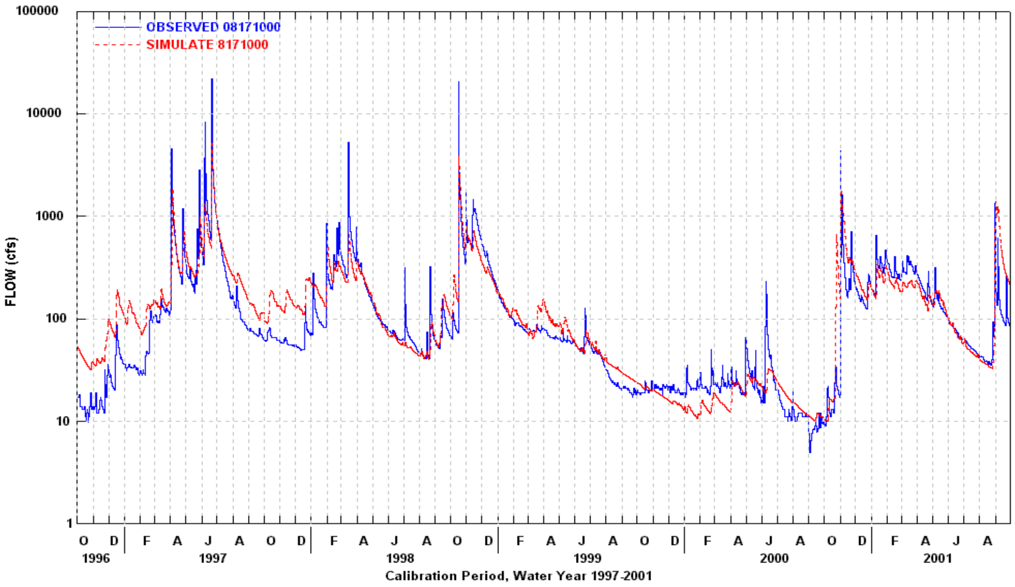


Figure 5.9.7 Daily Streamflow Comparison (Water Years 1997-2001: Blanco River at Wimberley, USGS #8171000)

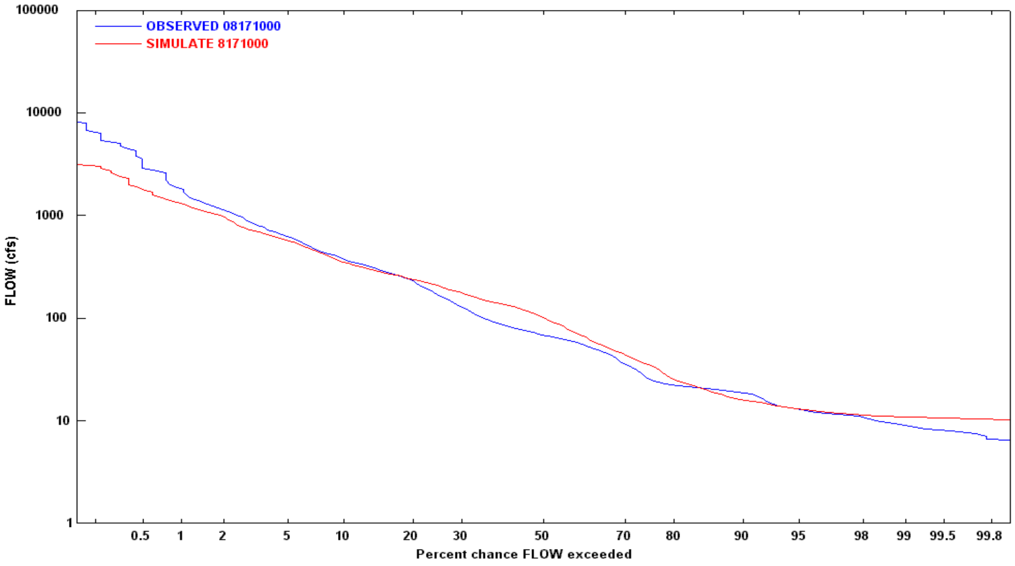


Figure 5.9.8 Daily Streamflow Frequency (Water Years 1997-2001: Blanco River at Wimberley, USGS #8171000)

Table 5.9.4 Calibration Statistics and Criteria (Water Years 1997-2001: Blanco River at Wimberley, USGS #8171000)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	7.60	6.63	-13%	10%	Good
10% high (inches)	4.05	2.94	-28%	10%	Poor
25% high (inches)	5.65	4.45	-21%	15%	Poor
50% Low (inches)	0.64	0.78	23%	15%	Poor
25% Low (inches)	0.17	0.18	9%	15%	Good
10% Low (inches)	0.05	0.05	3%	15%	Excellent
storm volume (inches)	2.75	1.43	-48%	20%	Poor
average storm peak (cfs)	16063.33	4838.90	70%	15%	Poor
summer volume (inches)	1.66	1.58	-5%	15%	Excellent
winter volume (inches)	1.59	1.42	-10%	10%	Good
summer storms (inches)	0.00	0.00	0%	10%	Excellent
winter storms (inches)	0.31	0.13	-58%	15%	Poor

5.9.2.1.2 Recharge Zone (Downstream Gages)

Figure 5.9.9 compares daily simulated and observed flow at stream gage 8171300 (Blanco River near Kyle) for the 5-year period between 1997 and 2001. The graph shows the simulated daily streamflow versus the observed daily streamflow. The flow duration curve, shown in Figure 5.9.10, indicates that the model does a very good job simulating streamflow across the recharge zone. Tables 5.9.5, 5.9.6, and 5.9.7 provide further statistical information regarding the calibration results.

Table 5.9.5 Comparison of Simulated and Observed Annual Runoff (Water Years 1997-2001: Blanco River near Kyle, USGS #8171300)

Water Year	Precipitation (inches)	Simulated Flow (inches)	Observed Flow (inches)	Percent Error
1997	38.78	11.87	11.75	0.99
1998	39.09	5.08	5.13	-1.03
1999	47.07	8.97	9.41	-4.60
2000	27.77	0.11	0.11	0.03
2001	49.72	6.52	5.74	13.46
Average	40.49	6.51	6.43	-1.26

Table 5.9.6 Daily and Monthly Statistics (Water Years 1997-2001: Blanco River near Kyle, USGS #8171300)

	Simulated	**Observed**
Daily Statistics		
Count	1826	1826
Mean (cfs)	195.03	197.49
Geometric Mean (cfs)	6.16	8.58
Standard Deviation (cfs)	901.40	837.71
Correlation Coefficient	0.99	
Coefficient of Determination	0.98	
Mean Error (cfs)	2.46	
Mean Absolute Error (cfs)	25.69	
Monthly Statistics		
Count	60	60
Mean (cfs)	195.77	198.21
Geometric Mean (cfs)	12.56	21.17
Standard Deviation (cfs)	403.36	393.21
Correlation Coefficient	1.00	
Coefficient of Determination	1.00	
Mean Error (cfs)	2.44	
Mean Absolute Error (cfs)	13.44	

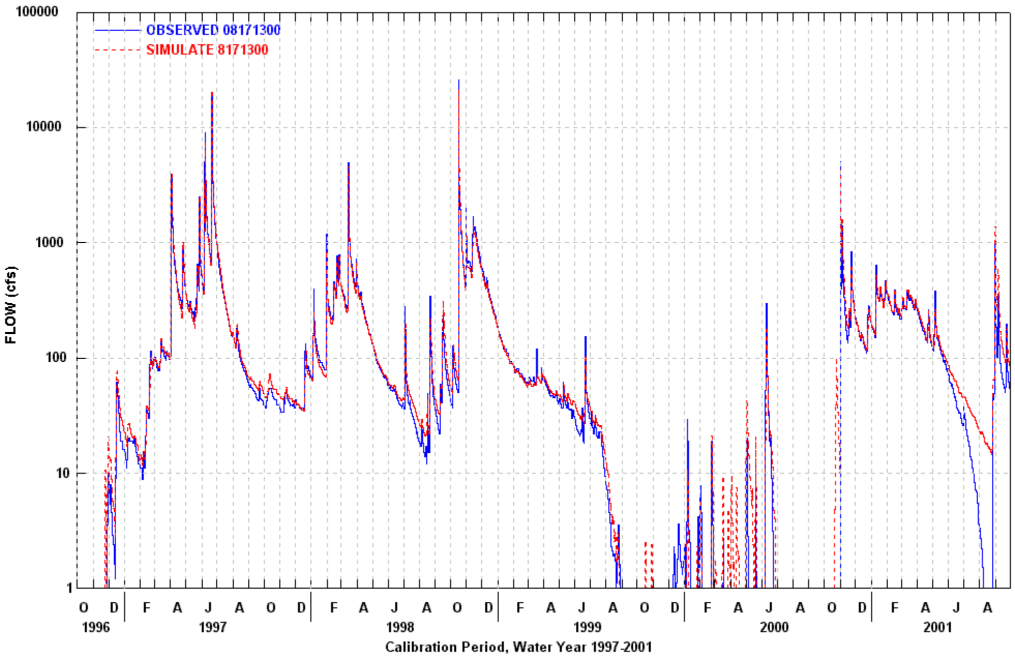


Figure 5.9.9 Daily Streamflow Comparison (Water Years 1997-2001: Blanco River near Kyle, USGS #8171300)

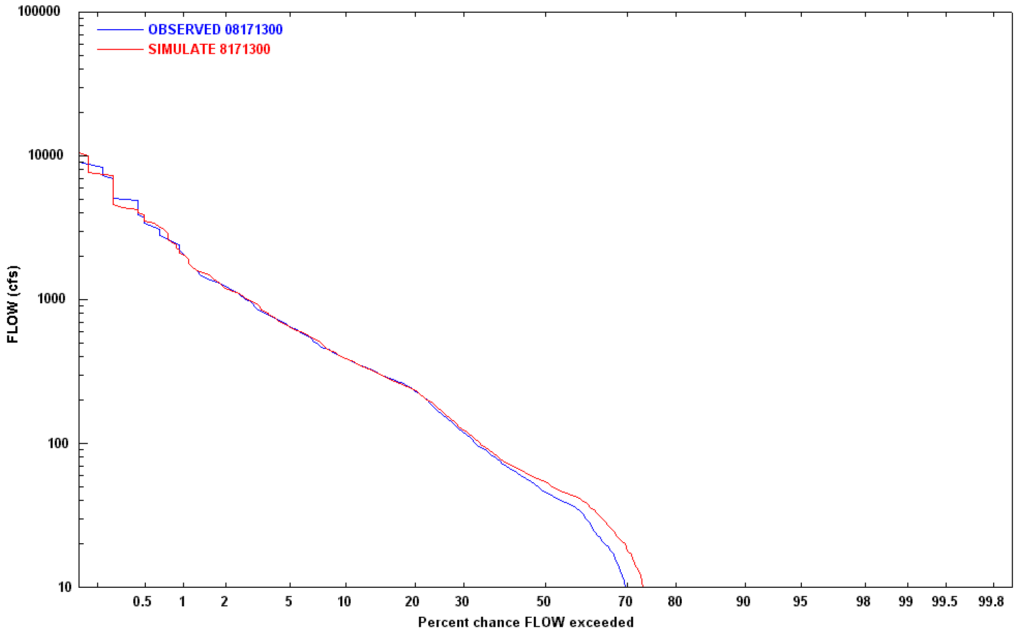


Figure 5.9.10 Daily Streamflow Frequency (Water Years 1997-2001: Blanco River near Kyle, USGS #8171300)

Table 5.9.7 Calibration Statistics and Criteria (Water Years 1997-2001: Blanco River near Kyle, USGS #8171300)

Calibration Target	Observed	Simulated	Difference	Criteria	Assessment
Total (inches)	6.43	6.51	1%	10%	Excellent
10% high (inches)	3.75	4.17	11%	10%	Good
25% high (inches)	5.26	5.49	4%	15%	Excellent
50% Low (inches)	0.20	0.27	36%	15%	Poor
25% Low (inches)	0.00	0.00	319%	15%	N/A
10% Low (inches)	0.00	0.00	0%	15%	Excellent
storm volume (inches)	2.64	2.59	-2%	20%	Excellent
average storm peak (cfs)	16846.67	23638.34	40%	15%	Poor
summer volume (inches)	1.25	1.40	12%	15%	Good
winter volume (inches)	1.29	1.28	-1%	10%	Excellent
summer storms (inches)	0.00	0.00	0%	10%	Excellent
winter storms (inches)	0.28	0.27	-3%	15%	Excellent

5.9.2.2 Water Balance

Table 5.9.8 provides a detailed water balance summary for the Blanco basin as simulated by the HSPF model.

Table 5.9.8 Mean Annual Simulated Water Balance in the Blanco Basin (Water Years 1997-2001)

	Contributing Zone		Recharge Zone		Contributing Zone Lower Glen Rose		Watershed Average
	Deep Soil	Shallow Soil	Deep Soil	Shallow Soil	Deep Soil	Shallow Soil	
Rainfall (in.)	34.56	34.56	38.26	38.26	34.56	34.56	**34.80**
Runoff (in.)							
Surface	0.05	0.36	0.62	0.97	0.05	0.28	**0.21**
Interflow	0.29	2.08	0.88	2.76	0.29	1.88	**1.03**
Baseflow	4.12	5.48	0.02	0.17	1.88	3.25	**4.27**
Total	4.46	7.92	1.52	3.90	2.22	5.41	**5.51**
Groundwater Inflow (in.)							
Deep	1.77	1.41	10.69	8.69	4.22	3.33	**2.26**
Active	4.12	5.48	0.02	0.17	1.88	3.25	**4.27**
Total	5.89	6.89	10.72	8.86	6.10	6.58	**6.53**
Evaporation (in.)							
Potential	58.92	58.92	58.92	58.92	58.92	58.92	**58.92**
Intercept St	8.83	8.77	8.58	9.22	9.19	9.67	**8.83**
Upper Zone	3.63	5.25	2.92	4.10	3.54	4.62	**4.20**
Lower Zone	11.49	10.20	13.28	11.88	11.66	10.60	**11.10**
Groundwater	1.89	0.00	0.13	0.00	1.66	0.00	**1.07**
Baseflow	0.70	0.00	0.02	0.00	0.56	0.00	**0.39**
Total	26.54	24.23	24.93	25.20	26.60	24.89	**25.59**
Area (ac)	139532	96095	10583	6333	9789	1049	**263381**
Area (%)	52.98	36.49	4.02	2.40	3.72	0.40	**100.00**

6. Simulation of Recharge (1950 – 2000)

The calibrated HSPF recharge models for each basin were used to estimate recharge to the Edwards aquifer from 1950 to 2000. To estimate recharge, the modeling approach was modified. Essentially, the contributing zone portion of the model is disregarded and replaced with the historical streamflow measurements at the upstream side of the recharge zone instead of the streamflow estimated by the contributing zone model. With this approach, the errors inherent in the simulated streamflow at the upstream gages are eliminated from the "recharge model" and do not affect the accuracy of the recharge estimates. Of course, the exception to this approach is when measured upstream streamflow does not cover the entire period between 1950 through 2000. In the sections below, we document when data for each upstream gage was not available and thus when the contributing zone models were used to estimate upstream flow in each basin.

If the models are to be used to assess strategies such as brush control, weather modification, or water quality in the contributing zone, then it will be important to understand the ramifications of the errors in the simulated streamflow from the contributing zone because a small change in upstream flow could change the results of the recharge prediction. Therefore, the application of the models to assess impact on recharge needs to be considered carefully to ensure that results are not biased. In light of this, the long-term streamflow comparisons are presented here so that the appropriateness of the contributing zone streamflow prediction can be assessed for particular applications. It is important to remember that the lack of fit between the observed and simulated streamflow shown in the daily streamflow duration curves (in some basins) does not impact the recharge estimates.

6.1 Nueces - West Nueces

6.1.1 Long-term Streamflow Comparison

Figure 6.1.1 shows the comparison of the observed and simulated daily streamflow duration plot for the upstream gage on the West Nueces River near Brackettville (USGS #8190500) between 1950 and 2000. The 50-year plot is shown here to provide insight into the models ability to simulate flow at the upstream gage over a long period of time. The long-term duration plot shows the same trend as the 5-year calibration plot that was presented in Section 5. As discussed in Section 5, the contributing zone models in the Nueces basin need to be better calibrated and more field studies should be completed to better understand why the current contributing zone model does not simulate the flow at Brackettville very well. Again, it is important to remember that the difference between the observed and simulated streamflow has no bearing on the recharge estimates because the observed streamflows were used to estimate the recharge. These daily streamflow duration plots are provided to illustrate the ability of the contributing zone model to simulate flow at the upstream gages over the 50-year simulation period.

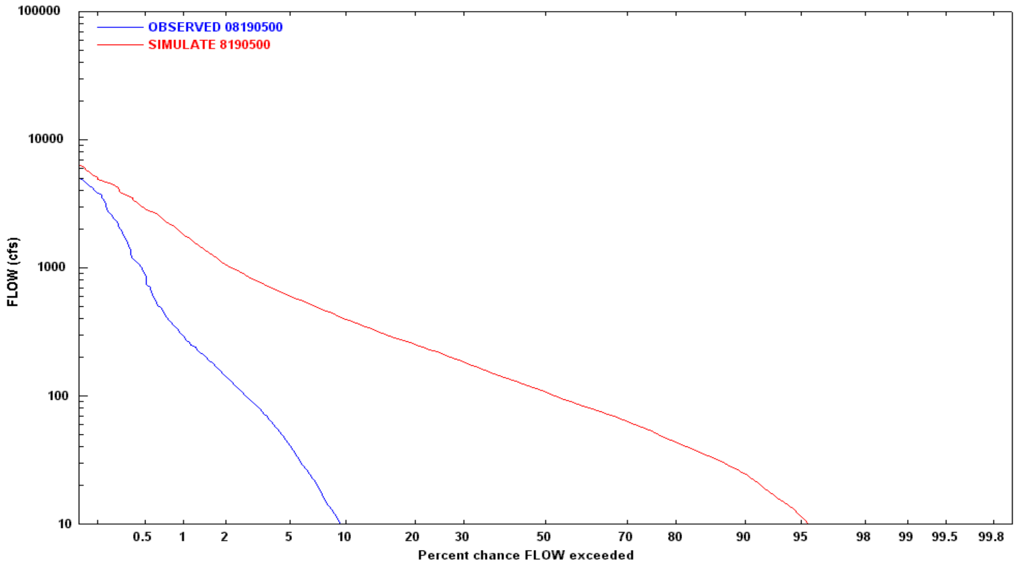


Figure 6.1.1 Daily Streamflow Frequency (1950-2000: West Nueces River near Brackettville, USGS #8190500)

Figure 6.1.2 shows the comparison of the observed and simulated daily streamflow duration plot for the upstream gage on the Nueces River near Laguna (USGS #8190000) between 1950 and 2000. The model does a terrible job of simulating streamflow in the contributing zone. However, as described above, this does not affect the prediction of recharge to the Edwards aquifer as long as streamflow measurements are available at Laguna and Brackettville.

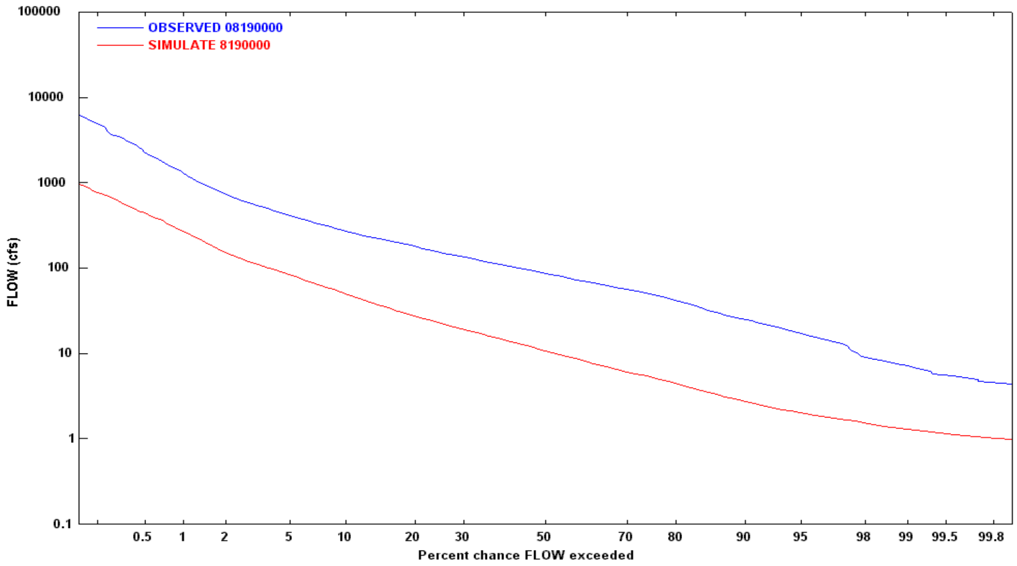


Figure 6.1.2 Daily Streamflow Frequency (1950-2000: Nueces River at Laguna, USGS #8190000)

Figure 6.1.3 shows the comparison of the observed and simulated daily streamflow duration plot for the downstream gage on the Nueces River below Uvalde (USGS #8192000) between 1950 and 2000. These values represent the simulated flows below Uvalde when the streamflow measurements from Laguna and Brackettville are used as the upstream input into the model instead of the streamflow simulated by the contributing zone model.

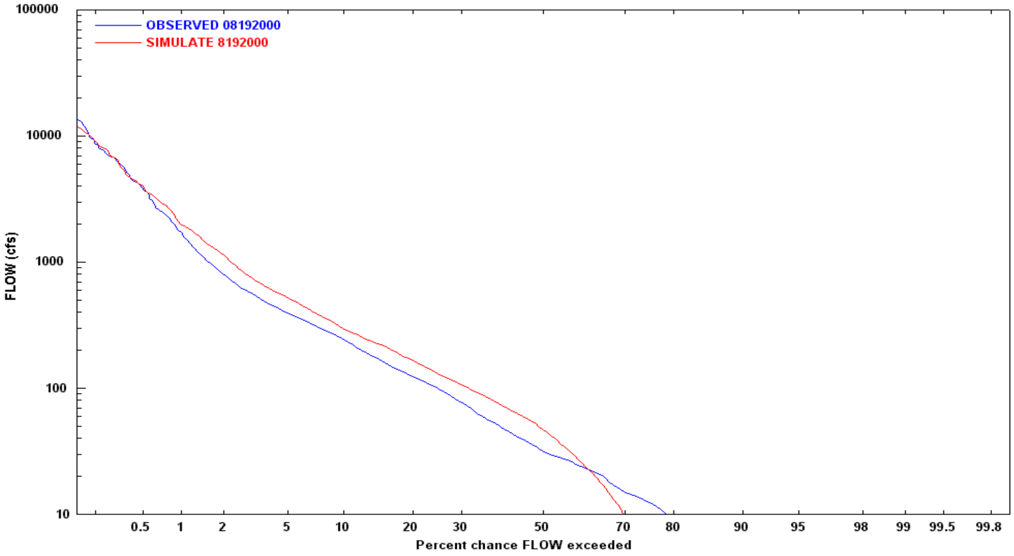


Figure 6.1.3 Daily Streamflow Frequency (1950-2000: Nueces River below Uvalde, USGS #8192000)

6.1.2 Recharge Estimates and Water Balance

Figure 6.1.4 shows the components of the recharge from the streams and the diffuse recharge from permeable land segments in the Nueces basin estimated by the HSPF model. On an annual basis, the stream recharge is more steady than the diffuse or “inter-stream” land recharge. The stream recharge varies from 18,100 to 65,900 ac-ft/yr, averages 44,751, and accounts for about 38% of the total recharge in the basin. Stream recharge accounted for 48% of the total recharge in the HDR pilot model of the Nueces basin (HDR, 2002). Inter-stream recharge varies from 5,550 to 231,000 ac-ft/yr, averages 74,863, and accounts for about 62% of the total recharge in the basin. The model predicts that in most years, the aquifer receives more water from diffuse recharge than from channel loss in the Nueces basin. Through the 47-year period, the average and median annual recharge predicted by the HSPF models in the Nueces basin is 119,594 and 106,000 ac-ft/yr, respectively. The HDR Nueces basin pilot model average recharge was 117,280 ac-ft/yr.

6.1.3 Comparison of HSPF to Previous Methods

Figure 6.1.5 shows a scatter plot of USGS and HDR recharge estimates plotted against the estimates developed from the HSPF model for the Nueces Basin. As usual, the USGS values are higher in some years. There is a significant scatter in the recharge estimates. In general, the HDR estimates are lower in “wet” years and tend to be close to or slightly higher than HSPF estimates in “dry” years.

Figure 6.1.6 compares the USGS and HSPF estimates on a yearly basis between 1950 and 2000. This figure indicates that the HSPF recharge values are somewhat higher during some of the drought of the 1950s, and that the USGS estimates are higher than the HSPF estimates in the wet years.

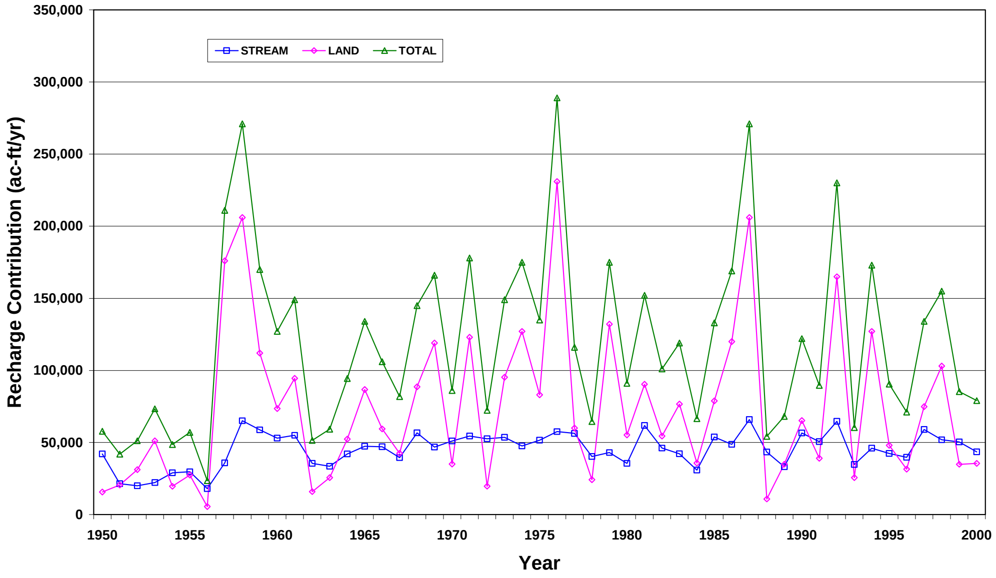


Figure 6.1.4 Annual Recharge from Streams and Land Components Estimated by HSPF - Nueces Basin

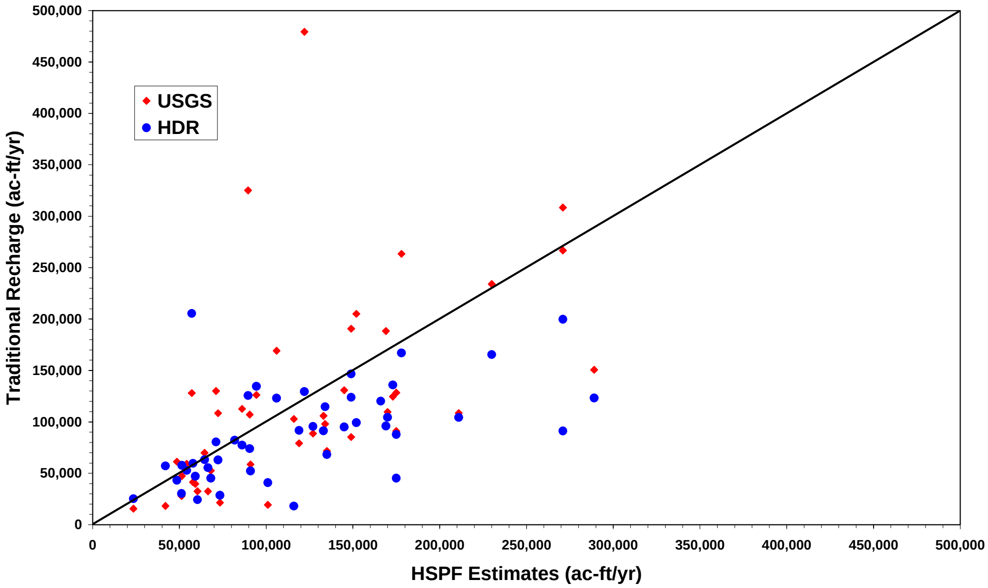


Figure 6.1.5 Scatter plot Recharge Comparison of Traditional Recharge Estimates to HSPF - Nueces Basin

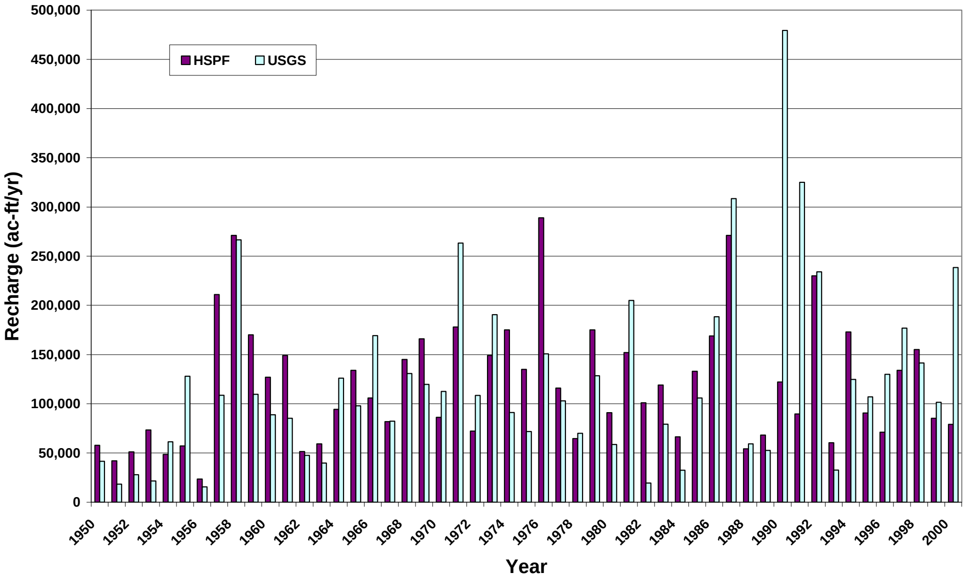


Figure 6.1.6 Annual Recharge Comparison of HSPF and USGS Estimates - Nueces Basin

Figure 6.1.7 compares the traditional HDR and HSPF estimates on a yearly basis between 1950 and 2000. This figure indicates that the HSPF recharge values are almost always higher than the HDR estimates. Figure 6.1.8 shows the 50-year cumulative recharge for the Nueces basin, which shows that the HSPF and traditional USGS estimates end up with about the same total volume and the HDR estimates lag by more than one million ac-ft over the 50-year simulation period ending in 2000.

Table 6.1.1 statistically summarizes the historical recharge estimates for all three methods; USGS, HDR, and HSPF. The table also shows the land and stream components of the HSPF recharge estimate. The statistics are computed for annual recharge values from all three methods. Because the HDR estimates were only available through 1996, all the statistics are calculated using 1950 through 1996 (47-year period) recharge estimates. Statistics computed include the minimum, average, maximum, and range, as well as the 10th, 25th, 50th (median), 75th, and 90th percentiles. None of these statistical measures provide a full description of the recharge in the basin, but together they provide insight into the distribution of the annual recharge on a temporal basis. These statistics are important because the annual recharge estimates for most basins, like many other environmental variables, are not normally distributed. Therefore, the arithmetic “average” recharge value may not represent the most probable value of recharge in a given year because the distribution is skewed.

To provide some insight into the non-normality (skewedness) of the annual recharge estimates, two other statistics were calculated, the skewness and kurtosis. Skewness characterizes the degree of asymmetry of a distribution around its mean. Positive skewness indicates a distribution with an asymmetric tail extending toward more positive values. Negative skewness indicates a distribution with an asymmetric tail extending toward more negative values. Because the USGS has several relatively high estimates of recharge, the USGS distribution has a higher skewness value than the HSPF or HDR values. Kurtosis characterizes the relative peakedness or flatness of a distribution compared with the normal distribution. Positive kurtosis indicates a relatively peaked distribution, while negative values indicate a relatively flat distribution. The USGS estimates also result in a higher kurtosis value.

The cumulative data indicate that the 62% of the recharge is from land recharge and the remaining 38% is from channel loss. The model indicates that the variation of annual land recharge is much greater than the variation in stream recharge. The HSPF annual average estimate of recharge is 119,594 ac-ft/yr, and varies from 23,500 to 289,000 ac-ft/yr. The HDR and USGS annual average recharge estimates are 88,608 and 119,524, respectively.

