ARBUCKLE-SIMPSON HYDROLOGY STUDY

DISTRIBUTED WATER RESOURCES ASSESSMENT

FINAL REPORT
Oklahoma Water Resources Board
3800 North Classen Blvd.
Oklahoma City, OK 73118

December 2008

Baxter E. Vieux, P.E., Ph.D. [1], **and Maria A. Moreno, B.S.** [2]
[1]Joseph A. Brandt Professor
Director, International Center for Natural Hazards and Disaster Research
[2]Graduate Research Assistant
School of Civil Engineering and Environmental Science
120 David L. Boren, Suite 3630
University of Oklahoma
Norman, Oklahoma 73072

EXECUTIVE SUMMARY

Streamflow and aquifer discharge in the Blue River basin constitutes the principal water source of Ada and Sulphur, where the water is used for public water supply, irrigation, recreation, agriculture, industrial use and mining. The upper part of the Blue River basin overlies the Arbuckle-Simpson aquifer where recharge from the land surface and discharge to the streams affects available water resources, both surface and groundwater. A large proportion of streamflow in the upper reaches of the Blue River derives from aquifer discharge especially during periods of low flow or drought. The change in storage of water in a stream-aquifer system for a specific time period, called a hydrologic water budget or balance, is affected by precipitation, surface runoff, baseflow, evaporation, and transpiration. Streamflow and its availability depend on these components and their relative magnitude geographically over the river basins and seasonally and inter-annually.

This study characterizes the hydrologic water budget in the Blue River basin and for the adjacent Clear and Muddy Boggy basins during the study period, 1994-2006. The water budget is computed by accounting for precipitation that becomes baseflow discharge from the aquifer, direct runoff and evapotranspiration. A distributed hydrologic model for the Blue River, Clear and Muddy Boggy Basins is used to develop timeseries and climatologic quantities of runoff at gauged and ungauged locations. The water budget for the Arbuckle Simpson aquifer and Blue River Basin shows that for the period 1994-2006, the annual streamflow averages 39,000 ac-ft at Connerville. The annual recharge volume above this location averages 29,000 ac-ft, ranging from 8,000 ac-ft to 55,000 ac-ft. Annually 20 % of precipitation becomes recharge above Connerville on average during the study period. The water budget for the Clear and Muddy Boggy is established from a combination of data analysis and hydrologic modeling to extend observed components. For the period 1994-2006, the annual streamflow averages 363,241 ac-ft near Caney in the Clear Boggy, and 506,354 ac-ft at Muddy Boggy near Farris. Annual baseflow at Clear boggy near Caney derived from hydrograph separation for the study period reveals that direct runoff averages 227,096 ac-ft, with baseflow averaging 136,145 ac-ft, whereas at Muddy Boggy near Farris, annual runoff and baseflow average 353,076 ac-ft and 153,276 ac-ft, respectively. Watershed yield averages 542, 470, and 494 ac-ft/mi^2, in the Blue River near Blue, Clear Boggy near Caney, and Muddy Boggy near Unger, respectively.

Table of Contents

Table of Tables

Table of Figures

INTRODUCTION

Streamflow is composed of direct runoff and baseflow, which are two separate though linked responses to precipitation. Baseflow is discharge from the aquifer that ultimately derives from precipitation that recharges the aquifer. The change in storage of water in a stream-aquifer system for a specific time period is affected by precipitation, surface runoff, baseflow, evaporation, and transpiration accounts for the components of the hydrologic water budget. These components govern the amount of water that an aquifer receives as recharge, ultimately discharging to the receiving stream. This report is organized in two parts: Part I Blue River, and Part II Clear and Muddy Boggy Basins.

BLUE RIVER BASIN

Components of the water budget are constructed from a diverse set of data sources and methods. Monthly water balances were constructed for the gauging stations in the Blue River near Connerville and Blue River near the town of Blue. A 500-m resolution distributed hydrologic model is constructed in Vflo™ for Blue River basin, in order to reconstruct streamflow through simulation of direct runoff and estimation of synthetic baseflow at gauged and ungauged locations. The model is refined to a resolution of 200 m covering the Hunton Anticline area, improving the soil model representation and providing more accurate estimation of direct runoff at Connerville. The 200-m resolution model supports estimation of distributed infiltration over the Hunton Anticline Area. Gridded infiltration maps for the period 1994-2006 using Vflo™, are validated for the period of observed records from the United States Geological Survey (USGS) at Connerville (2004-2006) using a water balance approach that estimates soil water fluxes particularly over the Blue River. Figure 1 shows the analytical framework for combining data and modeled components of the hydrologic cycle to form the water budget and to estimate recharge over the Hunton Anticline Area. Subsurface Watershed (BRSW), which discharges as baseflow measured at Connerville. Monthly actual evapotranspiration (aET) is computed from the water balance at Connerville (2004-2006), and extended back to 1994 using monthly aET at Blue River near Blue (1994-2004). Grids of infiltration and aET are used to derive distributed groundwater recharge (Gwr) over BRSW for the period 1994-2006. For purposes of validation, the Gwr estimates are compared with the water levels at the USGS Fittstown Gw Well.

CLEAR BOGGY AND MUDDY BOGGY BASINS

Estimation of runoff in the Clear and Muddy Boggy Basins is performed for identification of available water resources in these two basins where aquifer discharge, and recharge, are not major components of the water budget. Seasonal water balances are constructed at the gauging stations Clear Boggy near Caney, Muddy Boggy near Farris and Muddy Boggy near Unger using hydrometeorological data as available. A 500-m resolution Vflo™ model is constructed for these basins, and calibrated at the station Clear Boggy near Caney for the period May 2005 to May 2007. This model is used to estimate available water resources at internal ungauged locations.

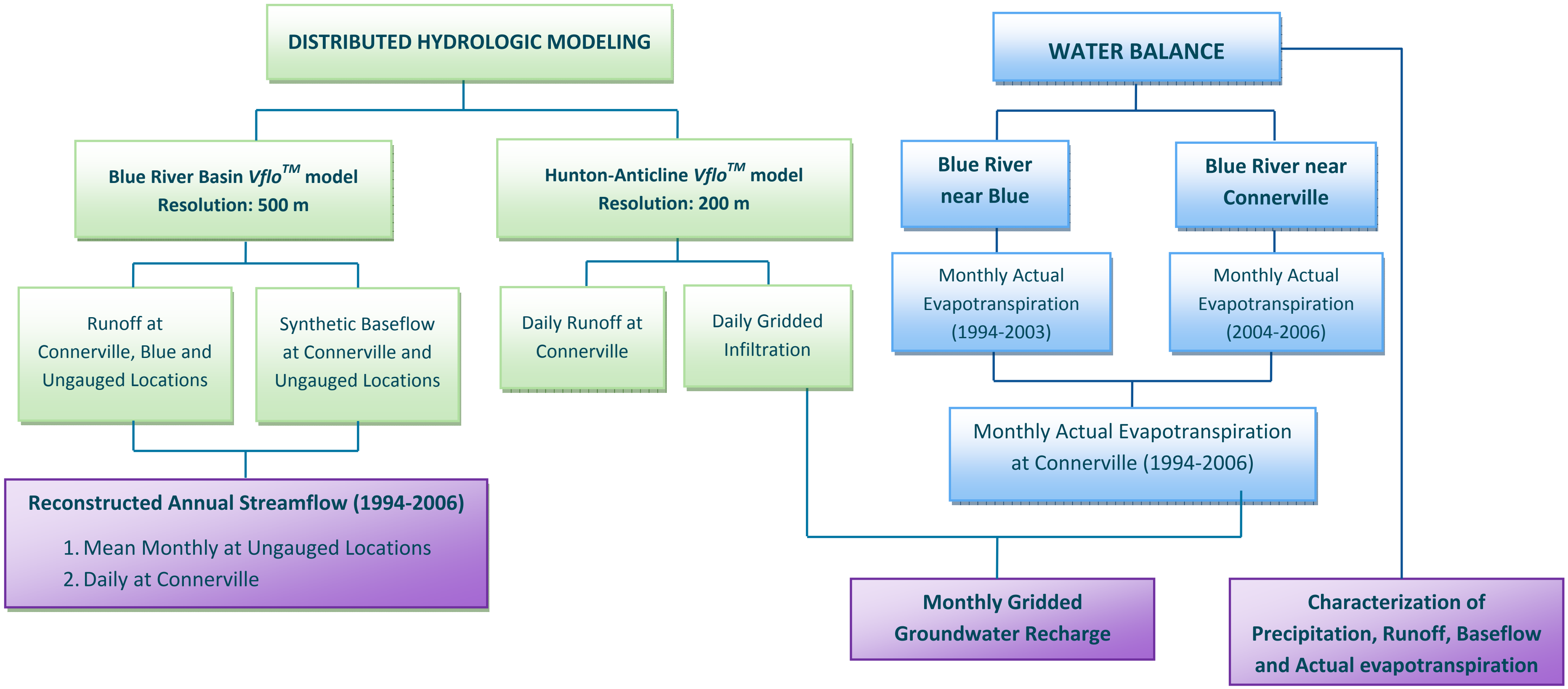


Figure 1. *Methodological approach for the recharge and water balance in the Blue River Basin. Distributed hydrologic modeling is shown in green, water balance in blue and principal results in purple.*

I. BLUE RIVER BASIN

Study Area

This study is developed for the Blue River basin, which is located in south central Oklahoma and covers an approximate area of 463 mi^2. The upper part of the basin overlies the Arbuckle-Simpson aquifer, which provides water to streams and rivers as baseflow, constituting the principal water source of many towns in the Chickasaw National Recreation area, including Ada and Sulphur, where the water is used for public water supply, irrigation, recreation, agriculture, industrial use and mining. Figure 2 shows the Blue River Basin and its main hydrologic features, including the two USGS gauging stations in the Blue River near Connerville (07332390) located at the contact between the Arbuckle group and the Tishomingo Granite, and the longer-term station Blue River near Blue (07332500) located about 50 miles downstream. The station Blue River at Milburn was is not used in this study, as records exist only for the period 1977-1979 and it is not currently operating in this basin. Delineation of subsurface watersheds within the aquifer was mapped by the Oklahoma Water Resources Board, using depth-to-water measurements in wells from the USGS (Neel, 2007). The resulting potentiometric maps of the subsurface were used to determine that the baseflow that is discharged to streams draining to Connerville is flowing from the Blue River Subsurface Watershed (BRSW), over an area of 79mi^2.

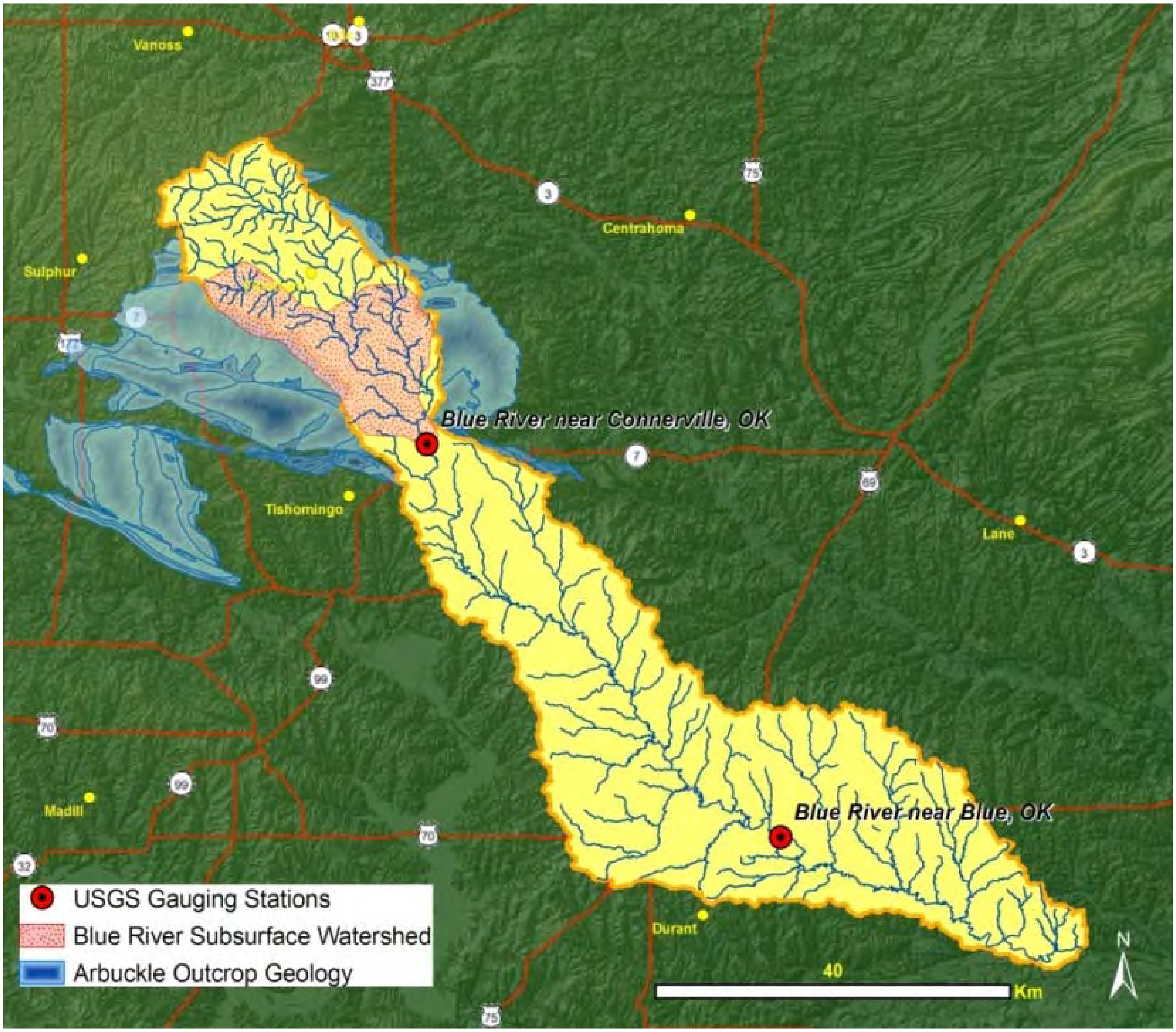


Figure 2. *Study area location of the Blue River Basin drainage network and stream gauges*

1. Hydrologic Water Balance at Gauging Stations

Monthly, annual and seasonal water balances are constructed for the gauging stations Blue River near Connerville and Blue River near Blue, using direct run off and baseflow derived from gauging stations. Fairchild et al. (1990) and Calderon (2005) have reported water budgets in the past for this basin, under the assumption that the baseflow discharged at Connerville drained from a subsurface area as large as the surface area. However, the water budget presented in this section includes the BRSW, which has an area of 79.02 mi^2 and provides baseflow to streams draining to the station Blue River near Connerville (OWRB, 2007). Table 1-1 presents the surface and subsurface drainage areas at both gauging stations according to Neel (2007). Additional details on gauging stations used in this study are found in the Appendices.

Table 1-1. Surface and subsurface areas at USGS gauging stations in the Blue River Basin, OK.

STATION	Surface Drainage Area	Subsurface Drainage Area*
Blue River near Connerville	162 mi^2	79.02 mi^2
Blue River near Blue	476 mi^2	393.02 mi^2

The water balance at the stations Blue River near Connerville and Blue River near Blue is computed in Ac-ft, using the conceptual mathematical model of the water budget shown in Eq. 1.1.

$$\Delta S = P - G\,w - R - (pET - aET) \qquad 1.1$$

Where *ΔS* is the change in storage, *P* is precipitation, *Gw* is baseflow, *R* is direct runoff, *pET* is potential evapotranspiration and *aET* is actual evapotranspiration. This hydrological budget assumes that there is no significant change in storage from year to year *(ΔS= 0*), which allows computing actual Evapotranspiration, *aET,* from pan evaporation. The data sources and methods for estimating each component are described below and summarized in Table 1-2.

Table 1-2. Summary of the data used for the water balance computations. Blue River Basin, OK.

COMPONENT	DATA		Blue River near Connerville	Blue River near Blue
Precipitation (P)	Gauge-corrected Radar	Station	NEXRAD Radar and Mesonet stations: *Centrahoma, Tishomingo, Sulphur, Ada, Ardmore, Lane, Madill, Newport, and Pauls Valley*	
		Period	Jan 2004 – Dec 2006	Jan 1994 – Dec 2006

Baseflow (Gw)	Derived from streamflow using the *PART* program	Station	USGS 07332390	USGS 07332500
		Period	Jan 2004 – Dec 2006	Jan 1994 – Dec 2006
Direct Runoff (R)	Streamflow daily time series, baseflow removed	Station	USGS 07332390	USGS 07332500
		Period	Jan 2004 – Dec 2006	Jan 1994 – Dec 2006
Potential Evapotranspiration (pET)	Monthly Short Grass Reference Evapotranspiration	Station	Mesonet stations: Tishomingo and Fittstown	Mesonet stations Altus Dam, Chickasha, McGee Creek Dam and Stillwater
		Period	Jan 2004 – Dec 2006	USGS 07332500

The components of the hydrologic water budget and usage in the modeling approach for this study are described below.

PRECIPITATION (P)

Precipitation estimates are provided over the watershed from a combination of radar and rain gauges. Distributed rainfall from radar is bias corrected using the Oklahoma Mesonet stations: *Centrahoma, Tishomingo, Sulphur, Ada, Ardmore, Lane, Madill, Newport, and Pauls Valley (OCS 2007a)*. The mean monthly values are gathered at both gauges by using the spatial Analyst in *ArcGIS*, which estimates the mean monthly precipitation over the drainage areas at each station. Values are computed over in Ac-ft over the surface drainage areas (refer to Table 1-1). Radar data processing performed by Vieux & Associates includes merging of Stage III products available from the NWS Arkansas-Red Basin River Forecast Center (ABRFC) and OCS Mesonet gauge data. Statistical control and quality enhancement results in rainfall input with improved accuracy at hourly time step for the period, 1994-2006, at approximately 4-km resolution. The precipitation data set is used as input to the distributed hydrologic model and as an aggregated timeseries over the subsurface drainage area contributing to Connerville. The latter product supports the quantification of a hydrologic water budget with rainfall over the specific area of interest in this study.

BASEFLOW (Gw)

The portion of the streamflow coming from groundwater discharge is baseflow, which fluctuates directly in response to fluctuations in groundwater levels in the Arbuckle Simpson aquifer (Fairchild, et al., 1990). This direct connection between aquifer discharge and streamflow is typical of unconfined aquifers that are connected to the surface, i.e. recharge becomes streamflow. Estimation of baseflow is derived by hydrograph separation applied to USGS daily streamflow records using the *PART* program, which estimates recharge to the aquifer following a significant rainfall from streamflow hydrographs (Rutledge, 1998). The hydrograph separation technique assumes that the drainage basin is underlain by an aquifer having homogeneous isotropic characteristics and that baseflow is equal to streamflow on non-runoff days (Rutledge, 2007). Baseflow at the two gauging stations is estimated using the PART program, over the subsurface watershed areas on a monthly basis.

DIRECT RUNOFF (R)

Precipitation that does not infiltrate into the soil profile, but flows downhill and contributes to streamflow, is obtained by hydrograph separation and from distributed modeling. First the streamflow records for the USGS gauge are used to constrain the hydrologic model, then the model is used to project the direct runoff for periods when USGS did not record measurements and for locations not gauged. Daily streamflow time series are retrieved from the USGS National Water Information System for the gauging stations. Once the baseflow is obtained with the PART program, direct runoff is computed as the difference between streamflow and baseflow. Monthly and climatological values are calculated in ac-ft over the surface drainage areas.

EVAPOTRANSPIRATION (ET)

Potential evapotranspiration (pET) represents the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration, at a maximum possible rate due to prevailing meteorological conditions, and subject to available water supply from soil moisture or water bodies. Potential evapotranspiration is rarely achieved because of the climate in the study area is limited by precipitation where the evaporative demand far exceeds available soil moisture over annual and interannual periods. Pan evaporation can be used to estimate potential rates, but availability of this measurement is limited to a few locations such as reservoirs, a research station, and the NWS as reported by Calderon (2005). However, pan evaporation measurements are not available for winter months and have limited duration making its use for the study period incomplete. Another method for estimation of pET is to use meteorological measurements at nearby stations. OCS computes pET using a Short Grass Reference Evapotranspiration (ETRS*)* model applied to Oklahoma Mesonet stations. Potential Evaporation is computed for Connerville on a monthly basis using ETRS at Tishomingo (January 2004-April 2005) and Fittstown (May 2005-December 2006), whereas pET at Blue River near Blue is estimated using data from the Oklahoma Mesonet stations Altus Dam, Chickasha, McGee Creek Dam and Stillwater (Calderon, 2005). However, the amount of water that is actually removed from the surface does not always proceed at the potential rate as pET, but rather depends on water supply coming from precipitation and is termed actual evapotranspiration (aET). Actual evapotranspiration is computed by adjusting the water balance, storage term to equal zero in each year as described by Eq. 1.1.

Computation of the water balance on a volumetric basis (in ac-ft) rather than as an average depth over a watershed, overcomes difficulty posed by the difference in area of the surface and subsurface drainage areas, that is, when runoff comes from a different area than the discharge from the aquifer. Tables 1-3 and 1-4 present the climatological water balance on a seasonal basis at Connerville and Blue, respectively. Drainage areas are used to compute precipitation, runoff and actual evapotranspiration, whereas baseflow is estimated over the subsurface drainage areas averaged for each month and year, as presented in these tables as climatological values. The last column of the tables shows each component expressed as a percentages of precipitation. Due to the voluminous data expressed as a timeseries for the study period, annual and monthly water balances at each station are presented in Appendices 1 and 2.

Analysis of the water budgets is computed by plotting the seasonal variation of each component, as depicted in Figures 3a and 4a for Connerville and Blue, respectively. The positive axis of the graph shows precipitation as the input of the hydrologic system, whereas the components depleting precipitation are shown in the negative axis. It can be noticed that the flow at Connerville responds rapidly to significant rainfall events and is typically high during the early spring, and then declines during June and July, reaching baseflow levels by July and August. Baseflow represents a more significant component than direct runoff at Connerville accounting for 12.5% of the precipitation, whereas direct runoff represents only 3.8%. This percentage of baseflow is higher in the upper part of the Blue River basin and it decreases at locations farther downstream, representing only 9.3 percent of the precipitation at Blue River near Blue.

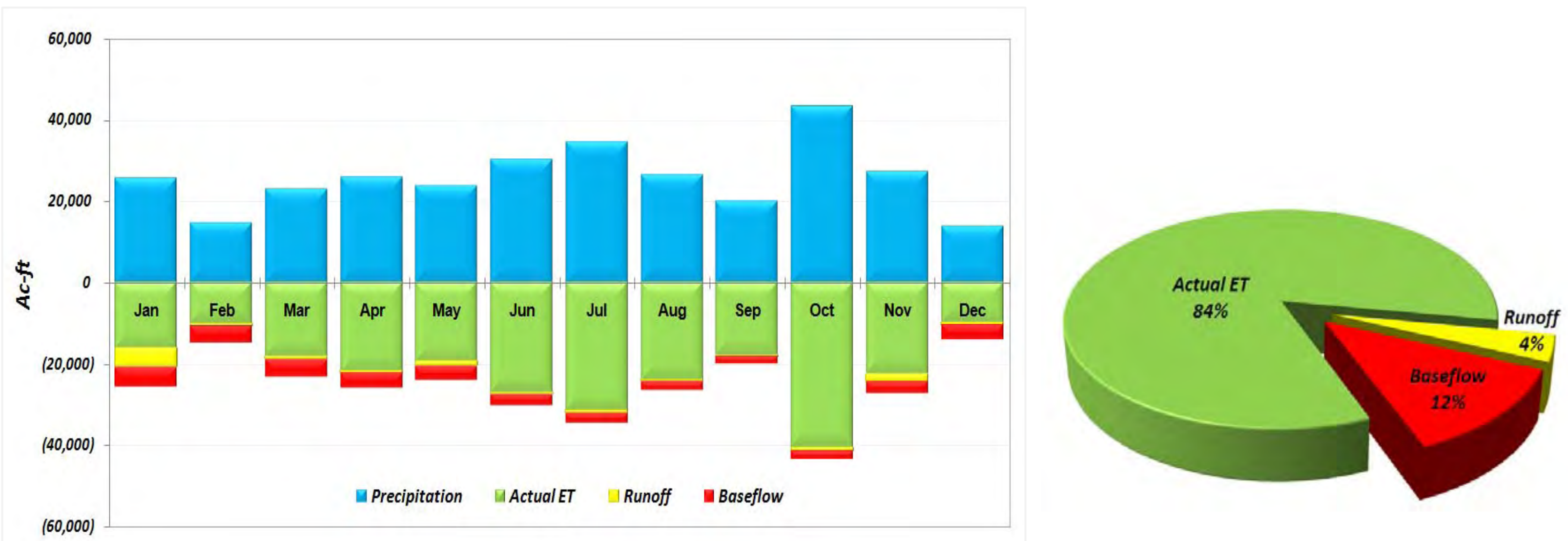
Analysis of the streamflow hydrographs at each gauging station indicates that baseflow at Connerville constitutes 77% of the average annual streamflow at Connerville, for the period 2004-2006, which is consistent with the 72% estimated in Circular 91, taking into consideration that in Circular 91 baseflow at Connerville is assumed to come from a subsurface watershed with the same area as the surface basin. Hence, baseflow is the main constituent of surface water at Connerville, and its seasonal pattern is critical because it may represent only a fraction of the total flow in the stream during periods of high streamflow, or may constitute the entire flow in the stream during periods of drought.

The summer and winter baseflow and direct runoff rates are affected not only by precipitation, but also from the transfer back to the atmosphere from soil and vegetative surfaces as actual evapotranspiration (aET), which removes about 84% of the precipitation at Connerville and 73% at Blue. Those differences can be attributed to rainfall distribution and intensities, as well as to soil types, and ecologic and local climatic variables over the respective drainage areas.

Actual evapotranspiration is the major component that depletes water that would otherwise be available for recharge. Compared to precipitation that averages 36.2 in/yr, actual evapotranspiration averages 26 in/yr for the period 2004-2006 at Connerville. This is consistent though lower than the 30 in/yr reported by Circular 91 for the period 1969-1971. Such differences are expected due to variation in precipitation for the two periods and other climatic conditions for the locale.

