Daily Water Availability Model
for the
Neches River Basin

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CHAPTER 1
INTRODUCTION

The Texas Commission on Environmental Quality (TCEQ) Water Availability Modeling (WAM) System consists of the generalized Water Rights Analysis Package (WRAP) modeling system and datasets for all of the river basins of Texas. The Texas WAM System was originally implemented by the TCEQ and its partner agencies and contractors during 1997-2003 pursuant to water management legislation enacted by the Texas Legislature in 1997 as Senate Bill 1. Capabilities provided by the WRAP and WAM System have been expanded over the years since their initial implementation. The original WRAP/WAM modeling system is based on a monthly computational time step. Later development of daily WRAP modeling capabilities and daily versions of the WAM datasets has been motivated by environmental flow standards established pursuant to the 2001 Senate Bill 2 and 2007 Senate Bill 3.

This report documents the following additions to the full authorization and current use scenario versions of the monthly Neches WAM last updated by the TCEQ in 2012.

- The original 1940-1996 hydrologic period-of-analysis is extended through 2019.
- The U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) Data Storage System (DSS) is fully employed in expanding and applying the WAM.
- A daily WAM is created by expanding the monthly WAM to include monthly-to-daily disaggregation of naturalized flows and other daily modeling features.
- Daily *SIMD* features are employed to incorporate USACE Fort Worth District flood control operations of Sam Rayburn Reservoir in the daily WAM.
- New expanded WRAP capabilities for simulating Senate Bill 3 (SB3) environmental flow standards (EFS) are implemented with the daily *SIMD* simulation model.
- Daily instream flow targets for SB3 EFS computed in a daily *SIMD* simulation are summed to monthly targets that are incorporated in the *SIM* input dataset for the monthly WAM.

Background and Motivation

The TCEQ WAM System consists of the WRAP modeling system, twenty sets of WRAP simulation input files covering all of the river basins of Texas, and related information. The generalized WRAP modeling system and a TCEQ WAM System input dataset or variation thereof for a particular river basin is called a water availability model or WAM. The monthly WAMs have been routinely applied since about 2002. The May 2019 expanded WRAP, which includes daily modeling capabilities, is documented by a set of manuals [1, 2, 3, 4, 5, 6]. Improvements and modifications to WRAP since previous versions are described in a revisions report [7]. [Numbers in brackets refer to the list of references at the end of the report.]

The Hydrologic Engineering Center (HEC) Data Storage System (DSS) and the *HEC-DSSVue* [8] component of the DSS have been fully integrated into the May 2019 version of the WRAP computer programs and manuals, as summarized in Chapter 6 of the WRAP *Users Manual* [2]. DSS is designed for efficient compilation, analysis, manipulation, and management of time series data, including datasets that may be extremely large. The DSS and its *HEC-DSSVue* user interface are employed extensively in the work documented by this report.

Development of the original monthly Neches WAM is documented by a 2001 report [9] prepared by Brown & Root and other consulting firms under contract with the Texas Natural Resources Conservation Commission (TNRCC), later renamed TCEQ. The original Neches WAM has a hydrologic period-of-analysis of 1940-1996. Research performed during 2013-2017 included applying preliminary developmental methods to extend the hydrologic period-of-analysis through 2015 along with converting the monthly WAM to daily [10, 11, 12]. The present June 2020 report documents a 1997-2019 extension of the hydrology using significantly improved methods and a new conversion of the monthly WAM to daily also using significantly improved methods.

Hydrology updates and daily WAMs for the Brazos and Trinity River Basins are documented by May 2019 and December 2019 technical reports [13, 14]. The methods for hydrology updates, conversion of monthly WAMs to daily, and application of daily simulations to develop monthly SB3 EFS targets for monthly WAMs implemented for the Brazos, Trinity, and Neches River Basins are also applicable for other river basins.

The TCEQ WAM System is based on a monthly computational time step, which is the generally optimal time step for water availability modeling. However, daily computations are needed to incorporate Senate Bill 3 (SB3) environmental flow standards (EFS), particularly high flow pulse components, in the WAMs and to model reservoir operations during floods. Creating a daily WAM by expanding an existing monthly WAM includes adding daily pattern flow hydrographs for disaggregating monthly naturalized flows to daily, adding optional forecasting and routing parameters, and setting other input parameters. The daily *SIMD* simulation model includes features for simulating reservoir flood control operations and tracking high pulse flows associated with environmental flow requirements.

The daily Neches WAM may be used in a broad range of applications including drought management decision support, environmental flow studies, reservoir system operational planning studies, and regional planning. This report focuses specifically on employing the daily WAM to incorporate SB3 EFS [15] in the monthly WAM. Daily instream flow targets computed in a daily *SIMD* simulation are summed to monthly targets and inserted in the monthly WAM simulation input dataset. The daily WAM is executed once to develop SB3 EFS instream flow targets for the monthly *SIM* input dataset employed routinely in the water management community.

Neches WAM Hydrology

The hydrology input dataset for the monthly and daily versions of the Neches WAM includes monthly naturalized flows (*IN* records) at 20 control points and net reservoir surface evaporation less precipitation depths (*EV* records) assigned to 12 control points. The daily Neches WAM also includes daily naturalized flows (*DF* records) at 17 control points that are used as pattern hydrographs within *SIMD* to disaggregate monthly naturalized flows to daily.

The original January 1940 through December 1996 hydrologic period-of-analysis has been updated as described in this report to extend from January 1940 through December 2019. The original 1940-1996 monthly naturalized flow volumes in acre-feet/month and net evaporation-precipitation rates in feet/month are adopted without modification, with the new data limited to the 1997-2019 extension. Daily naturalized flows for 1940-2019 in acre-feet/day are added with the conversion from monthly to daily. Monthly net evaporation-precipitation rates are uniformly distributed to daily in a daily *SIMD* simulation. With the *SIM/SIMD* hydrology input updated to cover January 1940 through December 2019, a simulation for 1940-2019 or any sub-period of years between 1940 and 2019 can be performed by setting *YRST* and *NYRS* on the *JD* record.

Hydrology Compilation

Updating the 1940-1996 hydrologic period-of-analysis to extend from January 1940 through December 2019 and converting to DSS consists of the following changes and additions.

- Daily flow pattern hydrographs used to disaggregate monthly naturalized flows to daily are recorded as *DF* records in the DSS file. These are 1940-2019 daily naturalized flows developed based on adjusting observed daily flows at gaging stations to remove the effects of reservoir storage and water use as explained in Chapter 4. The daily naturalized flows for 1997-2019 are summed to obtain the 1997-2019 monthly naturalized flows described in Chapter 5.

- The original FLO file and new DSS file contain monthly naturalized flows at 20 control points stored as *IN* records. The original 1940-1996 flow quantities are not changed. Monthly naturalized flows are added for 1997-2019 based on adjusting observed daily flows at gaging stations to remove the effects of reservoir storage and water use as explained in Chapter 4. Daily flow volumes are summed to monthly volumes as noted in Chapter 5.

- The original EVA file contains twelve sequences of *EV* record 1940-1996 monthly reservoir net evaporation less adjusted precipitation depths. These 1940-1996 quantities are not changed. The net evaporation-precipitation rates are extended to include 1997-2019 using essentially the same original basic concepts and converted from EVA text file format to DSS record format for the new hydrology DSS input file as explained in Chapter 6.

HEC-DSSVue is employed to analyze, compare, select between, and combine time series data sequences. Datasets and data compilation and synthesis strategies are explored and improved. Previously employed and new data collection and computational methods are investigated and combined. Although approximations are necessarily inherent in compiling and synthesizing data, comparative analysis of available datasets indicate that the methods employed in compiling and synthesizing data and the resulting datasets are reasonable and the optimal realistically available.

The work presented in this report builds upon and improves previous TCEQ-sponsored research and development at Texas A&M University expanding capabilities for (1) updating and refining *SIM/SIMD* hydrology input datasets and (2) daily modelling and associated simulation of SB3 EFS. Earlier research in converting the Neches WAM from monthly to daily and extending the hydrology is documented by technical reports submitted to the TCEQ in 2014 [10, 11] and 2017 [12]. The daily Neches WAM simulation input dataset documented by the present June 2020 report reflects the following methods that are different than those previously employed.

- *DF* record 1940-2015 pattern hydrographs were developed earlier using the daily Soil and Water Assessment Tool (SWAT) rainfall-runoff model [11, 18, 20]. The latest *DF* record 1940-2019 pattern hydrographs were developed by adjusting daily flows observed at gaging stations.

- The preceding *IN* record 1997-2015 monthly naturalized flows were developed using the monthly watershed rainfall-streamflow hydrologic regression model incorporated in the

WRAP program *HYD* [4, 10] along with other available flow data. The latest *IN* record 1997-2019 monthly naturalized flows were developed by adjusting daily flows observed at gaging stations and summing to monthly flows. The original 1940-1996 monthly naturalized flows are adopted without modification.

- Both the previous 1997-2015 [10] and latest 1997-2019 extensions combined concepts and databases applied in developing the original 1940-1996 monthly *EV* record net evaporation-precipitation depths with expanded capabilities provided by *HYD* and *HEC-DSSVue*.

- The original monthly Neches WAM has monthly naturalized flows stored as *IN* records in a FLO file and evaporation-precipitation depths as *EV* records in an EVA file. The original daily Neches WAM daily flows are stored as *DF* records in a DCF file. The *IN*, *EV*, and *DF* records are converted as described by this report to updated and improved hydrology datasets stored in a single *SIM/SIMD* input DSS file. Related time series datasets compiled in the process of developing the *SIM/SIMD* hydrology input dataset are stored in other auxiliary DSS files.

- Various aspects of daily modeling including features for modeling SB3 EFS have been updated and improved using expanded *SIMD* simulation capabilities incorporated in the May 2019 version of WRAP as explained in this report.

Data Storage System (DSS) Datasets

The *HEC-DSSVue* interface program is available from the USACE Hydrologic Engineering Center (HEC) website, is documented by a user's manual [8], and is used with data storage system (DSS) files which can be created in a variety of ways. The latest versions of the WRAP programs create and access DSS files. *HEC-DSSVue* is an integral component of WRAP as summarized in Chapter 6 of the WRAP *Users Manual* [2] and discussed throughout the WRAP manuals. *HEC-DSSVue* provides flexible easy-to-use capabilities for plotting graphs and performing an array of arithmetic operations and statistical analyses for time series datasets that can be extremely large.

HEC-DSSVue and the *HEC-SSP Statistical Software Package* [17] include similar features for downloading data from the National Water Information System (NWIS) website maintained by the U.S. Geological Survey (USGS). Modifications by the USGS to the NWIS website prevent the older *HEC-DSSVue* from accessing the site at present. Therefore, the *HEC-SSP* was used to download data from the USGS NWIS for the present Neches WAM work. *HEC-DSSVue* was used to organize and manipulate the data in the DSS files.

The data compilations and analyses documented in this report are accompanied by DSS files, easily accessible with *HEC-DSSVue*, which serve as appendices to the report. The DSS files described in Chapters 4, 5, and 6 document the WAM hydrology and support further continuing analyses. These files of daily stream flows (Chapter 4), monthly stream flow (Chapter 5), and monthly evaporation-precipitation depths (Chapter 6) have filenames NechesDailyFlows.DSS, NechesMonthlyFlows.DSS, and NechesEvapPrecip.DSS. The *SIM/SIMD* input DSS file with monthly naturalized flows (*IN* records), monthly net evaporation-precipitation depths (*EV* records), daily flow pattern hydrographs (*DF* records), and SB3 EFS target series (*TS* records) has the filename NechesHYD.DSS. Simulation results generated in Chapters 9 and 10 are also recorded in DSS files. Selected simulation results from multiple simulations are combined in a single file with filename NechesSimulationResults.DSS.

<u>Daily and Monthly Versions of the Neches WAM</u>

The monthly authorized use and current use scenario Neches WAM datasets last updated by the TCEQ in 2012 were expanded as described in this report to develop new daily and modified monthly versions of the WAM. The initial monthly Neches WAM from which the work began is described in Chapter 2.

Environmental flow standards (EFS) established in 2011 [15] through the Senate Bill 3 (SB3) process are incorporated in both the daily and monthly versions of the WAM as explained in Chapter 7. The SB3 EFS are modeled in the daily authorized and current use versions of the WAM as instream flow *IF* record rights using the new environmental standard *ES* and pulse flow *PF* record features of the May/September 2019 *SIMD*. Daily SB3 EFS targets from a daily *SIMD* simulation are summed to monthly for inclusion as target series *TS* records in the time series DSS file read by *SIM* for a monthly simulation.

The June 2020 daily and modified monthly authorized and current use scenario versions of the Neches WAM resulting from the work documented by this report include the following DSS and DIS files common to monthly *SIM* and daily *SIMD* simulations and separate *SIM* and *SIMD* DAT files. An auxiliary daily input DIF files provides routing parameters that allow routing to optionally be employed.

NechesHYD.DSS − *IN* records for 20 control points contain the original monthly naturalized flows for 1940-1996 and extended monthly naturalized flows for 1997-2019. *EV* records for 12 control points contain the original monthly net reservoir surface evaporation less precipitation depths for 1940-1996 and extended evaporation less adjusted precipitation depths for 1997-2019. Daily flow pattern hydrographs for 17 control points are recorded on *DF* records. *TS* records of SB3 EFS instream flow targets at five control points were created from the aggregated monthly totals of the SB3 EFS daily instream flow targets computed in a daily *SIMD* simulation.

Neches3.DIS and Neches8.DIS − The unmodified full authorization versus current use scenario versions of the flow distribution DIS file contains the flow distribution *FD* and watershed parameter *WP* records used to distribute monthly naturalized flows from 20 primary to over 300 secondary control points the same with the daily versus monthly versions of the WAM.

Neches.DIF − Routing parameters for 19 reaches between the 20 primary control points are stored on *RT* records. A daily *SIMD* simulation can be performed optionally with or without routing.

Neches3D.DAT and Neches8D.DAT − The daily authorized use (run 3) and current use (run 8) DAT files expand the monthly DAT files last updated by the TCEQ in 2012 by replacing the SB3 EFS with sets of *IF*, *ES*, and *PF* records, adding flood control operations of Sam Rayburn Reservoir, and adding input records controlling disaggregation of monthly naturalized flows to daily and other daily features.

Neches3M.DAT and Neches8M.DAT − The DAT files last updated by the TCEQ in 2012 are modified as follows in the June 2020 update. Records added to the DAT files by the TCEQ in 2012 to model SB3 EFS are removed and replaced with target series *TS* records of instream flow targets computed in a daily simulation and stored in the DSS file referenced by five sets of *IF* and *TS* records in the DAT file.

Auxiliary DSS Time Series Data Files

The *SIM/SIMD* input file with filename NechesHYD.DSS stores hydrology time series (*IN*, *EV*, *DF* records) and target time series (*TS* records) data as described on the preceding page 5. This file can be called either the hydrology or the time series input file. The same single *SIM/SIMD* hydrology or time series input file with filename NechesHYD.DSS is read by both *SIM* and *SIMD* for both the authorized use and current use versions of the WAM.

This report is also accompanied by DSS files with the following filenames developed along with the file NechesHYD.DSS as described in the chapters indicated in parenthesis.

NechesDailyFlows.DSS	(Chapters 3 and 4)
NechesMonthlyFlows.DSS	(Chapters 3 and 5)
NechesEvapPrecip.DSS	(Chapter 6)
NechesSimulationResults.DSS	(Chapters 9 and 10)

The contents of these four time series data files are outlined in Tables 4.14, 4.15, 4.16, 5.2, 5.3, 6.8, 9.15, and 9.16 of Chapters 4, 5, 6, and 9. The first three files listed above were compiled in conjunction with developing the hydrology input file NechesHYD.DSS. The fourth file contains selected results from the simulations presented in Chapters 9 and 10. These four DSS files serve as appendices to this report.

These four auxiliary files like all DSS files are read with *HEC-DSSVue*, which provides flexible comprehensive capabilities for organizing, managing, and analyzing time series data. *HEC-DSSVue* facilitates convenient graphical and tabular displays and statistical analyses of these time series datasets. The datasets can also be efficiently modified within *HEC-DSSVue*. For example, daily time series can be aggregated to monthly or annual. Monthly time series can be uniformly divided to daily or converted to annual. Quantities can be switched between flow rates in cubic feet per second (cfs) or other units and period volumes in acre-feet or other units. With *HEC-DSSVue*, the DSS files become very conveniently managed appendices to this report.

The first three DSS files listed above compile data relevant to the improved and updated 1940-2019 hydrology for the Neches WAM. Model-users can access and explore the DSS datasets with *HEC-DSSVue* to develop a better understanding of Neches WAM hydrology. The DSS files can be used in future updates of the WAM hydrology. The datasets in these DSS files can also support other studies independently of the WRAP/WAM *SIM* and *SIMD* simulation models to explore river system hydrology and perform comparative analyses of stream flow characteristics.

WRAP simulation studies with the full authorization and current use versions of the WAM are presented in Chapters 9 and 10, respectively. The last DSS file listed above stores selected *SIM* and *SIMD* simulation results as discussed in Chapters 9 and 10.

CHAPTER 2
NECHES RIVER BASIN AND NECHES WAM

The Neches River Basin delineated in Figures 2.1 and 2.2 is approximately 200 miles in length with a drainage area of about 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 Basin is bordered by the Trinity River Basin to the west, the Sabine River Basin to the east, and the Neches-Trinity Coastal Basin to the south. The Neches River originates in Van Zandt County in East Texas and discharges to the Sabine Lake Estuary near Port Arthur. The 2010 population of the Neches River Basin of about 802,000 is projected by the Texas Water Development Board to increase by 34% by the year 2030. Average annual rainfall ranges from 41 inches at the headwaters of the basin to 57 inches at the outlet.

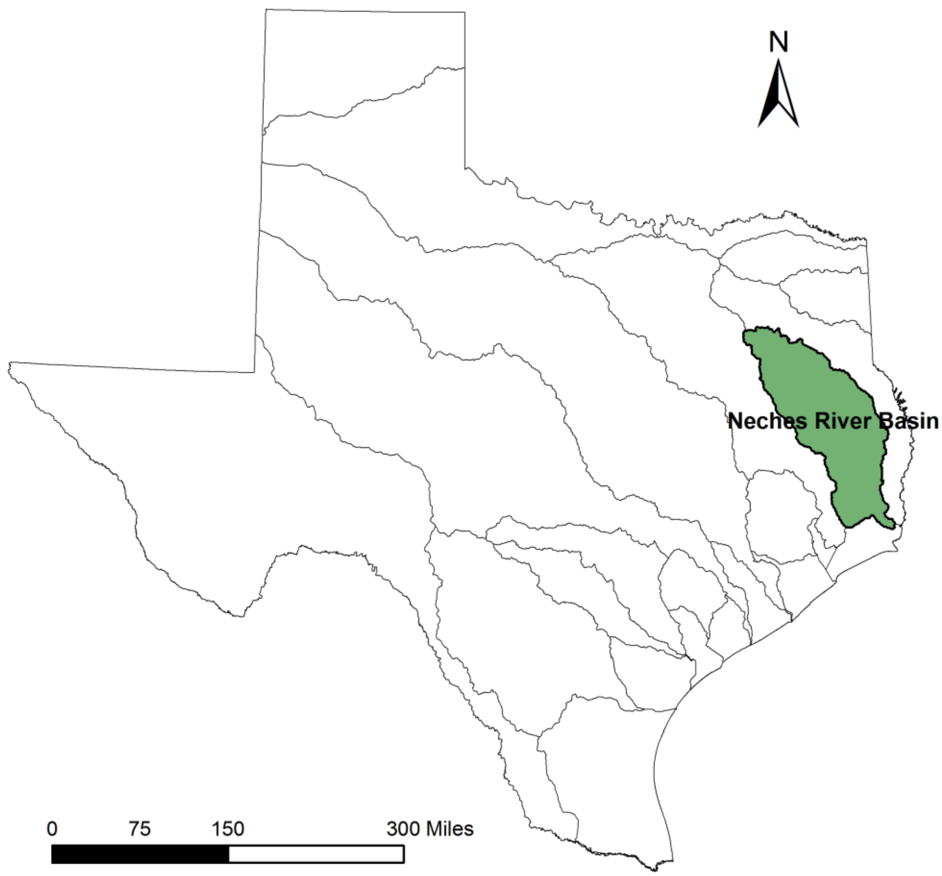

Figure 2.1 Location of Neches River Basin Relative to Other River Basins of Texas

Authorized and Current Use Versions of the Neches WAM Last Updated in 2012

The original Neches WAM was developed by Brown & Root Services and other partnering consulting engineering firms under contract with the Texas Natural Resource Conservation Commission (TNRCC), now renamed the TCEQ, as documented by a 2001 report titled *Neches River Basin Water Availability Study* [9]. The TCEQ has periodically updated the Neches WAM water rights data files along with the WAMs for the other river basins of the state.

