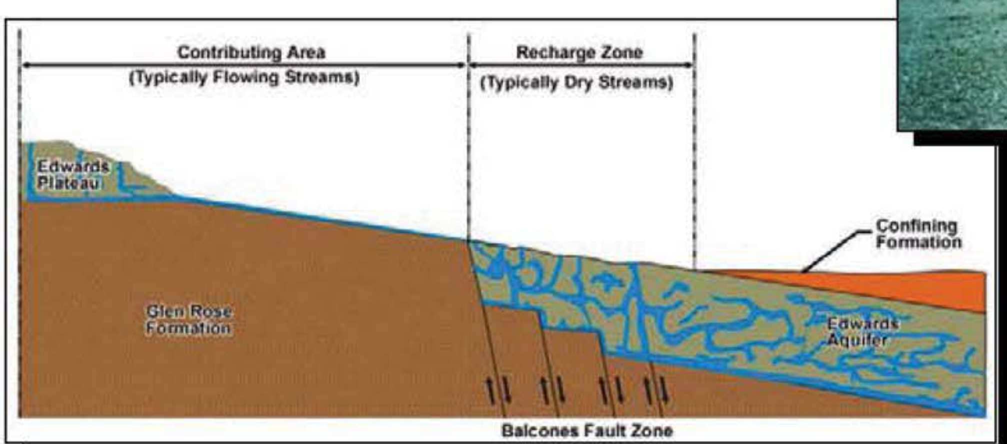
Pilot Recharge Models of the Nueces and Blanco River Basins

EDWARDS AQUIFER AUTHORITY

June 2002



HDR Engineering, Inc.

Pilot Recharge Models of the Nueces and Blanco River Basins

Prepared for:

EDWARDS AQUIFER AUTHORITY

Prepared by:

HDR Engineering, Inc.

June 2002

Pilot Recharge Models of the Nueces and Blanco River Basins

Samuel K. Vaugh, P.E., Vice President
HDR Engineering, Inc.

Angela D. Rodriguez
HDR Engineering, Inc.

R. Brian Perkins
HDR Engineering, Inc.

Table of Contents

Table of Contents (Concluded)

Section **Page**

Appendices

List of Figures

List of Figures (Continued)

List of Figures (Concluded)

List of Tables

Table **Page**

Executive Summary

ES.1 Introduction

Pilot Recharge Models of the Nueces and Blanco River (Recharge) Basins have been developed that provide accurate daily recharge data for use in calibration of the new Edwards Aquifer model presently under development by the U.S. Geological Survey (USGS). These recharge calculation models are based on a water balance approach using numerous hydrologic parameters. Parameters include measured streamflow, precipitation, evaporation, and diversions as well as soil type, antecedent soil moisture conditions, land use, and infiltration/leakage characteristics. The Edwards Aquifer Authority (EAA) has indicated that it would like to develop a single recharge calculation methodology to replace the two presently in use and ensure that this methodology is sufficiently accurate for both regulatory and research purposes. Furthermore, the EAA seeks recharge calculation methods and models sufficiently versatile to quantify enhanced recharge associated with new recharge dams, the precipitation enhancement (weather modification) program, and/or potential brush management initiatives.

Accurate and timely calculation of quantities of water entering the Edwards Aquifer as recharge is a fundamental prerequisite for informed management and regulation of the resource by the EAA. Traditionally, recharge estimates have been calculated by the USGS using methods dating back to the late 1970s[1] and published annually.[2] Alternative estimates of historical Edwards Aquifer recharge for the 1934-1996 period were developed by HDR Engineering, Inc. (HDR) in the course of studies sponsored by the Edwards Underground Water District,[3] Nueces River Authority,[4] and as part of the Trans-Texas Water Program.[5] Under both methods, estimates of Edwards Aquifer recharge have been developed for four recharge basins in the Nueces River Basin and five recharge basins in the Guadalupe - San Antonio River Basin. The

---

[1] USGS, "Method of Estimating Natural Recharge to the Edwards Aquifer in the San Antonio Area, Texas," Water Resources Investigations 78-10, April 1978.

[2] USGS, "Recharge to and Discharge from the Edwards Aquifer in the San Antonio Area, Texas, 1996," http://txwww.cr.usgs.gov/reports/info/97/recharge1/index.html, April, 1997.

[3] HDR, "Guadalupe - San Antonio River Basin Recharge Enhancement Study," Vol. 2, Edwards Underground Water District, September 1993.

[4] HDR, "Nueces River Basin Regional Water Supply Planning Study, Phase I," Vol. 2, Nueces River Authority, et al., May 1991.

[5] HDR, "Edwards Aquifer Recharge Analyses, Edwards Aquifer Recharge Update," Trans-Texas Water Program, West Central Study Area, Phase II, San Antonio River Authority, et al., March 1998.

Nueces and Blanco Recharge Basins, selected for development of pilot recharge models, are identified in Figure ES-1.

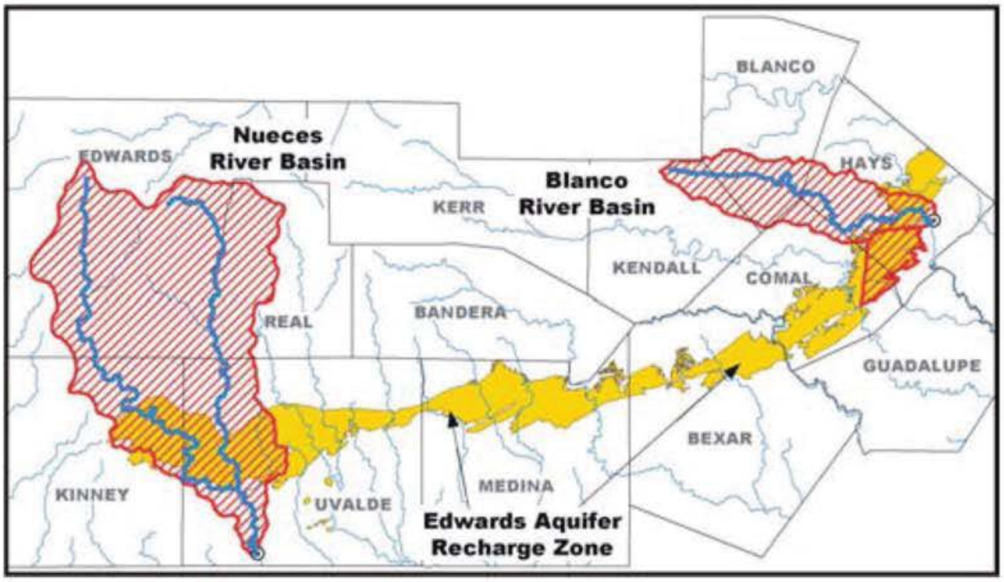


Figure ES-1. Pilot Recharge Basin Location Map

ES.2 Recharge Basins

The Nueces Recharge Basin is the westernmost area that contributes recharge to the San Antonio portion of Edwards Aquifer. The watershed area has steep slopes and thin soils and is mostly rangeland with some juniper, mesquite, and live oak forestation. The total inflow available for recharge includes all flow that passes the gauging stations on the Nueces River at Laguna (USGS# 08190000), the West Nueces River near Brackettville (USGS# 08190500), and runoff from the intervening watershed area between these two upper gauges and the gauging station on the Nueces River below Uvalde (USGS# 08192000). This intervening area is subdivided as shown in Figure ES-2 on the basis of geologic characteristics (i.e., aquifer contributing zone, recharge zone, and confined zone) and observed streamflow loss rates. The 430 square mile intervening watershed area is simulated in the pilot recharge model using eight land segments and seven river reaches, with the river reaches being defined in accordance with measurement points in an intensive streamflow loss survey conducted by the USGS.[6]

[6] USGS, "Streamflow Losses along the Balcones Fault Zone, Nueces River Basin, Texas," Report 83-4368, 1983.

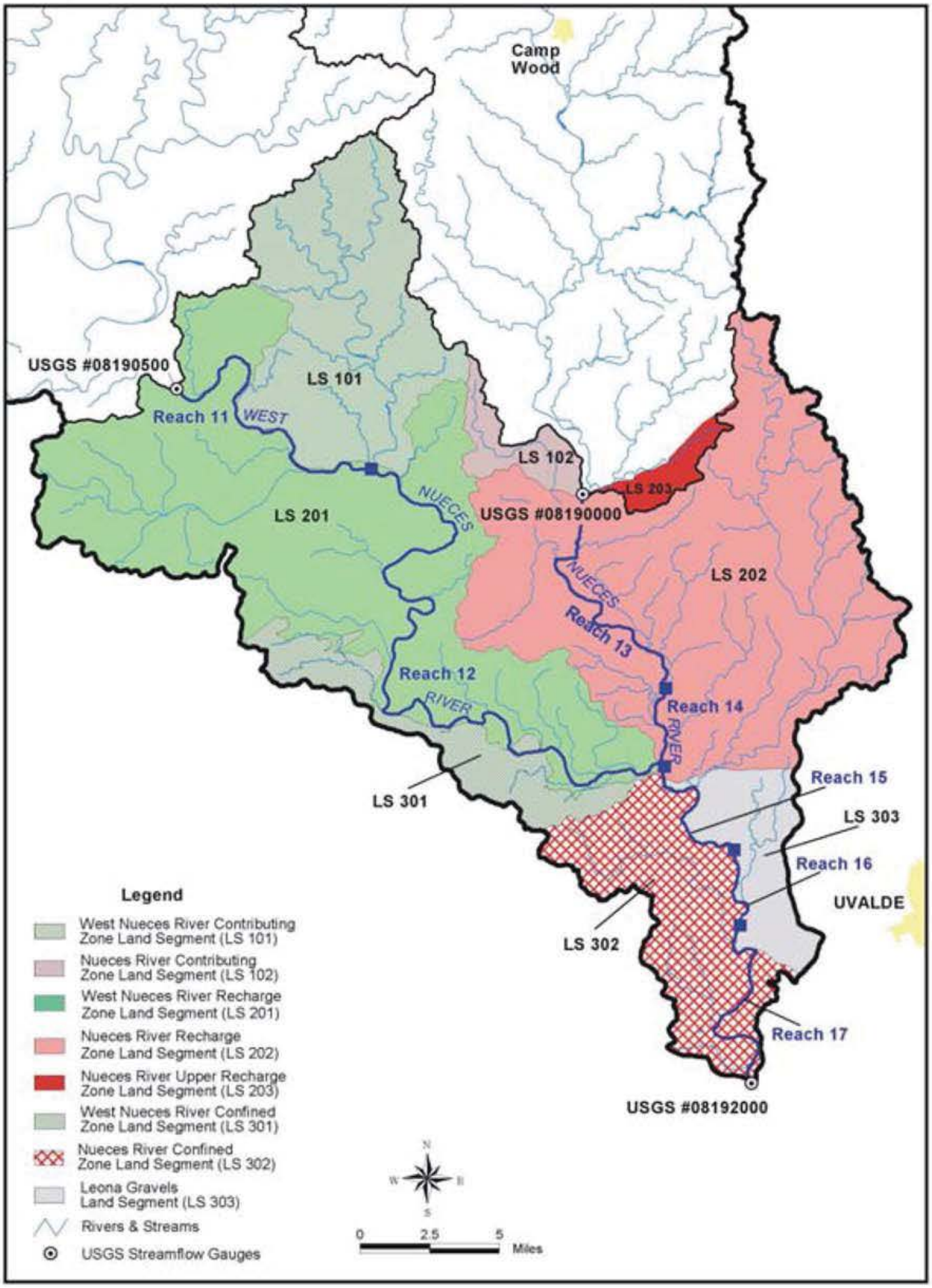


Figure ES-2. Land Segments and River Reaches in the Nueces Recharge Basin

The Blanco Recharge Basin is the easternmost basin that contributes recharge to the central portion of the Edwards Aquifer and sustains discharge from San Marcos Springs. The headwaters of the Blanco River lie in the Texas Hill Country and the river eventually flows to the Guadalupe Estuary via the San Marcos and the Guadalupe Rivers. The topography is classified as rocky with rolling hills and limestone outcrops, and the land is primarily used for ranching. Nearby cities include San Marcos and Kyle, both of which are downstream of the Edwards Aquifer outcrop. The Blanco River begins flowing over the Edwards Aquifer outcrop below the gauging station at Wimberley (USGS# 08171000) and exits the outcrop area just above the gauging station near Kyle (USGS# 08171300). The Wimberley and Kyle gauging stations have watershed areas of 355 square miles and 412 square miles, respectively. The intervening drainage area of 57 square miles is simulated in the pilot recharge model as three land segments and five river reaches as illustrated in Figure ES-3. Delineation of the Blanco River reaches is based, in part, upon channel loss surveys conducted by the Texas Board of Water Engineers.[7]

Traditionally, the watersheds of Sink, Purgatory, Alligator, and York Creeks over the Edwards Aquifer recharge zone have been modeled as part of the Blanco Recharge Basin as they are similar in topography, geology, and soil cover complex to the intervening drainage area between the Wimberley and Kyle gauges on the Blanco River. These watersheds are modeled as four land segments (Figure ES-3) and seven river reaches representative of seven existing flood retardation structures, which also serve to enhance Edwards Aquifer recharge.

ES.3 Pilot Recharge Models

The pilot recharge models for the Nueces and Blanco Recharge Basins use the Hydrologic Simulation Program-Fortran (HSPF) Release 11[8] to calculate daily recharge to the Edwards Aquifer. HSPF is based upon the Stanford Watershed Model developed in the late 1950s and includes significant enhancements and refinements completed during the last four

[7] Texas Board of Water Engineers, "Channel Gain and Loss Investigations, Texas Streams, 1918-1958," Bulletin 5807 D, April 1960.
[8] USGS, "Hydrologic Simulation Program – FORTRAN User's Manual for Release 11," September 1996.

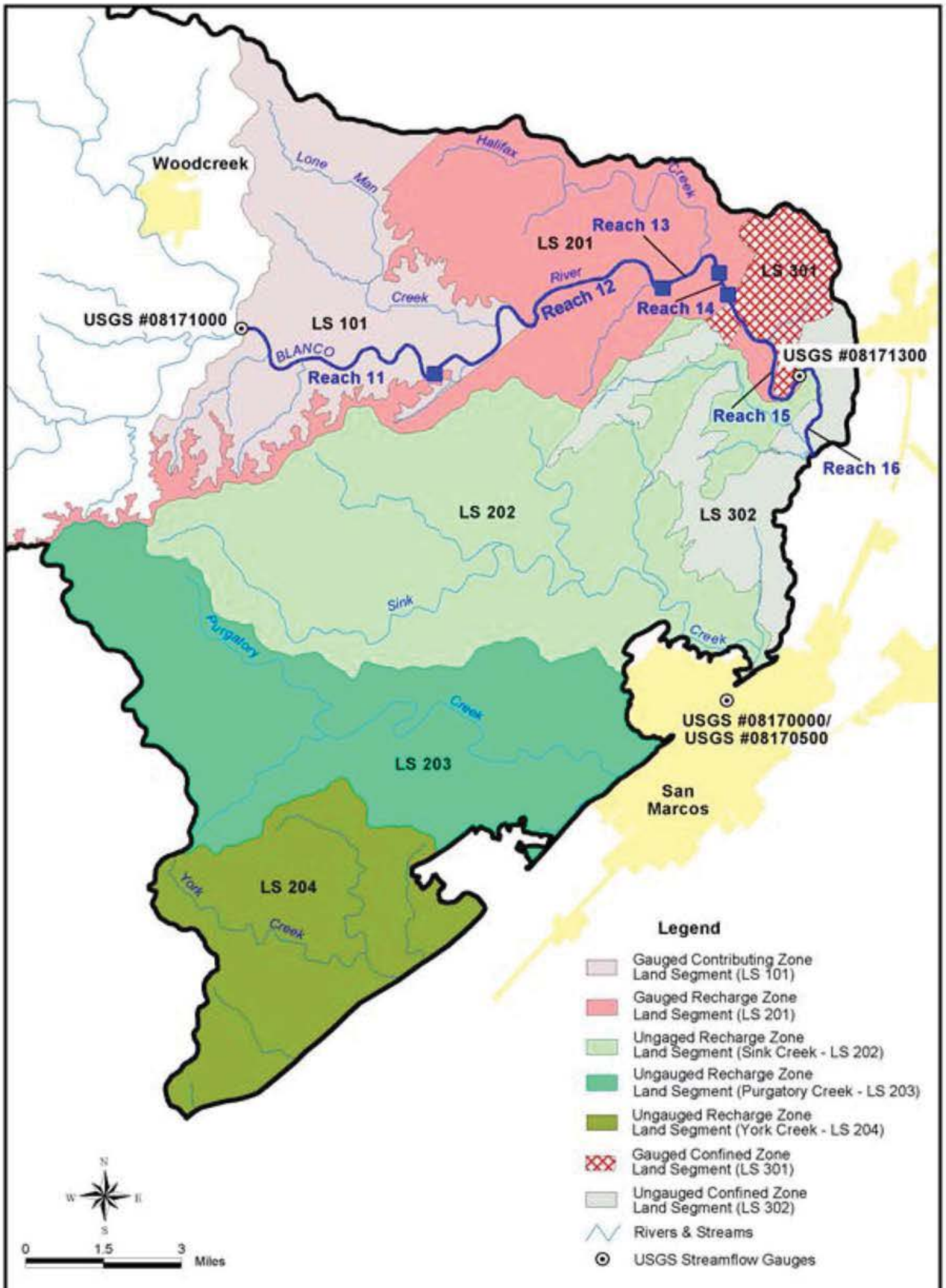


Figure ES-3. Land Segments and River Reaches in the Blanco Recharge Basin

decades. These enhancements and refinements include the development of a FORTRAN version incorporating several related models in the 1970s as well as development of pre-processing and post-processing software, algorithm enhancements, and use of the USGS Watershed Data Management (WDM) system. The pilot recharge models of the Nueces and Blanco Recharge Basins employ the hydrologic and hydraulic routines (modules) within HSPF to translate daily upstream flow, rainfall, and evaporation into recharge and downstream flow by simulation of interception, overland flow, infiltration, evapo-transpiration, shallow storage, deep percolation, and other hydrologic processes.

Key hydrologic parameters varied in calibration of the pilot recharge models were generally associated with infiltration rates and storage capacities at and below the ground surface, hydraulic routing factors, and evapo-transpiration indices for deep-rooted vegetation. The inter-relationships between and order of consideration of these key hydrologic parameters within the overall HSPF computational structure defined for the pilot recharge models is summarized in Figure ES-4. Calibration was accomplished through adjustment of these and other appropriate hydrologic parameters in HSPF to ensure that the models provide results consistent with available historical information including gauged streamflow immediately downstream of the recharge zone and traditional recharge estimates.

The primary and most direct measure of model calibration is the ability to replicate daily, monthly, and annual gauged streamflow volumes immediately downstream of the Edwards Aquifer recharge zone, particularly during stormflow recession and extended drought periods. Gauged streamflow series used for calibration include those for the Nueces River below Uvalde (USGS# 08192000) and the Blanco River near Kyle (USGS# 08171300). Figures ES-5 through ES-8 illustrate that the HSPF pilot recharge models are quite capable of accurately simulating both daily and annual streamflow at these locations. While these streamflow comparisons provide valuable information with respect to simulation of watershed response to rainfall, they do not specifically address the relative proportions of rainfall that do not appear as runoff, but are fated to recharge, evapo-transpiration, and/or transient storage. However, as simulation of streamflow and recharge are both most sensitive to evapo-transpiration from the near-surface strata, well-calibrated estimates of streamflow are indicative of sound estimates of recharge.

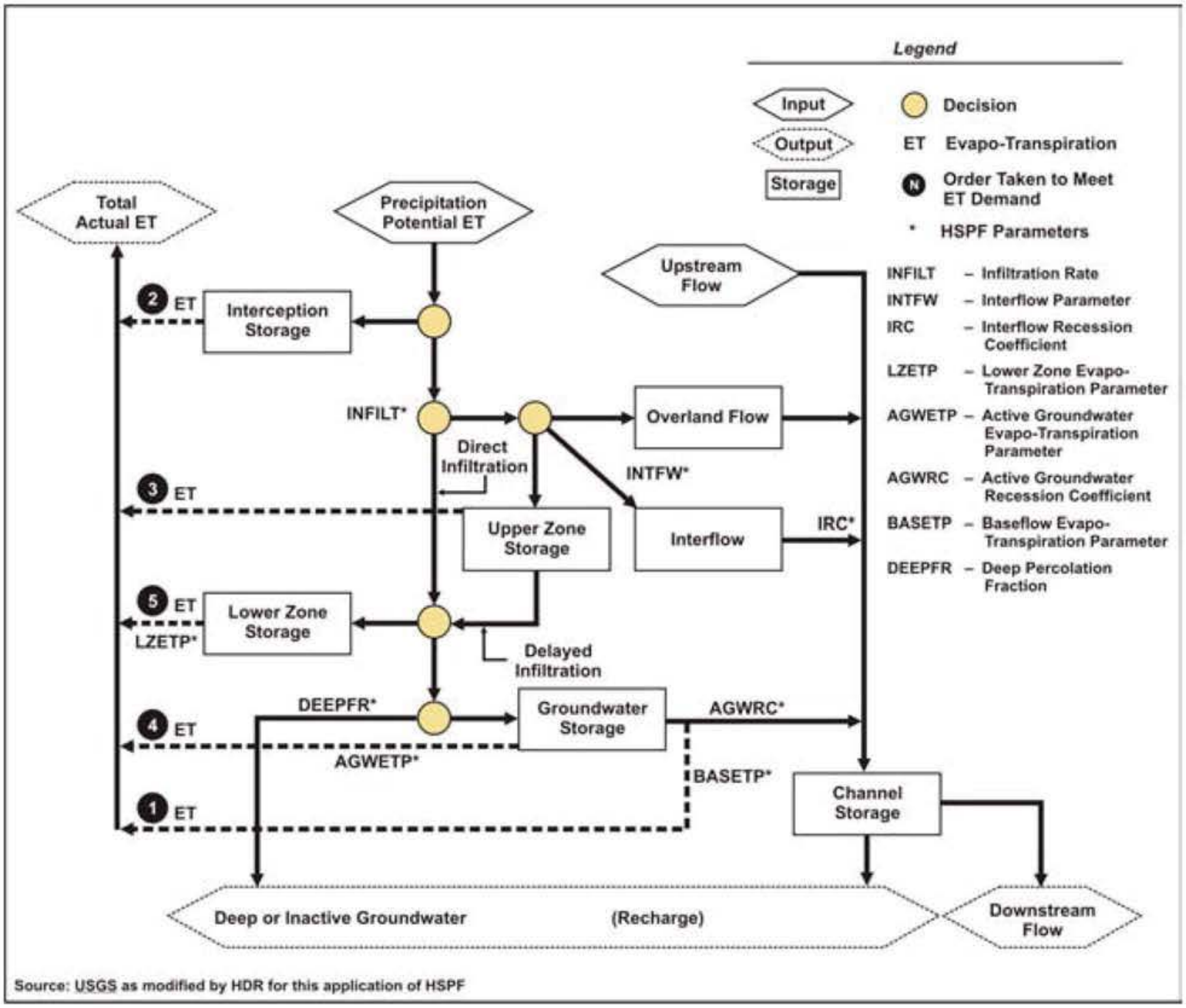


Figure ES-4. HSPF Computational Structure and Key Hydrologic Parameters for Pilot Recharge Model

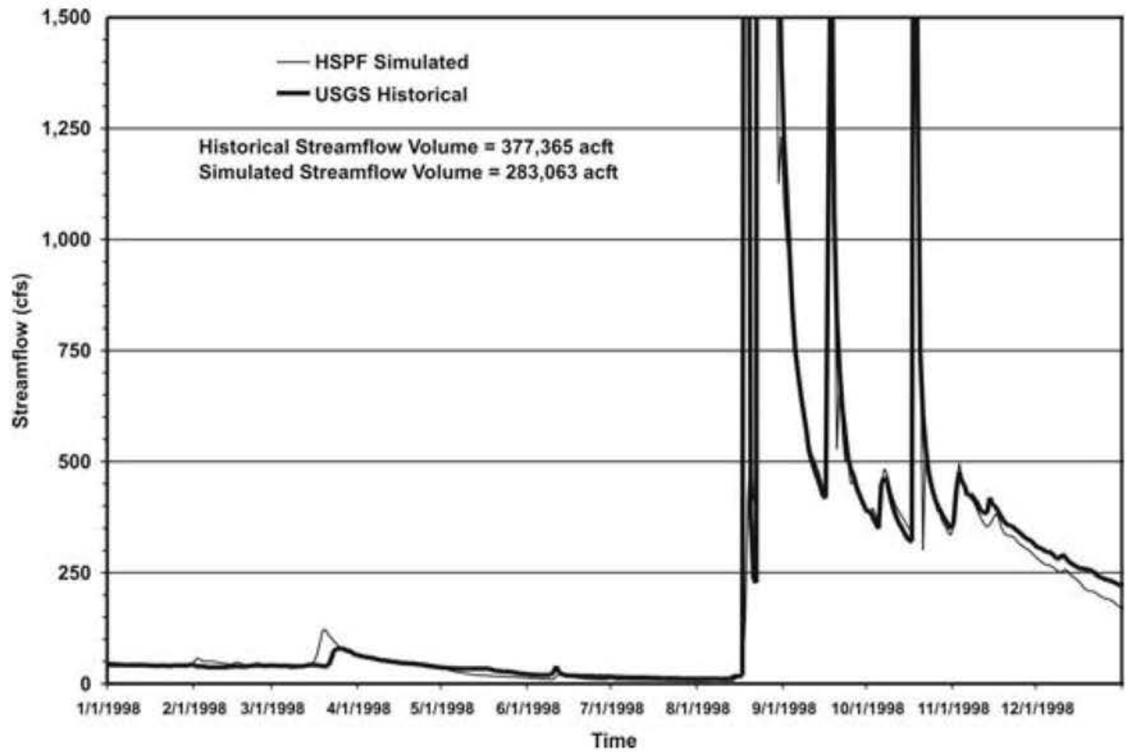


Figure ES-5. Nueces River @ Uvalde — Streamflow Comparison (1998)

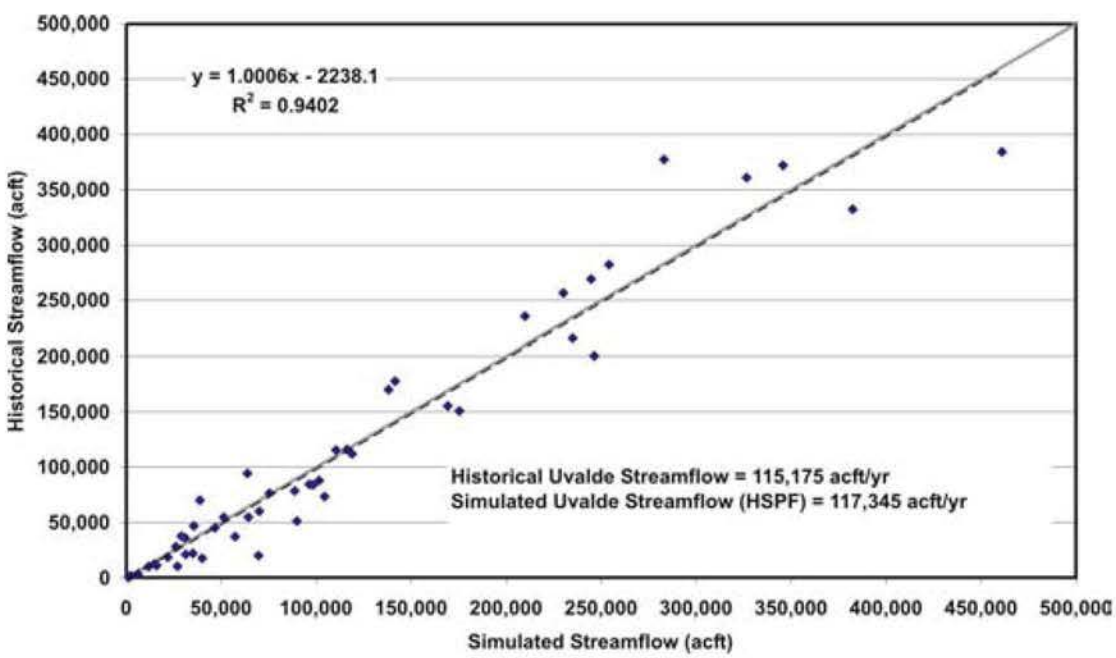


Figure ES-6. Nueces River @ Uvalde — Streamflow Comparison (1950 – 1998)
(1955 not Included in Calibration Analyses)

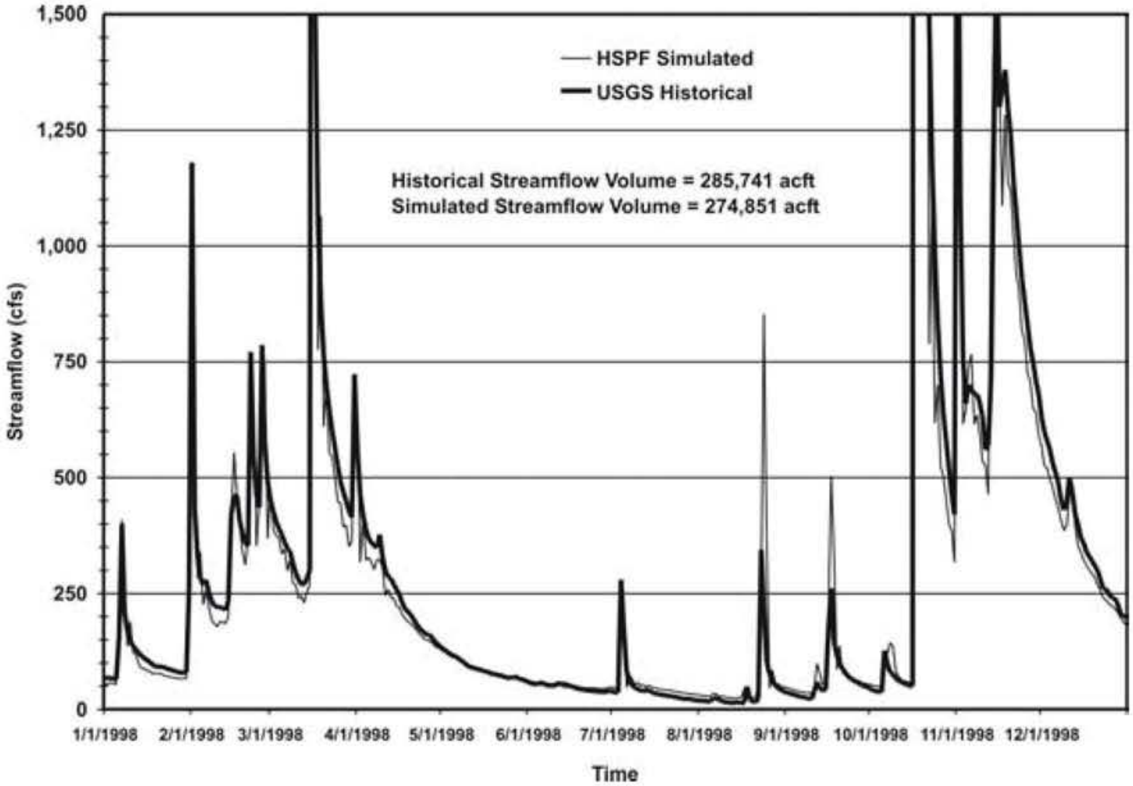


Figure ES-7. Blanco River @ Kyle — Streamflow Comparison (1998)

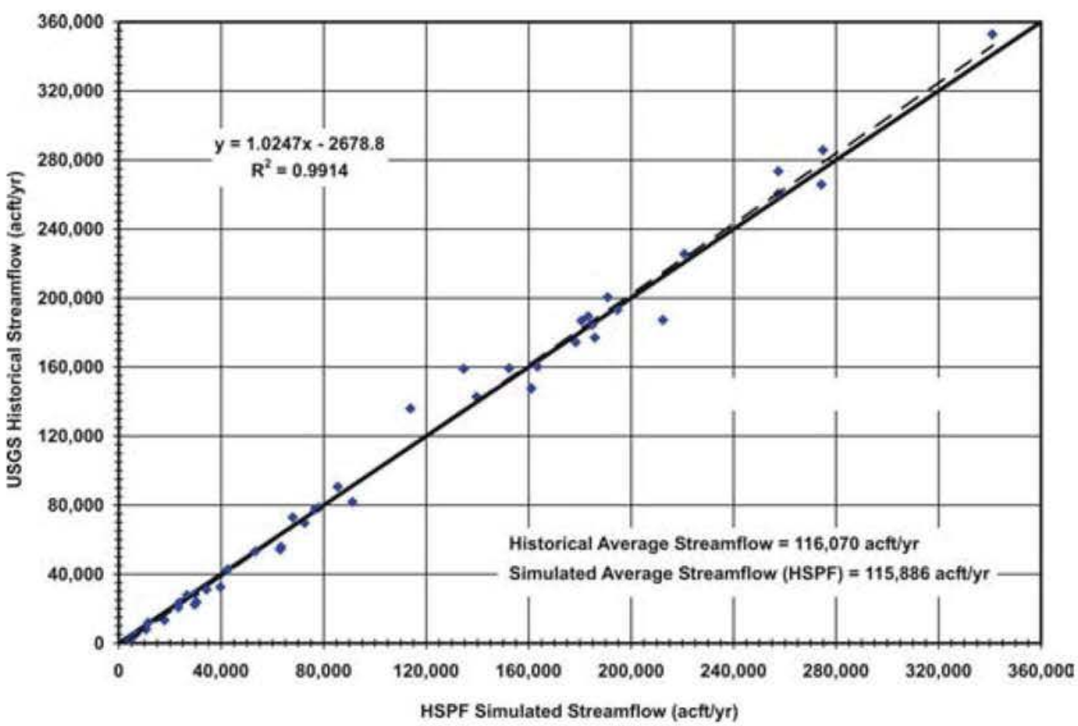


Figure ES-8. Blanco River @ Kyle — Streamflow Comparison (1956 – 1998)

Figures ES-9 and ES-10 illustrate the long-term average overall water balance for the Nueces and Blanco Recharge Basins, respectively. These figures are based on pilot recharge model application results, including both land segments and river reaches, for the entire simulation periods. The pilot recharge models produce estimates of historical Edwards Aquifer recharge that are consistent with traditional methods and with relevant research studies focused upon the Edwards (Balcones Fault Zone), Edwards Plateau, and Trinity Aquifers.

ES.4 Conclusions

Pilot Edwards Aquifer recharge calculation models of the Nueces and Blanco River (Recharge) Basins have been completed in the Hydrologic Simulation Program – Fortran (HSPF). In a manner consistent with Edwards Aquifer Authority (EAA) objectives, the pilot recharge models retain the strengths and overcome the weaknesses of traditional recharge calculation methods while providing versatile tools sufficiently accurate for both regulatory and research purposes. Specific advantages of these models over traditional methods include the following:

(1) Use of a water balance approach integrating many relevant hydrologic parameters including measured streamflow, precipitation, evaporation, and diversions as well as soil type, antecedent moisture conditions, land use, and interception/infiltration/evapo-transpiration characteristics.

(2) Computation of recharge on a daily, rather than monthly, timestep through direct simulation of watershed response to daily precipitation and streamflow inputs.

(3) Provision for geographical distribution of recharge into specified land segments and river reaches on the outcrop of the Edwards Aquifer.

(4) Ability to quantify effects of changes in watershed characteristics (dam construction, brush management, land development) and/or climatological influences (weather modification) on aquifer recharge.

(5) Limited capability to approximate inter-formational transfer of groundwater from the Edwards Plateau and Trinity Aquifers that contributes to Edwards Aquifer recharge.

Application of the pilot recharge model of the Nueces River (Recharge) Basin for the 1950 through 1998 historical simulation period results in the annual recharge estimates shown in Figure ES-11 and a long-term average recharge of 117,280 acft/yr. Similarly, application of the pilot recharge model of the Blanco River (Recharge) Basin for the 1956 through 1998 historical

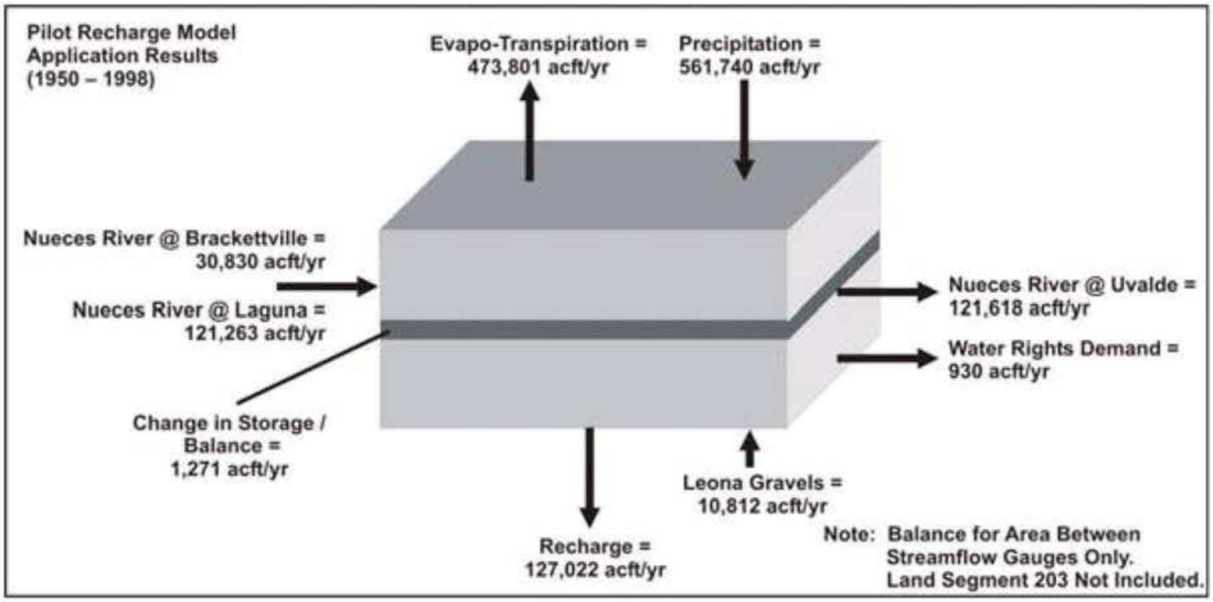


Figure ES-9. Nueces Recharge Basin — Overall Water Balance

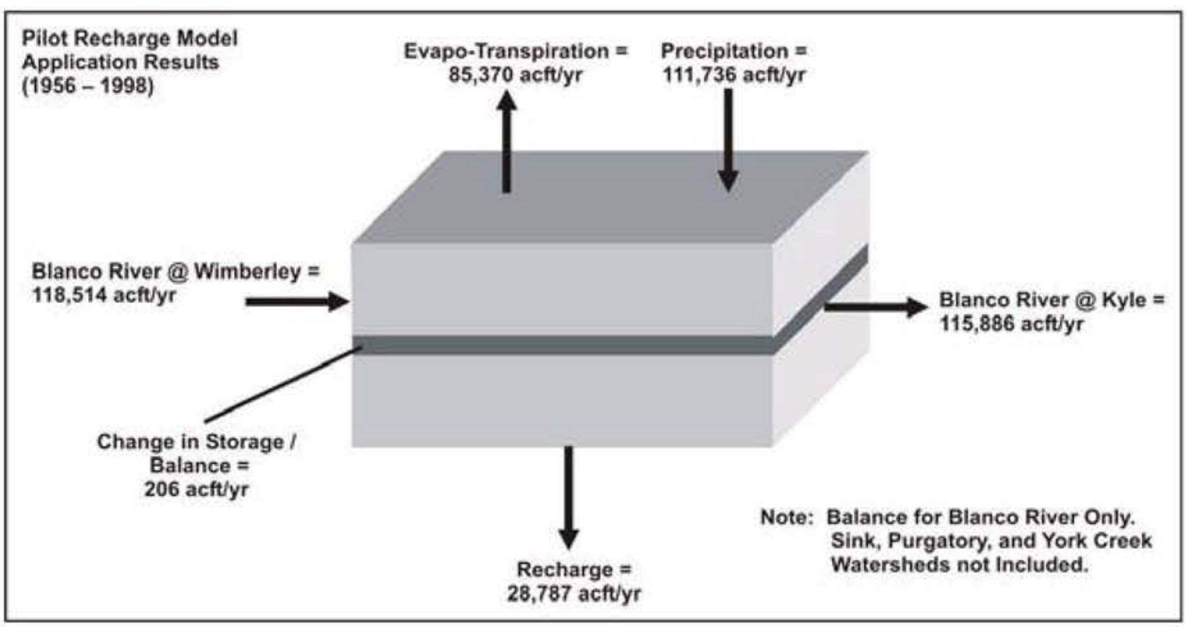


Figure ES-10. Blanco Recharge Basin — Overall Water Balance

simulation period results in the annual recharge estimates shown in Figure ES-12 and a long-term average recharge of 74,491 acft/yr. For comparable historical periods ending in 1996, Figure ES-13 compares long-term average recharge rates from the pilot recharge models to those based on traditional HDR and USGS methods. It is apparent in Figure ES-13 that Edwards Aquifer recharge derived by application of the pilot recharge models more closely approximates traditional USGS estimates in the Nueces Recharge Basin and traditional HDR estimates in the Blanco Recharge Basin.

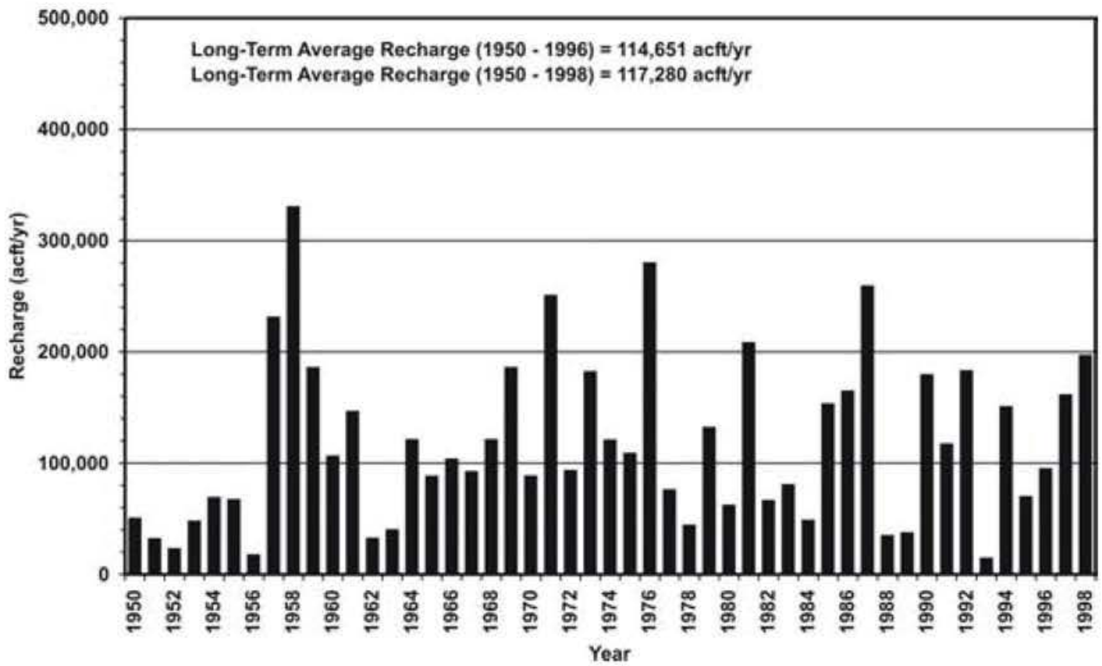


Figure ES-11. Historical Edwards Aquifer Recharge from the HSPF Pilot Recharge Model of the Nueces River (Recharge) Basin

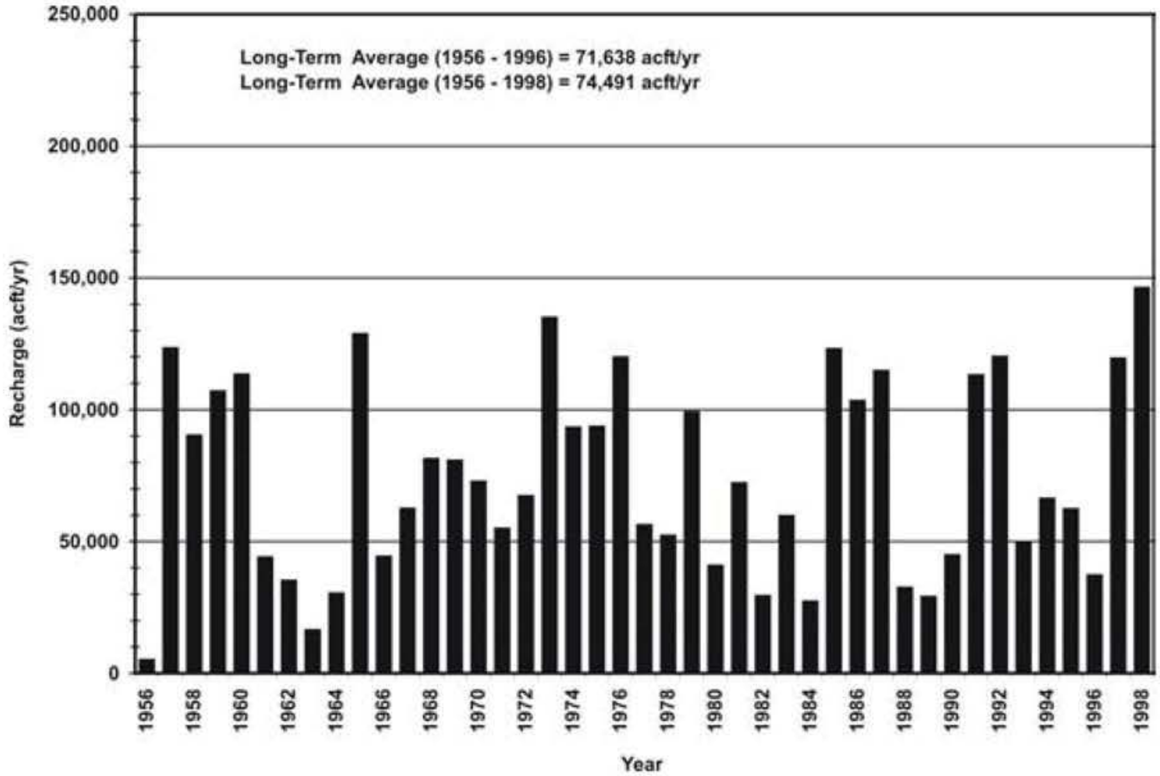


Figure ES-12. Historical Edwards Aquifer Recharge from the HSPF Pilot Recharge Model of the Blanco River (Recharge) Basin

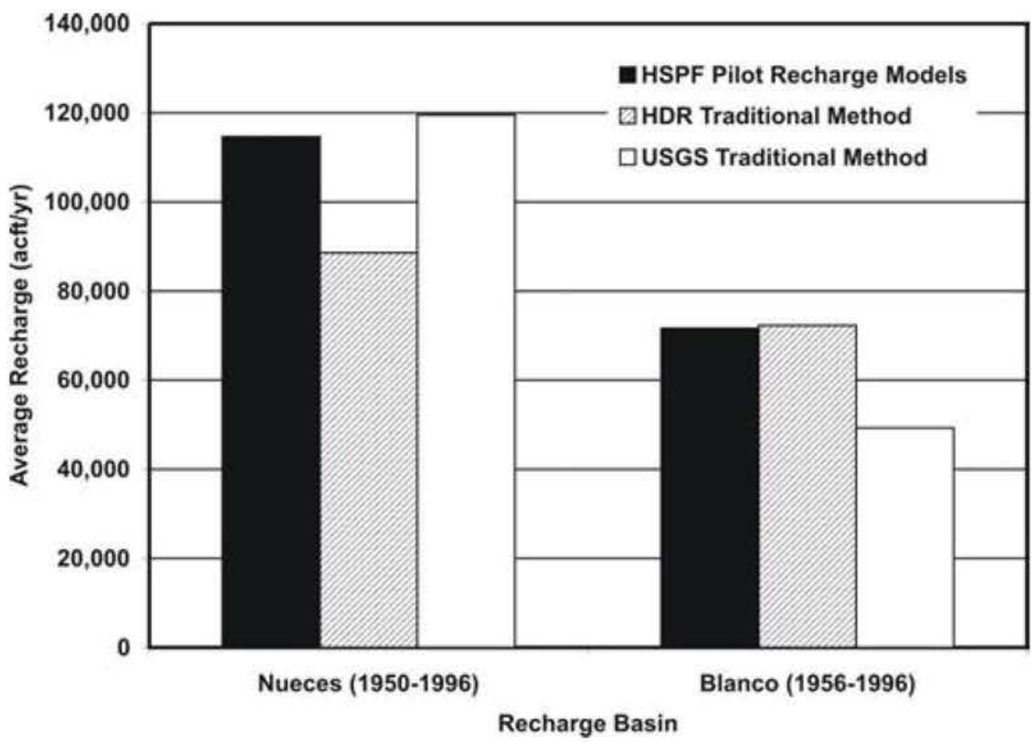


Figure ES-13. Long-Term Average Edwards Aquifer Recharge Comparison

ES.5 Recommendations

Following are recommendations based upon the development, calibration, and application of pilot recharge models of the Nueces and Blanco River (Recharge) Basins:

(1) Traditional estimates of historical Edwards Aquifer recharge in the Nueces and Blanco River (Recharge) Basins should be revised to those obtained through application of the calibrated pilot recharge models. Future annual or more frequent updates of Edwards Aquifer recharge estimates for these basins should be obtained through application of the pilot recharge models.

(2) Similar recharge models of the remaining seven recharge basins should be completed in the near future in order to ensure that the best possible estimates of historical recharge are available for final calibration of the new Edwards Aquifer model presently under development.

(3) Though it is a complex and technically challenging model, HSPF has proven to be quite capable of accurately simulating the hydrologic processes governing streamflow and recharge at the outcrop of the Edwards Aquifer. HSPF is, therefore, recommended for use in creating recharge models for the remaining seven recharge basins.

(4) Parameter selection and calibration of the pilot recharge models for the Nueces and Blanco Recharge Basins should be reviewed for regional consistency upon completion of comparable recharge models for the remaining seven recharge basins.

(5) Future incorporation of data from the EAA precipitation network and/or Nexrad Doppler radar systems will significantly improve estimates of areal precipitation (and recharge) in the Nueces and Blanco Recharge Basins as there are presently no National Weather Service stations located in the watersheds over the Edwards outcrop.

(6) Consideration should be given to more explicitly modeling the contributing areas upstream of the streamflow gauging stations on the Nueces River at Laguna, West Nueces River near Brackettville, and Blanco River at Wimberley. While direct use of the gauged streamflow records is appropriate for basic Edwards Aquifer recharge calculations, modeling could facilitate improved assessment of the potential effects of weather modification and/or brush management in these contributing areas on Edwards Aquifer recharge.

Section 1
Introduction

The Edwards Aquifer Authority (EAA) has developed *Pilot Recharge Models of the Nueces and Blanco River Basins* with the key objective of creating daily recharge calculation models that will provide accurate data for calibration and application of the new Edwards Aquifer simulation model presently under development by the U.S. Geological Survey (USGS). The EAA has emphasized that this recharge calculation model must be based on a water balance approach using as many relevant hydrologic parameters as feasible. Such relevant parameters include measured streamflow, precipitation, evaporation, and diversions as well as soil type, antecedent soil moisture conditions, land use, and infiltration/leakage characteristics. The EAA has indicated that it would prefer a single recharge calculation methodology to replace the two presently in use and ensure that this methodology is sufficiently accurate for both regulatory and research purposes. Furthermore, the EAA seeks recharge calculation methods and models sufficiently versatile to quantify enhanced recharge associated with new recharge dams, the precipitation enhancement (weather modification) program, and/or potential brush management initiatives.

Accurate and timely calculation of quantities of water entering the Edwards Aquifer as recharge is a fundamental prerequisite for informed management and regulation of the resource by the EAA. Traditionally, recharge estimates have been calculated by the USGS using methods dating back to the late 1970s[1] and published annually.[2] Alternative estimates of historical Edwards Aquifer recharge for the 1934-1996 period were developed by HDR Engineering, Inc. (HDR) in the course of studies sponsored by the Edwards Underground Water District,[3] Nueces River Authority,[4] and as part of the Trans-Texas Water Program.[5] Estimates of Edwards Aquifer recharge are reported for four recharge basins in the Nueces River Basin and five recharge basins

---

[1] USGS, "Method of Estimating Natural Recharge to the Edwards Aquifer in the San Antonio Area, Texas," Water Resources Investigations 78-10, April 1978.

