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FINAL TASK REPORT

NOAA National Weather Service
Hydrologic Modeling Calibrations
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In Cooperation With: The National Weather Service West Gulf River Forecast Center

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Acronyms and Abbreviations

Acronym	Description
AET	actual evapotranspiration
AHPS	Advanced Hydrologic Prediction Service
cfs	cubic feet per second
cfsd	cubic feet per second - daily average
CHPS	Community Hydrologic Prediction System
cms	cubic meters per second
DEM	digital elevation model
FAO-PM	FAO 56 Penman Monteith
FEWS	Flood Early Warning System
gSSURGO	Gridded Soil Survey Geographic Database
HRAP	Hydrologic Rainfall Analysis Project
KGE	Kling-Gupta efficiency
LAG/K	Lag and Attenuation Routing Model
MAP	Mean Areal Precipitation
MAPE	Evapotranspiration Potential Areal Mean
MAPX	Gridded Precipitation Areal Mean Estimated
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
NSE	Nash Sutcliffe Efficiency
OHD	Office of Hydrologic Development
PEADJ	Potential Evapotranspiration Adjustment Factor
PET	Potential Evapotranspiration
PIXML	Public Interface Extensible Markup Language
PRISM	Parameter-elevation Regressions on Independent Slopes Model
QIN	River Discharge Observed (Instantaneous)
QME	Mean River Discharge Observed (Daily)
RDHM	Research Distributed Hydrologic Model
RES-SNGL	Singular Reservoir Regulation Model
RMSE	root mean square error
RQOT	Reservoir Outflow
SAC-SMA	Sacramento Soil Moisture Accounting Model
SQIN	River Discharge Simulated (Instantaneous)
SQME	River Discharge Simulated Mean (Daily)
TWDB	Texas Water Development Board
UNIT-HG	Unit Hydrograph
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WGRFC	West Gulf River Forecast Center

Additional NWS Model Acronyms and Abbreviations

Acronym	Description
ADIMC	Additional Impervious Area
ADIMF	Additional Impervious Area Fraction
ADIMP	Additional fraction of impervious when tension water requirements are met
LZFPC	Lower Zone Free Primary Content
LZFPF	Lower Zone Primary Fraction
LZFPM	Lower zone primary free water storage max capacity (depth over catchment)
LZFSC	Lower Zone Free Supplemental Content
LZFSF	Lower Zone Free Water Fraction
LZFSM	Lower zone supplemental free water storage max capacity (depth over catchment)
LZPK	Lower zone primary free water later drainage rate (fraction of contents)
LZSK	Lower zone supplemental free water later drainage rate (fraction of contents)
LZTDEF	Lower Zone Tension Water Deficit
LZTWC	Lower Zone Tension Water Content
LZTWF	Lower Zone Tension Water Fraction
LZTWM	Lower zone tension water storage max capacity (depth over catchment)
PBASE	Percolation rate from upper zone free water into lower zone (capability during saturated conditions)
PCTIM	Fraction of catchment that produces impervious runoff during low flow conditions
POTIM	Sum of PCTIM and ADIMP
PRFEE	Direct percolation to lower zone free water (percentage of percolated water available to lower free water aquifers before all lower zone tension water deficiencies are met
REXP	Exponent -> determines rate of change of the percolation rate w/ changing lower zone water contents
RSERV	Fraction of lower zone free water below the catchment's root zone thus incapable of resupplying a deficiency of lower zone tension
SIDE	Ratio of non-channel subsurface outflow to channel base flow
SSOUT	Rate of flow conveyed by channel's porous base and must be available before flow can be observed
UZFWC	Upper Zone Free Water Content
UZFWF	Upper Zone Free Water Fraction
UZFWM	Upper zone free water storage max capacity (depth over catchment)
UZK	Lateral drainage rate of upper zone free water (fraction of contents per day)
UZTDEF	Upper Zone Tension Water Deficit
UZTWC	Upper Zone Tension Water Content
UZTWF	Upper Zone Tension Water Fraction
UZTWM	Upper zone tension water storage max capacity (depth over catchment)
Z	Proportional increase in percolation from sat. to dry condition

1. INTRODUCTION

Accurate and timely hydrologic forecasts by the National Weather Service (NWS) River Forecast Centers (RFCs) are essential to saving life and property. Reliable and up-to-date calibrations of the operational hydrologic and hydraulic models used by the NWS RFCs enhance streamflow forecast performance and further their mission. To support the streamflow forecasting efforts of the West Gulf River Forecast Center (WGRFC) in Texas, the Texas Water Development Board (TWDB) contracted Lynker Technologies (Lynker) to perform hydrologic, routing, and reservoir model calibrations on behalf of the WGRFC in four major river basins of the central and southeastern part of the state. This includes "contract-required" basin calibrations as well as additional "funding dependent" basin calibrations:

1. Hydrologic runoff calibrations for 83 WGRFC basins – Sacramento Soil Moisture Accounting runoff (SAC-SMA) models and Unit Hydrograph (UNIT-HG) models (59 required basins and 24 funding dependent basins)
2. Streamflow routing models (LAG/K; lag and attenuation) for 76 segments
3. Calibration of the Single Reservoir Regulation models (RES-SNGL) for Coleto Creek Reservoir, Lake Mexia, Lake Proctor, Lake Coleman, Hord's Creek Reservoir, Lake Brownwood, Waco Lake, and Lake Leon

Prior to model calibration, Lynker performed a thorough background analysis including a quality assurance and quality control of forcing data and a comprehensive water balance assessment. Lynker performed a manual calibration, inclusive of an intensive, in-house peer-review process, for the relevant runoff, routing, and reservoir models. This report details the calibration results for the 83 basins requested by WGRFC, including 53 basins in the Brazos forecast group ,18 basins in the Guadalupe forecast group, 8 basins in the Colorado forecast group, and 3 basins in the Nueces forecast group (Figure 1-1).

The following link can be used to view an interactive map of the calibration locations included in this task: https://arcg.is/1ue8GX

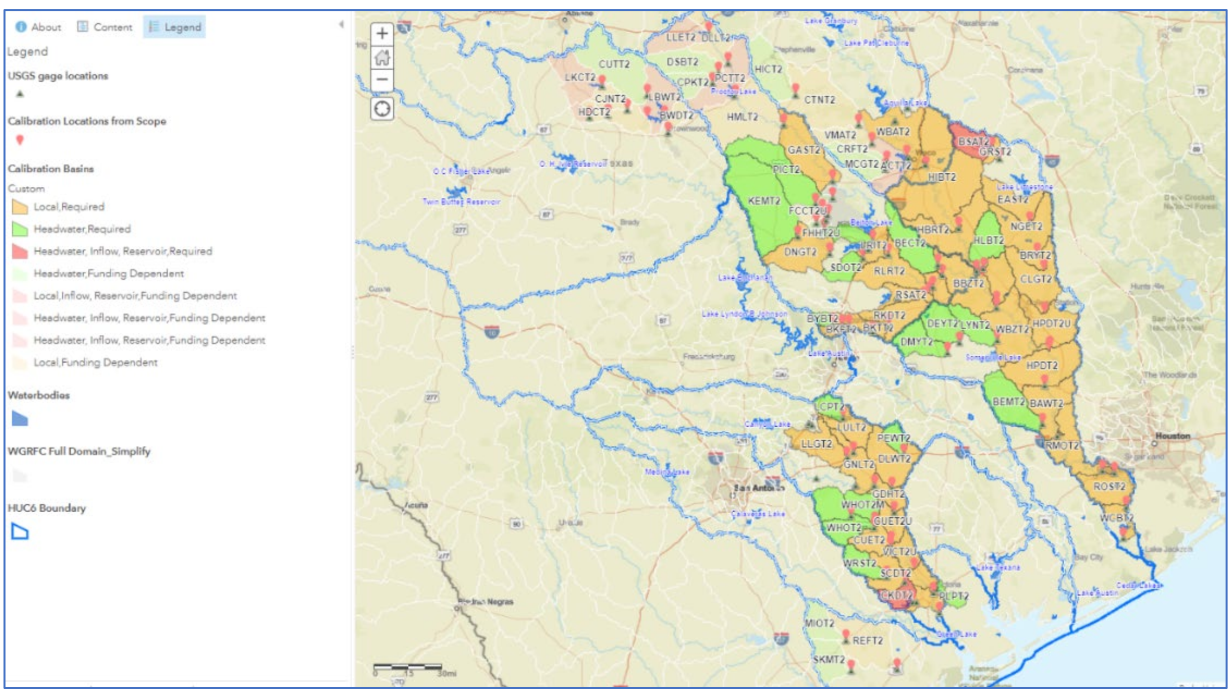


Figure 1-1. ArcGIS Online map of study domain showing the contractually required calibration sites (solid colors) as well as the "funding-dependent" calibration sites (transparent colors) calibrated on behalf of the WGRFC as contracted by TWDB, which include the Brazos, Guadalupe, Colorado, and Nueces River basins.

1.1. Summary of Calibration Tasks

The WGRFC emphasizes the desire to have an overall well-fitting hydrologic model that prioritizes the accurate prediction of flood events, while still performing adequately during low flow months for purposes of water supply planning, particularly in downstream basins. This project was divided into four separate sub-tasks, which also help to organize this report. They include:

1. Basin Hydrography (Chapter 2)
2. Water Balance Analysis (Chapter 3)
3. Hydrologic Runoff and Routing Calibrations (Chapter 4)
4. Reservoir Model Calibration (Chapter 5)

Note that Chapters 2 & 3 of this report include information for the 59 **required** calibration locations as well as 30 additional **funding-dependent** basins. These additional 30 locations were included in the basin hydrography geoprocessing and water balance workflows, but please note that calibrations were only performed for 24 of the 30 funding-dependent basins (calibration not performed for the Fort Hood basins: FHCT2, FCCT2U, FCCT2, FHGT2, FHHT2U, FHHT2).

All model calibrations of the required basins were performed using the NWS Community Hydrologic Prediction System (CHPS). Basin delineation and model forcing data, including precipitation (MAPX) and potential evapotranspiration (MAPE) grids, were provided by the WGRFC. An updated CHPS standalone (SA) operational configuration was also provided by WGRFC. The CHPS calibration configuration used by Lynker in model calibration was developed from the existing models and workflow files in the WGRFC SA-configuration.

In addition to this report, final project deliverables to WGRFC include:

- CHPS calibration standalone (wgrfc_calb)
- Updated ModuleParFiles and ColdStateFiles, and calibration related CHPS configuration files
- Supplemental data and other supporting files

Table 1-1 provides an overview of the study basins and important metadata. The order of this table was determined using the drainage network and the Hydrologic Unit Code (HUC) 8 basins, moving from upstream to downstream, beginning with required basins and followed by funding-dependent basins, where relevant. This report-specific order and the associated ID numbers is consistent in the subsequent tables and basin summary reports of Chapter 4.

Table 1-1. Summary of the calibration sites, including CH5ID, site name, forecast group, USGS gauge ID, model timestep, and site type

ID	Basin	Site Name	Forecast Group-Funding Status*	USGS ID	Model Timestep (hr)	Site Type
1	GAST2	Leon River at Gatesville	Brazos	08100500	3	Local
2	BNLT2	Nolan Creek at S Penelope, Belton	Brazos	08102595	1	Headwater
3	LRIT2	Little River at Little River	Brazos	08104500	1	Local
4	PICT2	Cowhouse Creek at Pidcoke	Brazos	08101000	3	Headwater
5	KEMT2	Lampasas River near Kempner	Brazos	08103800	3	Headwater
6	DNGT2	Lampasas River at Ding Dong	Brazos	08103940	3	Local
7	SDOT2	Salado Creek at Salado	Brazos	08104300	1	Headwater
8	BYBT2	Brushy Creek at Cedar Park, TX	Brazos	08105872	1	Headwater
9	BCIT2	Brushy Creek at IH 35, Round Rock, TX	Brazos	08105883	1	Local
10	BKFT2	Brushy Creek at Kenney Fort Blvd at Round Rock, TX	Brazos	08105888	1	Local
11	BSYT2	Brushy Creek at FM 973 near Coupland, TX	Brazos	08105897	1	Local

ID	Basin	Site Name	Forecast Group-Funding Status*	USGS ID	Model Timestep (hr)	Site Type
12	BKTT2	Brushy Creek at FM 619 near Taylor, TX	Brazos	08106050	1	Local
13	RKDT2	Brushy Creek near Rockdale	Brazos	no gauge	3	Local
14	RSAT2	San Gabriel River near Rockdale	Brazos	no gauge	3	Local
15	RLRT2	Little River near Rockdale	Brazos	08106350	3	Local
16	CMNT2	Little River near Cameron, TX	Brazos	08106500	3	Local
17	BECT2	Big Elm Creek at TX77 near Cameron	Brazos	08108250	3	Headwater
18	BBZT2	Brazos River at SH21 near Bryan	Brazos	08108700	3	Local
19	WBAT2	Brazos River at Waco	Brazos	08096500	3	Local
20	HIBT2	Brazos River near Highbank	Brazos	08098290	3	Local
21	BSAT2	Lake Mexia near Mexia	Brazos	08110300	3	Headwater,Inflow, Res
22	GRST2	Navasota River above Groesbeck	Brazos	08110325	3	Local
23	EAST2	Navasota River near Easterly	Brazos	08110500	3	Local
24	NGET2	Navasota River near Normangee	Brazos	08110800	3	Local
25	BRYT2	Navasota River near Bryan	Brazos	no gauge	3	Local
26	CLGT2	Navasota River near College Station	Brazos	no gauge	3	Local
27	HPDT2U	Upper Brazos River near Hempstead	Brazos	no gauge	3	Local
28	DMYT2	Middle Yegua Creek at Dime Box	Brazos	08109700	3	Headwater
29	DEYT2	East Yegua Creek near Dime Box	Brazos	08109800	3	Headwater
30	LYNT2	Davidson Creek near Lyons	Brazos	08110100	3	Headwater
31	HBRT2	Brazos River at FM485 near Hearne	Brazos	08098450	3	Local
32	HLBT2	Little Brazos River near Hearne	Brazos	08108780	3	Headwater
33	WBZT2U	Rest of Little Brazos above Washington	Brazos	no gauge	3	Local
34	WBZT2	Brazos River at Washington	Brazos	08110200	3	Local
35	HPDT2	Brazos River near Hempstead	Brazos	08111500	3	Local
36	BEMT2	Mill Creek near Bellville	Brazos	08111700	3	Headwater
37	BAWT2	Brazos River at San Felipe	Brazos	08111850	3	Local
38	RMOT2	Brazos River at Richmond	Brazos	08114000	3	Local
39	SLNT2	Brazos River near Sugar Land	Brazos	08114100	3	Local
40	ROST2	Brazos River near Rosharon	Brazos	08116650	3	Local
41	WCBT2	Brazos River near West Columbia	Brazos	08116850	3	Local
42	LCPT2	Plum Creek at Lockhart	Guadalupe	08172400	3	Headwater
43	LULT2	Plum Creek near Luling	Guadalupe	08173000	3	Local
44	LLGT2	San Marcos River at Luling	Guadalupe	08172000	3	Local
45	GNLT2	Guadalupe River at Gonzales	Guadalupe	08173900	3	Local
46	PEWT2	Peach Creek at Highway 90 near Waelder, TX	Guadalupe	08174550	3	Headwater
47	DLWT2	Peach Creek below Dilworth	Guadalupe	08174600	3	Local
48	GDHT2	Guadalupe River at Hwy 183 near Hochheim, TX	Guadalupe	08174700	3	Local
49	WHOT2U	Upper Sandies Creek near Westhoff	Guadalupe	08174970	3	Headwater
50	WHOT2M	Middle Sandies Creek near Westhoff	Guadalupe	no gauge	3	Headwater
51	WHOT2	Sandies Creek near Westhoff	Guadalupe	08175000	3	Headwater

ID	Basin	Site Name	Forecast Group-Funding Status*	USGS ID	Model Timestep (hr)	Site Type
52	CUET2U	Upper Guadalupe River at Cuero	Guadalupe	no gauge	3	Local
53	CUET2	Guadalupe River at Cuero, TX	Guadalupe	08175800	3	Local
54	WRST2	Fifteenmile Creek near Weser, TX	Guadalupe	08176550	3	Headwater
55	SCDT2	Coleto Creek near Schroeder	Guadalupe	08176900	3	Local
56	CKDT2	Coleto Creek Reservoir	Guadalupe	08177400	3	Headwater, Inflow, Res
57	VICT2U	Upper Guadalupe River at Victoria, TX	Guadalupe	no gauge	3	Local
58	VICT2	Guadalupe River at Victoria	Guadalupe	08176500	3	Local
59	DUPT2	Guadalupe River at du Pont Plant near Bloomington	Guadalupe	08177520	3	Local
60	LLET2	Leon Reservoir near Ranger	Brazos-FD	08099000	6	Headwater, Inflow, Res
61	CPKT2	Copperas Creek	Brazos-FD	08099382	3	Headwater
62	DSBT2	Sabana River near De Leon	Brazos-FD	08099300	3	Headwater
63	DLLT2	Leon River near De Leon	Brazos-FD	08099100	3	Local
64	PCTT2	Proctor Lake near Proctor	Brazos-FD	08099400	6	Local, Inflow, Res
65	HMLT2	Leon River near Hamilton	Brazos-FD	08100000	3	Local
66	*FHCT2	Henson Creek at W Range Rd near Gatesville	Brazos-FD	08100630	1	Headwater
67	*FCCT2U	Cowhouse Creek at Old Georgetown Rd near Ft Hood	Brazos-FD	08101200	1	Local
68	*FCCT2	Cowhouse Creek at W Range Rd near Ft Hood	Brazos-FD	08101300	1	Local
69	*FHGT2	House Creek at Old Gtn Rd near Ft Hood	Brazos-FD	08101310	1	Headwater
70	*FHHT2U	Clear Creek at Ft Hood	Brazos-FD	08101330	1	Headwater
71	*FHHT2	House Creek at W Range Rd near Ft Hood	Brazos-FD	08101340	1	Headwater
72	MCGT2	Middle Bosque River near McGregor	Brazos-FD	08095300	3	Headwater
73	HICT2	N Bosque River at Hico	Brazos-FD	08094800	3	Headwater
74	CTNT2	North Bosque River near Clifton	Brazos-FD	08095000	3	Local
75	VMAT2	North Bosque River at Valley Mills	Brazos-FD	08095200	3	Local
76	ACTT2	Waco Lake near Waco	Brazos-FD	08095550	0	Local, Inflow, Reservoir
77	CRFT2	Hog Creek near Crawford	Brazos-FD	08095400	3	Headwater
78	MCGT2	Middle Bosque River near McGregor	Brazos-FD	08095300	3	Headwater
79	LKCT2	Lake Coleman near Novice	Colorado-FD	08140770	3	Headwater, Inflow, Res
80	HORT2	Hords Creek Lake near Valera	Colorado-FD	08141000	3	Headwater, Inflow, Res
81	HDCT2	Hords Creek near Coleman	Colorado-FD	08142000	3	Local
82	CJNT2	Jim Ned Creek at CR 140 near Coleman	Colorado-FD	08140860	3	Local
83	LBWT2U	ungauged Jim Ned Creek	Colorado-FD	no gauge	3	Local
84	CUTT2	Pecan Bayou near Cross Cut	Colorado-FD	08140700	3	Headwater
85	LBWT2	Lake Brownwood near Brownwood	Colorado-FD	08143000	3	Local, Inflow, Res
86	BWDT2	Pecan Bayou at Brownwood	Colorado-FD	08143500	3	Local
87	SKMT2	Aransas River near Skidmore	Nueces-FD	08189700	1	Headwater
88	MIOT2	Medio Creek near Beeville	Nueces-FD	08189300	1	Headwater
89	REFT2	Mission River at Refugio	Nueces-FD	08189500	1	Local

Indicates Fort Hood basin not calibrated; "FD" indicates "funding-dependent" locations (e.g., ID#: 60-89), as identified in the TWDB scope of work. Though priority was given to the first 59 sites, the funding-dependent locations were also thoroughly calibrated.

2. BASIN HYDROGRAPHY

Parameter estimation is, in effect, an attempt at determining the mean set of basin characteristics that have been identified as most important in streamflow response. For example, Zone Percolation (ZPERC) is one of the parameters responsible for the percolation rate of the SAC-SMA model simulation, which itself is a reflection of the soil characteristics and land cover of a basin. Because of the importance of basin hydrography in a physically informed model calibration, the initial phase of the project focused on understanding the physical and hydrologic features of the study basins. This analysis primarily relied on the use of publicly available geospatial datasets but also included a general literature review of published reports from the U.S. Geological Survey (USGS) and TWDB. It was also informed by the expertise and institutional knowledge of WGRFC forecasters.

We extracted gridded datasets to produce summary statistics for each basin. Datasets used in the Basin Hydrography analysis and detailed in this report include:

- Land cover: 2016 National Land Cover Database (Homer et al, 2015), Available online at https://www.mrlc.gov/data/nlcd-2016-land-cover-conus

- Elevation and slope: National Hydrography Dataset Plus (NHDPlus) National Elevation Dataset (NED) - National Hydrography Dataset Plus (2012), Available online at *https://www.epa.gov/waterdata/nhdplus-national-hydrography-dataset-plus*

- Soil drainage characteristics: The Gridded Soil Survey Geographic (gSSURGO) Database, USDA-NRCS, (Soil Survey Staff, 2014), Available online at: *http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627*

- Natural groundwater recharge estimates: Wolock (2003), Available online at *http://water.usgs.gov/GIS/metadata/usgswrd/XML/rech48grd.xml*

- Climatological precipitation: PRISM Climate Group, Oregon State University, 2013. Available online at *http://www.prism.oregonstate.edu/*

- Hydrography: NHDPlus High Resolution (NHDPlus HR), U.S. Geological Survey, Available online at *http://nhd.usgs.gov/*

2.1. Land Cover

The 2016 National Land Cover Database (2016 NLCD) provides a 30-meter gridded dataset that uses Landsat satellite imagery, geospatial ancillary datasets, and a decision-tree of criteria to describe spatially explicit land cover in 16 classes for the United States. Land cover classifications provide insights to types of streamflow generation in a basin (e.g., impervious runoff from developed areas) or how much surface water is diverted for irrigation of cultivated crops. Although inferences of water usage from land cover are indirect, sometimes they are the best data available, making it an important early resource for the model calibration process. Figure 2-1 to Figure 2-5 summarize the distribution of land cover for each of the study basins. Table 2-1 summarizes each basin's land cover profile as a percent coverage of the total basin area.

The primary land cover classification in the study region is largely dominated by shrubs/scrubs (light brown), herbaceous cover (light tan), hay/pasture (yellow), cultivated crops (brown) and developed land (shades of pink/red) as shown in the maps for the Brazos (Figure 2-1 and Figure 2-2), Guadalupe (Figure 2-3), Colorado (Figure 2-4), and Nueces (Figure 2-5) forecast groups. In the Brazos River basin, there is significant variability and spatial grouping of land classes, with shrub/scrub and herbaceous land cover in the Little River (inland from the Interstate-35 corridor), more cultivated crops and hay/pasture in the Middle Brazos (south of Waco, near College Station), and increasingly developed land on the Lower Brazos near the coast (outside of Houston). In the Guadalupe River basin, most land cover is dominated by hay/pasture and cultivated crops, with areas of forest (shades of green). Generally, the Guadalupe is less developed than the Brazos, apart from the Interstate-35 corridor including San Marcos on the Middle Guadalupe and Victoria on the Lower Guadalupe. The Guadalupe also has fewer cultivated crops by land area than the Brazos. The Colorado forecast group is dominated by scrub/shrub land, with a smattering of forestland and small portions of cultivated crops. The Colorado also has a small area of development in the town of Coleman along Hords Creek. In the Nueces River basin, landcover is dominated by scrub/shrub and hay/pastures. The southwest corner of the forecast group has a bit of cultivated land. The small town of Beeville is north of the cultivated area in the southwest.

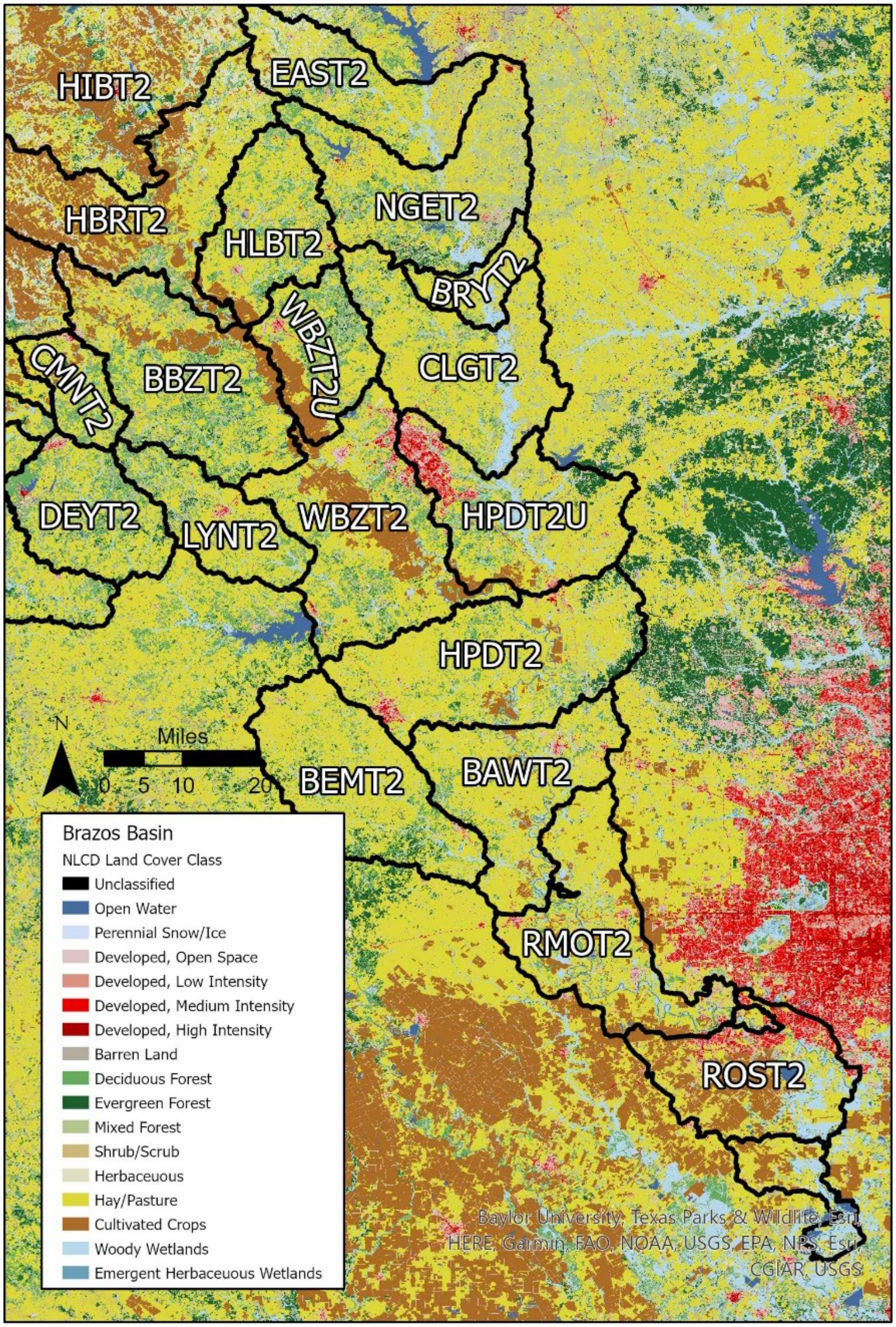


Figure 2-1. NLCD map of the calibration domain for the lower Brazos forecast group. CH5-IDs (basin IDs) for this and all subsequent figures correspond to the locations and information identified in Table 1-1.

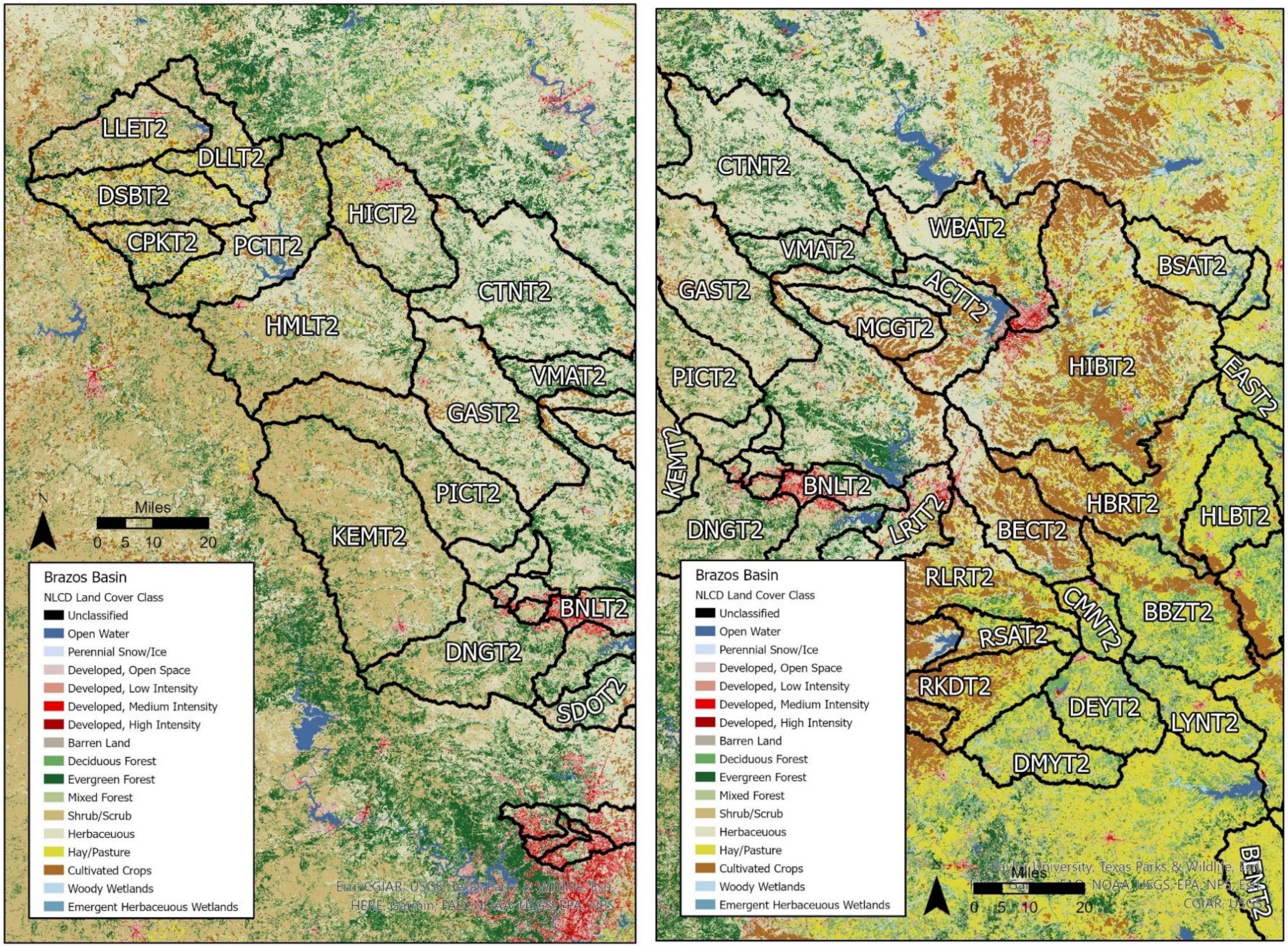


Figure 2-2: NLCD map of calibration domain for the upper (left) and middle (right) Brazos forecast group.

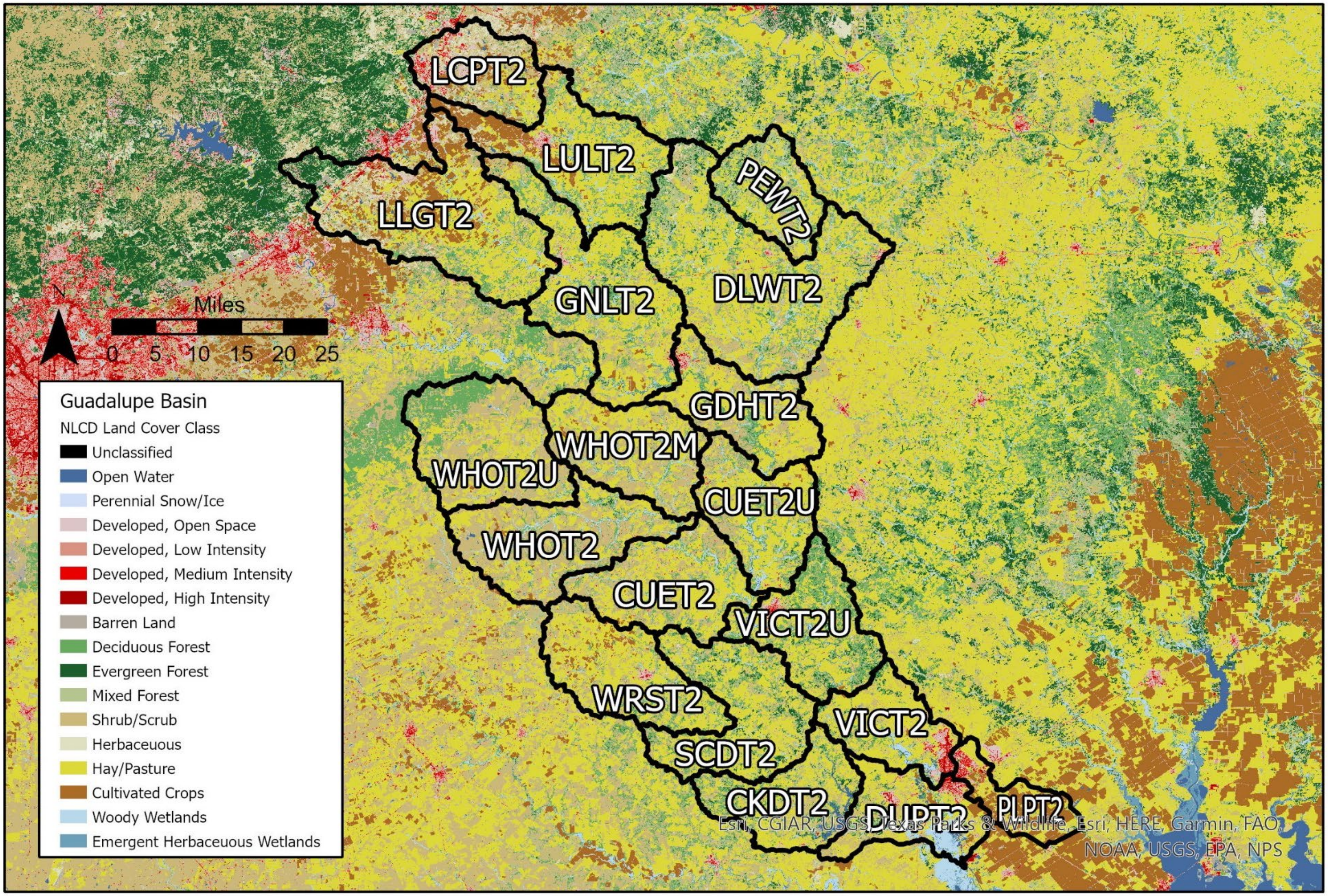


Figure 2-3. NLCD map of the calibration domain for the Guadalupe forecast group.

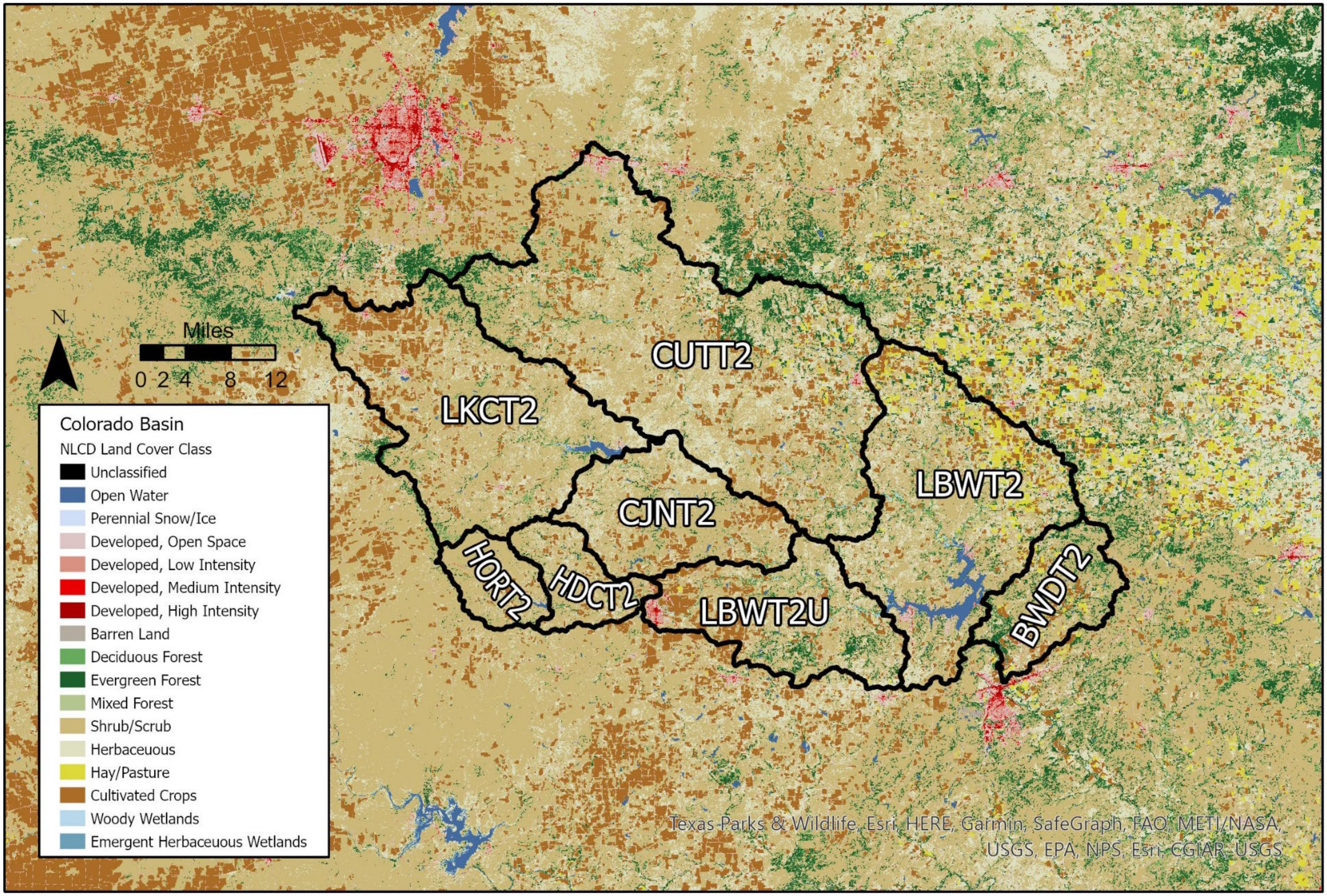


Figure 2-4. NLCD map of the calibration domain for Colorado forecast group.

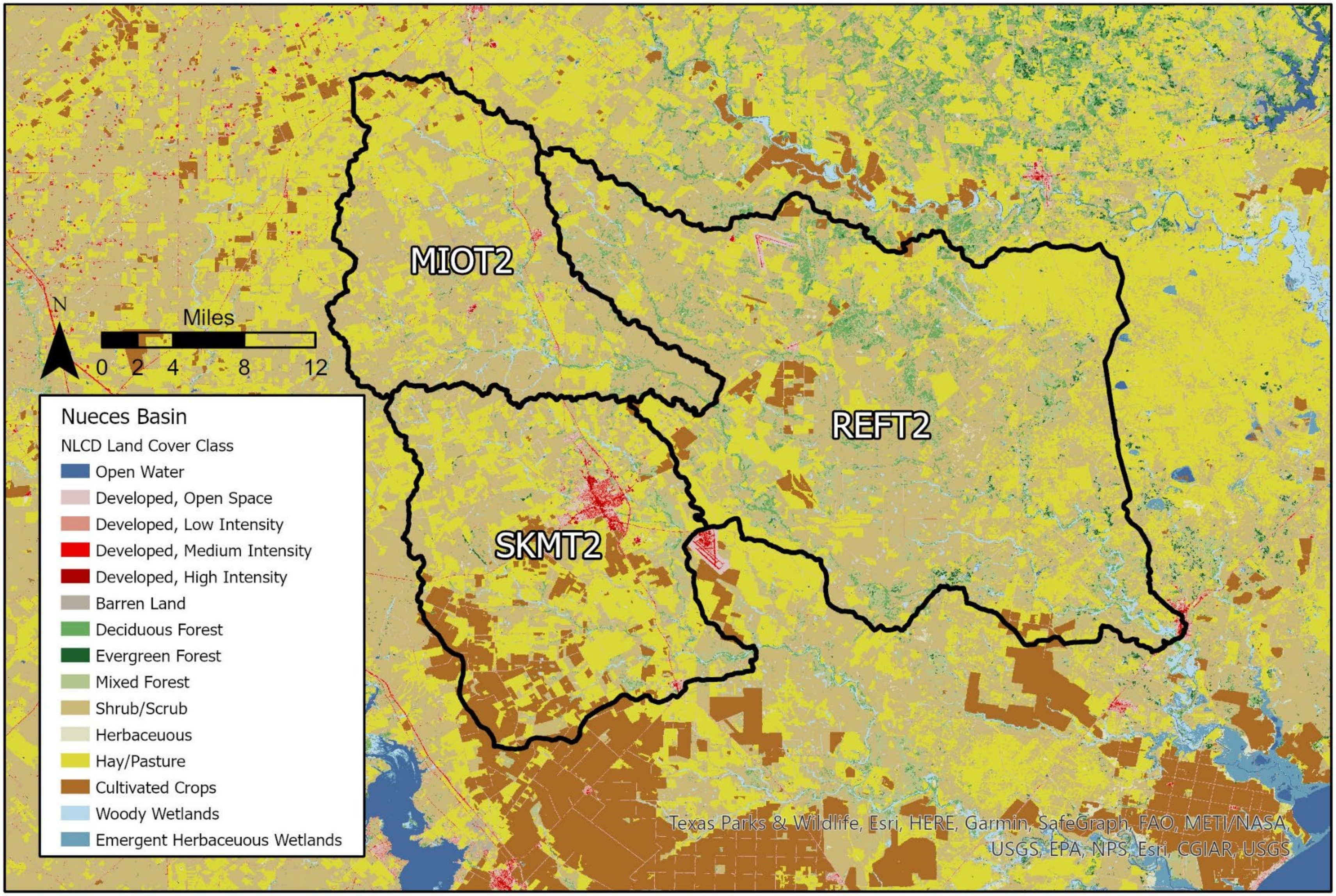


Figure 2-5. NLCD map of the calibration domain for the Nueces forecast group.

Table 2-1. NLCD (2016) land classes as a percent of basin area for the study domain

ID	Basin	Forecast group	Shrub/Scrub	Herbaceous	Hay/Pasture	Cultivated Crops	Woody Wetlands	Emergent Herbaceous Wetlands	Developed	Forest	Open Water	Perennial Snow/Ice	Barren Land
1	GAST2	Brazos	18.76	56.66	1.20	5.98	1.26	0.02	1.36	14.49	0.25	0.00	0.02
2	BNLT2	Brazos	4.08	29.11	1.27	1.15	1.52	0.04	40.51	21.12	0.44	0.00	0.74
3	LRIT2	Brazos	0.34	40.60	10.82	10.93	4.56	0.10	19.50	12.56	0.40	0.00	0.19
4	PICT2	Brazos	49.28	27.42	0.91	5.30	0.23	0.00	0.34	16.36	0.12	0.00	0.02
5	KEMT2	Brazos	65.57	16.37	0.48	2.39	0.14	0.00	0.90	13.94	0.17	0.00	0.03
6	DNGT2	Brazos	39.67	26.14	0.16	0.21	0.33	0.01	3.90	29.25	0.19	0.00	0.14
7	SDOT2	Brazos	4.25	56.82	0.51	4.00	0.77	0.01	2.11	30.19	0.11	0.00	1.22
8	BYBT2	Brazos	8.38	20.52	0.08	0.17	0.59	0.02	46.16	23.48	0.52	0.00	0.09
9	BCIT2	Brazos	1.93	6.53	0.00	0.00	0.93	0.02	68.74	21.05	0.69	0.00	0.11
10	BKFT2	Brazos	0.16	17.96	0.09	0.26	1.50	0.02	66.23	12.56	0.25	0.00	0.96
11	BSYT2	Brazos	0.42	34.90	2.68	18.63	2.87	0.08	31.01	4.91	0.62	0.00	3.88
12	BKTT2	Brazos	3.32	6.53	18.30	65.12	3.83	0.03	1.25	1.10	0.49	0.00	0.04
13	RKDT2	Brazos	4.25	4.50	38.23	38.89	3.17	0.11	3.03	7.12	0.62	0.00	0.10
14	RSAT2	Brazos	2.43	3.41	40.51	37.43	7.54	0.08	0.20	8.10	0.20	0.00	0.09
15	RLRT2	Brazos	0.83	23.15	27.91	34.07	4.03	0.14	1.99	7.00	0.74	0.00	0.13
16	CMNT2	Brazos	6.80	1.21	54.34	5.44	4.29	0.20	1.77	25.11	0.68	0.00	0.17
17	BECT2	Brazos	1.50	34.46	12.49	41.27	3.11	0.09	2.83	3.56	0.59	0.00	0.10
18	BBZT2	Brazos	5.05	2.01	42.55	14.78	2.31	0.27	0.97	30.72	1.03	0.00	0.31
19	WBAT2	Brazos	0.31	41.87	18.60	13.58	2.62	0.14	8.34	13.57	0.91	0.00	0.06
20	HIBT2	Brazos	0.51	28.30	22.82	33.61	3.69	0.28	3.27	6.07	1.41	0.00	0.04
21	BSAT2	Brazos	1.58	45.49	29.51	8.08	1.38	0.20	0.98	11.48	1.08	0.00	0.22
22	GRST2	Brazos	0.49	37.22	34.81	0.20	0.95	0.27	2.40	19.87	3.02	0.00	0.77
23	EAST2	Brazos	0.64	10.19	53.55	0.99	6.53	0.67	2.71	23.25	0.39	0.00	1.08
24	NGET2	Brazos	1.02	2.00	48.76	0.04	5.87	0.37	4.14	35.51	1.65	0.00	0.63
25	BRYT2	Brazos	0.99	1.68	60.46	0.00	9.73	0.91	2.35	23.28	0.50	0.00	0.10
26	CLGT2	Brazos	0.82	1.39	64.28	0.00	8.39	0.68	2.52	21.34	0.48	0.00	0.09
27	HPDT2U	Brazos	0.81	1.05	49.36	3.40	8.68	0.71	16.71	17.88	1.04	0.00	0.36
28	DMYT2	Brazos	7.73	2.02	51.27	0.14	5.67	0.60	1.17	30.13	0.83	0.00	0.43
29	DEYT2	Brazos	5.18	1.59	48.10	0.17	3.88	0.46	2.21	36.44	1.42	0.00	0.55
30	LYNT2	Brazos	2.50	0.57	59.14	0.23	3.98	0.34	2.72	29.81	0.39	0.00	0.31
31	HBRT2	Brazos	2.78	11.06	35.10	36.85	2.04	0.30	1.05	9.94	0.68	0.00	0.19
32	HLBT2	Brazos	1.31	1.20	58.37	5.48	3.68	0.30	2.80	25.81	0.33	0.00	0.73

ID	Basin	Forecast group	Shrub/Scrub	Herbaceous	Hay/Pasture	Cultivated Crops	Woody Wetlands	Emergent Herbaceous Wetlands	Developed	Forest	Open Water	Perennial Snow/Ice	Barren Land
33	WBZT2U	Brazos	0.92	0.88	41.46	17.26	2.10	0.20	3.45	32.81	0.74	0.00	0.19
34	WBZT2	Brazos	1.05	1.01	50.59	17.37	3.83	0.34	6.33	17.52	1.66	0.00	0.31
35	HPDT2	Brazos	1.06	1.45	67.03	2.93	4.90	0.20	4.75	16.41	1.04	0.00	0.21
36	BEMT2	Brazos	0.58	0.37	74.55	0.05	4.58	0.24	1.69	17.36	0.48	0.00	0.09
37	BAWT2	Brazos	0.99	1.34	71.75	3.31	6.97	0.58	2.45	10.63	1.57	0.00	0.42
38	RMOT2	Brazos	0.96	0.66	62.18	13.80	6.91	0.87	5.31	6.89	2.07	0.00	0.33
39	SLNT2	Brazos	0.83	1.67	40.75	3.37	7.55	0.40	30.76	6.87	6.34	0.00	1.45
40	ROST2	Brazos	1.01	1.61	29.40	30.27	10.62	0.72	19.48	4.26	2.45	0.00	0.18
41	WCBT2	Brazos	2.50	2.22	38.11	18.18	24.65	1.10	1.13	6.25	5.78	0.00	0.08
42	LCPT2	Guadalupe	32.83	19.21	14.67	13.49	1.06	0.04	11.73	5.31	1.26	0.00	0.41
43	LULT2	Guadalupe	11.27	3.18	46.35	14.61	3.82	0.06	2.36	17.82	0.45	0.00	0.09
44	LLGT2	Guadalupe	17.79	9.46	33.99	17.90	1.96	0.06	3.48	14.27	0.65	0.00	0.43
45	GNLT2	Guadalupe	17.07	1.10	52.89	1.74	3.19	0.36	1.95	20.95	0.64	0.00	0.10
46	PEWT2	Guadalupe	13.84	2.04	41.38	0.00	4.43	0.17	0.43	37.15	0.54	0.00	0.03
47	DLWT2	Guadalupe	17.87	1.63	49.77	0.05	3.92	0.15	1.54	24.63	0.37	0.00	0.07
48	GDHT2	Guadalupe	25.56	0.51	51.42	1.25	2.45	0.15	4.10	13.33	1.06	0.00	0.16
49	WHOT2U	Guadalupe	42.71	0.12	33.09	0.30	1.70	0.06	1.05	20.64	0.24	0.00	0.09
50	WHOT2M	Guadalupe	39.24	0.17	43.92	2.08	3.58	0.33	1.19	9.14	0.24	0.00	0.10
51	WHOT2	Guadalupe	50.34	0.18	29.61	1.31	4.75	0.11	2.12	10.87	0.64	0.00	0.06
52	CUET2U	Guadalupe	21.79	0.79	50.65	1.11	5.30	0.23	1.97	17.26	0.87	0.00	0.02
53	CUET2	Guadalupe	29.90	0.71	47.54	0.76	3.34	0.08	3.01	14.33	0.31	0.00	0.01
54	WRST2	Guadalupe	19.49	0.52	58.34	4.88	1.07	0.04	2.38	13.08	0.16	0.00	0.03
55	SCDT2	Guadalupe	17.33	0.55	53.06	0.09	1.44	0.09	0.54	26.79	0.08	0.00	0.03
56	CKDT2	Guadalupe	19.91	0.37	45.49	0.10	0.55	0.32	0.90	28.39	3.50	0.00	0.46
57	VICT2U	Guadalupe	14.09	0.98	40.65	0.44	2.38	0.15	3.38	36.95	0.86	0.00	0.11
58	VICT2	Guadalupe	12.12	0.37	56.42	1.33	3.58	0.22	11.10	12.87	1.55	0.00	0.45
59	DUPT2	Guadalupe	16.48	0.44	42.85	5.50	10.31	1.34	9.13	10.35	3.15	0.00	0.46
60	LLET2	Brazos	45.41	26.27	4.42	6.38	0.24	0.00	2.28	13.28	1.71	0.00	0.01
61	CPKT2	Brazos	32.90	27.98	11.15	9.94	0.30	0.01	0.67	16.32	0.71	0.00	0.03
62	DSBT2	Brazos	33.99	26.43	12.80	10.86	0.29	0.00	0.51	14.68	0.44	0.00	0.01
63	DLLT2	Brazos	34.09	28.92	12.43	6.29	0.61	0.00	0.56	15.80	1.31	0.00	0.00
64	PCTT2	Brazos	26.17	33.93	8.25	9.22	1.02	0.06	0.77	16.73	3.79	0.00	0.05
65	HMLT2	Brazos	41.59	33.33	3.17	6.09	0.51	0.02	1.01	13.75	0.48	0.00	0.06

ID	Basin	Forecast group	Shrub/Scrub	Herbaceous	Hay/Pasture	Cultivated Crops	Woody Wetlands	Emergent Herbaceous Wetlands	Developed	Forest	Open Water	Perennial Snow/Ice	Barren Land
66	FHCT2	Brazos	16.89	37.74	0.00	0.00	0.03	0.00	0.01	44.94	0.09	0.00	0.31
67	FCCT2U	Brazos	32.70	47.53	0.08	0.87	0.66	0.03	1.09	16.70	0.14	0.00	0.19
68	FCCT2	Brazos	24.96	53.43	0.00	0.00	1.06	0.07	2.21	17.53	0.18	0.00	0.55
69	FHGT2	Brazos	21.34	28.92	0.00	0.00	0.65	0.01	32.44	16.14	0.07	0.00	0.43
70	FHHT2U	Brazos	27.42	22.54	0.00	0.01	0.47	0.01	32.03	16.85	0.52	0.00	0.16
71	FHHT2	Brazos	19.85	41.98	0.00	0.00	1.55	0.01	25.48	9.29	0.50	0.00	1.34
72	MCGT2	Brazos	0.24	61.49	1.57	23.97	1.96	0.02	0.48	9.93	0.16	0.00	0.18
73	HICT2	Brazos	24.46	43.02	7.77	4.01	1.20	0.02	2.74	15.95	0.72	0.00	0.11
74	CTNT2	Brazos	4.47	67.30	1.22	2.25	1.24	0.02	1.00	22.01	0.46	0.00	0.03
75	VMAT2	Brazos	2.24	57.13	1.80	5.17	1.43	0.04	1.03	30.55	0.25	0.00	0.36
76	ACTT2	Brazos	0.23	41.23	7.37	23.47	3.43	0.23	6.93	11.08	5.74	0.00	0.29
77	CRFT2	Brazos	0.18	69.30	1.15	16.88	1.49	0.01	0.26	10.47	0.26	0.00	0.00
79	LKCT2	Colorado	65.68	13.45	0.00	13.14	0.07	0.09	0.74	5.59	1.22	0.00	0.01
80	HORT2	Colorado	82.71	7.29	0.00	5.27	0.12	0.19	0.73	2.74	0.84	0.00	0.11
81	HDCT2	Colorado	69.17	14.38	0.03	11.08	0.26	0.02	0.62	4.10	0.32	0.00	0.02
82	CJNT2	Colorado	64.99	18.28	0.04	11.68	0.24	0.01	0.25	3.82	0.68	0.00	0.00
83	LBWT2U	Colorado	52.82	16.74	0.50	16.00	0.54	0.01	2.12	10.59	0.67	0.00	0.01
84	CUTT2	Colorado	58.49	19.19	0.78	11.22	0.43	0.01	0.71	8.70	0.43	0.00	0.04
85	LBWT2	Colorado	50.39	19.86	5.88	8.85	0.32	0.05	1.30	9.30	4.03	0.00	0.02
86	BWDT2	Colorado	57.83	8.00	3.62	10.08	0.17	0.00	1.09	18.53	0.68	0.00	0.02
87	SKMT2	Nueces	33.62	0.21	38.25	15.22	1.76	0.07	5.29	5.41	0.04	0.00	0.14
88	MIOT2	Nueces	53.57	0.25	34.82	0.87	2.19	0.11	2.87	4.99	0.03	0.00	0.29
89	REFT2	Nueces	48.72	0.37	31.53	2.71	1.94	0.23	0.71	13.55	0.05	0.00	0.18

2.2. Elevation & Slope

Elevation data was obtained from the NHDPlusV2 database which uses the 10-meter resolution National Elevation Dataset. Maximum elevation in the study domain is approximately 2,100 feet in the Brazos forecast group and 1,200 feet in the Guadalupe forecast group (Table 2-2). The Colorado forecast group is slightly higher at a maximum elevation of 2,400 feet, while the Nueces is much lower at 550 feet. With minimal topographic relief, some precipitation in the study region is a result of frontal systems and large synoptic weather patterns with significant coastal influence. The Balcones Escarpment does induce some orographic lift in the area—the Guadalupe and the lower Colorado basins are particularly impacted by such uplift, as these areas lie in the flash flood valley. Basin elevation, and more importantly, basin slope is an important factor in determining the lag of upstream routed flows in the LAG/K model, although in practice, visual inspection of the hydrograph is more informative for streamflow routing calibrations.

Table 2-2. Elevation and slope statistics for the study domain

ID	Basin	Forecast Group	Min Elev (ft)	Max Elev (ft)	Mean Elev (ft)	Mean Slope (%)
1	GAST2	Brazos	731.36	1372.87	1038.67	3.85
2	BNLT2	Brazos	493.57	1043.14	805.44	3.61
3	LRIT2	Brazos	408.83	802.62	591.80	3.38
4	PICT2	Brazos	752.85	1775.82	1251.25	4.54
5	KEMT2	Brazos	834.58	1762.86	1321.63	4.75
6	DNGT2	Brazos	673.88	1566.17	1051.13	5.13
7	SDOT2	Brazos	558.53	1099.97	853.42	3.35
8	BYBT2	Brazos	766.60	1144.88	964.18	2.56
9	BCIT2	Brazos	698.13	1109.61	894.04	2.79
10	BKFT2	Brazos	652.92	1025.26	824.69	2.41
11	BSYT2	Brazos	520.41	994.09	723.66	2.62
12	BKTT2	Brazos	455.31	670.87	556.83	1.90
13	RKDT2	Brazos	340.26	782.97	513.33	2.24
14	RSAT2	Brazos	330.64	632.12	472.70	1.99
15	RLRT2	Brazos	310.99	912.60	524.91	2.40
16	CMNT2	Brazos	281.20	652.69	416.48	2.97
17	BECT2	Brazos	305.09	853.67	520.64	2.29
18	BBZT2	Brazos	200.43	657.91	361.20	3.21
19	WBAT2	Brazos	356.20	964.11	561.57	2.74
20	HIBT2	Brazos	281.63	874.51	486.42	2.20
21	BSAT2	Brazos	429.49	685.07	544.84	1.76
22	GRST2	Brazos	391.47	649.84	495.02	2.21
23	EAST2	Brazos	279.86	589.76	424.79	2.68
24	NGET2	Brazos	244.59	617.85	411.30	3.60
25	BRYT2	Brazos	228.05	570.90	338.03	2.24
26	CLGT2	Brazos	184.94	550.23	318.11	2.12
27	HPDT2U	Brazos	151.80	461.45	264.55	2.54
28	DMYT2	Brazos	300.10	757.91	466.34	3.04
29	DEYT2	Brazos	292.62	635.76	435.26	3.30
30	LYNT2	Brazos	230.12	633.83	381.85	2.84
31	HBRT2	Brazos	232.71	643.34	412.19	1.87
32	HLBT2	Brazos	249.18	605.74	394.28	2.66
33	WBZT2U	Brazos	216.67	550.98	336.52	2.68
34	WBZT2	Brazos	142.88	508.56	262.50	2.26
35	HPDT2	Brazos	125.07	521.65	266.61	3.48
36	BEMT2	Brazos	127.85	561.02	313.18	3.90
37	BAWT2	Brazos	100.46	421.16	210.89	2.33
38	RMOT2	Brazos	44.98	265.81	134.31	0.92

ID	Basin	Forecast Group	Min Elev (ft)	Max Elev (ft)	Mean Elev (ft)	Mean Slope (%)
39	SLNT2	Brazos	44.98	92.16	73.59	1.23
40	ROST2	Brazos	0.20	129.99	75.05	0.53
41	WCBT2	Brazos	0.03	142.91	48.75	0.65
42	LCPT2	Guadalupe	440.29	890.03	622.90	3.07
43	LULT2	Guadalupe	321.49	702.36	498.96	2.55
44	LLGT2	Guadalupe	325.43	1121.36	554.07	2.96
45	GNLT2	Guadalupe	241.77	664.67	394.21	3.07
46	PEWT2	Guadalupe	300.07	592.45	434.73	2.87
47	DLWT2	Guadalupe	219.72	736.06	390.19	2.79
48	GDHT2	Guadalupe	181.17	552.33	301.43	2.77
49	WHOT2U	Guadalupe	246.85	745.41	423.02	2.57
50	WHOT2M	Guadalupe	193.86	480.38	300.15	2.01
51	WHOT2	Guadalupe	184.32	581.10	326.59	2.43
52	CUET2U	Guadalupe	141.67	443.37	271.08	3.12
53	CUET2	Guadalupe	131.59	551.87	297.62	3.35
54	WRST2	Guadalupe	164.37	580.87	342.50	2.34
55	SCDT2	Guadalupe	102.59	403.31	241.42	2.06
56	CKDT2	Guadalupe	85.53	305.45	168.11	1.67
57	VICT2U	Guadalupe	73.06	373.46	207.37	2.83
58	VICT2	Guadalupe	39.96	236.15	130.44	1.59
59	DUPT2	Guadalupe	0.00	190.91	80.50	1.19
60	LLET2	Brazos	1369.16	2096.03	1584.20	2.79
61	CPKT2	Brazos	1240.45	1974.44	1520.64	2.98
62	DSBT2	Brazos	1219.62	2097.47	1536.25	2.47
63	DLLT2	Brazos	1218.04	1693.83	1436.55	2.75
64	PCTT2	Brazos	1138.68	1961.29	1374.01	3.46
65	HMLT2	Brazos	977.49	1864.96	1329.32	4.02
66	FHCT2	Brazos	863.22	1201.94	1045.81	5.50
67	FCCT2U	Brazos	704.76	1401.35	1007.37	4.88
68	FCCT2	Brazos	669.23	1185.40	884.70	5.48
69	FHGT2	Brazos	858.60	1288.02	1052.05	5.25
70	FHHT2U	Brazos	836.29	1225.62	1010.43	3.81
71	FHHT2	Brazos	726.31	1235.40	929.22	4.72
72	MCGT2	Brazos	532.02	1201.80	863.58	2.86
73	HICT2	Brazos	984.51	1623.33	1316.04	3.24
74	CTNT2	Brazos	610.17	1397.15	1033.92	4.51
75	VMAT2	Brazos	527.82	1286.15	889.29	5.20
76	ACTT2	Brazos	448.43	865.42	611.58	2.96
77	CRFT2	Brazos	564.21	1221.29	912.53	2.13
79	LKCT2	Colorado	1672.74	2366.04	1972.20	3.74
80	HORT2	Colorado	1900.26	2256.50	2053.47	3.79
81	HDCT2	Colorado	1678.87	2244.16	1906.62	3.00
82	CJNT2	Colorado	1475.16	2141.73	1721.06	3.50
83	LBWT2U	Colorado	1423.82	1845.54	1588.08	3.04
84	CUTT2	Colorado	1453.94	2326.38	1825.21	3.27
85	LBWT2	Colorado	1366.67	1977.59	1580.13	2.85
86	BWDT2	Colorado	1319.23	1973.06	1552.93	3.96
87	SKMT2	Nueces	75.03	439.44	241.32	1.67
88	MIOT2	Nueces	167.26	541.40	367.96	2.83
89	REFT2	Nueces	0.82	453.05	170.80	1.38

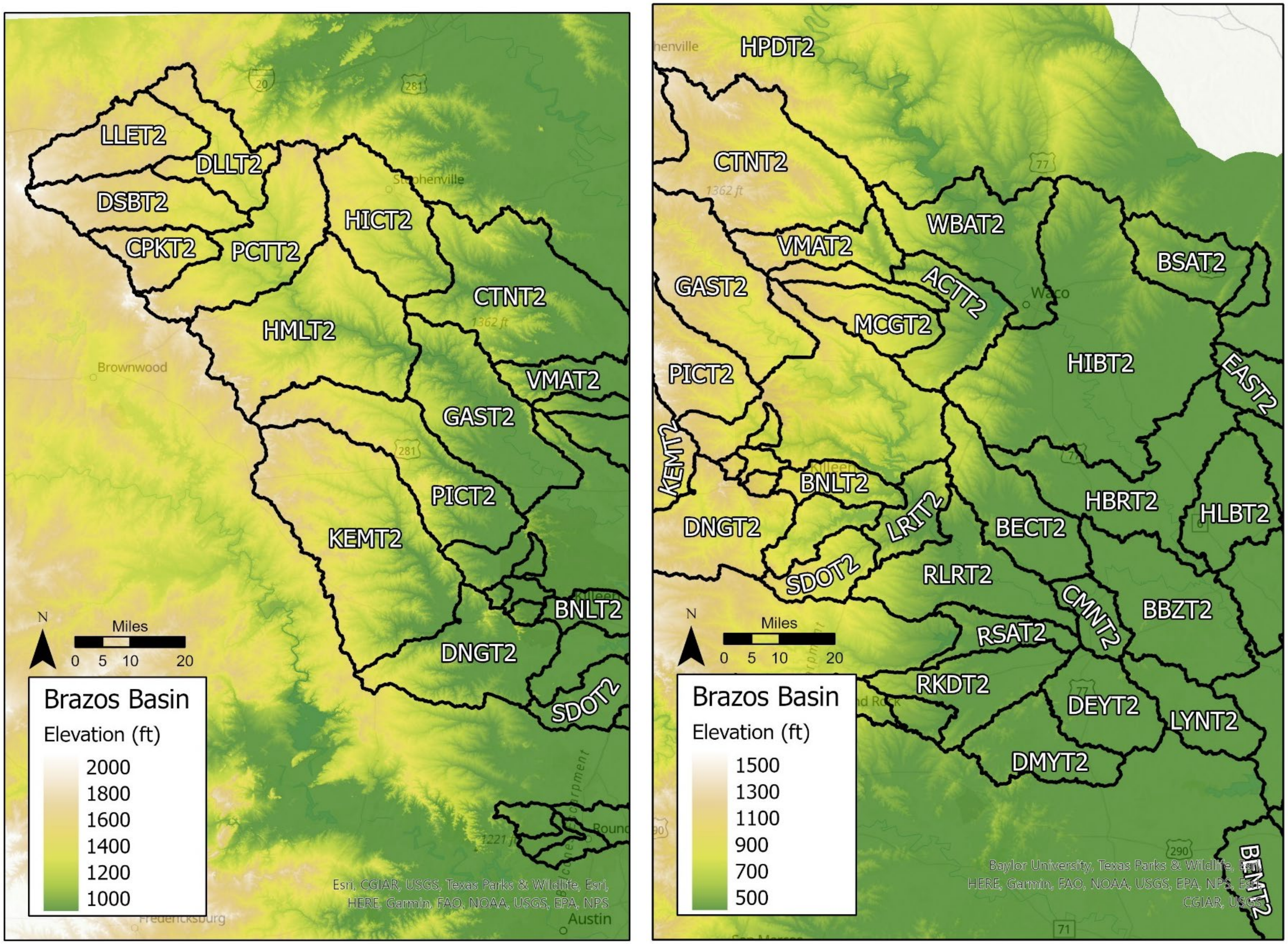


Figure 2-6. Elevation map of the calibration domain for the upper (left) and middle (right) Brazos forecast group.

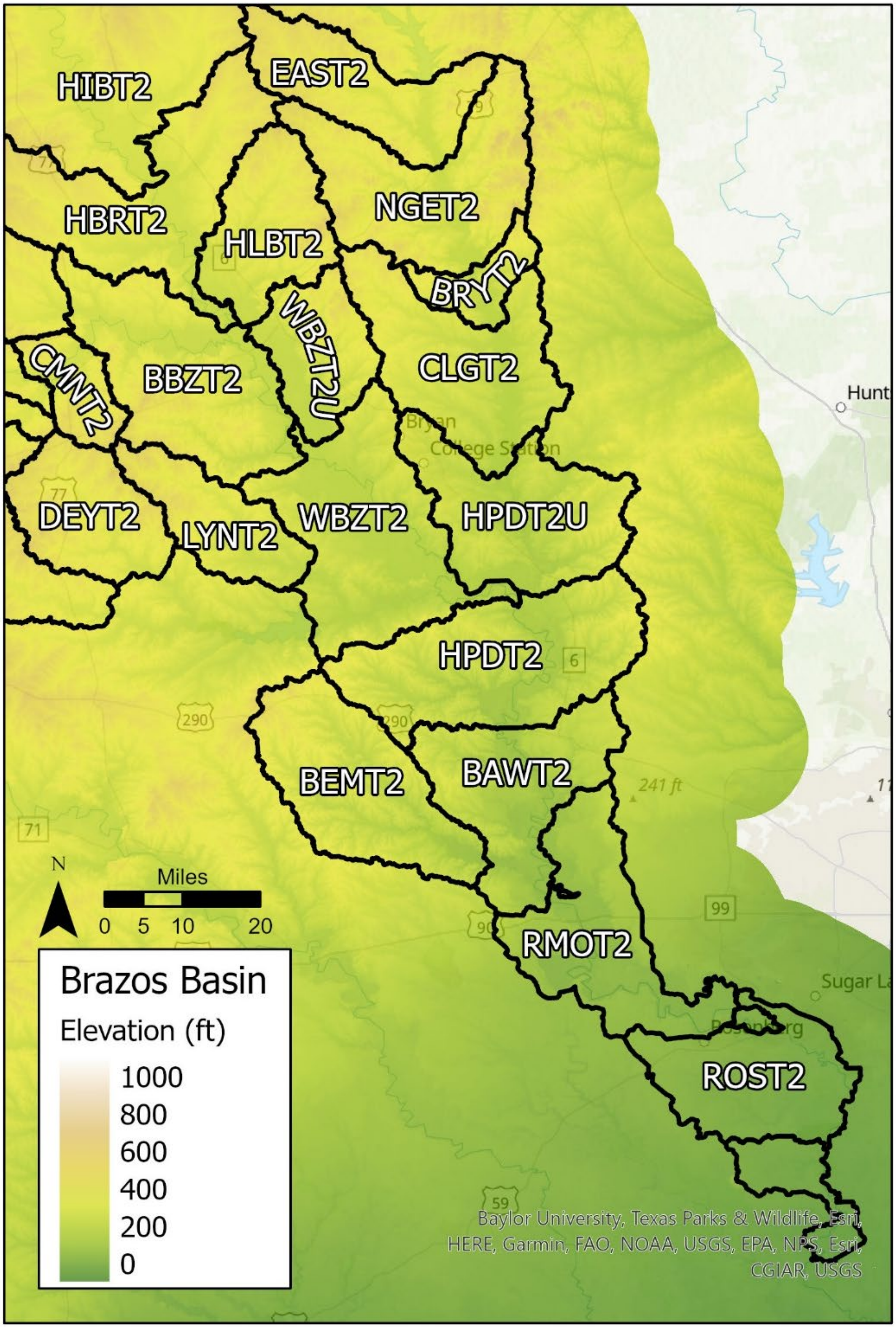


Figure 2-7. Elevation map of the calibration domain for the lower Brazos forecast group.

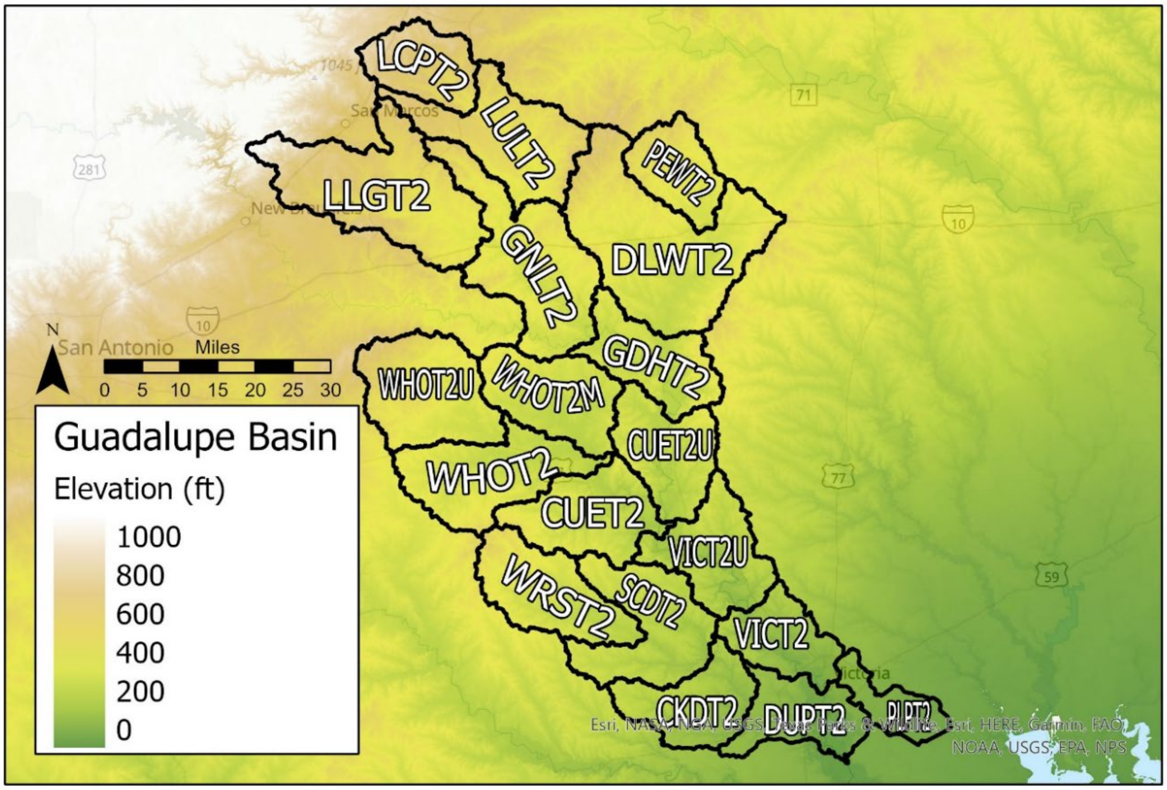


Figure 2-8. Elevation map of the calibration domain for the Guadalupe forecast group.

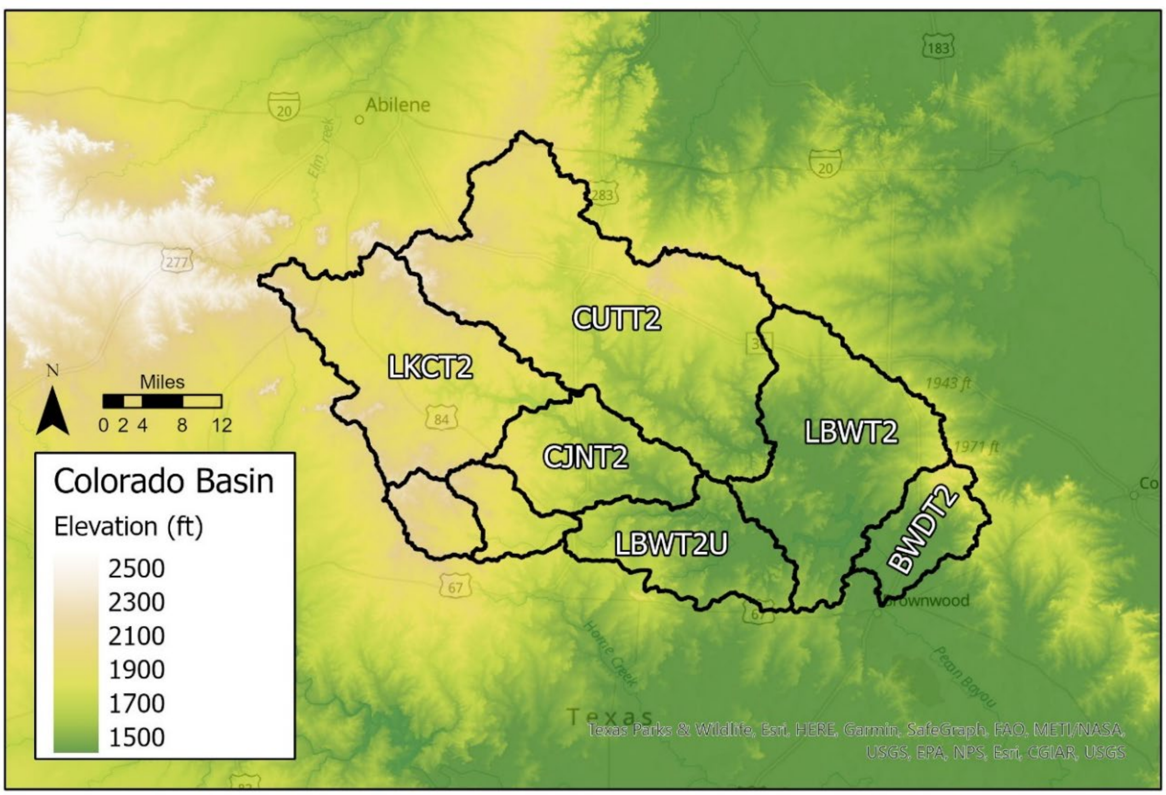


Figure 2-9. Elevation map of the calibration domain for the Colorado forecast group.

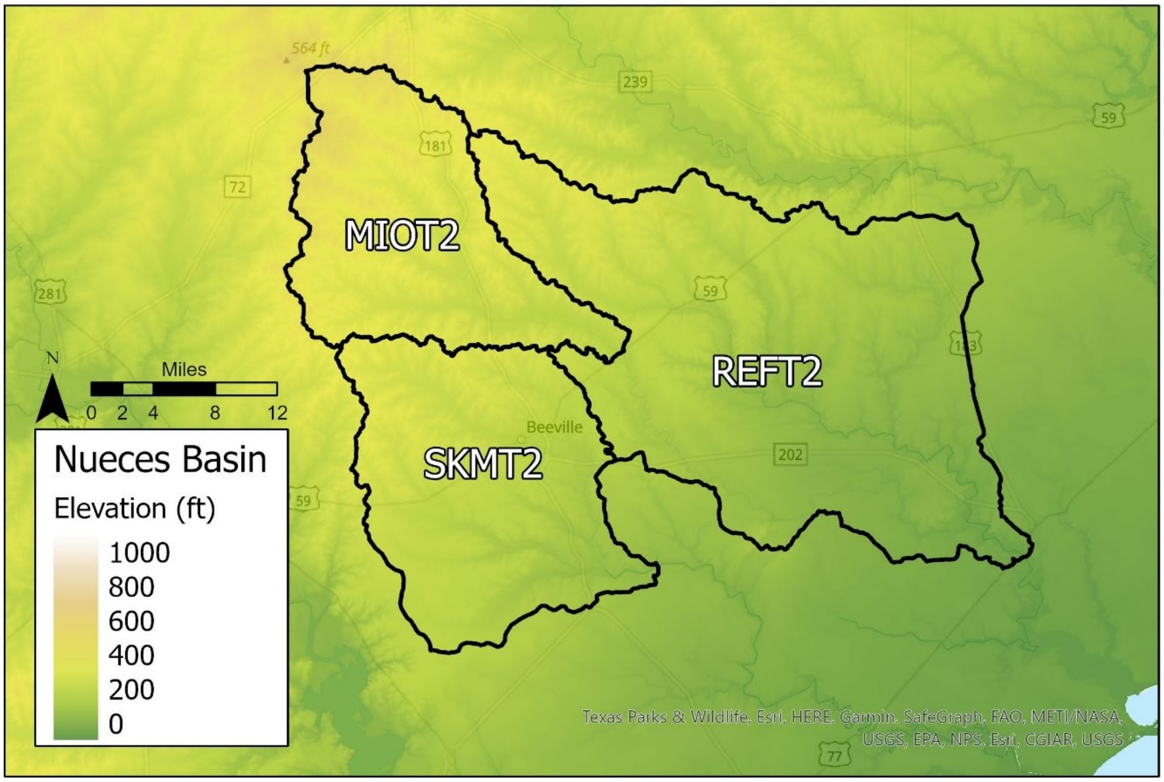


Figure 2-10. Elevation map of the calibration domain for the Nueces forecast group.

2.3. Soil Classes

The gridded Soil Survey Geographic (gSSURGO) database is a product of the U.S. Department of Agriculture-Natural Resource Conservation Service (USDA-NRCS) and contains the most detailed level of soil geographic data developed by the National Cooperative Soil Survey (10m grid resolution). Together with the NLCD, the gSSURGO database provides a basis for understanding the soil characteristics of the study region and the subsequent impact to the local hydrology. Soils are classified into four main groups based on the soil makeup and resulting runoff potential, including Type A, Type B, Type C, and Type D (Table 2-3), where Type A (sand) has the lowest runoff potential and Type D (clay loam) has the highest runoff potential.

In southeastern and central Texas, bands of similar soil classes generally trend from northeast to southwest, closely following the underlying geology of the state (Figure 2-12 to Figure 2-16). In the Upper Brazos, soil types are generally dominated by Type C/Sandy Clay Loam (Figure 2-11), transitioning into a more clay-dominated Type D/Clay Loam soil profile into the Middle and Lower Brazos (Figure 2-12 and Figure 2-13); basins closest to the coast have the largest percentage of clay soils (>80%) and very high runoff potential. The soil formation running from the Yegua Creek to upper Navasota River has a much lower runoff potential than other nearby areas, consisting of upwards of 25-30% of Type A/Sand. In contrast, the Guadalupe is generally more clay-dominated (Type D/Clay Loam) in the headwaters before transitioning into a more mixed and better drained Type A/Sand and Type C/Sandy Clay Loam soil profile in the Lower Guadalupe (Figure 2-14). Soil types are, however, extremely heterogeneous across the study domain, and even within an individual basin. Table 2-4 summarizes the soil coverage characteristics for each basin expressed as a percentage of the total basin area.

Table 2-3. USDA-NRCS soil groups and relative runoff potential.

Soil Type	Description	Relative Runoff Potential
A	Sand, loamy sand, or sandy loam	Low
B	Silt loam or loam	Moderate
C	Sandy clay loam	High
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay	Very High
A/D	Low runoff potential when drained and high runoff potential when undrained	Low-High
B/D	Moderately low runoff potential when drained and high runoff potential when undrained	Moderate-High
C/D	Moderately high runoff potential when drained and high runoff potential when undrained	High

Table 2-4. Soil area coverage characteristics for each basin (% of basin area) in the study domain.

ID	Basin	Forecast Group	A	B	C	D	A/D	B/D	C/D
1	GAST2	Brazos	0.61	17.21	43.66	38.52	0.00	0.00	0.00
2	BNLT2	Brazos	0.00	9.83	26.96	63.20	0.00	0.00	0.00
3	LRIT2	Brazos	0.00	15.24	20.09	64.67	0.00	0.00	0.00
4	PICT2	Brazos	0.00	14.78	36.70	48.52	0.00	0.00	0.00
5	KEMT2	Brazos	0.29	9.41	31.76	58.53	0.00	0.00	0.00
6	DNGT2	Brazos	0.36	7.69	17.12	74.83	0.00	0.00	0.00
7	SDOT2	Brazos	0.00	1.52	6.24	92.24	0.00	0.00	0.00
8	BYBT2	Brazos	0.00	4.07	0.25	95.68	0.00	0.00	0.00
9	BCIT2	Brazos	0.00	4.68	0.00	95.32	0.00	0.00	0.00
10	BKFT2	Brazos	0.00	3.26	1.75	94.99	0.00	0.00	0.00
11	BSYT2	Brazos	0.00	7.59	3.41	88.99	0.00	0.00	0.00
12	BKTT2	Brazos	0.00	5.88	0.00	94.12	0.00	0.00	0.00
13	RKDT2	Brazos	1.99	2.19	13.65	82.16	0.00	0.00	0.00
14	RSAT2	Brazos	0.86	4.59	17.95	76.60	0.00	0.00	0.00
15	RLRT2	Brazos	0.01	4.15	16.32	79.52	0.00	0.00	0.00
16	CMNT2	Brazos	9.59	5.96	24.72	59.73	0.00	0.00	0.00
17	BECT2	Brazos	0.00	0.49	6.19	93.32	0.00	0.00	0.00
18	BBZT2	Brazos	22.76	10.94	31.77	34.39	0.15	0.00	0.00
19	WBAT2	Brazos	2.96	17.87	19.19	59.98	0.00	0.00	0.00
20	HIBT2	Brazos	2.85	10.80	7.92	78.44	0.00	0.00	0.00
21	BSAT2	Brazos	0.01	8.25	5.72	86.02	0.00	0.00	0.00
22	GRST2	Brazos	1.83	18.82	18.64	60.72	0.00	0.00	0.00
23	EAST2	Brazos	11.94	24.72	8.39	52.70	1.24	1.01	0.00
24	NGET2	Brazos	29.22	24.00	15.87	26.98	3.06	0.78	0.09
25	BRYT2	Brazos	9.88	10.69	22.24	53.10	0.71	0.92	2.46
26	CLGT2	Brazos	10.89	6.28	17.69	61.83	0.05	2.60	0.66
27	HPDT2U	Brazos	6.00	5.14	13.10	70.86	1.19	2.16	1.55
28	DMYT2	Brazos	27.83	16.12	16.57	39.48	0.00	0.00	0.00
29	DEYT2	Brazos	28.26	19.92	26.27	25.22	0.33	0.00	0.00
30	LYNT2	Brazos	26.57	7.87	19.63	45.65	0.28	0.00	0.00
31	HBRT2	Brazos	4.97	12.01	6.43	76.58	0.00	0.00	0.00
32	HLBT2	Brazos	17.88	19.36	13.59	49.14	0.02	0.00	0.00
33	WBZT2U	Brazos	21.28	25.20	13.38	40.11	0.02	0.00	0.00
34	WBZT2	Brazos	5.99	10.90	10.59	72.49	0.00	0.03	0.00
35	HPDT2	Brazos	12.52	19.13	14.15	51.86	0.37	0.71	1.27
36	BEMT2	Brazos	12.82	16.03	11.43	58.92	0.24	0.54	0.02
37	BAWT2	Brazos	17.29	18.53	11.76	41.82	2.05	1.93	6.62
38	RMOT2	Brazos	2.35	15.65	16.37	54.58	0.03	0.62	10.40

ID	Basin	Forecast Group	A	B	C	D	A/D	B/D	C/D
39	SLNT2	Brazos	1.02	35.63	6.05	57.31	0.00	0.00	0.00
40	ROST2	Brazos	0.03	6.14	1.64	91.44	0.00	0.00	0.75
41	WCBT2	Brazos	0.00	8.98	0.79	88.82	0.00	0.00	1.40
42	LCPT2	Guadalupe	0.00	3.76	4.81	91.43	0.00	0.00	0.00
43	LULT2	Guadalupe	6.52	10.30	11.48	71.70	0.00	0.00	0.00
44	LLGT2	Guadalupe	4.40	6.27	7.37	81.96	0.00	0.00	0.00
45	GNLT2	Guadalupe	9.18	20.81	19.51	50.50	0.00	0.00	0.00
46	PEWT2	Guadalupe	26.27	6.17	16.90	50.66	0.00	0.00	0.00
47	DLWT2	Guadalupe	12.94	11.38	19.18	56.50	0.00	0.00	0.00
48	GDHT2	Guadalupe	3.90	20.56	16.50	59.04	0.00	0.00	0.00
49	WHOT2U	Guadalupe	28.96	8.31	25.18	37.55	0.00	0.00	0.00
50	WHOT2M	Guadalupe	2.16	10.12	10.28	77.44	0.00	0.00	0.00
51	WHOT2	Guadalupe	3.04	9.05	38.05	49.86	0.00	0.00	0.00
52	CUET2U	Guadalupe	25.09	25.27	5.06	44.58	0.00	0.00	0.00
53	CUET2	Guadalupe	31.51	15.87	25.54	27.08	0.00	0.00	0.00
54	WRST2	Guadalupe	21.52	19.93	36.76	21.79	0.00	0.00	0.00
55	SCDT2	Guadalupe	17.53	16.37	48.87	15.83	1.40	0.00	0.00
56	CKDT2	Guadalupe	3.53	8.34	7.33	71.52	4.94	0.00	4.34
57	VICT2U	Guadalupe	48.08	18.59	12.15	20.85	0.00	0.00	0.32
58	VICT2	Guadalupe	9.11	20.08	8.68	37.13	1.42	0.00	23.59
59	DUPT2	Guadalupe	3.00	19.26	0.25	55.65	4.82	0.00	17.02
60	LLET2	Brazos	12.12	6.54	58.12	23.22	0.00	0.00	0.00
61	CPKT2	Brazos	22.35	16.78	45.45	15.42	0.00	0.00	0.00
62	DSBT2	Brazos	20.76	11.26	47.31	20.67	0.00	0.00	0.00
63	DLLT2	Brazos	17.78	7.01	57.44	17.78	0.00	0.00	0.00
64	PCTT2	Brazos	15.25	21.11	44.25	19.39	0.00	0.00	0.00
65	HMLT2	Brazos	5.52	18.69	36.82	38.98	0.00	0.00	0.00
66	FHCT2	Brazos	0.00	0.21	15.74	84.05	0.00	0.00	0.00
67	FCCT2U	Brazos	0.00	10.41	37.22	52.37	0.00	0.00	0.00
68	FCCT2	Brazos	0.00	14.59	31.24	54.17	0.00	0.00	0.00
69	FHGT2	Brazos	0.00	2.73	46.72	50.55	0.00	0.00	0.00
70	FHHT2U	Brazos	0.00	1.29	67.15	31.56	0.00	0.00	0.00
71	FHHT2	Brazos	0.00	6.78	49.43	43.79	0.00	0.00	0.00
72	MCGT2	Brazos	0.00	1.92	38.37	59.71	0.00	0.00	0.00
73	HICT2	Brazos	2.87	16.59	48.45	32.08	0.00	0.00	0.00
74	CTNT2	Brazos	0.05	14.60	27.86	57.49	0.00	0.00	0.00
75	VMAT2	Brazos	0.00	13.33	26.71	59.96	0.00	0.00	0.00
76	ACTT2	Brazos	0.00	8.55	17.55	73.90	0.00	0.00	0.00
77	CRFT2	Brazos	0.00	2.29	36.73	60.98	0.00	0.00	0.00
79	LKCT2	Colorado	0.38	9.57	37.13	52.91	0.00	0.00	0.00
80	HORT2	Colorado	0.00	13.68	31.42	54.89	0.00	0.00	0.00
81	HDCT2	Colorado	0.00	12.46	35.34	52.20	0.00	0.00	0.00
82	CJNT2	Colorado	0.00	2.93	20.56	76.51	0.00	0.00	0.00
83	LBWT2U	Colorado	0.00	1.42	49.94	48.65	0.00	0.00	0.00
84	CUTT2	Colorado	1.58	2.91	43.63	51.88	0.00	0.00	0.00
85	LBWT2	Colorado	7.02	13.69	38.47	40.82	0.00	0.00	0.00
86	BWDT2	Colorado	2.29	15.49	53.00	29.22	0.00	0.00	0.00
87	SKMT2	Nueces	1.64	27.65	44.42	24.79	0.00	0.00	1.50
88	MIOT2	Nueces	1.84	50.74	22.27	22.11	0.00	0.00	3.04
89	REFT2	Nueces	4.88	10.52	73.01	10.59	0.00	0.00	1.01

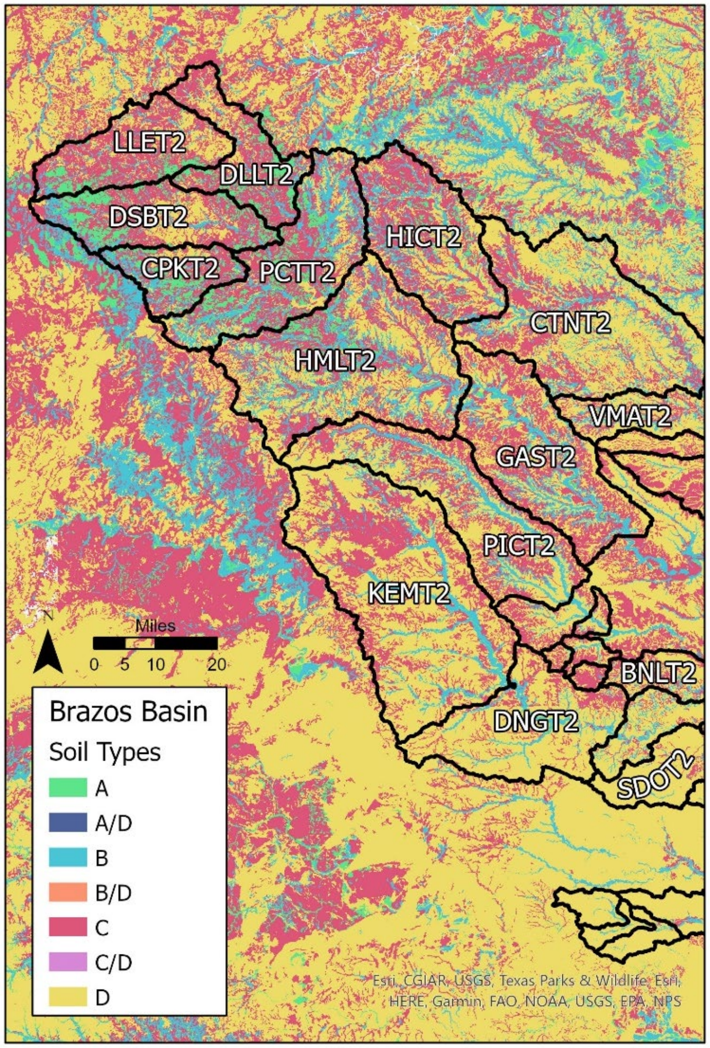


Figure 2-11: Soil classes for the upper Brazos forecast group

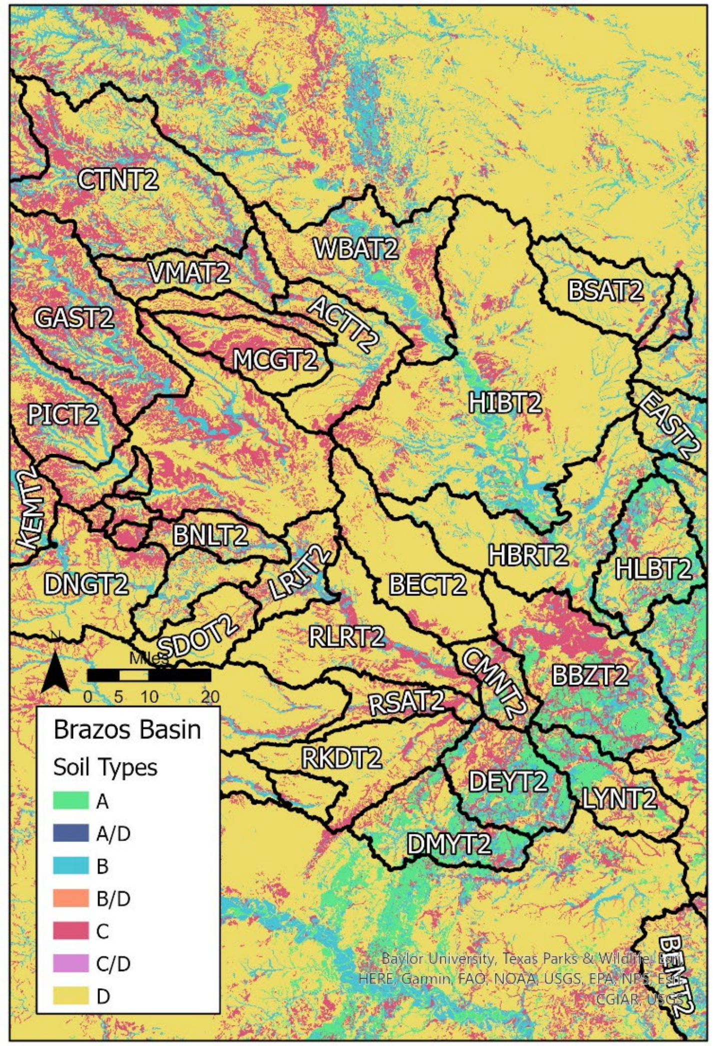


Figure 2-12: Soil classes for the middle Brazos forecast group

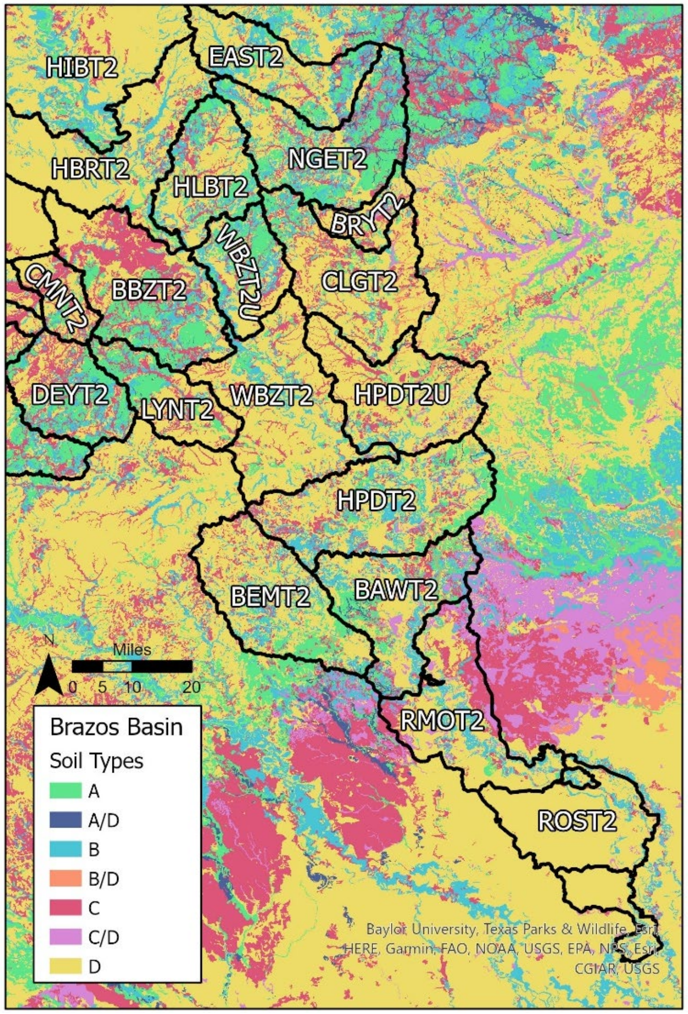


Figure 2-13: Soil classes for the Lower Brazos forecast group

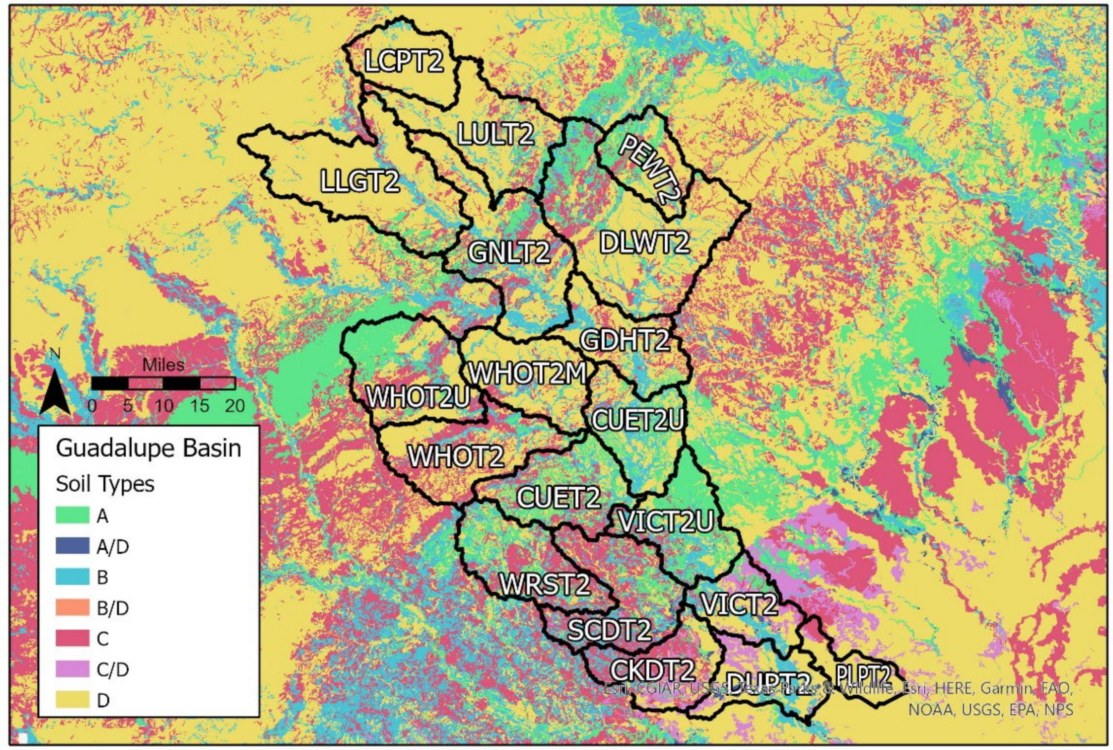


Figure 2-14: Soil classes for the Guadalupe forecast group

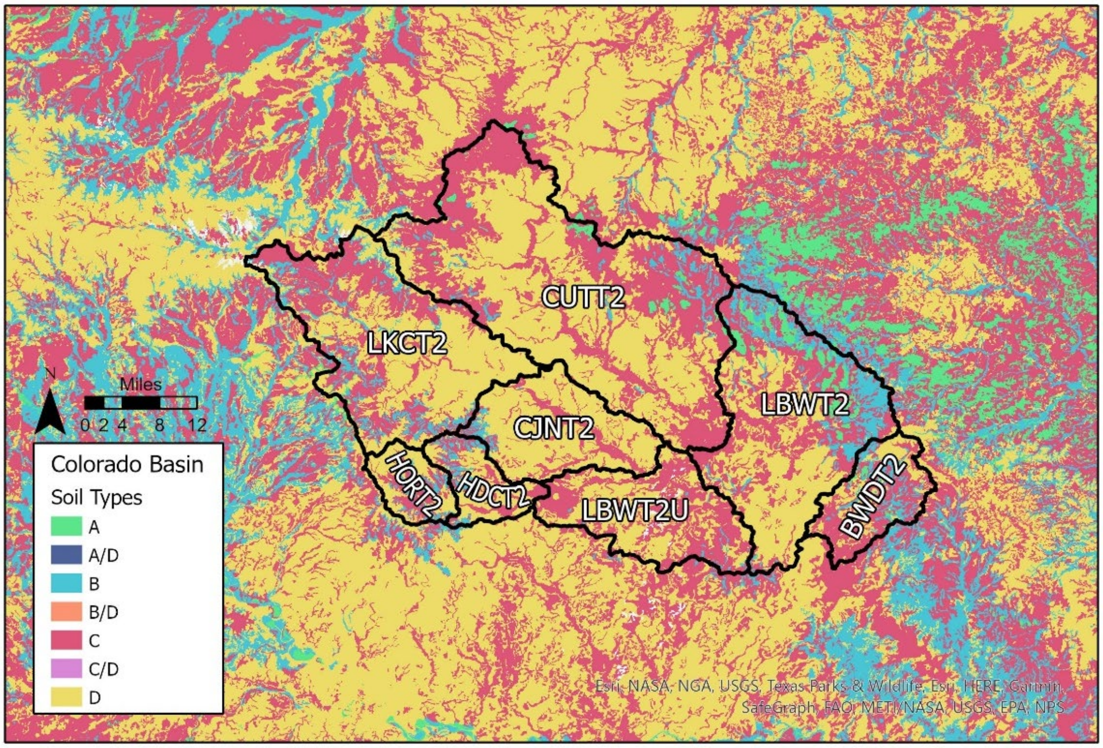


Figure 2-15: Soil classes for the Colorado forecast group

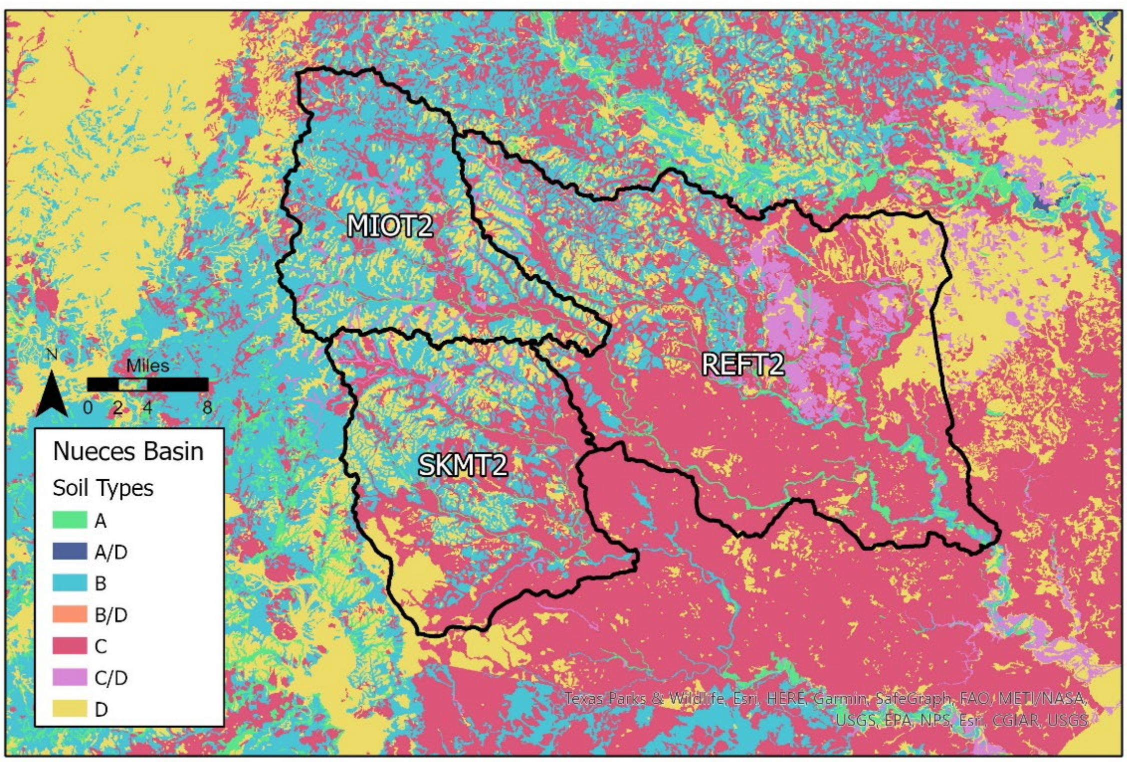


Figure 2-16: Soil classes for the Nueces forecast group

2.4. Groundwater Recharge

Wolock (2003) generated a gridded dataset of mean annual natural groundwater recharge for the continental U.S. using gridded base-flow index values and mean annual runoff values from a 1951–1981 annual runoff contour map. The methods used to generate these grids assume long-term average groundwater recharge is equal to long-term groundwater discharge to streams (i.e., no change in aquifer storage) and the baseflow index values reasonably represent the long-term percentage of groundwater discharge in streamflow. This approach to estimating groundwater recharge may underestimate recharge in areas where irrigation occurs extensively, areas with significant groundwater evapotranspiration (i.e., water table is located high enough for plant roots to be able to consume groundwater), or regions where near-stream groundwater pumping is significant. These factors can have a significant impact on groundwater storage which ultimately reduces the availability for groundwater discharge into nearby streams. Though the spatial resolution of this product is fairly coarse (1-km), this dataset is a helpful tool for determining areas of higher infiltration and ground water percolation in the study domain by identifying areas with higher mean annual recharge (Table 2-5).

On average, mean annual recharge is higher in the Brazos forecast group (1.0 inches/year, inclusive of funding-dependent sites) than in the Guadalupe (0.86 inches/year), as shown in Figure 2-17 to Figure 2-19 (Nueces and Colorado shown in Figure 2-22 and Figure 2-21), though spatial recharge patterns are highly variable, with higher recharge in areas such as the Little River, Brushy Creek, and the Middle Guadalupe. Higher groundwater recharge rates were noted for baseflow calibrations in these regions, particularly in the Middle Guadalupe basins.

Table 2-5. Estimates of annual streamflow loss to groundwater

ID	Basin	Forecast Group	Mean Annual Recharge (mm)	MAPX (mm) 2000–2020	% Recharge as Precipitation
1	GAST2	Brazos	12.46	59.62	21%
2	BNLT2	Brazos	44.06	58.52	75%
3	LRIT2	Brazos	40.80	60.91	67%
4	PICT2	Brazos	11.99	58.20	21%
5	KEMT2	Brazos	12.64	55.99	23%
6	DNGT2	Brazos	36.41	55.74	65%
7	SDOT2	Brazos	44.74	57.45	78%
8	BYBT2	Brazos	41.26	54.73	75%
9	BCIT2	Brazos	39.49	58.12	68%
10	BKFT2	Brazos	38.12	60.22	63%
11	BSYT2	Brazos	43.08	56.21	77%
12	BKTT2	Brazos	41.99	57.16	73%
13	RKDT2	Brazos	39.13	59.01	66%
14	RSAT2	Brazos	37.78	57.69	65%
15	RLRT2	Brazos	39.61	59.16	67%
16	CMNT2	Brazos	31.96	61.98	52%
17	BECT2	Brazos	38.19	61.31	62%
18	BBZT2	Brazos	25.52	64.53	40%
19	WBAT2	Brazos	23.27	62.62	37%
20	HIBT2	Brazos	24.96	63.92	39%
21	BSAT2	Brazos	18.10	68.17	27%
22	GRST2	Brazos	16.66	67.58	25%
23	EAST2	Brazos	14.59	65.95	22%
24	NGET2	Brazos	14.30	66.05	22%
25	BRYT2	Brazos	13.25	69.82	19%
26	CLGT2	Brazos	16.97	70.60	24%
27	HPDT2U	Brazos	20.26	75.60	27%
28	DMYT2	Brazos	26.19	62.53	42%
29	DEYT2	Brazos	24.44	64.03	38%
30	LYNT2	Brazos	19.73	66.52	30%

ID	Basin	Forecast Group	Mean Annual Recharge (mm)	MAPX (mm) 2000–2020	% Recharge as Precipitation
31	HBRT2	Brazos	26.60	63.24	42%
32	HLBT2	Brazos	17.43	63.36	28%
33	WBZT2U	Brazos	16.17	66.32	24%
34	WBZT2	Brazos	17.47	70.62	25%
35	HPDT2	Brazos	18.23	77.59	23%
36	BEMT2	Brazos	12.38	73.83	17%
37	BAWT2	Brazos	14.87	79.28	19%
38	RMOT2	Brazos	23.72	84.71	28%
39	SLNT2	Brazos	45.16	92.59	49%
40	ROST2	Brazos	54.43	88.30	62%
41	WCBT2	Brazos	95.52	86.55	110%
42	LCPT2	Guadalupe	34.18	59.73	57%
43	LULT2	Guadalupe	35.24	57.24	62%
44	LLGT2	Guadalupe	41.97	54.76	77%
45	GNLT2	Guadalupe	37.03	56.53	66%
46	PEWT2	Guadalupe	30.06	64.30	47%
47	DLWT2	Guadalupe	30.16	62.69	48%
48	GDHT2	Guadalupe	21.78	62.30	35%
49	WHOT2U	Guadalupe	18.60	58.34	32%
50	WHOT2M	Guadalupe	19.19	58.83	33%
51	WHOT2	Guadalupe	12.55	57.26	22%
52	CUET2U	Guadalupe	16.88	61.90	27%
53	CUET2	Guadalupe	12.91	57.47	22%
54	WRST2	Guadalupe	9.53	56.31	17%
55	SCDT2	Guadalupe	11.52	60.63	19%
56	CKDT2	Guadalupe	12.72	64.61	20%
57	VICT2U	Guadalupe	14.45	62.10	23%
58	VICT2	Guadalupe	16.89	69.26	24%
59	DUPT2	Guadalupe	17.04	70.19	24%
60	LLET2	Brazos	2.92	51.93	6%
61	CPKT2	Brazos	3.43	0.00	
62	DSBT2	Brazos	3.47	54.21	6%
63	DLLT2	Brazos	2.94	53.12	6%
64	PCTT2	Brazos	4.16	56.14	7%
65	HMLT2	Brazos	6.38	57.57	11%
66	FHCT2	Brazos	25.93	0.00	
67	FCCT2U	Brazos	23.08	0.00	
68	FCCT2	Brazos	31.22	0.00	
69	FHGT2	Brazos	32.11	0.00	
70	FHHT2U	Brazos	41.56	0.00	
71	FHHT2	Brazos	36.35	0.00	
72	MCGT2	Brazos	22.11	61.26	36%
73	HICT2	Brazos	7.38	56.02	13%
74	CTNT2	Brazos	10.38	60.21	17%
75	VMAT2	Brazos	11.91	61.27	19%
76	ACTT2	Brazos	28.52	62.23	46%
77	CRFT2	Brazos	16.77	61.09	27%
79	LKCT2	Colorado	3.78	46.55	8%
80	HORT2	Colorado	4.21	0.00	
81	HDCT2	Colorado	4.66	0.00	
82	CJNT2	Colorado	4.19	0.00	
83	LBWT2U	Colorado	4.33	52.30	8%
84	CUTT2	Colorado	4.25	50.20	8%

ID	Basin	Forecast Group	Mean Annual Recharge (mm)	MAPX (mm) 2000–2020	% Recharge as Precipitation
85	LBWT2	Colorado	3.71	54.22	7%
86	BWDT2	Colorado	3.62	55.02	7%
87	SKMT2	Nueces	2.67	52.27	5%
88	MIOT2	Nueces	4.12	52.17	8%
89	REFT2	Nueces	6.36	57.19	11%

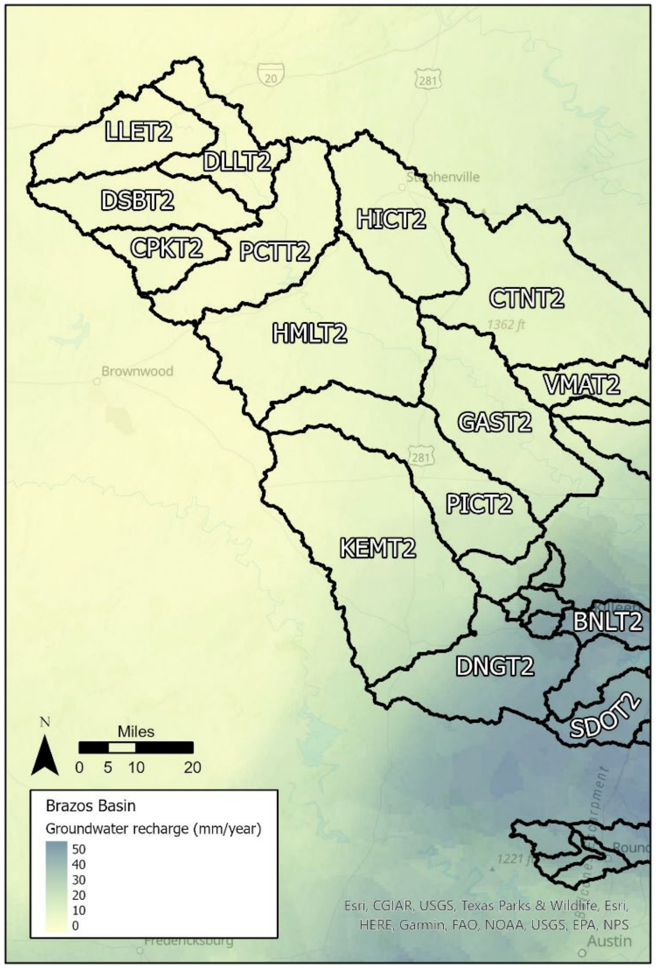


Figure 2-17. Groundwater recharge for the upper Brazos forecast group

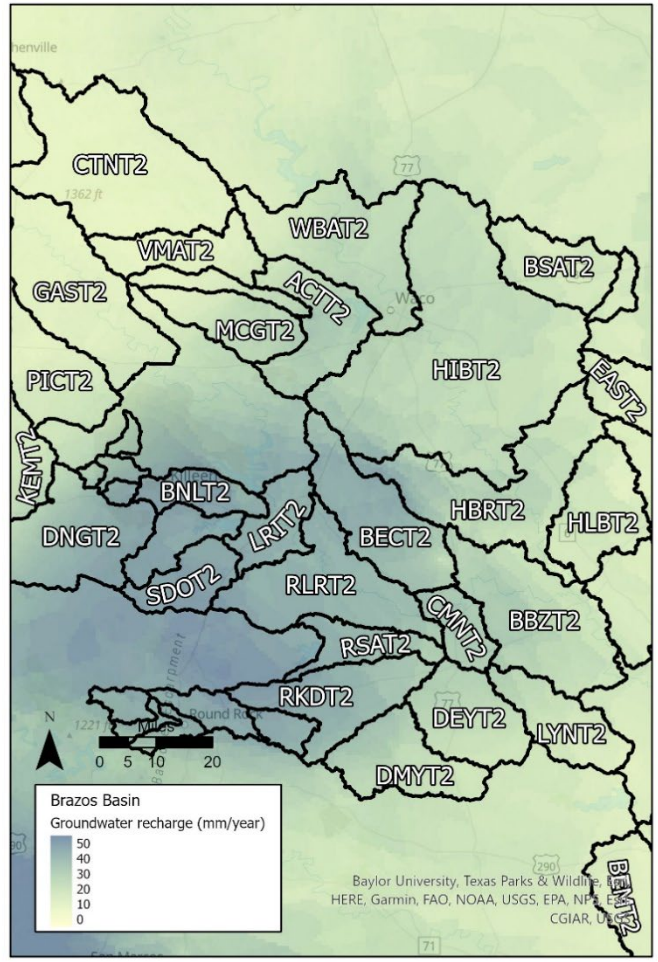


Figure 2-18. Groundwater recharge for the middle Brazos forecast group

Figure 2-20: Groundwater recharge for the lower Brazos forecast group

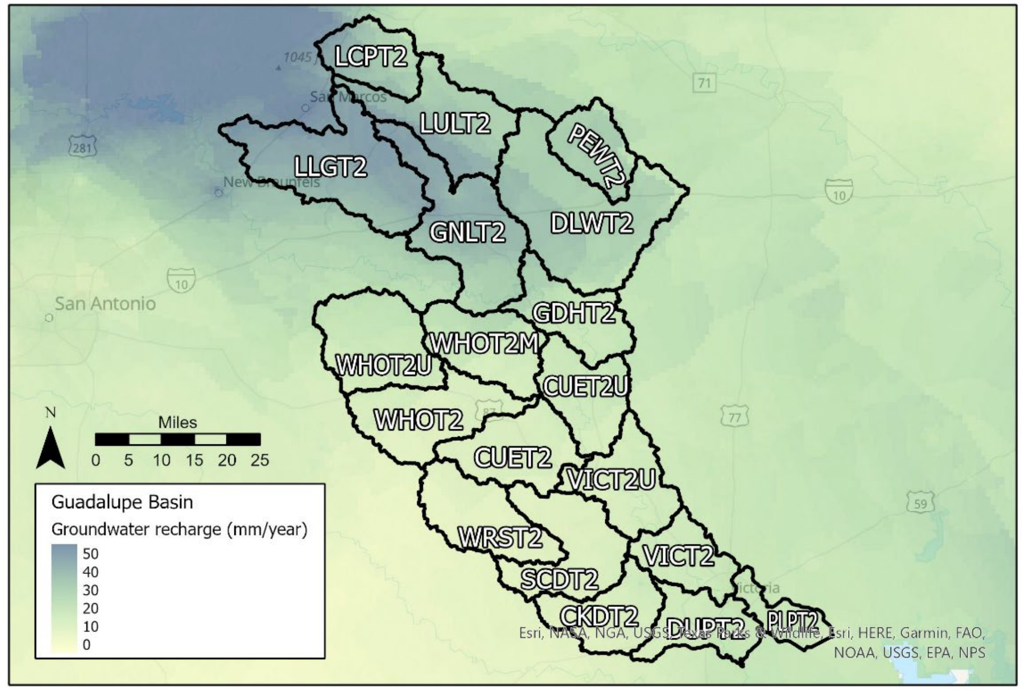


Figure 2-19: Groundwater recharge for the Guadalupe forecast group

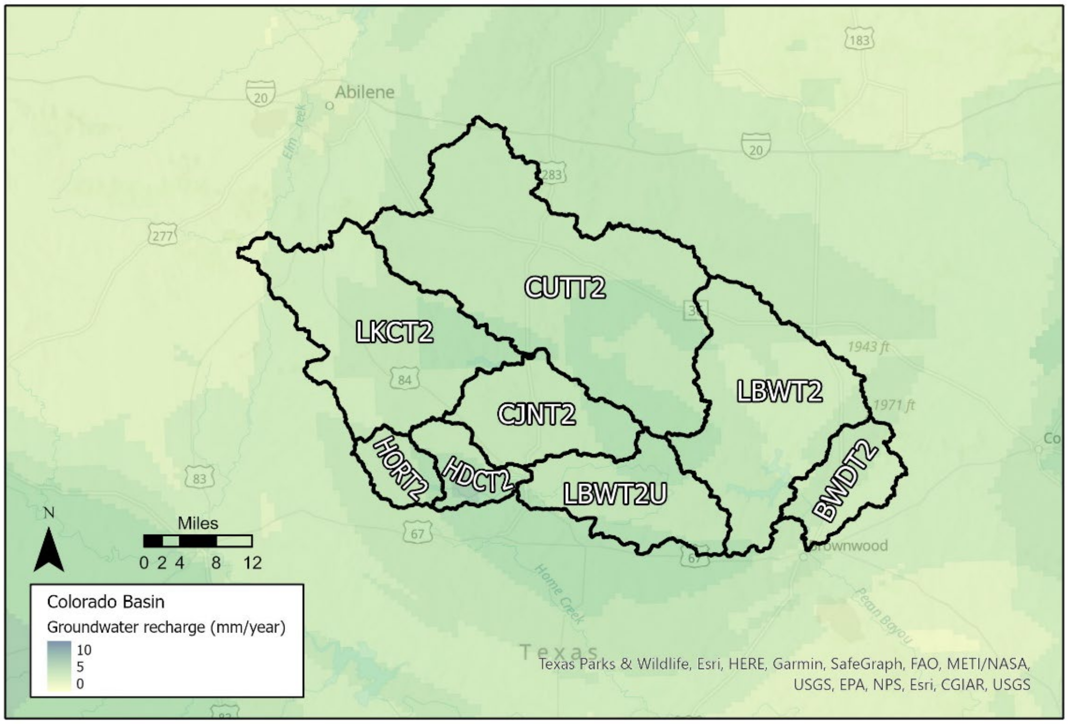


Figure 2-21. Groundwater recharge for the Colorado forecast group

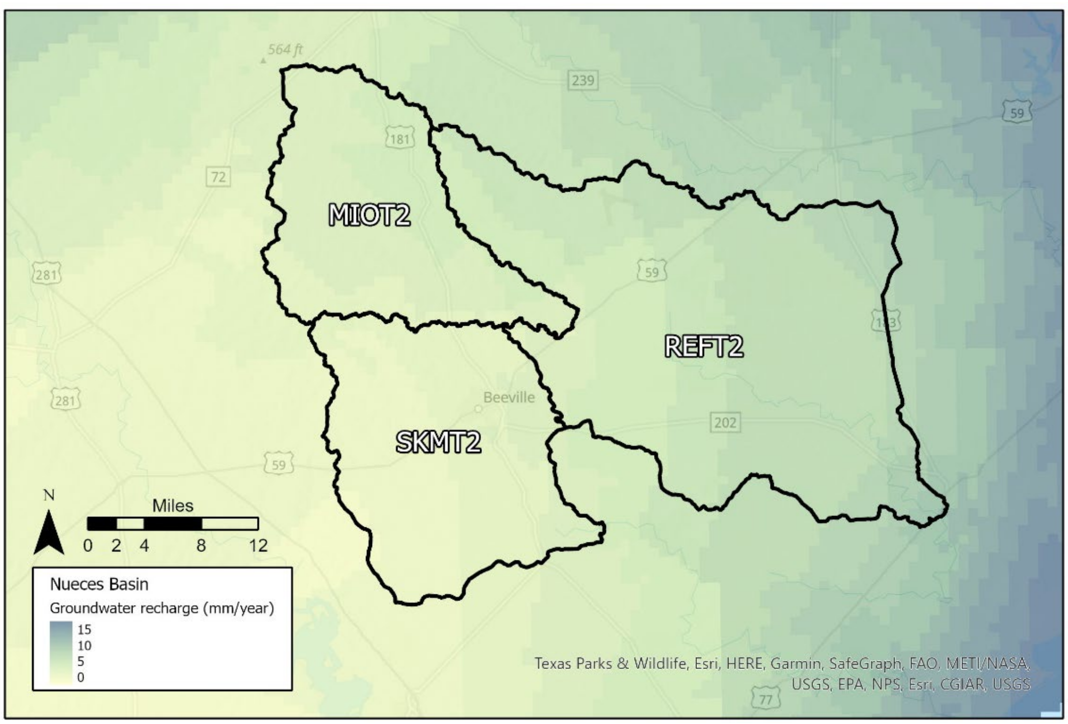


Figure 2-22. Groundwater recharge for the Nueces forecast group

3. WATER BALANCE ANALYSIS

Regional water balance computations are an important part of the hydrologic model calibration process. Biases in model forcing data will cause calibrated model parameters to take on unrealistic values and will reduce the quality of a simulation (Anderson, 2002), while missing information on surface water diversions (or even significant groundwater pumping) may affect the ability of a simulation to re-produce observations. The primary goal of the water balance analysis is to ensure that each subbasin's precipitation, evaporation, and runoff estimates are spatially consistent as well as physically realistic. The water balance analysis determines basins where precipitation or evapotranspiration data may need to be re-evaluated, or areas where potentially unaccounted-for diversions may be significantly affecting the water balance and resulting streamflow simulation. In short, a water balance is an important first check of the inputs to a model and the hydrology of the basin. A summary of the key data products used in this study is provided in Table 3-1. The general water balance equation is:

$$Precipitation = Streamflow + Evapotranspiration + \Delta Storage$$

Table 3-1: Overview of the primary hydrometeorological data products

Product	Metadata	
QME	**Description:**	Daily observed mean daily streamflow
	Source:	USGS
	Date Avail:	Varies by gauge (downloaded all available data 1990–2021)
	Purpose:	Water balance analysis, CHPS calibration benchmark, and ADJUSTQ downstream routing
QIN	**Description:**	Daily observed instantaneous streamflow (5min - 15min)
	Source:	USGS
	Date Avail:	Varies by gauge (downloaded all available data 1990–2021)
	Purpose:	CHPS calibration benchmark, and ADJUSTQ downstream routing
STG	**Description:**	Daily and instantaneous (15min) observed stream stage
	Source:	USGS
	Date Avail:	Varies by gauge (downloaded all available data 1990–2021)
	Purpose:	Converted to flow in CHPS using WGRFC rating curve, Calibration benchmark (where USGS flow no provided), and ADJUSTQ downstream routing
MAPX	**Description:**	Gridded hourly precipitation (aggregated to basin mean timeseries in CHPS)
	Source:	WGRFC
	Date Avail:	1/1/2000 – 10/1/2020
	Purpose:	Water balance analysis, Input to the SAC-SMA model
MAPE	**Description:**	Gridded daily potential evapotranspiration (aggregated to basin mean timeseries in CHPS)
	Source:	WGRFC
	Date Avail:	5/31/2009 – 10/1/2020 (missing much of 2015–2016)
	Purpose:	Water balance analysis, Input to the SAC-SMA model

3.1. Historical Data Record

The water balance analysis and hydrologic model calibration periods are dependent upon two important datasets: 1) the observed streamflow records for the basin outlet, and 2) the model forcing data (i.e., MAPX and MAPE). For both the water balance and subsequent model calibration, a period greater than 10 years with overlapping subbasin time intervals is ideal (Anderson, 2002); however, some of the basins in this calibration task do not have a complete record of observed USGS streamflow data relative to the study period (01-01-2000 to 10-01-2020). In support of the calibration task, the WGRFC provided gridded mean areal precipitation (MAPX) data for the 2000–2020 WY period for the calibration basins. Table 3-2 provides the number of water years for which there was sufficient data to use in the water balance analysis. Because MAPX data begin in 2000, they are often the limiting factor for the calibration and water balance analysis (i.e., USGS data often begin prior to 2000). For efficiency, we performed the water balance analysis for all 89 basins (including funding dependent sites). Table 3-2 also lists the simulation time period configured in CHPS to perform the calibration at each basin. Given the dependency for some basins simulations to have observed routed flow from an upstream (non-calibration) basin, a handful of basins have a start date later than 1/1/2000.

Table 3-2: Calibration period by basin with the available observed and QME data periods.

ID	Basin	Forecast Group	Calibration Info	Run Start	Run End	QME (# of WY's)
1	GAST2	Brazos	Local	10/2/2007	10/1/2020	13
2	BNLT2	Brazos	Headwater	1/1/2000	10/1/2020	2
2	BNLT2	Brazos	Headwater	1/1/2000	10/1/2020	2
3	LRIT2	Brazos	Local	10/2/2007	10/1/2020	6
4	PICT2	Brazos	Headwater	1/1/2000	10/1/2020	21
5	KEMT2	Brazos	Headwater	1/1/2000	10/1/2020	21
6	DNGT2	Brazos	Local	1/1/2000	10/1/2020	21
7	SDOT2	Brazos	Headwater	1/1/2000	10/1/2020	6
8	BYBT2	Brazos	Headwater	1/1/2000	10/1/2020	6
9	BCIT2	Brazos	Local	1/1/2000	10/1/2020	5
10	BKFT2	Brazos	Local	1/1/2000	10/1/2020	5
11	BSYT2	Brazos	Local	1/1/2000	10/1/2020	5
12	BKTT2	Brazos	Local	1/1/2000	10/1/2020	0
13	RKDT2	Brazos	Local	1/1/2000	10/1/2020	0
14	RSAT2	Brazos	Local	10/1/2007	10/1/2020	0
15	RLRT2	Brazos	Local	10/2/2007	10/1/2020	5
16	CMNT2	Brazos	Local	10/2/2007	10/1/2020	19
17	BECT2	Brazos	Headwater	1/1/2000	10/1/2020	0
18	BBZT2	Brazos	Local	10/2/2007	10/1/2020	21
19	WBAT2	Brazos	Local	5/6/2001	10/1/2020	19
20	HIBT2	Brazos	Local	1/1/2000	10/1/2020	21
21	BSAT2	Brazos	Headwater, Inflow, Reservoir	1/1/2000	10/1/2020	0
22	GRST2	Brazos	Local	10/2/2007	10/1/2020	21
23	EAST2	Brazos	Local	1/1/2000	10/1/2020	21
24	NGET2	Brazos	Local	1/1/2000	10/1/2020	21
25	BRYT2	Brazos	Local	1/1/2000	10/1/2020	21
26	CLGT2	Brazos	Local	1/1/2000	10/1/2020	0
27	HPDT2U	Brazos	Subbasin	1/1/2000	10/1/2020	0
28	DMYT2	Brazos	Headwater	1/1/2000	10/1/2020	21
29	DEYT2	Brazos	Headwater	1/1/2000	10/1/2020	21
30	LYNT2	Brazos	Headwater	1/1/2000	10/1/2020	21
31	HBRT2	Brazos	Local	1/1/2000	10/1/2020	3
32	HLBT2	Brazos	Headwater	1/1/2000	10/1/2020	0
33	WBZT2U	Brazos	Local	1/1/2000	10/1/2020	0
34	WBZT2	Brazos	Local	9/4/2008	10/1/2020	0

ID	Basin	Forecast Group	Calibration Info	Run Start	Run End	QME (# of WY's)
35	HPDT2	Brazos	Local	9/4/2008	10/1/2020	20
36	BEMT2	Brazos	Headwater	1/1/2000	10/1/2020	20
37	BAWT2	Brazos	Local	9/30/2000	10/1/2020	20
38	RMOT2	Brazos	Local	9/30/2000	10/1/2020	20
39	SLNT2	Brazos	Local	9/30/2000	10/1/2020	0
40	ROST2	Brazos	Local	9/30/2000	10/1/2020	21
41	WCBT2	Brazos	Local	9/30/2000	10/1/2020	0
42	LCPT2	Guadalupe	Headwater	1/1/2000	10/1/2020	21
43	LULT2	Guadalupe	Local	1/1/2000	10/1/2020	19
44	LLGT2	Guadalupe	Local	1/1/2000	10/1/2020	5
45	GNLT2	Guadalupe	Local	3/15/2005	10/1/2020	4
46	PEWT2	Guadalupe	Headwater	1/1/2000	10/1/2020	3
47	DLWT2	Guadalupe	Local	1/1/2000	10/1/2020	20
48	GDHT2	Guadalupe	Local			20
49	WHOT2U	Guadalupe	Subbasin	1/1/2000	10/1/2020	0
50	WHOT2M	Guadalupe	Subbasin	1/1/2000	10/1/2020	0
51	WHOT2	Guadalupe	Headwater	1/1/2000	10/1/2020	21
52	CUET2U	Guadalupe	Subbasin	1/1/2000	10/1/2020	0
53	CUET2	Guadalupe	Local	1/1/2000	10/1/2020	21
54	WRST2	Guadalupe	Local	1/1/2000	10/1/2020	0
55	SCDT2	Guadalupe	Local	1/1/2000	10/1/2020	19
56	CKDT2	Guadalupe	Headwater, Inflow, Reservoir	1/1/2000	10/1/2020	19
57	VICT2U	Guadalupe	Local	1/1/2000	10/1/2020	0
58	VICT2	Guadalupe	Local	1/1/2000	10/1/2020	21
59	DUPT2	Guadalupe	Local	1/1/2000	10/1/2020	5
60	LLET2	Brazos	Headwater, Inflow, Reservoir			0
61	CPKT2	Brazos	Headwater			5
62	DSBT2	Brazos	Headwater			21
63	DLLT2	Brazos	Local			13
64	PCTT2	Brazos	Local, Inflow, Reservoir			13
65	HMLT2	Brazos	Local			13
66	FHCT2	Brazos	Headwater			3
67	FCCT2U	Brazos	Subbasin			2
68	FCCT2	Brazos	Local			3
69	FHGT2	Brazos	Headwater			3
70	FHHT2U	Brazos	Subbasin			2
71	FHHT2	Brazos	Headwater			2
72	MCGT2	Brazos	Headwater			13
73	HICT2	Brazos	Headwater			0
74	CTNT2	Brazos	Local			21
75	VMAT2	Brazos	Local			19
76	ACTT2	Brazos	Local, Inflow, Reservoir			13
77	CRFT2	Brazos	Headwater			13
79	LKCT2	Colorado	Headwater, Inflow, Reservoir			0
80	HORT2	Colorado	Headwater, Inflow, Reservoir			0
81	HDCT2	Colorado	Local			5
82	CJNT2	Colorado	Local			0
83	LBWT2U	Colorado	Subbasin			0
84	CUTT2	Colorado	Headwater			0

ID	Basin	Forecast Group	Calibration Info	Run Start	Run End	QME (# of WY's)
85	LBWT2	Colorado	Local, Inflow, Reservoir			9
86	BWDT2	Colorado	Local			0
87	SKMT2	Nueces	Headwater			21
88	MIOT2	Nueces	Headwater			16
89	REFT2	Nueces	Local			16

3.2. Drainage Area Comparison

Discrepancies in the basin drainage area can have a substantial impact on the mass balance calculation. For example, errors in the drainage area can propagate to errors in water balance calculations, and ultimately poor model simulations (e.g., UNIT-HG runoff to streamflow conversion). To minimize this source of error, we compared WGRFC basin drainage area values (from WGRFC shapefile) to the USGS reported drainage area at the stream gauge locations (reported on the USGS gauge webpage where available). Drainage areas for all UNIT-HG parameter files were also provided in the CHPS ModuleParFiles by WGRFC. We calculated the "local" USGS drainage area by subtracting any incoming upstream gauge sites from the gauge site at the basin outlet (i.e., local = outlet – sum[upstream]). Most of the basins had <10% difference. However, we flagged 11 basins where differences between the WGRFC and USGS drainage areas was greater than 10%. We shared these results with WGRFC, and WGRFC advised that the primary source of error was likely from the older, coarser elevation data used by the USGS in their calculations (communicated with WGRFC in email thread dated 5/26/2021). All subsequent analyses use the WGRFC shapefiles as the authoritative basin drainage area (Table 3-3).

We also calculated the area values from the WGRFC-provided initial UNIT-HG files to confirm that the unit area of each curve matched the area provided in the shapefile. The calculated UNIT-HG area values are provided in the table below under the "UHG Drainage Area (sq mi)" column. Note that the "UHG Drainage Area" column in Table 3-3 denotes the area applied within the water balance spreadsheet analysis. Furthermore, the UNIT-HG area values for calibration for all basins were set to the true local basin drainage area (UHG Drainage Area column).

Table 3-3: Drainage area comparison between WGRFC basin boundary shapefile data and USGS data.

ID	Basin	Forecast Group	Gauge ID	WGRFC shapefile (sq mi)	UHG Drainage Area (sq mi)	USGS Calculated Local Drain Area (sq mi)	% Difference (between Calculated and shapefile)
1	GAST2	Brazos	8100500	451	451	451	0%
2	BNLT2	Brazos	8102595	112	112	112	0%
3	LRIT2	Brazos	8104500	139	139	97	-30%
4	PICT2	Brazos	8101000	456	456	455	0%
5	KEMT2	Brazos	8103800	817	817	818	0%
6	DNGT2	Brazos	8103940	378	378	377	0%
7	SDOT2	Brazos	8104300	136	136	136	0%
8	BYBT2	Brazos	8105872	43	43	44	2%
9	BCIT2	Brazos	8105883	28	28	27	-3%
10	BKFT2	Brazos	8105888	43	43	43	0%
11	BSYT2	Brazos	8105897	78	78	79	2%
12	BKTT2	Brazos	8106050	53	53	52	-2%
13	RKDT2	Brazos	8106300	262	262	261	-1%
14	RSAT2	Brazos	8106310	123	123	124	1%
15	RLRT2	Brazos	8106350	369	369	372	1%
16	CMNT2	Brazos	8106500	107	107	106	-1%
17	BECT2	Brazos	8108250	314	314	314	0%
18	BBZT2	Brazos	8108700	430	430	354	-18%
19	WBAT2	Brazos	8096500	408	408	409	0%
20	HIBT2	Brazos	8098290	1180	1180	877	-26%
21	BSAT2	Brazos	8110300	197	196	196	0%
22	GRST2	Brazos	8110325	43	43	43	0%
23	EAST2	Brazos	8110500	267	267	293	10%
24	NGET2	Brazos	8110800	397	397	319	-20%
25	BRYT2	Brazos	8111000	88	88	167	89%
26	CLGT2	Brazos	8111010	379	379	355	-6%
27	HPDT2U	Brazos	no gauge	352	352		
28	DMYT2	Brazos	8109700	236	236	236	0%
29	DEYT2	Brazos	8109800	239	239	244	2%
30	LYNT2	Brazos	8110100	195	195	195	0%
31	HBRT2	Brazos	8098450	464	464	880	90%
32	HLBT2	Brazos	8108780	248	248	245	-1%
33	WBZT2U	Brazos	no gauge	194	194		
34	WBZT2	Brazos	8110200	467	467	502	8%
35	HPDT2	Brazos	8111500	470	470	442	-6%
36	BEMT2	Brazos	8111700	377	376	376	0%
37	BAWT2	Brazos	8111850	341	341	414	21%
38	RMOT2	Brazos	8114000	369	369	437	18%
39	SLNT2	Brazos	8114100	12	12	15	21%
40	ROST2	Brazos	8116650	303	303	217	-28%
41	WCBT2	Brazos	8116850	101	101	158	57%
42	LCPT2	Guadalupe	8172400	112	112	112	0%
43	LULT2	Guadalupe	8173000	198	198	197	-1%
44	LLGT2	Guadalupe	8172000	293	293	291	-1%
45	GNLT2	Guadalupe	8173900	252	252	274	9%
46	PEWT2	Guadalupe	8174550	107	107	107	0%
47	DLWT2	Guadalupe	8174600	354	353	353	0%
48	GDHT2	Guadalupe	8174700	141	141	121	-14%

ID	Basin	Forecast Group	Gauge ID	WGRFC shapefile (sq mi)	UHG Drainage Area (sq mi)	USGS Calculated Local Drain Area (sq mi)	% Difference (between Calculated and shapefile)
49	WHOT2U	Guadalupe	8174970	197	197	197	0%
50	WHOT2M	Guadalupe	no gauge	159	159		
51	WHOT2	Guadalupe	8175000	194	194	193	0%
52	CUET2U	Guadalupe	no gauge	145	145		
53	CUET2	Guadalupe	8175800	165	165	169	2%
54	WRST2	Guadalupe	8176550	168	168	167	-1%
55	SCDT2	Guadalupe	8176900	189	189	190	1%
56	CKDT2	Guadalupe	8177400	137	137	137	0%
57	VICT2U	Guadalupe	no gauge	155	155		
58	VICT2	Guadalupe	8176500	113	113	109	-3%
59	DUPT2	Guadalupe	8177520	122	122	124	1%
60	LLET2	Brazos	8099000	258	258	259	0%
61	CPKT2	Brazos	8099382	144	144	143	0%
62	DSBT2	Brazos	8099300	269	269	264	-2%
63	DLLT2	Brazos	8099100	219	219	220	1%
64	PCTT2	Brazos	8099400	393	393	373	-5%
65	HMLT2	Brazos	8100000	647	647	632	-2%
66	FHCT2	Brazos	8100630	11	11	11	1%
67	FCCT2U	Brazos	8101200	81	81	81	0%
68	FCCT2	Brazos	8101300	21	21	21	-2%
69	FHGT2	Brazos	8101310	13	13	13	0%
70	FHHT2U	Brazos	8101330	18	18	18	1%
71	FHHT2	Brazos	8101340	29	29	28	-2%
72	MCGT2	Brazos	8095300	184	184	182	-1%
73	HICT2	Brazos	8094800	360	360	359	0%
74	CTNT2	Brazos	8095000	616	616	609	-1%
75	VMAT2	Brazos	8095200	182	182	178	-2%
76	ACTT2	Brazos	8095550	238	238	246	3%
77	CRFT2	Brazos	8095400	78	78	78	1%
79	LKCT2	Colorado	8140770	305	304	292	-4%
80	HORT2	Colorado	8141000	49	49	48	-2%
81	HDCT2	Colorado	8142000	58	58	59	1%
82	CJNT2	Colorado	8140860	144	145	157	9%
83	LBWT2U	Colorado	no gauge	158	158		
84	CUTT2	Colorado	8140700	544	544	532	-2%
85	LBWT2	Colorado	8143000	307	307	319	4%
86	BWDT2	Colorado	8143500	88	88	95	8%
87	SKMT2	Nueces	8189700	243	241	247	2%
88	MIOT2	Nueces	8189300	203	201	204	0%
89	REFT2	Nueces	8189500	492	493	486	-1%

3.3. Streamflow Data

We downloaded daily and instantaneous USGS streamflow (discharge and stage) using the USGS dataRetrieval package in R, when available. The daily QME (Table 3-5) and instantaneous streamflow data (QIN) (Table 3-6) were imported to the CHPS calibration stand-alone and added to the calibration plot displays. While the hourly and three-hourly data provide essential tools to help understand the flashy behavior at several of the calibration basins, there are occasional periods of missing QIN data for some of the basins. Basins with #N/A indicate that no daily or instantaneous streamflow data exist for that basin. If available, stage data were imported and converted to flow using WGRFC rating curves for basins with no USGS QME/QIN (associated with rating curve limitations). Basins where stage data were used are listed in Table 3-7.

To help extend the record of observed streamflow used in the water balance analysis, annual water year streamflow data for BAWT2, DNGT2, BRYT2, and GDHT2 were estimated using streamflow records from neighboring basins. We used a regression analysis to estimate mean annual streamflow data for the missing years (Table 3-4). The estimated water year values are solely used for the water balance analysis (not used for model calibration/evaluation).

For the water balance analysis, basins or subbasins that do not have historic streamflow data (or for which there are less than 2 years of data) were lumped into the local area for the first downstream basin with available streamflow data.

Table 3-4: Summary of filled streamflow data used in the water balance analysis.

Basin	Basin Used for Filling	Correlation R2	Years Overlap
GDHT2	GNLT2	0.98	4
BAWT2	HPDT2	0.99	7
DNGT2	KEMT2	0.99	4
BRYT2	EAST2	0.99	4

Table 3-5: Summary statistics of USGS daily streamflow data (QME), including period of record and mean, max, minimum, and standard deviation of flow

ID	Basin	Forecast Group	Daily Obs Count	Start Date	End Date	Mean QME (cfs)	Max QME (cfs)	Min QME (cfs)	Standard Deviation (cfs)	Max Flow Date	Min Flow Date
1	GAST2	Brazos	25811	10/1/1950	5/31/2021	440	49100	0.3	1236	12/21/1991	7/31/2012
2	BNLT2	Brazos	1161	3/28/2018	5/31/2021	74	2770	10.5	163	10/16/2018	9/2/2018
3	LRIT2	Brazos	23528	10/1/1923	5/31/2021	1273	25800	15.2	2197	9/8/2010	7/27/2018
4	PICT2	Brazos	25811	10/1/1950	5/31/2021	123	25600	0.0	697	12/20/1991	5/23/1996
5	KEMT2	Brazos	21428	10/1/1962	5/31/2021	198	42500	5.0	917	12/21/1991	9/18/1996
6	DNGT2	Brazos	2001	12/9/2015	5/31/2021	306	28700	0.3	1022	10/16/2018	7/31/2018
7	SDOT2	Brazos	2981	3/14/2013	5/31/2021	47	5070	3.5	171	5/3/2019	9/3/2013
8	BYBT2	Brazos	2465	9/1/2014	5/31/2021	38	809	0.0	66	8/21/2016	9/1/2014
9	BCIT2	Brazos	2386	11/19/2014	5/31/2021	70	1320	4.5	113	10/30/2015	7/30/2020
10	BKFT2	Brazos	2411	10/25/2014	5/31/2021	95	4230	0.9	178	5/25/2015	8/21/2020
11	BSYT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
12	BKTT2	Brazos	23	8/27/2017	5/2/2021	2185	4500	883.0	1142	1/3/2019	1/6/2019
13	RKDT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
14	RSAT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
15	RLRT2	Brazos	9448	2/12/1981	5/20/2021	285	1000	21.7	223	12/21/2000	6/20/2009
16	CMNT2	Brazos	38198	11/1/1916	5/31/2021	2055	71300	15.5	3585	12/22/1991	6/20/2009
17	BECT2	Brazos	191	6/18/2007	5/25/2021	2254	18400	111.0	2880	4/18/2016	7/11/2007
18	BBZT2	Brazos	10184	7/14/1993	5/31/2021	5225	84400	120.0	9354	7/16/2007	5/6/2014
19	WBAT2	Brazos	44803	1898-10-01	5/31/2021	2497	44000	0.5	5341	12/22/1991	11/6/1990
20	HIBT2	Brazos	20332	10/1/1965	5/31/2021	3157	70300	30.0	6253	12/22/1991	2/16/2000
21	BSAT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
22	GRST2	Brazos	15706	6/1/1978	5/31/2021	143	19400	0.0	749	4/29/2009	8/25/1990
23	EAST2	Brazos	35495	3/27/1924	5/31/2021	485	57400	3.2	2042	12/22/1991	10/24/1995
24	NGET2	Brazos	8827	4/1/1997	5/31/2021	528	39200	3.4	1875	3/11/2016	10/30/2011
25	BRYT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

ID	Basin	Forecast Group	Daily Obs Count	Start Date	End Date	Mean QME (cfs)	Max QME (cfs)	Min QME (cfs)	Standard Deviation (cfs)	Max Flow Date	Min Flow Date
26	CLGT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
27	HPDT2U	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
28	DMYT2	Brazos	21489	8/1/1962	5/31/2021	78	9470	0.0	352	12/22/1991	1/1/1990
29	DEYT2	Brazos	21489	8/1/1962	5/31/2021	78	11300	0.0	328	5/4/2019	7/4/1990
30	LYNT2	Brazos	21428	10/1/1962	5/31/2021	88	18200	0.0	488	8/28/2017	7/5/1990
31	HBRT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
32	HLBT2	Brazos	46	8/28/2017	5/27/2021	1564	5120	506.0	971	5/4/2019	1/8/2021
33	WBZT2U	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
34	WBZT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
35	HPDT2	Brazos	25811	10/1/1938	5/31/2021	7763	137000	58.0	12781	5/27/2016	11/2/2014
36	BEMT2	Brazos	18729	8/1/1963	5/31/2021	217	65700	0.0	1446	8/28/2017	6/12/2011
37	BAWT2	Brazos	2860	8/2/2013	5/31/2021	10328	141000	28.8	16200	8/29/2017	11/4/2014
38	RMOT2	Brazos	37315	1/1/1903	5/31/2021	8668	120000	182.0	13476	8/31/2017	12/8/2012
39	SLNT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
40	ROST2	Brazos	18482	4/1/1967	5/31/2021	9008	121000	27.0	13879	8/29/2017	7/21/2000
41	WCBT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
42	LCPT2	Guadalupe	22678	4/30/1959	5/31/2021	59	19400	0.0	350	10/18/1998	1/1/1990
43	LULT2	Guadalupe	30462	3/21/1930	5/31/2021	151	20700	0.4	768	8/27/2017	7/17/2009
44	LLGT2	Guadalupe	29995	4/18/1939	5/31/2021	470	90500	55.8	1442	10/18/1998	8/23/2009
45	GNLT2	Guadalupe	9008	10/1/1996	5/31/2021	1626	188000	101.0	3872	10/19/1998	9/5/2013
46	PEWT2	Guadalupe	1675	10/28/2016	5/31/2021	36	23800	0.0	721	8/28/2017	10/28/2016
47	DLWT2	Guadalupe	14939	8/1/1959	5/31/2021	128	40700	0.0	858	8/28/2017	10/16/2009
48	GDHT2	Guadalupe	203	1/28/2010	4/14/2011	1164	3340	412.0	679	2/16/2010	2/7/2011
49	WHOT2U	Guadalupe	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
50	WHOT2M	Guadalupe	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
51	WHOT2	Guadalupe	24282	3/10/1930	5/31/2021	129	31100	0.0	834	5/18/1992	7/28/2009
52	CUET2U	Guadalupe	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
53	CUET2	Guadalupe	20971	1/1/1964	5/31/2021	2004	338000	40.0	5603	10/20/1998	8/14/1996
54	WRST2	Guadalupe	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

ID	Basin	Forecast Group	Daily Obs Count	Start Date	End Date	Mean QME (cfs)	Max QME (cfs)	Min QME (cfs)	Standard Deviation (cfs)	Max Flow Date	Min Flow Date
55	SCDT2	Guadalupe	15369	10/1/1978	5/31/2021	72	24600	0.0	548	6/22/1997	10/21/1995
56	CKDT2	Guadalupe	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
57	VICT2U	Guadalupe	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
58	VICT2	Guadalupe	31621	11/4/1934	5/31/2021	2103	307000	38.0	5364	10/20/1998	8/20/1996
59	DUPT2	Guadalupe	3278	10/1/2011	5/18/2021	945	4300	84.7	763	9/7/2017	10/5/2011
60	LLET2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
61	CPKT2	Brazos	2251	4/3/2015	5/31/2021	40	6800	0.0	270	5/27/2016	6/7/2015
62	DSBT2	Brazos	17550	9/1/1960	5/31/2021	47	7940	0.0	341	5/30/2016	10/1/1999
63	DLLT2	Brazos	14619	9/1/1960	5/31/2021	95	18500	0.0	609	4/26/1990	6/6/2008
64	PCTT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
65	HMLT2	Brazos	20634	1/1/1925	5/31/2021	313	21200	0.0	929	12/21/1991	6/4/2011
66	FHCT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
67	FCCT2U	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
68	FCCT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
69	FHGT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
70	FHHT2U	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
71	FHHT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
72	MCGT2	Brazos	14538	8/19/1959	5/31/2021	84	11200	0.0	395	12/21/1991	8/16/2008
73	HICT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
74	CTNT2	Brazos	35673	10/1/1923	5/31/2021	310	96800	0.0	1829	12/21/1991	6/1/2000
75	VMAT2	Brazos	21921	8/1/1959	5/31/2021	394	123000	0.0	2062	12/21/1991	8/14/2000
76	ACTT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
77	CRFT2	Brazos	14534	8/17/1959	5/31/2021	30	1890	0.0	108	9/8/2010	10/28/2008
78	MCGT2	Brazos	14538	8/19/1959	5/31/2021	84	11200	0.0	395	12/21/1991	8/16/2008
79	LKCT2	Colorado	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
80	HORT2	Colorado	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
81	HDCT2	Colorado	13034	10/1/1940	5/31/2021	5	1010	0.0	37	5/30/2016	5/25/2018
82	CJNT2	Colorado	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
83	LBWT2U	Colorado	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

ID	Basin	Forecast Group	Daily Obs Count	Start Date	End Date	Mean QME (cfs)	Max QME (cfs)	Min QME (cfs)	Standard Deviation (cfs)	Max Flow Date	Min Flow Date
84	CUTT2	Colorado	3997	4/16/1968	5/26/2021	1785	13200	232.0	2240	5/30/2016	5/21/2016
85	LBWT2	Colorado	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
86	BWDT2	Colorado	21646	11/1/1923	10/4/1983	886	2530	350.0	583	4/25/2019	12/30/2018
87	SKMT2	Nueces	20885	3/27/1964	5/31/2021	34	29300	0.0	367	5/14/2004	6/4/1990
88	MIOT2	Nueces	12893	3/1/1962	5/31/2021	5	11200	0.0	137	11/16/2001	9/14/2001
89	REFT2	Nueces	29921	7/1/1939	5/31/2021	132	32100	0.0	801	9/1/2001	8/4/2009

Table 3-6: Summary statistics of USGS instantaneous streamflow data (QIN), including period of record and mean, max, minimum, and standard deviation of flow

ID	Basin	Forecast Group	End Date	Mean QIN (cfs)	Max QIN (cfs)	Min QIN (cfs)	Standard Deviation (cfs)	Max Flow Date	Min Flow Date
1	GAST2	Brazos	6/1/2021	328	16700	0.1	1016	10/17/2018	9/28/2013
2	BNLT2	Brazos	6/1/2021	74	5430	6.9	233	1/2/2019	7/26/2018
3	LRIT2	Brazos	6/1/2021	1015	50700	13.8	2037	9/8/2010	7/27/2018
4	PICT2	Brazos	6/1/2021	107	33200	0.0	649	1/29/2010	9/9/2009
5	KEMT2	Brazos	6/1/2021	126	30800	2.3	617	4/28/2009	5/4/2013
6	DNGT2	Brazos	6/1/2021	312	43000	0.2	1148	10/17/2018	7/31/2018
7	SDOT2	Brazos	6/1/2021	50	18400	3.4	268	5/3/2019	7/25/2018
8	BYBT2	Brazos	6/1/2021	38	3040	0.0	77	8/21/2016	9/1/2014
9	BCIT2	Brazos	6/1/2021	70	3650	1.9	130	10/30/2015	7/30/2020
10	BKFT2	Brazos	6/1/2021	96	31400	0.5	245	5/25/2015	8/22/2020
11	BSYT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
12	BKTT2	Brazos	6/1/2021	1857	7830	775.0	1437	3/28/2018	8/8/2017
13	RKDT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
14	RSAT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
15	RLRT2	Brazos	5/21/2021	262	1000	16.5	194	5/12/2012	6/21/2009
16	CMNT2	Brazos	6/1/2021	1699	40800	8.6	3308	5/27/2015	6/21/2009
17	BECT2	Brazos	6/1/2021	1688	28300	100.0	2640	4/18/2016	10/8/2009

ID	Basin	Forecast Group	End Date	Mean QIN (cfs)	Max QIN (cfs)	Min QIN (cfs)	Standard Deviation (cfs)	Max Flow Date	Min Flow Date
18	BBZT2	Brazos	6/1/2021	5368	85900	109.0	9583	7/16/2007	5/6/2014
19	WBAT2	Brazos	6/1/2021	2214	39900	0.0	4951	3/30/2007	2/7/1992
20	HIBT2	Brazos	6/1/2021	2836	42400	26.0	6043	11/1/2015	8/21/2013
21	BSAT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
22	GRST2	Brazos	6/1/2021	155	25600	0.0	905	4/29/2009	11/10/2007
23	EAST2	Brazos	6/1/2021	459	61800	0.0	2021	12/22/1991	11/19/1992
24	NGET2	Brazos	6/1/2021	523	54300	3.1	1932	5/1/2009	10/22/2011
25	BRYT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
26	CLGT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
27	HPDT2U	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
28	DMYT2	Brazos	6/1/2021	72	17300	0.0	394	10/31/2015	11/5/2008
29	DEYT2	Brazos	6/1/2021	68	16700	0.0	360	5/4/2019	8/6/2008
30	LYNT2	Brazos	6/1/2021	84	23500	0.0	559	8/28/2017	11/9/2007
31	HBRT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
32	HLBT2	Brazos	6/1/2021	1285	5330	390.0	951	5/4/2019	10/18/2018
33	WBZT2U	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
34	WBZT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
35	HPDT2	Brazos	6/1/2021	7841	153000	55.4	13249	5/27/2016	11/3/2014
36	BEMT2	Brazos	6/1/2021	182	85100	0.0	1712	5/28/2016	6/3/2011
37	BAWT2	Brazos	6/1/2021	10477	146000	15.5	16321	8/29/2017	8/26/2014
38	RMOT2	Brazos	6/1/2021	8605	122000	133.0	13823	9/1/2017	12/2/2012
39	SLNT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
40	ROST2	Brazos	6/1/2021	8873	133000	-125.0	14014	8/29/2017	7/7/2013
41	WCBT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
42	LCPT2	Guadalupe	6/1/2021	59	47200	0.0	455	10/18/1998	10/1/1991
43	LULT2	Guadalupe	6/1/2021	128	28100	0.3	693	8/27/2017	7/16/2009
44	LLGT2	Guadalupe	6/1/2021	468	206000	2.7	1761	10/18/1998	11/4/2014
45	GNLT2	Guadalupe	6/1/2021	1570	101000	23.1	2734	11/23/2004	10/1/2020
46	PEWT2	Guadalupe	6/1/2021	36	66900	0.0	1062	8/28/2017	10/27/2016

ID	Basin	Forecast Group	End Date	Mean QIN (cfs)	Max QIN (cfs)	Min QIN (cfs)	Standard Deviation (cfs)	Max Flow Date	Min Flow Date
47	DLWT2	Guadalupe	6/1/2021	128	47300	0.0	890	8/28/2017	10/15/2009
48	GDHT2	Guadalupe	6/1/2021	1261	36400	81.5	1848	8/29/2017	11/8/2020
49	WHOT2U	Guadalupe	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
50	WHOT2M	Guadalupe	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
51	WHOT2	Guadalupe	6/1/2021	121	38600	0.0	840	5/18/1992	8/12/1993
52	CUET2U	Guadalupe	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
53	CUET2	Guadalupe	6/1/2021	1940	473000	0.0	6288	10/20/1998	10/6/1997
54	WRST2	Guadalupe	3/22/2020	1878	5200	1000.0	962	5/16/2015	1/16/2010
55	SCDT2	Guadalupe	6/1/2021	68	44500	0.0	578	6/22/1997	10/21/1995
56	CKDT2	Guadalupe	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
57	VICT2U	Guadalupe	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
58	VICT2	Guadalupe	6/1/2021	1952	102000	36.0	3736	11/26/2004	8/21/1996
59	DUPT2	Guadalupe	5/31/2021	950	4660	80.3	781	3/18/2017	10/5/2011
60	LLET2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
61	CPKT2	Brazos	6/1/2021	40	9200	0.0	315	5/27/2016	5/1/2015
62	DSBT2	Brazos	6/1/2021	36	16500	0.0	318	5/30/2016	10/1/1999
63	DLLT2	Brazos	6/1/2021	58	15800	0.0	420	6/1/2016	6/5/2008
64	PCTT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
65	HMLT2	Brazos	6/1/2021	228	15100	0.0	841	5/29/2015	6/1/2011
66	FHCT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
67	FCCT2U	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
68	FCCT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
69	FHGT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
70	FHHT2U	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
71	FHHT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
72	MCGT2	Brazos	6/1/2021	77	18600	0.0	416	9/8/2010	8/6/2008
73	HICT2	Brazos	6/1/2021	123	20500	0.0	609	5/29/2015	7/23/1996
74	CTNT2	Brazos	6/1/2021	278	137000	0.0	1598	3/16/1998	5/26/2000
75	VMAT2	Brazos	6/1/2021	376	220000	0.0	2183	12/21/1991	8/12/2000

ID	Basin	Forecast Group	End Date	Mean QIN (cfs)	Max QIN (cfs)	Min QIN (cfs)	Standard Deviation (cfs)	Max Flow Date	Min Flow Date
76	ACTT2	Brazos	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
77	CRFT2	Brazos	6/1/2021	33	5970	0.0	144	4/5/1995	10/1/1994
78	MCGT2	Brazos	6/1/2021	77	18600	0.0	416	9/8/2010	8/6/2008
79	LKCT2	Colorado	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
80	HORT2	Colorado	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
81	HDCT2	Colorado	6/1/2021	5	3120	0.0	48	5/30/2016	5/25/2018
82	CJNT2	Colorado	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
83	LBWT2U	Colorado	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
84	CUTT2	Colorado	6/1/2021	1470	22700	200.0	2306	5/30/2016	11/2/2015
85	LBWT2	Colorado	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
86	BWDT2	Colorado	6/1/2021	939	3180	350.0	605	5/11/2019	12/15/2018
87	SKMT2	Nueces	6/1/2021	32	39500	0.0	405	5/14/2004	4/11/2001
88	MIOT2	Nueces	6/1/2021	4	15300	0.0	125	11/16/2001	9/14/2001
89	REFT2	Nueces	6/1/2021	123	46900	0.0	789	9/1/2001	5/22/2009

Table 3-7: Summary statistics of USGS stage data, including period of record and mean, max, minimum, and standard deviation of stage

Site No	Basin	Daily Count	Start Date	End Date	Mean STG (ft)	Max STG (ft)	Min STG (ft)	Standard Deviation (ft)	Date Max	Date Min
8105897	BSYT2	2491	11/20/2014	9/14/2021	6.03097	19.86	4.63	1.549418	9/22/2018	8/4/2018
8106350	RLRT2	12193	7/10/1987	9/14/2021	8.490721	36.24	1.21	5.975784	12/22/1991	2/11/1995
8098450	HBRT2	1541	6/27/2017	9/14/2021	19.93588	52.06	15.74	5.905682	1/4/2019	8/31/2020
8100630	FHCT2	1616	4/11/2017	9/14/2021	6.760481	8.08	6.37	0.373094	4/11/2017	3/2/2019
8101200	FCCT2U	1235	3/22/2018	9/14/2021	4.900863	26.23	3.77	1.151311	10/16/2018	7/17/2018
8101300	FCCT2	1612	4/13/2017	9/14/2021	5.031188	31.35	4.16	1.165916	10/16/2018	8/20/2018
8101310	FHGT2	1652	3/1/2017	9/14/2021	5.690435	8.52	4.19	1.271687	4/11/2017	8/29/2020
8101330	FHHT2U	1279	3/16/2018	9/14/2021	4.061266	6.65	2.38	0.459732	10/16/2018	9/1/2020
8101340	FHHT2	1607	4/11/2017	9/14/2021	5.197287	14.15	4.54	0.610544	4/11/2017	7/28/2018

Table 3-8: Summary statistics of USGS stage data, including period of record and mean, max, minimum, and standard deviation of stage

Site No	Basin	Forecast Group	Daily Count	Start Date	End Date	Mean STG (ft)	Max STG (ft)	Min STG (ft)	Standard Deviation (ft)	Date Max	Date Min
8098450	HBRT2	Brazos	1597	5/4/2017	9/17/2021	20.22	53.08	15.69	6.06	1/5/2019	9/1/2020
8100630	FHCT2	Brazos	1621	4/10/2017	9/17/2021	6.73	17.07	6.37	0.39	4/11/2017	2/28/2019
8101200	FCCT2U	Brazos	1276	3/21/2018	9/17/2021	4.89	30.48	3.75	1.19	10/16/2018	7/20/2018
8101300	FCCT2	Brazos	1619	4/12/2017	9/17/2021	5.06	35.74	3.90	1.24	10/16/2018	8/16/2020
8101310	FHGT2	Brazos	1662	2/28/2017	9/17/2021	5.59	19.64	4.15	1.28	6/24/2019	8/31/2020
8101330	FHHT2U	Brazos	1282	3/15/2018	9/17/2021	4.08	13.09	2.31	0.48	6/24/2019	9/2/2020
8101340	FHHT2	Brazos	1620	4/11/2017	9/17/2021	5.20	25.87	4.37	0.72	6/24/2019	8/10/2018

3.4. Precipitation

In a rainfall-runoff model, accurate and unbiased estimations of precipitation are crucial to producing reasonable simulations of streamflow. For model calibration, WGRFC provided a radar-based mean areal precipitation product, MAPX, identical to the precipitation data used in operational streamflow forecasting. We compare WGRFC's MAPX data with a benchmark precipitation product to measure agreement or divergence in the two products, which provides confidence in the overall quality of model forcing data. Specifically, we compared basin averaged precipitation values from the MAPX data with basin-average Parameter-elevation Regressions on Independent Slopes Model (PRISM) values (PRISM Climate Group, Oregon State University, 2013) across three different time periods: 2000–2020, 2010–2020, and 2015–2020 (Table 3-9). This comparison of the WGRFC MAPX product and the PRISM product shows that over time, the differences between the two datasets decrease, though PRISM consistently estimates more precipitation than MAPX. While a more thorough analysis of additional precipitation products is needed to more conclusively determine the overall skill of the MAPX data, this two-member analysis does suggest that the MAPX data are more closely aligned with PRISM data in the most recent decade, and especially the most recent five years. Because of this, and a greater availability of USGS records more recently, calibration efforts placed more value on the period 2010–2020 than the preceding decade. Basin specific results for the MAPX and PRISM comparison are shown in Table 3-10.

