Report

Development of the Hydrologic and Water Quality System for Oklahoma - OK HAWQS (FY 2020-2021)

Prepared for:
The Oklahoma Conservation Commission (OCC)

Prepared by:

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Introduction

The Soil and Water Assessment Tool (SWAT) developed by United States Department of Agriculture (USDA) Agricultural Research Service in Temple, Texas, has been the most widely used watershed-scale hydrology/water quality model in the world for over 20 years. It has been used in over 3,400 peer-reviewed publications and is the principal topic of at least two international SWAT conferences each year.

The Texas A&M Spatial Sciences Lab (SSL) and its cooperators have over 20 years of experience helping government, university, nongovernmental organizations and private organizations use SWAT to simulate the hydrology and water quality in the United States and internationally at watershed, river basin, national, and continental scales.

The standard version of SWAT requires detailed inputs related to weather, climate, topography, soils, land use, water infrastructure, and point-sources of pollution. As a result, it can be difficult to build and calibrate SWAT models for specific watersheds and river basins. To overcome this problem, over the last several years, the SSL has worked closely with United States Environmental Protection Agency (USEPA) to develop the Hydrologic And Water Quality System (HAWQS). HAWQS is a free, open-source, internet-based, SWAT-based platform using a point-and-click interface and powerful output visualization tools. HAWQS provides all input data (soils, weather, land use, topography, water bodies, point-sources of pollution, etc.) and graphical input/output interfaces for the contiguous 48 states. It requires no specialized software, hardware, or training in statistics or geographic information systems. As a result, HAWQS reduces by 90% the time and effort required to conduct calibrated SWAT-based watershed-scale environmental assessments.

This project developed a customized version of HAWQS for Oklahoma (OK-HAWQS). The specialized version includes:

- A calibrated SWAT model for the state of Oklahoma, as well as watersheds from surrounding states that drain into Oklahoma
- Up-to-date weather, soils, topography, and land use data for the watersheds of interest
- More detailed state and regional data than the national version of HAWQS, including the ability to simulate hydrology and water quality of Oklahoma streams at the HUC-12 scale
- Customized inputs and outputs designed to address priorities for Oklahoma Conservation Commission (OCC) and other state agencies.
- Enhanced graphical, statistical, database, and text-management tools to facilitate comparison of simulated and measured data
- The ability to quickly generate research and management reports describing the hydrologic and water quality impacts of alternative scenarios for land use, agricultural management, soil and water conservation practices, and climate.

Tasks 1-3: Data Development

The Oklahoma Water Resources Center (OWRC) hosted quarterly conference calls with OCC and SSL and discussed project status and progress including obtaining input on data gathering. SSL developed all OK-HAWQS inputs at the HUC-12 scale for all watersheds within and draining into OK. Input data were obtained on climate, atmospheric deposition, watershed boundaries, agricultural and nonagricultural land use, soil, elevation, stream network, dams, ponds, reservoirs, point sources, and management.

Tasks 4-6: Model Development, Calibration and Validation

SSL purchased and set up a dedicated server for OK-HAWQS at Texas A&M where they will be maintaining OK-HAWQS software and hardware support for the next two years. For the national

HAWQS only a subset of HUC8 watersheds are calibrated and even those need verification for appropriate local application. Thus, a detailed calibration was conducted for the OK-HAWQS using United States Geological Survey (USGS) streamflow data from 24 gage sites located in 12 unique HUC12 watersheds. The detailed calibration report is attached to this report and can be found at the OK-HAWQS website (https://ok.hawqs.tamu.edu/#/help). SSL will continue to refine the calibrated OK-HAWQS. This will include writing a script to convert SWAT outputs for easy coupling with lake models selected by the OCC.

Tasks 7: Training workshops

One webinar and one training workshop were held for potential OK-HAWQS users who were selected by the OCC and OWRC. The webinar was held on December 1st, 2020 at 1:00 PM to 2:00 PM, with an audience of 42 participants. The webinar covered an introduction to HAWQS and demonstrations to show how the model is run. The presentation was recorded and uploaded to the OWRC's YouTube channel (https://www.youtube.com/watch?v=_bPvmIBD0bc).

The training workshop was held on September 16th, 2021 at 9:00 AM to 12:00 PM and 45 participants attended. The workshop built on the presentation in the webinar and gave a detailed demonstration of the step-by-step approach in running the model. Participants were guided through the process of setting up an account and how to setup and run individual and group projects. The workshop was recorded and uploaded to the OWRC's YouTube channel (https://www.youtube.com/watch?v=oLECbbVoeFY).

Oklahoma (OK) HAWQS v1.0

Calibration Process

Version 1.0 – Released July 2021

Description of HAWQS and OK HAWQS

The Hydrologic and Water Quality System (HAWQS)[1] is a web-based interface that streamlines the development of SWAT watershed models by providing pre-loaded input data and modeling support capabilities for setting up models, running simulations, and processing outputs. SWAT is a commonly used public domain semi-distributed mechanistic watershed model that is used to evaluate the effects of land management and agricultural practices on water, sediment, and chemical fluxes across a wide range of watershed sizes, land uses, and physiographic provinces (Neitsch, et al., 2011). HAWQS provides pre-loaded national input data necessary to develop SWAT watershed models at resolutions that range from the 14-digit HUC (HUC14) to the 8-digit HUC (HUC8). Table 1 summarizes the input datasets available within the HAWQS 2.0 framework.

Table 1. HAWQS version 2.0 input data summary.

Input Dataset	Source	Specifications
Climate	National Climatic Data Center (NCDC) National Weather Service (NWS)/National Oceanic and Atmospheric Administration (NOAA)	1961 – 2018
	Parameter-elevation Regressions on Independent Slopes Model (PRISM)	1981 – 2018 (gridded)
	NOAA Next Generation Radar (NEXRAD)	2005 – 2018 (gridded)
	NEXRAD (bias corrected)	2005 – 2018 (gridded)
Atmosphere Deposition	National Atmospheric Deposition Program (NADP)	(1980 – 2010) monthly
Watershed Boundaries	National Hydrography Dataset Plus 2.0 (NHDPlus)	HUCs 8, 10, and 12
Land Use (non-agricultural)	National Land Cover Database (NLCD)	2016
Land Use (agricultural)	United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) Cropland Data Layer (CDL)	2016 – 2018
Soil	USDA Natural Resources Conservation Service (NRCS) Soil Survey Geographic Data (SSURGO)	County level 2019
Elevation	USGS National Elevation Dataset (NED) and Digital Elevation Model (DEM)	10 meter 2019
Stream Network	National Hydrography Dataset Plus 2.0 (NHDPlus)	2019
Dams, Ponds, and Reservoirs	National Inventory of Dams (NID) and NHDPlus 2.0	2018; 2019
Point Sources	Water Quality eXchange (WQX) and National Pollutant Discharge Elimination System (NPDES)	2020
Management Data	USDA-NRCS crop management zone data	2010

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[1] https://hawqs.tamu.edu/#/

A separate HAWQS interface was created to model all watersheds across the state of Oklahoma (OK). The new OK HAWQS[2] uses the same input data as HAWQS version 2.0 but has a finer resolution of calibration conducted for the platform.

Importance of Calibrating and Validating a Water Quality Model

Recently there has been an increase in the use of water quality models to evaluate the impacts of climate, land use, and management practices on the quantity and quality of water resources. To assure that a model's results are sufficiently accurate for these "real world" applications, calibration and validation of a water quality model are necessary. Calibration is an iterative process of testing model performance by adjusting input parameters in a way that the output from the model is reasonably close to observed values. Validation is an extension of the calibration process where the calibrated model is evaluated for a different period to assess if the calibrated model can reasonably represent the wide range of events in field observations. Therefore, the whole process of model calibration/validation is regarded as a systematic evaluation of errors or differences between model estimates and field observations as seen in Figure 1. While there are several methods of validating a model, the most commonly used procedure is the split-sample calibration/validation procedure. For a split-sample calibration/validation procedure only a portion of the available record of observed values is used for calibration, and once the final parameter set is established through calibration, simulation is performed for the remaining period of observed values, and goodness-of-fit between observed and simulated values is reassessed (Donigian, 2002).

