Appendix E
Model Configuration, Calibration and Validation

Basin: Arizona: Salt, Verde, and San Pedro Rivers (Ariz)

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Watershed Background

The Arizona (Salt, Verde, and San Pedro) basins are located in central and southern Arizona in EPA Region 9 (Cordy et al. 2000). The watershed includes large parts of two hydrologic provinces—the Central Highlands in the north and the Basin and Range Lowlands in the south. Five major river systems drain the area: the Gila, Salt, Verde, Santa Cruz and San Pedro Rivers. The selected model area includes perennial portions of the Salt and Verde River basins (in HUC 1506) that lie upstream of major impoundments, along with the San Pedro River (HUC 1505), for a total of 10 HUC8s with an area of 14,910 mi^2 (Figure 1 and Figure 2).

Land cover is primarily desert scrub and rangeland at low elevations with sparse forest at higher elevations (USGS, 2004; Cordy et al., 2000). The two major population centers of Arizona, Phoenix and Tucson, are located just downstream of the model area, while portions of Flagstaff, Prescott, and several smaller towns are within the Verde River watershed. Population growth is resulting in increasing demands on the limited water resources of the area. The climate is arid to semiarid and is characterized by variability from place to place as well as large differences in precipitation from one year to the next. Precipitation can be three times greater in wet years than in dry years.

The Verde and Salt River watersheds are in the Central Highlands hydrologic province, characterized by mountainous terrain with shallow, narrow intermountain basins. Forests and rangeland cover most of the area. The largest town in the province is Prescott and other small rural towns dot the region. Most of the perennial streams in the study area are in the Central Highlands. These streams derive their flow from precipitation in the mountains and from rainfall and snowmelt along the northeastern border of the basins. Many of the major streams with headwaters in the Central Highlands are perennial in their upper reaches but are captured for water supply for metropolitan Phoenix, power generation, and flood control before they reach the Basin and Range Lowlands.

The San Pedro watershed is in the Basin and Range Lowlands hydrologic province. The Basin and Range Lowlands are characterized by ephemeral streams, the largest water demands, and reliance on groundwater. Deep, broad alluvial basins separated by mountain ranges of small areal extent characterize this hydrologic province. There is very little natural streamflow because of an average annual rainfall of less than 10 to 15 inches except at the highest elevations. With the exception of some small, higher elevation streams and sections of the San Pedro River, most perennial streams in the Basin and Range Lowlands are dependent on treated wastewater effluent for their year-round flow. Water use in the Basin and Range Lowlands represents 96 percent of all water use in the Arizona basins. Agriculture is the largest water user. Because of the general lack of surface water resources in the Basin and Range Lowlands, groundwater is relied upon heavily to meet agricultural and municipal demands.

The lower portions of the rivers in the Arizona basins have been extensively engineered for water supply purposes (e.g., the Salt River Project) and also contain many reaches that flow only intermittently. Larger reservoirs are problematic for scenario simulations as future demands and reservoir management are not fully known, while intermittent streams are difficult to calibrate and can present problems for model performance. Therefore, the portions of the watershed chosen for simulation are upstream of major reservoirs and focus on perennial streams. The resulting three distinct study areas are the Verde, Salt, and San Pedro rivers (Figure 1 and Figure 2).

Water Body Characteristics

Verde River

The first area of study is the Verde River watershed upstream of Horseshoe Reservoir (Figure 1). The Verde River watershed comprises approximately 6,577 square miles (mi^2), while the area upstream of the northern end of Horseshoe Reservoir contains approximately 5,563 mi^2. The watershed trends south-southeast from Fraziers Well,

immediately south of the Colorado River watershed and the Grand Canyon National Park to its confluence with the Salt River on the east side of Phoenix. The study area ranges in elevation from over 11,000 feet (ft) where it drains a portion of Humphreys Peak north of Flagstaff to around 2,100 ft at the confluence of the Verde River with Horseshoe Reservoir.

The Verde Valley, which descends into the Central Highland province, is bounded by the Mogollon Rim to the north and northeast and by the Black Hills to the southwest (Owen-Joyce and Bell 1983). The headwaters of the Verde River are considered to be just below Sullivan Lake, an impoundment of Big Chino Wash. Upstream of this point lies a large drainage area that is dominated by intermittent flow (HUC 15060201). Within the Upper Verde watershed (HUC 15060202) from Sullivan Lake to Camp Verde, the Verde River flows through rugged country and drains high mountains to the north and east. Perennial flow in the Verde River is usually considered to start at the confluence with Granite Creek, just below Sullivan Lake. Granite Creek and its two tributaries originate in the mountainous area outside of Prescott. All three of these tributaries are dammed to provide water to the city of Prescott and the Chino Valley Irrigation District. Flow in Granite Creek is ephemeral at the point of confluence with the Verde River; however, about 25 percent of the baseflow in the Verde River at this point is believed to derive from groundwater transport out of the Granite Creek drainage (ADWR 2000).

The baseflow in the upper reaches of the Verde River is supported by groundwater discharges between Granite Creek and Paulden (Owen-Joyce and Bell 1983). From Paulden to Sycamore Creek the river gains additional groundwater discharges, primarily at Mormon Pocket. Sycamore Creek is an important tributary of the Verde River, draining the area west of Flagstaff, and has a spring-fed baseflow. The net result of these groundwater sources is a nearly constant baseflow of around 75 to 80 cfs at Clarkdale.

Groundwater throughout the Big Chino subwatershed occurs under both confined and unconfined conditions. Groundwater levels range from above surface due to confined conditions to over 200 feet below surface, with a depth to water in most wells of less than 80 ft (Schwab 1995). The major source of recharge for the Big Chino subwatershed is infiltration of runoff from the mountain fronts and flow within the major washes. Only a small percentage of the annual precipitation in the subwatershed reaches the groundwater table because the majority occurs in high intensity summer storm events and is lost as surface runoff, evaporation and transpiration by vegetation (Schwab 1995).

ADWR (2000) examined water budgets for 1996-97 for the Big Chino subwatershed plus the uppermost part of the Verde River to the USGS gage at Paulden and concluded that there was no net change in the groundwater storage. Inflows were estimated to be 26,760 acre-feet from natural recharge plus 8,010 acre-feet from incidental anthropogenic recharge. Of the total discharges, 19,050 acre-feet (55 percent) occurred as flow in the Verde River near Paulden and the remainder as groundwater pumpage.

An additional important factor in the hydrology of the Verde River watershed, particularly upstream of Paulden, is the construction of numerous stock pond impoundments used to capture surface runoff to support cattle ranching. These impoundments may act as recharge basins, but impede the flow of runoff that would otherwise have occurred. A survey of small impoundments upstream of Camp Verde was conducted in 1996. Approximately 2,635 impoundments ranging in size from 0.1 acres to approximately 350 acres in surface area were identified (ADWR 2000). No estimate of recharge has been calculated for these impoundments and no determination of the impact from restricting and/or impounding the natural runoff has ever been studied.

Salt River

The Salt River (including Tonto Creek) lies immediately to the east of the Verde River watershed and shares many similar characteristics. The model simulates these streams down to Roosevelt Reservoir (Figure 1). Like the Verde River watershed, the Salt River and Tonto Creek watersheds have high relief and are bounded by the Mogollon Rim. However, unlike the Verde watershed, these watersheds have less in the way of teleconnections to deep groundwater. Perennial springs are important in the upper reaches of the Salt; however, most of the water

discharged by these springs appears to derive from local sources. The Salt River watershed also has much less human influence than the Verde, with only 1.5 percent of the land area in private ownership. The bulk of the watershed is under tribal or US Forest Service ownership.

San Pedro River

The San Pedro River, a tributary of the Gila River, flows northward from the Arizona-Mexico border (Figure 2). The watershed consists of a large alluvial valley flanked by mountain ranges. The river is perennial in the southern (upstream) reaches, but only intermittent in the northern (downstream) reaches. As with the Verde River and Salt River watersheds, precipitation and temperature vary strongly with elevation, with most of the precipitation occurring at the higher elevations. The perennial portions of the river support important desert riparian forest habitat, and most of this section is contained within the San Pedro Riparian National Conservation Area.

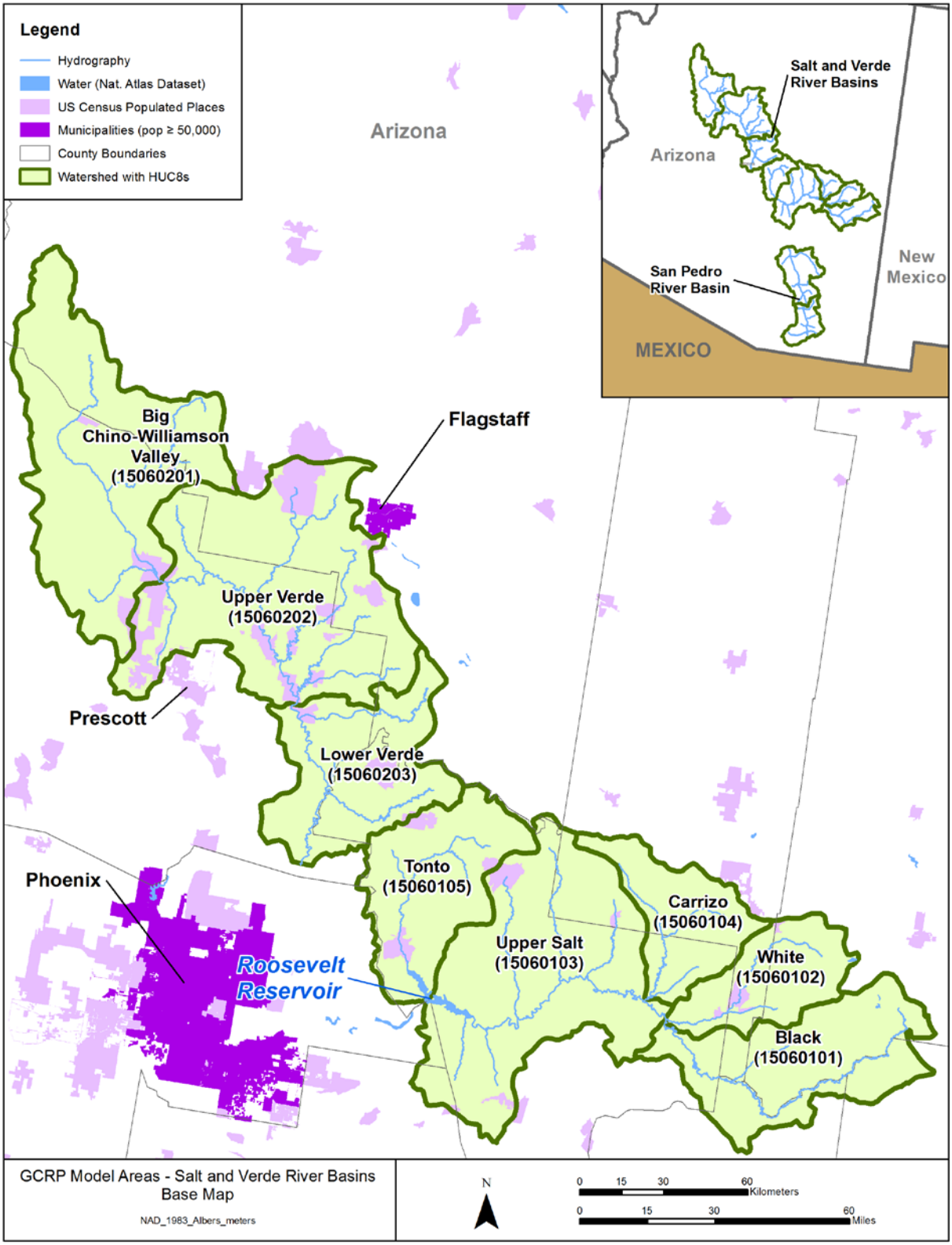


Figure 1. The Arizona basins – Verde and Salt River sections.

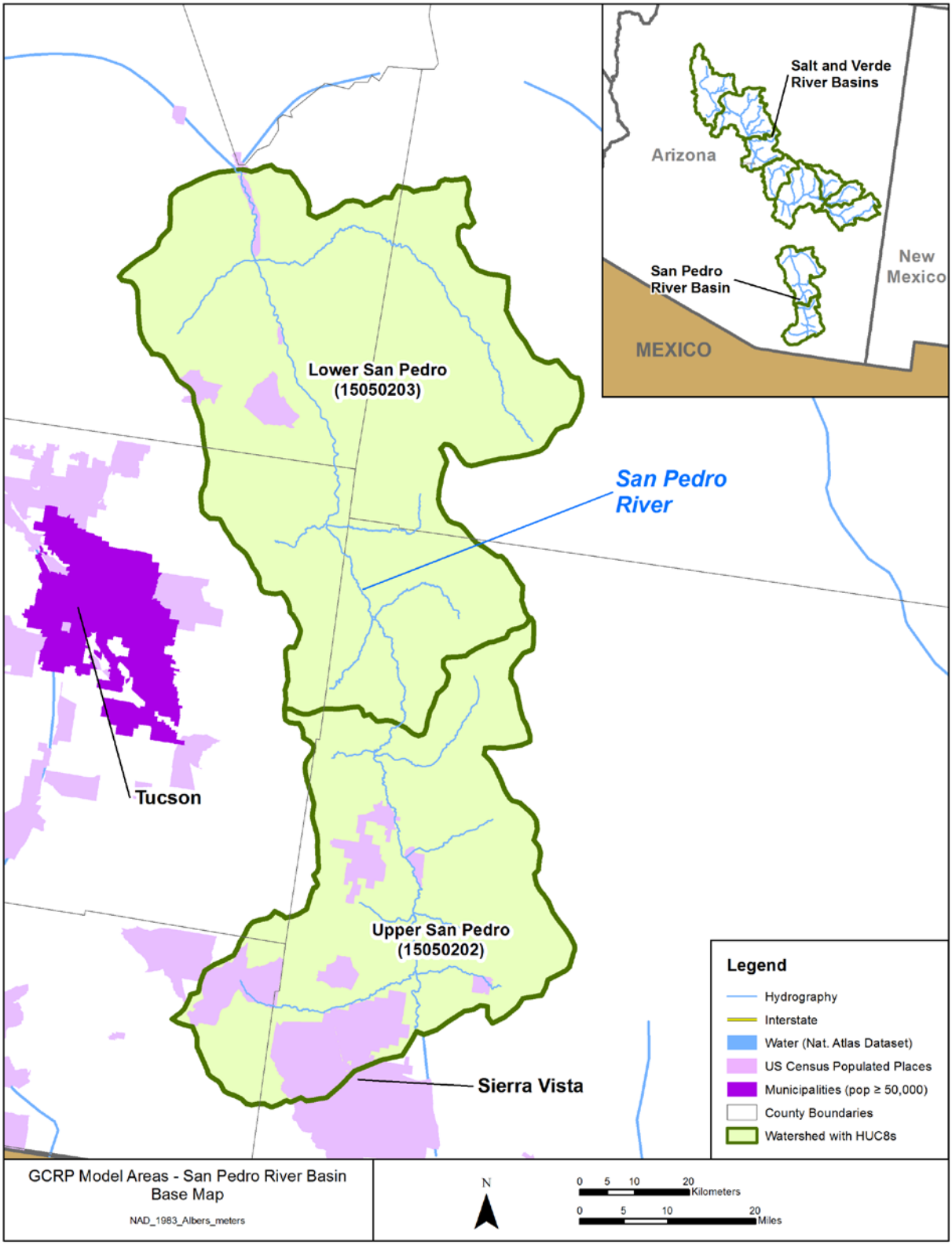


Figure 2. The Arizona basins – San Pedro River section.

Soil Characteristics

The hydrology of the Arizona Basin is strongly influenced by the soils and underlying geology of the watershed. These in turn reflect the complex geologic history of Arizona, which includes periods of marine inundation, volcanism, and uplift.

One of the most important characteristics of soils for watershed modeling is their hydrologic soil group (HSG). The 20 Watershed study utilized STATSGO soil survey HSG information during model set-up. Soils are classified into four hydrologic groups (SCS 1986), separated by runoff potential, as follows:

- A — Low runoff potential and high infiltration rates even when thoroughly wetted. Chiefly deep, well to excessively drained sands or gravels. High rate of water transmission (> 0.75 cm/hr).
- B — Moderate infiltration rates when thoroughly wetted. Chiefly moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. Moderate rate of water transmission (0.40—0.75 cm/hr).
- C — Low infiltration rates when thoroughly wetted. Chiefly soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. Low rate of water transmission (0.15—0.40 cm/hr).
- D — High runoff potential. Very low infiltration rates when thoroughly wetted. Chiefly clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, or shallow soils over nearly impervious material. Very low rate of water transmission (0—0.15 cm/hr).

The soils in the Verde River watershed are predominantly hydrologic group B soils while soils in the San Pedro River watershed are predominantly hydrologic group C soils. The Salt River watershed contains almost equal amounts of B, C, and D soils with a slight dominance of B soils.

Land Use Representation

Land use in the watershed is based on the 2001 National Land Cover Database (NLCD) coverage (Figure 3 and Figure 4) and is predominantly scrub/shrub chaparral blending into Sonoran paloverde at lower elevations and pinyon-juniper evergreen forest at higher elevations. Only a few small municipalities are located in the study watersheds and much of the land is in federal ownership.

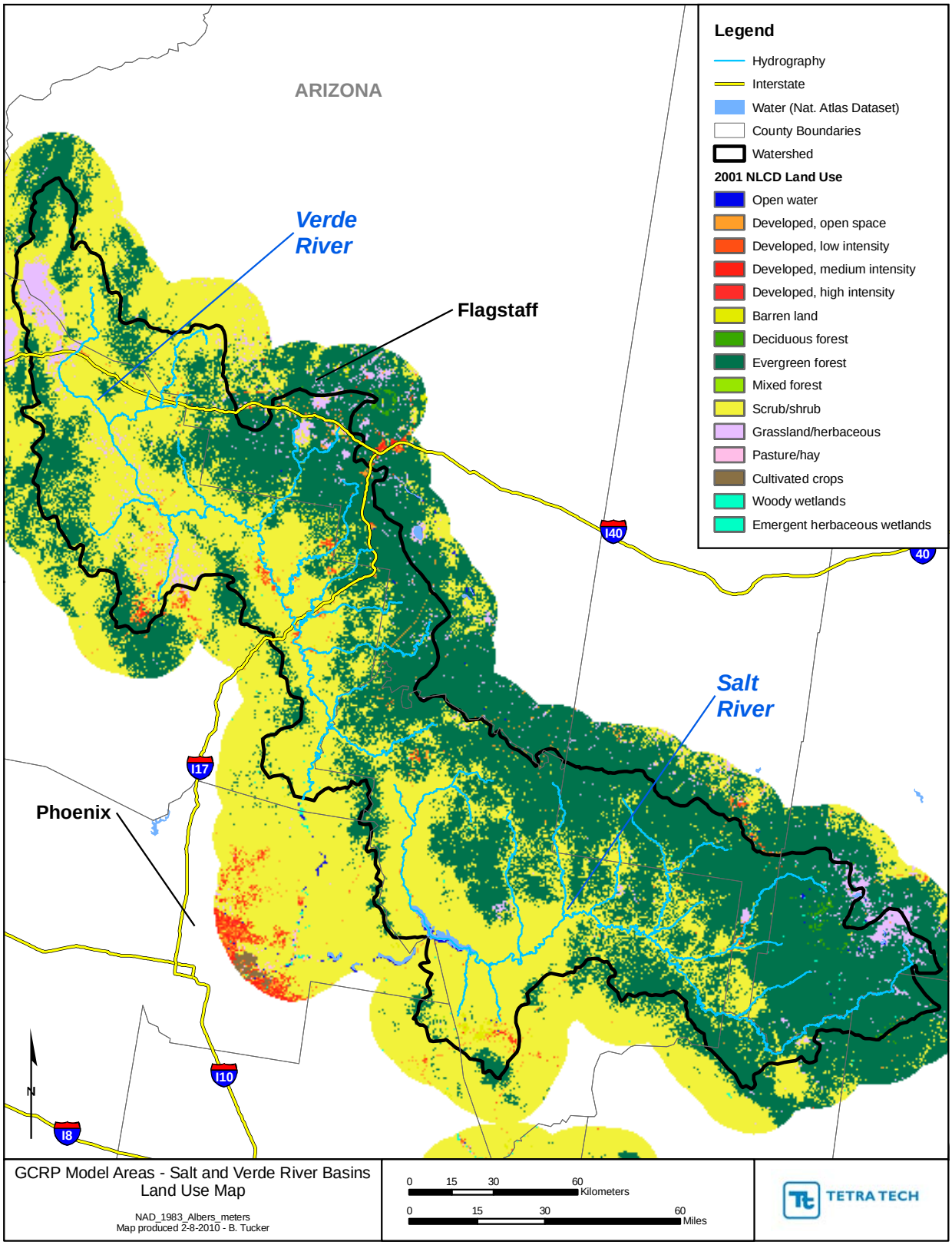


Figure 3. Land use in the Arizona basin – Verde and Salt River section.

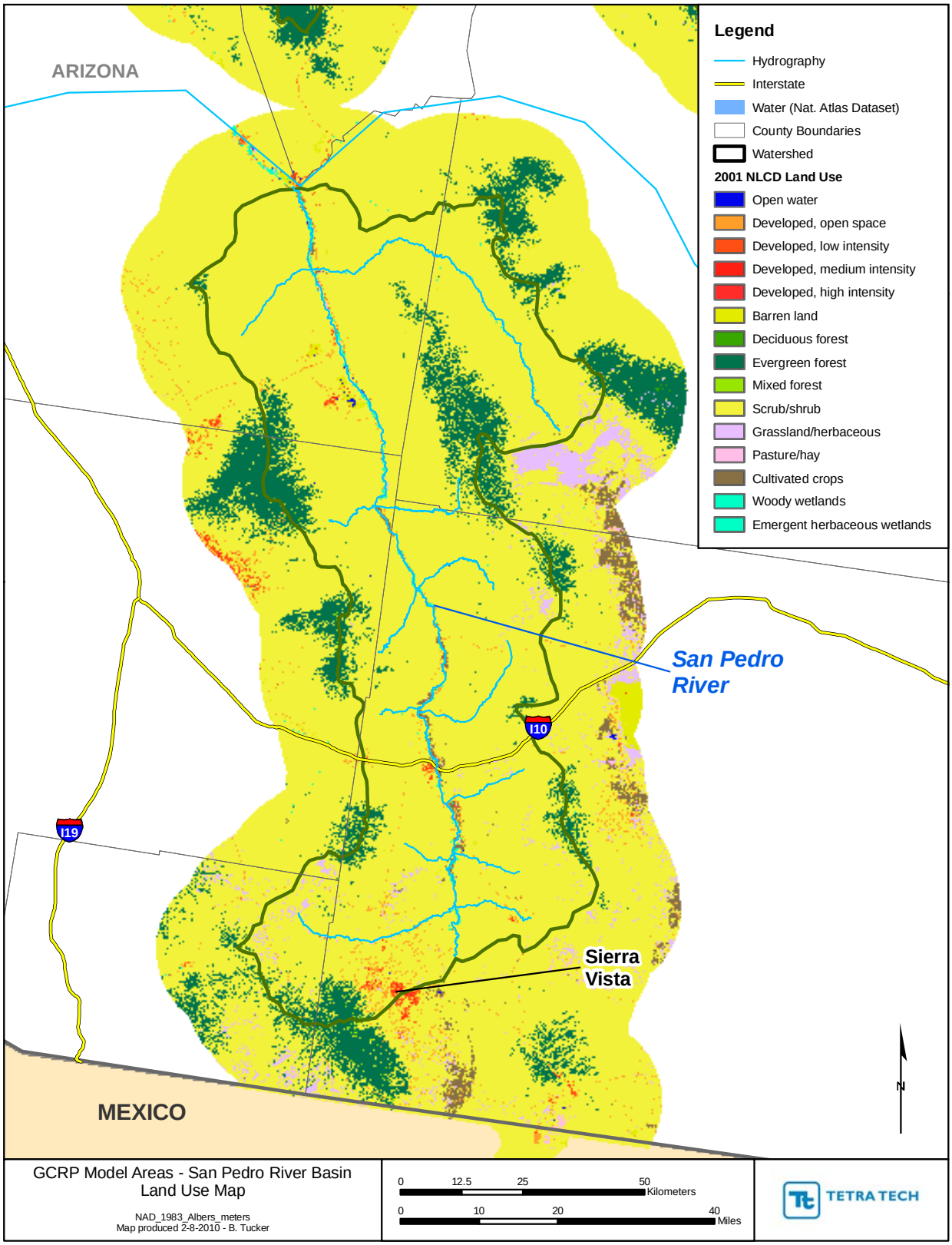


Figure 4. Land use in the Arizona basin – San Pedro River section.

NLCD land cover classes were aggregated according to the scheme shown in Table 1 then overlain with the soils HSG grid. Minor land uses with less than 5 percent coverage within a subwatershed were reassigned to more dominant classes. Pervious and impervious lands are specified separately for HSPF, so only one developed pervious class is used, along with an impervious class. HSPF simulates impervious land areas separately from pervious land. Impervious area distributions were also determined from the NLCD Urban Impervious data coverage. Specifically, percent impervious area was calculated over the whole basin for each of the four developed land use classes. These percentages were then used to separate out impervious land. NLCD impervious area data products are known to underestimate total imperviousness in rural areas. However, the model properly requires connected impervious area, not total impervious area, and the NLCD tabulation is assumed to provide a reasonable approximation of connected impervious area. Different developed land classes are specified separately in SWAT. In HSPF the WATER, BARREN, DEVPERV, and WETLAND classes are not subdivided by HSG; SWAT uses the built-in HRU overlay mechanism in the ArcSWAT interface.

Table 1. Aggregation of NLCD land cover classes

NLCD Class	Comments	SWAT class	HSPF (after processing)
11 Water	Water surface area usually accounted for as reach area	WATR	WATER
12 Perennial ice/snow		WATR	BARREN, Assume HSG D
21 Developed open space		URLD	DEVPERV; IMPERV
22 Dev. Low Intensity		URMD	
23 Dev. Med. Intensity		URHD	
24 Dev. High Intensity		UIDU	
31 Barren Land		SWRN	BARREN (D)
41 Forest	Deciduous	FRSD	FOREST (A,B,C,D)
42 Forest	Evergreen	FRSE	
43 Forest	Mixed	FRST	
51-52 Shrubland		RNGB	SHRUB (A,B,C,D)
71-74 Herbaceous Upland		RNGE	GRASS (A,B,C,D), BARREN (D)
81 Pasture/Hay		HAY or GRASS	GRASS (A,B,C,D)
82 Cultivated		AGRR	AGRI (A,B,C,D)
91-97 Wetland	Emergent & woody wetlands	WETF, WETL, WETN	WETLAND, Assume HSG D
98-99 Wetland	Aquatic bed wetlands (not emergent)	WATR	WATER

The distribution of land use in the watershed is summarized in Table 2. Note that the small areas in crop and hay production along the Verde mainstem and elsewhere do not meet the 5 percent threshold requirement in SWAT and are thus not explicitly included in the model; instead, the developed pervious land use implicitly includes those areas in crop production for SWAT.

Table 2. Land use distribution for the Arizona basins (2001 NLCD) (mi^2)

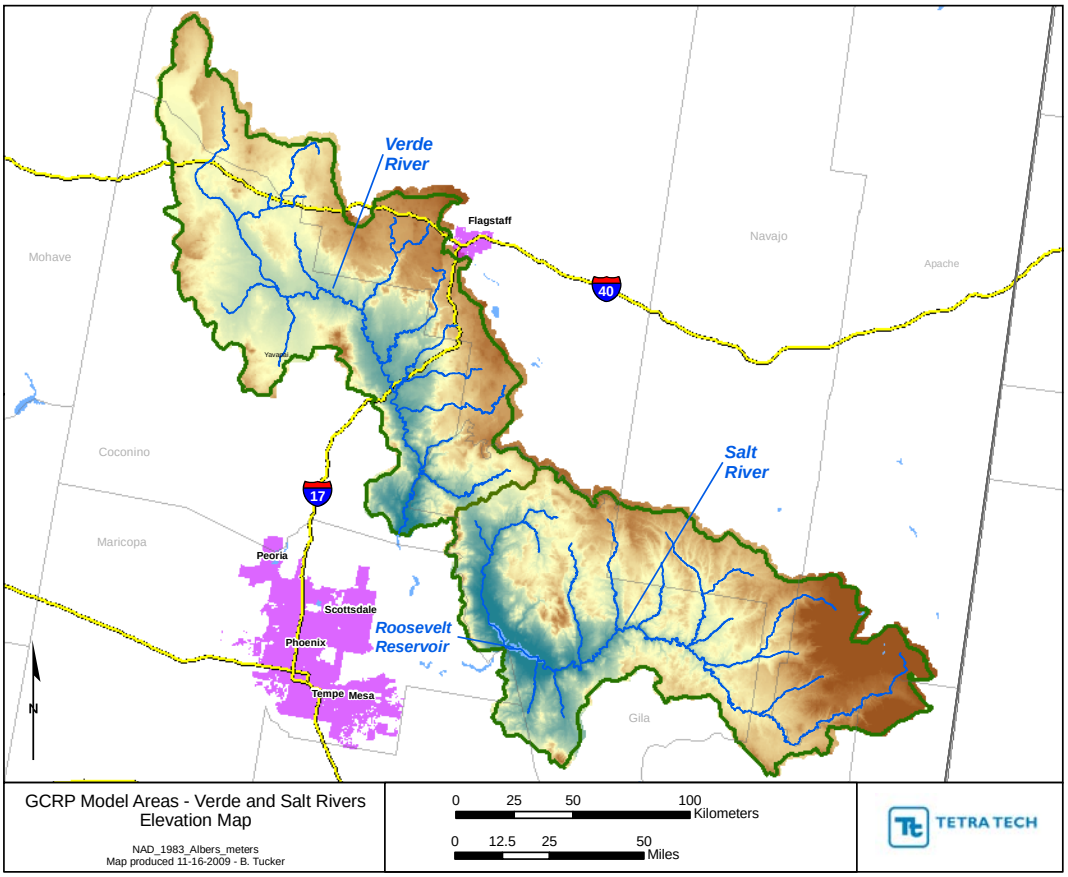
HUC 8 watershed	Open Water	Developed[a]				Barren Land	Forest	Shrubland	Pasture/Hay	Cultivated	Wetland	Total
		Open space	Low Density	Medium Density	High Density							
Upper San Pedro **15050202**	0.1	19.2	4.9	1.2	0.2	0.4	64.2	1,129.2	1.5	9.9	4.5	1,235.2
Lower San Pedro **15050203**	1.4	8.3	2.2	0.3	0.1	6.6	179.1	1,791.7	1.5	7.5	12.5	2,011.2
Black **15060101**	1.8	1.8	0.2	0.0	0.0	0.6	1,026.3	217.9	0.0	0.0	2.0	1,250.7
White **15060102**	1.6	4.5	1.2	0.2	0.0	0.5	537.2	89.9	0.1	0.0	3.2	638.4
Upper Salt **15060103**	16.7	10.4	5.1	1.4	0.3	14.0	950.1	1,251.9	0.7	0.0	4.7	2,255.2
Carrizo **15060104**	0.0	2.7	0.2	0.0	0.0	1.4	586.4	118.5	0.0	0.0	0.4	709.8
Tonto **15060105**	0.0	4.6	1.2	0.1	0.0	0.6	443.7	494.9	0.3	0.0	1.9	947.1
Big Chino-Williamson Valley **15060201**	0.1	11.8	3.5	0.2	0.0	3.8	615.8	1,514.8	1.4	0.0	0.9	2,152.4
Upper Verde **15060202**	1.2	48.0	25.1	5.3	0.6	15.3	1,256.8	1,143.2	2.5	0.0	6.1	2,504.1
Lower Verde **15060203**	0.3	9.8	4.0	0.4	0.1	1.0	582.0	601.3	1.9	0.0	4.6	1,205.4
Total	23.2	121.2	47.7	9.0	1.3	44.3	6,241.7	8,353.2	10.0	17.4	40.7	14,909.6

[a]The percent imperviousness applied to each of the developed land uses is as follows: open space (7.37%), low density (29.66%), medium density (53.71%), and high density (73.85%).

The HSPF model is set up on a hydrologic response unit (HRU) basis. For HSPF, HRUs were formed from an intersection of land use and hydrologic soil group, then further subdivided by precipitation gage and slope. SWAT HRUs were formed from an intersection of land use and SSURGO major soils.

Topography

The Salt, Verde, and San Pedro River watersheds are characterized by high relief (Figure 5) and precipitation and temperature vary greatly with elevation. The largest precipitation amounts and lowest temperatures occur at the high elevations along the Mogollon Rim on the north and east sides of the Salt and Verde River watersheds.



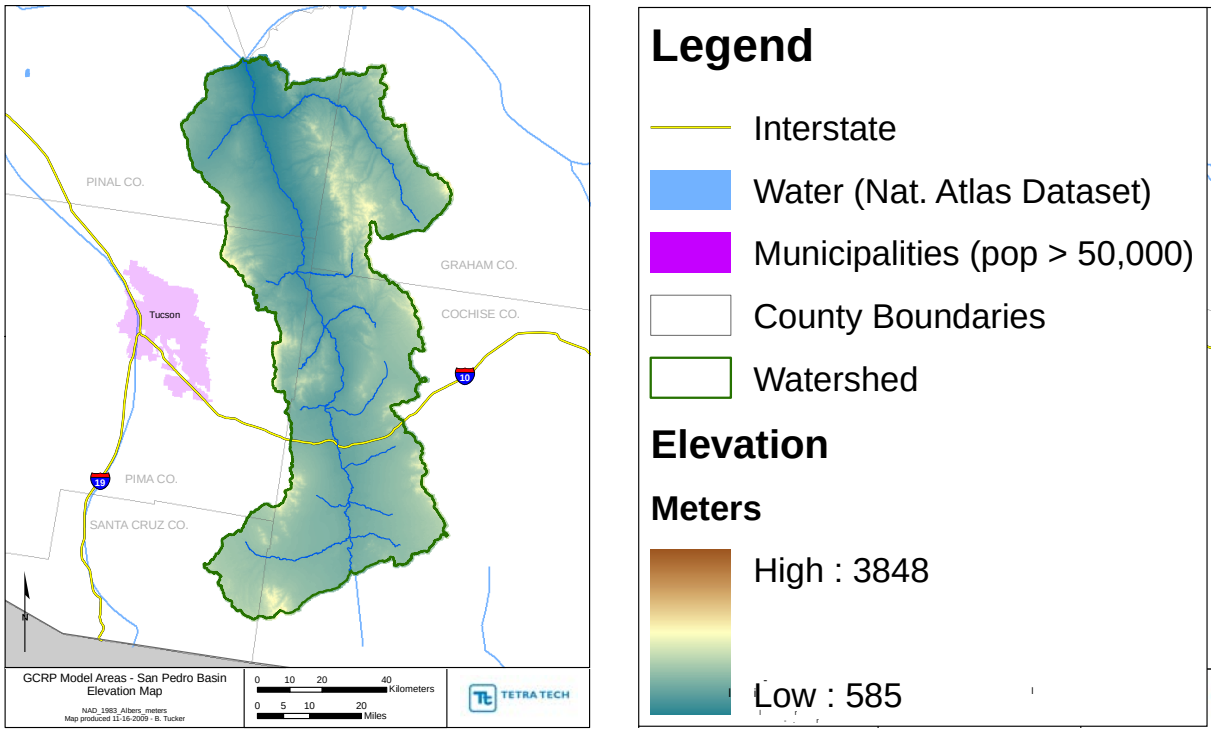


Figure 5. Topography of the Arizona Basins.