Table 3-9: Percent difference between MAPX and PRISM data

Comparison Period	% Difference between MAPX and PRISM
2000–2020	-4.8%
2010–2020	-2.7%
2015–2020	-1.2%

Table 3-10: Comparison of average annual precipitation (inches per year):PRISM data and WGRFC MAPX data for the 2000–2020 period.

ID	Basin	Forecast Group	MAPX (2000–2020)*	PRISM (2000–2020)	% Difference (MAP - PRISM)
1	GAST2	Brazos	59.62	61.28	-2.8%
2	BNLT2	Brazos	58.52	62.82	-7.4%
3	LRIT2	Brazos	60.91	65.23	-7.1%
4	PICT2	Brazos	58.20	58.34	-0.2%
5	KEMT2	Brazos	55.99	55.26	1.3%
6	DNGT2	Brazos	55.74	58.32	-4.6%
7	SDOT2	Brazos	57.45	62.04	-8.0%
8	BYBT2	Brazos	54.73	58.71	-7.3%
9	BCIT2	Brazos	58.12	61.12	-5.1%
10	BKFT2	Brazos	60.22	63.07	-4.7%
11	BSYT2	Brazos	56.21	61.76	-9.9%
12	BKTT2	Brazos	57.16	61.95	-8.4%
13	RKDT2	Brazos	59.01	64.12	-8.7%
14	RSAT2	Brazos	57.69	64.05	-11.0%
15	RLRT2	Brazos	59.16	64.91	-9.7%
16	CMNT2	Brazos	61.98	66.62	-7.5%
17	BECT2	Brazos	61.31	66.71	-8.8%
18	BBZT2	Brazos	64.53	69.46	-7.6%
19	WBAT2	Brazos	62.62	65.66	-4.8%
20	HIBT2	Brazos	63.92	68.15	-6.6%
21	BSAT2	Brazos	68.17	71.15	-4.4%

ID	Basin	Forecast Group	MAPX (2000–2020)*	PRISM (2000–2020)	% Difference (MAP - PRISM)
22	GRST2	Brazos	67.58	71.20	-5.4%
23	EAST2	Brazos	65.95	71.38	-8.2%
24	NGET2	Brazos	66.05	72.19	-9.3%
25	BRYT2	Brazos	69.82	75.72	-8.4%
26	CLGT2	Brazos	70.60	75.88	-7.5%
27	HPDT2U	Brazos	75.60	79.09	-4.6%
28	DMYT2	Brazos	62.53	66.77	-6.8%
29	DEYT2	Brazos	64.03	68.34	-6.7%
30	LYNT2	Brazos	66.52	71.49	-7.5%
31	HBRT2	Brazos	63.24	69.05	-9.2%
32	HLBT2	Brazos	63.36	69.79	-10.2%
33	WBZT2U	Brazos	66.32	71.88	-8.4%
34	WBZT2	Brazos	70.62	74.80	-5.9%
35	HPDT2	Brazos	77.59	80.72	-4.0%
36	BEMT2	Brazos	73.83	76.22	-3.2%
37	BAWT2	Brazos	79.28	79.67	-0.5%
38	RMOT2	Brazos	84.71	84.28	0.5%
39	SLNT2	Brazos	92.59	91.16	1.5%
40	ROST2	Brazos	88.30	88.68	-0.4%
41	WCBT2	Brazos	86.55	87.73	-1.4%
42	LCPT2	Guadalupe	59.73	63.35	-6.1%
43	LULT2	Guadalupe	57.24	61.35	-7.2%
44	LLGT2	Guadalupe	54.76	59.93	-9.4%
45	GNLT2	Guadalupe	56.53	61.19	-8.2%
46	PEWT2	Guadalupe	64.30	66.86	-4.0%
47	DLWT2	Guadalupe	62.69	65.38	-4.3%
48	GDHT2	Guadalupe	62.30	64.97	-4.3%
49	WHOT2U	Guadalupe	58.34	61.75	-5.8%
50	WHOT2M	Guadalupe	58.83	62.76	-6.7%
51	WHOT2	Guadalupe	57.26	60.73	-6.0%
52	CUET2U	Guadalupe	61.90	64.05	-3.5%
53	CUET2	Guadalupe	57.47	60.65	-5.5%
54	WRST2	Guadalupe	56.31	59.43	-5.5%
55	SCDT2	Guadalupe	60.63	62.73	-3.5%
56	CKDT2	Guadalupe	64.61	64.98	-0.6%
57	VICT2U	Guadalupe	62.10	64.51	-3.9%
58	VICT2	Guadalupe	69.26	68.94	0.5%
59	DUPT2	Guadalupe	70.19	69.16	1.5%
60	LLET2	Brazos	51.93	53.14	-2.3%
61	CPKT2	Brazos	0.00	56.59	
62	DSBT2	Brazos	54.21	54.66	-0.8%
63	DLLT2	Brazos	53.12	54.56	-2.7%
64	PCTT2	Brazos	56.14	56.89	-1.3%
65	HMLT2	Brazos	57.57	57.62	-0.1%
66	FHCT2	Brazos	0.00	60.98	
67	FCCT2U	Brazos	0.00	59.46	
68	FCCT2	Brazos	0.00	59.91	
69	FHGT2	Brazos	0.00	61.33	
70	FHHT2U	Brazos	0.00	62.14	
71	FHHT2	Brazos	0.00	61.51	
72	MCGT2	Brazos	61.26	64.25	-4.9%
73	HICT2	Brazos	56.02	59.08	-5.5%
74	CTNT2	Brazos	60.21	63.45	-5.4%

ID	Basin	Forecast Group	MAPX (2000–2020)*	PRISM (2000–2020)	% Difference (MAP - PRISM)
75	VMAT2	Brazos	61.27	64.23	-4.8%
76	ACTT2	Brazos	62.23	65.24	-4.8%
77	CRFT2	Brazos	61.09	63.95	-4.7%
79	LKCT2	Colorado	46.55	47.47	-2.0%
80	HORT2	Colorado	0.00	47.00	
81	HDCT2	Colorado	0.00	47.82	
82	CJNT2	Colorado	0.00	50.09	
83	LBWT2U	Colorado	52.30	51.47	1.6%
84	CUTT2	Colorado	50.20	50.27	-0.1%
85	LBWT2	Colorado	54.22	53.92	0.5%
86	BWDT2	Colorado	55.02	54.24	1.4%
87	SKMT2	Nueces	52.27	53.38	-2.1%
88	MIOT2	Nueces	52.17	52.93	-1.5%
89	REFT2	Nueces	57.19	59.58	-4.2%

**Some basins have a MAPX average of 0. These basins with a value of 0 are funding dependent basins, and we have yet to set up a fully functioning workflow in CHPS to calculate the water year. The final report will have these values populated.*

3.5. Potential Evapotranspiration (PET)

Accurate and unbiased estimates of evapotranspiration (ET) are critical to producing complete seasonal and annual water balances (Anderson, 2002). While modest errors in evapotranspiration data will generally not affect the simulation accuracy of individual storm events nearly as much as errors in precipitation data, biased ET data can lead to poor mass balance calculations (e.g., in reservoirs) and errors in the model parameterization, particularly for warm-season baseflow conditions.

We used the following data sources in the water balance analysis and/or model simulation:

1. Gridded daily MAPE (Mean Areal Potential Evapotranspiration; derived with solar and weather variables)
2. Cyclical climatological MAPE (derived using weather station climatology)
3. Apriori PET (Office of Hydrologic Development (OHD) gridded data files with monthly climatological PET values)
4. Food and Agriculture Organization-56 Penman-Monteith (FAO-PM) monthly climatological PET (calculated by Lynker)

For model calibration and associated project tasks, WGRFC provided Lynker with two MAPE data sources: 1) daily variable MAPE grids and 2) a cyclical climatology MAPE (Figure 3-1). These MAPE data were imported to CHPS using the "ImportGrids" workflow and the "ImportPIXML_Cyclic" workflow, respectively. As advised by WGRFC, we used the cyclic timeseries in the Public Interface Extensible Markup Language (PIXML) format to fill missing data during the daily variable MAPE data (e.g., Feb 2015-Oct 2016); additionally, the daily variable MAPE data are not available before 2009. WGRFC noted that the PIXML cyclical timeseries use a monthly MAPE cycle for clusters of basins, based on a small number of weather stations. The "Forcings Processing" workflow has been configured to generate a "MergeMAPE" variable using the Research Distributed Hydrologic Model (RDHM) gridded data first and the PIXML cyclic data when daily variable MAPE data is unavailable.

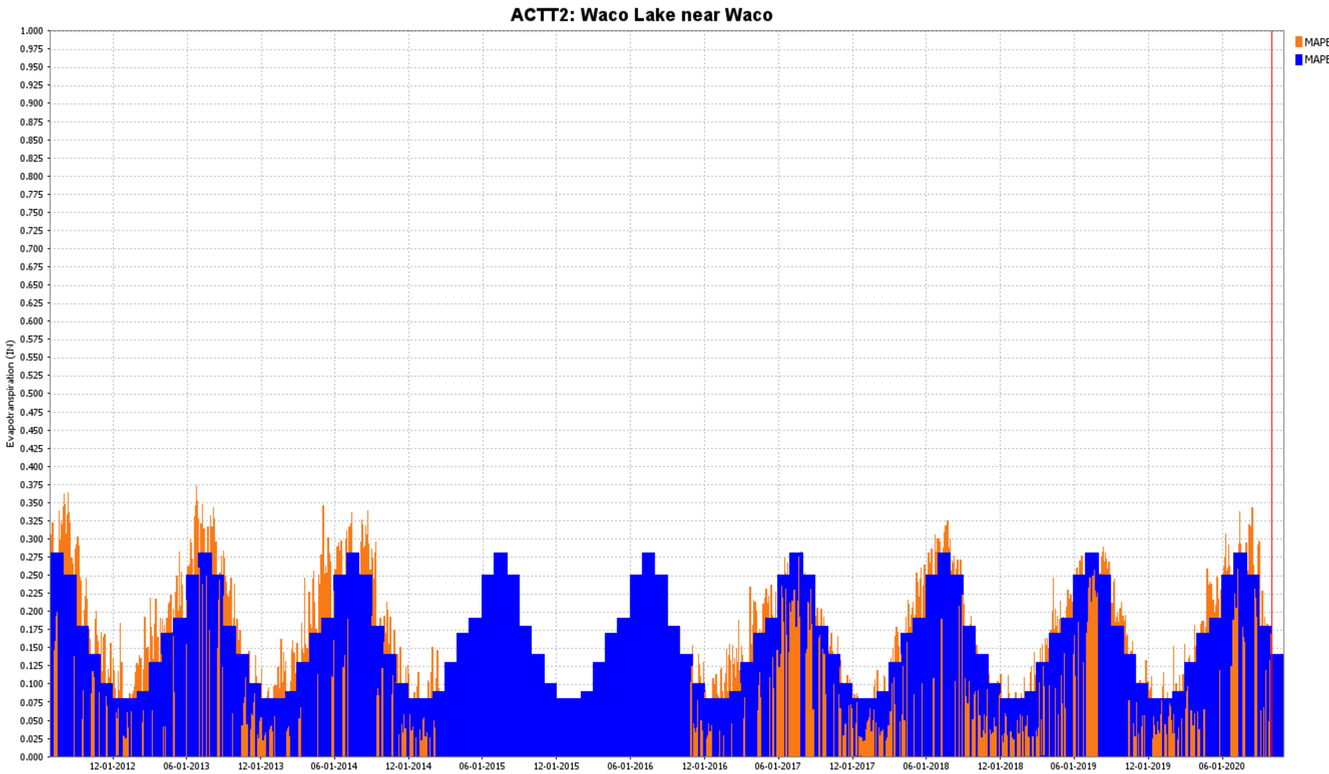


Figure 3-1: The daily MAPE grids (orange) and climatological MAPE (blue) provided to Lynker by WGRFC. Climatological MAPE was used to fill daily MAPE data where missing, e.g., late 2015.

Within the SAC-SMA module parameter files the "MAPE_INPUT" is set to TRUE for all of the calibrated basins, indicating that the monthly "ET_DEMAND_CURVE" parameters are applied as PE-adjustment factors. The SAC-SMA module parameter files obtained from the wgrfc_sa also contain PEADJ parameters (a blanket correction factor). To ensure a consistent comparison of all basins, the water balance analysis uses the MAPE-derived mean monthly PET data without any PE adjustment factors. The water balance analysis examined these monthly values for all existing basins and applied estimated values for new basins using neighboring basins as initial PET estimates.

Apriori PET estimates were extracted from the OHD gridded data files. Mid-month PE and PEadj CONUS grids (Hydrologic Rainfall Analysis Project (HRAP) projection) have been developed as input to the distributed hydrologic model (ftp://hydrology.nws.noaa.gov/pub/parameters/). Basin mean values were calculated by extracting grid values within the basin boundary shapefiles (mean gridded PE value multiplied by the mean gridded PEadj value). These monthly apriori values are primarily used as an additional comparison time series for the plots below.

Finally, the Food and Agriculture Organization-56 Penman-Monteith (FAO-PM) method for calculating PET (Allen et al., 2006) was also used as another benchmark to compare with the MAPE climatology. Inputs to the FAO-PM equation include monthly values of average maximum and minimum daily temperature, wind speed, sunshine duration, latitude, and elevation. We calculated the FAO-PM monthly PET values using site-specific wind data from nearby Automated Surface Observing System (ASOS) and Automated Weather Observing System (AWOS) sites along with PRISM monthly temperature data; sunshine duration was estimated using monthly climatology (1979–2011) North America Land Data Assimilation System (NLDAS) data.

3.6. Water Balance Ratios & Results

In each sub-basin, we convert the water year (WY) mean daily streamflow (QME in CFSD – average daily flow in cubic feet per second) to a runoff depth (RO in inches) by dividing QME by the basin area. Runoff as area-normalized depth, or specific discharge, reduces the dimensionality and allows for calculating other water balance metrics.

$$RO = \frac{QME}{Basin\ Area}$$

For downstream basins (i.e., local basins), we calculate the runoff values by subtracting upstream flows from downstream flows and dividing the result by the local basin area (Table 3-3). Calculating the ratios of water balance variables is one way to verify regional consistency between sub-basin; they can also be used to identify basin diversions and/or returns and establish whether there is a long-term systematic bias within a dataset. We calculate two important ratios as part of the water balance: 1) the ratio of runoff to precipitation, or the runoff coefficient (ROC; i.e. runoff ratio), and 2) the ratio of the actual evapotranspiration (AET) to potential evapotranspiration (AET/PET). Both ratios are unitless.

The ROC is an index measuring the amount of precipitation (MAPX) that reaches the basin outlet. ROC values range between 0 and 1, where a larger ROC value corresponds to a basin with a high runoff potential due to a low infiltration rate, low ET, a steep gradient, and/or largely developed areas with small amounts of vegetation, and a small ROC value corresponds to a basin with low runoff potential due to high ET, high infiltration (large storage), and/or large consumptive use. Although ROC values should be between 0 and 1, negative values can occur when the time of concentration is very long (usually the results of unusual groundwater dynamics), when precipitation and runoff data are poor, or when there are unaccounted for diversions in the basin. Conversely, ROC values greater than 1 can occur when the runoff depth is greater than the precipitation depth, indicating that more water is coming out of a basin than has been put into the basin. This situation can indicate an error in streamflow or precipitation data, or unaccounted for return flows.

$$ROC = \frac{RO}{MAPX}$$

Errors in the precipitation, runoff, or evapotranspiration data can also be identified by comparing regional AET/PET ratios. AET is calculated as the difference between MAPX and runoff depth (RO), where the RO includes any known diversions, channel losses, or return flows. Physically unrealistic or spatially inconsistent AET/PET ratios are often a consequence of biased precipitation or evapotranspiration data, poor streamflow data, and/or streamflow data that have not been naturalized by correcting for diversions or return flows.

$$AET = MAPX - RO$$

Final water balance analysis results are presented in Table 3-12, where sufficient data exist. Basins without adequate streamflow data were grouped with the next downstream basin with available streamflow data, with results presented under the most downstream basin with sufficient streamflow data (Table 3-11). Basins with some streamflow data and upstream basins with complete streamflow data were filled in using a regression. Otherwise, the number of years of analyzed data reflects the available data in each basin and the overlapping available data at downstream basins. Diversions/Return flow were not accounted for in the first phase of the water balance analysis. By not accounting for these factors in the initial water balance, basins with significant streamflow gains and losses were identified and flagged for the calibration task.

Table 3-11: Basins that were lumped with downstream basins in water balance due to lack of streamflow data

ID	Basin	Forecast Group	Basins that were lumped with downstream basin with streamflow data
3	LRIT2	Brazos	BNLT2
15	RLRT2	Brazos	BKTT2, RKDT2, RSAT2
18	BBZT2	Brazos	BECT2, HBRT2
34	WBZT2	Brazos	HLBT2
35	HPDT2	Brazos	WBZT2, WBZT2U, HLBT2, CLGT2, HPDT2U
40	ROST2	Brazos	SLNT2
47	DLWT2	Guadalupe	PEWT2
51	WHOT2	Guadalupe	WHOT2M, WHOT2U
55	SCDT2	Guadalupe	WRST2
74	CTNT2	Brazos	HICT2
81	HDCT2	Colorado	HORT2
85	LBWT2	Colorado	LBWT2U, CUTT2, CJNT2, LKCT2

Table 3-12: Water balance results, including daily streamflow (QME), runoff (RO), mean areal precipitation (MAP), runoff coefficient (ROC), actual evapotranspiration (AET), potential evapotranspiration (PET), AET/PET ratio, and AET as a percent of MAP.

ID	Basin	Forecast Group	Years in WB	Local QME (cfsd)	Adjusted QME (cfsd)	RO (inches)	MAP (inches)	ROC (RO/MAP)	AET (MAP-RO)	PET (inches)	AET/ PET	AET % of MAP
1	GAST2	Brazos	13	107.3	107.3	3.2	33.2	0.1	30.0	51.5	0.6	0.9
2	BNLT2	Brazos	2	90.6	90.6	11.0	37.7	0.3	26.8	55.8	0.5	0.7
3	LRIT2	Brazos	6	250.0	250.0	13.5	38.6	0.3	25.1	53.9	0.5	0.6
4	PICT2	Brazos	21	109.1	109.1	3.2	33.0	0.1	29.8	52.3	0.6	0.9
5	KEMT2	Brazos	21	165.9	165.9	2.8	31.8	0.1	29.0	52.3	0.6	0.9
6	DNGT2	Brazos	21	117.2	117.2	4.2	31.6	0.1	27.4	51.5	0.5	0.9
7	SDOT2	Brazos	6	58.4	58.4	5.8	37.7	0.1	31.9	52.3	0.6	0.8
8	BYBT2	Brazos	6	39.7	39.7	12.6	34.1	0.4	21.4	55.8	0.4	0.6
9	BCIT2	Brazos	5	32.3	32.3	15.9	36.1	0.4	20.2	55.8	0.4	0.6
10	BKFT2	Brazos	5	23.7	23.7	7.6	37.8	0.2	30.2	55.8	0.5	0.8
11	BSYT2	Brazos	5	15.8	15.8	2.8	34.1	0.1	31.4	55.8	0.6	0.9
12	BKTT2	Brazos	0	--	--	--	--	--	--	--	--	--
13	RKDT2	Brazos	0	--	--	--	--	--	--	--	--	--
14	RSAT2	Brazos	0	--	--	--	--	--	--	--	--	--
15	RLRT2	Brazos	5	570.0	570.0	9.6	38.9	0.2	29.3	52.5	0.6	0.8
16	CMNT2	Brazos	19	-125.7	-125.7	-16.0	34.4	-0.4	50.5	55.8	0.9	1.5
17	BECT2	Brazos	0	--	--	--	--	--	--	--	--	--
18	BBZT2	Brazos	21	609.5	609.5	6.8	35.9	0.2	29.0	54.5	0.5	0.8
19	WBAT2	Brazos	19	189.8	189.8	6.3	36.1	0.2	29.8	55.8	0.5	0.8
20	HIBT2	Brazos	21	669.0	669.0	7.7	36.2	0.2	28.5	52.3	0.5	0.8
21	BSAT2	Brazos	21	167.4	167.4	11.6	38.7	0.3	27.1	55.8	0.5	0.7
22	GRST2	Brazos	21	-19.2	-19.2	-6.1	38.4	-0.2	44.4	52.3	0.8	1.2
23	EAST2	Brazos	21	118.8	118.8	6.0	37.4	0.1	31.4	51.5	0.6	0.8
24	NGET2	Brazos	21	38.3	38.3	1.3	37.5	0.0	36.2	52.3	0.7	1.0
25	BRYT2	Brazos	21	143.8	143.8	22.2	39.6	0.5	17.5	55.8	0.3	0.4

ID	Basin	Forecast Group	Years in WB	Local QME (cfsd)	Adjusted QME (cfsd)	RO (inches)	MAP (inches)	ROC (RO/MAP)	AET (MAP-RO)	PET (inches)	AET/ PET	AET % of MAP
26	CLGT2	Brazos	0	--	--	--	--	--	--	--	--	--
27	HPDT2U	Brazos	0	--	--	--	--	--	--	--	--	--
28	DMYT2	Brazos	21	81.7	81.7	4.7	35.5	0.1	30.8	51.5	0.6	0.9
29	DEYT2	Brazos	21	76.8	76.8	4.4	36.3	0.1	32.0	51.5	0.6	0.9
30	LYNT2	Brazos	21	85.9	85.9	6.0	37.7	0.1	31.8	52.3	0.6	0.8
31	HBRT2	Brazos	3	165.5	165.5	4.8	40.0	0.1	35.2	52.3	0.7	0.9
32	HLBT2	Brazos	0	--	--	--	--	--	--	--	--	--
33	WBZT2U	Brazos	0	--	--	--	--	--	--	--	--	--
34	WBZT2	Brazos	0	--	--	--	--	--	--	--	--	--
35	HPDT2	Brazos	0	1216.3	1216.3	7.8	41.5	0.2	33.7	52.1	0.6	0.8
36	BEMT2	Brazos	20	198.6	198.6	7.2	42.5	0.1	35.3	55.8	0.6	0.8
37	BAWT2	Brazos	20	493.3	493.3	19.6	45.8	0.5	26.2	55.8	0.5	0.6
38	RMOT2	Brazos	20	-117.7	-117.7	-4.3	49.0	-0.2	53.3	52.3	1.0	1.1
39	SLNT2	Brazos	0	--	--	--	--	--	--	--	--	--
40	ROST2	Brazos	21	209.9	209.9	9.0	50.1	0.1	41.1	52.3	0.8	0.8
41	WCBT2	Brazos	0	--	--	--	--	--	--	--	--	--
42	LCPT2	Guadalupe	21	57.3	57.3	7.0	33.9	0.2	27.0	55.8	0.5	0.8
43	LULT2	Guadalupe	19	78.3	78.3	5.4	33.3	0.1	27.9	55.8	0.5	0.8
44	LLGT2	Guadalupe	5	299.8	299.8	13.9	36.7	0.4	22.8	55.8	0.4	0.6
45	GNLT2	Guadalupe	4	77.4	77.4	4.2	35.9	0.1	31.7	55.8	0.6	0.9
46	PEWT2	Guadalupe	3	10.1	10.1	1.3	37.9	0.0	36.7	55.8	0.7	1.0
47	DLWT2	Guadalupe	20	130.8	130.8	3.9	36.3	0.1	32.4	55.8	0.6	0.9
48	GDHT2	Guadalupe	20	-35.7	-35.7	-3.4	35.7	-0.1	39.1	55.8	0.7	1.1
49	WHOT2U	Guadalupe	0	--	--	--	--	--	--	--	--	--
50	WHOT2M	Guadalupe	0	--	--	--	--	--	--	--	--	--
51	WHOT2	Guadalupe	21	107.0	107.0	2.6	32.9	0.1	30.2	55.8	0.5	0.9
52	CUET2U	Guadalupe	0	--	--	--	--	--	--	--	--	--
53	CUET2	Guadalupe	21	57.2	57.2	2.5	33.7	0.0	31.2	55.8	0.6	0.9
54	WRST2	Guadalupe	0	--	--	--	--	--	--	--	--	--

ID	Basin	Forecast Group	Years in WB	Local QME (cfsd)	Adjusted QME (cfsd)	RO (inches)	MAP (inches)	ROC (RO/MAP)	AET (MAP-RO)	PET (inches)	AET/ PET	AET % of MAP
55	SCDT2	Guadalupe	19	65.5	65.5	2.5	34.1	0.1	31.6	55.8	0.6	0.9
56	CKDT2	Guadalupe	19	19.0	19.0	1.9	37.3	0.0	35.4	55.8	0.6	0.9
57	VICT2U	Guadalupe	0	--	--	--	--	--	--	--	--	--
58	VICT2	Guadalupe	21	100.9	100.9	5.1	36.9	0.1	31.8	55.8	0.6	0.9
59	DUPT2	Guadalupe	5	-96.7	-96.7	-10.8	33.6	-0.3	44.4	55.8	0.8	1.3
60	LLET2	Brazos	21	17.3	17.3	0.9	29.5	0.0	28.6	52.3	0.5	1.0
61	CPKT2	Brazos	5	39.9	39.9	3.8	40.0	0.1	36.3	51.5	0.7	0.9
62	DSBT2	Brazos	21	34.8	34.8	1.8	30.8	0.0	29.1	51.5	0.6	0.9
63	DLLT2	Brazos	6	80.9	80.9	5.0	37.1	0.1	32.1	51.5	0.6	0.9
64	PCTT2	Brazos	5	75.4	75.4	2.6	39.7	0.1	37.1	52.3	0.7	0.9
65	HMLT2	Brazos	13	77.6	77.6	1.6	32.0	0.0	30.3	52.3	0.6	0.9
66	FHCT2	Brazos	3	17.9	17.9	21.9	34.8	0.7	12.9	51.5	0.3	0.4
67	FCCT2U	Brazos	2	363.8	363.8	61.1	39.8	1.5	-21.3	51.5	-0.4	-0.5
68	FCCT2	Brazos	3	149.1	149.1	94.6	34.2	2.3	-60.4	51.5	-1.2	-1.8
69	FHGT2	Brazos	3	99.8	99.8	105.9	35.4	3.6	-70.5	51.5	-1.4	-2.0
70	FHHT2U	Brazos	2	187.4	187.4	140.5	40.1	3.5	-100.4	51.5	-1.9	-2.5
71	FHHT2	Brazos	2	-24.2	-24.2	-11.5	39.4	-0.2	50.8	51.5	1.0	1.3
72	MCGT2	Brazos	13	80.1	80.1	5.9	33.6	0.1	27.7	52.3	0.5	0.8
73	HICT2	Brazos	0	--	--	--	--	--	--	--	--	--
74	CTNT2	Brazos	21	265.5	265.5	3.7	33.3	0.1	29.6	51.8	0.6	0.9
75	VMAT2	Brazos	19	63.1	63.1	4.7	34.7	0.1	30.0	52.3	0.6	0.9
76	ACTT2	Brazos	13	-3.3	-3.3	-0.2	34.6	0.0	34.7	55.8	0.6	1.0
77	CRFT2	Brazos	13	30.6	30.6	5.3	34.1	0.1	28.7	51.5	0.6	0.8
78	MCGT2	Brazos	13	80.1	80.1	5.9	33.6	0.1	27.7	52.3	0.5	0.8
79	LKCT2	Colorado	0	--	--	--	--	--	--	--	--	--
80	HORT2	Colorado	0	--	--	--	--	--	--	--	--	--
81	HDCT2	Colorado	5	5.6	5.6	0.7	32.4	0.0	31.7	55.8	0.6	1.0
82	CJNT2	Colorado	0	--	--	--	--	--	--	--	--	--
83	LBWT2U	Colorado	0	--	--	--	--	--	--	--	--	--

ID	Basin	Forecast Group	Years in WB	Local QME (cfsd)	Adjusted QME (cfsd)	RO (inches)	MAP (inches)	ROC (RO/MAP)	AET (MAP-RO)	PET (inches)	AET/ PET	AET % of MAP
84	CUTT2	Colorado	0	--	--	--	--	--	--	--	--	--
85	LBWT2	Colorado	4	267.9	267.9	2.5	34.1	0.1	31.6	55.8	0.6	0.9
86	BWDT2	Colorado	0	--	--	--	--	--	--	--	--	--
87	SKMT2	Nueces	21	34.0	34.0	1.9	29.6	0.1	27.7	55.8	0.5	0.9
88	MIOT2	Nueces	16	5.9	5.9	0.4	30.0	0.0	29.6	55.8	0.5	1.0
89	REFT2	Nueces	16	125.7	125.7	3.5	33.0	0.1	29.6	55.8	0.5	0.9

3.6.1. Water Balance- Brazos

The Brazos forecast group contained 15 basins that were lumped with a downstream basin for the water balance calculations. This water balance grouping is done when streamflow data is not available for an upstream basin or subbasin (e.g., HICT2 basin was grouped in CTNT2). Most notably, missing streamflow data for 6 basins in the Middle Brazos—WBZT2, WBZT2U, HLBT2, CLGT2, BRYT2, and HPDT2U—required us to group all these basins into the local analysis for HPDT2. This also presented challenges to calibrations in this region.

Other lumped basins included BLNT2 (Belton Lake), an out-of-domain reservoir outlet basin, that was lumped with FHHT2, FHCT2, FCCT2, FHHT2U, FCCT2U, and FHGT2 due to extremely limited streamflow data. WCBT2 is the most downstream basin in our domain and does not have a QME record to conduct a water balance for this basin.

A small number of basins had significant negative ROC values indicative of forcing data errors, unaccounted diversions, or streamflow data issues. This was particularly true at downstream locations where known surface water diversions exist or in areas where there is significant groundwater pumping. For example, RMOT2, a basin near Houston, USGS remarks note that there are many diversions above the associated gauge (e.g., Figure 3-2). Further discussion about potential surface water diversions and efforts to account for these data challenges is presented in section 3.7.

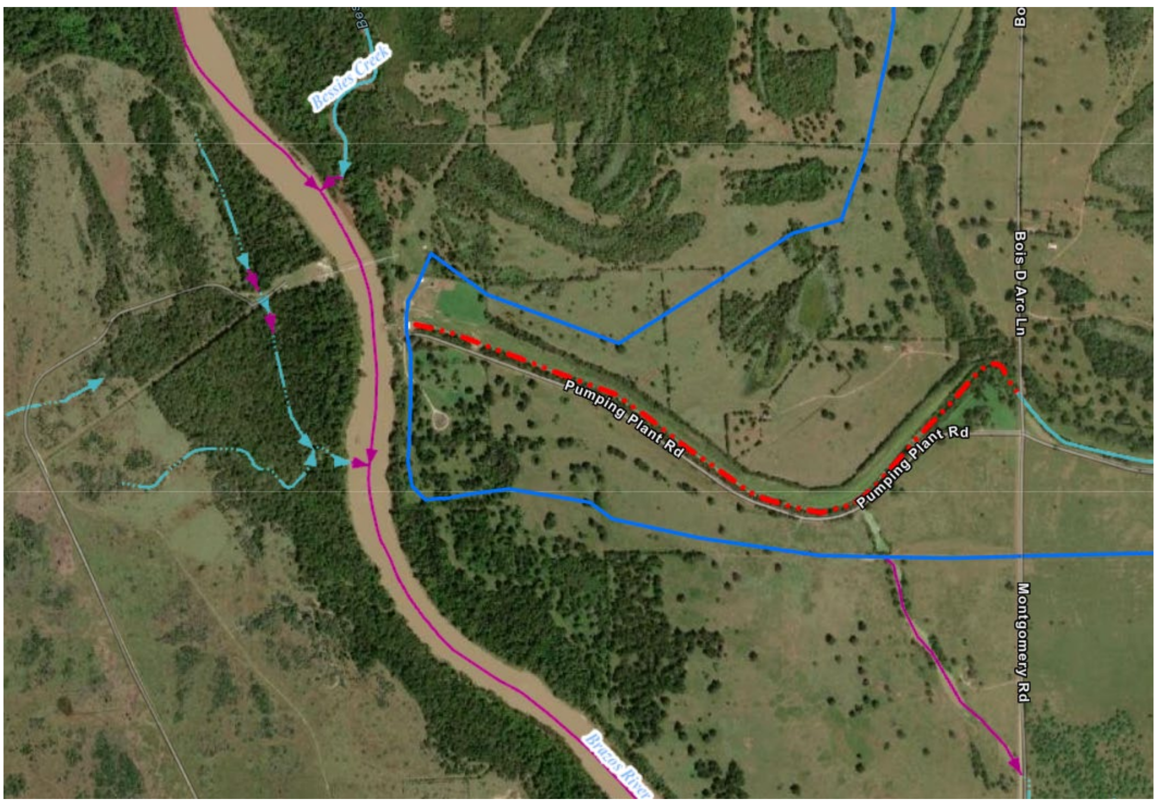


Figure 3-2: A Google Earth screenshot of RMOT2 showing a trans-basin diversion from the Brazos River south of Foster, TX.

3.6.2. Water Balance Results - Guadalupe

Though less developed than the Lower Brazos, the Guadalupe River also has significant apparent surface water diversions as revealed during the water balance analysis. One basin that the water balance highlighted as a particular concern is DUPT2 (ROC -0.30 and a negative average streamflow) in the Lower Guadalupe. Satellite imagery in this basin suggests that there is potentially significant industrial water use at the Du Pont refinery (Figure 3-3). USGS remarks also indicate surface water diversions in the Upper Guadalupe near San Marcos, as well as a large number of Soil Conservation Service flood-detention ponds designed to attenuate peak flows, and which likely affect shorter term water balance in those basins due to increased artificial storage.

Other basins in the Guadalupe forecast group identified as concerns during the water balance include GDHT2, which has a slightly negative ROC value of -0.06; USGS notes that flow at this location is affected by backwater from the Guadalupe River at times. Also noteworthy is significant Gonzales County groundwater pumping in the basin (42 KAF in 2017, 37 KAF in 2018) as reported by TWDB.

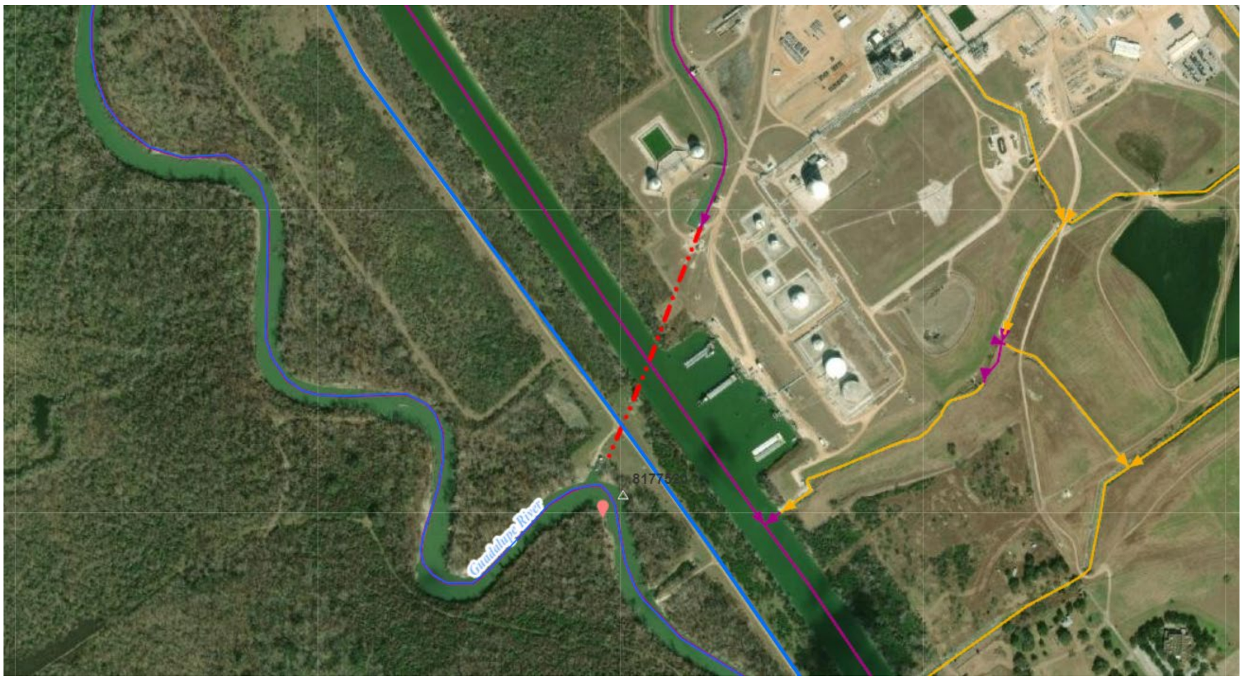


Figure 3-3: Apparent surface water diversions to the DuPont factory near the outlet of DUPT2.

3.7. Surface Water Diversions

Outside of minimally impacted headwater basins, naturalized streamflow (i.e., unregulated and not diverted) is more of an exception than a rule in the Brazos and Guadalupe River basins. This is particularly true along the mainstem of both rivers at downstream locations, where the waters of these two river systems support agricultural irrigation, municipal water supplies, and industrial uses. Indirectly, effects from groundwater pumping are another way the natural streamflow regime is impacted by human development, though on longer timescales. Because rainfall-runoff models such as SAC-SMA produce simulations of naturalized streamflow for a local basin, it is critical to note (through water balance calculations), and perhaps account for, upstream regulations and diversions during the model calibration process.

Seasonal biases in model simulations are one way to identify systematic differences between observed and simulated timeseries. A day of year (DOY) mean of a smoothed QIN/SQIN timeseries has the advantage of minimizing biases of individual events and instead pulling out seasonal influences which may be present in only one dataset, including e.g., surface water diversions used for irrigation. One basin where we observed strong seasonal biases is at ROST2, a local basin on the Lower Brazos outside of the Houston metropolitan area. The DOY mean timeseries shows that during the late summer months (i.e. DOY 200–250), simulated streamflow systematically over-predicts the observed streamflow by upwards of 100 CFS (Figure 3-4). While poor model calibration of the summer baseflows may explain this behavior in an upstream basin, such behavior in a downstream basin which is primarily comprised of routed upstream flows suggests that unaccounted for surface water diversions in the basin are biasing the simulation.

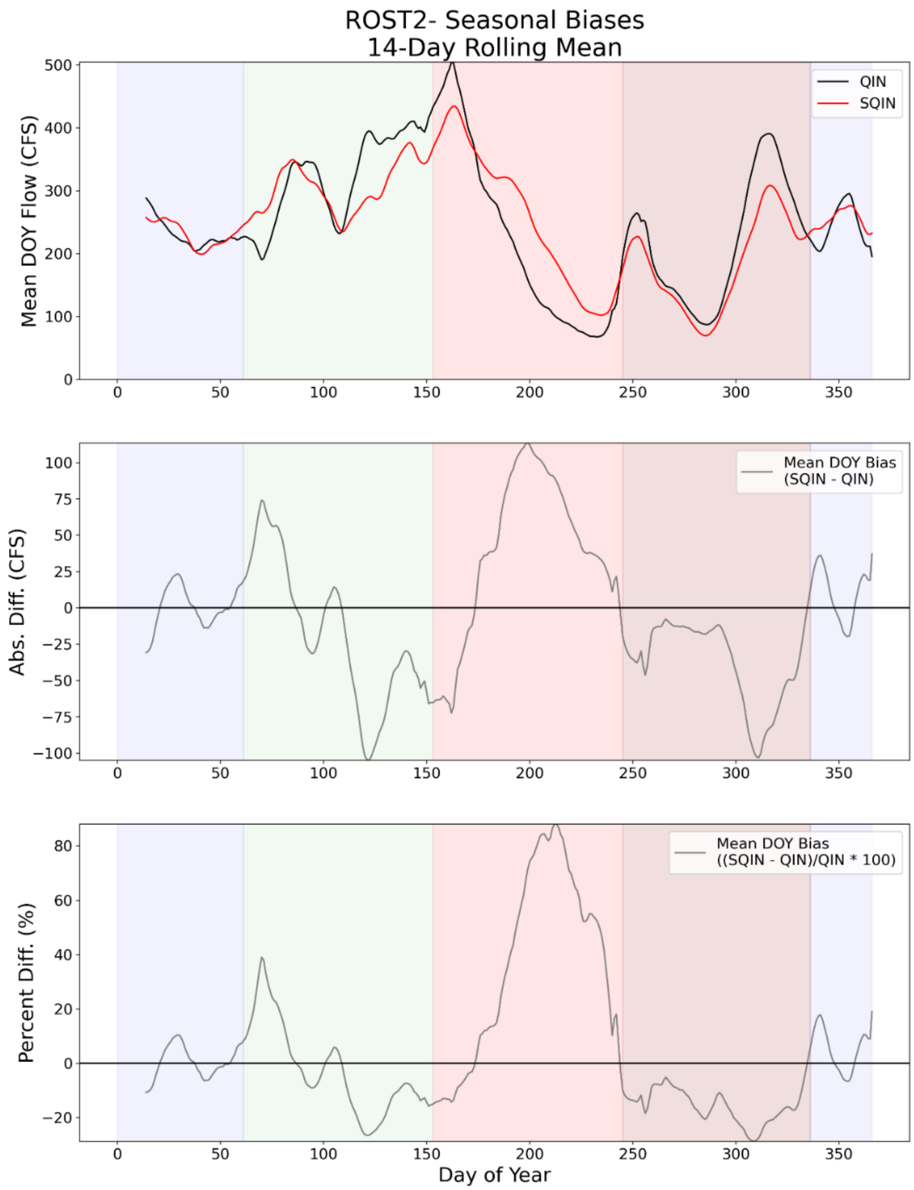


Figure 3-4: Mean day of year flows for QIN (black) and SQIN (red) at ROST2. The bottom two panels show the biases of the simulation as an absolute difference (middle) and a percent difference (bottom). Meteorological seasons are highlighted by the colored bands, e.g., DJF is in blue.

To understand the dynamics of major water uses in the Brazos River more fully, Lynker contacted the Brazos River Authority (BRA), the Gulf Coast Water Authority (GCWA), and other user groups in the basin. Conversations with Chris Higgins, Senior Hydrologist, and Aaron Abel, Water Services Manager, at the Brazos River Authority, as well as Lisa LaRue at the GWCA, were essential in understanding significant surface water diversions, and associated reservoir releases. While point source diversion data is not within the jurisdiction of the BRA, Chris Higgins was able to provide Lynker with reservoir releases for their largest three customers, NRG

Energy, DOW Chemical, and GCWA (Figure 3-5), with the caveat that such releases are supplemental to water rights held by their customers. Development of a CHANLOSS or CONSUSE model to account for these surface water diversions is dependent on obtaining or recreating a time series of point-source diversion data, which may or may not be possible, as these data are not held by BRA but rather individual users such as NRG, DOW, and GCWA. We were able to obtain data for NRG water use, but it only goes back to 2011.

As detailed in the individual basin summary reports (Chapter 4), Lynker requests that WGRFC reviews hydrologic and routing model calibrations as-is before advising as to whether investing further time and resources into recreating diversion data is a something that would be beneficial to WGRFC forecasts.

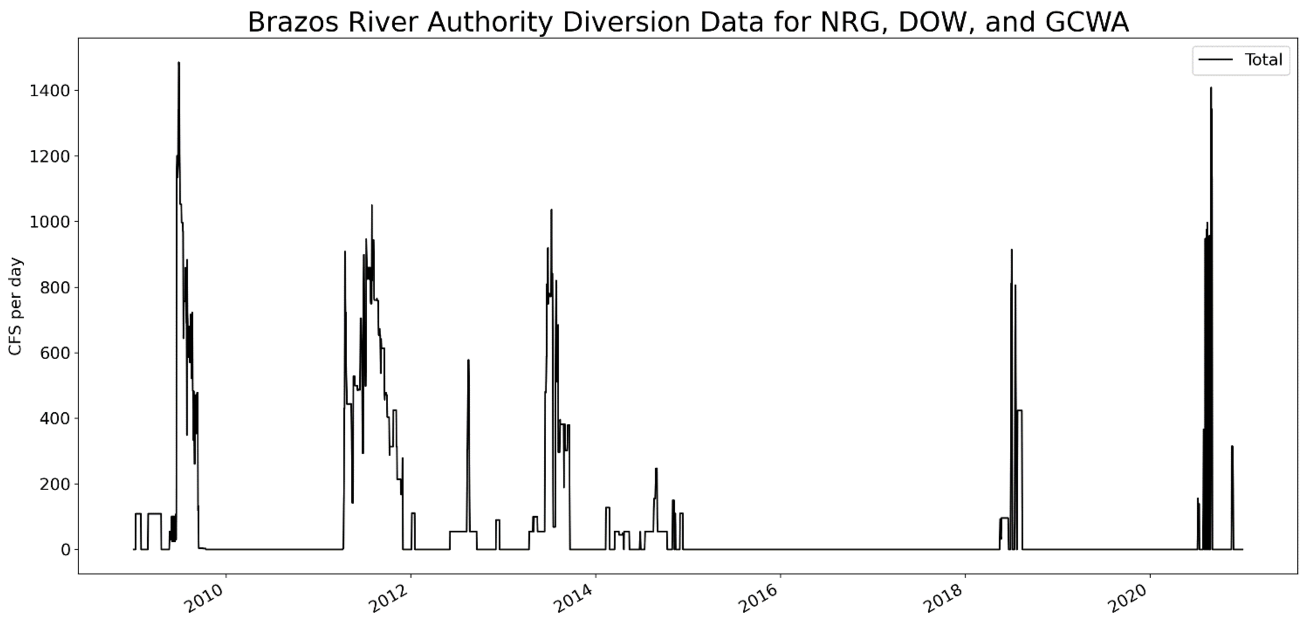


Figure 3-5: Surface water diversion data from the Brazos River Authority for their three major customers: NRG, DOW, and GCWA. Because customers may also hold individual water rights, these data are considered incomplete and furthermore only represent reservoir releases- not point-source diversions.

4. HYDROLOGIC RUNOFF AND ROUTING CALIBRATIONS

All analyses presented thus far have been in preparation for or in support of the hydrologic and routing model calibrations presented here in Chapter 4 and the reservoir calibrations presented in Chapter 5. Prior to presenting the results of the model calibrations, we first summarize the calibration approach used by the Lynker team.

SAC-SMA Calibration Approach

Lynker followed proven procedures and techniques to standardize, streamline, and optimize the manual calibration workflow. Calibration is a very specific and detail-oriented process that requires the use of standard procedures that have been proven to efficiently yield quality results, as summarized by Anderson (2002). In addition to following the Anderson methodology, parameter values were also analyzed for spatial consistency and physical realism (Table 4-1 and Table 4-2) as listed in Anderson (2006) and Anderson (2002). The specific steps followed during the hydrologic model calibration approach are as follows:

1. Identify available data and perform data quality control.

Select a calibration period to reflect a range of streamflow conditions.

For initial estimates of SAC-SMA model parameters, use initial WGRFC parameter estimates, parameter values from nearby basins, or initial parameter estimates developed from available soil, vegetation, or *a priori* datasets.

Adjust initial parameters to remove large biases between simulated and observed streamflow, including timing errors.

   a. Correct large timing errors associated with SAC-SMA model
   b. If overall volume error remains ≥ 10% then critically review water balance analysis for missed biases; may need to regenerate historical MAP data
   c. Confirm UNIT-HG ordinates properly reflect basin area

Adjust SAC-SMA model parameters to obtain a reasonable simulation of baseflow.

   d. Primary baseflow (LZPK, LZFPM)
   e. Secondary baseflow (LZSK, LZFSM)

Adjust SAC-SMA tension water capacity parameters (evapotranspiration and diffusion properties).

   f. Isolate the effect of tension water deficits in upper and lower SAC-SMA zones (UZTWM, LZTWM)
   g. Check PCTIM for percent impervious area

Adjust SAC-SMA storm runoff parameters.

   h. UZFWM – proper division between surface runoff and interflow
   i. UZK – correct timing of interflow
   j. ADIMP – additional impervious area if necessary
   k. Refine shape of percolation curve

Adjust SAC-SMA model parameters to improve monthly, seasonal and streamflow interval bias statistics.

   l. RIVA – riparian vegetation withdrawals
   m. UNIT-HG shape adjustments

ET-Demand curve adjustments. Use a variety of performance criteria to evaluate the accuracy of the hydrologic model simulation and establish the range of expected simulation errors.

Table 4-1: Feasible ranges for SAC-SMA parameters from Anderson (2006).

Parameter	Description	Range
LZFPM	The lower layer primary free water capacity, mm	10–1000
LZPK	Depletion rate of the lower layer primary free water storage, day-1	0.001–0.05
LZFSM	The lower layer supplemental free water capacity, mm	5–400
LZSK	Depletion rate of the lower layer supplemental free water storage, day^{-1}	0.01–0.35
UZTWM	The upper layer tension water capacity, mm	10–300
LZTWM	The lower layer tension water capacity, mm	10–500
UZFWM	The upper layer free water capacity, mm	5–150
UZK	Interflow depletion rate from the upper layer free water storage, day^{-1}	0.10–0.75
ZPERC	Ratio of maximum and minimum percolation rates	5–350
REXP	Shape parameter of the percolation curve	1–5
PFREE	Percolation fraction that goes directly to the lower layer free water storages	0.0–0.8
SIDE	Ratio of deep percolation from lower layer free water storages	

Table 4-2: Anderson (2002) guidelines for initial values of ZPERC and REXP.

General Soil Type	Hydrograph Characteristics	Initial ZPERC and REXP
Clay	Frequent surface runoff, Little baseflow (max of 1 mm/day), PBASE 2 - 4 mm/day	ZPERC: 150 - 300 REXP: 2.5 - 3.5
Silt	Some surface runoff - especially during larger storms, Moderate amount of baseflow (max of around 2 mm/day), PBASE: 4 - 8 mm/day	ZPERC: 40 - 150 REXP: 1.8 - 2.5
Sandy	No surface runoff or only during the very largest storm events, Considerable baseflow (max greater than 2.5 mm/day), PBASE: greater than 8 mm/day	ZPERC: 20 - 40 REXP: 1.4 - 1.8

During the calibration task, Lynker consulted WGRFC on specific parameter constraints and acceptable ranges used in their operations. This included, for example, the decision to maintain a consistent precipitation adjustment factor within the SAC-SMA (PXADJ=1.0). WGRFC staff indicated they wanted to optimize the simulation accuracy using any of the available parameters in hopes of reducing the use of time intensive modifications in their operational forecasts. During the calibration, Table 4-1 and Table 4-2 were to assist in developing the initial adjustments to the SAC-SMA parameters that realistically represented the soil conditions (and other basin characteristics) in each basin.

During the pre-calibration parameter assessment, we flagged basins LCPT2, SMRT2, LULT2, LULT2U for having nonzero SIDE parameter values, since the SIDE parameter has a direct impact on the simulated mass balance. These values were reset to zero at the onset of the calibration process. WGRFC noted that they support using the SIDE parameter when it can be justified, though we did not find there to be a case during model calibrations. Similarly, we also flagged basins that contained a pre-calibration PEADJ values greater than or less than 1.0 (Figure 4-1).

NAME	PEADJ	S
CPKT2	1.095	
LCPT2	0.997	
SLNT2	1.1	
VICT2	0.924	
VICT2U	0.924	
WHOT2	0.97	
WHOT2M	0.97	
WHOT2U	0.97	
WRST2	0.943	
SMRT2	0.997	
RMOT2	1.1	
ROST2	1.1	
SCDT2	0.943	
LLGT2	0.997	
LLGT2U	0.997	
LULT2	0.997	
LULT2U	0.997	
CUET2	0.952	
CUET2U	0.952	
DSBT2	1.095	
DUPT2	0.924	
CKDT2	0.943	
BAWT2	1.1	
BEMT2	1.1	

Figure 4-1: Pre-calibration basins flagged for having SAC-SMA PEADJ parameter values ≠1.0

At the request of WGRFC, monthly season PEADJ curves were implemented in the final hydrologic model calibrations. Seasonal and event-based biases were used to guide the calibration of these PEADJ curves.

UNIT-HG Calibration Approach

A unit hydrograph used in conjunction with the SAC-SMA simulated runoff must account for the delay and attenuation that occurs as local surface and subsurface runoff accumulates over the land surface and subsurface and as the water moves through the channel system within the basin (Anderson, 2002). Initial unit hydrograph ordinates were provided by the WGRFC and imported into CHPS. WGRFC indicated that several of the basin locations were updated to use a smaller timestep, e.g., from 6-hourly to 3-hourly. The new 1-hour/3-hour ordinates provided an adequate initial simulation overall, however, the flashy nature of some basins warranted substantial modifications during the calibration process to capture the rapid rise, peak, and recession of storm events. These changes are discussed in the basin summary reports below, where appropriate, but are also available in the supplemental materials folder. The UNIT-HG ModuleParFiles from the WGRFC SA contained a constant baseflow value for five locations (Figure 4-2); changes to this are also reflected in the individual basin summary reports.

CH5ID	Const Baseflow (cfs)
LCPT2	3
PEWT2	3
VICT2	5
VICT2U	5
SMRT2	7
LBWT2	3
LULT2U	3
DUPT2	5

Figure 4-2: Basins with non-zero constant baseflow values in the pre-calibrated UNIT-HG ModuleParFiles

LAG-K Calibration Approach

The WGRFC uses the LAG/K routing model at downstream basins to route the streamflow from upstream to downstream locations. Routing model parameters can most accurately be determined using several storm events with different magnitudes of streamflow. During the calibration process, the hourly QIN data (when available) were analyzed against the 1-hour or 3-hour SQIN data. When calibrating the routing parameters for each LAG/K model, modifications to the original lag and attenuation parameters were applied to many of the routed segments, where appropriate. As advised by WGRFC, we did not remove (or calibrate) LAG/K flow bins exceeding the routed flows. Initial LAG/K parameters were also compared to values from nearby basins of similar size and orientation. An iterative routing approach that compared upstream routed outflow contributions to total downstream streamflow was performed to reach an optimal parameter set.

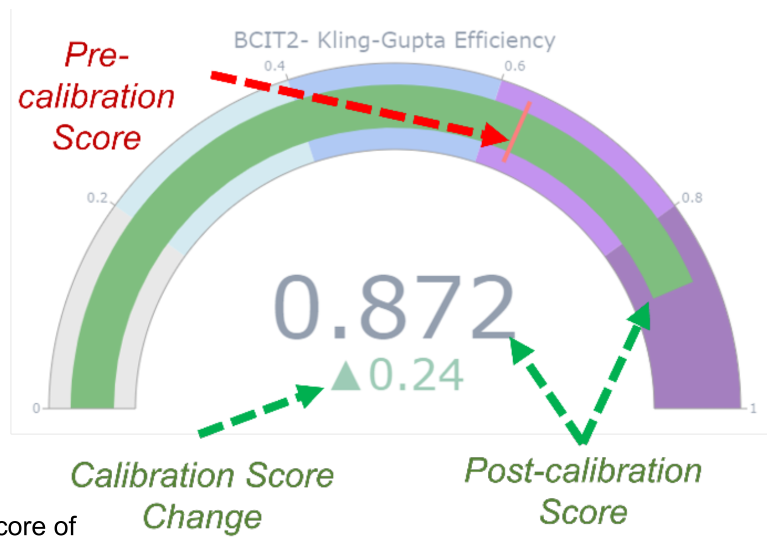
Many routing reaches were initially configured to use a variable lag and constant attenuation routing approach, and this configuration was largely maintained during the calibration process. The LAG/K model can be configured to use either a constant lag and attenuation or a variable lag and attenuation (varies with flow). During the calibration process, a small number of constant lag configurations were updated to use a variable approach. The LAG/K modifier functionality for the CHPS calibration configuration was used for all routing calibration modifications. This functionality allows for an easy pre-calibration to post-calibration comparison from the CHPS modifier display. We recommend WGRFC review the new routing models using the CHPS modifier tab (all calibrated modifiers are stored in the localDataStore), although plots showing LAG/K changes are also available in the supplemental materials directory.

4.1. Basin Calibration Summary

The WGRFC emphasizes the desire to have an overall well-fitting hydrologic model that prioritizes the accurate prediction of flood events, while still performing adequately during low flow months for purposes of water supply planning, particularly in downstream basins. While no specific statistical targets were identified by WGRFC staff, the primary goal of the model calibrations detailed herein was to provide model simulations that are well-correlated with and minimally biased to the observed streamflow records (where available) for the 2000–2020 study period. Though this entire twenty-year period was evaluated during the calibration, a particular emphasis was placed on performance during the most recent decade, in part due to clear hydrologic non-stationarity in certain basins, but also because the more recent streamflow record is generally more serially complete. Furthermore, an analysis of the MAPX and PRISM data suggests significant improvement in the last 5-10 years.

There are several notable flood events in central and southeastern Texas during the last twenty years that were regularly the focus of model calibration efforts. Due to the localized nature of rainfall intensity, spatially heterogeneous basin characteristics, and the large geographic area of the study domain, the severity of the flooding during any one of these events varied from basin to basin. However, the synoptic scale of the largest runoff-generating events (e.g., hurricanes) in this region often meant that flood-stage conditions were observable across much if not all of the study domain. Most notable were the August 2017 Hurricane Harvey floods. Record rainfall of more than 40 inches over the course of four days led to historic flooding in the Houston metropolitan area and other parts of southeast Texas. Other significant flooding of consideration included July 2002 ("South Central Texas Floods of 2002"), May 2015 ("Memorial Day Floods"), and April 2016 ("Tax Day Floods"). The Lynker team worked diligently to reproduce the hydrologic response to these and other flood events, and where appropriate, aimed to highlight these improvements in the individual basin summary reports and figures below.

Model fit was evaluated through an iterative process that combined expert optimization with statistical measurement and a rigorous in-house peer-review. Individual expertise of Lynker calibrators guided initial model calibration to reproduce critical parts of the hydrograph as outlined by Anderson (2002) and discussed earlier. However, statistical metrics were also calculated to objectively measure model performance and improvement. Though the statQME report feature within CHPS is a valuable tool for easily calculating statistics from daily data, Lynker calibrators developed a custom supplemental tool for calculating a suite of metrics from instantaneous data (for hydrologic models, either hourly or three-hourly). In addition to calculating more traditional metrics such as correlation coefficient, RMSE, and percent bias, Lynker also used a multi-criteria efficiency metric called the Kling-Gupta Efficiency (KGE; Gupta et al., 2009), a widely accepted improvement over the hydrologic modeling community's initial efficiency metric of choice, the Nash-Sutcliffe Efficiency (NSE; Nash and Sutcliffe, 1970). Importantly, while similar, there is not a one-to-one relationship between KGE and NSE (Knoben et al., 2019).



Though no "objective function" exists for manual calibration, the following basin summary reports do present the KGE score as a de facto objective function for clarity and conciseness. Because of this, and because of the novelty of the KGE score relative to other statistics favored by hydrologic modelers, it is worth de-constructing the KGE score briefly. Like the NSE score, the KGE score is composed of three components, which together integrates the timing (Pearson correlation coefficient), variability (standard deviation), and the magnitude (mean) of a basin's simulated versus observed streamflow response. Respectively, they are the correlation coefficient, the variability ratio, and the bias ratio (Equation 1). KGE values can range from negative infinity to a perfect score of one. In the basin summary reports below, KGE scores and their respective components are displayed for the period 2010–2020 in the gauge plots, where red lines mark the initial value (negative values displayed as zero), the green gauge and grey text notes the calibrated value, and the green or red text shows the delta.

Equation 1: Kling-Gupta Efficiency formula (Gupta et al., 2009)

$$KGE = 1 - \sqrt{(r-1)^2 + \left(\frac{\sigma_{sim}}{\sigma_{obs}} - 1\right)^2 + \left(\frac{\mu_{sim}}{\mu_{obs}} - 1\right)^2}$$

A high-level assessment of overall statistical performance as measured by the KGE score and its components shows significant improvement across the Brazos, Guadalupe, Colorado, and Nueces River basins. Figure 4-3 shows the distribution of the three KGE components before (blue) and after (orange) model calibration. First, we find that model timing, as measured by the Pearson correlation coefficient, improved from an initial mean value of 0.81 to 0.89 for the entire study period, and from 0.83 to 0.91 for the period 2010–2020 (Figure 4-3 dashed vertical lines on the left panels). Second, we find that the bias ratio, a simple ratio of the simulated mean to the observed mean (Equation 1), shows that prior to calibration, the bias ratio was quite high at a mean value of 1.12 for the period 2010–2020 (i.e., percent bias +12%). Following calibration, the bias ratio decreased to 1.01 (i.e., percent bias +1%; Figure 4-3 dashed vertical lines on the center panels). Finally, we find significant improvements to the overall model variability, or flashiness, as measured by the variability ratio, a simple ratio of the standard deviation of the simulation to the standard deviation of the observed (Equation 1); for the period 2010–2020, the variability ratio decreased from a mean value of 1.14 (i.e., simulated standard deviation was too high) to 1.02. While the true value of an intensive model re-calibration is in the details, these high-level mean statistics demonstrate that the latest calibration efforts are a significant improvement over initial parameter sets, particularly for the most recent 2010–2020 period. The KGE scores, which equally weight these three components (Equation 1), are shown below basin-by-basin for the period 2000–2020 (Figure 4-4, Table 13-1, and Table 13-2) and 2010–2020 (Figure 4-5, Table 13-3, Table 13-4).

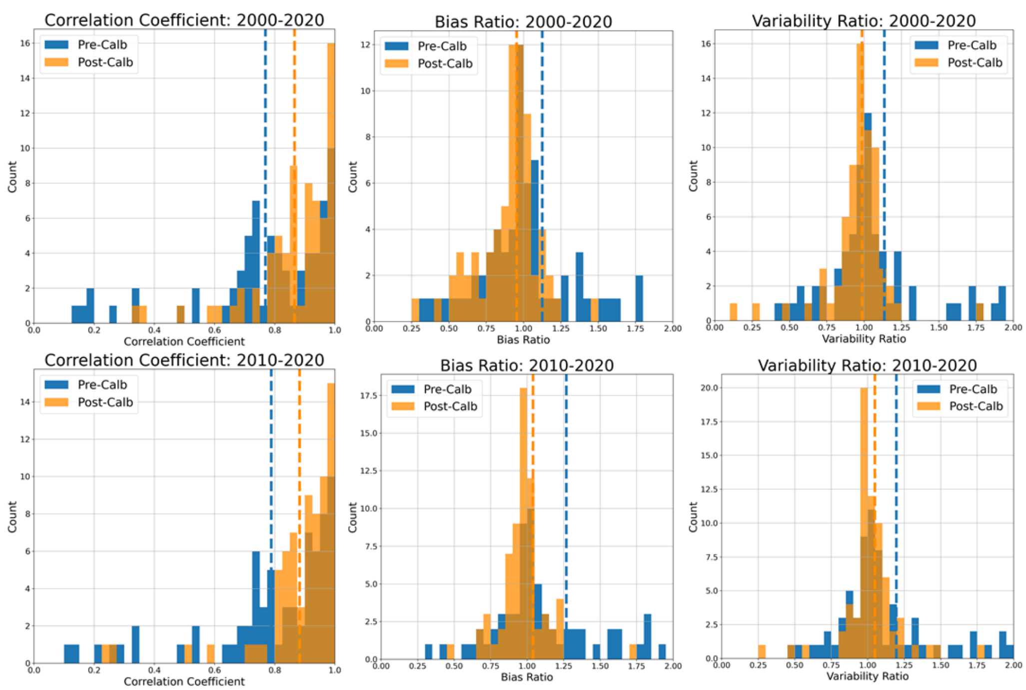


Figure 4-3: Histograms showing the distribution of the correlation coefficient (left), bias ratio (center), and variability ratio (right) for the periods 2000–2020 (top) and 2010–2020 (bottom) for basins. Blue shows initial values; orange show the calibrated values. Mean values are shown in the vertical dashed lines.

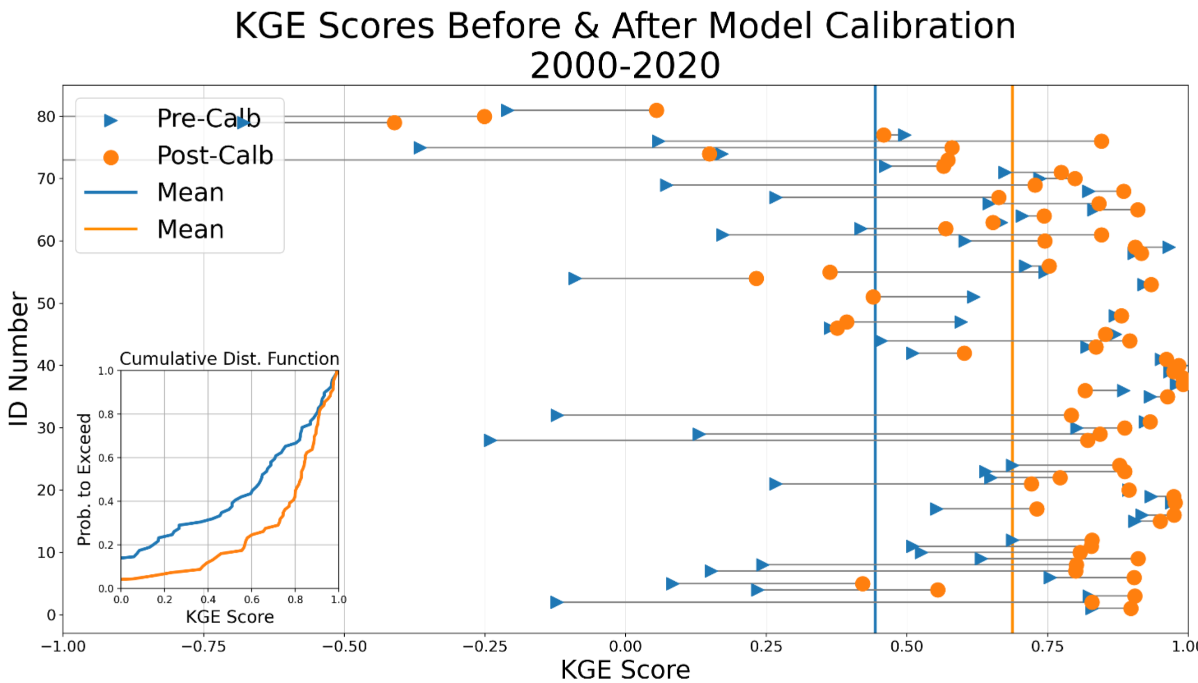


Figure 4-4: Simulation performance (2000–2020) as measured by the Kling-Gupta Efficiency (KGE) before (blue) and after (orange) model calibration for all 83 basins with QIN statistics (ID numbers consistent with tables). The subset plot is a cumulative distribution function showing the probability to exceed a given KGE score.

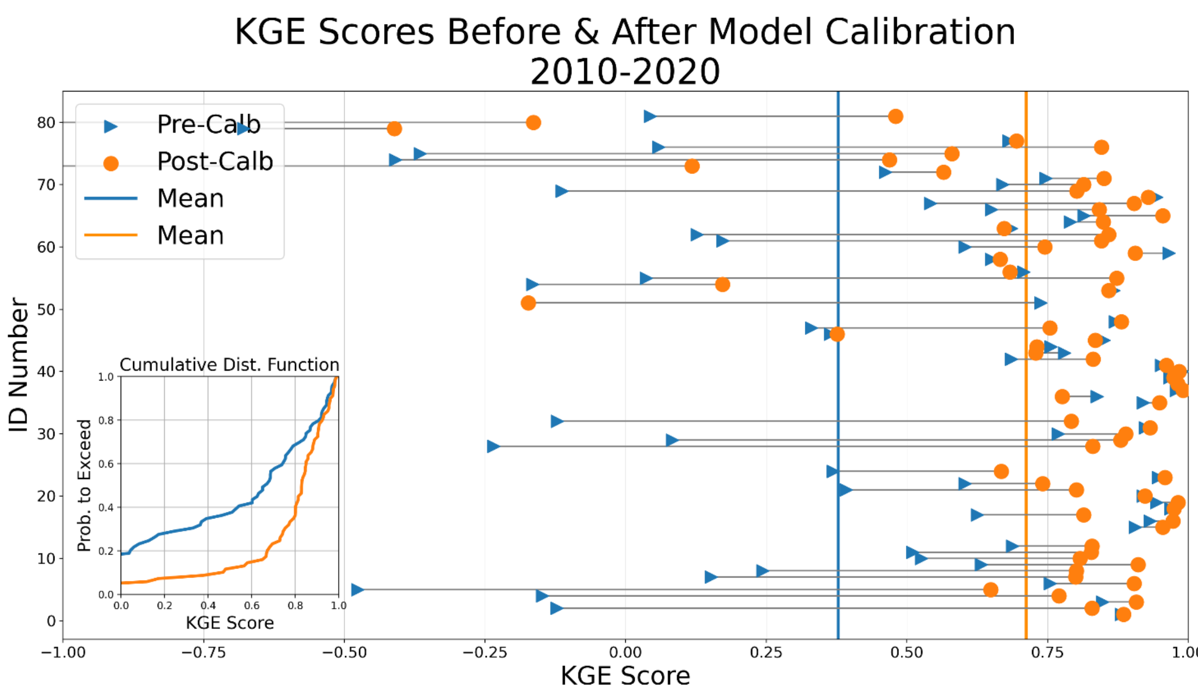


Figure 4-5: Simulation performance (2010–2020) as measured by the Kling-Gupta Efficiency (KGE) before (blue) and after (orange) model calibration for all 83 basins with QIN statistics (ID numbers consistent with tables). The subset plot is a cumulative distribution function showing the probability to exceed a given KGE score.

The following sub-sections organize the individual basin calibration notes by 1) forecast group, 2) hydrologic unit code (HUC)-6 watershed units, and finally, 3) HUC-8 watershed units. For each individual basin and hydrologic calibration, calibration notes are accompanied by a dashboard of figures to highlight important elements of the calibration. A more complete discussion on limitations of these calibration efforts, and sources of error for poorly performing basins (KGE < 0.5), please see Appendix I. Basin dashboards and their individual figures were developed exclusively by Lynker for the consistent and efficient communication of calibration statistics, peak flows, distribution of flows, and SAC-SMA parameters. Working from top left to bottom right, these figures include the following:

1) **Basin Map** – Delineates the watershed boundaries, basin elevation (feet), stream network, USGS gauges, and major roads.
2) **Gauge Plots** –Includes four sub-plots, which include the KGE score (top) and it's three components (bottom). Each sub-plot includes the initial pre-calibrated value (red line), calibrated value (green line and grey number), and the change between those two numbers (green number for increases, red number for decreases). Beginning on the bottom row, these three sub-plots include the correlation coefficient (a measure of timing, with values ranging from 0 to a perfect value of 1), the bias ratio (a measure of bias, calculated by the ratio of the simulated mean to the observed mean, with values ranging from 0 to 2, and a perfect score of 1), and the variability ratio (a measure of the variability, calculated by the ratio of the simulated standard deviation to the observed standard deviation, with values ranging from 0 to 2, and a perfect score of 1). The top plot, the KGE score, is a multi-metric criterion (Equation 1) which equally weighs all three of its components into a single score, with values ranging from 0 to a perfect value of 1. While it is possible for KGE scores to be less than 0 (possible ranges include negative infinity to 1), values less than 0 (very poor performance) are displayed on the Gauge Plots as 0.
3) **Timeseries Plots** – The two timeseries plots in the middle-left of the dashboard compare the observed QIN (black) and simulated SQIN (red) for monthly mean (top) and water year peak flow (bottom) values. These figures give a sense of overall model bias on a monthly basis, as well as a hint at the simulation performance during annual peak flows. Note that the peak flow timeseries may be misleading if the timing of SQIN peak flows is lagged from the QIN peak flows, since the day of peak flow is indexed only by QIN.
4) **Flow Duration Curve** – The plot on the middle-right of the dashboard shows the cumulative frequency curve of the percent of time specific discharge values were equaled or exceeded during the given period (2000–2020 in solid lines, 2010–2020 in dashed lines) for QIN (black) and SQIN (red). This figure shows the tendency of a simulation to over or under-simulate across a given flow range.
5) **SAC-SMA Parameter Plot** – The plot of the bottom of the dashboard illustrates SAC-SMA parameter values for the WGRFC initial (red line) and Lynker calibrated (blue line) values. It also highlights the Anderson (2008) suggested ranges (orange), the *a priori* range (green), and the initial range within the forecast group (purple), all of which were used as guidance during model calibration.

4.1.1. Calibration Summary – Brazos

4.1.1.1. Little HUC6

Leon HUC8

GAST2

GAST2 is a local basin along Leon River whose upstream basin (HMLT2) is a funding dependent site and has yet to be calibrated. Simulations for GAST2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08100500 (available from 1991-10-01 to present). The majority of flow in GAST2 comes from routed HMLT2, and evidence of releases from Proctor Lake can be seen throughout. USGS remarks note that there are numerous diversions above the gauge for irrigation, municipal supply (the city of Hamilton), and oil field operation. With 11% of land area developed, the basin is more developed than other nearby basins. Additionally, the soil characteristics of the basin are mostly split between Type C (sandy clay loam) and Type D (Clay Loam) soil. The single largest land cover class in the basin is herbaceous (57%).

GAST2 had low baseflows, with no flow at times. Baseflow below 5.5 CFS was not able to be well modeled. Flow surpassed the moderate flooding stage (10,100cfs) four times within the study period (2007–2020). Prior to calibration, simulations had a strong negative bias, under-simulating most events. Calibrations focused on increasing the magnitude and rate of recession of the flood events, particularly during the more significant flood events of the last ten years. LAG/K adjustments for HMLT2 (decreased LAG and K) were necessary. GAST2 and several other nearby basins experienced a big event in October 2018, which was a focus for this calibration. The UHG needed to be about 9 hours later and a slightly slower response.

Statistical improvements for this basin were only marginal, due to initial statistics being high already. KGE improved to 0.885 up from 0.881.

WGRFC feedback: *We need the crest to be "spikier" and peak higher and faster.*

Lynker response: We revised SAC-SMA and UHG parameters to improve the basin's response to events (Figure 4-6).

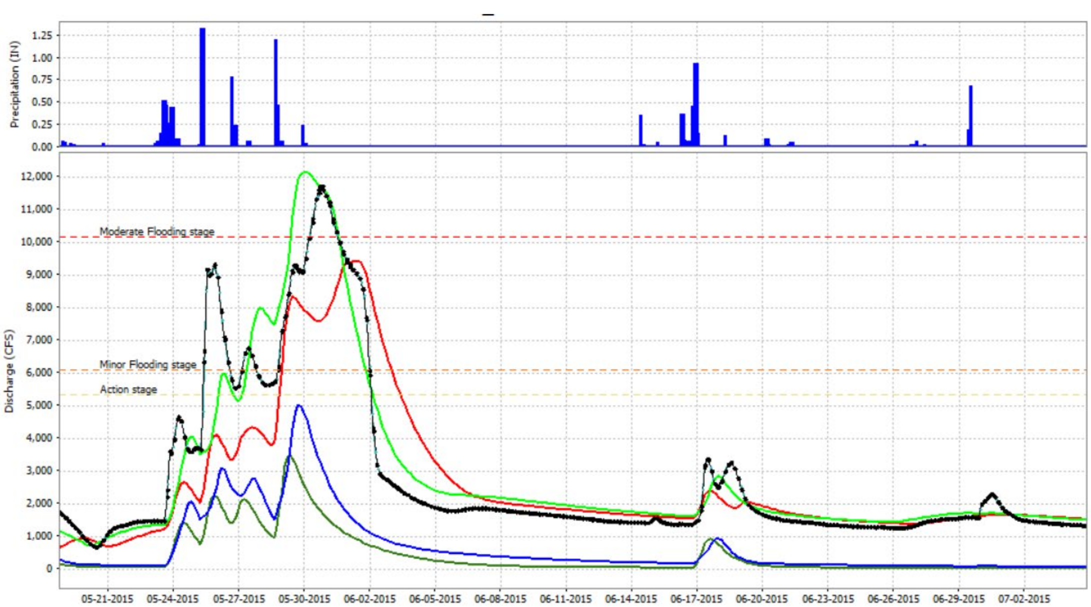
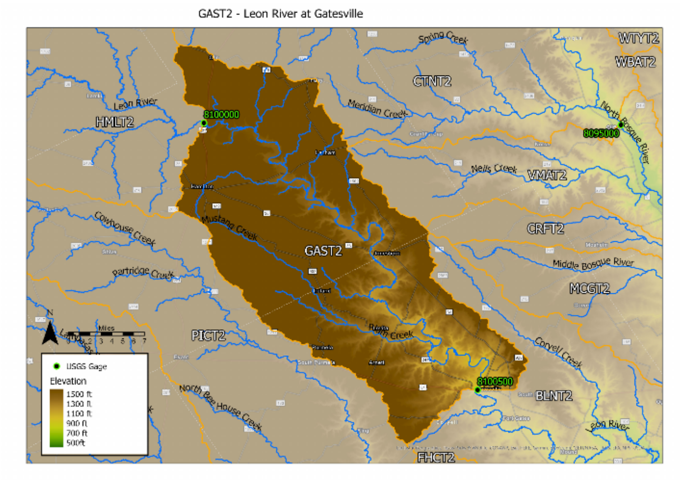
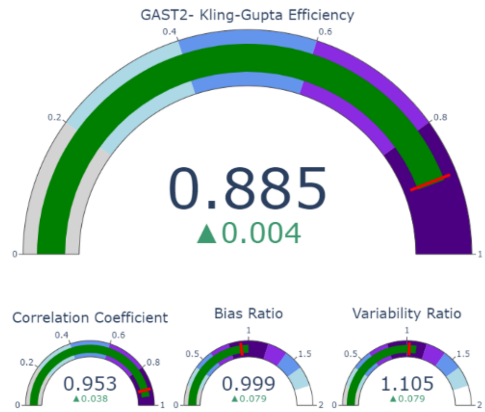
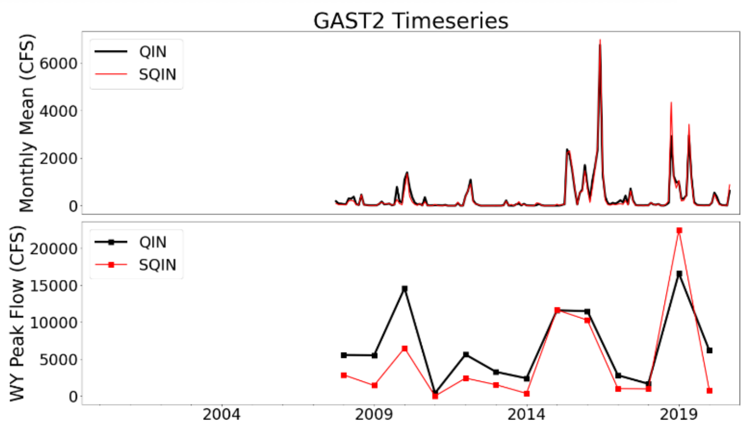


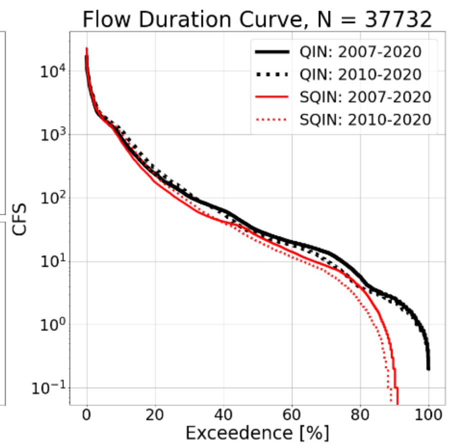
***Figure 4-6*: Improved calibration for GAST2 showing initial (red) and calibrated (lime green) simulations for a June 2015 flood. Dark blue and dark green lines show local flows only for initial and calibrated simulations, respectively.**

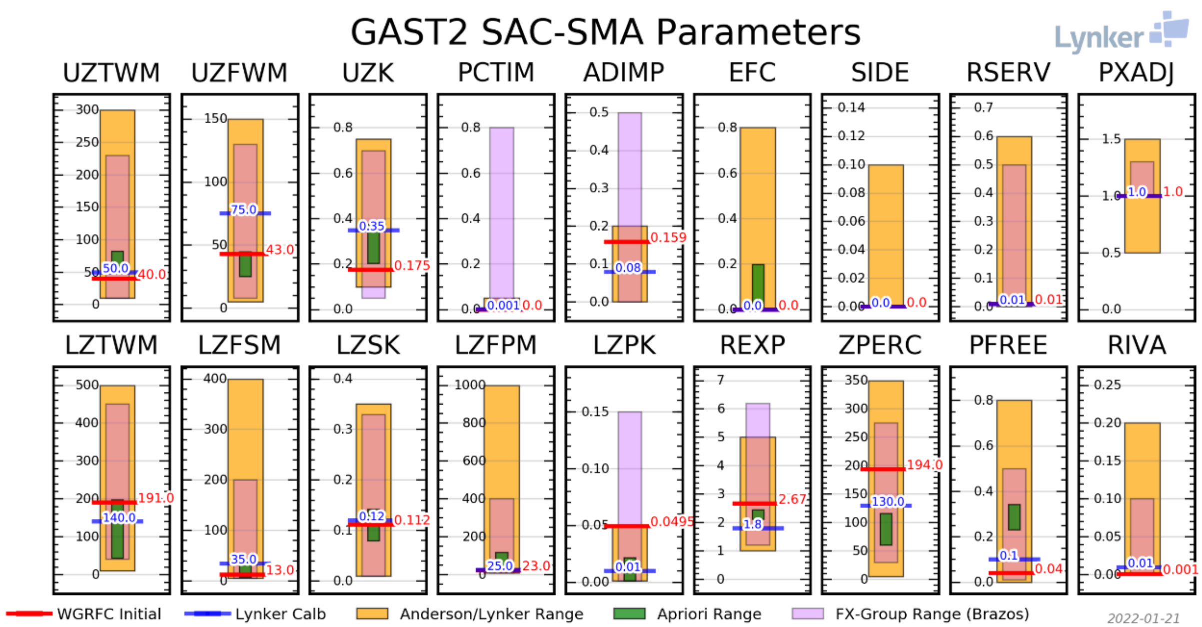
GAST2: Leon River at Gatesville











BNLT2

Nolan Creek at S Penelope, Belton is a smaller headwater basin of Nolan Creek, largely consisting of the town of Killeen. Simulations for BNLT2 were run at a 1-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08102595 (available from 2018-03-28 to present), though records are only rated as fair. Land class is primarily developed land (41%) and herbaceous (29%), with 63% Type D/Clay Loam soil.

The hydrology of BNLT2 can be described as quite flashy. Prior to calibration, events were muted or not registering, and baseflow was too low. Similar to other hourly calibrations, the UHG needed to be much earlier and considerably flashier (Figure 4-7). Final calibrations for BNLT2 were above average for a flashy headwater basin. The biggest events and baseflow were well calibrated, however it was challenging to simulate peak flows during the mid-range (2-5,000 CFS) events.

Statistical improvements were considerable, with a KGE improving from -0.122 to 0.829. Bias for the entire streamflow dataset improved from -67% to -0.158%, and for the top 0.1% of streamflow from -96% to -13%.

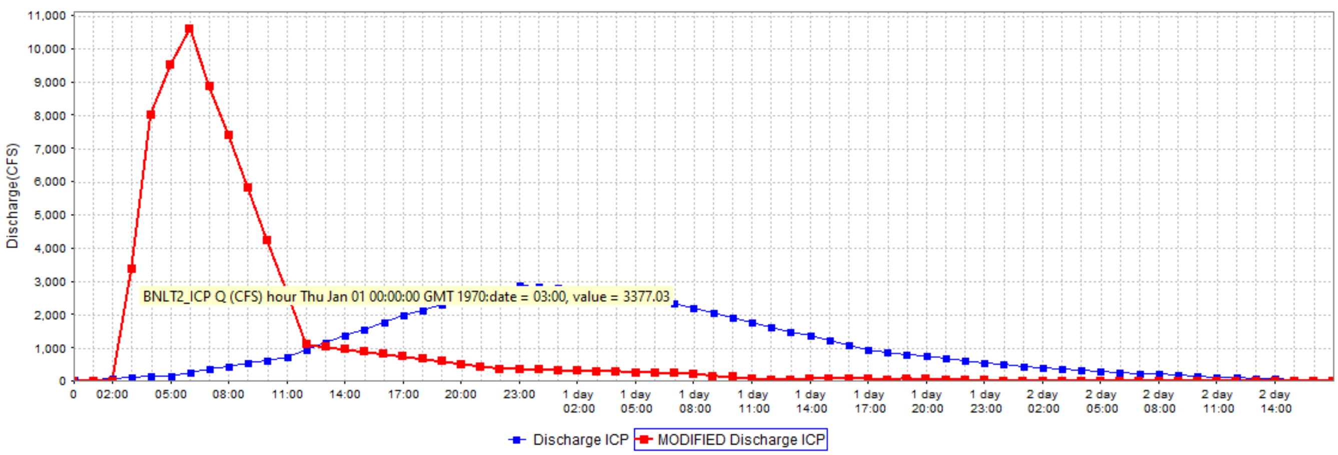
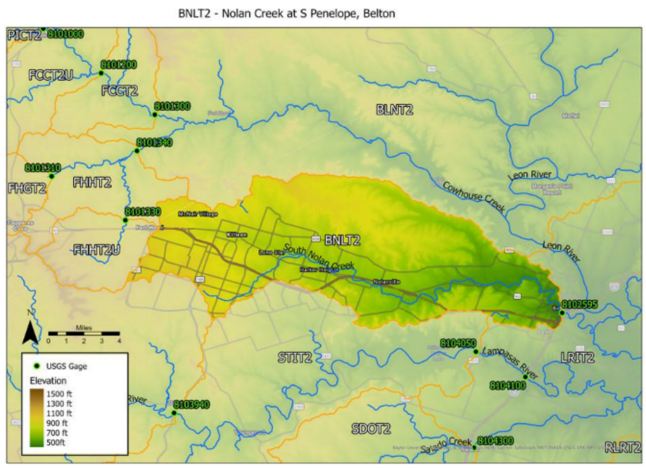
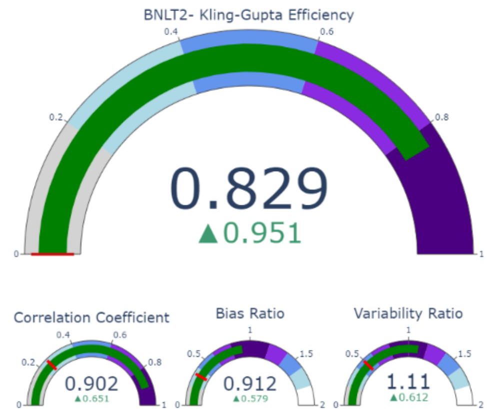
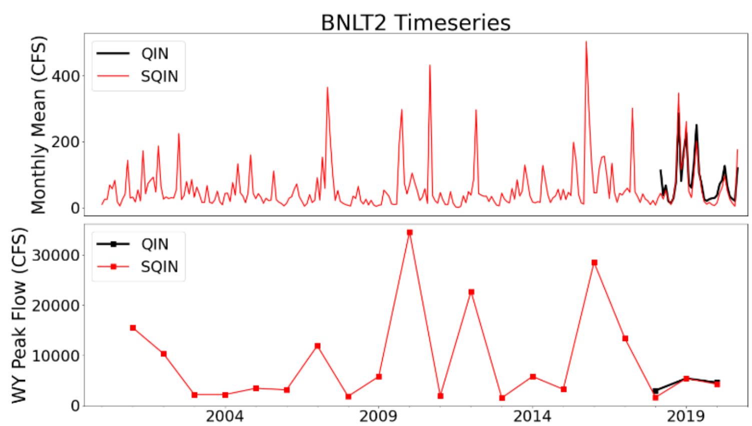


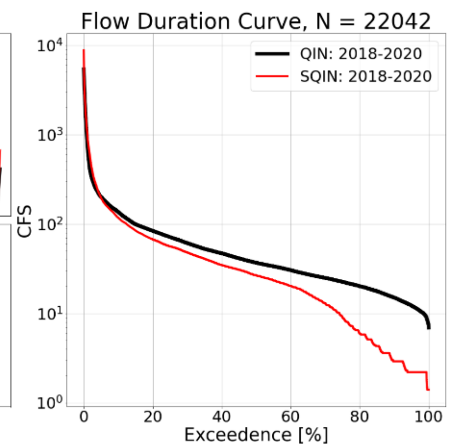
Figure 4-7: UHIT-HG for BNLT2 before (blue) and after (red) calibration.

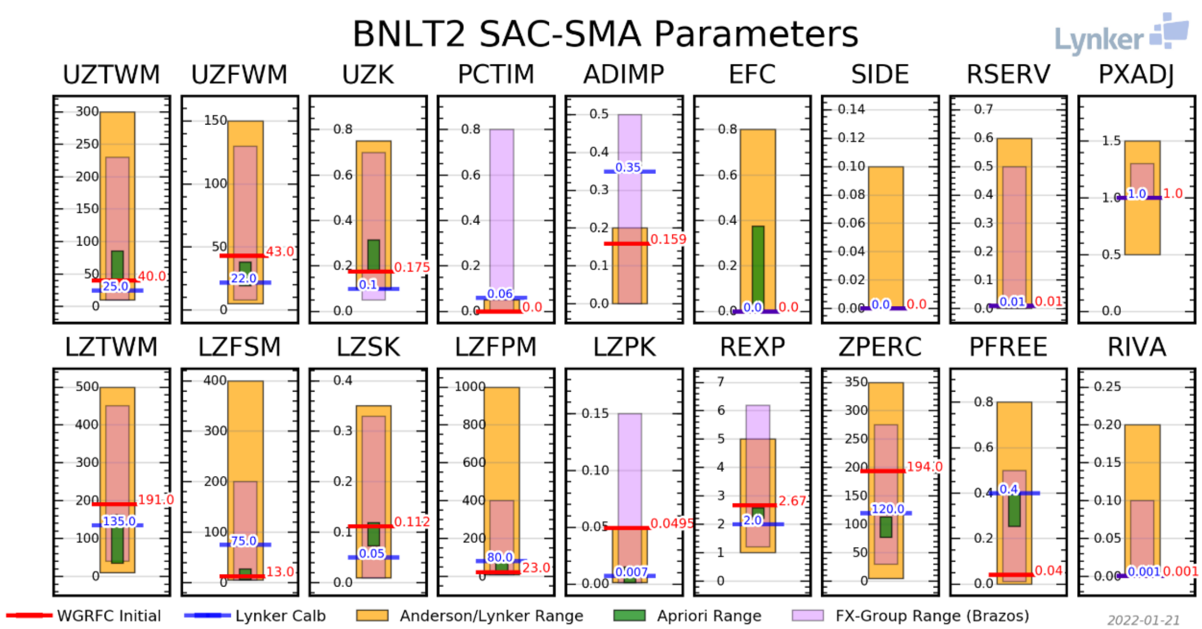
BNLT2: Nolan Creek at S Penelope, Belton











LRIT2

The LRIT2 basin is a local basin at the confluence of the Lampasas River (STIT2), Nolan Creek (BNLT2), Salado Creek (SDOT2), and Leon River (BLNT2), and the Stillhouse Hollow Lake and Belton Lake directly upstream as well. Simulations for LRIT2 were run on a 1-hourly timestep, calibrated to instantaneous flow data from USGS gauge 08104500 (available from 10-01-2007 to present). According to USGS gauge remarks, many small diversions upstream used for irrigation and municipal supply affect very low flow. Soil characteristics are notably clay dominated (65% soil type D), and the largest land cover class in the basin is herbaceous (41%).

At the confluence of several major tributaries, LRIT2 streamflow was mostly from upstream routed flows with limited local streamflow generation. Two of these basins (STIT2 and BLNT2) are outside of the study domain. There was consistently not enough routed flow or too flashy of flow from BLET2 (forecast point with USGS gauge 08102500 for out-of-domain upstream basin BLNT2), which caused high negative bias (Figure 4-8). LAG/K pairs were decreased for BNLT2, STIT2, and SDOT2. UGH curve was shifted about 15 hours earlier.

Statistical improvement for the entire period was minimal, though bias for the largest flood events (0.1%, >22603 CFS) improved from -53% to -5% during the period 2010–2020, and from -62% to -10% during the full 2000–2020 period of record. Adjustments to the timing and attenuation of all three routed flow components were critical in dialing in peak flow simulations.

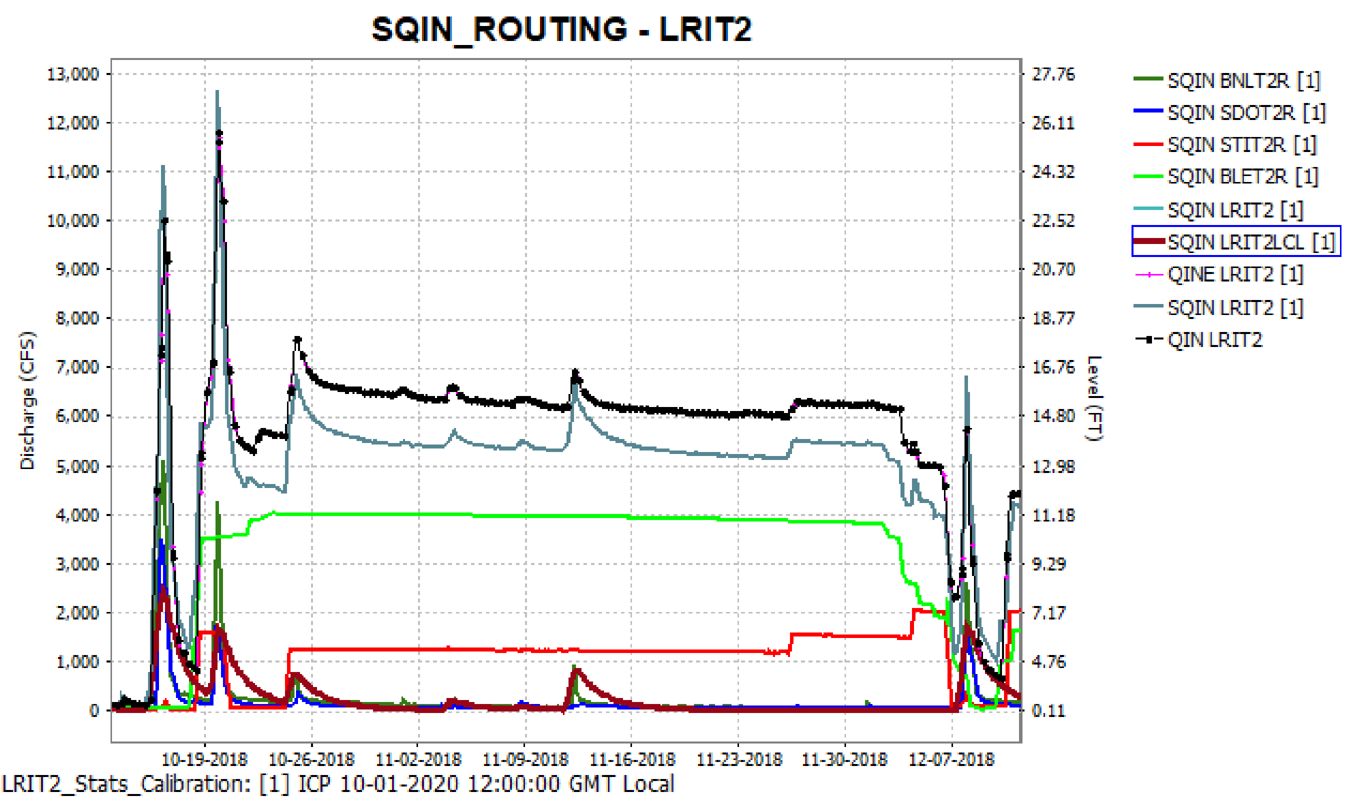
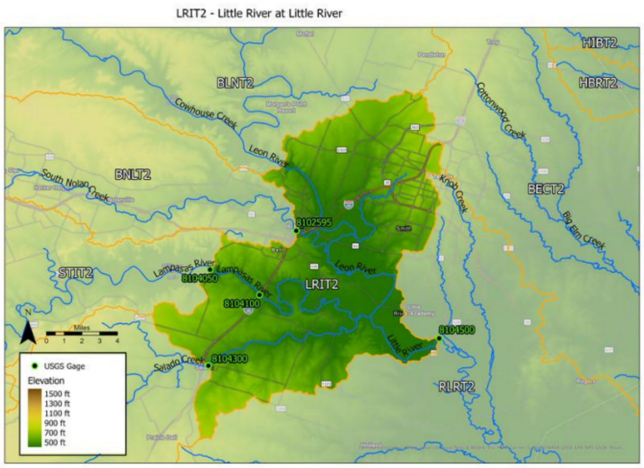
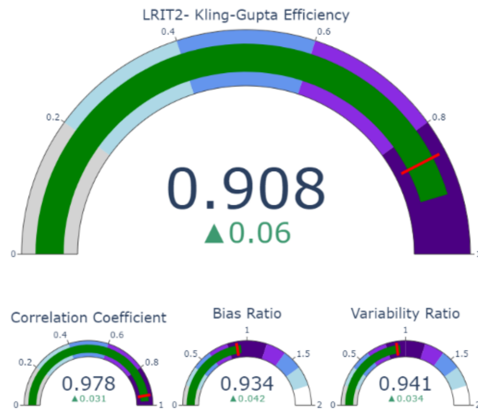
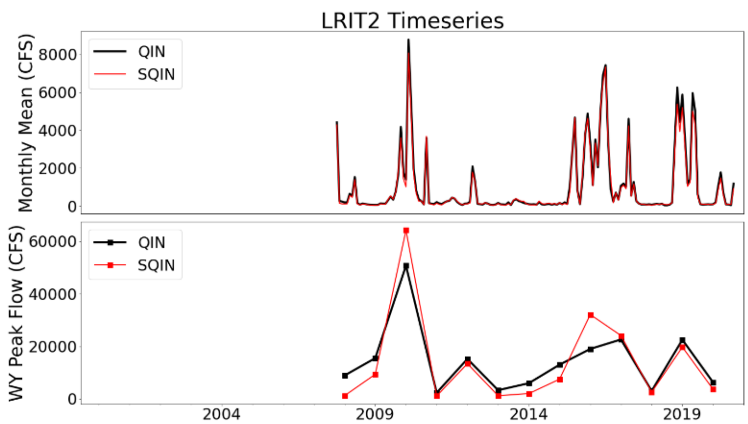


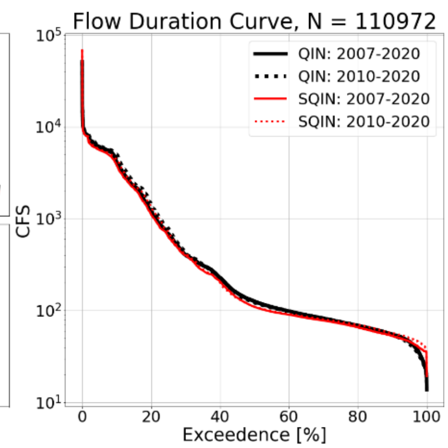
Figure 4-8: SQIN routing curve shows routed flows from BLET2 (lime green) and STIT2 (red) as major contributors to flow during reservoir releases.

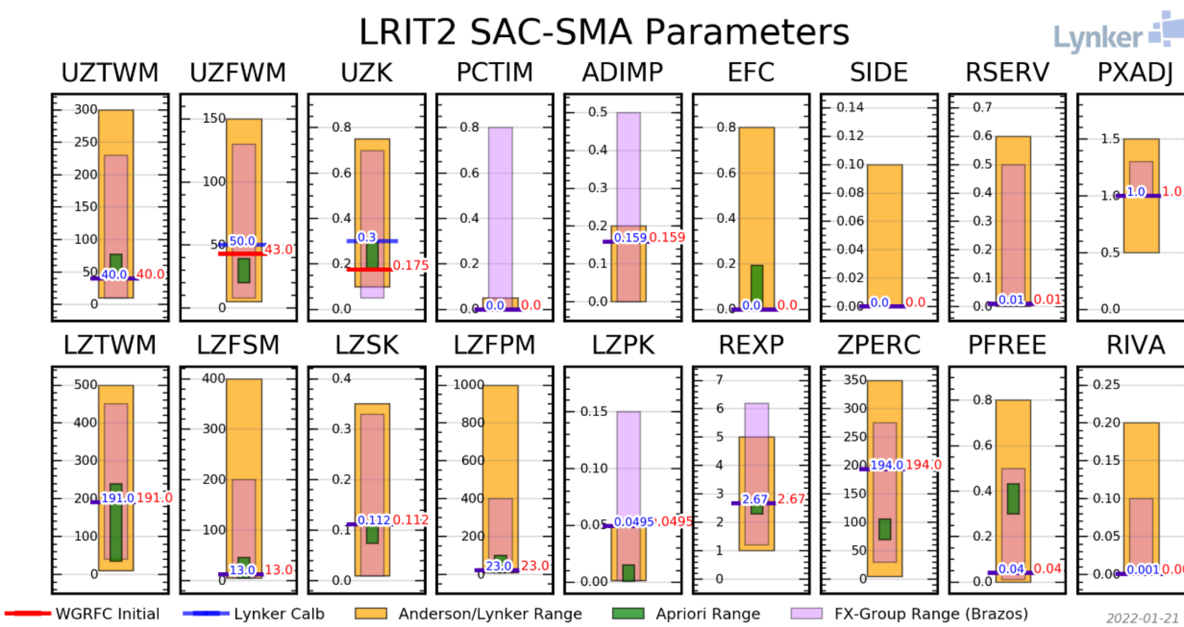
LRIT2: Little River at Little River











Cowhouse HUC8

PICT2

Cowhouse Creek at Pidcoke is a large headwater basin located west of Waco. Simulations for PICT2 were run on a 3-hour timestep, calibrated to instantaneous flow data from USGS gauge 08101000 (available from 10-01-2007 to present). USGS remarks note no known regulations or diversions. About half of the basin (48%) is Type D (Clay Loam) soil. The single largest land cover class in the basin is shrub/scrub (49%).

This basin has been flagged for showing a bias towards under-simulating flood events during the early period of its record (2010 and earlier) and over simulating more recent flood events. Based on our findings that showed better agreement between PRISM and MAPX for more recent events, more weight was placed on the calibration results for the most recent 5-10 years. For example, the precipitation event in January 2010 (peak flow 33,000 CFS), was very under-simulated, and an October 2018 event (peak flow 24,000cfs) was very over-simulated, despite nearly twice as much precipitation occurring at the later event (Figure 4-9). Baseflows at PICT2 were also notably difficult to calibrate due to very low primary baseflow, and very slow secondary baseflow recession rates. UGH curve was shifted later by about 3 hours.

Statistical improvements were significant, particularly as measured by the variability ratio, which was initially too high (i.e., the standard deviation was too high); the ratio improved from 1.953 to 0.918. KGE improved 0.77 from -0.148.

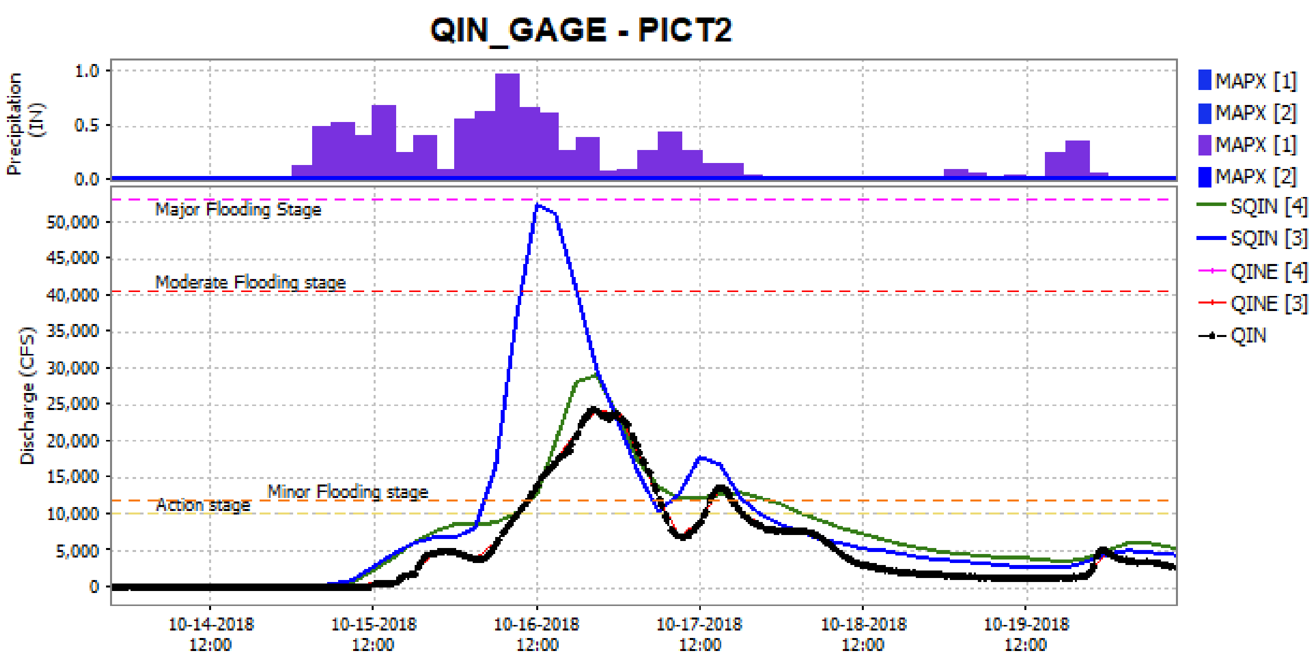
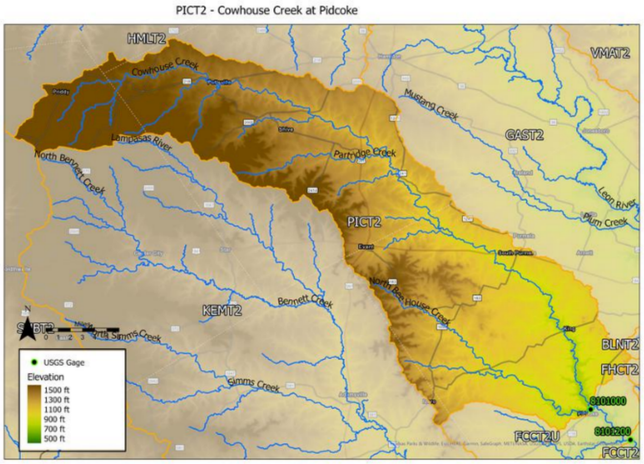
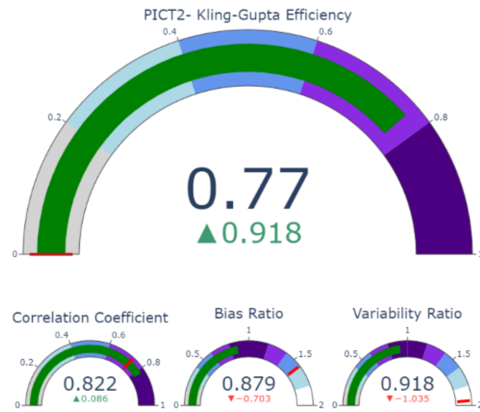
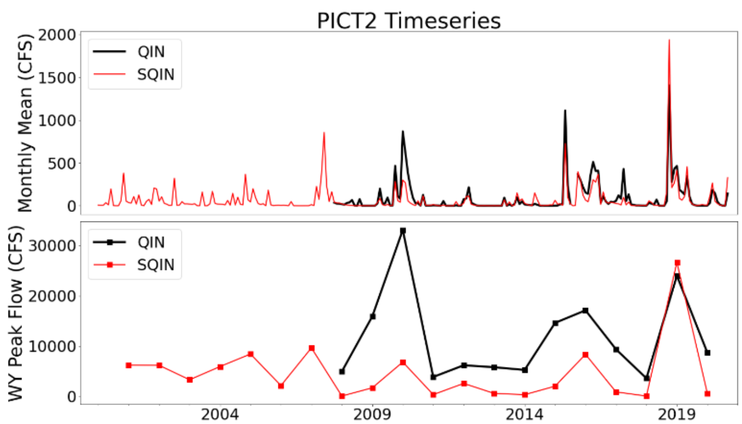


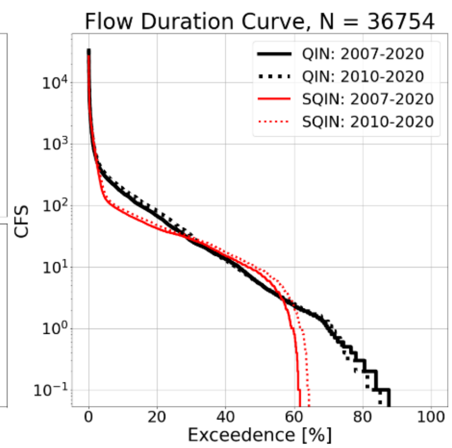
Figure 4-9: Improved calibration for PICT2 with initial (blue) and calibrated (green) simulations for October 2018 event.

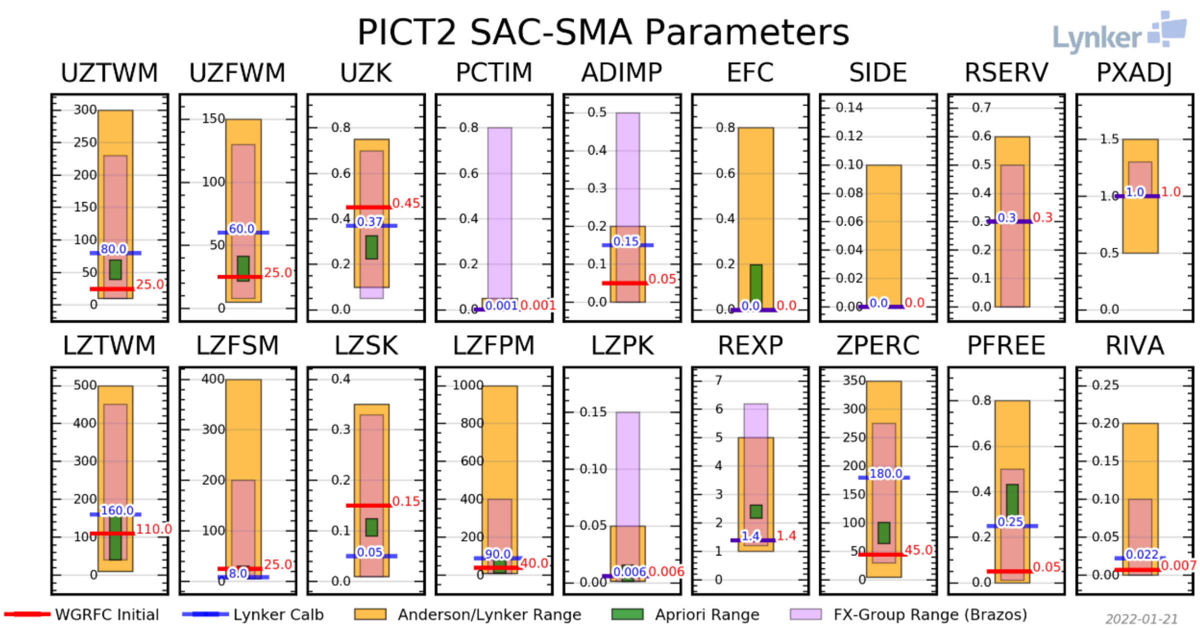
PICT2: Cowhouse Creek at Pidcoke











Lampasas HUC8

KEMT2

The Lampasas River near Kemper is another large headwater basin located west of Waco. Simulations for KEMT2 were run on a 3-hour timestep, calibrated to instantaneous flow data from USGS gauge 08103800 (available from 10-01-2007 to present). USGS remarks note many small diversions for irrigation and municipal supply, with at least 10% of contributing drainage area regulated. Over half of the basin (59%) is Type D (Clay Loam) soil. Two-thirds of the land cover class in the basin is classified as shrub/scrub (66%).

This is another basin flagged with a low bias in the MAPX data in the early period of record. Like PICT2, an early event in 2009 is extremely under-simulated while an equally intense event (the recurring October 2018 event) is over-simulated (Figure 4-10). Based on our findings that showed better agreement between PRISM and MAPX for more recent events, more weight was placed on the calibration results for the most recent 5-10 years. UHG curve was shifted earlier by 3 hours but kept its shape.

Statistical improvements in the KGE score (2010–2020) were attributable to decreases in overall bias (from 64% to -7%) and decreases in the flashiness (variability score). Calibrations were guided towards the most recent decade due to the tilt toward under-simulated flood events pre-2010.

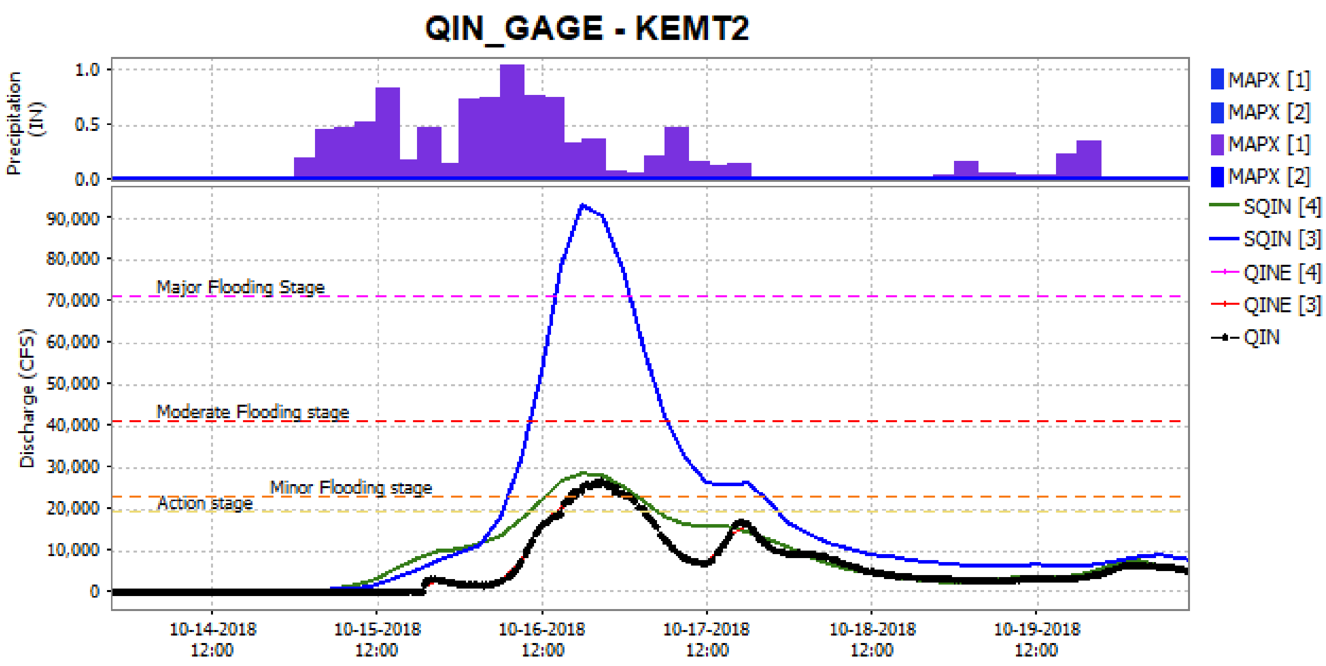
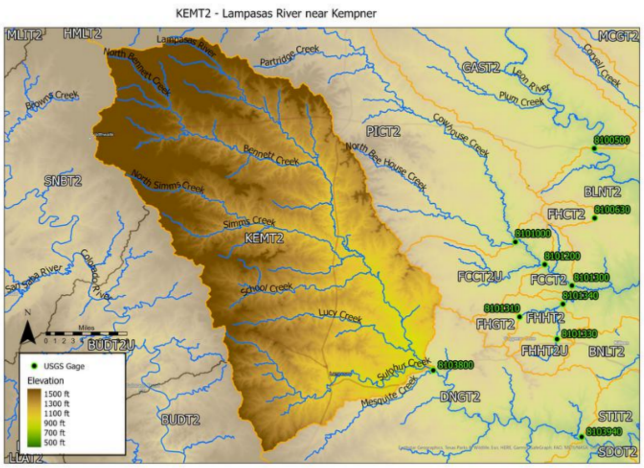
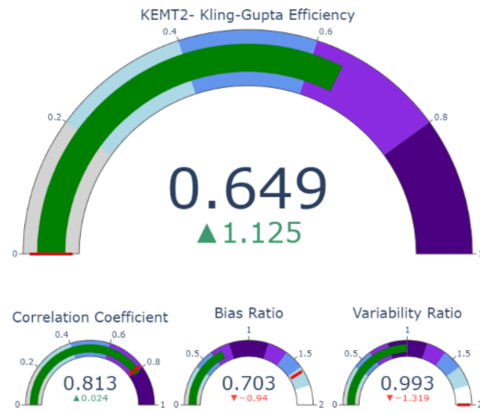
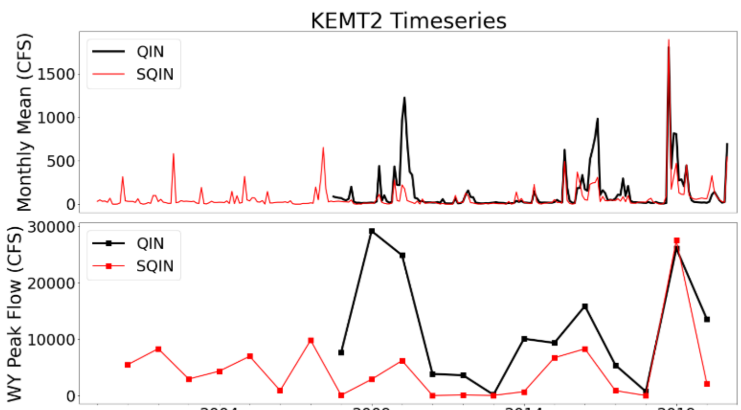


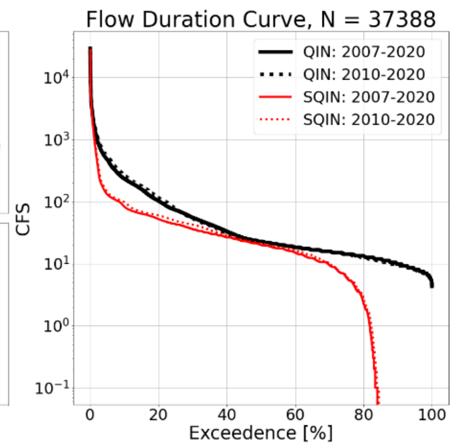
Figure 4-10: Improved calibration for KEMT2 with initial (blue) and calibrated (green) simulations for October 2018 event.

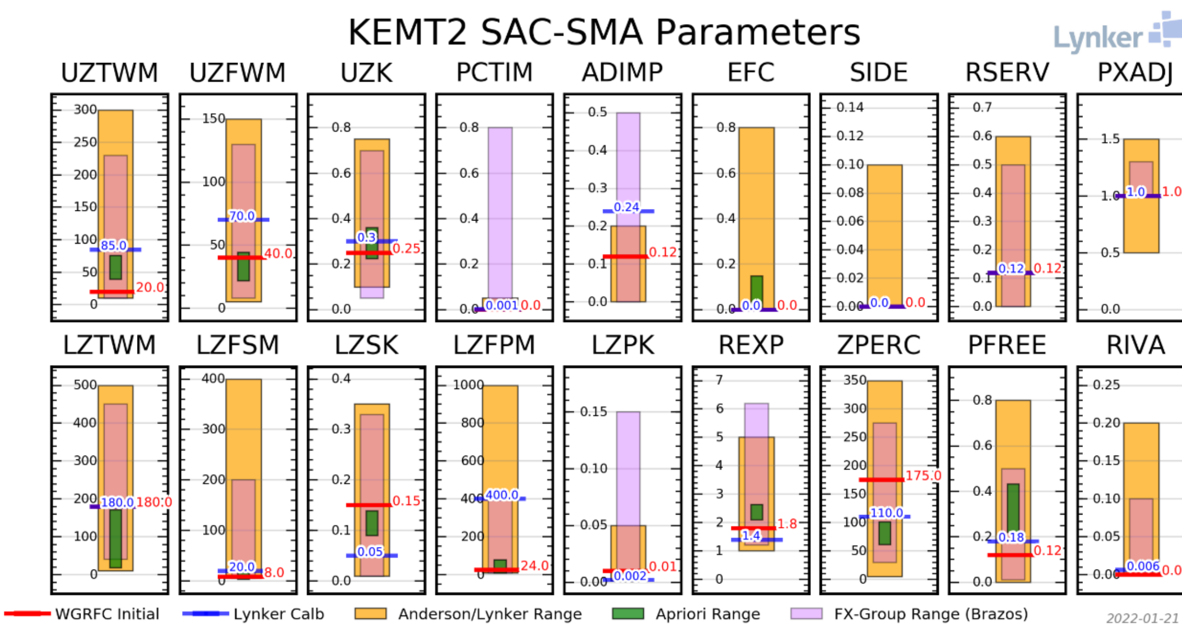
KEMT2: Lampasas River near Kempner











DNGT2

Lampasas River at Ding Dong is a local basin below KEMT2. Simulations for DNGT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS 08103940 (available from 12-10-2015 to present). The basin is clay-dominated, with 75% of the basin identified as having Type D (clay loam) soil. The single largest land cover class in the basin is shrub/scrub (40%).

DNGT2 is a perennial stream with high variability. 75% of streamflow is at or below 294 CFS, with its peak flow in the record hitting 42705 CFS. Baseflow below 20 CFS was often over-simulated. Peaks are well simulated, including the October 2018 flood of record (Figure 4-11). Decreased LAG/K pairs for upstream KEMT2 were necessary, as well as a 12-hour shift earlier in the UHG.

Final calibrations improved the KGE score from 0.755 to 0.904 for the period 2010–2020, mostly driven by improvements in the bias (-19% before, -7.5% after). Calibrations focused on the period after 2015 because of the limited USGS data.

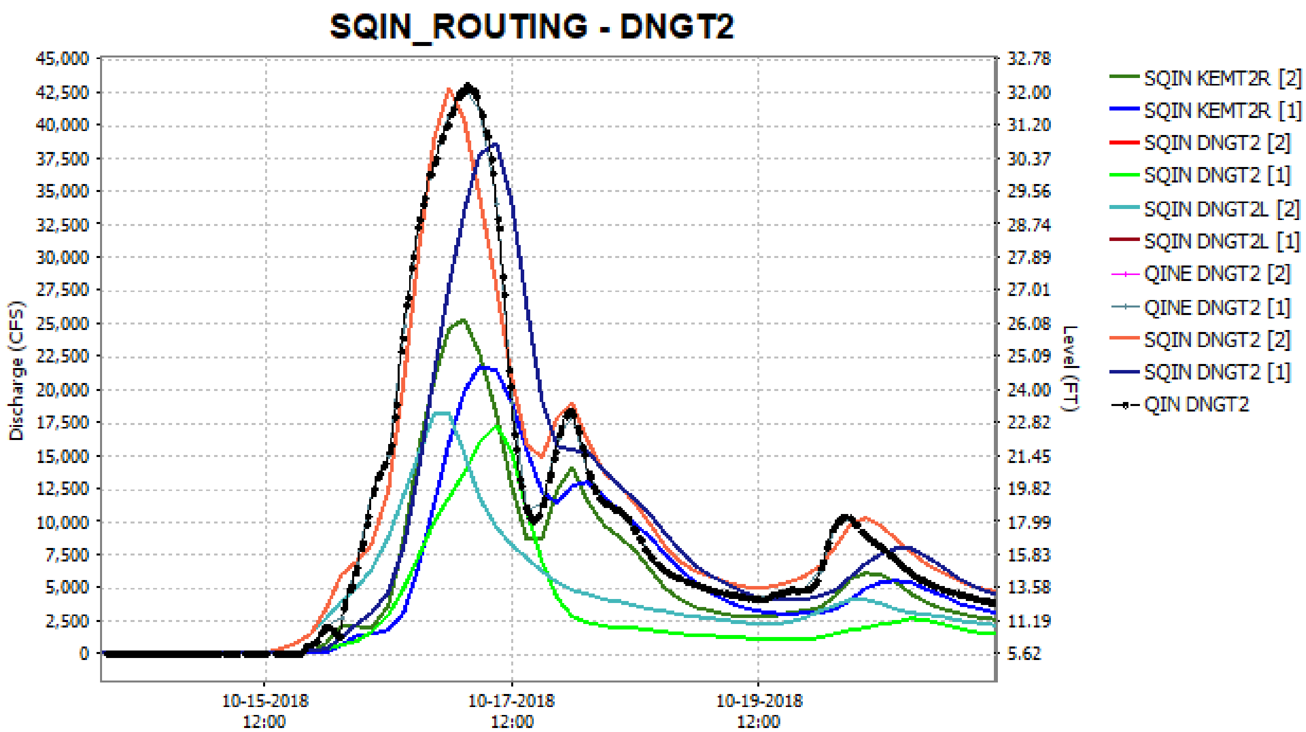
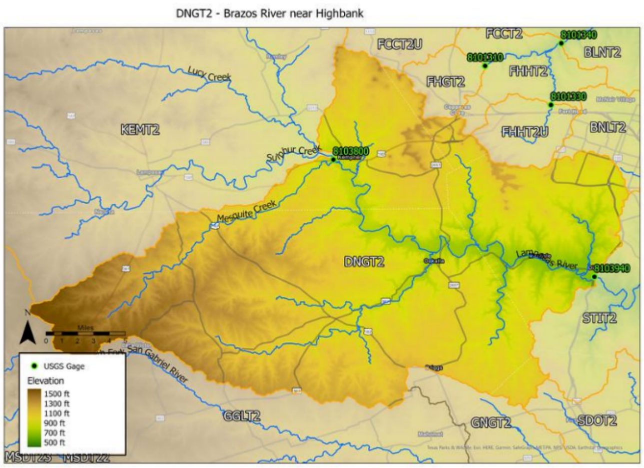
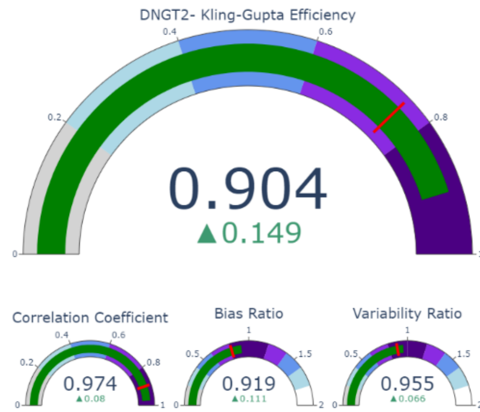
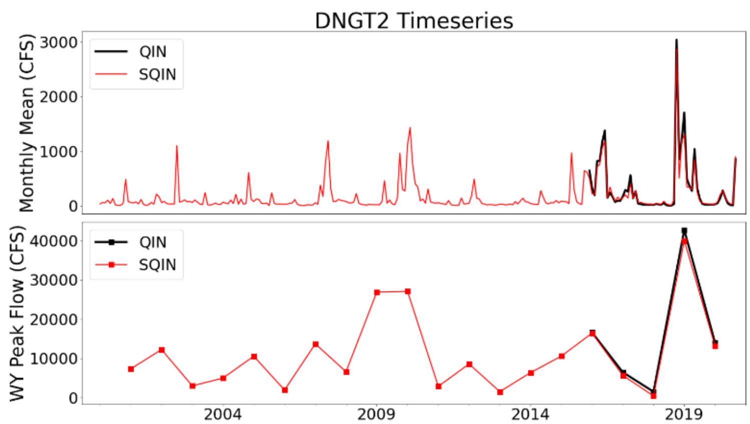


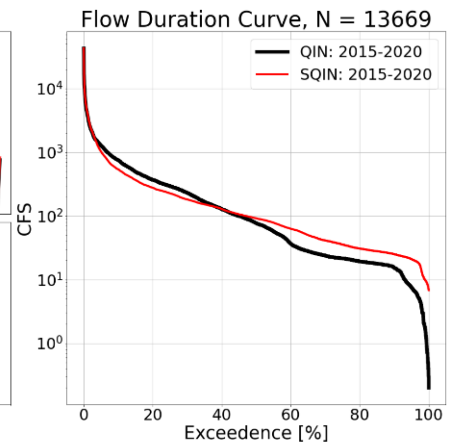
Figure 4-11: Improved calibration for DNGT2 (salmon) was driven by improvements to KEMT2 routed flows (dark green).

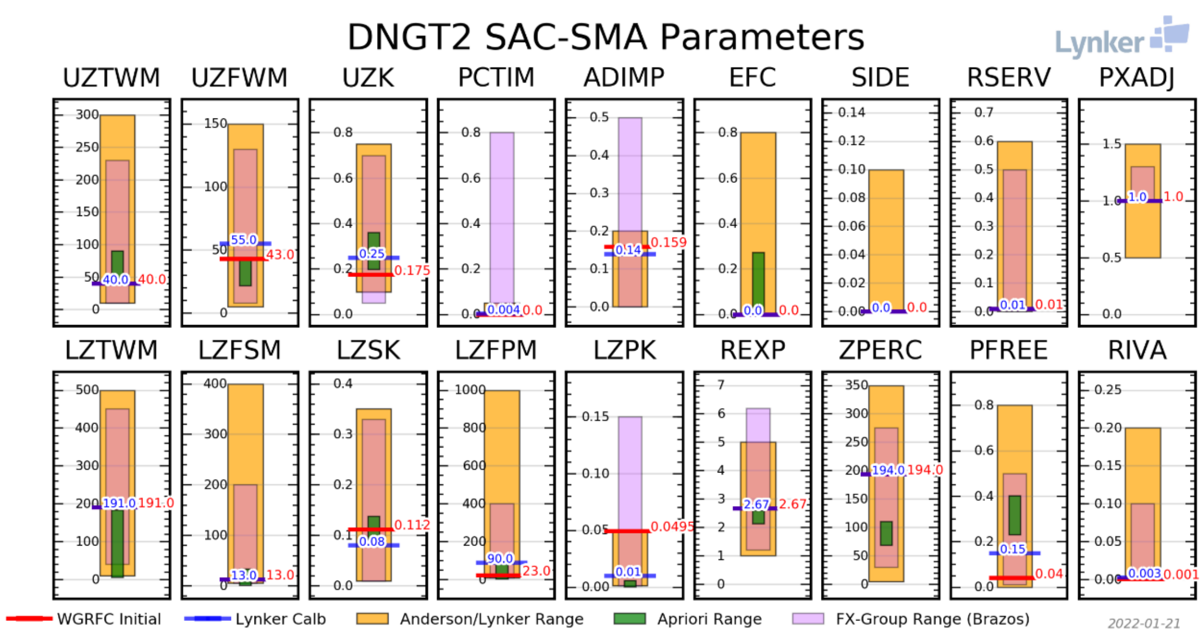
DNGT2: Lampasas River at Ding Dong











SDOT2

Salado Creek at Salado is a small headwater basin south of the city of Killeen and the Stillhouse Hollow Lake Reservoir. Simulations for SDOT2 were run at a 1-hourly timestep, calibrated to instantaneous discharge data from USGS 08104300 (available from 03-22-2013 to present). The basin is clay-dominated, with 92% of the basin identified as having Type D (clay loam) soil. The single largest land cover class in the basin is herbaceous (56%), with only 2% of the land cover classified as developed.

Up until January 2015, QIN data above 40 CFS was not recorded, so only the last 5 years of calibration results were considered. As expected, given the clay-dominated soil types and extent of development, SDOT2 is a very flashy basin characterized by low baseflows (< 44 CFS) and significant storm events (> 6,000 CFS, peaking at ~18,200 CFS within study period). Prior to calibration, simulations for this basin struggled with over-prediction in the beginning of the record, and under-prediction in the more recent record, particularly during the largest peaks. A significant alteration of the UHG curve was necessary, shifting the curve earlier by about 20 hours and higher, by about 6,000 CFS (Figure 4-12).

Statistical improvements were moderate, with the KGE score improving by 0.648, particularly as measured by the variability ratio, which was initially too low (i.e., the standard deviation of simulation was too small). High flow biases (top 1% of flows) were still under-simulated by –16.5%.

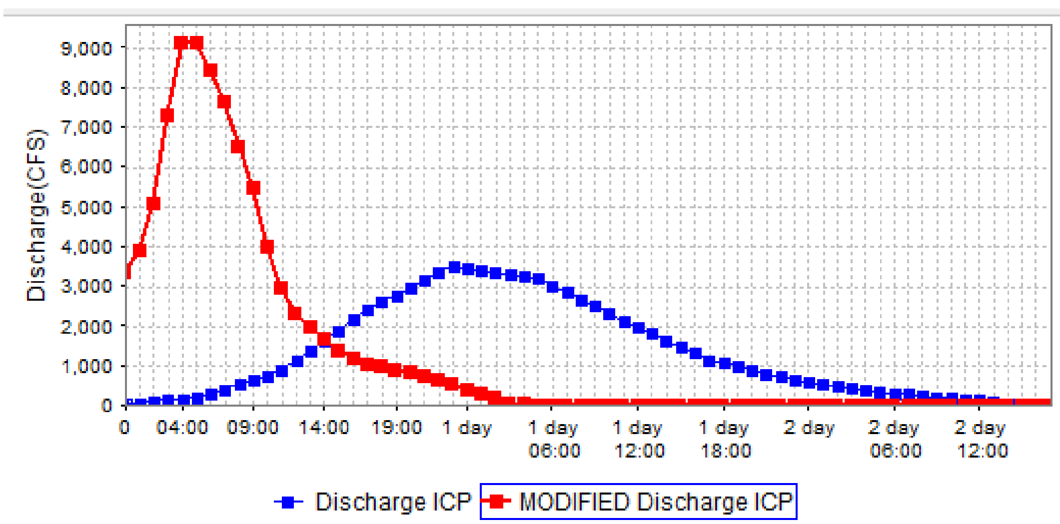
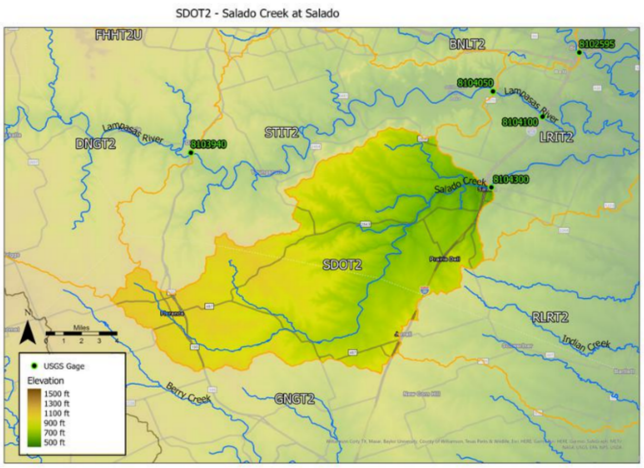
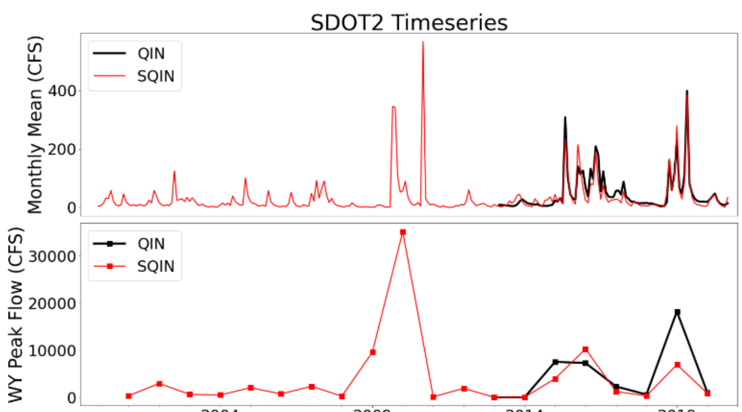
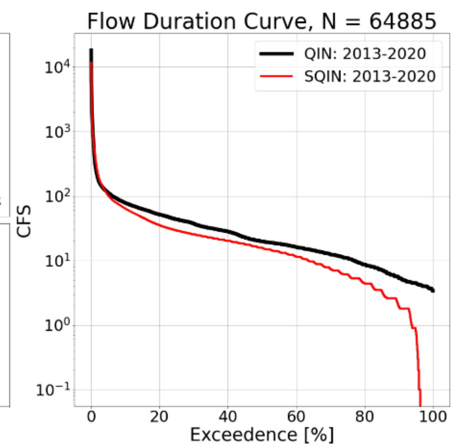


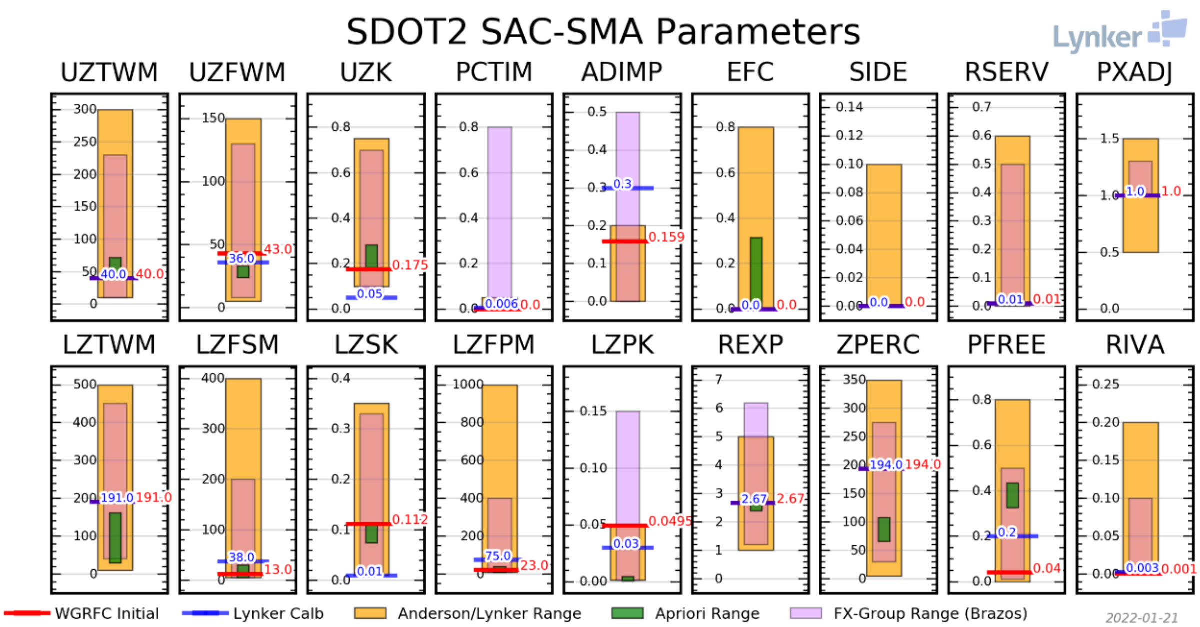
Figure 4-12: UNIT-HG curve modification for SDOT2 basin, with initial (blue) and calibrated (red) shown.

SDOT2: Salado Creek at Salado









San Gabriel HUC8

BYBT2

Brushy Creek at Cedar Park is a very small headwater basin located north of Austin, and was originally a part of RKDT2U. Simulations for BYBT2 were run at a 1-hourly timestep, calibrated to instantaneous discharge data from USGS 08105872 (available from 09-01-2014 to present). Nearly all (96%) of the basin is classified as soil type D (clay loam soil), and the largest land cover class in the basin is developed (46%) containing suburbs of Austin. USGS gauge remarks note that flow records are fair, except those discharges below 1 CFS, which are poor.

The small basin is highly variable, with low baseflow (<20 CFS) and peaks at 3,000 CFS in the study period. During calibration it was very difficult to elevate primary baseflow while not allowing simulated peaks to underperform. The biggest event in the study period in August of 2016 failed to be simulated adequately without significantly under-simulating baseflow (Figure 4-13). The ADIMP modifier was substantially increased to account for the flashiness of the developed/impervious land within BYBT2. The UHG curve was shifted significantly earlier and sharper to reflect the more flashy nature of this basin.

Statistical performance was improved as seen in the KGE score (2010–2020) from 0.24 to 0.801. The correlation coefficient of 0.85 is respectable for such a small headwater basin.

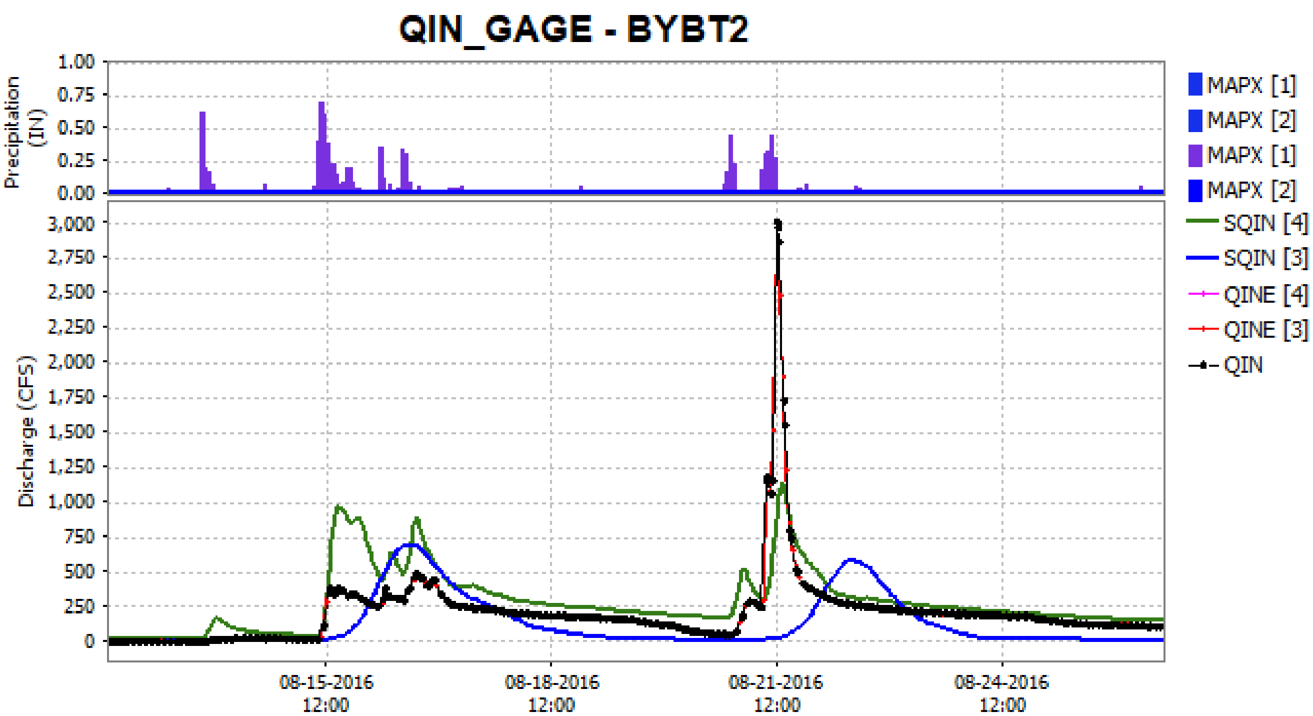
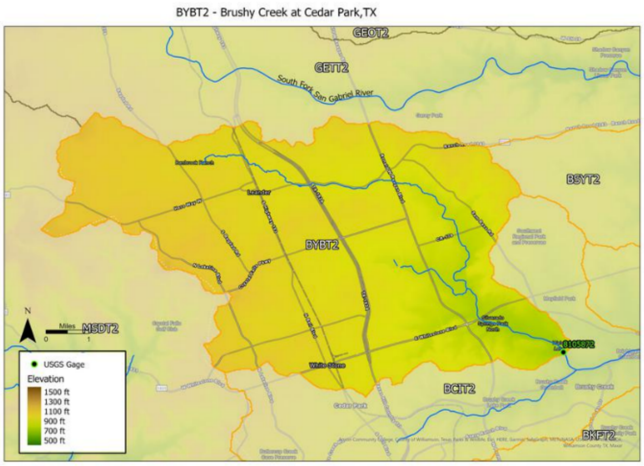
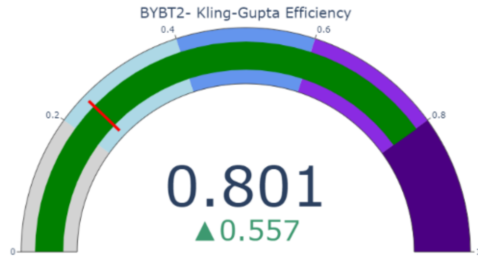
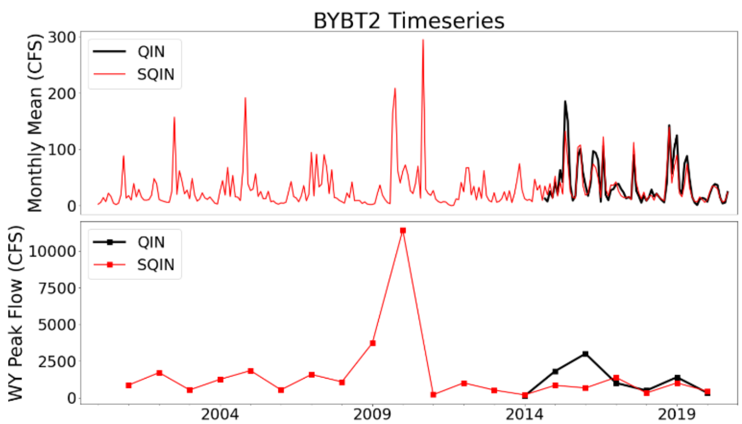


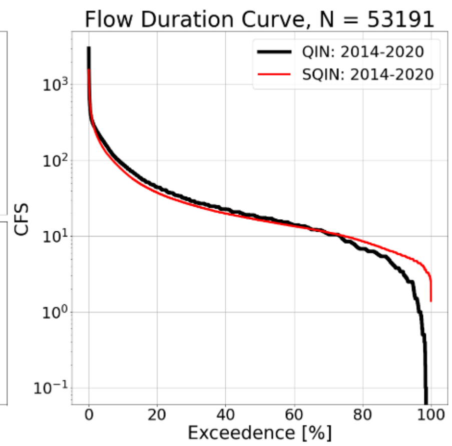
Figure 4-13: Improved calibration during a challenging event, which shows the initial (blue) and calibrated (green) simulations, characterized by better simulation timing and flashiness.

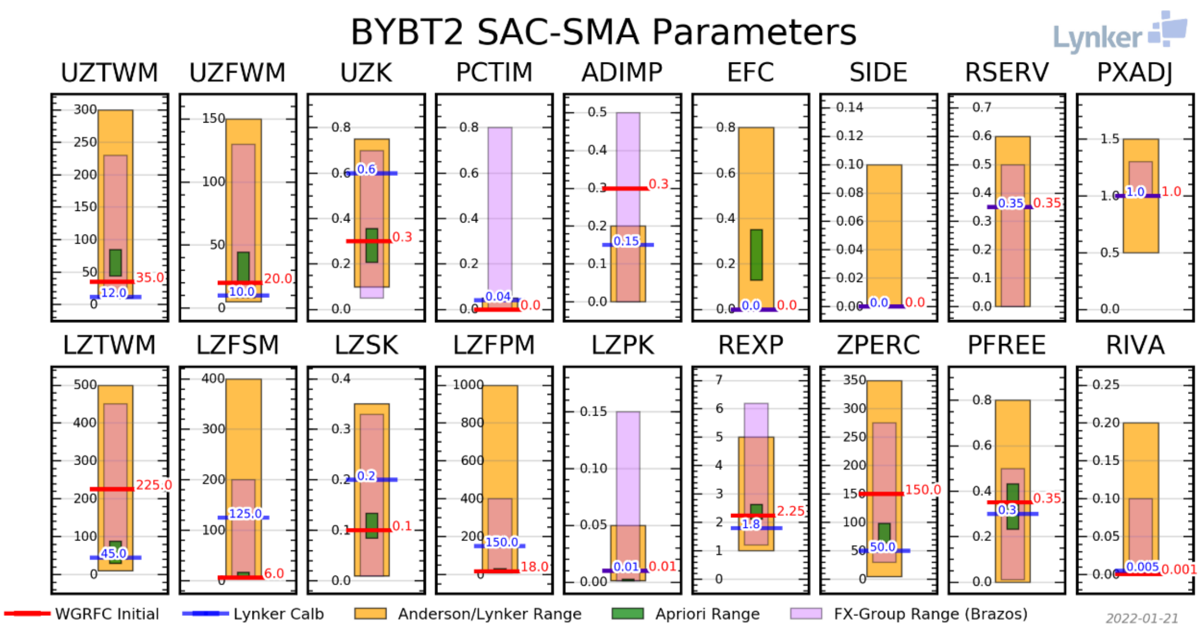
BYBT2: Brushy Creek at Cedar Park,TX











BCIT2

Brushy Creek at IH 35, Round Rock is a small local basin north of Austin, below BYBT2 and upstream of BKFT2, and was originally a part of RKDT2U. Simulations for BCIT2 were run at a 1-hourly timestep, calibrated to instantaneous discharge data from USGS 08105883 (available from 11-19-2014 to present). Similar to BYBT2, it is mostly of soil type D (95% clay loam), and mostly developed land cover (69%).

Despite being a local basin, BCIT2 exhibited similar flashiness to its upstream counterpart, BYBT2. Similar challenges from BYBT2 were also present in BCIT2, where the calibration under simulated baseflow and mid-sized events. Contribution from upstream routed flow of BYBT2 was about equal to local flow, with a few exceptions, including the August 2016 event (Figure 4-14). High-flow biases (top 1% of flows, > 3570 CFS) were only under-simulated by -3%, however overall bias could not be improved to more than -11%. UHG curve was shifted moderately earlier and sharper to reflect the flashier nature of this basin.

Statistical improvements were moderate, with the KGE score improving from 0.848 to 0.911 and the correlation coefficient ending at 0.959, both of which are reasonable for this size of small upstream basin.