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[2] https://ok.hawqs.tamu.edu/#/

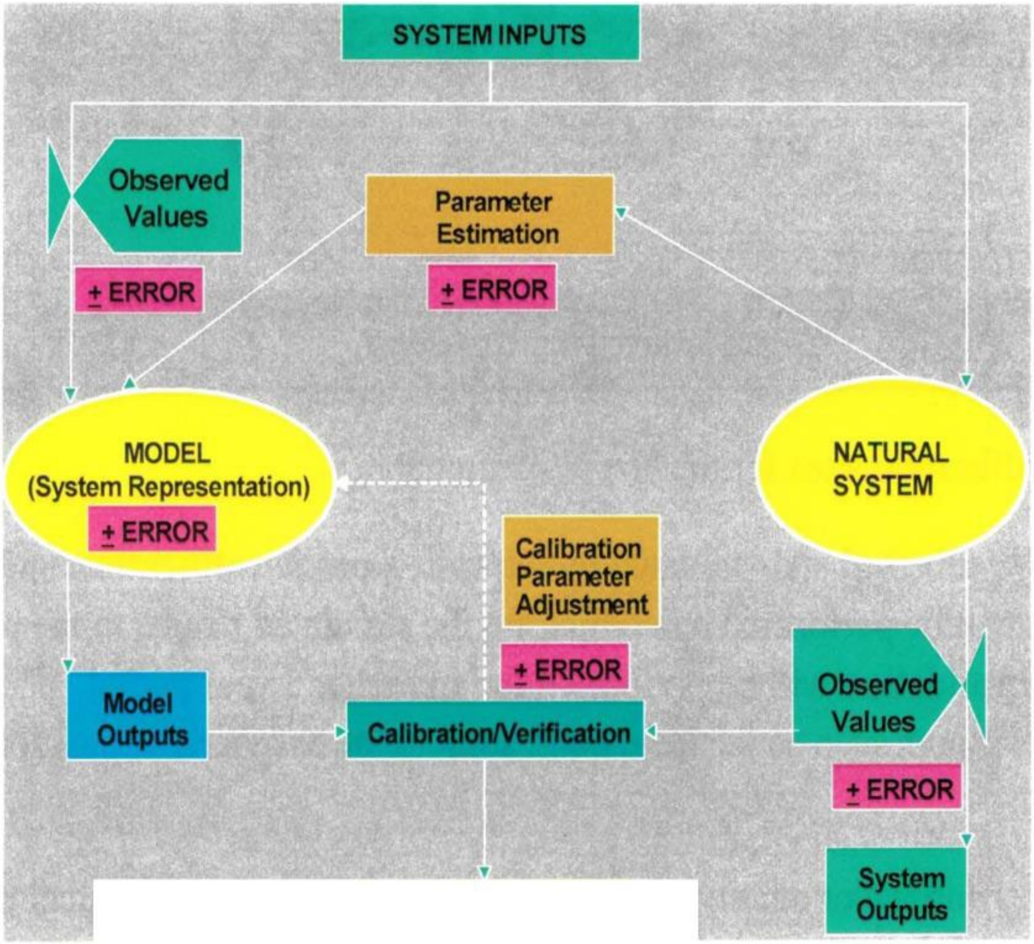

Figure 1. Calibration-Validation process (Donigian, 2002).

Methodology for Calibrating OK HAWQS

SWAT parameters in the initial national HAWQS model reflect default values from SWAT, as modified where applicable during HAWQS calibration. As noted in the HAWQS documentation, however, only a subset of HUC8 watersheds in HAWQS were calibrated, and even for those that were calibrated, users need to verify that the calibration is appropriate to the model application and perform their own calibration and validation as needed. For this reason, a detailed calibration was conducted for the OK HAWQS using USGS[3] streamflow data from 24 gauge sites located in 12 unique HUC12 watersheds (Table 2; Figure 2).

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[3] https://waterdata.usgs.gov/nwis/

Table 2. List of the 24 USGS streamflow gauges used to calibrate streamflow for OK HAWQS.

USGS Site	Site Name	Calibration Years	Latitude	Longitude
7151000	Salt Fork Arkansas River at Tonkawa, OK	2003-2018	36.67198	-97.3095
7152000	Chikaskia River near Blackwell, OK	1983-2018	36.81142	-97.2773
7191000	Big Cabin Creek near Big Cabin, OK	1983-2018	36.56842	-95.1522
7229300	Walnut Creek at Purcell, OK	1983-2018	34.99896	-97.367
7243500	Deep Fork near Beggs, OK	1983-2018	35.67399	-96.0686
7195500	Illinois River near Watts, OK	1983-2018	36.13008	-94.5722
7196000	Flint Creek near Kansas, OK	1983-2018	36.18647	-94.7069
7196500	Illinois River near Tahlequah, OK	1983-2018	35.92287	-94.9236
7197000	Baron Fork at Eldon, OK	2010-2018	35.9212	-94.8386
7196090	Illinois River at Chewey, OK	1983-2018	36.10425	-94.8273
7247250	Black Fork below Big Creek near Page, OK	1992-2018	34.77371	-94.5122
7301500	North Fork Red River near Carter, OK	1983-2018	35.16811	-99.5073
7303400	Elm Fork of North Fork Red River nr Carl, OK	1994-2018	35.01172	-99.9037
7315700	Mud Creek near Courtney, OK	1983-2018	34.00427	-97.567
7316500	Washita River near Cheyenne, OK	1983-2018	35.62644	-99.6684
7324200	Washita River near Hammon, OK	1983-2018	35.65644	-99.3062
7325000	Washita River near Clinton, OK	1983-2018	35.53088	-98.967
7326500	Washita River at Anadarko, OK	1983-2018	35.08423	-98.2434
7328100	Washita River at Alex, OK	1983-2018	34.9259	-97.7739
7328500	Washita River near Pauls Valley, OK	1983-2018	34.7548	-97.2514
7332500	Blue River near Blue, OK	1983-2018	33.99704	-96.2411
7335700	Kiamichi River near Big Cedar, OK	1983-2018	34.63844	-94.6127
7336200	Kiamichi River near Antlers, OK	1983-2018	34.24871	-95.6052
7337900	Glover River near Glover, OK	1983-2018	34.09761	-94.9022

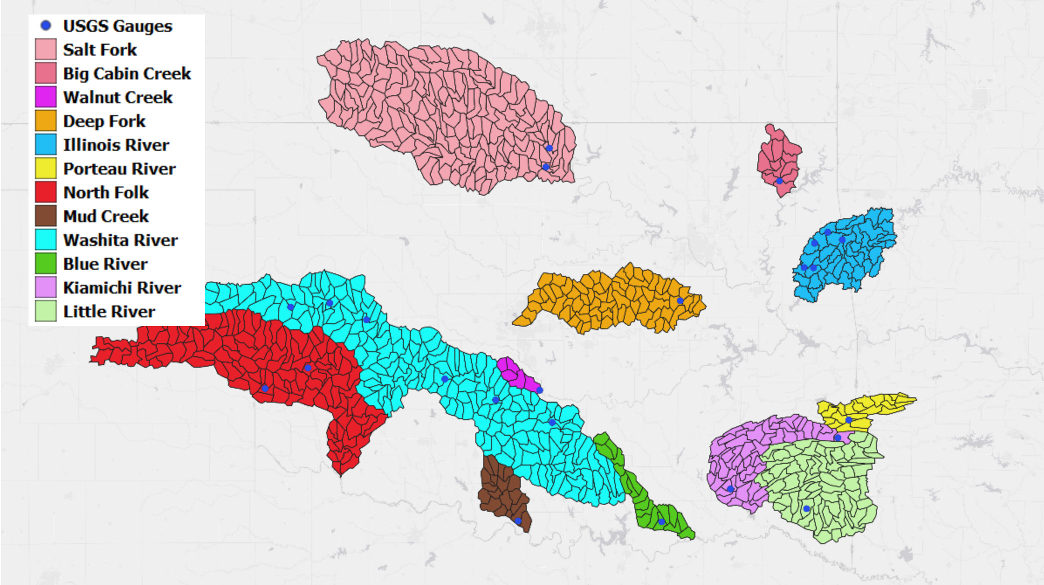

Figure 2. Locations of USGS gauges and watersheds used to calibrate the OK HAWQS.

The SWAT calibration procedure involved two main steps:

1) Run the statistical tests in SWAT's Calibration and Uncertainty Program (SWAT-CUP) to produce the calibration statistical metrics, and
2) Finalize the calibration parameters and update the project database and input files.

Utilization of SWAT-CUP Program During Calibration Process

SWAT-CUP[4] is a program that performs calibration, validation, and sensitivity and uncertainty analysis for SWAT models. The program links the Sequential Uncertainty Fitting v2 (SUFI2) routine, the Particle Swarm Optimization (PSO), the Generalized Likelihood Uncertainty Estimation (GLUE), the Parameter Solution (ParaSol), and the Markov Chain Monte Carlo (MCMC) to SWAT models. For OK HAWQS calibration the SUFI2 algorithm was used as it is the most flexible algorithm and the only algorithm that can be run with parallel processing within the SWAT-CUP program. This algorithm measures two values: the p-factor and r-factor. The p-factor is the percentage of observed data enveloped by the 95 percent prediction uncertainty (95PPU). The r-factor is the thickness of the 95PPU. The objective of the SUFI2 algorithm is to have the majority of observed values fall within a relatively small 95PPU. A comprehensive description of the SUFI2 algorithm can be found in Abbaspour et al. (2007). Within SWAT-CUP, there are 11 different statistical tests that can be used to evaluate model performance. Model performance is generally evaluated against three basic statistical tests: Percent bias (PBIAS); Nash-Sutcliffe efficiency (NSE); and Kling–Gupta efficiency (KGE), described in the following sections.