Point Sources

Only the two major dischargers with a design flow greater than 1 MGD are included in the simulation (Table 3 and Figure 6). These dischargers are Page Springs Fish Hatchery and the Pinal Creek Wastewater Treatment Plant (WWTP) in Globe, Arizona. Because of the arid climate and low population in the study watersheds, much of the wastewater that is generated is either used for irrigating golf courses or discharged to ephemeral washes that lack a direct surface connection to the river system.

Table 3. Major point source discharges in the Arizona basins

NPDES ID	Name	Design Flow (MGD)	Observed Flow (MGD) (1991-2006 average)
AZ0021245	Page Springs Fish Hatchery (AZ Game and Fish Department)	20.35	21.92
AZ0020249	Pinal Creek WWTP (City of Globe, AZ)	1.20	12.54

The discharges from Page Springs Fish Hatchery to Oak Creek are largely composed of natural groundwater. Some of this groundwater arises within the local subwatershed, and is thus already accounted for in the model. To prevent double-counting of this water, the reported discharges were reduced significantly to provide an approximate match to observed base flows in Oak Creek.

Several other smaller discharges reported in the study area were determined to be used primarily for irrigation or discharge to dry washes, do not cause live stream discharges and so are not explicitly included in the model. The San Jose WWTP major discharge at Bisbee, Arizona is in part used for irrigation, but also discharges to Greenbush Draw, tributary to the San Pedro. However, it enters the San Pedro upstream of the modeled area.

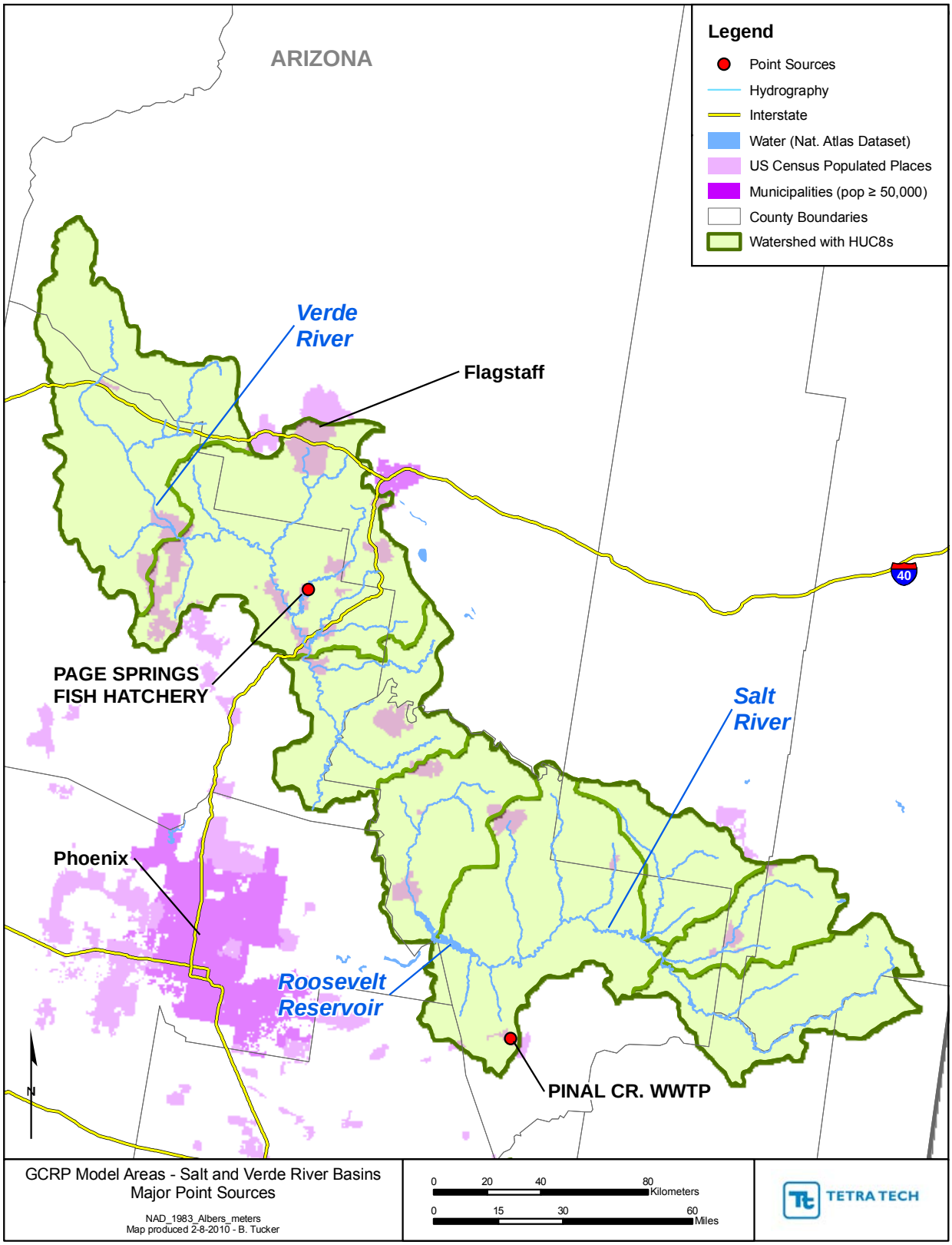


Figure 6. Major point sources in the Arizona basins.

Meteorological Data

The required meteorological data series for the 20 Watershed study are precipitation, air temperature, and potential evapotranspiration. The 20 Watershed model does not include water temperature or algal simulation and uses a degree-day method for snowmelt. These meteorological data are drawn from the BASINS4 Meteorological Database (USEPA 2008), which provides a consistent, quality-assured set of nationwide data with gaps filled and records disaggregated. Scenario application will require simulation over 30 years, so the available stations are those with a common 30-year period of record (or one that can be filled from an approximately co-located station) that covers the year 2001. A total of 29 precipitation stations were identified for use in the Arizona basins model with a common period of record of 10/1/1972-9/30/2002 (Table 4 and Figure 7 and Figure 8). Temperature records are sparser; where these are absent, temperature is taken from nearby stations with an elevation correction. For each weather station, Penman-Monteith reference evapotranspiration was calculated for use in HSPF using observed precipitation and temperature coupled with SWAT weather generator estimates of solar radiation, wind movement, cloud cover, and relative humidity.

For the 20 Watershed model applications, SWAT uses daily meteorological data, while HSPF requires hourly data. It is important to note that a majority of the meteorological stations available for the Arizona basins are Cooperative Summary of the Day stations that do not report sub-daily data. The BASINS4 dataset already has versions of the daily data that have been disaggregated to an hourly time step using template stations. For each daily station, this disaggregation was undertaken in reference to a single disaggregation template. Occasionally, this automated procedure provides undesirable results, particularly when the total rainfall for the day is very different between the subject station and the disaggregation template.

Table 4. Precipitation stations for the Arizona models

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (ft)
AZ020159	Alpine	33.8493	-109.146	X	8049
AZ020487	Ash Fork 3	35.199	-112.488		5074
AZ020670	Beaver Creek	34.6418	-111.783	X	3523
AZ020683	Benson 6 SE	31.8803	-110.24	X	1125
AZ020808	Black River Pumps	33.4783	-109.751	X	6065
AZ021231	Canelo 1 NW	31.559	-110.529		1527
AZ021330	Cascabel	32.3208	-110.413	X	959
AZ021614	Childs	34.3495	-111.698	X	2650
AZ021654	Chino Valley	34.757	-112.456	X	4749
AZ021870	Cochise 4 SSE	32.059	-109.89	X	1274
AZ022140	Coronado NM Hdqtrs	31.3457	-110.254	X	1598
AZ023010	Flagstaff AP	35.1442	-111.666	X	7003
AZ023828	Happy Jack RS	34.7433	-111.413	X	7478
AZ024453	Jerome	34.7523	-112.111	X	4950
AZ025512	Miami	33.4045	-110.87	X	3559
AZ026323	Payson	34.2315	-111.339	X	4907
AZ026601	Pinetop 2E	34.1243	-109.921		7200
AZ026653	Pleasant Valley RS	34.099	-110.944	X	5048
AZ026796	Prescott	34.5706	-112.432	X	5202
AZ026840	Punkin Center	33.8557	-111.306	X	2326

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (ft)
AZ027281	Roosevelt 1 WNW	33.6731	-111.15	X	2204
AZ027530	San Manuel	32.6014	-110.633	X	1055
AZ027708	Sedona	34.8957	-111.764	X	4218
AZ027716	Seligman	35.3323	-112.879	X	5248
AZ028619	Tombstone	31.7057	-110.056	X	1405
AZ028650	Tonto Creek Fish Hatchery 2	34.3839	-111.097		6389
AZ029158	Walnut Creek	34.9282	-112.809	X	5087
AZ029271	Whiteriver 1 SW	33.8169	-109.983	X	5120
AZ029359	Williams	35.2407	-112.19	X	6747

Orographic effects on precipitation and temperature are important throughout the region. This is addressed through use of the elevation bands option and the imposition of precipitation and temperature lapse rates in the SWAT model. All SWAT model subwatersheds are assigned at least one elevation band, and multiple elevation bands are used when the interquartile range of elevations within a subwatershed exceeds 375 m. For HSPF, whenever the precipitation station was located outside or near the edge of a model segment, a multiplier was applied to the data based on the ratio of the estimated median annual rainfall from isohyetal information and the long term annual average for the station. The evaporation data appeared to be estimates of pan evaporation, and ranged from 70 to 100 inches per year. They were therefore adjusted by a factor of 0.7 to reduce them to potential evapotranspiration. Some of the multipliers were adjusted slightly during the hydrology calibration.

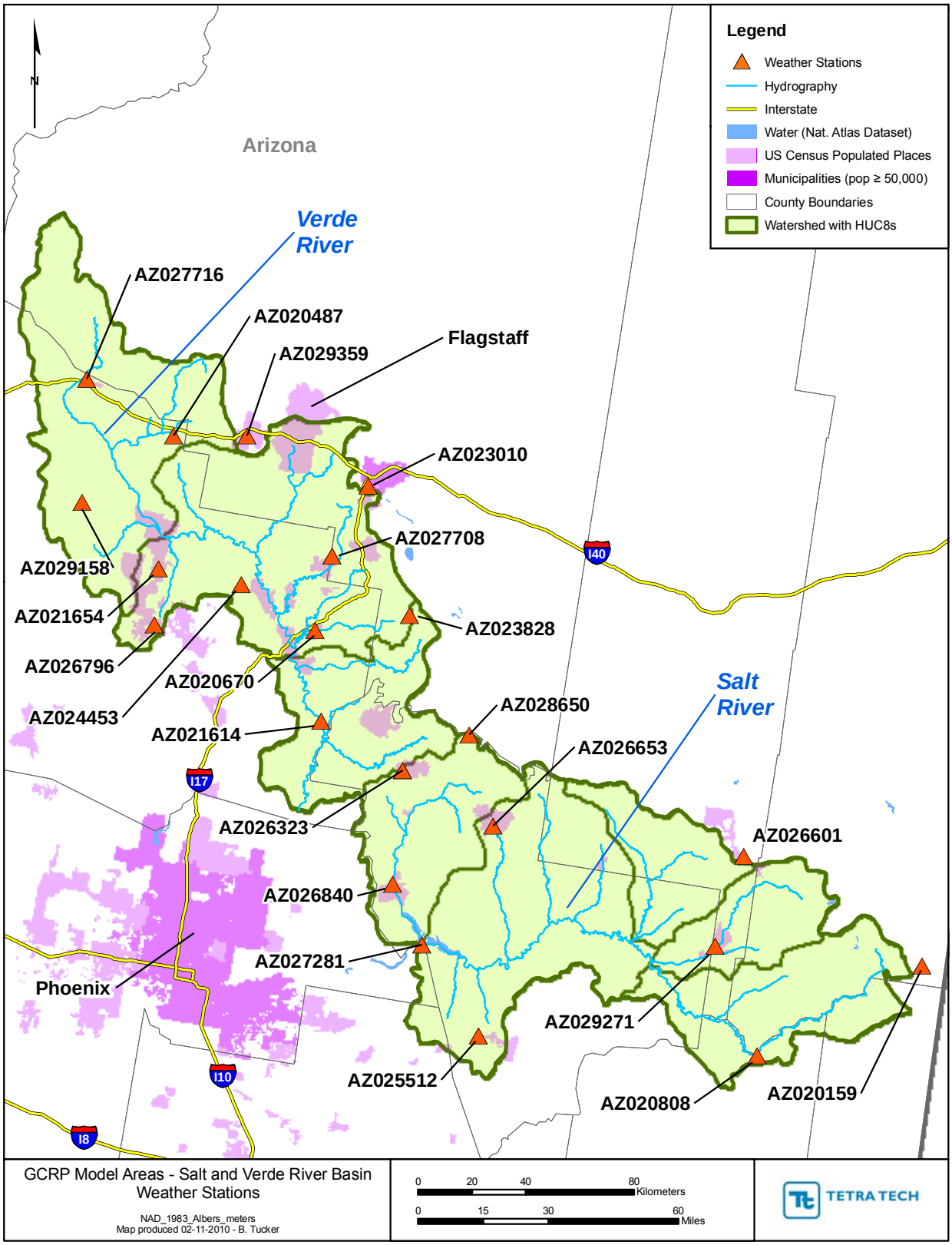


Figure 7. Weather stations for the Arizona basins model – Verde and Salt River section.

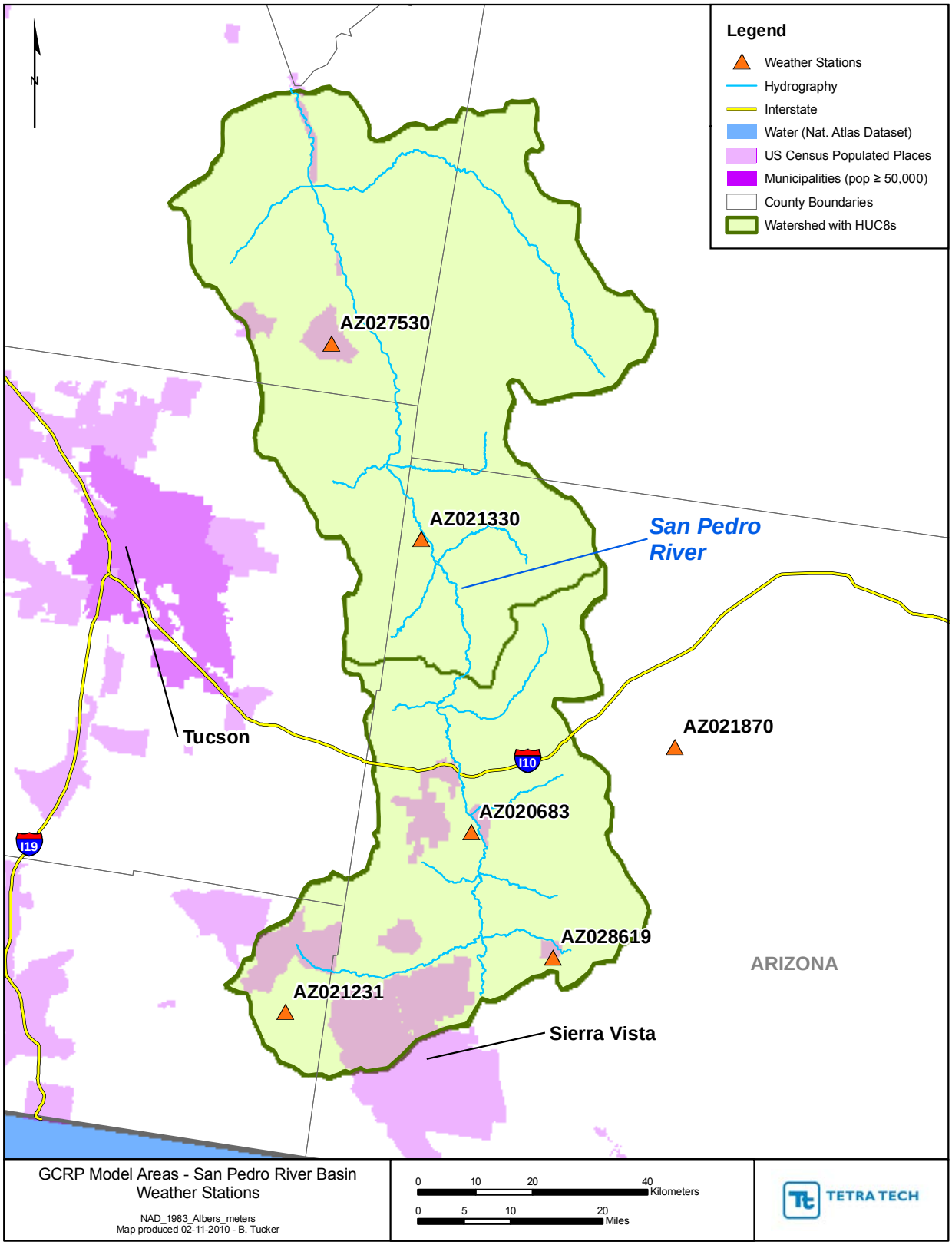


Figure 8. Weather stations for the Arizona basins model – San Pedro River section.

Watershed Segmentation

The Arizona basins were divided into 81 subwatersheds for the purposes of modeling (Figure 9 and Figure 10) – 30 in the Verde, 28 in the Salt, and 23 in the San Pedro river models. Initial calibration was conducted on the Verde River at Clarkdale. However, the parameters derived at this station were not fully transferable to other portions of the watershed, and additional calibration was conducted at multiple gage locations.

The Verde and Salt River models encompass entire watersheds upstream of major reservoirs – thus upstream boundary conditions are not required. However, for the Verde River watershed, boundary conditions are needed to account for the large influx of deep groundwater (much of it ultimately derived from infiltration many miles away in the Chino watershed) that enters the river in the reach near Paulden, Arizona.

The San Pedro River watershed extends into Mexico; however, the geospatial and meteorological data used to build the 20 Watershed models do not cover Mexico. Therefore, the San Pedro is simulated with an upstream boundary condition at the USGS gage on the San Pedro River at Charleston, Arizona (09471000). This is the most upstream gage with near complete records for the simulation period; the gage at Palominas (09470500), although closer to the Mexican border, has long periods of missing records.

Major reservoirs are generally avoided in the model setup; however, it is also necessary to account for storage in smaller reservoirs and stock ponds. For SWAT, these are specified using the Ponds option, based on information in ADWR (2009) and, for the Verde watershed, Tetra Tech (2001). Significant pond storage is considered in subwatersheds 11, 13, 15, 16, 17, 18, 19, 23, 25, 26, and 27 for the Verde River watershed. In the Salt River watershed there are reservoirs with nominal storage capacity near 25,000 acre feet in subwatersheds 20 and 21, although the normal capacity is only a fraction of this total. As these are headwater subwatersheds, these reservoirs are also treated as ponds. No reservoirs or ponds are simulated in the San Pedro watershed.

It should be noted that Sullivan Lake, at the head of the perennial portion of the Verde River watershed (subwatershed 14), intercepts flows out of the Chino watershed and has a significant impact on the progression of flood waves downstream. This lake is not directly represented in the model due to lack of information on storage characteristics.

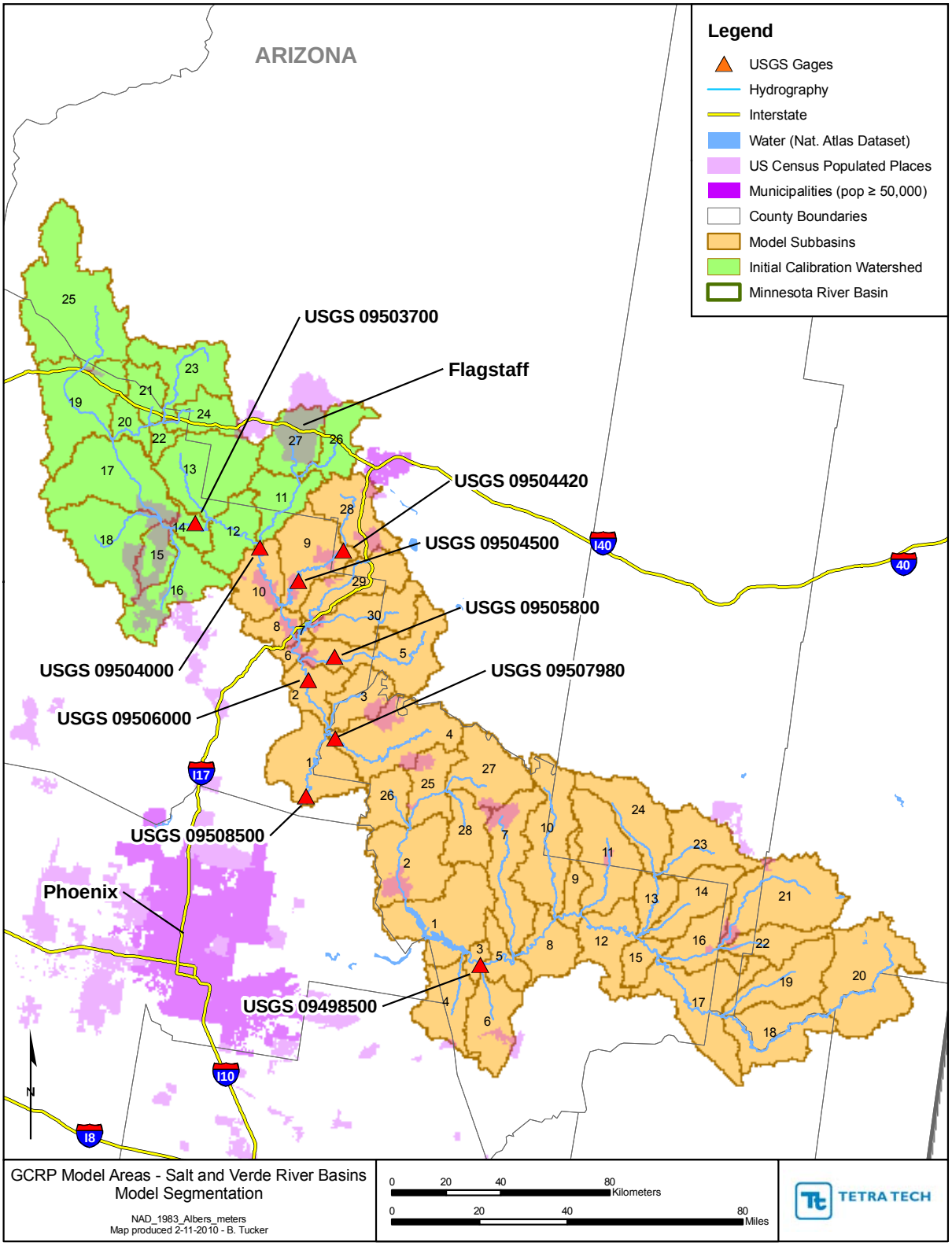


Figure 9. Model segmentation USGS stations utilized for the Arizona basins – Verde and Salt River section.

Note: SWAT subwatersheds numbering is shown; the HSPF model for this watershed uses the same subwatershed boundaries with an alternative internal numbering scheme.

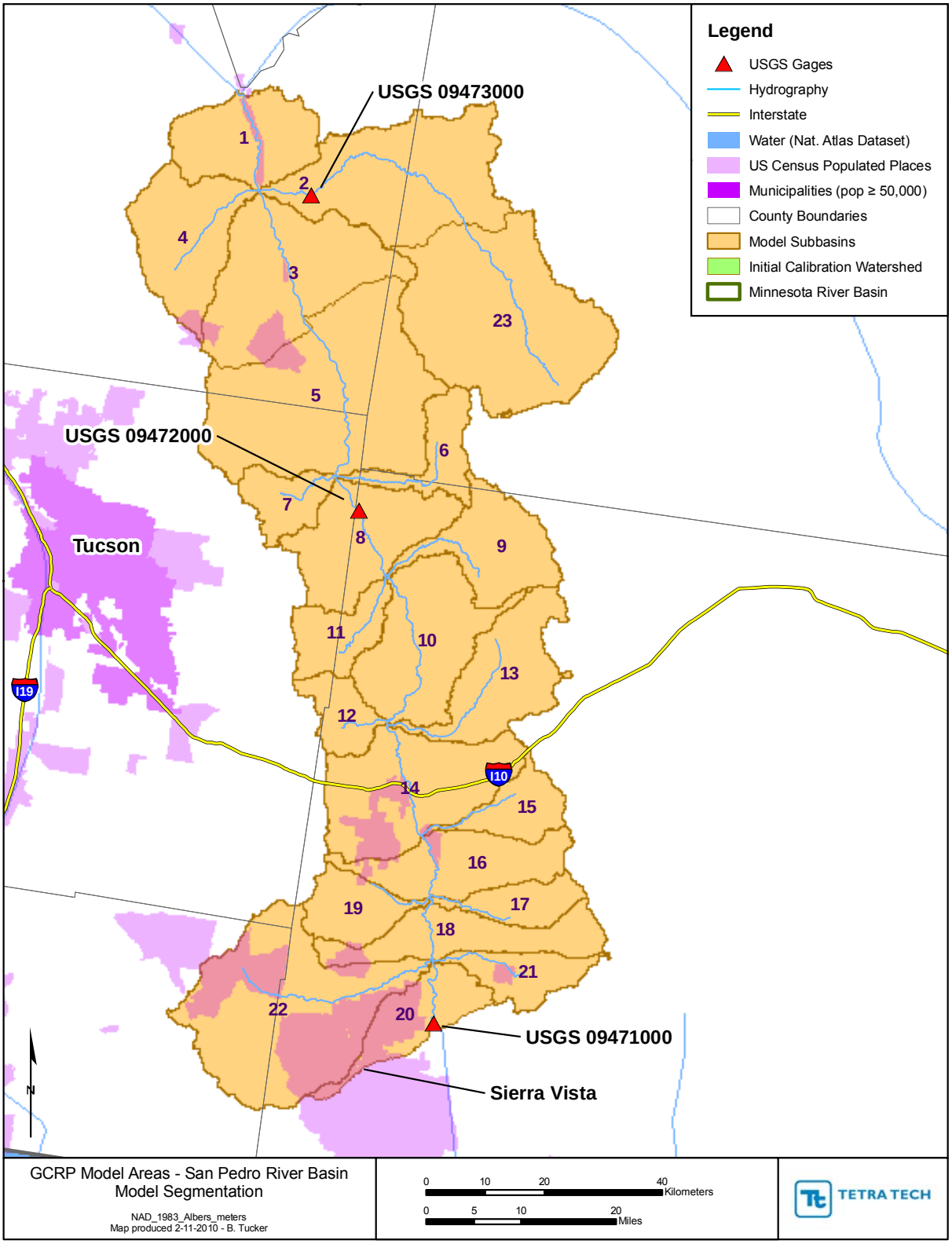


Figure 10. Model segmentation USGS stations utilized for the Arizona basins – San Pedro River section.

Note: SWAT subwatersheds numbering is shown; the HSPF model for this watershed uses the same subwatershed boundaries with an alternative internal numbering scheme.

Calibration Data and Locations

The site selected for initial calibration was the Verde River near Clarkdale, AZ (USGS gage 09504000); however, calibration and validation were pursued at multiple locations (Table 5, Figure 9 and Figure 10).

Table 5. Calibration and validation locations in the Arizona basins

Station name	USGS ID	Drainage area (mi^2)	Hydrology calibration	Water quality calibration
San Pedro River near Redington, AZ	09472000	2,927	X	
Aravaipa Creek near Mammoth,AZ	09473000	537	X	
Salt River near Roosevelt, AZ	09498500	4,306	X	X
Verde River near Paulden, AZ	09503700	2,507	X	
Verde River near Clarkdale, AZ	09504000	3,503	X	X
Oak Creek near Cornville, AZ	09504500	355	X	
West Clear Creek near Camp Verde, AZ	09505800	241	X	
Verde River near Camp Verde, AZ	09506000	5,009	X	X
East Verde River near Childs, AZ	09507980	331	X	
Verde River below Tangle Creek	09508500	5,858	X	X

The model hydrology calibration period was set to Water Years 1993-2002, with some variation according to gage variability. The end date was constrained by the common period of the set of 20 Watershed meteorological stations available for the watershed, and a 10 year calibration period was desired. Calibration was done on the later data, because of concerns that there may have been changes in land use and management over time. Hydrologic validation was then performed on Water Years 1983-1992. Water quality calibration used calendar years 1993-2002, while validation used 1986-1992, as limited data were available prior to 1986.

Other Relevant Features

Along the mainstem of the Verde River between Clarkdale and Camp Verde and on several tributaries there are substantial water diversions to support riparian agricultural production, primarily hay. ADWR (2000) identifies 24 diversion structures on the Verde River proper from near Clarkdale to below Camp Verde, 32 diversions along Oak Creek, and 12 diversions along Wet Beaver Creek, as well as several in other locations, and estimates that the total agricultural diversion amount between Perkinsville and Horseshoe Reservoir (most of it occurring in the Verde Valley, Oak Creek, and Wet Beaver Creek) amounts to 31,668 acre-feet per year. Very little of the water diverted for irrigation returns as surface flow (Owen-Joyce and Bell 1983); however, a substantial portion may return as subsurface flow. The water applied from these diversions is represented as irrigation applications in the model. During development of the previous SWAT model for the Verde it was found that a direct linkage of irrigation applications to river withdrawals did not provide satisfactory results and indeed tended to cause model instability. Therefore, the withdrawals and irrigation are uncoupled in the model: irrigation is represented as nominally occurring from an external source, while withdrawals from the river are specified separately as a consumptive use that occurs during the April-September growing season. Consumptive use withdrawals are applied to Verde model subwatersheds 6, 8, 9, 10, and 30. The status of agricultural diversions in the Salt and San Pedro watersheds is not fully known; however, growing season diversions from the river are assigned to improve flow closure, being assigned to subwatershed 8 in the San Pedro watershed and subwatershed 5 in the Salt River watershed.

A separate representation is used for the Prescott Valley area of the Verde River watershed model (subwatershed 16). Here, agriculture is supported by water stored in two small reservoirs (Granite and Willow). For this subwatershed, irrigation is represented as linked to and derived from water stored in these reservoirs (represented as ponds in the SWAT model).

Special notes are required regarding the East Verde River (Verde model subwatershed 4). The town of Payson, Arizona obtains its municipal supply from groundwater, which is pumped from the alluvium of the East Verde. The groundwater supply appears to be directly connected to surface water, and causes the East Verde to go dry at times. However, there is also a source of imported water in the East Verde, as water is brought from across the Mogollon Rim divide and discharged into the East Verde to augment Payson supplies. Detailed documentation was not obtained. For the purposes of the 20 Watershed model it is assumed that the imported water is essentially all consumed by Payson. Therefore, the stream is simulated as a losing reach, but the imported water is not explicitly simulated. Payson's wastewater discharges leave the watershed, and are primarily used for golf course irrigation in the Tonto Creek watershed (subwatershed 26 in the Salt River model).

HSPF Modeling

Changes Made to Base Data Provided

No changes were made to the meteorological or land use base data. Similar to the SWAT modeling, the Globe, Arizona point source total nitrogen and total phosphorus concentrations were reduced, since the recommended concentrations did not permit a reasonable calibration of total nitrogen and total phosphorus at the Roosevelt station.

Assumptions

An important feature of the Arizona basins is the complex interaction of surface and groundwater. As noted earlier, neither SWAT nor HSPF is capable of providing a detailed, process-based simulation of groundwater flow. It is therefore assumed that interactions with groundwater can be handled with the following simplifying assumptions:

- The local (within subwatershed) accumulation and discharge of shallow groundwater is adequately addressed by HSPF's active groundwater formulation.
- Discharges to streams from deep groundwater are represented as constant point sources, with discharge rates set based on flow information on major springs identified in the Arizona Water Atlas (ADWR 2009). This means that the model cannot account for seasonal variability in deep groundwater discharge, nor can it evaluate how such discharges may evolve in response to climate change.
- Losses to groundwater from stream reaches in alluvial basins are simulated based on channel conductivity. This makes such losses a function of flow and depth in the affected reaches. The HSPF model formulation, which is incorporated in the stream reach FTABLEs as a volume-based loss term does not take into account changes in local groundwater head; instead, the loss occurs continuously.

In the Verde River watershed, irrigation withdrawals and applications were modeled (similarly to the SWAT model) in the Verde Valley between Clarkdale and Camp Verde based on information provided in ADWR (2009). A total of 31,668 ac-ft/yr is withdrawn during April-September from selected reaches based on the relative amounts of grass and developed area in the reach watersheds. The HSPF irrigation module was used to apply this water to the grass and developed PERLND's using a constant application of 0.11 inches/day during the April-September period.

Hydrology Calibration

The starting parameters for the Arizona HSPF model were developed from an HSPF model of the San Francisco Bay area watersheds, particularly watersheds in eastern Alameda County. After the starting parameters were inserted into the model input files, average annual potential evapotranspiration values were computed and compared to published values. Through this process it was determined the input potential evapotranspiration time series should be reduced by multipliers, since the computation of these time series produced more PET on an average annual basis than the published values indicate. The default multipliers used for PET were 0.70; however, some of the multipliers were adjusted slightly during the hydrology calibration. Calibration adjustments focused on the following parameters:

- LZSN (lower zone nominal storage): LZSN was generally reduced from the initial values to shift flows to the wet period and reduce them in the summer. It was also used to increase total runoff.

- INFILT (index to mean soil infiltration rate): Infiltration was generally decreased from the high initial values to increase storm peaks, reduce low flows, and increase surface runoff.
- DEEPFR (fraction of groundwater inflow that will enter deep groundwater): small values of DEEPFR were used to attempt to reduce low flows and to reduce total flow volume. In the Salt River, the initial low values were not adjusted. In the Verde River at Paulden, DEEPFR was increased to a high value to represent the recharge losses in the Chino Basin; some of this groundwater returns to the river below the Paulden gage.
- BASETP (ET by riparian vegetation): Generally BASETP was increased over the initial values in order to provide some ET by riparian vegetation and improved the simulation of low flows.
- LZETP (lower zone E-T parameter): LZETP was generally increased to reduce flow, particularly the low flows, and to reduce total volumes.
- AGWRC (Groundwater recession rate): AGWRC was typically reduced from the initial values to help reproduce the brief, sudden storms that are experienced in the Arizona basin.

Obtaining a high quality fit to hydrology in the Arizona basin is difficult with HSPF due to the importance of groundwater, which is simplistically represented in the model. As in the SWAT model, the specification of groundwater discharges as constant values and the simulation of reach losses by channel conductivity without feedback from local groundwater elevations both introduce uncertainty.

Initial calibrations were performed for the two Verde River gages at Paulden and Clarkdale. The calibration period was set to the 10 water years from 10/01/1992 to 09/30/2002. The results at Clarkdale are summarized in Figures 11 through 17 and Tables 6 and 7. The fit at Clarkdale is fairly good, although the summer storm volumes are over-simulated. Predictions at Clarkdale are largely determined by model fit upstream at Paulden, where flows about 95 percent of the time consist of approximately constant base flow. Spring peaks occasionally push through from the Chino subwatershed. Accuracy in simulating these peaks is primarily affected by lack of an accurate representation of the hydraulic behavior of Sullivan Lake, and somewhat caused by the necessity of specifying constant values for channel conductivity to account for transmission losses, when in fact these loss rates are likely much reduced during the spring wet period. Parameter modifications to improve the peak spring flows out of the Chino subwatershed result in significant over-prediction of summer storm events.