Table 1-3. Climatological seasonal water balance at Blue River near Connerville (2004-2006)

Seasonal Water Balance at Blue River near Connerville (Ac-ft)														
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**	**%P**
P	25,751	14,833	23,168	25,951	23,963	30,281	34,540	26,481	20,154	43,378	27,382	14,025	**309,908**	**N/A**
R	4,570	500	638	503	998	368	479	206	262	850	1,833	566	**11,774**	**3.8**
Gw	4,945	4,134	4,297	3,657	3,515	2,871	2,533	2,227	1,856	2,103	3,028	3,518	**38,683**	**12.5**
aET	16,236	10,199	18,234	21,791	19,451	27,042	31,527	24,048	18,035	40,425	22,521	9,941	**259,451**	**83.7**

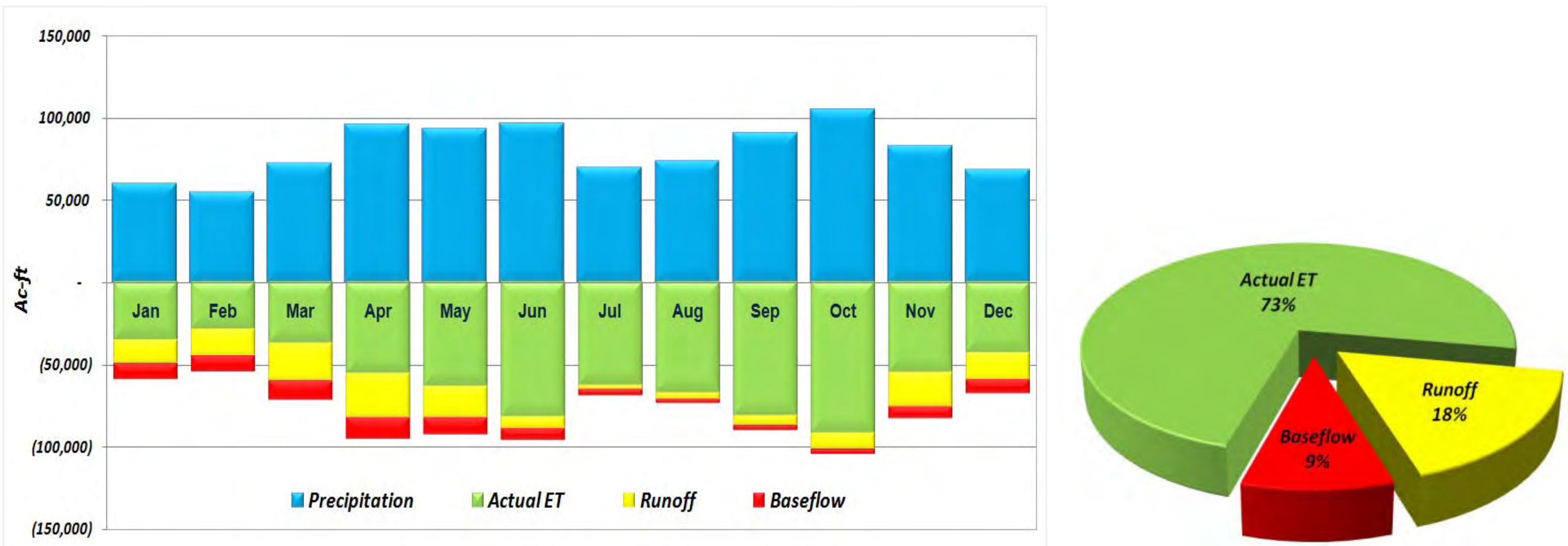


(a) **(b)**

Figure 3. *Water Balance at Blue River near Connerville (2004-2006), (a) Seasonal variation of the components in the budget; (b) Components expressed as a percentage of precipitation*

Table 1-4. Seasonal Water Balance at Blue River near Blue (1994-2006)

Seasonal Water Balance at Blue River near Blue (Ac-ft)														
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**	**%P**
P	59,616	54,661	72,199	95,316	93,095	96,240	69,393	73,611	90,073	104,860	82,743	67,844	**959,651**	**N/A**
R	14,559	16,582	22,456	26,801	19,206	7,587	2,606	4,051	6,192	9,776	20,681	16,107	**166,605**	**17.4**
Gw	9,939	9,166	12,183	12,743	10,662	7,117	3,873	2,432	2,799	3,376	6,752	8,273	**89,315**	**9.3**
aET	35,118	28,912	37,560	55,772	63,227	81,535	62,914	67,127	81,082	91,708	55,310	43,464	**703,731**	**73.3**



(a) **(b)**

Figure 4. Water Balance at Blue River near Blue (1994-2006), (a) Seasonal variation of the components in the budget; (b) Components expressed as a percentage of precipitation

WATER BUDGET SUMMARY

Monthly, annual and seasonal water balances are constructed for the gauging stations Blue River near Connerville (2004-2006) and Blue River near Blue (1994-2006). The results show that streamflow at Connerville responds rapidly to significant rainfall events. Baseflow is the main component of streamflow at Connerville representing 77% of the average annual at this station, and may constitute total streamflow in the summer months. Baseflow discharge is higher in the upper part of the Blue River basin and it decreases at locations farther downstream, representing only 9.3 percent of the precipitation at Blue River near Blue. Also, it was determined that the mean annual actual evapotranspiration at Connerville deplete 84% of the precipitation over the surface area draining to Connerville which amounts to 26 in/yr for the period 2004-2006.

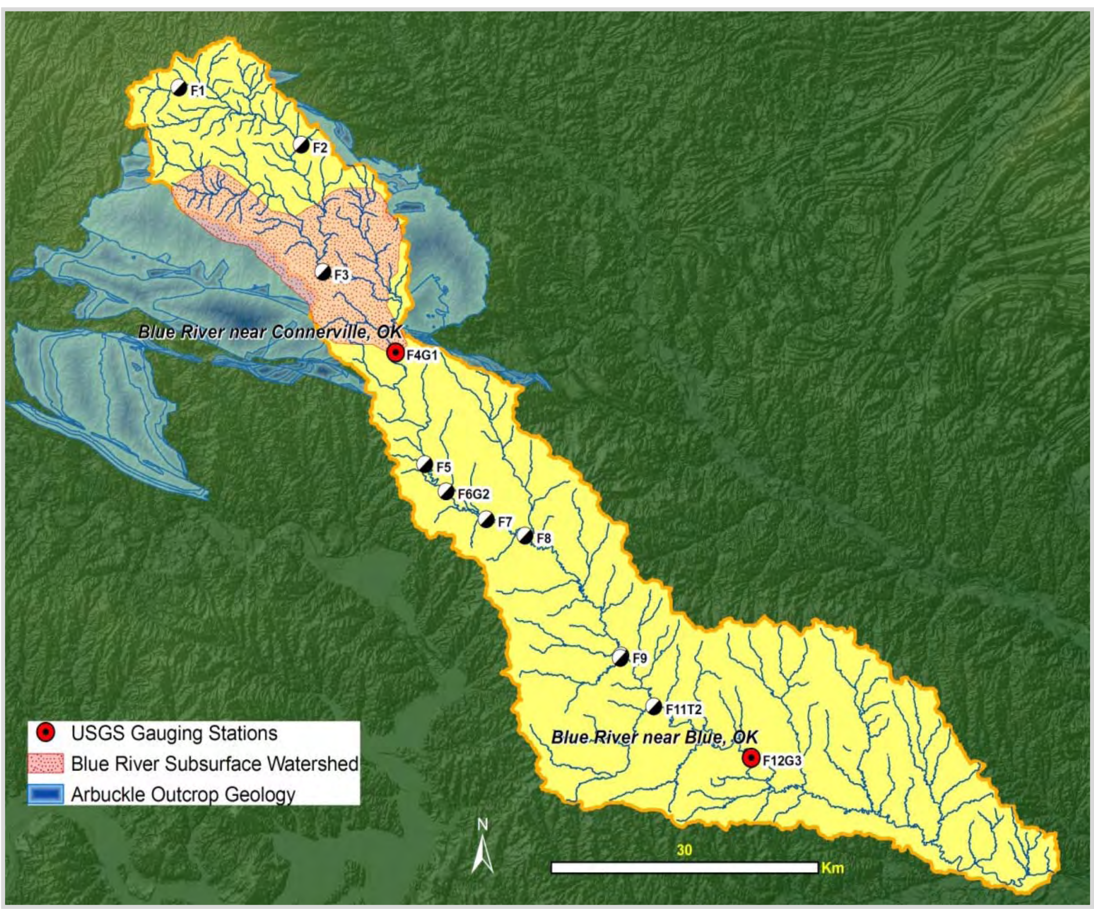
2. Estimation of Streamflow at Ungauged Locations

Streamflow is needed at interior locations of the Blue River where there are no measurements, or insufficient stream gauge records exist. A 500-m V*flo*™ hydrologic model for the Blue River basin provides a means for synthesizing direct runoff at interior points, while synthetic baseflow is generated based on a relationship between surface and subsurface drainage areas of the Blue River near Connerville and at Blue River near Blue.

Characterization of Ungauged Locations

Direct runoff and baseflow estimation is needed for surface water permits at the interior ungauged locations shown in Figure 5 and described in detail in Table 1-5. The following assumptions are valid for the methodology described in this section:

1. Estimation of direct runoff and baseflow is possible at interior points located on the Blue River.
2. The subsurface drainage areas used for baseflow estimation are calculated by proportioning the



surface drainage areas to the *Blue River Subsurface Watershed* (refer to Table 1-1).

Figure 5. *Interior Ungauged Locations in the Blue River Basin*

Table 1-5. Blue River Basin: Surface and Subsurface Drainage Areas at Interior Locations

Location ID	Latitude	Longitude	Surface drainage area (mi^2)	Subsurface areas (mi^2)
F1	34˚38’8.0’’N	96˚49’9.1’’W	10	N/A*
F2	34˚34’54.5’’N	96˚41’44.8’’W	44	N/A*
F3	34˚27’37.9’’N	96˚40’26.4’’W	113	N/A*
F4G1 –Connerville	34˚23’0.5’’N	96˚36’2.1’’W	162	79.0
F5	34˚16’37.9’’N	96˚34’14.2’’W	191	113.5
F6G2 -Milburn	34˚15’2.96’N	96˚32’57.8’’W	206	120.0
F7	34˚13’29.6’’N	96˚30’29.6’’W	224	185.8
F8	34˚12’31.49’’N	96˚28’10.4’’W	230	190.7
F9	34˚5’40.2’’N	96˚22’19.6’’W	344	284.9
F10T1	34˚5’32.0’’N	96˚22’16.1’’W	362	298.9
F11T2	34˚2’46.3’’N	96˚20’7.8’’W	428	354.2
F12G3 –Blue at Blue	33˚59’50.9’’N	96˚14’27.7’’W	476	392.9

*These subsurface drainage areas are not within the Blue River Subsurface Watershed and the synthetic relationship cannot be applied.

Direct Runoff at Ungauged Locations

Distributed hydrologic modeling is designed to represent the spatiotemporal characteristics of a watershed that transform rainfall into runoff (Vieux, 2004). The purpose of a distributed hydrologic model applied to the region of the Arbuckle Simpson Aquifer is to estimate distributed rainfall-runoff and recharge. This type of modeling is capable of generating estimations using geospatial maps such as soils, landuse, elevation and rainfall properties.

The 500-m V*flo*™ model of the Blue River basin was assembled by Calderon (2006). The model is run using *Vflo™* Long-term (version 1.5) to obtain daily values of direct runoff at the twelve locations in the Blue River basin. Bias-corrected radar is used as input of the model, for the period January 1994 to April 2007. Table 1-6 shows the seasonal results of direct runoff expressed as volumes in Ac-ft, for this period. The results show that runoff volumes vary proportionally to the drainage areas at each location, as presented in Table 1-6. Daily runoff was further refined at Connerville using a 200-m resolution model, which is described in more detail in Section 3.

Table 1-6. *Seasonal Direct Runoff at Interior Locations, Ac-ft (Jan1994 - Apr2007)*

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
F4G1 (79.0 mi^2)	2,312	3,930	3,920	2,809	3,919	2,600	1,277	1,930	3,882	1,602	1,710	1,037	**30,927**
F5 (113.5 mi^2)	3,031	5,187	4,979	3,226	4,609	2,845	1,359	2,036	4,198	1,816	2,578	1,223	**37,088**
F6G2 (120.0 mi^2)	3,415	5,768	5,513	3,560	4,920	2,975	1,407	2,101	4,362	1,935	3,119	1,319	**40,394**
F7 (185.7 mi^2)	3,912	6,438	6,255	4,060	5,327	3,092	1,440	2,205	4,542	2,133	3,898	1,498	**44,800**
F8 (190.7 mi^2)	4,061	6,641	6,515	4,206	5,466	3,142	1,465	2,261	4,609	2,207	4,159	1,568	**46,300**
F9 (284.8 mi^2)	7,095	11,046	11,601	8,784	9,787	5,383	3,196	4,433	8,114	5,582	9,652	4,051	**88,725**
F10T1 (298.8 mi^2)	7,722	11,933	12,684	10,303	11,302	6,279	3,896	5,146	9,347	7,023	10,865	4,815	**101,315**
F11T2 (354.2 mi^2)	9,585	14,765	15,852	14,124	14,741	8,273	5,797	6,453	12,446	9,385	14,343	6,752	**132,516**
F12 (392.9 mi^2)	10,815	16,734	18,188	15,921	16,951	9,697	6,761	7,279	13,977	10,448	16,072	8,766	**151,608**

Synthetic Baseflow at Ungauged Locations

A synthetic relationship is used to extend the period of baseflow at Connerville using longer term records from the station near Blue in the Blue River drainage area. Streamflow data from the USGS gauging stations Blue River near Connerville and Blue River near Blue are used to construct a regression relationship that relates surface and subsurface drainage areas that account for the Blue River Subsurface Watershed. Daily time series of observed baseflow are obtained at both gauging stations for the period October 2003 to May 2007, using the PART Program (Rutledge, 1998), as presented in Figure 6.

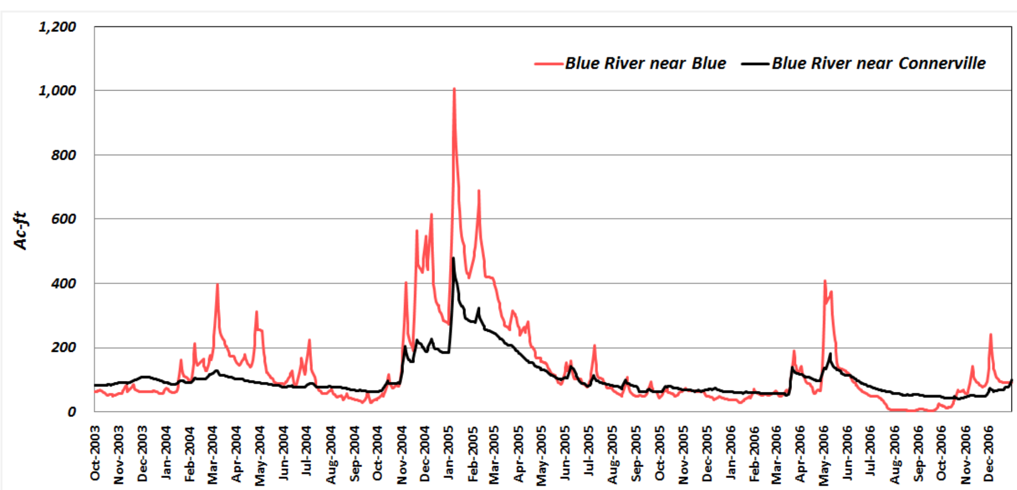


Figure 6. *Daily Time Series of Baseflow at Connerville and Blue, obtained with the PART program*

Similarities in the baseflow volumes at Connerville and at Blue lead to a numerical relation that allows generation of synthetic baseflow estimates. The ratio of the subsurface drainage areas at both stations is applied to baseflow records at Blue to generate baseflow at Connerville for years where no records exist. The combination of the ratio of subsurface drainage areas and the adjustment factor is called the *Baseflow Coefficient, Bc,* according to,

$$Bc = \frac{Sp}{Sb} + \alpha \qquad \textbf{1.2}$$

where *Sp* is the subsurface area at any interior point between Connerville and Blue, *Sb* is the subsurface area draining to Blue River near Blue (refer to Table 1-1) and α is the adjustment factor of 0.056 for the period affected by wetter or drier climatic conditions. Note that the units of the terms *Sp* and *Sb* are expressed in consistent units of area. The baseflow coefficient, *Bc*, is applied to the observed monthly baseflow obtained by hydrograph separation with the PART program. Considering that baseflow has shown to be higher at Connerville and decrease at locations farther downstream, as described in the water balance section.

Verification of the synthetic method to obtain baseflow is accomplished by computing the baseflow coefficient, *Bc*, for Connerville using Eq. 1.2, and applying it to daily baseflow values of the gauging station Blue River near Blue. The resulting synthetic baseflow at Connerville is plotted along with the observed baseflow at this gauging station, which is obtained with the PART program, and depicted in Figure 7. The synthetic baseflow shows a good overall agreement to the observed within 6.7 percent for the period October 2003 to May 2007.

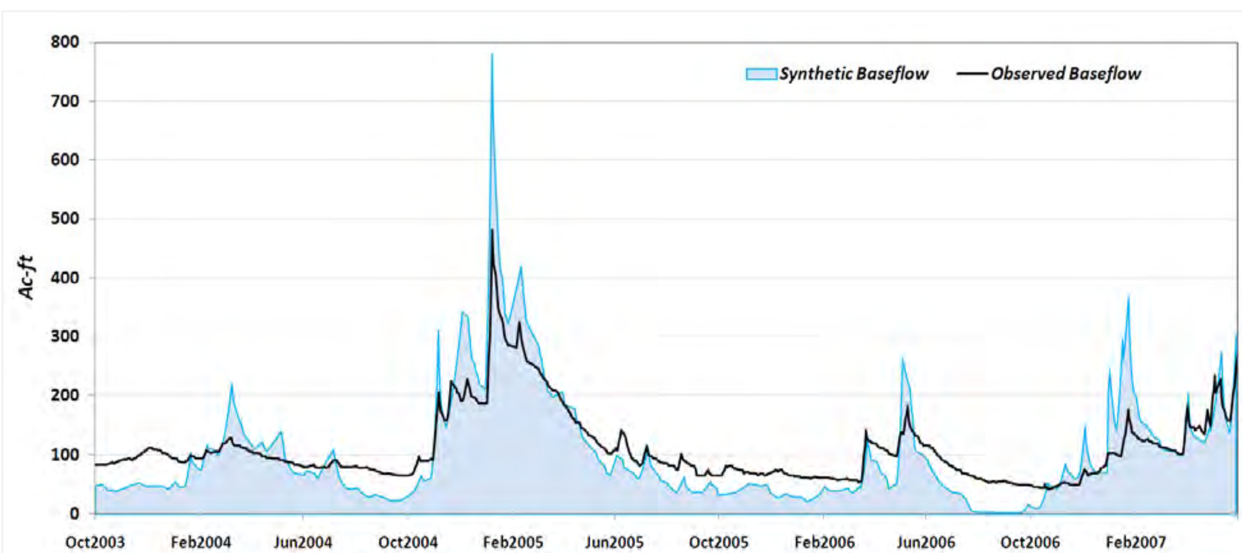


Figure 7. *Verification of the Synthetic Baseflow approach on a daily basis at Connerville.*

Daily time series of baseflow are then averaged for the period 1994-2006 to obtain seasonal baseflow at the interior locations, as shown in Table 1-7. Detailed long-term baseflow for the gauging stations Blue River near Blue and Blue River near Connerville is presented in Appendix 3.

Table 1-7. *Seasonal baseflow synthesized at interior locations in the Blue River Basin, 1994-2007 (Ac-ft)*

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
F4G1 (79.0 mi^2)	7,238	6,960	9,041	8,599	7,565	5,107	2,850	1,841	1,992	2,547	5,031	6,267	65,038
F5 (113.5 mi^2)	7,751	7,454	9,682	9,209	8,102	5,469	3,052	1,971	2,133	2,728	5,388	6,711	69,648
F6G2 (120.0 mi^2)	7,819	7,520	9,767	9,291	8,174	5,517	3,079	1,989	2,152	2,752	5,435	6,770	70,266
F7 (185.7 mi^2)	8,273	7,956	10,334	9,830	8,648	5,837	3,257	2,104	2,277	2,911	5,751	7,163	74,343
F8 (190.7 mi^2)	8,296	7,978	10,363	9,857	8,672	5,853	3,266	2,110	2,284	2,919	5,767	7,183	74,548
F9 (284.8 mi^2)	8,589	8,260	10,729	10,206	8,979	6,061	3,382	2,185	2,364	3,023	5,971	7,437	77,186
F10T1 (298.8 mi^2)	8,619	8,288	10,766	10,240	9,009	6,081	3,393	2,192	2,372	3,033	5,991	7,462	77,447
F11T2 (354.2 mi^2)	8,712	8,378	10,882	10,351	9,106	6,147	3,430	2,216	2,398	3,066	6,056	7,543	78,285
F12 (392.9 mi^2)	8,762	8,426	10,945	10,411	9,159	6,182	3,450	2,229	2,412	3,084	6,091	7,587	78,739

Reconstruction of Streamflow using a *Vflo™* Model and Synthetic Baseflow

Reconstructing streamflow records at ungauged location becomes particularly important for this study because there exists only one station (Blue River near Connerville, F4G1), that measures the discharge and runoff for the Hunton-Anticline Area. This gauging station has a short period of continuous streamflow records, which has become a constraint for the characterization of the streams of the Blue River Basin, and its intrinsic relation with baseflow discharging from the Arbuckle-Simpson Aquifer. Summing of direct runoff and baseflow results in streamflow at each interior location, which is presented in Table 1-8.

SUMMARY

Reconstruction of streamflow is important at locations where no or insufficient stream gauge records exist. Combination of distributed hydrologic modeling and synthetic baseflow provides reconstructed streamflow. A 500-m distributed model for the Blue River Basin was run using Vflo™, to obtain daily values of direct runoff at all twelve locations. Further refinement of runoff time series at Connerville was accomplished by running the 200-m resolution model described in the next section.

Synthetic baseflow was derived by applying the Baseflow Coefficient (Eq. 1.2) to baseflow at Blue River near Blue. Daily time series of synthetic baseflow were obtained at Connerville, and showed to agree to with 6.7% of the observed baseflow for the period October 2003 to May 2007. Finally, seasonal streamflow (1994-2006) was reconstructed for all locations on a seasonal basis, whereas daily time series of streamflow were gathered for Connerville, which is particularly important because of the lack of streamflow records at this station

Table 1-8. *Seasonal Streamflow at Interior Locations in the Blue River Basin, 1994-2007 (Ac-ft.)*

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
F4G1 (79.0 mi^2)	9,550	10,890	12,960	11,408	11,484	7,707	4,127	3,771	5,874	4,149	6,741	7,304	95,964
F5 (113.5 mi^2)	10,782	12,641	14,661	12,435	12,711	8,313	4,410	4,008	6,331	4,544	7,966	7,933	106,735
F6G2 (120.0 mi^2)	11,234	13,288	15,281	12,851	13,094	8,492	4,486	4,090	6,515	4,687	8,554	8,089	110,660
F7 (185.7 mi^2)	12,185	14,394	16,589	13,890	13,974	8,930	4,698	4,310	6,819	5,044	9,649	8,661	119,142
F8 (190.7 mi^2)	12,357	14,619	16,878	14,062	14,138	8,995	4,731	4,371	6,893	5,126	9,925	8,752	120,848
F9 (284.8 mi^2)	15,684	19,307	22,330	18,990	18,766	11,444	6,578	6,618	10,479	8,605	15,623	11,488	165,911
F10T1 (298.8 mi^2)	16,341	20,221	23,449	20,543	20,311	12,360	7,290	7,338	11,719	10,056	16,856	12,278	178,762
F11T2 (354.2 mi^2)	18,296	23,143	26,734	24,475	23,847	14,420	9,227	8,669	14,844	12,451	20,399	14,295	210,801
F12 (392.9 mi^2)	19,577	25,160	29,133	26,332	26,111	15,879	10,211	9,508	16,389	13,531	22,163	16,353	230,347

3. DISTRIBUTED HYDROLOGIC MODEL FOR THE HUNTON-ANTICLINE

Hydrologic modeling is used to extend the observed runoff records at the gauging station Blue River near Connerville. A 200-m resolution model is constructed for the Hunton Anticline area in the upper Blue River basin, which is more than 4x the resolution of the regional 500-m model of the Blue River basin used for obtaining runoff at ungauged locations, as described in Section 2. The higher resolution model at 200-m accounts for a more detailed variability of soil depth, and channel hydraulics capable of more accurately reproducing the surface runoff and infiltration at the event and seasonal scales

MODEL DESCRIPTION AND APPROACH

A distributed hydrologic model for the Hunton-Anticline area is assembled at 200-m resolution. The soils database, STATSGO (USDA, 1991), was used to generate the Green and Ampt parameters: effective porosity, wetting front suction head, and saturated hydraulic conductivity (Vieux, 2004). Digital terrain data is used to derive the slope and connectivity of the land surface, whereas land use/ cover dataset from the US Geological Survey are reclassified into representative parameters such as roughness or texture map. The drainage network is defined by *Vflo™*, using a grid-cell scheme that connects overland flow and channel grids using arrows. The resulting gridded network for the upper area of the Blue River Basin is depicted in Figure 8, where the green and blue arrows represent overland and channel cells, respectively. More details on other characteristics of the model are presented in Table 1-9.

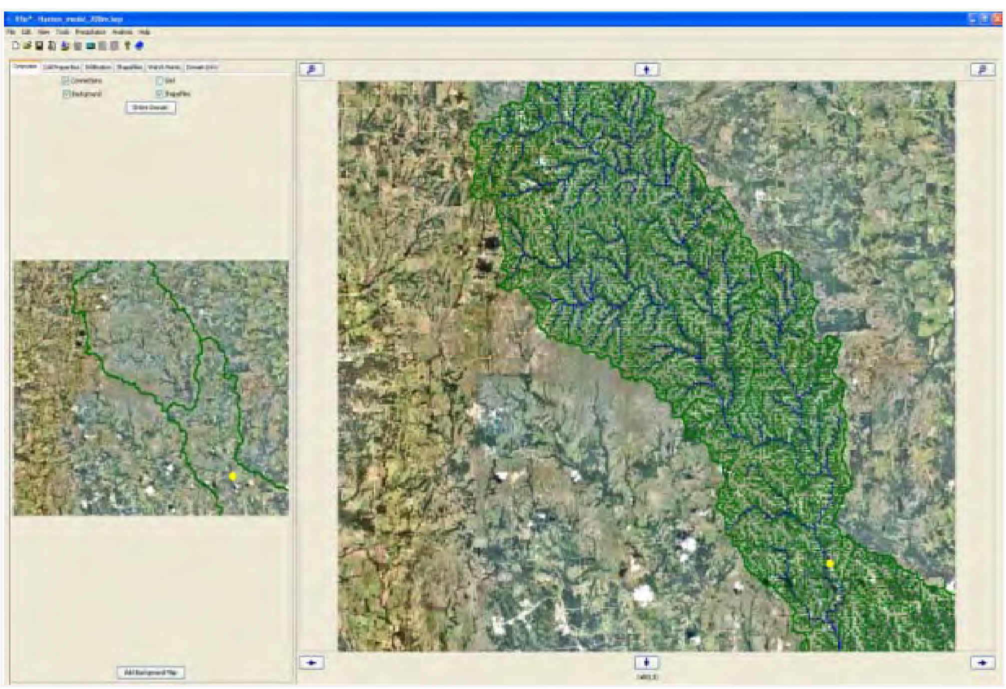


Figure 8. *Interface of the Distributed hydrologic model for the Hunton Anticline area of the Blue River basin.*

Table 1-9. *Characteristics of the Vflo™ model for the upper part of the Blue River Basin*

Connected Cells: 10,251 **Number of Overland Cells:** 8,887	**Number of Channel Cells:** 1,364 **Drainage Area:** 158.32 mi^2		
Parameter	**Minimum**	**Average**	**Maximum**
Roughness	0.01	0.043	0.13
Slope (%)	0.09	2.81	43.13
Hydraulic Conductivity (in/hr)	0.92	0.92	0.92
Wetting Front Suction (in)	1.57	5.49	12.2
Effective Porosity	0.31	0.44	0.49
Impervious	0.0	0.0	0.0
Soil Depth (in)	0.0	19.0	21.0

The precipitation input data is derived from gauge rainfall data and radar rainfall data produced by the US National Weather Service (NWS) and the Arkansas-Red River Basin Forecast Center (ARBRFC) at approximately 4 x 4 Km resolution. Precipitation data taken from radar rainfall records is used as hourly input values to the model and the gauge rainfall stations Centrahoma, Tishomingo, Sulphur, Ada, Ardmore, Lane, Madill, Newport, and Pauls Valley are used to adjust and correct radar rainfall data using a mean-field bias method described in Bedient et al. (2007).

Daily time series of direct runoff are obtained by hydrograph separation using the PART program. Figure 9 shows runoff in yellow and baseflow in red, as components of the long-term streamflow hydrographs for Connerville. The mean annual streamflow for the observed period October 2003 to March 2007 at Connerville is 37,276 cfs. The highest rainfall-runoff event for this period occurred on January 03-2005, when the peak hydrograph reached almost 4,600 cfs.

