CHAPTER 9
NECHES DAILY AND MODIFIED MONTHLY WAMS

A 2001 report prepared by a team of engineering firms for the Texas Natural Resources Conservation Commission (later renamed TCEQ) documents the original Neches WAM [88]. The original 1940-1996 hydrology was refined and extended through 2018 for TCEQ by a team of consulting firms [75]. Developmental Neches daily and modified monthly WAMs employing new SB3 EFS modeling features are documented by a 2020 report prepared at TAMU for TCEQ [9]. The updated daily and monthly WAMs with improved capabilities for simulating SB3 EFS discussed in this chapter include extending the hydrologic period-of-analysis through 2023.

Neches River Basin

The Neches River Basin delineated in Figures 9.1 and 9.2 is about 200 miles long with a drainage area of 10,000 square miles of which about one-third is drained by the Angelina River and two-thirds by the Neches River, Pine Island Bayou, and Village Creek. The Neches River discharges into the Sabine Lake Estuary near Port Arthur. Average annual rainfall ranges from less than 44 inches at the headwaters to over 54 inches in the lower basin. The location and size of the Neches Basin relative to the other major river basins are shown in Figure 9.1. The locations of the largest reservoirs and WAM primary control points are shown in the basin map of Figure 9.2.

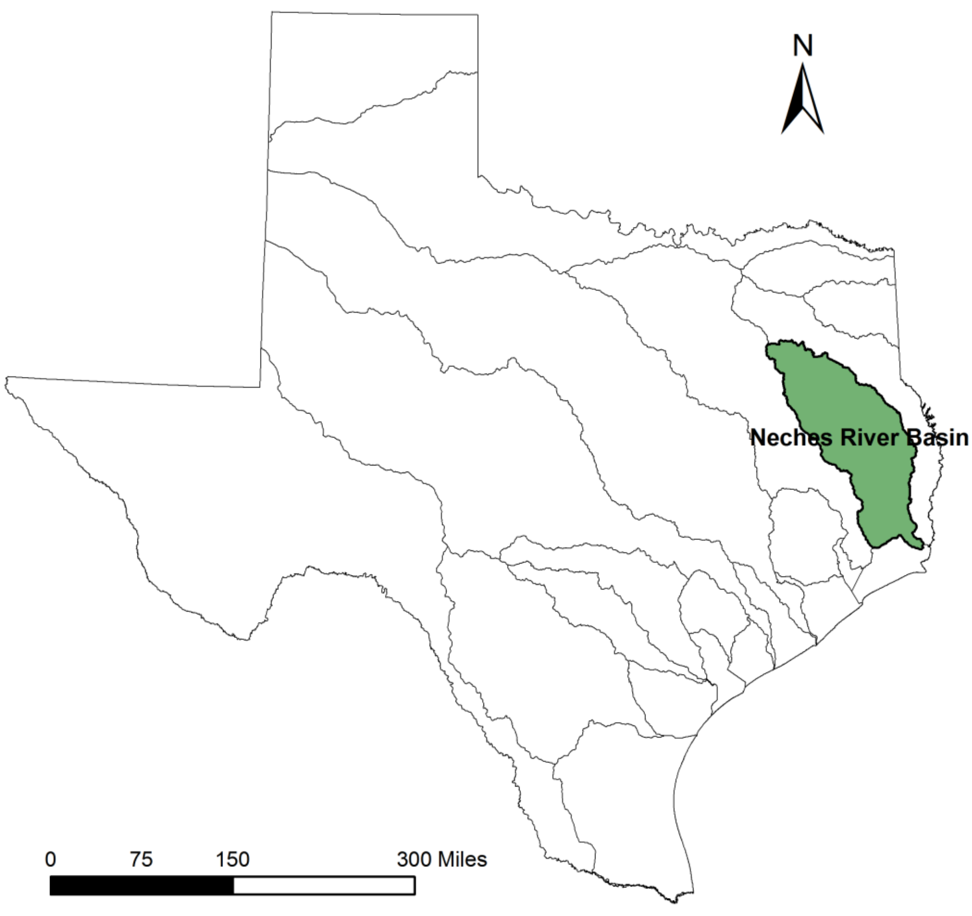

Figure 9.1 Location of Neches River Basin Relative to Other River Basins of Texas

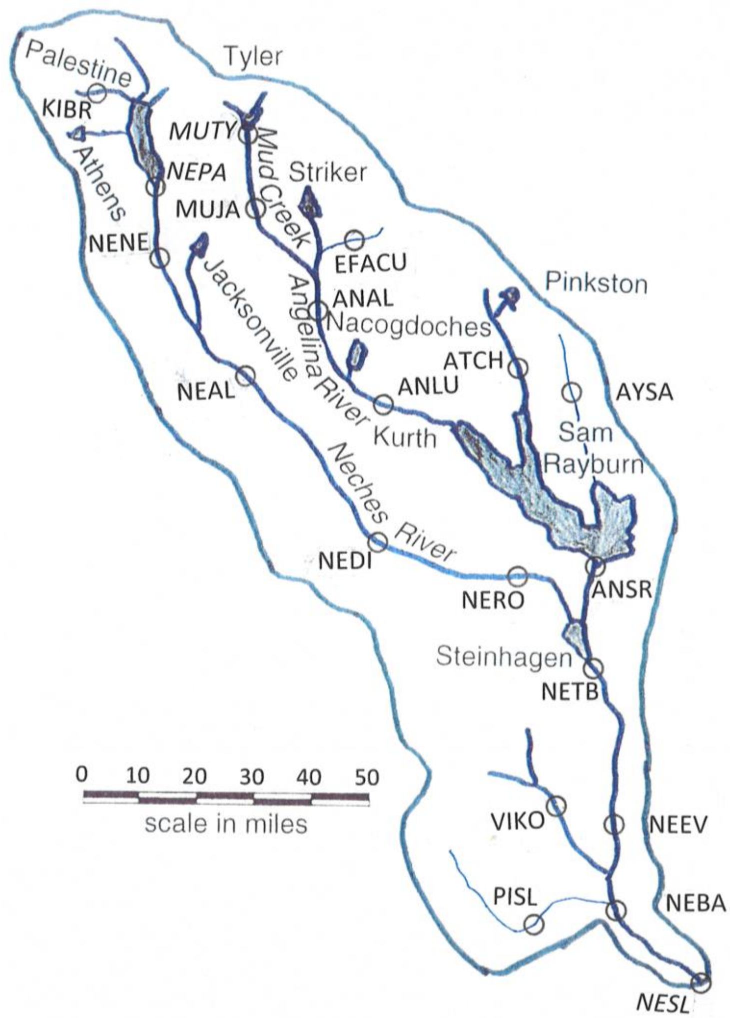

Figure 9.2 Largest Reservoirs and Primary Control Points

Counts of control points, water rights, and reservoirs in the Neches WAM and the other WAMs are compared in Tables 5.1 and 6.9 of Chapters 5 and 6. Daily, monthly, and annual means of observed flows of the Neches River at USGS gages near Rockland and Evadale (Table 4.7 and Figure 4.11, control points NERO and NEEV in Figure 9.2) are plotted in Figures B7 and B8 of Appendix B. Summations of the observed storage contents of the eight largest reservoirs in the Neches River Basin are plotted in Figures A3 and A31 of Appendix A. Period-of-record observed storage contents of Lakes Palestine and Sam Rayburn are plotted in Figures A15 and A16.

The 13 major reservoirs with at least 5,000 acre-feet of authorized storage capacity are listed in Table 9.1. The dates at which impoundment of water was initiated are tabulated in the fourth column. The authorized storage capacity and the storage capacity in the 2012 version of the current use scenario WAM are tabulated in the last two columns of Table 9.1. The 206 reservoirs in the full authorization Neches WAM have authorized storage capacities totaling 3,904,100 acre-feet. The 13 major reservoirs have a of total authorized storage capacity of 3,862,160 acre-feet, which is 98.9% of the total storage of the 206 reservoirs. Sam Rayburn Reservoir contains 74.2% of the total volume of authorized storage capacity in the Neches River Basin. Lake Palestine, the second largest reservoir in the basin, has 10.5% of the total authorized storage capacity.

Table 9.1
Major Reservoirs in the Neches River Basin

Reservoir	Dam	Stream	Initial Impound	Watershed Area (sq miles)	Conservation Capacity Authorized (acre-feet)	Conservation Capacity Current (acre-feet)
Sam Rayburn	Sam Rayburn	Angelina River	1965	3,449	2,898,200	2,898,200
Steinhagen	Town Bluff	Neches River	1951	7,573	94,250	66,972
Palestine	Blackburn Crossing	Neches River	1962	839	411,840	403,825
Tyler East	Mud Creek Dam	Mud Creek	1966	45.7	44,000	44,000
Tyler	Whitehouse Dam	Prairie Creek	1949	67.9	43,100	36,158
Athens	Athens	Flat Creek	1962	21.0	32,840	29,475
Jacksonville	Buckner	Gum Creek	1957	39.4	30,500	30,239
Striker	Striker	Striker Creek	1957	183	26,960	22,618
Kurth	Kurth (off-channel)	Angelina River	1961	4	16,200	14,600
Pinkston	Pinkston	Sandy Creek	1978	14.3	7,380	7,349
Nacogdoches	Loco	Bayo Loco Crk	1976	57.0	42,318	39,427
Naconiche	Naconiche	Naconiche Crk	−	28.1	9,072	9,072
Proposed Project Permitted but Not Yet Constructed						
Columbia	Columbia	Mud Creek	−		195,500	−

The U.S. Army Corps of Engineers (USACE) Fort Worth District (FWD) owns and operates Sam Rayburn Dam and Reservoir on the Angelina River and Town Bluff Dam and B. A. Steinhagen Reservoir on the Neches River for flood control, water supply, hydroelectric power generation, and recreation. The authorized storage capacity of Sam Rayburn Reservoir refers to the conservation pool storage capacity used for hydropower and municipal, industrial, and agricultural water supply. The flood control pool contains an additional 1,099,400 acre-feet of storage capacity that remains empty except during and following floods. The Lower Neches Valley Authority (LNVA) and City of Lufkin have contracted with USACE for water supply regulated by the two reservoirs. The LNVA is the primary nonfederal water supply sponsor. Water released through the hydropower turbines is diverted from the Neches River downstream for water supply.

B.A. Steinhagen Reservoir is located immediately downstream and functions as a re-regulation reservoir for Sam Rayburn Reservoir. The purposes of Steinhagen Reservoir are to re-regulate the intermittent power releases from Sam Rayburn Dam, provide head for hydroelectric power and diversion into a water supply canal, and provide some storage. Steinhagen Reservoir is operated to re-regulate the intermittent power releases from Sam Rayburn Dam for release as needed for municipal, industrial, and agricultural water supply diversions from the Lower Neches River for use in the adjoining Neches-Trinity coastal basin and lower Neches River Basin.

Lake Palestine and Blackburn Crossing Dam on the Neches River are owned and operated by the Upper Neches River Municipal Water Authority for municipal and industrial water supply and recreation. The City of Dallas in the upper Trinity River Basin has contracted with the Upper Neches River Municipal Water Authority for much of the storage in Lake Palestine. The City of Dallas in partnership with the Tarrant Regional Water Authority began construction in 2014 of a pipeline project for transporting water from Lake Palestine to the upper Trinity River Basin. Construction of the pipeline project is scheduled for completion in stages between 2018 and 2030.

Lakes Pinkston, Jacksonville, Nacogdoches, and Tyler are municipal water supply reservoirs owned and operated by the cities of Center, Jacksonville, Nacogdoches, and Tyler. Tyler Reservoir with two dams on two streams is treated in the WAM as two reservoirs. Lake Athens, owned by the Athens Municipal Water Authority, provides municipal water to the city of Athens in the Trinity River Basin. Striker Creek Reservoir, owned by the Angelina and Nacogdoches Counties Water Control and Improvement District No. 1, provides water for a steam-electric power plant and other industrial purposes. Lake Kurth is operated as an off-channel storage project for industrial water diversions from the Angelina River by Southland Paper Mills. Columbia Reservoir is included in the authorized use scenario WAM but is not included in the current use scenario WAM because, though authorized by a water right permit, the project has not yet been constructed.

Neches Monthly WAM Hydrology

The Neches WAM has 20 primary control points with naturalized monthly stream flow volumes provided on *IN* records and 12 sets of monthly reservoir net evaporation less adjusted precipitation depths stored on *EV* records [9, 75, 88]. Hydrologic periods-of-analysis for the original and updated versions of the WAM are shown in Table 6.9. The Neches WAM original simulation period of January 1940 through December 1996 [88] was refined and extended through December 2018 for the TCEQ by a team of consulting engineering firms [75]. A TCEQ-sponsored investigation at TAMU documented by the 2020 Neches Daily WAM Report [9] included extending the hydrologic period-of-analysis from January 1997 through December 2019. The period-of-analysis has been extended through December 2023 in conjunction with the present 2024 report. Alternative hydrology extension strategies are compared in this section of this chapter.

Monthly Naturalized Stream Flows

The Neches WAM original 1940-1996 hydrology was refined along with being extended through 2018 for the TCEQ through a consulting contract [75]. The 1940-2018 monthly naturalized flows from the official TCEQ WAM updated as described in the 2021 TCEQ consultant report [75] are adopted for the daily and modified monthly Neches WAMs presented later in this chapter along with the 2019-2023 *HYD* extension noted in the next paragraph.

The 1940-1996 sequences of *IN* and *EV* records have also been extended from January 1997 through December 2023 at TAMU using WRAP program *HYD* routines [4, 82]. The *HYD* hydrologic model for synthesizing monthly naturalized stream flows based on complex nonlinear regression with monthly precipitation and evaporation depths was calibrated using the original 1940-1996 naturalized flows and applied to generate 1997-2023 flows [4, 82]. The 2019-2023 *HYD* synthesized flows are adopted for the daily and modified monthly Neches WAMs. The 1997-2023 naturalized flows synthesized with *HYD* are included in comparative analyses.

TCEQ-sponsored research at TAMU documented by a 2020 daily Neches WAM report [9] included extending the hydrologic period-of-analysis through December 2019. The original 1940-1996 dataset of *IN* and *EV* records was adopted without modification. Monthly naturalized flows (*IN* records) and net evaporation-precipitation depths (*EV* records) for 1997-2019 were developed as explained in 2014 and 2020 reports [82, 9]. The naturalized flow extension for the 2020 Neches daily and modified monthly WAMs was different than for the other five case studies. *IN* record monthly naturalized flows were extended for the five other case study WAMs independently of

DF record daily flow pattern hydrographs. Daily naturalized flows are computed within *SIMD* by disaggregation of monthly naturalized flows in proportion to daily flow pattern hydrographs input on *DF* records. The 2020 daily Neches WAM report [9] describes a reversal of this process. Daily naturalized flows for the Neches WAM were developed first by approximate adjustments to daily observed flows. Monthly naturalized flows were then developed as the summation of daily naturalized flows. Compilation of *DF* records of daily flows is discussed later in this chapter.

Three alternative datasets of monthly naturalized flows (*IN* records) described in the three preceding paragraphs are compared in Tables 9.2-9.7 and Figures 9.3-9.6. These three variations of WAM naturalized flows are represented by the first, second, and third sets of statistics in the Tables 9.2-9.7. The legend for the plots of Figures 9.3-9.6 is shown in parenthesis in the list below.

1. TCEQ 2021 WAM 1940-2018 naturalized flows [75] and *HYD* 2019-2023 extension. This dataset is adopted for the daily and modified monthly WAMs. (blue solid line)
2. Original 2001 WAM 1940-1996 hydrology without modification [88] and WRAP program *HYD* 1997-2023 extension. (red dotted line)
3. Original 2001 WAM 1940-1996 hydrology without modification [88] and the 1997-2019 extension described in the 2020 Neches Daily WAM Report [9]. (green dashed line)

Monthly naturalized flows at control points NERO and NEEV from the three alternative datasets described above are compared in Tables 9.2-9.7 and Figures 9.3-9.6. Control points NERO and NEEV represent USGS gages on the Neches River near Rockland and Evadale, which are listed in Table 4.7 of Chapter 4 with locations shown in Figures 4.11 and 9.2. These gage sites have watershed areas of 2,398 and 7,885 square miles. The three hydrology datasets labeled 1, 2, and 3 above are likewise labeled 1, 2, and 3 in Tables 9.2-9.7. Flows of the Neches River at the USGS gage near Evadale (Figure 9.2) are heavily regulated by Sam Rayburn and B.A. Steinhagen Reservoirs (Table 9.1). Flows of the Neches River at the USGS gage near Rockland are only minimally affected by water resources development, regulation, and use.

The three alternative sequences of naturalized flows at control points NERO and NEEV are plotted in Figures 9.3-9.6. Figures 9.3 and 9.5 cover the entire 1940-2023 period-of-analysis. Figures 9.4 and 9.6 focus on the extension period. The original 1940-1996 flows (Table 9.2) are identical in the second and third datasets, but the first dataset reflects revisions from the original WAM. The 1997-2018 flows (Table 9.3) differ between all three datasets. The first and second datasets includes the same 2019-2023 extension (Table 9.4) developed with WRAP program *HYD*.

The Neches WAM original 1940-1996 hydrology was updated along with adding the 1997-2018 extension as documented in the 2021 TCEQ consultant contract report [75]. The 1940-1996 naturalized flows were revised. The 1940-1996 evaporation-precipitation depths were revised more than the flows in the 2021 report [75] dataset as discussed later in this chapter.

The *HYD* flow extension model was calibrated for each of the twenty primary control points in the Neches WAM using the original 1940-1996 naturalized flows and TWDB precipitation and evaporation depths. The number of TWDB quadrangles used in the hydrologic model ranged from one for upstream control points to eight quadrangles for the most downstream control points [82]. The twenty calibrated models were applied to synthesize naturalized flows initially for 1997-2012 [82] and later in conjunction with this 2024 report for 1940-2023.

Table 9.2
Statistics for 1940-1996 Monthly Naturalized Flows at Rockland Gage on Neches River

1940-1996 Monthly Flow Statistic in acre-feet	1 2021 Update [75]	2 2001 Original [88]	3 2001 Original [88]
median (acre-feet)	79,620	79,620	79,620
mean (acre-feet)	149,784	149,784	149,784
minimum (acre-feet)	0.0	0.0	0.0
maximum (acre-feet)	1,470,738	1,470,738	1,470,738
standard deviation (ac-ft)	182,340	182,340	182,340

Table 9.3
Statistics for 1997-2018 Monthly Naturalized Flows at Rockland Gage on Neches River

1997-2018 Monthly Flow Statistic in acre-feet	1 2021 Update [75]	2 Program *HYD*	3 2020 Report [9]
median (acre-feet)	79,940	74,811	78,751
mean (acre-feet)	164,203	150,568	159,959
minimum (acre-feet)	1,111	0.0	10.0
maximum (acre-feet)	1,035,093	1,097,022	984,545
standard deviation (ac-ft)	193,734	194,609	191,171

Table 9.4
Statistics for 2019-2023 Monthly Naturalized Flows at Rockland Gage on Neches River

2019-2023 Monthly Flow Statistic in acre-feet	1 2024 Adopted	2 Program *HYD*	3 2020 Report [9]
median (acre-feet)	89,108	89,108	-
mean (acre-feet)	158,635	158,635	-
minimum (acre-feet)	0.0	0.0	-
maximum (acre-feet)	908,871	908,871	-
standard deviation (ac-ft)	185,298	198,895	-

The first variation of *IN* record dataset of naturalized stream flows listed in the tables above was adopted for the daily and monthly WAMs presented later in this chapter. The latest 1940-2018 naturalized stream flows at 20 primary control points in the official TCEQ Neches WAM are extended through 2023 with *IN* records developed with program *HYD* in conjunction with the study reported in this 2024 report. The statistics in Tables 9.2-9.7 and the time series plots of Figures 9.3-9.6 provide comparisons of temporal variability of monthly naturalized flows over different time periods as well as comparisons between the alternative naturalized monthly stream flow datasets compiled employing different computational methods.

Table 9.5
Statistics for 1940-1996 Monthly Naturalized Flows at Evadale Gage on Neches River

1940-1996 Monthly Flow Statistic in acre-feet	1 2021 Update [75]	2 2001 Original [88]	3 2001 Original [88]
median (acre-feet)	231,371	220,026	220,026
mean (acre-feet)	391,498	381,354	381,354
minimum (acre-feet)	2,809	3,406	3,406
maximum (acre-feet)	3,061,346	3,061,346	3,061,346
standard deviation (ac-ft)	426,309	429,030	429,030

Table 9.6
Statistics for 1997-2018 Monthly Naturalized Flows at Evadale Gage on Neches River

1997-2018 Monthly Flow Statistic in acre-feet	1 2021 Update [75]	2 Program *HYD*	3 2020 Report [9]
median (acre-feet)	235,178	169,328	227,920
mean (acre-feet)	419,147	376,157	398,614
minimum (acre-feet)	17,499	1,364	0.0
maximum (acre-feet)	2,340,759	2,276,025	2,404,688
standard deviation (ac-ft)	432,167	472,316	432,686

Table 9.7
Statistics for 2019-2023 Monthly Naturalized Flows at Evadale Gage on Neches River

2019-2023 Monthly Flow Statistic in acre-feet	1 2024 Adopted	2 Program *HYD*	3 2020 Report [9]
median (acre-feet)	216,202	216,202	-
mean (acre-feet)	386,577	386,577	-
minimum (acre-feet)	1,436	1,436	-
maximum (acre-feet)	2,118,078	2,118,078	-
standard deviation (ac-ft)	434,845	434,845	-

Integer Labels for Datasets in Tables 9.2-9.7 and Legend for Figures 9.3-9.6 and 9.14-9.15

blue solid line - 1. TCEQ 2021 WAM 1940-2018 flows and *HYD* 2019-2023 extension.

red dotted line - 2. Original 2001 WAM 1940-1996 flows and *HYD* 1997-2023 extension.

green dashed - 3. Original 2001 WAM 1940-1996 flows and the 1997-2019 extension described in the 2020 Neches Daily WAM Report [9].

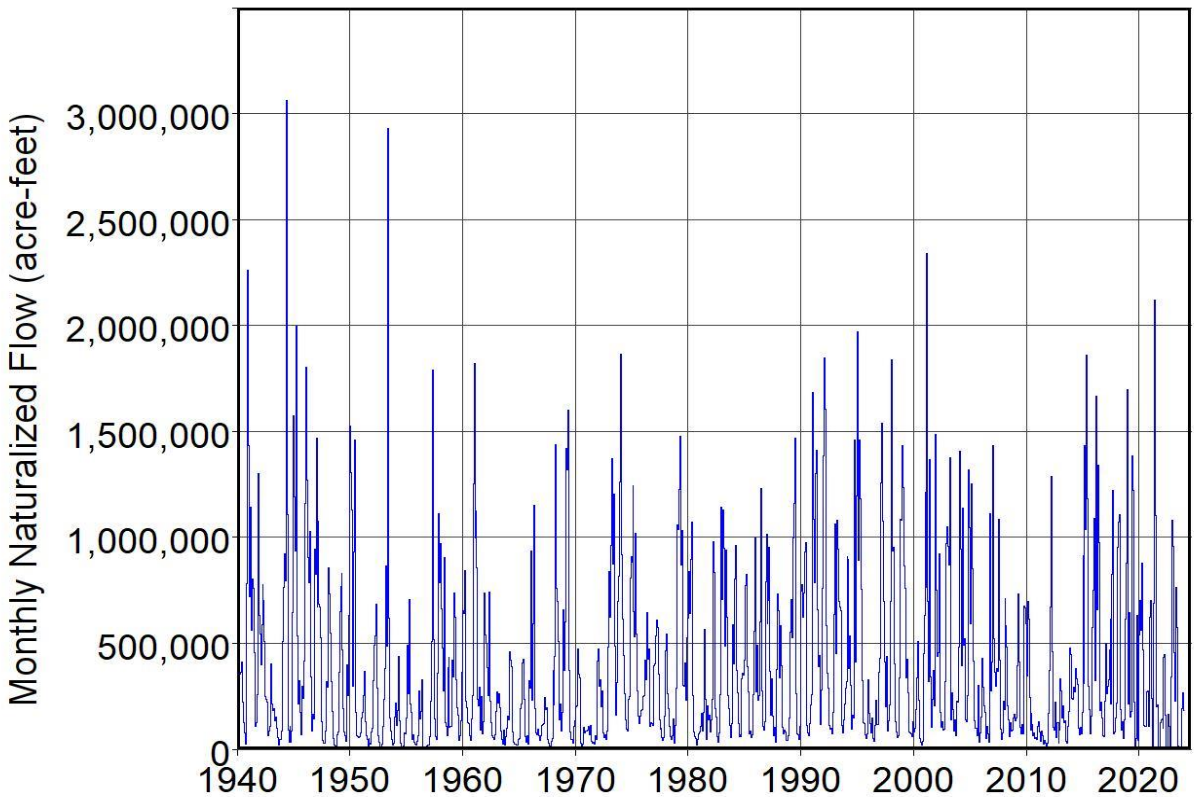

Figure 9.3 Monthly 1940-2023 Naturalized Flows of Neches River Near Evadale (NEEV)

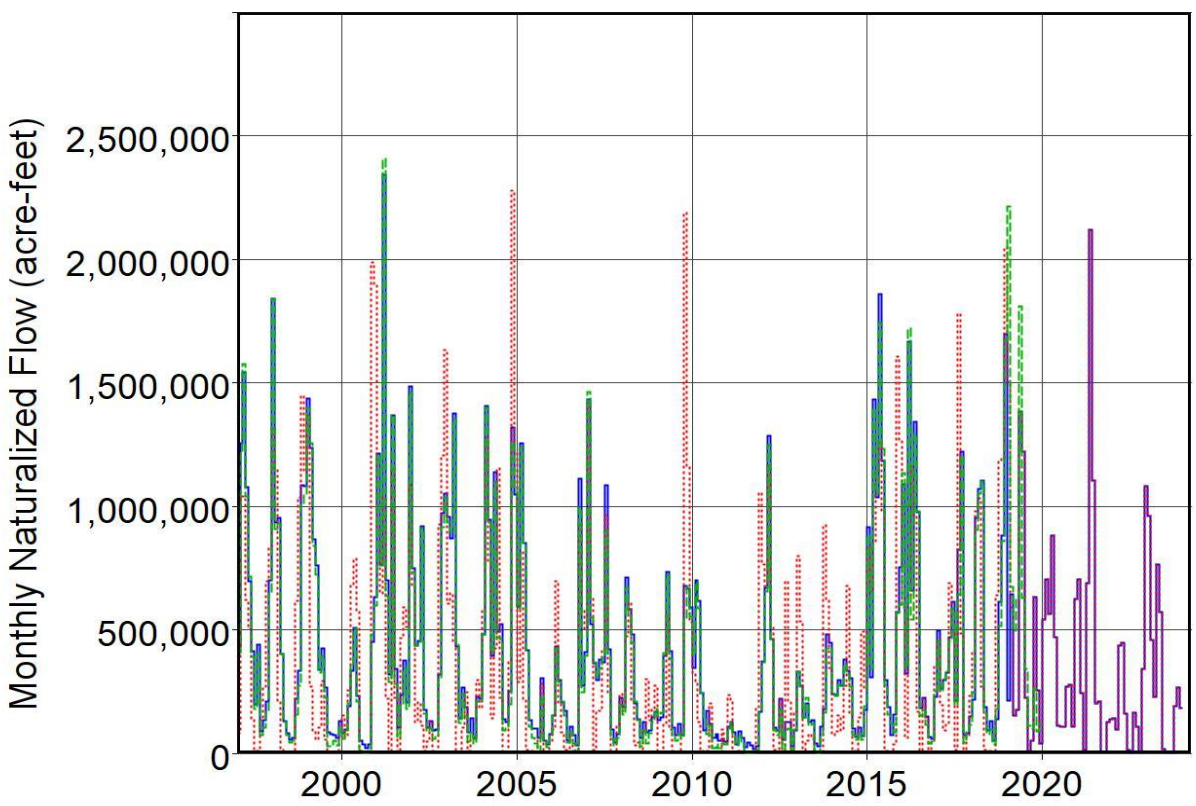

Figure 9.4 Monthly 1997-2023 Naturalized Flows of Neches River Near Evadale (NEEV)

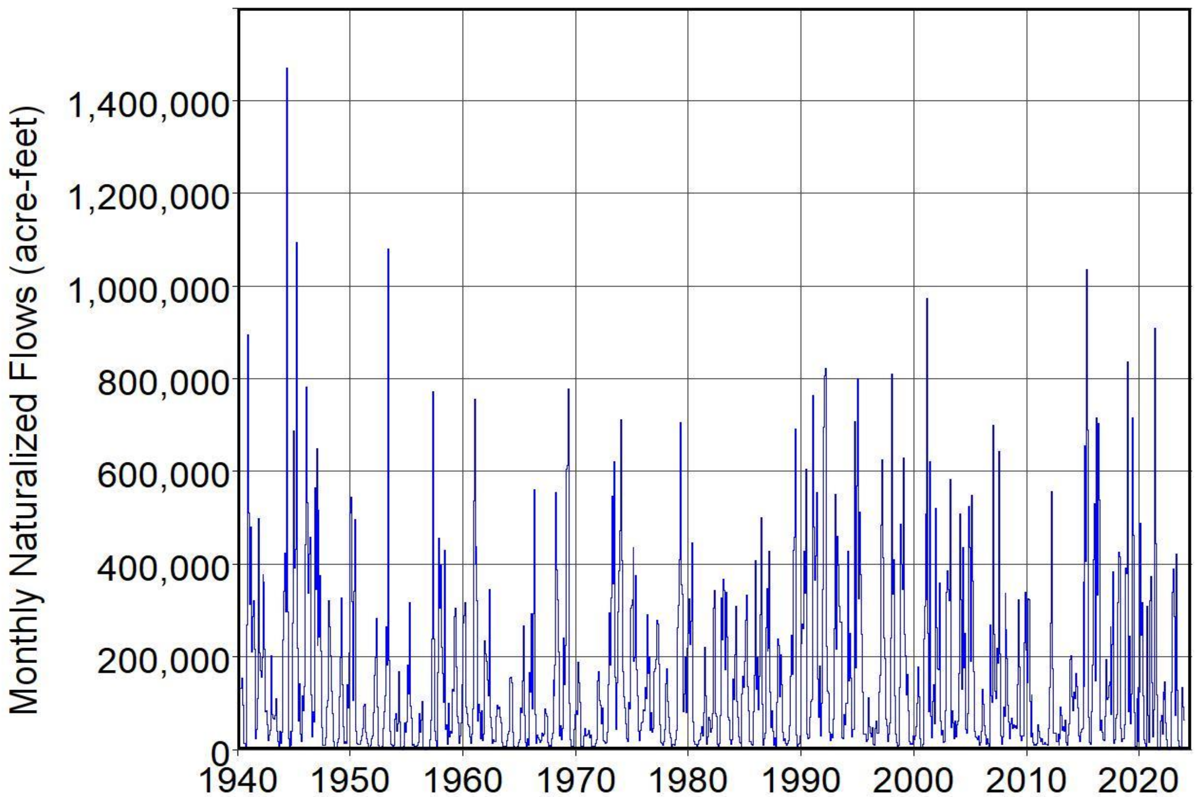

Figure 9.5 Monthly 1940-2023 Naturalized Flows of Neches River Near Rockland (NERO)

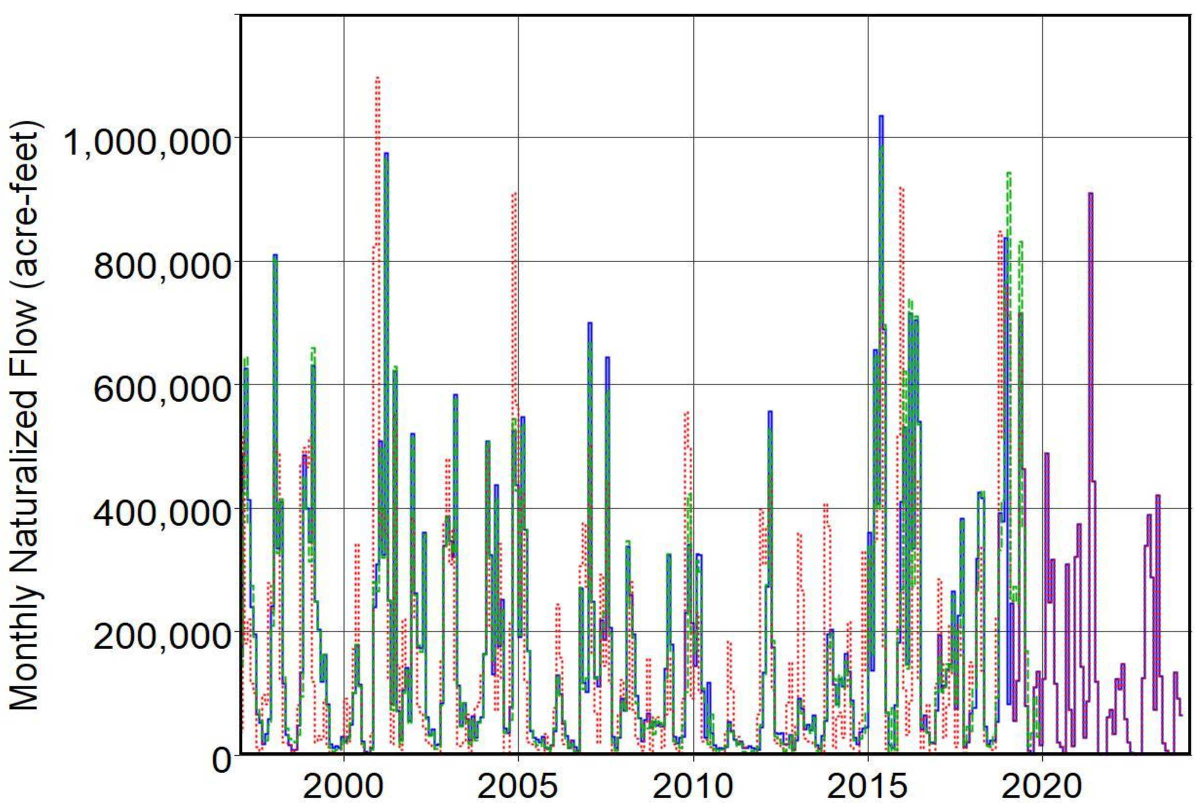

Figure 9.6 Monthly 1997-2023 Naturalized Flows of Neches River Near Rockland (NERO)

The 1940-2018 naturalized flows compiled as described in the 2021 Neches WAM Update Report [75] based on conventional methods for converting observed flows to naturalized flows conceptually should be the most accurate of the alternative sequences presented. This stream flow sequence is plotted as a **blue solid line** in the Figures 9.3-9.6 and labeled as alternative dataset 1 in Tables 9.2-9.7. Naturalized flows derived from the strategy of approximate adjustments of daily observed flows (alternative 3, **green dashed line**) explained in the 2020 Daily WAM Report [9] replicates the conventional approach (alternative 1, blue solid line) reasonably closely (Tables 9.3 and 9.6 and Figures 9.3 and 9.5).

The 2019-2023 naturalized flow extension using the WRAP program *HYD* is particularly relevant since the years 2022 and 2023 were unusually hot and dry, reflecting drought conditions. Program *HYD* can be applied again in 2025 upon TWDB completion of updating the precipitation and evaporation database through December 2024. However, relatively normal conditions of rainfall and stream flow have occurred during 2024. Thus, a later extension through 2024 will not be as significant as the 2019-2023 *HYD* extension in regard to assessing water availability and supply reliability which are governed largely by multiple-year drought conditions. Effects of alternative hydrology extension strategies on reservoir storage volumes are explored later.

Monthly Net Evaporation-Precipitation Depths

The Neches WAM includes twelve sets of *EV* record monthly net evaporation less adjusted precipitation depths. The TWDB database of monthly precipitation and reservoir evaporation depths was used to develop the original and updated *EV* records. Area-weighted averages of data for the quadrangles shown in Figure 9.7 were employed. Quadrangle 1940-2023 mean annual precipitation and 1954-2023 mean annual evaporation are shown in Figure 4.3 of Chapter 4.

Monthly evaporation and precipitation data for quadrangles 512, 513, 612, 613, 614, 712, 713, 714, 813, and 814 are employed in the original compilation and later extensions of hydrology for the Neches WAM. Annual and monthly means for each of the 12 months of the year for precipitation, reservoir evaporation, and differences between evaporation minus precipitation are tabulated in the 2020 report [9] along with various data analyses.

As previously noted, the original 1940-1996 Neches WAM hydrology was refined and extended through 2018 for TCEQ by a team of consulting engineering firms [75]. Irregularities encountered in the computation of naturalized flows motivated an investigation of gross reservoir evaporation rates. Pan coefficients used by TWDB in computing reservoir evaporation rates during the 1940-1996 analysis period were concluded to perhaps result in inaccurate reservoir evaporation estimates. The original evaporation data were replaced with evaporation rates based on more recently determined pan coefficients. The revisions significantly affected the computed evaporation rates. The updated evaporation rate computations also included other revisions. Other smaller revisions to 1940-1996 monthly naturalized flows were also included in the update [75].

The twelve sets of *EV* records in the Neches WAM correspond to the locations of 12 largest reservoirs. The twelve *EV* record sequences of net evaporation less adjusted precipitation depths adopted as explained in the 2001 and 2020 reports [88, 9] and later hydrology extension discussed in this 2024 report are area-weighted averages of data from the TWDB database for the ten quadrangles shown in Figure 9.7. Weighting factors are shown in Table 6.2 of the 2020 report [9].

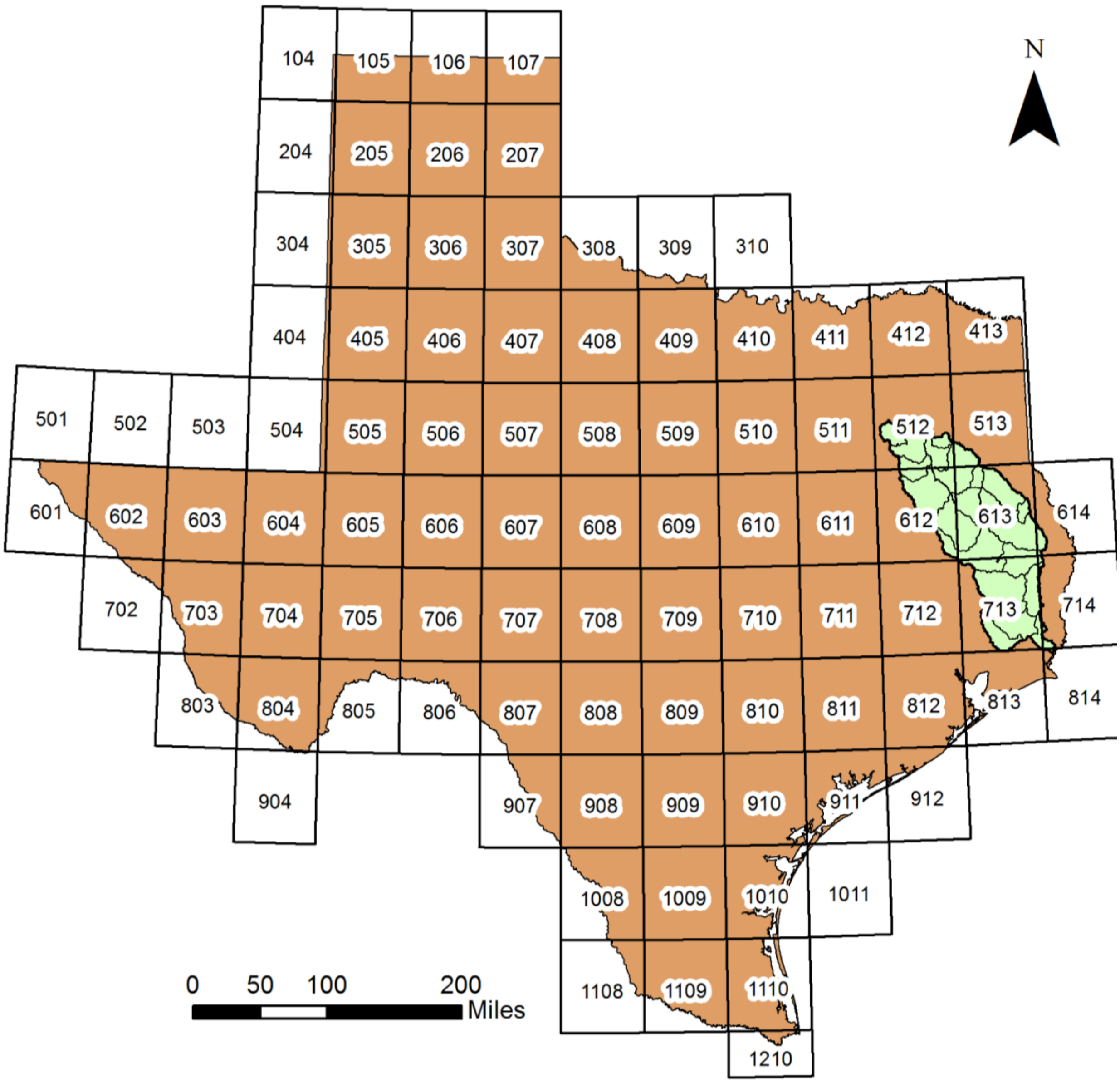

Figure 9.7 Quadrangles for TWDB Monthly Evaporation and Precipitation Databases

Adjustments to Prevent Double-Counting Precipitation

Naturalized stream flows reflect undeveloped conditions without reservoir projects and thus conceptually include some but not all the rain falling on the reservoir site. Adjustments are designed to prevent double-counting precipitation reflected in both *EV* and *IN* record quantities. Several of the WAMs have pre-adjusted quantities recorded on the *EV* records. Other WAMs activate *SIM/SIMD* features for performing adjustments within the simulation. The original Neches WAM and previous updates reflect adjustments performed during compilation of the *EV* records. Alternatively, the *SIM/SIMD* internal adjustment computation is employed in this 2024 update.

The precipitation adjustments for the *EV* record net evaporation-precipitation depths in the original Neches WAM and later updates are based on Equation 5.2 of Chapter 5 with its multiplier factor. The factors developed for the original 1940-1996 dataset are not documented in detail in the original 2001 WAM report [9]. Precipitation adjustment factors in Table 6.3 of the 2020 report [9] are computed using known values of adjusted 1940-1996 net evaporation-precipitation from the original EVA file and computed values of precipitation and evaporation depths from the TWDB datasets and quadrangle weighting equations. Monthly multipliers in Table 6.3 of the 2020 report [9] are averages of the unique multipliers derived each year of the period-of-analysis.

Options activated by parameters EPADJ and EWA(cp) on the *JD* and *CP* records are designed to account for the portion of the precipitation falling on the reservoir water surface that is reflected in the naturalized stream flows [1, 2]. As discussed in Chapter 5, these options (Table 5.2) were expanded in the 2024 *SIM/SIMD* update. The *SIM/SIMD* EPADJ and EWA(cp) feature has not been employed in the past in the Neches WAM but is explored in this chapter. Simulations with and without *SIM/SIMD* EPADJ option 4 (Table 5.2) are compared. EPADJ option 4 is adopted for the daily and modified monthly WAM simulations performed later in this chapter.

An unadjusted version of the Neches WAM evaporation minus precipitation depths input on *EV* records combined with EPADJ option 4 (Table 5.2) *SIM/SIMD* adjustment computations are adopted for the daily and modified monthly WAM simulations performed later in this chapter. The precipitation adjustment is omitted from the quantities recorded on the *EV* records along with activating the optional built-in *SIM/SIMD* computational routine for performing adjustments.

<u>Comparison of Alternative Evaporation-Precipitation Depth Datasets</u>

Statistics for sequences of net evaporation less precipitation depths for Sam Rayburn Reservoir and Lake Palestine are tabulated in Tables 9.9 through 9.11. The evaporation-precipitation time series are plotted in Figures 9.8 through 9.16. The legend for the figures and labels used in the tables to identify the alternative datasets of evaporation-precipitation depths are defined in Table 9.8. Alternatives 2, 3, and 4 are viable alternative strategies for developing *EV* records. Alternative 1 is generated with a *SIM* simulation with dataset 4 provided as input.

Table 9.8
Dataset Labels for Tables 9.9-9.11 and Legend for Figures 9.8-9.13

Table Label	Description of Evaporation-Precipitation Dataset	Plot Legend
1	Original 1940-1953 *EV* records, unadjusted 1954-2023 *EV* records, and EPADJ option 4 adjustments (this 2024 report).	blue solid line
2	TCEQ 2021 WAM *EV* records with 1940-2018 extension and update described in 2021 report [75].	red dotted line
3	Original WAM 1940-1996 *EV* records and 1997-2019 extension employing factors described in 2020 report [9].	green dashed line
4	Unadjusted 1940-2023 *EV* record evap-precip depths that serve as *EV* record input for alternative 1 (this 2024 report).	black dotted line

A *SIM* simulation was required to obtain the first sequence of evaporation-precipitation depths in Table 9.8 because precipitation adjustment computations activated by parameter EPADJ on the *JD* record are computed in the simulation. Alternative evaporation-precipitation datasets 2, 3, and 4 (Tables 9.8-9.11) are read directly from *EV* records in the *SIM* input DSS file.

As illustrated by Figure 4.3 in Chapter 4, mean annual reservoir evaporation rates vary significantly spatially across Texas and mean annual precipitation varies dramatically. Mean evaporation greatly exceeds mean precipitation in the western half of the state. Mean precipitation exceeds evaporation in the Sabine River Basin and portions of the Neches River Basin. High rainfall throughout the Neches Basin means that precipitation adjustment methods are particularly relevant for the Neches WAM. Net evaporation-precipitation depths are positive in a month if evaporation exceeds adjusted precipitation and are negative if adjusted precipitation exceeds evaporation. Adjustments to prevent double-counting precipitation included in both *IN* record naturalized flows and *EV* record net evaporation-precipitation result in decreasing precipitation.

Table 9.9
Statistics for 1954-1996 Monthly Evaporation Less Adjusted Precipitation Depths

	Sam Rayburn Reservoir				Lake Palestine			
EV Alternatives	1	2	3	4	1	2	3	4
median (feet)	0.03379	0.1550	0.0500	-0.02383	0.1074	0.2350	0.1300	0.05358
mean (feet)	0.03853	0.1671	0.04953	-0.03377	0.1300	0.2770	0.1344	0.07008
minimum (feet)	-0.6793	-0.4700	-0.1800	-0.8525	-0.5598	-0.5000	-0.6500	-0.8441
maximum (feet)	0.6193	0.8900	0.6700	0.5227	0.7983	1.1800	0.8000	0.7782
standard deviation (ft)	0.2065	0.2309	0.2186	0.2417	0.2197	0.2848	0.2382	0.2533

Table 9.10
Statistics for 1997-2018 Monthly Evaporation Less Adjusted Precipitation Depths

	Sam Rayburn Reservoir				Lake Palestine			
EV Alternatives	1	2	3	4	1	2	3	4
median (feet)	0.06483	0.1800	0.1325	-0.008912	0.1258	0.2700	0.1448	0.07782
mean (feet)	0.05391	0.1947	0.1123	-0.02888	0.1440	0.3106	0.1561	0.08235
minimum (feet)	-1.1386	-0.6600	-0.7895	-1.3157	-0.5403	-0.3700	-0.6991	-0.7960
maximum (feet)	0.6280	0.9800	0.6789	0.6161	0.8300	1.2800	0.8118	0.8063
standard deviation (ft)	0.2452	0.2622	0.2326	0.2918	0.2389	0.3076	0.2403	0.2806

Table 9.11
Statistics for 2019-2023 Monthly Evaporation Less Adjusted Precipitation Depths

	Sam Rayburn Reservoir				Lake Palestine			
EV Alternatives	1	2	3	4	1	2	3	4
median (feet)	-0006415	0.2823	-	-0.04661	0.09303	0.1183	-	0.5600
mean (feet)	0.01820	0.03649	-	-0.06068	0.1261	0.1405	-	0.06197
minimum (feet)	-0.3235	-0.4881	-	-0.7833	-0.2380	-0.3224	-	-0.5888
maximum (feet)	0.5619	0.5730	-	0.5613	0.7149	0.7186	-	0.7149
standard deviation (ft)	0.1814	0.1936	-	0.2436	0.2145	0.2288	-	0.2736

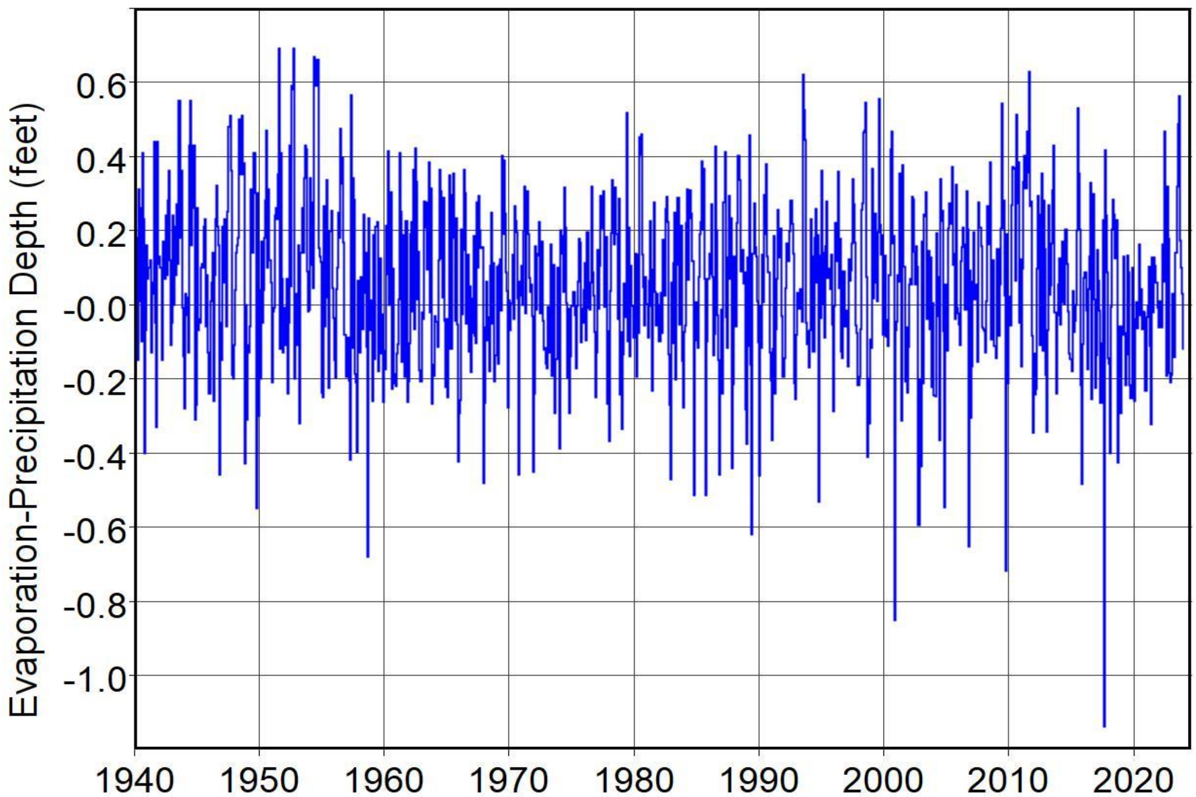

Figure 9.8 Dataset 1 Net Evaporation-Precipitation Depths for Sam Rayburn Reservoir

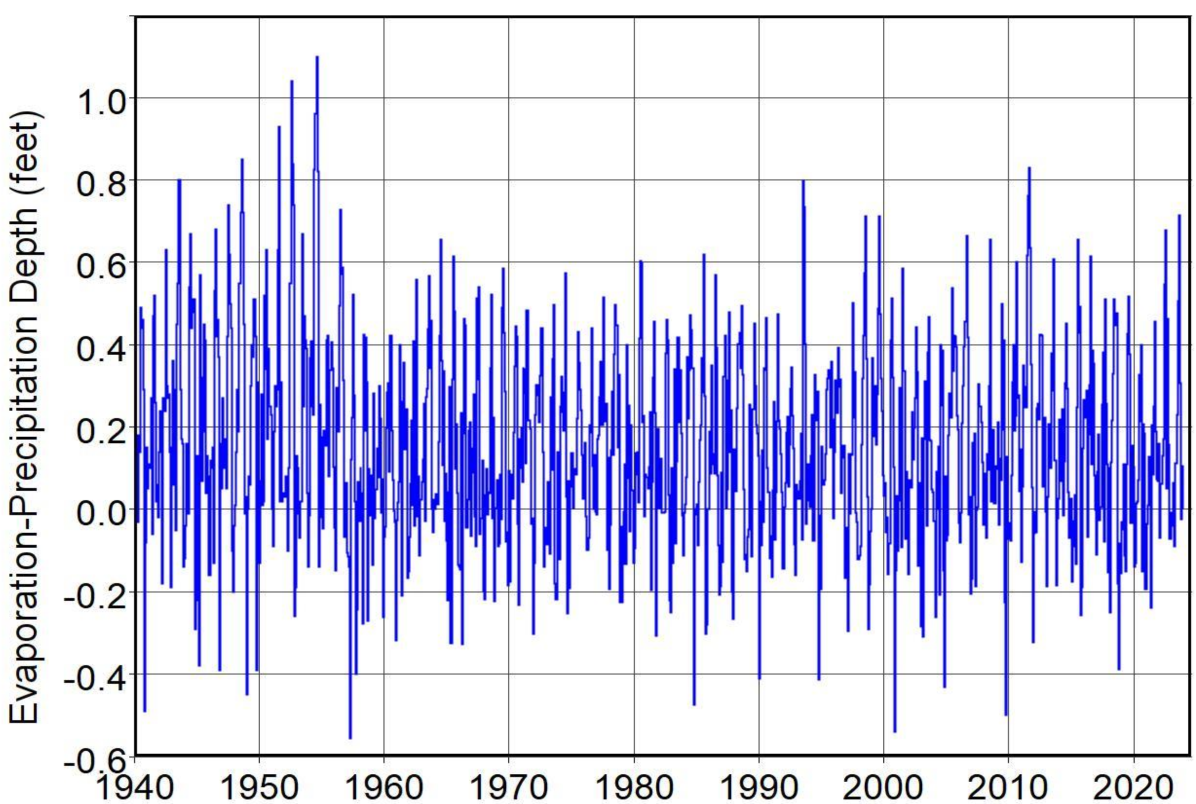

Figure 9.9 Dataset 1 Net Evaporation-Precipitation Depths for Lake Palestine

The evaporation-precipitation quantities for 1940-1953 are identical in all four alternative datasets. The online monthly reservoir evaporation database currently maintained by TWDB and employed in the WAMs includes data dating back to January 1954. Evaporation data for 1940-1953 has been compiled by TWDB differently than data after 1953.

Dataset 1 consists of quantities generated in a *SIM* simulation with dataset 4 incorporated in the *SIM* input data. As indicated in Table 9.8, alternative dataset 4 is comprised of the original 1940-1953 *EV* records and unadjusted 1954-2023 *EV* record evaporation-precipitation depths in feet stored in the *SIM/SIMD* time series input DSS file. Dataset 4 is input for a *SIM* simulation employing the new EPADJ option 4 and EPYEAR option on the *JD* record in the DAT file. The 1940-1953 *EV* record quantities reflect precipitation adjustments applied during compilation of the original 2001 Neches WAM [88]. The 1954-2023 portion of the monthly evaporation-precipitation depths on the *EV* records was compiled with program *HYD* simply subtracting precipitation depths from evaporation depths without activating *HYD* precipitation adjustment options. An entry of 1954 for EPYEAR on the *JD* record activates the *SIM* internal EPADJ feature for precipitation adjustments starting in January 1954 of the simulation. EPADJ option 4 is selected on the *JD* record. The new expanded precipitation adjustment options were added to *SIM* and *SIMD* in 2024.

Monthly 1954-2023 adjusted evaporation-precipitation depths from dataset 1 (Table 9.8) described in the preceding paragraph for Sam Rayburn Reservoir and Lake Palestine are plotted in Figures 9.8 and 9.9. Since EPADJ adjustments for 1954-2023 were applied within the *SIM* simulation computations, the sequences plotted in Figures 9.8 and 9.9 are from the *SIM* simulation results *DSS* output file created with variable EPD (DSSV=40) specified on the *OFV* input record.

Sam Rayburn Reservoir has the reservoir identifier RAYBRN and control point identifier 4411A1 in the Neches WAM. The WAM reservoir and control point identifiers for Lake Palestine are PALEST and 3254N1. Sam Rayburn is the largest reservoir located totally within Texas (Table 3.7 and Figure 3.2).

EV record dataset 4 defined in Table 9.8 was adopted for the daily and modified monthly WAMs discussed later in this chapter. With dataset 4 *EV* records in the *SIM* hydrology input DSS file, the quantities in dataset 1 are computed in the *SIM* simulation. The mean of the monthly adjusted evaporation-precipitation depths for Sam Rayburn Reservoir in dataset 1 during 1954-1996, 1997-2018, and 2019-2023 is 0.03853 feet, 0.5391 feet, and 0.01820 feet (Tables 9.9, 9.10, and 9.11). The 848 monthly evaporation-precipitation depths at Sam Rayburn Reservoir in dataset 1 (Table 9.8) during 1954-2023 range from a maximum of 0.6280 foot in August 2011 to a minimum of -1.1386 feet in August 2017 (Table 9.10).

The components of the net evaporation less adjusted precipitation depths at Sam Rayburn Reservoir during the months with the smallest and largest values of evaporation less adjusted precipitation depth in dataset 1 (Table 9.8) are compared in Table 9.12. The quantities in Table 9.12 are related as follows.

adjusted net evaporation-precipitation depth = evaporation – precipitation + adjustment

The *SIM* adjusted net evaporation-precipitation depth in feet is multiplied in *SIM* by the simulated beginning-of-month reservoir surface area in acres to obtain a volume in acre-feet. The monthly depths in Table 9.12 are shown in units of both feet and inches.

Table 9.12
Components of Adjusted Net Evaporation-Precipitation for Months
with Maximum and Minimum Final Depths in Dataset 1

Monthly Quantity	Final EP Maximum August 2011		Final EP Minimum August 2017	
	(feet)	(inches)	(feet)	(inches)
EV Record Quantity	0.61608	7.39	-1.31573	-15.79
Evaporation Depth	0.69921	8.39	0.43152	5.18
Precipitation Depth	0.08313	1.00	1.74725	20.97
Precipitation Adjustment	0.01197	0.14	0.17711	2.13
Final Evap-Precipitation Depth	0.62804	7.54	-1.13862	-13.66

The *SIM* and *SIMD* routine activated by EPADJ on the *JD* record to compute precipitation adjustments each month is described in Chapter 5 (pages 124-126) of this report and Chapter 3 of the *Reference Manual* [1]. The adjustment to remove a portion of the precipitation volume equivalent to the precipitation runoff volume reflected in the naturalized flow inflow to the reservoir in August 2011 and August 2017 are computed by *SIM* to be 0.01197 foot and 0.17711 foot, respectively (Table 9.12). The adjustment each month is computed in the simulation based on the naturalized flow at the control point of the reservoir, the watershed area above the reservoir control point, and the area of the reservoir water surface. The *SIM* computations are analogous to the traditional drainage area method for distributing stream flow from a gaged to ungaged site [1].

Simulated monthly adjusted evaporation less precipitation depths from dataset 1 of Tables 9.8-9.11 for Sam Rayburn Reservoir are plotted in Figures 9.8 and 9.9. The maximum and minimum depths during 1954-2023 of 0.62804 feet in August 2011 and -1.13862 feet in August 2017 are analyzed in Table 9.12 and can be seen in Figure 9.8. The adjusted net evaporation-precipitation depths during 1940-2053 were compiled differently than those during 2054-2023.

Sam Rayburn and Palestine sequences from datasets 1 (blue solid line) and 4 (green dotted line) defined in Table 9.8 are plotted in Figures 9.10 and 9.11. Another 1954-2023 series plotted in Figures 9.10 and 9.11 as purple dashes is comprised of only the evaporation depth component of the *EV* records of dataset 4. Precipitation depths are omitted in the purple dashed line. The differences between the evaporation-only plot and the other two plots is the omitted precipitation. The relative magnitudes of the components of adjusted evaporation-precipitation are illustrated.

Evaporation (evaporation-only) depths at Sam Rayburn Reservoir and Lake Palestine are plotted as purple dashed lines in Figures 9.10 and 9.11 as noted in the preceding paragraph. Evaporation from Sam Rayburn Reservoir ranges from 0.09812 feet (1.18 inches) in January 1966 to 0.6992 feet (8.39 inches) in August 2011, with a 1954-2023 mean of 0.3271 feet (3.93 inches). Evaporation from Lake Palestine ranges from 0.10040 feet (1.20 inches) in January 1974 to 0.8563 feet (10.28 inches) in August 2011, with a 1954-2023 mean of 0.3762 feet (4.51 inches).

Sam Rayburn and Palestine 1940-2023 sequences from evaporation-precipitation datasets 1 (blue solid line) and 2 (red dotted line) defined in Table 9.8 are plotted in Figures 9.12 and 9.13.

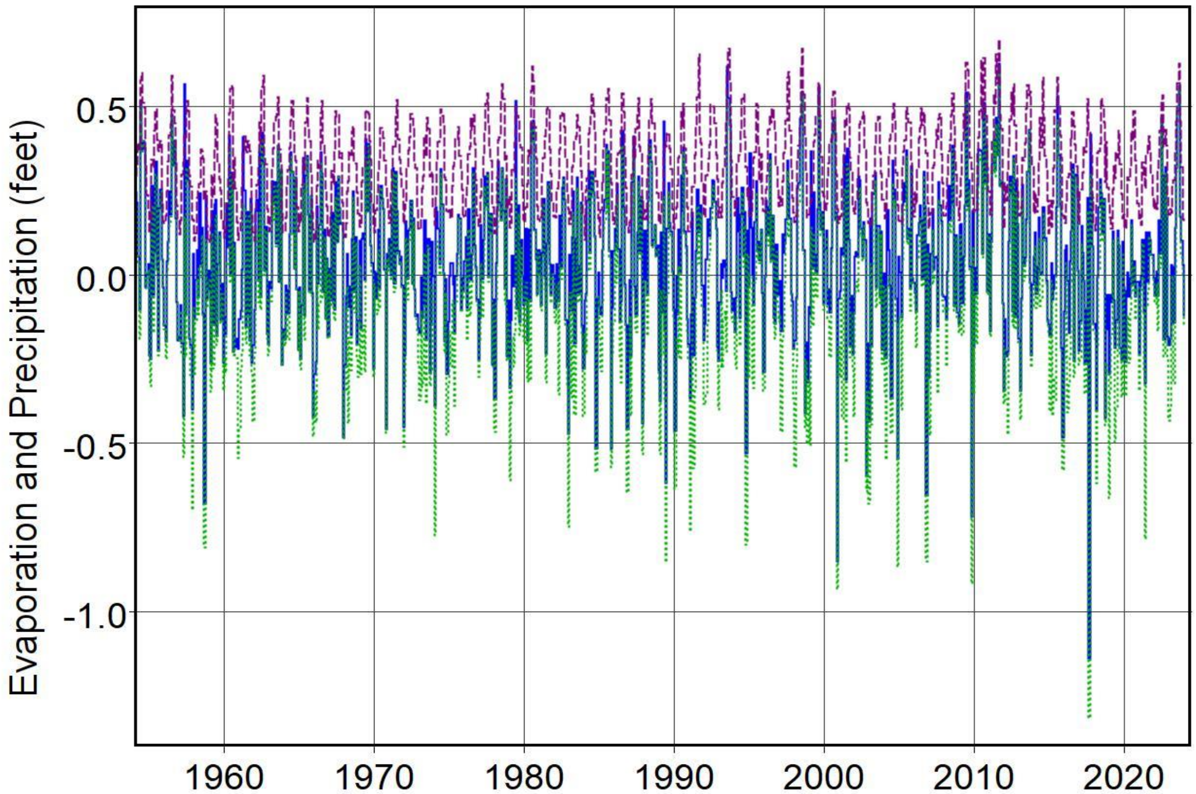

Figure 9.10 Datasets 1 and 4 (Table 9.8) and Evaporation-Only (purple dashes) at Sam Rayburn

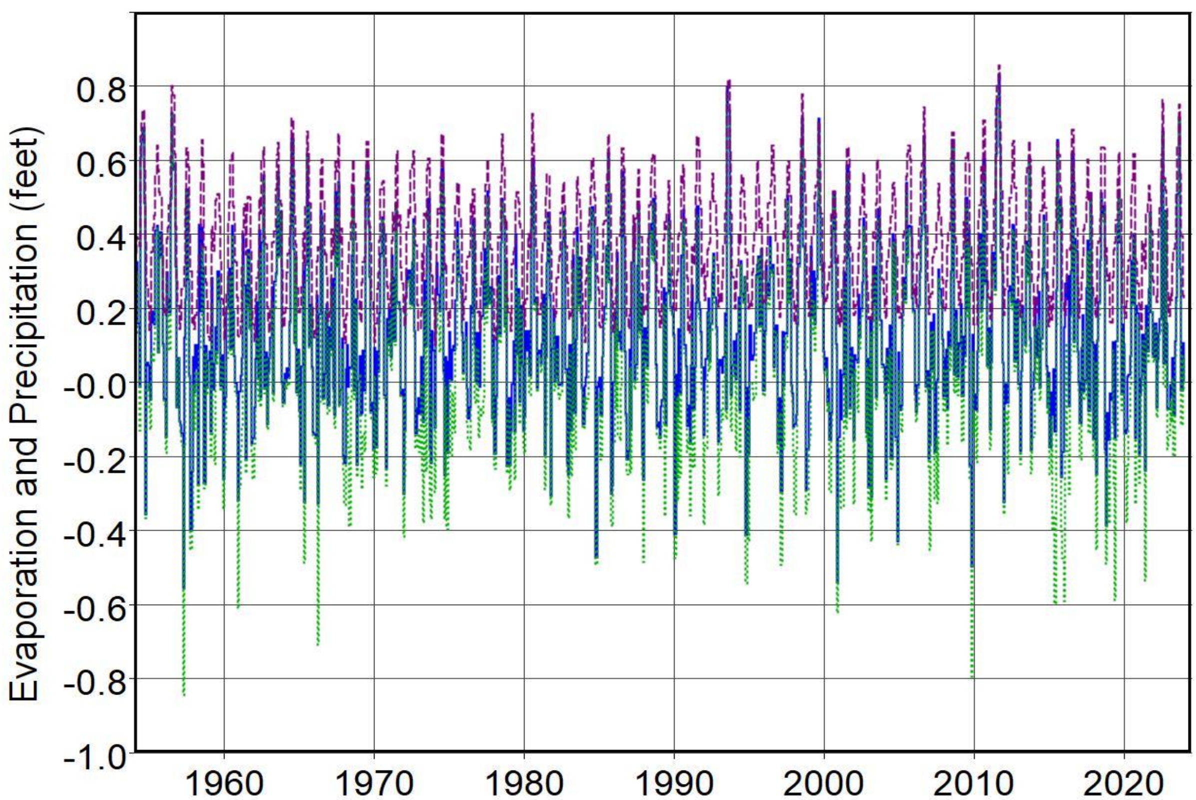

Figure 9.11 Datasets 1 and 4 (Table 9.8) and Evaporation-Only (purple dashes) at Lake Palestine

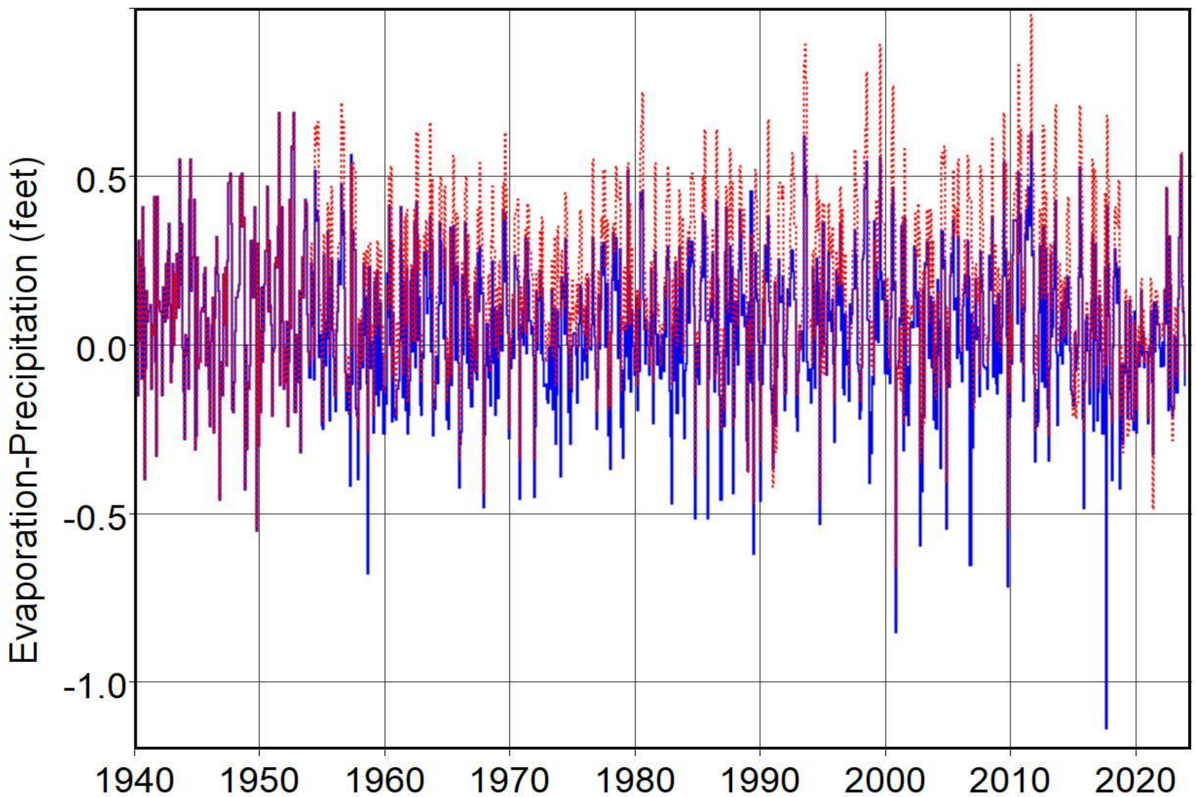

Figure 9.12 Evaporation-Precipitation Datasets 1 and 2 (Table 9.8) at Sam Rayburn Reservoir

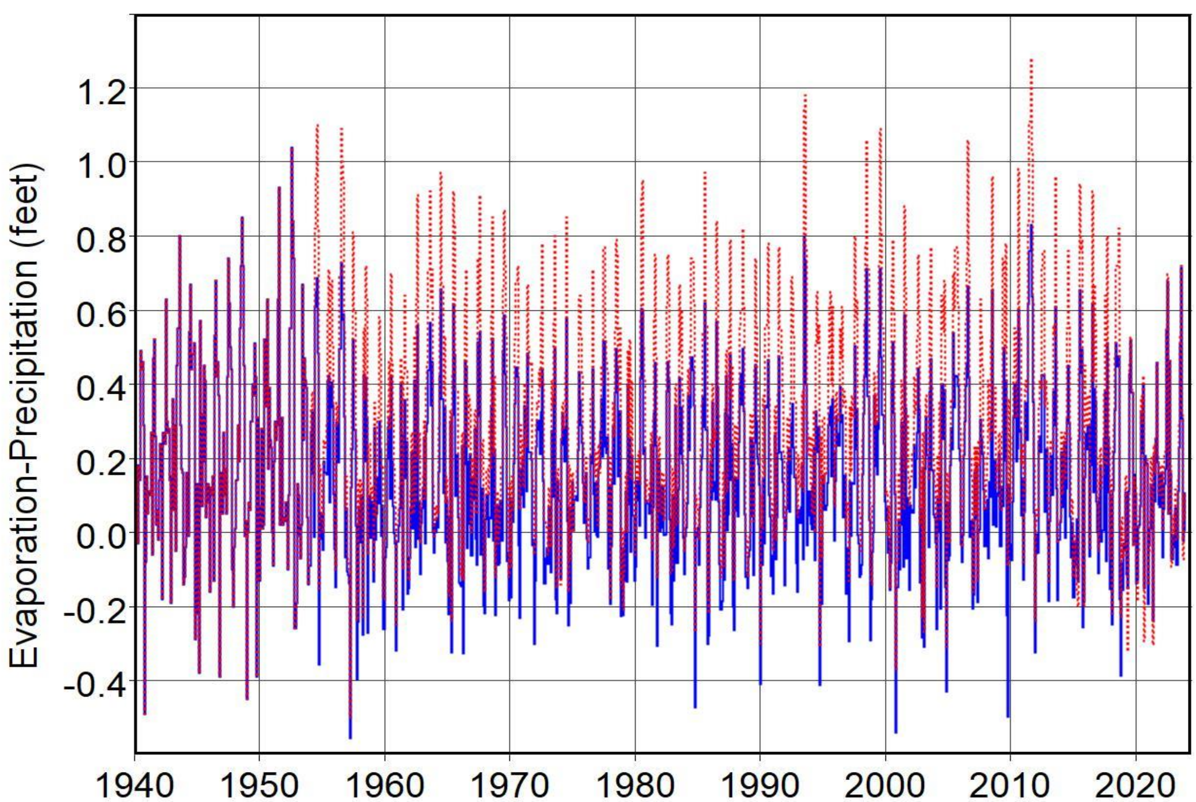

Figure 9.13 Evaporation-Precipitation Datasets 1 and 2 (Table 9.8) at Lake Palestine

Evaporation minus adjusted precipitation depths at Sam Rayburn Reservoir and Lake Palestine from datasets 1 and 2 defined in Table 9.8 are compared in Figures 9.12 and 9.13. The same 1940-1953 monthly quantities are adopted for both datasets. The 1954-2023 quantities differ significantly between the two alternative datasets. Statistics for the alternative evaporation-precipitation datasets for the 1954-1996, 1997-2018, and 2019-2023 sub-periods of the 1940-2023 hydrologic period-of-analysis are compared in Tables 9.9, 9.10, and 9.11.

EV records for dataset 1 are compiled as follows. The 1940-1953 *EV* records are from the latest (October 2023) updated TCEQ Neches WAM. The 1954-2023 EV records were compiled with WRAP program *HYD* employed monthly evaporation and precipitation depths downloaded from the TWDB database website in June 2024. EPADJ option 4 (Table 5.2) adjustments for precipitation reflected in the naturalized flow inflow to the reservoir were computed in the *SIM* simulation starting in January 1954 (EPYEAR=1954).

Dataset 2 *EV* records for 1940-2018 were compiled for TCEQ by a team of consulting firms [75]. The *EV* records of net evaporation-precipitation depths include adjustments for rainfall reflected in naturalized flow inflow to the reservoir computed by the consultants using empirically estimated runoff factors. Dataset 2 *EV* records covering 2018-2023 were compiled in conjunction with this 2024 report using *HYD* with TWDB monthly evaporation and precipitation data downloaded from the TWDB website in June 2024. Precipitation adjustments were performed within *HYD* using approximate multiplier factors dating back to 2001 and 2020 reports [88, 82, 9].

Evaporation-precipitation depths vary significantly between datasets 1 and 2 in Figures 9.12 and 9.13. Referring to Table 9.9, the 1954-1996 mean monthly depth in dataset 1 for Sam Rayburn Reservoir ranges from -0.6793 foot (-8.15 inches) to 0.6193 foot (7.43 inches), with a 1954-1996 mean of 0.03853 foot (0.46 inch). Monthly evaporation-precipitation from Lake Palestine ranges during 1954-1996 from -0.5598 foot (-6.72 inches) to 0.8563 feet (10.28 inches), with a 1954-2023 mean of 0.3762 feet (4.51 inches). Statistics for 1997-2018 are presented in Table 9.10. Referring to the 2019-2023 statistics in Table 9.11, the difference between the evaporation-precipitation means of 0.01820 foot and 0.03649 foot for datasets 1 and 2 results from differences in the precipitation adjustment methods employed.

The dataset of *EV* records defined as dataset 4 in Table 9.8 combined with *SIM/SIMD* computational features activated by EPADJ and EPYEAR on the *JD* record that result in dataset 1 are adopted for the daily and modified monthly WAMs discussed later in this chapter.

Simulated Reservoir Storage with Alternative Hydrology Datasets

The DAT file with modifications and the DIS file for the latest official TCEQ WAMs are adopted for all daily and monthly WAMs presented in Chapters 7 through 12. The FLO and EVA files of *IN* and *EV* records are converted to a DSS file for each of the six case studies including the Neches WAM. A version of the TCEQ full authorization WAM comprised of three files with the following filenames is employed in this section.

Neches3.DAT, Neches3.DIS, NechesHYD.DSS

The 1940-2023 end-of-month storage contents of Sam Rayburn Reservoir and Lake Palestine resulting from *SIM* simulations with alternative datasets discussed in preceding sections of this chapter and listed in Tables 9.13 and 9.14 are presented in Figures 9.14-9.17. Sam Rayburn Reservoir (WAM identifier RAYBRN) is located at WAM control point 4411A1. Lake Palestine (PALEST) is located at control point 3254N1. Fluctuations in storage contents are dramatic in Lake Palestine and relatively small in Sam Rayburn Reservoir in the full authorization WAM simulations. Differences in simulated reservoir storage contents with the different alternative *SIM* hydrology input datasets are significant but not dramatic in Figures 9.14, 9.15, 9.16, and 9.17.

Three alternative naturalized stream datasets are defined below in Table 9.13 and explored earlier in this chapter. Two of the previously discussed alternative approaches for handling *SIM* evaporation-precipitation input datasets are included in Table 9.14 below.

Table 9.13
Naturalized Flow Dataset Legend for Figures 9.14 and 9.15

Dataset	Description of Naturalized Flow Dataset	Figures 9.14 & 9.15
1	TCEQ 2021 WAM 1940-2018 naturalized flows [75] and *HYD* 2019-2023 extension.	blue solid line
2	Original 2001 WAM 1940-1996 hydrology [88] and WRAP program *HYD* 1997-2023 extension.	red dotted line
3	Original 2001 WAM 1940-1996 hydrology [88] and 1997-2019 extension described in the 2020 Neches Daily WAM Report [9].	green dashed line

Table 9.14
Evaporation-Precipitation Dataset Legend for Figures 9.16 and 9.17

Dataset	Description of Evaporation-Precipitation Dataset	Figures 9.16 & 9.17
1	Original 1940-1953 *EV* records and unadjusted 1954-2023 *EV* records with EPADJ option 4 adjustments (Chapter 5).	blue solid line
2	2021 WAM *EV* records with 1940-2018 extension/update documented in 2021 report [75].	red dotted line

The storage volumes plotted in Figures 9.14 and 9.15 are generated in three *SIM* simulations with alternative input datasets that incorporate *EV* record dataset 1 defined in Table 9.13 along with alternatively each of the three alternative *IN* record datasets defined in Table 9.13. The legend for Figures 9.14 and 9.15 is provided as the last column of Table 9.13.

The storage volumes plotted in Figures 9.16 and 9.17 are generated in two *SIM* simulations with alternative input datasets that incorporate *IN* record dataset 1 defined in Table 9.14 along with alternatively each of the two alternative *EV* record datasets defined in Table 9.13. The 1954-2023 portion of dataset 1 in Table 9.14 is computed within *SIM* employing the *EV* record dataset 4 defined in Table 9.8 for 1954-2023 (EPYEAR=1954 on *JD* record) along with the *SIM* routine activated by *JD* record EPADJ option 4. The legend for Figures 9.16 and 9.17 is provided as the last column of Table 9.13.