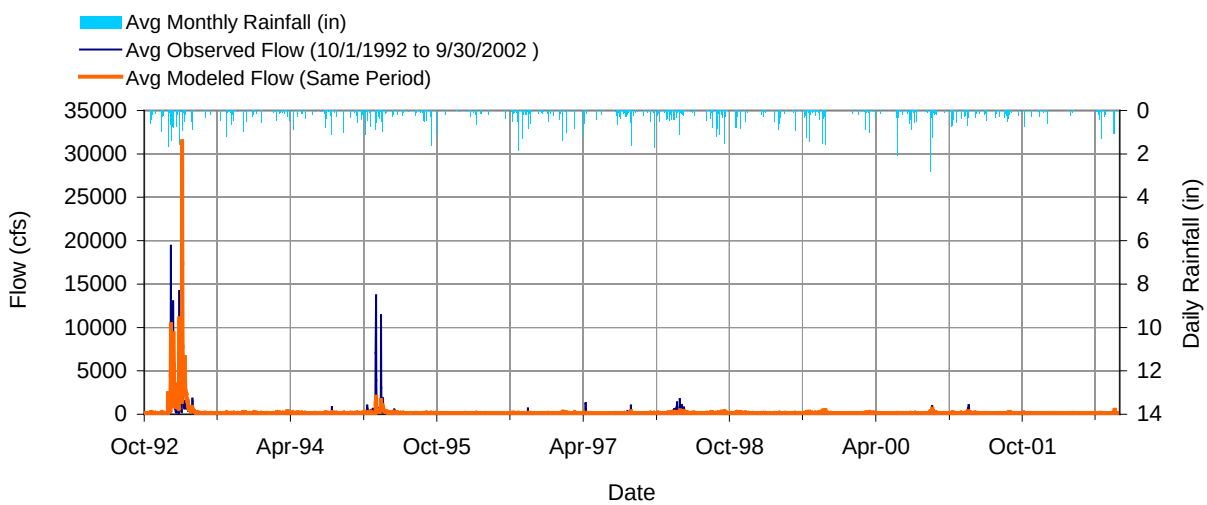


Figure 11. Mean daily flow at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (HSPF).

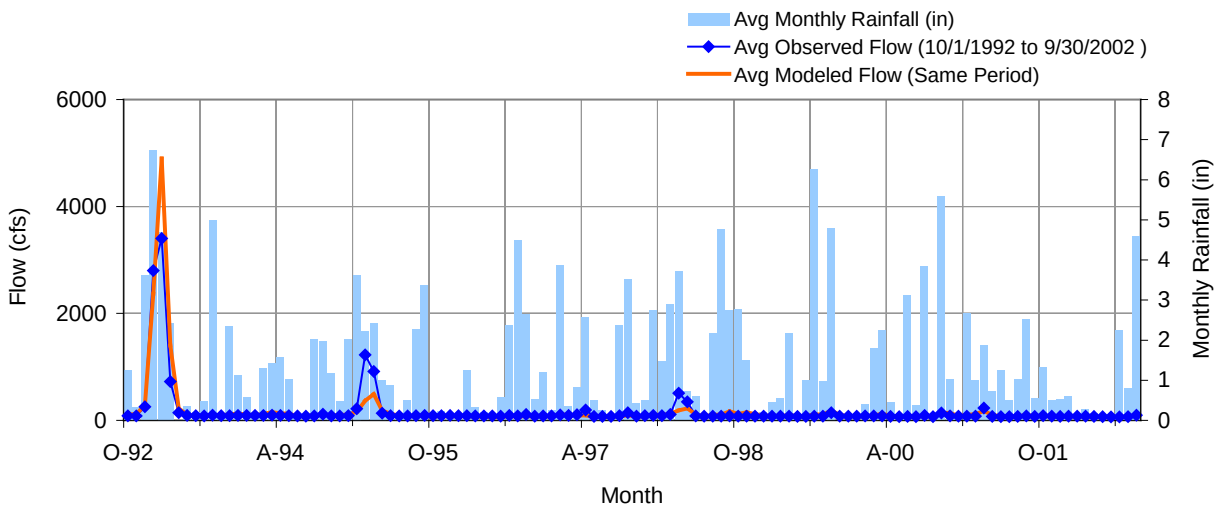


Figure 12. Mean monthly flow at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (HSPF).

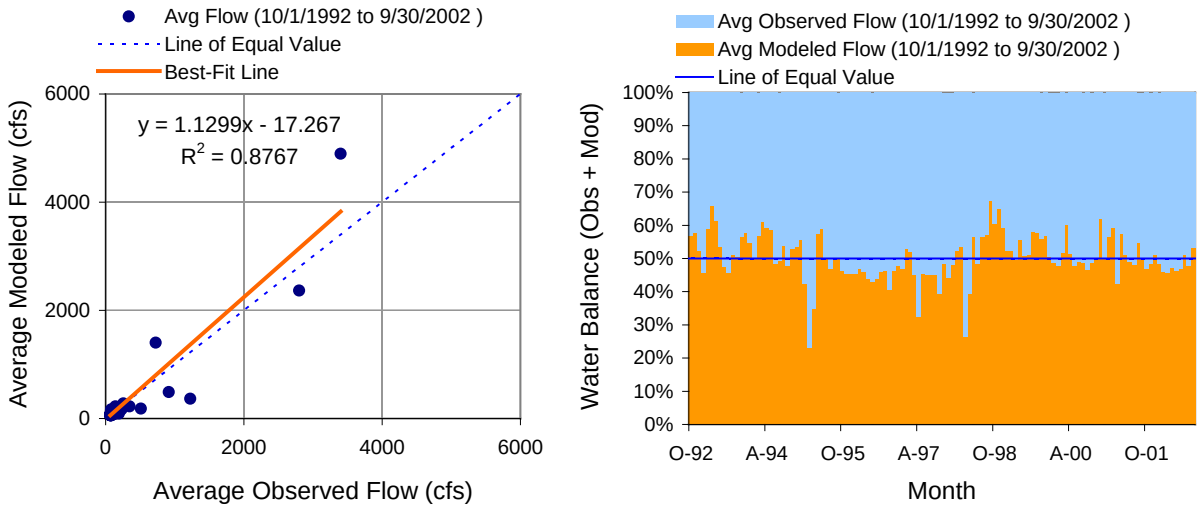


Figure 13. Monthly flow regression and temporal variation at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (HSPF).

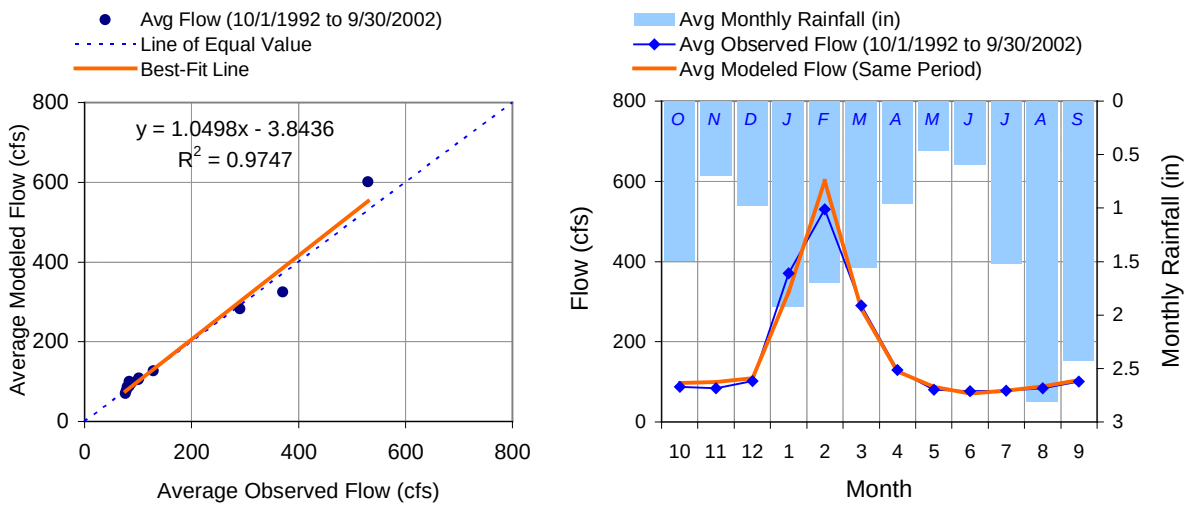


Figure 14. Seasonal regression and temporal aggregate at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (HSPF).

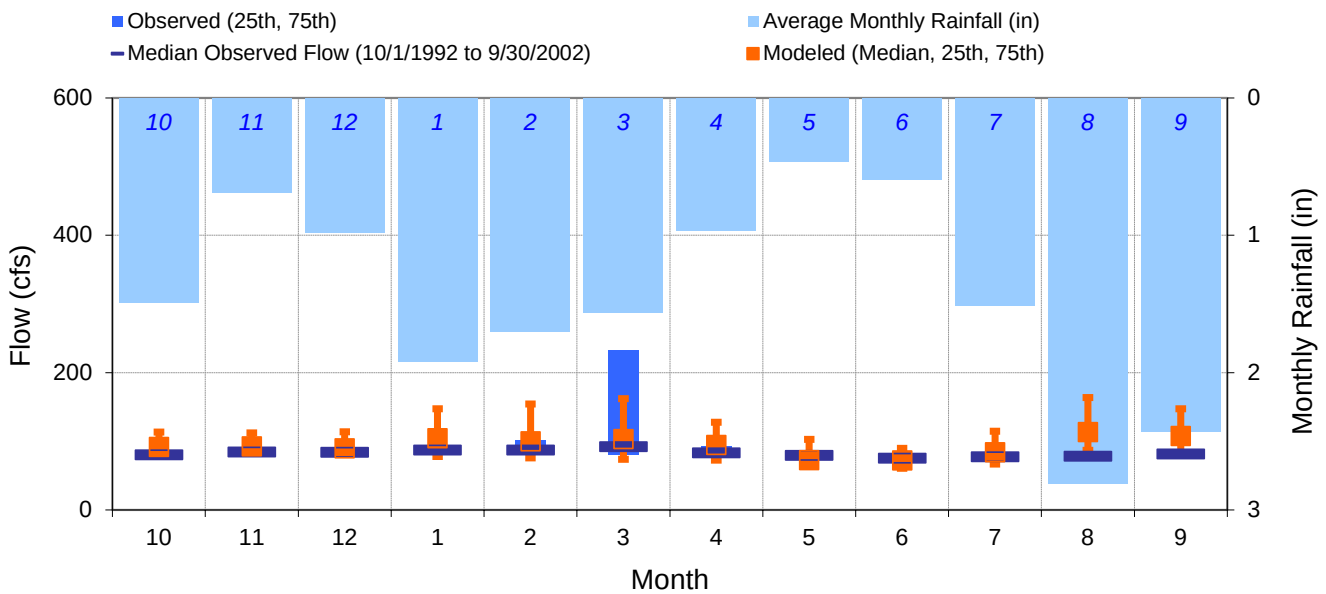


Figure 15. Seasonal medians and ranges at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (HSPF).

Table 6. Seasonal summary at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (HSPF)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	87.85	80.00	77.00	84.00	96.91	82.51	71.73	99.47
Nov	84.09	84.00	78.00	89.00	99.66	85.28	72.52	120.36
Dec	101.70	83.50	80.00	90.00	108.76	81.17	75.07	108.70
Jan	370.90	87.00	81.00	93.00	324.23	90.51	74.56	122.50
Feb	529.79	87.00	80.00	101.50	600.69	101.20	78.14	136.39
Mar	290.55	92.00	80.00	232.00	282.20	120.53	74.05	227.47
Apr	129.11	83.00	77.00	93.00	126.31	100.56	72.53	157.49
May	79.98	79.00	72.00	87.00	87.10	73.67	62.50	108.75
Jun	76.29	75.00	69.00	81.00	70.29	68.05	59.97	76.39
Jul	78.20	77.00	71.00	82.00	77.73	69.49	64.23	78.65
Aug	83.85	78.00	75.00	84.00	88.43	79.82	69.25	97.29
Sep	100.71	81.00	73.00	85.00	104.90	83.32	70.17	112.11

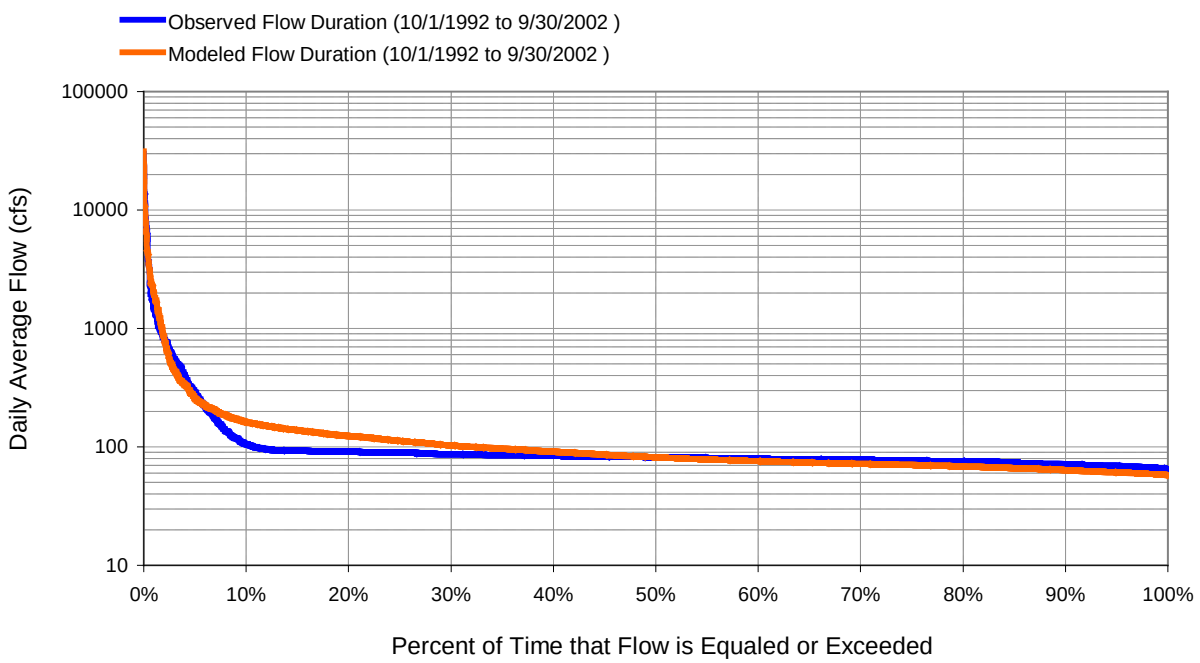


Figure 16. Flow exceedance at USGS 09504000 Verde River near Clarkdale, AZ – caalibration period (HSPF).

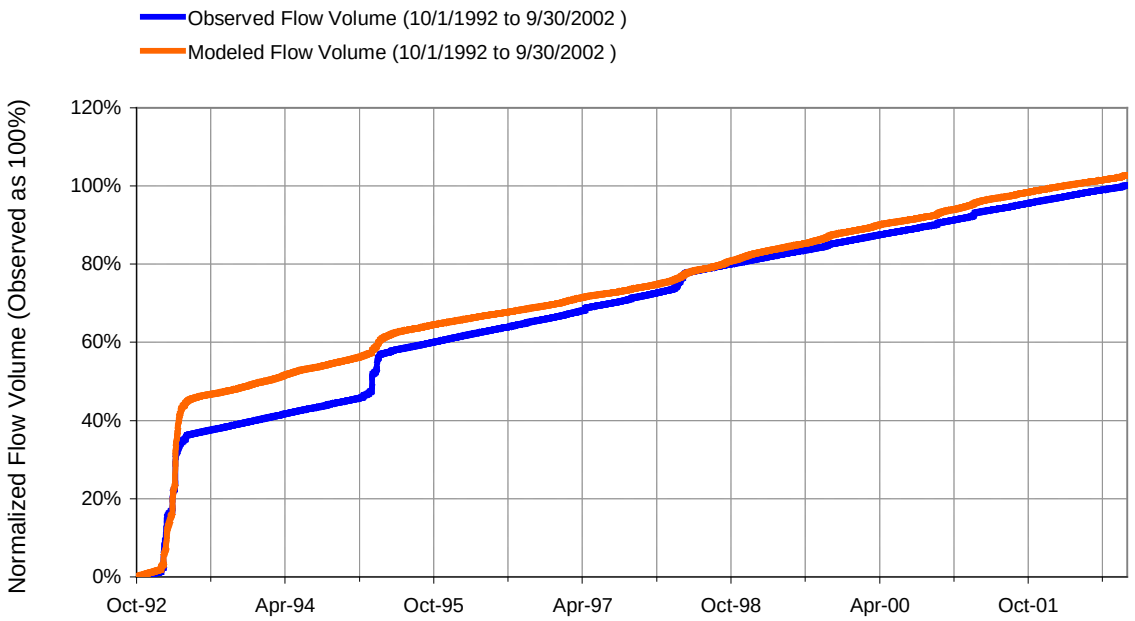


Figure 17. Flow accumulation at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (HSPF).

Table 7. Summary statistics at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (HSPF)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 101		USGS 09504000 VERDE RIVER NEAR CLARKDALE, AZ	
10-Year Analysis Period: 10/1/1992 - 9/30/2002 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 15060202 Latitude: 34.8522416 Longitude: -112.065994 Drainage Area (sq-mi): 3503	
Total Simulated In-stream Flow:	**0.66**	Total Observed In-stream Flow:	**0.64**
Total of simulated highest 10% flows:	**0.35**	Total of Observed highest 10% flows:	**0.36**
Total of Simulated lowest 50% flows:	**0.14**	Total of Observed Lowest 50% flows:	**0.15**
Simulated Summer Flow Volume (months 7-9):	**0.09**	Observed Summer Flow Volume (7-9):	**0.09**
Simulated Fall Flow Volume (months 10-12):	**0.10**	Observed Fall Flow Volume (10-12):	**0.09**
Simulated Winter Flow Volume (months 1-3):	**0.38**	Observed Winter Flow Volume (1-3):	**0.38**
Simulated Spring Flow Volume (months 4-6):	**0.09**	Observed Spring Flow Volume (4-6):	**0.09**
Total Simulated Storm Volume:	**0.25**	Total Observed Storm Volume:	**0.29**
Simulated Summer Storm Volume (7-9):	**0.02**	Observed Summer Storm Volume (7-9):	**0.01**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	2.43	10	
Error in 50% lowest flows:	-7.64	10	
Error in 10% highest flows:	-1.58	15	
Seasonal volume error - Summer:	3.15	30	
Seasonal volume error - Fall:	11.52 >>	30	Clear
Seasonal volume error - Winter:	0.83	30	
Seasonal volume error - Spring:	-0.50	30	
Error in storm volumes:	-15.79	20	
Error in summer storm volumes:	44.47	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.481	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.485	as E or E' approaches 1.0	
Monthly NSE	0.803		

Hydrology Validation

Like the SWAT modeling, validation for the Verde River near Clarkdale was performed for the period 10/1/1982 through 9/30/1992. Results are presented in Figures 18 through 24 and Tables 8 and 9. The HSPF validation results are fair, but are generally worse than during the calibration period. In particular, the storm peak volumes are under-predicted, likely due to the effort to reduce summer storm peaks in the calibration.

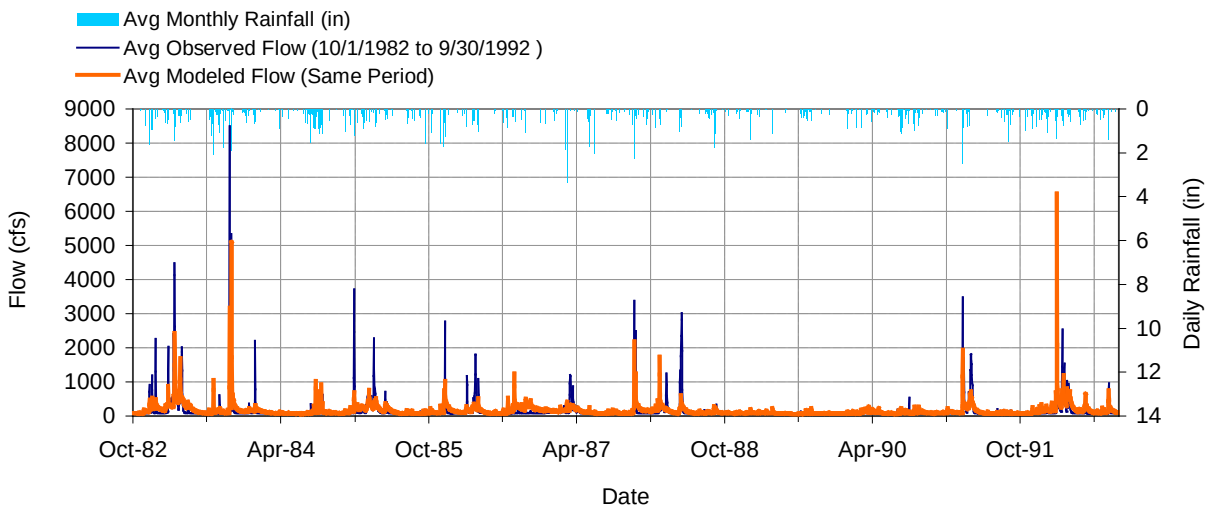


Figure 18. Mean daily flow at USGS 09504000 Verde River near Clarkdale, AZ – validation period (HSPF).

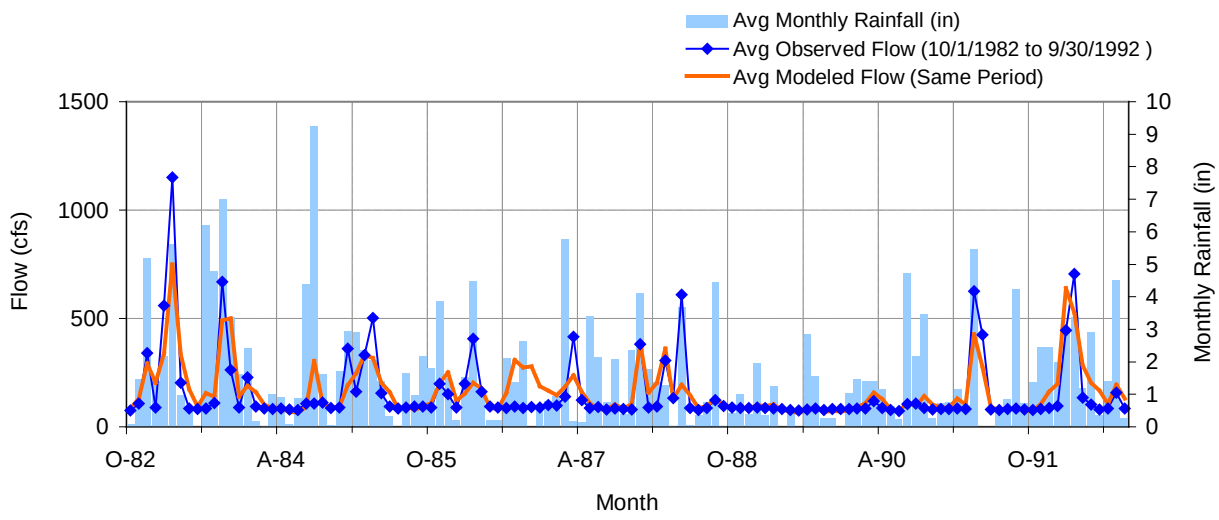


Figure 19. Mean monthly flow at USGS 09504000 Verde River near Clarkdale, AZ – validation period (HSPF).

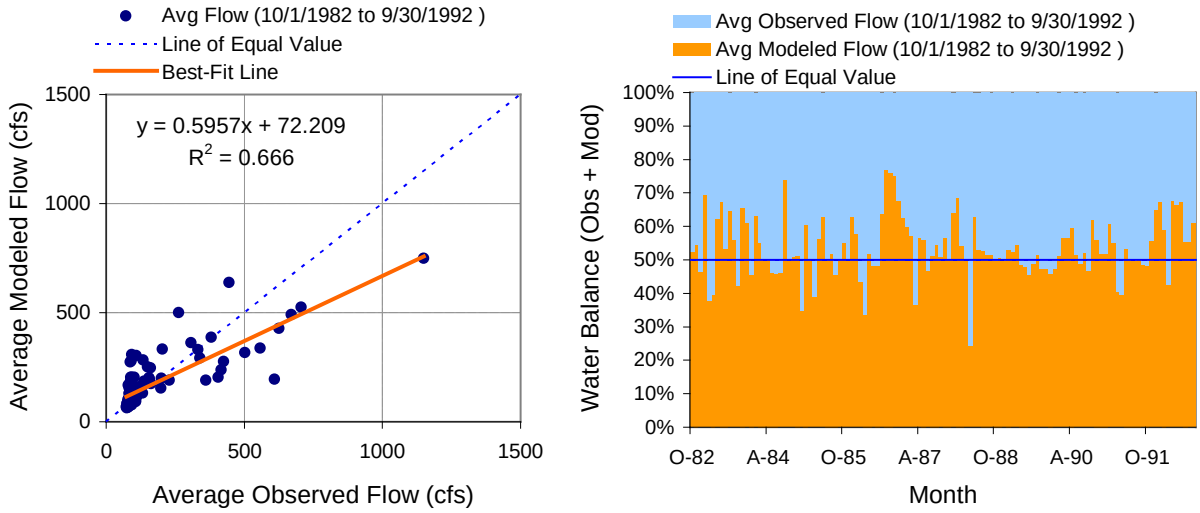


Figure 20. Monthly flow regression and temporal variation at USGS 09504000 Verde River near Clarkdale, AZ – validation period (HSPF).

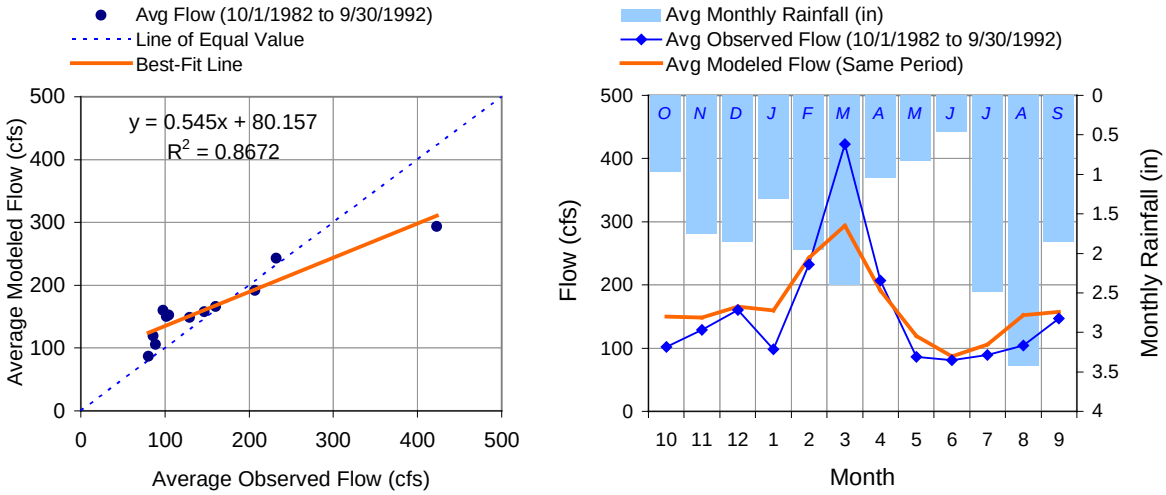


Figure 21. Seasonal regression and temporal aggregate at USGS 09504000 Verde River near Clarkdale, AZ – validation period (HSPF).

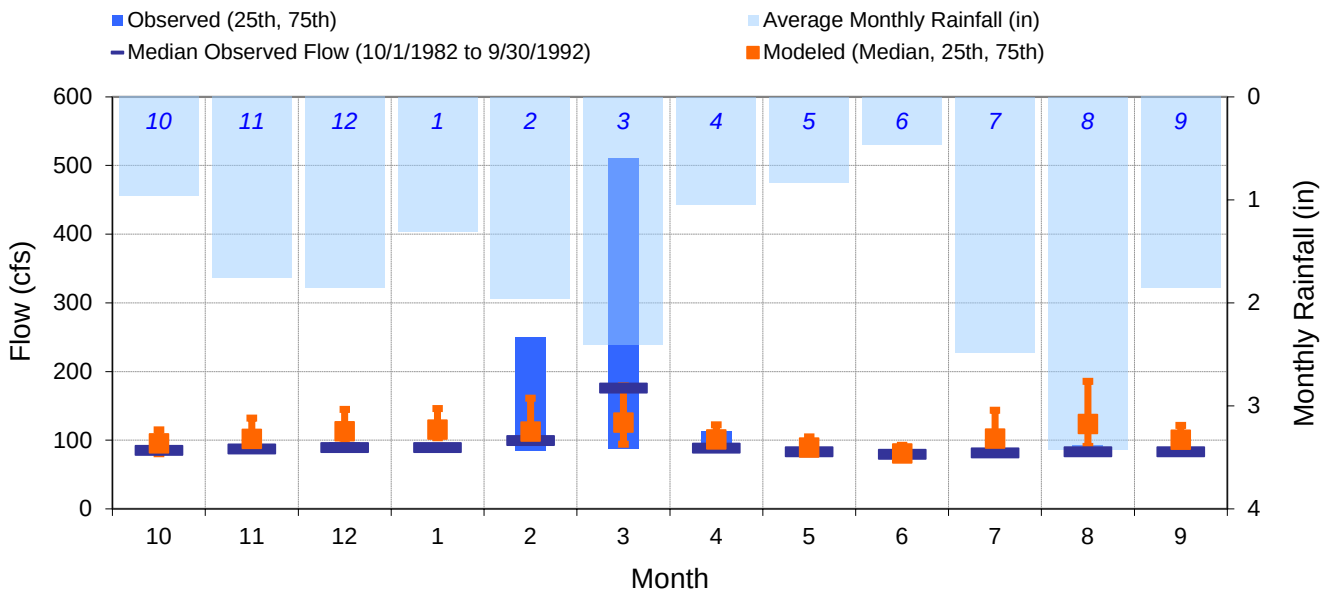


Figure 22. Seasonal medians and ranges at USGS 09504000 Verde River near Clarkdale, AZ – validation period (HSPF).

Table 8. Seasonal summary at USGS 09504000 Verde River near Clarkdale, AZ – validation period (HSPF)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	101.69	85.00	79.00	88.00	150.26	89.46	80.07	122.85
Nov	129.11	87.00	84.00	89.00	148.72	105.69	81.49	160.11
Dec	160.55	89.00	85.00	98.00	165.82	151.17	88.08	189.05
Jan	97.85	89.00	86.00	94.75	159.89	143.90	116.52	188.96
Feb	232.11	99.00	85.00	251.00	242.85	156.86	99.85	273.47
Mar	422.76	175.50	87.00	510.50	293.60	219.66	118.37	364.94
Apr	206.73	88.00	83.00	113.00	191.47	149.35	98.93	249.64
May	86.31	83.00	80.00	88.00	119.35	99.69	76.30	136.06
Jun	80.68	79.00	76.75	85.00	86.81	75.84	68.37	89.21
Jul	89.01	81.00	77.00	86.75	105.71	87.23	76.53	109.19
Aug	104.45	83.00	79.00	93.00	152.50	102.41	80.53	154.85
Sep	146.81	83.00	79.00	89.00	157.50	95.00	78.80	132.27

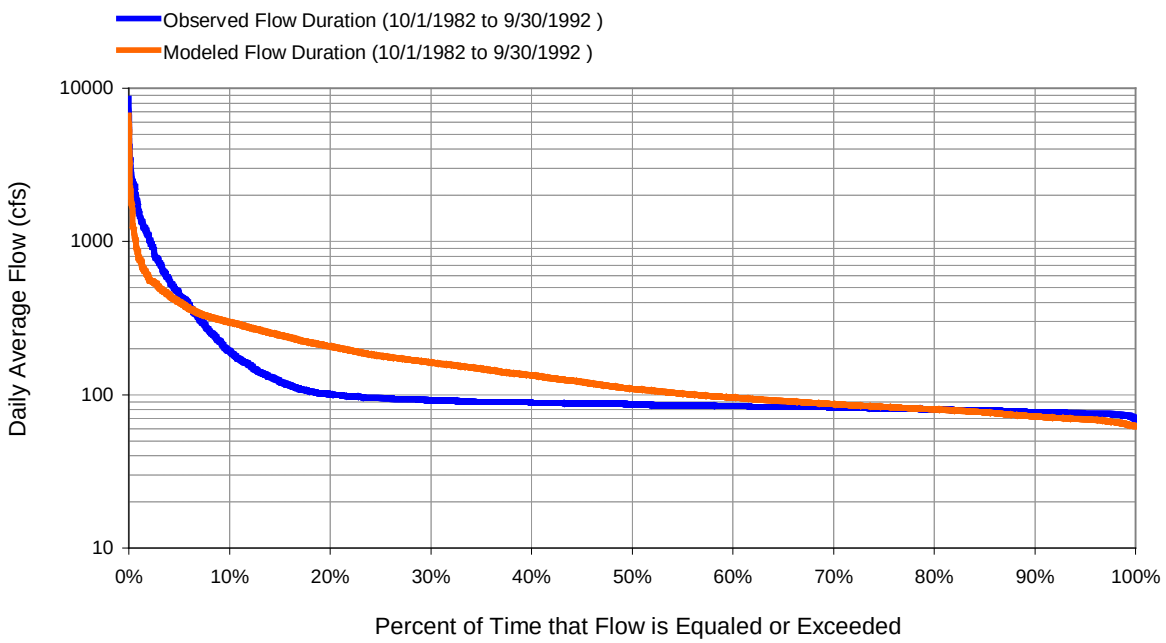


Figure 23. Flow exceedance at USGS 09504000 Verde River near Clarkdale, AZ – validation period (HSPF).

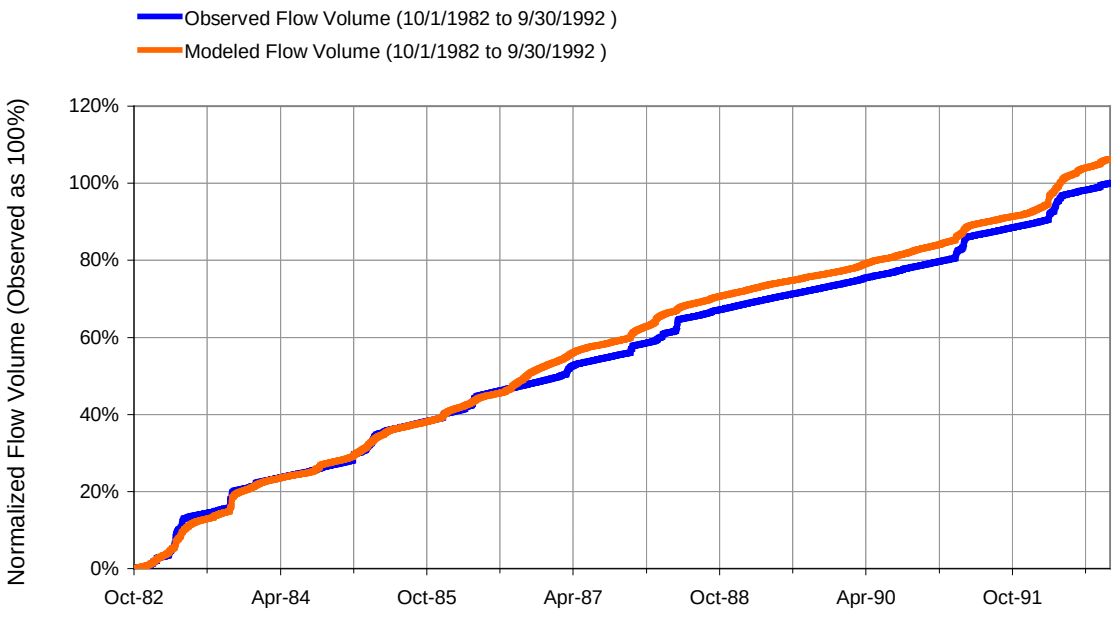


Figure 24. Flow accumulation at USGS 09504000 Verde River near Clarkdale, AZ – validation period (HSPF).