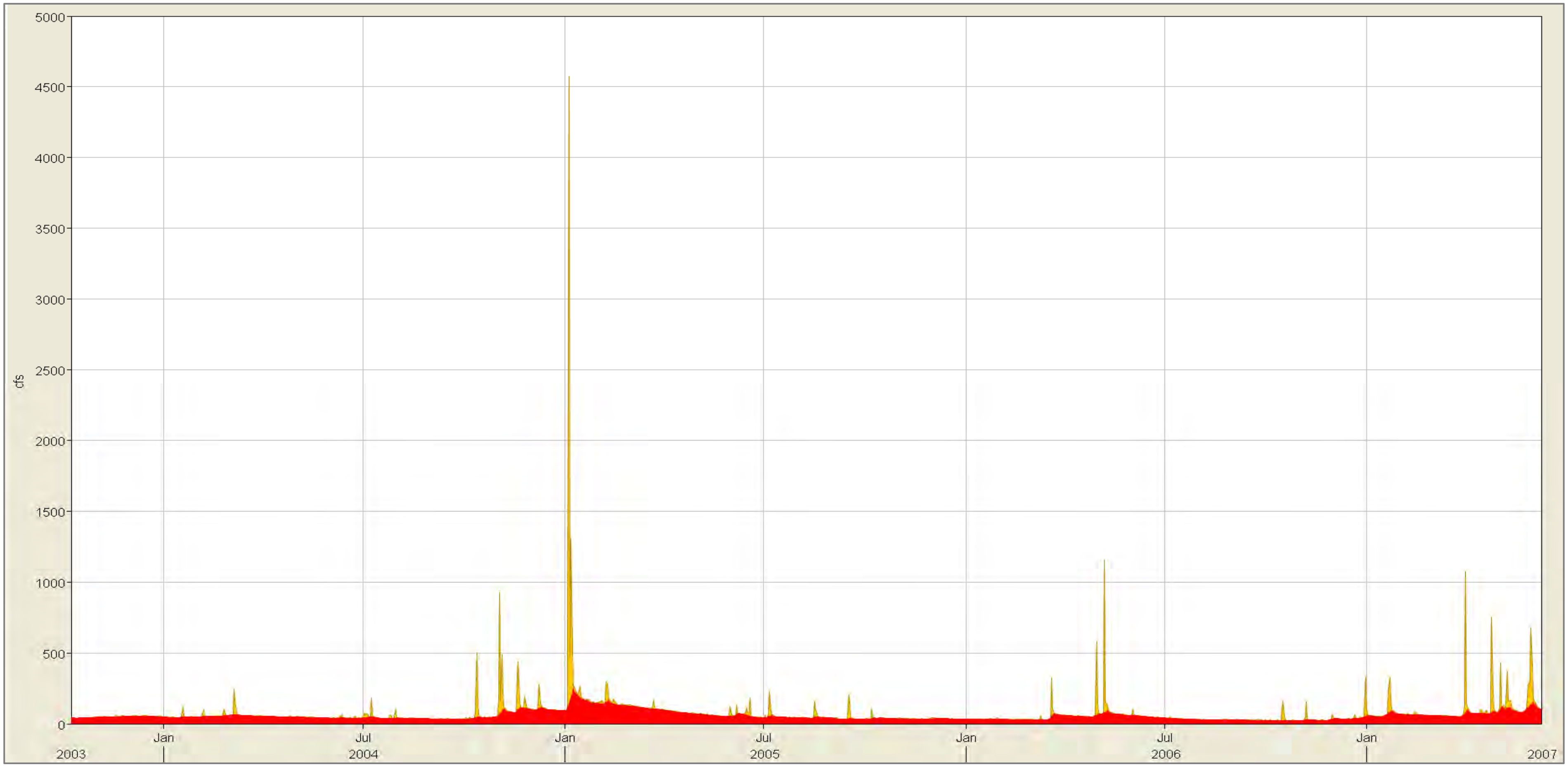


Figure 9. *Observed baseflow and direct runoff at Connerville (Oct2003-Mar-2007)*

Calibration of distributed hydrologic models seeks to estimate the spatial distribution of model parameters that minimize the differences between simulated and observed streamflow, by correctly identifying the dominant hydrologic processes. The *Vflo™* model is calibrated for the period of available streamflow records from October 2003 to May 2007, using the ordered physics-based parameter adjustment method described by Vieux and Moreda (2003). For this study, the final measure to assess prediction accuracy of the model is the Nash-Sutcliffe efficiency coefficient, which is widely used for comparison of continuous hydrographs (ASCE, 1993). Plots of cumulative flow and event scatter plots provide a method of assessing prediction ability over the entire simulation period. Figure 10 shows a comparison between the observed direct runoff and the simulated with the *Vflo™* model, for the event January 3, 2005.

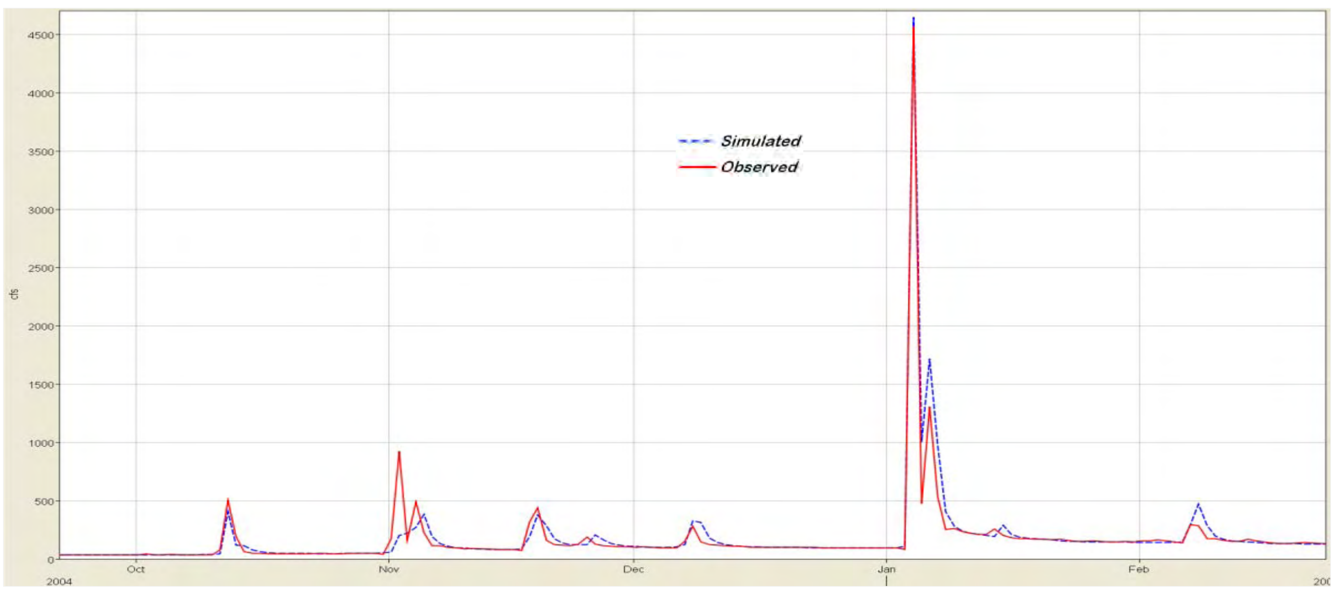


Figure 10. *Simulated vs. Observed Runoff Hydrographs at Connerville, after calibration (Oct2004-Mar2007)*

Daily time series of streamflow for the period October 2003 to March 2007 are obtained by addition of baseflow and runoff, which are obtained with *PART* and *Vflo™*, respectively. The resulting Nash-Sutcliffe efficiency coefficient for streamflow is 0.56. Good agreement in terms of cumulative streamflow volumes are presented in Figure 11, as an additional indicator of good prediction accuracy for the entire simulation period at Connerville. Statistically, the agreement between simulated and observed direct runoff at Connerville is 23 percent.

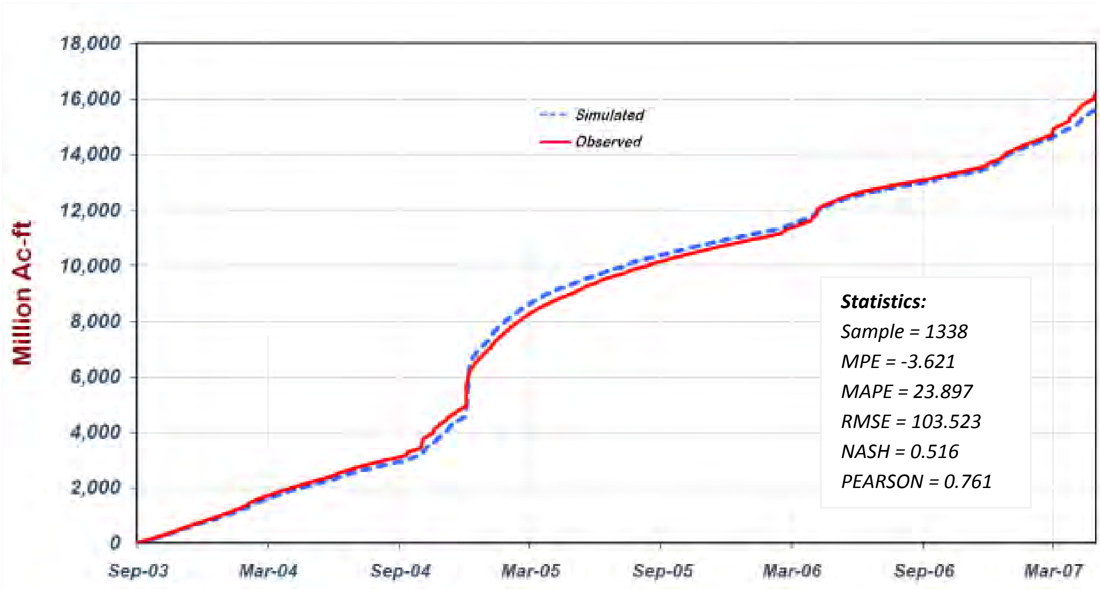


Figure 11. *Simulated vs. observed cumulative streamflow at Blue River near Connerville*

For the period when the stream gauge near Connerville was not operational, model simulations are used to extend daily runoff estimates at Connerville for the period before 2003, to cover the entire period beginning January 1994 through December 2006. Addition of those runoff estimates and the daily synthetic baseflow described in Section 2, leads to reconstructing streamflow at Connerville, as shown in Figure 12, where red represents baseflow, yellow runoff, and blue precipitation. Reconstruction of streamflow at this gauging station for the entire period on a daily basis, and maps of annual precipitation are presented in Appendix 4.

SUMMARY

In this section, we describe how the 200-m resolution model was assembled and calibrated in Vflo™ for the station Blue River near Connerville. This model is more than 4x the resolution of the regional 500-m model of the Blue River basin presented in section 2, which results in a more detailed variability of soil depth and channel hydraulics capable of more accurately reproducing the surface runoff and infiltration at the event and seasonal scales. Precipitation from radar is adjusted and corrected with nine Mesonet rain-gauges, and used as input of the model. Calibration of the model minimized the differences between simulated and observed runoff for the period October 2003 to May 2007. Runoff is simulated in Vflo™ and added to synthetic baseflow to obtain reconstructed streamflow for the period 1994-2006.

4. Distributed Groundwater Recharge

The calibrated model was used to generate annual gridded infiltration maps for the period 1994-2006 using *Vflo™*. Gridded infiltration is interpreted from *Vflo™* and validated for the period 2004-2006 using a water balance strictly constructed over the Blue River Subsurface Watershed. Grids of infiltration and actual evapotranspiration are used to derive distributed Gw over the Blue River Subsurface Watershed. The Gw_r estimates are validated on an annual basis using water levels at the USGS Fittstown Groundwater Well.

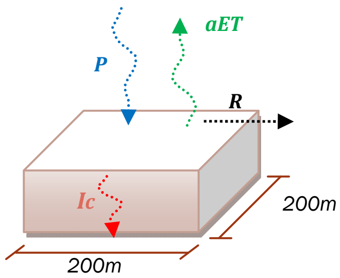
Soil Water Flux over the Blue River Subsurface Watershed

A climatological water balance is constructed specifically for the Blue River Subsurface Watershed (BRSW), to more accurately estimate the groundwater discharge over its 79mi2. The water balance is developed for the period January 2004 to December 2006, using hydro-meteorological data as presented in Table 1-10 (Appendix 5). The conceptual model and equations for components of the water budget is shown for a model grid cell in Figure 12. For purposes of computing the water balance, the net change in storage can be assumed to be zero.

Table 1-10. *Water Balance over the Blue River Subsurface Watershed (2004-2006)*

Component	Mean Annual (inches)	Total volume (inches)	Percentage of precipitation	Source
Precipitation	37.8	113.43	N/A	Radar rainfall (local bias)
Streamflow	11.8	35.50	N/A	USGS Streamflow
Runoff	2.65	7.94	7%	USGS Streamflow, baseflow is removed
Baseflow	9.19	27.56	24%	PART Program, using USGS streamflow
Actual ET	26.98	77.93	69%	Using pan Evaporation adjusted by assuming ΔS= 0 in the balance

At the grid cell, the amount of infiltration, *I*, is equal to the difference between precipitation, P, and runoff, *R*. The infiltrated precipitation is transported back to the atmosphere as actual evapotranspiration (*aET*) or is recharged to the aquifer. *Vflo™* simulates runoff as the difference between precipitation and runoff for each grid in the drainage network. The model output includes infiltrated volume at daily time steps as gridded maps at the 200-m model resolution. The theoretical value of infiltration (*I*) that is expected to occur at each cell can be written in terms of equations 1.3 and 1.4:



$$I = P - R \qquad 1.3$$

$$I = Gw + aET \qquad 1.4$$

Figure 12. *Water Balance Approach for a Vflo grid cell*

Where, *Gw* is the groundwater recharge that leaves the base of the soil model, and *aET* is the actual evapotranspiration. The expected infiltration over the subsurface watershed is computed using data from Table 1-10 and equations 1.3 and 1.4, for the period 2004-2006 as follows:

Expected Infiltration over the BRSW (2004-2006)

$$\mathbf{I = P\text{-}R = Gw + aET}$$

$$I = 113.43 \text{ in} - 7.94 \text{ in} = 27.56 \text{ in} + 77.93 \text{ in}$$

$$I = 105.49 \text{ inches}$$

$$I_{avg} = 33.2 \text{ in/yr} \qquad 1.5$$

The expected mean annual infiltration, I_{avg}, computed over the BRSW is 33.2 in/yr. This theoretical value is used to verify the mean value of the total infiltration grids obtained *with Vflo™* and described in the following section.

GRIDDED INFILTRATION OBTAINED WITH *VFLO™*

Distributed hydrologic modeling using *Vflo™* provides estimates of runoff and infiltration at each grid cell. Infiltration potential rates are calculated depending upon the initial degree of saturation, which is limited by rainfall intensities and potential evapotranspiration at every grid cell on an hourly basis. This physics-based mechanism allows accounting for seasonal and rainfall variations that lead to more accurate infiltration estimates.

Grids of daily infiltration are processed in GIS to obtain maps of monthly and annual infiltration over the BRSW area. Figure 13 shows the total infiltration grid obtained with *Vflo™* for the period 2004-2006, where the mean infiltration over the subsurface watershed area is 108.73 inches, and agrees with the expected value of 105.49 inches to within 3%. The mean annual infiltration is 33.2, and varies between 32.06 to 40.01 inches during this period, 2004-2006. The descriptive statistics related to the infiltration obtained with *Vflo™* are presented in Table 1-11.

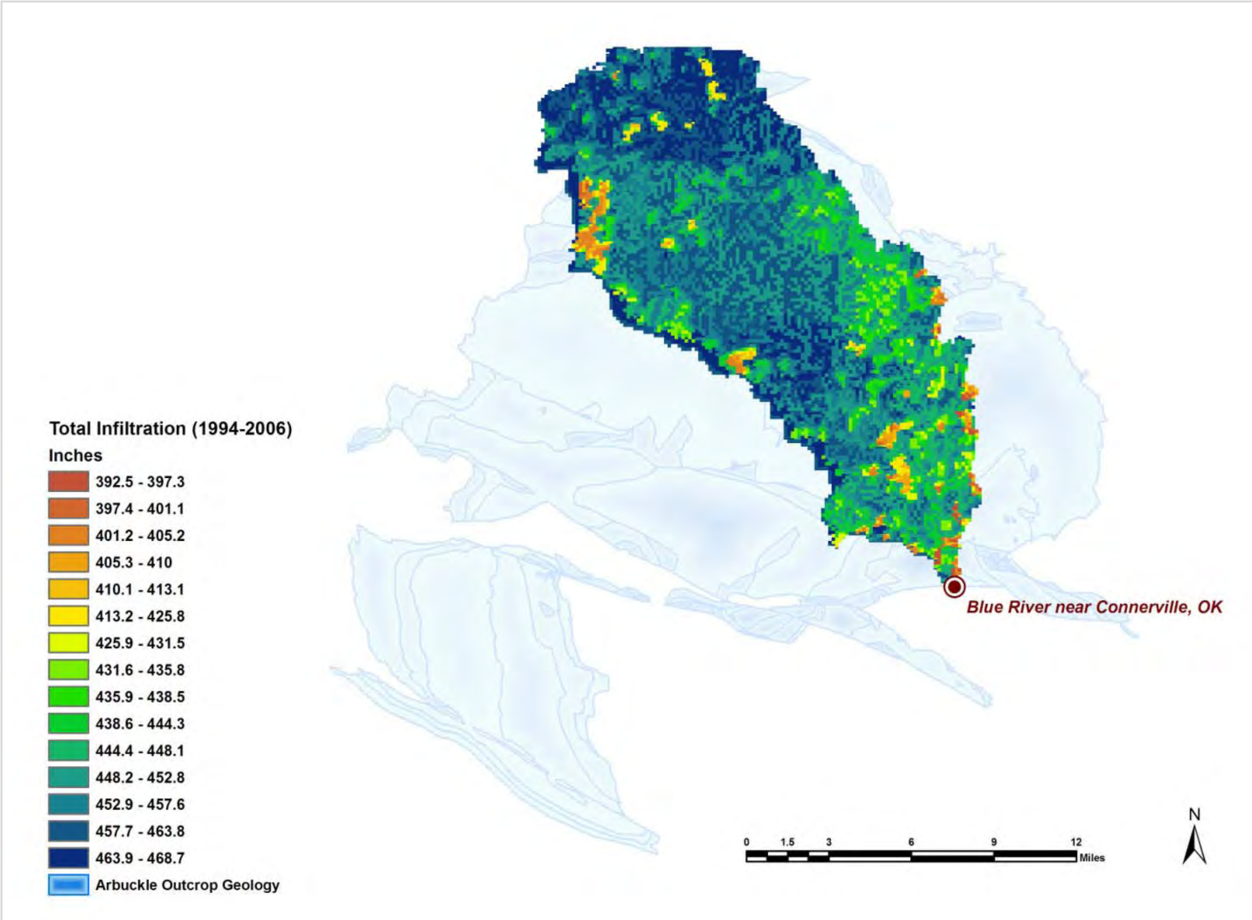


Figure 13. *Total infiltration over the Blue River Subsurface Watershed (2004-2006).*

Table 1-11. *Descriptive statistics for BRSW total infiltration over (2004-2006)*

Statistics	Infiltration (inches)			
	2004	2005	2006	Total
Mean Value	40.01	36.66	32.06	**108.73**
Minimum	33.09	29.63	24.66	
Maximum	41.73	39.86	34.78	
Standard Deviation	1.52	1.72	2.25	

Using the calibrated *Vflo™* model, gridded infiltration maps are produced that extend beyond the period of available streamflow records at Connerville (2004-2006), resulting in distributed infiltration for the entire study period, 1994-2006. A timeseries of the monthly infiltration over the BRSW are contained in Appendix 6 as a digital archive. Using the distributed model to extend estimates for the study period, 1994-2006, the annual infiltration averages 33.6 inches and ranges from 21.9 to 40.3 inches.

ACTUAL EVAPOTRANSPIRATION

Actual evapotranspiration is a major determinant of groundwater recharge. This parameter is computed over the BRSW by constructing a water balance for the period 2003-2006, as records are available at the station Blue River near Connerville. The water balance indicated that about 70% of the precipitation is removed as evapotranspiration over this area, as shown in Table 1-10. For years when no records are available at Connerville, aET cannot be derived from the water balance approach directly. A synthetic approach is taken to identify a proxy for aET such as a percentage of precipitation. Therefore, monthly water balances at Byrds Mill Spring and Blue River near Blue were tested to determine aET, as a percentage of precipitation, over the BRSW.

At Byrds Mill Spring, there is no runoff to this location because the aquifer discharges to the spring as baseflow. Therefore, aET is computed as the difference between precipitation and baseflow discharge at the spring. Following this approach, aET represents 88% of the precipitation, over the 54mi^2 of the Byrds Mill Spring Subsurface Watershed (BMSSW) for the period 1994-2006 (see Appendix 7). The seemingly high aET at Byrds Mill results because runoff is not accounted for at this station, which causes the appearance that nearly all of the precipitation infiltrates, which then mostly evaporates. Estimates of aET over BMSSW are almost 20% higher than those obtained for the BRSW, and therefore not considered as representative for the BRSW. While the temporal pattern of synthetic aET is consistent using BMSSW, its magnitude is too high to be of use for BRSW.

Another proxy for estimating aET was considered besides using the water budget for BMSSW. Monthly estimates of aET for the station Blue River near Blue are obtained with the water balance approach, as presented in Appendix 2. The mean annual aET at this gauging station for the period 1994 to 2006 is 73%, which is fairly close to the 69% estimated for 2004 to 2006 over the BRSW. Values of aET at Blue near Blue, expressed as percentage of precipitation, are applied to precipitation over BRSW in order to derive its particular aET for the period January 1994 to September 2003. Table 1-12 presents a comparison of the annual aET at the stations Blue River near Blue, Byrds Mill Spring and Blue River near Connerville.

Table 1-12. *Actual evapotranspiration at Blue River near Blue, Blue River near Connerville and Byrds Mill Sp.*

		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Mean Annual	
															2004- 2006	1994-2006
Precipitation at Blue near Blue	**in**	46.4	38.2	49.7	43.5	36.4	37.9	39.1	28.5	46.2	30.0	40.6	28.6	30.1	**33.1**	**38.1**
aET Blue near Blue	**in**	31.3	21.7	35.9	33.9	25.9	30.7	33.6	11.6	30.6	26.0	33.7	22.7	25.9	**27.4**	**28.0**
	%P	**67%**	57%	72%	78%	71%	81%	86%	41%	66%	87%	83%	80%	86%	**83%**	**73%**
Precipitation over BRSW (in)	**in**	40.0	33.9	43.1	40.1	36.6	36.7	40.2	24.5	41.3	26.7	40.5	34.8	32.3	**35.9**	**36.2**
aET Connerville (in)	**in**	26.9	19.2	31.0	31.2	26.0	29.7	34.5	10.0	27.3	23.2	***29.3****	***23.9****	***24.7****	**26.0**	**25.9**
	%P	**67%**	57%	72%	78%	71%	81%	86%	41%	66%	87%	***86%***	***78%***	***87%***	**84%**	**74%**

**aET is derived from observed data and computed using a water balance over BRSW (Appendix 4).*

As presented in Table 1-12, the mean annual aET for the period 2004-2006 is 83% at Blue River near Blue, and 84% at Connerville. This close agreement derived from observed records at both stations supports its use for extending the aET values at Connerville, and further estimation of recharge over the Hunton Anticline.

GRIDDED GROUNDWATER RECHARGE

The portion of water that infiltrates into the soil is assumed to either percolate to the aquifer or evapotranspirate to the atmosphere. *Vflo™* is configured to estimate infiltration and runoff, and consequently the groundwater recharge must be computed external to the model by adjusting the output, i.e. gridded infiltration (see Eq. 1.3 and 1.4). Groundwater recharge, Gw_r, is the difference between infiltration and actual evapotranspiration, *I – aET*, on a monthly and annual basis by applying Eq. 1.4.

Both infiltration and actual ET are computed over the BRSW. Infiltration values used for the computation of Gw_r are obtained from the *Vflo™* model, whereas actual ET is obtained from water balances at Blue River near Blue adjusted to BRSW. The spatial distributed Gw_r, is computed over the entire 1994-2006 period on a monthly basis. Figure 14 shows a distributed map of the mean annual Gw_r estimated for the period 1994-2006, using infiltration from the *Vflo™* model at 200-m resolution and aET as described in the previous section. Averaged over the contributing subsurface drainage, there was 34,380 Ac-ft of recharge for the period 1994-2006, ranging from 4.1 to 27.3 inches.

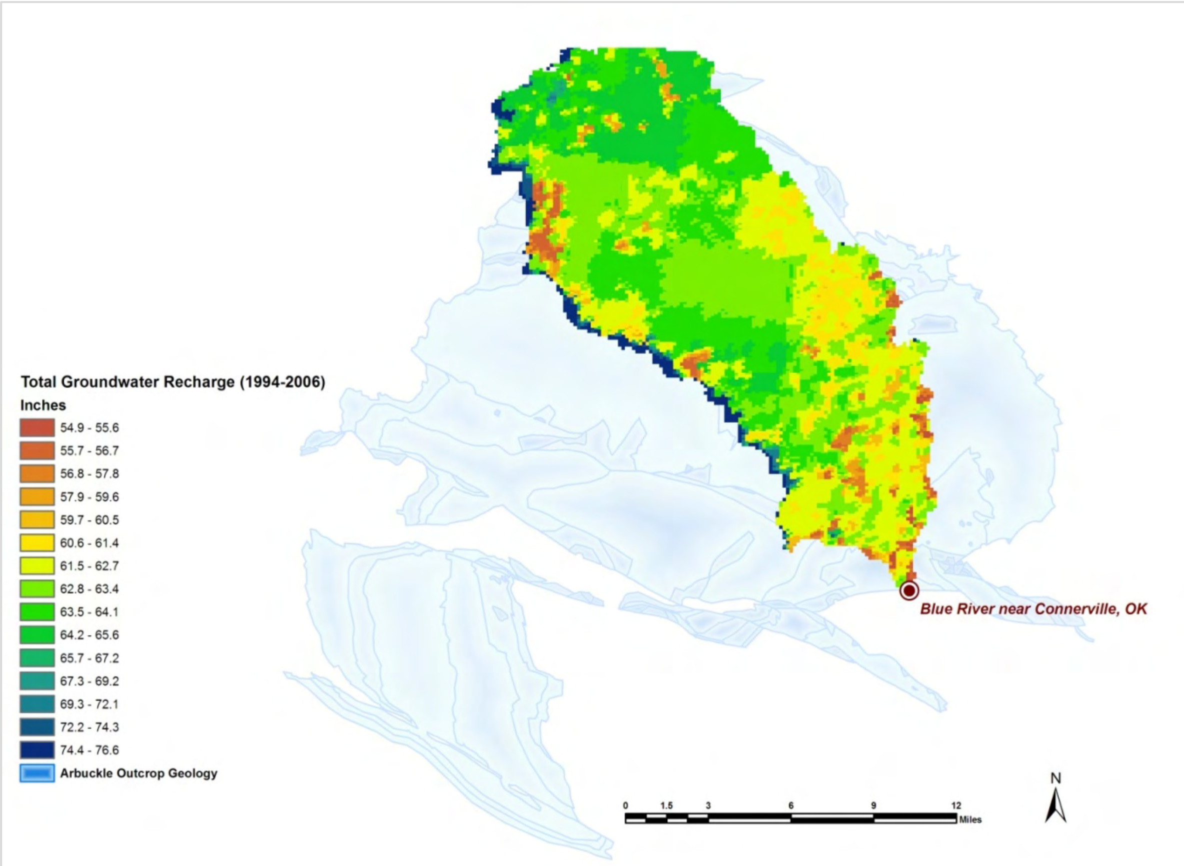


Figure 14. *Mean Annual Groundwater Recharge (Gw_r) over BRSW (1994-2006).*

Some of the local variation is dependent on assumed soil conditions at that may permit more or less infiltration. However, there is a trend over the area that confirms the importance of the spatial variability of this parameter, and its influence over the mean annual value. Validation of Gw_r is accomplished by comparison between expected values of infiltration (Eq. 1.4 and data from Appendix 5) and the estimated values obtained from *Vflo™*, as presented in Table 1-13 for the period 2004-2006, where the groundwater recharge estimated from *Vflo™* agrees to within 26% of the expected baseflow for the period 2004-2006.

Table 1-13. *Comparison between Estimated and Expected Infiltration and Groundwater Recharge (inches)*

Component		**2004**	**2005**	**2006**	**Total**	**Mean Annual**
Infiltration (I)	Estimated (*Vflo™*)	40.1	36.66	32.06	108.73	36.25
	Expected (Water Balance)	38.52	35.79	31.18	105.49	35.16
	Percentage Error	-3.9%	-2.4%	-3.1%	-3.1%	-3.1%

Baseflow (Gw)	Estimated (*Vflo™*)	8.3	6.8	5.1	20.2	6.7
	Expected (Water Balance)	9.18	11.9	6.4	27.59	9.2
	Percentage Error	9.6%	42.8%	20.3%	26.5%	26.5%

Once the groundwater estimates are validated, a water balance is constructed for the BRSW and presented in Table 1-14, where mean annual values of precipitation, runoff, infiltration, actual ET, and groundwater recharge are computed on an annual basis for the period 1994-2006. Monthly values of precipitation, infiltration, actual evapotranspiration and groundwater recharge are presented in Appendix 5. The data sources used in Table 1-14 are summarized as follows:

Precipitation (*P*): Gridded radar precipitation, Mean Field Bias corrected, is used as input of the *Vflo™* model for the Hunton Anticline area. Annual values are obtained using the Spatial Analyst in *ArcGIS®*.

Direct Runoff (*R*): Summation of daily time series at the station Blue River near Connerville, obtained from the *Vflo™* model.

Infiltration (*I*): Gridded infiltration obtained from the *Vflo™* model. Annual values are obtained using the spatial analyst in *ArcGIS*. Carryover from 1994 of model initialization (93% saturation) is removed.

Actual Evapotranspiration (*aET*): Computed for 2004, 2005, and 2006 developing a water balance at Connerville with available records. For 1994-2003 aET is derived from monthly water balances at Blue River near Blue, using aET as percentage of precipitation, and applying it to precipitation over BRSW to extend the record for the study period.

Recharge (Gw_r**):**

- Gw_r: Computed in Ac-ft, using infiltration and actual ET values from the table, applying *Eq. 1.4*.
- Gw_r use: Total permitted groundwater use (Ac-ft) allocated from 1994-2006, from wells *19590158, 19810609, 19850528*, which are located on the BRSW (Appendix 8).
- Net Gw_r: Deducting permitted groundwater use from the annual Gw volume

Ratio Gw_r **/P:** Computed using groundwater recharge and baseflow.