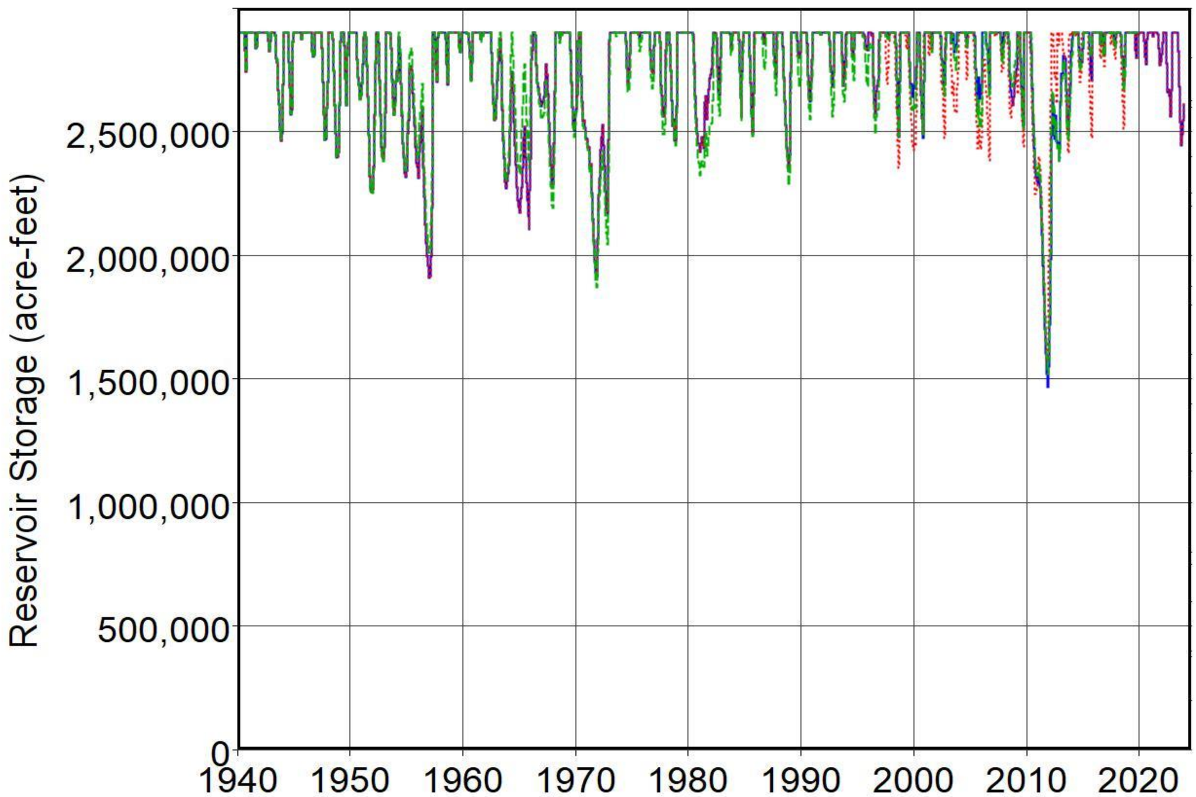

Figure 9.14 Sam Rayburn Storage with Evap-Precip Dataset 1 (Flow Legend in Table 9.13)

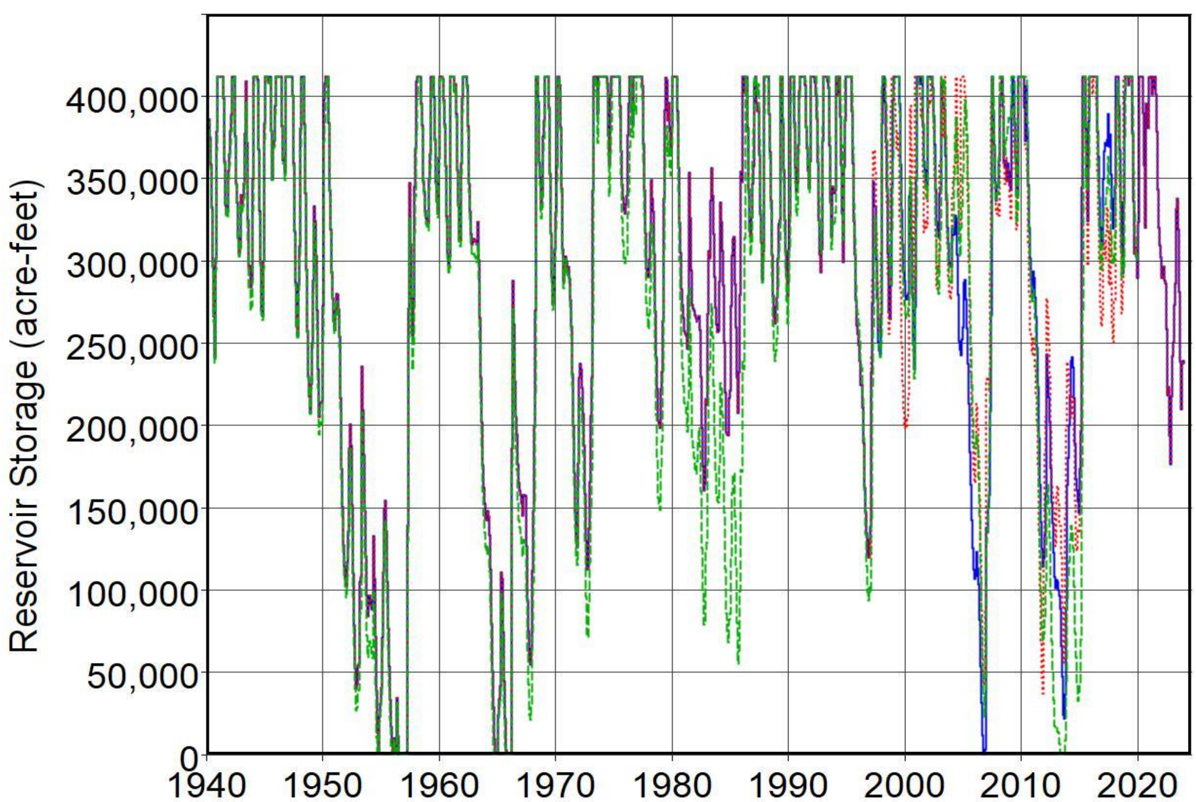

Figure 9.15 Lake Palestine Storage with Evap-Precip Dataset 1 (Flow Legend in Table 9.13)

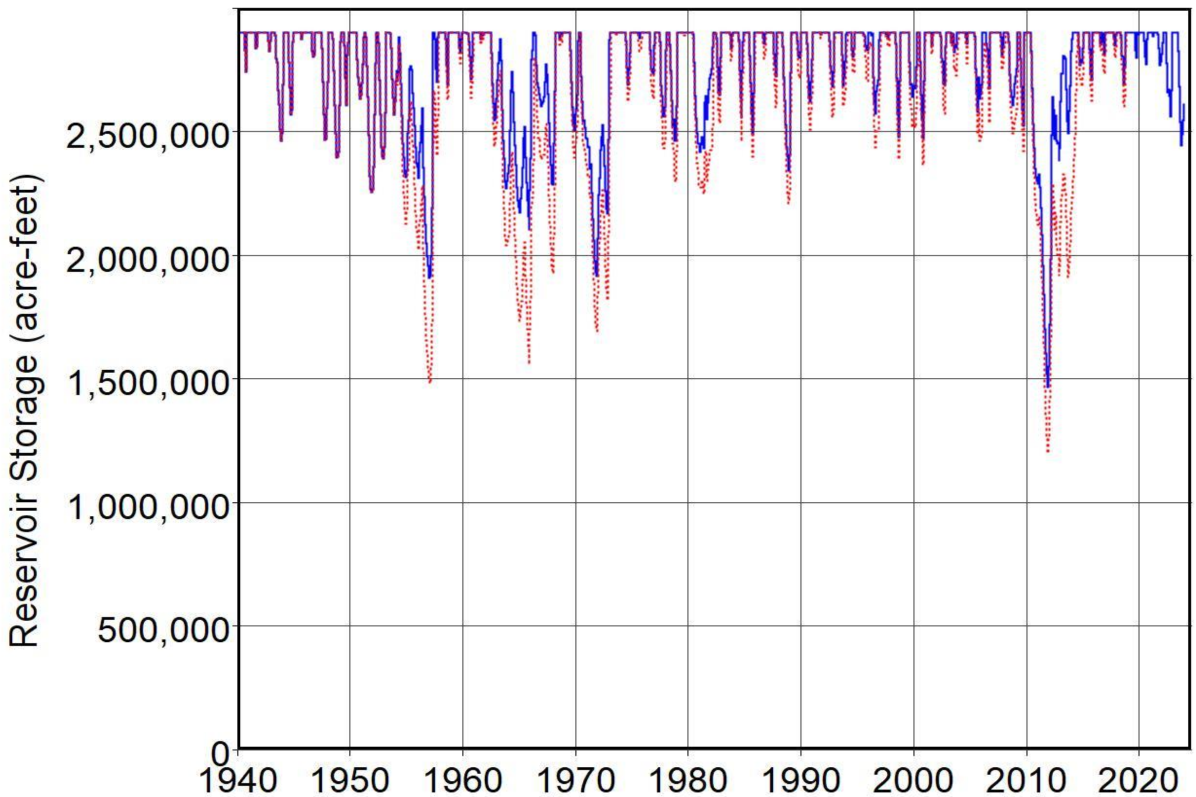

Figure 9.16 Sam Rayburn Storage with *IN* Record Dataset 1 (Evap-Precip Legend in Table 9.14)

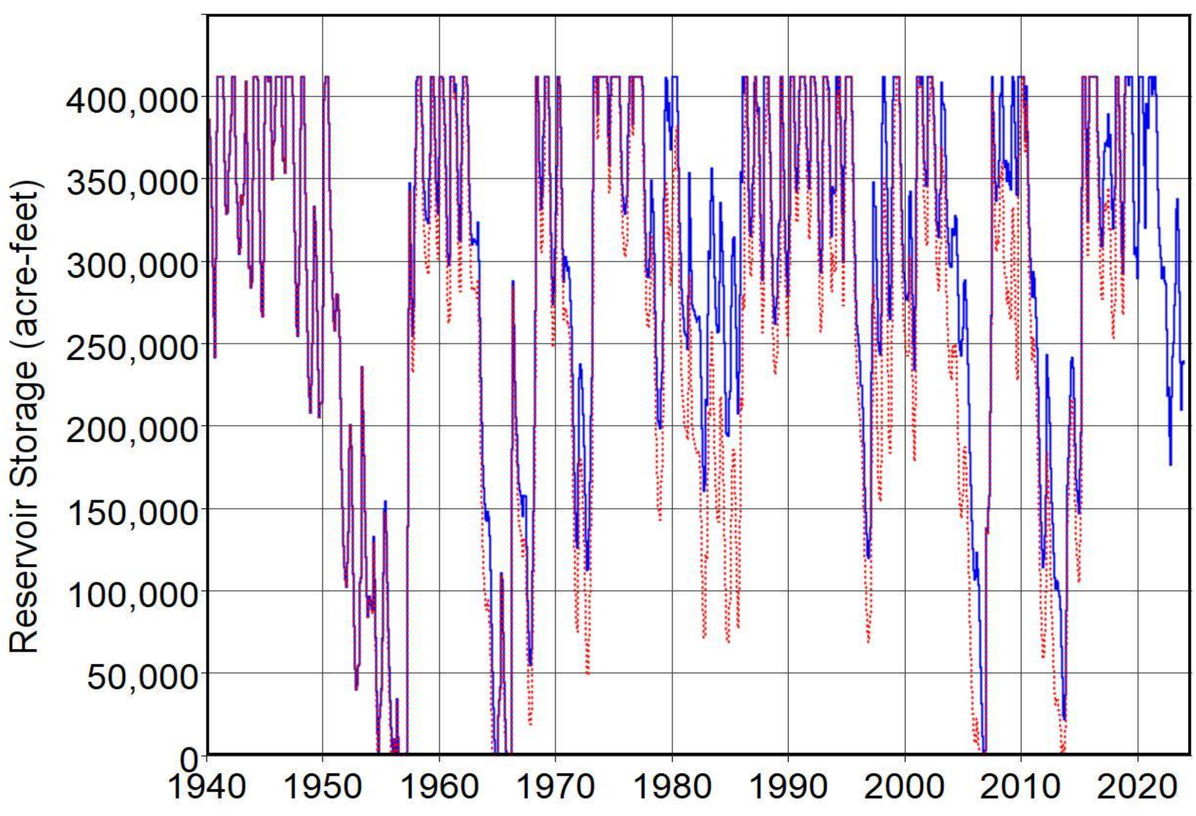

Figure 9.17 Lake Palestine Storage with *IN* Record Dataset 1 (Evap-Precip Legend Table 9.14)

Daily Neches WAM

The 2024 developmental daily version of the TCEQ full authorization WAM compiled as described in this section is comprised of four files with the following filenames.

NechesD.DAT, NechesD.DIS, NechesD.DIF, NechesHYD.DSS

The 2024 version of the daily WAM was created from the official TCEQ monthly WAM last updated by TCEQ on 10/1/2023.

The 1940-2018 *IN* and *EV* records in the monthly WAM last updated by TCEQ on 10/1/2023 were extended through December 2023 in the 2024 update as outlined in the preceding section. The naturalized flow dataset adopted for the daily and modified monthly WAMs is labeled dataset 1 in Table 9.13. TCEQ 2021 WAM 1940-2018 naturalized flows [75] were extended with program *HYD* to cover 2019-2023. The dataset of *EV* records defined as dataset 4 in Table 9.8 combined with *SIM/SIMD* features activated by EPADJ and EPYEAR on the *JD* record result in dataset 1 in Tables 9.8 and 9.14 and are adopted for the 2024 daily and modified monthly WAMs.

The 2020 daily Neches WAM report [9] documents development of full authorization and current use scenario daily and modified monthly versions of the WAM and associated research studies exploring various modeling issues. The 2020 daily full authorization WAM was developed from the TCEQ full authorization monthly WAM last updated in October 2012. A 2020 daily current use Neches WAM was developed from the TCEQ current use monthly WAM last dated in October 2012 [9]. The 2024 full authorization daily WAM was developed as explained in this chapter is an updated version of the daily WAM discussed in the 2020 report [9].

Development of the daily Neches WAM presented in this section includes the following major tasks described in Chapter 2.

1. Conversion of simulation control parameters from monthly to daily in the DAT file of the monthly full authorization WAM last updated by TCEQ on October 1, 2023.
2. Activation of naturalized flow disaggregation options on input records in the DAT and DIF files and compilation of *DF* record daily flow pattern hydrographs extending through 2023 stored in the hydrology input DSS file.
3. Compilation of lag and attenuation routing parameters stored in the DIF file.
4. Removal of the older types of input records approximating the SB3 EFS in the October 2023 DAT file along with addition of new environmental standard *ES*, hydrologic condition *HC*, pulse flow *PF*, and other related input records to model SB3 EFS that have been established at five USGS gage sites.
5. Addition of *FR*, *WS*, *FF*, *FV*, and *FQ* records in the DAT file to model flood control operations of Sam Rayburn Reservoir in the daily model. Monthly WAMs have no flood control operations.

SIMD Simulation Control Parameters

SIMD input parameters controlling simulation options activated in the conversion of a monthly WAM to daily are described on pages 28-29 of Chapter 2 and page 155 of Chapter 7 of this report as well as in Chapter 4 of the *Users Manual* [2] and in the 2020 daily Neches WAM report [9]. The *SIMD* input records in the daily Neches WAM DAT file containing parameters for controlling daily simulation options are replicated as Table 9.15. The *JT*, *JU*, and *OF* records control simulation input, output, and computation options. The *DF* records in Table 9.15 reference *DF* record daily pattern flow hydrographs read by *SIMD* from the hydrology input DSS file for use in disaggregating naturalized flows from monthly to daily.

Table 9.15
SIMD DAT File Input Records Controlling Simulation Options

```
**       1         2         3         4         5         6         7         8
**345678901234567890123456789012345678901234567890123456789012345678901234567890
**      |       |       |       |       |       |       |       |       |       |
JD    84    1940       1       0       0       0       4    1954       4      13
JO     6                                                                       3
JT
JU     1   1
OF     1   0   3   7   0   0                                 Neches
OFV    1   2   3  15  27  28  29
CO          NENE    NERO    ANAL    NEEV    VIKO
**CO        4411A1  3254N1
DF          KIBR    NENE    NEAL    NEDI    NERO    MUJA   EFACU    ANAL    ANLU
DF          ATCH    AYSA    ANSR    NETB    NEEV    VIKO    PISL    NEBA
```

Disaggregation of Monthly Naturalized Stream Flows to Daily

Disaggregation of monthly naturalized flow volumes to daily volumes is a basic key component of converting from a monthly WAM to a daily WAM. With the standard default DFMETH option 4 activated, *SIMD* disaggregates monthly naturalized flow volumes to daily volumes in proportion to daily pattern hydrographs while preserving the monthly volumes.

Disaggregation of monthly naturalized flow volumes in acre-feet/month to daily volumes in acre-feet/day at the 380 control points in the Neches WAM is controlled by parameters on the *JO* and *JU* records in the DAT file and a *DC* record in the DIF file along with the 17 daily flow pattern hydrographs on *DF* records in the DSS file. The procedure described in the next paragraph is activated by the following DIF file *DC* record for control point NESL with REPEAT and DFMETHOD options 2 and 4 activated.

DC   NESL   2   4   NEBA

Control point NESL is the Neches River outlet at Sabine Lake. Control point NEBA is the most downstream control point with *DF* record daily flows provided as input. Flows at computational accounting control points not encompassed within the actual stream system are disaggregated uniformly by DFMETH option 1 in *JU* record field 2.

Monthly naturalized stream flows at over 300 Neches WAM control points are disaggregated to daily using 1940-2023 daily flows at 17 control points that are stored as *DF* records in the hydrology time series input DSS file. The automated procedure in *SIMD* for repeating daily flows at multiple control points is described in Chapter 2 of the *Daily Manual* [5]. The automated procedure consists of using flows at the nearest downstream control point if available, otherwise finding flows at the nearest upstream control point, and lastly if necessary using flows from another tributary.

Daily Flow Pattern Hydrographs on *DF* Records

Daily naturalized flows extending from January 1940 through December 2019 were developed as explained in detail in Chapter 4 of the 2020 Daily Neches WAM Report for 17 of the 20 primary control points [9]. Alternative strategies for developing the daily naturalized flows were investigated. In addition to serving as daily flow pattern hydrographs, the daily naturalized flow volumes were summed to obtain monthly flow volumes. The previously developed 1940-2019 daily naturalized flows at 17 control points are adopted without change in the 2024 update. The daily flows are extended through December 2023 based on observed flows at USGS gages downloaded from the USGS National Water Information System (NWIS) website.

The following alternative approaches for developing daily naturalized stream flows are investigated and compared in the previous daily Neches WAM Report [9]. The final set of 1940-2019 flows adopted for the *DF* records incorporated in the 2020 version of the daily Neches WAM is a combination of flows from the first three compilations listed below. Flows from the fourth compilation based on the SWAT simulation model were not adopted.

1. observed daily flows at 16 USGS gages with and without naturalization adjustments
2. unregulated daily flows at five sites from a USACE Fort Worth District modeling system
3. observed daily releases from Sam Rayburn and B. A. Steinhagen Reservoirs from a USACE Fort Worth District water management website
4. simulated daily flows at all 20 primary control points computed with the Soil and Water Conservation Tool (SWAT) watershed rainfall-runoff model

The final set of 1940-2019 flows at 17 primary control points adopted for the 2020 daily WAM are incorporated in the 2024 updated version. The daily flows at the 17 sites are extended through 2023 with observed flows at 12 USGS gages. Five of the USGS gages were no longer in operation during 2019-2023. Information regarding the USGS gage sites is provided in Tables 4.1-4.4 of the 2020 report [9].

Daily flows on *DF* records are initially compiled in units of cfs for the daily WAMs. A *SIMD* simulation is performed with *DF* records with flows in cfs stored in the *SIMD* hydrology input DSS file. *SIMD* simulation results including daily naturalized flow volumes in acre-feet are recorded by *SIMD* in its simulation results DSS output file. The daily naturalized flows in acre-feet in the *SIMD* simulation results DSS file are converted to *DF* records which are copied within *HEC-DSSVue* to the *SIMD* hydrology input DSS file.

Routing and Forecasting

SIMD includes optional features for lag and attenuation of stream flow changes and forecasting in support of assessing stream flow availability and availability of stream channel flood flow capacities. The Neches WAM includes calibrated routing parameters for the 19 river reaches connecting the 20 primary control points. Calibration studies and analyses of the routing parameters and effects on simulation results are discussed in detail in the 2020 report [9].

With the calibrated routing parameters already incorporated in the WAM, routing with or without forecasting can be easily activated or deactivated in alternative executions of *SIMD*. Forecasting is problematic and is relevant only if routing is employed.

Developing monthly SB3 EFS instream flow targets from daily simulation results is the primary application considered in this 2024 report. Based on simulation results discussed in the 2020 report, routing was not activated in the final simulation adopted for generating the SB3 EFS targets. Likewise, routing and forecasting are not employed in the final simulations to determine SB3 EFS targets presented later in this chapter. However, as discussed in Chapter 13, routing could possibly be beneficial in other types of modeling applications.

Simulation of Flood Control Operations of Sam Rayburn Reservoir

Sam Rayburn Reservoir is the only reservoir in the Neches River Basin with a designated flood control pool controlled by human operation of gated outlets. The Sam Rayburn conservation pool and flood control pool storage capacities are 2,898,200 and 1,099,400 acre-feet, for a total capacity of 3,997,600 acre-feet. Flood control operations are the responsibility of the USACE Fort Worth District. The USACE flood control operating criteria is available at the website http://www.swf-wc.usace.army.mil/pertdata/NECHES.htm and is reproduced below as Table 9.16. Maximum allowable flood flow limits are shown for the turbine used for hydroelectric power generation at Sam Rayburn Dam and for the stream gage on the Neches River at Evadale. The flood control pool is emptied as expeditiously as practical without contributing to flows of the Neches River at Evadale exceeding 20,000 cfs or the flows at the dam exceeding the limits shown in Table 9.16.

Table 9.16
U.S. Army Corps of Engineers Flood Control Operation Criteria

Reservoir	Reservoir Surface Elevations (feet msl)	% Flood Storage Volume	Neches River Turbine	Neches River Evadale
			(cfs)	(cfs)
Sam Rayburn	164.4 – 165.0	0 – 6	4,200	20,000
	165.0 – 165.5	6 – 12	8,400	20,000
	165.5 – 173.0	12 – 100	no limit	20,000

Flood control reservoir operations are treated as a type of water right in *SIMD* as described in the *Daily Manual* [5]. Flood control rights are activated by *FR* records and are simulated along with all other *WR* and *IF* record water rights. The same reservoir may have any number of *WR* or *IF* record rights, with associated auxiliary records, and any number of *FR* record flood control rights. The flood control reservoir *FR* record, flood flow *FF* record, and the reservoir storage volume versus outflow *FV/FQ* record pair described in Chapter 4 of the *Users Manual* [2] are the only *SIMD* input records specifically for flood control. *FR* and *FF* records are used to model reservoir operations for flood control analogously to applying *WR*, *WS*, *OR*, and *IF* records to model operations for water supply, hydropower, and instream flow requirements. Records modeling flood control operations of Sam Rayburn Reservoir are replicated Tables 9.17 and 9.18.

Table 9.17
FR and *WS* Records for Flood Control Operation of Sam Rayburn Reservoir

```
**      1         2         3         4         5         6         7         8         9        10
**34567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456678
**     |       |       |       |       |       |       |       |       |       |               |
FR4411A19100000092000000       0  20000. 3997600         2898200                 RAYBURN-STOR    RAYBURN-REL
WSRAYBRN
```

Table 9.18
FV/FQ and *FF* Records for Flood Control Operation of Sam Rayburn Reservoir

```
**      1         2         3         4         5         6
**3456789012345678901234567890123456789012345678901234567890123 4
**     |       |       |       |       |       |       |       |
FVRAYBRN 2898200 2898250 2964164 2964200 3030128 3030200 3997600
FQ           0.0   4200.   4200.   8400.   8400. 20000.0 20000.0
FF  NEEV  20000.                  FFLIM-NEEV
```

The priority numbers for flood control reservoir storage and releases in *FR* record fields 3 and 4 are junior to all other water rights in the Neches WAM. The most restrictive of the *FF* record 20,000 cfs limit and *FV/FQ* record capacities control in each day.

SB3 Environmental Flow Standards

The original Neches WAM and subsequent updates to the monthly model have included instream flow requirements to protect downstream senior rights and provide for environmental flow needs. Environmental flow standards (EFS) established pursuant to the 2007 Senate Bill 3 (SB3) were added by the TCEQ to the October 2012 full authorization and September 2012 current use monthly WAMs prior to development of the daily WAM [9]. SB3 EFS are based on a flow regime that includes subsistence, base, and high pulse flows [1, 5]. Input records previously added to the monthly *SIM* DAT files to simulate SB3 EFS are removed in the conversion to a daily WAM. New features activated by *ES*, *HC*, and *PF* records designed specifically for modeling SB3 EFS are incorporated in the daily WAM. Daily targets computed in a daily simulation are aggregated to monthly quantities for input on target series *TS* records added to the monthly WAM time series input DSS file and referenced by new instream flow *IF* records added to the monthly DAT file.

Environmental Flow Standards (EFS) Established Pursuant to Senate Bill 3 (SB3) Process

The SB3 EFS for the Neches River Basin adopted on April 20, 2011 with an effective date of May 15, 2011 are published in the Texas Water Code [98]. The Bay and Basin Expert Science Team (BBEST) for the Sabine and Neches Rivers submitted its Recommendation Report to the Basin and Bay Area Stakeholder Committee (BBASC) and TCEQ in November 2009. The BBASC submitted its Recommendation Report to the TCEQ in May 2010. The standards for the Sabine and Neches Rivers were adopted by the TCEQ effective May 15, 2011. The priority date used for water availability modeling is November 30, 2009, corresponding to the date that the BBEST Report was received by TCEQ. The EFS published in the Texas Water Code and the supporting BBEST and BBASC reports for all the river basins with SB3 EFS are accessible through the TCEQ WAM website.

The "*environmental flow standards for surface water for the Sabine and Neches Rivers and Sabine Lake Bay*" are documented in Texas Administrative Code Title 30, Part 1, Chapter 298, Subchapter C. Instream flow standards are established at ten USGS gaging stations, including five sites in the Sabine River Basin and five sites in the Neches River Basin. Instream flow standards at the five Neches River Basin locations were incorporated into the daily Neches WAM using the modeling techniques described in this chapter. The Neches WAM primary control points corresponding to the five USGS gage sites are listed with descriptive information in Table 9.19. The locations of the control points (gage sites) are shown in Figure 9.2.

Table 9.19
Neches WAM Control Point Locations for SB3 EFS

WAM CP ID	USGS Gage No.	Location	Watershed Area (square miles)	Gage Period-of-Record
NENE	08032000	Neches River at Neches	1,145	1939-present
NERO	08033500	Neches River near Rockland	3,631	1903-present
ANAL	08036500	Angelina River near Alto	1,273	1940-present
NEEV	08041000	Neches River at Evadale	7,885	1904-present
VIKO	08041500	Village Creek near Kountze	861	1924-present

The instream flow standards consist of seasonal subsistence flows, base flows, and high flow pulses. Seasons are defined as follows: Winter (January-March), Spring (April-June), Summer (July-September), and Fall (October-December).

The flow limits in cfs for the subsistence flow standards for the five sites are shown on the left side of Table 9.20. Water right holders may not make diversions from the river if the flow at a control point is less than the applicable subsistence flow standard. If the flow is greater than the subsistence flow limit and less than the applicable base flow limit, water right holders may make diversions as long as the flow does not drop below the subsistence flow limit.

Base flow criteria are also shown in Table 9.20. If the flow at a site is greater than the applicable base flow standard and less than the applicable pulse flow trigger level (Table 9.21), water right holders may divert flow as long as the stream is at or above the base flow criterion.

High pulse flow criteria are outlined in Table 9.21 are engaged when flow at a gage site exceeds the applicable high flow pulse trigger level. Water right holders may not make diversions until either the applicable volume or duration time has passed since occurrence of the engagement trigger flow level. However, diversions can be made before the volume or duration criteria are met if the flow at the control point exceeds the high flow pulse trigger level, as long as diversions do not cause the flow to drop below the high flow pulse trigger level. One pulse per season is specified for the Winter and Summer seasons and two pulses per season is specified for Spring and Fall for all five sites. The tracking of pulse flow events each season is performed independently of preceding and subsequent seasons. Junior water right permits with authorized annual diversions of 10,000 acre-feet or less are not required to protect high flow pulse EFS. However, the Neches WAM does not incorporate this exemption for small diversion rights.

Table 9.20
Subsistence and Base Flow Standards

Control Point	Subsistence Flow Limits (cfs)				Base Flow Limits (cfs)			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
NENE	51	21	12	13	196	96	46	80
NERO	67	29	21	21	603	420	67	90
ANAL	55	18	11	16	277	90	40	52
NEEV	228	266	228	228	1,925	1,804	580	512
VIKO	83	49	41	41	264	117	77	98

Table 9.21
High Flow Pulse Standards

WAM CP ID	Criteria	Winter	Spring	Summer	Fall
	Trigger (cfs):	833	820	113	345
NENE	Volume (ac-ft):	19,104	20,405	1,339	5,391
	Duration (days):	10	12	4	8
	Trigger (cfs):	3,080	1,720	195	515
NERO	Volume (ac-ft):	82,195	39,935	1,548	8,172
	Duration (days):	14	12	5	8
	Trigger (cfs):	1,620	1,100	146	588
ANAL	Volume (ac-ft):	37,114	24,117	2,632	12,038
	Duration (days):	13	14	8	12
	Trigger (cfs):	2,020	3,830	1,540	1,570
NEEV	Volume (ac-ft):	20,920	68,784	21,605	17,815
	Duration (days):	6	12	9	7
	Trigger (cfs):	2,010	1,380	341	712
VIKO	Volume (ac-ft):	36,927	23,093	6,159	11,426
	Duration (days):	13	13	8	9

Modeling the Senate Bill 3 (SB3) Environmental Flow Standards (EFS)

Environmental standard *ES*, hydrologic condition *HC*, and pulse flow *PF* records designed specifically to model *IF* record instream flow rights in the format of SB3 EFS are described in the *Users and Reference Manuals* [1, 2]. Although employed in the daily Brazos (Chapter 5) and other WAMs, HC records are not needed for the Neches WAM since hydrologic condition is not used as a parameter in defining the SB3 EFS for the Neches River system.

The set of *SIMD* DAT file input records reproduced as Table 9.22 controls computation of daily instream flow targets for the SB3 EFS at the five control points. The high pulse flow component is separated from the subsistence and base flow components in Table 9.22 for purposes of recording separate simulation results in the *SIMD* output file. Alternatively, the pulse flow component can be combined with the subsistence and base flow components as a single *IF* record water right with only the final targets included in the simulation results.

Table 9.22
Instream Flow Rights that Model the SB3 EFS in the Daily Neches WAM DAT File

```
**       1         2         3         4         5         6         7         8         9        10
**345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
**     !       !       !       !       !       !       !       !       !       !       !       !       !
**
IF  NENE     -9.        20091130   2            IF-NENE-ES
ES SUBS      51.     51.     51.     21.     21.     21.     12.     12.     12.     13.     13.     13.
ES BASE     196.    196.    196.     96.     96.     96.     46.     46.     46.     80.     80.     80.
IF  NENE     -9.        20091130   2            IF-NENE-PF
ES PFES
PF   1 0    833.  19104.  10   1       1   3           2
PF   1 0    820.  20405.  12   2       4   6           2
PF   1 0    113   13390.   4   1       7   9           2
PF   1 0    345    5391.   8   2      10  12           2
IF  NERO     -9.        20091130   2            IF-NERO-ES
ES SUBS      67.     67.     67.     29.     29.     29.     21.     21.     21.     21.     21.     21.
ES BASE     603.    603.    603.    420.    420.    420.     67.     67.     67.     90.     90.     09.
IF  NERO     -9.        20091130   2            IF-NERO-PF
ES PFES
PF   1 0   3080.  82195.  14   1       1   3           2
PF   1 0   1720.  39935.  12   2       4   6           2
PF   1 0    195    1548.   5   1       7   9           2
PF   1 0    515    8172.   8   2      10  12           2
IF  ANAL     -9.        20091130   2            IF-ANAL-ES
ES SUBS      55.     55.     55.     18.     18.     18.     11.     11.     11.     16.     16.     16.
ES BASE     277.    277.    277.     90.     90.     90.     40.     40.     40.     52.     52.     52.
IF  ANAL     -9.        20091130   2            IF-ANAL-PF
ES PFES
PF   1 0   1620.  37114.  13   1       1   3           2
PF   1 0   1100.  24117.  14   2       4   6           2
PF   1 0    146.   2632.   8   1       7   9           2
PF   1 0    588.  12038.  12   2      10  12           2
IF  NEEV     -9.        20091130   2            IF-NEEV-ES
ES SUBS     228.    228.    228.    266.    266.    266.    228.    228.    228.    228.    228.    228.
ES BASE    1925.   1925.   1925.   1804.   1804.   1804.    580.    580.    580.    512.    512.    512.
IF  NEEV     -9.        20091130   2            IF-NEEV-PF
ES PFES
PF   1 0   2020.  20920.   6   1       1   3           2
PF   1 0   3830.  68784.  12   2       4   6           2
PF   1 0   1540   21605.   9   1       7   9           2
PF   1 0   1570   17815.   7   2      10  12           2
IF  VIKO     -9.        20091130   2            IF-VIKO-ES
ES SUBS      83.     83.     83.     49.     49.     49.     41.     41.     41.     41.     41.     41.
ES BASE     264.    264.    264.    117.    117.    117.     77.     77.     77.     98.     98.     98.
IF  VIKO     -9.        20091130   2            IF-VIKO-PF
ES PFES
PF   1 0   2010.  36927.  13   1       1   3           2
PF   1 0   1380.  23093.  13   2       4   6           2
PF   1 0    341    6159.   8   1       7   9           2
PF   1 0    712   11426.   9   2      10  12           2
```

Monthly WAM with Instream Flow Targets from the Daily WAM

Daily instream flow targets in acre-feet/day for the SB3 EFS computed in a daily *SIMD* simulation are summed by *SIMD* to monthly totals in acre-feet/month which are included in the *SIMD* simulation results. These time series of monthly targets are converted to target series *TS* records incorporated in the *SIM/SIMD* input DSS file and read in a monthly *SIM* simulation. The target series *TS* records of monthly instream flow targets in acre-feet/month stored in the DSS file have the pathname identifiers listed in Tables 9.23. The *TS* records in the DSS file are referenced by *TS* records in the DAT file which are replicated in Table 9.24.

Table 9.23
Pathnames for *TS* Records for the SB3 EFS in the
SIM and *SIMD* Shared Hydrology Input DSS File

Part A	Part B	Part C	Part D	Part E
NECHES	NENE	TS	01Jan1940-31Dec2023	1MON
NECHES	NERO	TS	01Jan1940-31Dec2023	1MON
NECHES	ANAL	TS	01Jan1940-31Dec2023	1MON
NECHES	NEEV	TS	01Jan1940-31Dec2023	1MON
NECHES	VIKO	TS	01Jan1940-31Dec2023	1MON

Table 9.24
Instream Flow Rights that Model the SB3 EFS in the DAT File

```
IF NENE                   20091130   2            IF-NENE
TS      DSS  NENE
IF NERO                   20091130   2            IF-NERO
TS      DSS  NERO
IF ANAL                   20091130   2            IF-ANAL
TS      DSS  ANAL
IF NEEV                   20091130   2            IF-NEEV
TS      DSS  NEEV
IF VIKO                   20091130   2            IF-VIKO
TS      DSS  VIKO
```

Previous and Improved Strategies for Simulating SB3 EFS

An initial developmental version of the daily *SIMD* first introduced in 2012 was subsequently expanded and improved through multiple versions over the years extending to the present [13]. The pulse flow options *PO* record was also added to *SIMD* during this developmental process. The environmental standard *ES* and hydrologic condition *HC* records were added to both *SIM* and *SIMD* in the July 2018 version of WRAP [13]. *PF* record capabilities are applicable only in *SIMD*. The *ES*, *HC*, *PF*, and *PO* records are designed specifically for modeling instream flow requirements formulated in SB3 EFS format.

SB3 EFS have been added to the monthly Neches WAM and other WAMs in the past using the same types of input records employed with other *WR* and *IF* record water rights. The five SB3 EFS are modeled in the official TCEQ Trinity WAM last updated by TCEQ on 10/1/2023 with several hundred *UC*, *CP*, *CI*, *IF*, *WR*, *TO*, *PX*, and *FS* records scattered throughout the DAT file. These initial records modeling the five SB3 EFS in the monthly WAM were removed and replaced in the daily WAM with the *IF*, *ES*, and *PF* records replicated as Table 9.22. The SB3 EFS are incorporated in the modified monthly WAM as outlined in Tables 9.23 and 9.24.

Comparison of Simulated Reservoir Storage for Alternative Modeling Premises

A version of the TCEQ full authorization WAM discussed earlier consists of three files with filenames: Neches3.DAT, Neches3.DIS, and NechesHYD.DSS. The 1940-2023 end-of-month storage contents of Sam Rayburn Reservoir and Lake Palestine resulting from *SIM* simulations with this WAM with alternative datasets listed in Tables 9.13 and 9.14 are plotted in Figures 9.14-9.17 for comparison. End-of-day storage contents resulting from *SIMD* simulations are added to the comparative analyses in this section. The one monthly *SIM* and three daily *SIMD* simulations in Figures 9.18-9.21 are listed in Table 9.25 and described in the following paragraphs.

Table 9.25
Simulations Generating Storage Volumes Plotted in Figures 9.18-9.21

Legend for Figures 9.18 and 9.19

SIMD daily simulation with no routing and no forecasting (**blue solid line**)
SIM monthly simulation (**red dotted line**)

Legend for Figures 9.20 and 9.21

SIMD simulation with no routing and no forecasting (**blue solid line**)
SIMD simulation with routing but no forecasting (**red dotted line**)
SIMD simulation with routing and forecasting with a forecast period of three days (**green dashed line**)

All daily storage sequences plotted with a **blue solid line** in Figures 9.18-9.21 represent the same *SIMD* simulation. Three alternative *SIMD* simulations performed with and without routing and forecasting are compared in Figures 9.20 and 9.21. The 2024 daily WAM is comprised of four files with filenames NechesD.DAT, NechesD.DIS, NechesD.DIF, and NechesHYD.DSS.

The storage volumes from one of the monthly *SIM* simulations of Figures 9.14-9.17 are also plotted in Figures 9.18-9.19. This *SIM* simulation combines dataset 1 defined in Table 9.13 with dataset 1 defined in Table 9.14. This is the basic monthly WAM prior to converting to daily and replacing the SB3 EFS. The storage sequences from this monthly *SIM* simulation are compared to daily storage volumes from a *SIMD* simulation without routing and forecasting in Figures 9.18 and 9.19. Plots of the 1,008 end-of-month storage volumes and 30,681 end-of-day storage volumes during the 1940-2023 hydrologic period-of-analysis of Sam Rayburn Reservoir and Lake Palestine generated by *SIM* and *SIMD* simulations are presented as Figures 9.18 and 9.19.

Sam Rayburn Reservoir has an authorized storage capacity of 2,898,200 acre-feet at top of conservation pool. The daily WAM includes a 1,099,400 acre-feet flood control pool raising the total storage capacity of Sam Rayburn Reservoir to 3,997,600 acre-feet. Lake Palestine has an authorized storage capacity of 411,840 acre-feet and no flood control storage. These two largest reservoirs contain 84.8% of the total authorized storage capacity of the 206 reservoirs in the full authorization Neches WAM. The plots of full authorization simulated storage for these two reservoirs provide meaningful insight regarding water availability in the Neches River Basin.

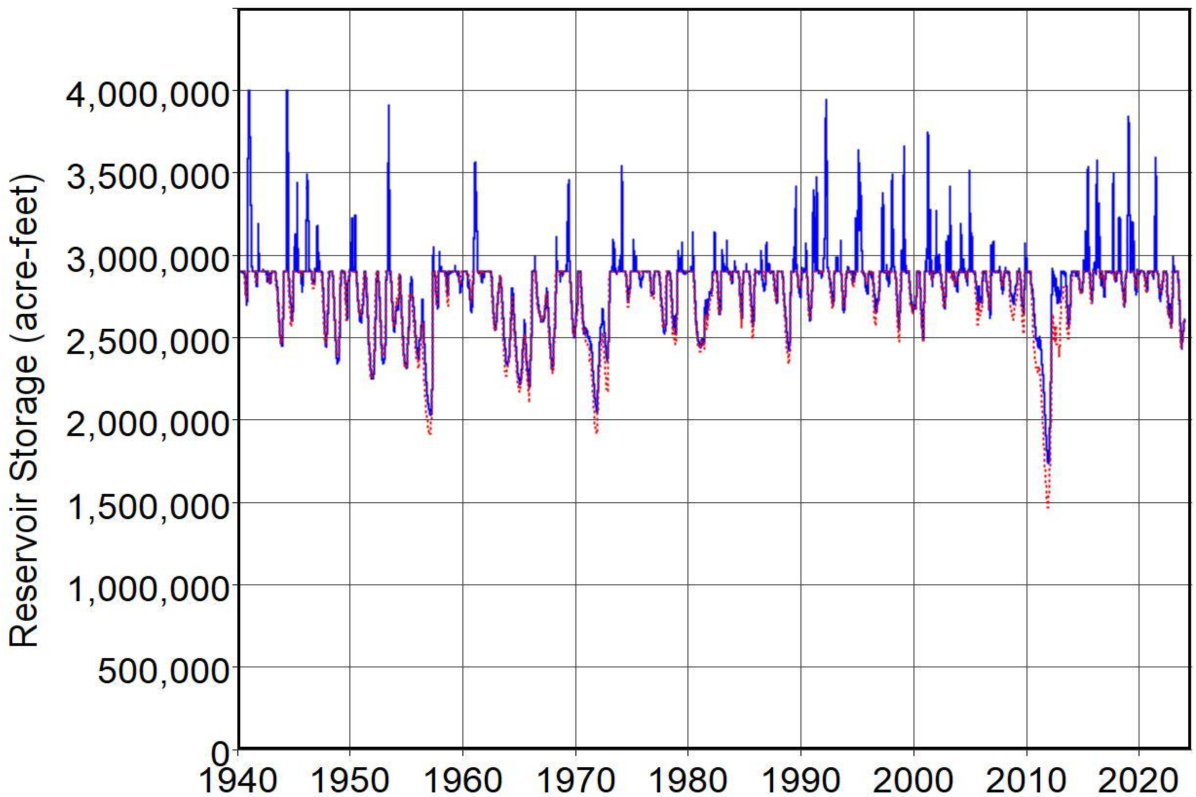

Figure 9.18 Sam Rayburn Storage from Monthly (**red dots**) and Daily (**blue solid**) WAMs

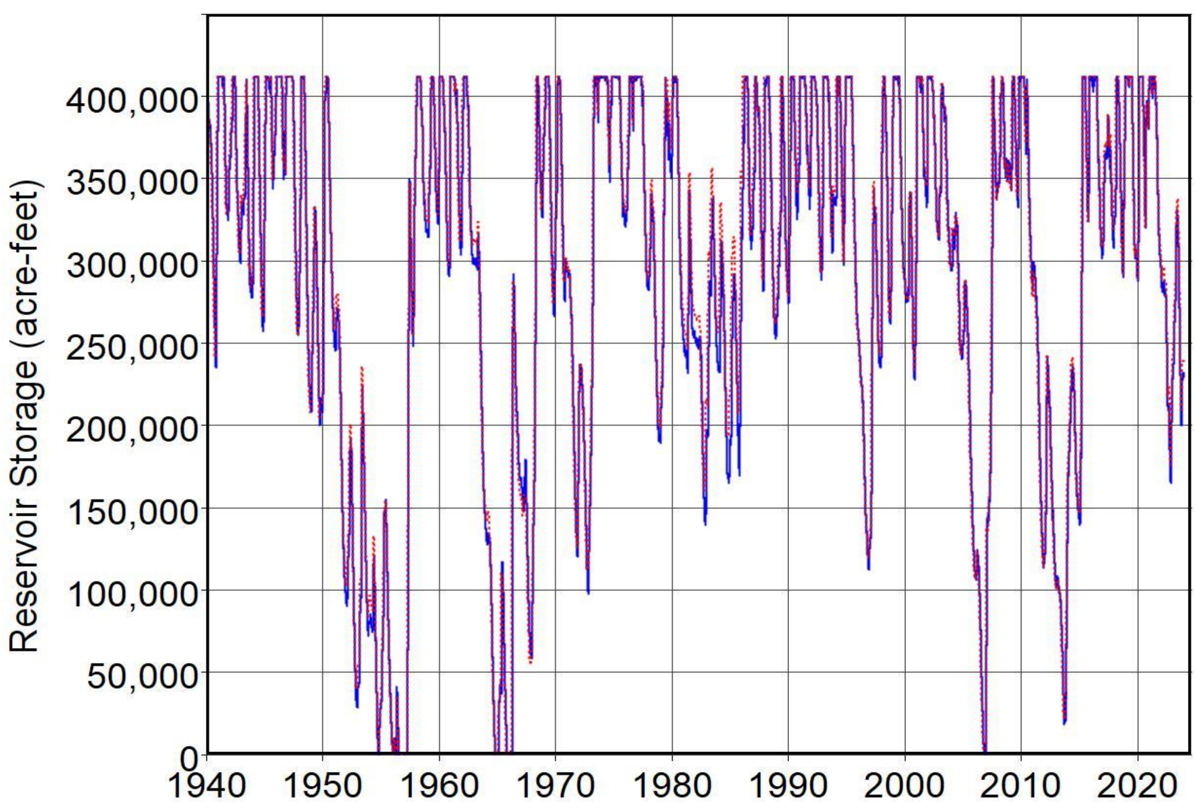

Figure 9.19 Lake Palestine Storage from Monthly (**red dots**) and Daily (**blue solid**) WAMs

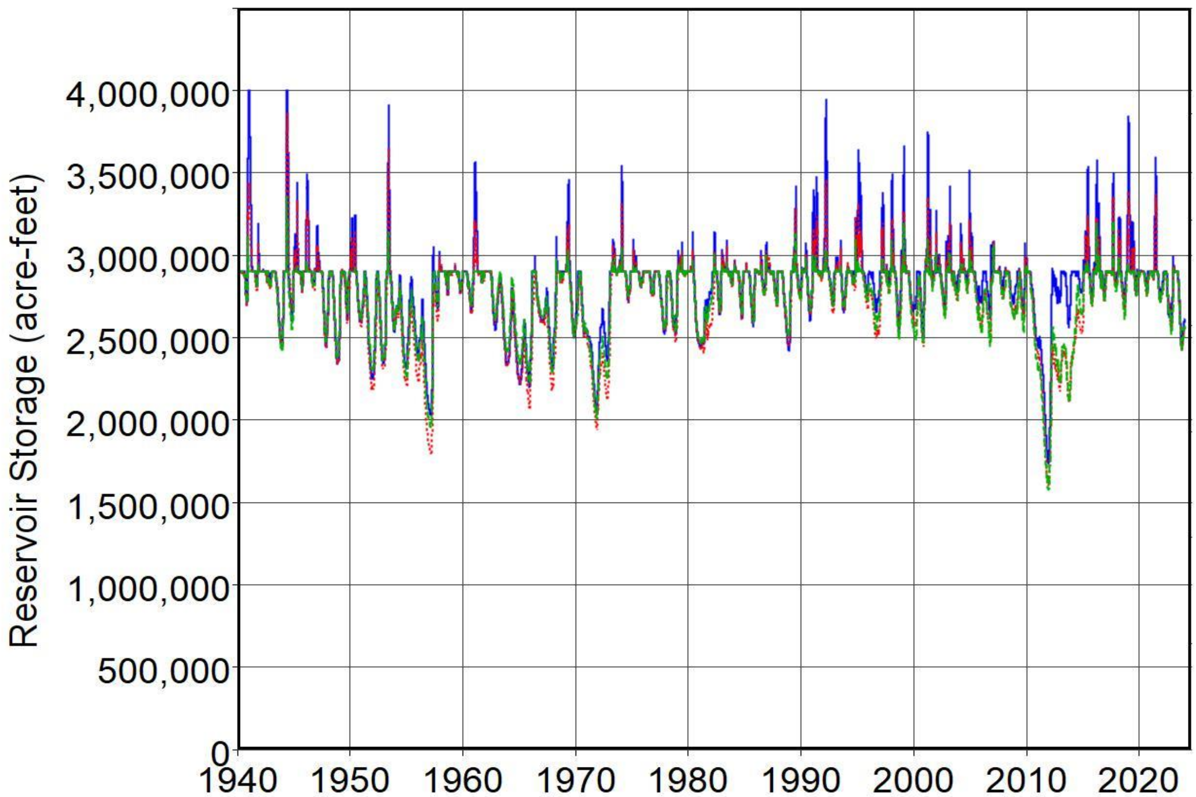

Figure 9.20 Daily Sam Rayburn Reservoir Storage With and Without Routing and Forecasting

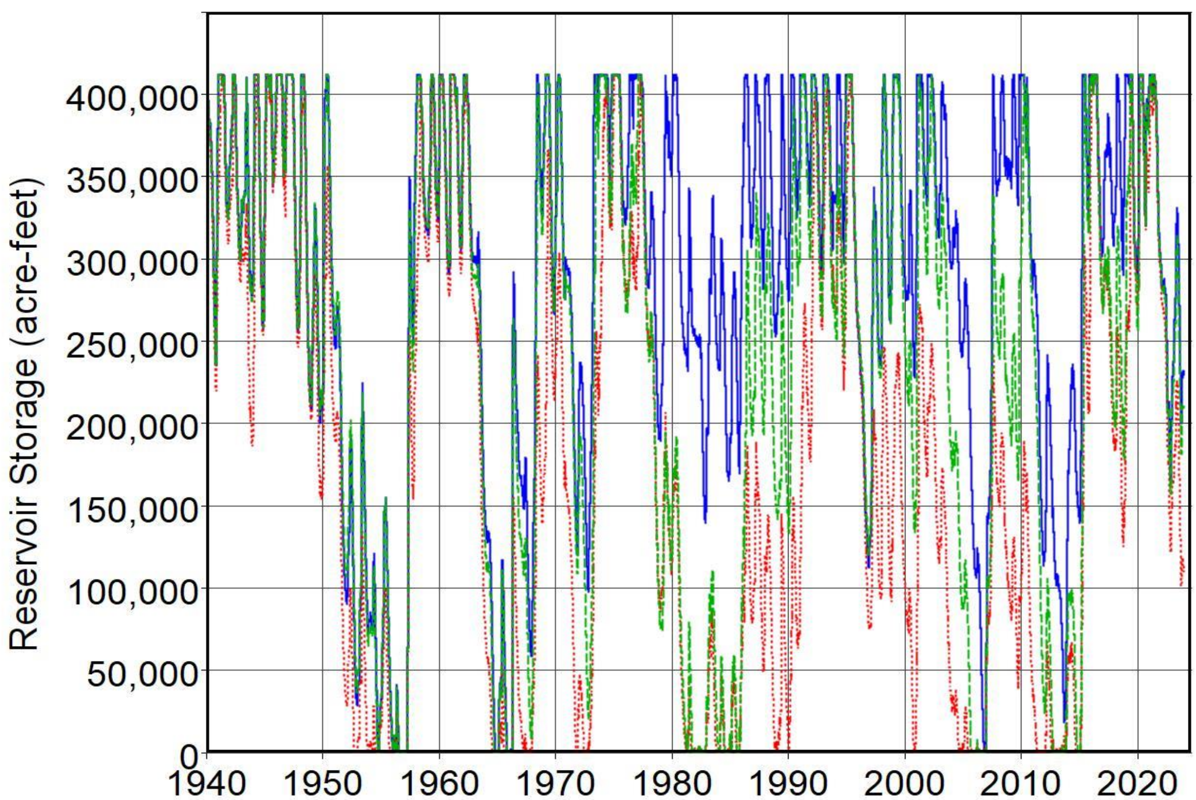

Figure 9.21 Lake Palestine Storage With and Without Routing and Forecasting (Table 9.25)

Plots of 30,681 end-of-day and 1,008 end-of-month storage volumes during the 1940-2023 hydrologic period-of-analysis are compared in Figures 9.18 and 9.19. High and low end-of-day peaks occurring within a month are captured in the daily simulation. The plots for a monthly *SIM* simulation linearly connect the end-of-month storage volumes. The daily versus monthly computational time step affects other aspects of the simulation as well. Within-month variability of stream flow is much greater than within-month variability of reservoir storage contents.

Conservation pool storage fluctuations in Sam Rayburn Reservoir in Figure 9.18 are almost the same in the monthly *SIM* and daily *SIMD* simulations. The daily *SIMD* simulation includes encroachments into the flood control pool. Outflows equal inflows in the monthly simulation when the conservation pool is full to authorized storage capacity. The *SIMD FV/FQ* records (Figure 9.18) include a maximum outflow at the dam of 20,000 cfs. The outlet capacity at the dam controls releases rather than the allowable flow of 20,000 cfs at the Evadale gage throughout the simulation.

Full authorization simulated storage depletions (draw-downs) in Lake Palestine plotted in Figure 9.19 are dramatic. Storage content fluctuations are almost the same in the daily *SIMD* and monthly *SIM* simulations in Figure 9.19. SB3 EFS are modeled differently in the daily versus monthly WAMs. However, the SB3 EFS are junior to the other water rights and thus have little if any effect on reservoir storage. Conversely, the SB3 EFS significantly affect unappropriated flows. Routing and forecasting are not activated in the daily *SIMD* simulation of Figures 9.18 and 9.19. The monthly *SIM* does not include lag and attenuation routing and forecasting features.

The effects of routing and forecasting on reservoir storage are illustrated in Figures 9.20 and 9.21. A legend defining the alternative simulations reflected in the plots is provided in Table 9.25. The effects routing and forecasting on conservation pool storage contents in Sam Rayburn Reservoir are significant but relatively small (Figure 9.20). The effects are greater for flood control pool operations. The effects of routing and forecasting on storage contents of Lake Palestine are great in Figure 9.21. Full authorization simulated storage in Lake Palestine located on the upper Neches River is significantly affected by more senior water rights in the lower basin. Routing and forecasting result in much greater drawdowns in Lake Palestine than Sam Rayburn Reservoir.

Lag and attenuation routing methodology and parameter calibration are explained in detail in the *Daily Manual* [5]. Routing and forecasting complexities and issues are discussed in Chapters 2 and 13 of the present report. The 2020 Daily Neches WAM Report [9] as well as the Brazos and Trinity Daily WAM Reports [7, 8] include detailed investigations of the effects and accuracy of routing and forecasting that support discussions in the present report. Complexities and inaccuracies associated with routing and forecasting are highlighted in Chapters 2 and 13 of the present report and explored in greater detail in the previous daily WAM reports [7, 8, 9].

With the calibrated routing parameters available from earlier studies [9, 36, 37], routing and forecasting are easily activated or deactivated in alternative *SIMD* simulations. Based on research results reported from the cited studies, both routing and forecasting were deactivated in the 2020 studies in simulations to develop SB3 EFS instream flow targets [9]. Likewise, routing and forecasting are not applied in the final daily *SIMD* simulation employed in the next section of this chapter to determine daily and monthly instream flow targets for the SBS EFS. Activation of routing with alternative forecast periods can be further investigated for applications emphasizing flood control operations or other aspects of water management.

SB3 EFS Instream Flow Targets

This last section of Chapter 9 focuses on instream flow targets for the environmental flow standards (EFS) previously established through the process created by the 1997 Senate Bill 3 (SB3) at five sites described in Table 9.19 with locations shown in Figure 9.2. Observed daily, monthly, and annual flows of the Neches River at Rockland and Evadale are plotted in Figures B7 and B8 of Appendix B. Naturalized monthly flows at control points NERO and NEEV are plotted in Figures 9.3-9.6. The 1940-2023 monthly SB3 EFS instream flow targets and shortages at the five control points are plotted as Figures C24, C25, C26, C27, and C28 of Appendix C.

SIMD and *SIM* Input Files for Daily and Modified Monthly WAMs

The daily full authorization *SIMD* input dataset consists of a set of files with the following filenames.

NechesD.DAT, Neches.DIS, Neches.DIF, NechesHYD.DSS

The daily WAM was executed with *SIMD* to generate monthly instream flow targets stored as *TS* records in the file NechesHYD.DSS that model the five sets of environmental flow standards. This modified monthly WAM is comprised of a set of *SIM* input files with the following filenames.

NechesM.DAT, Neches.DIS, NechesHYD.DSS

The same hydrology DSS file with filename NechesHYD.DSS can be read by either *SIM* and *SIMD* in various versions of the WAM input dataset. *HEC-DSSVue* reads any DSS file including *SIM* or *SIMD* input files or simulation results output files.

The adopted daily WAM includes the DAT file records replicated as Tables 9.15, 9.17, 9.18, and 9.22. Selection of quantities to include in simulation results output files and activation of various simulation options are controlled by input records replicated in Table 9.15. Routing and forecasting are deactivated in the simulations presented in this section but can be easily activated since routing parameter quantities are included on *RT* records in the DIF file. The hydrology input DSS file read by both *SIMD* and *SIM* includes the naturalized flows labeled dataset 1 in Table 9.13 and evaporation-precipitation depths defined as dataset 1 in Table 9.14.

The 1940-2023 monthly SB3 EFS instream flow targets and shortages in acre-feet/month at the five WAM control points are plotted as Figures C24 through C28 of Appendix C. The monthly instream flow targets plotted in Appendix C were computed by *SIMD* by summing the daily instream flow targets computed in the *SIMD* simulation (Tables 9.23 and 9.24). These instream flow targets stored on *TS* records in the time series DSS input file are read by *SIM*.

Statistics for Daily Stream Flow and SB3 EFS Targets

Statistics for the 1940-2023 daily observed stream flows, naturalized stream flows, simulated regulated and unappropriated stream flows, and SB3 EFS instream flow targets and shortages at the five USGS gage sites are compared in Table 9.26. These statistics for the 1940-2023 time series of 30,681 daily quantities are the mean (average), median (50% exceedance frequency), minimum and maximum. The quantities in Table 9.26 are all in units of cubic feet per second (cfs). *SIMD* performs simulation computations in units of acre-feet/day. Data management, unit conversions, and statistical computations were performed within *HEC-DSSVue*.

Table 9.26
Statistics for Daily Stream Flows and SB3 EFS Targets and Shortages

USGS Gage Location (town) Control Point Identifier	Neches NENE	Rockland NERO	Alto ANAL	Evadale NEEV	Kountze VIKO
		Mean of Daily Quantities (cfs)			
Observed Flows	698.9	2,478	865.8	6,250	886.3
Naturalized Flows	807.4	1,672	953.6	6,600	889.5
Regulated Flows	446.1	2,151	723.4	4,764	888.8
Unappropriated Flows	188.9	1,597	332.9	3,861	663.9
SB3 EFS Targets	100.6	320.3	150.9	878.4	186.8
Pulse Flow Targets	36.18	122.0	68.43	125.7	71.52
Subsistence/Base Flow Targets	72.31	228.2	92.70	817.1	125.5
SB3 EFS Target Shortages	2.100	2.754	0.7605	43.98	0.4258
		Median (50% Exceedance Frequency) of Daily Quantities (cfs)			
Observed Flows	249.0	926.0	314.0	3,310	333.0
Naturalized Flows	302.3	1,010	377.2	3,149	328.6
Regulated Flows	108.9	659.0	222.6	1,034	328.1
Unappropriated Flows	0.000	0.000	0.000	226.5	100.3
SB3 EFS Targets	51.00	90.00	52.00	512.0	98.00
Pulse Flow Targets	0.000	0.000	0.000	0.000	0.000
Subsistence/Base Flow Targets	51.00	67.00	52.00	512.0	98.00
SB3 EFS Target Shortages	0.000	0.000	0.000	0.000	0.000
		Minimum of Daily Quantities (cfs)			
Observed Flows	0.5600	1.600	0.000	63.00	9.810
Naturalized Flows	0.000	0.000	0.000	0.000	8.914
Regulated Flows	0.000	0.000	0.000	0.000	7.936
Unappropriated Flows	0.000	0.000	0.000	0.000	0.000
SB3 EFS Targets	12.00	21.00	11.00	228.0	41.00
Pulse Flow Targets	0.00	0.00	0.00	0.000	0.000
Subsistence/Base Flow Targets	12.00	21.00	11.00	228.0	41.00
SB3 EFS Target Shortages	0.000	0.000	0.000	0.000	0.000
		Maximum of Daily Quantities (cfs)			
Observed Flows	44,100	49,700	41,600	92,100	151,000
Naturalized Flows	44,013	49,687	43,043	152,552	150,969
Regulated Flows	42,628	49,066	38,428	75,319	150,972
Unappropriated Flows	18,196	41,280	17,561	74,739	150,895
SB3 EFS Targets	833.0	3,080	1,620	3,830	2,010
Pulse Flow Targets	833.0	3,080	1,620	3,830	2,010
Subsistence/Base Flow Targets	196.0	603.0	277.0	1,925	264.0
SB3 EFS Target Shortages	51.00	67.00	55.00	266.0	44.69

Observed, naturalized, and *SIMD* simulated regulated and unappropriated stream flows are extremely variable over time with a great range between minimum and maximum flows. The median of stream flows is much smaller than the mean for the quantities in Figure 9.26 since high flood flows increase the mean more than the median. Naturalized flows are generally higher than observed flows at these sites. Simulated regulated flows are generally but not always lower than naturalized flows. Simulated unappropriated flows are much lower than naturalized flows.

For example, the means of observed, naturalized, and *SIMD* simulated regulated and unappropriated stream daily flows at the Romayor gage on the lower Trinity River are 8,349 cfs, 8,952 cfs, 6,003 cfs, and 4,535 cfs. Observed, naturalized, and simulated regulated flows of 2,740 cfs, 3,494 cfs, and 1,749 cfs are exceeded during 50 percent of the 30,651 days of 1940-2023. Unappropriated flows are zero during more than 50 percent the of the 30,651 days. Minimum and maximum daily flows during 1940-2023 are also included in Table 8.14.

<u>*IF* Record Instream Flow Targets for the SB3 EFS</u>

A table accompanying the *OF* record description in the WRAP *Users Manual* [2] defines 43 time series variables that may be included in *SIM* and *SIMD* simulation results output files. The five variables that are forms of instream flow targets or shortages in meeting instream flow targets are listed in Table 8.15 of Chapter 8. Labels defining the quantities in *SIM/SIMD OF* records, *TABLES* input files, and *DSS* simulation results files are shown in Table 8.15.

The *IF* record water rights modeling SB3 EFS are the only IF records at the five control points (NENE, NERO, ANAL, NEEV, and VIKO) of the SB3 EFS. Any number of instream flow *IF* record water rights can be located at the same control point. Combining instream flow targets for multiple *IF* record rights at the same control point is controlled with *IF* record parameter IFM(if,2) with the following options: a junior target replaces a senior target; the largest target is adopted; the smallest target is adopted; or targets are added.

SB3 EFS are modeled as a set of *IF*, *HC*, *ES*, and *PF* records as explained in the *Daily and Users Manuals* [2, 4] and this report. The set of records replicated in Table 9.22 separate the pulse flow and subsistence/base flow components of the EFS into two separate *IF* record water rights. Pulse flow *PF* and subsistence/base flow *ES* records can be combined into a single *IF* record instream flow water right at a control point by removing the extra *IF* records without affecting the final combined instream flow targets. The extra *IF* records in Table 9.22 allow the pulse flow component and combined subsistence and base flow components of the SB3 EFS to be examined separately in Table 9.26 and Figures 9.22, 9.23, 9.24, 9.25, and 9.26.

The computation of a SB3 EFS target consists of computing a subsistence and base flow target as specified by *ES* records and a pulse flow target as specified by *PF* records. The larger of the two targets in each individual day is adopted as the final target applied in the simulation. However, both target components are recorded in the simulation results for information using labels listed in Table 8.15 of Chapter 8 replicated from Chapter 3 of the *Users Manual* [2]. Statistics for the final daily targets (IFT-CP or IFT-WR), pulse flow component of the daily targets (TIF-WR), subsistence/base flow component of daily targets (TIF-WR), and final shortage in meeting total combined daily targets (IFS-WR) are tabulated in Table 9.26. The final total combined daily targets (blue line) and the subsistence/base flow component (red line) are plotted in Figures 9.22-9.26. The difference between the final total instream flow targets and the subsistence and base flow component of the targets in Figures 9.22-9.26 is the pulse flow component.

The non-zero daily quantities for the high pulse flow component of the EFS targets are much larger than the subsistence and base flow quantities but occur only during infrequent flood or high flow events. The subsistence and base flow component of the EFS targets are relatively small quantities in each day but occur continuously.

Monthly summations of *SIMD* simulated SB3 EFS instream flow targets and shortages in meeting the targets are compared for each of the SB3 EFS sites in the 1940-2023 monthly time series plots in Appendix C. The means of either the 30,681 daily or 1,008 monthly SB3 EFS instream flow targets at control points NENE, NERO, ANAL, NEEV, and VIKO are 11.2%, 31.6.%, 11.5%, and 17.3% of the means of the regulated flows (Table 9.26). The means of the daily *SIMD* simulated shortages in meeting the daily SB3 EFS targets are 28.3%, 50.2%, 6.06%, and 5.51% of the means of the SB3 EFS targets at NENE, NERO, ANAL, NEEV, and VIKO.

SB3 EFS Instream Flow Targets and Shortages in the Modified Monthly WAM

The monthly totals of the daily instream flow targets are incorporated in the monthly WAM as outlined in Tables 9.23 and 9.24. The monthly summations of daily target volumes generated in the daily *SIMD* simulation are precisely replicated in the monthly targets provided as input to *SIM* in the monthly WAM dataset. Shortages in meeting the SB3 EFS are computed within the monthly *SIM* simulation based on monthly regulated flows computed in the *SIM* simulation. Monthly summations of daily *SIMD* target shortages differ from monthly target shortages computed in the *SIM* simulation for the same targets. The monthly shortages in Appendix C are *SIMD* summations of daily shortages, which differ from shortages computed in a *SIM* simulation.

Simulation computations are performed in units of acre-feet/day in *SIMD* and acre-feet/month in *SIM*. The quantities in Tables 9.26 and 9.27 are converted to cfs for consistent comparison. The mean of 30,681 daily target means in cfs or 1,008 monthly target means in cfs are the same 1940-2023 target mean in cfs. The EFS target means in Tables 9.26 and 9.27 are the same for daily *SIMD* and monthly *SIM* simulations. The other statistics differ between daily *SIMD* and monthly *SIM* simulations. The means of SB3 EFS targets in column 2 of Table 9.27 are the same in the daily *SIMD* and monthly *SIM* simulations but the target shortages differ in columns 3 and 4 as discussed in the preceding paragraph. The median of 30,681 daily targets is different than the median of 1,008 monthly targets.

Table 9.27
Comparison of Monthly *SIM* and Daily *SIMD* EFS Target and Shortage Means and Medians

SB3 EFS Site	Mean (cfs)			Median (cfs)			
	Targets	Shortages		Targets		Shortages	
	for Both	*SIMD*	*SIM*	*SIMD*	*SIM*	*SIMD*	*SIM*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NENE Neches River, Neches	100.6	2.100	0.2224	51.00	65.69	0.000	0.000
NERO Neches River, Rockland	320.3	2.754	0.5845	90.00	142.8	0.000	0.000
ANAL Angelina River, Alto	150.9	0.7605	0.3969	52.00	75.00	0.000	0.000
NEEV Neches River, Evadale	878.4	43.98	40.96	512.0	525.4	0.000	0.000
VIKO Village Creek, Kountze	186.8	0.4258	0.3243	98.0	115.3	0.000	0.000

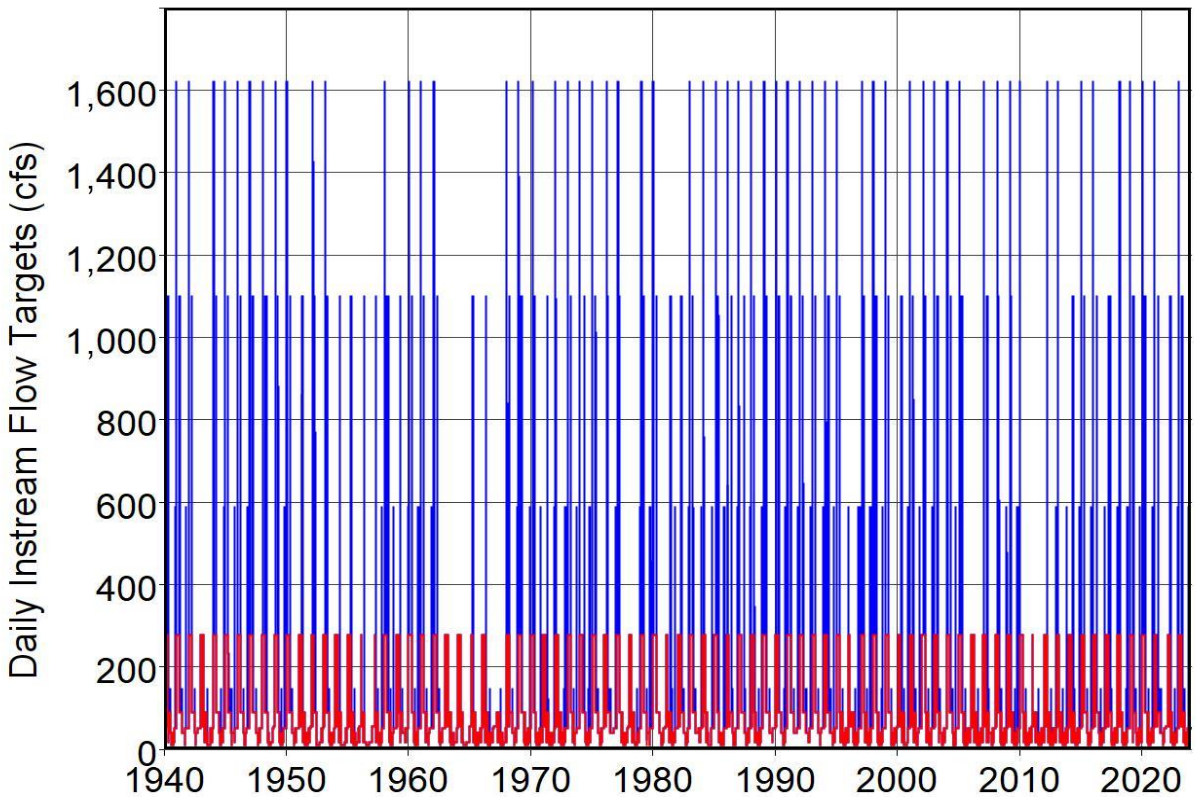

Figure 9.22 SB3 EFS Total (**blue**) and Subsistence/Base (**red**) Targets at Alto (ANAL)

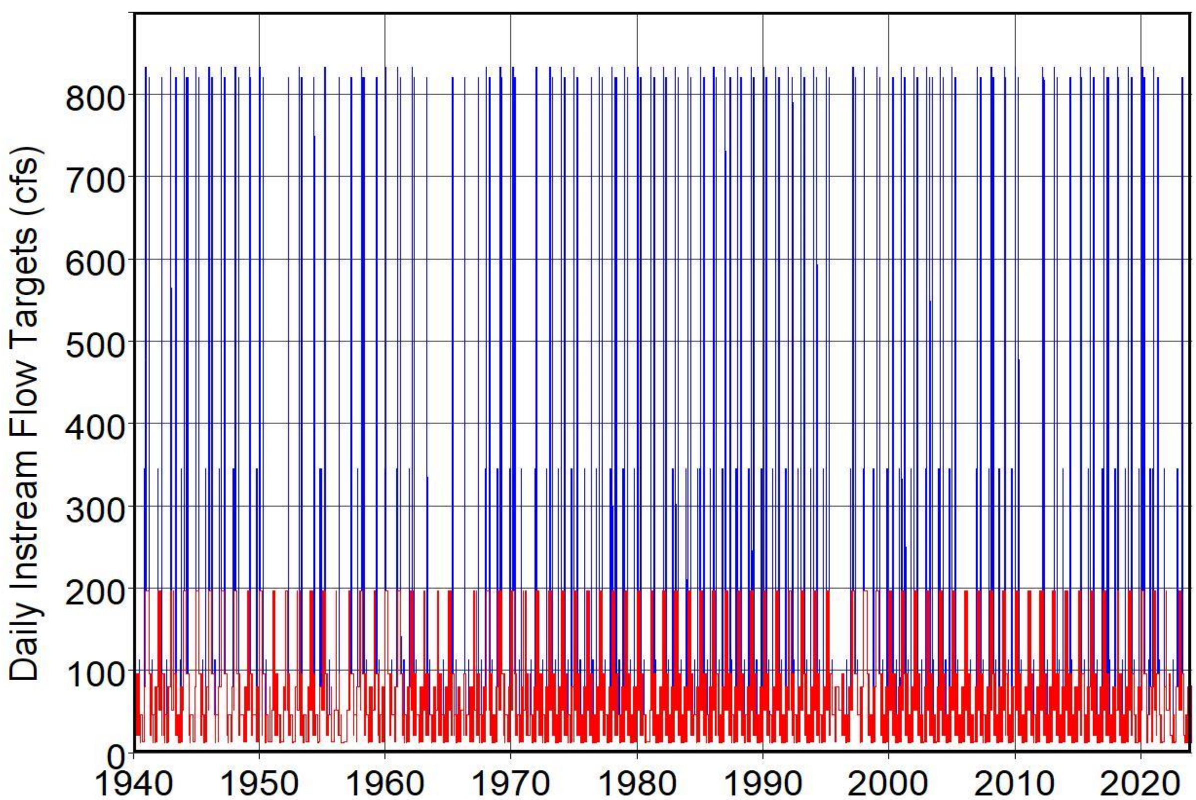

Figure 9.23 SB3 EFS Total (**blue**) and Subsistence/Base (**red**) Targets at Neches (NENE)

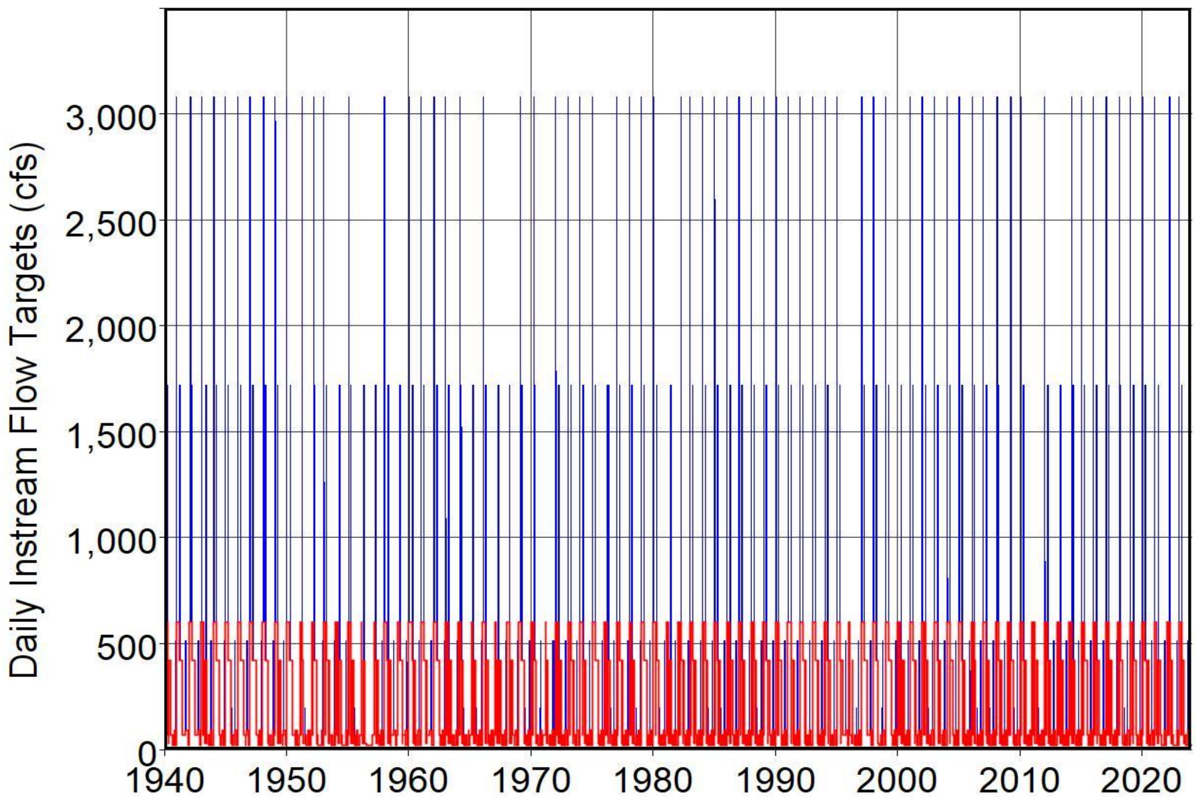

Figure 9.24 SB3 EFS Total (**blue**) and Subsistence/Base (**red**) Targets at Rockland (NERO)

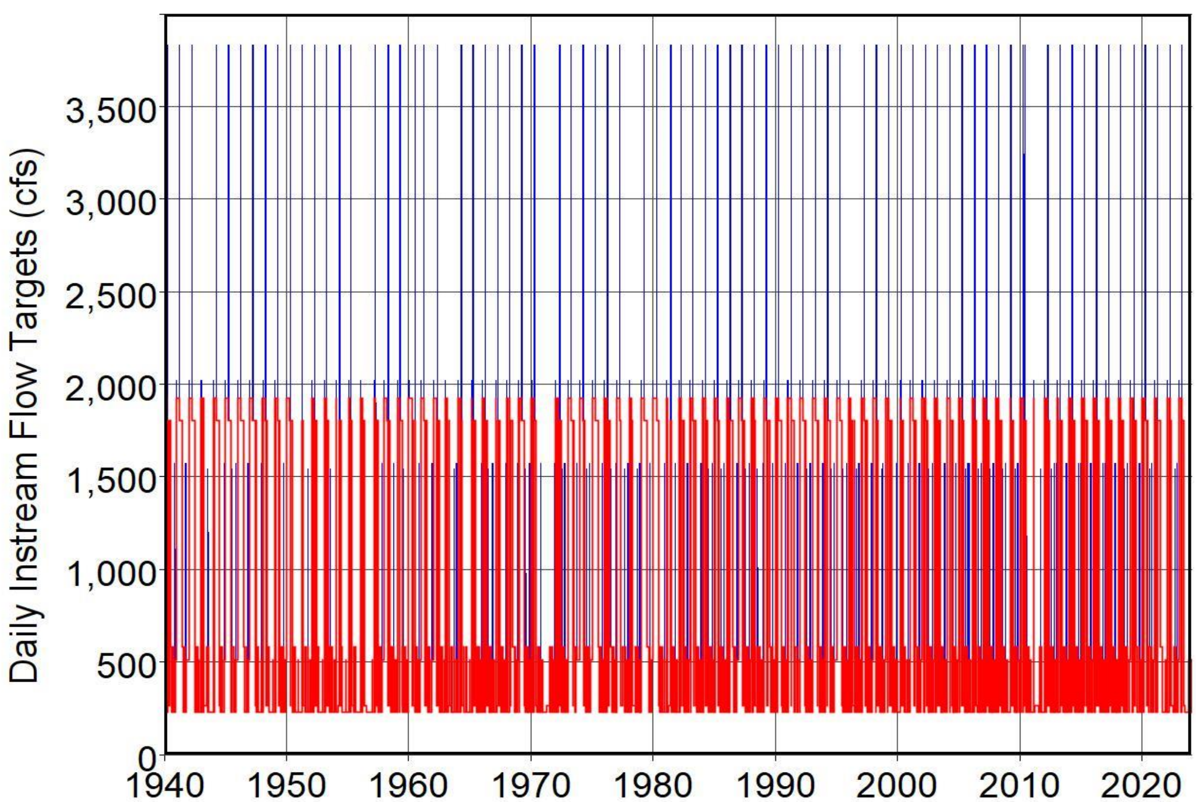

Figure 9.25 SB3 EFS Total (**blue**) and Subsistence/Base (**red**) Targets at Evadale (NEEV)

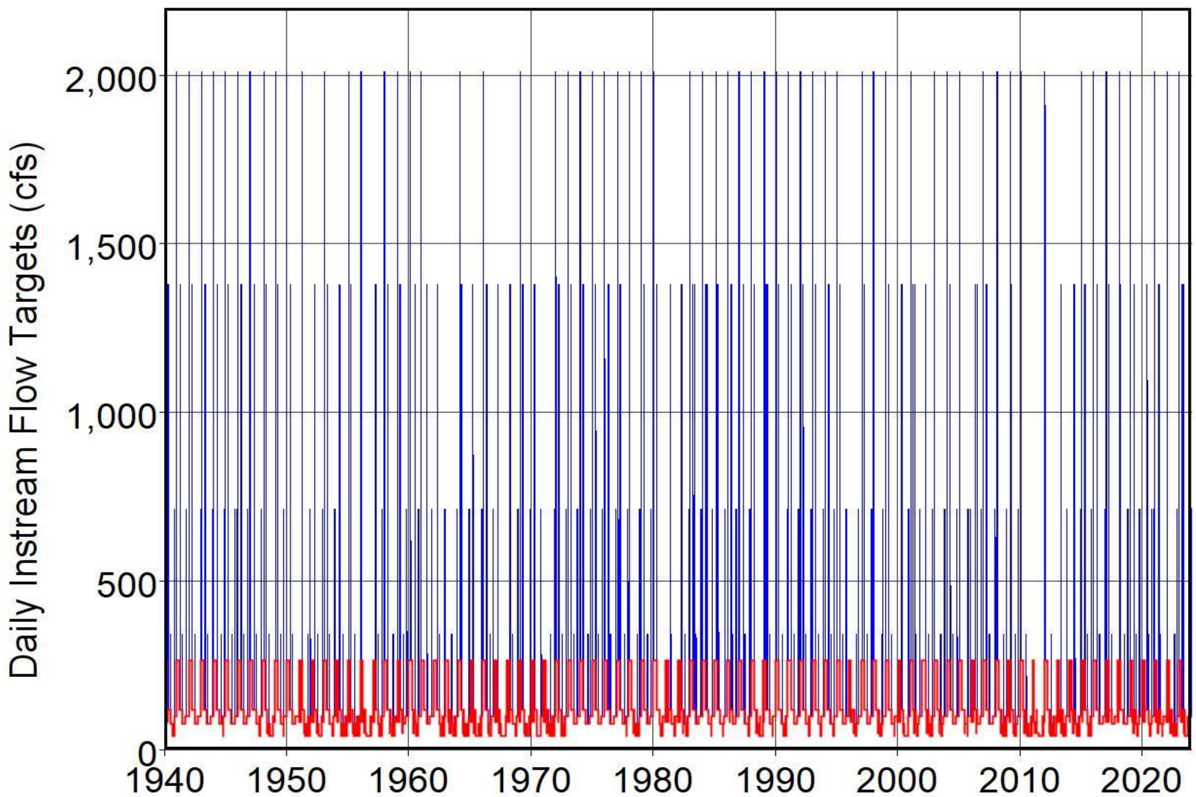

Figure 9.26 SB3 EFS Total (**blue**) and Subsistence/Base (**red**) Targets at Kountze (VIKO)

Flow rate units of acre-feet/month or acre-feet/day are employed in the *SIM* and *SIMD* simulation computations. Flow rates in the SB3 EFS are expressed in cfs. The WRAP programs read and create DSS files. All time series plots in this report were prepared with *HEC-DSSVue*. Unit conversions are conveniently performed within *HEC-DSSVue*.

As previously discussed, Figures 9.22, 9.23, 9.24, 9.25, and 9.26 are plots of the daily total instream flow target (**blue line**) for the SB3 EFS and the daily combined subsistence and base flow components (**red line**) of the SB3 EFS in the *SIMD* simulation with no routing and no forecasting. The difference between the plots is the pulse flow component. Units are cfs in these figures.

The 1940-2023 monthly SB3 EFS instream flow targets and shortages at the five control points in the *SIM* simulation are plotted in as Figures C24, C25, C26, C27, and C28 of Appendix C. The monthly SB3 EFS instream flow targets were generated with the daily *SIMD* simulation referenced in the preceding paragraph following the strategy outlined in Tables 9.23 and 9.24. The instream flow shortages plotted in the figures of Appendix C were generated in a monthly *SIM* simulation as previously discussed. The quantities in Appendix C were read by *HEC-DSSVue* from a *SIM* output DSS file in acre-feet/month and plotted in these same units.