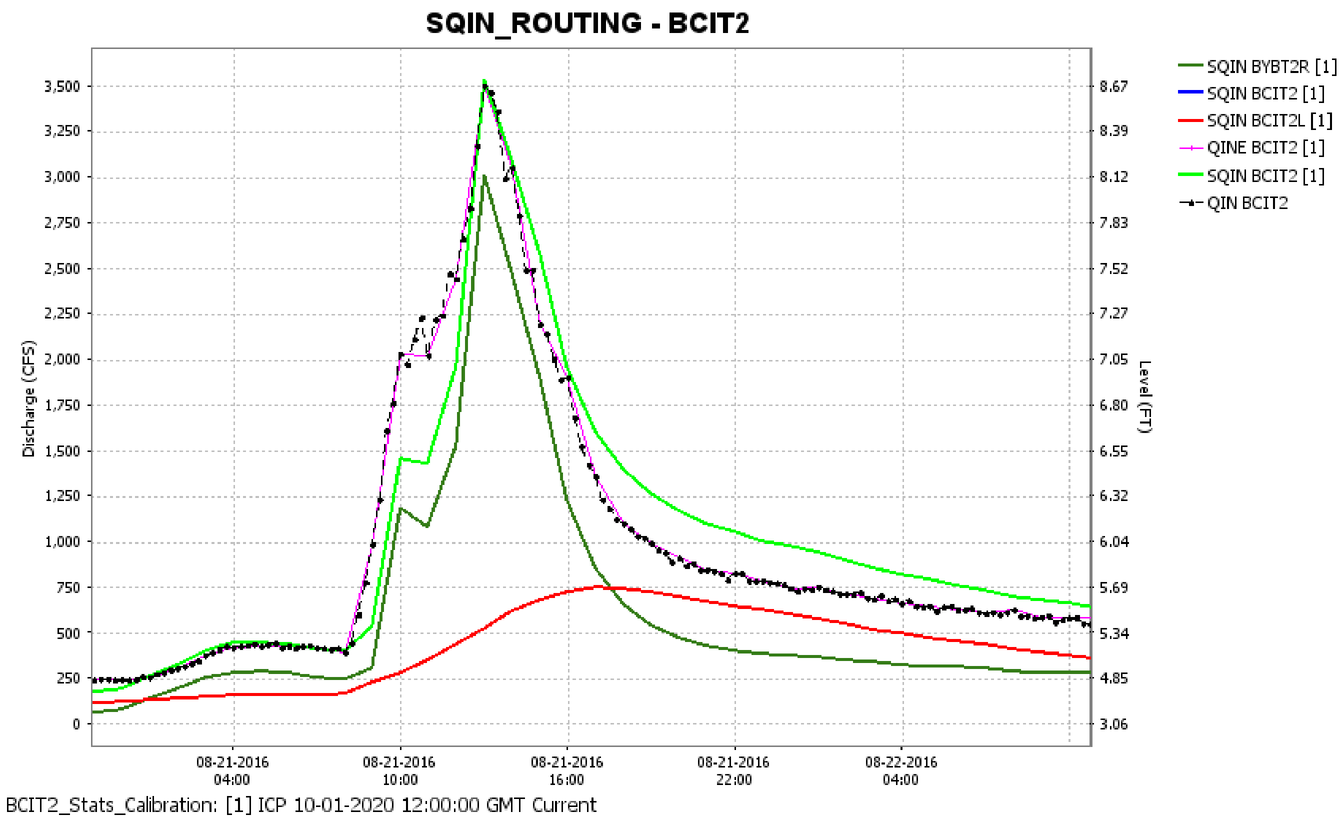
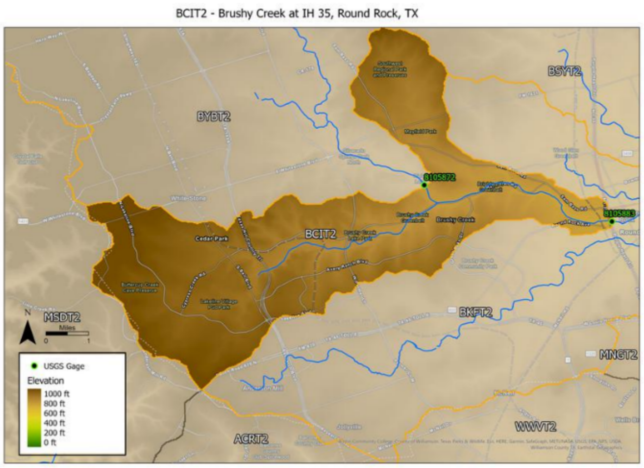
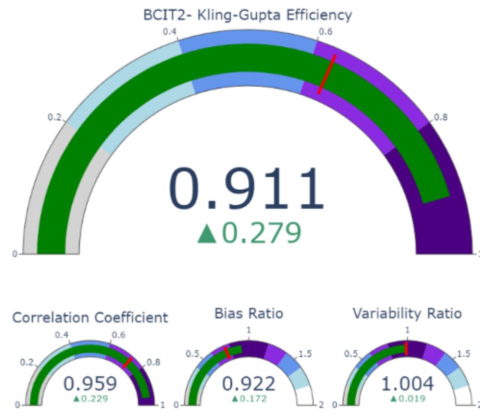
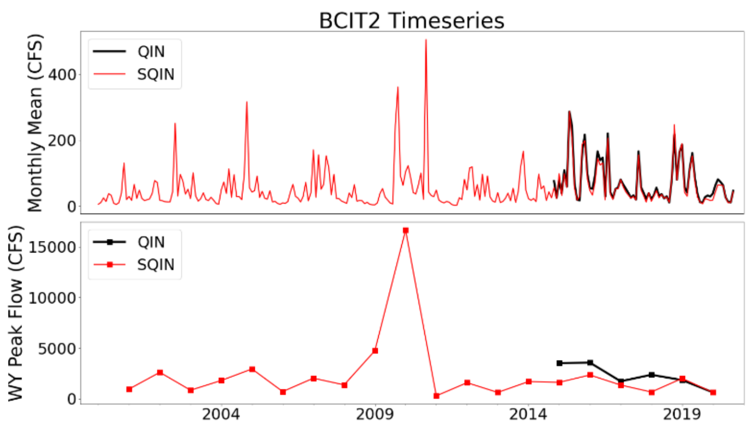


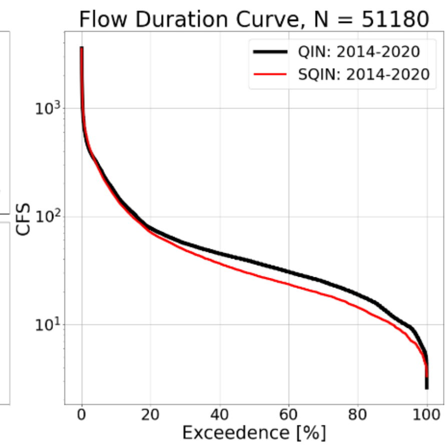
Figure 4-14: SQIN Routing plot illustrating the extent to which the routed flow from BCIT2 (dark green) drives the large August 2016 peak, which is well-verified.

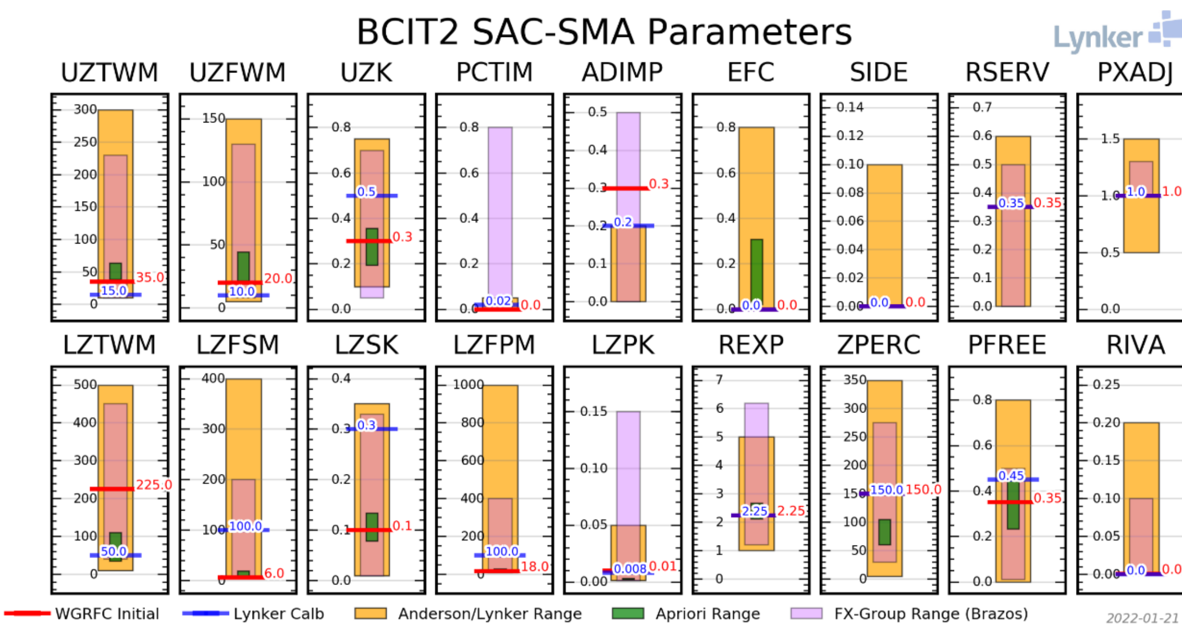
BCIT2: Brushy Creek at IH 35, Round Rock, TX











BKFT2

Brushy Creek at Kenney Fort Blvd at Round Rock is a local basin north of Austin, downstream of BCIT2, and was originally a part of RKDT2U. Simulations for BKFT2 were run at a 1-hourly timestep, calibrated to instantaneous discharge data from USGS 08105888 (available from 10-25-2014 to present). Soil characteristics for BKFT2 are similar to nearby basins in that a large majority (95%) of soil is classified as Type D/Clay Loam. The single largest land cover class in the basin is developed (62%).

It is unclear if QIN data for BKFT2 is erroneous or attributable to changes in Brushy Creek Dam in 2017/2018 which subsequently limited flooding events originating in the upper portions of the basin. Specifically, there is a moderate precipitation event in May of 2015 that is nearly 5x higher than any other event in the period of record, and lasts less than 8 hours (Figure 4-15). Confirmation of suspect data not available from NWS. Calibration of this event was not prioritized; all other portions of the simulation are good to adequate, though the flashy characteristics of the basin make peak flows difficult to simulate on a one-hourly timestep, particularly the baseflow. The UGH curve was again required to be shifted earlier nearly 24 hours.

KGE improved modestly from 0.778 to 0.808 (2010–2020), where the bias ratio and variability ratio largely stayed about the same, but the correlation coefficient improved (to 0.838 up from 0.532).

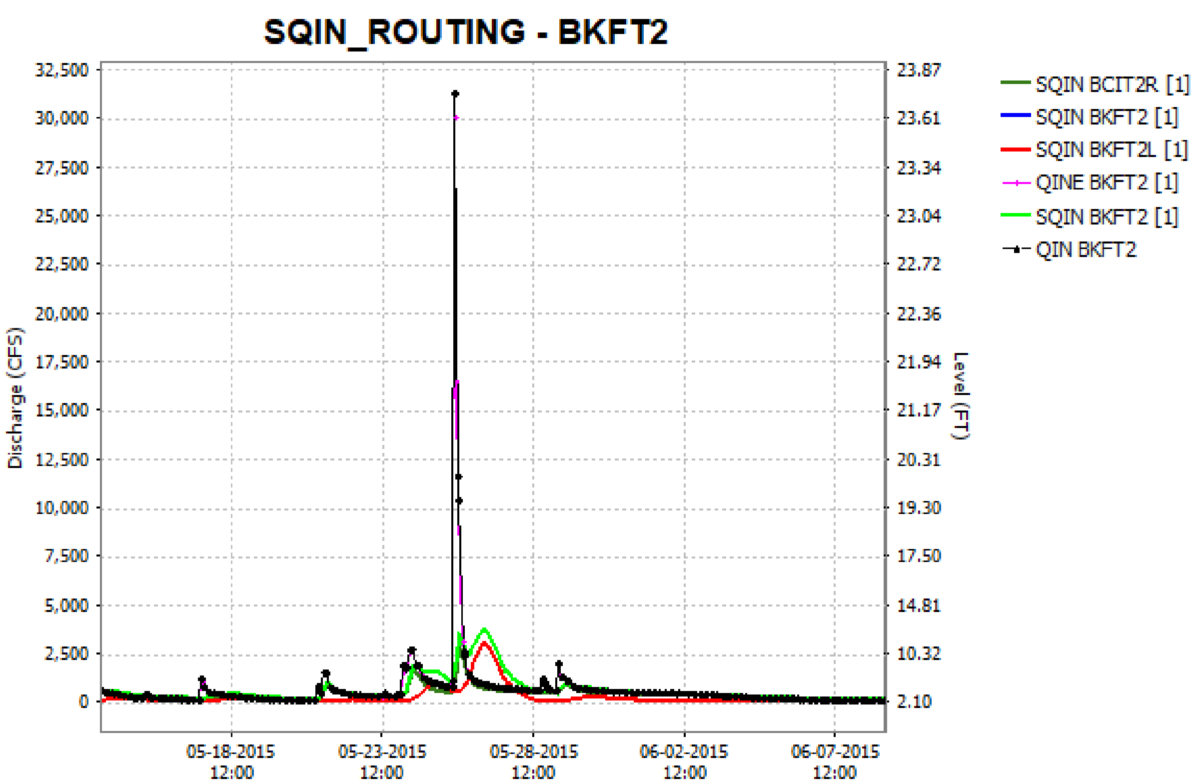
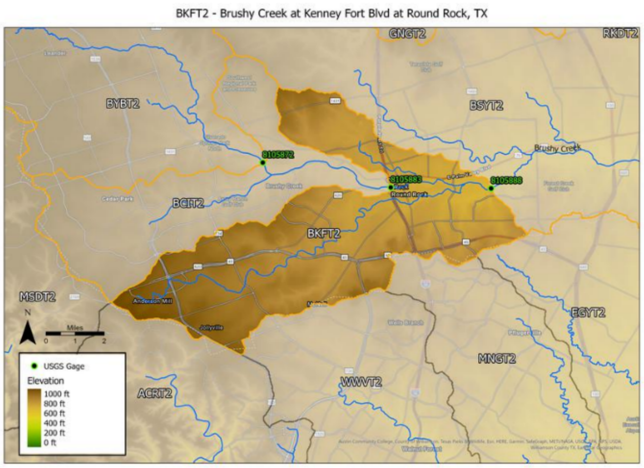
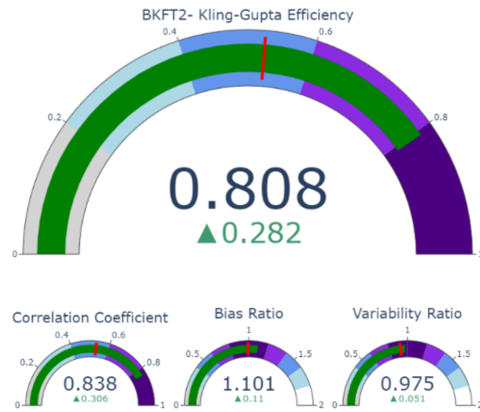
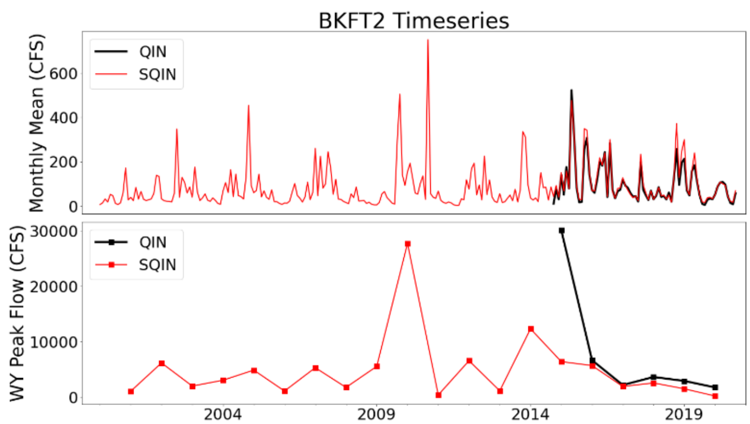


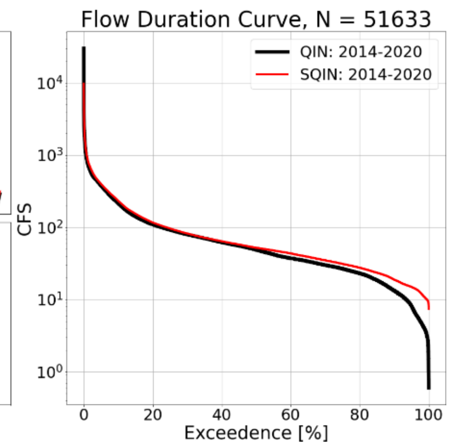
Figure 4-15: Questionable QIN data for the May 2015 event (peak flows >30 KCFS). Peak flows of this magnitude are not observed upstream or downstream of BKFT2.

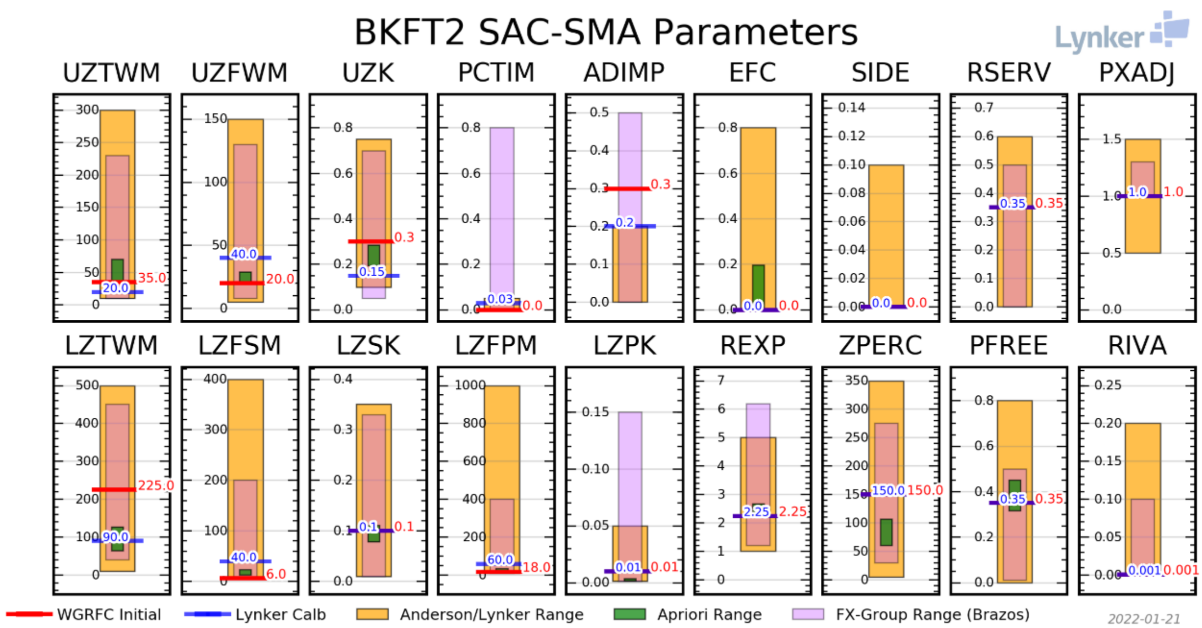
BKFT2: Brushy Creek at Kenney Fort Blvd at Round Rock, TX











BSYT2

Brushy Creek at FM 973 near Coupland is a local basin north of Austin, downstream of BKFT2, and was originally a part of RKDT2U. Simulations for BSYT2 were run at a 1-hourly timestep, calibrated from stage data converted to instantaneous data from USGS 08105897 (stage data available from 11-20-2014 to present). No discharge data were available, raising concerns about the stage-discharge relationship. Soil characteristics for BSYT2 are similar to nearby basins in that a large majority (89%) of soil is classified as Type D/Clay Loam. The single largest land cover class in the basin is herbaceous (35%), though a significant percentage of the area is also developed (31%).

BSYT2 is a highly variable perennial stream with baseflows < 40 CFS, and a peak flow of 7414 CFS in the period of record. LAG/K adjustments to BKFT2 (decreased LAG and K) were able to match the times of the hydrograph, however the out-of-place 31,000 CFS May 2015 in BKFT2 could not be masked with maximum amount of attenuation until we extended the rating curve (see Lynker response below). Calibrations focused on increasing the rainfall responsiveness of the basin, with larger magnitude flows for medium to large events (increasing ADIMP significantly). The UGH curve was again required to be shifted earlier about 20 hours.

Statistical improvements were modest, with KGE improving from 0.510 to 0.828, and overall bias modestly improving from 9% to 2.9%.

WGRFC feedback: *BSYT2 QIN has too little flow due to the synthetic rating curve on 5/26/2015. Curve might need to be adjusted. Obs are coming too low and shorting the volume downstream.*

Lynker response: We extended the rating curve for BSYT2 (stage only site) in order to improve the observed events in May 2015 by interpolating a seasoned rating curve from upstream BKFT2 – gauge 08105888. This allowed much more volume to flow downstream and improve the calibration. (Figure 4-16).

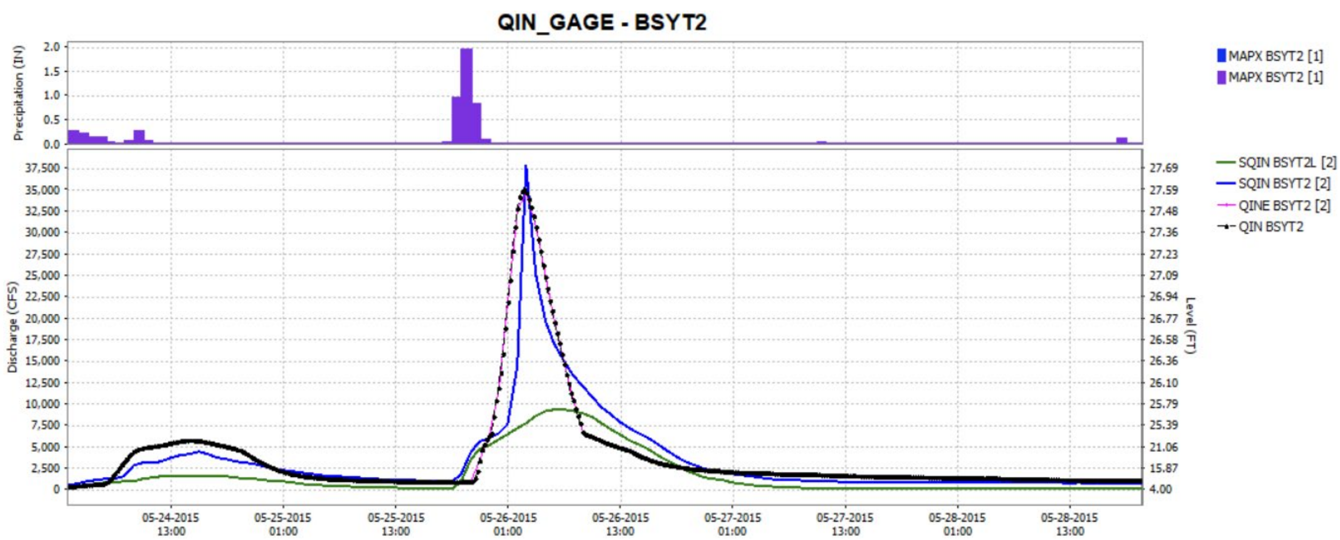
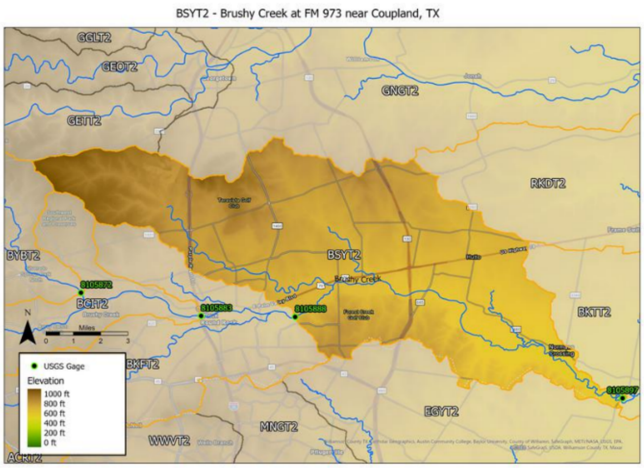
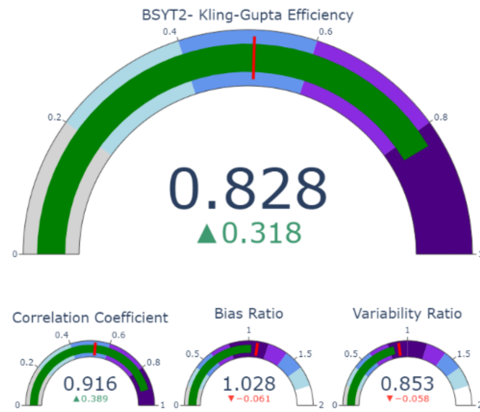
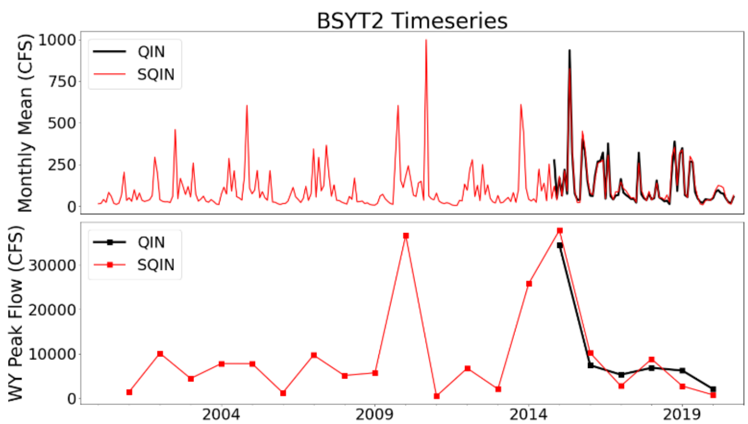


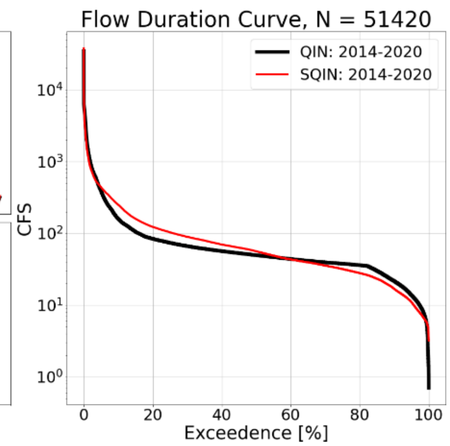
Figure 4-16: Improved calibration for BSYT2 after implementation of a new rating curve.

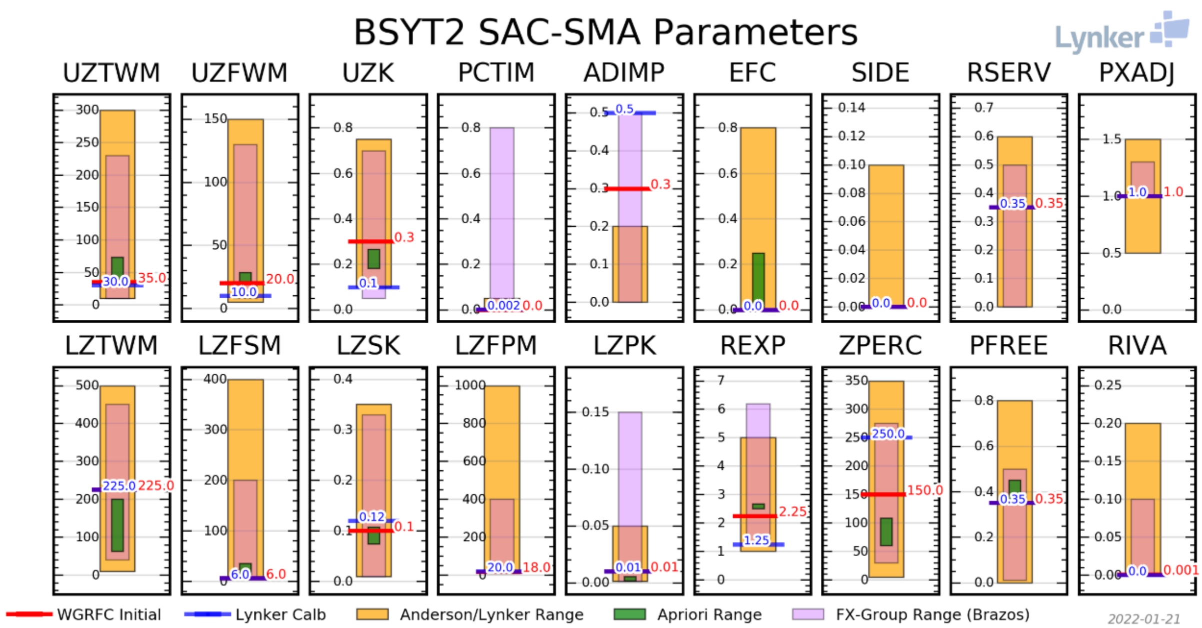
BSYT2: Brushy Creek at FM 973 near Coupland, TX











BKTT2

Brushy Creek at FM 619 near Taylor is a local basin north of Austin, downstream of BSYT2, and was originally a part of RKDT2U. Simulations for BKTT2 were run at a 1-hourly timestep, calibrated to instantaneous discharge data from USGS 08106050 (available from 05-22-2017 to present). Soil characteristics for BSYT2 are similar to nearby basins in that a large majority (94%) of soil is classified as Type D/Clay Loam. The single largest land cover class in the basin is cultivated crop (65%).

Discharge data is sporadic, only available from 2017 to 2020, only appearing for peaks that last a few days, and doesn't include baseflow QIN data, (minimum streamflow value at 775 cfs) (Figure 4-17). Due to the lack of complete data, calibrations for this basin relied on upstream modifiers and routed flow behavior. Increased lag and attenuation parameters were needed for the routed BSYT2 flow. The UGH curve was required to be shifted earlier nearly 12 hours, which is less than flashier upstream basins.

Statistical improvements for BKTT2 were marginal, due to the paucity of data available. KGE improved from 0.688 to 0.829.

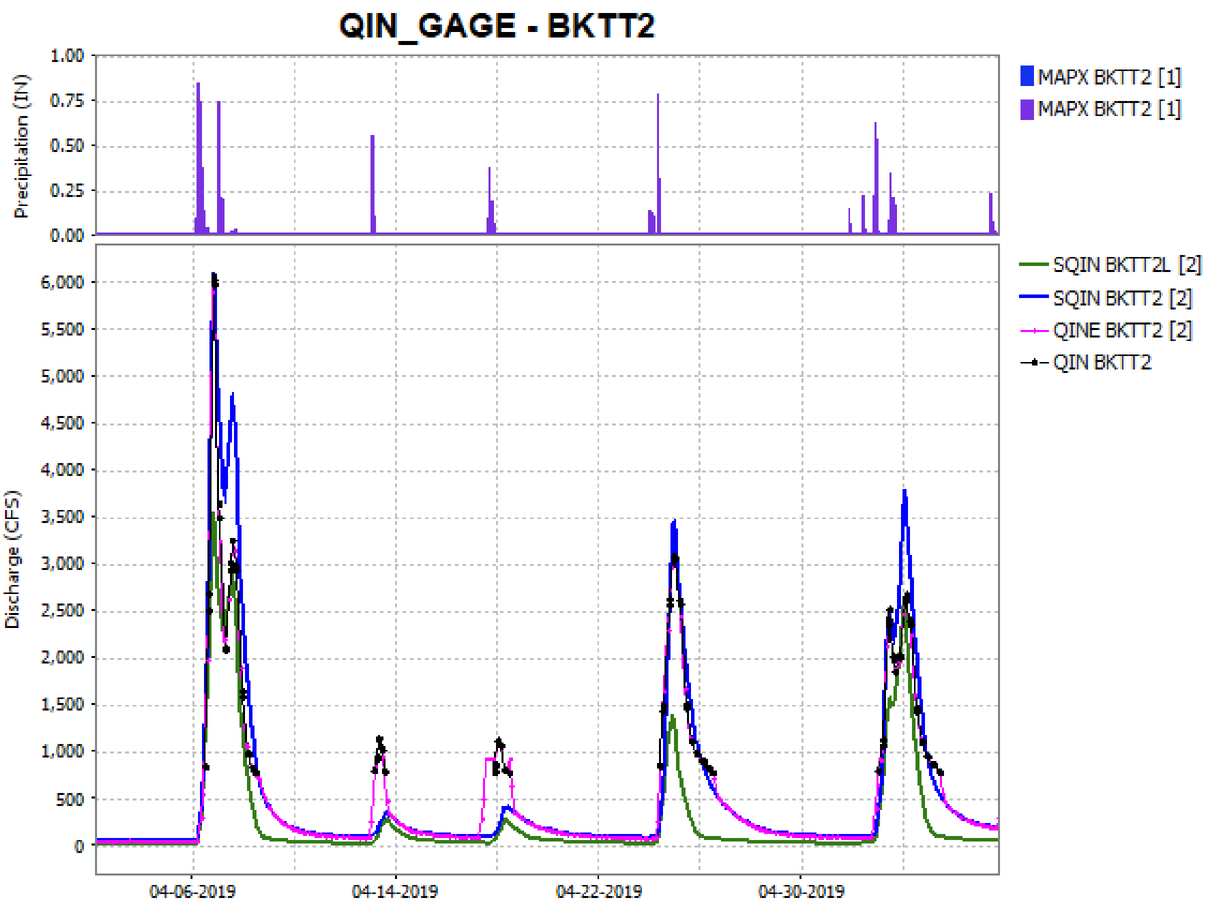
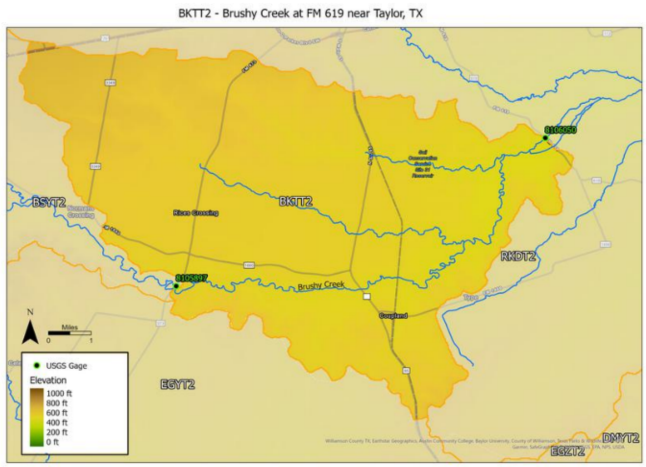
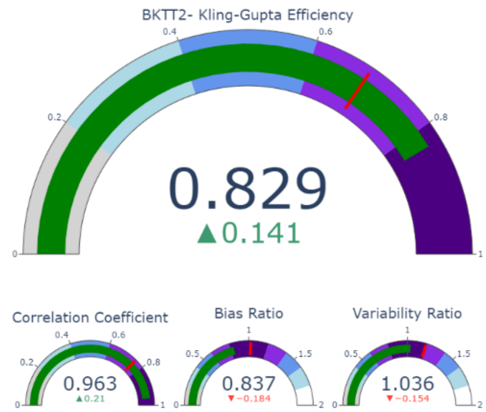
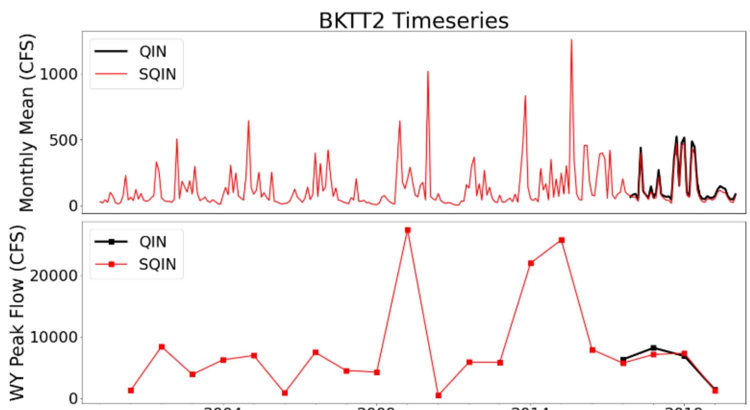


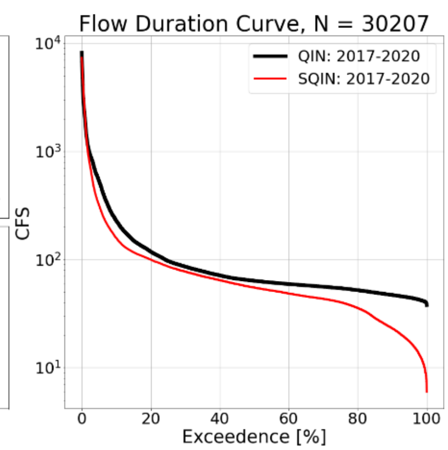
Figure 4-17: Limited QIN data (no flows below 775 CFS) were one challenge when calibrating baseflows for BKTT2

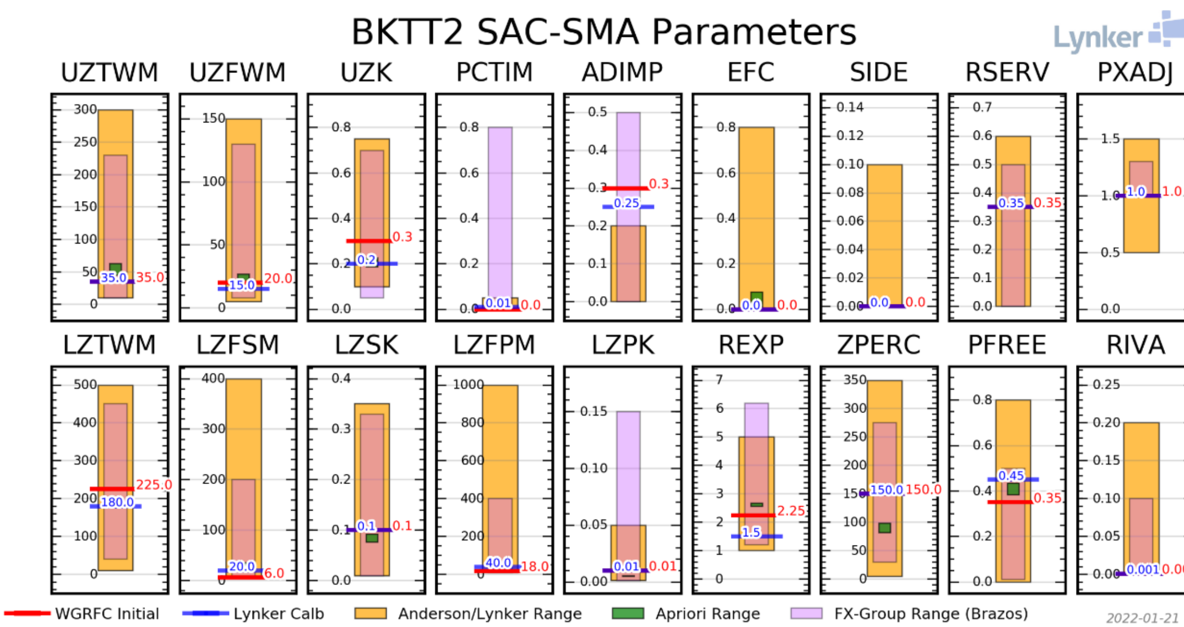
BKTT2: Brushy Creek at FM 619 near Taylor, TX









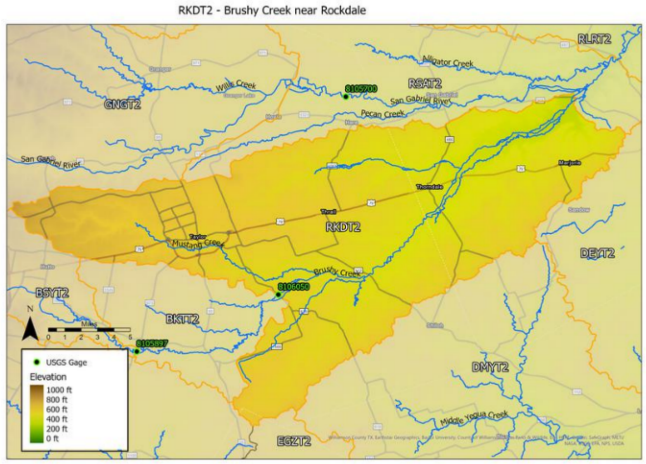


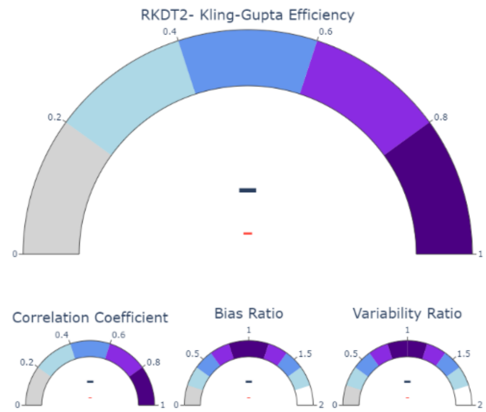
RKDT2

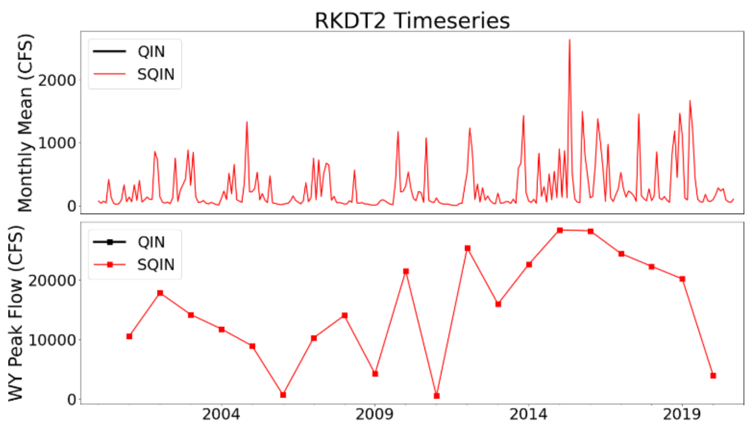
Brushy Creek near Rockdale is a local basin northeast of Austin and include the town of Taylor, Texas. This basin originally included BKTT2, BSTY2, BKFT2, BCIT2, and BYBT2. Simulations for RKDT2 were run on a 3-hourly timestep, however there is no current instantaneous, stage, or local data. An inactive USGS gauge 08106300 had data until 1980, but none in our period of interest. RKDT2 is a basin equally dominated by hay/pasture (38%) and cultivated land (39%), with clay-dominated soil characteristics (82% Type D/Clay Loam).

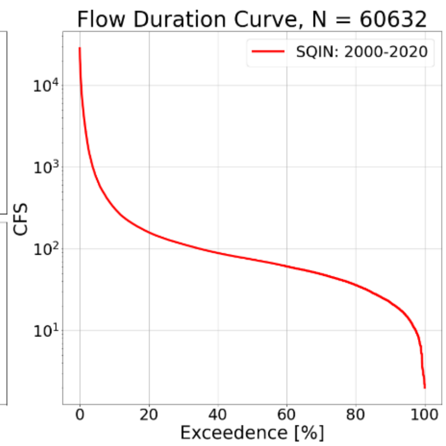
Due to the inactive gauge with no relevant discharge data, RKDT2 was calibrated with modifiers at RLRT2, with a focus on calibrating the magnitude and timing of flows for during major flood events downstream.

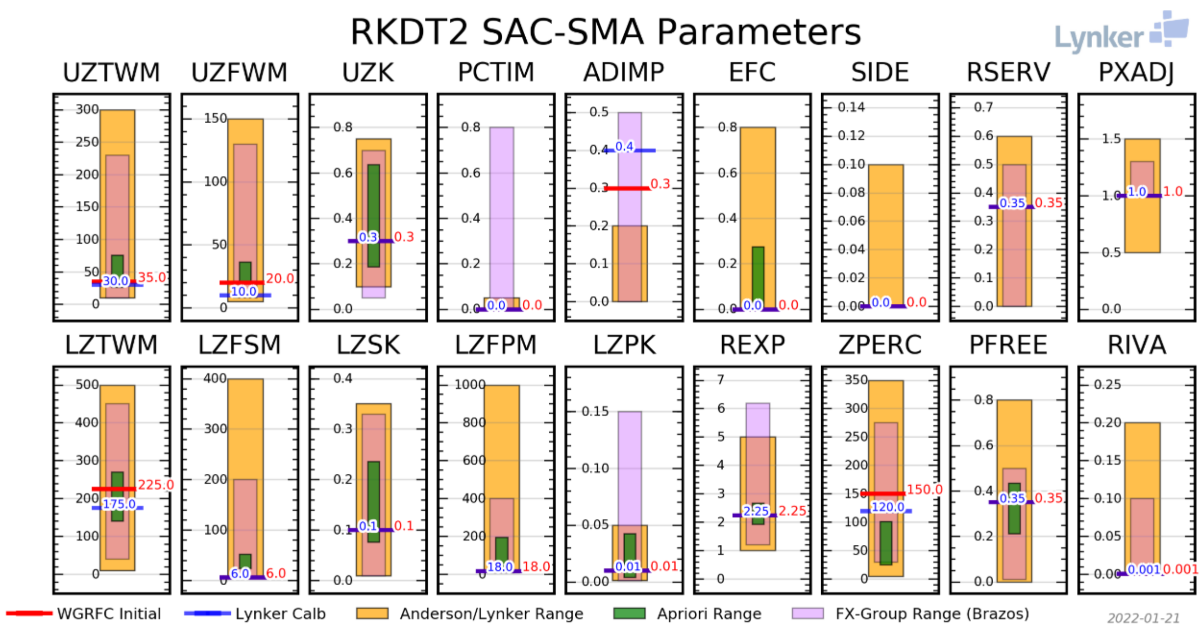
RKDT2: Brushy Creek near Rockdale









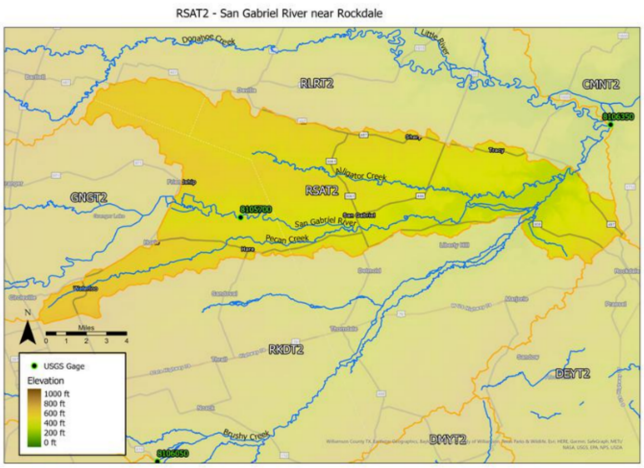


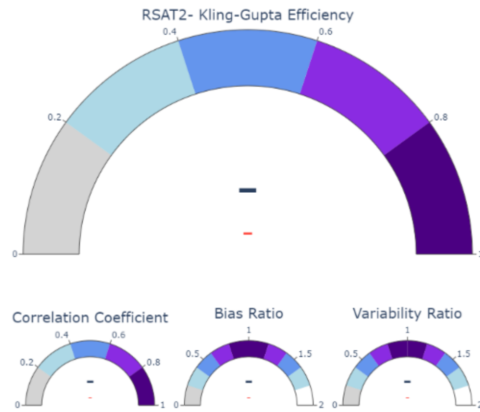
RSAT2

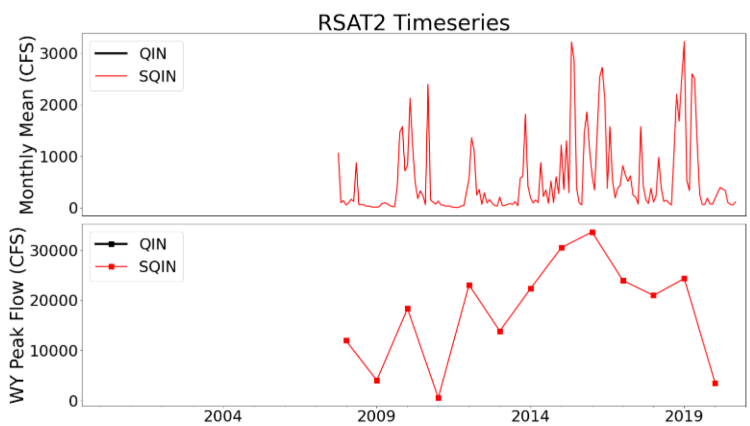
San Gabriel River near Rockdale is a local basin northeast of Austin directly downstream of Granger Lake and contains the confluence of San Gabriel River and Brush Creek. Simulations for RSAT2 were run on a 3-hourly timestep, however there is no current instantaneous, stage, or local data. An inactive USGS gauge 08106310 had data until 1992, but none in our period of interest. RSAT2 is a basin equally dominated by hay/pasture (40%) and cultivated land (37%), with clay-dominated soil characteristics (77% Type D/Clay Loam).

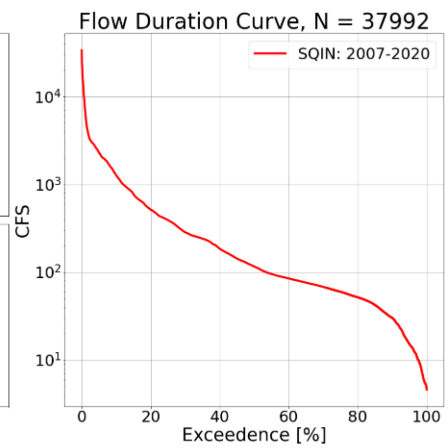
Due to the inactive gauge with no relevant discharge data, RSAT2 was calibrated with modifiers at RLRT2, with a focus on calibrating the magnitude and timing of flows for during major flood events downstream.

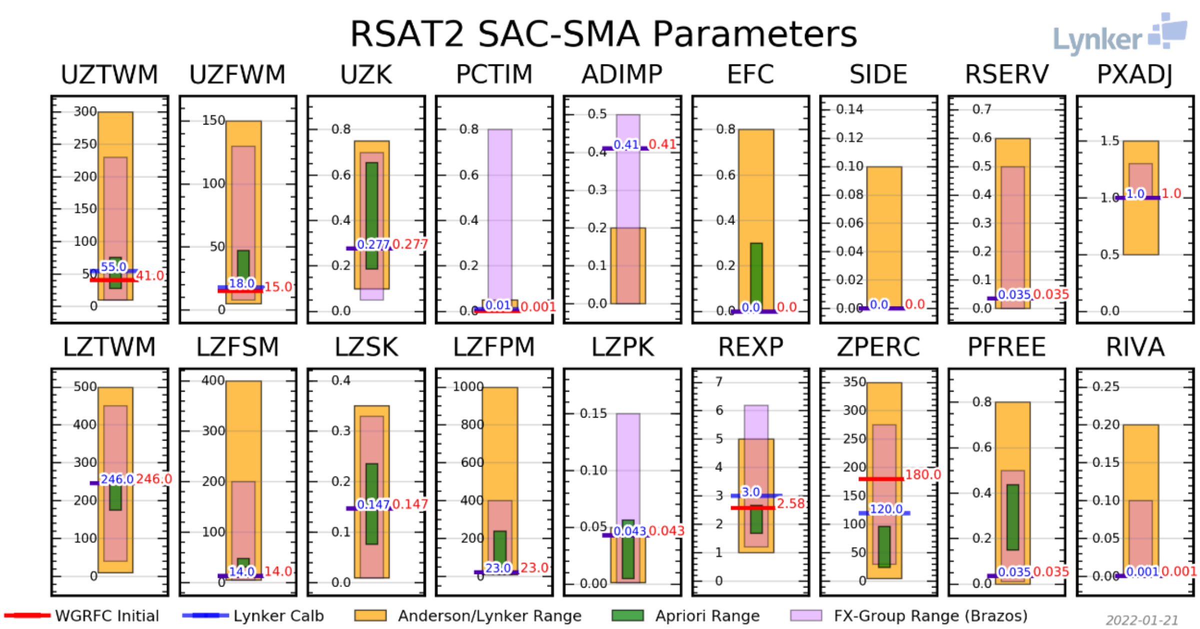
RSAT2: San Gabriel River near Rockdale











Little River HUC8

RLRT2

Little River near Rockdale is a large basin at the confluence of the San Gabriel River/Brushy Creek and the Little River. Simulations for RLRT2 were run at a 3-hourly timestep and calibrated to both instantaneous discharge data and stage data from USGS 08106350. Discharge data from USGS were only available below 997 CFS, so stage data supplemented this baseflow to fill gaps (both measurement types available from 10-01-2007 to present). USGS gauge remarks note that there is considerable water that is diverted for irrigation and municipal supply, and at least 10% of the contributing drainage area has been regulated. RLRT2 is made up of mostly clay loam (80% soil type D), and comprised of herbaceous (23%), hay/pasture (28%), and cultivated crops (34%).

RLRT2 was a challenging basin to calibrate, due to limited upstream data (RSAT2 and RKDT2). RLRT2 was used to calibrate upstream basins, however simulations from basins in Brushy Creek were never able to produce enough flow for events such as the flood of record (April 18th, 2016), which was under-simulated by 30,000 CFS. However, there is good reason to believe that the QIN data for this event are unreliable when compared to the CMNT2 flows on the same date, which only crest at 40,000 CFS. Simulated flow was under-estimated during 2014–2016, due to the lack of accurate peak measurement data from upstream, but late fall/early winter events were often over-simulated. UGH curve had to be shifted earlier slightly. Both upstream basins LRIT2 and RSAT2 required decreased LAG, and increased attenuation above 10,000 CFS and 8,000 CFS, respectively. The UHG peak was shifted earlier by about 6 hours.

Statistical improvements were minimal, as the basin's initial calibration parameters were already tuned well. Final KGE score was 0.955, with a correlation coefficient of 0.967.

WGRFC feedback: *RLRT2 - There are 4 simulations that got the flood category correct (2 underpredicted, 2 overpredicted). The status quo simulations for those 4 events look to be either similar or a bit better than the newly calibrated versions. On the overestimated events, consider adjustments to tamp down the surface runoff generated by ungauged upstream basin RKDT2. It seems to be producing more surface runoff than RSAT2 and RLRT2 local basins. Also there may be some room for additional K for the LAGK_RSAT2_RKDT2 model. Some movement towards making the SASCMA parameters for RKDT2, RSAT2, and RLRT2 more similar to each other could have the benefit of increasing runoff from RSAT2 and RLRT2 and decreasing surface runoff from RKDT2, which improves many of the overforecasted smaller events at RLRT2 without having much impact on the big events. The CHPS Rating Curve at RLRT2 had too much flow above 40,000 cfs. This was revealed by comparing estimated flows at RLRT2 to USGS flows at CMNT2. The rating curve at RLRT2 was generating too much flow for routing to CMNT2 for large events. A new rating was developed. Therefore, May 2015 and June 2016 are no longer underestimated in the model. In fact, simulations at RLRT2 are now in general too sharp and too high for most events. These basins also appear to be candidates for improvement by using variable monthly ET-Demand.*

Lynker response: RKDT2 and RSAT2, basins containing the lower Brushy Creek and the confluence with San Gabriel river have no flow or stage data. As suggested, model parameters for these basins and RLRT2 were adjusted for more spatial consistency. Increasing runoff from RSAT2 and RLRT2 and decreasing surface runoff from RKDT2 improved some of the smaller events where the initial calibration was previously over-forecasting.

Suggested changes were implemented, and additional small tweaks were made to the SACSMA parameters and LAG/K parameters for RLRT2. Changing the top of the rating curve significantly improved calibration of largest events (Figure 4-18). Downstream CMNT2 also improved due to the decreased routed flow coming from RLRT2.

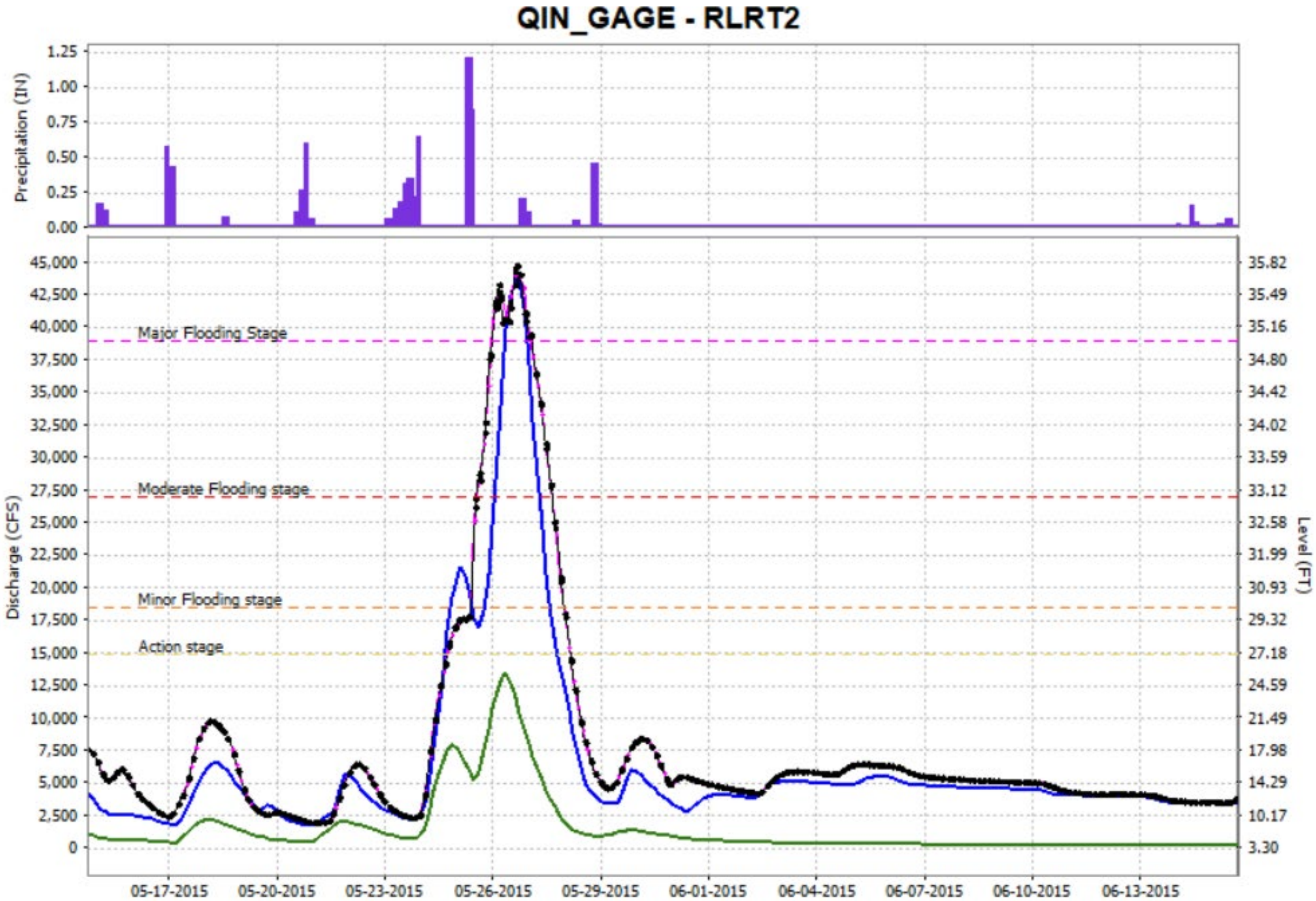
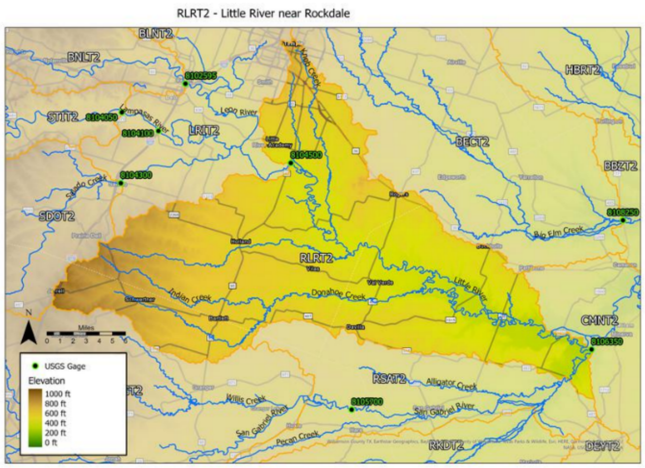
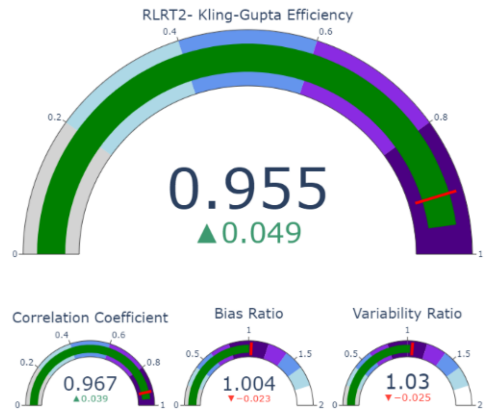
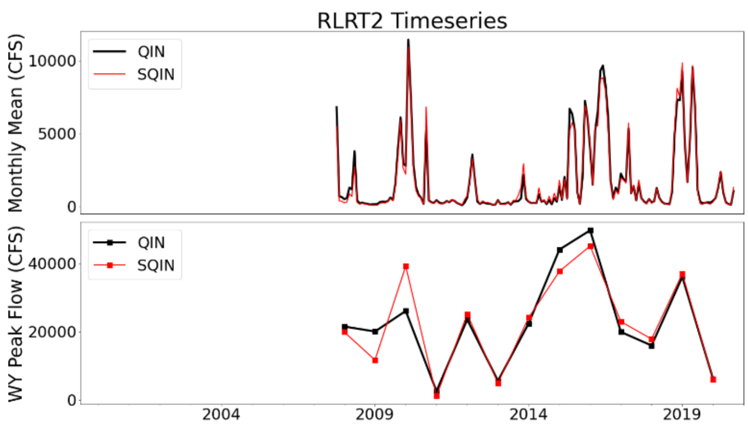


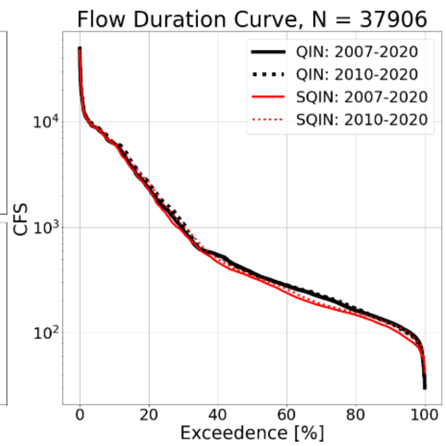
Figure 4-18: Changing the top of the rating curve significantly improved peak events, including the largest event in the period of record in 2015. Total flows are shown in blue, while local flows are in green; observed streamflow (QIN) is in black. Routed flows include RSAT2 and LRIT2, not shown here.

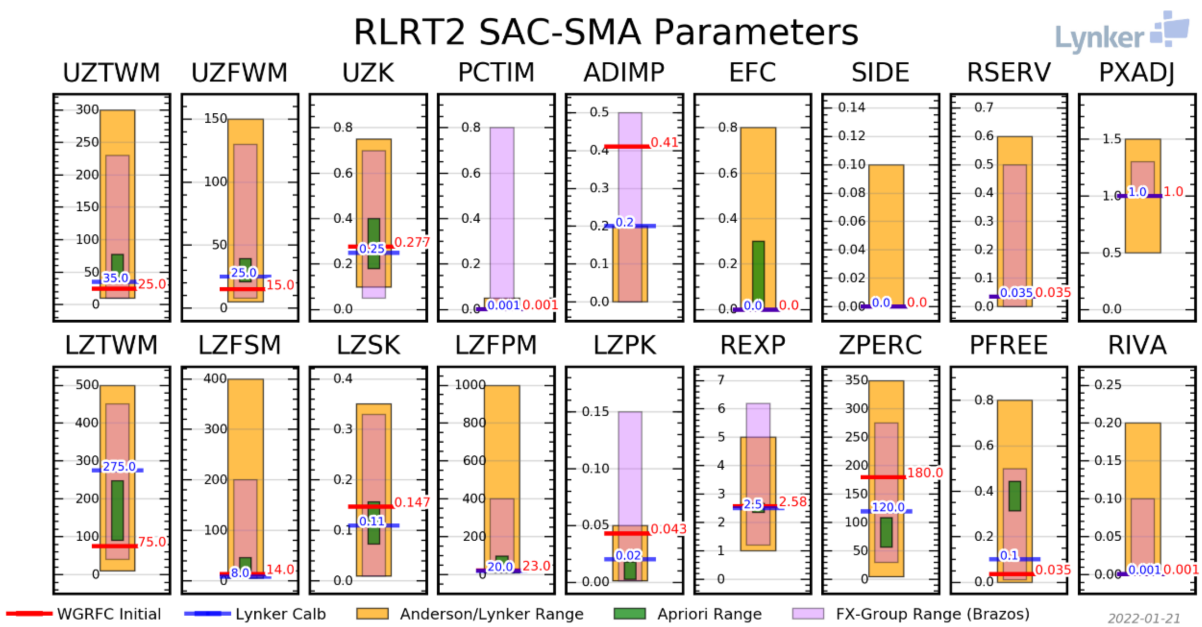
RLRT2: Little River near Rockdale











CMNT2

Little River near Cameron is a mid-sized basin downstream of RLRT2. Simulations for CMNT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08106500 (available 10-01-2007 to present). USGS remarks note that at least 10% of the drainage area is regulated. Diversions exist for irrigation and municipal use affect low flow, and there is occasionally no flow. Previously, this basin was run at a 6-hour time step. CMNT2 has less clay than upstream basins (60% Type D/Clay Loam), with a greater portion of the coarser Type A/Sandy Loam (10%) and Type C/Sandy Clam Loam (25%). The single largest land cover class in the basin is hay/pasture (54%), though a significant percentage of the area is also forested (25%).

CMNT2 streamflow was mostly (>90%) from upstream routed flows with limited local streamflow generation, resulting in much of the calibration focusing on LAG/K modeling. Decreased lag for low flow, and increased attenuation for high flow (above 18,000 CFS) were necessary. Changes in RLRT2 significantly improved the water balance issues first evident in CMNT2 (Figure 4-19). Other peak flow events are well-simulated, which is expected given the small area of CMNT2 and the significant upstream flows. The UHG did not need to be shifted.

Statistical improvements were again minimal, due to the basin's initial calibration parameters. However, effort was made to decrease the bias ratio and variability ratio down to as close to 1 as possible, to keep the standard deviation not too high.

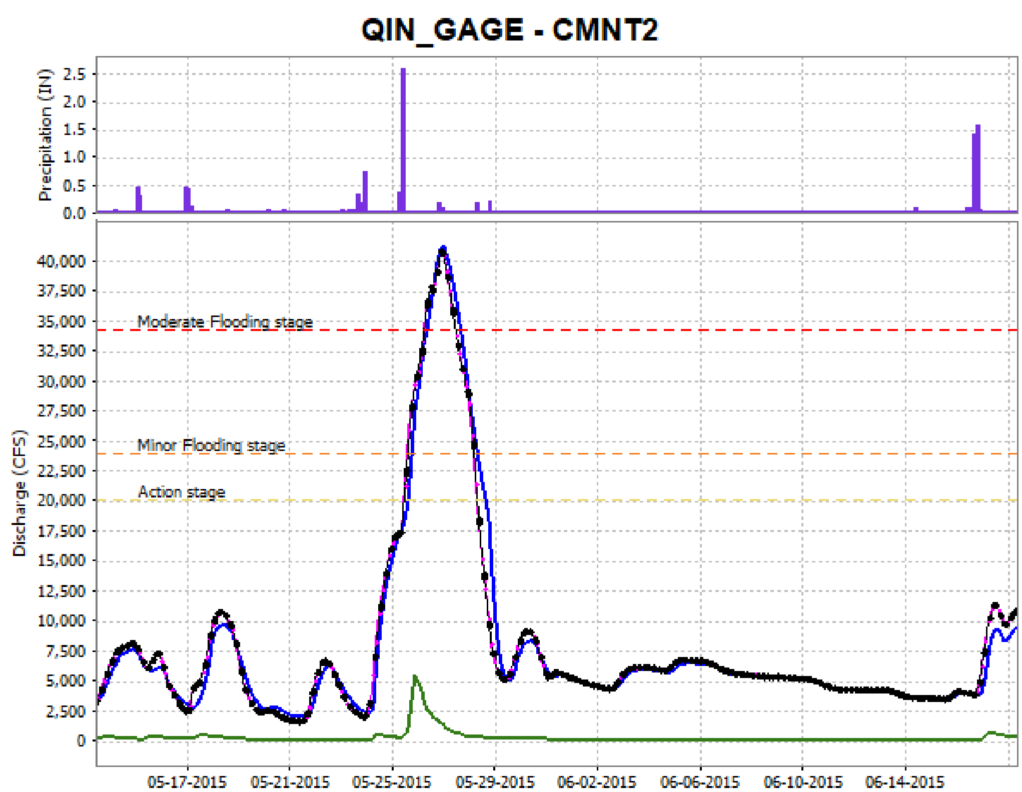
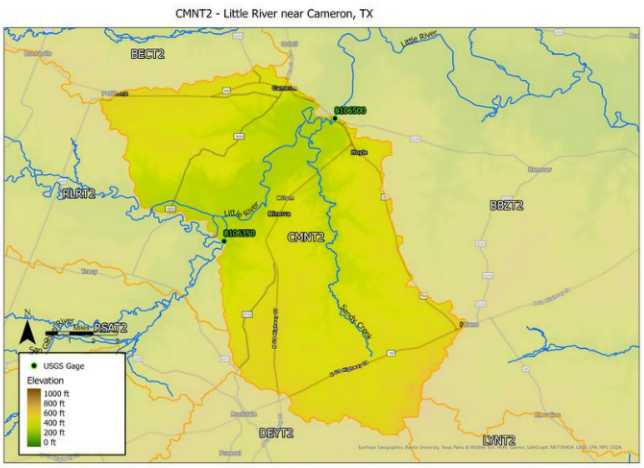
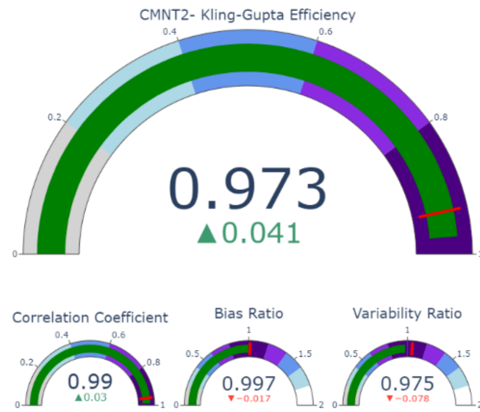
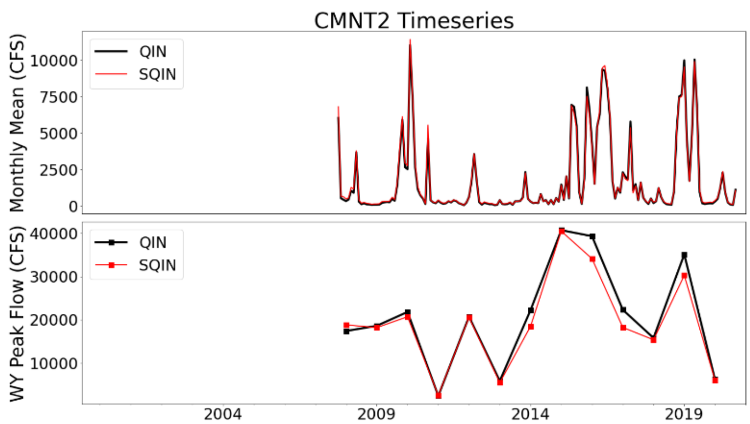


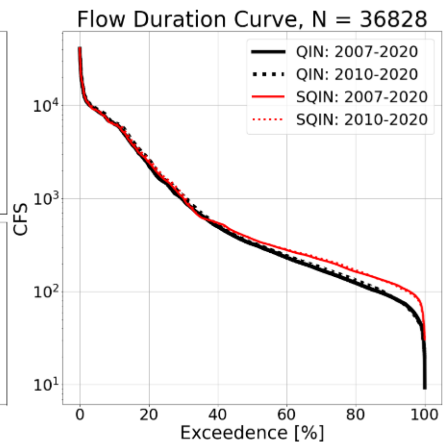
Figure 4-19: Improved calibration for CMNT2, with total flows in blue and local flows in green. Observed streamflow (QIN) is in black.

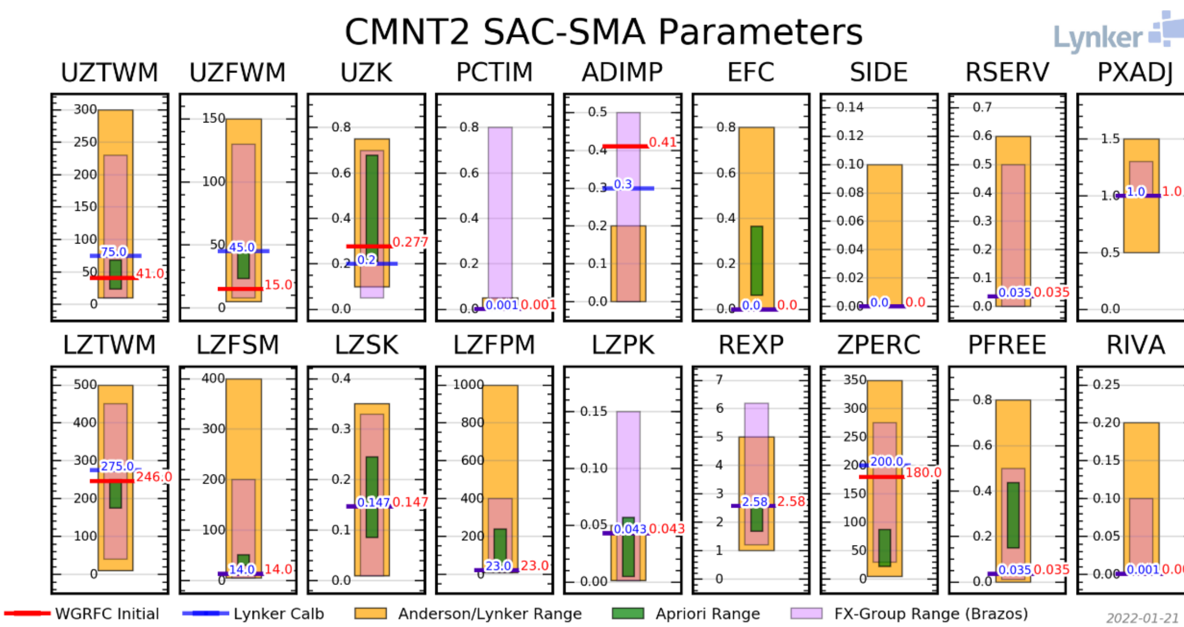
CMNT2: Little River near Cameron, TX











BECT2

Big Elm Creek at TX 77 near Cameron is a headwater basin for the Elm Creek tributary into the Brazos. Simulations for BECT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08108250 (available from 09-13-2009 to present), though records are only rated as fair. There are no known regulations or diversions in the basin. Land use is primarily cultivated crops (41%) or herbaceous (34%) with minimal development; 93% of soils are classified as Type D/Clay Loam.

This difficult to calibrate basin contains sporadic instantaneous data only above 1,000 CFS for just a month or so at a time. WGRFC did not have a rating curve for below 1,000 CFS. The highest peak (28,000 CFS) in the April 2016 corresponds to nearby basins with a significant event of that magnitude as well, however only the receding limb of the hydrograph has any data, making calibrating to the peak uncertain (Figure 4-20). Final calibration resulted in a good performance of the highest peaks, though some proved more elusive than others, made more challenging by the sparse streamflow records. The UHG curve was shifted 3 hours earlier.

Statistical performance improved modestly, despite the lack of streamflow data. The BECT2 KGE score increased from 0.625 to 0.814.

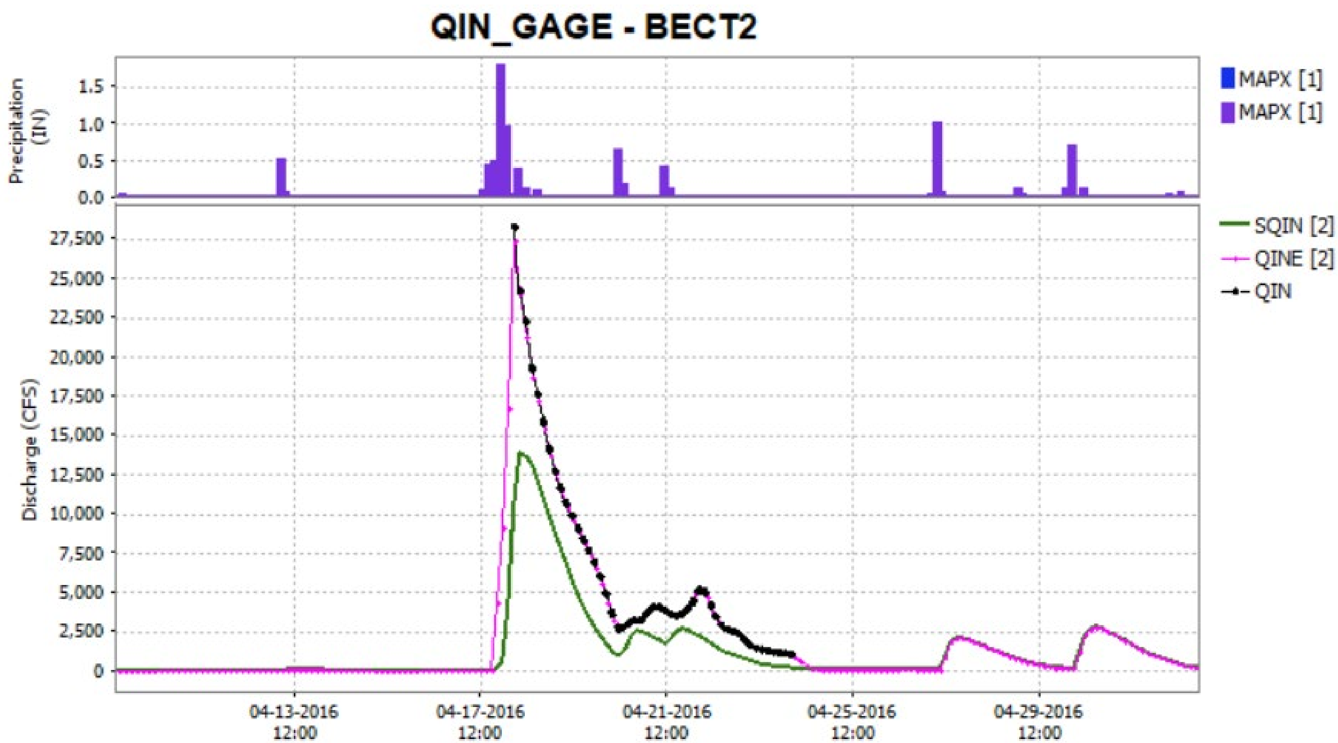
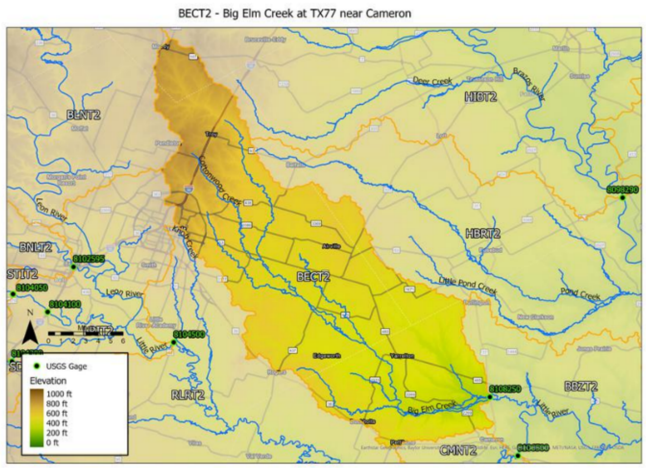
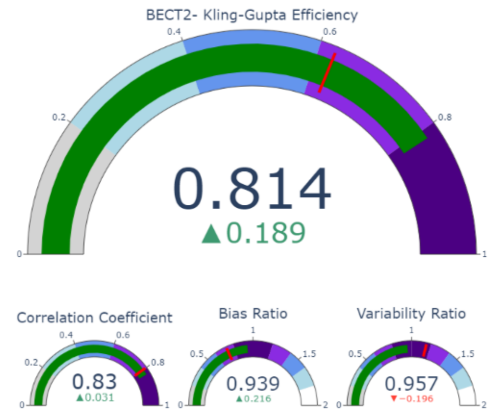
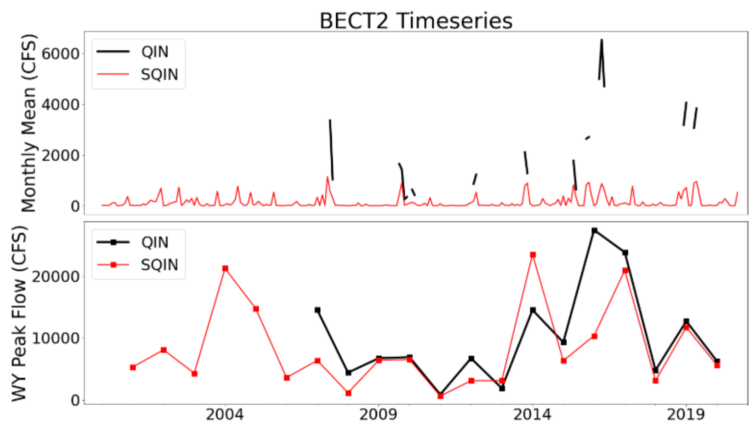


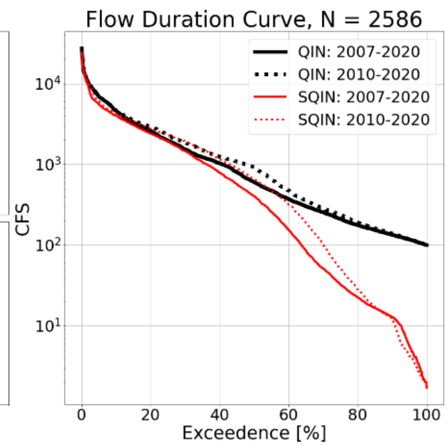
Figure 4-20: April 2016 event showing missing USGS QIN data for BECT2, one challenge of calibration at this site.

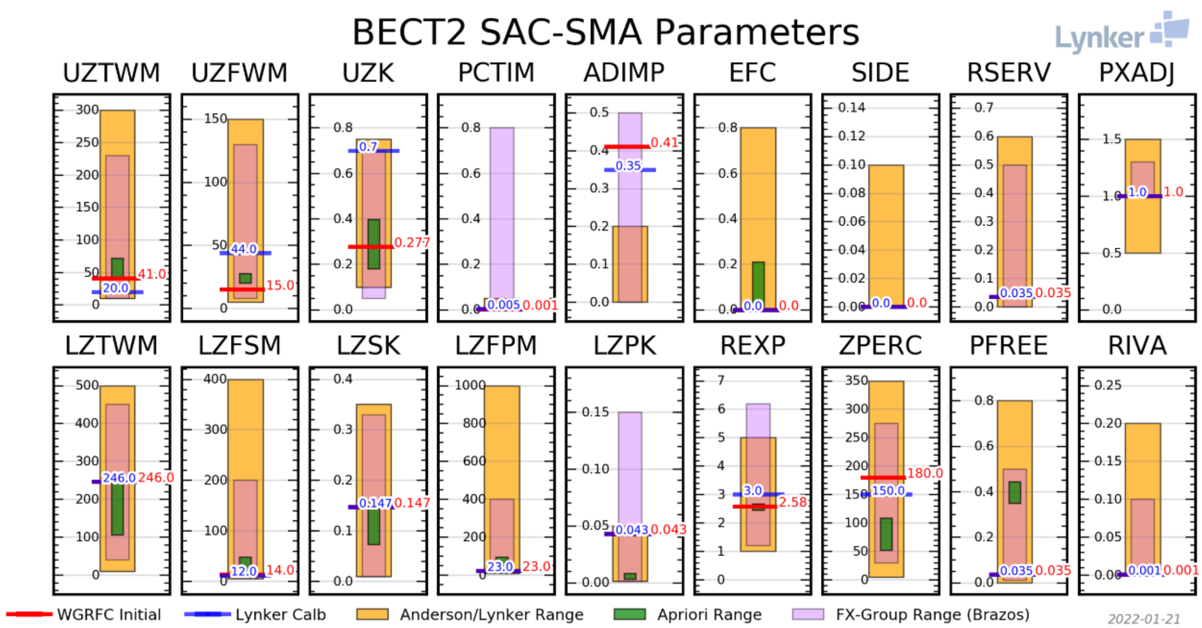
BECT2: Big Elm Creek at TX77 near Cameron











BBZT2

Brazos River at SH21 near Bryan is the confluence of the Little River and mainstem of the Brazos River, along with Big Elm tributary. Simulations for BBZT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08108700 (available from 07-15-1993 to present), though records are only rated as fair. At least 10% of the contributing drainage area has been regulated, with diversions for municipal, irrigation, and oil field operations that affect flow. Land use is primarily developed land (97%, although mostly open space and low intensity). BBZT2 has less clay than upstream basins (35% Type D/Clay Loam), with a greater portion of the coarser Type A/Sandy Loam (23%) and Type C/Sandy Clam Loam (32%).

Most of the streamflow (70-90%) is from routed flow from HBRT2 with limited local streamflow generation. Decreased lagging was necessary for upstream HBRT2, while increased lagging was required for upstream BECT2. More attenuation was necessary for both HBRT2 and BECT2. Occasionally, there was too much routed water, but overall, the simulation for both the local and routed flows was quite strong. Major flood events during January and May of 2019 were also significant focal points of calibrations efforts, primarily in the LAG/K model domain (Figure 4-21). UGH peak had to be shifted earlier by about 24 hours, with a longer receding limb.

Statistical improvement for the entire period was minimal, though bias for the largest flood events (0.1%, >32,000 CFS) decreased from 14% to 4% during the period 2010–2020, and from 9% to 0.8% during the full 2000–2020 period of record. Adjustments to the timing and attenuation of all three routed flow components were critical in dialing in peak flow simulations.

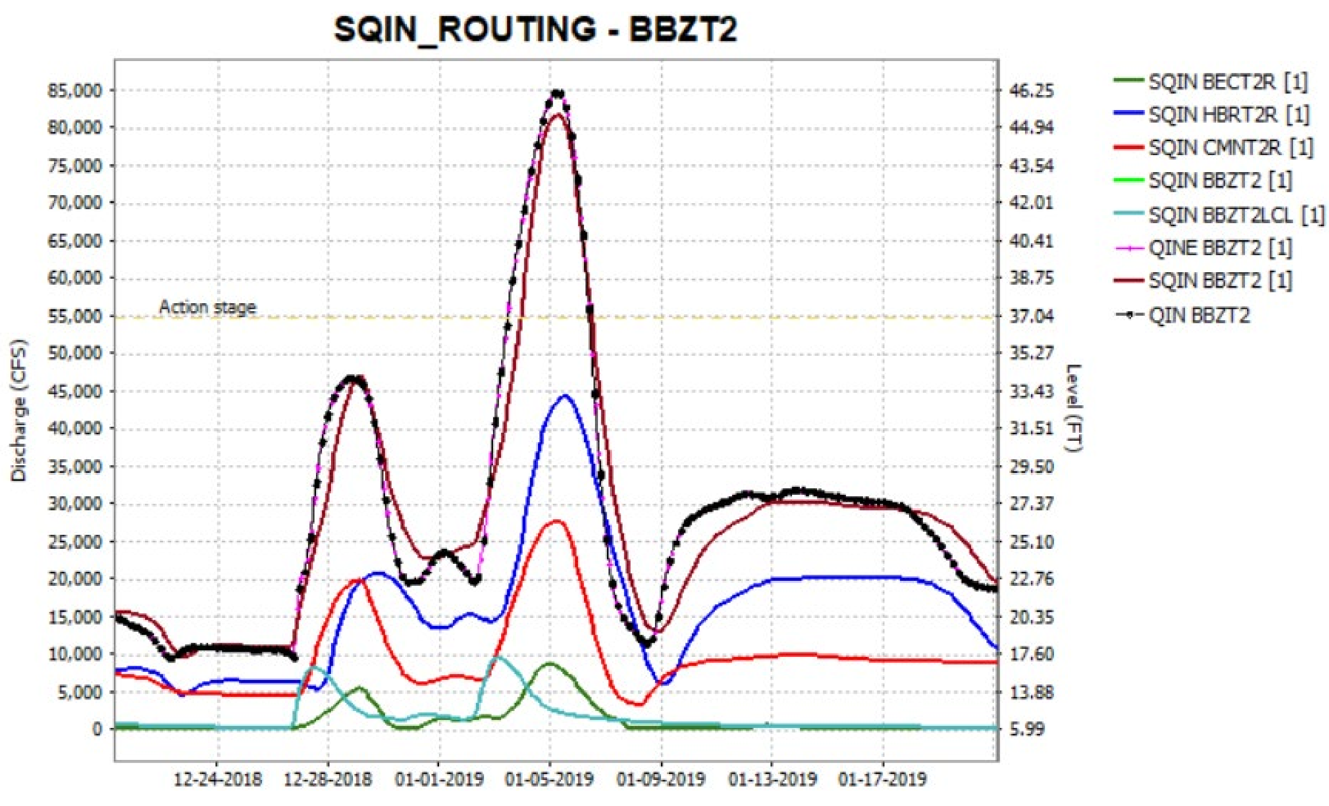
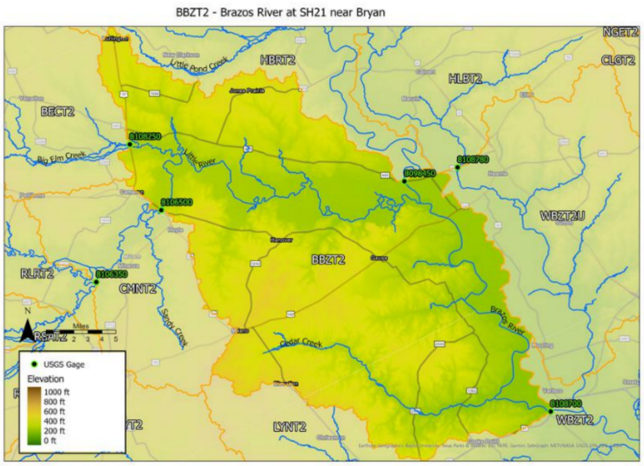
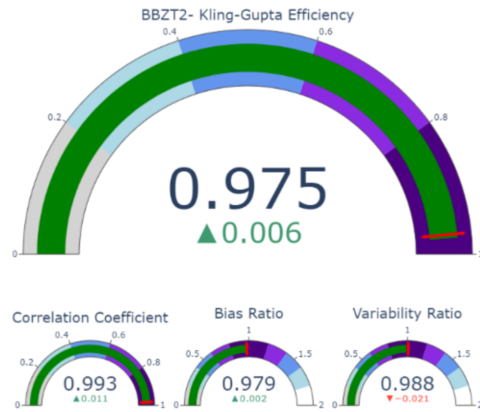
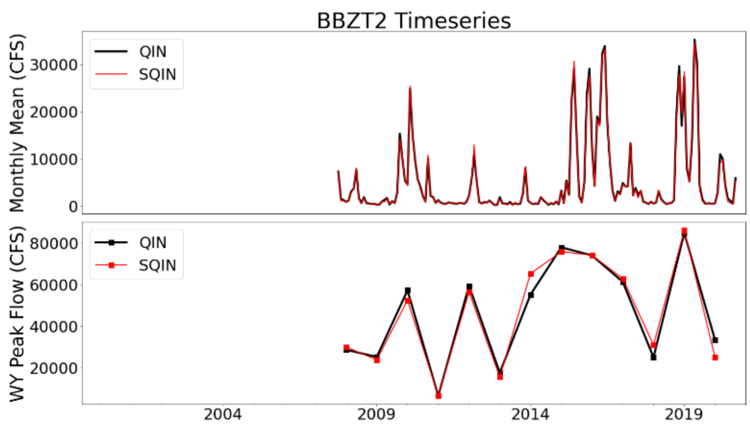


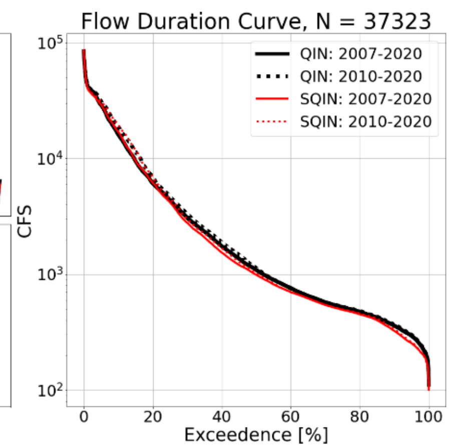
Figure 4-21: Improved calibration for BBZT2, showing the individual timing of routed flows from HBRT2 (blue), CMNT2 (red), and BECT2 (dark green). Local flows for BBZT2 are in teal, and total flows are in maroon.

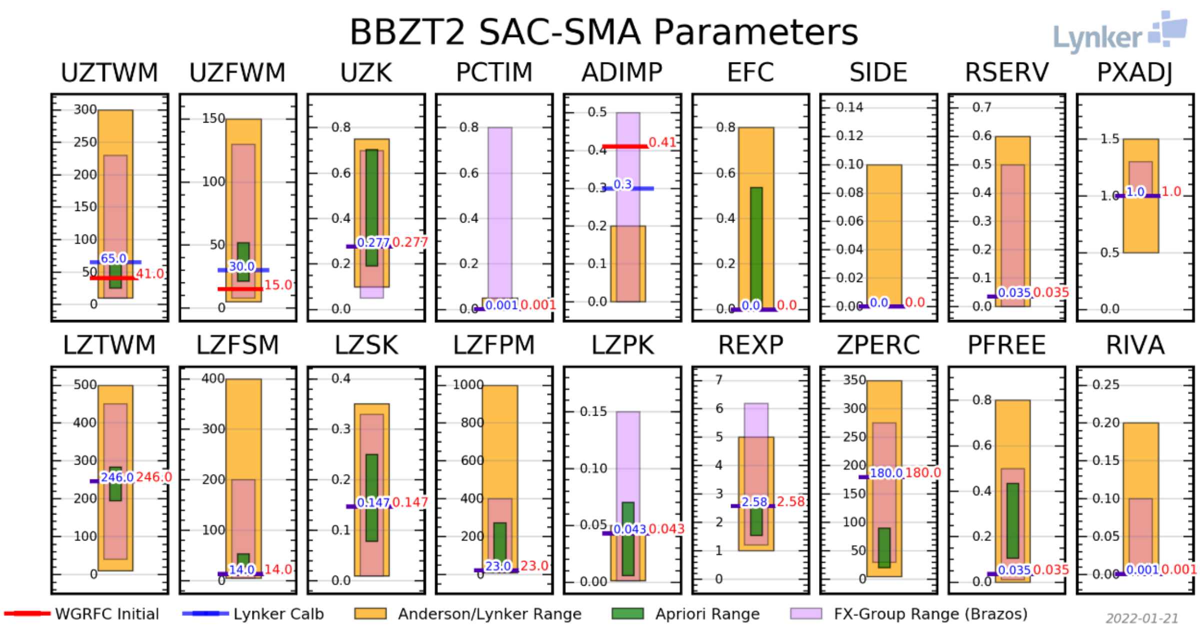
BBZT2: Brazos River at SH21 near Bryan











4.1.1.2. Middle Brazos-Bosque HUC6

Middle Brazos-Lake Whitney HUC8

WBAT2

Brazos River at Waco is a local basin located downstream of three major reservoirs: Lake Whitney (WTYT2), Waco Lake (ACTT2), and Aquilla Lake (AQIT2), which have inflows from the Brazos River, North Bosque River, and Aquilla Creek, respectively. Simulations for WBAT2, the most upstream basin on the mainstem of the Brazos River in the study domain, were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08096500 (available from 1987-11-09 to present). All upstream reservoirs have complete records dating back to at least the beginning of the study period, except for AQIT2, where records begin in 2001. USGS records for this basin are rated as fair, with significant diversions and regulations upstream from not only the reservoir operations, but also diversions for irrigation, municipal water supply, and oil field operations. WBAT2 is a heavily developed basin (8.3%) with clay-dominated soil characteristics (60% Type D/Clay Loam).

As the largest reservoir of the three, Lake Whitney contributes most of the routed flows to WBAT2, though significant releases from Waco Lake are also common. The diurnal releases from the hydroelectric operations at Whitney allowed for easy identification of routed flow source. LAG/K adjustments to WTYT2 (decreased LAG and K) were able to match times of the hydrograph where only Lake Whitney was contributing to basin flows. However, there were times when WTYT2 was inconsistently biased, which the calibration was not able to resolve. This is particularly evident in the timeseries below (Figure 4-22), where the August period of WTYT2 routed flows (dark green) are biased low, but the September period is biased high. These discrepancies between WTYT2 routed flows and WBAT2 QIN were challenging to reconcile within the limitations of the LAG/K models. A brief analysis comparing USACE Lake Whitney flows with the nearby downstream (~9 river miles) USGS gauge 08093100 highlights some discrepancies in flow measurements, but they are largely consistent with one another.

Statistical improvements for WBAT2 were most significant for peak flow events, particularly for flows greater than 30,000 CFS where PBIAS decreased from -16% to -3.5% (2010 to 2020). Overall model bias for this period decreased from -6.2% to -0.2% with a correlation coefficient of 0.993. While timing of routed flows is well calibrated, the magnitude of peak flow events was challenging to further improve within the constraints of routed flows.

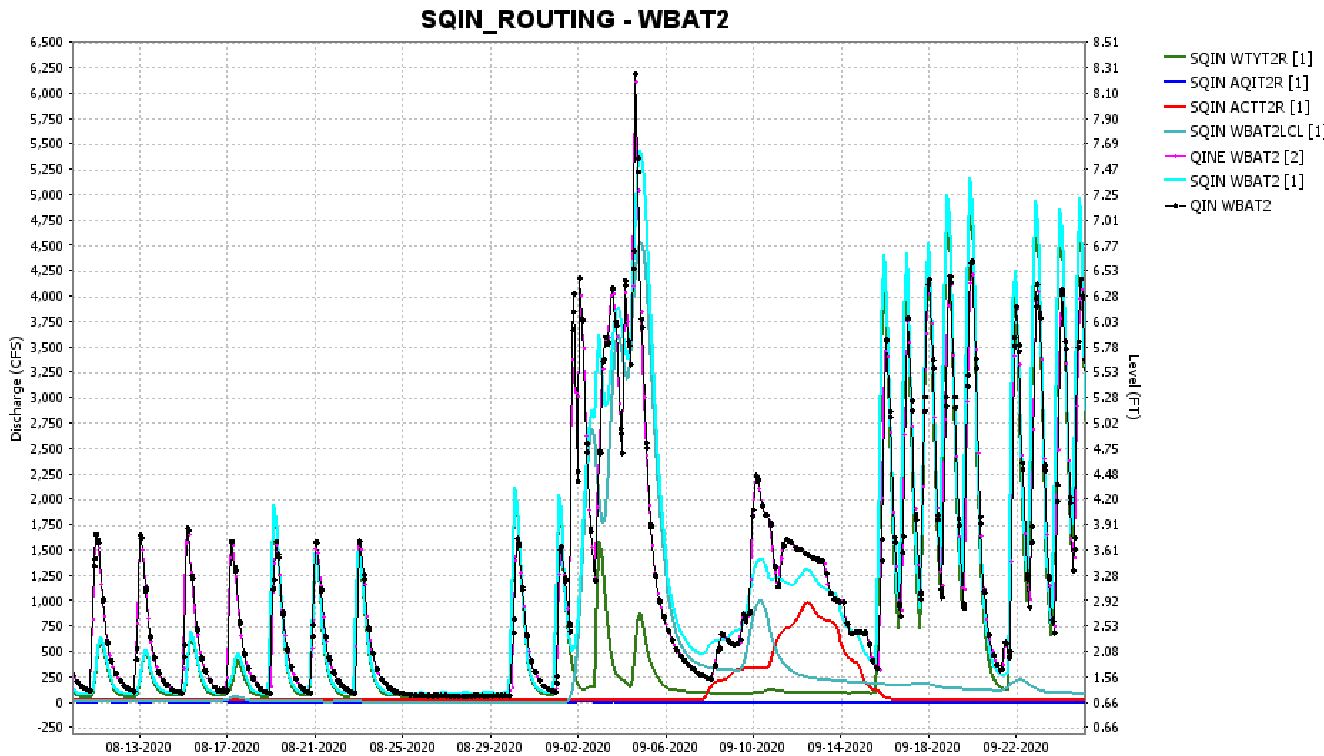
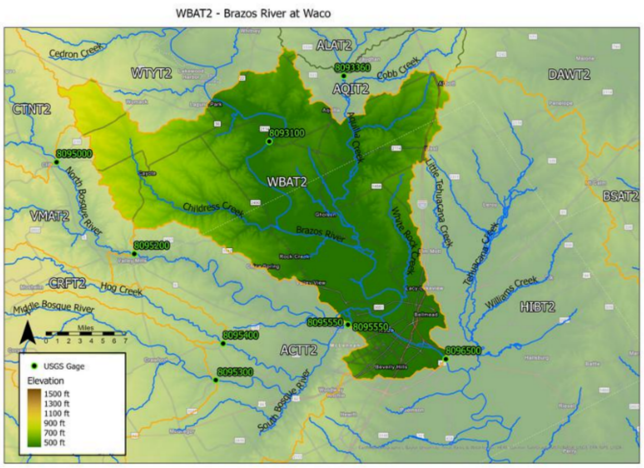
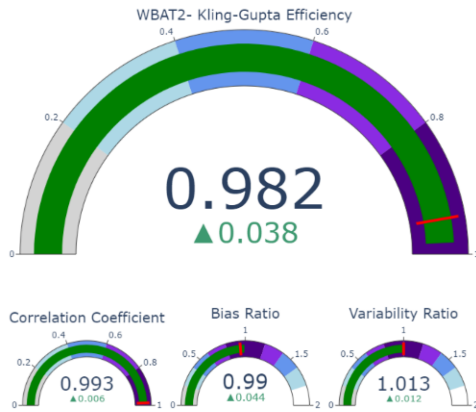
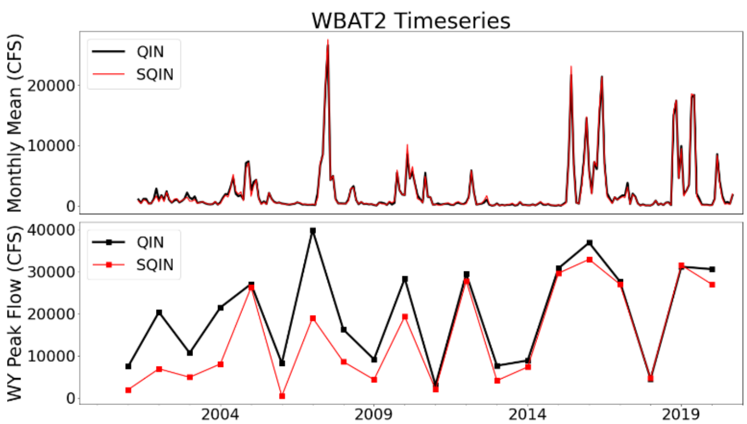


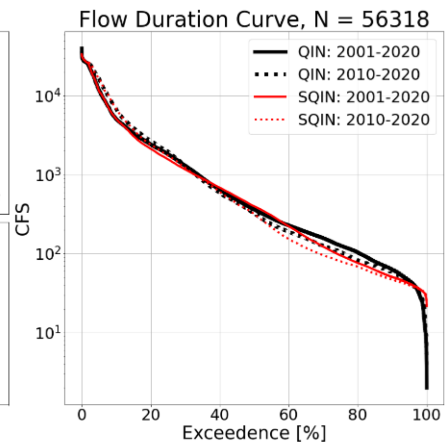
Figure 4-22: Routed flows from Lake Whitney hydroelectric operations (green) showing inconsistent bias relative to the observed QIN (black) from the early part of the period (low bias) to the late part of the period (no bias).

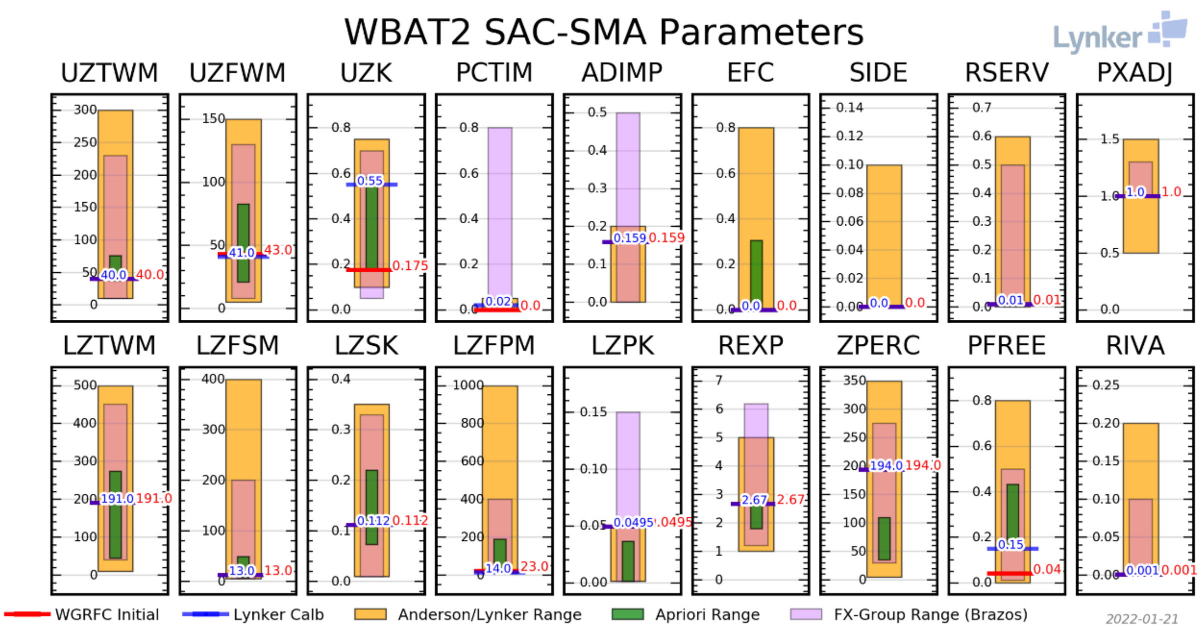
WBAT2: Brazos River at Waco











HIBT2

Brazos River near Highbank is a large (1,180 mi^2) local basin located downstream of WBAT2. Simulations for HIBT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08098290 (available from 2007-10-01 to present). USGS remarks that overall quality of the data is fair, with significant upstream regulation. Additionally, prior to the closure of Texas Power & Light Company's gas-fired power plant in 2010, water was diverted from 52-miles upstream (diversion point unknown) to Tradinghouse Creek Reservoir. Additional surface water diversions exist for municipal water supply, irrigation, and industrial uses. Being south of Waco, HIBT2 is less developed than WBAT2 (3.3%) with more land in cultivation (33.6%) or pasture (22.8%). HIBT2 is very clay-dominated, however, with 78% of soils classified as Type D/Clay Loam.

Because of the significant upstream regulation, HIBT2 is less flashy and flood-prone than other unregulated basins. Peak flows during the wetter late spring and early summer months (Figure 4-23) are consistently in the 30-40,000 CFS range, with late summer baseflows of around several hundred CFS or greater. Though a majority of the flow is routed from WBAT2, the large basin area of HIBT2 also produced significant local flows at times. During local streamflow generation, it was often difficult to generat sufficient flow to properly estimate peak flow magnitudes, with consistent under-simulation from January to June or July. Decreasing this bias without significantly over-simulating other parts of the hydrograph was challenging.

Overall KGE scores across 2010–2020 increased slightly for HIBT2 (KGE 0.92 to 0.923), though in return for significant improvement for the 0.1% highest flows (over 38,000 CFS), where bias decreased from 14% to 4.9% from 2010–2020, and from 14% to 2.6% for 2007–2020. Overall bias for the most recent decade was -7.8%, with a correlation coefficient of 0.987.

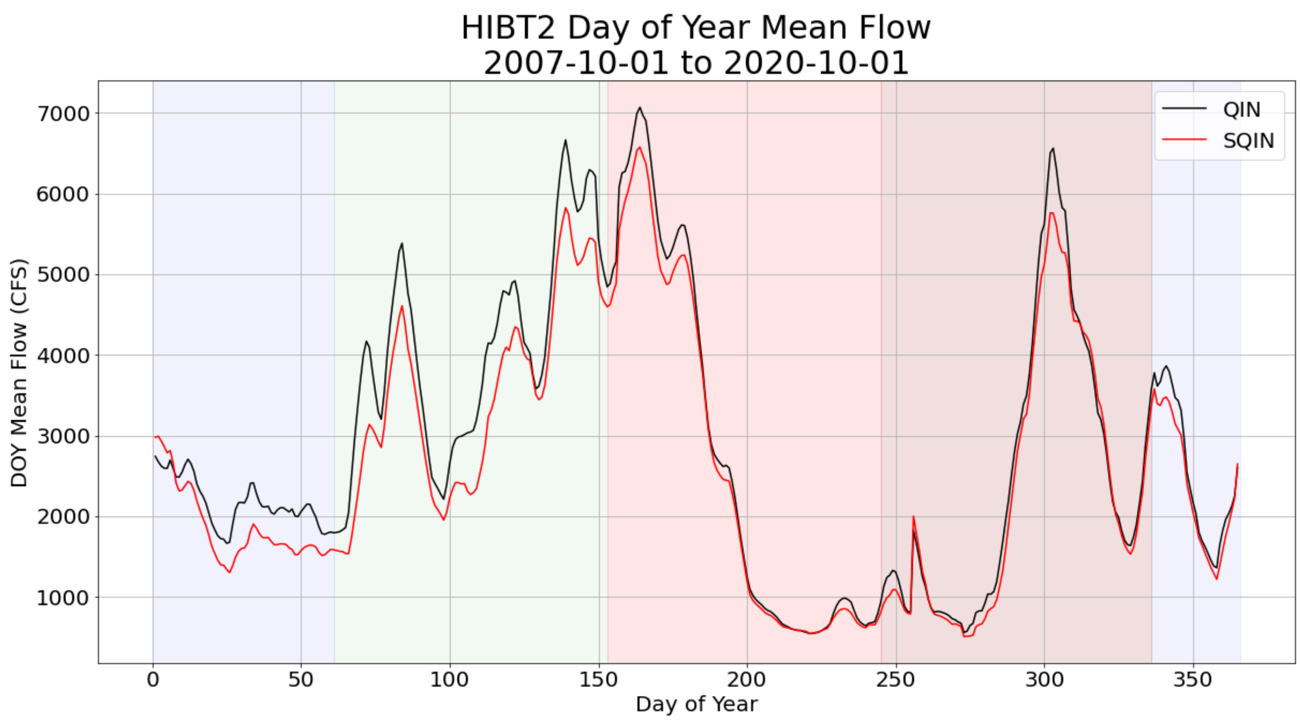
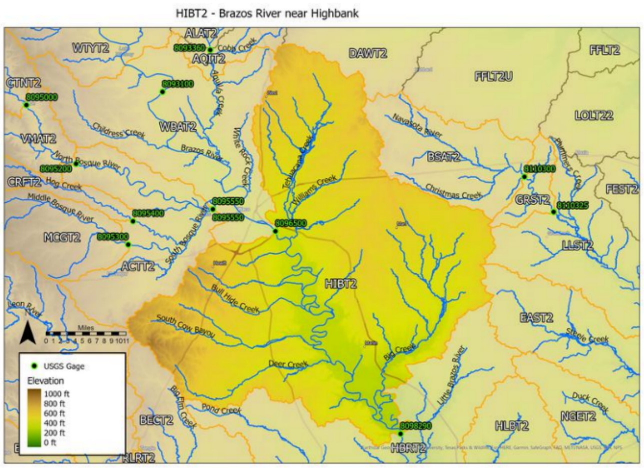
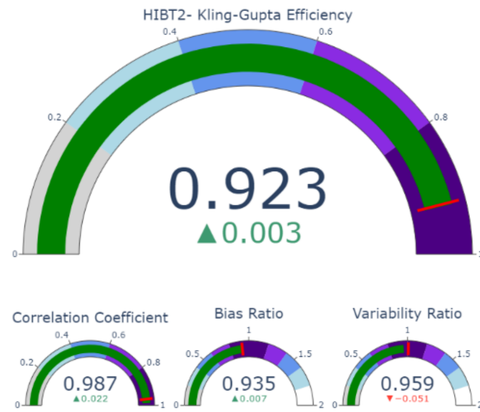
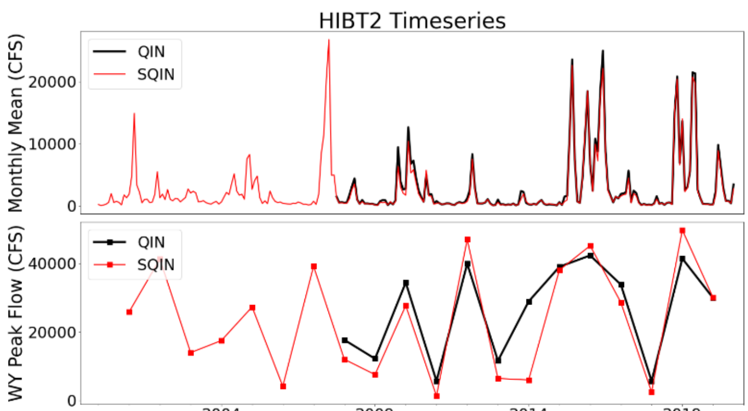


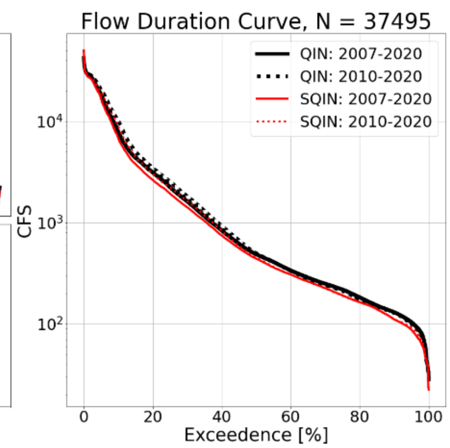
Figure 4-23: Mean day of year flows (original QIN/SQIN timeseries smoothed with a rolling mean) showing wet spring and fall conditions for HIBT2, and a low model bias, particularly in the spring. QIN in black; SQIN in red. Meteorological seasons are banded by colors, e.g., DJF is in blue.

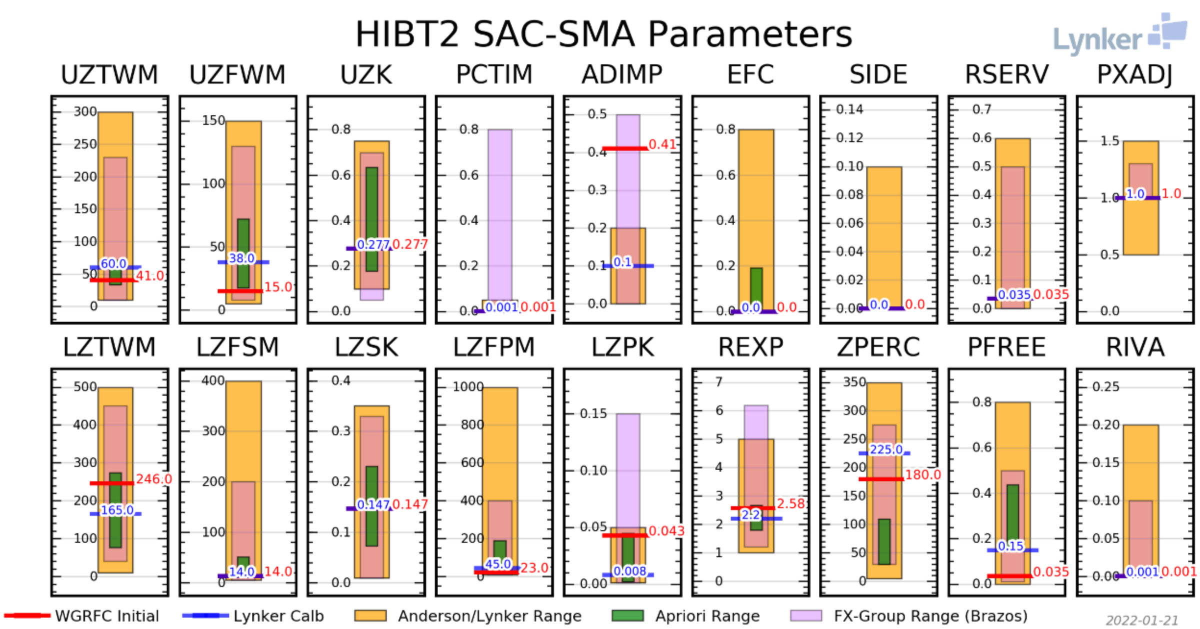
HIBT2: Brazos River near Highbank











4.1.1.3. Lower Brazos HUC6

Navasota HUC8

BSAT2

Lake Mexia near Mexia is a headwater basin that flows into Lake Mexia, a reservoir owned and operated by the Bistone Municipal Water Supply District for water supply and recreation purposes. Simulations for BSAT2 were run at a 3-hourly timestep, calibrated to instantaneous inflow data calculated from reservoir pool elevation data from the USGS gauge 08110300 (available from 2007-10-01 to present). Aside from the lake, no known regulations and diversions exist upstream. Soil characteristics in the basin are clay-dominated, with 86% of the basin with Type D/Clay Loam soil. The single largest land cover class in the basin is herbaceous (45%).

Calculated QIN inflow data provide a basis for calibration, though with less confidence than directly measured QIN data. For example, following a runoff event, it was common for QME inflow data to briefly dip below zero (Figure 4-24). Calibrations focused on increasing the rainfall responsiveness of the basin (peakier and earlier UNIT-HG, smaller UZTWM etc.)

Statistical improvement was hindered by a large negative bias, which was particularly evident for events above 17,000 CFS (calibrated PBIAS: -27%, initial PBIAS: -72%). Because QIN data are disaggregated daily inflow data, confidence of peak flow magnitudes is low, however.

WGRFC feedback: *SAC-SMA parameters and UHG need to be reviewed. SAC-SMA has a very small UZTWM when compared to adjacent basins such as: GRST2. This basin is too slow to rise and does not drain enough in the reservoir. Seasonal ET adjustment may also help out. Pool hangs too high in some events.*

Lynker response: We introduced a seasonal ET demand curve and increased UZTWM at this basin. We also shifted the UHG and aimed to increase peak flow simulations, though they were often still too low.

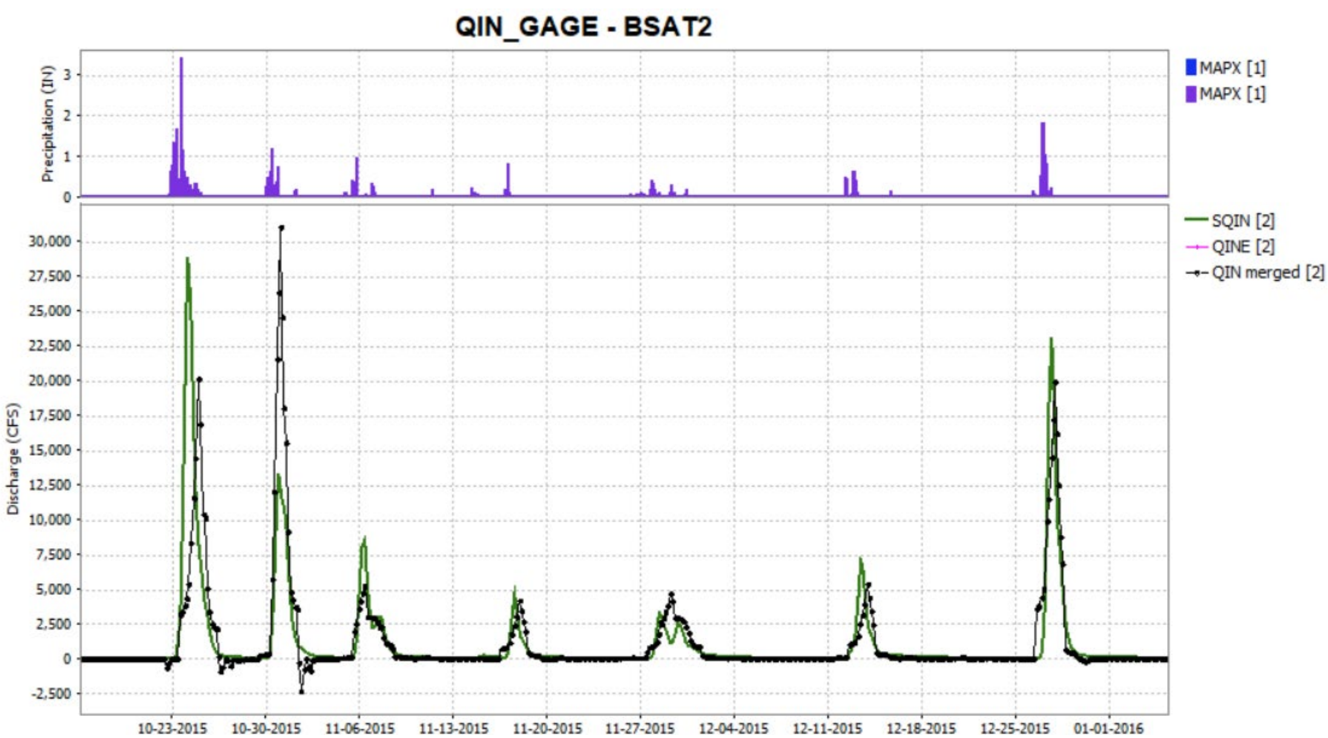
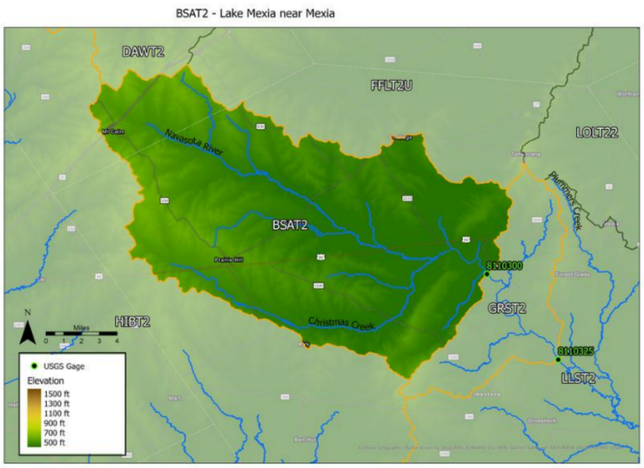
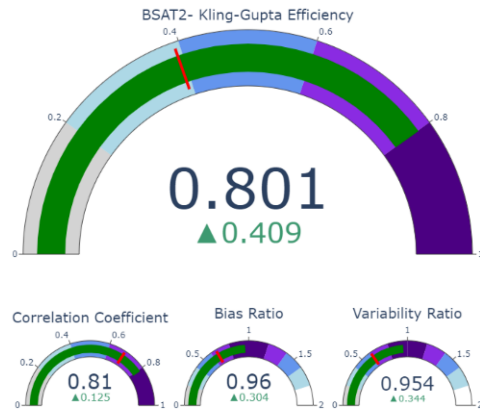
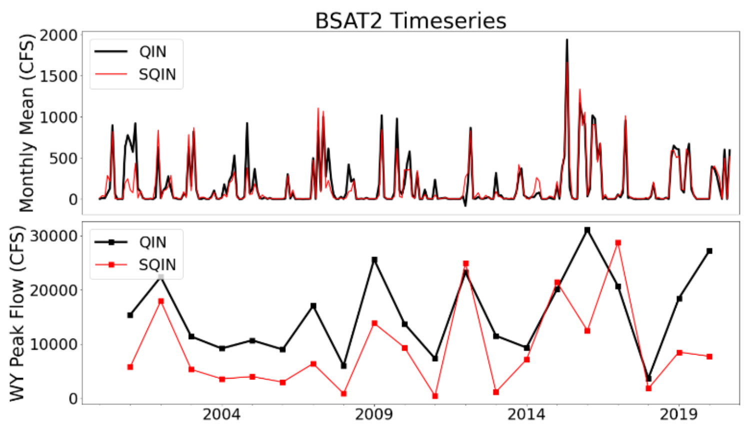


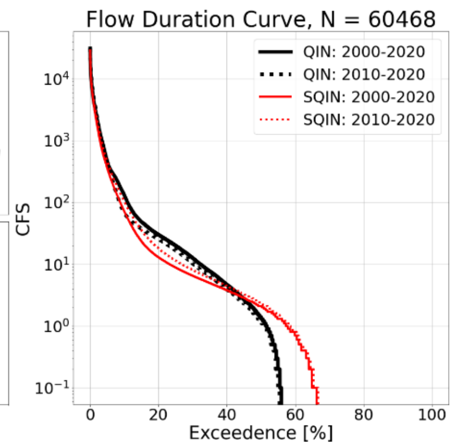
Figure 4-24: Calculated inflows to Lake Mexia (QIN, black line), disaggregated to instantaneous data. Note negative values, a by-product of the mass balance analysis used to estimate reservoir inflows.

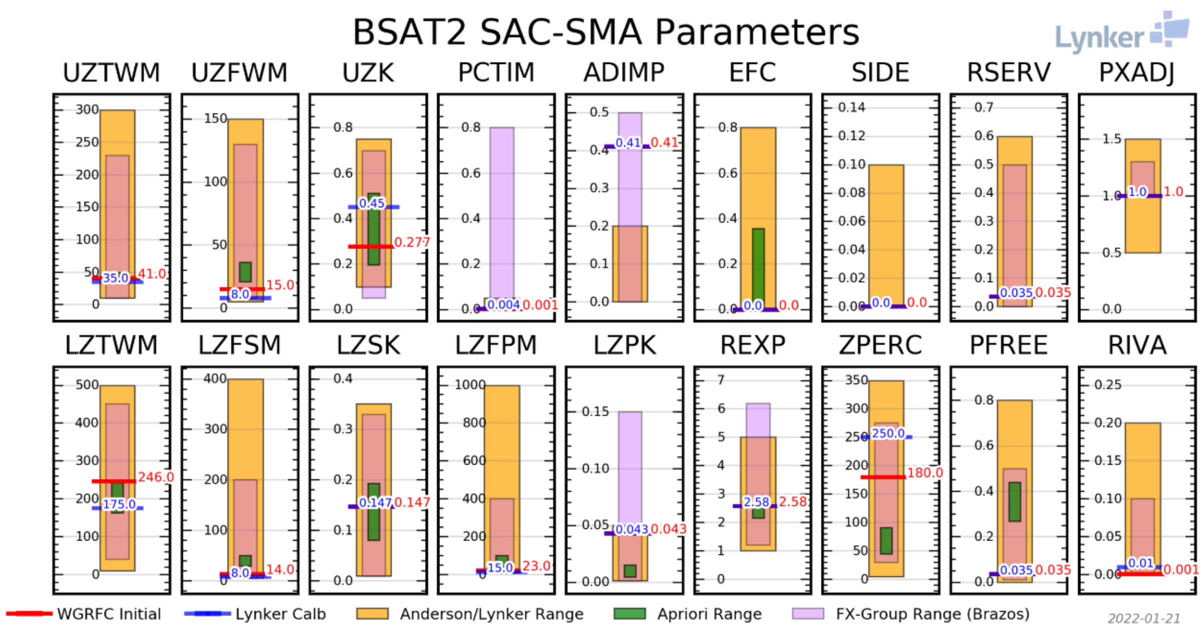
BSAT2: Lake Mexia near Mexia











GRST2

Navasota River above Groesbeck is a very small (43 mi^2) local basin downstream of Lake Mexia and BSAT2. Simulations for GRST2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08110325 (available from 2007-10-01 to present). USGS remarks note that records for this gauge are of fair quality, except for very low flows (< 1 CFS) which are poor. Furthermore, the USGS observes that more than 10% of the drainage area is regulated (i.e., Lake Mexia) and that there are many diversions present for irrigation, municipal water supply, and oil field operation.

GRST2 is an ephemeral stream, with little to no flow during the late summer; about 50% of the time, flows at GRST2 are less than 1 CFS. Evidence of diversions is apparent in the regular occurrences when routed BSAT2 flows exceed GRST2 outflows, driving a high model bias. Despite this, model calibrations focused on adjusting the timing of the center of mass of routed flows, and adjusting the SAC-SMA model parameters accordingly, including increasing PEADJ to 1.1 for all months. Larger flood events, such as the March 9th, 2016 example, produced good simulations.

Though overall bias was still very high (23% in 2010–2020), it is improved from the 31% bias prior to model calibration. The mean day of year flows highlight how this bias is most notable during the spring (March-May) months, though also during other times of the year. On an event basis, however, there are still significant peak flows that are under-simulated (April 29, 2009; observed peak flow 25 KCFS, simulated peak flow 19 KCFS;).

WGRFC feedback: *Timing issues at this location. When BSAT2 (Lk Mexia) is adjusted, please take another look at this point. There are timing issues, but the overall volume looks good. Adjustments at BSAT2 may improve or make it worse.*

Lynker response: LAG values were decreased to 1 across all flow ranges; no changes were made to the attenuation values or UHG, as nearly all flows at GRST2 are routed from BSAT2. Adjustments to the LAG were well verified for the most part, though occasionally the routed flows were too late. (Figure 4-25)

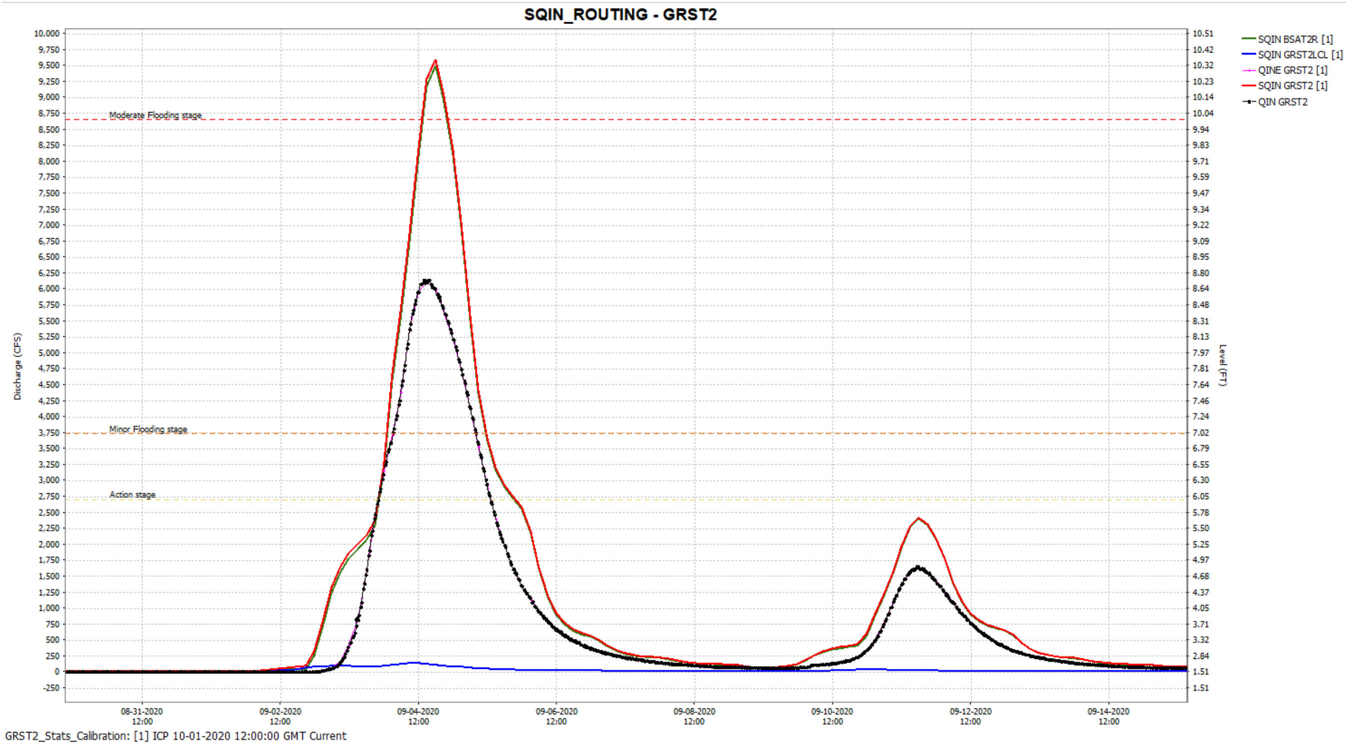
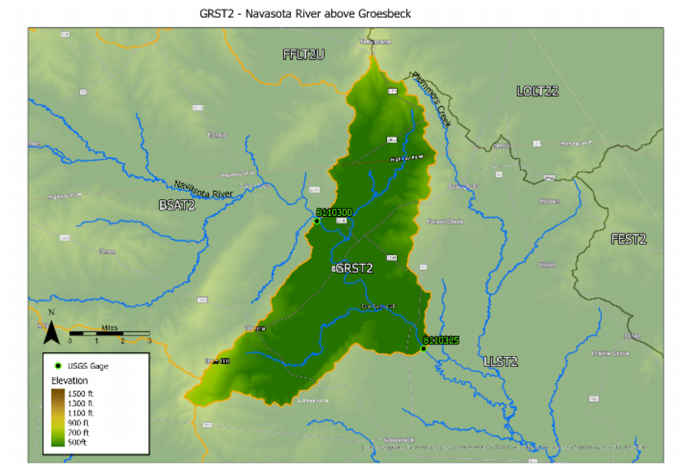
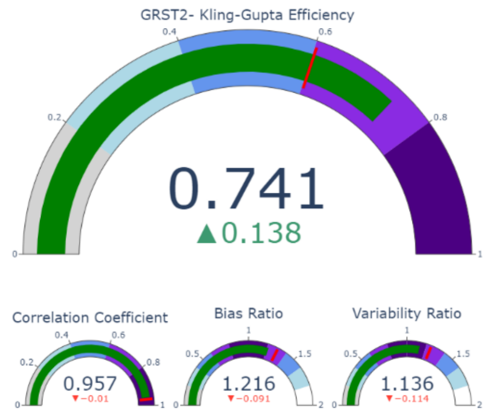
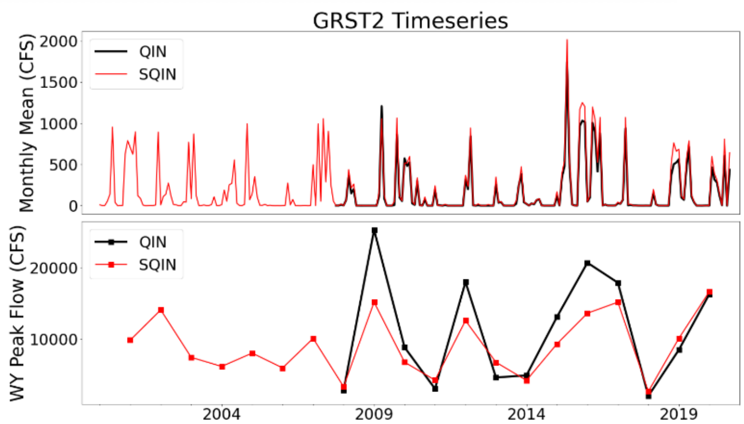


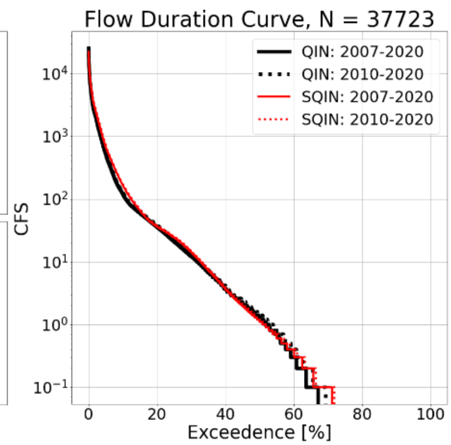
Figure 4-25: Improved calibration for GRST2 (red) showing a well-verified timing of the event, but a very large bias due to the BSAT2 routed flows.

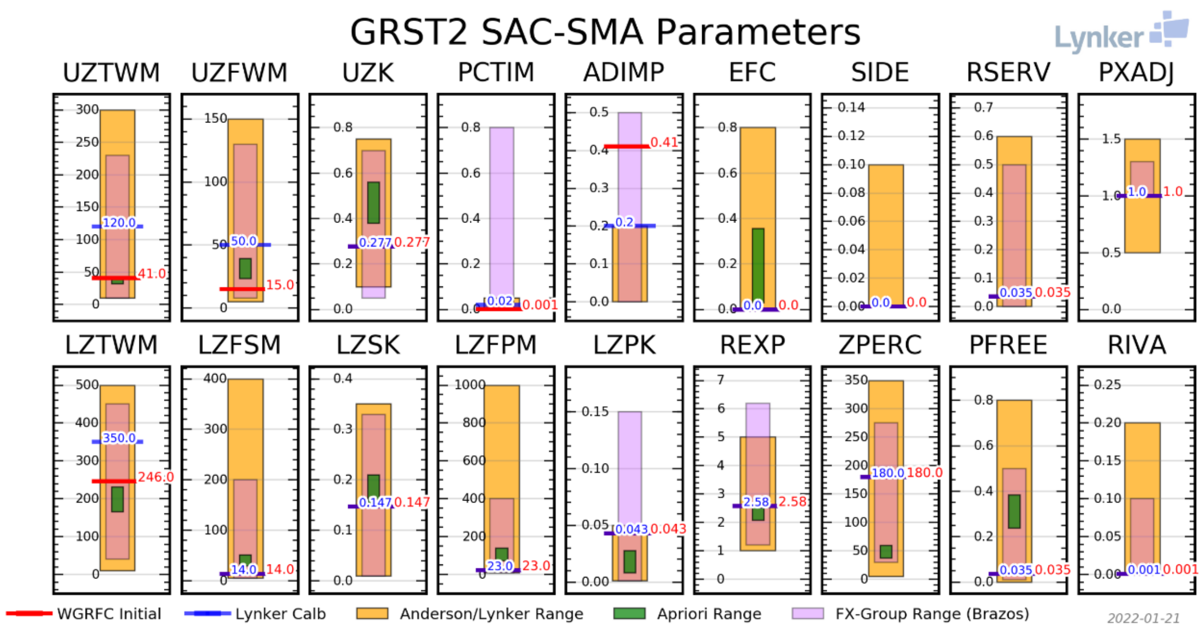
GRST2: Navasota River above Groesbeck











EAST2

Navasota River near Easterly is a local basin downstream of Lake Limestone and LLST2 (out of domain). Simulations for EAST2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08110500 (available from 1988-02-02 to present). As with the upstream basins on the Navasota River, the USGS notes that beyond the Lake Mexia and Lake Limestone operations, there are diversions for irrigation, municipal supply, and oil field operation, though records are rated as good. Soil characteristics in the basin are less clay-dominated (52% Type D/Clay Loam) than the headwaters of the Navasota, with a transition towards Type A/Sand soils towards the basin outlet.

Routed flows from LLST2 (Lake Limestone daily outflows from the Brazos River Authority) needed to be delayed to better simulate timing of peak flows. Generally, attenuation needed less adjustment. Local flows, on the other hand, were shifted significantly earlier via the UHG (see March 2016 event below). Adjustments to the UHG and local SAC-SMA parameters increased peak magnitude simulations. While overall quality of the BRA Lake Limestone data seemed good, a 166,000 CFS outflow from Lake Limestone on September 7, 2001 was flagged for review. Conversations with Chris Higgins of BRA confirmed that these data points were in error and corrections were made to the record.

Statistical improvement was modest, however the PBIAS for the greater 0.1% of flows (> 28,000 CFS) was decreased from -15% to -2.2% (2010–2020; see March 2016 Figure 4-26), though earlier in the record, there was less improvement for these larger flood events (initial PBIAS -16% to -7% from 2000–2020).

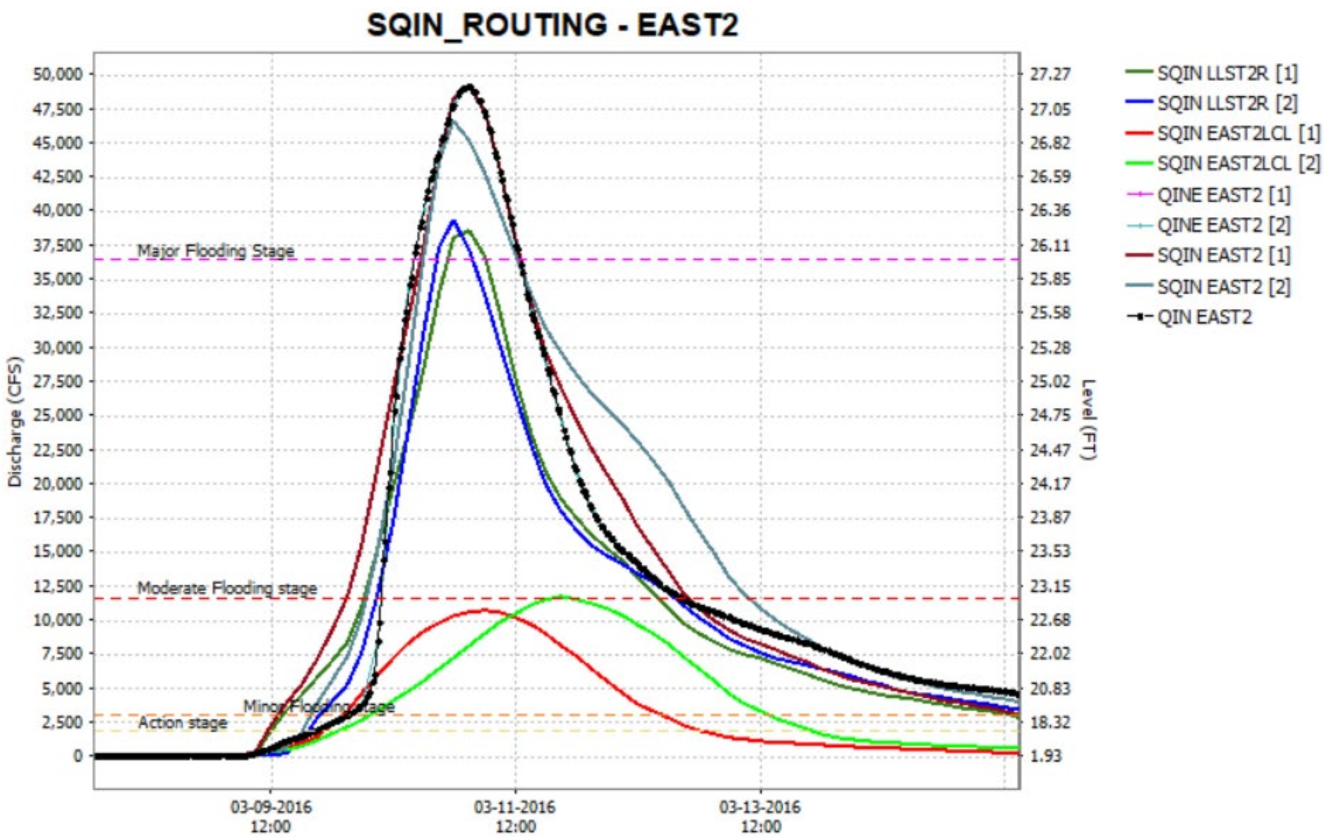
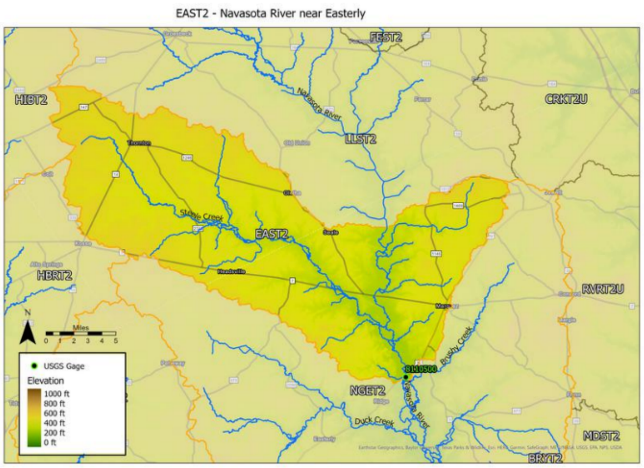
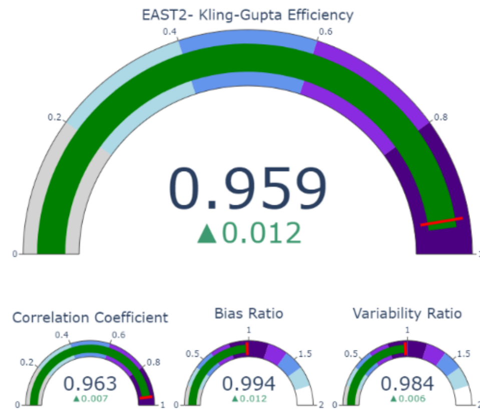
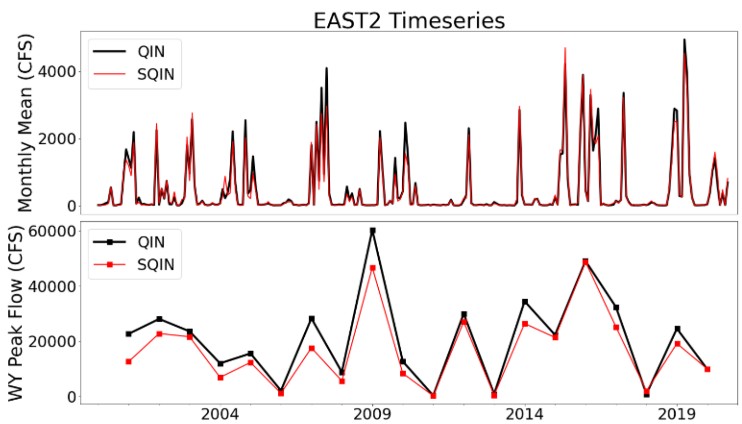


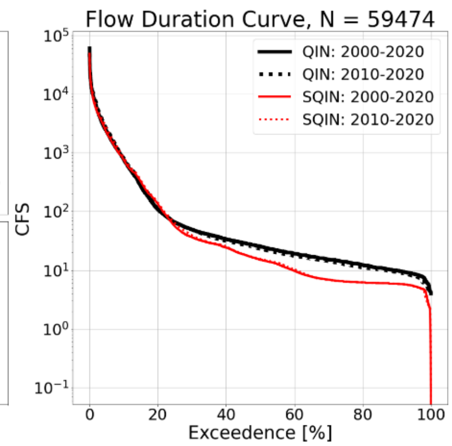
Figure 4-26: Improved calibration for EAST2 with SQIN before (grey-blue) and after (brown-red). Note improvements to the receding limb of the event.

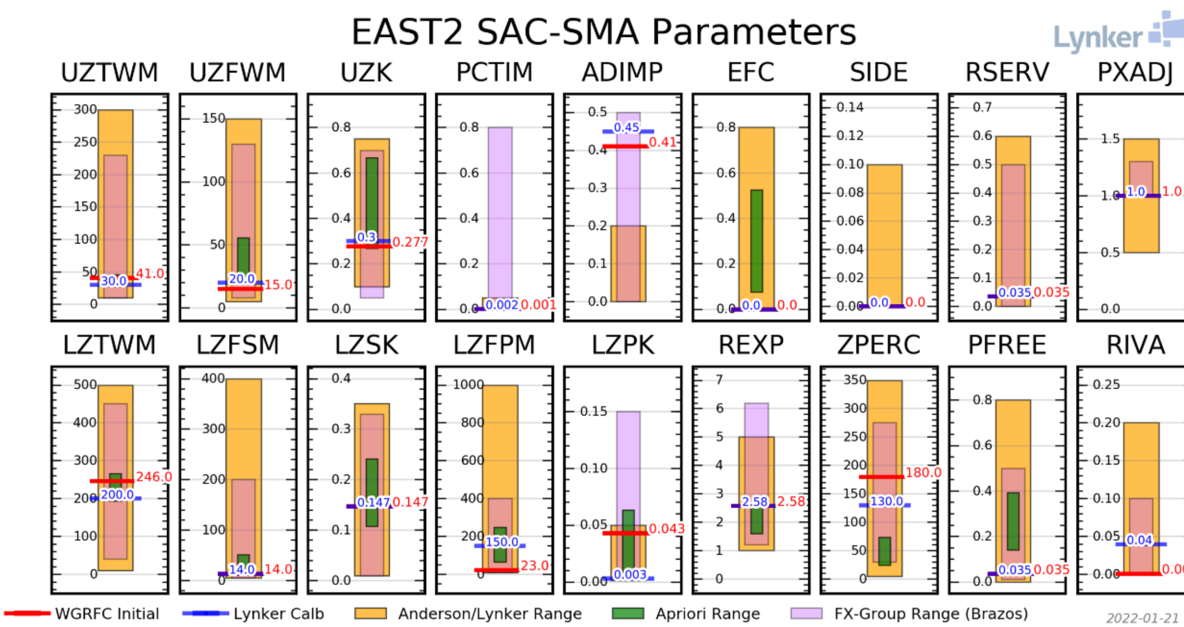
EAST2: Navasota River near Easterly











NGET2

Navasota River near Normangee is a local basin downstream of EAST2. Simulations for NGET2 were run at a 3-hourly timestep, calibrated to instantaneous discharge from USGS gauge 08110800 (available 1997-04-01 to present). USGS records are rated as good, with similar remarks noting above station diversions for irrigation, municipal supply, and oil field operations. Water balance analyses revealed that the upstream gauge (08110500) regularly measured higher flows than the outlet gauge (08110800), including for years 2015, 2016, 2017, and 2019 on an annual basis. Email correspondence with hydrologist Jeff East of the USGS Texas Water Science Center and WGRFC personal did not reveal any new local knowledge about storage losses or other surface water diversions, though a transition to Type A/Sand soil characteristics from EAST2 to NGET2 may suggest greater deep percolation.

As noted, there was consistently too much routed water from EAST2, leading to a high bias consistent with what WGRFC forecasters have observed. This was particularly evident from 2010–2020. WGRFC (email communications with Andrew Philpott) advised against implementation of a LOOKUP model due to a trend towards a smaller bias in the 2021 forecasting season. Knowing this, calibrations focused on adjustments to the LAG/K parameters and compensating with a higher UZTWM value to decrease surface runoff. PEADJ was also increased to 1.1 to decrease overall bias, though still favoring model over-simulation. The before (grey) and after (brown) for the March 11, 2016 event show good simulation of the timing and peak flow magnitude, despite too much water during the tail ends of the event (Figure 4-27).

Final calibrated model PBIAS was 32% (initially 50%), though this was much lower for the top 0.1% of flows (> 27,000 CFS; calibrated PBIAS 3.3% compared to 8% initially), as is evident in the water year peak flow timeseries.

WGRFC feedback: *Moderate level events are missing lag. Peaks too early in recent events. Re-evaluate the lags between 2,000 and 30,000 cfs. Consider adjusting flow thresholds in addition to the lag values.*

Lynker response: Significant discrepancies between NGET2 and the upstream routed flows from EAST2 made calibration for this basin difficult. In addition to adding a flow threshold at 4,000 CFS, we also increased lag values upwards of 15 hours. Attenuation values were also increased for some flow ranges. Like all other basins, an ET demand curve was added back in. No changes were made to the UHG.

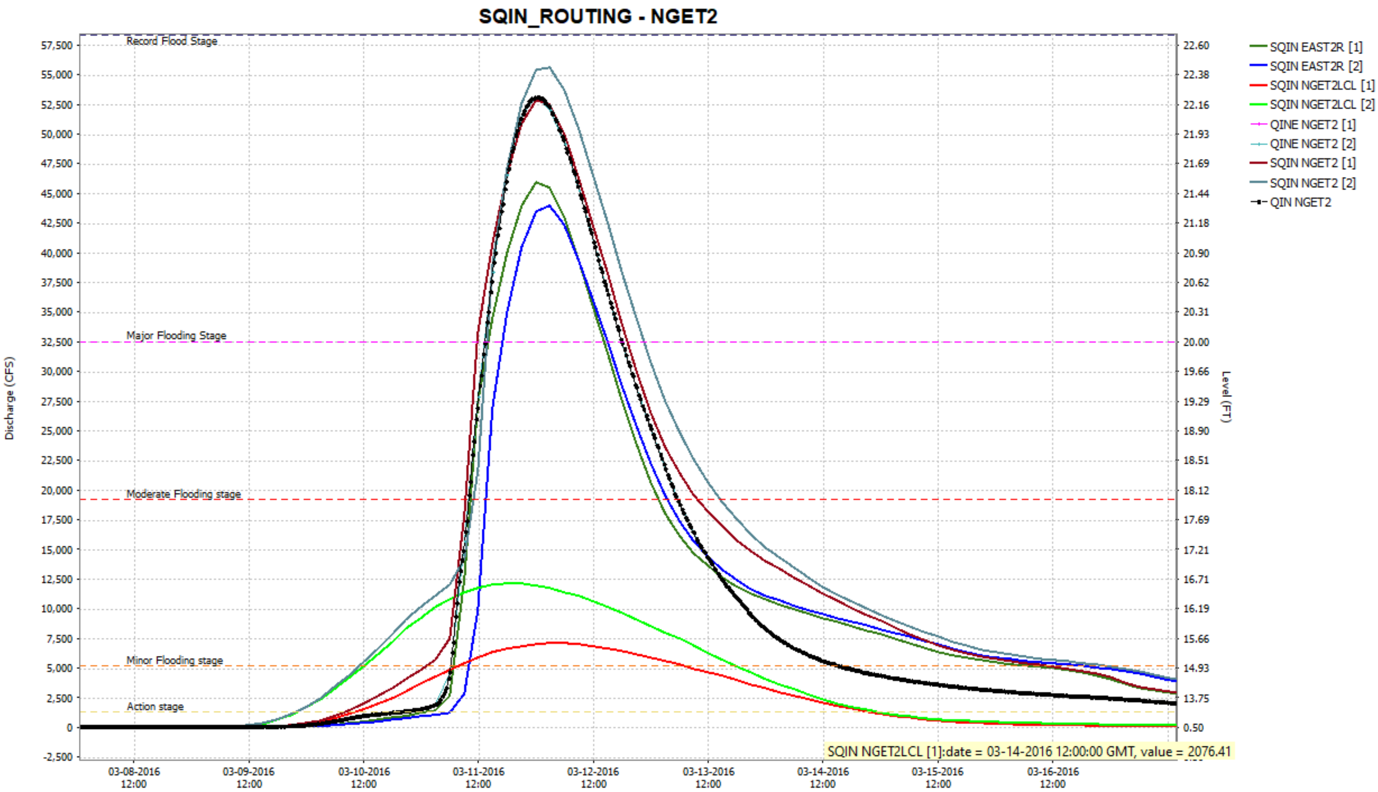
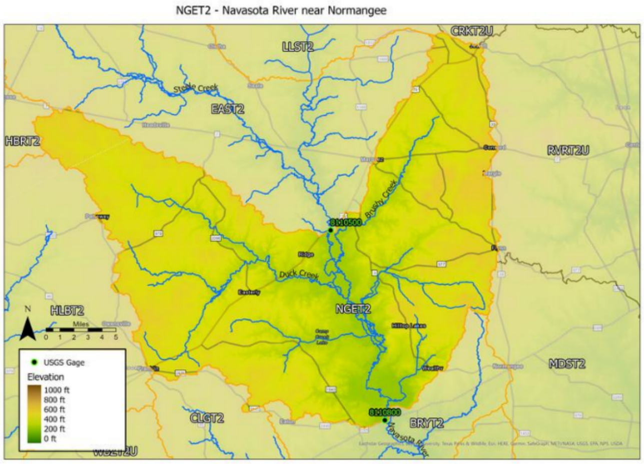
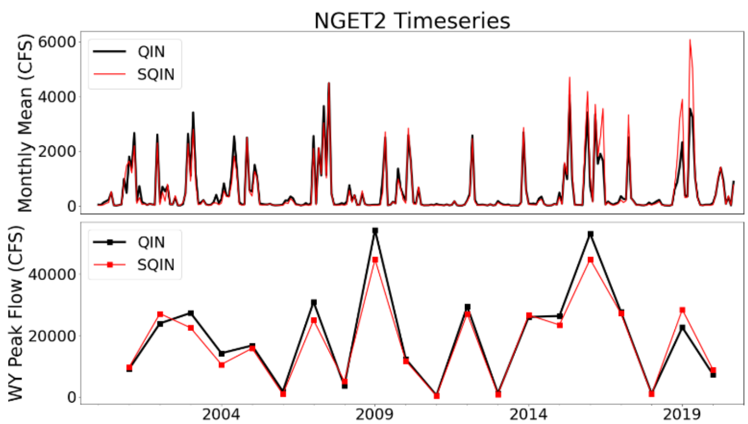
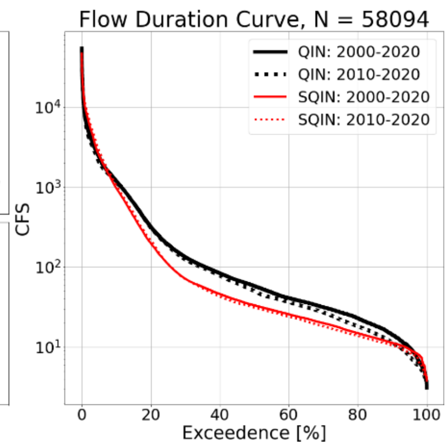


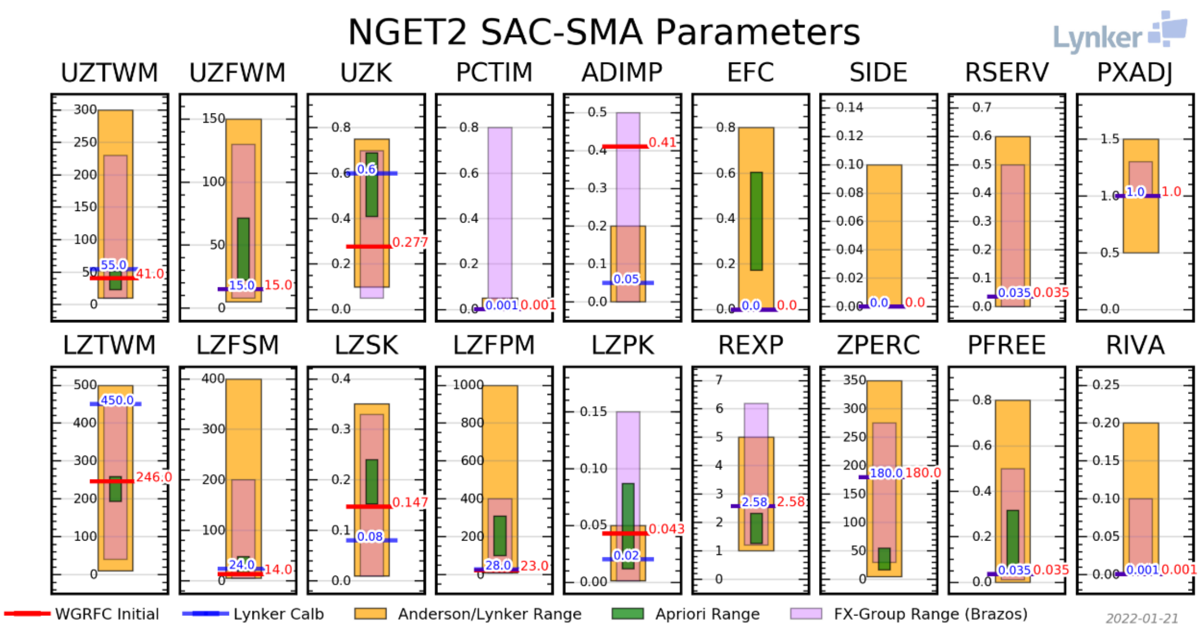
Figure 4-27: Improved calibrations to NGET2, with SQIN before (grey-blue) and after (brown-red) calibrations. Note the improvement of timing and magnitude of peak flows.