Table 9. Summary statistics at USGS 09504000 Verde River near Clarkdale, AZ – validation period (HSPF)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 101 10-Year Analysis Period: 10/1/1982 - 9/30/1992 Flow volumes are (inches/year) for upstream drainage area		USGS 09504000 VERDE RIVER NEAR CLARKDALE, AZ Hydrologic Unit Code: 15060202 Latitude: 34.8522416 Longitude: -112.065994 Drainage Area (sq-mi): 3503	
Total Simulated In-stream Flow:	**0.64**	Total Observed In-stream Flow:	**0.60**
Total of simulated highest 10% flows:	**0.21**	Total of Observed highest 10% flows:	**0.29**
Total of Simulated lowest 50% flows:	**0.16**	Total of Observed Lowest 50% flows:	**0.16**
Simulated Summer Flow Volume (months 7-9):	**0.14**	Observed Summer Flow Volume (7-9):	**0.11**
Simulated Fall Flow Volume (months 10-12):	**0.15**	Observed Fall Flow Volume (10-12):	**0.13**
Simulated Winter Flow Volume (months 1-3):	**0.22**	Observed Winter Flow Volume (1-3):	**0.24**
Simulated Spring Flow Volume (months 4-6):	**0.13**	Observed Spring Flow Volume (4-6):	**0.12**
Total Simulated Storm Volume:	**0.17**	Total Observed Storm Volume:	**0.23**
Simulated Summer Storm Volume (7-9):	**0.05**	Observed Summer Storm Volume (7-9):	**0.03**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	6.31	10	
Error in 50% lowest flows:	3.34	10	
Error in 10% highest flows:	**-27.25**	**15**	
Seasonal volume error - Summer:	22.38	30	
Seasonal volume error - Fall:	18.80	30	
Seasonal volume error - Winter:	-7.82	30	
Seasonal volume error - Spring:	6.64	30	
Error in storm volumes:	**-27.53**	**20**	
Error in summer storm volumes:	39.20	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.451	Model accuracy increases as E or E' approaches 1.0	
Baseline adjusted coefficient (Garrick), E':	0.325		
Monthly NSE	0.655		

Hydrology Results for Larger Watershed

As described above, parameters determined through calibration to the Verde River near Paulden and Clarkdale gages were not fully transferable to other gages in the watershed. Hydrology calibration was performed at a total of 10 gages in the Arizona basins – 6 in the Verde River watershed, 1 in the Salt River watershed, and 2 in the San Pedro River watershed. Only the gage at Roosevelt provides a long period of record for the Salt River watershed. The mainstem gage for the San Pedro River does not provide a rigorous calibration test because its flow is largely determined by the upstream boundary condition. Therefore, calibration was also performed on perennial Aravaipa Creek. The San Pedro gages ceased operation in 1995; therefore calibration was pursued over an earlier time period without a separate validation test.

Calibration results at all gages are summarized in Table 10 and are generally of similar quality to the fit obtained on the Verde River near Clarkdale. The generally close match between observed and predicted flow at the Salt River gage is shown in Figures 25 through 31 and Tables 11 and 12. Results of the validation exercise are summarized in Table 13. In general, the quality of fit during the validation period is similar to that in the calibration period, with some reductions in fit for some of the seasonal volume error terms, and also some improvements. The model is judged to be useful for scenario evaluation.

Table 10. Summary statistics (percent error) for all stations – calibration period WY 1992-2002 (HSPF)

Station	09472000 San Pedro nr Redington (1972-95)*	09473000 Aravaipa Crk nr Mammoth (1972-95)	09498500 Salt River nr Roosevelt	09503700 Verde River nr Paulden	09504000 Verde River nr Clarkdale	09504500 Oak Creek nr Cornville	09505800 W Clear Cr nr Camp Verde	09506000 Verde River nr Camp Verde	09507980 E Verde River nr Childs	09508500 Verde R below Tangle Cr
Error in total volume:	8.73	-2.49	4.48	9.41	2.43	2.64	7.50	-2.41	1.00	-5.03
Error in 50% lowest flows:	NA*	-3.74	2.24	8.37	-7.64	-12.56	-7.97	-34.63	64.01	-17.25
Error in 10% highest flows:	-5.26	1.89	7.56	5.57	-1.58	0.51	2.60	6.79	-1.53	-2.42
Seasonal volume error - Summer:	22.67	-0.61	20.18	20.17	3.15	-5.58	-3.67	-34.15	-4.49	-19.87
Seasonal volume error - Fall:	8.64	-7.68	11.78	15.98	11.52	24.57	13.45	-5.83	2.62	0.44
Seasonal volume error - Winter:	-3.27	2.64	2.79	5.12	0.83	7.67	1.00	6.53	1.47	-1.97
Seasonal volume error - Spring:	25.98	-11.01	-1.82	9.84	-0.50	-33.23	37.02	-18.47	-0.25	-14.97
Error in storm volumes:	-4.82	-13.40	30.67	-12.00	-15.79	-18.12	-33.88	-10.81	-11.92	-16.42
Error in summer storm volumes:	11.07	-3.99	21.62	111.20	44.47	-8.02	-44.53	-42.63	-57.76	-36.53
Daily Nash-Sutcliffe Coefficient, E:	0.574	0.553	0.529	0.624	0.481	0.078	0.451	0.661	0.689	0.703
Monthly Nash-Sutcliffe Coefficient, E:	0.908	0.425	0.930	0.835	0.803	0.443	0.803	0.803	0.946	0.921

*Note that median flow for the San Pedro River nr Redington is 0.

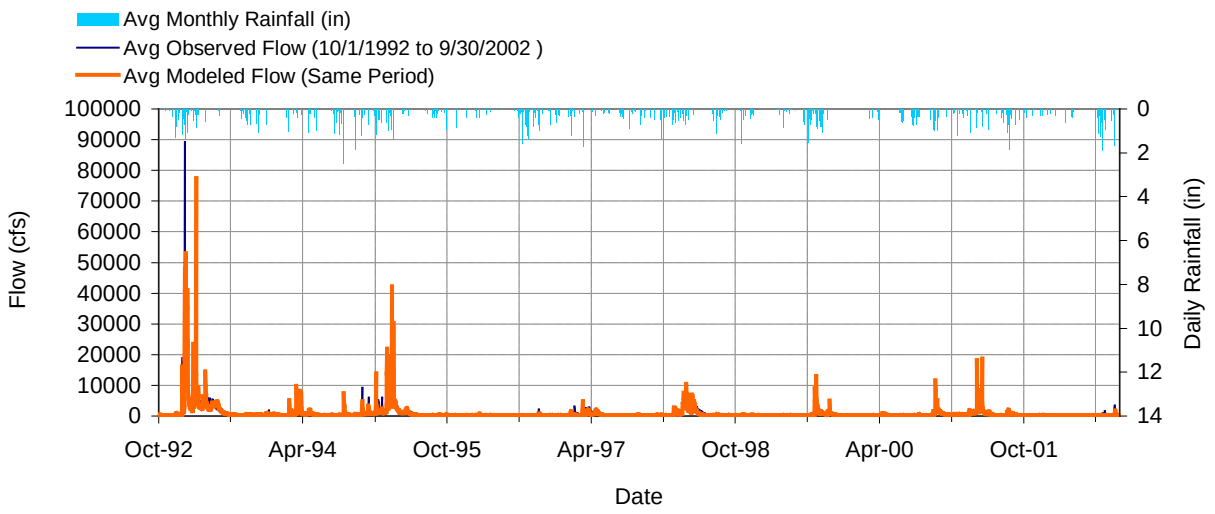


Figure 25. Mean daily flow at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (HSPF).

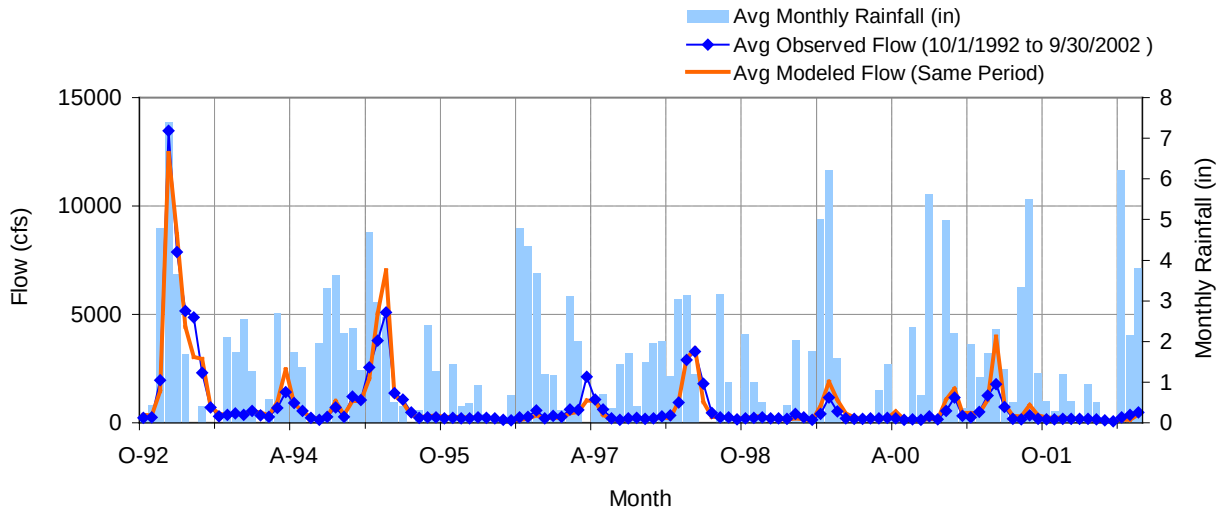


Figure 26. Mean monthly flow at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (HSPF).

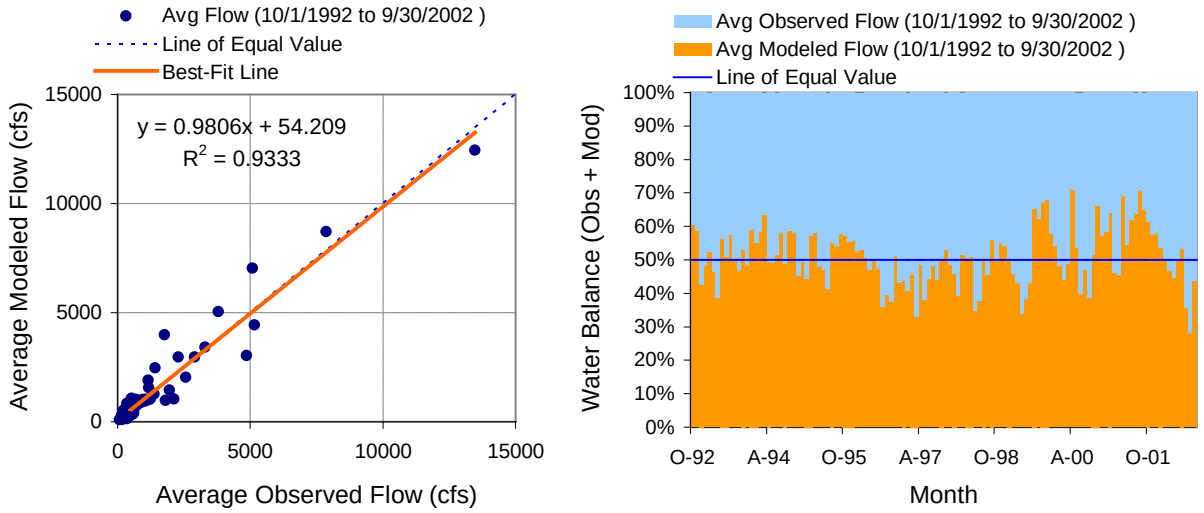


Figure 27. Monthly flow regression and temporal variation at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (HSPF).

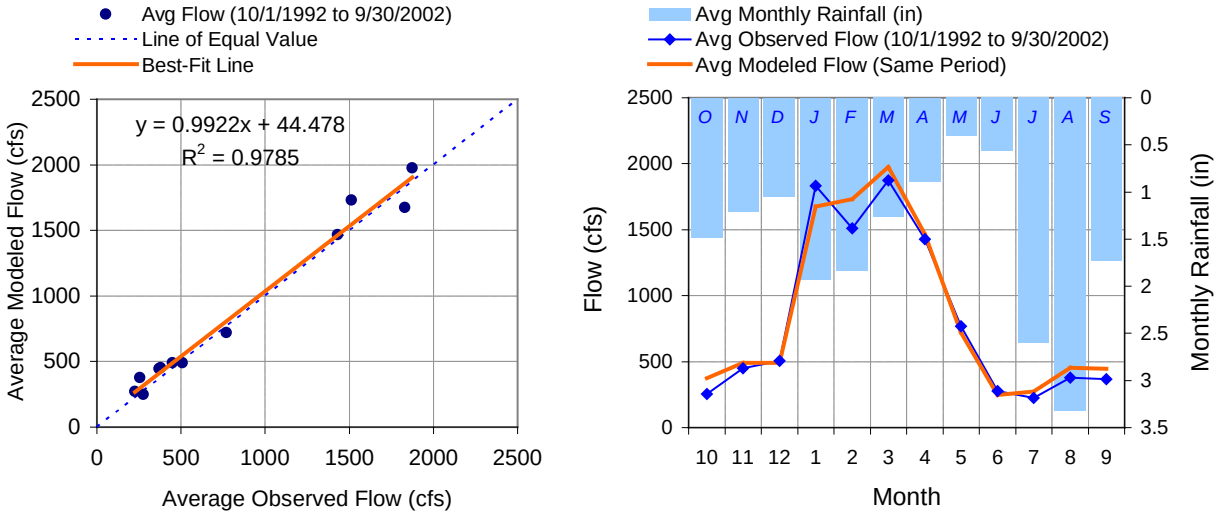


Figure 28. Seasonal regression and temporal aggregate at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (HSPF).

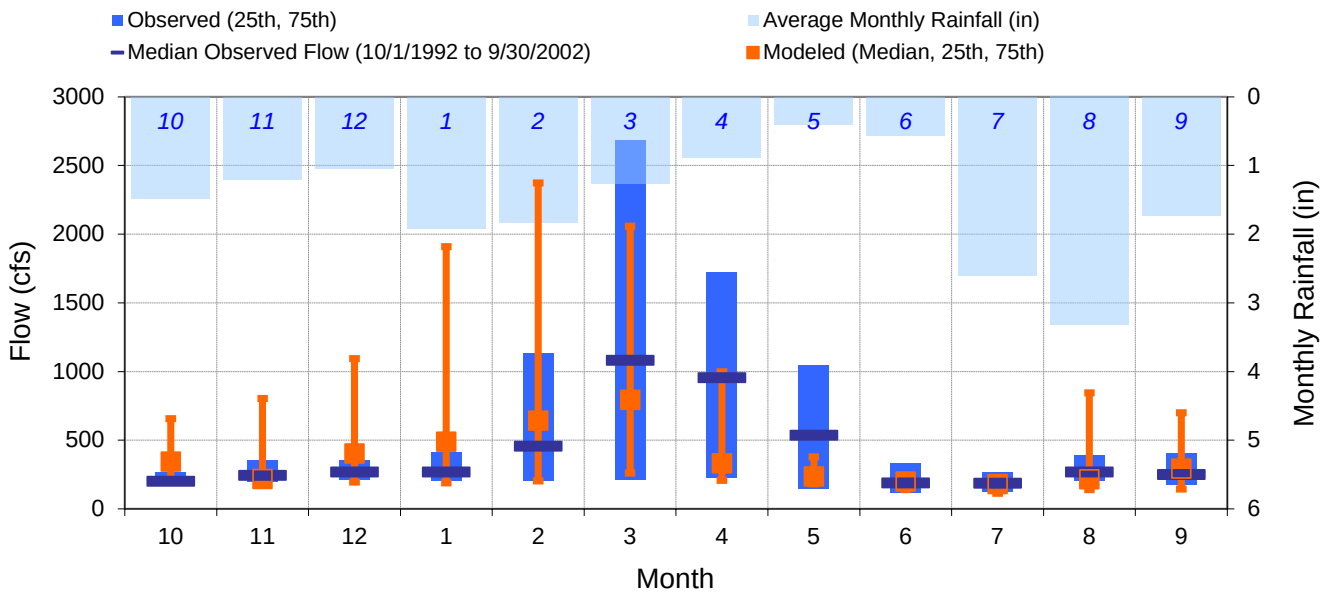


Figure 29. Seasonal medians and ranges at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (HSPF).

Table 11. Seasonal summary at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (HSPF)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	256.42	200.50	168.25	264.00	376.63	271.58	214.51	372.78
Nov	450.48	243.00	195.00	352.75	490.17	278.03	229.85	404.40
Dec	507.61	267.50	210.00	356.25	490.28	291.03	228.54	484.15
Jan	1831.48	267.00	204.00	413.25	1674.43	251.55	204.76	491.75
Feb	1511.59	455.50	206.00	1135.00	1731.21	340.99	182.31	1074.86
Mar	1875.51	1080.00	211.50	2682.50	1974.34	725.57	200.23	2429.07
Apr	1429.55	953.50	224.00	1722.50	1465.01	750.52	218.88	1974.37
May	768.86	535.00	150.25	1047.50	718.83	397.70	136.42	761.58
Jun	277.08	187.50	121.00	335.25	247.91	194.37	104.06	307.05
Jul	226.12	185.50	129.25	269.50	272.76	193.92	123.47	274.39
Aug	377.92	267.50	205.50	389.50	452.19	229.13	158.00	366.45
Sep	368.88	249.50	174.00	402.25	444.35	316.73	198.86	415.12

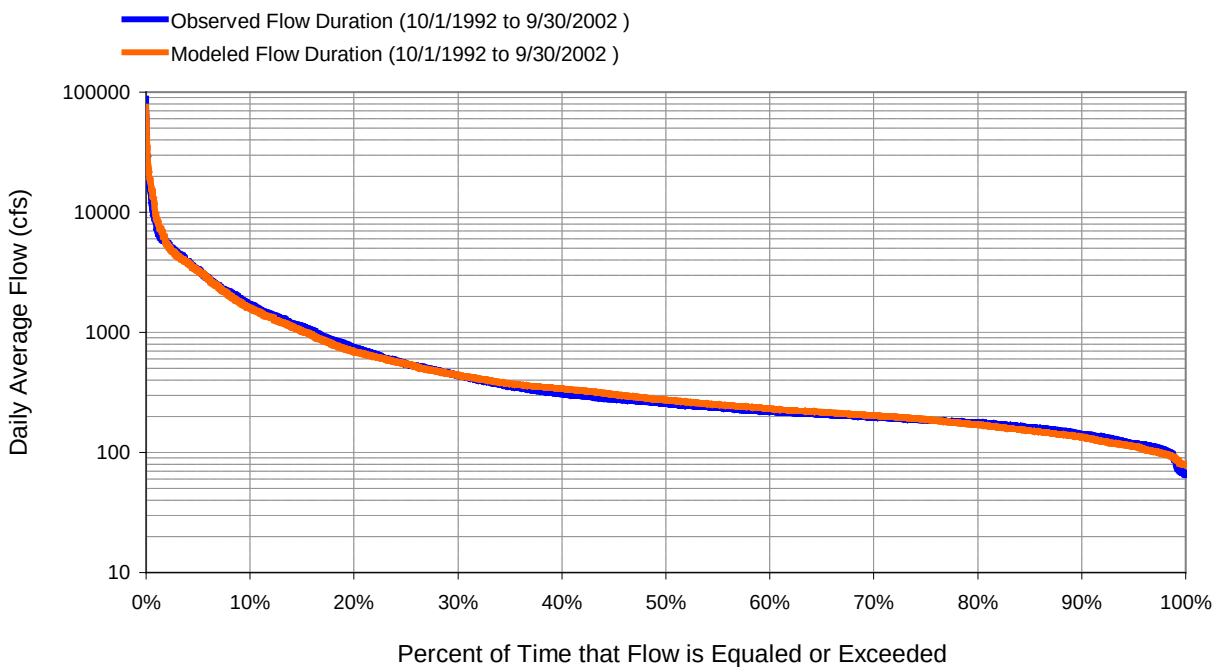


Figure 30. Flow duration at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (HSPF).

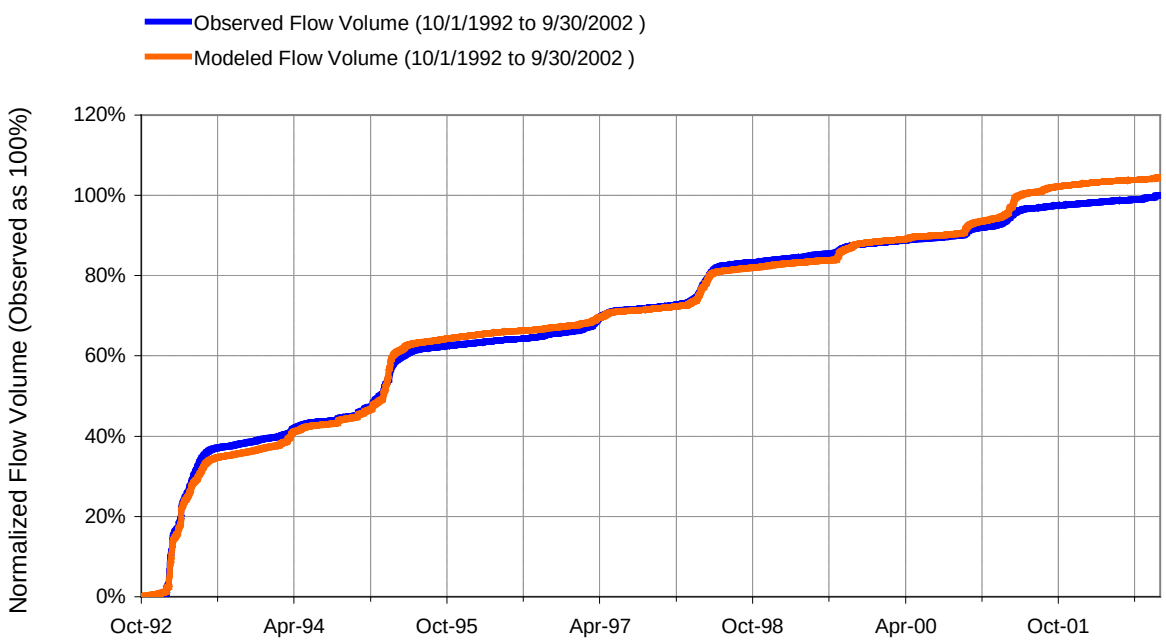


Figure 31. Flow accumulation at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (HSPF).

Table 12. Summary statistics at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (HSPF)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 103		USGS 09498500 SALT RIVER NEAR ROOSEVELT, AZ	
10-Year Analysis Period: 10/1/1992 - 9/30/2002 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 15060103 Latitude: 33.6194949 Longitude: -110.9215037 Drainage Area (sq-mi): 4306	
Total Simulated In-stream Flow:	**2.70**	Total Observed In-stream Flow:	**2.59**
Total of simulated highest 10% flows:	**1.67**	Total of Observed highest 10% flows:	**1.56**
Total of Simulated lowest 50% flows:	**0.29**	Total of Observed Lowest 50% flows:	**0.29**
Simulated Summer Flow Volume (months 7-9):	**0.31**	Observed Summer Flow Volume (7-9):	**0.26**
Simulated Fall Flow Volume (months 10-12):	**0.36**	Observed Fall Flow Volume (10-12):	**0.32**
Simulated Winter Flow Volume (months 1-3):	**1.40**	Observed Winter Flow Volume (1-3):	**1.36**
Simulated Spring Flow Volume (months 4-6):	**0.64**	Observed Spring Flow Volume (4-6):	**0.65**
Total Simulated Storm Volume:	**1.22**	Total Observed Storm Volume:	**0.94**
Simulated Summer Storm Volume (7-9):	**0.11**	Observed Summer Storm Volume (7-9):	**0.09**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	4.48	10	
Error in 50% lowest flows:	2.24	10	
Error in 10% highest flows:	7.56	15	
Seasonal volume error - Summer:	20.18	30	
Seasonal volume error - Fall:	11.78	30	
Seasonal volume error - Winter:	2.79	30	
Seasonal volume error - Spring:	-1.82	30	
Error in storm volumes:	**30.67**	**20**	
Error in summer storm volumes:	21.62	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.529	Model accuracy increases as E or E' approaches 1.0	
Baseline adjusted coefficient (Garrick), E':	0.539		
Monthly NSE	0.930		

Table 13.Summary statistics for all stations – validation period WY 1982-1992 (HSPF)

Station	09498500 Salt River nr Roosevelt	09503700 Verde River nr Paulden	09504000 Verde River nr Clarkdale	09504500 Oak Creek nr Cornville	09505800 W Clear Cr nr Camp Verde	09507980 E Verde River nr Childs	09508500 Verde R below Tangle Cr
Error in total volume:	-7.09	8.35	6.31	15.32	-9.69	31.18	-6.93
Error in 50% lowest flows:	-9.03	5.07	3.34	3.54	-9.99	8.49	-21.11
Error in 10% highest flows:	6.64	-11.57	-27.25	-9.47	-17.07	45.18	-13.91
Seasonal volume error - Summer:	16.38	-4.29	22.38	61.67	-26.78	-17.15	24.90
Seasonal volume error - Fall:	4.66	13.22	18.80	15.76	-37.41	28.39	-10.34
Seasonal volume error - Winter:	-26.48	16.64	-7.82	6.84	7.66	65.55	-5.86
Seasonal volume error - Spring:	1.49	8.64	6.64	12.03	-17.93	-26.11	-25.48
Error in storm volumes:	16.98	-14.00	-27.53	-17.61	-51.19	34.57	-16.03
Error in summer storm volumes:	40.28	-20.94	39.20	86.24	-74.51	-43.69	78.31
Daily Nash-Sutcliffe Coefficient of Efficiency, E:	0.354	0.443	0.451	0.545	0.232	-0.119	0.510
Monthly Nash-Sutcliffe Coefficient of Efficiency, E	0.786	0.614	0.320	0.755	0.655	0.335	0.809

Water Quality Calibration and Validation

The 20 Watershed models are designed to provide water quality simulation for total suspended solids (TSS), total nitrogen, and total phosphorus. The water quality calibration focuses on the replication of monthly loads, as specified in the project QAPP. Given the simplified approach to water quality simulation in the 20 Watershed model a close match to individual concentration observations cannot be expected. However, comparison to monthly loads presents challenges, as monthly loads are not observed. Instead, monthly loads must be estimated from scattered concentration grab samples and continuous flow records. Such estimation presents some uncertainty because it depends on the degree and form in which concentration and flow are correlated with one another. Further, the bulk of the load of sediment and sediment-associated phosphorus is likely to move through the system in a limited number of high flow events, which usually have not been monitored. As a result, the monthly load calibration is inevitably based on the comparison of two uncertain numbers. Nonetheless, calibration is able to achieve a fair agreement. The load comparisons were supported by detailed examinations of

the relationships of flows to loads and concentrations and the distribution of concentration prediction errors versus flow, time, and season, as well as standard time series plots.

For application on a nationwide basis, the 20 Watershed protocols assume that TSS and total phosphorus loads will likely exhibit a strong positive correlation to flow (and associated erosive processes), while total nitrogen loads, which often have a dominant groundwater component, will not. Accordingly, TSS and total phosphorus loads were estimated from observations using a flow-stratified log-log regression approach, while total nitrogen loads were estimated using a flow-stratified averaging estimator, consistent with the findings of Preston et al. (1989).

Water quality calibration and validation was done on the Verde River near Clarkdale, using 1993-2002 for calibration and 1986-1992 for validation. As with hydrology, calibration was performed on the later period as this better reflects the land use included in the model. The start of the validation period is constrained by data availability.

TSS calibration was performed by adjusting the coefficients in the soil detachment (KRER) and soil washoff (KSER) equations along with changes to the seasonal vegetation COVER. Furthermore, it was necessary to model scour of the soil matrix (i.e., gully erosion) in addition to losses of detached sediment. The washoff of detached sediment did not provide sufficient sediment losses to calibrate the model without severely degrading the channel bed.

Time series of simulated and estimated TSS loads at the Clarkdale station for both periods are shown in Figure 32 and statistics for the two periods are provided separately in Table 14. Visually, the model is roughly simulating the trends contained in the observed data. The key statistic in Table 14 (consistent with the QAPP) is the relative percent error, which shows the error in the prediction of monthly load normalized to the estimated load. Table 14 also shows the relative average absolute error, which is the average of the relative magnitude of errors in individual monthly load predictions. This number is inflated by outlier months in which the simulated and estimated loads differ by large amounts (which may be as easily due to uncertainty in the estimated load due to limited data as to problems with the model) and the third statistic, the relative median absolute error, is likely more relevant and shows good agreement.

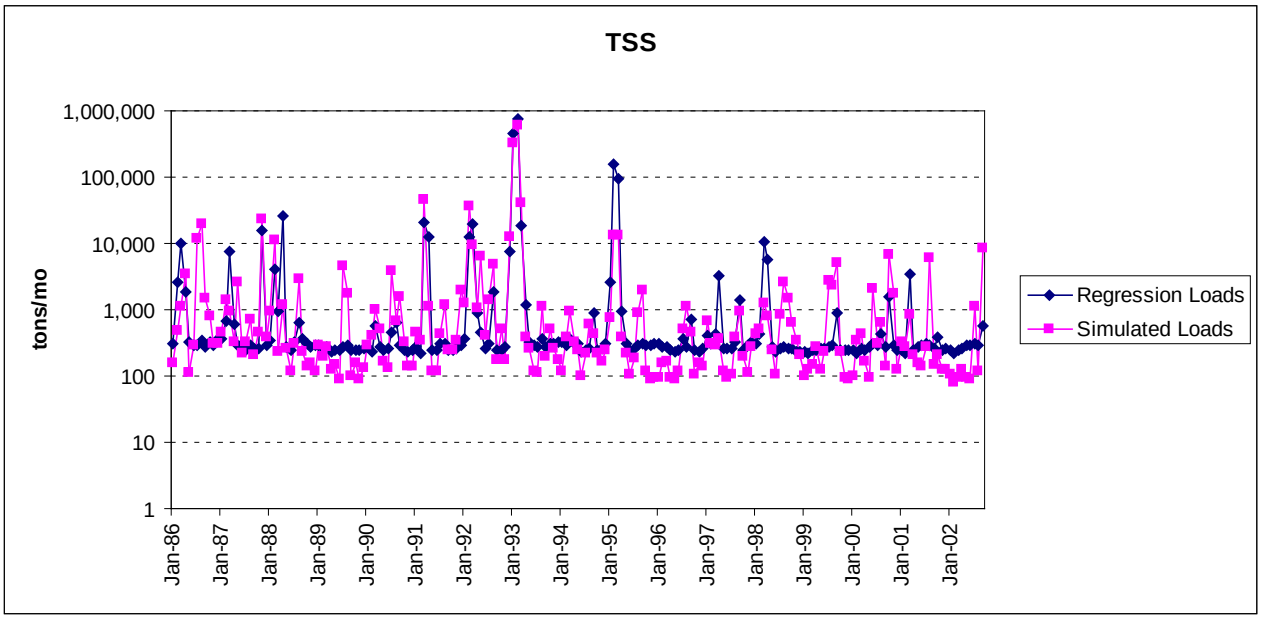


Figure 32. Fit for monthly load of TSS at USGS 09504000 Verde River near Clarkdale, AZ (HSPF).

Table 14. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression at USGS 09504000 Verde River near Clarkdale, AZ (HSPF)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Relative Percent Error	31%	-41%
Relative Average Absolute Error	40%	123%
Relative Median Absolute Error	1.1%	8.5%

Several other diagnostics were also examined to evaluate agreement between the model and observations. These are available in full in the calibration spreadsheets, but a few examples are provided below. First, load-flow power plots were compared for individual days (Figures 33 and 34). These show that the relationship between flow and load is reasonably consistent across the entire range of observed flows, for both the calibration and validation periods.

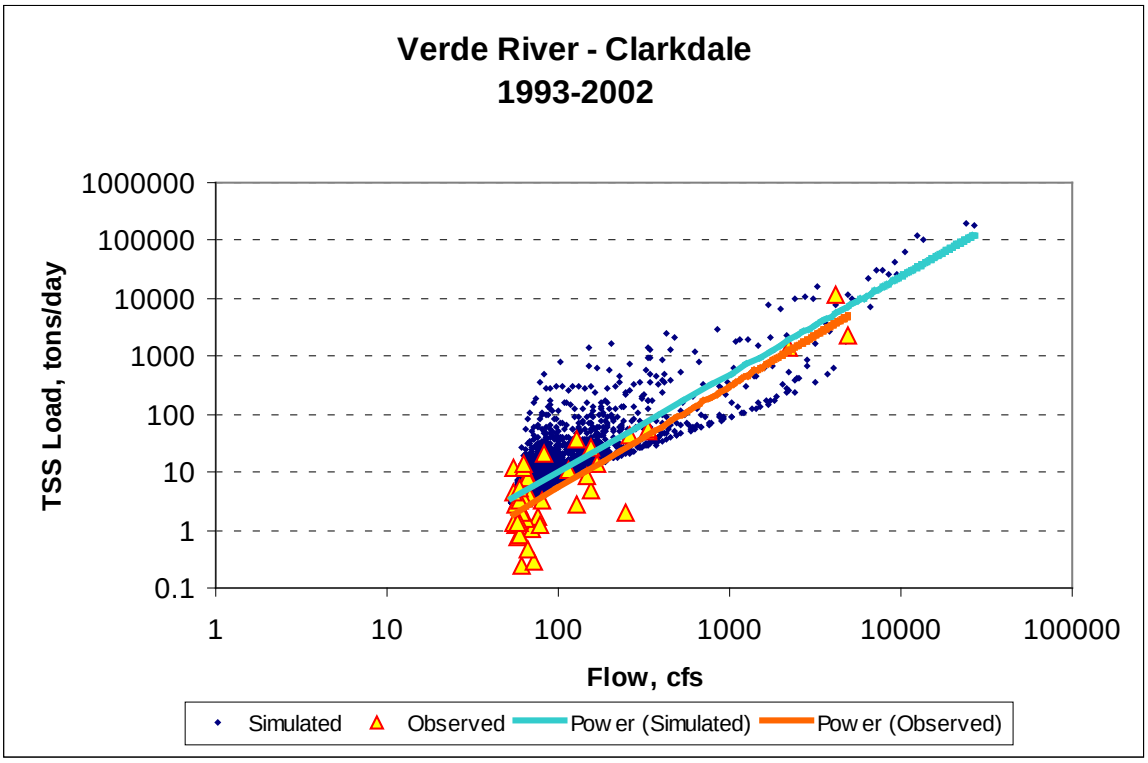


Figure 33. Power plot for observed and simulated TSS at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (HSPF).