The results presented in Table 1-14 show that groundwater recharge occurring over the BRSW for the period 1994-2006 averages 29,997 Ac-ft and ranges from 7,996 to 55,051 Ac-ft. The three largest recharge years appear to be 1994, 1995 and 2002. Whereas, the lowest recharge years are 2000, 2003, and 1998 and 2006. Because evaporative demand far exceeds precipitation in this locale, infiltration occurring over the BRSW is a process controlled by precipitation, because 93% of the rainfall infiltrates in the soil with only 7% becoming runoff above Connerville. Actual evapotranspiration becomes the main source of water depletion in the soil pores, which takes about 78% of the infiltrated water to the atmosphere (72% of precipitation), and leaves about 22% (20% of precipitation) for groundwater recharge. The theoretical baseflow estimated through hydrograph separation using the PART program, is 24% of precipitation (refer to Table 1-10), which supports the results obtained with *Vflo™*.

Verification of Gw_r estimates reported in Table 1-13, is accomplished for the period 1994-2006 using the available data from the USGS Fittstown Well. The results are plotted in Figure 15, where a good overall agreement is evident between the recharge to the aquifer and the water levels recorded at the USGS Fittstown well. While the quantities of recharge and water levels in the well are not directly comparable, they are related and follow a temporal correlation where periods of increased recharge occur when water levels rise, and conversely. The coincidence of low points in both timeseries is evident where 2000, 2003, and 2006 are the lowest in terms of water level and recharge. Agreement between water levels and recharge timeseries validates the estimated water budget components, especially, actual evapotransipration estimated by a proxy, i.e. as a fraction of precipitation.

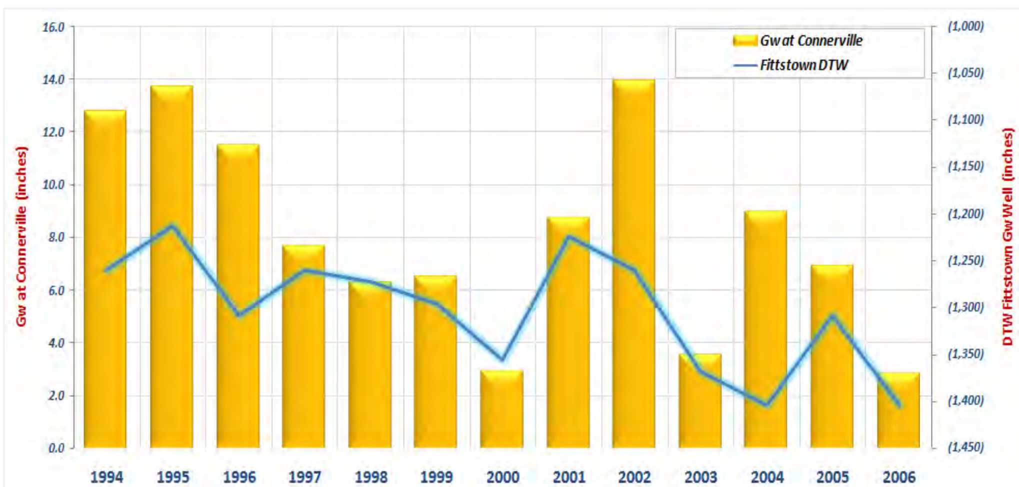


Figure 15. *Estimated groundwater recharge over BRSW compared to water levels at Fittstown Well.*

Table 1-13. *Total Annual Precipitation, Infiltration, Runoff, Actual ET and Groundwater Recharge over BRSW (1994-2006).*

	1994	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**Mean Annual**
Precip (in)	40.0	33.9	43.1	40.1	36.6	36.7	40.2	24.5	41.3	26.7	40.5	34.8	32.3	**36.2**
Precip (Ac-ft)	168,362	142,959	181,557	169,005	154,313	154,471	169,321	103,235	173,911	112,616	170,591	146,769	136,024	**152,548**
Runoff (in)	1.2	1.0	0.6	1.3	4.3	0.4	2.8	5.8	0.0 4	0.04	2.2	4.1	1.7	**2.0**
Runoff (Ac-ft)	5,096	4,355	2,469	5,385	18,119	1,776	11,810	24,501	174	174	9,325	17,133	7,015	**8,256**
Infiltration (in)	37.3	32.5	36.3	38.2	29.5	35.9	36.6	21.9	40.3	26.3	39.9	32.6	29.2	**33.6**
Infiltration (Ac-ft)	157,245	136,927	153,002	161,116	124,084	151,110	154,291	92,111	169,902	110,642	168,135	137,536	122,917	**141,463**
aET (in)	26.0	19.4	32.8	32.1	26.1	29.5	34.4	12.3	28.2	23.5	30.0	22.1	24.5	**26.2**
aET (Ac-ft)	109,459	81,782	138,384	135,319	110,041	124,100	145,036	51,870	118,614	98,980	126,368	92,989	103,267	**110,478**
Gw_r **(in)**	11.34	13.09	3.47	6.12	3.33	6.41	2.20	9.55	12.17	2.77	9.91	10.57	4.66	**7.4**
Gw_r **(Ac-ft)**	47,786	55,146	14,619	25,797	14,042	27,010	9,254	40,242	51,288	11,662	41,767	44,547	19,651	**30,985**
Gw_r **use (Ac-ft)**	26.0	19.4	32.8	32.1	26.1	29.5	34.4	12.3	28.2	23.5	30.0	22.1	24.5	**26.2**
Net Gw (Ac-ft)	47,702	55,051	14,455	25,625	13,875	26,912	8,063	39,544	51,134	7,996	39,258	44,197	16,152	**29,997**
GW/P	0.28	0.39	0.08	0.15	0.09	0.17	0.05	0.38	0.29	0.07	0.23	0.30	0.14	**0.20**

5. Summary and Conclusions

The water budget for the Blue River Basin and the BRSW draining to Connerville is established from a combination of data analysis and hydrologic modeling to extend observed components. The result of distributed modeling is an extension of the timeseries covering the study period from 1994-2006, and gridded recharge output for use in groundwater modeling. These distributed recharge maps represent an estimate of the soil water fluxes over the recharge area contributing to the Arbuckle member in the Hunton Anticline. Estimates of the groundwater recharge obtained with the model, Vflo™ are verified with available groundwater discharge records derived from the USGS gauging station at Connerville. The estimates of recharge agree well with the groundwater discharge computed from the water balance of the BRSW that drains to the Connerville stream gauging station. Estimates of actual evapotranspiration (aET) are refined for purposes of improving the estimates of recharge. For the period 1994-2006, the annual recharge produced is consistent with water levels at the Fittstown Well operated by the USGS.

From this analysis, recharge is 20% percent of precipitation, whereas streamflow runoff is only 4% of precipitation over the BRSW. Actual evapotranspiration results in 72% of infiltrated precipitation returning to the atmosphere. Precipitation averages 36 in/yr with a standard deviation of 6 inches. Annual groundwater recharge over the BRSW for the period 1994-2006 averages 29,997 ac-ft, ranging from 7,996 to 55,051 ac-ft per year. The three largest recharge years are 1994, 1995 and 2002, and the lowest are 2000, 2003, and 1998 and 2006. The year with recharge closest to the average was 2004. On a monthly basis, the lowest recharge occurs in September, averaging 1,300 ac-ft per month with a standard deviation of 1,000 ac-ft. The highest recharge is in April, averaging 5,600 ac-ft with a standard deviation of 5,000 ac-ft.

II. CLEAR AND MUDDY BOGGY BASINS

Study Area

Clear Boggy basin is located in the southwestern portion of Atoka County, comprising an area of 1,000mi^2. Clear Boggy Creek is the main stream in this basin, which collects waters from Jackfork, Coal, Goose, Leader, Delaware, Sandy, Caney, Funterhouse, Cowpen, Bois d'Arc and Meyhew creeks. Streamflow in the Clear Boggy basin is obtained from the USGS station, Clear Boggy Creek near Caney (07335000). The Muddy Boggy watershed has a drainage area of 2,429 mi^2 containing Lake Atoka and McGee Creek Dam reservoirs, as well as other tributaries that are collected downstream by Muddy Boggy Creek. Lake Atoka (constructed in 1959) provides almost half of the water supply for Oklahoma City, through a pipeline that pumps water to Lake Draper, draining an area of 176mi^2. McGee Creek Dam (constructed in 1987) is located about 15 miles southeast of the city of Atoka, Oklahoma, and supplies water to Oklahoma City, Soda, Atoka County, and the City of Atoka. The Clear Boggy and Muddy Boggy basins are contiguous to the Blue River basin, as depicted in Figure 16. Streamflow data is obtained in this basin from the USGS stations at Muddy Boggy near Farris (07334000), and Muddy Boggy near Unger (07335300)

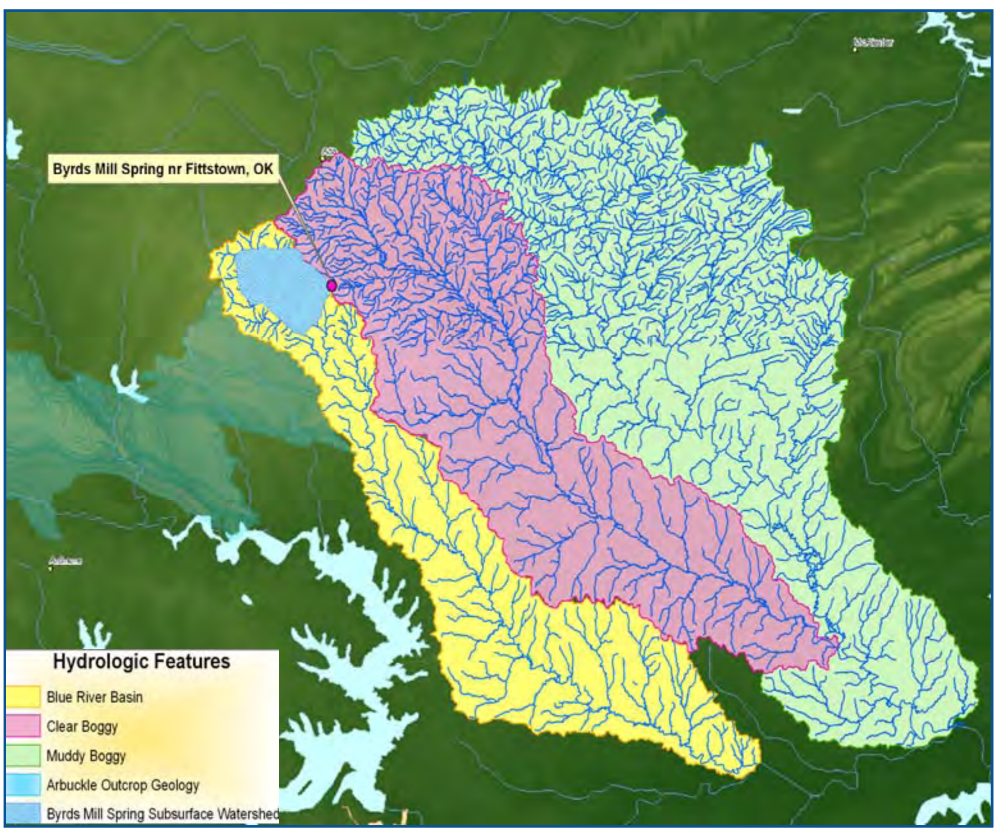


Figure 16. *Study area, Clear and Muddy Boggy basins adjacent to the Blue River basin*

Hydrologic Water Balance

Computation of the water balance components is completed by gathering and processing raw data for the selected stations, as is described in Table 2-1. Selection of gauging and pan evaporation stations was accomplished considering their location and availability of data records. Data is gathered for each component of the water balance, using the conceptual mathematical model of the overall water budget (refer to Eq. 1.1). The influence of reservoirs in Muddy Boggy basin is not considered as relevant in the water balance computations, which assumes that on average input equals output. Seasonal water balance for the period 1994 to 2006 is presented in Table 2-2, Table 2-3, Table 2-4, for Clear Boggy and Muddy Boggy Basins.

***Table 2-1.** Clear Boggy and Muddy Boggy: Data used in the water balance*

<table>
<tr><th colspan="2">COMPONENT</th><th>CLEAR BOGGY BASIN</th><th>MUDDY BOGGY BASIN</th></tr>
<tr><td rowspan="2">PRECIPITATION</td><td>Station</td><td colspan="2">NEXRAD radar and the following Mesonet stations: Centrahoma, Tishomingo, Sulphur, Ada, Ardmore, Lane, Madill, Newport, and Pauls Valley</td></tr>
<tr><td>Period of records</td><td>Jan1994 - Dec2005</td><td>Jan1994 - Dec2005</td></tr>
<tr><td rowspan="2">RUNOFF</td><td>Station</td><td>Clear Boggy near Caney
(USGS 07335000)</td><td>Muddy Boggy near Farris
(USGS 07334000)
Muddy Boggy near Unger
(USGS 07335300)</td></tr>
<tr><td>Period of records</td><td>Jan1978 - Dec1988</td><td>Jan1994 - Dec2006</td></tr>
<tr><td rowspan="2">BASEFLOW</td><td>Station</td><td>Clear Boggy near Caney</td><td>Muddy Boggy near Farris
Muddy Boggy near Unger</td></tr>
<tr><td>Period of records</td><td>1978-1988</td><td>1994-2006</td></tr>
<tr><td rowspan="2">POTENTIAL ET</td><td>Station</td><td>Centrahoma (Mesonet #25)</td><td>Lane (Mesonet #56)</td></tr>
<tr><td>Period of records</td><td>1994-2005</td><td>1994-2005</td></tr>
</table>

Table2-2. *Water Balance for Clear Boggy near Caney (1978-1988)*

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	In	2.14	2.51	3.24	3.67	3.44	3.31	1.88	2.81	2.87	4.09	2.79	3.00	**35.75**
	Ac-ft	82,176	96,384	124,416	140,928	132,096	127,104	72,192	107,904	110,208	157,056	107,136	115,200	**1,372,800**
R	In	0.16	0.49	0.87	0.58	1.11	0.65	0.10	0.04	0.07	0.93	0.25	0.25	**5.50**
	Ac-ft	6,319	18,851	33,303	22,167	42,659	24,925	3,875	1,361	2,828	35,852	9,565	9,495	**211,200**
Gw	In	0.23	0.33	0.51	0.41	0.44	0.46	0.10	0.04	0.04	0.25	0.26	0.23	**3.30**
	Ac-ft	9,007	12,742	19,514	15,744	16,721	17,839	3,735	1,501	1,571	9,425	9,844	8,972	**126,615**
aET	In	1.74	1.69	1.86	2.68	1.89	2.20	1.68	2.74	2.76	2.91	2.28	2.52	**26.95**
	Ac-ft	66,851	64,791	71,599	103,017	72,716	84,340	64,582	105,041	105,809	111,779	87,727	96,733	**1,034,985**

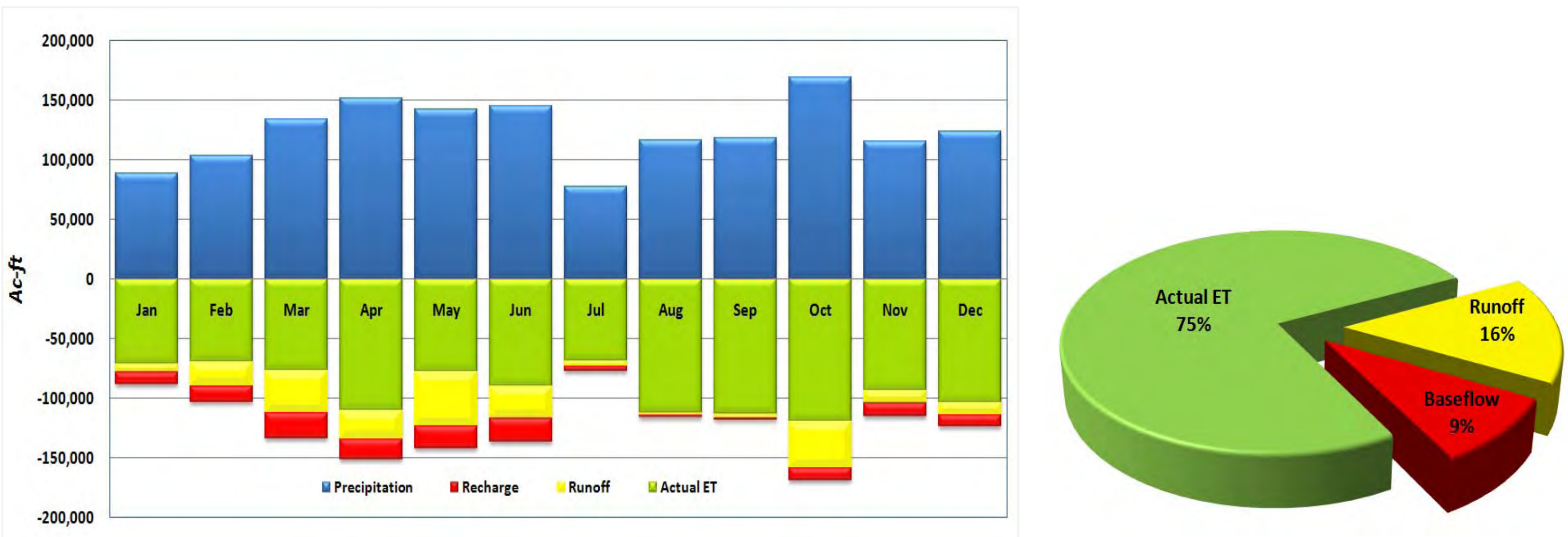


Figure 17. *Water Balance at Clear Boggy near Caney as a climatological budget (left) and components percentages of precipitation (right)*

Table 2-3. *Water Balance for Muddy Boggy near Farris (1994-2006)*

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	in	2.14	2.51	3.24	3.67	3.44	3.31	1.88	2.81	2.87	4.09	2.79	3.00	35.75
	Ac-ft	123,492	144,844	186,970	211,783	198,511	191,009	108,489	162,156	165,618	236,020	161,002	173,120	2,063,013
R	in	0.70	0.60	1.01	0.99	0.78	0.16	0.16	0.09	0.10	0.18	0.71	0.64	6.12
	Ac-ft	40,173	34,358	58,195	57,396	45,144	9,277	9,411	5,060	6,037	10,298	40,972	36,755	353,076
Gw	in	0.31	0.30	0.51	0.44	0.29	0.12	0.05	0.03	0.03	0.05	0.29	0.25	2.66
	Ac-ft	17,933	17,179	29,164	25,125	16,912	6,836	2,663	1,864	1,909	2,619	16,513	14,560	153,278
aET	in	1.13	1.62	1.73	2.24	2.36	3.03	1.67	2.69	2.73	3.87	1.79	2.11	26.98
	Ac-ft	65,386	93,307	99,611	129,263	136,454	174,896	96,415	155,231	157,672	223,103	103,517	121,805	1,556,660

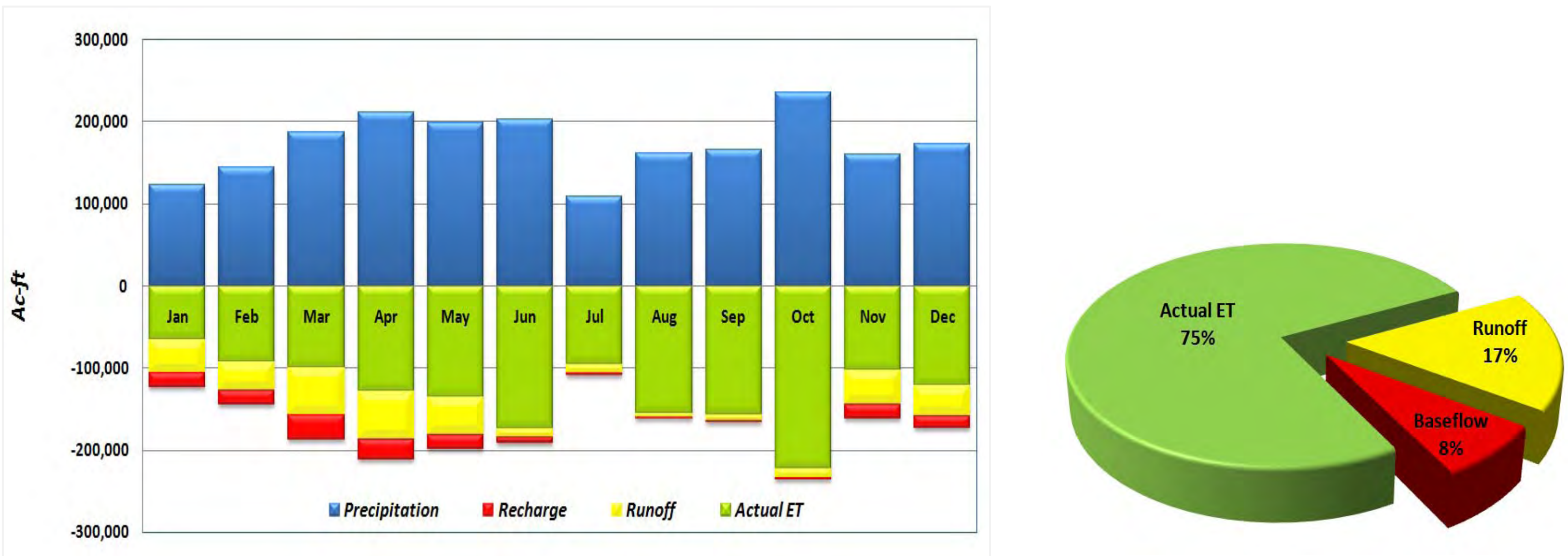


Figure 18. *Water Balance at Muddy Boggy near Farris (left), and climatological components expressed as a percentage of precipitation (right)*

__Table 2-4.__ Water Balance for Muddy Boggy near Unger (1994-2006)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	in	2.14	2.51	3.24	3.67	3.44	3.31	1.88	2.81	2.87	4.09	2.79	3.00	35.75
	Ac-ft	265,610	311,533	402,138	455,509	426,962	410,827	233,340	348,768	356,215	507,638	346,286	372,350	4,437,176
R	in	0.62	0.56	1.00	0.82	0.84	0.30	0.13	0.10	0.12	0.23	0.68	0.62	6.02
	Ac-ft	77,048	69,410	124,117	101,680	104,449	37,712	15,753	12,507	15,276	28,929	83,922	76,952	747,756
Gw	in	0.39	0.33	0.56	0.51	0.35	0.18	0.08	0.04	0.05	0.07	0.33	0.35	3.24
	Ac-ft	47,833	40,672	69,601	62,918	43,823	22,723	10,120	5,538	6,397	8,306	40,863	43,250	402,043
aET	in	1.13	1.62	1.68	2.34	2.25	2.82	1.67	2.66	2.70	3.79	1.78	2.03	26.49
	Ac-ft	140,729	201,451	208,421	290,911	278,690	350,391	207,466	330,724	334,543	470,403	221,501	252,148	3,287,377

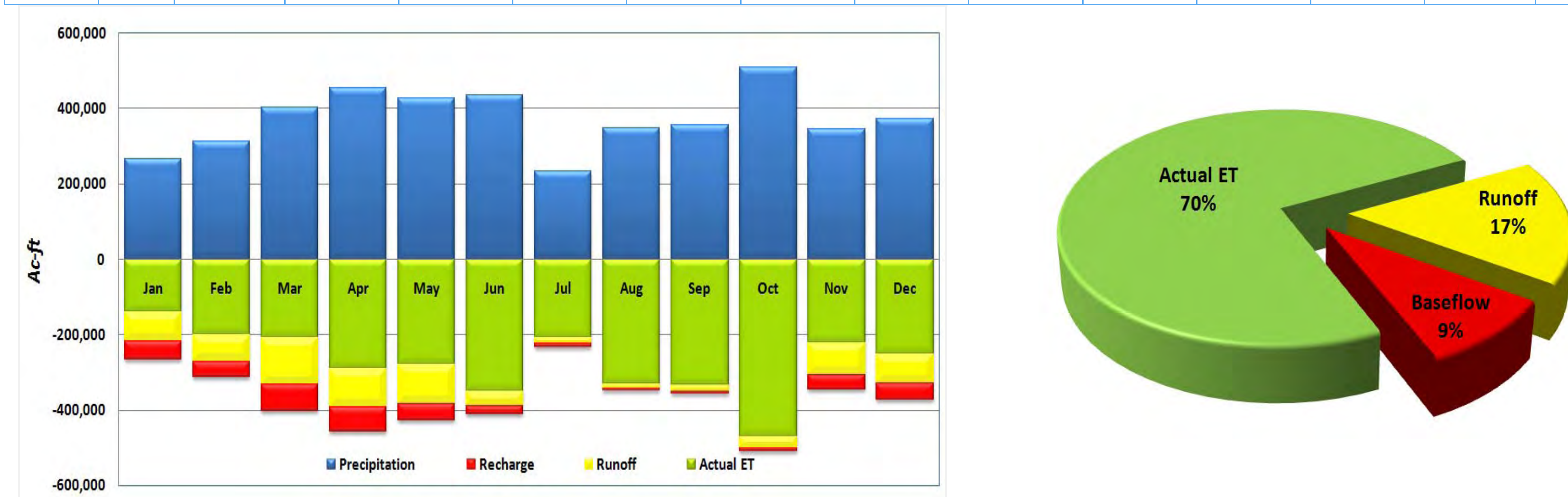


***Figure 19.** Water Balance at Muddy Boggy near Unger (left), and climatological components expressed as a percentage of precipitation (right)*

DISTRIBUTED HYDROLOGIC MODEL FOR CLEAR BOGGY AND MUDDY BOGGY BASINS

A distributed hydrologic model is constructed for the Clear Boggy and Muddy Boggy basins in order to extend the streamflow record and to derive the climatological distribution of surface water components. The model is assembled at a 500-m resolution, through GIS processing of geospatial data to derive hydrologic parameter maps that are subsequently used in *Vflo™*. Processing consisted of using a 10m resolution Digital Elevation Model to derive slope, flow direction, flow accumulation, stream definition and channel width maps. Figure 20 shows parameter maps of roughness, hydraulic conductivity, effective porosity and wetting front suction, which are obtained using reclassification values for land use and soils datasets, according to Vieux (2004), and imported into *Vflo™* as basis of the model.

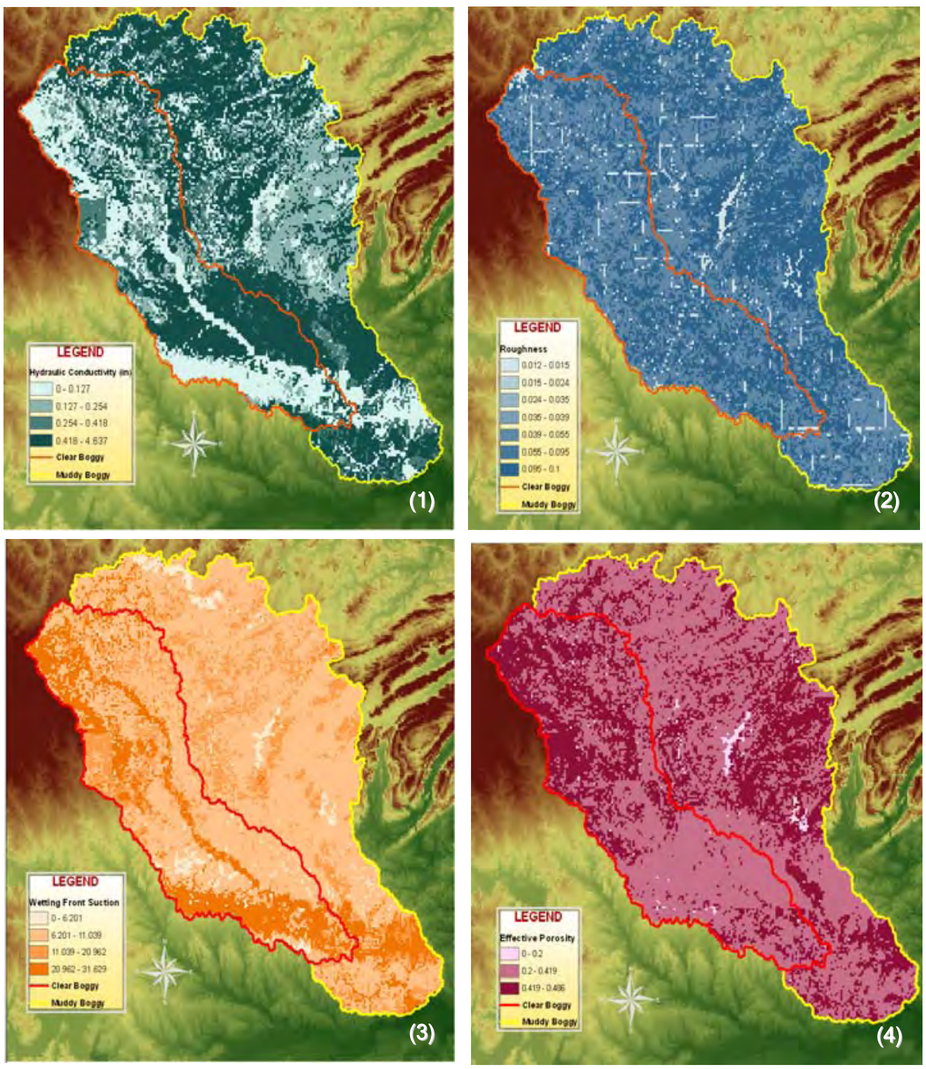


Figure 20. *Distributed parameter maps:* ***(1)*** *Hydraulic Roughness,* ***(2)*** *Hydraulic conductivity,* ***(3)*** *Effective Porosity, and* ***(4)*** *Wetting front suction.*

The distributed hydrologic model is calibrated by adjusting the parameters hydraulic conductivity and soil depth to bring continuously simulated discharge into agreement with observed. The calibrated model is then used to estimate direct runoff at gauged and ungauged interior locations. Figure 21 shows the interface of the 500-m resolution model, in which the USGS station Byrds Mill Spring near Fittstown is shown. However, because discharge from this spring does not flow to the stream network, it is not considered in the water balance.