CHAPTER 10
COLORADO DAILY AND MODIFIED MONTHLY WAMS

The term *Colorado WAM* refers to the WRAP simulation input dataset for the Colorado River Basin and adjoining Brazos-Colorado Coastal Basin available at the TCEQ water availability modeling (WAM) website and modified monthly or daily variations thereof. Development of the original monthly Colorado WAM is documented by a 2001 report [89] prepared by a team of engineering consulting firms for the Texas Natural Resources Conservation Commission (later renamed TCEQ). The original Colorado WAM had a hydrologic period-of-analysis of January 1940 through December 1998 which was later extended through December 2016.

The developmental daily full authorization Colorado WAM prepared at TAMU for TCEQ employing the new features of WRAP for modeling SB3 EFS is documented by a 2022 report [10] that explains in detail the development of daily WAM and modified monthly WAMs. Modeling complexities and issues are investigated. The studies include comparative analyses of the sensitivity of simulation results to daily *SIMD* versus monthly *SIM* models, alternative negative incremental flow ADJINC options, beginning-of-simulation storage options, lag and attenuation routing, alternative flow forecast periods, flood control operations, and SB3 EFS. The utility of DSS is demonstrated. New features in *SIM* and *SIMD* for labeling artificial control points, reservoirs, and water rights are introduced [10].

The daily WAM was developed as described in the 2022 report by converting the monthly Colorado WAM last updated by TCEQ in February 2020 to daily. The 2024 daily full authorization WAM described in the present report was developed by converting the monthly WAM last updated by TCEQ in October 2023 to daily. The 1940-2016 hydrologic period-of-analysis of the 2020, 2022, and 2023 versions of the Colorado WAM is extended through December 2023 for the 2024 daily and modified monthly versions presented in this chapter. All 2020 and later versions include the 2020 updated Lower Colorado River Authority (LCRA) water management plan [96, 97].

The daily WAM developed as explained in this chapter is employed to compute 1940-2023 daily and monthly instream flow targets for SB3 environment flow standards (EFS) at 14 sites in the Colorado River Basin [98]. The monthly SB3 EFS are organized as a target series *TS* record input dataset for the monthly WAM following the same procedure employed with all six case study WAMs presented in Chapters 7-12.

Colorado River Basin and Adjoining Brazos-Colorado Coastal Basin

The Colorado WAM combines the Colorado and adjoining Brazos-Colorado Coastal Basins. The Colorado River Basin extends from southeast New Mexico across Texas to Matagorda Bay as shown in Figure 10.1. The river basin has a total area of 45,570 square miles with 42,870 square miles are in Texas. About 11,830 square miles of the upper basin contributes essentially no inflow to the river system and is classified by USGS as non-contributing. The upper headwaters are at elevations of about 4,000 feet. The climate of the basin varies from arid in the northwest upper basin with an average annual precipitation of between 12 and 16 inches to humid subtropical in the southeast lower basin with average annual precipitation of about 44 inches. The major tributaries of the Colorado River are Beals Creek, Pecan Bayou, Concho River, San Saba River, Llano River, and Pedernales River, all entering the Colorado River upstream of the City of Austin.

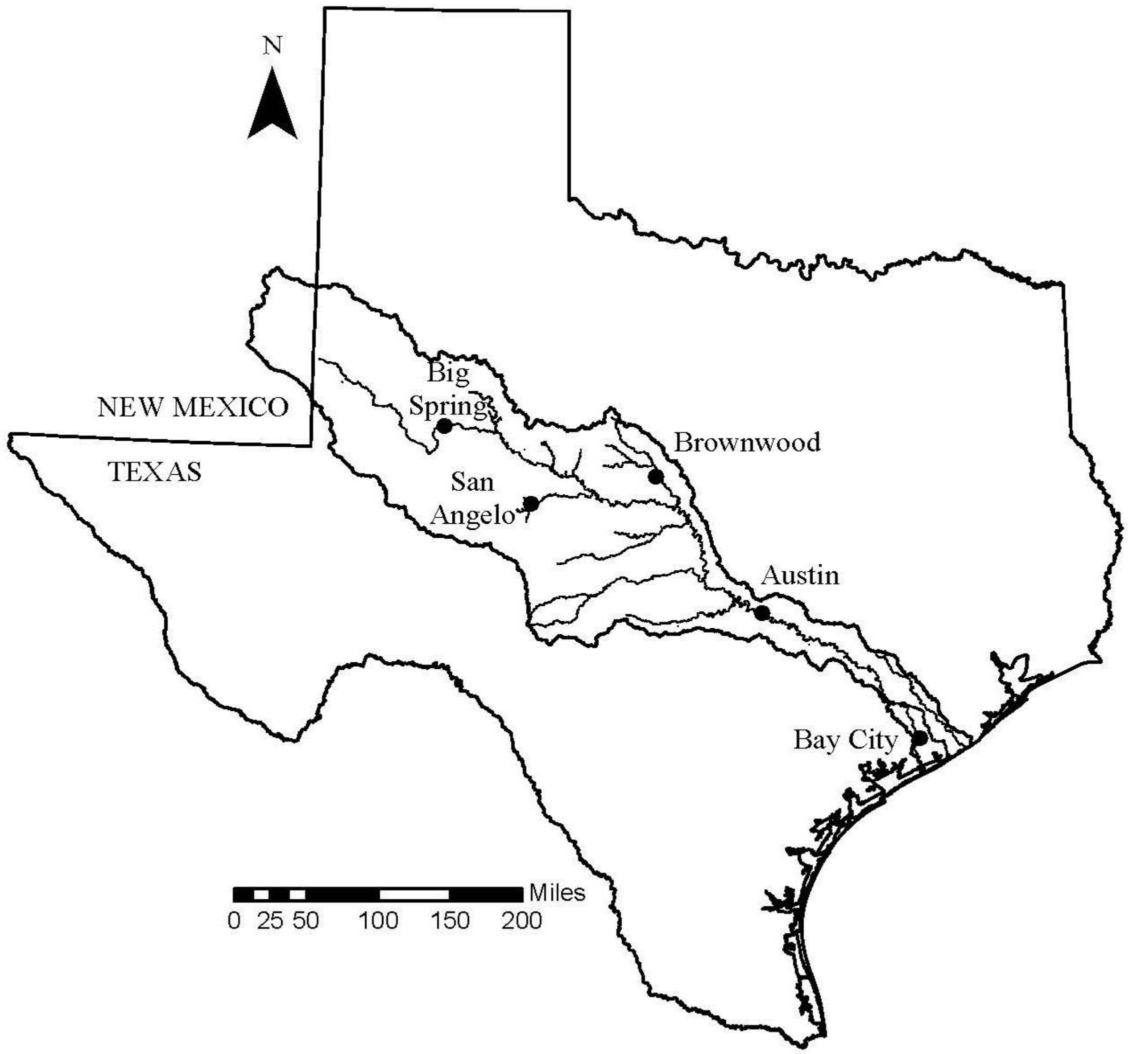

Figure 10.1 Colorado River Basin and Brazos-Colorado Coastal Basin

The Brazos-Colorado Coastal Basin is located to the east of the Colorado River Basin between the Colorado and Brazos River Basins. The watershed area is about 1,860 square miles. Main streams are the San Bernard River and Caney Creek. There are no major reservoirs in this coastal basin.

Austin is the largest city in the Colorado River Basin, fourth largest city in Texas, and one of the fastest growing large cities in the nation. The Colorado River flows through Austin and serves as the primary water supply source for the city. Austin both holds its own water rights and contracts with the Lower Colorado River Authority (LCRA) for water supplied under LCRA water rights. LCRA and the Colorado River Municipal Water District (CRMWD) control most of the reservoir storage capacity in the lower and upper basins, respectively. Lake Buchanan is viewed as the divide between the Upper and Lower Colorado River.

LCRA created by the Texas Legislature in 1934 has no taxing authority and operates solely on utility revenues and fees generated from supplying electrical energy, water, and community services. LCRA supplies wholesale electric power to 43 city-owned utilities and electric cooperatives that serve over a million people in Central Texas. The river authority owns and operates three gas-fired electric power plants, one coal-fired power plant, and six hydroelectric plants and also purchases electricity from three wind farms. LCRA manages more than 16,000 acres of recreational lands along the Colorado River and administers other programs supporting community and economic development. The agency operates the off-channel Lakes Bastrop and Fayette County (Cedar Creek) to provide cooling water for thermal-electric power plants as well as operating the six multiple-purpose Highland Lakes.

LCRA owns five and operates all six of the Highland Lake projects on the Colorado River. The lakes are listed in upstream-to-downstream order in Table 10.1. The authorized storage capacities in the third column are from the water right permits. The information in the last four columns is provided at the LCRA website. Capacities and water surface areas for Lakes Buchanan, LBJ, Marble Falls, and Travis reflect volumetric surveys performed during 2020-2021.

Table 10.1
Highland Lakes on the Colorado River Operated by LCRA

Dam	Lake	Authorized Capacity (acre-feet)	Actual Capacity (acre-feet)	Surface Area (acres)	Elevation at Top of Normal Pool (feet msl)	Elevation at Top of Dam (feet msl)
Buchanan	Buchanan	992,475	880,356	22,452	1,020	1,025.5
Inks	Inks	17,545	13,668	777	888	922
Wirtz	LBJ	138,500	131,618	6,432	825	838.5
Starke	Marble Falls	8,760	7,597	613	737	761.5
Mansfield	Travis	1,170,752	1,115,076	19,044	681	750
Tom Miller	Austin	21,000	24,644	1,830	492.8	517

Tom Miller Dam is owned by the City of Austin and operated by LCRA. Lake Austin is located in the City of Austin. The five other lakes are owned by LCRA and located upstream of Austin. Hydroelectric power plants at each of the six dams are operated to use water supply releases for downstream diverters to help meet peak electric power demands. Releases for only hydroelectric energy generation occur only during energy-related emergencies. Lake Travis has a flood control pool. Lake LBJ provides cooling water for a LCRA thermal-electric power plant. Lakes Buchanan and Travis contain water supply storage used primarily to supply municipal and industrial users in Austin and vicinity and agricultural irrigation needs primarily for the Gulf Coast, Lakeside, Garwood, and Pierce Ranch irrigation operations near the Gulf Coast.

The LCRA system is operated in accordance with a water management plan that governs water allocation during droughts when all LCRA customers cannot be fully supplied [96, 97]. Water is released from Lakes Buchanan and Travis whenever flows in the lower river are inadequate to meet downstream needs, including environmental instream river flows and freshwater inflows to Matagorda Bay. The water management plan divides supplies between *firm* (*uninterruptible*) and *interruptible* based on storage level triggers in Lakes Buchanan and Travis. Firm water is available even during a severe drought. During water shortages, interruptible water, which is used primarily for agricultural irrigation, is curtailed as necessary to protect firm water supply commitments for primarily municipal, industrial, and thermal-electric cooling uses.

The Colorado River Municipal Water District (CRMWD) is the largest reservoir owner, water right holder, and water supplier in the upper Colorado River Basin. The CRMWD was created by the Texas Legislature in 1949 for the purpose of providing water to its member cities of Odessa, Big Spring, and Snyder. The CRMWD also has water supply contracts with the cities of Midland, San Angelo, Stanton, Robert Lee, Grandfalls, Pyote, and Abilene and the Millersview-Doole Water Supply Corporation. CRMWD owns and operates J.B. Thomas, E.V. Spence, and O.H. Ivie Reservoirs, which have authorized water supply storage capacities of 204,000 acre-feet, 488,760 acre-feet, and 554,340 acre-feet. The CRMWD also operates four well fields used primarily to supplement surface water sources during the summer months.

The CRMWD owns nine other reservoirs that are used to prevent low-quality, high salinity water from flowing downstream. Water is permanently impounded or diverted for other uses. These nine salinity control impoundments are Sulphur Draw Reservoir, Red Lake Reservoir, Natural Dam Lake, Barber Reservoir, Mitchell County Reservoir, Red Draw Reservoir, Beals Creek Sump, Three Mile Lake, and Four Mile Lake.

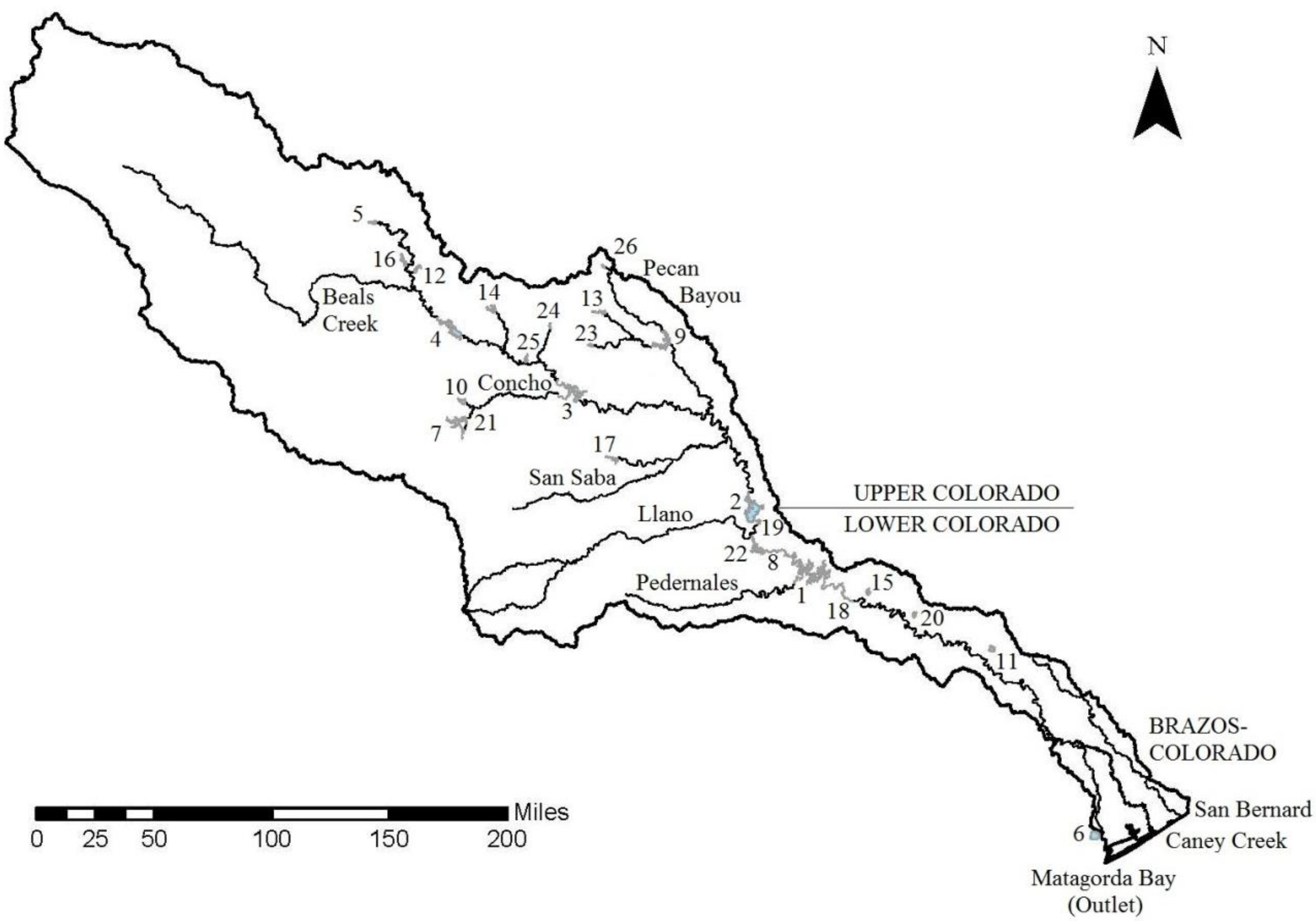

Figure 10.2 Major Tributaries and Largest Reservoirs

Table 10.2
Major Reservoirs in the Colorado Full Authorization WAM

Map ID	Reservoir	Reservoir Identifier	Control Point	Initial Impoundment	Authorized Capacity
					(acre-feet)
1	Lake Travis	TRAVIS	I20000	1940	1,170,752
2	Lake Buchanan	BUCHAN	I40000	1937	992,475
3	O.H. Ivie Reservoir	OHIVIE	D20050	1990	554,340
4	E.V. Spence Reservoir	SPENCE	B10050	1968	488,760
5	Lake J.B. Thomas	THOMAS	A30060	1952	204,000
6	STP Main Cooling Pond	STHTEX	M10024	1979	202,988
7	Twin Buttes Reservoir	TWINBU	C20240	1962	186,200
8	Lake LBJ	LAKLBJ	I21280	1951	138,500
9	Lake Brownwood	BROWNW	F30130	1933	135,963
10	O.C. Fisher Lake	OCFISH	C20040	1952	119,200
11	Fayette County (Cedar Cr)	CEDARC	J10121	1977	71,400
12	Champion Creek Reservoir	CHAMPI	B40000	1959	42,500
13	Lake Coleman	COLEMA	F30420	1966	40,000
14	Oak Creek Reservoir	OAKCRK	D40620	1953	39,360
15	Walter E. Long Lake	DECKER	J30330	1967	33,940
16	Lake Colorado City	COLOCI	B20020	1949	29,934
17	Brady Creek Reservoir	BRADYC	E20090	1963	30,000
18	Lake Austin	LKAUST	I10340	1939	21,000
19	Inks Lake	ROYINK	I20820	1938	17,545
20	Lake Bastrop	BASTRO	J30030	1964	16,590
21	Lake Nasworthy	NASWOR	C20240	1930	12,500
22	Lake Marble Falls	MARBLE	I20590	1957	8,760
23	Hords Creek Lake	HORDSC	F30370	1948	7,959
24	Lake Winters	ELMCRK	D30450	1983	8,374
25	Ballinger Municipal Lake	BALLIN	D40040	1978	6,050
26	Clyde Lake	LCLYDE	F31130	1970	5,748
-	Eagle Lake	EAGLAK	FK20050	1900	9,600
-	Mitchell County Reservoir	1008EV	B30010	1991	38,304
-	Phillips Petroleum	PRES	PHILL	-	16,118
-	Baylor Creek	BAYLOR	J10150	proposed	46,600
-	LCRA Permit 5731	FLDFLW	573141	proposed	500,000

The 486 reservoirs included in the full authorization Colorado WAM include 31 reservoirs with permitted storage capacities exceeding 5,000 acre-feet. These 31 major reservoirs listed in Table 10.2 include 29 existing reservoirs and two other permitted but not yet constructed projects. One of the two proposed but not yet constructed projects may consist of storage in multiple LCRA off-channel reservoirs though modeled in the WAM as a single storage project. The 29 existing major reservoirs with capacities summing to 4,648,860 acre-feet account for 87.7 percent of the authorized storage capacity of 5,303,830 acre-feet of the 486 reservoirs included in the WAM. The map identifiers in the first column of Table 10.2 refer to Figure 10.2.

The permitted storage capacity authorized by water right permits for the six Highland Lakes (Table 10.1) total 2,349,032 acre-feet, which is 50.5 percent of the authorized capacity of the existing 29 reservoirs with storage capacities exceeding 5,000 acre-feet and 44.3 percent of the total storage capacity of the 486 reservoirs in the authorized use scenario Colorado WAM.

Lakes J.B. Thomas, E.V. Spence, and O.H. Ivie Reservoirs owned and operated by the CRMWD have authorized storage capacities that total 1,247,100 acre-feet. These three reservoirs in the upper basin contain 26.8 percent of the permitted storage capacity of the 29 existing major reservoirs and 23.5 percent of the total permitted storage capacity of the 486 reservoirs included in the WAM. Thus, nine large reservoirs operated by the LCRA and CRMWD account for 77.3 percent of the permitted storage capacity of the 29 existing major reservoirs and 67.8 percent of the total permitted storage capacity of the 486 reservoirs included in the WAM. The LCRA and CRMWD also own and operate several smaller reservoirs in addition to these nine larger projects.

The Fort Worth District (FWD) of the U.S. Army Corps of Engineers (USACE) owns and operates Hords Creek Dam and Reservoir and O.C. Fisher Dam and Reservoir (formerly called San Angelo Dam and Reservoir) for flood control, water supply, and recreation. Hords Creek is by far the smallest Corps of Engineers reservoir in Texas. The Central Colorado River Authority has contracted for the water supply storage of Hords Creek Reservoir which is used to supply the City of Coleman. The Upper Colorado River Authority has contracted for the water supply storage of O.C. Fisher Reservoir. The USACE FWD is also responsible for operations of the flood control pools of two other reservoirs in the Colorado River Basin that were constructed by the U.S. Bureau of Reclamation and are now owned and operated by nonfederal project sponsors: Lake Travis owned by the LCRA and Twin Buttes Reservoir owned by the City of San Angelo.

Colorado WAM Data Files

The full authorization (run 3) WAM last updated by TCEQ on 10/1/2023 is comprised of six S*IM* input files with the following filenames: C3.DAT, C3.DIS, C3.FLO, C3.EVA, C3.HIS, and C3.FAD. The first tasks documented in this chapter consist of extending the hydrologic period-of-analysis through 2023 and storing the time series data (*IN*, *EV*, *HI*, and *FA* records) in a DSS file. The updated version of the monthly WAM consists of three *SIM* input files with the following filenames: Colorado3.DAT, Colorado3.DIS, and ColoradoHYD.DSS.

As discussed later in this chapter, the monthly WAM with 1940-2023 period-of-analysis is converted to a daily WAM comprised of four *SIMD* input files with the following filenames.

ColoradoD.DAT, Colorado.DIS, Colorado.DIF, ColoradoHYD.DSS

Daily instream flow targets for SB3 EFS at 14 sites are computed and summed to monthly totals in a daily *SIMD* simulation. The monthly SB3 EFS instream flow targets from the *SIMD* simulation results DSS output file are converted with *HEC-DSSVue* to time series *TS* records added to the *SIM/SIMD* hydrology DSS input file. The modified monthly WAM reads the *TS* records from the DSS input file. The modified monthly WAM consists of the following three *SIM* input files.

ColoradoM.DAT, Colorado.DIS, ColoradoHYD.DSS

The same hydrology DIS and DSS files are read by both *SIM* and *SIMD*. DSS files can contain any of records in any format. *SIM* and *SIMD* read only records relevant to the particular simulation, skipping over all other inapplicable records. The DIS file is identical for both *SIM* and *SIMD*.

<u>Components of Monthly Colorado WAM</u>

The 2022 Daily Colorado WAM Report [10] describes the components of various versions of the WAM in detail. Several features of the Colorado WAM are briefly highlighted as follows.

The WRAP simulation model *SIM* prints a listing in its message file of the number of various system components. The counts in the second, third, and fourth columns of Table 10.3 are discussed in the 2022 report [10]. The last two columns contain counts for more recent updates. The original 2001 WAM has been updated by TCEQ multiple times in addition to the updated versions included in Table 10.3. The last column in Table 10.3 is for the final modified monthly WAM developed as described later in this chapter. The message MSS file counts in Table 10.3 are totals that include the artificial control points, reservoirs, and water rights discussed in this section.

Table 10.3
Number of Model Components in Monthly Colorado WAM Datasets

Latest WAM DAT File Update Water Use Scenario	Aug 2007 Authorized	Aug 2007 Current	Feb 2020 Authorized	Oct 2023 Authorized	Nov 2024 Authorized
total number of control points	2,395	2,396	2,457	2,524	2,524
number of primary control points	45	45	45	45	45
sets of *EV* record evap-precip rates	48	47	48	48	48
number of reservoirs counted by *SIM*	511	510	526	527	527
number of *WR* record water rights	1,922	1,928	2,167	2,233	2,233
number of instream flow *IF* records	86	93	120	169	183
number of system water rights	132	134	446	462	476
number of drought index *DI* records	6	7	21	21	21
number of *FD* records in DIS file	2,206	2,206	2,240	2,249	2,249
hydrologic period-of-analysis	1940-1998	1940-1998	1940-2016	1940-2016	1940-2023

The hydrologic period-of-analysis is 1940-1998 for the original 2001 WAM and the 2007 WAM and 1940-2016 for the 2020 and 2023 updated versions. The 2020 and later updates employ the dual simulation option. The 2007 and earlier versions did not include the dual simulation feature which had not yet been added to *SIM*. Negative incremental flow adjustment ADJINC option 5 is activated in *JD* record field 9 in for the 2007, 2020, and 2023 versions of the Colorado WAM. Computational adjustments were performed during development of the naturalized flows to remove the majority of negative incrementals in the naturalized flow dataset.

<u>Artificial Control Points, Reservoirs, and Water Rights</u>

Use of artificial reservoirs, water rights, and control points to model various complexities of water management dates back to the original 2001 Colorado WAM and has continued with subsequent updates. Many of the artificial water rights, reservoirs, and control points were devised in conjunction with simulating the LCRA Water Management Plan [96, 97]. Artificial reservoirs, water rights, and reservoirs are included in WAMs for several other river basins but not to the extent as the Colorado WAM.

The term "*dummy*" control points and reservoirs has been used in the past rather than "*artificial*". The modeling concept of artificial or dummy components involves creatively devising schemes for performing water accounting computations using *SIM* features differently than their conventional representation of locations of actual physical features. Devised "*artificial*" water accounting schemes simulate various water management complexities.

The effects of artificial water rights, reservoirs, and control points on totals of *SIM* input DAT file quantities are illustrated by Table 10.4. The Colorado WAM last updated by TCEQ in October 2023 has 2,524 control points, which include 2,292 control points representing actual physical locations in the stream system. An additional 142 artificial control points are used in *SIM* water accounting computations to model certain water right complexities, rather than defining physical locations. The WAM includes 527 reservoirs with storage capacities that sum to 250,246,928 acre-feet of which 41 reservoirs are artificial and thus used only in the water accounting computations. The storage capacities of the 41 artificial reservoirs are arbitrarily large numbers and account for most of the total storage capacity of the 527 reservoirs in the WAM. The WAM simulates 486 actual physical storage facilities providing an authorized total capacity of 5,303,829 acre-feet.

Table 10.4
Comparison of Totals of WAM Artificial Versus Real River/Reservoir System Quantities

Quantity	Entire Dataset	Artificial	Actual (Real)
Number of Control Point *CP* Records	2,524	132	2,392
Number of Water Right *WR* Records	2,233	435	1,798
Total Diversion (*WR* AMT, acre-feet/year)	800,907,712	786,776,256	14,131,358
Number of Reservoirs	527	41	486
Total Storage Capacity (acre-feet)	250,246,928	244,983,200	5,303,829
Most Junior Water Right Priority	0	0	18641231
Most Senior Water Right Priority	99999999	99999999	20501231

Artificial control points, water rights, and reservoirs complicate the interpretation of the *SIM* input dataset and the simulation results. New features were added in the July 2022 versions of *SIM* and *TABLES* to improve clarity in analyzing the *SIM* input DAT file and *SIM* simulation results [2, 13]. Actual numerical values of individual variables are not altered, but inclusion or exclusion in aggregation or summation of quantities can be better controlled. Analyses of the input dataset and simulation results are performed more efficiently, conveniently, and thoroughly.

The new features for labeling artificial model components were adopted in the 2022 daily and modified monthly Colorado WAMs [10] and continued in the present update. The modification to the *SIM* input DAT file consists of adding the 17 control point output *CO* records and one water right output *WO* record with the ARTIF option activated shown in Table 10.5. *SIM*, *SIMD*, and *TABLES* automatically define any water right or reservoir located at a *CO* record designated artificial control point as being an artificial water right or reservoir. Additionally, water rights on a *WO* record with the ARTIF option activated are also designated as being artificial [2].

Table 10.5
Designation of Artificial System Components in the Colorado WAM

```
CO ARTIF  MENFK1  MENFK2  INKSTO  LBJSTO  FURSTO  MARSTO  AUSSTO     OFI
CO ARTIF  GARWRF  GULFRF  LAKERF  PIERRE  IRRTF1  IRRTF2  IRRTF3  IRRTF4  COASUB
CO ARTIF   FAKE1   FAKE2   FAKE3   FAKE4   FAKE5   FAKE6   FAKE7   FAKE8   FAKE9  FAKE10  FAKE11  FAKE12
CO ARTIF  FAKE13   TRACK  FAKE20  FAKE21  FAKE22  FAKE23  FAKE24  FAKE25  FAKE26  FAKE27  FAKE28  FAKE34
CO ARTIF  STPLIM  A-ZERO
CO ARTIF  IVIEFF  BRWNFF  FFOP60
CO ARTIF  SW-LIM  SWGLIM  FAK102  FAK103  SYSCNT  CUMINF  DRT-US  50S-TI  FAK104  FAK105  FAK106  33PCFL
CO ARTIF  50PCFL  FIXEDQ  EXTDRT  LS-DRT  HTI-00  HTI-01  HTI-02  DRTCND
CO ARTIF  STOMAR  STOJUL  AGNHEP  AGLHEP  EXDH14  LSDH14
CO ARTIF  LSDH15  ANY-CO  ANY-PT  ANYNOR  ANYLSD  EXTMAN  LSDMAN  ENV-BO  3MCFLW  FAKE29  AG-CUR  GW-CUR
CO ARTIF  GW-FCT  NG-FCT  GWFFCF  NGFFCF  OP60T1  OP60T2  OP60T3  OP60T4  FAKEBA  BAY-00  BAY-01  BAY-02
CO ARTIF  BAY-03  SPMBHE  2CSSCT  SEADAT  OP1EXC  OP2EXC  OP3EXC  OP4EXC  OP1MIN  OP2MIN  OP3MIN  OP4MIN
CO ARTIF  MB1-SF  MB1-FF  MB2-SF  MB2-FF  MB3-SF  MB3-FF  MB4-SF  MB4-FF  ENVCAP  EUS-01  EUS-02  EUS-03
CO ARTIF  EUS-04  EUS-05  EUS-06  EUS-07  EUS-08  EUS-09  EUS-10  EUS-11  EUS-12  DRTNUM  DRTCON  DRTKEY
CO ARTIF  MBHEFL
CO ARTIF  NJSEVT  NJSVD1  NJSVT2  NJSVT3  NJBDRY
CO ARTIF  GCE-TW  GCE-AR  DLYGCE  FAKEAO
WO ARTIF     STPDUMMYNO1     STPDUMMYNO2     STPDUMMYNO3     STPDUMMYNO4     11405731IV1     11405731BR1
```

Instream Flow *IF* Record Water Rights

Instream flow requirements are defined by 169 *IF* records in the full authorization scenario Colorado WAM last updated by TCEQ in October 2023. The 169 *IF* records represent instream flow requirements at fewer than 169 locations. Sets of multiple *IF* records are employed in combination to model instream flow requirements at single locations. The *IF* record water rights have priorities ranging from 19041231 to 20100804 (December 31, 1904 to August 4, 2010).

The instream flow requirements are modeled using various combinations of options. In many cases, instream flow requirements are modeled using only input parameters entered on the *IF* record. In other cases, instream flow requirements are modeled by combining *IF* record specifications with additional options activated using monthly use coefficient *UC*, reservoir storage *WS*, target options *TO*, flow switch *FS*, and/or drought index *DI/IS/IP/IM* records. *WR* record type 8 water rights are also used in combination with *TO* records to develop instream flow targets for *IF* record water rights. A *WR* record with the water right type 8 option selected does nothing but compute a target, though various options can the employed to compute that target. *IF* records may employ *TO* records that reference *WR* record water right type 8 targets.

The 169 *IF* records in the monthly Colorado WAM last updated by TCEQ in October 2023 protect downstream senior water rights and environmental instream flow needs. Several of the *IF* record water rights model minimum flow requirements at four gages on the Colorado River below Lake Travis and bay and estuary freshwater inflows to Matagorda Bay described in the LCRA Water Management Plan [96, 97]. Many of the *IF* record rights model instream flow requirements associated with particular water use permits for water supply diversions and storage at scattered locations throughout the river basin.

Environmental flow standards (EFS) established through a process mandated by the 2007 Senate Bill 3 (SB3) with priority dates of March 1, 2011 are added to the daily and modified monthly WAMs as described later in this chapter. The relationship between previous *IF* records and the new SB3 EFS are discussed in the 2022 Daily WAM Report [10]. The existing *IF* record rights in the monthly Colorado WAM are not altered in the conversion to a daily WAM other than uniformly distributing the monthly instream flow targets to the 28, 29, 30, or 31 days in each month. The new SB3 EFS described later are additional *IF* record water rights added to the WAM.

May 2019 and later versions of the WRAP simulation models *SIM* and *SIMD* include environmental standard *ES*, hydrologic condition *HC*, and pulse flow *PF* records designed for modeling environmental instream flow requirements formulated in the format adopted by the 2007 SB3 process. Both *SIM* and *SIMD* include *ES* and *HC* records. *PF* records are applicable only in a daily *SIMD* simulation. SB3 EFS are modeled with these records as explained later in this chapter.

Colorado Monthly WAM Hydrology

The versions of the monthly Colorado WAM last updated by TCEQ in February 2020 and October 2023 have the same 1940-2016 hydrologic period-of-analysis, same 45 primary control points with the same naturalized flows, and same 48 sequences of net evaporation less adjusted precipitation depths. February 2020 and October 2023 versions of the full authorization WAM have 2,457 and 2,524 total control points, respectively. The 2022 and updated 2024 daily WAMS both have daily flow *DF* records for each of the 45 primary control points based on observed daily flows. Flow adjustment *FA* records for spring flow are provided for 13 control points in the 2020, 2022, and 2024 versions of the WAMs. The 1940-2016 *IN*, *EV*, and *DF* record quantities are the same for all 2020 and later versions of the WAM. The period-of-analysis has been extended through 2023 for the 2024 daily and modified monthly versions of the WAM. The DAT file of all versions include 13 *TS* records used with *WR* and *TO* records for modeling requirements for bay inflows. The 2016 on the 13 *TS* records are updated to 2023 in the 2024 DAT files.

Adjustments to Naturalized Stream Flows for Spring Flows

Changes in groundwater pumping over time may in some cases affect stream flow. Simulating the reductions or increases in stream flow that result from changing groundwater levels is a complex problem. Groundwater use is not directly included in WRAP and the WAMs [1]. However, flow adjustments input on *FA* records are adopted in the Colorado WAM to approximate spring flows which are affected by groundwater use [81, 89].

The process for developing the original 1940-1998 naturalized flows documented by the 2001 WAM report [89] separated spring flows from naturalized stream flows at some sites. The procedure for dealing with spring flows in the original development of the naturalized flow dataset has been replicated with some modifications in later flow extensions [81]. In the 2023 and 2024 versions of the Colorado WAM explored in this chapter, observed sequences of spring flows at the 13 control points in Table 10.3 are included in the *SIM/SIMD* input as flow adjustment *FA* records.

The monthly quantities in acre-feet on flow adjustment *FA* records in a FAD or DSS file are added by *SIM* or *SIMD* to the naturalized flows at specified control points. The description of the *FA* record in the *Users Manual* [2] includes an explanation of three options for applying *FA* record flow adjustments within the simulation that are selected by the parameter FAD in *JO* record field 3. The Colorado WAM uses the default FAD option 1. With either of the FAD options, the quantities on *FA* records are added by *SIM* or *SIMD* to the monthly naturalized flows.

Table 10.6
Spring Flows on *FA* Records

Control Point	Springs	Mean Flow (ac-ft/month)	Multiplier
I10330	Barton Springs	3,488.846	1.000000
C30130	Wilkinson Springs	669.416	0.191873
I10320	Cold/Deep Eddy	139.550	0.039999
E10680	Deep Creek Springs	150.829	0.043232
C40130	Dove Creek Springs	571.637	0.163847
E10301	Hall/Big Springs	25.249	0.007237
E10610	Hart/Berry/Mud/Bogard	170.431	0.048850
E40530	Anson Springs	871.730	0.249862
E10300	Richland Springs	73.658	0.021112
E10590	Sloan/Walnut Springs	533.148	0.152815
C50570	Spring Creek Springs	482.431	0.138278
E10690	Sycamore/Cotton	82.939	0.023773
E40260	Main/Government	798.960	0.229004

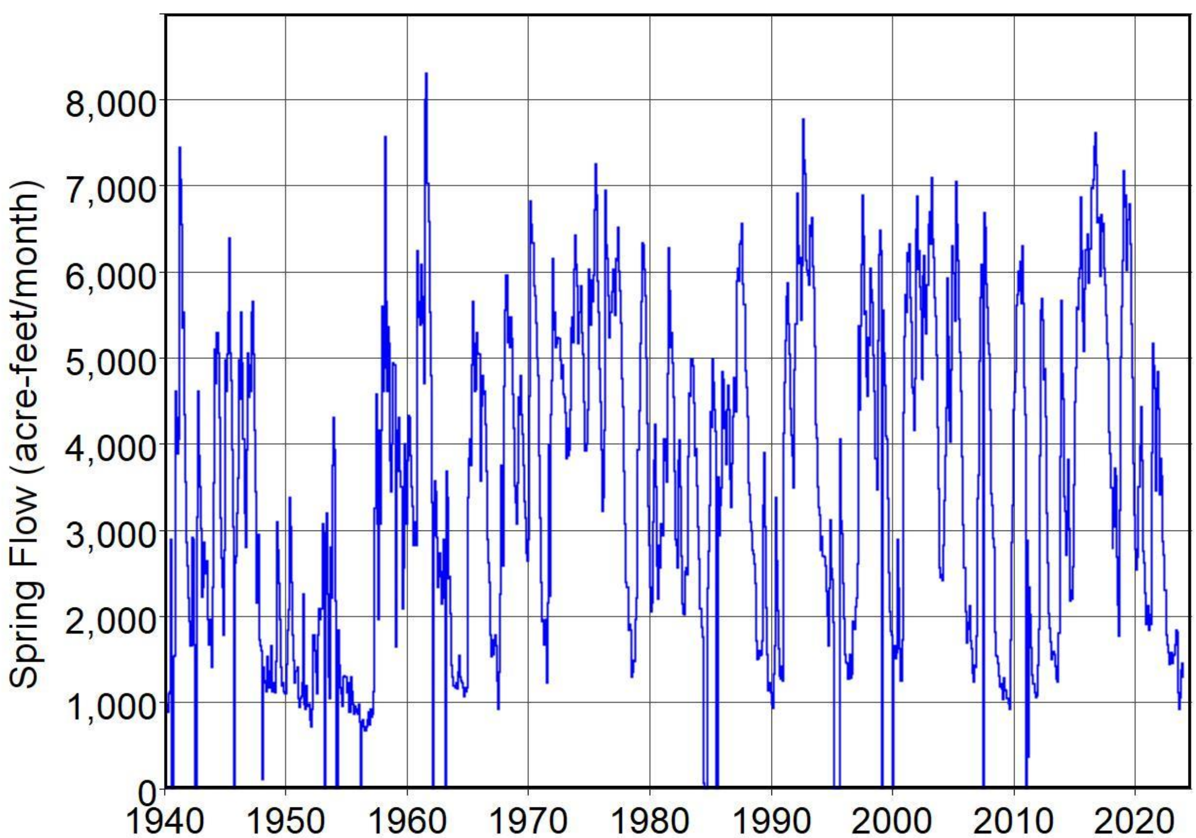

Figure 10.3 *FA* Record Flows at Barton Springs (Control Point I10330)

The flow adjustments are entered at a specified control point and cascade downstream within the simulation which includes accounting for channel losses. The *FA* record adjustments are added by *SIM* or *SIMD* to naturalized flows each month at the beginning of the simulation after the flow distribution routine and before the negative incremental flow adjustment routine. The naturalized flows at secondary control points computed from naturalized flows at primary control points do not include the *FA* record adjustments made at the primary control points.

The spring flows on the *FA* records of the Colorado WAM were excluded from the naturalized flows during the development of the naturalized flow dataset. The spring flows from the *FA* record adjustments are added back to the naturalized flows at the beginning of the *SIM/SIMD* simulation. The spring flows are very approximate. However, since spring flow quantities are separated from and then added back to the naturalized flows, *SIM/SIMD* simulation results may not necessarily be highly sensitive to the level of accuracy of the spring flows.

The *FA* record monthly flow adjustments for 1940-2016 are adopted without modification for the daily and modified monthly WAMs discussed in this chapter. Barton Springs is the only site for which spring flows are now found at the USGS NWIS website. Daily flows at Barton Springs were downloaded from the USGS NWIS, summed to monthly, and converted to *FA* records within *HEC-DSSVue*. The 1940-2016 mean flows at the 13 control points are tabulated in the last two columns of Table 10.3 in acre-feet/month and as a fraction of the 1940-2016 mean flow at Barton Springs. The *FA* record spring flow quantities for 2017-2023 at the 12 other control points were approximated as this fraction of the flows observed by the USGS at Barton Springs. Monthly 1940-2023 flows at Barton Springs are plotted in Figure 10.3.

<u>Hydrologic Index on *HI* Records</u>

The hydrologic index *HI* records stored in a HIS file in the October 2023 WAM are also included in the hydrology DSS file in the 2024 WAM. An *HI* record with 724 monthly quantities covering 1940-2016 for artificial control point G5000 is included in both the October 2023 and February 2020 versions of the WAM. *HI* records with 1940-2016 monthly quantities assigned to each of sixteen artificial control point labels are added in the October 2023 version.

The *HI* records are referenced by target options *TO* records in the DAT file used to define complex instream flow requirements at the following USGS gage sites. Water right priorities for these instream flow requirements are shown in the following list.

North Llano River Near Junction, priority 19131231 (December 31, 1913)
Llano River near Llano, priority 18981231 (December 31, 1898)
Concho River at Paint Rock, priority 19141219 (December 19, 1914)
Colorado River near San Saba, priority 19361231 (December 31, 1936)
San Saba River near San Saba, priority 19140629 (June 29, 1914)

The first site listed above is at WAM control point G50000 and has a single sequence of *HI* record 1940-2016 monthly hydrologic index values consisting of either zero or one. The number 1 is assigned to 38 of the 924 months. The number 0 is assigned for the remaining 886 months. The months with a *HI* record index of 1 consists of four months in 1946, July 1953 through August 1955, four months in 1957, and four months in 2015.

The four other USGS gage sites listed above are each represented by four *HI* records for a total of sixteen *HI* records. The 16 *HI* records are comprised of 1940-2016 sequences of 886 monthly quantities for four different hydrologic conditions. The quantities are either zero or one. Most months have a hydrologic index of zero.

The 1940-2016 hydrologic index quantities from the WAM last dated by TCEQ in October 2023 are adopted without modification for the 2024 daily and modified monthly WAMs developed in the present study. The seventeen *HI* records are extended through December 2023 in the present study by assigning zeros for all months during 2017-2023. This approximation should be reevaluated in more detailed and accurate future updates.

<u>Monthly Naturalized Stream Flow</u>

Monthly naturalized flows at the 45 primary control points are stored on *IN* records in the FLO or DSS files. Naturalized flows are synthesized during execution of *SIM* or *SIMD* for over 2,000 secondary control points based on information provided on DIS file *FD* and *WP* records and/or DAT file *CP* records. Naturalized flows are distributed to most secondary control points using the drainage area ratio method, which is combined with channel loss factors for some of the control points. The next computations in the *SIM* simulation, after the distribution of monthly naturalized flows from primary (flows on *IN* records) to secondary (ungaged) control points, is the addition to the monthly naturalized flows of adjustments from *FA* records [1, 2]. *SIMD* monthly-to-daily disaggregation computations occur after the *FA* record flow adjustments have been added [1, 4]. Thus, the monthly flow adjustments on the *FA* records are treated as components of the monthly naturalized flows that are disaggregated to daily in a daily *SIMD* simulation.

The original 1940-1998 hydrologic period-of-analysis of the Colorado WAM was updated by TCEQ to extend through 2013 and then more recently updated again to extend through 2016. The *SIM* simulation1940-2016 monthly hydrology input datasets in the official TCEQ WAM were adopted without modification, other than conversion to a DSS file, for the updated case study WAM discussed in this chapter. The hydrologic period-of-analysis is extended through 2023 in the present study using approximate methods intended for intermediate updates between more detailed updates. The 2017-2023 extension can be replaced in future more detailed updates.

The 1940-2016 monthly naturalized flows on *IN* records are extended from January 2017 through December 2023 at TAMU using WRAP program *HYD* routines [4, 81]. The *HYD* hydrologic model for synthesizing monthly naturalized stream flows based on complex nonlinear regression with monthly precipitation and evaporation depths was calibrated using the original 1940-1998 naturalized flows and applied to generate 1999-2023 monthly naturalized flows that include the 2017-2023 flows adopted for the daily and modified monthly Colorado WAMs.

<u>Monthly Net Evaporation-Precipitation Depths</u>

The Colorado WAM includes 48 sets of *EV* record monthly net evaporation less adjusted precipitation depths. The TWDB database of monthly precipitation and reservoir evaporation depths discussed in Chapter 4 was used to develop the original and updated *EV* records. Quadrangle 1940-2023 mean annual precipitation and 1954-2023 mean annual evaporation are shown in Figure 4.3 of Chapter 4.

Area-weighted averages of net evaporation-precipitation depths for the quadrangles in Figure 10.4 were employed in developing the 48 *EV* record data sequences. TWDB data for 18 quadrangles are each shared in the WAM by multiple reservoirs. The other 30 sets of *EV* records apply to 30 large reservoirs for which the evaporation-precipitation depths recorded on *EV* records were computed using weighted quantities for multiple quadrangles.

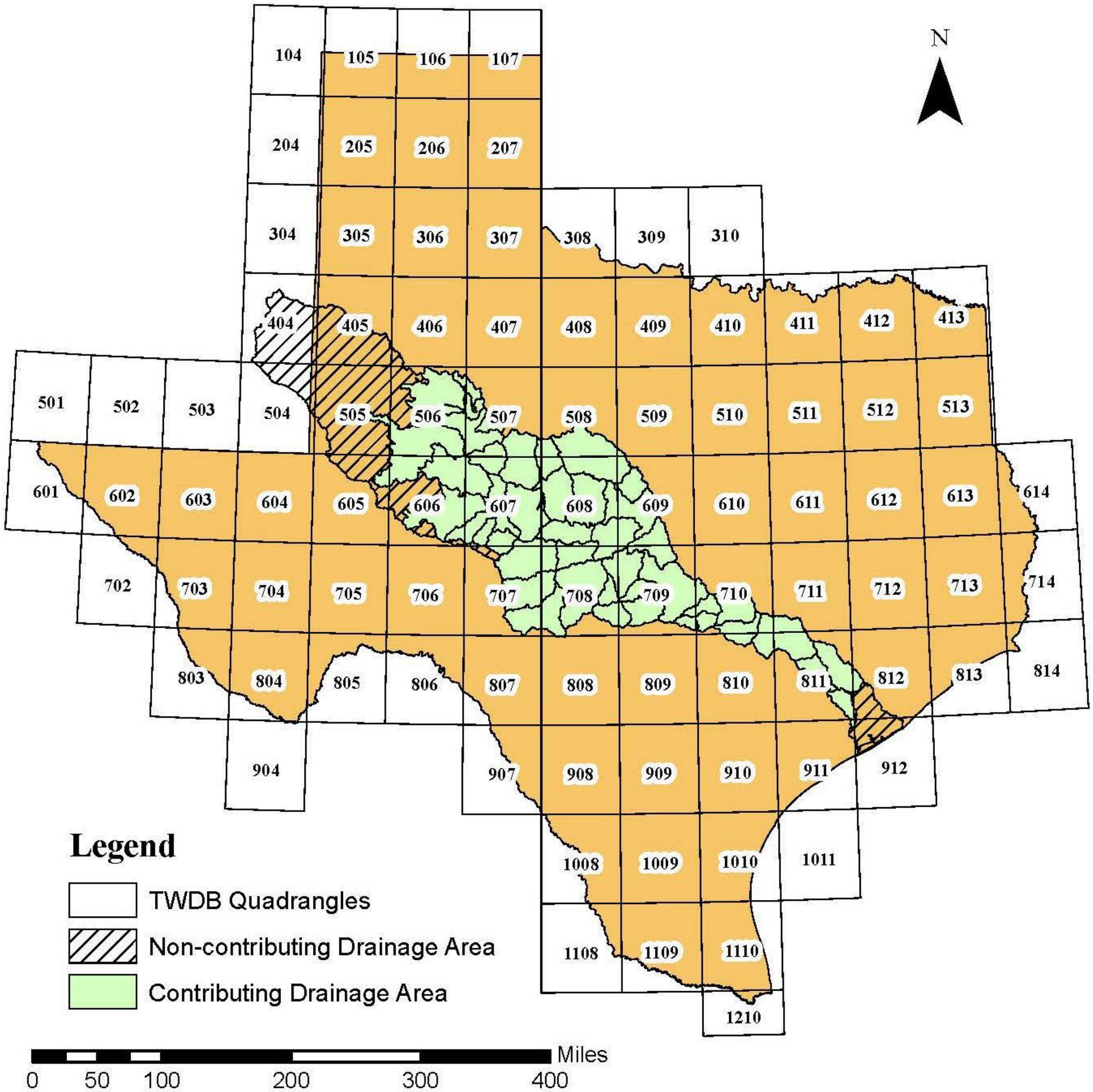

Figure 10.4 TWDB Monthly Evaporation and Precipitation Database Quadrangles [10]

As discussed in earlier chapters, *SIM* and *SIMD* include an option activated by parameter EPADJ on the *JD* record and EWA(cp) on *CP* records designed to account for the portion of the precipitation falling on the reservoir water surface that is also reflected in the naturalized stream flows. Adjustment computations are performed during the simulation based on the simulated reservoir water surface areas. However, this *SIM/SIMD* option is not employed in the Colorado

WAM. Rather, the net evaporation-precipitation rates on the *EV* records are adjusted during compilation of the simulation input dataset. Precipitation adjustments were performed for the original dataset by multiplying precipitation by a regional monthly runoff coefficient [89]. The regional monthly runoff coefficients were computed for various regions of the basin by relating historical monthly streamflow to corresponding historical monthly rainfall [89].

The various routines in WRAP program *HYD* are designed for compiling and updating WAM hydrology and otherwise manipulating and analyzing hydrologic time series datasets [4]. *HYD* includes features for reading, manipulating, and analyzing quadrangle monthly precipitation and evaporation depths from the TWDB database as well as other time series variables. Program *HYD* routines for compiling and extending *EV* record monthly net evaporation-precipitation depths were used to update the *EV* records for the Colorado WAM as well as the Brazos, Trinity, and Neches WAMs. Methods applied without benefit of *HYD* in the original compilation of the 1940-1998 *EV* records quantities were replicated with *HYD* in the 2017-2023 extensions.

Monthly *SIM* Simulation Results

SIM simulation results presented in Figures 10.5-10.7 and Tables 10.7-10.8 are from the full authorization WAM comprised of files with filenames Colorado3.DAT, Colorado3.DIS, and ColoradoHYD.DSS. This version of the WAM is the same as the version last updated by TCEQ in October 2023 except the hydrology time series input datasets have been extended through 2023 and consolidated into a single DSS file. The SB3 EFS discussed later have not yet been added.

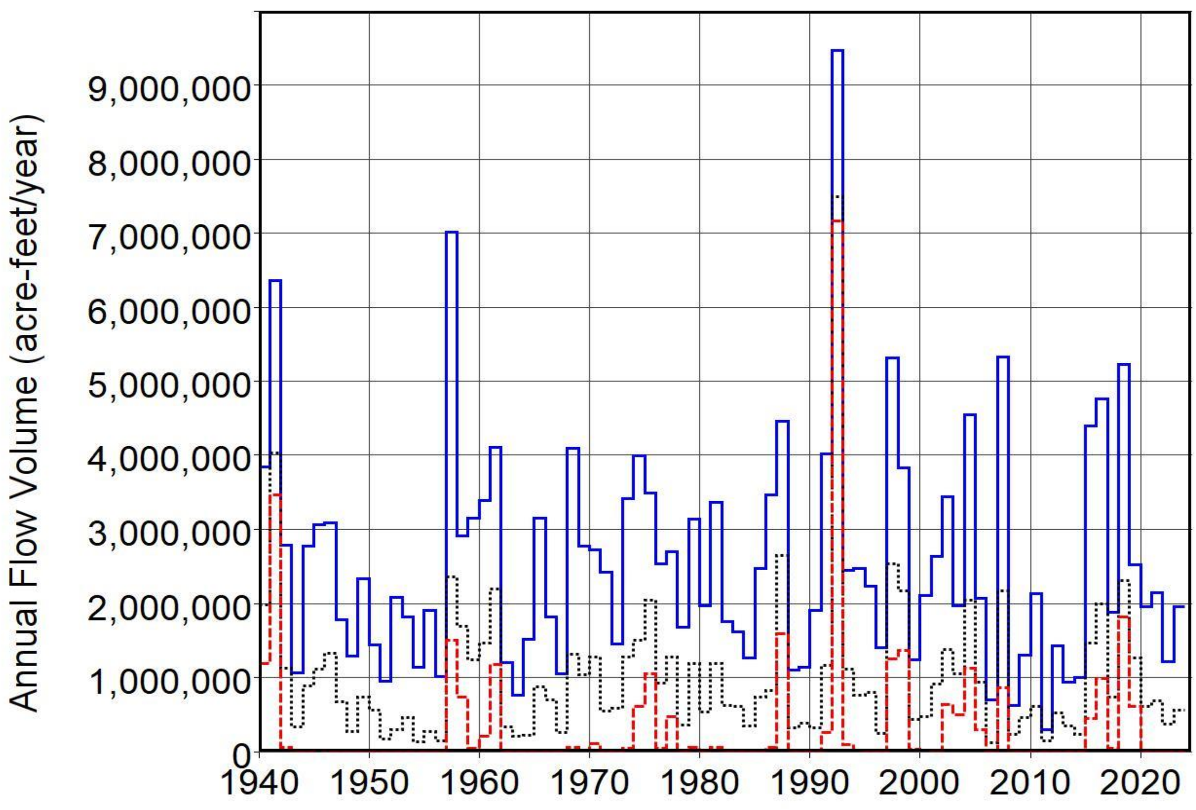

Figure 10.5 Annual Naturalized (**blue** solid line), Regulated (black dotted line), and Unappropriated (**red** dashed line) Flows at Control Point K10000

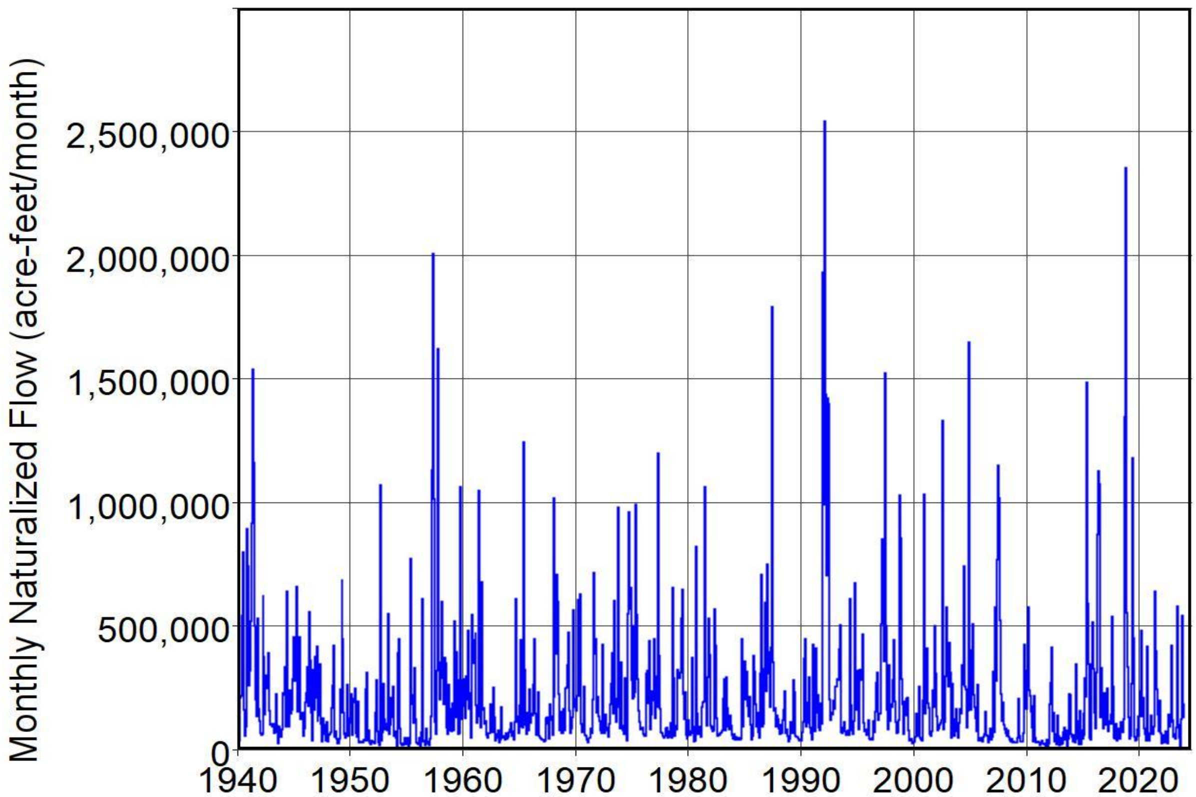

Figure 10.6 Monthly Naturalized Flows at Control Point K10000 near the Basin Outlet

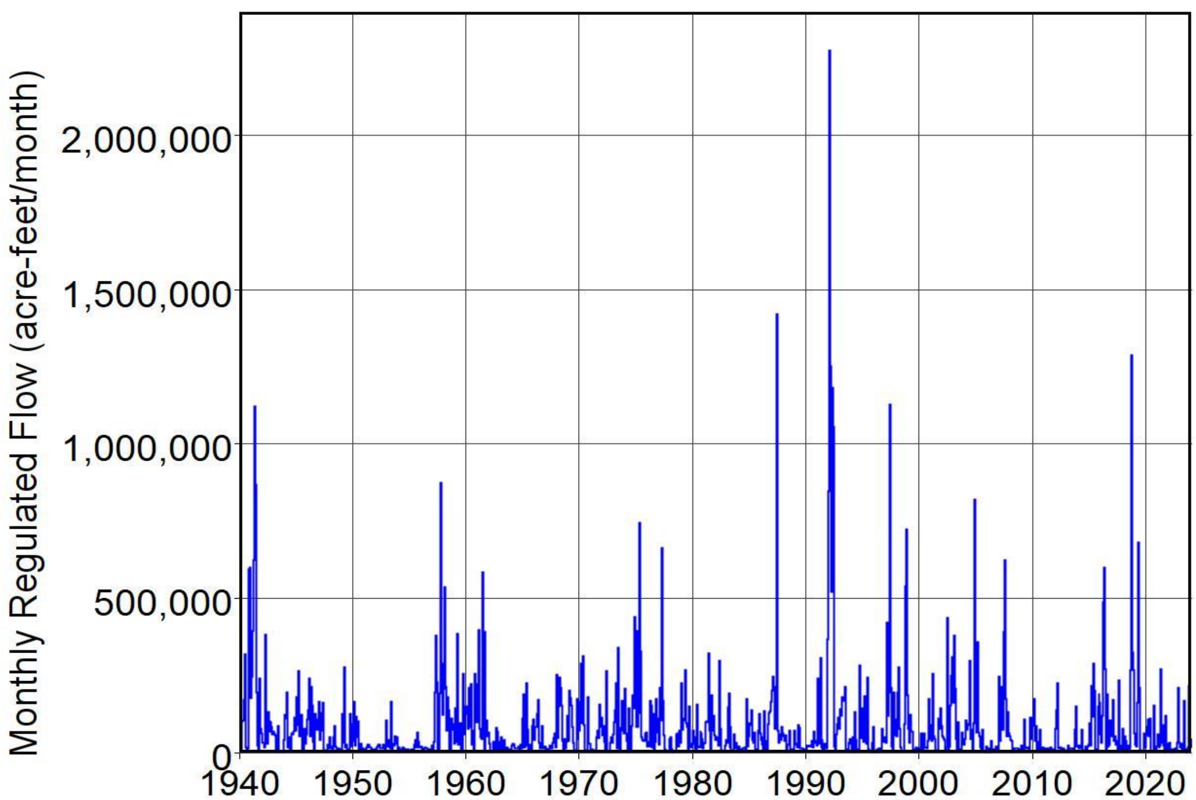

Figure 10.7 Monthly Regulated Flows at Control Point K10000 near the Basin Outlet

Annual and monthly stream flow volumes at control point K10000 near the basin outlet are plotted in Figures 10.5, 10.6, and 10.7. Control point K10000 is the site of the USGS gage on the Colorado River near Bay City, which has a watershed drainage area of 30,862 square miles. Simulated 1940-2023 annual naturalized, regulated, and unappropriated flow volumes in acre-feet/year are compared in Figure 10.5. Water rights reduce the annual naturalized flows to the annual regulated and unappropriated flows plotted in Figure 10.5. Figures 10.6 and 10.7 are plots of January 1940 through December 2023 WAM monthly naturalized and regulated flow volumes in acre-feet/month, respectively. These time series plots illustrate the great variability of stream flow in the Colorado River Basin that is characteristic of rivers and streams throughout Texas.

Tables 10.7 and 10.8 contain frequency metrics for monthly naturalized, regulated, and unappropriated flow volumes in acre-feet/month at two control points. These tables show the mean, standard deviation, and flow quantities equaled or exceeded during specified percentages of the 1,008 months of the 1940-2023 *SIM* simulation period-of-analysis.

Table 10.7
Statistical Frequency Metrics in acre-feet/month for
Naturalized, Regulated, and Unappropriated Flow of the Colorado River
at Control Point K10000 near Bay City and the Basin Outlet

Stream Flow Statistic	Naturalized	Regulated	Unappropriated
Mean (acre-feet/month)	214,990	85,586	29,936
Standard Deviation	279,080	162,767	146,000
Exceedance Frequency			
0.10%	2,539,554	2,266,533	2,265,044
0.20%	2,346,199	1,419,191	1,256,079
0.50%	1,782,827	1,179,904	1,179,102
1.00%	1,479,152	866,515	813,545
2.00%	1,146,062	597,992	455,518
5.00%	707,146	298,368	172,902
10.00%	501,795	207,700	24,062
15.00%	379,678	161,969	0.00
20.00%	311,095	120,154	0.00
30.00%	215,669	76,055	0.00
40.00%	157,118	52,773	0.00
50.00%	115,607	31,950	0.00
60.00%	84,844	19,396	0.00
70.00%	66,937	13,235	0.00
80.00%	52,186	9,670	0.00
85.00%	44,309	7,951	0.00
90.00%	36,718	4,325	0.00
95.00%	28,518	3,149	0.00
98.00%	20,600	2,720	0.00
99.00%	15,943	2,480	0.00
99.50%	11,887	2,356	0.00
99.80%	6,150	2,121	0.00
99.90%	670.0	78.86	0.00

Table 10.8
Statistical Metrics in acre-feet/month for Naturalized, Regulated, and Unappropriated Flow of the San Bernard River at the USGS Gage near Boling Represented by Control Point L10000

Stream Flow Statistic	Naturalized	Regulated	Unappropriated
Mean (acre-feet/month)	23,124	22,668	20,030
Standard Deviation	44,069	43,692	43,099
Exceedance Frequency			
0.10%	488,927	486,481	480,900
0.20%	337,489	336,656	334,185
0.50%	262,719	259,320	253,854
1.00%	232,692	229,309	223,699
2.00%	166,481	164,644	162,182
5.00%	112,570	110,992	107,141
10.00%	68,663	67,383	63,737
15.00%	47,810	46,807	44,197
20.00%	35,117	33,942	30,582
30.00%	18,615	17,772	12,956
40.00%	10,157	9,425	4,397
50.00%	5,572	5,550	0.00
60.00%	2,399	2,367	0.00
70.00%	0.00	0.00	0.00

HEC-DSSVue was used to compute the frequency metrics in Tables 10.7 and 10.8. The WRAP program *TABLES* 2FRE feature also develops tables with the mean, standard deviation, and flow quantities exceeded during specified percentages of the months (or days) of the simulation. *TABLES* and *HEC-DSSVue* compute exceedance frequency quantities a little differently [1]. *TABLES* employs the conventional relative frequency formula for exceedance frequency [Exceedance Frequency = (n/N)(100%)], where n is the number of times a quantity is exceeded in the N time periods in the analysis. *HEC-DSSVue* employs the classic Weibull formula [Exceedance Frequency = (n/(N+1))(100%)]. With a large N of the 1,008 months of a 1940-2023 analysis, the frequency estimates are almost the same with either alternative frequency formula.

Table 10.7 tabulates frequency metrics for monthly naturalized, regulated, and unappropriated flow volumes near the basin outlet (control point K10000). Figure 10.5 and Table 10.7 show the WRAP/WAM simulated effects of water resources development, management, and use on statistical frequency metrics of inflows to Matagorda Bay for the full authorization scenario. Control point L10000 of Table 10.8 in the coastal basin is the site of the USGS gage on the San Bernard River near Boling, which has a watershed drainage area of 725 square miles.

Reservoir storage content provides both a meaningful measure of water supply capabilities and a drought severity index. Reservoir storage contents is adopted in this report as a general summarizing metric describing water availability. The WRAP/WAM simulated end-of-month storage volumes plotted in Figures 10.8 and 10.9 represent estimated reservoir storage contents that would occur if all water right permit holders appropriated the full amounts of water authorized by their water rights during a hypothetical repetition of 1940-2023 natural hydrology. The plots reflect two alternative premises regarding reservoir storage at the beginning of January 1940.

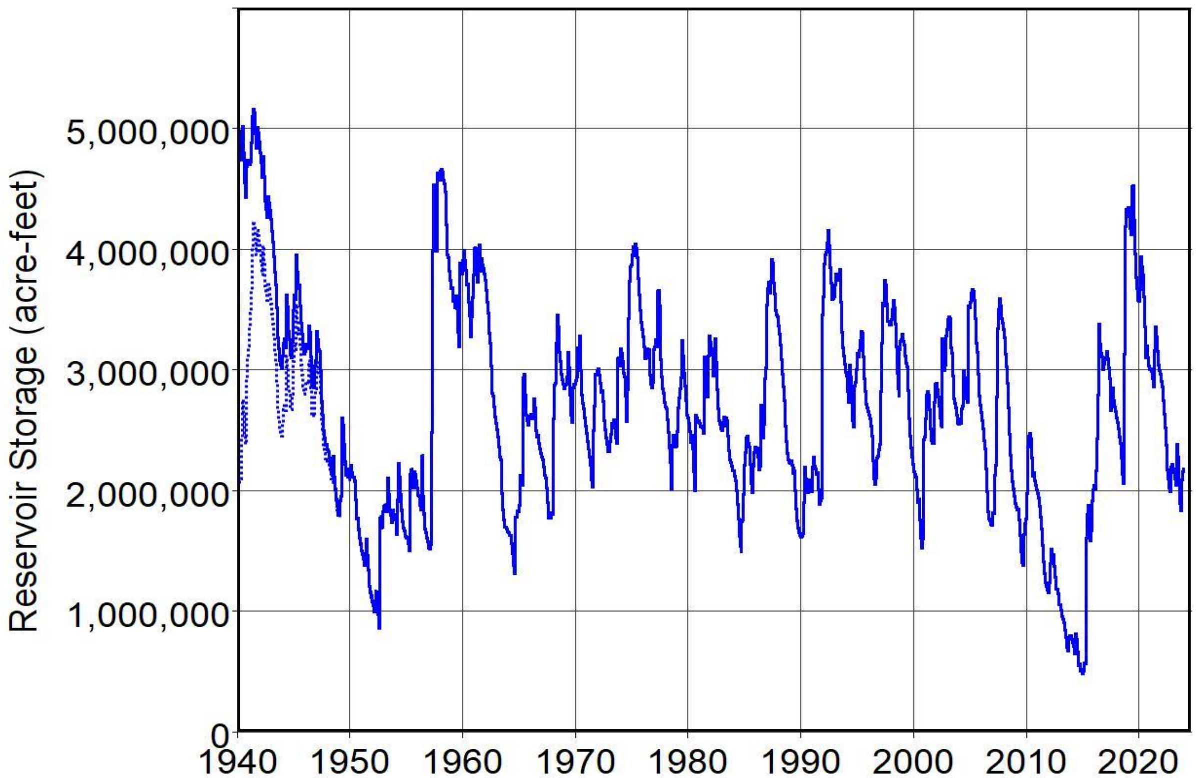

Figure 10.8 Total Simulated End-of-Month Storage Contents of 486 Reservoirs

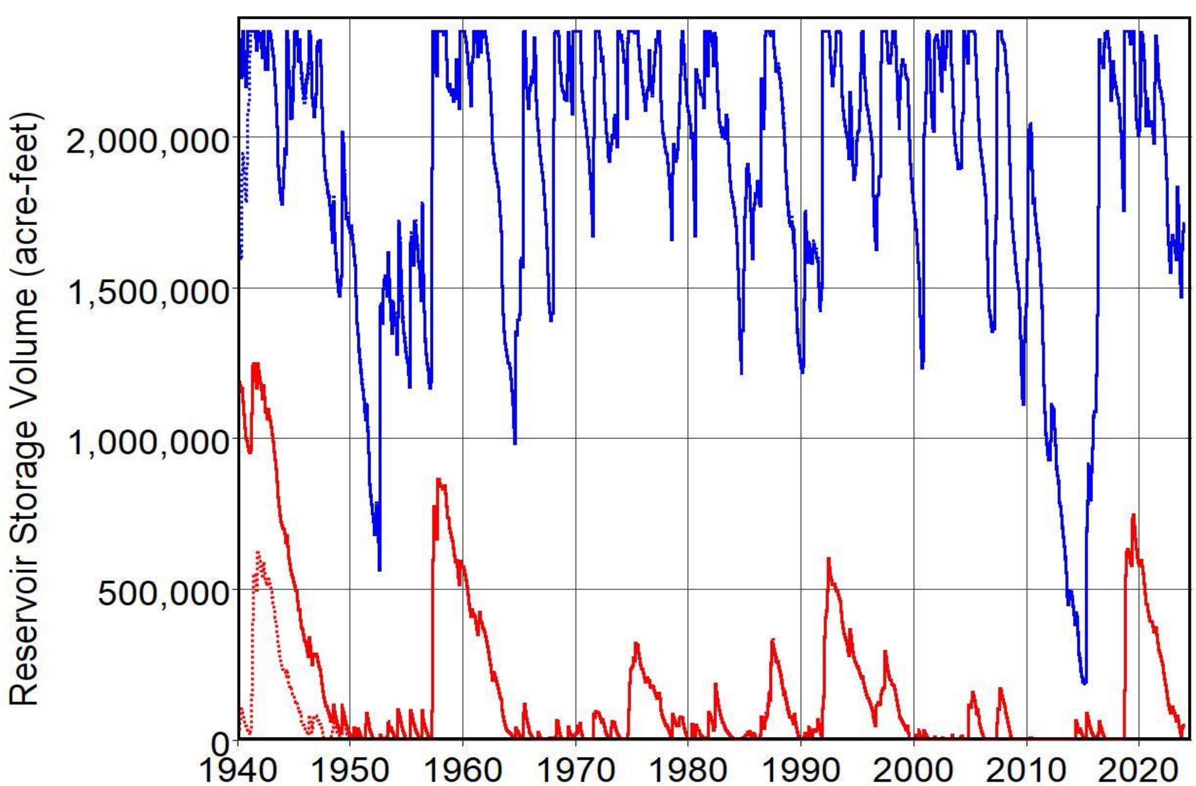

Figure 10.9 Total Storage Contents of Six Highland Lakes Operated by LCRA (blue line) and Three Reservoirs Operated by CRMWD (red line)

Conventional practice has been to initiate simulations with all reservoirs full to capacity. The alternative of setting the beginning-of-simulation storage contents equal to the end-of-simulation contents in each reservoir can be employed with the BES parameter on the *JO* record. The BES option storage results are shown as dotted lines in Figures 10.8 and 10.9. The maximum drawdowns during the 1950-1957 drought and later droughts are affected only minimally if at all by activation of the BES option as shown by the storage graphs.

The summation of end-of-month storage volume of the 486 reservoirs (excluding artificial) in the WAM is plotted in Figure 10.8. The 486 reservoirs have a total authorized storage capacity of 5,303,829 acre-feet. The maximum total storage contents after 1940 is 5,159,292 acre-feet in June 1941. The minimum of the summation of end-of-month storage contents of the 486 reservoirs during the 1940-2016 simulation is 477,059 acre-feet (8.99% of capacity) in December 2014. Storage of individual reservoirs tend to exhibit greater variability than the summation of storage contents of 484 reservoirs due to differences in the timing of drawdowns and refilling.

The total simulated storage contents of the six Highland Lakes and the three large CRMWD reservoirs (Ivie, Spence, Thomas, Table 10.2) located in the upper basin are plotted in Figure 10.9. The six Highland Lakes operated by the LCRA contain 44.3% of the authorized storage capacity of the 486 authorized storage facilities. O.H. Ivie, E.V. Spence, and J.B. Thomas Reservoirs contain 23.5% of the authorized storage capacity of the 486 authorized storage facilities.

The six Highland Lakes have a total authorized storage capacity of 2,349,032 acre-feet (Tables 10.1 and 10.2). All six of the reservoirs are full to capacity often in the simulation. The minimum total simulated storage contents of the six reservoirs is 7.87 percent of capacity occurring in February 2015. The last time during the 1940-2016 simulation that the six reservoirs are all full to their authorized capacities totaling 2,349,032 acre-feet is the end of June 2007. O.H. Ivie, E.V. Spence, and J.B. Thomas Reservoirs contain authorized storage capacities that total 1,247,100 acre-feet (Table 2.3). Figure 10.9 shows that these three CRMWD reservoirs located in the upper Colorado River Basin are empty or near empty during much of the 1940-2023 hydrologic period-of-analysis simulation.

Figures 10.5-10.9 and Tables 10.7 and 10.8 are derived from the results of a *SIM* simulation with the full authorization Colorado WAM as last updated by the TCEQ in October 2023 but with the hydrology extended through 2023 as explained earlier in this chapter. Simulation results reflect the premises, computational methods, and input datasets that comprise the WAM. This includes the hypothetical scenario of all water right permit holders storing and diverting the full amounts of water authorized by their permits during a repetition of 1940-2023 natural hydrology.

The selected simulation results presented here provides general overview insight regarding hydrologic characteristics and water availability in the Colorado River Basin. The time series plots and frequency metrics demonstrate the extreme variability of stream flow. Reservoir storage dampens stream flow variability. Reservoir outflow equals inflow in the *SIM* simulation in months during which a reservoir is completely full to authorized storage capacity. Reservoirs pass inflows for downstream water rights. Otherwise, with storage below capacity, inflows are stored. Figures 10.8 and 10.9 show that reservoirs are significantly below capacity during many of the 1,008 months of the 1940-2023 simulation. Flow variability and the effects of reservoir storage on flow variability are key considerations in converting the monthly WAM to daily.

Daily Colorado WAM

The 2024 developmental daily version of the TCEQ full authorization WAM developed as described in this section is comprised of four files with the following filenames.

ColoradoD.DAT, Colorado.DIS, Colorado.DIF, ColoradoHYD.DSS

The 2024 version of the daily WAM was created from the official TCEQ monthly WAM last updated by TCEQ as of 10/1/2023. The 1940-2016 hydrologic period-of-analysis of the monthly WAM last updated by TCEQ as of 10/1/2023 was extended through December 2023, and all time series input datasets are combined in the 2024 update into a single DSS file with filename ColoradoHYD.DSS as outlined in the preceding section.

The 2022 Daily Colorado WAM Report [10] documents development of full authorization daily and modified monthly WAMs and associated research studies exploring various modeling issues. The 2022 daily WAM was developed from the TCEQ full authorization monthly WAM last updated by TCEQ in February 2020. The 2024 full authorization daily WAM was developed from the monthly WAM last updated by TCEQ on 10/1/2023 as explained in this chapter similarly to the previous development of the version of the daily WAM discussed in the 2022 report [10].

Development of the daily Colorado WAM presented in this section includes the following tasks described in Chapter 2.

1. Conversion of simulation control parameters from monthly to daily in the DAT file of the monthly full authorization WAM last updated by TCEQ on October 1, 2023.
2. Activation of naturalized flow disaggregation options on input records in the DAT and DIF files and compilation of *DF* record daily flow pattern hydrographs extending through December 2023 stored in the hydrology input DSS file.
3. Compilation of lag and attenuation routing parameters stored in the DIF file.
4. Addition of instream flow *IF*, environmental standard *ES*, hydrologic condition *HC*, and pulse flow *PF* input records in the DAT file to model SB3 EFS that have been established at 14 USGS gage locations.
5. Addition of *FR*, *WS*, and *FF* records in the DAT file to model flood control operations of Travis, Twin Buttes, O.C. Fischer, and Hords Creek Reservoirs.

SIMD Simulation Control Parameters

SIMD input parameters controlling simulation options activated in the conversion of a monthly WAM to daily are described in general on pages 28-29 of Chapter 2 and as applied to the Brazos WAM in Chapter 7 of this report as well as in Chapter 4 of the *Users Manual* [2] and in the 2022 Daily Colorado WAM Report [10]. The *SIMD* input records in the daily Colorado WAM DAT file containing parameters for controlling daily simulation options are replicated as Table 10.9. The *JT*, *JU*, and *OF* records control simulation input, output, and computation options. The DAT file *FA* and *HI* records in Table 10.9 reference flow adjustment *FA* and hydrologic index *HI* records in the hydrology input DSS file. The *DF* records reference forty-five *DF* record daily pattern flow hydrographs read by *SIMD* from the hydrology input DSS file for use in disaggregating naturalized flows from monthly to daily.

Table 10.9
SIMD DAT File Input Records Controlling Simulation Options

```
**-------1---------2---------3---------4---------5---------6---------7-------
**34567890123456789012345678901234567890123456789012345678901234567890
       !       !       !       !       !       !       !       !       !
JD     84     1940       1       0       0               7               18
JO     6            1       1                                       2
JT
JU     1    0    0    0    2    3
OF     0    0    2    3                                    Colorado
OFV    1    2    3
CO         J10000  K20000
FA         C30130  C40130  C50570  E10300  E10301  E10590  E10610  E10680  E10690
FA         E40260  E40530  I10320  I10330  A30000  A10000  B20000  B10000  D40000
FA         D20000  D10000  F10000  I40000
HI         G50000  GR-AVE  GR-DRY  GR-SUB  GR-WET  PW-DRY  PW-SUB  PW-WET  QS-AVE
HI         QS-DRY  QS-SUB  QS-WET  TV-AVE  TV-DRY  TV-SUB  TV-WET
DF         A30000  A10000  B20000  B10000  D40000  D20000  D10000  F10000  I40000
DF         I20000  I10000  J30000  J20000  J10000  K20000
DF         K10000  A20000  B40000  B30000  C70000  C60000  C50000  C40000  C30000
DF         C20000  C10000  D30000  E40000  E30000  E10000
DF         E20000  F30000  F20000  G20000  G50000  G40000  G30000  G10000   H2000
DF         H10000  I30000  J50000  J40000  L20000  L10000
```

Disaggregation of Monthly Naturalized Stream Flows to Daily

Disaggregation of monthly naturalized flow volumes to daily volumes is a basic key component of converting from a monthly WAM to a daily WAM. With the standard default DFMETH option 4 activated, *SIMD* disaggregates monthly naturalized flow volumes to daily volumes in proportion to daily pattern hydrographs while preserving the monthly volumes.

SIM and *SIMD* read monthly naturalized stream flow volumes from inflow *IN* records for 45 primary control points. Both the monthly *SIM* and daily *SIMD* simulation synthesize monthly naturalized flows at the over 2,200 non-artificial secondary control points based on the monthly naturalized flows at the 45 primary control points and parameters read from control point *CP*, flow distribution *FD*, and watershed parameter *WP* records. *SIMD* distributes the monthly naturalized flow volumes at each of the non-artificial control points to the 28, 29 (February of leap years), 30, or 31 days in each of the 1,008 months of the 1940-2023 hydrologic period-of-analysis.

Control points K10000, L10000, and L20000 are near the outlets of the Colorado River, San Bernard River, and Boggy Creek which represent three separate watersheds. The procedure described in the next paragraph is activated by the following DIF file *DC* records for control points K10000, L10000, and L20000 with REPEAT and DFMETHOD options 2 and 4 activated.

```
DC K10000   2   4
DC L10000   2   4
DC L20000   2   4
```

Monthly naturalized stream flows at control points K10000, L10000, L20000, and over 2,200 control points located upstream of these three sites are disaggregated to daily using 1940-2023 daily flows at 45 control points stored as *DF* records in the hydrology input DSS file. Monthly volumes are distributed to daily volumes in proportion to daily flows while maintaining monthly volumes. The automated procedure in *SIMD* for repeating daily flows at multiple control points is described in Chapter 2 of the *Daily Manual* [4]. The automated procedure consists of using flows at the nearest downstream control point if available, otherwise finding flows at the nearest upstream control point, and lastly if necessary using flows from another tributary.

DFMETH option 1 is selected in *JU* record field 2 (column 8 in Table 10.9) to apply the uniform monthly-to-daily naturalized flow disaggregation option for all of the other control points not located upstream of control points K10000, L10000, and L20000. Thus, uniform disaggregation option (DFMETH=1) is applied to several control points in the coastal basin and all of the artificial control points that have monthly flows to disaggregate. Most artificial control points have zero naturalized flow, meaning disaggregation is not relevant.

The San Bernard River is the largest stream in the Brazos-Colorado Coastal Basin. Control point L10000 is included on the *DC* records discussed above. DFMETHOD(cp) option 4 is applied to L10000 and L20000 and control points in the coastal basin that are located above L10000 or L20000. Default DEMETH option 1 is applied to all other control points in the coastal basin.

As indicated by Table 10.4, the Colorado WAM has 2,524 control points of which 2,392 represent actual physically connected locations within the river system and the other 132 are artificial control points used in water accounting schemes. Input parameters CPID(cp,2) and CPIN(cp) in *CP* record fields 3 and 7 define stream system connectivity and sources of naturalized streamflow. The 132 artificial control points listed on the *CO* records of Table 10.5 have *CP* record entries of "OUT" for CPIN(cp) and "ZERO" or "NONE" for CPIN(cp) meaning no stream system connectivity and no naturalized stream flow.