NGET2: Navasota River near Normangee





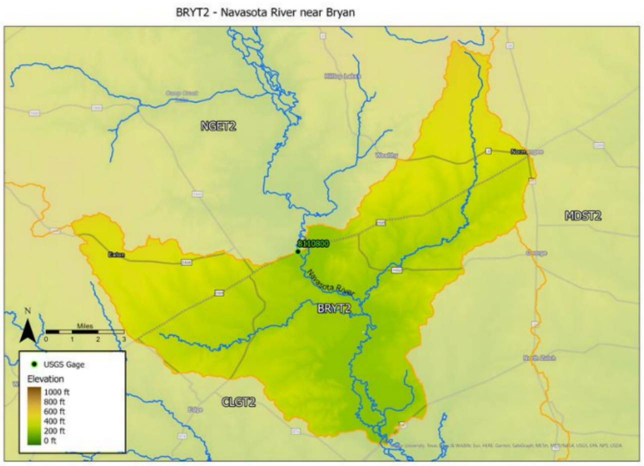


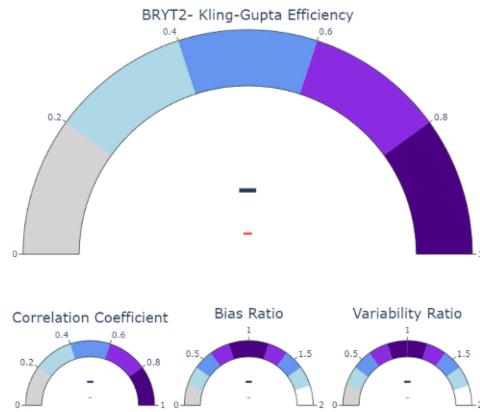


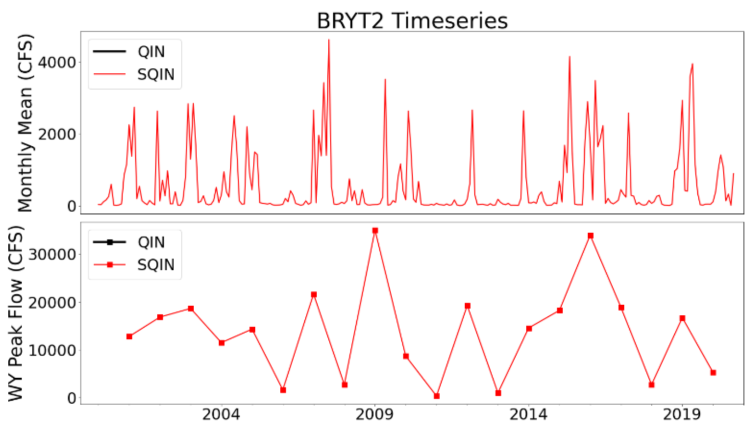
BRYT2

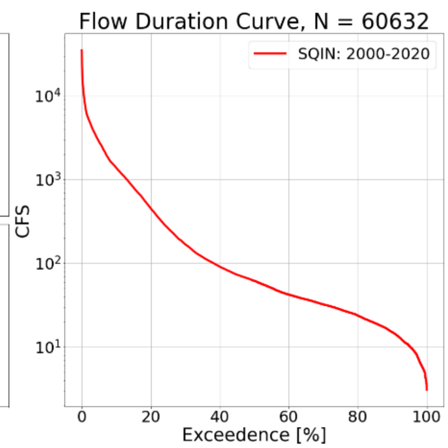
Navasota River near Bryan is a small local basin downstream of NGET2. Simulations for BRYT2 were run at a 3-hourly timestep, however there was no discharge data (instantaneous or daily) available during the period of study (USGS gauge 08111000 discontinued; active 1951-01-01 to 1997-03-31). Local flows from BRYT2 were not identifiable at the next downstream basin with observed data (HPDT2), so there was no basis to calibrate the default parameter values beyond adjusting the ET Demand Curve values to 1. Land cover and soil characteristics are similar relative to the average characteristics of the Navasota River basin.

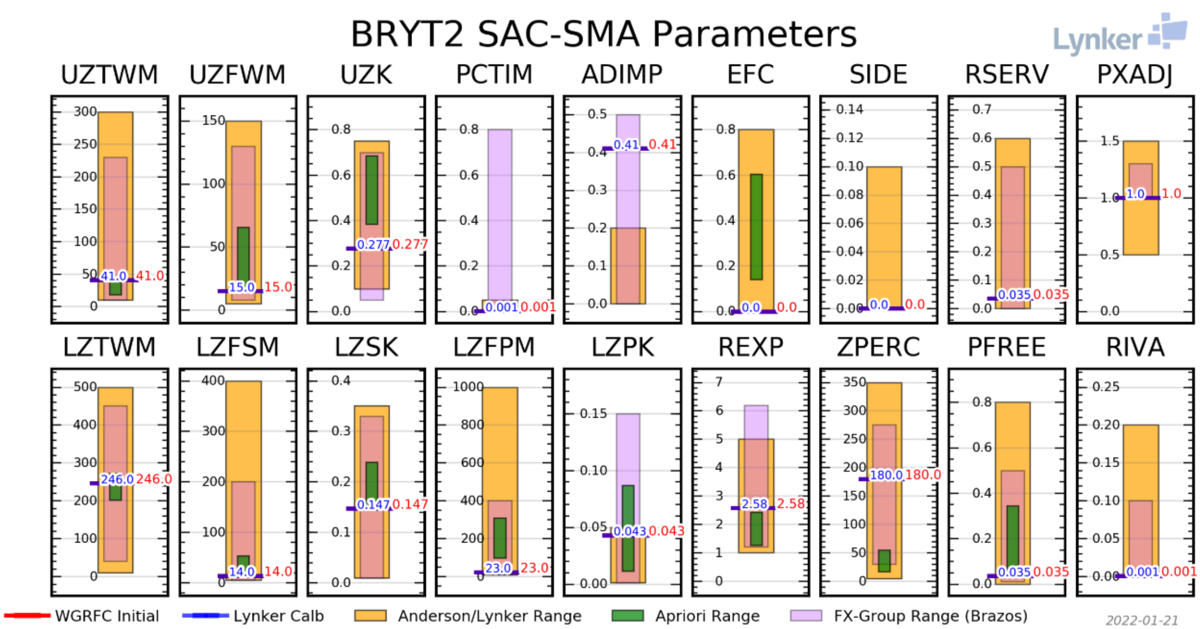
BRYT2: Navasota River near Bryan







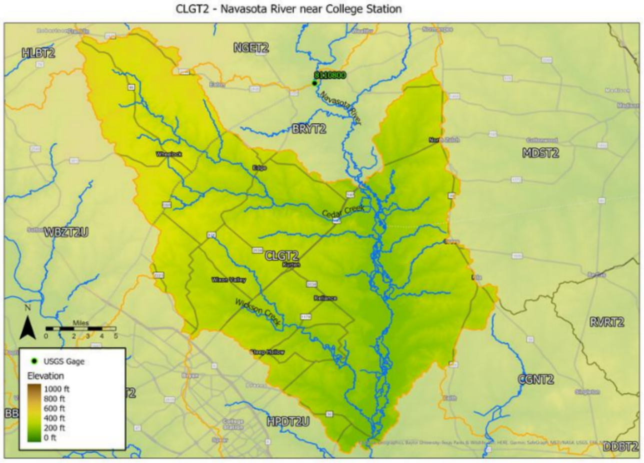


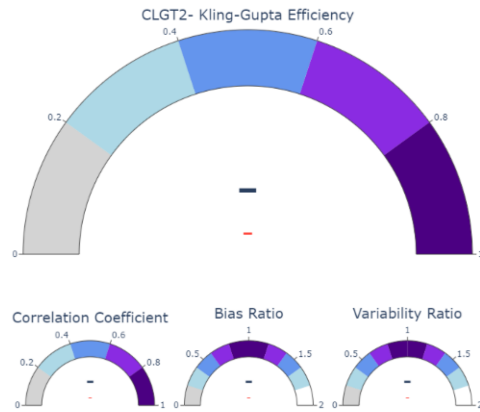


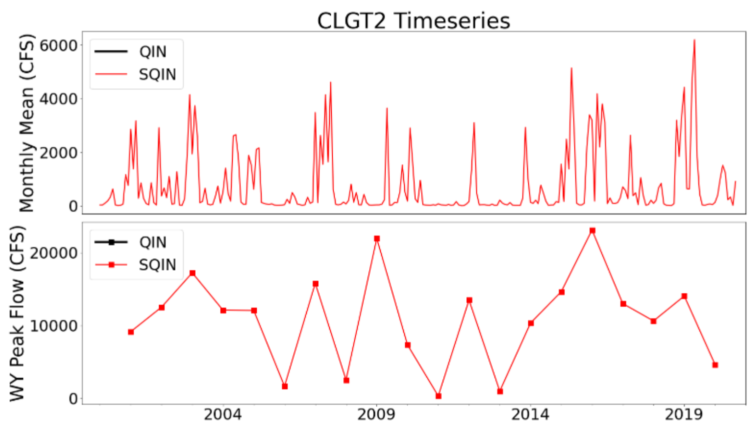
CLGT2

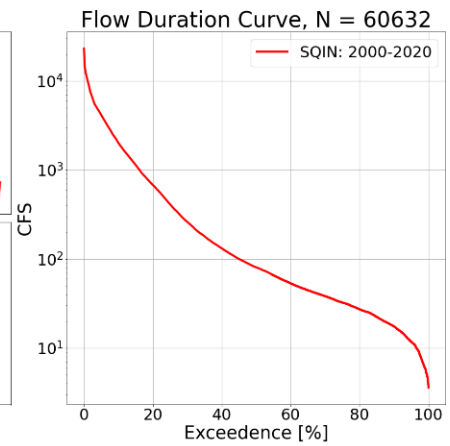
Navasota River near College Station is a local basin downstream of BRYT2. Simulations for CLGT2 were run at a 3-hourly timestep, however there was no discharge data (instantaneous or daily) available during the period of study (USGS gauge 08111010 discontinued; active 1977-05-01 to 1985-09-29). Local flows from CLGT2 were not identifiable at the next downstream basin with observed data (HPDT2), so there was no basis to calibrate the default parameter values beyond adjusting the ET Demand Curve values to 1. Land cover and soil characteristics are unremarkable relative to the average characteristics of the Navasota River basin.

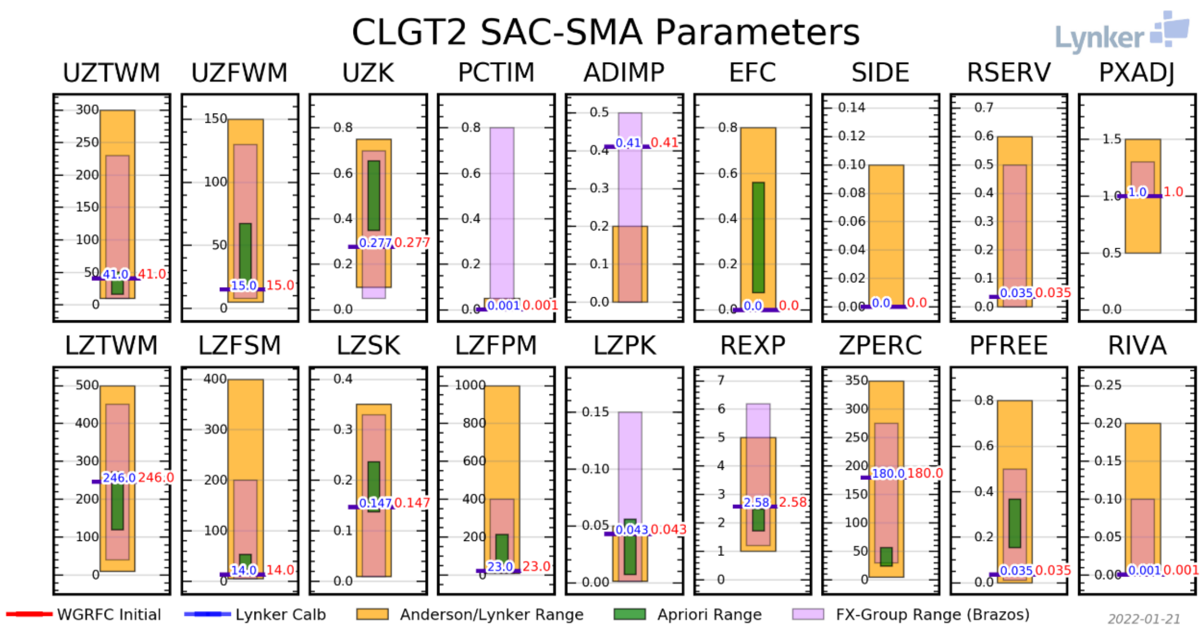
CLGT2: Navasota River near College Station











HPDT2U

Upper Brazos River near Hempstead is a local basin downstream of CLGT2. Simulations for HPDT2U were lumped with HPDT2 at a 3-hourly timestep. See additional calibration notes below in HPDT2. Land cover and soil characteristics are unremarkable relative to the average characteristics of the Navasota River basin.

Yegua HUC8

DMYT2

Middle Yegua Creek at Dime Box is a headwater basin and a tributary to Somerville Lake. Simulations for DMYT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08109700 (available from 2007-10-01 to present). USGS records note flow data as being of fair quality, except flows below 1 CFS which are poor. Several small, dammed lakes do exist in the basin, though they are insignificant in size relative to the overall drainage area. Inconsistencies were noted between USGS measured floods and WGRFC reported historic events. For example, USGS records indicate record peak flows on October 31, 2015, though the WGRFC marks the flood of record as May 4, 2019. Land cover for DMYT2 is classified primarily as hay/pasture (51%), with a considerable portion forested (30%). Soil types are mixed, though mostly Type D/Clay Loam (39%).

The hydrology of DMYT2 is characterized by intermittent flows, with periods of low or no flow during the later summer and flashy rainfall-driven events during the spring. Notably, the most recent five years were significantly wetter than the preceding period (2007–2014). During calibrations, particular attention was paid to the wet periods during the fall following the prolonged summer dry period. Initial modifiers for these periods produce too much runoff during the wet-up period, requiring increases to tension water parameters. The October 31, 2015 flood event and the preceding wet up around October 25 clearly illustrate this improvement (Figure 4-28).

Statistical improvement for DMYT2 was significant, with increases in KGE from -0.24 to 0.83 (period 2007–2020). Peak flows were still under simulated (Figure 4-28) though were improved over initial simulations. Decreases to the UZFWM were successful in decreasing these negative biases, however at the expense of other small to mid-sized runoff events.

WGRFC feedback: *Please review timing and adjust timing by up to 12 hours. Timing issues may be related to SAC-SMA or UHG.*

Lynker response: We revisited the timing of flows at DMYT2 and adjusted both the SAC-SMA parameters and UHG in response. Even after these adjustments, however, we found that the timing biases are inconsistent. For example, during the Major Flood of May 2019, peak flows are well verified, if a bit late. Conversely, simulations for the Major Flood of Halloween 2015 are early (see screenshot). In the case of this event, it was difficult to delay simulated peak flows enough, without negative impacts elsewhere. We attempted to balance our adjustments, favoring more recent events.

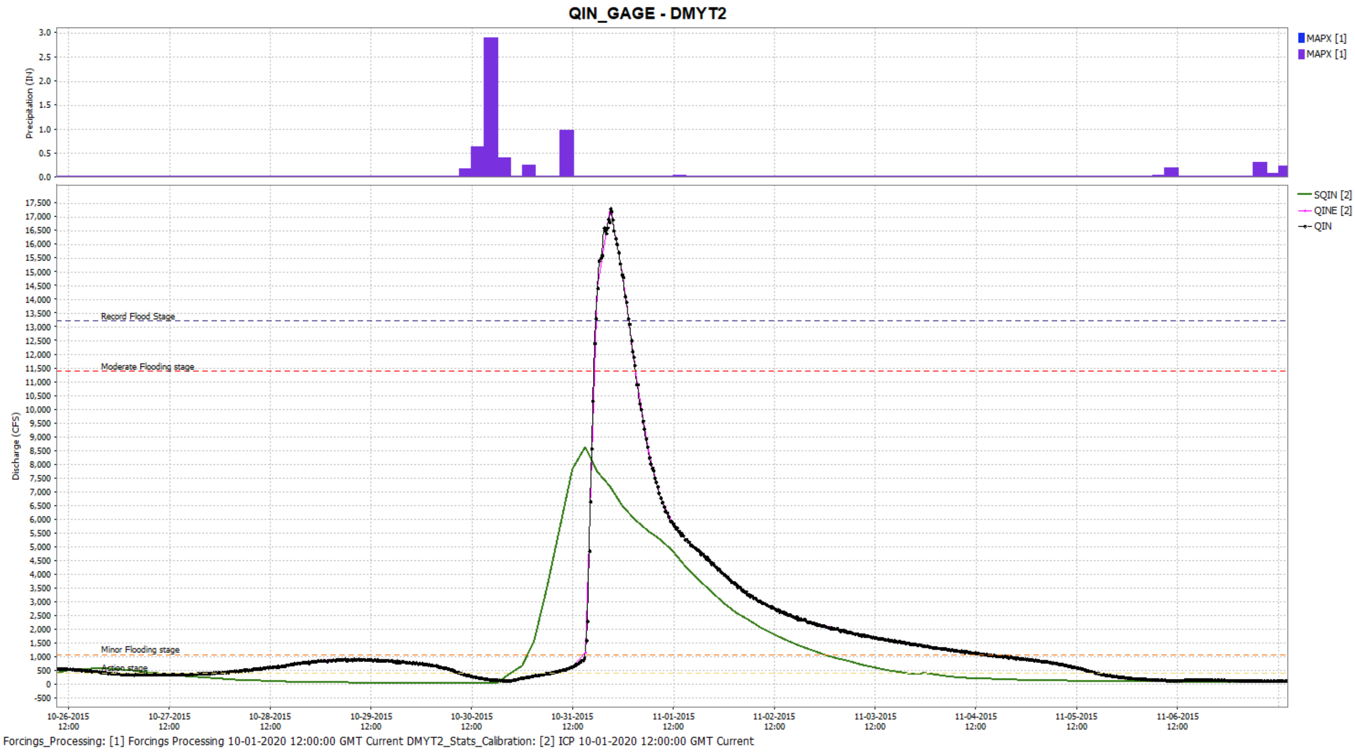
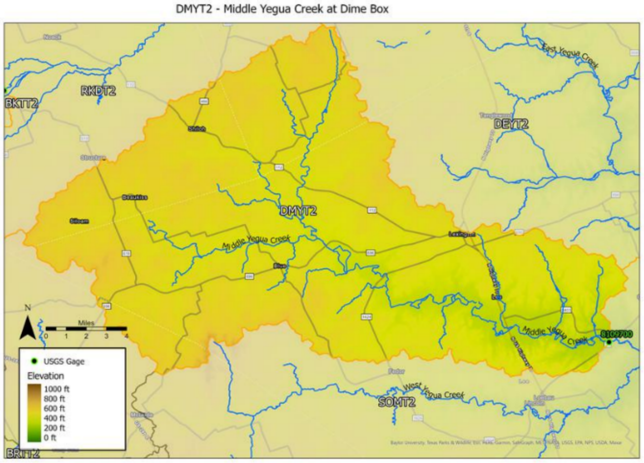
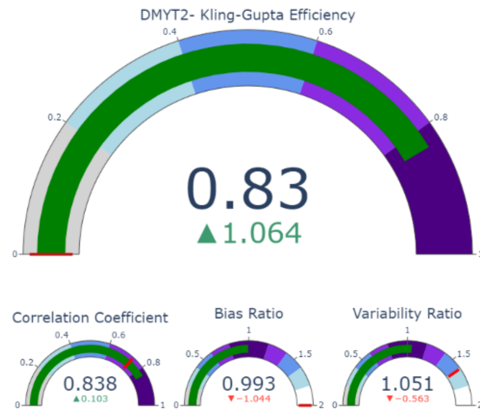
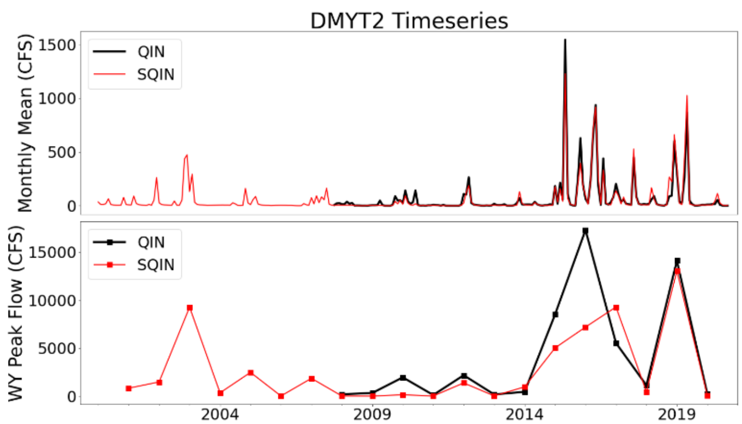


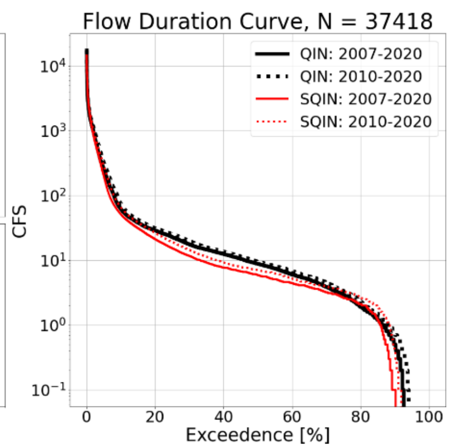
Figure 4-28: Improved calibration for DMYT2 (green), though peak flows are still under-estimated and too early.

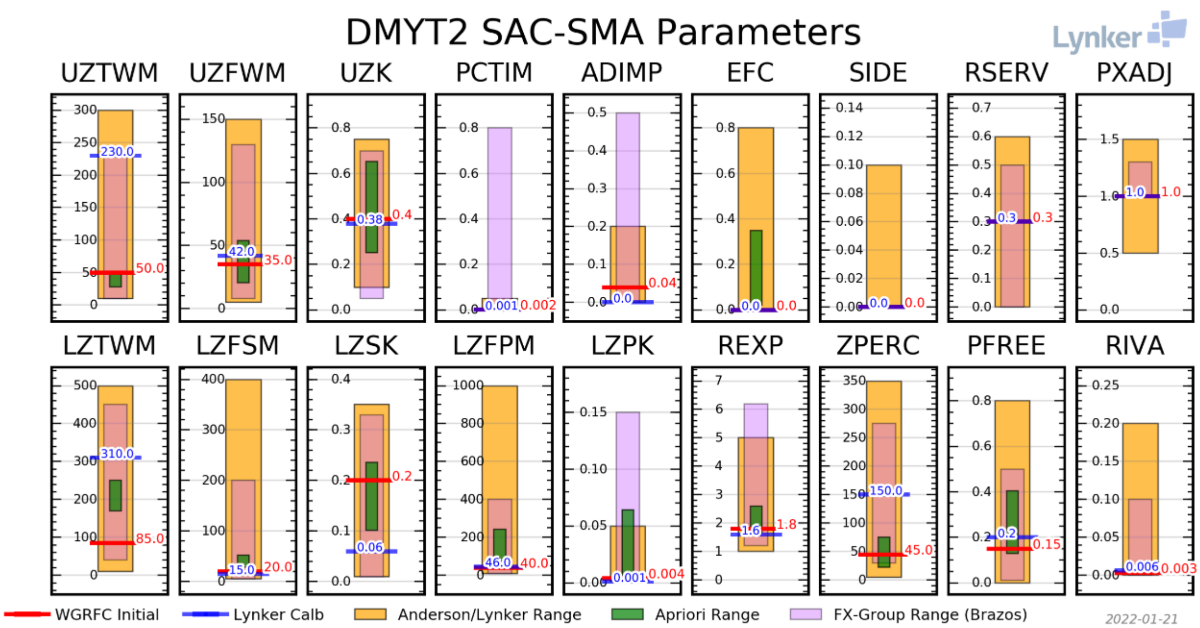
DMYT2: Middle Yegua Creek at Dime Box











DEYT2

East Yegua Creek near Dime Box is a headwater basin and a tributary of Somerville Lake. Simulations for DEYT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08109800 (available from 2007-10-01 to present). USGS records note that data quality is poor, with an unknown amount of regulation in the basin as well as irrigation diversions. At the headwaters of DEYT2 lies Alcoa Lake (capacity 15.7 KAF), a reservoir owned and operated by the Aluminum Company of America for industrial and recreational purposes. The TWDB website notes that the lake is maintained near the spillway level via a 12.5-mile trans-basin diversion from the Little River to the north. Land cover is similar to the nearby DMYT2, though soil classes in DEYT2 are characterized by slightly coarser soils (approximately evenly classified Type A, B, C, and D).

Hydrology for DEYT2 was similar in behavior to DMYT2, with intermittent flows, including no flow during the late summer months (approximately 10% of the time). As with many other headwater basins in the Brazos, the UHG needed to be significantly earlier and flashier. Significant adjustments to the tension water zones and percolation curve were needed to decrease very high initial model bias. A more drastic UNIT-HG peak with a quicker recession was also necessary.

Statistical improvement was significant at DEYT2, with KGE values increasing from 0.13 to 0.888 (0.08 to 0.87 in 2010–2020). Though correlation coefficients improved, the decrease in model bias from 77% to –4% was most notable. Peak flows were still under-simulated, but only by 8% for the more recent decade; the May 2019 flood of record highlights improvements to increased surface runoff generation (Figure 4-29). The flow duration curve highlights some of the challenges simulating the baseflow and deep percolations. For example, when small rain events would recharge primary baseflow (though for a short period of time), simulations would fail to refill the LZFPM to generate sufficient baseflow.

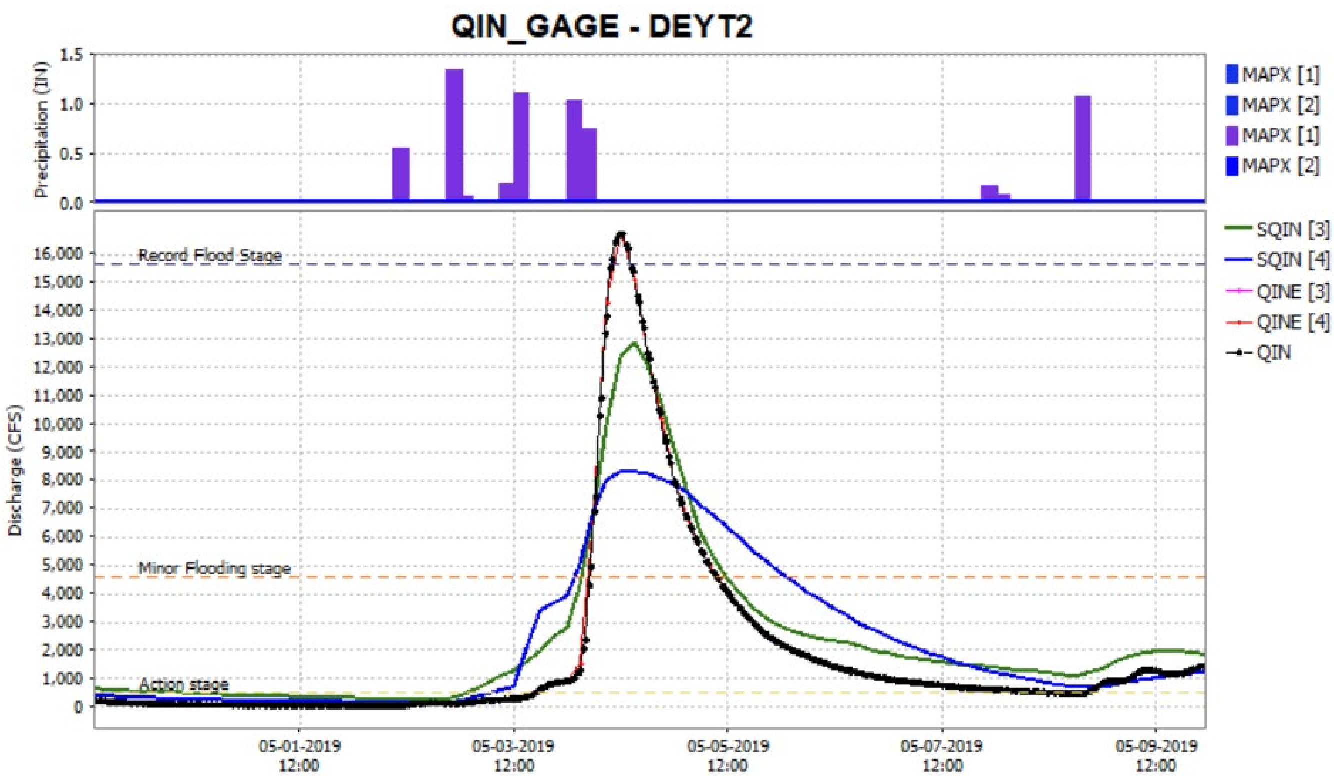
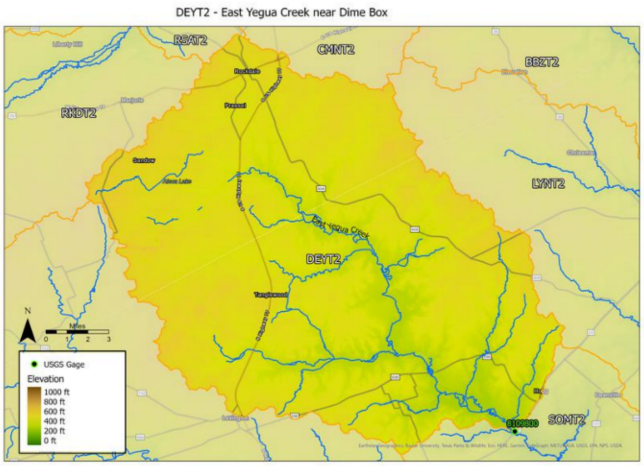
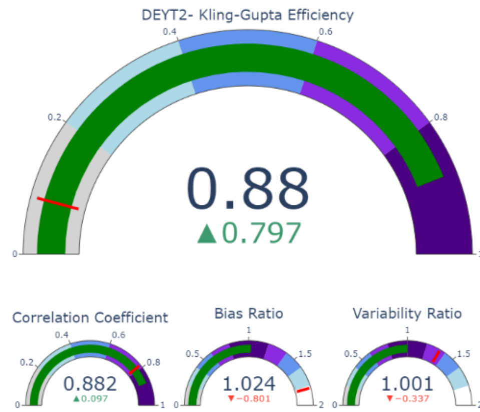
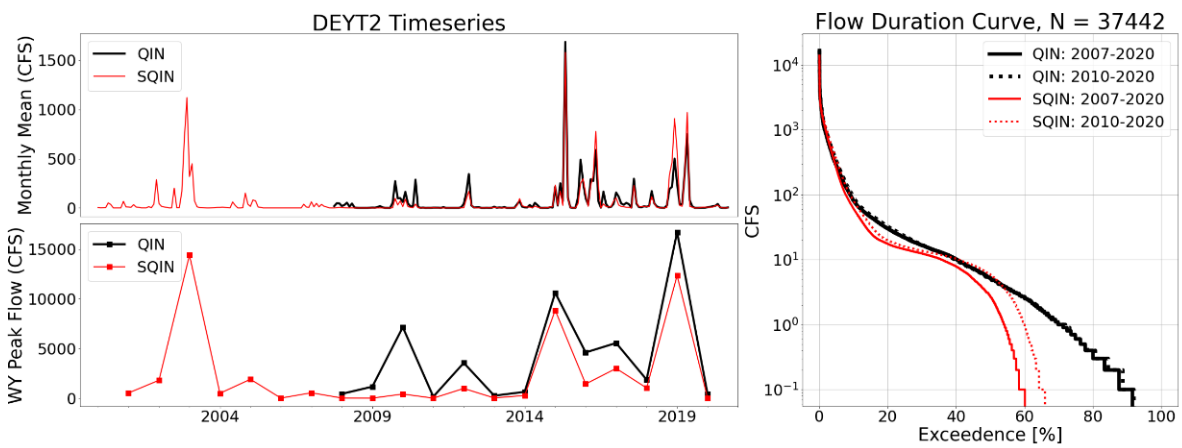


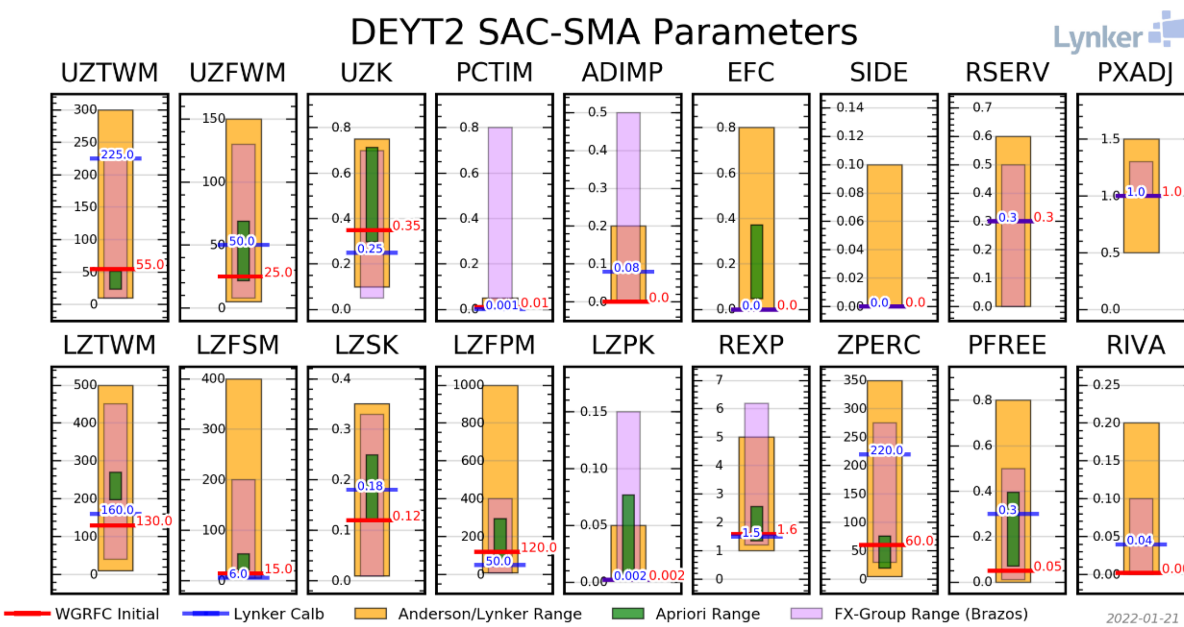
Figure 4-29: Improved calibration for DEYT2, with SQIN before (blue) and after (green) calibrations. Note improved flashiness and peak flow magnitude.

DEYT2: East Yegua Creek near Dime Box









LYNT2

Davidson Creek near Lyons is a headwater basin of lower Yegua Creek, joining between Somerville Lake and the Brazos River mainstem. Simulations for LYNT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08110100 (available from 2007-10-01 to present). USGS records note that the data quality is only fair, except for flows below 1 CFS which are poor. Although there are no known regulations or diversions in the basin, the City of Caldwell (population 55,000) does discharge wastewater effluent into the creek above the gauge. Land class is primarily hay/pasture (59%) and forest (30%), with 46% Type D/Clay Loam soil.

The hydrology for LYNT2 can be characterized as intermittent, with little to no flow during the late summer months, and very flashy flood events during other times of the year. Runoff response to rainfall events is minimal until UZTW saturation, usually in the fall. Good calibration of LYNT2 was dependent on lower percolation driven by smaller values of LZSK, LZPK, and ZPERC, which was also necessary to better simulate baseflows.

Final calibrations for LYNT2 were impressive for a headwater basin, with final KGE values of 0.889, a correlation coefficient of 0.93, and a PBIAS of –1.4% (2010–2020). The greatest 1% of peak flows (> 1,800 CFS) were only under-simulated by 4%, while the top 0.1% of flows (> 8,400 CFS) were under-simulated by 8% (e.g., Figure 4-30).

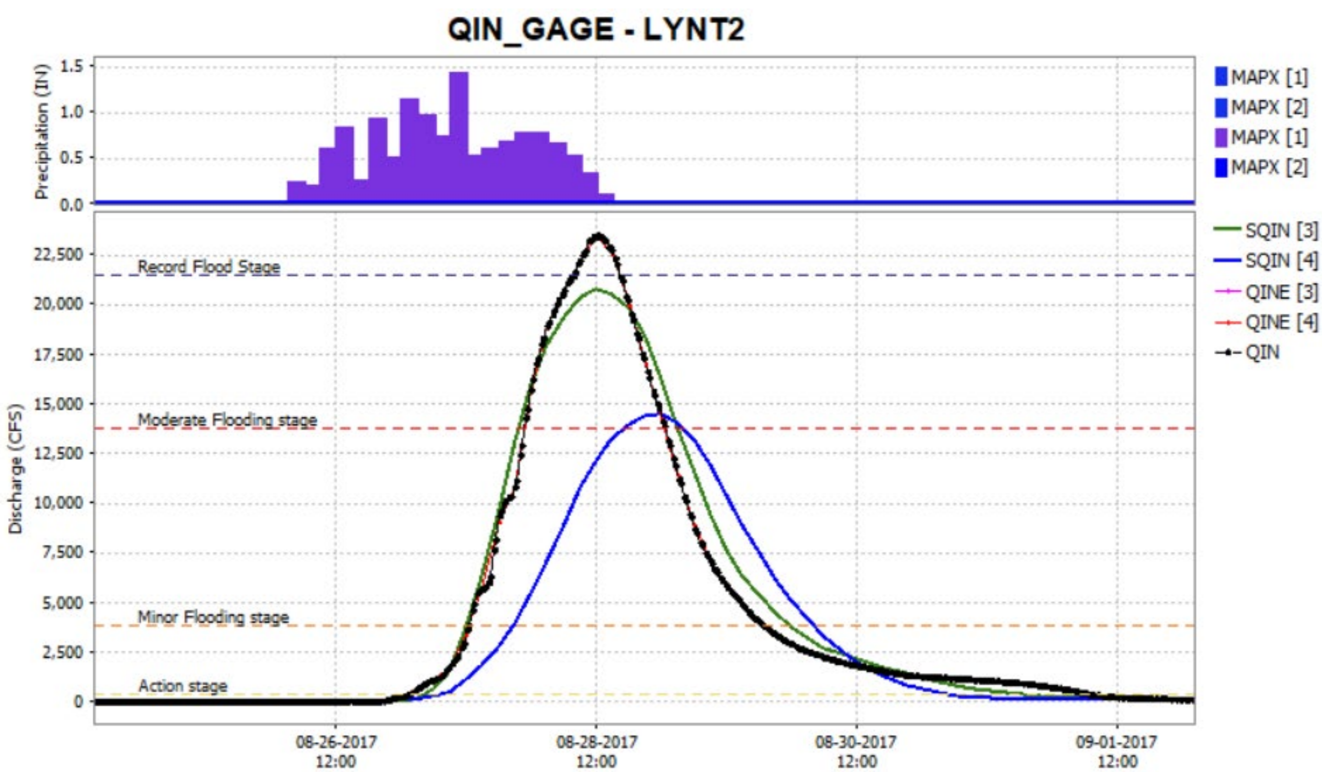
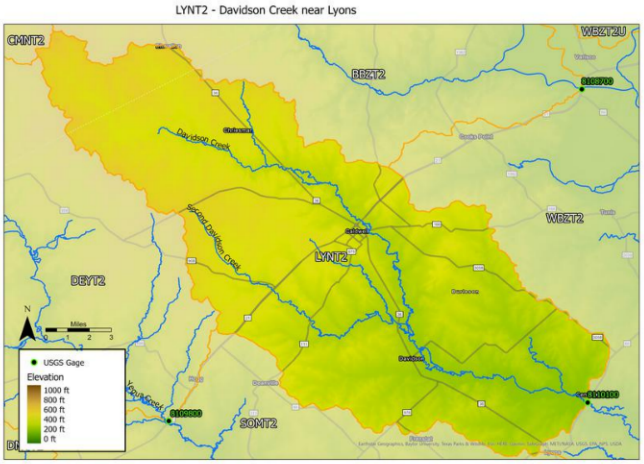
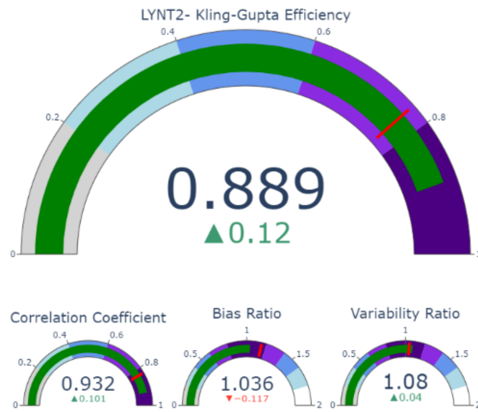
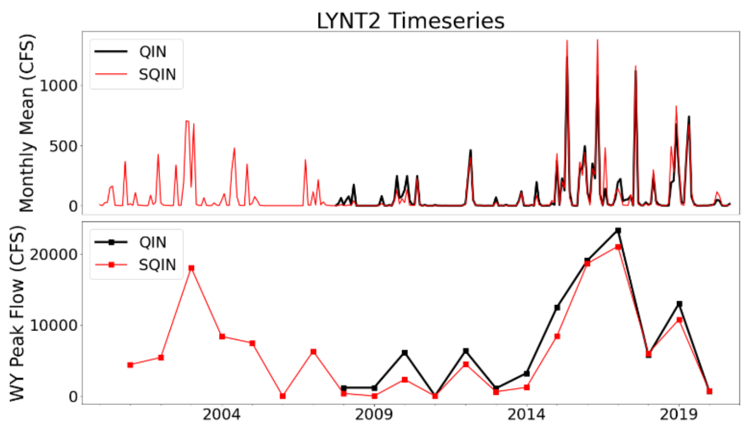


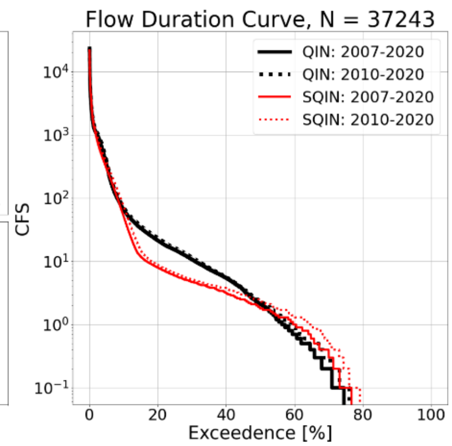
Figure 4-30: Improved calibrations for LYNT2, with SQIN before (blue) and after (green) calibrations. Note improved timing and peak magnitude.

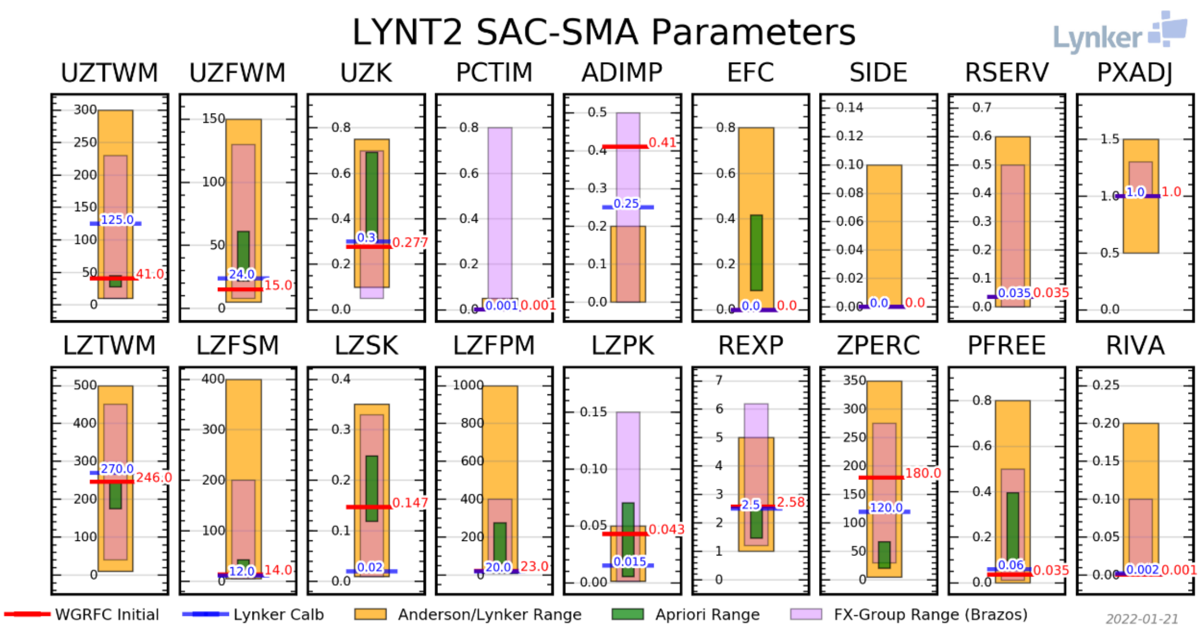
LYNT2: Davidson Creek near Lyons











Lower Brazos-Little Brazos HUC8

HBRT2

Brazos River at FM485 near Hearne is a local basin located downstream of HIBT2. Simulations for HBRT2 were run at a 3-hourly timestep, calibrated to instantaneous stage data from USGS 08098450 (available from 2017-05-04 to present), which was converted to instantaneous discharge using the WGRFC rating curve. Despite the short period of record, USGS remarks note that the stage data are of good quality, though the quality of the WGRFC rating curve used in this study is less certain. Land cover in HBRT2 is primarily cultivated (37%) and hay/pasture (35%) with minimal development (1%). Soil characteristics are similar to the Middle Brazos, with a clay-dominated composition (77% Type D/Clay Loam).

Notably, the diurnal hydroelectric flows from Lake Whitney are still observable here (routed from HIBT2), but it is often the case that these routed flows are much higher than the QIN data for HBRT2 (Figure 4-31). These findings suggest that at higher flows, the WGRFC rating curve is either under-estimating discharge for HBRT2, or that the USGS rating curve is over-estimating the upstream HIBT2, or some combination of the two. LAG/K calibrations focused primarily on getting the timing of routed flows right and tuning in baseflow. However, even with significant increased to LZFPM, baseflows were still under-simulated (see flow duration curve, next page).

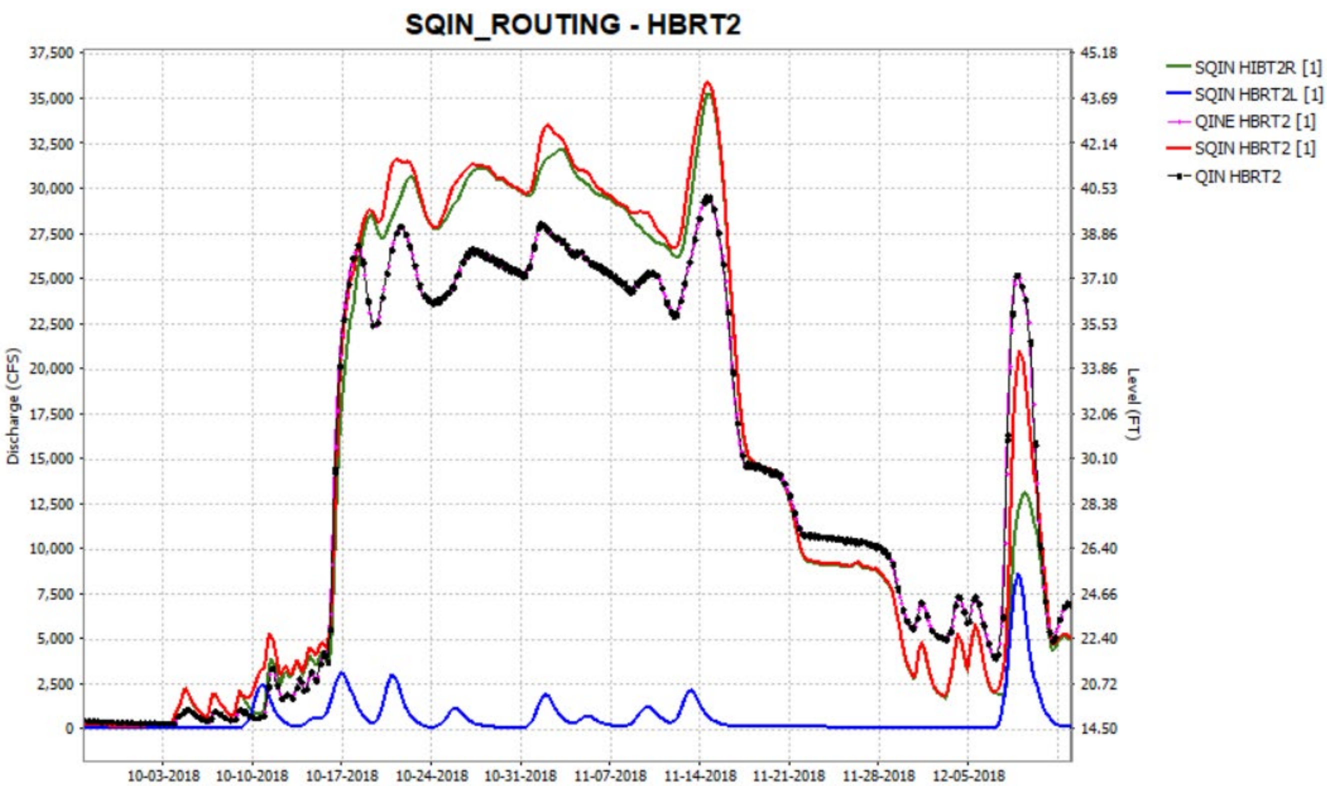
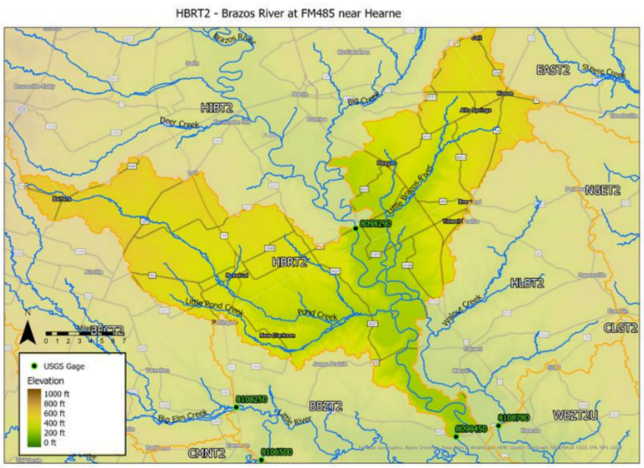
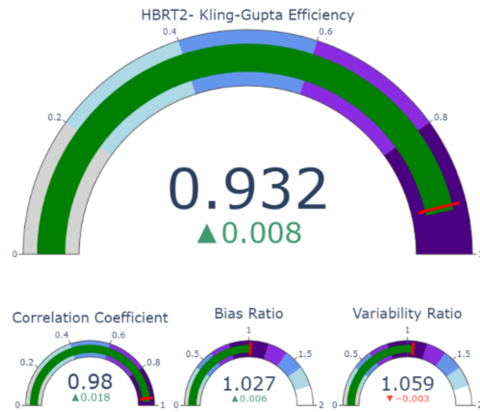
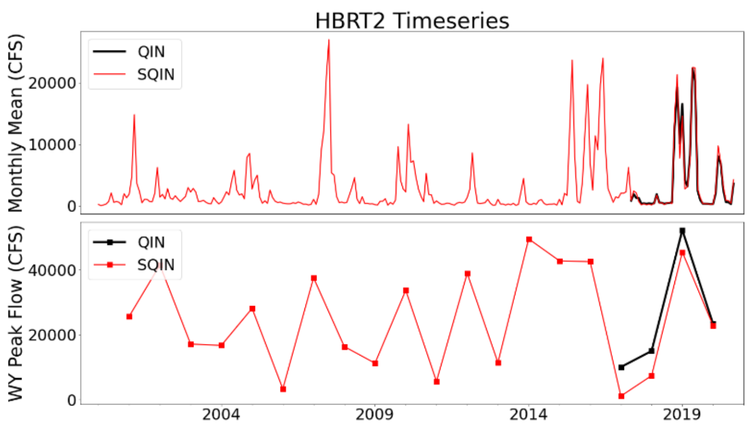


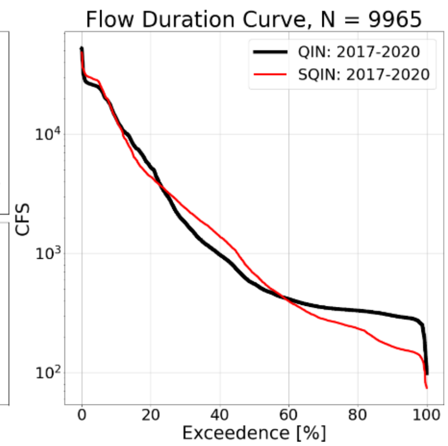
Figure 4-31: Example of routed upstream flows (green) exceeding the observed QIN at HBRT2.

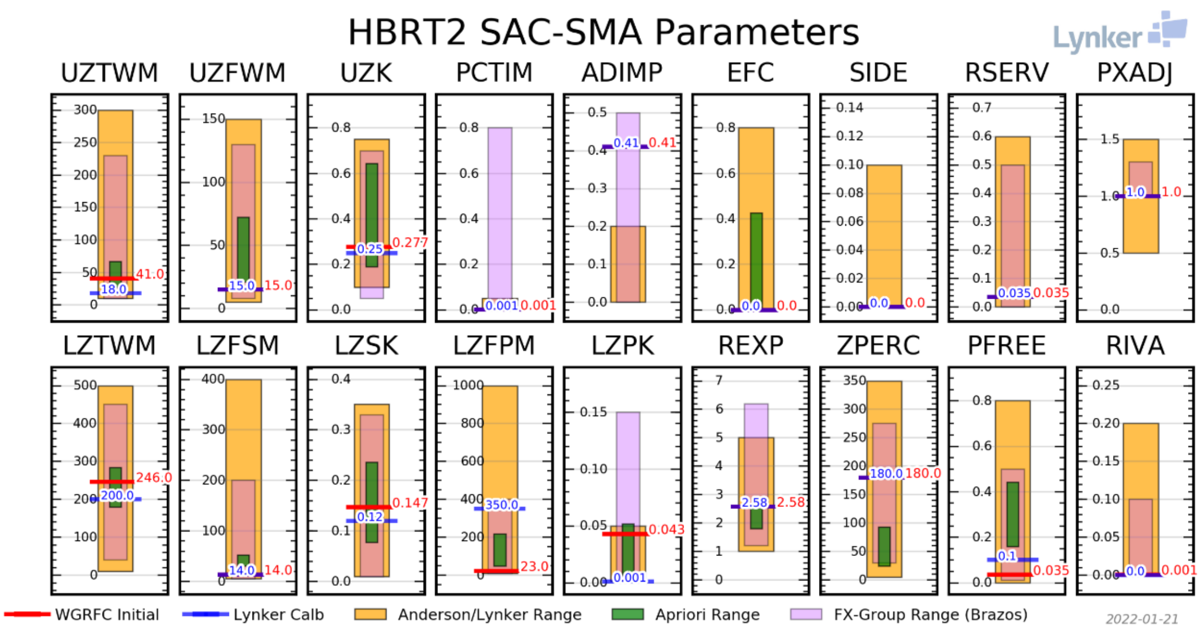
HBRT2: Brazos River at FM485 near Hearne











HLBT2

Little Brazos River near Hearne is a headwater basin in the Middle Brazos, flowing into WBZT2U. Simulations for HLBT2 were run at a 3-hourly timestep, calibrated to the very limited instantaneous discharge data from USGS gauge 08108780 (available from 2017-05-29 to present); no stage-discharge values from the USGS rating curve are available for flows below 400 CFS. HLBT2 is primarily hay/pasture (58%), with a coarser soil profile than much of the mainstem Brazos (only 49% Type D/Clay Loam soil).

Because there were limited QIN data (< 10 events spanning 2018–2019) at HLBT2, including no low flow observations, the calibration focused on improving event-based simulations. Increases in the UZTWM and UZFWM were important in decreasing the simulated runoff, which was had a large positive bias initially (Figure 4-32).

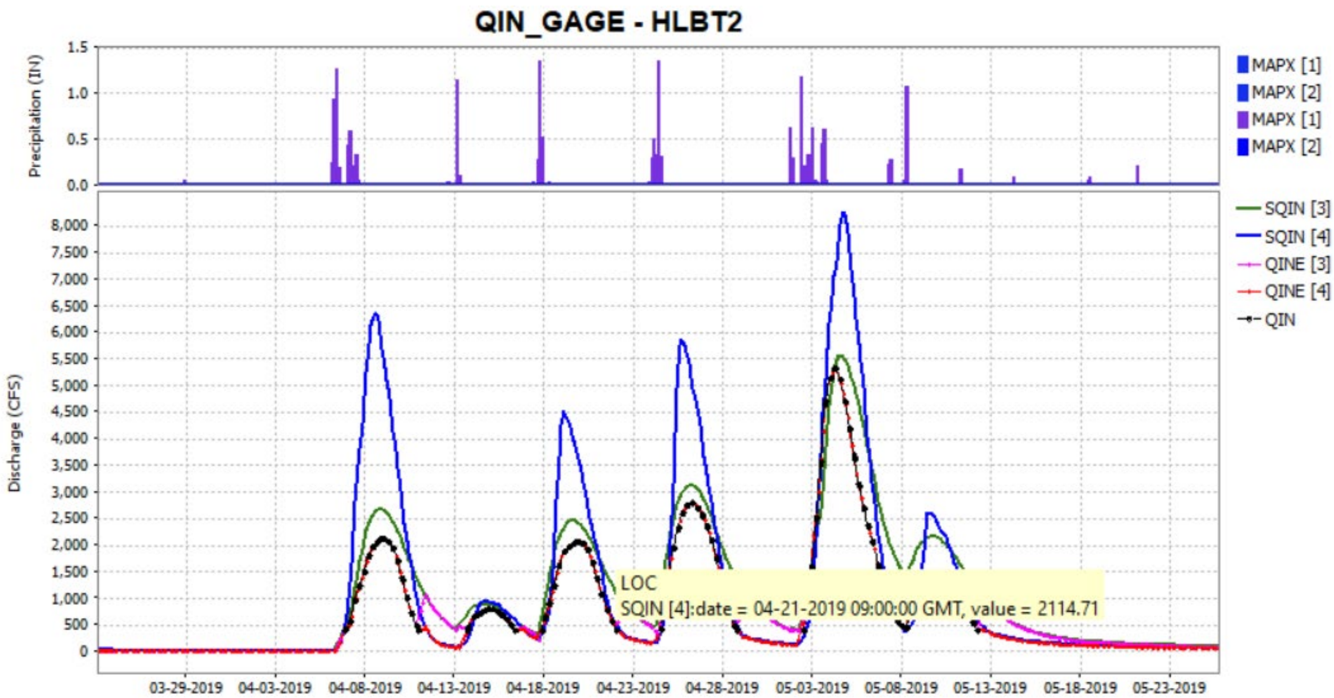
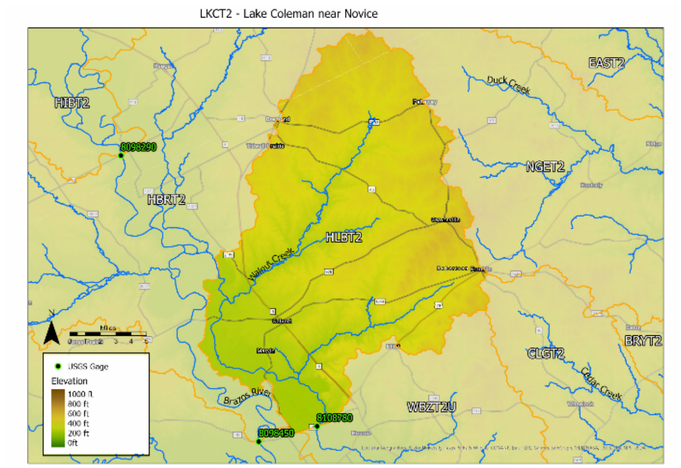
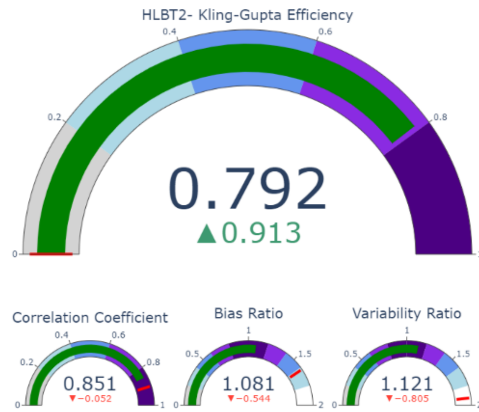
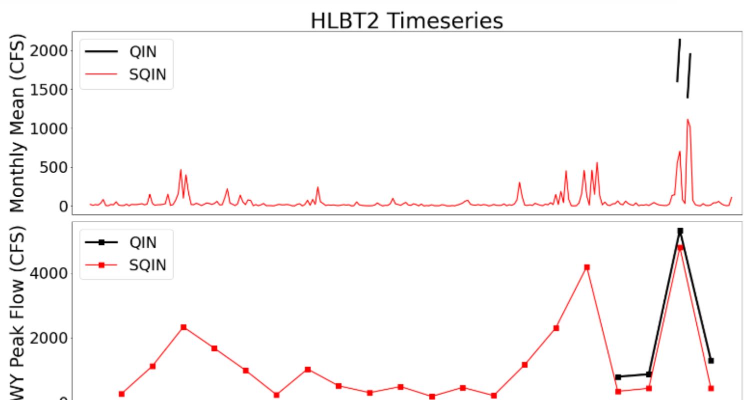


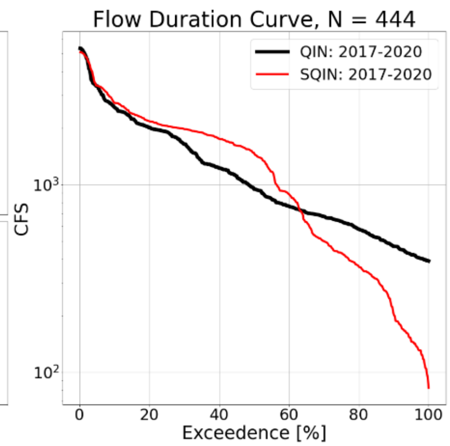
Figure 4-32: Improved calibrations for HLBT2, with SQIN before (blue) and after (green) calibrations.

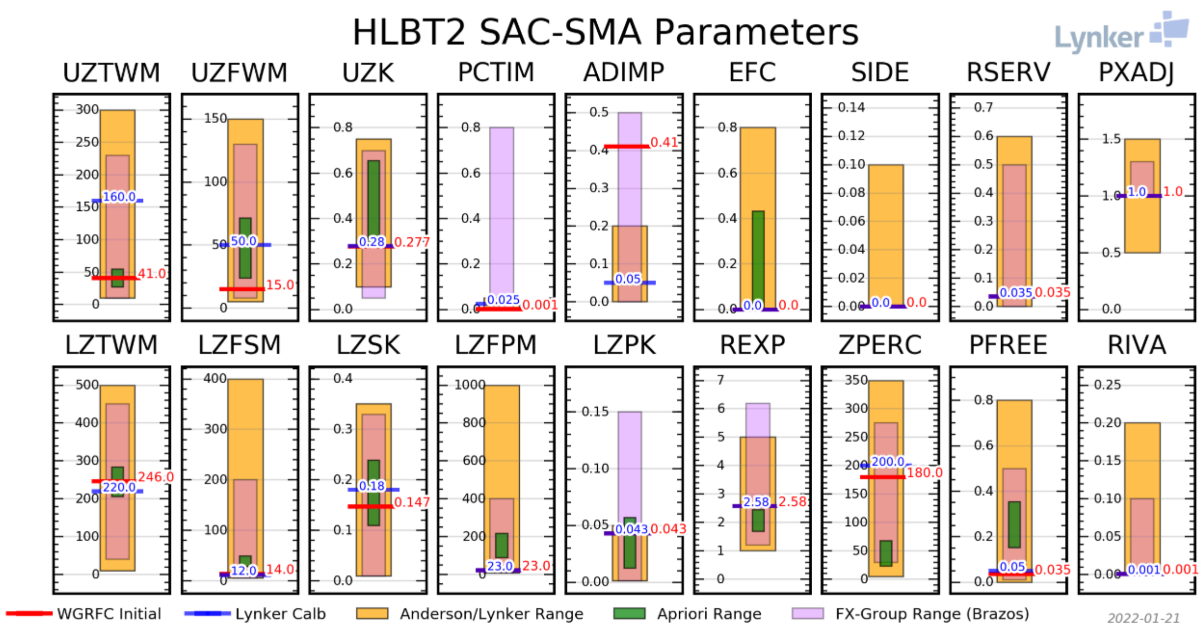
HLBT2: Little Brazos River near Hearne









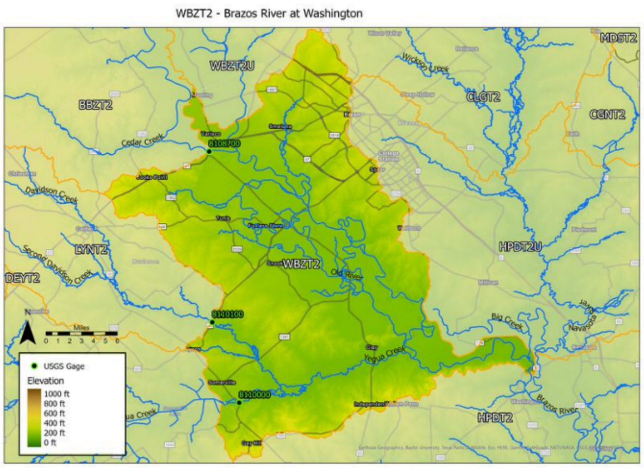


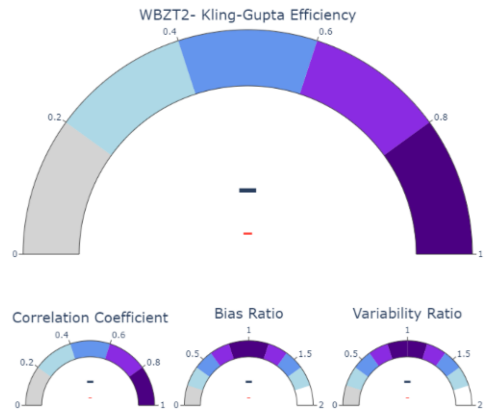
WBZT2/WBZT2U

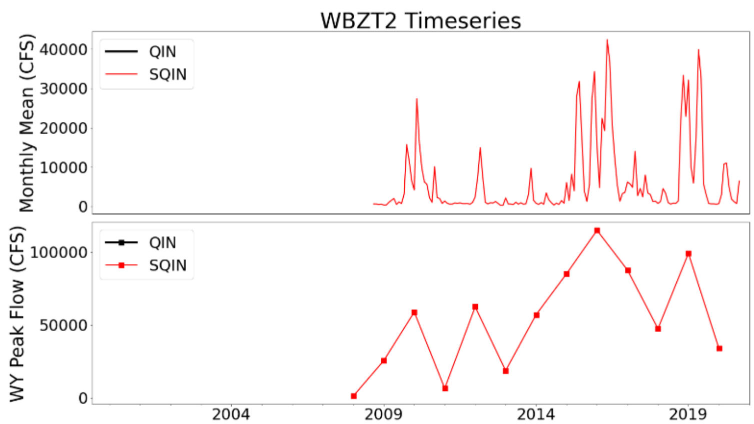
Brazos River at Washington (WBZT2) and Rest of Little Brazos above Washington (WBZT2U) are two lumped local basins at the confluence of the Little Brazos (WBZT2U), the mainstem Brazos (BBZT2), Davidson Creek (LYNT2), and Somerville Lake (SOMT2, out of domain). Simulations for WBZT2/WBZT2U were run at a 3-hourly timestep, however USGS gauge 08110200 was discontinued from 1994 until recently (2021-02-10) so there are no discharge or stage data to calibrate to. Additionally, there is no streamflow gauge for WBZT2U. Land cover for WBZT2 is fairly developed (6.3%) with 51% hay/pasture; WBZT2U is less developed. Soil characteristics are clay-dominated along the mainstem of the Brazos (WBZT2: 72% Type D/Clay Loam) with a coarser soil profile on the Little Brazos (WBZT2U: 21% Type A/Sand, 25% Type B/Silt Loam).

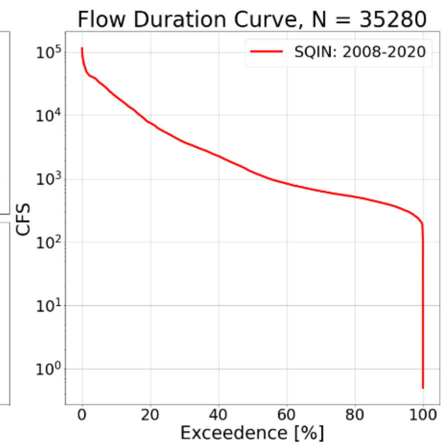
Calibrations for these two basins were informed using downstream flows at HPDT2. Calibrating the four LAG/K models (LYNT2, HLBT2, SMVT2, and BBZT2) for WBZT2 downstream at HPDT2, which is also the confluence of the Brazos and Navasota Rivers, was very difficult, so most LAG/K values were left at the initial parameter values. Similarly, SAC-SMA parameter calibration was quite light, with adjustments primarily to the upper zone parameters. All monthly ET demand values were set to one.

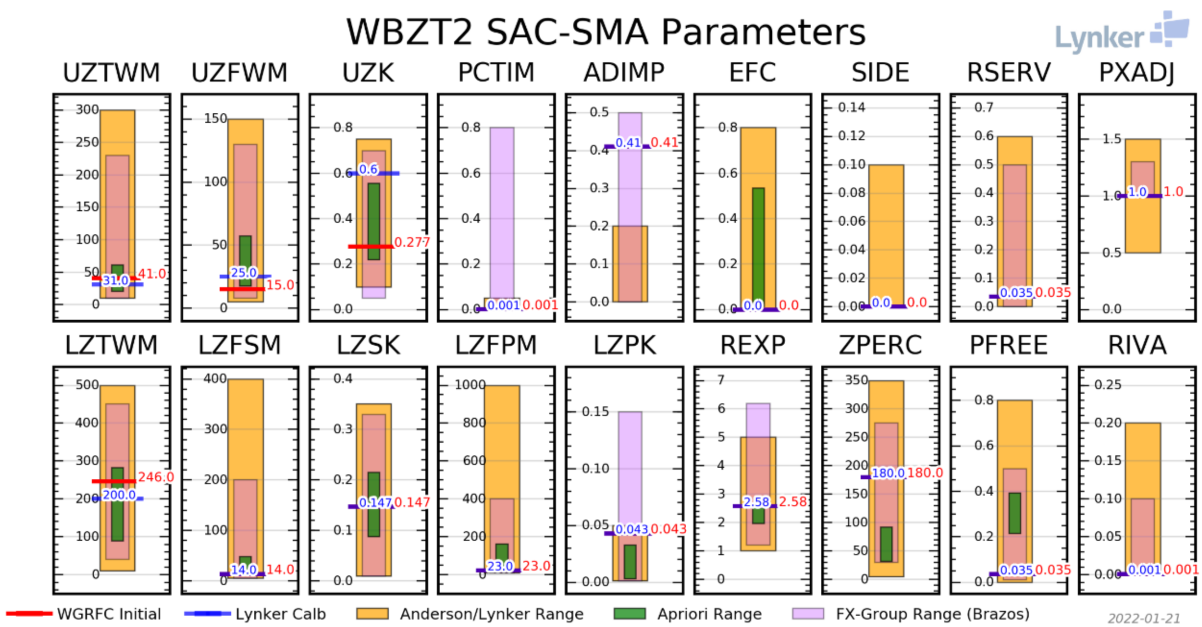
WBZT2: Brazos River at Washington











HPDT2

Brazos River at Hempstead is a local basin on the lower section of the Middle Brazos, downstream of WBZT2 and lumped with HPDT2U. Simulations for HPDT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08111500 (available from 1990-10-01 to present). This far downstream on the Brazos, there are significant diversions for irrigation, municipal water supply, industrial uses, and oil field operation, as noted by the USGS. HPDT2/HPDT2U are developed basins (5 and 17%, respectively), with a clay-dominated soil profile (52% and 71%, respectively).

HPDT2 was the crux of the Brazos River calibrations, with inflows from the Navasota River (HPDT2U), mainstem Brazos (WBZT2), Little River (WBZT2U), Somerville Lake (SOMT2), and Davidson Creek (LYNT2). Further complicating calibrations were missing upstream observational data in WBZT2, WBZT2U, BRYT2, and CLGT2. Adjustments to the LAG/K models, particularly for WBZT2/WBZTU, and adjustments to the UHG for both HPDT2 and HPDT2U, were critical for shifting the center of mass of events earlier, with overall greater attenuation. The May 2016 event below (omitting the routed components for clarity) demonstrates the significant improvement from before (red) and after (green) calibrations.

Statistical improvements for downstream basins such as HPDT2 are generally minimal, though we do observe significant improvement in both the timing and magnitude of the simulation (e.g., May 2016). Other significant peak flow events are also well simulated, as highlighted by the water year peak flow timeseries and the flow duration curve. For the period 2010–2020, PBIAS for the greatest 0.1% of flows (>100,000 CFS) decreased from 11.6% to 2.8% (Figure 4-33), while correlation coefficients increased from -0.18 to 0.991 (KGE -0.62 to KGE 0.949)

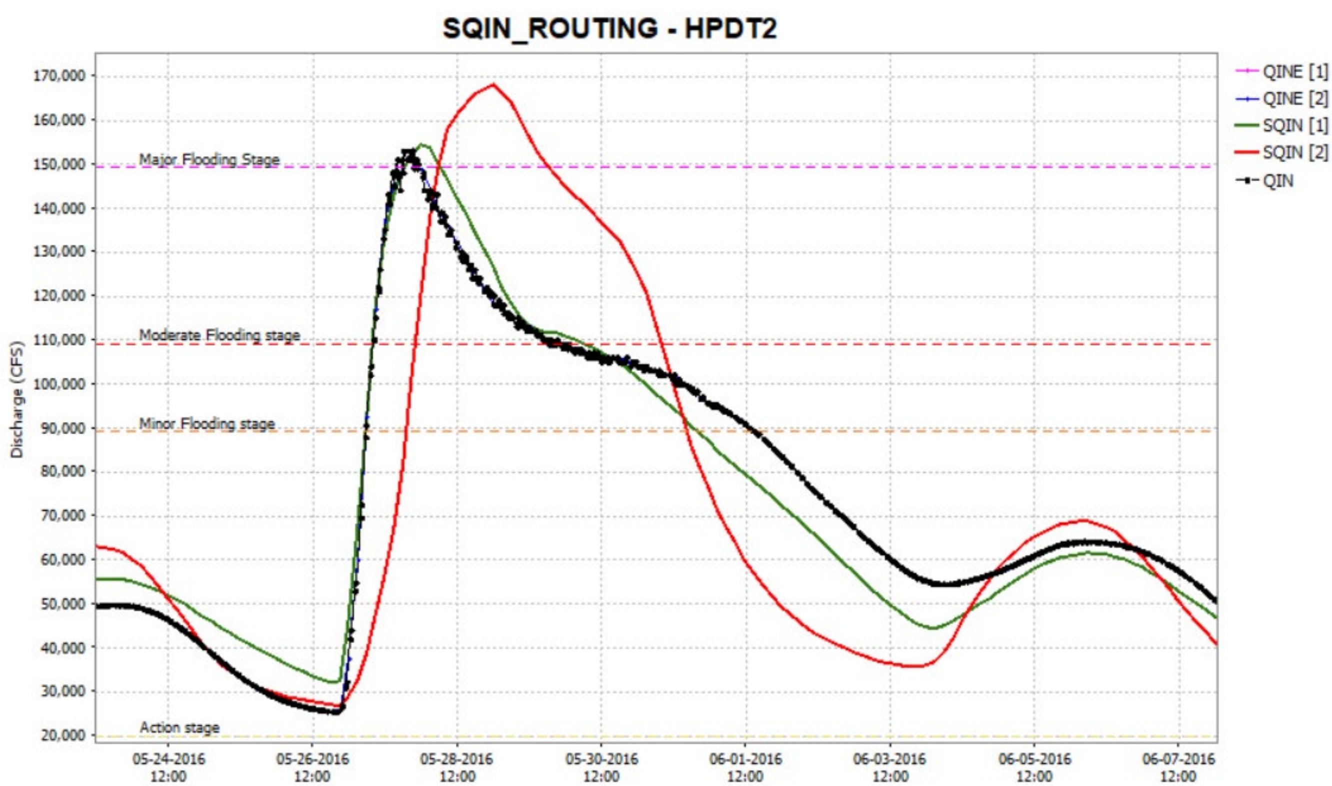
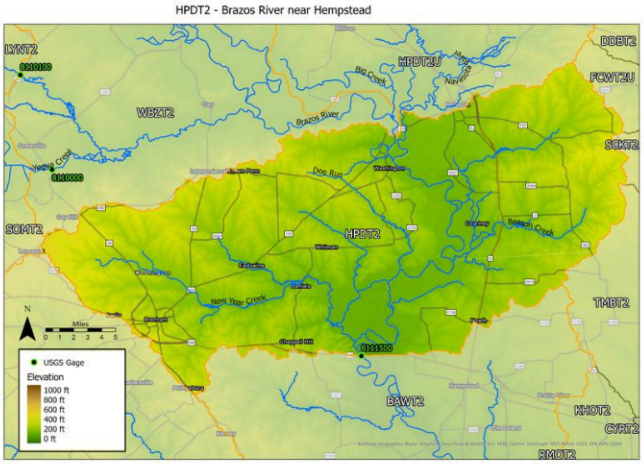
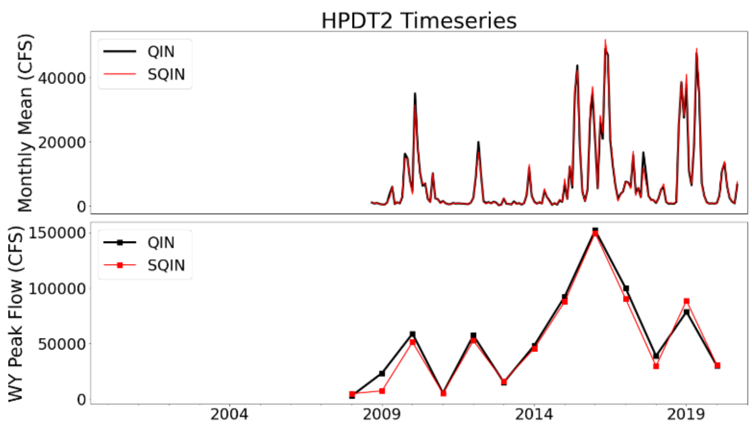
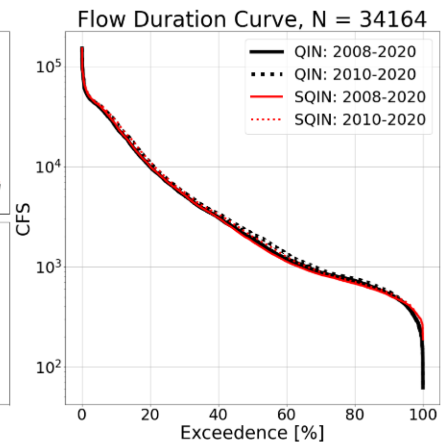


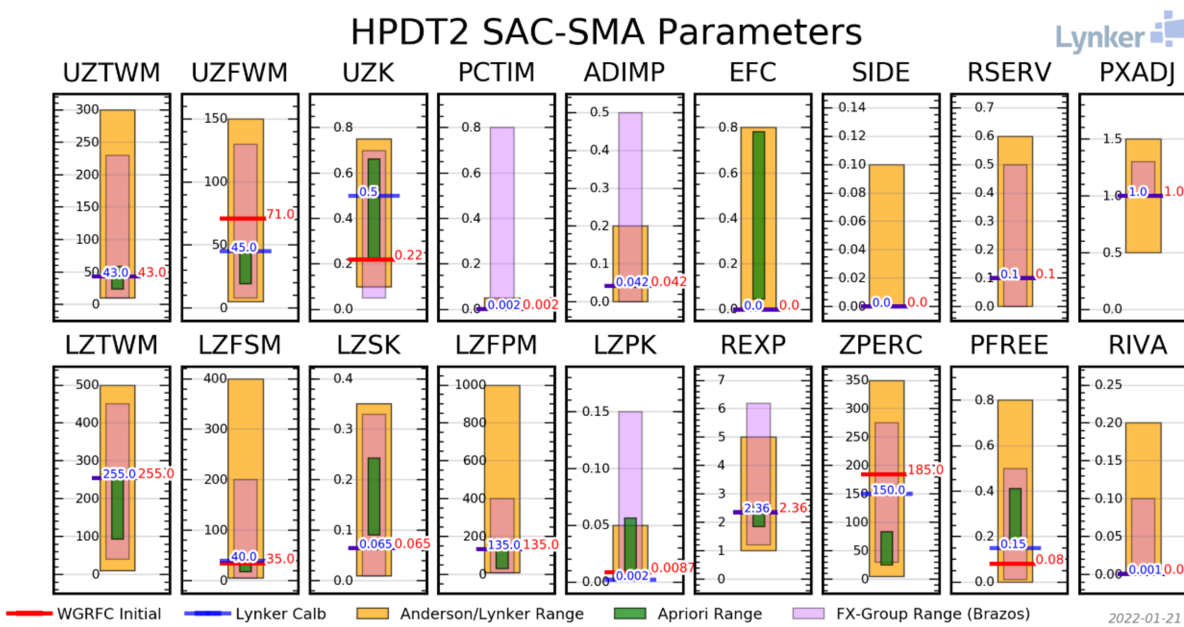
Figure 4-33: Improved calibrations for HPDT2, with SQIN before (red) and after (green) calibrations. Note improved timing, peak magnitude, and rate of recession.

HPDT2: Brazos River near Hempstead









Lower Brazos HUC8

BEMT2

Mill Creek near Bellville is a headwater basin of the Lower Brazos, flowing into BAWT2. Simulations for BEMT2 were run at a 3-hourly time step, calibrated to instantaneous discharge data from USGS gauge 08111700 (available from 2007-10-01 to present). USGS remarks note that there are no known diversions, but that the city of Bellville discharges sewage effluent into a tributary of Mill Creek. Additionally, during the summer of 2010, there was bridge construction and related pumping just upstream of the gauge. Land cover is primarily hay/pasture (75%) with minimal development (1.7%). Soil characteristics are 59% Type D/Clay Loam, with the remainder being a homogenous mix of Types A, B, and C.

BEMT2 is a very flashy perennial stream, with very low (< 5 CFS) flows during the late summer months and significant flood events (>80,000 CFS), usually in the spring, but also during the hurricane season. Though the overall simulation was good, flood simulations struggled to match the peak magnitude of the major 2016 (Memorial Day Storm) and 2017 (Hurricane Harvey) events. Additionally, missing data from the rising limb of the May 2016 flooding made calibration during this period highly uncertain. An earlier, peakier UHG and lower UZK and UZFWM parameter values were essential in the nice simulation for the April 2016 Tax Day Storm below (Figure 4-34). While lower LZTWM values produced a better simulation for the Harvey flooding, it led to significant over simulation during more moderate events.

Statistically, BEMT2 decreased from originally slightly from KGE 0.84 to 0.776 (2010–2020); peak flows greater than 25,000 CFS (top 0.1%) improving from KGE 0.48 to 0.70 during the same period. Biases for the top 0.1% peak flow events were still significant: PBIAS was still -11.6% (initially 12.2%).

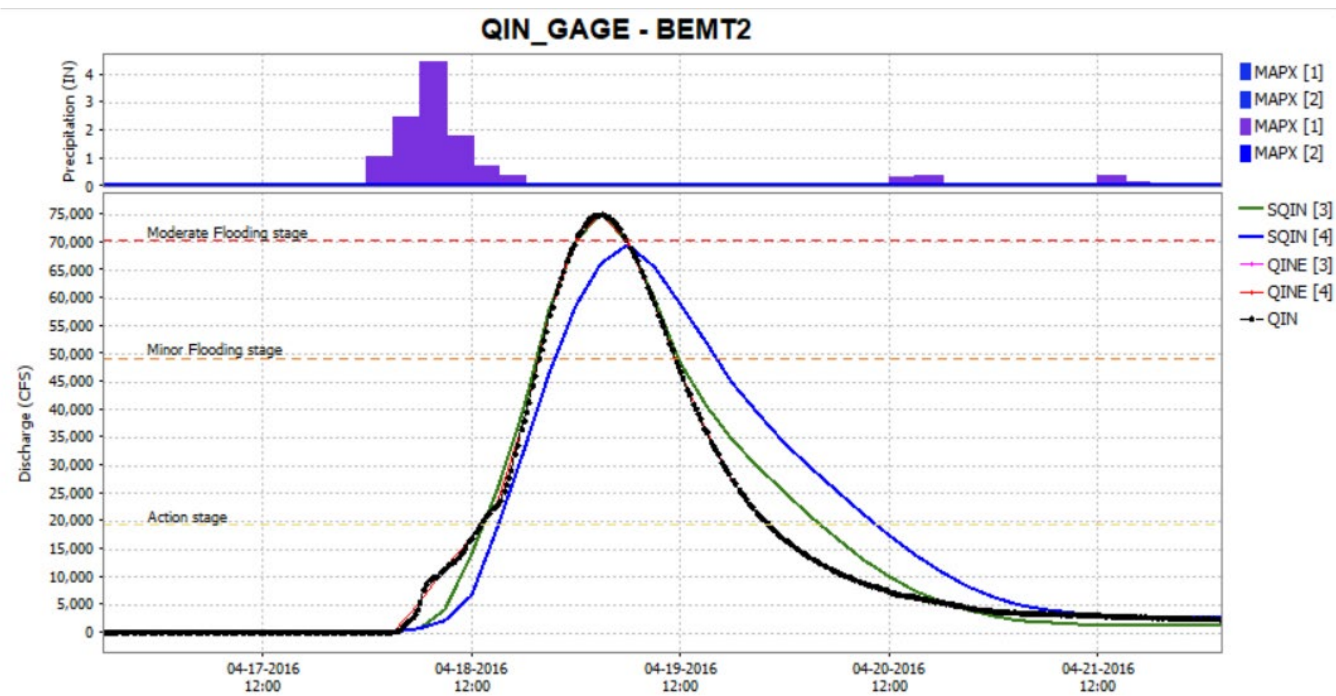
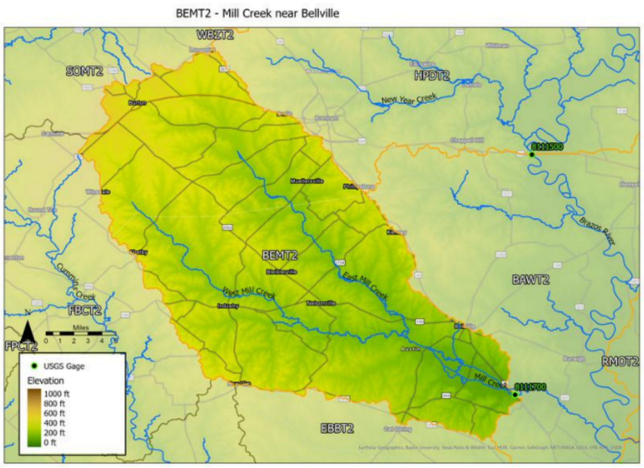
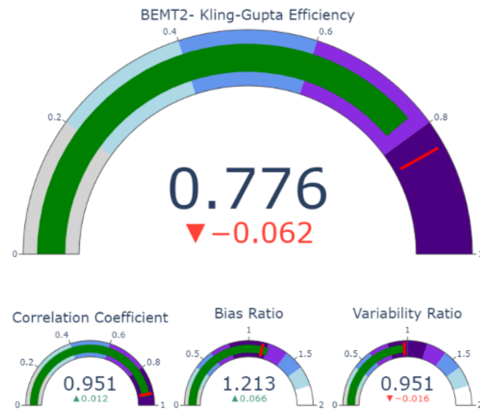
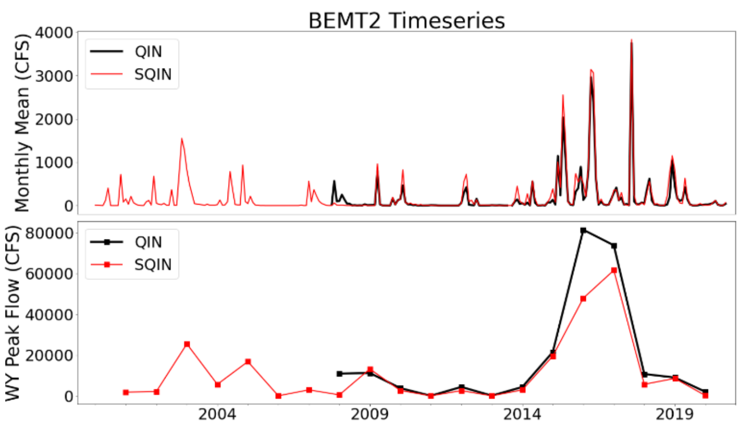


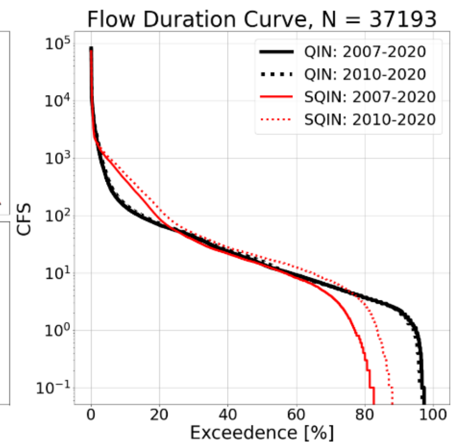
Figure 4-34: Improved calibrations for BEMT2, with SQIN before (blue) and after (green) calibrations.

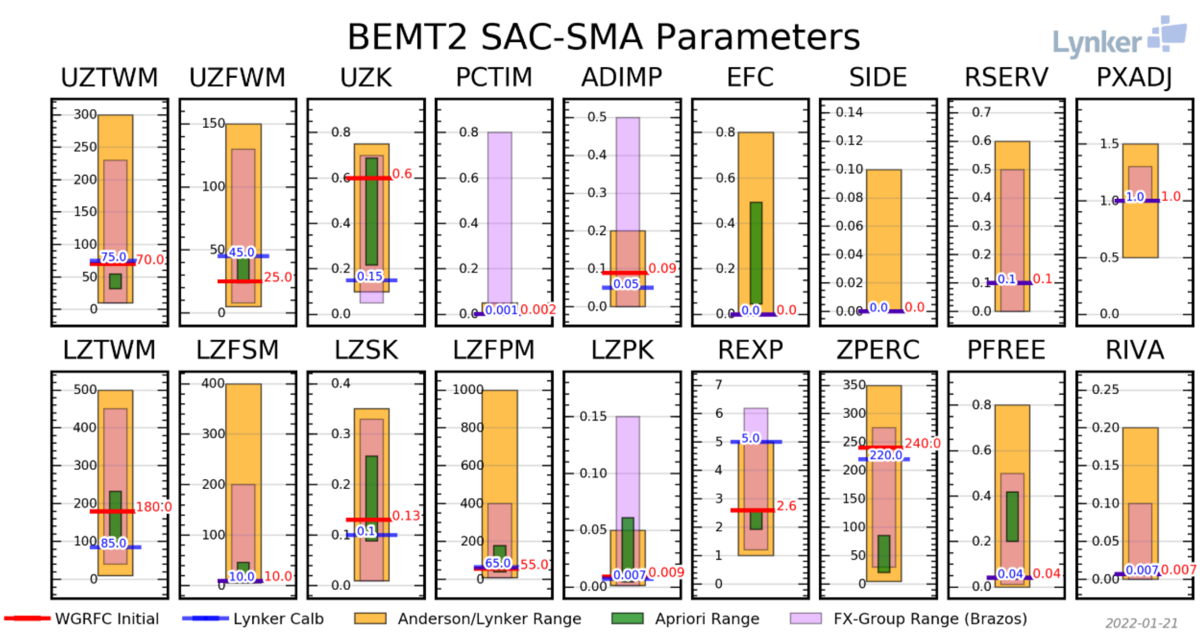
BEMT2: Mill Creek near Bellville











BAWT2

Brazos River at San Felipe is a local basin located downstream of HPDT2 and BEMT2 on the Lower Brazos. Simulations for BAWT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08111850 (available from 2013-08-02 to present). As is the case with the entire Lower Brazos, USGS remarks note that there are significant diversions for irrigation, municipal water supply, industrial uses, and oil field operations above this gauge. Land cover is primarily hay/pasture (72%) and a less clay-dominated soil profile than other parts of the Brazos (42% Type D/Clay Loam).

With the confluence of the Navasota and Brazos mainstem just upstream of BAWT2, and the addition of the Mill Creek tributary, by BAWT2, the Brazos River is a major river, with a meandering channel, a lower slope, and an overall less flashy profile. From 2013 to present, approximately 60% of the flows at BAWT2 were between 1,000 to 30,000 CFS. Flood events on the Lower Brazos are still significant, however, with peak flows upwards of 150,000 CFS, though from 2000–2015, simulations estimate peak flows of less than 100,000 CFS.

Due to the relatively large contribution of upstream routed flows from HPDT2, initial model performance was already quite good for BAWT2 and other local basins on the Lower Brazos. However, significant improvement was made to flood events top 0.1% of flows, or those greater than 130,000 CFS (initial KGE: -0.62, calibrated KGE: 0.82). Generally, greater attenuation for HPDT2 routed flows and increased interflow (decreased surface runoff), along with tension water adjustments, provided the best results. The Hurricane Harvey example in Figure 4-35 shows improvement from the initial (red) to calibrated (green) results, omitting the routed and local flow components for clarity.

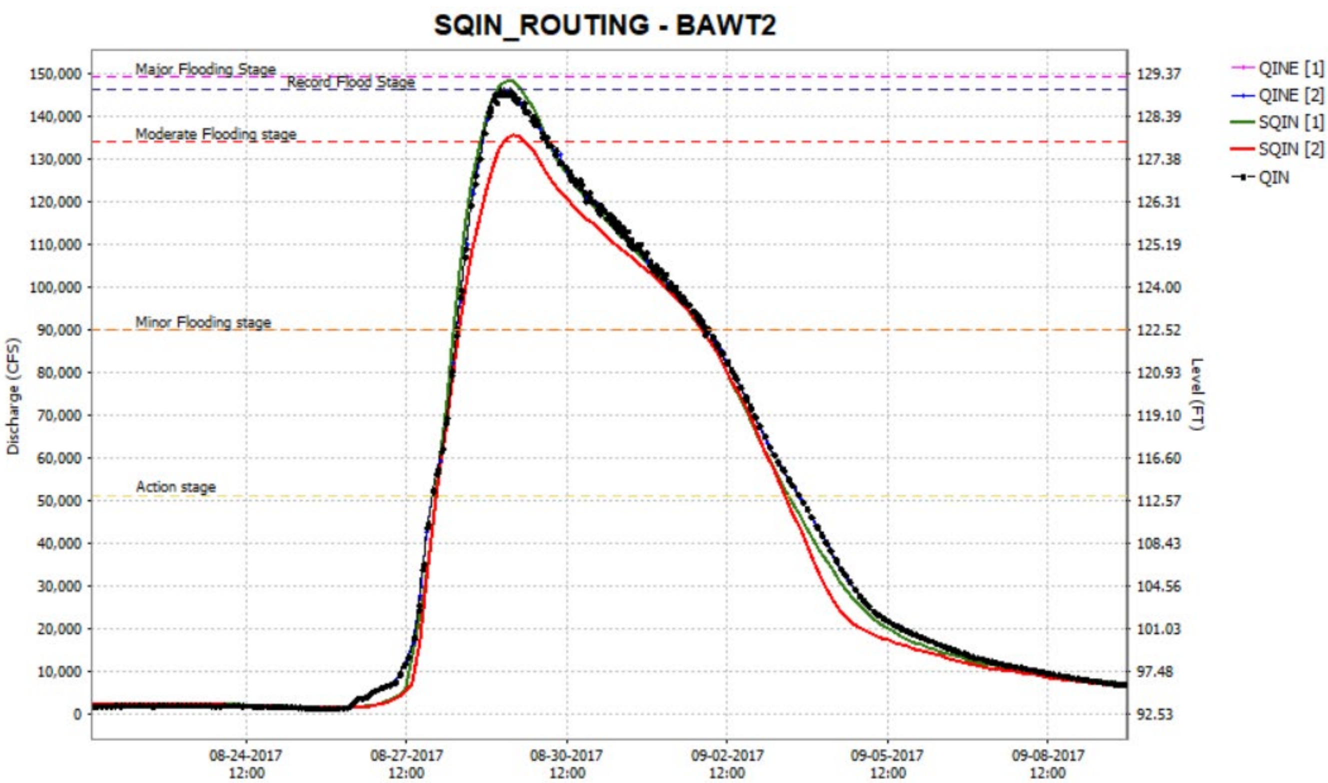
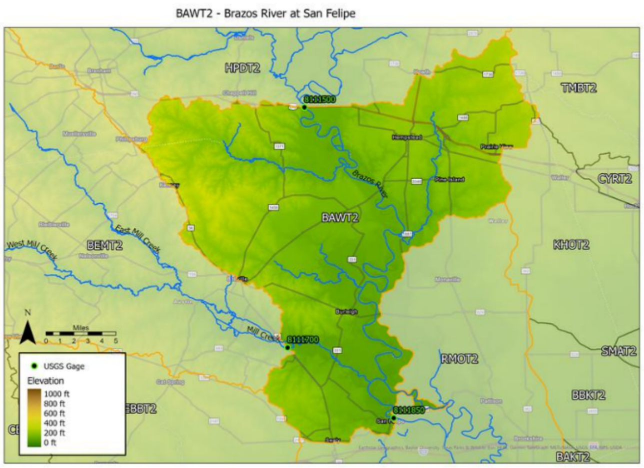
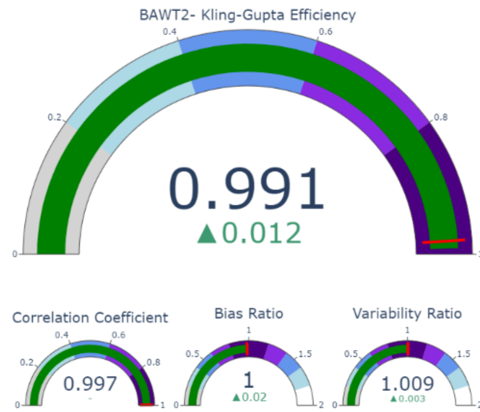
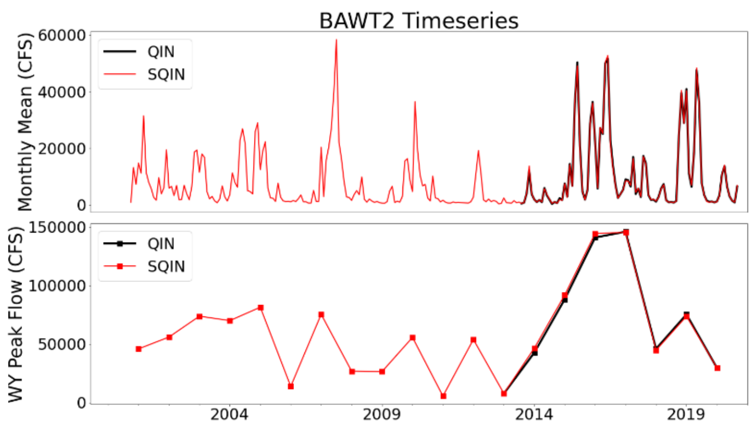


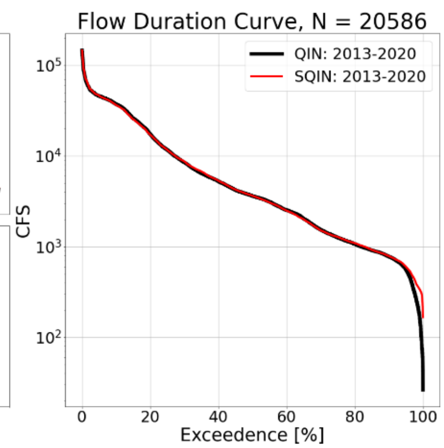
Figure 4-35: Improved calibrations for BAWT2, with SQIN before (red) and after (green) model calibrations.

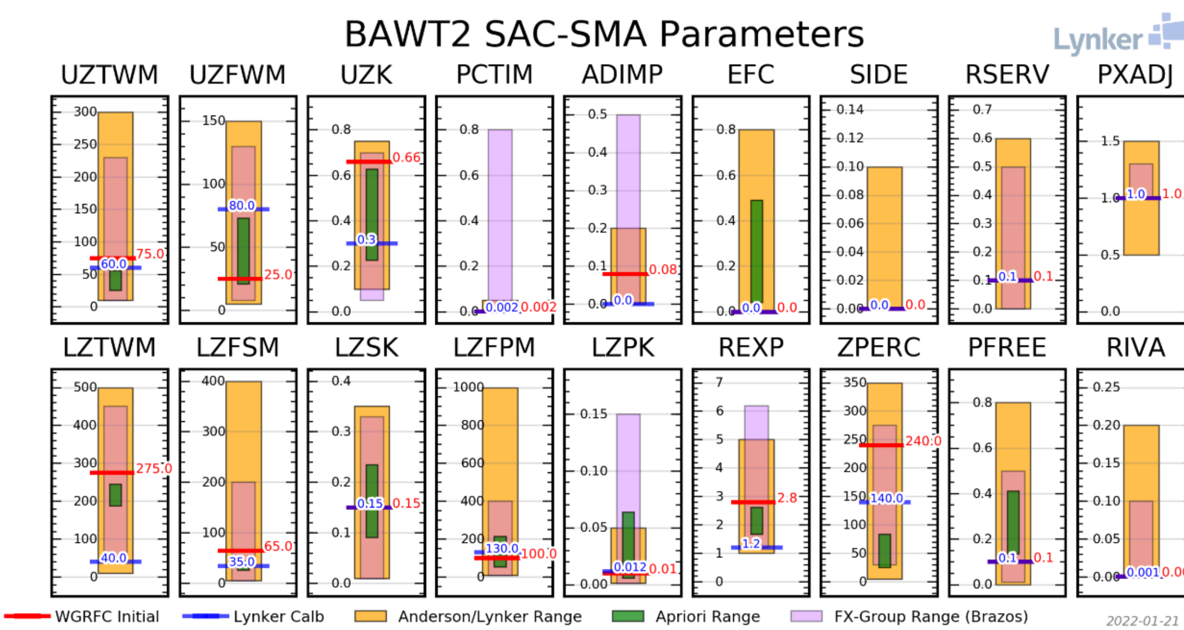
BAWT2: Brazos River at San Felipe











RMOT2

Brazos River at Richmond is a local basin located downstream of BAWT2 on the Lower Brazos. Simulations for RMOT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08114000 (available from 1991-10-01 to present). USGS remarks note that a “considerable” amount of water is diverted above the gauge for irrigation and municipal supply purposes. RMOT2 is moderately developed (5.3%) with significant hay/pasture (62%). Soil characteristics in the basin are of similar make-up to others in the surrounding area.

Conversations with Chris Higgins at the Brazos River Authority (BRA) confirmed that significant surface water diversions exist with RMOT2. Specifically, BRA highlighted two significant points of diversion within RMOT2. The first diversion is from the Gulf Coast Water Authority (GCWA) at the Shannon Pumping Station (N29.64471, W95.901622), which pumps water (primarily for irrigation) from the Brazos just south of Fulshear to League City via the American Canal System (A Canal). The second diversion that BRA noted is at the head of the Richmond Rice Association canal (N29.581170 W95.778624), diverted by NRG Energy for water cooling purposes at Smithers Lake (SLNT2). At present, neither of these diversions are accounted for in a CONSUSE or CHANLOSS model.

In general, this basin had too much upstream routed flow from BAWT2, which is consistent with our understanding of surface water diversions. PEADJ remained at 1.1 to partially offset this extra water. A delay was needed in the UHG to effectively capture peak flow timing and magnitude, particularly for Hurricane Harvey (Figure 4-36). Statistical performance decreased slightly across the period 2010–2020, however PBIAS for the greatest 0.1% of flows (> 105,000 CFS) decreased from -4.5% to 2.2%.

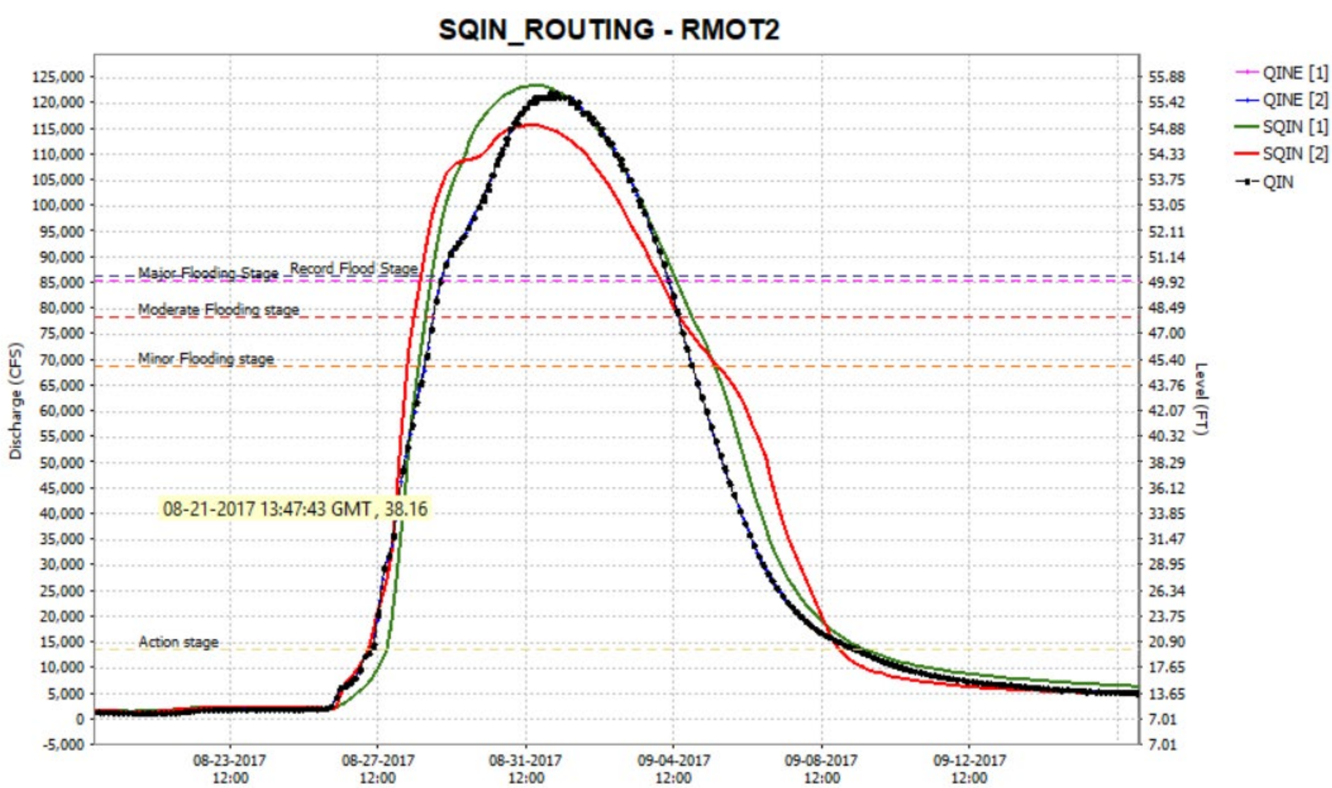
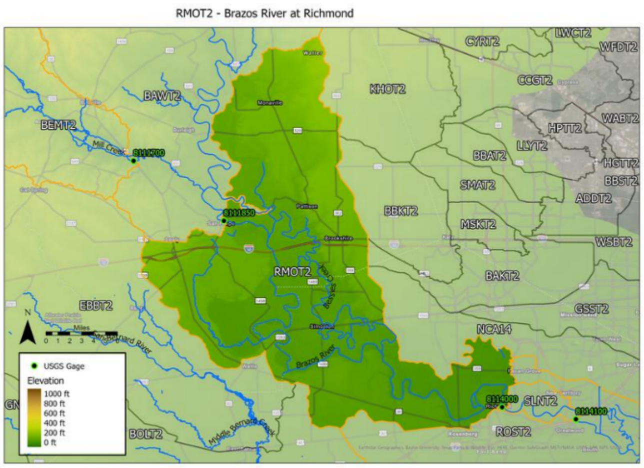
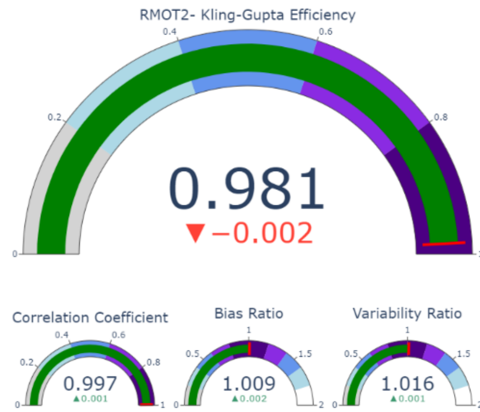
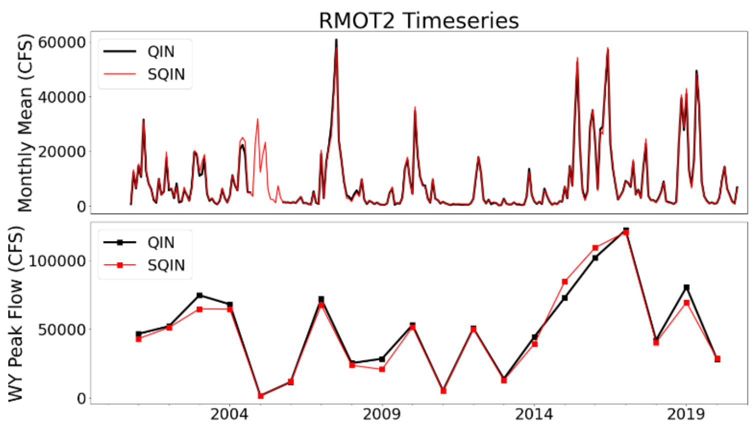


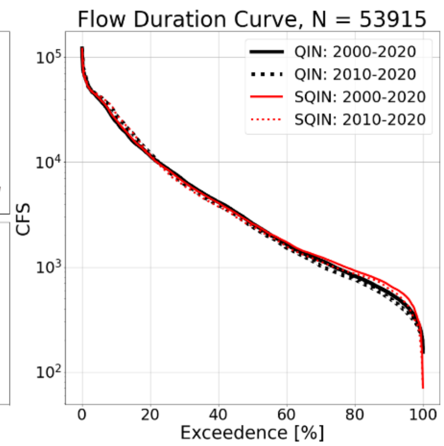
Figure 4-36: Improved calibrations for RMOT2, with SQIN before (red) and after (green) calibrations.

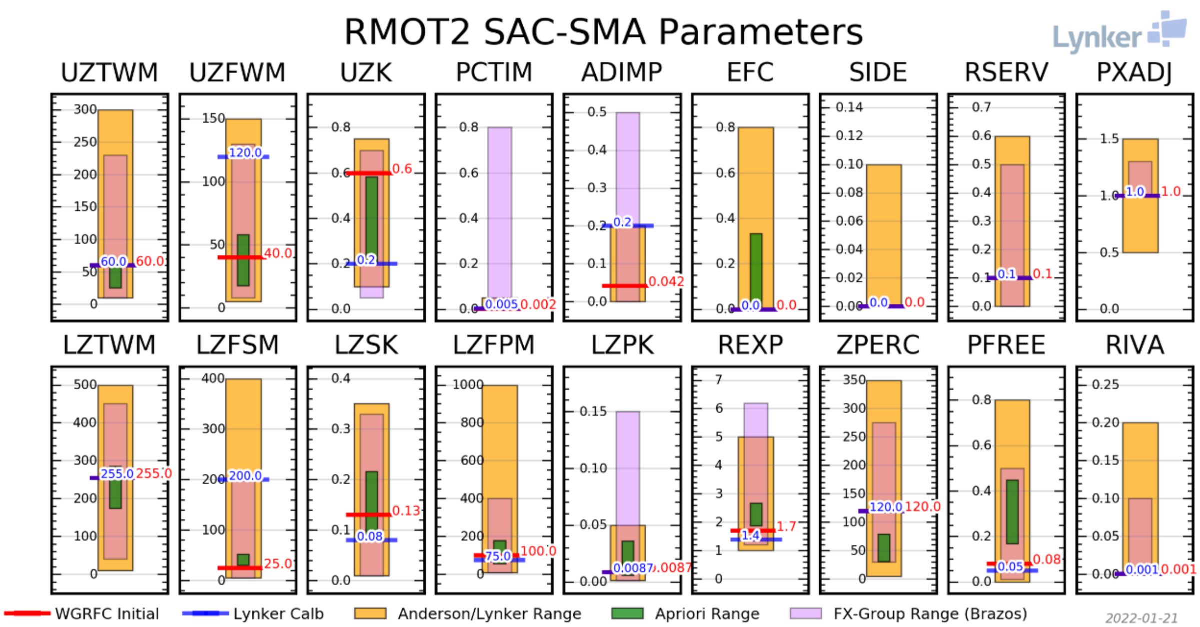
RMOT2: Brazos River at Richmond









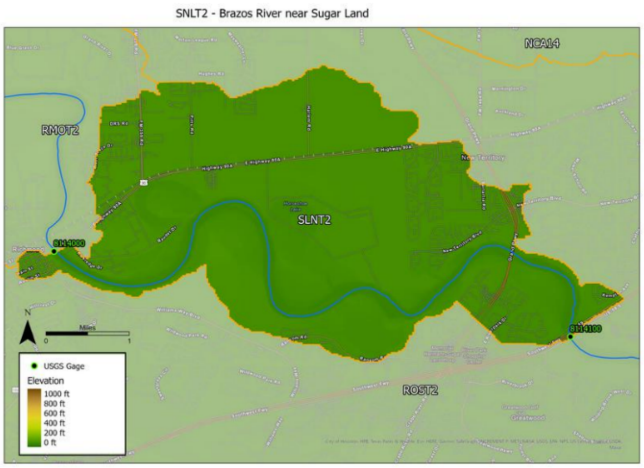


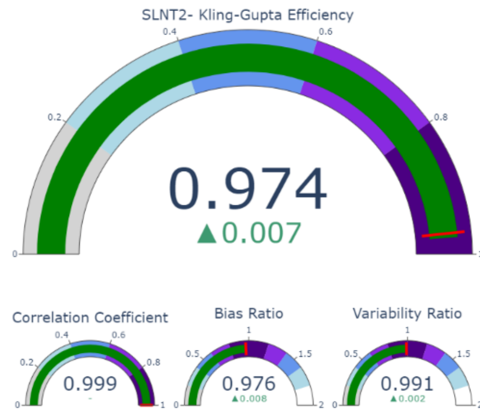
SLNT2

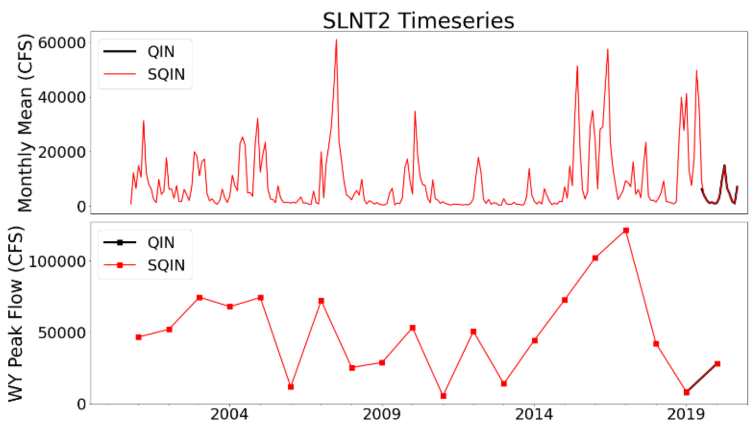
Brazos River near Sugar Land is a very small (12 mi^2) but highly developed (30.8%) local basin located downstream of RMOT2 on the Lower Brazos. Simulations for SLNT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08114100 (available from 2019-07-12 to present).

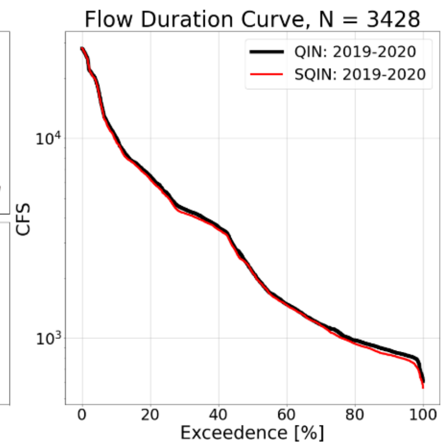
Due to the very short period of record (N = 3428 for QIN data), calibrations were mostly minor, though records downstream at ROST2 were also used for calibration. Mostly significantly, PCIM was increased to 0.8 to develop an appropriate hydrograph response for local storm flow; the UNIT-HG was also shifted earlier and made peakier, while UZTWM and UZFWM were both decreased. No significant flooding occurred during the short period of record.

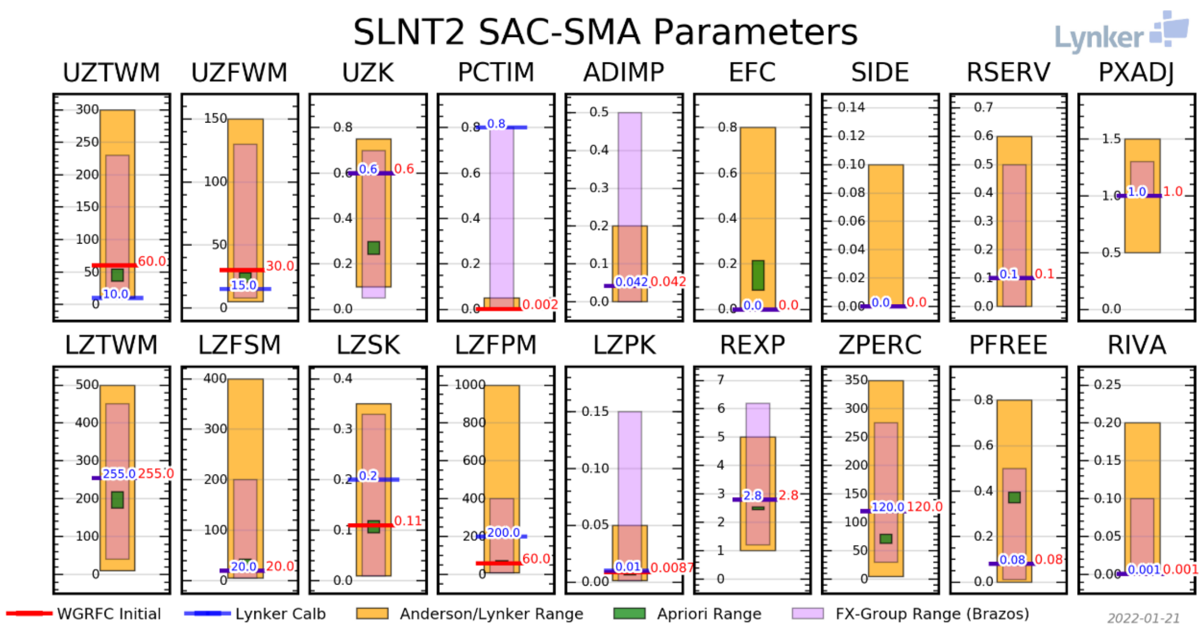
SLNT2: Brazos River near Sugar Land











ROST2

Brazos River near Rosharon is a local basin located downstream of SLNT2 on the Lower Brazos. Simulations for ROST2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08116650 (available from 2007-10-01 to present). USGS remarks do not note surface water diversions, but other sources point to considerable diversions in the basin. ROST2 is heavily developed (19%), and soil characteristics are nearly all Type D/Clay Loam (91%).

Conversations with Chris Higgins at the Brazos River Authority (BRA) confirmed that there are at least two significant surface water diversions exist within ROST2. The first diversion is from the Gulf Coast Water Authority (GCWA) at the *Brisco Pump Station* (N29.504172, W95.553167), which pumps into the Brisco Canal (Canal B) and is used primarily for rice irrigation in Brazoria County. The second diversion is just downstream at the May Pump Station (N29.455699 W95.532731; Canal J).

ROST2 needed significant attenuation both within the UHG and the LAG/K model (particularly for flows below 40,000 CFS). Routed flows from SLNT2 were often larger than ROST2, despite increased upstream attenuation at SLNT2. For example, the Hurricane Harvey secondary peak flow (from SLNT2, green in Figure 4-37) was over simulated by ~10,000 CFS, even after calibration. However, better peak flow simulation for this event (initial simulation in red) provided a better overall performance. Over-simulation at lower flows (evident in the flow duration curve) is suggestive of consumptive use on the river from the GCWA and other users.

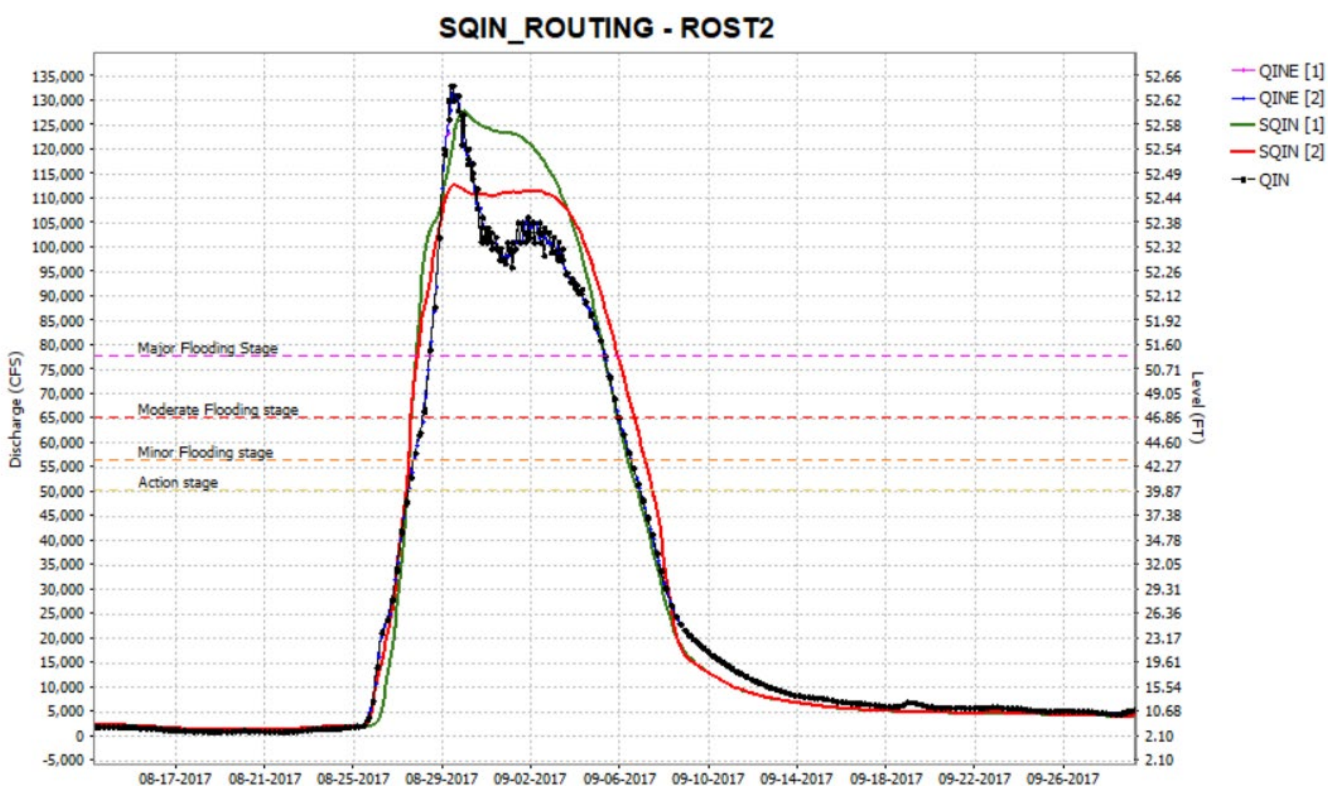
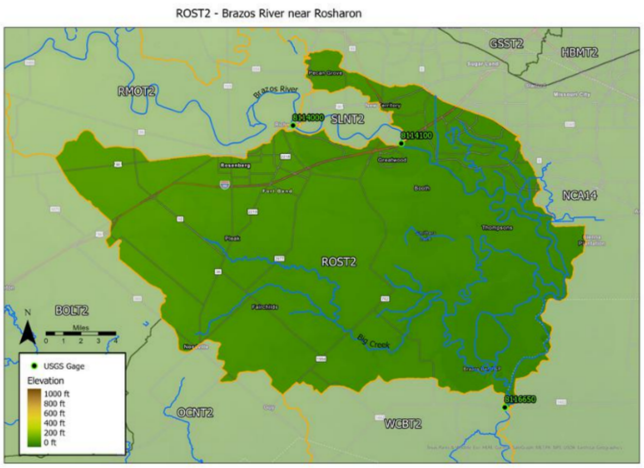
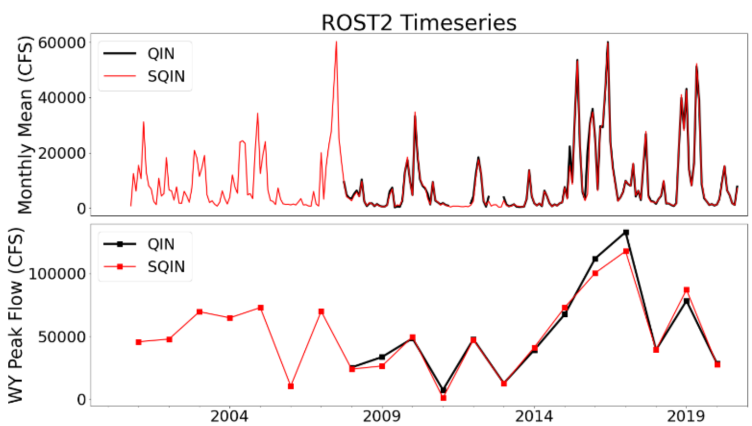
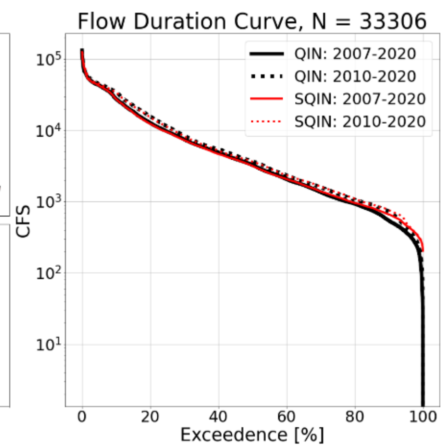


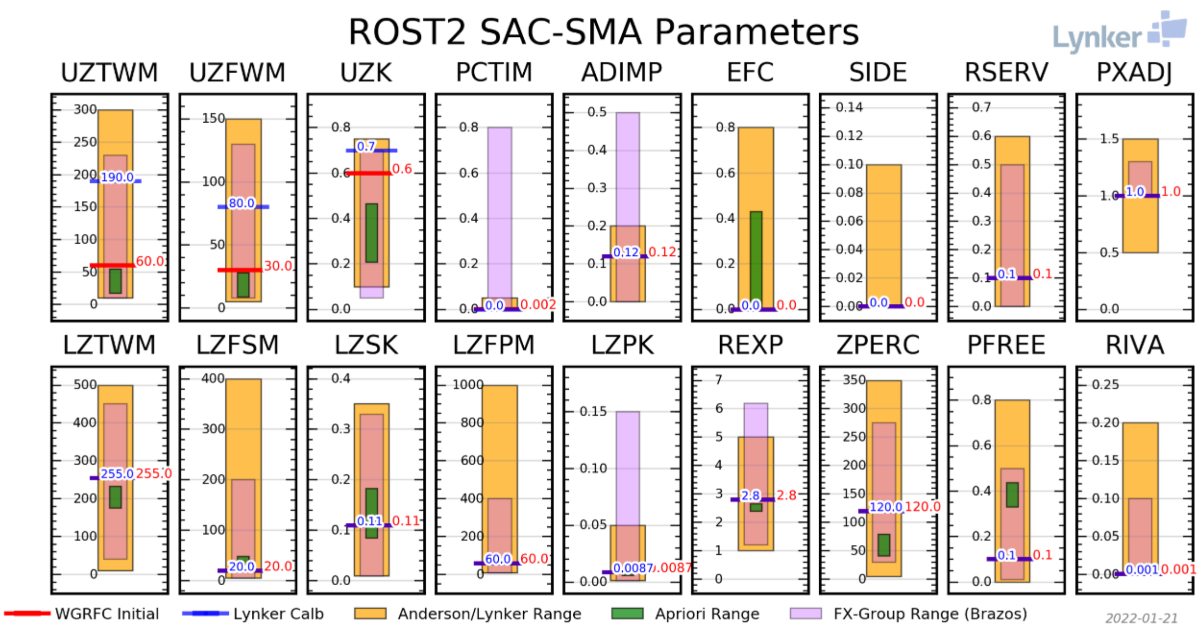
Figure 4-37: Improved calibrations for ROST2, with SQIN before (red) and after (green) calibrations.

ROST2: Brazos River near Rosharon









WCBT2

Brazos River near West Columbia is a local basin located downstream of ROST2 on the Lower Brazos. Simulations for WCBT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08116850 (available from 2017-07-21 to present). As the furthest downstream calibration basin in the Brazos River basin, a strong tidal influence, particularly evident during low flows, is evident at this USGS gauge. WCBT2 land cover is mostly hay/pasture (38%) and woody wetlands (25%) with a very clay-dominated soil profile (89% Type D/Clay Loam).

The observational data for WBCT2 is very short, with only one significant flood within the period of record (Hurricane Harvey; Figure 4-38). Significant increases to PCIM were helpful in correcting a significant under simulation during Harvey, though because more than 90% of flows for this event are from upstream, there were limited opportunities for improving the simulation outside of event timing.

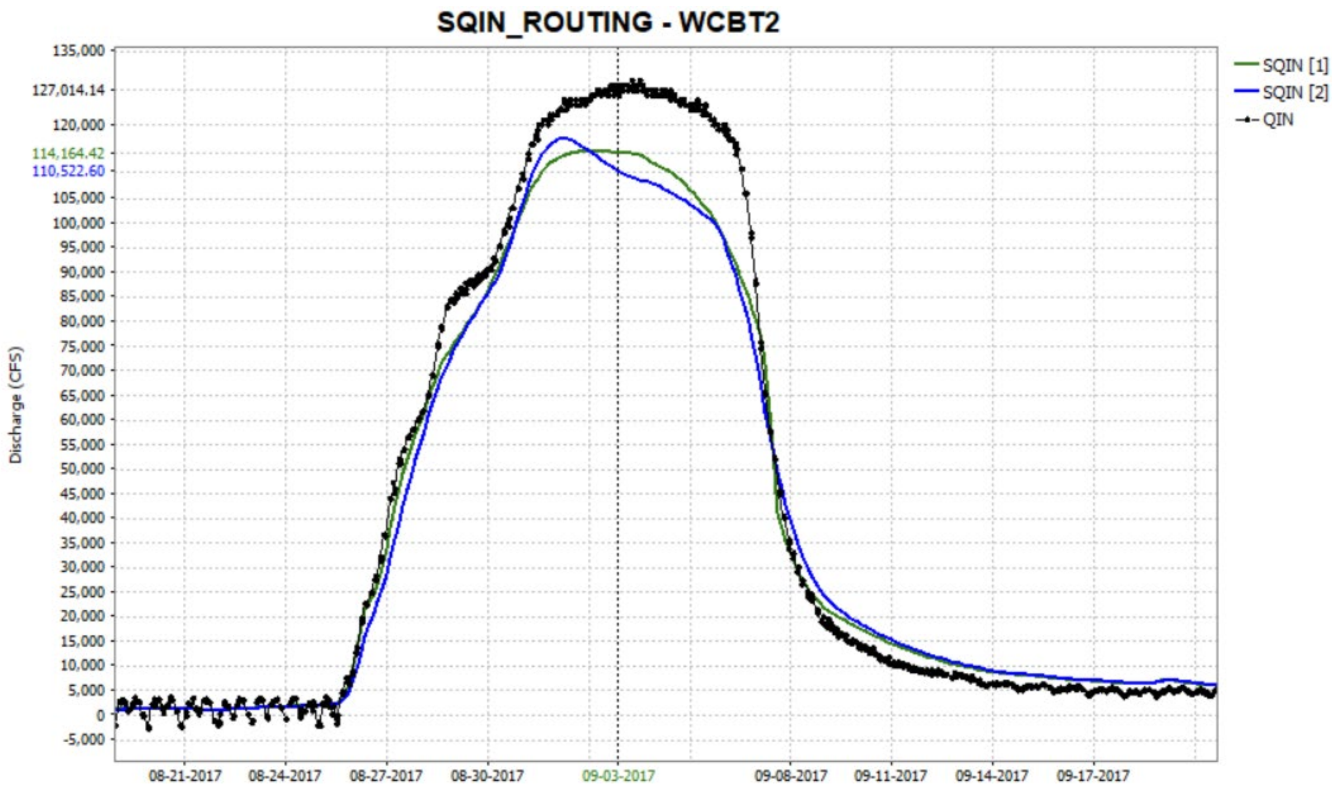
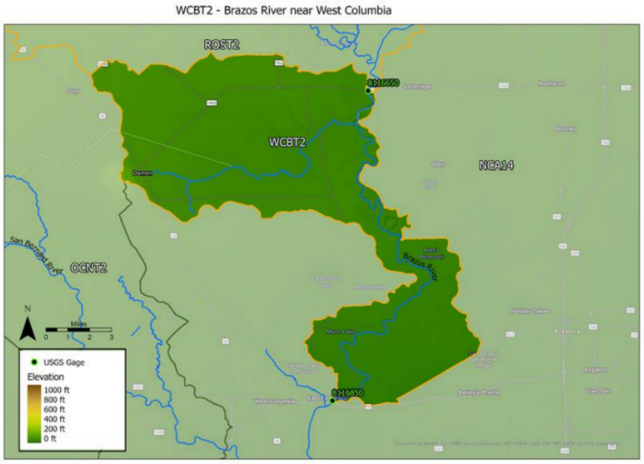
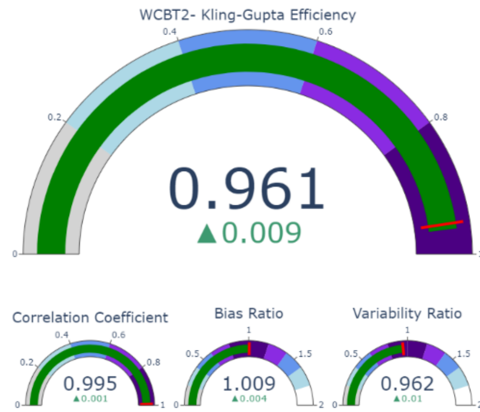
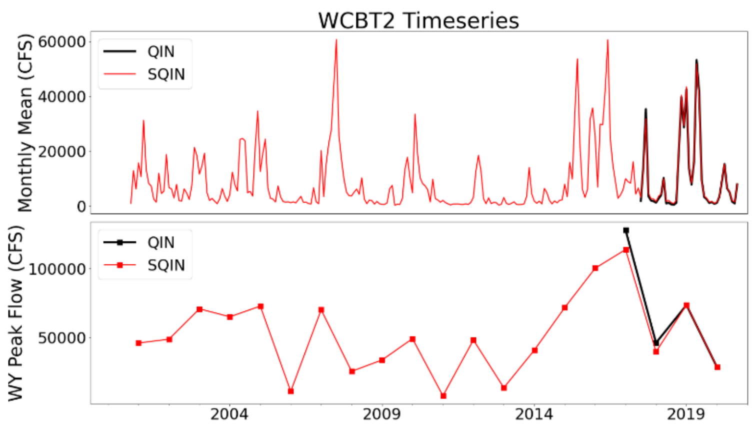


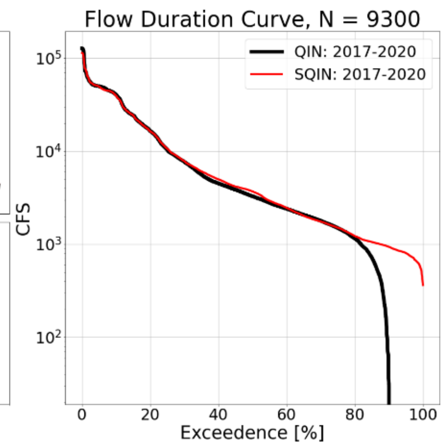
Figure 4-38: Improved calibrations for WCBT2, with SQIN before (blue) and after (green) calibrations.

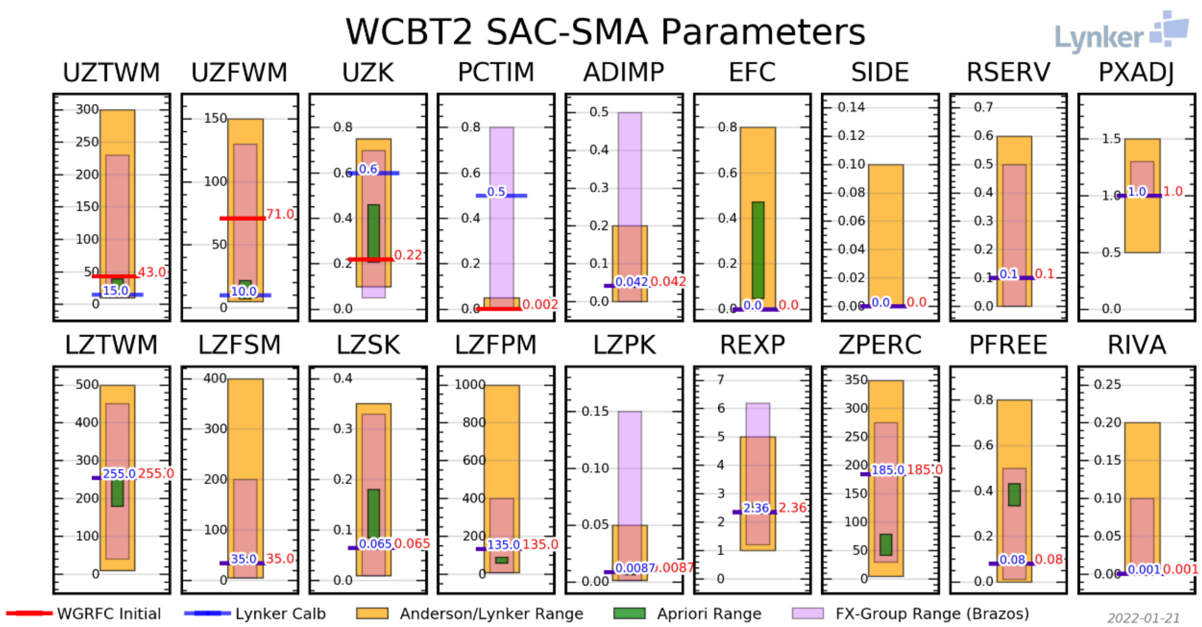
WCBT2: Brazos River near West Columbia











4.1.2. Calibration Summary – Guadalupe

4.1.2.1. Guadalupe HUC6

San Marcos HUC8

LCPT2

Plum Creek at Lockhart is a small (112 mi^2) headwater basin located south of Austin, a tributary to the San Marcos. Simulations for LCPT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08172400 (available from 1991-10-01 to present). Aside from numerous smaller Soil Conservation Service reservoirs located within the basin (flood detention ponds), there are no known surface water diversions. With 11% of land area developed, the basin is more developed than other nearby basins. Additionally, the soil characteristics of the basin are notably poor draining, with 91% of the basin with Type D (Clay Loam) soil. The single largest land cover class in the basin is shrub/scrub (33%).

As expected, given the clay-dominated soil types and extent of development, LCPT2 is a very flashy, ephemeral stream characterized by low baseflows (< 50 CFS) and significant storm events (> 5,000 CFS, peaking at ~37,500 CFS within study period). Prior to calibration, simulations were significantly under-estimating the magnitude of these peaky events, with slow recession (Figure 4-39). Baseflow simulations were generally biased high (constant baseflow values were initially set to 3 CFS, decreased to zero; SIDE was set to zero). Calibrations focused on increasing the magnitude and rate of recession of the flood events (in green, below), particularly during the more significant flood events of the last ten years. Adjustments to the UNIT-HG were considerable, focusing on a much flashier and slightly earlier curve.

Statistical improvements were significant, particularly as measured by the correlation coefficient and the variability ratio, which was initially too low (i.e., the standard deviation of simulation was too small). Overall biases were very small, though high flow biases (top 1% of flows) were still under-simulated by –14%.

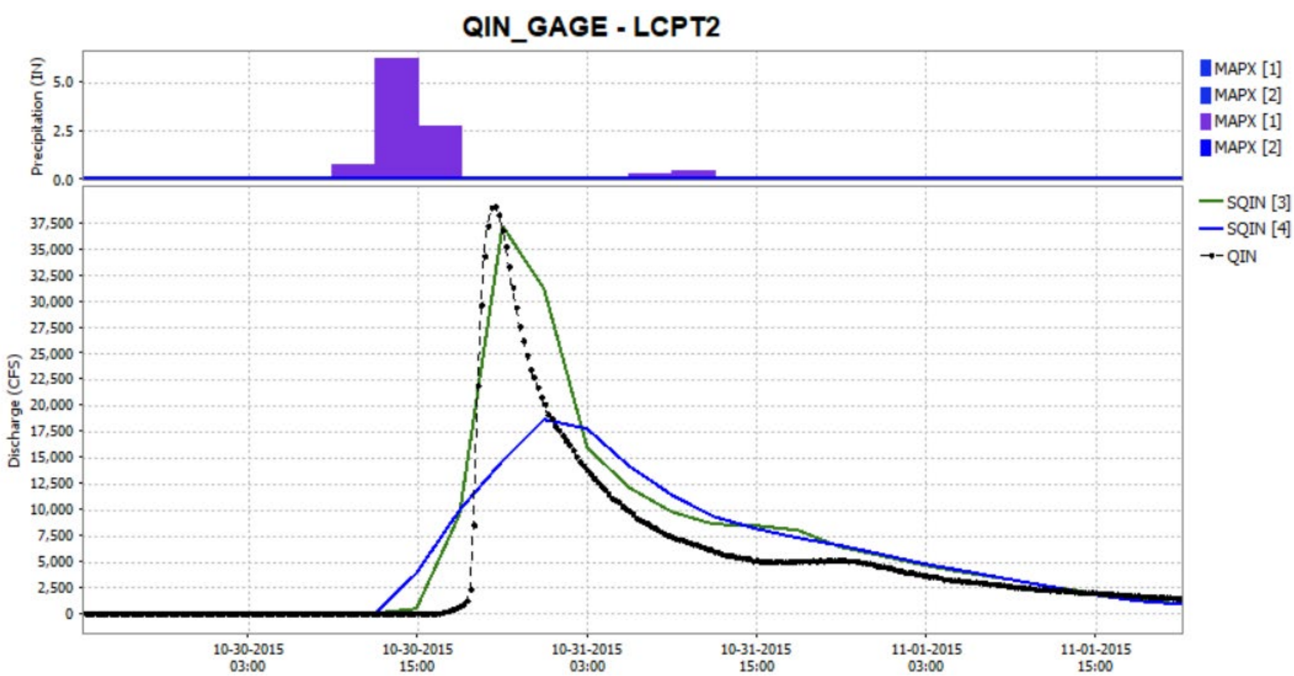
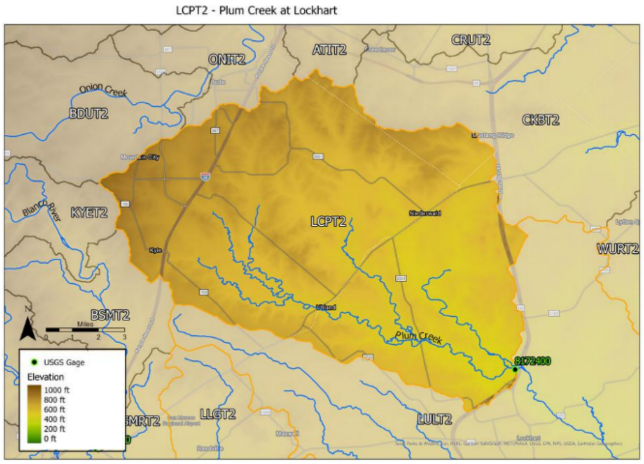
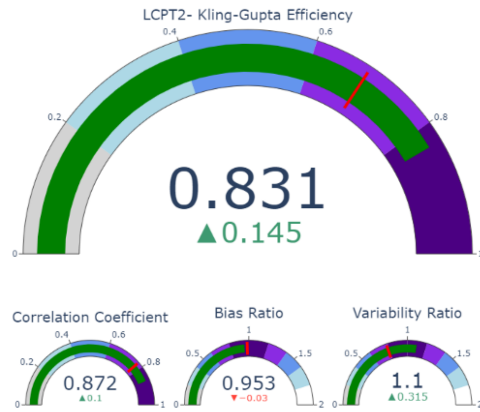
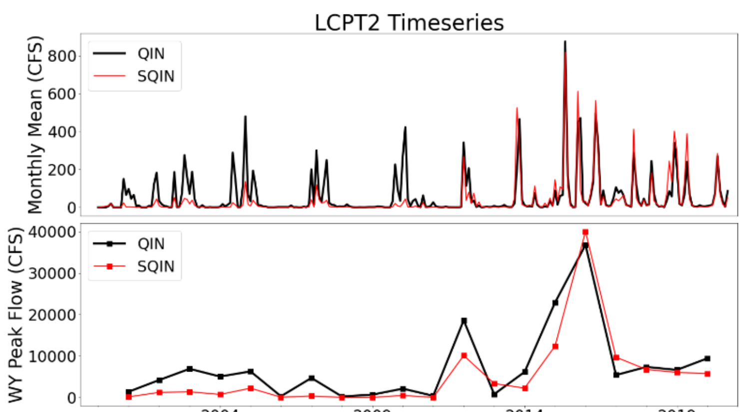


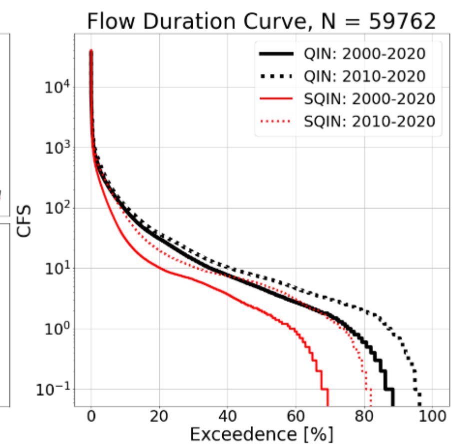
Figure 4-39: Improved calibrations for LCPT2, with before (blue) and after (green) calibrations. Note significantly improved flashiness and peak flow magnitude.

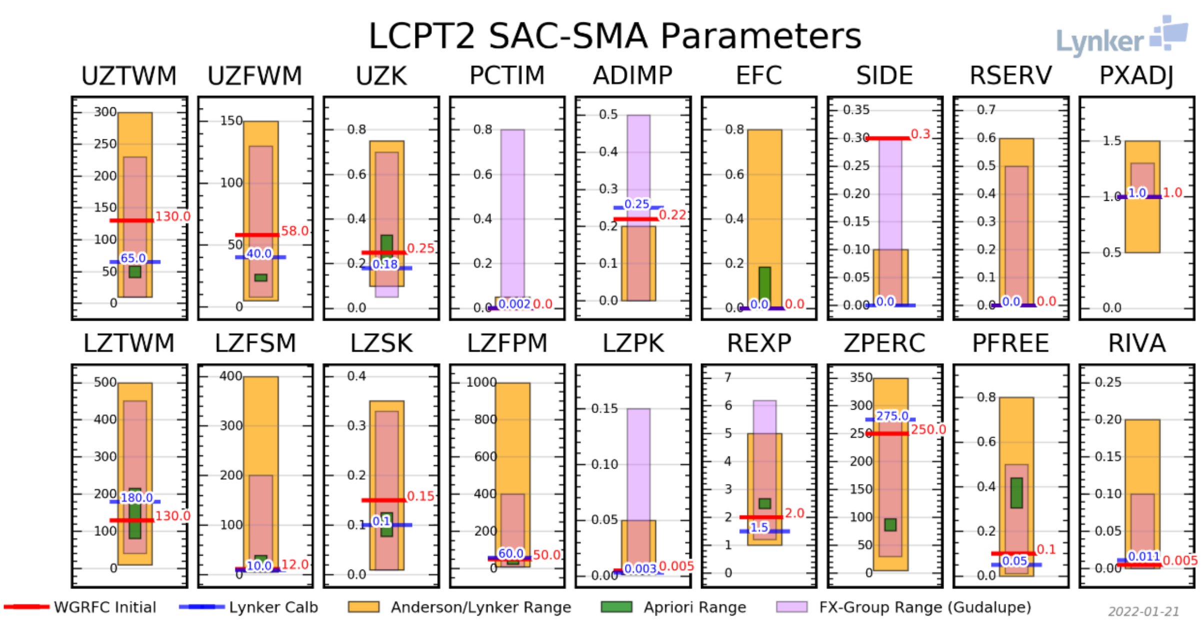
LCPT2: Plum Creek at Lockhart











LULT2

Plum Creek near Luling is a local basin located downstream of LCPT2 just upstream of the San Marcos. Simulations for LULT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08173000 (available from 1991-10-01 to present). Formerly, LCPT2 was grouped with LULT2. LULT2 is similar to LCPT2 in that there are numerous small Soil Conservation Service reservoirs (flood detention ponds) and other small lakes with no other known surface water diversions of significance. Relative to LCPT2, LULT2 it is a larger (157 mi^2), less developed (2.4%) basin with a slightly more permeable soil profile (71% Type D/Clay Loam). The single largest land cover class in the basin is hay/pasture (46%).

High bias (15% from 2010–2020) during the initial model simulation was the predominant concern going into model calibration. Peak flows were of a smaller magnitude and a longer duration than upstream basins, calling for increased routed flow attenuation in the single LCPT2 LAG/K model. PEADJ values were set back to one, and SIDE was set to zero. Slight changes to the UNIT-HG and ADIMP were important in correcting over-simulations in local flows, though secondary to increased attenuation for the routed flows.

Statistical changes in the KGE score (2010–2020) were attributable to decreases in overall bias (decreased by 11% to 4%; e.g., Figure 4-40) and decreases in the flashiness (variability score). Calibrations were guided towards the most recent decade due to increased flooding since 2011 (four Moderate Flood events since 2011; none above this stage in the USGS records prior to 2011). Unfortunately, the second largest flood of record and the largest flood in the study period is missing from the USGS streamflow data (May 27, 2015). Simulations prior to 2010 were consistently too low (i.e., solid red line on the flow duration curve).

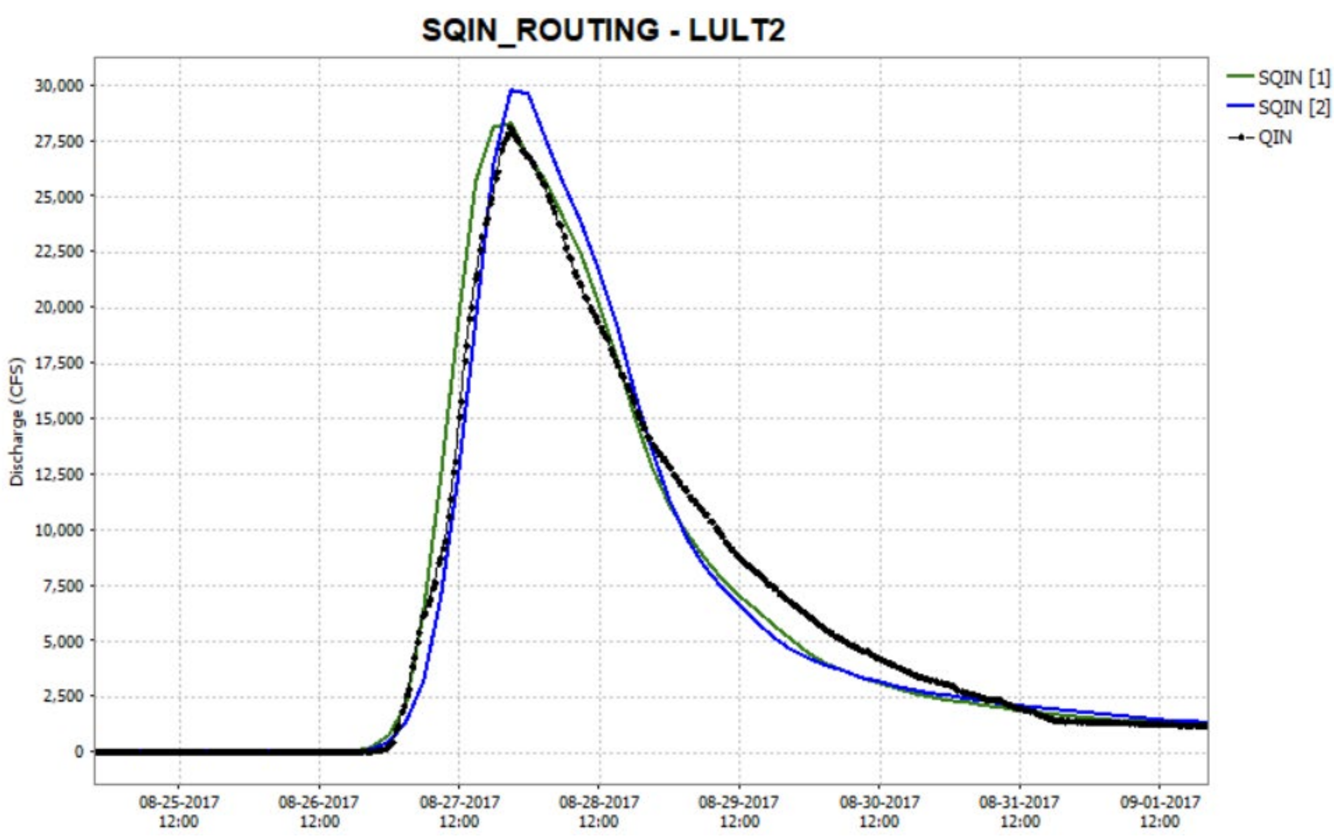
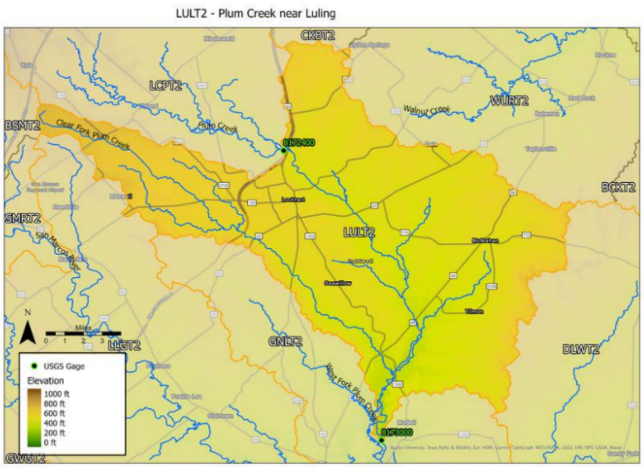
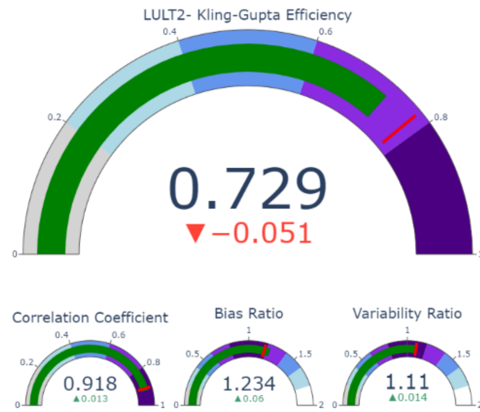
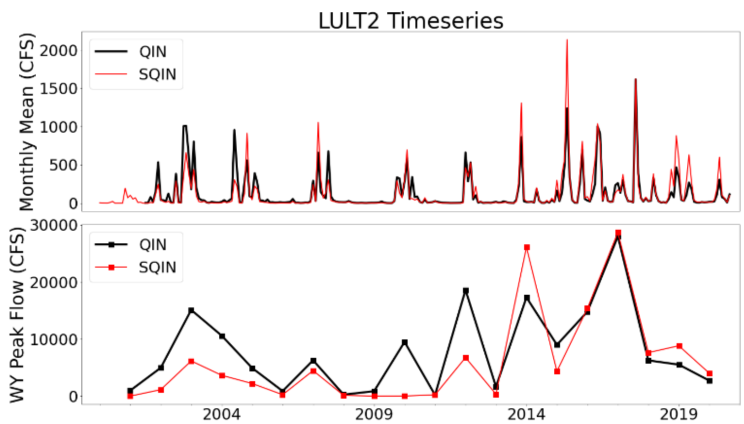


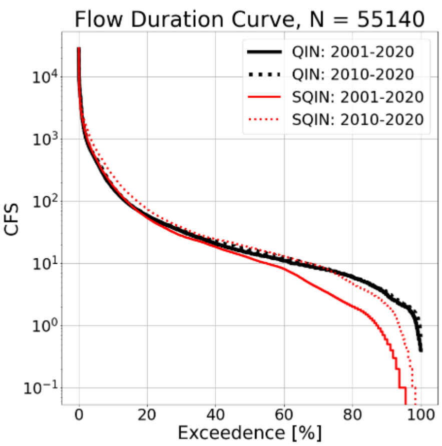
Figure 4-40: Improved calibration for LULT2, with SQIN before (blue) and after (green) calibration.