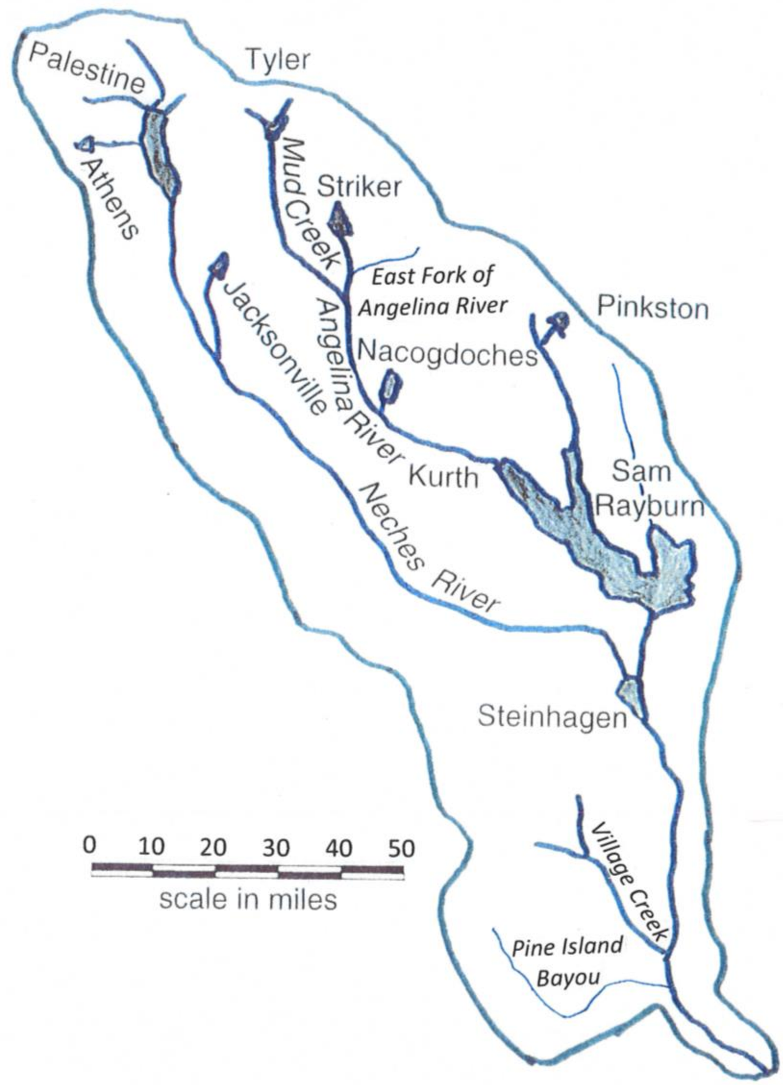

Figure 2.2 Major Tributaries and Largest Reservoirs in the Neches River Basin

The work documented in the present 2020 report started with the full authorization dataset last updated by the TCEQ on October 1, 2012 and the current conditions scenario dataset last updated by the TCEQ on September 9, 2012. These two datasets were downloaded from the TCEQ WAM website in January 2020 for use in this work. The Neches WAM files for the authorized use scenario (run 3) and current use scenario (run 8) have the filename roots Neches3 and Neches8, respectively, in the TCEQ WAM System. The labels run 3 and run 8 for the authorized and current use scenarios date back to the 1997-2002 creation of the WAM system [1].

The original January 1940 through December 1996 hydrologic period-of-analysis was extended through December 2019 in the present project expanding the Neches WAM. The hydrology input dataset for all versions of the Neches WAM include monthly naturalized flows (*IN* records) at 20 control points and net reservoir surface evaporation less precipitation depths (*EV* records) assigned to 12 control points. The naturalized flows at 20 control points are distributed to over 350 secondary control points based on specifications provided on flow distribution *FD* and watershed parameter *WP* records in the flow distribution DIS file.

The *WRAP* simulation model *SIM* prints a listing to its message MSS file of the number of various system components found in the input DAT and DIS files. The *SIM* counts in Table 2.1 are from the October 2012 authorized use and September 2012 current use datasets and preceding April 2010 authorized use dataset. Senate Bill 3 (SB3) environmental flow standards (EFS) are included in datasets updated in 2012 but are not in the 2010 dataset. Datasets with and without the SB3 EFS are compared in Table 2.2.

Table 2.1
Number of System Components in Neches WAM Datasets

Latest Update of Datasets Water Use Scenario Filename Root of DAT and DIS Files	Apr 2010 Authorized Neches3	Oct 2012 Authorized Neches3	Sep 2012 Current Neches8
total number of control point *CP* records	306	378	395
number of primary control points	20	20	20
control points with evap-precip *EV* records	12	12	12
number of reservoirs as counted by *SIM*	180	180	203
number of *WR* record water rights	328	399	385
number of instream flow *IF* record rights	19	75	78
number of system water rights	9	29	26
number of sets of water use *UC* records	33	43	43
number of *FD* records in DIS file	273	273	289

Table 2.2
Input Records in WAM Datasets With and Without Original SB3 EFS *IF* Record Rights

With or Without SB3 EFS	With SB3 EFS		Without SB3 EFS	
Latest Update of Datasets	Oct 2012	Sep 2012	Oct 2012	Sep 2012
Water Use Scenario	Authorized	Current	Authorized	Current
Filename	Neches3	Neches8	Neches3	Neches8
total number of control points	378	395	326	343
number of primary control points	20	20	20	20
control points with *EV* records	12	12	12	12
number of reservoirs	180	203	180	203
number of *WR* record water rights	399	385	334	320
number of *IF* record rights	75	78	20	23
number of system water rights	29	26	9	6
number of sets of *UC* records	43	43	33	33
number of *FD* records in DIS file	273	289	273	289

SB3 EFS [15] were adopted by the TCEQ effective May 2011 at five USGS gages in the Neches River Basin as discussed in Chapter 7. The 2010 version does not include the SB3 EFS. The full authorization dataset last updated by the TCEQ on October 1, 2012 and the current

conditions scenario dataset last updated by the TCEQ on September 9, 2012 reflect addition of *IF* record instream flow rights to model the environmental flow standards using monthly *SIM* simulation features available in 2012. The SB3 EFS at the five control points (NENE, NERO, ANAL, NEEV, VIKO) are modeled using additional *WR*, *IF*, *UC*, *WS*, *TO*, *PX*, *FS*, *CP*, and *CI* input records. The SB3 EFS added to the 2012 versions of the authorized and current use simulation input DAT files by the TCEQ during 2012 were removed for the DAT files compiled for the work documented by this June 2020 report.

Results from authorized and current use simulations with the SB3 EFS removed are plotted in Figures 2.3, 2.4, and 2.5. However, since the *IF* record rights modeling the SB3 EFS are the most junior water rights in the WAM, reservoir storage contents and regulated flows at the outlet are not affected by the SB3 EFS. Unappropriated flows at some control points are affected.

The summation of the simulated end-of-month storage contents for the 180 and 203 reservoirs in the full authorization and current use datasets are compared in Figure 2.3. The naturalized flows are the same in the authorized and current use datasets. The naturalized and simulated regulated flows for at control point NESL representing the outlet of the Neches River at Sabine Lake are plotted in Figures 2.4 and 2.5 for the full authorization and current use scenarios, respectively.

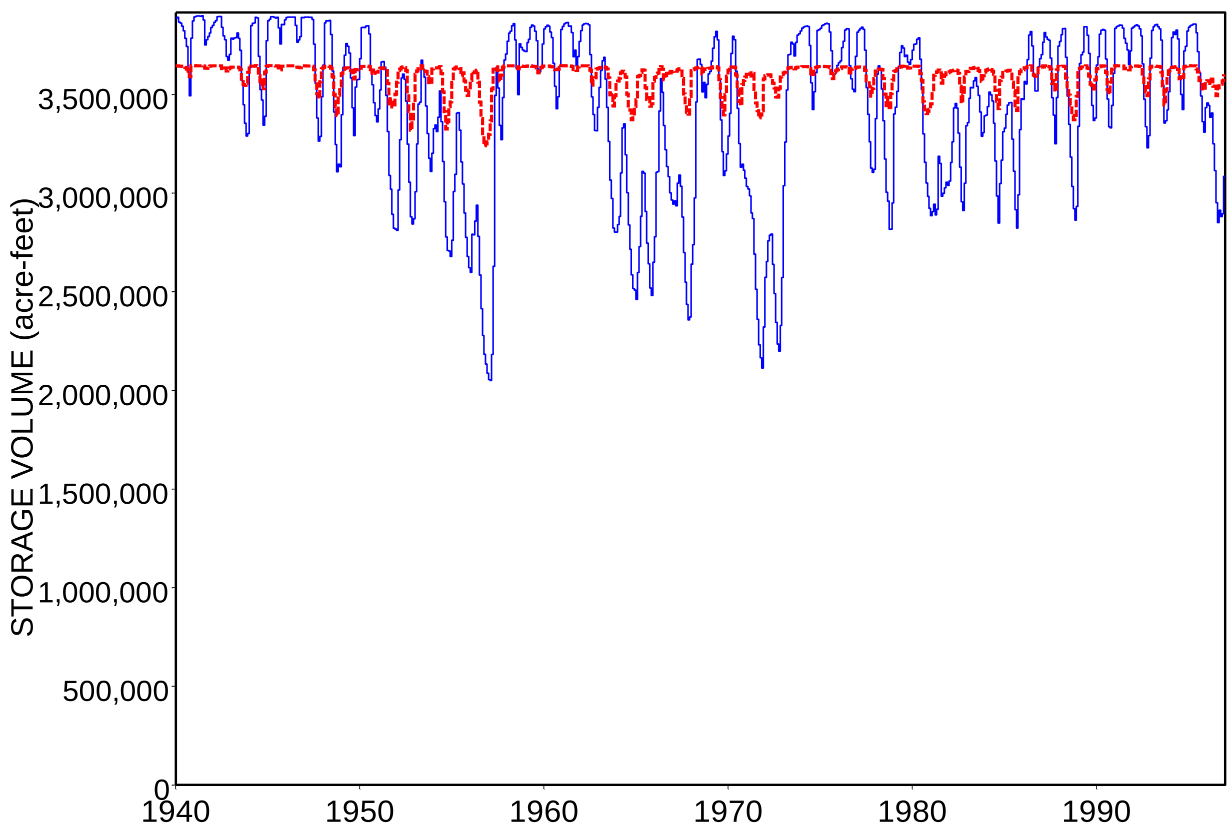

Figure 2.3 Sum of Simulated End-of-Month Storage Contents for All Reservoirs in Authorized Use (blue solid line) and Current Use (red dashed line) Versions of Neches WAM

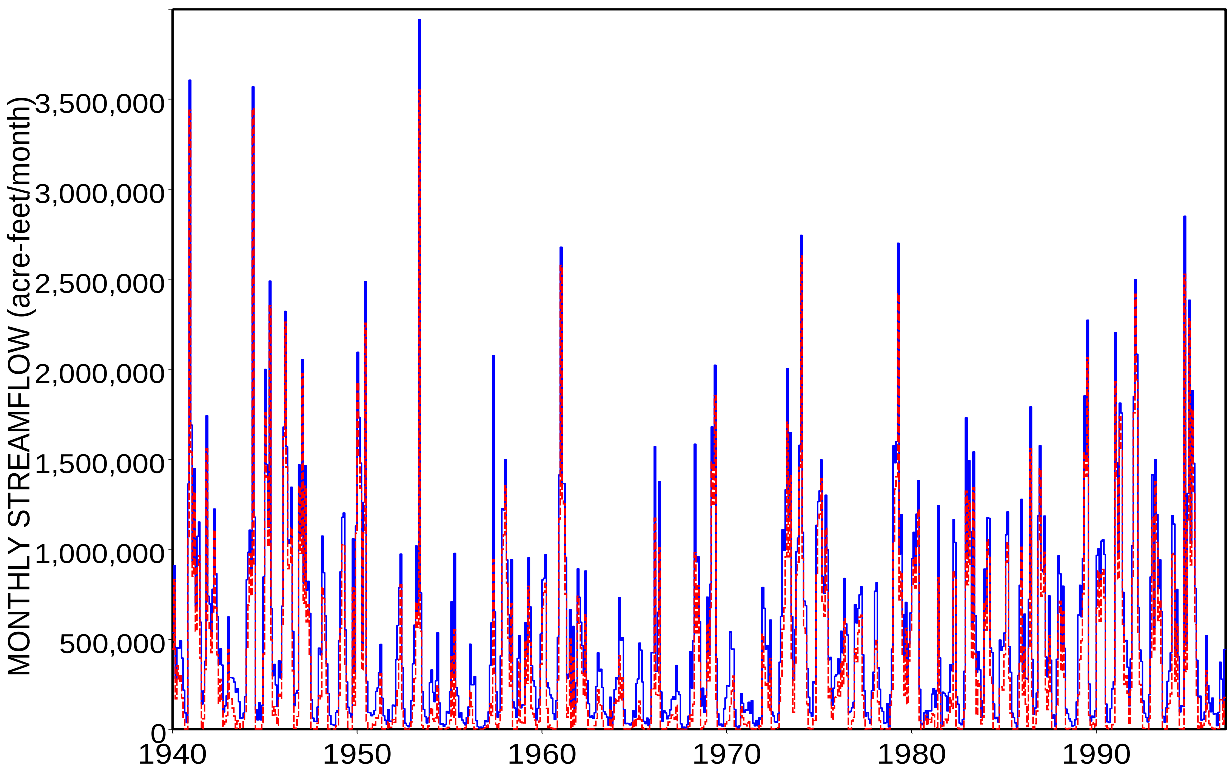

Figure 2.4 Monthly Naturalized (blue solid line) and Regulated (red dashed line) Flows at Outlet (control point NESL) in Authorized Use Version of Neches WAM

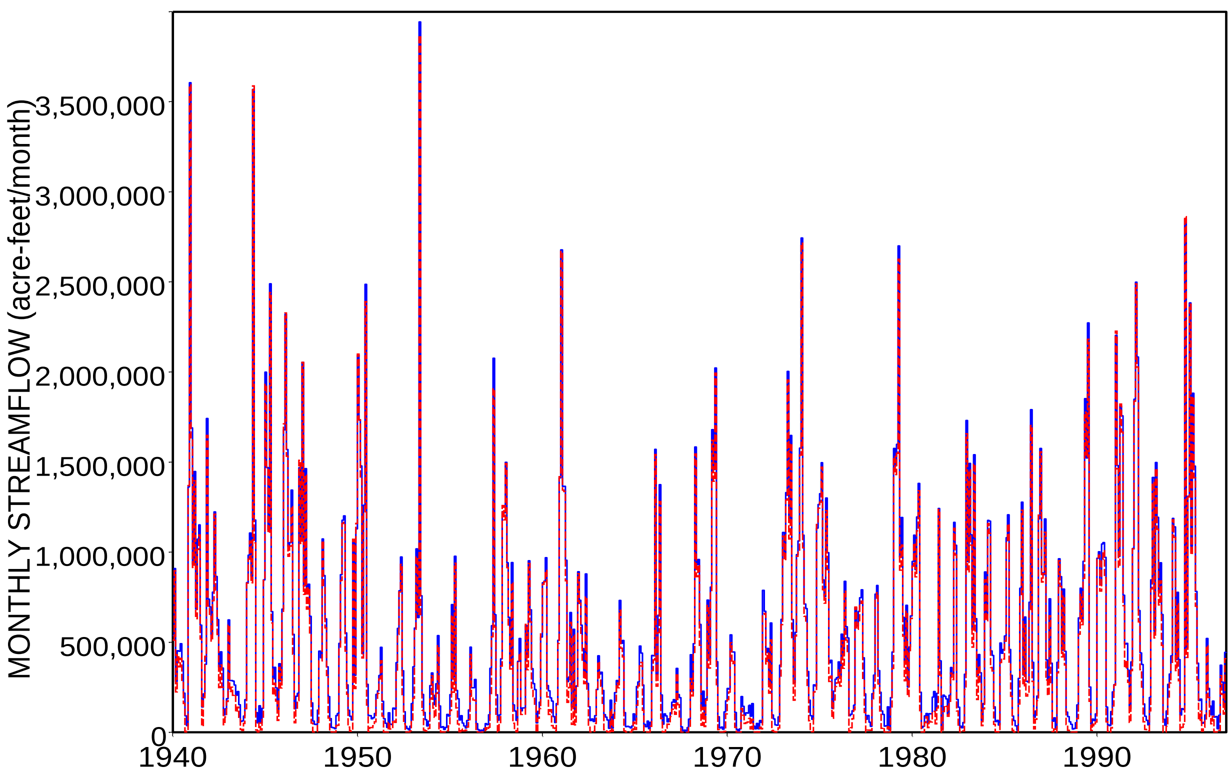

Figure 2.5 Monthly Naturalized (blue solid line) and Regulated (red dashed line) Flows at Outlet (control point NESL) in Current Use Version of Neches WAM

Water Rights and SB3 Environmental Flow Standards

Table 2.3 provides a summary of diversion rights in the October 2012 authorized use scenario WAM with the SB3 EFS removed. The annual authorized diversion amounts AMT from field 3 of the *WR* record are summed in Table 2.3 by type of water use. Hydroelectric power generation at Sam Ray Reservoir is generated without a hydropower water right.

Table 2.3
Water Rights Summary by Type of Use for Full Authorization Scenario

Type of Use	Number of Rights	Permitted Diversions	Range of Priority Dates From	To
		(acre-feet/year)		
municipal	29	523,077	1915	2000
industrial	49	751,607	1914	1990
irrigation	119	444,189	1913	1994
mining	6	1,287	1948	1977
recreation	99	0	1900	2002
other	32	10,271	1969	2010
Total	334	1,730,431		

Summaries of *WR* record water rights by control point created with a *TABLES* 1SUM record for the full authorization and current use scenarios, without the SB3 EFS, are tabulated in Tables 2.4 and 2.6, respectively. The annual diversion targets (AMT in *WR* record field 3) of the 36 water rights with of permitted amounts of 1,000 acre-feet or greater sum to a total of 1,7717,420 acre-feet/year, as shown in Table 2.4. The total permitted annual diversion amount for these 36 latgest diversion rights are 99.25% of the total summation of 1,730,431 acre-feet/year of the annual diversion targets of the 334 *WR* records in the full authorization DAT file.

The annual instream flow targets (AMT in *IF* record field 3) for the 20 *IF* records in the authorized use DAT file and 23 *IF* records in the current use DAT file are listed in Tables 2.5 and 2.7. The *IF* records for the SB3 EFS are not included in these summaries.

Table 2.4
Control Point Summary of *WR* Record Water Rights in Full Authorization DAT File
(36 WR Records with Annual Diversions of 1,000 acre-feet or Greater)

Control Point	Number Rights	Annual Diversion	Number Reservoirs	Storage Capacity	Priorities Range From	To
				(acre-feet)		
3256N	2	8,500	6	35,773	19550117	19550117
3254N1	2	212,400	2	411,959	19560430	19690915
3274N2	2	6,000	35	36,520	19230324	19550613
4853A	2	40,325	3	87,286	19471219	19471219
4537A	3	85,507	12	198,410	19851122	19851122
4847A	3	20,600	3	26,990	19551205	19680205

4864A	1	22,000	5	43,048	19700105	19700105
4404A	1	3,800	15	3,004,700	19720702	19720702
4411A1	1	28,000	0	0	19631112	19631112
4411N2	4	792,000	0	0	19631112	19631112
3237N	1	1,500	5	2,216	19781010	19781010
3254N2	2	25,310	16	10,472	19830425	19841001
4384N1	2	3,000	12	2,885	19661024	19830418
5555A1	1	10,000	4	153	20041103	20041103
4415N1	1	6,570	0	0	19150405	19150405
4411N4	2	55,516	14	3,103	19241231	19241231
4415N2	2	49,897	1	100	19250108	19250108
5508N	1	1,035	1	64	19941209	19941209
4411N5	1	107,108	0	0	19130812	19130812
4411N6	1	219,252	0	0	19131108	19131108
439341	1	19,100	9	27,298	19570905	19570905
Subtotal	36	1,717,420	180	3,904,100	19130812	20041103
Total	334	1,730,431	180	3,904,100	19001231	20101231

Table 2.5
Control Point Summary of *IF* Record Instream Flow Rights in Full Authorization DAT File
With SB3 Environmental Flow Standards Removed

Control Point	Number Rights	Annual Target (ac-ft/yr)	Priorities Range From	Priorities Range To
4393A1	1	4,344	19570905	19570905
5585A	1	57,196	19970430	19970430
575731	1	145	20020101	20020101
5015N	1	24	19850923	19850923
5184N	1	724	19880613	19880613
5228	1	140,218	20011023	20011023
3254N2	1	0	19670309	19670309
4370N	1	362	19830606	19830606
4094NN	1	2,896	19840110	19840110
4094N	1	47,792	19840110	19840110
4356A	1	7,238	19830418	19830418
5314A1	1	5,067	19900930	19900930
5629A	1	16,991	19991002	19991002
5134A2	1	81	19870526	19870526
5134A3	1	161	19870526	19870526
5555A1	2	6,664	19960709	20041103
4409A	1	1,095	20000221	20000221
5508N	1	361	19941209	19941209
NEBA	1	289,785	20010703	20010703
Total	20	581,144	19570905	20041103

Table 2.6
Control Point Summary of *WR* Record Water Rights in Current Use DAT File
(20 WR Records with Annual Diversions of 1,000 acre-feet or Greater)

Control Point	Number Rights	Annual Diversion	Number Reservoirs	Storage Capacity (acre-feet)	Priorities Range From	To
3254N1	1	10,849	19	414,612	19560430	19560430
3274N2	1	1,000	37	36,461	19230324	19230324
4853A	2	18,582	15	83,354	19471219	19471219
4847A	2	13,074	3	22,648	19551205	19551205
4864A	1	8,418	5	40,157	19700105	19700105
4404A	1	2,885	19	2,975,058	19720702	19720702
4411N2	2	141,558	0	0	19631112	19631112
4384N1	1	1,324	13	2,935	19661024	19661024
5555A1	1	10,000	4	153	20041103	20041103
4415N1	1	6,570	0	0	19150405	19150405
4411N4	2	55,516	21	3,534	19241231	19241231
4415N2	2	9,183	0	0	19250108	19250108
4411N5	1	107,108	0	0	19130812	19130812
4411N6	1	113,290	0	0	19131108	19131108
439341	1	11,137	10	25,959	19570905	19570905
Subtotal	20	510,494	203	3,656,259	19130812	20041103
Total	320	519,666	203	3,656,259	19001231	20101231

Table 2.7
Control Point Summary of *IF* Record Instream Flow Rights in Current Use DAT File
With SB3 Environmental Flow Standards Removed

Control Point	Number Rights	Annual Target (ac-ft/yr)	From	To
15676	1	57,025	20000801	20000801
4393A1	1	4,344	19570905	19570905
5585A	1	57,196	19970430	19970430
575731	1	145	20020101	20020101
5015N	1	24	19850923	19850923
5184N	1	724	19880613	19880613
5228	3	280,436	19910731	20011023
3254N2	1	0	19670309	19670309
4370N	1	362	19830606	19830606
4094NN	1	2,896	19840110	19840110
4094N	1	47,792	19840110	19840110
4356A	1	7,238	19830418	19830418
5314A1	1	5,067	19900930	19900930
5629A	1	16,991	19991002	19991002

5134A2	1	81	19870526	19870526
5134A3	1	161	19870526	19870526
5555A1	2	6,664	19960709	20041103
4409A	1	1,095	20000221	20000221
5508N	1	361	19941209	19941209
NEBA	1	289,785	20010703	20010703
Total	23	778,387	19570905	20041103

Reservoirs

The 180 reservoirs included in the April 2010 and October 2012 authorized use scenario Neches WAM include the 13 major reservoirs listed in Tables 2.8 and 2.9, which include all reservoirs that have permitted storage capacities exceeding 5,000 acre-feet. The total permitted conservation storage capacity of 3,852,160 acre-feet of the 13 major reservoirs listed in the tables account for 98.7 percent of the total storage capacity of 3,904,100 acre-feet in the 180 reservoirs in the authorized use scenario dataset. The total conservation storage capacity of 3,601,935 acre-feet of the 12 existing major reservoirs listed in Table 2.8 account for 98.5 percent of the total storage capacity of 3,656,259 acre-feet in the 203 reservoirs in the current use scenario dataset.