<u>Daily Flow Pattern Hydrographs on *DF* Records</u>

Daily naturalized flows at 45 control points extending from January 1940 through December 2016 were developed as explained in in Chapter 3 of the 2022 Daily Colorado WAM Report [10]. The daily flows were extended from 2017 through 2023 employing the same strategy. The daily flows are based on observed daily flows at 45 USGS gages listed in Tables 3.3, 3.4, and 3.4 of the 2022 report [10]. Their locations are shown in Figure 2.1 of the 2022 report [10].

The daily flow *DF* records are employed in the *SIMD* simulation for the sole purpose of serving as pattern hydrographs used in disaggregating monthly naturalized flows to daily. Therefore, only the pattern of the quantities on the *DF* records within each of the 1,004 months, not the actual magnitude of the individual quantities for each day, affect *SIMD* simulation results. The *DF* record daily flows can be in any units and are not required to reflect a specific single site. However, the *DF* records for the Colorado WAM contain daily naturalized flows in acre-feet/day. The *DF* records of daily naturalized flows can be easily tabulated or plotted in *HEC-DSSVue*.

The following tasks were performed in developing the original dataset of *DF* records of 1940-2016 daily flows at 45 control points and repeated the later 2017-2023 extension.

1. Available daily observed flow data were explored to select sites for inclusion in the dataset. A determination was made to develop *DF* records for each of the 45 primary control points.

2. Observed flows at relevant USGS gages as daily means in cfs were compiled as a DSS file from the USGS NWIS website using the data import feature of *HEC-DSSVue*.
3. The majority of the USGS gage sites do not have periods-of-record covering the entire WAM 1940-2023 simulation period. Gage records at two or more sites were combined as necessary to develop 1940-2023 sequences of daily flows in cfs for each of the 45 control points.
4. The 1940-2023 daily flows in cfs at the 45 control points were converted within *HEC-DSSVue* to a *SIMD* input dataset of *DF* records with flows in cfs. *SIMD* was executed with this dataset. The *SIMD* simulation results included naturalized daily flows in acre-feet/day.
5. The daily naturalized flows recorded by *SIMD* in its simulation results DSS file were converted within *HEC-DSSVue* to another dataset of *DF* records. This final dataset of *SIMD* input *DF* records consists of 1940-2023 daily naturalized flows in acre-feet/day at 45 control points.

Routing Stream Flow Changes and Forecasting Future Flows

SIMD includes optional features for lag and attenuation of stream flow changes and forecasting future flows in support of assessing stream flow availability and availability of stream channel flood flow capacities. Routing and methods for calibrating routing parameters are explained in the *Daily Manual* [5]. Calibration studies and analyses of the routing parameters and effects on simulation results are discussed in detail in the 2022 Daily Colorado WAM Report [10]. With the calibrated routing parameters incorporated in the WAM on *RT* records stored in the DIF file, routing with or without forecasting can be easily activated or deactivated in alternative executions of *SIMD*. As discussed in earlier chapters, forecasting controlled by *JU* record entries in the DAT file is problematic and is relevant only if routing is employed.

The *SIMD* daily input DIF file containing *RT* and *DC* records for the daily Colorado WAM is replicated as Table 10.10. Each *RT* record begins with the control point identifier for the upstream end of the routing reach. Values for the following routing parameters are provided on each *RT* record as explained in the *Daily Manual* [5]: routing method (option 1 lag and attenuation), lag in days for normal flows (LAG), attenuation in days for normal flows (ATT), lag in days for flood flows (LAGF), attenuation in days for flood flows (ATTF). The DIF file also contains three *DC* records with parameters controlling disaggregation of monthly naturalized flows to daily, which are discussed in a previous subsection of this chapter.

Calibrated routing parameters are assigned to 30 control points. Values for the lag parameters LAG and LAGF in days and attenuation parameters ATT and ATTF in days were estimated based on observed flow fluctuations between gaging stations for normal flows and high (flood) flows, respectively [5, 10]. LAG and ATT are applied in the *SIMD* simulation for normal water right operations. LAGF and ATTF are applied by *SIMD* for flood control operations. LAG and LAGF reflect travel times that vary between reaches with differences in reach lengths, flow velocity, and wave celerity. Calibration studies resulted in ATT and ATTF values of 1.0 day for all the 30 sets of parameters in Table 10.10. ATT and ATTF by definition cannot be less than 1.0 day and in general are expected to be 1.0 for many or most river reaches. The attenuation would be greater than 1.0 only for reaches with very long travel times.

Simulation studies exploring the effects of alternative modeling premises and methods on *SIMD* simulation results for the daily Colorado WAM are presented in the 2022 report [10]. These studies include analyses with and without routing and with no forecasting and forecasting with alternative forecast periods. Complexities and issues are explored. Extensive analyses presented in the 2022 report [10] resulted in the calibrated lag and attenuation parameters replicated in Table 10.10 and a forecast period of three days being adopted for the final daily WAM employed in the 2022 report [10]. However, variations in this modeling strategy including no routing and no forecasting were concluded to also generate meaningful information. Different modeling strategies may be warranted depending on circumstances and requirements of particular applications.

Table 10.10
SIMD Daily Input DIF File

```
DCK10000   2   4
DCL10000   2   4
DCL20000   2   4
RTD40000   1    1.24      1.0   1    1.00      1.0
RTD20000   1    1.09      1.0   1    1.00      1.0
RTD10000   1    1.96      1.0   1    1.01      1.0
RTF10000   1    1.30      1.0   1    0.67      1.0
RTI40000   1    2.16      1.0   1    1.11      1.0
RTI20000   1    1.13      1.0   1    1.07      1.0
RTI10000   1    1.06      1.0   1    1.00      1.0
RTJ30000   1    1.00      1.0   1    0.96      1.0
RTJ20000   1    1.93      1.0   1    1.04      1.0
RTJ10000   1    1.65      1.0   1    1.00      1.0
RTK20000   1    1.00      1.0   1    0.95      1.0
RTD30000   1    1.38      1.0   1    1.26      1.0
RTC50000   1    0.64      1.0   1    0.62      1.0
RTC20000   1    1.88      1.0   1    1.05      1.0
RTC10000   1    1.96      1.0   1    1.01      1.0
RTC40000   1    0.77      1.0   1    0.77      1.0
RTC60000   1    0.86      1.0   1    0.83      1.0
RTF30000   1    1.02      1.0   1    0.98      1.0
RTF20000   1    1.15      1.0   1    1.00      1.0
RTE30000   1    2.04      1.0   1    1.00      1.0
RTE10000   1    1.13      1.0   1    1.91      1.0
RTG50000   1    1.00      1.0   1    2.60      1.0
RTG40000   1    1.96      1.0   1    1.00      1.0
RTG30000   1    1.06      1.0   1    1.00      1.0
RTG10000   1    3.92      1.0   1    2.00      1.0
RTI30000   1    1.86      1.0   1    0.96      1.0
RTH20000   1    1.07      1.0   1    1.67      1.0
RTH10000   1    2.32      1.0   1    3.63      1.0
RTJ50000   1    1.11      1.0   1    1.00      1.0
RTJ40000   1    1.00      1.0   1    1.00      1.0
```

Developing monthly SB3 EFS instream flow targets from daily simulation results is the primary application of the daily *SIMD* considered in this 2024 report. Based on simulation results and considerations discussed in the 2022 Daily Colorado Report [10], routing with the routing parameters shown in Table 10.10 and a forecast period of three days are adopted for the daily *SIMD* simulations presented later in this chapter of the present report.

Simulation of Flood Control Reservoir Operations

Four multiple-purpose reservoirs with designated flood control pools are simulated in the daily Colorado WAM. Two of these reservoirs were constructed by the U.S. Bureau of Reclamation (USBR) and are owned and operated by non-federal entities. The other two reservoirs are owned and operated by the USACE Fort Worth District (FWD). The Mansfield Dam and Lake Travis project owned and operated by LCRA was constructed by the USBR and transferred to nonfederal ownership. Flood control operations are a collaborative responsible of the LCRA and USACE FWD. The Twin Buttes Dam and Reservoir project was also constructed by the USBR. The project is owned by the federal government and managed by the City of San Angelo. The USACE FWD is responsible for flood control operations. USACE FWD maintains and operates Hords Creek Dam and Reservoir and O. C. Fisher Dam and Reservoir for flood control, water supply, and recreation. Hords Creek Reservoir is by far the smallest USACE reservoir in Texas. The Central Colorado River Authority has contracted with the federal government for the water supply storage of Hords Creek Reservoir, which is used to supply the City of Coleman. The Upper Colorado River Authority has contracted for the water supply storage of O.C. Fisher Reservoir.

Flood control operations are incorporated into the daily *SIMD* input dataset by adding the following information to the *SIMD* input files. With the exception of LAGF and ATTF on *RT* records in the DIF file, the additional input data are inserted in the DAT file.

- Two sets of lag (LAG and LAGF) and attenuation (ATT and ATTF) routing parameters are input on routing *RT* records in the DIF file as discussed in the preceding section. The second set (LAGF and ATTF) are for routing releases from *FR* record flood control pools and reverse routing in determination of remaining flood flow channel capacity.
- Forecasting activated by FCST and FPRD on the *JU* record are applicable to the aspects of flood control operations specified by *FF* records as well as normal operations.
- Relevant *SV/SA* record volume/area tables and *DI/IP/IS* drought indices are extended to encompass the flood control storage pools above the top of conservation pools.
- *FR* and *FF* records are added to model operation of the flood control pools of the four reservoirs based on reservoir storage levels and flows at downstream control points. Priorities are set on *FR* records. *WS* records are used with *FR* records to provide reservoir identifiers.

Flood control operations are activated whenever the storage level is in the flood control pool. The flood control operating objective is to empty flood control pools expeditiously without making releases that contribute to downstream river flows exceeding allowable nondamaging flow limits. Outflow from surcharge storage above the flood control pool (Figure 3.1) and/or outlet structure capacities can be modeled with *FV/FQ* records. However, for the Colorado daily WAM, outflows are simply set equal to inflows whenever a flood control pool is full to capacity.

Storage capacities for each reservoir are tabulated in Table 10.11. Conservation storage capacities are from the full authorization monthly TCEQ WAM. Flood control storage capacities were determined from data available from USACE and TWDB websites [10]. The total storage capacity below the top of flood control pool is the summation of conservation pool and flood control pool storage capacities. Maximum nondamaging flow rates at downstream gage sites are shown in Table 10.12. Releases are also constrained by flow capacities and limits at the dam.

Table 10.11
Storage Capacities of Flood Control Reservoirs in the Colorado WAM

Reservoir	Stream	Drainage Area	Storage Capacity Conservation	Storage Capacity Flood Control	Storage Capacity at Top of Conservation	Storage Capacity at Top of Flood Control
		(sq miles)	(acre-feet)	(acre-feet)	(acre-feet)	(acre-feet)
Travis	Colorado River	26,230	1,170,752	798,253	1,170,752	1,969,005
Twin Buttes	South Concho	2,672	186,200	454,364	186,200	640,564
O. C. Fisher	North Concho	1,488	119,200	276,974	119,200	396,174
Hords Creek	Hords Creek	48	7,959	17,303	7,959	25,262

Table 10.12
Maximum Allowable Flood Flow Limits at USGS Stream Gage Stations

Control Point	Stream	Nearest City	Drainage Area	Flood Flow Limit
			(sq miles)	(cfs)
C20000	Concho River	San Angelo	4,139	25,000
C10000	Concho River	Paint Rock	5,185	25,000
F30300	Hords Creek	Coleman	107	10,000
I10000	Colorado River	Austin	27,611	30,000
J30000	Colorado River	Bastrop	28,580	45,000
J10000	Colorado River	Columbus	30,244	50,000

Reservoir flood control operations are defined by the *SIMD* flood reservoir *FR*, storage *WS*, and flood flow *FF* records in Figure 10.13, which are inserted in the DAT file. These input records are explained in Chapter 5 of the *Daily Manual* [4] and Chapter 4 of the *Users Manual* [2]. The *FF* records are deactivated by FCDEP on the *FR* records as discussed on the next page.

Table 10.13
FR and *WS* Records in the DAT File of the Daily Colorado WAM

```
**       1         2         3         4         5         6         7         8         9        10
**3456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678
**      |       |       |       |       |       |       |       |       |       |               |
FRI20000910000092000000       2  7500. 1969005.       1170752.                    TRAVIS-FRSTOR   TRAVIS-FRREL
WSTRAVIS
FRC20240910000092000000       2  5000.  640564.        186200.                    TWINBU-FRSTOR   TWINBU-FRREL
WSTWINBU
FRC20040910000092000000       2 25000.  396174.        119200.                    OCFISH-FRSTOR   OCFISH-FRREL
WSOCFISH
FRF30370910000092000000       2 10000.   25262.          7959.                    LEWDA1-FRSTOR   HORDSC-FRREL
WSHORDSC
**   FCDEP option 2 in FR record column 32 deactivates use of the FF records.
FFC20000  25000.                FFLIM-C20000
FFC10000  25000.                FFLIM-C10000
FFF30300  10000.                FFLIM-F30300
FFI10000  30000.                FFLIM-I10000
FFJ30000  45000.                FFLIM-J30000
FFJ10000  50000.                FFLIM-J10000
```

Simulation of flood control reservoir operations in *SIMD* is explained in Chapter 5 of the *Daily Manual* [5]. Releases are based on emptying flood control pools as expeditiously as possible without (1) exceeding flow capacities and limits at the dam/reservoir project and (2) contributing to exceeding non-damaging flow rates at any number of gages located distances downstream of the dam. Flood control operations in a *SIMD* simulation are based on (1) storage and flow capacities/limits at the dam/reservoir defined by an *FR* record and (2) flood flow limits at any number of downstream locations defined by *FF* records. In a monthly *SIM* simulation or daily *SIMD* simulation without *FR* and *FF* records, flood control pools are not modeled and reservoir outflows equal inflows whenever conservation storage content is at the authorized capacity.

The *FF* records in the daily Colorado WAM DAT file are deactivated by FCDEP on the *FR* records, which has the same effect as removing the *FF* records from the DAT file. In Table 10.13, flow limits at the dam are specified by FCMAX on the *FR* records (columns 33-40). Flow limits at downstream control points are specified on *FF* records. Parameter FCDEP option 2 on the *FR* records (column 32) deactivates use of the *FF* record downstream flow limits.

At any time during and following a flood event resulting in water rising into the flood control pool, releases from the flood control pool are constrained by both storage and flow conditions at the dam/reservoir project and stream flows at various distances downstream of the dam location. The most severe constraint controls release rates from the flood control pool at any time. Thus, eliminating consideration of flows at gages located various distances downstream of the dam tends to decrease the time required to empty reservoir flood control pools after a flood.

Issues with controlling releases from flood control pools based on stream flows at multiple gage sites located downstream specified on *FF* records are discussed in Chapters 7 and 8 in conjunction with the Brazos and Trinity WAMs. Flood flow limit *FF* records are deactivated in the Brazos, Trinity, and Colorado WAMs due to combinations of complexities related to routing, forecasting, negative incremental flows, and other factors. Forecasting is no longer relevant to flood control operations if downstream flow limits specified on *FF* records are not considered.

Environmental Flow Standards Established Pursuant to Senate Bill 3 Process

Environmental flow standards (EFS) at 14 USGS gage sites in the Colorado River Basin have been established by TCEQ in collaboration with a science team and stakeholder committee following procedures established pursuant to the 2007 Senate Bill 3 (SB3). These SB3 EFS are added to the daily Colorado WAM using *IF*, *ES*, *HC*, and *PF* input records inserted in the *SIMD* input DAT file. The daily *IF* record instream flow targets for the SB3 EFS computed in a daily *SIMD* simulation are summed to monthly totals and incorporated in the *SIM* input dataset for the modified monthly Colorado WAM. The SB3 EFS and modeling thereof are explained in detail in the 2022 Daily Colorado WAM Report [10] and briefly summarized as follows.

SB3 EFS at 14 USGS Gage Locations in the Colorado River Basin

The SB3 EFS for the Colorado River and tributaries published by TCEQ in the Texas Administrative Code [98] are described in the 2022 daily WAM report [10]. Flow limits and other metrics defining the SB3 EFS are tabulated in Tables 5.2 through 5.11 of the 2022 report [10]. SB3 EFS for the 14 locations in Table 10.15 are incorporated in the daily Colorado WAM.

Table 10.15
Locations of SB3 EFS in the Colorado River Basin

WAM CP ID	USGS Gage No.	Gage and Control Point Location	Watershed Area (square miles)
B20000	08123850	Colorado River above Silver	4,560
C30000	08128000	South Concho River at Christoval	258
C10000	08136500	Concho River at Paint Rock	5,185
D40000	08126380	Colorado River near Ballinger	6,090
D30000	08127000	Elm Creek at Ballinger	464
E10000	08146000	San Saba River at San Saba	3,048
F20000	08143600	Pecan Bayou near Mullin	2,074
F10000	08147000	Colorado River near San Saba	19,830
G10000	08151500	Llano River at Llano	4,201
H10000	08153500	Pedernales River near Johnson City	901
J50000	08158700	Onion Creek near Driftwood	124
J30000	08159200	Colorado River at Bastrop	28,580
J10000	08161000	Colorado River at Columbus	30,244
K20000	08162000	Colorado River at Wharton	30,601

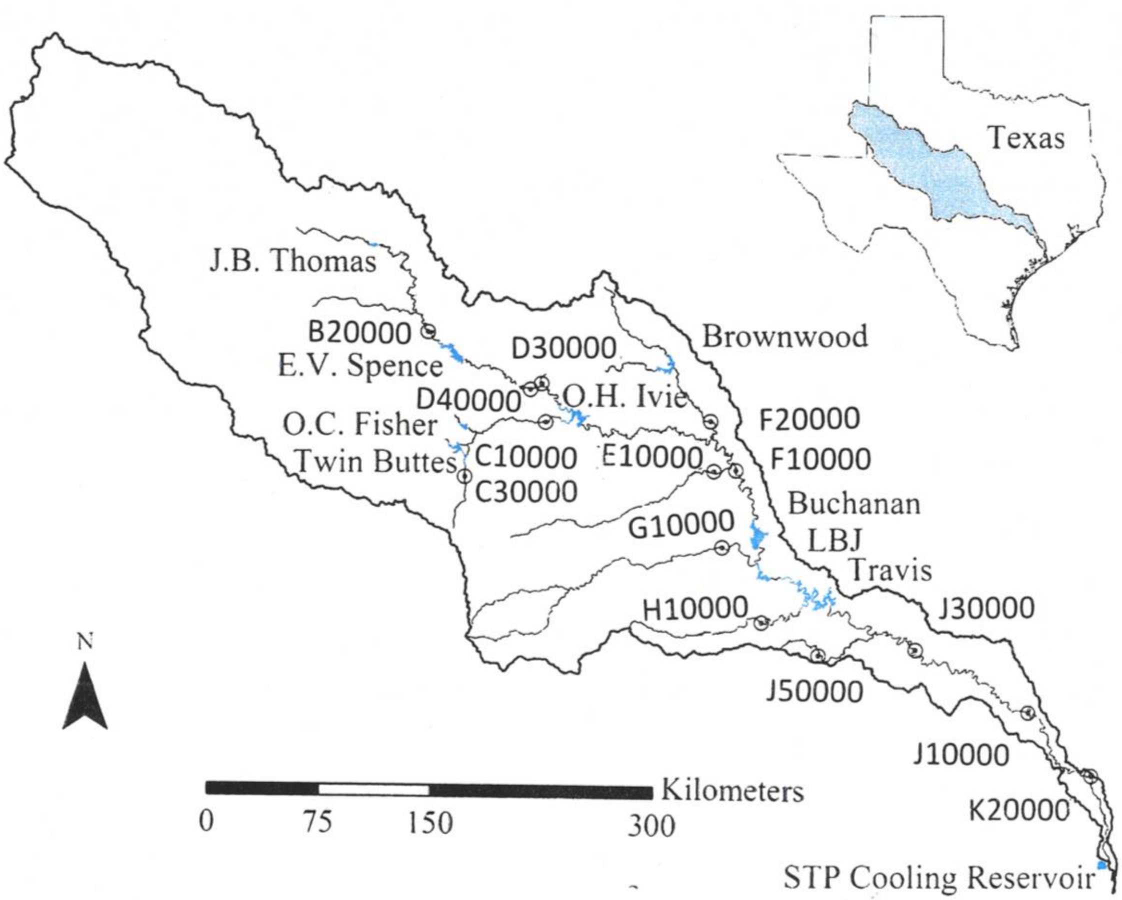

Figure 10.10 Locations of 14 SB3 EFS and 10 Largest Reservoirs

As noted in Table 3.1 of Chapter 3, the geographic area covered by "*Subchapter D* of *Chapter 298 Environmental Flow Standards* of Title 30 of the Texas Administrative Code [98] consists of the Colorado and Lavaca Rivers and their tributaries, bays, and estuaries. SB3 EFS have been established at the locations of 21 USGS stream flow gages, including 14 sites in the Colorado River Basin, five in the Lavaca River Basin, and two sites in the Colorado-Lavaca and Lavaca-Guadalupe Coastal Basins. The TCEQ established the EFS based on recommendations submitted by an expert science team and stakeholder committee in reports available through the TCEQ WAM website. SB3 EFS are based on a flow regime that includes subsistence, base, and high flow pulses as explained in Chapter 4 of the *WRAP Reference Manual* [1] and Chapter 6 of the *Daily Manual* [4] and illustrated by the six case study WAMs explored in this report.

Locations of the 14 SB3 EFS sites in relation to the ten largest reservoirs in the river basin are shown on the map of Figure 10.10. The SB3 EFS criteria are designed somewhat differently for the three gage sites on the Colorado River downstream of Lake Travis (control points J30000, J10000, and K20000) than for the eleven other locations. Hydrologic conditions are defined as a function of the combined storage contents of Lakes Travis and Buchanan for the three downstream control points J30000, J10000, and K20000. For the eleven other control points, hydrologic conditions are defined based on accumulated stream flow at the site in the preceding 12 months.

For all 14 locations, the hydrologic condition for a season is determined based on conditions on the last day of the preceding season. For control points located on the Colorado River above Lake Travis and tributaries, the hydrologic condition parameters were selected by the science team and stakeholder committee such that severe conditions occur approximately 5% of the time, dry conditions occur approximately 20% of the time, average conditions occur approximately 50% of the time, and wet conditions occur approximately 25% of the time. For control points located on the Colorado River below Lake Travis, the hydrologic condition parameters were selected with severe conditions occurring approximately 5% of the time, dry conditions about 45% of the time, and average conditions approximately 50% of the time.

The months selected to define the four seasons of the year are also a little different between the two groups of gage sites. November is a Fall month for the three downstream control points and a winter month for the eleven upstream control points.

Monthly-varying subsistence standards are applied only when the hydrologic condition is categorized as severe. For control points located on the Colorado River above Lake Travis or on tributaries, base flow standards vary seasonally and are specified for four hydrologic conditions: severe, dry, average, and wet. For control points located on the Colorado River below Lake Travis, base flow standards vary monthly and are specified for three hydrologic conditions: severe, dry, and average. For all locations, if flow at a control point is below applicable high flow pulse trigger levels and above the applicable base flow limit, a water right holder may divert water as long as the diversion does not cause the flow to drop below the applicable base flow limit [10, 98].

When the high flow pulse trigger level is reached, that flow level is protected by curtailing junior water rights until either a volume or duration criteria is met. For the three downstream sites, duration is the only termination criterion. For the eleven upstream sites, high pulse criteria are specified for two-per-season, one-per-season, and annual pulses. For the three downstream control points, criteria are specified for two-per-season, one per 18-month, and one per two-year pulses.

For all 14 locations, high flow pulses are independent of hydrologic conditions, and each season is independent of other seasons. If a requirement for a pulse event is satisfied during a season, a high flow pulse requirement is considered to be satisfied for each smaller event in that season. For example, if an annual pulse flow requirement is met in a season, then a one-per-season pulse flow and a two-per-season pulse flow requirements are met for that season.

Modeling SB3 Environmental Flow Standards

All 14 sets of *IF/HC/ES/PF* records simulating SB3 EFS are grouped together in the *SIMD* DAT file for convenience. For brevity, input records for only the most upstream and most downstream control points (B20000 and K20000) are included in Table 10.16. The sets of records modeling SB3 EFS at these two USGS gage sites illustrate the general format of input records for all locations.

Table 10.16
IF Record Instream Flow Rights for the SB3 EFS at Control Points B20000 and K20000

```
**        1         2         3         4         5         6         7         8         9        10
**3456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
**      !       !       !       !       !       !       !       !       !       !       !       !       !
IFB20000     -9.        20110301   2            B20000ES
HCB20000      RF  12  M   J S N       0.   4090.  16000.  57400.     -9.
ES SUBS1     1.0     1.0     1.0     1.0     1.0     1.0     1.0     1.0     1.0     1.0     1.0     1.0
ES BASE1     2.0     2.0     2.0     2.0     2.0     2.0     1.0     1.0     1.0     1.0     1.0     1.0
ES BASE2     2.0     2.0     2.0     2.0     2.0     2.0     1.0     1.0     1.0     1.0     1.0     1.0
ES BASE3     4.0     4.0     5.0     5.0     5.0     5.0     3.0     3.0     4.0     4.0     4.0     4.0
ES BASE4     7.0     7.0    12.0    12.0    12.0    12.0     8.0     8.0    10.0    10.0     7.0     7.0
**
IFB20000     -9.        20110301   2            B20000PF
HCB20000      RF  12  M   J S N       0.   4090.  16000.  57400.     -9.
ES PFES
PF   1 0     18.    120.  13   2      11   2           2
PF   1 0    600.   2500.   9   2       3   6           2
PF   1 0    100.    350.   6   2       7   8           2
PF   1 0    100.    400.   6   2       9  10           2
PF   1 0     42.    300.  15   1      11   2           2
PF   1 0   1800.   7900.  11   1       3   6           2
PF   1 0    330.   1400.   9   1       7   8           2
PF   1 0    430.   1800.   9   1       9  10           2
PF   1 0   3000.  13600.  17   1       1  12           2
**
IFK20000     -9.        20110301   2            K20000ES
HC  HCCP      ST       M   J S  D      0. 1103700 1737460    -9.
HCCP   2  I20000  I40000
ES SUBS1    315.    303.    204.    270.    304.    371.    212.    107.    188.    147.    173.    202.
ES BASE1    492.    597.    531.    561.    985.    984.    577.    314.    410.    360.    486.    470.
ES BASE2    492.    597.    531.    561.    985.    984.    577.    314.    410.    360.    486.    470.
ES BASE3    828.    895.   1020.    977.   1316.   1440.    895.    516.    610.    741.    755.    737.
IFK20000     -9.        20110301   2            K20000PF
HC  HCCP      ST       M   J S  D      0. 1103700 1737460    -9.
HCCP   2  I20000  I40000
ES PFES
PF   1 0   3000.      0.   4   2      12   2           2
PF   1 0   3000.      0.   4   2       3   6           2
PF   1 0   3000.      0.   4   2       7   8           2
PF   1 0   3000.      0.   4   2       9  11           2
PF   1 0   8000.      0.   2   1   17                  2
PF   1 0  27000.      0.   2   1   23                  2
```

Environmental standard *ES*, hydrologic condition *HC*, pulse flow *PF*, and pulse flow supplemental options *PO* records are designed specifically to model *IF* record instream flow rights in the format of SB3 EFS. Chapter 3 of the *Users Manual* [2] defines the input parameters entered on the types of input records that are applicable to both the monthly *SIM* and daily *SIMD*, which includes the *ES* and *HC* records. Chapter 4 of the *Users Manual* covers additional daily *SIMD* input records that are not applicable to the monthly *SIM*, including the *PF* and *PO* records. The 2022 Daily Colorado WAM Report [10] tabulates and explains the SB3 EFS metrics and replicates the complete set of *SIMD* input records employed to model the SB3 EFS at all 14 locations.

The *IF* record instream flow computed as specified by the DAT file input records in Table 10.16 targets are minimum flow limits that may constrain appropriation of stream flow by *WR* record water rights with junior priorities. The *IF* record targets are managed in the same manner as all water right targets within the *SIMD* simulation computations and output files. Options controlled by *IF* record field 3 and *PF* record field 15 create tables in the MSS and SMM message files that provide supplemental information that facilitates tracking the *ES* and *PF* record computations. These message file options are not activated in the dataset of Table 10.16 but can be activated whenever the information is of interest. The subsistence/base flows and high pulse flows are organized as separate water rights but can be combined as discussed the WRAP manuals and daily WAM reports and elsewhere in this report including Table 8.15.

Monthly WAM with Instream Flow Targets from the Daily WAM

A strategy for incorporating monthly instream flow targets computed in a daily *SIMD* simulation into the *SIM* input for a monthly WAM introduced in the last section of Chapter 6 of the *Daily Manual* [4] is applied for each of the six case studies in Chapters 7-12 of this report. Daily instream flow targets in acre-feet/day for the SB3 EFS computed in the daily *SIMD* simulation are summed by *SIMD* to monthly totals in acre-feet/month that are included in the *SIMD* simulation results. These time series of monthly targets are converted to target series *TS* records within *HEC-DSSVue* and incorporated in the input DSS file read in a monthly *SIM* simulation. The target series *TS* records of monthly instream flow targets in acre-feet/month stored in the DSS file have the pathname identifiers listed in Table 10.17. The target series *TS* records in the DSS file are referenced by *TS* records in the DAT file which are replicated in Table 10.18.

A daily *SIMD* simulation is performed with a set of *IF*, *ES*, and *PF* records controlling computation of daily instream flow targets for the SB3 EFS at the 14 control points. The daily instream flow targets in acre-feet/day are summed to monthly quantities in acre-feet/month within *SIMD*. The monthly targets are included in the *SIMD* simulation results DSS output file. The DSS records of monthly targets are copied from the daily *SIMD* simulation results DSS output file to the *SIM/SIM* hydrology input DSS file and the pathnames are revised using *HEC-DSSVue*.

The DSS file pathnames for the target series *TS* records are listed in Table 10.17. The *TS* records in the monthly *SIM* DAT file replicated in Table 10.18 reference the DSS file target series employed by the *IF* record water rights. IFM(if,2) option 2 in *IF* record field 7 activates the option to combine multiple *IF* record instream flow targets at the same control point by selecting the largest. With only one *IF* record at a control point, the IFM(if,2) option is not relevant. The results for daily and monthly simulations presented later in this chapter and Appendix C include daily and aggregated monthly instream flow targets for the SB3 EFS.

Table 10.17
Pathnames for *TS* Records for the SB3 EFS in the Hydrology Input DSS File

Part A	Part B	Part C	Part D	Part E
Colorado	B20000	TS	01Jan1940-31Dec2023	1MON
Colorado	C30000	TS	01Jan1940-31Dec2023	1MON
Colorado	C10000	TS	01Jan1940-31Dec2023	1MON
Colorado	D40000	TS	01Jan1940-31Dec2023	1MON
Colorado	C30000	TS	01Jan1940-31Dec2023	1MON
Colorado	E10000	TS	01Jan1940-31Dec2023	1MON
Colorado	F20000	TS	01Jan1940-31Dec2023	1MON
Colorado	F10000	TS	01Jan1940-31Dec2023	1MON
Colorado	G10000	TS	01Jan1940-31Dec2023	1MON
Colorado	H10000	TS	01Jan1940-31Dec2023	1MON
Colorado	J50000	TS	01Jan1940-31Dec2023	1MON
Colorado	J30000	TS	01Jan1940-31Dec2023	1MON
Colorado	J10000	TS	01Jan1940-31Dec2023	1MON
Colorado	K20000	TS	01Jan1940-31Dec2023	1MON

Table 10.18
Instream Flow Rights that Model the SB3 EFS in the DAT File of the Monthly WAM

```
IFB20000                  20110301    2             B20000ES
TS         DSS
IFC30000                  20110301    2             C30000ES
TS         DSS
IFC10000                  20110301    2             C10000ES
TS         DSS
IFD40000                  20110301    2             D40000ES
TS         DSS
IFD30000                  20110301    2             D30000ES
TS         DSS
IFE10000                  20110301    2             E10000ES
TS         DSS
IFF20000                  20110301    2             F20000ES
TS         DSS
IFF10000                  20110301    2             F10000ES
TS         DSS
IFG10000                  20110301    2             G10000ES
TS         DSS
IFH10000                  20110301    2             H10000ES
TS         DSS
IFJ50000                  20110301    2             J50000ES
TS         DSS
IFJ30000                  20110301    2             J30000ES
TS         DSS
IFJ10000                  20110301    2             J10000ES
TS         DSS
IFK20000                  20110301    2             K20000ES
TS         DSS
```

The instream flow *IF* records in Table 10.18 include the control point identifier, priority number (March 1, 2011), IFM(if,2) option 2 specification that the largest target is adopted if two or more *IF* record rights are assigned to the same control point, and water right identifier. The entry of DSS on the time series *TS* record following each *IF* record indicates that the time series is to be read by *SIM* from the DSS input file. Control point identifiers can be included on the *TS* records. However, blank control point fields on the *TS* records of Table 10.18 default to assigning the control points from the *IF* records. Parameter DSSTS on the simulation job options *JO* record near the beginning of the DAT file activates reading of *TS* records from the DSS input file. Likewise, parameters INEV, DSSFA, and DSSHI on the *JO* record alert *SIM* that time series quantities on *IN*, *EV*, *FA*, and *HI* records are also read from the DSS file.

Comparison of Simulated Reservoir Storage for Alternative Modeling Premises

Simulation results for the version of the TCEQ full authorization WAM discussed earlier in this chapter consisting of three files with filenames Colorado3.DAT, Colorado3.DIS, and ColoradoHYD.DSS are presented in Figures 10.8 and 10.9. Summations of the 1940-2023 end-of-month storage contents of the 486 reservoirs in the WAM are plotted in Figure 10.8. The total simulated storage contents of the six Highland Lakes operated by LCRA and total simulated storage contents of Lakes Ivie, Spence, and Thomas operated by CRMWD are compared in Figure 10.9. Storage contents from *SIMD* simulations are added to the comparative analyses as follows.

The daily WAM is comprised of four files with filenames ColoradoD.DAT, ColoradoD.DIS, ColoradoD.DIF, and ColoradoHYD.DSS that are employed, with the variations discussed below, in the daily *SIMD* simulations presented in this chapter. Monthly *SIM* simulation results from the WAM dataset referenced in the preceding paragraph are included for comparison in the reservoir storage plots of Figures 10.11, 10.12, and 10.13. The one monthly *SIM* and three daily *SIMD* simulations with storage results plotted in the figures are listed in Table 10.19.

Table 10.19
Legend for Storage Volumes Plots in Figures 10.11, 10.12, and 10.13

SIM monthly simulation (**blue solid line**)
SIMD simulation with routing and forecasting with a forecast period of three days (**red dotted line**)
SIMD simulation with routing but no forecasting (**green solid line**)
SIMD daily simulation with no routing and no forecasting (**black dashes**)

Figure 10.11 is comprised of 1940-2023 plots of the summation of storage contents of the 486 reservoirs in the full authorization Colorado WAM. Figure 10.12 shows the total storage contents of the six Highland Lakes on the lower Colorado River operated by LCRA. Figure 10.13 plots the summation of storage contents of Lakes O.H. Ivie, E. V. Spence, and J. B. Thomas in the upper basin operated by CRMWD. The authorized storage of the six Highland Lakes (Travis, Buchanan, LBJ, Austin, Marble Falls) operated by LCRA comprise 44.3 percent of the total authorized capacity of the 486 reservoirs in the WAM. CRMWD Lakes O.H. Ivie, E. V. Spence, and J. B. Thomas account for 23.5 percent of the total authorized storage of the 486 reservoirs.

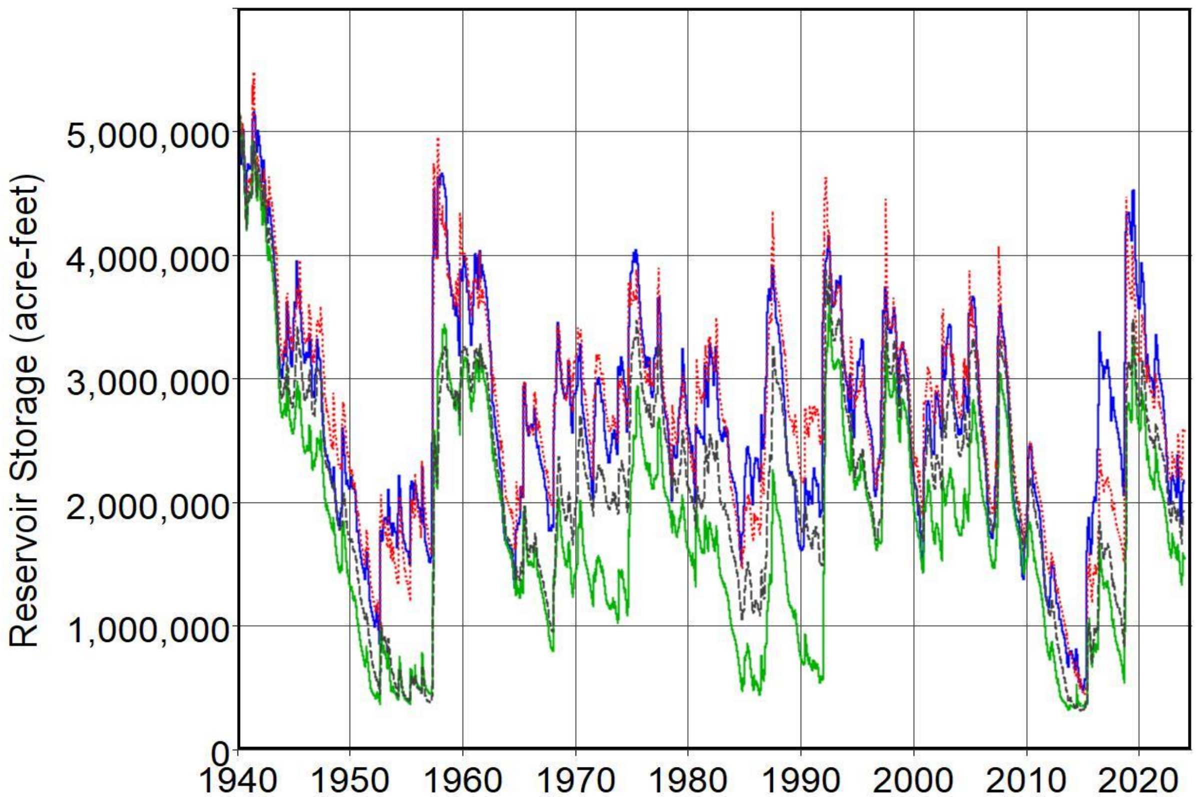

Figure 10.11 Storage in 486 Reservoirs from Monthly and Daily WAMs

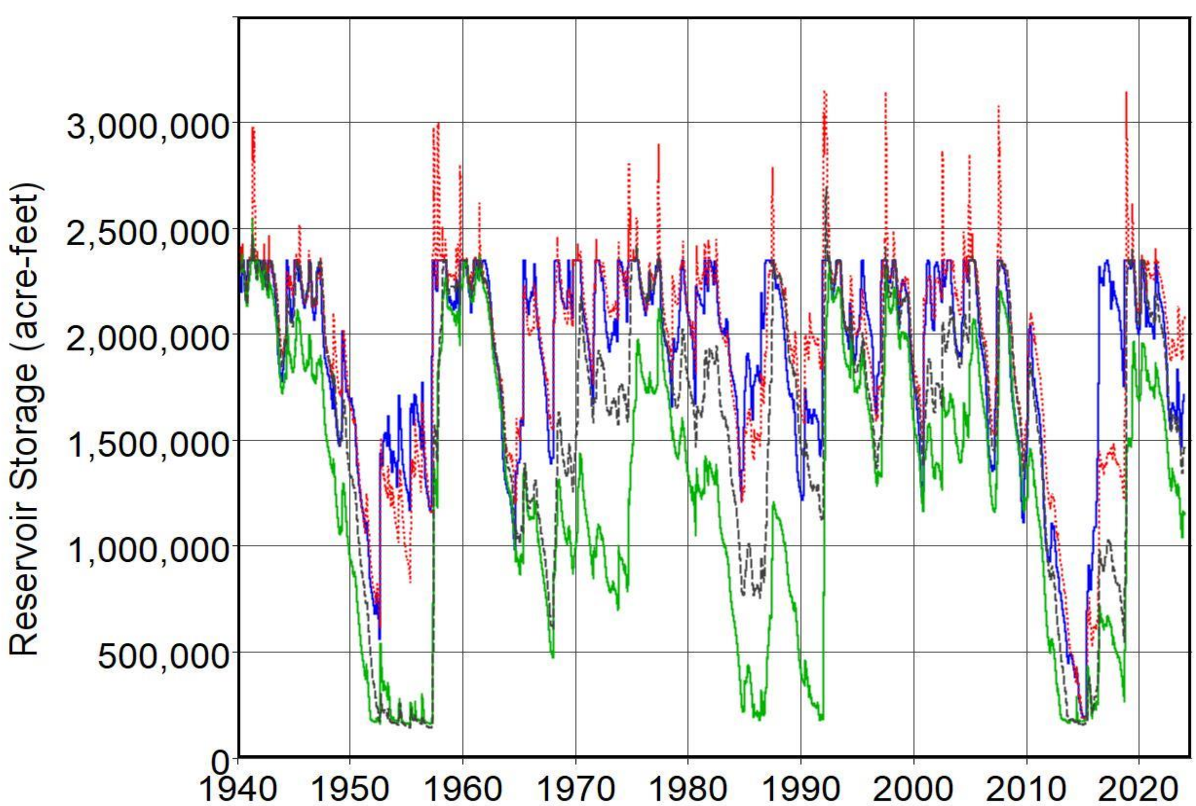

Figure 10.12 Monthly and Daily Storage in Six LCRA Reservoirs

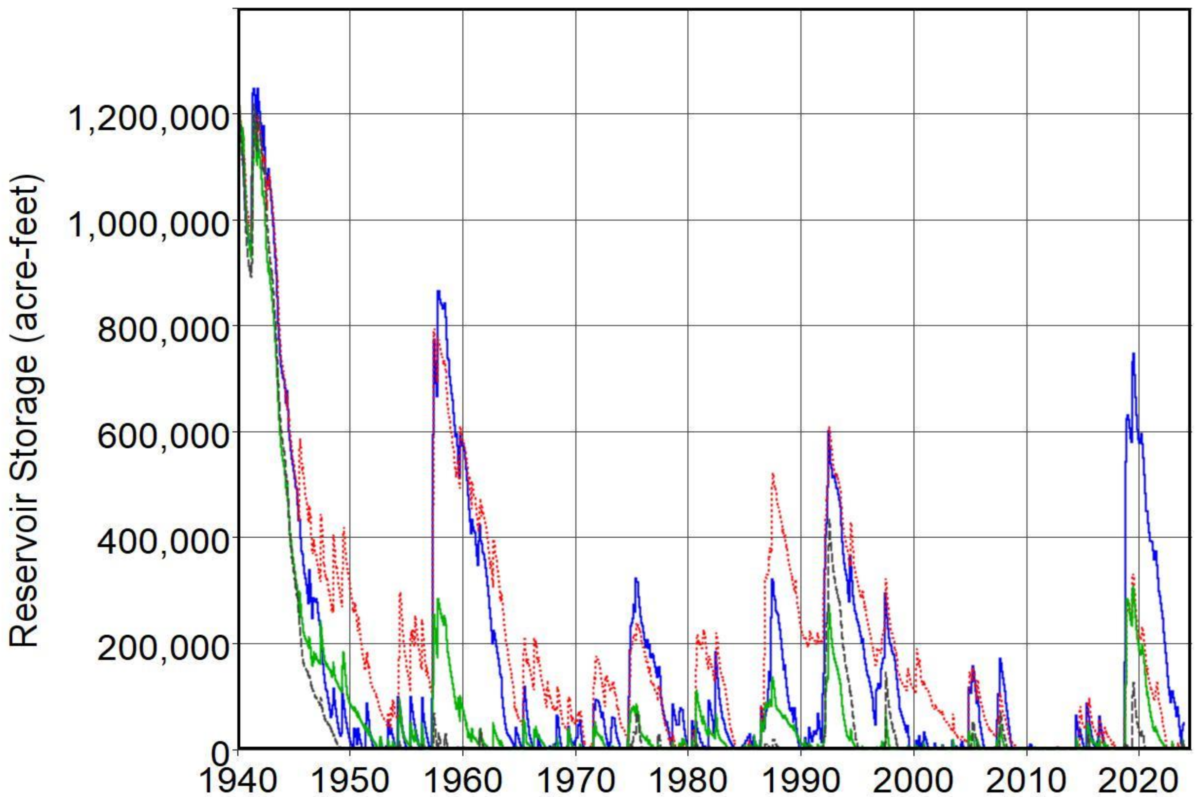

Figure 10.13 Monthly and Daily Storage in Three CRMWD Reservoirs

Plots of 30,681 end-of-day or 1,008 end-of-month simulated storage volumes during the 1940-2023 hydrologic period-of-analysis are compared for alternative modeling premises. Monthly *SIM* and daily *SIMD* simulation results are compared. Effects of routing and forecasting are illustrated by comparing storage results from the three daily *SIMD* simulations.

The lag and attenuation routing methodology and parameter calibration process are explained in the *Daily Manual* [5]. Routing and forecasting complexities and issues are discussed in Chapters 2 and 13 of the present report as well as in the case study chapters. The 2022 Daily Colorado WAM Report [10] as well as the Brazos, Trinity, and Neches Daily WAM Reports [7, 8, 9] include detailed investigations of the issues, effects, and accuracy of routing and forecasting.

Routing parameters at thirty control points and forecasting with a forecast period of three days was adopted based on simulation studies and analyses presented in the 2022 daily Colorado Report [10]. With the calibrated routing parameters available from earlier studies [10, 36, 37], routing and forecasting are easily activated or deactivated in alternative *SIMD* simulations. Forecast periods are easily changed. Subsets of the thirty routing reaches and other forecast periods were explored in previous comparative analyses [10]. As discussed in Chapters 7 through 13, routing has been adopted in this report for the Brazos and Colorado daily WAMs but not for the other four daily WAMs. The very long river reaches in the Colorado and Brazos River systems result in routing and forecasting being of greater applicability than in the smaller river systems.

SB3 EFS Instream Flow Targets

The *IF* record instream flow targets for the SB3 EFS presented in this final section of Chapter 10 were computed in a daily *SIMD* simulation that incorporated the routing parameters in Table 10.10 and a forecast period of three days. Reservoir storage plots from this *SIMD* simulation are represented with a red dotted line in Table 10.19 and Figures 10.11, 10.12, and 10.13. Daily and aggregated monthly instream flow targets from the daily *SIMD* simulated are presented.

This last section of Chapter 10 focuses on instream flow targets for the environmental flow standards (EFS) established through the process created by the 2007 Senate Bill 3 (SB3) at 14 sites described in Table 10.15 with locations shown in Figure 10.10. The computed 1940-2023 monthly SB3 EFS instream flow targets and shortages at the 14 control points are plotted as Figures C29 through C44 of Appendix C. Observed daily, monthly, and annual flows of the Colorado River at San Saba, Austin, and Columbus are plotted in Figures B10, B11, and B12 of Appendix B. Naturalized and simulated regulated monthly flows of the Colorado River at control point K1000 near the outlet are plotted earlier in this chapter as Figures 10.6 and 10.7. Statistics for daily observed, naturalized, simulated regulated, and unappropriated stream flow and SB3 EFS instream flow targets at five of the SB3 EFS locations are tabulated in Table 10.20 of this section. SB3 EFS daily targets from *SIMD* at the selected five locations are plotted in Figures 10.14-10.18.

SIMD and *SIM* Input Files for Daily and Modified Monthly WAMs

The daily full authorization *SIMD* input dataset consists of a set of files with the following filenames: ColoradoD.DAT, ColoradoD.DIS, ColoradoD.DIF, and ColoradoHYD.DSS. The daily WAM was executed with *SIMD* to generate monthly instream flow targets stored as *TS* records in the file ColoradoHYD.DSS that model the 14 sets of environmental flow standards. This modified monthly WAM is comprised of a set of *SIM* input files with the following filenames.

ColoradoM.DAT, Colorado.DIS, ColoradoHYD.DSS

The same hydrology DSS file with filename ColoradoHYD.DSS can be read by either *SIM* or *SIMD* in various versions of the WAM input dataset. *HEC-DSSVue* reads any DSS file including *SIM* or *SIMD* input files or simulation results output files.

Selected groups of records from the adopted daily WAM are replicated in this chapter. Selection of quantities to include in simulation results output files and activation of various simulation options are controlled by input records replicated in Table 10.9. Routing and forecasting are easily activated or deactivated since routing parameter quantities are included on *RT* records in the DIF file. Routing and forecasting with a forecast period of three days are activated in daily *SIMD* simulation that generated the SB3 EFS instream flow targets presented in this chapter. Other variations in the WAMs may be employed for various applications.

The 1940-2023 monthly SB3 EFS instream flow targets and shortages in acre-feet/month at the five WAM control points are plotted as Figures C29 through C44 of Appendix C. The monthly instream flow targets plotted in Appendix C were computed by *SIMD* by summing the daily instream flow targets computed in the *SIMD* simulation. These instream flow targets stored on *TS* records in the time series DSS input file are read by *SIM*.

Statistics for Daily Stream Flow and SB3 EFS Targets

Statistics for the 1940-2023 daily observed stream flows, naturalized flows, simulated regulated and unappropriated stream flows, and SB3 EFS instream flow targets and shortages at five of the 14 USGS gage sites in Table 10.15 are compared in Table 10.20. These statistics for the 1940-2023 time series of 30,681 daily quantities are the mean (average), median (50% exceedance frequency), minimum, and maximum. The quantities in Table 10.20 are in units of cubic feet per second (cfs). *SIMD* performs simulation computations in units of acre-feet/day. Data management, unit conversions, and statistical computations were performed within *HEC-DSSVue*.

The statistics for observed daily flows in Table 10.20 are for the portion of the WAM 1940-2023 period-of-analysis covered by the USGS gage period-of-record. The observed flows at the USGS gages on the Pedernales River at Johnson City and Colorado River at Wharton cover the entire 1940-2023 period-of-analysis. USGS gage records for the Colorado River and Pecan Bayou gages at Silver, Mullin, and Bastrop begin in September 1967, October 1967, and March 1960.

Observed, naturalized, and *SIMD* simulated regulated and unappropriated stream flows of the Colorado River and tributaries, like streams throughout Texas, are extremely variable over time. The median of stream flows is much smaller than the mean since high flood flows increase the mean more than the median. Naturalized flows are generally higher than observed flows at these sites. Simulated regulated flows are generally but not always lower than naturalized flows. Simulated unappropriated flows are much lower than naturalized flows. Since within-month variability is often large, daily stream flows tend to be exhibit much greater variability than monthly stream flows.

Components of the *IF* Record Instream Flow Targets for the SB3 EFS

A table accompanying the *OF* record description in the WRAP *Users Manual* [2] defines 43 time series variables that may be included in *SIM* and *SIMD* simulation results output files. The five variables that are forms of instream flow targets or shortages in meeting instream flow targets are listed in Table 8.15 of Chapter 8. Labels defining the quantities in *SIM/SIMD OF* records, *TABLES* input files, and *DSS* simulation results files are shown in Table 8.15.

SB3 EFS are modeled as a set of *IF*, *HC*, *ES*, and *PF* records as explained in the *Daily and Users Manuals* [2, 4] and this report. The set of records replicated in Table 10.16 separate the pulse flow and subsistence/base flow components of the EFS into two separate *IF* record water rights. Pulse flow *PF* and subsistence/base flow *ES* records can be combined into a single *IF* record instream flow water right at a control point by removing the extra *IF* records without affecting the final combined instream flow targets. The extra *IF* records in Table 10.16 allow the pulse flow component and combined subsistence and base flow components of the SB3 EFS to be examined separately in Tables 10.20 and 10.21 and Figures 10.13 through 10.27.

Computation of a SB3 EFS target consists of computing a subsistence and base flow target as specified by *ES* records and a pulse flow target as specified by *PF* records. The larger of the two targets in each individual day is adopted as the final target applied in the simulation. However, both target components are recorded in the simulation results for information using labels listed in Table 8.15 of Chapter 8 replicated from Chapter 3 of the *Users Manual* [2].

Table 10.20
Statistics for Daily Stream Flows and SB3 EFS Targets and Shortages

USGS Gage Location (town) Control Point Identifier	Silver B20000	Mullin F20000	Johnson C. H10000	Bastrop J30000	Wharton K20000
Mean of Daily Quantities (cfs)					
Observed Flows	59.52	158.17	329.47	2,013	2,609
Naturalized Flows	133.67	261.20	189.92	2,543	3,356
Regulated Flows	115.80	179.32	186.42	1,706	1,540
Unappropriated Flows	0.455	38.80	39.91	269.04	275.42
SB3 EFS Targets	16.74	25.30	54.34	566.25	920.80
Pulse Flow Targets	15.46	23.24	24.68	147.48	226.42
Subsistence/Base Flow Targets	1.347	2.251	17.00	441.60	735.05
SB3 EFS Target Shortages	0.230	0.186	6.497	75.76	300.12
Median (50% Exceedance Frequency) of Daily Quantities (cfs)					
Observed Flows	5.30	11.20	45.00	1,510	1,220
Naturalized Flows	9.98	29.65	49.47	1,153	1,475
Regulated Flows	6.55	10.34	46.20	537.97	329.0
Unappropriated Flows	0.00	0.00	0.00	0.00	0.00
SB3 EFS Targets	1.00	3.00	28.38	433.0	741.0
Pulse Flow Targets	0.00	0.00	0.00	0.00	0.00
Subsistence/Base Flow Targets	1.00	3.00	16.00	424.0	741.0
SB3 EFS Target Shortages	0.00	0.00	0.00	0.00	202.6
Minimum of Daily Quantities (cfs)					
Observed Flows	0.000	0.000	0.00	75.00	14.50
Naturalized Flows	0.00	0.00	0.00	60.70	45.48
Regulated Flows	0.00	0.00	0.00	27.17	0.00
Unappropriated Flows	0.00	0.00	0.00	0.00	0.00
SB3 EFS Targets	1.00	1.00	16.63	123.00	107.00
Pulse Flow Targets	0.00	0.00	0.00	0.00	0.00
Subsistence/Base Flow Targets	1.00	1.00	1.00	123.00	107.00
SB3 EFS Target Shortages	0.00	0.00	0.00	0.00	0.00
Maximum of Daily Quantities (cfs)					
Observed Flows	15,900	37,000	108,000	65,800	90,600
Naturalized Flows	33,559	38,354	128,974	145,843	176,526
Regulated Flows	31,703	30,240	128,824	133,767	145,178
Unappropriated Flows	117.05	26,244	18,230	73,499	44,129
SB3 EFS Targets	3,000	3,500	6,980	8,000	27,000
Pulse Flow Targets	3,000	3,500	6,980	8,000	27,000
Subsistence/Base Flow Targets	2.00	3.00	29.00	824.0	1,440
SB3 EFS Target Shortages	1.67	1.00	50.55	779.7	1,440

Table 10.20
Comparison of SB3 EFS Target Components

Control Point	Number of Days with Non-Zero Targets			1940-2023 Mean of 30,681 Targets		
	ES Record	*PF* Record	Combined	*ES* Record	*PF* Record	Combined
	(days)	(days)	(days)	(cfs)	(cfs)	(cfs)
B20000	30,681	1,476	30,681	1.35	15.46	16.74
F20000	30,681	2,241	30,681	2.51	23.24	25.30
H10000	30,681	993	30,681	17.00	24.68	54.34
J30000	30,681	1,683	30,681	441.60	147.48	566.25
K20000	30,681	1,749	30,681	735.05	226.42	920.80

Statistics for the final daily targets (IFT-CP or IFT-WR), pulse flow component of the daily targets (TIF-WR), subsistence/base flow component of daily targets (TIF-WR), and final shortage in meeting total combined daily targets (IFS-WR) are tabulated in Table 10.20. The final total combined daily targets (blue line) and the subsistence/base flow component (red line) are plotted in Figures 10.13-10.17. The difference between the two plots is the pulse flow component of the SB3 EFS.

Any number of instream flow *IF* record water rights can be located at the same control point. Combining instream flow targets for multiple *IF* record rights at the same control point is controlled with *IF* record parameter IFM(if,2) with the following options: a junior target replaces a senior target; the largest target is adopted; the smallest target is adopted; or targets are added. The largest of *ES* and *PF* record instream flow targets are adopted.

The non-zero daily quantities for the high flow pulse (*PF* record) component of the SB3 EFS targets are much larger than the subsistence and base flow (*ES* record) quantities but occur only during infrequent high flow events. The subsistence and base flow component of the SB3 EFS targets are relatively small quantities in each day but occur continuously. The combined subsistence and base flow (*ES* record) component is greater than zero in all 30,681 days of the 1940-2023 simulation. The high pulse flow (*PF* record) component of the SB3 EFS target is zero during most of the 30,681 days of the 1940-2023 simulation. The means of the high pulse targets defined by PF records averaged over the 30,681 days and the number of days with nonzero target quantities are tabulated in Table 10.20.

For example, as indicated by Tables 10.20 and 10.21, the mean of the high pulse flow targets at control point B20000 averaged over the 30,681 days of the 1940-2023 simulation is 15.46 cfs. The daily high pulse targets range from zero during 29,205 days to a maximum of 3,000 cfs during some of the days of some of 1,476 days with the high flow pulse events tracked. The daily combined subsistence and base flow target at B20000 ranges between 1.0 cfs and 3,000 cfs in each of 30,681 days with a 1940-2023 mean of 1.35 cfs. The total combined target in each individual day is the larger of the high pulse flow component and subsistence/base flow component. The total combined total ranges from 1,200 cfs to 4,500 cfs with an average of 64.74 cfs at control point B20000.

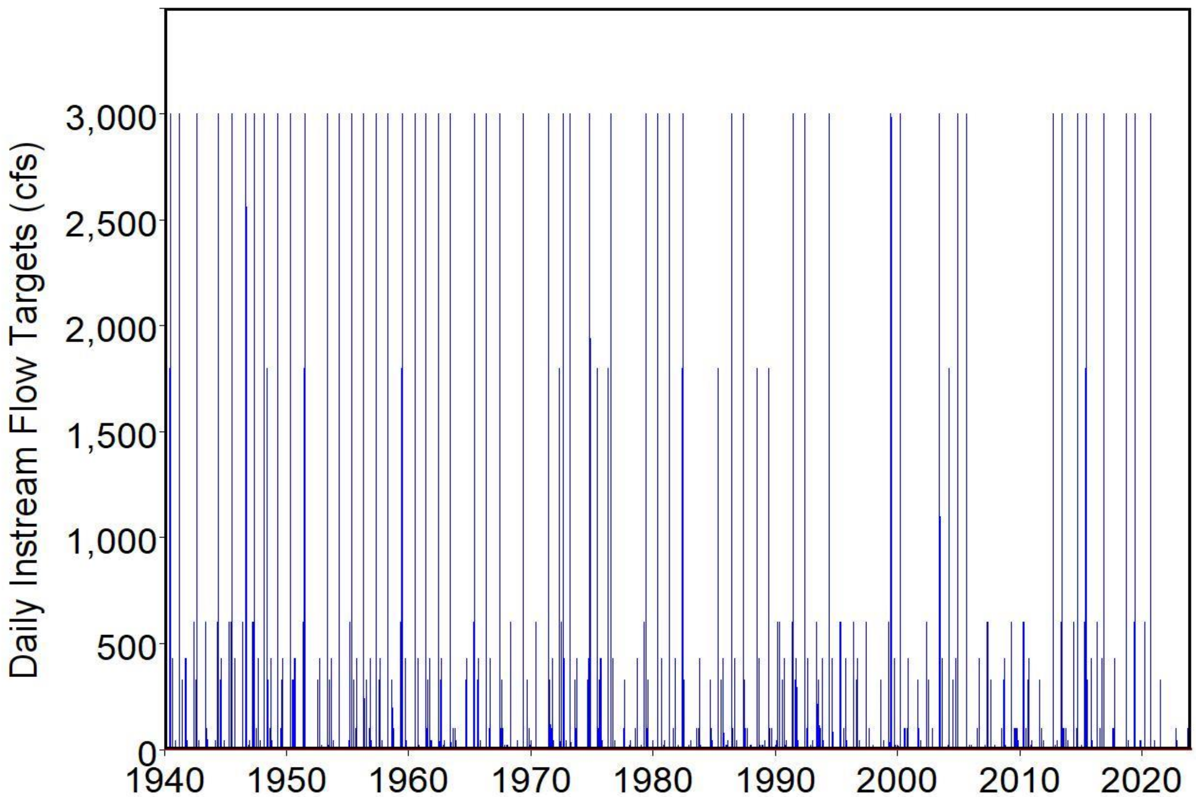

Figure 10.14 Total (**blue**) and Subsistence/Base (**red**) Targets for Colorado River at Silver

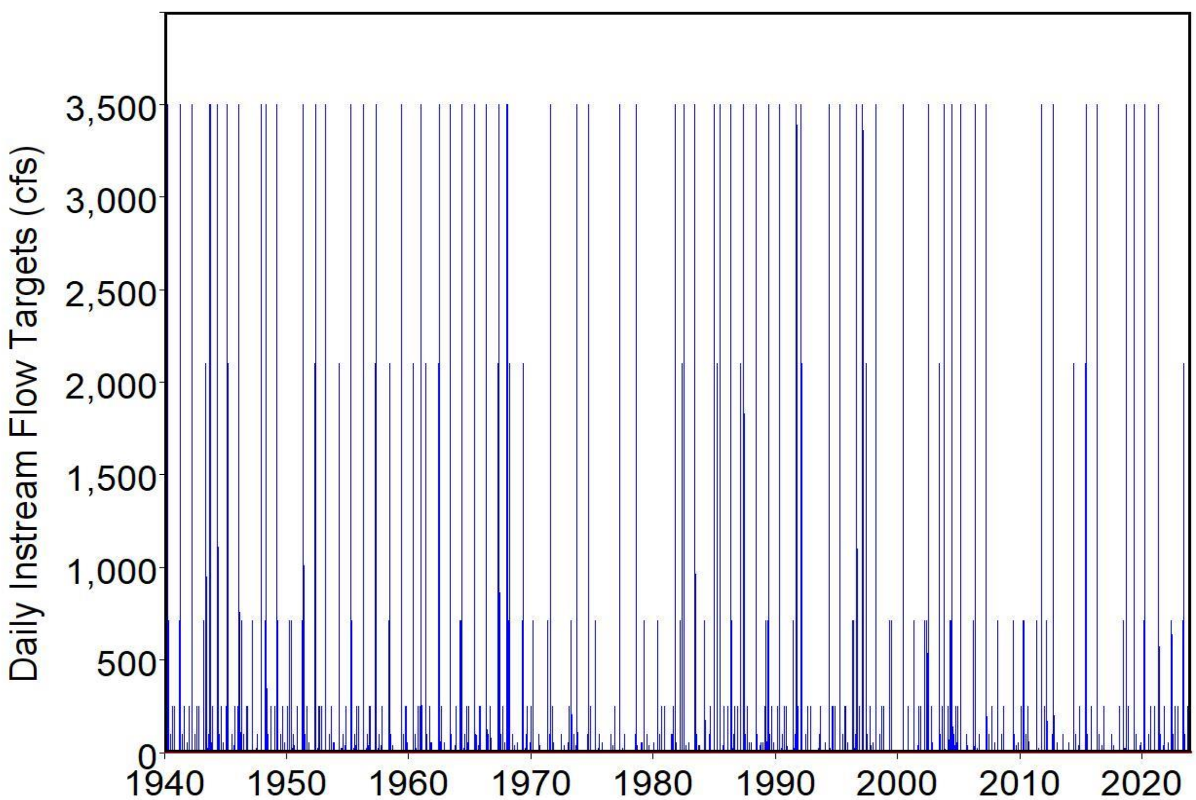

Figure 10.15 Total (**blue**) and Subsistence/Base (**red**) Targets for Pecan Bayou at Mullin

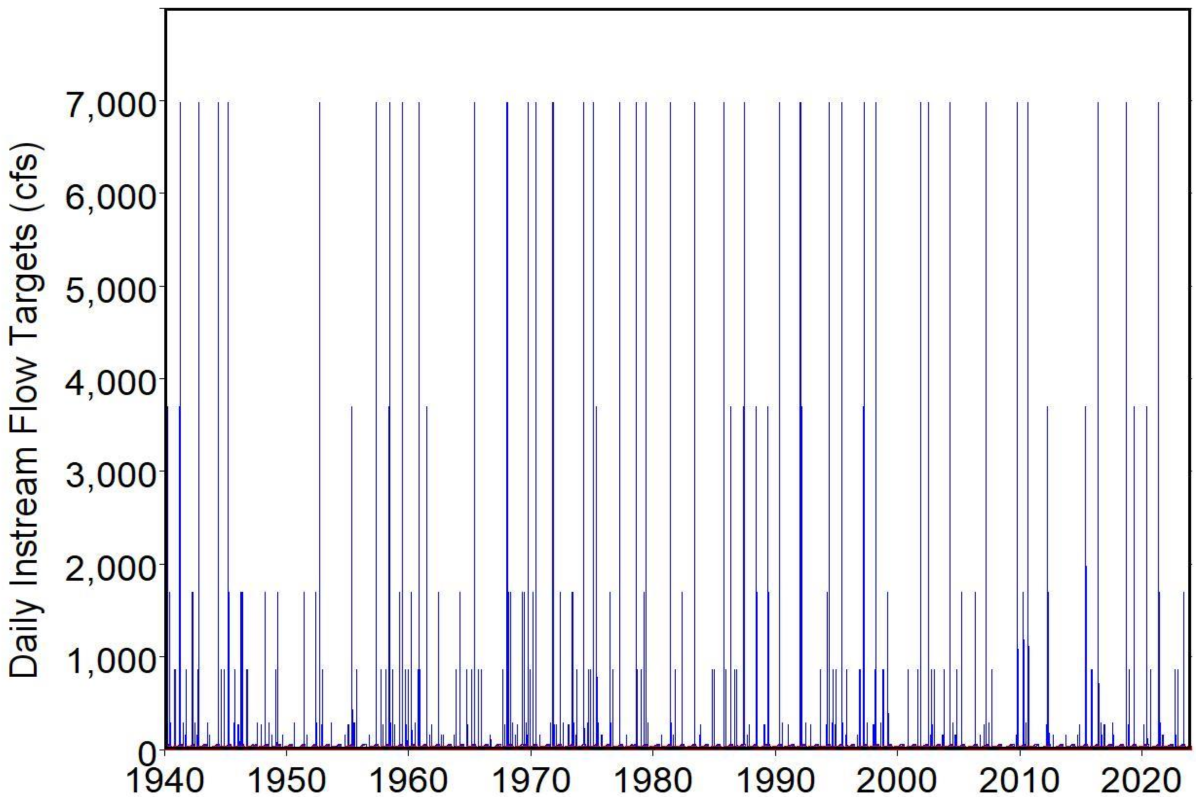

Figure 10.16 Total (**blue**) and Subsistence/Base (**red**) Targets for Pedernales R. at Johnson City

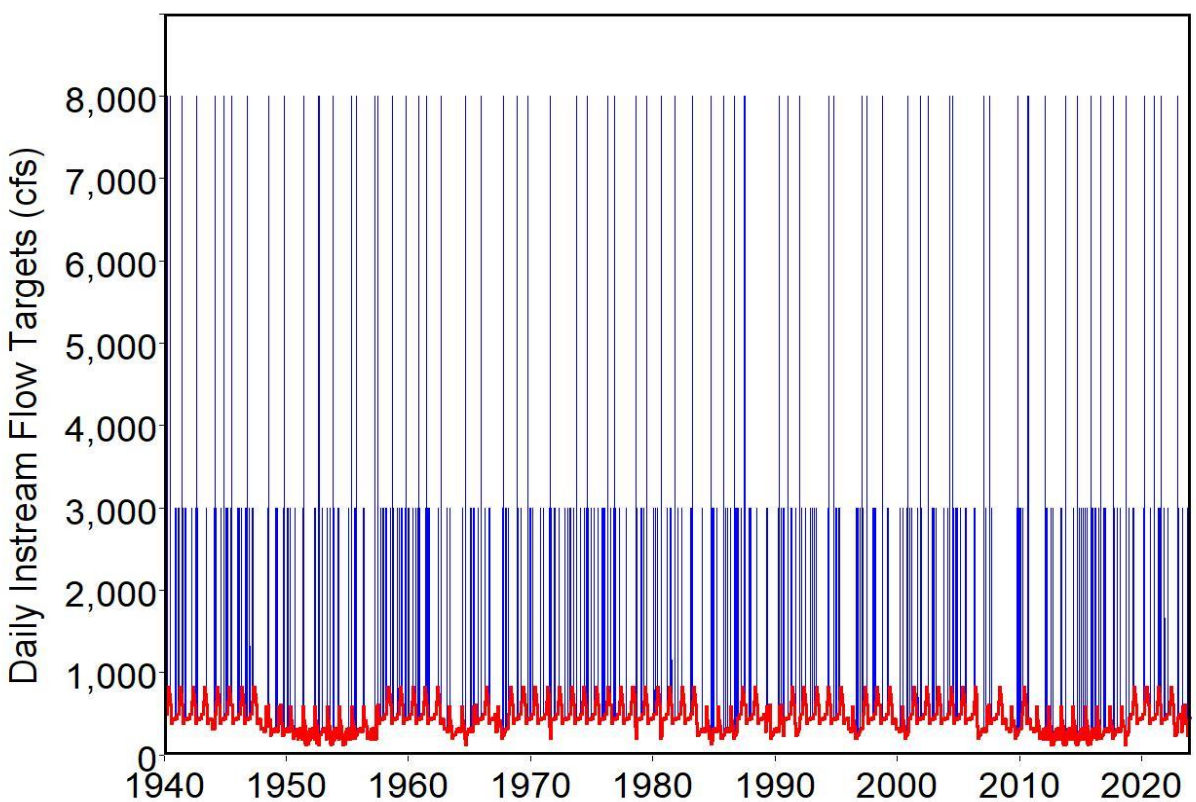

Figure 10.17 Total (**blue**) and Subsistence/Base (**red**) Targets for Colorado River at Bastrop

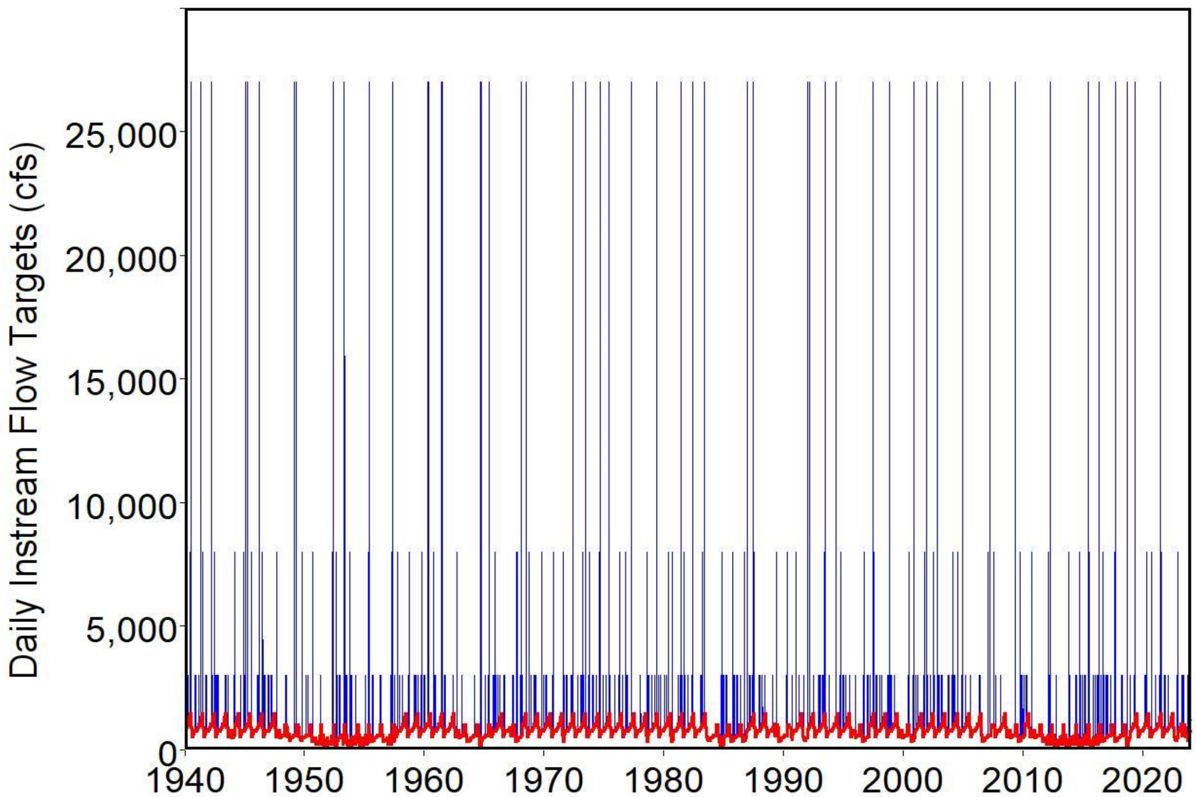

Figure 10.18 Total (**blue**) and Subsistence/Base (**red**) Targets for Colorado River at Wharton

The subsistence/base flow targets plotted as red lines in Figures 10.14-10.18 are essentially unrecognizable in Figures 10.14-10.16 due to the quantities being very small relatively to the pulse flow limits. For example, referring to Table 10.20, the subsistence/base flow component of the SB3 EFS target at control point B20000 (Colorado River at Silver) ranges between 1.0 cfs and 2.0 cfs which is very small relative to the maximum high pulse component of 3,000 cfs. The subsistence/base flow limits are relatively larger in Figures 10.17 and 10.18. The difference between the final total combined daily targets (blue line) and the subsistence/base flow component (red line) are plotted in Figures 10.14-10.18 is the pulse flow component of the SB3 EFS.

The SB3 EFS are described in detail in the 2022 Daily Colorado WAM Report [10]. Flow limits and other metrics defining the SB3 EFS are tabulated in Tables 5.2 through 5.11 of the 2022 report [10]. Metrics defined the SB3 EFS at two of the 14 sites are also shown in Table 10.16 of this chapter in the form of *SIMD* input records.

SB3 EFS Instream Flow Targets and Shortages in the Modified Monthly WAM

Monthly summations of *SIMD* simulated SB3 EFS instream flow targets and shortages in meeting the targets are compared for each of the 14 SB3 EFS sites in the 1940-2023 monthly time series plots in Appendix C. The monthly quantities for both targets and shortages plotted in Appendix C are summations of daily quantities performed within a daily *SIMD* simulation.

The monthly totals of the daily instream flow targets are incorporated in the monthly WAM as outlined in Tables 10.17 and 10.18. The monthly summations of daily target volumes generated in the daily *SIMD* simulation are replicated exactly in the monthly targets provided as input to *SIM* in the monthly WAM dataset. Shortages in meeting the SB3 EFS are computed within the monthly *SIM* simulation based on monthly regulated flows computed in the *SIM* simulation. Monthly summations of daily *SIMD* target shortages differ from monthly target shortages computed in the *SIM* simulation for the same targets. The monthly shortages in Appendix C are *SIMD* summations of daily shortages, which differ from shortages computed in a *SIM* simulation.

The 1940-2023 means and medians (50% exceedance frequency) of sets of 1,008 monthly quantities are compared in Table 10.22. Both the monthly *SIMD* and monthly *SIM* targets are the summation of daily *SIM* targets. The monthly *SIMD* shortages in Table 10.22 are summations of daily *SIMD* shortages. The *SIM* shortages computed within the monthly *SIM* simulation reflect differences in regulated flows and other differences between the monthly versus daily simulations. A median shortage of 0.000 acre-feet/month in Table 10.22 indicates the occurrence of zero shortage in meeting EFS targets in over 50% of the 1,008 months of the 1940-2023 simulations.

Table 10.22
Comparison of Monthly EFS Targets and Shortages from *SIM* and *SIMD*

SB3 EFS Site	Mean (acre-feet/month)			Median (acre-feet/month)			
	Targets for Both	Shortages *SIMD*	Shortages *SIM*	Targets *SIMD*	Targets *SIM*	Shortages *SIMD*	Shortages *SIM*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
B20000 Colorado River, Silver	1,011	4.873	9.019	115.0	115.0	0.000	0.000
F20000 Pecan Bayou, Mullin	1,527	2.653	157.6	184.5	184.5	0.000	0.000
H10000 Pedernales, Johnson City	3,281	269.3	243.0	1,745	1,745	0.000	0.000
J30000 Colorado River, Bastrop	34,185	1,868	1,747	27,653	27,653	0.000	0.000
K20000 Colorado River, Wharton	55,591	11,735	9,464	50,912	50,912	2,630	0.000

Simulation computations are performed in units of acre-feet/day in *SIMD* and acre-feet/month in *SIM*. Quantities in the SB3 EFS and *ES* and *PF* records are in cfs. The mean of 30,681 daily target means in cfs or 1,008 monthly target means in cfs are the same 1940-2023 target mean in cfs. The 1940-2023 median and other frequency statistics for 30,681 daily means in cfs of various quantities will often differ from the corresponding median and other frequency statistics for the 1,008 monthly means in cfs simply due to adopting daily versus averaging intervals. Within-month daily variability is lost in a monthly computational time interval.

The 1940-2023 monthly SB3 EFS instream flow targets and shortages at the 14 control points in the *SIMD* simulation are plotted in Appendix C. Both the monthly targets and monthly target shortages plotted in Appendix C are from the results of the daily *SIMD* simulation. The quantities in Appendix C were read by *HEC-DSSVue* from a *SIMD* output DSS file in acre-feet/month and plotted in these same units.

The monthly SB3 EFS instream flow targets generated with the daily *SIMD* simulation following the strategy outlined in Tables 10.17 and 10.18 were provided on *TS* records as input data for the monthly *SIM* simulation model. The corresponding instream flow target shortages differ from *SIMD* shortages as illustrated by Table 10.22.

CHAPTER 11
LAVACA DAILY AND MODIFIED MONTHLY WAMS

The original Lavaca WAM was completed by the U.S. Bureau of Reclamation (USBR) for the Texas Natural Resource Conservation Commission (TNRCC) in 2002 [90]. TNRCC was renamed TCEQ in September 2002. TCEQ has modified the monthly WAM at various times in the past. Daily and revised monthly versions of the Lavaca WAM were developed at TAMU for TCEQ as reported by the 2023 Daily Lavaca WAM Report [11]. SB3 EFS for the Colorado and Lavaca Rivers and Matagorda and Lavaca Bays adopted by the TCEQ in August 2012 are documented as Subchapter D of Chapter 298 of the Texas Administrative Code [98].

Each of the six case studies in Chapters 7-12 includes converting a monthly WAM to daily and inserting monthly SB3 EFS targets computed in a daily simulation into a modified monthly WAM. Reservoir flood control operations are added to the Brazos, Trinity, Neches, and Colorado daily WAMs (Chapters 7-10). The Lavaca and Nueces River Basins have no USACE flood control reservoirs and thus flood control operations are not addressed in Chapters 11 and 12. Approximate methods are employed to extend the hydrologic period-of-analysis through 2023 for all six case studies. A TWDB hydrology extension is adopted to extend the Lavaca WAM 1940-1996 period-of-analysis through 2023. The Lavaca WAM is the smallest of the six case study WAMs.

Lavaca River Basin

The 2,320 square mile Lavaca River Basin encompasses the smallest area of any of the 15 major river basins of Texas delineated in Figure 1.2 of Chapter 1. From its headwaters in Gonzales County, the Lavaca River flows to Lavaca Bay, which is a secondary bay of the Matagorda Bay system. Most of the reservoir storage capacity in the basin is provided by Lake Texana on the Navidad River. The Navidad River, Sandy Creek, and East and West Mustang Creeks flow into Lake Texana. The Navidad and Lavaca Rivers confluence downstream of Texana Dam before flowing into Lavaca Bay. Figure 11.1 is a basin map that includes the WAM control points at or near USGS stream gage sites listed in Table 11.1. The five gage sites at which SB3 EFS have been established are identified in the last column of Table 11.1

Table 11.1
WAM Control Points at or near USGS Gage Sites

Control Point	Location (stream and town)	Drainage Area (square miles)	Type CP	SB3 EFS
GS400	Lavaca River at Hallettsville	108	Primary	-
GS300	Lavaca River near Edna	817	Primary	EFS
GS600	Navidad River near Hallettsville	332	Primary	-
GS550	Navidad River near Speaks	437	Primary	-
DV501	Navidad at Strane Park near Edna	579	Secondary	EFS
GS1000	Sandy Creek near Ganado	289	Primary	EFS
GS500	Navidad River near Ganado	1,062	Primary	-
WGS800	West Mustang Creek near Ganado	178	Primary	EFS
ECB720	East Mustang Creek near Louise	53.9	Secondary	EFS

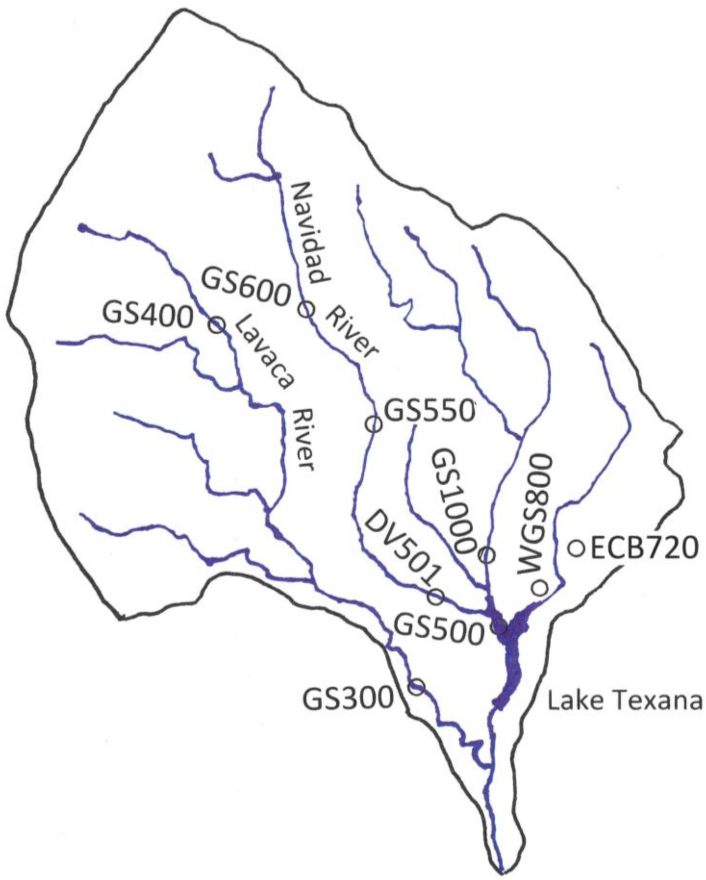

Figure 2.1 Control Points Located at or near USGS Gage Sites

Planning studies by the U.S. Bureau of Reclamation (USBR) during the 1960's resulted in proposed construction of a project known as Palmetto Bend Dam and Reservoir, Stages I and II. Stage I was a dam and reservoir on the Navidad River that was actually constructed with initial impoundment in 1980 and renamed Texana Dam and Reservoir. The proposed and water right authorized Stage II consisting of an adjacent dam on the Lavaca River has not yet been constructed. Authorized storage capacity for stage II is included in the full authorization WAM.