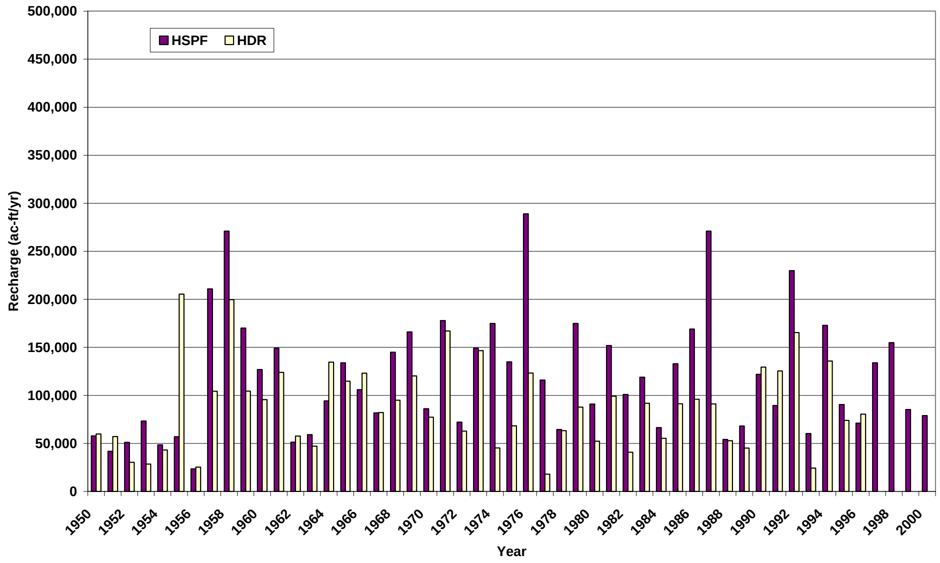


Figure 6.1.7 Annual Recharge Comparison of HSPF and HDR Estimates - Nueces Basin

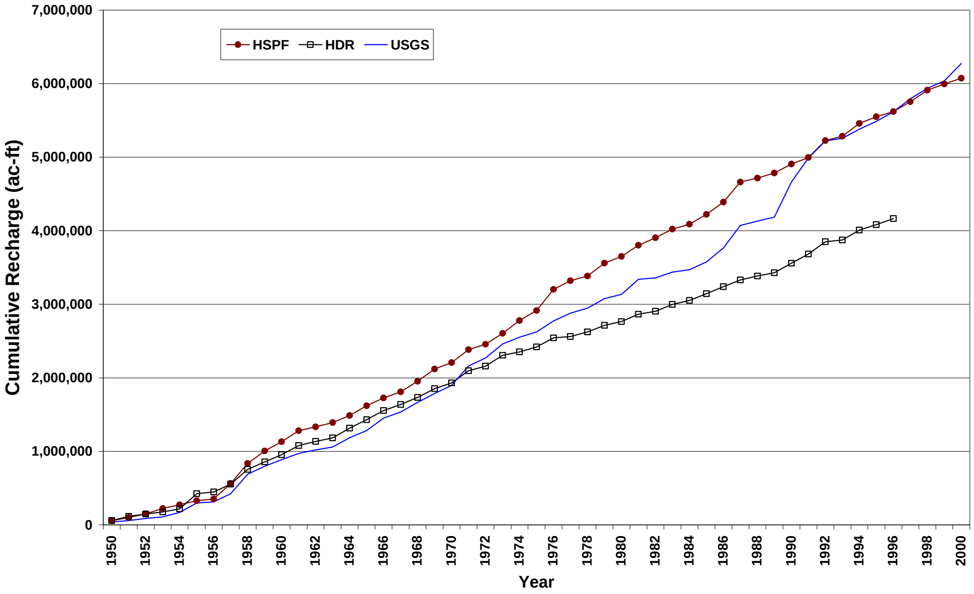


Figure 6.1.8 Cumulative Recharge Comparison - Nueces Basin

Table 6.1.1 Statistical Summary of Recharge Estimates - Nueces Basin

	HSPF Stream Recharge	HSPF Land Recharge	HSPF Recharge Total	HDR Recharge Estimate	USGS Recharge Estimate
47-year Total (af) [1]	2,103,300	3,518,550	5,620,900	4,164,561	5,617,617
Portion of HSPF Total	38%	62%	100%	NA	NA
Minimum (af/yr)	18,000	5,550	23,500	18,157	15,600
Average (af/yr)	44,751	74,863	119,594	88,608	119,524
Maximum (af/yr)	65,900	231,000	289,000	205,474	479,293
Range (af/yr)	47,900	225,450	265,500	187,317	463,693
10th Percentile (af/yr)	29,420	19,660	53,120	36,708	30,613
25th Percentile (af/yr)	35,700	31,350	67,300	54,123	58,937
50th Percentile (af/yr)	46,100	59,400	106,000	87,809	105,855
75th Percentile (af/yr)	53,750	103,650	159,000	121,672	130,342
90th Percentile (af/yr)	58,020	145,200	191,200	140,213	245,807
Skewness	-0.37	1.10	0.91	0.65	1.79
Kurtosis	-0.39	0.69	0.40	0.11	4.18

[1] – Statistics calculated for annual recharge estimates from 1950 to 1996

6.2 Frio-Dry Frio

6.2.1 Long-term Streamflow Comparison

Figure 6.2.1 compares daily simulated and observed flow at stream gage 8195000 (Frio River at Concan) for the 50-year period between 1950 and 2000. The flow duration curve indicates that the model simulates the overall hydrology of the contributing zone quite well. Figure 6.2.2 compares daily simulated and observed flow at stream gage 8196000 (Dry Frio near Reagan Wells) for the 48-year period from 1953-2000. The USGS streamflow data was not available for the Dry Frio gage near Reagan Wells until September 1952. Therefore, the contributing zone model was used to estimate streamflow at that gage (i.e., into the recharge zone) from January 1950 through August 1952 in order to estimate recharge to the Edwards aquifer. In addition, all recharge estimates for the Frio basin include the recharge (land and stream) from the ungaged area containing the Leona River north of Uvalde.

Figure 6.2.3 compares daily simulated and observed flow at stream gage 8197500 (Frio River near Uvalde). The model slightly overestimates flow at the gage.

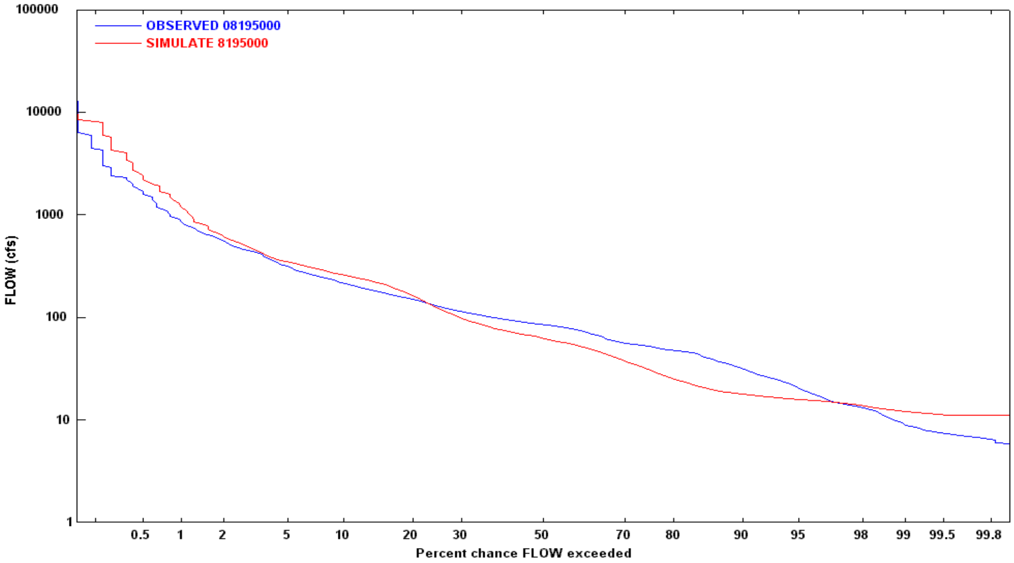


Figure 6.2.1 Daily Streamflow Frequency (1950-2000: Frio River at Concan, USGS #8195000)

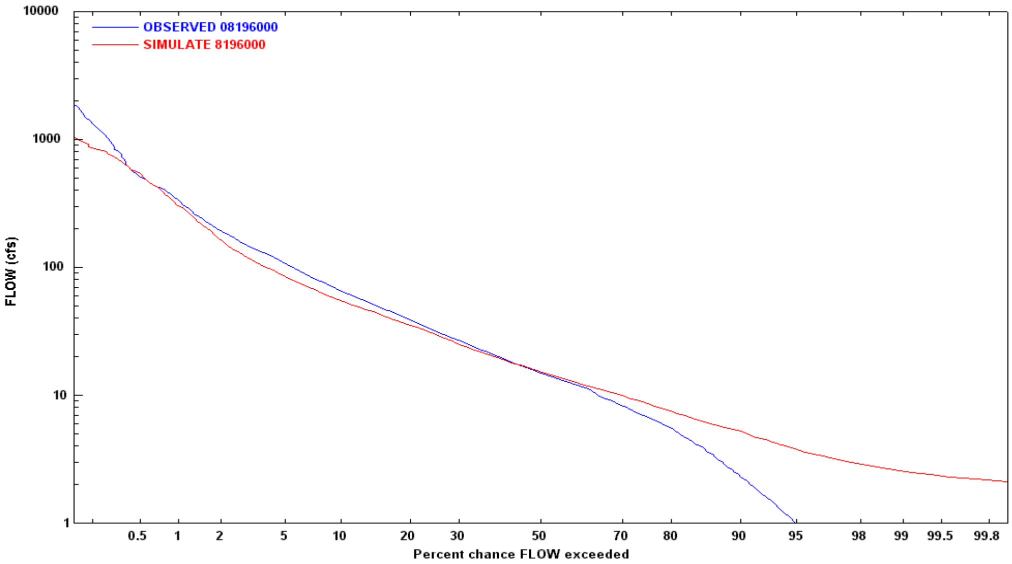


Figure 6.2.2 Daily Streamflow Frequency (1952-2000: Dry Frio River near Reagan Wells, USGS #8196000)

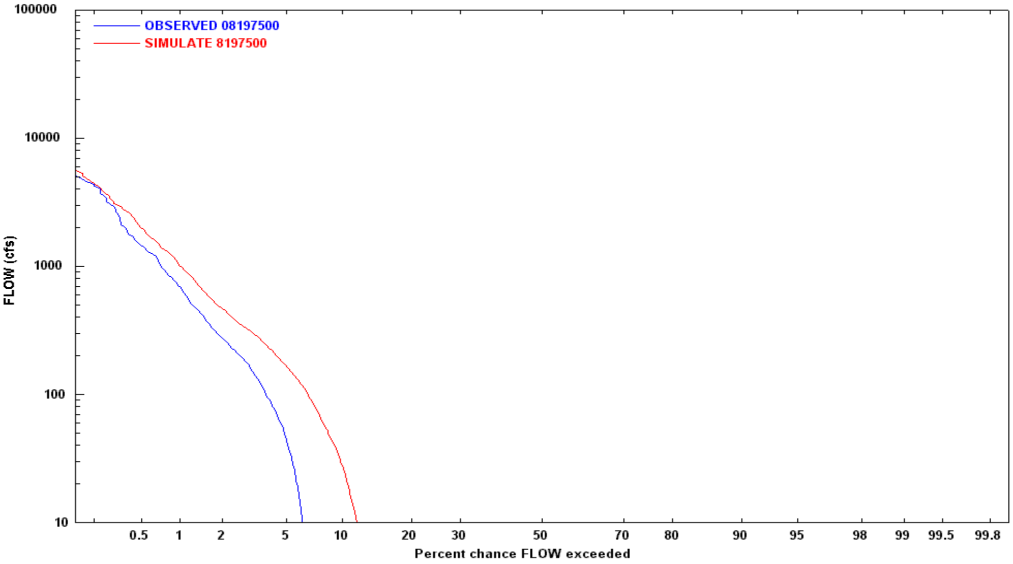


Figure 6.2.3 Daily Streamflow Frequency (1953-2000: Frio River below Dry Frio River near Uvalde, USGS #8197500)

6.2.2 Recharge Estimates and Water Balance

Figure 6.2.4 shows the components of the recharge from the streams and the land recharge in the Frio basin as estimated by the HSPF model. As compared to the Nueces basin, the stream and land segment recharge are much more variable and in the Frio basin, the stream loss accounts for most of the recharge. The stream recharge varies from 5070 to 188,000 ac-ft/yr, averages 87,133, and accounts for about 65% of the total recharge in the basin. Land recharge varies from 3,653 to 150,100 ac-ft/yr, averages 48,913 ac-ft/yr, and accounts for about 35% of the total recharge in the basin. Because of the significant channel loss in the Frio and Dry Frio River beds, the aquifer typically receives more water from channel loss than from land recharge. Through the 50-year period, the average and median total recharge in the Frio basin is 136,047 and 123,700 ac-ft/yr, respectively.

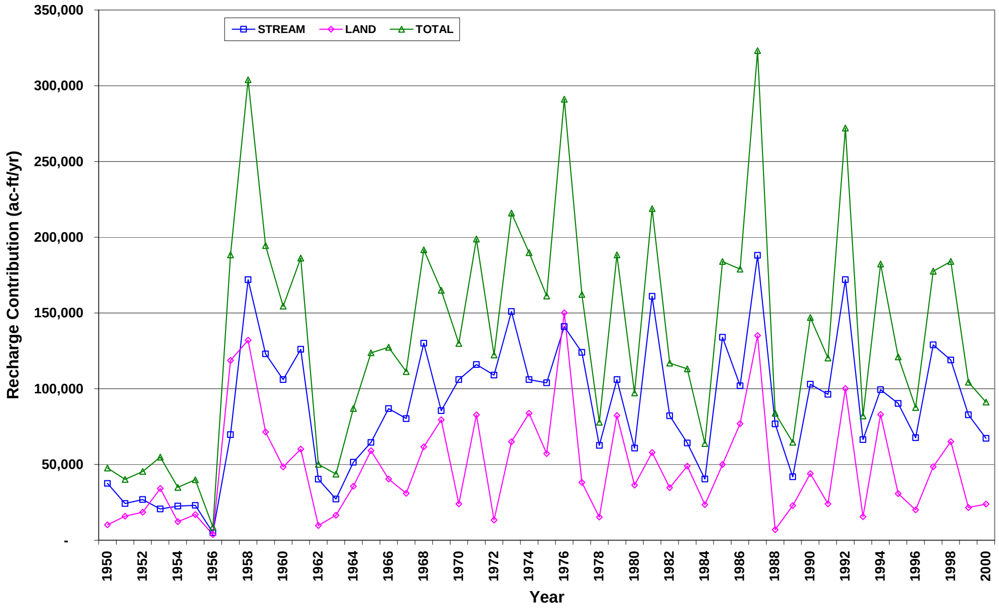


Figure 6.2.4 Annual Recharge from Streams and Land Components Estimated by HSPF - Frio Basin

6.2.3 Comparison of HSPF to Previous Methods

Figure 6.2.5 shows a scatter plot of USGS and HDR recharge estimates plotted against the estimates developed from the HSPF model. Figure 6.2.6 and 6.2.7 plot the annual recharge estimates from USGS and HDR with HSPF estimates, respectively. As with the Nueces recharge estimates, the HSPF estimates are typically than HDR estimates. Figure 6.2.8 shows the comparison of cumulative recharge for each method from 1950 through 2000. The cumulative HSPF recharge estimates are below the USGS but higher than HDR.

As usual, the USGS values are higher in some of the wet years. Table 6.2.1 statistically summarizes the historical recharge estimates for all three methods. The table also shows statistics for land and stream components of the HSPF recharge estimate. The cumulative data indicate that the 35% of the recharge is from land recharge and the remaining 65% is from channel loss. The HSPF annual average estimate of recharge is 136,047,309 ac-ft/yr, and varies from 8,723 to 323,200 ac-ft/yr. The HDR and USGS annual average recharge estimates are 119,933 and 148,887 ac-ft/yr, respectively.

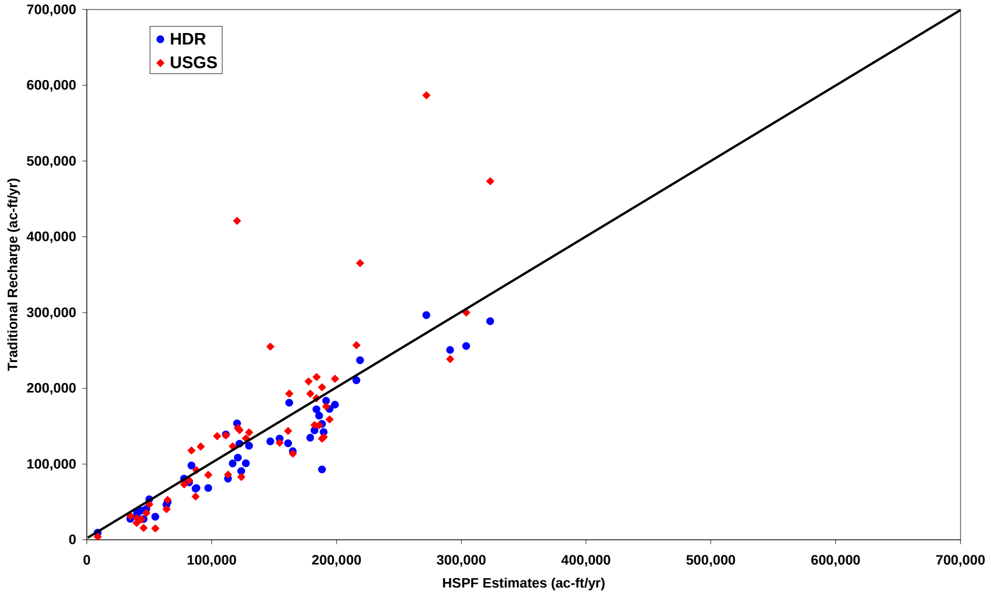


Figure 6.2.5 Scatter plot Recharge Comparison of Traditional Recharge Estimates to HSPF - Frio Basin

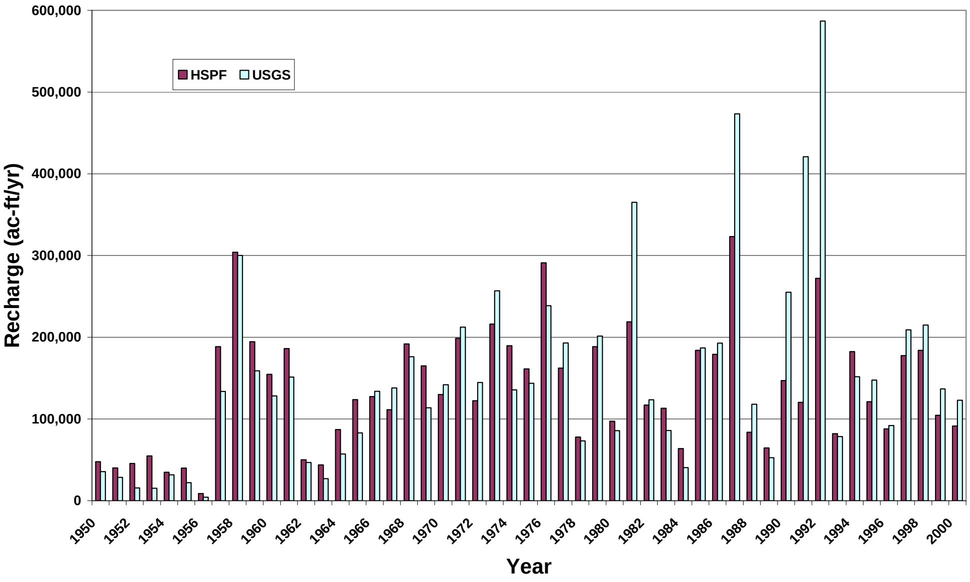


Figure 6.2.6 Annual Recharge Comparison of HSPF and USGS Estimates - Frio Basin

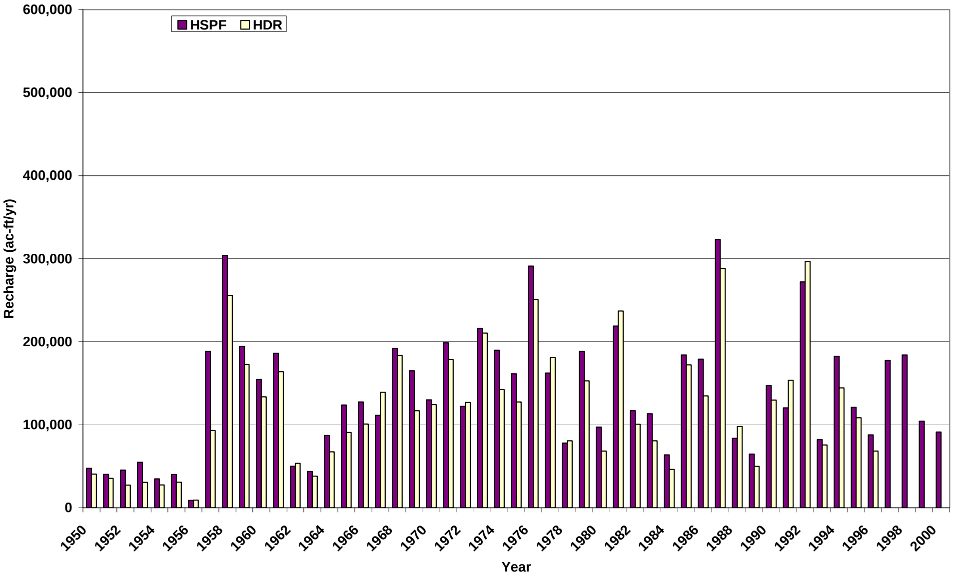


Figure 6.2.7 Annual Recharge Comparison of HSPF and HDR Estimates - Frio Basin

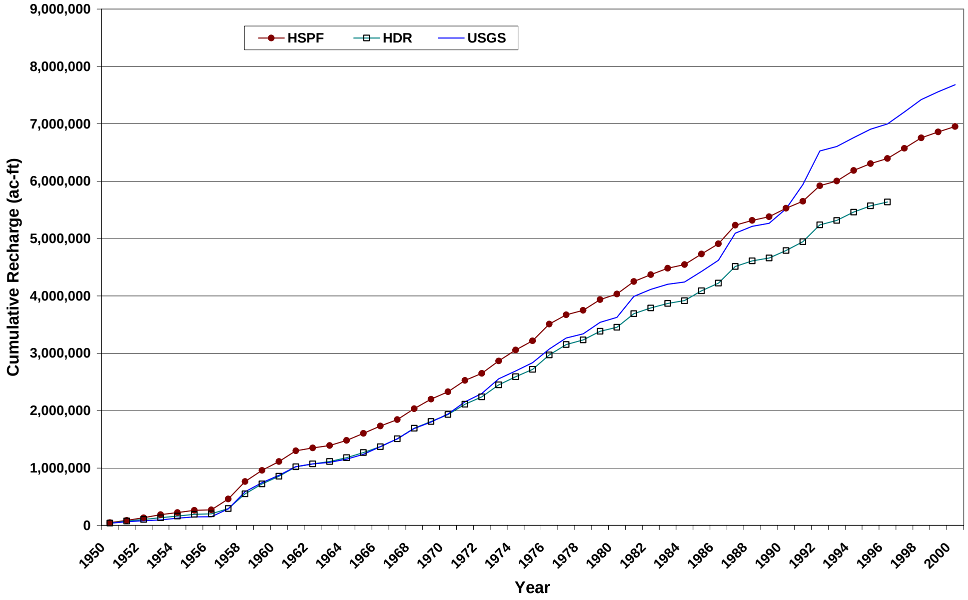


Figure 6.2.8 Cumulative Recharge Comparison - Frio Basin

Table 6.2.1 Statistical Summary of Recharge Estimates - Frio Basin

	HSPF Stream Recharge	HSPF Land Recharge	HSPF Recharge Total	HDR Recharge Estimate	USGS Recharge Estimate
47-year Total (af) [1]	4,095,270	2,298,923	6,394,193	5,636,829	6,997,709
Portion of HSPF Total	65%	35%	100%	NA	NA
Minimum (af/yr)	5,070	3,653	8,723	9,345	4,200
Average (af/yr)	87,133	48,913	136,047	119,933	148,887
Maximum (af/yr)	188,000	150,100	323,200	296,510	586,865
Range (af/yr)	182,930	146,447	314,477	287,165	582,665
10th Percentile (af/yr)	25,860	12,880	44,752	33,542	27,847
25th Percentile (af/yr)	56,150	19,270	79,965	67,849	65,122
50th Percentile (af/yr)	87,000	38,200	123,700	116,967	134,000
75th Percentile (af/yr)	112,500	68,250	187,300	158,711	189,853
90th Percentile (af/yr)	145,000	90,320	217,160	221,056	274,140
Skewness	0.22	1.07	0.55	0.67	1.67
Kurtosis	-0.55	0.66	-0.09	-0.02	3.42

[1] – Statistics calculated for annual recharge estimates from 1950 to 1996

6.3 Sabinal

6.3.1 Long-term Streamflow Comparison

Figure 6.3.1 compares daily simulated and observed flow at stream gage 8198000 (Sabinal River near Sabinal) for the 50-year period between 1950 and 2000. Overall, the simulated flows are higher than the observed flows. Figure 6.3.2 compares the simulated and observed streamflow frequency curves at stream gage 8198500 (Sabinal River at Sabinal) for the same 50-year period. The flow duration curve indicates that the model slightly over predicts the flow in the stream under most flow conditions.

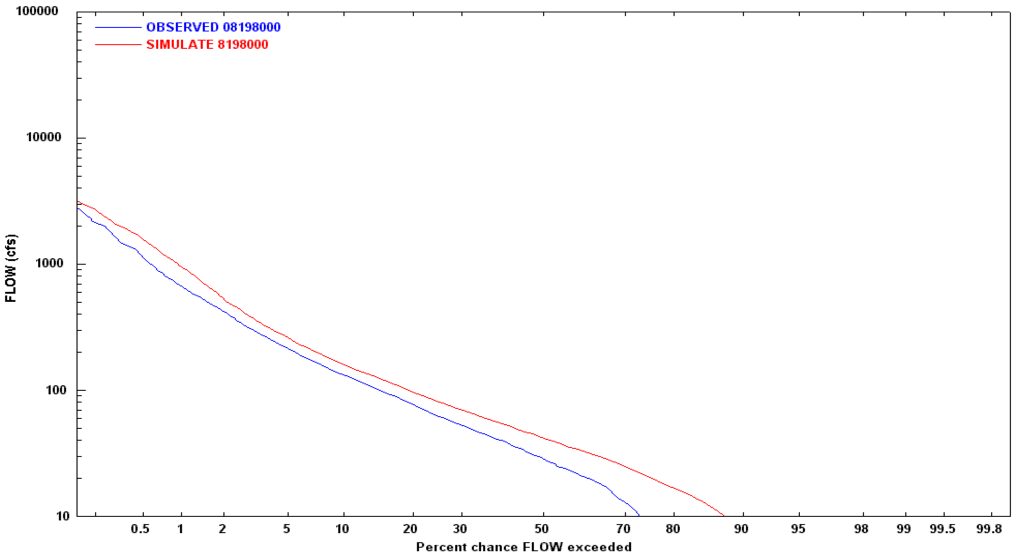


Figure 6.3.1 Daily Streamflow Frequency (1950-2000: Sabinal River near Sabinal, USGS #8198000)

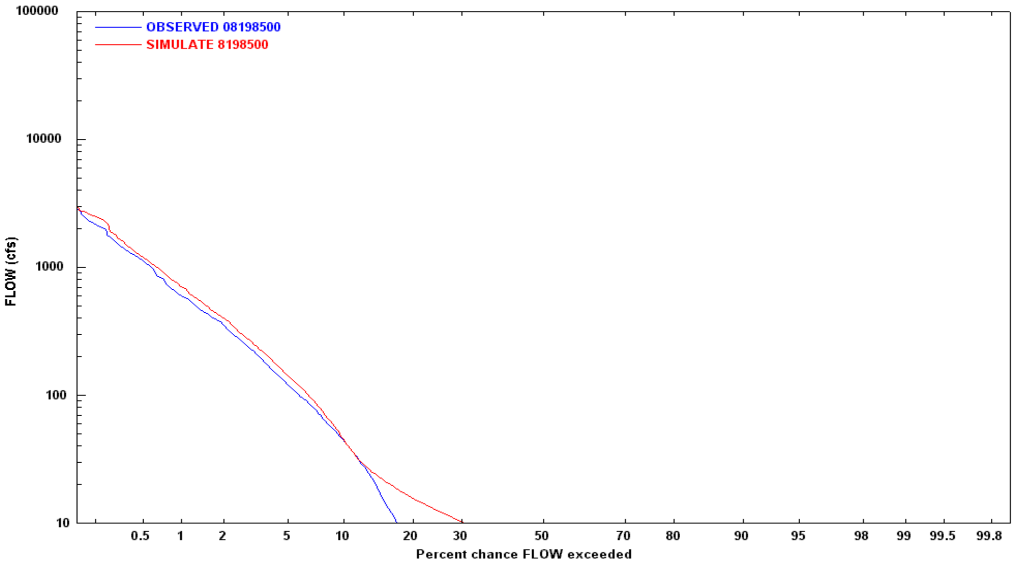


Figure 6.3.2 Daily Streamflow Frequency (1952-2000: Sabinal River at Sabinal, USGS #8198500)

6.3.2 Recharge Estimates and Water Balance

Figure 6.3.3 shows the components of the recharge from the streams and the land recharge in the Frio basin. As compared to the Nueces and Frio basin, the stream recharge represents a much higher percentage of the total recharge in the basin. This is mainly due to the relatively small recharge zone area in the Sabinal Basin. The stream recharge varies from 670 to 81,200 ac-ft/yr, averages 32,345, and accounts for about 93% of the total recharge in the basin. Through the 50-year period, the average and median recharge in the Sabinal basin is 32,345 and 29,900 ac-ft/yr, respectively.

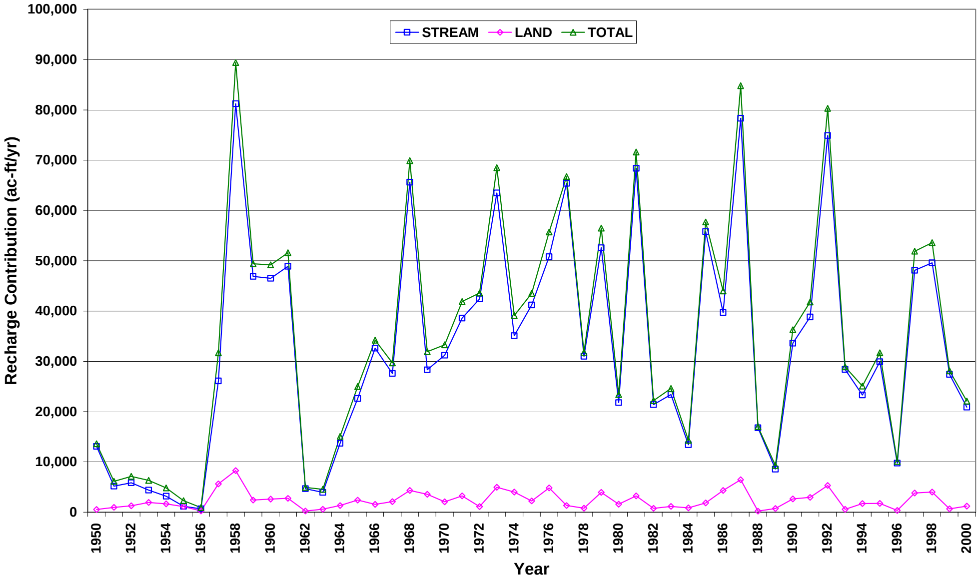


Figure 6.3.3 Annual Recharge from Streams and Land Components Estimated by HSPF - Sabinal Basin

6.3.3 Comparison of HSPF to Previous Methods

Figure 6.3.4 shows a scatter plot of USGS and HDR recharge estimates plotted against the estimates developed from the HSPF model. Figure 6.3.5 and 6.3.6 plot the annual recharge estimates from USGS and HDR with HSPF estimates, respectively. Figure 6.3.7 shows the comparison of cumulative recharge for each method from 1950 through 2000. Table 6.3.1 statistically summarizes the historical recharge estimates for all three methods.

As in most basins, there are a few USGS recharge estimates that are significantly higher than values estimated by other methods in some of the wet years. As shown Figures 6.3.4 and 6.3.6, the HSPF recharge estimates are very similar to HDR estimates, but there is more scatter in the USGS recharge. Table 6.3.1 table also shows statistics for land and stream components of the HSPF recharge estimate. The HSPF average estimate of recharge is 34,713 ac-ft/yr, and varies from 930 to 89,400 ac-ft/yr. The HDR and USGS annual average recharge estimates are 35,573 and 46,310 ac-ft/yr, respectively.