The locations of the 13 major reservoirs are shown on the maps of Figures 2.2 and 2.6. The numbers in the first column of Table 2.9 refer to the reservoir identifiers in Figure 2.6. The reservoirs are listed in descending order of permitted water supply storage capacity in Table 2.9 along with the WAM reservoir and control point identifiers. Tyler Reservoir with two dams on two streams is treated in the WAM datasets and Tables 2.8 and 2.9 as two reservoirs.

Table 2.8
Major Reservoirs in the Neches River Basin

Reservoir	Dam	Stream	Initial Impound	Watershed Area	Conservation Capacity Authorized	Conservation Capacity Current
				(sq miles)	(acre-feet)	(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	–

Figure 2.6 Major Tributaries and Largest Reservoirs in the Neches River Basin

Table 2.9
Reservoir Identification Numbers for the Map of Figure 2.6 and WAM Identifiers

Map ID	Reservoir	Reservoir Identifier	Control Point Identifier	Authorized Capacity) (acre-feet)
1	Sam Rayburn Reservoir	RAYBRN	4411A1	2,898,200
2	Lake Palestine	PALEST	3254N1	411,840
3	Lake Columbia	COLUMB	4537A	195,500
4	B.A. Steinhagen Lake	STEINH	4411N2	94,250
5	Lake Tyler (East)	TYLERE	4853B	44,000
6	Lake Tyler (West)	TYLERW	4853A	43,100
7	Lake Nacogdoches	NACH	4864A	42,318
8	Lake Athens	ATHENS	3256N	32,840
9	Lake Jacksonville	JACKSN	3274N2	30,500
10	Lake Striker	STRIKR	4847A	26,960
11	Lake Kurth	KURTH	439341 & 4393A1	16,200
12	Lake Naconiche	NACKNK	5585A	9,072
13	Pinkston Lake	PINKST	4404A	7,380

Columbia Reservoir is included in the authorized use scenario dataset but is not included in the current use scenario dataset because, though authorized by a water right permit, the project has not yet been constructed.

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, respectively. 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 Nacodoches Counties Water Control and Improvement District No. 1, provides water for steam-electric power plant cooling 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. The off-channel Lake Kurth at WAM control point 439341 can make streamflow depletions from the Angelina River at control point 4393A1.

USACE Sam Rayburn and B. A. Steinhagen Reservoirs

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. Sam Rayburn Reservoir contains 79.3 percent of the total conservation storage capacity of the 203 reservoirs in the current use scenario Neches WAM. B. A. Steinhagen Reservoir (Town Bluff Dam) has 1.8 percent of the total conservation storage capacity of the 203 reservoirs. Sam Rayburn Reservoir provides almost all of the total volume of flood control storage capacity in the Neches River Basin. The conservation storage capacity of Sam Rayburn Reservoir refers to the amount of water that is stored for hydroelectric power generation and municipal, industrial, 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 and City of Lufkin have contracted with the Corps of Engineers for water supply regulated by the two reservoirs. Water released through the hydropower turbines is diverted from the Neches River downstream for water supply. The Lower Neches Valley Authority is the primary nonfederal water supply sponsor. The City of Lufkin has contracted for a small amount of the conservation storage capacity of Sam Rayburn Reservoir but has not yet constructed facilities for diverting the water.

B.A. Steinhagen Reservoir is located immediately downstream and acts 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.

The USACE Fort Worth District owns and operates the two-reservoir system. The Lower Neches Valley Authority in Beaumont, Texas is the nonfederal sponsor that has contracted for most of the water supply. The Southwestern Power Administration of the U. S. Department of Energy markets the hydroelectric energy generated to the Sam Rayburn Municipal Power Agency for distribution to its customers in Jasper, Liberty, and Livingston, Texas and Vinton, Louisiana.

Water surface elevation plots downloaded from the USACE water management information website (https://www.swf-wc.usace.army.mil/cgi-bin/rcshtml.pl?csrf=M43Rz61hnn) are presented as Figures 2.7 and 2.8. The water surface elevations of Sam Rayburn and Steinhagen Reservoirs from initial impoundment through mid-January 2020 are shown. Dates of occurrence of historical maximun high and minium low storage levels are also labeled.

Daily water budget quantities for the two reservoirs were also downloaded from the USACE water management information website for use in the investigations of observed and naturalized flows discussed in Chapter 4. The USACE website provides measured daily reservoir storage elevations and release rates and also climatic data. Reservoir inflows are estimated in USACE water budget computations considering observed releases and storage changes and computed evaporation.

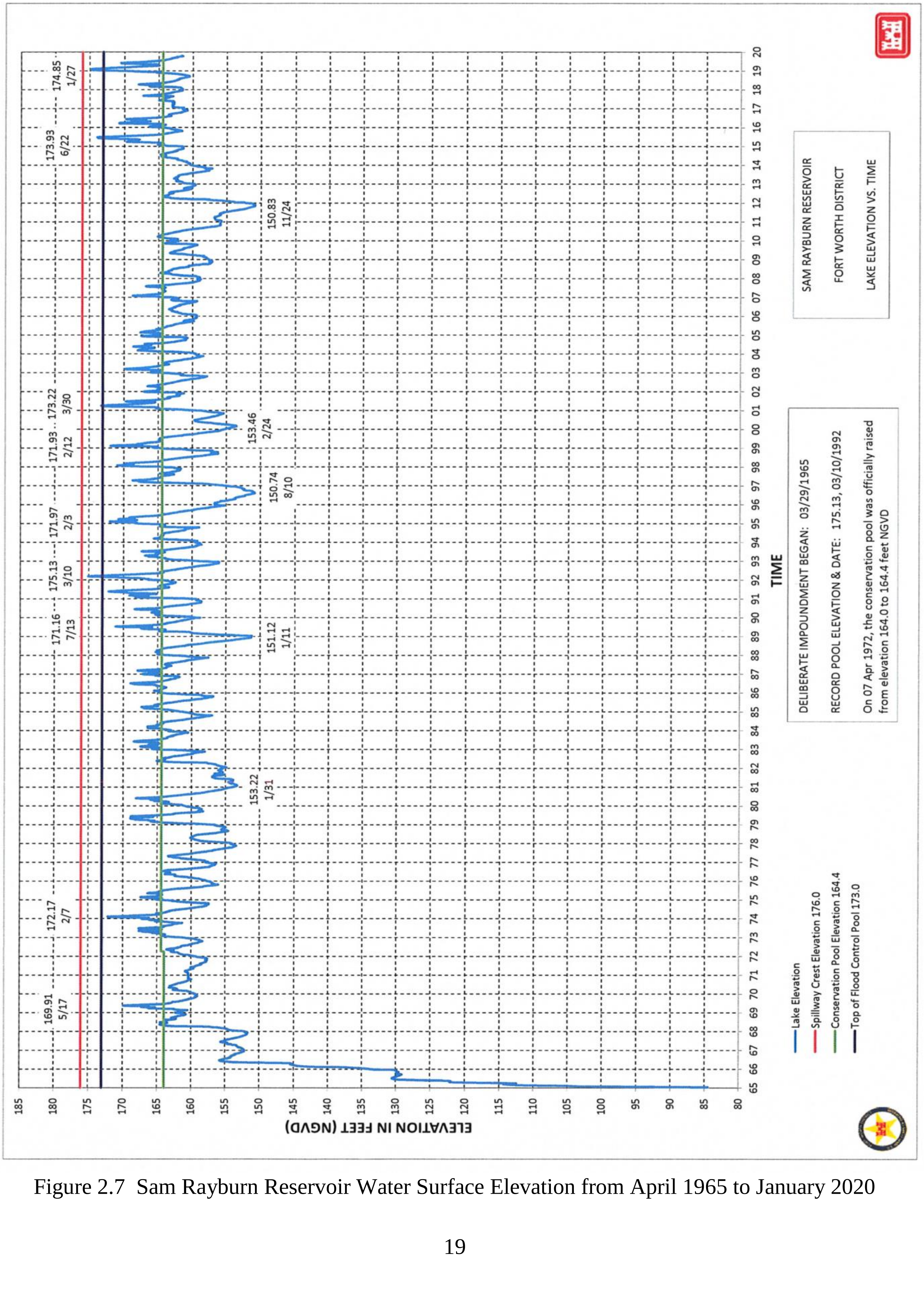

Figure 2.7 Sam Rayburn Reservoir Water Surface Elevation from April 1965 to January 2020

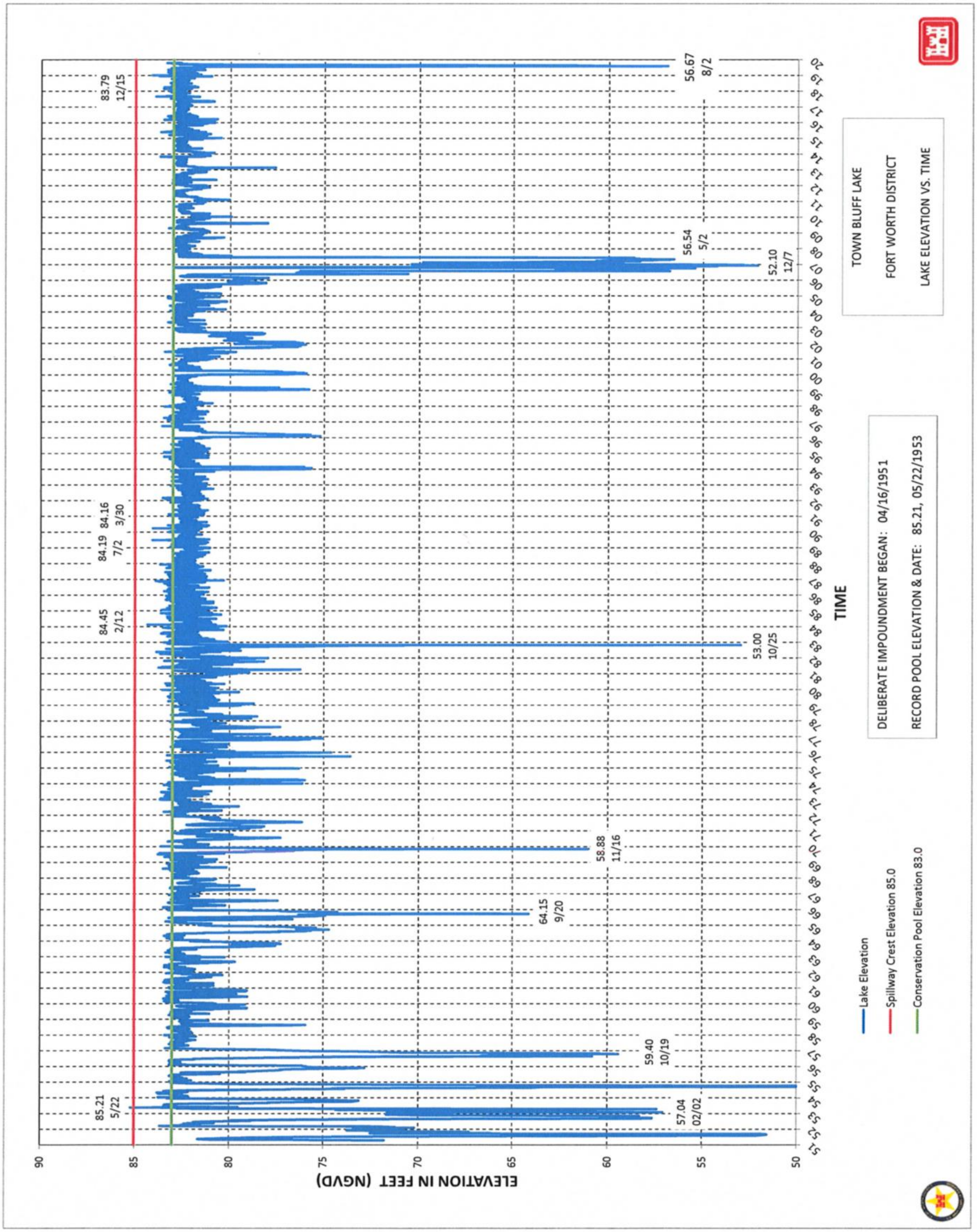

Figure 2.8 B.A. Steinhagen Reservoir Water Surface Elevation from April 1951 to January 2020

Texas Water Development Board (TWDB) Reservoir Database

The reservoirs listed in Table 2.10 are described at the TWDB website cited in the table heading. The water surface elevation, storage volume, and water surface area at the top of conservation pool shown in the table are replicated from the TWDB website. The first column of the table refers to Figure 2.6. The Figure 2.9 plot of the summation of storage contents in the reservoirs listed in Table 2.10 and the plots of Figures 2.10 through 2.16 of the storage contents of individual reservoirs from initial impoundment through the near the present (January 2020) are copied from the following website. https://www.waterdatafortexas.org/reservoirs/basin/neches

Table 2.10
Reservoir Information
http://www.twdb.texas.gov/surfacewater/rivers/reservoirs/

Map ID	Reservoir	Watershed Area (sq miles)	Top Pool Elevation (feet)	Storage Capacity (acre-feet)	Surface Area (acres)
1	Sam Rayburn	3,449	164.4	2,876,033	112,590
2	Palestine	839	345	367,312	23,112
4	B.A. Steinhagen	7,570	83	69,259	10,235
5 & 6	Tyler	107	375.4	77,284	4,714
7	Nacogdoches	89	279.0	39,523	2,212
8	Athens	21.6	440.0	29,475	1,799
9	Jacksonville	34	422	26,732	1,164
10	Striker	182	293	22,865	1,920
11	Kurth	4	197.5	14,769	726
13	Pinkston	14.3	298	7,380	523