Lake Texana was turned over to the Lavaca-Navidad River Authority (LNRA) after completion of construction by the USBR. The City of Corpus City is LNRA's largest water supply customer. Water is transported from Lake Texana by a 101-mile-long pipeline to supply the City of Corpus Christi in the Nueces-Rio Grande Coastal Basin. LNRA also supplies other water customers in the lower basin and adjoining coastal area. Most water use within the Lavaca River Basin is supplied from groundwater.

Almost all of the reservoir storage capacity in the Lavaca River Basin is contained in Lake Texana on the Navidad River owned and operated by LNRA. Lake Texana is the only existing major reservoir in the Lavaca River Basin. The authorized storage capacity is 170,300 acre-feet. The reservoir storage capacity was 159,845 acre-feet based on a 2010 TWDB hydrographic survey. Deliberate impoundment of water in Lake Texana began in May 1980. Storage capacity has been reduced over time due to sedimentation.

Lavaca WAM

The present Chapter 11 updates and builds upon the 2023 Daily Lavaca WAM Report [11]. The preceding more detailed 2023 report documents the development of both full authorization and current use scenario versions of the daily and modified monthly Lavaca WAM. This chapter, like the five other case study chapters, focuses on full authorization daily and monthly WAMs.

The 2023 Daily Lavaca WAM Report [11] like the five other daily WAM reports [7, 8, 9, 10, 12] adopts a modeling strategy in which a monthly WAM is modified by adding monthly SB3 EFS instream flow targets to the *SIM* input dataset that were computed by summing daily targets generated in a daily *SIMD* simulation. DSS files are used for storing *SIM* and *SIMD* time series input data (*IN*, *EV*, *DF*, and *TS* records) and simulation results. The initial *SIM* input dataset modified during 2022/2023 to create the January 2023 daily and monthly Lavaca WAMs consist of monthly full authorization and current use WAMs last updated by the TCEQ in 2014 and 2008, respectively [11].

The monthly full authorization Lavaca WAM last updated by TCEQ on October 1, 2023 is converted to a daily WAM as described in this chapter. Daily features developed for the earlier 2023 daily WAM [11] are employed to convert the monthly WAM last updated by TCEQ on October 1, 2023 to daily. The 1940-1996 period-of-analysis is extended through December 2023 using *EV* records for 1997-2023 compiled by TWDB staff and 1997-2023 *IN* records that include monthly naturalized flows at some control points developed by TWDB staff using linear regression with observed flows [78] and adoption of observed flows directly at other control points.

The full authorization Lavaca WAM last updated by TCEQ on October 1, 2023 is comprised of four *SIM* input files with the following filenames: lav3.DAT, lav3.DIS, lav3.FLO, and lav3.EVA. The 2024 daily and modified monthly versions of the WAM developed as explained in this chapter are comprised of the following *SIMD* and *SIM* input files.

LavacaHYD.DSS − The hydrology time series DSS file contains 1940-2023 monthly series of *IN* record naturalized flows, *EV* record net reservoir surface evaporation less precipitation depths, *TS* record monthly SB3 EFS instream flow targets, and 1940-2023 *DF* record daily flows. FLO and EVA files were converted to a DSS file and *DF* and *TS* records were added.

Lavaca.DIS − The flow distribution DIS file contains the flow distribution *FD* and watershed parameter *WP* records used to distribute monthly naturalized flows from 8 primary control points to 212 secondary control points the same with the daily versus monthly and authorized versus current use versions of the WAM. The *FD* and *WP* records and DIS file are not changed in the work during 2024 reported in this chapter.

Lavaca.DIF − The DIF file contains flow disaggregation specifications on a *DC* record. Optional routing *RT* records are not included in the DIF since routing is not employed.

LavacaD.DAT − The daily version of the full authorization scenario (run 3) DAT file with filename LavacaD.DAT expands the monthly DAT file with filename lav3.DAT.

LavacaM.DAT − The LavacaM version of the monthly full authorization DAT file with monthly SB3 EFS targets from a daily simulation replaces the monthly DAT file with filename lav3.DAT.

Counts of Input Records

The WRAP simulation models *SIM* and *SIMD* print a listing in their message (MSS) file of the number of various system components. Program *TABLES* 1RCT, 1SUM, and 1RES records provide summaries of data in a DAT file. Counts and totals for the alternative WAM versions noted on the preceding page are tabulated in Table 11.2. Runs 3 and 8 refer to the full authorization and current use water management scenarios. The six 2024 case study chapters in this report, including the 2024 Lavaca case study, include only full authorization (run 3) WAM versions.

Table 11.2
Number of Model Components in Lavaca WAM Datasets

(1)	(2)	(3)	(3)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
				2023 Neches WAM Report [11]				This Chapter		
Version Date	2008	2008	2014	2023	2023	2023	2023	2023	2024	2024
Monthly/Daily	Month	Month	Month	Month	Month	Daily	Daily	Month	Daily	Month
Scenario-Run	3	8	3	3	8	3	8	3	3	3
control points	185	184	342	185	184	185	184	220	220	220
IN records	7	7	7	7	7	7	7	8	8	8
EV records	7	7	7	7	7	7	7	7	7	7
reservoirs	22	21	22	22	21	22	21	22	22	22
WR records	72	68	212	72	69	72	69	86	70	70
IF record	30	30	130	35	35	40	40	61	40	35
FD record	167	167	172	167	167	167	167	179	179	179

The hydrologic period-of-analysis is January 1940 through December 1996 for the original 2002/2003 Lavaca WAM and versions updated by TCEQ in June 2008, September 2014, and October 2023. The period-of-analysis was extended through December 2021 for the January 2023 daily and modified monthly versions of the WAM developed as reported in the 2023 Daily WAM Report [11]. The period-of-analysis is further extended through 2023 as reported in this chapter.

The June 2008 full authorization (run 3) and current use scenario (run 8) datasets do not include SB3 EFS. The September 2014 full authorization (run 3) dataset includes draft records in the DAT file modeling SB3 EFS and a hydrologic index series HIS file added solely for modeling the SB3 EFS. The HIS file and DAT file records modeling SB3 EFS are removed and replaced in the January 2023 datasets developed as explained in the 2023 Daily WAM Report [11].

Development of the 2024 daily and modified monthly versions of the WAM presented in this chapter began with the full authorization WAM last updated by TCEQ on October 1, 2023 comprised of *SIM* input files with filenames: lav3.DAT, lav3.DIS, lav3.FLO, and lav3.EVA. Column 9 of Table 11.2 refers to this 2023 version of the TCEQ WAM. TCEQ has added the SB3 EFS to this October 2023 version of the WAM. Column 10 of Table 11.2 is a tabulation of record counts for the 2024 version of the daily WAM updated as described in this chapter. Column 11 refers to this 2024 version of the modified monthly *SIM* input dataset that contains monthly SB3 EFS targets computed in a daily *SIMD* simulation with the WAM referenced in column 10. The records modeling SB3 EFS in the column 9 WAM are removed and replaced.

Control Points, Water Rights, and Reservoirs

The October 2023 monthly WAM has 220 control points defined by *CP* records. Eight are primary with naturalized flows provided as *IN* records in the *SIM/SIMD* input. TCEQ added a new primary control point EP000 in the October 2023 update to more accurately reflect stream flows at the basin outlet. Control point EP000 at the outlet represents an ungaged location.

Monthly reservoir net evaporation-precipitation depths are input on *EV* records for seven of the eight primary control points (all but EP000). The nine USGS gage sites listed in Table 11.1 serve as control points (seven primary and two secondary) for all versions of the WAM. WRAP control point identifiers are arbitrarily created labels of six or less characters. "GS" was placed in the control point identifiers for the Lavaca WAM by the USBR developers to signify "gage sites".

The Lavaca WAM last updated by TCEQ in October 2023 has 86 *WR* records. Annual water supply diversion targets entered as AMT on the 86 *WR* records total 200,363 acre-feet, consisting of:

116,500 acre-feet diverted from Lake Texana with priorities between 19720515 and 20020701
48,122 acre-feet from Palmetto Bend Stage II with priorities between 19720515 and 19931006
35,741 ac-ft from all other diversion sources with priorities between 19030930 and 20020703

The Lavaca WAM last updated by TCEQ in October 2023 has 61 *IF* records with priorities ranging between 19720515 (May 15, 1972) and the SB3 EFS priority of 20110301 (March 1, 2011).

The full authorization WAM last updated by TCEQ in October 2023 includes 22 reservoirs with a total authorized storage capacity of 265,664 acre-feet. Lake Texana with a capacity of 170,300 acre-feet accounts for 64.1% of the total storage capacity. The permitted but not yet constructed Palmetto Bend Stage II Reservoir has a capacity of 93,340 acre-feet (35.1% of total). The other 20 reservoirs have a combined total authorized storage of 2,024 acre-feet. The current use scenario WAM last updated by TCEQ in June 2008 includes 21 reservoirs with a total storage capacity of 167,716 acre-feet, which includes Lake Texana with 165,692 acre-feet (98.8% of total) and the same twenty small reservoirs with a combined total storage capacity of 2,024 acre-feet.

Lavaca WAM Hydrology

The original Lavaca WAM developed by USBR for TNRCC (later renamed TCEQ) has a hydrologic period-of-analysis of January 1940 through December 1996 [90]. The versions last updated by TCEQ in June 2008, September 2014, and October 2023 employ the same original 1940-1996 monthly naturalized flows and evaporation-precipitation depths (*IN* and *EV* records). *IN* and *EV* record extensions compiled by TWDB hydrologists were adopted to extend hydrology through 2021 for the January 2023 daily and modified monthly versions of the WAM [11]. A further update of the *IN* and *EV* record extension available at the TWDB website was adopted to further extend the hydrologic period-of-analysis through 2023 as reported in this chapter.

As discussed in Chapter 5, TWDB intermediate extensions of *IN* record naturalized flows between TCEQ updates are based on linear regression with observed flows at the same site or nearby sites [78]. TWDB staff use the quadrangle evaporation and precipitation database discussed in Chapter 3 to extend *EV* records. TWDB *IN* and *EV* record extensions are available online.

Precipitation and Reservoir Evaporation Rates

The 2002 USBR/TNRCC Lavaca WAM Report [90] states that historical monthly gross evaporation and precipitation rates for Lake Texana were obtained from the Lavaca-Navidad River Authority. The TWDB quadrangle monthly evaporation and precipitation datasets appear to have been used for the twenty small reservoirs. The USBR developed *EV* records of net evaporation-precipitation rates by subtracting precipitation from evaporation depths. The WAM includes seven sets of *EV* records assigned the same identifiers as seven primary control points. The Lake Texana net evaporation-precipitation rates are assigned control point identifier GS300. TWDB staff used the TWDB monthly evaporation and precipitation database for the 1997-2023 *EV* record extension.

The WAM includes seven sets of *EV* records assigned the same identifiers as primary control points. Lake Texana net evaporation-precipitation rates are assigned control point identifier GS300. The seven 1940-2021 sequences of monthly net reservoir evaporation less precipitation depths in feet stored on *EV* records for the January 2023 Lavaca WAM consist of the original quantities for 1940-1996 and quantities for 1997-2021 compiled by the TWDB using their quadrangle database. The 2024 updated *EV* records include the TWDB extension through 2023.

Quadrangles 811 and 911 (Figure 4.1) encompass most of the Lavaca River Basin and all of Lake Texana. Most of Lake Texana is in quadrangle 811. Mean annual 1940-2023 precipitation depths and 1954-2023 evaporation depths (Figure 4.3) are 41.5 and 49.8 inches for quadrangle 811 and 39.6 and 50.1 inches for quadrangle 911. The averages of quantities for quadrangles 811 and 911 are considered reasonable approximations of precipitation and reservoir evaporation for the Lavaca River Basin. The basin-wide 1940-2023 annual precipitation in the Lavaca River Basin is estimated to have ranged from a minimum of 16.40 inches to a maximum of 61.85 inches, with an 84-year average of about 40.55 inches/year. The 1954-2023 average annual reservoir evaporation in the Lavaca River Basin is about 49.95 inches/year, ranging between minimum and maximum values of 35.85 and 61.25 inches.

Reservoir Evaporation-Precipitation Correction for
Precipitation Runoff Reflected in Naturalized Flows

Naturalized stream flows reflect undeveloped conditions without reservoir projects and thus include some but not all the rain falling on the undeveloped land area of the reservoir site. Computational options activated by input parameters EPADJ and EWA(cp) on the *JD* and *CP* records are designed to prevent double-counting portions of precipitation reflected in both *EV* and *IN* record quantities. The objective is to increase the net evaporation-precipitation to offset the portion of the precipitation reflected in both rainfall runoff from the reservoir site included in the *IN* records and the rainfall depths reflected in *EV* record. These adjustments to monthly precipitation depths in the reservoir evaporation minus precipitation depths input on *EV* records are discussed on pages 124-126 of Chapter 5 of this report as well as the *Reference* and *Users Manuals* [1, 2]. EPADJ and EWA(cp) options are defined in Table 5.2. The effects of the alternative options are explored with the other case study WAMs in the preceding chapters.

EV record monthly depths in feet are positive if reservoir evaporation exceeds precipitation falling on the water surface and negative if precipitation (or adjusted precipitation) is greater than evaporation. Precipitation adjustments normally decrease the net evaporation less precipitation.

WAM 1940-2023 monthly net evaporation less precipitation depths for Lake Texana are plotted in Figure 11.2 with and without adjustments. The red dotted line includes the adjustment for the precipitation that is conceptually included in the naturalized stream inflow to the reservoir. The blue solid line is the net evaporation-precipitation depths read by *SIM* from the *EV* record before the precipitation adjustment computations specified by EWA(cp) on *CP* records are performed within the simulation. The mean annual evaporation minus precipitation is 2.056 and 1.469 feet/year with and without the EWA(cp) adjustment, with a maximum monthly depth of 0.810 feet/month in August 1951 for both cases.

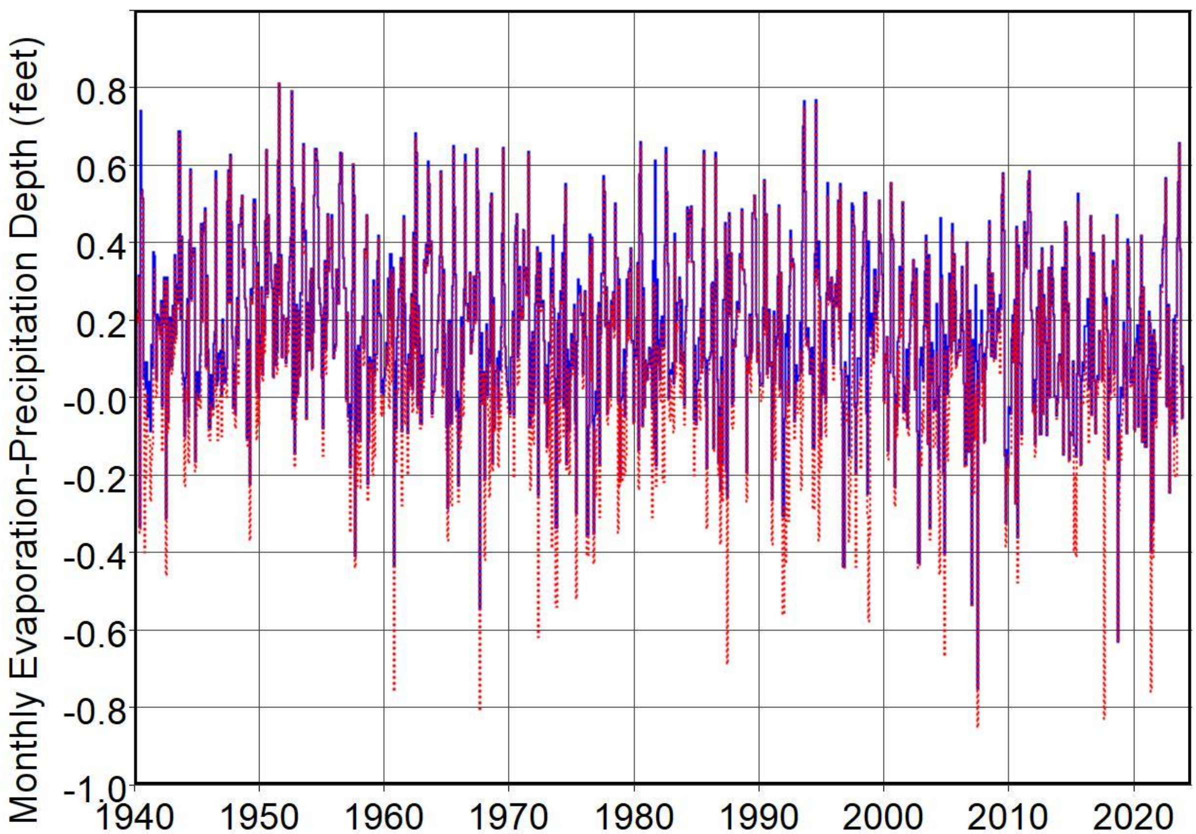

Figure 11.2 Monthly Net Evaporation-Precipitation Rates for Lake Texana
With (blue sloid line) and Without (red Dotted Line) Adjustments

SIM or *SIMD* computation of *EV* record depth adjustments is based on converting monthly naturalized stream flow volumes to a depth over a watershed area. EPADJ and EWA(cp) options may involve in some cases incremental naturalized stream flows between control points that may be negative, resulting in negative precipitation adjustments. Negative incremental naturalized flow in a month means that the downstream flow is less than the upstream flow. With −1 or −2 for EWA(cp) on *CP* records or the default EPADJ on the *JD* record, negative incremental naturalized flow results in a negative precipitation adjustment. New EWA(cp) options 1 and 2 were added to *SIM* and *SIMD* during 2024 as discussed in Chapter 5. The only difference between EWA(cp) options 1 and 2 versus −1 and −2 is handling of negative values for computed precipitation adjustments. The new options 1 and 2 change negative values of the computed precipitation adjustment to zero. Options −1 and −2 maintain any negatives that may occur.

EWA(cp) options −1 and −2 were adopted in the original Lavaca WAM and subsequent updates. Computed precipitation adjustments for the 22 reservoirs in the Lavaca WAM happen to have no negative values regardless of EWA(cp) option. Results are the same with EWA(cp) of 1 or −1. Likewise, switching EWA(cp) between 2 and −2 has no effect on Lavaca WAM results.

WAM Monthly Naturalized Flows

The original January 1940 through December 1996 hydrologic period-of-analysis has been updated to extend through December 2023 for the 2024 daily and modified monthly Lavaca WAMs as previously noted. Monthly naturalized flows for 1940-2023 at eight control points are stored on *IN* records in the *SIM/SIMD* simulation hydrology DSS input file. The monthly naturalized flows at over 100 secondary control points are synthesized during a *SIM/SIMD* simulation by applying drainage area ratios to the *IN* record flows at the eight primary control points as specified by *FD* and *WP* records in the DIS file [90, 11].

Almost all existing reservoir storage capacity in the Lavaca River Basin is in Lake Texana. Almost all use of surface water from the Lavaca Basin is supplied by Lake Texana. Most water supplied from Lake Texana is transported out of the Lavaca Basin. Surface water storage and use have had only minimal impact on observed flows at the original seven primary control points, none of which are located downstream of Lake Texana.

Versions of the WAM prior to the version last updated 10/01/2023 had seven primary control points. *IN* records were added at ungaged control point EP000 in the 10/01/2023 update, converting the outlet of the Lavaca River at Lavaca Bay to an eighth primary control point. The watershed drainage area on the *WP* record for control point EP000 is 2,322 square miles. For comparison, the watershed areas on *WP* records in the DIS file at control points GS300 and GS500 are 822 and 1,059 square miles. Thus, the drainage area for EP000 is 1.235 times larger than the combined drainage area of the upstream control points GS300 and GS500 (Figure 11.1). The drainage areas in Table 11.1 are from the USGS NWIS website and differ slightly from the areas on the *WP* records in the WAM DIS file.

The 1997-2023 monthly naturalized flows for control point EP000 are estimated for the 2024 daily and modified monthly WAMs based on 1940-2023 naturalized flows at control points GS300 and GS500 as follows. The means of the 1940-1996 naturalized flows on the *IN* records for control points GS300, GS500, and EP000 are 250,988 ac-ft/year, 427,106 ac-ft/year, and 860,402 ac-ft/year, respectively. Thus, the 1940-1996 mean flow at EP000 is 1.2689 times larger than the combined mean flow at the upstream control points GS300 and GS500. The *IN* record naturalized flow for each month of 1997-2023 at control point EP000 is computed as 126.89% of the summation of flows at control points GS300 and GS500.

The original *IN* records of 1940-1996 naturalized flows at the seven original primary control points were adopted without revision for both the January 2023 WAM hydrology dataset [11] and the updated 2024 dataset adopted in this chapter. *IN* records of 1997-2021 monthly naturalized flows for the 2023 WAM dataset and the 2022-2023 extension were compiled as follows as explained in detail in the 2023 report [11].

- Observed daily flows aggregated to monthly volumes were adopted for control points GS300, GS600, and WGS800. The one day of missing data at GS600 and WGS800 was synthesized by linear interpolation of flows in adjacent days.

- Extensions performed by the TWDB were adopted for control points GS400, GS550, and GS800. TWDB filled in gaps of missing data using linear regression.
- Control point GS550 has a continuous year and several other scattered days of missing data. The TWDB flow extension was adopted for the gaps with missing observed flows. The USGS observed flows were adopted for the remainder of the 1997-2021 extension period.

Reiterating from the preceding page, TCEQ recently converted control point EP000 from secondary to primary by adding *IN* records with 1940-1996 naturalized flows for EP000. The 1997-2023 monthly naturalized flows for control point EP000 were estimated for the 2024 daily and modified monthly WAMs based on 1940-2023 naturalized flows at control points GS300 and GS500. The *IN* record naturalized flow for each month of 1997-2023 at EP000 was computed based on the following ratio of 1940-2016 mean annual naturalized flows.

EP000 / (GS300+GS500) = 1.2689

WAM 1940-2023 naturalized monthly flows at control points EP000 GS300, and GS500 are plotted as Figures 11.3, 11.4, and 11.5. These plots demonstrate the extreme variability of monthly stream flow over time. Daily flows exhibit even greater variability.

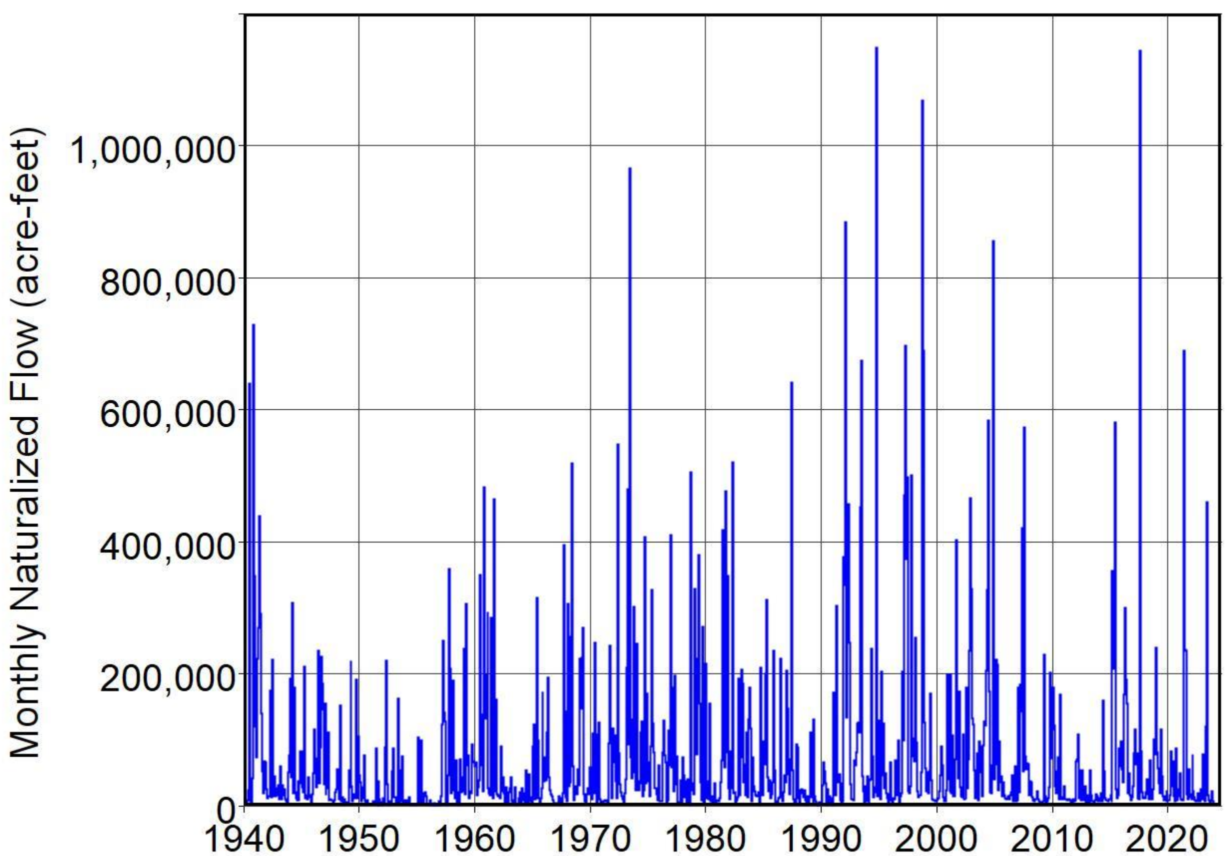

Figure 11.3 Monthly Naturalized Flows of the Lavaca River Near the Outlet at Lavaca Bay (Control Point EP000)

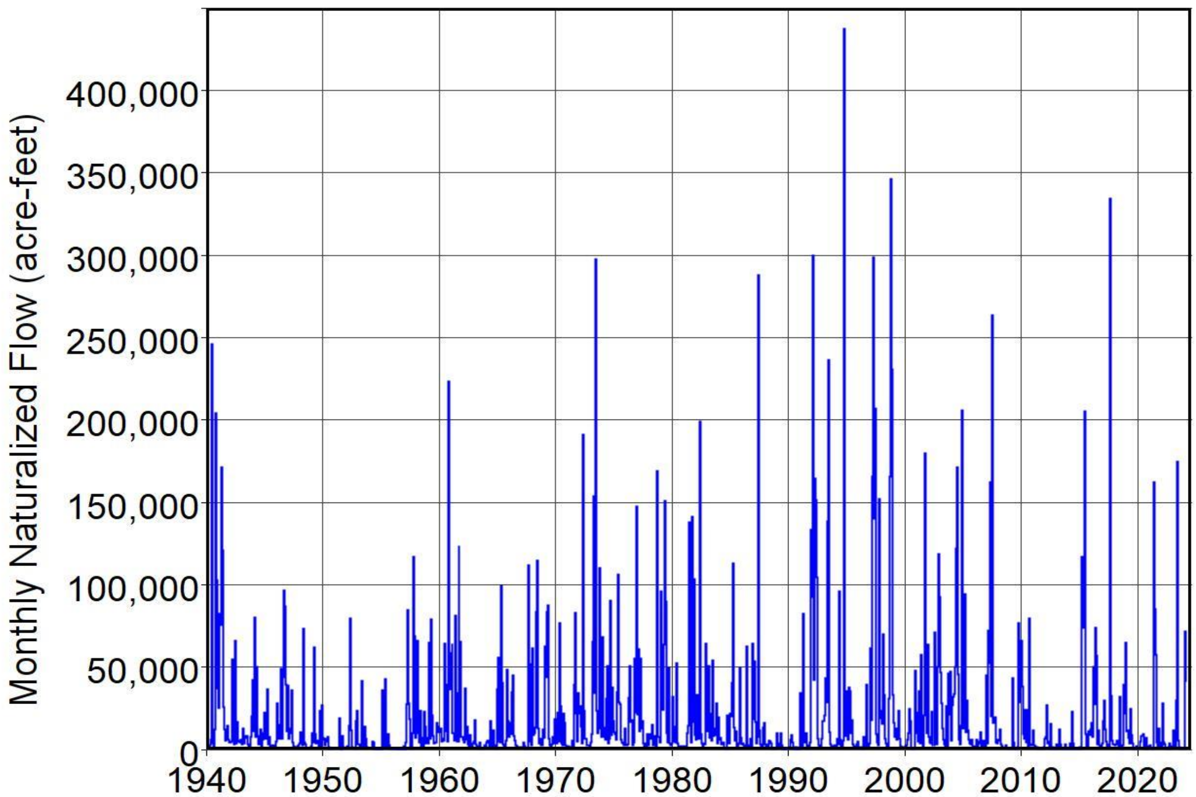

Figure 11.4 Monthly Naturalized Flows of Lavaca River near Edna (GS300)

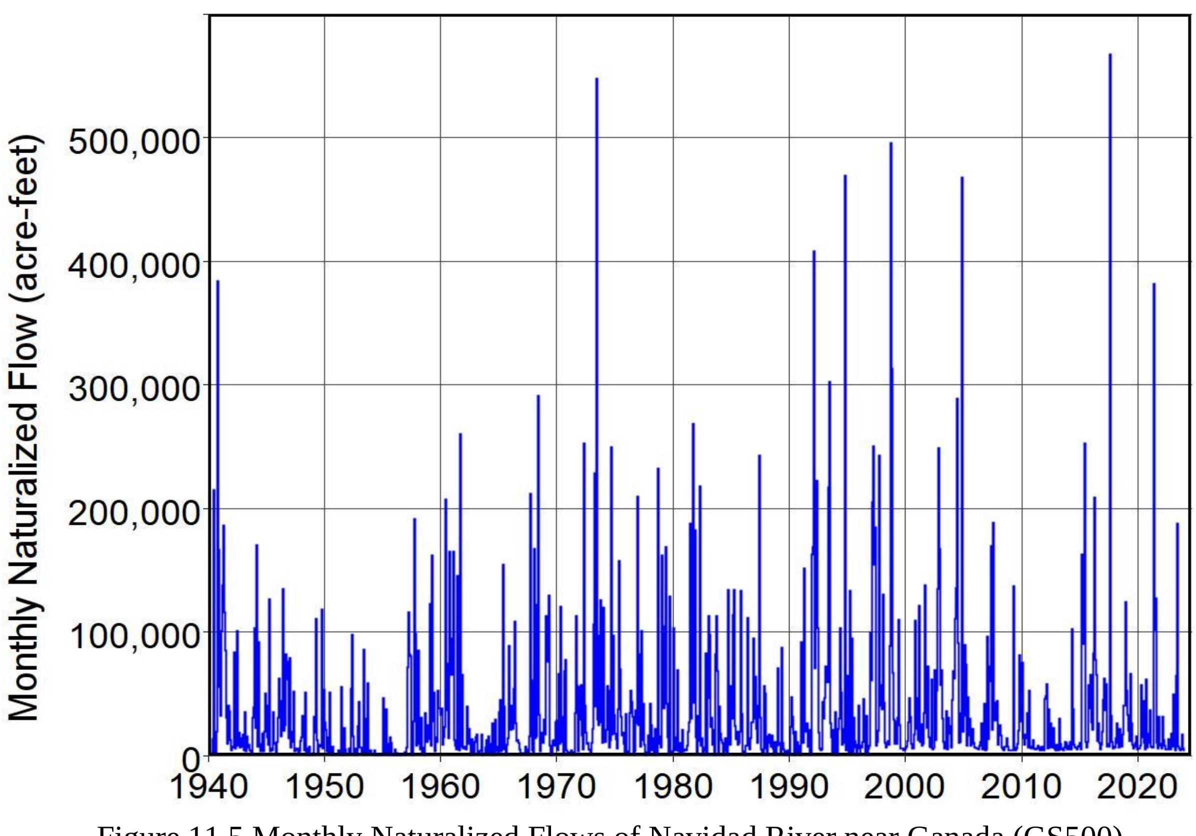

Figure 11.5 Monthly Naturalized Flows of Navidad River near Ganada (GS500)

Daily Lavaca WAM

A *JT* record is added to the DAT file to activate daily computations. The primary component of the conversion of the Lavaca WAM from a monthly to daily computational time step is the disaggregation of monthly naturalized flows to daily within the *SIMD* simulation based on input *DF* record daily flow pattern hydrographs. The SB3 EFS are incorporated in the daily WAM using sets of *IF*, *ES*, *HC*, and *PF* records. Target series *TS* records are used to incorporate the SB3 EFS in the monthly WAM. *SIM* and *SIMD* time series input data (*IN*, *EV*, *DF*, and *TS* records) are compiled in a single *SIM/SIMD* input DSS file.

Forecasting is relevant only if routing is activated. Routing parameters are needed only if routing is activated. Lag and attenuation routing parameters were included in the daily WAM datasets for the Brazos, Trinity, Neches, and Colorado WAMs as discussed in Chapters 7, 8, 9, and 10. Comparative simulations were performed with these previous daily WAMs with and without routing and forecasting [8, 9, 10, 11]. The Lavaca River Basin is much smaller than these other basins making routing and forecasting much less relevant. Routing and forecasting options are not activated in the Lavaca WAM, and routing parameters are considered unnecessary.

Simulation Input DAT File Records

The records replicated as Table 11.3 are found at the beginning of the daily DAT file. The *JT*, *JU*, and *OF* records control daily simulation input, output, and computation options. The *SIMD* *JT* and *JU* records are analogous to the *SIM/SIMD* *JD* and *JO* records. *SIM/SIMD* input records applicable in both monthly and daily simulations are covered in Chapter 3 of the *Users Manual* [2]. *SIMD* input records applicable only in a daily *SIMD* simulation are explained in Chapter 4 of the *Users Manual* [2]. Although *OF* record field 4 entry DSS(3) has options that are relevant only to a daily simulation as well as other parameters applicable to both monthly and daily simulations, the file options *OF* record is described in Chapter 3 of the *Users Manual*.

Table 11.3
SIMD DAT File Input Records for Controlling Daily Simulation Options

```
**      1       2       3       4       5       6       7       8
**345678901234567890123456789012345678901234567890123456789012345678901234567890
JD     82    1940       1       0       0               6
JO      6
JT                                                  0
JU      1   1
CO          GS300   DV501  GS1000  WGS800  ECB720
DF          GS300   GS400   GS500   GS550   GS600  GS1000  WGS800   DV501  ECB720
OF      0   0   2   1                                                  Lavaca
OFV    15
```

The following options activated on the records shown in Table 11.3 contribute to the conversion of the monthly WAM to daily.

- ADJINC option 4 or 6 in *JD* record field 8 (column 56) are the recommended standards for monthly simulations or daily simulations without forecasting. Option 5 was adopted in the original monthly Lavaca WAM.

- INEV option 6 in *JO* record field 2 (column 8) instructs *SIM* and *SIMD* to read *IN* and *EV* records from the hydrology DSS input file.
- DSS(3) option 2 is selected in *OF* record field 4 (column 16) to instruct *SIMD* to record both daily and monthly simulation results in a DSS output file. A one in *OF* record field 4 (column 20, DSS(4)=1) and variable 15 (instream flow target) on the accompanying *OFV* record results in instream flow targets for the five control points listed on the *CO* record being included in the simulation results DSS file.
- The input filename root Lavaca is entered in *OF* record field 12 to connect to the time series input file with filename LavacaHYD.DSS. With field 12 blank, by default, the filename of the DSS input file is the hydrology filename entered in *WinWRAP* which by default is the same as the DAT file.
- The *JT* record is required for a daily simulation, and the *JU* record activates certain daily options. Defaults are activated for blank fields or entries of zero on the *JT* and *JU* records.
- All fields of the *JT* record in Table 11.3 are blank. Several of these fields allow optional output tables to be created in the annual flood frequency AFF file and daily message SMM file. An entry of 1 for SUBFILE in field 11 (column 44) would activate the daily output SUB file.
- Flow disaggregation DFMETH option 1 (uniform) is set as the global default in *JU* record field 2 used for computational control points that do not reflect actual real stream flow sites. A *DC* record placed in the DIF file with REPEAT and DFMETHOD options 2 and 4 activate disaggregation option 4 based on *DF* record pattern hydrographs for all control points on the Lavaca River and its tributaries that have actual monthly naturalized stream flows.
- DFFILE option 1 is selected in *JU* record field 3 (column 12), meaning daily flow *DF* records are read from the hydrology input DSS file for the nine control points listed on the DAT file *DF* record in Table 11.3.

Disaggregation of Monthly Naturalized Stream Flow to Daily

Daily flows for the control points listed on a *DF* record in Table 11.3 are stored on *DF* records in the time series DSS input file along with the *IN* and *EV* records. The *DF* record daily flows are used by *SIMD* for disaggregating monthly naturalized stream flows to daily. Naturalized flow volumes in acre-feet/month are distributed to daily volumes in acre-feet/day in proportion to the daily flow pattern hydrographs recorded on *DF* records in the DSS file.

SIM and *SIMD* read monthly naturalized stream flow volumes from inflow *IN* records for the eight primary control points. Both monthly *SIM* and daily *SIMD* simulations synthesize monthly naturalized flows at the other secondary control points based on the monthly naturalized flows at the eight primary control points and parameters read from control point *CP*, flow distribution *FD*, and watershed parameter *WP* records. *SIMD* distributes the monthly naturalized flow volumes at each of the primary and secondary control points to the 28, 29 (February of leap years), 30, or 31 days in each of the 1,008 months of the 1940-2023 hydrologic period-of-analysis.

Ungaged primary control point EP000 represents the outlet of the Lavaca River Basin at Lavaca Bay. GS300 is the most downstream gaged control point on the Lavaca River. DFMETHOD option 4 employing daily flows from *DF* records is applied to all control points upstream of the outlet at control point EP000 and at control point EP000. *JU* record DFMETH option 1 (uniform) applies to all other control points including disconnected artificial control points. The procedure described in the next paragraph is activated by the following DIF input file *DC* record which activates REPEAT and DFMETHOD options 2 and 4.

```
DC   EP000    2    4    GS300
```

Monthly naturalized stream flows at control point EP000 and all other control points located upstream of EP000 are disaggregated to daily using 1940-2023 daily flows at nine control points stored as *DF* records in the hydrology input DSS file. Monthly volumes are distributed to daily volumes in proportion to daily flows while maintaining the monthly volumes. The automated procedure in *SIMD* for repeating daily flows at multiple control points is described in Chapter 2 of the *Daily Manual* [4]. The automated procedure consists of using flows at the nearest downstream control point if available, otherwise finding flows at the nearest upstream control point, and lastly if necessary using flows from another tributary.

DFMETH option 1 is selected in *JU* record field 2 (column 8 in Table 11.3) to apply the uniform monthly-to-daily naturalized flow disaggregation option for all of the other control points not located upstream of control point EP000. Thus, the selected default uniform disaggregation option (DFMETH=1) is applied to artificial control points employed in computational water accounting schemes that are not connected in the model to the actual outlet. Since GS300 is entered in field 5 of the *DC* record shown above, the *DF* record daily flow pattern hydrograph for control point GS300 found in the hydrology input file will also be applied for control point EP000.

<u>Daily Flow Pattern Hydrographs</u>

The dataset of *DF* records of daily 1940-2023 naturalized flow volumes in acre-feet at nine control points stored in the *SIMD* hydrology DSS input file with filename LavacaHYD.DSS are developed from daily means in cubic feet per second (cfs) of observed flow rates at USGS gages. The daily quantities on *DF* records are used in the *SIMD* simulation to determine the proportion of monthly naturalized flow volume to distribute to each of the 28, 29, 30, or 31 days in each of the 1,008 months of the 1940-2023 hydrologic period-of-analysis at all relevant control points.

The daily flow *DF* records are employed in the *SIMD* simulation for the sole purpose of serving as pattern hydrographs used in disaggregating monthly naturalized flows to daily. Therefore, only the pattern of the quantities on the *DF* records within each of the 1,008 months, not the actual magnitude of the individual quantities for each day, affect *SIMD* simulation results. The *DF* record daily flows can be in any units and are not required to reflect a specific single site. However, the *DF* records for the Lavaca WAM contain daily naturalized flows in acre-feet/day. The *DF* records of daily naturalized flows can be easily tabulated or plotted in *HEC-DSSVue*.

The following tasks were performed in developing the dataset of *DF* records of 1940-2021 daily flows at nine control points [11] and later extended through 2023 in the same manner.

1. Available daily observed flow data were explored to select control points for inclusion in the dataset of *DF* records. A determination was made to develop *DF* records for each of the nine control points listed in Table 11.4.

2. Observed flows at relevant USGS gages as daily means in cfs were compiled as a DSS file from the U.S. Geological Survey (USGS) National Water Information System (NWIS) website using the data import feature of *HEC-DSSVue*.
3. Eight of the nine gage sites do not have periods-of-record covering the entire WAM 1940-2023 hydrologic period-of-analysis. Gage records at two or more sites were combined as necessary to develop complete 1940-2023 sequences of observed daily flows in cfs.
4. The 1940-2023 daily flows in cfs at the nine control points were converted within *HEC-DSSVue* to a *SIMD* input dataset of *DF* records with flows in cfs. *SIMD* was executed with this dataset. The *SIMD* simulation results included naturalized daily flows in acre-feet/day.
5. The daily naturalized flows recorded by *SIMD* in its simulation results DSS file were converted within *HEC-DSSVue* to another dataset of *DF* records. This final dataset of *SIMD* input *DF* records consists of 1940-2023 daily naturalized flows in acre-feet/day at nine control points.

DF record daily flows are developed from observed flows at the USGS gages listed in Table 11.4. The observed daily flow records were downloaded from the U.S. Geological Survey (USGS) National Water Information System (NWIS) website using the data import feature of *HEC-DSSVue* Version 7. The data manipulations employed to develop the *DF* records of daily pattern hydrographs were performed using *HEC-DSSVue*. The data are stored in a DSS file.

Table 11.4
USGS Gage Sites Used in Developing the *DF* Record Daily Flow Dataset

CP	USGS Gage.	Location	Drainage Area	Missing
			(square miles)	(days)
GS400	08163500	Lavaca River at Hallettsville	108	8,400
GS300	08164000	Lavaca River near Edna	817	0
GS600	08164300	Navidad River near Hallettsville	332	7,945
GS550	08164350	Navidad River near Speaks	437	26,300
DV501	08164390	Navidad at Strane Park nr Edna	579	20,729
GS1000	08164450	Sandy Ck near Ganado	289	14,520
GS500	08164500	Navidad River near Ganado	1,062	15,918
WGS800	08164503	West Mustang Creek nr Ganado	178	13,789
ECB720	08164504	East Mustang Creek nr Louise	53.9	20,728

The number of days of missing data during the 30,681 days of the 1940-2023 analysis period is shown in the last column of Table 11.4. USGS gage 08164000 on the Lavaca River near Edna is the only gage station with a complete record covering the analysis period with no missing data. The other gages have multiple days of missing data during 1940-2023 ranging from 7,944 to 26,300 days. Gaps of missing daily flows at each gage site were filled in with daily flows at the other gages as explained in the 2023 Daily WAM Report [11].

The dataset of 1940-2023 observed daily flows in cfs at nine control points were converted to *DF* records within *HEC-DSSVue*. *SIMD* was executed with this dataset. *SIMD* simulation results included naturalized daily flows in acre-feet/day, which were converted within *HEC-DSSVue* to a dataset of *DF* records of 1940-2023 daily naturalized flows in acre-feet/day at nine control points.

Observed daily flows at the gage at control point GS300 extend from August 13, 1938 to the present. Mean daily flows and mean monthly flows in cfs at this gage from September 1938 through October 2024 are plotted in Figure 11.6. The vertical scale cuts off flows above 70,000 cfs for the maximum flood that peaks with a daily flow of 122,000 cfs on October 19, 1994. Statistics are compared in Table 11.5. The mean flow during 9/1/1938-10/31/2024 was 359.18 cfs. The average of 1,034 monthly means is 359.77 cfs. This dataset demonstrates extreme differences in variability for instantaneous flow rates averaged over a monthly versus daily time interval. Variability is measured by the median, minima, maxima, and standard deviations in Table 11.5.

Table 11.5
Statistics for Observed Flows of Lavaca River Near Edna (Control Point GS300)
During September 1938 through October 2024

Time Interval	Day	Month
Number of Periods	31,473	1,034
Mean (cfs)	359.18	359.77
Median (50% frequency) (cfs)	49.000	82.790
Minimum (cfs)	0.0000	0.0033333
Maximum (cfs)	122,000	7,118.5
Standard Deviation (cfs)	1,847.5	739.02

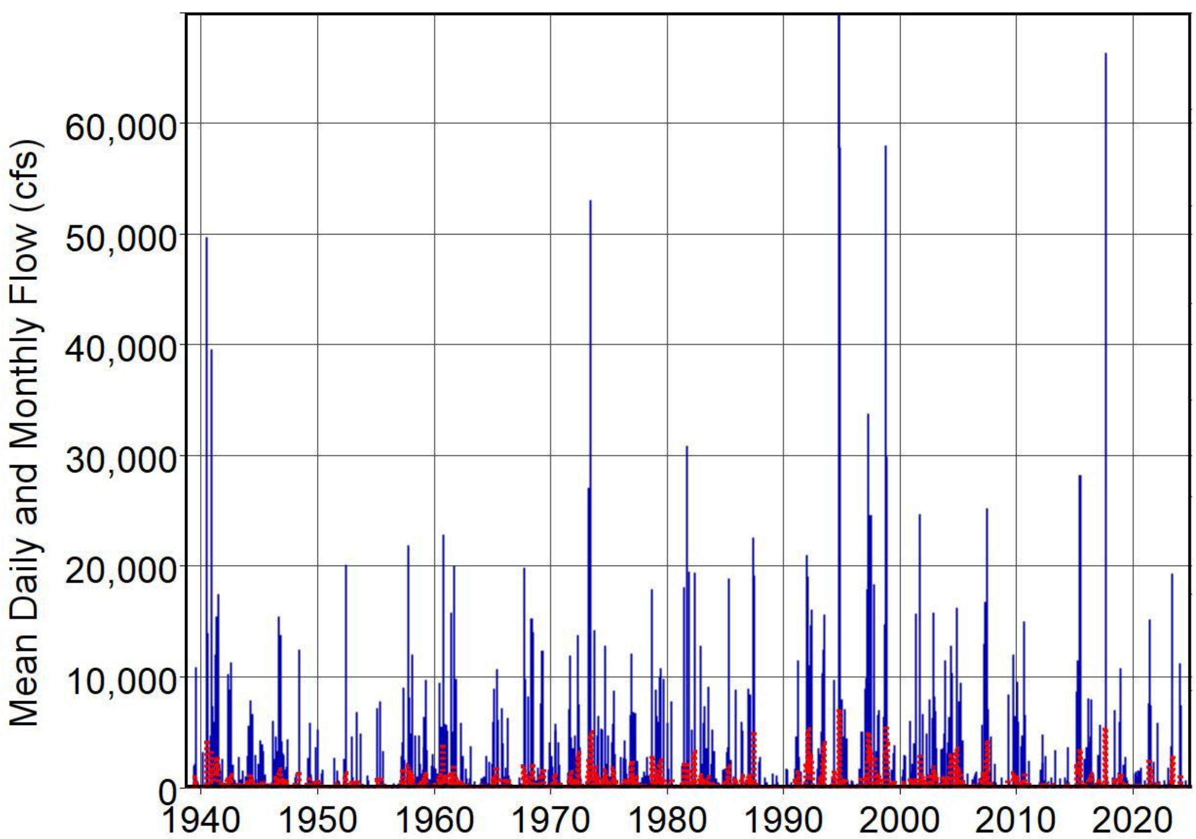

Figure 11.6 Daily (**blue solid**) and Monthly (**red dotted**) Flows of Lavaca River near Edna

Senate Bill 3 (SB3) Environmental Flow Standards (EFS)

Environmental flow standards (EFS) at five gage sites in the Lavaca River Basin were established by TCEQ in collaboration with a science team and stakeholder committee following procedures established by the 2007 Senate Bill 3 (SB3). The SB3 EFS are modeled in the daily Lavaca WAM using *IF*, *HC*, *ES*, and *PF* input records inserted in the *SIMD* input DAT file. Daily *IF* record instream flow targets for the SB3 EFS computed in a daily *SIMD* simulation are summed to monthly totals and incorporated in the monthly *SIM* input dataset for the Lavaca WAM.

Environmental Flow Standards Established Pursuant to Senate Bill 3 Process

The geographic area covered by "*Subchapter D* of Chapter 298 of Title 30 of the Texas Administrative Code [98] consists of the Colorado and Lavaca Rivers and their tributaries, bays, and estuaries. SB3 EFS have been established at the locations of 21 USGS stream flow gages, including 14 sites in the Colorado River Basin, five in the Lavaca River Basin, and two sites in the Colorado-Lavaca and Lavaca-Guadalupe Coastal Basins. The priority date for the EFS is March 1, 2011, the date the Basin and Bay Expert Science Team submitted its recommendations.

The EFS for the five locations in the Lavaca River Basin are incorporated in the daily Lavaca WAM as described later in this chapter. The five locations with SB3 EFS in the Lavaca River Basin are listed with descriptive information in Table 11.4. The locations of the gage sites are shown in Figure 11.1. Drainage areas from the USGS NWIS website and the *WP* records in the WAM DIS file are listed in the last two columns of Table 11.4.

Table 11.4
Locations of SB3 EFS in the Lavaca River Basin

CP	USGS Gage	Location (Stream and Town)	Drainage Area (square miles)	
			USGS	WAM WP
GS300	08164000	Lavaca River near Edna	817	822
DV501	08164390	Navidad at Strane Park near Edna	579	581
GS1000	08164450	Sandy Creek near Ganado	289	296
WGS800	08164503	West Mustang Creek near Ganado	178	168
ECB720	08164504	East Mustang Creek near Louise	53.9	54.4

The EFS established through the process created by the 2007 SB3 consist of subsistence flow, base flow, and high flow pulse components that may vary seasonally and with hydrologic conditions. Seasons are defined for the SB3 EFS in the Lavaca River Basin as follows: Winter (December, January, February), Spring (March, April, May, June), Summer (July, August), and Fall (September, October, November). The hydrologic condition for a season is determined based on conditions on the last day of the preceding season. The hydrologic condition determined at the beginning of each season is applied for the entire season.

Hydrologic condition is defined in the SB3 EFS as a function of the storage elevations in Lake Texana shown in the second column of Table 11.5 and incorporated in the full authorization and current use scenario WAMs as a function of the corresponding storage volumes in the last two columns of Table 5.3 [11]. The hydrologic condition parameters were selected by the science team and stakeholder committee such that severe conditions occur approximately 5% of the time, dry conditions occur approximately 20% of the time, average conditions occur approximately 50% of the time, and wet conditions occur approximately 25% of the time.

Table 11.5
Lake Texana Metrics Defining Hydrologic Conditions

Hydrologic Condition	Elevation (feet msl)	Reservoir Storage (acre-feet)		
		2020 TWDB	Full Authorization	Current Use WAM
Severe	Less than 39.95	Less than 126,903	Less than 134,509	Less than 129,901
Dry	39.95 – 43.00	126,903 – 153,367	134,509 – 160,973	129,901 – 156,365
Average	43.00 – 44.00	153,367 – 162,694	160,973 – 170,300	156,365 – 165,692
Wet	Greater than 44.00	≥ 162,694	≥ 170,300	≥ 165,692

Subsistence and Base Flow Standards

The subsistence standards with flow limits tabulated in Table 11.6 are applicable during severe hydrologic conditions when flow at a gage site is less than the dry base flow standards. Storage and diversion of flow are curtailed if actual stream flow drops below the subsistence limit during severe conditions. If actual flow is below the designated dry base flow limit and above the defined subsistence flow limit during severe hydrologic conditions, a water right holder may divert water as long as the diversion does not cause the flow to drop below the subsistence flow level.

Table 11.6
Flow Limits (cfs) in the Subsistence Flow Standards
for the Severe Hydrologic Condition

WAM Control Point	Seasonal Flow Limits (cfs)			
	Winter (cfs)	Spring (cfs)	Summer (cfs)	Fall (cfs)
GS300	8.5	10	1.3	1.2
DV501	1.0	2.8	1.2	2.2
GS1000	1.0	1.0	1.0	1.0
WGS800	1.0	1.0	1.0	1.0
ECB720	1.0	1.0	1.0	1.0

The flow criteria defining base flow levels are tabulated in Table 11.7. The base flow standards vary seasonally and between the four hydrologic conditions (severe, dry, average, and wet). If flow at a control point is below applicable high flow pulse trigger levels and above the applicable base flow standard, a water right holder may divert water as long as the diversion does not cause the flow to drop below the applicable base flow standard.

Table 11.7
Stream Flow Limits (cfs) Defining Base Flow Standards

WAM	Winter				Spring				Summer				Fall			
CP ID	Sev	Dry	Avg	Wet	Sev	Dry	Avg	Wet	Sev	Dry	Avg	Wet	Sev	Dry	Avg	Wet
GS300	30	30	55	94	30	30	55	94	20	20	48	33	20	20	33	58
DV501	14	14	35	71	18	18	35	71	24	24	47	84	17	17	35	71
GS1000	5	5	14	30	5	5	14	30	9	9	21	39	9	9	21	39
WGS800	4	4	9	20	5	5	11	20	10	10	18	32	6	6	14	26
ECB720	1	1	2	6	1	1	3	6	2	2	5	8	1	1	3	8

High Flow Pulse Standards

The high flow pulse components of the SB3 EFS are outlined in Table 11.8. The high pulse criteria are specified for a two-per-season pulse, a one-per-season pulse, and an annual pulse. When the high flow pulse trigger level is reached, that flow level is protected by curtailing junior water rights until either the specified volume or duration criteria in Table 11.8 is met. Junior rights can appropriate excess stream flow exceeding the trigger level at any of the five sites.

For all five gage locations, high flow pulses are independent of hydrologic conditions, and each season is independent of other seasons. If a requirement for a pulse event is satisfied during a season, a high flow pulse requirement is considered to be satisfied for each smaller event in that season. For example, if an annual pulse flow requirement is met in a season, then a one-per-season pulse flow requirement and a two-per-season pulse flow requirement are met for that season.

Water right holders are not required to cease diverting water or release stored water to produce a high flow pulse event if the trigger criterion is not met during a season. High flow pulses are preserved but not created. Water that was previously stored as authorized by a water right may be diverted or released regardless of applicable environmental flow requirements.

Applicability of SB3 Environmental Flow Standards

The priority date for the SB3 EFS for the Lavaca River Basin and the associated set-asides to be incorporated by the TCEQ in the water availability modeling system is March 1, 2011. Existing water rights with priorities senior to March 1, 2011 are not regulated to protect the SB3 EFS. The SB3 EFS may constrain water availability for diversions and storage authorized by permits with priority dates junior to March 1, 2011. The SB3 EFS may constrain curtailment of stream flow appropriations for diversions and refilling depleted storage capacity, but do not require releases of water from already in storage.

Other *IF* Record Instream Flow Requirements

The 2008 versions of the full authorization and current use Lavaca WAMs have 30 *IF* record instream flow rights with priorities ranging from 19720515 (May 15, 1972) to 2001001 (October 10, 2000). These *IF* records were in the WAMs before the SB3 EFS were created. None are located at the same control points assigned to the SB3 EFS. These existing *IF* record water rights are not altered in the conversion to a daily WAM other than uniformly distributing the monthly instream flow targets to the 28, 29, 30, or 31 days in each month.

Table 11.8
High Flow Pulse Standards

WAM CP ID	Season	Pulse Flow Criteria	Frequency		
			2 per season	1 per season	Annual
GS300	Winter	Trigger (cfs) Volume (ac-ft) Duration (days)	2,000 8,000 6	4,500 18,400 7	4,500 18,400 7
	Spring	Trigger (cfs) Volume (ac-ft) Duration (days)	4,500 18,400 7	4,500 18,400 7	
	Summer	Trigger (cfs) Volume (ac-ft) Duration (days)	88 370 4	420 1,800 6	
	Fall	Trigger (cfs) Volume (ac-ft) Duration (days)	1,600 6,100 5	4,500 18,000 6	
DV501	Winter	Trigger (cfs) Volume (ac-ft) Duration (days)	2,000 9,000 6	2,500 11,250 7	2,500 11,250 7
	Spring	Trigger (cfs) Volume (ac-ft) Duration (days)	2,500 11,250 7	2,500 11,250 7	
	Summer	Trigger (cfs) Volume (ac-ft) Duration (days)	200 1,000 5	610 3,400 6	
	Fall	Trigger (cfs) Volume (ac-ft) Duration (days)	2,000 8,700 6	2,500 11,250 7	
GS10000	Winter	Trigger (cfs) Volume (ac-ft) Duration (days)	800 4,000 6	1,800 10,000 8	2,200 12,200 10
	Spring	Trigger (cfs) Volume (ac-ft) Duration (days)	1,400 7,300 6	2,200 12,200 10	
	Summer	Trigger (cfs) Volume (ac-ft) Duration (days)	91 500 4	260 1,600 7	

	Fall	Trigger (cfs) Volume (ac-ft) Duration (days)	630 3,100 6	1,800 9,200 7	

Table 11.8 (Continued)
High Flow Pulse Standards

WAM CP ID	Season	Pulse Flow Criteria	Frequency		
			2 per season	1 per season	Annual
WGS800	Winter	Trigger (cfs) Volume (ac-ft) Duration (days)	470 2,400 6	1,000 5,600 8	1,000 5,600 8
	Spring	Trigger (cfs) Volume (ac-ft) Duration (days)	810 4,400 6	1,000 5,600 8	
	Summer	Trigger (cfs) Volume (ac-ft) Duration (days)	75 420 4	190 1,200 6	
	Fall	Trigger (cfs) Volume (ac-ft) Duration (days)	470 2,200 6	2,200 5,600 8	
ECB720	Winter	Trigger (cfs) Volume (ac-ft) Duration (days)	150 680 5	340 1,700 8	1,000 6,000 10
	Spring	Trigger (cfs) Volume (ac-ft) Duration (days)	280 1,400 7	550 3,000 9	
	Summer	Trigger (cfs) Volume (ac-ft) Duration (days)	20 100 5	60 310 6	
	Fall	Trigger (cfs) Volume (ac-ft) Duration (days)	150 650 6	430 2,100 7	

Daily *SIMD* Modeling of SB3 Environmental Flow Standards

Environmental standard *ES*, hydrologic condition *HC*, pulse flow *PF*, and pulse flow supplemental options *PO* records are designed specifically to model *IF* record instream flow rights in the format of SB3 EFS. Chapter 3 of the *Users Manual* [2] defines the input parameters entered on the types of input records that are applicable to both the monthly *SIM* and daily *SIMD*, which includes the *ES* and *HC* records. Chapter 4 of the *Users Manual* covers additional daily *SIMD* input records that are not applicable to the monthly *SIM*, including *PF* and *PO* records. *ES*, *HC*, and *PF* but not *PO* records are employed in the Lavaca daily WAM.

The *SIMD* DAT file input records for the SB3 EFS at control point GS300 are reproduced as Table 11.9. The sets of *IF*, *HC*, *ES*, and *PF* records for the SB3 EFS at the four other control points are in the same format with relevant numbers from Tables 11.5, 11.6, 11.7, and 11.8. These *IF* record instream flow targets are minimum flow limits that may constrain appropriation of stream flow by *WR* record water rights with junior priorities.

Table 11.9
Instream Flow Rights that Model the SB3 EFS in the Daily Lavaca WAM DAT File

```
**       1         2         3         4         5         6         7         8         9        10
**3456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
**    !       !       !       !       !       !       !       !       !       !       !       !       !
**
IF GS300     -9.         20110301   2            IF-GS300-ES
HC GS300   1  ST       M   J S  D      0. 134509. 160973. 170300.     -9.
ES SUBS1     8.5     8.5    10.0    10.0    10.0    10.0     1.3     1.3     1.2     1.2     1.2     8.5
ES BASE1    30.0    30.0    30.0    30.0    30.0    30.0    20.0    20.0    20.0    20.0    20.0    30.0
ES BASE2    30.0    30.0    30.0    30.0    30.0    30.0    20.0    20.0    20.0    20.0    20.0    30.0
ES BASE3    55.0    55.0    55.0    55.0    55.0    55.0    48.0    48.0    33.0    33.0    33.0    55.0
ES BASE4    94.0    94.0    94.0    94.0    94.0    94.0    33.0    33.0    58.0    58.0    58.0    94.0
IF GS300     -9.         20110301   2            IF-GS300-PF
ES PFES
PF   1 0   2000.   8000.   6   2      12   2           2
PF   1 0   4500.  18400.   7   2       3   6           2
PF   1 0     88     370.   4   2       7   8           2
PF   1 0   1600    6100.   5   2       9  11           2
PF   1 0   4500.  18400.   7   1      12   2           2
PF   1 0   4500.  18400.   7   1       3   6           2
PF   1 0    420    1800.   6   1       7   8           2
PF   1 0   4500   18400.   6   1       9  11           2
PF   1 0   4500.  18400.   7   1       1  12           2
```

The *IF* record targets are managed in the same manner as all water right targets within the *SIMD* simulation computations and output files. Options controlled by *IF* record field 3 and *PF* record field 15 create tables in the MSS and SMM message files that provide supplemental information that facilitates tracking the *ES* and *PF* record computations. These message file options are not activated in the dataset of Table 11.9 but can be easily activated whenever needed.

Sets of *IF*, *HC*, *ES*, and *PF* records for the SB3 EFS at the five control points are inserted with the other sets of *WR* and *IF* record water rights in the *SIMD* input DAT file. Each of the five *IF* record instream flow rights has a set of *HC*, *ES*, and *PF* records that provide the metrics replicated in Tables 11.5, 11.6, 11.7, and 11.8. The subsistence/base flow component and high pulse flow component of the EFS are organized as separate water rights in Table 11.9 but can be combined as discussed in the next paragraph and illustrated by Table 11.10.

In the dataset illustrated by Table 11.9 and simulation studies presented later in this chapter, the pulse flow components are modeled as separate *IF* record rights to facilitate recording pulse flow targets in the simulation results separately from the subsistence and base flow targets. This does not affect the total target quantities but rather allows the components of each target to be recorded separately in output files.

Subsidence/base flows and high flow pulses can be combined reducing the SB3 EFS from ten to five *IF* record water rights simply by removing the *IF* and *ES* records for each of the high flow pulse components. For example, the two water rights in Table 11.9 labeled with water right identifiers IF-GS300-ES and IF-GS300-PF are instream flow requirements at control point GS300. These two water rights are combined into a single water right in Table 11.10. With this format, all components of the SB3 EFS at a site can be modeled as a single *IF* record water right, with the only difference in simulation results being that combined rather that separate water right targets and target shortages are recorded in the *SIMD* output OUT and DSS files.

Table 11.10
Instream Flow Right that Models the SB3 EFS at Control Point GS300
with *ES* and *PF* Record Components Combined as a Single *IF* Record Right

```
IF GS300     -9.        20110301   2            IF-GS300-ES
HC GS300   1  ST       M   J S  D      0. 134509. 160973. 170300.     -9.
ES SUBS1    0.85    0.85    10.0    10.0    10.0    10.0     1.3     1.3     1.2     1.2     1.2    0.85
ES BASE1    30.0    30.0    30.0    30.0    30.0    30.0    20.0    20.0    20.0    20.0    20.0    30.0
ES BASE2    30.0    30.0    30.0    30.0    30.0    30.0    20.0    20.0    20.0    20.0    20.0    30.0
ES BASE3    55.0    55.0    55.0    55.0    55.0    55.0    48.0    48.0    33.0    33.0    33.0    55.0
ES BASE4    94.0    94.0    94.0    94.0    94.0    94.0    33.0    33.0    58.0    58.0    58.0    94.0
PF   1 0   2000.   8000.   6   2      12   2           2
PF   1 0   4500.  18400.   7   2       3   6           2
PF   1 0     88     370.   4   2       7   8           2
PF   1 0   1600    6100.   5   2       9  11           2
PF   1 0   4500.  18400.   7   1      12   2           2
PF   1 0   4500.  18400.   7   1       3   6           2
PF   1 0    420    1800.   6   1       7   8           2
PF   1 0   4500   18400.   6   1       9  11           2
PF   1 0   4500.  18400.   7   1       1  12           2
```

The five variables that are forms of instream flow targets or shortages in meeting instream flow targets are listed earlier in this report as Table 8.15 of Chapter 8. A table accompanying the *OF* record description in the WRAP *Users Manual* [2] defines all 43 time series variables that may be included in *SIM* and *SIMD* simulation results output files, which includes the five simulation results variables in Table 8.15.

Any number of instream flow *IF* record water rights can be located at the same WAM control point regardless of the various records used with the *IF* records for computing instream flow targets. Options for combining multiple targets at the same control point specified by *IF* and *PF* record parameters are listed in Table 11.11. Multiple instream flow targets at the same control point are combined in the Lavaca WAM and the other case study WAMs always using the option of adopting the largest target.

Table 11.11
Options for Combining Targets for Instream Flow Rights at the Same Control Point

IF record field 7	*PF* record field 14	Method for combining junior and senior targets.
1 (default)	1	The junior target replaces the senior target.
2	2 (default)	The largest target is adopted.
3	3	The smallest target is adopted.
–	4	The two targets are added together.

With two or more *IF* record rights at the same control point, the target for a junior right is combined with the target from the preceding senior right as specified by IFM(IF,2) in *IF* record field 7. The computation of a SB3 EFS target consists of computing a subsistence and base flow target as specified by *ES* records and a pulse flow target as specified by *PF* records. With pulse flow *PF* and subsistence/base flow *ES* records for the same *IF* record right, the instream flow targets are combined as specified in *PF* record field 14 as indicated in Table 11.11.

Monthly WAM with Instream Flow Targets from the Daily WAM

A strategy for incorporating monthly instream flow targets computed in a daily *SIMD* simulation into the *SIM* input for a monthly WAM outlined in the last section of Chapter 6 of the *Daily Manual* [4] is employed in each of the six case studies presented in this report and the preceding daily WAM reports [7, 8, 9, 10, 11, 12]. Daily instream flow targets in acre-feet/day for the SB3 EFS computed in the daily *SIMD* simulation are summed by *SIMD* to monthly totals in acre-feet/month that are included in the *SIMD* simulation results. These time series of monthly targets are converted to target series *TS* records within *HEC-DSSVue* and incorporated in the input DSS file read in a monthly *SIM* simulation.

The target series *TS* records of monthly instream flow targets in acre-feet/month stored in the DSS file of the Lavaca WAM have the pathname identifiers listed in Table 11.12. The *TS* records in the monthly *SIM* DAT file replicated in Table 11.13 reference the DSS file target series employed by the *IF* record water rights. Parameter DSSTS on the *JO* record activates reading of *TS* records from the DSS input file.

Table 11.12
Pathnames for *TS* Records for the SB3 EFS in the Hydrology Input DSS File

Part A	Part B	Part C	Part D	Part E
Lavaca	GS300	TS	01Jan1940-31Dec2023	1MON
Lavaca	DV501	TS	01Jan1940-31Dec2023	1MON
Lavaca	GS1000	TS	01Jan1940-31Dec2023	1MON
Lavaca	WGS800	TS	01Jan1940-31Dec2023	1MON
Lavaca	ECB720	TS	01Jan1940-31Dec2023	1MON

Table 11.13
Instream Flow Rights that Model the SB3 EFS in the DAT File of the Monthly WAM

```
IF GS300                20110301   2           GS300ES
TS       DSS
IF DV501                20110301   2           DV501ES
TS       DSS
IFGS1000                20110301   2           GS1000ES
TS       DSS
IFWGS800                20110301   2           WGS800ES
TS       DSS
IFECB720                20110301   2           ECB720ES
TS       DSS
```

A daily *SIMD* simulation is performed with the set of *IF*, *ES*, and *PF* records inserted in the DAT file to control computation of daily instream flow targets for the SB3 EFS at the five USGS gage sites (WAM control points). The daily instream flow targets in acre-feet/day are summed to monthly quantities in acre-feet/month included in the simulation results DSS file. The DSS records of monthly targets are copied from the daily *SIMD* simulation results DSS output file to the *SIM/SIM* hydrology input DSS file and the pathnames are revised using *HEC-DSSVue*.

Comparison of Simulated Reservoir Storage for Alternative Modeling Premises

SIM and *SIMD* simulated 1940-2023 reservoir storage contents for the initial monthly WAM last updated 10/1/2023, daily WAM, and modified monthly WAM described earlier in this chapter are compared in Table 11.14 and Figures 11.7 and 11.8. Storage volumes for Lake Texana and the summation of storage volumes in all other reservoirs excluding Lake Texana are included in the table and figures. *SIM* generates 1,008 end-of-month storage volumes for the 1940-2023 simulation. *SIMD* computes end-of-day storage volumes for the 30,681 days of the simulation and also outputs the 1,008 end-of-month volumes which are a subset of the 30,681 end-of-day volumes.

Table 11.14
Reservoir Storage Statistics

	Reservoir Storage Volume Statistics (acre-feet)			
Alternative WAM	Minimum	Median	Mean	Maximum
		Lake Texana		
Initial Monthly	26,841	155,656	149,183	170,300
SIMD Daily	28,038	158,866	152,055	170,300
SIMD Monthly	30,279	159,013	152,157	170,300
Modified Monthly	25,871	155,660	149,160	170,300
		Summation of All Reservoirs Except Lake Texana		
Initial Monthly	38,786	94,531	88,586	95,364
SIMD Daily	27,861	93,566	87,060	95,364
SIMD Monthly	28,644	93,454	87,090	95,364
Modified Monthly	28,453	94,147	87,304	95,364

The three full authorization WAM simulations result in similar storage sequences. The most severe drawdown occurs during the 1950's drought. The minimum end-of-day and end-of-month storage contents of Lake Texana of 28,038 and 30,270 acre-feet occur on February 12, 1957 and January 31, 1957 in the daily *SIMD* simulation. Lake Texana is full to its authorized capacity of 170,300 acre-feet frequently. The Lake Texana end-of-day contents equals or exceeds 158,866 acre-feet (median column of table) during 50% of the 30,681 days of the daily *SIMD* simulation.

The end-of-month storage contents generated with the monthly WAM last updated 10/1/2023, downloaded from the TCEQ WAM website, is plotted as a red dotted line in Figures 11.7 and 11.8. The end-of-day storage from the daily *SIMD* simulation is a blue solid line.

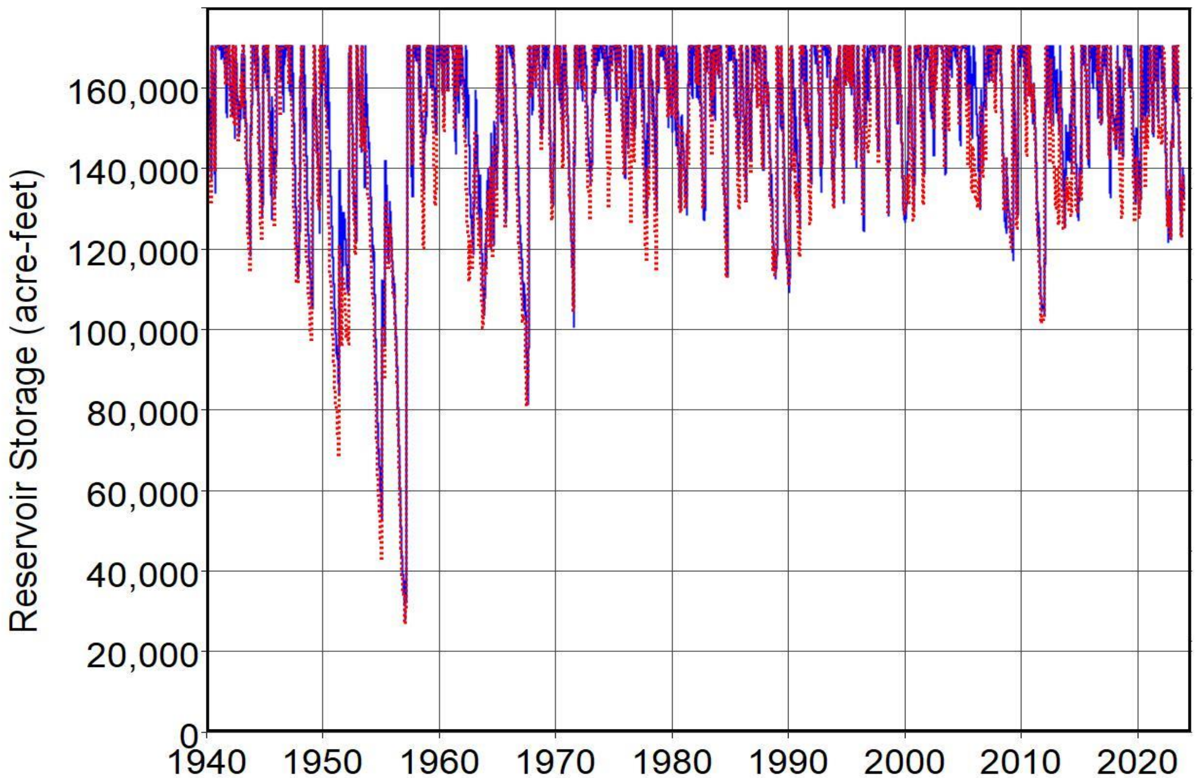

Figure 11.7 Texana Storage in Daily (blue solid) and Initial Monthly (red dotted) WAMs

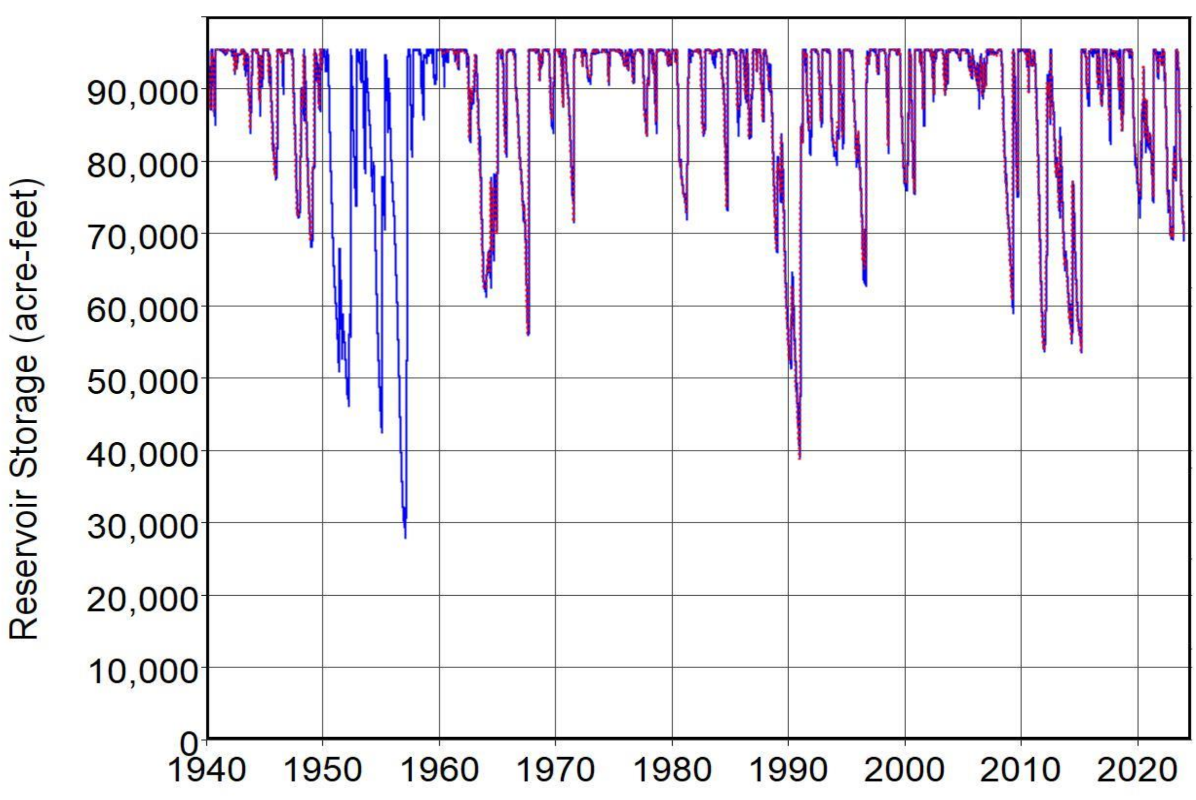

Figure 11.8 Storage in All Reservoirs Except Texana in Daily (blue solid line) and Initial Monthly (red dotted line) WAMs

The daily *SIMD* simulation and two monthly *SIM* simulations reflected in Table 11.14 and Figures 11.7 and 11.8 include the SB3 EFS. The SB3 EFS have no impact on reservoir storage volumes because the SB3 EFS priority date of March 1, 2011 is junior to all the other water rights in the WAM. Excluding the SB3 EFS, water right priority dates in the full authorization Lavaca WAM range from May 15, 1972 to October 1, 2000.

SB3 EFS Instream Flow Targets

Environmental flow standards (EFS) have been previously established through the process created by the 1997 Senate Bill 3 (SB3) at five sites described in Table 11.4 with locations shown in Figure 11.10. Quantitative metrics incorporated in the EFS are tabulated in Tables 11.5, 11.6, 11.7, and 11.8. Methods for incorporating the SB3 EFS in the daily and modified monthly versions of the WAM are outlined in the preceding sections of this chapter.

The daily full authorization *SIMD* input dataset consists of a set of files with the following filenames: LavacaD.DAT, LavacaD.DIS, LavacaD.DIF, and LavacaHYD.DSS. The daily WAM was executed with *SIMD* to generate monthly instream flow targets stored as *TS* records in the file LavacaHYD.DSS that simulate the five sets of environmental flow standards. This modified monthly WAM is comprised of a set of *SIM* input files with the following filenames.

LavacaM.DAT, LavacaM.DIS, LavacaHYD.DSS

The same hydrology DSS file with filename LavacaHYD.DSS can be read by either *SIM* and *SIMD* with various versions of the WAM input dataset. *HEC-DSSVue* reads any DSS file including *SIM* or *SIMD* input files or simulation results output files.

The 1940-2023 monthly SB3 EFS instream flow targets and shortages in acre-feet/month at the five WAM control points are plotted as Figures C32 through C36 of Appendix C. The SB3 EFS are modeled as *IF* record right water rights following the strategy outlined in Tables 11.12 and 11.13. The monthly instream flow targets plotted in Appendix C were computed within *SIMD* by summing the daily instream flow targets computed in the *SIMD* simulation. These instream flow targets stored on *TS* records in the time series DSS input file are read by *SIM*.

Statistics for Daily Stream Flow and SB3 EFS Targets

Observed daily, monthly, and annual flows of the Lavaca River near Hallettsville and Edna are plotted in Figures B12 and B13 of Appendix B. Daily and monthly observed flows of the Lavaca River near Edna are plotted in Figure 11.6. Naturalized monthly flows at control points EP000, GS300, and GS500 are plotted in Figures 11.4 and 11.5.

Statistics for the 1940-2023 daily naturalized stream flows, simulated regulated and unappropriated stream flows, and SB3 EFS instream flow targets and shortages at the five USGS gage locations in Table 11.4 are compared in Table 11.15. These statistics for the 1940-2023 time series of 30,681 daily quantities are the mean (average), median (50% exceedance frequency), minimum and maximum. The quantities in Table 11.15 are in units of cubic feet per second (cfs). *SIMD* performs simulation computations in units of acre-feet/day. A cfs is equivalent to 1.983471 acre-feet/day. SB3 EFS metrics (Tables 11.6-11.8) and USGS daily flow records are in cfs. Data management, unit conversions, and statistical computations were performed within *HEC-DSSVue*.