Percent bias (PBIAS)

PBIAS measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta, et al., 1999; Moriasi, et al., 2015). The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias (Gupta, et al., 1999; Moriasi, et al., 2015). PBIAS is calculated with the equation below where PBIAS is the deviation of data being evaluated, expressed as a percentage.

$$PBIAS = \frac{\left[\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right) * (100)\right]}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}$$

Where Y_i^{obs} is the *i*th observation for the constituent being evaluated, Y_i^{sim} is the *i*th simulated value for the constituent being evaluated, and *n* is the total number of observations. For streamflow calibration a PBIAS value between +/- 25% indicates a significant simulation.

Nash-Sutcliffe efficiency (NSE)

NSE is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") (Nash & Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right]$$

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[4] https://swat.tamu.edu/software/swat-cup/

Where Y_i^{obs} is the *i*th observation for the constituent being evaluated, Y_i^{sim} is the *i*th simulated value for the constituent being evaluated, Y^{mean} is the mean of observed data for the constituent being evaluated, and *n* is the total number of observations.

NSE ranges between negative infinity and 1.0, with 1.0 being the optimal value (a perfect model fit) and values <0.0 indicating that the mean observed value is a better predictor than the simulated value, thereby demonstrating unacceptable model performance. Good performance is indicated by values >0.5 and acceptable performance by values between 0.0 and 0.5 (Moriasi, et al., 2007).

Kling–Gupta efficiency (KGE)

KGE (Gupta, et al., 2009) is a performance indicator based on the equal weighting of linear correlation (r), bias ratio (β), and variability (γ), between simulated and observed data:

$$KGE = 1 - \sqrt{(r-1)^2 + (\gamma-1)^2 + (\beta-1)^2}$$

Where γ is standard deviation of simulated/standard deviation of observed, β is mean of simulated/mean of observed, and r is the linear regression coefficient between simulated and measured data. The calibration results range between negative infinity and 1.0, with 1.0 begin a perfect model fit. KGE values larger than 0.5 are considered satisfactory for streamflow (Moriasi et al., 2007).

KGE captures three additional statistics: mean, standard deviation, and r^2 (coefficient of determination). In most cases, evaluation of KGE encompasses the conclusions that can be made from evaluating PBIAS and, to a lesser extent, NSE. Therefore, KGE was used as the primary calibration metric to evaluate model performance for OK HAWQS.

Two limitations of SWAT Calibration are:

1) Transferring calibrated parameters between similar hydrologic regions may not always generate satisfactory results. In such cases expert opinion will be used to modify the calibration parameters.
2) Model outputs may not produce an acceptable match with observed data in locations downstream of reservoirs

Individual Calibration Locations and Parameters

A summary of the SWAT-CUP performance metrics and streamflow statistics for each of the SWAT simulated streamflow and observed USGS gauge streamflow are found in Table 3. Figures 3-14 show a snapshot from the OK HAWQS interface for each of the HUC12 watersheds and their upstream subbasins used to calibrate the OK HAWQS model. Tables 4-15 provide the list of parameters that were adjusted during the calibration found with SWAT-CUP from the KGE performance matrix iteration for each of the watersheds. Parameters that start with a “V” were replaced with the Fitted Value, parameters that start with an “R” were multiplied by the Fitted Value, and parameters that start with an “A” increased (or decreased if negative) by the Fitted value. An accompanying spreadsheet with detailed statistics for each calibrated location along with the parameters used for calibration can be found on the OK HAWQS website associated with this document.

Table 3. Calibration statistics for SWAT watershed models evaluated for cumulative effects, based on mean monthly flows. Mean and Standard Deviation (StdDev) of simulated and observed flow are in m^3/s. *KGE values greater than 0.5 (**BOLD**) indicate satisfactory streamflow simulations.*

Watershed	HUC12	USGS Site	p-factor	r-factor	R2	NS	bR2	PBIAS	KGE	Mean_sim (Mean_obs)	StdDev_sim (StdDev_obs)
Salt Fork	110600040905	7151000	0.42	1.62	0.55	-5.25	0.26	-170.9	-1.55	57.61(21.27)	93.37(32.53)
Salt Fork	110600040905	7152000	0.77	0.71	0.82	0.80	0.77	-2.4	**0.89**	22.17(21.66)	31.56(30.42)
Big Cabin Creek	110702090208	7191000	0.61	0.62	0.88	0.88	0.72	-1.2	**0.86**	11.61(11.47)	15.68(17.98)
Walnut Creek	110902020205	7229300	0.67	0.68	0.63	0.62	0.44	-12.8	**0.73**	4.02(3.57)	4.84(5.52)
Deep Fork	111003030908	7243500	0.53	0.61	0.80	0.77	0.72	-14.8	**0.82**	34.88(30.38)	45.50(44.92)
Illinois River	111101030906	7196000	0.14	0.00	0.88	0.81	0.80	-7.6	**0.80**	3.73(3.47)	4.48(3.81)
Illinois River	111101030906	7195500	0.23	0.00	0.93	0.90	0.86	-3.6	**0.87**	20.94(20.21)	23.52(21.11)
Illinois River	111101030906	7197000	0.17	0.00	0.90	0.88	0.87	-17.1	**0.82**	12.41(10.60)	12.88(12.65)
Illinois River	111101030906	7196090	0.18	0.00	0.95	0.91	0.85	-6.5	**0.84**	27.31(25.63)	39.19(34.23)
Illinois River	111101030906	7196500	0.24	0.00	0.92	0.91	0.90	0.1	**0.92**	30.51(30.55)	34.34(32.29)
Porteau River	111101050502	7247250	0.60	0.34	0.84	0.78	0.54	13.4	**0.66**	2.14(2.47)	2.36(3.37)
North Fork	111203030510	7301500	0.64	6.79	0.65	-0.17	0.47	-16.8	0.25	3.90(3.34)	8.72(5.11)
North Fork	111203030510	7303400	0.68	3.83	0.46	-2.13	0.30	-60.0	-0.44	1.35(0.84)	4.20(1.86)
Mud Creek	111302010405	7315700	0.55	0.63	0.72	0.72	0.58	-4.0	**0.83**	6.50(6.25)	12.08(12.91)
Washita River	111303040205	7316500	0.48	3.23	0.51	-7.63	0.22	-159.3	-1.79	1.81(0.70)	2.90(0.88)
Washita River	111303040205	7324200	0.49	1.77	0.45	-3.87	0.26	-112.1	-0.98	4.13(1.95)	7.23(2.79)
Washita River	111303040205	7325000	0.43	1.04	0.44	-1.44	0.33	-62.6	-0.21	6.59(4.05)	12.70(6.44)
Washita River	111303040205	7326500	0.40	0.52	0.65	0.55	0.55	25.9	**0.67**	12.00(16.18)	23.67(22.48)
Washita River	111303040205	7328100	0.49	0.71	0.74	0.66	0.73	8.4	**0.79**	20.73(22.64)	32.94(28.88)
Washita River	111303040205	7328500	0.56	0.64	0.68	0.64	0.57	7.7	**0.81**	29.72(32.19)	42.62(41.65)
Blue River	111401020209	7332500	0.80	0.65	0.89	0.89	0.79	-5.6	**0.90**	10.39(9.83)	14.70(15.58)
Kiamichi River	111401050707	7335700	0.53	0.55	0.86	0.84	0.76	-15.4	**0.82**	2.86(2.48)	2.78(2.93)
Kiamichi River	111401050707	7336200	0.54	0.47	0.91	0.88	0.68	7.4	**0.77**	40.45(43.67)	43.27(55.10)
Little River	111401090102	7337900	0.44	0.50	0.77	0.63	0.75	-27.0	**0.66**	18.69(14.71)	20.67(17.58)