Figure 6.3.7 indicates that the cumulative recharge estimate from HSPF is smaller than traditional estimates and significantly smaller than the USGS estimate. Table 3.6.1 shows that over the 47-year comparison period, the HSPF cumulative recharge estimate is about 600,000 acre-feet smaller than the USGS cumulative value, and only about 40,000 acre-feet less than the HDR estimate.

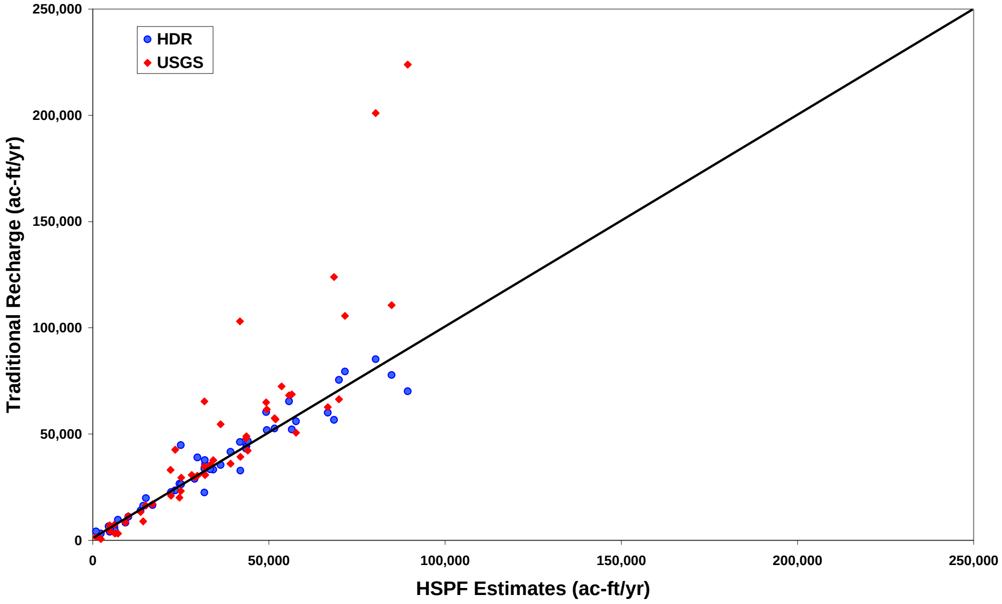


Figure 6.3.4 Scatter plot Recharge Comparison of Traditional Recharge Estimates to HSPF - Sabinal Basin

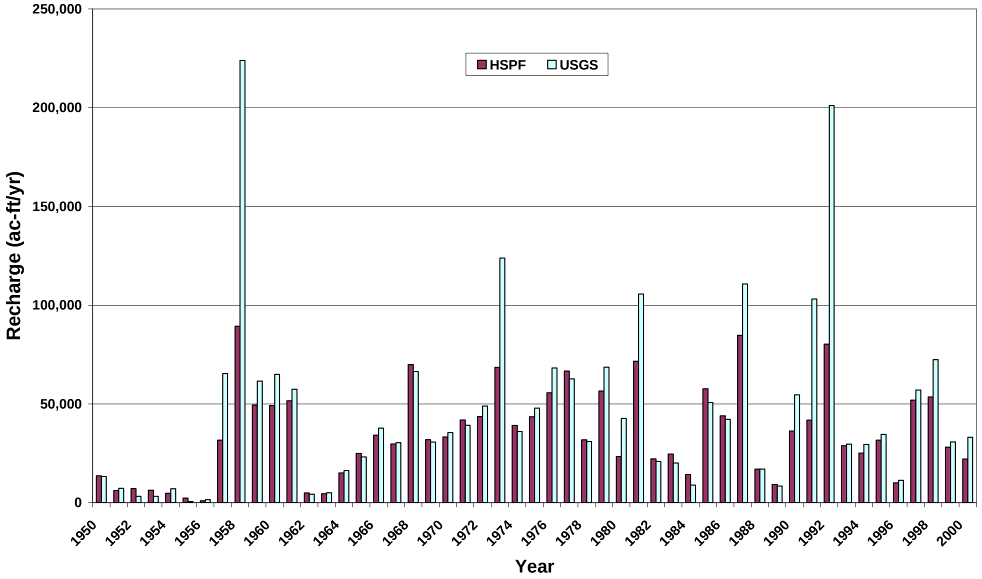


Figure 6.3.5 Annual Recharge Comparison of HSPF and USGS Estimates - Sabinal Basin

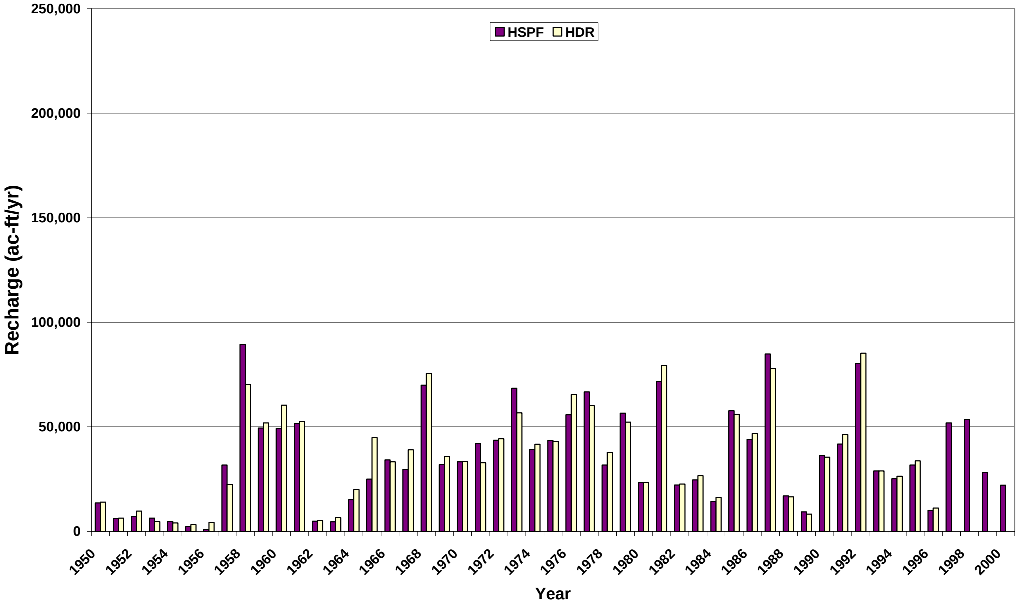


Figure 6.3.6 Annual Recharge Comparison of HSPF and HDR Estimates - Sabinal Basin

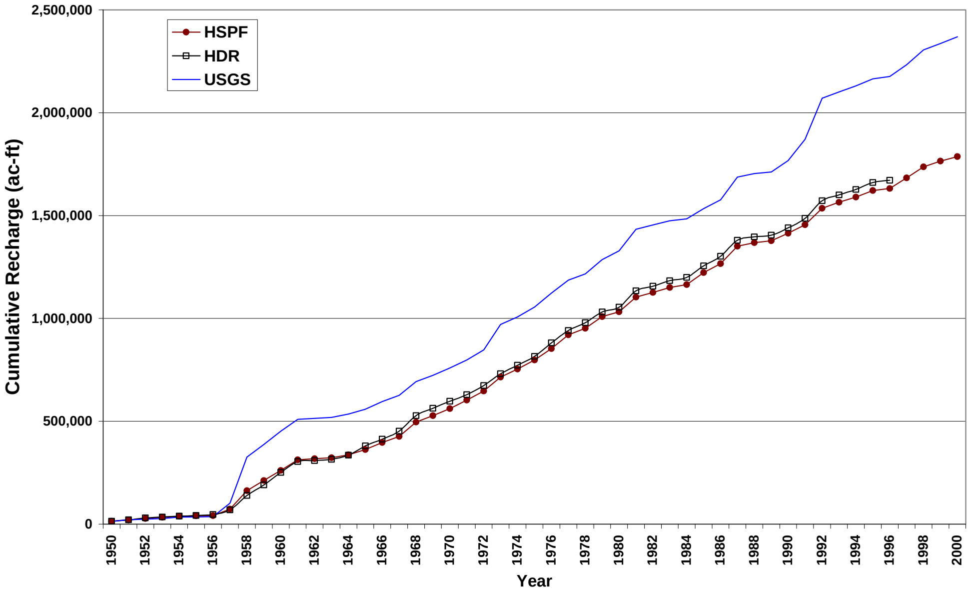


Figure 6.3.7 Cumulative Recharge Comparison - Sabinal Basin

Table 6.3.1 Statistical Summary of Recharge Estimates - Sabinal Basin

	HSPF Stream Recharge	HSPF Land Recharge	HSPF Recharge Total	HDR Recharge Estimate	USGS Recharge Estimate
47-year Total (af) [1]	1,520,200	110,760	1,631,500	1,671,935	2,176,552
Portion of HSPF Total	93%	7%	100%	NA	NA
Minimum (af/yr)	670	219	930	3,206	590
Average (af/yr)	32,345	2,357	34,713	35,573	46,310
Maximum (af/yr)	81,200	8,280	89,400	85,216	223,850
Range (af/yr)	80,530	8,061	88,470	82,010	223,260
10th Percentile (af/yr)	4,550	556	5,648	5,876	4,715
25th Percentile (af/yr)	13,550	1,038	14,700	16,381	14,803
50th Percentile (af/yr)	29,900	1,850	31,800	33,694	35,437
75th Percentile (af/yr)	46,700	3,245	49,300	52,023	62,133
90th Percentile (af/yr)	65,480	4,902	69,060	67,297	104,101
Skewness	0.49	1.21	0.53	0.36	2.14
Kurtosis	-0.57	1.37	-0.46	-0.73	5.58

[1] – Statistics calculated for annual recharge estimates from 1950 to 1996

6.4 Area Between Sabinal and Medina

USGS streamflow data was not available for stream gage 8201500 (Seco Creek at Miller Ranch near Utopia) for dates before 1961. Therefore, the contributing zone model was used to estimate streamflow at that gage (i.e., into the recharge zone) from 1950 through 1961 in order to estimate recharge to the Edwards aquifer. In addition, the contributing zone model was also used to estimate streamflow in the Hondo creek from 1950 to 1952.

6.4.1 Long-term Streamflow Comparison

Figure 6.4.1 compares daily simulated and observed flow at stream gage 8201500 (Seco Creek at Miller Ranch near Utopia) for the 50-year period between 1950 and 2000. The flow duration curve indicates that the model generally simulates flow from the contributing zone relatively well. Figure 6.4.2 compares daily simulated and observed flow at stream gage 8200000 (Hondo Creek near Tarpley). Overall, the agreement between the observed and simulated flow is good. Figure 6.4.3 compares daily simulated and observed flow at stream gage 8202700 (Seco Creek at Rowe Ranch near D'Hanis) for the same 50-year period. Figure 6.3.2 compares daily simulated and observed flow at stream gage 8200700 (Hondo Creek at King Waterhole near Hondo).

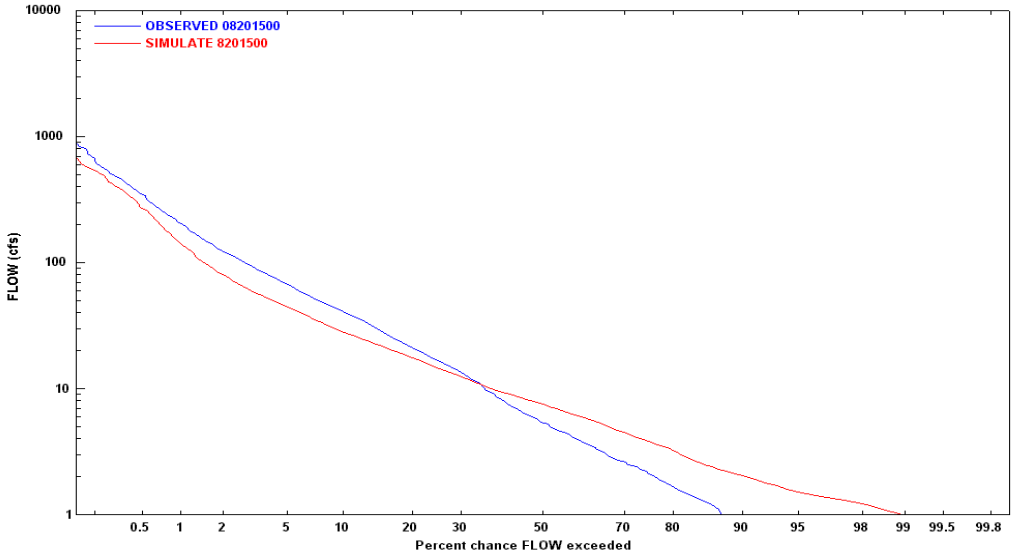


Figure 6.4.1 Daily Streamflow Frequency (1961-2000: Seco Creek at Miller Ranch near Utopia, USGS # 8201500)

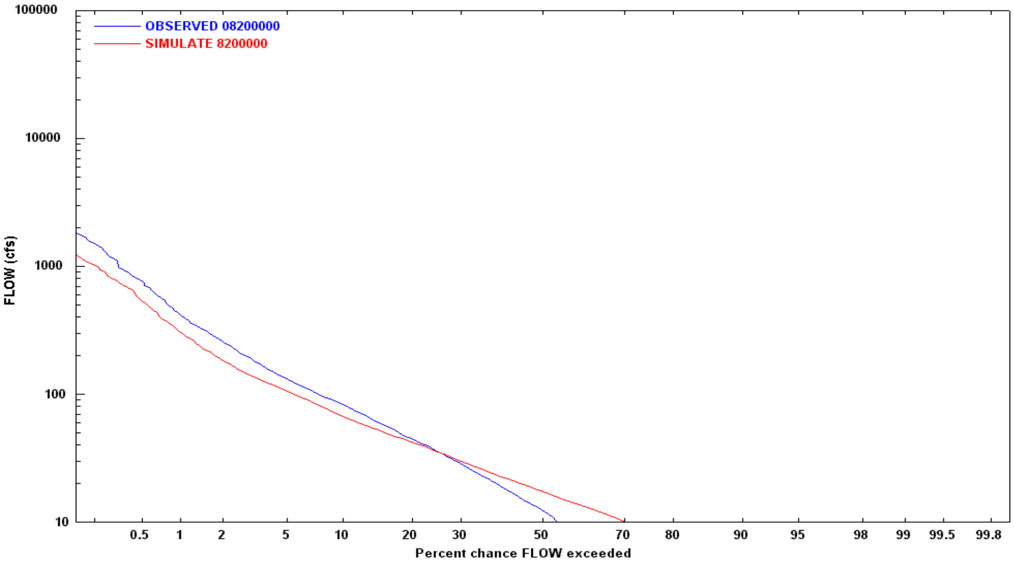


Figure 6.4.2 Daily Streamflow Frequency (1952-2000: Hondo Creek near Tarpley, USGS #8200000)

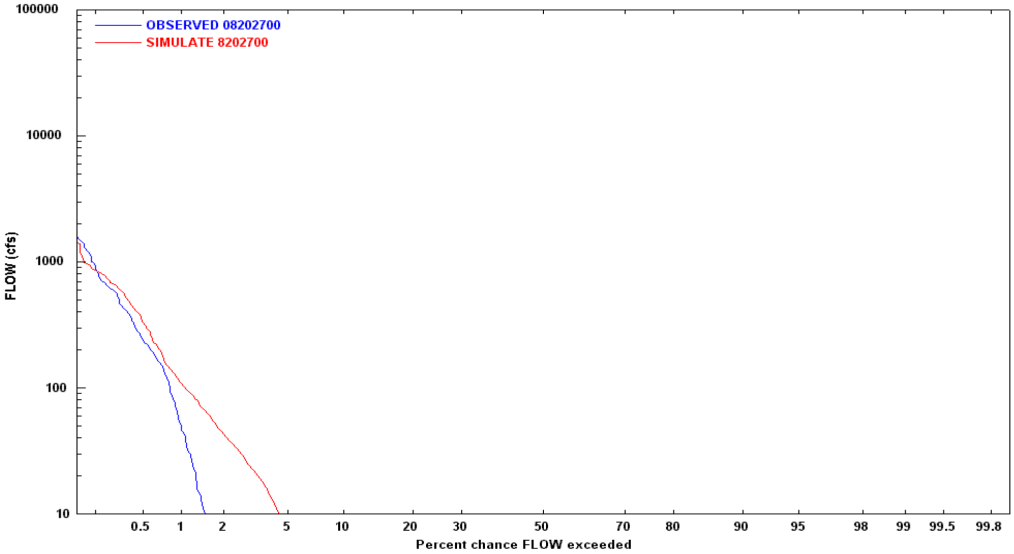


Figure 6.4.3 Daily Streamflow Frequency (1960-2000: Seco Creek at Rowe Ranch near D'Hanis, USGS #8202700)

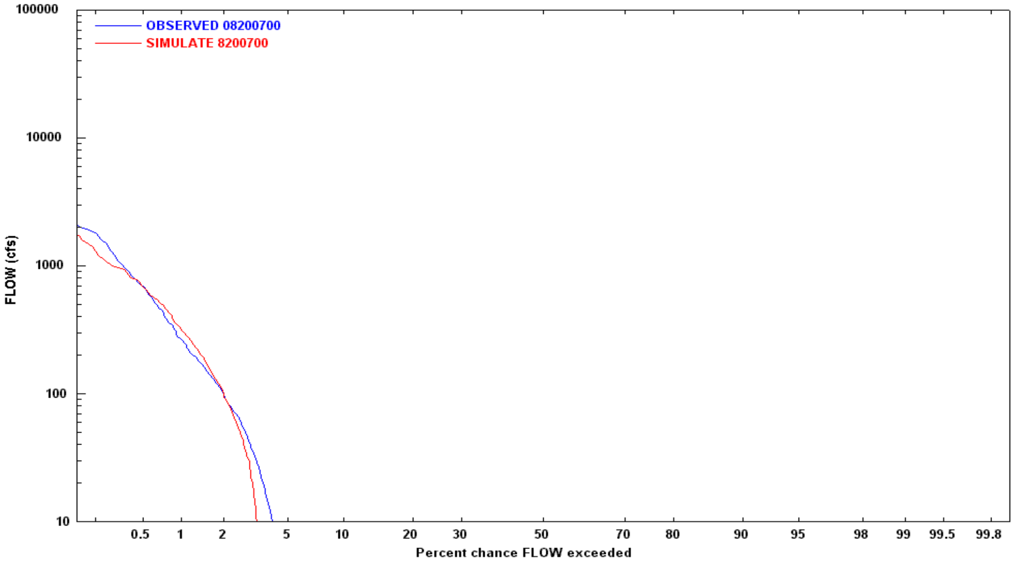


Figure 6.4.4 Daily Streamflow Frequency (1960-2000: Hondo Creek at King Waterhole near Hondo, USGS #8200700)

6.4.2 Recharge Estimates and Water Balance

Figure 6.4.5 shows the components of the recharge from the streams and the land recharge in the basin. Stream recharge represents 55% of the total recharge in the basin and varies from 962 to 123,700 ac-ft/yr, and averages 33,925 ac-ft/yr. Land recharge in the Seco and Hondo Creek recharge zone accounts for 45% of the total recharge and averages 27,948 ac-ft/yr.

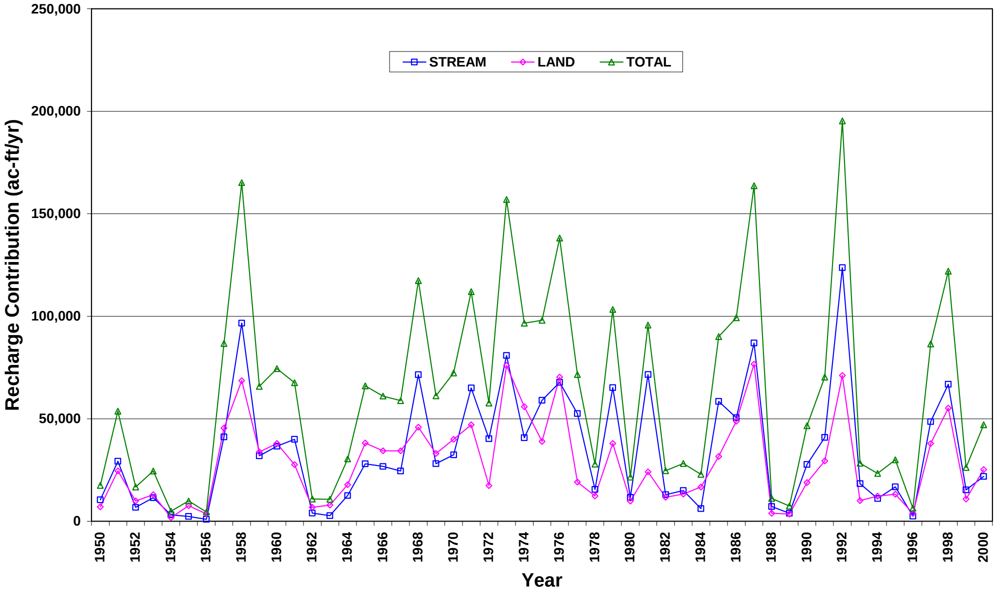


Figure 6.4.5 Annual Recharge from Streams and Land Components Estimated by HSPF - Area Between Sabinal and Medina Basins

6.4.3 Comparison of HSPF to Previous Methods

Figure 6.4.6 shows a scatter plot of USGS and HDR recharge estimates plotted against the estimates developed from the HSPF model. Figure 6.4.7 and 6.4.8 plot the annual recharge estimates from USGS and HDR with HSPF estimates, respectively. Figure 6.4.9 shows the comparison of cumulative recharge for each method from 1950 through 2000. Table 6.4.1 statistically summarizes the historical recharge estimates for all three methods. All of these figures indicate that the HSPF model generally predicts less recharge than the traditional methods.

As shown Figures 6.4.7 and 6.4.8, the HSPF recharge estimates are significantly lower than the traditional methods in 1958, 1968, 1973, 1979, 1981, 1987, and 1992. Table 6.4.1 also shows statistics for land and stream components of the HSPF recharge estimate. The HSPF average estimate of recharge is 61,874 ac-ft/yr, and varies from 4,530 to 195,300 ac-ft/yr. The HDR and USGS average recharge estimates are 100,748 and 117,296 ac-ft/yr, respectively.

Figure 6.4.9 indicates that the cumulative recharge estimate from HSPF is smaller than traditional estimates and significantly smaller than the USGS estimate. Table 6.4.9 shows that over the 47-year comparison period, the HSPF cumulative recharge estimate is over 2.5 million acre-feet smaller than the USGS value, and about 1.8 million acre-feet less than the HDR estimate.

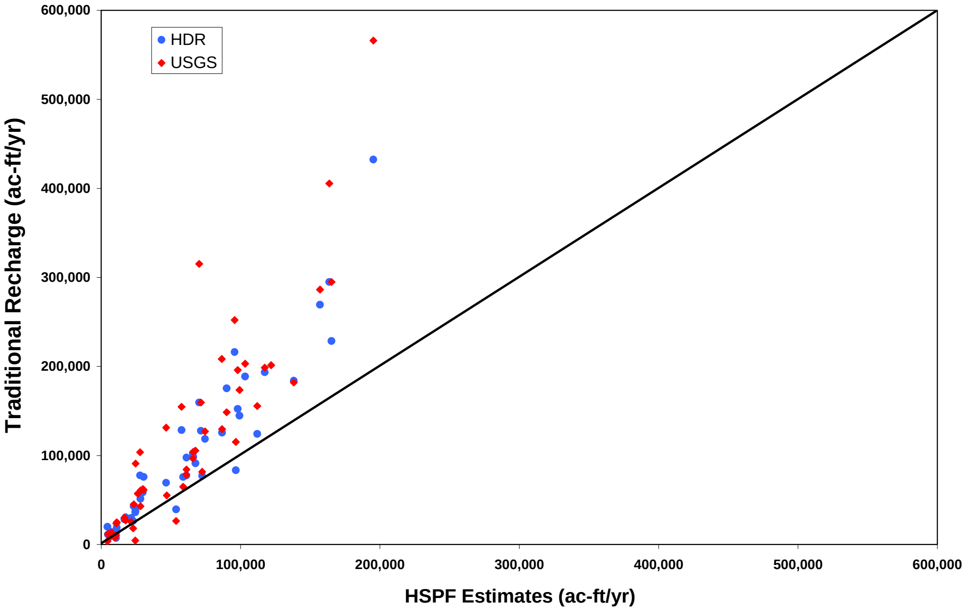


Figure 6.4.6 Scatter plot Recharge Comparison of Traditional Recharge Estimates to HSPF - Area Between Sabinal and Medina Basins

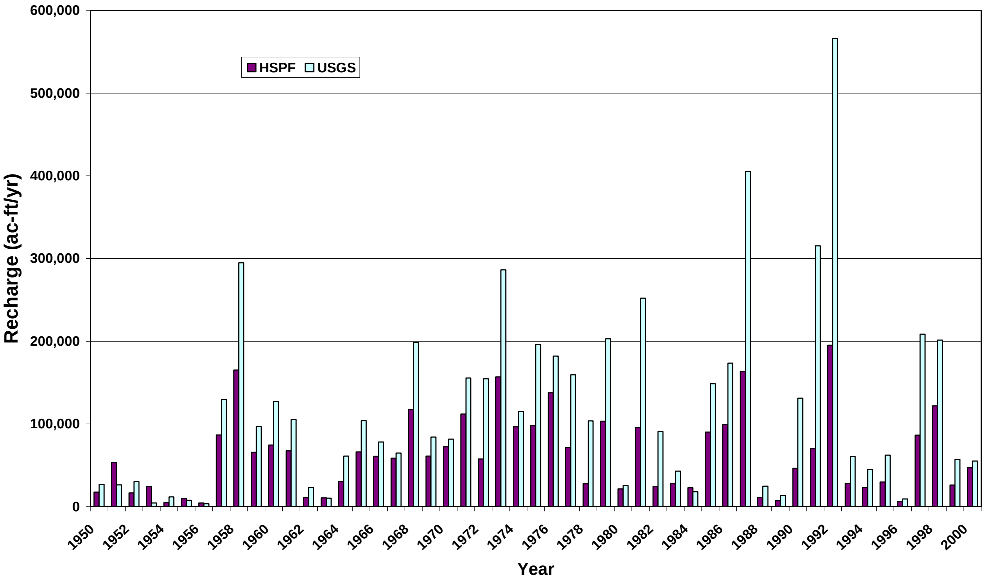


Figure 6.4.7 Annual Recharge Comparison of HSPF and USGS Estimates - Area Between Sabinal and Medina Basins

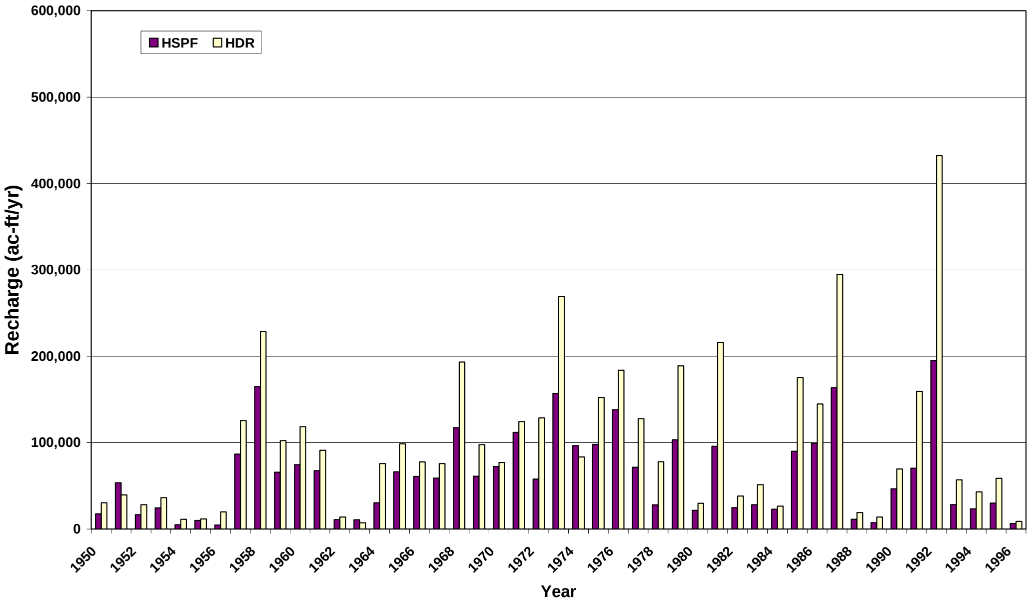


Figure 6.4.8 Annual Recharge Comparison of HSPF and HDR Estimates - Area Between Sabinal and Medina Basins

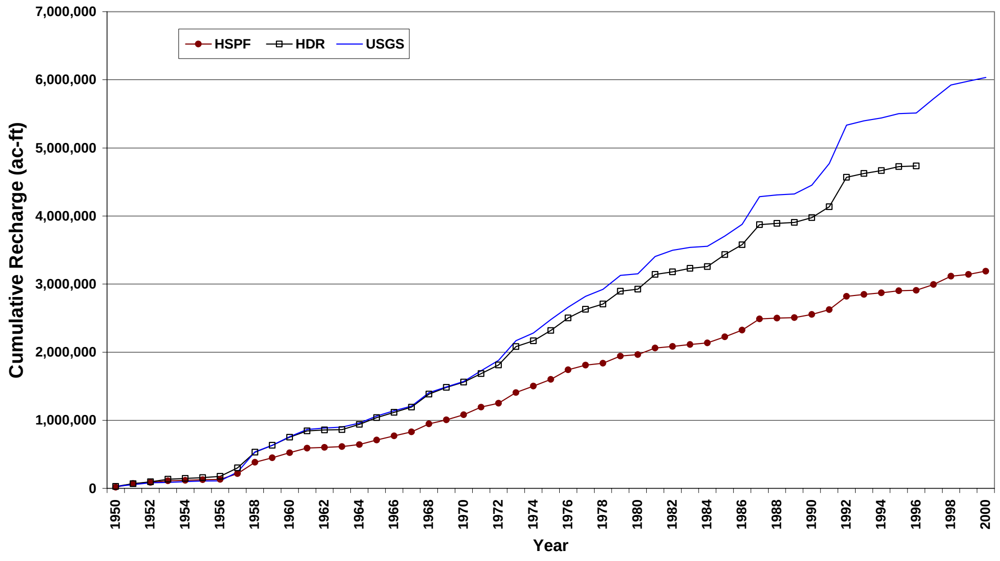


Figure 6.4.9 Cumulative Recharge Comparison - Area Between Sabinal and Medina Basins

Table 6.4.1 Statistical Summary of Recharge Estimates – Area Between Sabinal and Medina Basin

	HSPF Stream Recharge	HSPF Land Recharge	HSPF Recharge Total	HDR Recharge Estimate	USGS Recharge Estimate
47-year Total (af) [1]	1,594,481	1,313,550	2,908,080	4,735,159	5,512,923
Portion of HSPF Total	55%	45%	100%	NA	NA
Minimum (af/yr)	962	1,780	4,530	7,290	3,600
Average (af/yr)	33,925	27,948	61,874	100,748	117,296
Maximum (af/yr)	123,700	76,600	195,300	432,413	566,117
Range (af/yr)	122,738	74,820	190,770	425,123	562,517
10th Percentile (af/yr)	3,623	5,684	10,394	13,843	11,260
25th Percentile (af/yr)	11,290	10,900	23,130	33,343	26,700
50th Percentile (af/yr)	28,020	24,100	58,800	77,539	90,919
75th Percentile (af/yr)	51,500	38,600	92,900	136,652	157,532
90th Percentile (af/yr)	71,540	60,980	125,720	202,474	265,817
Skewness	1.04	0.84	0.90	1.58	1.82
Kurtosis	0.74	-0.13	0.25	3.37	4.34

[1] – Statistics calculated for annual recharge estimates from 1950 to 1996

6.5 Medina

The USGS streamflow data was not available for stream gage 8178880 (Medina River at Bandera) for dates before 1982. Therefore, the contributing zone model was used to estimate streamflow at that gage (i.e., into the recharge zone) from 1950 through 1982 in order to estimate recharge to the Edwards aquifer. Loss from Medina Lake was attributed to Edwards aquifer recharge.

6.5.1 Long-term Streamflow Comparison

Figure 6.5.1 compares daily simulated and observed flow at stream gage 8178880 (Medina River at Bandera) for the 19-year period between 1982 and 2000. The agreement between the observed and simulated flow is very good and indicates that the model is capable of simulating the hydrologic dynamics of the contributing zone above Bandera quite well.