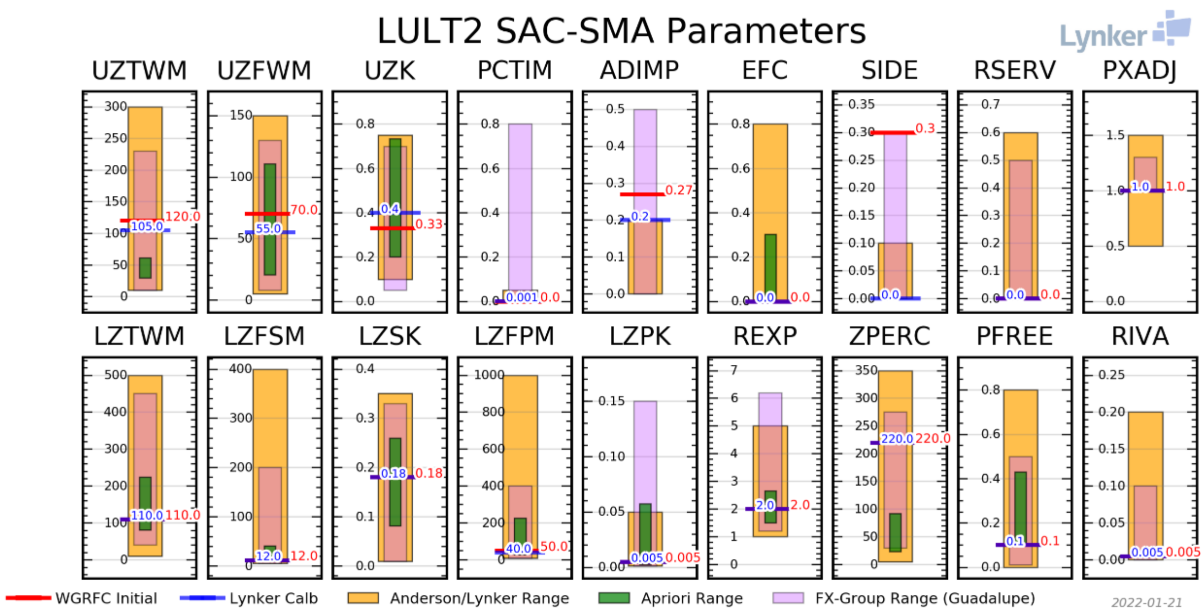
LULT2: Plum Creek near Luling











LLGT2

San Marcos River at Luling is a local basin near San Marcos located downstream of SMRT2, which lies outside of the study domain, but is measured by USGS gauge 08171400 (records fair). Simulations for LLGT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08172000 (available 1986-10-14 to present). Formerly, LLGT2 consisted of LLGT2U and LLGT2. USGS records note that there are a series of Soil Conservation Service flood-detaining ponds that regulate flow in the basin, which appear concentrated on York Creek, a tributary. Soil characteristics for LLGT2 are similar to nearby basins in that a large majority (82%) of soil is classified as Type D/Clay Loam. The single largest land cover class in the basin is hay/pasture (34%).

As a local basin on the San Marcos River, most of the streamflow from LLGT2 is routed from the upstream basin SMRT2, which likewise routes most flows from BSMT2 (USGS gauge 08171350) but also some from SRUT2 (USGS gauge 08170500). In preparing streamflow data for import to CHPS, it was evident that during major flood stages (e.g., Halloween 2015), measured streamflow at BSMT2, SMRT2, and LLGT2 was inconsistent upstream to downstream. USGS-flagged QIN data for SMRT2 (USGS gauge 08171400) appeared to be most suspect when compared to routed QIN data at BSMT2 and the raw QIN data at LLGT2. Thus, all data points for USGS gauge 08171400 marked as “estimated” by the USGS were removed (approximately 30 data points). Previous conversations with the USGS Texas Water Science Center suggest it could be a combination of storage losses, a poor USGS rating curve, or other unknown factors. Regardless, routing of simulated flows for these events generally provided better performance at LLGT2.

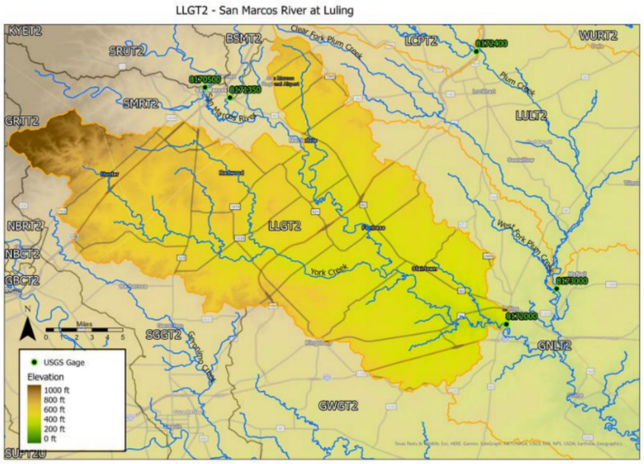
Statistical performance was hindered by the fair quality of the upstream routed flows, which appeared to both at times exceed and during other times under-estimate flows at the basin outlet; even after model calibration, overall model bias was still –32% (-14% for flows > 2,600 CFS). After reviewing the initial calibrations, WGRFC requested that we revisit high flow events. Revised calibrations attempt to increase peak flow simulations and opt for higher model bias that favors slight over-predictions during large events rather than minimized biases for the period of record.

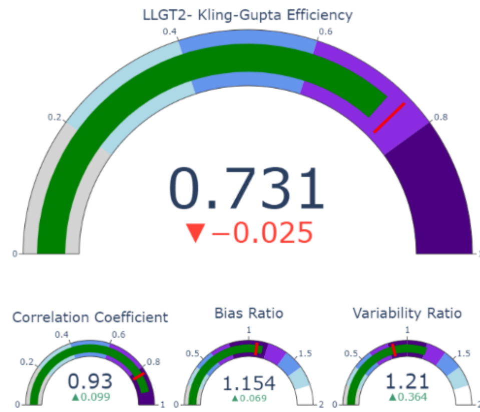
WGRFC feedback: *We noted that there is not much improvement over the original parameters, and in some events we may be not improving at all. Can you take another look at this one and see if any improvement is possible by emphasizing the peaks vs fitting statistics? This is definitely a point where we would prefer a slightly high bias over a perfect fit. A good example is the 5.25.2015 event. We think that this is a Lag/K routing issue, and K should be lowered. Try decreasing the K from a value of 10 to a much lower value between 1 and 4. We did notice that the event in May 2020 looks better.*

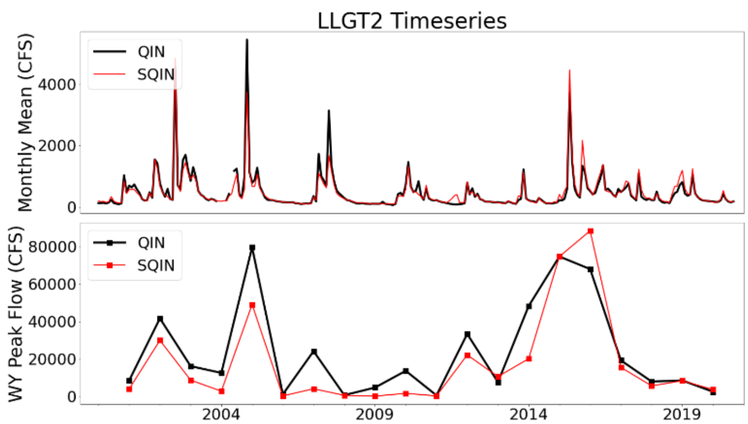
Lynker update: We revisited LLGT2 with the goal of improving the magnitude and timing of peak flow events. In addition to adding an ET Demand Curve, we also significantly increased UZK, decreased UZTWM, and adjusted the baseflow parameters. While we were generally successful in increasing peak flows across the board, there were limitations to the improvements we could make. For example, the November 1 2013 simulations remained stubbornly low. Furthermore, timing issues are inconsistent, and thus difficult to address within the parameterizations of the UHG and LAG-K omdeks. It is likely that calibration the upstream basins at SMRT2 and BSMT2 (out of domain) would further improve simulations at LLGT2.

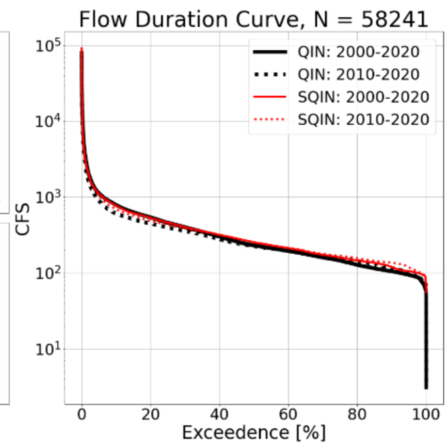
We decreased the K value in the largest flow bin from 10 to 6. While this improves the 05-25-2015 event (new calibration = blue; old calibration = pink), please note it is at the expense of the 10-31-2015, which is now over-simulated by 20,000 CFS. As you note, the calibration challenges at LLGT2 are largely inherited from upstream simulations, which are outside of the calibration domain (although we did introduce modifiers at SMRT2 because of these very issues).

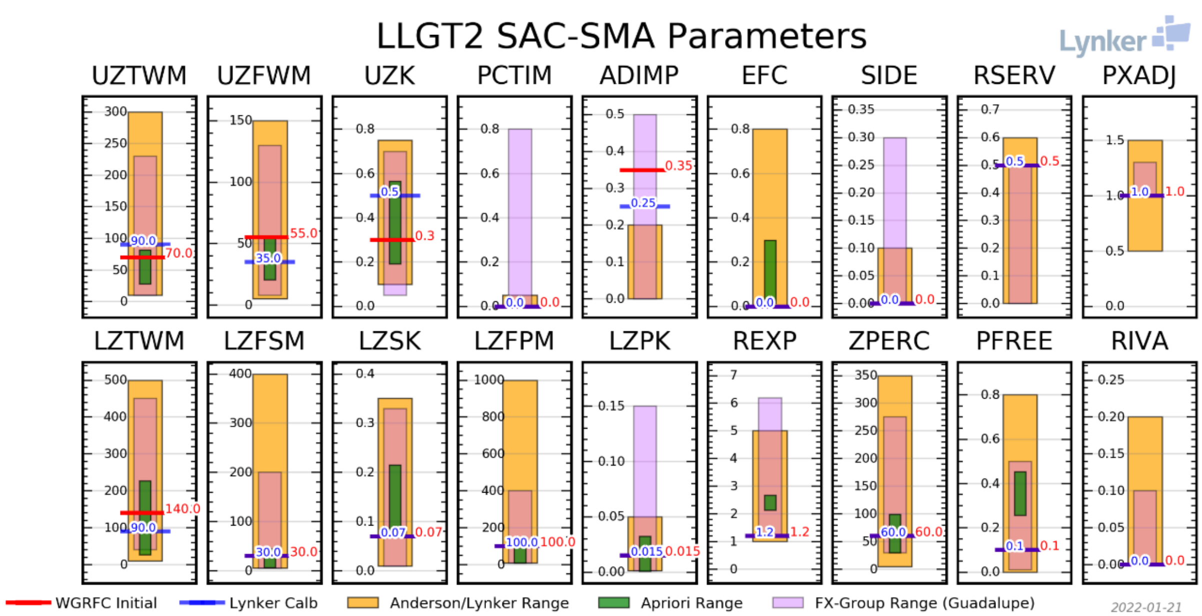
LLGT2: San Marcos River at Luling











GNLT2

Guadalupe River at Gonzales is a local basin at the confluence of the Guadalupe River (GWGT2), San Marcos Rivers (LLGT2), and the smaller Plum Creek (LULT2). Simulations for GNLT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08173900 (available 1996-10-12 to present). USGS remarks note that at least 10% of the drainage area is regulated. Diversions exist for irrigation and municipal use (unknown quantities). Previously, this basin was run at a 6-hour time step. GNLT2 has less clay than upstream basins (51% Type D/Clay Loam), with a greater portion of the coarser Type B/Silt Loam (21%) and Type C/Sandy Clam Loam (20%). The single largest land cover class in the basin is hay/pasture (53%), though a significant percentage of the area is also forested (21%).

At the confluence of several major tributaries, GNLT2 streamflow was mostly (80-90%) from upstream routed flows with limited local streamflow generation. One of these basins, GWGT2 on the mainstem of the Guadalupe, is outside of the study domain. Furthermore, GWGT2 (USGS gauge 08169845) has no observed streamflow data prior to 2016. Because of this, more weight was placed on the last years four years of the record when GWGT2 observed data were available for the most precise LAG/K calibrations, including the fourth largest flood of record on August 28th, 2017. Major flood events during May (Figure 4-41) and October of 2015 were also significant focal points of calibrations efforts, primarily in the LAG/K model domain.

Statistical changes for the entire period were minimal, though bias for the largest flood events (0.1%, >32,000 CFS) decreased from 14% to 4% during the period 2010–2020, and from 9% to 0.8% during the full 2000–2020 period of record. Adjustments to the timing and attenuation of all three routed flow components were critical in dialing in peak flow simulations.

WGRFC feedback: *Still missing a lot of peaks in this basin and we see some timing issues. See if this one can be improved by increasing the peaks.*

Lynker response: Peak flows were increased by adjusting UZTWM and UZFWM, and decreasing attenuation, particularly for LLGT2R, but also for GWGT2R and LULT2R. Additional adjustments to the LAG served to correct timing issues by shifting flows earlier. These adjustments verify well for most events (e.g., November 1, 2015), however it is evident that during others, simulated flows are too early (e.g., November 2, 2013). On the whole, these adjustments seem like a notable improvement over the initial calibrations.

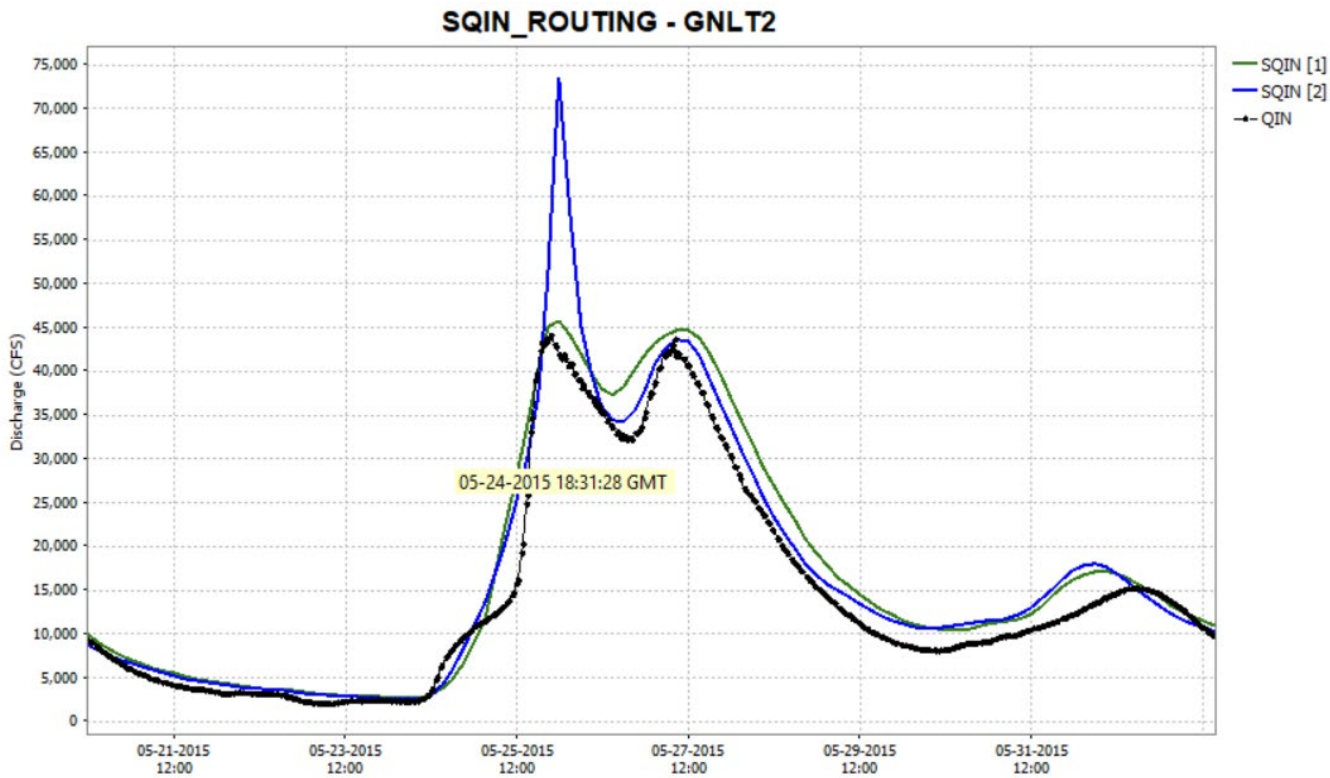
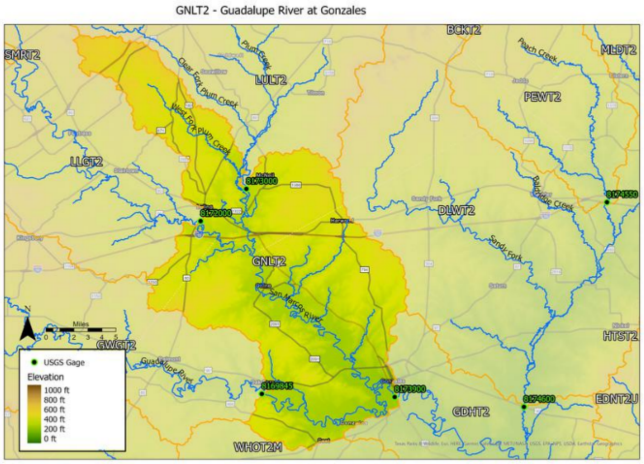
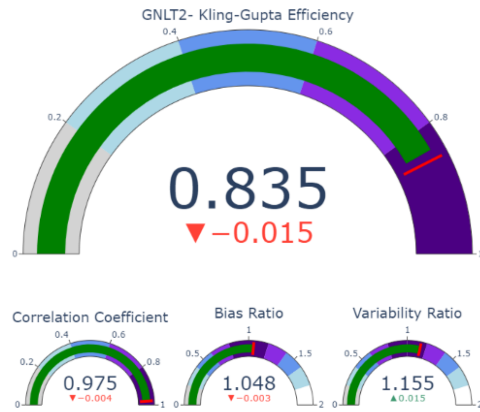
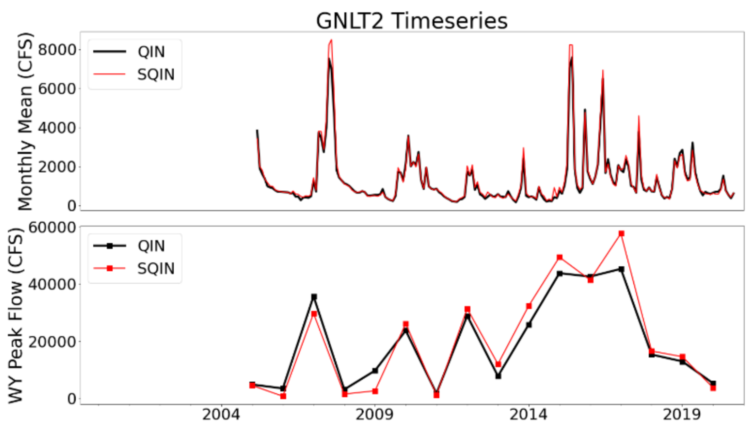


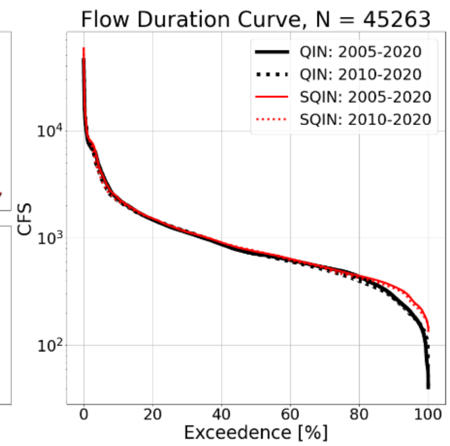
Figure 4-41: Improved calibration for GNLT2, with SQIN before (blue) and after (green) calibration. Attenuated upstream routed flows at high flows decreased the initial 70 KCFS peak.

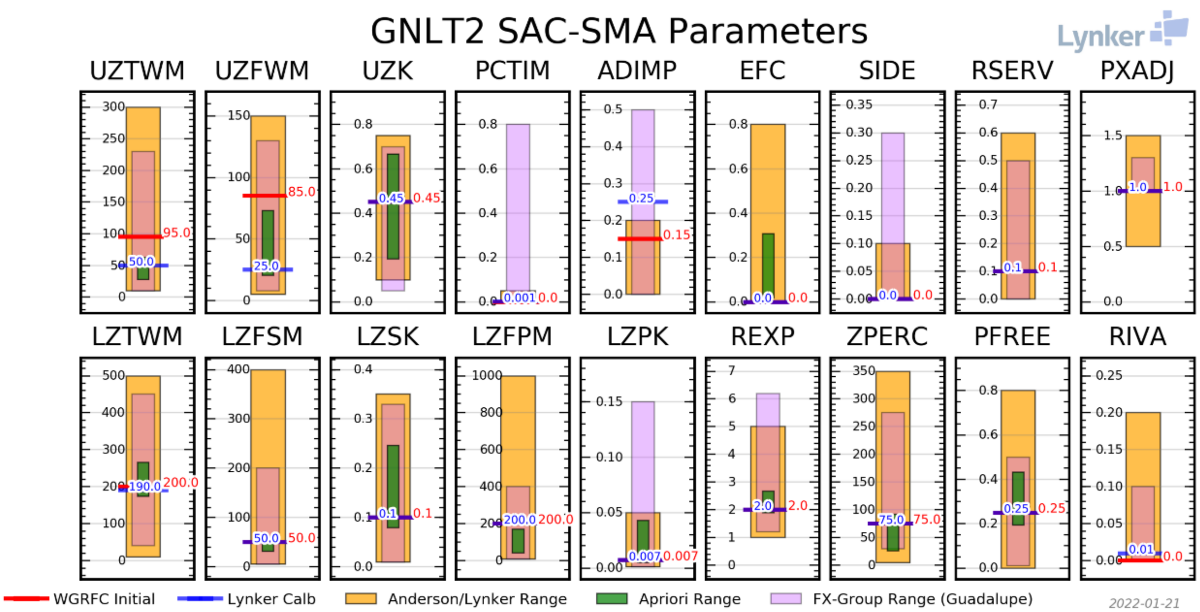
GNLT2: Guadalupe River at Gonzales











Middle Guadalupe HUC8

PEWT2

Peach Creek at Highway 90 near Waelder is a headwater basin for the Peach Creek tributary to the Middle Guadalupe. Simulations for PEWT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08174550 (available from 2016-10-27 to present), though records are only rated as fair. There are no known regulations or diversions in the basin. Land use is primarily hay/pasture (41%) or forested (37%) with minimal development; 51% of soils are classified as Type D/Clay Loam.

Streamflow in the headwaters of Peach Creek is uneventful (<2,000 CFS) except for significant flooding in 2017 from Hurricane Harvey (peak flows 66,000 CFS, Figure 4-42). Due to the historic nature of the flooding in PEWT2, instantaneous data for this event are estimated flows, as denoted by the USGS records. Simulations of the Harvey event peaked at approximately 21,000 CFS, but only through significant parameter adjustment that caused very poor performance during all other times. Difficulty during this event suggests that either 1) USGS estimated flows are too high, and/or 2) MAP data from WGRFC for this event is too low. As an experiment, increasing PXADJ to 2 simulated peak flows of up to 60,000 CFS; no adjustments to PXADJ were implemented, however this demonstrates what are likely structural errors in the forcing data. Constant baseflow was adjusted from three to zero.

Final statistical performance for this basin was poor and is flagged for review by WGRFC. While the correlation coefficient is a respectable 0.85, and overall bias is only –6.9%, the model as forced by the current precipitation data is unable to represent both the historic flooding of Hurricane Harvey and the more typical conditions of the basin.

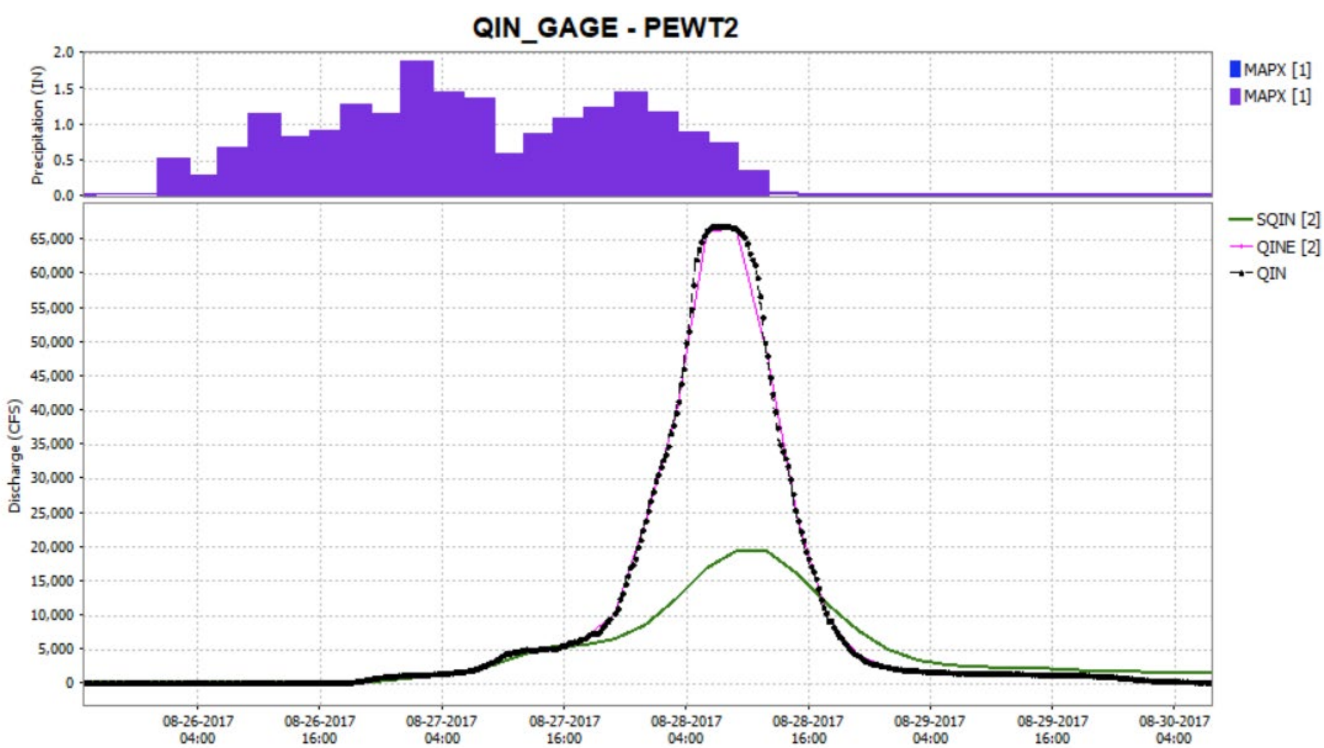
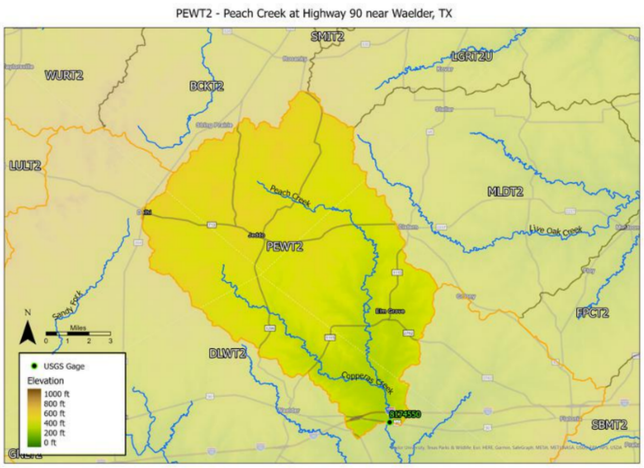
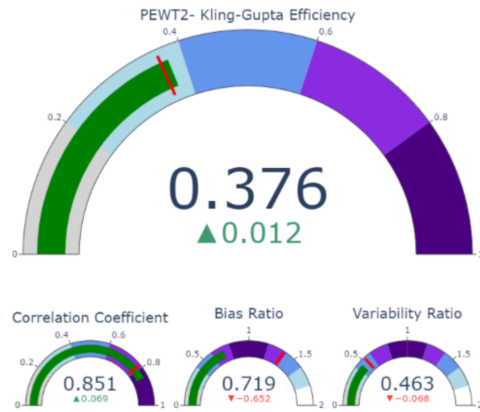
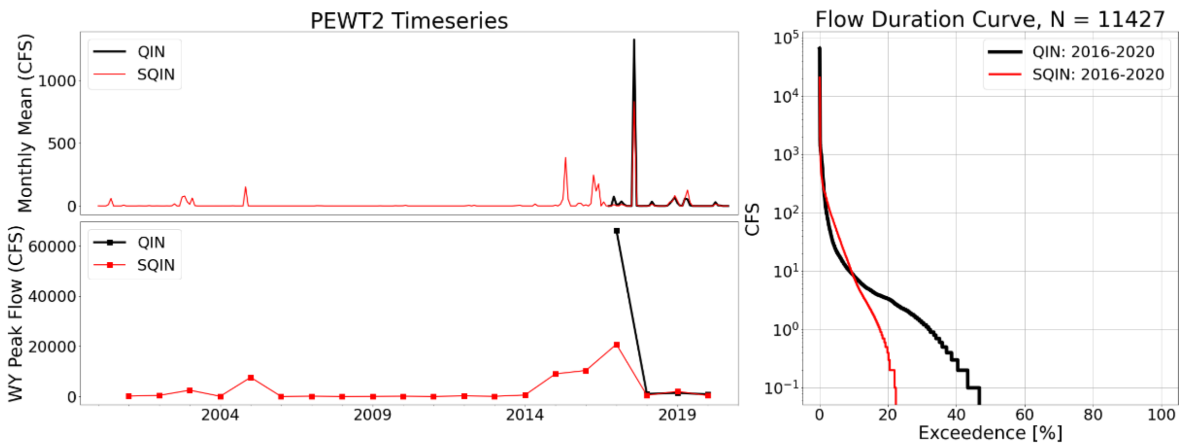


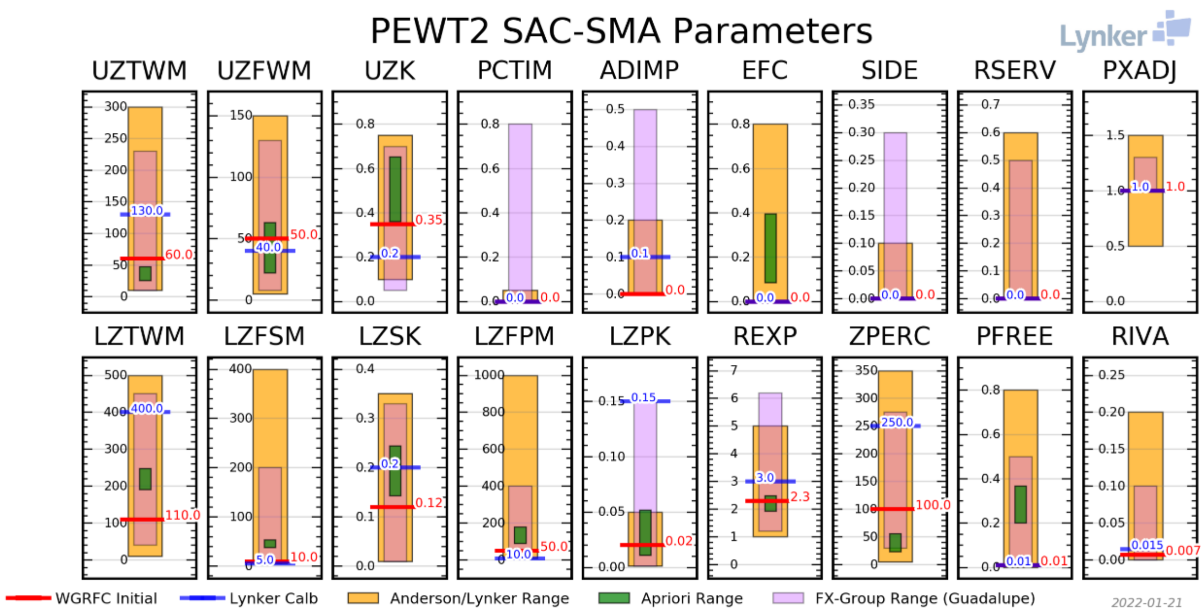
Figure 4-42: Likely over-estimation of peak observed QIN (black) for PEWT2 (USGS 08174550) during Hurricane Harvey.

PEWT2: Peach Creek at Highway 90 near Waelder, TX









DLWT2

Peach Creek below Dilworth is a local basin downstream of PEWT2, with a large local drainage area (354 mi^2), including the Sandy Fork. Simulations for DLWT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08174600 (available from 2000-10-01 to present). Land cover and soil types for DLWT2 are similar to PEWT2, though slightly more developed (1.5%). DLWT2 is otherwise unremarkable.

Streamflow records for DLWT2 are similarly dominated by the Hurricane Harvey flood event (peak flow 46,000 CFS, Figure 4-43), with more typical events in the 5-15,000 CFS range, and warm season baseflows of very low to no flow. Calibration efforts were also focused on simulation of the Harvey peak flows (calibration in green below compared to initial simulation in blue), though the timing of the recession was difficult to match. The timing of more recent moderate events (~5,000 CFS) is not verified well, however shifting the UHG earlier to fix this leads to significant timing issues for major floods. Significant attenuation of PEWT2 flows was essential, as was an increase in the UZFWM for the local flows. It was difficult to simulate enough surface runoff without significantly over-simulating the event, suggesting that the PEWT2 flows estimated by the USGS and routed to DLWT2 may be unrealistically high (though USGS flows from gauge 08174600 are also marked as estimations for this event). Furthermore, good calibration of Harvey came at the expense of decent baseflow calibrations, as is apparent in the QIN/SQIN divergence in the flow duration curve.

Final calibrations improved the KGE score (from 0.33 to 0.754) for the period 2010–2020, mostly driven by improvements in the bias (32.8% before, -0.2% after). Calibrations focused on the period after 2016 because of the limited USGS data from PEWT2.

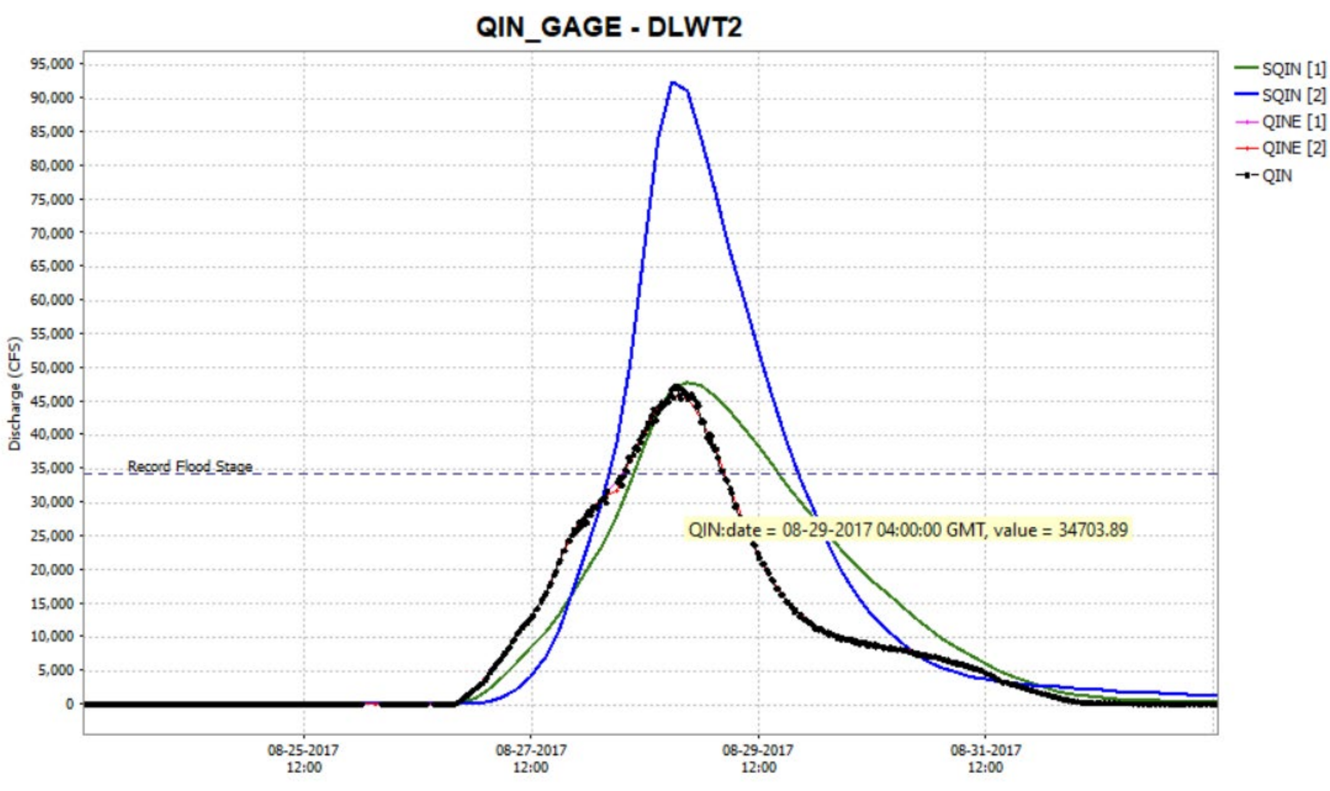
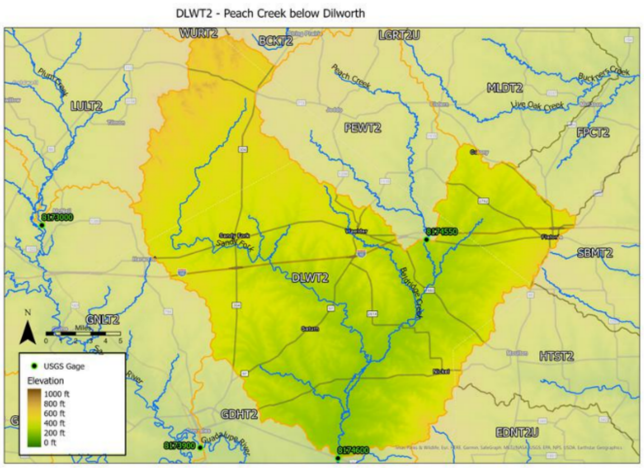
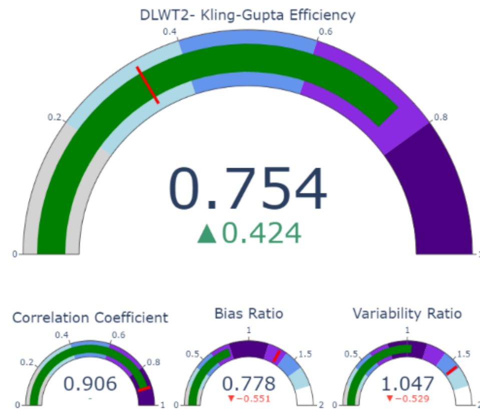
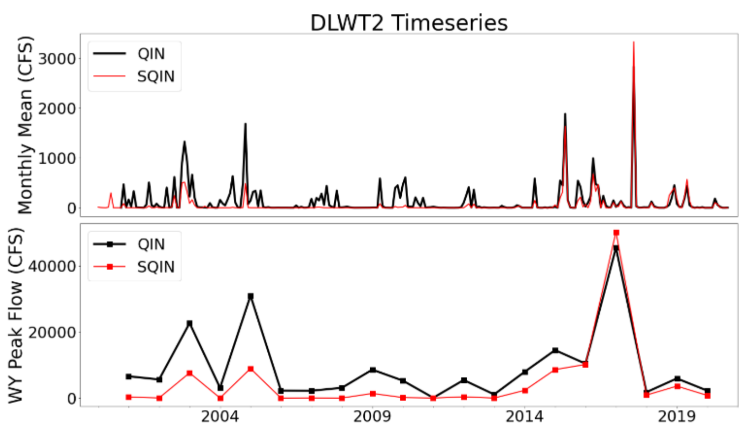


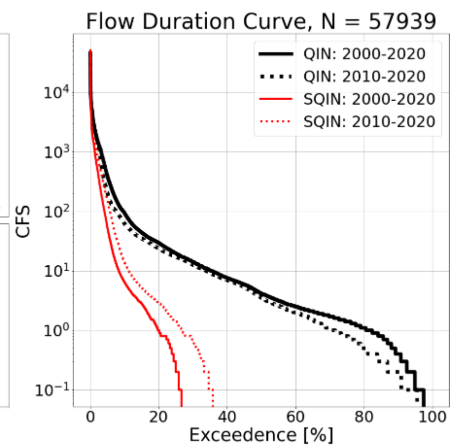
Figure 4-43: Improved calibration for DLWT2, with SQIN before (blue) and after (green) calibration.

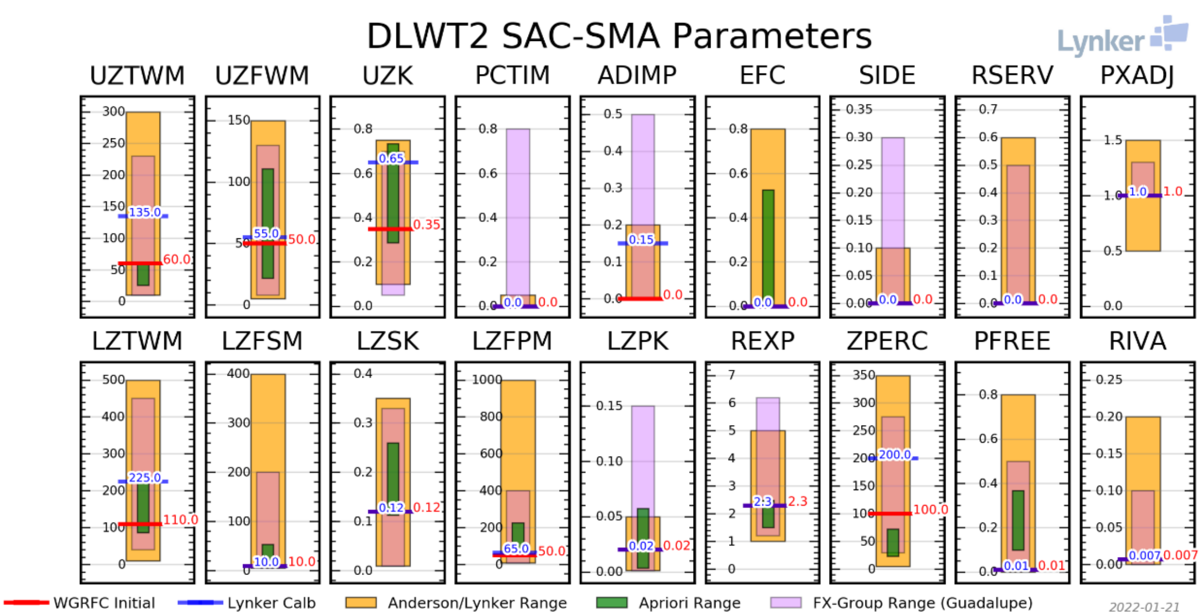
DLWT2: Peach Creek below Dilworth











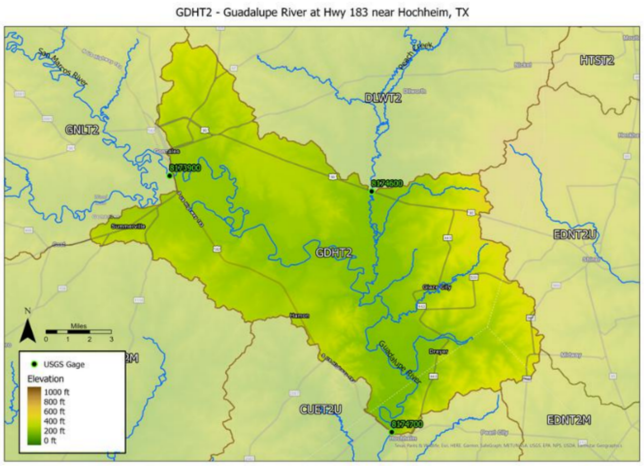
GDHT2

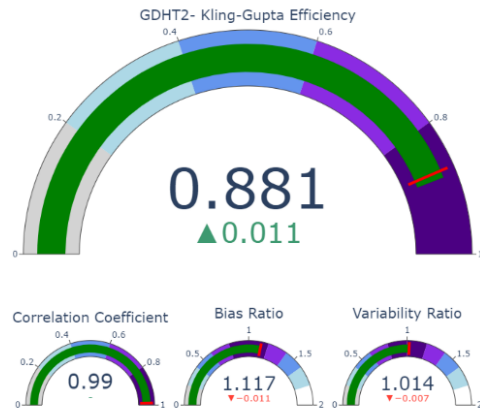
Guadalupe River at Highway 183 near Hochheim is a local basin at the confluence Peach Creek with the mainstem of the Guadalupe River. Simulations for GDHT2 were run at a 3-hourly timestep, calibrated to instantaneous stage data from USGS gauge 08174700 (available from 2016-06-10 to present) converted to discharge data using the WGRFC rating curve, as recommended by Andrew Philpott at the WGRFC. GDHT2 is primarily classified as Type D/Clay Loam soil (59%), with 4% of the land area classified as developed. The single largest land cover class in the basin is hay/pasture (51%).

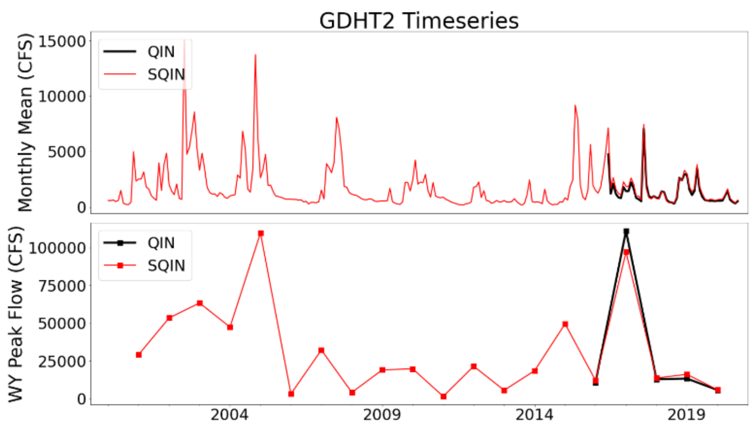
As a relatively small basin (141 mi^2) relative to the overall drainage area of the Upper Guadalupe and tributaries, GDHT2 streamflow is mostly from the upstream basins GNLT2 and DLWT2. With a short period of record, GDHT2 calibration efforts were again centered around Hurricane Harvey, but also the more regularly recurring 10-15,000 CFS events. Significant increases in routed flow attenuation, particularly for higher flows, was critical in decreasing the high positive bias in the simulation. However, the volume of water from upstream basins still far exceeded the measured discharge of GDHT2. The USGS estimated streamflow from DLWT2 is particularly suspect.

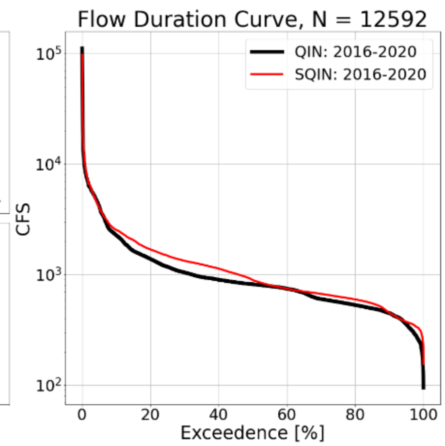
Statistical improvement was significant during the largest flood events (the highest 0.1% of flows, i.e. >30,000 CFS), with bias decreasing from an initial 130% to 7%. Overall KGE improved from 0.34 to 0.88, with a final correlation coefficient of 0.99, though final bias was quite high at 12.3% (routed flows from GNLT2 often exceeded QIN for GDHT2, suggestive of unknown surface water diversions in the basin).

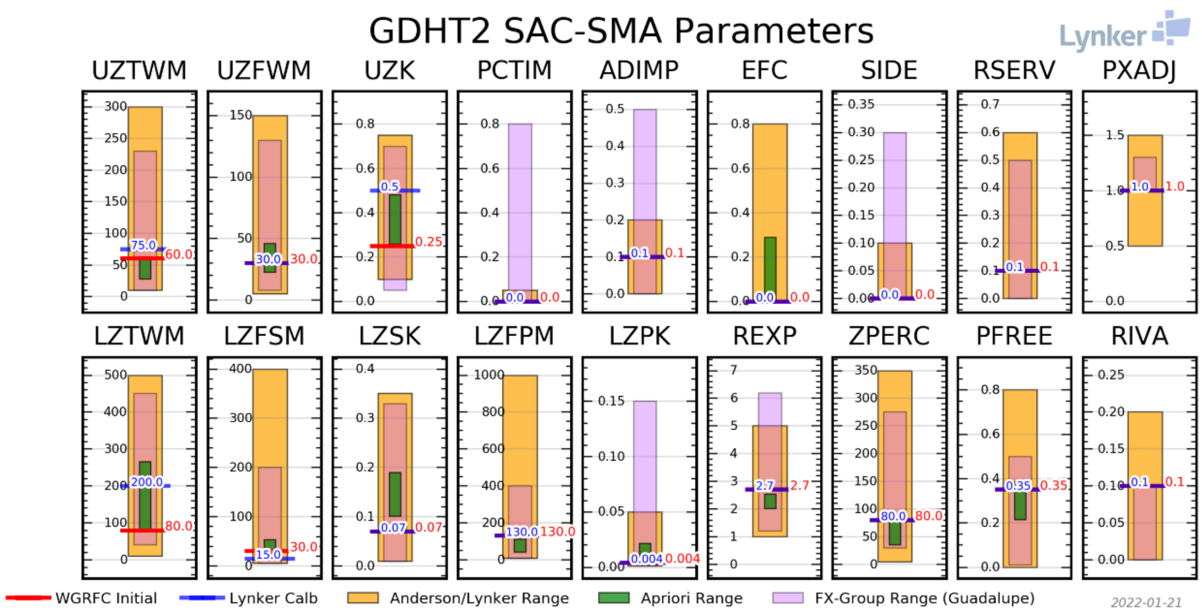
GDHT2: Guadalupe River at Hwy 183 near Hochheim, TX











WHOT2/WHOT2M/WHOT2U

Sandies Creek near Westhoff (WHOT2), Middle Sandies Creek near Westhoff (WHOT2M) and Upper Sandies Creek near Westhoff (WHOT2U) are headwater basins to the confluence of the Guadlupe River at Cuero. Simulations for WHOT2U were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08174970 (available from 2017-01-01 to 2019-04-23) and 08175000 (available from 1991-10-01 to present). USGS remarks note that there are no known regulation or diversions. The basins land use is predominantly shrub/scrub (39-50%) and hay/pasture (29-43%) with minimal development. Soil characteristics in the basins are more permeable mixture of sand/clay (29% Type A/25% Type C/38% Type D) in the upstream WHOT2U basin and trend to more clay-dominated downstream (77% Type D) in WHOT2M and (38% Type C/50% Type D) in WHOT2.

Statistical improvement was significant for WHOT2, with a decrease in the PBIAS from 34.6Z% to 8.5% during the period 2010–2020. The largest 0.1% of flows (>6,5000 CFS) where still over-simulated (Figure 4-44), but the PBIAS for these largest events decreased from 9.9% to 7.8%. WHOT2U, the other sub-basin where QIN data were available, also saw significant statistical improvement, though the streamflow records were much shorter (2017 to present). For example, initial PBIAS at WHOT2U was over 150%, improving to a still high but much improved 35%. Final KGE for WHOT2U was 0.62 (initially -1.16).

WGRFC feedback: *There is a timing issue in this basin. Water from the upper basin shows up at the outlet way too fast (faster than the middle and local basin) and there is too much runoff volume from the upper basin. We used a recent event from October 2021 as a validation exercise and the upper basin routing speed really causes an issue. This will inevitably lead to impacts in the lower basin, so parameters may need adjustment in those basins as well.*

This basin seems to be under forecasting peaks and volumes more than in the previous version. It appears we need to generate more surface runoff. Try a smaller UZTWM and lower the percolation rate. We also noted that ET may be too aggressive and may be drying the model out too fast.

Lynker response: We revisited the timing issues for WHOT2 and increased the lag for the upper basin routed flows and made some adjustments to the unit hydrographs. These changes seemed to help a few events but also made others not as good as they were previously. A couple of the events we looked at were August 22, 2016, May 2015 and 2016. Here are screen shots of the draft calibration results and after our adjustments for the August 2016 event.

We agree that the simulation under-predicts peaks and volumes at WHOT2. As requested, we decreased the UZTWM from 75 to 50 (initial value 40), and further lowered the percolation rate (ZPERC from 25 to 15; initial value 65). We also set PEADJ back to the initial value of 0.97, from 1.0 and dampened the ET Demand Curve further. Lastly, we also adjusted the parameters upstream at WHOT2U, favoring a higher bias. While each of these changes increased peak flow simulations, there are still Major Floods that are grossly underestimated, such as 11-21-2009 (simulation 5.7KCFS, observation 13KCFS). The timing of routed flows from WHOT2U are also inconsistently too early (e.g., 8/23/2016) but for most events, the LAG is well verified.

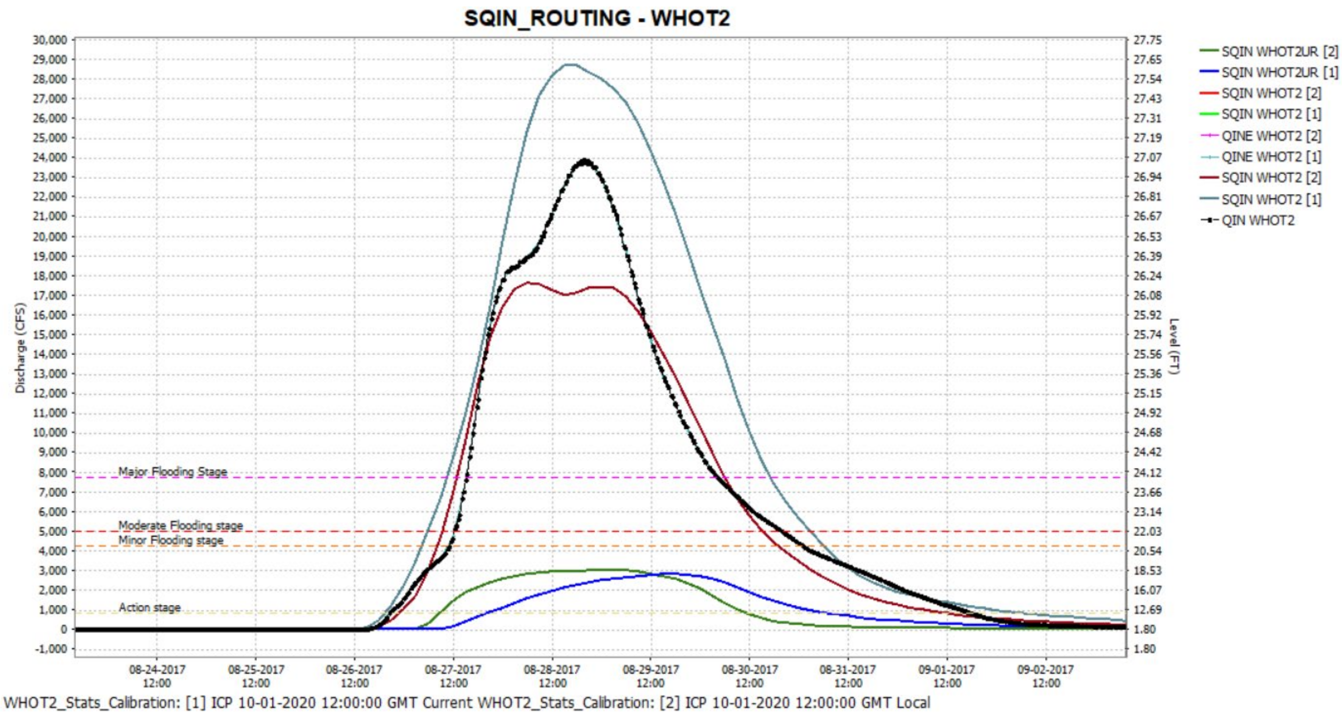
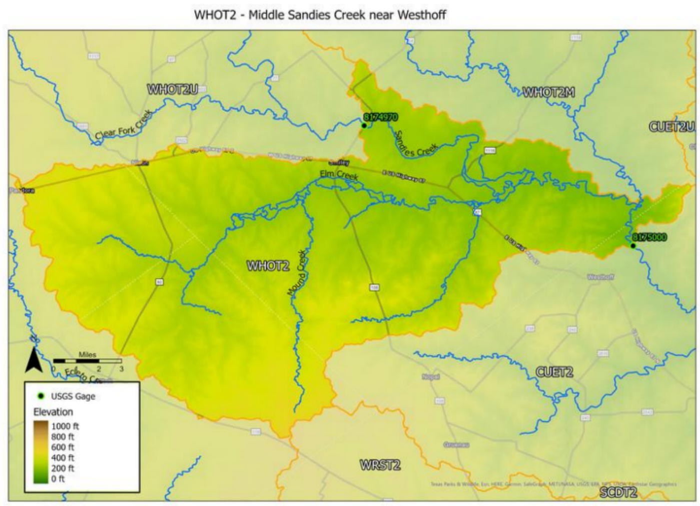
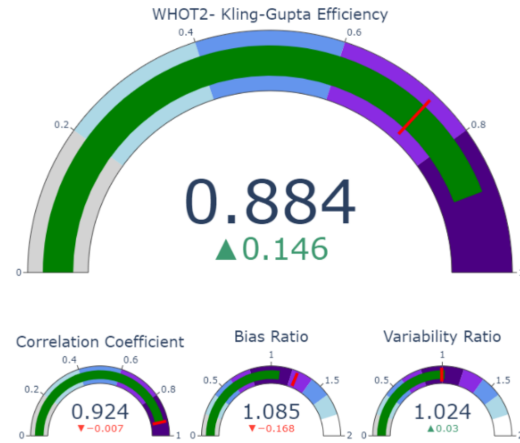
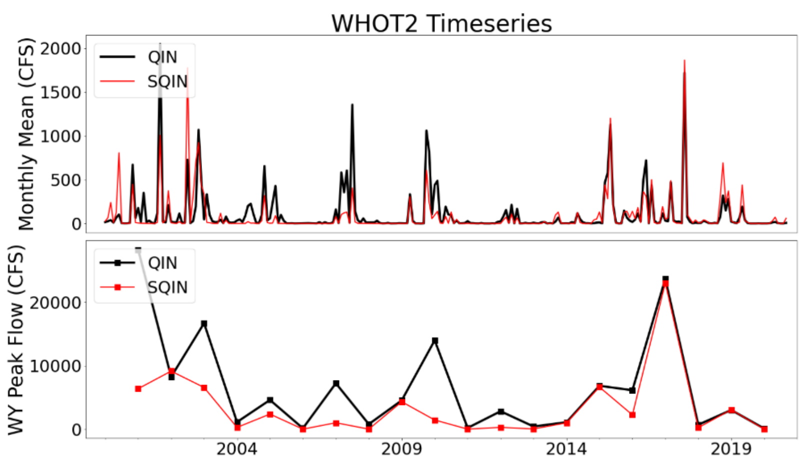


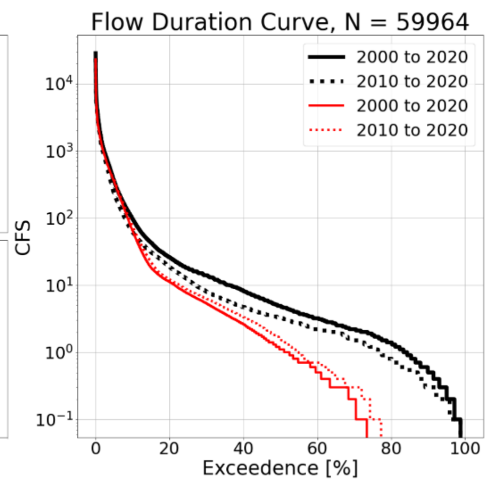
Figure 4-44: Improved calibration for WHOT2, with SQIN before (maroon) and after (grey). Guidance was received to favor over-simulations for peak flows in the challenging basins of the Guadalupe.

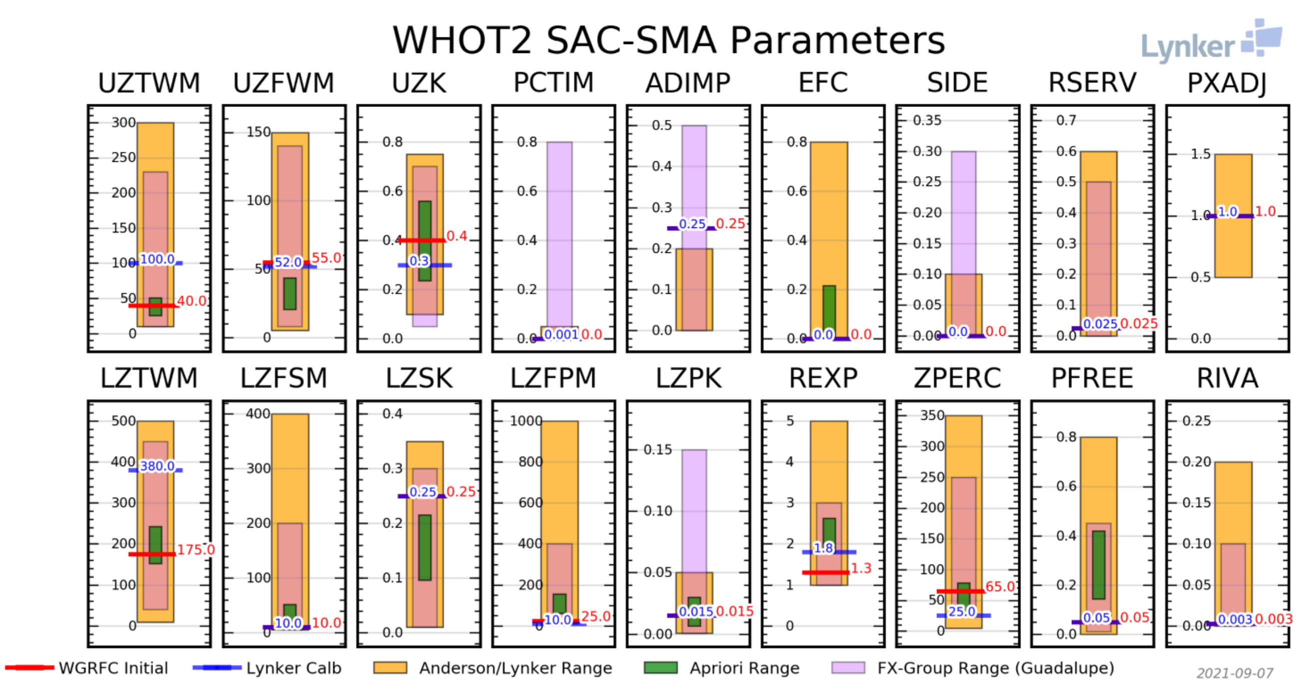
WHOT2: Sandies Creek near Westhoff











CUET2U/CUET2

Guadalupe River at Cuero (CUET2) and the Upper Guadalupe at Cuero (CUET2U) are two lumped local basins located downstream of WHOT2 and GDHT2 on the Middle Guadalupe, at the confluence of Sandies Creek and the mainstem. Simulations for CUET2/CUET2U were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08175800 (available from 1986-10-01 to present). USGS remarks note that at least 10% of the drainage area is regulated, with flow affected by discharge from 53 floodwater-retarding structures in the Comal, San Marcos, and Plum Creek basins. Additionally, many small diversions exist above the gauge. CUET2/CUET2U are mostly hay/pasture (48/51%) and are minimally developed (3/2%). Soil characteristics in the basin are more clay-dominated upstream at CUET2U (46% Type D/Clay Loam) while CUET2 is more permeable (32% Type A/Sand, 27% Type D/Clay Loam).

With an upper local catchment (CUET2U) and significant upstream routed flows from GDHT2R and WHOT2R, local flows from CUET2 are minimal. Calibration efforts focused on improving routed flow simulation through increased attenuation at lower flows, and decreased attenuation at higher flows. LAG was generally shifted earlier, though the UNIT-HGs were both shifted later by several timesteps (6-9 hours). Prior to 2016, routed flows from GDHT2 are SQIN, though the quality of observed streamflow data from GDHT2 is still an issue for the largest events (Figure 4-45).

Statistical improvement was modest for CUET2, with the greatest improvements to bias (decreased from 5% to 0.6% for 2010–2020; decreased from 6.3% to 3.4% in 2000–2020). The largest 0.1% of flows (>45,000 CFS) were still under-simulated by -22% (Figure 4-45), though the timing of these events did improve (correlation coefficient increased from 0.93 to 0.948 for 2010–2020).

WGRFC feedback: *Peaks still seem a little low at this forecast point. Is there anything that can be done to bring them up a little? Note: Known issue with this point - USGS has way too much flow for Harvey, so we did not consider the Harvey peak in our comments.*

Lynker response: We revisited CUET2/CUET2U and adjusted the attenuation for GDHT2R and WHOT2R to better simulate the peak flows. In our assessment, most events (outside of Harvey) are over-simulated, however we did favor this outcome over under-simulations in our re-calibration. Local runoff generation from CUET2 and CUET2U was also increased.

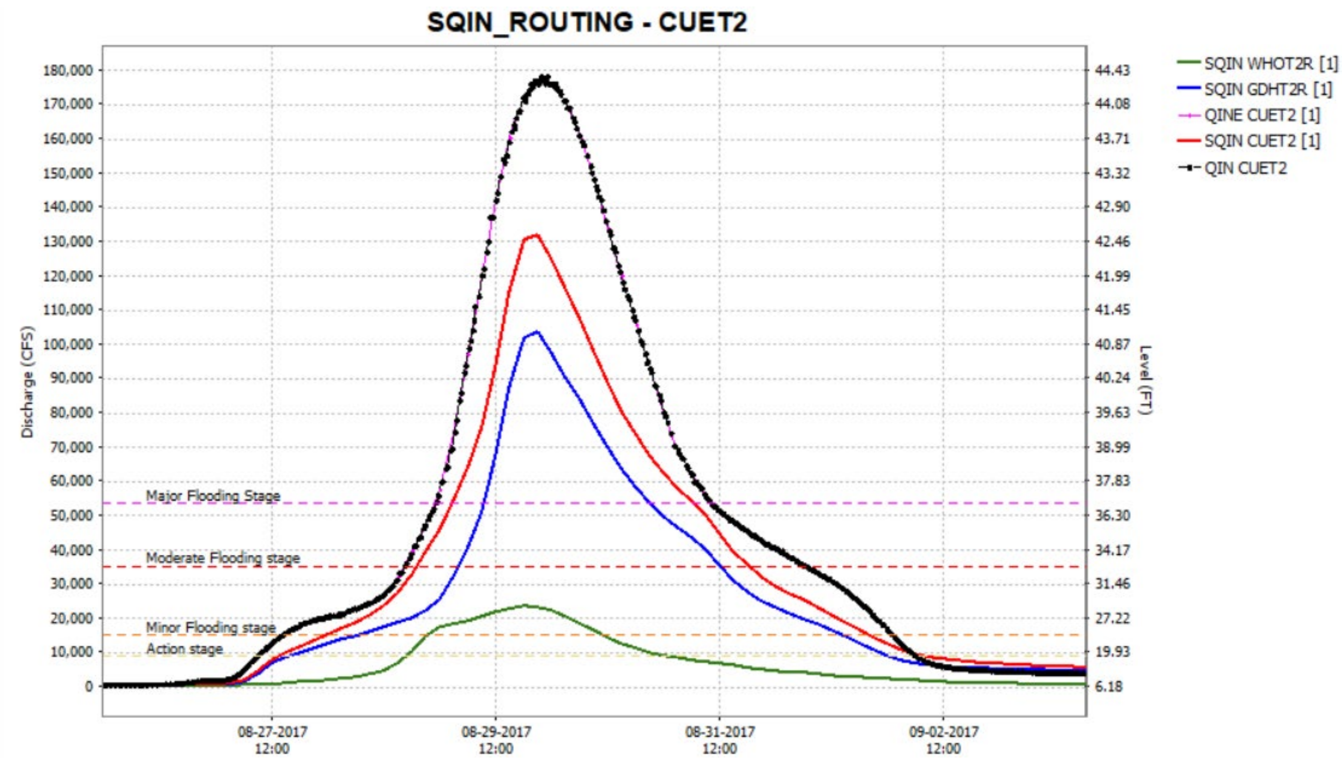
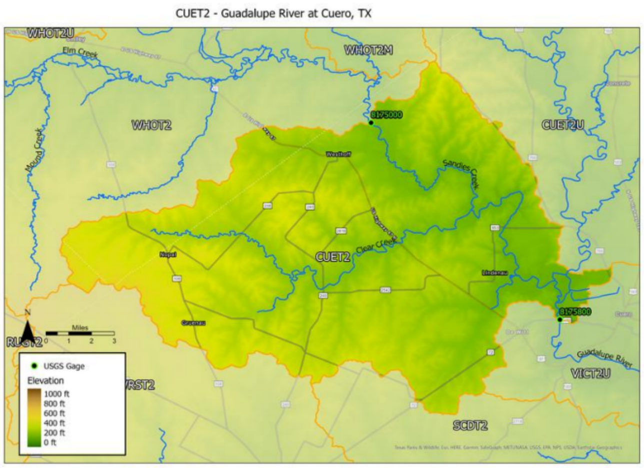
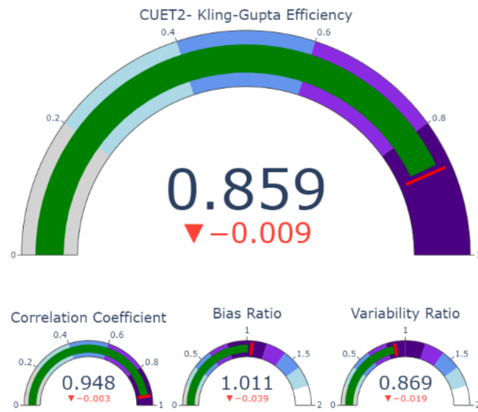
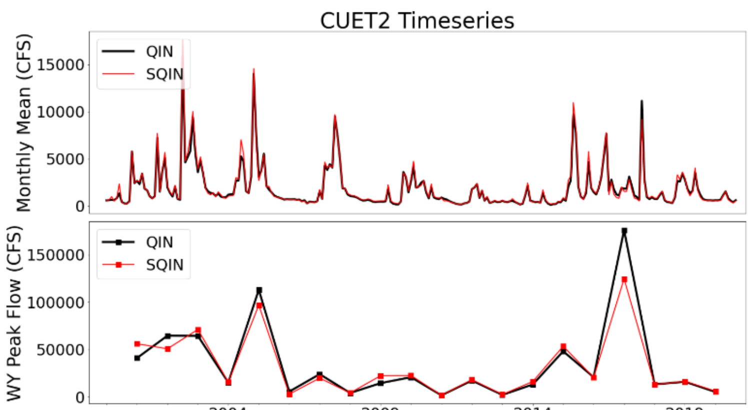


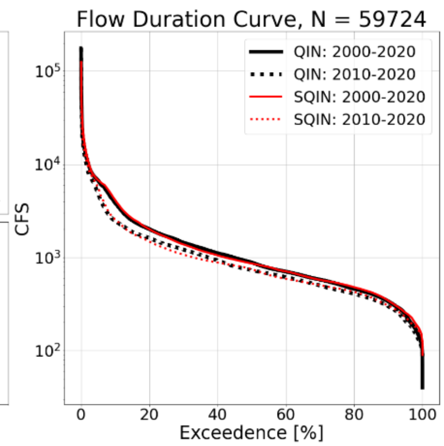
Figure 4-45: An example demonstrating how routed flows from GDHT2 QIN data (blue) are insufficient relative to CUET2 QIN (black).

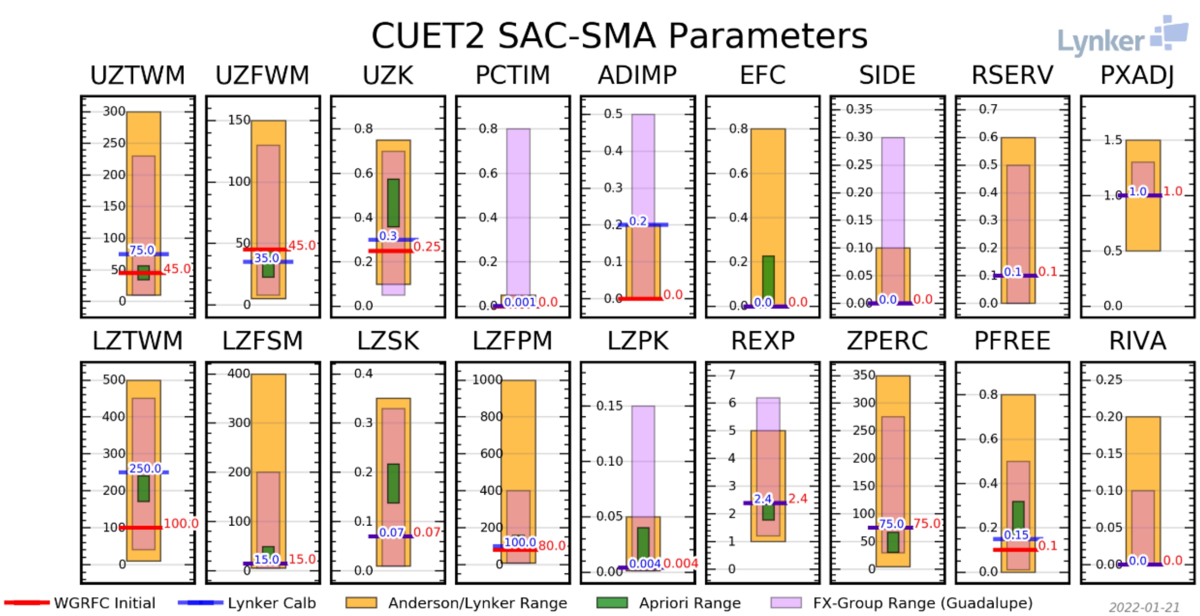
CUET2: Guadalupe River at Cuero, TX











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Lower Guadalupe HUC8

WRST2

Fifteenmile Creek near Weser, TX is a headwater basin for Coleto Creek. Simulations for WRST2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08176550 (available from 2009-09-29 to 2021-07-10). USGS remarks note that there are no known regulation or diversions. The basin land use is predominantly hay/pasture (58%) with minimal development. The soils in the basin range are an equal mixture ranging from sand to clay (~20% Types A, B, and D) with a slightly higher percentage (37% Type C) sandy clay loam.

The calibration of WRST2 was hindered by a lack of rating curve values for flows less than 1,000 CFS. The WRST2 routed flows at SCDT2 allowed for some calibration of parameters based on events dominated by WRST2 flows, though in the end, calibration at WRST2 was minimal, with most adjustments focused to the UZFWM, UZK, and percolation parameters. Without baseflows to calibrate to, it was difficult to finely tune percolation and lower zone parameters so that peak flows were more reasonably simulated. As an example, calibrations were able to decrease peak flows for the April 2015 event without decreasing the May 2015 event, though reasonable increases to the May 2015 event were never achieved (Figure 4-46). Because of poor calibration, and lack of QIN/QME data, statistics for WRST2 improved, but were still unimpressive.

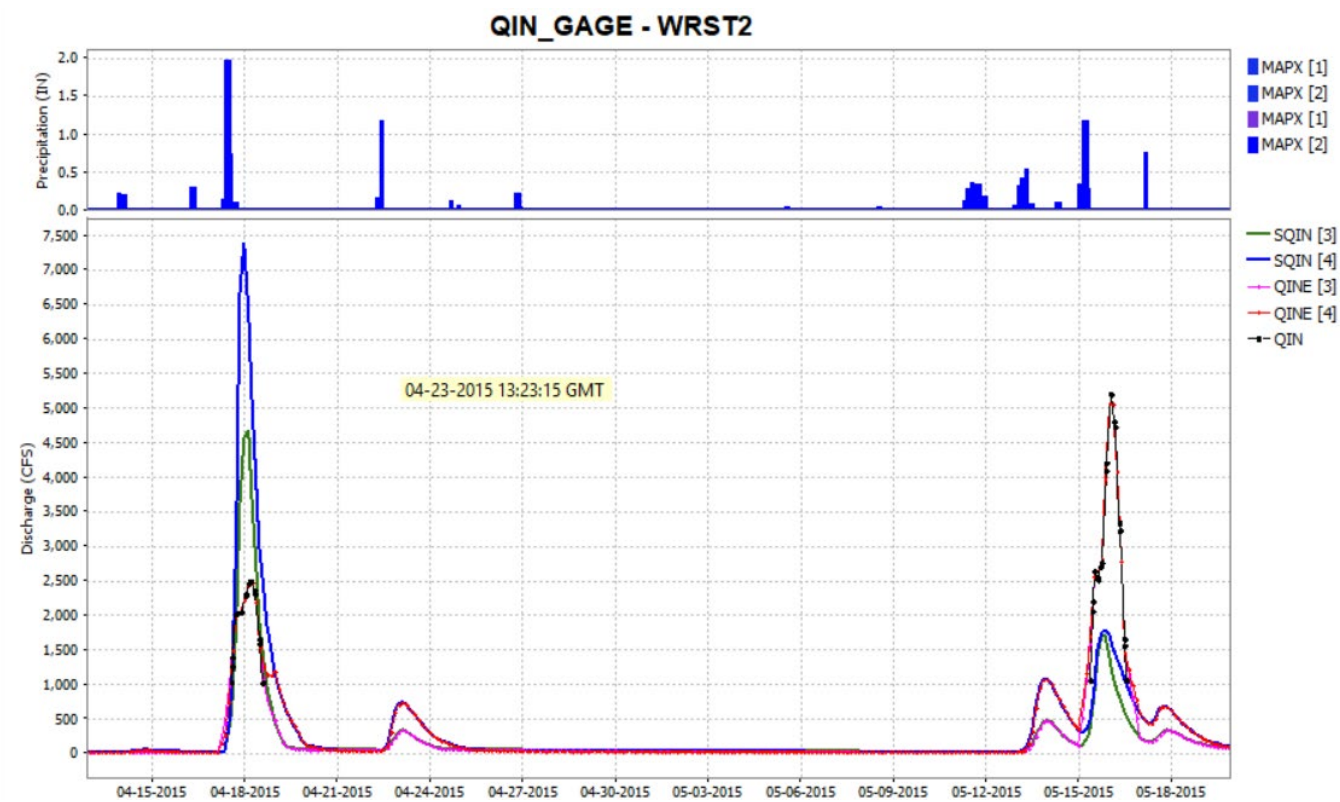
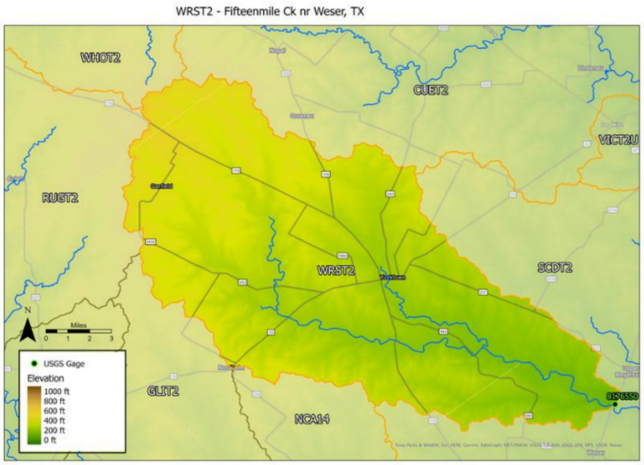
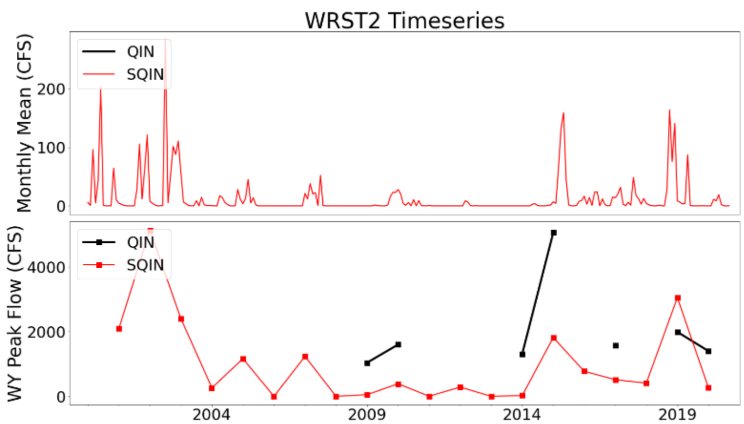
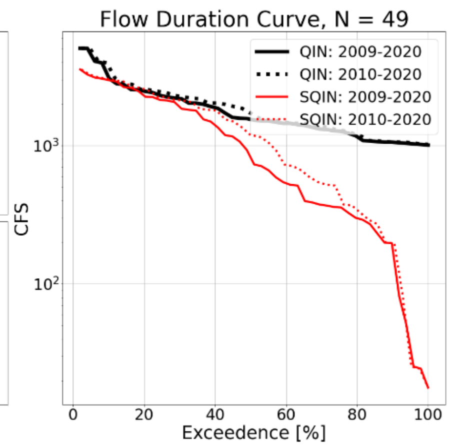


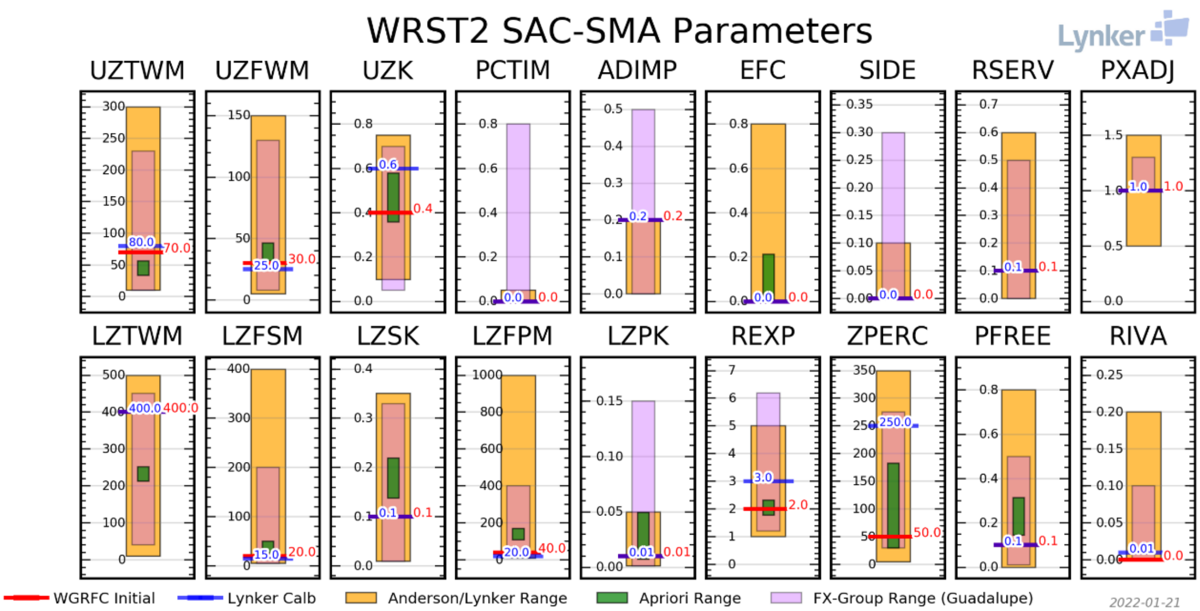
Figure 4-46: Improved calibration for WRST2, with SQIN before (blue) and after (green) calibration.

WRST2: Fifteenmile Creek near Weser, TX









SCDT2

Coleto Creek near Shroeder is a local basin downstream of WRST2. Simulations for SCDT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08176900 (available from 1991-10-01 to present). USGS remarks note that there are no known regulation or diversions. The basin land use is predominantly hay/pasture (53%) with minimal development. The soils in the basin are predominantly sandy clay loam (49% Type C) and 16-17% for each of Types A, B, and D.

Calibrations at SCDT2 were also used for calibrating the upstream hydrologic model at WRST2. Over-simulations for SCDT2 was initially significant (90% PBIAS, 2010–2020) however increased UZTWM and ZPERC and decreased UZK parameter values, along with small increases in the attenuation of routed flows, were able to decrease model bias to 1.3%. Peak flows during the 2000–2010 period were significantly under-simulated. Significant improvements were made for the April 2015 flood (Figure 4-47).

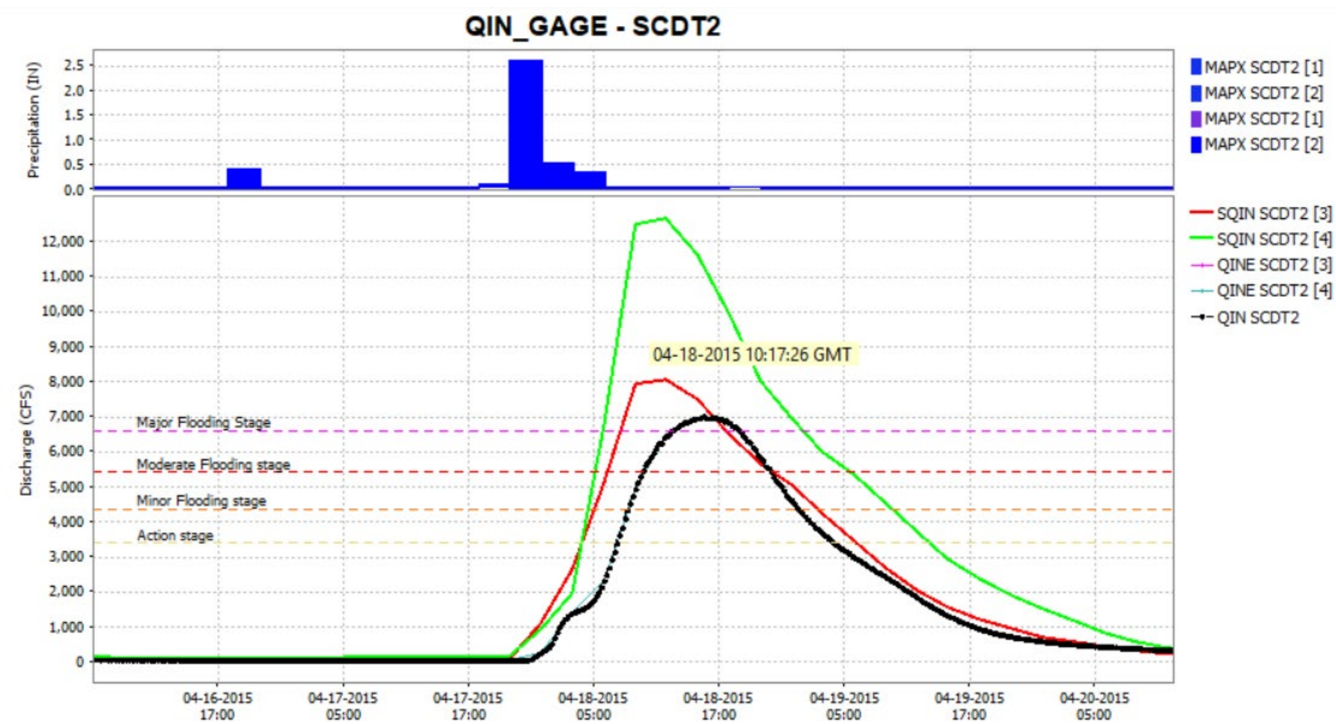
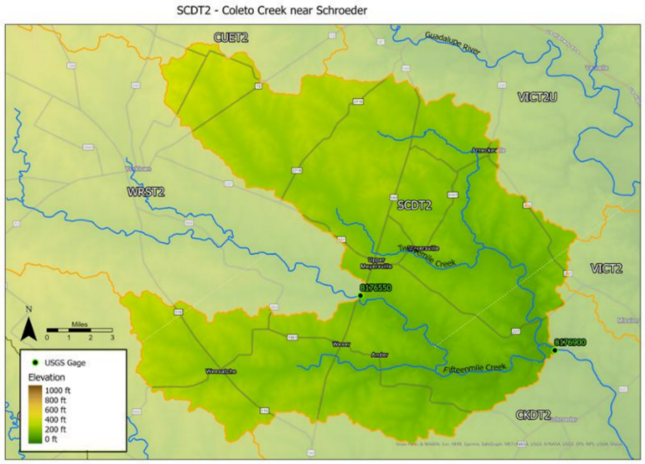
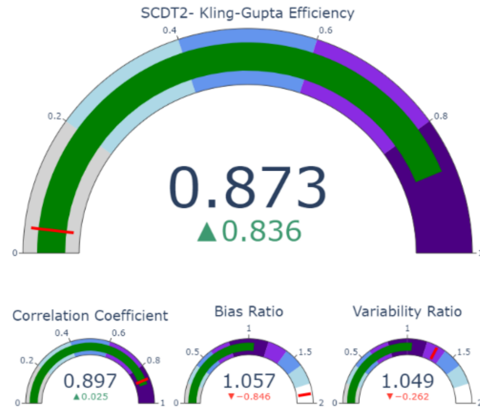
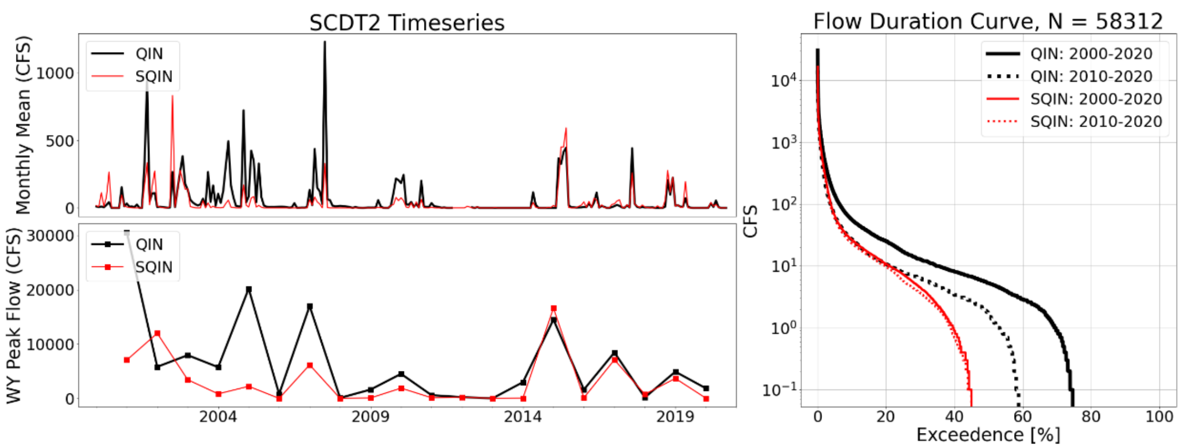


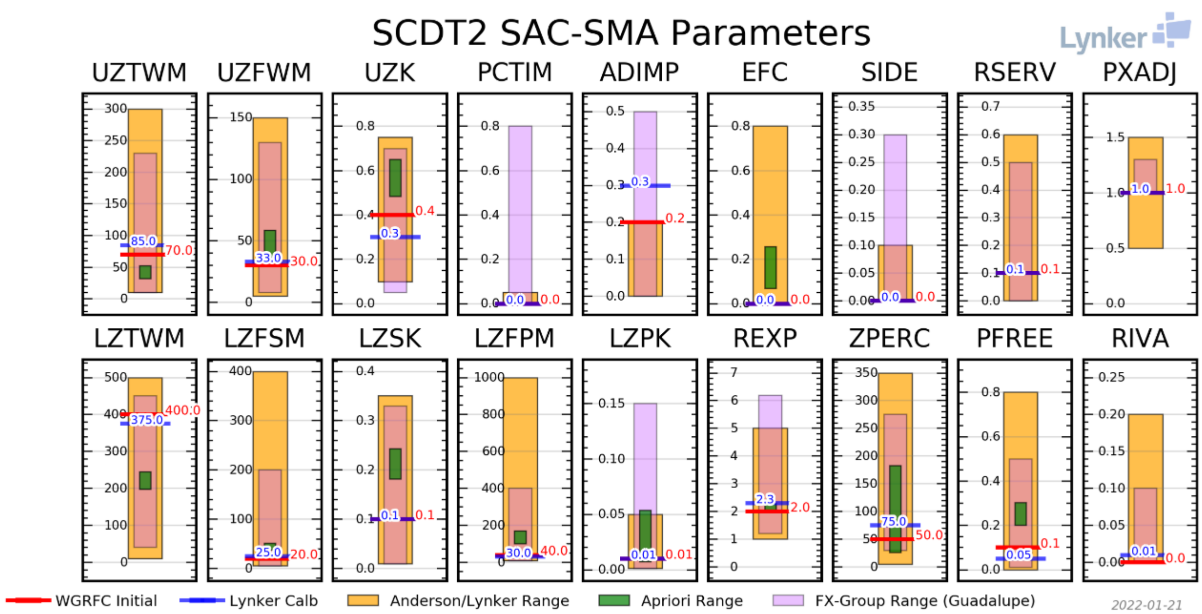
Figure 4-47: Improved calibration for SCDT2, with SQIN before (lime green) and after (red) calibration.

SCDT2: Coleto Creek near Schroeder









CKDT2

Coleto Creek Reservoir is a headwater basin that flows into Coleto Creek Reservoir, owned and operated by Guadalupe-Blanco River Authority to provide a power station cooling pond for electric power generation and recreation purposes. Simulations for CKDT2 were run at a 3-hourly timestep, calibrated to daily inflow data calculated from reservoir pool elevation data from the USGS gauge 08177400 (available from 10/1999 to present). The Guadalupe-Blanco River Authority provided supplementary instantaneous reservoir outflow data for three storm events (May 2010, June 2015, and August 2017), which were combined with the USGS data to make a complete outflow dataset. Soil characteristics in the basin are clay-dominated, with 72% Type D/ clay loam soil. The land use is predominantly hay/pasture at 45%.

Calibrations focused on increasing flashiness of the model simulation through adjustments to the UNIT-HG, decreased lag and attenuation, decreased UZFWM, and increased ADIMP/UZK, among other changes (Figure 4-48).

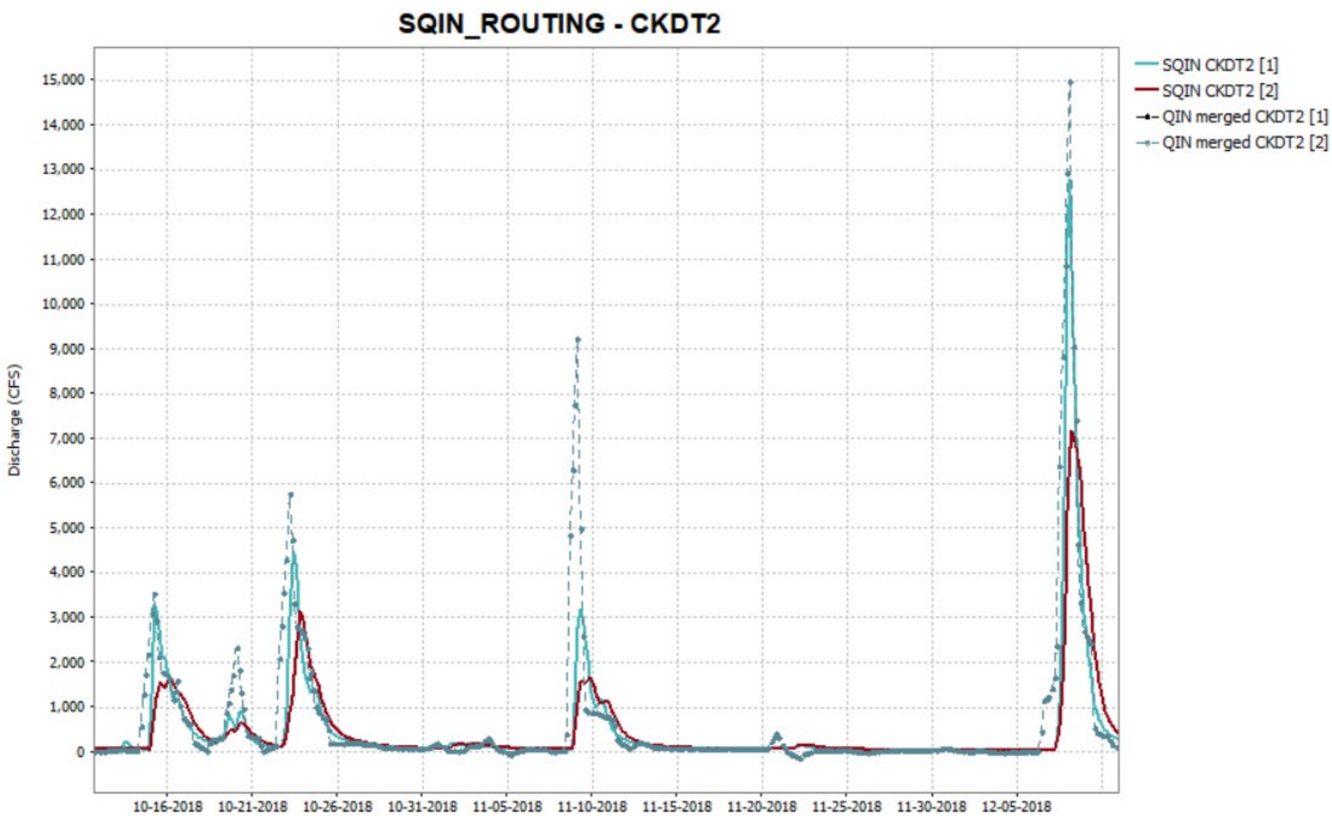
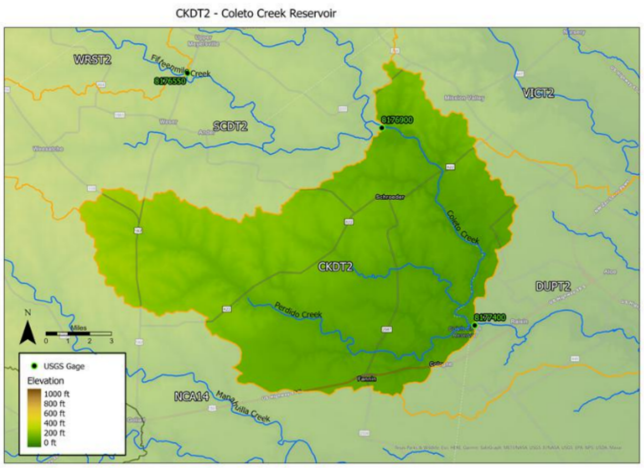
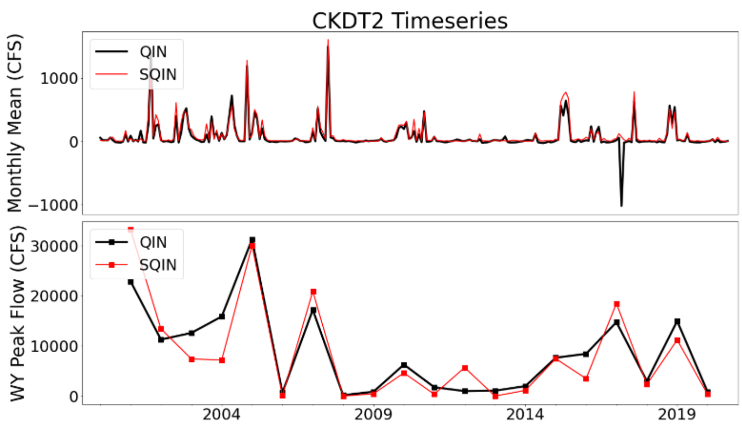
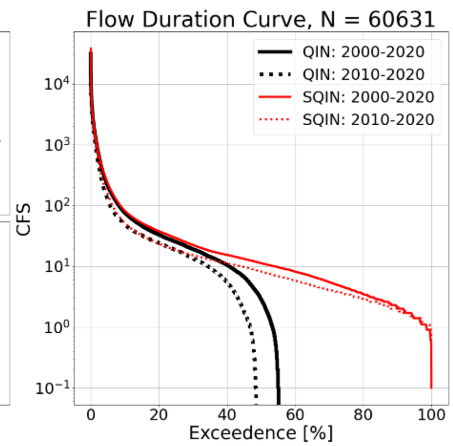


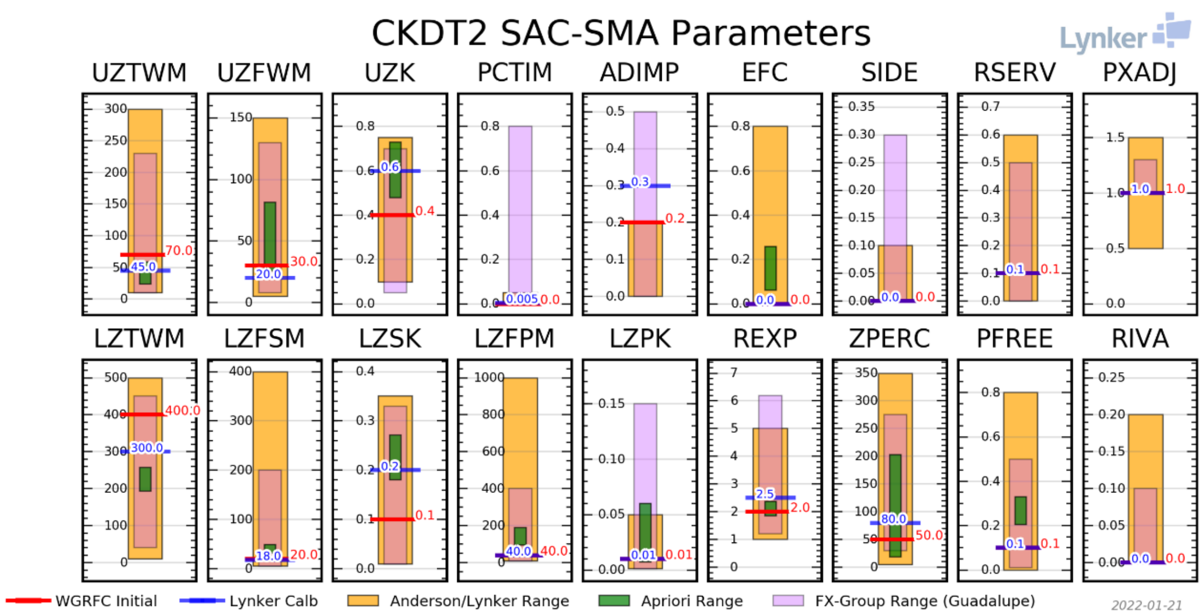
Figure 4-48: Improved calibration for CKDT2, with SQIN before (brown-red) and after (light blue) calibration.

CKDT2: Coleto Creek Reservoir









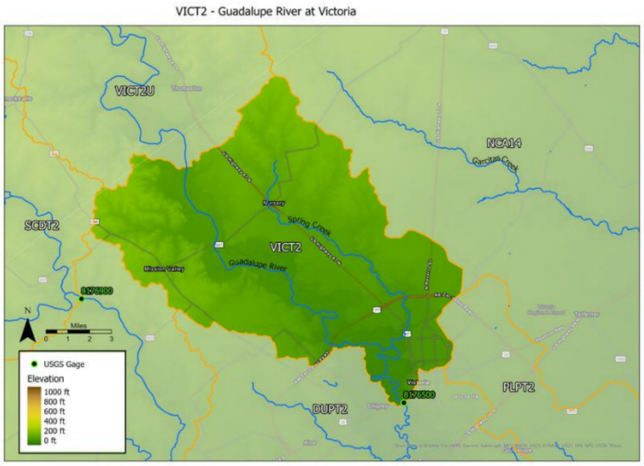
VICT2/VICT2U

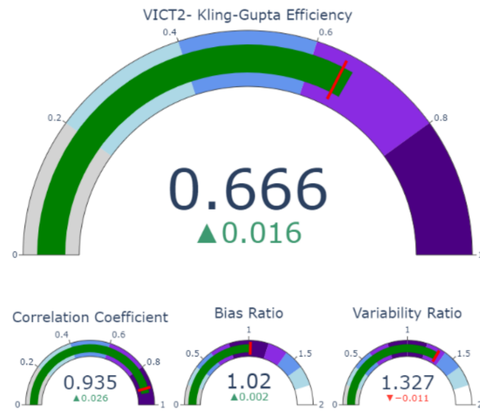
Guadalupe River at Victoria (VICT2) and the Upper Guadalupe River at Victoria (VICT2U) are two lumped local basins located downstream of CUET2 on the Lower Guadalupe. Simulations for VICT2/VICT2U were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08176500 (available from 1986-10-01 to present). No USGS records are available at VICT2U. USGS remarks note that there are many diversions and regulations upstream. Additionally, USGS reports that the City of Victoria releases wastewater effluent into the river, though perhaps below the station. VICT2/VICT2U are mostly hay/pasture (56/41%) and forest (13/37%) with a coarser soil profile at VICT2U (48% Type A/Sand) and more clay at VICT2 (37% Type D/Clay Loam).

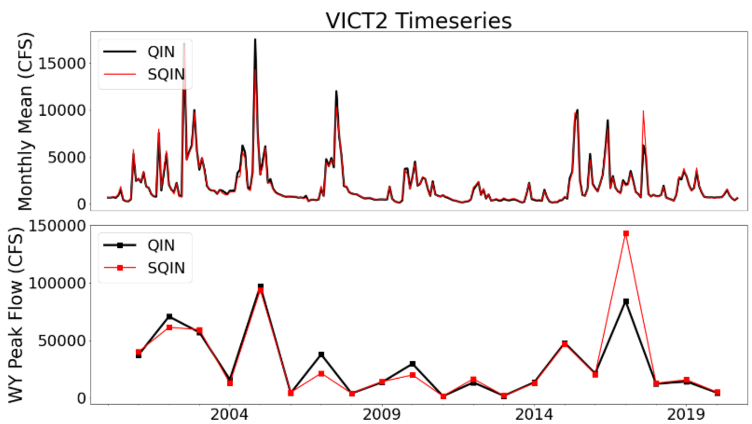
Local flows at VICT2/VICT2U are minimal relative to upstream routed flows for CUET2. Calibration efforts focused on adjusting the LAG/K model parameters to delay and slightly attenuate routed flows from their initial parameter values. Significant attention was given to the Memorial Day 2015 flood and Hurricane Harvey, although disagreements between CUET2 and VICT2 QIN data during Harvey limited calibration improvements. For example, even after attenuation, routed peak flows from CUET2 during Harvey were 145,000 CFS, whereas VICT2 peak flows were only 84,000 CFS. Efforts were made to balance improvement of simulation timing for Harvey, while still providing good simulations for other major (November 2004, May 2015 etc.) and moderate flood events. The calibrated UNIT-HG is using a constant baseflow parameter of 5 CFS for VICT2 and 5 CFS for VICT2U.

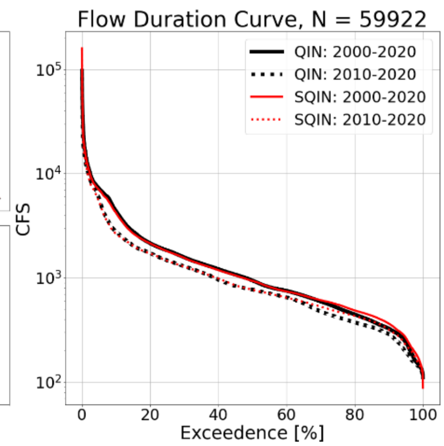
Statistical improvements were small, but bias decreased, for example, from 4.4% to 2% for 2010–2020, and the correlation coefficient increased to 0.95 from 0.92. Correlation coefficient also improved notably for the greatest 0.1% of flows (>44,000 CFS) from 0.63 to 0.82, indicating improved timing of simulation, however the high bias from the CUET2 routed flows during Harvey was still over 50%.

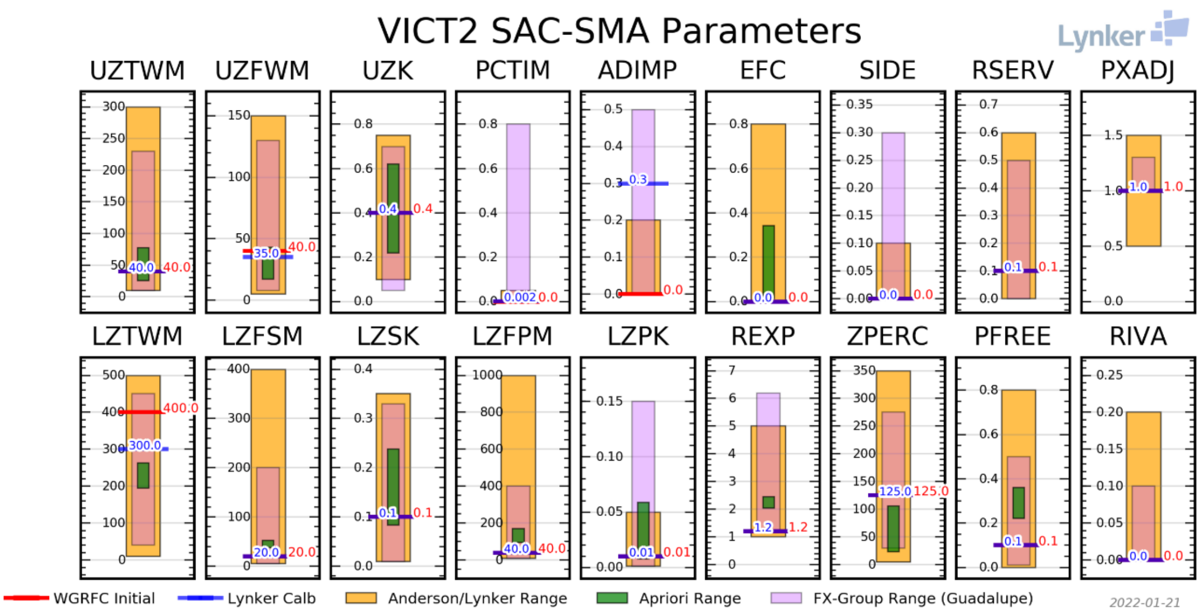
VICT2: Guadalupe River at Victoria











DUPT2

Guadalupe River at du Pont Plant near Bloomington (DUPT2) is a local basin located downstream of VICT2 and CKDT2 on the Lower Guadalupe. Simulations for DUPT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08177520 (available from 2011-10-01 to present. USGS remarks note that there are many diversions and regulations upstream, and that records are only of fair quality. DUPT2 is mostly hay/pasture (43%) and is heavily developed (9%) and a clay-dominated soil classification (56% Type D/Clay Loam).

Local flows at DUPT2 are minimal relative to upstream routed flows for VICT2. Calibration efforts focused on adjusting the LAG/K model parameters to increase the attenuation of routed flows from their initial parameter values, although because flows above 4,660 CFS are missing from the record, default parameters were left in place for higher flow bins. Note that the peak simulated flows for the period 2011–2020 (timeseries, next page) are higher than the SQIN timeseries suggest. This is because in the WY Peak Flow timeseries are identified using the QIN record, if there are any QIN data for that water year. The calibrated UNIT-HG has a constant baseflow of 5 CFS.

Statistical improvements were small, but bias decreased, for example, from 1.6% to 0.1%. Baseflows were over-simulated, largely because during the warm season, VICT2 routed flows were greater than DUPT2 QIN data, though calibrating decreased bias in the first quartile of flows (<400 CFS) from 12.3% to 9%.

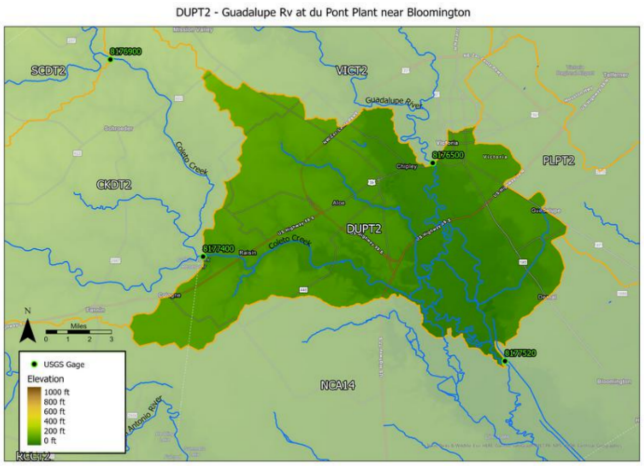
WGRFC feedback: *The report stated that only low flows were used below 4,600 cfs. We have a decent synthetic rating for this location that can be used for the high flows. The SAC-SMA parameters are too high and probably realistic at this location (ex: UZTWM = 200) Lag/K routing also needs some improvement. Please take another look at this one using the WGRFC rating. Andrew dropped the rating into the shared folder for your use.*

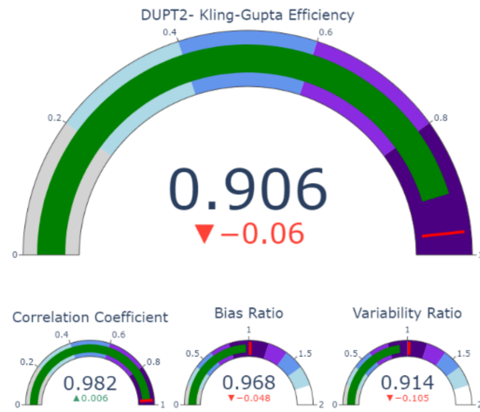
Specific link to the rating which is in data_from_wgrfc/CHPS

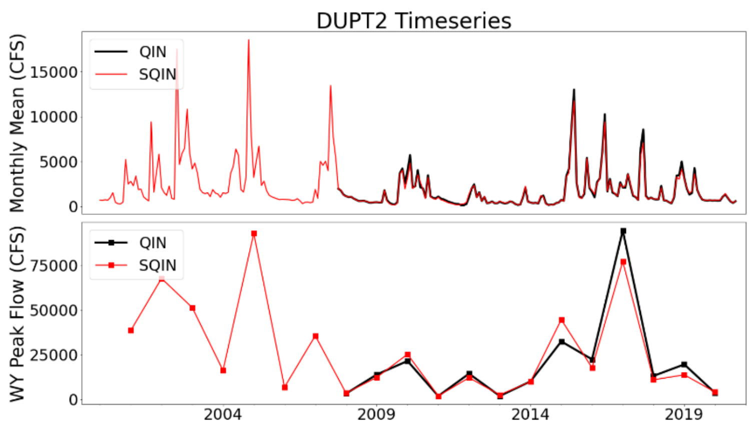
https://drive.google.com/file/d/1x83kfRsS1Bwxc6nx5vGVsNQVa1VHNLDR/view?usp=sharing

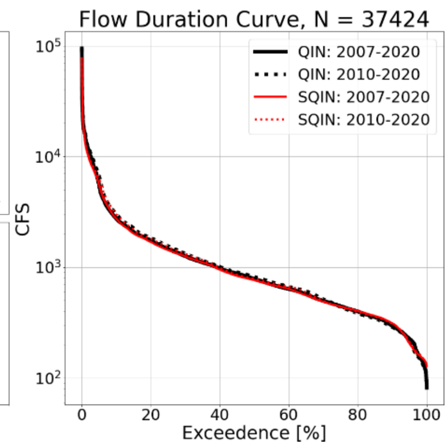
Lynker response: Missing USGS flow data were supplemented with stage data for flows greater than 4,600 CFS. Following this update, we performed a re-calibration of this site to ensure adequate simulation of peak flow timing and magnitudes. We imported the new rating curve for DUPT2 and decreased the lag for high flow range. Even though the flow volumes are often times too high (e.g., May 31, 2015) or too low (e.g., Hurricane Harvey), the changes did improve the timing by ~ 3 hours.

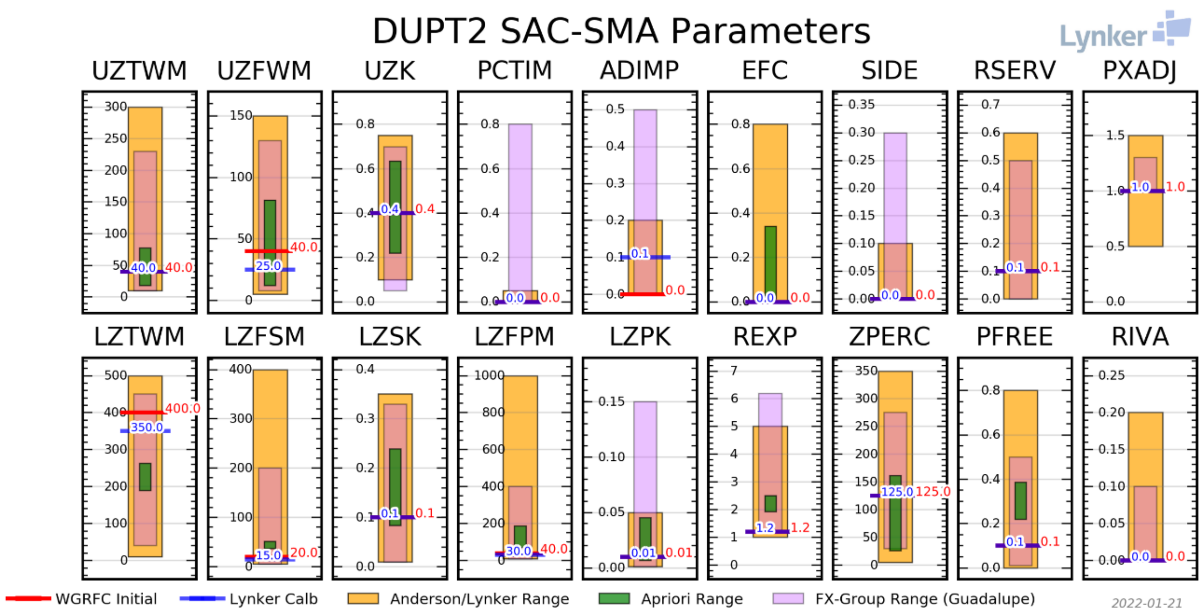
DUPT2: Guadalupe River at du Pont Plant near Bloomington











4.1.3. Funding Dependent Calibration Summary – Brazos & Colorado

4.1.3.1. Little HUC6

Leon HUC8

LLET2

Leon Reservoir near Ranger is a headwater basin that flows into Lake Leon. Simulations for LLET2 were run at a 6-hourly timestep, calibrated to calculated daily inflow data from a mass balance analysis (inflows available from 2014-05-01 to present). Lake Leon is primarily used as a water supply reservoir, owned by the Eastland County Water Supply District (ECWSD), and operated as a fill and spill reservoir. The mass balance analysis used to calculate inflow data was limited to the period beginning in 2014 due to the availability of daily drinking water release data; other components include NOAA TR33/34 evaporation estimates, MAPX precipitation data, and reservoir storage, pool elevation (USGS 08099000), and surface area data from ECWSD/HDR. Land cover for LLET2 is primarily shrub/scrub (45.4%) and herbaceous (26.3%); 2.3% of the basin is developed. Soil types are primarily Type C/Sandy Clay Loam (58.1%).

Availability of daily inflow data guided model calibration efforts to the larger events most concentrated during the period 2015–2016. Initial simulations generally under-simulated peak flows. Adjustments to the UZTWM, UZFWM, LZTWM, and ET Demand Curve were most effective in increasing these peak flows (Figure 4-49), though simulations still under-predicted more moderate events during a wet-up period. Low flow calibrations were limited due to unreliable inflow data as evidenced by negative baseflow values.

Final statistical improvement for LLET2 was moderate with a KGE score improving from 0.67 to 0.745, though the largest 0.1% of events (>5,170 CFS) were still significantly under-predicted; initial bias for this highest flow range was -57.3%, calibrated bias was -38.6%. The 3,000 CFS event in April 2016 (Figure 4-49) is an example where the initial simulation (red) greatly under-simulated peak flows, while the calibrated simulation (blue) slightly under-simulated peak flows. Because inflows are calculated from a mass balance analysis, peak flow magnitudes should be evaluated with caution.

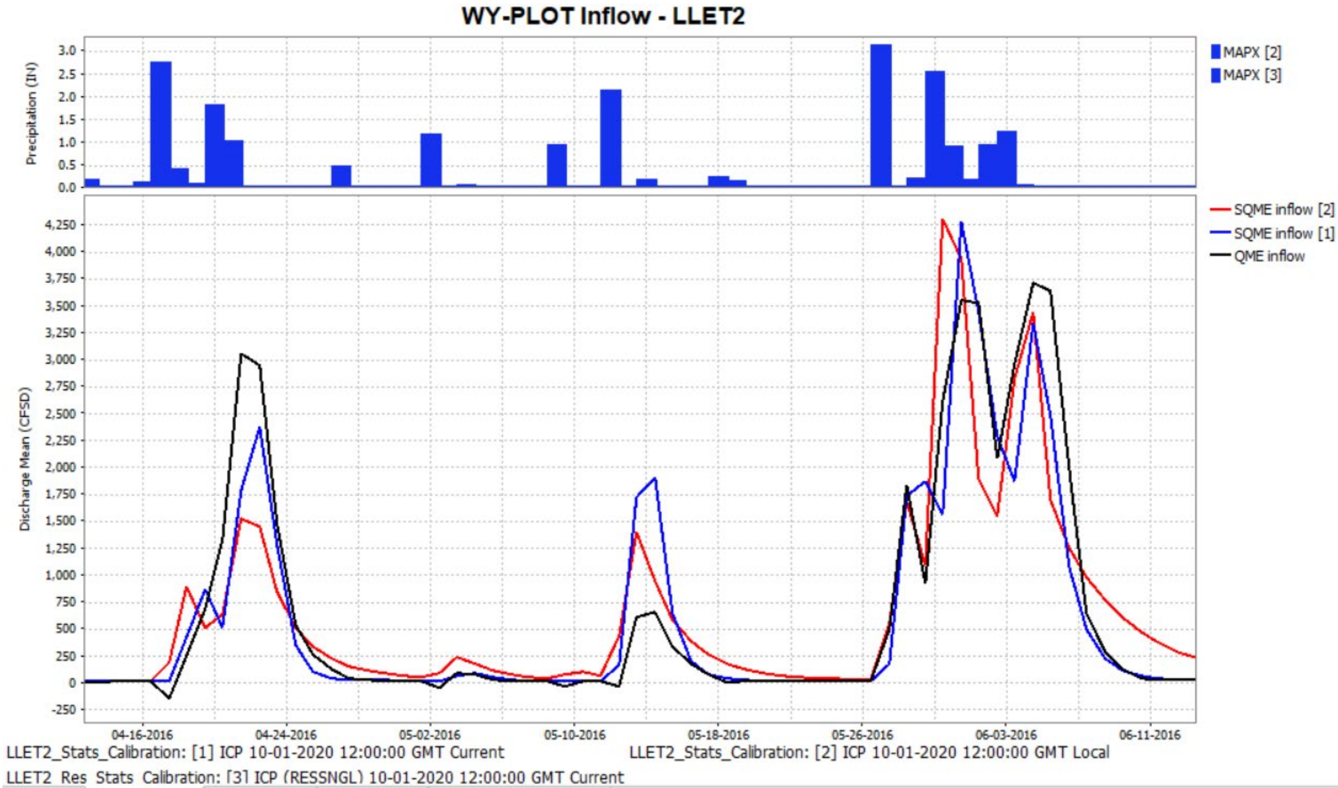
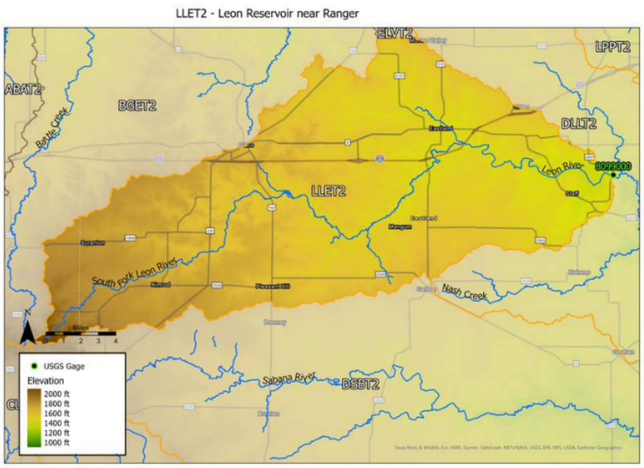
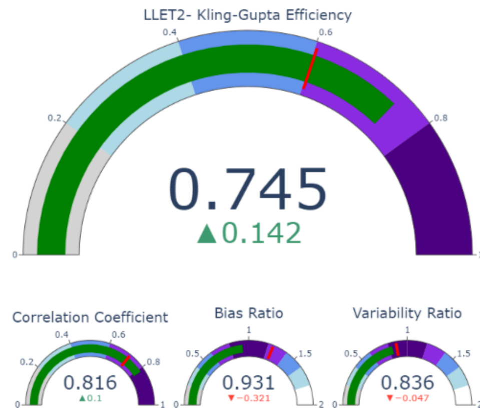
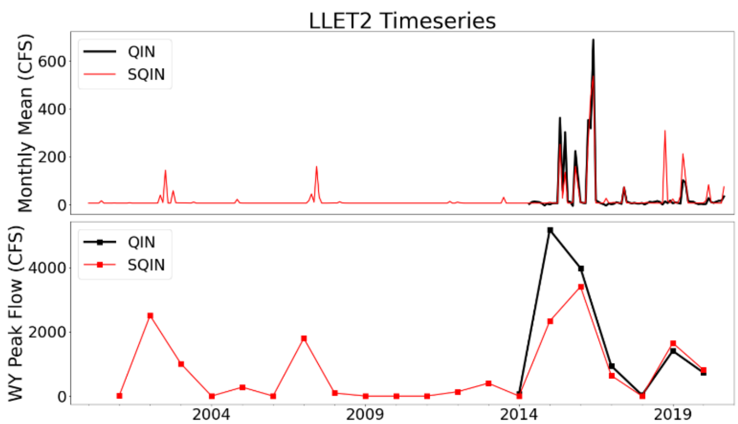


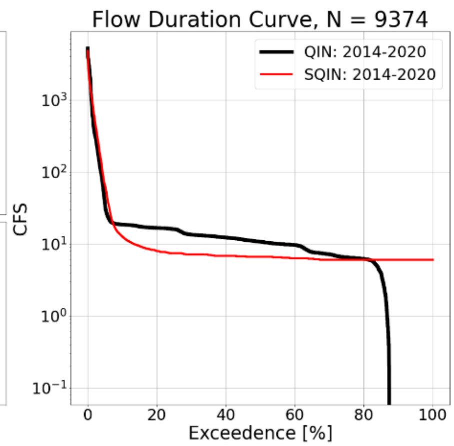
Figure 4-49: Improved calibration for LLET2, with SQME before (red) and after (blue) calibration.

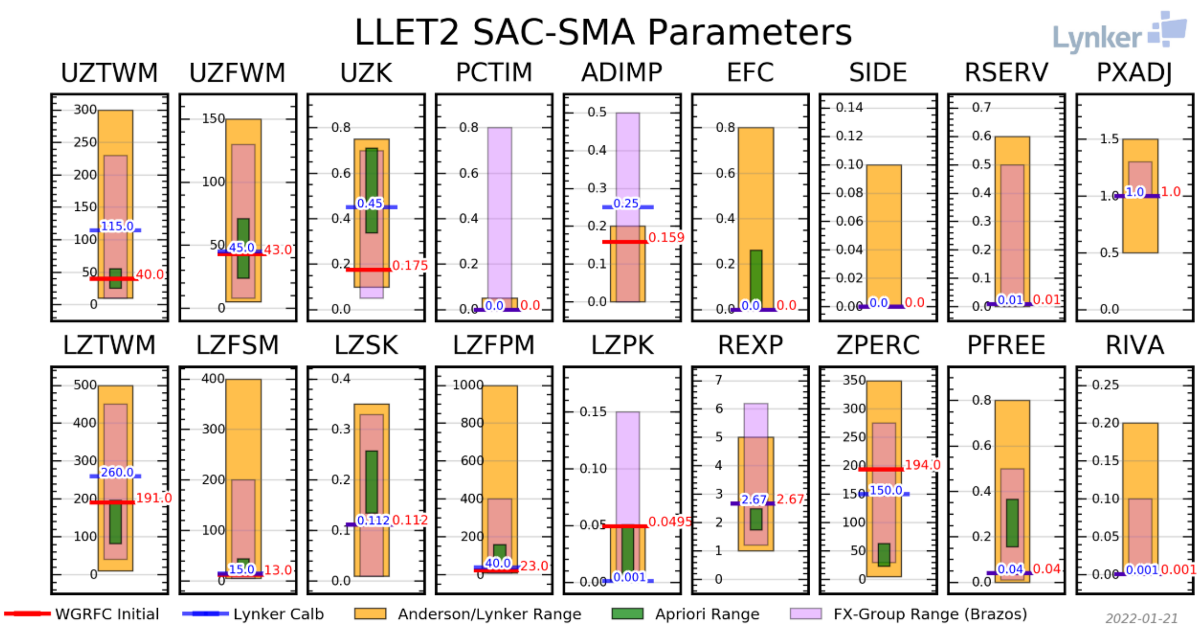
LLET2: Leon Reservoir near Ranger











CPKT2

Copperas Creek is a headwater basin near Comanche, Texas. Simulations for CPKT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08099382 (available from 2015-04-02 to present). USGS remarks note that surface water diversions for farm and ranch use may occur upstream of then gauge. Land cover for CPKT2 is primarily shrub/scrub (32.9%) and herbaceous (28.0%) with little development; soil characteristics are mostly Type C/Sandy Clay Loam (45.4%) and Type A/Sand (22.4%).

Initial simulations for CPKT2 performed poorly (KGE 0.17) primarily due to a strong positive bias (76.6%) driven by excessive storm runoff, especially during times of the year with low or no flows. Increases to the UZTWM, LZTWM, and ZPERC corrected this behavior; PEADJ values were increased slightly, though the monthly ET Demand curve was dampened. Despite significant increases to the tension water parameters, it was challenging to dampen the hydrograph response of a very wet October 2018, which followed a prolonged dry period, without significantly under-simulating earlier large events such as July 2015.

Final statistical improvement for CPKT2 was significant, with KGE increasing from 0.17 to 0.846. While overall PBIAS was very low (-0.9%, initially 76.6%), the largest 0.1% of flows (> 6,100 CFS) were still under-simulated by 20%, though this was a significant improvement over the initial PBIAS of -38.9% for this flow range.

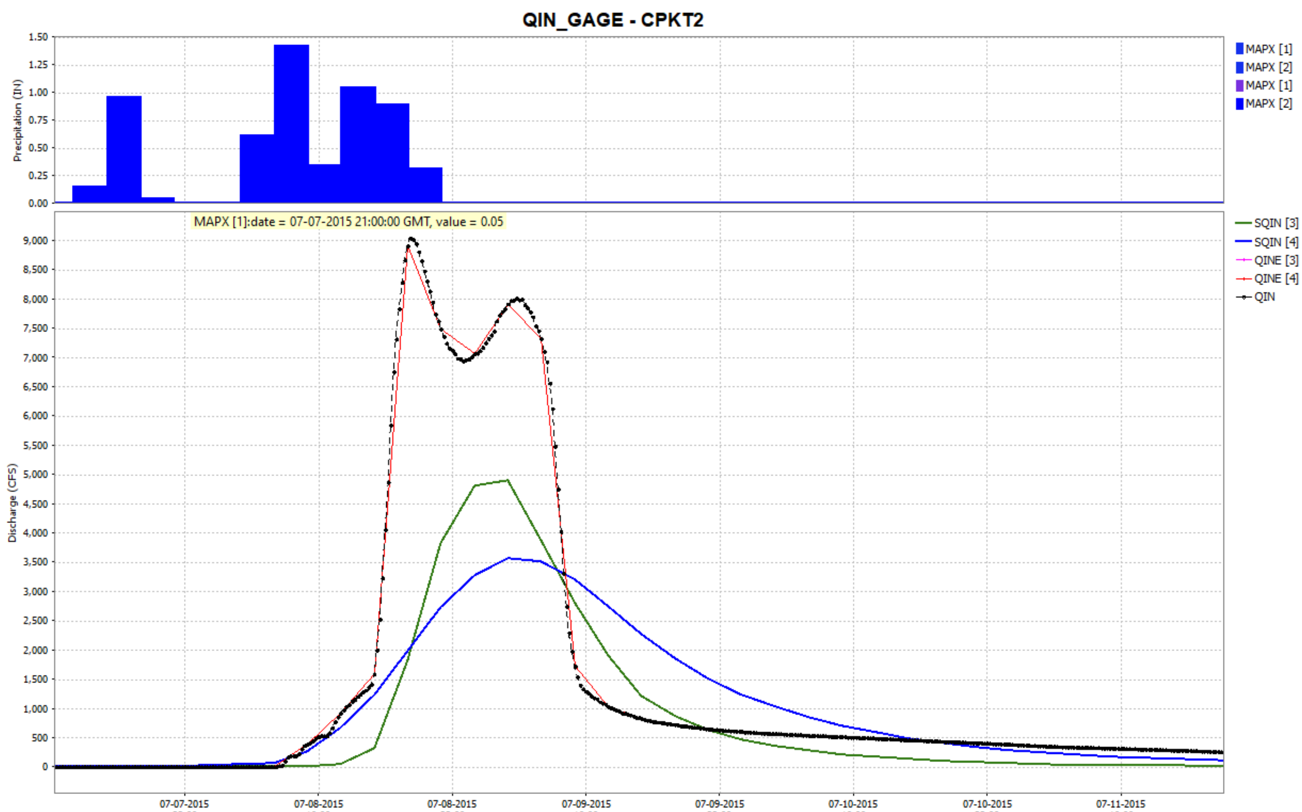
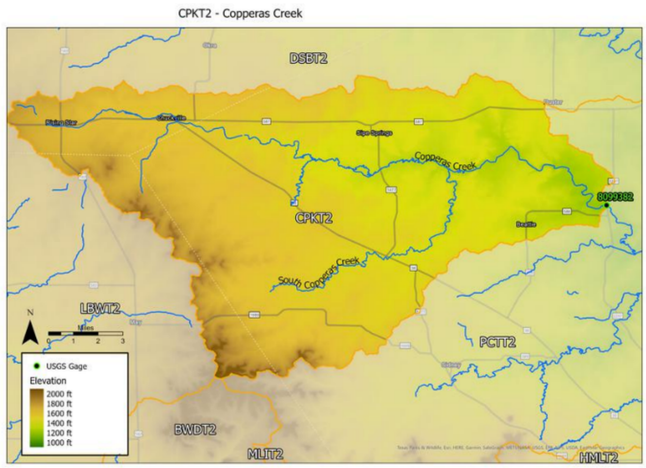
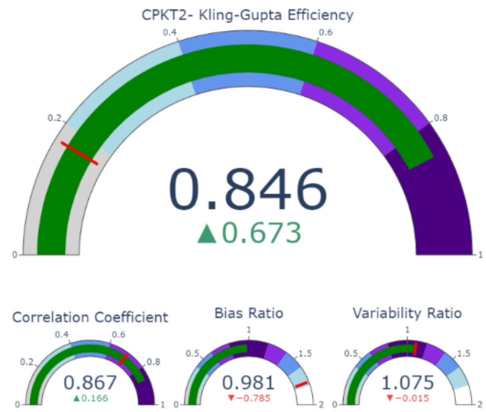
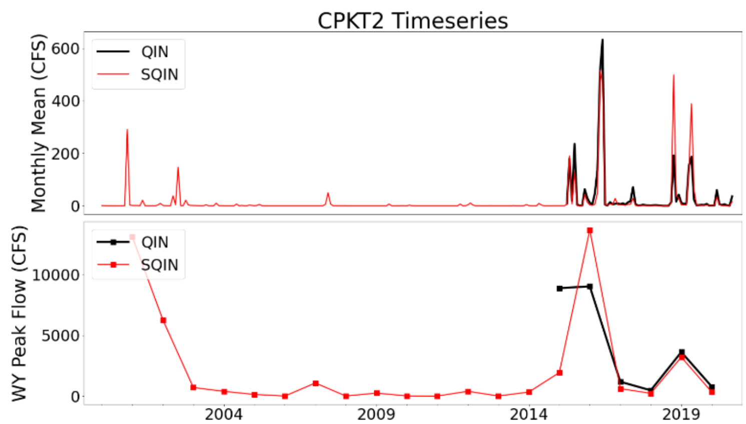


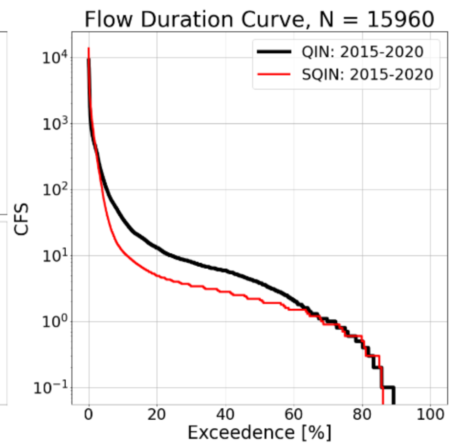
Figure 4-50: Improved calibration for CPKT2, with SQIN before (blue) and after (green) calibration.

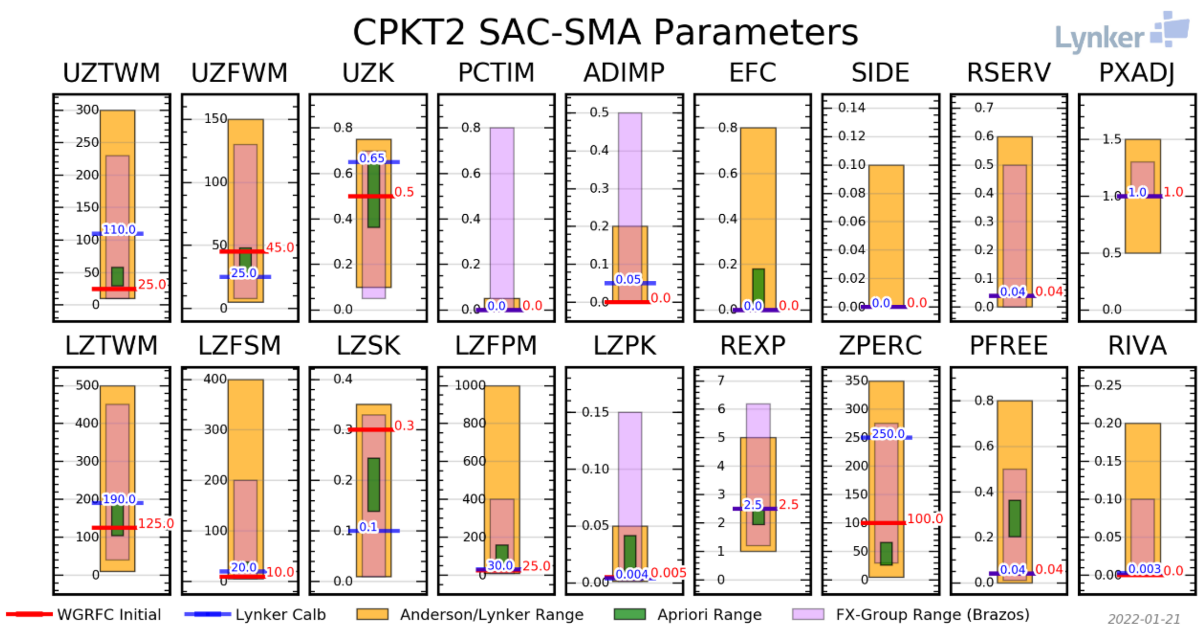
CPKT2: Copperas Creek











DSBT2

Sabana River near De Leon is a headwater basin of the Upper Little. Simulations for DSBT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08099300 (available from 1995-05-06 to present). USGS remarks that flows may be affected by Nabors Lake, upstream of Spring Branch. Land cover for DSBT2 is primarily shrub/scrub (34.0%) and herbaceous (26.4%) with little development; soil characteristics are mostly Type C/Sandy Clay Loam (47.3%) and Type A/Sand (20.8%).

Like other nearby headwater basins, DSBT2 is an intermittent stream, with little (<1 CFS) to no flow approximately 50% of the year. Initial simulations generated runoff too frequently, as indicated by the high initial bias (82.7% for the period 2010–2020). Significant adjustments to the tension water parameters decreased final overall bias to -1.6% for the period 2010–2020, although biases were too low for the full record. Significant improvements were also made to peak flow simulations (green line, Figure 4-51).

Final statistical improvement for DSBT2 was significant, with KGE increasing from 0.13 to 0.859 for the period 2010–2020. The series of late May to early June 2016 events were the largest on record and showed good improvement in the simulation of the peak magnitudes and timing. Smaller, flashier events were challenging for the simulation to capture, so greater emphasis was placed on the larger flood events.

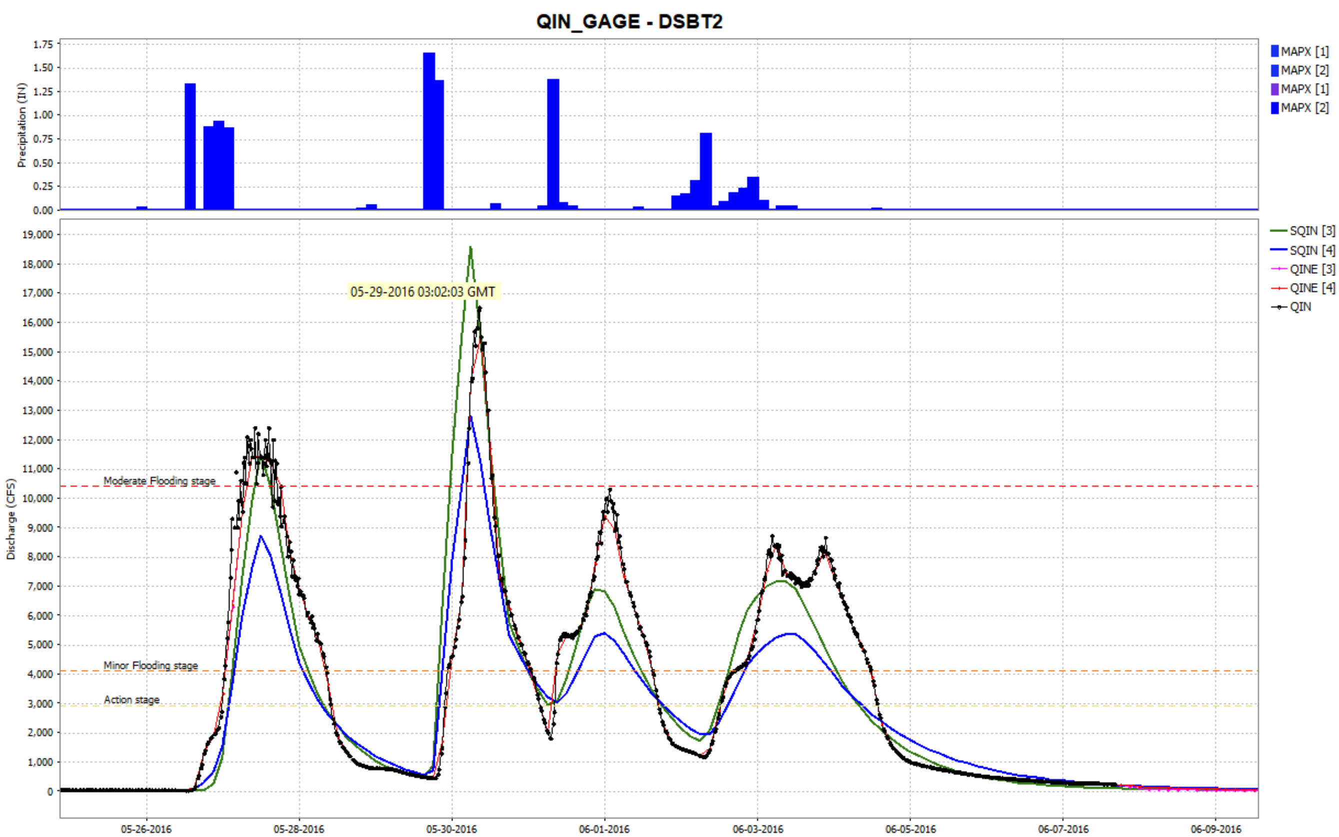
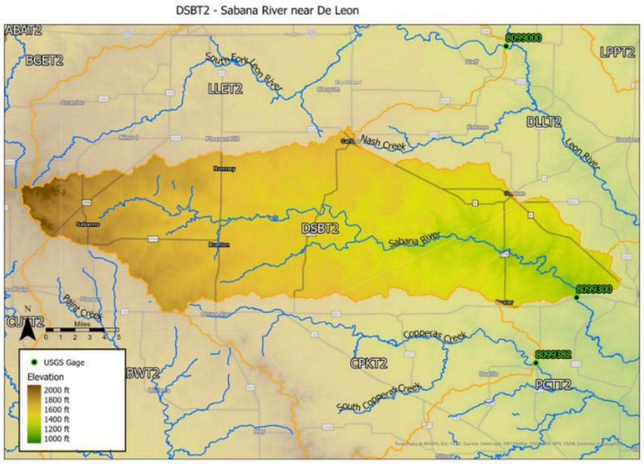
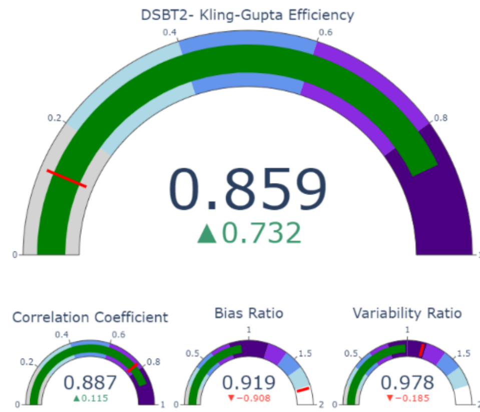
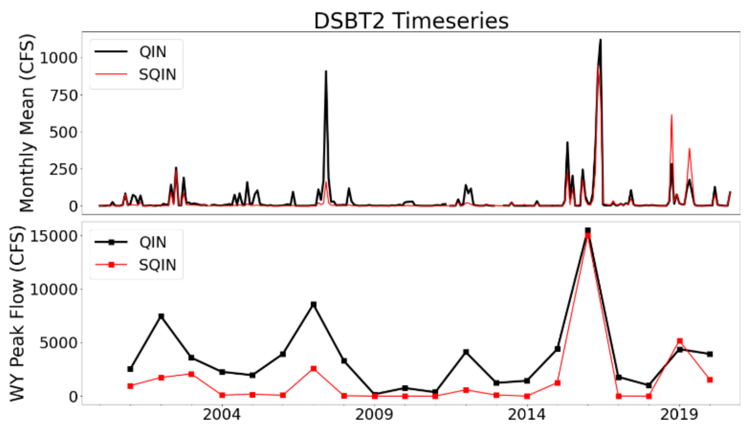


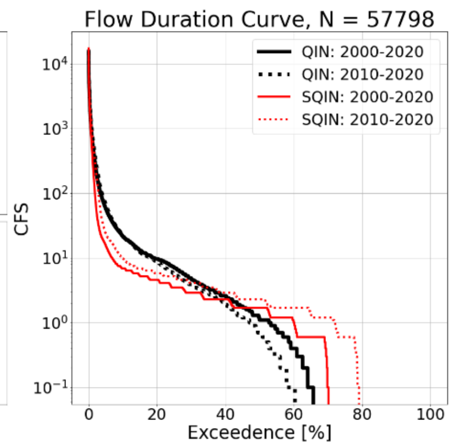
Figure 4-51: Improved calibration for DSBT2, with SQIN before (blue) and after (green) calibration.

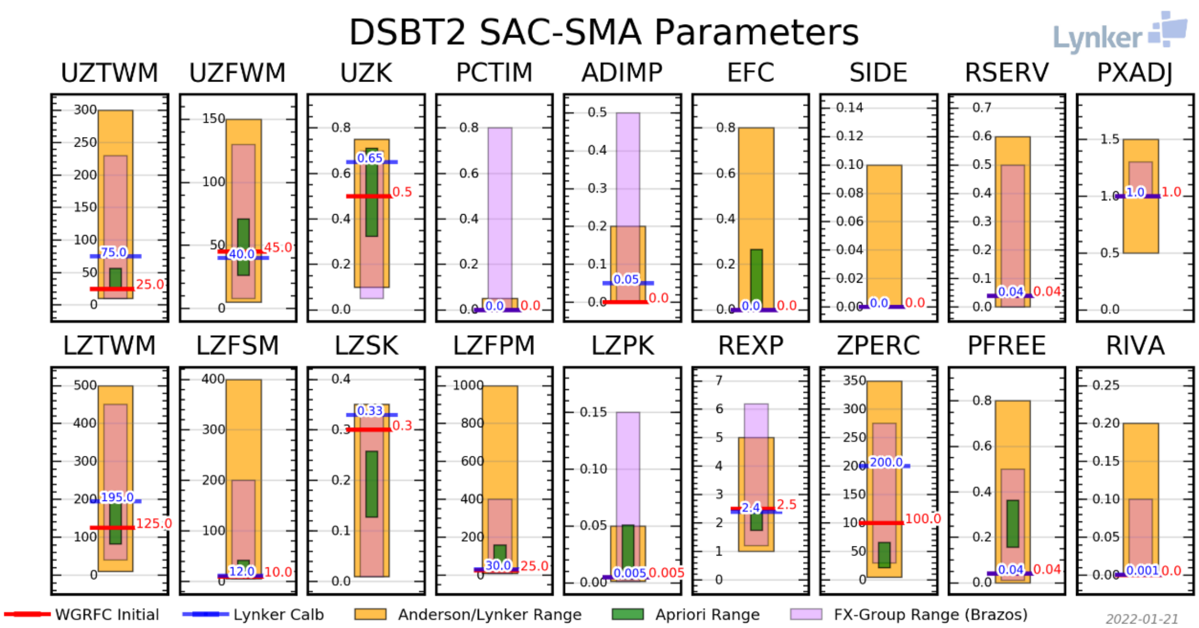
DSBT2: Sabana River near De Leon











DLLT2

Leon River near De Leon is a local basin located downstream of Lake Leon and just upstream of Proctor Lake, including the Nash Creek tributary. Simulations for DLLT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS 08099100 (available from 2007-10-01 to present). USGS remarks note that there are numerous diversions for municipal, steam power plant operations, and other uses that exceed 10% of the contributing drainage area. Land cover for DLLT2 is primarily shrub/scrub (34.1%) and herbaceous (28.9%), and soil classes are dominated by Type C/Sand Clay Loam (57.4%).

DLLT2 is also an intermittent stream, with annual peak flows generally below 5,000 CFS (exceptions in 2015/2016), and flows dropping below 1 CFS approximately 50% of the time. Initial simulations were biased low (bias -25%), particularly during baseflow conditions. Calibrations focused on adjusting the timing of runoff (green line, Figure 4-52), while also increasing UZK and ADIMP parameters. As is illustrated by the May 2016 series of rainfall events, it was difficult to verify peak flow magnitudes while also simulating enough recharge to dampen the second of the three sharp runoff peaks. Missing data for this event, one of only several Moderate floods, added greater uncertainty to model calibrations for high flow events.

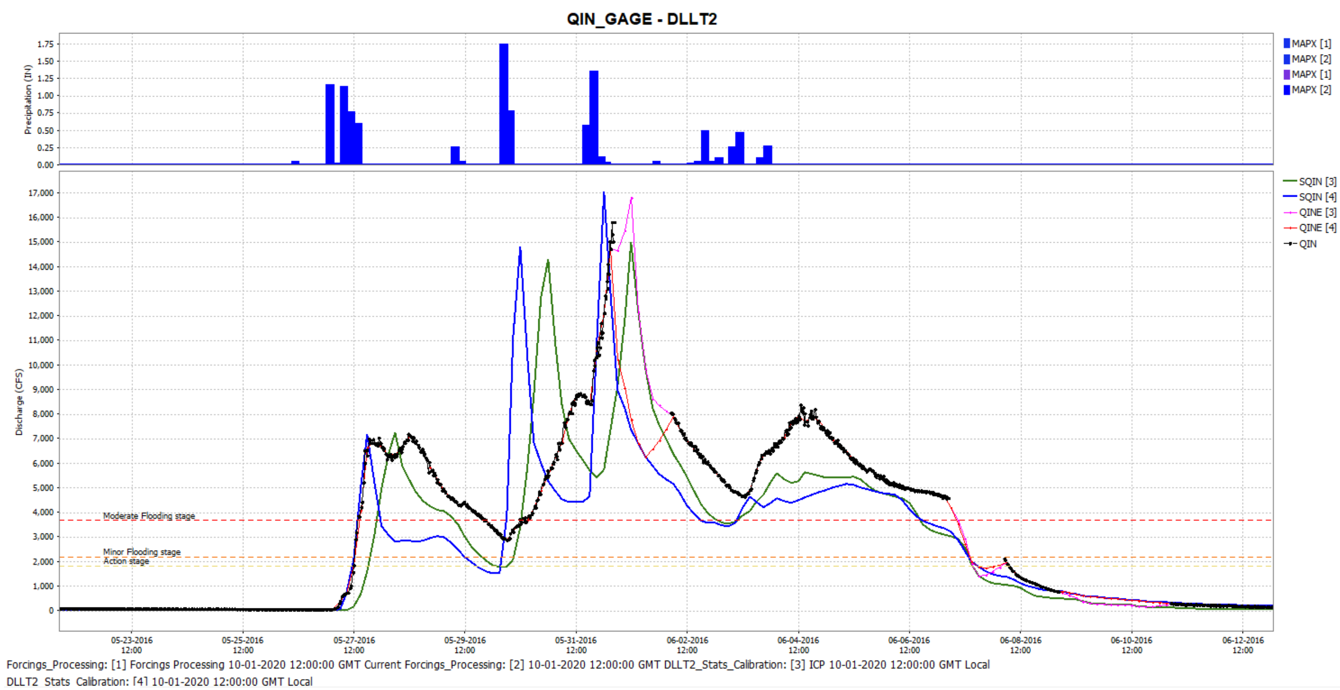
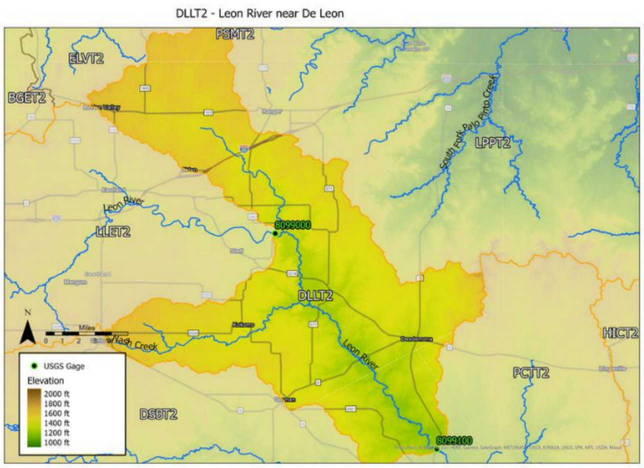
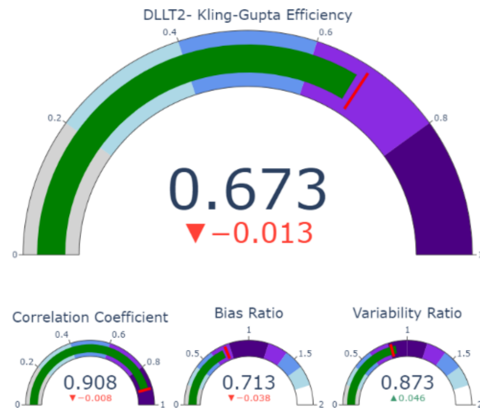
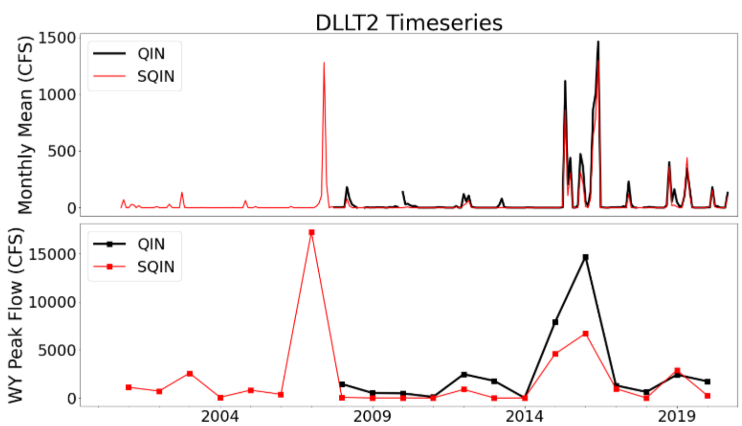


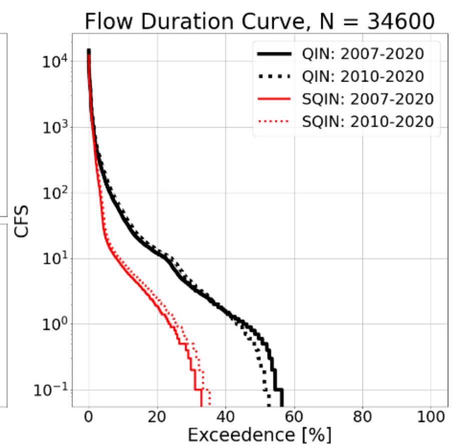
Figure 4-52: Improved calibration for DLLT2, with SQIN before (blue) and after (green) calibration.