[2] USGS, "Recharge to and Discharge from the Edwards Aquifer in the San Antonio Area, Texas, 1996," http://txwww.cr.usgs.gov/reports/info/97/recharge1/index.html, April, 1997.

[3] HDR, "Guadalupe - San Antonio River Basin Recharge Enhancement Study," Vol. 2, Edwards Underground Water District, September 1993.

[4] HDR, "Nueces River Basin Regional Water Supply Planning Study, Phase I," Vol. 2, Nueces River Authority, et al., May 1991.

[5] HDR, "Edwards Aquifer Recharge Analyses, Edwards Aquifer Recharge Update," Trans-Texas Water Program, West Central Study Area, Phase II, San Antonio River Authority, et al., March 1998.

in the Guadalupe - San Antonio River Basin. The Nueces and Blanco River (Recharge) Basins, selected for development of pilot recharge models, are identified in Figure 1-1. Traditional HDR recharge estimates differ significantly from those published by the USGS in terms of both geographical and temporal distribution. The greatest volumetric differences are evident in the Nueces and Blanco Recharge Basins, hence their selection for pilot recharge model development.

This report documents the development of new recharge calculation methodologies and models that are consistent with EAA objectives. Section 2 provides a brief description of the recharge basins and outlines traditional recharge calculation methods to ensure that the new methods will retain the strengths and overcome the weaknesses of those presently in use. Pilot recharge models of the Nueces and Blanco Recharge Basins are described in Section 3. In Section 4, the data necessary to assemble, calibrate, and apply the pilot recharge models are identified and pertinent assumptions are noted. Section 5 details the calibration and application of the pilot recharge models and presents the resulting estimates of historical Edwards Aquifer recharge for the Nueces and Blanco Recharge Basins. Conclusions and recommendations are summarized in Section 6.

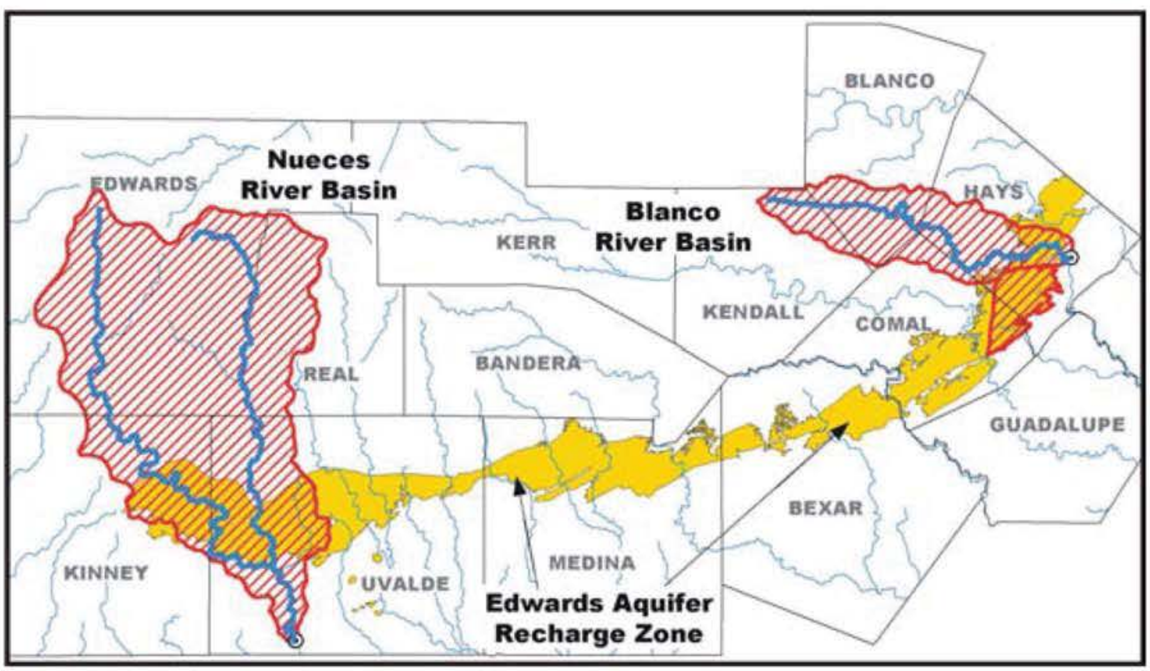


Figure 1-1. Pilot Recharge Basin Location Map

Section 2
Recharge Basins and
Traditional Recharge Calculation Methods

2.1 Recharge Basins

The Nueces Recharge Basin is the westernmost area that contributes recharge to the portion of Edwards Aquifer generally flowing towards the City of San Antonio and Comal and San Marcos Springs. The watershed area has steep slopes and thin soils and is mostly rangeland dominated by juniper, mesquite and live oak. The total inflow available for recharge includes all flow that passes the gauging stations on the Nueces River at Laguna (USGS# 08190000), the West Nueces River near Brackettville (USGS# 08190500), and runoff from for the intervening watershed area between these two upper gauges and the gauging station on the Nueces River below Uvalde (USGS# 08192000). This intervening area encompasses some 430 square miles representing about 23 percent of the total watershed area upstream of the gauge below Uvalde. Flows typically occur in the Balcones Fault Zone of the West Nueces River for only a few days following heavy rains in the area. Most of the time, only flood flow passes the gauge on the West Nueces River at Brackettville and it is assumed that only the flow passing the gauge site contributes recharge to the Edwards Aquifer extending south and east of the gauging station. Any recharge into the Edwards formation which occurs upstream of the West Nueces gauge is not considered in recharge calculations for the San Antonio portion of the aquifer.

The Blanco Recharge Basin is the easternmost basin that contributes recharge to the central portion of the Edwards Aquifer. A significant component of the discharge from San Marcos Springs is attributable to recharge that occurs in the Blanco Recharge Basin. The headwaters of the Blanco River lie in the Texas Hill Country and it eventually flows to the Guadalupe Estuary via the San Marcos and the Guadalupe Rivers. The topography is classified as rocky with rolling hills and limestone outcrops, and the land is primarily used for ranching. Cities in the Blanco Recharge Basin include San Marcos and Kyle, both of which are on the downstream side of the Edwards Aquifer outcrop. The Blanco River begins flowing over the Edwards Aquifer outcrop just below the gauging station at Wimberley (USGS# 08171000) and exits the outcrop area just above the gauging station near Kyle (USGS# 08171300). The Wimberley and Kyle gauging stations have watershed areas of 355 square miles and 412 square miles, respectively. The intervening drainage area of 57 square miles, most of which is over the Edwards Aquifer outcrop, represents about 14 percent of the total drainage area above the gauge near Kyle. Historically, the ungauged watersheds of Sink, Purgatory, Alligator, and York Creeks over the Edwards Aquifer recharge zone have been modeled as part of the Blanco Recharge Basin. The ungauged partner areas over the outcrop encompass about 100 square miles and are similar in topography, geology, and soil cover complex to the intervening drainage area between the Wimberley and Kyle gauges on the Blanco River.

2.2 Traditional Recharge Calculation Methods

Recharge to the Edwards Aquifer in the Nueces and Blanco Recharge Basins has traditionally been estimated using methods developed by the U.S. Geological Survey (USGS)[1] and HDR Engineering, Inc. (HDR).[2,3] These two recharge calculation methods are summarized in Appendix E and compared in Appendix F. The traditional USGS and HDR methods are quite similar in that they both use a basic water balance equation to estimate recharge in each basin on a monthly time interval. There are notable methodological differences, however, in the development of specific terms within the water balance equation. The principal differences in recharge calculation methodology and procedures pertinent to the Nueces and Blanco Recharge Basins are associated with:

- Estimation of potential runoff volumes for gauged and ungauged areas located atop the recharge zone with due consideration of local precipitation and watershed characteristics;
- Base flow / flood flow separation at gauges upstream of the recharge zone and accounting for storage in the Edwards Plateau Aquifer; and
- Accounting for relatively small reported surface water diversions.

More detailed information regarding these methodological differences for the Nueces and Blanco Recharge Basins is provided in Appendix F.

[1] USGS, "Method of Estimating Natural Recharge to the Edwards Aquifer in the San Antonio Area, Texas," Water Resources Investigations 78-10, April, 1978.

[2] HDR, "Guadalupe - San Antonio River Basin Recharge Enhancement Study," Vol. 2, Edwards Underground Water District, September, 1993.

[3] HDR, "Nueces River Basin Regional Water Supply Planning Study, Phase I," Vol. 2, Nueces River Authority, et al., May, 1991.

2.3 General Assessment of Traditional Recharge Calculation Methods

Pilot recharge models have been developed that are consistent with EAA objectives and retain the strengths and overcome the weaknesses of the traditional recharge calculation methods. Several perceived strengths and weaknesses of the traditional methods discussed in Appendices E and F are summarized as follows:

Strengths

- Straightforward recharge computation procedure for most watersheds;
- Limited data requirements (streamflow, precipitation, and curve number); and
- Direct use of measured streamflow at long-term USGS gauging stations.

Weaknesses

- No provisions for geographical distribution of recharge within a recharge basin (e.g. separation of mainstem and tributary recharge, consideration of measured loss rates in stream segments traversing the outcrop);
- Dependence upon assumption that portions of a watershed atop the outcrop will respond to measured precipitation similarly to a partner watershed ("lumped parameter" modeling);
- No direct consideration of daily precipitation sequences which can significantly affect both runoff and recharge estimates;
- Recharge not readily computed or reported on a daily timestep;
- Limited capability to account for changes in watershed characteristics over time (e.g. land development, dam construction, brush proliferation) and/or climatological influences (e.g., weather modification);
- Appropriate accounting for discharge from the Edwards-Trinity (Plateau) and Trinity Aquifers that contributes to recharge of the Edwards Aquifer; and
- Data from the EAA precipitation network not used.

It is believed that the pilot recharge models described herein address many of the weaknesses and provide technically sound estimates of recharge that can be readily utilized in the calibration and application of the new Edwards Aquifer simulation model.

Section 3
Pilot Recharge Models

3.1 General Description

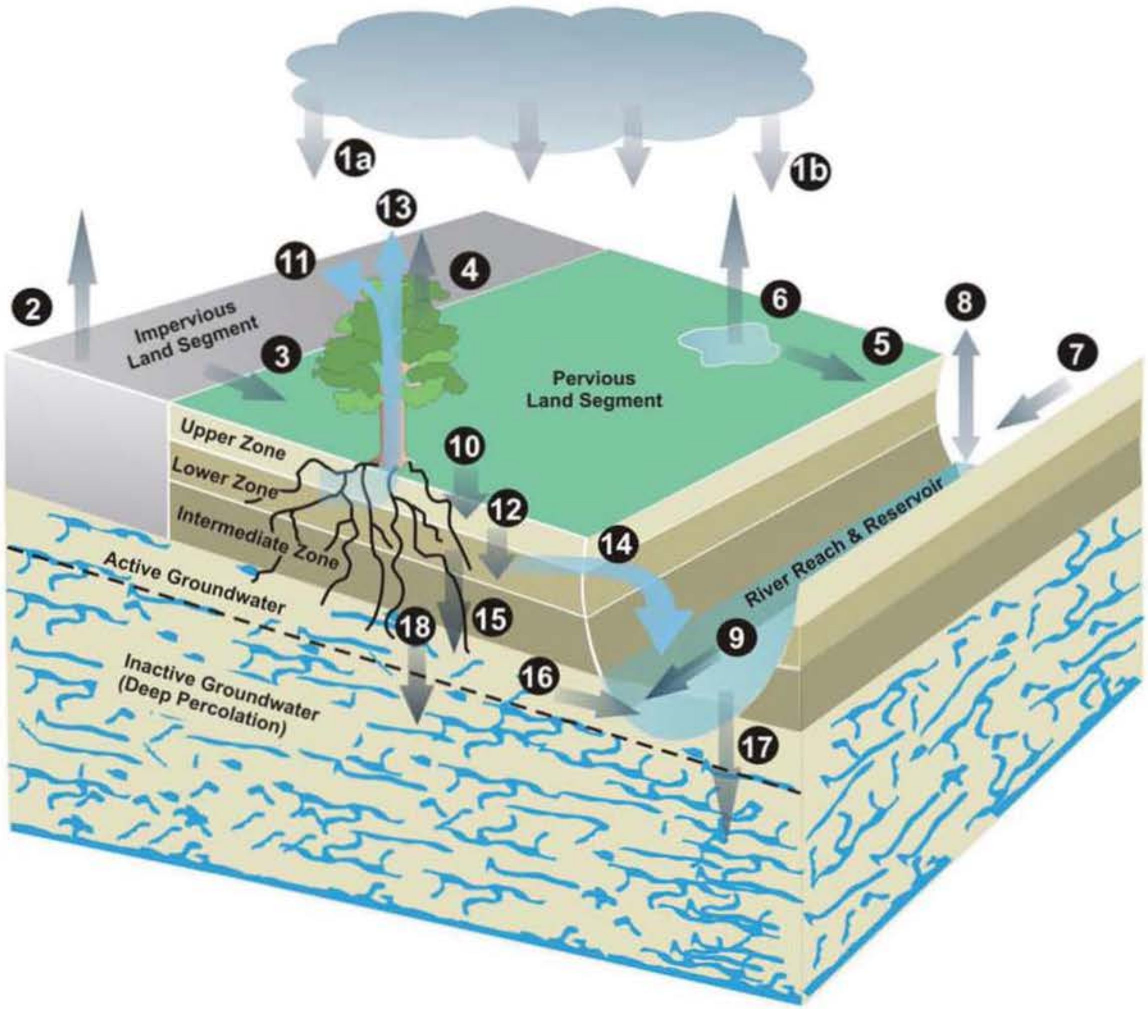
The pilot recharge models for the Nueces and Blanco Recharge Basins use the Hydrologic Simulation Program-Fortran (HSPF) Release 11[1] to calculate daily recharge to the Edwards Aquifer. The pilot recharge models are based on water balance procedures using hydrologic and hydraulic parameters as necessary to generate daily recharge volumes.

HSPF is based upon the Stanford Watershed Model developed in the late 1950s, with significant enhancements and refinements occurring over the last four decades. These enhancements and refinements include the addition of water-quality processes and development of a FORTRAN version incorporating several related models in the 1970s as well as development of preprocessing and post processing software, algorithm enhancements, and use of the USGS Watershed Data Management (WDM) system. The pilot recharge modeling of the Nueces and Blanco Recharge Basins utilizes the hydrologic and hydraulic routines (modules) of HSPF.

HSPF uses continuous rainfall and evaporation records to compute streamflow hydrographs and simulate interception, infiltration, leakage, deep percolation, and other hydrologic processes. Hydrologic processes and simulation routines in HSPF used in the pilot recharge models are listed and illustrated in Figure 3-1. Following is a brief, general summary of HSPF operations from a current hydrology text.

> "Rainfall is distributed into interception loss, rainfall on impervious areas, which contributes directly to runoff, and an infiltrated portion. Infiltration is divided into (1) surface runoff and interflow which moves through the upper soil zone to channel flow and (2) flow into the lower soil zone or groundwater storage, which contributes to active and inactive groundwater storage. The model utilizes three soil moisture zones: an upper soil zone, a lower soil zone, and a groundwater storage zone. Rapid runoff is accounted for in the upper zone. Both the upper and lower zones influence factors such as overland flow, infiltration, and groundwater storage. Water that is computed as moving into the lower zone can move into deep groundwater storage, some of which can become base flow to a stream. Total stream flow is a combination of overland flow, interflow, and groundwater flow. More than 20 parameters are needed to describe the hydrologic parameters. The program user must supply parameters for each of the various processes."[2]

[1] USGS, "Hydrologic Simulation Program – FORTRAN User's Manual for Release 11," September 1996.
[2] Maidment, D.R. ed. "Handbook of Hydrology" McGraw Hill, San Francisco 1993.



Hydrologic Process	Reference #
Precipitation on Impervious Land Segment	1a
Evaporation from Impervious Land Segment	2
Runoff from Impervious Land Segment	3
Precipitation on Pervious Land Segment	1b
Evaporation from Interception Storage	4
Runoff from Pervious Land Segment	5
Evaporation from Detention Storage	6
Inflow from Upstream Reach Segment	7
Net Evaporation from Free Surface Area	8
Outflow to Downstream Reach Segment	9
Infiltration	10
Evapo-Transpiration from Upper Root Zone	11
Percolation (from Upper Zone to Lower Zone)	12
Evapo-Transpiration from Lower Root Zone	13
Interflow	14
Active Groundwater Inflow	15
Baseflow	16
Channel Losses	17
Recharge to Inactive Groundwater (Deep Percolation)	18

EDWARDS AQUIFER AUTHORITY

Figure 3-1. HSPF Water Balance Process

HDR

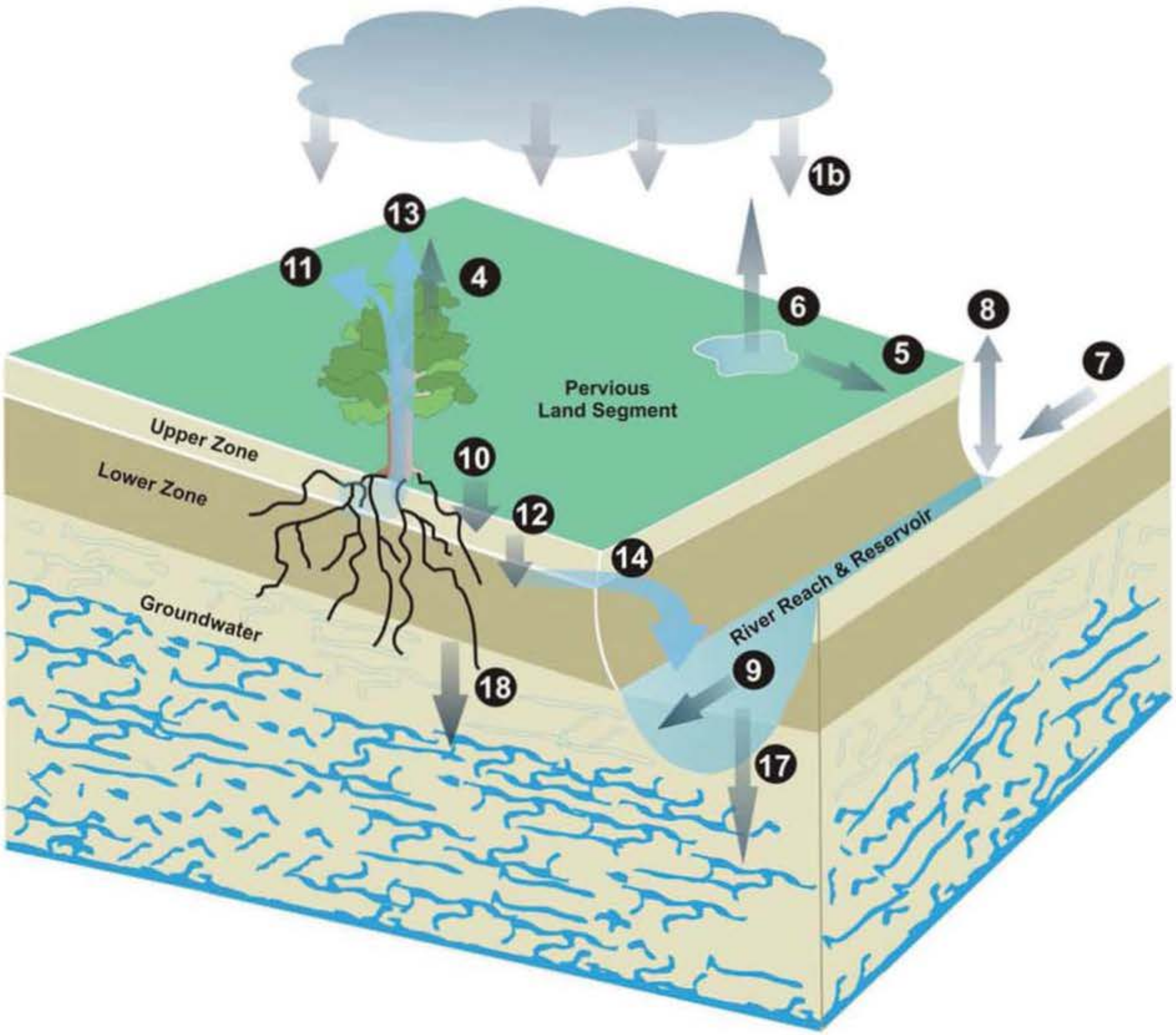
Selection of appropriate parameter values for the HSPF pilot recharge models is discussed at length in Sections 4 and 5. Edwards Aquifer recharge is represented as Channel Losses and Recharge to Inactive Groundwater or Deep Percolation (Reference Numbers 17 and 18 in Figure 3-1 in the HSPF pilot recharge models).

3.2 HSPF Structure and Key Modules

HSPF consists of a set of modules arranged in a hierarchical structure, which permit the continuous simulation of a range of hydrologic and water quality processes. The model is divided into three major modules. They are the pervious land segment module (PERLD), the impervious land segment module (IMPLD), and the river reach and reservoir module (RCHRES). Land segments, subdivisions of the simulated watershed, are classified as either pervious or impervious. Based upon this classification, the land segment is modeled using the representative land segment module. A pervious land segment is defined as a land segment that has the capacity to allow enough infiltration to influence the water budget. An impervious land segment is one in which the land segment has little or no infiltration occurring. The third module, RCHRES, simulates the processes that occur in a free-flowing river reach or a completely mixed reservoir, the surface waters of the watershed. The two major modules used in the pilot recharge models are the PERLD and RCHRES modules.

The absence of cities and towns over the Edwards outcrop in the two basins eliminates the need to model impervious land segments, and therefore, eliminates the processes associated with the impervious land segment (see Reference Numbers 1a, 2, and 3 in Figure 3-1). Furthermore, the geologic characteristics of the land over the outcrop are such that the streams are generally losing reaches, and the groundwater table is typically lower than the bottom of the streambed. Where and when this is the case, groundwater is inactive with respect to leakage into the stream thereby eliminating the active groundwater zone in areas over the outcrop. These specific changes are shown in Figure 3-2, a representation of the model over much of Edwards Aquifer recharge zone.

Since the pilot recharge models use only the hydraulic processes of HSPF and impervious areas are insignificant, the sub-modules of the two major modules used are limited to the hydraulic sub-modules. They are the PWATER sub-module and the HYDR sub-module.



Hydrologic Process	Reference #
Precipitation on Pervious Land Segment	1b
Evaporation from Interception Storage	4
Runoff from Pervious Land Segment	5
Evaporation from Detention Storage	6
Inflow from Upstream Reach Segment	7
Net Evaporation from Free Surface Area	8
Outflow to Downstream Reach Segment	9
Infiltration	10
Evapo-Transpiration from Upper Root Zone	11
Percolation (from Upper Zone to Lower Zone)	12
Evapo-Transpiration from Lower Root Zone	13
Interflow	14
Channel Losses	17
Recharge to Inactive Groundwater (Deep Percolation)	18

EDWARDS AQUIFER
AUTHORITY

Figure 3-2. HSPF Water Balance Process Over Edwards Aquifer Outcrop

HDR

PWATER is the water budget simulation sub-module for the PERLD module, and will determine the fate of water from precipitation as it falls upon pervious land segments. The HYDR sub-module is the water balance routine for the RCHRES module, and accounts for the water movement in the surface watercourses of the basins.

3.3 Practical Application of HSPF Recharge Model

Figure 3-3 is a flowchart illustrating the process by which the databases are developed, HSPF is executed, and the output data sets are retrieved for analysis and presentation. Utilizing HSPF to quantify recharge requires an appropriately coded User Control Input (UCI) file as well as daily time series data. The daily time series data sets are included in a Watershed Data Management (WDM) file. This WDM file is created and populated with time series data using the USGS IOWDM program, which runs in DOS. The WDM is organized into individual datasets. Empty datasets that will be used to store output time series in the WDM are created using another USGS program called ANNIE. ANNIE functions include file creation, data set management, and data analysis, modification, and display. Running HSPF requires the HSPF executable file (HSPFL.EXE), a batch file (HSPF.BAT), the UCI file and a WDM file containing the time series data. The UCI file includes information that identifies the data set number of each required time series (e.g., precipitation, streamflow, and evaporation). After execution, HSPF outputs the simulated results into designated time series data sets in the WDM file. HSPF creates an echo file (*.ECH) that is a detailed account of HSPF processing of the input data. An *.OUT file is also created which includes an annual record of the water balance in each land segment and river reach. The output time series are retrieved from the WDM file using ANNIE. Output time series are analyzed and graphically displayed using Microsoft Excel.

The contents of each WDM for the Blanco and Nueces Recharge Basins, including data set number and description of each time series, are outlined in Appendix C. The UCI files for the Nueces and Blanco Basins are included in Appendix B.

Future application of HSPF with additional hydrologic data (future precipitation, streamflow, and evaporation), land use changes, and/or projects (recharge enhancement facilities, weather modification, brush management, etc.) can be performed to determine recharge to the aquifer. However, the UCI file, WDM, will need to be developed using IOWDM and ANNIE to amend the period of record and existing data sets.

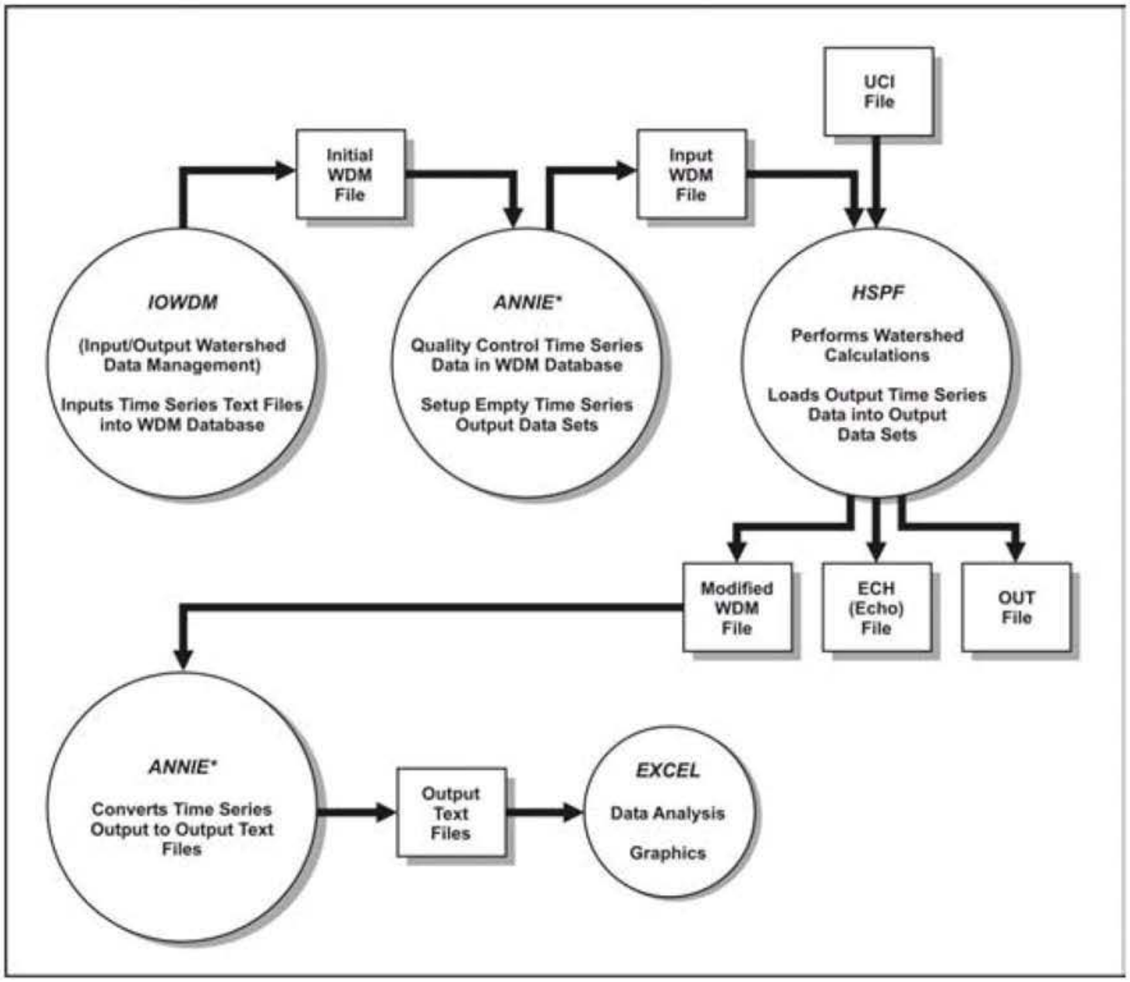


Figure 3-3. Model Application Flowchart

3.4 Defined Study Areas

3.4.1 Nueces Recharge Basin Study Area

The upper boundary of the Nueces Recharge Basin area modeled using HSPF is defined by the gauging stations on the Nueces River at Laguna (USGS# 08190000) and the West Nueces River near Brackettville (USGS# 08190500) (Figure 3-4). The lower boundary is defined by the gauging station on the Nueces River below Uvalde (USGS# 08192000). The intervening watershed between the gauges is subdivided based upon geologic characteristics (i.e., aquifer contributing zone, recharge zone, and confined zone) as shown in Figure 3-5. This intervening watershed area is simulated in HSPF using eight Pervious Land Segments (PLS) and seven River

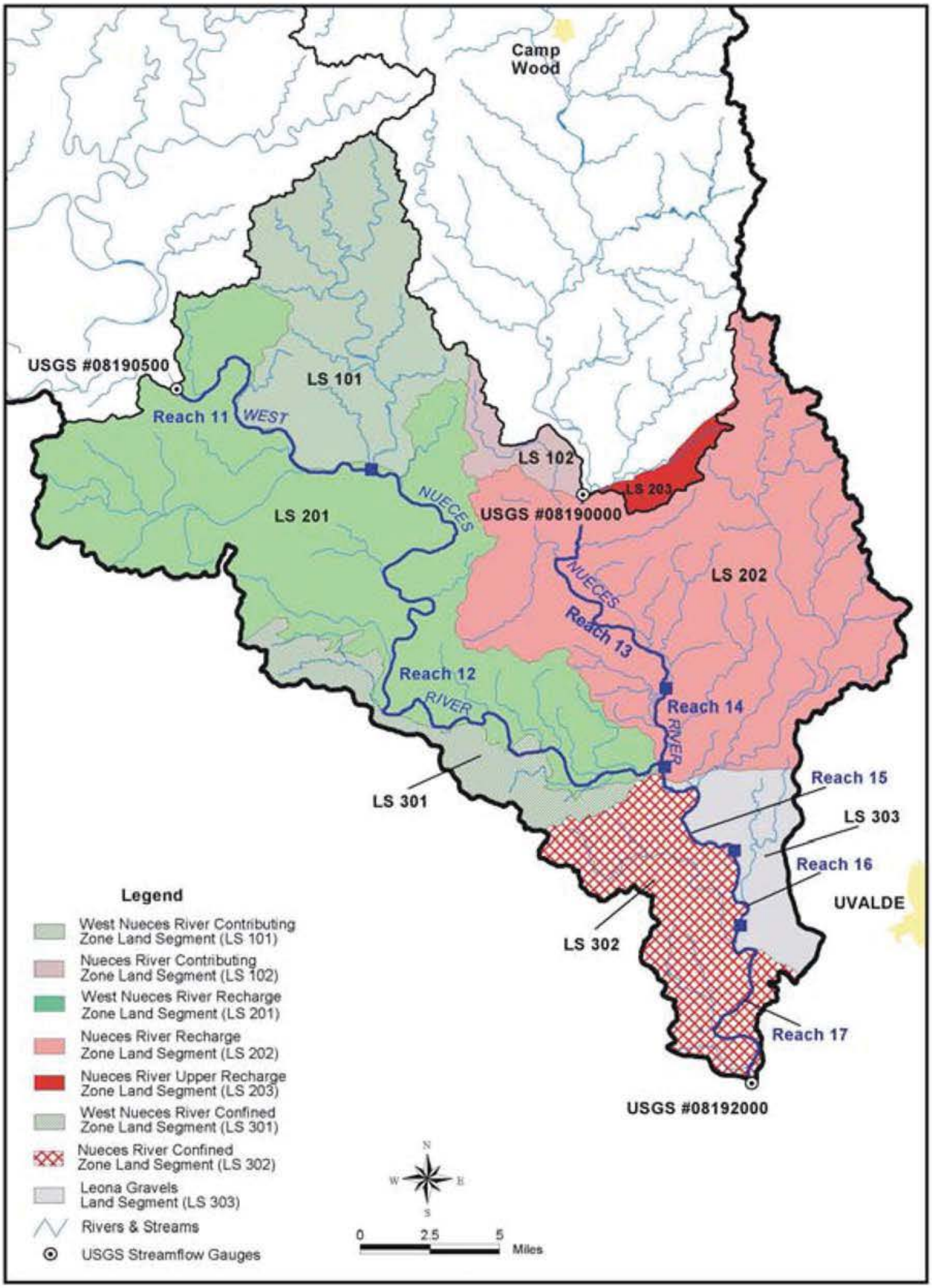


Figure 3-4. Land Segments and River Reaches in the Nueces Recharge Basin

Reach Segments (RCHRES). The streamflow loss segments, as identified in a channel loss survey conducted by the USGS,[3] define these river reaches. The watershed is subdivided into pervious land segments based upon geologic characteristics (i.e., aquifer contributing zone, recharge zone, and confined zone). Within the Nueces Recharge Basin, two of the eight PLS are in the aquifer contributing zone (above the outcrop and below the Laguna and Brackettville streamflow gauges), three of the PLS are directly over the outcrop, and three of the PLS are below the outcrop area (over the confined zone of the Edwards Aquifer).

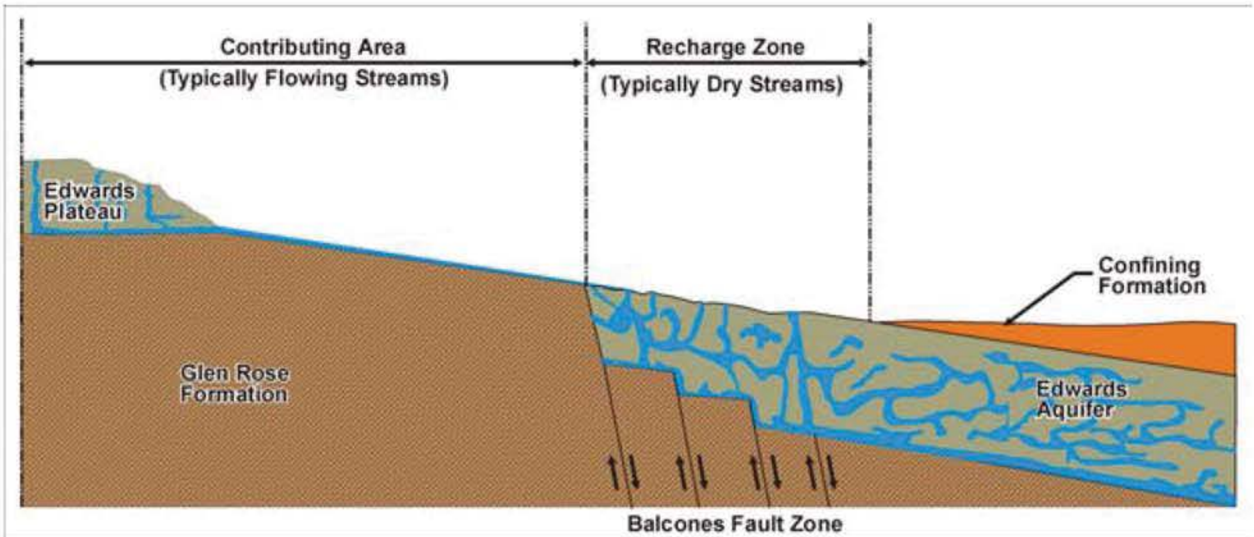


Figure 3-5. Profile Schematic of Typical Edwards Outcrop

3.4.2 Blanco Recharge Basin Study Area

The upper boundary of the Blanco Recharge Basin area modeled using HSPF is defined by the gauging station on the Blanco River at Wimberley (USGS# 08171000), and the lower boundary is defined by the gauging station on the Blanco River near Kyle (USGS# 08171300). This portion of the basin is simulated in HSPF as three Pervious Land Segments (PLS) and five River Reach Segments (RCHRES) as illustrated in Figure 3-6. In addition, the ungauged portion of the Blanco Recharge Basin is modeled as four PLS and seven RCHRES. The seven RCHRES in the ungauged portion represent seven flood retardation structures, which also serve to enhance Edwards Aquifer recharge (see Section 4.12).

[3] USGS, "Streamflow Losses along the Balcones Fault Zone, Nueces River Basin, Texas," Report 83-4368, 1983.

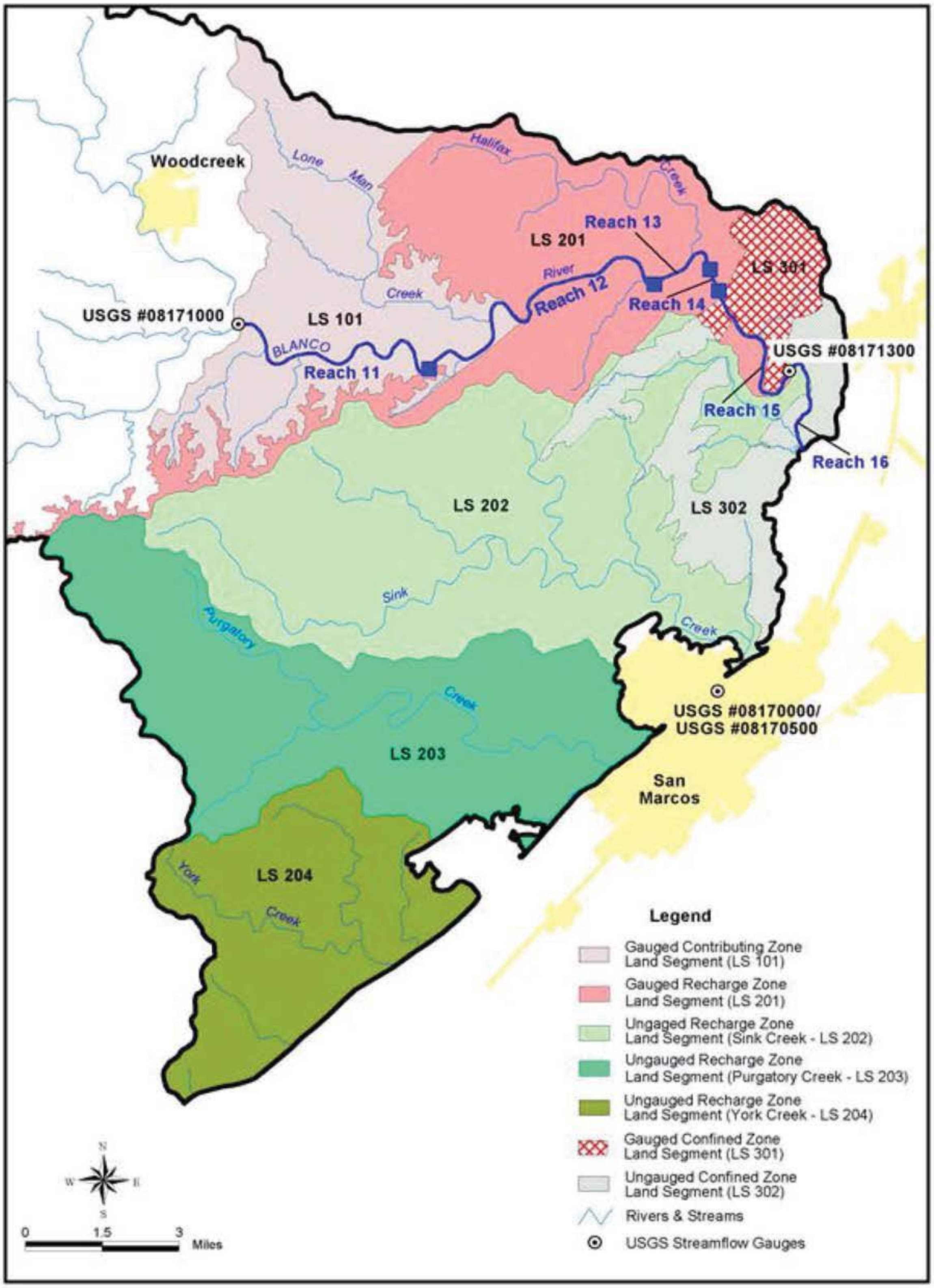


Figure 3-6. Land Segments and River Reaches in the Blanco Recharge Basin

Within the Blanco Recharge Basin, one of the seven PLS is in the aquifer contributing zone (above the outcrop and below the Wimberley streamflow gauge); four of the PLS are directly over the outcrop, of which three are in the ungauged partner areas of Sink, Purgatory, York, and Alligator Creeks (ungauged portion); and two of the PLS are below the outcrop area (over the confined zone of the aquifer). The Blanco River is subdivided into several river reach segments, based upon channel loss surveys conducted by the Texas Board of Water Engineers.[4]

[4] Texas Board of Water Engineers, "Channel Gain and Loss Investigations, Texas Streams, 1918-1958," Bulletin 5807 D, April 1960.

Section 4
Data Collection, Compilation, and Refinement

4.1 Streamflow

Historical streamflow data for the following United States Geological Survey (USGS) streamflow gauging stations was acquired from the National Water Information System database (NWIS) via the USGS website at http://water.usgs.gov/nwis/:

- Blanco River at Wimberley (USGS # 08171000) [Sept 1924 – Present];
- Blanco River near Kyle (USGS # 08171300) [June 1956 – Present];
- San Marcos River at San Marcos Springs (USGS # 08170000) [May 1956 – Present];
- San Marcos River at San Marcos (USGS # 08170500) [July 1915 – Present];
- Nueces River at Laguna (USGS # 08190000) [Oct 1923 – Present];
- West Nueces River near Brackettville (USGS # 08190500) [Sept 1939 – Present]; and
- Nueces River below Uvalde (USGS # 08192000) [Oct 1927 – Present].

The database contains daily mean streamflow for the period of record at each site. Figures 4-1 and 4-2 show the locations of these seven streamflow gages in the Nueces and Blanco Recharge Basins, respectively. Historical streamflows from stations upstream of the outcrop of the Edwards Aquifer are used as direct input to the pilot recharge models. Records from stations downstream of the Edwards outcrop are a key reference in the calibration of the pilot recharge models.

The USGS began separately reporting springflow and total flow in the upper San Marcos River watershed below San Marcos Springs in October 1994. The difference between reported total flow and springflow is primarily runoff from the Sink Creek watershed which outfalls to Spring Lake. Calculated runoff from the Sink Creek watershed is typically zero, however, four storm events resulting in daily average runoff in excess of 50 cfs have occurred since October 1994. The peak daily mean runoff since October 1994 is 5,959 cfs recorded on October 17, 1998. Calculated runoff from the Sink Creek watershed was considered in the calibration of the pilot recharge model for the Blanco Recharge Basin.

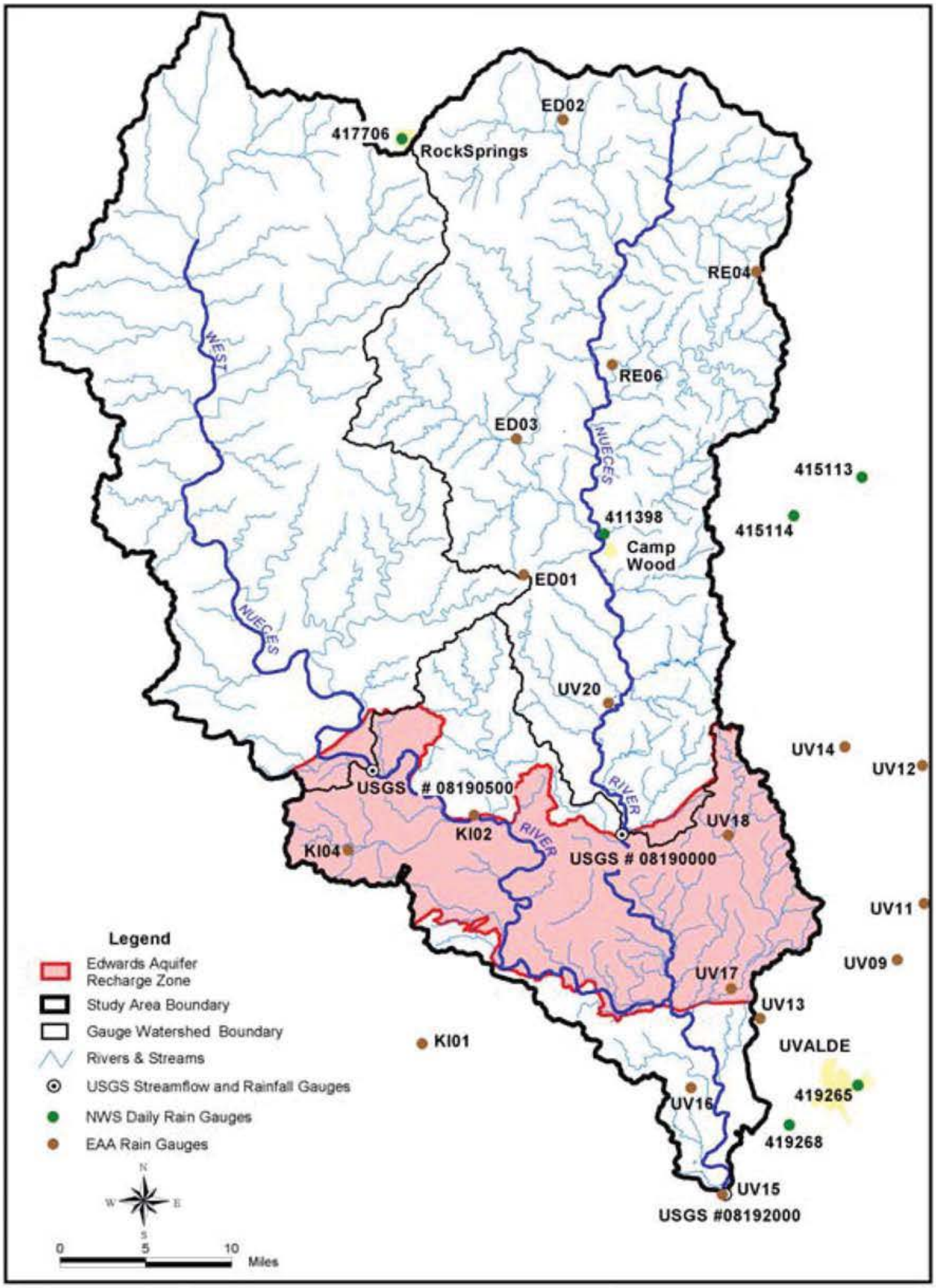


Figure 4-1. Nueces Study Area — Streams and Gauges

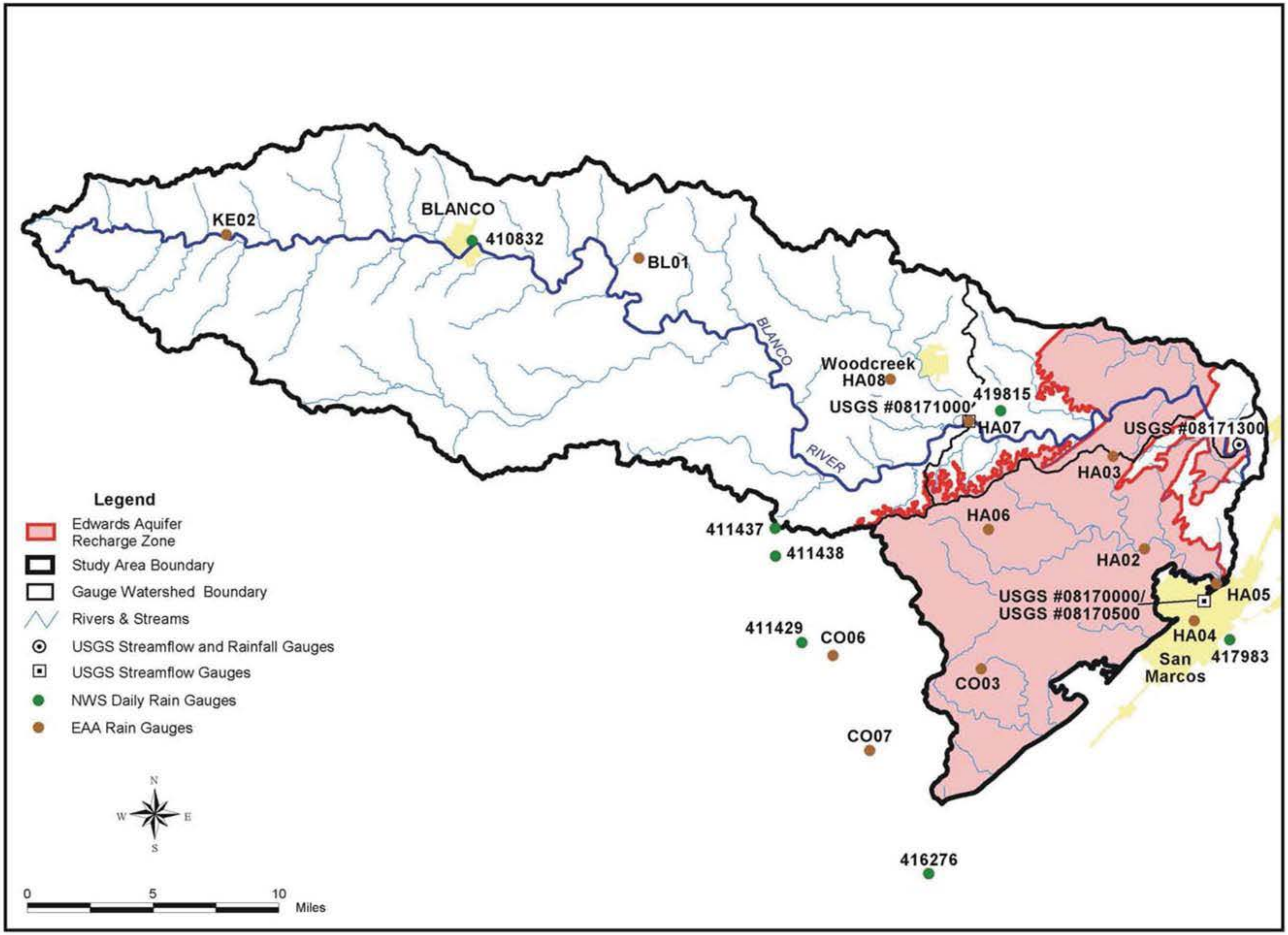


Figure 4-2. Blanco Study Area — Streams and Gauges

4.2 Precipitation

Daily precipitation data was obtained from the National Weather Service (NWS), Edwards Aquifer Authority (EAA), and the USGS. The locations of active precipitation stations proximate to the Nueces and Blanco Recharge Basins are shown in Figures 4-1 and 4-2, respectively. The available periods of record for these stations is highly variable. The NWS stations generally have the longest periods of record with many extending from the 1920s to the present. Records from the EAA network of precipitation stations, however, are available only from the late 1990s to the present. Additional intermittent precipitation records were provided by the USGS for the period extending from 1988 to the present. The USGS precipitation gauges are located at their streamflow gauging stations including three in the Nueces Recharge Basin and one in the Blanco Recharge Basin. Daily precipitation is used in the modeling process because of the limited availability and data intensive nature of hourly records. Furthermore, the primary goal of the model calibration process is to replicate long-term streamflow (and recharge) volumes rather than peak discharge rates during individual storm events.

The compiled data from the NWS precipitation gauging stations was used to develop historical time series of areal precipitation data for each of the land segments in the Nueces and Blanco Recharge Basins using GIS techniques. Data from EAA and USGS precipitation gauging stations was deemed too limited in availability and/or accuracy for consistent use in the development of areal precipitation for the pilot recharge models at this time. However, it is believed that use of data to be collected by the EAA gauging network will improve estimates of areal precipitation and recharge in the future.

Areal precipitation is defined herein as the average precipitation depth over a specified area such as a watershed or land segment used in the pilot recharge models. From the modeling perspective, use of areal precipitation limits the number of land segment divisions, which, in turn, eases calibration efforts. Additionally, use of areal precipitation allows the model structure to remain constant when: (1) An existing precipitation gauge has missing or invalid data values; (2) Precipitation gauges are added in the future; and/or (3) Existing precipitation gauges are discontinued in the future.