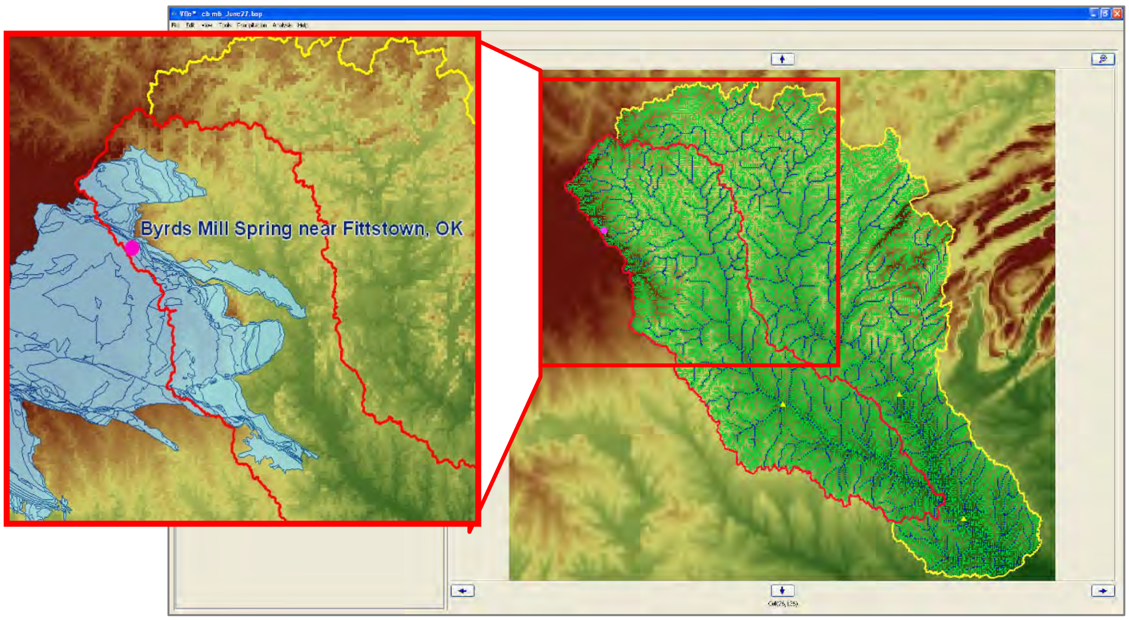


Figure 21. *Distributed Hydrologic Model for Clear Boggy and Muddy Boggy basins.* ***(a)*** *Interface of the 500-m resolution model*

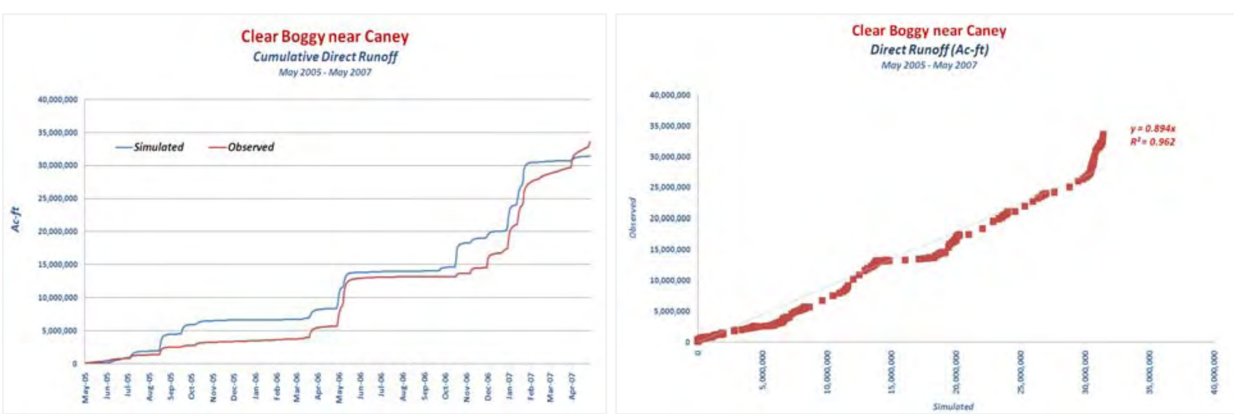


Figure 22*. Cumulative runoff volume of the calibrated model near Caney.*

The timeseries shows generally good agreement in temporal coherence and ending volume during the study period. During periods of runoff the model sometimes overestimates the cumulative volume. When the simulated volume is plotted against observed volume, the temporal evolution shows a linear relationship with a slope of 0.89 over the study period. The year with the lowest monthly baseflow in Clear Boggy was 1980, when baseflow during August was negligible, and amounted to 24,774 ac-ft for that year. For Muddy Boggy, the lowest baseflow occurs in August 2006 with 1,154 ac-ft, which accounted for a total of 35,201 ac-ft. The year with the highest monthly baseflow in Clear Boggy was 1985, when baseflow during April was 80,516 ac-ft, and amounted to 338,579ac-ft for that year. For Muddy Boggy, the highest baseflow occurs in January 1998 with 123,492 ac-ft that accounted for a total of 241,791 ac-ft. Drawing conclusions from the water budget at both stations Caney (Table 2-2) and Farris (Table 2-3), streamflow amounts to 24% of precipitation on an annual average basis. The average annual streamflow volume during the study period ranges from 3,078 ac-ft to 63,850 ac-ft at Caney, and from 6,925 ac-ft to 87,359ac-ft at Farris.

SUMMARY AND CONCLUSIONS

The water budget for Clear Boggy and Muddy Boggy basins is established from a combination of data analysis and hydrologic modeling to extend observed components. For the period 1994-2006, the annual streamflow averages 363,241 ac-ft at the station Clear Boggy near Caney, and 506,354 ac-ft at Muddy boggy near Farris. Annual baseflow at Clear boggy near Caney derived from hydrograph separation for the study period reveals that direct runoff averages 227,096 ac-ft, with baseflow averaging 136,145 ac-ft, whereas at Muddy Boggy near Farris runoff and baseflow average 353,076 ac-ft and 153,276 ac-ft, respectively. The lowest monthly baseflow occurs in August at both gauging stations, being 1,614 ac-ft per month at Caney and 1,864 ac-ft per month at Farris. The watershed yield is 470 and 494 ac-ft/mi^2 for the Clear Boggy near Caney, and Muddy Boggy near Unger, respectively.

REFERENCES

1. ASCE, 1993. "Criteria for evaluation of watershed models". Task Committee on Definition of Criteria for Evaluation of Watershed Models of the Watershed Management, Irrigation, and Drainage Division. American Society of Civil Engineering, *J. Irrig. Drain. Eng.*, 119:3, 429–442
2. Burke, E., 2003. "The Arbuckle-Simpson Hydrology study, Management and protection of an Oklahoma Water Resource", The Oklahoma Water Resources Board (OWRB).
3. Bedient, P.B., Huber, W.C., Vieux, B.E., 2007. *Hydrology and Floodplain Analysis*. Fourth Edition, Prentice Hall Inc, Upper Saddle River. ISBN-0131745891
4. Calderon, C.E., 2006. "Spatio-temporal variability of evapotranspiration rates and its effect on distributed hydrologic modeling of a regional water balance"
5. Fairchild, R.W., Hanson, R.L., Davis, R.E., 1990. "Hydrology of the Arbuckle Mountains Area, South Central Oklahoma", Circular 91, Oklahoma Geological Survey –OGS, 112 pages.
6. Menzel, R.G., Schiebe F. R. and McHenry J. R., 1985. *Sediment Properties and Deposition in Lake Atoka, Oklahoma.* USDA-ARS Water Quality and Watershed Research Laboratory. *Proceedings Oklahoma Academy of Sciences. 65:45* Available on Internet at: http://oklahoma.sierraclub.org/cimarron/conservation/LakeAtoka%5CUSDA-ARS.pdf
7. Neel, C. R., 2007. *Arbuckle Simpson Study: Subsurface Watershed Delineation Procedure and Summary.* OWRB, pp. 6.
8. U.S Department of Interior and OWRB, 1991. "Hydrologic Investigation of the Blue River Basin, Oklahoma"
9. OWRB, 2007. Arbuckle-Simpson Hydrology Study Newsletter. March. Available online: http://www.owrb.ok.gov/studies/groundwater/arbuckle_simpson/pdf/arbuckle_newsletter_0307.pdf
10. OWRB, 2003. The Arbuckle-Simpson Hydrology study Management and protection of an Oklahoma Water Resource, The Oklahoma Water Resources Board.
11. Rutledge, A.T., 2007. "Program User Guide for PART," U.S. Geological Survey – Water resources application software. Software is available at http://water.usgs.gov/ogw/part
12. Rutledge, A.T., 1998. "Computer Programs for describing the Recession of Ground-Water Discharge and for Estimating Mean Ground-Water Recharge and Discharge from Streamflow Records-Update". U.S. Geological Survey, Water-Resources Investigations Report 98-4148.
13. Scanlon, B.R., Tachovsky, J.A., Reedy, R., Nicot, J.P., Keese, K. and Slade, R.M., 2005. "Groundwater-Surface Water Interactions in Texas". Implications for Water Resources and Contaminant Transport (TCEQ). Bureau of Economic Geology, the University of Texas at Austin, 240 pages.
14. USDA, 1991. "State Soil Geographic (STATSGO) Data Base", National Cartography and GIS Center, U.S. Department of Agriculture, Natural Resources and Conservation Service
15. USBR, 2007. *McGee Creek Dam project.* United States Department of Interior, Bureau of reclamation. Available on Internet.
16. Vieux, B.E., 2004. *Distributed Hydrologic Modeling using GIS.* Second Edition, Kluwer Academic Publishers. ISBN-978-1-4020-2459-7.

DATA SOURCES

- **OKLAHOMA CLIMATOLOGICAL SURVEY (OCS), 2007a.** *Proper Siting of Mesonet Stations.* http://www.mesonet.org/
- **OKLAHOMA CLIMATOLOGICAL SURVEY (OCS), 2007b.** *Monthly Rainfall Statistics.* http://climate.mesonet.org/monthly_summary.html
- **MESONET, 2007.** *Shapefile: Oklahoma Mesonet stations.* http://okmesonet.ocs.ou.edu/sites/
- **MESONET, 2001.** *Product Catalog: products from The Oklahoma Mesonet.* Oklahoma State University and The University of Oklahoma. http://www.mesonet.ou.edu/mesonet_catalog_lr.pdf
- **USGS, 2007.** *Daily data and monthly statistics.* United States Geological Survey, National Water Information System. http://nwis.waterdata.usgs.gov/usa/nwis/
- **USGS, 1994.** *Hydrologic Units Maps.* United States Geological Survey Water-Supply, Paper 2294. Available on Internet at http://pubs.usgs.gov/wsp/wsp2294/pdf/wsp_2294_c.pdf
- **USDA 2007.** *Digital Ortho Quad TerraServer.* Retrieved 03/08/07 by request on ftp://gateway1.ftw.nrcs.usda.gov/Gateway/427822/orthoimagery_MDOQAPFO_427822_01/ortho_imagery
- **USDA, Soil Survey Staff, Natural Resources Conservation Service.** *U.S. General Soil Map (STATSGO) for State.* Available on http://datagateway.nrcs.usda.gov/GatewayHome.html .
- **The Seamless Data Distribution System (SDDS).** *National Elevation Dataset (NED).* http://seamless.usgs.gov/

III. APPENDICES

APPENDIX 1: ANNUAL WATER BALANCES FOR THE STATION BLUE RIVER NEAR CONNERVILLE

Baseflow values are estimated over the Subsurface Watershed Area of 79mi^2
Other surface components are estimated over the surface drainage area, 162mi^2

CONNERVILLE 2004													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	15,279	26,906	24,186	27,199	16,514	46,625	56,381	17,183	12,739	51,969	44,966	9,874	**349,820**
R	243	397	746	104	76	232	762	60	71	1,707	4,864	657	**9,920**
Gw	2,859	3,054	3,590	2,944	2,692	2,384	2,570	2,346	1,998	2,599	5,503	6,123	**38,662**
aET	12,177	23,455	19,850	24,151	13,746	44,008	53,048	14,777	10,671	47,663	34,598	3,095	**301,239**

CONNERVILLE 2005													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	48,944	15,575	7,120	7,193	29,731	30,456	40,534	54,439	26,286	29,507	8,530	2,654	**300,970**
R	13,349	1,020	277	121	282	709	614	475	625	248	122	123	**17,966**
Gw	10,062	7,682	6,720	4,790	3,596	3,268	2,881	2,611	2,039	2,316	2,049	2,142	**50,156**
aET	25,533	6,873	123	2,282	25,853	26,480	37,039	51,353	23,622	26,943	6,359	388	**232,847**

CONNERVILLE 2006													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	13,032	2,018	38,199	43,461	25,644	13,762	6,704	7,822	21,435	48,658	28,651	29,548	**278,936**
R	119	85	890	1,284	2,634	163	60	84	91	596	513	918	**7,437**
Gw	1,913	1,665	2,581	3,238	4,256	2,960	2,149	1,724	1,530	1,393	1,532	2,290	**27,231**
aET	11,000	269	34,728	38,939	18,754	10,638	4,495	6,014	19,814	46,670	26,606	26,340	**244,267**

APPENDIX 2: ANNUAL WATER BALANCES FOR THE STATION BLUE RIVER NEAR BLUE

Baseflow values are estimated over the Subsurface Watershed Area of 393mi^2.
Other components are estimated over the surface drainage area, 472mi^2.

BLUE RIVER NEAR BLUE, 1994													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	41,788	67,842	88,509	130,448	148,774	48,433	173,897	81,033	99,460	131,531	105,652	51,404	**1,168,773**
R	3,543	14,857	27,528	29,891	75,985	4,378	5,537	2,864	3,751	6,791	52,958	26,424	**254,508**
Gw	9,213	8,761	16,356	8,211	17,605	11,168	6,546	4,396	4,042	5,061	14,836	20,328	**126,522**
aET	29,031	44,224	44,625	92,346	55,184	32,887	161,815	73,773	91,667	119,679	37,858	4,652	**787,742**

BLUE RIVER NEAR BLUE, 1995													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	48,987	3,046	112,978	27,503	211,380	109,504	91,178	17,193	130,423	27,414	20,265	62,757	**962,628**
R	4,911	2,355	45,692	48,222	111,846	30,925	4,166	1,150	9,531	1,343	1,276	3,055	**264,471**
Gw	20,328	11,715	18,068	23,900	28,923	20,769	8,378	5,279	4,227	3,934	3,244	3,810	**152,576**
aET	23,749	11,024	49,218	55,381	70,612	57,810	78,633	10,764	116,665	22,137	15,744	55,892	**567,629**

BLUE RIVER NEAR BLUE, 1996													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	40,579	6,520	74,261	99,359	17,118	114,539	149,102	189,253	161,789	153,482	230,839	16,438	**1,253,280**
R	3,117	757	6,177	23,362	1,106	4,590	3,860	17,293	22,226	61,354	103,688	8,900	**256,431**
Gw	4,643	2,733	2,908	6,992	5,176	3,320	2,457	3,330	6,252	7,664	25,809	22,775	**94,060**
aET	32,820	3,030	65,176	69,005	10,836	106,629	142,784	168,630	133,311	84,464	101,342	15,237	**933,263**

BLUE RIVER NEAR BLUE, 1997													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	16,312	159,725	51,530	154,338	139,964	84,910	45,589	75,872	26,331	123,752	63,437	154,313	**1,096,072**
R	3,538	48,394	12,236	26,624	9,846	8,496	1,591	833	393	969	1,255	25,873	**140,049**
Gw	12,738	15,654	17,521	17,022	13,331	8,821	4,212	2,797	1,735	2,178	2,225	5,376	**103,610**
aET	36	95,677	21,773	110,692	116,786	67,593	39,786	72,242	24,203	120,605	59,957	123,063	**852,413**

BLUE RIVER NEAR BLUE, 1998													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	162,670	42,014	150,889	45,539	25,400	61,498	7,527	43,348	57,420	134,249	82,065	103,714	**916,335**
R	76,584	6,321	63,693	5,472	1,748	2,614	473	421	485	2,435	2,130	8,200	**170,576**
Gw	18,673	13,941	22,199	15,130	7,376	4,286	2,029	1,081	863	1,761	2,700	4,478	**94,516**
aET	67,414	21,753	64,997	24,937	16,276	54,598	5,025	41,846	56,072	130,053	77,235	91,036	**651,242**

BLUE RIVER NEAR BLUE, 1999													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	53,166	9,012	107,213	105,804	152,273	116,452	48,660	55,507	116,452	75,646	17,546	97,320	**955,051**
R	3,635	1,635	6,433	20,573	11,047	6,296	2,845	671	2,421	946	864	2,902	**60,268**
Gw	6,877	5,525	12,844	33,932	20,202	13,287	7,662	3,347	5,330	3,168	3,006	5,608	**120,788**
aET	42,654	1,852	87,936	51,299	121,025	96,869	38,153	51,489	108,701	71,532	13,676	88,810	**773,995**

BLUE RIVER NEAR BLUE, YEAR: 2000													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	54,299	39,900	80,681	77,307	67,892	153,180	38,792	503	36,250	162,821	162,292	110,637	**984,554**
R	1,134	2,561	3,167	2,907	3,825	1,754	634	85	58	6,803	29,502	47,070	**99,499**
Gw	2,632	2,750	4,838	4,572	4,311	2,876	1,151	317	153	1,137	7,567	8,106	**40,410**
aET	50,533	34,589	72,675	69,828	59,756	148,550	37,007	101	36,038	154,881	125,223	55,461	**844,645**

BLUE RIVER NEAR BLUE, 2001													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	71,845	151,241	-	61,373	89,441	28,144	6,067	70,460	129,542	68,673	24,645	17,118	**718,548**
R	27,457	107,354	22,411	32,264	11,127	1,760	1,434	693	30,018	32,074	1,149	38,450	**306,191**
Gw	14,894	22,100	23,908	14,055	10,268	6,024	3,708	1,640	3,912	6,554	4,800	8,428	**120,289**
aET	29,494	21,787	46,319	15,054	68,046	20,360	925	68,127	95,613	30,045	18,696	29,761	**444,226**

BLUE RIVER NEAR BLUE, 2002													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	58,176	29,100	143,186	161,437	65,853	92,764	86,445	160,178	90,700	136,137	22,857	117,711	**1,164,544**
R	5,574	12,038	76,140	113,415	5,083	6,749	2,692	26,266	5,248	8,541	2,850	22,173	**286,770**
Gw	7,339	8,233	10,967	22,360	12,213	8,599	5,170	4,878	4,445	5,503	7,149	9,716	**106,571**
aET	45,262	8,829	56,080	25,662	48,558	77,415	78,583	129,034	81,007	122,093	12,858	85,821	**771,202**

BLUE RIVER NEAR BLUE, 2003													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	14,601	62,984	33,606	24,217	99,359	154,564	13,241	77,861	151,191	11,454	82,921	29,176	**755,175**
R	3,953	5,766	5,590	1,268	3,012	21,929	376	474	4,154	536	1,390	616	**49,064**
Gw	10,412	8,228	9,468	4,870	3,920	4,302	1,681	866	2,287	1,785	2,042	1,897	**51,760**
aET	235	48,990	18,548	18,078	92,428	128,333	11,185	76,521	144,750	9,133	79,489	26,662	**654,351**

BLUE RIVER NEAR BLUE, 2004													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	50,800	66,156	44,859	109,378	52,461	196,604	90,246	60,391	38,968	137,648	154,413	20,516	**1,022,440**
R	6,326	4,171	7,378	19,264	3,841	5,816	4,727	719	628	2,778	55,423	7,408	**118,479**
Gw	2,731	4,260	6,957	5,268	4,221	3,319	3,059	1,538	1,129	2,249	9,808	12,104	**56,643**
aET	41,743	57,724	30,524	84,846	44,399	187,468	82,460	58,134	37,212	132,621	89,182	1,005	**847,319**

BLUE RIVER NEAR BLUE, 2005													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	111,316	48,182	36,149	35,369	73,254	64,066	135,684	81,511	54,676	69,554	3,071	7,049	**719,882**
R	48,609	8,799	3,880	5,310	2,066	2,824	5,332	1,138	1,220	658	538	384	**80,757**
Gw	17,500	13,700	9,581	6,682	3,754	3,332	3,330	2,009	1,770	1,768	1,936	1,321	**66,681**
aET	45,207	25,683	22,688	23,376	67,434	57,911	127,022	78,364	51,687	67,128	598	5,344	**572,444**

BLUE RIVER NEAR BLUE, 2006													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	59,616	54,661	72,199	95,316	93,095	96,240	69,393	73,611	90,073	104,860	82,743	67,844	**959,651**
R	14,559	16,582	22,456	26,801	19,206	7,587	2,606	4,051	6,192	9,776	20,681	16,107	**166,605**
Gw	9,939	9,166	12,183	12,743	10,662	7,117	3,873	2,432	2,799	3,376	6,752	8,273	**89,315**
aET	35,118	28,912	37,560	55,772	63,227	81,535	62,914	67,127	81,082	91,708	55,310	43,464	**703,731**

APPENDIX 3: LONG-TERM BASEFLOW AT BLUE RIVER NEAR BLUE AND BLUE RIVER NEAR CONNERVILLE OBTAINED WITH THE PART PROGRAM.

Baseflow Blue River near Blue (cfs)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1994	9,199	8,572	16,098	7,735	17,143	11,081	6,481	4,390	3,972	5,018	14,426	20,070
1995	15,471	11,708	17,980	23,625	28,433	20,279	8,363	5,227	4,181	3,972	3,136	3,763
1996	4,599	2,718	2,927	6,899	5,227	3,345	2,300	3,136	5,645	7,526	23,625	22,370
1997	12,753	15,262	17,143	16,098	12,962	8,781	4,181	2,718	1,673	2,091	2,300	5,436
1998	18,398	13,798	21,952	15,053	7,317	4,181	2,091	1,045	836	1,673	2,718	4,390
1999	3,136	3,763	6,272	13,171	8,990	6,690	4,809	2,718	2,927	2,300	2,091	2,718
2000	2,509	2,718	4,599	4,599	4,181	2,718	1,045	418	209	1,045	7,108	7,945
2001	14,635	21,534	23,625	13,798	10,244	6,063	3,763	1,673	3,972	6,481	4,809	8,363
2002	7,526	7,945	10,871	22,161	12,126	8,363	5,018	4,809	4,390	5,227	6,899	9,408
2003	10,244	8,154	9,408	4,809	3,763	4,181	1,673	836	2,300	1,882	2,091	1,882
2004	2,718	4,181	6,899	5,227	4,181	3,136	3,136	1,463	1,045	2,300	9,617	11,917
2005	17,562	13,589	9,408	6,690	3,763	3,345	3,345	1,882	1,673	1,673	1,882	1,254
2006	1,254	1,463	2,718	2,718	7,108	2,509	1,045	209	209	1,045	2,718	4,390
Baseflow Blue River near Connerville (cfs)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1,994	7,211	6,719	12,618	6,063	13,438	8,685	5,080	3,441	3,114	3,933	11,307	15,732
1,995	12,127	9,177	14,093	18,518	22,287	15,896	6,555	4,097	3,278	3,114	2,458	2,950
1,996	3,605	2,130	2,294	5,408	4,097	2,622	1,803	2,458	4,425	5,900	18,518	17,535
1,997	9,996	11,963	13,438	12,618	10,160	6,883	3,278	2,130	1,311	1,639	1,803	4,261
1,998	14,421	10,816	17,207	11,799	5,736	3,278	1,639	819	656	1,311	2,130	3,441
1,999	2,458	2,950	4,916	10,324	7,047	5,244	3,769	2,130	2,294	1,803	1,639	2,130
2,000	1,967	2,130	3,605	3,605	3,278	2,130	819	328	164	819	5,572	6,227
2,001	11,471	16,879	18,518	10,816	8,030	4,752	2,950	1,311	3,114	5,080	3,769	6,555
2,002	5,900	6,227	8,522	17,371	9,505	6,555	3,933	3,769	3,441	4,097	5,408	7,374
2,003	8,030	6,391	7,374	3,769	2,950	3,278	1,311	656	1,803	2,444	2,949	3,244
2,004	2,865	3,076	3,623	2,949	2,697	2,402	2,612	2,359	2,022	2,612	5,688	6,194
2,005	2,654	7,795	6,783	4,803	3,623	3,371	2,907	2,612	2,065	2,317	2,065	2,191
2,006	1,938	1,685	2,654	3,286	4,298	2,949	2,149	1,727	1,559	1,433	1,559	2,359

Baseflow at Connerville from Jan1994-Sep2003 is obtained synthetically as described in section 2

APPENDIX 4: RECONSTRUCTED STREAMFLOW AT BLUE RIVER NEAR CONNERVILLE (CFS)

Streamflow is obtained by addition of runoff (Vflo™) and synthetic baseflow for the period 1994-2003. Observed streamflow from records at this gauging station are presented for the period 2003-2006

Blue River near Connerville: Monthly Reconstructed Streamflow (cfs)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1994	7,460	6,955	17,159	6,300	14,140	8,996	5,276	3,563	3,276	4,075	12,353	16,390	**105,944**
1995	12,550	9,500	14,936	19,169	24,727	18,833	6,786	4,239	3,404	3,233	2,544	3,052	**122,974**
1996	3,730	2,204	2,374	5,651	4,254	2,713	1,880	2,560	4,813	6,214	20,737	18,642	**75,773**
1997	10,344	17,082	14,123	13,257	10,562	7,155	3,392	2,259	1,363	1,698	1,867	4,640	**87,744**
1998	20,197	11,940	29,979	12,218	5,935	3,443	1,698	848	678	1,411	2,219	3,756	**94,323**
1999	2,595	3,118	5,279	11,045	7,367	5,911	3,938	2,205	2,912	1,869	1,696	2,204	**50,140**
2000	2,035	2,204	3,735	3,730	3,391	2,205	848	339	170	1,306	8,607	15,215	**43,785**
2001	21,047	32,085	20,394	11,192	8,308	4,917	3,052	1,356	3,222	5,277	3,903	6,782	**121,536**
2002	6,104	6,443	8,817	18,189	9,839	6,785	4,071	4,033	3,565	4,239	5,595	7,649	**85,330**
2003	8,413	6,614	7,630	3,900	3,052	3,391	1,356	678	1,936	2,530	3,052	3,357	**45,909**
2004	2,964	3,205	3,980	3,053	2,790	2,521	2,837	2,444	2,093	2,872	7,441	7,026	**43,226**
2005	13,558	8,757	7,022	4,970	3,749	3,501	3,111	3,070	2,231	2,413	2,136	2,267	**56,785**
2006	2,005	1,744	2,814	3,519	5,076	3,054	2,223	1,787	1,613	1,915	1,624	1,830	**9,203**

BLUE RIVER NEAR CONNERVILLE: DAILY RECONSTRUCTED STREAMFLOW (CFS)