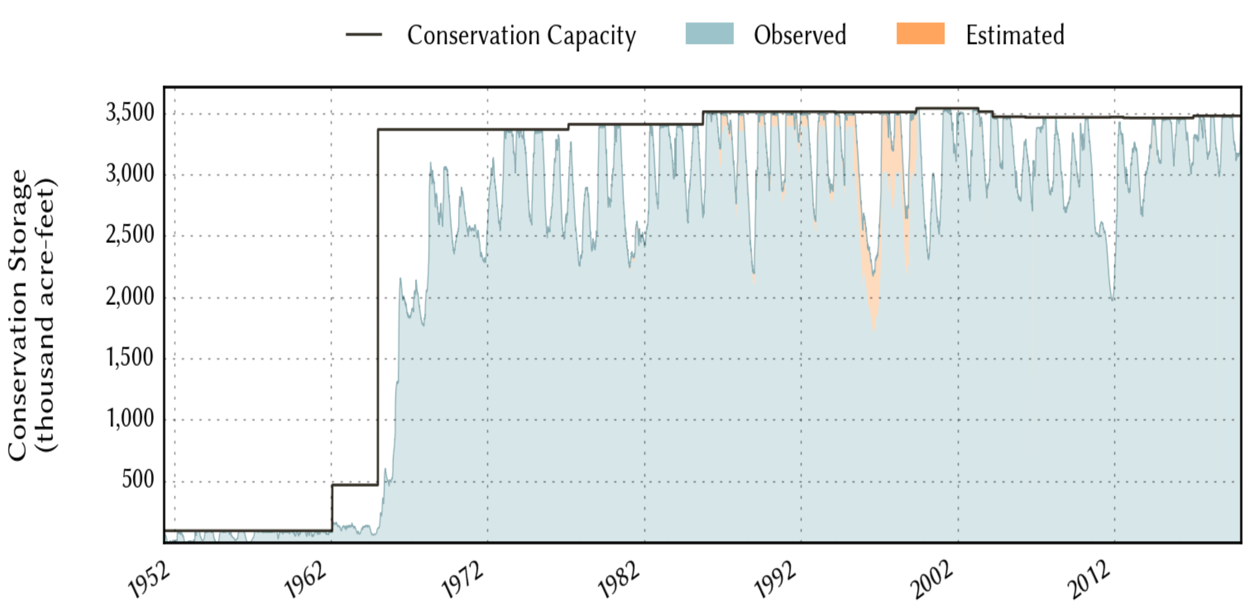

Figure 2.9 Summation of Storage Contents of the Reservoirs Listed in Table 2.10

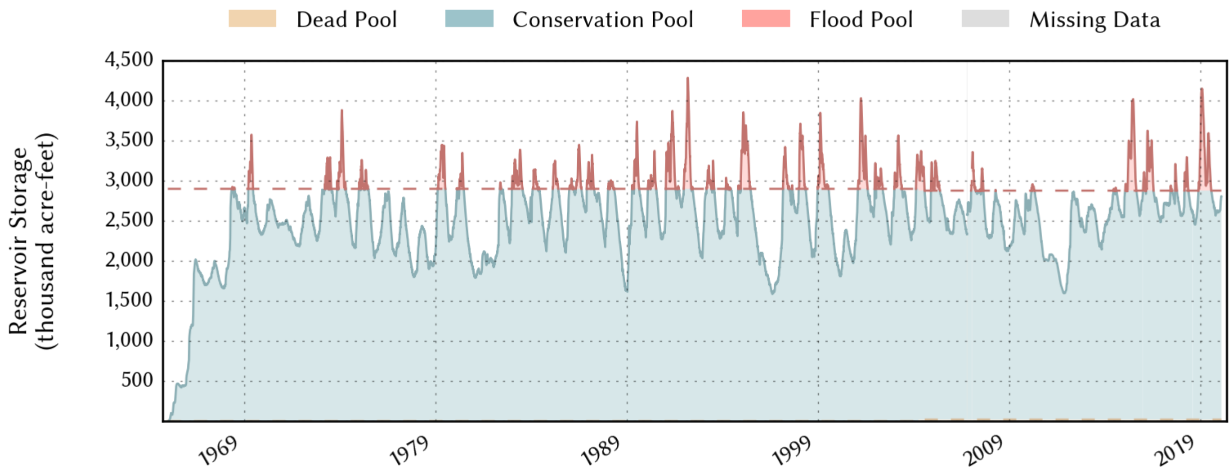

Figure 2.10 Storage Contents of Sam Rayburn Reservoir

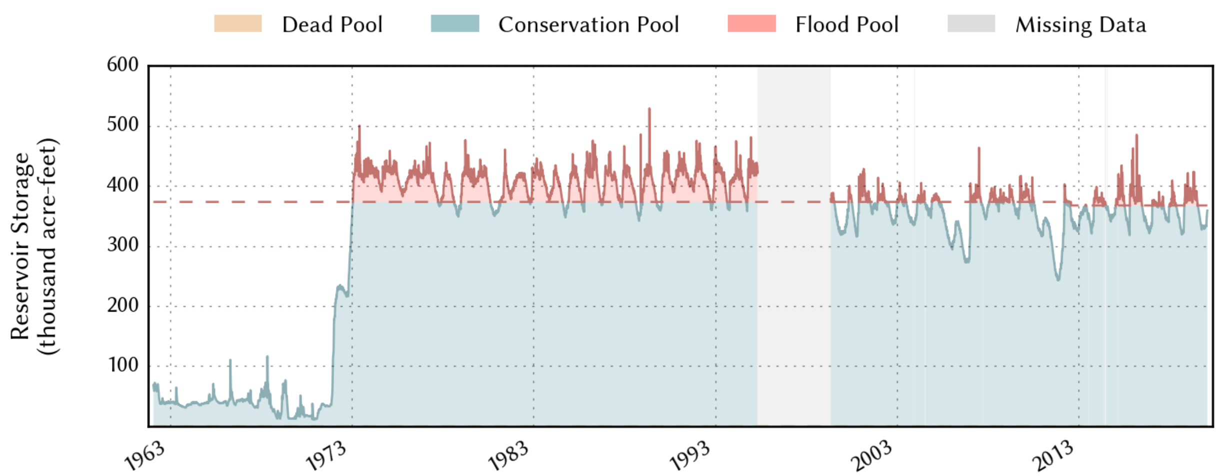

Figure 2.11 Storage Contents of Lake Palestine

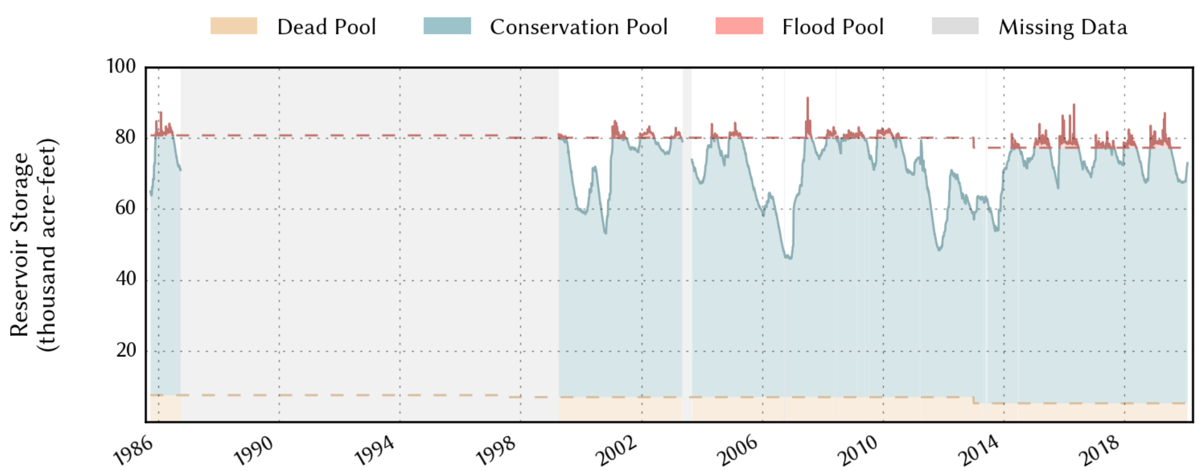

Figure 2.12 Storage Contents of Lake Tyler

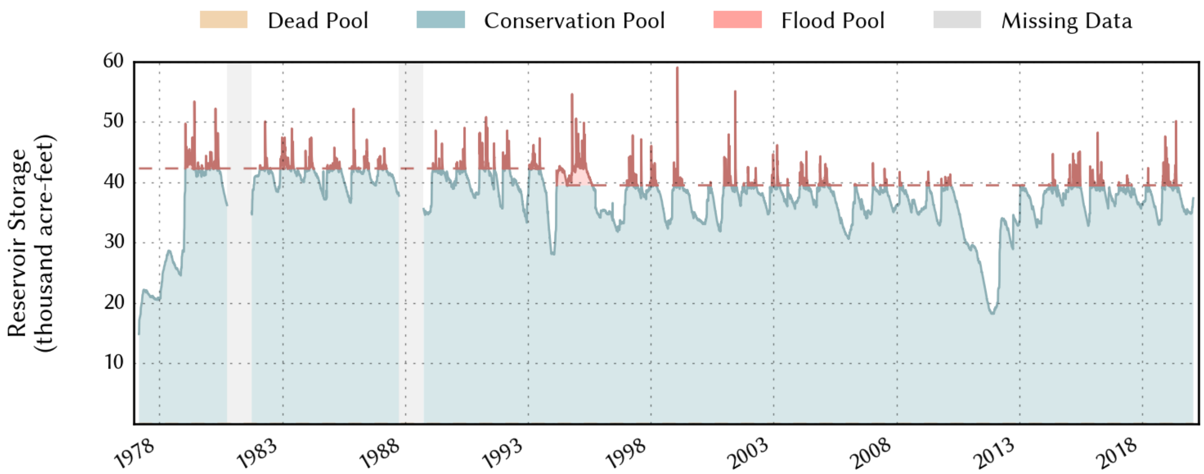

Figure 2.13 Storage Contents of Lake Nacodoches

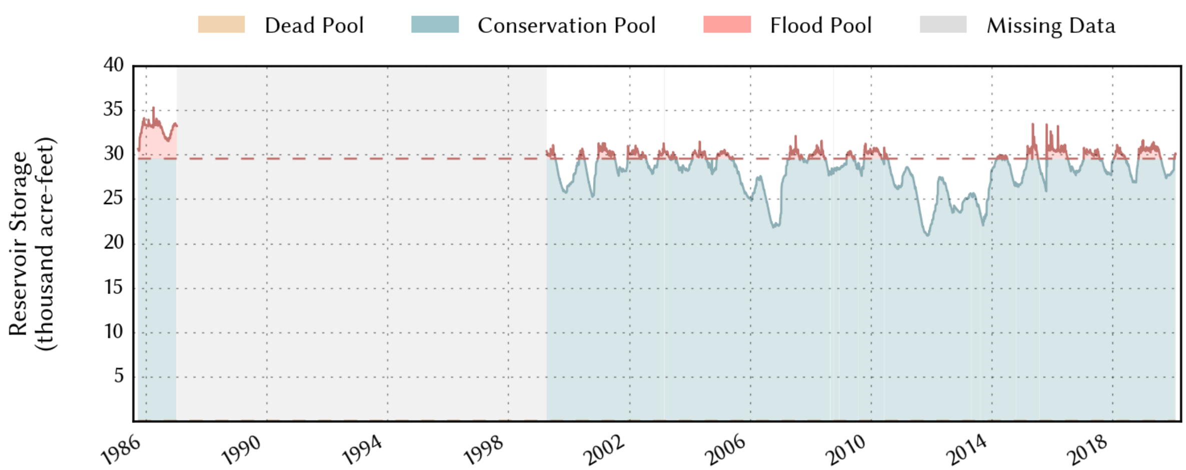

Figure 2.14 Storage Contents of Lake Athens

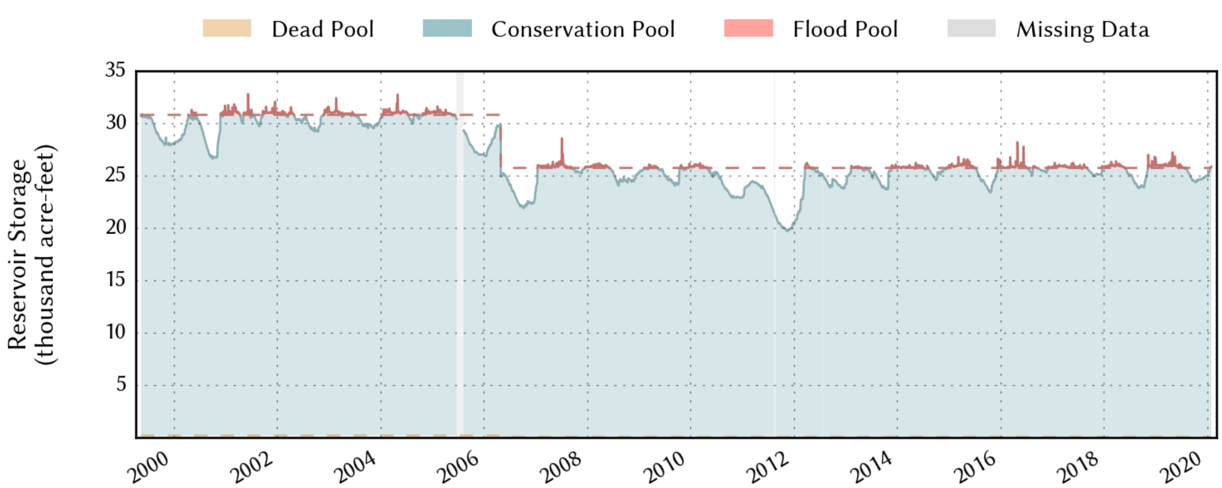

Figure 2.15 Storage Contents of Lake Jacksonville

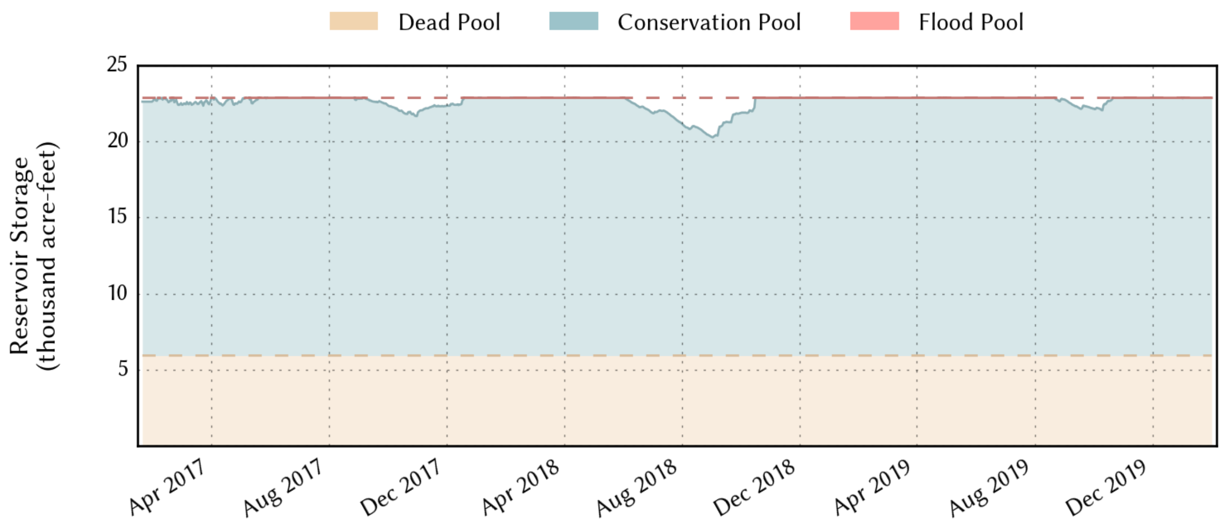

Figure 2.16 Storage Contents of Lake Striker

The TWDB reservoir database is derived from measurements recorded by the USGS and reservoir operators. The USGS NWIS website includes measurements of daily reservoir water surface elevations (in feet) and storage volumes (in acre-feet), including quantites for the seven reservoirs in the Neches River Basin listed in Table 2.11. The periods-of-analysis for the observed daily storage volumes and surface elevations at these seven gages are listed in Table 2.11.

Table 2.11
Periods-of-Record for Daily Reservoir Volumes and Surface Elevations at USGS Gages

Reservoir	USGS Gage Identifier	Period-of-Analysis Storage Volume	Period-of-Analysis Surface Elevation
Athens	08031290	Oct 1985 – Sep 2002	Apr 1999 – present
Palestine	08031400	Feb 1962 – Sep 2009	May 1999 – present
Jacksonville	0803220	May 1999 – Sep 2010	May 1999 – present
Tyler	08034000	Oct 1985 – Sep 2002	Apr 1999 – present
Nacogdoches	08036700	Mar 1977 – present	Oct 1996 – present
Sam Rayburn	08039300	Jan 1965 – Sep 2010	Jun 1988 – present
B. A. Steinhagen	08040000	May 1951 – Sep 2010	Oct 1987 – present

Water supply diversion rights associated with reservoirs are listed in Table 2.12 [16]. Water rights for run-of-river water supply diversions without reservoir storage are not included in Table 2.12. The authorized annual diversions listed in the last column total 1,268,137 acre-feet/year. Diversions from Sam Rayburn and B.A. Steinhagen Reservoirs and Lake Palestine account for 83.4 percent of the total permitted diversions listed in Table 2.12. Lake Columbia is permitted but has not been actually constructed. The other permitted reservoirs actually exist.

Table 2.12
Water Supply Diversion Rights Associated with the Reservoirs

Reservoir	Water Right	Priority Date	County	Permitted Diversion (acre-feet/year)
Lakes Sam Rayburn and Steinhagen System	CA-4411	multiple	Jasper	820,000
Lake Palestine System	CA-4853	01/05/1970 06/27/1977	Anderson	238,110
Lake Tyler/Tyler East	CA-4853	multiple	Smith	40,325
Lake Nacogdoches	CA-4864	05/24/1988	Nacogdoches	22,000
Striker Creek Lake	CA-4847	01/10/1984	Rusk	20,600
Lake Kurth	CA-4393	09/01/1957	Angelina	19,100
Lake Athens	CA-3256	01/17/1955	Henderson	8,500
Lake Jacksonville	CA-3274	06/13/1955	Cherokee	6,200
Pinkston Reservoir	CA-4404	02/07/1972	Shelby	3,800
Bellwood Lake	CA-3237	11/10/1915 10/10/1978	Smith	2,200
San Augustine City	CA-4409	11/01/1957	San Augustine	1,285
Lake Timpson	CA-4399	05/09/1955	Shelby	350
Rusk City Lake	CA-4219	06/01/1982	Cherokee	160
Lake Columbia	CA-4537	01/22/1985	Cherokee	85,507

Water Use

The summaries of estimated annual water use tabulated in Tables 2.13 and 2.14 were compiled from the historical water use data collected by the TWDB annually, which is available at the website: http://www.twdb.texas.gov/waterplanning/waterusesurvey/estimates/index.asp. The data is for water used within the Neches River Basin. Amounts supplied from the basin are significantly different than amounts used within the basin due to large interbasin transfers of water. Diversions from the Neches River and tributaries supply users in Jefferson County in the adjoining Trinity-Neches coastal basin that includes the cities of Beaumont and Port Arthur.

The annual water use from surface versus groundwater sources is shown in Table 2.13. About 52.5% of the water use in the basin is supplied from surface water sources and 47.5% from groundwater. Annual water use by type of use is shown in Table 2.14. The category *power* refers to consumptive use by steam-electric power plants. The other water use categories are withdrawals rather than consumptive use. The population in the Neches Basin is also tabulated by year.

The TCEQ maintains a database of water use reported by water right permit holders at the website: https://www.tceq.texas.gov/permitting/water_rights/wr-permitting/wrwud. Monthly diversions are recorded in Excel spreadsheets.

Table 2.13
Historical Use of Surface and Ground Water in the Neches River Basin
http://www.twdb.texas.gov/waterplanning/waterusesurvey/estimates/index.asp

Year	Total (ac-ft)	Surface Water Use (ac-ft)	Surface Water Use (% Total)	Ground Water Use (ac-ft)	Ground Water Use (% Total)
1974	310,002	170,173	54.9%	139,829	45.1%
1980	318,227	170,604	53.6%	147,623	46.4%
1984	306,746	163,904	53.4%	142,842	46.6%
1985	307,553	163,266	53.1%	144,287	46.9%
1986	293,124	151,813	51.8%	141,311	48.2%
1990	303,553	167,978	55.3%	135,575	44.7%
1995	295,272	153,933	52.1%	141,339	47.9%
1996	283,416	144,717	51.1%	138,699	48.9%
1997	291,055	149,157	51.2%	141,898	48.8%
1998	320,232	171,027	53.4%	149,205	46.6%
1999	284,963	139,994	49.1%	144,969	50.9%
2000	288,360	137,190	47.6%	151,170	52.4%
2001	297,506	154,695	52.0%	142,811	48.0%
2002	268,547	127,504	47.5%	141,043	52.5%
2003	276,495	136,738	49.5%	139,757	50.5%
2004	265,216	145,693	54.9%	119,523	45.1%
2005	272,041	134,930	49.6%	137,111	50.4%
2006	278,802	143,726	51.6%	135,076	48.4%
2007	257,313	130,527	50.7%	126,786	49.3%
2008	262,241	134,623	51.3%	127,618	48.7%
2009	241,620	125,246	51.8%	116,374	48.2%
2010	269,924	152,936	56.7%	116,988	43.3%
2011	280,070	157,110	56.1%	122,960	43.9%
2012	273,710	147,972	54.1%	125,738	45.9%
2013	267,383	144,167	53.9%	123,216	46.1%
2014	253,842	138,264	54.5%	115,578	45.5%
2015	263,830	141,355	53.6%	122,475	46.4%
2016	279,130	154,352	55.3%	124,778	44.7%
2017	247,714	132,419	53.5%	115,295	46.5%

Water supply and use in the 20 counties in the East Texas Regional Planning Area (SB1 Region I) are described in the 2016 Regional Water Plan [16]. SB1 Region I encompasses almost all of the Neches Basin shown in darker blue in the map of Figure 2.17 from the regional planning report. The 2020 demand for water in the East Texas Regional Planning Area is estimated to be 1,108,800 acre-feet/year, categorized as municipal (17.0%), manufacturing (54.9%), mining (2.5%), steam electric power (7.4%), livestock (2.2%), and irrigation (16.0%) [15]. The total 2020 water demand of 1,108,800 acre-feet/year is distributed among counties as follows: Jefferson (66.5%), Orange (5.8%), Smith (3.0%), (Rusk 2.5%), and 16 other counties (22.2%).

Much of the water supplied from the Neches River and its tributaries is used in Jefferson County in the adjoining Trinity-Neches coastal basin that includes the cities of Beaumont and Port

Arthur. The Lower Neches Valley Authority (LNVA) is the nonfederal water supply sponsor for the USACE Sam Rayburn and B. A. Steinhagen Reservoirs. The LNVA pumps water from the lower Neches River and Pine Island Bayou for delivery through a 400-mile canal system in Jefferson, Chambers, and Liberty Counties to many cities, water districts, industries, and farms.

Table 2.14
Historical Annual Water Use by Type of Use

Year	Basin Population	Annual Water Use within the Neches River Basin in acre-feet					
		Municipal	Manufacturing	Mining	Power	Irrigation	Livestock
1974		57,346	194,643	3,902	6,279	35,979	11,853
1980	506,400	80,076	180,356	4,879	12,211	32,406	8,299
1984		82,593	163,995	2,698	8,820	38,275	10,365
1985		84,888	162,276	9,645	6,734	34,583	9,427
1990	553,400	86,290	162,317	7,744	5,957	31,061	10,184
1986		81,760	154,609	11,635	5,344	30,752	9,024
1995		96,501	153,198	8,858	5,595	20,943	10,177
1996		97,445	143,170	8,897	5,692	17,432	10,780
1997		96,040	155,355	8,845	3,247	17,999	9,569
1998		107,462	155,573	8,610	2,959	35,530	10,098
1999		102,218	137,300	8,610	2,959	23,264	10,612
2000	618,066	120,683	140,528	10	2,503	13,392	11,244
2001	624,461	113,230	140,542	12	7,248	25,666	10,808
2002	630,410	110,496	129,813	5	6,769	10,799	10,665
2003	632,960	108,550	130,614	31	6,780	20,139	10,381
2004	639,729	109,840	119,912	57	630	24,542	10,235
2005	641,813	118,911	121,245	6	606	20,821	10,452
2006	647,673	122,090	127,080	6	743	18,158	10,725
2007	651,718	109,625	118,011	3	931	18,589	10,154
2008	655,583	111,396	119,051	2,623	883	17,430	10,858
2009	662,828	106,626	105,678	2,816	753	14,456	11,291
2010	662,047	111,974	111,856	3,013	213	19,547	23,321
2011	669,577	123,785	106,489	2,041	1,150	23,570	23,035
2012	675,160	119,754	112,581	1,683	1,151	13,411	25,130
2013	675,206	114,337	111,479	2,566	308	14,462	24,231
2014	677,850	107,83200	110,284	1,461	504	12,288	21,475
2015	681,515	110,418	119,087	1,722	341	10,563	21,699
2016	677,819	111,153	129,117	1,618	5,300	9,565	22,377
2017	682,377	102,608	120,571	2,032	4,888	7,865	9,750

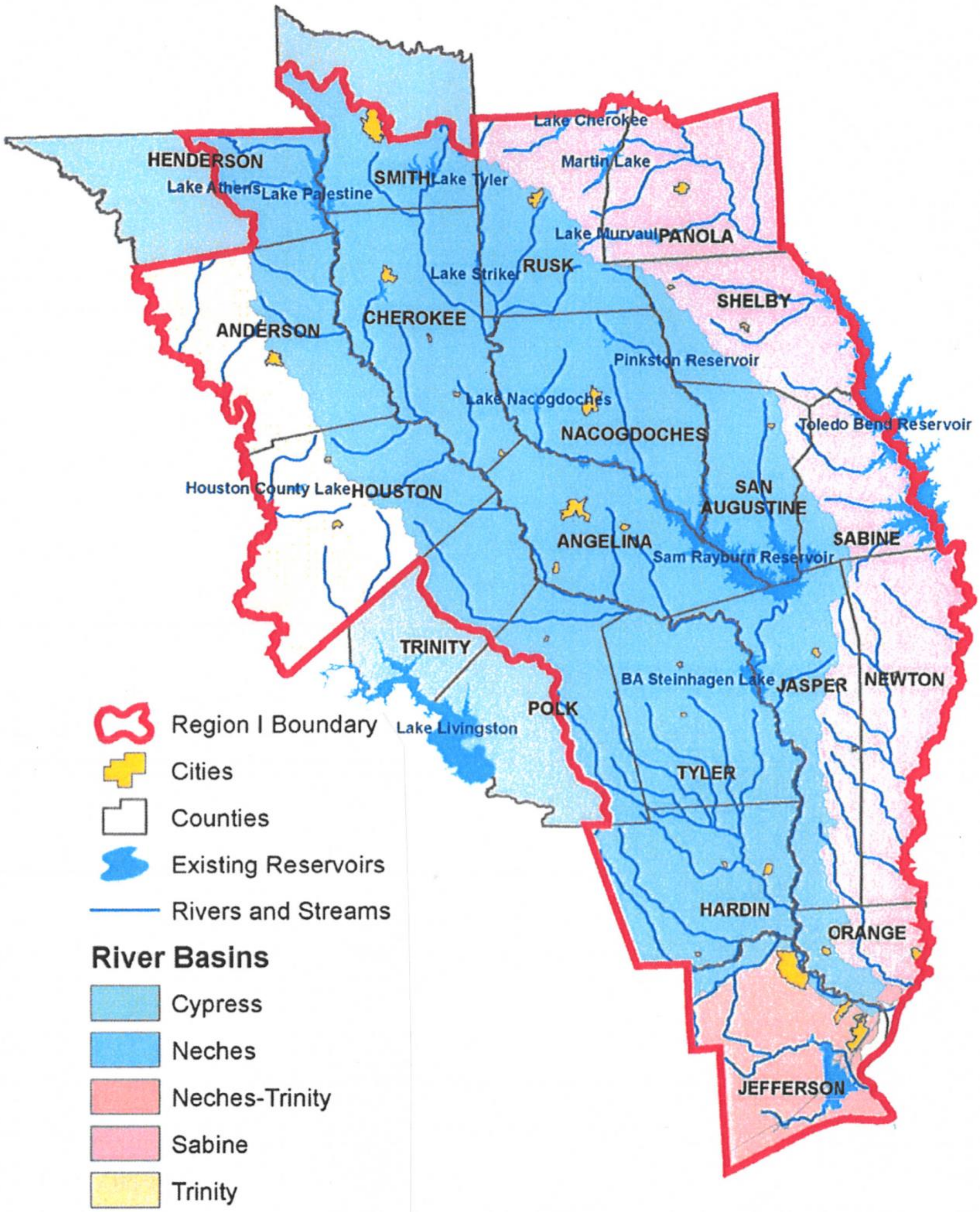

Figure 2.17 Senate Bill 1 East Texas Regional Planning Area [16]

CHAPTER 3
ALTERNATIVE SOURCES OF NATURALIZED STREAM FLOWS

The Neches WAM contains monthly naturalized flows at the 20 control points shown in Table 4.1 and Figure 4.1 of Chapter 4. The original 1940-1996 monthly naturalized flow are adopted in the June 2020 daily and monthly versions of the WAM. The update of monthly naturalized flows consists of extending the flows through December 2019 and conversion to DSS format. The daily *SIMD* input data also includes daily flows at 17 control points for use within the simulation as daily pattern hydrographs for disaggregating monthly naturalized flows to daily.

Compilation of daily flows for the daily Neches WAM is covered in Chapter 4. Compilation of the monthly naturalized flows used in both the monthly and daily versions of the WAM is described in Chapter 5. Compilation of monthly flow volumes in acre-feet/month includes summations of daily flow volumes in acre-feet/day.

Compilation of the daily and monthly flows actually adopted for the June 2020 Neches WAM is described in Chapters 4 and 5. The present Chapter 3 summarizes the various sources of flow data investigated in past and present hydrology compilations for the Neches WAM. Some of the datasets that were developed are not actually adopted in the final June 2020 WAM. Comparative analyses of alternative datasets support selection of the flow data actually adopted.

The daily and monthly naturalized flows incorporated in the June 2020 Neches WAM are based on naturalization adjustments to observed USGS and USACE measured flows as described in Chapters 4 and 5. Monthly flows were extended for the preceding developmental 2014 daily Neches WAM [11] using a hydrologic rainfall-streamflow regression model incorporated in the WRAP program *HYD* [4, 10] as briefly discussed in this chapter. Daily flows for the preliminary developmental 2014 daily Neches WAM [11] were synthesized with the Soil and Water Assessment Tool (SWAT) watershed rainfall-runoff modeling system as discussed in this chapter.