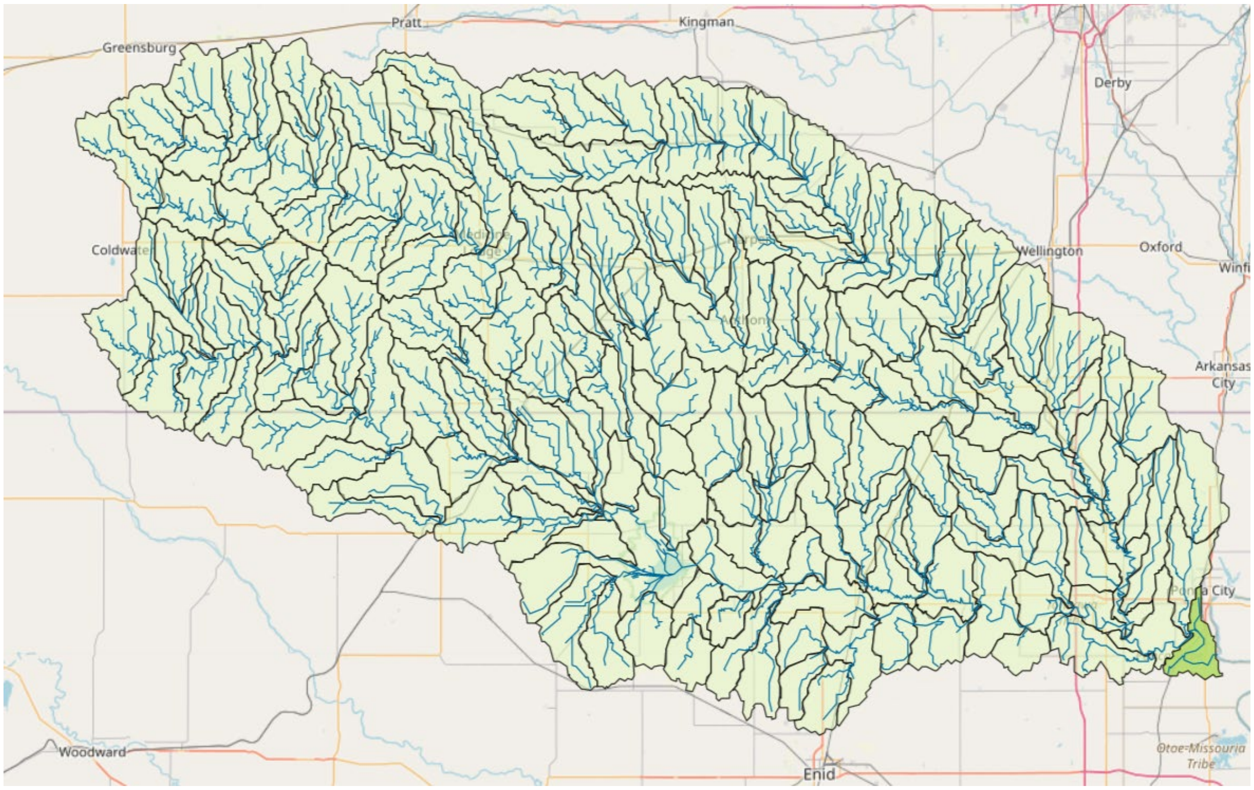

Figure 3. OK HAWQS Salt Fork (HUC12) 110600040905 watershed outlet and upstream subbasins.

Table 4. Calibration parameters adjusted during calibration including range of acceptable values for Salt Fork watershed.

Salt Fork; HUC12 = 110600040905			
Parameter Name	**Fitted Value**	**Minimum Value**	**Maximum Value**
V__EPCO.hru	0.74	0.5	1
R__CN2.mgt	0.03	-0.1	0.1
V__ALPHA_BF.gw	0.48	0.005	0.5
A__GW_DELAY.gw	-23.91	-30	90
A__GWQMN.gw	-510.65	-1000	1000
V__GW_REVAP.gw	0.06	0.02	0.1
A__RCHRG_DP.gw	-0.04	-0.05	0.05
A__REVAPMN.gw	-206.14	-750	750
V__ESCO.hru	0.64	0.5	0.85
R__SOL_AWC(..).sol	0.02	-0.05	0.05
V__CANMX.hru	5.97	0	10
V__SLSOIL.hru	127.04	0	150
V__LAT_TTIME.hru	7.94	0	14
V__ALPHA_BF_D.gw	0.79	0	1
V__SMTMP.bsn	1.54	0	2
V__SFTMP.bsn	-0.81	-2	2
V__SMFMX.bsn	3.63	2	4.5
V__SMFMN.bsn	2.45	0	2.5
V__TIMP.bsn	0.29	0	1

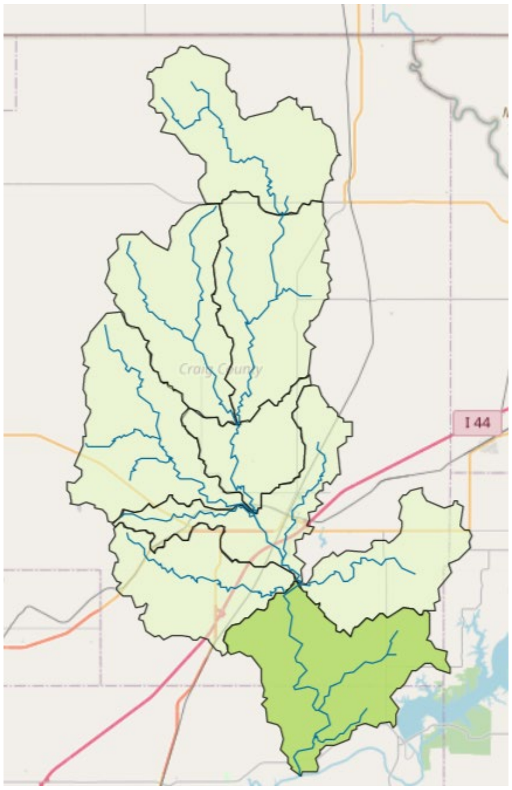

Figure 4. OK HAWQS Big Cabin Creek (HUC12) 110702090208 watershed outlet and upstream subbasins.

Table 5. Calibration parameters adjusted during calibration including range of acceptable values for Big Cabin Creek watershed.

Big Cabin Creek; HUC12 = 110702090208			
Parameter Name	**Fitted Value**	**Minimum Value**	**Maximum Value**
V__EPCO.hru	0.26	0	1
R__CN2.mgt	0.07	-0.1	1
V__ALPHA_BF.gw	0.46	0.005	0.5
A__GW_DELAY.gw	-19.26	-30	90
A__GWQMN.gw	-682.77	-1000	1000
V__GW_REVAP.gw	0.18	0.02	0.2
A__RCHRG_DP.gw	-0.03	-0.05	0.05
A__REVAPMN.gw	-215.20	-750	750
V__ESCO.hru	0.52	0.4	0.75
R__SOL_AWC(..).sol	0.01	-0.05	0.05
V__CANMX.hru	1.54	0	10
V__SLSOIL.hru	20.71	0	60
V__LAT_TTIME.hru	3.88	0	14
V__ALPHA_BF_D.gw	0.17	0	1
V__SMTMP.bsn	1.17	0	2
V__SFTMP.bsn	-0.45	-2	2
V__SMFMX.bsn	2.33	2	4.5
V__SMFMN.bsn	1.46	0	2.5
V__TIMP.bsn	0.95	0	1

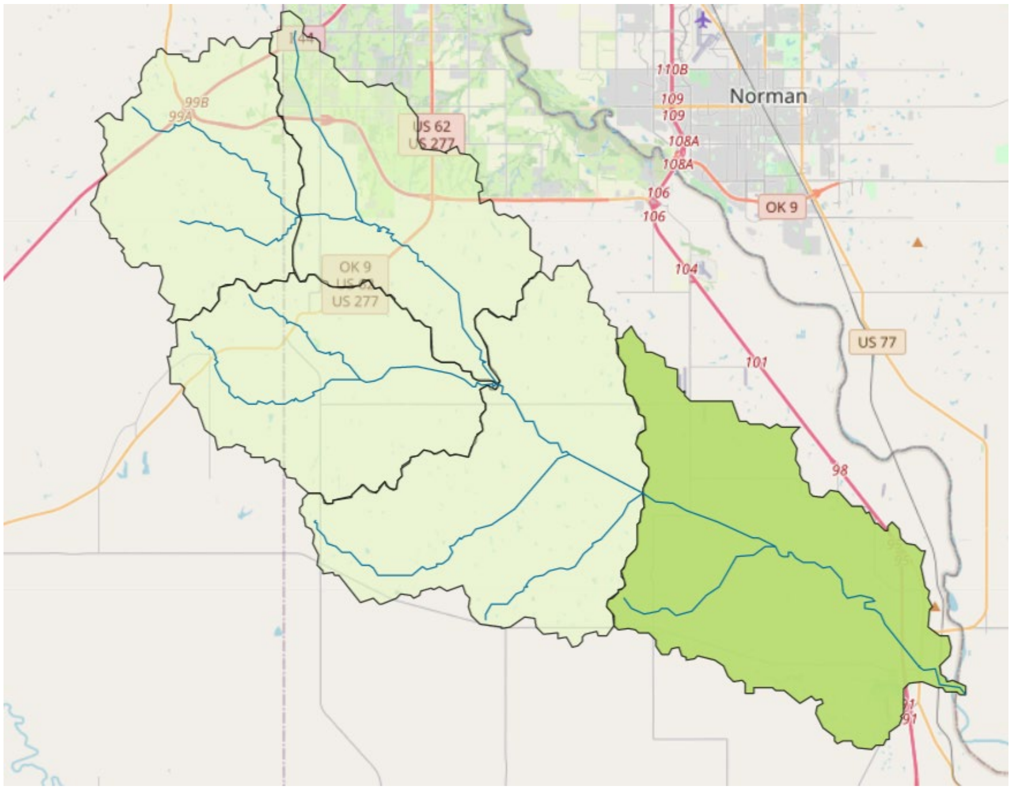

Figure 5. OK HAWQS Walnut Creek (HUC12) 110902020205 watershed outlet and upstream subbasins.