Time	Baseflow	Runoff	Streamflow
2-Jan-94	116.7	0.0	116.7
3-Jan-94	116.7	0.0	116.7
4-Jan-94	116.7	0.0	116.7
5-Jan-94	116.7	0.0	116.7
6-Jan-94	116.7	0.0	116.7
7-Jan-94	116.7	0.0	116.7
8-Jan-94	113.7	0.0	113.7
9-Jan-94	111.3	0.0	111.3
10-Jan-94	109.0	0.0	109.0
11-Jan-94	109.0	0.0	109.0
12-Jan-94	109.0	0.0	109.0
13-Jan-94	109.0	0.0	109.0
14-Jan-94	109.0	0.0	109.0
15-Jan-94	109.0	0.0	109.0
16-Jan-94	109.0	0.0	109.0
17-Jan-94	109.0	0.0	109.0
18-Jan-94	110.5	0.0	110.5
19-Jan-94	112.0	0.0	112.0
20-Jan-94	113.6	0.0	113.6
21-Jan-94	115.1	0.0	115.1
22-Jan-94	116.7	0.0	116.7
23-Jan-94	118.3	0.0	118.3
24-Jan-94	117.5	0.0	117.5
25-Jan-94	116.5	0.0	116.5
26-Jan-94	115.6	0.0	115.6
27-Jan-94	114.6	0.0	114.6
28-Jan-94	113.7	0.0	113.7
29-Jan-94	112.7	0.0	112.7
30-Jan-94	111.8	0.0	111.8
31-Jan-94	110.8	0.0	110.8
1-Feb-94	109.9	0.0	109.9
2-Feb-94	109.0	0.0	109.0
3-Feb-94	105.1	0.0	105.1
4-Feb-94	104.4	0.0	104.4
5-Feb-94	103.6	0.0	103.6
6-Feb-94	102.1	0.0	102.1
7-Feb-94	100.5	0.0	100.5
8-Feb-94	99.0	0.0	99.0
9-Feb-94	98.2	0.0	98.2
10-Feb-94	99.1	0.0	99.1
11-Feb-94	100.1	0.0	100.1
12-Feb-94	101.0	0.0	101.0
13-Feb-94	102.0	0.0	102.0
14-Feb-94	103.0	0.0	103.0
15-Feb-94	103.9	0.0	103.9
16-Feb-94	104.9	0.0	104.9
17-Feb-94	105.9	0.0	105.9
18-Feb-94	99.7	0.0	99.7
19-Feb-94	94.3	0.0	94.3
20-Feb-94	91.2	0.0	91.2
21-Feb-94	90.5	0.0	90.5
22-Feb-94	96.9	0.0	96.9
23-Feb-94	103.7	1.6	105.3
24-Feb-94	111.1	0.8	111.9
25-Feb-94	119.0	0.3	119.3
26-Feb-94	127.4	0.2	127.6
27-Feb-94	136.5	0.2	136.7
28-Feb-94	146.1	0.2	146.3
1-Mar-94	156.5	17.6	174.1
2-Mar-94	167.6	888.7	1,056.3
3-Mar-94	179.5	1,100.7	1,280.2
4-Mar-94	192.2	209.3	401.5
5-Mar-94	205.8	64.3	270.1
6-Mar-94	220.4	28.8	249.3
7-Mar-94	236.1	15.5	251.6
8-Mar-94	252.8	9.4	262.2
9-Mar-94	240.4	6.3	246.7
10-Mar-94	238.9	1,257.4	1,496.2

11-Mar-94	237.3	283.4	520.7
12-Mar-94	235.7	80.0	315.8
13-Mar-94	234.2	34.7	268.9
14-Mar-94	232.7	18.2	250.8
15-Mar-94	231.1	10.8	242.0
16-Mar-94	229.6	7.0	236.6
17-Mar-94	208.0	4.8	212.8
18-Mar-94	192.5	3.5	196.0
19-Mar-94	187.9	2.6	190.5
20-Mar-94	178.6	2.0	180.6
21-Mar-94	169.3	1.6	170.9
22-Mar-94	162.4	1.3	163.6
23-Mar-94	153.9	1.0	154.9
24-Mar-94	149.2	0.9	150.1
25-Mar-94	148.4	0.7	149.2
26-Mar-94	147.7	0.6	148.3
27-Mar-94	143.8	0.5	144.3
28-Mar-94	140.7	0.4	141.2
29-Mar-94	139.9	0.4	140.3
30-Mar-94	134.5	0.3	134.9
31-Mar-94	127.6	0.3	127.9
1-Apr-94	124.5	0.3	124.7
2-Apr-94	122.2	0.2	122.4
3-Apr-94	122.2	0.2	122.4
4-Apr-94	121.4	0.2	121.6
5-Apr-94	119.1	0.2	119.3
6-Apr-94	113.7	0.2	113.8
7-Apr-94	111.1	0.1	111.2
8-Apr-94	108.5	0.1	108.6
9-Apr-94	106.0	0.1	106.2
10-Apr-94	103.6	0.1	103.7
11-Apr-94	103.6	0.1	103.7
12-Apr-94	103.6	0.1	103.7
13-Apr-94	100.1	0.1	100.2
14-Apr-94	96.7	0.1	96.8
15-Apr-94	93.4	0.1	93.5
16-Apr-94	90.3	0.1	90.4
17-Apr-94	87.2	0.1	87.3
18-Apr-94	84.3	0.1	84.3
19-Apr-94	82.0	0.1	82.0
20-Apr-94	78.1	0.1	78.2
21-Apr-94	77.4	0.1	77.5
22-Apr-94	76.8	0.1	76.8
23-Apr-94	76.1	0.0	76.2
24-Apr-94	75.5	0.0	75.5
25-Apr-94	74.9	0.0	74.9
26-Apr-94	74.2	0.0	74.3
27-Apr-94	82.5	0.0	82.6
28-Apr-94	91.8	0.0	91.8
29-Apr-94	102.1	0.0	102.1
30-Apr-94	113.5	8.0	121.5
1-May-94	126.2	15.4	141.6
2-May-94	140.4	2.0	142.4
3-May-94	156.1	31.6	187.7
4-May-94	173.6	61.3	235.0
5-May-94	193.1	47.7	240.8
6-May-94	214.7	25.2	240.0
7-May-94	238.8	13.3	252.1
8-May-94	265.6	10.3	275.9
9-May-94	295.3	6.5	301.8
10-May-94	274.5	4.4	278.8
11-May-94	261.6	3.1	264.7
12-May-94	249.4	2.3	251.7

13-May-94	237.8	1.8	239.5
14-May-94	226.7	1.4	228.1
15-May-94	216.1	1.1	217.2
16-May-94	206.0	0.9	206.9
17-May-94	196.3	0.8	197.1
18-May-94	187.2	0.6	187.8
19-May-94	178.4	0.5	179.0
20-May-94	170.1	0.5	170.5
21-May-94	159.3	0.4	159.7
22-May-94	152.3	0.3	152.7
23-May-94	145.4	0.3	145.6
24-May-94	140.7	0.3	141.0
25-May-94	135.3	0.2	135.5
26-May-94	141.2	0.2	141.4
27-May-94	147.3	0.2	147.5
28-May-94	153.7	0.2	153.8
29-May-94	160.3	0.2	160.5
30-May-94	167.3	0.2	167.4
31-May-94	174.5	0.1	174.6
1-Jun-94	182.1	0.2	182.2
2-Jun-94	189.9	0.4	190.3
3-Jun-94	198.2	0.5	198.6
4-Jun-94	206.8	0.4	207.1
5-Jun-94	215.7	0.2	215.9
6-Jun-94	200.2	0.2	200.4
7-Jun-94	184.8	0.9	185.7
8-Jun-94	172.4	1.1	173.5
9-Jun-94	163.9	0.9	164.8
10-Jun-94	156.9	0.7	157.7
11-Jun-94	152.5	0.6	153.1
12-Jun-94	148.2	0.5	148.7
13-Jun-94	144.0	0.4	144.5
14-Jun-94	140.0	0.4	140.4
15-Jun-94	136.0	0.3	136.4
16-Jun-94	132.2	0.3	132.5
17-Jun-94	128.6	0.2	128.9
18-Jun-94	125.1	0.2	125.3
19-Jun-94	121.7	0.2	121.9
20-Jun-94	118.4	0.2	118.6
21-Jun-94	115.2	0.1	115.3
22-Jun-94	112.9	0.1	113.0
23-Jun-94	108.2	0.1	108.4
24-Jun-94	105.9	0.1	106.0
25-Jun-94	105.9	0.1	106.0
26-Jun-94	105.1	0.1	105.3
27-Jun-94	96.6	0.1	96.7
28-Jun-94	93.6	0.1	93.6
29-Jun-94	91.2	0.1	91.3
30-Jun-94	88.9	0.1	89.0
1-Jul-94	86.8	0.1	86.9
2-Jul-94	84.7	0.1	84.8
3-Jul-94	82.7	0.1	82.8
4-Jul-94	80.8	0.1	80.8
5-Jul-94	78.9	0.1	78.9
6-Jul-94	77.3	0.1	77.4
7-Jul-94	78.0	0.1	78.1
8-Jul-94	78.7	0.1	78.7
9-Jul-94	79.4	0.1	79.4
10-Jul-94	80.1	0.0	80.1
11-Jul-94	80.8	2.1	82.9
12-Jul-94	81.5	1.4	82.9
13-Jul-94	82.2	0.3	82.4

14-Jul-94	82.9	2.4	85.3
15-Jul-94	83.6	2.1	85.7
16-Jul-94	84.4	1.6	86.0
17-Jul-94	85.1	1.2	86.3
18-Jul-94	85.8	0.9	86.7
19-Jul-94	86.6	0.7	87.3
20-Jul-94	79.6	0.7	80.3
21-Jul-94	75.8	0.8	76.6
22-Jul-94	73.4	0.8	74.3
23-Jul-94	72.5	0.7	73.2
24-Jul-94	71.6	0.6	72.2
25-Jul-94	70.6	0.5	71.1
26-Jul-94	69.7	0.4	70.1
27-Jul-94	68.8	0.4	69.2
28-Jul-94	68.8	0.3	69.1
29-Jul-94	67.3	0.3	67.5
30-Jul-94	63.4	0.3	63.6
31-Jul-94	63.4	0.2	63.6
1-Aug-94	62.6	0.2	62.8
2-Aug-94	61.8	0.2	62.0
3-Aug-94	61.0	0.2	61.2
4-Aug-94	60.3	0.2	60.5
5-Aug-94	59.5	0.2	59.7
6-Aug-94	59.4	0.1	59.6
7-Aug-94	59.4	0.1	59.5
8-Aug-94	59.3	0.1	59.4
9-Aug-94	59.2	0.1	59.3
10-Aug-94	59.1	0.1	59.2
11-Aug-94	59.0	0.1	59.1
12-Aug-94	58.9	0.1	59.0
13-Aug-94	58.8	0.1	58.9
14-Aug-94	58.8	0.1	58.8
15-Aug-94	56.4	0.1	56.5
16-Aug-94	55.7	0.1	55.7
17-Aug-94	55.7	0.1	55.7
18-Aug-94	54.9	0.1	54.9
19-Aug-94	52.6	0.0	52.6
20-Aug-94	51.8	0.0	51.8
21-Aug-94	51.2	0.0	51.3
22-Aug-94	50.7	0.0	50.7
23-Aug-94	50.1	0.0	50.1
24-Aug-94	49.6	0.0	49.6
25-Aug-94	49.0	0.0	49.0
26-Aug-94	48.5	0.0	48.5
27-Aug-94	47.9	0.0	48.0
28-Aug-94	45.6	0.0	45.6
29-Aug-94	44.8	0.0	44.9
30-Aug-94	43.3	0.0	43.3
31-Aug-94	42.5	0.0	42.5
1-Sep-94	42.7	0.0	42.7
2-Sep-94	42.9	0.0	42.9
3-Sep-94	43.1	0.0	43.1
4-Sep-94	43.3	0.0	43.3
5-Sep-94	43.5	0.0	43.5
6-Sep-94	43.7	0.0	43.7
7-Sep-94	43.9	0.0	43.9
8-Sep-94	44.0	0.0	44.0
9-Sep-94	44.2	0.0	44.2
10-Sep-94	44.4	0.0	44.4
11-Sep-94	44.6	0.0	44.6
12-Sep-94	44.8	0.0	44.8
13-Sep-94	45.0	2.5	47.5

14-Sep-94	45.2	3.2	48.4
15-Sep-94	45.4	2.1	47.5
16-Sep-94	45.6	1.5	47.1
17-Sep-94	46.4	26.1	72.5
18-Sep-94	48.6	9.0	57.5
19-Sep-94	50.8	3.0	53.8
20-Sep-94	53.2	1.3	54.6
21-Sep-94	55.7	0.7	56.5
22-Sep-94	58.3	0.5	58.8
23-Sep-94	61.1	0.3	61.4
24-Sep-94	59.5	0.3	59.8
25-Sep-94	58.8	0.2	59.0
26-Sep-94	55.7	0.2	55.9
27-Sep-94	54.1	0.7	54.8
28-Sep-94	51.8	0.8	52.7
29-Sep-94	51.8	0.7	52.5
30-Sep-94	50.3	0.6	50.8
1-Oct-94	50.3	0.5	50.7
2-Oct-94	49.5	0.4	49.9
3-Oct-94	48.7	0.4	49.1
4-Oct-94	48.7	0.3	49.0
5-Oct-94	47.2	0.3	47.4
6-Oct-94	46.4	0.2	46.6
7-Oct-94	45.6	0.2	45.8
8-Oct-94	46.2	0.2	46.4
9-Oct-94	46.7	0.2	46.9
10-Oct-94	47.3	0.1	47.4
11-Oct-94	47.9	0.1	48.0
12-Oct-94	48.5	0.1	48.6
13-Oct-94	49.1	0.1	49.2
14-Oct-94	49.7	0.1	49.8
15-Oct-94	50.3	0.1	50.3
16-Oct-94	50.3	0.1	50.3
17-Oct-94	50.3	0.1	50.3
18-Oct-94	51.0	0.1	51.1
19-Oct-94	52.6	0.1	52.7
20-Oct-94	54.6	0.1	54.7

21-Oct-94	56.7	0.1	56.8
22-Oct-94	58.9	0.1	59.0
23-Oct-94	61.1	0.1	61.2
24-Oct-94	63.5	0.1	63.6
25-Oct-94	65.9	0.1	66.0
26-Oct-94	68.5	0.3	68.8
27-Oct-94	71.1	0.6	71.8
28-Oct-94	73.9	0.3	74.1
29-Oct-94	76.7	0.1	76.8
30-Oct-94	79.7	0.1	79.7
31-Oct-94	82.7	0.1	82.8
1-Nov-94	75.8	0.1	75.9
2-Nov-94	70.4	0.1	70.4
3-Nov-94	68.8	0.1	68.9
4-Nov-94	68.8	0.1	68.9
5-Nov-94	68.8	0.0	68.9
6-Nov-94	72.9	1.1	74.0
7-Nov-94	77.3	0.7	78.0
8-Nov-94	81.9	3.1	85.0
9-Nov-94	86.8	2.7	89.5
10-Nov-94	92.0	9.5	101.5
11-Nov-94	97.5	6.3	103.9
12-Nov-94	103.4	6.1	109.4
13-Nov-94	109.6	3.4	113.0
14-Nov-94	116.1	1.7	117.9
15-Nov-94	123.1	112.1	235.2
16-Nov-94	130.5	82.5	213.0
17-Nov-94	138.3	26.4	164.7
18-Nov-94	146.6	16.9	163.5
19-Nov-94	155.3	10.2	165.5
20-Nov-94	164.7	6.5	171.1
21-Nov-94	174.5	92.6	267.1
22-Nov-94	185.0	123.0	307.9
23-Nov-94	196.0	68.7	264.7
24-Nov-94	207.8	31.1	238.9
25-Nov-94	220.2	15.9	236.1
26-Nov-94	233.4	9.3	242.7
27-Nov-94	247.4	6.0	253.4

28-Nov-94	242.8	4.1	246.9
29-Nov-94	229.1	3.0	232.1
30-Nov-94	216.2	2.2	218.4
1-Dec-94	204.0	1.7	205.7
2-Dec-94	192.5	1.4	193.9
3-Dec-94	186.3	1.1	187.4
4-Dec-94	185.6	0.9	186.4
5-Dec-94	185.6	0.8	186.3
6-Dec-94	184.8	0.6	185.4
7-Dec-94	178.6	0.5	179.1
8-Dec-94	174.0	0.4	174.4
9-Dec-94	191.4	1.4	192.8
10-Dec-94	210.7	20.9	231.6
11-Dec-94	231.9	14.1	246.0
12-Dec-94	255.2	10.6	265.8
13-Dec-94	280.9	12.6	293.5
14-Dec-94	309.1	10.5	319.6
15-Dec-94	340.2	7.3	347.5
16-Dec-94	328.8	5.0	333.9
17-Dec-94	317.9	3.5	321.4
18-Dec-94	307.3	2.6	309.9
19-Dec-94	297.0	2.0	299.0
20-Dec-94	287.1	1.6	288.7
21-Dec-94	277.5	1.4	278.9
22-Dec-94	268.3	2.5	270.8
23-Dec-94	251.3	1.9	253.1
24-Dec-94	236.6	1.4	237.9
25-Dec-94	226.5	1.0	227.6
26-Dec-94	219.6	0.8	220.4
27-Dec-94	214.2	0.6	214.8
28-Dec-94	210.3	0.5	210.8
29-Dec-94	209.5	0.5	210.0
30-Dec-94	209.5	0.4	209.9
31-Dec-94	207.2	0.3	207.5

Daily data for the period 1995-2006 can be accessed in the attached CD

APPENDIX 5: WATER BALANCES OVER THE BLUE RIVER SUBSURFACE WATERSHED

	Blue River near Connerville 2004 (inches)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	1.65	3.43	2.13	3.63	1.29	7.27	4.91	2.09	1.09	7.94	4.02	1.28	**40.73**
R	0.04	0.08	0.16	0.01	0.01	0.04	0.17	0.00	0.01	0.39	1.12	0.13	**2.21**
Gw	0.67	0.72	0.85	0.69	0.63	0.56	0.61	0.55	0.47	0.61	1.30	1.45	**9.18**
aET	0.92	2.62	1.11	2.92	0.64	6.66	4.13	1.53	0.61	6.93	1.59	0.31	**29.96**
I = P-R	1.60	3.35	1.97	3.61	1.28	7.22	4.74	2.08	1.08	7.55	2.90	1.14	**38.52**

	Blue River near Connerville 2005 (inches)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	5.71	1.62	1.91	4.96	3.22	3.58	5.01	6.75	3.52	3.15	0.11	0.32	**39.86**
R	3.10	0.22	0.05	0.01	0.06	0.16	0.14	0.10	0.14	0.05	0.02	0.02	**4.07**
Gw	2.39	1.82	1.61	1.14	0.85	0.78	0.68	0.62	0.48	0.55	0.49	0.51	**11.92**
aET	0.22	0.42	0.26	3.81	2.31	2.65	4.19	6.03	2.90	2.55	0.40	0.21	**25.94**
I = P-R	2.61	1.40	1.86	4.95	3.16	3.42	4.87	6.65	3.38	3.10	0.09	0.30	**35.79**

	Blue River near Connerville 2006 (inches)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	1.58	1.21	4.41	4.96	3.11	0.75	0.61	1.14	2.69	5.84	3.23	3.31	**32.84**
R	0.02	0.02	0.20	0.29	0.61	0.03	0.01	0.01	0.02	0.14	0.12	0.21	**1.66**
Gw	0.45	0.40	0.61	0.77	1.01	0.70	0.51	0.41	0.36	0.33	0.36	0.54	**6.46**
aET	1.10	0.80	3.60	3.90	1.49	0.02	0.09	0.72	2.31	5.37	2.75	2.56	**24.71**
I = P-R	1.56	1.19	4.21	4.67	2.50	0.72	0.60	1.13	2.67	5.70	3.11	3.10	**31.18**

Appendix 6: Monthly Precipitation, Infiltration, Actual Evapotranspiration and GW Recharge over the Blue River Subsurface Watershed

Precipitation over BRSW (inches)													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
1994	0.89	1.96	3.03	4.44	5.65	0.38	4.59	1.47	6.18	3.65	6.51	1.23	**39.96**
1995	1.86	0.01	4.47	4.28	7.50	4.09	2.82	0.94	4.35	0.73	0.66	2.22	**33.93**
1996	1.17	0.13	3.03	4.91	0.76	3.10	6.07	6.00	6.89	4.08	6.41	0.54	**43.09**
1997	0.28	6.29	0.79	5.50	4.08	2.99	2.42	5.43	1.27	4.16	1.89	5.00	**40.11**
1998	6.58	1.65	5.87	1.67	1.10	3.56	0.25	2.26	1.82	5.38	3.08	3.42	**36.62**
1999	2.35	0.40	5.13	4.80	4.62	5.09	0.75	1.93	7.18	1.71	0.92	1.81	**36.66**
2000	2.70	1.73	3.82	2.66	2.83	6.24	2.12	0.00	0.97	6.86	5.08	5.18	**40.19**
2001	3.65	5.80	0.00	1.50	2.69	1.80	0.36	1.68	3.22	2.68	0.92	0.19	**24.50**
2002	1.05	0.80	3.91	5.48	2.44	4.11	3.69	6.07	3.67	4.40	0.77	4.89	**41.28**
2003	0.08	2.57	1.18	1.38	3.79	4.51	0.74	3.34	4.83	0.45	2.64	1.23	**26.73**
2004	1.77	3.11	2.80	3.15	1.91	5.40	6.53	1.99	1.47	6.01	5.20	1.14	**40.49**
2005	5.66	1.80	0.82	0.83	3.44	3.53	4.69	6.30	3.04	3.42	0.99	0.31	**34.83**
2006	1.51	0.23	4.42	5.03	2.97	1.59	0.78	0.91	2.48	5.63	3.32	3.42	**32.28**

	Infiltration over BRSW, from *Vflo™* grids												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
1994	1.83	2.14	0.99	2.05	5.90	0.46	4.55	1.64	6.29	3.78	6.49	1.19	**37.32**
1995	1.89	0.03	4.37	4.42	6.86	3.21	2.79	0.93	4.36	0.75	0.68	2.22	**32.50**
1996	1.18	0.13	3.03	4.99	0.80	3.06	5.51	6.11	1.27	4.05	5.64	0.54	**36.31**
1997	0.29	4.43	0.74	5.52	4.05	3.03	2.43	5.49	1.31	4.14	1.89	4.92	**38.24**
1998	5.23	1.46	3.06	1.67	1.10	0.74	0.74	1.92	1.83	5.27	3.06	3.35	**29.45**
1999	2.33	0.40	5.02	4.70	4.57	5.05	0.74	1.92	5.94	1.69	1.69	1.83	**35.86**
2000	2.71	1.74	3.77	2.65	2.85	6.19	2.08	0.00	0.96	6.60	4.48	2.59	**36.62**
2001	1.48	1.72	3.77	1.49	2.65	1.82	0.32	1.70	3.14	2.67	0.93	0.19	**21.86**
2002	0.46	0.80	3.90	5.35	2.45	4.05	3.68	5.99	3.69	4.34	0.77	4.84	**40.32**
2003	0.08	2.56	1.18	1.34	3.74	4.53	3.68	3.31	1.49	0.45	2.66	1.24	**26.26**
2004	1.78	3.11	2.74	3.13	1.96	5.38	6.53	1.97	1.49	5.75	5.04	1.03	**39.91**
2005	3.76	1.58	0.83	0.85	3.42	3.59	4.70	6.17	3.10	3.35	0.99	0.30	**32.64**
2006	1.50	0.24	4.47	4.98	2.83	1.68	0.84	0.90	2.56	5.50	3.32	0.37	**29.17**

Appendix 6 Cont'd

	Actual Evapotranspiration												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1994	0.61	1.27	1.53	3.14	2.09	0.26	4.27	1.34	5.70	3.32	2.33	0.11	**25.98**
1995	0.90	0.05	1.95	1.86	2.51	2.16	2.43	0.59	3.89	0.59	0.52	1.97	**19.41**
1996	0.95	0.06	2.66	3.41	0.48	2.89	5.82	5.35	5.68	2.24	2.81	0.50	**32.84**
1997	0.00	3.77	0.33	3.95	3.41	2.38	2.11	5.17	1.17	4.06	1.79	3.99	**32.12**
1998	2.73	0.85	2.53	0.91	0.70	3.16	0.16	2.18	1.78	5.21	2.90	3.00	**26.12**
1999	1.88	0.08	4.21	2.33	3.67	4.23	0.58	1.79	6.70	1.61	0.71	1.65	**29.45**
2000	2.51	1.50	3.44	2.40	2.49	6.05	2.03	0.00	0.96	6.53	3.92	2.60	**34.42**
2001	1.50	0.84	0.00	0.37	2.05	1.30	0.06	1.62	2.38	1.17	0.70	0.33	**12.31**
2002	0.81	0.24	1.53	0.87	1.80	3.43	3.35	4.89	3.27	3.94	0.44	3.57	**28.15**
2003	0.00	2.00	0.65	1.03	3.53	3.74	0.62	3.29	4.62	0.36	2.53	1.13	**23.49**
2004	1.04	2.31	1.78	2.43	1.26	4.78	5.74	1.42	0.99	5.01	2.77	0.45	**29.99**
2005	0.18	0.24	0.83	0.32	2.53	2.59	3.87	5.58	2.42	2.81	0.48	0.22	**22.07**
2006	1.03	0.18	3.61	3.97	1.35	0.86	0.26	0.48	2.10	5.17	2.84	2.67	**24.51**

	Gw Recharge over BRSW												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1994	1.21	0.87	0	0	3.80	0.21	0.28	0.30	0.59	0.46	4.16	1.08	**11.34**
1995	0.99	0	2.42	2.56	4.36	1.05	0.36	0.34	0.46	0.16	0.16	0.25	**13.09**
1996	0.24	0.07	0.37	1.58	0.32	0.17	0	0.76	0	1.81	2.83	0.04	**3.47**
1997	0.29	0.66	0.41	1.58	0.64	0.65	0.31	0.33	0.14	0.09	0.11	0.93	**6.12**
1998	2.50	0.61	0.53	0.76	0.40	0	0.58	0	0.06	0.06	0.17	0.34	**3.33**
1999	0.45	0.32	0.81	2.37	0.90	0.82	0.16	0.14	0	0.07	0.97	0.17	**6.41**
2000	0.19	0.24	0.34	0.25	0.36	0.15	0.05	0.00	0.00	0.07	0.56	0	**2.20**
2001	0	0.88	3.77	1.13	0.60	0.51	0.27	0.07	0.76	1.50	0.23	0	**9.55**
2002	0	0.56	2.37	4.48	0.64	0.62	0.33	1.10	0.42	0.40	0.34	1.28	**12.17**
2003	0.08	0.57	0.53	0.31	0.21	0.79	3.06	0.02	-3.13	0.10	0.13	0.11	**2.77**
2004	0.74	0.81	0.96	0.69	0.69	0.59	0.79	0.55	0.50	0.74	2.26	0.58	**9.91**
2005	3.58	1.34	0.00	0.53	0.89	1.00	0.83	0.59	0.68	0.53	0.51	0.08	**10.57**

2006	0.47	0.06	0.86	1.01	1.48	0.82	0.58	0.42	0.46	0.33	0.48	0	**4.66**

APPENDIX 7: WATER BALANCE AT USGS 07334200 BYRDS MILL SPRING NR FITTSTOWN,OK

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Mean Annual
P (in)	39.9	34.4	42.8	39.6	36.3	38.2	39.9	20.5	40.7	27.0	40.7	39.9	32.8	**36.37**
Gw (in)	4.85	5.22	4.19	4.67	4.65	5.14	3.39	5.18	4.86	3.28	2.83	4.45	2.71	**4.26**
aET (in)	35.1	29.2	38.6	34.9	31.7	33.0	36.5	15.3	35.9	23.8	37.9	35.4	30.1	**32.10**
aET (%P)	88	85	90	88	87	87	91	75	88	88	93	89	92	**88**

**Gw data gathered from USGS 07334200 02N-06E-34 CCD 1 Byrds Mill Spring nr Fittstown,OK (Combined Spring flow)*

Appendix 8: Permitted Groundwater Use Well locations over the BRSW in Ac-ft (1994-2006)