Original 1940-1996 Monthly Naturalized Flows

The original 1940-1996 monthly naturalized flows and net evaporation rates are adopted for the June 2020 WAM without modification. The original dataset is documented by the 2001 WAM report [9]. Sequences of monthly naturalized flows for 1940-1996 at the 16 gaged primary control points were developed by adjusting actual observed flows to remove the effects of human activities, based conceptually on the following general equation.

Naturalized Flow = Historical Gaged Flow + Upstream Diversions – Upstream Return Flows + Changes in Upstream Reservoir Storage + Upstream Reservoir Evaporation

Historical gaged flow was determined using available stream flow or reservoir release data available from the U.S. Geological Survey (USGS) and Texas Natural Resource Conservation Commission (TNRCC). For many control point locations, observed data were not available for the full 1940-1996 period-of-analysis. Missing data were estimated using statistical regression relationships and available data from nearby gages. The flow synthesis relationships were developed using least squares regression analysis with regression coefficients determined based on data for sub-periods of the periods-of-record with overlapping data [9].

Historical upstream diversions and return flows were obtained from TNRCC records or estimated when data was not available. Historical changes in upstream reservoir storage contents were obtained from USGS records, records from other entities, or estimates. Storage content changes were not evaluated for Lake Kurth because of its relatively small contributing drainage area. Likewise, estimates of storage content changes were not made for reservoirs with less than 5,000 acre-feet of storage capacity [9].

WRAP Program *HYD* Hydrologic Model Relating Monthly Naturalized Flows to Monthly Precipitation and Evaporation

A WRAP program *HYD* methodology described in the *Hydrology Manual* [4] was employed during 2013 to extend the Neches WAM naturalized monthly flows to cover 1997-2012 as described in detail in the 2014 Neches WAM hydrology extension report [10]. Monthly naturalized flows were extended in this manner for several WAMs including the Neches.

The *HYD* watershed rainfall-streamflow model extends monthly naturalized flows based on relating naturalized flow sequences to corresponding monthly precipitation and reservoir evaporation rate sequences from TWDB databases described in Chapter 6. The TWDB maintains datasets of monthly precipitation and evaporation depths for 92 one-degree latitude by one-degree longitude quadrangles shown in Figure 6.1. The *HYD* flow extension model has been calibrated for each of the 20 primary control points in the Neches WAM using the original naturalized flows along with concurrent TWDB precipitation and evaporation depths for relevant quadrangles [10]. The calibrated flow extension model is used to compute flows for the period from January 1997 through December 2019 using 1997-2019 TWDB precipitation and evaporation depths as input.

Program *HYD* consists of various routines designed to facilitate developing and updating net evaporation-precipitation rates and monthly naturalized flows included in *SIM/SIMD* monthly simulation input datasets. The *HYD* methodology referenced here is described in detail in Chapters 6 and 8 of the *Hydrology Manual* [4]. The hydrologic model is essentially a physically relevant regression model with numerous parameters to be calibrated (regressed). Complex optimization algorithms are automated within *HYD* to perform the iterative search for optimal parameter values. With the model calibration completed, flows can be further extended each year in the future as the TWDB continues to update the precipitation and evaporation datasets. The same TWDB dataset is used to extend both the naturalized flows and the net evaporation-precipitation rates.

The 1940-2019 monthly naturalized stream flows at the 20 primary control points generated with the *HYD* hydrologic model are included in the DSS file with filename NechesMonthlyFlows.DSS presented in Chapter 5. This is the ninth (last) dataset listed in Table 5.1. These *HYD* synthesized monthly naturalized flows could be used to extend the original 1940-1996 flows through 1997-2019 but were not. The alternative dataset actually adopted as described in Chapters 4 and 5 required much more effort to develop but is considered to be more accurate.

Comparative analyses of the previously extended flows and observed flows and otherwise synthesized flows have been performed [10, 12]. The Neches WAM monthly naturalized flows have recently been extended through 2019 using the previously calibrated model. However, the *HYD* extended flows are not actually adopted for inclusion in the June 2020 Neches WAM.

Findings and Conclusions Regarding the *WRAP-HYD* Hydrologic Model

Calibration of the *HYD* flow extension model requires significant time and expertise. However, after the flow extension model has been calibrated for each individual control point, the extension of naturalized flows is performed expeditiously for periodic updates. Since the extended naturalized flows are based on the original naturalized flows, approximations and inaccuracies inherent in the original flows are also reflected in the extended flows. Although the computed flow in particular individual months may be inaccurate, sometimes too high and sometimes too low, the methodology appears to replicate well the relevant statistical characteristics of the original flows.

The *HYD* model produces reasonably realistic sequences of monthly naturalized flows that can be expeditiously updated annually as the observed precipitation and evaporation for the next year becomes available. The same TWDB dataset is used to extend both the naturalized flows and the net evaporation-precipitation rates. The method is particularly useful if the original monthly naturalized flows are based on complete stream gage records and accurately naturalized but stream gages have been terminated or the effects recent human activities on stream flow are very complex.

The *HYD* model generates 1997-2019 flow sequences that closely replicates the statistical characteristics of the original 1940-1996 Neches WAM naturalized flows. The records of observed flows for the USGS gages cover portions both but have significant gaps of missing data during both the original 1940-1996 and extended 1997-2019 sub-periods.

The procedures adopted for the final adopted daily and monthly flows described in Chapters 4 and 5 are based on naturalization adjustments to observed flows and filling in gaps of missing flows by relating naturalized flows at neighboring gages, which are considered to be more accurate than the *HYD* model. The flows generated with the *HYD* hydrologic model are not used.

Daily and Monthly Observed Flows at USGS Gages

The 20 primary control points in Table 4.1 and Figure 4.1 include the sites of 16 USGS gaging stations. The DSS files described in Chapters 4 and 5 of this report contain recorded daily flows observed at the 16 USGS gages and monthly flows derived from summing the daily flows.

Instantaneous flow measurements are recorded by the U.S. Geological Survey (USGS) as mean daily flows in cubic feet per second (cfs). Sequences of daily mean flow rates in cfs are downloaded from the USGS National Water Information System (NWIS) website. The mean daily flows are averaged to obtain mean monthly flow rates in cfs. Daily flow volumes in acre-feet/day are summed to monthly volumes in acre-feet/month.

HEC-DSSVue [8] and the *HEC-SSP Statistical Software Package* [17] include similar features for downloading data from the USGS NWIS website. Changes by the USGS to the NWIS prevent the older *HEC-DSSVue* from accessing the website at present. Therefore, the *HEC-SSP* was used to download data from the USGS NWIS for the Neches WAM. *HEC-DSSVue* was used to organize and manipulate the data in the DSS files.

Periods-of-record are tabulated later in Table 4.2. Only four of the 16 gages have complete flow records for the period from 1940-2019. The other gages have significant numbers of years of missing records. Also, the fact that observed flows reflect actual water resources development and use rather than purely natural hydrology is a key concern. Flows at some gages reflect significant regulation while flows at other gages are affected only minimally by human water management.

Unregulated Daily Flows from the USACE Modeling System

The Fort Worth District (FWD) of the U.S. Army Corps of Engineers (USACE) has developed reservoir operation models to support operations of USACE reservoirs. Operation of multiple-purpose USACE reservoirs are simulated in the USACE modeling system with a particular focus on flood control operations. USACE daily unregulated flows are analogous to WAM monthly naturalized flows. Both are based on simulating natural or unregulated conditions by adjusting observed gage flows to remove the effects of human water resources management, regulation, and use. However, whereas development of the WAM monthly naturalized flows is motivated largely by water supply activities, development of the daily USACE unregulated flows is motivated largely by flood control operations.

The USACE FWD has provided daily unregulated flows from their modeling system for use in developing the daily WAMs. The USACE unregulated flows have been used in the Brazos [13] and Trinity [14] daily WAMs. Daily flows extending from January 1, 1929 through December 31, 2011 at five sites in the Neches River Basin were available from the USACE modeling system. The five sites correspond to Neches WAM control points NERO, ANSR, NETB, NEEV, and NEBA. USACE 1940-1996 unregulated flow data at four of these sites are adopted in the June 2020 Neches WAM for daily flow pattern hydrographs as explained in Chapter 4.

Synthesizing Daily Flows with SWAT Watershed Rainfall-Runoff Model

The feasibility of employing watershed rainfall-runoff models to develop daily flow hydrographs has also been investigated in conjunction with developing and updating the hydrology for *SIM*/*SIMD* input datasets [11, 18, 19, 20]. The concept is to synthesize daily flow hydrographs from observed daily rainfall data and parameters representing the characteristics of the watershed. Daily flows can be used as *DF* record daily pattern hydrographs and/or aggregated to monthly totals to extend *IN* record monthly naturalized flows. SWAT was selected as the most appropriate of the various available watershed models for this type of application [11, 18, 19, 20].

Soil and Water Assessment Tool (SWAT) Modeling System

The Soil and Water Assessment Tool (SWAT) is one of several available generalized watershed models that simulate the hydrologic processes that convert precipitation to stream flow. SWAT was developed by the USDA Agricultural Research Service and Texas A&M AgriLife Research Service and has been applied by numerous scientists and engineers throughout the world for many years. SWAT computes daily stream flow and water quality constituent loads at stream sites that result from inputted observed or stochastically generated daily rainfall based on parameters reflecting the characteristics of the watersheds. SWAT software and documentation are available at http://swat.tamu.edu/ .

SWAT was investigated during 1998-1999 in conjunction with the initial development of the TCEQ WAM System for use in distributing naturalized monthly flows from gaged to ungaged sites [18]. SWAT was combined with the Brazos WAM in a university research study performed during 2002-2004 [19] to analyze the potential impacts of climate change on monthly naturalized flows. More recently, the use of SWAT in developing *DF* record daily flows for *SIMD* has been explored [20].

SWAT is a physically-based, semi-distributed, continuous-simulation, daily rainfall-runoff model. SWAT simulates river basin hydrology for each day of a long period that may extend over many years based on rainfall and other input data characterizing climate, land cover, soil, and other watershed conditions. The modeling system provides options for automatically producing parameter values from geographical information system (GIS) data such as digital elevation models (DEMs) and soil and land cover databases. Hydrological response units (HRUs) are the basic computational units in the SWAT. The model divides a watershed into sub-basins and further divides a sub-basin into homogeneous spatial units, called HRUs, characterized by similar soil, land cover, and topographical conditions. Sequences of daily rainfall at rain gage sites are provided as input. The SWAT weather generator can be applied to automatically generate daily rainfall and other weather data. Periods of missing rainfall data can be synthesized with the weather generator.

The SWAT modeling system uses climate data from the rainfall and weather gage station that is nearest to the centroid of each sub-basin. Surface runoff from daily rainfall is calculated by the NRCS curve number method based upon soil, land cover, and antecedent rainfall conditions. Base flows are computed from the interaction among surface, subsurface, and ground water. The surface runoff in a hydrologic resource unit (HRU) is routed through the river system within a sub-basin using the Manning equation. The surface runoff from a sub-basin is routed through channels to an outlet point using the variable storage or Muskingum hydrologic routing methods.

The SWAT simulation may include various natural hydrologic losses such as evapotranspiration, transmission losses, and infiltration. The model calculates evaporation from soil and transpiration from plants separately. Actual soil evaporation is calculated from exponential functions of soil depth and water content. Plant transpiration is computed by using a linear function of potential evapotranspiration and leaf area index.

The Hydrologic and Water Quality System (HAWQS) is a web-based interactive water quantity and quality modeling system that employs SWAT as its core modeling engine. A Beta version of HAWQS was released in June 2016. HAWQS was developed and is maintained by the Texas A&M University Spatial Sciences Laboratory under the sponsorship of the U.S. Environmental Protection Agency. HAWQS software, documentation, and online information are accessible at https://epahawqs.tamu.edu/. HAWQS is designed to simplify application of SWAT but introduces significant additional approximations. Conventional SWAT simulations are typically based on extensive parameter calibration studies for the particular watershed application. HAWQS employs databases of generic pre-calibrated parameters that are generally more approximate.

HAWQS is employed online by users as follows. The user creates a project for a modeling scenario and changes variables and inputs using web interfaces. To run the simulation, HAWQS connects with the latest version of the SWAT simulation model to process the inputs, data and other information. SWAT finishes processing and generates outputs, and HAWQS stores outputs centrally. Users can view results through a web interface, save results, and run additional scenarios.

SWAT Generated Flows for the Daily Neches WAM

The 2014 developmental version of the daily Neches WAM [11] incorporates 1940-2013 *DF* record daily flows in the DCF file for the 20 primary control points for use within *SIMD* in disaggregating monthly flows to daily. All daily flows in the 2014 developmental daily Neches WAM were developed by Ryu [11, 20] employing SWAT to model natural undeveloped watershed conditions with observed precipitation. SWAT synthesized daily flows were also summed to monthly volumes for comparative analyses. The SWAT simulations and comparisons between USGS gaged flows, USACE unregulated flows, and SWAT synthesized flows are presented in the daily WAM report [11] and Ryu's Ph.D. dissertation [20].

Measured rainfall data was used, and other climate data was generated within SWAT by its weather generator. Daily rainfall daily data were provided as input and daily flows generated for a SWAT simulation period that extended from January 1, 1940 through December 31, 2013. Of the more than one hundred rainfall stations within the Neches River Basin, only the 31 rainfall stations that have relatively long periods-of-record were adopted for this study [20].

Calibration is generally expected to significantly improve the accuracy of the SWAT results in most applications if accurate gaged stream flow data are available for calibration. The daily SWAT model was calibrated for the 20 Neches WAM primary control points to reproduce the monthly naturalized flows. The 2012 version of the SWAT-CUP semi-automated calibration model was used with the sequential uncertainty fitting algorithm (http://swat.tamu.edu/).

The 1940-2013 daily naturalized stream flows at the 20 primary control points generated with the SWAT watershed rainfall-runoff model are included in the DSS file with filename NechesDailyFlows.DSS presented in Chapter 4 of this report. This is the fifth dataset listed in Table 4.15. These *SWAT* synthesized daily naturalized flows are not used as *DF* record daily pattern hydrographs in the June 2020 WAM because the alternative dataset described in Chapter 4 developed based on naturalizing observed flows is more accurate.

In conclusion, SWAT and/or HAWQS potentially provide an alternative approach for generating daily flow pattern hydrographs for input as *DF* record daily flows to the WRAP daily simulation model *SIMD*. SWAT generated daily flows can be aggregated to monthly totals for use in extending *IN* record monthly naturalized flows. Key issues include (1) the expertise and effort required to compile rainfall and watershed parameter input data for SWAT, perform parameter calibration studies, and perform the watershed rainfall-runoff simulations and (2) the approximations and inaccuracies inherent in watershed modeling.

Comparative analyses have been performed with SWAT generated 1940-2013 daily and aggregated monthly flows, available USGS observed flows, USACE unregulated 1940-2011 daily and aggregated monthly flows, *HYD* synthesized 1940-2012 monthly naturalized flows, and the original WAM 1940-1996 monthly naturalized flows [12, 20]. The SWAT generated flows were found to be very approximate. Low flows generated with SWAT were particularly problematic. For example, simulation results included excessive numbers of days with zero flows. Other available methods for compiling daily and monthly naturalized flows for the WAMs based on adjustments to observed flows were concluded to generally be more accurate.

CHAPTER 4
DAILY STREAM FLOW

The 20 WAM primary control points are listed in Table 4.1. Their map locations are shown in Figure 4.1. Daily naturalized flows extending from January 1940 through December 2019 are developed as explained in Chapter 4 for 17 of the 20 primary control points.

- January 1940 through December 2019 daily flows at these 17 control points serve as pattern hydrographs used within the *SIMD* simulation to disaggregate monthly naturalized flows to daily at the over 300 control points in the Neches WAM. The 1940-2019 daily flow pattern hydrographs for 17 sites are repeated within a *SIMD* simulation at the over 300 other control points using a standard automatically-applied *SIMD* algorithm.
- January 1997 through December 2019 daily naturalized flow volumes are summed to monthly volumes for use in extending the original 1940-1996 monthly naturalized flows through December 2019 as discussed in Chapter 5. The 1940-2019 monthly naturalized flows at 20 primary control points are distributed to the over 300 secondary control points in a *SIM* or *SIMD* simulation based on parameters read from the flow distribution DIS input file.

WAM Primary Control Points

Primary control points are locations at which monthly naturalized flows are provided as *IN* records in a *SIM* or *SIMD* input dataset. Naturalized flows at all other control points, called *secondary* control points, are computed within a *SIM* or *SIMD* simulation based on the naturalized flows provided at the primary control points and watershed parameters provided on flow distribution *FD* and watershed parameter *WP* records in the DIS file and/or control point *CP* records in the DAT file. Flow distribution option 7 based on drainage area ratios is employed for synthesizing flows at the over 300 secondary control points in the Neches WAM.

The Neches WAM has 20 primary control points, which are listed in Tables 4.1, 4.2, 4.3, and 4.4. Their locations are shown in the maps of Figures 4.1 and 4.3. Monthly naturalized flows for the period 1940-1996 are stored in the original FLO file. Monthly naturalized flows for 1940-2019 are provided in the hydrology DSS file of the June 2020 WAM. Annual means of the 1940-1996 and 1940-2019 naturalized flows are listed in the last two columns of Table 4.1. Naturalized flows are synthesized during execution of *SIM* for the over 300 secondary control points based on information provided in the flow distribution DIS file.

Sixteen of the 20 primary control points represent USGS stream gage stations. The 20 primary control points correspond to the sites of USGS stream gaging stations, with the exception of control points NEPA, MUTY, and ANSR, which represent the locations of dams, and control point NESL which represents the basin outlet where the Neches River flows into Sabine Lake.

Compilation of 1940-2019 monthly naturalized flows for the 20 primary control points is described in Chapter 5. Hydrographs of 1940-2019 daily flows are developed for 17 of the 20 primary control points, which includes 16 USGS stream flow gage sites and the site of Sam Rayburn Dam (control point ANSR) as described here in Chapter 4. Daily flows are employed in disaggregating monthly naturalized flows to daily and also used in extending the original 1940-1996 monthly flows at the primary control points through 2019.

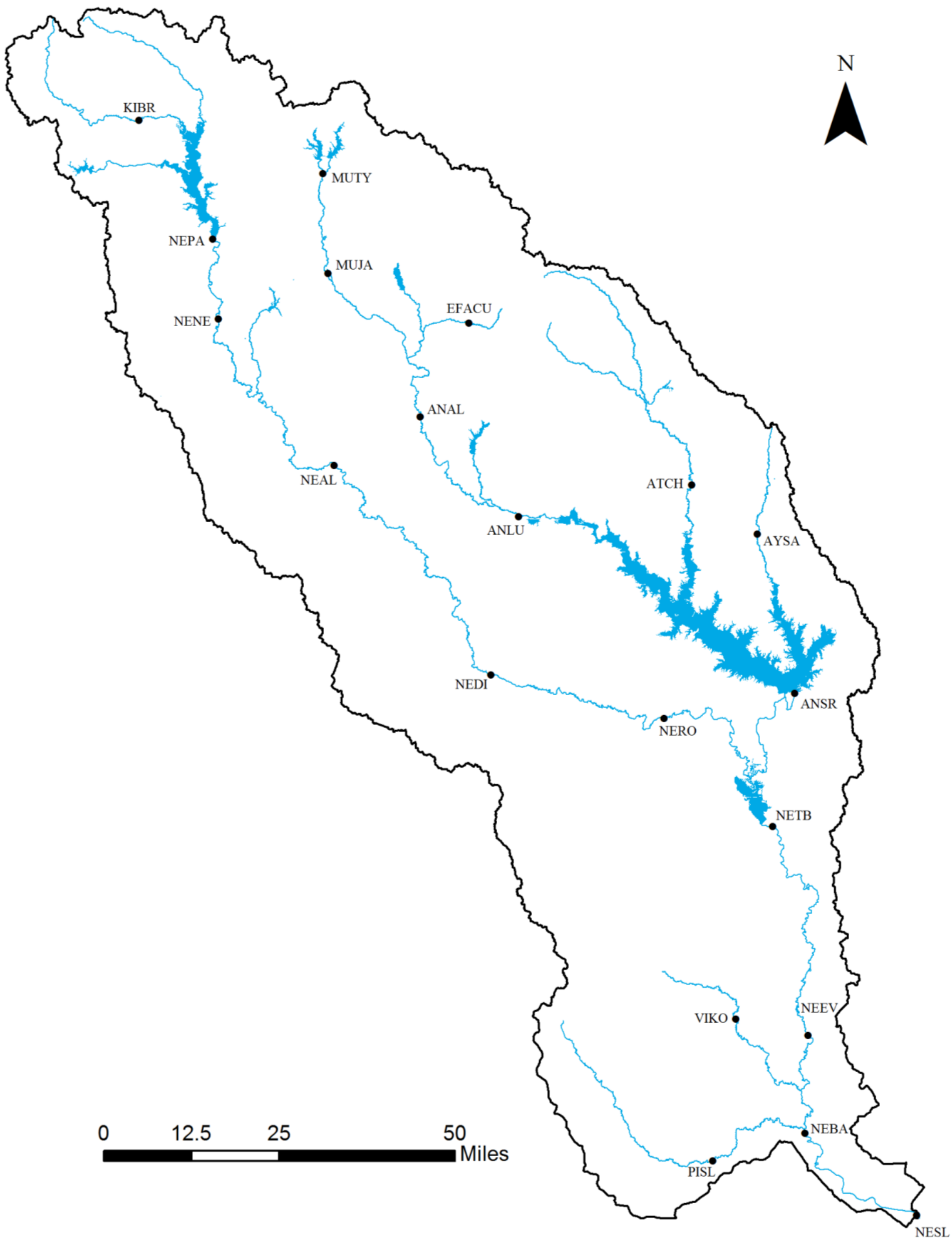

Figure 4.1 Map of Primary Control Points in the Neches WAM

Table 4.1
Primary Control Points in the Neches WAM

Control Point	USGS Gage Number	Location Stream and Nearest Town	Drainage Area	Mean Naturalized Flow 1940-1996	Mean Naturalized Flow 1940-2019
			sq. miles	ac-ft/yr	ac-ft/yr
KIBR	08031200	Kickapoo Creek near Brownsboro	232	110,304	109,709
NEPA	None	Neches River at Lake Palestine	837	367,859	367,980
NENE	08032000	Neches River near Neches	1,145	558,775	558,959
NEAL	08032500	Neches River near Alto	1,943	891,590	967,277
NEDI	08033000	Neches River near Diboll	2,724	1,249,565	1,292,166
NERO	08033500	Neches River near Rockland	3,631	1,774,488	1,833,443
MUTY	None	Mud Creek at Lakes Tyler and Tyler East	114	60,352	59,532
MUJA	08034500	Mud Creek near Jacksonville	376	202,637	199,905
EFACU	08033900	East Fork Angelina River near Cushing	157	89,776	89,082
ANAL	08036500	Angelina River near Alto	1,273	684,709	680,399
ANLU	08037000	Angelina River near Lufkin	1,601	889,818	881,054
ATCH	08038000	Attoyac Bayou near Chireno	504	332,719	332,918
AYSA	08039100	Ayish Bayou near San Augustine	89	71,299	70,907
ANSR	None	Angelina River at Sam Rayburn Dam	3,452	1,990,549	2,009,947
NETB	08040600	Neches River near Town Bluff	7,571	4,173,046	4,262,439
NEEV	08041000	Neches River at Evadale	7,885	4,576,250	4,669,344
VIKO	08041500	Village Creek near Kountze	861	639,756	649,961
PISL	08041700	Pine Island Bayou near Sour Lake	368	323,123	325,712
NEBA	08041780	Neches Saltwater Barrier at Beaumont	9,826	6,044,722	6,160,294
NESL	None	Neches River at Sabine Lake	10,025	6,234,720	6,353,916