Table 11.15
Statistics for Daily Stream Flows and SB3 EFS Targets and Shortages

USGS Gage Location (stream) Control Point Identifier	Lavaca R. GS300	Navidad R. DV501	Sandy Cr. GS1000	W. Mustang WGS800	E Mustang ECB720
Mean of Daily Quantities (cfs)					
Naturalized Flows	11,057	9,541	5,075	3,801	1,234
Regulated Flows	11,007	9,469	4,880	3,666	1,200
Unappropriated Flows	8,086	5,511	2,933	2,141	649
SB3 EFS Targets	64.740	53.653	33.335	21.556	8.382
Pulse Flow Targets	45.948	40.280	29.454	17.913	7.336
Subsistence/Base Flow Targets	19.499	14.003	4.143	3.901	1.102
SB3 EFS Target Shortages	0.2380	0.1178	0.2930	0.1138	0.2015
Median (50% Exceedance Frequency) of Daily Quantities (cfs)					
Naturalized Flows	2,548	3,036	1,413	1,358	440.9
Regulated Flows	2,515	3,012	1,200	1,180	407.1
Unappropriated Flows	86.92	0.000	0.000	0.000	0.000
SB3 EFS Targets	20.000	17.000	5.000	4.000	1.000
Pulse Flow Targets	0.000	0.000	0.000	0.000	0.000
Subsistence/Base Flow Targets	20.000	17.000	5.000	4.000	1.000
SB3 EFS Target Shortages	0.0000	0.0000	0.0000	0.0000	0.0000
Minimum of Daily Quantities (cfs)					
Naturalized Flows	0.0	0.0	0.0	0.0	0.0
Regulated Flows	0.0	0.0	0.0	0.0	0.0
Unappropriated Flows	0.0	0.0	0.0	0.0	0.0
SB3 EFS Targets	1.2000	1.0000	1.0000	1.0000	1.0000
Pulse Flow Targets	0.0	0.0	0.0	0.0	0.0
Subsistence/Base Flow Targets	1.2000	14.0032	1.0000	1.0000	1.0000
SB3 EFS Target Shortages	0.0000	0.0000	0.0000	0.0000	0.0000
Maximum of Daily Quantities (cfs)					
Naturalized Flows	220,573	178,230	90,414	67,851	22,037
Regulated Flows	220,348	177,545	90,343	67,843	22,015
Unappropriated Flows	211,343	174,189	87,330	67,460	21,798
SB3 EFS Targets	4,500	2,500	2,200	1,000	1,000
Pulse Flow Targets	4,500	2,500	2,200	1,000	1,000
Subsistence/Base Flow Targets	30.000	24.000	9.000	10.000	2.000
SB3 EFS Target Shortages	10.000	2.800	1.000	1.000	1.000

Figures 11.9-11.13 are plots of the daily total instream flow targets and the combined daily subsistence and base flow components of the SB3 EFS target at the five sites. The difference between the two plots is the pulse flow component of the SB3 EFS target.

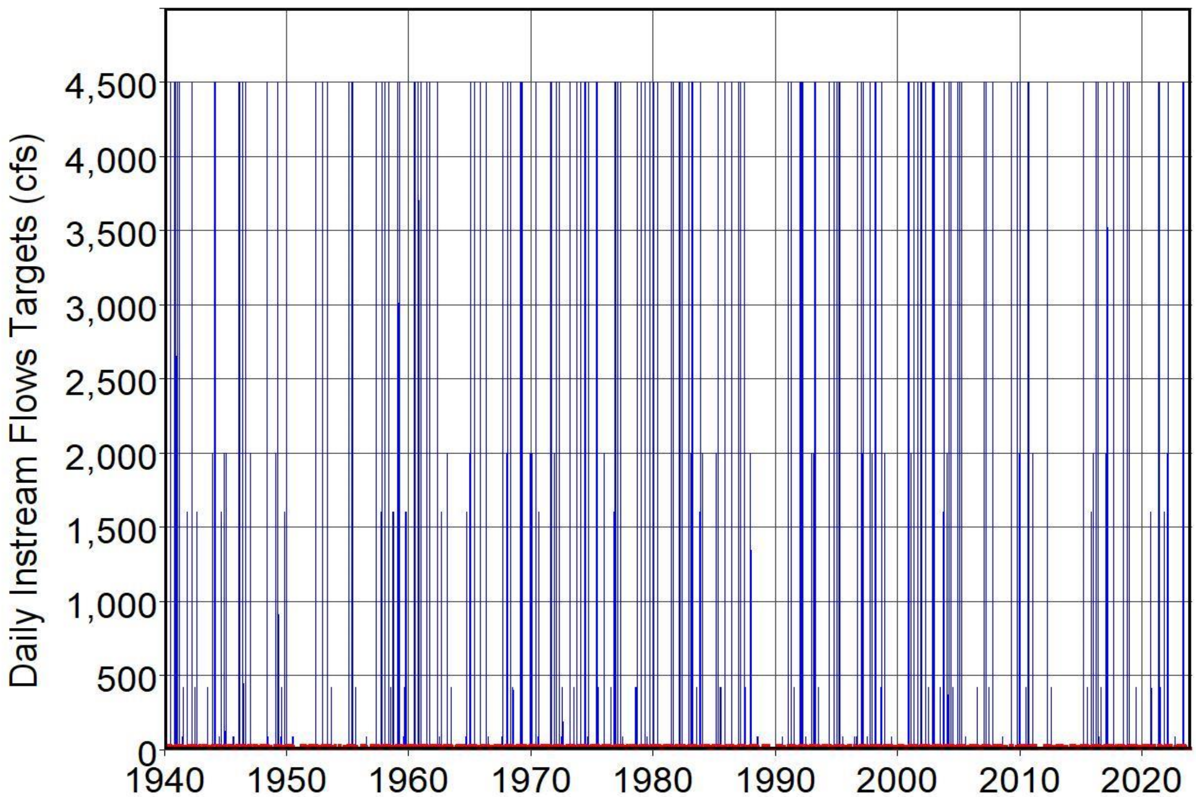

Figure 11.9 SB3 EFS Total (**blue line**) and Subsistence/Base (**red line**) Targets at GS300

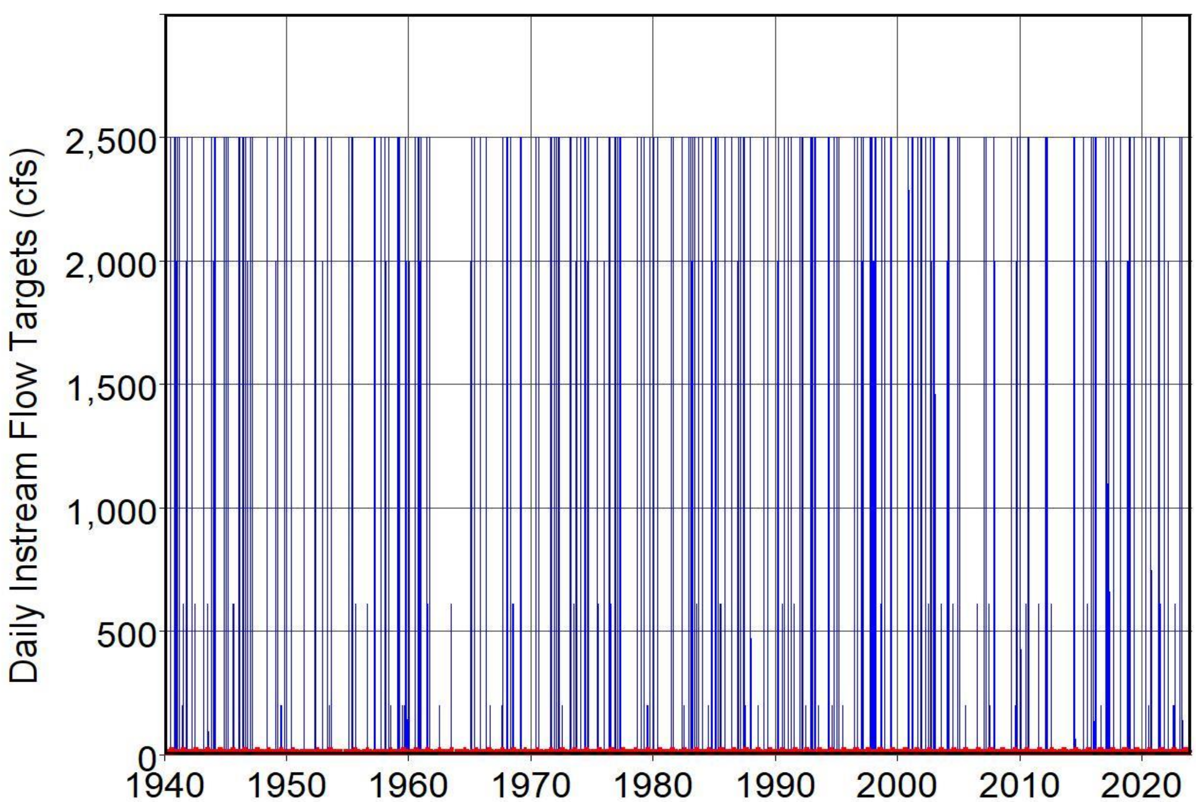

Figure 11.10 SB3 EFS Total (**blue line**) and Subsistence/Base (**red line**) Targets at DV501

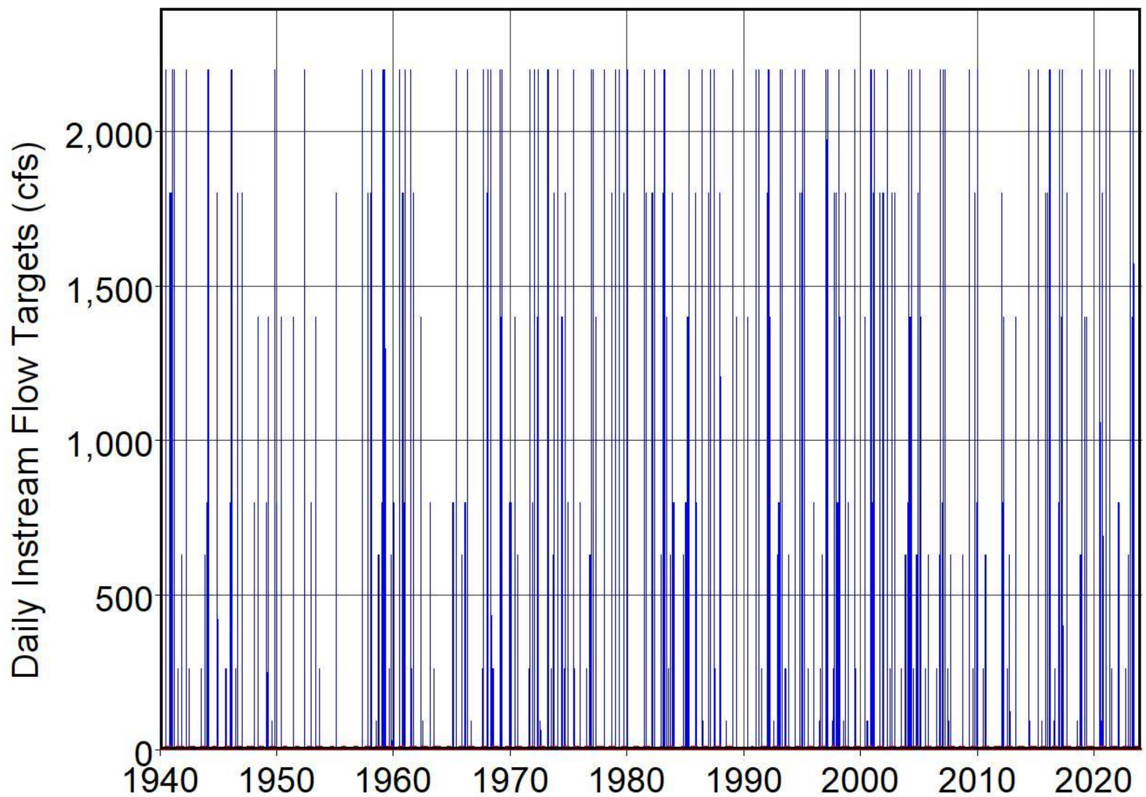

Figure 11.11 SB3 EFS Total (**blue line**) and Subsistence/Base (**red line**) Targets at GS1000

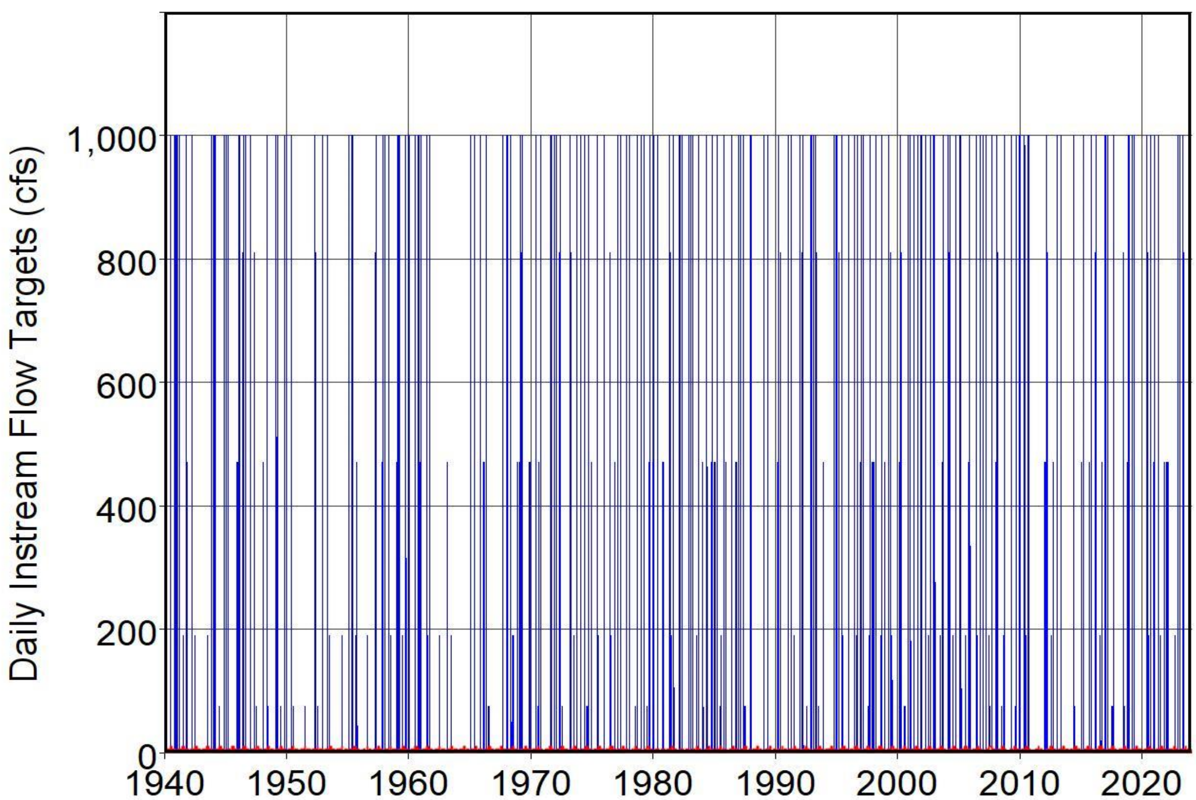

Figure 11.12 SB3 EFS Total (**blue line**) and Subsistence/Base (**red line**) Targets at WS800

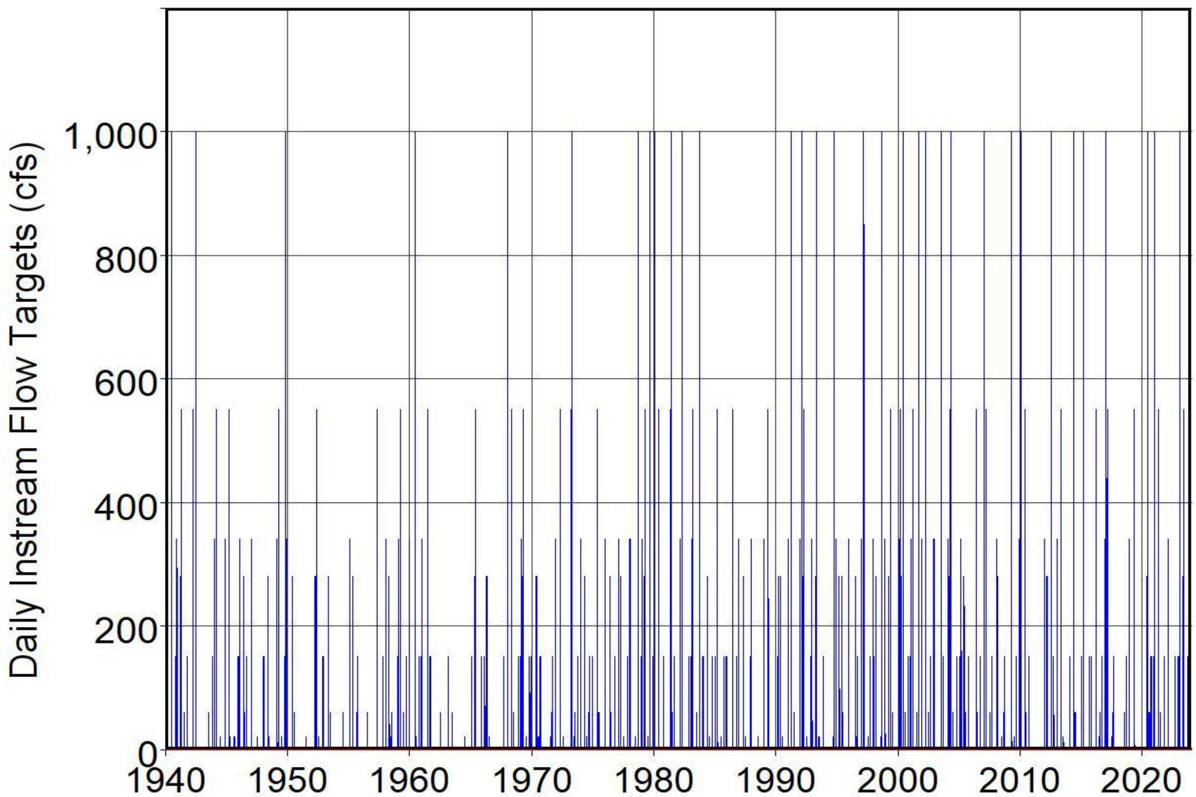

Figure 11.13 SB3 EFS Total (**blue line**) and Subsistence/Base (**red line**) Targets at ECB720

SB3 EFS Components

The computation of a daily SB3 EFS target in a *SIMD* simulation consists of computing a subsistence and base flow target as specified by *ES* and *HC* records and a pulse flow target as specified by *PF* and *HC* records. The larger of the two targets in each day is adopted as the final target. However, both target components can be recorded in the simulation results for information using labels listed in Table 8.15 of Chapter 8 replicated from Chapter 3 of the *Users Manual* [2]. Statistics for the final daily targets (IFT-CP or IFT-WR), pulse flow component (TIF-WR), subsistence/base flow component (TIF-WR), and final shortage in meeting total combined daily targets (IFS-CP or IFS-WR) are tabulated in Table 11.15. The final total combined daily targets and the subsistence/base flow component are plotted in Figures 11.9 through 11.13. The difference each day between the final total instream flow target and the subsistence and base flow component of the target in Figures 11.9-11.13 is the pulse flow component.

The non-zero daily quantities for the high flow pulse (*PF* record) component of the SB3 EFS targets are much larger than the subsistence and base flow (*ES* record) quantities but occur only during infrequent flood or high flow events. The subsistence and base flow component of the SB3 EFS targets are relatively small quantities in each day but occur continuously. The combined subsistence and base flow (*ES* record) component is greater than zero in all 30,681 days of the 1940-2023 simulation. The high pulse flow (*PF* record) component of the SB3 EFS target is zero during most of the 30,681 days of the 1940-2023 simulation. The means averaged over the 30,681 days and the number of days with nonzero target quantities are tabulated in Table 11.16.

Table 11.16
Comparison of SB3 EFS Target Components

Control Point	Number of Days with Non-Zero Targets			1940-2023 Mean of 30,681 Targets		
	ES Record	*PF* Record	Combined	*ES* Record	*PF* Record	Combined
	(days)	(days)	(days)	(cfs)	(cfs)	(cfs)
GS300	30,681	855	30,681	19.499	45.948	64.740
DV501	30,681	1,092	30,681	14.003	40.280	53.653
GS1000	30,681	1,266	30,681	4.143	29.454	33.335
WGS800	30,681	1,344	30,681	3.901	17.913	21.556
ECB720	30,681	1,410	30,681	1.102	7.336	8.382

The mean of the high pulse flow targets at control point GS300 averaged over the 30,681 days of the 1940-2023 simulation is 45.948 cfs, The daily high pulse targets range from zero during 29,826 days to a maximum of 4,500 cfs during some days of high flow pulse tracking. The daily combined subsistence and base flow target at GS300 ranges between 1.200 cfs and 30.00 cfs in each of 30,681 days with a 1940-2023 mean of 19.499 cfs. The actual final target in each individual day is the larger of the high pulse flow component and subsistence/base flow component, which ranges from 1,200 cfs to 4,500 cfs with an average of 64.740 cfs at GS300 (Table 11.15).

The *ES*, *HC*, *PF*, and *PO* records are designed for modeling instream flow requirements in the format adopted by the SB3 EFS process. *ES*, *HC*, *PF*, and *PO* records are all incorporated in *SIMD*. The *ES* and *HC* records are also included in *SIM*. The case studies in this report do not use the *PO* record which provides additional options that can used with the *PF* record. *HC* records can be used to define hydrologic conditions for both subsistence and base flow standards (*ES* record) and high flow pulse standards (*PF* record). However, the SB3 EFS in the Lavaca Basin used hydrologic conditions in defining only subsistence and base flow standards. High flow pulse standards are defined as a function of season but without consideration of hydrologic condition.

Subsistence and base flow limits defined as a function of season and hydrologic condition are tabulated in Table 11.6 and 11.7. Hydrologic conditions are defined as a function of storage in Lake Texana as outlined in Table 11.5. Switches between base flow and subsistence flow standards are controlled by WAM regulated flows in a *SIM* or *SIMD* simulation.

Metrics defining the high flow pulse components of the SB3 EFS are tabulated in Table 11.8. Tracking of a high flow pulse begins when the WAM regulated stream flow exceeds the trigger stream flow levels in cfs shown in Table 11.8. The high flow pulse is tracked in the simulation until either the accumulated volume or duration limit is reached. High pulse flow event duration limits for the SB3 EFS in the Lavaca Basin range between 4 and 10 days.

Alternative Strategies for Modeling SB3 EFS in a Monthly WAM

In addition to water supply diversion and storage rights, the Lavaca WAM has thirty *IF* record instream flow rights with priorities ranging from 19720515 to 20001001 (May 15, 1972 to October 1, 2000). The SB3 EFS have a priority of 20110301 (March 1, 2011). The thirty other instream flow rights are located at different control points than the five SB3 EFS. The existing instream flow *IF* record rights are not altered in conversion to a daily WAM other than uniformly dividing the instream flow targets between the 28, 29, 30, or 31 days in each month.

Eighteen of the twenty WAMs listed in Table 5.1 of Chapter 5 contain *IF* record water rights that model instream flow requirements established before the 2007 SB3. Most of the pre-SB3 instream flow requirements are minimum flow limits specified as an annual flow volume entered on an *IF* record and distributed to each of the 12 months of the year based on factors on a *UC* record. More complicated instream flow requirements, are modeled with complex combinations of various input records combined with the *IF* record. *IF*, *TO*, *SO*, *FS*, *CV*, *DI*, *IS*, *IP*, *CI*, *UC*, *WR*, and *CP* records are employed in various ways to model complex *IF* record rights.

The relatively new *ES* and *HC* records could also be employed to model many of the instream flow requirements other than SB3 EFS. The *HC* and *ES* record routines were first introduced in the July 2018 versions of *SIM* and *SIMD*. An initial developmental version of the *PF* and *PO* record routines introduced in the August 2012 *SIMD* was significantly refined in the July 2018 *SIMD*. *HC*, *ES*, *PF*, and *PO* records are structured specifically in SB3 EFS format but can also be applied to other forms of instream flow requirements. *PF* and *PO* records are read only by *SIMD*. *HC* and *ES* records are read and applied by both *SIMD* and *SIM*.

Results from monthly *SIM* and daily *SIMD* simulations are compared in Table 11.17. The exact same *HC* and *ES* records are inserted in both *SIM* and *SIMD* in the simulations of Table 11.7. No modifications are required in *HC* and *ES* records between *SIM* versus *SIMD*. Monthly SB3 EFS targets computed in a daily *SIMD* simulation are aggregated to monthly within *SIMD* for input to a monthly *SIM* on *TS* records as discussed throughout this report. Thus, daily SB3 EFS targets are replicated in the monthly *SIM* targets. However, the corresponding monthly shortages computed in the monthly *SIM* simulation differ from the monthly aggregation of daily shortages.

Table 11.17
Means of 1940-2023 Simulated SB3 EFS Targets and Shortages in cfs

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	SIM with *ES*&*HC* Records		*SIM* with *SIMD* Targets on *TS* Records			
Control Point	*ES* Record Target (cfs)	Target Shortage (cfs)	*ES* Record Target (cfs)	*PF* Record Target (cfs)	Combined Target (cfs)	Target Shortage (cfs)
GS300	21.529	0.1494	19.499	45.948	64.740	0.2380
DV501	16.364	0.0366	14.003	40.280	53.653	0.1178
GS1000	4.978	0.1975	4.143	29.454	33.335	0.2930
WGS800	4.734	0.06355	3.901	17.913	21.556	0.1138
ECB720	1.133	0.07658	1.102	7.336	8.382	0.2015

The combined subsistence and base flow targets and corresponding target shortages in columns 2 and 3 of Table 11.17 are from a monthly *SIM* simulation with the *HC* and *ES* records included directly in the *SIM* input DAT file. This alternative *SIM* simulation does not include high flow pulse components of the SB3 EFS.

The 1940-2023 means of daily or monthly subsistence/base flow (*ES* record) and high flow pulse (*PF* record) targets in columns 4 and 5 of Table 11.17 are from a daily *SIMD* simulation. The 1940-2023 means of the combined *ES* and *PF* targets in column 6 reflect the results of the daily *SIMD* simulation incorporated in the monthly *SIM* simulation as targets on *TS* records read by *SIM* from the DSS input file.

The 1940-2023 means of monthly shortages in column 7 of Table 11.17 are from monthly *SIM* results. Monthly targets from the *SIMD* simulation (column 6) are replicated in the *SIM* input DSS file. However, the target shortages of column 7 from a *SIM* simulation are based on monthly regulated flows computed in the *SIM* simulation along with targets from the daily *SIMD* simulation. Thus, the SB3 EFS target shortages computed by *SIM* reflected in the 1940-2023 means of column 7 differ from target shortages from the daily *SIMD* simulation which are based on daily regulated flows computed in the daily *SIMD* simulation.

SB3 EFS are actually implemented based on observed stream flows. By default, SB3 EFS are activated in a *SIM* or *SIMD* simulation based on simulated regulated flows. The *HC* record includes a switch for adopting naturalized flow or other options instead of regulated flows. The case studies in this report all employ the default option of basing SB3 EFS decisions on simulated regulated flows at the control point of the SB3 EFS.

Relevance of Stream Flow Variability

Effects of varying the computational time interval, such as between daily and monthly, are discussed in Chapter 2 of the Reference Manual [1]. The daily mean flows during each of the 28, 29, 30, or 31 days of a particular month tend to vary significantly from the mean monthly flow for that month. Within-month daily variability tends to be much greater during high pulse flows than during periods of low flows. Simulating the high flow pulse component of SB3 EFS with a monthly computational time step is extremely approximate, perhaps essentially meaningless.

The difference in variability with monthly versus daily averaging intervals is illustrated by the flows of the Lavaca River at Edna explored in Table 11.5 and Figure 11.6. The maximum daily mean flow rate of 122,000 cfs during the period-of-record at the USGS gage on the Lavaca River near Edna occurred during October 19, 1994. Daily means during October 1994 ranged between 12.0 cfs during October 6 and 7 to 122,000 cfs on October 19, with a monthly mean for October 1994 of 7,118 cfs. The maximum flow rate during October 1994 with a monthly versus daily averaging-interval (computational time step) is 7,118 cfs and 122,000 cfs, respectively.

The second largest maximum daily flow rate of the Lavaca River near Edna (Figure 11.6) was 66,300 cfs during August 29, 2017. The minimum daily flow during August 2017 was 0.47 cfs during August 21. The monthly mean for August 2017 was 5,433 cfs. The maximum flow rate during October 1994 with a monthly versus daily averaging-interval is 7,118 and 66,300 cfs.

Within-month variability of regulated flows is fundamental to defining high flow pulses. Tracking of a pulse event begins when the WAM regulated stream flow exceeds the trigger stream flow levels in cfs shown in Table 11.8. The high flow pulse event is tracked until either the accumulated volume or duration limit is reached. The duration limits range between 4 and 10 days.

Subsistence and base flow limits defined as a function of season and hydrologic condition are tabulated in Table 11.6 and 11.7. Hydrologic conditions are defined as a function of storage in Lake Texana as outlined in Table 11.5. Switches between base flow and subsistence flow standards are controlled by WAM regulated flows in a *SIM* or *SIMD* simulation. Within-month variability in simulated regulated flows affect adoption of subsistence versus base flow standards. However, effects of monthly versus daily time intervals affect the subsistence and base flow components of SB3 EFS much less than the pulse flow component.

<u>SB3 EFS in Alternative Versions of the Lavaca WAM</u>

A preliminary draft modeling strategy was adopted by TCEQ for incorporating the SB3 EFS in the monthly full authorization Lavaca WAM in 2014 prior to development of new WRAP modeling capabilities employing newly created *ES*, *HC*, *PF*, and *PO* records. A revised strategy for modeling the SB3 EFS directly in the monthly WAM without the daily WAM was employed by TCEQ in the updated October 2023 monthly WAM. The strategy for incorporating the SB3 EFS in the daily and modified monthly WAMs adopted for all six case studies of Chapters 7-12 is implemented for the Lavaca WAM as discussed in preceding sections of this chapter.

The draft 2014 version of the WAM contains a total of about 1,922 input records in the DAT file. About 1,415 of these input records were added specifically to model the SB3 EFS at the five control points. Subsistence, base, and high flow pulse components are included. The other approximately 507 records in the DAT file simulate all aspects of the WAM other than the SB3 EFS. The approximately 1,922 records in the 2014 WAM DAT file simulating the SB3 EFS consist of *IF*, *UC*, *CI*, *CP*, *WR*, *TO*, and *FS* records.

The version of the monthly Lavaca last updated by TCEQ in October 2023 simulates the SB3 EFS including subsistence, base, and high flow pulse components using about 583 input records inserted in the DAT file. The total of about 1,111 DAT file records include another 528 records modeling all aspects of the WAM other than the SB3 EFS. The SB3 EFS are modeled with about 583 *IF*, *ES*, *HC*, *CP*, *WR*, and *TO* records added specifically for the SB3 EFS. The monthly WAM last updated by TCEQ in October 2023 was converted to a daily WAM as described in this chapter. The 583 *IF*, *ES*, *HC*, *CP*, *WR*, and *TO* records were removed from the monthly WAM and replaced in the daily WAM with a set of 84 *IF*, *ES*, *HC*, and *PF* records.

A strategy adopted for all six case studies is comprised of computing SB3 EFS targets in a daily *SIMD* simulation which are aggregated to monthly quantities for input on *TS* records in the monthly WAM. A set of 84 *IF*, *ES*, *HC*, and *PF* records is incorporated in the daily *SIMD* DAT file for the Lavaca WAM in the format illustrated by Table 11.10. The daily DAT file has a total of about 647 input records. Monthly SB3 EFS results included in the *SIMD* simulation results are converted to *TS* records with DSS pathnames listed in Table 11.12. Each of the five *TS* records in the DSS input file contains SB3 EFS targets for the 1,008 months of the 1940-2023 simulation. The five *TS* records in the DSS file (Table 11.12) are referenced by a set of ten *IF* and *TS* records (Table 11.13) in the monthly DAT file. Monthly targets and shortages from the *SIMD* daily simulation with the daily Lavaca WAM are plotted as Figures C43 through C47 of Appendix C.

CHAPTER 12
NUECES DAILY AND MODIFIED MONTHLY WAMS

The original Nueces WAM was completed in 1999 [91] by HDR Engineering for TNRCC (later renamed TCEQ). TCEQ has modified the monthly WAM as new permits and amendments were submitted and approved. Developmental daily and modified monthly versions of the WAM with SB3 EFS added were developed in research at TAMU sponsored by TCEQ during 2022-2023 [12]. This chapter summarizes the 2023 report [12] and presents additional updates and analyses.

The daily and modified monthly WAM versions presented in this chapter were created by modifying the monthly full authorization WAM last updated by TCEQ as of October 1, 2023. Similar previous modifications to the January 2013 versions of the full authorization and current use WAMs are described by the June 2023 report [12]. The daily and modified monthly WAMs include addition of SB3 EFS at 17 stream locations established by TCEQ effective March 2014.

The June 2023 report [12] presents daily and modified monthly versions of the Nueces WAM for both the full authorization (run 3) and current use (run 8) scenarios. The present Chapter 12 as well as the preceding case study chapters of this report deal with only the full authorization (run 3) scenario versions of the WAMs.

The original Nueces WAM [91] and the current official version last updated by TCEQ as of October 1, 2023 have a hydrologic period-of-analysis of January 1934 through December 1996. The 2023 daily and modified WAMs [12] include a hydrology extension through December 2021 employing a 1997-2021 dataset of *IN* and *EV* records developed by TWDB. The updated daily and modified WAMs presented in this chapter include a hydrology extension through December 2023 employing an extended 1997-2023 dataset of *IN* and *EV* records developed by TWDB.

Nueces River Basin

Figure 12.1 is a map of the 16,700 square mile Nueces River Basin. The Nueces River flows into Nueces Bay, which is a northwestern extension of Corpus Christi Bay. The City of Corpus Christi is in Nueces County adjacent to the southwest side of Nueces Bay and Corpus Christi Bay, mostly in the Nueces-Rio Grande Coastal Basin. Most surface water use supplied from the Nueces River Basin is used by the City of Corpus Christi and its water customers for municipal and industrial use. The majority of water supplied by Corpus Christi from the city-owned and operated Choke Canyon Reservoir and Lake Corpus Christi is diverted downstream at the Calallen diversion dam and saltwater barrier located on the Nueces River about twelve miles upstream of the river outlet into Nueces Bay.

The 2020 census population of the City of Corpus Christi is 317,800. The 2020 census populations of Nueces, San Patricio, and Jim Wells Counties (Figure 12.1) are 353,200, 68,800, and 38,890. The City of Corpus Christi supplies water throughout these three counties. Mean annual rainfall and reservoir evaporation rates in the Nueces River Basin are 25.0 inches and 58.4 inches, respectively. Most rainfall in the basin originates from localized convective thunderstorms or from tropical storms and hurricanes covering wider areas. The sporadic nature of rainfall in the basin results in intermittent, highly variable stream flows. Short periods of high flows in the streams and rivers are preceded and followed by long periods of low or zero flows.

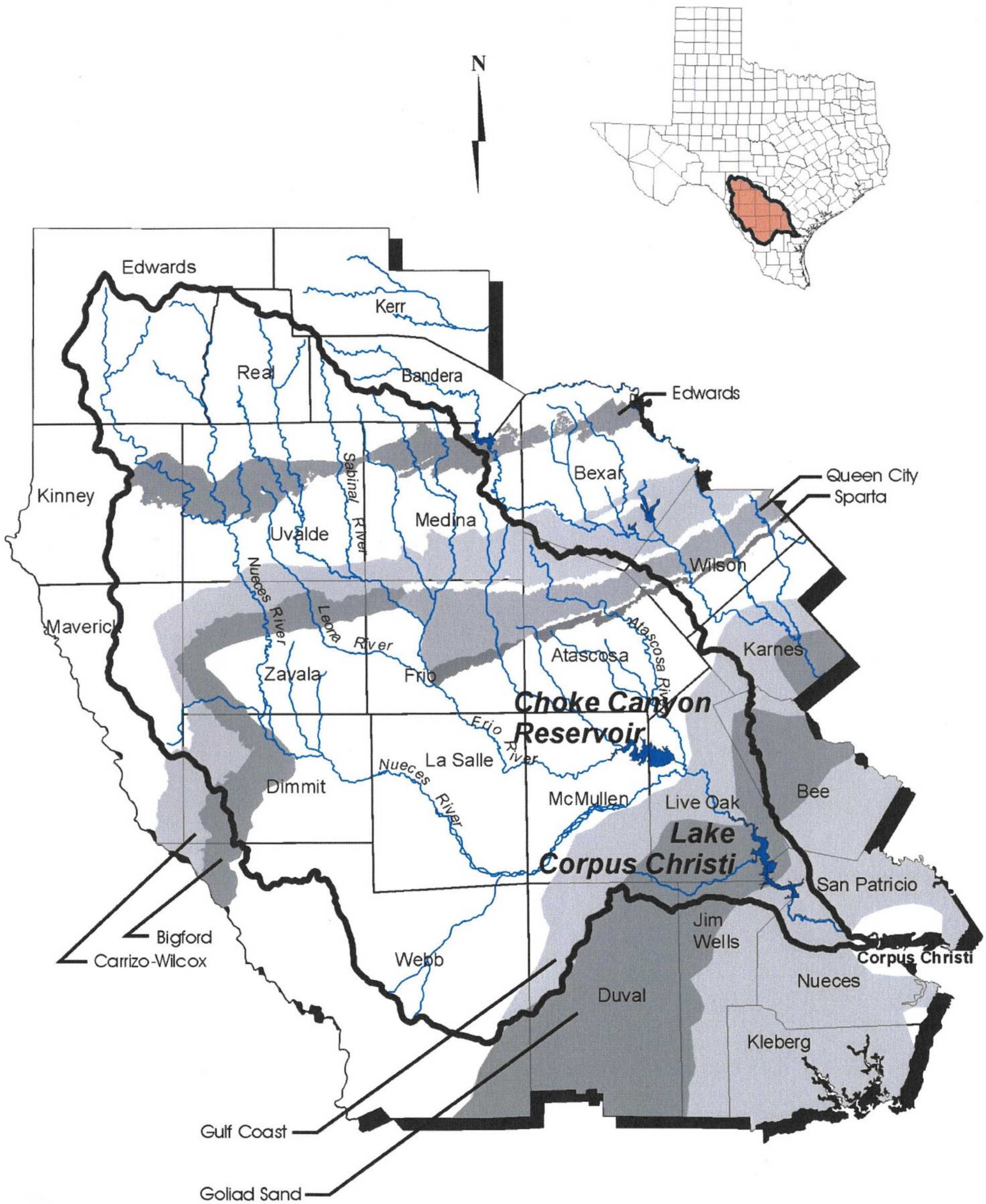

Figure 12.1 Nueces River Basin and Underlying Aquifers [91]

The following two aspects of the Nueces River Basin combine to make water availability modeling somewhat different here than for other river basins of Texas.

1. Only minimal use of surface water occurs within the Nueces Basin. Most use of surface water from the Nueces River and tributaries occurs in the adjoining coastal basins from diversions near the basin outlet. Reservoir storage is dominated by the two-reservoir Choke Canyon Reservoir and Lake Corpus Christi System located in the lower basin. The population of the basin is small. Most water use within the basin is supplied by groundwater.

2. The hydrology of the Nueces River Basin is greatly affected by interactions between stream flow and groundwater, much more than in other river basins. Effects are primarily through stream flow recharge of groundwater systems but also through spring flows to streams. Although stream flow in all river basins is affected by interactions between surface and groundwater, the interactions in the Nueces River Basin are much greater than typically occurring in other river basins in Texas.

Most surface water use from the Nueces River Basin occurs in the Nueces-Rio Grande Coastal Basin. Most water use within the Nueces River Basin is supplied from groundwater. Groundwater supplies are declining. Uvalde, with a 2020 population of 24,560, is the largest city located within the Nueces Basin. The Edwards Aquifer is the primary source of supply for Uvalde.

The hydrology of the basin is complicated by interactions between surface and ground water. As indicated in Figure 12.1, the Nueces River and its tributaries cross major aquifer outcrop or recharge zones. The Edwards Aquifer recharge zone accounts for the largest volume of stream flow loss to groundwater in the basin. Stream flow recharge of the Carrizo-Wilcox, Bigford, Queen City, Sparta, Gulf Coast, and Goliad Sand groundwater formations is also significant.

The Edwards recharge zone extends across middle reaches of the Nueces River and tributaries that include the Frio River, Sabinal River, and other smaller streams. Flows from these streams flow into the underlying fractured limestone contributing to aquifer recharge. Most groundwater aquifers in Texas are comprised largely of sand and gravel. The unique Edwards Aquifer consists of caverns through limestone that are essentially underground rivers. The principal Edwards recharge zone is a 1,500 square mile area of fractured and cavernous limestone exposed on the surface allowing large quantities of water to enter the aquifer. This recharge zone extends across the upper portions of the Nueces, San Antonio, and Guadalupe River Basins in the Hill Country just north of the cities of Uvalde, Hondo, San Antonio, and New Braunfels.

<u>Reservoirs in the Nueces River Basin</u>

Choke Canyon Reservoir and Lake Corpus Christi are the only reservoirs in the WAM with authorized storage capacities of 5,000 acre-feet or greater. Information describing these two reservoirs is provided in Table 12.1. The two reservoirs have a total combined authorized storage capacity of 1,000,000 acre-feet, which accounts for 96.1% of the total authorized storage capacity of 1,040,446 acre-feet in the 121 reservoirs included in the full authorization Nueces WAM. Choke Canyon Reservoir and Lake Corpus Christi have a total storage capacity of 918,600 acre-feet accounting for 97.5% of the total capacity of 959,830 acre-feet of 125 reservoirs in the current use scenario WAM [12]. The storage capacities and surface areas in the last two lines of Table 12.1 are from a TWDB website and are based on sediment surveys conducted by TWDB in 2012.

Table 12.1
Choke Canyon Reservoir and Lake Corpus Christi

Reservoir	Choke Canyon	Corpus Christi
River	Frio River	Nueces River
Watershed Area (square miles)	4,667	16,660
Initial Impoundment Date	May 1982	April 1958
Storage Capacity (acre-feet)		
Full Authorization WAM	700,000	300,000
Current Use WAM	693,350	225,250
TWDB 2012 Surveys	662,820	254,730
Surface Area in 2012 (acres)	25,440	18,700

Choke Canyon Reservoir on the Frio River was constructed by the U.S. Bureau of Reclamation and is jointly owned by the Nueces River Authority (20%) and City of Corpus Christi (80%). Choke Canyon Dam is in Live Oak County about four miles west of the City of Three Rivers. The reservoir began to impound water in 1982. Choke Canyon Reservoir has an authorized storage capacity of 700,000 acre-feet, but a 2012 TWDB volumetric survey indicated that the capacity had been reduced by sedimentation to 662,820 acre-feet. The surface area at capacity is 25,440 acres. The watershed area above the dam is 4,667 square miles.

Lake Corpus Christi impounded by Wesley E. Seale Dam is owned and operated by the City of Corpus Christi for water supply and recreation. Impoundment began in 1958. In addition to supplying its own residents, the City of Corpus Christi sells water to the San Patricio Municipal Water District, Alice Water Authority, and several cities and industries. Lake Corpus Christi has an authorized storage capacity of 300,000 acre-feet and according to a 2012 site survey by the TWDB a reduced capacity of 254,730 acre-feet with a surface area of 18,700 acres. The watershed area above the dam is 16,660 square miles.

Simulated storage contents of Choke Canyon Reservoir and Lake Corpus Christi computed in a monthly full authorization simulation with a 1934-2023 hydrologic period-of-analysis are plotted in Figure 12.2 to illustrate the extent to which the water resources of the Nueces River Basin have been appropriated. Storage drawdowns are dramatic in the full authorization simulation. Figure 12.2 helps explain the motivation for the interbasin water transport projects discussed in the next section. Storage drawdowns from a current use WAM simulation are also severe but much less severe than in the full authorization scenario [12]. The current use scenario reflects estimates of water use in the 1990's and loss of storage capacity due to sedimentation. Observed storage of the two-reservoir system is plotted in Table A6 of Appendix A. The monthly simulation of Figure 12.2 was performed with the DAT file last updated by TCEQ 10/1/2023 combined with extended 1934-2023 hydrology. The reservoirs are assumed to be full to capacity at the beginning of the simulation which results in unrealistically high simulated storage contents during 1934-1938 but has no effect on simulation results after 1938.

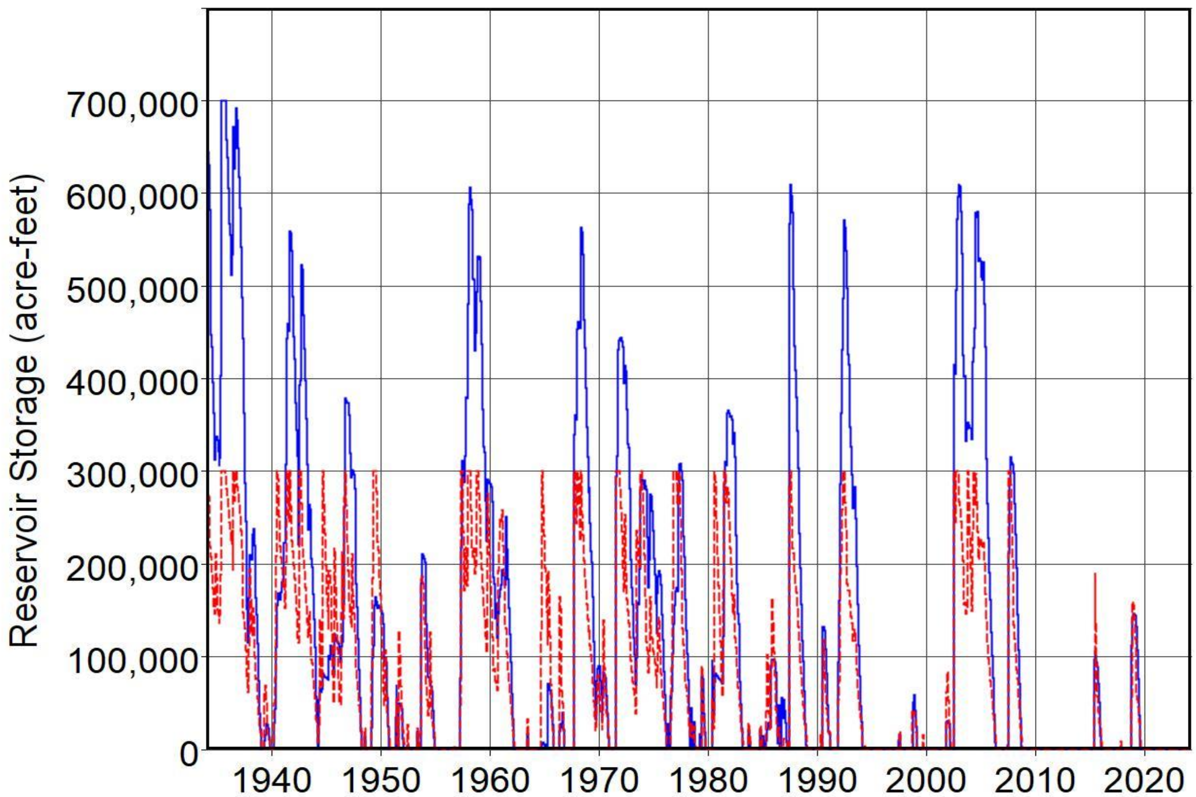

Figure 12.2 Simulated Storage in Lakes Choke Canyon (blue solid) and Corpus Christi (red dots)

Interbasin Water Transport and Possible Future Seawater Desalination

Water supplies initially developed from sources in the Nueces River Basin have been supplemented since the 1990's by inter-basin transfer of water by pipeline from the Lavaca and Colorado River Basins. The City of Corpus Christi now operates a water supply system for the Coastal Bend Region that obtains water from Choke Canyon Reservoir on the Frio River, Lake Corpus Christi on the Nueces River, Lake Texana on the Navidad River, and the Colorado River. Growing water demands have motivated interbasin water transport projects.

The City of Corpus Christi and Nueces River Authority completed the Mary Rhodes Pipeline Project in two phases at the locations shown in the map of Figure 12.3 available at the Nueces River Authority website. The first phase completed in 1999 transports water to Corpus Christi by pipeline from Lake Texana on the Navidad River in the Lavaca River Basin. The second phase completed in 2016 added water from the Colorado River to the supply transported to Corpus Christi from Lake Texana. The City of Corpus Christi acquired water rights during the 1990's for the Navidad River and Colorado River water.

The first phase of the Mary Rhodes Pipeline Project consists of a 101-mile long, 64-inch diameter pipeline constructed of reinforced concrete in a steel cylinder and two pumping stations that connects Lake Texana and the O. N. Stevens Water Treatment Plant in Corpus Christi. The Texana pipeline was constructed during 1998-1999 and has been supplying a major portion of the water used in the Coastal Bend Region since 1999. The second phase of the interbasin water transport system completed in 2016 consists of a 42-mile-long pipeline from a pumping station on the Colorado River near Bay City that connects to the Texana pipeline.

The City of Corpus Christi, Port of Corpus Christi Authority, and private industrial companies have investigated the feasibility of seawater desalination over the past several decades. Multiple projects for construction of seawater desalination plants in the Corpus Christi area continue to be investigated. Currently, no seawater desalination plant supplying municipal or agricultural water use is in operation in Texas. According to a TWDB desalination database, Texas has thirty-six municipal desalination facilities with a total capacity of 100,769 acre-feet/year that treat brackish ground water and sixteen plants with a total capacity of 72,443 acre-feet/year that treat brackish surface water (https://www.twdb.texas.gov/innovativewater/desal/index.asp). None treat seawater. The Corpus Christi region is perhaps the most likely candidate to become the first region in Texas to supplement its municipal water supplies by construction of a seawater desalination plant.

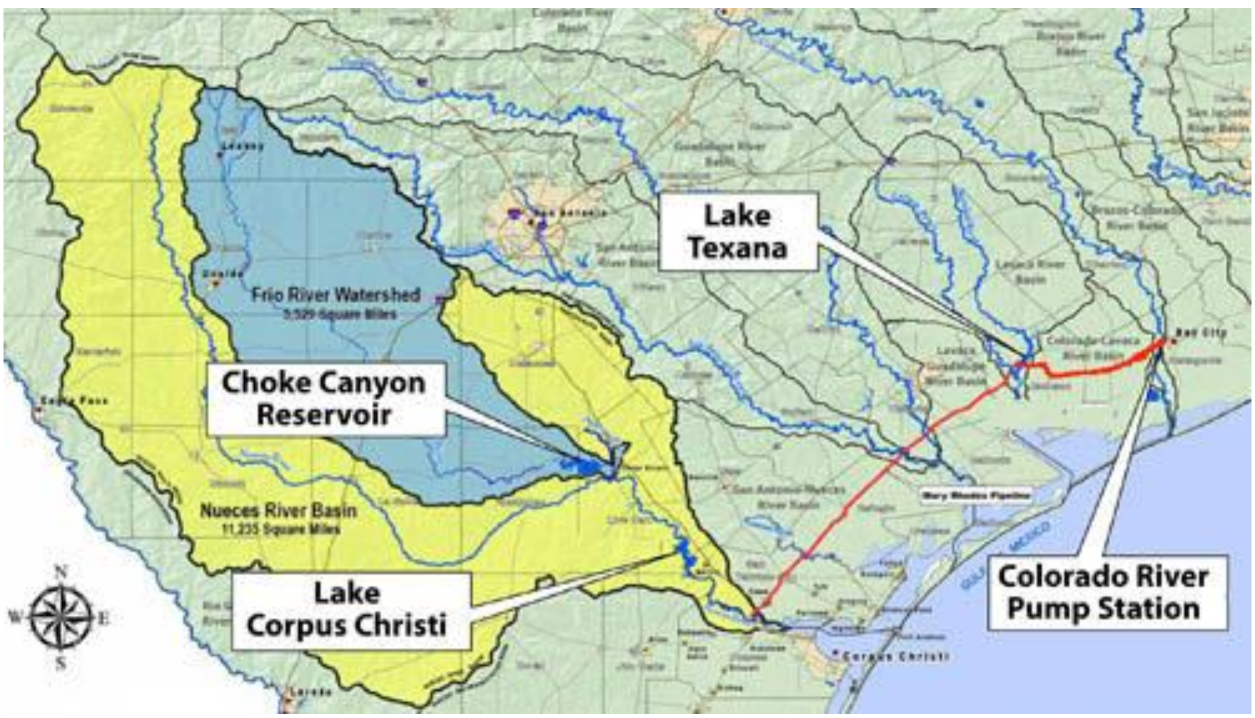

Figure 12.3 Water Supply System Owned and Operated by City of Corpus Christi and Nueces River Authority (source: Nueces River Authority website)

Nueces WAM

The initial datasets modified to create the January 2025 daily and monthly WAMs consist of the monthly full authorization WAM last updated by TCEQ on October 1, 2023, which is comprised of the following data files: N_RUN3.dat, N_RUN3.dis, N_RUN.eva, and N_RUN.inf. The *IN* and *EV* records from the text files N_RUN.inf and RUN.eva are combined into a single DSS file with filename NuecesHYD.DSS for the 2024-2025 update. The daily and modified monthly WAMs with SB3 EFS added presented later in this chapter are comprised of files with the following filenames: NuecesD.DAT, NuecesM.DAT, Nueces.DIS, and NuecesHYD.DSS.

Input Record Counts

Record counts from the simulation MSS file are tabulated in Table 12.2. The expanded daily and monthly WAMs described in the June 2023 report [12] were developed by modifying the monthly WAM last updated by TCEQ in January 2013. The 2025 versions documented in this chapter were developed by modifying the monthly WAM last updated by TCEQ in October 2023.

Table 12.2
Number of Model Components in Nueces Full Authorization WAM Datasets

Latest Update of Datasets Monthly or Daily Time Step Filename Root for DAT File	Jan 2013 Monthly N_Run3	Oct 2023 Monthly N_Run3	Jan 2025 Daily NuecesD	Jan 2025 Monthly NuecesM
total number of control points	543	676	546	546
primary control points	41	41	41	41
evap-precip control points	10	10	10	10
number of reservoirs	121	122	122	122
WR record water rights	374	481	379	379
instream flow *IF* record rights	30	127	71	54
drought index *DI* records	3	3	3	3
FD records in DIS file	465	473	468	468

Primary control points CP11, CP14, CP20, and CP23 are included on control point *CP* records in the original and later versions of the DAT file but not actually used in the simulation. Naturalized flow *IN* records are also included for these four control points in the hydrology dataset though not actually used in the simulation. Only 37 primary control points are actually used in computations performed in the *SIM* or *SIMD* simulation.

INMETHOD option 6 based on drainage areas and channel loss factors is selected on control point *CP* records for distributing flows to most secondary control points using parameters from flow distribution *FD*, watershed parameter *WP*, and control point *CP* records in the DIS and DAT files. Negative incremental flow ADJINC option 5 is activated on the *JD* record for monthly versions of the Nueces WAM. Daily standard ADJINC option 6 is activated for daily WAMs.

SB3 EFS were not included in the WAM last updated by TCEQ in January 2013. SB3 EFS are added for four of the 17 EFS sites in the WAM version updated by TCEQ in October 2023. The October 2023 full authorization WAM includes SB3 EFS at the Frio River at Tilden, Frio River near Derby, Nueces River near Three Rivers, and Nueces River near Mathis. The DAT file for the full authorization October 2023 WAM includes a total of about 2,860 input records. About 715 records or 25% of the total number of input records in the October 2023 DAT file had been added to model SB3 EFS at four control points. As discussed later, these 715 records are removed in the January 2025 daily and modified monthly WAMs. Twenty daily flow *DF* records, 17 sets of *IF* and *ES* records, and 17 sets of *IF* and *PF* records were added in the daily WAM to convert from monthly to daily and simulate SB3 EFS. Seventeen *IF* records and 17 target series *TS* records are added in the modified monthly WAM to model the SB3 EFS at 17 sites.

Reservoirs and Water Rights

Quantities for the full authorization monthly WAM last updated by TCEQ in January 2013 are noted as follows. These quantities are essentially the same in the October 2023 update except for the addition of SB3 EFS at four control points. The modifications in the January 2025 version focus on addition of SB3 EFS at 17 control points. Choke Canyon Reservoir and Lake Corpus Christi are the only reservoirs in the Nueces WAM with authorized storage capacities equaling or exceeding 5,000 acre-feet. Pertinent metrics describing the two reservoirs are tabulated in Table 12.1. Choke Canyon Reservoir and Lake Corpus Christi have a total combined authorized storage capacity of 1,000,000 acre-feet, which accounts for 96.1 percent of the total authorized storage capacity of 1,040,446 acre-feet in the reservoirs included in the full authorization Nueces WAM.

The 374 water right *WR* records in the 2013 full authorization WAM simulate diversion and storage rights with priority dates ranging from December 31, 1885 to November 9, 1999. The 30 instream flow *IF* records in the 2013 full authorization WAM have priority dates ranging from February 2, 1924 to April 23, 1997. Several "dummy" accounting *WR* and *IF* records are assigned priorities of 99999999. The diversion amounts on the *WR* and *IF* records in the DAT file of all versions of the WAM sum to greater than the total actual water right amounts due to "dummy" water rights employed in water accounting schemes to model complexities of system operations.

Authorized diversion amounts totaling 533,416 acre-feet/year are distributed among types of use as follows: municipal (41.54%), industrial (43.05%), irrigation (14.92%), aquifer recharge (0.429%), mining (0.0491%), recreation (0.00825%), and other (0.00525%). The larger water rights with annual diversion amounts of 2,000 acre-feet or greater are listed in Table 12.3 by owner. These water rights with annual diversion amounts of at least 2,000 acre-feet account for 91.8% of the total authorized annual diversion volume and 96.9% of the authorized storage capacity in the full authorization WAM. Authorized diversion and authorized consumptive use are the same for the water rights listed in Table 12.3, but different for some smaller rights. The water right labels in Table 12.3 are numbers from water use permits or certificates of adjudication.

Table 12.3
Largest Water Rights

Water Right	Owner	Diversions (ac-ft/year)	Storage (acre-feet)	Reservoir
2464	City of Corpus Christi	304,898	300,000	Lake Corpus Christi
			1,175	Calallen Reservoir
3214	City of Corpus Christi & Nueces River Authority	139,000	700,000	Choke Canyon Reservoir
3082	Zavala-Dimmitt Co. WCID	28,000	5,633	Upper Nueces and others
2466	Nueces County WCID #3	11,546	0	
3091	Turkey Creek Ranches	2,098	0	
3239	Holland Dam & Irrigation	2,023	700	
3207	Bexar-Medina-Atascosa County WCID #1	2,000	730	
Total		489,565	1,008,238	

Operations of the Choke Canyon Reservoir (CCR) and Lake Corpus Christi (LCC) System and the Nueces WAM reflect special conditions in the certificate of adjudication for CCR that provide for maintenance of freshwater inflows to the Nueces Estuary. The special conditions include a monthly schedule of minimum desired freshwater inflows to Nueces Bay totaling between 97,000 and 138,000 acre-feet/year to be provided by spills, return flows, and runoff below Lake Corpus Christi, and/or dedicated passage of inflows through the CCR/LLC System. Provisions for temporary reduction or suspension of freshwater inflow requirements are based on CCR/LLC storage, monthly inflow banking, salinity variations in upper Nueces Bay, and implementation of drought contingency measures [91].

Nueces WAM Hydrology

The monthly and daily versions of the Nueces WAM include the same channel loss factors (*CP* records), flow distribution parameters (*FD* and *WP* records), and 1934-2023 hydrologic period-of-analysis (previously 1934-1996) monthly naturalized stream flows (*IN* records) and net evaporation-precipitation depths (*EV* records). The daily WAM also includes 1934-2023 sequences of daily stream flows on *DF* records that serve as pattern hydrographs in converting monthly naturalized flow volumes to daily quantities in the *SIMD* simulation.

Forty-one control points have naturalized stream flows provided as input on *IN* records, but only 37 of the primary control points are actually used in the simulation. Monthly naturalized flows at over 500 secondary control points are computed during a *SIM* or *SIMD* simulation based on the monthly naturalized stream flows read from *IN* records and watershed parameters read from flow distribution *FD* and watershed parameter *WP* records in the DIS file and channel loss factors and INMETHOD(cp) option selections from the *CP* records in the DAT file. Monthly naturalized flows at most secondary control points in the Nueces WAM are synthesized with INMETHOD(cp) option 6 based on channel loss factors and watershed areas.

Channel Loss and Delivery Factors

Stream flow in the Nueces River Basin is greatly affected by interactions with subsurface flow, generally much more than in other river basins. Effects are primarily through stream flow recharge of groundwater systems but also through spring flows to streams. Although stream flow in all river basins is affected by interactions between surface and groundwater, the interactions in the Nueces River Basin are much greater than typically occurring in other river basins. Thus, channel loss factors input on control point CP records are generally larger in the Nueces WAM per length of stream than in the other WAMs.

The Nueces River and its tributaries cross aquifer outcrop recharge zones of the Edwards, Carrizo-Wilcox, Bigford, Queen City, Sparta, Gulf Coast, and Goliad Sand groundwater formations as shown in Figure 12.1. The streams contribute to recharge of all these aquifers. However, the Edwards Aquifer recharge zone accounts for the largest volume of stream flow loss to groundwater. HDR Engineering, Inc. [71, 91] estimated the 1934-1996 average annual recharge to the Edwards Aquifer to be 333,400 acre-feet/year. For comparison, this quantity of stream flow volume recharging the Edwards Aquifer is 62.5 percent as large as the 533,416 acre-feet/year total of all authorized diversions from the Nueces River and tributaries.

The estimated 333,400 acre-feet/year recharge of the Edwards Aquifer and additional quantities of recharge to the several other groundwater systems occur in the upper and middle regions of the basin. Most of the 533,416 acre-feet/year of authorized water supply diversions are from the lower reach of the Nueces River. Spring flow also contributes to stream flow in the upper basin. The authorized use of stream flow includes groundwater recharge enhancement projects sponsored by the Edwards Aquifer Authority.

The channel loss factor (C_L) assigned to a control point and associated *SIM* or *SIMD* computed delivery factor (DF) are applied to the flow change at that location to simulate losses in the downstream stream reach [1, 2]. A channel loss factor (C_L) is the fraction of the flow at an upstream control point lost through seepage, evapotranspiration, aquifer recharge, and other unaccounted for reasons before reaching a downstream control point. Channel loss factors (C_L) are input on *CP* records [2]. Delivery factors (DF) are computed within the *SIM* or *SIMD* simulation as DF=1.0-C_L. The channel loss and delivery factors employed in the Nueces WAM to estimate losses of flow between primary control points at USGS gages are tabulated in Table 12.4 [71, 91].

Table 12.4
Channel Loss Factors (C_L) and Delivery Factors (DF=1.0-C_L)

	Control Points		Loss	Delivery
Stream	From	To	Factor	Factor
Nueces River	CP01	CP03	0.05	0.95
West Nueces River	CP02	CP03	0.03	0.97
Nueces River	CP03	CP04	0.47	0.53
Nueces River	CP04	CP05	0.26	0.74
Nueces River	CP05	CP06	0.35	0.65
Nueces River	CP06	CP20	0.18	0.82
Frio River	CP07	CP09	0.49	0.51
Dry Frio River	CP08	CP09	0.22	0.78
Frio River	CP09	CP25	0.49	0.51
Sabinal River	CP12	CP13	0.26	0.84
Sabinal River	CP13	CP25	0.49	0.51
Seco Creek	CP16	CP17	0.49	0.51
Seco Creek	CP17	CP25	0.49	0.51
Hondo Creek	CP18	CP19	0.23	0.77
Hondo Creek	CP19	CP25	0.49	0.51
Verde Creek	CP21	CP22	0.23	0.77
Verde Creek	CP22	CP25	0.49	0.51
Leona River	CP10	CP24	0.49	0.51
Leona River	CP24	CP25	0.49	0.51
Frio River	CP25	CP27	0.34	0.66
San Miguel Creek	CP26	CP27	0.47	0.53
Frio River	CP27	CP29	0.05	0.95
Atascosa River	CP28	CP29	0.10	0.90
Nueces River	CP29	CP30	0.26	0.74
Nueces River	CP30	CP31	0.07	0.93

The following example illustrates application of the delivery factors (DF = 1.0 – C_L). The reach of the Nueces River from control point CP03 through control points CP04 and CP05 to control point CP06 has a delivery factor (DF) of 0.2549 computed as (0.53)(0.74)(0.65)=0.2549. For each 100 acre-feet of water entering the Nueces River at CP3, an estimated 25.49 acre-feet reaches CP06 under natural conditions and the other 74.51 acre-feet is loss. Likewise, for each 100 acre-feet of water diverted from the Nueces River at CP3, an estimated 25.49 acre-feet reduction in flow occurs at CP06. The other 74.51 acre-feet would not have reached CP06 even without the 100 acre-feet diversion at CP03. Control point CP03 and this entire example reach are located well below the Edwards recharge zone. Thus, this reach does not cross the Edwards recharge zone.

Channel losses affect aspects of WRAP/WAM modeling in which stream flow changes at upstream locations are relevant further downstream. Channel loss factors affect both conversion of observed flows to monthly naturalized flows for incorporation in the WAM simulation input datasets and the results of *SIM* and *SIMD* simulation computations. Delivery factors are applied to changes in flow volumes resulting from diversions, return flows, refilling reservoirs, releases from storage, and other flow changes as the flow changes propagate downstream.

Loss factors for the Nueces River and tributaries are very high compared to other river systems. However, effects of the large loss factors on *SIM* and *SIMD* simulation computations are reduced by the occurrence of most of the simulated diversions and reservoir storage changes in the lower basin downstream of the stream reaches with the highest channel losses. Observed and corresponding adjusted naturalized flows reflect channel losses occurring upstream. Regulated and unappropriated flow computations in the simulation are affected by channel loss factors for upstream reaches.

Hydrologic Characteristics of Nueces River Basin

Hydrologic characteristics of the Nueces River Basin are further explored in Tables 12.5 and 12.6 and Figures 12.4, 12.5, and 12.6. Naturalized monthly flows of the Nueces River at Three Rivers are plotted in Figure 12.4. Means of 1934-2021 observed daily flows at 21 USGS gages are tabulated in Table 12.5 in cfs and as an annual volume equivalent to covering the watershed above the gage to a depth in inches. The days of missing data during are shown in the fourth column of Table 12.5. The mean annual precipitation varies a little across the Nueces River Basin with a basin-wide average of about 25 inches. The mean annual stream flow quantities in the last column of Table 12.5 are much smaller than the mean 25 inches/year mean annual rainfall. Most of the rainfall never reaches the stream flow gage sites.

A comparison of observed flow at control points CP01 and CP03 on the Nueces River near Laguna and Uvalde illustrates the effects of the Edwards outcrop on stream flow. The river reach between control points CP01 and CP03 crosses the recharge zone of the Edwards Aquifer. Watershed drainage areas are 737 and 1,961 at the upstream and downstream gage sites. The median daily flows exceeded 50% of the time at CP01 and CP03 are 78.0 cfs and 25.0 cfs, respectively. The upstream and downstream mean flows are 164.9 and 146.4 cfs, respectively. Mean and lesser flows are smaller at the downstream gage site that at the upstream gage site. The maximum observed flows are 107,000 cfs and 171,000 cfs at the upstream (CP01) and downstream (CP3) gage sites. Flood flows greatly exceed the recharge capacity of the Edwards Aquifer recharge zone and thus are not affected as much as low flows by groundwater recharge.

Table 12.5
Observed Stream Flows at USGS Gage Sites in Annual Volume Equivalents in Inches

Control Point	Location (Stream, Town)	Area (sq miles)	Missing Days	Mean Flow (cfs)	Mean Flow (inches/yr)
CP01	Nueces River, Laguna	737	0	164.9	3.04
CP02	W. Nueces R., Brackettville	694	4,106	32.84	0.64
CP03	Nueces River, Uvalde	1,861	0	146.4	1.07
CP04	Nueces River, Asherton	4,082	2,465	178.3	0.59
CP05	Nueces River, Cotulla	5,171	0	236.5	0.62
CP06	Nueces River, Tilden	8,093	3,299	363.3	0.61
CP07	Frio River, Concan	389	0	119.6	4.18
CP08	Dry Frio Riv. Reagan Wells	126	6,818	34.83	3.75
CP09	Frio River, Uvalde	631	7,215	36.70	0.79
CP12	Sabinal River, Sabinal	206	3,195	46.50	3.07
CP13	Sabinal River, Sabinal	241	19,265	35.06	1.98
CP16	Seco Creek, Utopia	45.0	28,795	15.40	4.65
CP17	Seco Creek, D'Hanis	168	9,801	7.928	0.64
CP18	Hondo Creek, Tarpley	95.6	6,806	40.23	5.72
CP19	Hondo Creek, Hondo	149	15,410	16.75	1.53
CP25	Frio River, Derby	3,429	1,462	132.1	0.52
CP26	San Miguel Creek, Tilden	783	20,180	36.29	0.63
CP27	Frio River, Calliham	5,491	14,893	254.4	0.63
CP28	Atascosa River, Whitsett	1,171	273	114.7	1.33
CP29	Nueces River, Three Rivers	15,427	0	707.3	0.62
CP30	Nueces River, Mathis	16,660	2,042	650.0	0.53

Table 12.6
Comparison of Precipitation and Observed Stream Flow at Sites Throughout Texas

USGS Gage Location	Drainage Area (sq miles)	Mean Precip (inches/yr)	Mean Flow (inches/yr)	Mean Flow (% Precip)
Nueces River at Three Rivers	15,427	24.8	0.662	2.67%
Nueces River at Mathis	16,503	24.8	0.574	2.31%
Canadian River near Amarillo	19,445	19.5	0.218	1.12%
Canadian River near Canadian	22,866	19.5	0.189	0.97%
Guadalupe River at Victoria	5,198	32.7	5.079	15.53%
Colorado River near Bay City	30,837	23.5	1.085	4.62%
Brazos River at Richmond	35,541	28.9	2.807	9.71%
Trinity River at Romayor	17,186	39.4	6.126	15.55%
Neches River at Evadale	7,951	48.7	10.46	21.48%
Sabine River near Ruliff	9,329	47.8	11.81	24.71%

The quantities in Table 12.6 comparing the Nueces River Basin with other locations throughout Texas are from a 2014 Texas Water Resources Institute technical report sponsored by TCEQ [51]. Means of observed stream flow at USGS gages with long gage records located near basin outlets are compared with long-term means of precipitation averaged over the river basins. For example, Table 12.6 indicates that the mean observed flow of the Nueces River at Mathis is an estimated 2.31% of the precipitation falling on the basin above this stream gage site. This long-term mean observed flow as a percentage of watershed precipitation can be compared with quantities for other locations in Texas ranging from 0.97% on the Canadian River near the City of Canadian to 24.7% on the Sabine River near the City of Ruliff. Stream flow at a gage site expressed as a percentage of the precipitation falling on its watershed is very small in the Nueces River Basin.

Observed period-of-record mean daily, monthly, and annual flow rates in cfs at the USGS gages on the Frio River at Derby (control point CP25), Nueces River at Three Rivers (CP29), and Nueces River at Mathis (CP30) are plotted in Figures B14, B15, and B16 of Appendix B. The more detailed exploration of Nueces River Basin hydrology in the June 2023 report [12] includes plots of daily observed flows at all the control points listed in Table 12.5. Naturalized monthly flow volumes in acre-feet of the Nueces River at Three Rivers (CP29) are plotted in Figure 12.4. This site is just downstream of Choke Canyon Dam and the confluences of the Frio, Atascosa, and Frio Rivers near the City of Three Rivers. The period-of-record of observed flows at the CP29 gage site extends from July 1, 1915 to the present with no missing daily data. As indicated in Table 12.5, the watershed area above CP29 is 15,427 square miles, which can be compared to the watershed area of 16,660 square miles above the USGS gage on the Nueces River at Mathis (CP30) just downstream of Wesley E. Seale Dam impounding Lake Corpus Christi.

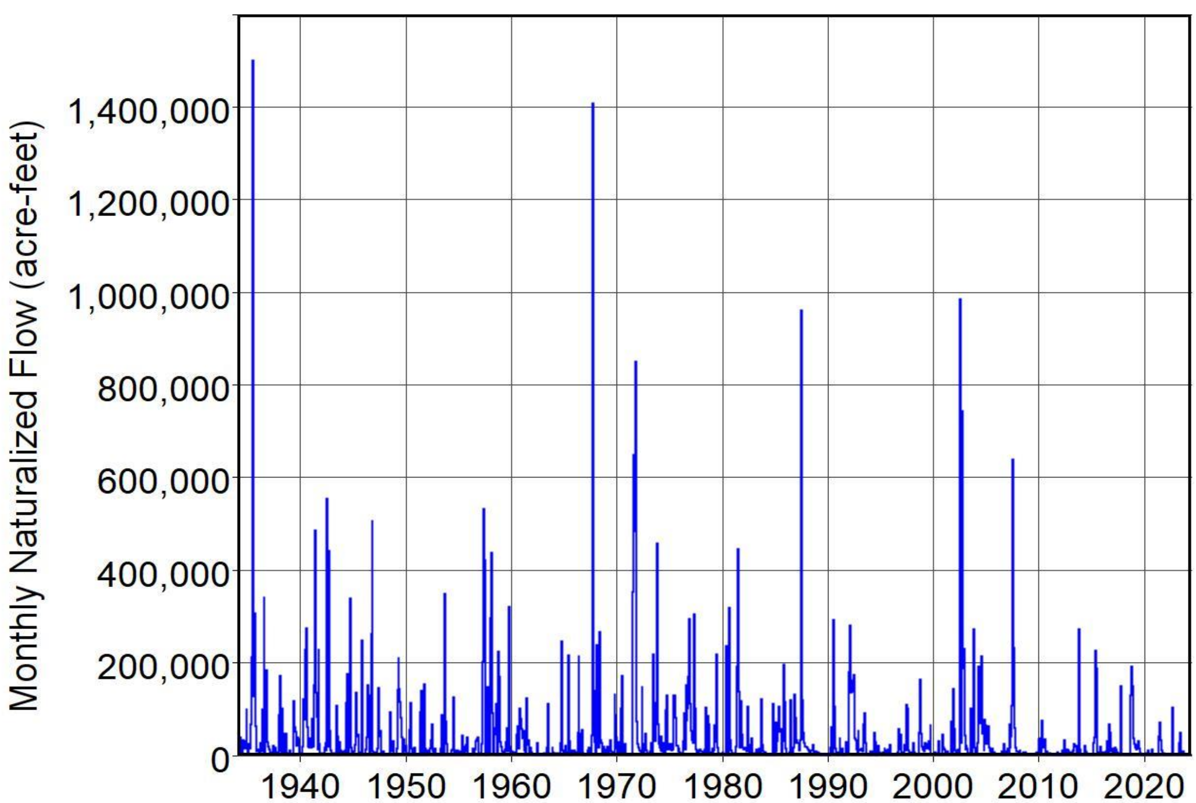

Figure 12.4 Naturalized Monthly Flows of the Nueces River at Three Rivers (CP29)

TWDB 1997-2023 Hydrologic Period-of-Analysis Extension

TWDB applies the latest extended monthly naturalized flows (*IN* records) and evaporation-precipitation rates (*EV* records) updated by TCEQ and its contractors for the WAMs that have recently updated hydrology. TWDB staff have developed approximate intermediate extensions for use in SB1 planning studies for the *IN* and *EV* records for nine WAMs including the Nueces WAM that have not been recently updated by the TCEQ. The extended *IN* record naturalized flow datasets were generated by TWDB staff using linear regression between historical gaged flow and available existing naturalized flow and between naturalized flows at different locations [78]. The TWDB hydrology extensions are discussed in Chapter 5 and applied in the Trinity, Lavaca, and Nueces WAM studies of Chapters 8, 11, and 12. The 1934-1996 Nueces WAM hydrologic period-of-analysis was extended through 2023 for the work presented in this chapter by appending 1997-2023 sequences of *IN* and *EV* records available online from the TWDB website.

Monthly Naturalized Flow Volumes

WAM primary control points are defined as locations for which monthly naturalized stream flows are provided as *IN* records in a *SIM* or *SIMD* simulation input dataset. Monthly naturalized flows at secondary control points are synthesized within an execution of *SIM* or *SIMD* based on the *IN* record flows at primary control points and watershed parameters provided on control point *CP*, flow distribution *FD*, and watershed parameter *WP* records.

The Nueces WAM has a total of forty-one primary control points. However, data on the *CP* and *IN* records for control points CP11, CP14, CP20, and CP23 are not actually used in the *SIM/SIMD* simulation. These four control points are retained in the input files but not included in the tables and discussions of this report. Only a few of the 756 months of the original 1934-1996 period-of-analysis have non-zero flows on the *IN* records of these four control points. The 1934-1996 naturalized flow data for these control points appear to be incomplete and incorrect. The unused control points CP11, CP14, CP20, and CP23 are located at sites without USGS gages.

Upper basin primary control point CP22 on Verde Creek in Bexar County also represents an ungaged location. No water rights, reservoirs, or other water management features are assigned to CP22. Control point CP22 has a channel loss factor on its *CP* record and naturalized flows on *IN* records. *IN* records for CP22 for 1934-1996 are included in the original *INF* file and 1997-2021 TWDB extended *IN* records. However, *IN* records are missing for years 2022 and 2023 of the 1997-2023 TWDB extended *IN* records. *IN* records with all zeros were added in the present study for 2022-2023 for control point CP22. This issue can be explored further in future updates.

Monthly Net Reservoir Evaporation-Precipitation Rates

The WAM dataset reflects a compilation of 1934-1996 data from multiple TWDB and other sources employed to develop *EV* records for Choke Canyon Reservoir and Lake Corpus Christi. The original January 1934 through December 1996 hydrologic period-of-analysis for the original Nueces WAM was extended through December 2023 for the 2025 WAM by appending 1997-2023 sequences of *IN* and *EV* records available online from the TWDB as discussed earlier. *EV* record evaporation-precipitation depths in feet for Choke Canyon Reservoir and Lake Corpus Christi (labeled as control points CP27 and CP30) are plotted as Figures 12.5 and 12.6.

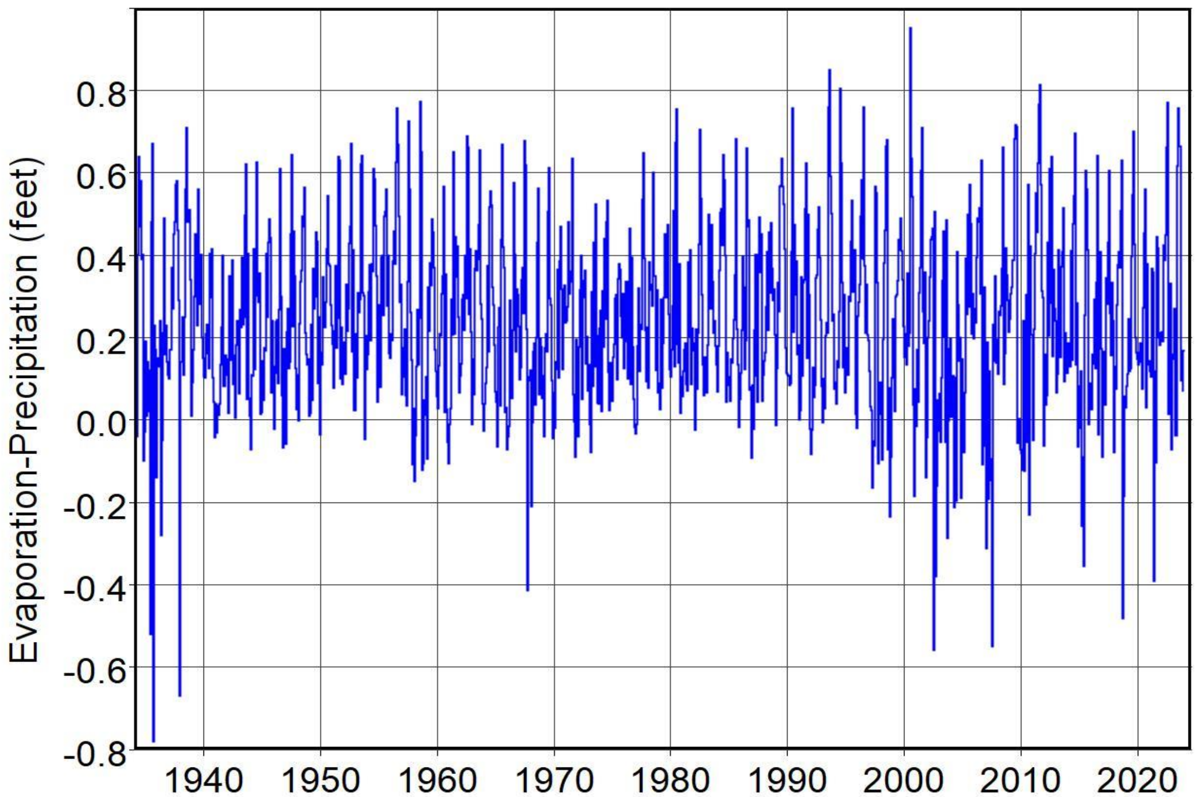

Figure 12.5 Net Evaporation-Precipitation Depths for Choke Canyon Reservoir (CP27)

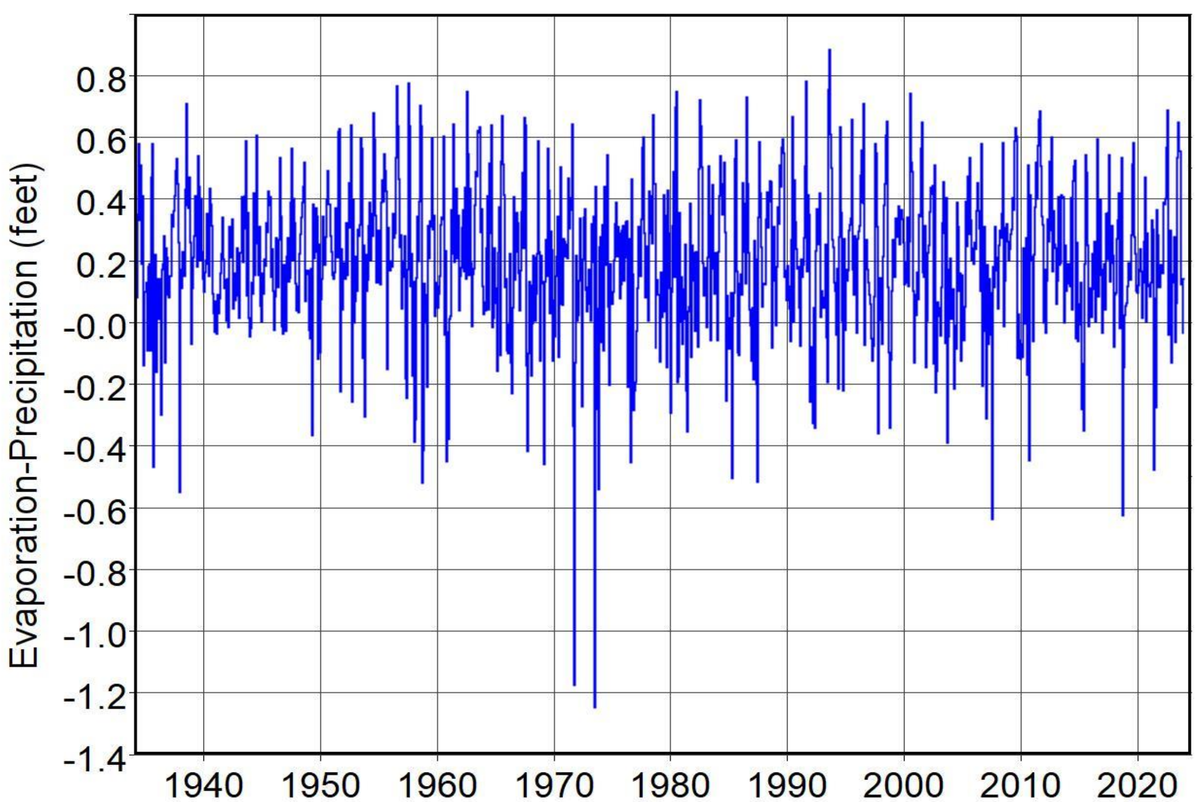

Figure 12.6 Net Evaporation-Precipitation Depths for Lake Corpus Christi (CP30)

The Nueces WAM hydrology dataset includes ten hydrologic period-of-analysis sequences of net reservoir surface evaporation less precipitation rates on *EV* records. The small reservoirs are assigned evaporation-precipitation from the TWDB quadrangle evaporation and precipitation database discussed in Chapter 5 which has been modified over the initial 1934-1996 period-of-analysis. Net evaporation-precipitation data from the TWDB database for quadrangles 910, 807, 808, 908, 907, 909, and 809 are used with the many small reservoirs.