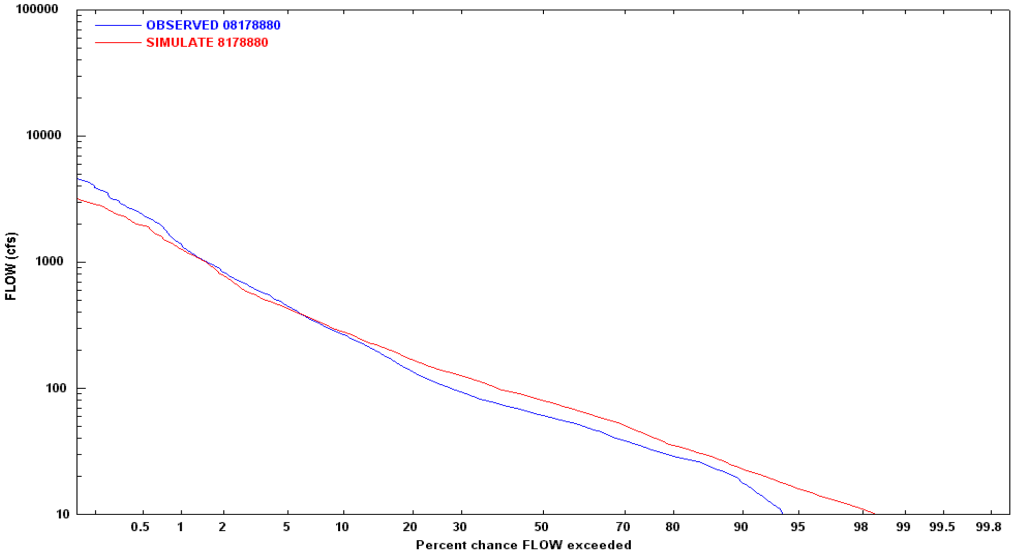


Figure 6.5.1 Daily Streamflow Frequency (1982-2000: Medina River at Bandera, USGS #8178880)

Figure 6.5.2 compares daily simulated and observed flow at stream gage 8180500 (Medina River at Riomedina) for the 50-year period between 1950 and 2000. The agreement between the observed and simulated flow is not very good and indicates that there may be hydrologic dynamics or reservoir operations that are not appropriately represented in the model.

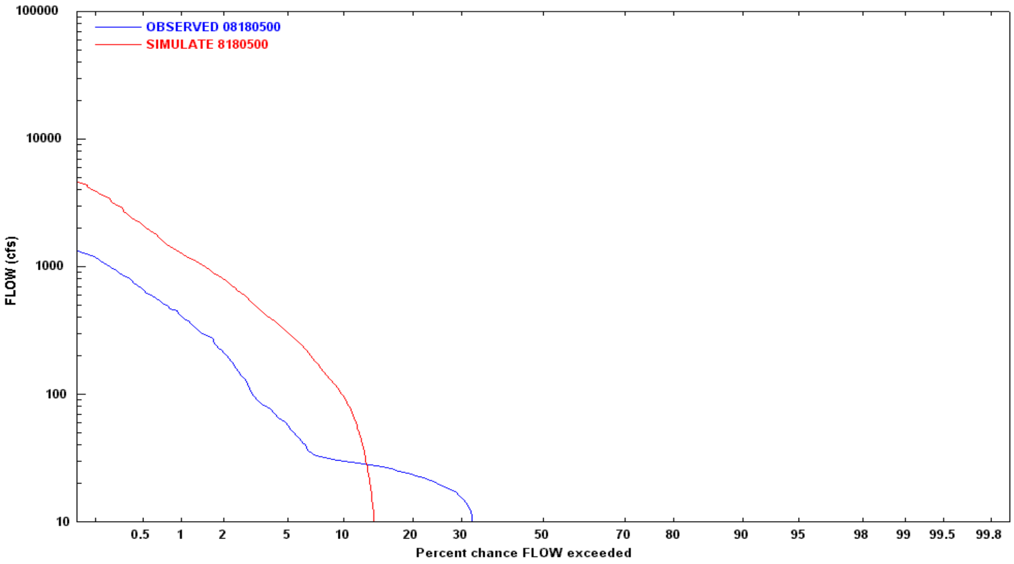


Figure 6.5.2 Daily Streamflow Frequency (1950-2000: Medina River near Riomedina, USGS #8180500)

6.5.2 Recharge Estimates and Water Balance

Figure 6.5.3 shows the components of the recharge from the streams and the land recharge in the basin based on the HSPF simulations. According to the HSPF model, stream recharge represents about 83% of the total recharge in the basin; averages 45,726 and varies from 15,500 to 66,800 ac-ft/yr, while the median value is 46,900 ac-ft/yr. Land recharge in the Medina recharge zone accounts for 17% of the total recharge and averages 7,668 ac-ft/yr.

6.5.3 Comparison of HSPF to Previous Methods

Figure 6.5.4 shows a scatter plot of USGS and HDR recharge estimates plotted against the estimates developed from the HSPF model. Figure 6.5.5 and 6.5.6 plot the annual recharge estimates from USGS and HDR with HSPF estimates, respectively. Figure 6.5.7 shows the comparison of cumulative recharge for each method from 1950 through 2000. Table 6.5.1 statistically summarizes the historical recharge estimates for all three methods. All of these figures indicate that the HSPF model generally predicts slightly less recharge than the USGS method, and more than the HDR method.

Table 6.5.1 shows the HSPF average estimate of recharge is 45,726 ac-ft/yr, and varies from 15,500 to 66,800 ac-ft/yr. The HDR and USGS average recharge estimates are 42,826 and 64,115 ac-ft/yr, respectively.

Figure 6.5.7 indicates that the cumulative recharge estimate from HSPF is slightly higher than the HDR estimate. Table 6.5.1 shows that over the 47-year comparison period, the HSPF cumulative recharge estimate is almost 1 million acre-feet smaller than the USGS recharge estimates. The skewness and kurtosis values indicate that the HSPF distribution of recharge is relatively normal.

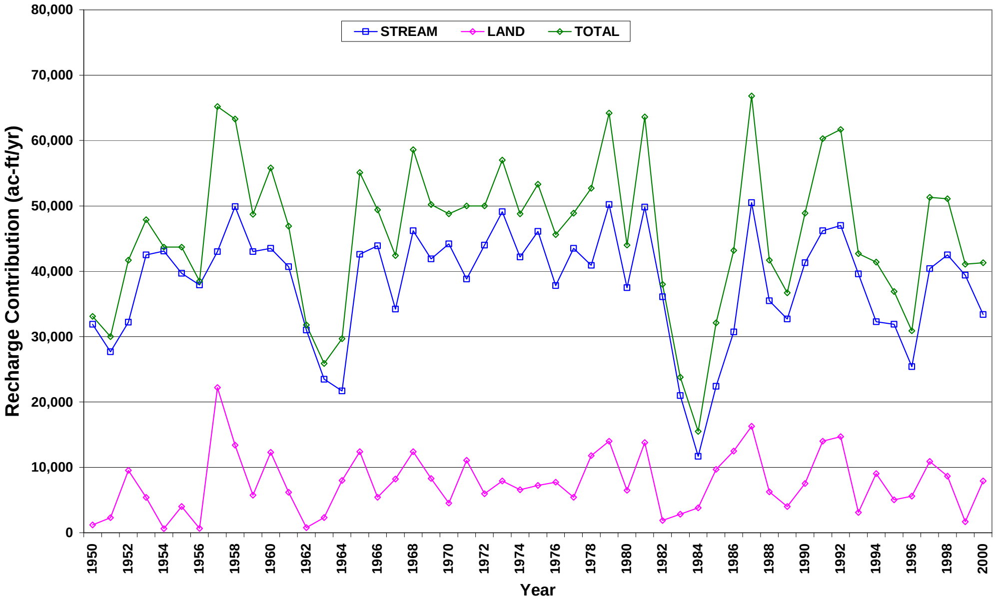


Figure 6.5.3 Annual Recharge from Streams and Land Components Estimated by HSPF - Medina Basin

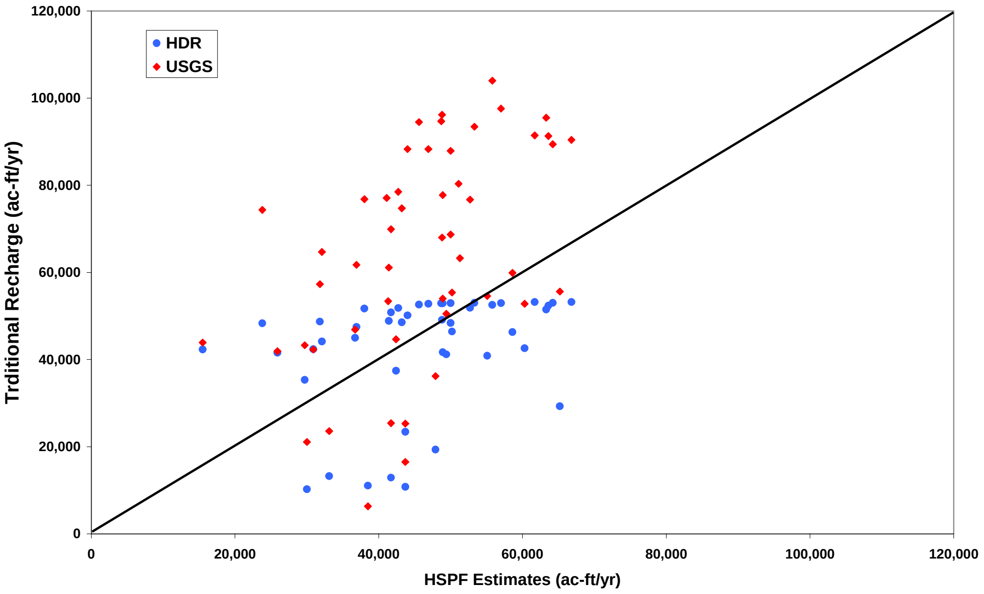


Figure 6.5.4 Scatter plot Recharge Comparison of Traditional Recharge Estimates to HSPF - Medina Basin

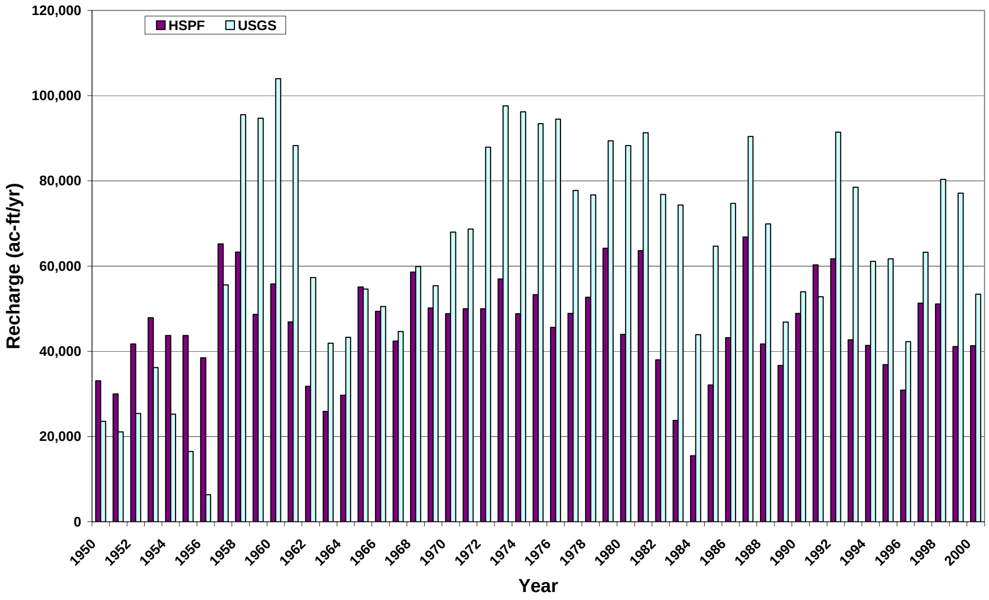


Figure 6.5.5 Annual Recharge Comparison of HSPF and USGS Estimates - Medina Basin

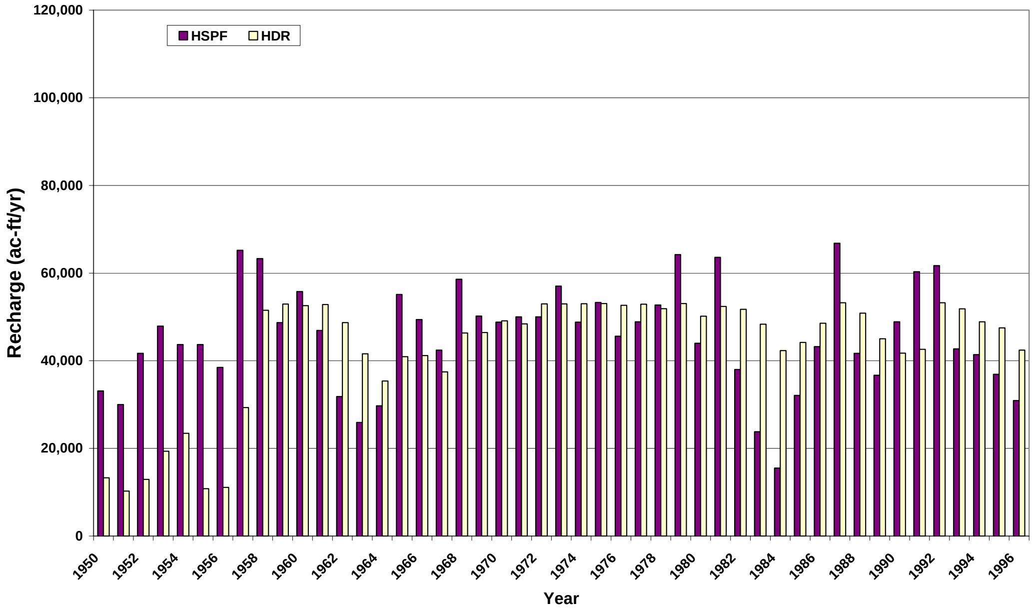


Figure 6.5.6 Annual Recharge Comparison of HSPF and HDR Estimates - Medina Basin

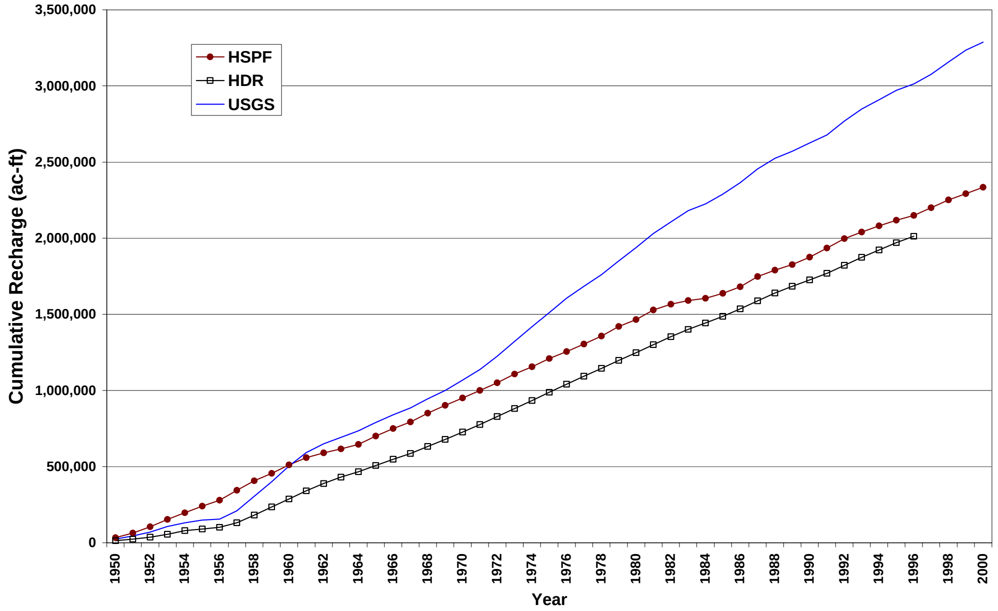


Figure 6.5.7 Cumulative Recharge Comparison - Medina Basin

Table 6.5.1 Statistical Summary of Recharge Estimates - Medina Basin

	HSPF Stream Recharge	HSPF Land Recharge	HSPF Recharge Total	HDR Recharge Estimate	USGS Recharge Estimate
47-year Total (af) [1]	1,788,500	360,416	2,149,100	2,012,826	3,013,389
Portion of HSPF Total	83%	17%	100%	NA	NA
Minimum (af/yr)	11,700	614	15,500	10,256	6,350
Average (af/yr)	38,053	7,668	45,726	42,826	64,115
Maximum (af/yr)	50,500	22,200	66,800	53,217	104,000
Range (af/yr)	38,800	21,586	51,300	42,961	97,650
10th Percentile (af/yr)	24,640	2,138	30,540	16,915	25,360
25th Percentile (af/yr)	32,250	4,280	38,250	41,374	45,759
50th Percentile (af/yr)	40,700	6,580	46,900	48,401	64,700
75th Percentile (af/yr)	43,700	11,450	53,000	52,458	88,300
90th Percentile (af/yr)	47,840	13,880	62,340	52,986	94,580
Skewness	-0.89	0.70	-0.26	-1.53	-0.38
Kurtosis	0.51	0.47	-0.19	1.14	-0.72

[1] – Statistics calculated for annual recharge estimates from 1950 to 1996

6.6 Area Between Medina and Cibolo

The USGS streamflow data was not available for stream gage 8178585 (Salado Creek at Wilderness Road at San Antonio) for dates before 1997. Therefore, the contributing zone model was used to estimate streamflow at that gage (i.e., into the recharge zone) from 1950 through 1997 in order to estimate recharge to the Edwards aquifer.

6.6.1 Long-term Streamflow Comparison

Figure 6.6.1 shows the comparison of observed and simulated streamflow duration curves for stream gage 8178585 (Salado Creek at Wilderness Road at San Antonio). The flow duration curve indicates that the model generally over estimates streamflow. Because this model was used to estimate streamflow above the recharge zone between 1950-1996, the overestimated streamflow values may cause overestimation of recharge for this stream reach.

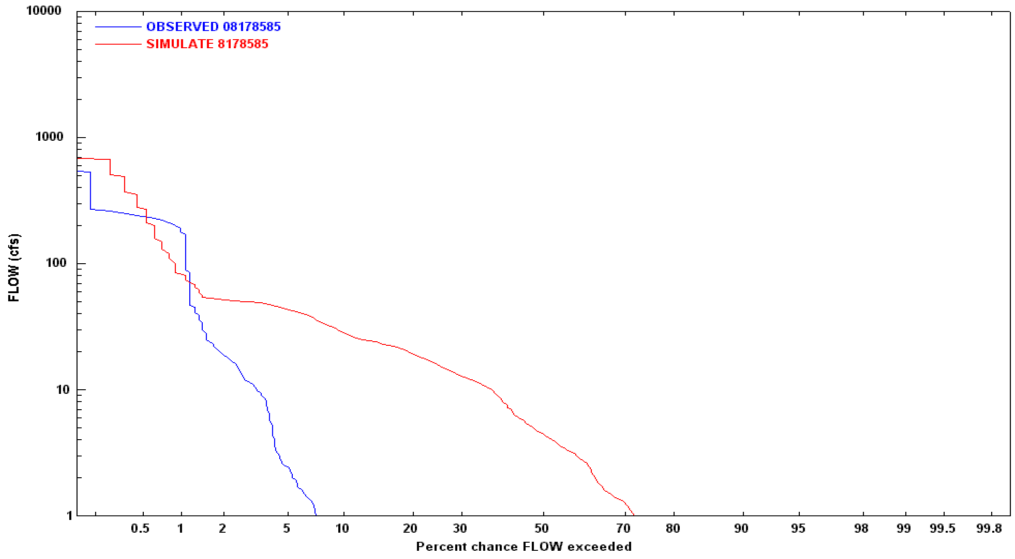


Figure 6.6.1 Daily Streamflow Frequency (1998-2000: Salado Creek near Wilderness Road at San Antonio, USGS #8178585)

Figure 6.6.2 compares daily simulated and observed flow at stream gage 8178700 (Salado Creek at Loop 410 at San Antonio) for a 40-year period between 1960 and 2000. The flow duration curve indicates that the model generally under estimates high flow events and over estimates low flow conditions, but overall provides a reasonable estimate of streamflow.

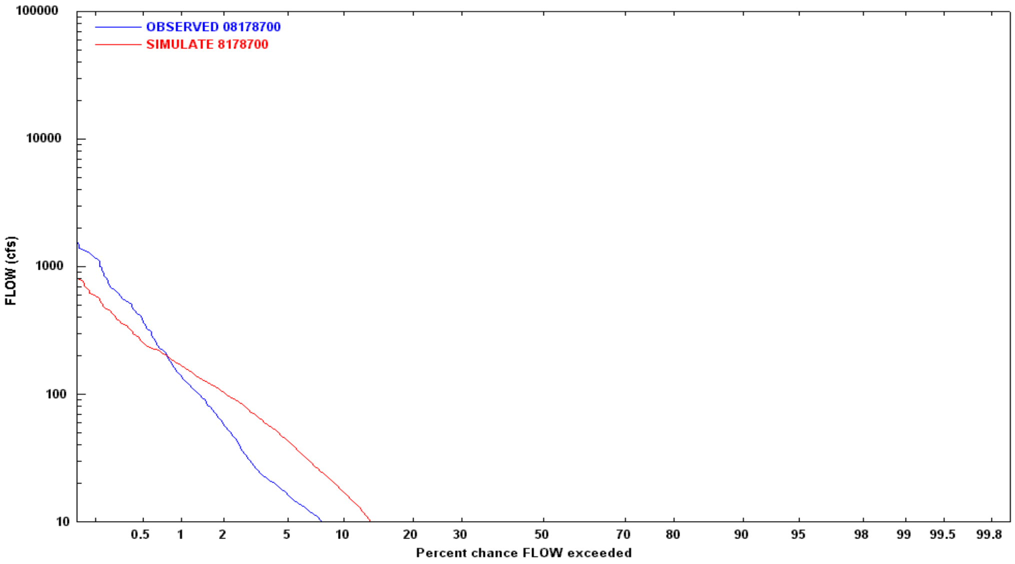


Figure 6.6.2 Daily Streamflow Frequency (1960-2000: Salado Creek at Loop 410 at San Antonio, USGS #8178700)

6.6.2 Recharge Estimates and Water Balance

Figure 6.6.3 shows the components of the recharge from the streams and the land recharge in the area between Medina and Cibolo basins. The stream recharge varies from 3,330 to 155,000 ac-ft/yr, averages 45,752, and accounts for about 47% of the total recharge in the basin. Land recharge varies from 3,9700 to 140,570 ac-ft/yr, averages 51,803, and accounts for about 53% of the total recharge in the basin. The model predicts that in most years, the aquifer receives more water from land recharge than from channel loss. Through the 50-year period, the average annual recharge in the area between Medina and Cibolo basins is 97,555 ac-ft/yr and the median value is 83,160 ac-ft/yr.

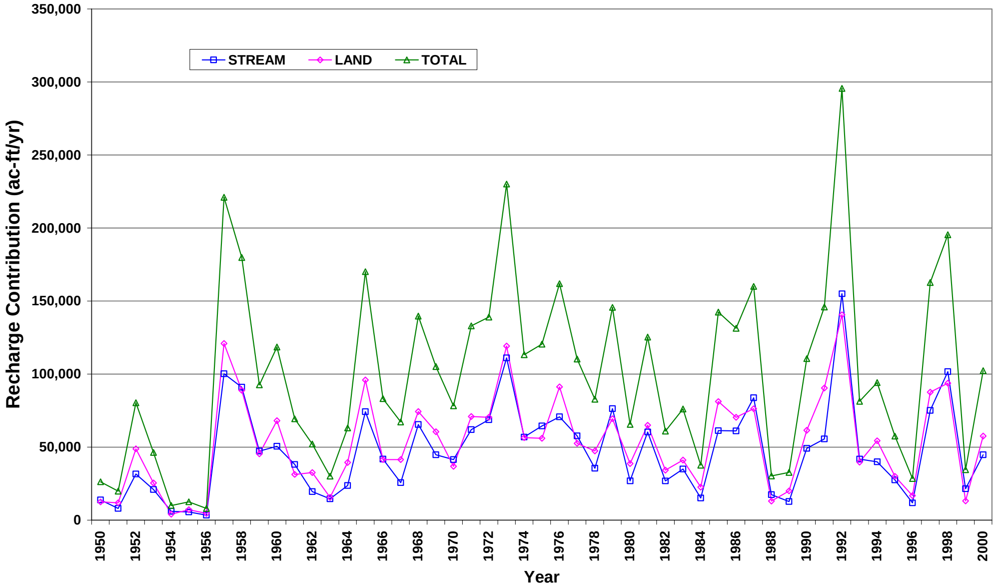


Figure 6.6.3 Annual Recharge from Streams and Land Components Estimated by HSPF - Area Between Medina and Cibolo Basins

6.6.3 Comparison of HSPF to Previous Methods

Figure 6.6.4 shows a scatter plot of USGS and HDR recharge estimates plotted against the estimates developed from the HSPF model. Figure 6.6.5 and 6.6.6 plot the annual recharge estimates from USGS and HDR with HSPF estimates, respectively. Figure 6.6.7 shows the comparison of cumulative recharge for each method from 1950 through 2000. Table 6.6.1 statistically summarizes the historical recharge estimates for all three methods as well as the land and stream components of the HSPF recharge estimate.

As shown Figure 6.6.4, the HSPF recharge estimates are generally slightly higher than traditional estimates and that the variability in the estimates can be significant. The HSPF average estimate of recharge is 97,555 ac-ft/yr, and varies from 7,891 to 295,570 ac-ft/yr. The HDR and USGS average recharge estimates are 87,087 and 71,022 ac-ft/yr, respectively. Figure 6.6.7 indicates that the cumulative recharge estimate from HSPF is greater than traditional estimates.

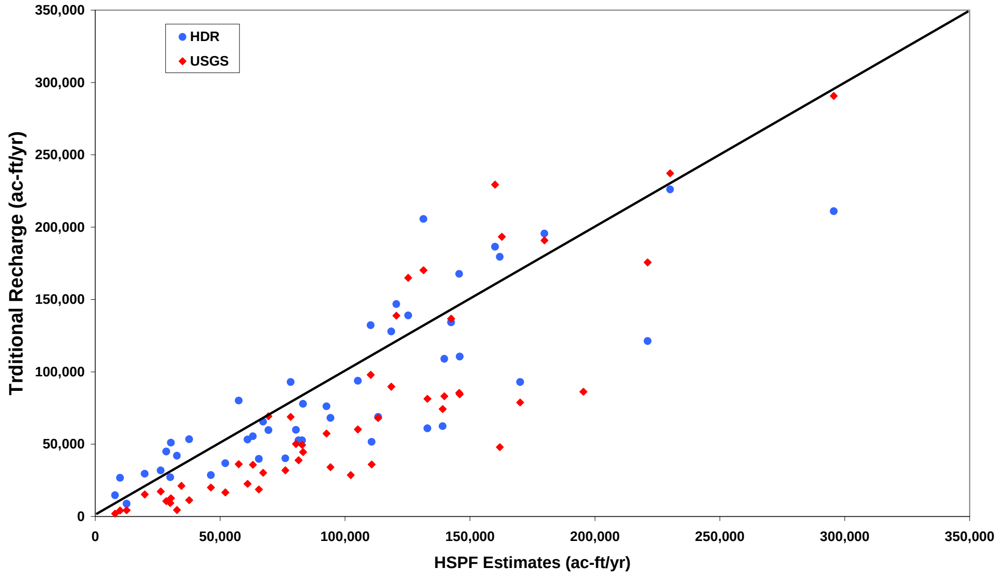


Figure 6.6.4 Scatter plot Recharge Comparison of Traditional Recharge Estimates to HSPF - Area Between Medina and Cibolo Basins

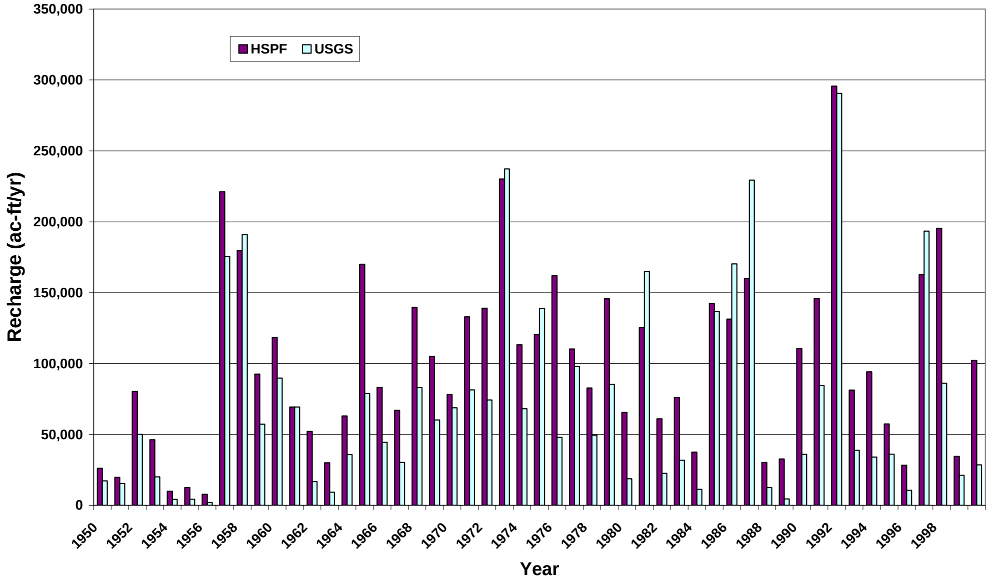


Figure 6.6.5 Annual Recharge Comparison of HSPF and USGS Estimates - Area Between Medina and Cibolo Basins

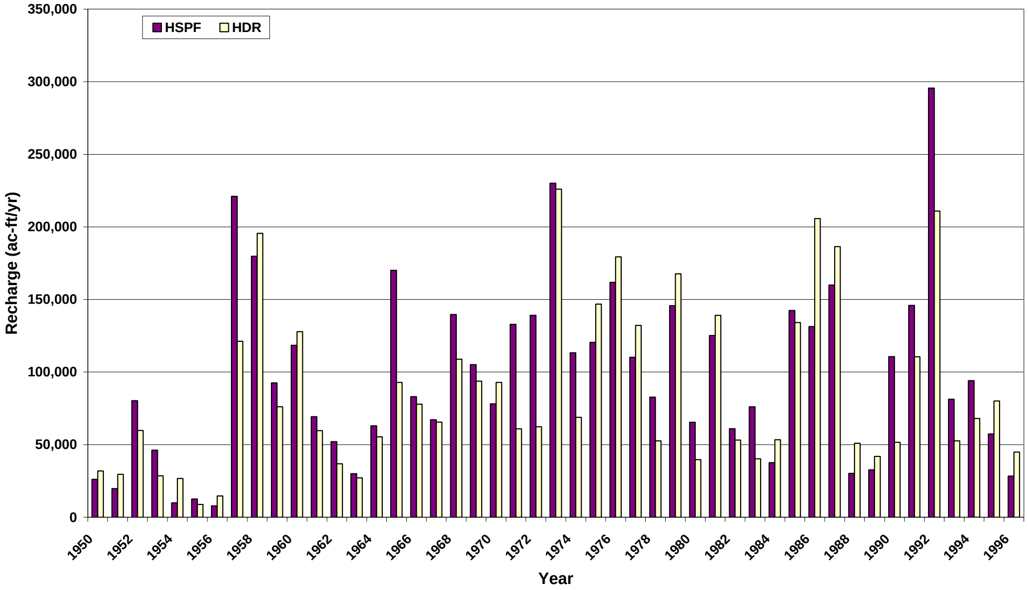


Figure 6.6.6 Annual Recharge Comparison of HSPF and HDR - Area Between Medina and Cibolo Basins

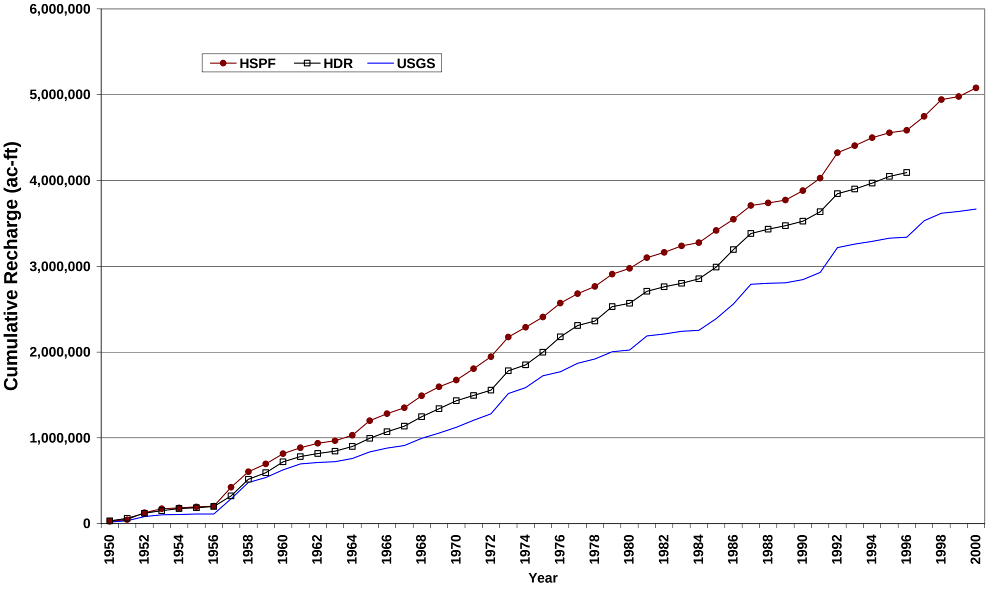


Figure 6.6.7 Cumulative Recharge Comparison - Area Between Medina and Cibolo Basins

Table 6.6.1 Statistical Summary of Recharge Estimates – Area Between Medina and Cibolo Basins

	HSPF Stream Recharge	HSPF Land Recharge	HSPF Recharge Total	HDR Recharge Estimate	USGS Recharge Estimate
47-year Total (af) [1]	2,150,340	2,434,750	4,585,090	4,093,078	3,338,044
Portion of HSPF Total	47%	53%	100%	NA	NA
Minimum (af/yr)	3,330	3,970	7,891	8,840	2,000
Average (af/yr)	45,752	51,803	97,555	87,087	71,022
Maximum (af/yr)	155,000	140,570	295,570	226,070	290,639
Range (af/yr)	151,670	136,600	287,679	217,230	288,639
10th Percentile (af/yr)	12,336	12,736	27,546	29,222	10,100
25th Percentile (af/yr)	22,235	30,565	54,755	47,997	19,436
50th Percentile (af/yr)	41,700	47,280	83,160	65,563	49,547
75th Percentile (af/yr)	61,600	70,365	135,990	124,561	84,924
90th Percentile (af/yr)	79,300	90,724	165,178	182,223	172,392
Skewness	1.14	0.69	0.89	0.93	1.48
Kurtosis	2.15	0.32	1.12	-0.12	1.77

[1] – Statistics calculated for annual recharge estimates from 1950 to 1996

6.7 Cibolo and Comal

The USGS streamflow data was not available for stream gage 8183850 (Cibolo Creek at IH10 above Boerne) for dates before 1996. Therefore, the contributing zone model was used to estimate streamflow at that gage (i.e., into the recharge zone) from 1950 through 1997 in order to estimate recharge to the Edwards aquifer. It is important to note that channel loss upstream from watershed 325 (see Figure 5.76) was not attributed to Edwards aquifer recharge, even though the official recharge zone extends up Cibolo Creek for over 10 miles. This professional judgment is based on our field experience regarding groundwater flow in northern Bexar County in the vicinity of Cibolo Creek. Simulations indicate that the total recharge in this area averages about 50,000 ac-ft/yr.