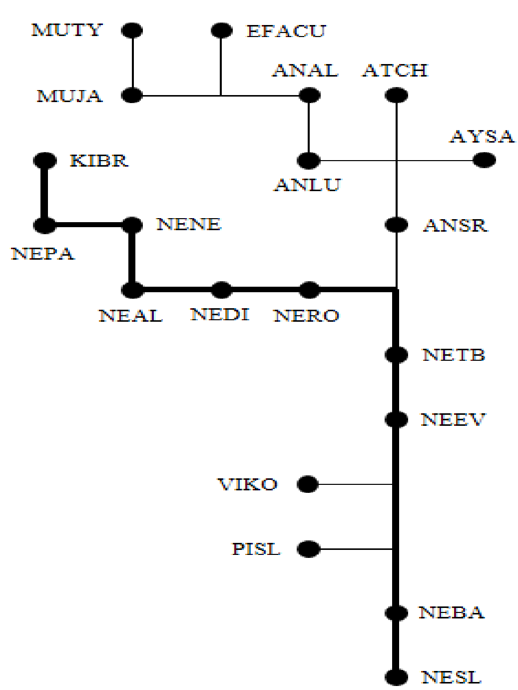

Figure 4.2 Schematic of Primary Control Points in the Neches WAM

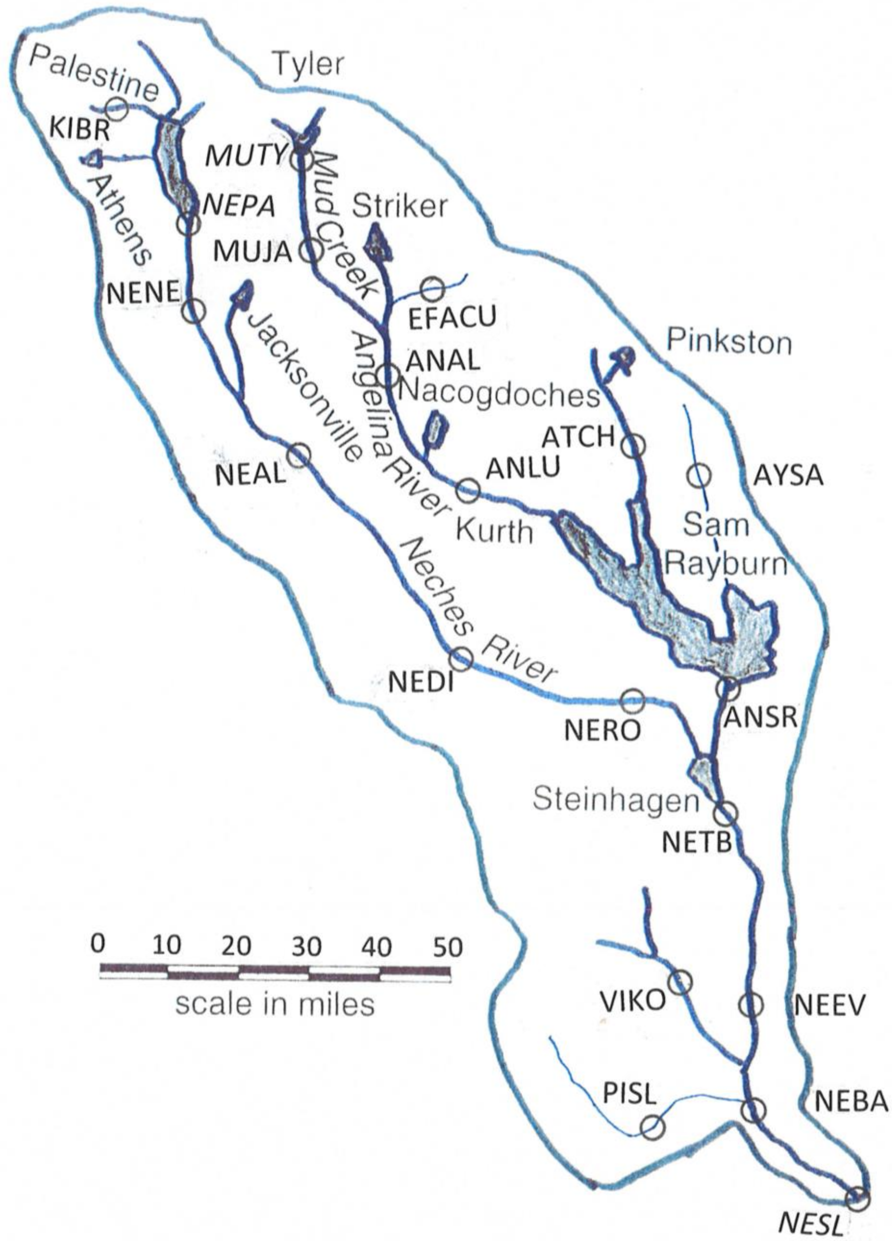

Figure 4.3 Major Reservoirs and WAM Primary Control Points

Sources of Daily River Flow Data

Daily flows at 17 of the 20 primary control points are developed as described in this chapter by compiling, comparing, selecting, adjusting, and combining flow data from three sources.

1. period-of-record observed daily flows at 16 control points representing 16 gages maintained by the U.S. Geological Survey (USGS)
2. 1923-2011 unregulated daily flows at five control points from a U.S. Army Corps of Engineers (USACE) Fort Worth District (FWD) modeling system
3. period-of-record observed daily releases from Sam Rayburn and B. A. Steinhagen Reservoirs from the USACE FWD water management website

The time periods for which daily flow data are available from these three sources at each of the 17 control points are shown in Table 4.2. All twenty primary control points are included in Table 4.2 and Figures 4.1 and 4.3. The three control points with no daily flow data are indicated by italics.

Table 4.2
Stream Flow Data Availability

Control Point	Control Point and Gage Location	Basin Area (sq. miles)	USGS Gages	USACE Model	Reservoir Releases
KIBR	Kickapoo Creek near Brownsboro	232	1962-1989	–	–
NEPA	*Neches River at Lake Palestine*	837	–	–	–
NENE	Neches River near Neches	1,145	1939-present	–	–
NEAL	Neches River near Alto	1,943	1944-1978	–	–
NEDI	Neches River near Diboll	2,724	1923- present	–	–
NERO	Neches River near Rockland	3,631	1903-present	1923-2011	–
MUTY	*Mud Creek at Lakes Tyler & Tyler East*	114	–	–	–
MUJA	Mud Creek near Jacksonville	376	1939-present	–	–
EFACU	East Fork Angelina River near Cushing	157	1964-present	–	–
ANAL	Angelina River near Alto	1,273	1940-present	–	–
ANLU	Angelina River near Lufkin	1,601	1923-1979	–	–
ATCH	Attoyac Bayou near Chireno	504	1924-1985	–	–
AYSA	Ayish Bayou near San Augustine	89	1959-1985	–	–
ANSR	Angelina River at Sam Rayburn Dam	3,452	–	1923-2011	1975-present
NETB	Neches River near Town Bluff	7,571	1951-present	1923-2011	1981-present
NEEV	Neches River at Evadale	7,885	1904-present	1923-2011	–
VIKO	Village Creek near Kountze	861	1924-present	–	–
PISL	Pine Island Bayou near Sour Lake	368	1967-present	–	–
NEBA	Neches River at Beaumont	9,826	2003-present	1923-2011	–
NESL	*Neches River at Sabine Lake*	10,025	–	–	–

These and other alternative sources of daily and monthly stream flow data are discussed in the preceding Chapter 3. The naturalized stream flow datasets generated with the daily *SWAT* and monthly *HYD* watershed rainfall-runoff models discussed in Chapter 3 were not actually adopted for inclusion in the final WAM hydrology dataset described in Chapters 4 and 5. However, these other two alternative datasets are included for comparative analyses in the DSS files of daily and monthly flows accompanying this report. As discussed in Chapter 3, comparative analyses of alternative datasets supported selection of data for actual use in compiling the final adopted datasets of daily and monthly naturalized flows.

The 20 primary control points located at the sites shown Figure 4.1 are listed in Table 4.1 with their WAM identifiers and watershed drainage areas in square miles. Control point NESL, which has no gage, represents the outlet of the Neches River at Sabine Lake. Control points ANSR, MUTY, and NEPA represent the Angelina River below Sam Rayburn Dam, Mud Creek at Lakes Tyler and Tyler East Dams, and the Neches River at Blackburn Crossing Dam (Lake Palestine) which also have no USGS stream gage. The other 16 primary control points are sites of USGS gages. Observed daily flows at gages are adjusted as described later in this chapter to develop daily naturalized flows that are summed to monthly naturalized flows as discussed in the next chapter.

As noted in the preceding Chapter 3, the USACE Fort Worth District maintains a modeling system based on a daily computational time step to support operations of multiple-purpose Corps of Engineers reservoirs. Daily unregulated flows in the Fort Worth District simulation models are analogous to WAM monthly naturalized flows. Both are based on simulating natural or unregulated conditions by adjusting observed gage flows to remove the effects of human water resources management, regulation, and use. However, whereas development of the WAM monthly naturalized flows is motivated primarily by water supply, development of the daily USACE unregulated flows is motivated largely by flood control operations. USACE unregulated flows have been used for portions of pattern hydrographs in the Brazos [13] and Trinity [14] daily WAMs. Daily flows extending from January 1, 1929 through December 31, 2011 at five sites in the Neches River Basin were also provided by the USACE Fort Worth District. These five sites correspond to Neches WAM control points NERO, ANSR, NETB, NEEV, and NEBA.

Water management information including descriptions of dams, appurtenant structures, and reservoir pools and daily observed storage/release/inflow data and weather data for the 25 USACE FWD reservoirs in Texas are available at: https://www.swf-wc.usace.army.mil/cgi-bin/rcshtml.pl?csrf=M43Rz61hnn. Sam Rayburn and Steinhagen Reservoirs are owned and operated by the USACE FWD and included at this website as discussed in Chapter 2. Control points ANSR and NETB are downstream of these two dams. The USACE estimates inflows to Sam Rayburn Reservoir and Steinhagen Reservoir based on water budget computations considering releases, evaporation, and storage changes. Daily water budgets of storage, release, and inflow downloaded from this website were used in the analyses of hydrologic characteristics of the river/reservoir system. Reservoir outflows are treated as observed stream flows at the dams.

Observed Daily Flows at USGS Gage Stations

Sixteen of the 20 control points listed in Tables 4.1 and 4.2 with locations shown in the maps of Figures 4.1 and 4.3 represent USGS gages. Daily mean flow rates in cubic feet per second (cfs) at these sites were downloaded from the USGS National Water Information System (NWIS) website. The periods-of-record of the 16 gages are listed in the fourth column of Table 4.3. The number of days during the period-of-record with missing data is shown in the fifth column. The last column provides notations regarding the sub-periods during which the data gaps occur.

Daily flow data were downloaded from the USGS NWIS website in January 2020 and again on March 5, 2020 during the process of finalizing the datasets. A previous hydrology investigation for the Neches WAM documented by a April 2017 report [12] included downloading daily flows at the gages listed in Table 4.3 from the USGS NWIS website on July 17, 2016. Daily flow data were then available through July 16, 2016.

Most of the data for the period before July 17, 2016 are identically the same in the datasets downloaded in January and March 2020 versus July 2016, but there are some differences. The USGS routinely refines recently collected provisional data. Thus, the last several months of data have often been refined by the time of later downloads, including those datasets discussed here. With the exceptions of refinements in recent provisional data and gaps of missing data noted in the next paragraph, the quantites in the datasets downloaded in July 2016 versus January/March 2020 are generally identical. The dataset downloaded in March 2020 is adopted with the modifications described in the next three paragraphs.

Table 4.3
Periods-of-Record for Observed Daily Flow at U.S. Geological Survey (USGS) Gages

Control Point	USGS Gage	Stream and Nearest Town	Period-of-Record	Missing Days	Periods of Missing Data
KIBR	08031200	Kickapoo Creek, Brownsboro	May 1962 −Sep1989	0	None
NENE	08032000	Neches River, Neches	Feb 1939 – present	0	None
NEAL	08032500	Neches River, Alto	Jan 1944 – Dec 1978	0	None
NEDI	08033000	Neches River, Diboll	Oct 1923 – present	15,521	Oct25-Mar39&Oct85-Sep14
NERO	08033500	Neches River, Rockland	Jul 1903 – present	0	None
MUJA	08034500	Mud Creek, Jacksonville	May 1939 – present	7,962	Oct 1979 – Jul 2001
EFACU	08033900	East Fork Angelina, Cushing	Jan 1964 – present	9,496	Oct 1989 – Sep 2015
ANAL	08036500	Angelina River, Alto	Oct 1940 – present	7,610	13 periods
ANLU	08037000	Angelina River, Lufkin	Oct 1923 – Sep 1979	1,766	Oct 1934 – Jul 1939
ATCH	08038000	Attoyac Bayou, Chireno	Feb 1924 – Sep 1985	5,386	Oct25-Jul39&Nov54-Sep55
AYSA	08039100	Ayish Bayou, San Augustine	Feb 1959 – Sep 1985	0	None
NETB	08040600	Neches River, Town Bluff	Apr 1951 – present	0	None
NEEV	08041000	Neches River, Evadale	Aug 1904 – present	5,204	Jan 1907 – Mar 1921
VIKO	08041500	Village Creek, Kountze	Jun 1924 – present	4,284	Oct 1927-Apr 1939 & five
PISL	08041700	Pine Island Bayou, Sour Lake	Oct 1967 – present	0	None
NEBA	08041780	Neches, Salt Barrier Beaumont	Jun 2003 – present	58	22 periods

Table 4.4
Periods-of-Record During 1940-2019 for Observed Daily Flow at the 16 USGS Gages

Control Point	Location by Stream and Nearest Town	Period During 1940-2019 With Daily Flows	Days with Data	Days Missing	1940-2019 Missing
KIBR	Kickapoo Creek, Brownsboro	May 1962 – Sep 1989	10,014	0	19,206
NENE	Neches River, Neches	Jan 1940 – Dec 2019	29,220	0	0
NEAL	Neches River, Alto	Jan 1944 – Sep 1978	12,784	0	16,436
NEDI	Neches River, Diboll	Jan 1940 – Sep 1985 Oct 2014 – Dec 2019	18,629	10,591	10,591
NERO	Neches River, Rockland	Jan 1940 – Dec 2019	29,220	0	0
MUJA	Mud Creek, Jacksonville	Jan 1940 – Dec 2019	21,258	7,962	7,962
EFACU	East Fork Angelina, Cushing	Jan 1964 – Sep 1989 Oct 2015 – Dec 2019	10,958	9,496	18,262
ANAL	Angelina River, Alto	Oct 1940 – Dec 2019	21,336	7,610	7,884
ANLU	Angelina River, Lufkin	Jan 1940 – Sep 1979	14,517	0	14,703
ATCH	Attoyac Bayou, Chireno	Jan 1940 – Sep 1985	16,376	334	12,844
AYSA	Ayish Bayou, San Augustine	Feb 1959 – Sep 1985	9,723	0	19,497
NETB	Neches River, Town Bluff	Apr 1951 – Dec 2019	25,112	0	4,108
NEEV	Neches River, Evadale	Jan 1940 – Dec 2019	29,220	0	0
VIKO	Village Creek, Kountze	Jan 1940 – Dec 2019	29,166	54	54(0)
PISL	Pine Island Bayou, Sour Lake	Oct 1967 – Dec 2019	19,085	0	10,135
NEBA	Neches, Salt Barrier Beaumont	Jun 2003 – Dec 2019	5,996	58	23,224

The USGS gages at WAM control points NENE, NETB, NEEV, and PISL have gaps of missing data in the January/March 2020 downloads for which data are available in the July 2016 download. The data gaps in the March 2020 download are filled with the data from the July 2016 download. These gaps of missing daily flows in the more recent download are the periods October 1987 through September 2001 at NENE, October 1990 through September 2000 at NETB, October 1986 through September 2000 at NEEV, and both September 1987 through September 1996 and October 1998 through September 2001 at PISL. The dataset downloaded in July 2016 had zero days of missing data during the periods-of-record of the USGS gages at control points NENE, NETB, and PISL. The gage at NEEV had no days of missing data after March 1921.

The USGS gage at control point VIKO has missing daily flow data for 4,250 days during October 1927 through April 1939 and during 54 days divided between five different sub-periods after 1940. For the 54 days of missing data after 1940, each of the five gaps of one or more days was filled with the average of the flows in the preceding day and following day.

The gage at NEBA has flows missing during 22 different periods of its June 2003 to present period-of-record that total 58 days of missing data. Each of these 22 gaps of one or more days was filled with the average of the flows in the preceding day and following day. Negative quantities are recorded for four days at this gage. The four negative daily flows were changed to zero.

Sub-periods of 1940-2019 covered by the gage records are shown in the third column of Table 4.4. The period 1940-2019 contains 29,220 days. The number of days with data during 1940-2019 is shown in the fourth column of Table 4.4. The next-to-last column indicates the number of days of missing data during the period shown in the third column. The last column shows the number of days during January 1940 through December 2019 with missing daily flows.

Daily means of observed stream flow rates in cfs can be accessed through the USGS NWIS website for 25 gages. The other nine gages not adopted here have very short periods-of-record. Several of these other gages terminate before 1940. Of these nine gages, gage 08041740 on Pine Island Bayou near Beaumont, with a period-of-record of October 2003 to present, is the only currently active gage. The others were terminated many years ago. Gage 08041740 on Pine Island Bayou is located upstream of the BI Pump Plant and has a watershed area of 633 square miles, compared to the upstream control point PISL watershed area of 368 square miles.

Eleven of the 16 gages listed in Tables 4.1 through 4.4 are currently active. The other five gages have periods-of-record that end between 1979 and 1989. The gages at control points NENE, NERO, and NEEV are the only gages with no days of missing daily mean flows during 1940-2019. With only scattered gaps of missing data totalling 54 days sythesized, control point VIKO is also viewed as having a complete set of 1940-2019 actual observed daily mean flows.

Stream Flow Characteristics

Homogeneous stream flow datasets reflecting natural or otherwise defined stationary conditions are required for the WAMs. Development of sequences of daily and monthly naturalized river flows for the Neches WAM was based on adjusting observed flows to remove non-stationarities. Strategies for developing datasets of naturalized flows reflect consideration of the variability, stationarity, storage attenuation, and other characteristics of stream flow.