4.3 Evaporation

HSPF uses gross water surface evaporation rates both directly and as maximum potential evapo-transpiration rates. Potential evapo-transpiration rates are used to simulate historical (actual) evapo-transpiration subject to temporally variant climatic and soil moisture conditions as well as specified hydrologic characteristics. Monthly gross water surface evaporation rates representative of the Nueces and Blanco Recharge Basins for January 1954 through December 1998 were obtained from the Texas Water Development Board (TWDB).[1] Monthly evaporation rates prior to 1954 and after 1939 were computed by correlation with previously published TWDB data.[2] Should gross evaporation data prior to 1940 be needed, it can be estimated from proximate pan data compiled by the TWDB.[3] Estimates of potential evapo-transpiration used in the pilot recharge models are reasonably consistent with those available from the Texas ET Network,[4] regional weather stations (including Sea World, NCDC# 418169), and other sources.[5] It is noted that the HSPF model includes routines capable of uniformly distributing monthly evaporation rates to the daily computational timestep adopted for the pilot recharge models. It is believed that a uniform daily distribution of unique monthly rates is satisfactory for computation of Edwards Aquifer recharge.

4.4 Soils and Land Use Coverages

Soils data was obtained from the Natural Resource Conservation Service (NRCS), formerly the Soil Conservation Service (SCS), which is an agency within the United States Department of Agriculture. The original scale of the soils data (STATSGO) to be used is 1:250,000. The data was downloaded from the NRCS website at http://www.ftw.nrcs.usda.gov/stat_data.html. The NRCS is in the process of mapping more detailed soils data in the form of the Soil Survey Geographic database (SSURGO), which consists of soils data at a scale 1:24,000. However, the only counties in the EAA study areas for which this data is currently available are Edwards, Kinney, and Real.

For the purposes of hydrologic simulation and recharge calculation, soils have been generally categorized, based on permeability characteristics, into the four SCS Hydrologic Soil Groups: "A" for sands, loamy sands, and sandy loams; "B" for silt loam and loams; "C" for sandy clay loams; and "D" for clay loams, silty clay loams, sandy clay, silty clay, and clay. Figures 4-3 and 4-4 are soils maps for the Nueces and Blanco Recharge Basins, respectively. Soil classification and permeability characteristics provide qualitative guidance regarding relative infiltration rates for previous land segments modeled in HSPF.

---

[1] TWDB, "Monthly Reservoir Evaporation Rates for Texas Using GIS," March 1998
[2] TWDB, "Monthly Reservoir Evaporation Rates for Texas, 1940 through 1965," Report 64, October 1967.
[3] TWDB, "Evaporation Data in Texas, Compilation Report, January 1907 - December 1970," Report 192, June 1975.
[4] Texas A&M University, "Average Historic PET," Texas ET Network, Texas Cooperative Extension, Texas Agricultural Experiment Station, http://texaset.tamu.edu/pet.php.
[5] Potential Evapo-Transpiration data prior to 9/1/2001 available from the Texas A&M Research & Extension Center at Uvalde is considered high and scheduled to be recalculated per personal communication with Dr. M. Keith Owens in June 2002.

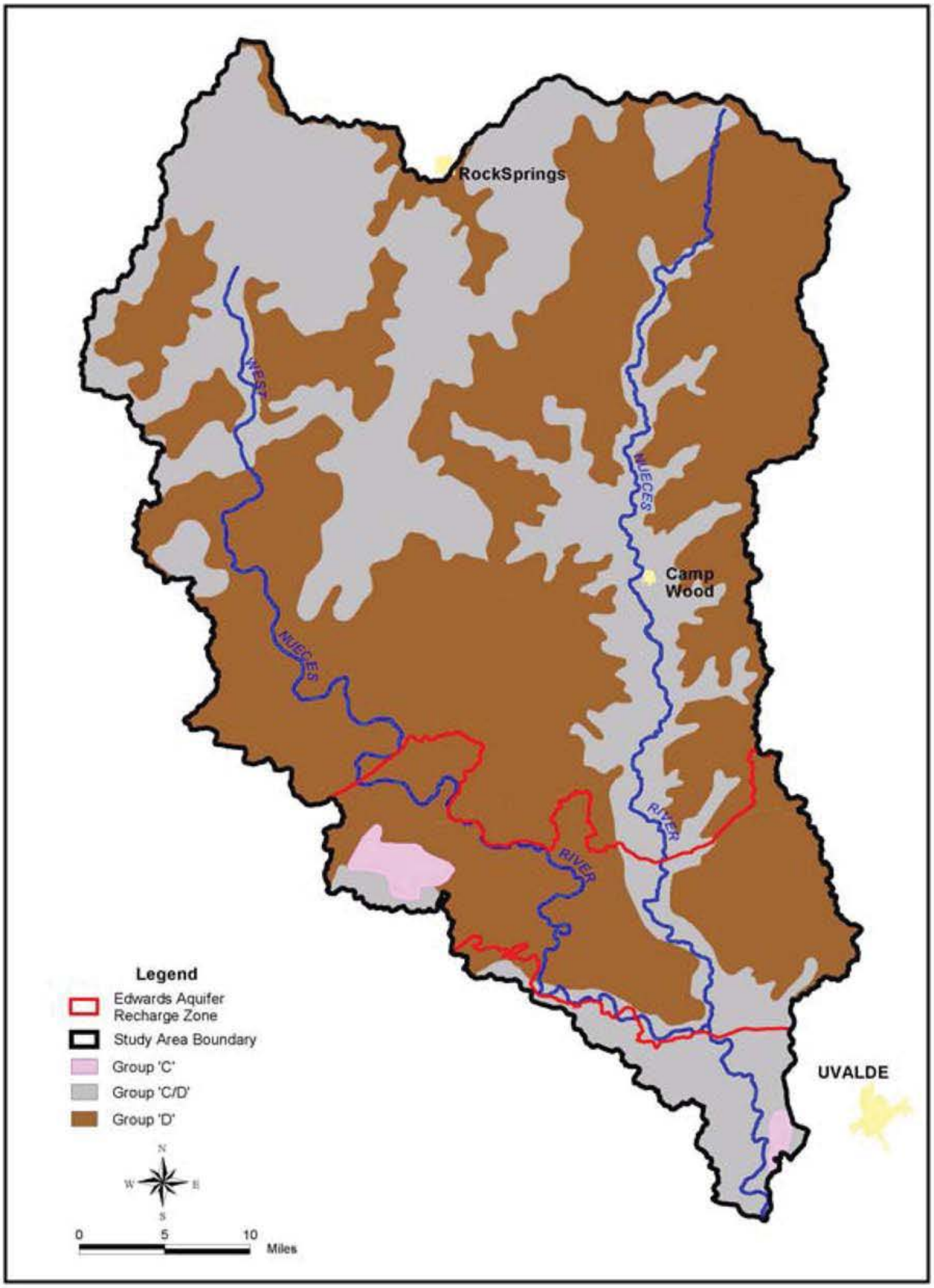


Figure 4-3. Nueces Study Area — Soils

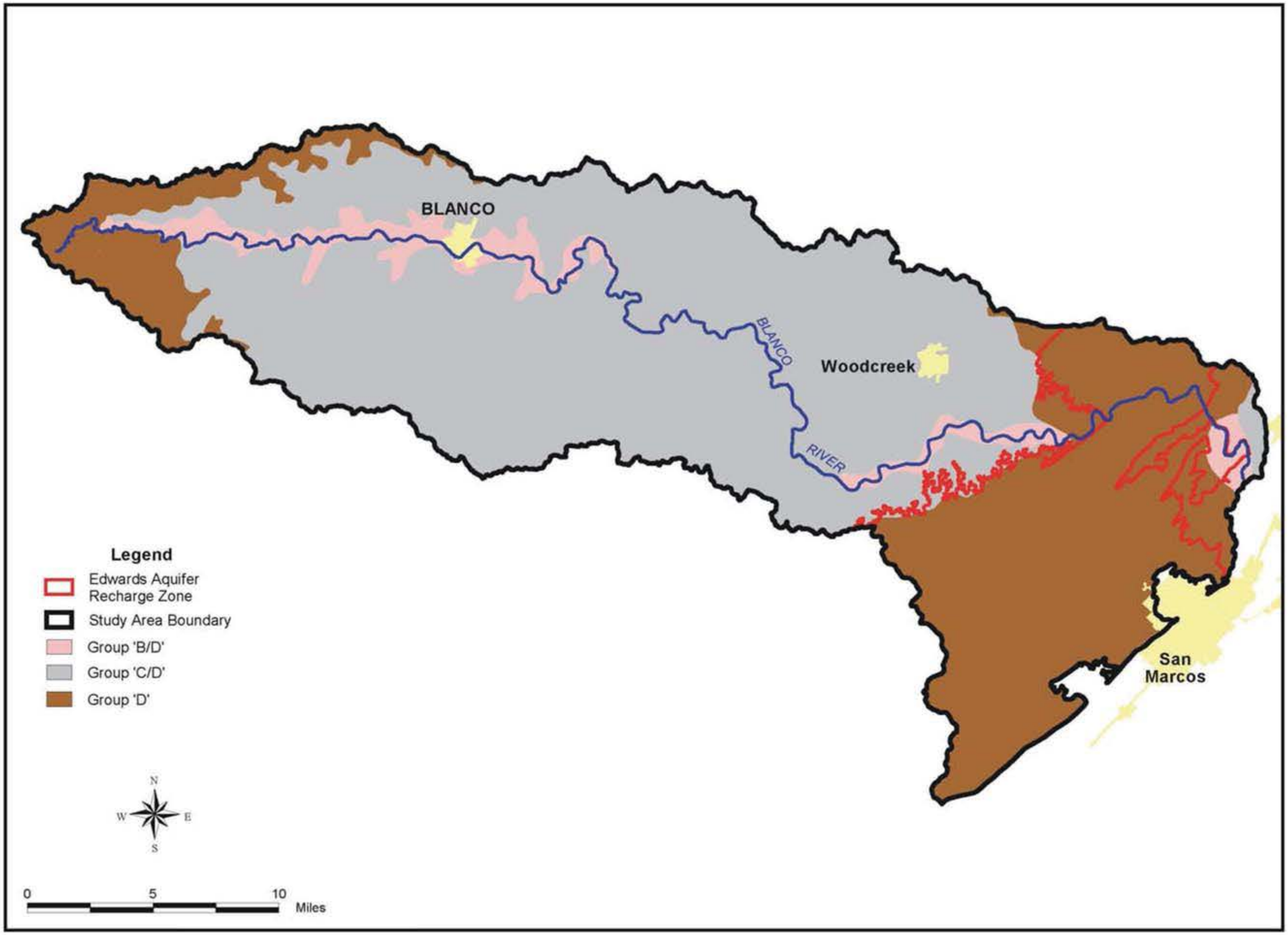


Figure 4-4. Blanco Study Area — Soils

Land use data was created by the USGS[6] in 1986 and obtained from the Texas Natural Resource and Information System (TNRIS). The land use was mapped and coded using the Anderson classification system.[7] Figures 4-5 and 4-6 are land use maps for the Nueces and Blanco Recharge Basins, respectively. Any changes in land use within the recharge basins since 1986 are not believed to be significant due to the large sizes and undeveloped, rural nature of the watersheds.

4.5 Edwards Aquifer Outcrop Coverage

The boundary of the outcrop of the Edwards Aquifer was provided by the Edwards Aquifer Authority.[8] Visual comparisons indicate that this outcrop boundary delineation includes greater definition than those available from other sources.

4.6 Stream Network

The electronic stream network used in Figures 4-1 and 4-2 is the Reach File Version 3 (RF3) obtained from the Environmental Protection Agency (EPA). The new National Hydrography Dataset (NHD), also provided by the EPA, was obtained from the EPA website.

4.7 Historical Water Level Data from Long-Term Wells

The TWDB monitors several wells in or near the outcrop of the Edwards Aquifer. These wells include two near San Marcos (Well ID #6701305 and Well ID #6701203) in the Blanco Recharge Basin and several in the Nueces Recharge Basin. Historical records for these wells were obtained from the TWDB website at: http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWDatabaseReports/GWdatabaserpt.htm. Historical records for the City of Uvalde well (ID # 6950302) in the Nueces Recharge Basin were provided by the EAA.

[6] USGS, "Land Use and Land Cover Digital Data from 1:250,000 and 1:100,000 Scale Maps," Earth Science Information Center, Reston, Virginia, 1986.
[7] Anderson, J.R., et al., "A Land Use and Land Cover Classification System for Use with Remote Sensor Data," Geological Survey Professional Paper 964, 1976.
[8] Electronic Mail, Steve Johnson, Edwards Aquifer Authority, August 9, 2001.

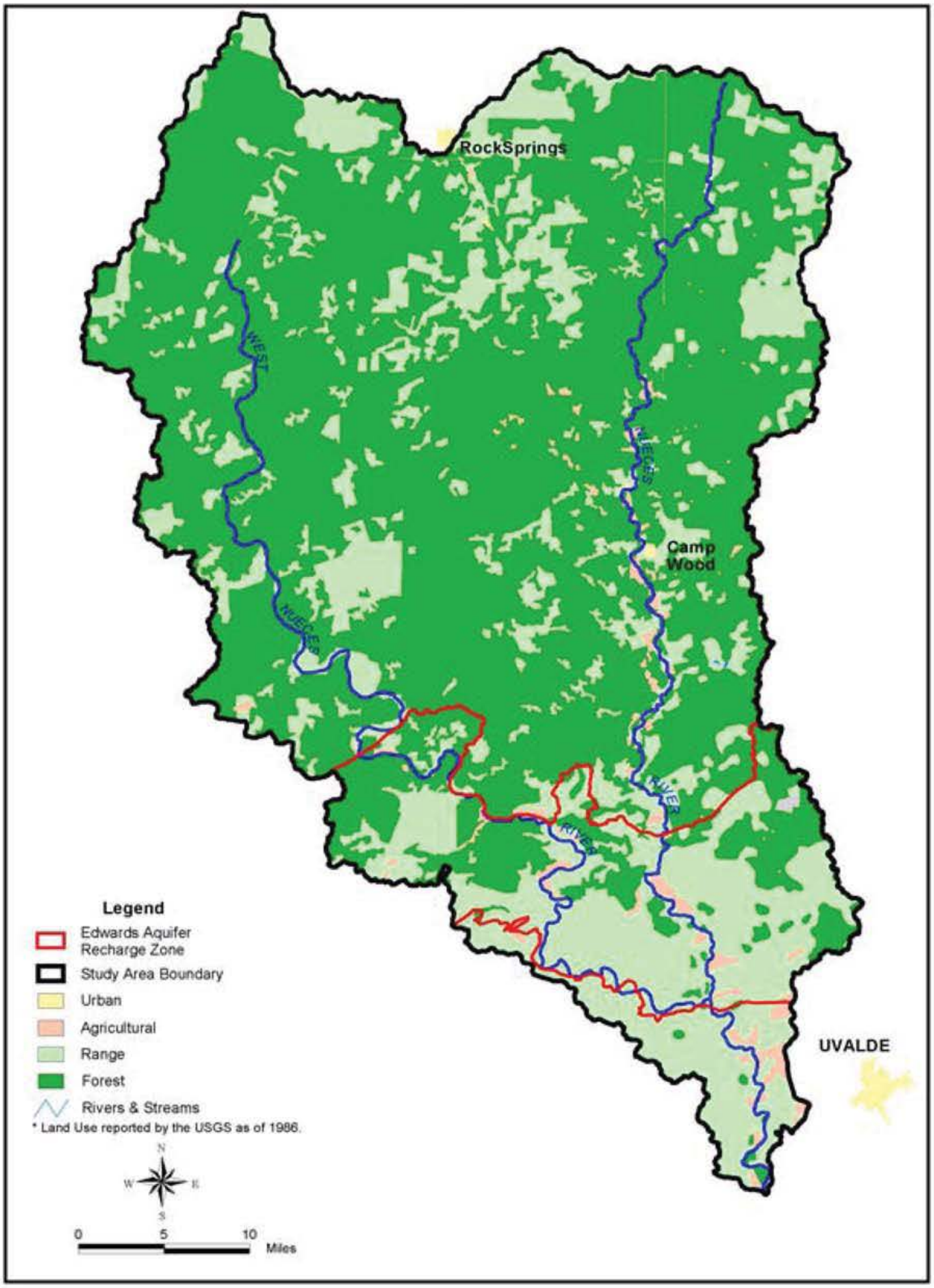


Figure 4-5. Nueces Study Area — Land Use

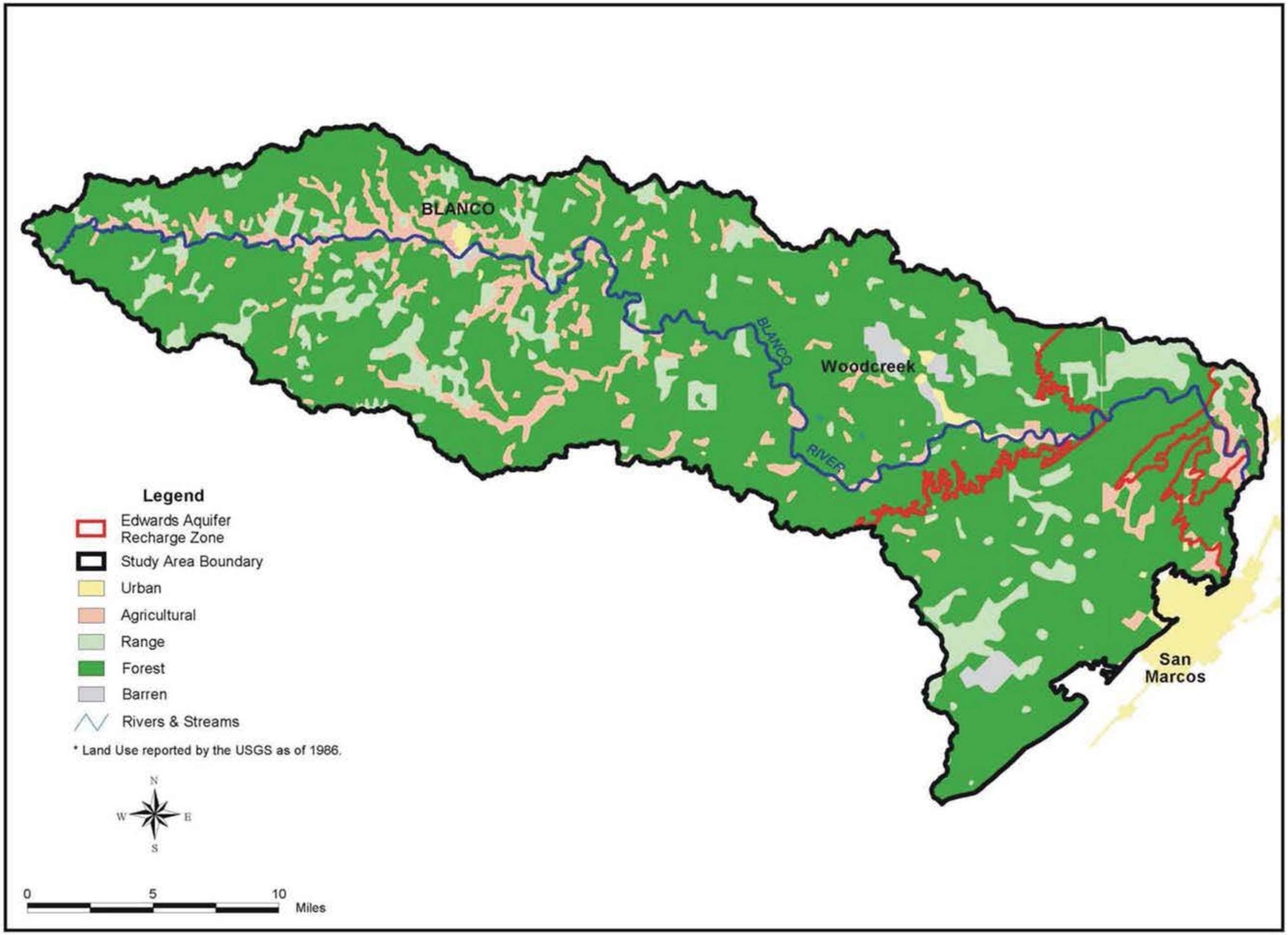


Figure 4-6. Blanco Study Area — Land Use

4.8 Historical Water Use Records

Aggregated monthly records of reported water use associated with water rights located within the Nueces and Blanco Recharge Basins were obtained from the Texas Natural Resource Conservation Commission (TNRCC). Such records are presently available through 1998 and were obtained by HDR in the course of previous studies.[9,10,11,12] Reported water use in the Nueces Recharge Basin averaged 930 acft/yr during the 1950 through 1998 historical period and are accounted for in the calculation of historical recharge using the pilot recharge models. In the Blanco Recharge Basin, neither authorized diversions nor reported water use are sufficient to justify consideration in the pilot recharge model at this time.

4.9 Channel Losses

4.9.1 Nueces River Channel Loss

Channel losses for the segments of the Nueces and West Nueces Rivers over the Edwards outcrop were calculated using the information from surveys conducted by the USGS[13] and the Texas Board of Water Engineers.[14] Data from the two reports were compiled with the upstream and downstream flow measurements for each reach. An apparent loss rate was calculated (loss rate = downstream flow minus upstream flow). The loss rates were then plotted with the associated upstream flows in order to develop a quantitative relationship between the two. For upstream flowrates (Nueces River at Laguna) of 107 cfs and less, the downstream flowrate was zero. This indicated a 1:1 relationship between channel loss and upstream flowrate for streamflows less than the threshold flow of 107 cfs. Linear regression was used to obtain a relationship between upstream flowrates and channel losses for streamflows greater than 107 cfs. Figure 4-7 illustrates these relationships between streamflow for Nueces River at Laguna and associated channel losses across the Edwards outcrop.

---

[9] HDR Engineering, "Guadalupe – San Antonio River Basin Recharge Enhancement Study", Edwards Underground Water District, Volume II, 1993

[10] HDR Engineering, "Nueces River Basin Regional Water Supply Planning Study – Phase I", Nueces River Authority, Et. al., Volume II, 1991.

[11] HDR Engineering, "Water Availability in the Guadalupe – San Antonio River Basin", TNRCC, 1999.

[12] HDR Engineering, "Water Availability in the Nueces River Basin", TNRCC, 1999

[13] USGS, "Streamflow Losses along the Balcones Fault Zone, Nueces River Basin, Texas," Report 83-4368, 1983.

[14] Texas Board of Water Engineers, "Channel Gain and Loss Investigations, Texas Streams, 1918-1958," Bulletin 5807 D, April 1960.

4.9.2 Blanco River Channel Loss

Initially, channel losses for the losing reach segments of the Blanco River were calculated using information in a survey conducted by the Texas Board of Water Engineers.[15] However, due to the limited survey information available for the Blanco River between Wimberley and Kyle gauges, an alternate procedure was developed using historical stream gauge records for the Blanco River at Wimberley and near Kyle, to calculate the relationship between channel loss over the Edwards outcrop and upstream flowrates.

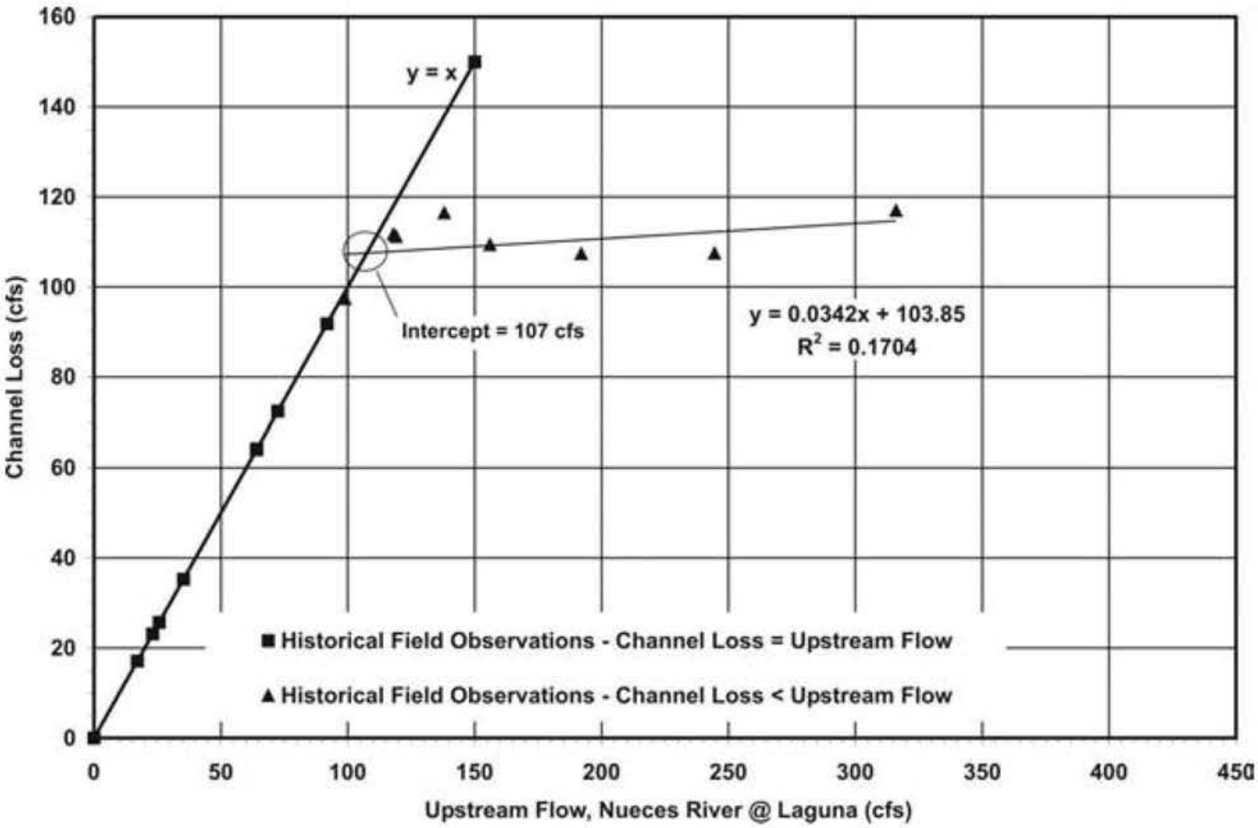


Figure 4-7. Nueces River Channel Loss Between Laguna Gauge and Uvalde Gauge

Daily streamflows were isolated for periods when the 14-day total antecedent rainfall was less than 0.5 inches, thus ensuring that the gauges at Wimberley and Kyle recorded little, if any direct storm runoff. Subtracting the upstream from the downstream flowrate, an apparent channel loss was calculated. Then, for all days having the same upstream flowrate, an average channel loss was calculated. For flowrates at Wimberley less than 16 cfs, the channel loss was equal to the upstream flowrate (1:1 relationship). Examination of flowrates at Wimberley above

16 cfs showed that average channel loss over the Edwards outcrop could reasonably be assumed a constant value of 16 cfs. Figure 4-8 illustrates these relationships between streamflow at Blanco River at Wimberley and the associated channel losses.

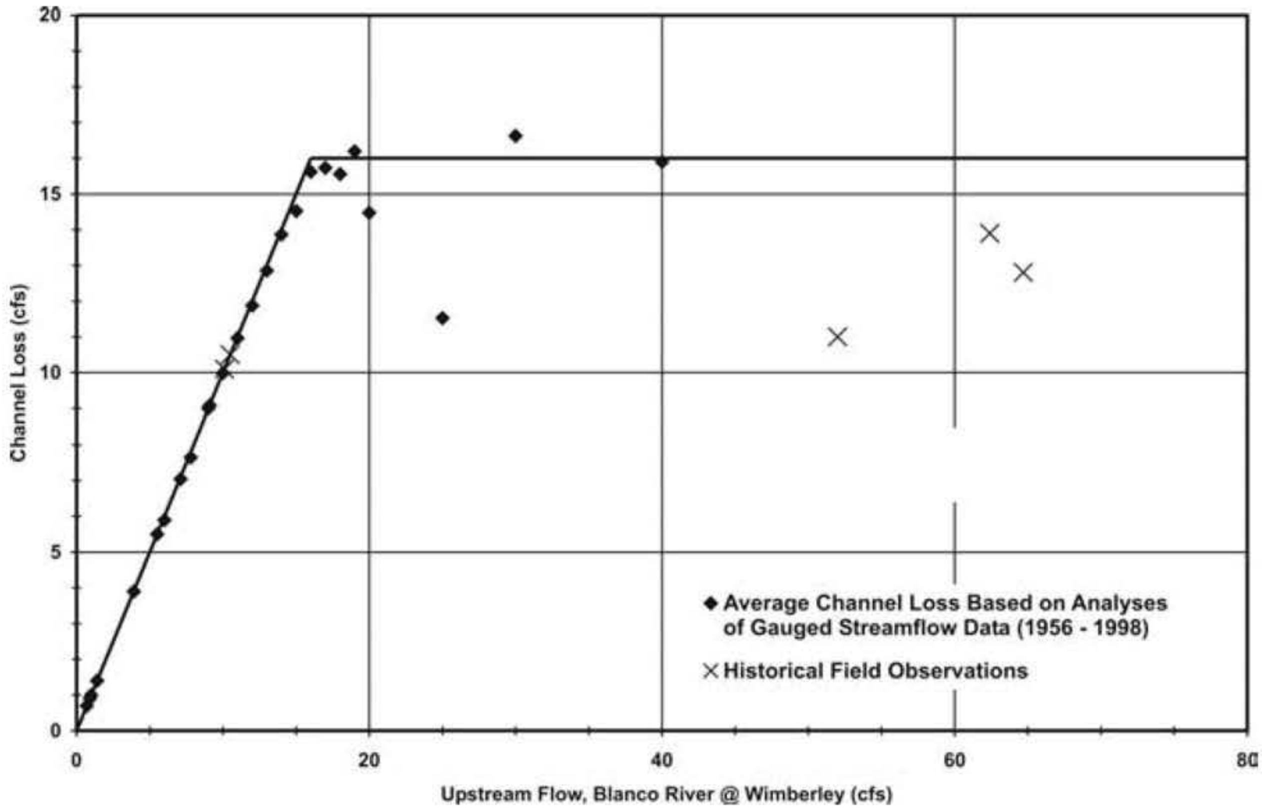


Figure 4-8. Blanco River Channel Loss Between Wimberley Gauge and Kyle Gauge

4.10 Leona Gravels in Nueces Recharge Basin

Streamflow losses typically occur in the West Nueces and Nueces Rivers over the entire Edwards Aquifer recharge zone. However, near the basin outlet, there are two gaining reaches of the Nueces River within the Leona Gravels. This area is considered specifically within HSPF as unique pervious land segments and river reaches including an active groundwater zone, with appropriate hydrologic parameters to differentiate it from the other segments within the Nueces Recharge Basin.

The contribution of water to the most downstream Nueces River reach (RCHRES 17) from the Leona Gravels was determined by correlating water levels in the Edwards Aquifer monitoring well at Uvalde (#6950302) to the flow at the Uvalde gauge on the Nueces River

[15] Ibid.

when the Laguna gauge recorded flows of less than 100 cfs. It has been observed that when flow is less than 100 cfs at Laguna (see Section 4.9), the flow is lost to recharge over the Edwards outcrop, and the concurrent flow that is recorded at the Uvalde gauge is contributed by local runoff or leakage from the Leona Gravels. Figure 4-9 is a plot of Uvalde well level versus Nueces River flow at the Uvalde gauge. There is a defined curve along the upper boundary of the well level data and the lower boundary of the streamflow data that represents the minimum contribution of the Edwards Aquifer to the Nueces River via the Leona Gravels. Based on long-term records for the Uvalde well provided by the EAA and the curve in Figure 4-9, historical leakage from the Edwards Aquifer to the Nueces River through the Leona Gravels was calculated and included as a daily time series in the pilot recharge model of the Nueces Recharge Basin.

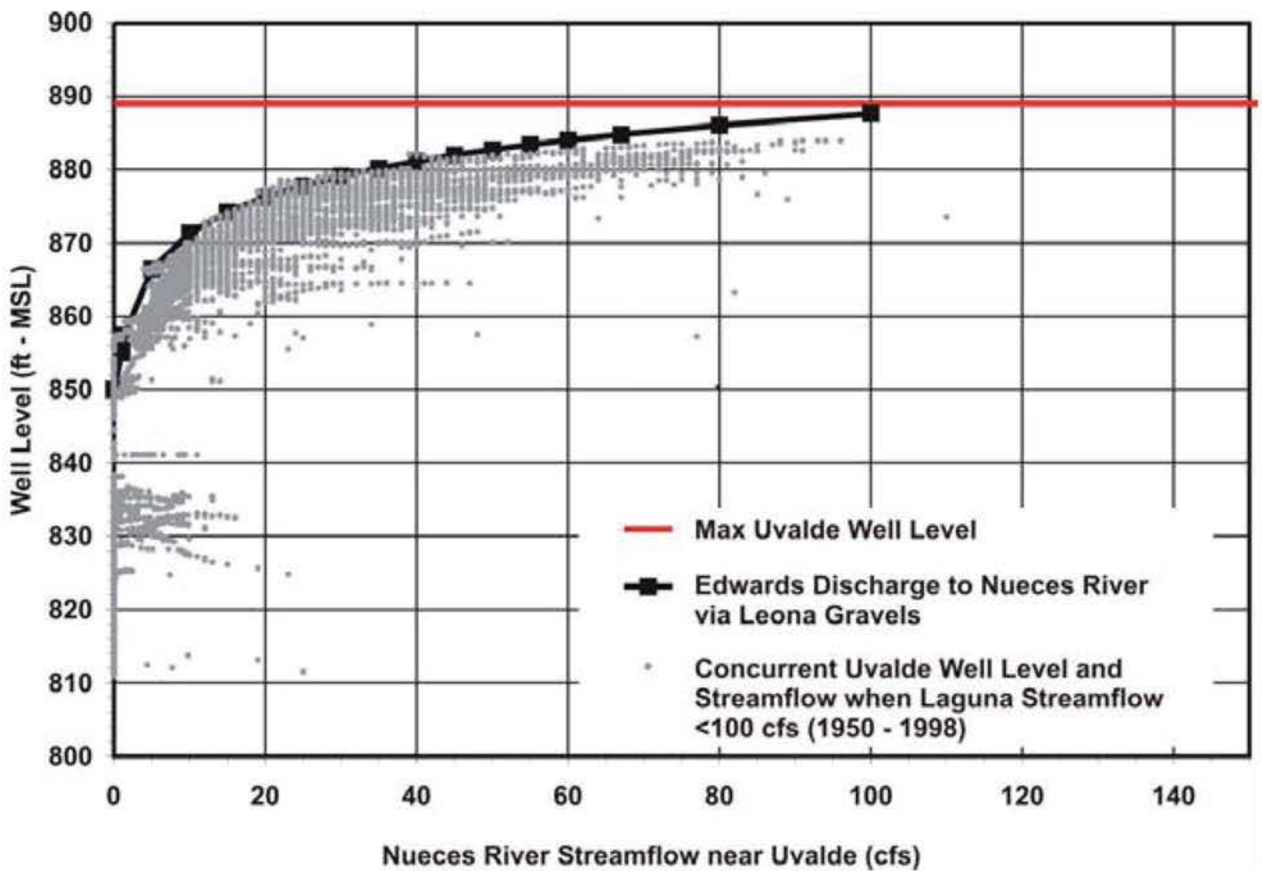


Figure 4-9. Edwards Discharge to Nueces River via Leona Gravels

4.11 Groundwater Divide on West Nueces River

Previous estimations of recharge did not consider recharge into the Edwards Aquifer which occurs upstream of the West Nueces River gauge near Brackettville in their calculations.

This area apparently contributes recharge to the Edwards formation; however, this groundwater is not believed to flow towards Uvalde and San Antonio.[16] The gauges on the West Nueces River (USGS# 08190500) and Nueces River (USGS# 08190000) are at the upper boundaries of the modeled watershed and no recharge occurring upstream is included in totals for the Nueces Recharge Basin.

4.12 Flood Retardation Structure (FRS) Recharge

There are several flood retardation structures designed and constructed by the Natural Resource Conservation Service (NRCS) within the Blanco Recharge Basin.[17] There are two such structures on York Creek, and five in the upper San Marcos River watershed (Sink and Purgatory Creeks). The two flood structures on York Creek control 15.73 square miles, and the five flood structures on Sink and Purgatory Creeks control 78.17 square miles, totaling 93.9 square miles of the 102.9 square miles of the "ungauged" portion of the Blanco Recharge Basin. These seven flood control structures have a total flood storage capacity of 22,688 acft, including sediment reserve. HSPF is used to model these structures as reservoirs, using available information regarding relationships between reservoir stage, storage, discharge, and recharge rate. The two structures in the York Creek watershed were constructed between 1963 and 1967, and the five structures in the Sink Creek and Purgatory Creek watersheds were constructed between 1981 and 1989. As eight different simulations would be required to specifically simulate the phased implementation of the flood control and soil conservation program, these seven structures were modeled as though they existed during the entire 1956 through 1998 simulation period. Information regarding the limited effects of this assumption on Edwards Aquifer recharge estimates is included in Section 5.3.5.

[16] USGS, "Method of Estimating Natural Recharge to the Edwards Aquifer in the San Antonio Area, Texas," Water Resources Investigations 78-10, April 1978.
[17] HDR Engineering, "Trans-Texas Water Program, Edwards Aquifer Recharge Analyses, West Central Texas Study Area – Phase II," San Antonio River Authority, et al, March 1998.

Section 5
Model Calibration and Application

5.1 Introduction

Section 5 includes discussions of the calibration and application of pilot recharge models for the Nueces (Section 5.2) and Blanco (Section 5.3) Recharge Basins. These models have been developed using the Hydrologic Simulation Package – Fortran (HSPF)[1] described in Section 3 and extensive hydrological and physical data resources described in Section 4. Sections 5.2 and 5.3 focus on the following:

- Definition of watershed structure in terms of land segments and river reaches;
- Initial selection and calibration of hydrologic parameters used by HSPF for each of the recharge basins;
- Assessment of the sensitivity of simulated streamflows and recharge estimates to variations in hydrologic parameters;
- Application of the calibrated pilot recharge models;
- Summaries of the simulated water balance for each recharge basin;
- Verification of calibration by comparison of simulated streamflows to gauged historical streamflows;
- Presentation of new estimates of historical Edwards Aquifer recharge from the pilot recharge models; and
- Comparison of new recharge estimates to traditional estimates.

Key hydrologic parameters varied in calibration of the pilot recharge models were generally associated with infiltration rates and storage capacities at and below the ground surface, hydraulic routing factors, and evapo-transpiration indices for deep-rooted vegetation. The inter-relationships between and order of consideration of these key hydrologic parameters within the overall HSPF computational structure defined for the pilot recharge models is summarized in Figure 5-1. Calibration was accomplished through adjustment of these and other appropriate hydrologic parameters in HSPF to ensure that the models provide results consistent with at least three sets of available historical information. These sets of historical information include gauged streamflow immediately downstream of the recharge zone, baseflow immediately upstream of the recharge zone as an indicator of minimum recharge rate over the Edwards

[1] USGS, "Hydrologic Simulation Program – FORTRAN User's Manual for Release 11," September 1996.

outcrop, and traditional estimates of historical recharge. Utility of each of these sets of historical information in the calibration process is described in the following paragraphs.

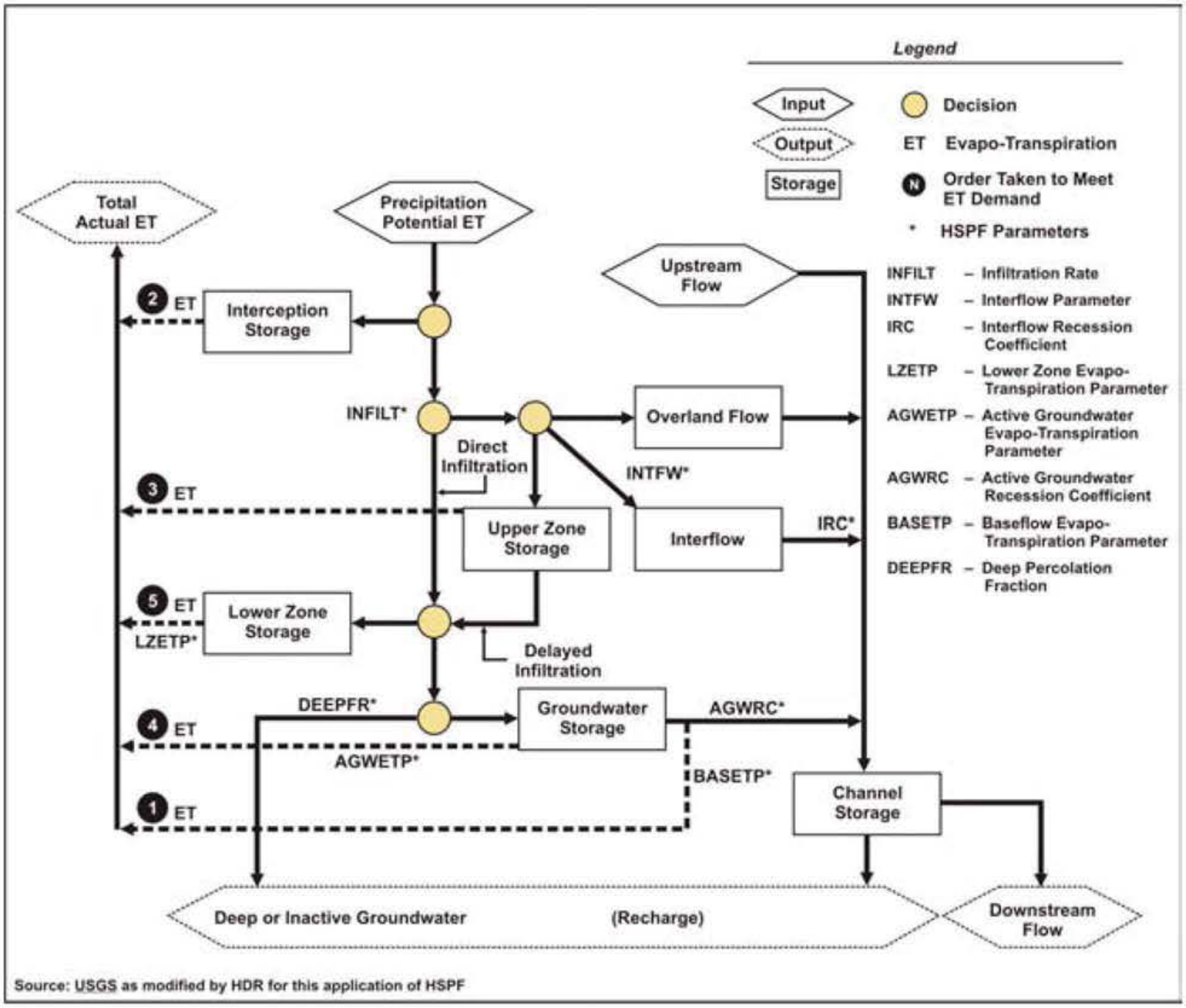


Figure 5-1. HSPF Computational Structure and Key Hydrologic Parameters for Pilot Recharge Model

The primary and most direct measure of model calibration is the ability to replicate daily, monthly, and annual gauged streamflow volumes immediately downstream of the Edwards Aquifer recharge zone. Gauged streamflow series used for calibration include those for the Nueces River near Uvalde (USGS# 08192000) and the Blanco River at Kyle (USGS# 08171300). In addition, long-term surface runoff records for the Dry Comal Creek watershed were considered for calibration of HSPF segments in the Blanco Recharge Basin including Sink, Purgatory, York, and Alligator Creeks, as the hydrologic characteristics of these watersheds are similar. The focus of the calibration effort was to replicate cumulative streamflow volumes over extended periods, rather than peak discharge rates during specific flood events. Particular attention in the calibration process was also given to replication of gauged streamflow frequencies, storm runoff recession characteristics, and low flows during extended drought.

While these streamflow comparisons provide valuable information with respect to simulation of watershed response to rainfall, they do not specifically address the relative proportions of rainfall which do not appear as runoff, but are fated to recharge, evapo-transpiration, and/or transient storage. Published research and referenced traditional estimates of Edwards Aquifer recharge provide some insight into model calibration in terms of the fate of rainfall that does not appear as runoff. Historical recharge estimates obtained from the pilot recharge models are compared to traditional recharge estimates developed by HDR and the USGS in the course of previous studies. These comparisons are primarily based on annual recharge volumes for historical periods of over 40 years in length.

A secondary measure of model calibration considers available information for the watersheds upstream of the Balcones Fault Zone as reflected in gauged streamflow records for the Nueces River at Laguna (USGS# 08190000) and the Blanco River at Wimberley (USGS# 08171000). Gauged streamflows at these locations include both storm runoff and baseflow discharged from the Edwards Plateau Aquifer where it contacts older, less permeable formations. Assuming that the hydrologic characteristics of the Edwards formation on the plateau and in the fault zone are similar (with the exception of the effects of faulting), the baseflow per unit area on the plateau is an indication of minimum recharge per unit area in the fault zone (exclusive of that occurring within the bed and banks of the Nueces, West Nueces, and Blanco Rivers). Baseflow estimates[2] were extracted from the gauged streamflow records and used for comparison to recharge calculated using the pilot recharge models. These comparisons are reported in terms of recharge as a percentage of rainfall.

[2] USGS and USBR, "Base Flow Index (BFI)," Version 4.12, February 2001.

5.2 Nueces Recharge Basin

5.2.1 Input File Parameters

The watershed structure and input file parameters required by HSPF to simulate hydrologic processes within the Nueces Recharge Basin are discussed in this section. The spatial information necessary to represent each basin, which is included in the Users Control Input (UCI) file, includes the area of each land segment (PLS), river reach (RHCRES) length and hydraulic capacity, and the connectivity between each land segment and river reach. There are 17 parameter values within the UCI file that are used to describe the hydrologic characteristics of each land segment in the Nueces Recharge Basin. The complete UCI file is included in Appendix B.

Initial parameter values were chosen for each land segment based upon soil types, land use, topography and vegetative cover. For example, initial parameter values for the interception storage capacity (CEPSC) and lower zone evapo-transpiration parameter (LZETP) were determined for each land use type (keyed to vegetation composition) within the Nueces Recharge Basin watersheds from published research by W.A. Dugas[3] and T.L. Thurow,[4] and HSPF guidance documents.[5,6] The ultimate value of each parameter for individual PLS was determined by calculating a weighted average value based on the percentage of each land use type within the land segment. Land use types included agricultural, forest, range, and barren land. Similar determination of initial parameter values for infiltration rate (INFILT), upper zone storage capacity (UZSN) and lower zone storage capacity (LZSN) within each land segment was accomplished using soils information from STATSGO[7] and the Natural Resource Conservation Service (NRCS), formerly Soil Conservation Service (SCS).[8]

---

[3] Dugas, W.A. and R.A. Hicks. 1998. Effect of removal of *Juniperus ashei* on evapotranspiration and runoff in the Seco Creek watershed. *Water Resources Research.* 34(6): 1499-1509.
[4] Thurow, T.L. and J.W. Hester. 1997. How an increase or reduction in juniper cover alters rangeland hydrology. (pages 4-9 to 4-22) In: C.A. Taylor (editor). *Proceedings of 1997 Juniper Symposium*. Texas Agricultural Experiment Station Technical Report 97-1, Sonora, Texas, 228 pages.
[5] USGS Workshop: "River Basin Simulation Using HSPF Model," October 28-29, Austin TX 1991.
[6] Donigal, A.S. et al. 1984. Application Guide for Hydrological Simulation Program – Fortran (HSPF). EPA-600/3-84-065. 196 pages.
[7] USDS-NRCS Soil Survey Division; National State Soil Geographic Database (STATSGO). Map Scale – 1:250,000. http://www.ftw.nrcs.usds.gov/stat_data.html.
[8] 1970, United States Department of Agriculture, Soil Conservation Service and Texas Agricultural Experiment Station. *Soil Survey of Uvalde County, Texas.*
1992, United States Department of Agriculture, Soil Conservation Service and Texas Agricultural Experiment Station. *Soil Survey of Kinney County, Texas*

5.2.1.1 Land Segments and River Reaches

The Nueces Recharge Basin is simulated in HSPF as eight distinct pervious land segments that cover a total of 435 square miles. Two land segments comprise the contributing zone to the Edwards Aquifer; three land segments represent the recharge zone; two segments are the downdip zone; and one includes the Leona Gravels. Table 5-1 includes the total area of each land segment in square miles and the ID number assigned to each.

Table 5-1. Nueces Recharge Basin Land Segments

Land Segment ID	Description	Area (sqmi)
101	West Nueces Contributing	61.4
102	Nueces River Contributing	8.2
201	West Nueces Recharge	141.8
202	Nueces River Recharge	137.4
203	Upper Nueces Recharge	5.2
301	West Nueces Downdip	21.3
302	Nueces River Downdip	40.5
303	Leona Gravels	19.2
	Total	435.0

The West Nueces River and Nueces River within the Nueces Recharge Basin are simulated in HSPF as seven individual reaches (RCHRES). The West Nueces is divided into two reaches and the Nueces River into five. The location at which each of the rivers is divided is based upon the channel loss characteristics of each reach as measured in previous studies.[9,10] The ID number and length of each reach is described in Table 5-2.

[9] Land, L.F, C.W. Boning, L. Harmsen, and R.D. Reeves. 1983. Streamflow Losses along the Balcones Fault Zone, Nueces River Basin, Texas. USGS Report 83-4368. 72 Pages.
[10] Texas Board of Water Engineers. 1960. Channel Gain and Loss Investigations, Texas Streams, 1918-1958. Bulletin 5807 D. 270 Pages.

Table 5-2. Nueces Recharge Basin River Reaches

River Reach ID	Description	Length (miles)
11	West Nueces River	12.5
12	West Nueces River	29.5
	Subtotal	42.0
13	Nueces River	11.2
14	Nueces River	3.2
15	Nueces River	6.0
16	Nueces River	3.2
17	Nueces River	8.9
	Subtotal	32.5

The linkage between land segments and river reaches is described in the UCI file as the area of each land segment that contributes runoff to each river reach. This connectivity is summarized in Table 5-3.

5.2.1.2 Calibration Parameters

After selecting initial parameters in the Nueces Recharge Basin, the HSPF model was calibrated by adjusting the parameters listed in Table 5-4 which includes a brief description of each of the parameters and the range of values recommended by the USGS for application of HSPF. The final calibration value for each parameter for the land segments over the outcrop is also listed in Table 5-4. For comparison purposes, the value of each parameter used for application of HSPF in the Helotes Creek watershed by the USGS is also included in Table 5-4. Due to differing study objectives and other factors, it is emphasized that parameter selections by the USGS for the Helotes Creek watershed and by HDR for the Nueces Recharge Basin may not necessarily be consistent with one another. The USGS Helotes Creek HSPF application was performed on an hourly timestep using a three-year calibration period for a relatively small urbanizing watershed with a primary focus on flood flow simulation. The Nueces Recharge Basin HSPF application, on the other hand, was performed on a daily timestep using a calibration period in excess of 45 years for a large rural watershed with a primary focus on Edwards Aquifer recharge simulation. The data ranges and calibration values for the parameters listed in Table 5-4 are represented graphically in Figure 5-2.

Table 5-3. Nueces Recharge Basin Land Segment and River Reach Connectivity

Land Segment ID	Contributing Watershed Area (Sqmi)	River Reach ID
101	8.1	11
201	62.0	11
101	53.3	12
102	0.1	12
201	79.7	12
202	0.1	12
202	52.5	12
301	21.3	12
302	0.0	12
101	0.0	13
102	8.1	13
201	0.1	13
201	0.0	14
202	18.6	14
201	0.0	15
202	65.3	15
301	0.0	15
302	4.1	15
303	5.6	15
202	0.9	16
301	0.0	16
302	2.3	16
303	9.1	16
302	34.1	17
303	4.5	17
203	5.2	N/A*
Total	435.0	

* Runoff from the Upper Nueces Recharge Land Segment is accounted for at the USGS Gage at Laguna (#08190000).