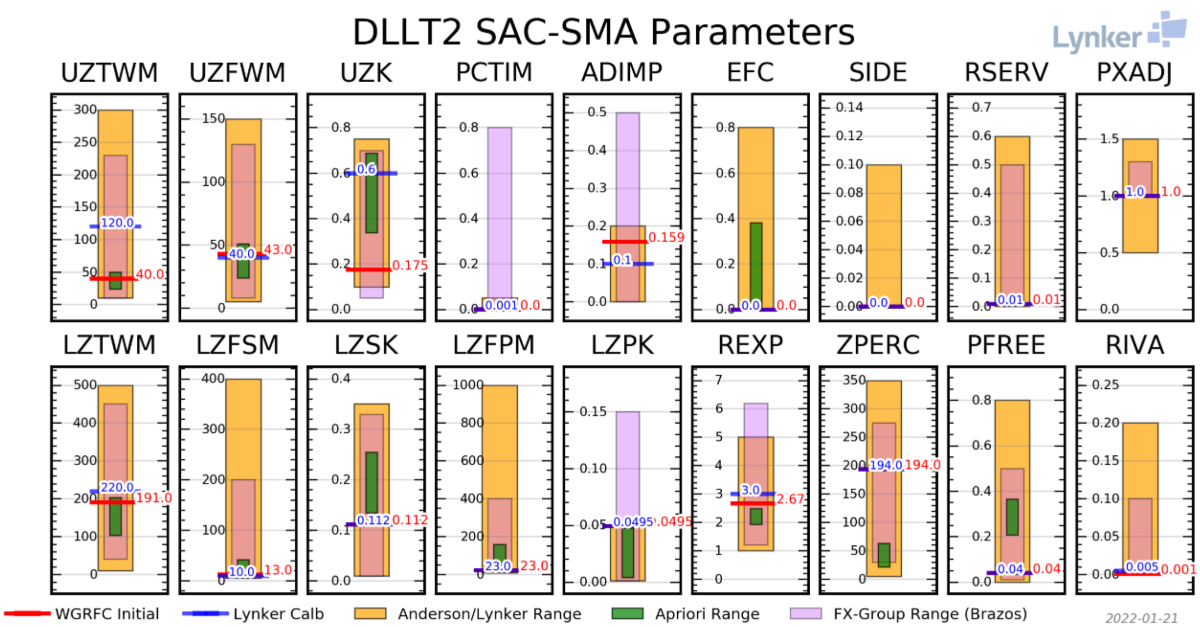
DLLT2: Leon River near De Leon











PCTT2

Proctor Lake near Proctor is a local basin at the confluence of Rush Creek and the Leon and Sabana Rivers. Proctor Lake is a USACE reservoir built in 1960 and operated for flood control and water conservation. Simulations for PCTT2 were run at a 6-hourly timestep, calibrated to daily inflow data from the USACE (available from 1963 to present). USGS remarks note that inflows to the lake are regulated by Leon Reservoir outflows (LLET2) as well as discharge from 23 floodwater-retarding structures (capacity ~44,000 acre-feet). Land cover and soil classes for PCTT2 are similar to other upstream basins (e.g., DLLT2), with primarily shrub/scrub (26.1%) and herbaceous (33.9%) land cover and Type C/Sandy Clay Loam (44.2%) soils.

Initial simulations for PCTT2 were well verified to begin with. Adjustments were made to shift simulations earlier, both through a shift in the UHG and decreased LAG for some flow ranges across all routed components (i.e., DLLT2R, DSBT2R, and CPKT2R). Timing shifts increased the correlation coefficient to 0.95. Peak flows were still biased low, however disaggregated daily inflows are unlikely to represent actual peak inflows. Furthermore, there were several events where there is a slow-duration recession from peak inflows of ~1,000 CFS that simulations were unable to replicate (Figure 4-53). The character of these recessions suggests an unaccounted for upstream routed flow, likely from the slow release from the 23 floodwater-retarding structures.

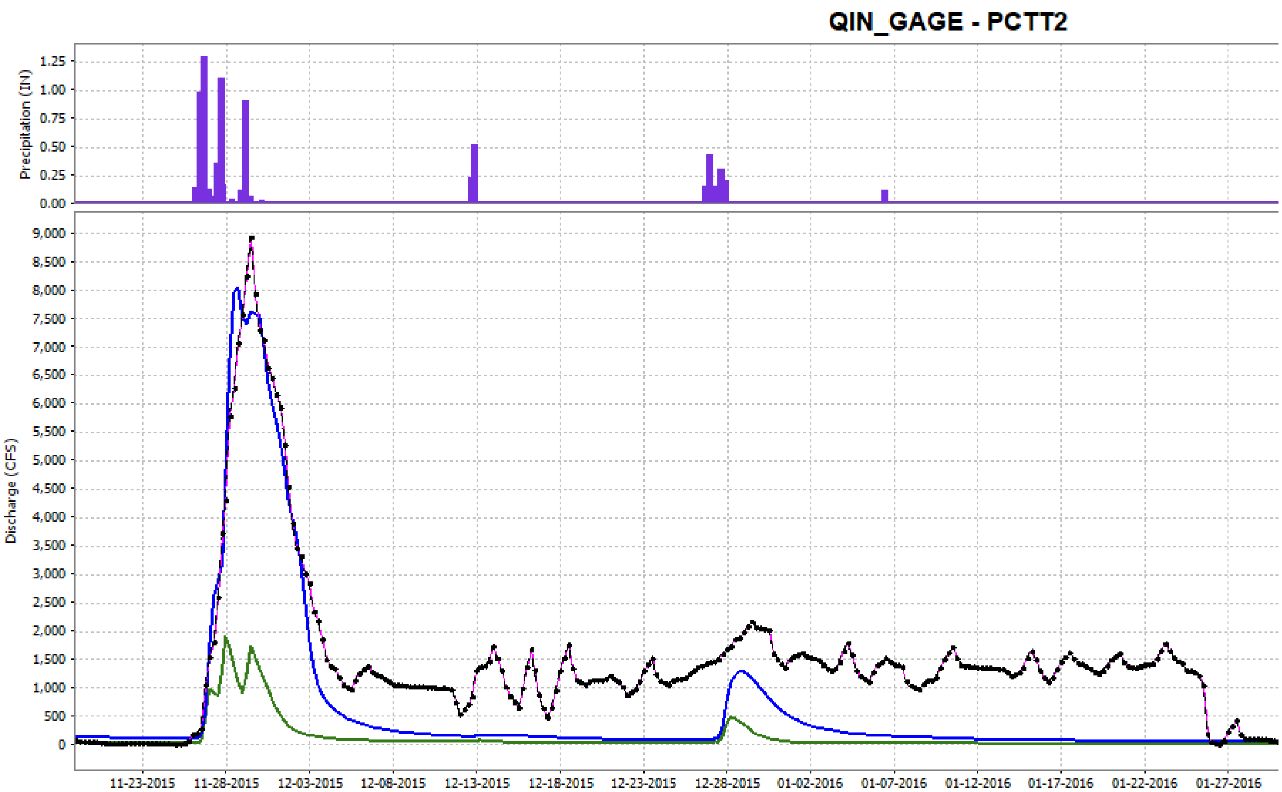
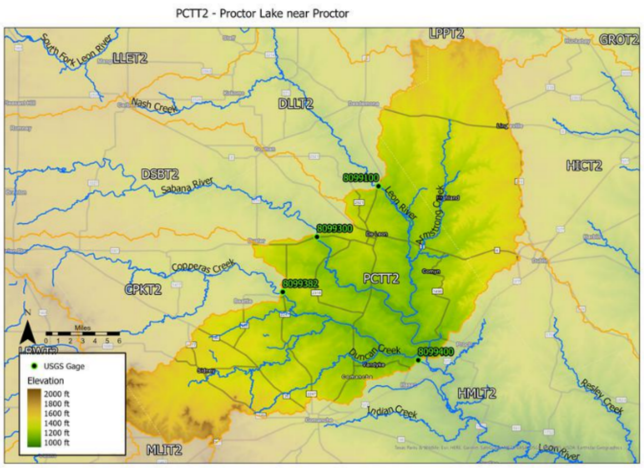
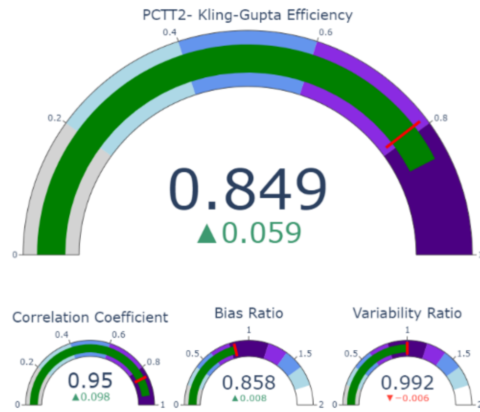
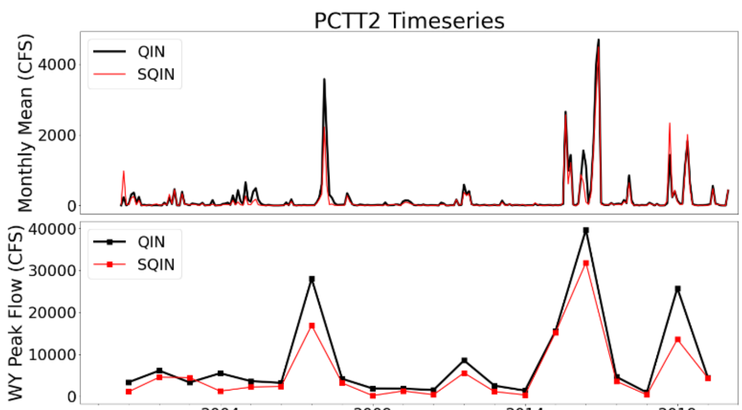


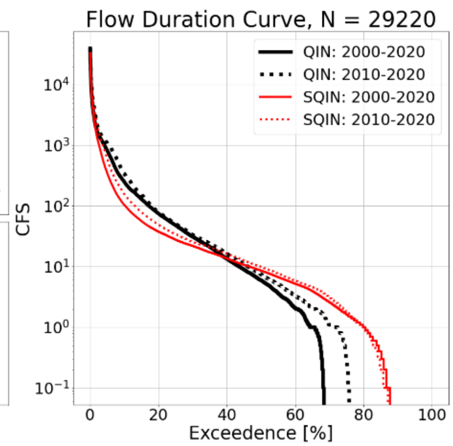
Figure 4-53: Improved calibration for PCTT2, showing total flow (blue) and local flows (green). Routed flows are from DSBT2, DLLT2, and CPKT2, not shown here.

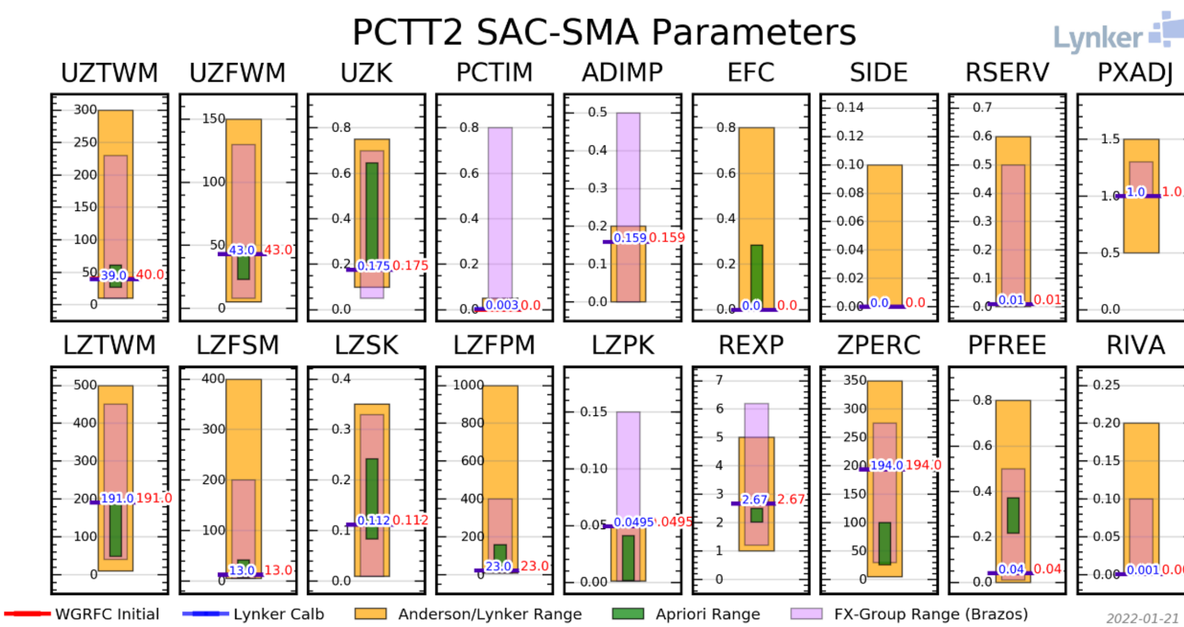
PCTT2: Proctor Lake near Proctor











HMLT2

Leon River near Hamilton is a downstream basin below Lake Leon. Simulations for HMLT2 were run at a 3-hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08099100 (available from 2007-10-01 to present). USGS remarks note that there are numerous upstream diversions for irrigation, municipal supply, and industrial uses, with flood-retarding structures also present upstream. Outflows from Lake Leon, a “fill and spill” reservoir, are only observed during moderate or larger precipitation events, dependent on the initial pool elevation level. Land cover for HMLT2 is primarily shrub/scrub (41.6%) and herbaceous (33.3%). Development in the basin is minimal by area (1%). Soil characteristics are primarily Type D/Clay Loam (39.9%) and Type C/Sandy Clay Loam (36.8%).

Initial simulations at HMLT2 were biased high, with significant over-simulation during moderate flood stage events (Figure 4-54). Increases to tension water parameters (UZTWM and LZTWM) were effective in reducing this bias, though a small positive bias was still observed. Other important adjustments included decreases to the PCTT2R lag values and larger negative monthly PEadj values for the winter months.

Final statistical performance for HMLT2 was very good, with a final KGE of 0.955 (2010 to 2020). High flow biases (top 0.1%, >9900 CFS, moderate flood stage) decreased from 16.7% to 2.9%, with a final correlation coefficient of 0.956. The October 2018 event (Figure 4-54) illustrates some of these improvements made during flood stage.

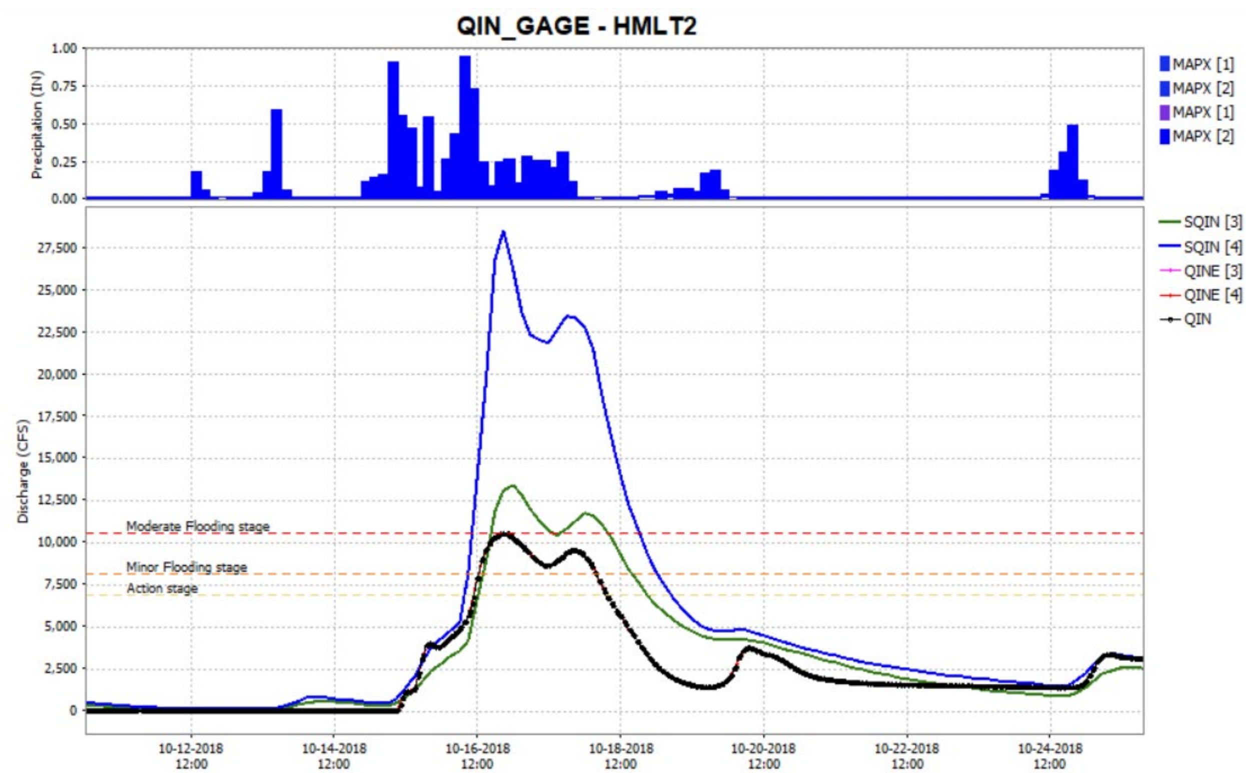
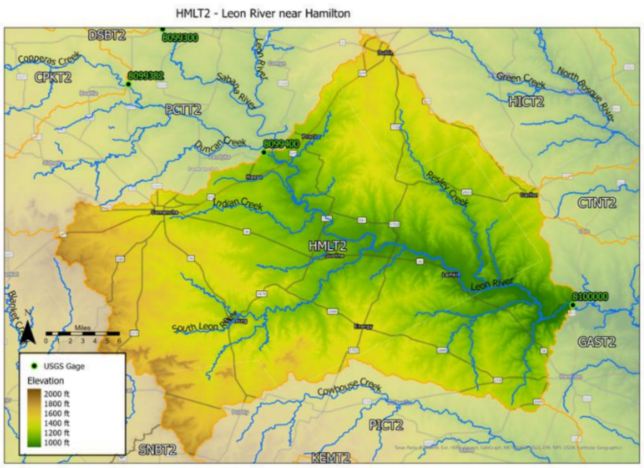
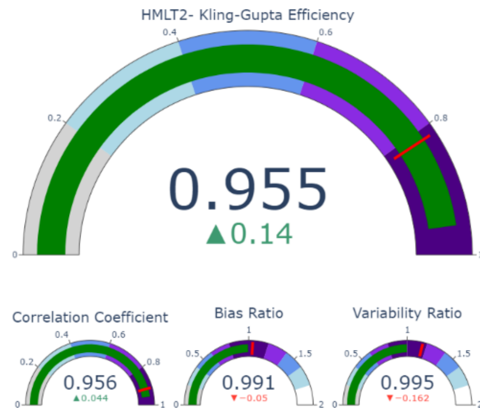
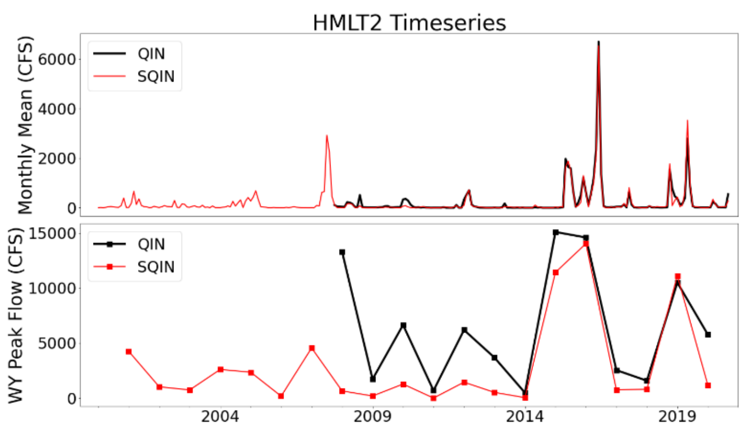


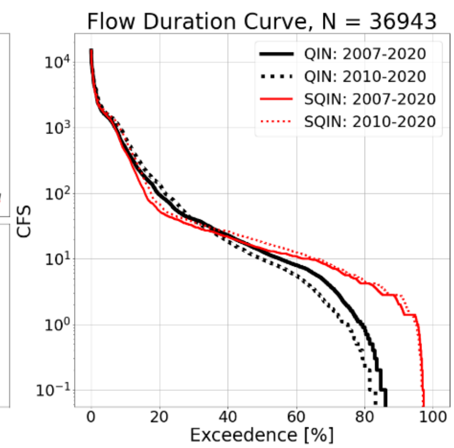
Figure 4-54: Improved calibration for HMLT2, with SQIN before (blue) and after (green) calibration.

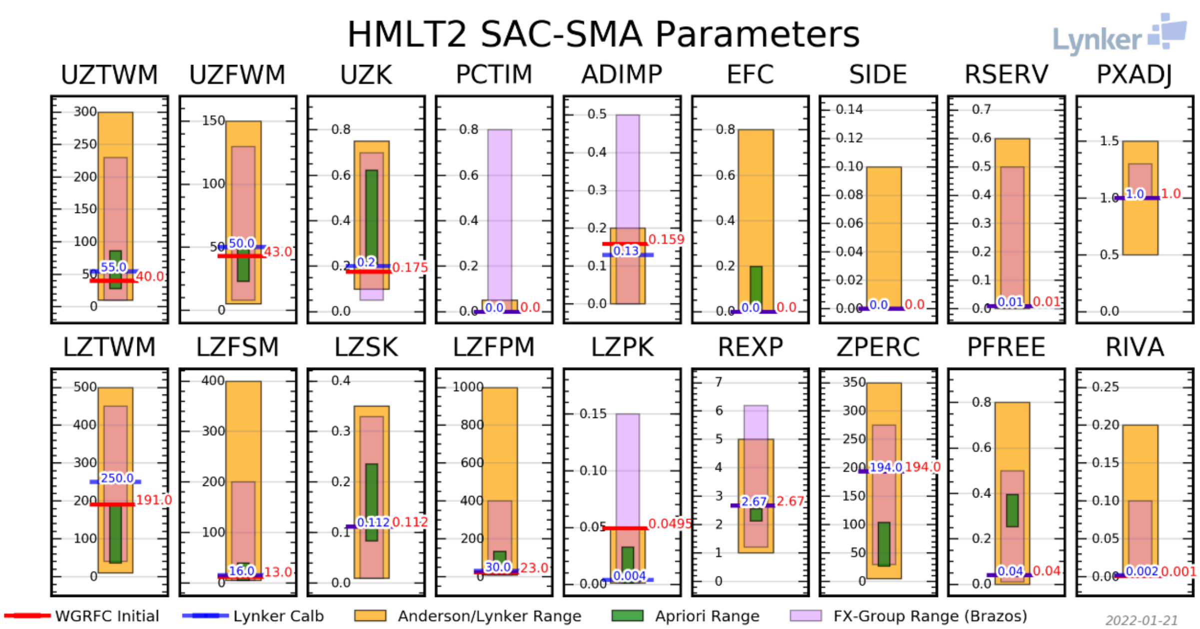
HMLT2: Leon River near Hamilton











4.1.3.2. Middle Brazos-Bosque HUC6

Bosque HUC8/ North Bosque HUC8

HICT2

North Bosque River at Hico, TX is a headwater basin of the Bosque River. Simulations for HICT2 use a 3-hour timestep, and models are calibrated to instantaneous discharge data from USGS gauge 08094800 (available from 2014-04-15 to present). USGS remarks note no major upstream diversions, but at least 10% of contributing drainage area has been regulated. At times flow is affected by discharge from floodwater-retarding structures controlling runoff from 202 mi² in the North Bosque River and Green Creek drainage basins. Landcover is mostly herbaceous (43%) and scrub/shrub cover (24%) with minimal land development (2.7%). Soil characteristics are primarily Type D/Clay Loam (32%) and Type C/Sandy Clay Loam (48%).

HICT2 is an intermittent stream, with little (<1 CFS) to no flow more than 50% of the year. A wet month in May 2015 generated the highest peak event in the period of record, reaching a minor flooding stage of about 20,500 CFS. Significant adjustments to the lower tension water parameter and the percolation parameters improved simulation performance. We shifted the UNIT-HG curve earlier in time to create larger and more responsive events. An event in October 2018 that is present in many of the surrounding basins has heavy precipitation but observed QIN data is much lower than any simulation (Figure 4-55).

Final statistical improvement for HICT2 was moderate, with KGE increasing from 0.646 to 0.842. The May 2015 events showed good improvement in the simulation of the peak magnitudes and timing. Smaller, flashier events were challenging for the simulation to capture, so we placed greater emphasis on the larger flood events.

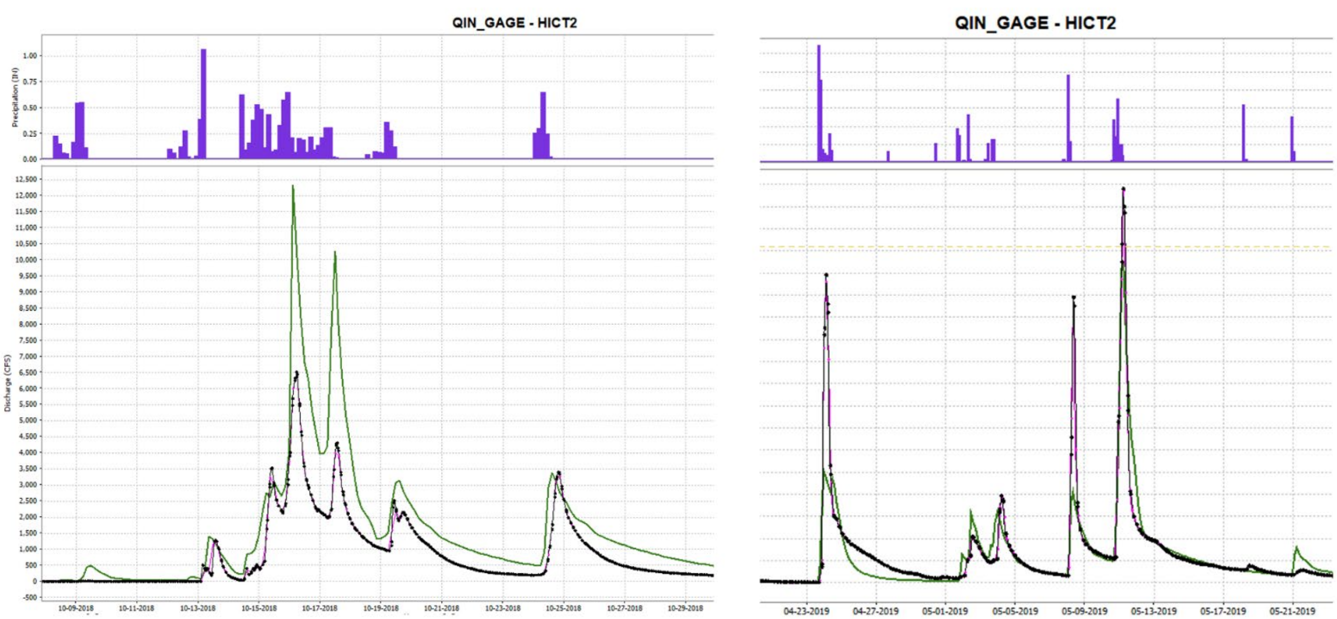
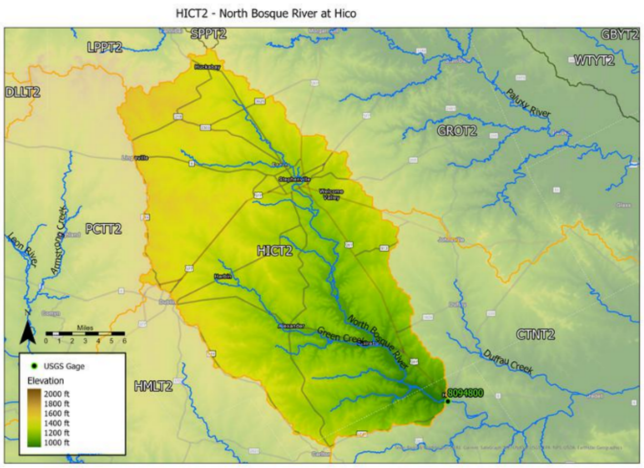
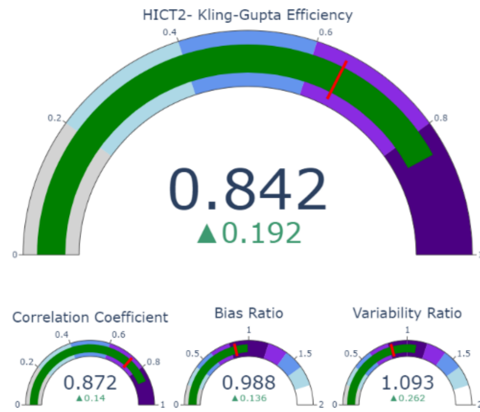
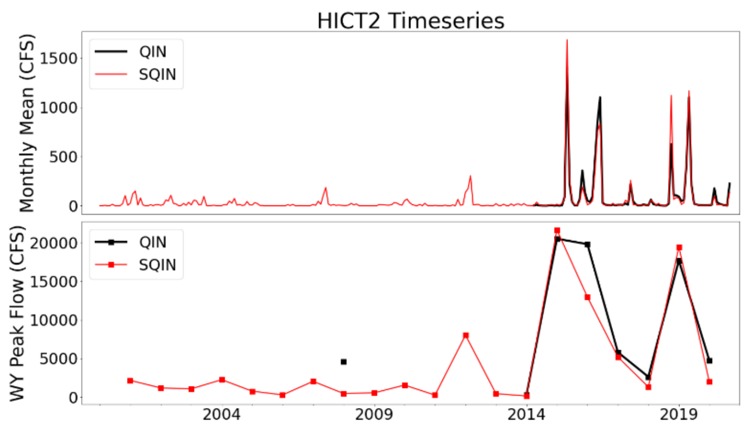


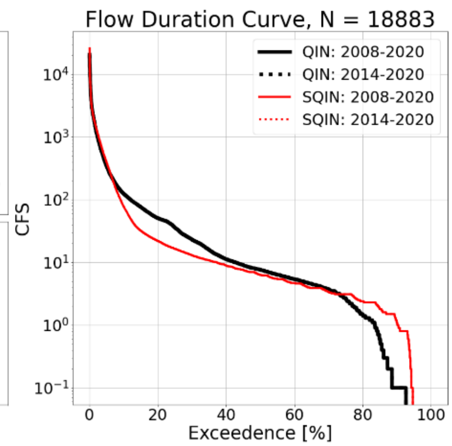
Figure 4-55: Differences between two different events about 6 months apart from one another, which illustrate both over-simulation (2018, left) and slight under-simulation (2019, right)- a challenge of calibration at HICT2. SQIN is in green and observed streamflow (QIN) is in black.

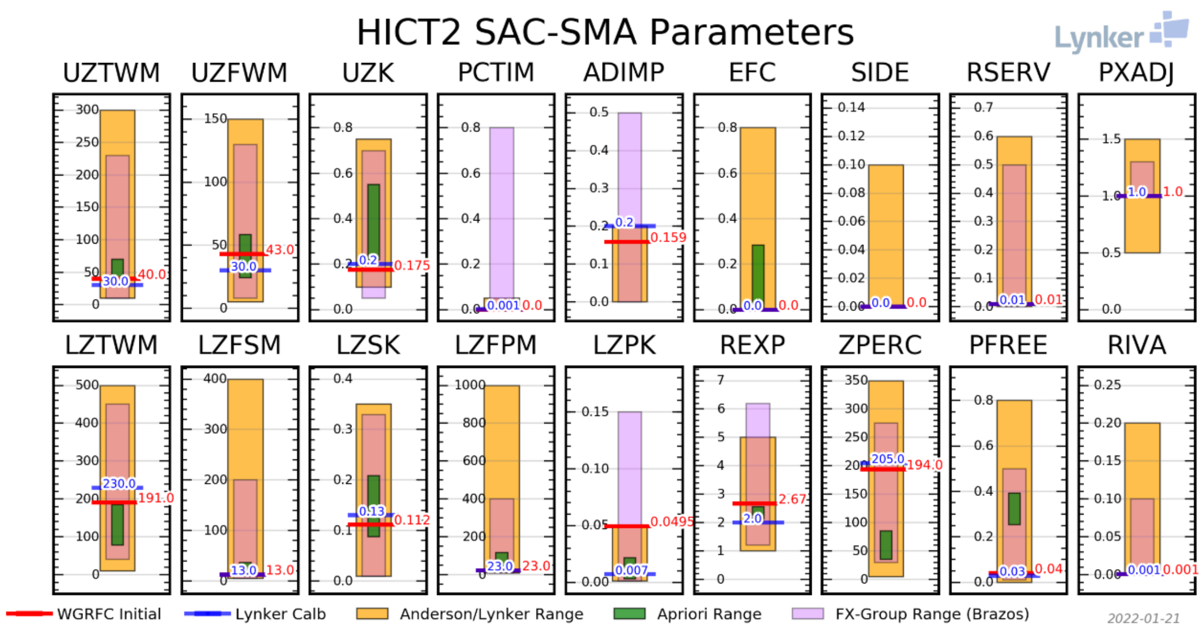
HICT2: N Bosque River at Hico











CTNT2

North Bosque River near Clifton is a downstream basin west of Lake Whitney. Simulations for CTNT2 were run at a 3 hourly timestep, calibrated to instantaneous discharge data from USGS gauge 08095000 (available from 1994-10-01 to present). Like the upstream HICT2, CTNT2 USGS gauge remarks note that flow is sometimes affected by discharge from floodwater-retarding structures controlling runoff from 202 mi² in the North Bosque River and Green Creek drainage basins, in addition to several municipal withdrawal and wastewater effluent discharge. Herbaceous (67.3%) and forest (22%) are the dominant land cover types. Development in the basin is minimal by area (1%). Soil characteristics are primarily Type D/Clay Loam (57.5%) and Type C/Sandy Clay Loam (27.9%).

Like upstream HICT2, CTNT2 is an intermittent stream with low flow (< 1 CFS) more than 50% of the year. Initial simulations were biased low, as indicated by the large negative percent bias metric (-31.2% for the period 2010–2020). The calibration simulation encompassed 2010–2020. An under-simulated event in June of 2007 was particularly noteworthy, perhaps due to biased precipitation data earlier in the calibration simulation. Significant adjustments to the tension water parameters and the lower zone buckets decreased final overall bias to -2.3% for the period 2010–2020, although biases were too low for the full record. The UNIT-HG curve was modestly changed to incorporate a slightly higher peak and longer recession tail.

KGE scores improved from initial simulation, from 0.551 to 0.904. High flow biases still exist in the final calibration during low flow periods in the fall months (Figure 4-56). Overall model bias for this period decreased from -31.2% to -2.4% with a correlation coefficient of 0.907.

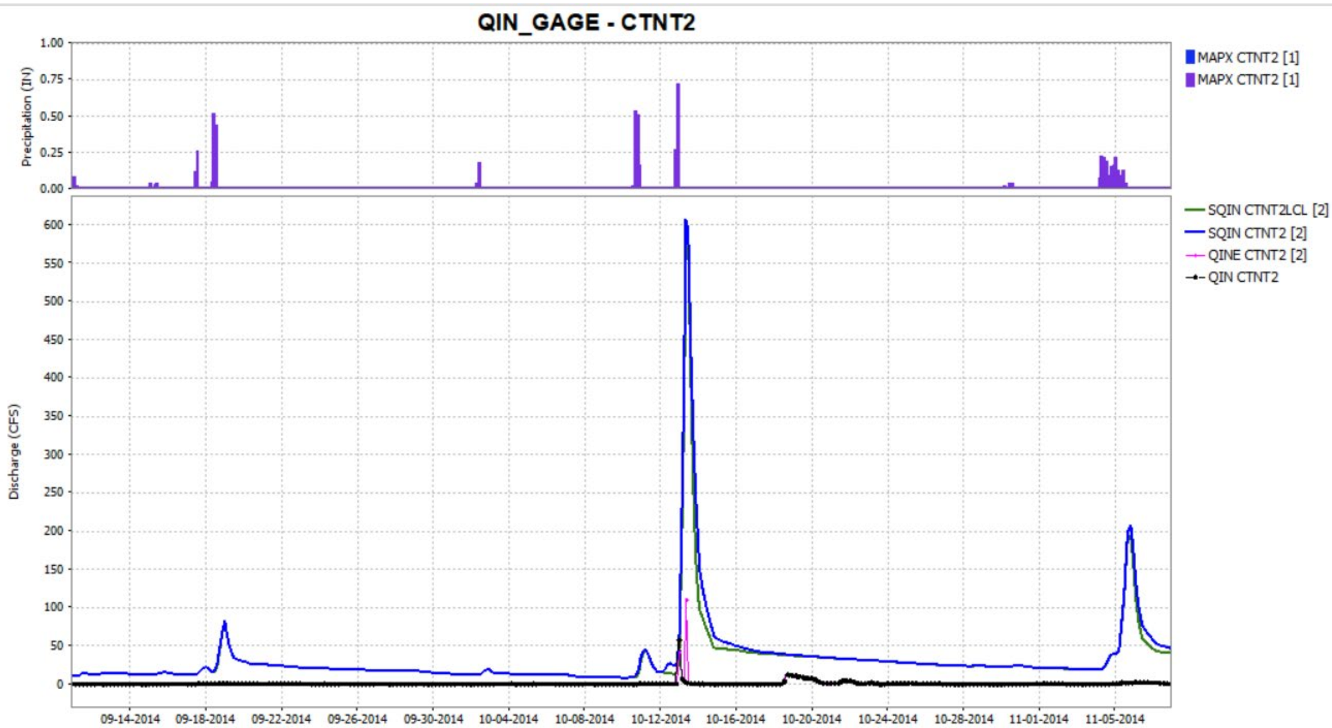
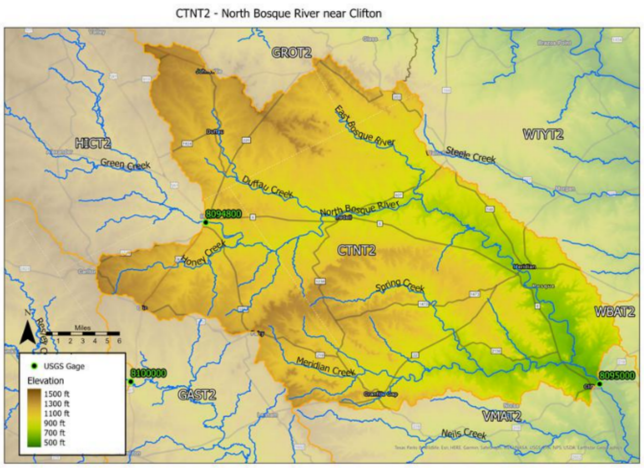
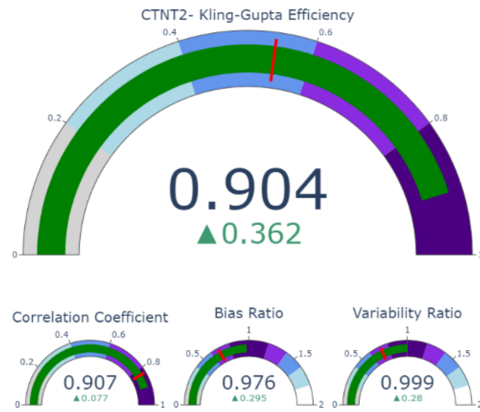
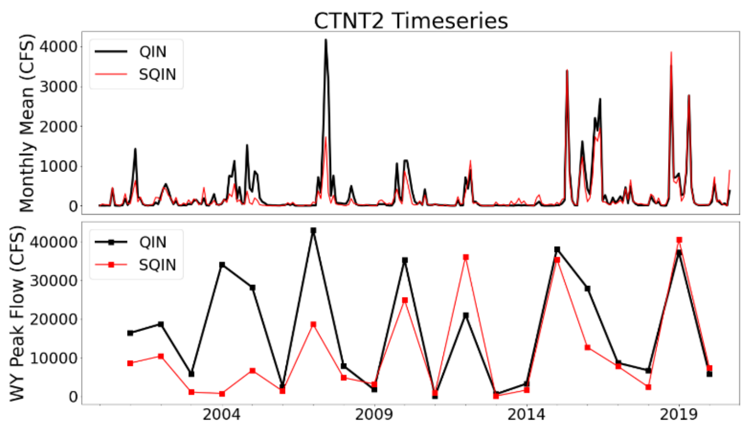


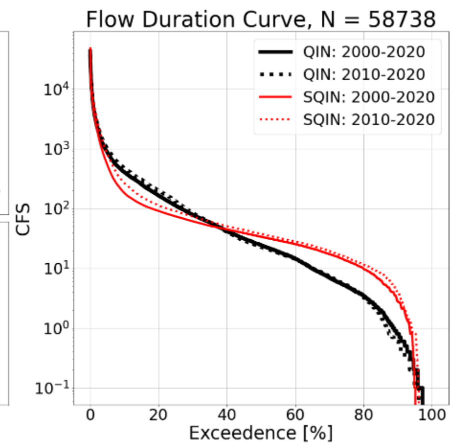
Figure 4-56: High flow biases at CTNT2 (SQIN, blue) were challenging to correct for, even with high PEADJ values in September-November. Observed streamflow (QIN) is in black.

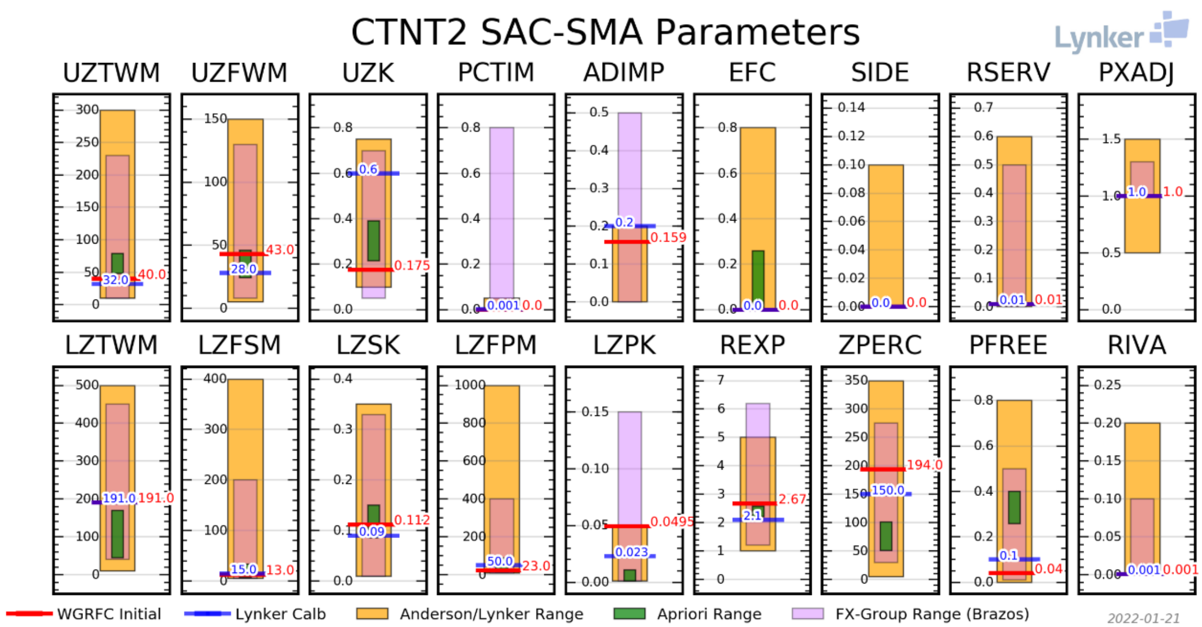
CTNT2: North Bosque River near Clifton











VMAT2

North Bosque River at Valley Mills is a downstream basin located just upstream of Waco Lake. VMAT2 is configured with a 3-hour simulation timestep and was calibrated to instantaneous discharge data from USGS gauge 08095200 (available from 1991-10-01 to present, with occasional gaps). USGS gauge remarks note that at least 10% of the contributing drainage area is regulated, and there exists several small diversions. Like upstream CTNT2, land cover is majority herbaceous (57.1%) and forest (30.6%); soil characteristics are primarily Type D/Clay Loam (60.0%) and Type C/Sandy Clay Loam (26.7%).

The majority of VMAT2 consists of routed flow from upstream CTNT2. Decreased attenuation of upstream routed flow was necessary. The biggest events occur in April of 2016 and October 2018, which were focuses of this calibration.

Initial calibration results were already quite good (Figure 4-57). Small improvements are evident in the larger event peaks. Final KGE score was 0.929.

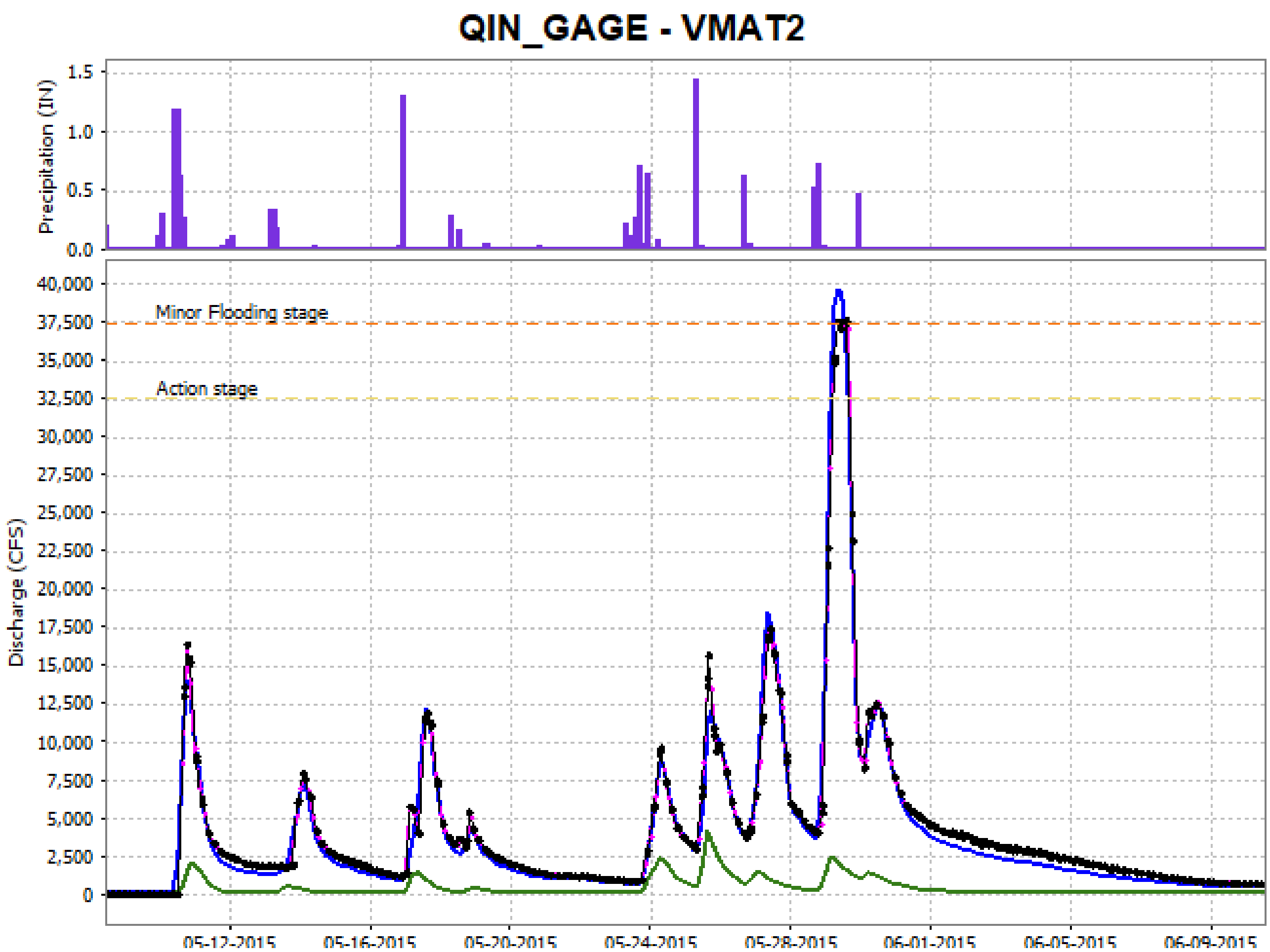
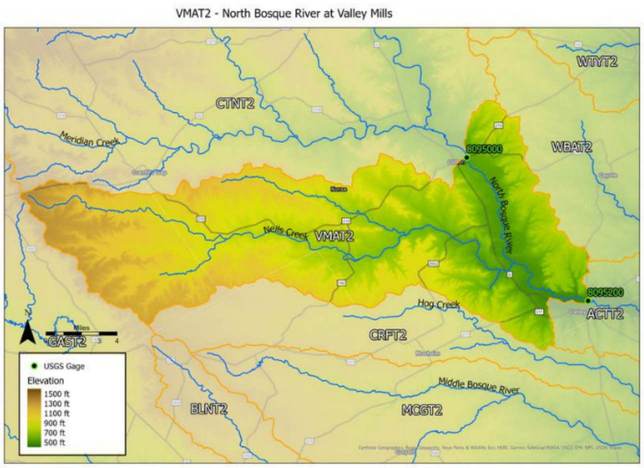
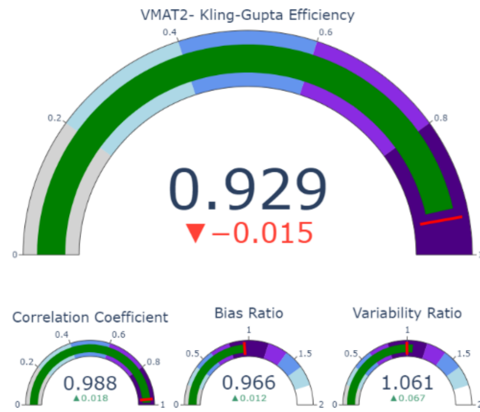
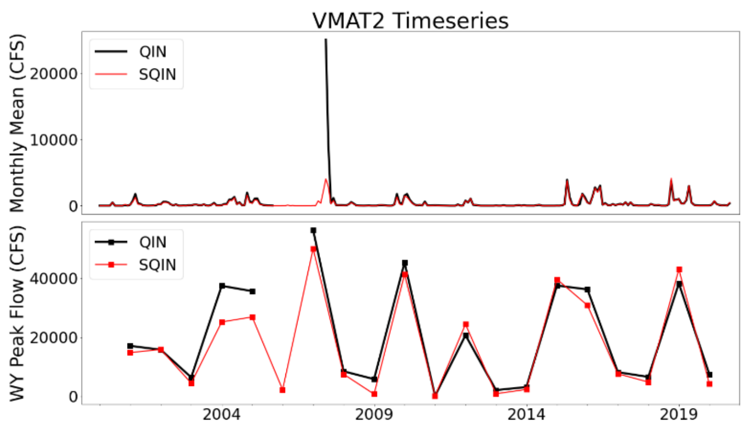


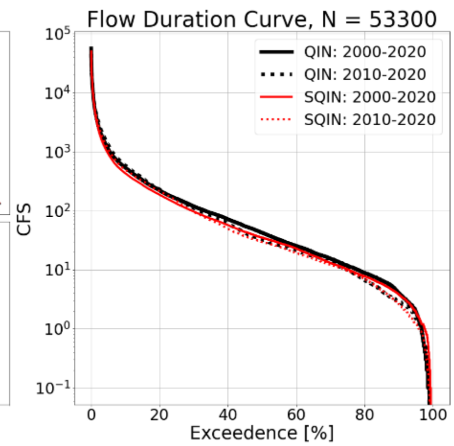
Figure 4-57: Final calibration of VMAT2 captures the timing and magnitude of small and large events quite well (total flows in blue, local flows in green).

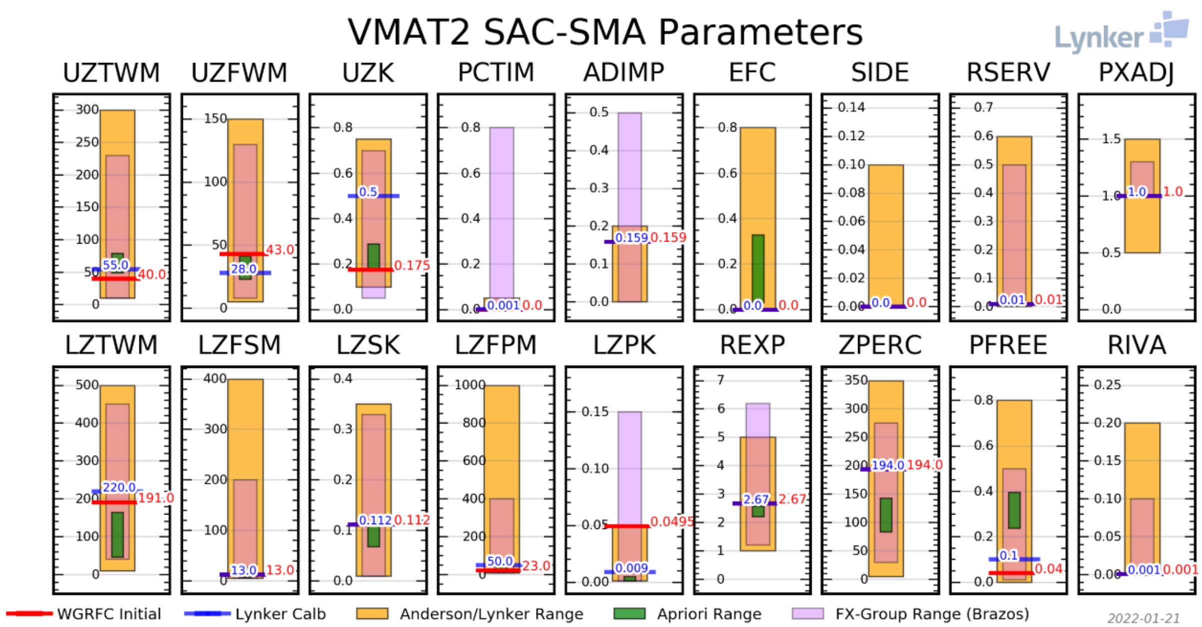
VMAT2: North Bosque River at Valley Mills











CRFT2

Hog Creek near Crawford is a narrow headwater basin located just upstream of Waco Lake. CRFT2 is configured with a 3-hour simulation timestep and calibrated to instantaneous discharge data from USGS gauge 08095400 (available from 2007-10-01 to present). CRFT2 is an ephemeral stream, and USGS records notes that discharges below 5 CFS are “poor estimates”. The majority of the basin’s land cover is herbaceous cover (69.3%) with a small amount (16.9%) covered by cultivated crops; soil characteristics are primarily Type D/Clay Loam (61.0%) and Type C/Sandy Clay Loam (36.7%).

CRFT2 is another ephemeral stream with flashy streamflow events. Receding limbs were particularly difficult to match. Another difficulty was the regular occurrence of precipitation events with no response in the observed data (Figure 4-58). For example, an event in September of 2013 with at least 3 inches of total precipitation added no streamflow to the dried streambed. Simulations were able to decrease the peak of the SQIN data from 5,500 CFS to about 450 CFS. Streamflow data for CRFT2 should be re-examined.

Statistical improvements for CRFT2 were substantial, going from -0.103 to 0.802 for the 2010–2020 period. Significant overbias of events was present before calibration efforts. Bias in the top 0.1% (>1380 CFS) of flows improved from 116% to -0.09%.

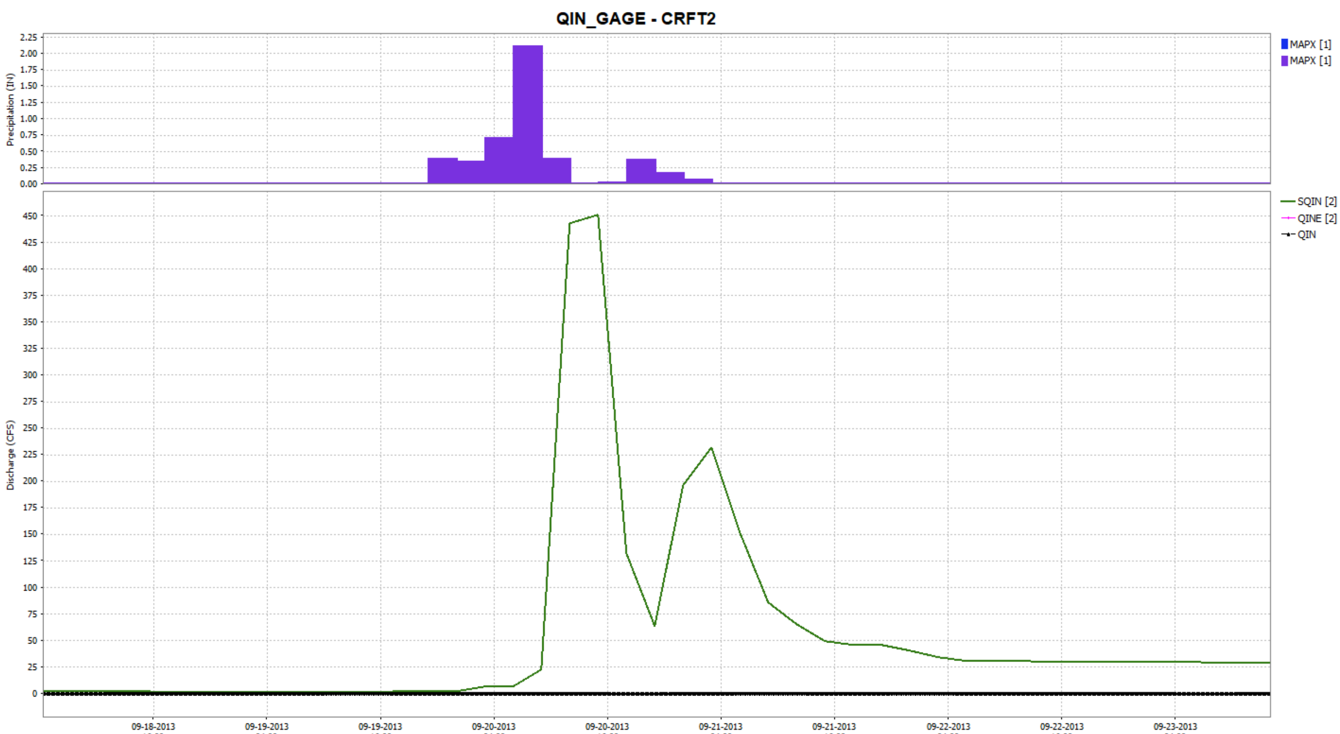
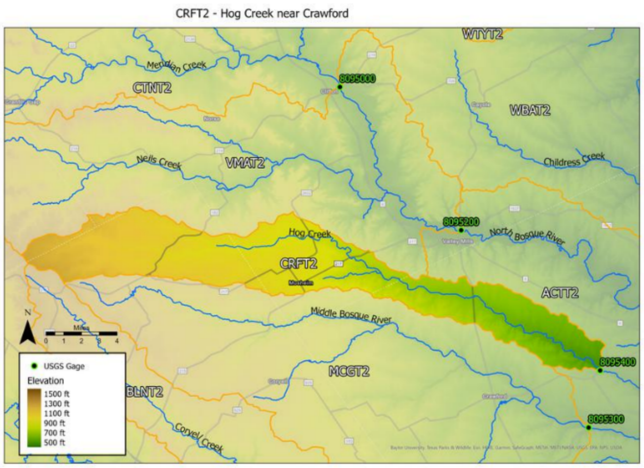
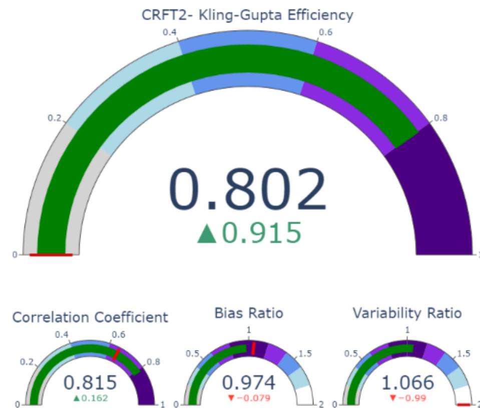
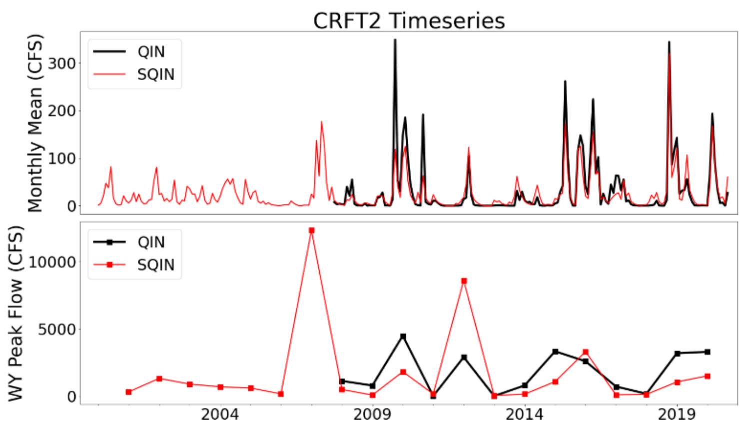


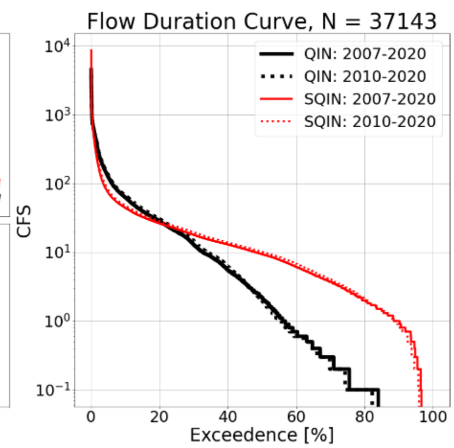
Figure 4-58: Despite a large rainfall event in September 2013 (>3 inches, purple), USGS data recorded no observed streamflow (QIN, black line), suggesting errors in either the USGS streamflow data or MAPX forcing data. Simulated streamflow (SQIN) is shown in green.

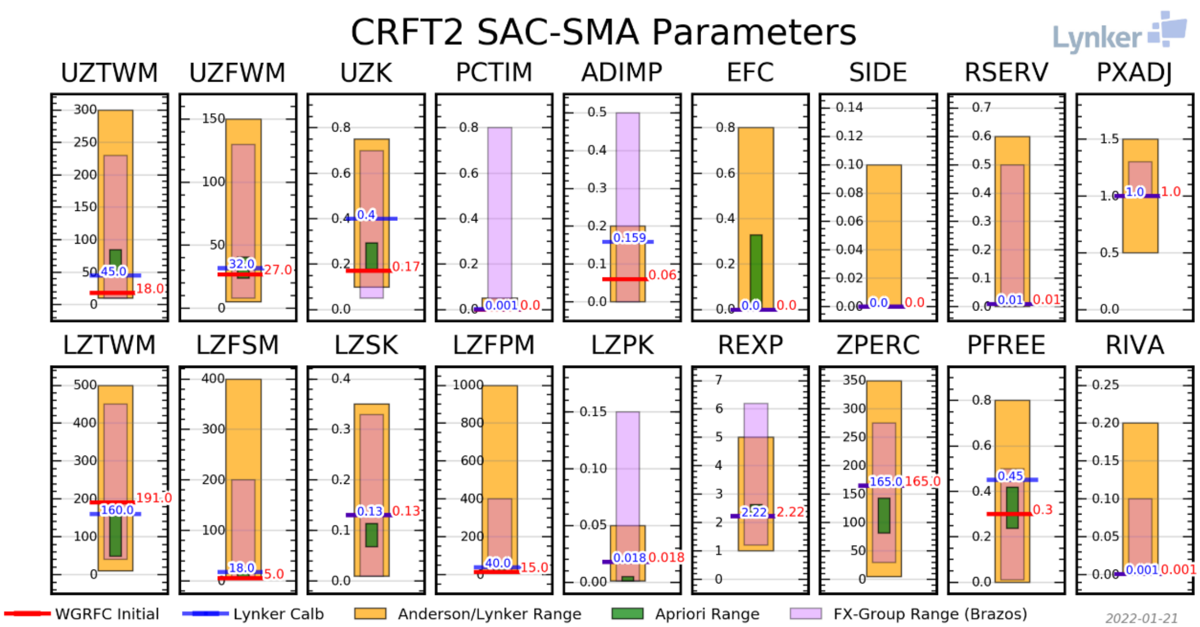
CRFT2: Hog Creek near Crawford











MCGT2

Middle Bosque River near McGregor is a headwater basin located just upstream of Waco Lake. CRFT2 is configured with a 3-hour simulation timestep and calibrated to instantaneous discharge data from USGS gauge 08095300 (available from 2007-10-01 to present). USGS remarks note that streamflow data below 5 CFS is poor, and there is no flow at times. Land cover for MCGT2 is primarily herbaceous (61.5%) with less than one percent of land area classified as developed. Soil characteristics are more clay dominated, with most soils classified as Type D/Clay Loam (59.7%) or Type C/Sandy Clay Loam (38.6%).

Streamflow surpassed minor flooding stage twice in the period of record, in October 2009 and in September of 2010 (Figure 4-59). These were focuses of the calibration. High bias existed prior to calibration, due to over-simulation of non-event periods. Adjustments focused heavily on tension parameters and percolation parameters.

Statistical improvements were modest; however, the PBIAS for flows greater than 5,584 CFS decreased from 24.5% to -3.3% (2010–2020), though earlier in the record, there was less improvement for these larger flood events (initial PBIAS 17.5% to -10.7% from 2000–2020). The KGE score improved from 0.67 to 0.814 between 2010–2020.

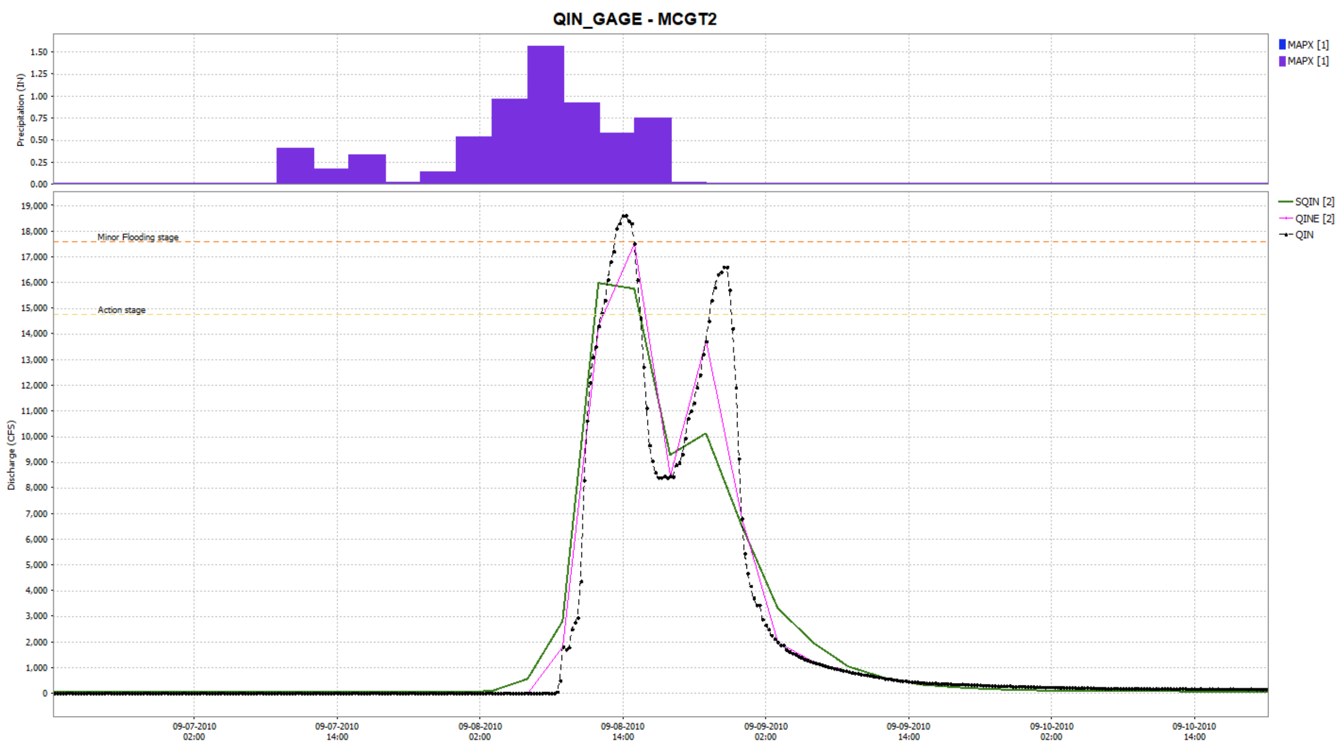
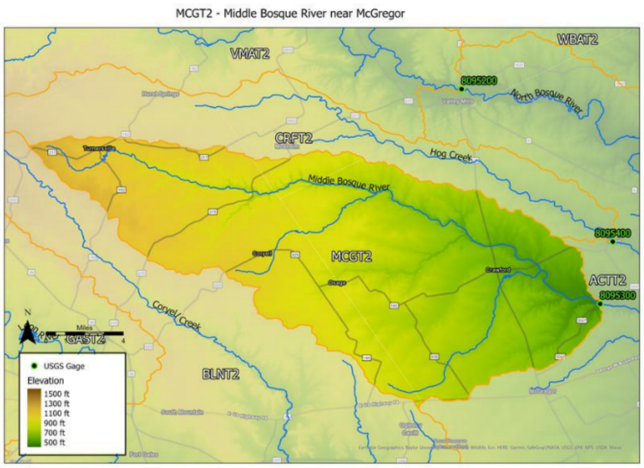
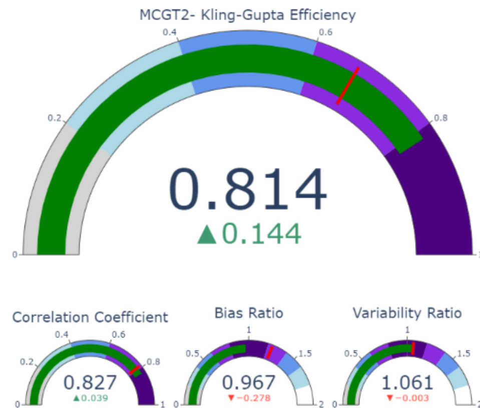
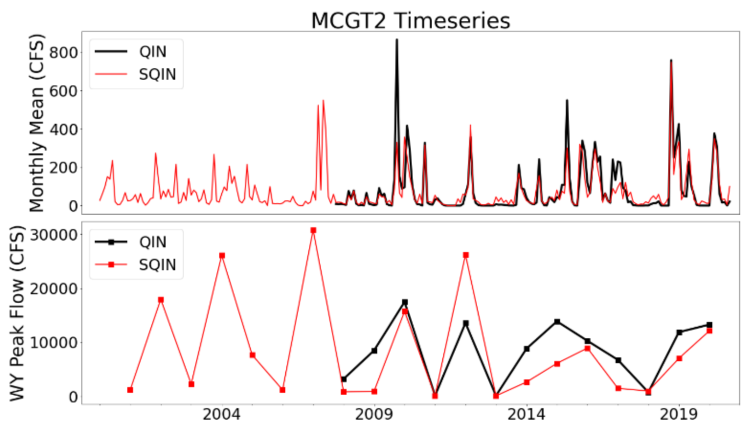


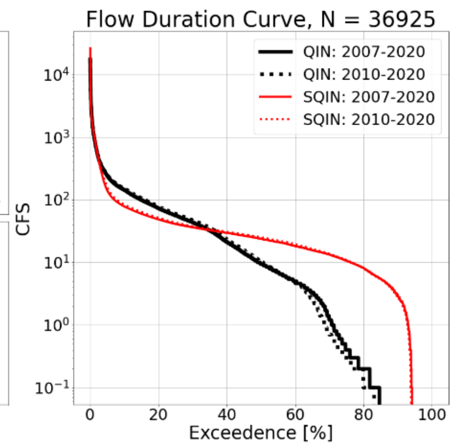
Figure 4-59: Improved calibration for MCGT2 (green line) demonstrating the well-verified, flashy nature of this September 2010 event. Observed streamflow (QIN) is in black.

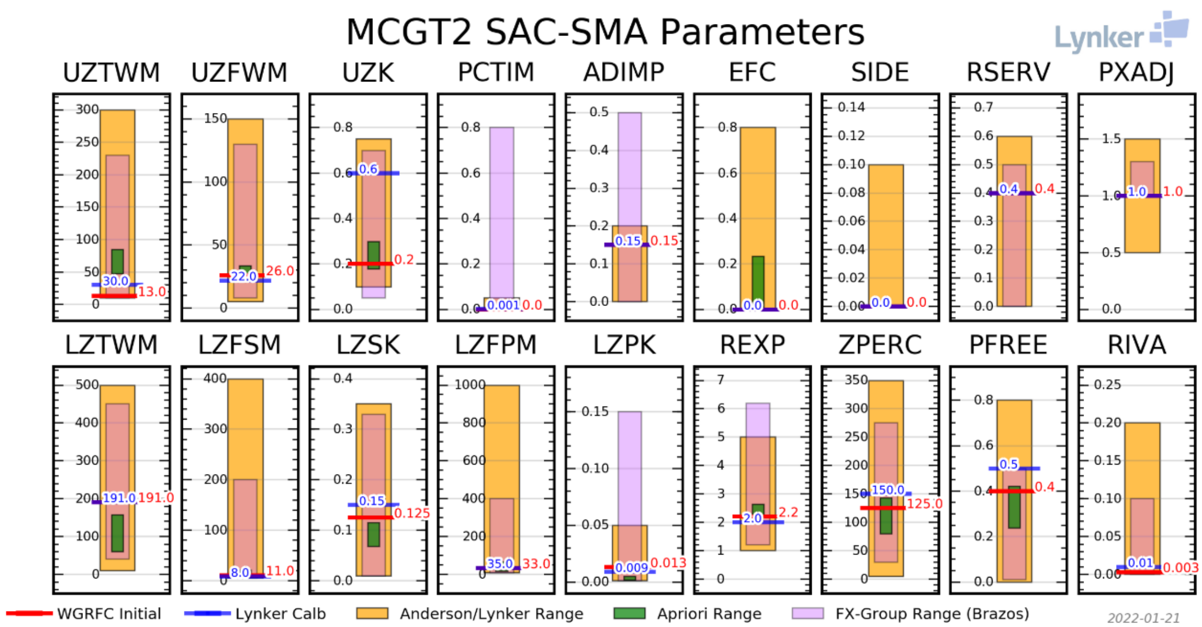
MCGT2: Middle Bosque River near McGregor











ACTT2

Waco Lake near Waco is a downstream basin that has the North Bosque River, the Middle Bosque River, and Hog Creek all flowing into Waco Lake. ACTT2 uses a 3-hour simulation timestep and is calibrated to daily inflow data from USACE (available from 1965-01-01 to present). USGS notes that Waco Lake and spillway was built for flood control and water conservation and is owned by the US Army Corps of Engineers. Land cover for ACTT2 is primarily herbaceous (41.2%) and cultivated crops (23.5%). Soil characteristics are more clay dominated, with most soils classified as Type D/Clay Loam (73.9%) or Type C/Sandy Clay Loam (17.6%).

The majority of flow comes from routed flow, specifically from upstream VMAT2, the North Bosque River inflow (Figure 4-60). Lag and attenuation parameters decreased significantly for VMAT2, and moderately for MCGT2. Note that the 3-hour observed inflow timeseries (disaggregated from daily calculated inflows) was shifted by 6 hours to account for the central time conversion to GMT.

A negative monthly bias still exists across all months, with a total PBIAS of -13.1%, which improved from -17.1%. Statistical improvement in the calibration was small to modest with KGE improving from 0.747 to 0.850.

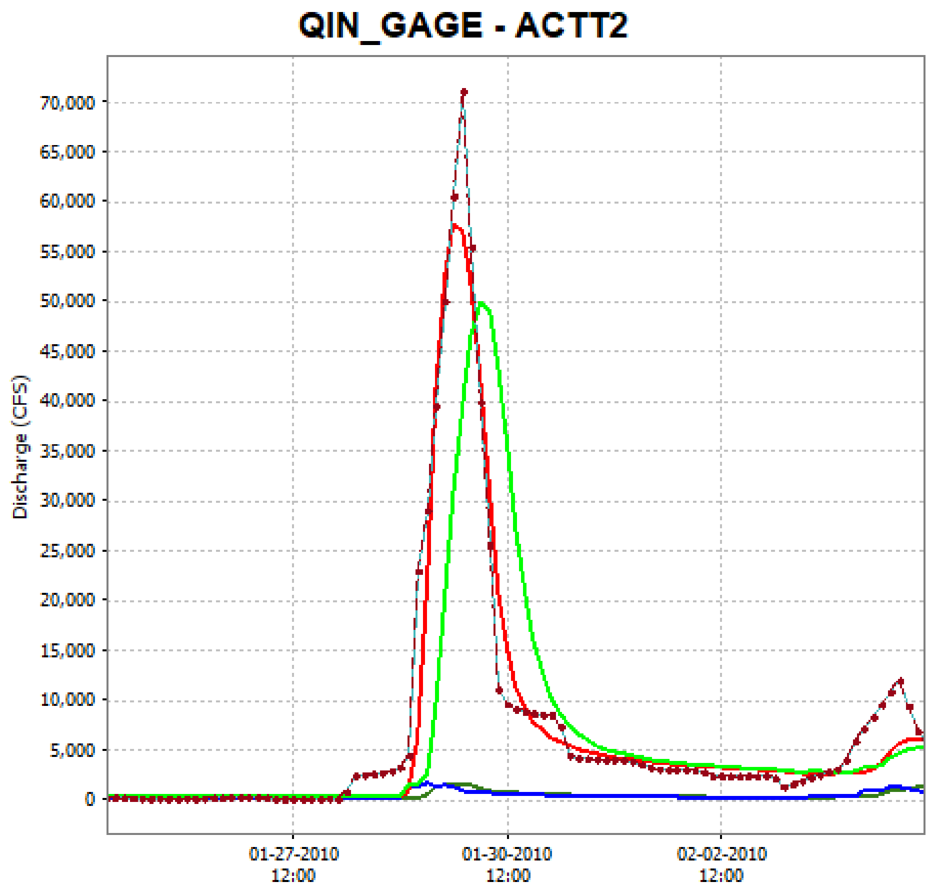
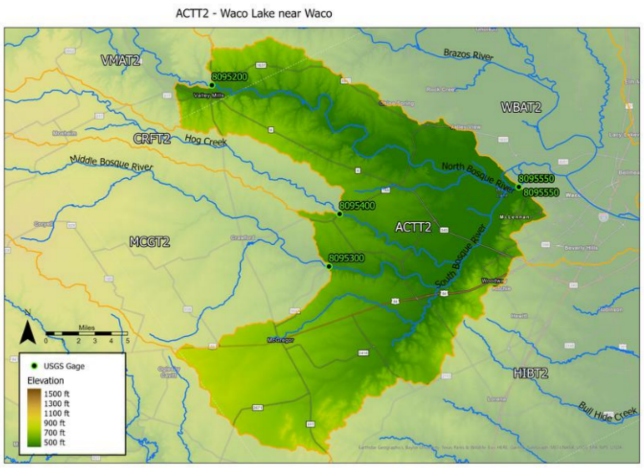
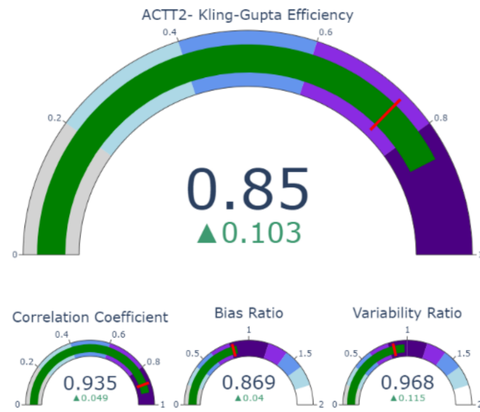
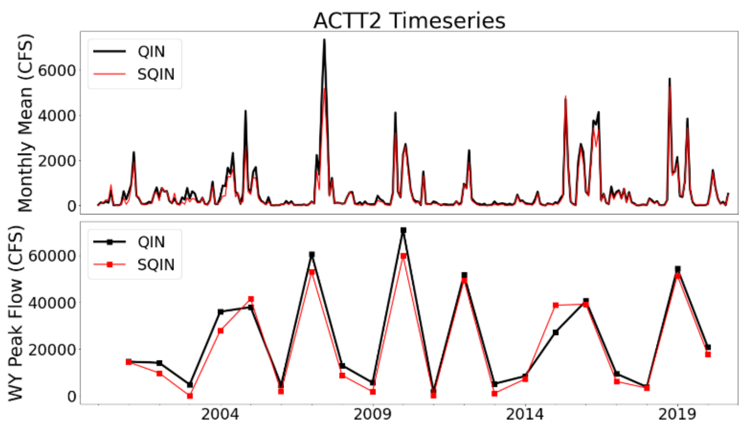


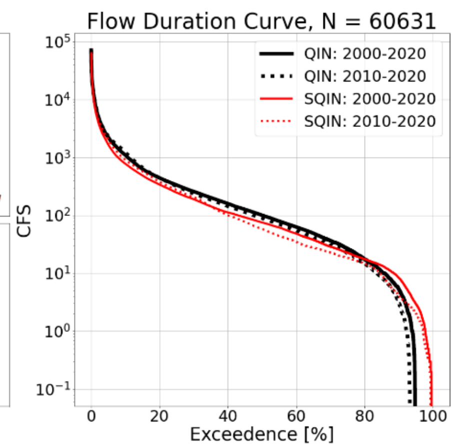
Figure 4-60: Calibration improvements were made in the timing and magnitude of large events such as this one from January 2010. Initial total ACTT2 inflow (lime green) compared to calibration inflow (red). Small local flows (before in blue, after in dark green) highlight that nearly all flows are routed from VMAT2.

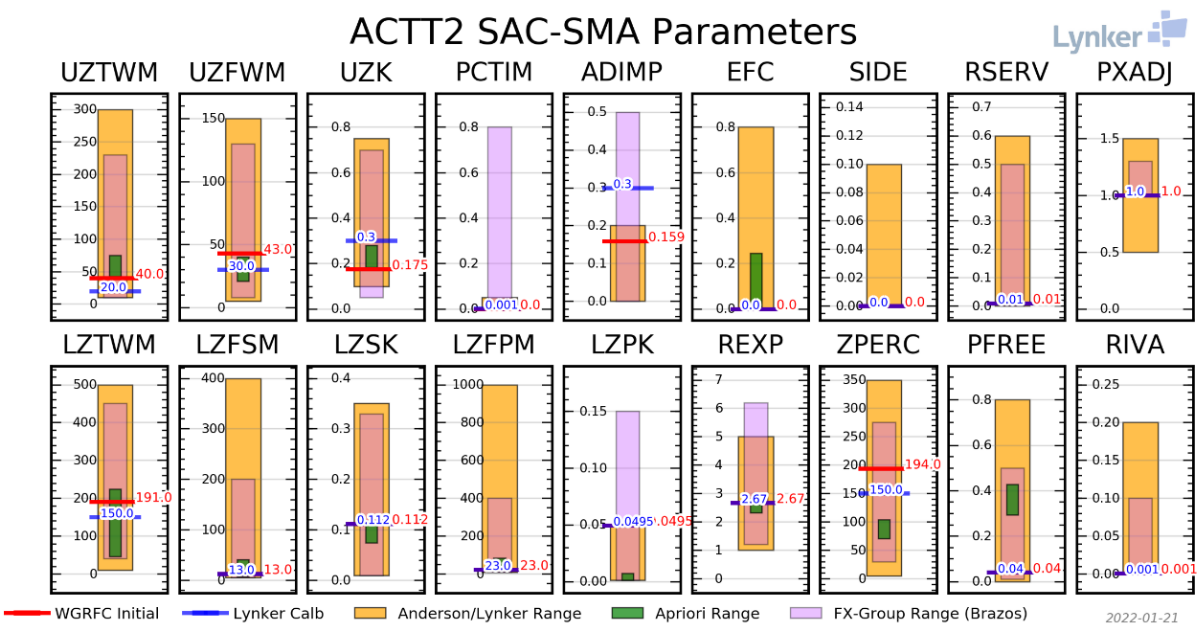
ACTT2: Waco Lake near Waco











4.1.3.3. Middle Colorado-Concho HUC6

Jim Ned HUC8/Pecan Bayou HUC8

CUTT2

Pecan Bayou near Cross Cut is a large headwater basin located upstream of Lake Brownwood. CUTT2 uses a 3-hour simulation timestep and is calibrated to instantaneous discharge data from USGS gauge 08140700 (available from 2015-10-31 to present for flows greater than 200 CFS). USGS remarks note that streamflow is impacted by several large Soil Conservation flood-retarding ponds, which are assumed to affect flows by greater than 10 percent. Land cover for CUTT2 is primarily shrub/scrub (58.5%) with less than one percent of land area classified as developed. Soil characteristics are more clay dominated, with most soils classified as Type D/Clay Loam (51.9%) or Type C/Sandy Clay Loam (43.6%).

Observed flow data for flood magnitudes are limited at this site with less than 10 events above Action Stage, and only three events greater than 10,000 CFS (record flows ~22,700 CFS). Initial simulations were not generating enough surface runoff and were also generally too late (blue line in Figure 4-61). A shift earlier in the UHG, as well as a smaller UZFWM and a larger ADIMP, were found to be effective in increasing the magnitude of peak flows, though moderate events were generally under-simulated.

Final KGE values increased from 0.46 to 0.567, reflecting greater correlation coefficients (0.72) and lower PBAIS (-5.68%).

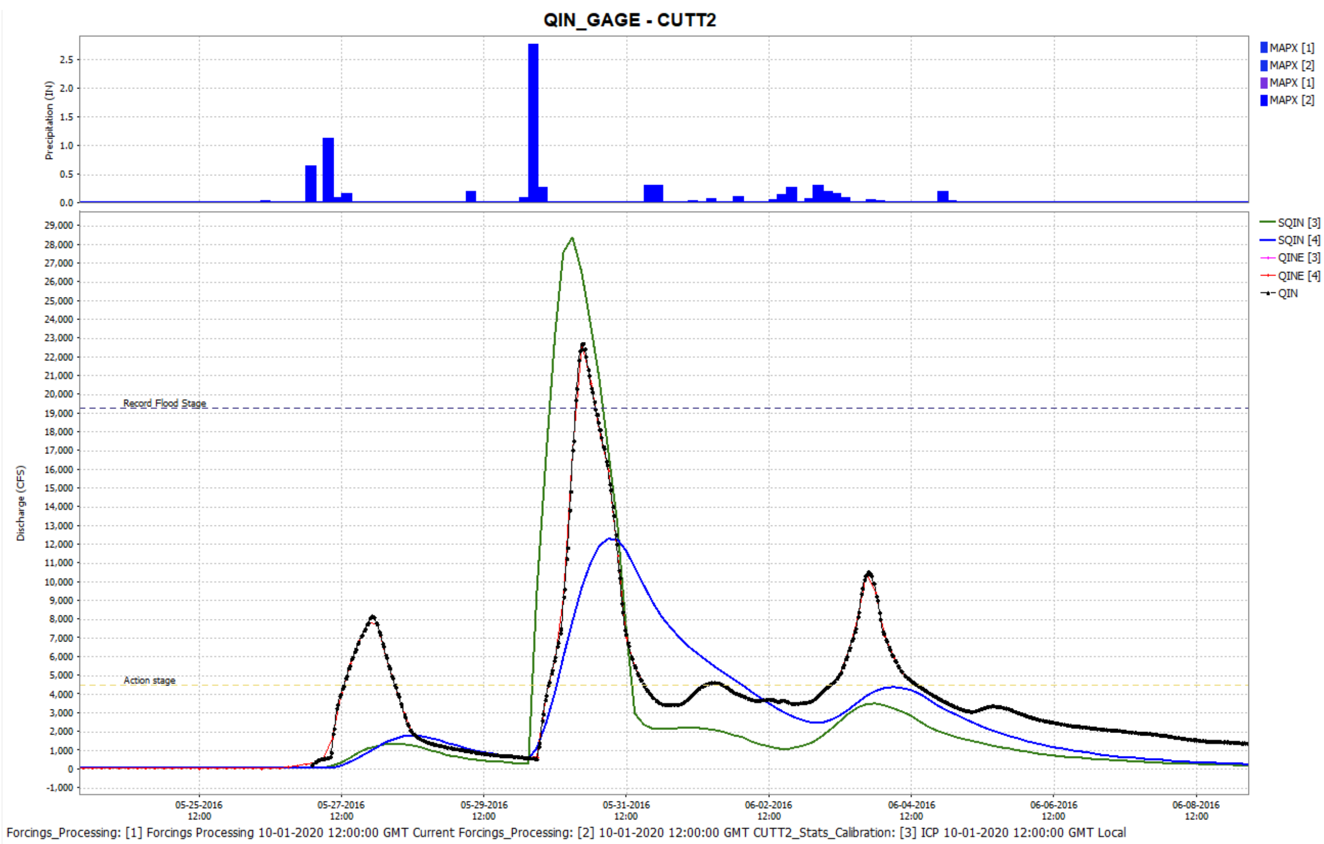
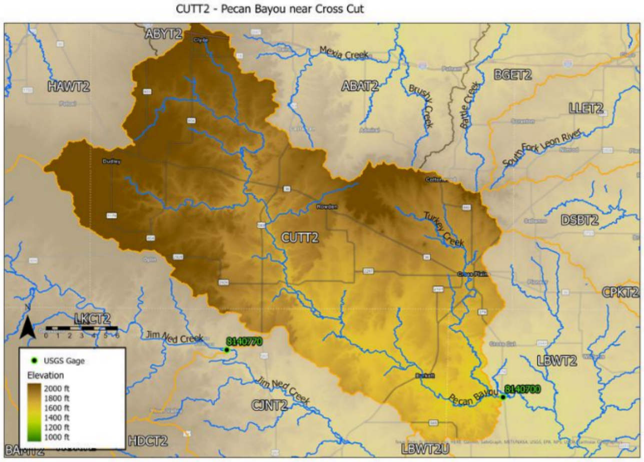
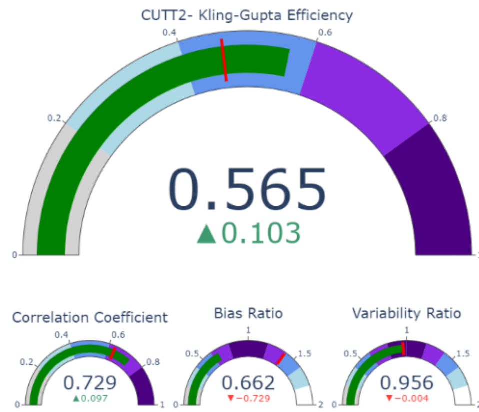
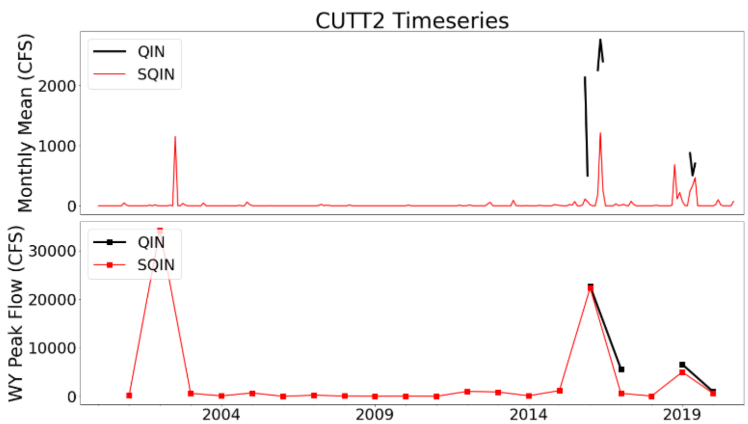


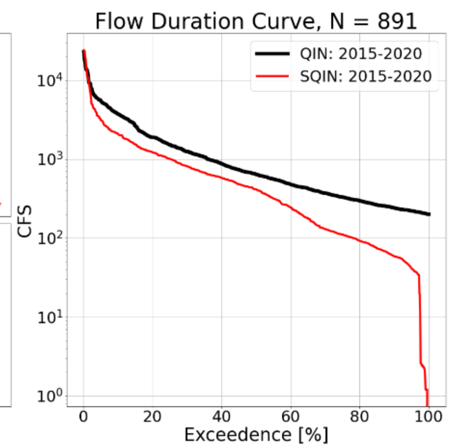
Figure 4-61: Improved calibrations for CUTT2, with SQIN before (blue) and after (green) calibration.

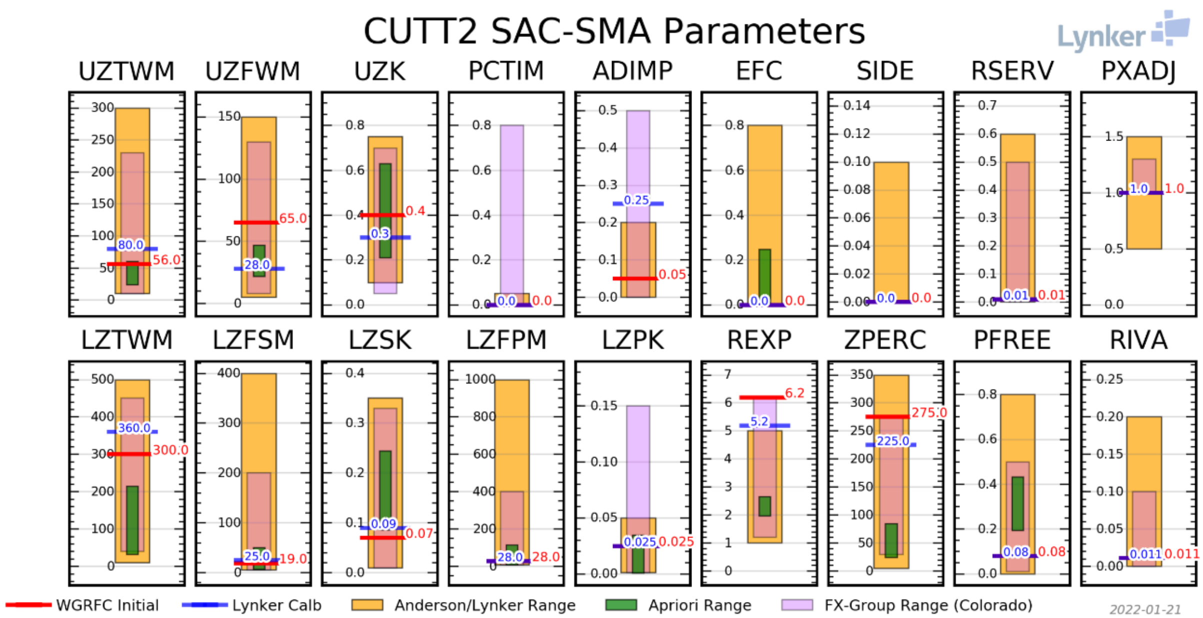
CUTT2: Pecan Bayou near Cross Cut











LKCT2

Lake Coleman near Novice is a headwater basin of Jim Ned Creek. LKCT2 uses a 3-hour simulation timestep and is calibrated to calculated daily inflow data from a mass balance analysis (available from 2000-10-01 to present). Lake Coleman is primarily used as a water supply reservoir, owned by the City of Coleman, and operated as a fill and spill reservoir. The mass balance analysis used to calculate inflows was incomplete due to the absence of consumptive use data; other components of the analysis included NOAA TR33/34 evaporation estimates, MAPX precipitation data, pool elevation data from the USGS (08140770), and surface area data from TWDB. Land cover for LKCT2 is primarily shrub/scrub (65.7%); 0.7% of the basin is developed. Soil types are primarily Type D/ Clay Loam (52.9%).

Because of incomplete consumptive use data for Lake Coleman, and a highly uncertain elevation-discharge relationship, WGRFC advised that calibrations for LKCT2 only consider high inflow events where there were no outflows from the reservoir. All timesteps where outflows were observed were omitted from the inflow timeseries. Estimated peak inflow events thus never exceeded 3,000 CFS, despite simulations suggesting likely peak inflows above 10,000 CFS. Calibration to these more moderate sized events aimed to decrease the initial over-simulations (blue line in Figure 4-62). While correlation coefficient of the final simulation was satisfactory (0.75), the final simulation was still biased very high (124.3% from 2010 to 2020; 51.6% from 2000–2020).

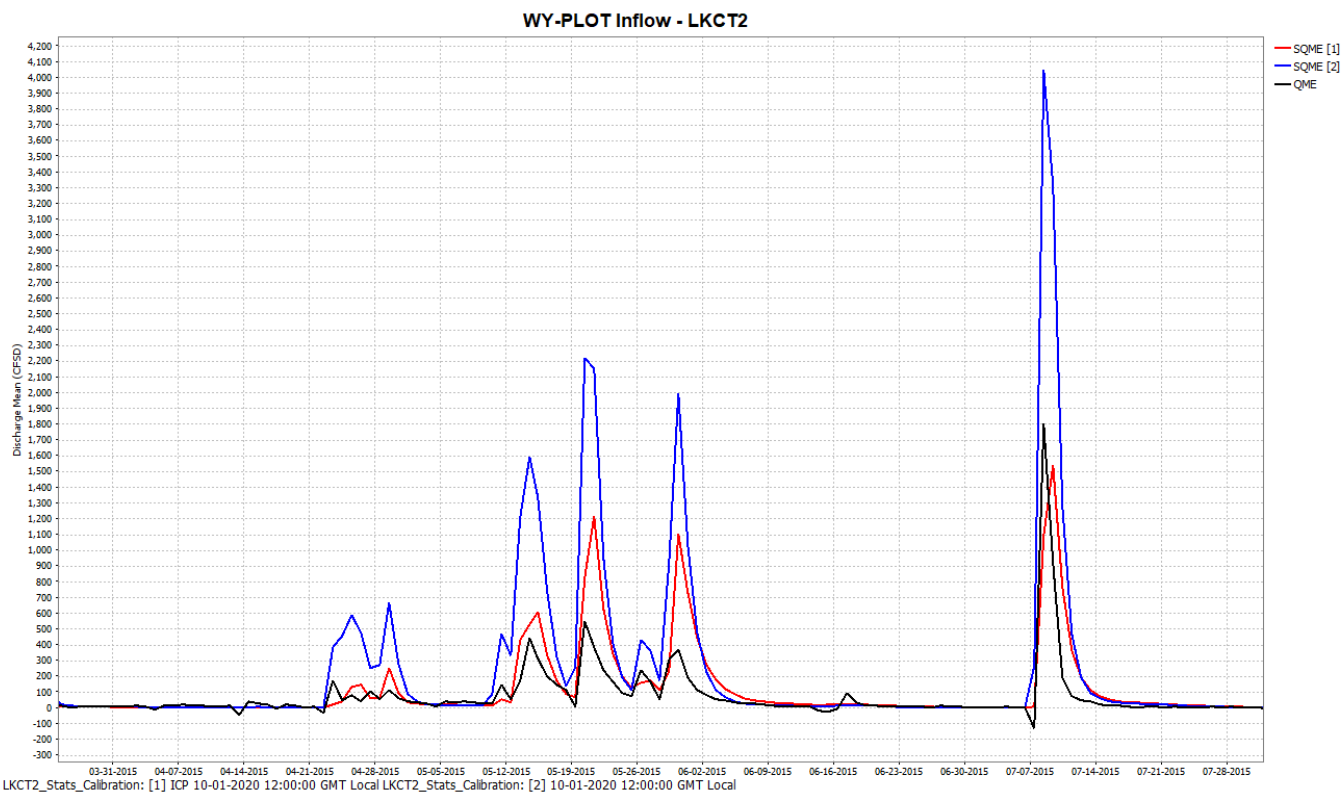
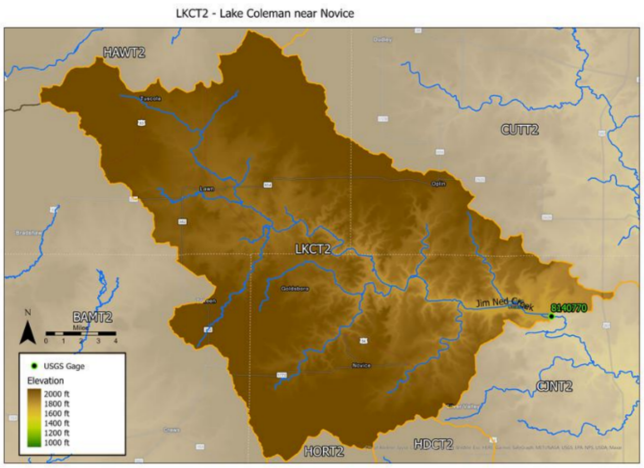
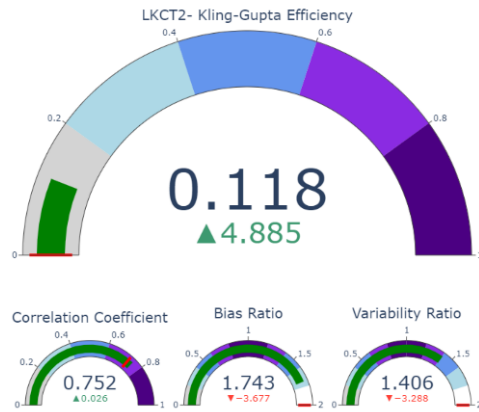
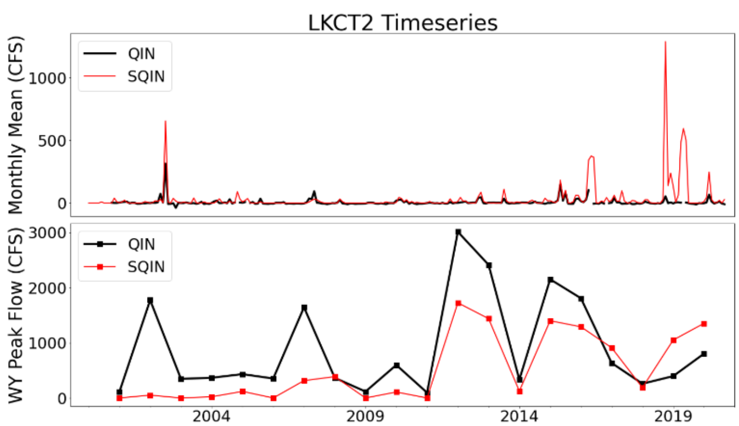


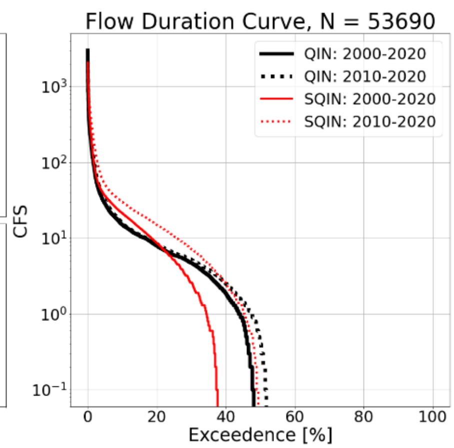
Figure 4-62: Improved calibrations for LKCT2, with SQME before (blue) and after (red) calibration.

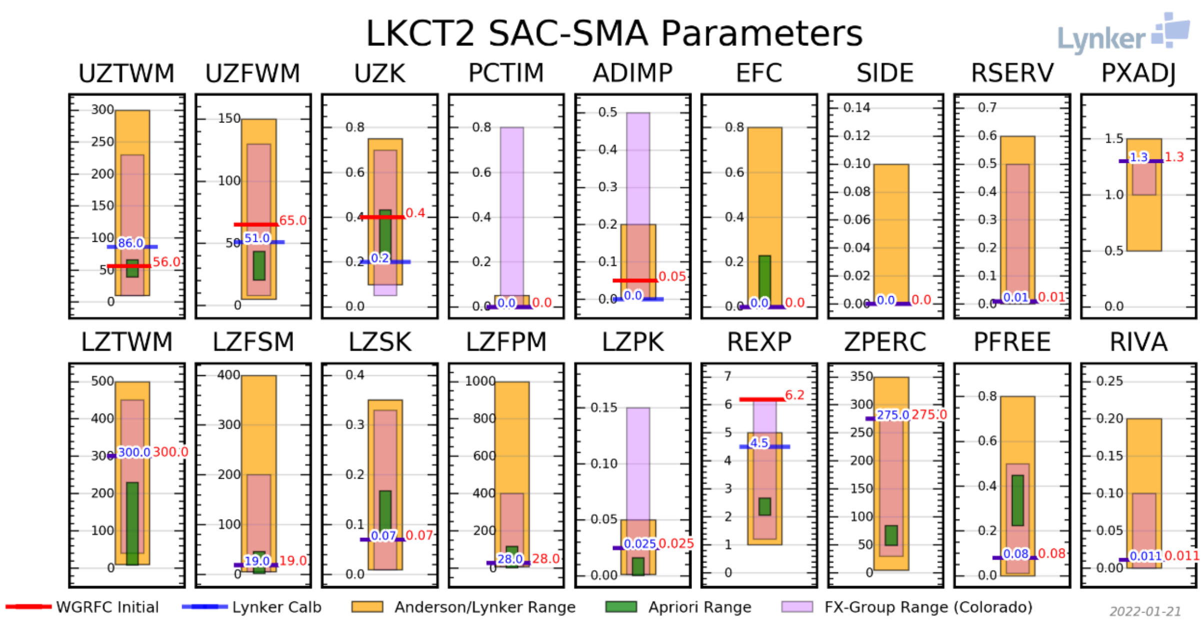
LKCT2: Lake Coleman near Novice











HORT2

Hords Creek Lake near Valera is a headwater basin located above the City of Coleman. HORT2 is configured to use a 3-hour simulation timestep and is calibrated to daily inflow data from the USACE (available from 1946 to present). Hords Creek Lake is formed by a rolled earthfill dam and is primarily used as a water supply reservoir for the City of Coleman, with a conservation pool storage of 8,100 AF. It is owned and operated by the USACE. Land cover for HORT2 is primarily shrub/scrub (82.7%); 0.7% of the basin is developed. Soil types are primarily Type D/ Clay Loam (54.9%).

Calibrations for HORT2 were challenging and plagued by significant bias. During the first half of the record (2000–2010), simulations significantly under-simulated observed inflows, with steadily decreasing accumulated bias (bottom panel, Figure 4-63). From 2012 onwards, these biases level off, and we begin to see over-simulations, particularly in 2018–2020. Efforts to improve this bias during the more recent 2010–2020 period were partially successful (calibrated PBIAS 2.2%), though individual events are not often verified by the simulation.

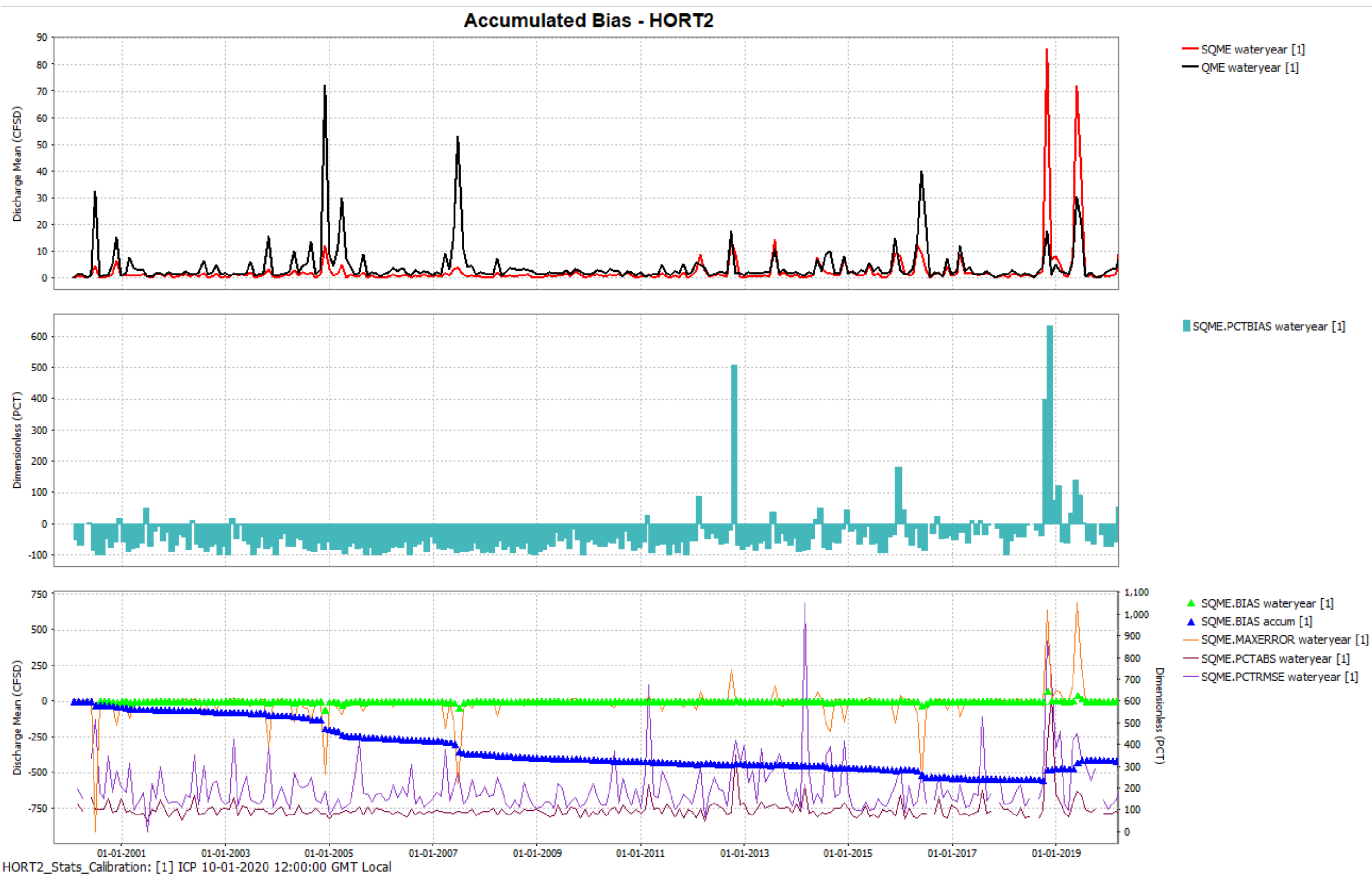
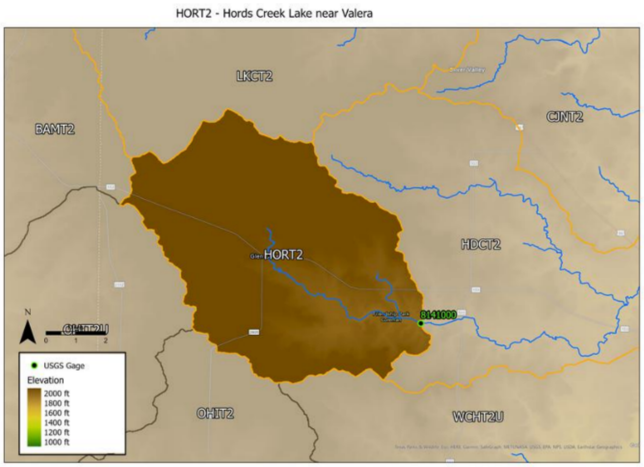
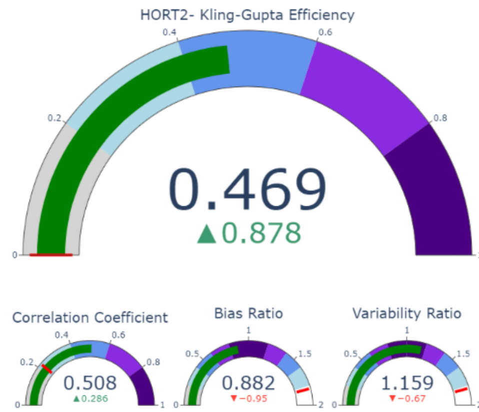
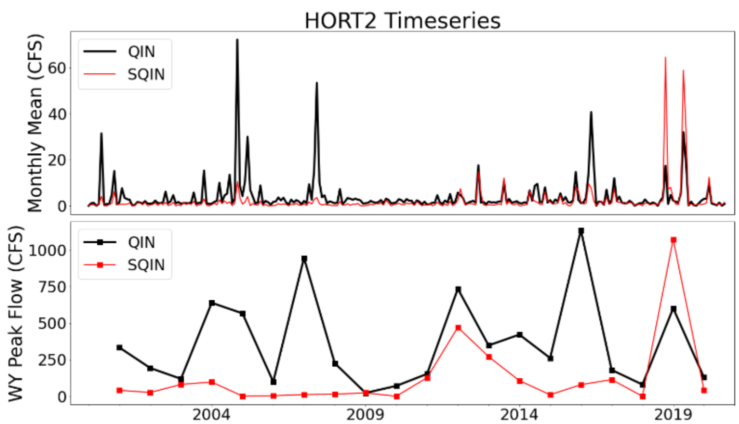


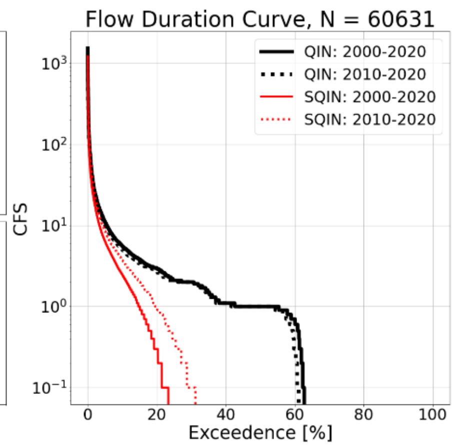
Figure 4-63: HORT2 accumulated bias plot showing low mode bias, with QME/SQME (top), Percent Bias (middle), and Accumulated Bias (bottom).

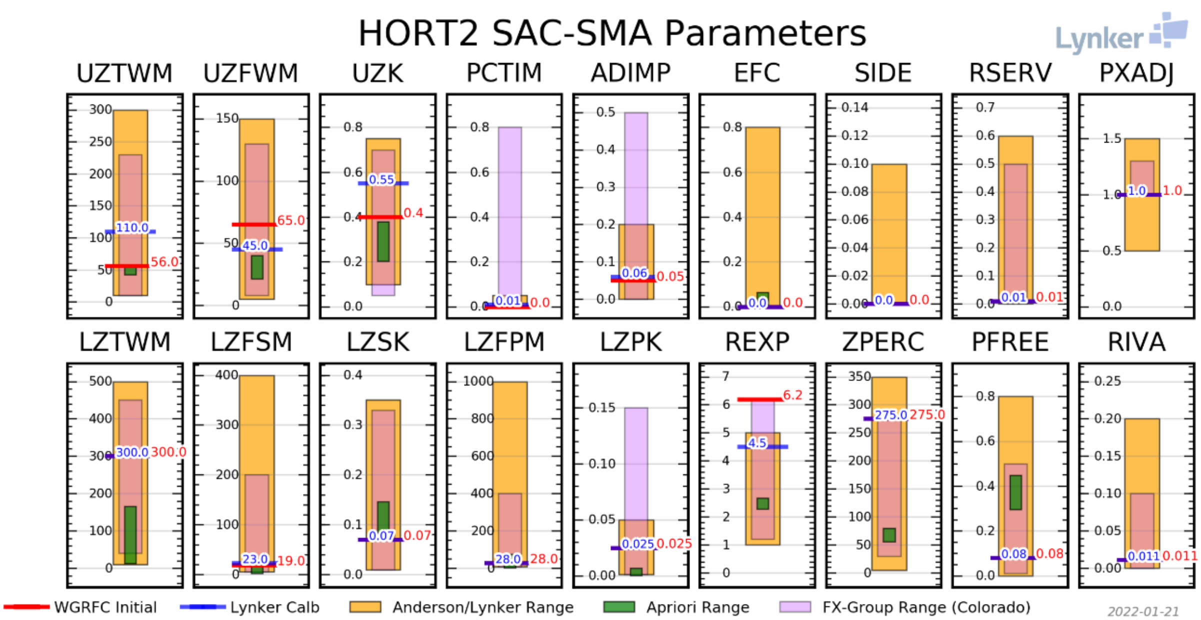
HORT2: Hords Creek Lake near Valera











HDCT2

Hords Creek near Coleman is a local basin located downstream of Hords Creek Lake. HDCT2 uses a 3-hour simulation timestep and is calibrated to instantaneous discharge data from USGS gauge 08142000 (available from 2015-06-18 to present). USGS remarks note that flows at HDCT2 are largely controlled by the upstream reservoir. Land cover for HDCT2 is primarily shrub/scrub (69.2%); 0.6% of the basin is developed. Soil types are primarily Type D/ Clay Loam (52.2%).

Outflows from Hords Creek Lake are minimal, with only three observed outflow events from 1997 to present. Initial simulations were too delayed and not flashy enough (too much interflow; green line, Figure 4-64). Calibrations corrected this observed behavior primarily through decreased UZFWM and increased UZFWM and ADIMP. We also introduced changes to limit the curvature of the percolation curve (REXP) and increase percolation across a wider range of LZDEFR values.

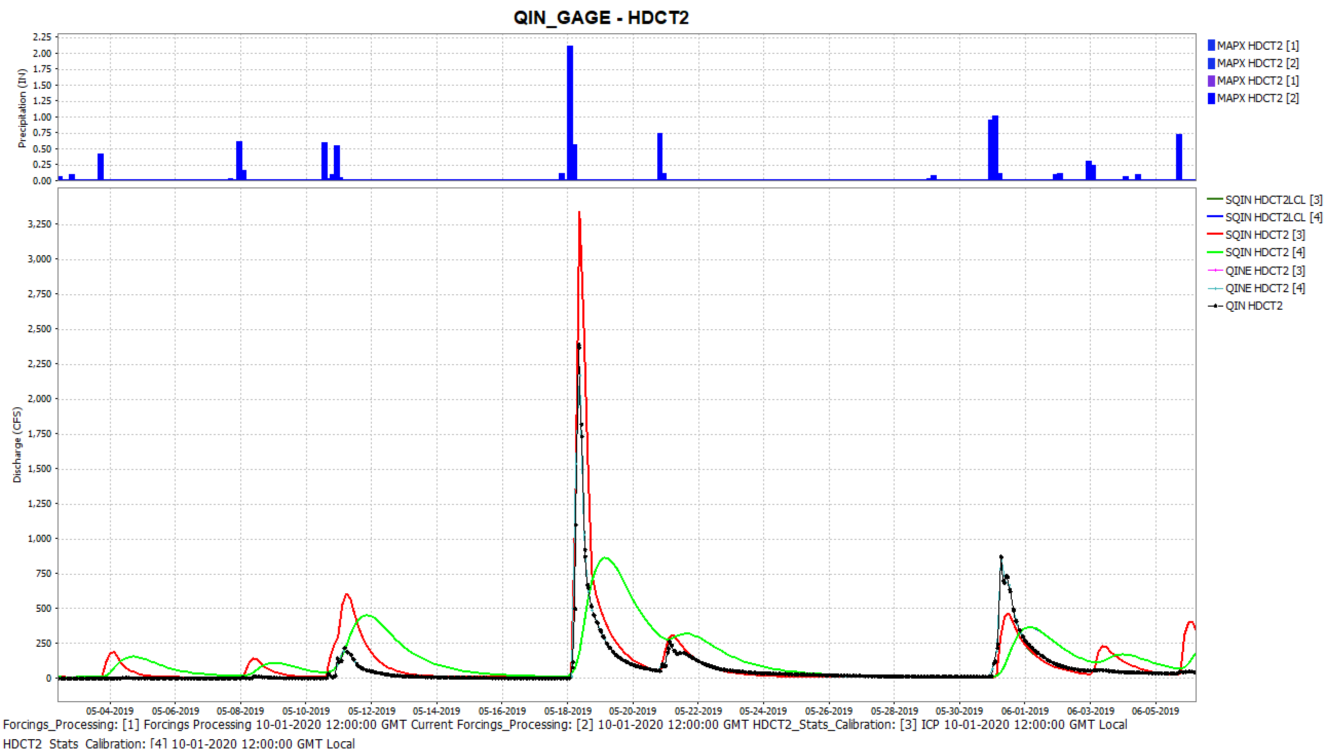
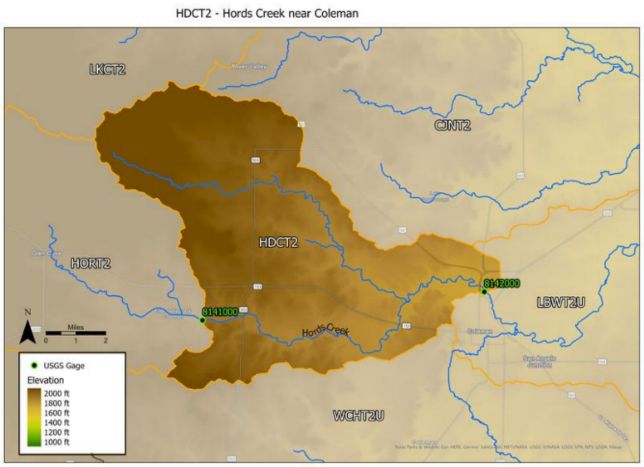
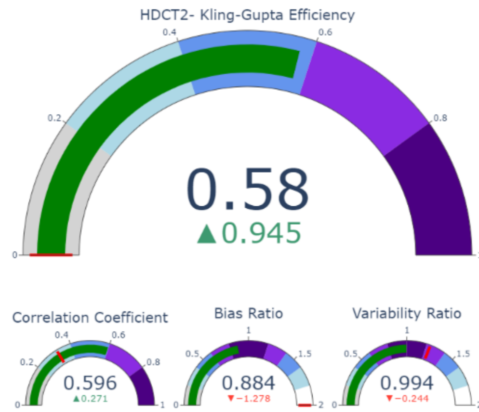
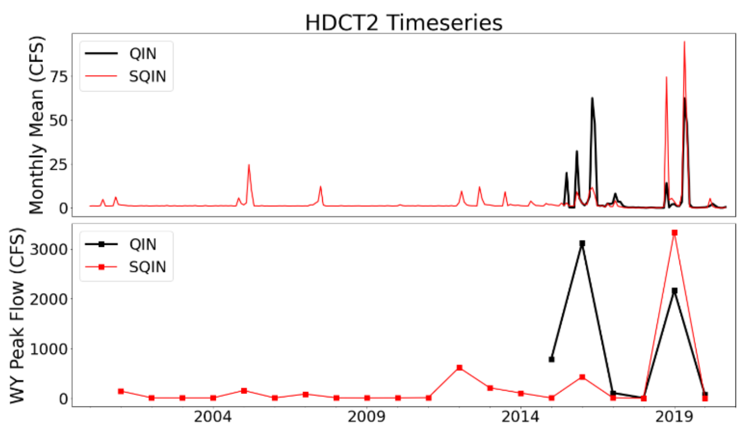


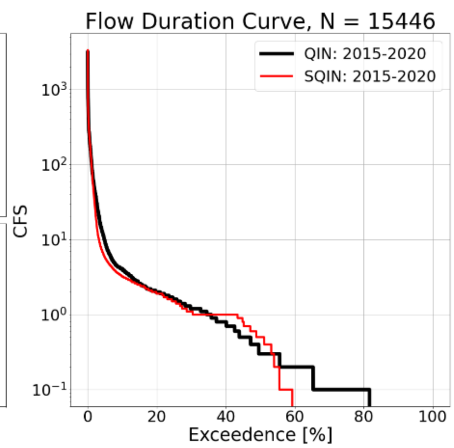
Figure 4-64: Improved calibrations for HDCT2, with SQIN before (green) and after (red) calibration.

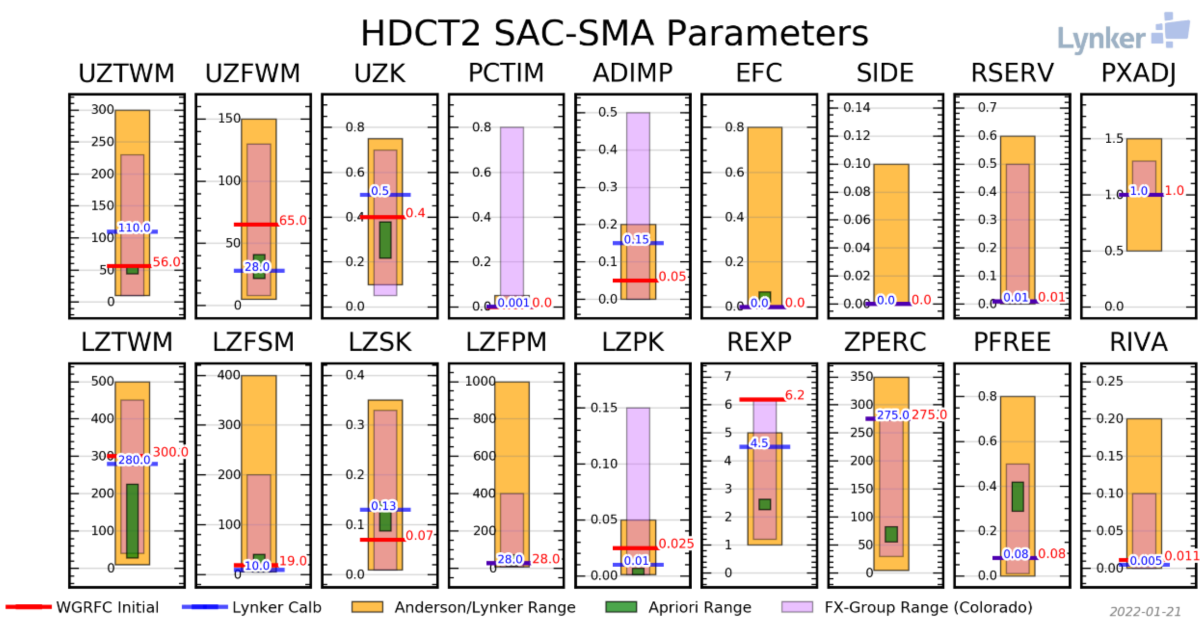
HDCT2: Hords Creek near Coleman











CJNT2

Jim Ned Creek at CR 140 near Coleman is a local basin located downstream of Lake Coleman. CJNT2 uses a 3-hour simulation timestep and is calibrated to instantaneous discharge data from USGS gauge 08140860 (available from 2017-06-19 to present). USGS remarks note that flows at CJNT2 are largely controlled by the upstream reservoir. Land cover for CJNT2 is primarily shrub/scrub (65.0%); 0.2% of the basin is developed. Soil types are primarily Type D/ Clay Loam (76.5%).

Initial simulations for CJNT2 significantly over-simulated the wet-up events of October 2018 (blue line, Figure 4-65) and April 2019. Changes to the percolation curve and increases to the UZTWM and LZTWM dampened this specific hydrograph response and decreased overall model bias from PBIAS 59.2% to 10.0%. The calibrated correlation coefficient (0.923) and KGE score (0.846) show good skill, though the period of record is not long enough to appropriately evaluate model performance for a wide range of flows.

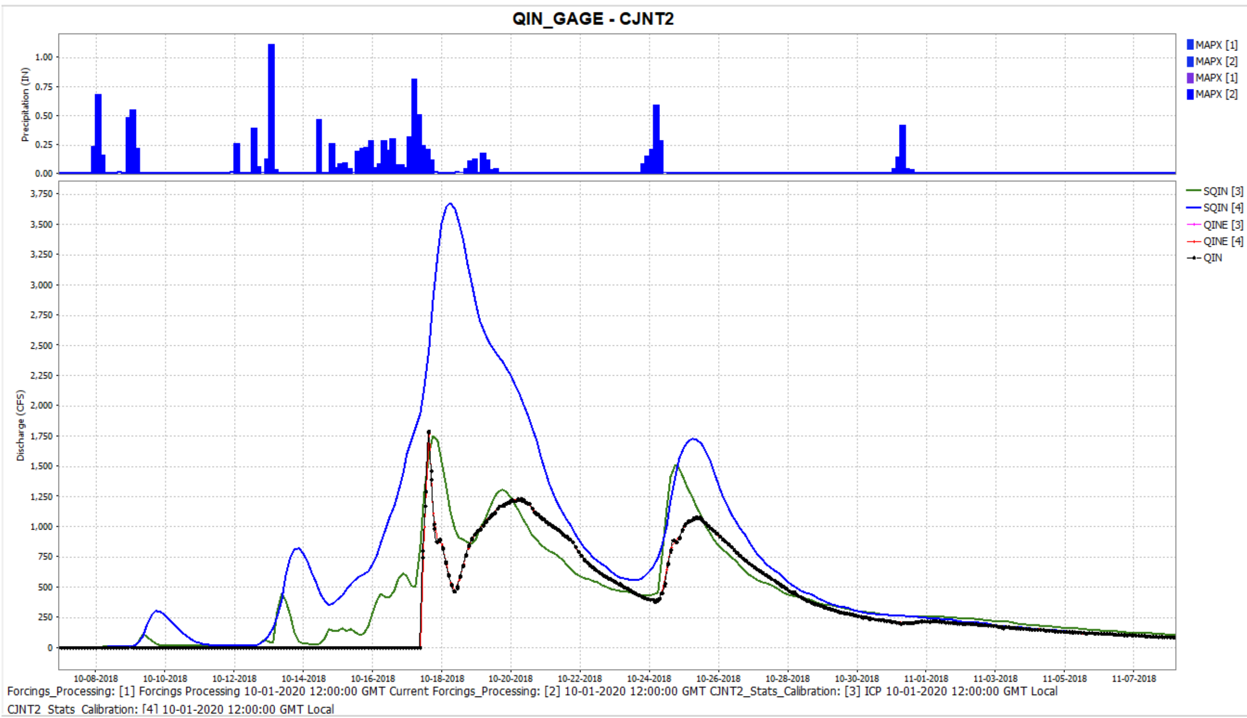
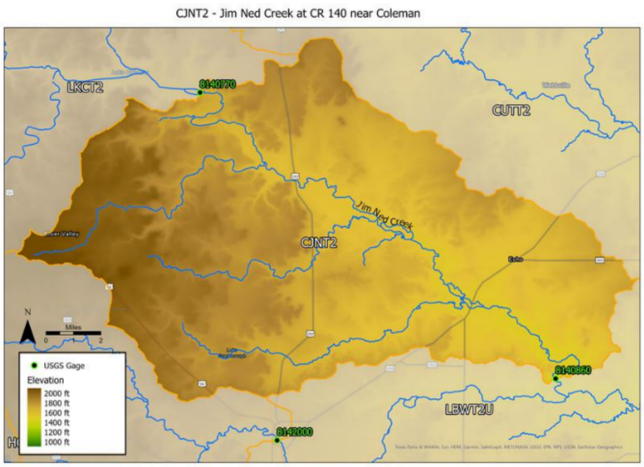
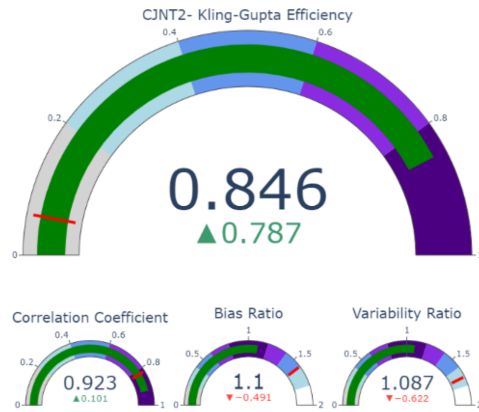
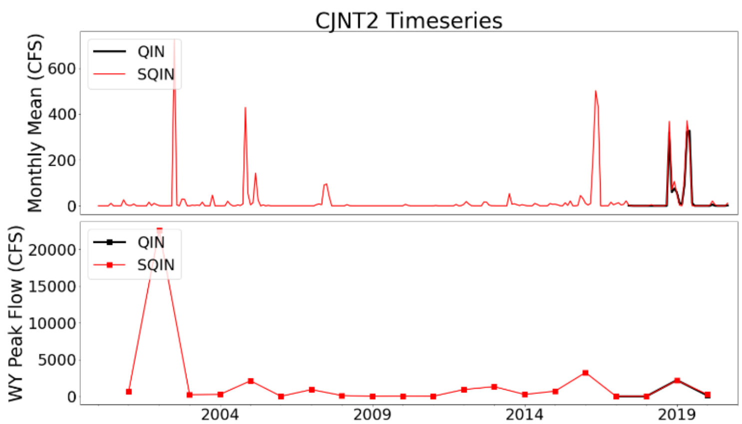


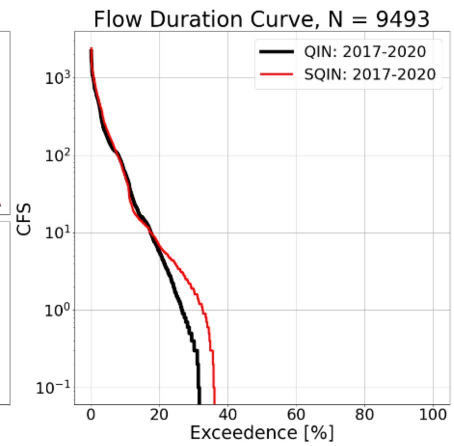
Figure 4-65: Improved calibrations for CJNT2, with SQIN before (blue) and after (green) calibration.

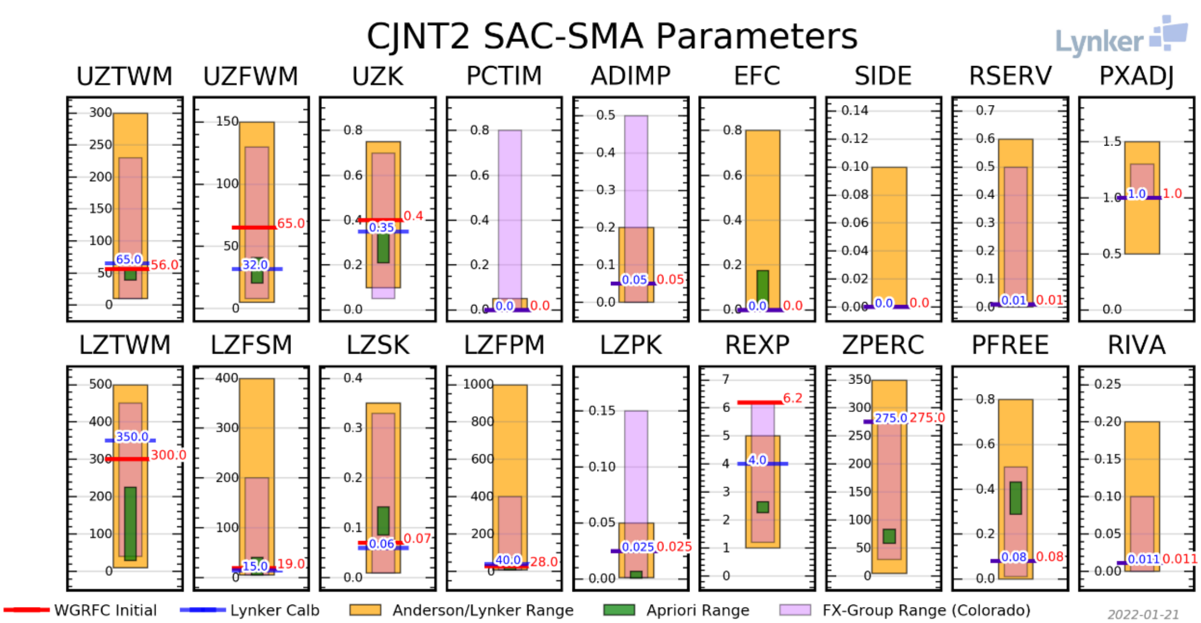
CJNT2: Jim Ned Creek at CR 140 near Coleman











LBWT2/LBWT2U

Lake Brownwood near Brownwood is a local basin located at the confluence of Jim Ned Creek and Pecan Bayou. LBWT2 uses a 3-hour simulation timestep and is calibrated to calculated daily inflow data derived from a mass balance analysis (available from 2000-01-01 to present). Lake Brownwood is primarily used for irrigation, municipal, and industrial supply. Upstream flows are affected by fifty-nine flood-detention ponds, which have a combined capacity of 73,310 AF. Data for the mass balance analysis was derived from NOAA TR33/34 evaporation estimates, MAPX precipitation data, pool elevation data from the USGS (08143000), BCWID diversion data, and surface area data from TWDB. Land cover for LBWT2 and upstream LBWT2U is primarily shrub/scrub (50.4/52.8%, respectively for LBWT2 and LBWT2U); 1.3/2.1% of the basin is developed. Soil types are primarily Type D/Clay Loam (40.8/48.6%) and Type C/Sandy Clay Loam (38.5/49.9%).

Initial simulations for LBWT2 and the upstream LBWT2U (no observed streamflow data) often under-simulated moderate to major inflow events to Lake Brownwood (blue line, Figure 4-66). Calibrations increased UZK and PCTIM to adjust interflow timing and increase the amount of impervious runoff. We also introduced adjustments to the percolation curve and UHG. Upstream calibrations at LBWT2U were inferred downstream at LBWT2 due to the absence of available streamflow data. LBWT2U calibrations decreased the UZTWM and LZTWM values, and increased surface runoff generation with a smaller UZFWM. Even with these changes, simulations are still biased low, particularly in the earlier part of the record. However, there are reasons to question the accuracy of some of the USACE inflow data, e.g., the ~14,000 CFS inflow event on November 29, 2018 is suspect: it is neither preceded by any measurable precipitation or notable upstream streamflow events at CUTT2 or CJNT2 for the two weeks prior.

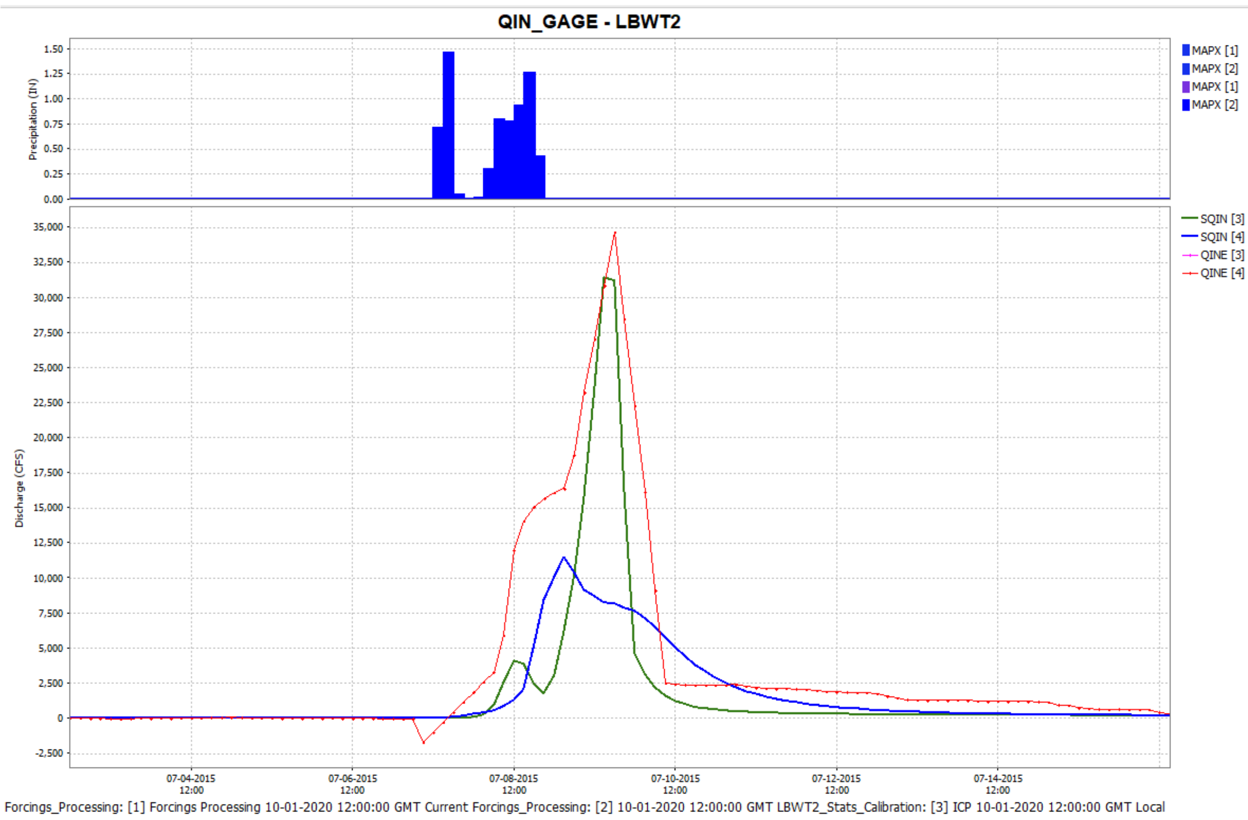
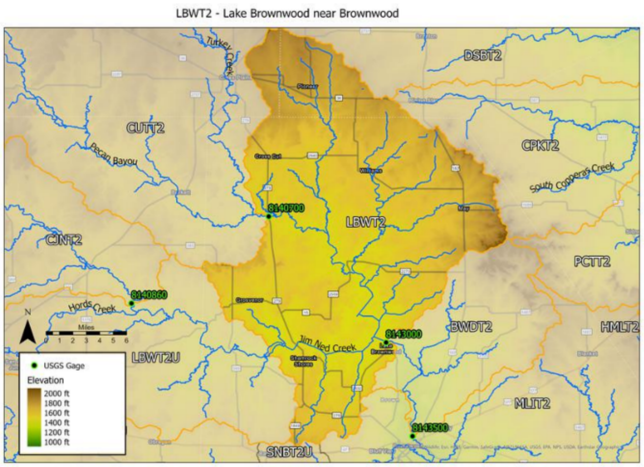
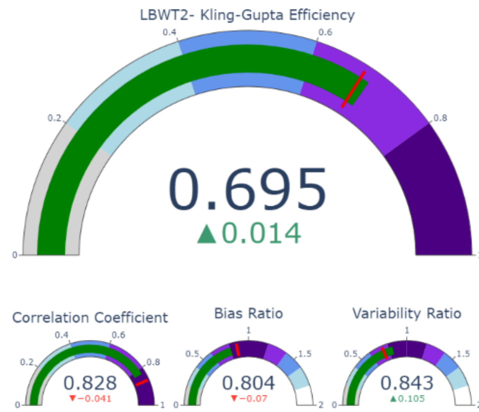
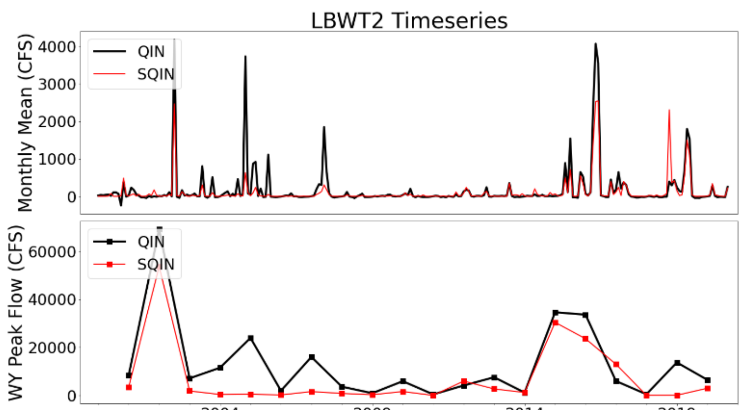


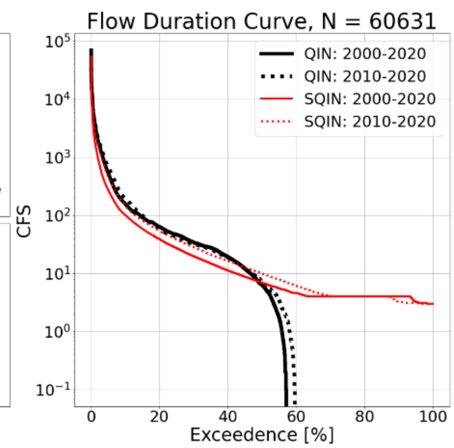
Figure 4-66: Improved calibrations for LBWT2, with SQIN before (blue) and after (green) calibration.

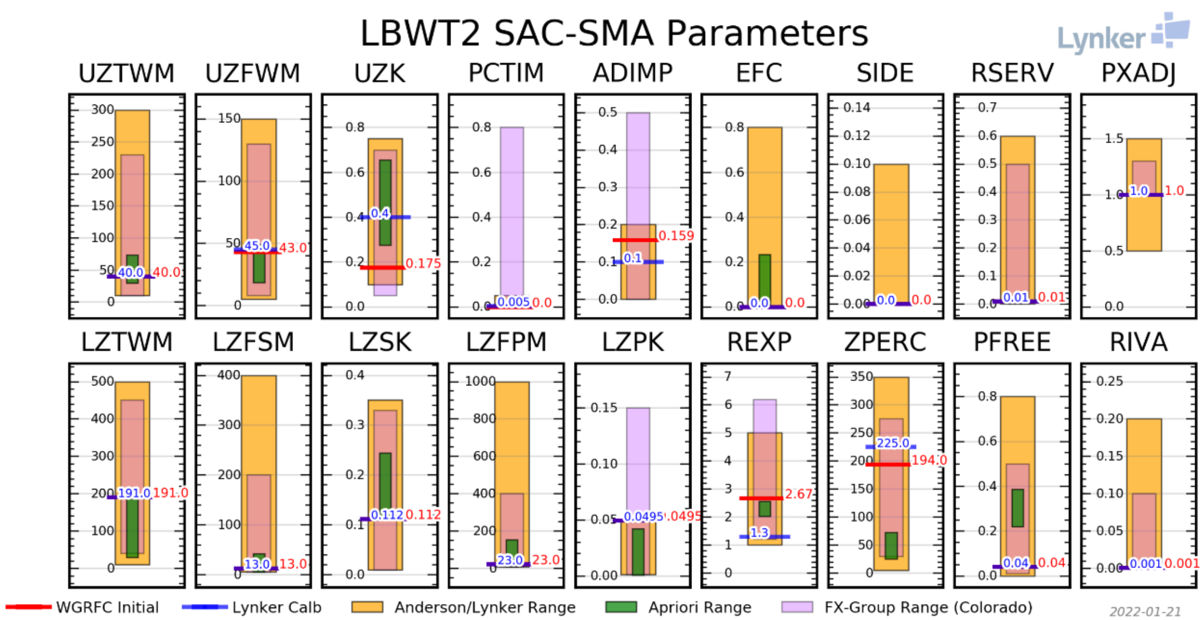
LBWT2: Lake Brownwood near Brownwood











BWDT2

Pecan Bayou at Brownwood is a local basin located downstream of Lake Brownwood. BWDT2 uses a 3-hour simulation timestep and is calibrated to instantaneous discharge data from USGS gauge 08143500 (available from 2018-10-17 to present). USGS records note that flows at BWDT2 are largely controlled by outflows from Lake Brownwood, though there are also small local tributaries (Salt, Red Hole, and Elm Creeks). Land cover for BWDT2 is primarily shrub/scrub (57.8%); 1.1% of the basin is developed. Soil types are primarily Type C/Sandy Clay Loam (53.0%).

In addition to having a limited observed streamflow record (< 2 years), BWDT2 also has an incomplete rating curve, with no discharge estimates below 350 CFS (stage 6.68 feet). Because of the limited records, and only one significant series of releases from Lake Brownwood (April – June 2019), parameter adjustments were modest. Additionally, routed flows from LBWT2R commonly exceeded observed flows, suggesting significant unaccounted for consumptive use. To compensate for this and dampen local flows (green line, Figure 4-67), UZTWM was increased and UZK was decreased.

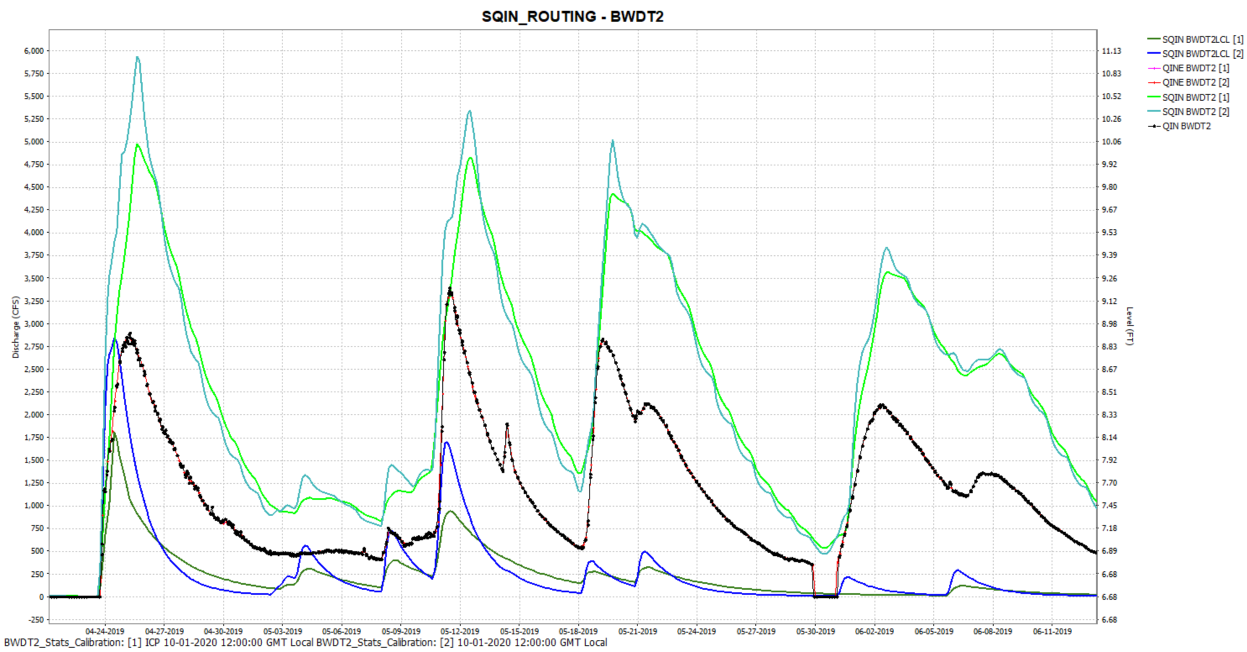
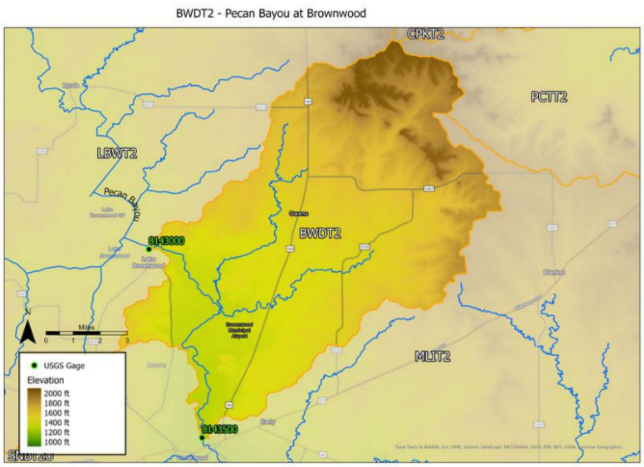
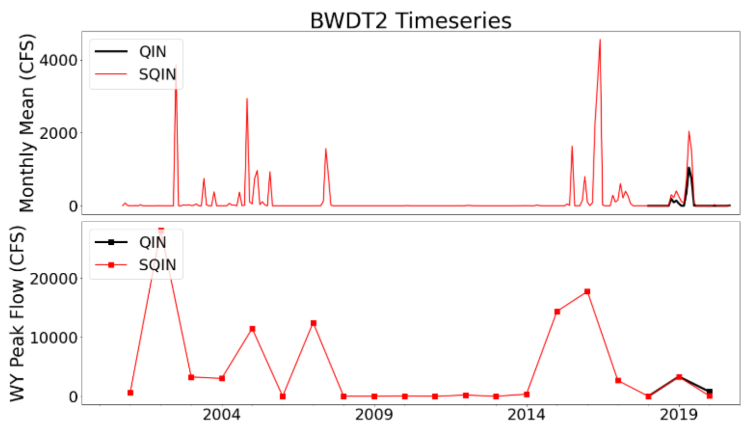
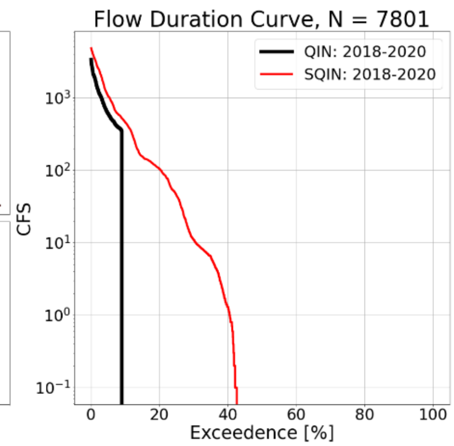


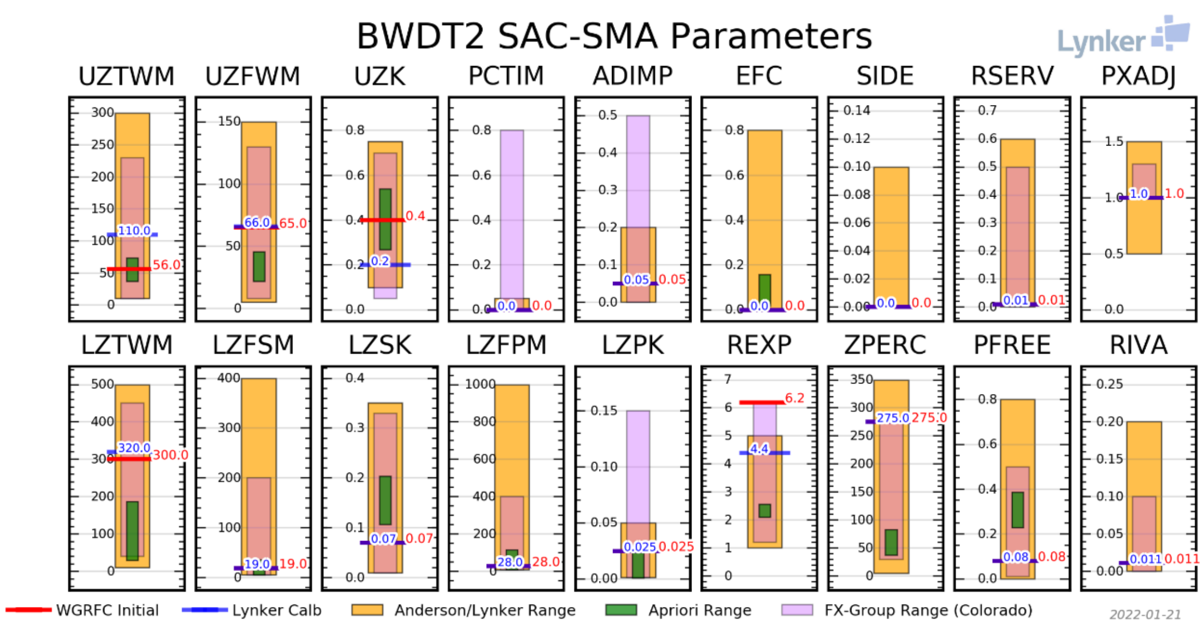
Figure 4-67: Improved calibrations for BWDT2, with SQIN before (dark blue and light blue) and after (dark green and lime green) calibration. Note improvements to the flashiness of the local flows (dark blue).

BWDT2: Pecan Bayou at Brownwood









4.1.4. Funding Dependent Calibration Summary – Nueces

4.1.4.1. Central Texas Coastal HUC6

Aransas HUC8/Missions HUC8

MIOT2

Medio Creek near Beeville (MIOT2) is a headwater basin. MIOT2 uses a 1-hour simulation timestep and is calibrated to instantaneous discharge data from USGS gauge 08189300 (available from 2001-09-14 to present). USGS remarks note that there are no known regulation or diversions. The basin land use is predominantly shrub/scrub (54%) and hay/pasture (35%) with minimal development. The soils are predominantly Type B (51%) With the remaining 49% being split mostly evenly between Type C and D.

The primary challenge with this basin calibration is the ability to produce adequate runoff response for the larger observed flow events while limiting the prevalence of false alarm responses for rainfall events of similar magnitude. Timing of events was also inconsistent with modifications that improve the simulation for some events often caused a degradation for other events. We settled on a slightly more delayed and attenuated UNIT-HG. Post-calibration statistical improvement was modest. Additional attention was given to the November 2001 event – the largest event in the calibration period (Figure 4-68).