SIM and *SIMD* include an evaporation-precipitation adjustment option activated by *JD* record parameter EPADJ or *CP* record EWA(cp) designed to prevent double-counting the precipitation runoff from the land area covered by a reservoir that is reflected in the naturalized stream flows. This option is activated for all the reservoirs in the Nueces WAM except Lake Corpus Christi. The naturalized flows representing inflows to Lake Corpus Christi were computed differently in the original WAM than the naturalized flows at the other control points.

Refinements added to the precipitation adjustment options in *SIM* and *SIMD* during 2024 are described in Chapter 5. EPADJ and EWA(cp) options are listed in Table 5.2. One 2024 *SIM/SIMD* refinement is an warning message for control points with specification of both (1) a precipitation adjustment option and (2) the option of having no evaporation-precipitation depth simulation input or associated computations. This warning message is generated for numerous control points in the 2023 Nueces WAM. The EWA option is deactivated in the 2025 WAM for the control points that have no evaporation-precipitation. This has no effect on simulation results but prevents the inclusion of the numerous repetitions of the warning message in the MSS file.

Yield/Reliability and Firm Yield Analyses

Simulated storage contents of Choke Canyon Reservoir (CCR) and Lake Corpus Christi (LCC) computed in a monthly full authorization simulation with the extended 1934-2023 hydrologic period-of-analysis are plotted in Figure 12.2. The severe drawdowns demonstrate that the authorized diversion amounts in water rights held by the City of Corpus Christi and Nueces River Authority far exceed firm yield. The analysis presented in this section provides further insight regarding the reliability of water supplies from Choke Canyon Reservoir and Lake Corpus Christi. The monthly Nueces WAM DAT file last updated by TCEQ on 10/1/2023 combined with the hydrology update described in the preceding section of this chapter were employed with the simulations reflected in Figures 12.2 and 12.7 and the firm yield analyses of Tables 12.7 and 12.8.

The program *SIM* firm yield feature controlled by the *FY* record is described on pages 133-139 of Chapter 6 of this report as well as the *Reference* and *Users Manuals* [1, 2]. The *FY* record used to produce Tables 12.7 and 12.8 is replicated as follows.

```
FY      1 450000. 100000.  10000.   1000.                     CCR/LCC
```

As indicated by Table 12.3, water rights 2464 and 3214 have authorized diversion amounts of 304,898 and 139,000 acre-feet/year, totaling 443,899 acre-feet/year. The diversions are supplied by releases from Choke Canyon Reservoir and Lake Corpus Christi, with most of the water supply pumped from the Calallen diversion dam and reservoir located near the Nueces River outlet. These diversions authorized by water rights 2464 and 3214 are modeled in the WAM with 13 *WR* records labeled with group identifier CCR/LCC and sets of supporting *UC*, *WS*, and *OR* records. Priorities on the thirteen *WR* records vary between 19131226, 19250115, 19310521, and 19760719.

Table 12.7
SIM Yield-Reliability YRO File Table for the CCR/LCC System

Yield Versus Reliability Table for the Following Water Supply Diversion Right(s):

0.000	percent: C2464_1	C2464	CCR/LCC
0.000	percent: C2464_2	C2464	CCR/LCC
33.792	percent: C2464_3	3C2464	CCR/LCC
0.152	percent: C2464_4	4C2464	CCR/LCC
0.913	percent: C2464_5	5C2464	CCR/LCC
0.032	percent: C2464_6	6C2464	CCR/LCC
33.792	percent: C2464_7	7C2464	CCR/LCC
0.003	percent: C2464_8	8C2464	CCR/LCC
0.003	percent: C2464_9	9C2464	CCR/LCC
0.113	percent: C3214_3	C3214	CCR/LCC
0.045	percent: C3214_4	C3214	CCR/LCC
13.465	percent: C3214_1	1C3214	CCR/LCC
17.691	percent: C3214_2	2C3214	CCR/LCC

If more than one right, the target amount is distributed using the percentages shown above. The total number of periods is 1080. The period reliability is the percentage of the periods for which at least 100.0 percent (FY record field 2; default=100%) of the target is supplied.

The table ends with the maximum target that results in a mean annual shortage of less than 0.05 units if such a firm yield is possible.

Iteration	Level	Annual Target	Mean Shortage	Actual	Volume Reliability (%)	Periods Without Shortage	Period Reliability (%)
1	0	450000.0	144532.3	305467.7	67.88	632	58.52
2	1	350000.0	80205.5	269794.5	77.08	746	69.07
3	1	250000.0	33254.9	216745.1	86.70	868	80.37
4	1	150000.0	5664.2	144335.8	96.22	994	92.04
5	1	50000.0	0.00	50000.0	100.00	1080	100.00

6	2	140000.0	3959.3	136040.7	97.17	1005	93.06
7	2	130000.0	2913.5	127086.5	97.76	1014	93.89
8	2	120000.0	1901.7	118098.4	98.42	1025	94.91
9	2	110000.0	1017.7	108982.3	99.07	1044	96.67
10	2	100000.0	510.9	99489.1	99.49	1055	97.69
11	2	90000.0	72.9	89927.1	99.92	1060	98.15
12	2	80000.0	1.13	79998.9	100.00	1070	99.07
13	2	70000.0	0.36	69999.6	100.00	1076	99.63
14	2	60000.0	0.00	60000.0	100.00	1080	100.00

15	3	69000.0	0.36	68999.6	100.00	1076	99.63
16	3	68000.0	0.28	67999.7	100.00	1077	99.72
17	3	67000.0	0.27	66999.7	100.00	1077	99.72
18	3	66000.0	0.19	65999.8	100.00	1078	99.81
19	3	65000.0	0.10	64999.9	100.00	1079	99.91
20	3	64000.0	0.00	64000.0	100.00	1080	100.00

21	4	64900.0	0.10	64899.9	100.00	1079	99.91
22	4	64800.0	0.10	64799.9	100.00	1079	99.91
23	4	64700.0	0.10	64699.9	100.00	1079	99.91
24	4	64600.0	0.10	64599.9	100.00	1079	99.91
25	4	64500.0	0.10	64499.9	100.00	1079	99.91
26	4	64400.0	0.10	64399.9	100.00	1079	99.91
27	4	64300.0	0.10	64299.9	100.00	1079	99.91
28	4	64200.0	0.10	64199.9	100.00	1079	99.91
29	4	64100.0	0.10	64099.9	100.00	1079	99.91
30	4	64000.0	0.00	64000.0	100.00	1080	100.00

The CCR/LCC diversion targets totaling 443,899 acre-feet/year (Table 12.3) represent 83.2% of the total of 533,416 acre-feet/year for all authorized diversions included in the full authorization Nueces WAM. Water right summation 1SUM tables created with *TABLES* based on reading all 481 *WR* records in the DAT file include annual diversions totaling 1,164,613 acre-feet/year. However, this total includes dummy (artificial) water rights employed in modeling complicated operating strategies. The new *SIM/SIMD* options for labeling artificial water rights, reservoirs, and control points discussed in Chapters 2 and 10 could be adopted for the Nueces WAM in the future to simplify interpretation of *SIM* input datasets and simulation results.

The reliability analysis results recorded in the YRO file from 30 automated *SIM* iterative simulations controlled by the *FY* record are replicated in Table 12.7. The combined diversion target is for a group of 13 *WR* records with group identifier CCR/LCC. With the default MFY option 1 selected on the *FY* record, the total diversion in each repetitive simulation is allocated between the 13 *WR* record rights in proportion to the AMT entered on each *WR* record. These total to 443,899 acre-feet/year, the total authorized diversion amount for water rights 2464 and 3214 (Table 12.3). The 13 water rights are listed at the beginning of the YRO file (Table 12.7) with their fraction of the total Choke Canyon Reservoir (CCR) and Lake Corpus Christi (LCC) system annual diversion.

The combination of diversion targets totaling 450,000 acre-feet/year for the 13 *WR* record rights with group identifier CCR/LCC have volume and period reliabilities of 67.88% and 58.52% (Table 12.7). Lowering the diversion target to 350,000 acre-feet/year increases the volume and period reliabilities to 77.08% and 69.07%. The actual authorized total diversion target of 443,899 acre-feet/year is between the 350,000 and 450,000 acre-feet/year targets included in Table 12.7.

The last line of the YRO file table (Table 12.7) from the last of the 30 iterative simulations indicates that the two-reservoir system firm yield is 64,000 acre-feet/year. Firm yield is defined as the maximum annual diversion amount supplied with a reliability of 100.0% based on all the premises reflected in the model. The simulated storage contents of each of the two reservoirs with the diversion target set at the firm yield of 64,000 acre-feet/year are plotted in Figure 12.7. The 64,000 acre-feet/year diversion is allocated between the water rights listed in the YRO file of Table 12.7 in proportion to the fractions shown in the table. *FY* record field 14 parameter SIM3 allows simulation results to be recorded in the OUT output file. *TABLES* converts simulation results from the OUT file to a DSS file.

October 2002 is the last time during the January 1934 through December 2023 hydrologic period-of-analysis that Choke Canyon Reservoir is full to its capacity of 700,000 acre-feet. Choke Canyon Reservoir just empties (372 acre-feet) in April 2015 and does not completely refill again before the December 2023 end of the simulation. With a minimum storage of 48,587 acre-feet in April 2013, Lake Corpus Christi never completely empties during the 1934-2023 simulation.

Although most of the total diversion volume is pumped from the Nueces River at the Calallen diversion dam supplied by releases from either of the two upstream reservoirs, some upstream diversions can be supplied only from Choke Canyon Reservoir. The operation rules *OR* record default of equally balancing storage contents as a percentage of capacity between the two reservoirs is employed in the simulation. The two-reservoir system firm yield could perhaps be increased slightly by revising *OR* record parameters to shift toward more releases from Lake Corpus Christi with a corresponding decrease in releases from Choke Canyon Reservoir.

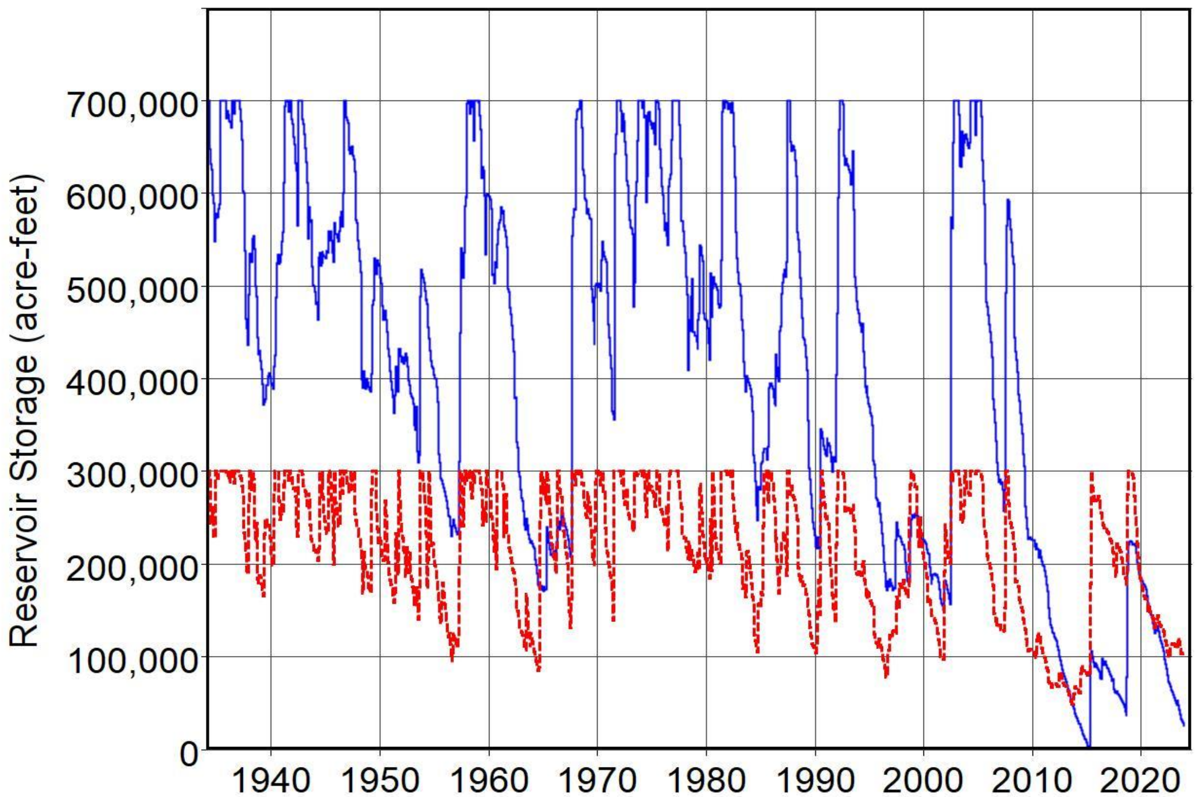

Figure 12.7 Choke Canyon Reservoir (blue solid line) and Lake Corpus Christi (red dashed line) Storage Contents for a CCR/CCL Firm Yield of 64,000 acre-feet/year

Effects of Bay and Estuary Inflow Requirements

The original 1999 Nueces WAM and updated versions include maintenance of prescribed minimum inflows to Nueces Bay in conjunction with operation of the CCR/LCC system. The bay and estuary inflow requirements are modeled with sets of *WR*, *WS*, *OR*, *TO*, *CP*, *UC*, and *IF* records. These freshwater inflow requirements have a priority number of 99999999 making them junior to the other rights. However, operations of the CCR/LCC system contribute to maintenance of the inflow requirements. Thus, reservoir storage levels are affected. The bay and estuary inflow requirements vary between 97,000 and 138,000 acre-feet/year depending on storage levels in the two reservoirs. Effects of maintaining minimum freshwater inflows to the bay system on water supply reliabilities and firm yield are demonstrated in Table 12.8. The bay and estuary inflow requirements are removed in the *SIM* simulation that generated the YRO file table of Table 12.8.

Results of repeating the firm yield analysis with the bay and estuary inflow requirements removed are presented as Table 12.8. The *SIM* simulation generating the YRO file of Table 12.8 is identical to the simulation producing the YRO file of Table 12.7 except for removal from the DAT file of the input records simulating the bay and estuary inflow requirements. The two-reservoir system firm yield of 104,500 acre-feet/year of Table 12.8 can be compared with the two-reservoir system firm yield of 64,000 acre-feet/year of Table 12.7. The bay and estuary inflow requirements result in a reduction in the water supply firm yield. The two-reservoir CCR/CCL system firm yields of 64,000 and 104,500 acre-feet/year are both much smaller than the corresponding authorized water supply diversion of 443,899 acre-feet/year.

Table 12.8
SIM Yield-Reliability YRO File Table for the CCR/LCC System
with the Bay and Estuary Inflow Requirements Removed from the DAT File

```
Yield Versus Reliability Table for the Following Water Supply Diversion Right(s):

          0.000 percent: C2464_1          C2464     CCR/LCC
          0.000 percent: C2464_2          C2464     CCR/LCC
         33.792 percent: C2464_3          3C2464    CCR/LCC
          0.152 percent: C2464_4          4C2464    CCR/LCC
          0.913 percent: C2464_5          5C2464    CCR/LCC
          0.032 percent: C2464_6          6C2464    CCR/LCC
         33.792 percent: C2464_7          7C2464    CCR/LCC
          0.003 percent: C2464_8          8C2464    CCR/LCC
          0.003 percent: C2464_9          9C2464    CCR/LCC
          0.113 percent: C3214_3          C3214     CCR/LCC
          0.045 percent: C3214_4          C3214     CCR/LCC
         13.465 percent: C3214_1          1C3214    CCR/LCC
         17.691 percent: C3214_2          2C3214    CCR/LCC

 If more than one right, the target amount is distributed using the percentages
 shown above. The total number of periods is 1080. The period reliability is the
 percentage of the periods for which at least 100.0 percent (FY record field 2;
 default=100%) of the target is supplied.

 The table ends with the maximum target that results in a mean annual shortage
 of less than 0.05 units if such a firm yield is possible.
```

Iteration	Level	Annual Target	Mean Shortage	Actual	Volume Reliability (%)	Periods Without Shortage	Period Reliability (%)
1	0	450000.0	134891.1	315108.9	70.02	662	61.30
2	1	350000.0	71230.3	278769.7	79.65	783	72.50
3	1	250000.0	27509.1	222490.9	89.00	903	83.61
4	1	150000.0	3981.4	146018.6	97.35	1018	94.26
5	1	50000.0	0.00	50000.0	100.00	1080	100.00

6	2	140000.0	2709.9	137290.0	98.06	1028	95.19
7	2	130000.0	1627.3	128372.7	98.75	1039	96.20
8	2	120000.0	671.0	119329.0	99.44	1053	97.50
9	2	110000.0	126.1	109873.9	99.89	1071	99.17
10	2	100000.0	0.00	100000.0	100.00	1080	100.00

11	3	109000.0	88.4	108911.6	99.92	1074	99.44
12	3	108000.0	43.9	107956.1	99.96	1074	99.44
13	3	107000.0	0.56	106999.4	100.00	1076	99.63
14	3	106000.0	0.31	105999.7	100.00	1078	99.81
15	3	105000.0	0.30	104999.7	100.00	1078	99.81
16	3	104000.0	0.00	104000.0	100.00	1080	100.00

17	4	104900.0	0.17	104899.8	100.00	1079	99.91
18	4	104800.0	0.17	104799.8	100.00	1079	99.91
19	4	104700.0	0.17	104699.8	100.00	1079	99.91
20	4	104600.0	0.17	104599.8	100.00	1079	99.91
21	4	104500.0	0.00	104500.0	100.00	1080	100.00

Effects of 1934-1996 Versus 1934-2023 Hydrologic Period-of-Analysis

The versions of the Nueces WAM from the 1999 original WAM through the version last updated by TCEQ 10/1/2023 have a period-of-analysis of 1934-1996. An intermediate hydrology extension for 1997-2023 developed by TWDB was combined with the 1934-1996 hydrology of the preceding 2023 WAM for the 2025 WAM presented in this report. The effects on reliability and firm yield estimates of lengthening the hydrologic period-of-analysis is examined as follows.

The WAM that generated the YRO file of Table 12.7 and reservoir storage plots of Figure 12.7 was employed for the additional simulation discussed here with only one input parameter changed. NYRS in *JD* record field 2 was changed from 90 years to 63 years, reducing the hydrologic period-of-analysis from 1934-2023 back to the original 1934-1996. The *FY* record remained unchanged in the execution of *SIM* with a shorter simulation period. The bay and estuary inflow requirements discussed in the preceding section remain in the DAT file.

The resulting YRO file yield/reliability table (not included in this report) indicates that the two-reservoir CCR/LCC system have volume and period reliabilities of 78.51% and 70.90% for a diversion target of 450,000 acre-feet/year. These reliabilities of 78.51% and 70.90% with a 1934-1996 simulation can be compared with volume and period reliabilities of 67.88% and 58.52% (Table 12.7) for the corresponding previous 1934-2023 simulation. The CCC/CCR system firm yield with a 1934-1996 period-of-analysis is 155,400 acre-feet/year compared to 64,000 acre-feet/year (Table 12.7) with an extended 1934-2023 period-of-analysis. Figure 12.8 is a plot of 1934-1996 simulated reservoir storage contents in Choke Canyon Reservoir (CCR) and Lake Corpus Christi (LCC) for the CCR/LCC system firm yield of 155,400 acre-feet/year.

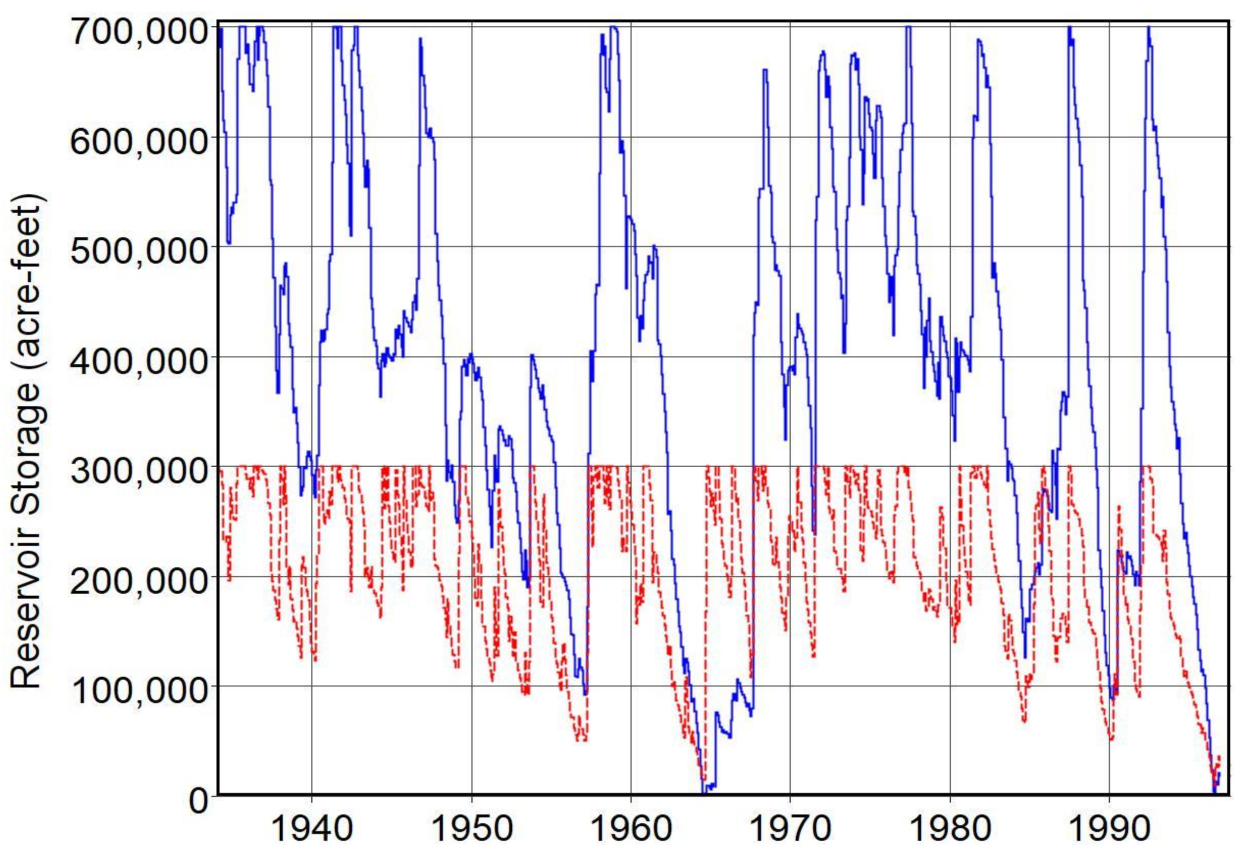

Figure 12.8 Choke Canyon Reservoir (blue solid line) and Lake Corpus Christi (red dashed line) Storage Contents for a CCR/CCL Firm Yield of 155,400 acre-feet/year

Environmental Flow Standards Established Pursuant to Senate Bill 3 Process

The SB3 EFS for the Nueces River Basin adopted February 12, 2014 are published as "*Subchapter F: Nueces River and Corpus Christi and Baffin Bays*" of Chapter 298 Environmental flow Standards of the Texas Administrative Code [98]. The Nueces River and tributaries and Corpus Christi and Baffin Bays and associated tributary streams and estuaries are covered. SB3 EFS are established at the sites of 19 USGS stream flow gages. The TCEQ established the EFS based on recommendations submitted by an expert science team and stakeholder committee in reports available at the TCEQ environmental flows website. The priority date for the EFS and the associated set-asides to be incorporated in the water availability modeling system is October 28, 2011, the date the expert science team submitted its recommendations.

SB3 EFS at 17 USGS Gages in the Nueces River Basin

SB3 EFS included in *Subchapter F* [98] are located at 17 USGS gage sites in the Nueces River Basin and two other USGS gage sites in the Nueces-Rio Grande Coastal Basin. The EFS at the 17 gage sites listed in Table 12.9 are incorporated in the daily and modified monthly Nueces WAMs. Watershed areas in Table 12.9 in square miles are from the USGS NWIS website and WAM DIS file. Sixteen of the 17 gage sites in the Nueces River Basin with SB3 EFS are WAM primary control points. The two SB3 EFS sites in the Nueces-Rio Grande Coastal Basin are:

USGS gage 08211520 on Oso Creek at Corpus Christi (drainage area = 90.3 square miles)
USGS gage 08211900 on San Fernando Creek at Alice (drainage area = 507 square miles)

Table 12.9
Seventeen SB3 EFS Sites in the Nueces River Basin

Control Point	USGS Gage	Location	Watershed Area USGS (sq miles)	Watershed Area WAM (sq miles)
CP01	08190000	Nueces River at Laguna	737	757.35
CP02	08190500	West Nueces River near Bracketville	694	687.1
CP03	08192000	Nueces River below Uvalde	1,861	1,863.16
CP05	08194000	Nueces River at Cotulla	5,171	5,193.11
CP06	08194500	Nueces River near Tilden	8,093	8,144.2
CP07	08195000	Frio River at Concan	389	393.18
CP08	08196000	Dry Frio River near Reagan Wells	126	124.32
CP12	08198000	Sabinal River near Sabinal	206	208.49
CP13	08198500	Sabinal River at Sabinal	241	246.82
CP16	08201500	Seco Creek at Miller Ranch near Utopia	45.0	45.19
CP18	08200000	Hondo Creek near Tarpley	95.6	97.42
CP25	08205500	Frio River near Derby	3,429	3,428.13
320603	08206600	Frio River at Tilden	4,493	4,469.81
CP26	08206700	San Miguel Creek near Tilden	783	784.26
CP28	08208000	Atascosa River at Whitsett	1,171	1,148.67
CP29	08210000	Nueces River near Three Rivers	15,427	15,460.6
CP30	08211000	Nueces River near Mathis	16,660	16,542.1

Table 12.10
Seasons Defined in the Environmental Flow Standards

Season	Control Points CP01, CP02, CP06, CP07, CP08	All Other Control Points
Winter	December through March	November through March
Spring	April, May, and June	April, May, and June
Summer	July, August, September	July and August
Fall	October and November	September and October

EFS established through the process created by the 2007 SB3 consist of subsistence flow, base flow, and high flow pulse components that may vary seasonally and with hydrologic conditions. Seasons are defined in Table 12.10 for the EFS in the Nueces Basin. Seasons for the EFS at the gage sites represented by the five control points CP01, CP02, CP06, CP07, CP08 are defined differently than for the EFS at the other gage sites. Unlike EFS established in other river basins, the EFS in the Nueces River Basin are not varied as a function of hydrologic condition.

Subsistence and base flow limits in cfs are tabulated in Table 12.11. The flow quantities specified in the EFS for the 17 USGS gage sites vary seasonally. The subsistence standards with flow limits tabulated in Table 12.11 are applicable during severe hydrologic conditions when flow at a gage site is less than the base flow limits in Table 12.11.

Table 12.11
Stream Flow Limits for EFS Subsistence and Base Flow Components

Control	Winter		Spring		Summer		Fall	
Point	Subsist	Base	Subsist	Base	Subsist	Base	Subsist	Base
	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
CP01	14	65	18	65	16	48	14	65
CP02	1	1	1	1	1	1	1	1
CP03	1	21	1	21	1	17	1	19
CP05	1	6	1	10	1	7	1	15
CP06	1	1	1	3	1	1	1	12
CP07	11	61	10	61	10	47	10	55
CP08	1	12	1	9	1	8	1	12
CP12	1	21	1	21	1	13	1	21
CP13	1	2	1	1	1	1	1	2
CP16	1	4	1	3	1	3	1	4
CP18	1	6	1	5	1	9	1	8
CP25	1	17	1	11	1	7	1	12
320603	1	12	1	7	1	2	1	3
CP26	1	2	1	2	1	1	1	2
CP28	1	9	1	5	1	4	1	4
CP29	1	37	1	37	1	30	1	37
CP30	37	96	37	120	37	140	37	110

The priority date for the SB3 EFS and associated set-asides to be incorporated in the water availability modeling system is October 28, 2011. For a junior water right holder to which an environmental flow standard applies, the water right holder may not store or divert water, unless the flow at the measurement point is above the applicable subsistence flow standard [98]. If the flow at the measurement point is above the subsistence flow standard but below the base flow standard, then the water right holder must allow the applicable subsistence flow plus 50% of the difference between measured streamflow and the applicable subsistence flow limit to flow pass the measurement point. Any remaining available flow may be diverted or stored in accordance with the water right permit, subject to senior water rights [98].

For a water right holder to which an environmental flow standard applies, at a measurement point that applies to the water right, when the flow at the measurement point is above the applicable base flow standard but below any applicable high flow pulse trigger levels, the water right holder may store or divert water according to its permit, subject to senior water rights [98].

Quantities defining the high flow pulse components of the SB3 EFS are tabulated in Table 12.12. High flow pulse standards are applicable only if actual flows are higher than the subsistence and base flow quantities in Table 12.11. When the high flow pulse trigger level is reached, that flow level is protected by curtailing junior water rights until either the specified volume or duration criteria in Table 12.12 is met. Junior rights can appropriate excess stream flow exceeding the trigger level but cannot reduce flow to below the trigger level. The high pulse criteria include specification of minimum numbers of events per season and events per year.

The first column of Table 12.12 lists the 17 WAM control points that represent the USGS gage sites of the SB3 EFS. All of the control points except control point 320603 are primary control points with monthly naturalized flows provided in the WAM simulation input dataset. The second column of Table 12.12 shows the number of high flow pulses per season or year that are protected by the EFS. The frequency of a defined pulse event is either one, two, or three in each of the four defined seasons (Table 12.10) of the year or one or two pulse events each year.

The quantities defining the individual high flow pulses are provided in the last four columns of Table 12.12. Seasonal events have sets of three parameters for each of the four seasons for which high flow pulses are protected. Some seasons at some sites have no high pulse standards. Annual events have a single set of three parameters applicable for the entire year. The three parameters are the (1) flow trigger in cfs that defines a high flow pulse event, (2) volume termination criterion in acre-feet, and (3) duration termination criterion in days. A high flow pulse event begins when the trigger flow level is exceeded and continues as long as the trigger flow level is exceeded or until either of the two termination criteria is met. The termination criteria limits are the cumulative volume of flow in acre-feet and the duration in days of the high flow pulse.

High flow pulses in each season are independent of other seasons. If a requirement for a pulse event is satisfied during a season, a high flow pulse requirement is considered to be satisfied for each smaller event in that season. High flow pulses are preserved but not created. Water right holders are not required to cease diverting water or release stored water to produce a high flow pulse event. Water that was previously stored as authorized by a water right may be diverted or released regardless of applicable environmental flow requirements.

Table 12.12
High Flow Pulse Components of the Environmental Flow Standards

Control Point	Frequency	Winter cfs/ac-ft/days	Spring cfs/ac-ft/days	Summer cfs/ac-ft/days	Fall cfs/ac-ft/days
CP01	2/season	None	99/1,560/9	none	None
	1/season	None	390/6,070/17	170/3,100/14	None
	2/year	trigger 590 cfs; volume 11,300 ac-ft; duration 26 days			
CP02	1/season	None	5/76/10	5/84/13	None
	2/year	trigger 25 cfs; volume 360 ac-ft; duration 16 days			
CP03	1/season	None	110/1,280/11	none	50/690/11
	2/year	trigger 510 cfs; volume 8,240 ac-ft; duration 26 days			
CP05	2/season	None	190/2,370/17	none	35/360/14
	1/season	96/1,570/20	none	100/1,030/16	none
CP06	3/season	None	89/930/14	none	29/250/10
	2/season	87/1,260/18	280/3,360/18	11/96/10	220/2,390/16
	1/season	300/4,610/22	880/12,200/22	320/4,390/21	840/10,900/23
CP07	2/season	None	120/1,320/8	none	None
	1/season	89/2,100/12	300/3,550/12	240/2,990/13	79/900/5
	2/year	trigger 540 cfs; volume 9,430 ac-ft; duration 24 days			
CP08	2/season	None	30/370/9	none	None
	1/season	32/650/13	120/1,470/16	81/1,100/15	35/620/13
	2/year	trigger 210 cfs; volume 3,500 ac-ft; duration 26 days			
CP12	2/season	None	64/750/10	none	None
	1/season	62/1,530,17	180/2,210/15	100/1,180/12	53/840/12
	2/year	trigger 330 cfs; volume 5,420 ac-ft; duration 24 days			
CP13	1/season	21/310/11	56/430/9	none	20/150/6
	2/year	trigger 230 cfs; volume: 2,680 ac-ft; duration 17 days			
	1/year	trigger 1,070; volume: 6,690 ac-ft; duration 29 days			
CP16	2/season	None	33/360/12	none	None
	1/season	21/290/12	91/1,140/17	38/360/11	23/270/11
	2/year	trigger 120 cfs; volume 1,710 ac-ft; duration 21 days			
CP18	2/season	16/200/8	91/950/12	24/220/7	None
	1/season	61/1,020/15	290/3,360/18	90/890/12	50/580/11
	2/year	trigger 330 cfs; volume 4,530 ac-ft; duration 22 days			
CP25	2/season	None	210/1,810/14	none	None
	1/season	87/1,450/20	900/7,940/17	58/510/13	350/4,340/24
	2/year	trigger 1,670; volume 18,800 ac-ft; duration 25 days			
320603	2/season	86/1,070/13	460/4,470/14	36/280/9	120/1,080/12
	1/season	390/5,320/20	none	270/2,440/14	960/10,400/20
CP26	2/season	45/470/16	220/1,560/14	16/110/10	44/310/12
	1/season	160/1,580/19	690/4,940/16	160/1,040/13	300/2,010/15
	2/year	trigger 990 cfs; volume 7,310 ac-ft; duration 18 days			
CP28	2/season	230/1,960/14	600/4,280/13	37/280/7	100/720/9

	1/season	730/5,720/18	1,770/12,500/16	250/1,960/12	620/4,320/14
	2/year	trigger 1,990 cfs; volume 14,800 ac-ft; duration 19 days			
CP29	2/season	720/8,460/13	1,600/22,200/16	280/2,520/9	710/7,920/13
	1/season	2,050/26,800/18	4,090/64,600/22	1,100/13,600/15	2,420/34,200/19
CP30	2/season	590/6,270/9	420/5,090/9	none	240/2,670/7
	1/season	1,120/14,200/12	2,540/49,400/19	370/4,970/10	1,550/24,700/15

Existing water rights with priorities senior to the SB3 EFS priority date of October 28, 2011 (20111028) are not regulated to protect the SB3 EFS. The SB3 EFS may constrain water availability for diversions and storage authorized by permits with priority dates junior to October 28, 2011. The SB3 EFS may constrain curtailment of stream flow appropriations for diversions and refilling depleted storage capacity, but do not require releases of water already in storage.

<u>Other *IF* Record Instream Flow Requirements</u>

The 2013 full authorization and current use versions of the WAM have 30 and 32 *IF* record instream flow rights, respectively, with priority dates ranging from 19140224 (February 15, 1914) to 20080718 (July 18, 2008). An *IF* record used for accounting computations in modeling the Choke Canyon Reservoir and Lake Corpus Christi System is assigned a priority of 99999999. These *IF* records were in the WAMs before the SB3 EFS were created. The existing *IF* record water rights are not otherwise altered in the conversion to a daily WAM other than uniformly distributing the monthly targets to the 28, 29, 30, or 31 days in each month. The only *IF* record right not associated with SB3 EFS that is located at the same control point as SB3 EFS is at CP07 on the Frio River at Concan with an uniformly distributed annual target of 33,295 acre-feet/year.

<u>Modeling SB3 Environmental Flow Standards</u>

Environmental flow standards (EFS) established pursuant to the 2007 Senate Bill 3 (SB3) are based on a flow regime that includes subsistence, base, and high pulse flows as explained in Chapter 4 of the *WRAP Reference Manual* [2] and Chapter 6 of the *Daily Manual* [5] and illustrated by the SB3 EFS for the six case study WAMs described in Chapters 7-12 of this report. Environmental standard *ES*, hydrologic condition *HC*, pulse flow *PF*, and pulse flow supplemental options *PO* records are designed specifically to model *IF* record instream flow rights in the format of SB3 EFS. Chapter 3 of the *Users Manual* [3] defines the input parameters entered on the types of input records that are applicable to both the monthly *SIM* and daily *SIMD*, which includes the *ES* and *HC* records. Chapter 4 of the *Users Manual* covers additional daily *SIMD* input records that are not applicable to the monthly *SIM*, including the *PF* and *PO* records.

The *SIMD* DAT file input records for control points CP01 and CP29 are reproduced as Table 12.13. The sets of *IF*, *ES*, and *PF* records for the SB3 EFS at the 15 other locations are in the same format with relevant numbers from Tables 12.11 and 12.12.

The pulse flow components of the 17 EFS are separated from the subsistence/base flow components allowing simulation results to be recorded separately for 34 *IF* record water rights associated with *ES* versus *PF* records. Subsidence flows, base flows, and high flow pulses can be combined reducing the 34 *IF* record water rights to 17 *IF* record water rights by removing the *IF* and *ES* records for each of the high flow pulse components. For example, the first two water rights in Table 12.13 labeled with water right identifiers IF-CP01-ES and IF-CP01-PF are instream flow requirements at control point CP01. These two water rights are combined in Table 12.14. With this format, all components of the SB3 EFS are modeled as a single *IF* record water right, with the only difference in simulation results being that combined rather than separate water right targets and target shortages are recorded in the *SIMD* output OUT and DSS files.

Table 12.13
Instream Flow Rights that Model the SB3 EFS in the Daily Nueces WAM DAT File

```
IF  CP01     -9.        20111028   2           IF-CP01-ES
ES SF50      14.     14.      14.     18.     18.     18.     16.     16.     16.     14.     14.     14.
ES BASE      65.     65.      65.     65.     65.     65.     48.     48.     48.     65.     65.     65.
IF  CP01     -9.        20111028   2           IF-CP01-PF
ES PFES
PF   1 0     99.   1560.   9   2       4   6          2
PF   1 0    390.   6070.  17   1       4   6          2
PF   1 0    170.   3100.  14   1       7   9          2
PF   1 0    590.  11300.  26   2       1  12          2
**
IF  CP29     -9.        20111028   2           IF-CP29-ES
ES SF50       1.      1.       1.      1.      1.      1.      1.      1.      1.      1.      1.      1.
ES BASE      37.     37.      37.     37.     37.     37.     30.     30.     37.     37.     37.     37.
IF  CP29     -9.        20111028   2           IF-CP29-PF
ES PFES
PF   1 0    720.   8460.  18   2      11   3          2
PF   1 0   1660.  22200.  16   2       4   6          2
PF   1 0    280.   2520.   9   2       7   8          2
PF   1 0    710.   7920.  13   2       9  10          2
PF   1 0   2050.  26800.  18   1      11   3          2
PF   1 0   4090.  64600.  22   1       4   6          2
PF   1 0   1100.  13600.  15   1       7   8          2
PF   1 0   2420.  34320.  19   1       9  10          2
**
```

Table 12.14
Instream Flow Right that Models the SB3 EFS at Control Point CP01
with *ES* and *PF* Record Components Combined as a Single *IF* Record Right

```
IF  CP01     -9.        20111028   2           IF-CP01
ES SF50      14.     14.      14.     18.     18.     18.     16.     16.     16.     14.     14.     14.
ES BASE      65.     65.      65.     65.     65.     65.     48.     48.     48.     65.     65.     65.
PF   1 0     99.   1560.   9   2       4   6          2
PF   1 0    390.   6070.  17   1       4   6          2
PF   1 0    170.   3100.  14   1       7   9          2
PF   1 0    590.  11300.  26   2       1  12          2
```

A table in the *Users Manual* [2] lists 43 time series variables that may be included in *SIM* and *SIMD* simulation results output files. Five of these variables are forms of instream flow targets or shortages in meeting instream flow targets. These five instream flow targets and shortage quantities are listed in the first column of Table 12.15. The second column refers to the *OF* record labels listed in the *Users Manual* used to select variables for inclusion in the *SIM/SIMD* output DSS file. The labels in DSS pathname part C of the output records are listed in the third column. The corresponding *TABLES* monthly and daily time series input records are listed in the last two columns of Table 12.15. The DSS pathname part C labels in the third column are adopted in the following discussion for referring to the quantities listed in Table 12.15.

Table 12.15
Instream Flow Targets and Shortages in *SIM/SIMD* Simulation Results

Instream Flow Target or Shortage	*SIM/SIMD* *OR* Record	DSS Record Part C	*TABLES* Monthly	*TABLES* Daily
final target at control point	15. IFT	IFT-CP	2IFT	6IFT
shortage for final control point target	16. IFS	IFS-CP	2IFS	6IFS
combined target for IF water right	27. IFT	IFT-WR	2IFT	6IFT
shortage for IF water right	28. IFS	IFS-WR	2IFS	6IFS
individual target for IF water right	29. TIF	TIF-WR	2TIF	6TIF

With only one *IF* record instream flow water right located at a control point, the IFT-CP, IFT-WR, and TIF-WR targets are the same. IFT-CP, IFT-WR, and TIF-WR instream flow targets are different only in the case of two or more *IF* record rights located at the same control point. An IFT-CP target refers to the final target at the control point at the completion of the priority sequenced simulation computations. TIF-WR refers to the instream flow target computed for an individual *IF* record right without consideration of any other *IF* record rights located at the same control point. IFT-WR refers to the instream flow target for an *IF* record right after combining with the target for the preceding *IF* record right in the water rights priority sequence.

Any number of instream flow *IF* record water rights can be located at the same control point regardless of the records used with the *IF* records for computing instream flow targets. Various options are provided for combining targets for two or more *IF* record rights at the same control point. The target for a junior right is combined with the target from the preceding senior right as specified by IFM(IF,2) in *IF* record field 7. The IFM(IF,2) target combining options are as follows: (1) junior target replaces senior target, (2) largest target is adopted, (3) smallest target is adopted, and (4) targets are added. These options are also applicable for combining consecutive *PF* record targets for a single *IF* record right as specified in *PF* record field 14.

Multiple instream flow target components for SB3 EFS are combined in the daily WAM simulation using the option of adopting the largest target each day. As noted in the preceding section, the only *IF* record right not associated with SB3 EFS that is located at the same control point as SB3 EFS is at CP07 on the Frio River at Concan. The larger of the targets for the *IF* record right modeling SB3 EFS and the other more senior *IF* record right is adopted each day or month.

Monthly WAM with Instream Flow Targets from the Daily WAM

A strategy introduced in the *Daily Manual* [5] for incorporating monthly instream flow targets computed in a daily *SIMD* simulation into the *SIM* input for a monthly WAM has been employed with the Brazos, Trinity, Neches, Colorado, Lavaca, and Nueces daily WAMs as discussed throughout this report. Daily instream flow targets in acre-feet/day computed in a daily simulation are summed by *SIMD* to monthly totals in acre-feet/month included in the *SIMD* simulation results. These time series of monthly targets are converted to target series *TS* records within *HEC-DSSVue* and incorporated in the input DSS file read in a monthly *SIM* simulation. The *TS* records of monthly instream flow targets in acre-feet/month stored in the DSS file have the pathname identifiers listed in Table 12.16. The target series *TS* records in the DSS file are referenced by *TS* records in the DAT file which are replicated in Table 12.17.

Table 12.16
Pathnames for Target Series *TS* Records for SB3 EFS in the Hydrology DSS File

Part A	Part B	Part C	Part D	Part E
Nueces	CP01	TS	01Jan1934-31Dec2023	1Month
Nueces	CP02	TS	01Jan1934-31Dec2022	1Month
Nueces	CP03	TS	01Jan1934-31Dec2023	1Month
Nueces	CP04	TS	01Jan1934-31Dec2023	1Month
Nueces	CP05	TS	01Jan1934-31Dec2023	1Month
Nueces	CP06	TS	01Jan1934-31Dec2023	1Month
Nueces	CP07	TS	01Jan1934-31Dec2023	1Month
Nueces	CP08	TS	01Jan1934-31Dec2023	1Month
Nueces	CP12	TS	01Jan1934-31Dec2023	1Month
Nueces	CP13	TS	01Jan1934-31Dec2023	1Month
Nueces	CP16	TS	01Jan1934-31Dec2023	1Month
Nueces	CP18	TS	01Jan1934-31Dec2023	1Month
Nueces	CP25	TS	01Jan1934-31Dec2023	1Month
Nueces	320603	TS	01Jan1934-31Dec2023	1Month
Nueces	CP28	TS	01Jan1934-31Dec2023	1Month
Nueces	CP29	TS	01Jan1934-31Dec2023	1Month
Nueces	CP30	TS	01Jan1934-31Dec2023	1Month

A daily *SIMD* simulation is performed with the set of *IF*, *ES*, and *PF* records inserted in the DAT file to control computation of IFT and TIF (Table 12.15) daily instream flow targets for the SB3 EFS at the 17 USGS gaging stations (WAM control points). The daily TIF instream flow targets in acre-feet/day are summed to monthly quantities in acre-feet/month, which are included in the simulation results DSS file. The DSS records of monthly targets are copied from the daily *SIMD* simulation results DSS output file to the *SIM/SIM* hydrology input DSS file. The pathnames are revised using *HEC-DSSVue*.

The DSS file pathnames for the target series *TS* records are listed in Table 12.16. The *TS* records in the monthly *SIM* DAT file replicated in Table 12.17 reference the DSS file target series employed by the *IF* record water rights. *IF* record IFM(if,2) option 2 activates the option to combine multiple *IF* record instream flow targets at the same control point by selecting the largest. With only one *IF* record at a control point, the IFM(if,2) option is not relevant.

SB3 EFS at control points CP25, 320603, CP29, and CP30 are included in the monthly Nueces WAM last updated by TCEQ on October 1, 2023 without use of *HC*, *ES*, and *PF* records. The SB3 EFS at these four locations are modeled in the October 2023 DAT file using about 715 *IF*, *WR*, *TO*, *FS*, *UC*, *CP*, *CI*, and ** records comprising about 25% of the total number of records in the DAT file. These 715 records in the DAT file and several *FD* and *WP* records in the DIS file modeling SB3 EFS at these four control points were removed along with adoption of the strategy outlined on the preceding pages for adding SB3 EFS at 17 control points.

Table 12.17
Instream Flow Rights that Model the SB3 EFS in the DAT File of the Monthly WAM

```
IF  CP01                 20111028   2            CP01ES
TS        DSS
IF  CP02                 20111028   2            CP02ES
TS        DSS
IF  CP03                 20111028   2            CP03ES
TS        DSS
IF  CP05                 20111028   2            CP05ES
TS        DSS
IF  CP06                 20111028   2            CP06ES
TS        DSS
IF  CP07                 20111028   2            CP07ES
TS        DSS
IF  CP08                 20111028   2            CP08ES
TS        DSS
IF  CP12                 20111028   2            CP12ES
TS        DSS
IF  CP13                 20111028   2            CP13ES
TS        DSS
IF  CP16                 20111028   2            CP16ES
TS        DSS
IF  CP18                 20111028   2            CP18ES
TS        DSS
IF  CP25                 20111028   2            CP25ES
TS        DSS
IF320603                 20111028   2            CP320603ES
TS        DSS
IF  CP26                 20111028   2            CP26ES
TS        DSS
IF  CP28                 20111028   2            CP28ES
TS        DSS
IF  CP29                 20111028   2            CP29ES
TS        DSS
IF  CP30                 20111028   2            CP30ES
TS        DSS
```

Conversion of Monthly Daily WAM to Daily

The monthly Nueces WAM last updated by TCEQ 10/01/2023 was converted to a daily time step as described in this section. SB3 EFS were added to the daily WAM as described in the preceding section. Unlike the daily Brazos, Trinity, Colorado, and Neches WAMs of Chapters 7, 8, 9, and 10, there are no flood control reservoir operations to add to the daily Nueces WAM.

Nonactivation of Routing and Forecasting

Based on experience with the case study daily WAMs and the characteristics of the Nueces River Basin, lag and attenuation routing and forecasting are not employed in the Nueces WAM. The purpose of routing is to adjust flow changes for the lag and attenuation effects of stream reaches with lag times that are significantly long relative to the computational interval of one day. Stream reaches between key locations in the Nueces Basin are not excessively long. Forecasting is relevant only if routing is activated. Routing was concluded to not contribute positively, though possibly adversely, to model accuracy for the Nueces River system and was not adopted.

Disaggregation of naturalized flows from monthly to daily is based on daily flow pattern hydrographs that for many control points in the Nueces WAM combine daily flows at two or three sites. The combination of daily observed flows at multiple sites is one of multiple factors, discussed in other chapters of this report, that contributes to invalidation of forecasting and routing computations. Complexities of negative incremental flow adjustment options is another reason for not activating forecasting and routing options that is particularly relevant for the Nueces WAM.

Naturalized Stream Flow Disaggregation

Disaggregation of monthly naturalized flows to daily is the main component of the conversion of a monthly WAM to daily. Stream flow is extremely variable. Capturing within-month daily variability in the monthly-to-daily disaggregation of naturalized stream flow is the key central motivation for converting a monthly WAM to daily. The standard default DFMETHOD option 4 method of converting monthly naturalized flows to daily in proportion to *DF* record daily flows while preserving monthly volumes was adopted for the daily Nueces WAM as well as for the five other daily WAMs described in the preceding Chapters 7 through 11.

All other monthly time series input data in the daily Nueces WAM are uniformly disaggregated from monthly to daily. *SIMD* includes no alternative other than a uniform distribution for monthly-to-daily disaggregation of *EV* record net evaporation-precipitation depths or *CI* record constant inflows. These monthly quantities are uniformly disaggregated to daily by *SIMD* in proportion to the number of days in each month.

SIM and *SIMD* read monthly naturalized stream flow volumes from inflow *IN* records for 37 primary control points. Both monthly *SIM* and daily *SIMD* simulations synthesize monthly naturalized flows at over 500 other secondary control points based on the monthly naturalized flows at the 37 primary control points and parameters read from *CP*, *FD*, and *WP* records. *SIMD* distributes the monthly naturalized flow volumes at each of the over 540 control points to the 28, 29 (February of leap years), 30, or 31 days in each of the 1,080 months of the 1934-2023 hydrologic period-of-analysis.

Control point CPEST represents the outlet of the Nueces River at Nueces Bay. CP30 is the most downstream control point with daily flows on *DF* records. DFMETHOD option 4 employing daily flows from *DF* records is applied to all control points upstream of the outlet at control point CPEST and at control point CPEST. *JU* record DFMETH option 1 (uniform) applies to all other control points including disconnected "dummy" accounting control points. The procedure described in the next paragraph is activated by the following DIF input file *DC* record which activates REPEAT and DFMETHOD options 2 and 4 and assigns CP30 daily flows to CPEST.

```
DC   CPEST   2   4    CP30
```

Monthly naturalized stream flows at control point CPEST and all other control points located upstream of CPEST are disaggregated to daily using 1934-2023 daily flows at 20 control points stored as *DF* records in the hydrology input DSS file. Monthly volumes are distributed to daily volumes in proportion to daily flows while maintaining the monthly volumes. The automated procedure in *SIMD* for repeating daily flows at multiple control points is described in Chapter 2 of the *Daily Manual* [5]. The automated procedure consists of using flows at the nearest downstream control point if available, otherwise finding flows at the nearest upstream control point, and lastly if necessary, using flows from another tributary.

DFMETH option 1 is selected on the *JU* record to apply the uniform monthly-to-daily naturalized flow disaggregation option for all of the other control points not located upstream of control point CPEST. Thus, the selected default uniform disaggregation option (DFMETH=1) is applied to dummy control points employed in computational water accounting schemes that are not actually physically connected in the model to the actual outlet.

Daily Flow Pattern Hydrographs

Daily flow *DF* records are employed in a *SIMD* simulation for the sole purpose of serving as pattern hydrographs used in disaggregating monthly naturalized flows to daily. Only the pattern of the quantities on the *DF* records within each of the 1,080 months, not the actual magnitude of the quantities for each day, affect *SIMD* simulation results. Therefore, *DF* record daily flows can be in any units and are not required to reflect a specific single site. However, the *DF* records for the Nueces WAM and the daily WAMs of Chapters 7-11 contain daily naturalized flows in acre-feet/day. *DF* records of daily naturalized flows can be easily tabulated or plotted in *HEC-DSSVue*.

DF records of 1934-2023 daily naturalized flow volumes in acre-feet at the 20 control points in Table 12.18 were developed from daily means in cfs of observed flow rates at USGS gages. The dataset of *DF* records is stored in the hydrology DSS input file with filename NuecesHYD.DSS. Periods-of-record for the USGS gages are tabulated in the fourth column of Table 12.18. The number of days of missing observed data during the WAM hydrologic period-of-analysis is shown in the next-to-last column. For gages with missing daily flows during 1934-2023, complete months of daily data for months with missing daily data are filled in with flows from the gage site listed in the last column of Table 12.18.

The following tasks were performed in 2022 [12] to develop *DF* records of 1934-2021 daily flows and repeated during January 2025 to develop *DF* record 1934-2023 daily flows.

1. Observed flows at relevant gages as daily means in cfs were compiled as a DSS file from the USGS NWIS website using the data import feature of *HEC-DSSVue*.
2. Fifteen of the twenty selected gages do not have periods-of-record covering the entire WAM 1934-2023 hydrologic period-of-analysis. Gage records at two or more sites were combined as necessary to develop complete 1934-2023 sequences of observed daily flows in cfs.
3. The 1934-2023 daily flows in cfs at the twenty control points were converted within *HEC-DSSVue* to a *SIMD* input dataset of *DF* records with flows in cfs. *SIMD* was executed with this dataset. The *SIMD* simulation results included naturalized daily flows in acre-feet/day.
4. The daily naturalized flows recorded by *SIMD* in its simulation results DSS file were converted within *HEC-DSSVue* to a dataset of *DF* records. This final dataset of *SIMD* input *DF* records consists of 1934-2023 daily naturalized flows in acre-feet/day at twenty control points.

Table 12.18
Primary Control Points at USGS Gage Sites
Used in Developing the *DF* Record Daily Flows

Control Point	Location (Stream, Town)	Drainage Area (sq miles)	Period-of-Record	Missing Days	Fill-In CP
CP01	Nueces River, Laguna	737	1Oct1923-present	0	complete
CP02	W. Nueces R., Brackettville	694	28Sep1939-present	4,106	CP01
CP03	Nueces River, Uvalde	1,861	1Oct1927-present	0	complete
CP04	Nueces River, Asherton	4,082	1Oct1939-present	2,465	CP05
CP05	Nueces River, Cotulla	5,171	1Oct1926-present	0	complete
CP06	Nueces River, Tilden	8,093	1Dec1942-present	3,299	CP04
CP07	Frio River, Concan	389	30Sep1924-present	0	complete
CP08	Dry Frio Riv. Reagan Wells	126	1Sep1952-present	6,818	CP07
CP09	Frio River, Uvalde	631	1Oct1953-present	7,215	CP07
CP12	Sabinal River, Sabinal	206	1Oct1942-present	3,195	CP05
CP13	Sabinal River, Sabinal	241	30Sep1986-present	19,265	CP12
CP17	Seco Creek, D’Hanis	168	1Nov1960-present	9,801	CP29
CP18	Hondo Creek, Tarpley	95.6	20Aug1952-present	6,806	CP29
CP19	Hondo Creek, Hondo	149	1Oct1960-23Jul2006	15,410	CP29
CP25	Frio River, Derby	3,429	1Aug1915-present	1,462	CP05
CP26	San Miguel Creek, Tilden	783	25Jan1964-present	20,180	CP28
CP27	Frio River, Calliham	5,491	1Oct1924-23Mar1981	14,893	CP25
CP28	Atascosa River, Whitsett	1,171	22May1932-present	273	CP26
CP29	Nueces River, Three Rivers	15,427	1Jul,1915-present	0	complete
CP30	Nueces River, Mathis	16,660	5Aug1939-present	2,042	CP29

The final adopted dataset of *DF* records consists of January 1934 through December 2023 daily naturalized stream flow volumes in acre-feet/day at the 20 control points that serve as pattern hydrographs in disaggregating monthly naturalized flows to daily in a *SIMD* simulation. The January 1934 through December 2023 daily naturalized stream flows of the Nueces River at Laguna (CP01) and Three Rivers (CP29) are plotted in Figures 12.9 and 12.10. As indicated by Table 12.5, the watershed areas for these two SB3 EFS gage sites are 737 and 15,427 square miles. The 1934-2021 *DF* record flows at the 20 control points are plotted in the June 2023 report [12].

Daily WAM Simulation Control Input Parameters

The daily Nueces WAM *SIMD* input dataset consists of DAT, DIS, DIF, and DSS files. One no longer needed control point is removed from the initial October 2023 flow distribution DIS file (*FD* and *WP* records) as previously noted. The same DIS and DSS hydrology input files are shared by both the daily and expanded monthly WAM versions.

The records replicated as Table 12.19 are found at the beginning of the daily DAT file. The *JT*, *JO*, *JU*, and *OF* records control daily simulation input, output, and computation options.

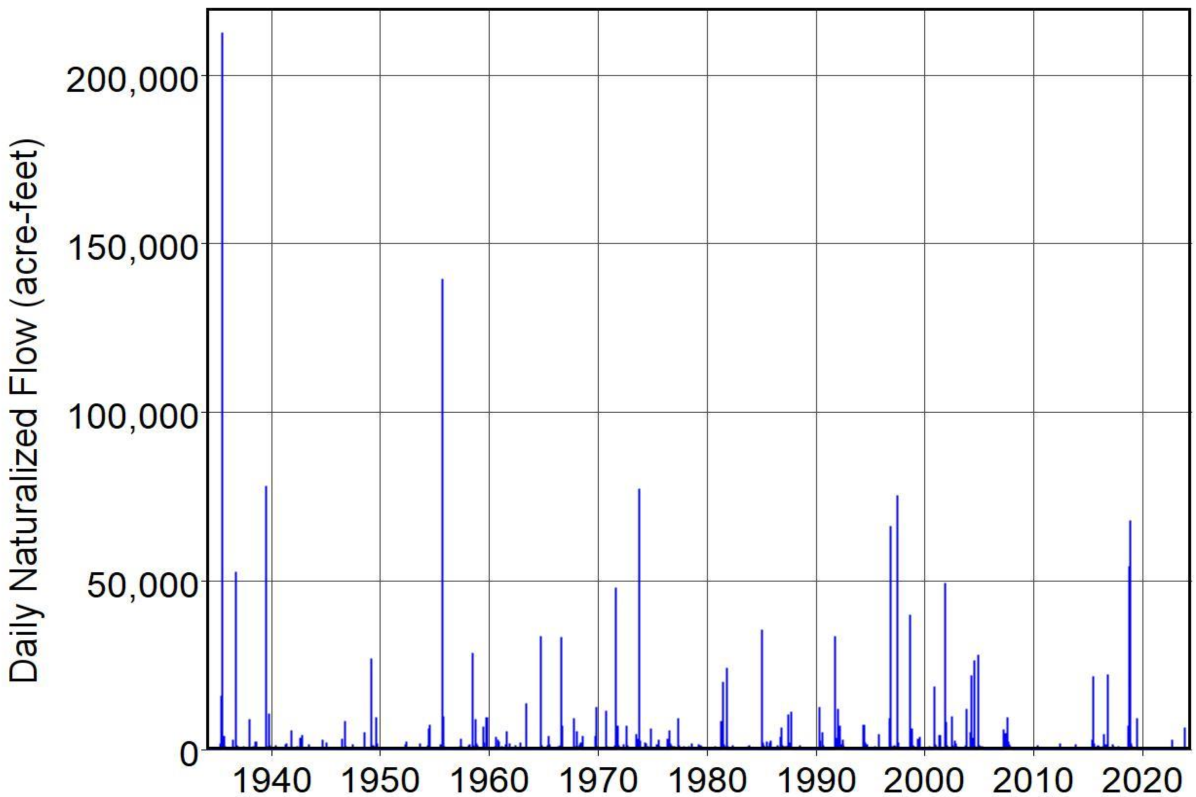

Figure 12.9 Daily Naturalized Flows of Nueces River at Laguna (CP01)

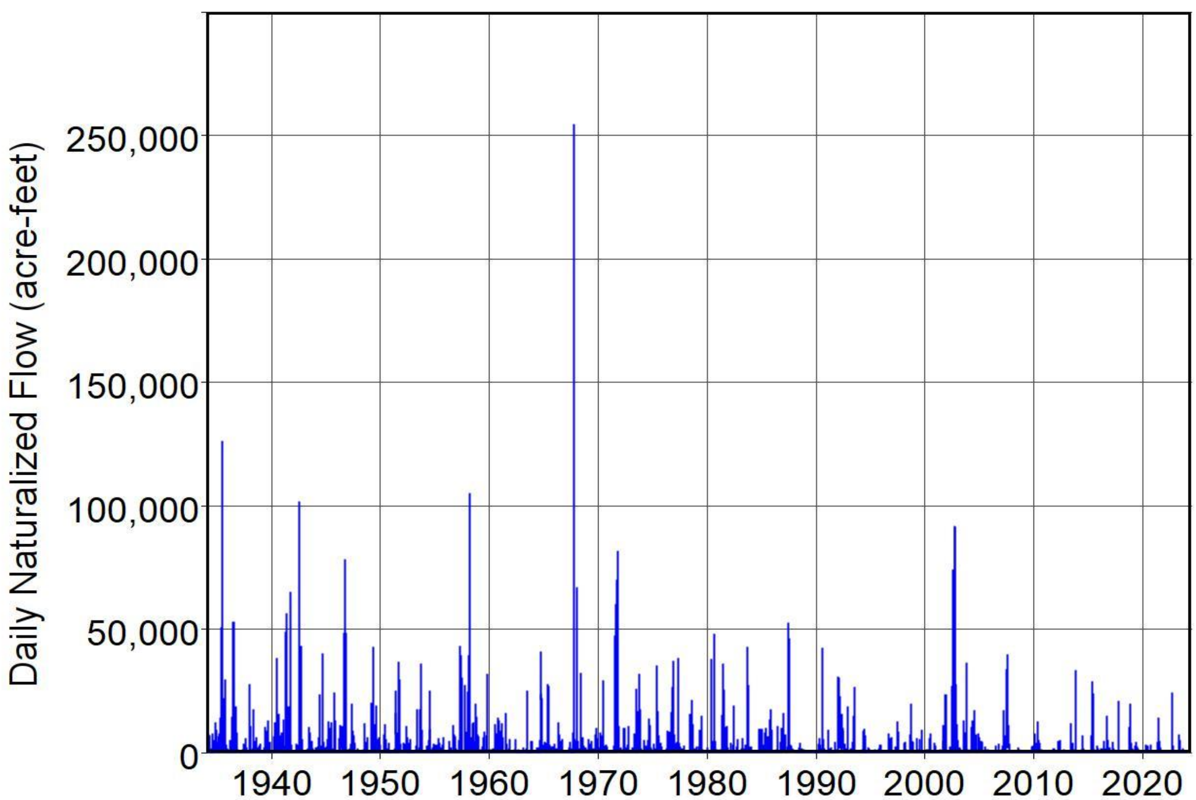

Figure 12.10 Daily Naturalized Flows of Nueces River at Three Rivers (CP29)

Table 12.19

SIMD DAT File Input Records for Controlling Daily Simulation Options

```
**       1         2         3         4         5         6         7         8
**345678901234567890123456789012345678901234567890123456789012345678901234567890
JD    90    1934       1       0       0               4
JO     6
JT                                                 0
JU     1   1
OF     0   0   2   1                                         Nueces
OFV   15
CO          CP01    CP02    CP03    CP05    CP06    CP07    CP08    CP12    CP13
CO          CP16    CP18    CP25  320603    CP26    CP28    CP29    CP30
DF          CP01    CP02    CP03    CP04    CP05    CP06    CP07    CP08    CP09
DF          CP12    CP13    CP17    CP18    CP19    CP25    CP26    CP27    CP28
DF          CP29    CP30
```

The following options are activated on the records shown in Table 12.19.

- *JO* record *ADJINC* options 4 or 6 (column 56) are recommended for monthly simulations or daily simulations without forecasting. Option 5 was adopted in the original monthly WAM.
- INEV option 6 in *JO* record field 2 (column 8) instructs *SIM* and *SIMD* to read *IN* and *EV* records from the hydrology DSS input file.
- Defaults on the required *JT* record are activated for blank fields. All fields of the *JT* record in Table 12.19 are blank. Positive entries would result in creation of optional output tables.
- Flow disaggregation DFMETH option 1 (uniform) is set as the global default in *JU* record field 2 used for computational control points that do not reflect actual real stream flow sites. A *DC* record placed in the DIF file with REPEAT and DFMETHOD options 2 and 4 activate disaggregation option 4 based on *DF* record pattern hydrographs for all control points on the Nueces River and its tributaries that have actual monthly naturalized stream flows.
- DSS(3) option 2 in *OF* record column 16 instructs *SIMD* to store both daily and monthly results in a DSS output file. A one in *OF* record column 20 (DSS(4)=1) and variable 15 (instream flow target) on the *OFV* record results in instream flow targets for the 17 control points with SB3 EFS listed on *CO* records being included in the simulation results DSS file.
- The DSS input filename root Nueces in *OF* record field 12 connects to the hydrology time series input file with filename NuecesHYD.DSS. With field 12 blank, by default, the filename of the DSS input file is the same as the DIS file which by default is the same as the DAT file.

The *CO* records list control points to include in OUT and DSS output files. The *DF* records in the DAT file list the control points for which *DF* record daily flows are read from the DSS input file. SB3 EFS at 17 control points are added to the DAT file as sets of *IF*, *ES*, and *PF* records as previously discussed. The control points with SB3 EFS are optionally listed on *CO* records as shown in in Table 12.19 to have their instream flow targets output as option 15 on the *OFV* record. Daily flows for the control points listed on *DF* records in Table 12.19 are stored on *DF* records in the hydrology time series DSS input file along with the *IN* and *EV* records. DFFILE option 1 in *JU* record field 3 (column 12) means daily flow *DF* records are read from the input DSS file for the 20 control points listed on the DAT file *DF* record in Table 12.19.

SB3 EFS at 17 control points are added to the DAT file as sets of *IF*, *ES*, and *PF* records as previously discussed. The control points with SB3 EFS are optionally listed on *CO* records as shown in in Table 12.19 to have their instream flow targets output as option 15 on the *OFV* record. Daily flows for the control points listed on *DF* records in Table 12.19 are stored on *DF* records in the hydrology time series DSS input file along with the *IN* and *EV* records. DFFILE option 1 in *JU* record field 3 (column 12) means daily flow *DF* records are read from the input DSS file for the 20 control points listed on the DAT file *DF* record in Table 12.19.

Comparison of Storage Volumes for Alternative Modeling Premises

SIM generates 1,080 end-of-month storage volumes for a 1934-2023 simulation. *SIMD* computes end-of-day storage volumes for the 32,872 days of the simulation and also outputs the 1,080 end-of-month volumes which are a subset of the 32,872 end-of-day volumes. *SIM* and *SIMD* simulated 1934-2023 reservoir storage contents for Choke Canyon Reservoir (CCR) and Lake Corpus Christi (LCC) are compared in Table 12.20 for: (1) the *SIM* simulation with the initial monthly WAM last updated by TCEQ 10/1/2023; (2) both *SIMD* daily and monthly summations from the 2025 daily WAM; and (3) simulation results with the 2025 modified monthly WAM. The statistics in Table 12.20 include the mean storage contents and the storage contents equaled or exceeded during 70%, 50%, and 30% of the 1,080 months or 32,872 days of the simulations.

Table 12.20
Reservoir Storage Volume Statistics for the 1934-2023 Period-of-Analysis

	Reservoir Storage Volume Statistics (acre-feet)			
Alternative WAM	Mean	70%	Median (50%)	30%
Choke Canyon Reservoir (CCR) with Authorized Capacity of 700,000 acre-feet				
2023 *SIM* Monthly	132,209	0.0	33,024	168,670
2025 *SIMD* Daily	166,852	3,784	102,369	272,086
2025 *SIMD* Monthly	166,590	3,756	102,363	271,953
2025 Modified Monthly	204,320	13,690	155,603	311,295
Lake Corpus Christi (LCC) with Authorized Capacity of 300,000 acre-feet				
2023 *SIM* Monthly	83,568	0.0	33,286	130,496
2025 *SIMD* Daily	132,435	20,088	129,743	217,159
2025 *SIMD* Monthly	132,511	19,582	129,812	219,187
2025 Modified Monthly	125,697	23,779	116,836	202,253

The initial monthly WAM last updated by TCEQ 10/1/2023 is listed first in Table 12.20. As discussed earlier in this chapter, this 10/1/2023 version of the TCEQ monthly WAM includes SB3 EFS at four control points (CP25, 320603, CP29, and CP30) modeled with *IF*, *WR*, *TO*, *FS*, *UC*, *CP*, and *CI* records, rather than *IF*, *HC*, *ES*, and *PF* records. The January 2025 daily WAM with simulation results included in Table 12.20 and Figure 12.11 incorporates SB3 EFS at 17 control points (Table 12.9) modeled with *IF*, *HC*, *ES*, and *PF* records (Table 12.13). The January 2025 monthly WAM in Table 12.20 is modified to incorporate monthly SB3 EFS targets at the 17 control points derived from the daily *SIMD* simulation (Tables 12.16 and 12.17).

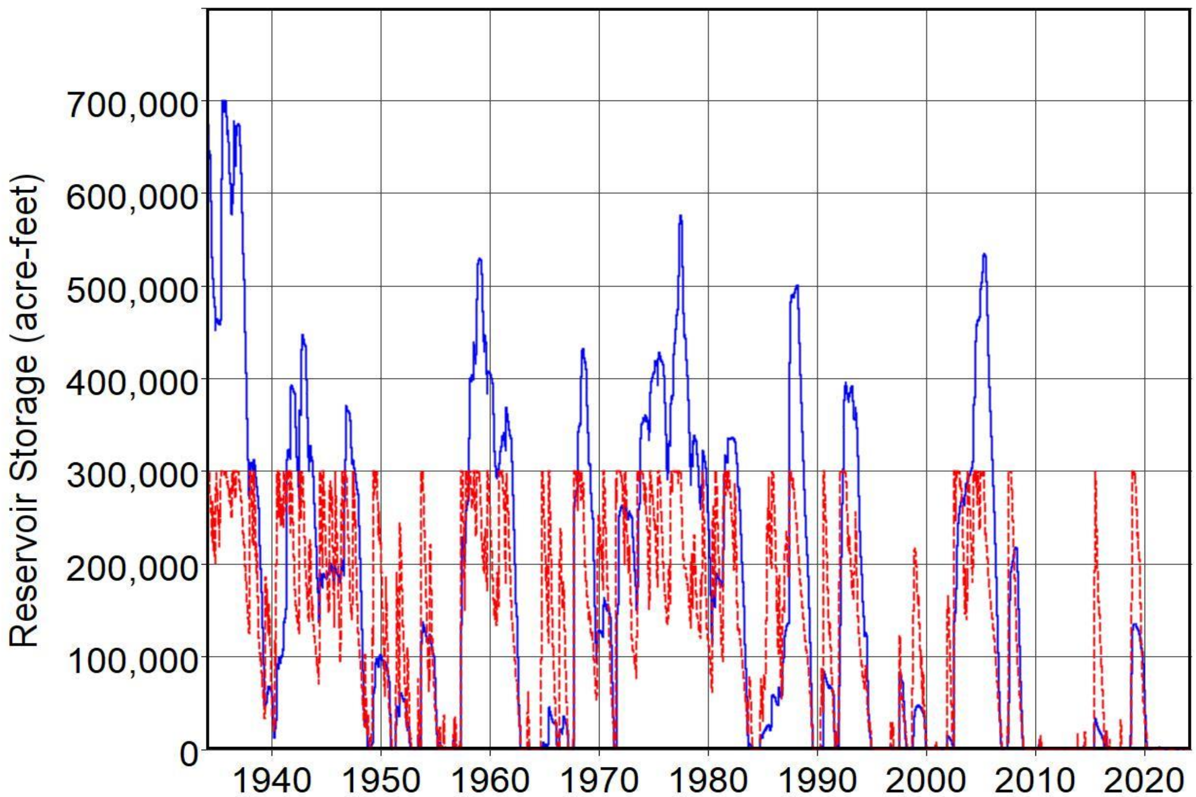

Figure 12.11 Daily Storage in CCR (blue solid line) and LLC (red dashed line)

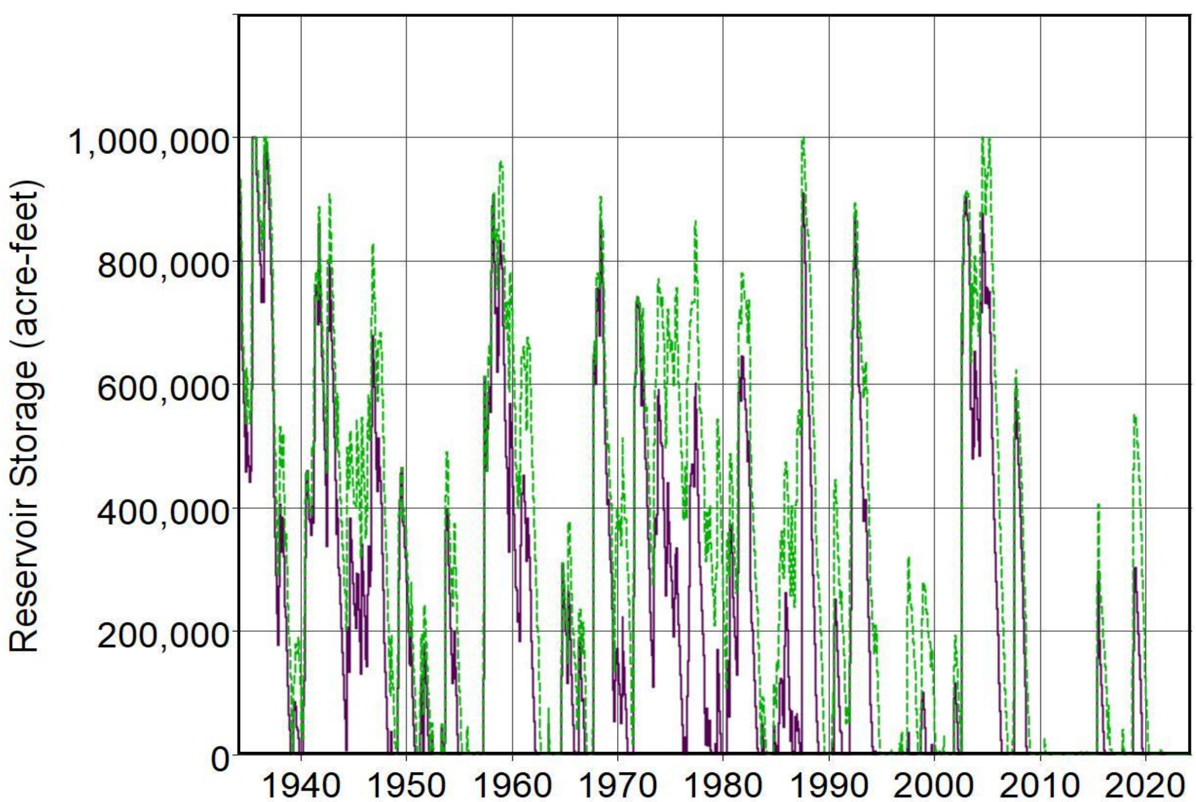

Figure 12.12 CCR/LLC Storage from 2023 (solid) and 2025 Monthly (dashed) WAMs

Figure 12.11 Legend		Figure 12.12 Legend	
2025 Daily CCR	blue solid line	2023 Monthly Total	purple solid line
2025 Daily LCC	red dashed line	2025 Monthly Total	green dashed line

SIM 1934-2023 end-of-month storage contents of Choke Canyon Reservoir (CCR) and Lake Corpus Christi (LCC) from a simulation with the 10/1/2023 monthly WAM are plotted in Figure 12.2. *SIMD* end-of-day storage contents of each of the two reservoirs generated by the 2025 daily WAM are plotted in Figure 12.11. The total combined CCR/LCC storage contents from the 10/1/2023 *SIM* monthly WAM and 2025 modified monthly WAM are compared in Figure 12.12.

The storage content of each reservoir at the beginning of the simulation is not known and represents a basic WAM modeling assumption. All reservoirs are assumed to be full to their authorized storage capacities at the beginning of the simulation in each of the twenty WAMs listed in Table 5.1 of Chapter 5 as well as at the beginning of the Nueces WAM simulations presented in this chapter. Although generally considered a reasonable simplifying approximation for most of the other nineteen WAMs, the dramatic drawdowns in Figures 12.2, 12.11, and 12.12 indicate that assuming Choke Canyon Reservoir and Lake Corpus Christi to be full to their authorized storage capacities of 700,000 and 300,000 acre-feet at the beginning of the 1934-2023 simulation is not realistic. The simulated storage contents during the first several years before the first complete emptying of the reservoirs is unrealistically high. The *SIM/SIMD* beginning-ending storage (BES) option discussed in Chapter 7 (Figure 7.8) is based on setting the beginning-of-simulation storage contents equal to the storage contents at the end of the simulation. For the Nueces WAM, the BES option would mean beginning the simulation with the reservoirs essentially empty.

SB3 EFS Instream Flow Targets

Environmental flow standards (EFS) with effective date of March 6, 2014 and priority date of October 28, 2011 have been established through the process created by the 1997 Senate Bill 3 (SB3) at 17 sites described in Table 12.9. Quantitative metrics incorporated in the SB3 EFS are tabulated in Tables 12.11 and 12.12. Methods for incorporating the SB3 EFS in the daily and modified monthly versions of the WAM are outlined in Tables 12.13, 12.14, 12.16, and 12.17.

The daily full authorization *SIMD* input dataset consists of a set of files with the following filenames: NuecesD.DAT, Nueces.DIS, Nueces.DIF, and NuecesHYD.DSS. The daily WAM was executed with *SIMD* to generate monthly instream flow targets stored as *TS* records in the file NuecesHYD.DSS that simulate the 17 sets of environmental flow standards. This modified monthly WAM is comprised of a set of *SIM* input files with the following filenames: NuecesM.DAT, Nueces.DIS, and NuecesHYD.DSS. The same hydrology DSS file with filename NuecesHYD.DSS can be read by either *SIM* or *SIMD* with various versions of the WAM input dataset. *HEC-DSSVue* reads any DSS file including *SIM* or *SIMD* input files or simulation results output files. The same flow distribution file Nueces.DIS is read by *SIM* and *SIMD*.

The 1934-2023 monthly SB3 EFS instream flow targets and shortages in acre-feet/month at the seventeen WAM control points are plotted as Figures C32 through C48 of Appendix C. The monthly instream flow targets plotted in Appendix C were computed within *SIMD* by summing the daily instream flow targets computed in the *SIMD* simulation. These instream flow targets stored on *TS* records in the time series DSS input file are read by *SIM*.

Statistics for Daily Stream Flow and SB3 EFS Targets and Shortages

Observed daily, monthly, and annual flows of the Frio River at Derby, Nueces River at Three Rivers, and Nueces River at Mathis are plotted in Figures B14, B15, and B16 of Appendix B. Monthly naturalized flows of the Nueces River at Three Rivers (control point CP29) are plotted in Figure 12.4. Daily naturalized flows of the Nueces River at Laguna (CP01) and Three Rivers (CP29) are plotted in Figure 12.9 and 12.10.

Statistics for the 1934-2023 daily naturalized stream flows, simulated regulated and unappropriated stream flows, and SB3 EFS instream flow targets and shortages at five of the USGS gage locations described in Tables 12.9 and 12.18 are compared in Table 12.21. These statistics in cfs for the 1934-2023 time series of 32,872 daily quantities are the mean (average), median (50% exceedance frequency), minimum and maximum. The number of days with high pulse targets is also shown in Table 12.21. Data management and statistical computations were performed within *HEC-DSSVue*.

Figures 12.13-12.17 are plots of the daily total instream flow targets and the combined daily subsistence and base flow components of the SB3 EFS target in cfs at the five sites. The difference between the two plots is the pulse flow component of the SB3 EFS target. Monthly total SB3 EFS targets and shortages in acre-feet/month for all 17 sites are plotted in Appendix C.