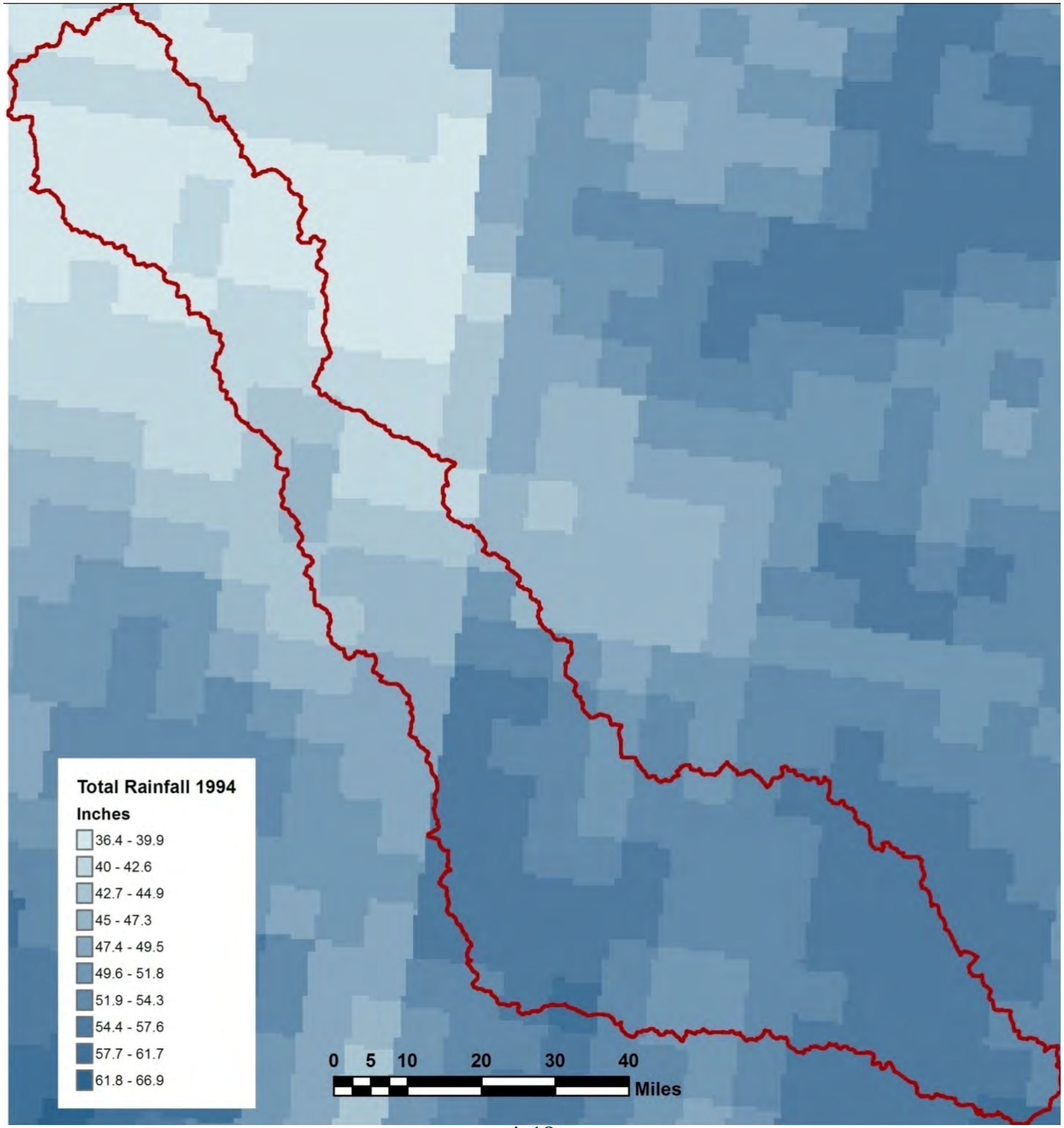
City of Ada Well # 19590158													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
2006	124.72	131.48	34.04	30.97	15.87	183.10	38.37	54.86	52.81	52.54	16.59	24.17	759.53
2005	0.00	0.00	1.99	0.00	0.00	0.00	0.00	163.95	0.00	58.40	5.55	102.23	332.13
2004	617.11	535.76	18.02	0.12	36.61	148.29	237.20	285.51	265.71	346.49	18.23	0.03	2,509.09
2003	2.98	9.70	14.85	5.22	3.16	122.94	344.71	647.04	641.48	551.78	651.36	653.36	3,648.58
2002	12.46	8.90	1.38	3.38	1.26	6.66	12.46	0.00	21.39	60.00	9.51	5.22	142.62
2001	0.00	3.56	1.50	1.26	2.98	3.38	68.38	209.67	236.80	8.90	9.58	6.32	552.33
2000	1.26	0.00	0.00	0.00	0.00	0.00	51.13	228.06	506.26	197.18	51.07	0.00	1034.96
1999	0.00	0.00	0.00	0.00	0.00	0.00	1.53	0.03	0.00	7.33	0.00	0.00	8.90
1998	0.00	0.00	0.00	0.00	0.00	5.55	135.74	30.87	65.15	0.00	0.00	0.00	237.33
1997	0.00	0.00	5.55	0.00	0.00	5.74	0.00	0.58	3.77	4.54	0.00	0.00	20.19
1996	0.00	0.00	4.11	0.00	0.00	2.58	5.19	30.20	0.00	0.00	0.00	6.29	48.37
1995	0.00	0.00	4.98	0.00	0.00	0.00	0.00	0.00	4.90	0.00	0.00	0.00	9.88
1994	0.05	1.24	0.62	0.51	0.56	0.59	0.47	0.60	0.45	2.59	4.63	0.69	13.00

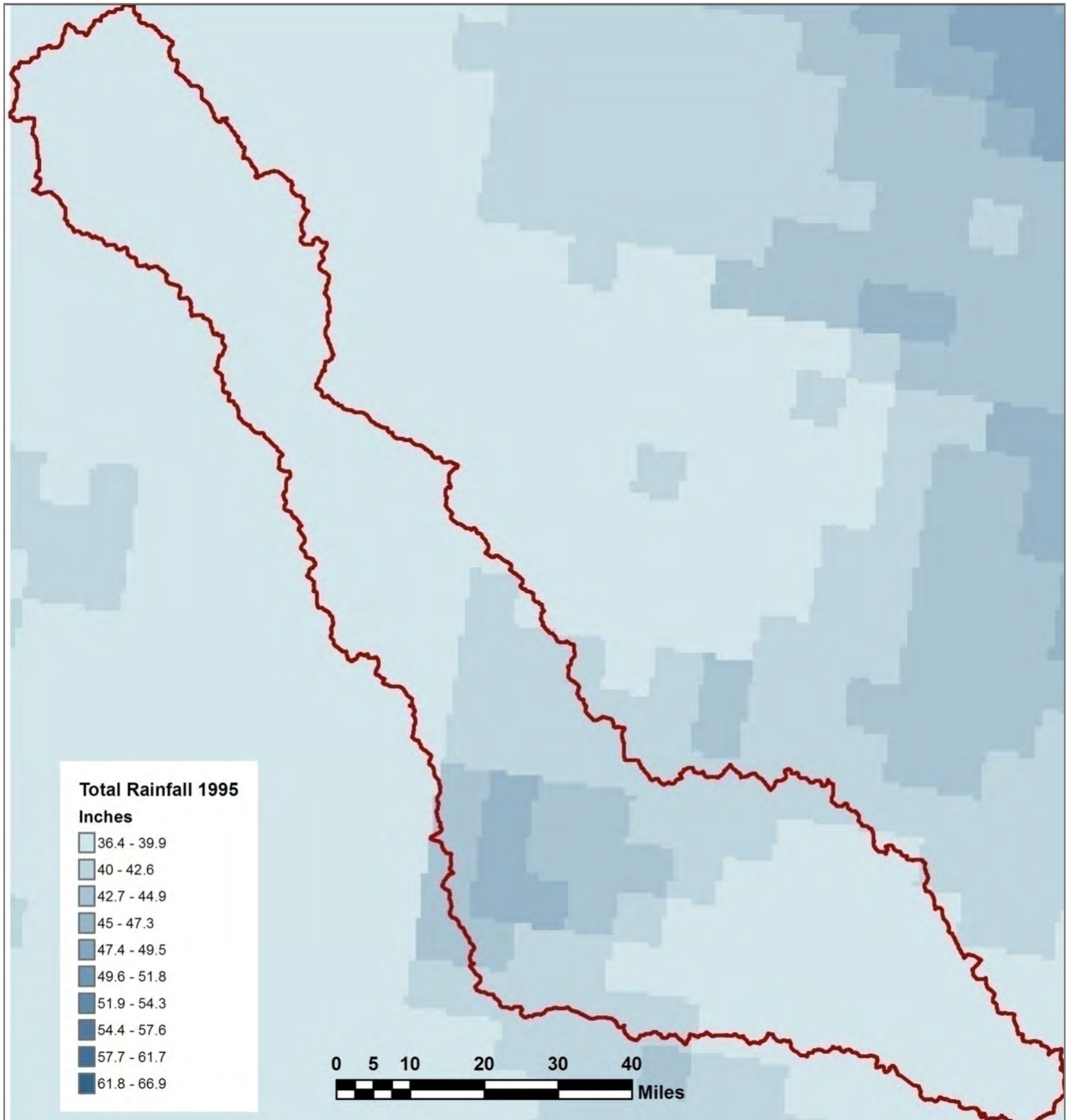
Barnett Walter Well # 19810609													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
2006	0.00	0.00	0.00	0.00	0.00	6.86	7.07	7.50	0.00	0.00	0.00	0.00	21.43
2005	0.00	0.00	0.00	0.00	0.00	8.06	8.32	8.82	0.00	0.00	0.00	0.00	25.20
2004	0.00	0.00	0.00	0.00	0.00	0.32	0.33	0.35	0.00	0.00	0.00	0.00	1.00
2003	0.00	0.00	0.00	0.00	0.00	5.86	6.04	6.41	0.00	0.00	0.00	0.00	18.30
2002	0.00	0.00	0.00	0.00	0.00	3.46	3.56	3.78	0.00	0.00	0.00	0.00	10.80
2001	0.00	0.00	0.00	0.00	0.00	14.40	14.85	15.75	0.00	0.00	0.00	0.00	45.00
2000	0.00	0.00	0.00	0.00	0.00	18.02	18.58	19.71	0.00	0.00	0.00	0.00	56.30
1999	0.00	0.00	0.00	0.00	0.00	12.42	12.80	13.58	0.00	0.00	0.00	0.00	38.80
1998	0.00	0.00	0.00	0.00	0.00	18.66	19.24	20.41	0.00	0.00	0.00	0.00	58.30
1997	0.00	0.00	0.00	0.00	0.00	16.54	17.06	18.10	0.00	0.00	0.00	0.00	51.70
1996	0.00	0.00	0.00	0.00	0.00	14.40	14.85	15.75	0.00	0.00	0.00	0.00	45.00
1995	0.00	0.00	0.00	0.00	0.00	14.40	14.85	15.75	0.00	0.00	0.00	0.00	45.00
1994	0.00	0.00	0.00	0.00	0.00	10.82	11.15	11.83	0.00	0.00	0.00	0.00	33.80

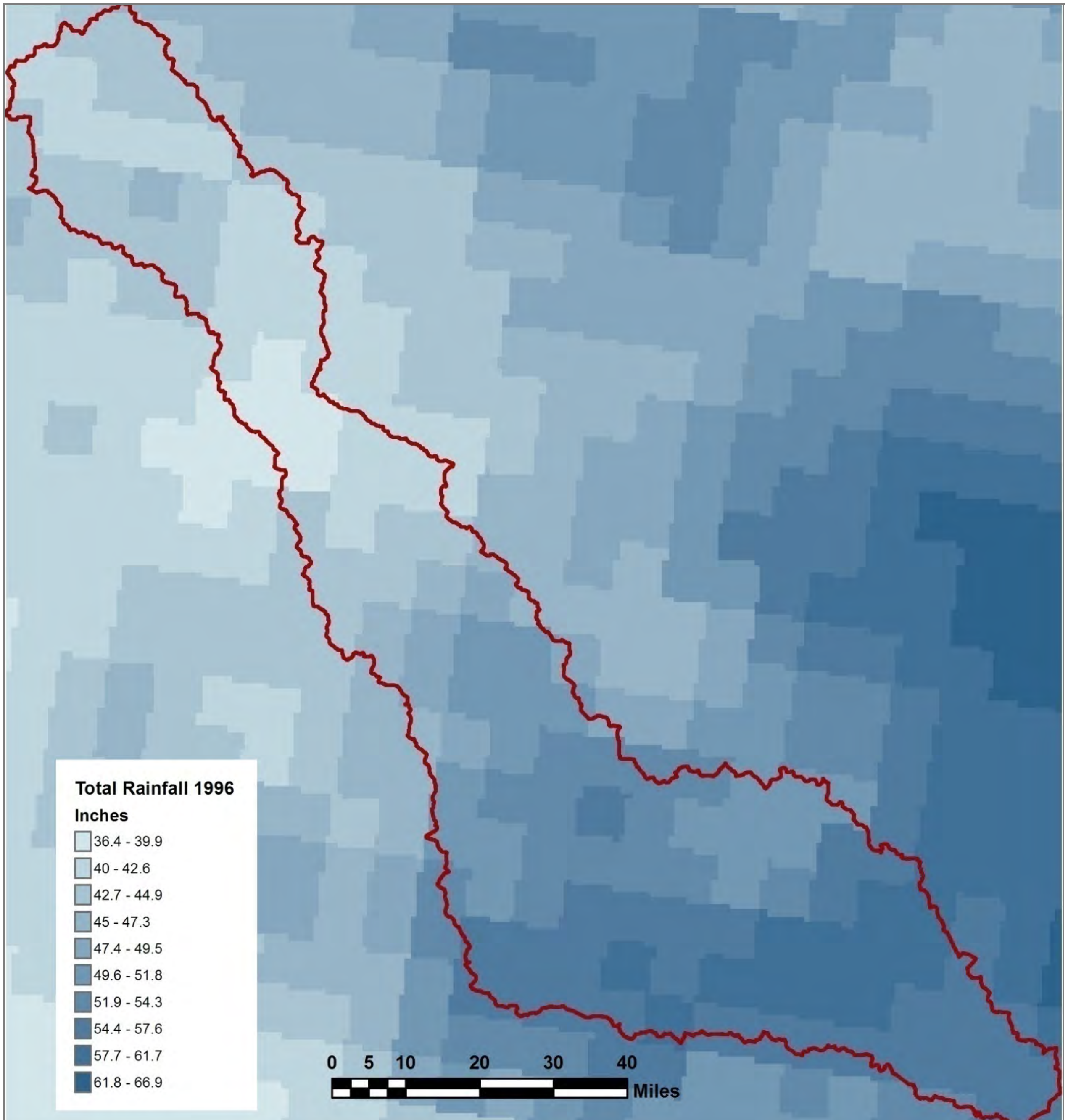
Inslee Theo Well # 19850528													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
2006	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	100.05

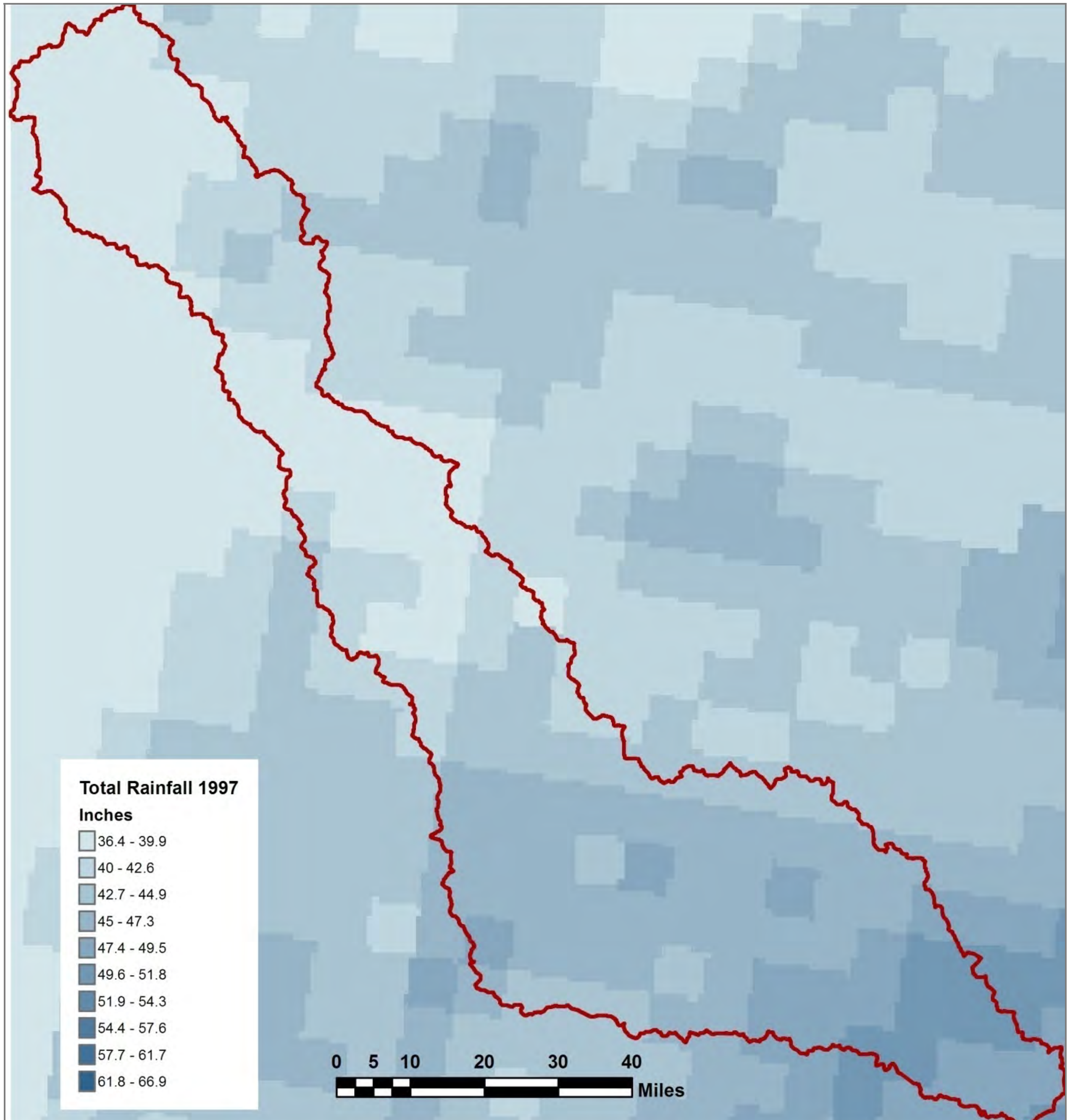
2005	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	100.05
2004	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	100.05
2003	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	100.05
2002	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	100.05
2001	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	100.05
2000	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	100.05
1999	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	100.05
1998	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	100.05
1997	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	100.05
1996	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	100.05
1995	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	2.91	34.92
1994	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	36.83

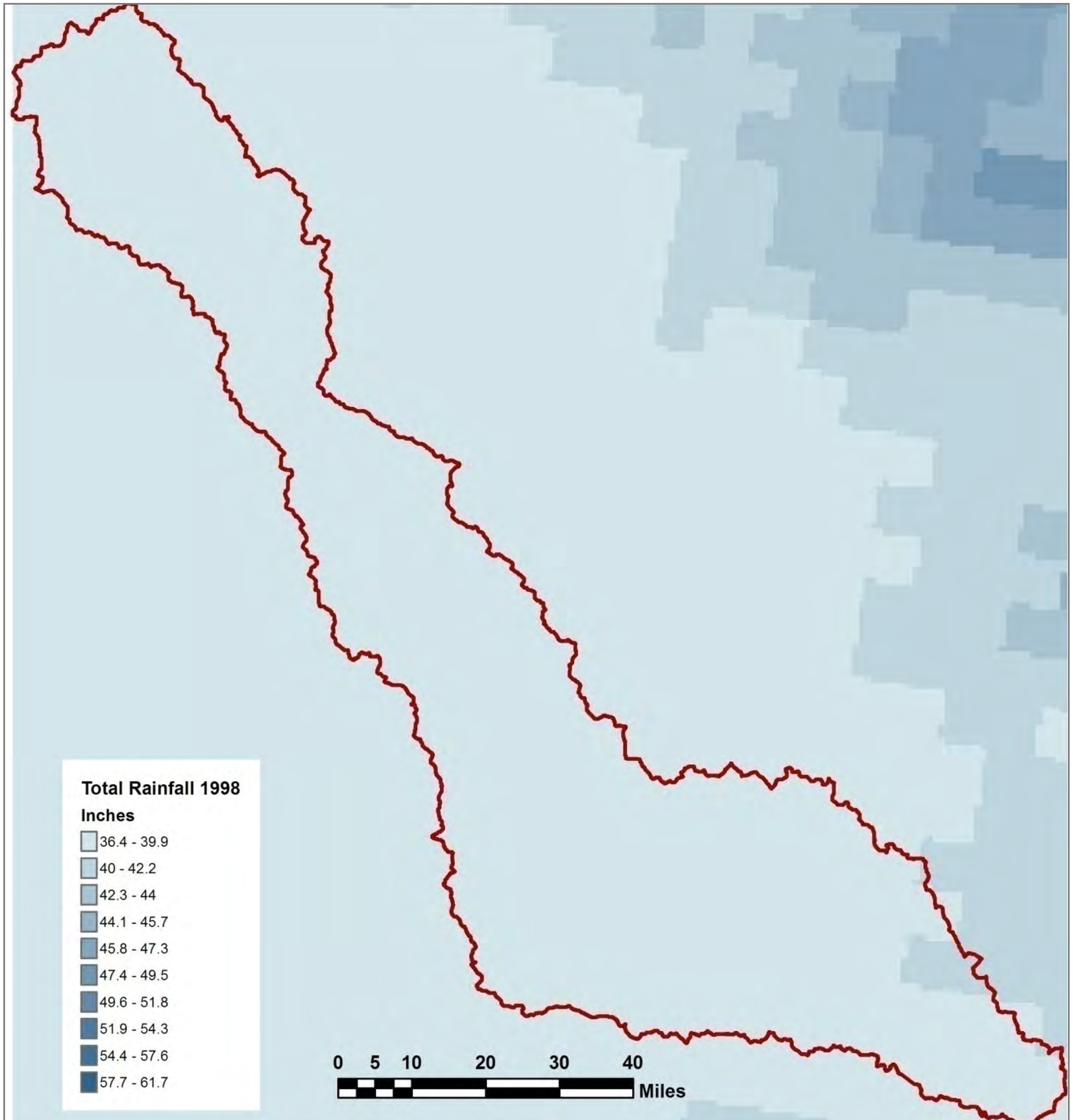
Appendix 9: Distributed Annual Precipitation over the Blue River basin (1994-2006)

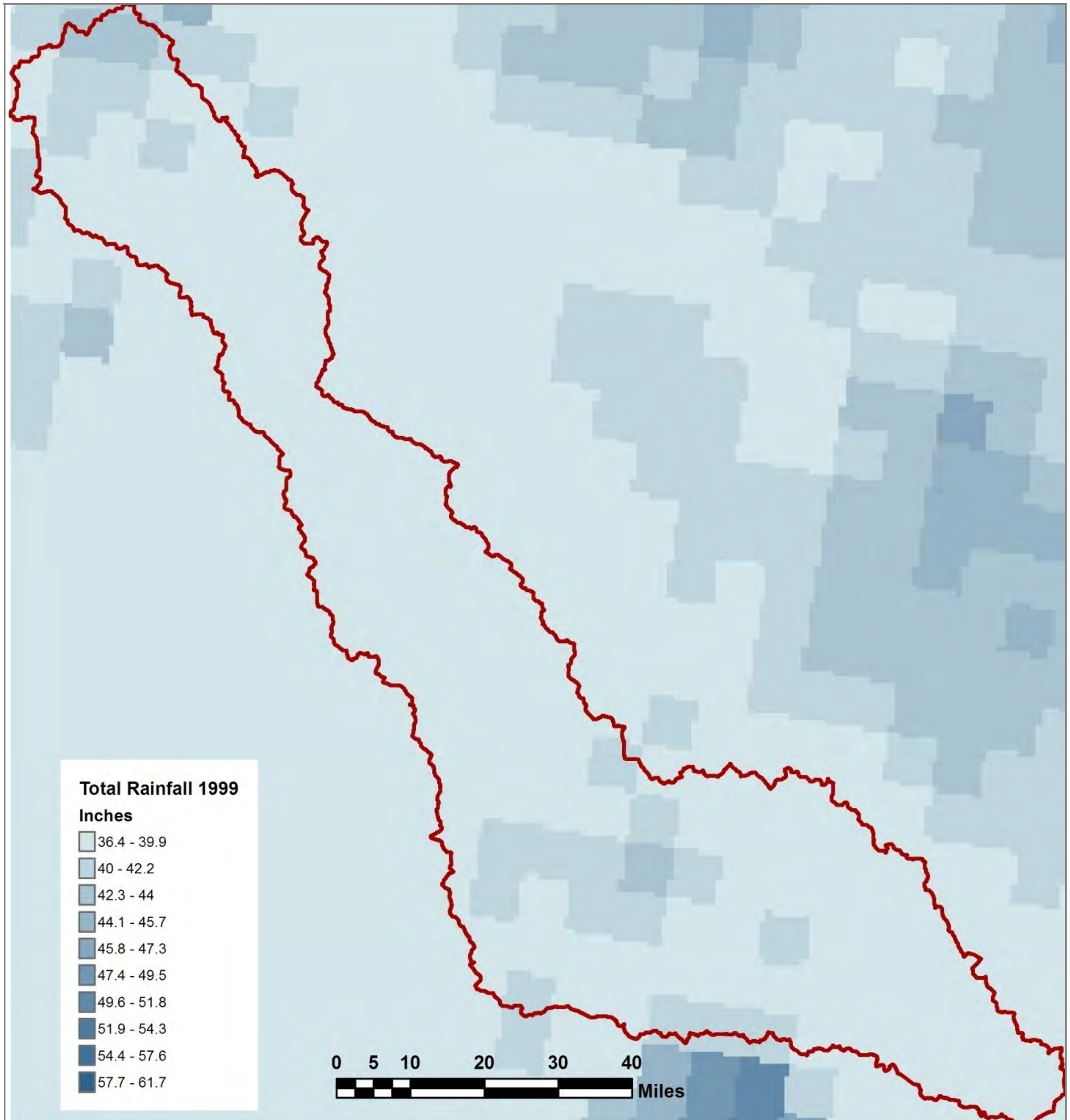

Total Rainfall 1994
Inches
36.4 - 39.9
40 - 42.6
42.7 - 44.9
45 - 47.3
47.4 - 49.5
49.6 - 51.8
51.9 - 54.3
54.4 - 57.6
57.7 - 61.7
61.8 - 66.9
0 5 10 20 30 40
Miles

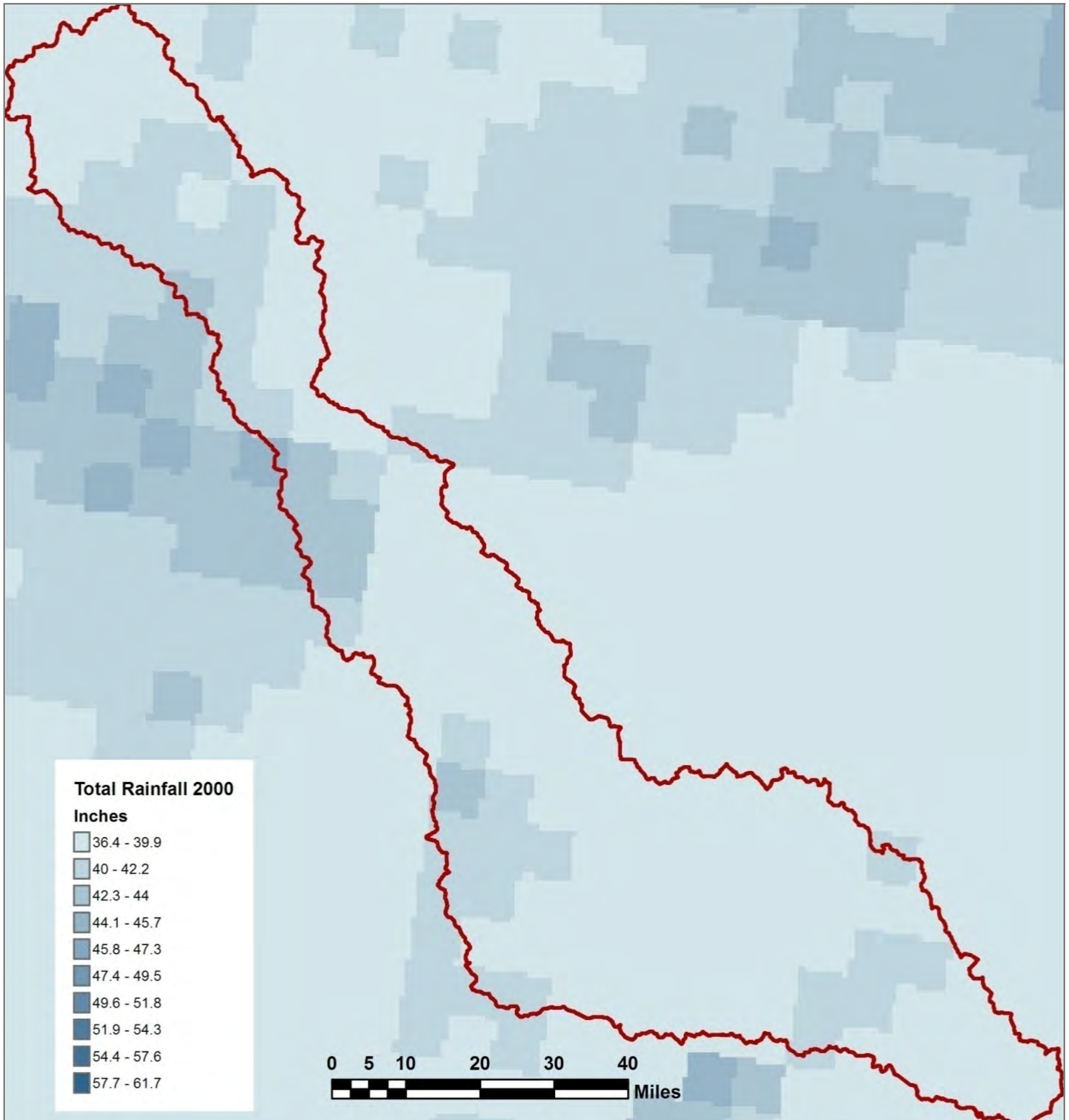

Total Rainfall 1995
Inches
36.4 - 39.9
40 - 42.6
42.7 - 44.9
45 - 47.3
47.4 - 49.5
49.6 - 51.8
51.9 - 54.3
54.4 - 57.6
57.7 - 61.7
61.8 - 66.9
0 5 10 20 30 40
Miles