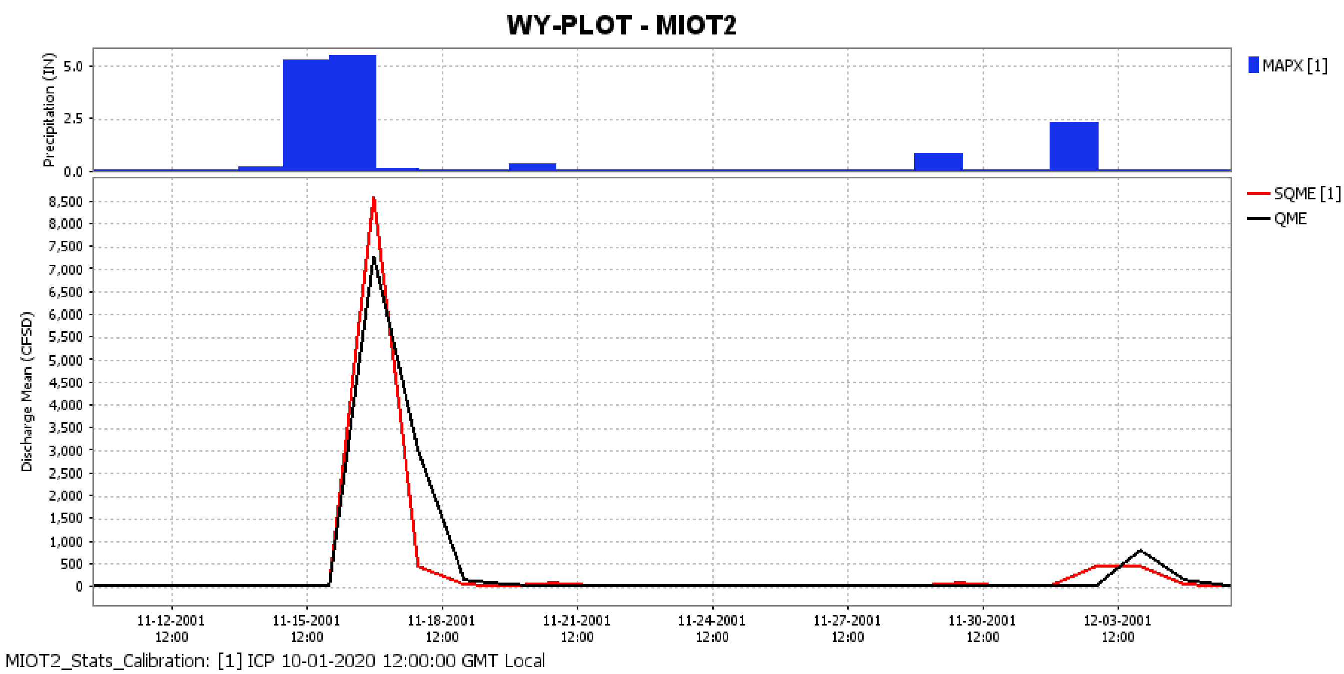
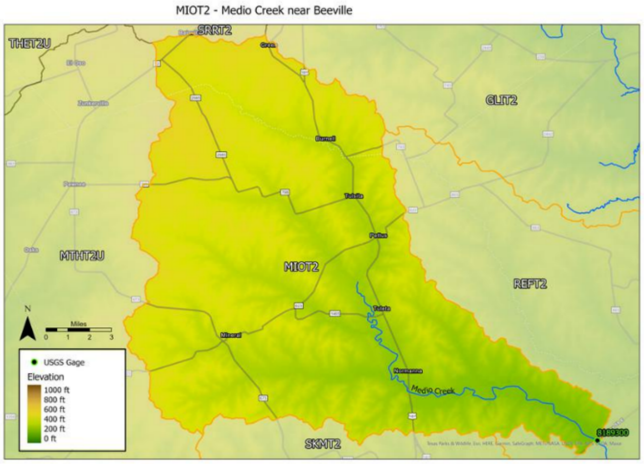
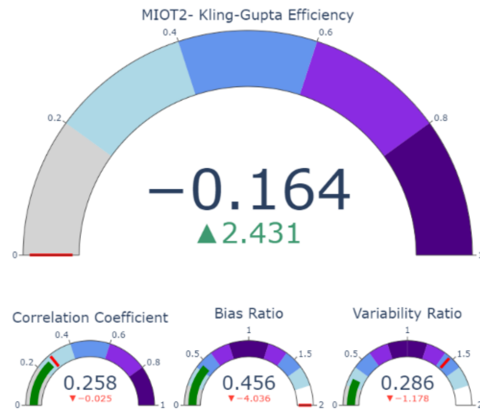
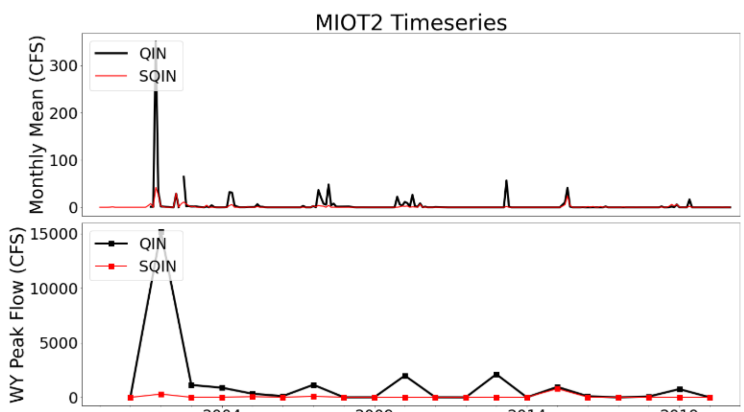


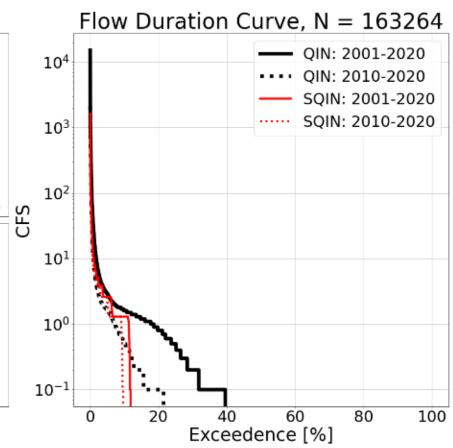
Figure 4-68: MIOT2 simulated (red) vs. observed (black) daily streamflow for a November 2001 event.

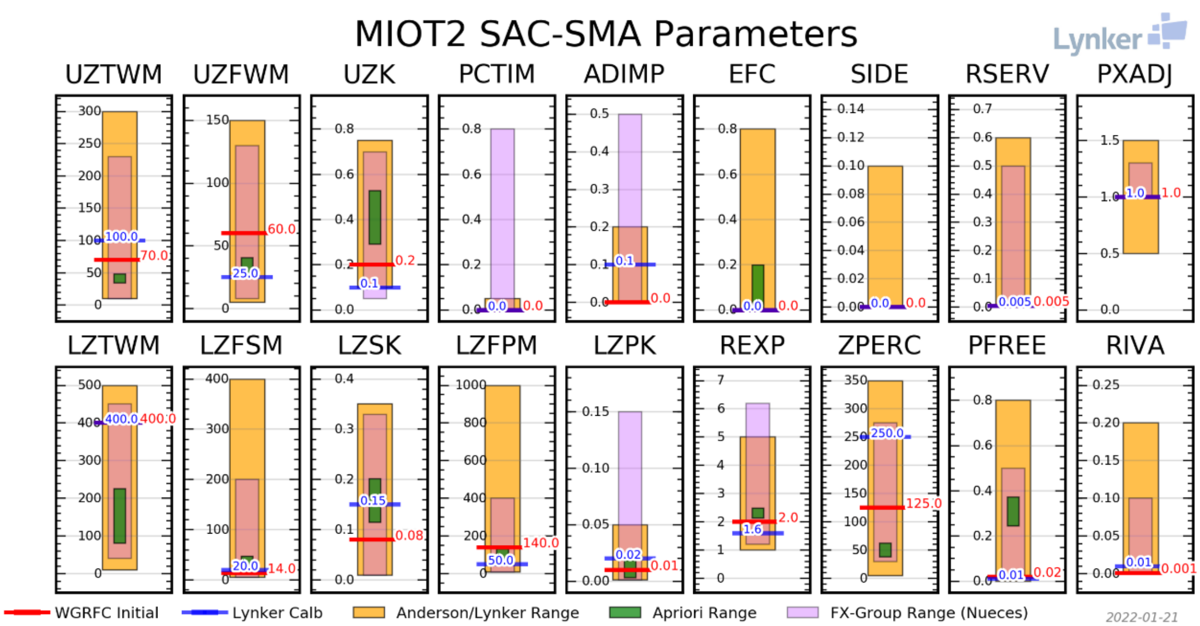
MIOT2: Medio Creek near Beeville











SKMT2

Aransas River near Skidmore (SKMT2) is a headwater basin. Simulations for SKMT2 use a 1-hour timestep and models were calibrated to instantaneous discharge data from USGS gauge 08189700 (available from 1995-10-06 to present). USGS remarks note that there are no known regulation or diversions. The City of Beeville discharges wastewater effluent into the river via Poesta Creek 3.8 mi upstream. The basin land use includes hay/pasture (39%) and shrub/scrub (34%) with slightly more development (5%) than the neighboring Nueces basins. The soils in the basin predominantly type C (44%) with much of the rest split between Type B (28%) and Type D (25%).

Calibration for SKMT2 focused on the most recent 5-10 years. Prior to calibration, we noted that events generally over-simulated the peak magnitude (blue line Figure 4-69) and baseflows were under simulated. Additionally, there was simulated runoff for events that did not appear to show a streamflow response. The persistently under-simulated baseflow issue was addressed by adding a constant 2 cfs baseflow to the UNIT-HG parameterization which is justified by the USGS gauge remarks noting that there is effluent discharge added to the river upstream. The unit hydrograph also had to be drawn out significantly to help address timing issues of the responses, which may be the result of converting this model to use a 1-hour timestep.

Statistical improvement was modest but overall, the calibration show more consistency in the responses.

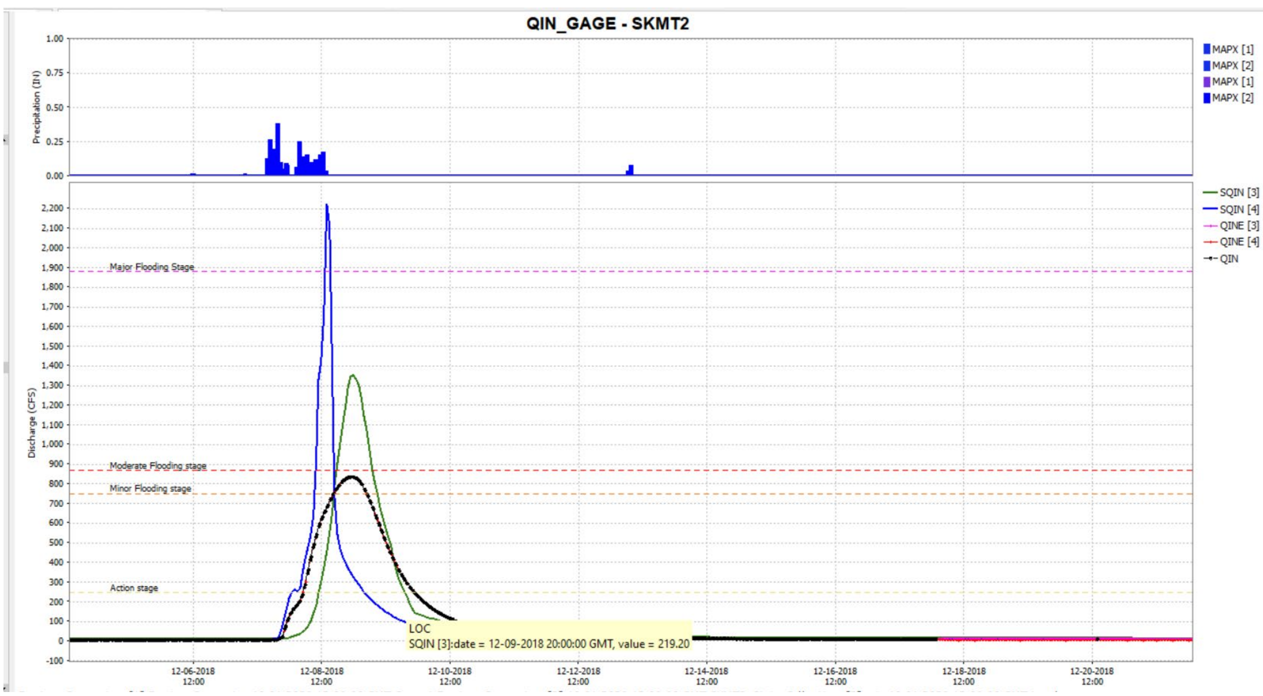
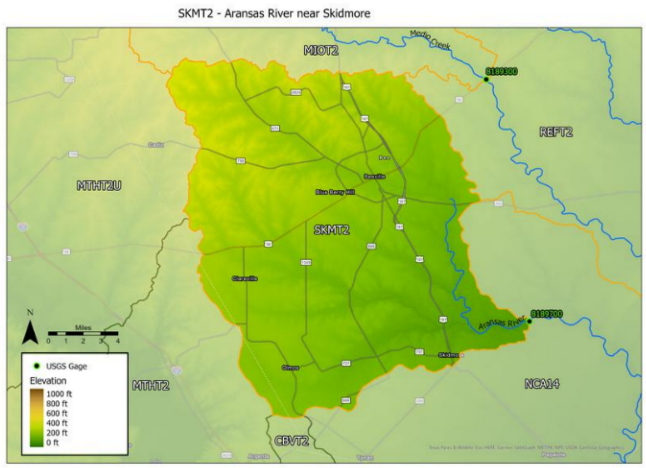
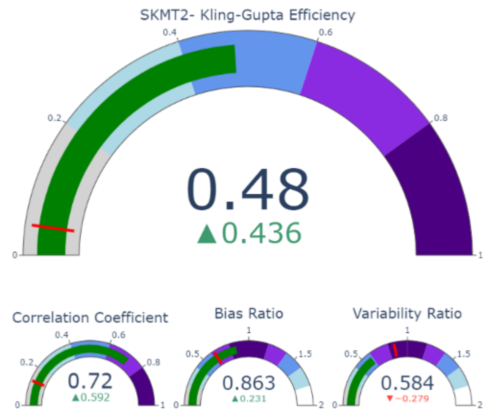
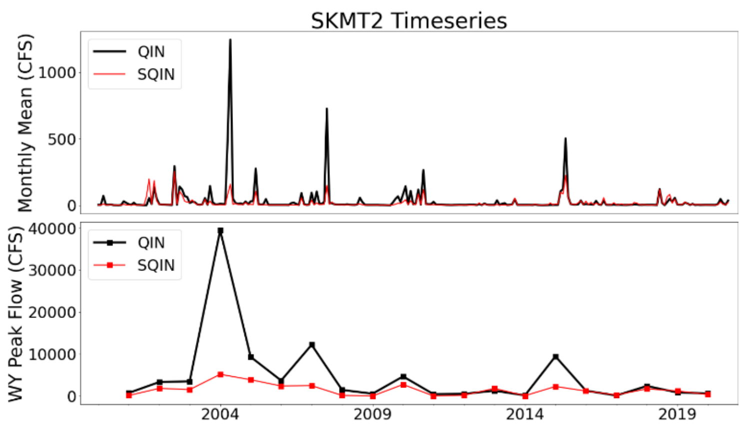


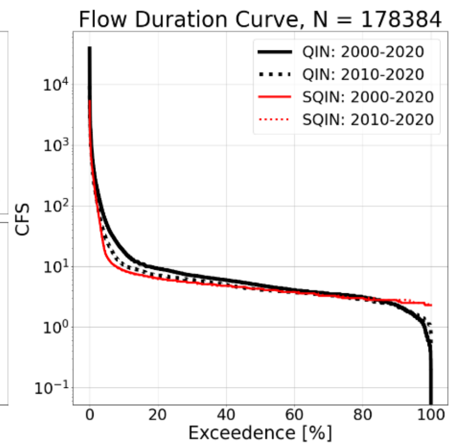
Figure 4-69: Improved calibrations for SKMT2, with SQIN before (blue) and after (green) calibration.

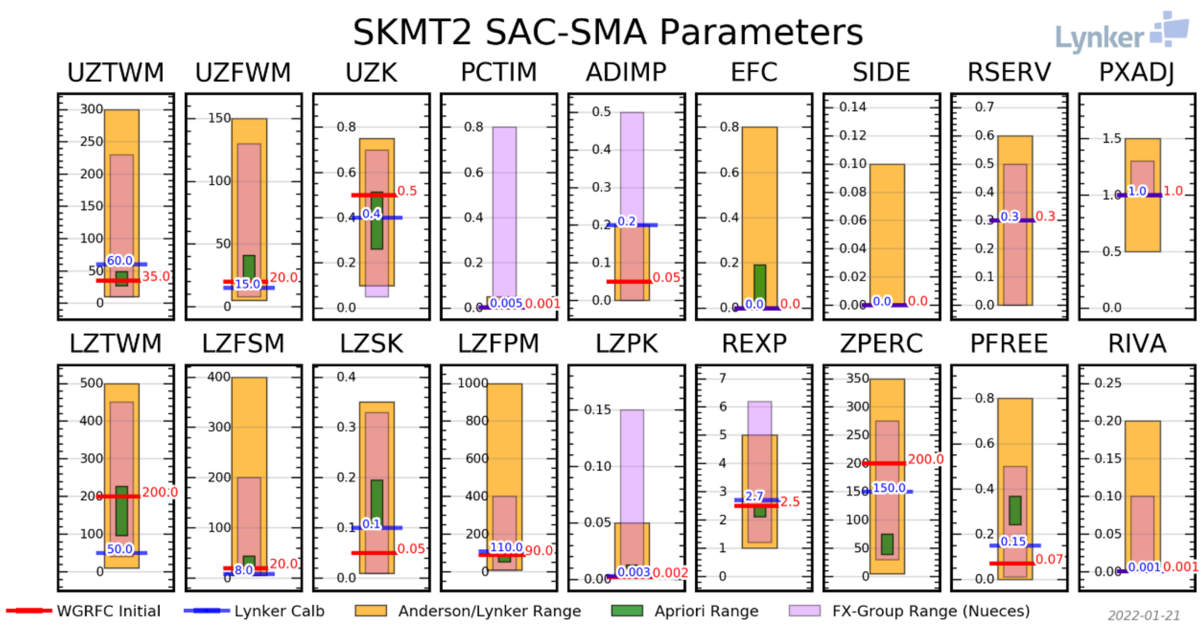
SKMT2: Aransas River near Skidmore











REFT2

Mission River at Refugio (REFT2) is a local basin downstream of MIOT2. Simulations for REFT2 use a 1-hour timestep, and models were calibrated to instantaneous discharge data from USGS gauge 08189500 (available from 1988-06-01 to present). USGS remarks note that there is no known regulation, but there are several small diversions above the station. The basin land use is predominantly shrub/scrub (49%) and hay/pasture (32%) with minimal development. The soils in this basin are primarily Type C (73%).

Calibration for REFT2 focused heavily on the last 5-10 years as performance in the first 10 years was inconsistent. The unit hydrograph had to be attenuated significantly in order to address many of the timing issues with local flows. The lag and attenuation were also both increased to create better performance in the routed flows from MIOT2. Pre-calibration most events over simulated and timing was too early (Figure 4-70).

Final statistical improvement was significant, and the final calibrations show responses that are much improved for many events.

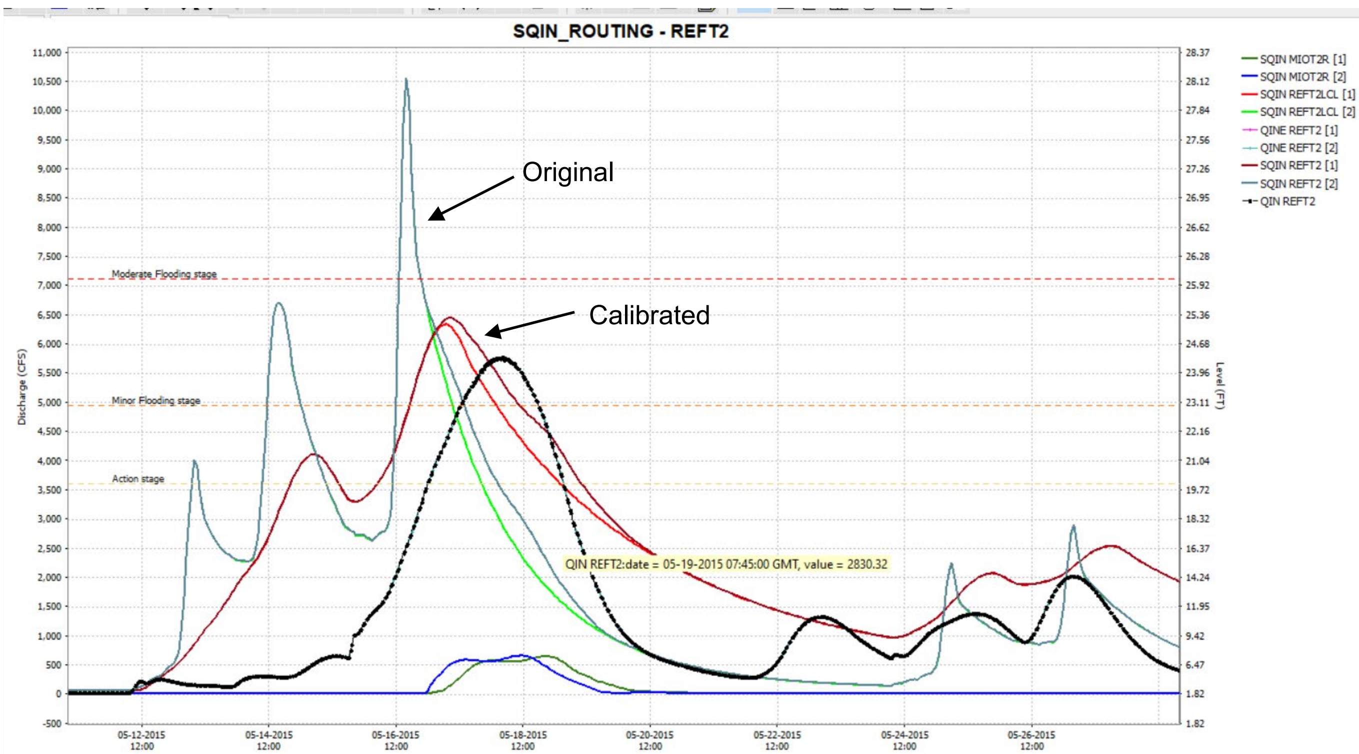
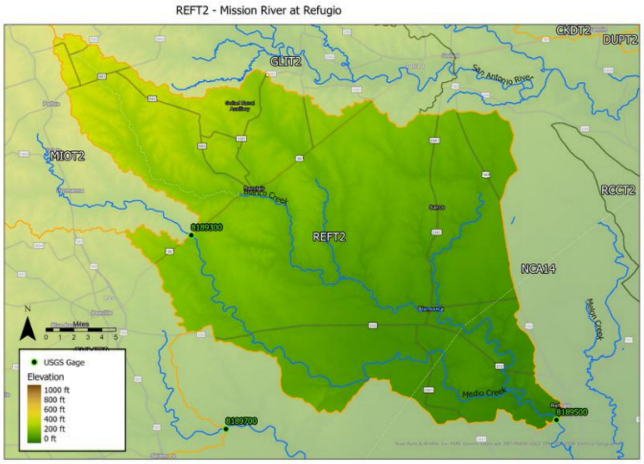
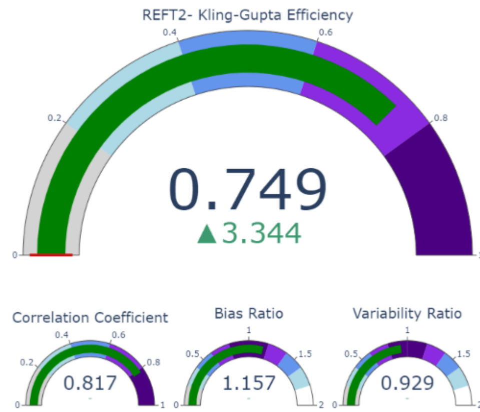
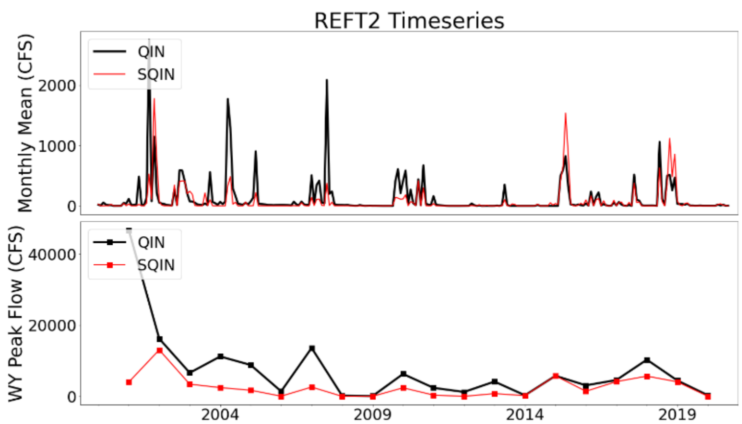


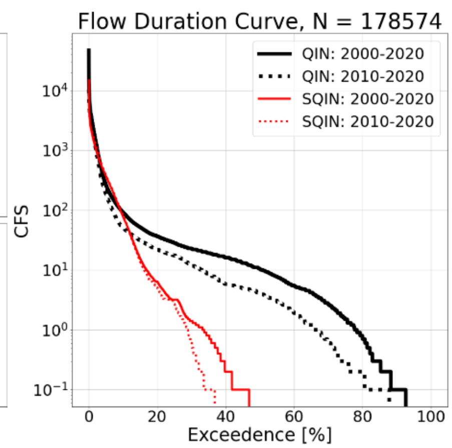
Figure 4-70: Improved calibrations for REFT2, before (light grey and lime green) and after (maroon and red) calibration.

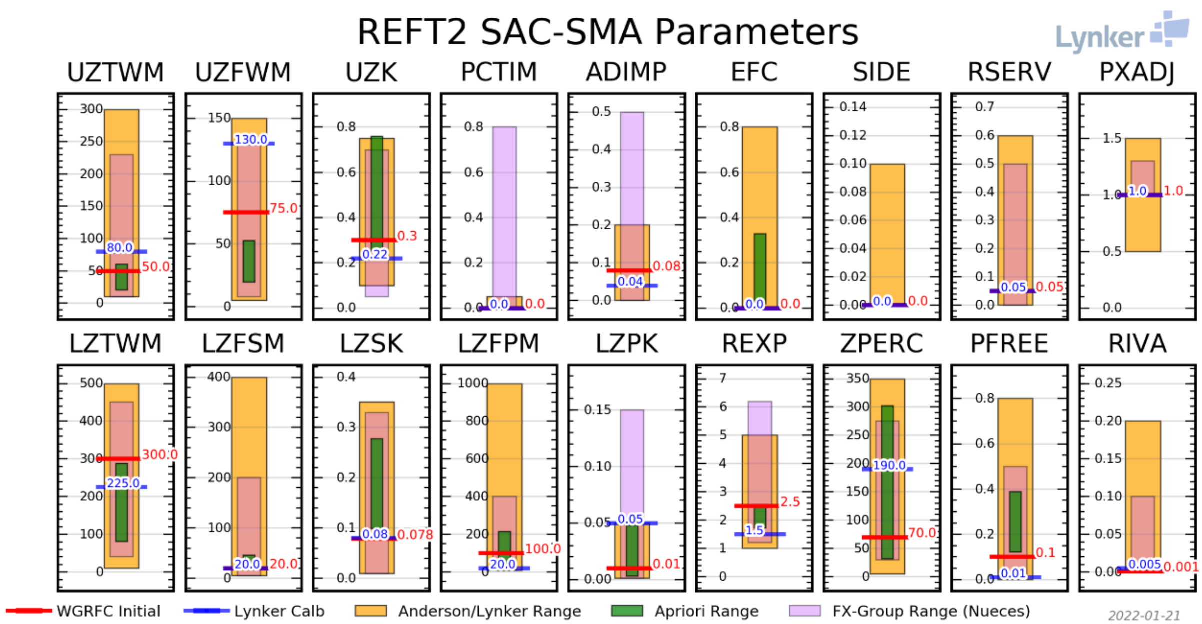
REFT2: Mission River at Refugio









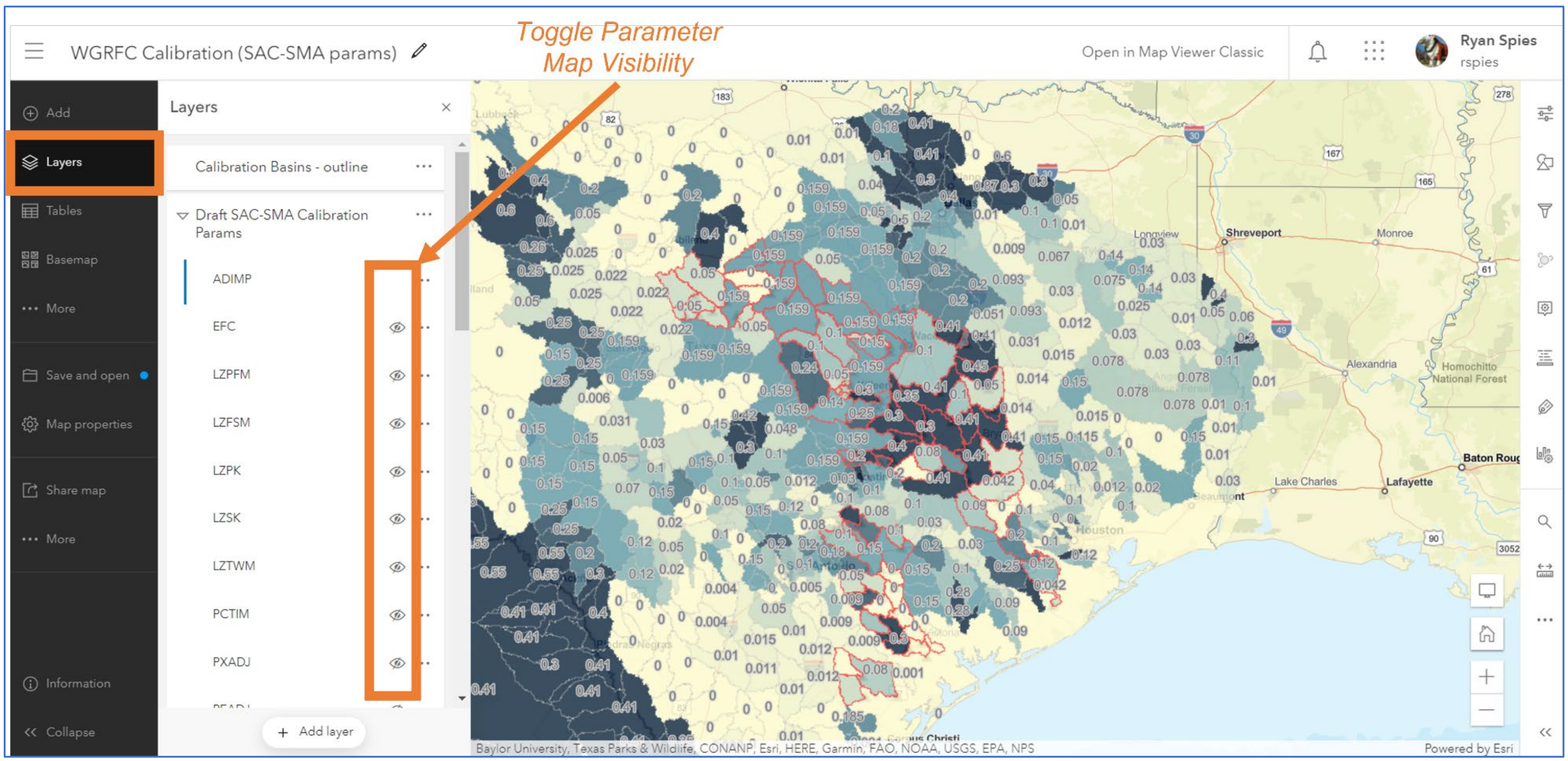


4.2. Calibrated Parameters

A basin boundary shapefile with all WGRFC SAC-SMA parameters values is provided in the supplemental files provided with the project deliverables. We have also published the basin parameter shapefile to an ArcGIS Online map for easy viewing and reviewing the spatial distribution for each parameter. Lastly, the following pages contain tables with parameter values grouped by major river basins.

View the calibrated SAC-SMA parameters on the online map HERE.

To toggle through parameters, click on the Layers tab on the left menu bar, select "Final Calibrated SAC-SMA Parameters" and click/un-click the eye icon. Be sure to only select one parameter at a time to view.



4.2.1. Brazos

Throughout the calibration process we routinely reference the map of SAC-SMA parameter values (pre-calibration) to help ensure spatial consistency where possible. We then updated the SAC-SMA parameter map with calibrated parameter values to examine the spatial changes during the peer review process. Table 4-3 through Table 4-8 (sorted by forecast group) contain the full list of the SAC-SMA calibrated parameter values for each basin.

Table 4-3: Final SAC-SMA calibration parameter values for the Brazos basins

Basin	PCTIM	ADIMP	RIVA	UZTWM	UZFWM	UZK	ZPERC	REXP	LZTWM	LZFPM	LZFSM	LZPK	LZSK	PFREE	RSERV
GAST2	0.001	0.08	0.01	50	75	0.35	130	1.8	140	25	35	0.01	0.12	0.1	0.01
BNLT2	0.06	0.35	0.001	25	22	0.1	120	2	135	80	75	0.007	0.05	0.4	0.01
LRIT2	0	0.159	0.001	40	50	0.3	194	2.67	191	23	13	0.0495	0.112	0.04	0.01
PICT2	0.001	0.15	0.022	80	60	0.37	180	1.4	160	90	8	0.006	0.05	0.25	0.3
KEMT2	0.001	0.24	0.006	85	70	0.3	110	1.4	180	400	20	0.002	0.05	0.18	0.12
DNGT2	0.004	0.14	0.003	40	55	0.25	194	2.67	191	90	13	0.01	0.08	0.15	0.01
SDOT2	0.006	0.3	0.003	40	36	0.05	194	2.67	191	75	38	0.03	0.01	0.2	0.01
BYBT2	0.04	0.15	0.005	12	10	0.6	50	1.8	45	150	125	0.01	0.2	0.3	0.35
BCIT2	0.02	0.2	0	15	10	0.5	150	2.25	50	100	100	0.008	0.3	0.45	0.35
BKFT2	0.03	0.2	0.001	20	40	0.15	150	2.25	90	60	40	0.01	0.1	0.35	0.35
BSYT2	0.002	0.5	0	30	10	0.1	250	1.25	225	20	6	0.01	0.12	0.35	0.35
BKTT2	0.01	0.25	0.001	35	15	0.2	150	1.5	180	40	20	0.01	0.1	0.45	0.35
RKDT2	0	0.4	0.001	30	10	0.3	120	2.25	175	18	6	0.01	0.1	0.35	0.35
RSAT2	0.01	0.41	0.001	55	18	0.277	120	3	246	23	14	0.043	0.147	0.035	0.035
RLRT2	0.001	0.2	0.001	35	25	0.25	120	2.5	275	20	8	0.02	0.11	0.1	0.035
CMNT2	0.001	0.3	0.001	75	45	0.2	200	2.58	275	23	14	0.043	0.147	0.035	0.035
BECT2	0.005	0.35	0.001	20	44	0.7	150	3	246	23	12	0.043	0.147	0.035	0.035
BBZT2	0.001	0.3	0.001	65	30	0.277	180	2.58	246	23	14	0.043	0.147	0.035	0.035
WBAT2	0.02	0.159	0.001	40	41	0.55	194	2.67	191	14	13	0.0495	0.112	0.15	0.01
HIBT2	0.001	0.1	0.001	60	38	0.277	225	2.2	165	45	14	0.008	0.147	0.15	0.035
BSAT2	0.004	0.41	0.01	35	8	0.45	250	2.58	175	15	8	0.043	0.147	0.035	0.035
GRST2	0.02	0.2	0.001	120	50	0.277	180	2.58	350	23	14	0.043	0.147	0.035	0.035
EAST2	0.002	0.45	0.04	30	20	0.3	130	2.58	200	150	14	0.003	0.147	0.035	0.035

Basin	PCTIM	ADIMP	RIVA	UZTWM	UZFWM	UZK	ZPERC	REXP	LZTWM	LZFPM	LZFSM	LZPK	LZSK	PFREE	RSERV
NGET2	0.001	0.05	0.001	55	15	0.6	180	2.58	450	28	24	0.02	0.08	0.035	0.035
BRYT2	0.001	0.41	0.001	41	15	0.277	180	2.58	246	23	14	0.043	0.147	0.035	0.035
CLGT2	0.001	0.41	0.001	41	15	0.277	180	2.58	246	23	14	0.043	0.147	0.035	0.035
HPDT2U	0.002	0.042	0.001	20	45	0.6	185	2.36	255	135	35	0.0087	0.065	0.08	0.1
DMYT2	0.001	0	0.006	230	42	0.38	150	1.6	310	46	15	0.001	0.06	0.2	0.3
DEYT2	0.001	0.08	0.04	225	50	0.25	220	1.5	160	50	6	0.002	0.18	0.3	0.3
LYNT2	0.001	0.25	0.002	125	24	0.3	120	2.5	270	20	12	0.015	0.02	0.06	0.035
HBRT2	0.001	0.41	0	18	15	0.25	180	2.58	200	350	14	0.001	0.12	0.1	0.035
HLBT2	0.025	0.05	0.001	160	50	0.28	200	2.58	220	23	12	0.043	0.18	0.05	0.035
WBZT2U	0.001	0.41	0.001	31	25	0.6	180	2.58	200	23	14	0.043	0.147	0.035	0.035
WBZT2	0.001	0.41	0.001	31	25	0.6	180	2.58	200	23	14	0.043	0.147	0.035	0.035
HPDT2	0.002	0.042	0.001	43	45	0.5	150	2.36	255	135	40	0.002	0.065	0.15	0.1
BEMT2	0.001	0.05	0.007	75	45	0.15	220	5	85	65	10	0.007	0.1	0.04	0.1
BAWT2	0.002	0	0.001	60	80	0.3	140	1.2	40	130	35	0.012	0.15	0.1	0.1
RMOT2	0.005	0.2	0.001	60	120	0.2	120	1.4	255	75	200	0.0087	0.08	0.05	0.1
SLNT2	0.8	0.042	0.001	10	15	0.6	120	2.8	255	200	20	0.01	0.2	0.08	0.1
ROST2	0	0.12	0.001	190	80	0.7	120	2.8	255	60	20	0.0087	0.11	0.1	0.1
WCBT2	0.5	0.042	0.001	15	10	0.6	185	2.36	255	135	35	0.0087	0.065	0.08	0.1

Table 4-4. Final SAC-SMA ET calibration parameter values for the Brazos basins

Basin	MAPE Input	PEADJ	JAN_ET	FEB_ET	MAR_ET	APR_ET	MAY_ET	JUN_ET	JUL_ET	AUG_ET	SEP_ET	OCT_ET	NOV_ET	DEC_ET
GAST2	TRUE	1	0.9	0.88	0.92	0.99	1.08	1.15	1.3	1.42	1.48	1.44	1.2	1
BNLT2	TRUE	1	1	1	1	1.01	1.07	1.13	1.2	1.3	1.34	1.29	1.13	1
LRIT2	TRUE	1	1	1	1	1	1	1.05	1.12	1.23	1.25	1.18	1.1	1
PICT2	TRUE	1	1	1	1	1.01	1.03	1.05	1.1	1.12	1.15	1.2	1.12	1
KEMT2	TRUE	1	0.98	0.98	1	1.06	1.17	1.25	1.35	1.47	1.47	1.35	1.22	1.02
DNGT2	TRUE	1	0.98	0.98	1	1.06	1.13	1.22	1.29	1.35	1.37	1.31	1.22	1.02
SDOT2	TRUE	1	1	1	1	1	1.04	1.1	1.21	1.29	1.31	1.2	1.09	1
BYBT2	TRUE	1	0.75	0.76	0.83	0.9	1	1.14	1.35	1.55	1.5	1.39	1.12	0.84

Basin	MAPE Input	PEADJ	JAN_ET	FEB_ET	MAR_ET	APR_ET	MAY_ET	JUN_ET	JUL_ET	AUG_ET	SEP_ET	OCT_ET	NOV_ET	DEC_ET
BCIT2	TRUE	1	0.69	0.68	0.85	0.91	1	1.2	1.53	1.51	1.44	1.22	0.95	0.68
BKFT2	TRUE	1	0.67	0.66	0.83	0.9	1	1.23	1.57	1.56	1.44	1.22	0.95	0.68
BSYT2	TRUE	1	0.87	0.86	0.9	0.95	1	1.19	1.27	1.25	1.24	1.13	0.97	0.91
BKTT2	TRUE	1	0.74	0.75	0.92	0.91	0.98	0.98	1.19	1.25	1.29	1.2	1	0.88
RKDT2	TRUE	1	0.67	0.66	0.84	0.9	0.99	1.25	1.5	1.55	1.44	1.22	0.94	0.69
RSAT2	TRUE	1	0.69	0.84	0.95	1	1.2	1.3	1.5	1.55	1.44	1.22	1	0.7
RLRT2	TRUE	1	0.67	0.66	0.84	0.9	0.99	1.25	1.55	1.55	1.44	1.22	0.94	0.69
CMNT2	TRUE	1	1	1	1	1	1.02	1.05	1.08	1.11	1.11	1.12	1.07	1
BECT2	TRUE	1	1	1	1	1.01	1.03	1.06	1.11	1.15	1.2	1.15	1.1	1
BBZT2	TRUE	1	0.67	0.66	0.84	0.9	0.99	1.25	1.55	1.55	1.44	1.22	0.94	0.69
WBAT2	TRUE	1	0.92	0.92	0.95	1.01	1.08	1.17	1.31	1.42	1.43	1.33	1.13	1
HIBT2	TRUE	1	0.9	0.9	0.9	0.94	1	1.12	1.24	1.29	1.2	1.03	0.87	0.69
BSAT2	TRUE	1	0.61	0.61	0.64	0.69	0.81	1.02	1.16	1.21	1.13	1.03	0.89	0.68
GRST2	TRUE	1.1	1.06	1.05	1.05	1.05	1.08	1.23	1.55	1.57	1.44	1.25	1.1	1
EAST2	TRUE	1	0.89	0.9	0.9	0.92	1.06	1.21	1.31	1.36	1.3	1.12	0.93	0.67
NGET2	TRUE	1.1	1.04	1.04	1.06	1.1	1.19	1.3	1.37	1.4	1.35	1.28	1.18	1.08
BRYT2	TRUE	1	0.67	0.66	0.84	0.9	0.99	1.25	1.55	1.55	1.44	1.22	0.94	0.69
CLGT2	TRUE	1	0.67	0.66	0.84	0.9	0.99	1.25	1.55	1.55	1.44	1.22	0.94	0.69
HPDT2U	TRUE	1	0.92	0.93	0.98	1.07	1.15	1.16	1.18	1.17	1.16	1.15	1.08	0.95
DMYT2	TRUE	1	0.84	0.68	0.65	0.86	0.92	0.96	1.03	1.25	1.35	1.4	1.05	1
DEYT2	TRUE	1	0.93	0.93	0.94	1	1.02	1.07	1.1	1.1	1.1	1.03	1	1
LYNT2	TRUE	1	0.88	0.87	0.87	0.9	1	1.05	1.09	1.12	1.14	1.09	1.02	0.9
HBRT2	TRUE	1	0.85	0.84	0.87	0.93	1	1.25	1.55	1.55	1.44	1.22	0.94	0.69
HLBT2	TRUE	1	0.85	0.86	0.92	1.06	1.19	1.31	1.43	1.41	1.34	1.09	0.88	0.64
WBZT2U	TRUE	1	0.67	0.66	0.84	0.9	0.99	1.25	1.55	1.55	1.44	1.22	0.94	0.69
WBZT2	TRUE	1	0.67	0.66	0.84	0.9	0.99	1.25	1.55	1.55	1.44	1.22	0.94	0.69
HPDT2	TRUE	1	0.92	0.93	0.98	1.07	1.15	1.16	1.18	1.17	1.17	1.16	1.13	0.95
BEMT2	TRUE	1.1	1	1	1	1.02	1.06	1.19	1.3	1.44	1.5	1.6	1.3	1.02
BAWT2	TRUE	1.1	0.88	0.93	0.98	1.13	1.25	1.34	1.36	1.36	1.31	1.22	1.14	0.95

Basin	MAPE Input	PEADJ	JAN_ET	FEB_ET	MAR_ET	APR_ET	MAY_ET	JUN_ET	JUL_ET	AUG_ET	SEP_ET	OCT_ET	NOV_ET	DEC_ET
RMOT2	TRUE	1.1	0.92	0.93	0.96	1.01	1.08	1.3	1.38	1.4	1.4	1.35	1.26	1.09
SLNT2	TRUE	1	0.92	0.9	0.92	0.99	1.04	1.12	1.15	1.17	1.16	1.13	1.09	1.03
ROST2	TRUE	1.1	0.7	0.63	0.69	0.96	1.16	1.25	1.36	1.39	1.35	1.26	1.16	0.95
WCBT2	TRUE	1.05	1.03	1.04	1.06	1.08	1.12	1.13	1.14	1.18	1.25	1.27	1.25	1.1

4.2.2. Guadalupe

Table 4-5: Final SAC-SMA calibration parameter values for the Guadalupe basins

Basin	PCTIM	ADIMP	RIVA	UZTWM	UZFWM	UZK	ZPERC	REXP	LZTWM	LZFPM	LZFSM	LZPK	LZSK	PFREE	RSERV
LCPT2	0.002	0.25	0.011	65	40	0.18	275	1.5	180	60	10	0.003	0.1	0.05	0
LULT2	0.001	0.2	0.005	105	55	0.4	220	2	110	40	12	0.005	0.18	0.1	0
LLGT2	0	0.25	0	90	35	0.5	60	1.2	90	100	30	0.015	0.07	0.1	0.5
GNLT2	0.001	0.25	0.01	50	25	0.45	75	2	190	200	50	0.007	0.1	0.25	0.1
PEWT2	0	0.1	0.015	130	40	0.2	250	3	400	10	5	0.15	0.2	0.01	0
DLWT2	0	0.15	0.007	135	55	0.65	200	2.3	225	65	10	0.02	0.12	0.01	0
GDHT2	0	0.1	0.1	75	30	0.5	80	2.7	200	130	15	0.004	0.07	0.35	0.1
WHOT2U	0	0.05	0.02	100	75	0.6	90	3	200	25	15	0.005	0.23	0.06	0.025
WHOT2M	0	0.05	0.003	50	40	0.3	30	4.5	200	10	15	0.005	0.25	0.05	0.025
WHOT2	0.001	0.25	0.003	50	40	0.3	40	4	200	10	10	0.015	0.25	0.05	0.025
CUET2U	0.001	0.2	0	75	35	0.3	75	2.4	250	100	15	0.004	0.07	0.15	0.1
CUET2	0.001	0.2	0	75	35	0.3	75	2.4	250	100	15	0.004	0.07	0.15	0.1
WRST2	0	0.2	0.01	80	25	0.6	250	3	400	20	15	0.01	0.1	0.1	0.1
SCDT2	0	0.3	0.01	85	33	0.3	75	2.3	375	30	25	0.01	0.1	0.05	0.1
CKDT2	0.005	0.3	0	45	20	0.6	80	2.5	300	40	18	0.01	0.2	0.1	0.1
VICT2U	0.002	0.3	0	40	25	0.4	125	1.2	300	40	20	0.01	0.1	0.1	0.1
VICT2	0.002	0.3	0	40	35	0.4	125	1.2	300	40	20	0.01	0.1	0.1	0.1
DUPT2	0	0.1	0	40	25	0.4	125	1.2	350	30	15	0.01	0.1	0.1	0.1

Basin	MAPE_Input	PEADJ	JAN_ET	FEB_ET	MAR_ET	APR_ET	MAY_ET	JUN_ET	JUL_ET	AUG_ET	SEP_ET	OCT_ET	NOV_ET	DEC_ET
LCPT2	TRUE	1	0.69	0.68	0.67	0.76	0.87	1.02	1.13	1.24	1.25	1.22	0.98	0.76
LULT2	TRUE	1	0.65	0.63	0.64	0.76	0.93	0.99	1.04	1.1	1.16	1.18	1.11	0.91
LLGT2	TRUE	1	0.64	0.59	0.7	0.85	1	1.16	1.34	1.4	1.41	1.29	1.07	0.69
GNLT2	TRUE	1	1.05	1.01	1	1.09	1.23	1.35	1.41	1.43	1.43	1.4	1.28	1.05
PEWT2	TRUE	1	1.09	1.02	0.93	0.86	0.92	1	1.18	1.37	1.56	1.56	1.49	1.31
DLWT2	TRUE	1	1.22	1.08	1.03	0.94	1.03	1.17	1.27	1.39	1.44	1.46	1.36	1.26
GDHT2	TRUE	1	1	1	1.01	1.03	1.06	1.12	1.19	1.22	1.21	1.18	1.09	0.98
WHOT2U	TRUE	1	1.15	1.02	0.96	0.94	1.02	1.15	1.21	1.23	1.25	1.23	1.16	1.07
WHOT2M	TRUE	0.97	1.04	0.99	0.93	0.91	1	1.07	1.16	1.23	1.23	1.2	1.14	1.03
WHOT2	TRUE	0.97	1.07	1	0.93	0.91	1.02	1.12	1.17	1.23	1.23	1.2	1.16	1.03
CUET2U	TRUE	1	0.84	0.82	0.84	0.95	1.11	1.23	1.25	1.25	1.23	1.18	1.1	1.02
CUET2	TRUE	1	0.84	0.82	0.84	0.95	1.11	1.23	1.25	1.25	1.23	1.18	1.1	1.02
WRST2	TRUE	1	0.94	0.93	0.94	1	1.15	1.41	1.57	1.52	1.38	1.17	0.97	0.83
SCDT2	TRUE	1	0.84	0.84	0.86	0.97	1.09	1.32	1.47	1.48	1.39	1.24	0.93	0.77
CKDT2	TRUE	1	0.88	0.88	0.9	0.97	1.09	1.25	1.35	1.36	1.29	1.17	0.97	0.83
VICT2U	TRUE	1	0.67	0.66	0.84	0.9	0.99	1.25	1.55	1.55	1.44	1.22	0.94	0.69
VICT2	TRUE	1	0.67	0.66	0.84	0.9	0.99	1.25	1.55	1.55	1.44	1.22	0.94	0.69
DUPT2	TRUE	1	0.67	0.66	0.84	0.9	0.99	1.25	1.55	1.55	1.44	1.22	0.94	0.69

Table 4-6: Final SAC-SMA ET calibration parameter values for the Guadalupe basins

Basin	MAPE_Input	PEADJ	JAN_ET	FEB_ET	MAR_ET	APR_ET	MAY_ET	JUN_ET	JUL_ET	AUG_ET	SEP_ET	OCT_ET	NOV_ET	DEC_ET
LCPT2	TRUE	1	0.69	0.68	0.67	0.76	0.87	1.02	1.13	1.24	1.25	1.22	0.98	0.76
LULT2	TRUE	1	0.65	0.63	0.64	0.76	0.93	0.99	1.04	1.1	1.16	1.18	1.11	0.91
LLGT2	TRUE	1	0.64	0.59	0.7	0.85	1	1.16	1.34	1.4	1.41	1.29	1.07	0.69
GNLT2	TRUE	1	1.05	1.01	1	1.09	1.23	1.35	1.41	1.43	1.43	1.4	1.28	1.05
PEWT2	TRUE	1	1.09	1.02	0.93	0.86	0.92	1	1.18	1.37	1.56	1.56	1.49	1.31
DLWT2	TRUE	1	1.22	1.08	1.03	0.94	1.03	1.17	1.27	1.39	1.44	1.46	1.36	1.26
GDHT2	TRUE	1	1	1	1.01	1.03	1.06	1.12	1.19	1.22	1.21	1.18	1.09	0.98
WHOT2U	TRUE	1	1.15	1.02	0.96	0.94	1.02	1.15	1.21	1.23	1.25	1.23	1.16	1.07

WHOT2M	TRUE	0.97	1.04	0.99	0.93	0.91	1	1.07	1.16	1.23	1.23	1.2	1.14	1.03
WHOT2	TRUE	0.97	1.07	1	0.93	0.91	1.02	1.12	1.17	1.23	1.23	1.2	1.16	1.03
CUET2U	TRUE	1	0.84	0.82	0.84	0.95	1.11	1.23	1.25	1.25	1.23	1.18	1.1	1.02
CUET2	TRUE	1	0.84	0.82	0.84	0.95	1.11	1.23	1.25	1.25	1.23	1.18	1.1	1.02
WRST2	TRUE	1	0.94	0.93	0.94	1	1.15	1.41	1.57	1.52	1.38	1.17	0.97	0.83
SCDT2	TRUE	1	0.84	0.84	0.86	0.97	1.09	1.32	1.47	1.48	1.39	1.24	0.93	0.77
CKDT2	TRUE	1	0.88	0.88	0.9	0.97	1.09	1.25	1.35	1.36	1.29	1.17	0.97	0.83
VICT2U	TRUE	1	0.67	0.66	0.84	0.9	0.99	1.25	1.55	1.55	1.44	1.22	0.94	0.69
VICT2	TRUE	1	0.67	0.66	0.84	0.9	0.99	1.25	1.55	1.55	1.44	1.22	0.94	0.69
DUPT2	TRUE	1	0.67	0.66	0.84	0.9	0.99	1.25	1.55	1.55	1.44	1.22	0.94	0.69

4.2.3. Funding Dependent Basins

Table 4-7: Final SAC-SMA calibration parameter values for basins in the Brazos, Colorado, and Nueces forecast groups

Basin	fx_group	PCTIM	ADIMP	RIVA	UZTWM	UZFWM	UZK	ZPERC	REXP	LZTWM	LZFPM	LZFSM	LZPK	LZSK	PFREE	RSERV
LLET2	Brazos	0	0.25	0.001	115	45	0.45	150	2.67	260	40	15	0.001	0.112	0.04	0.01
CPKT2	Brazos	0	0.05	0.003	110	25	0.65	250	2.5	190	30	20	0.004	0.1	0.04	0.04
DSBT2	Brazos	0	0.05	0.001	75	40	0.65	200	2.4	195	30	12	0.005	0.33	0.04	0.04
DLLT2	Brazos	0.001	0.1	0.005	120	40	0.6	194	3	220	23	10	0.0495	0.112	0.04	0.01
PCTT2	Brazos	0.003	0.159	0.001	39	43	0.175	194	2.67	191	23	13	0.0495	0.112	0.04	0.01
HMLT2	Brazos	0	0.13	0.002	55	50	0.2	194	2.67	250	30	16	0.004	0.112	0.04	0.01
MCGT2	Brazos	0.001	0.15	0.01	30	22	0.6	150	2	191	35	8	0.009	0.15	0.5	0.4
HICT2	Brazos	0.001	0.2	0.001	30	30	0.2	205	2	230	23	13	0.007	0.13	0.03	0.01
CTNT2	Brazos	0.001	0.2	0.001	32	28	0.6	150	2.1	191	50	15	0.023	0.09	0.1	0.01
VMAT2	Brazos	0.001	0.159	0.001	55	28	0.5	194	2.67	220	50	13	0.009	0.112	0.1	0.01
ACTT2	Brazos	0.001	0.3	0.001	20	30	0.3	150	2.67	150	23	13	0.0495	0.112	0.04	0.01
CRFT2	Brazos	0.001	0.159	0.001	45	32	0.4	165	2.22	160	40	18	0.018	0.13	0.45	0.01
LKCT2	Colorado	0	0	0.011	86	51	0.2	275	4.5	300	28	19	0.025	0.07	0.08	0.01
HORT2	Colorado	0.01	0.06	0.011	110	45	0.55	275	4.5	300	28	23	0.025	0.07	0.08	0.01
HDCT2	Colorado	0.001	0.15	0.005	110	28	0.5	275	4.5	280	28	10	0.01	0.13	0.08	0.01

CJNT2	Colorado	0	0.05	0.011	65	32	0.35	275	4	350	40	15	0.025	0.06	0.08	0.01
LBWT2U	Colorado	0	0.15	0.011	30	20	0.4	275	6.2	191	28	19	0.025	0.07	0.08	0.01
CUTT2	Colorado	0	0.25	0.011	80	28	0.3	225	5.2	360	28	25	0.025	0.09	0.08	0.01
LBWT2	Colorado	0.005	0.1	0.001	40	45	0.4	225	1.3	191	23	13	0.0495	0.112	0.04	0.01
BWDT2	Colorado	0	0.05	0.011	110	66	0.2	275	4.4	320	28	19	0.025	0.07	0.08	0.01
SKMT2	Nueces	0.005	0.2	0.001	60	15	0.4	150	2.7	50	110	8	0.003	0.1	0.15	0.3
MIOT2	Nueces	0	0.1	0.01	100	25	0.1	250	1.6	400	50	20	0.02	0.15	0.01	0.005
REFT2	Nueces	0	0.04	0.005	80	130	0.22	190	1.5	225	20	20	0.05	0.08	0.01	0.05

Table 4-8: Final SAC-SMA ET calibration parameter values for basins in the Brazos, Colorado, and Nueces forecast groups

Basin	MAPE_Input	PEADJ	JAN_ET	FEB_ET	MAR_ET	APR_ET	MAY_ET	JUN_ET	JUL_ET	AUG_ET	SEP_ET	OCT_ET	NOV_ET	DEC_ET
LLET2	TRUE	1	0.86	0.86	0.86	0.92	1.04	1.19	1.37	1.5	1.56	1.49	1.22	0.95
CPKT2	TRUE	1.1	0.95	0.95	0.97	0.97	0.97	0.98	1	1.07	1.11	1.14	1.07	1
DSBT2	TRUE	1.095	0.81	0.81	0.83	0.89	0.98	1.07	1.14	1.23	1.29	1.25	1.18	1
DLLT2	TRUE	1	0.69	0.67	0.66	0.78	1.08	1.29	1.54	1.82	1.81	1.63	1.23	1.02
PCTT2	TRUE	1	0.98	0.98	1	1.06	1.17	1.29	1.54	1.82	1.81	1.62	1.22	1.02
HMLT2	TRUE	1	0.68	0.63	0.76	1.02	1.22	1.43	1.65	1.83	1.85	1.61	1.07	0.84
MCGT2	TRUE	1	0.84	0.84	0.87	0.95	1.08	1.22	1.54	1.82	1.86	1.75	1.15	0.87
HICT2	TRUE	1	0.8	0.8	0.81	0.9	1.01	1.27	1.51	1.89	1.91	1.72	1.19	0.9
CTNT2	TRUE	1	0.76	0.75	0.76	0.91	1	1.14	1.38	1.64	1.78	1.61	1.13	0.9
VMAT2	TRUE	1	0.9	0.9	0.9	0.94	1.04	1.17	1.46	1.76	1.81	1.77	1.24	0.93
ACTT2	TRUE	1	0.98	0.98	1	1.06	1.17	1.29	1.54	1.82	1.81	1.62	1.22	1.02
CRFT2	TRUE	1	0.85	0.85	0.85	1	0.99	1.18	1.54	1.82	1.86	1.78	1.13	0.84
LKCT2	TRUE	1	0.75	0.75	0.79	0.89	1.05	1.28	1.35	1.42	1.41	1.39	1.09	0.8
HORT2	TRUE	1	0.75	0.75	0.79	0.89	1.05	1.28	1.35	1.42	1.41	1.39	1.09	0.8
HDCT2	TRUE	1	0.75	0.75	0.79	0.85	0.98	1.12	1.27	1.48	1.53	1.5	1.18	0.89
CJNT2	TRUE	1	0.75	0.75	0.79	0.89	1.05	1.28	1.35	1.42	1.41	1.39	1.09	0.8
LBWT2U	TRUE	1	0.75	0.75	0.79	0.89	1.05	1.28	1.35	1.42	1.41	1.39	1.09	0.8
CUTT2	TRUE	1	0.82	0.85	0.89	0.94	1.02	1.12	1.18	1.2	1.21	1.16	1.06	0.98
LBWT2	TRUE	1	0.98	0.98	1	1.06	1.17	1.29	1.54	1.82	1.81	1.62	1.22	1.02

BWDT2	TRUE	1	0.75	0.75	0.79	0.89	1.05	1.28	1.35	1.42	1.41	1.39	1.09	0.8
SKMT2	TRUE	1	0.97	0.94	0.94	0.94	0.97	1	1.02	1.04	1.05	1.03	1.01	1
MIOT2	TRUE	1	1	0.97	0.97	0.97	1	1.03	1.12	1.18	1.2	1.1	1.02	1
REFT2	TRUE	1	0.97	0.92	0.91	0.93	1	1.06	1.12	1.14	1.07	0.97	0.95	0.94

4.3. Conclusions and Recommendations for Hydrologic Calibrations

Individual basin summary reports aim to provide a brief two-page highlight of the calibration, including the important characteristics of a basin, identified limitations of the initial simulation, significant and notable changes made during the calibration, improvements in the statistics, and as appropriate, screenshots or other supporting figures. Additions were also made to include feedback received from WGRFC during the iterative calibration process, and efforts made to incorporate those suggestions. As with any manual calibration, the true value of this work is in these details, and each calibration is often a stand-alone finished product. While all calibrations were able to achieve some degree of improvement, ranging from more minor (e.g., downstream basins with simple LAG/K routing models) to significant (e.g., headwater basins or complex downstream basins), all of which should provide enhanced operational forecasting for WGRFC, we also recognize there are and always will be opportunities to improve these forecasts. We appreciate all of the feedback WGRFC provided to improve the final calibrations. We are confident that the final efforts of this calibration will meaningfully improve the streamflow forecasting products put forth by WGRFC for all stakeholders, including the people and State of Texas.

Limitations and Challenges

Some of the key limitations and challenges identified during the calibration process included:

1. **Limitations downstream basin calibration due to poorly estimated and/or unreliable USGS streamflow data** (e.g., unrealistic conservation of mass between upstream to downstream observations)
    - Examples were highlighted in the basin summary reports but include the Lower Guadalupe and parts of the Navasota River. The Lower Brazos is also affected by data shortcomings.
    - More thoroughly documenting and discussing data quality concerns with the USGS and other relevant agencies may serve future calibration efforts well (e.g., emphasizing the importance of consistency between a series of gauges along a reach for future calibration work).
2. **Degraded simulation performance prior to 2010**
    - Significant differences in simulation performance were commonly observed between 2000–2010 and 2010–2020. This could be due to a number of factors, including:
        - Less reliable precipitation data, missing or unreliable USGS flows, changing land use/ land cover patterns, hydrologic non-stationarity, and/or other unidentified issues
    - While the initial benchmark analysis comparing PRISM and MAPX data suggests significant improvement in the last 5-10 years, a more rigorous analysis comparing MAPX to other precipitation products would likely be beneficial in understanding how the forcings data affected these performance trends, and perhaps highlight opportunities for improving forcing data products
3. **Seasonal differences between the gridded daily MAPE climatology and the Lynker-derived FAO-PM PET climatology**
    - These differences in PET are unlikely to affect simulations on a shorter time scale but may contribute to systematic biases over longer time periods. While PEADJ curves can effectively compensate for any seasonal biases, further research is warranted to implement PEADJ curves using a more systematic approach, or better yet, limit the need for PEADJ curves altogether
4. **Uncalibrated upstream basins (e.g., above LLGT2) create situations where upstream simulation biases are passed downstream and impact the model parameterization**
    - Future adjustments to basins upstream of the Middle Guadalupe will require recalibration of LLGT2, and perhaps other basins.
        - Not knowing what WGRFC calibration priorities already exist, the basins in the Upper/Middle Guadalupe seem like good candidates for further calibration, particularly given their proximity to population centers
    - Similarly, because of poorly constrained inflow data for reservoirs, any upstream hydrologic model errors will be propagated downstream to the reservoir models. While opportunities for increased gaging above reservoirs may be limited, this is an important consideration when evaluating RES-SNGL model performance

Incorporation of WGRFC Feedback

We submitted an initial draft of this report to WGRFC on September 17th, 2021. After receiving feedback from WGRFC on this initial draft report and calibrations, Lynker made a number of adjustments and improvements to the approach and methods. These included:

1. Adding in an ET Demand adjustment curve for every basin, paying particular attention to basins with seasonal bias, e.g., overestimation in the summer and underestimation in the spring. The implementation of the seasonal vegetation PEADJ curves had mixed results, but generally added some measurable improvements and was included for all basins to ensure consistency.
2. Updating site data (BSYT2 and RLRT2) that were originally imported into CHPS on a GMT time zone, instead of local time.
3. Adjusting Guadalupe calibrations to favor a “slightly high bias” with better peak flow performance instead of a holistic (period of record) calibration. Initial calibrations attempted to balance simulations of timing, model bias, model variability, peak flow magnitudes, and dry season baseflows. Statistical optimization was not the main priority, rather efforts were made to produce a well-balanced, non-biased simulation that attempted to also optimize peak flow performance. However, given this feedback from WGRFC, Lynker calibrators revisited all basins within the Guadalupe, placing greater emphasis on peak flow simulations, with less emphasis on the overall model bias. In addition to reintroducing an ET demand curve, we also generally decreased tension water and free water parameters to increase surface runoff during Moderate to Major Flood events. All adjustments were implemented on a basin-by-basin basis and are reflected in the updated basin summary reports, figures, and tables.

Future Opportunities

Throughout the calibration process, the Lynker team identified several opportunities to further improve WGRFC forecasts. While these opportunities were the outside the scope of this calibration project, they have been noted throughout this report. They include:

1. Implementing a series of consumptive use and/or channel loss/gain models to better simulate the complex water use behaviors at low flows along the Lower Brazos domain (pending further collaboration and data sharing with TWDB, the Brazos River Authority (BRA), and the Gulf Coast Water Authority (GCWA))
2. Performing an updated calibration for basins in the Guadalupe forecast group above LLGT2 (due to the uncertainty from routing upstream, un-calibrated simulated flows)
3. Gathering another year’s worth of data for the Fort Hood basins for use in a more comprehensive and scientific review of the rating curve prior to calibration.

5. RESERVOIR OPERATIONAL SCHEME CALIBRATION

A goal of the WGRFC is to improve river forecasts by modeling the reservoirs within hydrologic forecast basins. Since reservoirs store and release water with a different timing than that of natural runoff, reservoir models are critical to forecasting streamflow at downstream locations. In support of these forecasting efforts, Lynker was tasked to perform reservoir model calibrations for the WGRFC. Of specific focus was the calibration of the Single Reservoir Regulation Operation (RES-SNGL) reservoir models for Lake Mexia and Coleto Creek Reservoir, but also for the six funding-dependent reservoirs, Waco Lake, Proctor Lake, Hord's Creek Reservoir, Lake Coleman, Lake Brownwood, and Lake Leon.

5.1. Dam/Reservoirs

Lake Mexia (BSAT2) is a headwater fill and spill type reservoir owned and operated by Bistone Municipal Water Supply District. The reservoir was built in 1960 and impounds the Navasota River, a tributary of the Brazos River in Limestone County (TWDB, 2021a; Figure 5-1). A reservoir survey was completed by TWDB in 2008, which measured the capacity to be 4,687 acre-feet (af) and the area to be 1,009 acres (ac) at the conservation pool elevation of 448.3 feet (NGVD 29). The reservoir releases from an uncontrolled spillway at an elevation of 448.3 feet (TWDB, 2009).

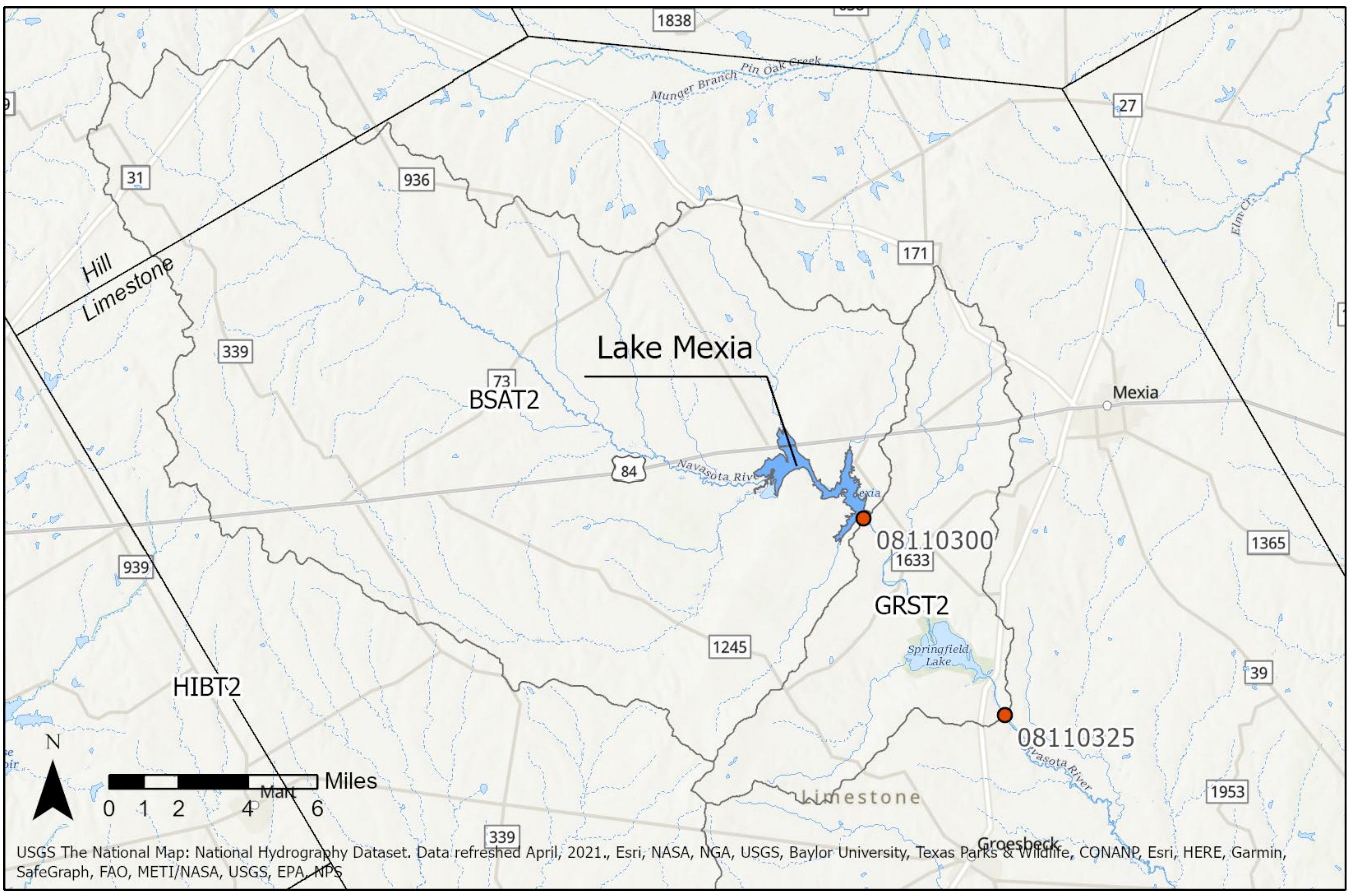


Figure 5-1: Lake Mexia location map.

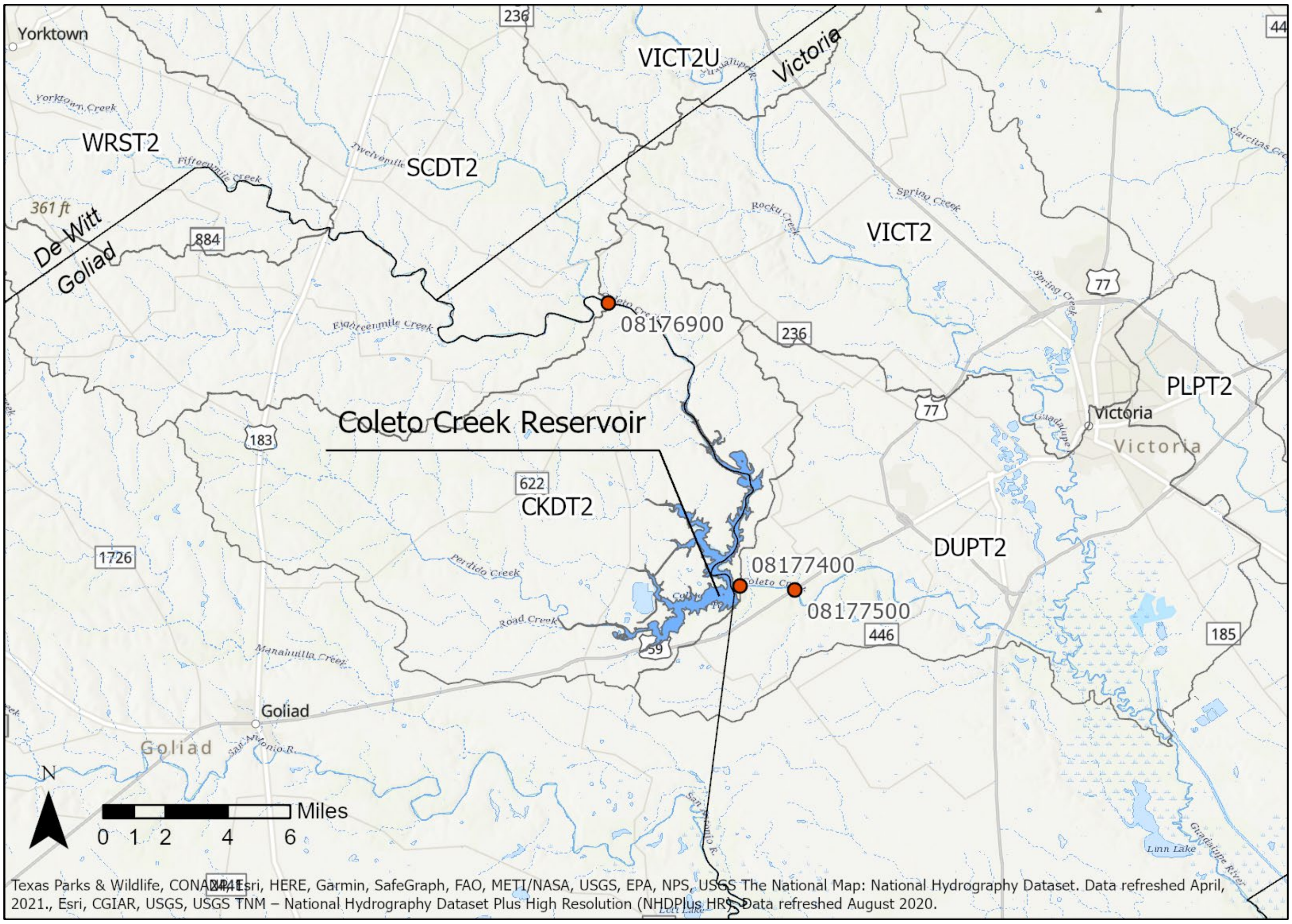


Figure 5-2: Coleto Creek Reservoir location map.

Coleto Creek Reservoir is operated by the Guadalupe-Blanco River Authority to provide cooling water to the adjacent power plant, as well as recreational opportunities. The reservoir was built in 1980 and impounds Coleto Creek in Victoria and Goliad Counties, which is a tributary of the Guadalupe River (TWDB, 2021b) (Figure 5-2). The reservoir storage is 31,040 af at the conservation pool elevation of 98 feet (datum NGVD29 +80). The maximum design elevation for the reservoir is 114.8 feet and the top of the dam is 120.0 feet (TWDB, 2021c).

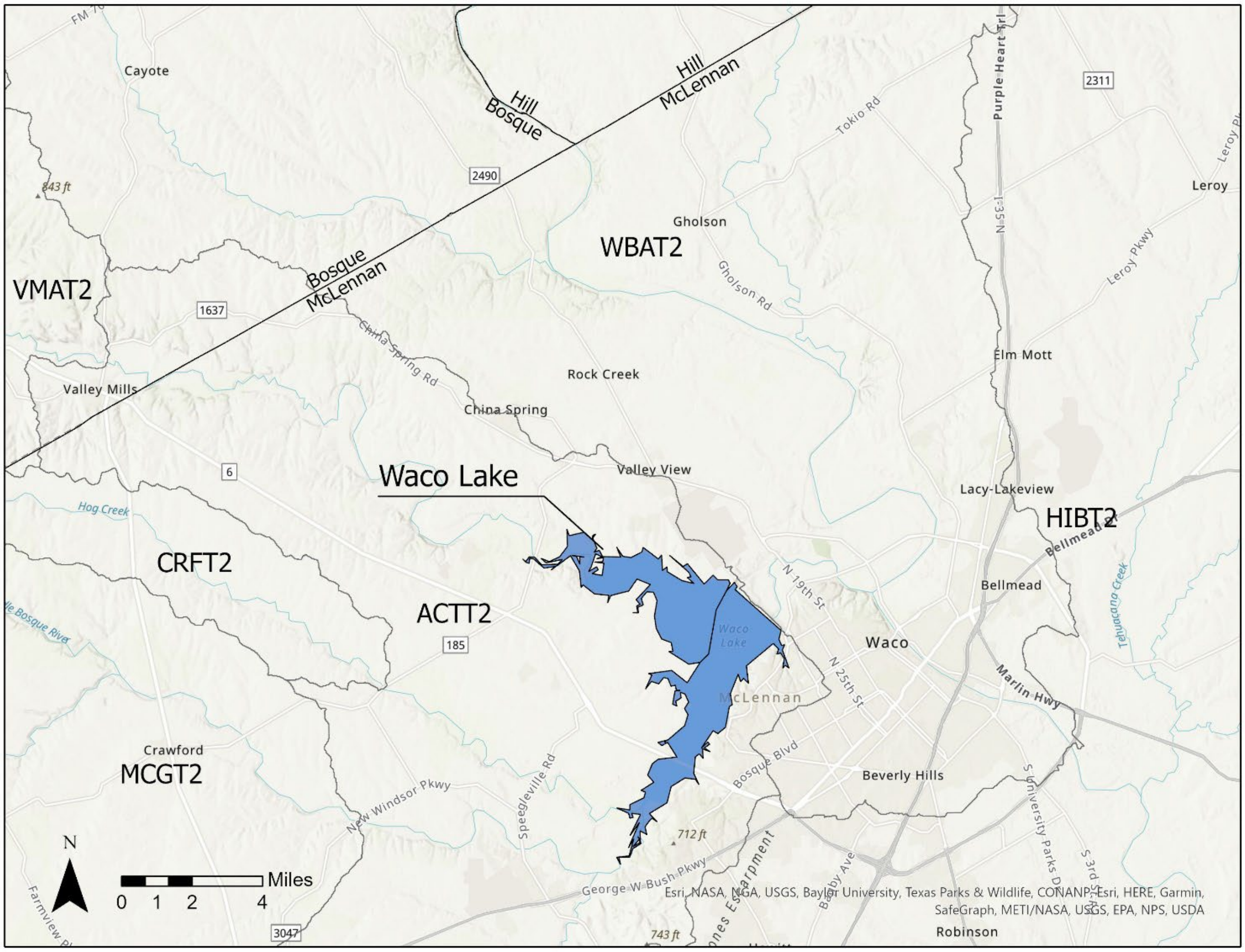


Figure 5-3: Waco Lake Reservoir location map.

Waco Lake is located about two miles west of Waco in McLennan County, on the Bosque River, a tributary of the Brazos River (Figure 5-3Figure 5-3: Waco Lake Reservoir location map). The lake is owned by the U.S. Government and operated by the United States Army Corps of Engineers for purposes of municipal and industrial water supply, flood control, conservation, and recreation. The water rights are allocated to the City of Waco and the Brazos River Authority. The new Waco Lake was authorized for construction under the Flood Control Act approved September 3, 1954. Construction of this lake began in June 1958, and deliberate impoundment of water began in February 1965. The new Waco Dam was an earthfill structure, 24,618 feet long and 140 feet high, with a concrete spillway 560 feet wide. The top of the dam is at an elevation of 514.6 feet above mean sea level. The maximum design water surface may reach up to 505 feet above mean sea level. The top of flood control pool is defined at the elevation of 500 feet above mean sea level. The drainage area above the dam is 1,670 square miles.

Figure 5-4: Hord's Creek Reservoir location map

Hords Creek Lake is located about five miles west of Coleman in Coleman County, on Hords Creek, a tributary of Jim Ned Creek, which is a tributary of Pecan Bayou, which in turn is a tributary of the Colorado River (Figure 5-4). This reservoir is owned by the United State Government and was built and is operated by the U.S. Army Corps of Engineers, Fort Worth District for flood control, water supply and recreational purposes. This lake was one of the first Corps of Engineers projects to be placed in operation within the state of Texas and is one of the smallest. The top of the dam is at elevation of 1,939 feet above mean sea level. Maximum design water surface can reach

1,933.6 feet above mean sea level. There is an uncontrolled spillway 500 feet long on the south abutment with a crest at elevation of 1,920 feet above mean sea level.

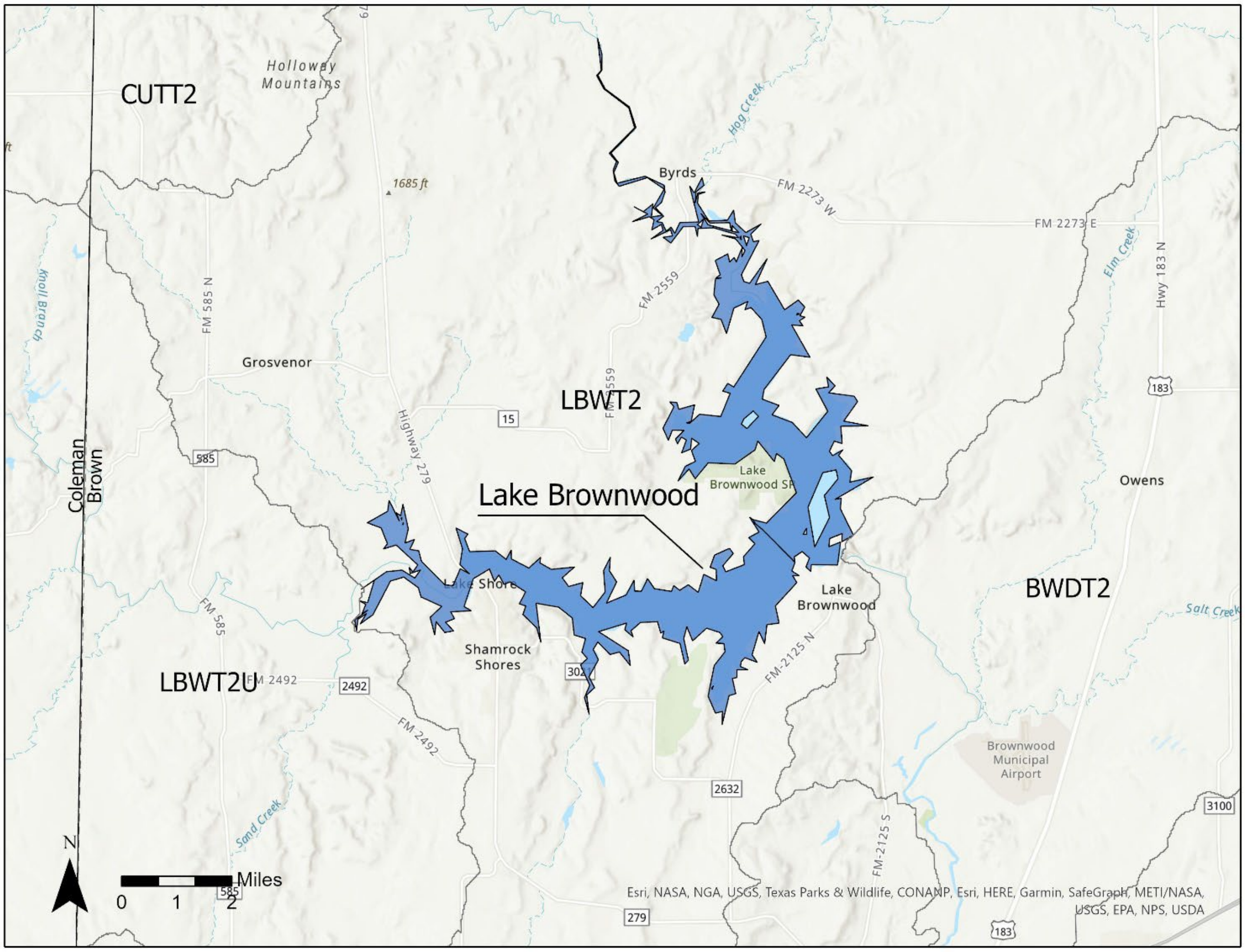


Figure 5-5: Lake Brownwood Reservoir location map

Lake Brownwood is located eight miles north of City of Brownwood in Brown County, on Pecan Bayou, tributaries of Colorado River and impounded on both Pecan Bayou and its tributary, Jim Ned Creek (Figure 5-5). The Lake is owned and operated by Brown County Water Improvement District #1 for water supply and recreational purposes. The uncontrolled emergency spillway is at the north end of the dam with a crest elevation of 1,425 feet above mean sea level. According to TWDB 2013 survey, the Lake has a capacity of 131,530 acre feet and encompasses a surface area of 6,814 acres at conservation pool elevation, 1,425 feet above mean sea level (NAVD88). The dam controls a drainage area of about 1,535 square miles.

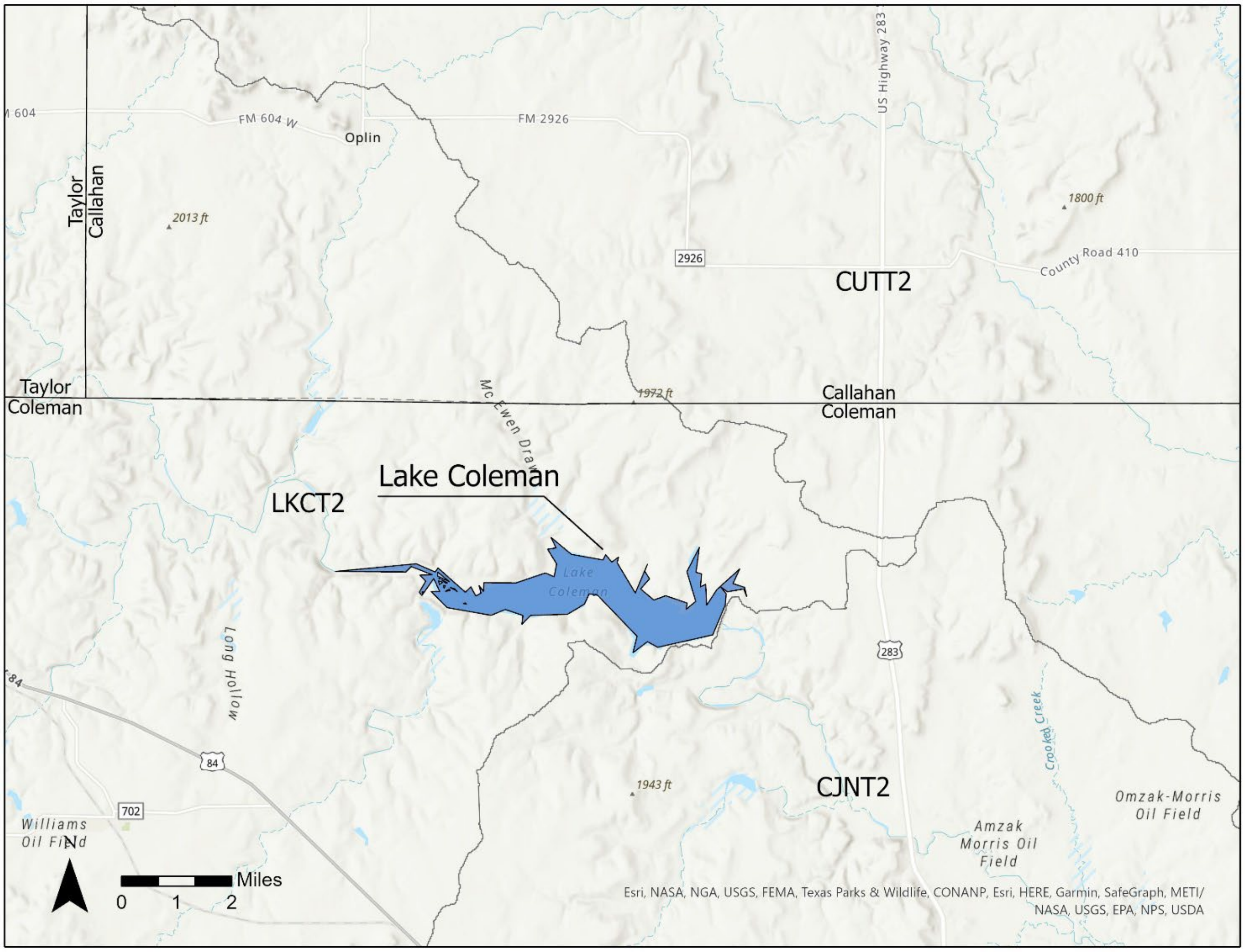


Figure 5-6: Lake Coleman Reservoir location map

Coleman Lake (also known as Coleman Reservoir) is located about fourteen miles north of Coleman in Coleman County, on Jim Ned Creek, a tributary of the Pecan Bayou which is a tributary of the Colorado River (Figure 5-6). The lake is owned and operated by the City of Coleman for municipal water supply and recreational purposes. The top of the dam is at elevation of 1,740.0 feet above mean sea level. The uncontrolled emergency spillway is 1,726.0 feet above mean sea level at its crest. The 28-foot drop inlet service spillway is also uncontrolled and has an elevation of 1717.5 feet above mean sea level at its crest. According to TWDB 2006 survey, the reservoir has a capacity of 38,094 acre-feet encompassing a surface area of 1,811 acres at the conservation pool elevation of 1,717.5 feet above mean sea level. The drainage area above the dam is 292 square miles.

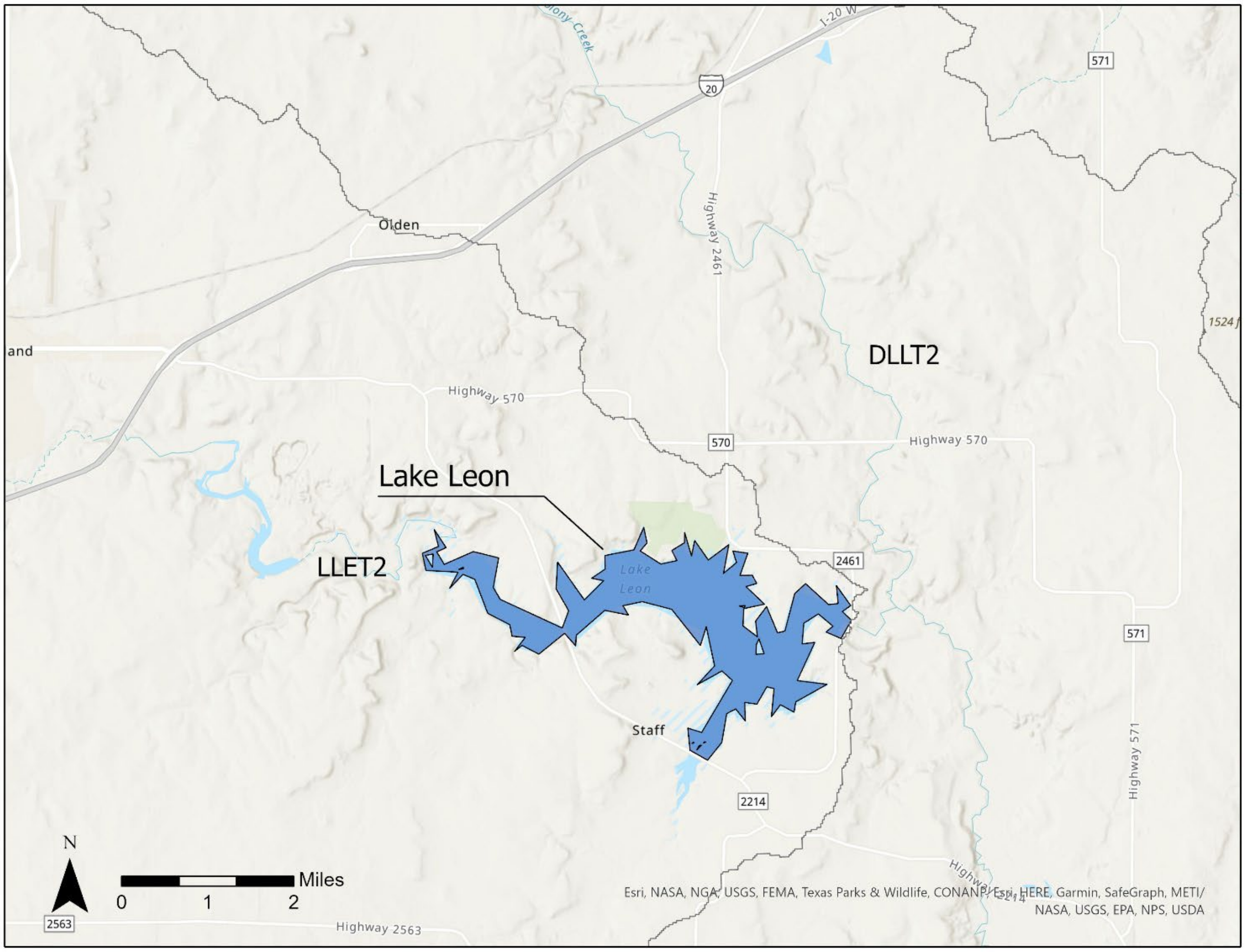


Figure 5-7: Lake Leon Reservoir location map

Lake Leon, also known as Leon Reservoir, is located five miles southeast of Eastland in Eastland County, on the Leon River, a tributary of Little River, which is tributary to the Brazos River (Figure 5-7). The reservoir is owned by the Eastland County Water Supply District for municipal and industrial water supply purposes. The uncontrolled emergency spillway is located at the south end of the dam and is cut through at natural ground with a crest of 1,200 feet long at elevation 1,382.0 feet above mean sea level. The uncontrolled service spillway (circular drop inlet) is located near the center of the dam with crest elevation at 1,375.0 feet above mean sea level. According to 2015 TWDB survey, the reservoir has a capacity of 28,042 acre-feet and a surface area of 1,756 acres at conservation pool elevation of 1,375 feet above sea level. The dam controls a drainage area of 252 square miles.

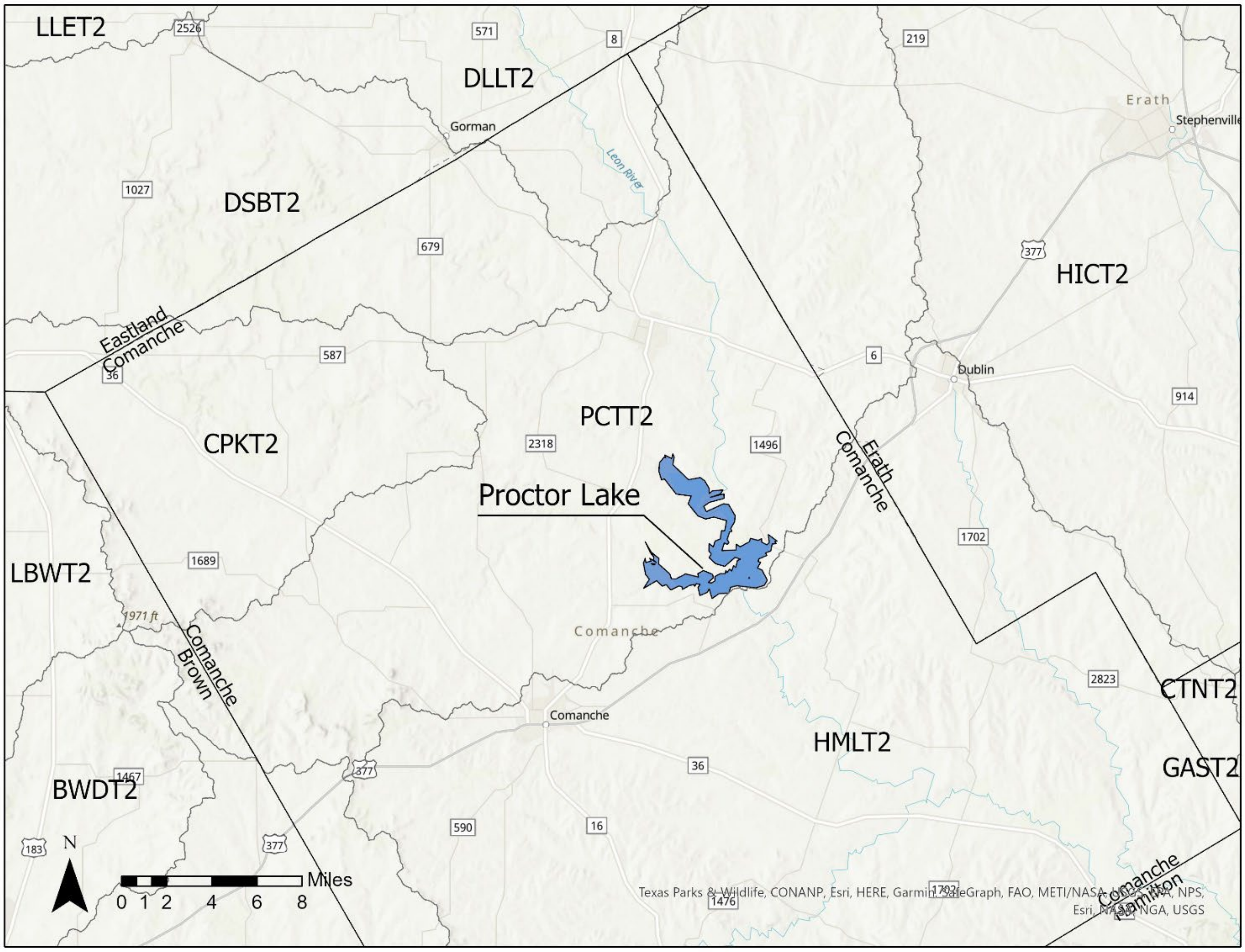


Figure 5-8: Lake Proctor Reservoir location map

Proctor Lake is located approximately three miles northwest of the city of Proctor in the Comanche County, on Leon River, a tributary of the Little River which is a tributary to the Brazos River (Figure 5-8). The lake was built, and is owned by the United State of America and operated by the U.S. Army Corps of Engineers for flood control, water supply, and recreational purposes. The top of the dam is at an elevation of 1,206 feet above mean sea level. The maximum design water surface may reach up to 1,201 feet above mean sea level. The crest is at an elevation of 1,162 feet above mean sea level. Based on data from 1946 survey, at the top of the flood control pool, at an elevation 1,197 feet above mean sea level, the lake will cover 14,010 acres and stores 374,200 acre-feet water. According to the TWDB 2012 volumetric survey, at the top of the conservation pool, at an elevation of 1,162 feet above mean sea level, the lake has a capacity of 54,762 acre feet encompassing a water surface of 4,615 acres. The dam controls a drainage area of about 1,265 square miles.

5.2. Water Balance Calculations

Regional water balance computations are an important part of the hydrologic model calibration process. When performing reservoir calibrations, the water balance analysis is often the only means of determining the reservoir inflows, except for U.S. Army Corp of Engineers (USACE) operated reservoirs, where inflow estimates are made available. In addition to using inflow data for calibrating the upstream hydrologic model, the mass balance is also critical for evaluating other variables of the reservoir, including the storage, outflows, and pool elevation timeseries. The following sections describe the water balance analysis for each reservoir, where applicable, and the data used in this analysis.

The water balance calculations involved analyzing historic outflows and storage as well as parametric data, such as elevation-discharge and elevation-storage curves. Inflows were calculated at a daily timestep using the following mass balance equation, rearranged to solve for inflows:

$$\Delta Storage\ = Inflows + [(MAPX - Evaporation\ Depth) * Lake\ Area]\ \text{-}\ Outflows$$

$$Inflows = \Delta Storage + Outflows + [(Evaporation\ Depth - Mean\ Areal\ Precipitation) * Lake\ Area]$$

where Inflow is reservoir inflow, ΔStorage is the change in reservoir storage, and Outflow is the downstream reservoir outflow.

5.2.1. Lake Mexia

Historical reservoir data are limited at Lake Mexia, where the only continuous data are from USGS gauge 08110300 which measures pool elevation data, available at both daily and instantaneous timesteps. The pool elevation data were used to calculate reservoir contents using the elevation-capacity table. The pool elevation data were also used to calculate reservoir outflow using the elevation-discharge table for the uncontrolled spillway, since outflow only occurs when the reservoir pool elevation reaches the spillway crest at 448.3 ft. The data and periods of record available for Lake Mexia are provided in Table 5-1. We obtained parametric reservoir data, including the elevation-capacity table and the elevation-discharge table, from the Bistone Municipal Water Supply District.

Table 5-1: Lake Mexia data summary

Data	Pool Elevation	Pool Storage	Reservoir Outflow	Precipitation	Evaporation	Reservoir Inflow
Instantaneous Data	USGS 08110300 (10/2007-5/2021)	Calculated	Calculated	MAPX (3hr)	---	---
Daily Data	USGS 08110300 (4/1999-5/2021)	Calculated	Calculated	MAPX (aggregated from 3hr)	TWDB and NOAA (monthly)	Calculated

TWDB produces a daily gridded gross and net (i.e., accounting for precipitation) lake surface evaporation product for Texas (available online at https://waterdatafortexas.org/lake-evaporation-rainfall) (TWDB, 2021d), which was analyzed for Lake Mexia (grid 611). This data was compared with monthly average pan evaporation values (Class A pan) from the NOAA TR-34 manual (Farnsworth et al., 1982) as a part of the mass balance analysis. Three pan evaporation stations were selected from Table 1 of the NOAA TR-34 manual (Navarro Mills Dam, Whitney Dam, and Waco Dam), which were averaged together for an average pan evaporation value. Because pan evaporation values are biased high compared to actual lake evaporation (free water surface evaporation or lake evaporation), monthly correction factors ("Pan Coefficients") are used to convert to lake evaporation. This conversion allows for direct comparison of the TWDB and NOAA methodologies (Table 5-2), which generally were within <5% of one another. Given the broadly established nature of the NOAA TR-34 manual, the final mass balance for Lake Mexia and all other reservoirs uses the NOAA evaporation estimates.

Table 5-2: Lake Mexia evaporation data

	Lake Surface	NOAA Pan Evaporation				Pan Coeff.	Lake Surface
Month	TWDB Gross Evaporation (in.)	Navarro Mills Dam[(a)]	Whitney Dam[(a)]	Waco Dam[(a)]	Average Pan Evaporation (in.)[(a)]	TWDB Pan Coefficients (Grid 611)	Lake Evaporation (in.)
January	3.07	3.00	2.95	3.00	2.98	0.74	2.27
February	2.93	4.09	3.88	4.28	4.08	0.71	2.86
March	4.10	6.42	6.05	6.43	6.30	0.70	4.42
April	4.87	7.33	7.20	7.30	7.28	0.69	5.00
May	5.43	8.31	8.46	8.02	8.26	0.63	5.20
June	6.91	10.06	10.65	10.40	10.37	0.69	7.15
July	7.83	11.68	12.39	12.09	12.05	0.70	8.44
August	7.98	10.77	11.38	11.08	11.08	0.71	7.87
September	6.37	7.69	8.33	8.03	8.02	0.74	5.94
October	5.07	6.42	6.24	6.52	6.39	0.77	4.92
November	3.72	4.17	4.02	4.46	4.22	0.79	3.32
December	2.92	3.09	3.12	3.35	3.19	0.77	2.40
Annual	**61.19**	**83.03**	**84.67**	**84.96**	**84.22**	**0.72**	**59.80**

[(a)] NOAA Technical Report 34, Table 1 (Farnsworth et al., 1982).

5.2.2. Coleto Creek Reservoir

Historical reservoir data for Coleto Creek Reservoir are available for pool elevation and reservoir outflow. Pool elevation is measured at USGS gauge 08177400, and streamflow is measured approximately 1.5 miles downstream at USGS gauge 08177500, which is used as reservoir outflow data. The Guadalupe-Blanco River Authority provided supplementary instantaneous reservoir outflow data for three storm events (May 2010, June 2015, and August 2017), which were combined with the USGS data to make a complete outflow dataset. The data and periods of record available for Coleto Creek Reservoir are provided in Table 5-3. Parametric reservoir data which includes the elevation-capacity table were obtained from the TWDB.

Table 5-3: Coleto Creek Reservoir data summary

Data	Pool Elevation	Pool Storage	Reservoir Outflow	Precipitation	Evaporation	Reservoir Inflow
Instantaneous Data	USGS 08177400 (10/2007-5/2021)	Calculated	USGS 08177500 (10/2007-5/2021)	MAPX (3 hr)	---	---
Daily Data	USGS 08177400 (10/1999-5/2021)	Calculated	USGS 08177500[(a)] (10/1999-5/2021)	MAPX (aggregated 3hr)	TWDB and NOAA (monthly)	Calculated

[(a)] USGS 08177500 supplemented with reservoir outflow data from GBRA for May 2010, June 2015, and August 2017.

Outflow Data

In our discussions with the WGRFC about the calibration of the Coleto Creek Reservoir model, staff cautioned against the use of USGS gauge 08177500 as an accurate measurement of actual reservoir releases. However, the GBRA does not maintain continuous reservoir release records for Coleto Creek Reservoir, and the outflow data provided by the WGRFC are limited, so there is no alternative data source. We thoroughly investigated all outflow data with USGS staff and the WGRFC, including actual instantaneous (30-minute) reservoir release provided by the GBRA for four storm events (May 15-16, 2010, June 17-18, 2015, August 26-27, 2017, and July 7-10, 2021). Figure 5-9 shows the GBRA reservoir release data and the USGS flow data at gauge 08177500 for the four storm events, which indicate the USGS flow data overestimates Coleto Creek Reservoir releases (the approximate percent different for the 2010, 2015, 2017, and 2021 storm events is 30%, 50%, 80%, and 30%, respectively). Although the USGS gauge is 1.5 miles downstream of the reservoir, there are no significant streams that contribute to the river between the dam and gauge 08177500 so we expect the flows to be similar in magnitude.

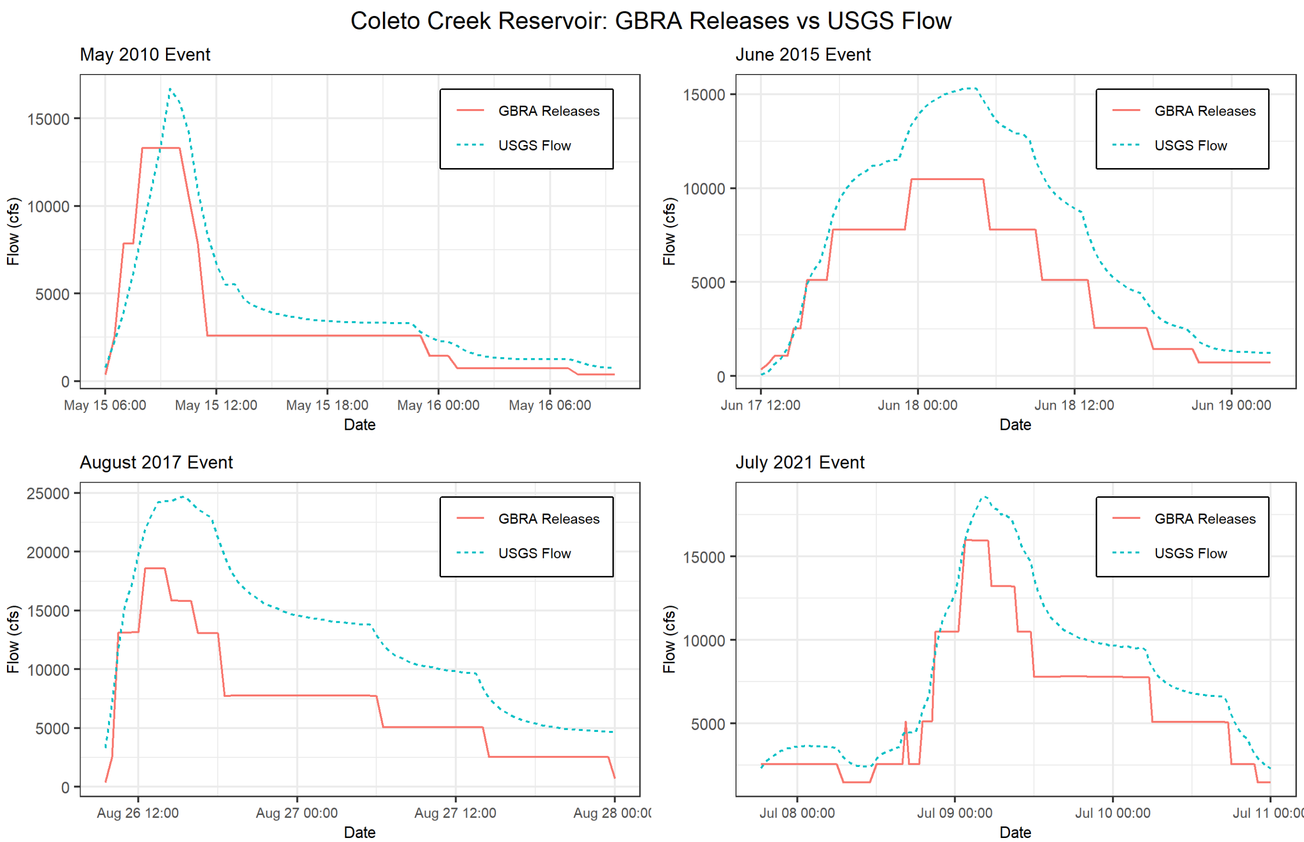


Figure 5-9: Coleto Creek Reservoir outflow comparison (USGS versus GBRA)

At issue is the accuracy of the USGS rating curve at gauge 08177500. The rating curve was updated in July 2021 to reflect two discrete flow measurements made by USGS staff on July 9 (measurements 632 and 633 from the streamflow measurements web page (USGS, 2021a). The new rating curve measures 24 feet of stage to be approximately 14,500 cfs, whereas the old rating curve measured 24 feet of stage to be approximately 24,700 cfs. USGS staff informed us that significant vegetation was present in the channel during the July 9 measurements and is suspected to be the cause of the shift in the rating curve, and that if the vegetation were to be removed in the future the rating curve may “shift back to the right where our original curve was drawn” (J.W. East, personal communication, August 3, 2021). As a part of the outflow analysis, we re-analyzed the historical USGS gauge 08177500 flow data by back-calculating streamflow from gauge height data using the new July 2021 rating curve. In general, the back-calculated USGS flow for the four storm events showed improved performance compared to the GBRA data with relative percent differences of -20%, -20%, -2%, and 30% for the 2010, 2015, 2017, and 2021 storm events, respectively, indicating a possible underestimation of reservoir releases. Although we considered back-calculating the USGS gauge 08177500 flow data, there was no way of knowing when it was appropriate to use the new (July 2021) rating curve (1 year, 5 years, etc.). Additionally, since this reservoir is one component of the larger NWS CHPS framework, we were concerned about modifying the historical USGS data, when the 'original' USGS data would continue to be implemented for downstream operations (basin CCVT2), and the USGS would not back-calculate their previous flow data to align with the new rating curve. Therefore, when it was available, the GBRA reservoir release data replaced the USGS gauge 08177500 flow to provide a compromise solution (Figure 5-10).

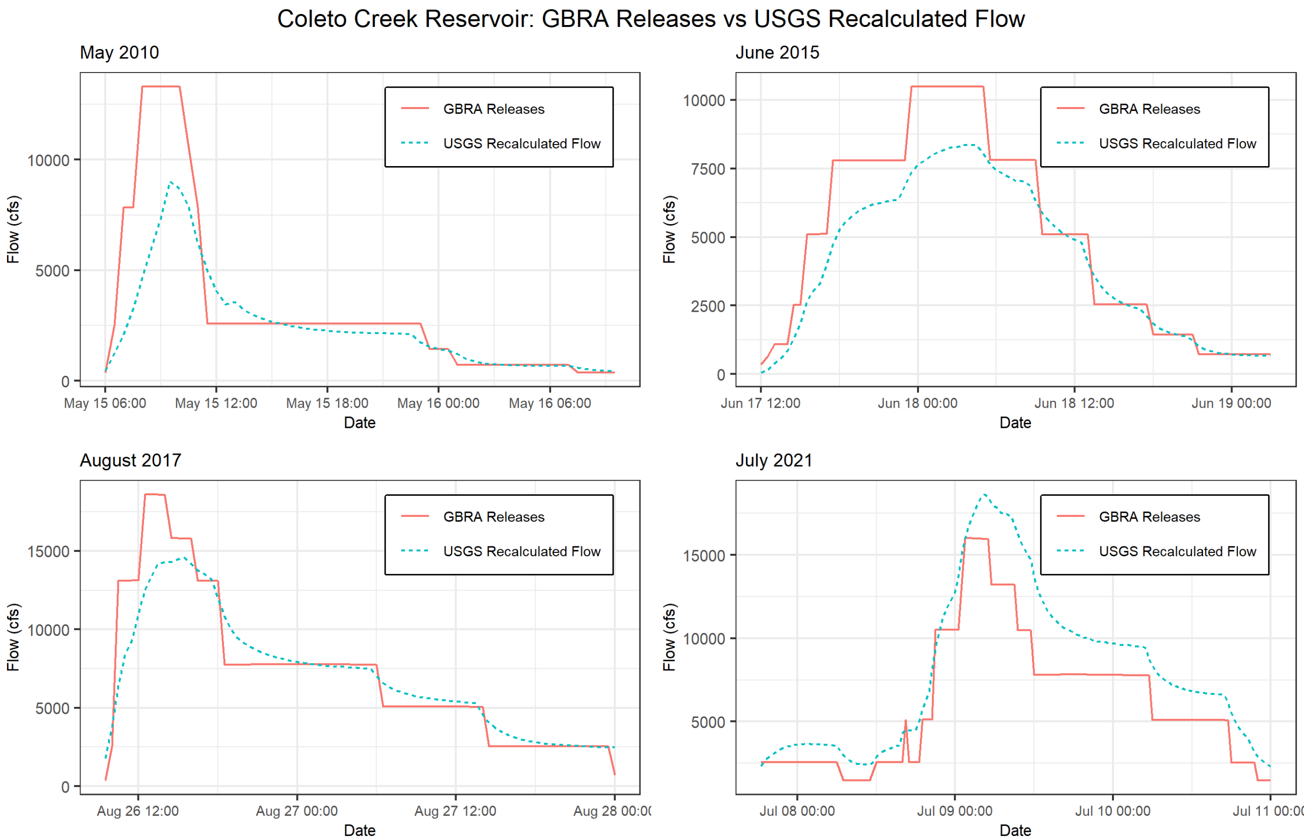


Figure 5-10: Coleto Creek Reservoir outflow comparison (USGS-adjusted vs GBRA)

Evaporation Data

The TWDB produces a monthly gridded gross and net evaporation product for Texas (available online at https://waterdatafortexas.org/lake-evaporation-rainfall), which was analyzed for Coleto Creek Reservoir (grid 910). This data was compared with monthly average pan evaporation values (Class A pan) from the NOAA TR-34 manual (Farnsworth et al., 1982) as a part of the mass balance analysis. Three pan evaporation stations adjacent to Coleto Creek Reservoir from Table 1 of the NOAA TR-34 manual include: Beeville, Thompson's 3 WSW, and Point Comfort. Pan evaporation values are biased high compared to actual lake evaporation (free water surface evaporation or lake evaporation) and are therefore converted to lake evaporation using monthly pan coefficients from the TWDB for grid 910. The TWDB and NOAA evaporation values are provided in Table 5-4, along with monthly pan evaporation coefficients and the monthly lake evaporation rates.

Table 5-4: Coleto Creek Reservoir Evaporation

	Lake Surface	NOAA Pan Evaporation				Pan Coeff.	Lake Surface
Month	TWDB Gross Evaporation (in.)	Beeville[(a)]	Thompson's 3 WSW[(a)]	Point Comfort[(a)]	Average Pan Evaporation (in.)[(a)]	TWDB Pan Coefficient (Grid 910)	Lake Evaporation (in.)
January	2.25	3.36	2.87	3.08	3.10	0.72	2.23
February	2.56	3.66	3.74	3.85	3.75	0.70	2.63
March	3.85	5.13	4.89	5.53	5.18	0.70	3.63
April	4.47	5.93	5.79	6.51	6.08	0.69	4.19
May	5.02	6.84	7.26	8.53	7.54	0.64	4.83
June	6.12	7.75	7.8	9.92	8.49	0.69	5.86
July	6.86	8.47	7.76	10.76	9.00	0.70	6.30
August	6.48	8.18	7.26	9.88	8.44	0.70	5.91
September	5.15	6.3	5.92	7.46	6.56	0.72	4.72
October	4.40	5.43	5.25	6.46	5.71	0.75	4.29
November	3.04	4.17	4.24	4.37	4.26	0.76	3.24
December	2.40	3.57	2.96	3.4	3.31	0.75	2.48
Annual	**52.61**	**68.79**	**65.74**	**79.75**	**71.43**	**0.71**	**50.30**

[(a)] NOAA Technical Report 34, Table 1 (Farnsworth et al., 1982).

5.2.3. Funding Dependent – Lake Proctor

Lake Proctor is owned and operated by the U.S. Army Corps of Engineers (USACE). In addition to reporting pool elevation and reservoirs outflows, the USACE also provides estimates of daily inflows. Because USACE calculates inflows, no water balance calculations were performed for PCTT2. The USACE data for Lake Proctor is shown in Table 5-5.

Table 5-5: Lake Proctor Reservoir data summary

Data	Pool Elevation	Pool Storage	Reservoir Outflow	Precipitation	Evaporation	Reservoir Inflow
Instantaneous Data	USACE (4/1997–4/2021)	---	USACE (4/1997–4/2021)	MAPX (6 hr)	---	---
Daily Data	USACE (4/1997–4/2021)	USACE (1963–2021)	---	MAPX (aggregated from 6hr)	TWDB and NOAA (monthly)	USACE (1963–2021)

5.2.4. Funding Dependent — Lake Coleman

Historical reservoir data is limited at Lake Coleman, where the only available continuous data are from USGS gauge 08140770, which measures pool elevation on a daily timestep from 2007 to present (Table 5-6). The pool elevation data were used to calculate reservoir contents using the elevation-capacity table obtained from the City of Coleman, Texas. The pool elevation data were also used to calculate reservoir outflow using the elevation-discharge table for the uncontrolled spillway that was within the existing WGRFC Lake Coleman RES-SNGL reservoir model parameter file. Officials at the City were unaware of any records on the elevation-discharge of the spillway, and thus the elevation-discharge curve could not be independently verified. Therefore, the only outflow data for Lake Coleman were ‘spills’ when the reservoir pool exceeded the spillway crest (1717.5 ft.) calculated using the unverified elevation-discharge table.

Table 5-6: Lake Coleman Reservoir data summary

Data	Pool Elevation	Pool Storage	Reservoir Outflow	Precipitation	Evaporation	Reservoir Inflow
Daily Data	USGS 08140770 (2007-10-01 to present)	Calculated	Calculated	MAPX (aggregated from 3-hr)	TWDB and NOAA (monthly)	Calculated

Inflows to the reservoir were calculated using a mass balance equation presented in section 5.2.1. Sub-daily (3-hourly) precipitation data for LKCT2 were extracted from the MAPX timeseries in CHPS and aggregated to a daily time step. Evaporation data from TWDB was compared to monthly average pan evaporation values (Class A pan) from the NOAA TR-34 manual, as described in section 5.2.1. For consistency between reservoirs, the NOAA monthly pan evaporation values and coefficients were used to estimate the monthly free water evaporation within the final mass balance calculations.

5.2.5. Funding Dependent – Hord's Creek Reservoir

Hords Creek Lake is owned and operated by the U.S. Army Corps of Engineers (USACE). In addition to reporting pool elevation and reservoirs outflows, the USACE also provides estimates of daily inflows. Because USACE calculates inflows, no water balance calculations were performed for HORT2. The USACE data for Hords Creek Lake is shown in Table 5-7.

Table 5-7: Hord's Creek Reservoir data summary

Data	Pool Elevation	Pool Storage	Reservoir Outflow	Precipitation	Evaporation	Reservoir Inflow
Instantaneous Data	USACE (1/2000–10/2021)	---	USACE (4/1997–4/2021)	MAPX (3hr)	---	---
Daily Data	USACE (1948–2021)	USACE (1981–2021)	---	MAPX (aggregated from 3hr)	TWDB and NOAA (monthly)	USACE (1948–2021)

5.2.6. Funding Dependent — Lake Brownwood

Historical reservoir data is limited at Lake Brownwood, where the only available continuous data are from USGS gauge 08143000, which measures pool elevation on both a daily and 15-minute timestep from 2007 to present (Table 5-8). The pool elevation data were used to calculate reservoir contents using the elevation-capacity table obtained from the Brown County Water Improvement District #1 (BCWID). The reservoir outflow data was calculated using the elevation-discharge table provided by the BCWID for the uncontrolled emergency spillway at a crest elevation of 1,425 ft. There are also three reservoir outlets below the spillway crest, but because no historical release data exists, calculated discharges only included outflows from the spillway.

Table 5-8: Lake Brownwood Reservoir data summary

Data	Pool Elevation	Pool Storage	Reservoir Outflow	Precipitation	Evaporation	Reservoir Inflow
Daily Data	USGS 08143000 (2007-10-01 to present)	Calculated	Calculated	MAPX (aggregated from 3-hourly)	TWDB and NOAA (monthly)	Calculated

Inflows to the reservoir were calculated using a mass balance equation presented in section 5.2.1. Sub-daily (3-hourly) precipitation data for basin LBWT2 were extracted from the MAPX timeseries in CHPS and aggregated to a daily time step. Evaporation data from TWDB was compared to monthly average pan evaporation values (Class A pan) from the NOAA TR-34 manual, as described in section 5.2.1. For consistency between reservoirs, the NOAA monthly pan evaporation values and coefficients were used to estimate the monthly free water evaporation within the final mass balance calculations.

5.2.7. Funding Dependent – Waco Lake

Waco Lake is owned and operated by the U.S. Army Corps of Engineers (USACE). In addition to reporting pool elevation and reservoirs outflows, the USACE also provides estimates of daily inflows. Because USACE calculates inflows, no water balance calculations were performed for ACTT2. The USACE data for Waco Lake is shown in Table 5-9.

Table 5-9: Waco Lake Reservoir data summary

Data	Pool Elevation	Pool Storage	Reservoir Outflow	Precipitation	Evaporation	Reservoir Inflow
Instantaneous Data	USACE (10/2007–11/2021)	---	USACE (4/1997–4/2021)	MAPX (3hr)	---	---
Daily Data	---	USACE (1965–2021)	---	MAPX (aggregated from 3hr)	TWDB and NOAA (monthly)	USACE (1965–2021)

5.2.8. Funding Dependent – Lake Leon

Historical reservoir data is limited at Lake Leon, where the only available continuous data are from USGS gauge 08099000, which measures pool elevation on both a daily and 15-minute timestep from 1999 to present (although reservoir storage was previously available from the USGS, but only until 2003) (Table 5-10). The pool elevation data were used to calculate reservoir contents using the elevation-capacity table obtained from the Eastland County Water Supply District (ECWSD). The pool elevation data were also used to calculate reservoir outflow using the elevation-discharge table for the uncontrolled emergency spillway at a crest elevation of 1,382 ft.

Table 5-10: Lake Leon Reservoir data summary

Data	Pool Elevation	Pool Storage	Reservoir Outflow	Precipitation	Evaporation	Reservoir Inflow
Daily Data	USGS 08099000 (1999-03-30 to present)	Calculated	Calculated	MAPX (aggregated from 6-hourly)	TWDB and NOAA (monthly)	Calculated

Inflows to the reservoir were calculated using a mass balance equation presented in section 5.2.1. Sub-daily (6-hourly) precipitation data for LLET2 were extracted from the MAPX timeseries in CHPS and aggregated to a daily time step. Evaporation data from TWDB was compared to monthly average pan evaporation values (Class A pan) from the NOAA TR-34 manual, as described in section 5.2.1. For consistency between reservoirs, the NOAA monthly pan evaporation values and coefficients were used to estimate the monthly free water evaporation within the final mass balance calculations.

5.3. RES-SNGL Calibration

The Single Reservoir Regulation Operation (RES-SNGL) reservoir models were calibrated to historical pool elevation and outflow data for the period of record, January 2000 – April 2021. Reservoir inflow data calculated via mass balance is typically used as the reservoir model input or forcing. However, the negative inflows would break the RES-SNGL models, so the reservoir models were forced with simulated flow from the calibrated hydrologic models. Thus, the hydrologic models for the basins that contained the reservoirs (BSAT2 for Lake Mexia and CKDT2 for Coleto Creek Reservoir) were calibrated using the inflows calculated via mass balance, and then the simulated basin outflow (which does not contain negative values) was used to force the reservoir models. RES-SNGL models include the ability to adjust pool elevation and outflow to match observed.

5.3.1. Lake Mexia: BSAT2

Lake Mexia is operated primarily as a "fill-and-spill" reservoir via its uncontrolled spillway. The reservoir does not typically make releases until the spillway crest (448.3 ft MSL) is reached, at which point releases are prescribed by the reservoir elevation and spillway characteristics. In our initial calibration we reviewed current data from Bistone Municipal Water Supply District and made a few minor adjustments to the elevation-volume curve and the uncontrolled spillway parameters. Additionally, we found that evaporation alone did not do a good job of representing reservoir drawdown. We added a rule to make a continuous release of 0.6 cfs to account for drawdown during low inflow periods.

5.3.1.1. Sources of uncertainty

Lake Mexia calculated inflows are based on parameters derived from pool elevation. Since Lake Mexia operates primarily with an uncontrolled spillway, outflow is a function of elevation using the elevation-discharge table for the spillway. Reservoir volume and evaporation are also functions of the elevation-volume curve provided by the Bistone Municipal Water Supply District.

5.3.1.2. Key events

July 2015 Event

The recorded reservoir outflow data (RQME) shows a release of 0 cfs for this whole period but the reservoir draws down significantly. Since there are no measured reservoir releases, this indicates there is a small continuous release occurring from the reservoir, separate from the uncontrolled spillway. The calibrated model is programmed to continuously release about 0.6 cfs to help improve model performance. In the top half of Figure 5-11 below, the blue line (PELV) is the observed reservoir pool elevation, and the red line (SPEL) is the simulated reservoir pool elevation, and in the bottom half of the figure, the dark blue line shows the (simulated) reservoir inflow (QME), which is well-verified.

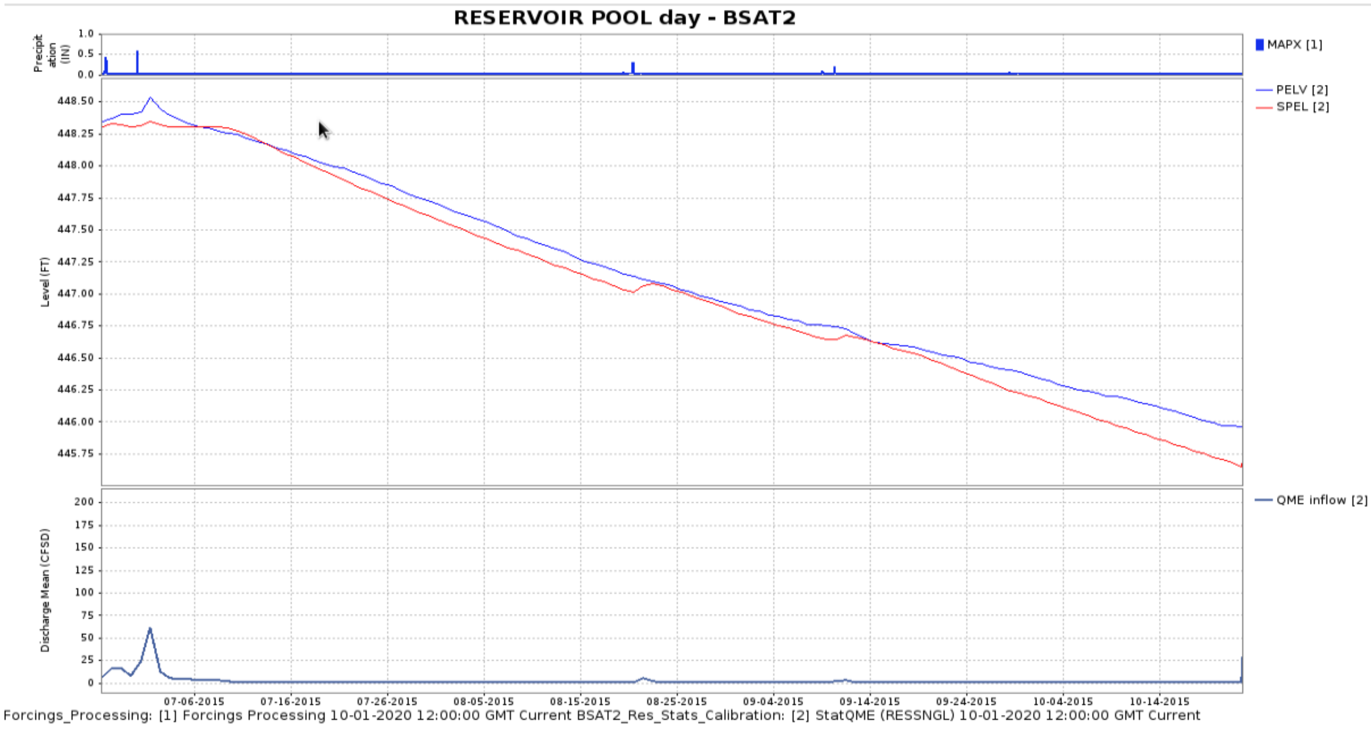


Figure 5-11: Lake Mexia pool elevation, comparing observed (blue) and simulated (red) during a 2015

October 2015 Event

The model typically performs better with high flow events, though the uncertainty in reservoir contents and outflows mean that outflow events do not always match (Figure 5-12). In the event shown below, the reservoir is above the uncontrolled spillway, so about 100% of inflows are released in each timestep. The observed outflow is less than the simulated outflow for the first event and greater than the simulated outflow for the second event. This can be attributed to uncertainty in either simulated inflows or in the measured outflows.

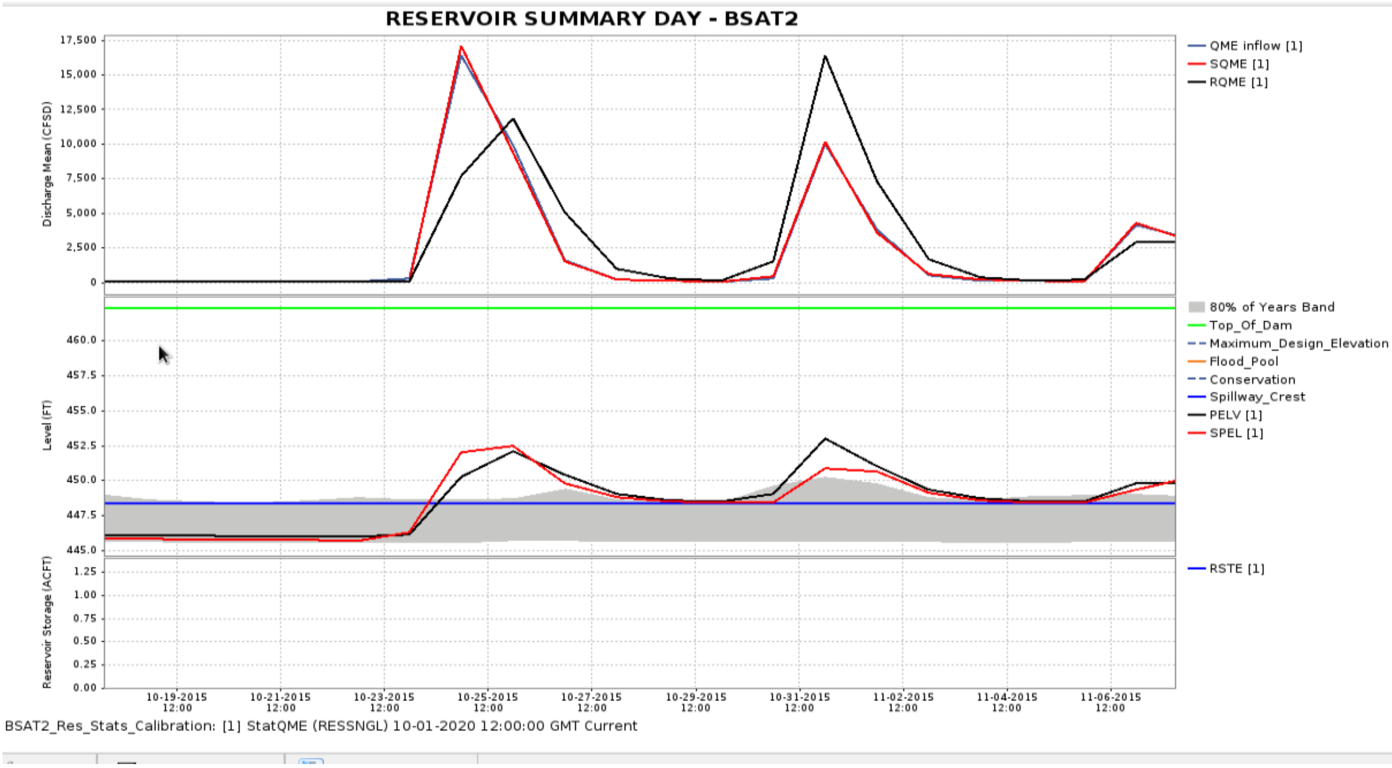


Figure 5-12: Improved calibration for BSAT2 RES-SNGL model showing simulated outflows (top, red) and pool elevation (bottom, red). Observations are in black.

In general, the calibrated reservoir model provides a small improvement from the previous reservoir model, largely due to the fact that the uncontrolled spillway at Lake Mexia makes reservoir operations very simple. The updated model does improve performance of the reservoir pool elevation by prescribing a small release to capture the pool drawdown. Both pre and post-calibration models perform well during high inflow events when the reservoir is nearly full, and releases are made according to the elevation-discharge table.

5.3.2. Coleto Creek Reservoir: CKDT2

Coleto Creek Reservoir is operated to provide cooling water to the power plant and serve as a recreational area. It releases water from seven 40 by 28 foot gates operating at pool elevations of 71 feet to 99.4 feet (USGS, 2021b). The reservoir has an emergency spillway crest at 107.3 feet, a maximum design elevation of 114.8 feet, and the top of the dam is at 120.0 feet (TWDB, 2021c). The conservation pool is at 98 feet, and releases are typically made to maintain a reservoir pool elevation at or below this level. The reservoir operations appear to have changed around 1999, where previously the reservoir was operated to maintain about 37,000 af and now (1999-present) the reservoir maintains about 31,000 af. The maximum reservoir pool elevation since 1999 is 99.94 feet with a storage volume of 36,680 af (USGS, 2021b). Since the reservoir makes releases using its spillway gates, the releases can be configured as-needed by the reservoir operators. In some instances, the reservoir will make releases in advance of a precipitation event, and in other instances the reservoir will make releases to maintain a pool elevation of 99 feet rather than 98 feet.

The new reservoir operating rules allow the reservoir to maintain its elevation at or below the uncontrolled spillway, while also lowering the reservoir level to 94.6 feet MSL during period of low inflow.

Prior to calibration, the Coleto Creek Reservoir model did not represent pool elevation well since there was no way to release excess water as the pool elevation increased. Prior to our calibration the RES-SNGL model utilized the SETQ scheme (operating rule), which sets a prescribed reservoir outflow. To determine the baseline model performance, we set the RES-SNGL model to not use prescribed outflow or pool elevation data which allows the reservoir to determine pool and release in each timestep. Figure 5-13 shows the simulated pool elevation (SPEL) in red and the observed pool elevation (PELV) in blue, characterized by over-simulated SPEL.

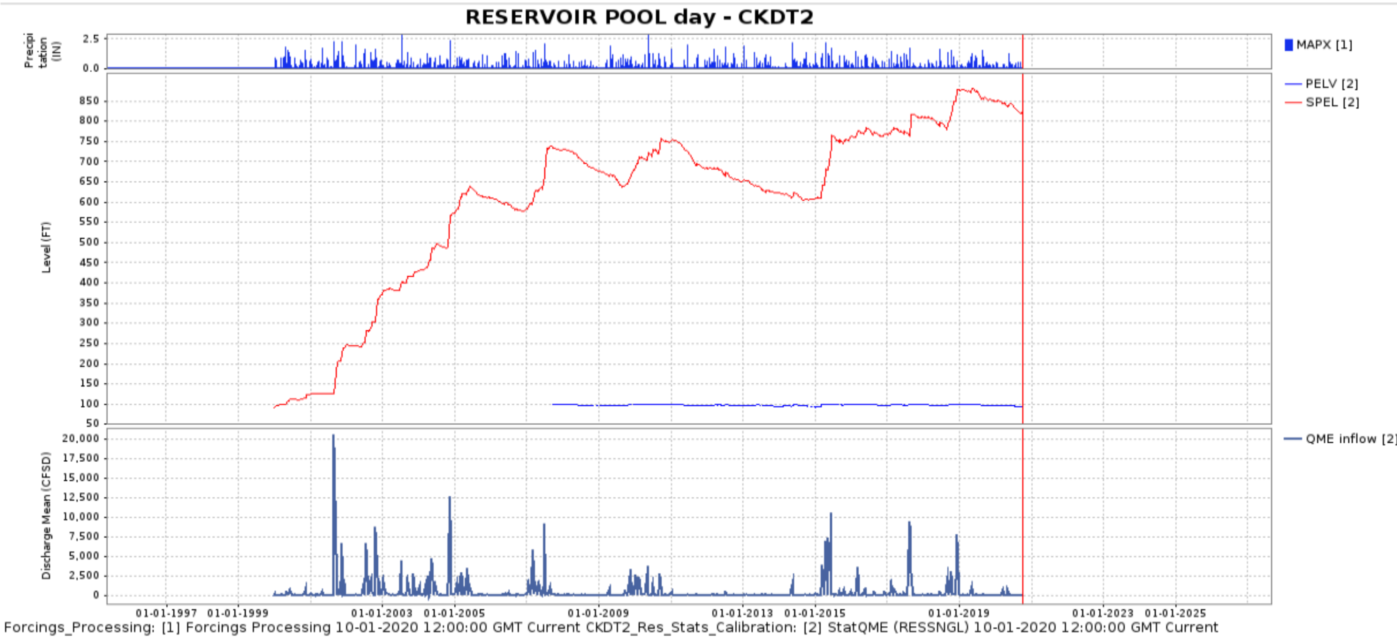


Figure 5-13: Coleto Creek prior to model calibration illustrating the run-away simulated pool elevation (red) as compared to the observed pool elevation (blue, middle panel).

5.3.2.1. Key Events

August 2017 Event

In this event the simulated releases from Coleto Creek Reservoir are less than the observed outflow, where nearly 100% of the simulated inflows were released in the simulated outflow. This difference may be due to the difference of inflow data being used, where the model is using simulated inflows and the observed data is using calculated (mass balance) inflows. Also in this event, the simulated releases begin earlier than the observed releases, which may be due to the higher simulated initial pool elevation contents leading up to this event. A lower initial pool elevation in the observed period means that the reservoir has more space to absorb a large inflow event before triggering releases. In the top panel of Figure 5-14, the simulated outflow is shown with the red line (SQME), observed outflow is shown with the black line (RQME), and simulated inflow is shown with the dark blue line (QME inflow). In the bottom half of Figure 5-14, the simulated pool elevation is shown in red (SPEL) and the observed pool elevation is shown in black (PELV).

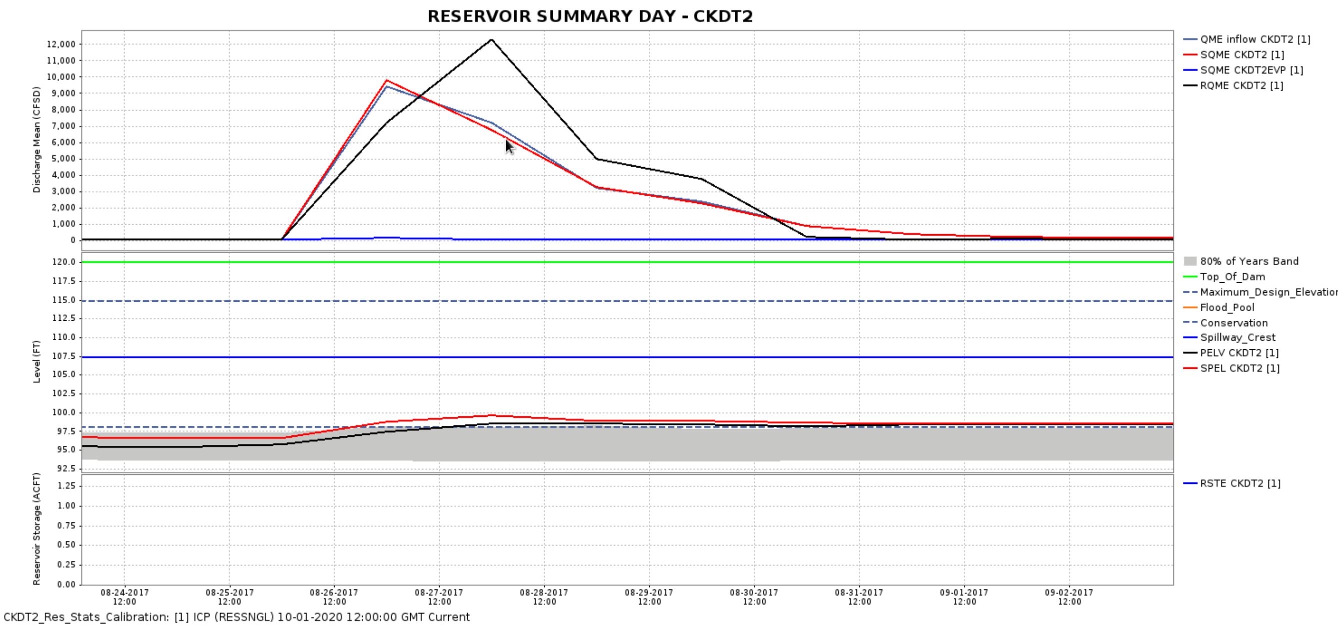


Figure 5-14: Improved calibration for CKDT2 RES-SNGL model showing SQME outflows (top panel, red) and pool elevation (bottom panel, red).

November 2014 Event

Since the reservoir model was forced using flows simulated by the hydrologic model for basin (CKDT2), there are discrepancies in inflow events between the observed reservoir data and the simulated inflows. Inflow events are shown based on rainfall and the hydrologic models, but those are not reflected in the observed reservoir pool elevation or outflow timeseries. In Figure 5-15, the simulated inflow event on November 6, 2014 shown with the dark blue line (QME inflow) does not trigger an increase in the observed pool elevation, but the simulated pool elevation does respond to the inflow event. The observed pool elevation (PELV) is show with the blue line and the simulated pool elevation (SPEL) is shown with the red line in Figure 5-16.

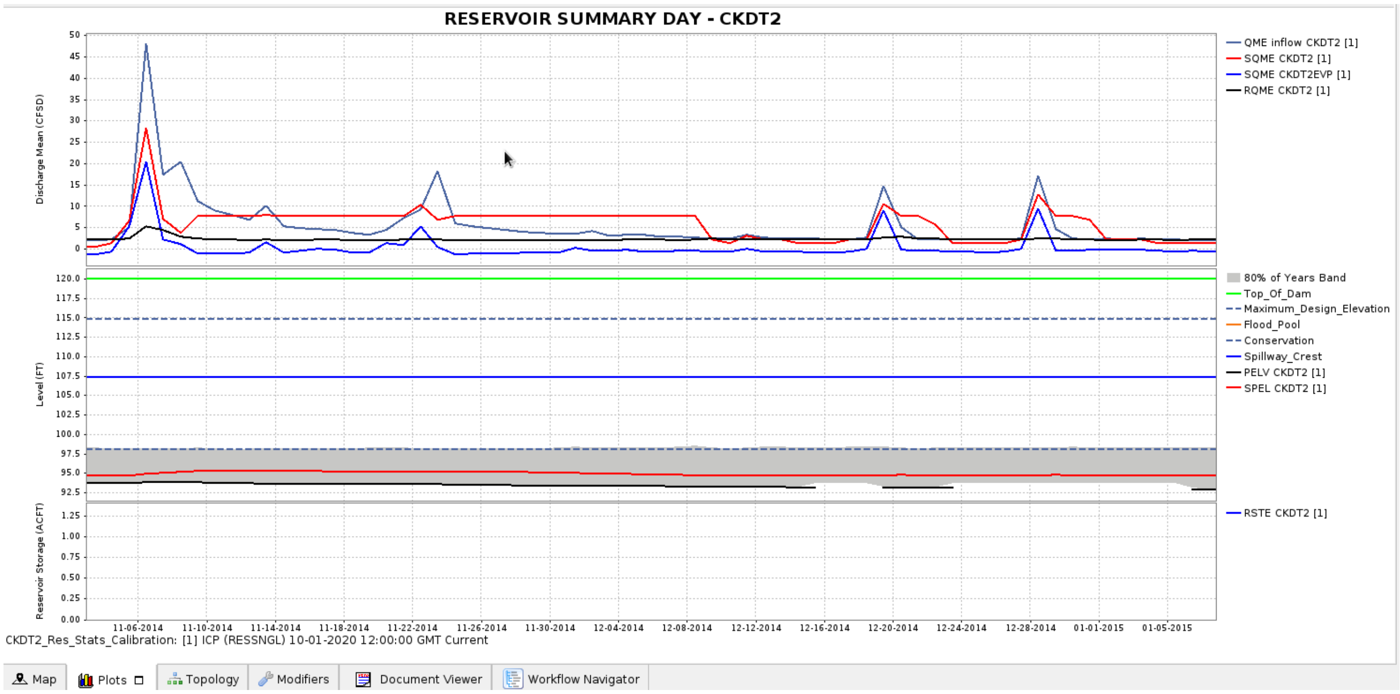


Figure 5-15: Coleto Creek simulated outflows (top panel, red) and pool elevation (bottom panel, red)

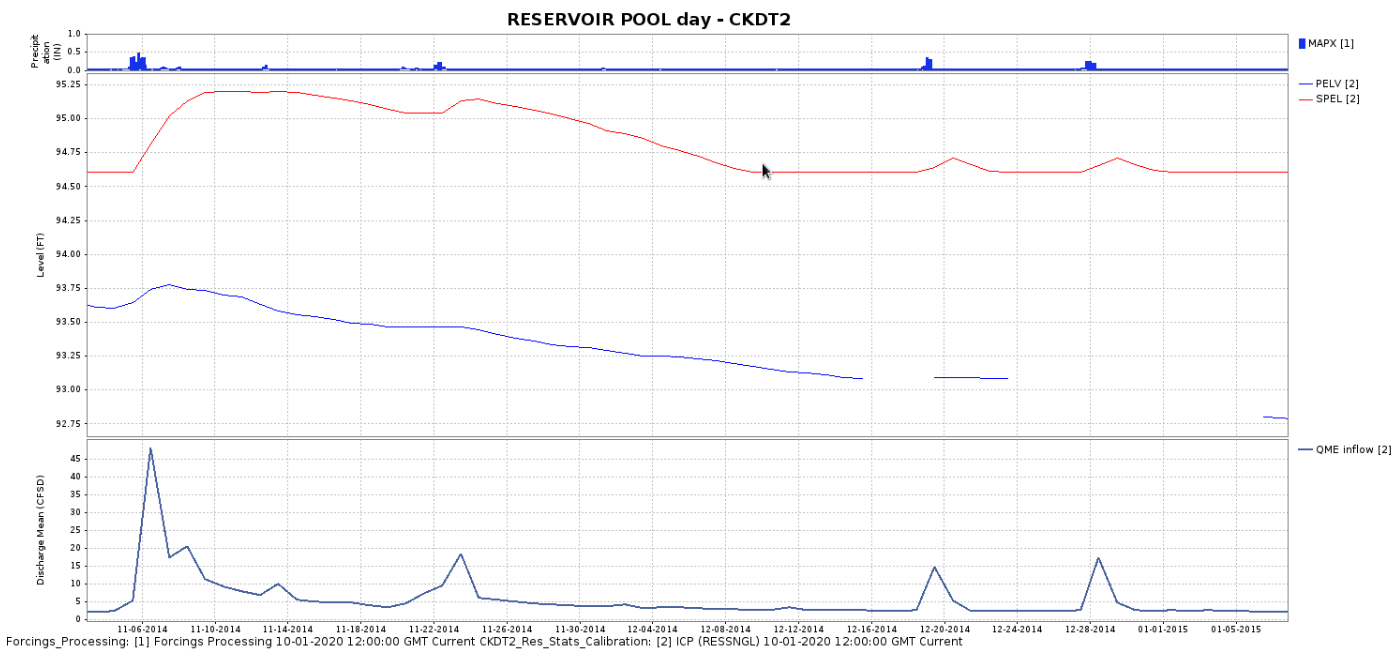


Figure 5-16: Coleto Creek simulated pool elevation (top panel, red), and QME inflows (bottom panel).

April 2009 Event

The simulated inflow shows a significant inflow event on April 28, 2009, but the historical reservoir contents and outflow do not reflect this event, resulting in a large difference between simulated and observed pool elevation. In the top half of Figure 5-17, the red line shows simulated pool elevation (SPEL) which increases from about 94.5 feet to 98.5 feet, whereas the observed pool elevation (PELV) shown with the blue line only increases to about 96.0 feet. In the top panel of Figure 5-18, the simulated outflow (SQME) shown with the red line peaks at about 850 cfs, while the observed outflow shown with the black line (RQME) shows no additional release. This is another example of how use of simulated inflow can create artificial differences between observed and simulated reservoir results.

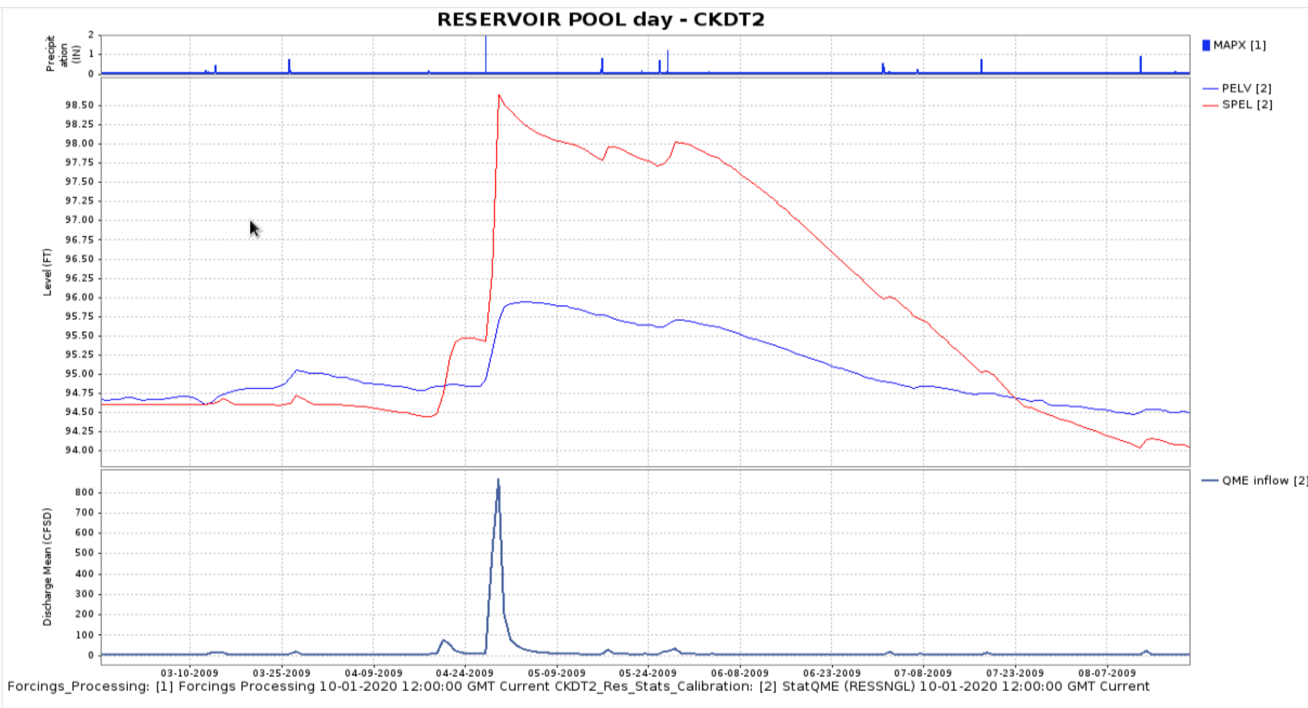


Figure 5-17: Coleto Creek Reservoir simulated inflow event. SPEL in red; PELV in blue (middle panel).

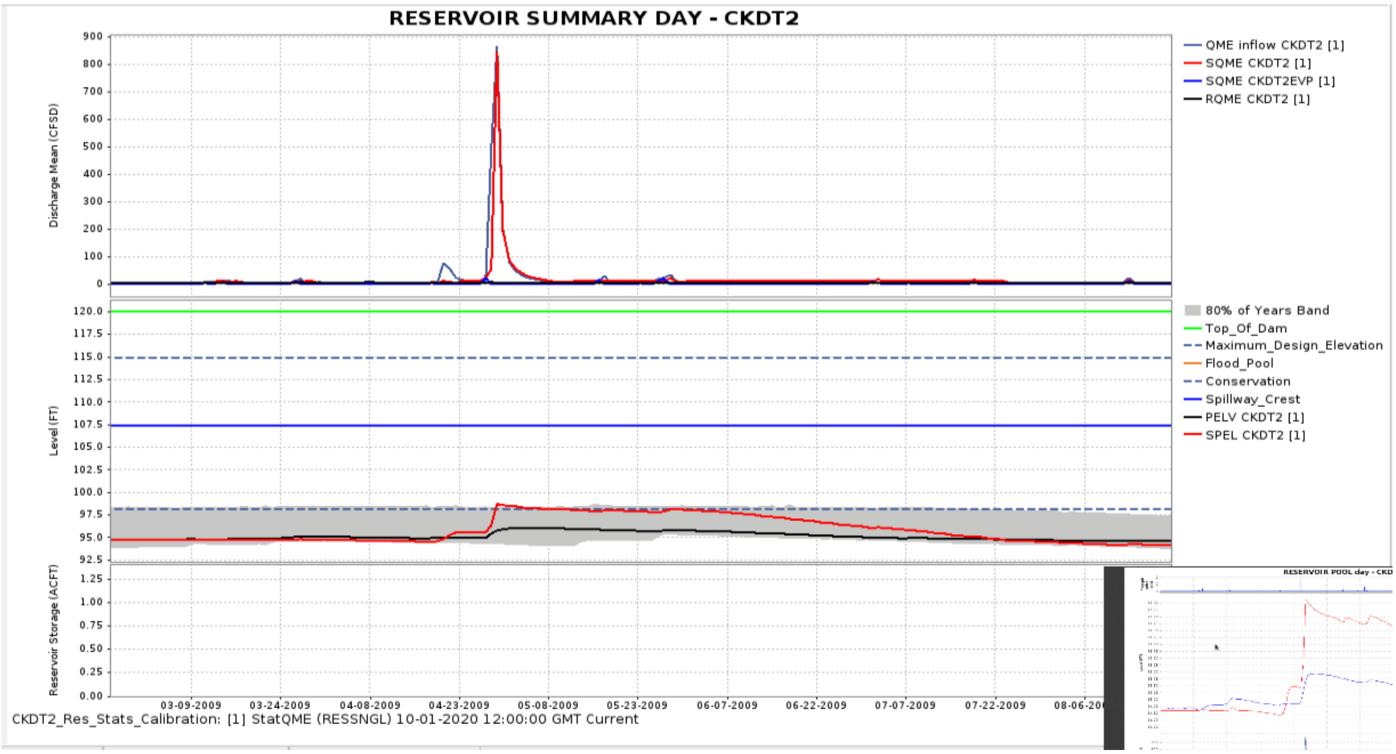


Figure 5-18: Coleto Creek Reservoir simulated inflow event. SQME in red; SQME in blue (top panel).

The observed pool elevation data in Figure 5-19 shows how reservoir operations can deviate from programmed modeling rules. Reservoir operators can initiate preemptive releases when a major event is forecasted, and target reservoir elevation can vary by a few feet when at or above the conservation pool. This is not uncommon in reservoir modeling where programmed rules are more strict but actual reservoir operations are implemented at the discretion of operators.

In the period shown below (11/23/2009 to 5/1/2010) the historic pool elevation stays above the top of the conservation pool (98.0 feet MSL), where it appears to return to pool elevations between 98.2 and 98.4 feet after inflow events. In the top half of Figure 5-19, the observed pool elevation is shown with the blue line (PELV) and the simulated pool elevation is shown with the red line (SPEL).

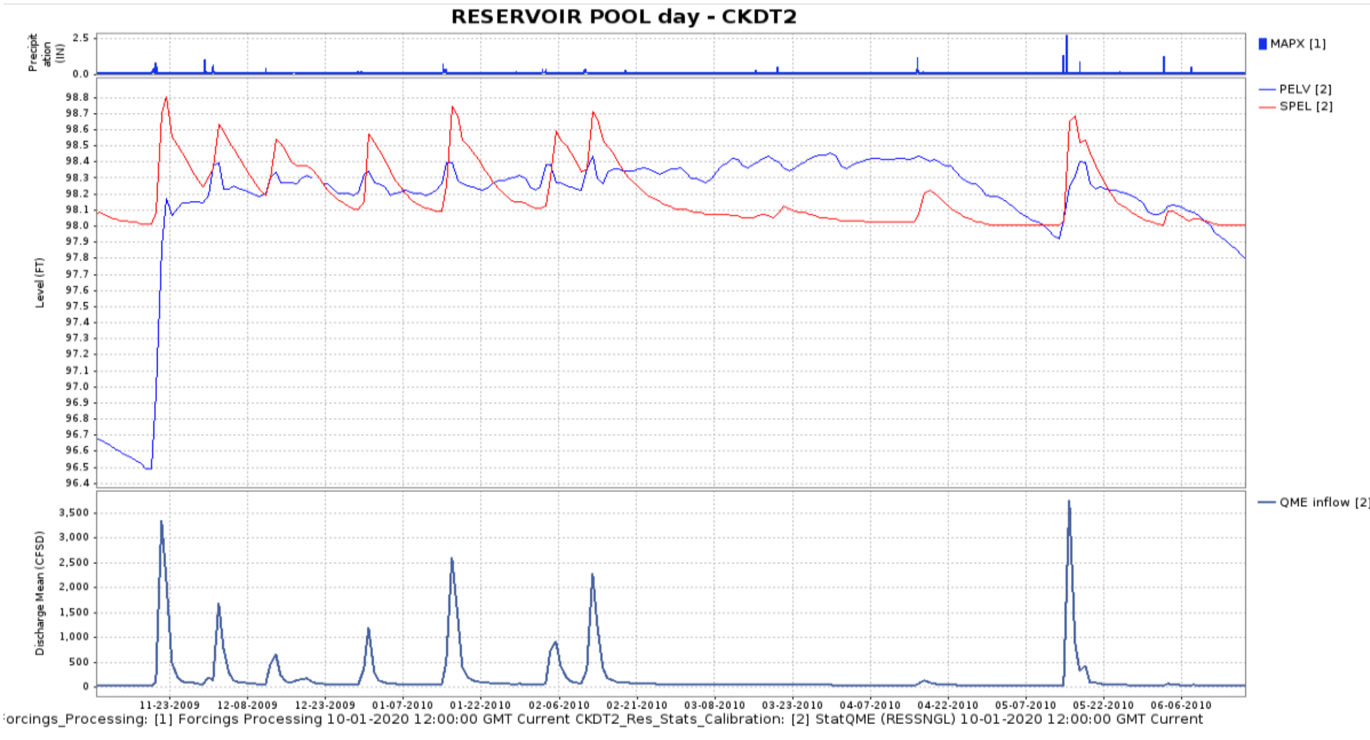


Figure 5-19: Coleto Creek Reservoir Operation Detail (11/23/2009 – 6/6/2010)

5.3.3. Lake Proctor: PCCT2

5.3.3.1. Overview

Proctor Lake is located approximately three miles northwest of the city of Proctor in the Comanche County, on Leon River, a tributary of the Little River which is a tributary to the Brazos River. The lake is operated by the U.S. Army Corps of Engineers for flood control, water supply, and recreational purposes. The lake has a storage capacity of 54,762 acre-feet (af) at the top of the conservation pool, which is also the spillway crest, at an elevation of 1,162 ft above mean sea level. The top of the flood control pool is at an elevation of 1,197 ft with a storage volume of 374,200 af. The maximum recorded storage was 382,900 af on May 3, 1990.