Table 6. Calibration parameters adjusted during calibration including range of acceptable values for Walnut Creek watershed.

Walnut Creek; HUC12 = 110902020205			
Parameter Name	**Fitted Value**	**Minimum Value**	**Maximum Value**
V__EPCO.hru	0.51	0.5	1
R__CN2.mgt	-0.04	-0.1	0.1
V__ALPHA_BF.gw	0.11	0.005	0.5
A__GW_DELAY.gw	-1.95	-30	90
A__GWQMN.gw	580.31	-1000	1000
V__GW_REVAP.gw	0.10	0.02	0.1
A__RCHRG_DP.gw	-0.04	-0.05	0.05
A__REVAPMN.gw	128.35	-750	750
V__ESCO.hru	0.58	0.5	0.85
R__SOL_AWC(..).sol	-0.04	-0.05	0.05
V__CANMX.hru	0.10	0	10
V__SLSOIL.hru	27.05	0	60
V__LAT_TTIME.hru	0.53	0	14
V__ALPHA_BF_D.gw	0.25	0	1
V__SMTMP.bsn	0.68	0	2
V__SFTMP.bsn	1.05	-2	2
V__SMFMX.bsn	2.21	2	4.5
V__SMFMN.bsn	1.80	0	2.5
V__TIMP.bsn	0.92	0	1

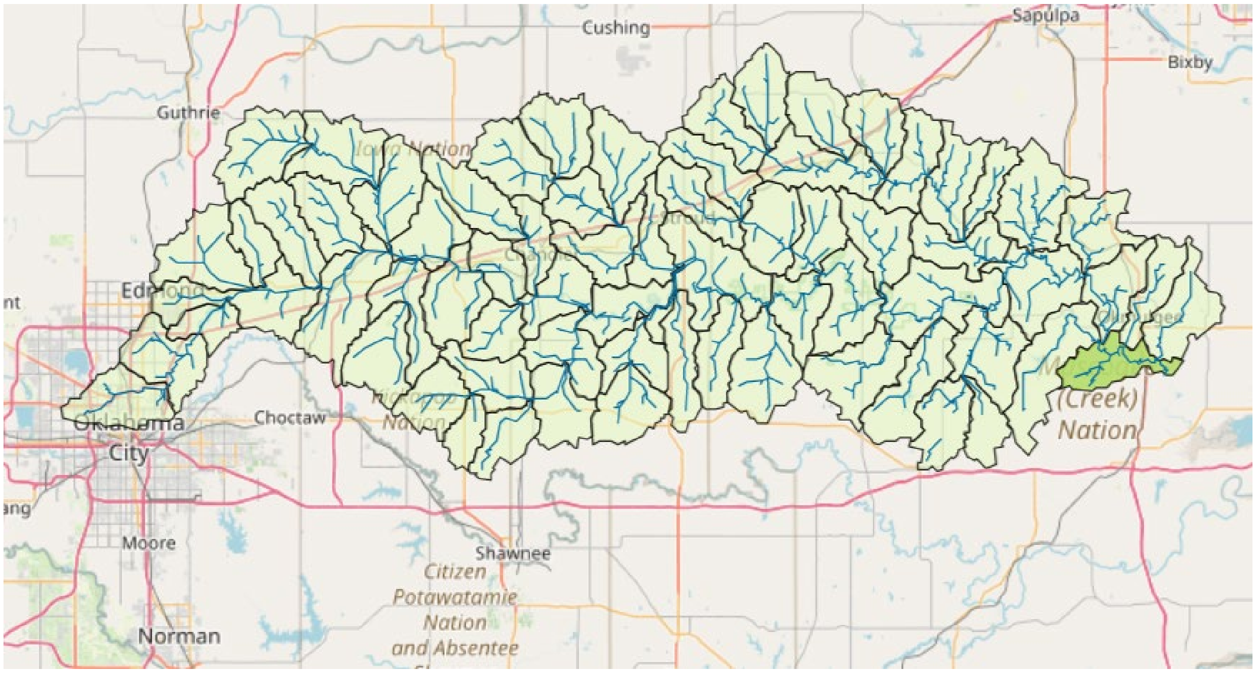

Figure 6. OK HAWQS Deep Fork (HUC12) 111003030908 watershed outlet and upstream subbasins.

Table 7. Calibration parameters adjusted during calibration including range of acceptable values for Deep Fork watershed.

Deep Fork; HUC12 = 111003030908			
Parameter Name	**Fitted Value**	**Minimum Value**	**Maximum Value**
V__EPCO.hru	0.91	0.5	1
R__CN2.mgt	-0.09	-0.1	0.1
V__ALPHA_BF.gw	0.08	0.005	0.5
A__GW_DELAY.gw	-25.27	-30	90
A__GWQMN.gw	-43.32	-1000	1000
V__GW_REVAP.gw	0.09	0.02	0.1
A__RCHRG_DP.gw	-0.03	-0.05	0.05
A__REVAPMN.gw	295.63	-750	750
V__ESCO.hru	0.50	0.5	0.85
R__SOL_AWC(..).sol	-0.03	-0.05	0.05
V__CANMX.hru	4.30	0	10
V__SLSOIL.hru	32.87	0	150
V__LAT_TTIME.hru	0.44	0	14
V__ALPHA_BF_D.gw	0.98	0	1
V__SMTMP.bsn	1.73	0	2
V__SFTMP.bsn	1.40	-2	2
V__SMFMX.bsn	4.41	2	4.5
V__SMFMN.bsn	0.25	0	2.5
V__TIMP.bsn	0.57	0	1

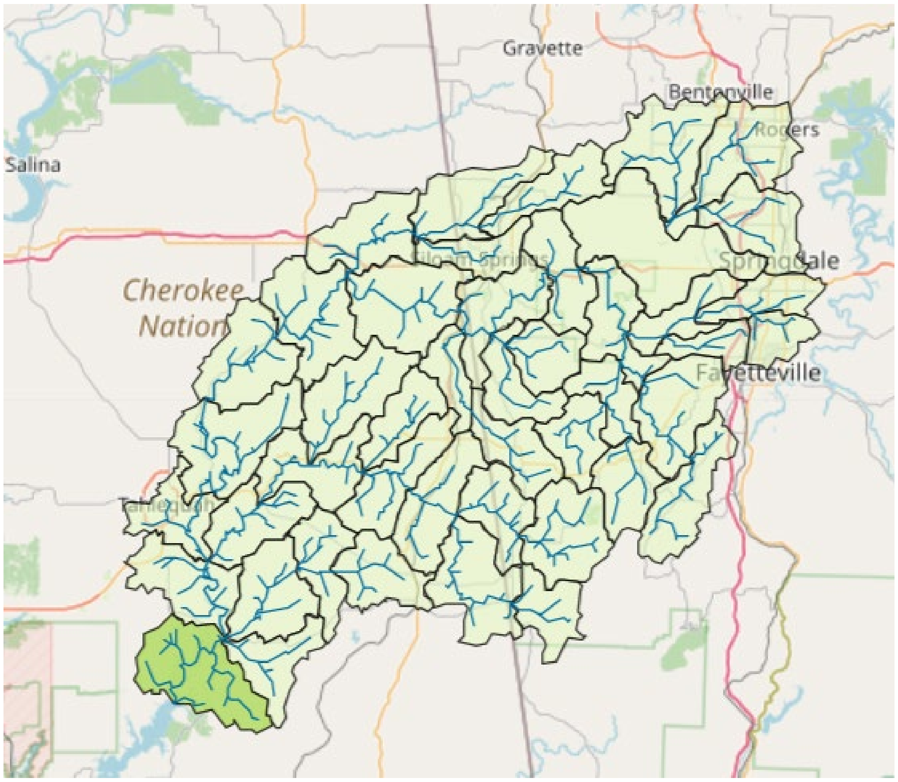

Figure 7. OK HAWQS Illinois River (HUC12) 111101030906 watershed outlet and upstream subbasins.

Table 8. Calibration parameters adjusted during calibration including range of acceptable values for Illinois River watershed.