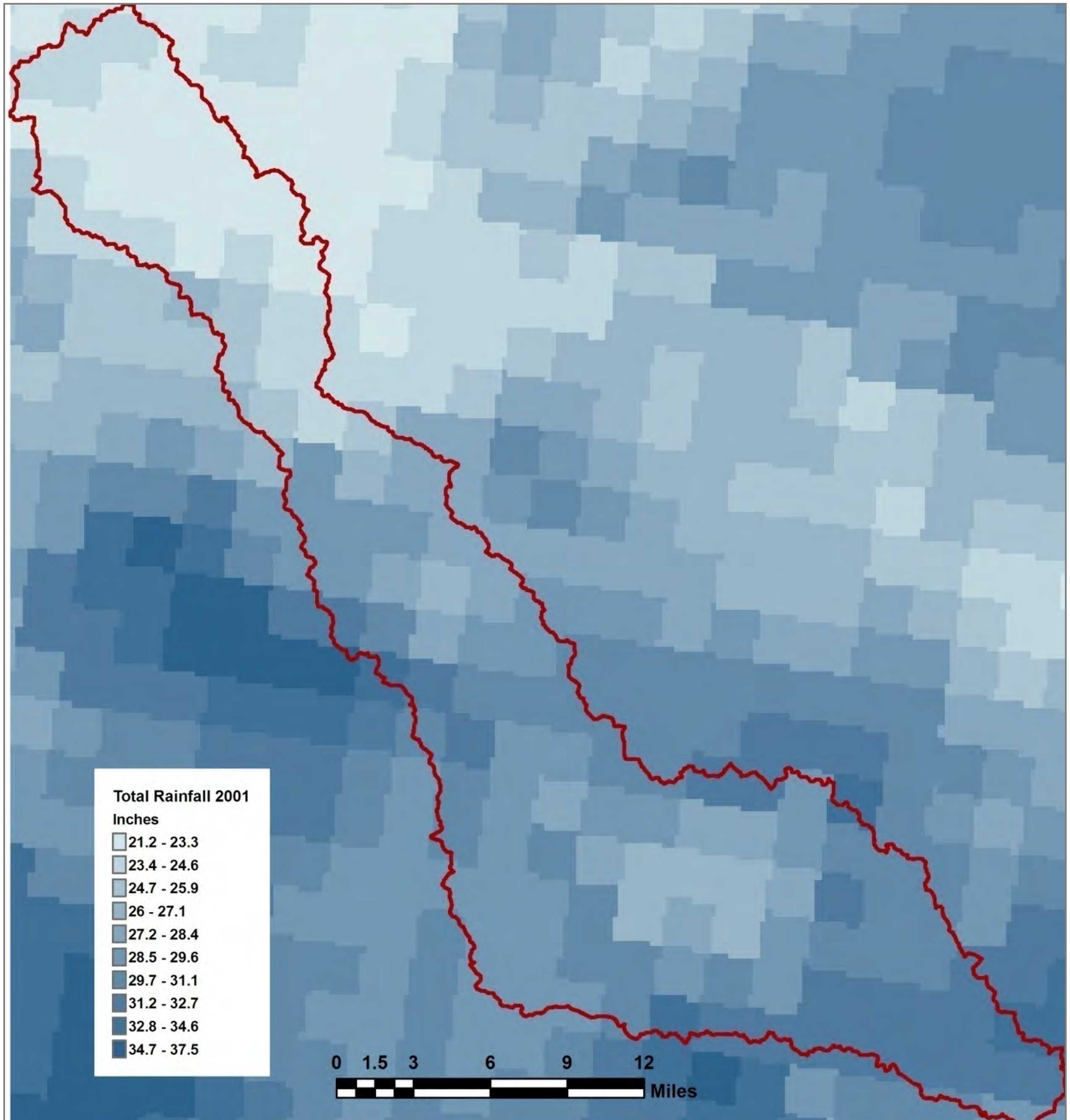

Total Rainfall 1996
Inches
36.4 - 39.9
40 - 42.6
42.7 - 44.9
45 - 47.3
47.4 - 49.5
49.6 - 51.8
51.9 - 54.3
54.4 - 57.6
57.7 - 61.7
61.8 - 66.9
0 5 10 20 30 40
Miles

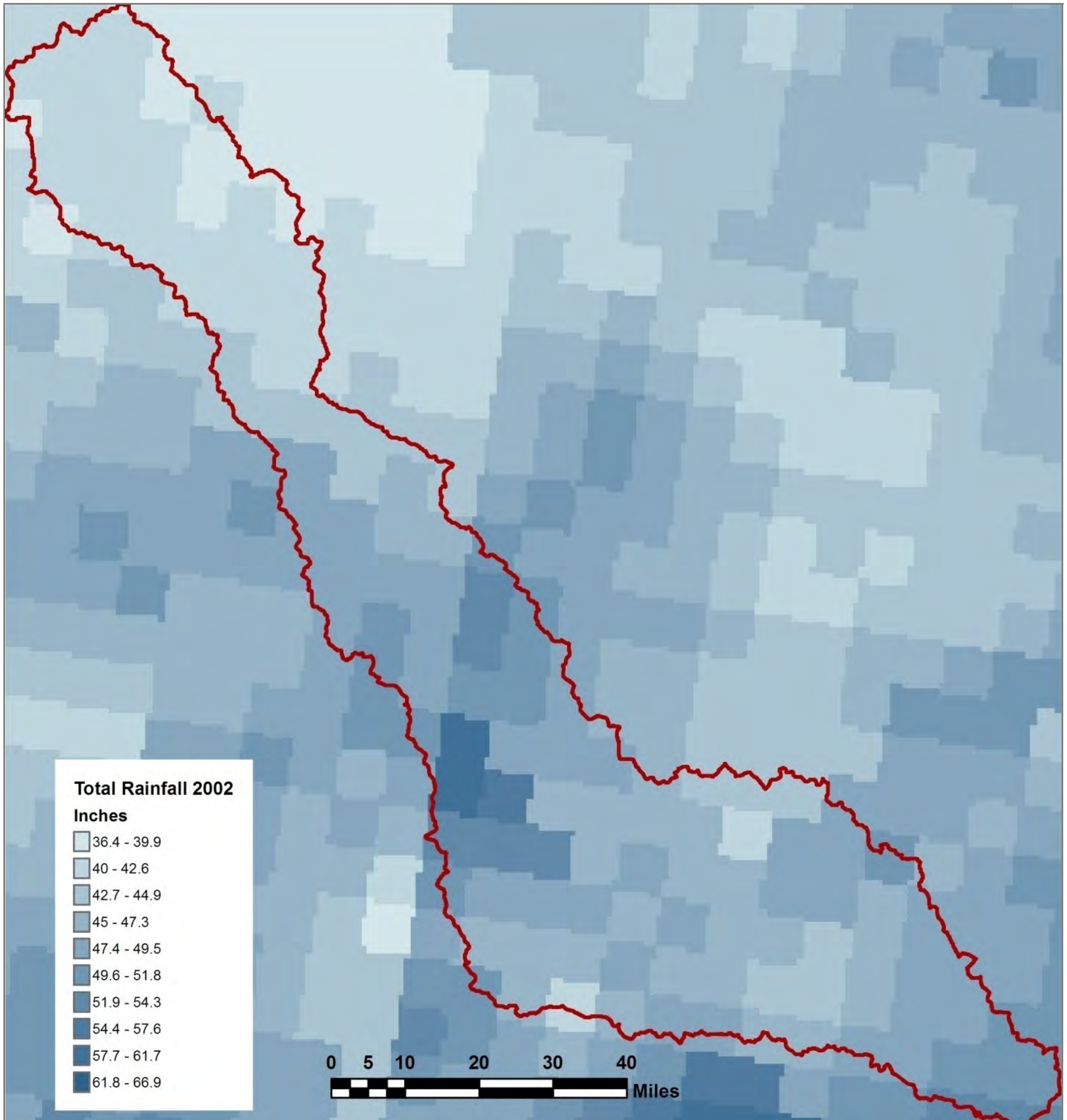

Total Rainfall 1997
Inches
36.4 - 39.9
40 - 42.6
42.7 - 44.9
45 - 47.3
47.4 - 49.5
49.6 - 51.8
51.9 - 54.3
54.4 - 57.6
57.7 - 61.7
61.8 - 66.9
0 5 10 20 30 40
Miles

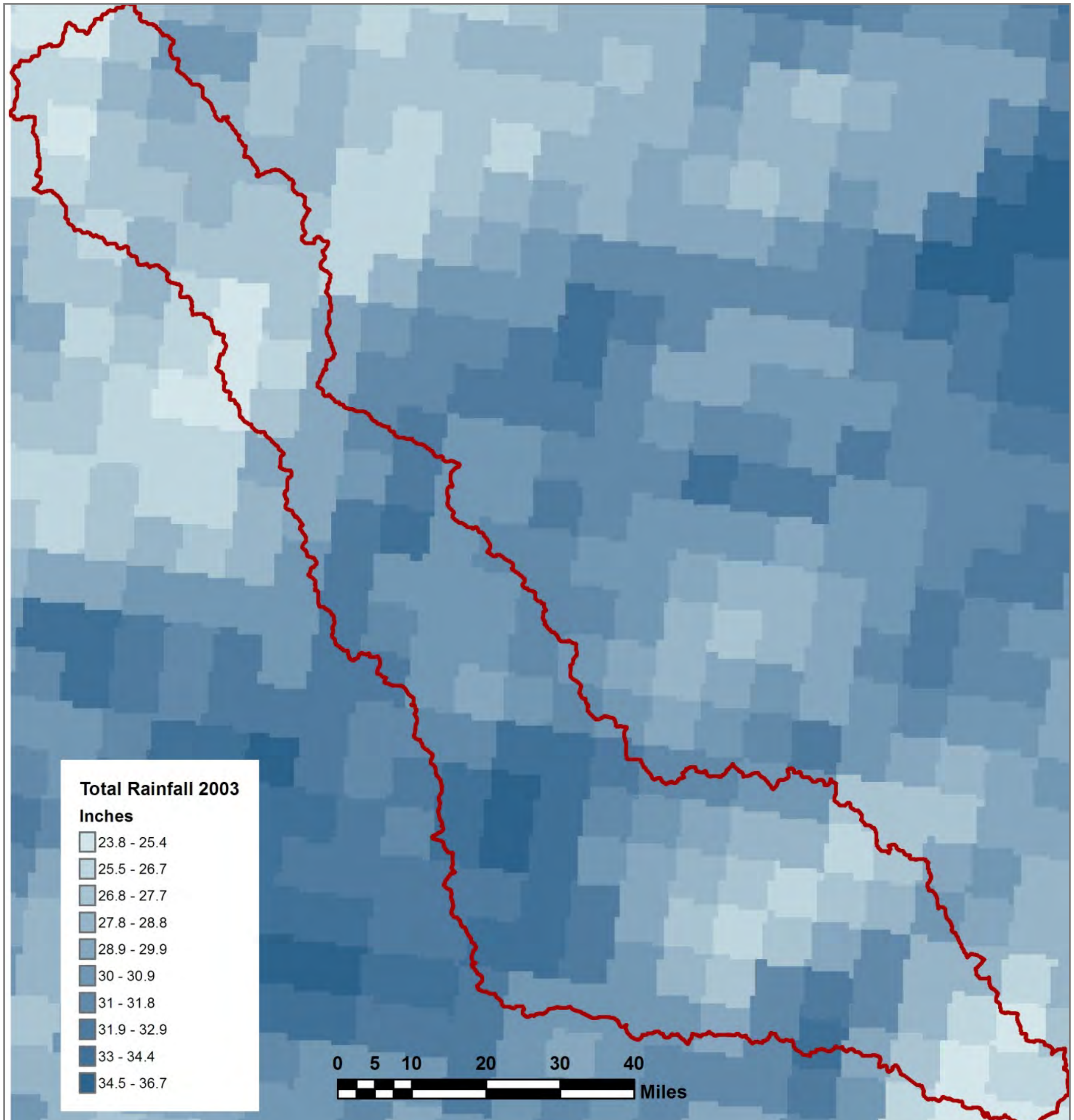

Total Rainfall 1998
Inches
36.4 - 39.9
40 - 42.2
42.3 - 44
44.1 - 45.7
45.8 - 47.3
47.4 - 49.5
49.6 - 51.8
51.9 - 54.3
54.4 - 57.6
57.7 - 61.7
0 5 10 20 30 40
Miles

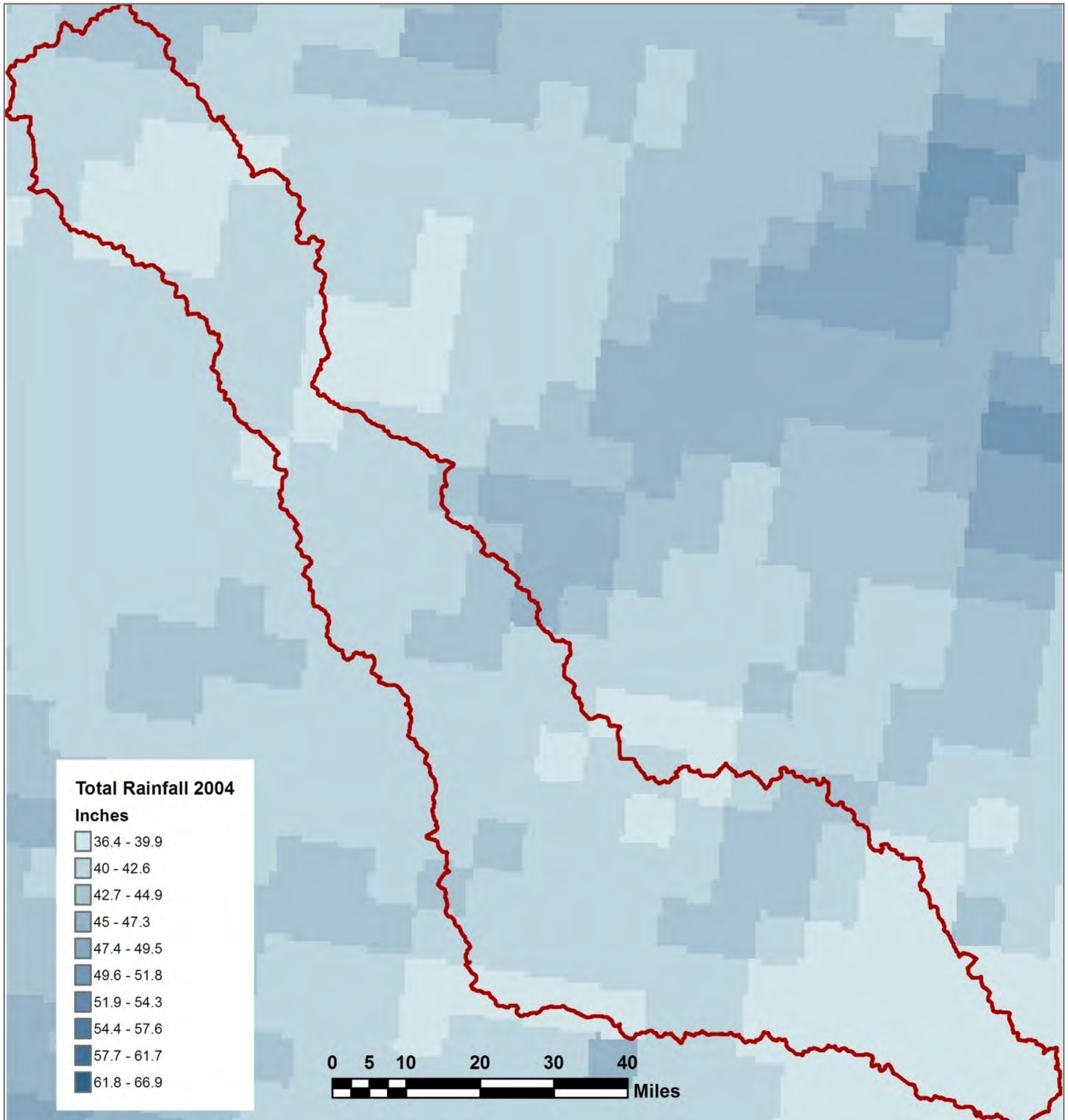

Total Rainfall 1999
Inches
36.4 - 39.9
40 - 42.2
42.3 - 44
44.1 - 45.7
45.8 - 47.3
47.4 - 49.5
49.6 - 51.8
51.9 - 54.3
54.4 - 57.6
57.7 - 61.7
0 5 10 20 30 40
Miles

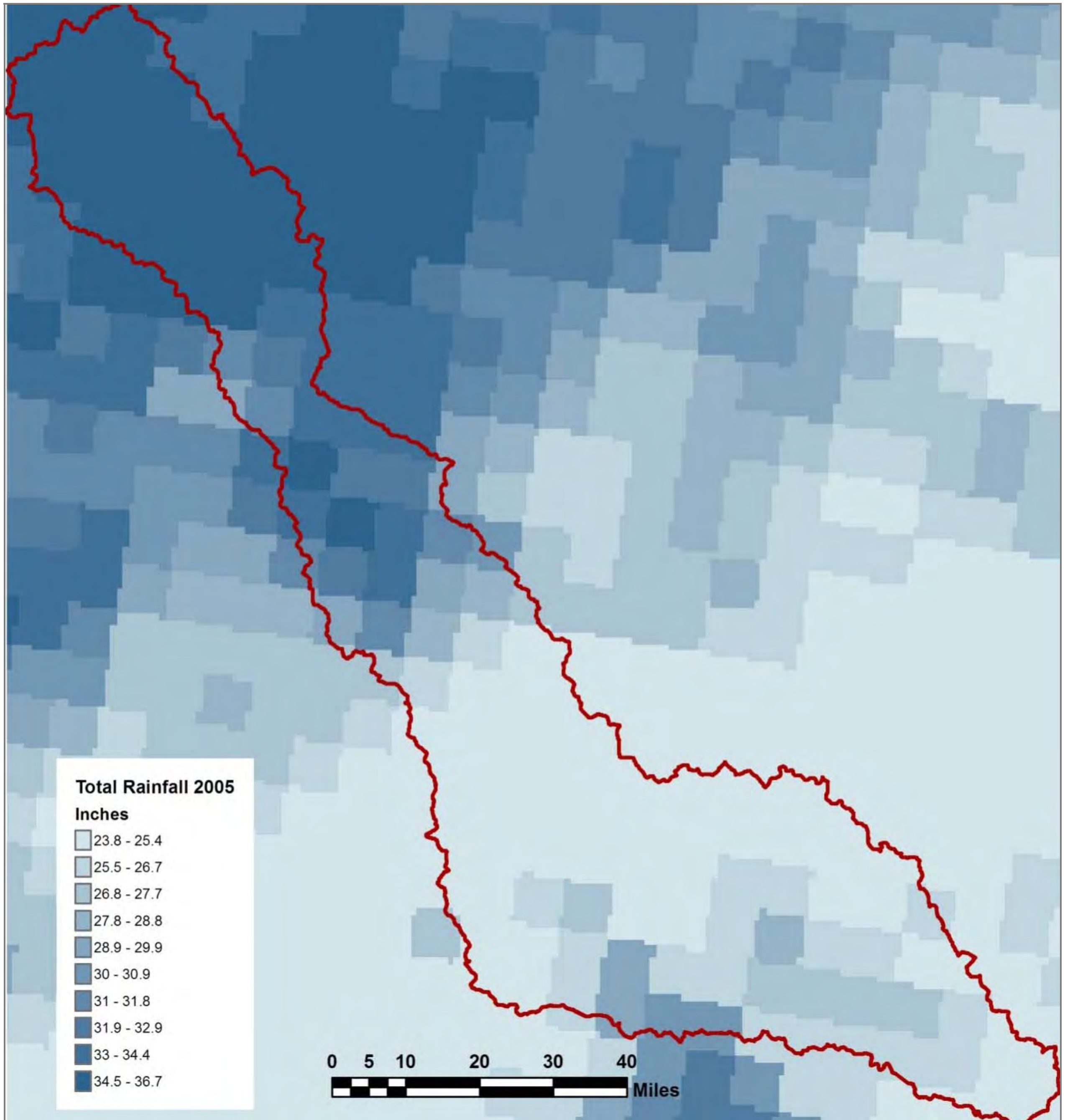

Total Rainfall 2000
Inches
36.4 - 39.9
40 - 42.2
42.3 - 44
44.1 - 45.7
45.8 - 47.3
47.4 - 49.5
49.6 - 51.8
51.9 - 54.3
54.4 - 57.6
57.7 - 61.7
0 5 10 20 30 40
Miles

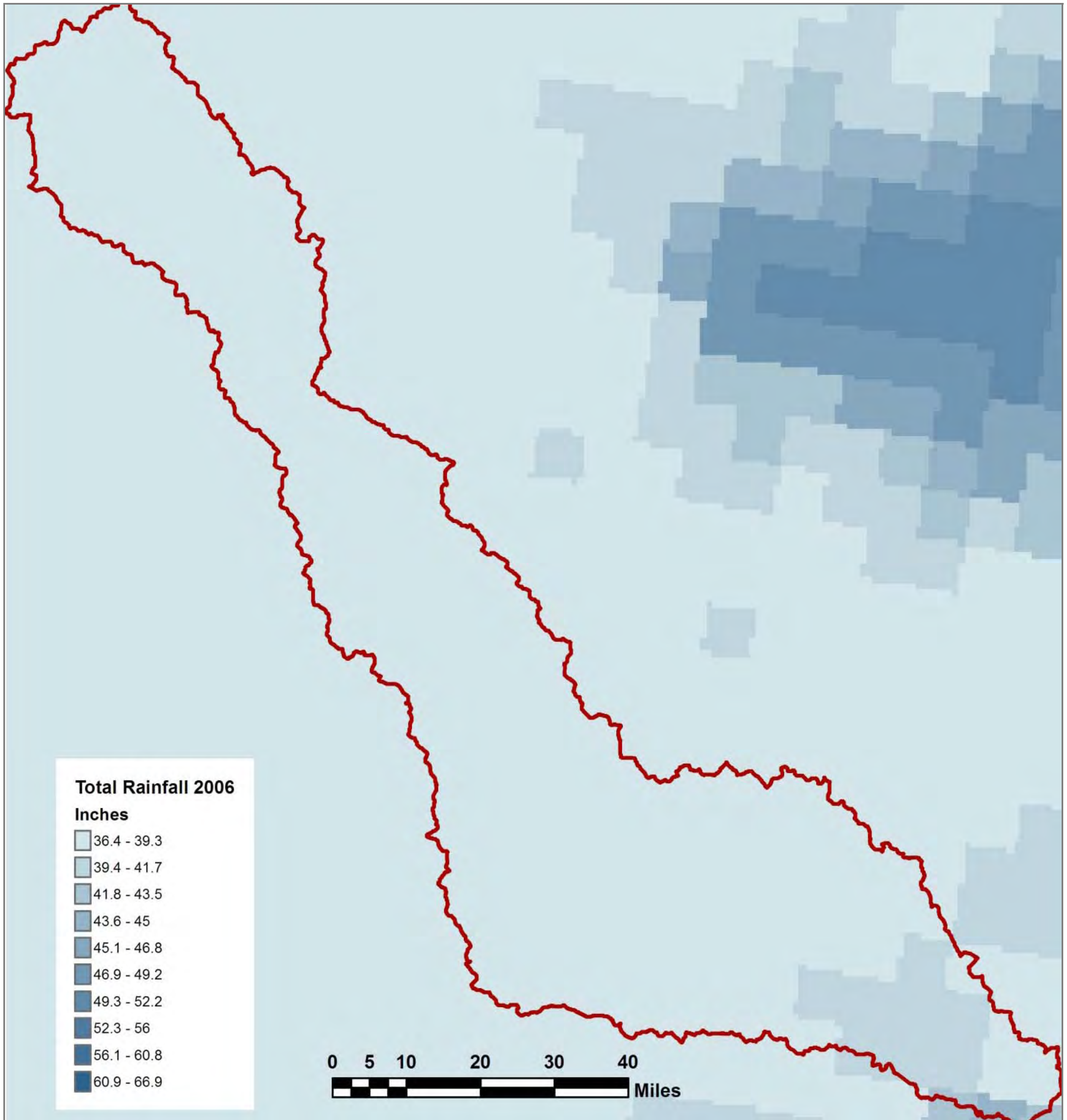

Total Rainfall 2001
Inches
21.2 - 23.3
23.4 - 24.6
24.7 - 25.9
26 - 27.1
27.2 - 28.4
28.5 - 29.6
29.7 - 31.1
31.2 - 32.7
32.8 - 34.6
34.7 - 37.5
0 1.5 3 6 9 12
Miles


Total Rainfall 2002
Inches
36.4 - 39.9
40 - 42.6
42.7 - 44.9
45 - 47.3
47.4 - 49.5
49.6 - 51.8
51.9 - 54.3
54.4 - 57.6
57.7 - 61.7
61.8 - 66.9
0 5 10 20 30 40
Miles


Total Rainfall 2003
Inches
23.8 - 25.4
25.5 - 26.7
26.8 - 27.7
27.8 - 28.8
28.9 - 29.9
30 - 30.9
31 - 31.8
31.9 - 32.9
33 - 34.4
34.5 - 36.7
0 5 10 20 30 40
Miles


Total Rainfall 2004
Inches
36.4 - 39.9
40 - 42.6
42.7 - 44.9
45 - 47.3
47.4 - 49.5
49.6 - 51.8
51.9 - 54.3
54.4 - 57.6
57.7 - 61.7
61.8 - 66.9
0 5 10 20 30 40
Miles


Total Rainfall 2005
Inches
23.8 - 25.4
25.5 - 26.7
26.8 - 27.7
27.8 - 28.8
28.9 - 29.9
30 - 30.9
31 - 31.8
31.9 - 32.9
33 - 34.4
34.5 - 36.7
0 5 10 20 30 40
Miles


Total Rainfall 2006
Inches
36.4 - 39.3
39.4 - 41.7
41.8 - 43.5
43.6 - 45
45.1 - 46.8
46.9 - 49.2
49.3 - 52.2
52.3 - 56
56.1 - 60.8
60.9 - 66.9
0 5 10 20 30 40
Miles

Appendix 10: Gauging stations used in this study

STATION	BLUE RIVER BASIN HUC 11140102				
	Bluer River near Connerville	**Blue River near Blue**	**Byrds Mill Spring nr Fittstown,OK**	**Fittstown Gw Well**	**Fittstown**
ID Number	USGS 07332390	USGS 07332500	USGS 07334200 02N-06E-34 CCD 1	USGS 343457096404501 01N-06E-04 CAD 1	Mesonet #127
Latitude	34°23'00"N	33°59'49"N	34°35'40"N	34°34'57"N	34° 33' 7"
Longitude	96°36'01"	96°14'27"	96°39'55"	96°40'45"	96° 43' 4"
County	Johnston	Bryan	Pontotoc	Pontotoc	Pontotoc
Drainage area	162 mi^2	476 mi^2	52 mi^2	-	-
Datum of Gage (above sea level)	892 feet	504 feet	1,022 feet	1,155 feet	1,148 meters

***Source:** http://nwis.waterdata.usgs.gov/usa/nwis/

STATION	CLEAR BOGGY BASIN HUC 11140104		MUDDY BOGGY BASIN HUC 11140103		
	Clear Boggy Creek near Caney	**Centrahoma**	**Muddy Boggy near Farris**	**Muddy Boggy near Unger**	**Lane**
ID Number	USGS 07335000	Mesonet # 23	USGS 07334000	USGS 07335300	Mesonet # 56
Latitude	34°15'09"	34° 36' 32"	34°16'17"	34°01'36"	34° 18' 31"
Longitude	96°12'19"	96° 19' 58"	95°54'43"	95°45'00"	95° 59' 49"
County	Atoka	Coal	Atoka	Choctaw	Atoka
Drainage area	720 mi^2	-	1,087 mi^2	2,273 mi^2	-
Datum of Gage (above sea level)	485.05 feet	642.41 feet	439.58 feet	392.72 feet	593.83 feet

***Source:** http://nwis.waterdata.usgs.gov/usa/nwis/

Appendix 11: Parameter maps used to assemble the 200-m resolution *Vflo™* mode