Table 5-4. Nueces Recharge Basin Calibration Parameters for Land Segments in Edwards Outcrop

Parameter	Name	Minimum[1]	Maximum[1]	Nueces Outcrop Value	USGS Value (Helotes)[2]	Notes[1]
CEPSC	Interception Storage Capacity Coefficient	0.05	0.2	0.12	0.1	General Range 0.05 - 0.20
INFILT	Infiltration Rate	0.01	0.1	0.04	0.15	Recommended Range 0.01 - 0.1
LZSN	Lower Zone Nominal Storage	0.01	20.0	2.5	5.0	Recommended Range 5.0 - 20.0
LZETP	Lower Zone Evapo-Transpiration Parameter	0.25	0.9	0.28	0.1	Initial Estimates: 0.25 for Rangeland, 0.7 - 0.9 for Heavily Forested Land
UZSN	Upper Zone Nominal Storage	0.01	2.8	0.16	0.25	Recommended Range 0.06 - 0.14 times LZSN
INTFW	Interflow Parameter	0.50	5.0	2.0	0.2	Recommended Range 0.5 to 5.0
KVARY	Non-Exponential Groundwater Recession Parameter	0.0	9999999	0.0	2.0	Should be 0.0 initially; Suggested adjustment of AGWRC & INFILT first
IRC	Interflow Recession Coefficient	0.0	0.999	0.9	0.1	Used to Adjust Hydrograph Shape, Does Not Affect Volumes.
AGWRC	Active Groundwater Recession Coefficient	0.001	0.999	0.99	0.98	$AGWRC = (Q_{t_2}/Q_{t_1})^{(1/n)}$ $n = t_2 - t_1$ (in days)
AGWETP	Active Groundwater Evapo-Transpiration Parameter	0.0	1.0	0.0	0.0	Used for final low flow refinement
BASETP	Baseflow Evapo-Transpiration Parameter	0.0	1.0	0.0	0.0	E-T from Riparian Vegetation
DEEPFR	Deep Percolation Fraction	0.0	1.0	1.0	0.95	Values > 0, shouldn't be used unless can be justified

[1] Based on information from USGS Workshop "River Basin Simulation Using the HSPF Model," Austin, Texas, October 28-29, 1991.
[2] USGS application of HSPF for Helotes Creek, Received via Personal Communication from USGS in San Antonio, Texas.

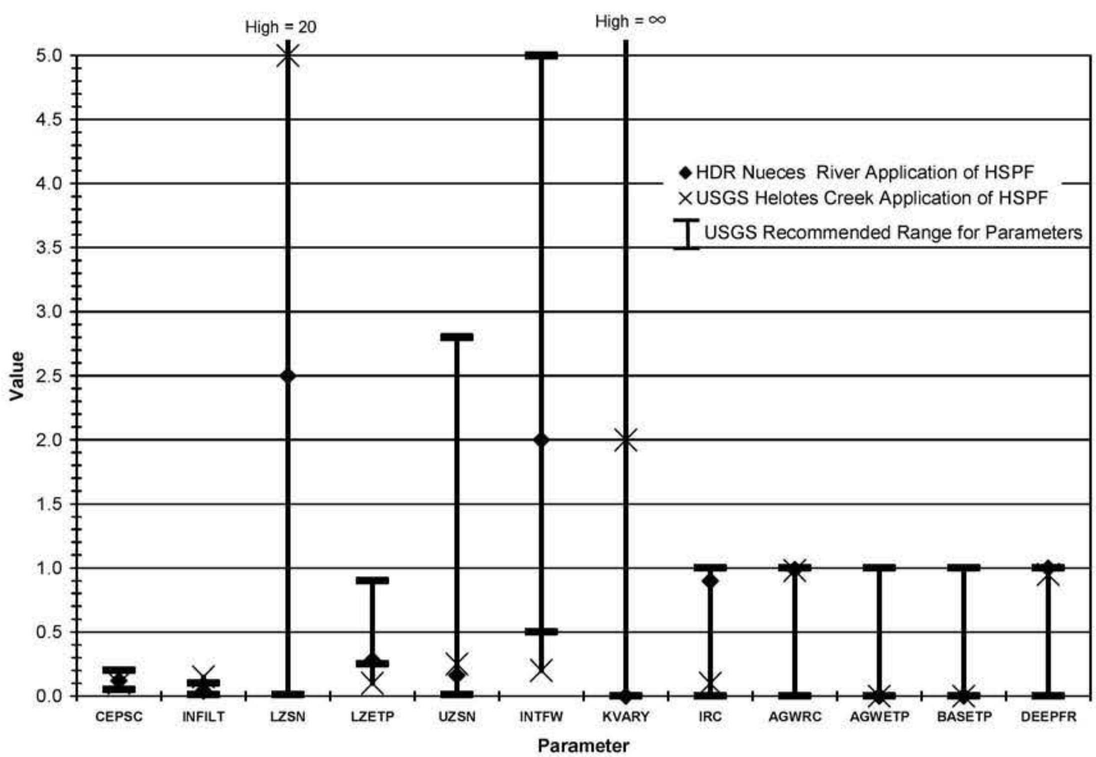


Figure 5-2. Nueces Recharge Basin Calibration Parameters for Land Segments in Edwards Outcrop

All of the calibration parameters for the Nueces Recharge Basin are within the acceptable range of values. The calibrated parameters that are in the high end of this range include IRC, AGWRC, and DEEPFR. Calibration parameters CEPSC, INFILT, LZSN, and INTFW are in the middle of the recommended range. At the low end of the range are calibration parameters LZETP, UZSN, KVARY, AGWETP, and BASETP. The relative positions of these parameter values within the ranges recommended by the USGS is consistent with the outcrop of a karst limestone aquifer in a semi-arid, rural setting dominated by rangeland including some forested areas with live oak, ashe-juniper, and mesquite trees.

5.2.2 Sensitivity Analyses

Sensitivity analyses were performed by individually varying nine key parameters from their calibrated values in order to gauge the relative changes in streamflow and recharge estimates. The nine parameters were individually increased and decreased by 50 percent of the calibrated value, when possible. Certain calibrated values are near the recommended upper/lower bounds for the parameters, and thus increasing/decreasing the parameter value by 50 percent is not possible. The percentage changes in long-term annual averages of recharge and streamflow were calculated. Table 5-5 provides a summary of the streamflow and recharge sensitivity analyses for nine key hydrologic parameters in the pilot recharge model of the Nueces Recharge Basin.

Review of Table 5-5 indicates that simulated streamflow is most sensitive to evapo-transpiration from the near-surface strata (LZETP), active groundwater recession rate (AGWRC), nominal storage within the near-surface strata (UZSN/LZSN), and infiltration rate at the soil surface (INFILT). Similarly, recharge is most sensitive to evapo-transpiration from the near-surface strata (LZETP), deep percolation rate from the near-surface strata into the Edwards Aquifer (DEEPFR), and nominal storage within the near-surface strata (UZSN/LZSN). As simulation of streamflow and recharge are both most sensitive to evapo-transpiration from the near-surface strata (LZETP), well-calibrated estimates of streamflow (which are readily evaluated by comparison to gauged streamflow records) are indicative of sound estimates of recharge (for which there are no physically definitive measured data for comparison).

Table 5-5. Nueces Recharge Basin — Parameter Sensitivity Analyses

Nueces River Streamflow near Uvalde

Parameter	Units	Calibrated Value	Calibrated Average Annual Streamflow* (acft/yr)	Low Parameter Value (LPV)	LPV Average Annual Streamflow* (acft/yr)	% Difference - Streamflow (LPV to Calibration)	High Parameter Value (HPV)	HPV Average Annual Streamflow* (acft/yr)	% Difference - Streamflow (HPV to Calibration)
CEPSC	1/day	0.12	116,937	0.06	118,359	1.22%	0.18	116,670	-0.23%
INFILT	in/hr	0.04	116,937	0.02	126,044	7.79%	0.06	114,703	-1.91%
LZSN	in	2.5	116,937	1.3	122,857	5.06%	3.8	114,801	-1.83%
LZETP		0.28	116,937	0.14	126,868	8.49%	0.42	112,306	-3.96%
UZSN	in	0.16	116,937	0.08	119,984	2.61%	0.24	115,365	-1.34%
UZSN/LZSN		0.16/2.5	116,937	0.08/1.3	124,974	6.87%	0.24/3.8	112,867	-3.48%
INTFW		2.0	116,937	1.0	118,005	0.91%	3.0	117,138	0.17%
AGWRC	1/day	0.99	116,937	0.50	130,979	12.01%	-	-	-
DEEPFR		1.0	116,937	0.5	124,892	6.80%	-	-	-

Edwards Aquifer Recharge

Parameter	Units	Calibrated Value	Calibrated Average Annual Recharge (acft/yr)	Low Parameter Value (LPV)	LPV Average Annual Recharge (acft/yr)	% Difference - Recharge (LPV to Calibration)	High Parameter Value (HPV)	HPV Average Annual Recharge (acft/yr)	% Difference - Recharge (HPV to Calibration)
CEPSC	1/day	0.12	114,651	0.06	129,089	12.59%	0.18	109,598	-4.41%
INFILT	in/hr	0.04	114,651	0.02	108,347	-5.50%	0.06	121,135	5.66%
LZSN	in	2.5	114,651	1.3	130,121	13.49%	3.8	106,759	-6.88%
LZETP		0.28	114,651	0.14	163,712	42.79%	0.42	92,268	-19.52%
UZSN	in	0.16	114,651	0.08	118,776	3.60%	0.24	113,111	-1.34%
UZSN/LZSN		0.16/2.5	114,651	0.08/1.3	130,762	14.05%	0.24/3.8	106,546	-7.07%
INTFW		2.0	114,651	1.0	114,934	0.25%	3.0	117,467	2.46%
AGWRC	1/day	0.99	114,651	0.50	119,318	4.07%	-	-	-
DEEPFR		1.0	114,651	0.5	89,243	-22.16%	-	-	-

*Does not include 1955

5.2.3 Water Balance

The simulated water balance from the pilot recharge model for the land segments in the Nueces Recharge Basin is shown in Table 5-6. For the simulation period from 1950 to 1998, there is an average annual balance of 1,214 acft/yr (0.2 percent of precipitation) that results, in part, from the selection of initial values for several soil strata storage parameters used by HSPF. This balance could be reduced by iterative application of the model to more specifically define initial storage parameter values (thereby modifying the change in storage over the simulation period), however, resulting changes in Edwards Aquifer recharge and other components of the water balance would be very small.

The fate of precipitation on the land segments is illustrated by percent in Figure 5-3. Together, simulated evapo-transpiration (including interception) and Edwards recharge account for almost 96 percent of precipitation on the land segments. HSPF results are consistent with the findings of research supported by the Texas Agriculture Experiment Station and based on studies of the Cusenbary Draw watershed on the Edwards Plateau in Sutton County.[11] Researchers reported that more than 94 percent of precipitation is converted to interception loss, transpiration, and soil evaporation as percentages of woody cover exceed 10 percent on an areal basis. Estimates of potential evapo-transpiration used in the pilot recharge models are reasonably consistent with those available from the Texas ET Network,[12] regional weather stations (including Sea World, NCDC# 418169), and other sources.[13] Long-term average "actual" evapo-transpiration simulated by HSPF is about one-third of potential evapo-transpiration in the Nueces Recharge Basin as compared to about one-half of potential evapo-transpiration in the Blanco Recharge Basin. This is consistent with less frequent rainfall and lower soil moisture typical of the Nueces Recharge Basin.

[11] Wu, X. B., Redeker, E. J., and Thurow, T. L., "Vegetation and Water Yield Dynamics in an Edwards Plateau Watershed," Journal of Range Management, March 2001.
[12] Texas A&M University, "Average Historic PET," Texas ET Network, Texas Cooperative Extension, Texas Agricultural Experiment Station, http://texaset.tamu.edu/pet.php.
[13] Potential Evapo-Transpiration data prior to 9/1/2001 available from the Texas A&M Research & Extension Center at Uvalde is considered high and scheduled to be recalculated per personal communication with Dr. M. Keith Owens in June 2002.

Table 5-6. Nueces Recharge Basin Water Balance for Land Segments

Land Segment ID	Precipitation (acft/yr)	Total Actual E-T (acft/yr)	Runoff / Outflow[1] (acft/yr)	Change in Storage (acft/yr)	Edwards Recharge (acft/yr)	Recharge to Younger Formations (acft/yr)	Balance (acft/yr)
101	86,478	75,788	5,667	126	4,583	--	313
102	11,629	9,974	614	32	987	--	21
201	177,152	145,539	2,727	164	28,322	--	400
202	181,000	145,189	3,351	191	31,994	--	275
203	7,268	5,601	215	8	1,434	--	9
301	26,647	24,650	1,744	115	--	83	55
302	52,485	47,602	4,371	232	--	193	86
303	24,907	22,609	2,046	108	--	90	54
Total	567,565	476,952	20,735	977	67,321	366	1,214

[1] Portions of this outflow recharge the Edwards Aquifer in river reaches over the outcrop.

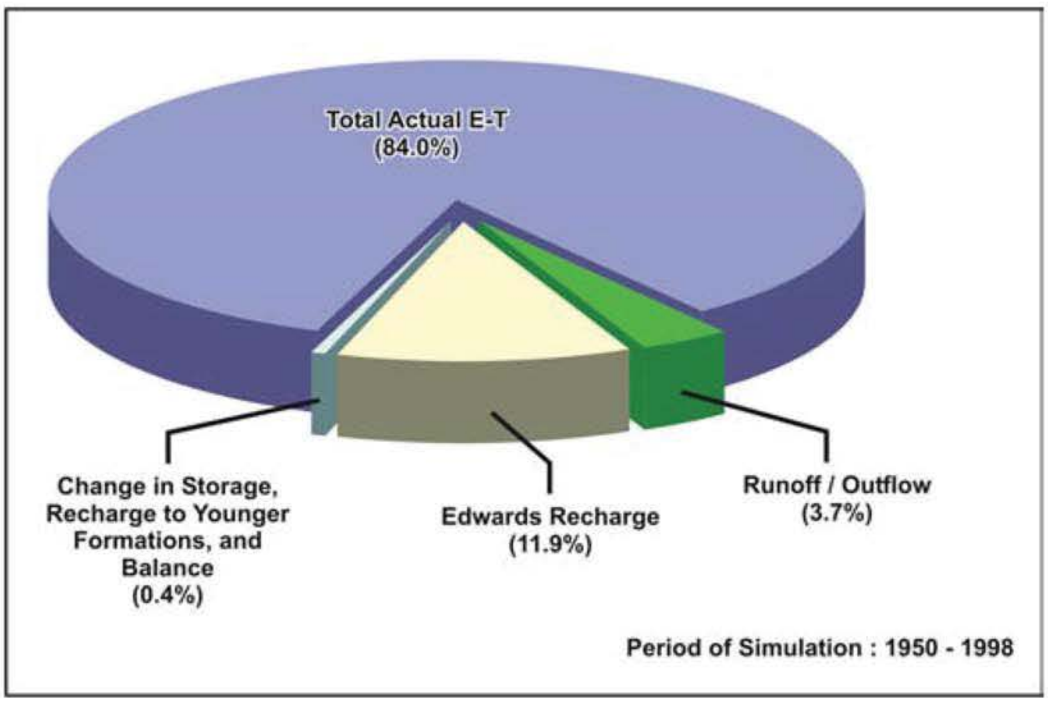


Figure 5-3. Nueces Recharge Basin — Fate of Precipitation on Land Segments

Figure 5-4 summarizes the water balance of the entire Nueces Recharge Basin simulation, including both land segments and river reaches for the entire simulation period. The recharge value included in this figure is the gross simulated recharge. Net recharge is obtained by accounting for the transfer of water to the lower reach of the Nueces River from the Edwards formation through the Leona Gravels as described in Section 4.10. This computation of net recharge is consistent with traditional methods and appropriate for use in groundwater simulation models that do not explicitly simulate such losses from the Edwards Aquifer to the Nueces River.

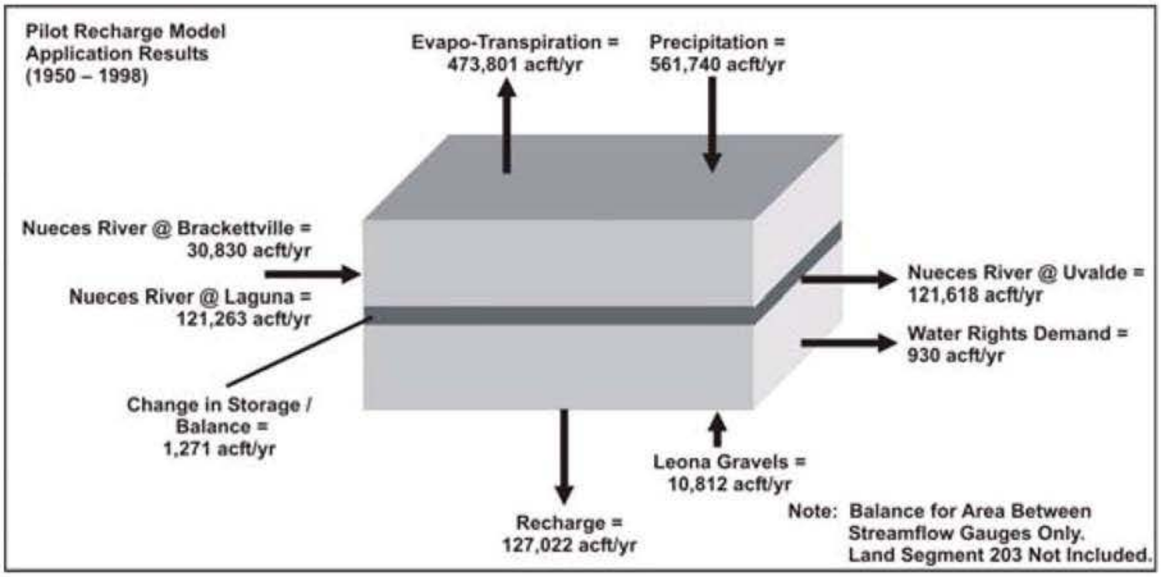


Figure 5-4. Nueces Recharge Basin — Overall Water Balance

5.2.4 Streamflow Comparisons

HSPF simulates surface and sub-surface hydrologic processes occurring in the defined land segments including runoff, interflow, and baseflow, all of which contribute lateral inflow to river reaches from the land segments. The river reaches are connected in the HSPF model through a series of linkages assigning outflows from an upstream reach as inflows to a downstream reach. The outflow from the final downstream reach in the HSPF pilot recharge model is the simulated streamflow at the site of the USGS gauging station on the Nueces River near Uvalde. The simulated streamflows from the HSPF model are compared to the actual historical streamflow data by consideration of long-term averages, daily time series for selected years, daily streamflow frequency, and annual totals.

5.2.4.1 Long-Term Averages

The historical annual average streamflow for the Nueces River near Uvalde (1950-1998) is 115,175 acft/yr, and the simulated annual average streamflow is 117,345 acft/yr, a difference of 2,170 acft/yr or about 1.9 percent.

5.2.4.2 Time Series for Selected Years and Daily Streamflow Frequency

Four years were chosen for direct daily comparison of simulated streamflows to historical gauged streamflows. These years are representative of: recent (1998), average (1968), wet (1958), and dry (1993) conditions. Historical and simulated streamflows for the Nueces River near Uvalde are presented in Figures 5-5 through 5-8 for the representative years. Review of these figures indicates that the calibrated HSPF model provides a very reasonable simulation of daily streamflows, particularly during stormflow recession periods and extended baseflow periods during mild to severe drought. With respect to recharge occurring in the river, accurate simulation of these stormflow recession and baseflow periods is more important than matching peak daily discharges.

Accurate simulation of low flows during early 1998, late 1968, and all of 1993 is primarily a result of accounting for Edwards Aquifer discharge to the Nueces River through the Leona Gravels as described in Section 4.10. On the other hand, inaccuracies in simulation of runoff from storm events in early 1958 may be associated with inadequate estimates of daily precipitation within the 430 square mile intervening watershed above the gauge near Uvalde and below the gauges upstream of the Edwards outcrop. Use of precipitation data from the EAA network should minimize these inaccuracies in the future.

Figure 5-9 provides a comparison of the frequency of occurrence of simulated and gauged historical streamflows for the Nueces River near Uvalde. HSPF clearly performs quite well in simulating the frequency of occurrence of streamflows less than 300 cfs.

5.2.4.3 Annual Values

Annual values of historical gauged streamflow and HSPF simulated streamflow are compared in Figure 5-10. Linear regression is used to measure how closely the simulated streamflows approximate the historical streamflows over the full range of observed annual values. Ideally, the regression equation would have a slope coefficient of 1.0, an intercept of 0.0, and a coefficient of determination (r^2) of 1.0 indicating a perfect match between simulated and historical streamflows.

As is apparent in Figure 5-10, simulated streamflows from the HSPF recharge model are highly correlated with historical streamflows on an annual basis. Application of the Students t test[14] to the linear regression coefficients indicates that one cannot reject that the slope coefficient is equal to 1.0 and the intercept is equal to 0.0 with a statistically significant degree of confidence. It is noted that calendar year 1955 was excluded from the streamflow comparison because the greatest instantaneous peak discharge recorded for the Nueces River near Uvalde (USGS# 08192000) occurred during that year.

[14] Haan, C.T., "Statistical Methods in Hydrology," Iowa State University Press, 1977.

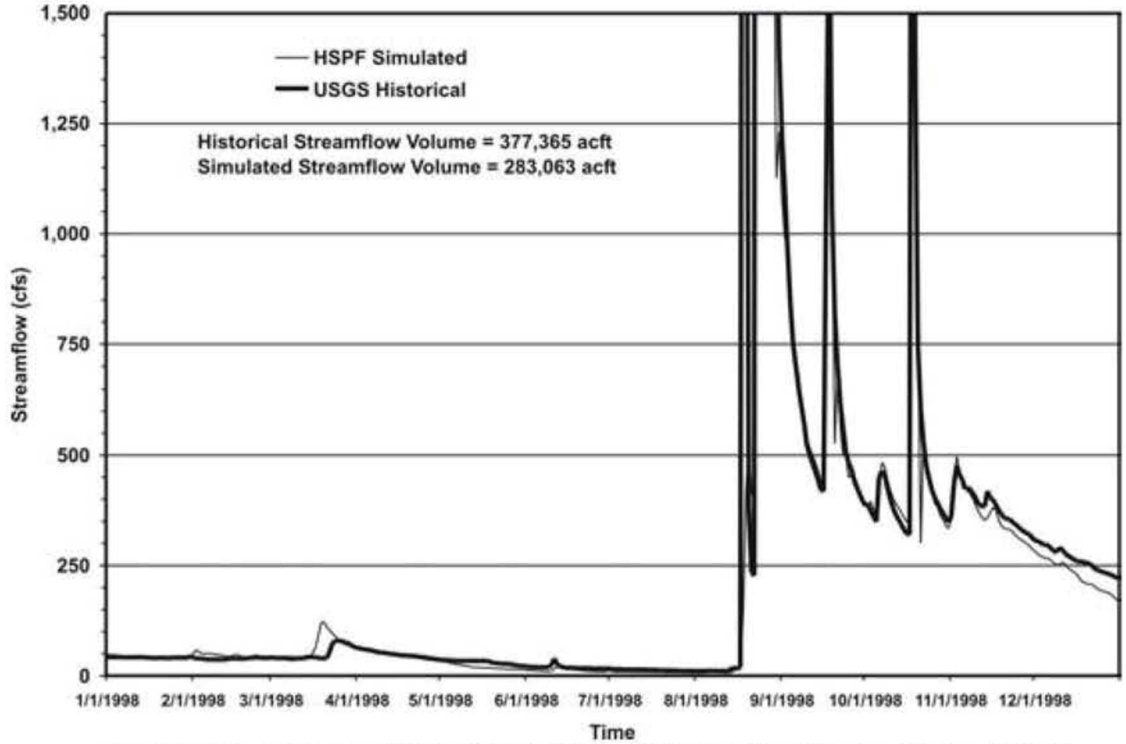


Figure 5-5. Nueces River @ Uvalde — Streamflow Comparison (1998)

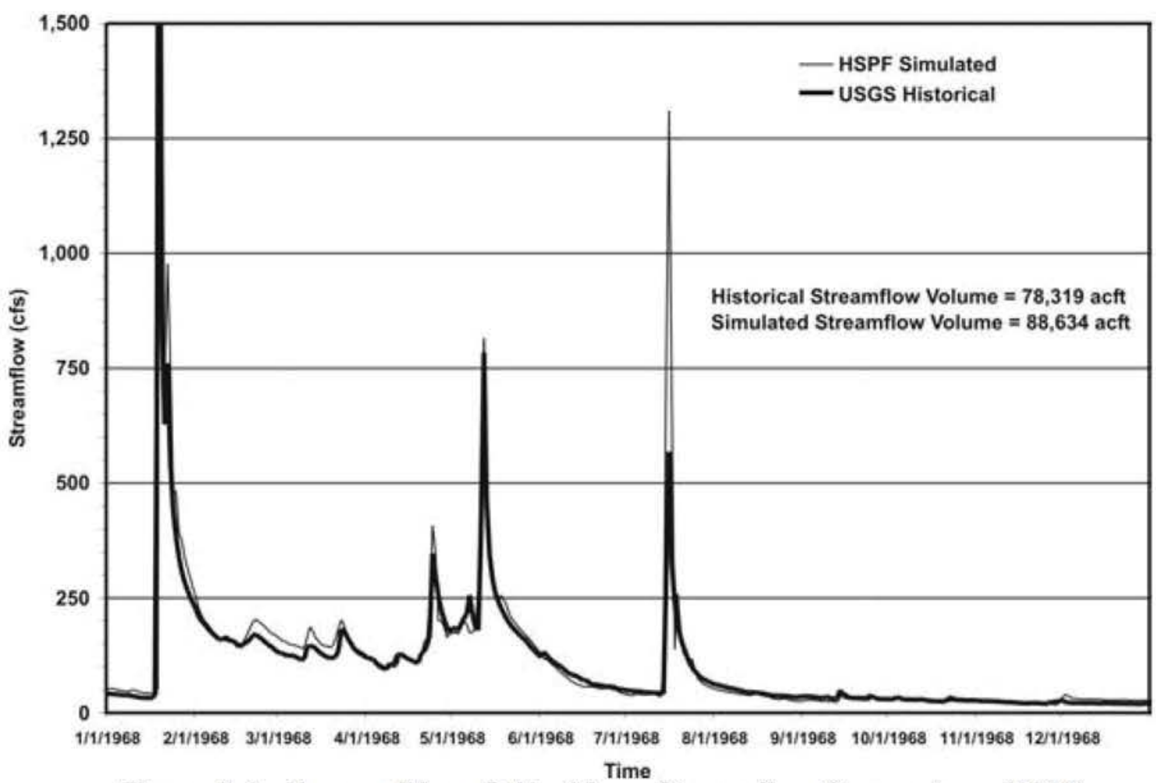


Figure 5-6. Nueces River @ Uvalde — Streamflow Comparison (1968)

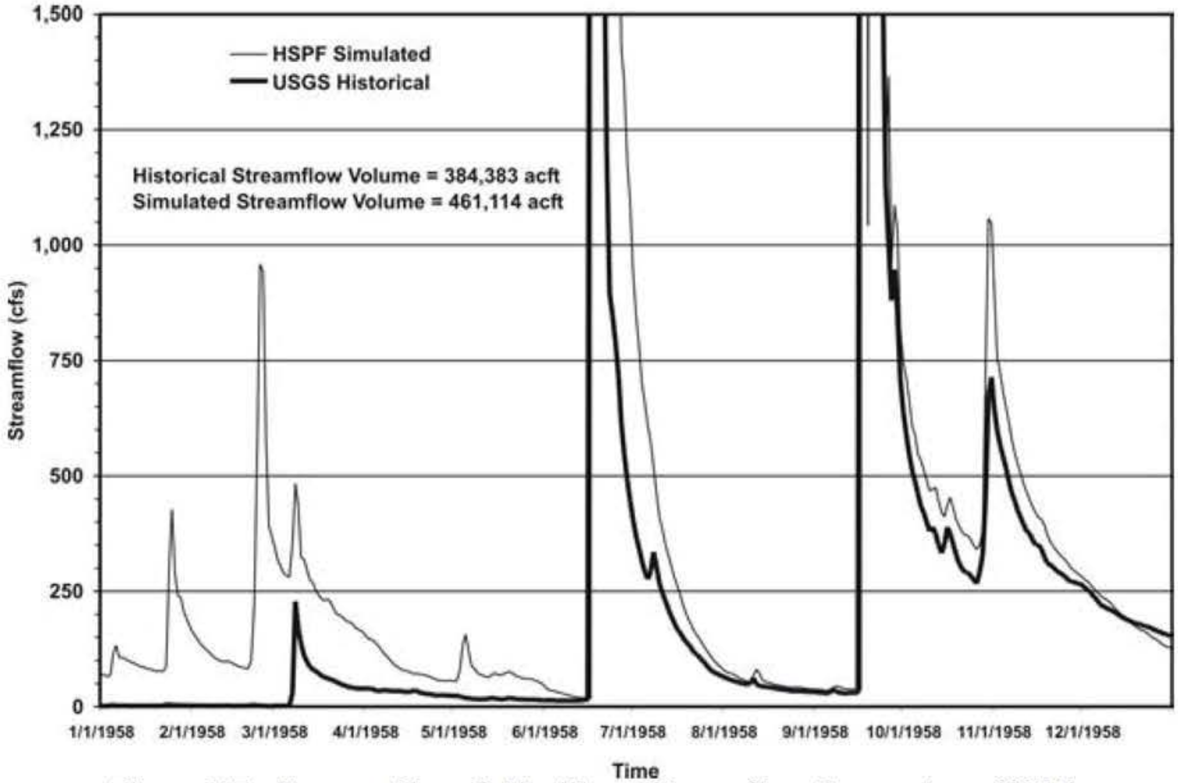


Figure 5-7. Nueces River @ Uvalde — Streamflow Comparison (1958)

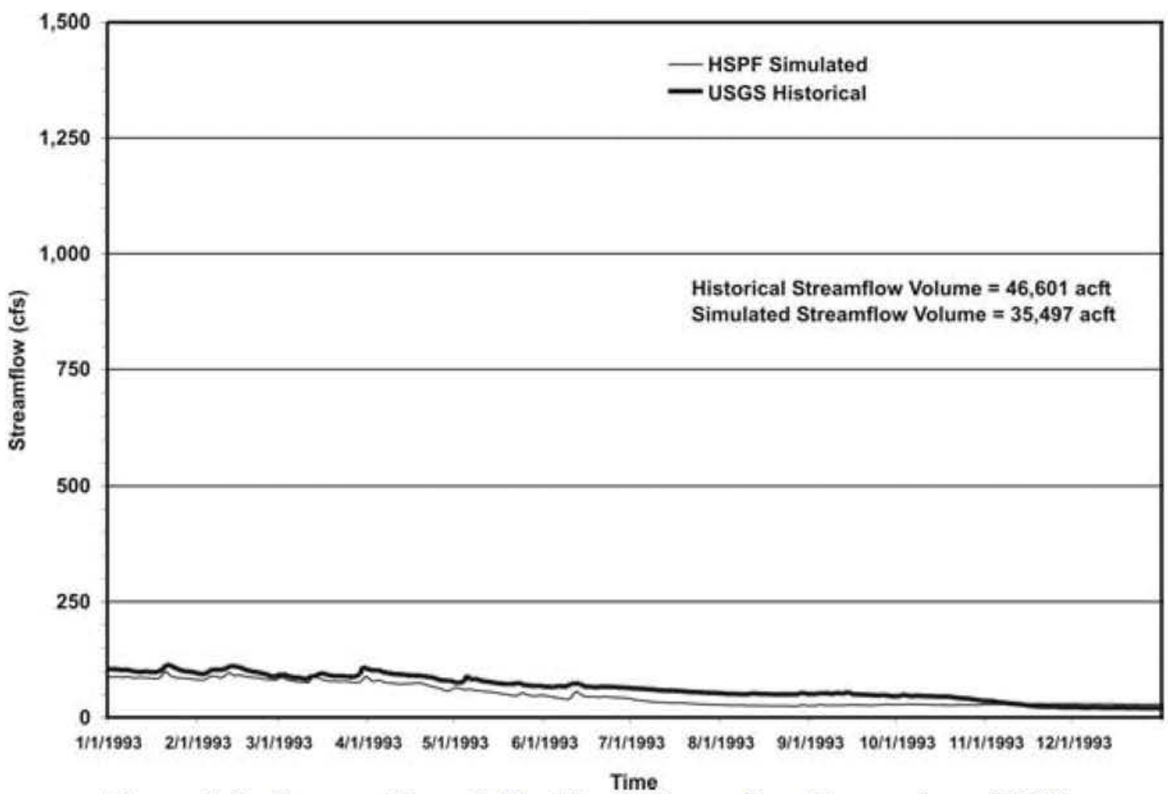


Figure 5-8. Nueces River @ Uvalde — Streamflow Comparison (1993)

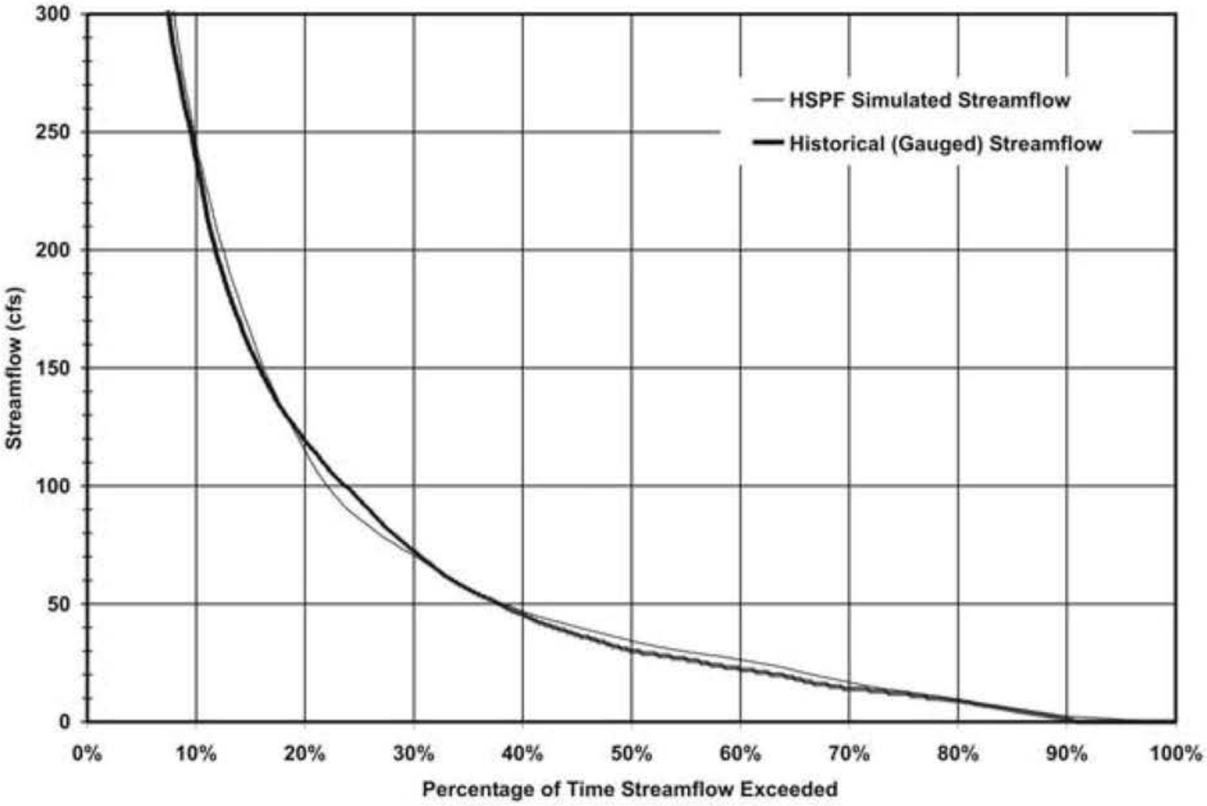


Figure 5-9. Nueces River @ Uvalde — Daily Streamflow Frequency (1950 – 1998)

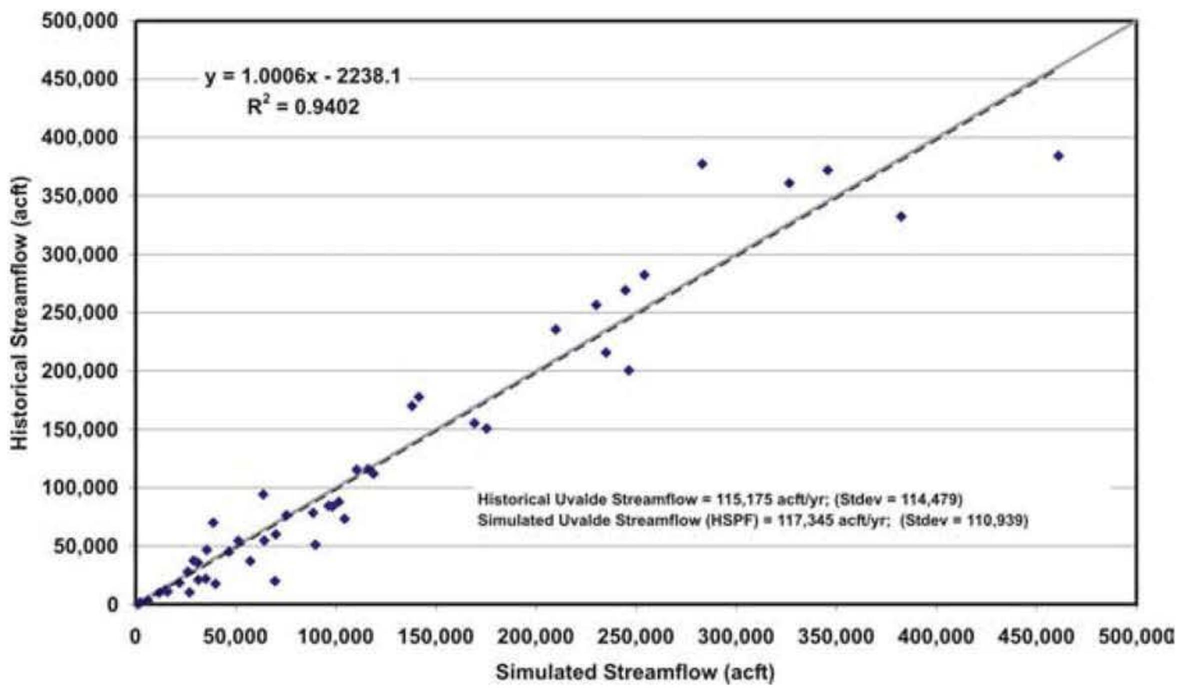


Figure 5-10. Nueces River @ Uvalde — Streamflow Comparison (1950 – 1998)
(1955 not Included in Calibration Analyses)

5.2.5 Calibrated Recharge Estimates

The calibrated pilot recharge model of the Nueces Recharge Basin, as formulated in HSPF, was applied for the full 1950 through 1998 historical period for which hydrologic data are available. Calculated annual Edwards Aquifer recharge for the full historical period averages 117,280 acft and ranged from a minimum of 14,334 acft in 1993 to a maximum of 330,368 acft in 1958. Approximately 48 percent of the calculated recharge occurs in the Nueces and West Nueces River reaches and 52 percent occurs in the land segments including the outcrop of the Edwards formation. Additional information regarding the geographical distribution of recharge for use in the new Edwards Aquifer model is included in Appendix G. A summary of monthly recharge estimates for the Nueces Recharge Basin is included in Appendix A.

Simulation results for the 1950 through 1996 historical period have been extracted for direct comparison of new to traditional estimates of Edwards Aquifer recharge. Simulated annual recharge estimates from HSPF are compared to the those previously reported by HDR[15] in Figures 5-11 and 5-12 and to those previously reported by the USGS[16] in Figures 5-13 and 5-14. It is apparent upon consideration of these figures that HSPF simulated recharge is more highly correlated with traditional recharge estimates developed by the USGS than those developed by HDR. Long-term (1950-1996) average USGS recharge (119,524 acft/yr) is about 4.3 percent greater than that from HSPF (114,651 acft/yr) while the comparable average previously developed by HDR (88,608 acft/yr) is about 22.7 percent less than that from HSPF. Cumulative recharge estimates from HSPF and the two traditional methods are summarized in Figure 5-15 for the historical period beginning in 1950. Differences between HSPF and traditional HDR and USGS recharge estimates are justified by refined/enhanced watershed simulation capabilities in the HSPF pilot recharge model, including daily timestep computations and more explicit representation of watershed characteristics and hydrologic processes.

Baseflows have been extracted from the daily streamflow records for the gauging station on the Nueces River at Laguna for use as an approximation of Edwards Plateau Aquifer recharge and an indicator of minimum recharge occurring outside of the bed and banks of the Nueces and West Nueces Rivers on the outcrop of the Edwards Aquifer. For the 1950 through 1996

[15] HDR, "Edwards Aquifer Recharge Analyses, Edwards Aquifer Recharge Update," Trans-Texas Water Program, West Central Study Area, Phase II, San Antonio River Authority, et al., March 1998..
[16] USGS, "Method of Estimating Natural Recharge to the Edwards Aquifer in the San Antonio Area, Texas," Water Resources Investigations 78-10, April 1978.

historical period, these baseflows are indicative of an average Edwards Plateau Aquifer recharge rate of about 69,800 acft/yr, alternatively expressed as 1.78 inches/yr or 7.1 percent of average annual rainfall. This is within the range of estimated recharge rates for the Trinity Aquifer in the Hill Country area reported by the Texas Water Development Board[17] (1.5 to 11.0 percent of average annual rainfall). Application of the calibrated pilot recharge model results in an average Edwards Aquifer recharge rate, exclusive of that directly occurring in the rivers, of about 60,000 acft/yr, alternatively expressed as 2.62 inches/yr or 10.7 percent of average annual rainfall. Hence, the pilot recharge model indicates that recharge as a percentage of average annual rainfall is approximately 51 percent greater over the outcrop of the Edwards Aquifer than over the outcrop of the Edwards Plateau Aquifer.

[17] TWDB, "Groundwater Availability of the Trinity Aquifer, Hill Country Area, Texas: Numerical Simulations through 2050," Report 353, September 2000.

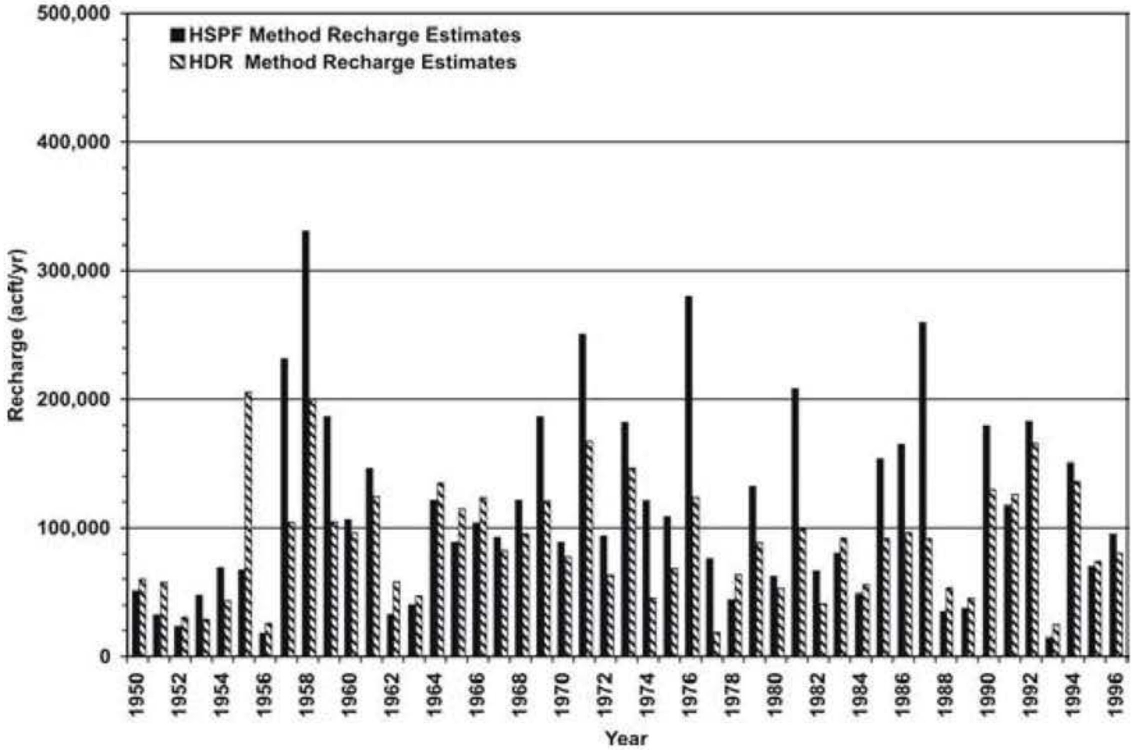


Figure 5-11. Nueces Recharge Basin — Annual Recharge Comparison with Traditional HDR Estimates

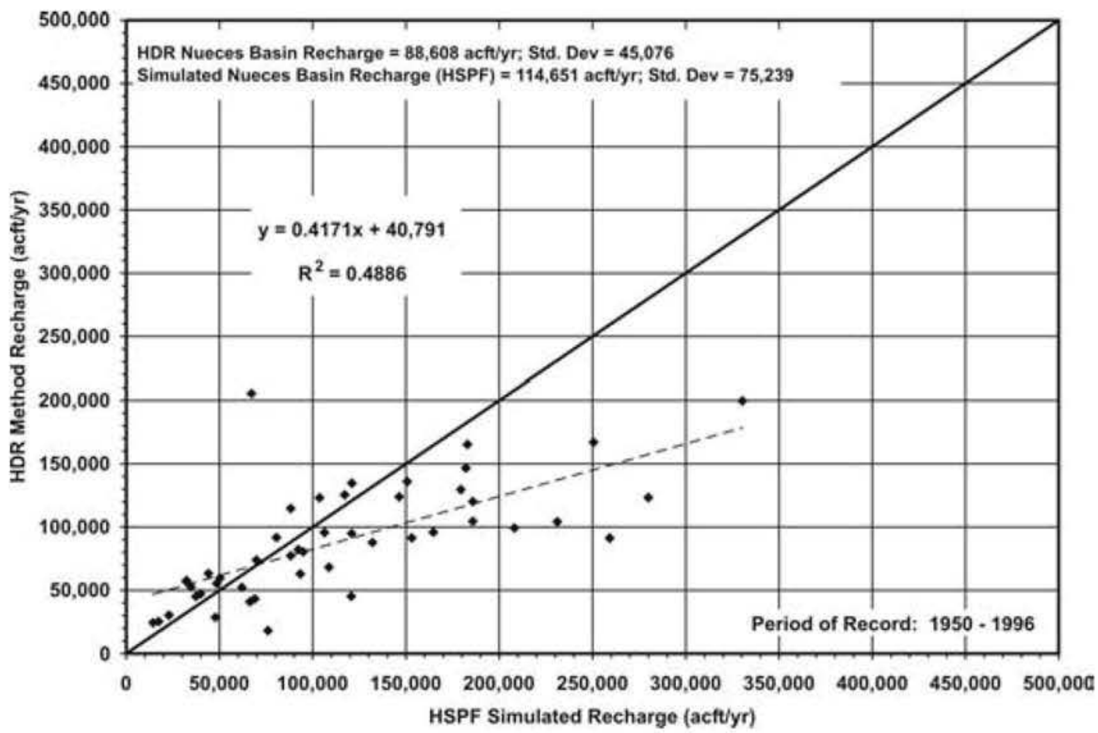


Figure 5-12. Nueces Recharge Basin — Recharge Comparison with Traditional HDR Estimates

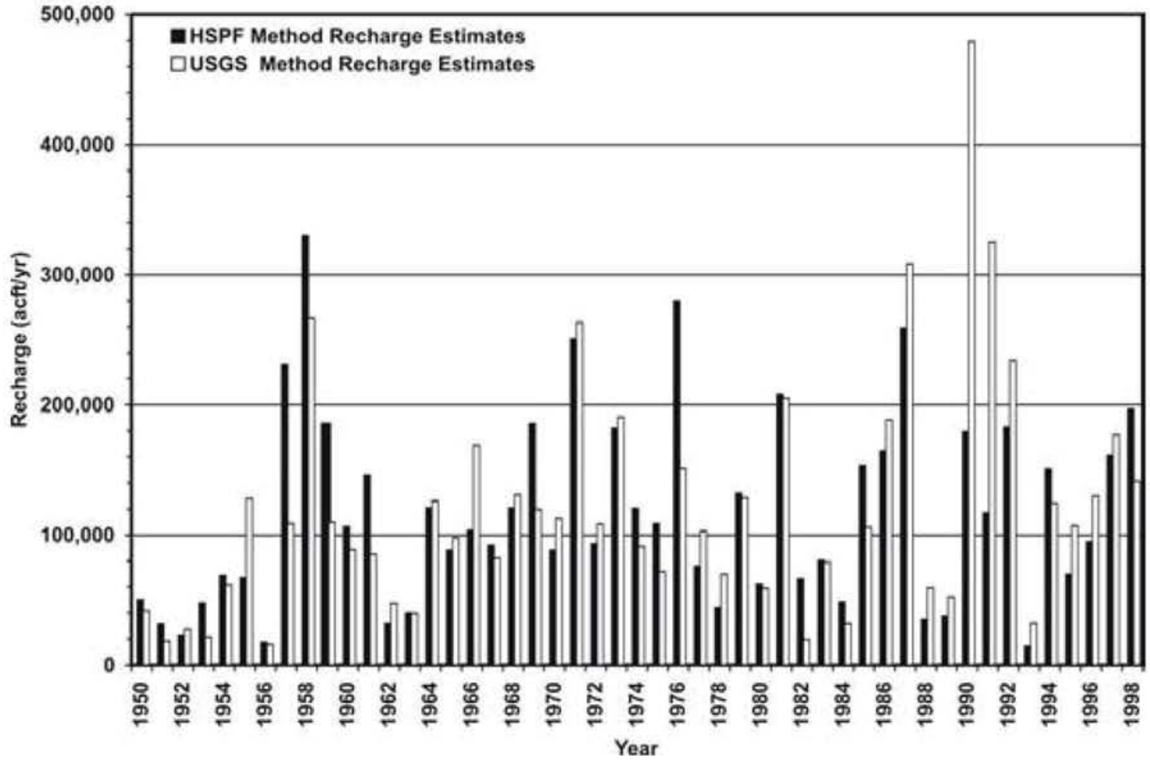


Figure 5-13. Nueces Recharge Basin — Annual Recharge Comparison with Traditional USGS Estimates

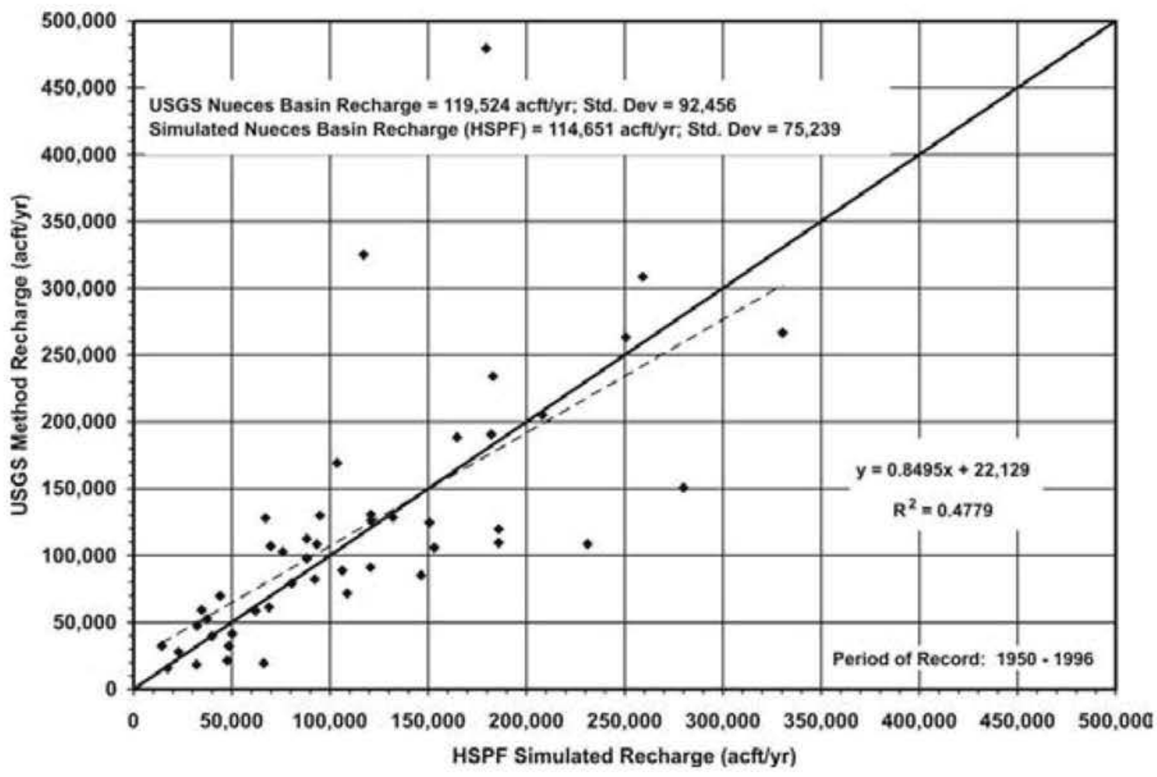


Figure 5-14. Nueces Recharge Basin — Recharge Comparison with Traditional USGS Estimates

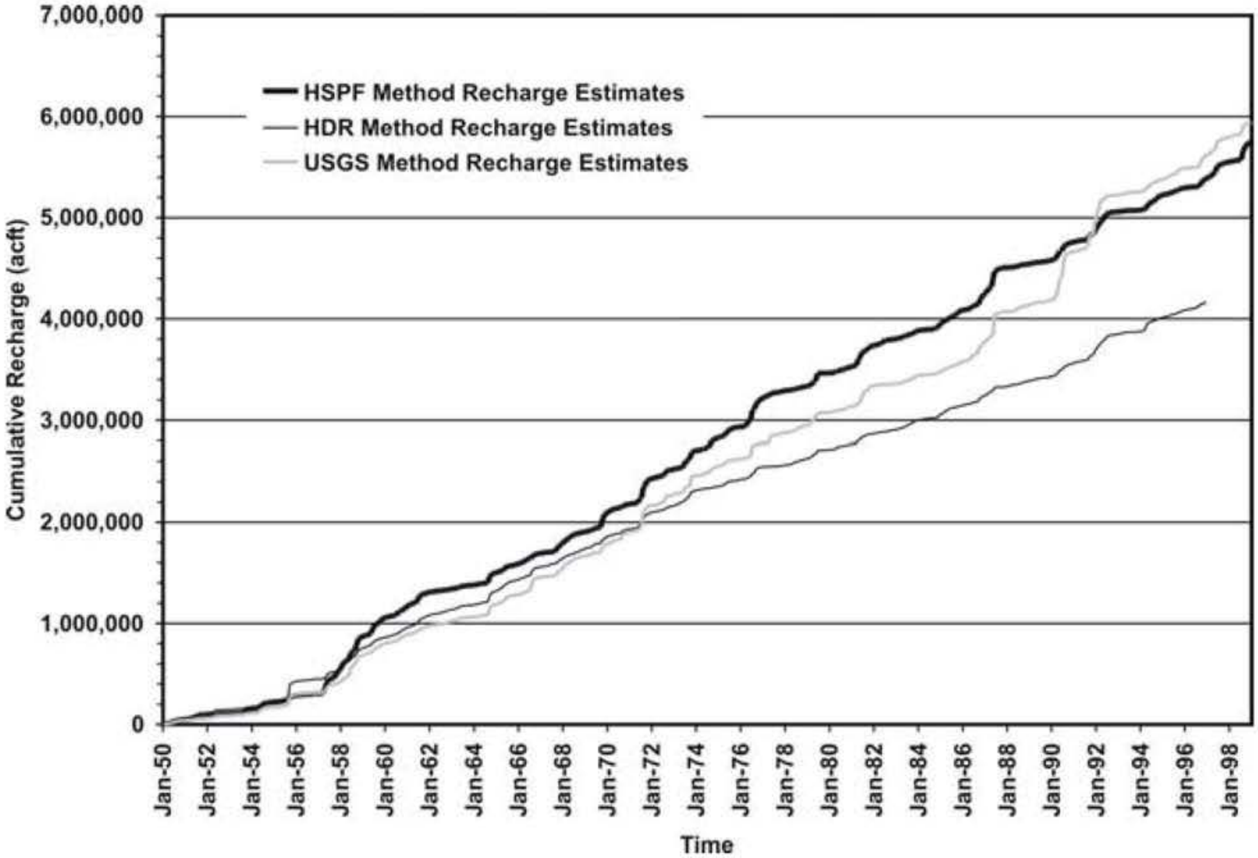


Figure 5-15. Nueces Recharge Basin — Cumulative Recharge Comparison

5.3 Blanco Recharge Basin

5.3.1 Input File Parameters

The watershed structure and input file parameters required by HSPF to simulate hydrologic processes within the Blanco Recharge Basin are discussed in this section. The spatial information necessary to represent each basin, which is included in the Users Control Input (UCI) file, includes the area of each land segment (PLS), river reach (RHCRES) length and hydraulic capacity, and the connectivity between each land segment and river reach. There are 17 parameter values within the UCI file that are used to describe the hydrologic characteristics of each land segment in the Blanco Recharge Basin. The complete UCI file is included in Appendix B.