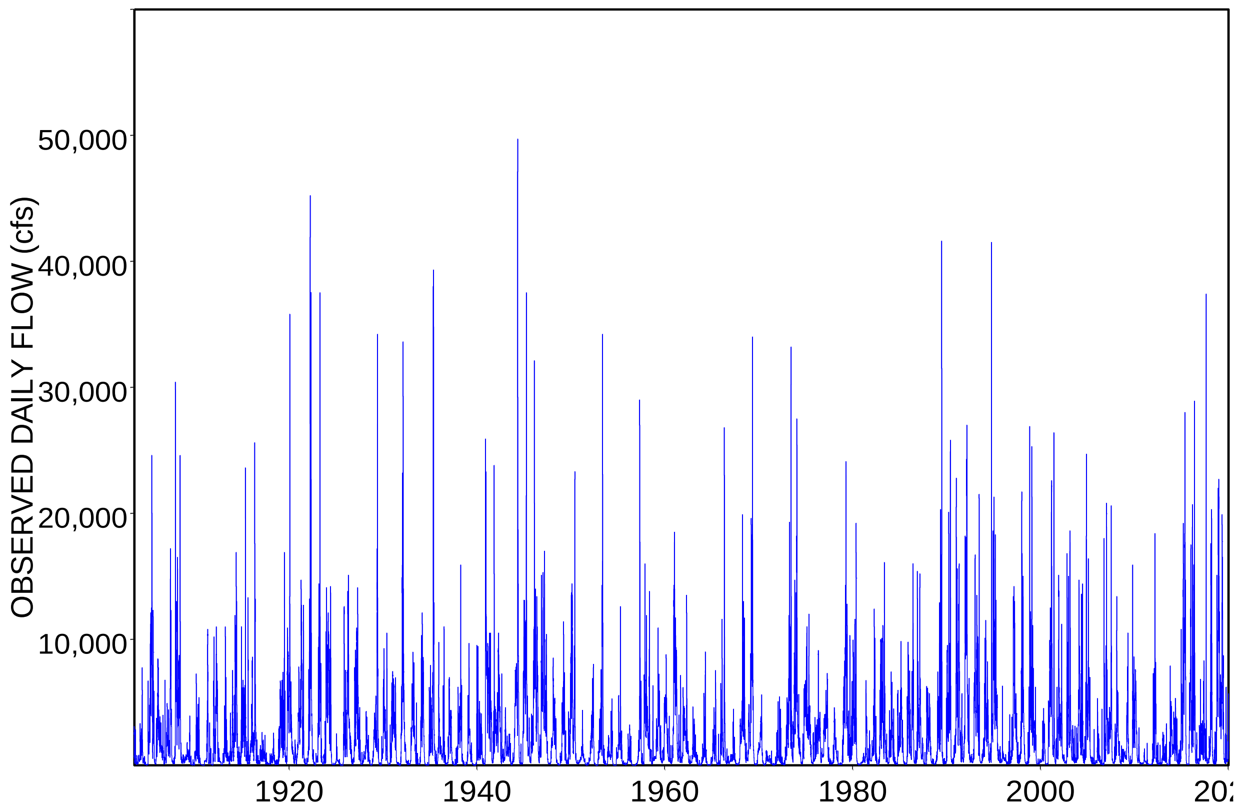

Figure 4.4 Daily Mean Flow (cfs) of the Neches River near Rockland (Control Point NERO)

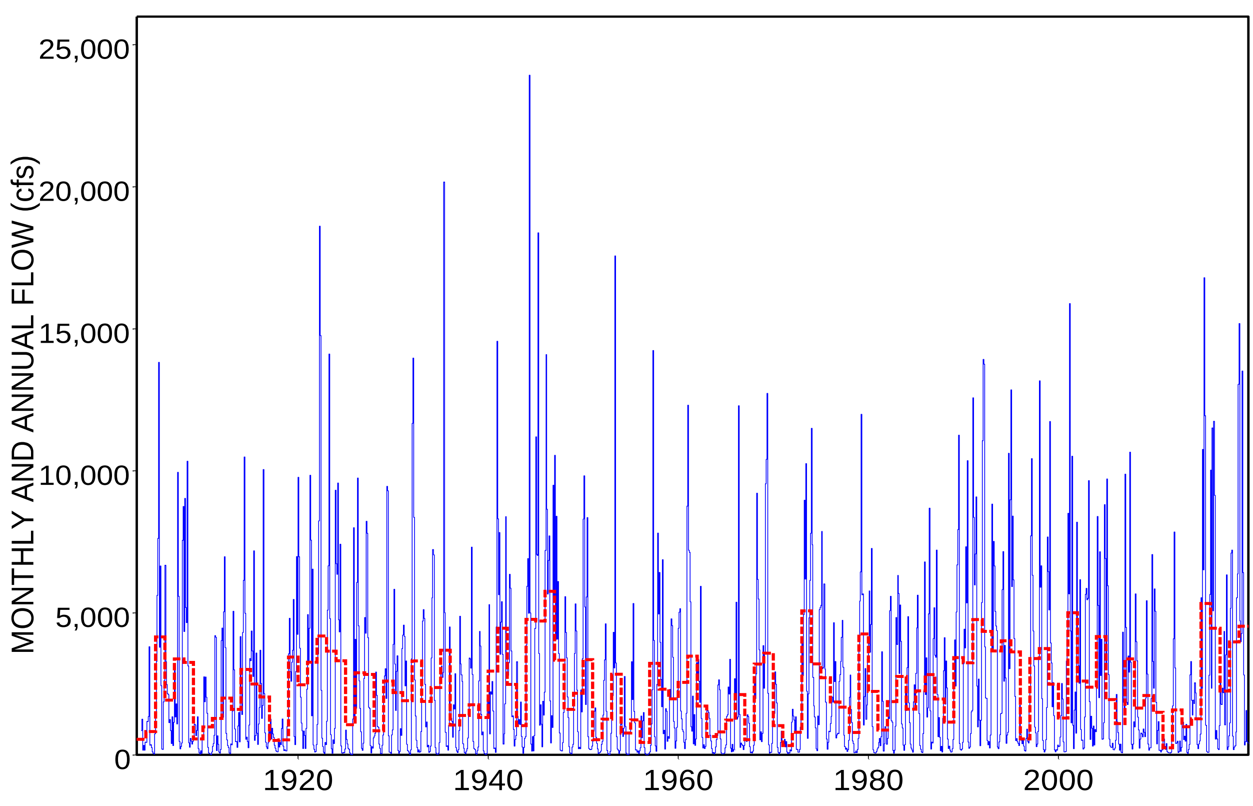

Figure 4.5 Monthly (blue solid) and Annual (red dashed) Mean Flow (cfs) at NERO

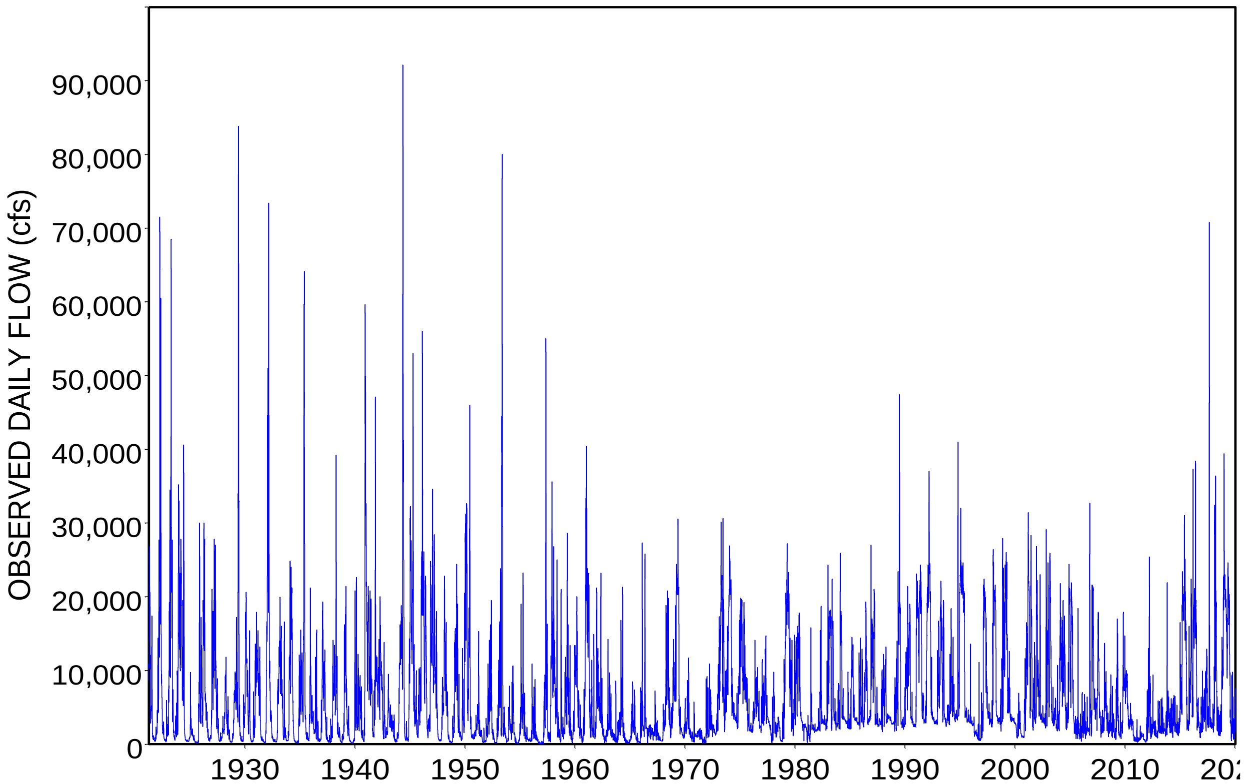

Figure 4.6 Daily Mean Flow (cfs) of the Neches River near Evadale (Control Point NEEV)

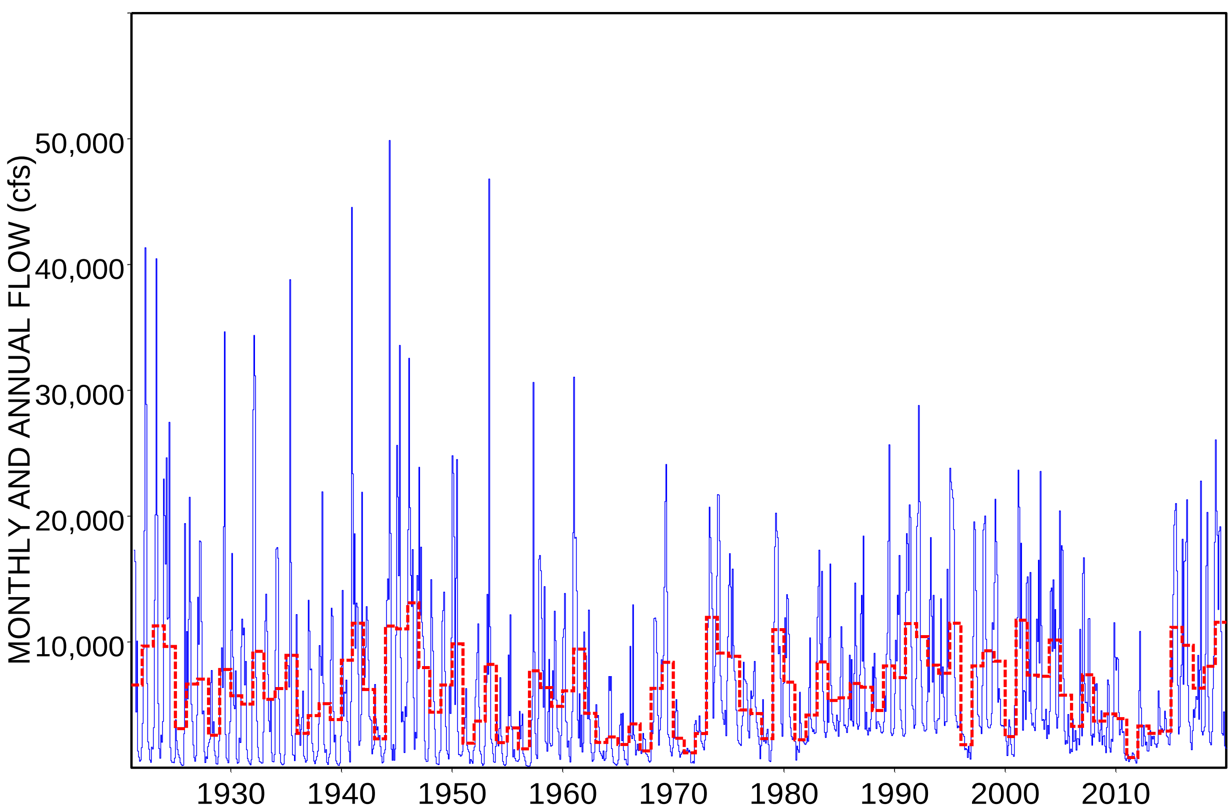

Figure 4.7 Monthly (blue solid) and Annual (red dashed) Mean Flow (cfs) at NEEV

Characteristics of Actual Observed River Flows

Only four of the 16 USGS gages have complete records covering the entire period from January 1940 to the present. The gages on the Neches River near Rockland and Evadale (control points NERO and NEEV) have the longest periods-of-record. Daily mean rates in cfs of observed flow of the Neches River near Rockland from July 1, 1903 through January 21, 2020 and at Evadale from April 1, 1921 through January 21, 2020 are plotted in Figures 4.4 and 4.6. Monthly and annual means of these daily means are compared in Figures 4.5 and 4.7. Plots and statistical metrics of the finally adopted monthly naturalized flows at all of the gage sites are presented in Chapter 5. All of the daily and monthly flows stored in the DSS files that accompany this report are efficiently viewed and analyzed using *HEC-DSSVue*.

Stream flow rates fluctuate continuously. USGS gage measurements are recorded as mean daily flows in cubic feet per second (cfs). Daily means are averaged over the days of each month to obtain monthly means or over the days of each year to obtain annual flows. Variability is reduced with the larger averaging time interval. Maximum flood peaks are lowered and minimum flows during low flow periods tend to increase with an increase in the size of the measurement or computational time interval. Daily mean flow rates in cfs are less variable than instantaneous flow rates. Monthly means in cfs are less variable than daily flows in cfs.

The decreases in daily flood flows of the Neches River near Evadale due to flood control operations of Sam Rayburn and B. A. Steinhagen Reservoirs are clearly evident in Figure 4.6, somewhat dissipated in the monthly means of Figure 4.7, and totally lost in the annual means of Figure 4.7. The reservoir storage attenuation impacts on river flows at downstream locations are dissipated with an increase in time interval used to record observed or computed mean flow rates or flow volumes and to perform simulation computations. The effects of dams on river flows also diminish with distance downstream from the dam.

Stream flows are naturally highly variable. Human activities affect both variability and stationarity (homogeneity over time) of flows. Both variability and stationarity are important.

The observed flows of the Neches River in Figures 4.4-4.7 illustrate the extreme variability characteristic of rivers throughout Texas as well as the Neches River and tributaries. Flows fluctuate greatly with extremes of floods and droughts as well as less severe continuous variability.

Stationarity or temporal homogeneity refers to absence of permanent modifications. Permanent changes or long-term trends resulting from water resources development and use and other factors vary greatly between sites on the streams of Texas. Long-term changes in stream flow characteristics are difficult to detect and measure due to great continuous variability. Permanent modifications or trends vary greatly with location but tend to be small compared to continuous extreme variability. The objective of naturalization computations is to remove non-stationarities.

Factors that Affect Stream Flow Stationarity

WAM naturalized flows should conceptually reflect conditions without the reservoirs, water users, and water management strategies represented by data in the *SIM/SIMD* water rights input DAT file. This condition is normally assumed to be natural conditions without the effects of human activities. Thus, "*naturalized*" stream flows are viewed as flows for "*natural*" conditions. Observed flows are adjusted to remove "*significant*" impacts of water development and use, realizing that quantifying all effects of all human activities is not feasible nor warranted. Conceptually, "*naturalized*" flows on *DF* and *IN* records are perhaps more appropriately viewed as representative of current and/or future conditions without the human activities modeled by the data in the DAT file, as illustrated by the examples in the following two paragraphs.

Land use changes associated with urbanization and agriculture are usually assumed from a WAM perspective to have negligible impact on stream flows. However, naturalized flows should conceptually represent current or future actual rather than natural land use. The objective would be for the WAM to reflect a homogeneous defined condition of watershed development.

Almost half of the water use in the Neches River Basin is from groundwater, which is not included in surface water right permits or the WAMs. Conceptually, historical effects on stream flow of return flows from groundwater would be removed from the naturalized flow and current or future conditions of return flows from groundwater supplies would be added to the DAT file to be precisely consistent. Spring flows should also represent defined groundwater use conditions.

Analyses of the 1940-2018 monthly precipitation data discussed in Chapter 6 indicate that monthly precipitation during 1940-2018 throughout Texas and the Neches River Basin has been extremely variable but appears to be essentially stationary with no long-term trends or permanent changes over time [4]. Likewise, the 1954-2018 TWDB reservoir evaporation rates exhibit extreme variability, particularly seasonal variability, but no clearly apparent long-term trends.

Long-term changes in stream flow characteristics are associated primarily with dam construction and other aspects of water resources development and use. The relative magnitudes of the quantities tabulated in Table 4.5 provide general insight regarding the potential impacts of water resources development and use on the flows of the Neches River and tributaries.

Table 4.5
Estimates of Annual Quantities for Comparison

	acre-feet/year
1940-2019 mean observed flow of Neches River at Rockland (NERO)	1,805,500
1940-2019 mean observed flow of Neches River at Evadale (NEEV)	4,553,000
Evaporation from Sam Rayburn, Steinhagen, and Palestine Reservoirs	583,570
Precipitation falling on Sam Rayburn, Steinhagen, Palestine Reservoirs	619,800
2008-2017 water use in the Neches River Basin (Table 2.13)	263,950
(surface water use)	(142,840)
(ground water use)	(121,100)
2020 total water use in East Texas Regional Planning Area (Figure 2.17)	1,108,800
(Jefferson County)	(737,350)

The 1940-2019 mean flow of the Neches River at the gage near Evadale (control point NEEV) is indicated in Table 4.5 to be 4,553,000 acre-feet/year. The Evadale gage site has a watershed area of 7,885 square miles, which is 78.7 percent of the total Neches River Basin watershed area of 10,025 square miles. The 1940-2019 mean annual flow of Village Creek near Kountze (VIKO, watershed area 861 square miles) is 650,400 acre-feet/year. The watersheds above these two gages represent 87.2 percent of the total watershed area above the outlet of the Neches River at Sabine Lake (control point NESL). The 1940-2019 mean annual flows at these two gages total 5,203,000 acre-feet/year.

The total conservation storage capacity of the 203 reservoirs in the current use scenario WAM is 3,656,260 acre-feet. The 12 reservoirs listed in Table 2.9 contain 98.5 percent of the total storage capacity of the 203 reservoirs and essentially all of the flood control storage volume. Historical storage contents for seven of the larger reservoirs are plotted as Figures 2.9-2.16.

Sam Rayburn and B. A. Steinhagen Reservoirs owned and operated by the USACE contain 79.3 and 1.8 percent, respectively, of the total conservation storage capacity of the 203 reservoirs in the current use scenario Neches WAM. Sam Rayburn Reservoir accounts for almost all of the total volume of flood control storage capacity in the Neches River Basin. Sam Rayburn and B. A. Steinhagen Reservoirs as well as the other reservoirs in the basin are described in Chapter 2. Historical observed water surface elevations of Sam Rayburn and B. A. Steinhagen Reservoirs are plotted in Figures 2.7 and 2.8.

The evaporation from the water surface and precipitation on the water surface of the three largest reservoirs (Sam Rayburn, Palestine, Steinhagen) shown in Table 4.5 are estimated using surface areas from Table 2.10 and mean evaporation and precipitation rate data from Chapter 6 and assuming the reservoirs are full to top of conservation pool. The historical fluctuations of water levels shown in the figures in Chapter 2 indicate that the top of conservation pool assumption is realistic for this estimate. The average precipitation volume of 619,800 acre-feet/year falling on the water surface of these three reservoirs exceeds the corresponding average evaporation of 583,570 acre-feet/year. Both the reservoir surface precipitation and evaporation exceed the total water use within the Neches River Basin, not counting transfers to the adjoining coastal basin.

The total within-basin water use of approximately 263,950 acre-feet/year includes 142,840 acre-feet/year from surface water and 121,100 acre-feet/year from groundwater. Significant portions of the water supply diversions are returned to the river as wastewater treatment plant effluents and thermal-power plant and irrigation return flows.

Total water use in the SB1 East Texas Regional Planning Area (Figure 2.17) greatly exceeds the total water use in the Neches River Basin, which is encompassed by the planning area. About 66.5 percent of the water use in the SB3 planning area is in Jefferson County in the Neches-Trinity coastal basin. Water supply diversions from the lower Neches River and Pine Island Bayou supply water users in Jefferson and other counties in the coastal basin. Much of the total amount of water diverted from the Neches River and its tributuries is diverted at pumping stations located downstream of the USGS gaging station on the Neches River at Evadale, Village Creek near Kountz, and Pine Island Bayou near Sour Lake (control points NEEV, VIKO, and PISL).

Adjustments that Convert Observed Flow to Naturalized Flow

The conversion of daily or monthly observed flow volumes to naturalized flow volumes is generally viewed conceptually as follows.

Naturalized Flow = Historical Observed Flow + Upstream Diversions
– Upstream Return Flows from Surface Water Use
– Upstream Return Flows from Ground Water Use
+ Upstream Reservoir Evaporation – Upstream Reservoir Surface Precipitation
+ Increases in Upstream Reservoir Storage – Decreases in Upstream Reservoir Storage
+ or – other factors such as land use or climate changes

The flow adjustments consist of quantities added to or subtracted from observed stream flows to compute naturalized stream flows. The computations conceptually should include lag, attenuation, and channel losses associated with the flow changes. The stream flow adjustments reflect the characteristics of river basin hydrology and water resources development, allocation, and, use.

Precipitation falling on the watershed is the primary source of inflows to the river/reservoir system. Combined evaporation and transpiration is the largest component of the outflow from most river basins. Precipitation falling directly on reservoir water surfaces represents a major inflow to reservoirs as well as the precipitation falling on the watershed. Evaporation from reservoir surfaces represents the largest diversion of water from reservoirs in the Neches River Basin. Precipitation will fall on the water surface or the land area otherwise covered by the reservoir with or without a reservoir. Likewise, evaporation and/or transpiration at a reservoir site occurs with or without the reservoir. Estimating the difference between evapotranspiration and rainfall contributions to stream flow with-versus-without reservoirs is necessarily approximate.

Diversions for municipal, industrial, and agricultural use and releases through hydroelectric power turbines are supplied from reservoir storage. Diversions from reservoirs decrease reservoir storage levels. The impacts of storage draw-downs on downstream stream flow occur later when the storage is refilled. Thus, high flows contribute to supply water needs during low flow periods. Reservoirs decrease flood flows and increase flows during dry periods. Reservoirs significantly, sometimes greatly, affect flows at downstream locations in individual days with only minimal effects on long-term mean flows.

The methodology for developing naturalized flows for the Neches WAM is explained in later in this chapter. The methodology reflects the basic concepts summarized in the following paragraphs.

Control points NEEV, VIKO, and PISL define the downstream limits for which naturalized flows are computed directly by adjusting observed flows. Naturalized flows at control points NEBA and NESL, located further downstream, are synthesized based on naturalized flows at NEEV, VIKO, and PISL. The majority of the surface water use supplied by the Neches Basin is through diversions from the lower Neches River and Pine Island Bayou at sites downstream of NEEV, VIKO, and PISL. The wateshed area above these three control points represents 90.9 percent of the total area of the Neches River Basin above its outlet at control point NESL.

Water supply diversions and return flows from surface and ground water sources occurring upstream of control points NEBA and NESL are not included in the naturalization computations. Surface water supply diversions, if included, would increase naturalized flows. Return flows from surface and groundwater sources, if included, would decrease naturalized flows. Omission of both water supply diversions and return flows is expected to have negligible effect on naturalized flows.

Daily observed flows are adjusted for daily changes in storage volume and net evaporation-precipitation at major upstream reservoirs. The *EV* record net evaporation-precipitation rates developed in Chapter 6 are also used in the computations described here for converting observed flows to naturalized flows. The monthly *EV* record net evaporation-precipitation rates are uniformly disaggregated to daily rates for use in the flow naturalization computations.

Compilation of Daily and Monthly Naturalized Flows

The June 2020 Neches WAM hydrology input DSS file includes January 1940 through December 2019 monthly naturalized flows on *IN* records at 20 control points and *DF* record daily naturalized flows at 17 of the 20 control points. The daily flows serve the following two purposes.