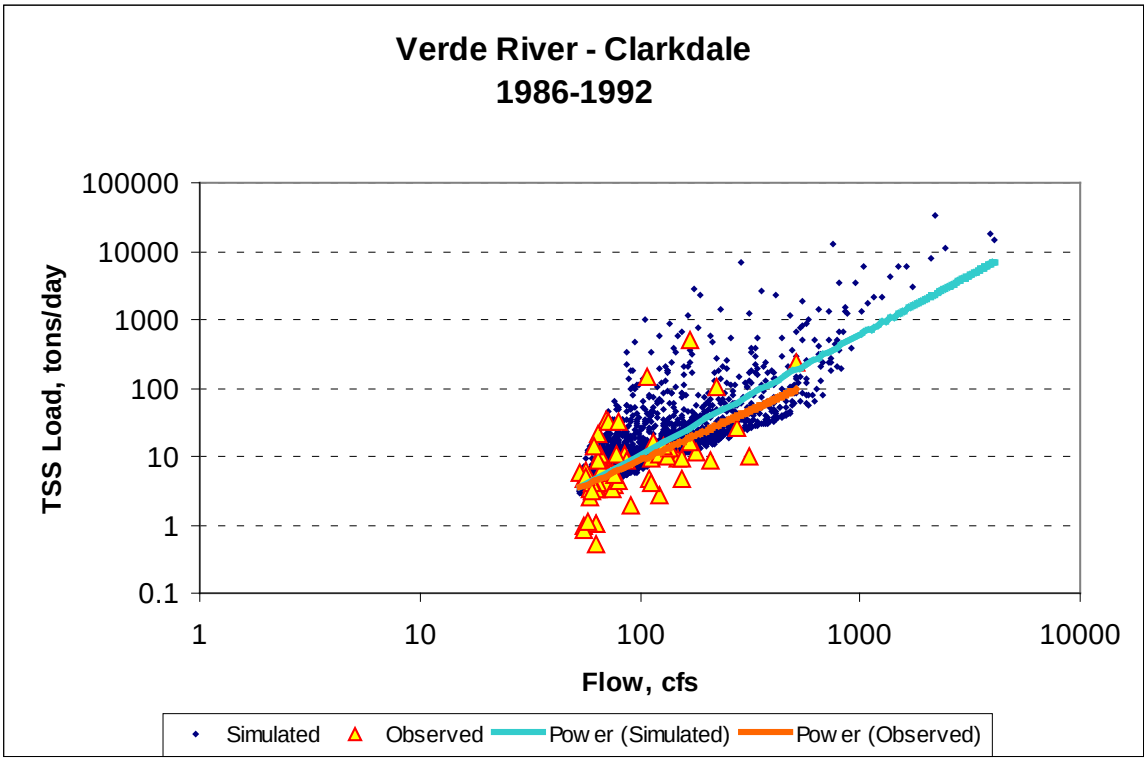


Figure 34. Power plot for observed and simulated TSS at USGS 09504000 Verde River near Clarkdale, AZ – validation period (HSPF).

A standard time series plot (Figure 35) shows that observed and simulated concentrations achieve at best a fair agreement, and the model may deviate substantially from individual observations. However, the concentration statistics (Table 15) show that reasonably low median errors are achieved.

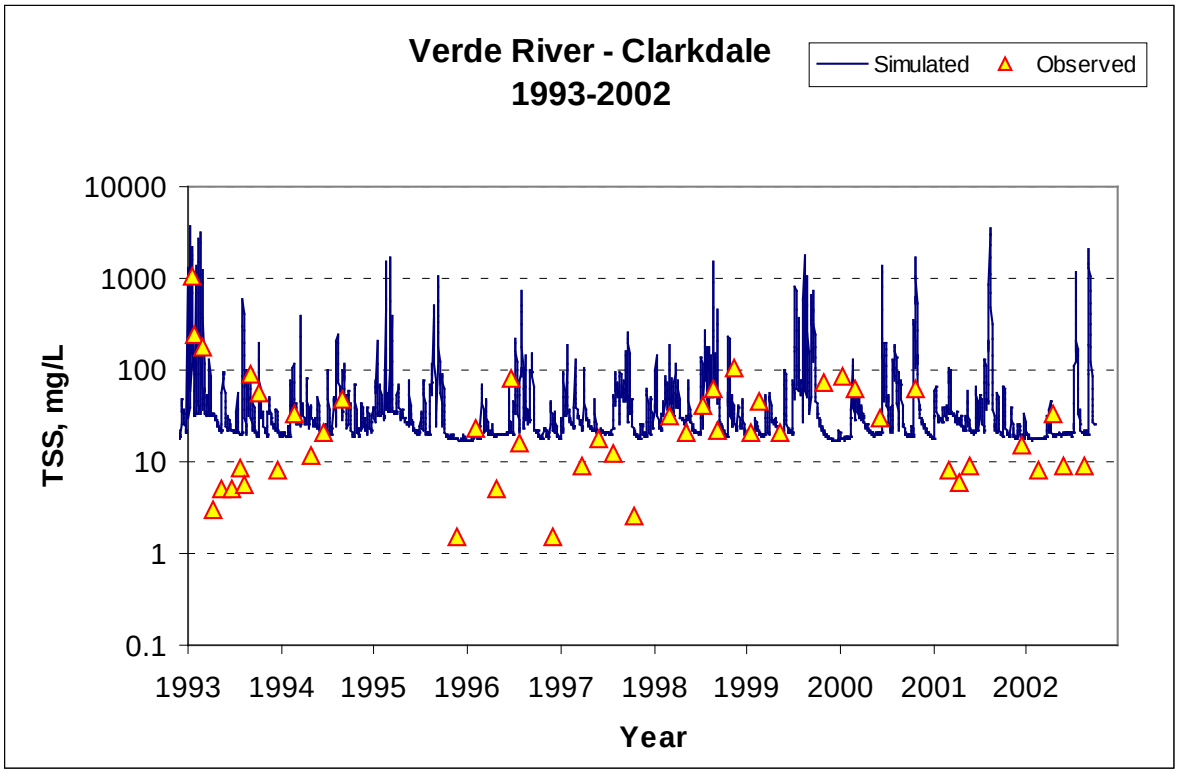


Figure 35. Time series plot of TSS concentration at USGS 09504000 Verde River near Clarkdale, AZ (HSPF).

Table 15. Relative errors (observed minus predicted) for TSS concentration at USGS 09504000 Verde River near Clarkdale, AZ (HSPF).

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Count	47	62
Concentration Average Error	-104%	7.3%
Concentration Median Error	-19%	-1.0%

For simulation of total phosphorus, calibration was performed primarily through adjustment of the potency factors and the subsurface concentrations. Total nitrogen calibration was accomplished primarily by adjusting the subsurface concentrations and secondarily by the accumulation-washoff parameters. Monthly loading time series for total phosphorus are shown in Figure 36 and the load statistics are summarized in Table 16. The model reproduces the general trend in monthly loads, but is significantly lower than the peak loads predicted by the regression method, resulting in high relative percent errors for both the calibration and validation periods. It should be noted that the available data are limited, particularly for high flow events. Thus, the estimates of "observed" load are also subject to considerable uncertainty.

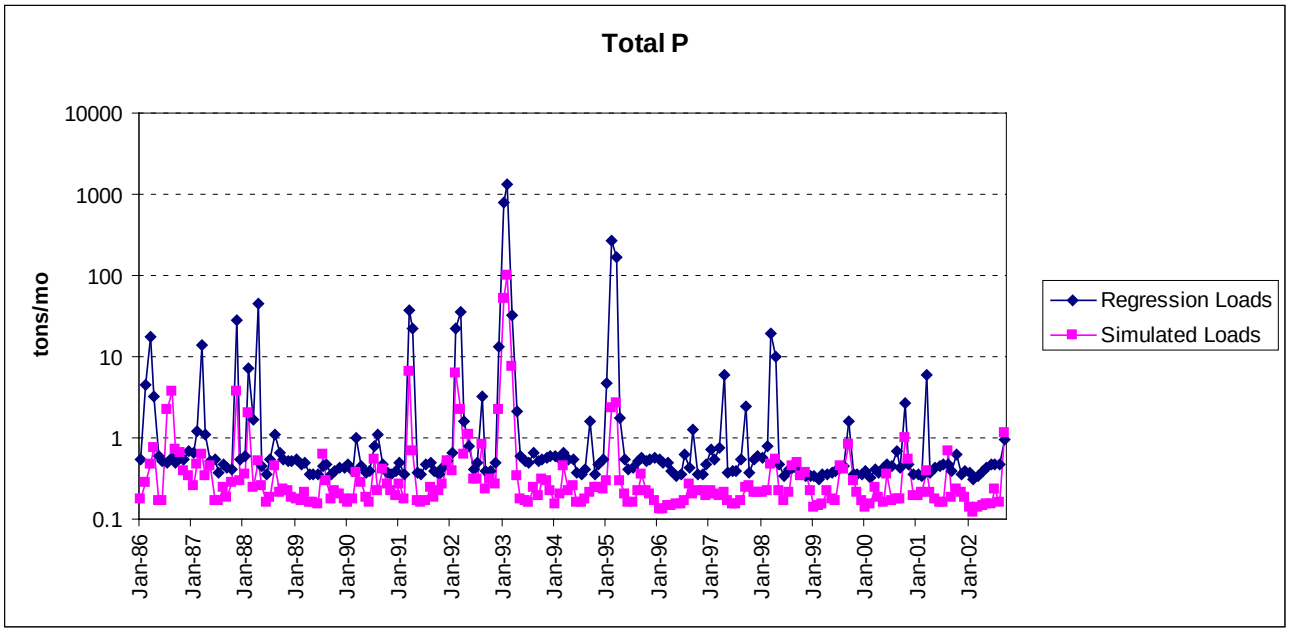


Figure 36. Fit for monthly load of total phosphorus at USGS 09504000 Verde River near Clarkdale, AZ (HSPF).

Table 16. Model fit statistics (observed minus predicted) for monthly total phosphorus loads using stratified regression

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Relative Percent Error	87%	66%
Average Absolute Error	87%	78%
Median Absolute Error	0.6%	5.1%

Additional diagnostics for total phosphorus included flow-load power plots (Figures 37 and 38), concentration time series plots (Figure 39) and analysis of concentration errors (Table 17). While these show approximate agreement, the model often overpredicts total phosphorus concentrations under lower flow conditions.

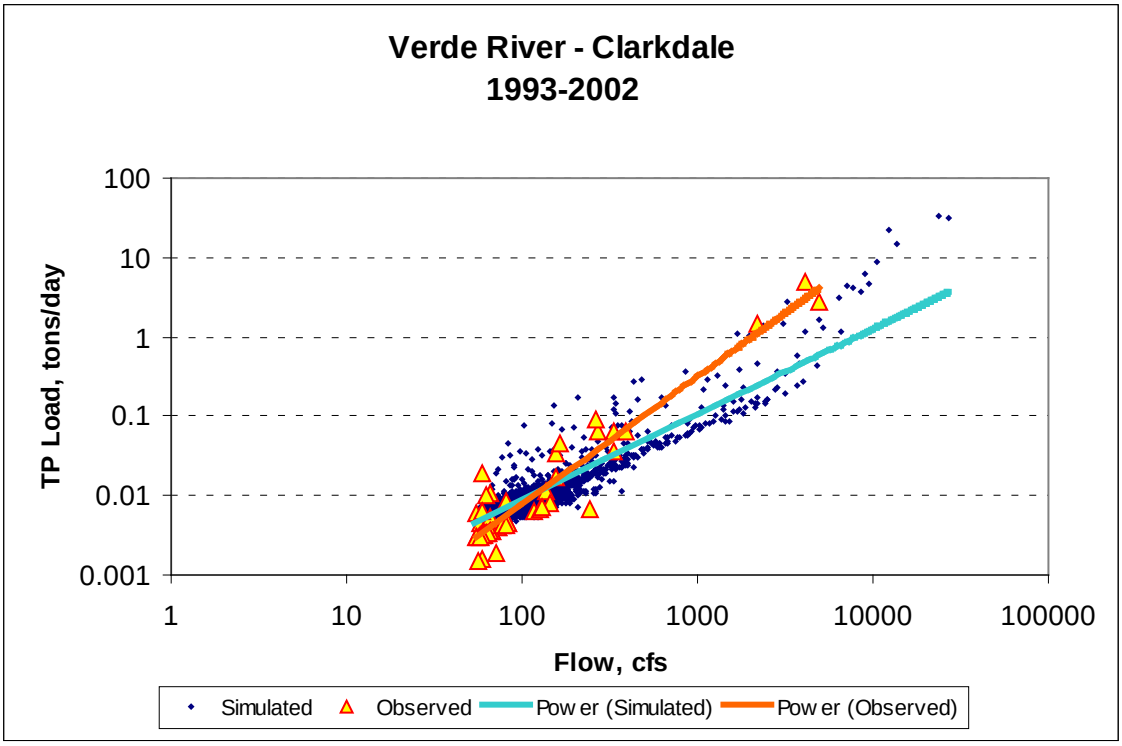


Figure 37. Power plot for observed and simulated total phosphorus at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (HSPF).

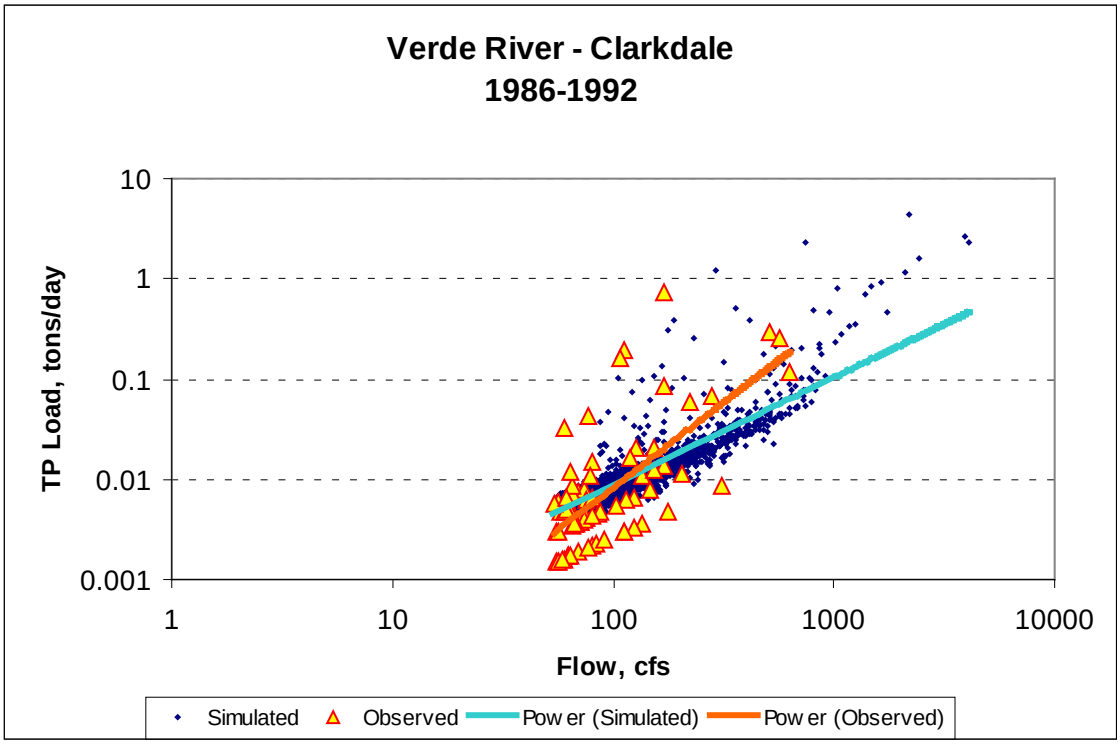


Figure 38. Power plot for observed and simulated total phosphorus at USGS 09504000 Verde River near Clarkdale, AZ – validation period (HSPF).

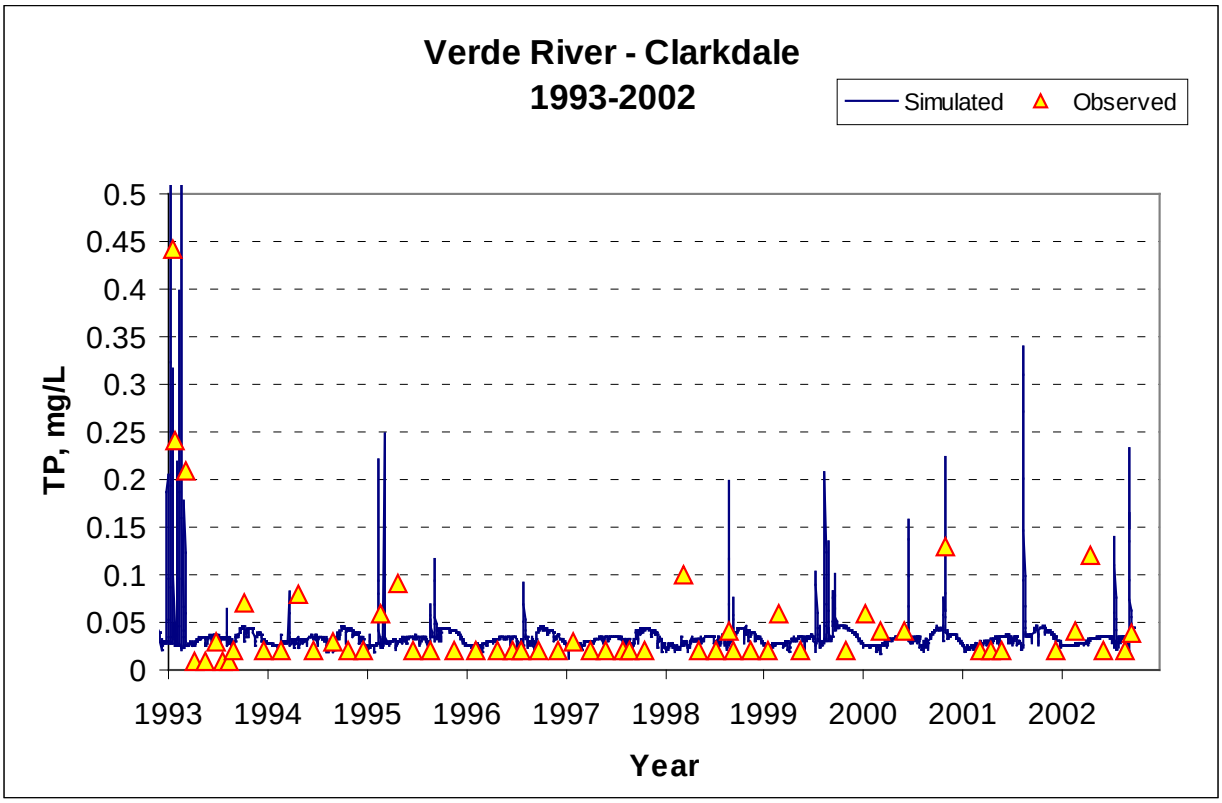


Figure 39. Time series plot of total phosphorus concentration at USGS 09504000 Verde River near Clarkdale, AZ (HSPF).

Table 17. Relative errors (observed minus predicted) for total phosphorus concentration at USGS 09504000 Verde River near Clarkdale, AZ (HSPF)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Count	57	75
Concentration Average Error	16%	54%
Concentration Median Error	-23%	-8.5%

Fewer data are available for total nitrogen because many sampling events omitted one or more nitrogen species. This increases the uncertainty of the comparison. Results for total nitrogen are summarized in Figures 40 through 43 and Tables 18 and 19 following the same format as total phosphorus. The loading results are fair, and are generally better than those obtained for total phosphorus; however, there is significant uncertainty in the prediction of individual total nitrogen observations. Total nitrogen concentrations at base flow are generally over-predicted.

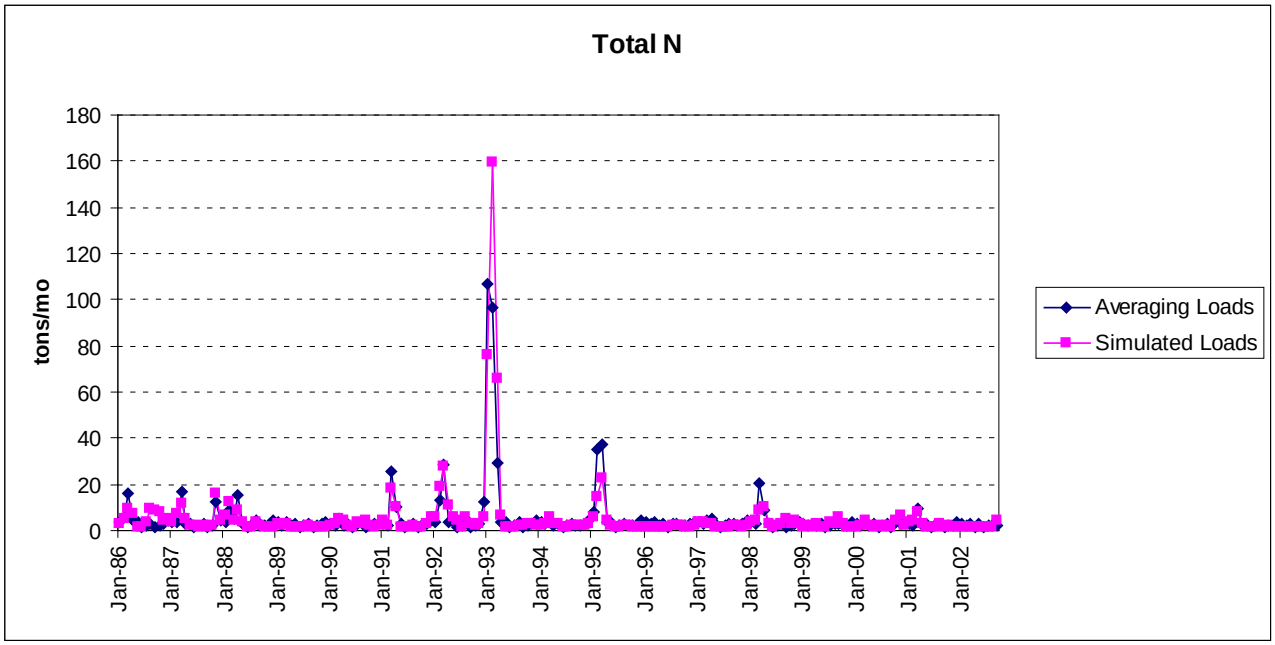


Figure 40. Fit for monthly load of total nitrogen at USGS 09504000 Verde River near Clarkdale, AZ (HSPF).

Table 18. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator (HSPF)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Relative Percent Error	1.6%	-2.7%
Average Absolute Error	45%	37%
Median Absolute Error	17%	18%

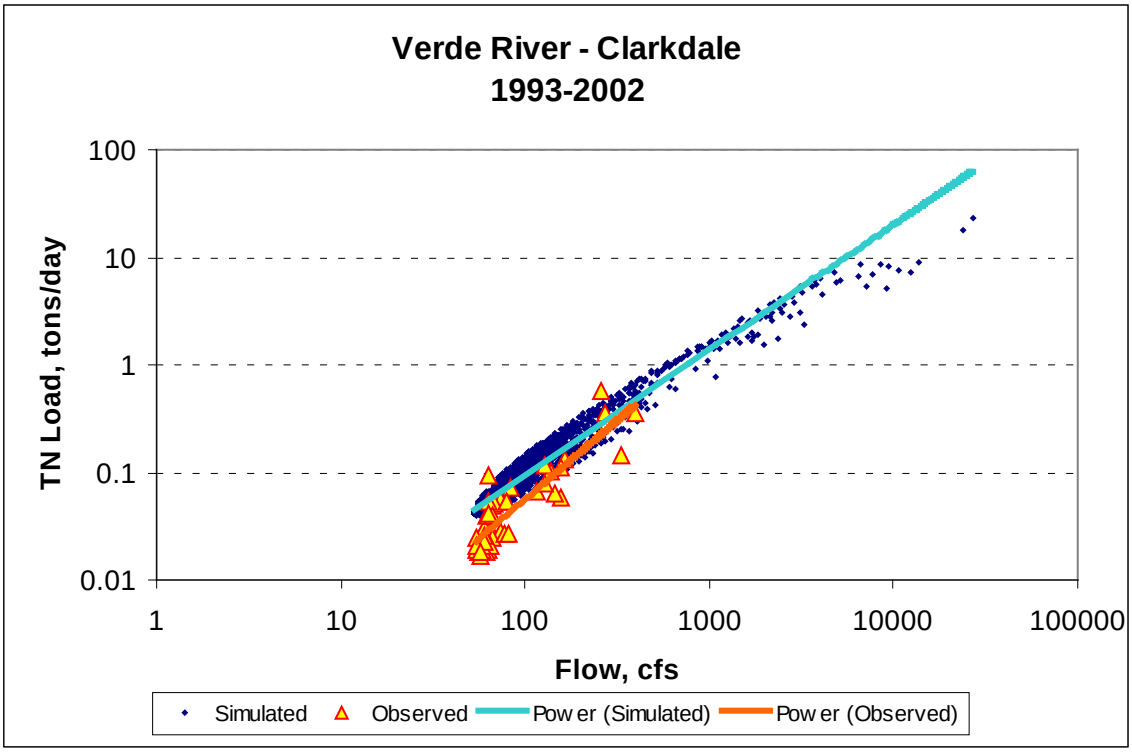


Figure 41. Power plot for observed and simulated total nitrogen at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (HSPF).

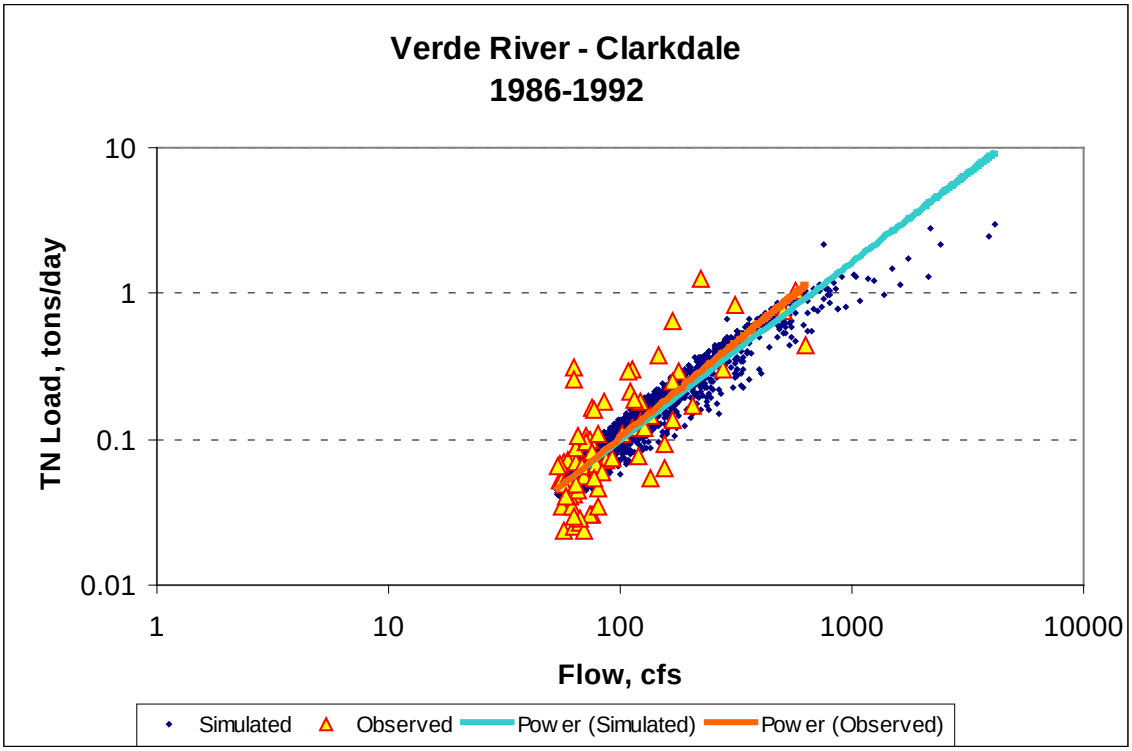


Figure 42. Power plot for observed and simulated total nitrogen at USGS 09504000 Verde River near Clarkdale, AZ – validation period (HSPF).

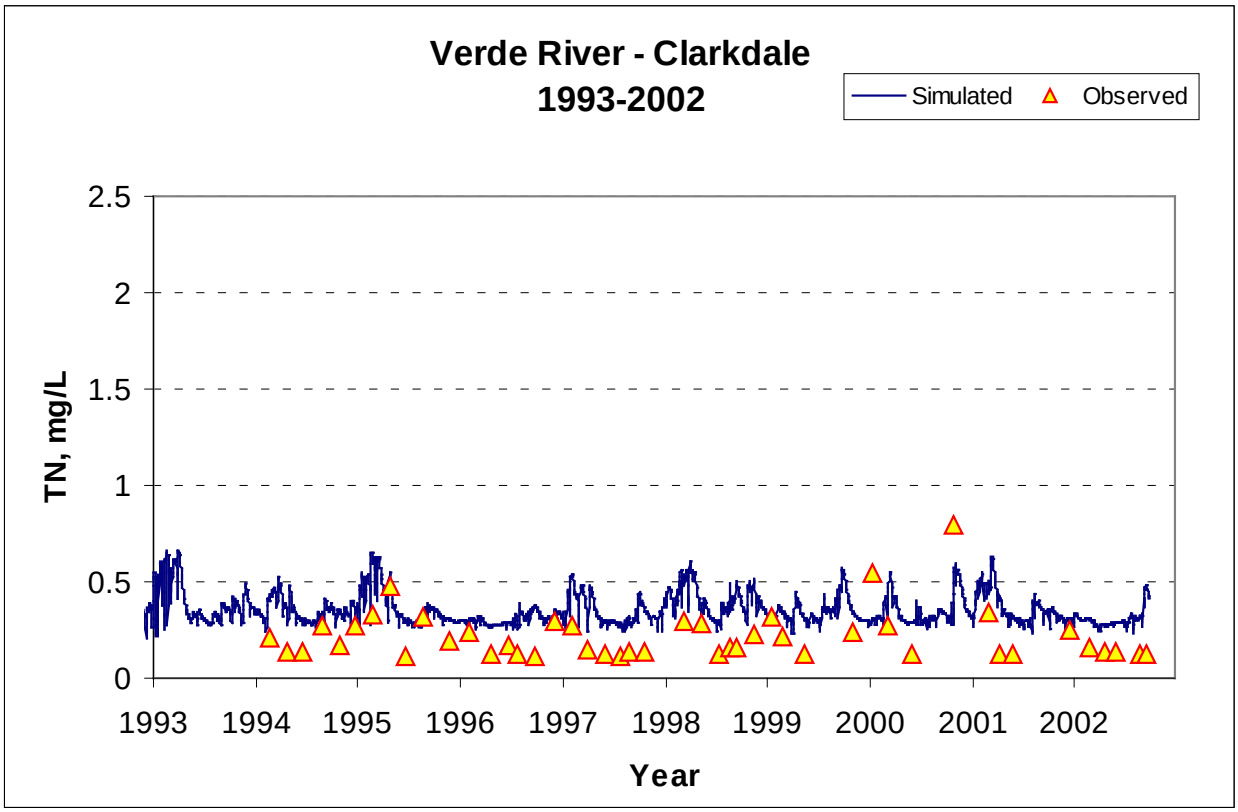


Figure 43. Time series plot of total nitrogen concentration at USGS 09504000 Verde River near Clarkdale, AZ (HSPF).

Table 19. Relative errors (observed minus predicted) for total nitrogen concentration at USGS 09504000 Verde River near Clarkdale, AZ (HSPF)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Count	46	75
Concentration Average Error	-63%	22%
Concentration Median Error	-70%	1.9%

Water Quality Results for Larger Watershed

Summary statistics for the water quality calibration and validation at two other stations in the watershed (i.e., Salt River near Roosevelt and Verde River below Tangle Creek) are provided in Tables 20 and 21 along with the Clarkdale statistics. Water quality was not calibrated at the Camp Verde station on the Verde River because of the lack of observed data at that location. And no water quality calibration was done in the San Pedro River. In most cases, total nitrogen loads are better predicted than total phosphorus and TSS loads. Simulated TSS and total phosphorus loads in the Verde River are lower than those estimated from observations, but this may reflect, in part, the uncertainty in the regression-based load estimates as water quality observations during high flows are sparse. Water quality results in the Salt River are generally better than the Verde River.

Table 20. Summary statistics (observed minus predicted) for water quality for all stations – calibration period 1993-2002 (HSPF)

Station	09498500 Salt River nr Roosevelt	09504000 Verde River nr Clarkdale	09508500 Verde River below Tangle Cr
Relative Percent Error TSS Load	-10	31	81
TSS Concentration Median Percent Error	0.80	-19	-5.6
Relative Percent Error TP Load	-29	87	75
TP Concentration Median Percent Error	-0.53	-23	-17
Relative Percent Error TN Load	-8.2	1.6	-2.7
TN Concentration Median Percent Error	-3.5	-70	-64

Table 21. Summary statistics (observed minus predicted) for water quality for all stations – validation period 1986-1992 (HSPF)

Station	09498500 Salt River nr Roosevelt	09504000 Verde River nr Clarkdale	09508500 Verde River below Tangle Cr
Relative Percent Error TSS Load	4.8	-41	2.1
TSS Concentration Median Percent Error	1.8	-1.0	-28
Relative Percent Error TP Load	52	78	46
TP Concentration Median Percent Error	8.9	-8.5	-12
Relative Percent Error TN Load	10	-2.7	10
TN Concentration Median Percent Error	-21	1.9	-15

SWAT Modeling

A SWAT model already exists for the Verde River portion of the watershed (Tetra Tech 2001). This model was calibrated for hydrology and nutrients. The existence of this earlier model provides a useful basis for parameter initialization, and is one of the reasons that the Arizona basins were selected as a pilot site. However, there are also significant differences to the 20 Watershed model. Because of these differences in approach the two models are substantively different, and not all model parameters are transferable. Nonetheless, the earlier model does provide important insights and parameter starting values that are incorporated into the 20 Watershed model.

A key aspect of the Arizona basins models is the intimate linkage of surface and groundwater hydrology. Perennial flow in various river segments is supported by groundwater discharge that, in the case of the Verde watershed, may arise from distant teleconnections. Many of the river reaches in alluvial valleys also lose flow to groundwater, at least on a seasonal basis. Both SWAT and HSPF models include simplified mass-balance accounting of groundwater at a local (subwatershed) scale, but neither model contains a detailed simulation of surface and groundwater interactions. In SWAT, the presence of deep groundwater discharges derived from sources outside a model subwatershed can be addressed through specification of these inflows as point sources. This is adequate for calibration, but there is no provision in the model for direct consideration of how these sources may change in the face of climate change. SWAT also provides for simulation of losing river reaches through specification of a rate of bed conductivity. This approach does not account for interaction with the seasonal water table. In many cases, alluvial river reaches may gain from groundwater during the wet season when water tables are high and lose to the alluvial aquifer during dry seasons. SWAT is, however, constrained to simulation of these interactions solely as a bed conductivity rate. This means that the behavior of seasonally losing reaches can only be roughly approximated in the model.