6.7.1 Long-term Streamflow Comparison

Figure 6.7.1 compares daily simulated and observed flow at stream gage 8183850 (Cibolo Creek at IH10 above Boerne) for the period between 1996 and 2000. The agreement between the observed and simulated flow is good in general but estimated flows greater than about 40 cfs tend to be consistently high. Figure 6.7.2 compares daily simulated and observed flow at stream gage 8185000 (Cibolo Creek at Selma) for the same 50-year period. The flow duration curve indicates that the model generally simulates slightly too much streamflow.

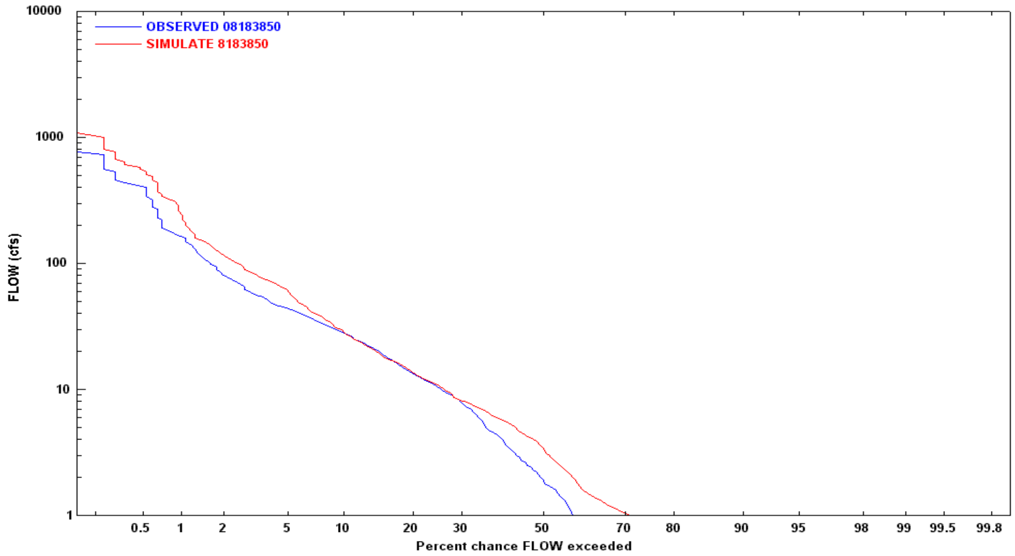


Figure 6.7.1 Daily Streamflow Frequency (1996-2000: Cibolo Creek at IH10 above Boerne, USGS #8183850)

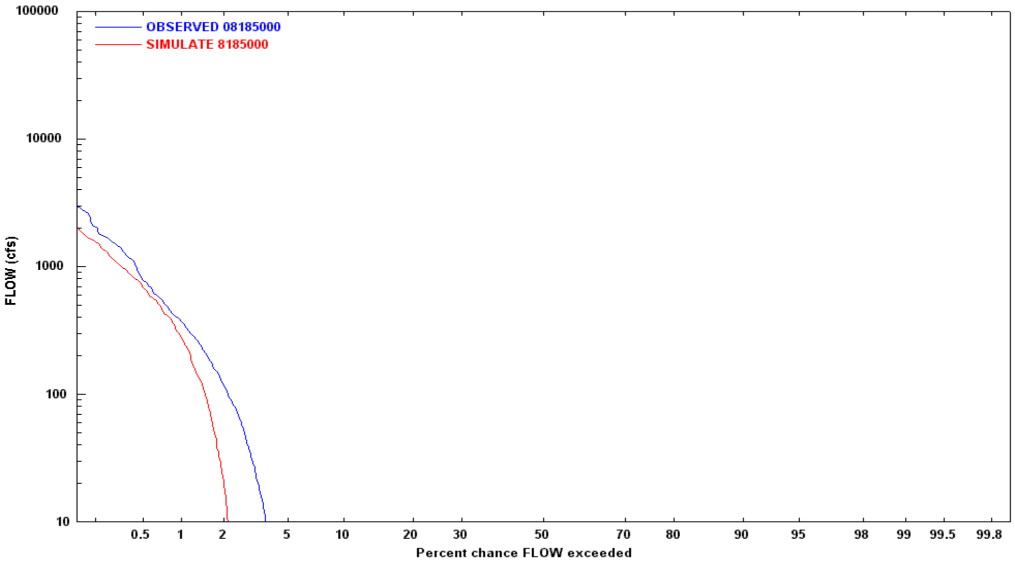


Figure 6.7.2 Daily Streamflow Frequency (1950-2000: Cibolo Creek at Selma, USGS #8185000)

6.7.2 Recharge Estimates and Water Balance

Figure 6.7.3 shows the components of the recharge from the streams and the land recharge in the Cibolo basin. The stream recharge varies from 2,424 to 69,600 ac-ft/yr, averages 26,829, and accounts for about 33% of the total recharge in the basin. Land recharge varies from 5,749 to 131,800 ac-ft/yr, averages 52,998, and accounts for about 67% of the total recharge in the basin. Through the 47-year comparison period, the average annual recharge in the Cibolo basin is 79,826 ac-ft/yr.

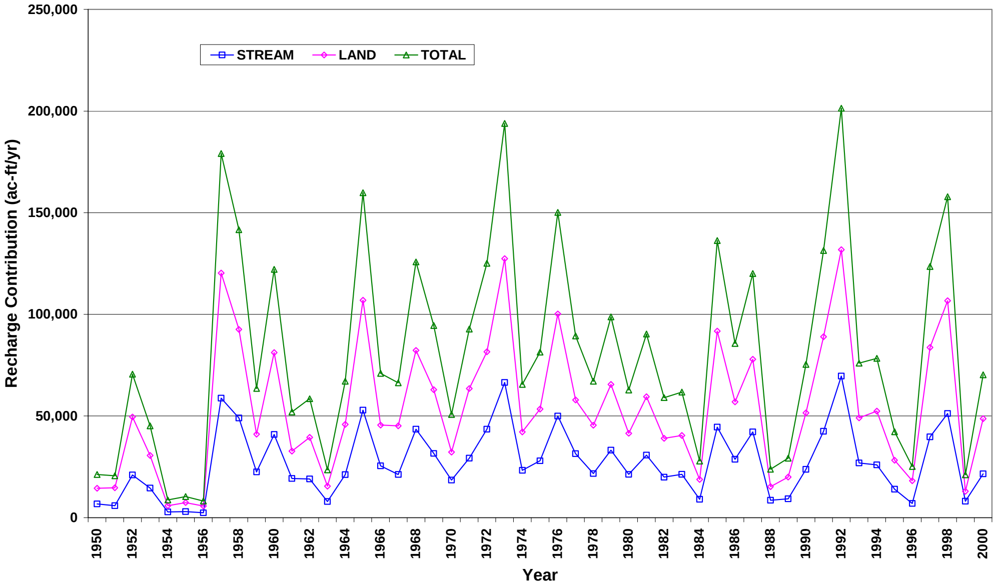


Figure 6.7.3 Annual Recharge from Streams and Land Components Estimated by HSPF - Cibolo Basin

6.7.3 Comparison of HSPF to Previous Methods

Figure 6.7.4 shows a scatter plot of USGS and HDR recharge estimates plotted against the estimates developed from the HSPF model. Figure 6.7.5 and 6.7.6 plot the annual recharge estimates from USGS and HDR with HSPF estimates, respectively. Figure 6.7.7 shows the comparison of cumulative recharge for each method from 1950 through 2000. Table 6.7.1 statistically summarizes the historical recharge estimates for all three methods and the land and stream components of the HSPF recharge estimate. All of these figures indicate that the HSPF model generally predicts less recharge than either of the traditional methods. HSPF values are generally lower because the recharge in the upper reaches of Cibolo Creek has not been added to the Edwards aquifer recharge. If this recharge had been added to the total, all the methods would compare relatively well.

The scatter plot indicates that there is significant variability in recharge estimates even under similar hydrologic conditions. Table 6.7.1 shows the HSPF average estimate of recharge is 79,826 ac-ft/yr, and varies from 8,173 to 201,400 ac-ft/yr. The HDR and USGS average recharge estimates are 111,402 and 107,101 ac-ft/yr, respectively.

Figure 6.7.7 indicates that the cumulative recharge estimate from HSPF is higher than estimates from traditional methods. Table 6.5.1 shows that over the 47-year comparison period, the HSPF cumulative recharge estimate is over 1 million acre-feet less than the USGS recharge estimates for the Cibolo basin.

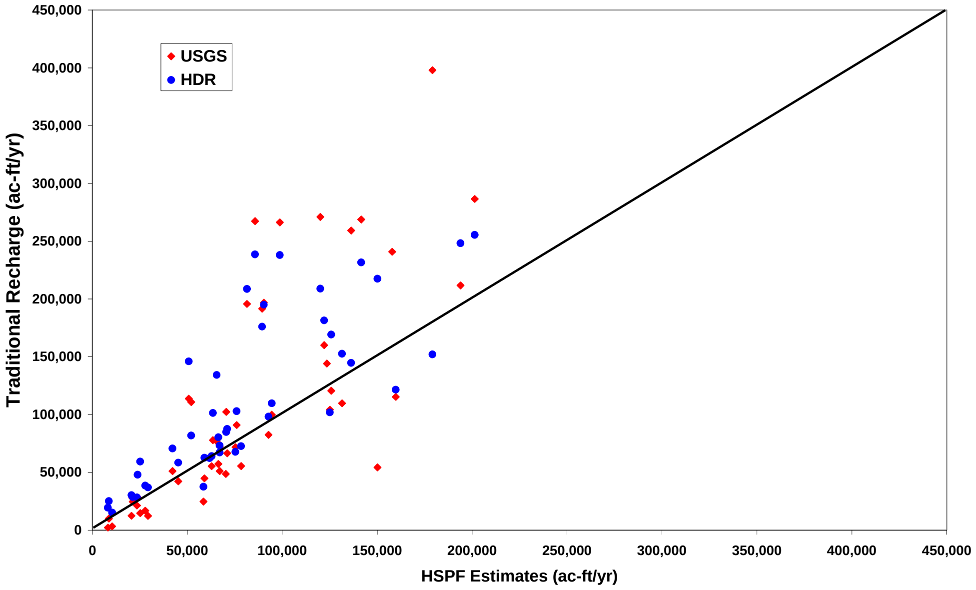


Figure 6.7.4 Scatter plot Recharge Comparison of Traditional Recharge Estimates to HSPF - Cibolo Basin

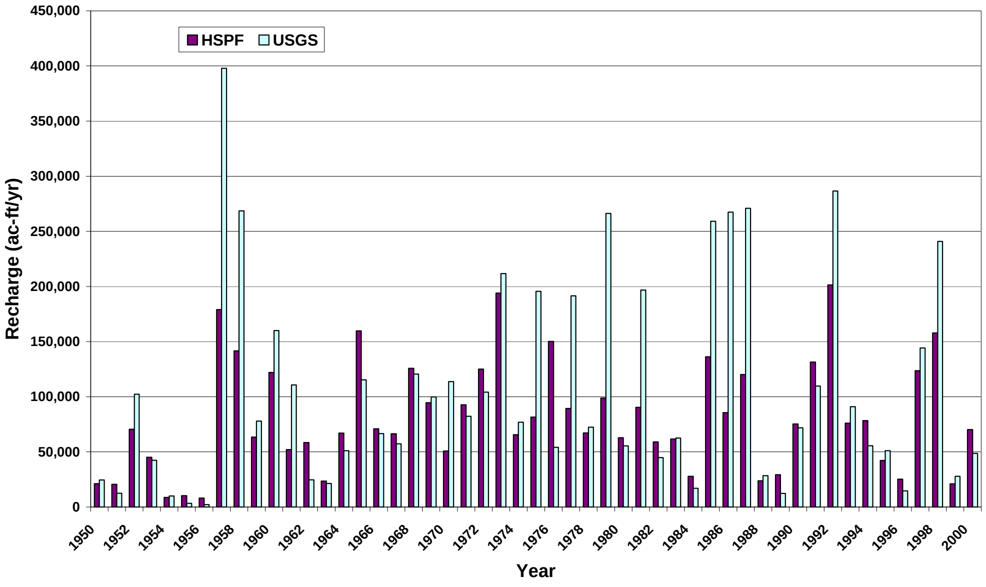


Figure 6.7.5 Annual Recharge Comparison of HSPF and USGS Estimates - Cibolo Basin

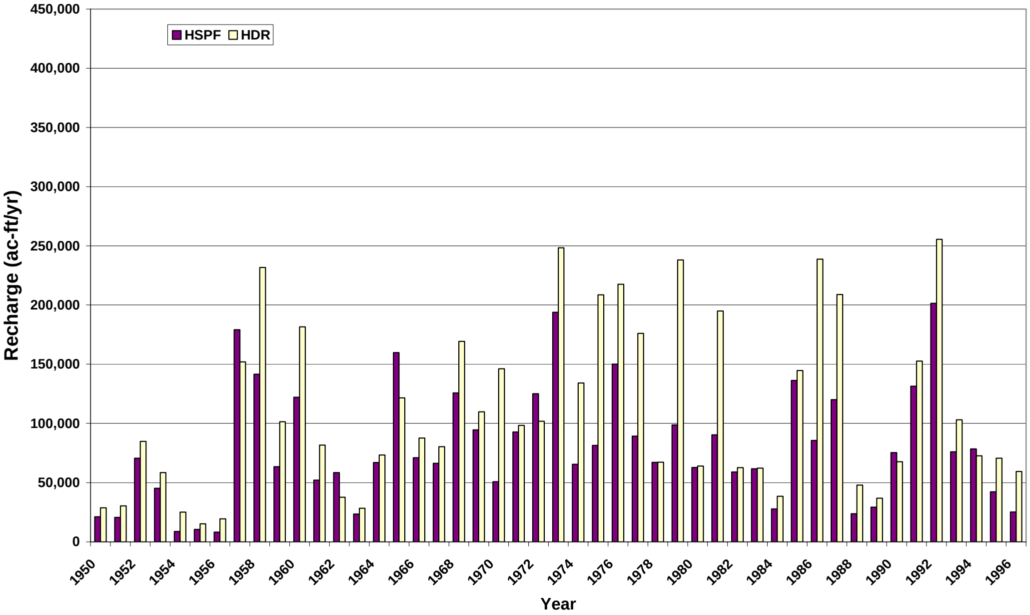


Figure 6.7.6 Annual Recharge Comparison of HSPF and HDR - Cibolo Basin

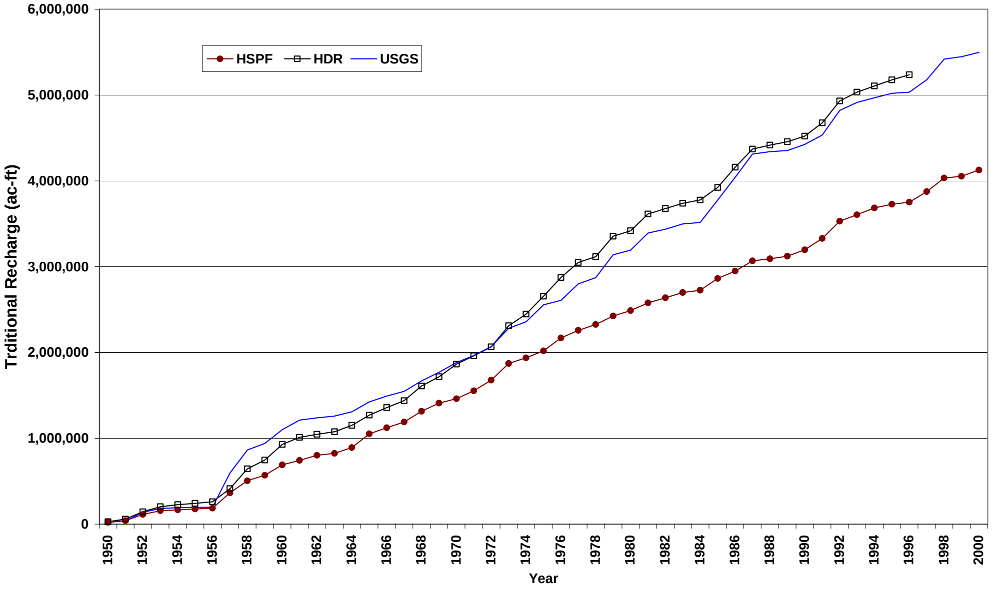


Figure 6.7.7 Cumulative Recharge Comparison - Cibolo Basin

Table 6.7.1 Statistical Summary of Recharge Estimates – Cibolo Basin

	HSPF Stream Recharge	HSPF Land Recharge	HSPF Recharge Total	HDR Recharge Estimate	USGS Recharge Estimate
47-year Total (af) [1]	1,260,941	2,490,885	3,751,826	5,235,881	5,033,742
Portion of HSPF Total	33%	67%	100%	NA	NA
Minimum (af/yr)	2,424	5,749	8,173	15,177	2,200
Average (af/yr)	26,829	52,998	79,826	111,402	107,101
Maximum (af/yr)	69,600	131,800	201,400	255,486	397,900
Range (af/yr)	67,176	126,051	193,227	240,309	395,700
10th Percentile (af/yr)	6,940	15,024	22,590	29,659	13,845
25th Percentile (af/yr)	16,535	31,445	47,980	60,842	43,581
50th Percentile (af/yr)	23,310	45,880	70,540	87,606	76,924
75th Percentile (af/yr)	37,050	71,720	109,420	160,935	140,350
90th Percentile (af/yr)	49,400	95,640	145,040	223,163	266,717
Skewness	0.69	0.69	0.69	0.60	1.19
Kurtosis	0.06	-0.06	-0.02	-0.85	0.78

[1] – Statistics calculated for annual recharge estimates from 1950 to 1996

6.8 Guadalupe

6.8.1 Long-term Streamflow Comparison

Figure 6.8.1 shows the comparison of observed and simulated streamflow duration curves for stream gage 8168500 (Guadalupe River at New Braunfels) for the period between 1950 and 2000. The flow duration curve indicates that the model reproduces observed streamflows with good reliability.

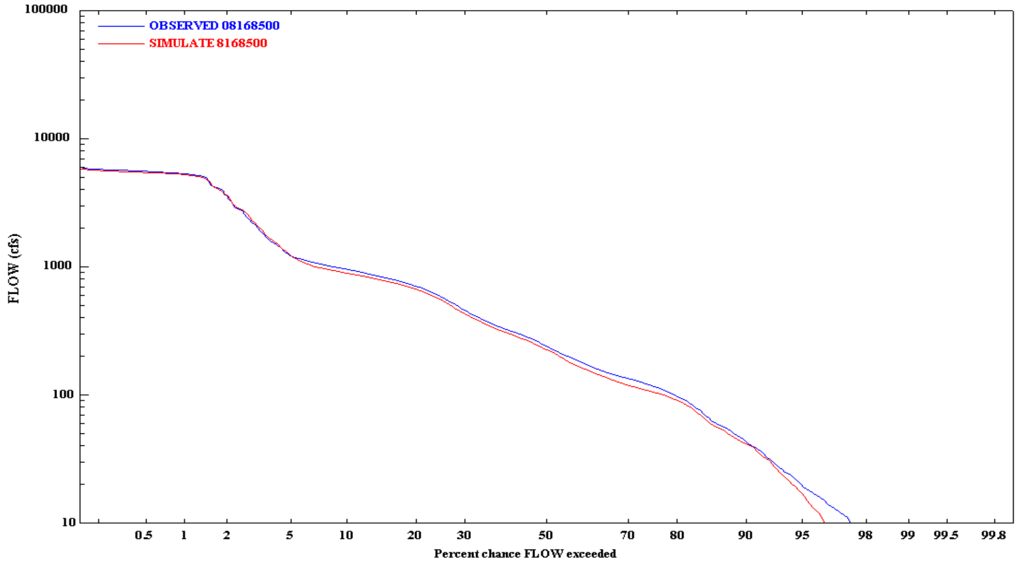


Figure 6.8.1 Daily Streamflow Frequency (1950-2000: Guadalupe River at New Braunfels, USGS #8168500)

6.8.2 Recharge Estimates and Water Balance

Figure 6.8.2 shows the components of the recharge from the streams and the land recharge in the basin. On average, stream recharge represents about 36% of the total recharge in the basin and varies from 9,190 to 10,200 ac-ft/yr, averages 9,959 ac-ft/yr. Land recharge in the recharge zone accounts for 64% of the total recharge and averages 17,855 ac-ft/yr.

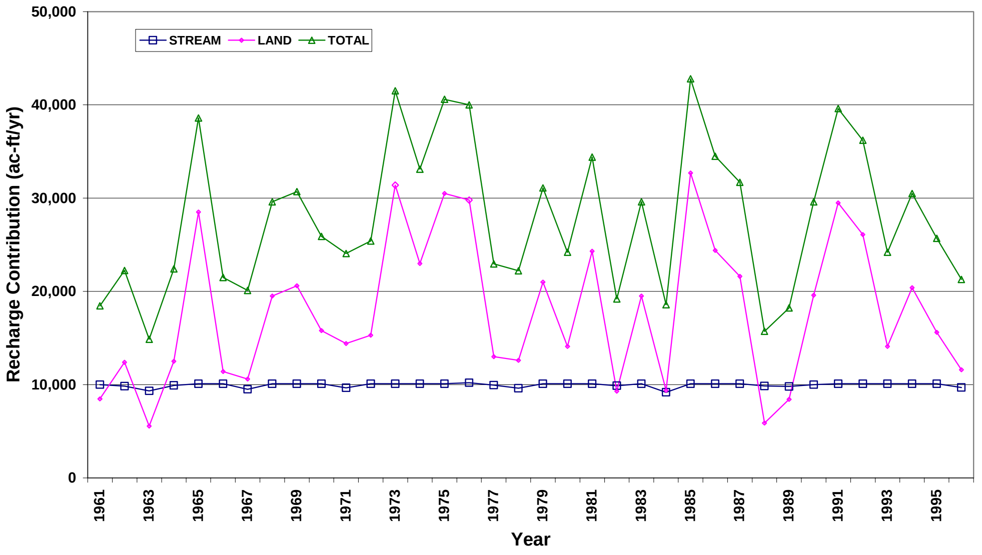


Figure 6.8.2 Annual Recharge from Streams and Land Components Estimated by HSPF - Guadalupe Basin

6.8.3 Comparison of HSPF to Previous Methods

Figure 6.8.3 shows a scatter plot of HDR recharge estimates plotted against the estimates developed from the HSPF model. Figure 6.8.4 plots the annual recharge estimates HDR with HSPF estimates. Figure 6.8.5 shows the comparison of cumulative recharge for each method from 1961 through 2000. Table 6.8.1 statistically summarizes the historical recharge estimates for the HDR and HSPF recharge estimates as well as the land and stream components of the HSPF recharge estimate. These figures indicate that the HSPF model predicts about 2.5 times higher recharge than the HDR method. The scatter plot indicates that there is significant variability in recharge estimates even under similar hydrologic conditions.

Table 6.8.1 shows the HSPF average estimate of recharge is 27,814 ac-ft/yr, and varies from 14,870 to 42,800 ac-ft/yr. The HDR method estimates an average of 5,904 ac-ft/yr. Figure 6.8.5 indicates that the cumulative recharge estimate from HSPF is about 800,000 acre-feet greater than the HDR recharge estimate over the 36-year calculation period. As shown in Figure 6.8.2, the stream recharge estimated by the HSPF model is relatively steady, but the land recharge can vary significantly depending on precipitation and weather patterns.

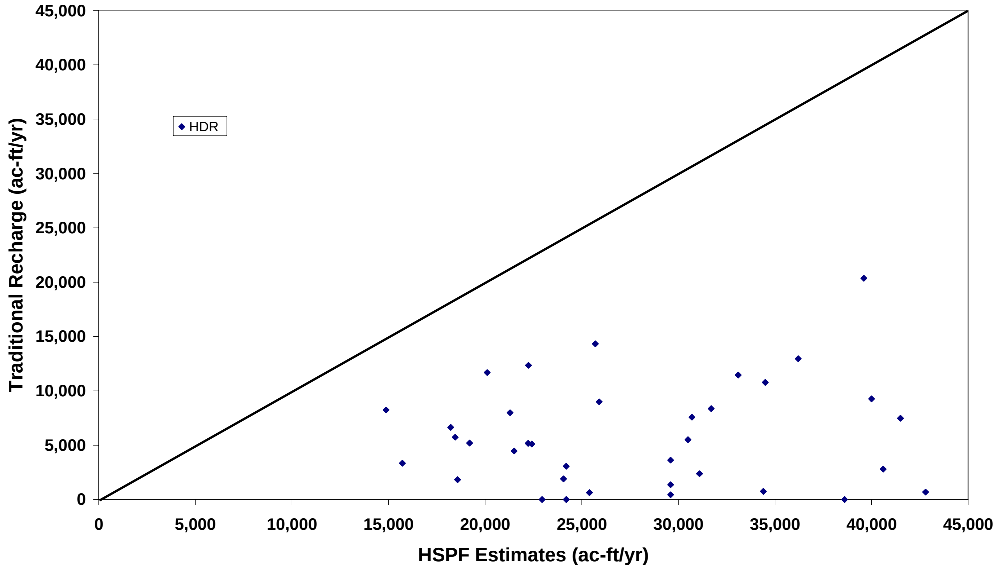


Figure 6.8.3 Scatter plot Recharge Comparison of HSPF and HDR Estimates - Guadalupe Basin

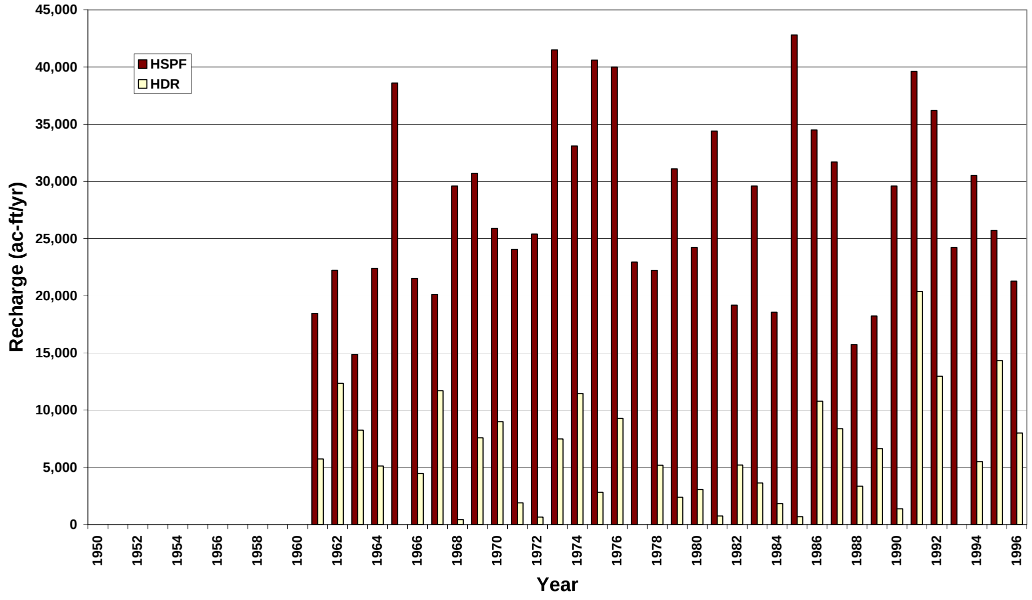


Figure 6.8.4 Annual Recharge Comparison of HSPF and HDR Estimates - Guadalupe Basin

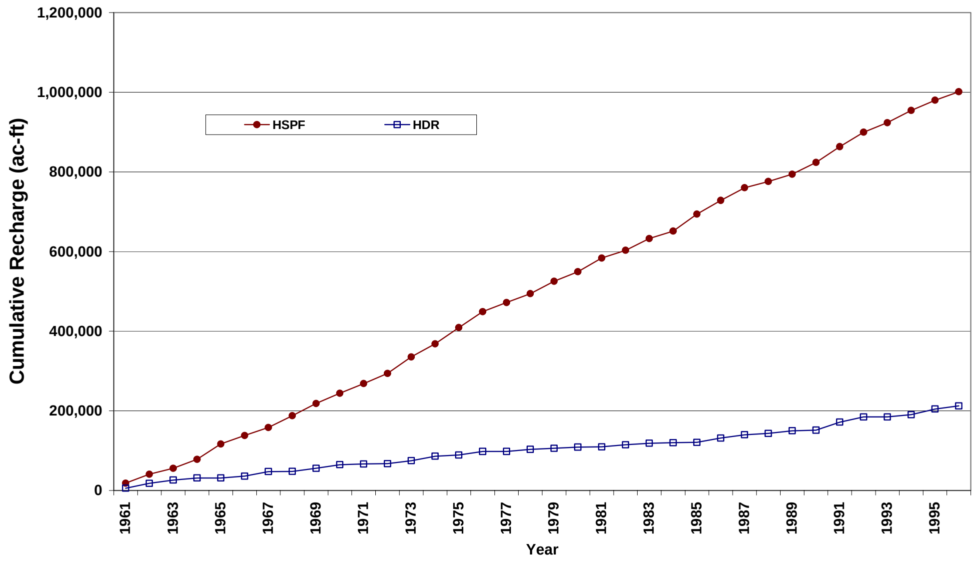


Figure 6.8.5 Cumulative Recharge Comparison - Guadalupe Basin

Table 6.8.1 Statistical Summary of Recharge Estimates – Guadalupe Basin

	HSPF Stream Recharge	HSPF Land Recharge	HSPF Recharge Total	HDR Recharge Estimate	USGS Recharge Estimate
36-year Total (af) [1]	358,510	642,780	1,001,290	212,550	-
Portion of HSPF Total	36%	64%	100%	NA	NA
Minimum (af/yr)	9,190	5,550	14,870	-	-
Average (af/yr)	9,959	17,855	27,814	5,904	-
Maximum (af/yr)	10,200	32,700	42,800	20,363	-
Range (af/yr)	1,010	27,150	27,930	20,363	-
10th Percentile (af/yr)	9,640	8,880	18,510	538	-
25th Percentile (af/yr)	9,880	12,200	22,040	1,882	-
50th Percentile (af/yr)	10,100	15,700	25,800	5,186	-
75th Percentile (af/yr)	10,100	23,325	33,425	8,524	-
90th Percentile (af/yr)	10,100	29,650	39,800	12,022	-
Skewness	-1.81	0.36	0.33	0.88	-
Kurtosis	2.80	-0.93	-0.95	0.71	-

[1] – Statistics calculated for annual recharge estimates from 1961 to 1996

6.9 Blanco

6.9.1 Long-term Streamflow Comparison

Figure 6.9.1 compares daily simulated and observed flow at stream gage 8171000 (Blanco River at Wimberley) for the 50-year period between 1950 and 2000. Overall, the comparison between the simulated and observed flows is very good and indicates that the model is capable of simulating the hydrology of the contributing zone.