Initial parameter values were chosen for each land segment based upon soil types, land use, topography and vegetative cover. For example, initial parameter values for the interception storage capacity (CEPSC) and lower zone evapo-transpiration parameter (LZETP) were determined for each land use type (keyed to vegetation composition) within the Blanco Recharge Basin watersheds from published research by W.A. Dugas[18] and T.L. Thurow,[19] and HSPF guidance documents.[20,21] The ultimate value of each parameter for individual PLS was determined by calculating a weighted average value based on the percentage of each land use type within the land segment. Land use types included agricultural, forest, range, and barren land. Similar determination of initial parameter values for infiltration rate (INFILT), upper zone storage capacity (UZSN) and lower zone storage capacity (LZSN) within each land segment was accomplished using soils information from STATSGO[22] and the Natural Resource Conservation Service (NRCS), formerly Soil Conservation Service (SCS).[23]

[18] Dugas, W.A. and R.A. Hicks. 1998. Effect of removal of *Juniperus ashei* on evapotranspiration and runoff in the Seco Creek watershed. *Water Resources Research.* 34(6): 1499-1509.
[19] Thurow, T.L. and J.W. Hester. 1997. How an increase or reduction in juniper cover alters rangeland hydrology. (pages 4-9 to 4-22) In: C.A. Taylor (editor). *Proceedings of 1997 Juniper Symposium*. Texas Agricultural Experiment Station Technical Report 97-1, Sonora, Texas, 228 pages.
[20] USGS Workshop: "River Basin Simulation Using HSPF Model," October 28-29, Austin TX 1991.
[21] Donigal, A.S. et al. 1984. Application Guide for Hydrological Simulation Program – Fortran (HSPF). EPA-600/3-84-065. 196 pages.
[22] USDS-NRCS Soil Survey Division; National State Soil Geographic Database (STATSGO). Map Scale – 1:250,000. http://www.ftw.nrcs.usds.gov/stat_data.html.
[23] 1984, United States Department of Agriculture, Soil Conservation Service and Texas Agricultural Experiment Station. *Soil Survey of Comal and Hays Counties, Texas.*

5.3.1.1 Land Segments and River Reaches

The Blanco Recharge Basin is simulated in HSPF as seven distinct pervious land segments that cover a total of 171.3 square miles. One land segment comprises the contributing zone to the Edwards Aquifer; four land segments represent the recharge zone; and two segments are the downdip zone. Table 5-7 includes the total area of each land segment in square miles and the ID number assigned to each.

Table 5-7. Blanco Recharge Basin Land Segments

Land Segment ID	*LS Description*	*Area (sqmi)*
101	Blanco River Contributing	24.6
201	Blanco River Recharge	28.3
202	Sink Creek Recharge	46.3
203	Purgatory Creek Recharge	35.0
204	York Creek Recharge	21.2
301	Blanco River Downdip	4.4
302	Ungaged Downdip	11.5
	Total	171.3

The Blanco River, Sink Creek, Purgatory Creek, and York Creek within the Blanco Recharge Basin are simulated in HSPF as 16 individual reaches (RCHRES). The Blanco River is divided into six reaches; Sink Creek is divided into four reaches (three are flood retardation structures); Purgatory Creek is divided into three reaches (two are flood retardation structures); and York Creek is divided into three reaches (two are flood retardation structures). The location at which the Blanco River is divided is based upon the channel loss characteristics of each reach as measured in previous studies.[24] The ID number and length of each reach is summarized in Table 5-8.

[24] Texas Board of Water Engineers. 1960. Channel Gain and Loss Investigations, Texas Streams, 1918-1958. Bulletin 5807 D. 270 Pages.

Table 5-8. Blanco Recharge Basin River Reaches

River Reaches ID	Description	Length (miles)
11	Blanco River	5.2
12	Blanco River	6.5
13	Blanco River	1.5
14	Blanco River	0.5
15	Blanco River	3.2
16	Blanco River	2.2
21	Upper San Marcos FRS#1 (Sink)	N/A
22	Upper San Marcos FRS#2 (Sink)	N/A
23	Upper San Marcos FRS#3 (Sink)	N/A
26	Below Upper San Marcos FRS#3	N/A
24	Upper San Marcos FRS#4 (Purgatory)	N/A
25	Upper San Marcos FRS#5 (Purgatory)	N/A
27	Below Upper San Marcos FRS#5	N/A
31	York Creek FRS#1	N/A
32	York Creek FRS#2	N/A
33	Below York Creek FRS#1&2	N/A

FRS = Flood Retardation Structure

The linkage between land segments and river reaches is described in the UCI file as the area of each land segment that contributes runoff to each river reach. This connectivity is summarized in Table 5-9.

5.3.1.2 Calibration Parameters

After selecting initial parameters in the Blanco Recharge Basin, the HSPF model was calibrated by adjusting the parameters listed in Table 5-10 which includes a brief description of each of the parameters and the range of values recommended by the USGS for application of HSPF. The final calibration value for each parameter for the land segments over the outcrop is also listed in Table 5-10. For general comparison purposes, the value of each parameter used for application of HSPF in the Helotes Creek watershed by the USGS is also included in Table 5-10. Due to differing study objectives and other factors, it is emphasized that parameter selections by the USGS for the Helotes Creek watershed and by HDR for the Blanco Recharge Basin may not necessarily be consistent with one another. The USGS Helotes Creek HSPF application was performed on an hourly timestep using a 3-year calibration period for a relatively small urbanizing watershed with a primary focus on flood flow simulation. The Blanco Recharge

Table 5-9. Blanco Recharge Basin Land Segment and River Reach Connectivity

Land Segment ID	Contributing Watershed Area (sqmi)	River Reaches ID
101	10.5	11
201	2.9	11
101	13.4	12
201	10.6	12
101	0.7	13
201	13.1	13
301	0.1	13
201	0.8	14
301	0.3	14
201	0.9	15
301	4.0	15
202	4.2	16
302	7.2	16
202	33.0	21
302	0.4	21
202	3.5	22
302	0.8	22
202	4.6	23
302	1.0	23
203	20.1	24
203	14.3	25
202	1.0	26
302	2.1	26
203	0.6	27
204	12.8	31
204	2.8	32
204	5.6	33
Total	171.3	

Table 5-10. Blanco Recharge Basin Calibration Parameters for Land Segments in Edwards Outcrop

Parameter	Name	Minimum[1]	Maximum[1]	Blanco Outcrop Value	USGS Value (Helotes)[2]	Notes[1]
CEPSC	Interception Storage Capacity Coefficient	0.05	0.2	0.12	0.1	General Range 0.05 - 0.20
INFILT	Infiltration Rate	0.01	0.1	0.04	0.15	Recommended Range 0.01 - 0.1
LZSN	Lower Zone Nominal Storage	0.01	20.0	4.0	5.0	Recommended Range 5.0 - 20.0
LZETP	Lower Zone Evapo-Transpiration Parameter	0.25	0.9	0.3	0.1	Initial Estimates: 0.25 for Rangeland, 0.7 - 0.9 for Heavily Forested Land
UZSN	Upper Zone Nominal Storage	0.01	2.8	0.4	0.25	Recommended Range of 0.06 - 0.14 times LZSN
INTFW	Interflow Parameter	0.50	5.0	0.5	0.2	Recommended Range of 0.5 to 5.0
KVARY	Non-Exponential Groundwater Recession Parameter	0.0	9999999	4.0	2.0	Should be 0.0 initially; Suggested adjustment of AGWRC & INFILT first
IRC	Interflow Recession Coefficient	0.0	0.999	0.9	0.1	Used to Adjust Hydrograph Shape, Does Not Affect Volumes.
AGWRC	Active Groundwater Recession Coefficient	0.001	0.999	0.93	0.98	$AGWRC = (Q_{t_2}/Q_{t_1})^{(1/n)}$ $n = t_2 - t_1$ in days
AGWETP	Active Groundwater Evapo-Transpiration Parameter	0.0	1.0	0.2	0.0	Used for final low flow refinement
BASETP	Baseflow Evapo-Transpiration Parameter	0.0	1.0	0.4	0.0	E-T from Riparian Vegetation
DEEPFR	Deep Percolation Fraction	0.0	1.0	1.0	0.95	Values > 0, shouldn't be used unless justified

[1] Based on information from USGS Workshop "River Basin Simulation Using the HSPF Model"; October 28-29, 1991; Austin; TX
[2] USGS Application of HSPF on Helotes Creek, Received via Personal Correspondence

Basin HSPF application, on the other hand, was performed on a daily timestep using a calibration period in excess of 40 years for rural watersheds with a primary focus on Edwards Aquifer recharge simulation. The data ranges and calibration values for the parameters listed in Table 5-10 are represented graphically in Figure 5-16.

All of the calibration parameters for the Blanco Recharge Basin are within the acceptable range of values. The calibrated parameters that are in the high end of this range include IRC, AGWRC, and DEEPFR. Calibration parameters CEPSC, INFILT, and LZSN are in the middle of the recommended range. At the low end of the range are calibration parameters LZETP, UZSN, KVARY, INTFW, AGWETP, and BASETP. The relative positions of these parameter values within the ranges recommended by the USGS is consistent with the outcrop of a karst limestone aquifer in a semi-arid, rural setting dominated by rangeland including some forested areas with live oak and ashe-juniper trees.

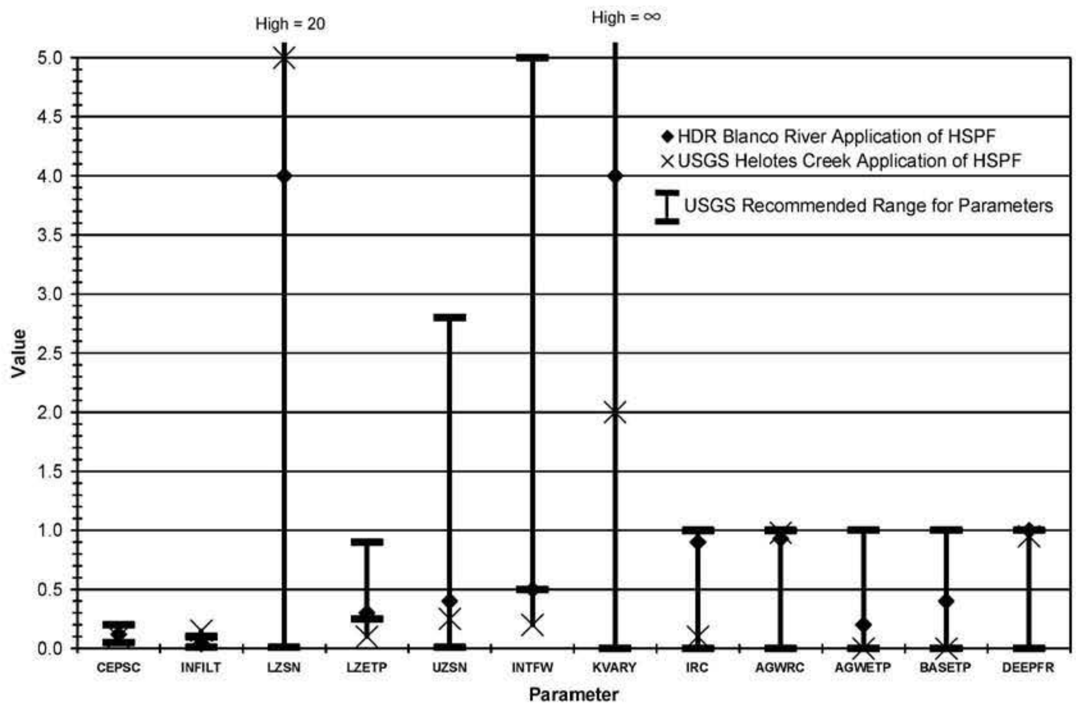


Figure 5-16. Blanco Recharge Basin Calibration Parameters for Land Segments in Edwards Outcrop

5.3.2 Sensitivity Analyses

Sensitivity analyses were performed by individually varying nine key parameters from their calibrated values in order to gauge the relative changes in streamflow and recharge estimates. The nine parameters were individually increased and decreased by 50 percent of the calibrated value, when possible. Certain calibrated values are near the recommended upper/lower bounds for the parameters, and thus increasing/decreasing the parameter value by 50 percent is not possible. The percentage changes in long-term annual averages of recharge and streamflow were calculated. Table 5-5 provides a summary of the streamflow and recharge sensitivity analyses for nine key hydrologic parameters in the pilot recharge model of the Blanco Recharge Basin.

Review of Table 5-11 indicates that simulated streamflow is most sensitive to active groundwater recession rate (AGWRC), evapo-transpiration from the near-surface strata (LZETP), nominal storage within the near-surface strata (UZSN/LZSN), and deep percolation rate from the near-surface strata into the Edwards Aquifer (DEEPFR). Similarly, recharge is

Table 5-11. Blanco Recharge Basin — Parameter Sensitivity Analyses

Blanco River Streamflow near Uvalde

Parameter	Units	Calibrated Value	Calibrated Average Annual Streamflow (acft/yr)	Low Parameter Value (LPV)	LPV Average Annual Streamflow (acft/yr)	% Difference - Streamflow (LPV to Calibration)	High Parameter Value (HPV)	HPV Average Annual Streamflow (acft/yr)	% Difference - Streamflow (HPV to Calibration)
CEPSC	in	0.12	115,886	0.06	116,242	0.31%	0.18	115,603	-0.24%
INFILT	in/hr	0.04	115,886	0.02	118,445	2.21%	0.06	115,217	-0.58%
LZSN	in	4.0	115,886	2.0	117,952	1.78%	6.0	114,826	-0.91%
LZETP	-	0.3	115,886	0.15	120,204	3.73%	0.45	113,414	-2.13%
UZSN	in	0.4	115,886	0.2	117,112	1.06%	0.6	115,192	-0.60%
UZSN/LZSN	in/in	0.4/4.0	115,886	0.2/2.0	119,168	2.83%	0.6/6.0	114,138	-1.51%
INTFW	-	0.5	115,886	0.25	115,890	0.00%	0.75	115,875	-0.01%
AGWRC	1/day	0.93	115,886	0.47	127,531	10.05%	-	-	-
DEEPFR	-	1.0	115,886	0.50	120,853	4.29%	-	-	-

Edwards Aquifer Recharge

Parameter	Units	Calibrated Value	Calibrated Average Annual Recharge (acft/yr)	Low Parameter Value (LPV)	LPV Average Annual Recharge (acft/yr)	% Difference - Recharge (LPV to Calibration)	High Parameter Value (HPV)	HPV Average Annual Recharge (acft/yr)	% Difference - Recharge (HPV to Calibration)
CEPSC	in	0.12	71,638	0.06	73,569	2.70%	0.18	70,315	-1.85%
INFILT	in/hr	0.04	71,638	0.02	67,381	-5.94%	0.06	73,338	2.37%
LZSN	in	4.0	71,638	2.0	72,668	1.44%	6.0	70,883	-1.05%
LZETP	-	0.3	71,638	0.15	79,149	10.48%	0.45	66,191	-7.60%
UZSN	in	0.4	71,638	0.2	73,132	2.09%	0.6	70,647	-1.38%
UZSN/LZSN	in/in	0.4/4.0	71,638	0.2/2.0	74,676	4.24%	0.6/6.0	70,069	-2.19%
INTFW	-	0.5	71,638	0.25	71,634	-0.01%	0.75	71,649	0.02%
AGWRC	1/day	0.93	71,638	0.47	71,112	-0.73%	-	-	-
DEEPFR	-	1.0	71,638	0.50	63,872	-10.84%	-	-	-

most sensitive to evapo-transpiration from the near-surface strata (LZETP), deep percolation rate from the near-surface strata into the Edwards Aquifer (DEEPFR), and nominal storage within the near-surface strata (UZSN/LZSN). As simulation of streamflow and recharge are both highly sensitive to evapo-transpiration from the near-surface strata (LZETP), well-calibrated estimates of streamflow (which are readily evaluated by comparison to gauged streamflow records) are indicative of sound estimates of recharge (for which there are no physically definitive measured data for comparison).

5.3.3 Water Balance

The simulated water balance from the pilot recharge model for the land segments in the Blanco Recharge Basin is shown in Table 5-12. For the simulation period from 1956 to 1998, there is an average annual balance of 212 acft/yr (0.06 percent of precipitation) that results from the selection of initial values for several soil strata storage parameters used by HSPF. This balance could be eliminated by iterative application of the model to more specifically define initial storage parameter values (thereby modifying the change in storage over the simulation period), however, resulting changes in Edwards Aquifer recharge and other components of the water balance would be negligible.

The fate of precipitation on the land segments is illustrated by percent in Figure 5-17. Together, simulated evapo-transpiration (including interception) and Edwards recharge account for almost 94 percent of precipitation on the land segments. HSPF results are consistent with the findings of research supported by the Texas Agriculture Experiment Station and based on studies of the Cusenbary Draw watershed on the Edwards Plateau in Sutton County.[25] Researchers reported that more than 94 percent of precipitation is converted to interception loss, transpiration, and soil evaporation as percentages of woody cover exceed 10 percent on an areal basis. Furthermore, comparison of long-term average areal precipitation (32.62 in/yr) and natural runoff (1.05 in/yr) for the nearby Dry Comal Creek watershed located on the outcrop of the Edwards Aquifer indicates that approximately 97 percent of precipitation is "consumed" by evapo-transpiration and Edwards recharge. Estimates of potential evapo-transpiration used in the pilot recharge models are reasonably consistent with those available from the Texas ET

[25] Wu, X. B., Redeker, E. J., and Thurow, T. L., "Vegetation and Water Yield Dynamics in an Edwards Plateau Watershed,: Journal of Range Management, March 2001.

Table 5-12. Blanco Basin Water Balance for Land Segments

Land Segment ID	Precipitation (acft/yr)	Total Actual E-T (acft/yr)	Runoff / Outflow[1] (acft/yr)	Change in Storage (acft/yr)	Edwards Recharge (acft/yr)	Recharge to Younger Formations (acft/yr)	Balance (acft/yr)
LS 101	48,367	38,507	5,186	164	4,462	-	48
LS 201	54,249	39,339	1,376	175	13,283	-	76
LS 202	83,614	61,963	3,043	180	18,312	-	116
LS 203	67,914	50,725	2,804	123	14,159	-	104
LS 204	40,481	30,303	1,647	101	8,359	-	72
LS 301	8,936	7,341	1,472	19	-	79	23
LS 302	22,443	18,181	4,202	72	-	214	-227
Total	**326,004**	**246,360**	**19,730**	**834**	**58,575**	**293**	**212**

[1] Portions of this outflow recharges to the Edwards Aquifer in river reaches.

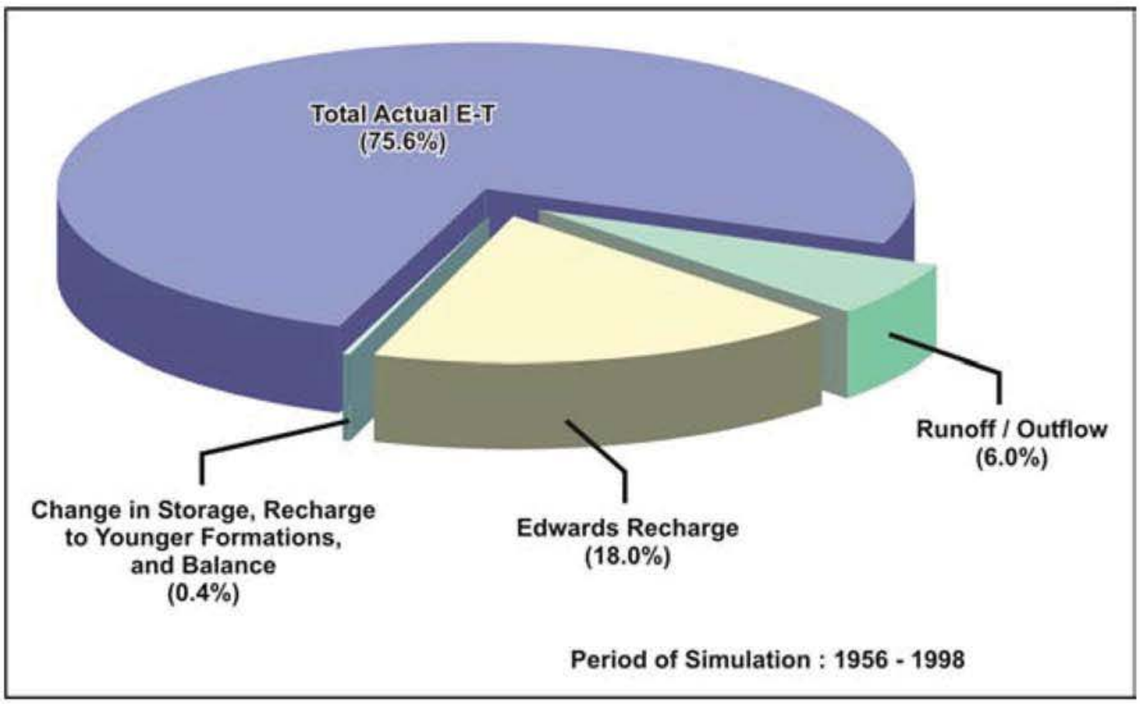


Figure 5-17. Blanco Recharge Basin — Fate of Precipitation on Land Segments

Network,[26] regional weather stations (including Sea World, NCDC# 418169), and other sources.[27] Long-term average "actual" evapo-transpiration simulated by HSPF is about one-half of potential evapo-transpiration in the Blanco Recharge Basin as compared to about one-third of potential evapo-transpiration in the Nueces Recharge Basin. This is consistent with more frequent rainfall and higher soil moisture typical of the Blanco Recharge Basin. Figure 5-18 summarizes the water balance for the Blanco River portion of the Blanco Recharge Basin, including both land segments and river reaches for the entire simulation period.

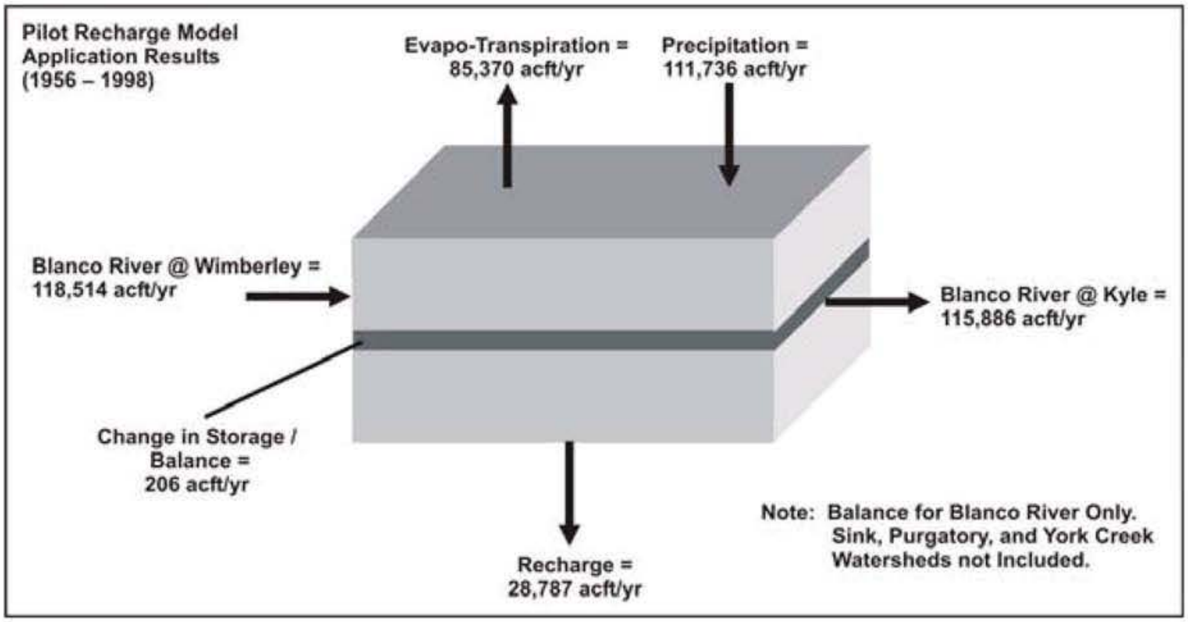


Figure 5-18. Blanco Recharge Basin —Water Balance

5.3.4 Streamflow Comparisons

HSPF simulates surface and sub-surface hydrologic processes occurring in the defined land segments including runoff, interflow, and baseflow, all of which contribute lateral inflow to river reaches from the land segments. The river reaches are connected in the HSPF model through a series of linkages assigning outflows from an upstream reach as inflows to a downstream reach. The outflow from the fifth downstream reach in the HSPF pilot recharge

[26] Texas A&M University, "Average Historic PET," Texas ET Network, Texas Cooperative Extension, Texas Agricultural Experiment Station, http://texaset.tamu.edu/pet.php.
[27] Potential Evapo-Transpiration data prior to 9/1/2001 available from the Texas A&M Research & Extension Center at Uvalde is considered high and scheduled to be recalculated per personal communication with Dr. M. Keith Owens in June 2002.

model is the simulated streamflow at the site of the USGS gauging station on the Blanco River near Kyle. The simulated streamflows from the HSPF model are compared to the actual historical streamflow data by consideration of long-term averages, daily time series for selected years, daily streamflow frequency, and annual totals. Due to limited period of record and number of storm events generating runoff, historical runoff records from the Sink Creek watershed (derived by comparison of San Marcos springflow and gauged streamflow on the San Marcos River published by the USGS) were not used for calibration of the pilot recharge model.

5.3.4.1 Long-Term Averages

The historical annual average streamflow for the Blanco River near Kyle (1956-1998) is 116,070 acft/yr, and the simulated annual average streamflow is 115,886 acft/yr, a difference of 184 acft/yr or about 0.2 percent. Average simulated runoff from the ungauged or indirectly gauged areas over the Edwards Outcrop in the Blanco Recharge Basin (1.23 in/yr or 3.6 percent of rainfall) is comparable to actual runoff from the nearby Dry Comal Creek watershed (1.05 in/yr or 3.2 percent of rainfall).

5.3.4.2 Time Series for Selected Years and Daily Streamflow Frequency

Four years were chosen for direct daily comparison of simulated streamflows to historical gauged streamflows. These years are representative of: recent (1998), average (1968), wet (1957), and dry (1996) conditions. Historical and simulated streamflows for the Blanco River near Kyle are presented in Figures 5-19 through 5-22 for the representative years. Review of these figures indicates that the calibrated HSPF model provides a very reasonable simulation of daily streamflows, particularly during stormflow recession periods. With respect to recharge occurring in the river, accurate simulation of these stormflow recession periods is more important than matching peak daily discharges. The relatively small intervening watershed area between the Blanco River streamflow gauging stations at Wimberley and Kyle, and the proximity of the National Weather Service precipitation gauge at San Marcos both contribute to the accuracy of the simulations. Use of precipitation data from the EAA network should enhance the accuracy of streamflow simulation and recharge estimates in the future.

Figure 5-23 provides a comparison of the frequency of occurrence of simulated and gauged historical streamflows for the Blanco River near Kyle. HSPF clearly performs quite well in simulating the frequency of occurrence of streamflows less than 300 cfs.

5.3.4.3 Annual Values

Annual values of historical gauged streamflow and HSPF simulated streamflow are compared in Figure 5-24. Linear regression is used to measure how closely the simulated streamflows approximate the historical streamflows over the full range of observed annual values. Ideally, the regression equation would have a slope coefficient of 1.0, an intercept of 0.0, and a coefficient of determination (r^2) of 1.0 indicating a perfect match between simulated and historical streamflow.

As is apparent in Figure 5-24, simulated streamflows from the HSPF recharge model are highly correlated with historical streamflows on an annual basis. Application of the Students t test[28] to the linear regression coefficients indicates that one cannot reject that the slope coefficient is equal to 1.0 and the intercept is equal to 0.0 with a statistically significant degree of confidence.

[28] Haan, C.T., "Statistical Methods in Hydrology," Iowa State University Press, 1977.

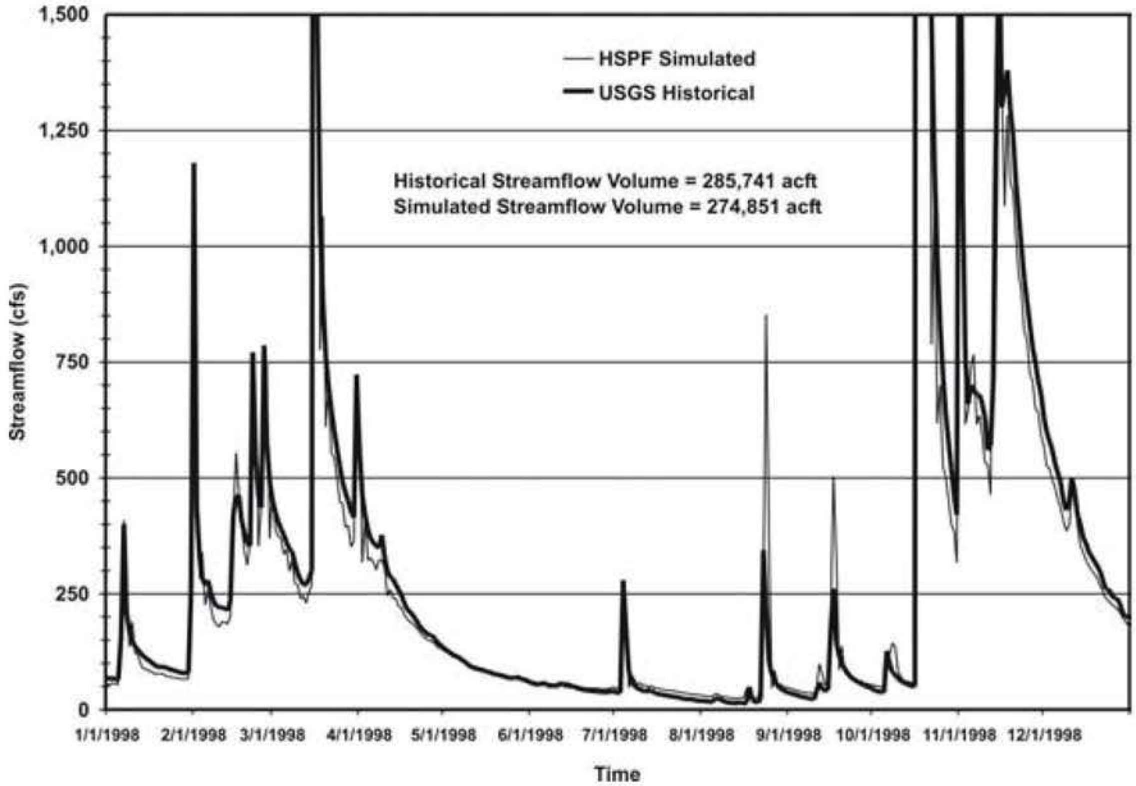


Figure 5-19. Blanco River @ Kyle — Streamflow Comparison (1998)

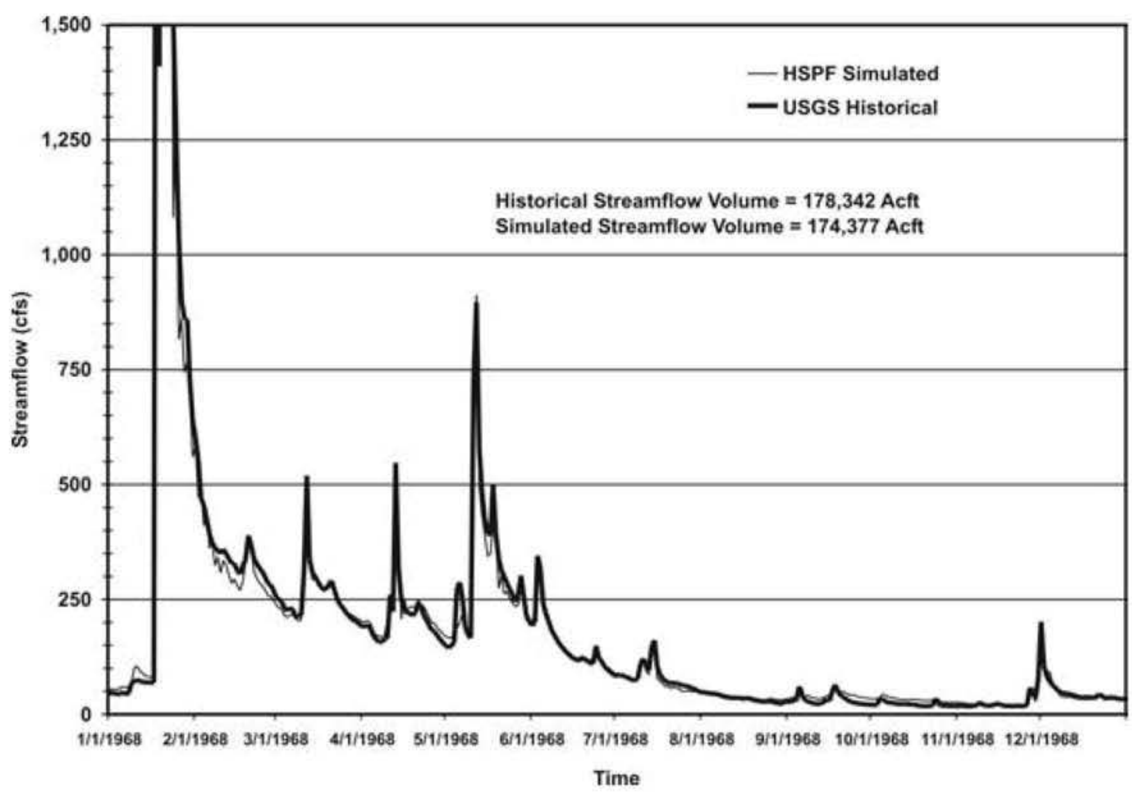


Figure 5-20. Blanco River @ Kyle — Streamflow Comparison (1968)

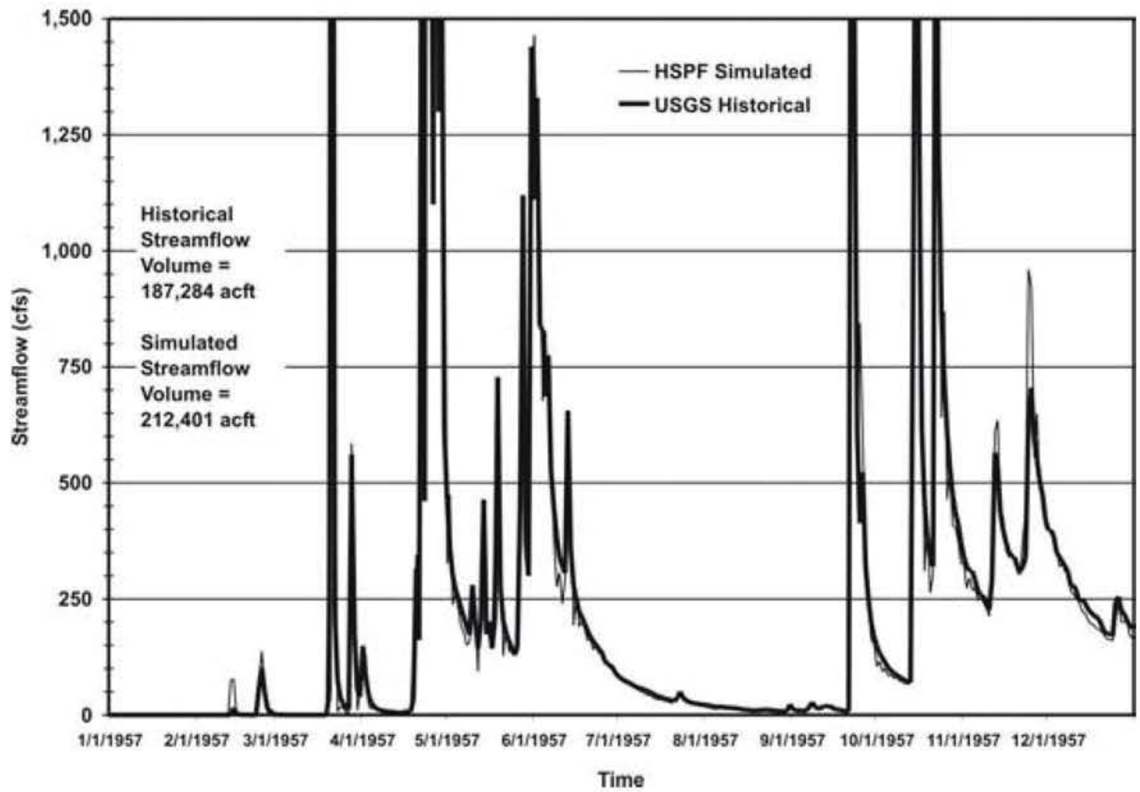


Figure 5-21. Blanco River @ Kyle — Streamflow Comparison (1957)

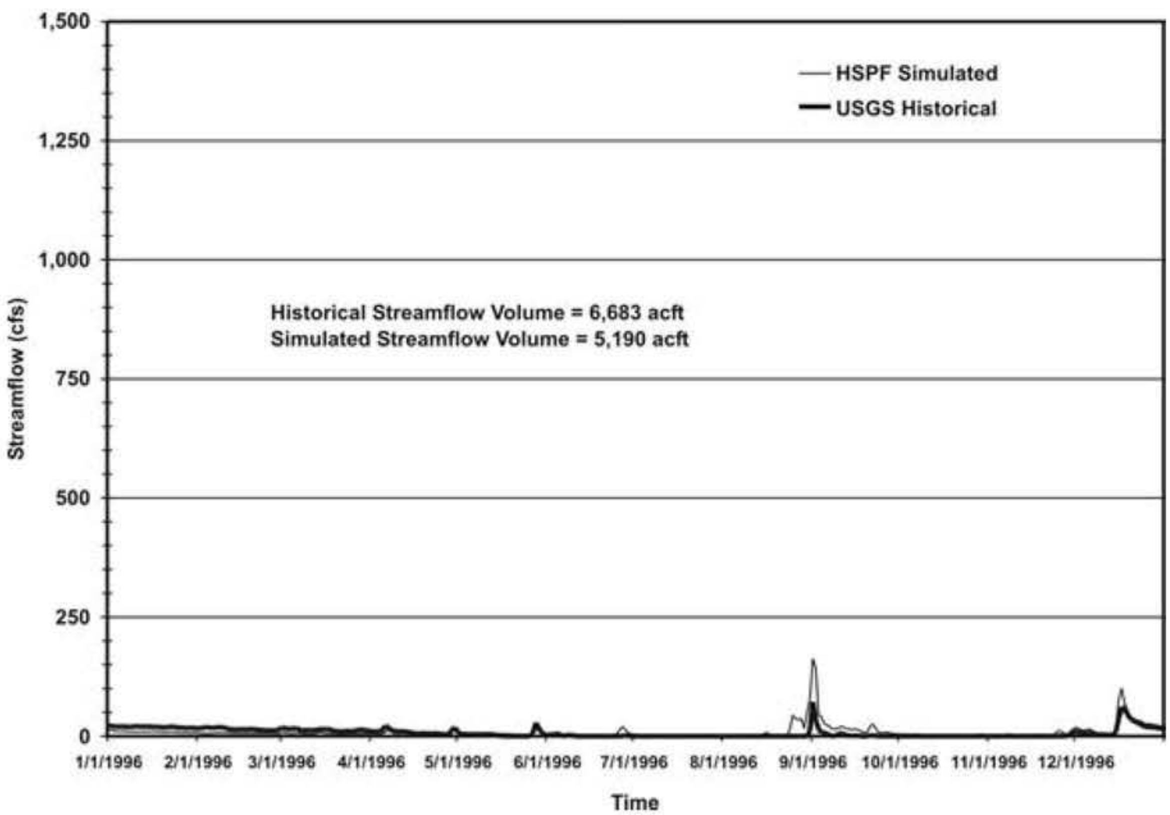


Figure 5-22. Blanco River @ Kyle — Streamflow Comparison (1996)

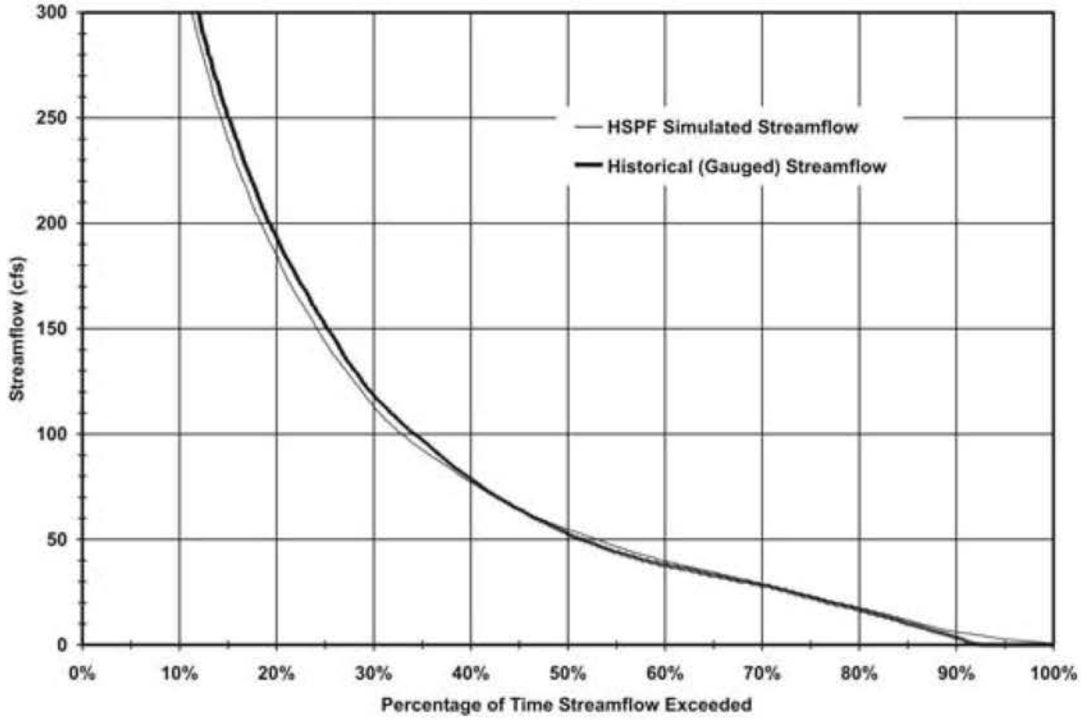


Figure 5-23. Blanco River @ Kyle — Daily Streamflow Frequency (1956 – 1998)

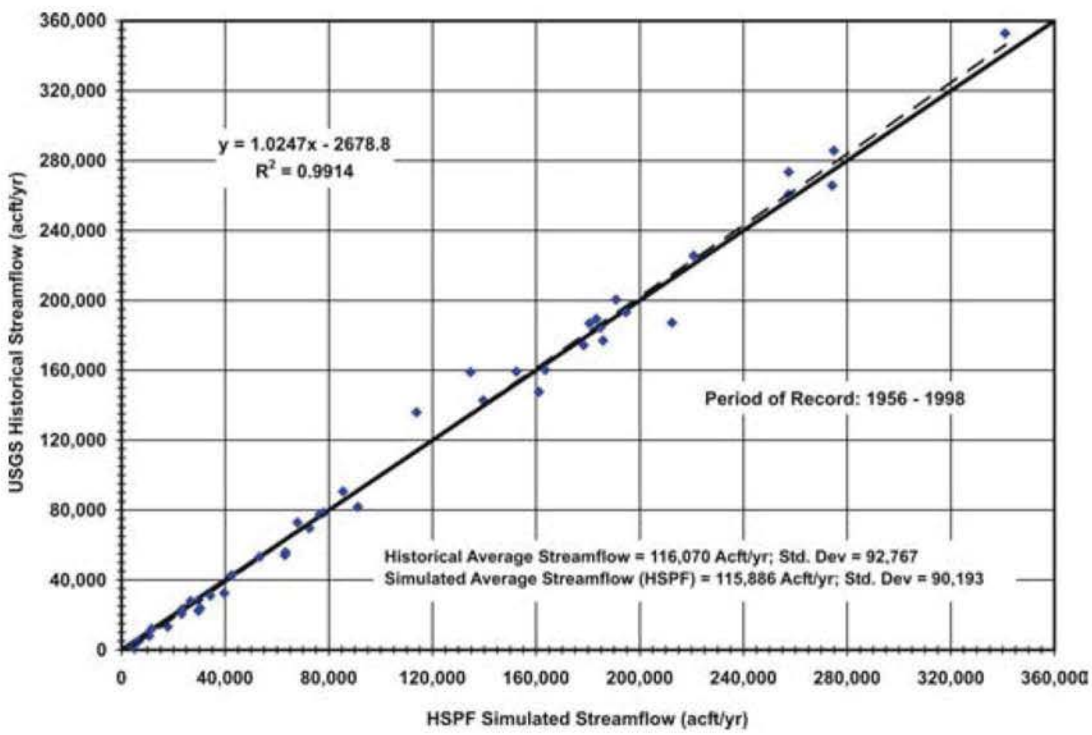


Figure 5-24. Blanco River @ Kyle — Streamflow Comparison (1956 – 1998)

5.3.5 Calibrated Recharge Estimates

The calibrated pilot recharge model of the Blanco Recharge Basin, as formulated in HSPF, was applied for the full 1956 through 1998 historical period for which hydrologic data are available. Calculated annual Edwards Aquifer recharge for the full historical period averages 74,491 acft and ranges from a minimum of 5,267 acft in 1956 to a maximum of 146,387 acft in 1998. Edwards Aquifer recharge associated with the seven existing flood retardation structures averages almost 4,300 acft/yr or about 5.8 percent of that for the entire Blanco Recharge Basin (assuming all of the existing structures were in operation for the full 1956 through 1998 historical simulation period). Accounting for the phased historical implementation of these structures could reduce basin recharge estimates as follows[29]: (1) 5.8 percent to 5.0 percent (1956 – 1980); (2) 2.9 percent to 0.4 percent (1981-1988); and (3) 0.0 percent (1989-1998). Approximately 15 percent of the calculated recharge occurs in the Blanco River reaches, 24 percent occurs in the land segments tributary to the Blanco River between the gauges at Wimberley and near Kyle, and 61 percent occurs in the Sink, Purgatory, and York Creek watersheds. Additional information regarding the geographical distribution of recharge for use in the new Edwards Aquifer model is included in Appendix G. A summary of monthly recharge estimates for the Blanco Recharge Basin is included in Appendix A.

Simulation results for the 1956 through 1996 historical period have been extracted for direct comparison of new to traditional estimates of Edwards Aquifer recharge. Simulated annual recharge estimates from HSPF are compared to the those previously reported by HDR[30] in Figures 5-25 and 5-26 and to those previously reported by the USGS[31] in Figures 5-27 and 5-28. It is apparent upon consideration of these figures that HSPF simulated recharge is more highly correlated with traditional recharge estimates developed by HDR than those developed by the USGS. Long-term (1956-1996) average HDR recharge (72,261 acft/yr) is about 0.9 percent greater than that from HSPF (71,638 acft/yr) while the comparable average previously developed by the USGS (49,254 acft/yr) is about 31.2 percent less than that from HSPF. Long-term average recharge for the seven flood retardation structures in the Sink, Purgatory, and York Creek watersheds is comparable to that derived using alternative methods as part of a previous

[29] Percentage reductions are based on reported year of construction completion and long-term average recharge associated with each of the seven structures, as compared to long-term average recharge for the entire Blanco Recharge Basin.

[30] HDR, "Edwards Aquifer Recharge Analyses, Edwards Aquifer Recharge Update," Trans-Texas Water Program, West Central Study Area, Phase II, San Antonio River Authority, et al., March 1998.

study.[32] Cumulative recharge estimates from HSPF and the two traditional methods are summarized in Figure 5-29 for the historical period beginning in 1956. Differences between HSPF and traditional HDR and USGS recharge estimates are justified by refined/enhanced watershed simulation capabilities of the HSPF pilot recharge model, including daily timestep computations and more explicit representation of watershed characteristics and hydrologic processes.

Baseflows have been extracted from the daily streamflow records for the gauging station on the Blanco River at Wimberley for use as an approximation of Trinity Aquifer recharge and an indicator of minimum recharge occurring outside of the bed and banks of the Blanco River on the outcrop of the Edwards Aquifer. For the 1950 through 1996 historical period, these baseflows are indicative of an average Trinity Aquifer recharge rate of about 64,200 acft/yr, alternatively expressed as 3.39 inches/yr or 10.3 percent of average annual rainfall. This is within the range of estimated recharge rates for the Trinity Aquifer in the Hill Country area reported by the Texas Water Development Board[33] (1.5 to 11.0 percent of average annual rainfall). Application of the calibrated pilot recharge model results in an average Edwards Aquifer recharge rate, exclusive of that occurring directly in the river, of about 16,800 acft/yr, alternatively expressed as 5.53 inches/yr or 16.2 percent of average annual rainfall. Hence, the pilot recharge model indicates that recharge as a percentage of average annual rainfall is approximately 57 percent greater over the outcrop of the Edwards Aquifer than over the outcrop of the Trinity Aquifer.