Changes Made to Base Data Provided

No changes were made to the meteorological or land use base data. For the Globe, Arizona point source it is clear that phosphorus concentrations downstream during baseflow conditions are much less than would be expected from the estimated phosphorus load from this WWTP. This may be due to a rapid loss of phosphorus in the near field immediately downstream of the discharge, likely due to settling of particulate matter. Discounting total phosphorus load in the effluent to 1/8 of the nominal value provided resolved this problem during calibration.

Assumptions

A key feature of the Arizona basins is the complex interaction of surface and groundwater. As noted above, neither SWAT nor HSPF is capable of providing a detailed, process-based simulation of groundwater flow. It is therefore assumed that interactions with groundwater can be handled with the following simplifying assumptions:

- The local (within a subwatershed) accumulation and discharge of shallow groundwater is adequately addressed by SWAT's linear storage reservoir formulation.
- Discharges to stream from deep groundwater are represented as constant point sources, with discharge rates set based on flow information on major springs identified in the Arizona Water Atlas (ADWR 2009). This means that the model cannot account for seasonal variability in deep groundwater discharge, nor can it evaluate how such discharges may evolve in response to climate change.
- Losses to groundwater from stream reaches in alluvial basins are simulated based on channel conductivity. This makes such losses a function of flow, wetted perimeter, and travel time in the affected reaches. The SWAT model formulation does not take into account changes in local groundwater head; instead, the loss occurs continuously. In addition, SWAT partitions channel losses to deep groundwater and bank storage using a fixed ratio.

Hydrology Calibration

Obtaining a high quality fit to hydrology in the Arizona basins is difficult with SWAT due to the importance of groundwater interaction terms, which are simplistically addressed in the model. The specification of groundwater discharges as constant values and the simulation of reach losses by channel conductivity without feedback from local groundwater elevations both introduce uncertainty. In addition, the model formulation requires specification of several factors at a global level, not allowing for spatial variability, including the fraction of transmission losses assigned to deep groundwater (TRNSRCH), the intensity of direct evaporation from the channel (EVRCH), and the parameters controlling snow melt.

Calibration adjustments focused on the following parameters:

- Curve numbers (varied systematically by land use)
- ESCO (soil evaporation compensation factor)
- Reach conductivity
- Bank storage and recession rates
- Groundwater "revap" rates

Initial calibrations were performed for the Verde River at Clarkdale and are summarized in Figures 44 through 50 Tables 22 and 23. The fit is fair at best, although the total volume errors are small. However, predictions at Clarkdale are largely determined by model fit upstream at Paulden, where flows about 95 percent of the time consist of approximately constant baseflow. Spring peaks occasionally push through from the Chino watershed. Accuracy in simulating these peaks appears to be affected by 1) lack of an accurate representation of the hydraulic behavior of Sullivan Lake, and 2) the necessity of specifying constant values for channel conductivity to account for transmission losses, when in fact these loss rates are likely much reduced during the spring wet period. Modifications to increase spring flows out of the Chino watershed rapidly results in severe over-prediction of response to summer storm events. The Nash-Sutcliffe coefficient is near zero because flows tend to remain approximately constant during dry periods.

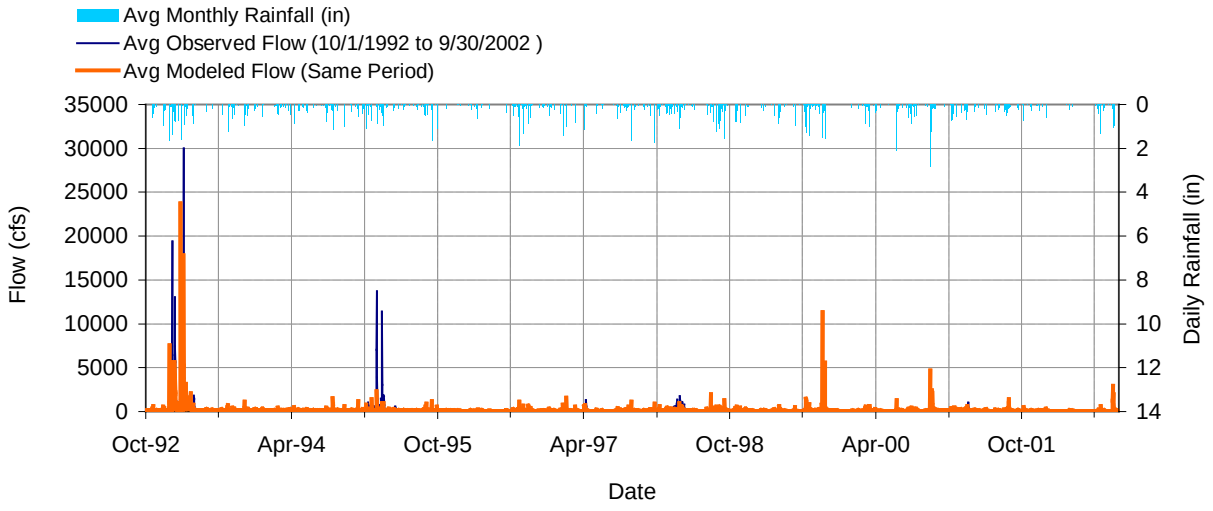


Figure 44. Mean daily flow at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (SWAT).

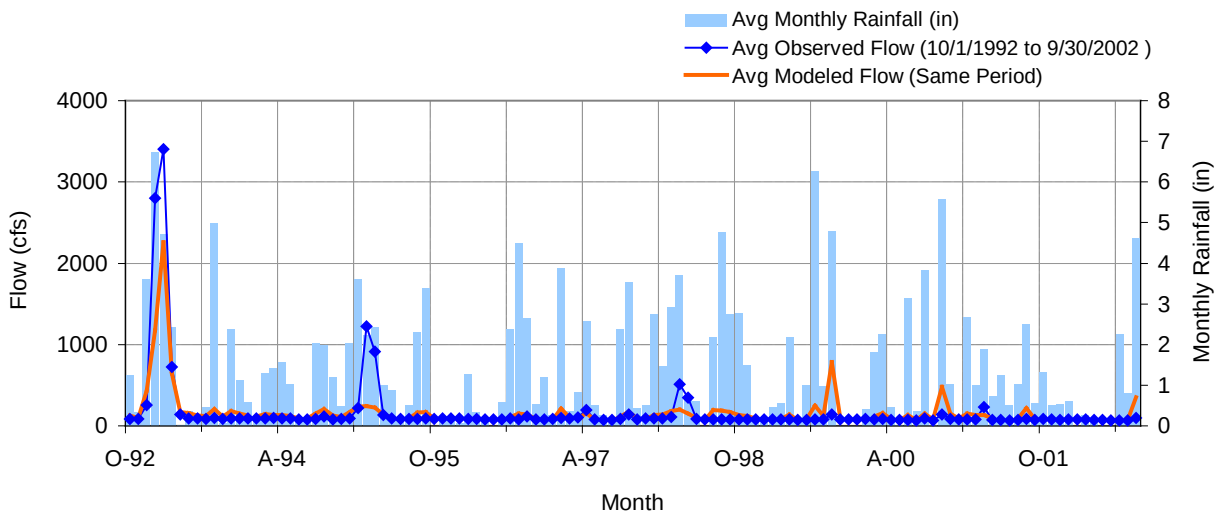


Figure 45. Mean monthly flow at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (SWAT).

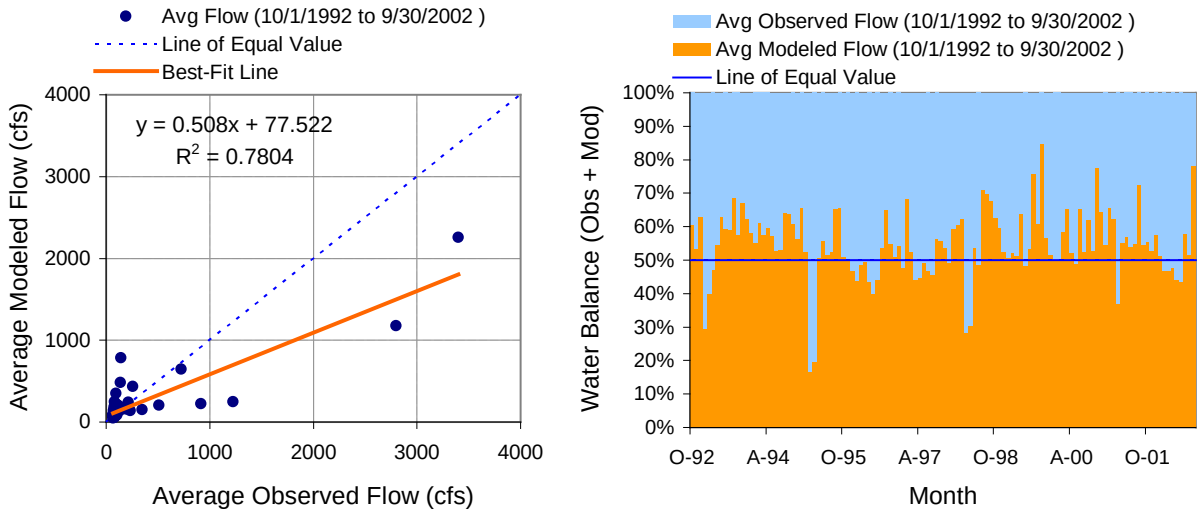


Figure 46. Monthly flow regression and temporal variation at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (SWAT).

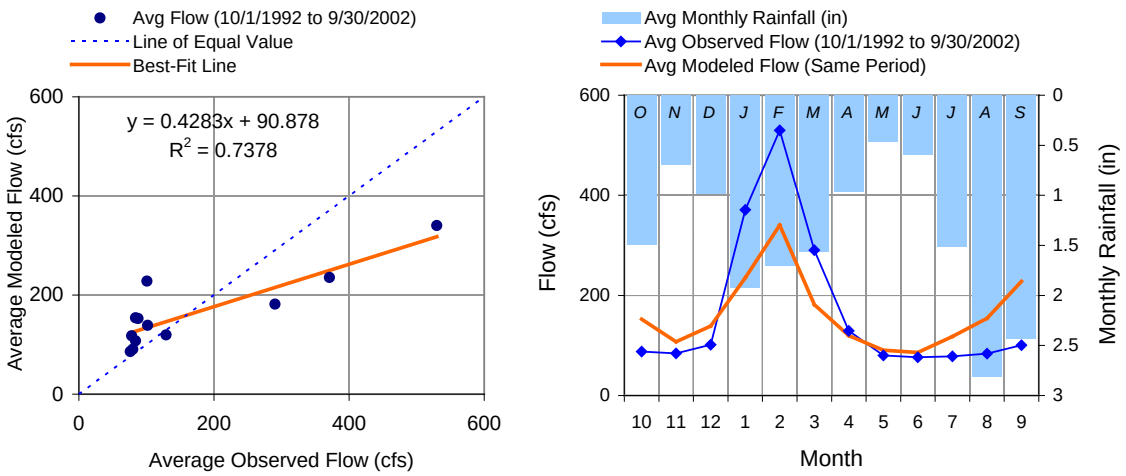


Figure 47. Seasonal regression and temporal aggregate at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (SWAT).

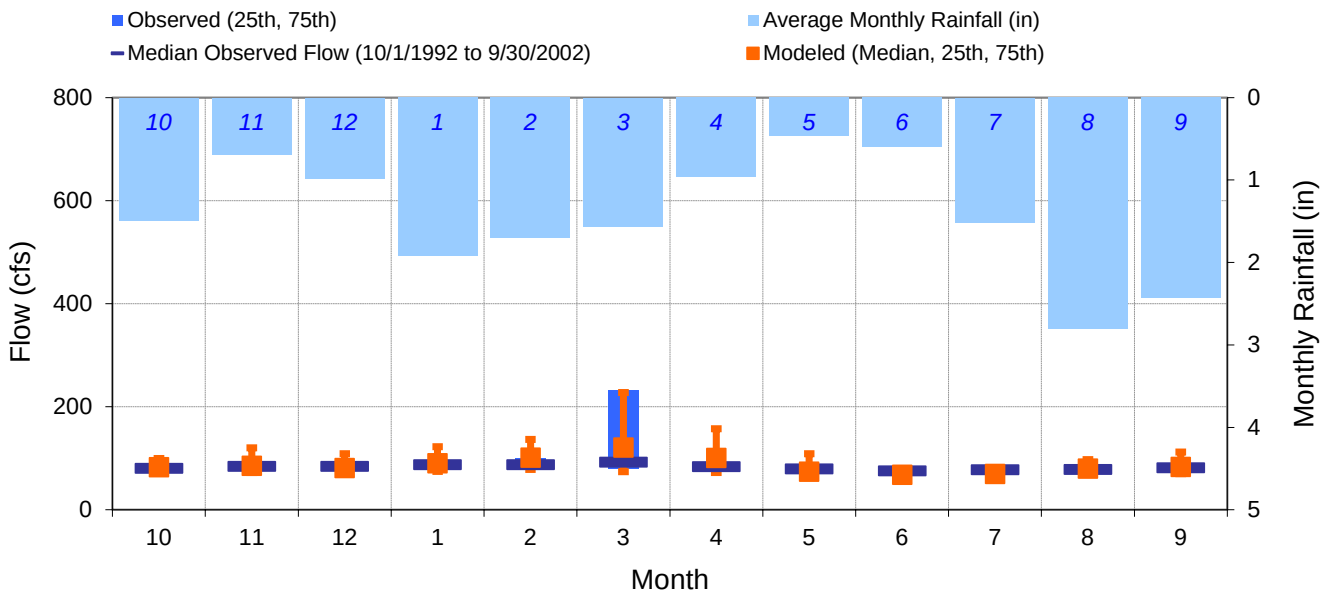


Figure 48. Seasonal medians and ranges at at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (SWAT).

Table 22. Seasonal summary at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (SWAT)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	87.85	80.00	77.00	84.00	152.63	91.66	82.39	113.64
Nov	84.09	84.00	78.00	89.00	107.60	92.48	82.01	112.22
Dec	101.70	83.50	80.00	90.00	138.79	89.91	80.83	114.00
Jan	370.90	87.00	81.00	93.00	235.56	104.44	78.08	147.50
Feb	529.79	87.00	80.00	101.50	340.35	99.91	76.04	154.28
Mar	290.55	92.00	80.00	232.00	181.43	103.13	73.67	161.90
Apr	129.11	83.00	77.00	93.00	119.69	94.57	72.58	127.94
May	79.98	79.00	72.00	87.00	90.37	72.78	64.29	102.97
Jun	76.29	75.00	69.00	81.00	86.15	72.08	60.86	89.61
Jul	78.20	77.00	71.00	82.00	117.83	84.24	66.98	114.69
Aug	83.85	78.00	75.00	84.00	154.15	113.30	86.81	163.60
Sep	100.71	81.00	73.00	85.00	228.15	107.68	79.88	147.35

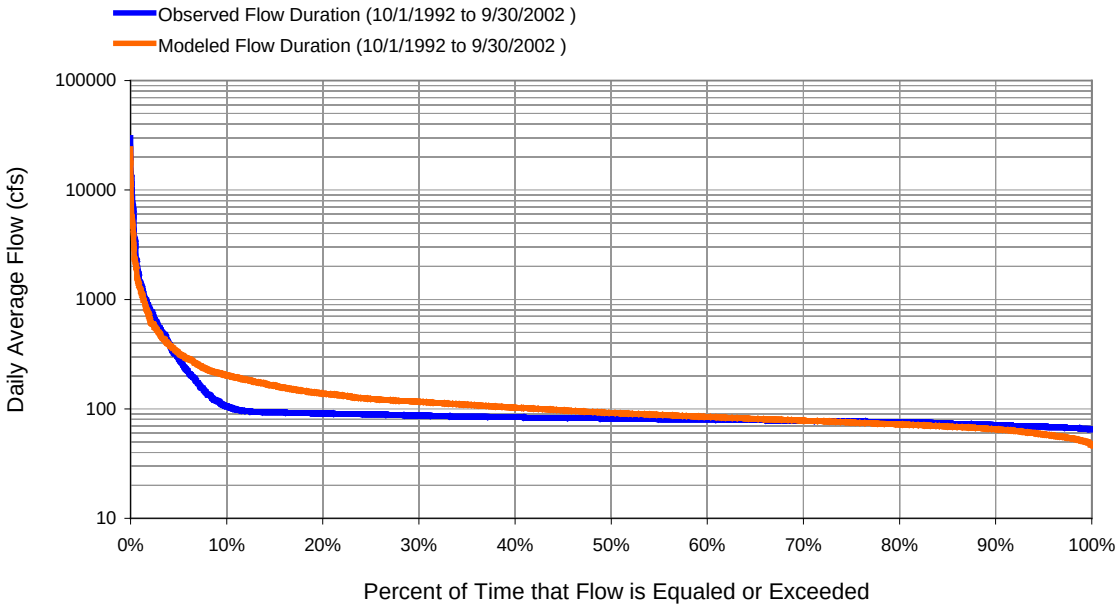


Figure 49. Flow exceedance at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (SWAT).

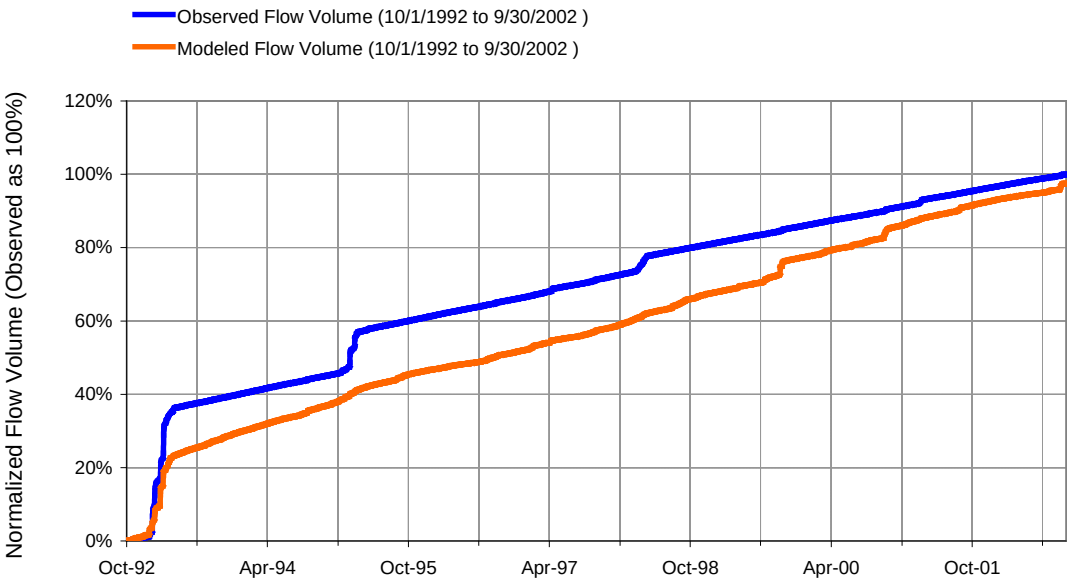


Figure 50. Flow accumulation at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (SWAT).

Table 23. Summary statistics at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (SWAT)

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 10		USGS 09504000 VERDE RIVER NEAR CLARKDALE, AZ	
10-Year Analysis Period: 10/1/1992 - 9/30/2002 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 15060202 Latitude: 34.8522416 Longitude: -112.065994 Drainage Area (sq-mi): 3503	
Total Simulated In-stream Flow:	**0.63**	Total Observed In-stream Flow:	**0.64**
Total of simulated highest 10% flows:	**0.29**	Total of Observed highest 10% flows:	**0.36**
Total of Simulated lowest 50% flows:	**0.14**	Total of Observed Lowest 50% flows:	**0.15**
Simulated Summer Flow Volume (months 7-9):	**0.16**	Observed Summer Flow Volume (7-9):	**0.09**
Simulated Fall Flow Volume (months 10-12):	**0.13**	Observed Fall Flow Volume (10-12):	**0.09**
Simulated Winter Flow Volume (months 1-3):	**0.24**	Observed Winter Flow Volume (1-3):	**0.38**
Simulated Spring Flow Volume (months 4-6):	**0.10**	Observed Spring Flow Volume (4-6):	**0.09**
Total Simulated Storm Volume:	**0.28**	Total Observed Storm Volume:	**0.29**
Simulated Summer Storm Volume (7-9):	**0.08**	Observed Summer Storm Volume (7-9):	**0.01**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-2.46	10	
Error in 50% lowest flows:	-1.74	10	
Error in 10% highest flows:	**-19.34**	**15**	
Seasonal volume error - Summer:	**89.89**	**30**	
Seasonal volume error - Fall:	**46.00** >>	**30**	Clear
Seasonal volume error - Winter:	**-36.45**	**30**	
Seasonal volume error - Spring:	3.88	30	
Error in storm volumes:	-3.32	20	
Error in summer storm volumes:	**593.89**	**50**	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.030	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.236	as E or E' approaches 1.0	
Monthly NSE	0.685		

Hydrology Validation

Validation for the Verde River near Clarkdale was performed for the period 10/1/1982 through 9/30/1992. Results are presented in Figures 51 through 57 and Table 24 and 25. The validation results are generally similar to those of the calibration period, and indeed are better on some statistics, indicating that the model is not over-fit to the specific conditions of the calibration period.

It is important to recognize that the validation uses the 2001 land use as a static representation. While the watershed has remained largely in National Forest, Indian Reservations and unoccupied rangeland, important temporal changes have occurred as a result of intermittent wildfires. Areas of recent burns typically have decreased evapotranspiration and increased direct runoff. These, however, are not represented in the model. In addition, the PET estimates for the 20 Watershed model use SWAT weather generator statistics for solar radiation, cloud cover, wind, and relative humidity – essentially assuming that the central tendency of these factors has not changed over time.

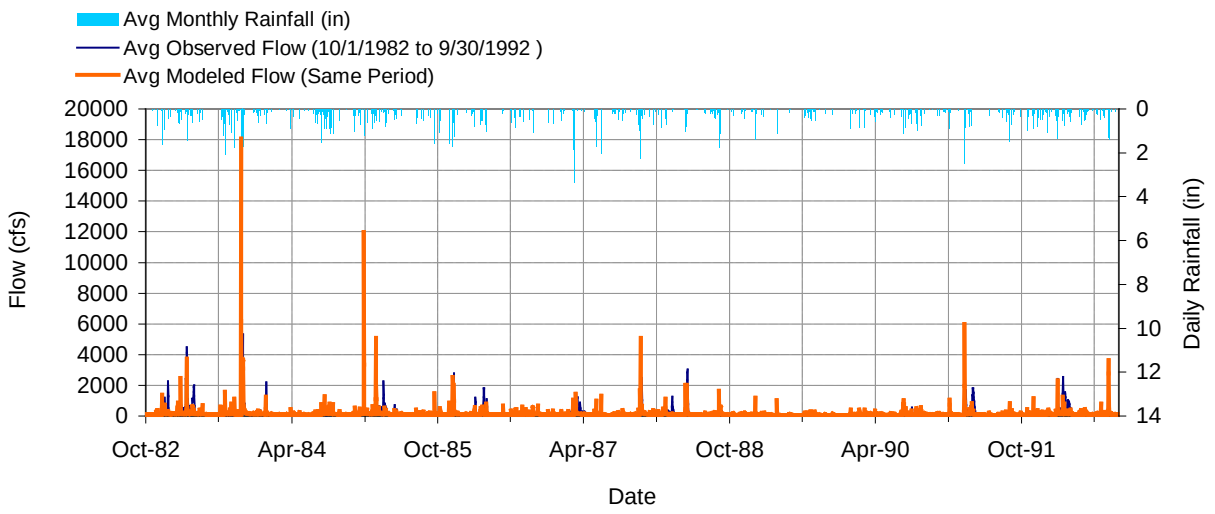


Figure 51. Mean daily flow at USGS 09504000 Verde River near Clarkdale, AZ – validation period (SWAT).

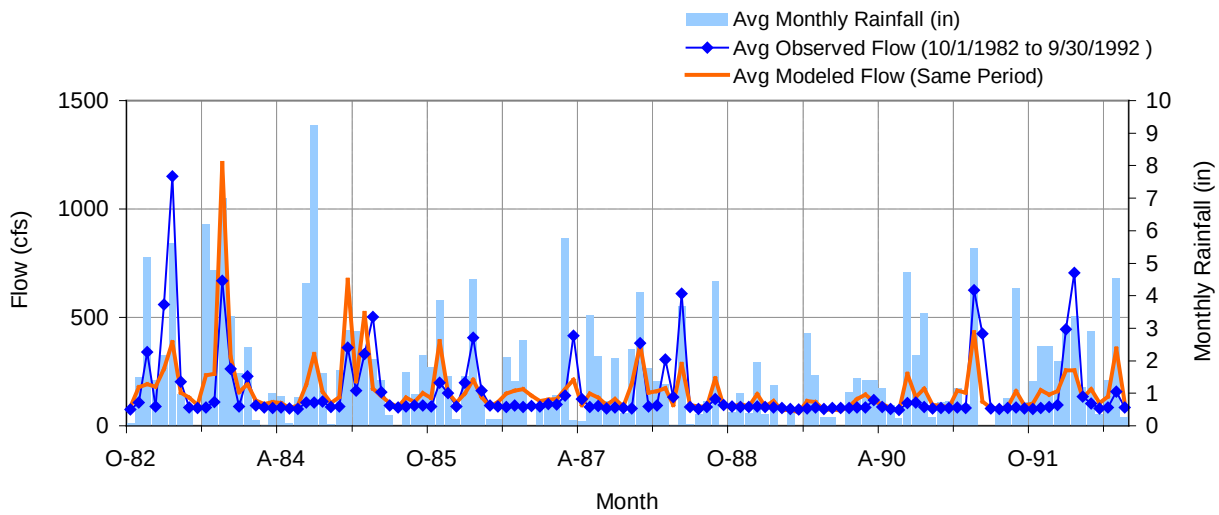


Figure 52. Mean monthly flow at USGS 09504000 Verde River near Clarkdale, AZ – validation period (SWAT).

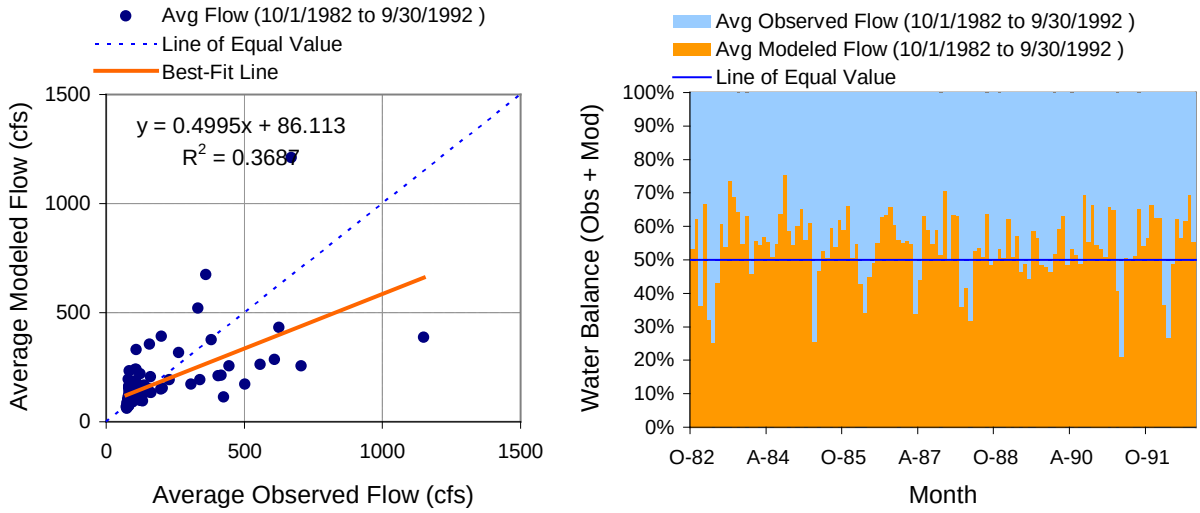


Figure 53. Monthly flow regression and temporal variation at USGS 09504000 Verde River near Clarkdale, AZ – validation period (SWAT).

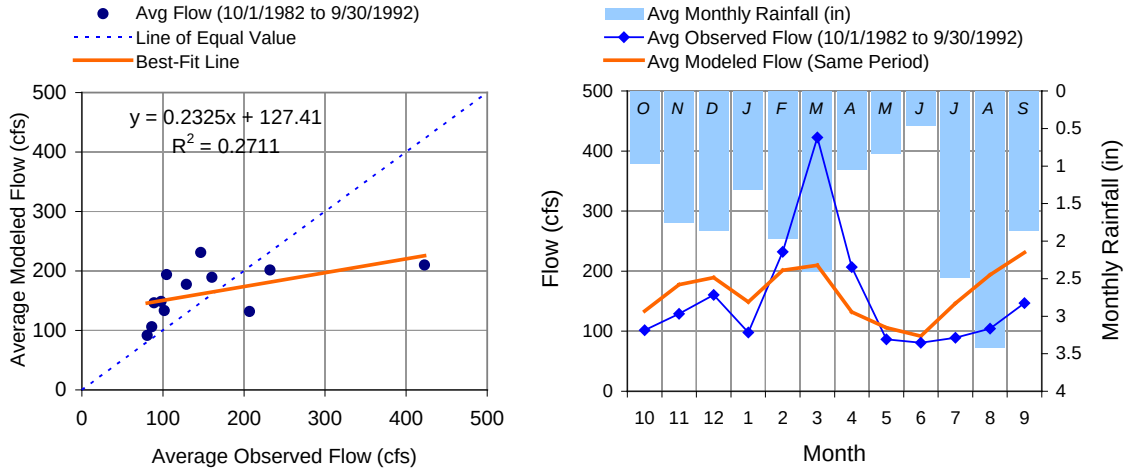


Figure 54. Seasonal regression and temporal aggregate at USGS 09504000 Verde River near Clarkdale, AZ – validation period (SWAT).

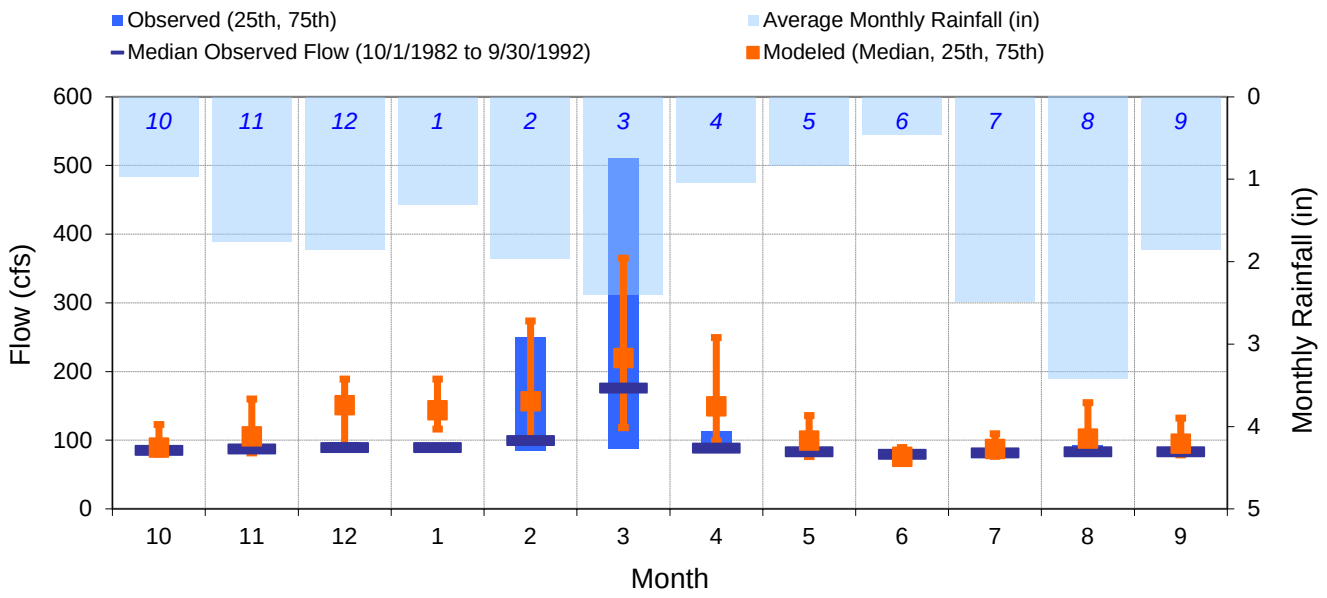


Figure 55. Seasonal medians and ranges at USGS 09504000 Verde River near Clarkdale, AZ – validation period (SWAT).

Table 24. Seasonal summary at USGS 09504000 Verde River near Clarkdale, AZ – validation period (SWAT)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	101.69	85.00	79.00	88.00	133.41	95.42	80.47	115.23
Nov	129.11	87.00	84.00	89.00	177.41	102.19	85.14	132.23
Dec	160.55	89.00	85.00	98.00	189.36	113.19	93.62	145.09
Jan	97.85	89.00	86.00	94.75	148.63	115.42	103.86	146.28
Feb	232.11	99.00	85.00	251.00	201.41	112.81	98.46	161.08
Mar	422.76	175.50	87.00	510.50	209.87	125.61	94.45	179.31
Apr	206.73	88.00	83.00	113.00	131.86	101.34	88.26	122.62
May	86.31	83.00	80.00	88.00	106.03	89.26	80.14	104.86
Jun	80.68	79.00	76.75	85.00	91.66	80.87	72.39	92.45
Jul	89.01	81.00	77.00	86.75	146.37	102.31	82.18	143.73
Aug	104.45	83.00	79.00	93.00	194.00	123.61	91.04	185.62
Sep	146.81	83.00	79.00	89.00	230.93	100.94	84.97	121.65

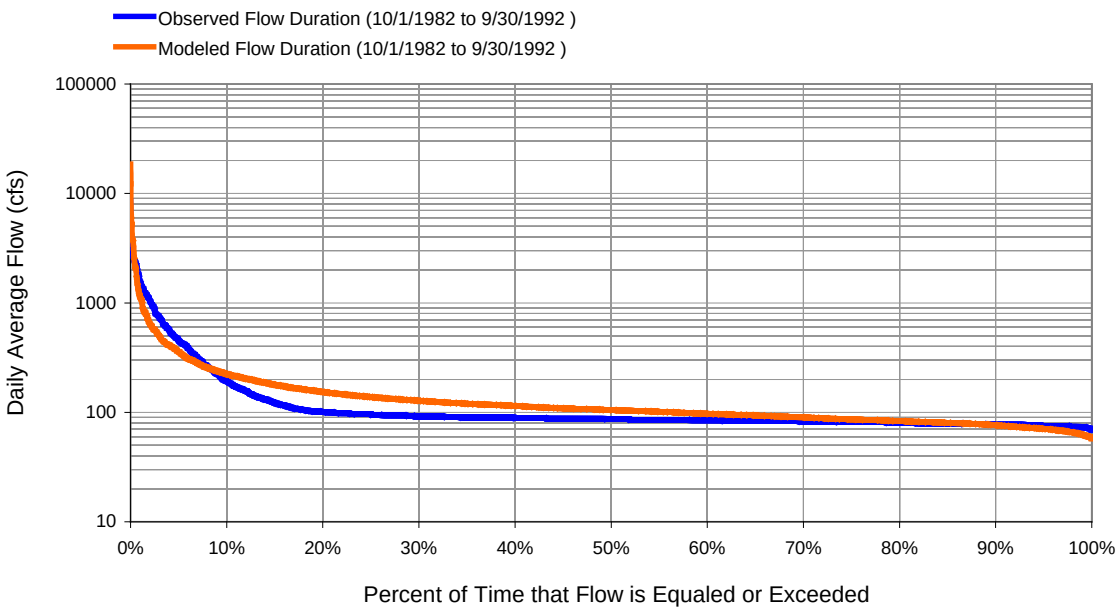


Figure 56. Flow exceedance at USGS 09504000 Verde River near Clarkdale, AZ – validation period (SWAT).