Illinois River; HUC12 = 111101030906			
Parameter Name	**Fitted Value**	**Minimum Value**	**Maximum Value**
V__EPCO.hru	0.85	0.5	1
R__CN2.mgt	0.09	-0.1	0.1
V__ALPHA_BF.gw	0.08	0.005	0.1
A__GW_DELAY.gw	-28.02	-30	90
A__GWQMN.gw	-747.00	-1000	1000
V__GW_REVAP.gw	0.08	0.02	0.1
A__RCHRG_DP.gw	-0.01	-0.05	0.05
A__REVAPMN.gw	-147.75	-750	750
V__ESCO.hru	0.82	0.6	0.85
R__SOL_AWC(..).sol	0.00	-0.05	0.05
V__CANMX.hru	8.36	0	10
V__SLSOIL.hru	67.43	0	150
V__LAT_TTIME.hru	12.13	0	14
V__ALPHA_BF_D.gw	0.84	0	1

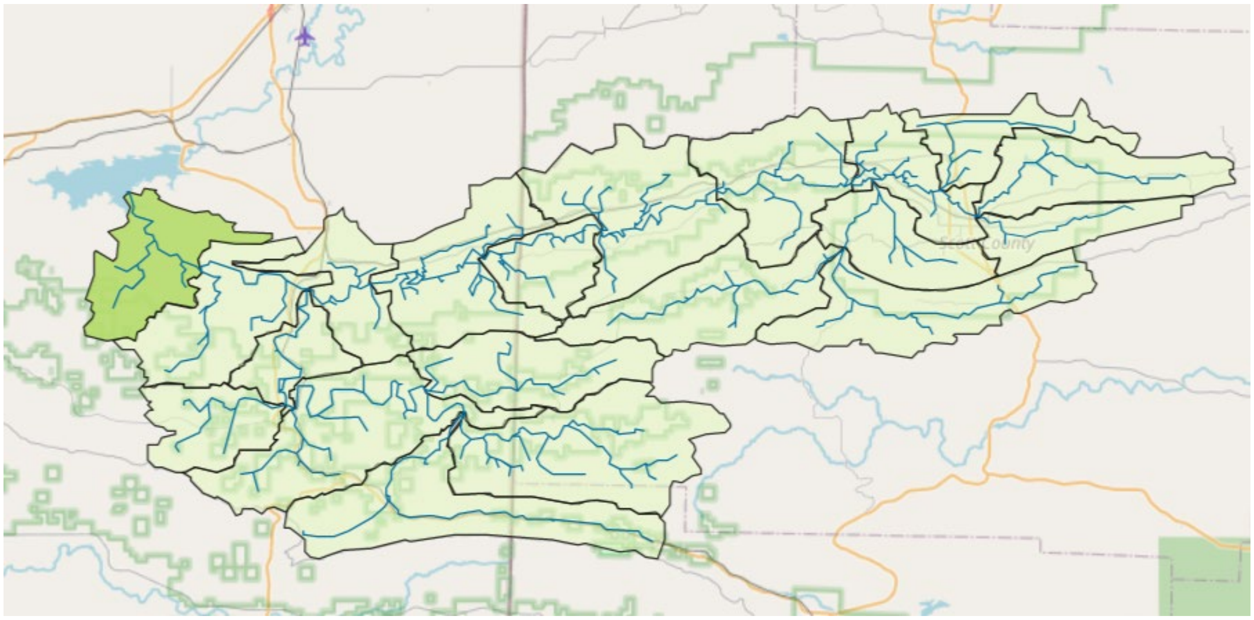

Figure 8. OK HAWQS for Porteau River (HUC12) 111101050502 watershed outlet and upstream subbasins.

Table 9. Calibration parameters adjusted during calibration including range of acceptable values for Porteau River watershed.

Porteau River; HUC12 = 111101050502			
Parameter Name	**Fitted Value**	**Minimum Value**	**Maximum Value**
V__EPCO.hru	0.55	0.5	1
R__CN2.mgt	0.10	-0.1	0.1
V__ALPHA_BF.gw	0.30	0.005	0.5
A__GW_DELAY.gw	-15.64	-30	90
A__GWQMN.gw	-585.94	-1000	1000
V__GW_REVAP.gw	0.04	0.02	0.1
A__RCHRG_DP.gw	0.02	-0.05	0.05
A__REVAPMN.gw	-143.29	-750	750
V__ESCO.hru	0.75	0.5	0.85
R__SOL_AWC(..).sol	0.03	-0.05	0.05
V__CANMX.hru	0.70	0	10
V__SLSOIL.hru	131.62	0	150
V__LAT_TTIME.hru	10.23	0	14
V__ALPHA_BF_D.gw	0.50	0	1
V__SMTMP.bsn	0.36	0	2
V__SFTMP.bsn	1.49	-2	2
V__SMFMX.bsn	2.23	2	4.5
V__SMFMN.bsn	1.40	0	2.5
V__TIMP.bsn	0.43	0	1

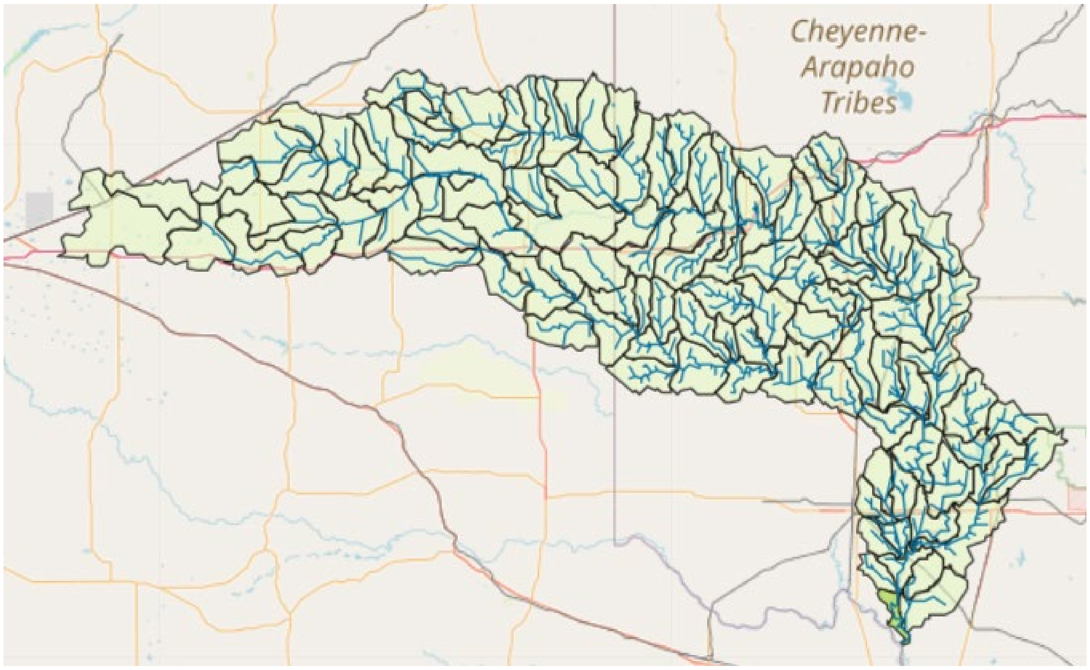

Figure 9. OK HAWQS North Fork (HUC12) 111203030510 watershed outlet and upstream subbasins.

Table 10. Calibration parameters adjusted during calibration including range of acceptable values for North Fork watershed.

North Fork; HUC12 = 111203030510			
Parameter Name	**Fitted Value**	**Minimum Value**	**Maximum Value**
V__EPCO.hru	0.68	0.5	1
R__CN2.mgt	-0.09	-0.1	0
V__ALPHA_BF.gw	0.08	0.005	0.5
A__GW_DELAY.gw	46.92	-30	90
A__GWQMN.gw	955.07	-1000	1000
V__GW_REVAP.gw	0.18	0.02	0.2
A__RCHRG_DP.gw	-0.04	-0.05	0.05
A__REVAPMN.gw	529.88	-750	750
V__ESCO.hru	0.45	0.4	0.85
R__SOL_AWC(..).sol	0.02	0	0.05
V__CANMX.hru	7.25	0	10
V__SLSOIL.hru	72.79	0	120
V__LAT_TTIME.hru	13.16	0	14
V__ALPHA_BF_D.gw	0.40	0	1
V__SMTMP.bsn	1.74	0	2
V__SFTMP.bsn	1.54	-2	2
V__SMFMX.bsn	4.30	2	4.5
V__SMFMN.bsn	1.02	0	2.5
V__TIMP.bsn	0.70	0	1

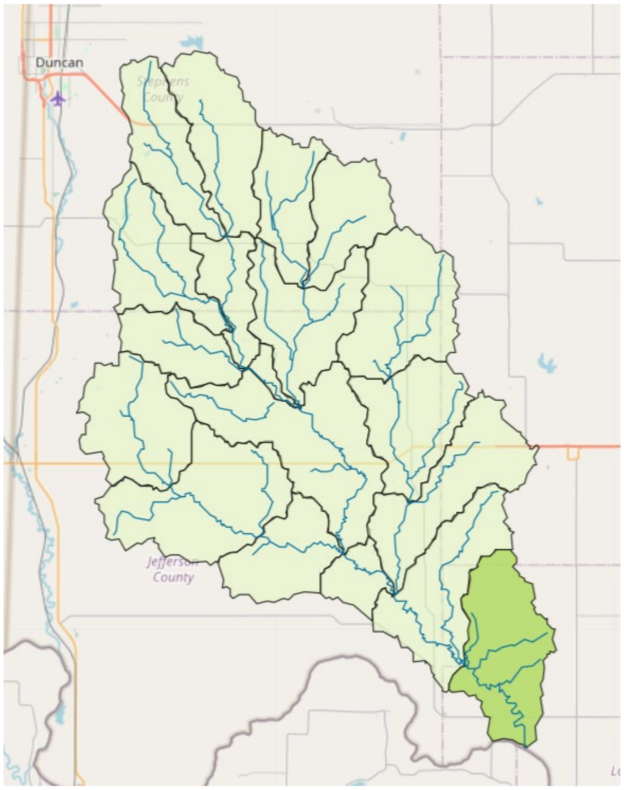

Figure 10. OK HAWQS Mud Creek (HUC12) 111302010405 watershed outlet and upstream subbasins.