[31] USGS, "Method of Estimating Natural Recharge to the Edwards Aquifer in the San Antonio Area, Texas," Water Resources Investigations 78-10, April 1978.
[32] HDR Engineering, "Recharge Enhancement Study – Guadalupe-San Antonio River Basin – Phase I - Volume II," Edwards Underground Water District, September 1993.
[33] TWDB, "Groundwater Availability of the Trinity Aquifer, Hill Country Area, Texas: Numerical Simulations through 2050," Report 353, September 2000.

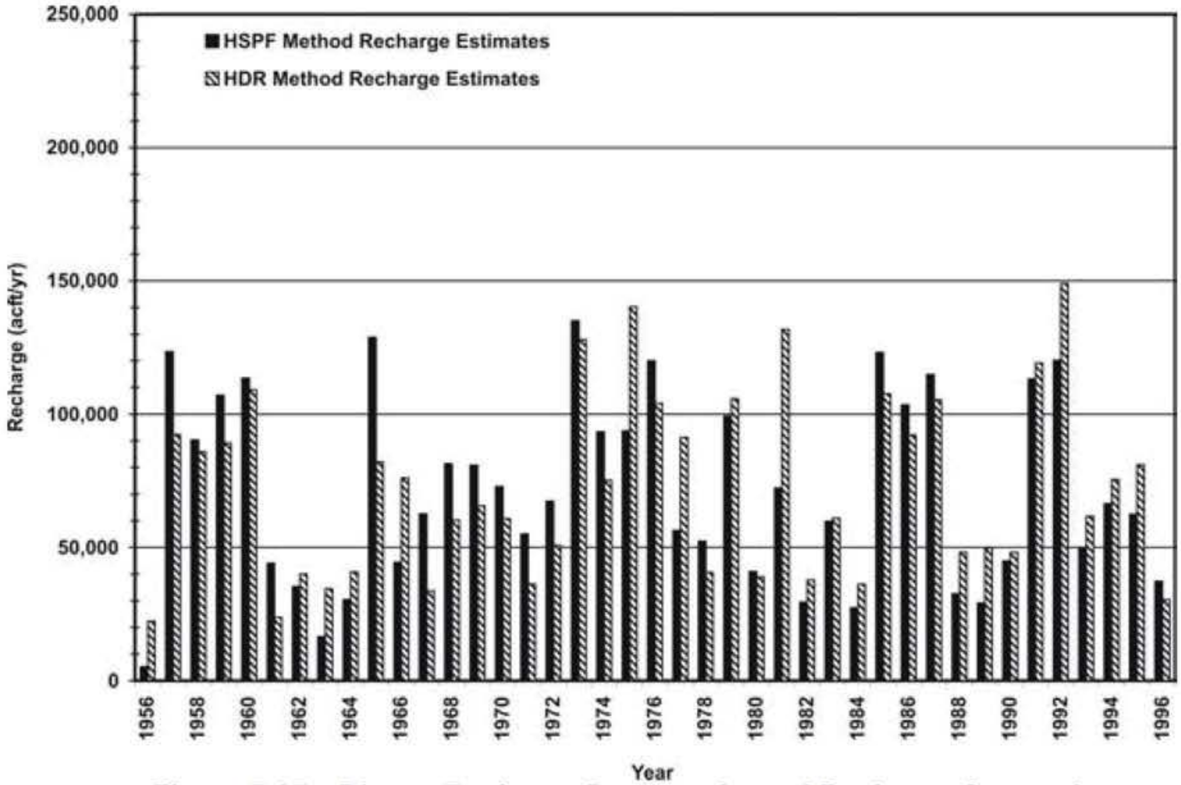


Figure 5-25. ***Blanco Recharge Basin — Annual Recharge Comparison with Traditional HDR Estimates***

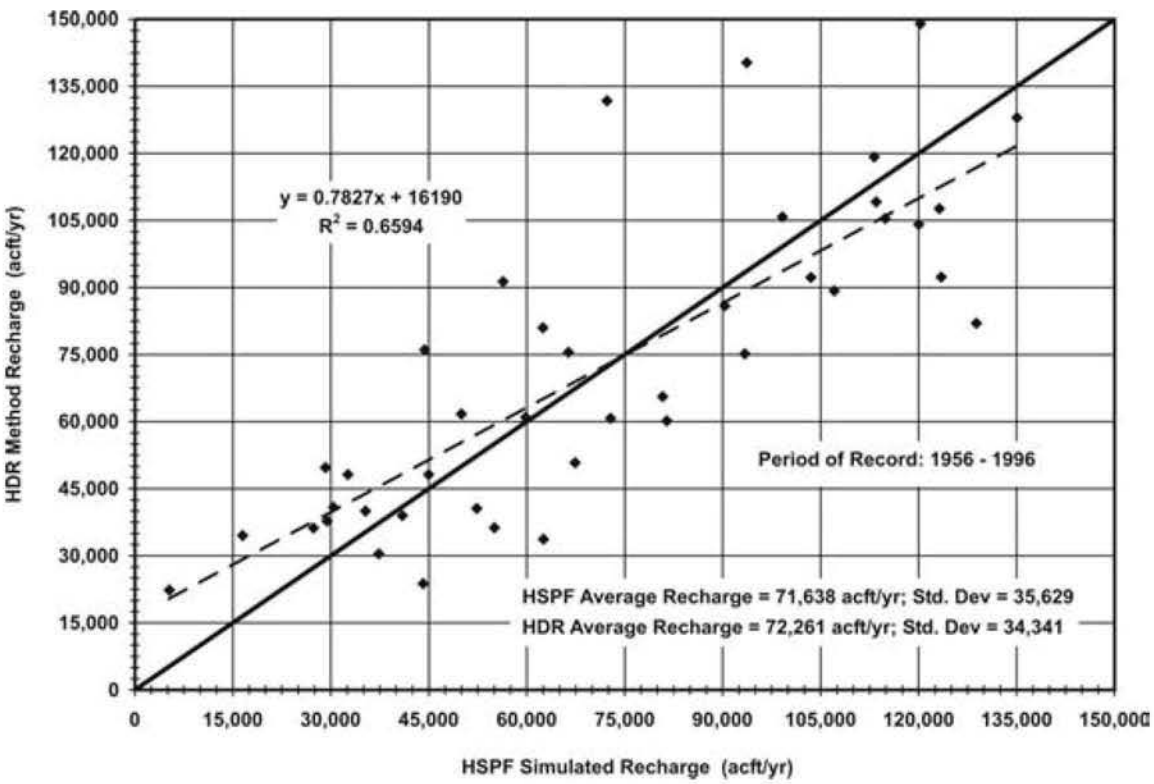


Figure 5-26. ***Blanco Recharge Basin — Recharge Comparison with Traditional HDR Estimates***

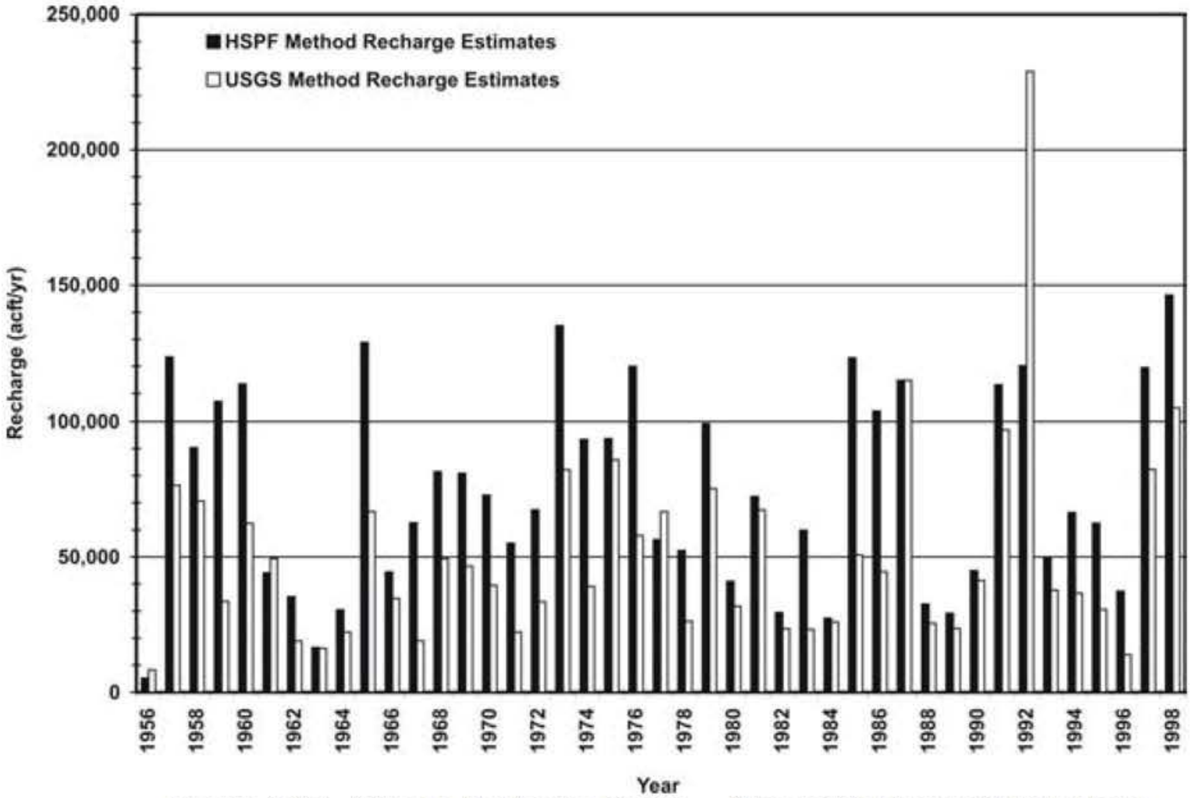


Figure 5-27. Blanco Recharge Basin — Annual Recharge Comparison with Traditional USGS Estimates

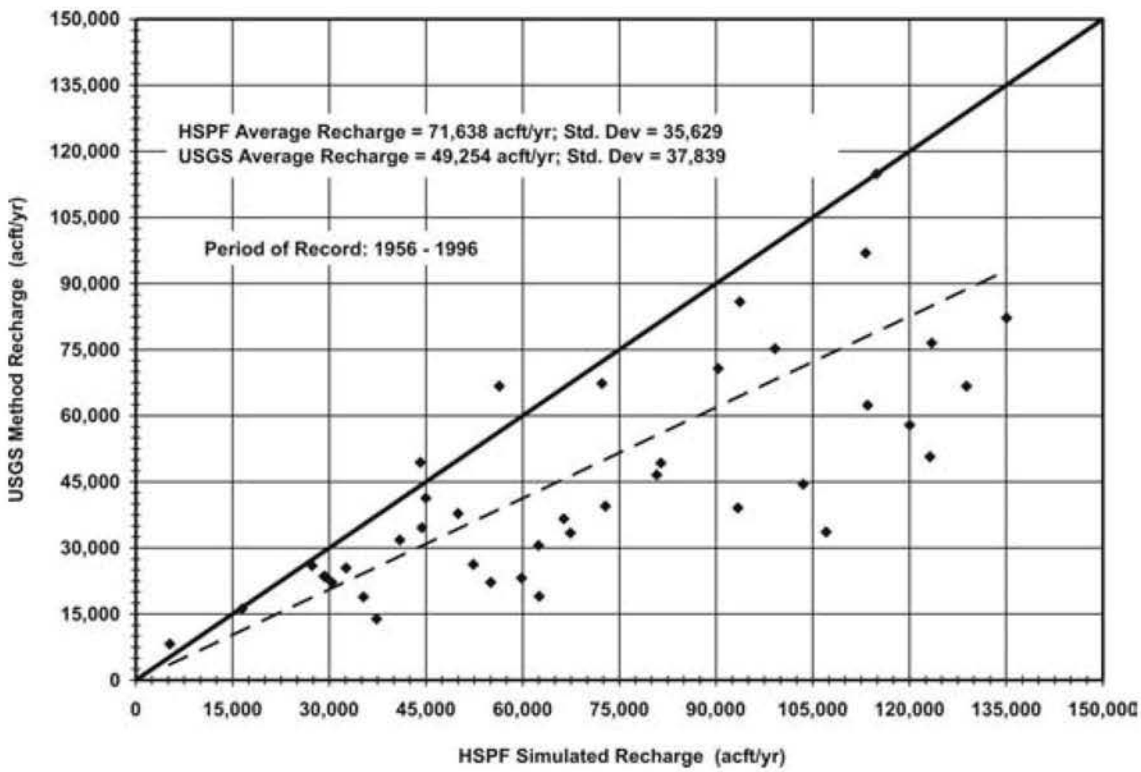


Figure 5-28. Blanco Recharge Basin — Recharge Comparison with Traditional USGS Estimates

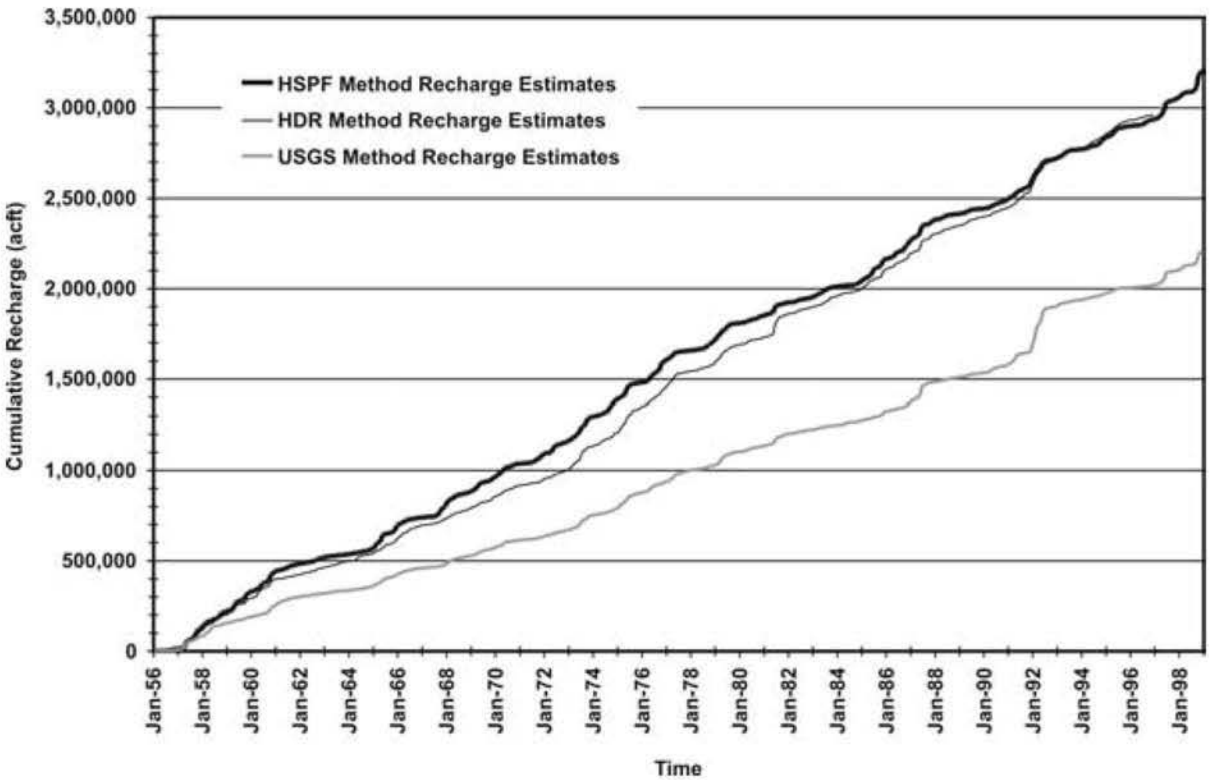


Figure 5-29. Blanco Recharge Basin — Cumulative Recharge Comparison

Section 6
Conclusions and Recommendations

6.1 Conclusions

Pilot Edwards Aquifer recharge calculation models of the Nueces and Blanco River (Recharge) Basins have been completed in the Hydrologic Simulation Program – Fortran (HSPF) originally developed by the U.S. Geological Survey (USGS). In a manner consistent with Edwards Aquifer Authority (EAA) objectives, the pilot recharge models retain the strengths and overcome the weaknesses of traditional recharge calculation methods while providing versatile tools sufficiently accurate for both regulatory and research purposes. Specific advantages of these models over traditional methods include the following:

(1) Use of a water balance approach integrating many relevant hydrologic parameters including measured streamflow, precipitation, evaporation, and diversions as well as soil type, antecedent moisture conditions, land use, and interception/infiltration/ evapo-transpiration characteristics.

(2) Computation of recharge on a daily, rather than monthly, timestep through direct simulation of watershed response to daily precipitation and streamflow inputs.

(3) Provision for geographical distribution of recharge into specified land segments and river reaches on the outcrop of the Edwards Aquifer.

(4) Ability to quantify effects of changes in watershed characteristics (dam construction, brush management, land development) and/or climatological influences (weather modification) on aquifer recharge.

(5) Limited capability to approximate inter-formational transfer of groundwater from the Edwards Plateau and Trinity Aquifers that contributes to Edwards Aquifer recharge.

Calibration and validity of the HSPF pilot recharge models is confirmed by their ability to replicate historical streamflows at gauging stations located immediately downstream of the Edwards Aquifer outcrop, particularly during stormflow recession and extended drought periods. In addition, the models produce estimates of historical Edwards Aquifer recharge that are reasonably consistent with traditional methods and with relevant research studies focused upon the Edwards (Balcones Fault Zone), Edwards Plateau, and Trinity Aquifers. Application of the pilot recharge model of the Nueces River (Recharge) Basin for the 1950 through 1996 historical period results in a long-term average recharge of 114,651 acft/yr. Similarly, application of the pilot recharge model of the Blanco River (Recharge) Basin for the 1956 through 1996 historical period results in a long-term average recharge of 71,638 acft/yr. Figure 6-1 compares these long-term average recharge rates to those based on traditional methods for the same historical periods. It is apparent in Figure 6-1 (and in additional comparisons presented in Section 5) that Edwards Aquifer recharge derived by application of the pilot recharge models more closely approximates traditional USGS estimates in the Nueces Recharge Basin and traditional HDR estimates in the Blanco Recharge Basin.

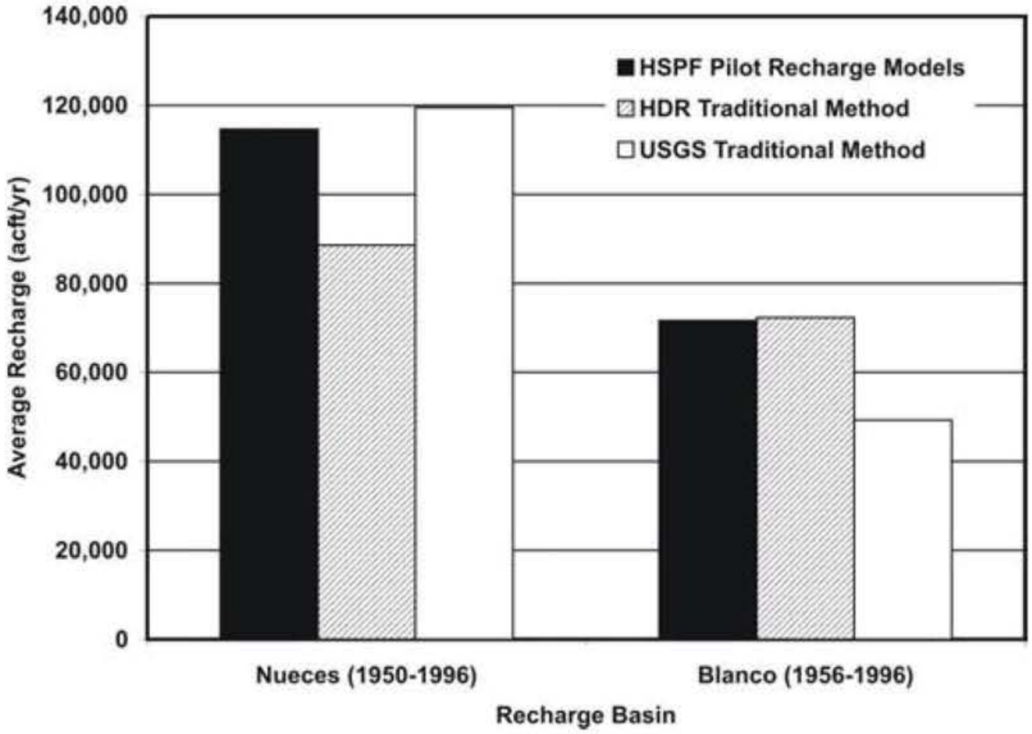


Figure 6-1. Long-Term Average Edwards Aquifer Recharge Comparison

6.2 Recommendations

Following are recommendations based upon the development, calibration, and application of pilot recharge models of the Nueces and Blanco River (Recharge) Basins:

(1) Traditional estimates of historical Edwards Aquifer recharge in the Nueces and Blanco River (Recharge) Basins should be revised to those obtained through application of the calibrated pilot recharge models. Future annual or more frequent updates of Edwards Aquifer recharge estimates for these basins should be obtained through application of the pilot recharge models.

(2) Similar recharge models of the remaining seven recharge basins should be completed in the near future in order to ensure that the best possible estimates of historical recharge are available for final calibration and application of the new Edwards Aquifer model presently under development.

(3) Though it is a complex and technically challenging model, HSPF has proven to be quite capable of accurately simulating the hydrologic processes governing streamflow and recharge at the outcrop of the Edwards Aquifer. HSPF is, therefore, recommended for use in creating recharge models for the remaining seven recharge basins.

(4) Parameter selection and calibration of the pilot recharge models for the Nueces and Blanco Recharge Basins should be reviewed for regional consistency upon completion of comparable recharge models for the remaining seven recharge basins.

(5) Future incorporation of data from the EAA precipitation network and/or NexRad Doppler radar systems will significantly improve estimates of areal precipitation (and recharge) in the Nueces and Blanco Recharge Basins as there are presently no National Weather Service stations located in the watersheds over the Edwards outcrop.

(6) Consideration should be given to more explicitly modeling the contributing areas upstream of the streamflow gauging stations on the Nueces River at Laguna, West Nueces River near Brackettville, and Blanco River at Wimberley. While direct use of the gauged streamflow records is appropriate for basic Edwards Aquifer recharge calculations, modeling could facilitate improved assessment of the potential effects of weather modification and/or brush management in these contributing areas on Edwards Aquifer recharge.

Historical Edwards Aquifer Recharge from the HSPF Pilot Recharge Model of the Nueces River (Recharge) Basin

Units = acft

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
1950	3,767	3,454	3,245	2,547	6,662	8,354	5,847	3,904	5,861	2,391	1,960	2,248	50,240
1951	2,058	1,802	3,596	2,433	7,463	6,368	963	666	446	3,760	1,059	1,353	31,968
1952	901	1,287	1,713	3,177	9,048	3,044	1,219	568	486	339	422	702	22,906
1953	786	1,012	1,584	1,571	950	540	331	2,961	27,079	7,292	1,982	1,679	47,770
1954	1,486	1,265	1,180	1,383	13,926	25,288	10,220	3,582	1,433	6,656	1,269	1,215	68,902
1955	1,464	1,616	1,634	1,247	2,806	3,680	11,924	3,645	17,155	10,798	7,349	3,748	67,067
1956	2,544	2,142	2,055	1,551	1,343	924	672	447	463	4,654	272	264	17,333
1957	270	371	575	45,879	58,932	38,912	3,461	1,647	4,710	42,250	20,654	13,420	231,081
1958	39,613	30,287	19,067	7,984	14,745	58,028	18,309	8,213	46,422	65,357	13,903	8,438	330,368
1959	6,836	6,002	5,068	6,034	13,959	50,297	28,985	8,450	6,141	34,540	12,526	7,024	185,864
1960	5,314	6,053	4,740	3,731	3,526	2,174	14,916	22,876	5,876	13,927	7,880	15,272	106,284
1961	14,279	16,625	5,399	4,494	3,463	22,388	47,016	8,990	4,600	9,703	5,127	4,217	146,301
1962	3,280	2,664	2,676	2,689	2,075	4,536	1,491	1,736	1,562	2,609	3,894	3,107	32,319
1963	2,635	3,531	2,782	3,261	12,238	5,081	1,637	810	2,189	2,024	1,774	1,965	39,925
1964	2,087	3,090	3,512	4,151	4,038	1,772	998	1,418	65,792	21,351	7,375	5,309	120,893
1965	4,629	7,468	4,911	6,143	23,788	13,144	6,265	2,934	3,521	3,419	3,357	8,549	88,128
1966	7,707	4,597	2,842	13,863	19,091	3,757	2,799	20,372	14,326	6,337	4,211	3,733	103,636
1967	3,388	2,742	2,569	3,216	1,648	1,668	1,366	2,672	24,334	18,762	21,226	8,645	92,235
1968	21,927	14,854	12,416	10,226	22,532	7,861	8,218	4,368	5,294	4,388	3,832	4,961	120,876
1969	3,823	3,085	2,831	5,468	15,574	7,650	1,526	2,849	4,051	87,760	32,813	18,396	185,827
1970	10,198	15,008	8,921	4,908	6,174	5,065	2,644	1,965	17,839	7,356	4,316	3,820	88,215
1971	3,362	2,750	3,293	2,676	1,901	37,279	9,945	104,051	18,843	49,415	8,396	8,683	250,594
1972	6,478	4,941	4,028	3,786	6,232	4,547	3,246	37,552	10,570	4,759	3,720	3,377	93,238
1973	3,217	5,303	4,233	4,642	2,380	21,933	43,863	6,195	9,432	68,528	7,169	5,204	182,100
1974	4,212	2,554	2,195	1,445	16,427	2,709	107	32,585	33,200	9,587	8,997	6,546	120,564
1975	3,894	11,289	3,274	6,458	31,530	13,312	14,654	12,033	3,866	3,579	2,547	2,274	108,711
1976	2,098	1,816	1,833	20,058	37,790	6,517	97,019	14,752	40,199	30,222	13,264	14,420	279,988
1977	11,806	7,087	3,144	13,993	14,517	4,769	3,064	1,838	643	3,569	8,717	2,779	75,925
1978	1,788	1,899	1,999	2,954	2,604	9,874	474	8,210	3,210	1,749	6,704	2,581	44,046
1979	2,606	7,270	13,870	22,059	5,171	75,566	2,943	1,063	276	-40	386	859	132,027
1980	1,369	1,556	1,774	1,556	19,020	1,500	595	5,505	11,605	3,189	7,211	7,173	62,052
1981	4,285	1,907	7,115	54,489	19,397	52,677	11,191	6,665	8,143	31,649	5,892	4,699	208,109
1982	3,955	6,443	3,905	3,072	18,259	8,852	10,566	1,743	1,340	1,410	2,483	4,206	66,236
1983	4,531	3,226	7,280	2,129	5,199	14,741	4,149	2,914	3,922	11,462	16,655	4,288	80,495
1984	3,997	2,662	2,288	1,891	1,498	1,462	881	627	589	16,180	5,080	11,375	48,531
1985	30,974	13,484	9,512	6,692	10,305	15,887	9,452	2,734	7,302	32,288	9,659	4,785	153,076
1986	4,994	3,536	2,983	2,537	5,908	27,817	3,128	1,620	5,984	55,887	19,941	30,297	164,631
1987	7,310	31,536	19,486	9,729	87,050	72,504	9,239	6,715	10,413	2,190	1,561	1,472	259,204
1988	795	1,091	1,611	1,388	1,810	6,767	8,232	3,230	3,630	2,762	1,740	1,618	34,674
1989	4,107	4,903	3,092	2,676	2,415	2,679	1,293	1,860	629	3,231	6,701	3,725	37,310

Units = acft

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
1990	2,861	4,545	15,500	38,192	28,695	5,170	41,451	15,616	11,867	6,287	5,208	3,991	179,385
1991	4,454	4,086	3,289	3,190	2,869	2,833	2,952	2,197	38,168	9,910	6,544	36,599	117,091
1992	28,394	32,845	23,710	12,651	31,022	30,785	9,456	6,235	2,511	1,645	1,773	1,925	182,951
1993	2,040	2,580	2,374	2,233	1,635	1,077	1	-721	-243	556	1,229	1,572	14,334
1994	3,931	2,557	8,336	10,525	46,587	5,445	6,468	2,637	31,443	9,705	13,263	9,675	150,574
1995	3,927	2,661	4,483	2,869	8,650	9,920	3,008	1,764	18,267	4,306	6,782	3,118	69,755
1996	2,438	2,010	2,119	1,987	1,614	1,531	1,168	1,891	27,642	23,555	17,582	11,319	94,856
1997	7,508	6,307	14,436	19,464	16,919	57,595	10,348	5,952	4,513	10,931	3,982	3,271	161,225
1998	3,106	3,710	5,038	3,878	2,477	2,923	897	90,462	29,626	34,286	14,180	6,292	196,874
Average (1950-1998)	**6,192**	**6,235**	**5,500**	**8,065**	**13,752**	**15,698**	**9,808**	**9,857**	**12,187**	**16,091**	**7,440**	**6,453**	**117,280**
Average (1950-1996)	**6,230**	**6,287**	**5,320**	**7,911**	**13,925**	**15,078**	**9,986**	**8,225**	**11,979**	**15,814**	**7,370**	**6,524**	**114,651**

Historical Edwards Aquifer Recharge from the HSPF Pilot Recharge Model of the Blanco River (Recharge) Basin

Units = acft

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
1956	783	732	336	283	599	187	107	213	519	384	498	625	5,267
1957	538	840	3,402	23,919	17,486	12,548	1,879	1,308	20,503	22,590	13,042	5,400	123,453
1958	9,959	17,120	6,051	3,547	7,874	1,795	4,447	1,279	13,572	17,289	4,646	2,747	90,325
1959	1,468	10,509	1,190	12,205	24,187	9,807	1,740	3,240	1,684	26,711	10,079	4,273	107,094
1960	5,541	5,133	3,715	6,036	7,104	21,741	2,517	5,693	2,001	35,853	7,027	11,163	113,522
1961	4,482	5,209	1,432	1,918	990	8,127	8,409	1,447	2,052	2,858	4,994	2,209	44,128
1962	1,559	1,711	1,661	2,931	1,280	2,529	1,412	1,093	11,682	2,146	1,979	5,319	35,303
1963	1,201	3,338	1,115	1,658	1,167	1,113	1,024	1,309	1,361	893	1,277	1,044	16,503
1964	1,648	2,739	1,715	1,429	1,137	5,394	1,064	845	2,733	2,228	6,516	2,964	30,412
1965	5,267	24,843	3,625	6,692	36,127	6,496	1,657	1,138	1,765	6,696	5,202	29,342	128,850
1966	5,074	8,467	3,190	6,029	8,744	2,386	1,016	2,211	3,984	1,327	958	1,001	44,387
1967	990	894	1,249	1,136	1,984	777	1,157	897	23,285	10,527	15,743	3,919	62,559
1968	29,117	6,959	4,455	7,975	7,965	6,558	3,017	1,032	3,222	1,702	3,151	6,278	81,430
1969	3,067	7,024	8,105	13,236	14,360	5,872	1,111	1,400	2,578	6,610	5,509	11,932	80,805
1970	3,951	11,181	7,271	4,913	23,953	1,948	1,136	2,004	7,617	6,925	959	990	72,846
1971	990	893	974	957	1,500	1,784	819	9,877	6,114	6,713	9,284	15,135	55,040
1972	3,561	1,799	1,013	1,121	28,549	9,182	3,125	5,597	1,924	2,318	7,255	1,951	67,394
1973	7,820	8,619	5,546	14,309	3,742	18,471	23,724	3,358	18,514	26,530	3,028	1,387	135,050
1974	6,472	917	1,486	1,362	11,283	2,550	1,336	12,434	21,779	5,527	22,431	5,816	93,392
1975	3,668	12,777	2,036	6,370	31,139	21,565	3,937	4,593	1,883	2,858	1,064	1,798	93,688
1976	1,233	994	1,111	14,989	18,060	4,828	15,183	3,215	5,658	40,014	8,610	6,141	120,036
1977	10,717	5,400	3,307	19,454	6,801	3,512	990	1,046	958	1,007	2,193	990	56,376
1978	1,001	1,458	1,265	1,431	1,714	3,790	927	4,190	16,275	1,142	14,709	4,431	52,335
1979	17,174	8,888	18,514	10,430	8,459	5,958	19,214	3,933	2,915	1,059	958	1,636	99,139
1980	1,619	1,703	1,355	1,223	9,964	3,089	1,001	1,220	9,255	2,122	5,496	2,910	40,959
1981	4,441	3,299	4,235	2,149	3,024	36,340	5,683	1,777	1,543	4,871	3,816	1,118	72,295
1982	1,255	994	1,016	1,223	8,993	3,281	1,055	2,499	1,341	1,331	2,726	3,726	29,440
1983	4,389	4,510	10,511	1,018	6,284	10,932	6,980	3,171	5,452	2,789	2,362	1,435	59,830
1984	1,708	1,142	1,125	926	879	1,139	757	651	635	6,748	3,251	8,384	27,346