Figure 6.9.2 compares the simulated and observed streamflow frequency curves at stream gage 8171300 (Blanco River near Kyle) for the same 50-year period. The flow duration curve indicates that the model does an excellent job of simulating streamflow conditions.

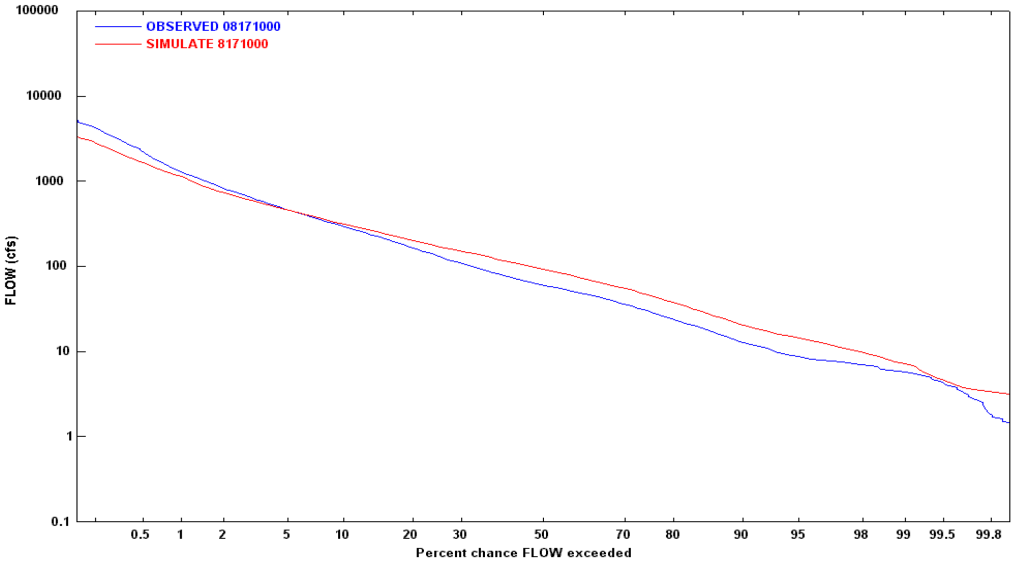


Figure 6.9.1 Daily Streamflow Frequency (1950-2000: Blanco River at Wimberley, USGS #8171000)

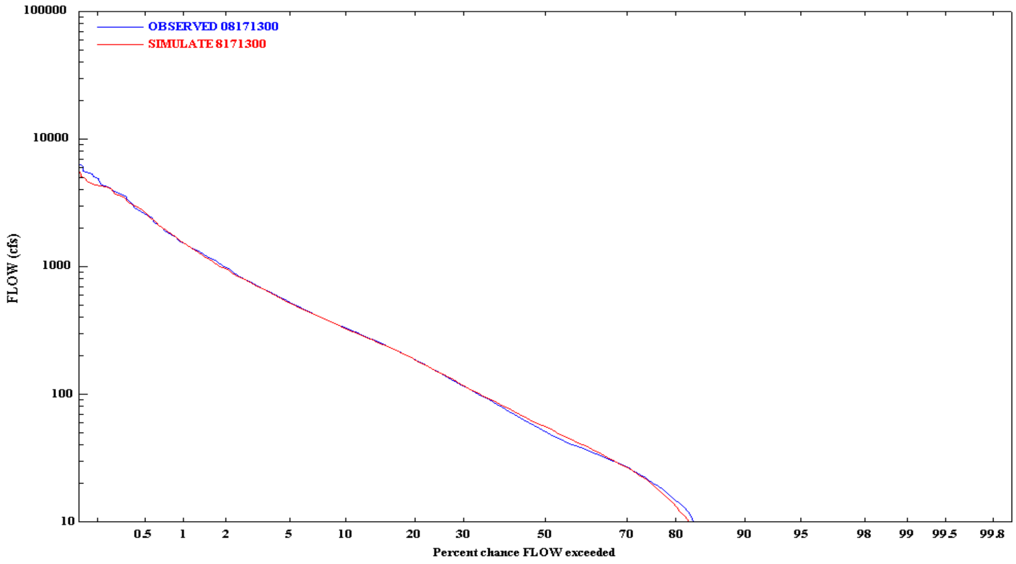


Figure 6.9.2 Daily Streamflow Frequency (1956-2000: Blanco River near Kyle, USGS #8171300)

6.9.2 Recharge Estimates and Water Balance

Figure 6.9.3 shows the components of the recharge from the streams and the land recharge in the basin. On average, stream recharge represents about 24% of the total recharge in the basin and varies from 5,889 to 35,260 ac-ft/yr, averages 20,341 ac-ft/yr. Land recharge in the recharge zone accounts for 76% of the total recharge and averages 62,667 ac-ft/yr. As illustrated in Figure 6.9.3, the model indicates that land recharge is much more variable than stream recharge.

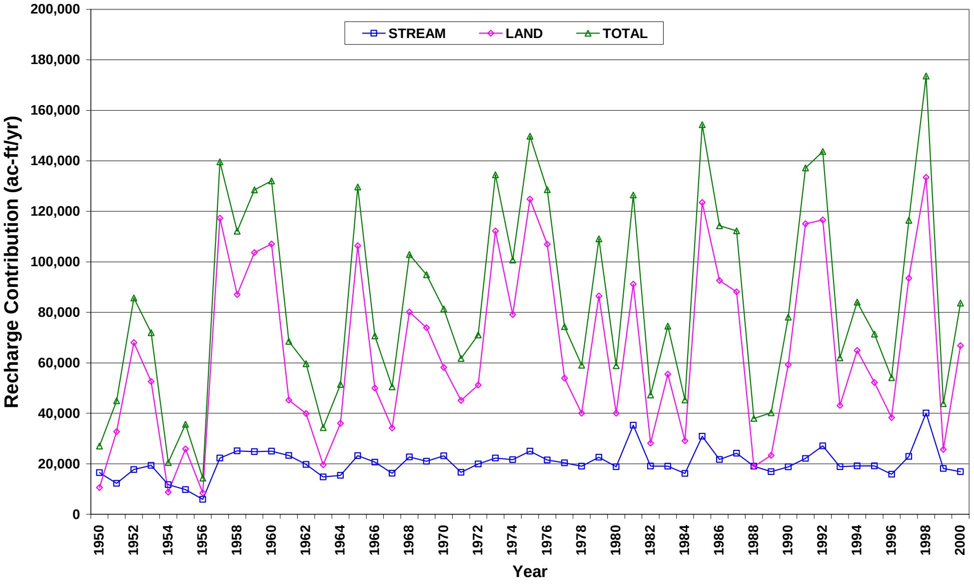


Figure 6.9.3 Annual Recharge from Streams and Land Components Estimated by HSPF - Blanco Basin

6.9.3 Comparison of HSPF to Previous Methods

Figure 6.9.4 shows a scatter plot of USGS and HDR recharge estimates plotted against the estimates developed from the HSPF model. Figure 6.9.5 and 6.9.6 plot the annual recharge estimates from USGS and HDR with HSPF estimates, respectively. Figure 6.9.7 shows the comparison of cumulative recharge for each method from 1950 through 2000. Table 6.9.1 statistically summarizes the historical recharge estimates for all three methods and the land and stream components of the HSPF recharge estimate. All of these figures indicate that the HSPF model generally predicts higher recharge than either of the traditional methods. The scatter plot indicates that there is significant variability in recharge estimates even under similar hydrologic conditions.

Table 6.9.1 shows the HSPF average estimate of recharge is 82,708 ac-ft/yr, and varies from 14,319 to 154,380 ac-ft/yr. The HDR and USGS average recharge estimates are 67,608 and 44,962 ac-ft/yr, respectively. The HDR pilot model for the Blanco basin estimated average recharge at 71,638 ac-ft/yr.

Figure 6.9.7 indicates that the cumulative recharge estimate from HSPF is higher than estimates from traditional methods. Table 6.5.1 shows that over the 47-year comparison period, the HSPF cumulative recharge estimate is almost 1.8 million acre-feet greater than the USGS recharge estimate and about 600,000 ac-ft greater than HDR.

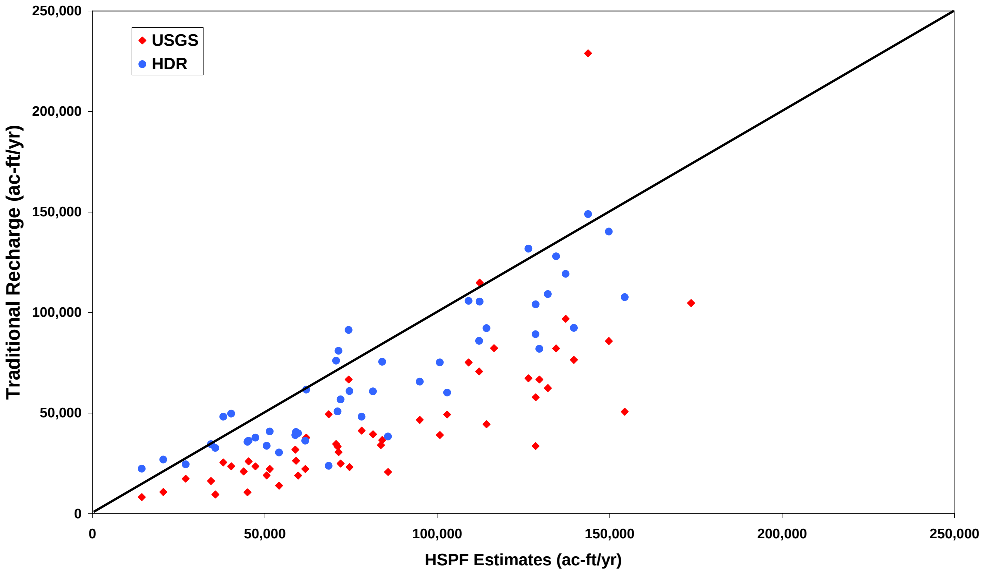


Figure 6.9.4 Scatter plot Recharge Comparison of Traditional Recharge Estimates to HSPF - Blanco Basin

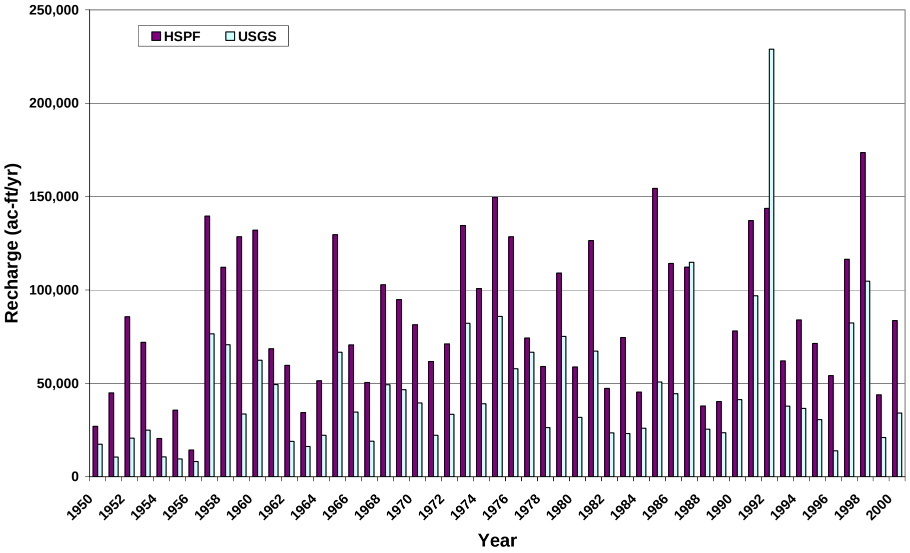


Figure 6.9.5 Annual Recharge Comparison of HSPF and USGS Estimates - Blanco Basin

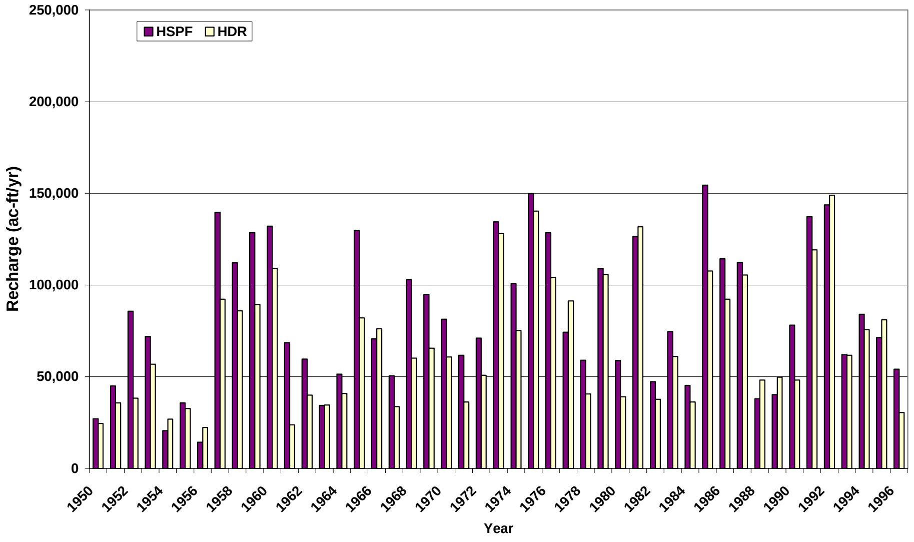


Figure 6.9.6 Annual Recharge Comparison of HSPF and HDR Estimates - Blanco Basin

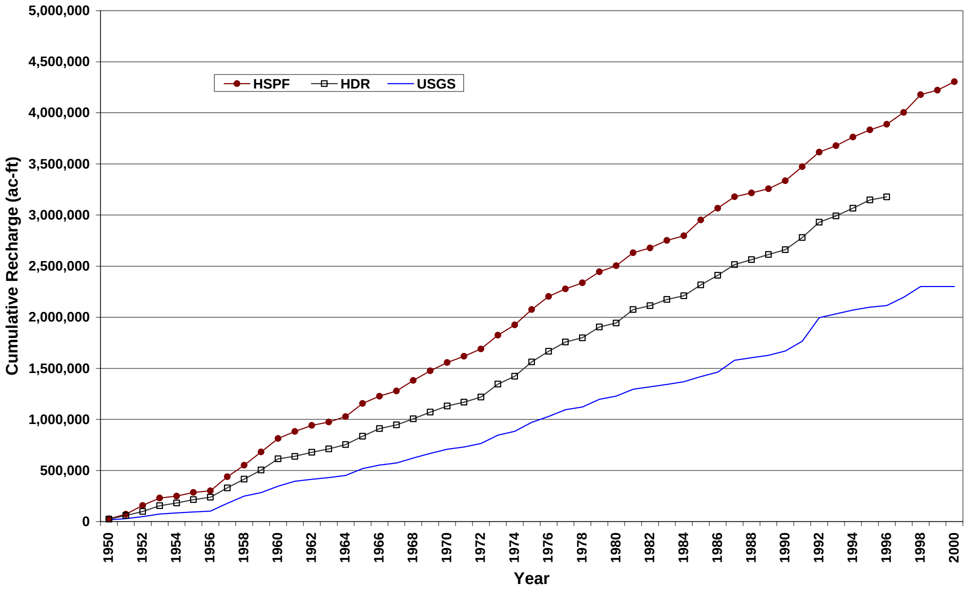


Figure 6.9.7 Cumulative Recharge Comparison - Blanco Basin

Table 6.9.1 Statistical Summary of Recharge Estimates – Blanco Basin

	HSPF Stream Recharge	HSPF Land Recharge	HSPF Recharge Total	HDR Recharge Estimate	USGS Recharge Estimate
47-year Total (af) [1]	941,940	2,945,340	3,887,280	3,177,594	2,113,230
Portion of HSPF Total	24%	76%	100%	NA	NA
Minimum (af/yr)	5,889	8,430	14,319	22,330	8,200
Average (af/yr)	20,041	62,667	82,708	67,608	44,962
Maximum (af/yr)	35,260	124,800	154,380	148,965	228,939
Range (af/yr)	29,371	116,370	140,061	126,635	220,739
10th Percentile (af/yr)	15,183	21,840	37,031	31,748	15,274
25th Percentile (af/yr)	17,310	37,150	52,789	38,059	22,678
50th Percentile (af/yr)	19,732	53,900	74,313	60,771	34,600
75th Percentile (af/yr)	22,665	89,650	113,287	91,785	60,145
90th Percentile (af/yr)	24,968	113,360	135,578	113,174	78,780
Skewness	0.06	0.30	0.23	0.64	2.91
Kurtosis	2.04	-1.09	-1.06	-0.60	12.40

[1] – Statistics calculated for annual recharge estimates from 1950 to 1996

6.10 All Basins

Figure 6.10.1 shows the comparison of cumulative recharge for all nine basins from 1950 through 2000 for each method. The total recharge to the Edwards aquifer estimated by the HSPF models is about 2 million ac-ft less than the USGS estimate, and less than one million ac-ft greater than the HDR estimates during the 47-year comparison period.

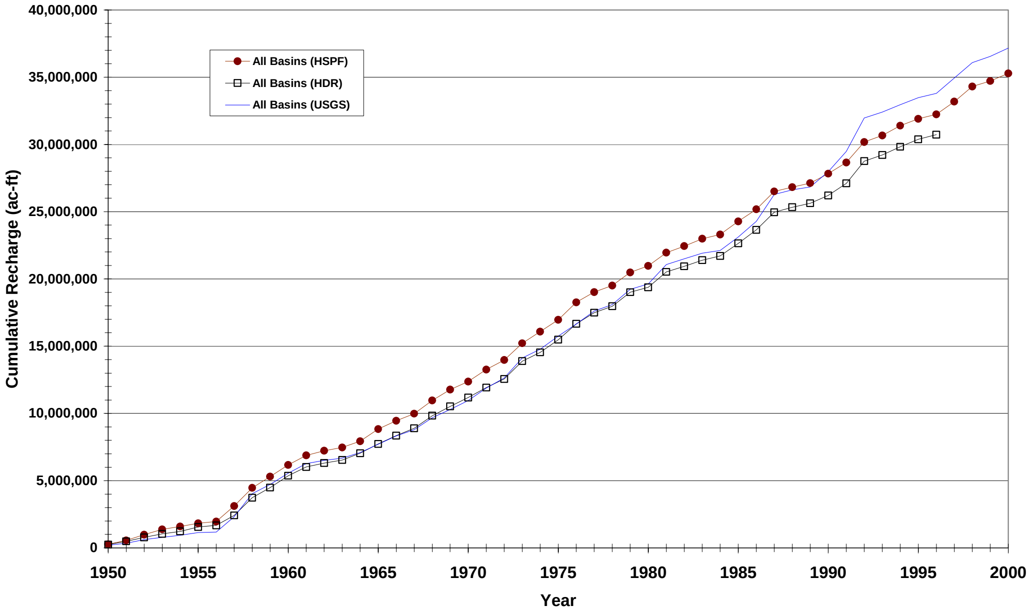


Figure 6.10.1 Cumulative Recharge Comparison – All Nine Basins

Table 6.10.1 provides a statistical summary of the historical recharge estimates for all three methods for all nine basins. The table shows the HSPF, HDR and USGS average estimates of recharge are 679,346; 661,703; and 719,217 ac-ft/yr, respectively. The median estimates are 694,445; 621,898; and 615,231 ac-ft/yr, respectively. In general, the USGS estimates have a much wider range and tend to have a few outliers in very wet years.

Figure 6.10.2 graphically illustrates the annual total recharge estimates for each of the three methods for all nine basins. Each method estimates similar trends from year to year, but the USGS method tends to have the highest outliers in wet years. In 1958, 1981, 1987, and 1992, the USGS method estimate recharge that is significantly higher than the other methods. In 1992, the USGS estimate is almost one million ac-ft greater than the HSPF or HDR estimates; but in most years, the totals are much closer.

Table 6.10.1 Statistical Summary of Recharge Estimates – All Basins

	HSPF Recharge Estimate	HDR Recharge Estimate	USGS Recharge Estimate
47-year Total (af)	31,929,259	31,100,062	33,803,206
Minimum (af/yr)	106,566	153,385	43,760
Average (af/yr)	679,346	661,703	719,217
Maximum (af/yr)	1,516,290	1,661,173	2,485,693
Range (af/yr)	1,409,724	1,507,788	2,441,933
10th Percentile (af/yr)	253,205	272,868	183,443
25th Percentile (af/yr)	384,609	361,941	339,844
50th Percentile (af/yr)	694,445	621,898	615,231
75th Percentile (af/yr)	896,283	908,107	962,560
90th Percentile (af/yr)	1,172,668	1,164,904	1,463,606
Skewness	0.45	0.79	1.30
Kurtosis	-0.47	0.15	1.91

[1] – Statistics calculated for annual recharge estimates from 1950 to 1996

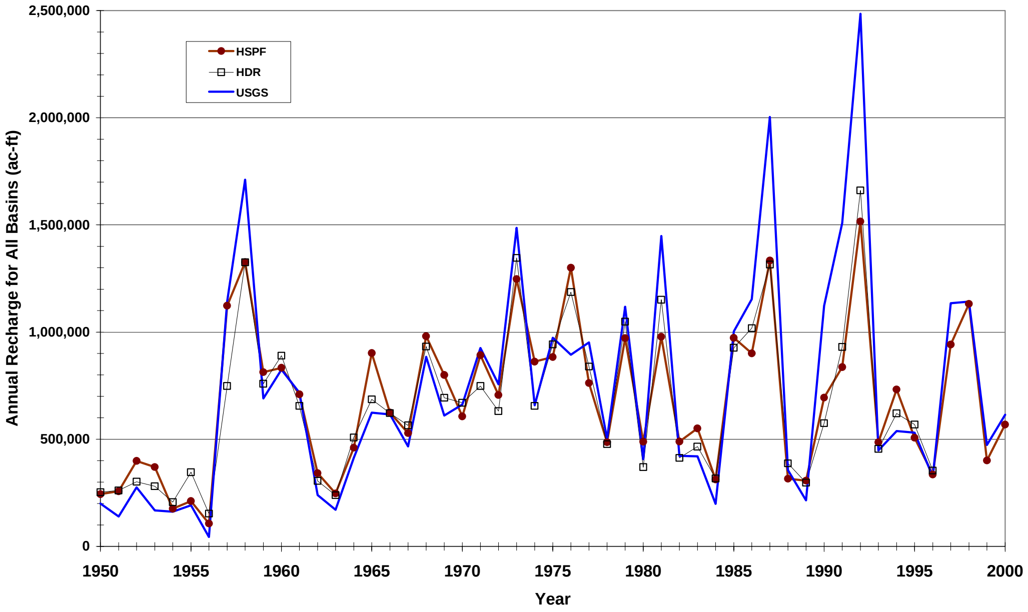


Figure 6.10.2 Annual Recharge Estimates for All Basins

Figure 6.10.3 shows the comparison of cumulative recharge for the four basins (Nueces, Frio, Sabinal, and Sabinal-Medina) within the Nueces River Basin from 1950 through 2000 for each method. The total recharge to the Edwards aquifer estimated by the HSPF models is slightly greater than the HDR estimates, and about 4 million ac-ft less than the USGS estimate.

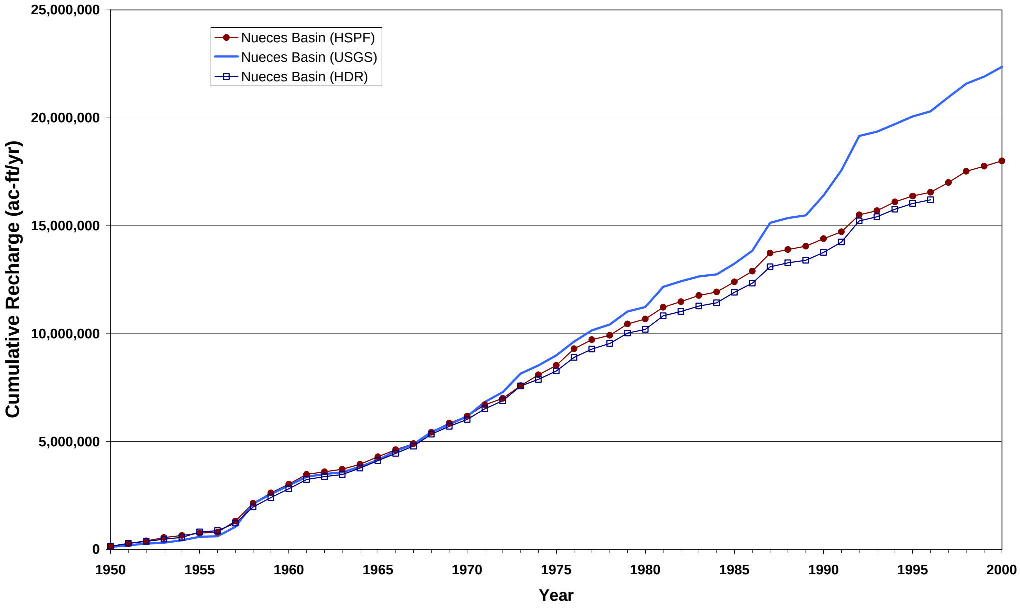


Figure 6.10.3 Cumulative Recharge Comparison – Nueces River Basin (Nueces, Frio, Sabinal, and Sabinal-Medina Watersheds)

Figure 6.10.4 shows the comparison of cumulative recharge for the three basins (Medina, Medina-Cibolo, Cibolo) within the San Antonio River Basin from 1950 through 2000 for each method. The total recharge to the Edwards aquifer estimated by the HSPF models is less than traditional estimates by about 1 million ac-ft.

Figure 6.10.5 shows the comparison of cumulative recharge for the two basins (Guadalupe and Blanco) within the Guadalupe-Blanco River Basin from 1950 through 2000 for each method. The total recharge to the Edwards aquifer estimated by the HSPF models (5.8 million ac-ft) is slightly more than double the USGS estimate of (2.4 million ac-ft).

Figure 6.10.6 shows the average percentage of recharge that comes from land segments (not streams) in each basin as estimated by the HSPF models. The portion originating from land segments varies from 7% in the Sabinal basin to over 75% in the Blanco basin. The models indicate that on average, about 50% of the recharge to the Edwards aquifer comes from land segments.

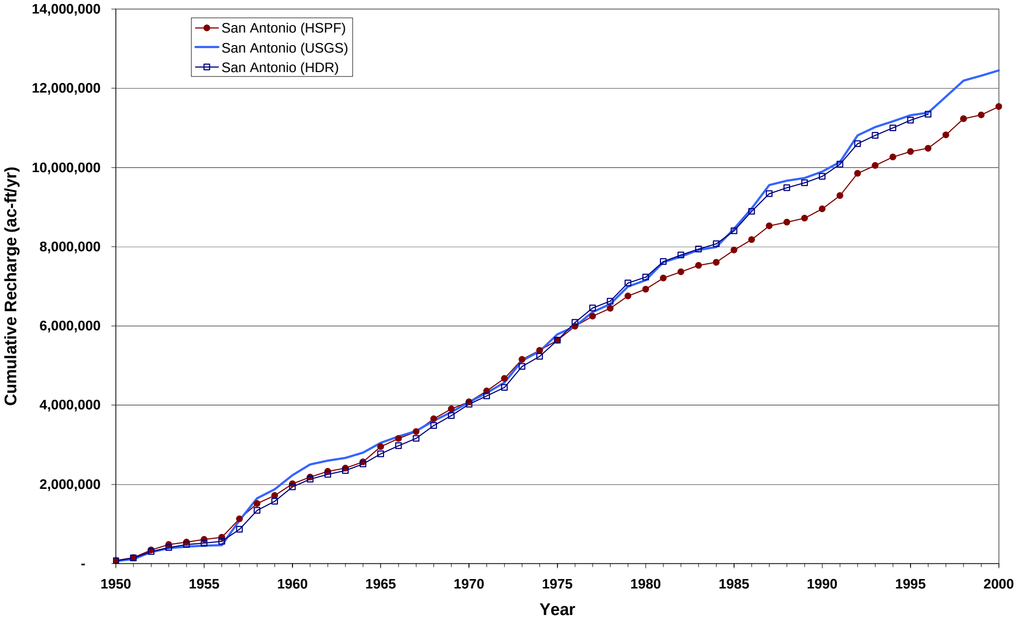


Figure 6.10.4 Cumulative Recharge Comparison – San Antonio River Basin (Medina, Medina-Cibolo, Cibolo, and Comal Watersheds)

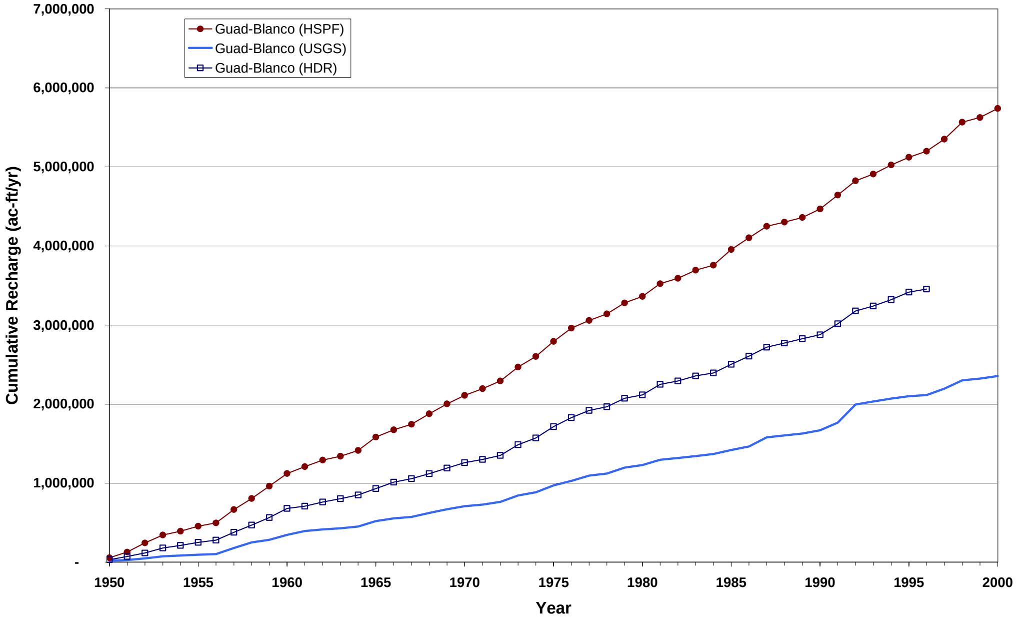


Figure 6.10.5 Cumulative Recharge Comparison – Guadalupe-Blanco River Basin (Guadalupe and Blanco Watersheds)

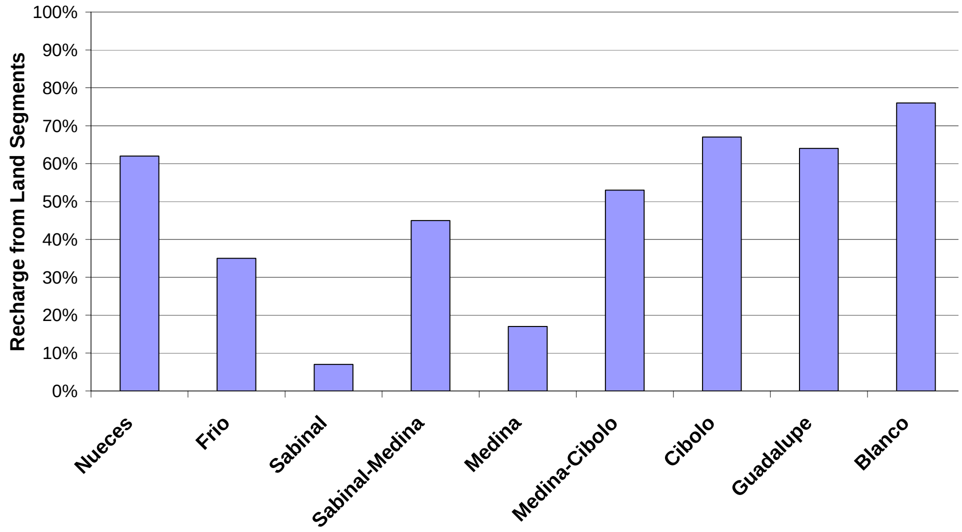


Figure 6.10.6 Percent of Recharge from Land Segments in Each Basin Estimated by HSPF Models

Figure 6.10.7 illustrates the volumetric contribution of each basin to the total land segment recharge for the Edwards aquifer as estimated by the HSPF models between 1950 and 2000. According to HSPF models, the Nueces and Blanco basins contribute the largest amount of land segment recharge to the aquifer on a volumetric basis.