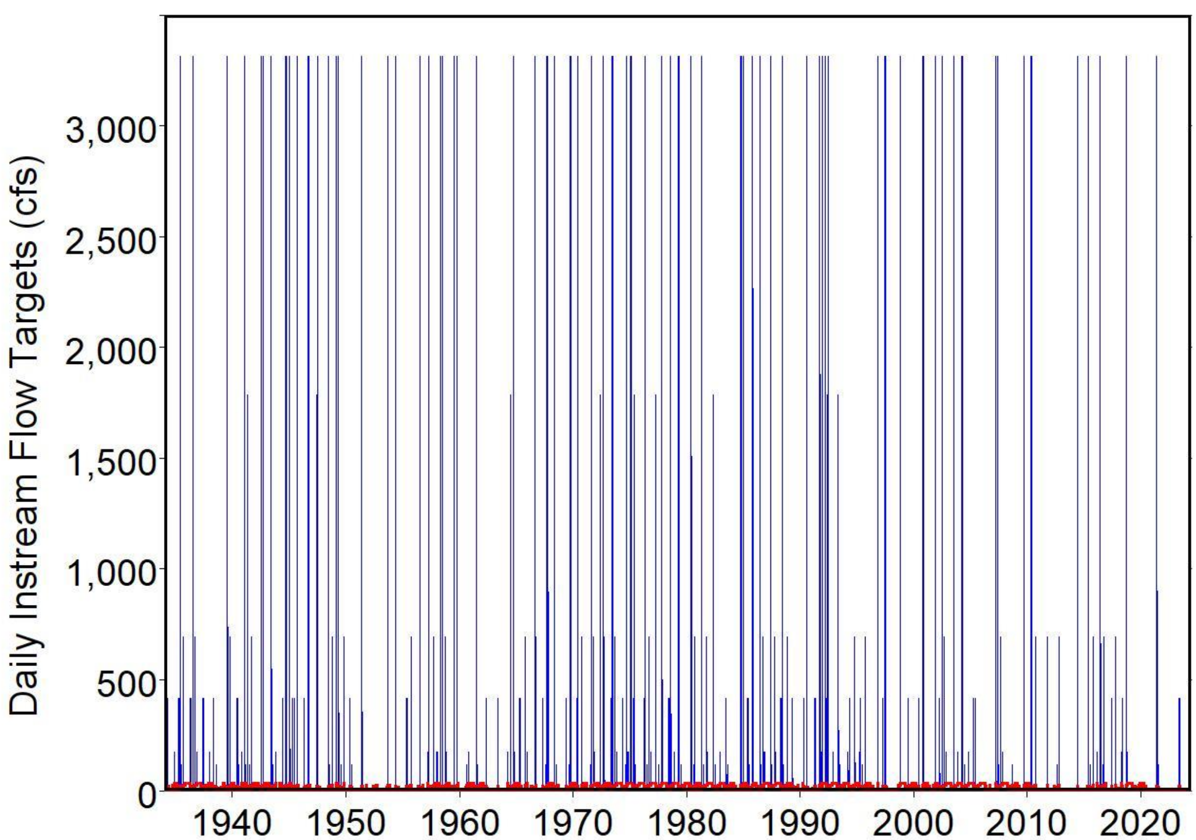

Figure 12.13 SB3 EFS Total (**blue line**) and Subsistence/Base (**red line**) Targets at the Gage on the Frio River Near Derby (CP25)

Table 12.21
Statistics for Daily Stream Flows and SB3 EFS Targets and Shortages

River	Frio	Frio	Nueces	Nueces	Nueces
Gage Location (Nearest Town)	Derby	Tilden	Laguna	Three Rivers	Mathis
Control Point Identifier	CP25	320603	CP01	CP29	CP30
Mean of Daily Quantities (cfs)					
Naturalized Flows	131.9	170.9	163.9	723.2	718.6
Regulated Flows	128.3	166.4	159.9	671.8	672.4
Unappropriated Flows	9.941	13.01	13.98	232.4	269.1
SB3 EFS Targets	24.64	16.08	57.38	118.3	123.9
Pulse Flow Targets	19.00	11.82	14.57	93.31	36.71
Subsistence/Base Flow Targets	6.295	4.635	46.91	28.75	95.43
SB3 EFS Target Shortages	0.4409	0.3357	0.2957	0.05513	3.418
Median (50% Exceedance Frequency) of Daily Quantities (cfs)					
Naturalized Flows	6.864	13.52	77.84	73.56	116.9
Regulated Flows	3.885	9.832	74.71	121.5	469.2
Unappropriated Flows	0.000	0.000	0.000	0.000	0.000
SB3 EFS Targets	2.554	3.000	48.00	37.00	96.00
Pulse Flow Targets	0.000	0.000	0.000	0.000	0.000
Subsistence/Base Flow Targets	2.473	2.606	48.00	37.00	96.00
SB3 EFS Target Shortages	0.000	1.000	0.000	0.000	0.000
Minimum of Daily Quantities (cfs)					
Naturalized Flows	0.0	0.0	0.0	0.0	0.0
Regulated Flows	0.0	0.0	0.0	0.0	0.0
Unappropriated Flows	0.0	0.0	0.0	0.0	0.0
SB3 EFS Targets	1.000	1.000	14.00	1.000	37.0
Pulse Flow Targets	0.000	0.0	0.0	0.0	0.0
Subsistence/Base Flow Targets	1.000	1.000	14.00	1.000	37.00
SB3 EFS Target Shortages	0.000	0.000	0.000	0.000	0.000
Number of Days with Non-Zero Pulse Flow Targets During the 32,872 Days of 1934-2023					
Pulse Flow Targets	2,051	2,284	2,331	3,575	2,486
Maximum of Daily Quantities (cfs)					
Naturalized Flows	65,320	48,866	107,013	128,099	137,473
Regulated Flows	65,262	48,718	106,999	98,532	119,254
Unappropriated Flows	12,313	15,386	5,309	95,505	119,144
SB3 EFS Targets	1,700	960.0	590.0	4,090	2,540
Pulse Flow Targets	1,700	960.0	590.0	4,090	2,540
Subsistence/Base Flow Targets	17.00	12.00	65.00	37.00	140.0
SB3 EFS Target Shortages	1.000	1.000	15.28	1.000	37.00

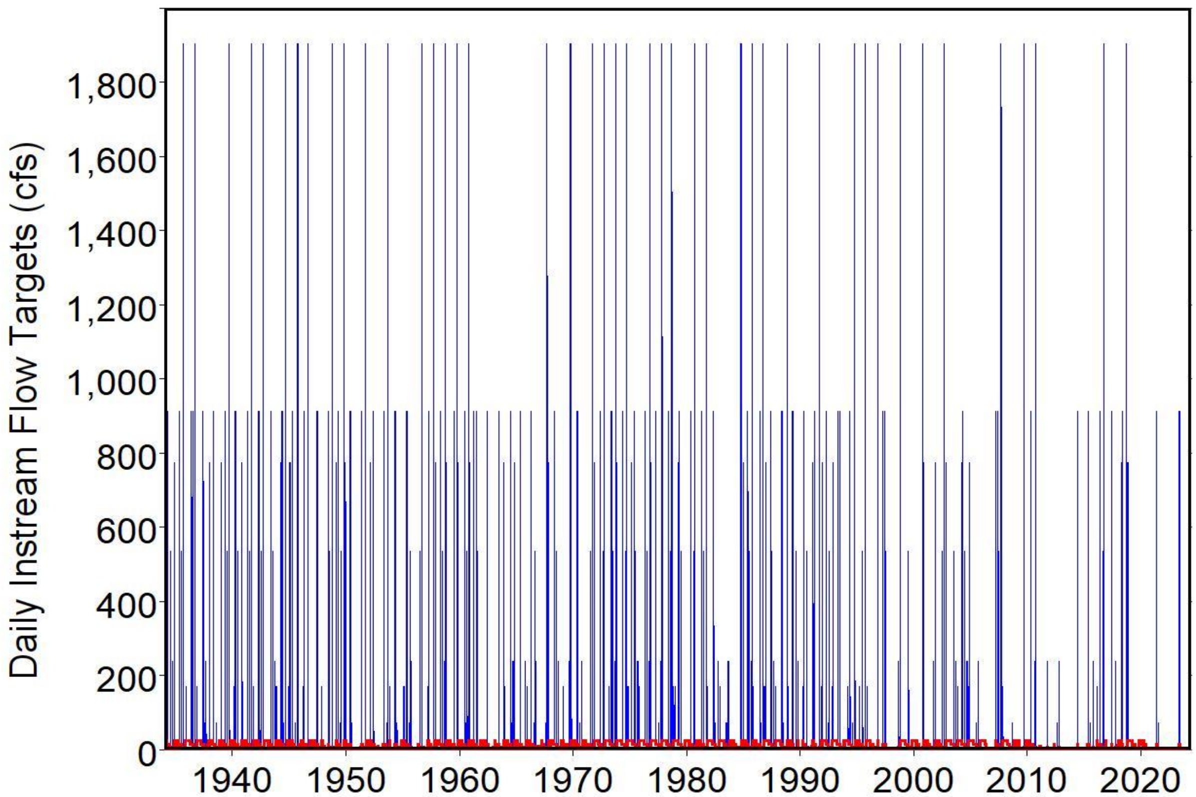

Figure 12.14 Total (**blue line**) and Subsistence/Base (**red line**) Targets, Frio at Tilden (320603)

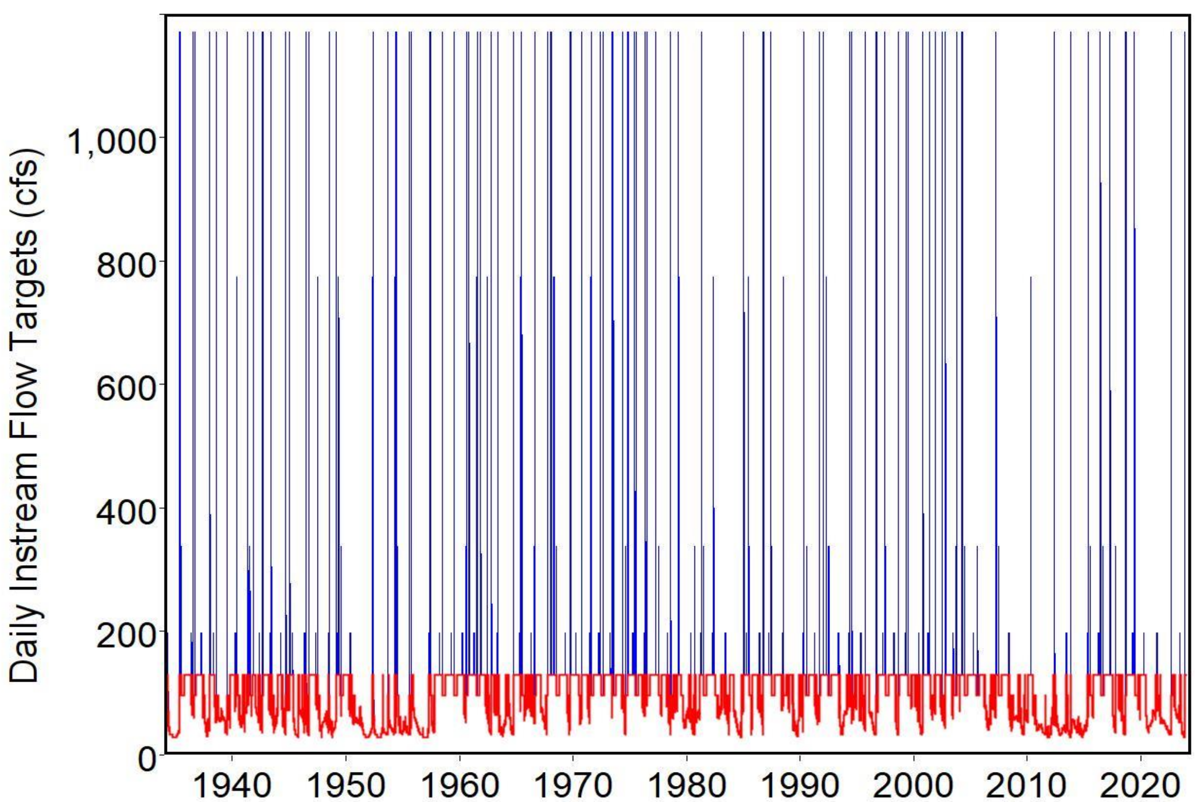

Figure 12.15 SB3 EFS Total (**blue line**) and Subsistence/Base (**red line**) Targets at CP1

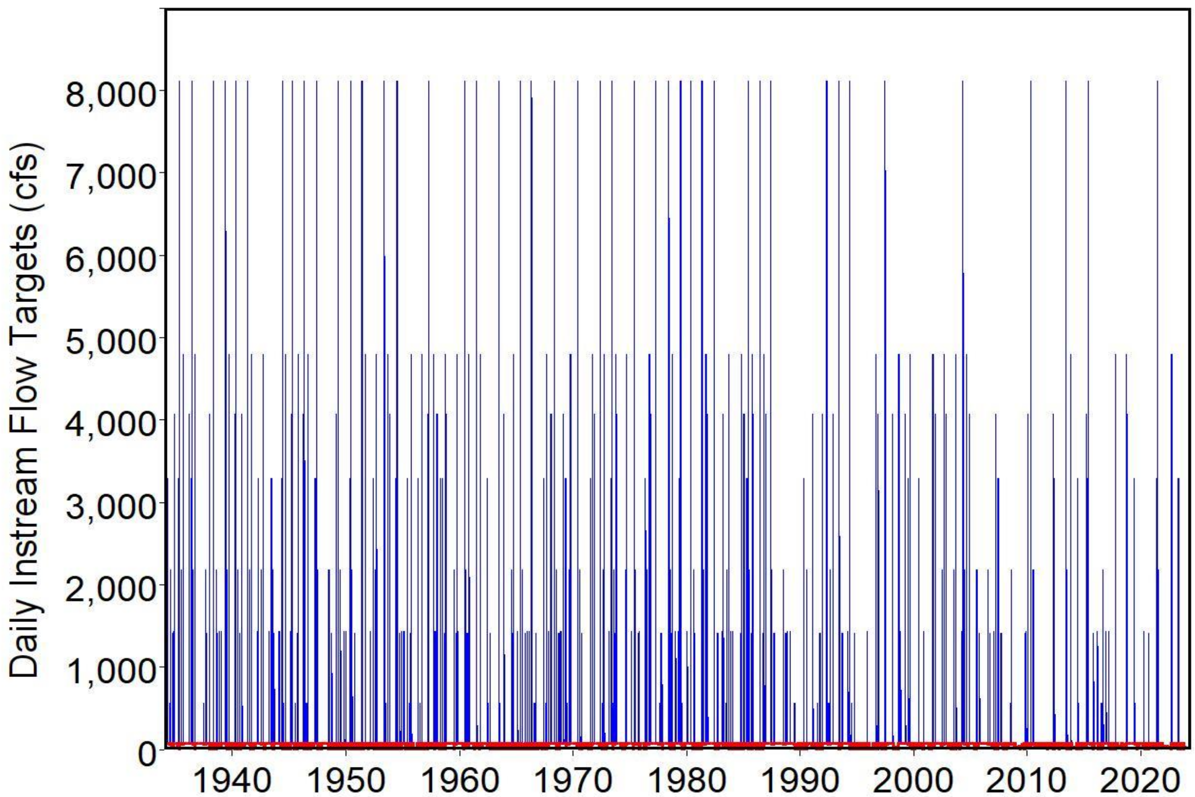

Figure 12.16 SB3 EFS Total (**blue line**) and Subsistence/Base (**red line**) Targets at CP29

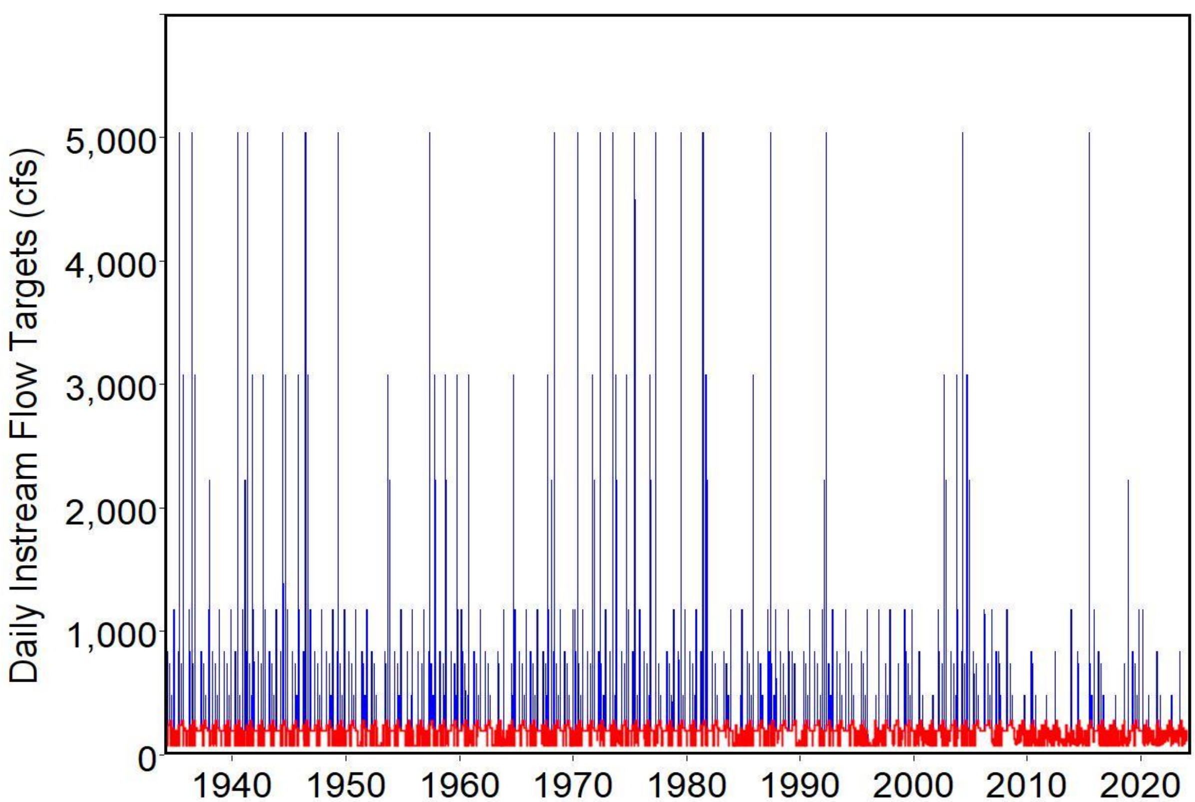

Figure 12.17 SB3 EFS Total (**blue line**) and Subsistence/Base (**red line**) Targets at CP30

CHAPTER 13
SUMMARY, SYNTHESIS, AND GUIDANCE

Modeling and analysis of water availability is essential for effective water management. Water agencies and consulting engineering firms have accumulated extensive experience over 25 years of employing the generalized WRAP modeling system with WAM datasets for the major river basins and coastal basins of Texas. WRAP/WAM modeling is well established. However, certain capabilities developed during recent years have not yet been fully implemented. This report and associated datasets support improvements in addressing complexities in WRAP/WAM assessments of surface water availability and supply reliability. This final chapter highlights and synthesizes information presented in the preceding 12 chapters and associated appendices. Guidance for incorporating environmental flow standards and dealing with other complexities of hydrology and water management in water availability modeling is summarized.

Hydrologic Variability and Stationarity

Variability and stationarity or non-stationarity of precipitation, reservoir evaporation rates, river flows, and reservoir storage contents play governing roles in water management and WRAP modeling of water management. Hydrologic conditions in Texas vary greatly both spatially and temporally. Stationarity and departures therefrom refer to long-term constant conditions over time as affected by permanent changes or long-term trends.

Spatial hydroclimatic differences ranging from arid and semiarid western regions to water-abundant eastern regions of Texas are dramatic. Flows in rivers throughout the state are extremely variable over time with continuous, storm event, seasonal, and multiple-year fluctuations reflecting extremes of droughts and floods along with more frequent but less severe fluctuations. Stream flow variability is driven by variability in precipitation and evaporation. Hydrologic variability and associated supply reliability, flood risk, and future uncertainty are fundamental to water management. Large volumes of reservoir storage are essential for developing water supplies with acceptable levels of reliability and reducing flood flows to reduce damages and protect public safety.

Stationarity as well as variability characteristics of precipitation, evaporation, stream flow, and reservoir storage are explored in Chapter 4 and elsewhere throughout this report. Stationarity or non-stationarity of hydrologic variables, reservoir storage, and water use as well as temporal (over time) and spatial (with location) variability are fundamental to river/reservoir/use system water management and water availability assessments. Precipitation and evaporation are affected by climate stationarity/nonstationarity. Stream flow and reservoir storage content are affected by changes in watershed land use and water resources development, allocation, management, and use as well as precipitation and evaporation.

Precipitation and Reservoir Evaporation

Any permanent or long-term changes in monthly or annual precipitation in Texas that may have resulted since 1940 from global warming or other phenomena are hidden by the great rainfall variability to the extent of being undetectable by the analyses discussed in Chapter 4. No permanent changes or multiple-decade long trends in precipitation are evident in the 1940-2024 time series of monthly and annual precipitation depths investigated in Chapter 4.

Increases in reservoir evaporation in Texas and elsewhere would be consistent with global warming. Based on the data analyses discussed in Chapter 4, reservoir evaporation rates appear to have possibly increased. However, any long-term increases in evaporation during 1954-2024 are obscured by variability and measurement impreciseness and thus difficult to accurately detect.

Stream Flow

Naturalized flows at WAM primary control points are comprised of observed flows adjusted to remove the effects of water development and other human activities in order to approximate stationary conditions. Time series plots and linear regression analysis indicate that monthly naturalized stream flows, with some exceptions, are reasonably stationary at most control points in the WAMs. Although investigated in research studies, climate change has not been incorporated in routine adjustments of observed stream flows to obtain monthly naturalized flows.

Actual observed historical stream flows are significantly different than natural flows under undeveloped conditions for many river reaches in Texas. Conversely, the differences between natural and actual observed historical flows are negligible in many other river reaches. Storage and water use associated with major reservoirs account for most of the differences between natural condition and actual condition flows on major rivers of Texas. Major rivers with large watersheds are different in this regard than streams in smaller urban watersheds where urban land use changes often dominate permanent changes in the characteristics of stormwater runoff and stream flow.

Permanent changes (non-stationarity) in river flow characteristics have resulted primarily from changes in water use accompanying population growth and construction of dams, reservoirs, conveyance facilities, and other infrastructure for storing, transporting, and using water. The impacts are significant, diverse, and vary with location. The impacts of water development and use on low flows are very different than on high flows. Regulation of rivers by dams reduces flood flows but may increase low flows at downstream locations. Changes in median (50% exceedance) flows are different than changes in average flows. The effects of a dam and associated water supply diversions on flows just below a dam or diversion site are much less evident further downstream.

Reservoir Storage as a Drought Index and Measure of Water Availability

The majority of the simulation studies performed with WRAP and the WAMs focus on estimating period and volume reliabilities for water supply diversion rights of interest. The case studies in this report rely largely on time series plots of simulated reservoir storage contents to provide a more general expression of water availability. Storage contents computed for a stationary scenario of water development, allocation, management, and use during a long stationary hydrologic period-of-analysis also serves as a meaningful drought index. Simulated reservoir storage contents reflects both hydrology and water management and use.

The greatest WRAP/WAM simulated reservoir drawdowns during the stationary 1940-2023 hydrology resulting from the stationary full authorization water use scenario occur during either the 1950-1957 or 2010-2014 droughts at most major reservoirs in the six case study WAMs as well as in other WAMs for the other river basins of the state. The 1950-1957 drought ended with widespread flooding during April-May 1957 from one of the greatest floods on record in Texas. The 2010-2014 drought was followed by a rainfall-abundant 2015 with major floods.

Although simulated drawdowns are greater at some major reservoirs during 2010-2014, simulated drawdowns are more severe during 1950-1957 than 2010-2014 at the majority of the major reservoirs. The driest single year on record for over half of Texas is 2011. Full authorization WAM simulations indicate that water managers and users in most areas of the Trinity, Brazos, and Lavaca River Basins have never experienced drought conditions as hydrologically severe as 1950-1957 under conditions of population and economic growth and associated water needs reflected in presently active water rights. Storage depletions during the 1950-1957 versus 2010-2014 droughts are somewhat more comparable in Colorado and Neches full authorization WAM simulations.

The economic cost of drought is dependent upon economic development and water needs as well as meteorological and hydrological drought severity. Recent droughts in Texas were more economically costly than the 1950-1957 drought due to population and economic growth that has occurred since 1957.

Water Availability Modeling Framework

The WRAP/WAM simulation modeling strategy combines (1) past river system hydrology adjusted to reflect stationary undeveloped conditions with (2) a defined stationary scenario of water resources development, allocation, management, and use. Water supply reliability and stream flow and reservoir storage frequency metrics are computed from simulation results.

1. River system hydrology is represented primarily by sequences of monthly naturalized stream flow volumes and monthly reservoir evaporation-precipitation depths extending over a hydrologic period-of-analysis long enough to meaningfully reflect relevant magnitude and variability characteristics of stream flow and reservoir surface precipitation and evaporation.

    a. *SIM* and *SIMD* monthly naturalized flow input datasets on *IN* records conceptually reflect conditions without the water development, allocation, management, and use modeled in the WAMs. *IN* record datasets contain past actual stream flow adjusted to remove effects of human activities to reflect stationary near-natural conditions. Monthly naturalized flows at secondary control points with no *IN* records are computed in a *SIM* or *SIMD* simulation based on flows at primary control points (defined as having *IN* records) and parameters input on control point *CP*, flow distribution *FD*, and watershed parameter *WP* records.

    b. Monthly net reservoir surface evaporation depths less depths of precipitation falling on reservoir surfaces are recorded on *EV* records. The simulation models *SIM* and *SIMD* include options for adjusting the *EV* record depths for precipitation runoff from land at reservoir sites that is included in the naturalized stream flows.

2. The WRAP term "*model water right*" refers to a water right *WR* record or instream flow *IF* record and supporting input records that simulate water use demands or requirements and the constructed facilities and institutional practices employed to meet the requirements. The full authorization scenario adopted in the six case studies of Chapters 7-12 is based on the premise that all water right holders store and/or divert the full amount of water to which they are entitled by certificates of adjudication or water use permits. TCEQ employs full authorization WAMs in administering the statewide water rights system. Other scenarios of water resources development, allocation, management, and use, such as the current use scenario, are also used in water right administration, planning studies, and other types of modeling applications.

Analyses of Simulation Results

Water supply reliability, hydroelectric reliability, stream flow frequency, and reservoir storage frequency metrics are computed from *SIM* or *SIMD* simulation results using routines in the WRAP program *TABLES*. Period and volume reliability metrics from *TABLES* are primary measures of water supply capabilities employed in evaluating water use permit applications and associated water management plans. Program *TABLES* also provides an extensive array other tabulations and summary tables for organizing simulation input datasets and simulation results. Firm yields are often computed in planning studies employing the *FY* record feature of *SIM*. *HEC-DSSVue* also includes various statistical analysis features including basic statistics, frequency (duration) analysis, and other analyses as well as comprehensive time series plotting capabilities.

The full authorization scenario of constructed infrastructure and water allocation, management, and use practices are simulated in the case studies of Chapters 7-12 assuming a hypothetical repetition of 1934-2023 hydrology for the Nueces WAM and 1940-2023 hydrology for the five other WAMs. Water managers prepare for the future, not the past. However, simulations of capabilities for supplying specified water needs and requirements with existing or proposed constructed infrastructure and management practices during a hypothetical repetition of 1940-2023 natural hydrology provide meaningful insight from both a statistical or probabilistic perspective and various other perspectives. Reliability and frequency metrics are employed in criteria for assessing water availability. An array of information such as stream flow and reservoir storage plots contribute to an enhanced understanding of hydrology and water management capabilities.

Simulation Modes

The following alternative modeling and analysis modes for applying the WRAP simulation models *SIM* and *SIMD* are outlined in Chapter 2: conventional long-term monthly *SIM* or daily *SIMD* simulations; iterative search for firm yield controlled by *FY* record; short-term conditional reliability modeling controlled by *CR* record; and salinity tracking with program *SALT*.

Simulations with the monthly WAMs for the six case studies of Chapters 7-12 illustrate the conventional *SIM* simulation mode. A particular water management/use scenario of interest, such as the full authorization or current use scenario, is simulated for each month of a hydrologic period-of-analysis such as 1940-2023. Monthly *SIM* simulations have been performed routinely by agency and consulting firm professional staff since 2000. As of 2025, daily *SIMD* simulations have been performed primarily in research studies at Texas A&M University (TAMU) sponsored by TCEQ.

The *SIM/SIMD FY* record controls automated repetitions of *SIM* or *SIMD* simulations in an iterative search for the firm yield for one or multiple diversion or hydropower targets. Firm yield is defined as the maximum target that can be supplied with no shortages based on premises reflected in the WAM. The automated firm yield feature is illustrated by an example in Chapter 6.

Short-term conditional reliability modeling (CRM) with *SIM* and *TABLES* is also illustrated in the example presented in Chapter 6. CRM consists of developing frequency and reliability statistics for a future period typically ranging from a month to a year but optionally longer than a year that are conditioned on known present or beginning reservoir storage levels. CRM supports real-time drought management operations or operational planning for future drought.

Many automated *SIM* CRM short-term forecast simulations with different hydrology sequences begin with the same beginning reservoir storage contents. The probabilities of reservoir storage contents equaling or exceeding various levels at various future times such as one year from now, at the end of the irrigation season, or several months later in the drought are conditioned on present volumes of water in storage. Likelihoods of supplying diversion targets and maintaining reservoir storage and instream flow levels over the specified short-term future period are also included in CRM assessments conditioned on present or beginning reservoir storage levels.

With a WAM 1940-2023 hydrology dataset, *SIM* may perform 83 (starting in February-December) or 84 (starting in January) annual automated simulations with each of the 12-month hydrology sequences beginning at the same selected date with the same specified beginning reservoir storage contents. Program *TABLES* computes water supply reliability and reservoir storage and stream flow frequency metrics from the results of the 83 or 84 short-term *SIM* simulations. Different CRM options reflect varying levels of computational complexity. The basic *TABLES* simple equal-weight statistical analysis of *SIM* simulation results is best for most CRM applications. More sophisticated *TABLES* probability analysis options may be employed in certain situations that perhaps warrant the additional computational complexity.

Supply availability may depend upon water quality as well as quantity. Development of the WRAP salinity simulation program *SALT* was motivated by natural salt pollution from geologic formations in the upper watersheds of the Pecos, Colorado, Brazos, and Red River Basins in Texas, Oklahoma, Kansas, and New Mexico. Natural salt pollution in this region severely affects the quality of large volumes of water in large reservoirs and rivers further downstream. The main application of the WRAP program *SALT* to date has been research studies during 2001-2002 at TAMU on the effects of natural salt pollution and proposed salinity control projects in the upper Brazos River Basin on water supply capabilities of Possum Kingdom, Granbury, and Whitney Reservoirs and the overall Brazos River system [34, 35].

Application of *SALT* salinity tracking capabilities begins with a conventional simulation performed with *SIM*. Program *SALT* reads simulated regulated monthly stream flow volumes and end-of-month reservoir storage volumes from a *SIM* simulation results output file. *SALT* also reads an input file of salinity loads or concentrations entering the river system, which for the Brazos studies included total dissolved solids, sulphate, and chloride. The *SALT* simulation computations consist of tracking the salt loads and concentrations throughout the river and reservoir system. Water supply reliability metrics are computed for specified allowable salinity levels.

WRAP Programs, HEC-DSS, and HEC-DSSVue

The WRAP user interface program *WinWRAP*, monthly simulation model *SIM*, and post-simulation program *TABLES* have been extensively applied by TCEQ, TWDB, river authority, and consulting firm professionals over the past twenty-five years. Programs *SIMD*, *DAY*, and *DAYH* are the daily modeling components of WRAP and to date have been employed primarily in TAMU research studies sponsored by TCEQ. Creation and application of the WRAP monthly hydrology time series compilation and analysis program *HYD* in TCEQ sponsored research studies at TAMU evolved over multiple years following later after compilation of the original WAMs during 1998-2002. The WRAP salinity tracking program *SALT* was developed and applied during 2000-2012 in research studies at TAMU funded by multiple sponsors.

Most applications of WRAP and the WAMs have employed the *SIM* monthly simulation model with simulation results organized in various summary tables created with *TABLES*. The tables developed by the WRAP program *TABLES* include optional variations of tables displaying:

- period and volume reliabilities for water supply or hydroelectric energy generation
- other supplemental indices of water supply capabilities
- frequency metrics for any of the 43 different *SIM* simulation results variables such as reservoir storage volumes, reservoir surface elevations, net evaporation-precipitation volumes or naturalized, regulated, or unappropriated stream flow
- volume budgets
- various other simulation results tabulations and summaries
- summaries of various types of input data read from a simulation input DAT file

Program *TABLES* also includes similar routines for organizing and analyzing daily *SIMD* simulation results and input datasets and program *SALT* simulation results.

The WRAP daily simulation model *SIMD* is an expanded version of the monthly *SIM* with additional features relevant only in daily simulations. Programs *DAY* and *DAYH* covered in the *Daily Manual* [5] consist primarily of alternative routing parameter calibration routines. Daily *SIMD* simulation capabilities discussed throughout this report are summarized later in this chapter.

As discussed throughout this report, *HEC-DSSVue* developed and maintained by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE) has been adopted as an integral and important component of the WRAP modeling system. *HEC-DSSVue* and the WRAP program *TABLES* provide certain overlapping time series analysis capabilities. Both include statistical frequency analysis routines. However, *HEC-DSSVue* and *TABLES* each include multiple significant capabilities not provided by the other. *TABLES* includes water supply reliability analysis capabilities not included in *HEC-DSSVue*. *TABLES* has no graphics or plotting capabilities. *HEC-DSSVue* provides convenient, comprehensive time series plotting capabilities. All time series plots in this report and all the WRAP manuals were created using *HEC-DSSVue*.

USACE HEC developed and continues to maintain, improve, and expand perhaps the most extensively applied hydrology, hydraulics, and water management software packages in the United States and world. The many generalized simulation models, supporting documentation, and other software products developed by HEC are available for download free-of-charge at the HEC website (https://www.hec.usace.army.mil/). The HEC-DSS (Data Storage System) system for managing time series data is incorporated in the HEC simulation models and various non-HEC models including the WRAP programs *SIM*, *SIMD*, *HYD*, and *TABLES*.

DSS files store data in a binary format written and read only by software with DSS capabilities. WRAP programs *SIM*, *SIMD*, *HYD*, and *TABLES* include file management options for creating and reading binary DSS files. The WRAP programs also include options for creating and reading ordinary text files. Thus, WRAP programs can be employed either with or without DSS files. The program *HEC-DSSVue* provides capabilities for managing, organizing, manipulating, and tabularly or graphically displaying data in DSS files and can also read and create Microsoft Excel and other types of files. *HEC-DSSVue* includes capabilities for downloading datasets from the USGS National Water Information System (NWIS) and other databases. *HEC-DSSVue* was used to download observed daily stream flow data from the NWIS for the case studies.

Most past applications of the WRAP/WAM modeling system have been monthly *SIM* simulations without use of DSS. However, DSS files and *HEC-DSSVue* significantly enhance monthly modeling applications and are practically essential for managing daily *SIMD* simulation studies with large input and output datasets. DSS files and *HEC-DSSVue* provide extremely useful and efficient capabilities for compiling, managing, manipulating, and analyzing *SIM* and *SIMD* monthly and daily time series data including both input datasets and simulation results. WRAP programs *TABLES* and *HYD* also create, write to, and read from DSS files and can be employed in combination with program *HEC-DSSVue*.

<u>Small to Large and Simple to Complex</u>

The generalized WRAP modeling system provides a flexible array of optional modeling capabilities necessitated by the diverse water management practices found throughout Texas. Many WRAP applications require only the basics outlined in the *Fundamentals Manual* [3]. However, an array of modeling features explained in the *Reference*, *Users*, *Hydrology*, and *Daily Manuals* [1, 2, 4, 5] may be employed as needed to address diverse water management complexities. Although most water rights reflected in 10,070 *WR* and 3,527 *IF* records in the 20 WAMs listed in Table 5.1 are modeled with simple sets of several input records, some require more complex combinations of input parameters and records. Multiple options for the same computation or data management task increase flexibility but further complicate the modeling system.

The twenty WAMs listed in Table 5.1 vary greatly in size and complexity. The number of reservoirs range from zero in the Colorado-Lavaca Coastal WAM to 695 and 699 reservoirs in the Brazos and Trinity WAMs. The number of control point *CP* records range from 53 in the San Antonio-Nueces Coastal Basin WAM to 4,468 in the Brazos WAM. The number of water right *WR* records vary from 12 in the San Antonio-Nueces WAM to 2,470 in the Brazos WAM. Most water rights are relatively simply to model. Multiple-reservoir, multiple-objective system operations with firm and interruptible supply commitments and other complicating features, such as those of the Lower Colorado River Authority and Brazos River Authority, are much more complex to model.

The Brazos, Trinity, and Colorado WAMs discussed in Chapters 7, 8, and 10 are very complex. The Neches, Nueces, and Lavaca WAMs discussed in Chapters 9, 11, and 12 are smaller and less complex. Several of the WAMs listed in Table 5.1 are smaller and simpler than those explored in Chapters 7-12. The complicated Rio Grande WAM incorporates unique complexities.

The *SIM* simulation model may be employed to estimate the firm yield and/or the yield versus reliability relationship for a single water supply reservoir such as the example in Chapter 6, which is a relatively simple endeavor. Conversely, the modeling system may be used to explore interactions between numerous water users, types of water use, and complex operations of extensive constructed facilities including multiple-purpose, multiple-reservoir systems in a large region encompassing multiple river basins and inter-basin water transfers.

WRAP can be applied to model water development/management/allocation/use in specific river/reservoir systems, river basins, or multiple-basin regions located anyplace in the world. For applications outside of Texas, without input datasets (WAMs) having been previously developed, complete input datasets must be developed for the water management systems of concern. WRAP has been applied in various states and countries for various types of analyses. The effort required to develop WAM input datasets and perform simulation studies varies greatly depending on the size and complexity of the river/river/use system and water management practices being simulated.

Texas Water Availability Models (WAMs)

The twenty WRAP simulation input datasets listed in Table 5.1 have already been developed and are readily available at the TCEQ WAM website. As noted in Chapter 1, the original WAMs were created by a team of state agencies (TCEQ, TWDB, TPWD) lead by TCEQ and contractors comprised of engineering consulting firms and university research entities. WRAP applications in Texas are greatly simplified by the availability of the twenty WAMs covering all of the state. Routine applications of WRAP in Texas consist of modifying existing *SIM* input DAT files by incorporating water projects, management strategies, and water use needs of interest.

TCEQ maintenance of the WAMs includes both updating the water development/ allocation/management/use data (water rights) and extending the hydrologic period-of-analysis (*IN* and *EV* records). TCEQ routinely updates the water rights information in the DAT files of relevant WAMs as new or amended water use permits and associated water management plans are evaluated and approved. A September 2023 TCEQ report [15] describes past and planned future hydrology updates (hydrologic period-of-analysis extensions). TWDB maintains cyclically updated versions of the WAMs employed in the SB1 regional and statewide planning process.

Intermediate WAM Hydrology Extensions

The hydrologic periods-of-analysis for the monthly naturalized flows (*IN* records) and net evaporation-precipitation depths (*EV* records) for the Brazos, Trinity, Neches, Colorado, Lavaca, and Nueces WAMs last updated by TCEQ 10/1/2023 and currently available at the TCEQ WAM website are 1940-2018, 1940-1996, 1940-2018, 1940-2016, 1940-1996, and 1940-1996. The original WAMs were completed before 2000, with simulation periods extending through 1996, 1997, or 1998. Later hydrology updates by TCEQ or consulting firm contractors extended naturalized flows by applying conventional methods based on adjusting observed flows [15].

Conventional WAM hydrology updates (Chapter 5), particularly the *IN* record monthly naturalized flows, require significant time and effort and thus have been performed only infrequently [15]. Approximate *IN* and *EV* record extensions through 2023 are incorporated in the six case study WAMs of this report. The generally more approximate methods employed in the case studies of Chapters 7-12 to extend naturalized monthly flows through December 2023 are designed for intermediate hydrology updates between generally more accurate updates employing conventional methods. The reservoir net evaporation-precipitation extensions (*EV* records) through 2023 in the six case study WAMs are based on the TWDB monthly precipitation and evaporation database described in Chapter 4 and are generally consistent with the original WAMs and previous hydrology extensions. Two alternative approximate strategies for extending monthly naturalized flows described in Chapters 5 and 6 are applied in the case studies of Chapters 7-12.

A WRAP program *HYD* hydrologic model relates monthly naturalized stream flows with monthly quadrangle precipitation and evaporation depths from the TWDB database. Naturalized flow (*IN* record) extensions through 2023 developed with the program *HYD* hydrologic model were adopted for the Brazos, Trinity, Colorado, and Neches daily and modified monthly WAMs.

Sequences of *IN* and *EV* records available from the TWDB were adopted for the 1997-2023 hydrology extensions for the Trinity, Lavaca, and Nueces WAMs. The *IN* record naturalized flow extensions developed by TWDB staff are based on standard linear regression of monthly naturalized flows with observed stream flows. Trinity WAM naturalized flow extensions generated with the TWDB regression versus WRAP program *HYD* model are compared in Chapter 8.

The WRAP program *HYD* hydrologic model is based on complex nonlinear regression of naturalized monthly flows with quadrangle monthly precipitation and reservoir evaporation depths from the TWDB database described in Chapter 4. Models for each individual primary control point are calibrated based on the original monthly naturalized flow volumes and corresponding monthly precipitation and evaporation depths for the quadrangles encompassing the watershed of the control point. Calibration of models for each primary control point requires significant time and effort. However, upon completion of the calibration process, the resulting *HYD* input HIN file can be easily applied to extend the WAM naturalized flows each year upon completion of the annual TWDB update of the database of quadrangle monthly precipitation and evaporation depths.

Program *HYD* input HIN files with calibrated models for extending naturalized flows for the Guadalupe/San Antonio (GSA) and Sabine WAMs not included in this report as well as the Brazos, Trinity, Colorado, and Neches WAMs were developed in past research at TAMU sponsored by TCEQ. Extensive effort was required to calibrate these hydrologic models in the past studies. However, the calibrated models are easily applied to extend the naturalized flows. Previously developed *HYD* input HIN files for extending the *EV* records, which are much easier to compile than *IN* records, were also employed in the hydrology updates. *HYD* input datasets for extending the *IN* and *EV* record sequences have not been developed for the Lavaca and Nueces WAMs.

TWDB 1997-2023 *IN* and *EV* record extensions are adopted for the Lavaca and Nueces WAMs of Chapters 11 and 12. TWDB staff have developed *IN* and *EV* record extensions for nine WAMs, including the Trinity, Lavaca, and Nueces WAMs included in this report and six others, for use as intermediate updates for planning studies between more detailed TCEQ sponsored updates employing conventional methods. Reservoir evaporation-precipitation (*EV* record) compilations are similar in the original WAMs and all extensions. TWDB intermediate monthly natural stream flow extensions are based on regression with observed flows employing standard textbook least-squares linear regression.

Advantages and disadvantages of the two different strategies for intermediate extensions of monthly naturalized flow have not been investigated sufficiently for definitive conclusions. Each of the two methods probably produces better estimates of naturalized flows than the other for some months at some locations. All hydrology extensions incorporated in the six case studies appear to have generated reasonable extended sequences of monthly naturalized stream flows.

Extending the hydrologic period-of-analysis improves the accuracy and level-of-confidence placed in estimates of water supply reliability and reservoir storage and stream flow frequency metrics derived from WAM simulation results. Water managers know that droughts more hydrologically and economically severe than the worst droughts in the period-of-analysis will occur in the future, though the future timing of the next record-breaking extreme drought is unknown. However, WAM simulations based on past hydrologic conditions facilitate probabilistic estimates of reliability and frequency metrics and other meaningful analyses of water availability.

Extending a 1940-1996 or 1940-2016 period-of-analysis through 2023 improves water availability assessments. Relevant hydrologic variables including droughts and floods fluctuate over time and spatially between and within river basins. The most severe full authorization WAM simulated reservoir drawdowns for the case studies occur during 1950-1957 or 2010-2014 for most major reservoirs. The most severe drawdowns for a smaller number of major reservoirs occur in the full authorization simulations during other drought periods. Several large reservoirs, located primarily in the western half of the state, are experiencing dramatic actual drawdowns during 2024/2025 that began 10 to 20 years or longer ago and are continuing into the unknown future.

The 1940-2023 statewide mean annual precipitation is 28.0 inches. Referring to Table 4.1, statewide mean annual precipitation has ranged from lows of 13.6 inches in 2011 and 16.7 inches in 1956 to highs of 39.9 inches in 2015 and 40.6 inches in 1941. The 2022 and 2023 statewide mean annual precipitation was 22.6 inches and 24.5 inches. Although nine other years during 1940-2023 had smaller statewide rainfall totals than January-December 2022, the highest mean annual temperatures on record for much of Texas and planet Earth occurred during 2022.

A simulation with all reservoirs full to capacity at the beginning of 1940 starts within several wet years before reaching the 1950-1957 most severe drought for the majority of Texas and later 2010-2014 most severe drought since 1940 for much of Texas. The 1950-1957 drought began gradually and ended with widespread, intensive flooding in April-May 1957. The 2010-2014 drought was followed by the 2015 second highest annual rainfall since 1940. A 1940-2023 simulation includes continuous less dramatic hydrologic fluctuations along with the extremes.

Application of the Modeling System

Application of the WRAP simulation models *SIM* and *SIMD* with a WAM input dataset includes the following tasks.

1. A WAM is developed or modified following the detailed instructions provided in the *Users Manual* for each of the input records in the simulation input files. Modifications to an existing WAM to model actual or proposed changes in water management or use generally focus on the DAT input file.
2. WRAP simulation features and options defined by parameters on input records are creatively adopted and combined to model unique or complicated water rights.
3. The selection of simulation results to be recorded in OUT, DSS, CRM, or YRO output files is organized.
4. *SIM* or *SIMD* are executed within the interface program *WinWRAP*.
5. Errors and problems in the WAM input dataset are detected and corrected. *SIM* or *SIMD* is executed repetitively with changes to input data until all detectable errors are corrected and issues are addressed.
6. Simulation results are organized and analyzed with *TABLES* and *HEC-DSSVue*.

SIM simulation results recorded in an OUT and/or DSS file consist of quantities for 43 variables, or selected subsets thereof, for each month of the hydrologic period-of-analysis for selected control points, water rights, or reservoirs. *SIMD* simulation results include quantities for the same 43 simulation results variables, or selected subsets thereof, for each day of the period-of-analysis. *SIMD* also provides the option of including monthly aggregation of daily quantities for each month of the simulation. Daily and monthly flow quantities are in acre-feet/day and acre-feet/month. End-of-day and end-of-month reservoir storage quantities are in acre-feet. Each of the 43 simulation results variables is associated with either control points, water rights, and/or reservoirs. The 43 simulation results variables are listed with the *OF* record instructions in Chapter 3 of the *Users Manual* [2] and defined in detail in Chapter 6 of the *Reference Manual* [1].

SIM and *SIMD* time series simulation results are managed, organized, summarized, and analyzed with the WRAP program *TABLES* and the Hydrologic Engineering Center (HEC) program *HEC-DSSVue* which has been adopted as an integral component of WRAP. Both programs include an array of flexible capabilities for organizing, tabulating, and manipulating time series datasets. *TABLES* includes water supply and hydropower reliability analysis features not available in *HEC-DSSVue*. *HEC-DSSVue* has comprehensive time series plotting capabilities and a feature for downloading datasets from the USGS National Water Information System not provided by *TABLES*. Both *TABLES* and *HEC-DSSVue* compute basic statistics and perform frequency analyses. WRAP applications of DSS files and *HEC-DSSVue* are described in detail in Chapter 6 of the *WRAP Users Manual* [2] and discussed throughout the WRAP manuals.

Modification of WAM files requires use of either the *Users Manual* [2] or *Fundamentals Manual* [3]. The *Users Manual* explains in detail *SIM*, *SIMD*, and *TABLES* input and output files, input parameters on the 61 types of input records shared by *SIM* and *SIMD* and 16 additional record types used only by *SIMD*, and the input records that control *TABLES* routines. The *Fundamentals Manual* includes explanations for 25 of the 61 types of *SIM* input records and the most commonly used of the *TABLES* input records. The *Fundamentals Manual* covering basics is sufficient for simpler applications of *SIM* and *TABLES*. The much more comprehensive *Users Manual* is required for the diverse complexities encountered in applying *SIM*, *SIMD*, and *TABLES*. The *Fundamentals Manual* is designed as an introductory instructional manual for new WRAP users but can also be a convenient quick reference document for experienced WRAP users.

Detection and correcting blunders and irregularities in input data files and simulation results is a fundamental central component of applying essentially all computer modeling systems, including WRAP. Insertion of new input records and modifying existing input records in a WAM without blunders would be a rare occurrence. All new WRAP users should review "*Chapter 9 Detecting Errors and Irregularities in Data Files*" of the *Reference Manual* [1]. The WRAP programs have numerous error and warning checks. Errors detectable by routines coded in the computer programs result in termination of program execution with an error message written in the message file. Warning messages without termination of program execution alert users to potential irregularities that perhaps should be investigated. Other features facilitate tracking of progress in reading input, performing computations, and recording results. Error and warning tracking features of the WRAP programs are relevant only with computer-detectable blunders and irregularities. WAM datasets and modifications thereto along with simulation results must be meticulously scrutinized by model users to check accuracy and reasonableness of input data and associated simulation results.

Computer simulation models are simplified approximations of actual natural and constructed systems designed to provide meaningful information for relevant types of modeling and analysis applications. Modeling endeavors such as creating, modifying, and applying WAMs typically balance the sometimes conflicting but also sometimes complimentary objectives of: (1) making the model as accurate as possible and (2) keeping the model as simple as possible. Improvements in model accuracy often require increased model complexity. However, unnecessary complexity may be detrimental to model accuracy as well as increasing the time, effort, and expertise required to use the model. Professional judgment is required to balance model accuracy and keeping the model as simple as possible to understand and apply. The fundamental concept of balancing accuracy and simplicity/complexity, relevant to modeling in general, is illustrated in the following discussion of daily versus monthly WAMs.

Daily WRAP Modeling Capabilities

Stream flow and other variables simulated in water availability modeling fluctuate continually over time. Simulation computations dealing with continuously varying variables are necessarily performed with a fixed computational time step. The monthly *SIM* completely ignores within-month variability. Both daily *SIMD* and monthly *SIM* simulations completely ignore within-day hourly or continuous instantaneous variability. Variability of stream flow and other hydrologic variables are decreased by averaging over larger time intervals. A 1940-2023 sequence of mean daily stream flow rates in cfs averaged within each daily time step exhibit greater variability than the 1940-2023 monthly flows in cfs at the same location averaged in each month.

Daily Versus Monthly Simulation Models

Using a monthly computational time step in water availability modeling as routinely employed in Texas with the WRAP/WAM modeling system is appropriate and effective. Daily WRAP modeling capabilities supplement rather than replace conventional monthly modeling capabilities. Addition of daily features to WRAP has been motivated primarily by environmental flow standards (EFS) established pursuant to the 2007 Senate Bill 3 (SB3).

The effects of computational time step choice on simulation results vary with different water management modeling situations and applications. A monthly computational time step is generally optimal for water availability modeling of water supply capabilities in traditional applications supporting administration of the water rights system and regional and statewide planning. A monthly interval is optimum for assessing water supply capabilities of reservoirs with large storage capacities. Environmental flow standards can be modeled much more accurately using a daily interval. In general, all components of environmental flow regimes can be modeled more accurately with a daily than with a monthly model. However, improved accuracy in tracking high flow pulses represents a particularly significant advantage of a daily computational time step.

Conversion from a monthly to daily model is also essential for meaningfully simulating reservoir flood control operations and surcharge storage. Simulation of integrated water management strategies considering interactions between environmental instream flow requirements; reservoir flood control operations; surcharge operations of water supply reservoirs during floods; and other water supply, hydroelectric power generation, water quality, erosion control, and recreation objectives may also benefit from more detailed daily simulations.

Differences between monthly and daily simulations result primarily from the great variability of stream flow characteristic of river flows throughout Texas. Modeling within-month stream flow variability is the most significant aspect of the daily *SIMD* simulation model. Developing daily pattern stream flow hydrographs is the most important aspect of converting from a monthly to daily WAM.

In a daily simulation, refilling reservoir storage and meeting water supply demands in each day depends on the volume of stream flow available in that day. A monthly simulation averages stream flow availability over the month, balancing high and low flows during the month somewhat analogously to reservoir storage. Timing of stream flows within the month does not constrain availability for storage or diversion. The effects of reservoir storage significantly diminish the effects of within-month timing of daily flows. Run-of-river diversion and instream flow targets and shortages in meeting targets are significantly affected by within-month stream flow variability. Environmental high flow pulse standards are defined by rapid stream flow fluctuations that are essentially smoothed-out with a monthly computational time step. Likewise, simulation of reservoir operations during intense flood events becomes essentially meaningless with a monthly computational time step. Most large water supply diversions are supplied from storage in major reservoirs with little effect on reliability associated with a monthly versus daily simulation interval.

Daily *SIMD* Simulation Model

Components of the daily WRAP modeling system are outlined in Table 2.1 of Chapter 2. The daily *SIMD* simulation model includes all the modeling capabilities of the monthly *SIM* simulation model. *SIMD* includes additional monthly-to-daily disaggregation, routing, and forecasting features needed and/or relevant for dealing with complexities in a daily model that do not occur in a monthly simulation. The daily computational time step provides opportunities not possible with a monthly time step to add reservoir flood control operations and high flow pulse components of environmental flow standards to the simulation model.

Most applications of daily WRAP modeling capabilities to date have been in research and development endeavors at TAMU sponsored by TCEQ. The Brazos, Trinity, Neches, Colorado, Lavaca, and Nueces daily WAMs and simulation studies performed with these daily WAMs are documented by previous reports [7, 8, 9, 10, 11, 12] and further explored in Chapters 7 through 12 of this report. These six daily WAMs represent very different river basins reflecting the diversity of hydrology and water management throughout Texas. However, basic findings regarding modeling strategies and methods from the six different simulation studies are similar and complementary. These studies provide a significant experience base for developing guidance for daily WAM modeling in general. Chapters 7-12 each address certain topics not emphasized in the other five chapters along with focusing on certain methods and issues shared by all six case studies.

The *SIMD* daily modeling features listed in Table 2.1 are a series of optional capabilities that can be added singly or in combination to convert a monthly WAM to daily. Much of the complexity of *SIMD*, as well as the WRAP/WAM modeling system in general, is due to multiple optional alternative methods for performing the same tasks. *SIMD* modeling tasks are listed in Table 2.2 along with alternative approaches for performing each task. Methods generally adopted for the six daily WAMs are also identified in Table 2.2. The methods adopted for the six case studies are recommended for similar future WAM applications. Other options may be relevant in other different types of WAM applications.

Monthly-to-Daily Disaggregation

Disaggregation of monthly naturalized flows to daily is the main key component of converting a monthly WAM to daily. Instream flow targets simulated with environmental standard *ES* and pulse flow *PF* records are computed daily in *SIMD* with daily fluctuations. Likewise, reservoir releases from flood storage controlled by *FR* records are computed daily. Other instream flow and water supply diversion targets are computed as monthly quantities distributed, by default, uniformly over the days within each month. Options for non-uniform distribution of diversion and instream flow targets (other than SB3 EFS *ES* and *PF* record targets) are not activated in the case studies presented in this report. Monthly *EV* record evaporation-precipitation depths are always distributed uniformly to the days in each month in a daily *SIMD* simulation. *SIMD* knows the number of days (28, 29 (leap year February), 30, or 31) in each month.

SIMD simulations have been performed directly with daily stream flows without providing monthly naturalized flows as input, primarily in research studies for systems outside of Texas. However, daily applications with the six case study WAMs have been based on disaggregating monthly naturalized flows to daily. Future applications of *SIMD* with the Texas WAMs are likewise expected to generally include monthly-to-daily disaggregation of naturalized flows.

Selection between alternative methods for disaggregating monthly naturalized flows to daily is made with input parameter DFMETH on the daily simulation options *JU* record. The default standard alternative consists of employing daily flow *DF* record flow pattern hydrographs with automatic repetition. The monthly flows are distributed to each day in proportion to the *DF* record daily flows while maintaining the total monthly flow volume in each month. An alternative option consisting of uniformly distributing the monthly naturalized flows to the days of each month requires no *DF* record daily flows but is appropriate only if daily variability is not relevant or important. The six daily WAMs employ primarily the standard option 4 based on *DF* record flow patterns, with the uniform distribution option 1 used only in special cases. The other flow disaggregation options are not used in the case studies.

The recommended standard *SIMD* naturalized flow disaggregation method employs *DF* record flow pattern hydrographs with automatic repetition. The *DF* records for one control point could conceptually be repeated for all control points. Adding different *DF* records for as many control points as practical increases the accuracy of capturing the differences in variability at different locations in the stream system. The automatic repetition algorithm employed within *SIMD* to repeat the same *DF* record pattern flows at any number of control points is explained in Chapter 2 of the *Daily Manual* [5].

Compilation of *DF* record daily flows for the six daily WAMs is described in general in Chapter 5 and for each specific WAM in Chapters 7 through 12. Most of the *DF* record flows are derived from daily observed flows at USGS gage sites downloaded with *HEC-DSSVue* from the National Water Information System (NWIS). As indicated by Table 6.9, the Brazos, Trinity, Neches, Colorado, Lavaca, and Nueces WAMs have daily flow *DF* records for 58, 49, 17, 45, 9, and 20 control points. These daily flows at input at a total of 198 control points are used within the *SIMD* simulations to disaggregate monthly flows to daily at a total of over 9,000 control points. Repetition of the same *DF* record daily flow pattern at multiple control points is an approximation that contributes along with various other factors to issues with routing discussed in the next section.

Routing and Forecasting

Streamflow depletions for water supply diversions and refilling reservoir storage, reservoir releases, and return flows result in stream flow changes that propagate through river reaches to downstream control points. An option allowing return flows to be returned in the next month may be employed in monthly WAMs to allow senior rights access to upstream junior return flows. Likewise, hydropower releases in a monthly simulation may be released to the river in the next month. Otherwise, flow changes in a monthly *SIM* simulation have no routing computations to simulate lag and attenuation of flow changes. Flow changes are assumed to propagate to the river system outlet within the current month. This is an approximation since, in reality, the effects of diversions and refilling reservoir storage late in a particular month may still be propagating downstream during the first several days of the next month or longer.

Flow changes in a *SIMD* daily simulation can also be assumed to propagate through river reaches to the outlet within the current day. The assumption of complete propagation in a single time period is significantly more approximate or inaccurate in a daily *SIMD* simulation than in a monthly *SIM* simulation. *SIMD* includes routing options to lag and attenuate flow changes in their downstream progression. However, routing computations are approximate and inaccurate. Forecasting is relevant only if routing is activated. Forecasting is also approximate and inaccurate. In general, routing and forecasting computations should be activated in *SIMD* simulations only if the particular characteristics of the modeling application warrant their use.

WRAP daily procedures for calibration of lag and attenuation routing parameters, routing, forecasting, and related computations are explained in detail the *Daily Manual* [5] and summarized briefly along with discussion of complexities and issues in Chapter 2 of this report. Routing and forecasting are investigated in the six case study daily WAM reports [7, 8, 9, 10, 11, 12] and further explored in Chapters 7 through 12 of this report.

Previous research of routing methods and daily WAM simulation studies cited in this report and further analyses presented in this report support the following general observations.

1. The lag and attenuation routing and forecasting algorithms developed for *SIMD* and the statistical parameter calibration methodology implemented in program *DAY* are reasonable and optimal methodologies for incorporating routing and forecasting in the daily *SIMD* simulation. The issues inherent in routing daily flow changes and forecasting future flows discussed in this report cannot be better addressed by revising these computational methodologies. Complexities are related to an array of factors that cannot be accurately measured or modeled.
2. Routing is very approximate, generally does not dramatically affect *SIMD* simulation results, and may or may not contribute to model validity. Routing may be beneficial without forecasting in situations in which precise preservation of water right priorities is not required.
3. Forecasting significantly affects simulation results and may adversely affect accuracy/validity. Forecasting can be easily switched on and off. The forecast period represents the number of days into the future considered in determining water availability constrained by downstream senior water rights and downstream nondamaging flows governing releases from reservoir flood control pools. The forecast period is an input parameter that is difficult to accurately estimate. Forecasting of future flows is highly uncertain in actual real-time operations as well as in the simulation model.

4. Interactions between negative incremental flow adjustments, routing, forecasting, and other flow adjustments are complex. Negative incremental flow adjustment options in particular significantly affect stream flow availability in the water rights priority simulation. Flow forecasting significantly magnifies these effects by considering all days of the forecast period.

The Brazos, Trinity, Neches, and Colorado daily WAMs include lag and attenuation routing parameters for 67, 39, 19, and 30 control points, respectively. No routing parameters were developed for the Lavaca and Nueces daily WAMs based on the conclusion that incorporation of routing would not beneficially contribute to accuracy of the simulation. Relevant stream lengths in the Lavaca and Nueces River Basins are much shorter than in the other four larger river systems. Calibration of routing parameters requires significant effort, time, and expertise. However, routing is easily activated or deactivated in *SIMD*. Forecasting is relevant only if routing is activated. Forecasting is easily activated or deactivated. The choice of forecast period is highly subjective.

Simulation studies with the Brazos, Trinity, Neches, and Colorado daily WAMs included comparative analysis of simulation results with and without routing. In general, simulation results with the four daily WAMs that have calibrated routing parameters were found not to be overly sensitive to routing strategies and the values of routing parameters. Reasonable and similar simulation results can be obtained with or without routing. With routing, results vary only minimally with significant changes to routing parameter values and selections of routing reaches.

As discussed in Chapters 8 and 9, routing is deactivated in the final adopted daily Trinity and Neches WAMs. The *RT* records remain in the DIF file for future use as desired, but the final adopted daily Trinity and Neches WAMs were concluded to be better without routing.

The Brazos and Colorado River Basins are larger with longer river reaches than the Trinity and Neches River Basins. As discussed in Chapters 7 and 10, routing is employed in the final adopted daily Brazos and Colorado WAMs in some reaches but with a relatively short forecast period. The daily Brazos and Colorado WAMs are concluded to be valid models with little difference in simulation results either with or without routing as long as the selected forecast period is relatively short. Simulation results become unreasonable if the forecast period is long. Forecasting is activated in any of the daily WAMs only if routing is activated.

Flood Control Pools and Surcharge Storage

In a monthly *SIM* simulation, outflow equals inflow with no flow attenuation (storage) whenever the reservoir is full to the top of conservation (authorized) storage capacity. *SIMD* includes comprehensive capabilities for modeling flood pool operations of single reservoirs or multiple-reservoir systems with releases controlled by a combination of dam outlet capacities and operations and specified allowable non-damaging stream flow levels at any number of gaging stations located at downstream sites. Flood control operations affect reservoir storage contents and downstream river flows only during high flow periods when the reservoir conservation storage is full to capacity. *SIMD* also includes capabilities for simulating flow through surcharge storage of reservoirs with or without flood control pool operations.

Reservoir operating procedures are described in Chapter 3. Reservoir design and operation include dividing the total storage capacity of a reservoir into one or more vertical zones, or pools, defined by designated water surface elevations as illustrated by Figure 3.1 on page 63. Conservation storage is used primarily for water supply, hydroelectric power generation, and/or recreation. The reservoir water surface is maintained at or as near the designated top of conservation pool elevation as stream flows and water demands allow. The water right term "authorized storage capacity" typically refers to total conservation pool capacity.

Most nonfederal water supply reservoirs have no designated flood control pool. Multipurpose USACE reservoirs are divided into a flood control pool and a conservation pool, with the two pools operated separately. The bottom of the flood control pool is the top of the conservation pool (Figure 3.1). The flood control pool remains empty except during and immediately following flood events. Nonfederal water supply sponsors contract for storage in the conservation pool, with USACE flood control operations activated only when the water level rises into the flood control pool. Flood control pools are emptied as quickly as feasible without contributing to downstream flooding, subject to the constraint of assuring that a maximum design water surface is never exceeded.

Surcharge storage occurs when the total combined flood control and/or conservation pools are full to capacity (Figure 3.1). Outflows from surcharge storage are controlled by the hydraulics of ungated outlet structures with outflows increasing or decreasing with increases and decreases in storage levels. Storage contents increase when inflows are greater than outflows and vice versa.

Flood control reservoir operations are treated as a type of water right in *SIMD*. In WRAP terminology, a water right is a set of water control requirements, reservoir storage facilities, and operating rules. Flood control rights are activated by *FR* records and are simulated along with all other *WR* and *IF* record water rights. Flood control features of *SIMD* may simulate any number of reservoirs operated as a multiple-reservoir system based on outlet capacities (entered on *FR* and *FQ/FV* records) and specified allowable nondamaging stream flow rates (on *FF* records) at any number of downstream control points.

The daily Brazos, Trinity, Neches, and Colorado WAMs include nine, eight, one, and four multipurpose reservoirs with flood control pools. The daily Lavaca and Nueces WAMs include no flood control storage capacity. Flood control operations of Sam Rayburn Reservoir are modeled in the Neches WAM with *FR* and *FQ/FV* records constraining flood pool releases based on conditions at the dam site and a *FF* record constraining releases based on flows at a single gage (control point) located some distance downstream. Flood flow *FF* records with downstream allowable nondamaging flows are also included in the daily Brazos, Trinity, and Colorado WAMs. However, an option is activated on the flood reservoir *FR* records in these three WAMs that deactivates the downstream maximum flow limits on the *FF* records, resulting in releases from the flood control pools being constrained only by maximum allowable flow limits at or near the dam sites.

The *FF* record downstream flow limits in the daily Brazos, Trinity, and Colorado WAMs resulted were deactivated because of uncertainties regarding the accuracy of simulation results related to complexities in the routing, forecasting, and negative incremental flow adjustment algorithms employed in constraining reservoir flood releases based on flows at multiple control points located significant distances downstream of the dams. Additional research is needed to further test and perhaps refine the use of downstream flood flow limits on *FF* records in simulating reservoir flood control operations. Large continuous conservation pool drawdowns in several multipurpose reservoirs result in storage levels seldom, if ever, raising into the flood control pools.

A *FV/FQ* record pair describes a relationship between reservoir storage volume (*FV* record) and outflow rates (*FQ* record) for a particular reservoir for either a designated flood control pool or surcharge storage. The *FV/FQ* table of reservoir storage volume versus outflow represents the hydraulics of the outlet structures. Inclusion of *FV* and *FQ* records in a WAM requires a table of reservoir storage volume versus outflow rates which is available from reservoir owners for most major reservoirs. *FV* and *FQ* records can be used to model a component of the operating rules for flood control pools in multipurpose UASCE reservoirs.

FV and *FQ* records can also be used to model the lag and attenuation (storage) effects of river flows through the outlet structures of water supply, hydropower, and/or recreation reservoirs with no flood control pool when the reservoir is full to capacity and overflowing. To date, surcharge storage has not been included in the daily WAMs for conservation-only reservoirs with no flood control pool. However, using *FV*/*FQ* records to route flows through surcharge storage can be relevant for studies investigating operations of conservation-only reservoirs with no designated flood control pool during flood conditions. The temporary storage effects of surcharge storage on high flow pulse components of SB3 EFS at downstream locations may also be of interest.

SB3 Environmental Flow Standards

TCEQ has established environmental flow standards (EFS) for the river basin and bay systems listed in Table 3.1 on page 57 through a process created by Senate Bill 3 (SB3) enacted by the Texas Legislature in 2007. The SB3 process for establishing EFS and the structure of SB3 EFS are described in Chapter 3. The SB3 EFS are published in the Texas Administrative Code [98]. SB3 EFS are incorporated in the Brazos, Trinity, Neches, Colorado, Lavaca, and Nueces daily and modified monthly WAMs at 19, 4, 5, 14, 5, and 17 control points (Tables 3.1 and 6.9) representing USGS gage sites as described in Chapters 7 through 12. SB3 EFS have also been established at 28 other gage sites not located in the six case study WAM river basins (Table 3.1).

Hydrologic condition *HC*, environmental standard *ES*, pulse flow *PF*, and pulse options *PO* records are designed to express instream flow *IF* record water rights in the format of EFS established through the process created by the 2007 SB3. The *HC* and *ES* records implementing the new modeling strategy were added in the July 2018 version of *SIM* and *SIMD*. *PF* and *PO* records were introduced earlier and refined in the July 2018 version of *SIMD*. *ES* records model subsistence and base flow components of SB3 EFS for either a monthly *SIM* or daily *SIMD* simulation. Pulse flow *PF* and pulse options *PO* records are included only in the daily *SIMD*. The high flow pulse components of SB3 EFS track and preserve specified high flow or flood events. Tracking of rapidly varying high flow or flood events as specified by *PF* records generally requires a daily rather than monthly computational time interval. *PO* records were not used in the six daily WAMs of Chapters 7-12 since supplemental options provided by *PO* records are not needed.

WRAP/WAM Modeling of Instream Flow Requirements

Most of the 1,993 *IF* records in the 20 WAMs in Table 5.1 simulate instream flow requirements established before enactment of the 2007 SB3. These older instream flow requirements were incorporated into the WAMs before *ES*, *HC*, *PF*, and *PO* records were added to *SIM* and *SIMD* to define *IF* record water rights specifically in the structured format of SB3 EFS. Other auxiliary records applicable to either *IF* record or *WR* record water rights are combined with

IF records to model the instream flow requirements established before or independently of the 2007 SB3 and have also been used in initial efforts in modeling SB3 EFS.

The new capabilities for specifying *IF* record instream flow requirements in the SB3 EFS format using sets of *IF*, *ES*, *HC*, *PF*, and *PO* records greatly simplify incorporation of SB3 EFS in the WAMs as well as improve accuracy. Although applied to date only for simulating SB3 EFS, *HC* and *ES* records provide flexible generic capabilities that can be employed with *IF* records and, if needed, with combinations of other types of records to simulate various water management situations. *ES* and *HC* records are included in both *SIM* and *SIMD*. *PF* and *PO* records are designed specifically for tracking and preserving high flow pulses and are included only in *SIMD*.

ES records model subsistence and base flow components of EFS. Subsidence and base flow limits are entered on *ES* records in cfs. Subsistence limits control if the regulated flow (or optionally naturalized flow) is below base flow limits. *PF* and *PO* records model high pulse flow components of EFS. Any or all components of the EFS may vary seasonally or monthly. Any or all components of the flow standards may vary with hydrologic conditions as specified on *HC* records, which are defined based on preceding simulated cumulative stream flow over a specified time period, preceding reservoir storage content, or a hydrologic index input on *HI* records.

The same *HC* and *ES* records are used for both monthly *SIM* and daily *SIMD* simulations. The multiple alternative sequences of twelve monthly subsistence and base flow limit quantities are the same in either a monthly or daily simulation. Monthly volume limits are uniformly subdivided into daily volume limits in a daily simulation. The selection between subsistence, base, and high flow limits each day depends upon daily regulated (default) or naturalized (optional) stream flows in a *SIMD* simulation. Instream flow targets based on regulated flows depend on regulated flow at the particular point in the water rights priority sequence computations. Stream flow rates in cfs averaged over a month versus averaged over a day will differ, sometimes greatly.

High flow pulses are tracked and preserved as specified by *PF* records, optionally supplemented with additional options by *PO* records. Flood or high flow pulse components of SB3 EFS represent runoff from intense rainfall events, typically characterized by rapid stream flow fluctuations over relatively short periods of time. Stream flow rates averaged over a day are very different than rates averaged over a month. High flow pulse triggers are applied to regulated flow rates which, as shown throughout this report, vary greatly with daily versus monthly averaging periods. Duration criteria range from 2 days to 26 days for the multiple high flow pulses each year tracked by *PF* records. Volume criteria further shorten the length in days of high flow pulse events.

<u>Comparison of SB3 EFS Components</u>

The six WAMs discussed in Chapters 6 through 12 include SB3 EFS at 64 control points representing USGS gage sites. Monthly instream flow targets in acre-feet/month and associated shortages in meeting the targets for the SB3 EFS at the 64 locations are plotted in Appendix C. As discussed later in the final subsection of this chapter, the quantities plotted in Appendix C are monthly summations of daily quantities in acre-feet/day computed in a daily *SIMD* simulation.

Statistics for the subsistence/base flow component and high flow pulse component of daily instream flow targets for 28 of the 64 SB3 EFS locations in the six WAMs are compared in Tables

7.11, 8.14, 9.26, 10.20, 11.15, and 12.21 on pages 183, 234, 275, 319, 351, and 398, respectively. Statistics for the daily final combined SB3 EFS instream flow target and associated target shortages are also included in these tables. Figures 7.10-7.13, 8.28-8.31, 9.22-9.26, 11.9-11.13, and 12.14-12.17 are plots of the (1) daily combined subsidence/base and high pulse flow targets and (2) subsidence/base targets. The difference between the two plots is the high flow pulse component.

Table 13.1 further illustrates the relative magnitudes and variations in daily SB3 EFS quantities. The 1934-2023 and 1940-2023 periods-of-analysis of the Nueces WAM and five other WAMs are comprised of 32,872 and 30,681 days. The means (averages), medians (50% exceedance), minima, and maxima in cubic feet per second (cfs) in Tables 7.11, 8.14, 9.26, 10.20, 11.15, and 12.21 are for the 30,681 or 32,872 daily quantities from daily *SIMD* simulations. The means in Table 13.1 are averages of quantities at the 28 selected control points from Tables 7.11, 8.14, 9.26, 10.20, 11.15, and 12.21. The metrics in Table 13.1 include the minimum and maximum quantities at the 28 SB3 EFS sites and the average of the mean quantities at the 28 sites. The average of the mean quantities at the 28 sites are also expressed as a percentage of the naturalized, regulated, and unappropriated stream flows at the 28 sites in the last three columns of Table 13.1.

Table 13.1
Comparison of Averages of Components of SB3 EFS Instream Flow Targets
at the 28 Control Points Included in Tables 7.11, 8.14, 9.26, 10.20, 11.15, and 12.21

Instream Flow	Range of Means at 28 Sites		Mean of	Mean as Percent of Stream Flow		
Target Component	Minimum	Maximum	28 Means	Naturalized	Regulated	Unapprop
	(cfs)	(cfs)	(cfs)	(%)	(%)	(%)
Subsistence/Base	1.347	1,836	221.21	7.64	9.39	15.71
High Flow Pulse	6.643	375.5	87.28	3.01	3.70	6.20
Final Combined	16.08	2,104	299.38	10.34	12.70	21.26
Target Shortage	0.0551	472.0	46.68	1.61	1.98	3.31

The hydrologic period-of-analysis mean of the final combined SB3 EFS instream flow targets range from 16.08 cfs at the Tilden gage on the Frio River (Table 12.21 and 13.1) to 2,104 cfs at the Richmond gage on the Brazos River (Tables 7.11 and 13.1). The average of the final combined SB3 EFS instream flow targets at the 28 sites is 299.38 cfs (Table 13.1), which is equivalent to 12.70% of the average simulated regulated flow at the 28 control points (Table 13.1).

The larger of the subsistence and base flow component of the daily instream flow targets defined by *ES* records and high flow pulse component defined by *PF* records is adopted in each day of the *SIMD* simulation. The subsistence and base flow (*ES* record) component is greater than zero in all 30,681 days of the 1940-2023 or 32,872 days of the 1934-2023 simulations. The high flow pulse (*PF* record) component of the SB3 EFS instream flow target is zero during about 89% to 98% of the days of the simulation with non-zero high flow pulses being tracked during an average of about 7% of the days of the simulation at the 28 sites. Several pulses of several days duration each are tracked during each year of the simulation. The hydrologic period-of-analysis averages of the daily high flow pulses defined by *PF* records are significantly smaller than *ES* record subsidence/base flow components. The high flow pulse components are much larger than subsidence/base flow components during the days of the high flow events defined by *PF* records.

The period-of-analysis means of the shortages in meeting the 30,681 or 32,872 daily SB3 EFS instream flow targets are tabulated as the last line of 13.1. Shortages are generally failures to meet the subsistence/base flow (*ES* record) rather than failures to meet the high flow pulse (*PF* record) component of the instream flow targets. Subsistence flow and base flow specifications are minimum regulated flow limits to be maintained. Regulated flows may not reach the subsistence and base flow minimum limits during periods of low flows and thus shortages occur.

High flow pulses are tracked and protected from appropriation by junior water rights and thus conceptually should not experience shortages. However, regulated flow changes in the priority-sequenced water right computations. A high flow pulse event is defined at the priority of the SB3 EFS. The default option is for *SIMD* to compute instream flow shortages at the completion of the water right priority sequence, which could be different than the regulated flow at the priority of the SB3 EFS, resulting in computed shortages to the SB3 EFS targets. However, with very junior SB3 EFS, regulated flows generally do not change computationally after defining high flow pulses.

Incorporating Daily Instream Flow Targets in a Monthly WAM

A proposed strategy for incorporating monthly instream flow targets for SB3 EFS computed in a daily *SIMD* simulation is demonstrated in simulation studies documented in the previous six daily WAM reports [7, 8, 9, 10, 11, 12] and Chapters 7 through 12 of this report. Daily *IF* record instream flow targets for SB3 EFS are computed and summed to monthly quantities within the daily *SIMD* simulation for input to the monthly *SIM* simulation input dataset. The monthly *SIM* simulation model is applied with the SB3 EFS modeled as instream flow *IF* record water rights with targets defined as target series *TS* records in the simulation input DSS file.

Daily *IF* record instream flow targets for SB3 EFS at a total of 64 control points modeled with sets of *HC*, *ES*, and *PF* records were computed in *SIMD* simulations with the Brazos, Trinity, Neches, Colorado, Lavaca, and Nueces daily WAMs. Monthly summations in acre-feet/month of daily EFS instream flow target volumes in acre-feet/day included in *SIMD* simulation results DSS files for each of the six WAMs were inserted as target series *TS* records in the DSS input files read by *SIM* and *SIMD* in both monthly and daily simulations. These monthly summations of daily SB3 EFS instream flow targets are assigned in *SIM* simulations with the six monthly WAMs to instream flow *IF* record water rights inserted in the *SIM* input DAT files by sets of records replicated in Tables 7.13, 8.12, 9.24, 10.18, 11.13, and 12.17.

With adoption of this proposed strategy, conventional applications of the monthly WAMs can continue generally with no additional complexity imposed upon model-users. The daily WAMs can be applied by TCEQ staff or contractors to establish and periodically adjust monthly SB3 EFS targets somewhat analogously to occasional updates to extend the hydrologic period-of-analysis. Monthly WAMs with SB3 EFS monthly instream flow targets previously derived from daily *SIMD* simulations can be applied by model-users in conventional WAM applications.

The monthly instream flow targets and associated shortages in meeting the targets in ac-ft for the SB3 EFS at the 64 control points (gage sites) in the six WAMs are plotted in Appendix C. The quantities plotted in Appendix C are monthly summations of daily targets and associated daily shortages in acre-feet/month computed in daily *SIMD* simulations by summing daily quantities in acre-feet/day. The monthly targets from daily summations are incorporated in the monthly WAMs.

Monthly totals of daily SB3 EFS instream flow targets are precisely replicated in the monthly WAM with this proposed approach. However, shortages in meeting the targets may differ significantly between the monthly *SIM* and daily *SIMD* simulations. Monthly regulated stream flows and associated instream flow target shortages are computed within the monthly simulation. High flow pulse components of SB3 EFS conceptually are preserved fully without shortage. Shortages in meeting subsistence and base flow targets occur in time periods in which simulated regulated stream flows are less than EFS minimum instream flow limits.

With this strategy for combining daily and monthly WAMs, daily SB3 EFS "set-aside" volumes of stream flow are incorporated in the monthly WAM, appropriately reducing quantities of stream flow available for further appropriation by junior appropriators. However, shortages in satisfying instream flow requirements, which depend on monthly versus daily regulated stream flows, are not modeled at the same level of accuracy in monthly versus daily simulations. Monthly naturalized, regulated, and unappropriated stream flows, which affect capabilities for meeting the monthly SB3 EFS instream flow targets, do not reflect within-month variability.

The proposed strategy for combining daily and monthly WAMs is relevant for evaluating water use permit applications where the effects of the SB3 EFS on unappropriated stream flows available for additional water use is the primary concern regarding the SB3 EFS. The strategy is also valid for various types of planning studies. Daily WAMs can be employed directly, without combining with monthly WAMs, in many other types of studies with input data varied in alternative daily *SIMD* simulations to explore various water management strategies and issues. *SIMD* simulation studies performed directly with daily WAMs can facilitate environmental flow studies in which assessments of capabilities for meeting the SB EFS are a primary concern.

Variations of the strategy for incorporating SB3 EFS in the WAMs are also possible. As previously discussed, the strategy adopted for inserting monthly SB3 EFS in the six WAMs consists of inserting monthly summations of the combined daily targets that include subsistence and base flow (*ES* record) and high flow pulse (*PF* record) components as time series (*TS* records) in the DSS input file referenced by *IF* records in the monthly WAM DAT file. The subsistence and base flow (*ES* record) component and high flow pulse (*PF* record) component can also be stored on separate DSS file *TS* records providing the option of conveniently performing monthly *SIM* simulations optionally with either one or the other or both SB3 EFS components. Another possible variation of the methodology is to store monthly net target less shortages from a daily *SIMD* simulation on the *TS* records in the DSS file referenced by *IF* records in the DAT file.

The sets of *HC* and *ES* records inserted in the daily *SIMD* input DAT files can alternatively be inserted with *IF* records directly into the monthly *SIM* DAT files without modification. Minimum flow limits for the subsistence and base flow standards are entered on the *ES* records in units of cfs. *SIM* and *SIMD* convert the *ES* record flow rates in cfs to acre-feet/month acre-feet/month and acre-feet/day, respectively. Hydrologic conditions are defined on a monthly basis. Computed monthly regulated flows are employed in *SIM* to apply the SB3 EFS subsistence and base flow standards. Loss of within-month daily variations in both flow limits and regulated flows in the monthly *SIM* simulation means the monthly simulation is generally less accurate than a daily simulation. However, within-month daily variations in low stream flows are generally much less pronounced than variations in high flow events. *PF* records are not applicable in the monthly *SIM* for the reasons previously discussed.