Units = acft

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
1985	9,334	6,188	7,682	5,221	3,853	28,163	15,232	996	4,955	5,790	32,170	3,599	123,183
1986	4,169	4,192	1,692	1,368	16,850	13,896	1,143	1,161	5,874	22,801	4,871	25,477	103,493
1987	4,711	12,253	5,387	1,505	18,145	38,512	6,170	1,589	1,804	1,016	18,443	5,338	114,873
1988	1,663	2,148	2,867	1,516	10,988	3,068	4,164	1,432	1,315	1,509	958	985	32,614
1989	2,787	1,073	2,410	3,221	8,594	4,634	1,200	1,280	860	1,407	977	745	29,188
1990	845	1,228	4,259	4,877	8,492	2,517	8,475	1,240	2,899	3,217	5,880	1,041	44,970
1991	15,538	6,522	4,184	10,672	10,159	8,276	3,960	3,660	10,566	1,877	1,603	36,198	113,215
1992	19,810	20,819	19,344	7,749	20,612	16,002	3,203	2,283	1,652	990	2,911	4,881	120,257
1993	4,412	5,858	7,231	4,546	12,308	8,787	993	990	958	1,358	1,423	1,106	49,971
1994	1,225	1,514	3,481	1,887	9,215	2,824	990	1,317	3,631	19,131	4,254	16,914	66,384
1995	2,852	2,793	5,102	9,219	19,199	9,114	2,445	1,573	4,103	1,730	3,106	1,233	62,468
1996	989	882	924	1,224	1,137	3,075	545	11,749	9,066	853	2,434	4,449	37,327
1997	2,032	6,036	4,848	18,770	15,386	47,316	2,402	3,803	1,640	6,256	3,621	7,464	119,575
1998	6,031	14,398	7,314	1,307	1,085	1,025	1,601	7,536	18,561	65,573	17,400	4,555	146,387
Average (1950-1998)	**5,049**	**5,721**	**4,157**	**5,673**	**10,497**	**9,323**	**3,929**	**2,867**	**6,063**	**8,913**	**6,252**	**6,048**	**74,491**
Average (1950-1996)	**5,098**	**5,501**	**4,063**	**5,460**	**10,607**	**8,599**	**4,023**	**2,730**	**5,866**	**7,596**	**6,044**	**6,050**	**71,638**

```
RUN
GLOBAL
 Blanco Recharge Basin, Texas
  START       1956  1  1  0  0  END    1998 12 31 24  0
  RUN INTERP OUTPUT LEVEL    3
  RESUME     0 RUN     1 TSSFL     0 WDMSFL    0 UNITS     1
END GLOBAL
FILES
<type>  <fun>***<------------fname------------------------------------------->
MESSU       25    blanco.ech
WDM         26    blanco.wdm
            90    blanco.out
END FILES
OPN SEQUENCE
    INGRP              INDELT 24:00
      PERLND     101
      PERLND     201
      PERLND     202
      PERLND     203
      PERLND     204
      PERLND     301
      PERLND     302
      RCHRES      11
      RCHRES      12
      RCHRES      13
      RCHRES      14
      RCHRES      15
      RCHRES      16
      RCHRES      21
      RCHRES      22
      RCHRES      23
      RCHRES      24
      RCHRES      25
      RCHRES      26
      RCHRES      27
      RCHRES      31
      RCHRES      32
      RCHRES      33
      RCHRES      91
      RCHRES      92
      RCHRES      93
      RCHRES      94
    END INGRP
END OPN SEQUENCE
PERLND
  ACTIVITY
    <PLS >               Active Sections                                     ***
    x -  x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ***
  101         0    0    1    0    0    0    0    0    0    0    0    0
  201  204    0    0    1    0    0    0    0    0    0    0    0    0
  301  302    0    0    1    0    0    0    0    0    0    0    0    0
  END ACTIVITY
  PRINT-INFO
     <PLS> ******************** Print-flags ************************ PIVL  PYR
     x - x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC *********
  101         4    4    5    4    4    4    4    4    4    4    4    4    1   12
  201  204    4    4    5    4    4    4    4    4    4    4    4    4    1   12
  301  302    4    4    5    4    4    4    4    4    4    4    4    4    1   12
  END PRINT-INFO
  GEN-INFO
*** BR IS BLANCO RIV, SC IS SINK CRK, PC IS PURGATORY CRK, AND YC IS YORK CRK***
    <PLS >      Name           NBLKS   Unit-systems   Printer***
    x -  x                                 t-series Engl Metr***
                                            in  out          ***
  101     BR-CONTRIBUTING         1         1    1   90    0
  201     BR-RECHARGE ZONE        1         1    1   90    0
  202     SC-RECHARGE ZONE        1         1    1   90    0
  203     PC-RECHARGE ZONE        1         1    1   90    0
  204     YC-RECHARGE ZONE        1         1    1   90    0
  301     BR-DOWNDIP              1         1    1   90    0
  302     SC-DOWNDIP              1         1    1   90    0
  END GEN-INFO
```

```
  PWAT-PARM1
*** <PLS >                  Flags
*** x -  x CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE
  101         0    1    1    0    0    0    0    0    0
  201         0    1    1    0    0    0    0    0    0
  202  204    0    1    1    0    0    0    0    0    0
  301  302    0    1    1    0    0    0    0    0    0
  END PWAT-PARM1
  PWAT-PARM2
***  <PLS>     FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
***   x - x                (in)   (in/hr)      (ft)              (1/in)   (1/day)
  101             0.0       4.0     0.025     300.0      0.10       4.0      0.93
  201             0.0       4.0     0.040     300.0      0.10       4.0      0.93
  202             0.0       4.0     0.035     300.0      0.10       4.0      0.93
  203             0.0       4.0     0.035     300.0      0.10       4.0      0.93
  204             0.0       4.0     0.035     300.0      0.10       4.0      0.93
  301             0.0       4.0     0.025     300.0      0.10       4.0      0.93
  302             0.0       4.0     0.025     300.0      0.10       4.0      0.93
  END PWAT-PARM2
  PWAT-PARM3
***  <PLS>     PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
***   x - x   (deg F)   (deg F)
  101            40.0      35.0       2.0       2.0      0.40       0.4       0.2
  201  204       40.0      35.0       2.0       2.0      1.00       0.4       0.2
  301  302       40.0      35.0       2.0       2.0      0.05       0.4       0.2
  END PWAT-PARM3
  PWAT-PARM4
*** <PLS >      CEPSC      UZSN      NSUR     INTFW       IRC     LZETP
*** x -  x       (in)      (in)                       (1/day)
  101            0.12       0.4      0.15       0.5      0.90      0.30
  201            0.12       0.4      0.15       0.5      0.90      0.30
  202            0.13       0.4      0.15       0.5      0.90      0.30
  203            0.13       0.4      0.15       0.5      0.90      0.30
  204            0.12       0.4      0.15       0.5      0.90      0.30
  301            0.16       0.4      0.15       0.5      0.90      0.30
  302            0.12       0.4      0.15       0.5      0.90      0.30
  END PWAT-PARM4
  PWAT-STATE1
*** <PLS >  PWATER state variables (in)
*** x -  x       CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
  101             0.0       0.0       0.2       0.0       2.0       0.2       0.0
  201             0.0       0.0       0.2       0.0       2.0       0.2       0.0
  202             0.0       0.0       0.2       0.0       2.0       0.2       0.0
  203             0.0       0.0       0.2       0.0       2.0       0.2       0.0
  204             0.0       0.0       0.2       0.0       2.0       0.2       0.0
  301             0.0       0.0       0.2       0.0       2.0       0.2       0.0
  302             0.0       0.0       0.2       0.0       2.0       0.2       0.0
  END PWAT-STATE1
END PERLND
RCHRES
  ACTIVITY
*** RCHRES  Active sections
*** x -  x HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG
   11   16    1    0    0    0    0    0    0    0    0    0
   21   27    1    0    0    0    0    0    0    0    0    0
   31   33    1    0    0    0    0    0    0    0    0    0
   91   94    1    0    0    0    0    0    0    0    0    0
  END ACTIVITY
  PRINT-INFO
*** RCHRES  Printout level flags
*** x -  x HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB PIVL  PYR
   11   16    5    6    6    6    6    6    6    6    6    6    1   12
   21   27    5    6    6    6    6    6    6    6    6    6    1   12
   31   33    5    6    6    6    6    6    6    6    6    6    1   12
   91   94    5    6    6    6    6    6    6    6    6    6    1   12
  END PRINT-INFO
```

```
  GEN-INFO
***              Name          Nexits     Unit Systems     Printer
*** RCHRES                                  t-series   Engl Metr LKFG
*** x -  x                                    in  out
   11      BLRIV BEL WIMB          1          1    1    90    0    0
   12      BLRIV SEG 2             2          1    1    90    0    0
   13      BLRIV SEG 3             2          1    1    90    0    0
   14      BLRIV SEG 4             2          1    1    90    0    0
   15      BLRIV ABV KYLE          2          1    1    90    0    0
   16      BLRIV BEL KYLE          2          1    1    90    0    0
   21      UPR SAN MRCS FRS1       2          1    1    90    0    1
   22      UPR SAN MRCS FRS2       2          1    1    90    0    1
   23      UPR SAN MRCS FRS3       2          1    1    90    0    1
   24      UPR SAN MRCS FRS4       2          1    1    90    0    1
   25      UPR SAN MRCS FRS5       2          1    1    90    0    1
   31      YORK CRK FRS1           2          1    1    90    0    1
   32      YORK CRK FRS2           2          1    1    90    0    1
   26      BELOW USM FRS3          1          1    1    90    0    0
   27      BELOW USM FRS5          1          1    1    90    0    0
   33      BELOW YC FRS1&2         1          1    1    90    0    0
   91      BLANCO CHNL LOSS        1          1    1    90    0    0
   92      SINK CRK CHNL LOSS      1          1    1    90    0    0
   93      PRGTY CRK CHNL LOSS     1          1    1    90    0    0
   94      YORK CRK CHNL LOSS      1          1    1    90    0    0
  END GEN-INFO
  HYDR-PARM1
***         Flags for HYDR section
    RCHRES  VC A1 A2 A3  ODFVFG for each *** ODGTFG for each      FUNCT  for each
     x - x  FG FG FG FG  possible    exit *** possible    exit      possible    exit
   11        0  1  0  0   4  0  0  0  0        0  0  0  0  0        1  1  1  1  1
   12   15   0  1  0  0   4  5  0  0  0        0  0  0  0  0        1  1  1  1  1
   16        0  1  0  0   4  0  0  0  0        0  0  0  0  0        1  1  1  1  1
   21   25   0  1  0  0   4  5  0  0  0        0  0  0  0  0        1  1  1  1  1
   26   27   0  1  0  0   4  0  0  0  0        0  0  0  0  0        1  1  1  1  1
   31   32   0  1  0  0   4  5  0  0  0        0  0  0  0  0        1  1  1  1  1
   33        0  1  0  0   4  0  0  0  0        0  0  0  0  0        1  1  1  1  1
   91   94   0  0  0  0   4  0  0  0  0        0  0  0  0  0        1  1  1  1  1
  END HYDR-PARM1
  HYDR-PARM2
*** RCHRES FTBW FTBU        LEN      DELTH      STCOR         KS       DB50
*** x -  x                (miles)     (ft)       (ft)                  (in)
   11        0.0 11.0       5.2      60.3        0.0         0.5      0.01
   12        0.0 12.0       6.5      81.5        0.0         0.5      0.01
   13        0.0 13.0       1.5      16.3        0.0         0.5      0.01
   14        0.0 14.0       0.5       3.5        0.0         0.5      0.01
   15        0.0 15.0       3.2      26.8        0.0         0.5      0.01
   16        0.0 16.0       2.2      10.0        0.0         0.5      0.01
   21        0.0 21.0       0.1       1.0        0.0         0.5      0.01
   22        0.0 22.0       0.1       1.0        0.0         0.5      0.01
   23        0.0 23.0       0.1       1.0        0.0         0.5      0.01
   24        0.0 24.0       0.1       1.0        0.0         0.5      0.01
   25        0.0 25.0       0.1       1.0        0.0         0.5      0.01
   31        0.0 31.0       0.1       1.0        0.0         0.5      0.01
   32        0.0 32.0       0.1       1.0        0.0         0.5      0.01
   26   27   0 0 26.0       0.1       1.0        0.0         0.5      0.01
   33        0 0 26.0       0.1       1.0        0.0         0.5      0.01
   91   94   0.0 91.0       0.1       1.0        0.0         0.5      0.01
  END HYDR-PARM2
  HYDR-INIT
***          Initial conditions for HYDR section
*** RCHRES        VOL  CAT Initial value  of COLIND     initial  value  of OUTDGT
***  x - x      ac-ft       for each possible   exit  for each possible exit,ft3
   11   16       0.00  0.0  4.0  4.0  4.0  4.0  4.0        0.0  0.0  0.0  0.0  0.0
   21   27       0.00  0.0  4.0  4.0  4.0  4.0  4.0        0.0  0.0  0.0  0.0  0.0
   31   33       0.00  0.0  4.0  4.0  4.0  4.0  4.0        0.0  0.0  0.0  0.0  0.0
   91   94       0.00  0.0  4.0  4.0  4.0  4.0  4.0        0.0  0.0  0.0  0.0  0.0
  END HYDR-INIT
END RCHRES
```

```
  EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member->***
<Name>   x <Name> x tem strg<-factor->strg <Name>   x   x        <Name> x x***
WDM     51 flow  10 ENGL      1.9835       RCHRES  11      EXTNL  IVOL    1 1
WDM     61 prcp  10 ENGL                   RCHRES  11   12 EXTNL  PREC    1 1
WDM     41 evap  10 ENGL                   RCHRES  11   12 EXTNL  POTEV   1 1
WDM     62 prcp  10 ENGL                   RCHRES  13   15 EXTNL  PREC    1 1
WDM     42 evap  10 ENGL                   RCHRES  13   15 EXTNL  POTEV   1 1
WDM     66 prcp  10 ENGL                   RCHRES  16      EXTNL  PREC    1 1
WDM     46 evap  10 ENGL                   RCHRES  16      EXTNL  POTEV   1 1
WDM     63 prcp  10 ENGL                   RCHRES  21   23 EXTNL  PREC    1 1
WDM     43 evap  10 ENGL                   RCHRES  21   23 EXTNL  POTEV   1 1
WDM     64 prcp  10 ENGL                   RCHRES  24   25 EXTNL  PREC    1 1
WDM     44 evap  10 ENGL                   RCHRES  24   25 EXTNL  POTEV   1 1
WDM     65 prcp  10 ENGL                   RCHRES  31   32 EXTNL  PREC    1 1
WDM     45 evap  10 ENGL                   RCHRES  31   32 EXTNL  POTEV   1 1
WDM     61 prcp  10 ENGL                   PERLND 101      EXTNL  PREC    1 1
WDM     41 evap  10 ENGL                   PERLND 101      EXTNL  PETINP  1 1
WDM     62 prcp  10 ENGL                   PERLND 201      EXTNL  PREC    1 1
WDM     42 evap  10 ENGL                   PERLND 201      EXTNL  PETINP  1 1
WDM     63 prcp  10 ENGL                   PERLND 202      EXTNL  PREC    1 1
WDM     43 evap  10 ENGL                   PERLND 202      EXTNL  PETINP  1 1
WDM     64 prcp  10 ENGL                   PERLND 203      EXTNL  PREC    1 1
WDM     44 evap  10 ENGL                   PERLND 203      EXTNL  PETINP  1 1
WDM     65 prcp  10 ENGL                   PERLND 204      EXTNL  PREC    1 1
WDM     45 evap  10 ENGL                   PERLND 204      EXTNL  PETINP  1 1
WDM     66 prcp  10 ENGL                   PERLND 301      EXTNL  PREC    1 1
WDM     46 evap  10 ENGL                   PERLND 301      EXTNL  PETINP  1 1
WDM     67 prcp  10 ENGL                   PERLND 302      EXTNL  PREC    1 1
WDM     47 evap  10 ENGL                   PERLND 302      EXTNL  PETINP  1 1
END EXT SOURCES
EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Aggr Amd ***
<Name>   x        <Name> x x<-factor->strg <Name>   x <Name>qf  tem strg strg***
SIMULATED FLOW AT BLANCO RIVER AT KYLE ***
RCHRES  15 ROFLOW ROVOL  1                 WDM      71 simq    1 ENGL      REPL
SIMULATED FLOW AT UPPER SAN MARCOS GAUGE ***
RCHRES  26 ROFLOW ROVOL  1                 WDM      72 flow    1 ENGL      REPL
SIMULATED PRECIP & EVAP FROM REACHES 1 -5 ***
RCHRES  11 HYDR   VOLEV  1                 WDM      90 evap    1 ENGL      REPL***
RCHRES  12 HYDR   VOLEV  1                 WDM      91 evap    1 ENGL      REPL***
RCHRES  13 HYDR   VOLEV  1                 WDM      92 evap    1 ENGL      REPL***
RCHRES  14 HYDR   VOLEV  1                 WDM      93 evap    1 ENGL      REPL***
RCHRES  15 HYDR   VOLEV  1                 WDM      94 evap    1 ENGL      REPL***
RCHRES  11 HYDR   PRSUPY 1                 WDM      95 rain    1 ENGL      REPL***
RCHRES  12 HYDR   PRSUPY 1                 WDM      96 rain    1 ENGL      REPL***
RCHRES  13 HYDR   PRSUPY 1                 WDM      97 rain    1 ENGL      REPL***
RCHRES  14 HYDR   PRSUPY 1                 WDM      98 rain    1 ENGL      REPL***
RCHRES  15 HYDR   PRSUPY 1                 WDM      99 rain    1 ENGL      REPL***
RECHARGE FROM EACH BLANCO RIVER REACH SEGMENT ***
RCHRES  12 HYDR   OVOL   2                 WDM      75 rchg    1 ENGL      REPL
RCHRES  13 HYDR   OVOL   2                 WDM      76 rchg    1 ENGL      REPL
RCHRES  14 HYDR   OVOL   2                 WDM      77 rchg    1 ENGL      REPL
RCHRES  15 HYDR   OVOL   2                 WDM      78 rchg    1 ENGL      REPL
RECHARGE FROM EACH SINK CREEK FRS ***
RCHRES  21 HYDR   OVOL   2                 WDM      79 rchg    1 ENGL      REPL
RCHRES  22 HYDR   OVOL   2                 WDM      80 rchg    1 ENGL      REPL
RCHRES  23 HYDR   OVOL   2                 WDM      81 rchg    1 ENGL      REPL
RECHARGE FROM EACH PURGATORY CREEK FRS ***
RCHRES  24 HYDR   OVOL   2                 WDM      82 rchg    1 ENGL      REPL
RCHRES  25 HYDR   OVOL   2                 WDM      83 rchg    1 ENGL      REPL
RECHARGE FROM EACH YORK CREEK FRS ***
RCHRES  31 HYDR   OVOL   2                 WDM      84 rchg    1 ENGL      REPL
RCHRES  32 HYDR   OVOL   2                 WDM      85 rchg    1 ENGL      REPL
RECHARGE FROM LAND SEGMENTS ABOVE OUTCROP ***
PERLND 101 PWATER IGWI                     WDM     171 igwi    1 ENGL      REPL
RECHARGE FROM LAND SEGMENTS OVER OUTCROP ***
PERLND 201 PWATER IGWI                     WDM     271 igwi    1 ENGL      REPL
PERLND 202 PWATER IGWI                     WDM     272 igwi    1 ENGL      REPL
PERLND 203 PWATER IGWI                     WDM     273 igwi    1 ENGL      REPL
PERLND 204 PWATER IGWI                     WDM     274 igwi    1 ENGL      REPL
WATER LOST (RECHARGE TO ANOTHER FORMATION) FROM LAND SEGMENTS OVER OUTCROP ***
PERLND 301 PWATER IGWI                     WDM     371 igwi    1 ENGL      REPL
```

```
PERLND 302 PWATER IGWI                      WDM    372 igwi   1 ENGL       REPL
TOTAL ACTUAL E-T FROM ALL LAND SEGMENTS ***
PERLND 101 PWATER TAET                      WDM    181 taet   1 ENGL       REPL
PERLND 201 PWATER TAET                      WDM    281 taet   1 ENGL       REPL
PERLND 202 PWATER TAET                      WDM    282 taet   1 ENGL       REPL
PERLND 203 PWATER TAET                      WDM    283 taet   1 ENGL       REPL
PERLND 204 PWATER TAET                      WDM    284 taet   1 ENGL       REPL
PERLND 301 PWATER TAET                      WDM    381 taet   1 ENGL       REPL
PERLND 302 PWATER TAET                      WDM    382 taet   1 ENGL       REPL
SURFACE RUNOFF FROM ALL LAND SEGMENTS ***
PERLND 101 PWATER SURO                      WDM    191 suro   1 ENGL       REPL
PERLND 201 PWATER SURO                      WDM    291 suro   1 ENGL       REPL
PERLND 202 PWATER SURO                      WDM    292 suro   1 ENGL       REPL
PERLND 203 PWATER SURO                      WDM    293 suro   1 ENGL       REPL
PERLND 204 PWATER SURO                      WDM    294 suro   1 ENGL       REPL
PERLND 301 PWATER SURO                      WDM    391 suro   1 ENGL       REPL
PERLND 302 PWATER SURO                      WDM    392 suro   1 ENGL       REPL
TOTAL STORAGE AMOUNTS FROM ALL LAND SEGMENTS ***
PERLND 101 PWATER PERS                      WDM    151 stor   1 ENGL       REPL
PERLND 201 PWATER PERS                      WDM    251 stor   1 ENGL       REPL
PERLND 202 PWATER PERS                      WDM    252 stor   1 ENGL       REPL
PERLND 203 PWATER PERS                      WDM    253 stor   1 ENGL       REPL
PERLND 204 PWATER PERS                      WDM    254 stor   1 ENGL       REPL
PERLND 301 PWATER PERS                      WDM    351 stor   1 ENGL       REPL
PERLND 302 PWATER PERS                      WDM    352 stor   1 ENGL       REPL
TOTAL OUTFLOW FROM ALL LAND SEGMENTS ***
PERLND 101 PWATER PERO                      WDM    161 outq   1 ENGL       REPL
PERLND 201 PWATER PERO                      WDM    261 outq   1 ENGL       REPL
PERLND 202 PWATER PERO                      WDM    262 outq   1 ENGL       REPL
PERLND 203 PWATER PERO                      WDM    263 outq   1 ENGL       REPL
PERLND 204 PWATER PERO                      WDM    264 outq   1 ENGL       REPL
PERLND 301 PWATER PERO                      WDM    361 outq   1 ENGL       REPL
PERLND 302 PWATER PERO                      WDM    362 outq   1 ENGL       REPL
END EXT TARGETS
SCHEMATIC
<-Volume->                  <--Area-->      <-Volume->  <ML#> ***
<Name>   x                  <-factor->      <Name>   x        ***
LAND SEGMENT CONNECTIVITY TO REACHES***
PERLND 101                      6735.0      RCHRES  11       1
PERLND 101                      8613.0      RCHRES  12       1
PERLND 101                       426.0      RCHRES  13       1
PERLND 201                      1366.0      RCHRES  11       1
PERLND 201                      6771.3      RCHRES  12       1
PERLND 201                      8477.8      RCHRES  13       1
PERLND 201                       502.5      RCHRES  14       1
PERLND 201                       585.2      RCHRES  15       1
PERLND 202                      2669.5      RCHRES  16       1
PERLND 202                     21094.1      RCHRES  21       1
PERLND 202                      2284.4      RCHRES  22       1
PERLND 202                      2455.7      RCHRES  23       1
PERLND 202                      1166.1      RCHRES  26       1
PERLND 203                     12908.8      RCHRES  24       1
PERLND 203                      9222.4      RCHRES  25       1
PERLND 203                       384.0      RCHRES  27       1
PERLND 204                      8275.2      RCHRES  31       1
PERLND 204                      1792.0      RCHRES  32       1
PERLND 204                      3584.0      RCHRES  33       1
PERLND 301                        96.6      RCHRES  13       1
PERLND 301                       233.8      RCHRES  14       1
PERLND 301                      2596.5      RCHRES  15       1
PERLND 302                      4707.7      RCHRES  16       1
PERLND 302                       230.5      RCHRES  21       1
PERLND 302                       504.0      RCHRES  22       1
PERLND 302                       499.7      RCHRES  23       1
PERLND 302                      1451.3      RCHRES  26       1
BLANCO RIVER REACH CONNECTIVITY ***
RCHRES  11                                  RCHRES  12       4
RCHRES  12                                  RCHRES  13       4
RCHRES  13                                  RCHRES  14       4
RCHRES  14                                  RCHRES  15       4
RCHRES  15                                  RCHRES  16       4
RCHRES  12                                  RCHRES  91       3
RCHRES  13                                  RCHRES  91       3
```

```
RCHRES  14                                 RCHRES  91       3
RCHRES  15                                 RCHRES  91       3
SINK CREEK REACH CONNECTIVITY ***
RCHRES  21                                 RCHRES  23       4
RCHRES  22                                 RCHRES  23       4
RCHRES  23                                 RCHRES  26       4
RCHRES  21                                 RCHRES  92       3
RCHRES  22                                 RCHRES  92       3
RCHRES  23                                 RCHRES  92       3
PURGATORY CREEK REACH CONNECTIVITY ***
RCHRES  24                                 RCHRES  25       4
RCHRES  25                                 RCHRES  27       4
RCHRES  24                                 RCHRES  93       3
RCHRES  25                                 RCHRES  93       3
YORK CREEK REACH CONNECTIVITY ***
RCHRES  31                                 RCHRES  33       4
RCHRES  32                                 RCHRES  33       4
RCHRES  31                                 RCHRES  94       3
RCHRES  32                                 RCHRES  94       3
END SCHEMATIC
MASS-LINK
  MASS-LINK        1
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->strg <Name>                <Name> x x  ***
PERLND     PWATER PERO       0.0833333     RCHRES         INFLOW IVOL
  END MASS-LINK    1
  MASS-LINK        2
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->strg <Name>                <Name> x x  ***
RCHRES     HYDR   ROVOL                    RCHRES         INFLOW IVOL
  END MASS-LINK    2
  MASS-LINK        3
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->strg <Name>                <Name> x x  ***
RCHRES     HYDR   OVOL   2                 RCHRES         INFLOW IVOL
  END MASS-LINK    3
  MASS-LINK        4
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->strg <Name>                <Name> x x  ***
RCHRES     HYDR   OVOL   1                 RCHRES         INFLOW IVOL
  END MASS-LINK    4
END MASS-LINK
FTABLES
  FTABLE      11
    9    4
11        Upper Blanco River (Below Wimberley)      5.22***
     DEPTH      AREA    VOLUME     DISCH   CH LOSS ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
         0         0         0         0         0
         1        26         3        94         0
         2        61        56       517         0
         3        66       103      1314         0
         4        71       173      2320         0
         5        74       245      3469         0
         6        77       321      4828         0
        10        88       652     12290         0
      37.5       606     10178    212490         0
  END FTABLE 11
```

```
  FTABLE     12
   11    5
12         Blanco River Segment 2               6.51***
     DEPTH      AREA    VOLUME      DISCH   CH LOSS ***
      (FT)   (ACRES)   (AC-FT)      (CFS)     (MIN) ***
         0         0         0          0         0
      0.33        12         4        2.8       2.8
         1        78        30         31       2.8
         2        96       113        291       2.8
         3       102       211        792       2.8
         4       109       316       1487       2.8
         5       120       431       2321       2.8
         6       147       690       4445       2.8
         8       186      1601      15411       2.8
        15       193      2112      23771       2.8
        40       305      8807     185909       2.8
  END FTABLE 12
  FTABLE     13
   11    5
13         Blanco River Segment 3               1.53***
     DEPTH      AREA    VOLUME      DISCH   CH LOSS ***
      (FT)   (ACRES)   (AC-FT)      (CFS)     (MIN) ***
         0         0         0          0         0
      0.53         5         2        5.7       5.7
         1        18         7         31       5.7
         2        22        27        291       5.7
         3        24        50        792       5.7
         4        26        74       1487       5.7
         5        28       101       2321       5.7
         6        35       162       4445       5.7
         8        44       376      15411       5.7
        15        45       496      23771       5.7
        40        72      2070     185909       5.7
  END FTABLE 13
  FTABLE     14
   10    5
14         Blanco River Segment 4               0.46***
     DEPTH      AREA    VOLUME      DISCH   CH LOSS ***
      (FT)   (ACRES)   (AC-FT)      (CFS)     (MIN) ***
         0         0         0          0         0
      0.33         3         4        7.1       7.1
         1         8         7        174       7.1
         2         9        16        574       7.1
         4        18        44       1976       7.1
         6        19        81       5334       7.1
         8        20       119       9937       7.1
        10        20       159      15664       7.1
        15        22       264      34428       7.1
        40        60      1088     185735       7.1
  END FTABLE 14
  FTABLE     15
   11    5
15         Blanco River above Kyle Gauge        3.24***
     DEPTH      AREA    VOLUME      DISCH   CH LOSS ***
      (FT)   (ACRES)   (AC-FT)      (CFS)     (MIN) ***
         0         0         0          0         0
      0.25         8         4        0.5       0.5
         1        19        21         21       0.5
         2        21        33        156       0.5
         4        25        79        722       0.5
         6        27       130       1687       0.5
         8        31       188       3189       0.5
        10        48       481       5214       0.5
        12        50       500       7704       0.5
        15        58       516      12400       0.5
        40       241      3548     202900       0.5
  END FTABLE 15
```

```
  FTABLE     16
   9    4
16          Blanco River below Kyle Gauge        2.17***
     DEPTH      AREA    VOLUME      DISCH    CH LOSS ***
      (FT)   (ACRES)   (AC-FT)      (CFS)      (MIN)  ***
         0         0         0          0          0
         2        14        22        156          0
         4        16        53        722          0
         6        18        87       1687          0
         8        21       126       3189          0
        10        32       322       5214          0
        12        33       338       7704          0
        15        39       346      12400          0
        40       162      2376     202900          0
  END FTABLE 16
  FTABLE     21
   20    5
    21     Upper San Marcos FRS #1  (Sink Crk)***
     DEPTH      AREA    VOLUME      DISCH    CH LOSS***
      (FT)   (ACRES)   (AC-FT)      (CFS)      (MIN)***
         0         0         0          0          0
         1         2         4          0         12
         5         9        25          0         51
         9        22        86          0        133
        10        25       107          0        151
        13        38       206          0        183
        16        51       304          0        185
        17        58       398        113        187
        21        82       678        225        191
        25       103      1047        249        196
        29       123      1498        271        200
        33       144      2032        292        204
        37       167      2654        311        209
        41       198      3384        329        215
        45       235      4249        346        222
        49       275      5267        362        230
        53       316      6447        378        238
        57       364      7806        393        248
        59       395      8683        401        255
        75       500     20000      11317        255
  END FTABLE 21
  FTABLE     22
   14    5
    22     Upper San Marcos FRS #2  (Sink Crk)***
     DEPTH      AREA    VOLUME      DISCH    CH LOSS***
      (FT)   (ACRES)   (AC-FT)      (CFS)      (MIN)***
         0         0         0          0          0
         1         1         1          0          0
         5         5        12          0          1
         9        11        43          0          2
        13        17        93          0          3
        13        18       100         16          4
        17        27       189         91          5
        21        36       313        101          7
        25        48       480        110         10
        29        65       705        118         13
        33        84      1002        125         17
        36       102      1275        131         21
        37       108      1386        133         22
        40       300     10000       8614         22
  END FTABLE 22
```

```
FTABLE     23
 12    5
  23     Upper San Marcos FRS #3 (Sink Crk)***
   DEPTH      AREA    VOLUME     DISCH   CH LOSS***
    (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN)***
       0         0         0         0         0
       1         1         1         0         0
       5         4        10         0         1
       9         9        35         0         2
      13        14        80         0         3
      16        20       127         0         4
      17        22       151       105         4
      21        40       273       720         8
      25        55       461       802        10
      29        68       706       876        13
      33        85      1011       942        16
      40       100     10000      8989        16
END FTABLE 23
FTABLE     24
 20    5
  24     Upper San Marcos FRS #4 (Purgatory Crk)***
   DEPTH      AREA    VOLUME     DISCH   CH LOSS***
    (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN)***
       0         0         0         0         0
       8         4        11         0         1
      12        11        39         0         4
      20        17       152         0         7
      23        21       215         0         8
      28        26       323       279        10
      32        30       434       300        12
      36        34       561       319        14
      40        42       712       338        17
      44        52       899       355        21
      48        60      1122       372        24
      52        68      1378       388        27
      56        76      1665       403        29
      60        84      1984       418        30
      64        96      2343       432        31
      68       110      2753       446        33
      72       123      3218       460        35
      76       146      3755       473        39
      82       180      4788       493        43
     100       300     10000      5212        43
END FTABLE 24
FTABLE     25
 17    5
  25     Upper San Marcos FRS #5 (Purgatory Crk)***
   DEPTH      AREA    VOLUME     DISCH   CH LOSS***
    (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN)***
       0         0         0         0         0
       1         1         2         0         6
       5         6        16         0        36
       9         9        46         0        51
      13        11        84         0        67
      17        23       161         0       139
      19        30       215         0       182
      21        37       269       252       221
      25        47       435       597       281
      29        58       644       661       351
      33        81       921       719       430
      37        95      1271       773       463
      41       106      1672       824       490
      45       125      2134       871       535
      49       154      2691       916       603
      52       172      3167       947       646
      75       300     10000      6832       646
END FTABLE 25
```

```
  FTABLE     31
   16    5
    31     York Creek FRS #1***
     DEPTH      AREA    VOLUME      DISCH   CH LOSS***
      (FT)   (ACRES)   (AC-FT)      (CFS)      (MIN)***
         0         0         0          0          0
         1        16        94          0         10
         3        19       135          0         11
         5        20       166         50         12
         9        26       258         53         16
        13        32       374         56         19
        17        39       516         59         24
        21        49       692         61         30
        25        59       908         64         36
        29        70      1166         66         42
        33        82      1470         69         50
        37        95      1824         71         57
        41       110      2234         73         67
        45       128      2710         76         77
        48       148      3718         77         89
        75       300     10000       6282         89
  END FTABLE 31
  FTABLE     32
   11    5
    32     York Creek FRS #2***
     DEPTH      AREA    VOLUME      DISCH   CH LOSS***
      (FT)   (ACRES)   (AC-FT)      (CFS)      (MIN)***
         0         0         0          0          0
         1         8        30          0          5
         5        10        69          0          6
         6        11        77         22          7
         9        14       114         46          8
        13        17       176         51         10
        17        22       254         55         13
        21        27       352         59         16
        25        32       470         62         19
        28        36       586         65         22
        50        50      5000       4414         22
  END FTABLE 32
  FTABLE     26
   9    4
    26     GENERIC REACH SEGMENT***
     DEPTH      AREA    VOLUME      DISCH   CH LOSS***
      (FT)   (ACRES)   (AC-FT)      (CFS)      (MIN)***
         0         0         0          0          0
         5        50       500        500          0
        10       100      1500       1500          0
        15       150      3000       3000          0
        20       200      5000       5000          0
        25       250      7500       7500          0
        30       300     10500      10500          0
        35       350     14000      14000          0
        40       400     50000      50000          0
  END FTABLE 26
  FTABLE     91
   4    4
    91     GENERIC STORAGE***
     DEPTH      AREA    VOLUME      DISCH   CH LOSS***
      (FT)   (ACRES)   (AC-FT)      (CFS)      (MIN)***
       0.0       0.0       0.0        0.0        0.0
      90.0     900.0    9000.0        0.0
     900.0    9000.0   90000.0        0.0
    9000.0   90000.0  900000.0        0.0
  END FTABLE 91
END FTABLES
END RUN
```

```
RUN
GLOBAL
 Edwards Aquifer Recharge, Nueces Basin, Texas
  START       1950  1  1  0  0  END    1998 12 31 24  0
  RUN INTERP OUTPUT LEVEL    3
  RESUME     0 RUN     1 TSSFL     0 WDMSFL    0 UNITS     1
END GLOBAL
FILES
<type>  <fun>***<------------fname-------------------------------------------->
MESSU      25    Nueces.ech
WDM        26    Nueces.wdm
           90    Nueces.out
END FILES
OPN SEQUENCE
    INGRP              INDELT 24: 0
      PERLND     101
      PERLND     102
      PERLND     201
      PERLND     202
      PERLND     203
      PERLND     301
      PERLND     302
      PERLND     303
      RCHRES      11
      RCHRES      12
      RCHRES      13
      RCHRES      14
      RCHRES      15
      RCHRES      16
      RCHRES      17
      RCHRES      90
      RCHRES      91
      RCHRES      92
      RCHRES      93
      RCHRES      94
      RCHRES      95
      RCHRES      97
    END INGRP
END OPN SEQUENCE
PERLND
  ACTIVITY
    <PLS >               Active Sections                             ***
    x -  x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ***
  101  102    0    0    1    0    0    0    0    0    0    0    0    0
  201  203    0    0    1    0    0    0    0    0    0    0    0    0
  301  303    0    0    1    0    0    0    0    0    0    0    0    0
  END ACTIVITY
  PRINT-INFO
     <PLS> ********************* Print-flags ************************ PIVL  PYR
     x - x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC *********
  101  102    6    6    5    6    6    6    6    6    6    6    6    6    1   12
  201  203    6    6    5    6    6    6    6    6    6    6    6    6    1   12
  301  303    6    6    5    6    6    6    6    6    6    6    6    6    1   12
  END PRINT-INFO
  GEN-INFO
*** NW is West Nueces River, NR is Nueces River, UN is Upper Nueces-upstream of Laguna Gage***
    <PLS >      Name           NBLKS   Unit-systems   Printer***
    x -  x                             t-series Engl Metr***
                                         in  out          ***
  101     WN-CONTRIBUTING         1        1    1   90    0
  102     NR-CONTRIBUTING         1        1    1   90    0
  201     WN-RECHARGE             1        1    1   90    0
  202     NR-RECHARGE             1        1    1   90    0
  203     UN-RECHARGE             1        1    1   90    0
  301     WN-DOWNDIP              1        1    1   90    0
  302     NR-DOWNDIP              1        1    1   90    0
  303     LEONA GRAVELS           1        1    1   90    0
  END GEN-INFO
```

```
  PWAT-PARM1
*** <PLS >                Flags
*** x -   x CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE
  101  102    0    1    1    0    0    0    0    0    0
  201  203    0    1    1    0    0    0    0    0    0
  301  303    0    1    1    0    0    0    0    0    0
  END PWAT-PARM1
  PWAT-PARM2
***  <PLS>     FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
***   x - x                (in)   (in/hr)      (ft)              (1/in)   (1/day)
  101             0.0       2.5      0.02     300.0      0.06       0.0      0.99
  102             0.0       2.5      0.03     300.0      0.05       0.0      0.99
  201             0.0       2.5      0.04     350.0      0.04       0.0      0.99
  202             0.0       2.5      0.04     350.0      0.04       0.0      0.99
  203             0.0       2.5      0.04     300.0      0.09       0.0      0.99
  301             0.0       3.0      0.03     350.0      0.01       0.0      0.99
  302             0.0       3.0      0.03     350.0      0.02       0.0      0.99
  303             0.0       3.0      0.03     350.0      0.01       0.0      0.99
  END PWAT-PARM2
  PWAT-PARM3
***  <PLS>     PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
***   x - x   (deg F)   (deg F)
  101            40.0      35.0       2.0       2.0      0.40       0.0       0.1
  102            40.0      35.0       2.0       2.0      0.40       0.1       0.1
  201            40.0      35.0       2.0       2.0      1.00       0.0       0.1
  202            40.0      35.0       2.0       2.0      1.00       0.0       0.1
  203            40.0      35.0       2.0       2.0      1.00       0.0       0.1
  301            40.0      35.0       2.0       2.0      0.02       0.1       0.1
  302            40.0      35.0       2.0       2.0      0.02       0.1       0.1
  303            40.0      35.0       2.0       2.0      0.02       0.1       0.1
  END PWAT-PARM3
  PWAT-PARM4
*** <PLS >      CEPSC      UZSN      NSUR     INTFW       IRC     LZETP
*** x -   x      (in)      (in)                         (1/day)
  101            0.14      0.17      0.15      2.00      0.90      0.37
  102            0.12      0.17      0.15      2.00      0.90      0.27
  201            0.12      0.16      0.15      2.00      0.90      0.28
  202            0.12      0.16      0.15      2.00      0.90      0.28
  203            0.12      0.16      0.15      2.00      0.90      0.28
  301            0.12      0.20      0.15      2.00      0.90      0.20
  302            0.10      0.20      0.15      2.00      0.90      0.22
  303            0.09      0.20      0.15      2.00      0.90      0.23
  END PWAT-PARM4
  PWAT-STATE1
***  <PLS>  PWATER state variables (in)
***   x - x      CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
  101             0.0       0.0       0.1       0.0       0.5       0.0       0.0
  102             0.0       0.0       0.1       0.0       0.5       0.0       0.0
  201             0.0       0.0       0.1       0.0       0.5       0.0       0.0
  202             0.0       0.0       0.1       0.0       0.5       0.0       0.0
  203             0.0       0.0       0.1       0.0       0.5       0.0       0.0
  301             0.0       0.0       0.1       0.0       0.5       0.0       0.0
  302             0.0       0.0       0.1       0.0       0.5       0.0       0.0
  303             0.0       0.0       0.1       0.0       0.5       0.0       0.0
  END PWAT-STATE1
END PERLND
RCHRES
  ACTIVITY
*** RCHRES  Active sections
*** x -   x HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG
   11          1    0    0    0    0    0    0    0    0    0
   12          1    0    0    0    0    0    0    0    0    0
   13          1    0    0    0    0    0    0    0    0    0
   14          1    0    0    0    0    0    0    0    0    0
   15          1    0    0    0    0    0    0    0    0    0
   16          1    0    0    0    0    0    0    0    0    0
   17          1    0    0    0    0    0    0    0    0    0
   90   97     1    0    0    0    0    0    0    0    0    0
  END ACTIVITY
```

```
  PRINT-INFO
*** RCHRES  Printout level flags
*** x -   x HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB PIVL  PYR
   11   17    5    6    6    6    6    6    6    6    6    6    1   12
   90   97    5    6    6    6    6    6    6    6    6    6    1   12
  END PRINT-INFO
  GEN-INFO
***              Name          Nexits   Unit Systems   Printer
*** RCHRES                              t-series  Engl Metr LKFG
*** x -  x                                in  out
   11      WEST NUECES SEG 11       2        1    1   90    0    0
   12      WEST NUECES SEG 12       2        1    1   90    0    0
   13      NUECES RIVER SEG 13      3        1    1   90    0    0
   14      NUECES RIVER SEG 14      2        1    1   90    0    0
   15      NUECES RIVER SEG 15      2        1    1   90    0    0
   16      NUECES RIVER SEG 16      2        1    1   90    0    0
   17      NUECES RIVER SEG 17      2        1    1   90    0    0
   90      WN 11    CH LOSSES       1        1    1   90    0    0
   91      WN 12    CH LOSSES       1        1    1   90    0    0
   92      NR 13    CH LOSSES       1        1    1   90    0    0
   93      NR 14    CH LOSSES       1        1    1   90    0    0
   94      NR 15    CH LOSSES       1        1    1   90    0    0
   95      NR 16    CH LOSSES       1        1    1   90    0    0
   97      UPPER NUECES REACH       1        1    1   90    0    0
  END GEN-INFO
  HYDR-PARM1
***         Flags for HYDR section
    RCHRES  VC A1 A2 A3  ODFVFG for each *** ODGTFG for each      FUNCT  for each
     x - x  FG FG FG FG  possible   exit *** possible    exit      possible    exit
   11   12   0  1  0  0    4  5  0  0  0        0  0  0  0  0        1  1  1  1  1
   13        0  1  0  0    4  5  0  0  0        0  0  1  0  0        1  1  1  1  1
   14   16   0  1  0  0    4  5  0  0  0        0  0  0  0  0        1  1  1  1  1
   17        0  1  0  0    4  0  0  0  0        0  1  0  0  0        1  1  1  1  1
   90   95   0  0  0  0    4  0  0  0  0        0  0  0  0  0        1  1  1  1  1
   97        0  0  0  0    4  0  0  0  0        0  0  0  0  0        1  1  1  1  1
  END HYDR-PARM1
  HYDR-PARM2
*** RCHRES FTBW FTBU        LEN      DELTH      STCOR        KS       DB50
*** x -  x              (miles)       (ft)       (ft)                 (in)
   11        0.0 11.0      12.5      120.0        0.0        0.5      0.01
   12        0.0 12.0      29.5      260.0        0.0        0.5      0.01
   13        0.0 13.0      11.2      128.0        0.0        0.5      0.01
   14        0.0 14.0       3.2       40.0        0.0        0.5      0.01
   15        0.0 15.0       6.0       43.0        0.0        0.5      0.01
   16        0.0 16.0       3.2       31.0        0.0        0.5      0.01
   17        0.0 17.0       8.9       66.0        0.0        0.5      0.01
   90   95   0.0 90.0       0.1        1.0        0.0        0.5      0.01
   97        0.0 90.0       0.1        1.0        0.0        0.5      0.01
  END HYDR-PARM2
  HYDR-INIT
***         Initial conditions for HYDR section
*** RCHRES        VOL  CAT Initial value  of COLIND      initial  value  of OUTDGT
***  x - x      ac-ft      for each possible   exit  for each possible exit,ft3
   11   17       0.00  0.0  4.0  4.0  4.0  4.0  4.0        0.0  0.0  0.0  0.0  0.0
   90   95       0.00  0.0  4.0  4.0  4.0  4.0  4.0        0.0  0.0  0.0  0.0  0.0
   97            0.00  0.0  4.0  4.0  4.0  4.0  4.0        0.0  0.0  0.0  0.0  0.0
  END HYDR-INIT
END RCHRES
EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   x <Name> x tem strg<-factor->strg <Name>   x   x        <Name> x x  ***
WDM     51 FLOW   10 ENGL       1.9835      RCHRES  11      EXTNL  IVOL    1 1
WDM     52 FLOW   10 ENGL       1.9835      RCHRES  13      EXTNL  IVOL    1 1
WDM     53 FLOW   10 ENGL       1.9835      RCHRES  17      EXTNL  IVOL    1 1
WDM     63 PREC   10 ENGL                   RCHRES  11   12 EXTNL  PREC    1 1
WDM     43 EVAP   10 ENGL                   RCHRES  11   12 EXTNL  POTEV   1 1
WDM     64 PREC   10 ENGL                   RCHRES  13   14 EXTNL  PREC    1 1
WDM     44 EVAP   10 ENGL                   RCHRES  13   14 EXTNL  POTEV   1 1
WDM     67 PREC   10 ENGL                   RCHRES  15   17 EXTNL  PREC    1 1
WDM     47 EVAP   10 ENGL                   RCHRES  15   17 EXTNL  POTEV   1 1
WDM     67 PREC   10 ENGL                   RCHRES  90   95 EXTNL  PREC    1 1
WDM     47 EVAP   10 ENGL                   RCHRES  90   95 EXTNL  POTEV   1 1
WDM     65 PREC   10 ENGL                   RCHRES  97      EXTNL  PREC    1 1
```

```
WDM      45 EVAP  10 ENGL                   RCHRES  97      EXTNL  POTEV  1 1
WDM      61 PREC  10 ENGL                   PERLND 101      EXTNL  PREC   1 1
WDM      41 EVAP  10 ENGL                   PERLND 101      EXTNL  PETINP 1 1
WDM      62 PREC  10 ENGL                   PERLND 102      EXTNL  PREC   1 1
WDM      42 EVAP  10 ENGL                   PERLND 102      EXTNL  PETINP 1 1
WDM      63 PREC  10 ENGL                   PERLND 201      EXTNL  PREC   1 1
WDM      43 EVAP  10 ENGL                   PERLND 201      EXTNL  PETINP 1 1
WDM      64 PREC  10 ENGL                   PERLND 202      EXTNL  PREC   1 1
WDM      44 EVAP  10 ENGL                   PERLND 202      EXTNL  PETINP 1 1
WDM      65 PREC  10 ENGL                   PERLND 203      EXTNL  PREC   1 1
WDM      45 EVAP  10 ENGL                   PERLND 203      EXTNL  PETINP 1 1
WDM      66 PREC  10 ENGL                   PERLND 301      EXTNL  PREC   1 1
WDM      46 EVAP  10 ENGL                   PERLND 301      EXTNL  PETINP 1 1
WDM      67 PREC  10 ENGL                   PERLND 302      EXTNL  PREC   1 1
WDM      47 EVAP  10 ENGL                   PERLND 302      EXTNL  PETINP 1 1
WDM      68 PREC  10 ENGL                   PERLND 303      EXTNL  PREC   1 1
WDM      48 EVAP  10 ENGL                   PERLND 303      EXTNL  PETINP 1 1
WDM      31 WRDM  10 ENGL       0.504       RCHRES  13      EXTNL  OUTDGT 1 1
WDM      32 WRDM  10 ENGL       0.504       RCHRES  17      EXTNL  OUTDGT 1 1
END EXT SOURCES
EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Aggr Amd ***
<Name>   x        <Name> x x<-factor->strg <Name>   x <Name>qf  tem strg strg***
*** SIMULATED FLOW ON NUECES RIVER AT UVALDE ***
RCHRES  17 HYDR   OVOL   1                  WDM      70 FLOW   1 ENGL       REPL
*** RECHARGE FROM EACH RIVER REACH SEGMENT ***
RCHRES  11 HYDR   OVOL   2                  WDM      71 RCHG   1 ENGL       REPL
RCHRES  12 HYDR   OVOL   2                  WDM      72 RCHG   1 ENGL       REPL
RCHRES  13 HYDR   OVOL   2                  WDM      73 RCHG   1 ENGL       REPL
RCHRES  14 HYDR   OVOL   2                  WDM      74 RCHG   1 ENGL       REPL
RCHRES  15 HYDR   OVOL   2                  WDM      75 RCHG   1 ENGL       REPL
RCHRES  16 HYDR   OVOL   2                  WDM      76 RCHG   1 ENGL       REPL
*** Water Rights OUTFLOW FROM RCHRES 17 ***
RCHRES  17 HYDR   OVOL   2                  WDM      77 WRDM   1 ENGL       REPL
*** WATER RIGHTS OUTFLOW FROM RCHRES 13 ***
RCHRES  13 HYDR   OVOL   3                  WDM      78 WRDM   1 ENGL       REPL
*** TOTAL EVAPORATIVE LOSSES FROM RIVER REACHES ***
RCHRES  11 HYDR   VOLEV  1                  WDM     511 VLEV   1 ENGL       REPL
RCHRES  12 HYDR   VOLEV  1                  WDM     512 VLEV   1 ENGL       REPL
RCHRES  13 HYDR   VOLEV  1                  WDM     513 VLEV   1 ENGL       REPL
RCHRES  14 HYDR   VOLEV  1                  WDM     514 VLEV   1 ENGL       REPL
RCHRES  15 HYDR   VOLEV  1                  WDM     515 VLEV   1 ENGL       REPL
RCHRES  16 HYDR   VOLEV  1                  WDM     516 VLEV   1 ENGL       REPL
RCHRES  17 HYDR   VOLEV  1                  WDM     517 VLEV   1 ENGL       REPL
*** VOLUME OF WATER CONTRIBUTED BY PRECIPITATION***
RCHRES  11 HYDR   PRSUPY 1                  WDM     611 PREC   1 ENGL       REPL
RCHRES  12 HYDR   PRSUPY 1                  WDM     612 PREC   1 ENGL       REPL
RCHRES  13 HYDR   PRSUPY 1                  WDM     613 PREC   1 ENGL       REPL
RCHRES  14 HYDR   PRSUPY 1                  WDM     614 PREC   1 ENGL       REPL
RCHRES  15 HYDR   PRSUPY 1                  WDM     615 PREC   1 ENGL       REPL
RCHRES  16 HYDR   PRSUPY 1                  WDM     616 PREC   1 ENGL       REPL
RCHRES  17 HYDR   PRSUPY 1                  WDM     617 PREC   1 ENGL       REPL
*** RECHARGE FROM LAND SEGMENTS OVER CONTRIBUTING ZONE ***
PERLND 101 PWATER IGWI                      WDM     111 IGWI   1 ENGL       REPL
PERLND 102 PWATER IGWI                      WDM     112 IGWI   1 ENGL       REPL
*** RECHARGE FROM LAND SEGMENTS OVER OUTCROP ***
PERLND 201 PWATER IGWI                      WDM     211 IGWI   1 ENGL       REPL
PERLND 202 PWATER IGWI                      WDM     212 IGWI   1 ENGL       REPL
PERLND 203 PWATER IGWI                      WDM     213 IGWI   1 ENGL       REPL
*** RECHARGE FROM LAND SEGMENTS OVER DOWNDIP ***
PERLND 301 PWATER IGWI                      WDM     311 IGWI   1 ENGL       REPL
PERLND 302 PWATER IGWI                      WDM     312 IGWI   1 ENGL       REPL
*** RECHARGE FROM LAND SEGMENTS OVER LEONA GRAVELS ***
PERLND 303 PWATER IGWI                      WDM     313 IGWI   1 ENGL       REPL
*** TOTAL ACTUAL E-T FROM ALL LAND SEGMENTS ***
PERLND 101 PWATER TAET                      WDM     121 TAET   1 ENGL       REPL
PERLND 102 PWATER TAET                      WDM     122 TAET   1 ENGL       REPL
PERLND 201 PWATER TAET                      WDM     221 TAET   1 ENGL       REPL
PERLND 202 PWATER TAET                      WDM     222 TAET   1 ENGL       REPL
PERLND 203 PWATER TAET                      WDM     223 TAET   1 ENGL       REPL
PERLND 301 PWATER TAET                      WDM     321 TAET   1 ENGL       REPL
PERLND 302 PWATER TAET                      WDM     322 TAET   1 ENGL       REPL
PERLND 303 PWATER TAET                      WDM     323 TAET   1 ENGL       REPL
```

```
*** TOTAL SURFACE RUNOFF FROM ALL LAND SEGMENTS ***
PERLND 101 PWATER SURO                          WDM    131 SURO    1 ENGL      REPL
PERLND 102 PWATER SURO                          WDM    132 SURO    1 ENGL      REPL
PERLND 201 PWATER SURO                          WDM    231 SURO    1 ENGL      REPL
PERLND 202 PWATER SURO                          WDM    232 SURO    1 ENGL      REPL
PERLND 203 PWATER SURO                          WDM    233 SURO    1 ENGL      REPL
PERLND 301 PWATER SURO                          WDM    331 SURO    1 ENGL      REPL
PERLND 302 PWATER SURO                          WDM    332 SURO    1 ENGL      REPL
PERLND 303 PWATER SURO                          WDM    333 SURO    1 ENGL      REPL
*** TOTAL OUTFLOW FROM ALL LAND SEGMENTS ***
PERLND 101 PWATER PERO                          WDM    141 PERO    1 ENGL      REPL
PERLND 102 PWATER PERO                          WDM    142 PERO    1 ENGL      REPL
PERLND 201 PWATER PERO                          WDM    241 PERO    1 ENGL      REPL
PERLND 202 PWATER PERO                          WDM    242 PERO    1 ENGL      REPL
PERLND 203 PWATER PERO                          WDM    243 PERO    1 ENGL      REPL
PERLND 301 PWATER PERO                          WDM    341 PERO    1 ENGL      REPL
PERLND 302 PWATER PERO                          WDM    342 PERO    1 ENGL      REPL
PERLND 303 PWATER PERO                          WDM    343 PERO    1 ENGL      REPL
***TOTAL STORAGE AMOUNTS FROM ALL LAND SEGMENTS ***
PERLND 101 PWATER PERS                          WDM    151 STOR    1 ENGL      REPL
PERLND 102 PWATER PERS                          WDM    152 STOR    1 ENGL      REPL
PERLND 201 PWATER PERS                          WDM    251 STOR    1 ENGL      REPL
PERLND 202 PWATER PERS                          WDM    252 STOR    1 ENGL      REPL
PERLND 203 PWATER PERS                          WDM    253 STOR    1 ENGL      REPL
PERLND 301 PWATER PERS                          WDM    351 STOR    1 ENGL      REPL
PERLND 302 PWATER PERS                          WDM    352 STOR    1 ENGL      REPL
PERLND 303 PWATER PERS                          WDM    353 STOR    1 ENGL      REPL
END EXT TARGETS
SCHEMATIC
<-Volume->                  <--Area-->     <-Volume->  <ML#> ***
<Name>   x                  <-factor->     <Name>   x        ***
***PERLND 101 IS WEST NUECES CONTRIBUTING***
PERLND 101                     5165.32     RCHRES  11       1
PERLND 101                    34095.83     RCHRES  12       1
PERLND 101                       31.69     RCHRES  13       1
***PERLND 102 IS NUECES RIVER CONTRIBUTING***
PERLND 102                       35.93     RCHRES  12       1
PERLND 102                     5211.15     RCHRES  13       1
***PERLND 201 IS WEST NUECES RECHARGE***
PERLND 201                    39665.19     RCHRES  11       1
PERLND 201                    51034.23     RCHRES  12       1
PERLND 201                       63.32     RCHRES  13       1
PERLND 201                       34.60     RCHRES  14       1
PERLND 201                        2.45     RCHRES  15       1
***PERLND 202 IS NUECES RIVER RECHARGE***
PERLND 202                       82.49     RCHRES  12       1
PERLND 202                    33586.20     RCHRES  12       1
PERLND 202                    11876.43     RCHRES  14       1
PERLND 202                    41761.47     RCHRES  15       1
PERLND 202                      581.37     RCHRES  16       1
***PERLND 203 IS NUECES UPPER RECHARGE ***
PERLND 203                     3296.00     RCHRES  97       1
***PERLND 301 IS WEST NUECES RIVER DOWNDIP***
PERLND 301                    13619.92     RCHRES  12       1
PERLND 301                        6.45     RCHRES  15       1
PERLND 301                        5.70     RCHRES  16       1
***PERLND 302 IS NUECES RIVER DOWNDIP***
PERLND 302                       18.44     RCHRES  12       1
PERLND 302                     2619.88     RCHRES  15       1
PERLND 302                     1444.65     RCHRES  16       1
PERLND 302                    21828.02     RCHRES  17       1
***PERLND 303 IS LEONA GRAVELS***
PERLND 303                     3561.05     RCHRES  15       1
PERLND 303                     5839.98     RCHRES  16       1
PERLND 303                     2895.34     RCHRES  17       1
***RIVER REACHES***
RCHRES  11                                 RCHRES  12       4
RCHRES  12                                 RCHRES  15       4
RCHRES  13                                 RCHRES  14       4
RCHRES  14                                 RCHRES  15       4
RCHRES  15                                 RCHRES  16       4
RCHRES  16                                 RCHRES  17       4
RCHRES  11                                 RCHRES  90       3
```

```
RCHRES  12                                  RCHRES  91      3
RCHRES  13                                  RCHRES  92      3
RCHRES  14                                  RCHRES  93      3
RCHRES  15                                  RCHRES  94      3
RCHRES  16                                  RCHRES  95      3
END SCHEMATIC
MASS-LINK
  MASS-LINK        1
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->strg <Name>                <Name> x x  ***
PERLND     PWATER PERO       0.0833333     RCHRES         INFLOW IVOL
  END MASS-LINK    1
  MASS-LINK        2
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->strg <Name>                <Name> x x  ***
RCHRES     HYDR   OVOL  3                  RCHRES         INFLOW IVOL
  END MASS-LINK    2
  MASS-LINK        3
*** Outflow to channel losses                                                ***
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->strg <Name>                <Name> x x  ***
RCHRES     HYDR   OVOL   2                 RCHRES         INFLOW IVOL
  END MASS-LINK    3
  MASS-LINK        4
*** Outflow (discharge) to next RCHRES                                       ***
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->strg <Name>                <Name> x x  ***
RCHRES     HYDR   OVOL   1                 RCHRES         INFLOW IVOL
  END MASS-LINK    4
END MASS-LINK
FTABLES
  FTABLE     11
   rows cols                                    ***
   13    5
11        West Nueces Segment 11          12.46 ***
     DEPTH      AREA    VOLUME     DISCH  CH LOSS ***
      (FT)   (ACRES)   (AC-FT)     (CFS)    (MIN) ***
       0.0       0.0       0.0       0.0      0.0
       2.0     167.2     268.8      29.4     29.4
       2.6     171.7     372.1      92.6     92.6
       3.0     174.7     441.0     157.4     92.6
       4.0     185.2     620.7     500.6     92.6
       5.0     196.2     811.0    1020.0     92.6
       6.0     205.4    1011.9    1750.0     92.6
       7.0     214.5    1221.8    2700.0     92.6
       8.0     227.3    1442.3    3900.0     92.6
       9.0     248.1    1676.4    5350.0     92.6
      10.0     295.6    1948.3    7080.0     92.6
      20.0    1170.3    8075.6   45000.0     92.6
      31.0    2794.1   29879.8  237300.0     92.6
  END FTABLE 11
  FTABLE     12
   13    5
12        West Nueces Segment 12           29.5 ***
     DEPTH      AREA    VOLUME     DISCH  CH LOSS ***
       0.0       0.0       0.0       0.0      0.0
       0.5     575.3     135.9      22.3     22.3
       0.7     614.0     253.9      60.5     60.5
       0.9     679.8     382.6     112.0    112.0
       1.1     738.4     525.6     179.9    179.9
       1.2     795.3     616.8     219.2    219.2
       1.3     817.1     683.0     260.2    219.2
       1.5    1004.8     865.3     336.3    219.2
       1.7    1079.9    1072.7     458.4    219.2
       5.0    2003.9    6007.3    5358.9    219.2
      10.0    3898.6   21232.8   28219.9    219.2
      20.0    7329.6   77576.1  160565.6    219.2
      30.0   10522.7  166837.7  452107.3    219.2
  END FTABLE 12
```

```
  FTABLE     13
   13    5
13        Nueces River Segment 13            11.22 ***
     DEPTH      AREA    VOLUME      DISCH  CH LOSS ***
      (FT)   (ACRES)   (AC-FT)      (CFS)    (MIN) ***
       0.0       0.0       0.0        0.0      0.0
       3.0      74.3     125.1        3.0      3.0
       3.5      83.2     164.6       22.0     22.0
       3.7      86.8     182.6       41.0     41.0
       4.0      92.2     208.1      110.0     41.1
       4.5     100.9     257.0      323.3     43.9
       5.0     109.5     308.7      701.0     48.8
       5.5     118.0     365.8     1262.0     56.2
      10.0     295.1    1383.1    11330.0    187.7
      15.0     409.5    3250.4    29000.0    418.6
      20.0     581.4    5476.7    67600.0    922.9
      30.0    1836.4   17567.1   234000.0   3096.8
      35.0    2463.9   28317.9   307000.0   4050.6
  END FTABLE 13
  FTABLE     14
   14    5
14        Nueces River Segment 14             3.21 ***
     DEPTH      AREA    VOLUME      DISCH  CH LOSS ***
      (FT)   (ACRES)   (AC-FT)      (CFS)    (MIN) ***
       0.0       0.0       0.0        0.0      0.0
       0.2       7.4       0.7        0.6      0.6
       0.3      18.3       4.1        3.9      3.9
       1.3      44.6      36.2      112.6      3.9
       2.0      67.7      71.6      266.1      4.1
       2.5     114.2     117.1      426.3      4.2
       3.0     160.9     185.6      731.1      4.6
       3.5     207.5     277.8     1208.7      5.2
       4.0     254.1     393.0     1882.4      6.0
       5.0     282.1     473.9     2398.6      6.7
      10.0     846.5    5536.4    69351.1     88.8
      20.0    1129.5   15415.8   315309.2    390.5
      30.0    1412.5   28125.8   739961.1    911.5
      35.0    1554.0   35542.3  1025552.7   1261.9
  END FTABLE 14
  FTABLE     15
   13    5
15        Nueces River Segment 15             5.98 ***
     DEPTH      AREA    VOLUME      DISCH  CH LOSS ***
      (FT)   (ACRES)   (AC-FT)      (CFS)    (MIN) ***
       0.0       0.0       0.0        0.0      0.0
       1.0      10.6       2.9        2.4      2.4
       1.3      15.8       6.4        7.2      7.2
       2.0      28.1      22.5       37.1      7.2
       3.0      45.7      59.4      135.8      7.2
       4.0      63.3     113.8      322.7      7.7
       5.0      80.9     186.3      623.2      8.4
       7.0     132.9     392.1     1547.6     10.5
      10.0     231.7     939.4     4584.5     17.4
      20.0     526.0    4750.7    39523.5     97.2
      30.0    1219.8   12889.3   119131.0    279.1
      35.0    2224.5   20902.5   178762.8    415.4
      40.0    2833.9   33893.9   340503.4    784.9
  END FTABLE 15
```

```
  FTABLE     16
   14    5
16         Nueces River Segment 16            3.16 ***
     DEPTH      AREA    VOLUME      DISCH   CH LOSS ***
     ( FT)   (ACRES)   (AC-FT)      (CFS)     (MIN) ***
       0.0       0.0       0.0        0.0       0.0
       0.5      37.0      10.8       20.1      20.1
       0.8      41.8      20.8       55.4      55.4
       1.0      45.9      30.8      100.2      55.4
       1.5      54.9      58.2      256.6      58.0
       2.0      63.9      87.7      459.4      61.6
       2.5      72.8     121.8      727.6      66.3
       3.0      81.7     160.5     1066.6      72.3
       3.5      90.7     203.8     1481.7      79.6
       4.0      99.6     251.3     1973.3      88.3
       5.0     117.5     359.7     3213.5     110.1
      10.0     206.0    1228.0    17106.6     355.0
      20.0     512.1    4406.0    78382.6    1434.9
      30.0    1024.6   12090.0   265555.9    4733.6
  END FTABLE 16
  FTABLE     17
   12    4
17         Nueces River Segment 17            8.86 ***
     DEPTH      AREA    VOLUME      DISCH   CH LOSS ***
      (FT)   (ACRES)   (AC-FT)      (CFS)     (MIN) ***
       0.0       0.0       0.0        0.0       0.0
       4.0     299.2     325.0      437.7       0.0
       4.5     327.5     511.4      775.0       0.0
       5.0     365.2     684.1     1169.0       0.0
       7.0     500.2    1568.1     3156.0       0.0
       8.0     507.6    2071.3     4110.0       0.0
       9.0     543.3    2585.4     5327.0       0.0
      10.0     672.8    3194.6     7000.0       0.0
      12.0     931.6    4798.1    15130.0       0.0
      15.0    1420.5    8251.1    45620.0       0.0
      20.0    2656.6   18317.8   117900.0       0.0
      25.0    3956.1   34848.6   203000.0       0.0

  END FTABLE 17
  FTABLE     90
    4    4
90         Null River Segment                          ***
     DEPTH      AREA    VOLUME      DISCH   CH LOSS ***
      (FT)   (ACRES)   (AC-FT)      (CFS)     (MIN) ***
       0.0       0.0       0.0        0.0
      10.0     100.0    2000.0        0.0
     100.0    1000.0  300000.0        0.0
    1000.0   10000.0 4000000.0        0.0

  END FTABLE 90
END FTABLES
END RUN
```

Nueces Recharge Basin
Time Series Input

Segment # / Reach #	Time Series Data Type	*.wdm Data Set #
101	Precipitation on Land Segment	61
102	Precipitation on Land Segment	62
201	Precipitation on Land Segment	63
202	Precipitation on Land Segment	64
203	Precipitation on Land Segment	65
301	Precipitation on Land Segment	66
302	Precipitation on Land Segment	67
303	Precipitation on Land Segment	68
101	Evaporation on Land Segment	41
102	Evaporation on Land Segment	42
201	Evaporation on Land Segment	43
202	Evaporation on Land Segment	44
203	Evaporation on Land Segment	45
301	Evaporation on Land Segment	46
302	Evaporation on Land Segment	47
303	Evaporation on Land Segment	48
11	Upstream Inflow at Bracketville	51
13	Upstream Inflow at Laguna	52
17	Infllow from Leona Gravels	53
13	Water Rights Out of Reach	31
17	Water Rights Out of Reach	32
11	Precipitation on Reach	63
12	Precipitation on Reach	63
13	Precipitation on Reach	64
14	Precipitation on Reach	64
15	Precipitation on Reach	67
16	Precipitation on Reach	67
17	Precipitation on Reach	67
11	Evaporation on Reach	43
12	Evaporation on Reach	43
13	Evaporation on Reach	44
14	Evaporation on Reach	44
15	Evaporation on Reach	47
16	Evaporation on Reach	47
17	Evaporation on Reach	47

Nueces Recharge Basin
Time Series Output

Segment # / Reach #	Time Series Data Type	*.wdm Data Set #
101	Simulated Recharge from Land Segment	111
102	Simulated Recharge from Land Segment	112
201	Simulated Recharge from Land Segment	211
202	Simulated Recharge from Land Segment	212
203	Simulated Recharge from Land Segment	213
301	Simulated Recharge from Land Segment	311
302	Simulated Recharge from Land Segment	312
303	Simulated Recharge from Land Segment	313
101	Simulated Total Actual E-T from Land Segment	121
102	Simulated Total Actual E-T from Land Segment	122
201	Simulated Total Actual E-T from Land Segment	221
202	Simulated Total Actual E-T from Land Segment	222
203	Simulated Total Actual E-T from Land Segment	223
301	Simulated Total Actual E-T from Land Segment	321
302	Simulated Total Actual E-T from Land Segment	322
303	Simulated Total Actual E-T from Land Segment	323
101	Simulated Surface Runoff from Land Segment	131
102	Simulated Surface Runoff from Land Segment	132
201	Simulated Surface Runoff from Land Segment	231
202	Simulated Surface Runoff from Land Segment	232
203	Simulated Surface Runoff from Land Segment	233
301	Simulated Surface Runoff from Land Segment	331
302	Simulated Surface Runoff from Land Segment	332
303	Simulated Surface Runoff from Land Segment	333
101	Simulated Storage in Land Segment	151
102	Simulated Storage in Land Segment	152
201	Simulated Storage in Land Segment	251
202	Simulated Storage in Land Segment	252
203	Simulated Storage in Land Segment	253
301	Simulated Storage in Land Segment	351
302	Simulated Storage in Land Segment	352
303	Simulated Storage in Land Segment	353
101	Simulated Total Outflow from Land Segment	141
102	Simulated Total Outflow from Land Segment	142
201	Simulated Total Outflow from Land Segment	241
202	Simulated Total Outflow from Land Segment	242
203	Simulated Total Outflow from Land Segment	243
301	Simulated Total Outflow from Land Segment	341
302	Simulated Total Outflow from Land Segment	342
303	Simulated Total Outflow from Land Segment	343
17	Simulated Streamflow at Uvalde	70
11	Simulated Recharge from Reach	71
12	Simulated Recharge from Reach	72
13	Simulated Recharge from Reach	73
14	Simulated Recharge from Reach	74
15	Simulated Recharge from Reach	75
16	Simulated Recharge from Reach	76
17	Simulated Recharge from Reach	77

Blanco Recharge Basin
Time Series Input

Segment # / Reach #	Time Series Data Type	*.wdm Data Set #
101	Precipitation on Land Segment	61
201	Precipitation on Land Segment	62
202	Precipitation on Land Segment	63
203	Precipitation on Land Segment	64
204	Precipitation on Land Segment	65
301	Precipitation on Land Segment	66
302	Precipitation on Land Segment	67
101	Evaporation on Land Segment	41
201	Evaporation on Land Segment	42
202	Evaporation on Land Segment	43
203	Evaporation on Land Segment	44
204	Evaporation on Land Segment	45
301	Evaporation on Land Segment	46
302	Evaporation on Land Segment	47
11	Upstream Inflow to Reach at Wimberley	51
11	Precipitation on Reach	61
12	Precipitation on Reach	61
13	Precipitation on Reach	62
14	Precipitation on Reach	62
15	Precipitation on Reach	62
16	Precipitation on Reach	66
21	Precipitation on Reach	63
22	Precipitation on Reach	63
23	Precipitation on Reach	63
24	Precipitation on Reach	64
25	Precipitation on Reach	64
31	Precipitation on Reach	65
32	Precipitation on Reach	65
11	Evaporation on Reach	41
12	Evaporation on Reach	41
13	Evaporation on Reach	42
14	Evaporation on Reach	42
15	Evaporation on Reach	42
16	Evaporation on Reach	46
21	Evaporation on Reach	43
22	Evaporation on Reach	43
23	Evaporation on Reach	43
24	Evaporation on Reach	44
25	Evaporation on Reach	44
31	Evaporation on Reach	45
32	Evaporation on Reach	45

Blanco Recharge Basin
Time Series Output

Segment # / Reach #	Time Series Data Type	*.wdm Data Set #
101	Simulated Recharge from Land Segment	171
201	Simulated Recharge from Land Segment	271
202	Simulated Recharge from Land Segment	272
203	Simulated Recharge from Land Segment	273
204	Simulated Recharge from Land Segment	274
301	Simulated Recharge from Land Segment	371
302	Simulated Recharge from Land Segment	372
101	Simulated Total Actual E-T from Land Segment	181
201	Simulated Total Actual E-T from Land Segment	281
202	Simulated Total Actual E-T from Land Segment	282
203	Simulated Total Actual E-T from Land Segment	283
204	Simulated Total Actual E-T from Land Segment	284
301	Simulated Total Actual E-T from Land Segment	381
302	Simulated Total Actual E-T from Land Segment	382
101	Simulated Surface Runoff from Land Segment	191
201	Simulated Surface Runoff from Land Segment	291
202	Simulated Surface Runoff from Land Segment	292
203	Simulated Surface Runoff from Land Segment	293
204	Simulated Surface Runoff from Land Segment	294
301	Simulated Surface Runoff from Land Segment	391
302	Simulated Surface Runoff from Land Segment	392
101	Simulated Storage in Land Segment	151
201	Simulated Storage in Land Segment	251
202	Simulated Storage in Land Segment	252
203	Simulated Storage in Land Segment	253
204	Simulated Storage in Land Segment	254
301	Simulated Storage in Land Segment	351
302	Simulated Storage in Land Segment	352
101	Simulated Total Outflow from Land Segment	161
201	Simulated Total Outflow from Land Segment	261
202	Simulated Total Outflow from Land Segment	262
203	Simulated Total Outflow from Land Segment	263
204	Simulated Total Outflow from Land Segment	264
301	Simulated Total Outflow from Land Segment	361
302	Simulated Total Outflow from Land Segment	362
15	Simulated Streamflow at Kyle	71
26	Simulated Streamflow at San Marcos	72
11	Simulated Evaporation on Reach	90
12	Simulated Evaporation on Reach	91
13	Simulated Evaporation on Reach	92
14	Simulated Evaporation on Reach	93
15	Simulated Evaporation on Reach	94
11	Simulated Precipitation on Reach	95
12	Simulated Precipitation on Reach	96
13	Simulated Precipitation on Reach	97
14	Simulated Precipitation on Reach	98
15	Simulated Precipitation on Reach	99

Blanco Recharge Basin
Time Series Output (Concluded)

Segment # / Reach #	***Time Series Data Type***	****.wdm Data Set #***
12	Simulated Recharge from Reach	75
13	Simulated Recharge from Reach	76
14	Simulated Recharge from Reach	77
15	Simulated Recharge from Reach	78
21	Simulated Recharge from FRS	79
22	Simulated Recharge from FRS	80
23	Simulated Recharge from FRS	81
24	Simulated Recharge from FRS	82
25	Simulated Recharge from FRS	83
31	Simulated Recharge from FRS	84
32	Simulated Recharge from FRS	85

Water Resources Applications Software

Summary of ANNIE

NAME

annie - Interactive hydrologic analyses and data management

ABSTRACT

ANNIE is a program designed to help users interactively store, retrieve, list, plot, check, and update spatial, parametric, and time-series data for hydrologic models and analyses. Data are stored in a direct access file called a Watershed Data Management (WDM) file. Many hydrologic and water-quality models and analyses developed by the U.S. Geological Survey (USGS) and the Environmental Protection Agency (EPA) currently use WDM files. The WDM file provides users with a common data base for many applications, thus eliminating the need to reformat data from one application to another. There is also an expanding library of subroutines for graphics, user interaction, and data storage and retrieval available to application programmers designing software utilizing WDM files.