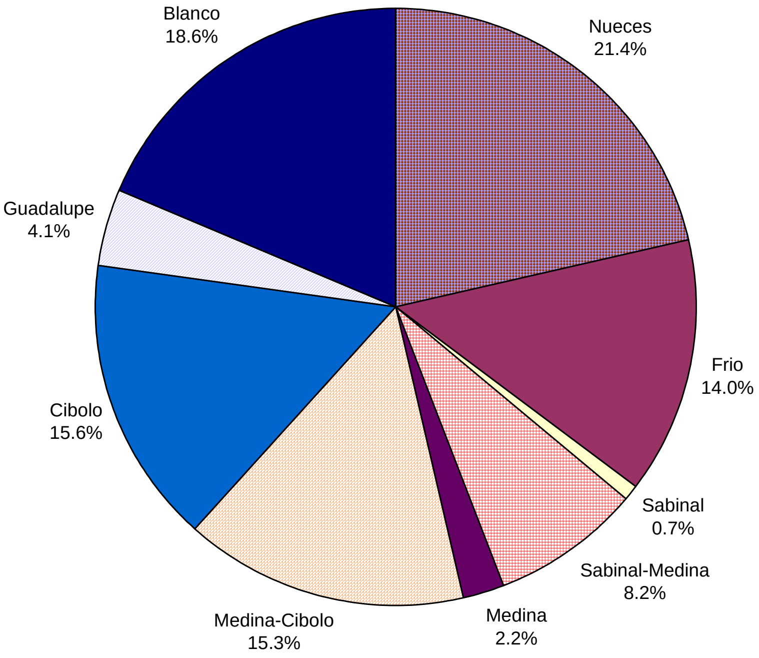


Figure 6.10.7 Volumetric Contribution of Each Basin to the Total Land Recharge (1950-2000) Estimated by HSPF Models

Figure 6.10.8 illustrates the volumetric contribution of each basin to the total recharge for the Edwards aquifer as estimated by the HSPF models between 1950 and 2000. According to HSPF models, the Frio, Nueces, and Medina-Cibolo basins contribute the largest amount of total recharge (land and stream) to the aquifer on a volumetric basis.

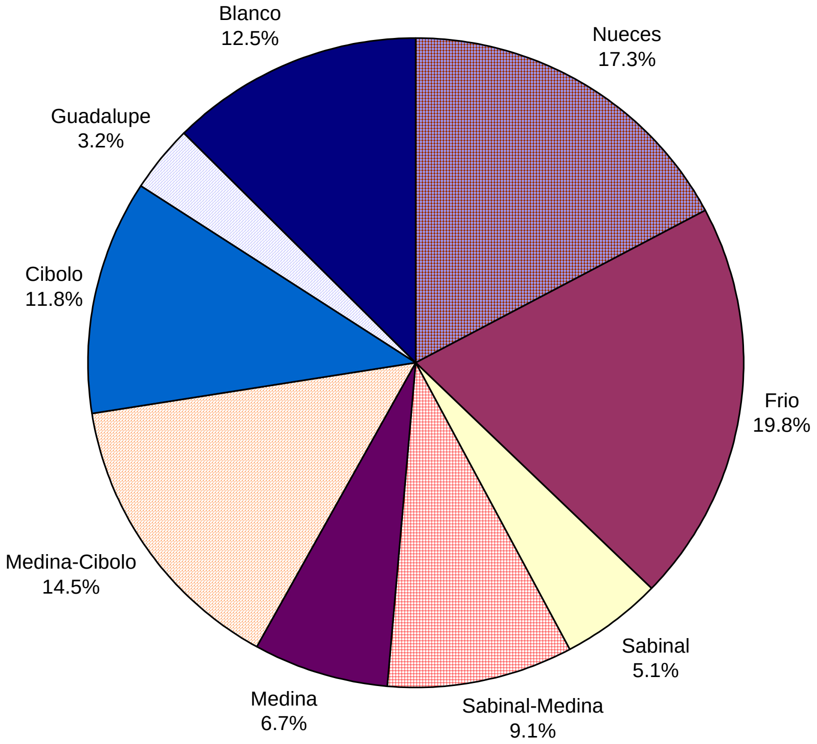


Figure 6.10.8 Volumetric Contribution of Each Basin to the Total Recharge (1950-2000) Estimated by HSPF Models

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7. Limitations of the Models

In general, the limitations of the approach outlined above are a function of the limitations of the available precipitation, evaporation, and streamflow data and the simplification of the hydrologic cycle as represented by the algorithms in HSPF.

7.1 Data Limitations

The aerial variability of the precipitation throughout the nine-basin study area is only partially recorded by the existing precipitation stations. There will be rainfall events that impact one part of a basin (or basins) without being accurately measured at a precipitation gauge. HSPF will not be able to accurately simulate these events because the actual precipitation will be different than the measured precipitation. This problem is particularly true for isolated thunderstorm events. However, it is assumed that major storm events cover a large enough land area to include at least one precipitation station. Some smaller events will be missed and some will be over represented (rain fell at the gauge, but not over the entire basin), but on average the annual rainfall will be well represented and the annual runoff volume computed by HSPF will be accurate.

The limitations of evaporation data are not as significant as the limitations of the precipitation data to the computation of runoff and recharge. This is because evaporation aerial variability is not as great as it is for precipitation and there are sufficient evaporation stations to accurately represent all of the nine basins.

Streamflow data can be a limitation if the period of record does not include major flow events or if the rating curve changes with each event. These limitations are not a major concern for the nine-basin models. Of course, ungauged basins are a limitation as well. For the nine-basin models, this limitation will be addressed by using HSPF parameter values from adjacent gauged and calibrated basins to help calibrate ungauged areas.

Channel loss estimates are perhaps the biggest uncertainty in some of the basins. Because of the nature of the studies and the various hydrologic conditions under which they are completed, it is difficult to ascertain precise values of channel loss along reaches in the recharge area. In addition, during heavy storms, the channel losses that occur in tributaries to the main waterways could serve as an important additional source of recharge that has not been explicitly measured or incorporated into the models.

7.2 Limiting Assumptions of HSPF

HSPF's simplified representation of the nine basins, their complex geology, and the hydrologic cycle is a limitation. Real world hydrology is more complex than any computer model. However, the goal is not to accurately represent the flow of every drop of water in the nine basins and follow it on its path to recharge, streamflow, or evaporation, but to accurately represent the major physical processes and compute the distribution of all of the water to recharge, streamflow, or evaporation.

The grouping of different soils and geology, slope, and vegetation into PERLND categories is another simplification of the nine basins. Once again, it is not important to represent all of the combinations of soils, geology, slope, and vegetation, but to represent the major combinations that impact the basin hydrology significantly.

Using the same modeling philosophy, it may not be necessary to model all of the runoff pathways or minor stream channels in each basin, but rather to model the major rivers, tributaries, and flood retardation structures and reflect their impacts on the movement of water through the basins to recharge and downstream flow locations.

7.3 Limits of Model Applicability

None of the above described limitations compromise the validity of the HSPF models, but they do serve as a reminder of the inherent assumptions required to model any real-world system and the importance of identifying and accurately representing the major components of the hydrologic system.

Determining the accuracy of an estimation method requires that we know the “right” answer to the problem we are trying to solve (Croley, 2000). Unfortunately, there is no direct way to measure recharge to the Edwards aquifer. Therefore, we are somewhat limited in determining potential errors in the recharge estimates, but it is possible to compare recharge estimates to other estimates, as was done in Section 6. To produce more accurate estimates of recharge, it will be necessary to better understand the entire aquifer system, which will require more data collection, field studies, research, and modeling. Recommendations to improve our understanding of the aquifer and our techniques of analyses are included in Section 8.

8. Recommendations for Future Improvements and Study

Determining the accuracy of an estimation method requires that we know the “right” answer to the problem we are trying to solve (Croley, 2000). Unfortunately, there is no direct way to measure recharge to the Edwards aquifer. We can only monitor and study parts of the system and then meld together many kinds of information into a conceptual and quantitative understanding of the system. Therefore, to produce more accurate estimates of recharge, it will be necessary to better understand the entire aquifer system, which requires more data collection, field studies, research, and modeling. Recommendations for future studies to improve our understanding of the system fall into two broad categories, data and model improvements, which are discussed below.

8.1 Data Improvements – Field Studies

To improve the accuracy of the conceptual and quantitative models, there are several areas of field study that should be pursued.

Rainfall-Runoff-Evaporation Studies

Our understanding of recharge processes on the Edwards Plateau needs to be improved. This study indicates that direct recharge from land segments (between streams) may contribute as much as half the total volumetric recharge to the Edwards aquifer. There is still considerable uncertainty as to the relative importance of direct recharge in areas outside of stream channels versus recharge that takes place as a result of transmission loss within streams in the recharge zone. Large-scale rainfall simulation experiments, similar to that conducted at the Honey Creek State Natural Area, may provide some insight in terms of relative contribution of recharge from the areas between streams.

Additional insight into timing and amount of recharge can be provided through micro-meteorological work that allows direct measurement of evapotranspiration over a relatively large area. For example, work by Dugas and others (1998) in Seco Creek using the Bowen ratio method indicates that average annual evapotranspiration accounts for only about 65% of the water budget; in other words, the remaining 35% of the water is available for streamflow and/or deep recharge. This result contrasts with most estimates of evapotranspiration on the Edwards Plateau, arrived at via the water budget method (whereby evapotranspiration is assumed to be equal to the difference between average precipitation and streamflow). Additional evapotranspiration studies are now being conducted at the Honey Creek State Natural Area and the Freeman Ranch that should provide additional insight into recharge processes. Multi-scale watershed studies should be conducted on the Edwards aquifer recharge zone to determine water balance in different areas. Tracers and other innovative techniques should be used to determine the fate of runoff and infiltration.

Tracer Studies

Groundwater tracer studies should be completed in several areas to provide more insight into the movement of groundwater in the Edwards aquifer. Tracer studies near Cibolo Creek and in the Comal watershed could help determine the magnitude and fate of recharge in this area and help determine how much of the recharge flows to the Edwards aquifer and what path it takes under different flow conditions. Tracer studies in the Nueces basin may help determine the cause of the bad calibration for the HSPF model (in the contributing zone) by identifying if there are significant flow paths between the West Nueces and the Nueces. Tracer studies could also be used in conjunction with detailed gain-loss studies to better assess bank storage and stream gage issues.

Detailed Channel Loss Studies

Channel loss studies should be completed in selected areas of the recharge zone that exhibit relatively high channel loss. The USGS (2002b) documents streamflow losses at various streamflows in the Salado Creek Basin in Bexar County after a storm during October 17-19, 1998. These data indicate that channel loss can vary with streamflow. Therefore, channel loss studies should be completed in several reaches over the recharge zone under different flow conditions. These measurements should be collected on simultaneous days or weeks by the same crew and in the same locations. It may be advantageous to combine these studies with tracer studies.

Assessment of Stream Gages

The West Nueces stream gage should be assessed to determine how much streamflow (if any) is moving through the gravels and not being measured. A new location may be required for this gage.

Field Estimation of Land Management Modeling Parameters

The HSPF models developed in this study are extremely useful tools for performing assessment of land management changes. The models can be used to assess brush control, weather modification, land development, point and non-point source runoff, water quality and other issues. However, there can be a huge leap of faith in estimating how actual land management changes affect model parameters.

Many times, researchers will complete a sensitivity study in which, for example, the affect of brush control is assumed to increase infiltration and runoff by a certain percent. Then, the model will be used to determine the impact on streamflow (and inferred water supply) or groundwater recharge based on some assumed change in evapotranspiration, infiltration, or other modeling parameters. While this is a helpful exercise for assessing the general benefit of a land management change, it may lead to erroneous results if the wrong assumptions are made regarding the relative change in model parameters based on a particular management practice. Therefore, more fieldwork is needed to help assess how particular land management techniques affect model parameters. Then, the modeling tools can be used to develop results to complete an appropriate cost-benefit analysis.

Pumping Estimates

Although not directly related to this study, one of the most uncertain variables in the water balance equation for the Edwards aquifer is the quantity and distribution of pumping. The error in recharge estimates cannot be reduced to a lower level than the error in the pumping estimates. There are institutional and legal hurdles to obtaining better pumping estimates, but from a scientific perspective, it is a critical issue in better understanding the aquifer system.

Precipitation Data

NEXRAD precipitation data would be helpful in filling in gaps in the data and providing much better geographic and temporal coverage for rainfall data throughout the contributing and recharge zones.

8.2 Model Improvements

Historical Precipitation Data

It is not likely that historical precipitation data for simulating recharge will be located. However, future enhancements to the model should include increased density of historical precipitation data from the Authority precipitation gages (after 2000).

Refine Model Calibration

The HSPF models should be recalibrated using recent (after 2000) precipitation data. Several basins should be selected to determine the utility of the precipitation data for improved model calibration. Authority precipitation gage data and NEXRAD data should improve model calibration.

Link Surface water and Groundwater Models

The HSPF models could be directly linked to the MODFLOW model. This would take significant effort and might prove cumbersome, but would allow a closer coupling of the surface water and groundwater systems.

Detailed Assessment of Synoptic Water Level Data

As more synoptic and continuous groundwater levels are collected, a more in depth assessment should be completed to assess the correlation of recharge events to water level changes in the aquifer.

Small-Scale Highly Detailed HSPF Models

Small-scale highly detailed HSPF models that are consistent in scale with the field studies over the recharge zone should be developed. These small-scale models could be used to more appropriately determine model parameters and more precisely simulate the water balance for a small watershed and assess the results of the field studies.

Water Quality Models

The HSPF models should be extended in some areas to simulate water quality.

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9. Conclusions

Hydrologic models have been developed for the nine basins that recharge the San Antonio section of the Edwards Aquifer and recharge estimates from these models have been implemented into recharge data for the Edwards Aquifer MODFLOW model. The models have been calibrated for the basins of the (1) Nueces/West Nueces Rivers, (2) Frio/Dry Frio Rivers, (3) Sabinal River, (4) area between Sabinal and Medina River (Seco and Hondo Creeks), (5) Medina River, (6) area between Medina and Cibolo (San Geronimo, Helotes, and Salado Creeks), (7) Cibolo/Dry Comal Creeks, (8) Guadalupe River, and (9) Blanco River.

The hydrologic models were developed using the Hydrologic Simulation Program-Fortran (HSPF) computer model. HSPF incorporates rainfall, evaporation, topography, channel loss information, land use and vegetation data, geologic and soil characteristics, water diversions, and other information to simulate the hydrologic processes that occur in each watershed on an hourly basis. The models are calibrated to observed streamflow data from stream gages in the basins and honor measured channel loss information in the Edwards aquifer recharge zone. The HSPF models provide a historical water budget, and hourly estimates of each component of hydrologic process in the basin, including stormwater runoff, evaporation, quantity of water transported over the land surface and through various soil zones, and recharge to the Edwards aquifer. The models can produce a time history of the hydrologic process along any stream or in any sub-watershed within each basin.

The calibration process included comparison of both daily, monthly, and annual streamflow values and individual storm events. All of these comparisons were performed to ensure the best possible calibration of hydrologic parameters. In addition, continuous observed streamflow data (simulated and observed values) were analyzed on a frequency basis and their resulting cumulative distributions (e.g., flow duration curves) compared to assess the model behavior and agreement over the full range of observations.

Sensitivity analysis indicates that streamflow and recharge estimates are both sensitive to changes in the key model input parameters that affect the infiltration-runoff dynamics in the watersheds. One of the most sensitive parameters is the channel loss estimate. These relationships have been based on 115 individual gain-loss studies in the nine basins.

Model results indicate that the recharge estimates from the HSPF models are generally comparable to traditional methods (see Figure 6.10.1). However, the recharge estimates for some basins are higher than previous estimates and others are lower. For the western four basins that are a part of the Nueces River Basin (Nueces, Frio, Sabinal, and Sabinal-Medina), the cumulative recharge for the period between 1950-1996 falls between the USGS and HDR traditional estimates. For the three basins that are a part of the San Antonio River Basin (Medina, Medina-Cibolo, and Cibolo) the cumulative recharge estimates for the same time period are slightly lower than historically estimated by the USGS and HDR methods. In the Guadalupe River Basin (Guadalupe and Blanco), the HSPF recharge estimates are higher than traditional estimates.

Model results indicate that the source of recharge varies dramatically among the basins depending on the channel loss characteristics, areal extent of recharge zone, and upstream flow from the contributing zone. In some basins, the land recharge is a major component of the overall recharge and in other basins (e.g., Sabinal) the recharge is dominated by channel loss. The cumulative recharge estimates from the HSPF models indicate that the volume of recharge from the land segments over the 50-year simulation period is about 50% of the total recharge for the nine basins.

The historical average recharge estimates for HSPF, HDR and USGS are 679,346; 661,703; and 719,217 ac-ft/yr, respectively. The median estimates are 694,445; 621,898; and 615,231 ac-ft/yr, respectively. In general, the USGS estimates have a much wider range and tend to have a few outliers in very wet years.

Some contributing zone models calibrated better than others. In general, the calibrated streamflow results from the model indicate that the "contributing zone" models are useful and appropriate for simulating hydrologic conditions in the upper part of each basin and simulating flow at the upstream flow gage.

The HSPF models are valuable tools for simulating the hydrology of the nine basins and assessing recharge under various hydrologic conditions. The models provide a new tool for assessing hourly hydrology, which could not be done with the traditional methods. They simulate each basin more discretely than the traditional methods do; which makes the models more appropriate for evaluating recharge enhancement, water quality and many other technical and regulatory issues.

To improve the accuracy of the models, more detailed field studies should be completed in selected areas of the recharge zone. These assessments should include field-scale rainfall-runoff and evaporation studies, tracer studies, channel loss studies, and other evaluations. Suggested model improvements include incorporating more detailed precipitation data from Authority rain gages that has been collected since this study was initiated; developing model parameters with models for smaller watersheds; and enhancing the existing models to simulate water quality.

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APPENDIX A

Comparison Of Traditional Recharge Estimates for the Edwards Aquifer

Comparison of USGS and Trans-Texas (HDR) Methods

Historically, the United States Geological Survey (USGS) has calculated used a water balance method to calculate recharge to the Edwards aquifer (Puente, 1978). As a part of the Trans-Texas project, HDR Engineering, Inc. (HDR, 1998) used slightly different methods to calculate recharge to the Edwards Aquifer. Both approaches are water balance methods that rely on total monthly flows in gauges upstream and downstream of the recharge zone. The basic approach is the same, but minor modifications in the HDR methodology are designed to overcome some of the simplifying assumptions of the USGS method. The USGS method and assumptions are described below.

Puente (1978) describes the general equation the USGS method uses for calculating monthly recharge as:

$$R = (Q_U + SI - Q_L) * 1.9835$$

Where R = monthly recharge (acre-feet)

Q_U = volume of flow at upper gauge (cfs-days)

SI = volume of runoff (including infiltration) resulting from precipitation in the intervening area (cfs-days)

Q_L = volume of flow at the lower gauge (cfs-days)

And

$$SI = (\Delta A / A_U) * Q_{TU}$$

ΔA = drainage area between upper and lower gauges (sq. miles)

A_U = drainage area above upper gauge (sq. miles)

Q_{TU} = volume of water contributed by storm above upper gauge (cfs-days).

For each basin, there are various modifications that may be implemented in calculating the recharge because of the geographic relationship between the recharge zone and the contributing streams.

Major assumptions employed by the USGS method include:

- storm characteristics (intensity, duration, geographical extent, etc.) are identical in the entire watershed above the upper gauge and in the intervening area above the lower gauge,
- rainfall-runoff characteristics (antecedent moisture, vegetation, slope, soil and geology, etc.) are identical in the entire watershed above the upper gauge and in the intervening area above the lower gauge,
- rainfall adjustment between gauged and ungauged areas can be made on a monthly basis,

- relationships between baseflow and groundwater in storage developed by USGS for each basin are appropriate for all conditions and at any time, regardless of climatologic variations, and
- diversions and/or return flows are insignificant.

The HDR method uses the same basic methodology with minor adjustments. The HDR method accounts for diversions and/or return flows by using naturalized flow at the downstream gauge, rather than the gauged flow. The HDR method also calculates runoff components differently by accounting for potential differences in runoff characteristics and antecedent moisture content above the upper gauge and in the intervening area above the lower gauge.

Although both methods are relatively straightforward and generally rely on measured or observable data. Weaknesses of the traditional methods include:

- Daily recharge is not estimated;
- Runoff estimates do not consider rainfall intensity, duration, and geographical extent within the recharge and contributing zones;
- Does not objectively incorporate the soil conditions in the runoff estimate based on fundamental climatologic variables such as rainfall and evaporation;
- Inadequate consideration of potential variations in baseflow due to climate variation (precipitation and evapotranspiration dynamics);
- Does not estimate recharge occurring from the Edwards-Trinity (Plateau) and Trinity aquifer;
- No way to directly incorporate measured loss rates from gain-loss studies;
- Limited capability to estimate changes in recharge and other hydrologic responses due to changes in vegetation;
- Does not provide a good basis for assessing water quality concerns from nonpoint sources in the recharge or contributing zone.

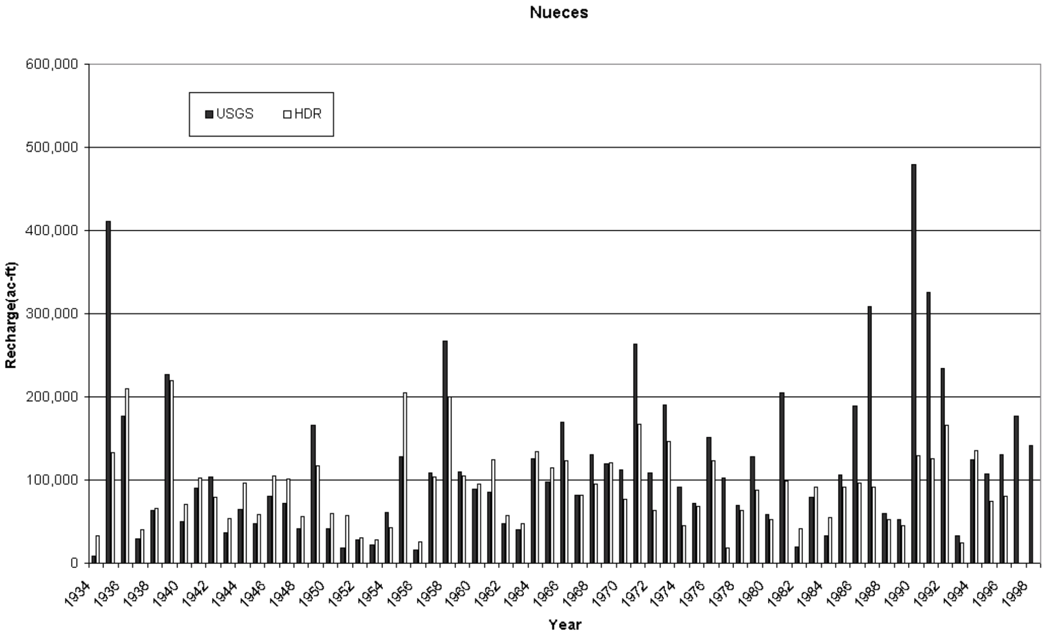
The HSPF models for the nine basins provide a method for overcoming each of these weaknesses. Weaknesses and assumptions of the HSPF models are discussed in Section 2.

Comparison of USGS and Trans-Texas (HDR) Historical Recharge Estimates

Historical yearly recharge estimates (for calendar years 1934-1998) from USGS and HDR for the nine basins are compared graphically in Figures A.1 through A.10. Figure A.1 compares the USGS and HDR recharge estimates for Nueces basin with a scatter plot and time series. Figures A.2 through A.7 compare the recharge estimates for the Frio, Sabinal, Sabinal-Medina, Medina, Medina-Cibolo, and Cibolo basins. Figure A.8 shows the yearly HDR recharge estimates for Guadalupe basin only because the USGS has historically assumed that no recharge occurs in the Guadalupe basin and therefore, a direct comparison is not possible. Figure A.9 compares the USGS and HDR recharge estimates for the Blanco basin. Finally, Figure A.10 illustrates the comparison of HDR and USGS estimated recharge (total recharge) for all nine basins.

The graphs show the following patterns. First, in the eight basins compared here, the USGS estimates during “wet” years are usually significantly higher than the HDR estimates. In some cases, the USGS estimate is twice as big as the HDR estimate in wet years. HDR (2002) discuss four reasons why this may occur. Second, HDR estimates are consistently higher in two basins (area between Medina and Cibolo and Cibolo-Comal) except for the years exhibiting the largest recharge. Years exhibiting low recharge for the area between Medina and Cibolo are substantially higher than USGS estimates. Figure A.10 indicates that the total estimated recharge for all nine basins from the HDR method, as compared to the USGS method, is consistently higher in the low-recharge years, and consistently lower in the high-recharge years.

Figure A. 1 Comparison of USGS and HDR Recharge Estimates for the Nueces Basin



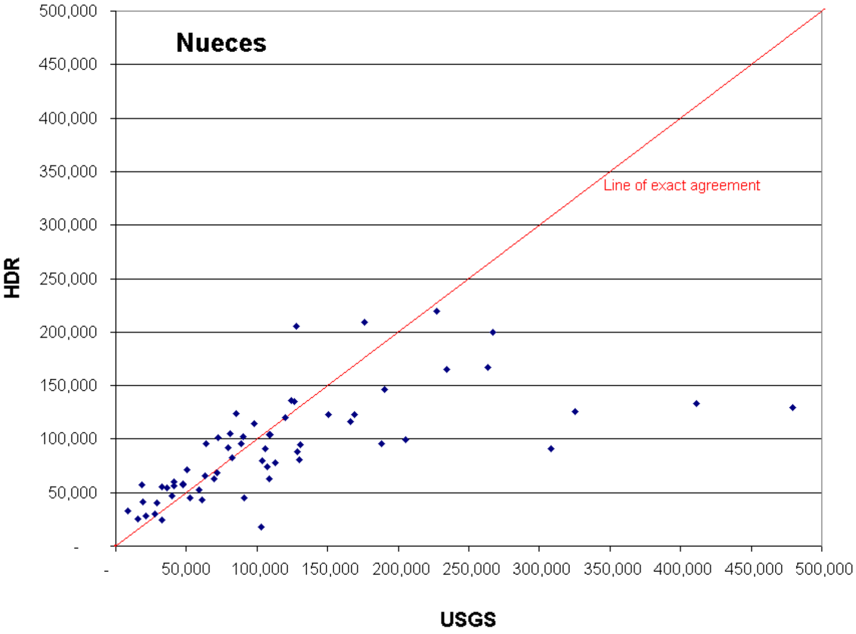
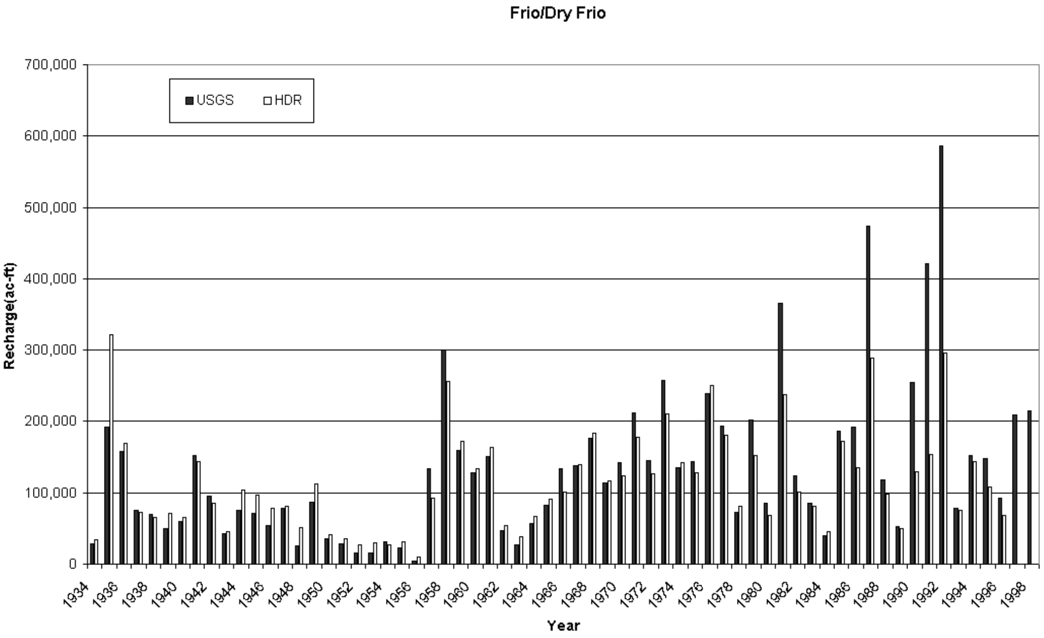


Figure A. 2 Comparison of USGS and HDR Recharge Estimates for the Frio Basin



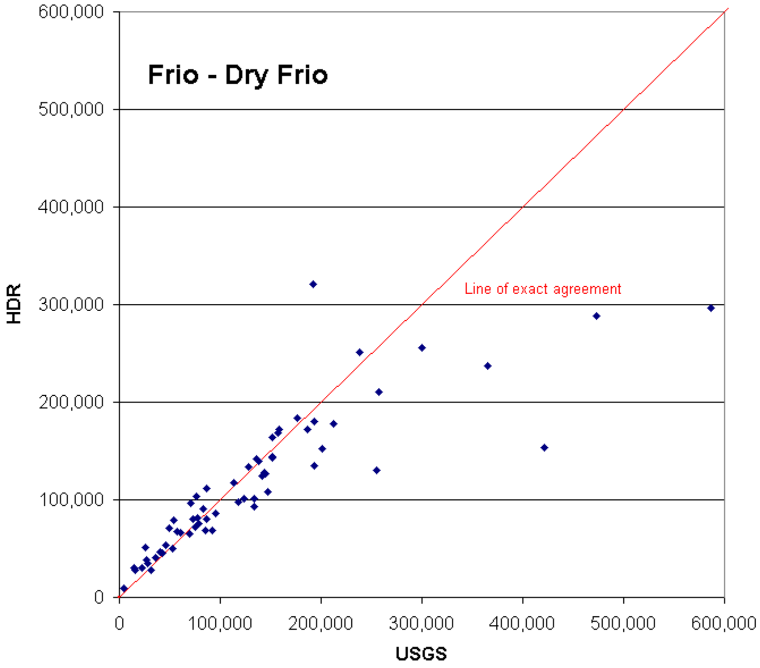
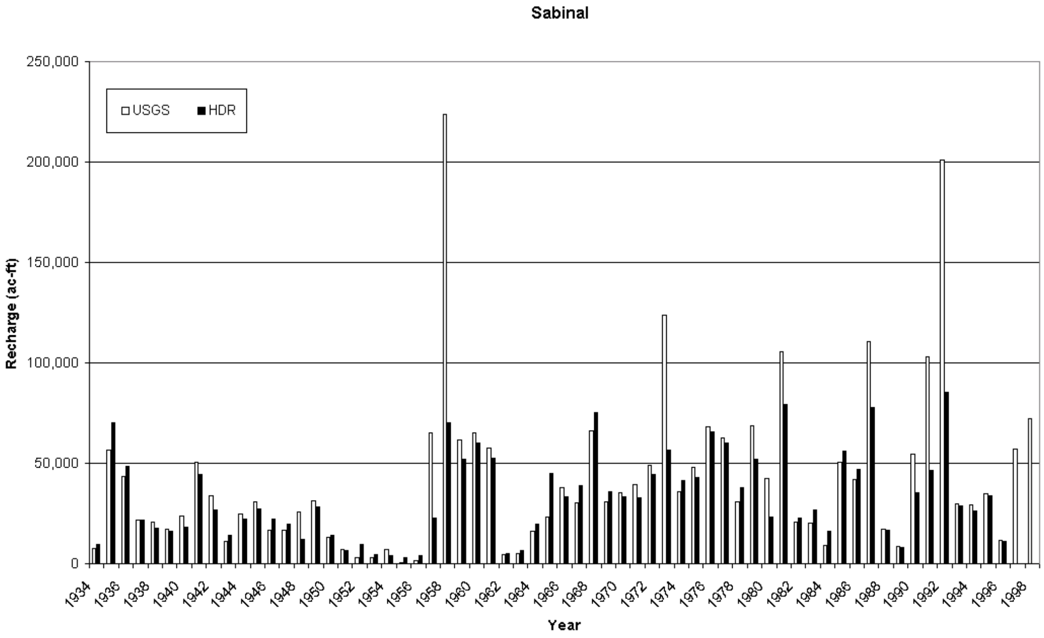