5.3.3.2. Key Events

Prior to calibration, the Lake Proctor model did not represent pool elevation well, most likely because there was no rule to release excess water at higher pool elevations. Prior to calibration, the RES-SNGL model utilized a single SETQ operating rule, which sets a prescribed reservoir discharge rate in units of cubic feet per second per day (CFSD). Figure 5-20 shows simulated pool elevation (SPEL) in red and the observed pool elevation (PELV) in blue, prior to model calibration; note the excessively high SPEL by 2020. These CHPS screenshots illustrate the insufficient releases and run-away pool elevations from the initial simulation.

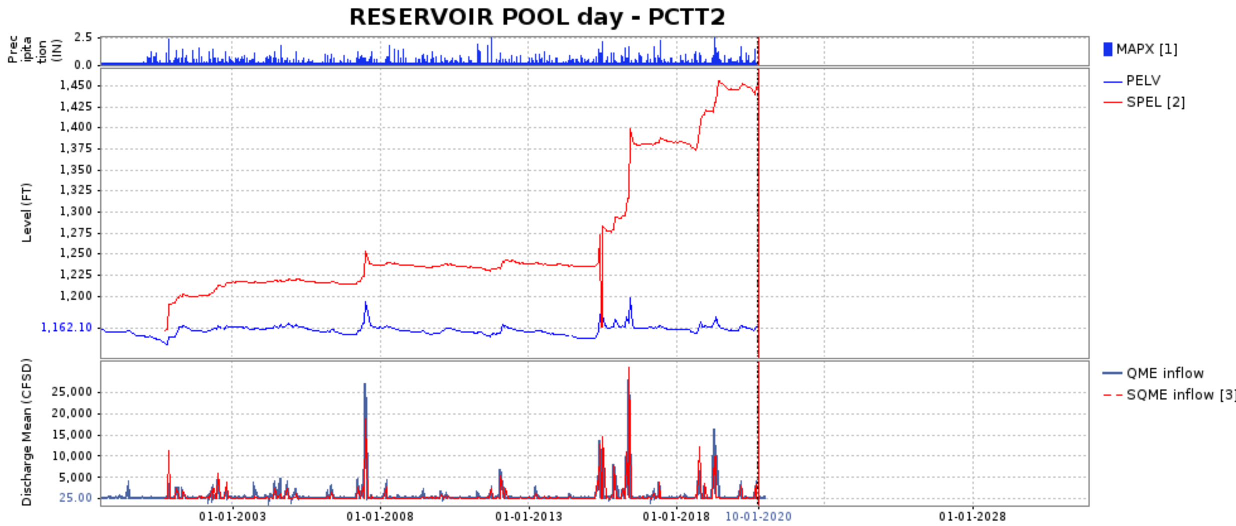


Figure 5-20. Lake Proctor simulated (red) vs observed (blue) pool elevation (top plot) prior to model calibration.

Here we present results from key flood events that highlight performance of the calibrated reservoir models with revised FILLSPILL rules (including QLIM and QSLUICE releases) and updated SETQ rules. Specific event examples include June 2016, May 2015, and January 2012.

June 2016 Event

Leading up to the May/June 2016 inflow event (Figure 5-21), we observe a small but sustained, month-long outflow (top panel, black line) followed by two large releases (>10,000 CFSD) at the end of May and beginning of June. Several FILLSPILL rules were added during calibration to improve low-level releases before and after the event (red, SQME). Most critical to this were the QLIM and QSLUICE parameterizations, which allowed for more controlled, gated releases. While the timing of the simulated releases is earlier than the observed releases, and pool elevations are too high, the RES-SNGL simulation is effective at attenuating the April 2016 inflow and the first of the large May 2016 inflows.

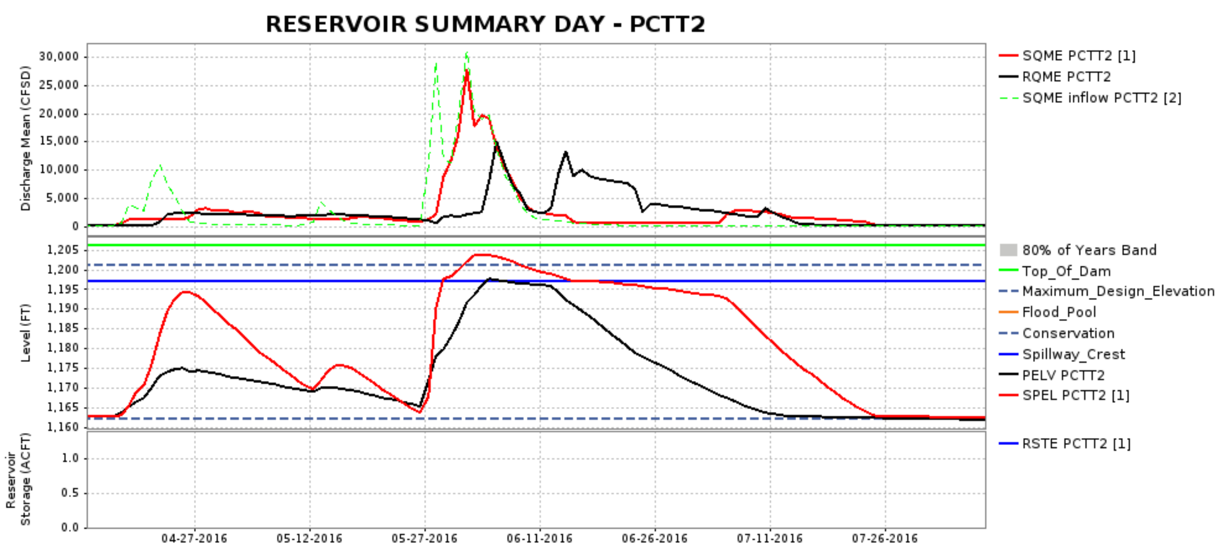


Figure 5-21. Calibrated model results show simulated outflows (red, top panel) and simulated pool elevations (red, bottom panel).

During extended dry periods, it is common for Lake Proctor to be drawn down considerably. Though less important than reservoir outflows, it is important for the model to represent drawdowns ahead of large inflow events. Figure 5-22 shows one of these extended drawdown periods from 2013–2015. In the top panel, the blue line (PELV) is the observed pool elevation, and the red line (SPEL) is the simulated pool elevation. Inflows are displayed in the bottom panel, where the red line shows the (simulated) reservoir inflow (SQME). During this period, simulated drawdowns are affected by a steady series of inflow events that regularly cause an uptick in pool elevation (e.g., May 2014). The differences in PELV and SPEL are likely because the reservoir model is using simulated rather than observed reservoir inflows, and/or that evaporation and/or consumptive use is under-estimated.

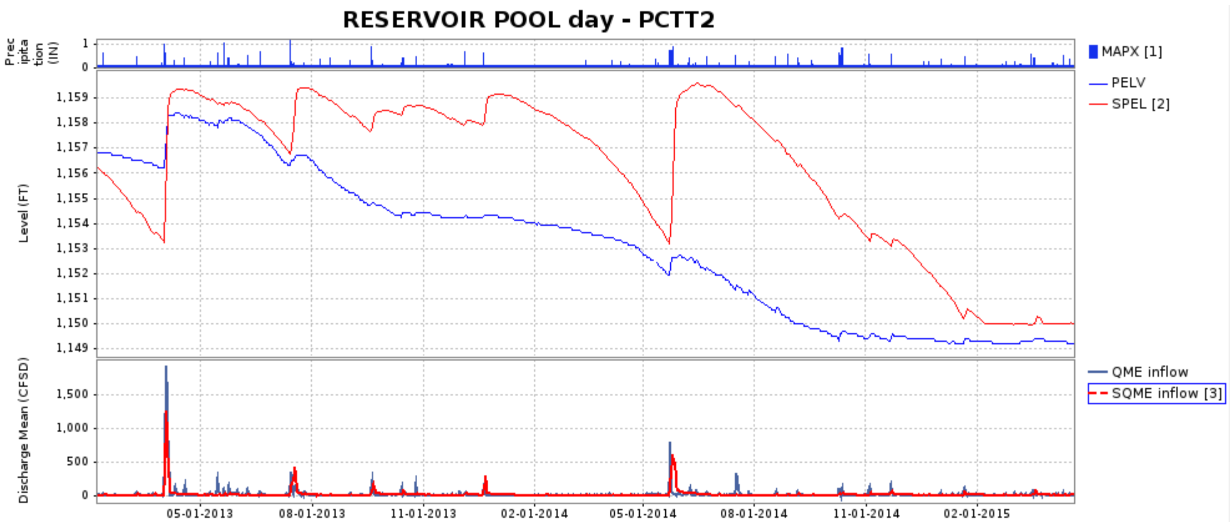


Figure 5-22. Observed (blue) vs. simulated (red) pool elevations during the 2013–2015 drawdown period.

May 2019 Event

The Proctor Lake May 2019 inflow event is a clear illustration of the attenuation of large inflows by the flood pool and reservoir operations (Figure 5-23). By looking at the outflows during this period (top panel, black) where observed outflows are much less than observed inflows, it is evident that controlled gate releases are occurring. To recreate this behavior, we use three FILLSPILL rules which act as a series of gated releases depending on the SPEL. This parameterization can be seen in the simulated outflows (top panel, red line), where the first gated release occurs early on in the event (~1,500 CFSD) and the second gate release happens at high pool elevations later on in the event (~4,500 CFSD). For downstream flood forecasting applications, well-calibrated outflows are a priority over well-calibrated pool elevations.

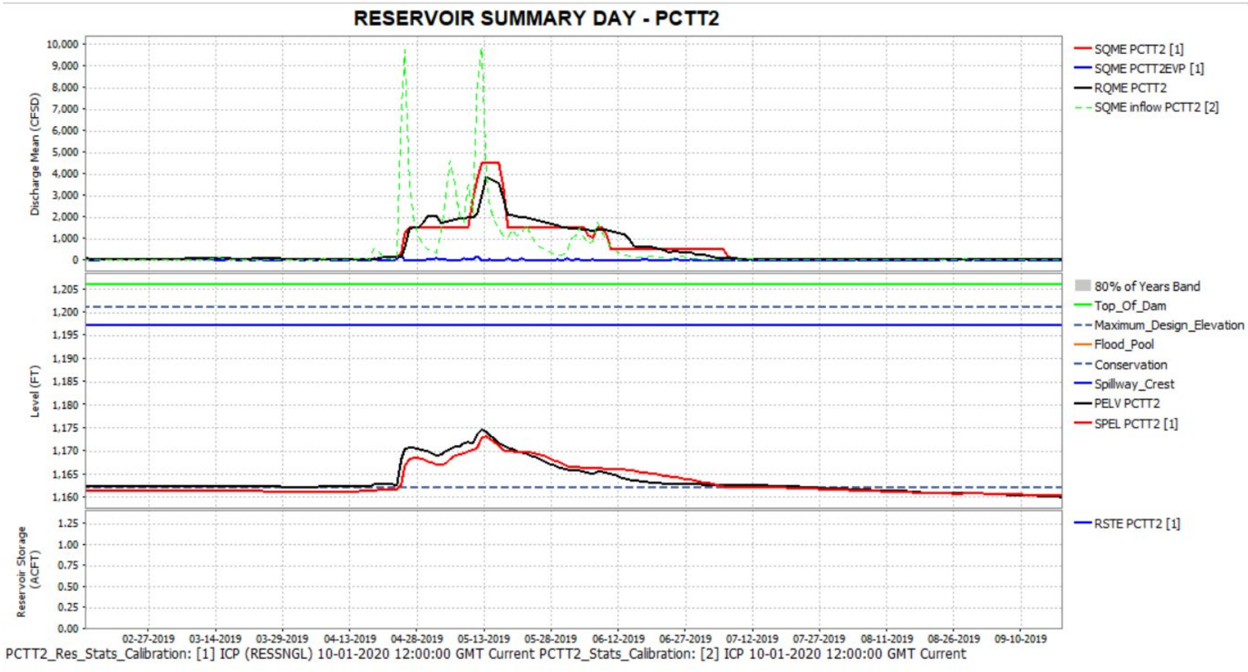


Figure 5-23. Inflow event in 2019 shows slower discharge and drawdown behaviors.

January 2012 Event

Another illustration of the attenuation of inflow events is illustrated in winter of 2012 (Figure 5-24). During this period, peak inflows are >5,000 CFSD (top panel, green line), while peak outflows are <500 CFSD (top panel, red line), and simulated pool elevations are kept low in the flood pool. This first FILLSPILL rule uses the QLIM and QSLUICE parameterizations to release small outflows while pool elevations are in the flood pool, but below the spillway crest. Similar parameterization can be observed in the RES-SNGL models for ACTT2, and to a lesser extent, HORT2.

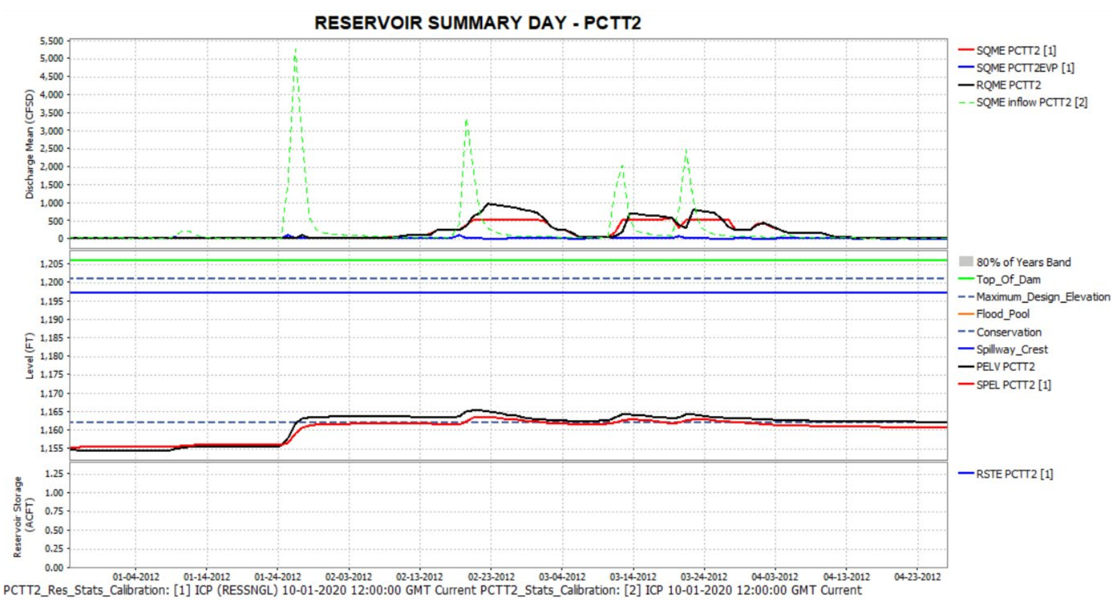


Figure 5-24. Well-calibrated outflows for PCTT2 show attenuated peak outflows (top panel, red line).

5.3.4. Lake Coleman: LKCT2

5.3.4.1. Overview

Lake Coleman is located about fourteen miles north of Coleman in Coleman County, on Jim Ned Creek, a tributary of the Pecan Bayou which is a tributary of the Colorado River. The lake is owned and operated by the City of Coleman for municipal water supply and recreational purposes. The reservoir has a 28-ft drop inlet service spillway that is uncontrolled with a crest elevation at 1717.5 ft above mean sea level. It also has an uncontrolled emergency spillway with an elevation crest at an elevation of 1,726 ft above mean sea level. According to TWDB records, the reservoir has never reached the second spillway, with a max elevation recording at 1723 ft on July 8th, 2002.

5.3.4.2. Sources of Uncertainty

Since Lake Coleman operates primarily with an uncontrolled spillway, the outflow is a function of elevation and the elevation-discharge curve of the spillway, which is poorly constrained. While the City of Coleman was able to provide the reservoir elevation-capacity curve, there were no records of an elevation-discharge curve for either of the two uncontrolled spillways, the service spillway and the emergency spillway. Therefore, calibrations assumed that the TWDB elevation-discharge curve included in the existing RES-SNGL file correctly represents the releases from both uncontrolled spillways. This curve includes discharge values for elevations ranging from 1717.5 ft (the elevation crest of the service spillway) to 1740 ft (the top of the dam).

5.3.4.3. Key Events

Here we present results from key flood events that describe the RES-SNGL behavior during peak reservoir discharge and pool elevations to illustrate the operating rules of the calibration. Specific event examples include May 2015, July 2015, and November 2018.

Pool elevations were well simulated from 2002–2007, during which time pool elevation stayed close to conservation pool before a significant drawdown in 2007. Reservoir drawdown during the subsequent drought period of 2008–2015 was much more substantial and longer than the 2007 drawdown, and simulated pool elevation returned to near conservation pool due to regular inflows throughout the period. Outflow is zero throughout this period, suggesting that inflow is consumed but not simulated during drawdown. This was a major source of differentiation between the calibration efforts and the observed pool elevation and outflow. Long-term pool elevation is shown in Figure 5-25, where the blue line (PELV) is the observed reservoir pool elevation, and the red line (SPEL) is the simulated reservoir pool elevation.

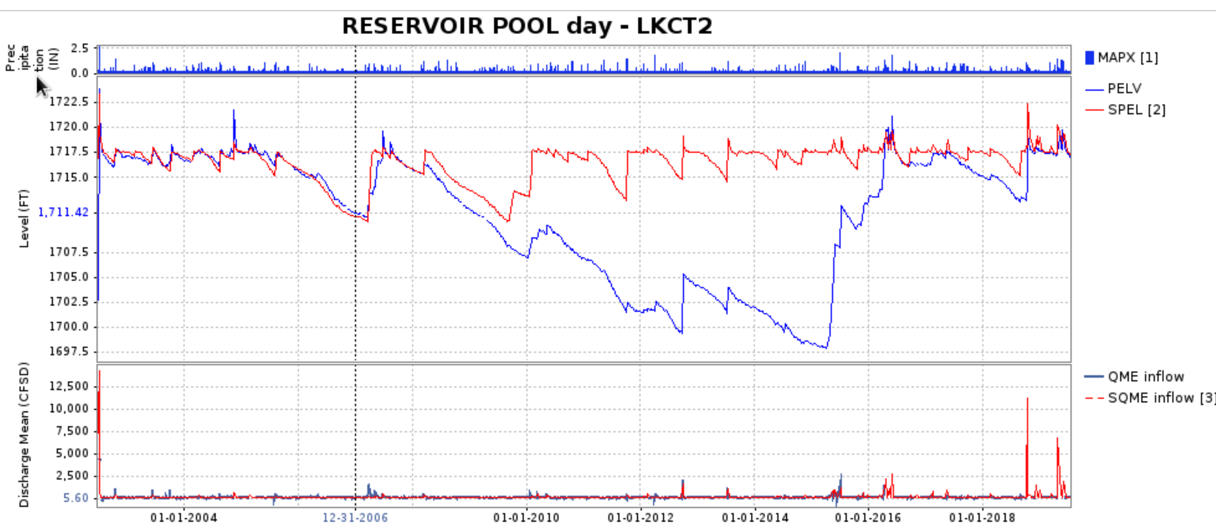


Figure 5-25. Final calibrated simulated vs observed pool elevation.

July 2015 Event

To simulate operational forecasting conditions, a series of shorter simulations were re-run with updated state files. These experiments demonstrate the increased skillfulness of the model for shorter lead-time forecasting. For example, in June 2015, storage contents were updated to evaluate the model sensitivity to large inflow events (Figure 5-26). Re-running from July forward with an updated states file (teal line, bottom panel) highlighted how easily the inflows filled the conservation pool, suggesting that the simulated inflows were too large for this event.

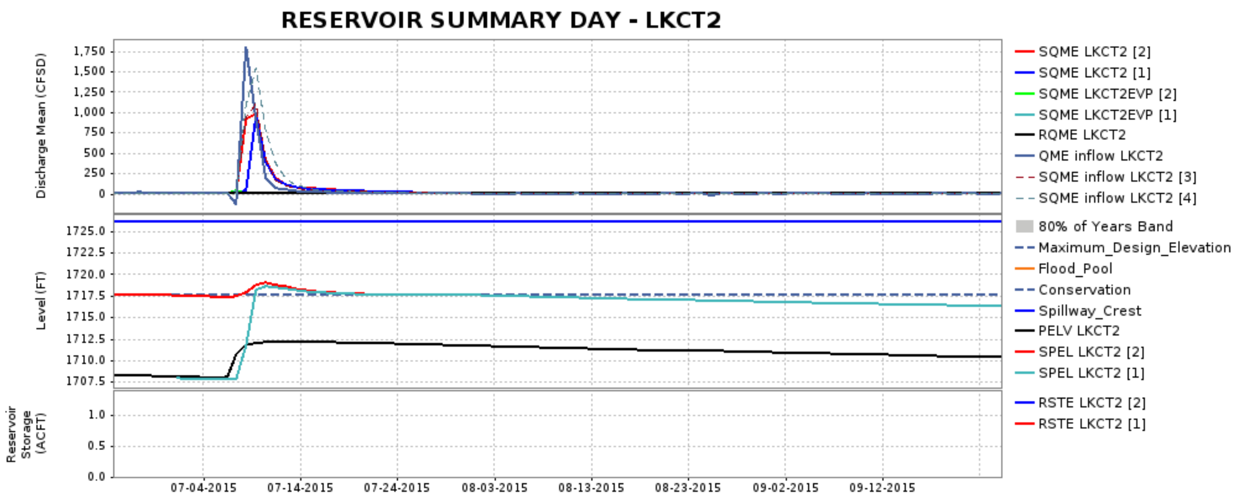


Figure 5-26. Updated initial storage content states on 07/01/2015

May 2015 Event

Similarly, in May 2015, the initial storage states were decreased from 2000 to 1700 (Figure 5-27) to evaluate model sensitivity to large inflows and calibrated SETQ values. In this experiment, simulated pool elevation is the teal line on the bottom panel. Inflows easily filled the reservoir to the top of the conservation pool.

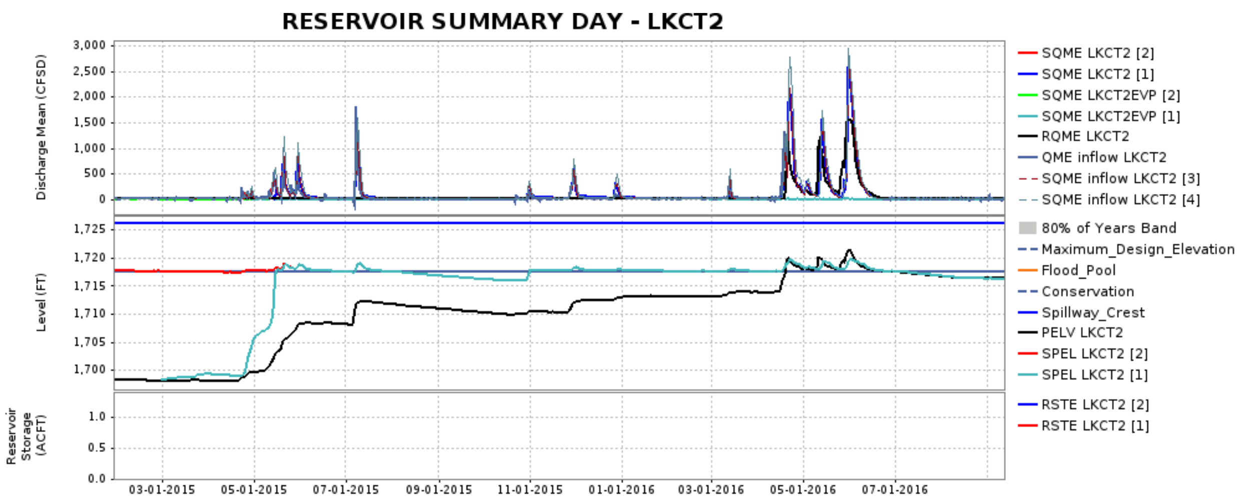


Figure 5-27. Updated initial storage content states on 03/01/2015.

November 2018 Event

Initial simulations prior to calibration over-estimated pool elevations (Figure 5-28, red line, bottom panel). Updates to the elevation-discharge curve (a highly uncertain parametrization) allowed for more discharge from the spillway, which lowered the peak pool elevation (teal line, bottom panel)

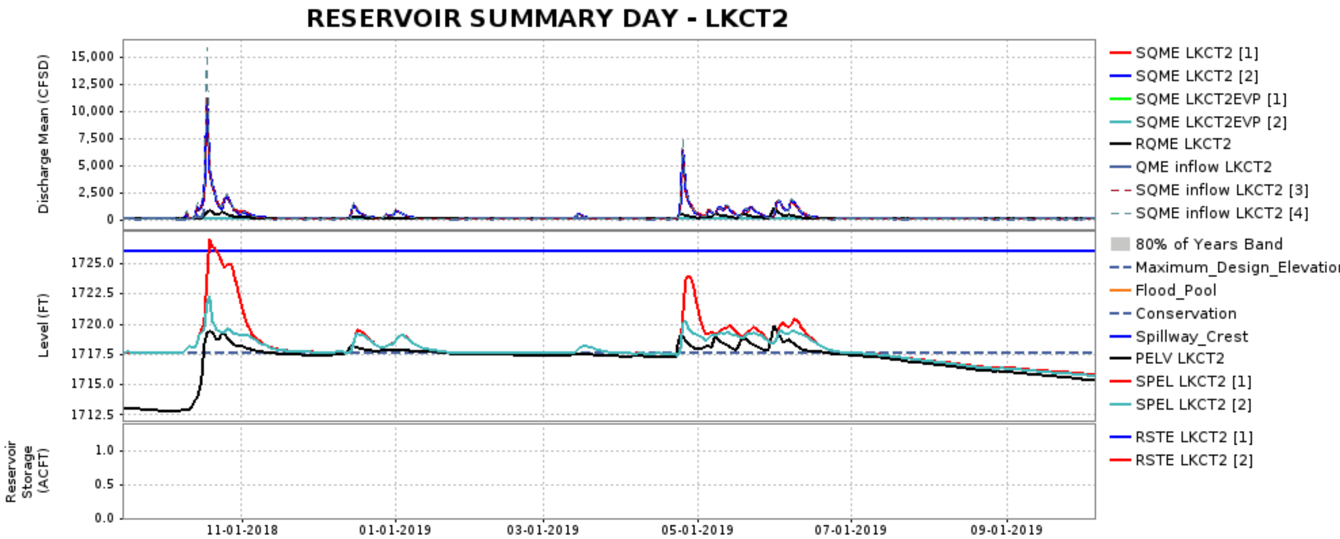


Figure 5-28. Pool elevation above conservation pool and outflow was decreased due to changes in elevation-discharge curve.

5.3.5. Hord's Creek Reservoir: HORT2

5.3.5.1. Overview

Hord's Creek Reservoir, also referred to as Hord's Creek Lake, is located approximately 8 miles west of Coleman in the Colorado River Basin at the headwaters of Hord's Creek, a tributary to Jim Ned Creek, and eventually, Lake Brownwood. The reservoir is operated by the U.S. Army Corps of Engineers for flood control, water supply (for the City of Coleman), and recreational purposes. The conservation pool elevation is 1,900 ft above mean sea level, with an approximate conservation pool storage capacity of 8,640 af. Operations are characterized as fill-and-spill, with a 500-ft uncontrolled, emergency spillway with a crest elevation of 1,920 ft, though there is also a service spillway with a crest of 1,900 ft.

5.3.5.2. Key Events

RES-SNGL was not previously configured at HORT2 within the WGRFC stand-alone calibration configuration. Initial calibration efforts introduced a series of rules to describe the uncontrolled spillway characteristics as well as the consumptive use patterns of the City of Coleman and other users, such as irrigators. Significant reservoir drawdowns during the 2005–2007 and 2009–2015 periods were a focus, though calibrations prioritized reservoir outflows for flood forecasting purposes.

Long-term pool elevation was difficult to simulate throughout the duration of the 2009–2015 drought (red line, Figure 5-29), with simulated inflows artificially filling the reservoir in 2012. Simulated inflows from HORT2 often exceeded the consumptive use rates of SETQ(1) and SETQ(2), and despite significant improvements in the calibration, it was difficult to simulate the drawdown without significantly under-estimating PELEV during the 2005–2007 period. To recreate operational forecasting, a series of simulations were re-run during this period with updated state files. These experiments demonstrate the increased skillfulness of the model for shorter lead-time forecasting.

The only observed reservoir outflows were in February/March 2005 and July 2007. Pool elevation came close to the spillway crest in June 2016 and July 2019 but did not reach the spillway; no releases were observed during this time.

One challenge with simulated pool elevations and reservoir outflows is that inflows to Hord's Creek Reservoir (Figure 5-29, green line) were notably higher during the 2012–2020 period. It is unclear if this is an artifact of MAPX and/or the hydrologic model calibrations of HORT2, or if these are climatologically accurate.

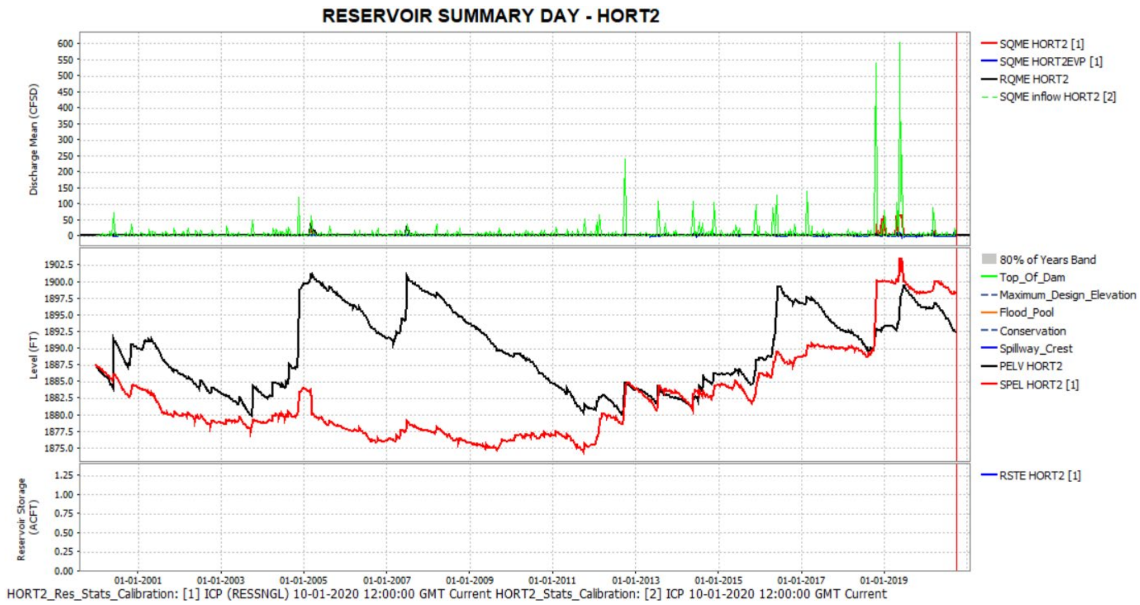


Figure 5-29. Calibrated pool elevation (red) and observed pool elevation (black). Only two reservoir outflows (2005 and 2007) were recorded during the 20 year period of record.

June 2019 Event

Despite no observed outflows outside of the March 2005 and July 2007 events, a wet period in June 2019 highlights the simulated gated releases at HORT2 (Figure 5-30), akin to parametrization implemented at PCTT2 and ACTT2. As simulated pool elevations crest into the flood pool (bottom panel, red line) driven by a series of large (>500 CFSD) inflows, gated releases remain small (~60 CFSD) with the simulated pool elevation is kept below the spillway crest.

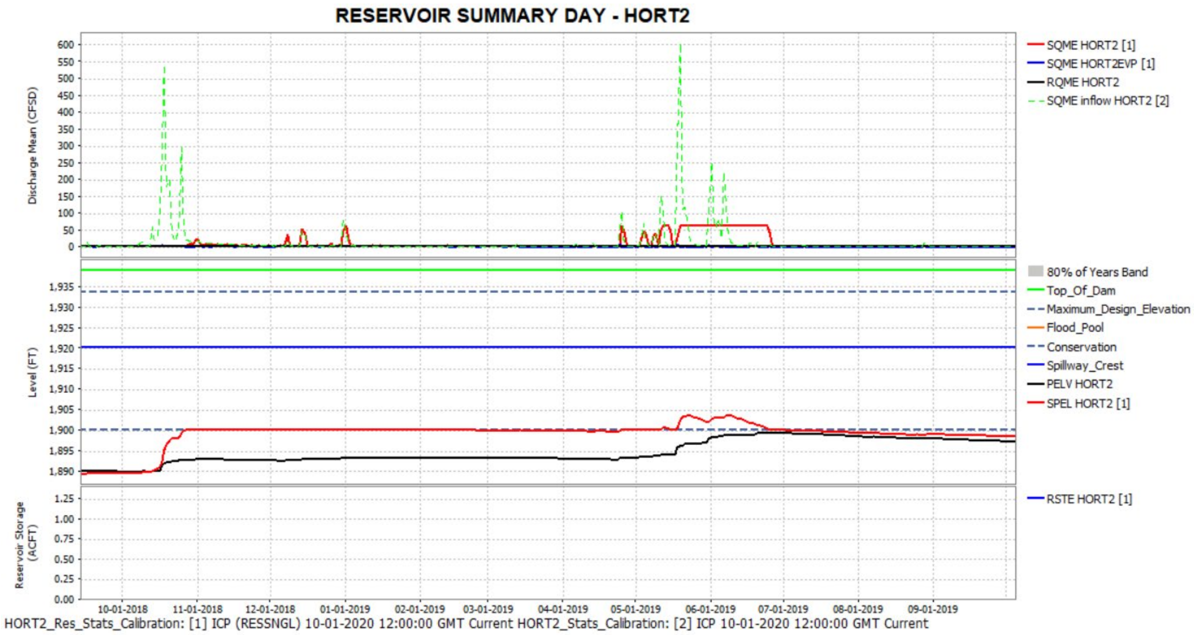


Figure 5-30: Large inflows (top panel, green line) during a wet period are released as attenuated outflows (top panel, red line)

5.3.6. Lake Brownwood: LBWT2

5.3.6.1. Overview

Lake Brownwood is located eight miles north of Brownwood on Pecan Bayou, a tributary to the Colorado River. The reservoir is owned and operated by the Brown County Water Improvement District #1 (BCWID) for water supply and recreational purposes. A 2013 TWDB survey estimated that the reservoir has a capacity of 131,530 af at the conservation pool elevation of 1,425 ft above mean sea level. Lake Brownwood has an uncontrolled spillway (emergency spillway) at 1,425 ft. The reservoir also has three outlets at 1,360 ft, 1,380 ft, and 1408.5 ft but there is no historical reservoir release data for Lake Brownwood. Therefore, all reservoir releases were calculated using pool elevation data and the elevation-discharge table for the uncontrolled spillway.

5.3.6.2. Key Events

Prior to calibration, simulated pool elevation had no significant drawdowns, rarely drawing below 1,424 ft (Figure 5-31, bottom panel, red line). As a result, RES-SNGL simulations continuously over-estimated outflows during the latter half of the drought (e.g., 2012–2015; Figure 5-31, top panel, red line).

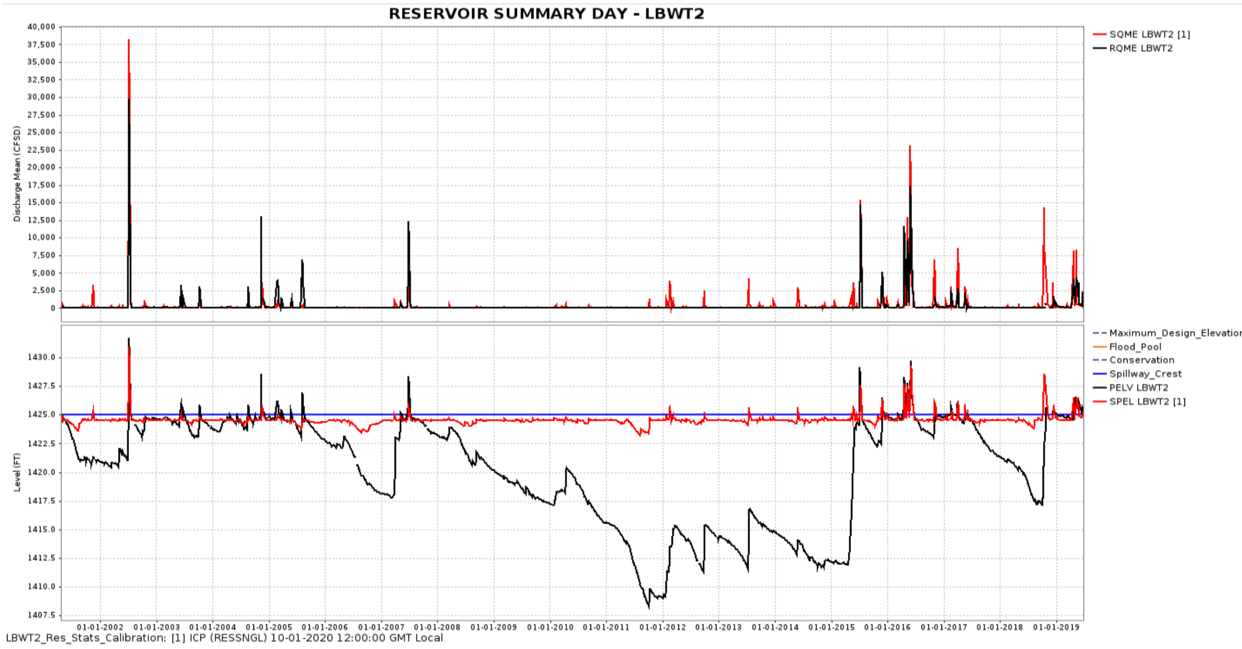


Figure 5-31: Pre-calibration SQME (red, top) and SPEL (red, bottom) compared to observations in black.

To increase drawdowns and decrease false-alarm outflows, three SETQ rules were introduced during calibration (Figure 5-32, red lines). During the first of these rules, when pool elevations are below the spillway crest, a constant rate of 125 cubic feet per second per day (CFSD) are withdrawn from the reservoir (Figure 5-32, bottom panel, red line). This increases drawdowns during dry periods such as 2005–2007 and 2009–2015. However, simulated inflows still often exceeded available storage in the model, filling the reservoir to pool conservation. To address this within the limitations of RES-SNGL, a second SETQ rule was introduced that increases consumptive use when inflows are greater than 10 CFSD, and pool elevations are between the spillway crest and 1,420 ft. Lastly, the FILLSPILL elevation-discharge curve was also updated with the latest data from the TWDB 2013 Survey.

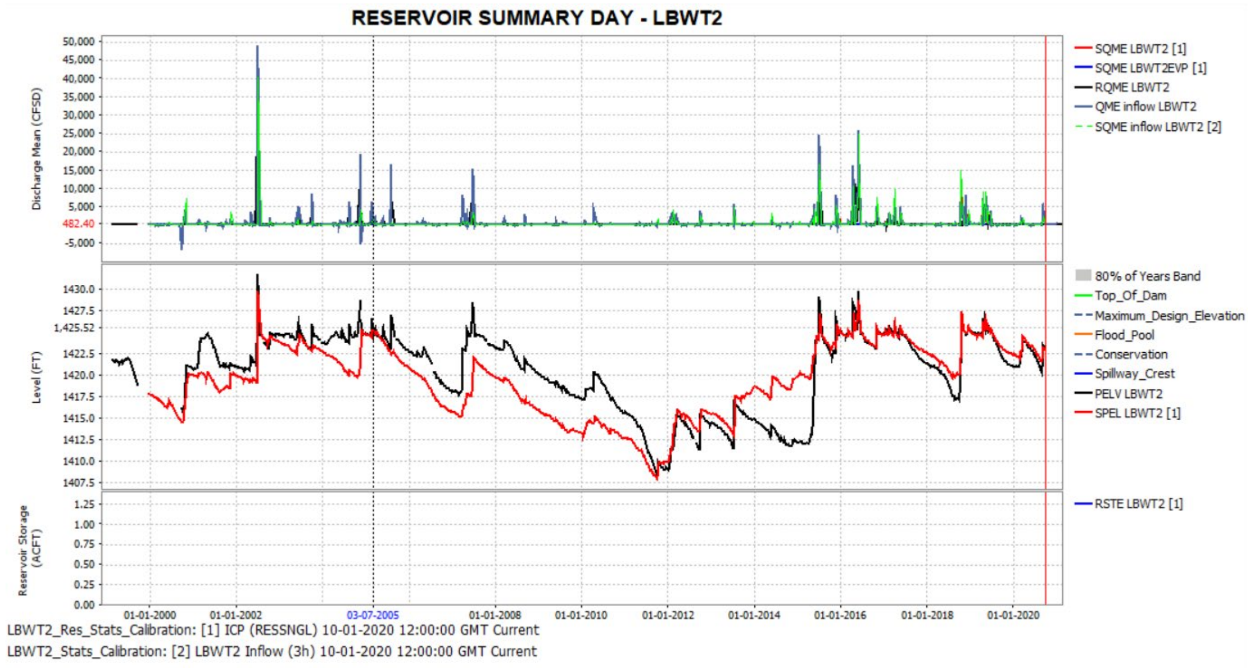


Figure 5-32: Calibrated SQME (red, top) and SPEL (red, bottom) compared to observations.

May 2016 Event

When updating the ColdStates file with storage contents of 15,250 CMSD and running a simulation beginning on May 24th, we observe the overall, pool elevation simulations are reasonable, though biased low (Figure 5-33, bottom panel, red line). This is likely because simulated inflows (lime green dashed line, top panel) are consistently lower than the calculated inflows. Despite this, the outflows for the three peaks on May 29th, June 1st, and June 5th are well-verified, as is the drawdown after the event. A more attenuated elevation-discharge relationship for the uncontrolled spillway may be more appropriate.

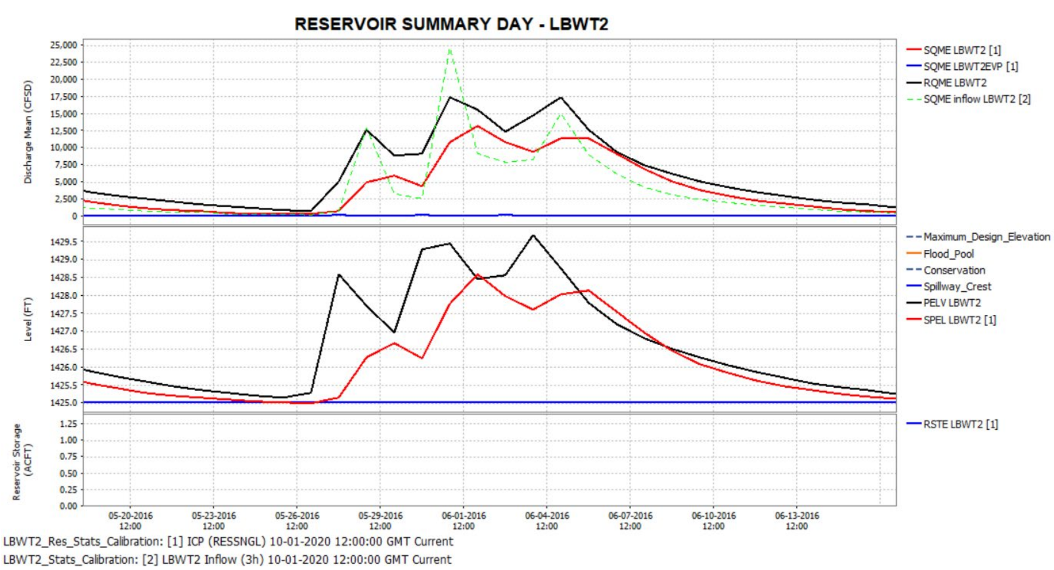


Figure 5-33: Shorter-term simulation run with updated storage content states (SQME and SPEL in red).

5.3.7. Waco Lake: ACTT2

5.3.7.1. Overview

Waco Lake is located two miles west of Waco on the Bosque River, a tributary to the Brazos River. The lake is owned and operated by the USACE for purposes of municipal and industrial water supply, flood control, conservation, and recreation. The new Waco Dam (completed 1965) has a conservation storage capacity of 189,773 af, with a conservation pool elevation of 462 ft above mean sea level. Flood control storage is 553,300 af, from 462 ft to 500 ft. In addition to the outlet works, Waco Lake also has an ogee gate-controlled spillway with a crest elevation of 465 ft. Fourteen tainter gates, each 40 ft wide and 35 ft high, are mounted on the crest. The emergency spillway crest elevation is at 500 ft, which is also the top of the flood control pool. The highest pool elevation since 2000 June 6 2016 at 485 ft. Drainage above the dam is 1,670 square miles.

5.3.7.2. Key Events

Waco Lake is a significant reservoir with complicated reservoir operations that are difficult to re-create in RES-SNGL. One critical feature of the Waco Lake reservoir operations is that large inflow events are attenuated and released slowly via the series of 14 tainter gates. Current calibrations rely on a series of three FILLSPILL rules to release via the defined QLIM and QSLUICE values when pool elevations are less than the crest of the spillway (500 ft) but above the conservation pool (462.2 ft). The uncontrolled spillway releases inflows for pool elevation values greater than 500 ft. Because uncontrolled releases are equal to outflows in RES-SNGL, inflows above the spillway crest are released by the model too quickly, leading to an over-simulation of peak outflows (Figure 5-34, top panel, red line). Implementation of the SPILLWAY and POOLQ rules were trialed, however they were unsuccessful in remedying this behavior.

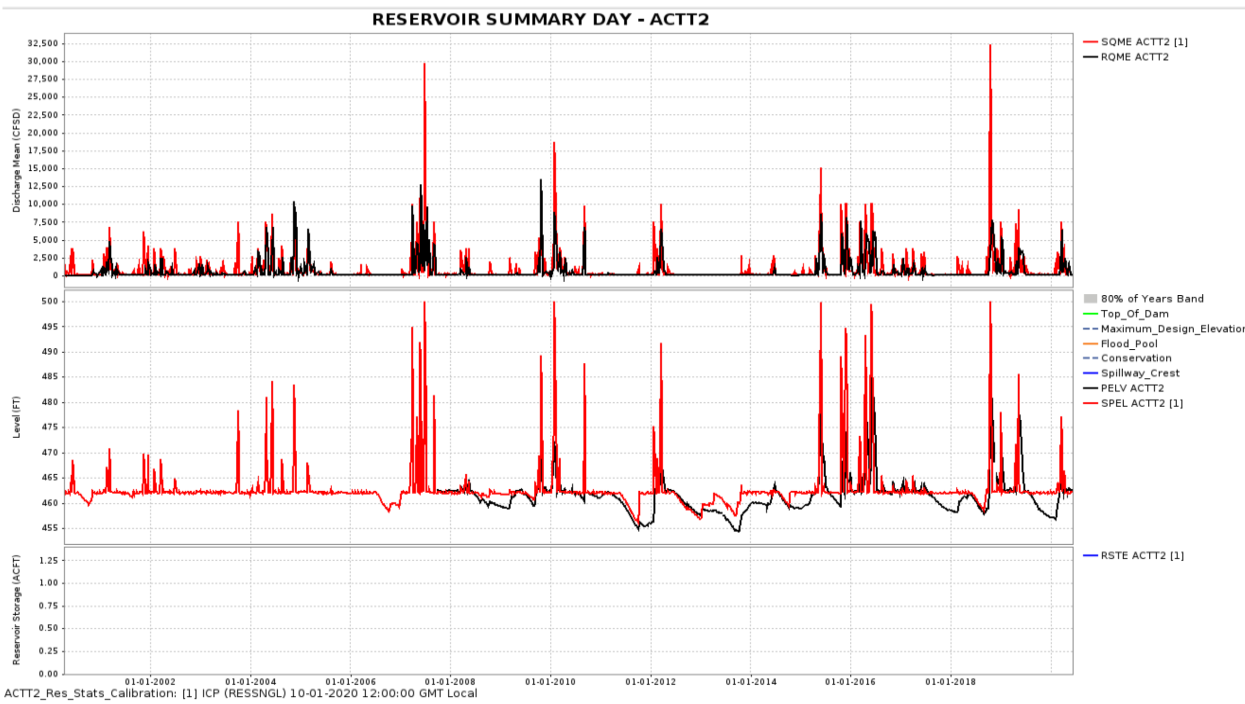


Figure 5-34: Calibrated SQME (red, top) and SPEL (red, bottom). While pool elevations are over-simulated, the focus of calibrations was attenuating the inflows to decrease simulated peak outflows to a more reasonable level.

Figure 5-35 illustrates the simulated gated releases (top panel, red line) as trigged by the three FILLSPILL rules when simulated pool elevations (bottom panel, red line) are in the flood pool. This configuration of three FILLSPILL rules attenuates peak inflows (top panel, green line) and produces more reasonable outflow estimates (top panel, red line), the priority of the calibration for downstream flood forecasting purposes.

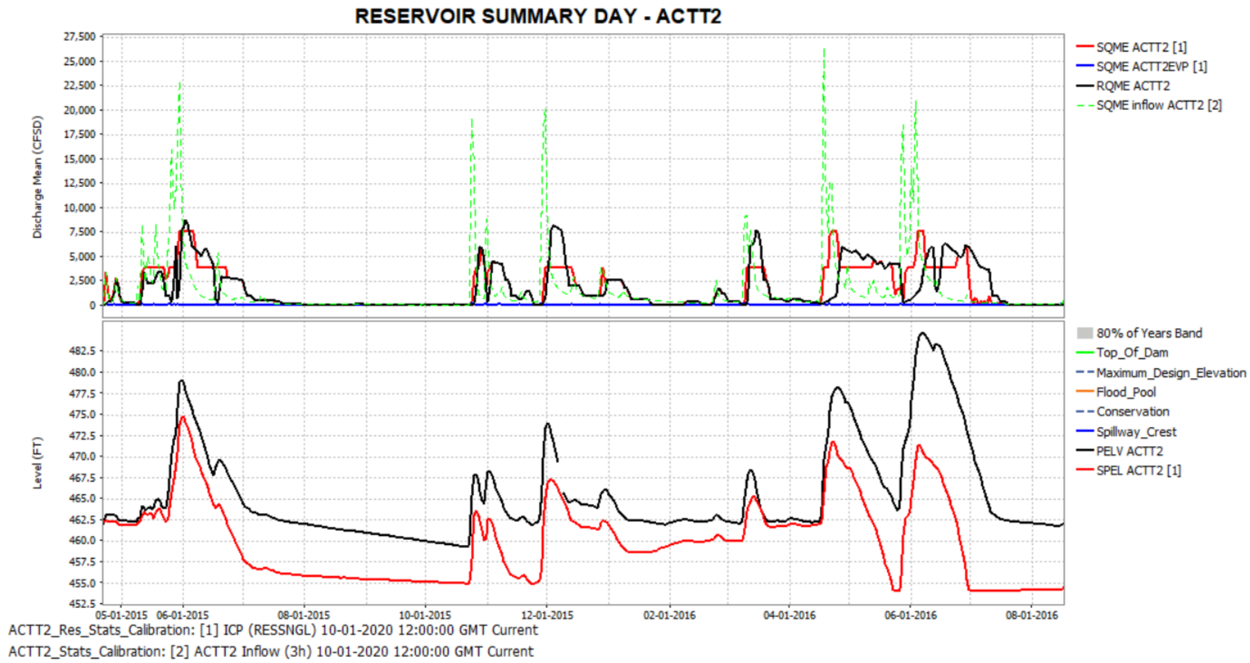


Figure 5-35: Simulated gated releases (top panel, red line) resulting from the FILLSPILL rules for spillway operations. Simulated outflows were the true focus of RES-SNGL calibration efforts.

5.3.8. Lake Leon: LLET2

5.3.8.1. Overview

Lake Leon, also known as Leon Reservoir, is located five miles southeast of Eastland, on the Leon River, a tributary of Little River, which is a tributary to the Brazos River. The reservoir is owned by the Eastland County Water Supply District for municipal and industrial water supply purposes. The uncontrolled emergency spillway is at an elevation of 1,382 ft above mean sea level. The conservation pool is at an elevation of 1,375 ft above mean sea level. According to 2015 TWDB survey, the reservoir has a capacity of 28,042 af and a surface area of 1,756 ac at conservation pool elevation of 1,375 ft above sea level.

5.3.8.2. Key Events

Prior to calibration, simulated pool elevations for LLET2 had no significant drawdowns, rarely dropping below 1,375 ft (Figure 5-36, bottom panel, red line). To increase drawdowns, three SETQ rules were introduced during calibration (Figure 5-36, bottom panel, teal line). During the first of these rules, when pool elevations are below the spillway crest, a constant rate of ~6 CFSD are withdrawn from the reservoir. This increases drawdowns during dry periods such as 2005–2007 and 2009–2015. However, inflows between 2013 and 2015 caused pool elevation to jump up and then decrease more slowly. Thus, a second SETQ rule was introduced that withdraws ~ 1 CFSD below a pool elevation of 1368 ft.

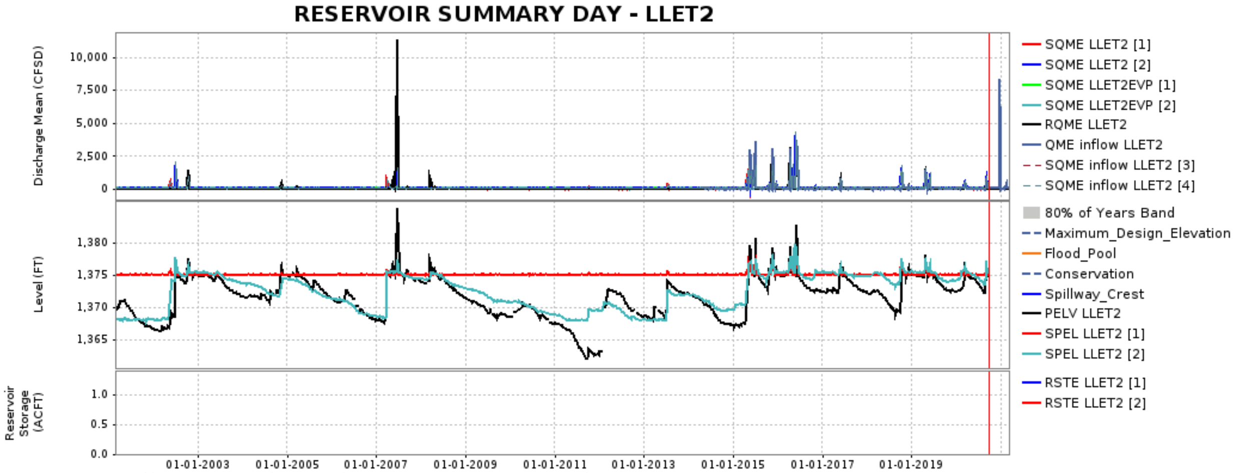


Figure 5-36. Calibrated model run (teal) compared to observed pool elevation (black).

June 2007 Event

The biggest inflow event of the period of record begins on June 23rd (Figure 5-37), and was significantly under-simulated, even after model calibration. The elevation discharge curve was recently updated by HDR (obtained from Eastland County Water Supply District); the more likely source of error is under-simulated inflows from the LLET2 hydrologic model (green dashed line, top panel).

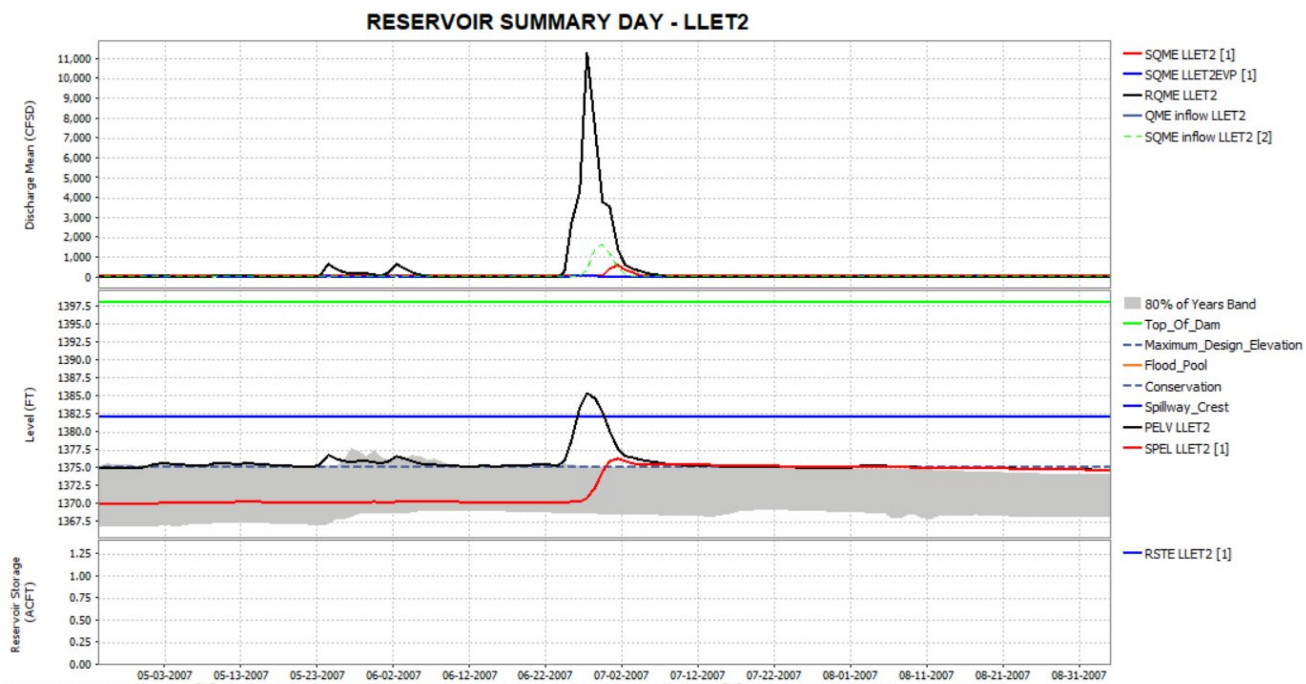


Figure 5-37. Under-simulated inflow event in June 2007. Simulated inflows are in lime-green, top panel.

May 2015 Event

The May to June 2015 period is a good example of a well-calibrated series of inflow events with reasonable pool elevations and outflows (Figure 5-38, red lines). The first of these ~1,500 CFSD inflows (top panel, green line) fills the LLET2 conservation pool to ~1,372 ft (bottom panel, red line), with no simulated outflows. By late May, the second inflow event pushes the reservoir into the flood pool, triggering spillway releases (top panel, red line). Though under-simulated, this event is generally well-verified given the simulated inflows from the LLET2 hydrologic model.

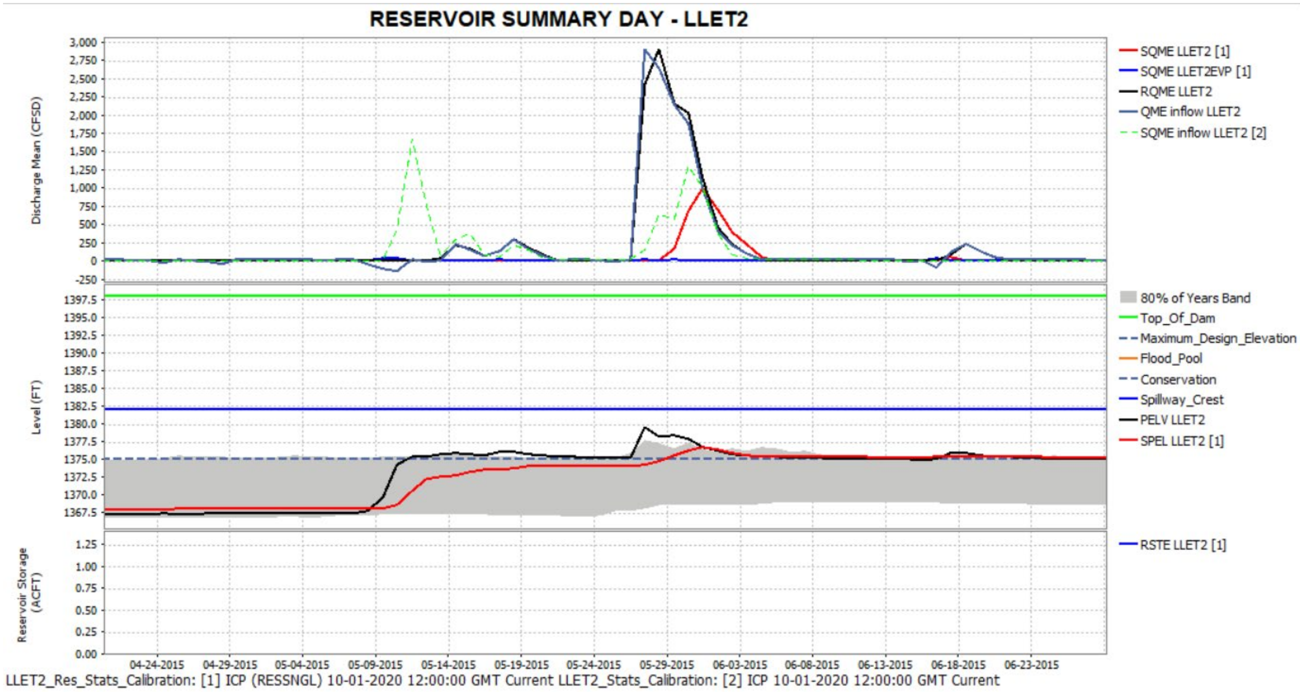


Figure 5-38. Two inflow events (lime-green, top panel) that first fill the conservation pool and then rise into the flood pool (red, bottom panel).

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7. APPENDIX A – SUPPLEMENTAL MATERIALS

In addition to this calibration report document, Lynker has provided additional project files (access from shared Google Drive folder). The following outline provides an overview of the directories and underlying content. Additional details regarding some of the plots and graphics are provided in subsequent appendices.

\BasinSummaryReports

Contents: High resolution PDF and PNG files containing the basin summary graphics provided in section 4.1 (2 files for each calibration basin)

\ColdStateFiles_res_final_calb

Contents: Eight basin directories with the updated RESSNGL ColdStateFiles (also includes updated ColdStateFiles for hydrologic models). These files are also provided in the CHPS calibration configuration (\Config\ColdStateFiles)

\LAGK_plots

Contents: Basins PNG files with calibrated LAG/K plots showing the lag-flow and attenuation-flow value pairs for calibrated models

\ModuleParFiles_final_calb

Contents: Final calibrated xml ModuleParFiles organized into "Lag_K", "RESSNGL", "SAC_SMA" and "UH" directories. These files are also provided in the provided CHPS calibration configuration (\Config\ModuleParFiles)

\PET_comparison_plots

Contents: ET-Demand monthly climatology comparison plots for all calibrated basins

\raster_hydrograph_analysis_plots

Contents: PNG files containing Lynker's raster hydrograph plots (top: daily streamflow hydrograph, middle: SQME vs. QME daily bias – post-calibration, SQME annual accumulated bias – post-calibration)

\shapefiles_agol

Contents: Shapefiles (and associated files) for all layers used in the project ArcGIS Online maps. Refer to the "_README.txt" for information on specific shapefiles.

\UHG_plot_compare

Contents: Basin PNG files with plots comparing pre-calibration vs. post-calibration Unit Hydrograph ordinates

\water_balance_analysis

Contents: Multiple spreadsheets containing data analysis summaries and water balance calculations used to support the hydrologic calibration process.

\wgrfc_rating_curves_modified

Contents: Updated Chps_Ratings_1940.xml with newly revised rating curves for BSMT2, CJNT2, DUPT2, FCCT2, FCCT2U, FHCT2, FHGT2, FHHT2, and FHHT2U. Note: Fort Hood locations provided by WGRFC but were not used for calibration.

Draft Calb Feedback & Revisions_googledoc.pdf → This pdf is a copy of the google doc that WGRFC and Lynker staff used to facilitate calibration questions and revisions during the draft calibration review process.

8. APPENDIX B – POTENTIAL EVAPOTRANSPIRATION COMPARISON

Plots showing the monthly climatology of four different PET sources are available in the supplemental data files provided with this report: *supplemental_materials\PET_comparison_plots*

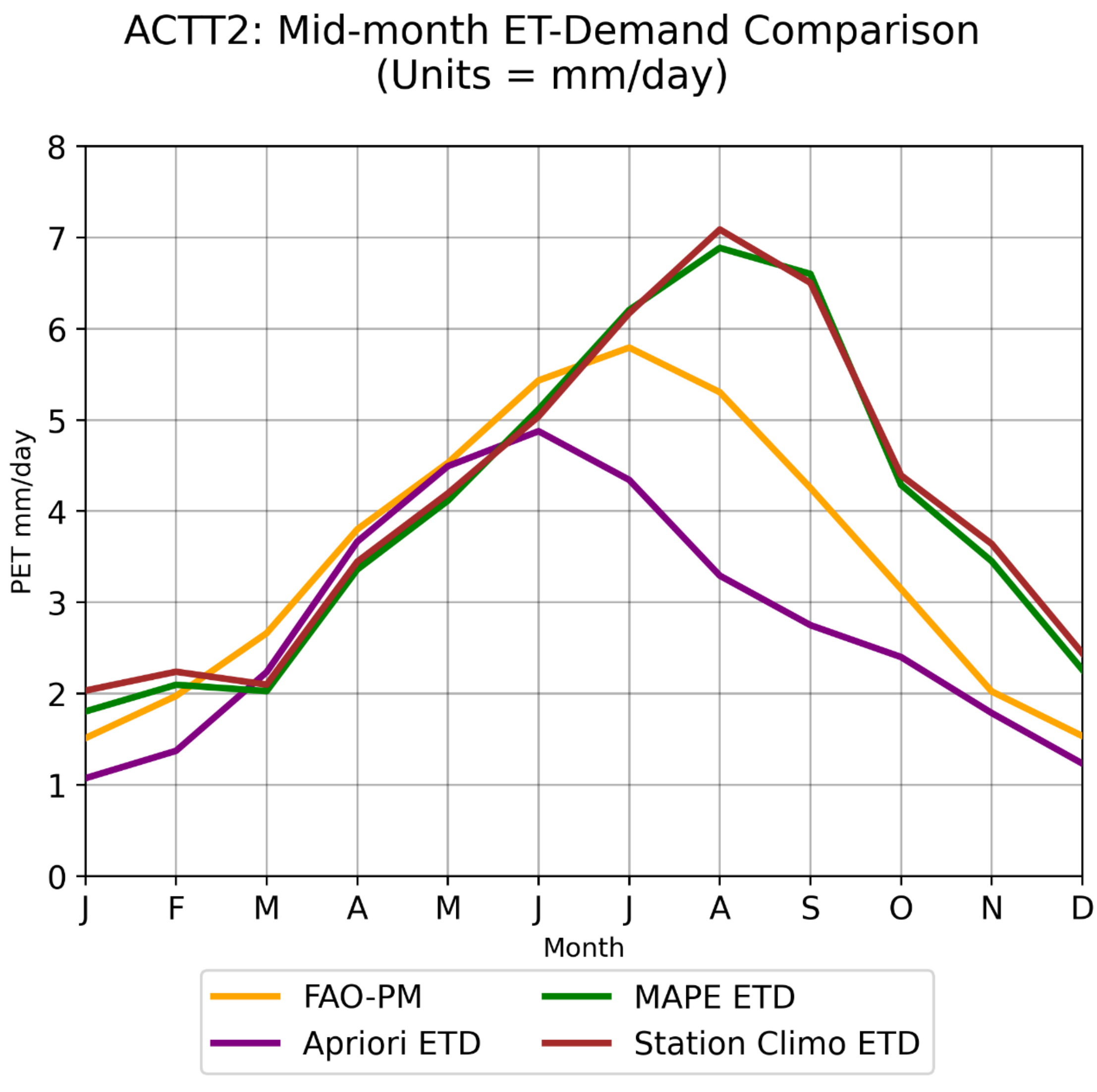


Figure 7-1: Example of monthly PET plot for ACTT2.

9. APPENDIX C – CALIBRATED UNIT HYDROGRAPH PLOTS

Plots showing the pre-calibration UNIG-HG and post-calibration UNIT-HG are available for all calibration basins in the supplemental data files provided with this report: *\supplemental_materials\UHG_plot_compare*

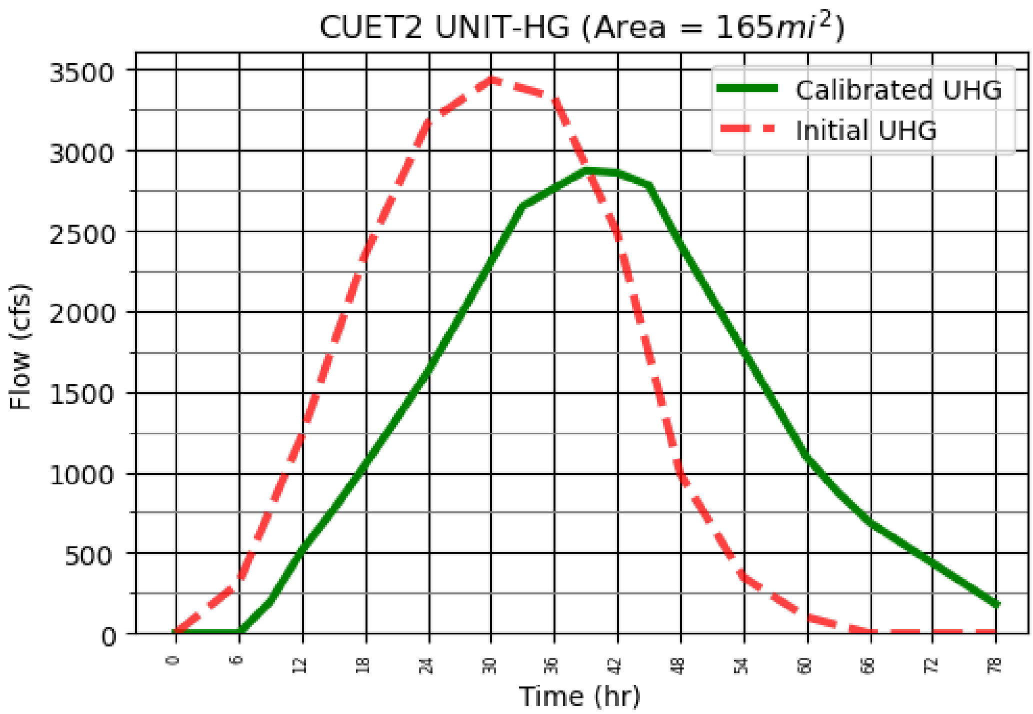


Figure 8-1: Example of UNIT-HG comparison plot showing pre-calibration UNIT-HG (red) and post-calibrated UNIT-HG (green) for CUET2.

10. APPENDIX D – CALIBRATED VARIABLE LAG AND VARIABLE K PARAMETERS

Plots showing the post-calibration variable lag and attenuation pairs are available for all calibrated routing models are available in the supplemental data files provided with this report: *\supplemental_files\LAGK_plots*

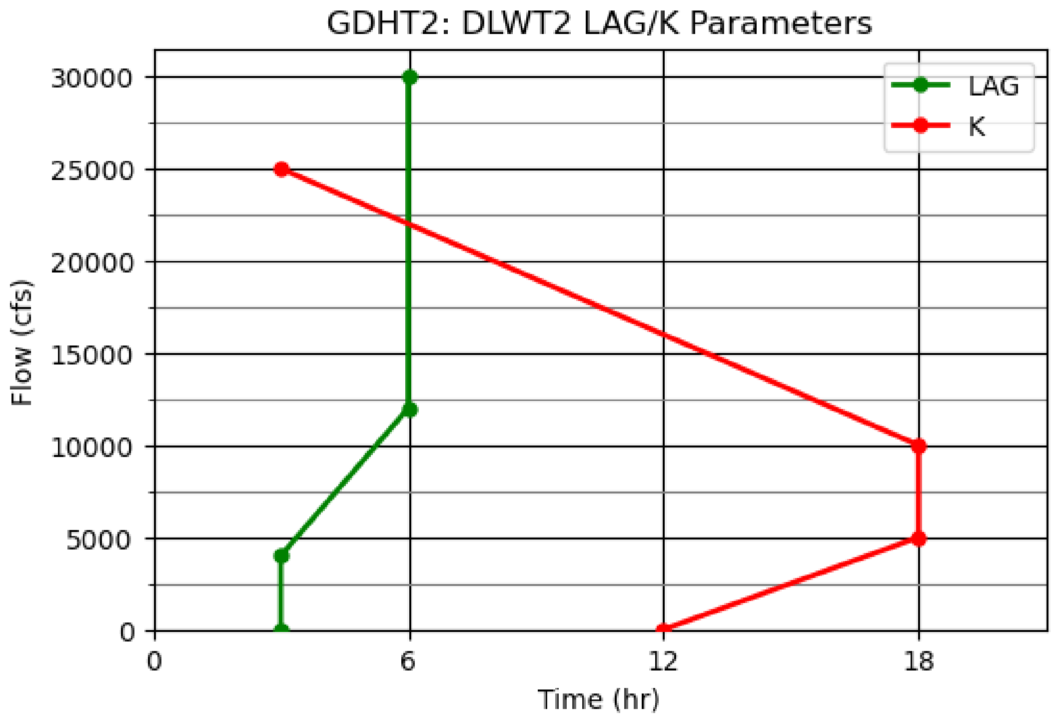


Figure 9-1: Example of LAG/K plot for GDHT2 after calibration.

11. APPENDIX E – RASTER HYDROGRAPH CALIBRATION ANALYSIS PLOTS

Plots showing the post-calibration daily simulation timeseries in raster hydrograph format are available in the supplemental data files provided with this report: *\supplemental_files\raster_hydrograph_analysis_plots*

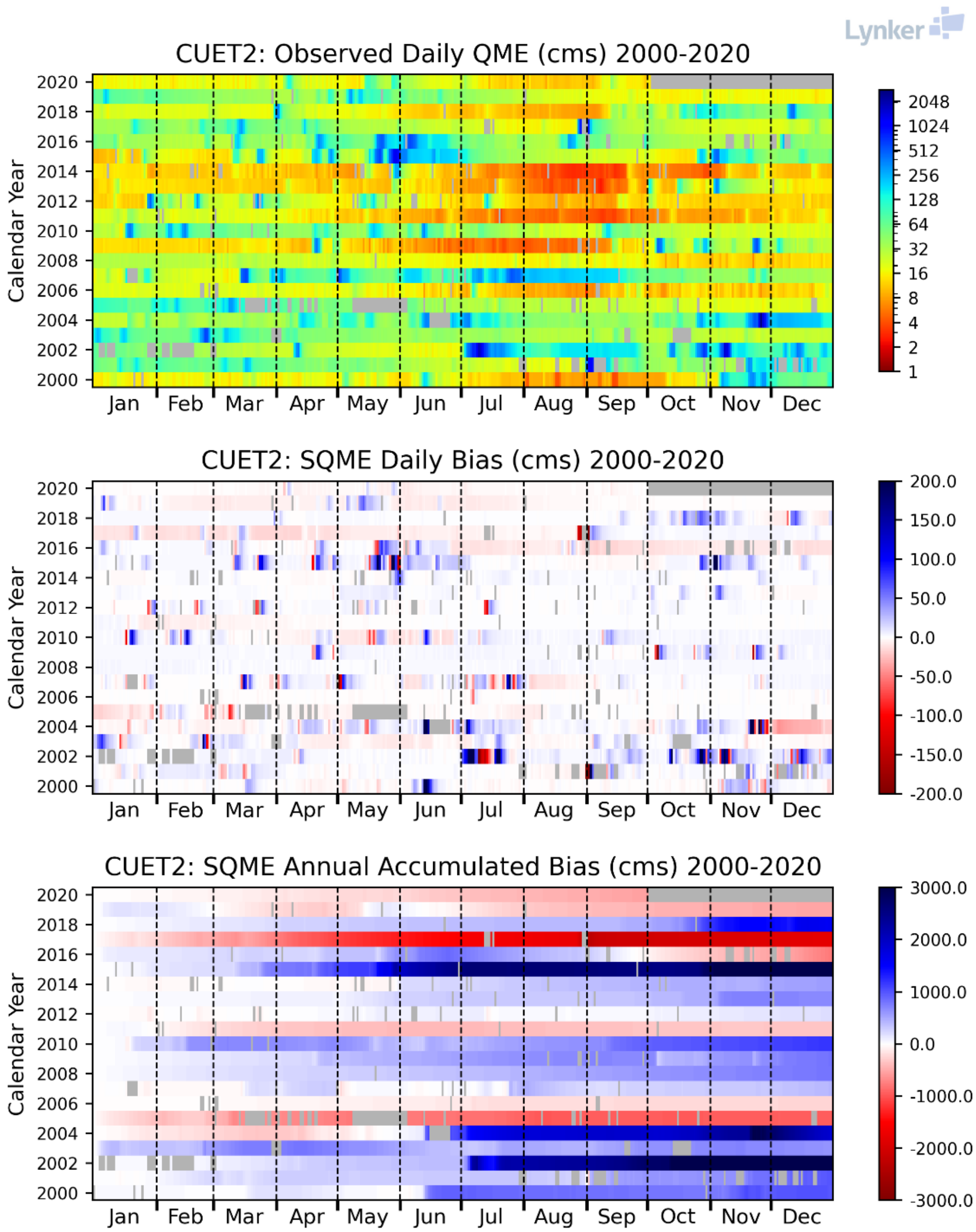


Figure 10-1: Example QME, SQME daily bias, and SQME accumulated bias plots for CUET2.

12. APPENDIX F – STREAMFLOW DATA PERIOD OF RECORD

Table 11-1. Daily streamflow period of records for basins in the Brazos River basin

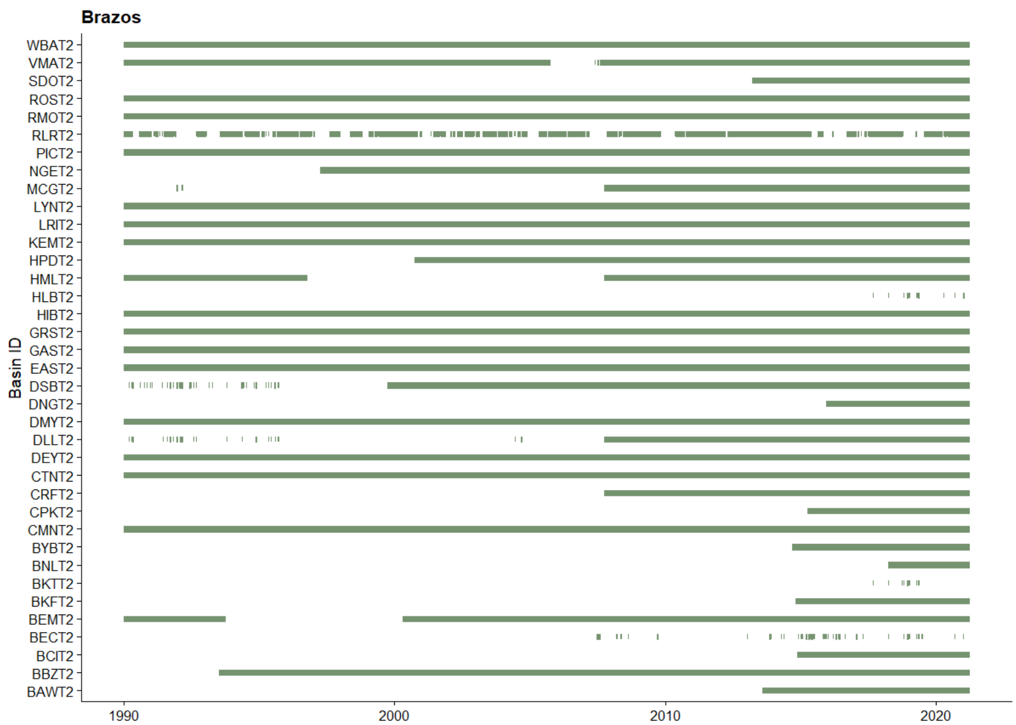


Table 11-2. Daily streamflow period of record for basins in Colorado River basin

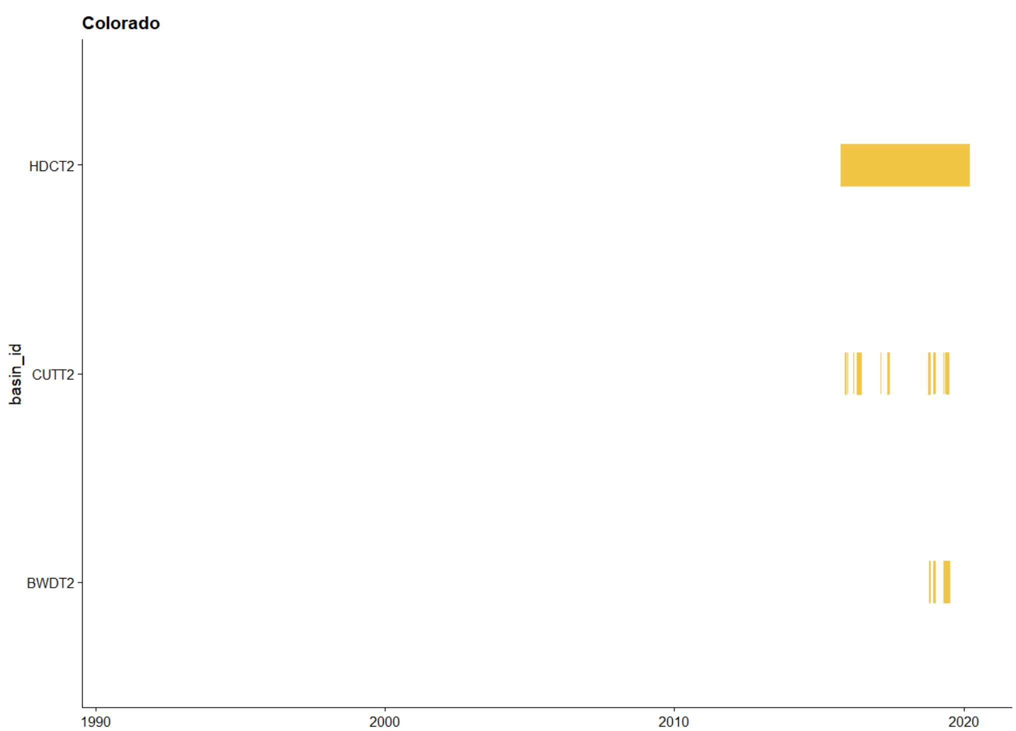


Table 11-3. Daily streamflow period of record for basins in Guadalupe River basin

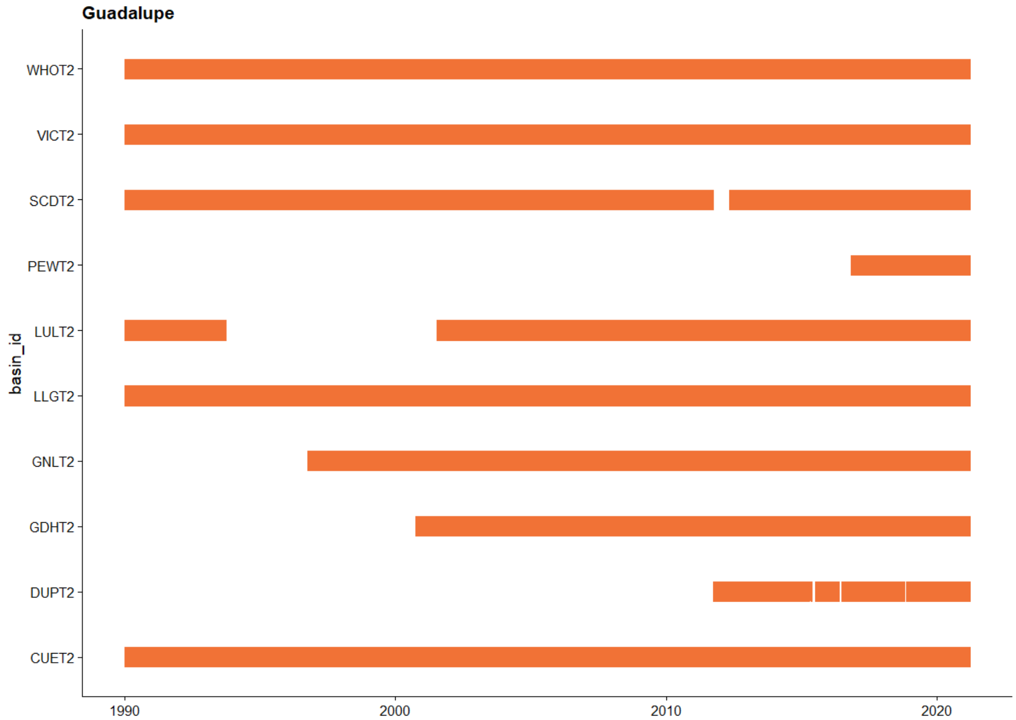
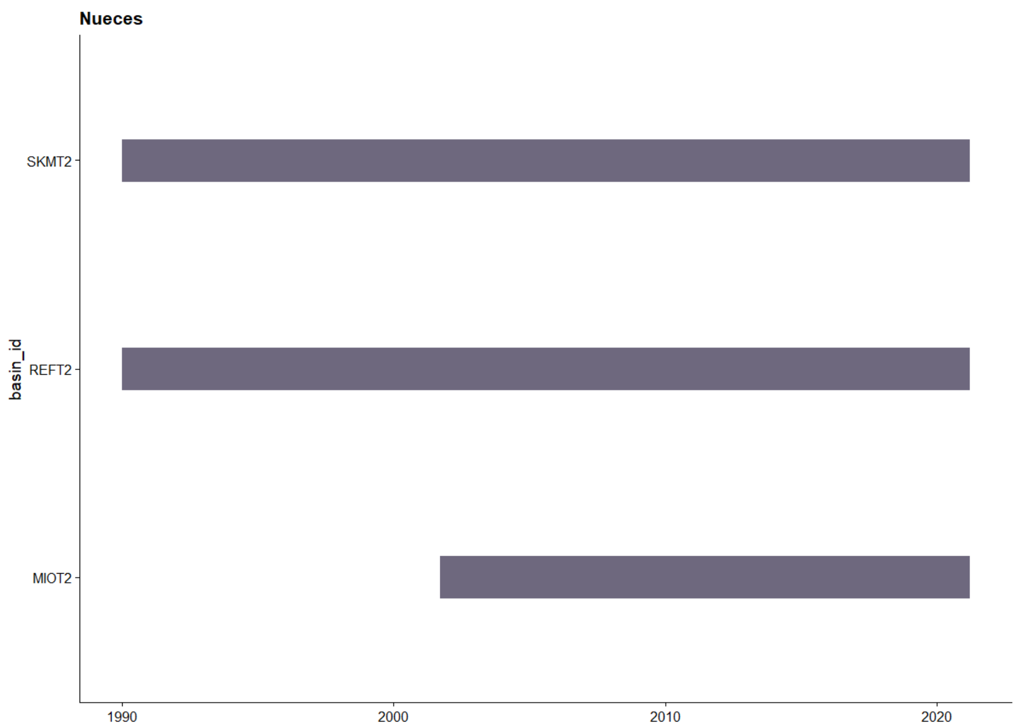


Table 11-4. Daily streamflow period of record for basins in Nueces River basin



13. APPENDIX G – USGS GAUGE REMARKS

ID	Basin	Forecast Group	USGS Gauge Remarks
1	GAST2	Brazos	Records good. Since 1954, at least 10% of contributing drainage area has been regulated. There are numerous diversions above station for irrigation, municipal supply, and oil field operation. The city of Hamilton, located about 70 mi upstream from this station, diverts flow from the river for municipal use and returns wastewater effluent to the stream. No flow at times. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1854, about 35 ft in May 1908, from information by local residents. EXTREMES FOR PERIOD PRIOR TO REGULATION - WATER YEARS,1951-1953: Maximum discharge, 7,230 ft³/s May 28, 1952 (gauge height, 24.79 ft.) No flow at times in 1951-52. AVERAGE DISCHARGE FOR PERIOD PRIOR TO REGULATION - 3 years, (water years, 1951-53), 84.3 ft³/s (61,060 acre-ft/yr)
2	BNLT2	Brazos	Records fair.
3	LRIT2	Brazos	Records fair. Since Mar. 1954, at least 10% of contributing drainage area has been regulated. Wastewater effluent is returned upstream of station from Fort Hood military installation and by the cities of Killeen, Nolanville, and Harker Heights. Many small diversions upstream for irrigation and municipal supply affect very low flow. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1900, 46.8 ft in Sept. 1921, from information by local residents. EXTREMES FOR PERIOD PRIOR TO REGULATION - WATER YEARS 1924-1929: Maximum discharge, 28,400 ft³/s Oct. 2, 1927, (gauge height 43.3 ft); minimum, 8.9 ft³/s Aug. 12, 1925. AVERAGE DISCHARGE FOR PERIOD PRIOR TO REGULATION - 5 years (water years 1924-28), 709 ft³/s (513,700 acre-ft/yr).
4	PICT2	Brazos	Records poor. No known regulation or diversions. No flow at times. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1882, occurred in 1900 and 1944 (stage about 37.5 ft), from information by local residents.
5	KEMT2	Brazos	Records good. Since water year 1974, at least 10% of contributing drainage area has been regulated. There are many small diversions above station for irrigation and for municipal supply. The city of Lampasas diverts water upstream from this station and returns wastewater effluent to Sulphur Creek upstream from station. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1871, occurred in Sept. 1873 (stage about 45 ft). Flood of May 13, 1957, reached a stage of 37 ft, and flood of Oct. 4, 1959, reached a stage of 34 ft, from information by local residents. EXTREMES FOR PERIOD PRIOR TO REGULATION - WATER YEARS 1963-1973: Maximum discharge, 71,000 ft³/s, May 16, 1965 (gauge height, 32.98 ft), minimum daily, 1.4 ft³/s, July 17, 1971. AVERAGE DISCHARGE FOR PERIOD PRIOR TO REGULATION - 11 years (water years 1963-73), 151 ft³/s (109,400 acre-ft/yr).

ID	Basin	Forecast Group	USGS Gauge Remarks
6	DNGT2	Brazos	Records Fair.
7	SDOT2	Brazos	Records fair. No known regulations or diversions. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically.
8	BYBT2	Brazos	Records fair except for discharges below 1 ft³/s, which are poor.
9	BCIT2	Brazos	Records fair.
10	BKFT2	Brazos	Records fair.
11	BSYT2	Brazos	Records good. EXTREMES FOR PERIOD OF RECORD - November 2014 to current year: Maximum elevation, 27.59 ft, May 25, 2014, minimum elevation, 4.83 ft, Sept. 27, 2015.
12	BKTT2	Brazos	Records good.
13	RKDT2	Brazos	
14	RSAT2	Brazos	
15	RLRT2	Brazos	Records fair. Since installation of gauge at least 10% of contributing drainage area has been regulated. There are numerous diversions for irrigation and municipal supply above station. The Aluminum Company of America diverts water from Little River to their plant reservoir. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES FOR PERIOD OF RECORD - Maximum gauge height, 38.34 ft, Dec. 21, 1991 (maximum discharge not determined); minimum daily discharge 13.0 ft³/s May 9, 1984.
16	CMNT2	Brazos	Records fair. Since water year 1954, at least 10% of contributing drainage area has been regulated. Many small diversions for irrigation and municipal supply affect low flow. The Aluminum Company of America diverts water 10.9 mi upstream from the gauge for use at their Rockdale plant resevoir. The city of Cameron diverts water for municipal use 2.1 mi upstream from gauge. Wastewater effluent is returned to the river upstream from gauge. No flow at times. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Flood in 1852 reached about the same stage as that of Sept. 10, 1921. Flood in Dec. 1913, reached a stage of 49.0 ft. Stages based on information furnished by local resident. EXTREMES FOR PERIOD PRIOR TO REGULATION - WATER YEARS, 1917-1953: Maximum discharge since 1852, 647,000 ft³/s, Sept. 10, 1921 (gauge height, 53.2 ft, present datum, from floodmark), from rating curve extended above 110,000 ft³/s, on basis of slope-area measurement of 647,000 ft³/s. AVERAGE DISCHARGE FOR PERIOD PRIOR TO REGULATION - 36 years (water years 1917-53), prior to regulation by Belton Lake, 1,807 ft³/s (1,309,000 acre-ft/yr).
17	BECT2	Brazos	Records fair. No known regulations or diversions. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically.
18	BBZT2	Brazos	Records fair. Since installation of gauge at least 10% of contributing drainage area has been regulated. Many small diversions above station for irrigation, municipal, industrial, and oil field operation. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Flood of Dec. 5, 1913, reached a stage of 61 ft, present site and datum, from information by Texas and New Orleans Railroad Co. at their bridge 200 ft upstream. Flood in 1854 reached about the same stage as flood of Dec. 5, 1913.

ID	Basin	Forecast Group	USGS Gauge Remarks
19	WBAT2	Brazos	Records fair. Since water year 1941, at least 10% of contributing drainage area has been regulated. There are diversions above station for municipal supply, irrigation, and for oil field operations of varying that affect flow. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage for 1847-98, 34.63 ft May 28, 1885, from floodmark at site 3.9 mi upstream. EXTREMES FOR PERIOD PRIOR TO REGULATION - WATER YEARS 1899-1940: Maximum discharge since 1847, 246,000 ft^3/s Sept. 27, 1936 (gauge height, 40.90 ft), at former site and datum, levee on left bank was overtopped and broken by flood; no flow Aug. 20, 21, 1918, and for several days in Aug. 1923. AVERAGE DISCHARGE FOR PERIOD PRIOR TO REGULATION - 42 years (water years 1899-1940), 2,560 ft^3/s (1,855,000 acre-ft/yr).
20	HIBT2	Brazos	Records fair. Since installation of gauge in 1965 at least 10% of contributing drainage area has been regulated. Water is diverted from the river about 52 miles upstream from this station by Texas Power and Light Co. to Tradinghouse Reservoir. Many diversions above station for municipal supply, irrigation, and industrial uses. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stages since at least 1909, 42 ft in Dec. 1913 and 40 ft in Sept. 1936, from information by local residents.
21	BSAT2	Brazos	Records good. The lake is formed by an earthfill dam, 1,645 ft long, including a 520-ft uncontrolled concrete ogee-type spillway near the center of dam. The dam was completed and deliberate impoundment of water began June 5, 1961. The dam is owned by the Bistone Municipal Water District. Data regarding the dam and lake are given in the following table: Elevation (feet) Top of dam.. 462.3 Crest of spillway.. 448.3 Lowest gated outlet (invert)... 442.1 Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES FOR PERIOD OF RECORD - July 1961 to Sept. 1986, Apr. 1999 to Sept. 2002: Maximum contents, 22,460 acre-ft, May 11, 1979; minimum contents, 2,440 acre-ft, Jan. 15, 1964; July 1961 to Sept. 1986, Apr. 1999 to current year: maximum elevation, 455.36 ft, May 11, 1979; minimum elevation, 445.09 ft, Dec. 9 & 10, 2006.
22	GRST2	Brazos	Records fair except for estimated daily discharges and discharges below 1 ft^3/s, which are poor. Since installation of the gauge in 1975 at least 10% of contributing drainage area has been regulated. There are several diversions above the gauge for irrigation, municipal supply, and oil field operation. The city of Groesbeck diverts water from the pool at the gauge for municipal use, and returns wastewater effluent into river downstream from the gauge. No flow at times. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1910, 26 ft in 1910 and 1944, from information by local residents.
23	EAST2	Brazos	Records good. Since water year 1961, at least 10% of contributing drainage area has been regulated. There are numerous diversions above station for irrigation, municipal supply, and oil field operation. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since 1845, 29 ft in June 1899, from information by local residents (discharge, 90,000 ft^3/s), from rating curve extended above 60,000 ft^3/s. EXTREMES FOR PERIOD PRIOR TO REGULATION - WATER YEARS, 1924-1960: Maximum discharge, 60,300 ft^3/s May 2, 1944 (gauge height, 27.13 ft at datum then in use); no flow at times.

ID	Basin	Forecast Group	USGS Gauge Remarks
			AVERAGE DISCHARGE FOR PERIOD PRIOR TO REGULATION - 36 years (water years 1925-60), 406 ft³/s, 294,100 acre-ft/yr.
24	NGET2	Brazos	Records good. Since installation of gauge at least 10% of contributing drainage area has been regulated. There are numerous diversions above station for irrigation, municipal supply and oil field operations. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically.
25	BRYT2	Brazos	
26	CLGT2	Brazos	
27	HPDT2U	Brazos	
28	DMYT2	Brazos	Records fair except for flows below 1 ft³/s, which are poor. No known regulation or diversions. No flow at times.
29	DEYT2	Brazos	Records poor. Unknown amount of regulation. Diversions above station for irrigation. No flow at times. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1886, 17 ft in 1899 and 1957, from information by local residents.
30	LYNT2	Brazos	Records fair, except those discharges below 1 ft³/s, which are poor. No known regulation or diversions. The city of Caldwell discharges wastewater effluent into creek above station. No flow at times. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Flood in 1947 reached a stage of 17 ft, from information by local resident.
31	HBRT2	Brazos	Records good.
32	HLBT2	Brazos	Records Good.
33	WBZT2U	Brazos	
34	WBZT2	Brazos	
35	HPDT2	Brazos	Since installation of gauge, at least 10% of contributing drainage area has been regulated. There are many diversions above station for irrigation, municipal and industrial uses, and oil field operations. Gauge height associated with historical peak discharge is referenced to datum currently in use. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1899, 66.1 ft Dec. 8, 1913, at site 1,500 ft downstream at present datum, from information by Texas and New Orleans Railroad Co., obtained at bridge 6,000 ft downstream. Flood of July 4, 1899, reached a stage of 63.6 ft, at site 1,500 ft downstream at present datum, from information by Texas and New Orleans Railroad Co.
36	BEMT2	Brazos	No known regulation or diversions. During the year, the city of Bellville discharges sewage effluent into a tributary of Mill Creek above gauge. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. Bridge construction 60 feet upstream of gauge in late summer 2010. Some intermittent pumpage adjacent to gauge during construction period. Pumpage not evident in stage record as gauge pool unaffected. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since 1899, 22.8 ft in 1940, from information by local residents and the Texas Department of Transportation.

ID	Basin	Forecast Group	USGS Gauge Remarks
37	BAWT2	Brazos	Since installation of gauge, at least 10% of contributing drainage area has been regulated. There are many diversions above station for irrigation, municipal and industrial uses, and oil field operations. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES FOR PERIOD OF RECORD - Maximum discharge, 88,600 ft³/s, Jun. 1, 2015, gauge-height 122.29 ft.
37	BAWT2	Brazos	Since installation of gauge, at least 10% of contributing drainage area has been regulated. There are many diversions above station for irrigation, municipal and industrial uses, and oil field operations. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES FOR PERIOD OF RECORD - Maximum discharge, 88,600 ft³/s, Jun. 1, 2015, gauge-height 122.29 ft.
38	RMOT2	Brazos	Since water year 1941, at least 10% of contributing drainage area has been regulated. Considerable water is diverted above station for irrigation and municipal supply. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1852, 61.2 ft, Dec. 10, 1913, present datum, from floodmarks on right bank 1,000 ft upstream from gauge. From information by Texas and New Orleans Railroad Co., stages of other floods at railroad bridge, present datum, are as follows: May 1884, 56.7 ft; June 13, 1885, 57.7 ft; July 1899, 58.6 ft; May 2, 1915, 56.3 ft; and May 9, 1922, 53.9 ft. EXTREMES FOR PERIOD PRIOR TO REGULATION - WATER YEARS, 1903-1906, 1923-1940: Maximum discharge, 123,000 ft³/s, June 6, 1929 (gauge height, 53.6 ft, from floodmark), present site and datum; minimum daily, 35 ft³/s, Aug. 23, 1934. AVERAGE DISCHARGE FOR PERIOD PRIOR TO REGULATION - 20 years (water years 1904-05, 1923-40) 7,209 ft³/s (5,223,000 acre-ft/yr).
39	SLNT2	Brazos	
40	ROST2	Brazos	Beginning in April 2008, water-quality data collected as part of the USGS National Monitoring Network (NMN). Some records listed in the "Period of Record" for surface water and water quality may not be available electronically.
41	WCBT2	Brazos	
42	LCPT2	Guadalupe	Records fair for Water Year. No known diversions above station. Flow is affected at times by discharge from the flood-detention pools of 17 floodwater-retarding structures. These structures control runoff from 67.8 square miles above this station. Since 1964, at least 10% of contributing drainage area has been regulated. No flow at times. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1905, 22 ft in June 1936 at present site; flood in 1951 reached a stage of 20 ft at present site, from information by local resident. EXTREMES FOR PERIOD PRIOR TO REGULATION - WATER YEARS 1959-1963: Maximum discharge, 26,600 ft³/s Oct. 29, 1960 (gauge height, 20.62 ft). No flow at times. AVERAGE DISCHARGE FOR PERIOD PRIOR TO REGULATION - 4 years (water years 1959-63), 48.2 ft³/s (34,940 acre-ft/yr).

ID	Basin	Forecast Group	USGS Gauge Remarks
43	LULT2	Guadalupe	Water Year records fair except for estimated daily which are considered poor. No known diversions above station. Flow is affected at times by discharge from the flood-detention pools of 27 floodwater-retarding structures. These structures control runoff from 119 mi² above this station. Since 1964, at least 10% of contributing drainage area has been regulated. No flow at times. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1868, that of Oct. 18, 1998; flood in 1913 reached about same stage as that of July 1, 1936, from information by local residents. EXTREMES FOR PERIOD PRIOR TO REGULATION - WATER YEARS 1930-63: Maximum discharge, 78,500 ft³/s, July 1, 1936, gauge height, 30.70 ft from floodmarks (at datum then in use), from rating curve extended above 37,500 ft³/s; no flow at times. AVERAGE DISCHARGE FOR PERIOD PRIOR TO REGULATION - 33 years (water years 1930-63) 90.3 ft³/s (65,370 acre-ft/yr).
44	LLGT2	Guadalupe	Water Year records fair. Since 1984, at least 10% of contributing drainage area has been regulated by discharge from the flood-detention pools of at least 18 floodwater-retarding structures. These structures control runoff from 105 mi² in the Town, Sink, and York Creek drainage basins. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. Dam at site, as well as diversion were worked on in 2015. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1859, 40.4 ft in 1869 or 1870, from information by Texas Department of Transportation. Flood of May 29, 1929, reached a stage of 37.1 ft and is the second highest known. EXTREMES FOR PERIOD PRIOR TO REGULATION - WATER YEARS 1939-1983: Maximum discharge, 57,000 ft³/s Sept. 12, 1952 (gauge height, 34.95 ft); minimum daily, 43 ft³/s Aug. 12, 1951. AVERAGE DISCHARGE FOR PERIOD PRIOR TO REGULATION - 44 years (water years 1939-83), 370 ft³/s (268,100 acre-ft/yr).
45	GNLT2	Guadalupe	WY records good. Since water year 1928, at least 10% of contributing drainage area has been regulated. Some water is diverted for irrigation and municipal use (amounts unknown). Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Flood of May 29, 1929, reached a stage of 38.3 ft, National Weather Service datum.
46	PEWT2	Guadalupe	Records rated fair. No known regulation or diversions. No flow at times. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically.
47	DLWT2	Guadalupe	
48	GDHT2	Guadalupe	Water Year records fair to poor. Constant debris ending up in downstream low water crossing colvert. No known regulation or diversions above station. Flow affected at times by backwater from the Guadalupe River. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1840, 35.3 ft in June 1940; flood of June 30, 1936 reached a stage of 32.8 ft, but may have been affected by backwater from the Guadalupe River, from information by local residents.
49	WHOT2U	Guadalupe	
50	WHOT2M	Guadalupe	

ID	Basin	Forecast Group	USGS Gauge Remarks
51	WHOT2	Guadalupe	Records good for Water Year. No known regulation or diversions. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum discharge since at least 1864, 92,700 ft³/s, July 2, 1936 (gauge height, 33.1 ft, from floodmarks), on basis of computation of peak flow, at present site and datum. Flood in Oct. 1913 reached a stage of 26.0 ft, present site and datum, from information by local residents.
52	CUET2U	Guadalupe	
53	CUET2	Guadalupe	Records good for the Water Year. Since installation of gauge in 1964, at least 10% of contributing drainage area has been regulated. Flow is affected at times by discharge from the flood-detention pools of 53 floodwater-retarding structures. These structures control runoff from 302 mi² in the Comal, San Marcos, and Plum Creek drainage basins. Many small diversions above station. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1900 probably occurred July 2, 1936, 44.33 ft, present site and datum, from information by Texas Department of Transportation.
54	WRST2	Guadalupe	Records good for WY. No known regulation or diversions. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. See RMS Period Analysis Notes for additional information. EXTREMES FOR PERIOD OF RECORD - Maximum discharge, 13,800 ft³/s June 21, 1997 (gauge height, 26.68 ft), from rating curve extended above 2,840 ft³/s; no flow many days.
55	SCDT2	Guadalupe	No known regulation or diversions. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum discharges since at least 1872 at site 3.5 mi downstream, 122,000 ft³/s Sept. 21, 1967 (slope-area measurement of peak flow), 63,700 ft³/s Oct. 16, 1946, and 46,700 ft³/s in Oct. 1925, from information by local resident.

ID	Basin	Forecast Group	USGS Gauge Remarks
56	CKDT2	Guadalupe	Some records listed in the "Period of Record" for surface water may not be available electronically. The reservoir system consists of the main reservoir, Turkey Creek Arm, and Sulphur Creek Arm. Figures shown below are the elevations of the main reservoir only. As of July 1999, the Turkey Creek Arm and Sulphur Creek Arm stations are operated by the Guadalupe-Blanco River Authority. Cooling water is diverted from the main reservoir through the Central Power and Light coal-fired generating plant, through a canal to the Sulphur Creek Arm, and then through a canal to Turkey Creek Arm, where it is released back into the main reservoir. The system was built for the Guadalupe-Blanco River Authority, and storage began in Feb. 1980. From Feb. 1980 to Sept. 2000, total daily contents of the main reservoir, the Turkey Creek Arm, and the Sulphur Creek Arm were published as station 08177400. Revised daily contents for Turkey Creek Arm are stored as station 08177240 Turkey Creek Arm of Coleto Creek Reservoir near Schroeder and revised daily contents for Sulphur Creek Arm are stored as station 08177380 Sulphur Creek Arm of Coleto Creek Reservoir near Fannin. The main reservoir is formed by a compacted earthfill dam 20,800 ft long, including a 2,000-foot uncontrolled spillway and a 403-foot wide concrete outlet structure with seven 40- x 28-foot spillway gates. Low-flow releases are made through the dam by a controlled 8-inch pipe. Turkey Creek Arm is formed by a compacted earthfill dam 2,250 ft long, including a 186-ft wide concrete outlet structure with two 40- x 11-foot spillway gates. Sulphur Creek Arm is formed by a compacted earthfill dam 1,030 ft long, including a 186-foot wide concrete outlet structure with two 40- by 11-foot spillway gates. Data regarding the dam are given in the following table: Elevation (feet) Top of dam.. 119.0 Emergency spillway.. 107.3 Top of spillway gates... 99.4 Crest of spillway.. 71.0 EXTREMES FOR PERIOD OF RECORD - Maximum contents, 36,680 acre-ft, Aug. 31, 2001, elevation, 99.94 ft; maximum elevation 101.10 ft, Nov. 21, 2004; minimum since reservoir was first filled in May 1980, 20,330 acre-ft, Aug. 20, 21, 1996, elevation, 93.27 ft.
57	VICT2U	Guadalupe	
58	VICT2	Guadalupe	Records good for Water Year. Since installation of gauge in 1934, at least 10% of contributing drainage area has been regulated. There are many diversions above station. The city of Victoria releases wastewater effluent into the river below this station. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Flood of June 1, 1929, reached a stage of 30.2 ft, present site and datum, maximum stage since at least 1833, that of July 3, 1936.
59	DUPT2	Guadalupe	Records fair for WY. Since installation of gauge in Feb. 1999, at least 10% of contributing drainage area has been regulated. There are many diversions above station. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Flood of Oct. 20, 1998, reached a gauge height of 33.92 ft, from National Weather Service floodmark. EXTREMES FOR PERIOD OF RECORD - Maximum gauge height, 28.75 ft, Nov. 26, 2004; minimum gauge height, 6.55 ft, Aug. 4, 2009.

ID	Basin	Forecast Group	USGS Gauge Remarks
60	LLET2	Brazos	The reservoir is formed by a rolled earthfill dam 3,700 ft long. Storage began in Apr. 1954 and dam was completed in June 1954. The emergency spillway is a 1,200-foot-wide cut through natural ground near the left end of dam. The service spillway is an uncontrolled circular concrete drop inlet designed for a maximum discharge of 5,000 ft³/s through an 11-foot-diameter concrete conduit. The dam is the property of Eastland County Water Supply District and was built to impound water for municipal use by the cities of Ranger, Olden, and Eastland. Data regarding the dam are given in the following table: Elevation (feet) Top of dam.. 1,398.0 Crest of emergency spillway.. 1,382.0 Crest of service spillway.. 1,375.0 Lowest gated outlet (invert)... 1,335.0 EXTREMES FOR PERIOD OF RECORD - Maximum contents observed, 40,640 acre-ft, June 13, 1967, elevation, 1,382.20 ft; minimum contents, 14,420 acre-ft, Oct. 15, 2000, elevation, 1,364.79 ft. Maximum elevation observed, 1,385.60 ft, June 28, 2007; minimum elevation, 1,364.79 ft, Oct. 15, 2000.
61	CPKT2	Brazos	No known regulation. Diversions for farm and ranch use may occur upstream from station. No flow at times. Some records listed in the period of record may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - None known EXTREMES FOR PERIOD OF RECORD - Maximum discharge, 9,200 ft³/sec, May 27, 2016, gauge height, 19.55 ft.
62	DSBT2	Brazos	Flow may be slightly affected by Nabors Lake 0.4 mi upstream on Spring Branch. No flow at times. Some records listed in the period of record may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since 1890, 24 ft in May 1908, from information by local resident.
63	DLLT2	Brazos	Since installation of gauge at least 10% of contributing drainage area has been regulated. There are numerous diversions above station for municipal, steam power plant operation, and other uses. Some records listed in the period of record may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - A stage of 19.3 ft occurred in May 1908 at a point 2,000 ft downstream from present gauge site and is the highest since that time, from information by local resident. EXTREMES FOR PERIOD OF RECORD - Maximum discharge, 24,500 ft³/s Apr. 26, 1990 (gauge height, 19.00 ft, from floodmarks), from rating curve extended above 17,600 ft³/s; prior to Apr. 26, 1990, maximum discharge, 7,540 ft³/s June 21, 1968, (gauge height, 15.50 ft); no flow for many days most years.

ID	Basin	Forecast Group	USGS Gauge Remarks
64	PCTT2	Brazos	Intermittent missing record is the result of editing erroneous values. Some records listed in the period of record may not be available electronically. The lake is formed by a reinforced concrete gated structure and rolled earthfill dam, total length 13,460 ft. The lake was operated as a detention basin from Jan. 30 to July 5, 1963. The gates were closed July 6, 1963, but the lake was operated as a detention basin to elevation 1,156.0 ft until construction was completed. Deliberate impoundment began Sept. 30, 1963. The spillway is a gated concrete gravity structure located on the left bank, with an ogee weir section and basin. The spillway is controlled by eleven 40.0- by 35.0-foot tainter gates. The spillway was designed to discharge 431,800 ft³/s at an elevation of 1,201.0 ft. The lake is operated for flood control and water conservation. Inflow is partly regulated by Leon Reservoir (station 08099000, conservation pool storage 26,420 acre-ft). Inflow is also affected at times by discharge from the flood-detention pools of 23 floodwater-retarding structures with a combined detention capacity of 43,690 acre-ft. These structures control runoff from 172 mi² in the Leon River and Rush Creek drainage basins. Borrow is not included in capacity totals. The dam is owned by the U.S. Army Corps of Engineers. Conservation pool storage is 55,590 acre-ft. Data regarding the dam are given in the following table: Elevation (feet) Top of dam.. 1,206.0 Design flood.. 1,201.0 Top of gates.. 1,197.0 Crest of spillway (top of conservation pool).......................... 1,162.0 Lowest gated outlet (invert)... 1,128.0 EXTREMES FOR PERIOD OF RECORD - Maximum contents, 383,100 acre-ft, May 2, 1990, elevation, 1,197.63 ft; minimum since first filling of lake, 6,090 acre-ft, Oct. 28, 2000, elevation, 1,142.36 ft. Maximum elevation, 1,197.66.60 ft, June 04, 2016; minimum elevation, 1,142.36 ft, Oct. 28, 2000.
65	HMLT2	Brazos	Records fair. Since water year 1954, at least 10% of contributing drainage area has been regulated. There are numerous diversions above station for irrigation, municipal supply, and industrial uses. At times flow is affected by discharge from floodwater-retarding structures controlling runoff from 43.9 mi². Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since 1858, 38.4 ft in May 1908 and Dec. 1913; flood in Sept. 1911 reached a stage of 37.0 ft, all at present site and datum, from information by local residents. The flood in Oct. 1959 reached a stage of 34.1 ft, present datum. EXTREMES FOR PERIOD PRIOR TO REGULATION - WATER YEARS 1925-1931: Maximum discharge, 5,680 ft³/s, May 22, 1931, gauge height, 20.00 ft; no flow at times. AVERAGE DISCHARGE FOR PERIOD PRIOR TO REGULATION - 6 years (water years 1926-31) prior to regulation by Lake Leon, 130 ft³/s (94,200 acre-ft/yr).
66	FHCT2	Brazos	Records fair.
67	FCCT2U	Brazos	
68	FCCT2	Brazos	Records fair.
69	FHGT2	Brazos	Records fair.
70	FHHT2U	Brazos	Records fair.
71	FHHT2	Brazos	Records fair.

ID	Basin	Forecast Group	USGS Gauge Remarks
72	MCGT2	Brazos	Records fair except for estimated daily discharges and daily discharges below 5 ft³/s, which are poor. No known regulation or diversions. No flow at times. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Flood of 1889, which reached a stage of 28.5 ft. A flood in 1957 reached a stage of 28.2 ft; and floods in 1913 and 1942 or 1943 reached a stage of about 28 ft, from information by local residents.
73	HICT2	Brazos	Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. Since installation of gauge, at least 10% of contributing drainage area has been regulated. At times flow is affected by discharge from floodwater-retarding structures controlling runoff from 202 mi² in the North Bosque River and Green Creek drainage basins. The City of Stephenville discharges wastewater effluent into the river above this station. No known diversions. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1880, 27.6 ft May 23, 1952, from floodmarks (discharge, 87,800 ft³/s, by contracted-opening measurement). AVERAGE DISCHARGE FOR PERIOD OF RECORD - 36 years (water years 1963-98), 68.6 ft³/s (49,710 acre-ft/year).
74	CTNT2	Brazos	Records fair. At least 10% of contributing drainage area is regulated. At times flow is affected by discharge from floodwater-retarding structures controlling runoff from 202 mi² in the North Bosque River and Green Creek drainage basins, in addition to several municipal withdrawal and wastewater effluent discharge. No flow at times. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Flood of May 9, 1922, reached a stage of about 32 ft, from information by local residents.
75	VMAT2	Brazos	Records fair. Since installation of gauge, at least 10% of contributing drainage area has been regulated. There are several small diversions above station. No flow at times. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since 1868, flood in May 1908 reached a stage of 43 ft. Floods in Sept. 1936 and Apr. 1945 reached a stage of about 38 ft, from information by local residents.
76	ACTT2	Brazos	Records good. The lake is formed by a rolled earthfill dam 24,618 ft long, including spillway. The lake was built for flood control and water conservation. From Oct. 1, 1964, to Feb. 26, 1965, the lake was operated as a detention basin only. On Feb. 26, 1965, old Lake Waco was breached and deliberate impoundment began. The spillway is controlled by fourteen 40.0-by 35.0-foot tainter gates. The outlet works consists of three gate-controlled outlets, 6.7 by 20.0 ft, opening into a 20.0-foot-diameter concrete conduit and two 54-inch concrete pipes. Low-flow releases are made through two 54-inch butterfly valves. Flow into two wet wells is controlled by four 5.0- by 6.0-foot slide gates. The dam is the property of the U.S. Army Corps of Engineers. Data regarding the dam are given in the following table: Elevation (feet) Top of dam.. 510.0 Design flood... 505.0 Top of gates... 500.0 Crest of spillway .... 465.0 Top of conservation pool .... 462.0 Lowest controlled outlet (invert)................................... 400.0 Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES FOR PERIOD OF RECORD - Feb. 1965 to Sept. 2002: Maximum contents, 521,100 acre-ft, Dec. 24, 1991; minimum since normal operating level was reached, 86,300 acre-ft, Oct. 8, 1984; Feb. 1965 to current year: Maximum elevation, 488.48 ft, Dec. 24, 1991, minimum elevation, 445.10 ft, Oct. 8, 1984.

ID	Basin	Forecast Group	USGS Gauge Remarks
77	CRFT2	Brazos	Records rated fair except for estimated daily discharges and discharges below 5 ft³/s, which are poor. Since water year 1980, at least 10% of the contributing drainage area has been regulated. These structures control runoff from 42.0 mi² in the Hog Creek drainage basin. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since 1900, 17.5 ft Sept. 26, 1936. Flood in Apr. or May 1957 reached a stage of 15.7 ft, from information by local residents. EXTREMES FOR PERIOD PRIOR TO REGULATION - WATER YEARS 1959-1979: Maximum discharge, 15,400 ft³/s Oct. 4, 1959 (gauge height, 14.31 ft); no flow at times. AVERAGE DISCHARGE FOR PERIOD PRIOR TO REGULATION - 20 years (water years 1960–1979), 37.7 ft³/s (27,310 acre-ft/yr).
79	LKCT2	Colorado	The lake is formed by a rolled earthfill dam 3,200 ft long. Impoundment began April 1966, and dam was completed in May 1966. The top of the dam was raised 2.0 ft in 1975. The dam and reservoir are owned and operated by the city of Coleman. The uncontrolled emergency spillway is 1,500 ft long across natural earth. The uncontrolled morning glory service spillway is 28 ft wide at the crest. A service outlet is provided for small releases through a 24-inch conduit. Water may be pumped from reservoir for municipal and industrial use. Data regarding the dam are given in the following table: Elevation (feet) Top of dam.. 1,742.0 Crest of emergency spillway.. 1,726.0 Crest of service spillway.. 1,717.5 Lowest gated outlet (invert)... 1,662.5 EXTREMES FOR PERIOD OF RECORD - Feb. 1999 to Sept. 2002: Maximum contents, 53,740 acre-ft, July 7, 2002; minimum contents, 12,750 acre-ft, May 2, 3, 2002; Feb. 1999 to current year: Maximum elevation, 1,724.10 ft, July 7, 2002; minimum elevation, 1,697.88 ft, April 11,12, 13, 2015.
80	HORT2	Colorado	The lake is formed by a rolled earthfill dam 6,800 ft long, including spillway. Deliberate impoundment of water began Apr. 7, 1948, and the dam was completed in June 1948. The spillway is an excavated channel through natural ground, 500 ft wide, located about 600 ft from the right end of dam. The spillway consists of three concrete conduits; two controlled by 5.0- by 6.0-foot slide gates, and a third uncontrolled ogee spillway 4.0 ft wide and 19.5 ft high. The dam is owned by the U.S. Army Corps of Engineers. The lake is operated for flood control and municipal water supply for the city of Coleman, records of diversions can be obtained from the U.S. Army Corps of Engineers. The capacity table of Aug. 1974 was based on a sedimentation survey made in 1948. Flow is affected at times by discharge from the flood-detention pool of one floodwater-retarding structure with a detention capacity of 1,370 acre-ft. This structure controls runoff from 6.82 mi² in the Jim Ned Creek drainage basin. Conservation pool storage is 8,112 acre-ft. Data regarding the dam are given in the following table: Elevation (feet) Top of dam.. 1,939.0 Design flood... 1,933.6 Crest of spillway.. 1,920.0 Crest of spillway (top of conservation pool)......................... 1,900.0 Lowest gated outlet (invert)... 1,856.0 Water-quality records available from Jan. 1981 to Aug. 1982 were published separately as: Site ID Site name 314959099333701 Hords Ck Lk Site AC nr Valera, TX 315002099341301 Hords Ck Lk Site CC nr Valera, TX 315020099344601 Hords Ck Lk Site DC nr Valera, TX 315021099341501 Hords Ck Lk Site BC nr Valera, TX

ID	Basin	Forecast Group	USGS Gauge Remarks
			EXTREMES FOR PERIOD OF RECORD - Apr. 1948 to Sept. 2002: Maximum contents, 12,790 acre-ft, May 1, 1956; minimum contents since first appreciable storage in June 1951, 1,550 acre-ft, Sept. 2, 1984; Apr. 1948 to current year: Maximum elevation, 1907.31 ft, Mar. 4, 1992; minimum elevation, 1,878.01 ft, Sept. 2, 1984.
81	HDCT2	Colorado	Since 1948 flow largely regulated by Hords Creek Reservoir (station 08141000) from which the city of Coleman obtains part of its municipal water supply. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1876 occurred in July or September 1900 and reached a stage about 6.3 ft higher than that of Apr. 30, 1956, at a point near the municipal light and powerplant about 4,750 ft downstream from present gauge. Flood of July 3, 1932, reached a stage about 2.6 ft higher than that of Apr. 30, 1956, at the same downstream point. Data pertaining to stage of floods in 1900 and 1932, from information by local residents. EXTREMES FOR PERIOD OF RECORD - Maximum discharge, 25,100 ft³/s Apr. 30, 1956 (gauge height, 21.50 ft at former datum), from rating curve extended above 4,800 ft³/s on basis of slope-area measurement of 8,640 ft³/s and contracted opening measurement of 25,100 ft³/s; no flow at times. Maximum discharge, 3,120 ft³/s May. 30, 2016 (gauge height, 9.63 ft at current datum). No flow at times. AVERAGE DISCHARGE FOR PERIOD OF RECORD - 30 years (water years 1940-70), 8.68 ft³/s (6,290 acre-ft/yr).
82	CJNT2	Colorado	Flow largely regulated by Lake Coleman nr. Novice, TX (station number 08140770). This river flows into Lake Brownwood. The dam for Lake Brownwood is located about 26.4 miles downstream from the gauge. EXTREMES OUTSIDE PERIOD OF RECORD - None known. EXTREMES FOR PERIOD OF RECORD - May 18, 2019, Maximum discharge, 2,220 ft³/s, Gauge-height, 17.98 ft. No flow at times most years.
83	LBWT2U	Colorado	
84	CUTT2	Colorado	The gauge is impacted by several large Soil Conservation retention ponds upstream. Historically, these retentions are assumed to affect flows by 10 percent or more. EXTREMES OUTSIDE PERIOD OF RECORD - None known. EXTREMES FOR PERIOD OF RECORD - Maximum discharge, 22,700 ft³/s, Gauge-height, 27.22 ft., 2016/05/30. No flow many days
85	LBWT2	Colorado	The lake is formed by a rolled earthfill dam, 1,580 ft long. The dam was completed in 1933 and deliberate impoundment began in July 1933. In Aug. 1983, work was completed to reinforce backside of dam, which raised the top 20 ft. The uncontrolled emergency spillway is a broad-crested weir 479 ft long located 800 ft to left of dam. The controlled service spillway consists of two 48-inch horseshoe-shaped concrete conduits. Water is used for irrigation, municipal, and industrial supply. Flow is affected at times by discharge from the flood-detention pools of 59 floodwater-retarding structures with a combined capacity of 73,310 acre-ft. These structures control runoff from 353 mi² in the Jim Ned Creek and Pecan Bayou drainage basins. Records of diversions may be obtained from the Brown County Water Improvement District No.1. The dam is owned by Brown County WID No. 1. Data regarding the dam are given in the following table: Elevation (feet) Top of dam... 1,470.0 Crest of spillway.. 1,424.6 Lowest gated outlet (invert)... 1,329.5

ID	Basin	Forecast Group	USGS Gauge Remarks
			EXTREMES FOR PERIOD OF RECORD - Maximum contents, 198,000 acre-ft, July 7, 2002, elevation, 1,432.12 ft; minimum contents observed, 11,900 acre-ft, July 15, 1934, elevation, 1,389.0 ft.
86	BWDT2	Colorado	Flow largely regulated by Lake Brownwood near Brownwood, TX. Diversion at Lake Brownwood, 10 miles upstream (see records for Brown County Water Improvement District No. 1 canal). EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage known, 21.7ft in September 1900, from information by Gulf, Colorado and Santa Fe Railway Co. EXTREMES FOR PERIOD OF RECORD - 1917-18, 1923-60: Maximum discharge, 31,600cfs Oct. 14, 1930 (gauge height, 16.92ft). Flood of July 3, 1932, probably the greatest known, reached a discharge of about 235,000cfs as it entered Brownwood Reservior (computed from rate of change of contents in reservoir; data furnished by engineers of Brown County Water Improvement District No. 1).
87	SKMT2	Nueces	The city of Beeville discharges wastewater effluent into the river via Poesta Creek 3.8 mi upstream. No known regulation or diversions. No flow at times. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Flood of Sept. 1954 reached a stage of 33 ft (discharge, 19,600 ft^3/s), from information by local resident. Maximum stage since at least 1914, that of Sept. 22, 1967.
88	MIOT2	Nueces	No known regulation or diversions. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Maximum stage since at least 1914, that of Sept. 22, 1967. A stage of about 31 ft (discharge 25,500 ft^3/s) occurred in Sept. 1919, from information from local resident.
89	REFT2	Nueces	No known regulation. There are several small diversions above station. Some records listed in the "Period of Record" for surface water and water quality may not be available electronically. EXTREMES OUTSIDE PERIOD OF RECORD - Floods in Aug. 1914 and May 17, 1938, reached a stage of 32.3 ft, from information by local residents. Maximum stage since about 1899, that of Sept. 12, 1971.

14. APPENDIX H – BEFORE/AFTER STATISTICS

Table 13-1: KGE, Correlation, Bias Ratio, and Variability Ratio statistics for the period 2000–2020; required sites.

2000 to 2020 Statistics- Required Basins										
ID	Basin	Fcst Group	Initial KGE	Calb KGE	Initial Corr.	Calb Corr.	Initial Bias Ratio	Calb Bias Ratio	Initial Var. Ratio	Calb Var. Ratio
1	GAST2	Brazos	0.83	0.90	0.90	0.93	0.87	0.95	0.99	1.06
2	BNLT2	Brazos	-0.12	0.83	0.25	0.90	0.33	0.91	0.50	1.11
3	LRIT2	Brazos	0.82	0.91	0.92	0.98	0.88	0.93	0.90	0.95
4	PICT2	Brazos	0.24	0.56	0.71	0.74	1.41	0.76	1.58	0.74
5	KEMT2	Brazos	0.08	0.42	0.66	0.69	1.36	0.57	1.77	0.77
6	DNGT2	Brazos	0.76	0.90	0.89	0.97	0.81	0.92	0.89	0.96
7	SDOT2	Brazos	0.15	0.80	0.34	0.87	0.56	0.85	0.70	1.00
8	BYBT2	Brazos	0.24	0.80	0.48	0.86	0.45	0.90	1.01	0.90
9	BCIT2	Brazos	0.63	0.91	0.73	0.96	0.75	0.92	0.99	1.00
10	BKFT2	Brazos	0.53	0.81	0.53	0.84	0.99	1.10	0.92	0.98
11	BSYT2	Brazos	0.51	0.83	0.53	0.92	1.09	1.03	0.91	0.85
12	BKTT2	Brazos	0.69	0.83	0.75	0.96	1.02	0.84	1.19	1.04
13	RKDT2	Brazos								
14	RSAT2	Brazos								
15	RLRT2	Brazos	0.91	0.95	0.91	0.97	0.98	0.97	0.99	1.02
16	CMNT2	Brazos	0.92	0.98	0.95	0.99	1.01	1.02	1.07	0.99
17	BECT2	Brazos	0.55	0.73	0.78	0.82	0.62	0.83	1.03	0.90
18	BBZT2	Brazos	0.97	0.98	0.98	0.99	0.98	0.98	1.01	0.99
19	WBAT2	Brazos	0.93	0.97	0.98	0.99	0.94	0.98	1.00	1.02
20	HIBT2	Brazos	0.89	0.90	0.96	0.98	0.90	0.91	0.99	0.95
21	BSAT2	Brazos	0.27	0.72	0.66	0.79	0.52	0.83	0.56	0.93
22	GRST2	Brazos	0.65	0.77	0.96	0.95	1.28	1.20	1.20	1.10
23	EAST2	Brazos	0.64	0.89	0.72	0.96	0.96	0.93	1.22	0.92
24	NGET2	Brazos	0.69	0.88	0.95	0.93	1.22	1.03	1.22	1.10
25	BRYT2	Brazos								
26	CLGT2	Brazos								
27	HPDT2U	Brazos								
28	DMYT2	Brazos	-0.24	0.82	0.74	0.84	2.04	0.95	1.62	1.05
29	DEYT2	Brazos	0.13	0.84	0.79	0.86	1.77	0.93	1.35	0.98
30	LYNT2	Brazos	0.80	0.89	0.83	0.92	1.09	0.96	1.04	1.07
31	HBRT2	Brazos	0.92	0.93	0.96	0.98	1.02	1.03	1.06	1.06
32	HLBT2	Brazos	-0.12	0.79	0.90	0.85	1.63	1.08	1.93	1.12
33	WBZT2U	Brazos								
34	WBZT2	Brazos								
35	HPDT2	Brazos	0.93	0.96	0.97	0.99	1.00	1.02	1.06	1.03
36	BEMT2	Brazos	0.89	0.82	0.94	0.95	1.09	1.17	0.97	0.95
37	BAWT2	Brazos	0.98	0.99	1.00	1.00	0.98	1.00	1.01	1.01
38	RMOT2	Brazos	0.99	0.99	0.99	0.99	1.00	1.01	1.00	1.00
39	SLNT2	Brazos	0.97	0.97	1.00	1.00	0.97	0.98	0.99	0.99
40	ROST2	Brazos	0.99	0.98	1.00	0.99	0.99	1.00	1.01	1.02
41	WCBT2	Brazos	0.95	0.96	0.99	1.00	1.01	1.01	0.95	0.96
42	LCPT2	Guad.	0.51	0.60	0.74	0.82	0.69	0.64	0.73	1.01
43	LULT2	Guad.	0.82	0.84	0.85	0.85	0.91	0.95	0.94	0.95
44	LLGT2	Guad.	0.45	0.90	0.74	0.90	0.73	1.00	0.60	0.98
45	GNLT2	Guad.	0.87	0.85	0.98	0.98	1.06	1.05	1.12	1.14
46	PEWT2	Guad.	0.36	0.38	0.78	0.85	1.37	0.72	0.53	0.46
47	DLWT2	Guad.	0.60	0.39	0.82	0.81	0.82	0.44	1.31	0.86
48	GDHT2	Guad.	0.87	0.88	0.99	0.99	1.13	1.12	1.02	1.01
49	WHOT2U	Guad.	-1.16	-2.18	0.68	0.91	2.53	3.46	2.49	3.02
50	WHOT2M	Guad.								
51	WHOT2	Guad.	0.62	0.44	0.79	0.81	0.82	1.48	0.74	1.23
52	CUET2U	Guad.								
53	CUET2	Guad.	0.92	0.93	0.95	0.95	1.06	1.03	1.00	0.99
54	WRST2	Guad.	-0.09	0.23	0.19	0.33	0.92	0.65	1.72	1.09
55	SCDT2	Guad.	0.75	0.36	0.78	0.68	1.07	0.59	0.90	0.64
56	CKDT2	Guad.	0.71	0.75	0.73	0.87	1.08	1.12	1.03	1.17
57	VICT2U	Guad.								
58	VICT2	Guad.	0.90	0.92	0.94	0.95	0.99	0.99	1.07	1.07

59	DUPT2	Guad.	0.97	0.91	0.98	0.98	1.02	0.96	1.02	0.92

Table 13-2: KGE, Correlation, Bias Ratio, and Variability Ratio statistics for the period 2000–2020; funding dependent sites.

2000 to 2020 Statistics- Funding Dependent Basins										
ID	Basin	Fcst Group	Initial KGE	Calb KGE	Initial Corr.	Calb Corr.	Initial Bias Ratio	Calb Bias Ratio	Initial Var. Ratio	Calb Var. Ratio
60	LLET2	Brazos-FD	0.60	0.75	0.72	0.82	1.25	0.93	0.88	0.84
61	CPKT2	Brazos-FD	0.17	0.85	0.70	0.87	1.77	0.98	1.09	1.08
62	DSBT2	Brazos-FD	0.42	0.57	0.73	0.79	1.50	0.65	1.10	0.86
63	DLLT2	Brazos-FD	0.67	0.65	0.92	0.91	0.73	0.69	0.83	0.87
64	PCTT2	Brazos-FD	0.71	0.74	0.84	0.92	0.76	0.77	0.92	0.92
65	HMLT2	Brazos-FD	0.83	0.91	0.90	0.94	0.99	0.94	1.13	0.98
66	HICT2	Brazos-FD	0.65	0.84	0.73	0.87	0.85	0.98	0.83	1.09
67	CTNT2	Brazos-FD	0.27	0.66	0.74	0.83	0.48	0.77	0.56	0.82
68	VMAT2	Brazos-FD	0.82	0.89	0.96	0.98	0.88	0.90	0.88	0.96
69	CRFT2	Brazos-FD	0.07	0.73	0.69	0.78	0.96	0.87	1.87	0.90
70	MCGT2	Brazos-FD	0.74	0.80	0.80	0.83	1.18	0.89	1.00	0.97
71	ACTT2	Brazos-FD	0.67	0.77	0.84	0.91	0.79	0.81	0.81	0.92
72	CUTT2	Colorado	0.46	0.57	0.63	0.73	1.39	0.66	0.96	0.96
73	LKCT2	Colorado	-3.28	0.57	0.68	0.67	3.95	1.21	4.08	1.18
74	HORT2	Colorado	0.17	0.15	0.18	0.36	0.97	0.52	1.13	0.71
75	HDCT2	Colorado	-0.37	0.58	0.33	0.60	2.16	0.88	1.24	0.99
76	CJNT2	Colorado	0.06	0.85	0.82	0.92	1.59	1.10	1.71	1.09
77	LBWT2	Colorado	0.50	0.46	0.81	0.78	0.67	0.59	0.67	0.72
78	LBWT2U	Colorado								
79	BWDT2	Colorado	-0.68	-0.41	0.95	0.95	2.40	2.17	1.92	1.79
80	MIOT2	Nueces	-1.28	-0.25	0.95	0.48	2.35	0.25	2.64	0.14
81	SKMT2	Nueces	-0.21	0.06	0.14	0.62	0.37	0.51	0.42	0.29
82	REFT2	Nueces	-0.21	0.28		0.63		0.63		0.50

Table 13-3: KGE, Correlation, Bias Ratio, and Variability Ratio statistics for the period 2010–2020; required sites.

2010 to 2020 Statistics- Required Basins										
ID	Basin	Fcst Group	Initial KGE	Calb KGE	Initial Corr.	Calb Corr.	Initial Bias Ratio	Calb Bias Ratio	Initial Var. Ratio	Calb Var. Ratio
1	GAST2	Brazos	0.88	0.89	0.92	0.95	0.92	1.00	1.03	1.11
2	BNLT2	Brazos	-0.12	0.83	0.25	0.90	0.33	0.91	0.50	1.11
3	LRIT2	Brazos	0.85	0.91	0.95	0.98	0.89	0.93	0.91	0.94
4	PICT2	Brazos	-0.15	0.77	0.74	0.82	1.58	0.88	1.95	0.92
5	KEMT2	Brazos	-0.48	0.65	0.79	0.81	1.64	0.70	2.31	0.99
6	DNGT2	Brazos	0.76	0.90	0.89	0.97	0.81	0.92	0.89	0.96
7	SDOT2	Brazos	0.15	0.80	0.34	0.87	0.56	0.85	0.70	1.00
8	BYBT2	Brazos	0.24	0.80	0.48	0.86	0.45	0.90	1.01	0.90
9	BCIT2	Brazos	0.63	0.91	0.73	0.96	0.75	0.92	0.99	1.00
10	BKFT2	Brazos	0.53	0.81	0.53	0.84	0.99	1.10	0.92	0.98
11	BSYT2	Brazos	0.51	0.83	0.53	0.92	1.09	1.03	0.91	0.85
12	BKTT2	Brazos	0.69	0.83	0.75	0.96	1.02	0.84	1.19	1.04
13	RKDT2	Brazos								
14	RSAT2	Brazos								
15	RLRT2	Brazos	0.91	0.96	0.93	0.97	1.03	1.00	1.06	1.03
16	CMNT2	Brazos	0.93	0.97	0.96	0.99	1.01	1.00	1.05	0.98
17	BECT2	Brazos	0.63	0.81	0.80	0.83	0.72	0.94	1.15	0.96
18	BBZT2	Brazos	0.97	0.98	0.98	0.99	0.98	0.98	1.01	0.99
19	WBAT2	Brazos	0.94	0.98	0.99	0.99	0.95	0.99	1.00	1.01
20	HIBT2	Brazos	0.92	0.92	0.97	0.99	0.93	0.94	1.01	0.96
21	BSAT2	Brazos	0.39	0.80	0.69	0.81	0.66	0.96	0.61	0.95
22	GRST2	Brazos	0.60	0.74	0.97	0.96	1.31	1.22	1.25	1.14
23	EAST2	Brazos	0.95	0.96	0.96	0.96	0.98	0.99	0.98	0.98
24	NGET2	Brazos	0.37	0.67	0.94	0.92	1.50	1.23	1.38	1.22
25	BRYT2	Brazos								
26	CLGT2	Brazos								
27	HPDT2U	Brazos								
28	DMYT2	Brazos	-0.23	0.83	0.74	0.84	2.04	0.99	1.61	1.05
29	DEYT2	Brazos	0.08	0.88	0.79	0.88	1.83	1.02	1.34	1.00
30	LYNT2	Brazos	0.77	0.89	0.83	0.93	1.15	1.04	1.04	1.08
31	HBRT2	Brazos	0.92	0.93	0.96	0.98	1.02	1.03	1.06	1.06
32	HLBT2	Brazos	-0.12	0.79	0.90	0.85	1.63	1.08	1.93	1.12
33	WBZT2U	Brazos								
34	WBZT2	Brazos								
35	HPDT2	Brazos	0.92	0.95	0.97	0.99	1.02	1.03	1.07	1.04
36	BEMT2	Brazos	0.84	0.78	0.94	0.95	1.15	1.21	0.97	0.95
37	BAWT2	Brazos	0.98	0.99	1.00	1.00	0.98	1.00	1.01	1.01
38	RMOT2	Brazos	0.98	0.98	1.00	1.00	1.01	1.01	1.02	1.02
39	SLNT2	Brazos	0.97	0.97	1.00	1.00	0.97	0.98	0.99	0.99
40	ROST2	Brazos	0.99	0.98	1.00	1.00	1.00	1.00	1.01	1.02
41	WCBT2	Brazos	0.95	0.96	0.99	1.00	1.01	1.01	0.95	0.96
42	LCPT2	Guad.	0.69	0.83	0.77	0.87	0.98	0.95	0.79	1.10
43	LULT2	Guad.	0.78	0.73	0.91	0.92	1.17	1.23	1.10	1.11
44	LLGT2	Guad.	0.76	0.73	0.83	0.93	1.09	1.15	0.85	1.21
45	GNLT2	Guad.	0.85	0.84	0.98	0.98	1.05	1.05	1.14	1.16
46	PEWT2	Guad.	0.36	0.38	0.78	0.85	1.37	0.72	0.53	0.46
47	DLWT2	Guad.	0.33	0.75	0.91	0.91	1.33	0.78	1.58	1.05
48	GDHT2	Guad.	0.87	0.88	0.99	0.99	1.13	1.12	1.02	1.01
49	WHOT2U	Guad.	-1.16	-2.18	0.68	0.91	2.53	3.46	2.49	3.02
50	WHOT2M	Guad.								
51	WHOT2	Guad.	0.74	-0.17	0.93	0.94	1.25	2.06	0.99	1.49
52	CUET2U	Guad.								
53	CUET2	Guad.	0.87	0.86	0.95	0.95	1.05	1.01	0.89	0.87
54	WRST2	Guad.	-0.17	0.17	0.10	0.23	0.97	0.70	1.74	1.06
55	SCDT2	Guad.	0.04	0.87	0.87	0.90	1.90	1.06	1.31	1.05
56	CKDT2	Guad.	0.71	0.68	0.74	0.85	1.11	1.18	1.07	1.22
57	VICT2U	Guad.								
58	VICT2	Guad.	0.65	0.67	0.91	0.94	1.02	1.02	1.34	1.33
59	DUPT2	Guad.	0.97	0.91	0.98	0.98	1.02	0.97	1.02	0.91

Table 13-4: KGE, Correlation, Bias Ratio, and Variability Ratio statistics for the period 2010–2020; funding dependent sites.

2010 to 2020 Statistics- Funding Dependent Basins										
ID	Basin	Fcst Group	Initial KGE	Calb KGE	Initial Corr.	Calb Corr.	Initial Bias Ratio	Calb Bias Ratio	Initial Var. Ratio	Calb Var. Ratio
60	LLET2	Brazos-FD	0.60	0.75	0.72	0.82	1.25	0.93	0.88	0.84
61	CPKT2	Brazos-FD	0.17	0.85	0.70	0.87	1.77	0.98	1.09	1.08
62	DSBT2	Brazos-FD	0.13	0.86	0.77	0.89	1.83	0.92	1.16	0.98
63	DLLT2	Brazos-FD	0.69	0.67	0.92	0.91	0.75	0.71	0.83	0.87
64	PCTT2	Brazos-FD	0.79	0.85	0.85	0.95	0.85	0.86	1.00	0.99
65	HMLT2	Brazos-FD	0.82	0.96	0.91	0.96	1.04	0.99	1.16	1.00
66	HICT2	Brazos-FD	0.65	0.84	0.73	0.87	0.85	0.99	0.83	1.09
67	CTNT2	Brazos-FD	0.54	0.90	0.83	0.91	0.68	0.98	0.72	1.00
68	VMAT2	Brazos-FD	0.94	0.93	0.97	0.99	0.95	0.97	0.99	1.06
69	CRFT2	Brazos-FD	-0.11	0.80	0.65	0.82	1.05	0.97	2.06	1.07
70	MCGT2	Brazos-FD	0.67	0.81	0.79	0.83	1.25	0.97	1.06	1.06
71	ACTT2	Brazos-FD	0.75	0.85	0.89	0.94	0.83	0.87	0.85	0.97
72	CUTT2	Colorado	0.46	0.57	0.63	0.73	1.39	0.66	0.96	0.96
73	LKCT2	Colorado	-4.77	0.12	0.73	0.75	5.42	1.74	4.69	1.41
74	HORT2	Colorado	-0.41	0.47	0.22	0.51	1.83	0.88	1.83	1.16
75	HDCT2	Colorado	-0.37	0.58	0.33	0.60	2.16	0.88	1.24	0.99
76	CJNT2	Colorado	0.06	0.85	0.82	0.92	1.59	1.10	1.71	1.09
77	LBWT2	Colorado	0.68	0.70	0.87	0.83	0.87	0.80	0.74	0.84
78	LBWT2U	Colorado								
79	BWDT2	Colorado	-0.68	-0.41	0.95	0.95	2.40	2.17	1.92	1.79
80	MIOT2	Nueces	-2.60	-0.16	0.28	0.26	4.49	0.46	1.46	0.29
81	SKMT2	Nueces	0.04	0.48	0.13	0.72	0.63	0.86	0.86	0.58
82	REFT2	Nueces	0.04	0.75		0.82		1.16		0.93

15. APPENDIX I – A NOTE ON UNDER-PERFORMING CALIBRATIONS

Hydrologic model calibration attempts to improve the performance of streamflow simulation through reasonable adjustments of the model parameters. While calibration generally yields significant improvements in model performance, it is not unusual for structural biases and errors in the model and forcing data to prevent satisfactory performance. One common source of error in hydrologic model simulations is the model forcing data. Though calibrations can compensate for minor errors in the forcing data (e.g., increasing evapotranspiration to offset forcing data that have too much precipitation), there are limitations to this, especially if the forcing data are too dry (it can be difficult to generate enough runoff if there is not enough precipitation). Further examination of the WGRFC MAPX data with respect to other gridded precipitation products is one approach that might be successful in identifying systematic biases and/or errors in the precipitation forcing data.

Another possible source of error in model calibration is in the streamflow data. Hydrologic model calibrations can only be as good as the observed streamflow data. Particularly at high flows, the stage-discharge relationships used to calculate streamflow may only be based on a handful of measurements. For record floods (e.g., Hurricane Harvey), USGS estimates of streamflow are completely reliant on professional judgement to extrapolate these curves beyond any field-based measurements. This is particularly true for gages with periods of record less than 10 years, or those most impacted by significant hydrologic non-stationarity due to upstream development or climate change. Continued support of the USGS stream gaging network by the State of Texas and TWDB will ensure that future model calibration efforts are based on well-measured streamflow with sufficiently long periods of record for model calibration (generally 10-20 years). Examples where USGS records limited calibration efforts during this project are noted throughout the report and include the Navasota River, portions of the Middle Guadalupe, and notably, Fort Hood, where insufficient streamflow records prevented model calibration altogether.

Lastly, other challenges in producing a well-verified simulation could relate to model structure. As a conceptual hydrologic model, SAC-SMA has proven to be a highly adaptable model that when well-calibrated, can produce accurate simulations across a range of landscapes and conditions. However, there are known limitations to the model which may contribute to poor performance in certain conditions or basins. One well-cited limitation of the SAC-SMA model is that it is generally considered ineffective for very small basins, especially under flashy conditions, where large soil moisture deficits need to first be overcome before surface runoff can be generated.

Lynker has employed best practices developed by the National Weather Service to work around these biases and errors, where present, and calibrate the models around them where able. Further improvement to poorly performing basins is a time-consuming and difficult prospect, with a potentially low return on investment, given the limitations of the model structure. While it is important to acknowledge these potential limitations of the calibration efforts, it is also imperative to note that the most valuable resource of any River Forecast Center is the in-house knowledge and expertise of the forecasters. It is the with great skill that these forecasters employ their professional judgement and adjust streamflow forecasts in real-time, as needed.

16. APPENDIX J – TWDB REPORT REVISIONS AND RESPONSES

Required Changes (submitted by TWDB – 3/1/2022)

Please recheck the document and correct typos such as the following (not exhaustive):

- Throughout report: please use "n" dash when denoting a time period (i.e., use 1990–2021 instead of 1990-2021).
  - *Response: Replaced all occurrences throughout the document*
- Page 9, Introduction, 1st numbered sentence, "1. Hydrologic runoff calibrations for 82 WGRFC basins" should be "1. Hydrologic runoff calibrations for 83 WGRFC basins.'"
  - *Response: Corrected - "83"*
- Page 10–12, Table 1-1 and other instances in the report, please use either "gauge" or "gage" and not both as currently used.
  - *Response: Replaced all "gage" occurrences with "gauge"*
- Page 42, 2nd paragraph, 2nd sentence, "in the table below und" should be "in the table below under."
  - *Response: Corrected - "under"*
- Page 45, Table 3-4, column heading "Based Used for Filling" should be "Basin Used for Filling."
  - *Response: Corrected - "Basin"*
- Page 56, Section 3.5. Potential Evapotranspiration, please spell out PIXML on first use and include it in the list of acronyms.
  - *Response: Revised to spell out acronym in section 3.5 - "Public Interface Extensible Markup Language" and added it to the list of acronyms*
- Page 56, Section 3.5. Potential Evapotranspiration, please spell out RDHM on first use.
  - *Response: Revised to spell out acronym in section 3.5 - "Research Distributed Hydrologic Model"*
- Page 56, Section 3.5. Potential Evapotranspiration, please spell out OHD on first use.
  - *Response: Revised to spell out acronym in section 3.5 - "Office of Hydrologic Development"*
- Page 57, Section 3.5. Potential Evapotranspiration, please spell out HRAP on first use.
  - *Response: Revised to spell out acronym in section 3.5 - "Hydrologic Rainfall Analysis Project"*
- Page 84, 1st paragraph, 2nd sentence, "Simulations for PICT2" should be "Simulations for KEMT2."
  - *Response: Revised with "KEMT2"*
- Page 102, 1st paragraph, 2nd sentence, "Simulations for RKDT2" should be "Simulations for RSAT2."
  - *Response: Revised with "RSAT2"*
- Page 107, 2nd paragraph, 1st sentence, "LAG/K modeling Decreased lag for low flow" should be "LAG/K modeling. Decreased lag for low flow."
  - *Response: Revised*
- Page 124, Figure 4-27 title, "Note the improvement timing" should be "Note the improvement of timing."
  - *Response: Revised*
- Page 191, 3rd paragraph, 2nd sentence, "overall PBIAS was very flow" should be "overall PBIAS was very low."
  - *Response: Revised*
- Page 193, 1st paragraph, 1st sentence, "Sabana River near De Leoni" should be "Sabana River near De Leon."
  - *Response: Revised*
- Page 255, Evaporation Data, please change the reference to a "daily gridded…product" to a "monthly gridded…product".
  - *Response: Revised with "monthly"*
- Page 292–295, Appendix G, please adjust the column width for Forecast Group so that "Guadalupe" is on one line.
  - *Response: Revised*

- Page 249, 1st paragraph, 6th sentence, "capacity of 38.094 acre-feet" should be "capacity of 38,094 acre-feet."
    - *Response: Revised with "38,094"*
- In section 1.1 of the report, please provide a list of the Fort Hood basins that were not calibrated (i.e., FHCT2, FCCT2U, FCCT2, FHGT2, FHHT2U, FHHT2).
    - *Response: These basins are now called out in the body of the text and also in Table 1-1*
- Page 14, Basin hydrography, Section 2.1. Land Cover, please include a summary of land cover types in the Colorado and Nueces forecast watersheds, similar to that included for the Brazos and the Guadalupe.
    - *Response: Additional text included in Section 2.1*
- Page 22, Basin hydrography, Section 2.2. Elevation & Slope, 1st paragraph, 3rd sentence, "most precipitation….is a result of frontal systems and large synoptic weather patterns rather than orographic uplift" is not quite correct. The Balcones Escarpment does induce orographic uplift. The Guadalupe and the lower Colorado basins are particularly impacted by such uplift (e.g., areas within these basins that lie in the flash flood alley).
    - *Response: Revised text in Section 2.2: The Balcones Escarpment does induce some orographic lift in the area—the Guadalupe and the lower Colorado basins are particularly impacted by such uplift, as these areas lie in the flash flood valley*
- Page 23, Basin hydrography, Section 2.3. Soil Classes, 1st paragraph, please include the spatial resolution of the dataset.
    - *Response: Revised text in Section 2.3 to include resolution: 10m grid resolution*
- Page 23, Basin hydrography, Section 2.3. Soil Classes, 2nd paragraph, please include clarification of the statement "soil classes generally trend from northeast to southwest".
    - *Response: Revised text in Section 2.3: In southeastern and central Texas, bands of similar soil classes generally trend from northeast to southwest, closely following the underlying geology of the state (Figure 2 12 to Figure 2 16)*
- Page 33, Basin hydrography, Section 2.4. Groundwater Recharge, 1st paragraph, 3rd sentence": please comment on whether the approach discussed is also likely to over-estimate recharge given that it does not account for groundwater pumping, given the assumption that there is no change in aquifer storage.
    - *Response: Revised text in Section 2.4 (paraphrased from Wolock (2003) : This approach to estimating groundwater recharge may underestimate recharge in areas where irrigation occurs extensively, areas with significant groundwater evapotranspiration (i.e., water table is located high enough for plant roots to be able to consume groundwater), or regions where near-stream groundwater pumping is significant. These factors can have a significant impact on groundwater storage which ultimately reduces the availability for groundwater discharge into nearby streams.*
- Page 33, Basin hydrography, Section 2.4. Groundwater Recharge, 1st paragraph, 3rd sentence": please clarify what "groundwater evapotranspiration" is.
    - *Please refer to the USGS metadata description provided here: https://water.usgs.gov/GIS/metadata/usgswrd/XML/rech48grd.xml. Our interpretation of "groundwater evapotranspiration" is evaporation and transpiration that occurs in the zones where groundwater is near the ground surface (e.g. wetlands). Under these conditions, the water table is located high enough for plant roots to be able to consume groundwater.*
- Page 54, Table 3-10, Please provide units for the precipitation data (e.g., average inches of precipitation per year).
    - *Response: Revised caption → Table 3 10: Comparison of average annual precipitation (inches per year):PRISM data and WGRFC MAPX data for the 2000–2020 period.*
- Please clarify or reconcile the following two conflicting statements regarding the range KGE scores. Page 72, 4th paragraph, 5th sentence: "KGE values can range from negative infinity to a perfect score of one." Page 75, description of Gage Plots, 4th sentence: "the KGE score … with values ranging from 0 to a perfect value of 1.
    - *Response: Text added: "While it is possible for KGE scores to be less than 0 (possible ranges include negative infinity to 1), values less than 0 (very poor performance) are displayed on the Gauge Plots as 0."*

- Please provide a section in the report that describes of the project deliverables in the folder "supplemental_materials." This can be very concise, one to two pages. It does not need to list out every file, just the general contents of the directories.
  - *Response: Please refer to the new Appendix A in the revised calibration report. Appendix A now provides an overview of the folders and content in the Google Drive "\supplemental_materials". The README.txt in the Google Drive folder also contains the same information.*

Suggested Changes

- List of Figures and Tables, pages ii-vii, suggest using two columns so that the page numbers and text do not overlap.
  - *Response: Updated these tables to enforce a right indent spacing between the text and page numbers for better readability*
- Page 13. The link for the land cover data used for this report is incorrect or out-of-date. Please provide the correct link. → Land cover: 2016 National Land Cover Database (Homer et al, 2015), Available online at http://www.mrlc.gov/nlcd2011.php
  - *Response: Updated hyperlink: https://www.mrlc.gov/data/nlcd-2016-land-cover-conus*
- A number of SAC-SMA model acronyms used in the report are not included in the list of acronyms (page viii) or Table 4-1 (page 69) (for example: ADIMP, PBASE, PCTIM, RESERV, RIVA, and UNIT-HG). A comprehensive table or list with definitions of all SAC-SMA model acronyms used in the report would be very helpful.
  - *Response: Added new "Additional NWS Model Acronyms and Abbreviations" table below the existing acronym table*
- Page 74, Figure 4-4 suggests there are still a handful of "clunkers" (KGE score < 0.5). Does Lynker have any suggestions on what should be done with these (e.g., further investigation, identify diversions, etc.) or is that to be expected?
  - *Response: Appendix I, "A Note on Under-Performing Calibrations", was added as a discussion on these poorly performing model calibrations.*
- The following figures would benefit from a legend or further description in the titles.
  - Page 76, Figure 4-6, Not clear what black, blue, and dark green lines represent.
    - *Response: Figure caption has been revised.*
  - Page 105, Figure 4-18, Not clear what black line represents.
    - *Response: Figure caption has been revised.*
  - Page 107, Figure 4-19, Not clear what black line represents.
    - *Response: Figure caption has been revised.*
  - Page 201, Figure 4-55, Not clear what any of the lines represent. Also needs a vertical scale with units.
    - *Response: Figure caption has been revised, and a vertical scale was added to the figure.*
  - Page 203, Figure 4-56, Not clear what any of the lines represent. Title of vertical axis is partially clipped off.
    - *Response: Figure caption has been revised, and the figure was replaced with a new screenshot capturing the full y-axis label.*
  - Page 207, Figure 4-58, Not clear what any of the lines represent.
    - *Response: Figure caption has been revised, and a the figure was replaced with a full CHPS screenshot.*
  - Page 209, Figure 4-59, Not clear what any of the lines represent.
    - *Response: Figure caption has been revised, and a the figure was replaced with a full CHPS screenshot.*
- A consistent color scheme on figures would make them easier to interpret. For example, the following figures use different color schemes for the same data:
  - Page 76, Figure 4-6, Initial (red) and calibrated (lime green)

- Page 82, Figure 4-9, Initial (blue) and calibrated (green)
  - *Response: Because each basin includes streamflow from a varying number of upstream basins (i.e., "routed" flows), and the screenshots in this report are from different CHPS plots, it is not always possible for consistent color schemes to be used throughout the report. This feature is hard-wired into CHPS. For simpler plots (e.g., "QIN_GAGE" plots), it is generally the case that initial simulations are in dark blue, and calibrated simulations are in dark green. However, figure captions delineate these color schemes, as appropriate.*

- Suggest making the following figures more readable with the following changes:
  - *Response: We have attempted to improve the readability of the following figures by increasing the figure sizes. Note that these figures are screenshots taken from the CHPS interface, and unfortunately, it is not always possible to improve the resolution or font sizes.*
    - Page 76, Figure 4-6, Please adjust the title on top, it appears to be partially cut.
    - Page 113, Figure 4-22, very difficult to read. Please consider enlarging figure.
    - Page 119, Figure 4-25, very difficult to read. Please consider adjusting scale/font size.
    - Page 124, Figure 4-27, very difficult to read. Please consider adjusting scale/font size.
    - Page 131, Figure 4-28, very difficult to read. Please consider adjusting scale/font size.
    - Page 217, Figure 4-63, very difficult to read. Please consider enlarging figure.
    - Page 260, Figures 5-11 and 5-12, very difficult to read. Please consider adjusting scale/font size.
    - Page 261, Figure 5-13, very difficult to read. Please consider adjusting scale/font size.
    - Page 263, Figures 5-15 and 5-16, very difficult to read. Please consider adjusting scale/font size.
    - Page 264, Figures 5-17 and 5-18, very difficult to read. Please consider adjusting scale/font size.
    - Page 265, Figure 5-19, very difficult to read. Please consider adjusting scale/font size.