METHOD

A WDM file is a binary, direct-access file used to store hydrologic, hydraulic, meteorologic, water-quality, and physiographic data. The WDM file is organized into data sets. Each data set contains a specific type of data, such as streamflow at a specific site or air temperature at a weather station. Each data set contains attributes that describe the data, such as station identification number, time step of data, latitude, and longitude. A WDM file may contain a single data set or as many as 200,000 data sets. A data set may be described by a few attributes or by hundreds of attributes. Data can be added, deleted, and modified without restructuring the data in the file. Space from deleted data sets is reused.

The Annie Interactive Development Environment (AIDE) user interface is used. This character-based interface provides a consistent look and feel across different computer platforms, including DOS-based PC, UNIX, and minicomputers. The AIDE interface is used with most of the interactive programs that use the WDM file.

HISTORY

The original design and implementation of the WDM file was a cooperative effort between the USGS and the Soil Conservation Service in 1983. Additional types of data sets have been implemented by the USGS and EPA. ANNIE, IOWDM, and HSPF were the original programs that used the WDM file in 1984. Since then, over a dozen programs have been developed or modified by the USGS and EPA to use the WDM file. USGS maintains and distributes the official version of the WDM library.

Version 4.0 2000/11/01 - Corrected problem introduced in the June 29, 1998, revisions, which caused some small negative numbers to be exported as "*****". This was a problem for data values in the range -0.01 - -0.09. With respect to time series data stored in a wdm file, this range of data is occasionally seen in temperature data. All WDM data sets now contain the date the data set was created and the date the data set was last modified. Program wdmrx is included with the compiled distributions to trouble-shoot problems in wdm files.

Version 3.0 - there was no 3.0 distribution.

Version 2.5 1998/06/29 - Corrected problem introduced when the number of significant digits in Archive/Export files was increased to 6. The Import option was not reading the first digit in some cases.

Version 2.4 1998/03/06 - Updated to incorporate corrections and changes made in lib library; there are two noteworthy changes. (1) In some instances, the common time period that was determined by the software may actually have been shorter than the actual common time period; this has been corrected. (2) The Archive/Export option will now output the time-series data values with six significant digits (values were previously output with four significant digits).

Version 2.3 1997/02/06 - New version number to reflect use of updated library (previously used lib3.0, now updated to lib3.1). There were a number of miscellaneous changes made in the library, none of which should be noticed in ANNIE. However, several scripts and the make file needed to be changed to point to the new library. The make file now includes building the test.wdm file needed by the graph.sh tests.

Version 2.2 1996/03/01 - General release.

DATA REQUIREMENTS

Data may be input to a WDM file by hand but can be converted (more effectively) to WDM format by the IOWDM program. IOWDM can convert data to WDM format from a generic flat file format or from the following WATSTORE card image formats: daily, unit, basin, peak, and n-day data.

OUTPUT OPTIONS

Data can be output in multiple graphical, tabular, and text file formats. An output option is available to export data to a format that can be directly converted by ANNIE to a WDM file. This option is helpful for transferring data between WDM files including transferring data between files on different computer platforms on which ANNIE is implemented.

SYSTEM REQUIREMENTS

ANNIE is written in Fortran 77 with the following extension: use of include files. The ANN, WAIDE, GRAPH, STATS, AIDE, WDM, ADWDM, and UTIL libraries from LIBANNE are required to recompile. For more information, see System Requirements in LIBANNE.

APPLICATIONS

Widely used in watershed modeling projects, regional regression analysis projects, and time-series data management efforts.

DOCUMENTATION

Flynn, K.M., Hummel, P.R., Lumb, A.M., and Kittle, J.L., Jr., 1995, User's manual for ANNIE, version 2, a computer program for interactive hydrologic data management: U.S. Geological Survey Water-Resources Investigations Report 95-4085, 211 p.

REFERENCES

Kittle, J.L., Jr., Hummel, P.R., and Imhoff, J.C., 1989, ANNIE-IDE, a system for developing interactive user interfaces for environmental models (programmers guide): U.S. Environmental Protection Agency, EPA/600/3-89/034, Environmental Research Laboratory, Athens, Ga., 166 p.

Lumb, A.M., Carsel, R.F., and Kittle, J.L., Jr., 1988, Data management for water-quality modeling development and use: Proceedings of the International Symposium on Water Quality Modeling of Agricultural Non-Point Sources, 14 p.

Lumb, A.M., and Kittle, J.L., Jr., 1985, ANNIE - Interactive processing of data bases for hydrologic models: Proceedings of the International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology.

Lumb, A.M., Kittle, J.L., Jr., and Flynn, K.M., 1990, Users manual for ANNIE, a computer program for interactive hydrologic analyses and data management: U.S. Geological Survey Water-Resources Investigations Report 89-4080, 236 p.

TRAINING

Watershed Systems Modeling I (SW2008TC), offered annually at the USGS National Training Center.

Watershed Systems Modeling II (SW3018TC), offered upon request at the USGS National Training Center.
Statistical Approach to Surface-Water Hydrologic Analysis (SW2011TC), offered annually at the USGS National Training

```
Center.

River Basin Water-Quality Modeling (ID2146TC), offered
annually at the USGS National Training Center.
```

CONTACTS

```
Operation and Distribution:
   U.S. Geological Survey
   Hydrologic Analysis Software Support Program
   437 National Center
   Reston, VA 20192

   h2osoft@usgs.gov

Official versions of U.S. Geological Survey water-resources
analysis software are available for electronic retrieval via
the World Wide Web (WWW) at:

           http://water.usgs.gov/software/

and via anonymous File Transfer Protocol (FTP) from:

           water.usgs.gov (path: /pub/software).

The WWW page and anonymous FTP directory from which the
ANNIE software can be retrieved are, respectively:

           http://water.usgs.gov/software/annie.html
                         --and--
           /pub/software/surface_water/annie

See
http://water.usgs.gov/software/ordering_documentation.html
for information on ordering printed copies of USGS
publications.
```

SEE ALSO

```
hass-cui(1) - Character-based user interface

iowdm(1) - Program to store time-series data in a WDM file

wdm(1) - Watershed Data Management system
```

Water Resources Applications Software

Geochemical || Ground Water || Surface Water || Water Quality || General

Summary of IOWDM

NAME

iowdm - Input and Output for a Watershed Data Management (WDM) file

ABSTRACT

IOWDM is designed to reformat data to and from a WDM file. Data in selected WATSTORE card-image formats and flat file formats can be added to a WDM file.

METHOD

A WDM file is a binary, direct-access file used to store hydrologic, hydraulic, meteorologic, water-quality, and physiographic data. The WDM file is organized into data sets. Each data set contains a specific type of data, such as streamflow at a specific site or air temperature at a weather station. Each data set contains attributes that describe the data, such as station identification number, time step of data, latitude, and longitude. A WDM file may contain a single data set or as many as 200,000 data sets. A data set may be described by a few attributes or by hundreds of attributes. Data can be added, deleted, and modified without restructuring the data in the file. Space from deleted data sets is reused.

HISTORY

Version 4.1 2002/02/25 - Updated to use latest libanne libraries, version 4.0 dated September 27, 2001. Calculation for last available group for attribute data and time series data have been corrected.

Version 4.0 2001/02/08 - In the Input/Timeseries option, increased the maximum allowed value for TSBYR from 2000 to 1000000.

Version 4.0 2000/11/01 - The Input menu now includes an option to save summary information to a file. All WDM data sets now contain the date the data set was created and the date the data set was last modified.

Version 3.0 - There was no 3.0 distribution.

Version 2.4 1998/06/18 - Change in Input/Peak option.

Partial duration peaks, (peaks above a base and less than an annual maximum, record type "4") are not longer stored in the WDM file. These peaks were causing incorrect results in the peakfq program. peakfq analysis should be checked to verify that partial duration peaks were not included.

Version 2.3 1998/01/13 - Correction in flat time-series option. In some cases of long records with time step shorter than a day, a part of the record was shifted in time. Also, in some instances where the user specified the begin and end date for the data, the last time step was not written to the WDM file. Data sets can be checked for this problem by examining data values at the end of the record.

Version 2.2 1996/03/01 - Added flat file options.

Version 2.1 1994 - Updates.

1994 - Distributed as iowdm2.0. Option to read WATSTORE n-day high/low flows added to the iowdm.1.0 version.

1992 - Distributed as iowdm.1.0. IOWDM was revised to use the AIDE user interface. This version read WATSTORE basin characteristics, annual peak flows, daily values, and unit values. There was no output option.

1989 - Distributed with ANNIE0189. Used an interactive, question-answer, scrolling user interface. Read WATSTORE basin characteristics, annual peak flows, daily values, unit values, and n-day high/low flows, HSPF sequential files and PLTGEN files, a user-defined flat file, and Carter daily and unit values files. Wrote WATSTORE daily and unit values.

DATA REQUIREMENTS

Data in the following WATSTORE card-image formats may be written to a WDM file:

- o daily values (3 cards with optional Z, H, N, and 2 cards)
- o unit values (B-cards with optional Z, H, N, and 2 cards)
- o basin and streamflow characteristics (1 and 2 cards)
- o n-day high and/or low flow (2 and 3 cards)
- o annual peak flows (3 and 4 cards with optional Z, H, N, and 2 cards)

Flat file formats:

- o time series, RDB
- o time series, tabular
- o attributes, tabular
- o attributes, list

OUTPUT OPTIONS

The IOWDM file writes data from formatted input files to the

WDM file. No other output options are currently supported.

SYSTEM REQUIREMENTS

IOWDM is written in Fortran 77 with the following extension: use of include files. The WAIDE, AIDE, WDM, ADWDM, and UTIL libraries from LIBANNE are required to recompile. For more information, see System Requirements in LIBANNE.

APPLICATIONS

IOWDM is used in support of projects that use a WDM file for data management.

DOCUMENTATION

Text files are included with the distribution.

Lumb, A.M., Kittle, J.L., Jr., and Flynn, K.M., 1990, Users manual for ANNIE, a computer program for interactive hydrologic analyses and data management: U.S. Geological Survey Water-Resources Investigations Report 89-4080, 236 p. (Documents the 1990 version included in the ANNIE program.)

RELATED DOCUMENTATION

Flynn, K.M., Hummel, P.R., Lumb, A.M., Kittle, J.L., Jr., 1995, User's manual for ANNIE, version 2, a computer program for interactive hydrologic data management: U.S. Geological Survey Water-Resources Investigations Report 95-4085, 211 p.

TRAINING

There are no regularly scheduled classes for IOWDM. The use of the program is included as part of the introductory exercises in other classes.

Watershed Systems Modeling I (SW2008TC), offered annually at the USGS National Training Center.

Statistical Approach to Surface-Water Hydrologic Analysis (SW2011TC), offered annually at the USGS National Training Center.

River Basin Water-Quality Modeling (ID2146TC), offered annually at the USGS National Training Center.

CONTACTS

Operation and Distribution:

U.S. Geological Survey
Hydrologic Analysis Software Support Program
437 National Center
Reston, VA 20192

h2osoft@usgs.gov

Official versions of U.S. Geological Survey water-resources analysis software are available for electronic retrieval via the World Wide Web (WWW) at:

```
            http://water.usgs.gov/software/

     and via anonymous File Transfer Protocol (FTP) from:

            water.usgs.gov (path: /pub/software).

     The WWW page and anonymous FTP directory from which the
     IOWDM software can be retrieved are, respectively:

            http://water.usgs.gov/software/iowdm.html
                           --and--
            /pub/software/surface_water/iowdm

     See
     http://water.usgs.gov/software/ordering_documentation.html
     for information on ordering printed copies of USGS
     publications.
```

SEE ALSO

annie(1) - Program to list, table, plot data in a WDM file

hass-cui(1) - Character-based user interface

wdm(1) - Watershed Data Management system

Appendix E
Summary of Traditional Recharge Calculations

E.1 Nueces Basin Recharge Calculations

E.1.1 USGS Recharge Calculation Method

The USGS method for calculating recharge is a water balance equation that utilizes the known streamflow, provided by long-term streamflow gauges, both above and below the Edwards Aquifer Recharge Zone (outcrop), and approximations of runoff from the intervening drainage area. Estimates of recharge to the Edwards Aquifer in the Nueces Recharge Basin by the USGS are calculated using the following equation:

$$R_{nwn} = Q_n + Q_{wn} + (SI_n)(RF_n) - Q_{nbu} \qquad (1)$$

where,

R_{nwn} = Monthly Recharge;

Q_n = Total Monthly Flow, Nueces River at Laguna;

Q_{wn} = Total Monthly Flow, West Nueces River near Brackettville;

Q_{nbu} = Total Monthly Flow, Nueces River below Uvalde;

SI_n = Monthly Runoff in the intervening area;

RF_n = Rainfall Ratio obtained by the equation:

$$RF_n = \frac{LP_n}{UP_n} \qquad (2)$$

where,

LP_n = Average monthly precipitation in the intervening area between the upper gauges (Laguna and Brackettville) and the lower gauge at Uvalde;

UP_n = Average monthly precipitation in the drainage area above the Laguna and Brackettville gauges.

RF_n is set to unity if the value is between 0.8 and 1.2. The product of SI_n and RF_n is the estimate of potential monthly runoff for the area between the two upper gages and the lower gauge

(483 square miles[1]). Runoff is assumed to be proportional to the runoff in the drainage area (764 square miles[1]) above the gauge at Laguna. The calculation for SI_n is as follows:

$$SI_n = \frac{A_{in}}{A_{un}}\left(C_n + A_n + B_n\right) \tag{3}$$

where,

A_{in} = Intervening area between the upper and lower gauging stations (483 sq. mi.);

A_{un} = Area above the Brackettville and Laguna gauging stations (764 sq. mi.); and

C_n = Flood flow component, Nueces River at Laguna;

A_n = Initial increase in base flow during a flood, Nueces River at Laguna;

B_n = Base-flow component, Nueces River at Laguna.

C_n and A_n are obtained from analyses of the streamflow records at the Laguna gage. B_n is obtained from an equation relating ground-water storage in the Edwards Plateau Aquifer and base flow at the Laguna gage. Estimates of SI_n are made only for the months in which significant storms occur. If a storm overlaps into the following month, the runoff is distributed proportionately according to the flood flow occurring during each month.

E.1.2 HDR Recharge Calculation Method

The HDR recharge method, like the USGS method, uses a water balance equation as in Equation 1. However, the HDR method accounts for water rights diversions and/or return flows by using the naturalized flow at the downstream gauge, rather than the gauged flow. The USGS method does not account for water rights diversions and/or return flows between the upstream and downstream gages. Additionally, the HDR method approximates the runoff factor of the equation differently. With these small, but important, differences, the equation for determining historical recharge in the Nueces Recharge Basin becomes:

$$R_{nwn} = Q_n + Q_{wn} + QI_n - \left(Q_{nbu} + WR\right) \tag{4}$$

[1] The USGS model used for recharge calculation has not been modified to account for drainage area revisions published in 1984.

where,

QI_n = Potential Runoff in the Intervening Area; and

WR= Reported Water Rights Diversions in the Intervening Area.

The term, QI_n, in the above equation, which is most difficult to quantify, is estimated using a variation of the SCS runoff curve number procedure[2,3]. This procedure is indexed to the gauged watershed above Laguna and employs a monthly calibration procedure taking into account differences in drainage area, soil cover complex, and precipitation. QI_n is estimated from the following equation:

$$QI_n = \frac{640}{12} A_{in} \frac{(P - \frac{200}{CN} + 2)^2}{(P + \frac{800}{CN} - 8)} \tag{5}$$

where,

A_{in} = Intervening area between the upper and lower gauging stations;

P = Areal precipitation; and

CN = Composite SCS Curve Number for the watershed.

E.2 Blanco Basin Recharge Calculations

E.2.1 USGS Recharge Calculation Method

The USGS recharge calculation method in the Blanco Recharge Basin is similar to the method used by USGS in the Nueces Recharge Basin. It is a water balance equation that utilizes gauged streamflow both above and below the Edwards Aquifer recharge zone (outcrop), and approximations of runoff from the intervening drainage area. The equation for the Blanco Recharge Basin recharge estimates is as follows:

$$R_b = Q_w + (SI_b)(RF_b) - Q_k \tag{6}$$

---

[2] HDR, "Guadalupe - San Antonio River Basin Recharge Enhancement Study," Vol. 2, Edwards Underground Water District, September, 1993.

[3] HDR, "Nueces River Basin Regional Water Supply Planning Study, Phase I," Vol. 2, Nueces River Authority, et al., May, 1991.

where,

R_b = Monthly Recharge;

Q_w = Total Monthly Streamflow, Blanco River at Wimberley;

Q_k = Total Monthly Streamflow, Blanco River at Kyle;

SI_b = Monthly Runoff in the intervening area, and

RF_b = Rainfall Ratio obtained by the equation:

$$RF_b = \frac{LP_b}{UP_b} \tag{7}$$

where,

LP_b = Average monthly precipitation in the intervening area between the Kyle and Wimberley gauges, and;

UP_b = Average monthly precipitation in the drainage area above the Kyle gauge.

RF_b is set to unity if the value is between 0.8 and 1.2. The product of SI_b and RF_b is the estimate of potential monthly runoff for the area between the Kyle gauge and the Wimberley gauge (57 square miles). Runoff is assumed to be proportional to the runoff in the drainage area (355 square miles) above the gauge at Wimberley. The calculation for SI_b is as follows:

$$SI_b = \frac{A_{ib}}{A_{ub}}(C_b + B_b + A_b) \tag{8}$$

where,

A_{ib} = Intervening area between the Kyle and Wimberley gauging stations (57 sq. mi.);

A_{ub} = Area above the Wimberley gauging station (355 sq. mi.);

C_b = Flood flow component, Blanco River at Wimberley;

A_b = Initial increase in base flow during a flood, Blanco River at Wimberley; and

B_b = Base-flow component, Blanco River at Wimberley.

C_b and A_b are obtained from analyses of the streamflow records at the Wimberley gauge. B_b is obtained from an equation relating ground-water storage in the Trinity Aquifer and base flow at the Wimberley gauge. Estimates of SI_b are made only for the months in which significant storms occur. If a storm overlaps into the following month, the runoff is distributed proportionately according to the flood flow occurring during each month.

For the ungauged portion of the Blanco Recharge Area (the watersheds of Purgatory Creek, Sink Creek, York Creek, and Alligator Creek), the USGS approximates the unit recharge in this area by averaging unit runoff for three surrounding gauged watersheds not believed to contribute recharge to the Edwards and subtracting unit runoff for the Dry Comal Creek watershed which is located on the Edwards Aquifer recharge zone to obtain unit recharge. Unit recharge is then multiplied by the 94 square mile area of the ungauged portion of the Blanco Recharge Basin to obtain total recharge. The three surrounding gauged watersheds are the Blanco River above the Wimberley gauge, the Guadalupe River between the Sattler and New Braunfels gauges, and Plum Creek above the Lockhart gauge. It is important to note that the three surrounding watersheds differ from the ungauged recharge area in both average rainfall per year and SCS Curve Number (an indicator of potential runoff characteristics).

E.2.2 HDR Recharge Calculation Method

The differences between the HDR and USGS recharge calculations in the Blanco Recharge Basin are the similar to those in the Nueces Recharge Basin. The HDR method for calculating recharge in the Blanco Recharge Basin uses a water balance equation that accounts for water rights diversions and/or return flows by using the naturalized flow at the downstream gauge, rather than the gauged flow. The HDR method also approximates the runoff factor of the equation using a variation of the SCS runoff curve number procedure. Estimates of recharge to the Edwards Aquifer in the Blanco Recharge Basin are calculated by HDR using the following equation:

$$R_b = Q_W + QI_{\mathrm{b}} - (Q_k + WR) \tag{9}$$

where,

QI_b = Potential Runoff for the Intervening Area, as estimated from the following equation:

$$QI_b = \frac{640}{12} A_{ib} \frac{(P - \frac{200}{CN} + 2)^2}{(P + \frac{800}{CN} - 8)} \quad (10)$$

where,

A_{ib} =Intervening area between the Kyle and Wimberley gauging stations;

P = Areal precipitation; and

CN = Composite SCS Curve Number for the watershed.

The term QI_b is estimated using a variation of the SCS runoff curve number procedure. This procedure is indexed to the gauged watershed above Kyle and employs a monthly calibration procedure taking into account differences in drainage area, soil cover complex, and precipitation.

For the ungauged partner area (Sink, Purgatory, Alligator, and York Creeks) of the Blanco Recharge Area, the HDR method uses the same techniques for recharge as described in Equations 9 and 10. Because the ungauged partner area does not have a gauge upstream of the recharge zone, and the downstream gauge has a limited period of record, the calculation of recharge is almost entirely dependent upon the estimation of potential runoff. Potential runoff in this area was calculated using Equation 10 and includes monthly calibration with an adjacent gauged watershed (Blanco River at Wimberley).

Appendix F
Comparison of Traditional Recharge Calculation Methods

F.1 Nueces Recharge Basin

Long-term average recharge for the Nueces Recharge Basin estimated by the USGS is some 25,045 acft/yr (27.7 percent) greater than that estimated by HDR.[1] Figures F-1 and F-2 compare USGS and HDR historical annual recharge estimates through 1996. As indicated in these figures, USGS estimates of recharge significantly exceed HDR estimates in wet years and tend to be somewhat less than HDR estimates in dry years.

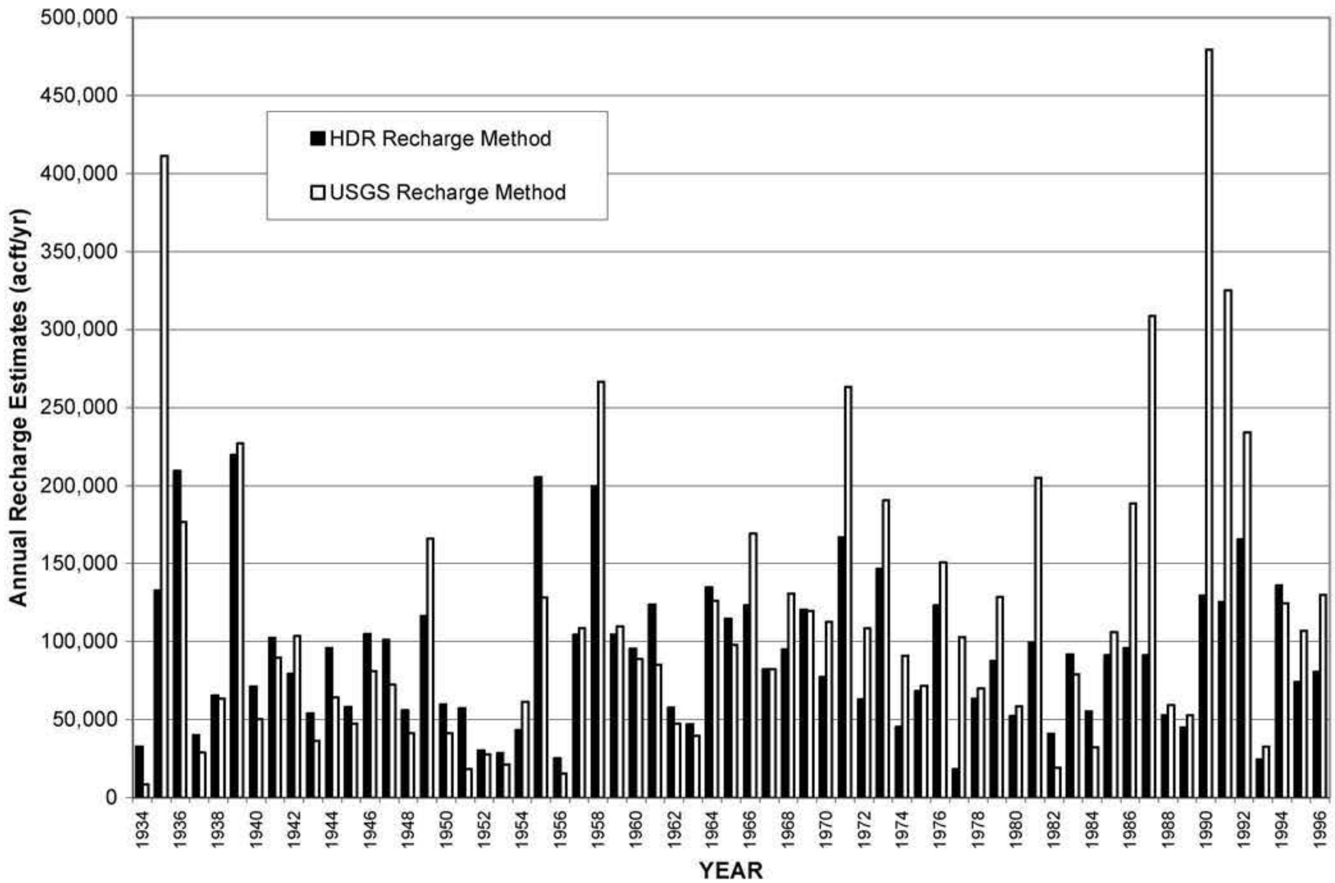


Figure F-1. Long-Term Edwards Aquifer Recharge Comparisons — Nueces Recharge Basin

[1] HDR, "Edwards Aquifer Recharge Analyses, Edwards Aquifer Recharge Update," Trans-Texas Water Program, West Central Study Area, Phase II, San Antonio River Authority, et al., March 1998.

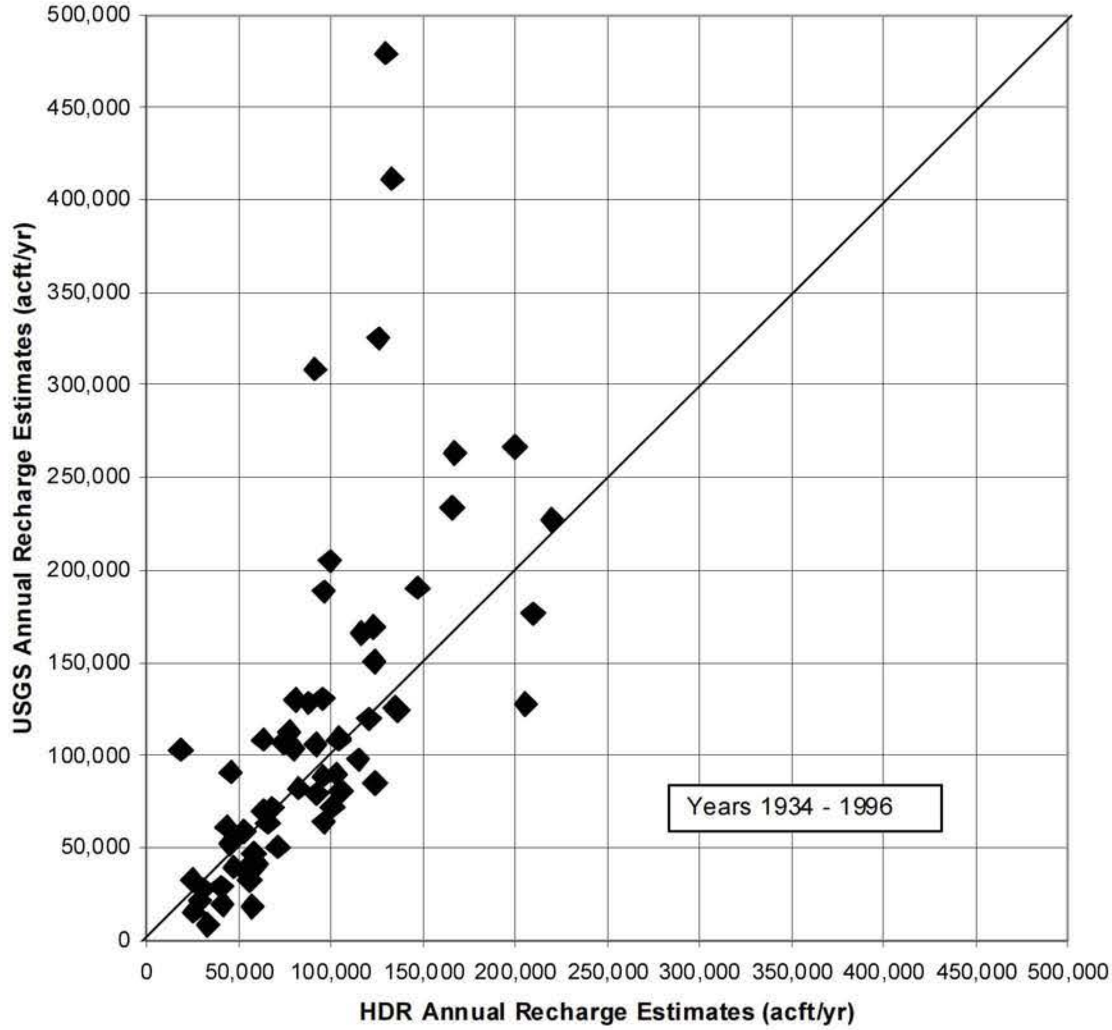


Figure F-2. Long-Term Edwards Aquifer Recharge Comparisons — Nueces Recharge Basin

There are four key elements in the USGS procedure that result in estimates of potential runoff over the Edwards Aquifer outcrop and historical recharge in the Nueces Recharge Basin that are greater than those computed by HDR. These elements involve: (1) Use of an equation ("base flow curve") relating storage in the Edwards Plateau Aquifer contributing to base flow upstream of the Edwards Aquifer outcrop in the estimation of potential runoff for the area over the outcrop; (2) Accounting for differences in soil cover complex upstream of Laguna and over the outcrop; (3) Updated drainage areas upstream of the gauges located at Laguna, near

Brackettville, and below Uvalde; and (4) Accounting for reported surface water diversions from the stream segment below the Laguna gauge and above the Uvalde gauge. Each of these elements is discussed in the following paragraphs.

Review of USGS recharge calculations for the year 2000 shows months in which selection of minimum and maximum base flow at Laguna and use of the base flow curve lead to estimates of potential runoff from the area over the outcrop that actually exceed the total gauged streamflow at Laguna. This situation should not occur as the outcrop area is only 58 percent of that upstream of Laguna and received substantially less precipitation during these months. HDR procedures do not distinguish between base and flood flow at Laguna in the estimation of potential runoff over the outcrop.

Compilation of soil cover complex information in a previous study[2] resulted in the selection of normal antecedent moisture condition (AMC II) curve numbers of 87 for the watershed above Laguna and 84 for the watershed over the Edwards Aquifer outcrop. The greater the curve number, the greater the runoff for a given precipitation event. For example, unit runoff (acft/sqmi) resulting from a 2.0-inch rainfall event would be almost 22 percent greater in a watershed with a curve number of 87 than in a watershed with a curve number of 84. USGS recharge calculation procedures do not consider differences in soil cover complex between the area above Laguna and the area over the outcrop and, therefore, overestimates potential runoff and recharge in the outcrop area.

Review of USGS recharge calculations for the year 2000 shows that updated drainage areas published in 1984[3] for gauges in the Nueces Recharge Basin are not used. Use of the outdated drainage areas by the USGS results in at least an 8.4 percent overestimation of potential runoff originating over the outcrop and, ultimately, overestimation of recharge. HDR recharge calculations use the updated drainage areas.

The USGS procedure does not account for reported diversions under surface water rights authorized to divert and use up to 2,249 acft/yr from the Nueces River below Laguna and above Uvalde for irrigation purposes. Depending upon utilization of these rights in a given year, this may result in overestimation of recharge. Reported water rights diversions are reflected in HDR historical recharge estimates.

[2] HDR, Op. Cit., May 1991.
[3] USGS, "Water Resources Data, Texas, Water Year 1983," Water Data Report TX-83-3, 1984.

In addition, there is one key element in the USGS procedure that results in estimates of potential runoff over the Edwards Aquifer outcrop and historical recharge in the Nueces Recharge Basin that are less than those computed by HDR. This situation occurs during dry periods during which the USGS assumes that all flow passing Laguna is base flow, thereby assigning flood flow at Laguna and potential runoff over the outcrop to zero.

F.2 Blanco Recharge Basin

Long-term average recharge for the Blanco Recharge Basin estimated by the USGS is some 25,022 acft/yr (37.7 percent) less than that estimated by HDR[4]. Figures F-3 and F-4 compare USGS and HDR historical annual recharge estimates through 1996. As indicated in these figures, USGS estimates of recharge are significantly less than HDR estimates in all but two years (1987 and 1992). These two years included major storm events and/or record high flows.

There are three key elements in the USGS procedure that result in estimates of potential runoff over the Edwards Aquifer outcrop and historical recharge in the Blanco Recharge Basin that are less than those computed by HDR. These elements involve: (1) Accounting for differences in soil cover complex over the outcrop and in partner watersheds above Wimberley (Blanco River), Lockhart (Plum Creek), and New Braunfels (Guadalupe River); (2) Accounting for Flood Retardation Structures in the ungauged area over the outcrop (Sink, Purgatory, and York Creeks); and (3) Assigning flood flow at Wimberley and potential runoff over the outcrop to zero during dry periods. Each of these elements is discussed in the following paragraphs.

USGS recharge calculation procedures do not consider differences in soil cover complex between selected partner areas and the area over the outcrop resulting in consistent underestimation of potential runoff and Edwards Aquifer recharge in the Blanco Recharge Basin. Compilation of soil cover complex information in a previous study[5] resulted in the selection of normal antecedent moisture condition (AMC II) curve numbers of 84.3 and 86.4 for the respective gauged (Blanco River below Wimberley and above Kyle) and ungauged (Sink, Purgatory, York, and Alligator Creeks) areas over the Edwards Aquifer outcrop. The partner watershed selected by the USGS for estimation of potential runoff in the gauged area over the

[4] HDR, "Edwards Aquifer Recharge Analyses, Edwards Aquifer Recharge Update," Trans-Texas Water Program, West Central Study Area, Phase II, San Antonio River Authority, et al., March 1998.
[5] HDR, Op. Cit., September 1993.

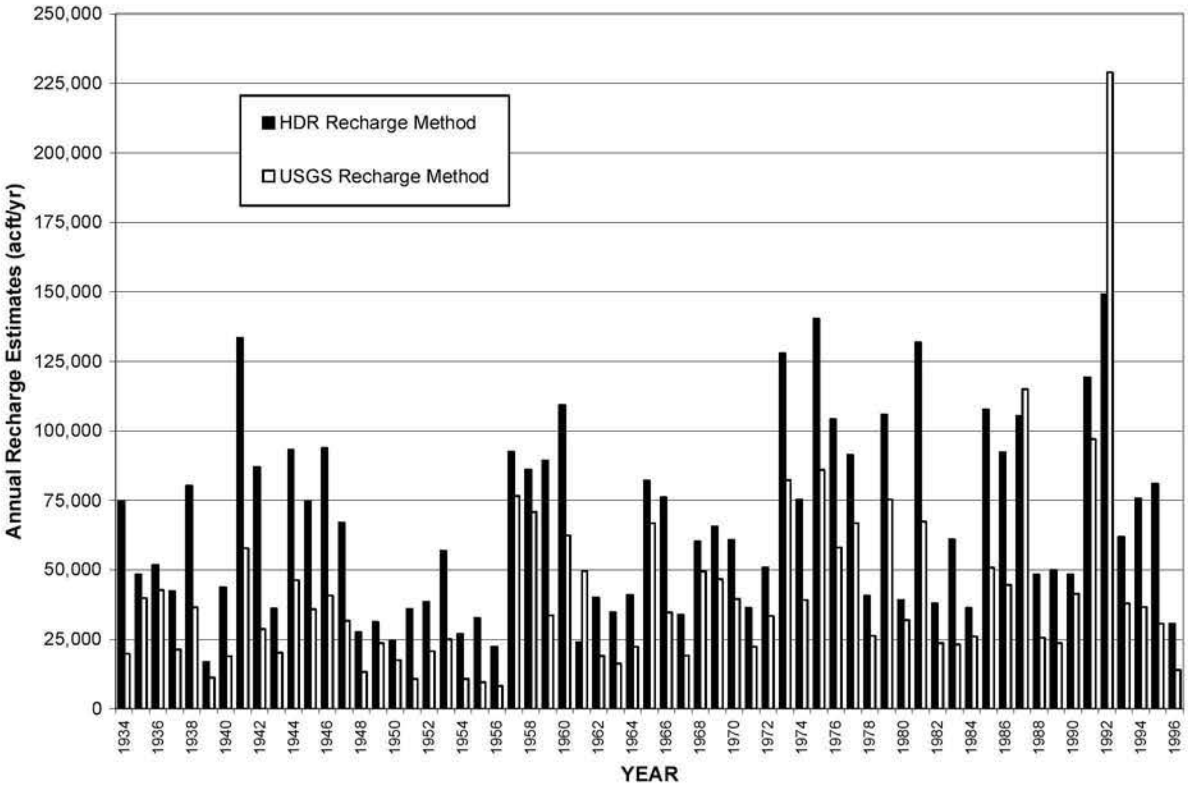


Figure F-3. Long-Term Edwards Aquifer Recharge Comparisons — Blanco Recharge Basin

outcrop is the Blanco River above Wimberley and has an AMC II curve number (CN) of 82.6. Similarly, the three partner watersheds selected by the USGS for estimation of potential runoff in the ungauged area over the outcrop include the Blanco River above Wimberley (CN = 82.6), the Guadalupe River below Sattler and above New Braunfels (CN = 83.7), and Plum Creek above Lockhart (CN = 85.7). The average curve number for these three partner watersheds is 84. First considering the 55 square mile gauged area over the outcrop, unit runoff (acft/sqmi) resulting from a 2.0-inch rainfall event would be almost 11 percent greater in a watershed with a curve number of 84.3 than in a watershed with a curve number of 82.6. Similarly, unit runoff resulting from a 2.0-inch rainfall event would be more than 14 percent greater in the 94 square mile ungauged watershed over the outcrop with a curve number of 86.4 than in the partner watersheds having an average curve number of 84. Furthermore, one of the three partner areas for the ungauged portion of this recharge basin (the Guadalupe River below Sattler and above New Braunfels) is located on the outcrop of the Edwards Aquifer resulting in lower actual unit runoff amounts than indicated by soil cover complex.

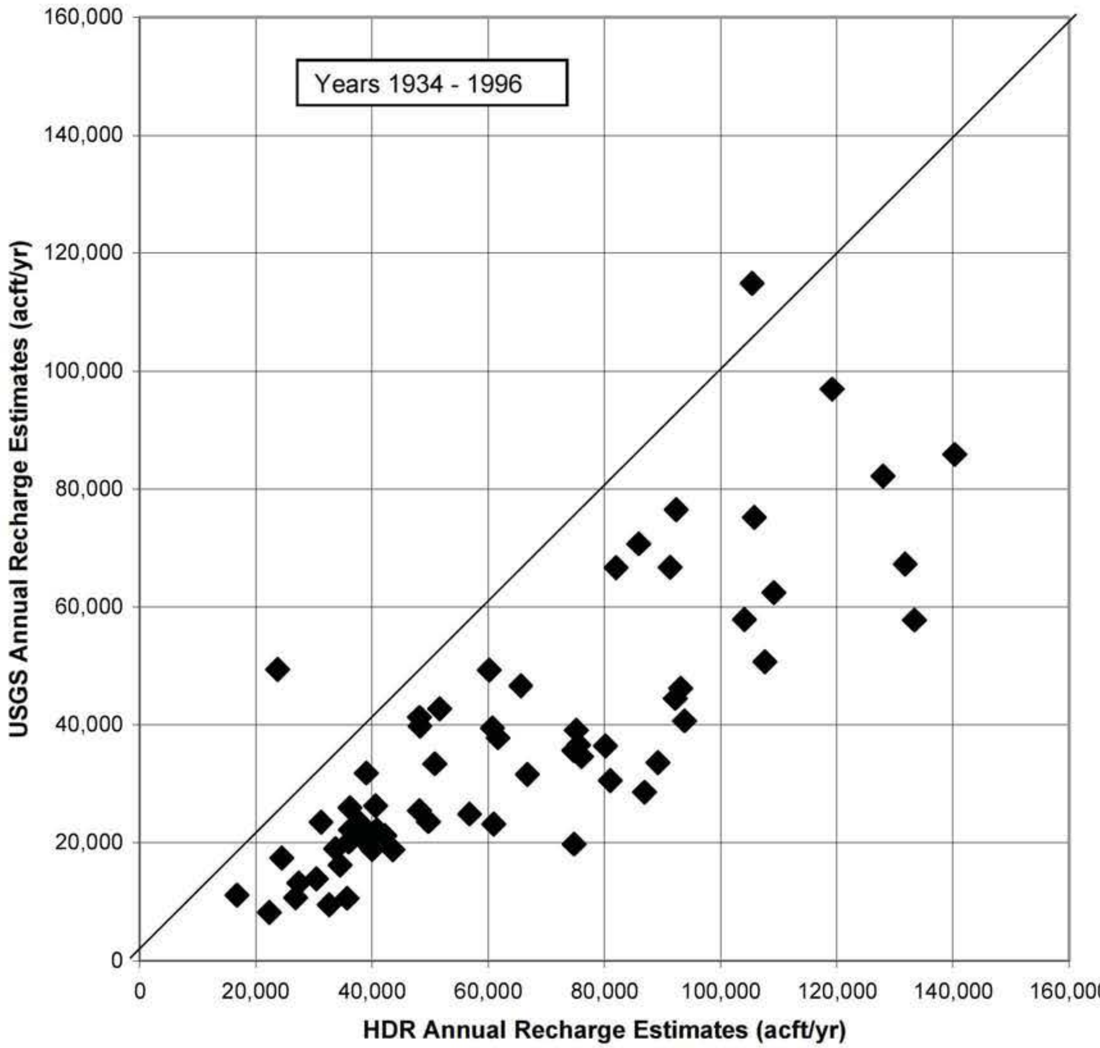


Figure F-4. Long-Term Edwards Aquifer Recharge Comparisons — Blanco Recharge Basin

More than 99 percent of the 94 square mile ungauged watershed area over the Edwards Aquifer outcrop within the Blanco Recharge Basin is controlled by seven flood retardation structures. These structures serve not only a flood control function, but also enhance recharge by impounding waters that would otherwise have flowed downstream and allowing them to percolate into the aquifer. This phenomenon is partially accounted for in the USGS recharge computation procedure by use of runoff from the nearby Dry Comal Creek watershed as an indicator of runoff escaping the outcrop. Approximately 57 percent of the 130 square mile Dry Comal Creek watershed is controlled by flood retardation structures. Nevertheless unit runoff from the Dry Comal Creek watershed still exceeds that for ungauged outcrop area in the Blanco Recharge Basin resulting in underestimation of recharge.

Another key element in the USGS procedures that results in estimates of potential runoff over the Edwards Aquifer outcrop and historical recharge in the gauged portion of Blanco Recharge Basin that are less than those computed by HDR is the assumption that all flow passing Wimberley in dry times is base flow, thereby assigning flood flow at Wimberley and potential runoff over the outcrop to zero. Review of USGS recharge calculations for the year 2000 shows that there are months during which more than two inches of precipitation fell over the outcrop without indication of potential runoff. It is believed that a 2.0-inch rainfall event over the outcrop will contribute to recharge even if little or none of this rainfall would appear as surface runoff at the downstream edge of the outcrop.

In addition, there is one key element in the USGS procedures that results in estimates of potential runoff over the Edwards Aquifer outcrop and historical recharge in the Blanco Recharge Basin that are greater than those computed by HDR. Review of USGS recharge calculations for the year 2000 shows months in which selection of minimum and maximum base flow at Wimberley and use of a base flow curve lead to estimates of potential runoff from the area over the outcrop that actually exceed the total gauged streamflow at Wimberley. HDR procedures do not distinguish between base and flood flow at Wimberley in the estimation of potential runoff over the outcrop.

Appendix G
Geographical Recharge Distribution

The pilot recharge models of the Nueces and Blanco Recharge Basins, as configured in Hydrologic Simulation Program – Fortran (HSPF), calculate recharge or deep percolation occurring in defined land segments using the variable identified as IGWI (Inactive Groundwater Inflow) which is representative of flux between active and inactive groundwater storage. Inactive groundwater is water that has percolated to a sufficient depth that it is no longer subject to depletion by evapo-transpiration or discharge into incised river or stream reaches. Additional recharge associated with channel losses in river reaches or impoundments created by Flood Retardation Structures is calculated as a function of streamflow and/or storage. Finally, the pilot recharge models include approximate accounting for inter-formational transfer of groundwater between the Trinity or Edwards Plateau Aquifers and the Edwards Aquifer as referenced in previous studies.[1,2]

Daily or monthly recharge estimates from the pilot models are geographically distributed into a cell grid defined by the U.S. Geological Survey (USGS) for their ongoing development of a new simulation model of the Edwards Aquifer constructed on a MODFLOW platform. It is generally assumed that recharge per unit area is uniform within each defined land segment and that recharge per unit stream distance is uniform within each defined river reach. More specifically, Geographic Information System (GIS) techniques are used to superimpose HSPF land segments and river reaches over the outcrop onto the MODFLOW cell grid and uniformly distribute calculated land segment and river reach recharge amounts for each timestep. Recharge amounts associated with inter-formational transfer are then added to the Edwards Aquifer outcrop cells along the boundaries with the Trinity or Edwards Plateau outcrops. Figure G-1 provides a schematic illustration of geographical recharge distribution through projection of a cell grid onto a generic outcrop land segment and river reach.

---

[1] USGS, "Hydrologic Framework of the Edwards-Trinity Aquifer System, West-Central Texas," Paper 1421-B, 1996.
[2] TWDB, "Groundwater Availability of the Trinity Aquifer, Hill Country Area, Texas: Numerical Simulations through 2050," Report 353, 2000.

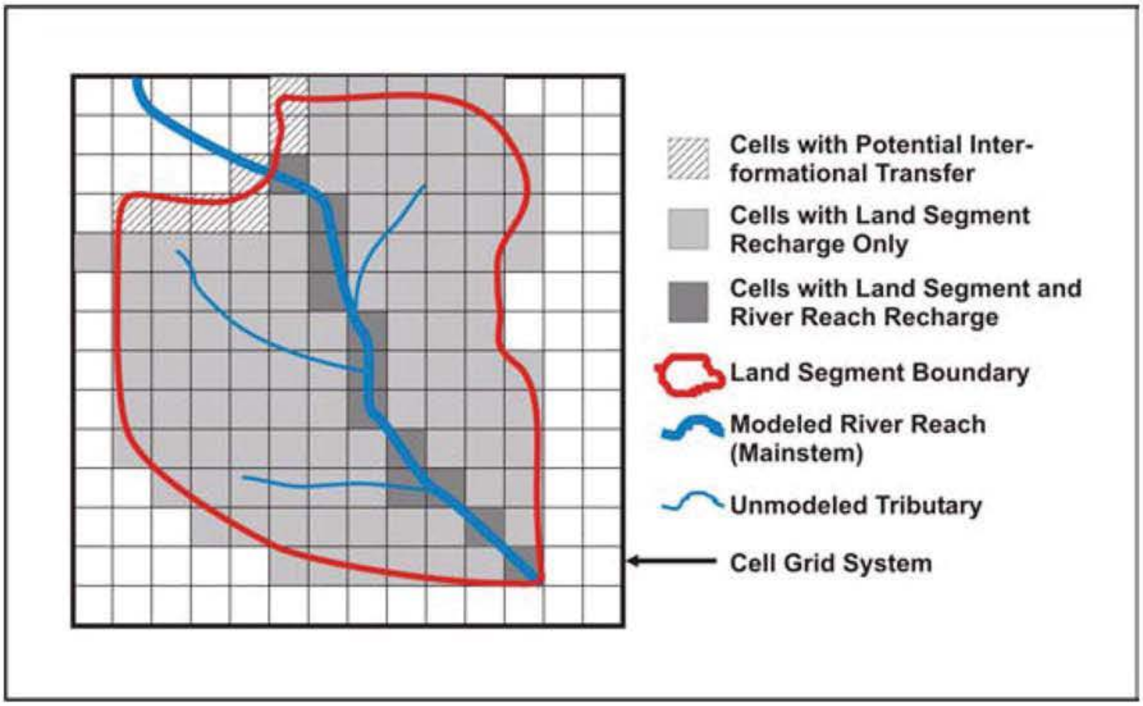


Figure G-1. Schematic Illustration of Geographical Recharge Distribution Within a Cell Grid System