Figure A. 3 Comparison of USGS and HDR Recharge Estimates for the Sabinal Basin



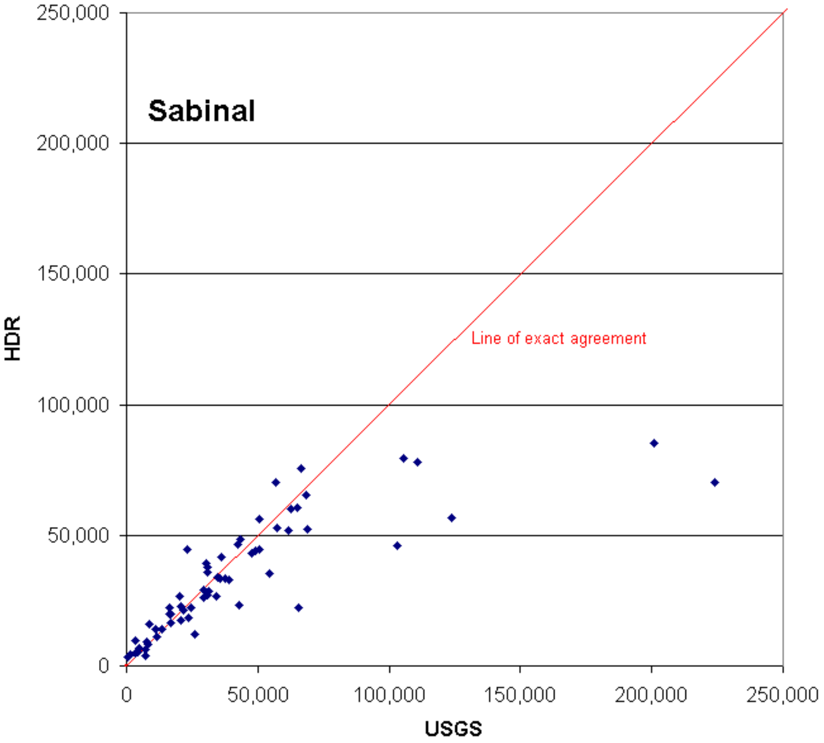
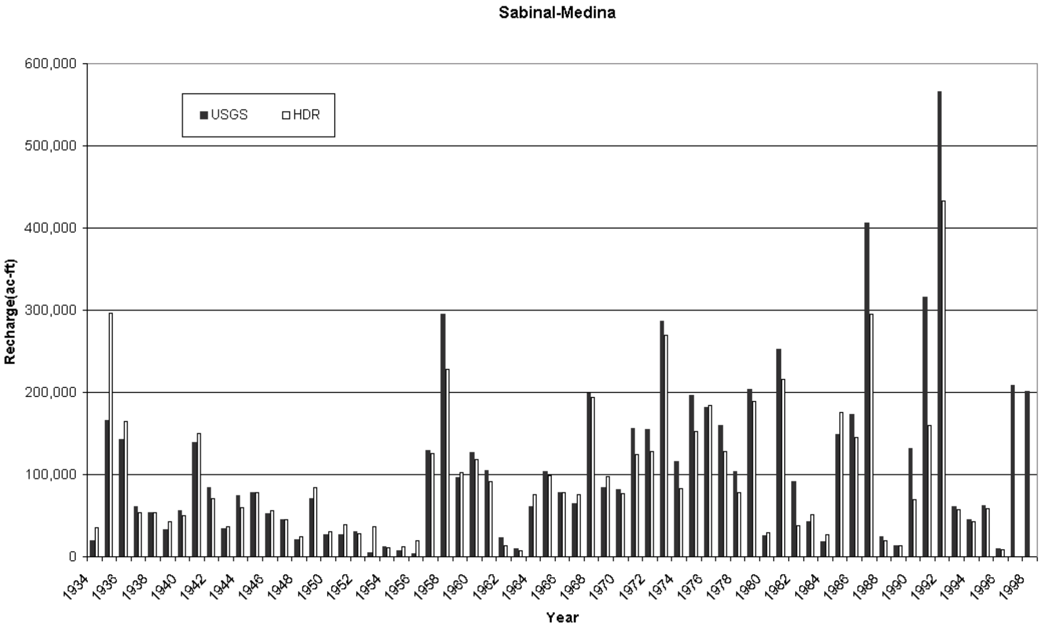


Figure A. 4 Comparison of USGS and HDR Recharge Estimates for the Sabinal-Medina Basin



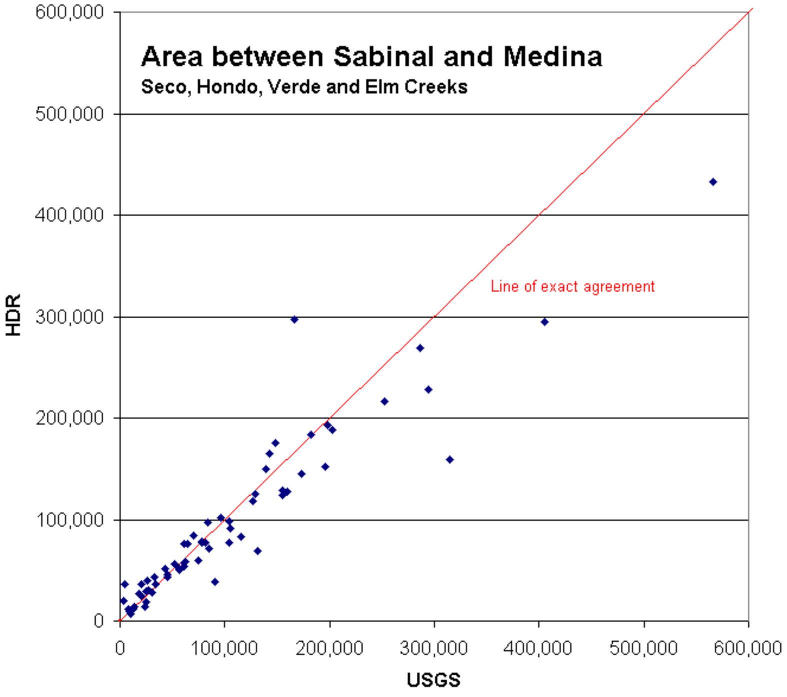
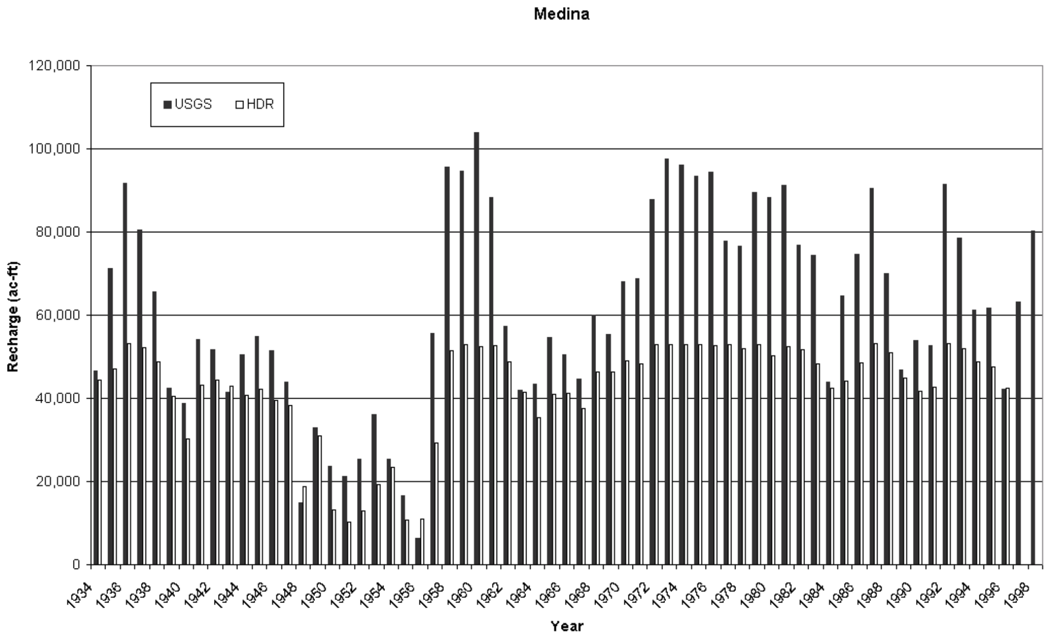


Figure A. 5 Comparison of USGS and HDR Recharge Estimates for the Medina Basin



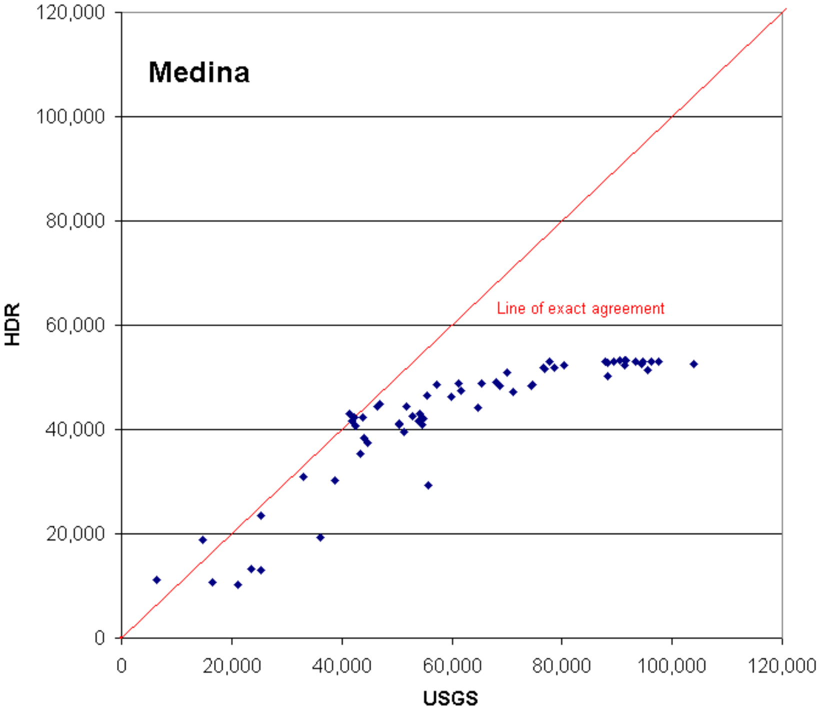
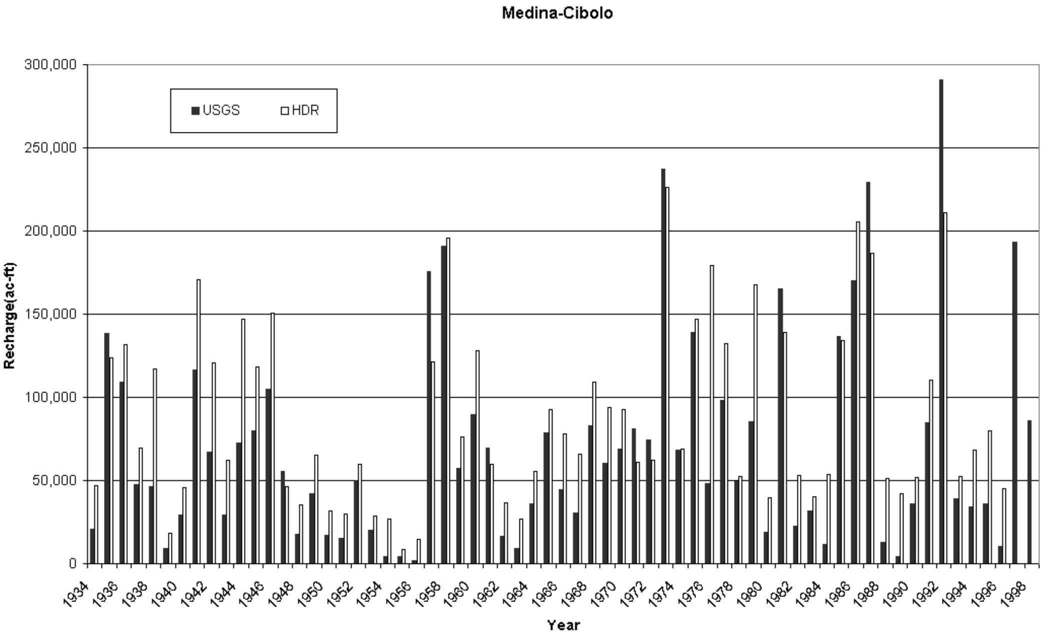


Figure A. 6 Comparison of USGS and HDR Recharge Estimates for the Medina-Cibolo Basin



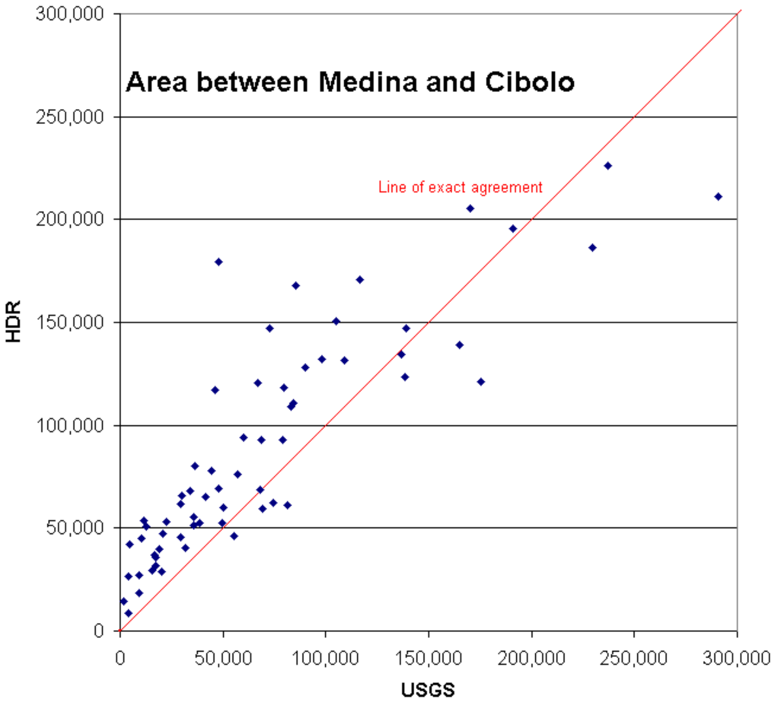
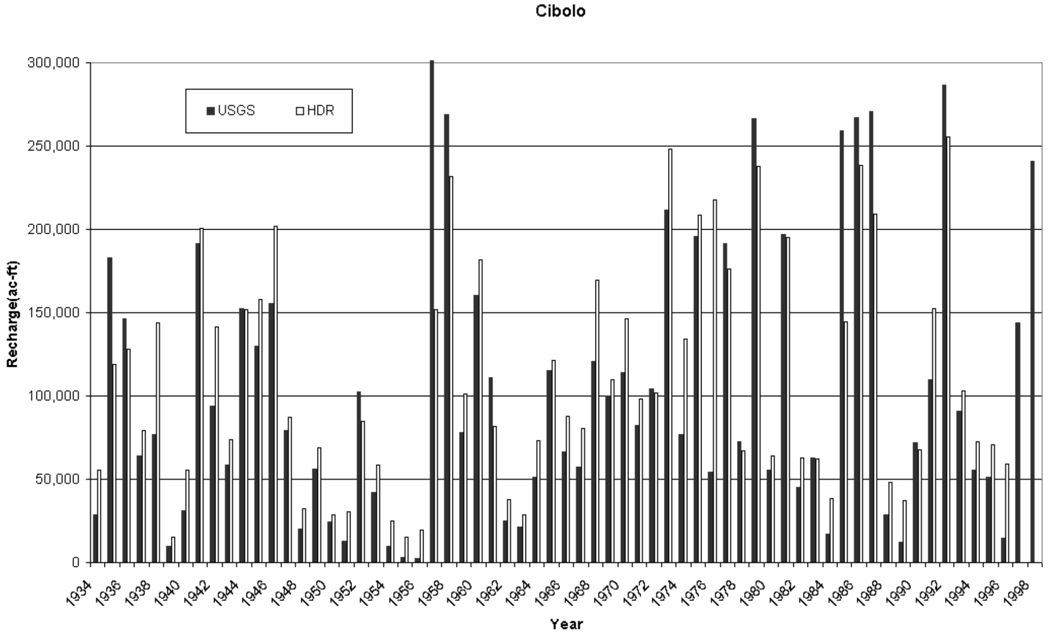


Figure A. 7 Comparison of USGS and HDR Recharge Estimates for the Cibolo Basin



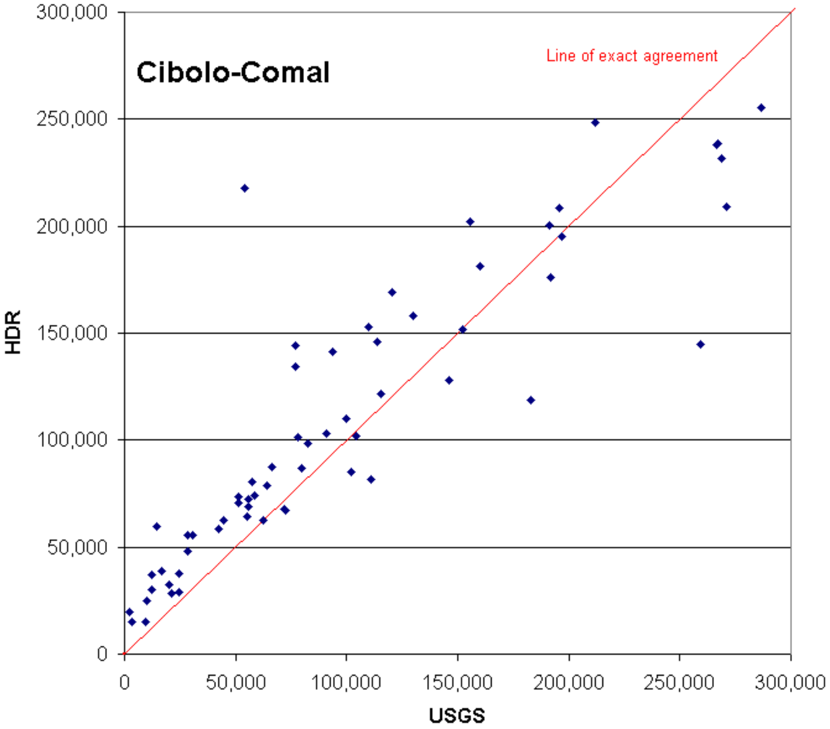


Figure A. 8 HDR Recharge Estimates for the Guadalupe Basin

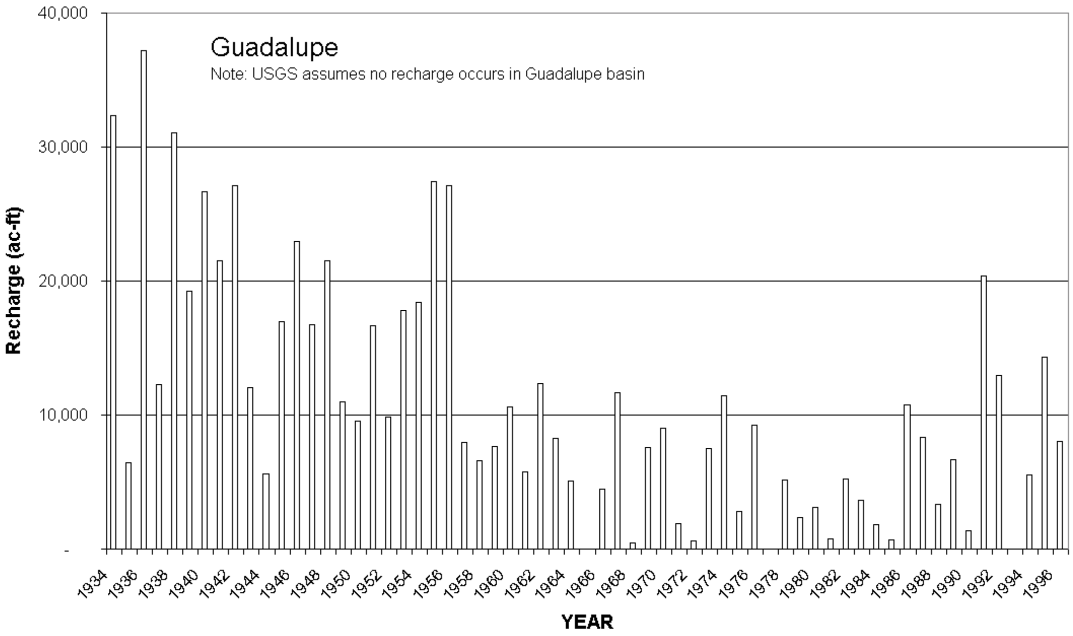
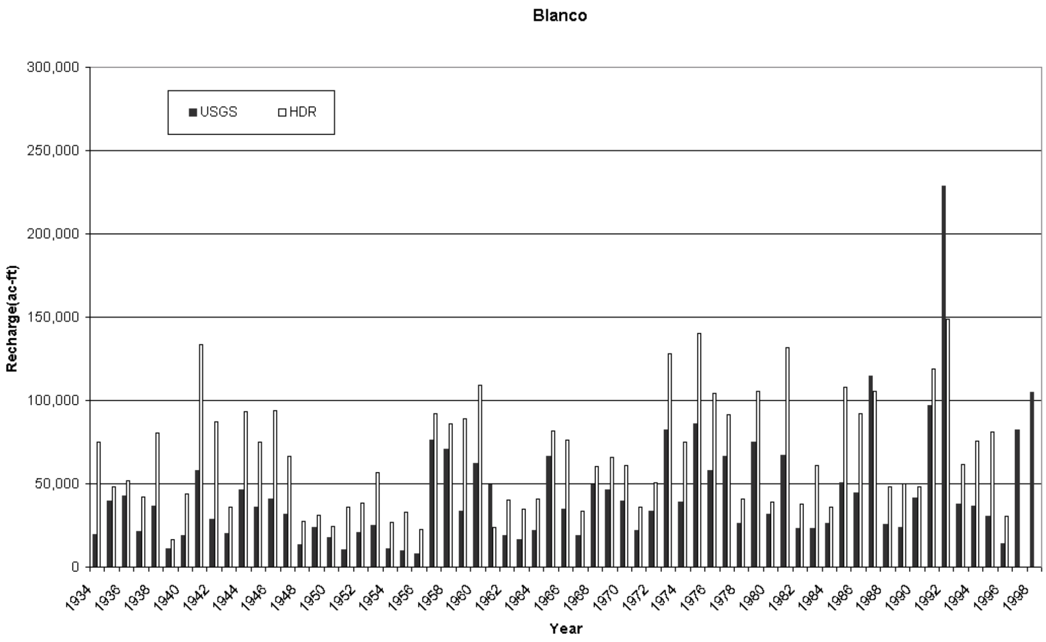


Figure A. 9 Comparison of USGS and HDR Recharge Estimates for the Frio Basin



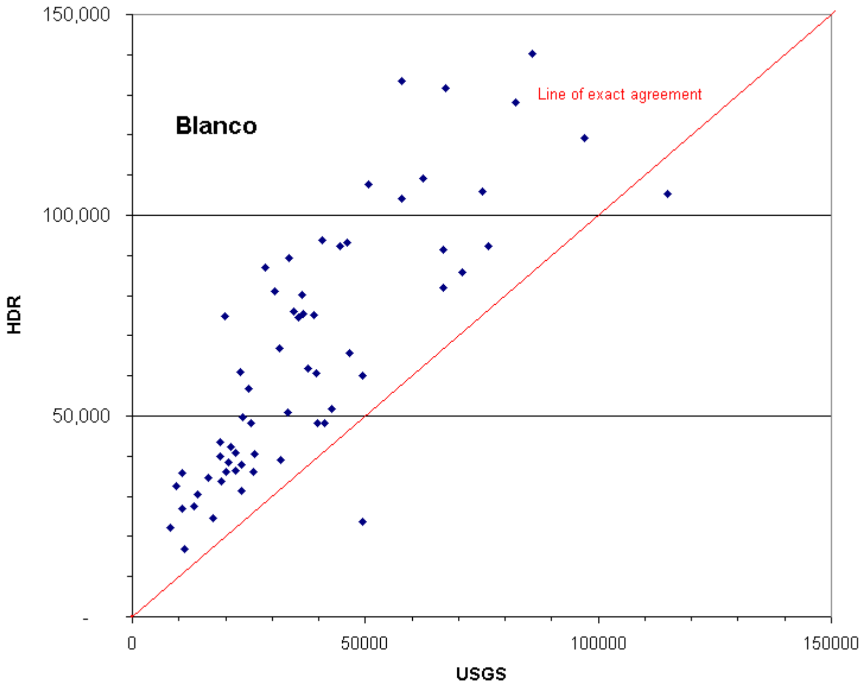
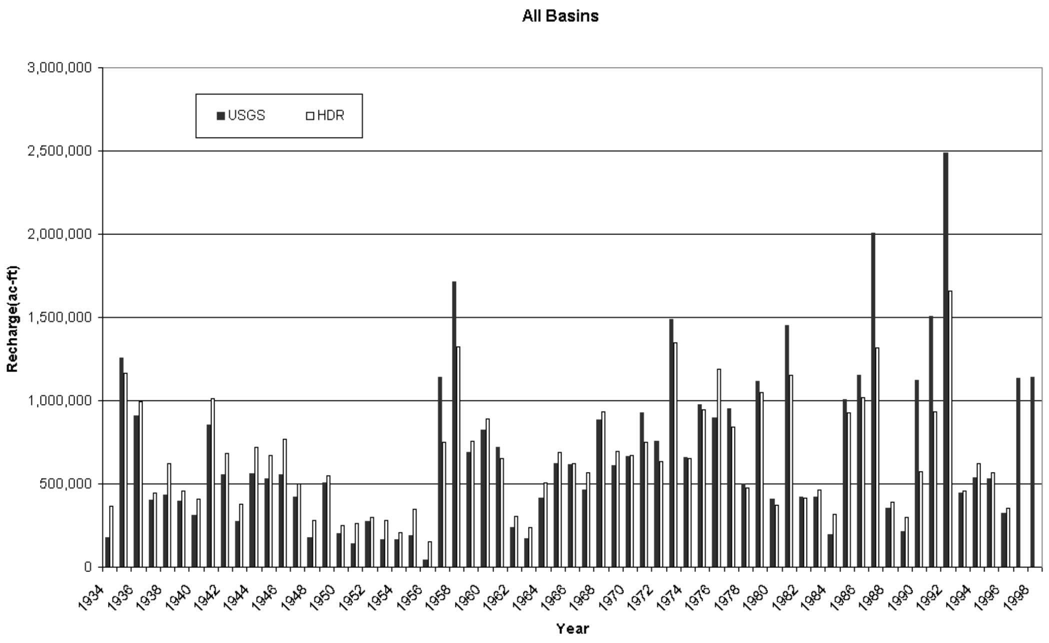
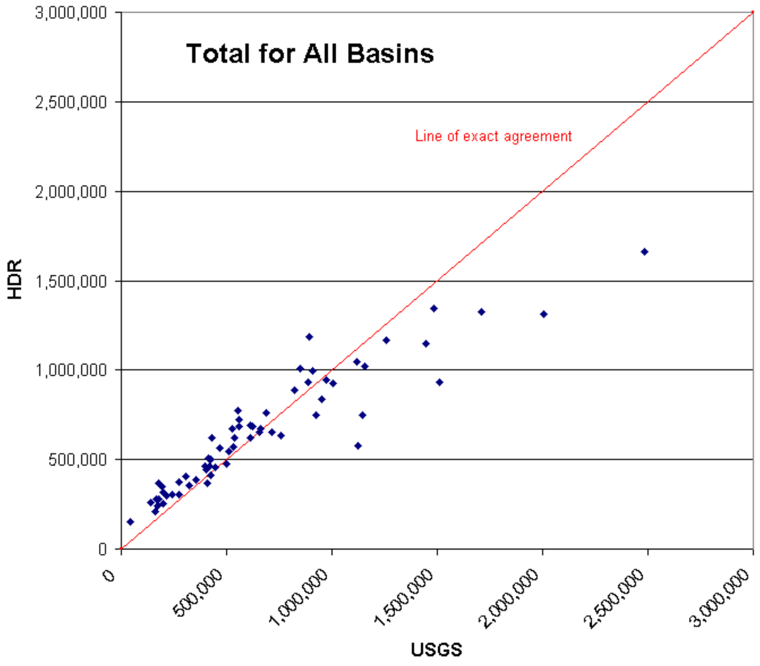


Figure A. 10 Comparison of USGS and HDR Recharge Estimates for all basins





APPENDIX B

Comparison of Pilot Models and Full-Basin HSPF Models

The Nueces and Blanco River Basin pilot models have been reviewed in terms of appropriateness and consistency for simulating the hydrologic processes of the Edwards aquifer and parameters incorporated in the HSPF model. The review focused on differences between the pilot and full basin models and assumptions that may impact the accuracy of the recharge calculations or the predictive capability of the models.

The pilot models provide good tools for estimating daily recharge for the Nueces and Blanco River basins. The models simulate observed flows relatively well given the uncertainties and limitations associated with input data (precipitation, evapotranspiration, etc.). Although the results of the models are very good from the standpoint of matching measured streamflow, there are a few issues regarding implementation of the HSPF model in the seven basins model that will enhance the models and their applicability to assess important issues. Table B.1 identifies differences in the pilot models and, for comparison purposes, how these issues will be addressed in the HSPF models for the seven basins.

Table B. 1 Comparison of Pilot Models and Full Basin Models

Feature or Parameter	**Pilot Models**		**Full basin models**
	Nueces	Blanco	
Contributing Zone	Not included in scope of work	Not included in scope of work	Included
PERLND	Based on geography and precipitation	Based on geography and precipitation	Based on topography, geology, soils, vegetation, precipitation
IRC	Values (0.90) more typical of AGWRC	Values (0.90) more typical of AGWRC	Values in the expected range of 0.30 to 0.70
NSUR	Values low (0.15)	Values low (0.15)	Values in expected range of 0.25 to 0.35
Stream reaches	Too short for 1-day simulation time step (RCHRES 14,15,16)	Too short for 1-day simulation time step (RCHRES 11-16)	Stream channel reach lengths range of 0.3 to 12 miles
Initial value of COLIND	Initial value of COLIND for 2nd exit set to 4.0 (1st exit value)	Initial value of COLIND for 2nd exit set to 4.0 (1st exit value)	Value of COLIND for 2nd exit set to 5.0
AGWETP	AGWETP values set to 0.1	AGWETP values set to 0.2	AGWETP values range from 0.0 to 0.05
Impervious Cover	No impervious land segment	No impervious land segment	Impervious land segment in Salado watershed
Rainfall and evaporation on	Rainfall and evaporation on	Rainfall and evaporation on every	Rainfall and evaporation only on lakes and

Table B. 1 Comparison of Pilot Models and Full Basin Models

Feature or Parameter	Pilot Models		Full basin models
	Nueces	Blanco	
every RCHRES including subsurface (RCHRES 90-97)	every RCHRES including subsurface (RCHRES 90-97)	RCHRES not including subsurface	reservoirs (surface areas not part of PERLND)

PERLND - An application module (of HSPF) that simulates the water quantity and quality processes that occur on a pervious land segment.
IRC - Interflow recession coefficient.
AGWRC - Groundwater recession rate, or ratio of current groundwater discharge to that from 24 hours earlier
NSUR - Manning's n (roughness) for overland flow.
COLIND - Column Index Value, indicating which (pair of) columns in RCHTAB are used to evaluate outflow demand.
RCHTAB - Stage-Volume-Discharge table associated with each RCHRES.
RCHRES - An application module (of HSPF) that simulates the water quantity and quality processes that occur in a reach of open or closed channel or a completely mixed lake.
AGWETP - Fraction of remaining evapotranspiration from active groundwater layer.

The major differences in the pilot HSPF models and the full-basin models are related PERLNDs (pervious land segments) and RCHRESs (stream channel reaches). As described below, PERLNDs should be based on hydrologic factors, such as, soils, geology, and vegetation, in addition to precipitation and evaporation gauge locations.

The sizing of the stream channel reaches (RCHRESs) was inconsistent with the HSPF simulation time step of one day (24 hours). In the pilot models many of the reaches were too short to accurately represent the actual travel time from the upstream end of a reach to the downstream end. Rainfall and evaporation was also included for each RCHRES. This is only appropriate if the stream channel surface area is subtracted from the adjacent PERLND area. Otherwise, for each of these reaches the precipitation and evaporation is double counted. Precipitation and evaporation should not have been included for subsurface reaches, such as pilot study Nueces RCHRESs 90 through 97. These subsurface reaches, by definition, have no surface area on which rain can fall or water can evaporate.