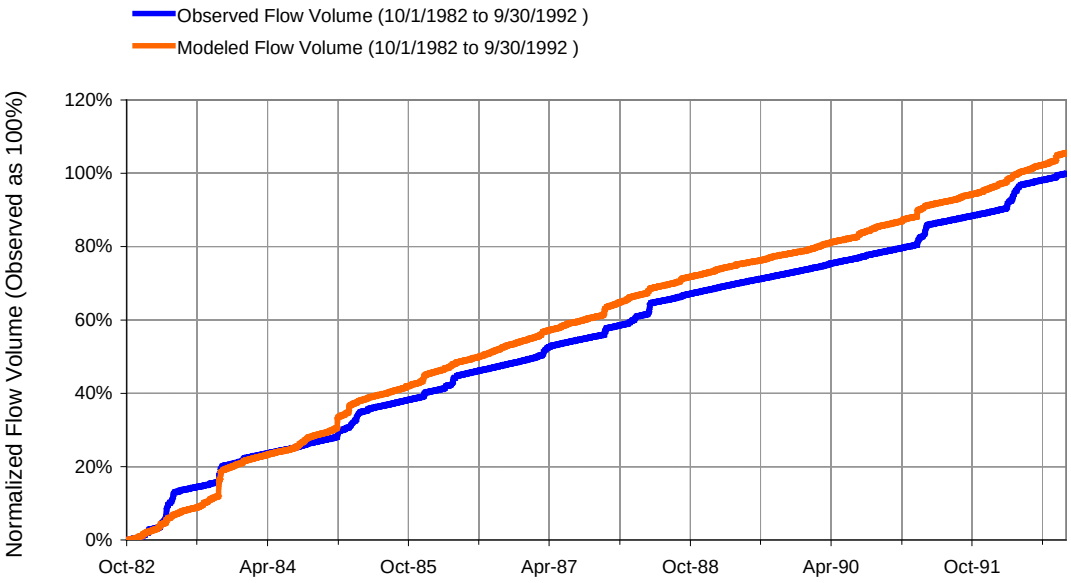


Figure 57. Flow accumulation at USGS 09504000 Verde River near Clarkdale, AZ – validation period (SWAT).

Table 25. Summary statistics at USGS 09504000 Verde River near Clarkdale, AZ – validation period (SWAT)

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 10 10-Year Analysis Period: 10/1/1982 - 9/30/1992 Flow volumes are (inches/year) for upstream drainage area		USGS 09504000 VERDE RIVER NEAR CLARKDALE, AZ Hydrologic Unit Code: 15060202 Latitude: 34.8522416 Longitude: -112.065994 Drainage Area (sq-mi): 3503	
Total Simulated In-stream Flow:	**0.63**	Total Observed In-stream Flow:	**0.60**
Total of simulated highest 10% flows:	**0.26**	Total of Observed highest 10% flows:	**0.29**
Total of Simulated lowest 50% flows:	**0.16**	Total of Observed Lowest 50% flows:	**0.16**
Simulated Summer Flow Volume (months 7-9):	**0.19**	Observed Summer Flow Volume (7-9):	**0.11**
Simulated Fall Flow Volume (months 10-12):	**0.16**	Observed Fall Flow Volume (10-12):	**0.13**
Simulated Winter Flow Volume (months 1-3):	**0.18**	Observed Winter Flow Volume (1-3):	**0.24**
Simulated Spring Flow Volume (months 4-6):	**0.11**	Observed Spring Flow Volume (4-6):	**0.12**
Total Simulated Storm Volume:	**0.26**	Total Observed Storm Volume:	**0.23**
Simulated Summer Storm Volume (7-9):	**0.10**	Observed Summer Storm Volume (7-9):	**0.03**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	5.68	10	
Error in 50% lowest flows:	5.17	10	
Error in 10% highest flows:	-9.70	15	
Seasonal volume error - Summer:	**68.04**	**30**	
Seasonal volume error - Fall:	27.70	30	
Seasonal volume error - Winter:	-25.96	30	
Seasonal volume error - Spring:	-11.56	30	
Error in storm volumes:	12.44	20	
Error in summer storm volumes:	**197.67**	**50**	
Nash-Sutcliffe Coefficient of Efficiency, E:	-0.996	Model accuracy increases as E or E' approaches 1.0	
Baseline adjusted coefficient (Garrick), E':	0.121		
Monthly NSE	0.320		

Hydrology Results for Larger Watershed

As described above, parameters determined through calibration to the Verde River near Clarkdale gage were not fully transferable to other gages in the watershed. Therefore, calibration was pursued at a total of 10 gages in the Arizona basins – six in the Verde River watershed, one in the Salt River watershed, and two in the San Pedro River watersheds. Only the gage at Roosevelt provides a long period of record for the Salt River watershed. The mainstem gage for the San Pedro River does not provide a rigorous calibration test because its flow is largely determined by the upstream boundary condition. Therefore, calibration was also pursued on perennial Aravaipa Creek. The two San Pedro gages ceased operation in 1995; therefore calibration was pursued over an earlier time period without a separate validation test.

Calibration results at all gages are summarized in Table 26 and are generally of similar quality to the fit obtained on the Verde River near Clarkdale. The fit for the East Verde River is believed to be relatively poor due to the influences of Payson water withdrawals. The generally close match between observed and predicted flow at the Salt River gage is shown in Figures 58 through 64 and Tables 27 and 28. Results of the validation exercise are summarized in Table 29. In general, the quality of fit during the validation period is similar to that in the calibration period. Thus, the model is judged to be useful for scenario evaluation.

Table 26. Summary statistics (percent error) at all stations – calibration period WY 1992-2002 (SWAT)

Station	09472000 San Pedro nr Redington (1972-95)*	09473000 Aravaipa Crk nr Mammoth (1972-95)	09498500 Salt River nr Roosevelt	09503700 Verde River nr Paulden	09504000 Verde River nr Clarkdale	09504500 Oak Creek nr Cornville	09505800 W Clear Cr nr Camp Verde	09506000 Verde River nr Camp Verde	09507980 E Verde River nr Childs	09508500 Verde R below Tangle Cr
Error in total volume:	-6.74	3.46	9.43	9.15	-2.46	-2.63	9.45	7.68	-6.21	1.68
Error in 50% lowest flows:	NA*	-1.25	-7.16	-1.14	-1.74	-17.90	-10.22	8.49	56.51	-17.85
Error in 10% highest flows:	-7.97	2.62	4.52	8.65	-19.34	-10.31	7.29	-5.00	-6.56	-7.27
Seasonal volume error - Summer:	-4.82	53.40	58.85	110.89	89.89	96.08	49.24	100.98	156.62	96.88
Seasonal volume error - Fall:	8.09	-3.31	103.52	56.82	46.00	27.01	26.17	44.07	58.54	47.60
Seasonal volume error - Winter:	-20.25	-10.77	6.95	-24.75	-36.45	-22.05	2.87	-13.37	-35.02	-19.30
Seasonal volume error - Spring:	-7.04	7.82	-51.64	-1.39	3.88	-4.10	2.23	3.38	0.08	-7.60
Error in storm volumes:	1.49	-27.95	16.40	19.48	-3.32	-10.98	21.24	9.94	17.92	16.89
Error in summer storm volumes:	-3.89	73.05	103.32	875.65	593.89	205.71	96.30	153.62	338.25	262.34
Daily Nash-Sutcliffe Coefficient of Efficiency, E:	-0.362	0.629	0.222	-0.864	0.030	0.454	-0.021	0.225	0.311	0.250
Monthly Nash-Sutcliffe Coefficient of Efficiency, E:	0.690	0.717	0.783	0.777	0.320	0.728	0.804	0.880	0.736	0.860

* Note that median flow for the San Pedro River nr Redington is 0.

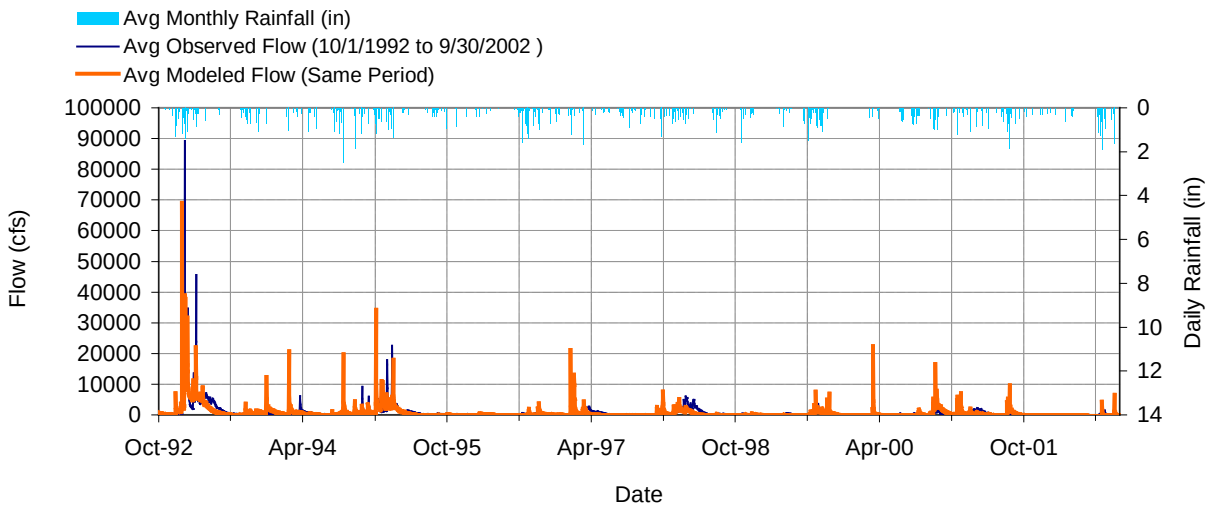


Figure 58. Mean daily flow at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (SWAT).

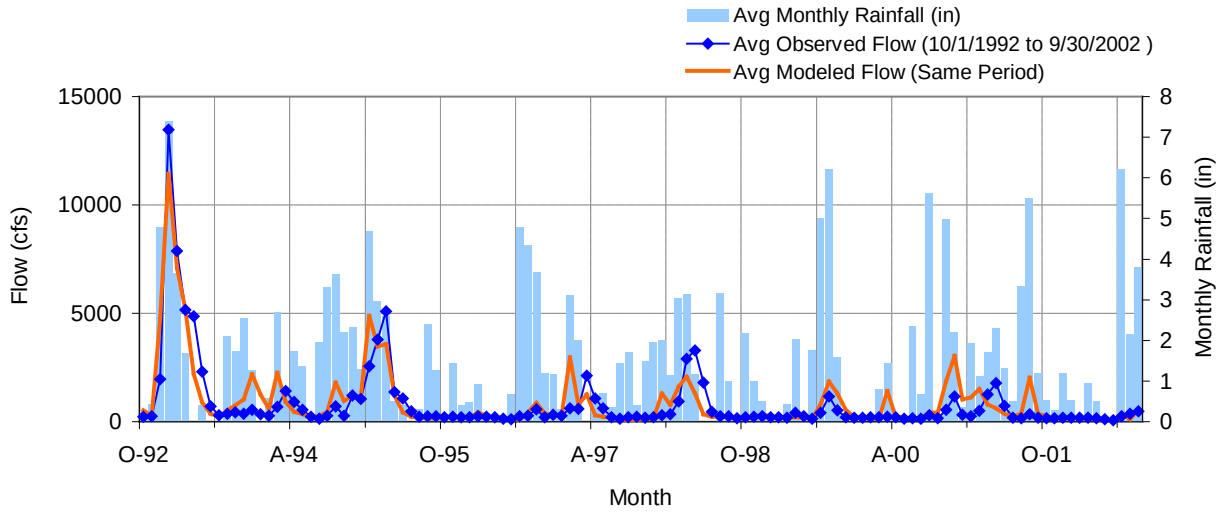


Figure 59. Mean monthly flow at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (SWAT).

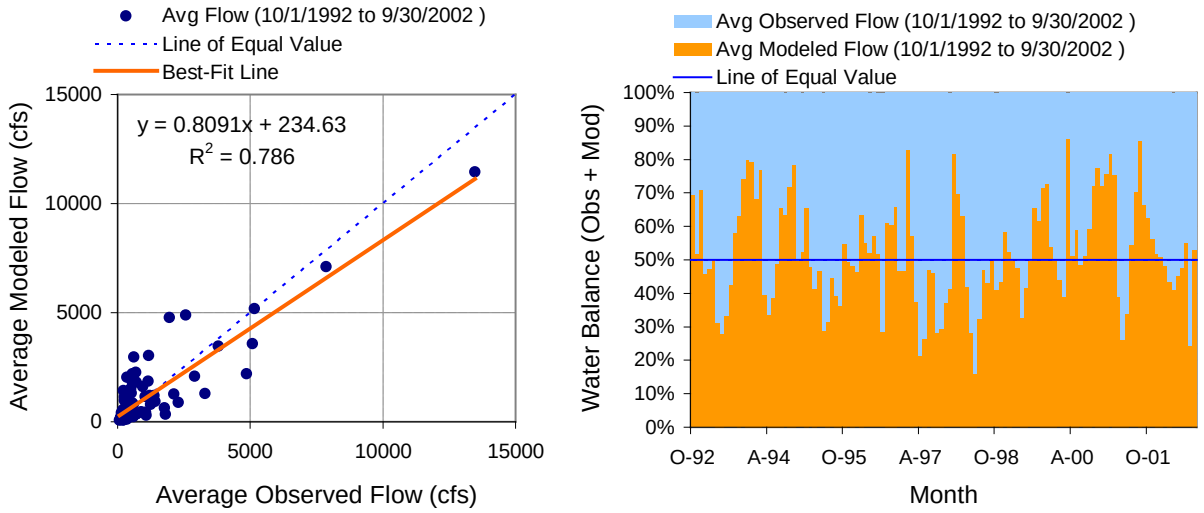


Figure 60. Monthly flow regression and temporal variation at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (SWAT).

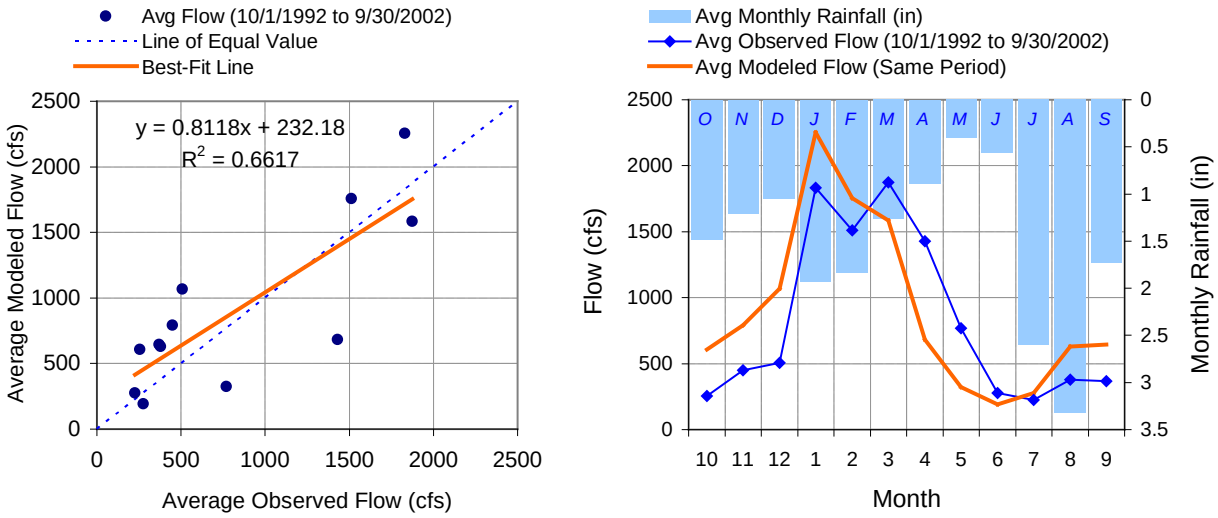


Figure 61. Seasonal regression and temporal aggregate at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (SWAT).

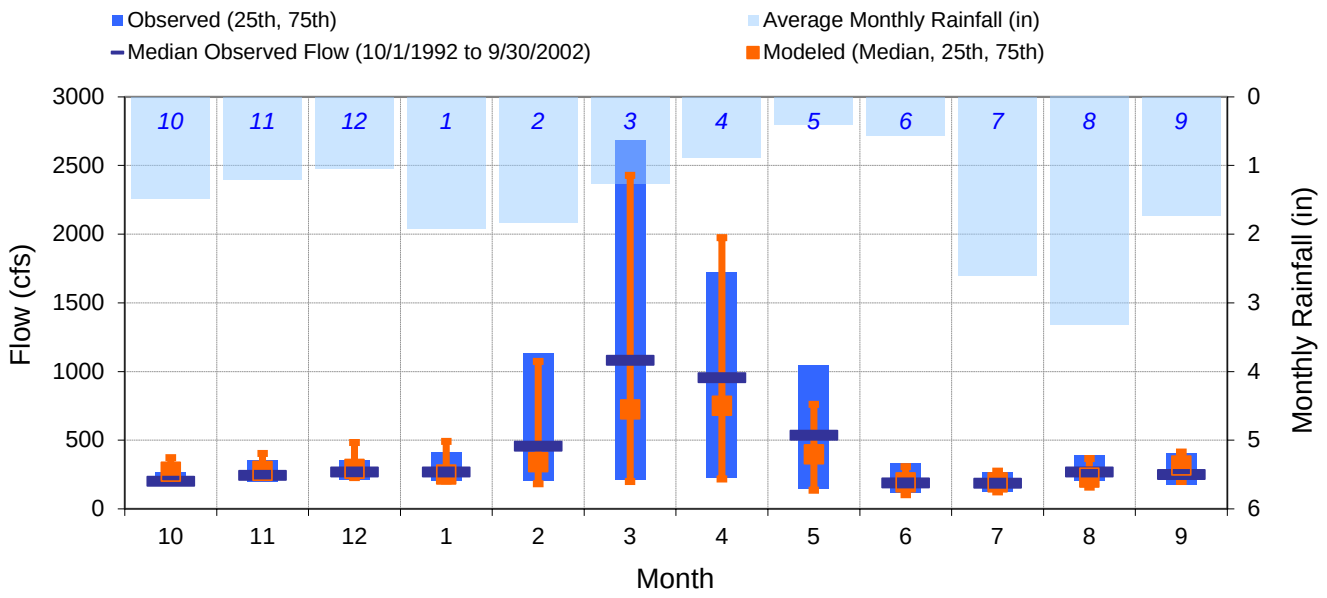


Figure 62. Seasonal medians and ranges at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (SWAT).

Table 27. Seasonal summary at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (SWAT)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	256.42	200.50	168.25	264.00	608.17	344.34	198.53	657.22
Nov	450.48	243.00	195.00	352.75	791.68	218.51	204.55	804.13
Dec	507.61	267.50	210.00	356.25	1067.82	403.31	196.21	1094.30
Jan	1831.48	267.00	204.00	413.25	2253.82	489.18	188.76	1909.69
Feb	1511.59	455.50	206.00	1135.00	1755.74	642.09	204.73	2372.74
Mar	1875.51	1080.00	211.50	2682.50	1584.27	794.67	261.51	2058.55
Apr	1429.55	953.50	224.00	1722.50	683.25	331.92	207.45	998.65
May	768.86	535.00	150.25	1047.50	324.01	236.85	184.00	380.12
Jun	277.08	187.50	121.00	335.25	191.56	199.95	141.41	225.64
Jul	226.12	185.50	129.25	269.50	275.63	180.78	113.41	207.08
Aug	377.92	267.50	205.50	389.50	628.63	216.21	140.01	844.51
Sep	368.88	249.50	174.00	402.25	643.08	293.31	144.25	699.35

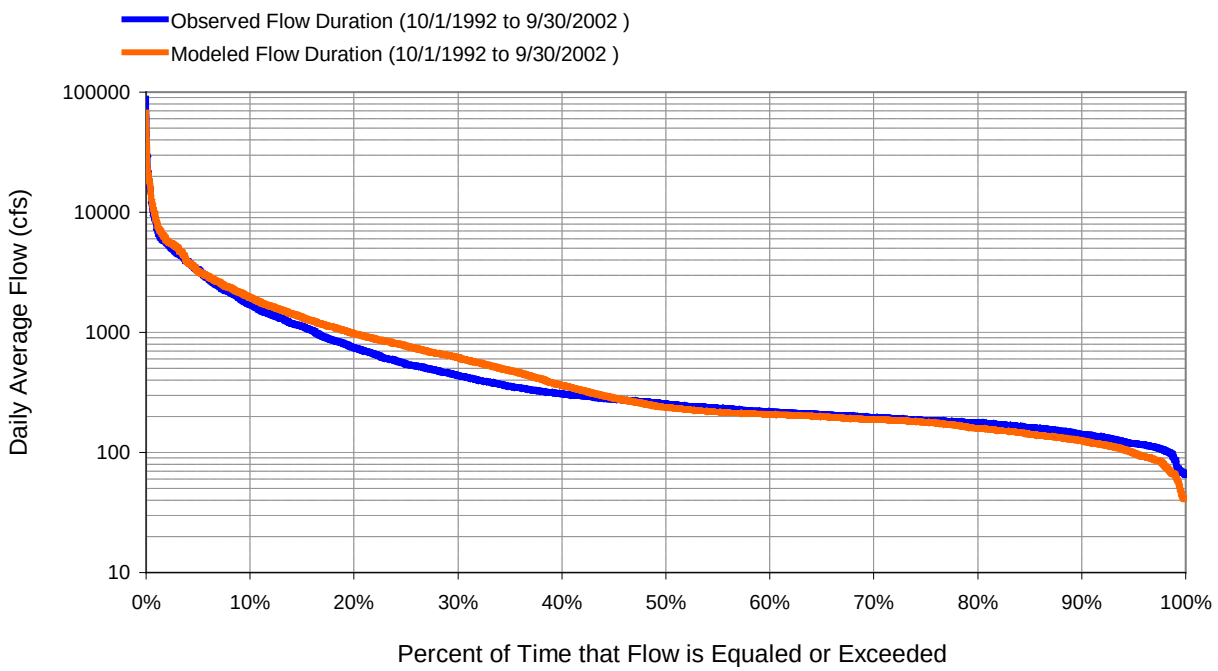


Figure 63. Flow exceedence at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (SWAT).

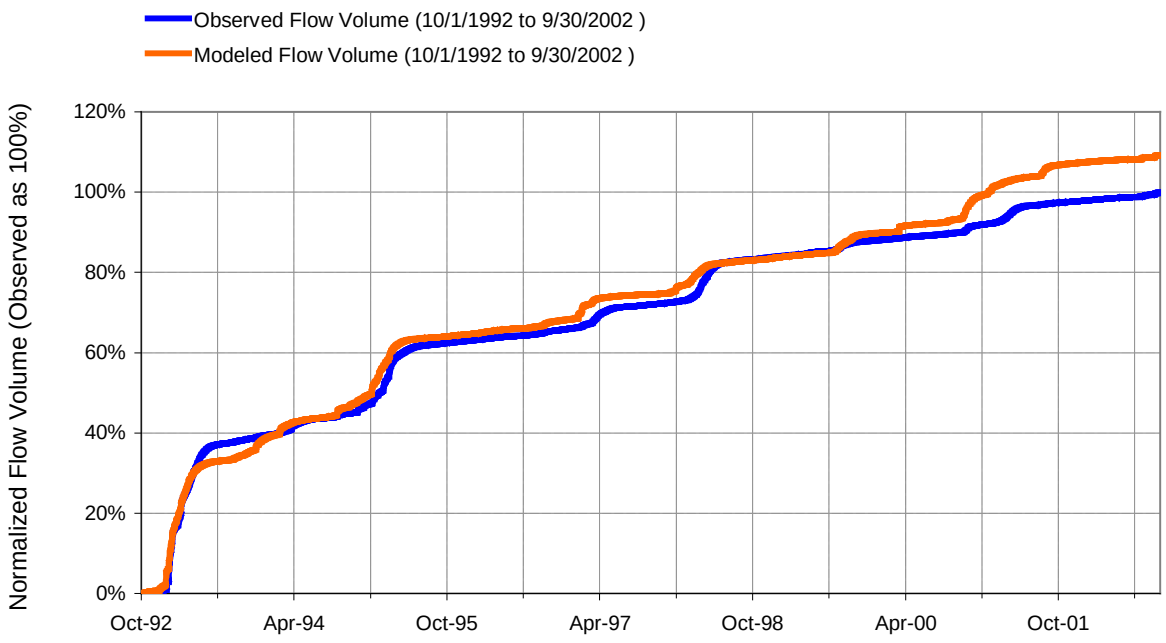


Figure 64. Flow accumulation at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (SWAT).

Table 28. Summary statistics at USGS 09498500 Salt River near Roosevelt, AZ – calibration period (SWAT)

SWAT Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM OUTLET 3		USGS 09498500 SALT RIVER NEAR ROOSEVELT, AZ		
10-Year Analysis Period: 10/1/1992 - 9/30/2002 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 15060103 Latitude: 33.6194949 Longitude: -110.9215037 Drainage Area (sq-mi): 4306		
Total Simulated In-stream Flow:	**2.83**	Total Observed In-stream Flow:		**2.59**
Total of simulated highest 10% flows:	**1.63**	Total of Observed highest 10% flows:		**1.56**
Total of Simulated lowest 50% flows:	**0.27**	Total of Observed Lowest 50% flows:		**0.29**
Simulated Summer Flow Volume (months 7-9):	**0.41**	Observed Summer Flow Volume (7-9):		**0.26**
Simulated Fall Flow Volume (months 10-12):	**0.65**	Observed Fall Flow Volume (10-12):		**0.32**
Simulated Winter Flow Volume (months 1-3):	**1.46**	Observed Winter Flow Volume (1-3):		**1.36**
Simulated Spring Flow Volume (months 4-6):	**0.31**	Observed Spring Flow Volume (4-6):		**0.65**
Total Simulated Storm Volume:	**1.09**	Total Observed Storm Volume:		**0.94**
Simulated Summer Storm Volume (7-9):	**0.18**	Observed Summer Storm Volume (7-9):		**0.09**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*Run (n-1)*	*Run (n-2)*
Error in total volume:	9.43	10	2.65	5.65
Error in 50% lowest flows:	-7.16	10	3.27	13.54
Error in 10% highest flows:	4.52	15	-3.14	-2.75
Seasonal volume error - Summer:	**58.85**	**30**	**73.05**	**86.02**
Seasonal volume error - Fall:	**103.52** >>	**30**	**77.83** Clear	**91.08**
Seasonal volume error - Winter:	6.95	30	0.17	0.25
Seasonal volume error - Spring:	**-51.64**	**30**	**-57.34**	**-57.27**
Error in storm volumes:	16.40	20	5.26	5.60
Error in summer storm volumes:	**103.32**	**50**	**110.10**	**112.10**
Nash-Sutcliffe Coefficient of Efficiency, E:	0.222	Model accuracy increases	0.363	0.360
Baseline adjusted coefficient (Garrick), E':	0.314	as E or E' approaches 1.0	0.335	0.317
Monthly NSE	0.783			

Table 29. Summary statistics at all stations – validation period WY 1982-1992 (SWAT)

Station	09498500 Salt River nr Roosevelt	09503700 Verde River nr Paulden	09504000 Verde River nr Clarkdale	09504500 Oak Creek nr Cornville	09505800 W Clear Cr nr Camp Verde	09507980 E Verde River nr Childs	09508500 Verde R below Tangle Cr
Error in total volume:	-1.76	38.73	5.68	15.80	-0.57	23.55	7.96
Error in 50% lowest flows:	-18.12	-2.09	5.17	13.08	-28.71	1.12	11.91
Error in 10% highest flows:	-2.86	78.10	-9.70	-3.77	-0.02	53.33	-2.37
Seasonal volume error - Summer:	58.01	50.18	68.04	197.59	18.18	141.05	157.67
Seasonal volume error - Fall:	54.85	67.27	27.70	24.82	-10.18	45.31	17.43
Seasonal volume error - Winter:	-0.60	31.00	-25.96	-16.44	11.25	-6.66	-17.53
Seasonal volume error - Spring:	-60.95	-1.16	-11.56	-8.90	-33.19	-18.58	-30.60
Error in storm volumes:	6.42	108.63	12.44	18.06	34.57	91.61	19.33
Error in summer storm volumes:	99.23	107.87	197.67	370.81	-9.73	310.39	332.99
Daily Nash-Sutcliffe Coefficient of Efficiency, E:	-0.072	-2.028	-0.996	-0.061	-1.666	-1.193	-0.191
Monthly Nash-Sutcliffe Coefficient of Efficiency, E:	0.446	-0.034	0.320	0.395	-0.161	0.736	0.441

Water Quality Calibration and Validation

The 20 Watershed models are designed to provide water quality simulation for total suspended solids (TSS), total nitrogen, and total phosphorus. The water quality calibration focuses on the replication of monthly loads, as specified in the project QAPP. Given the simplified approach to water quality simulation in the 20 Watershed model a close match to individual concentration observations cannot be expected. However, comparison to monthly loads presents challenges, as monthly loads are not observed. Instead, monthly loads must be estimated from scattered concentration grab samples and continuous flow records. Such estimation is fraught with uncertainty because it depends on the degree and form in which concentration and flow are correlated with one another. Further, the bulk of the load of sediment and sediment-associated phosphorus is likely to move through the system in a limited number of high flow events that typically are not monitored. As a result, the monthly load calibration is inevitably based on the comparison of two uncertain numbers. Nonetheless, calibration is able to achieve a fair agreement. The load comparisons were supported by detailed examinations of the relationships of

flows to loads and concentrations and the distribution of concentration prediction errors versus flow, time, and season, as well as standard time series plots.

For application on a nationwide basis, the 20 Watershed protocols assume that sediment and phosphorus loads will likely exhibit a strong positive correlation to flow (and associated erosive processes), while total nitrogen loads, which often have a dominant groundwater component, will not. Accordingly, sediment and phosphorus loads were estimated from observations using a flow-stratified log-log regression approach, while total nitrogen loads were estimated using a flow-stratified averaging estimator, consistent with the findings of Preston et al. (1989).

Initial calibration and validation of water quality was done on the Verde River near Clarkdale, using 1993-2002 for calibration and 1986-1992 for validation. As with hydrology, water quality calibration was performed on the later period as this better reflects the land use included in the model. The start of the validation period was constrained by data availability.

Sediment concentrations in larger, higher-order alluvial streams are largely determined by channel scour, deposition, and transport capacity rather than by upland sediment load. The SWAT representation of these channel processes is rather simplistic. First, the maximum transport capacity concentration (C_{mx}) is determined as $C_{mx} = SPCON \cdot V_{pk}^{SPEXP}$, where V_{pk} is the peak velocity, estimated by a simple ratio to the average rate of flow, and SPCON and SPEXP are user-defined parameters. When the predicted sediment concentration in the reach exceeds C_{mx} the excess is assumed to settle out. If the predicted sediment concentration in the reach is less than C_{mx}, additional sediment may be scoured from the channel to make up the difference, depending on the channel erodibility factor, K_{ch} (cm/hr/Pa). There is no provision for the different transport characteristics of different sediment size fractions. Further, the SPCON and SPEXP parameters are specified at the global level and do not vary by reach. As a result, the ability of SWAT to match individual TSS observations is rather limited.

By judicious adjustment of the SPCON, SPEXP, and K_{ch} parameters combined with the SWAT default MUSLE representation of upland sediment yield a reasonable representation of sediment load can be obtained. Time series of simulated and estimated sediment loads at the Clarkdale station for both periods are shown in Figure 65 and statistics for the two periods are provided separately in Table 30. The key statistic in the table is the relative percent error, which shows the error in the prediction of monthly load normalized to the estimated load. The table also shows the relative average absolute error, which is the average of the relative magnitude of errors in individual monthly load predictions. This number is inflated by outlier months in which the simulated and estimated loads differ by large amounts (which may be as easily due to uncertainty in the estimated load due to limited data as to problems with the model) and the third statistic, the relative median absolute error, is likely more relevant and shows good agreement.

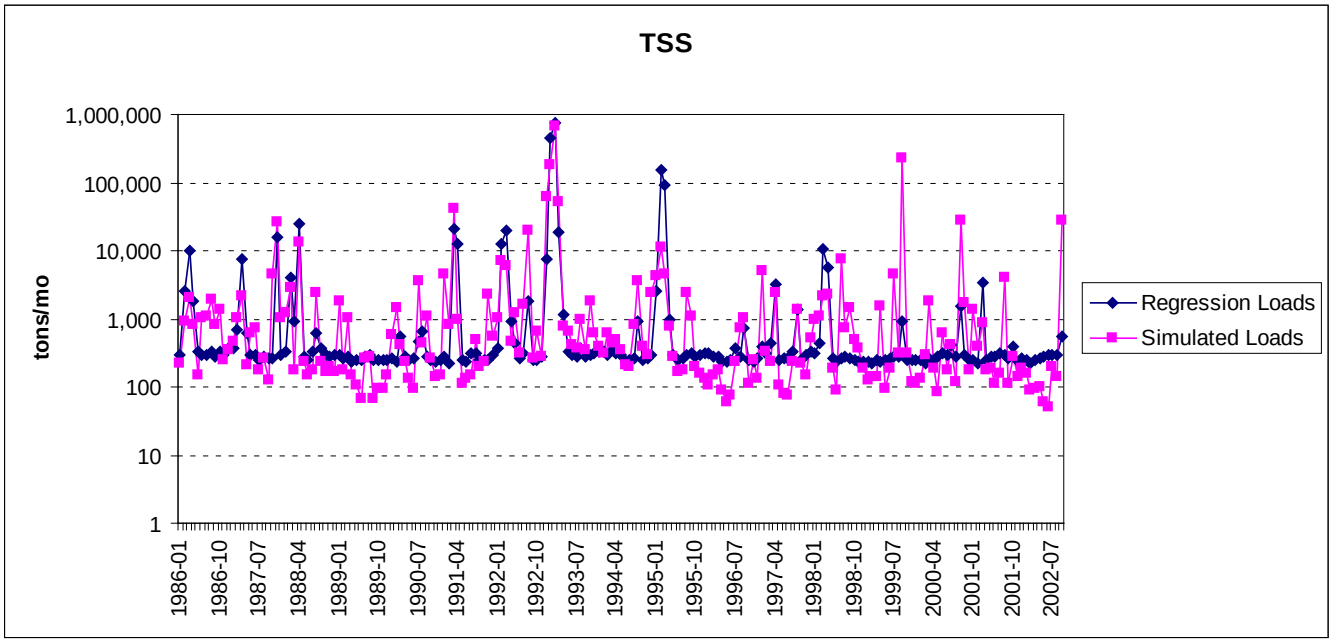


Figure 65. Fit for monthly load of TSS at USGS 09504000 Verde River near Clarkdale, AZ (SWAT).

Table 30. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression at USGS 09504000 Verde River near Clarkdale, AZ (SWAT)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Relative Percent Error	16.9%	-42.6%
Relative Average Absolute Error	64%	122%
Relative Median Absolute Error	0.5%	0.8%

A variety of other diagnostics were also examined to evaluate agreement between the model and observations. These are available in full in the calibration spreadsheets, but a few examples are provided below. First, load-flow power plots were compared for individual days (Figures 66 and 67). These show that the relationship between flow and load is reasonably consistent across the entire range of observed flows, for both the calibration and validation periods.