Table 11. Calibration parameters adjusted during calibration including range of acceptable values for Mud Creek watershed.

Mud Creek; HUC12 = 111302010405			
Parameter Name	**Fitted Value**	**Minimum Value**	**Maximum Value**
V__EPCO.hru	0.63	0.5	1
R__CN2.mgt	-0.04	-0.1	0.1
V__ALPHA_BF.gw	0.49	0.005	0.5
A__GW_DELAY.gw	-22.22	-30	90
A__GWQMN.gw	-605.11	-1000	1000
V__GW_REVAP.gw	0.19	0.02	0.2
A__RCHRG_DP.gw	0.04	-0.05	0.05
A__REVAPMN.gw	-449.57	-750	750
V__ESCO.hru	0.66	0.5	0.85
R__SOL_AWC(..).sol	0.00	0	0.05
V__CANMX.hru	4.34	0	10
V__SLSOIL.hru	54.03	0	120
V__LAT_TTIME.hru	2.53	0	14
V__ALPHA_BF_D.gw	0.51	0	1
V__SMTMP.bsn	0.85	0	2
V__SFTMP.bsn	-1.21	-2	2
V__SMFMX.bsn	2.25	2	4.5
V__SMFMN.bsn	1.93	0	2.5
V__TIMP.bsn	0.43	0	1

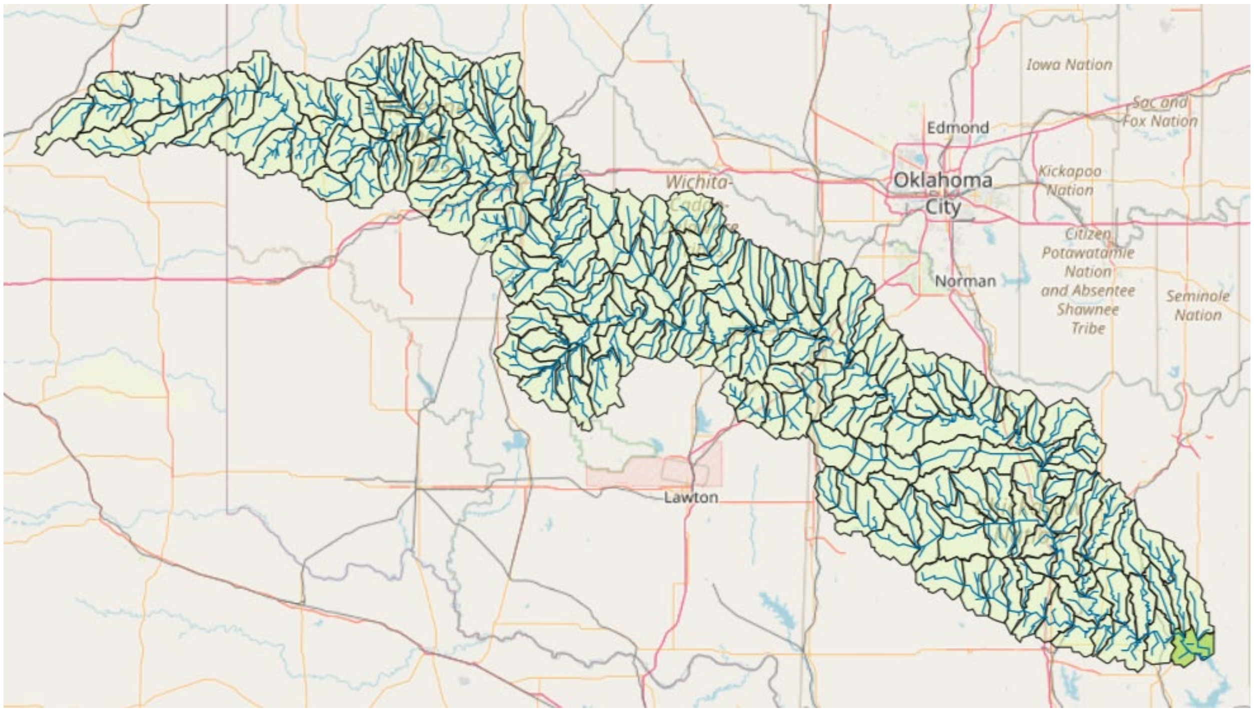

Figure 11. OK HAWQS Washita River (HUC12) 111303040205 watershed outlet and upstream subbasins.

Table 12. Calibration parameters adjusted during calibration including range of acceptable values for Washita River watershed.

Washita River; HUC12 = 111303040205			
Parameter Name	**Fitted Value**	**Minimum Value**	**Maximum Value**
V__EPCO.hru	0.74	0	1
R__CN2.mgt	-0.09	-0.1	0
V__ALPHA_BF.gw	0.29	0.005	0.5
A__GW_DELAY.gw	60.55	-30	90
A__GWQMN.gw	40.48	-1000	1000
V__GW_REVAP.gw	0.17	0.02	0.2
A__RCHRG_DP.gw	0.03	-0.05	0.05
A__REVAPMN.gw	-749.47	-750	750
V__ESCO.hru	0.62	0.4	0.75
R__SOL_AWC(..).sol	0.04	0	0.05
V__CANMX.hru	3.04	0	10
V__SLSOIL.hru	109.99	0	120
V__LAT_TTIME.hru	12.42	0	14
V__ALPHA_BF_D.gw	0.22	0	1
V__SMTMP.bsn	1.44	0	2
V__SFTMP.bsn	0.04	-2	2
V__SMFMX.bsn	3.16	2	4.5
V__SMFMN.bsn	0.12	0	2.5
V__TIMP.bsn	1.00	0	1

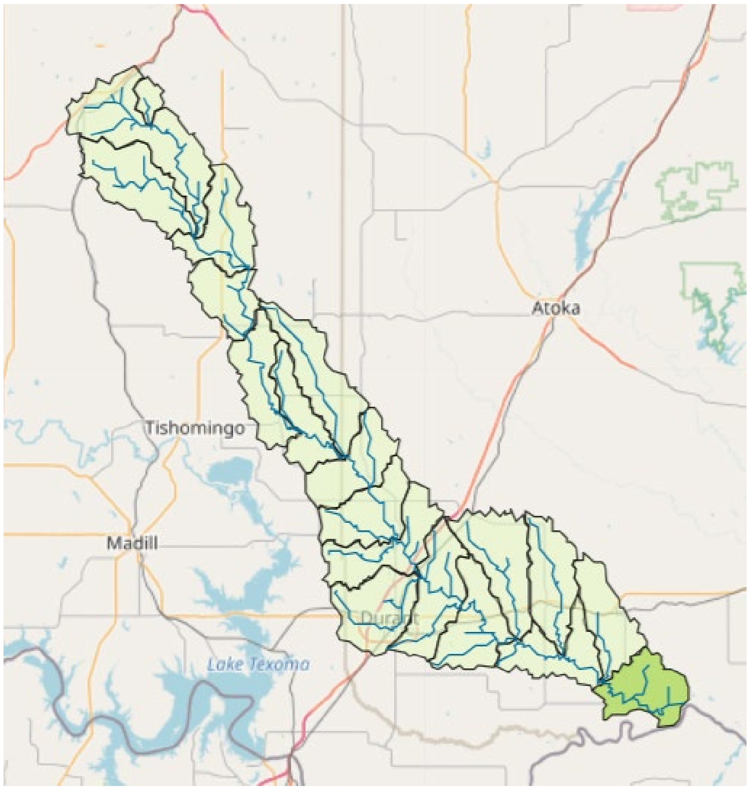

Figure 12. OK HAWQS Blue River (HUC12) 111401020209 watershed outlet and upstream subbasins.

Table 13. Calibration parameters adjusted during calibration including range of acceptable values for Blue River watershed.

Blue River; HUC12 = 111401020209			
Parameter Name	**Fitted Value**	**Minimum Value**	**Maximum Value**
V__EPCO.hru	0.43	0	1
R__CN2.mgt	-0.03	-0.1	1
V__ALPHA_BF.gw	0.24	0.005	0.5
A__GW_DELAY.gw	-21.88	-30	90
A__GWQMN.gw	167.61	-1000	1000
V__GW_REVAP.gw	0.13	0.02	0.2
A__RCHRG_DP.gw	0.02	-0.05	0.05
A__REVAPMN.gw	-566.05	-750	750
V__ESCO.hru	0.68	0.4	0.75
R__SOL_AWC(..).sol	-0.01	-0.05	0.05
V__CANMX.hru	3.71	0	10
V__SLSOIL.hru	20.94	0	60
V__LAT_TTIME.hru	5.11	0	14
V__ALPHA_BF_D.gw	0.84	0	1
V__SMTMP.bsn	1.21	0	2
V__SFTMP.bsn	-1.80	-2	2
V__SMFMX.bsn	2.69	2	4.5
V__SMFMN.bsn	0.21	0	2.5
V__TIMP.bsn	0.49	0	1

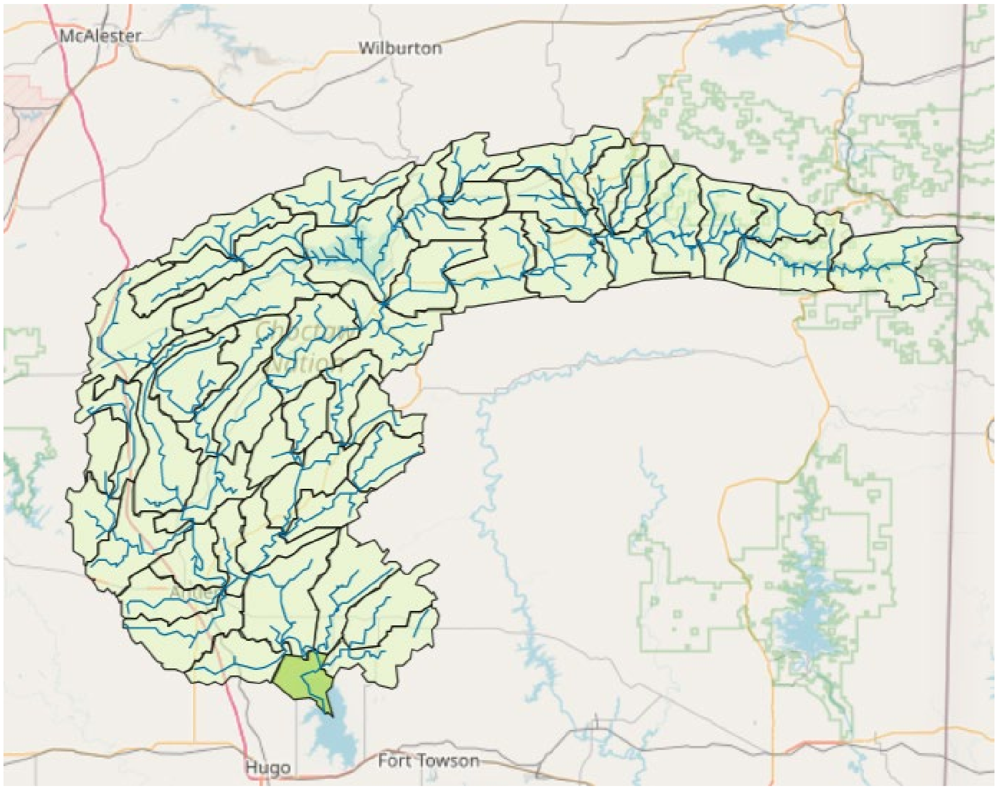

Figure 13. OK HAWQS Kiamichi River (HUC12) 111401050707 watershed outlet and upstream subbasins.

Table 14. Calibration parameters adjusted during calibration including range of acceptable values for Kiamichi River watershed.

Kiamichi River; HUC12 = 111401050707			
Parameter Name	**Fitted Value**	**Minimum Value**	**Maximum Value**
V__EPCO.hru	0.88	0.5	1
R__CN2.mgt	0.07	-0.1	0.1
V__ALPHA_BF.gw	0.29	0.005	0.5
A__GW_DELAY.gw	-27.19	-30	90
A__GWQMN.gw	-826.96	-1000	1000
V__GW_REVAP.gw	0.08	0.02	0.1
A__RCHRG_DP.gw	-0.04	-0.05	0.05
A__REVAPMN.gw	730.64	-750	750
V__ESCO.hru	0.56	0.5	0.85
R__SOL_AWC(..).sol	0.02	-0.05	0.05
V__CANMX.hru	6.10	0	10
V__SLSOIL.hru	21.44	0	150
V__LAT_TTIME.hru	3.09	0	14
V__ALPHA_BF_D.gw	0.54	0	1
V__SMTMP.bsn	1.52	0	2
V__SFTMP.bsn	0.64	-2	2
V__SMFMX.bsn	4.36	2	4.5
V__SMFMN.bsn	1.55	0	2.5
V__TIMP.bsn	0.80	0	1

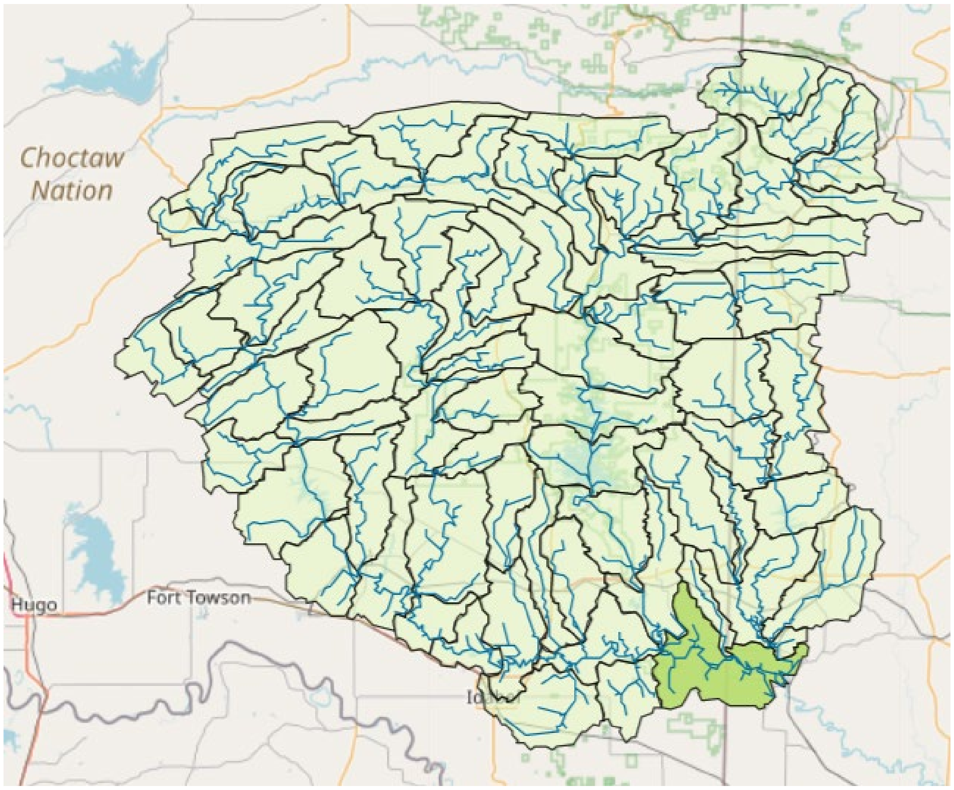

Figure 14. OK HAWQS Little River (HUC12) 111401090102 watershed outlet and upstream subbasins.

Table 15. Calibration parameters adjusted during calibration including range of acceptable values for Little River watershed.

Little River; HUC12 = 111401090102			
Parameter Name	**Fitted Value**	**Minimum Value**	**Maximum Value**
V__EPCO.hru	0.66	0	1
R__CN2.mgt	-0.09	-0.1	0.1
V__ALPHA_BF.gw	0.29	0.005	0.5
A__GW_DELAY.gw	84.44	-30	90
A__GWQMN.gw	754.30	-1000	1000
V__GW_REVAP.gw	0.14	0.02	0.15
A__RCHRG_DP.gw	0.03	-0.05	0.05
A__REVAPMN.gw	-716.30	-750	750
V__ESCO.hru	0.69	0.5	0.85
R__SOL_AWC(..).sol	0.04	0	0.05
V__CANMX.hru	8.44	0	10
V__SLSOIL.hru	87.26	0	150
V__LAT_TTIME.hru	11.80	0	14
V__ALPHA_BF_D.gw	0.62	0	1
V__SMTMP.bsn	0.22	0	2
V__SFTMP.bsn	1.39	-2	2
V__SMFMX.bsn	2.60	2	4.5
V__SMFMN.bsn	0.75	0	2.5
V__TIMP.bsn	0.81	0	1

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