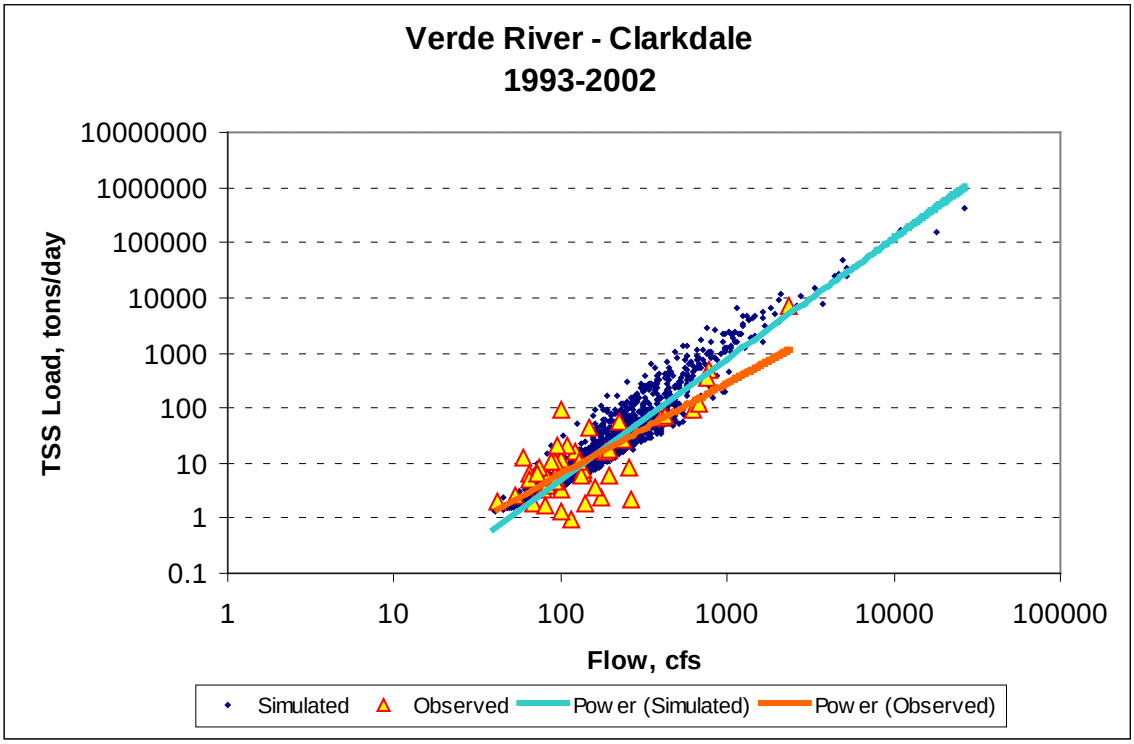


Figure 66. Power plot for observed and simulated TSS at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (SWAT).

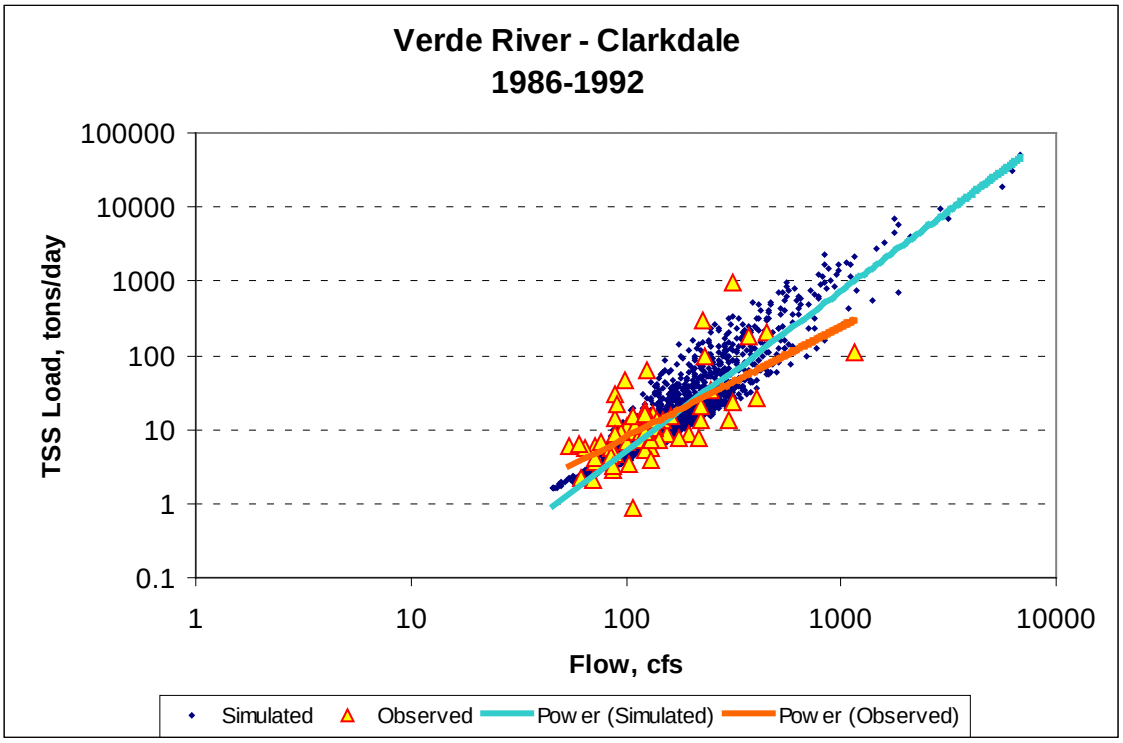


Figure 67. Power plot for observed and simulated TSS at USGS 09504000 Verde River near Clarkdale, AZ – validation period (SWAT).

Standard time series plots (Figure 68) show that observed and simulated concentrations achieve at best a fair agreement, and the model may deviate substantially from individual observations. However, statistics on concentration (0) show that low median errors are achieved (Table 31).

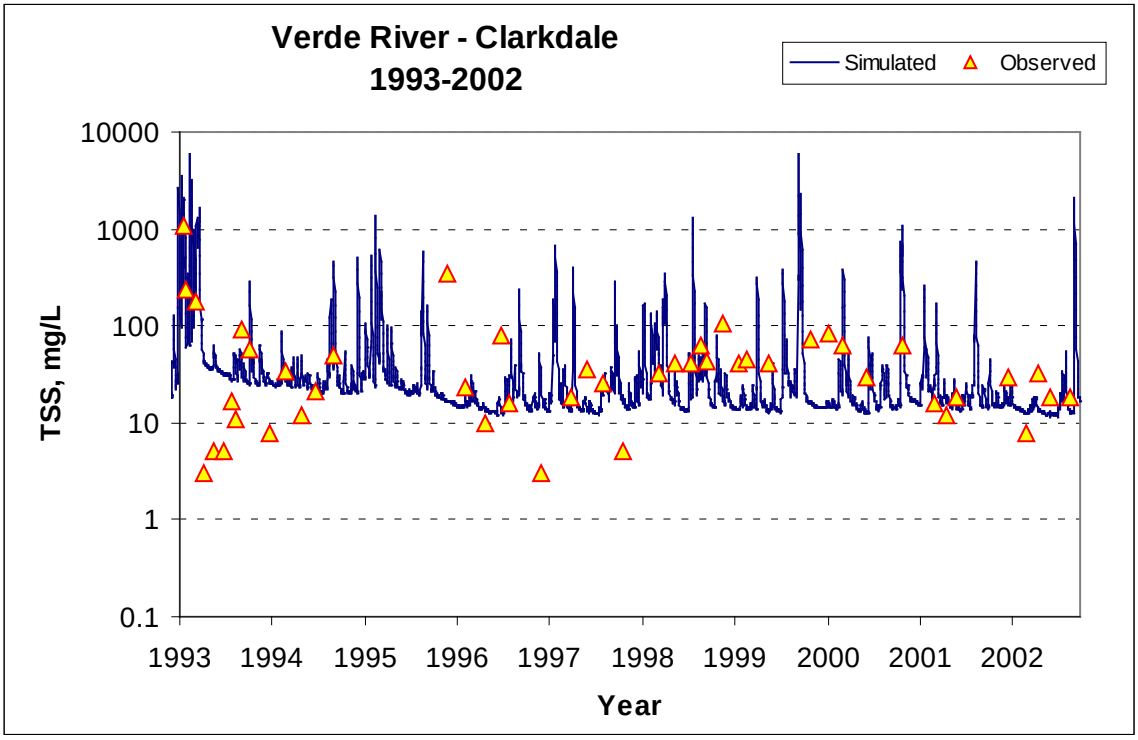


Figure 68. Time series plot of TSS concentration at USGS 09504000 Verde River near Clarkdale, AZ (SWAT).

Table 31. Relative errors (observed minus predicted) for TSS concentration at USGS 09504000 Verde River near Clarkdale, AZ (SWAT)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Count	47	62
Concentration Average Error	-22%	32%
Concentration Median Error	3.3%	9.3%

For simulation of total phosphorus and total nitrogen, calibration was advanced primarily through adjustment of the PPERCO and NPERCO coefficients. Monthly loading series for total phosphorus are shown in Figure 69 and load statistics are summarized in Table 32. The model reproduces the general trend in monthly loads, but is significantly lower than the peak loads predicted by the regression method, resulting in high relative percent errors for both the calibration and validation periods. It should be noted that the available data are limited, particularly for high flow events. Thus, the estimates of “observed” load are also subject to considerable uncertainty.

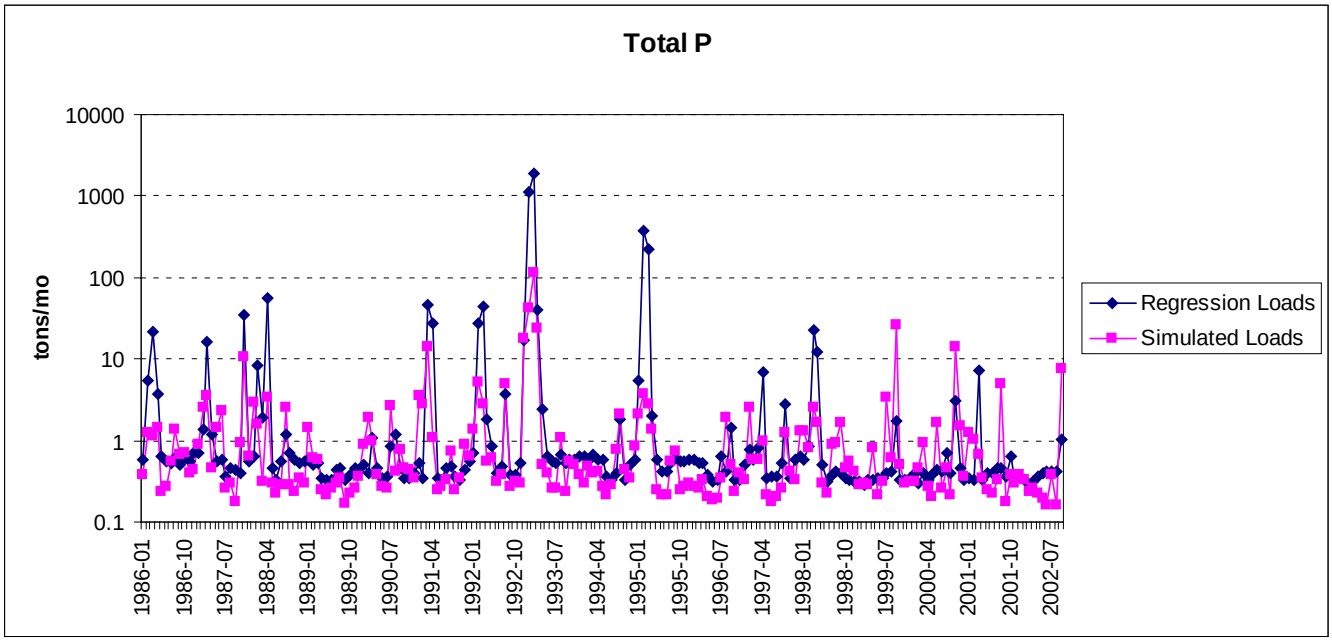


Figure 69. Fit for monthly load of total phosphorus at USGS 09504000 Verde River near Clarkdale, AZ (SWAT).

Table 32. Model fit statistics (observed minus predicted) for monthly total phosphorus loads using stratified regression (SWAT)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Relative Percent Error	83.5%	31.4%
Average Absolute Error	93%	83%
Median Absolute Error	0.3%	13.1%

As with TSS, additional diagnostics for total phosphorus included flow-load power plots (Figures 70 and 71), time series plots (Figure 72) and analysis of concentration errors (Table 33). While these show approximate agreement, the model often overpredicts total phosphorus concentrations under lower flow conditions, although not on a consistent basis.

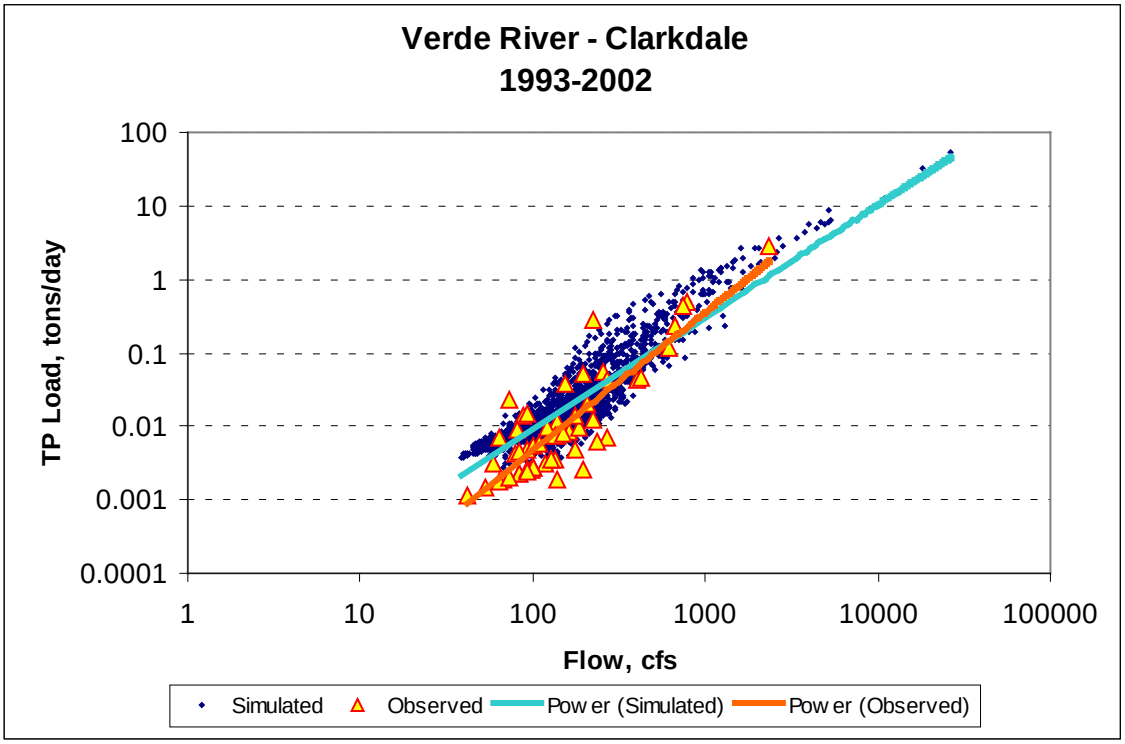


Figure 70. Power Plot for Observed and Simulated total phosphorus at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (SWAT).

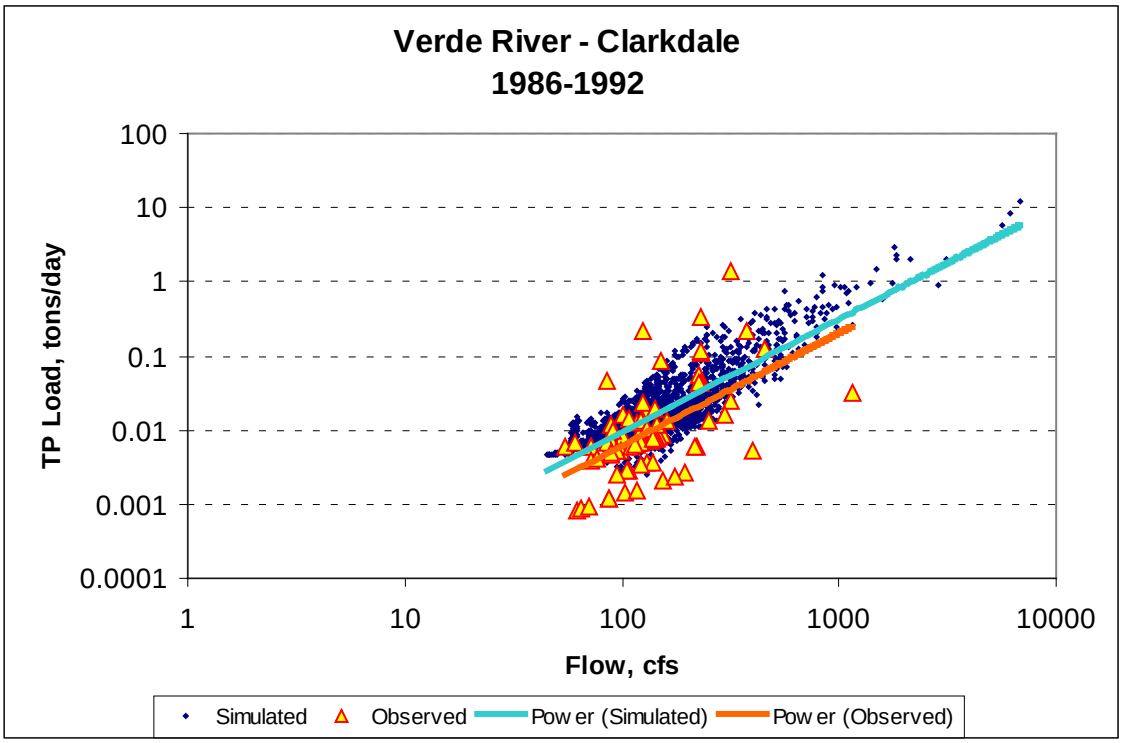


Figure 71. Power plot for observed and simulated total phosphorus at USGS 09504000 Verde River near Clarkdale, AZ – validation period (SWAT).

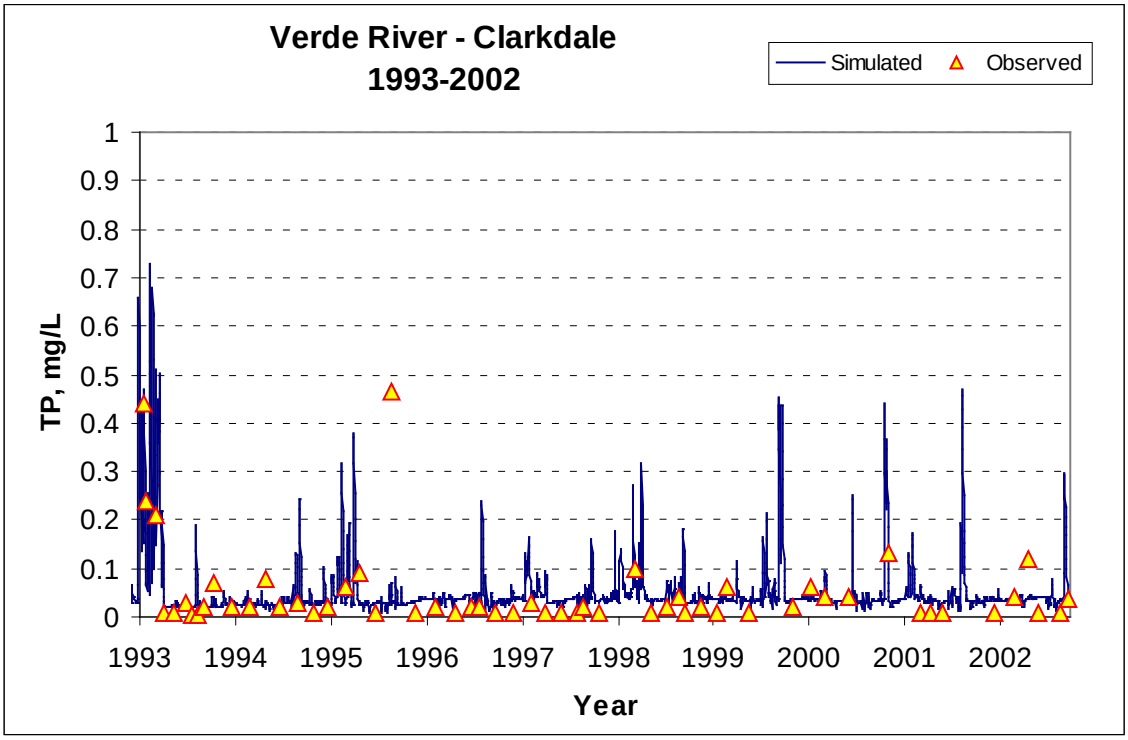


Figure 72. Time series plot of total phosphorus concentration at USGS 09504000 Verde River near Clarkdale, AZ (SWAT).

Table 33. Relative errors (observed minus predicted) for total phosphorus concentration at USGS 09504000 Verde River near Clarkdale, AZ (SWAT)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Count	57	75
Concentration Average Error	-11%	31%
Concentration Median Error	-33%	-17%

For total nitrogen, fewer data are available because many sampling events omitted one or more nitrogen species. This increases the uncertainty of the comparison. Results for total nitrogen are summarized in Figures 73 through 76 and Tables 34 and 35, following the same format as total phosphorus. The loading results are acceptable, and generally better than those obtained for total phosphorus. However, there is significant uncertainty in the prediction of individual nitrogen observations.

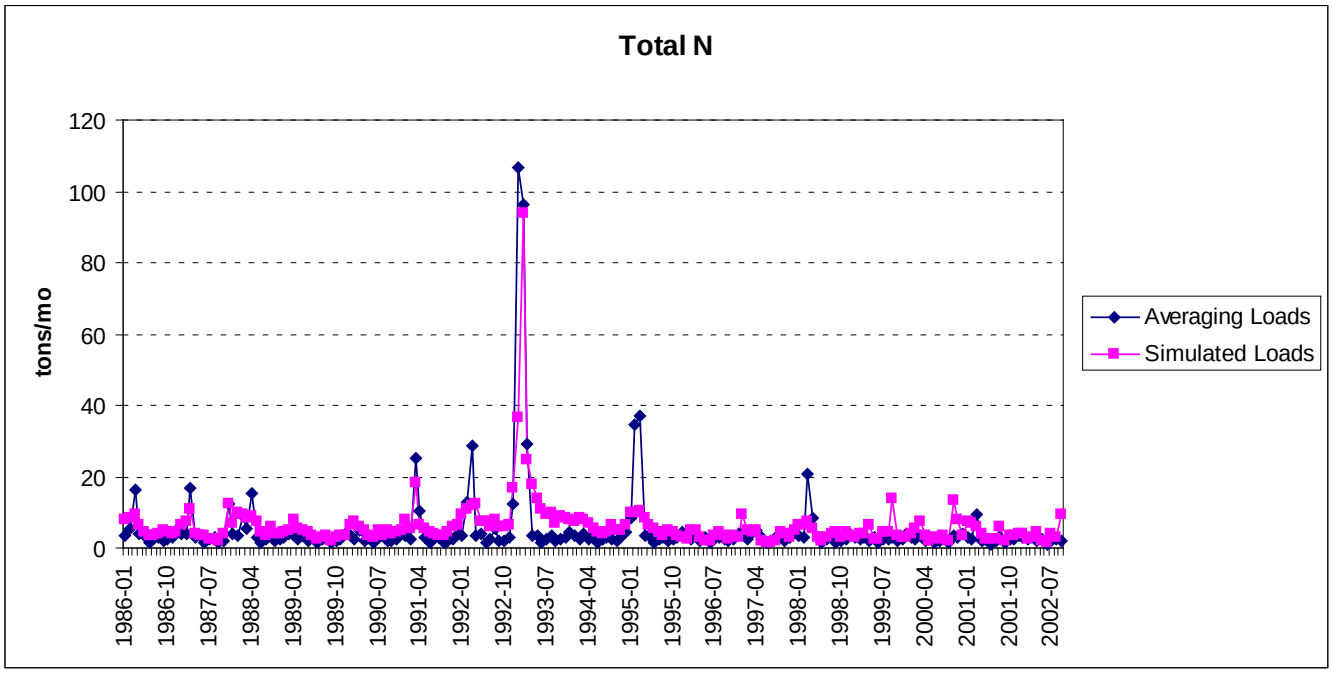


Figure 73. Fit for monthly load of total nitrogen at USGS 09504000 Verde River near Clarkdale, AZ (SWAT).

Table 34. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator (SWAT)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Relative Percent Error	-14.4%	-15.9%
Average Absolute Error	84%	67%
Median Absolute Error	13%	48%

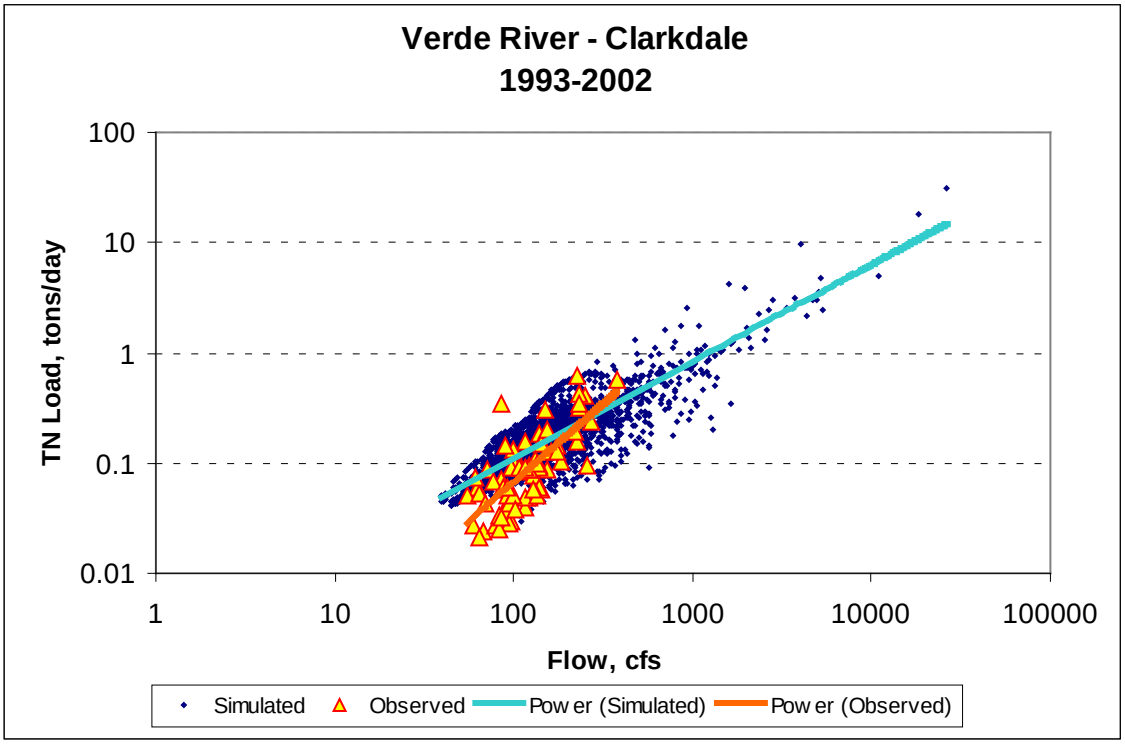


Figure 74. Power plot for observed and simulated total nitrogen at USGS 09504000 Verde River near Clarkdale, AZ – calibration period (SWAT).

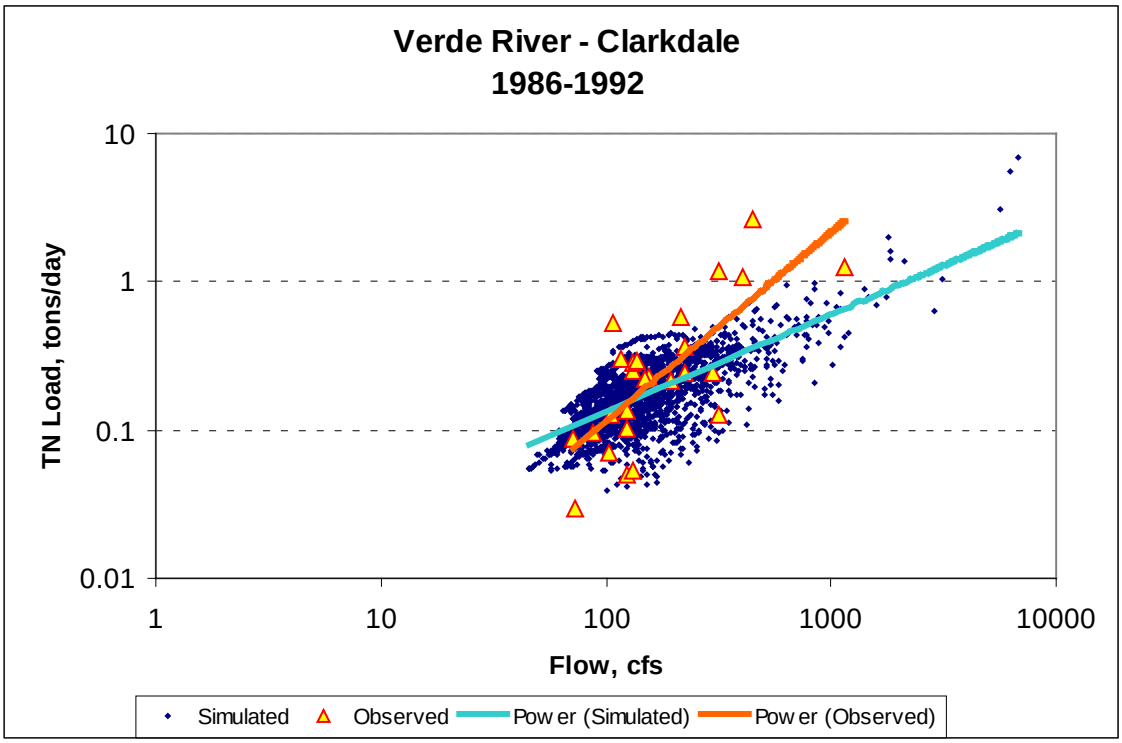


Figure 75. Power plot for observed and simulated total nitrogen at USGS 09504000 Verde River near Clarkdale, AZ – validation period (SWAT).

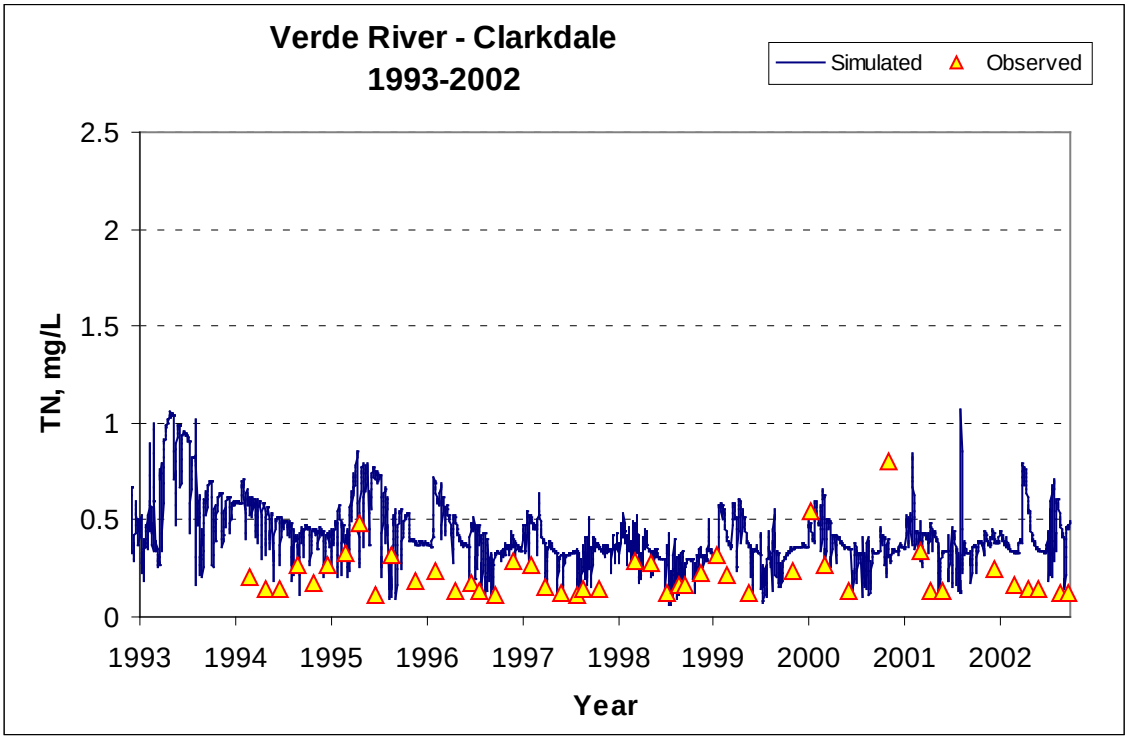


Figure 76. Time series plot of total nitrogen concentration at USGS 09504000 Verde River near Clarkdale, AZ (SWAT).

Table 35. Relative errors (observed minus predicted) for total nitrogen concentration at USGS 09504000 Verde River near Clarkdale, AZ (SWAT)

Statistic	Calibration period (1993-2002)	Validation period (1986-1992)
Count	46	75
Concentration Average Error	-83%	1.3%
Concentration Median Error	-90%	-18%

Water Quality Results for Larger Watershed

Summary statistics for the water quality calibration and validation at other stations in the watershed are provided in Tables 36 and 37, respectively. In most cases, nitrogen loads are better predicted than phosphorus and TSS loads. In a majority of cases simulated TSS and total phosphorus loads are lower than those estimated from observations, but this may reflect in part the uncertainty in the regression-based load estimates as water quality observations during high flows are sparse.

Table 36. Summary statistics (observed minus predicted) for water quality at all stations – calibration period 1993-2002 (SWAT)

Station	09498500 Salt River nr Roosevelt	09504000 Verde River nr Clarkdale	09508500 Verde River below Tangle Cr
Relative Percent Error TSS Load	41.1	16.9	17.7
TSS Concentration Median Percent Error	-15	3.4	2.0
Relative Percent Error TP Load	61.0	83.5	33.8
TP Concentration Median Percent Error	-2	-33	-19.9
Relative Percent Error TN Load	9.5	-14.4	17.0
TN Concentration Median Percent Error	-4	-90	-60

Table 37. Summary statistics (observed minus predicted) for water quality at all stations – validation period 1986-1992 (SWAT)

Station	09498500 Salt River nr Roosevelt	09504000 Verde River nr Clarkdale	09508500 Verde River below Tangle Cr
Relative Percent Error TSS Load	-0.6	-42.6	-55.1
TSS Concentration Median Percent Error	-16	9.3	0.35
Relative Percent Error TP Load	54.2	31.4	-41.4
TP Concentration Median Percent Error	-18	-17	-5.8
Relative Percent Error TN Load	18.0	-15.9	-20.3
TN Concentration Median Percent Error	-36	-18	-13

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