1. *DF* record 1940-2019 daily naturalized flows at 17 sites are used within the *SIMD* simulation to disaggregate monthly naturalized flows to daily at all of the over 300 control points.
2. The 1997-2019 subset of the 1940-2019 monthly totals of the daily naturalized flows are used as discussed in Chapter 5 to extend the original 1940-1996 *IN* record monthly naturalized flows through December 2019. The daily flow volumes in acre-feet/day are summed to monthly flow volumes in acre-feet/month.

The WRAP daily simulation model *SIMD* disaggregates monthly naturalized flow volumes to daily volumes in proportion to the flows in input daily pattern hydrographs while preserving the monthly volumes [5]. Although monthly and daily flow volumes in a *SIMD* simulation are in acre-feet, flow rates in cfs or other units can be used for the *DF* record flow sequences defining patterns since only relative, not absolute, quantities are relevant. However, the final daily flows adopted for the Neches WAM pattern hydrographs are daily naturalized flow volumes in acre-feet/day.

The *SIMD* time series input DSS file contains daily flow *DF* records of 1940-2019 sequences of daily naturalized flows at 17 control points developed as explained in this chapter. The 1940-1996 daily naturalized flows initially developed as described in this chapter are further adjusted within *SIMD* to sum to the original 1940-1996 monthly naturalized flows. The adjusted daily naturalized flows are obtained from the results of a *SIMD* simulation with the initial daily naturalized flows provided as *DF* records in the *SIMD* hydrology input DSS file.

The original WAM [9] has a hydrologic period-of-analysis of 1940-1996. The 1940-1996 monthly naturalized flows at 20 primary control points were adopted without modification. Daily naturalized flows are used to extend the *IN* record monthly naturalized flows through 2019.

In addition to the Neches WAM simulation input files, other DSS files are introduced in Chapter 1 and described in Chapters 4, 5, and 6 that were compiled for use in exploring river system hydrology as well as supporting development and future updates of the WAM input files. The organization of the auxiliary daily flow DSS file is summarized later in the present Chapter 4.

Periods of daily flows at the 20 primary control points available from alternative sources are shown in Table 4.2. Daily flow availability is further summarized in Table 4.6. Daily flow data from one or more of the three previously described data sources listed in Table 4.6 are available for 17 control points. No data are available at control points NEPA, MUTY, and NESL. Sub-periods of data availability during 1940-1996 and 1997-2019 at the 17 sites are listed in Table 4.6.

Table 4.6
Daily Flow Data Availability during of 1940-1996 and 1997-2019 at 17 Control Points

Control	USGS Gage Measurements		USACE Model		USACE Reservoirs	
Point	1940-1996	1997-2019	1940-1996	1997-2019	1940-1996	1997-2019
KIBR	1962-1989	–	–	–	–	–
NENE	Complete	complete	–	–	–	–
NEAL	1944-1978	–	–	–	–	–
NEDI	1940-1985	2015-2019	–	–	–	–
NERO	Complete	complete	complete	1997-2011	–	–
MUJA	1940-1979	2001-2019	–	–	–	–
EFACU	1964-1989	2016-2019	–	–	–	–
ANAL	13 gaps of missing data		–	–	–	–
ANLU	1940-1979	–	–	–	–	–
ATCH	1940-54, 1956-85	–	–	–	–	–
AYSA	1959-1985	–	–	–	–	–
ANSR	–	–	complete	1997-2011	1975-1996	Complete
NETB	1951-1990	complete	complete	1997-2011	1981-1996	Complete
NEEV	Complete	complete	complete	1997-2011	–	–
VIKO	Complete	complete	–	–	–	–
PISL	1967-1996	complete	–	–	–	–
NEBA	–	2003-2019	complete	1997-2011	–	–

Daily naturalized flows are developed for the sites and time periods for which observed stream flow data are available. Actual stream flows are adjusted to reflect the effects of reservoirs located upstream based on reservoir storage changes and net evaporation-precipitation. Periods of missing daily naturalized flows at a control point are synthesized based on available naturalized flows at one or more other control points.

The sequences of daily naturalized flows were developed based on the following choices regarding the use of available daily stream flow data.

1. USACE Fort Worth District 1997-2019 observed outflows from Sam Rayburn Reservoir are adopted as 1997-2019 observed flows at control point ANSR.
2. USACE Fort Worth District unregulated flows are used for 1940-1996 daily pattern hydrographs for control points ANSR, NETB, NEEV, and NEBA.
3. Observed daily flows at USGS gaging stations are used for the 16 gage sites for sub-periods of 1940-2019 not included in items 1 and 2 above.

USGS observed and USACE unregulated flows are identical at control point NERO for their common period-of-record of 1923-2011. USACE unregulated flows match very closely with USGS observed flows at control points NETB, NEEV, and NEBA. The differences between the USGS gaged and USACE unregulated flows reflect the effects of Sam Rayburn and B.A. Steinhagen Reservoirs located upstream. There is no USGS stream gage at control point ANSR or any other site between Sam Rayburn Dam and Town Bluff Dam at B. A. Steinhagen Reservoir.

Compilation of 1940-2019 Daily Naturalized Flows at 17 Control Points

The procedure adopted for developing a dataset of 1940-2019 daily naturalized flows at 17 control points includes the following tasks.

1. Compilation of observed actual daily flows at the 17 sites for the sub-periods of 1940-2019 for which flow data are available.
2. Conversion of actual flows to naturalized flows by approximate computational adjustments to remove impacts of upstream reservoir net evaporation-precipitation and storage fluctuations.
3. Filling in gaps of missing daily naturalized flows based on relationships with daily naturalized flows at one or more other sites.
4. Aggregation of daily flows to monthly flows.
5. Adjustment of daily naturalized flows in a *SIMD* simulation to replicate monthly flows.

The sources of flows for the compilation of 1940-2019 daily naturalized flows at the 17 sites are outlined in Table 4.7. Control point (gaging station) locations are shown Figure 4.1. Naturalized daily flows are initially developed only for the sub-periods of 1940-2019 for which necessary data are available. The gaps of missing daily naturalized flows during 1940-2019 are then synthesized based on naturalized flows at other control points as outlined later in Table 4.12.

Table 4.7
Sources of 1940-2019 Daily Flows Adopted for the 17 Control Points

Control Point	Location	USGS Gages	USACE Model	Rayburn Releases	Days Missing
KIBR	Kickapoo Creek, Brownsboro	1962-1989	–	–	19,207
NENE	Neches River, Neches	1940-2019	–	–	0
NEAL	Neches River, Alto	1944-1978	–	–	16,437
NEDI	Neches River, Diboll	1940-2019	–	–	10,591
NERO	Neches River, Rockland	1940-2019	–	–	0
MUJA	Mud Creek, Jacksonville	1940-2019	–	–	7,962
EFACU	East Fork Angelina, Cushing	1964-2019	–	–	18,263
ANAL	Angelina River, Alto	1940-2019	–	–	7,884
ANLU	Angelina River, Lufkin	1940-1979	–	–	14,703
ATCH	Attoyac Bayou, Chireno	1940-1985	–	–	12,844
AYSA	Ayish Bayou, San Augustine	1959-1985	–	–	19,498
ANSR	Angelina River, Sam Rayburn	–	1940-1996	1997-2019	0
NETB	Neches River, Town Bluff	1997-2019	1940-1996	–	0
NEEV	Neches River, Evadale	1997-2019	1940-1996	–	0
VIKO	Village Creek, Kountze	1940-2019	–	–	0
PISL	Pine Island Bayou, Sour Lake	1967-2019	–	–	10,136
NEBA	Neches River, Beaumont	2012-2019	1940-1996	–	23,224

Control point NETB represents the USGS gage site located immediately downstream of Town Bluff Dam which impounds B. A. Steinhagen Reservoir. The gage represented by control point NETB has a period-of-record of April 1951 to present. The 1997-2019 observed daily flows at this USGS gage are used to develop daily and monthly naturalized flows. The daily unregulated flows from the USACE model are adopted as 1940-1996 daily naturalized flows. The dataset of USACE measured releases from B. A. Steinhagen Reservoir are not used.

Control point ANSR represents the site of stream flows immediately downstream of Sam Rayburn Dam. Releases from the reservoir measured by the USACE are treated as actual daily observed flows at control points ANSR. There is no USGS gage at control point ANSR.

The naturalized flows at control points NEBA and NESL are derived from naturalized flows at upstream control points NEEV, VIKO, and PISL. Thus, removal of the effects of water diversions and return flows occurring downstream of NEEV, VIKO, and PISL is indirectly represented in the naturalized flows at NEBA and NESL. This strategy addresses both the lack of observed flow data at control points NEBA and NESL and the situation with the largest water supply diversions in the basin occurring downstream of control points NEEV, VIKO, and PISL.

Adjustments for Upstream Reservoirs

Actual observed daily flows at the 17 control points are converted to naturalized daily flows by adjusting for the effects of selected reservoirs located upstream. The effects of Lakes Sam Rayburn, B. A. Steinhagen, Palestine, Tyler, Nacogdoches, Athens, Jacksonville, and Striker on river flows at downstream control points are approximated in the flow naturalization process based on historical storage contents data discussed in Chapter 2 and reservoir evaporation and precipitation rates described in Chapter 6. The effects of these reservoirs included in the daily naturalization computations are limited to storage change and evaporation from and rainfall on the reservoir water surface.

Daily storage contents of Sam Rayburn and B. A. Stainhahen Reservoirs from the USACE FWD water management information website were used for the flow adjustment computations. Naturalized flow adjustments were computed for the control points (ANSR, NETB, NEEV, NEBA) downstream of Rayburn and Steinhagen Reservoirs for 1997-2019. Unregulated flows from the USACE FWD modeling system were adopted as 1940-1996 naturalized flows at control points ANSR, NETB, NEEV, and NEBA. Plots of Sam Rayburn and B. A. Steinhagen water surface elevaions are presented as Figures 2.7 and 2.8.

Plots of storage contents for the reservoirs listed in Tables 4.8 and 4.9 from the TWDB website are replicated as Figures 2.9 through 2.16 of Chapter 2. Storage data were downloaded from the TWDB website for use in the flow adjustment computations. The periods-of-record for daily reservoir storage contents and water surface areas from the TWDB database are listed in the sixth and seventh columns of Table 4.8. The storage data is complete for the periods shown, but the surface area data has multiple long gaps during the periods-of-record listed. The storage contents from the TWDB database for Lakes Palestine, Tyler, Nacogdoches, Athens, Jacksonville, and Striker were adopted for the flow naturalization computations. Due to limitations in the periods covered by the surface area data, daily reservoir surface areas were computed as described in the following paragraphs, rather than using the TWDB recorded areas.

Table 4.8
Periods-of-Analysis of TWDB Reservoir Storage Contents and Surface Area Data
http://www.twdb.texas.gov/surfacewater/rivers/reservoirs/

Reservoir	Watershed Area (sq miles)	Storage Capacity (acre-feet)	Surface Area (acres)	Initial Impound	TWDB Dataset Period-of-Record	
					Storage	Surface Area
Sam Rayburn	3,449	2,876,033	112,500	1965	Jan1965-present	Apr 2004-present
Steinhagen	7,573	69,259	10,235	1951	May1951-present	May 2003-present
Palestine	839	367,312	23,112	1962	Feb1962-May/1995	May1999-present
					May1999-present	with multiple gaps
Tyler	107	77,284	4,714	1949/66	Oct1985-Oct1986	Apr 1999-present
					Apr1999-present	with multiple gaps
Nacogdoches	89	39,523	2,212	1976	Mar1977-present	Oct 1992-present
Athens	21.6	29,475	1,799	1962	Oct1985-Jan1987	Apr 1999-present
					Apr1999-present	with multiple gaps
Jacksonville	34	26,732	1,164	1957	May1999-present	May 2006-present
Striker	182	22,865	1,920	1957	Jan2017-present	Jan 2017-present

Daily reservoir water surface areas were estimated using the regression equation with the coefficients a and b shown in Table 4.9 computed with data from elevation versus storage volume and surface area tables available at the TWDB reservoir website. Storage levels representing the historical operating range of each reservoir were selected for the regression computations. As shown in Figures 2.7-2.15, draw-downs of these reservoirs have been relatively small.

Table 4.9
Reservoir Storage Volume Versus Surface Area Regression Equations

$$\text{area} = a\,(\text{storage})^{b}$$

Sam Rayburn	a = 5.00023	b = 0.674331
B. A. Steinhagen	a = 0.401107	b = 0.915921
Palestine	a = 21.0347	b = 0.54573
Tyler	a = 12.0825	b =0.528329
Nacogdoches	a = 2.378685	b = 0.643802
Athens	a = 0.035106	b = 1.05309
Jacksonville	a = 85.12752	b = 0.249885
Striker	a = 0.083971	b = 1.00000

The available storage data (Figure 2.14) for Striker Reservoir begins in January 2017, though initial impoundment dates back to 1957. The computation of flow naturalization adjustments for Striker Reservoir are based on the assumption of a constant storage level with water surface area of 1,920 acres. The reservoir is owned and operated by the Angelina-Nacogdoches Counties Water Control and Improvement District No. 1 to provide cooling water for two thermal-electric power plants. The storage contents are relatively constant over time.

Daily net evaporation-precipitation volumes in acre-feet are computed as water surface areas in acres multiplied by net evaporation-precipitation depths in feet/day. Time series of net precipitation less evaporation rates covering each day since initial impoundment for each of the reservoirs were computed based on the following component tasks.

1. Daily observed reservoir storage contents for each reservoir, along with other data, were downloaded from the TWDB and USACE websites into Excel spreadsheets.
2. Daily water surface areas were computed by combining the daily storage volumes with the regression equation of Table 4.10 within either the Excel spreadsheet or *HEC-DSSVue*.
3. Compilation of monthly net evaporation less adjusted precipitation rates is described in Chapter 6. The net evaporation-precipitation rates on *EV* records in the *SIM/SIM* hydrology DSS input file are used in the computations described here as well as in *SIM/SIMD* simulations.
4. The 1940-2019 monthly *EV* record evaporation-precipitation depths are uniformly distributed to each of the days of each of the months within *HEC-DSSVue*.
5. Daily evaporation-precipitation volumes are computed within *HEC-DSSVue* by multiplying daily water surface areas by daily net evaporation-precipitation depths.

The daily flow adjustments associated with the reservoirs listed in Tables 4.8 and 4.9 consist of the summation of the change in reservoir storage and the estimated net evaporation-precipitation. The adjustment was applied within *HEC-DSSVue* at all control points located at and downstream of the dams. The relevant reservoirs located upstream of each of the control points are listed in Table 4.10. The daily naturalized flow at each control point was computed as follows.

naturalized flow = actual flow + adjustments for reservoirs located upstream

Table 4.10
Reservoirs Located Upstream of Each of the 17 Control Points

CP	Location	Upstream Reservoirs
KIBR	Kickapoo Creek, Brownsboro	none
NENE	Neches River, Neches	Athens, Palestine
NEAL	Neches River, Alto	Athens, Palestine, Jacksonville
NEDI	Neches River, Diboll	Athens, Palestine, Jacksonville
NERO	Neches River, Rockland	Athens, Palestine, Jacksonville
MUJA	Mud Creek, Jacksonville	Tyler
EFACU	East Fork Angelina, Cushing	none
ANAL	Angelina River, Alto	Tyler, Striker
ANLU	Angelina River, Lufkin	Tyler, Striker, Nacogdoches
ATCH	Attoyac Bayou, Chireno	none
AYSA	Ayish Bayou, San Augustine	none
ANSR	Angelina River, Sam Rayburn	Tyler, Striker, Nacogdoches, Sam Rayburn
NETB	Neches River, Town Bluff	all eight reservoirs
NEEV	Neches River, Evadale	all eight reservoirs
VIKO	Village Creek, Kountze	none
PISL	Pine Island Bayou, Sour Lake	none
NEBA	Neches River, Beaumont	all eight reservoirs

Filling in Gaps of Missing Daily Naturalized Flows

The actual daily flows were first adjusted as described in the preceding section to develop estimates of daily naturalized flows. Gaps of missing daily naturalized flows were then synthesized based on daily naturalized flows at one or more other gage sites. The periods covered by the naturalized flows compiled as described in the preceding section are listed in Table 4.11.

Table 4.11
Periods of 1940-2019 with Naturalized Flow Data

CP	Mean Flow (ac-ft/day)	Days	January 1940 through December 2019 Period-of-Data
ANAL	1,669	21,336	Oct 40, Jun-Sep 41, Feb-Mar 42, Jul 42-Dec 43, Jul-Nov 44, Jun 45, Aug-Sep 45, Nov 45, Jul-Oct 46, Jun 47-Jan 48, Apr 48, May-Dec 48, Mar 49, Mar 59-Sep 94, Sep 01-Dec 19
ANLU	2,338	14,517	Jan 1940 – Sep 1979
ANSR	3,757	29,220	complete
ATCH	887.0	16,376	Jan 1940 – Oct 1954 and Oct 55 – Sep 1985
AYSA	165.6	9,723	17 Feb 1959 – 30 Sep 1985
EFACU	235.7	10,958	Jan 1964 – Sep 1989 and Oct 2015 – Dec 2019
KIBR	266.9	10,014	May 1962 – Sep 1989
MUJA	507.9	21,258	Jan 1940 – Sep 1979 and 18 Jul 2001 – 31 Dec 2019
NEAL	2,374	12,784	Jan 1944 – Dec 1978
NEBA	9,998	29,220	complete
NEDI	3,434	18,629	Jan 40 – Sep 85 and Oct 2014 – Dec 2019
NEEV	7,785	29,220	complete
NENE	1,537	29,220	complete
NERO	5,036	29,220	complete
NETB	7,785	29,220	complete
PISL	434.4	19,085	Oct 1967 – Dec 2019
VIKO	1,781	29,220	complete

Table 4.11 indicates that upon completion of the compilations described in the preceding section, daily naturalized flows for the entire January 1940 through December 2019 period-of-analysis are available, with no gaps, for control points ANSR, NETB, NEEV, NENE, NERO, and VIKO. The adopted final daily naturalized flows for control points ANSR, NETB, and NEEV consists of unregulared flows from the USACE FWD modeling system for 1940-1996 combined with adjusted 1997-2019 observed flows. Observed flows include reservoir releases for ANSR and USGS gage measurements for the other control points. Control points NENE, NERO, and VIKO represent USGS gage sites with complete records with no gaps for 1940-2019. Observed flows at VIKO are adopted as naturalized flows without adjustments. Flows at the other sites are adjusted.

Gaps of missing data must be filled as discussed in this section for control points ANAL, ATCH, AYSA, EFACU, KIBR, MUJA, NEAL, NEBA, NEDI, and PISL. Daily naturalized flows for the gaps of missing flows are computed as outlined in the last column of Table 4.12.

Table 4.12
Relationships for Synthesizing Daily Naturalized Flows for Gaps of Missing Data

Control Point	Location	Daily Naturalized Flow Synthesis Equation
KIBR	Kickapoo Creek, Brownsboro	$F_{KIBR} = 0.193318\ F_{NENE}$
NEAL	Neches River, Alto	$F_{NEAL} = 0.812704\ F_{NNI}$
NEDI	Neches River, Diboll	$F_{NEDI} = 1.02109\ F_{NNI}$
ANAL	Angelina River, Alto	$F_{ANAL} = 0.779335\ F_{ANLU}$ (Jan 1940 –Sep 1979)
		$F_{ANAL} = 0.519124\ F_{NNI}$ (Oct 1979-Dec 2019)
MUJA	Mud Creek, Jacksonville	$F_{MUJA} = 0.285793\ F_{ANAL}$
EFACU	East Fork Angelina, Cushing	$F_{EFACU} = 0.138276\ F_{ANAL}$
ANLU	Angelina River, Lufkin	$F_{ANLU} = 1.28313\ F_{ANAL}$
ATCH	Attoyac Bayou, Chireno	$F_{ATCH} = 0.497841\ F_{ANAL}$
AYSA	Ayish Bayou, San Augustine	$F_{AYSA} = 0.104422\ F_{ANAL}$
PISL	Pine Island Bayou, Sour Lake	$F_{PISL} = 0.498500\ F_{VIKO}$
NEBA	Neches River, Beaumont	$F_{NEBA} = 1.09128\ (F_{NEEV} + F_{VIKO} + F_{PISL})$

Relationships for synthesizing daily naturalized flows in acre-feet/day are presented in the last column of Table 4.12. These equations contain multiplier factors computed as the ratio of mean daily naturalized flows at the two relevant control points for the sub-period of 1940-2019 with flows are available at both sites, which are listed in Table 4.11. Thus, naturalized flows at a gage site are transferred to another gage site based on replicating means of naturalized flows.

For example, the daily naturalized flows at control point KIBR during the periods January 1940 through April 1962 and October 1990 through December 2019 (Table 4.11) are computed with the following equation (Table 4.12).

$$F_{KIBR} = 0.193318 \times F_{NENE}$$

The terms F_{KIBR} and F_{NENE} in this equation represent the daily naturalized flows at control points KIBR and NENE. The multiplier 0.193318 is the ratio of the means of the daily naturalized flows during May 1962 through September 1989 at the two control points.

Incremental Flows Between Control Points NENE and NERO (F_{NNI})

The term F_{NNI} in Table 4.12 refers to 1940-2019 incremental daily natural flows in acre-feet/day entering the Neches River between control points NENE and NERO. The sole purpose of the F_{NNI} flows is for use in filling in gaps of missing flows at other control points.

Control points NENE and NERO represent the USGS gages on the Neches River near Neches and Rockland. These two gages have complete records with no gaps for the 1940-2019 period-of-analysis. The incremental observed flows between these two gages are considered to be a close approximation of incremental naturalized flows. Lakes Palestine and Athens located above both gage sites are assumed to have similar effects on flows at both NENE and NERO and no effects of incremental flows between NENE and NERO. Lake Jacksonville is located above NERO but not above NENE and thus does affect incremental flows, though only minimally.

The 1940-2019 sequence of NERO-NENE incremental (NNI) daily naturalized flows (F_{NNI}) are computed as the observed daily flows at NERO less the lagged flows at NENE adjusted for Lake Jacksonville. The computed F_{NNI} reflect the following two adjustments.

1. The daily observed flows at control point NENE are lagged by two days to approximate travel time before being subtracted from the observed flows at control point NERO.
2. The resulting incremental flows are naturalized by adding the flow naturalization adjustments for Lake Jacksonville.

The F_{NNI} are computed without consideration of Lakes Athens and Palestine. The effects of Lakes Athens and Palestine are assumed to be the same on the flows at control points NENE, NEAL, NEDI, and NERO, cancel out in the subtractions, and thus are not included in the computation of the time series quantities F_{NNI} referenced in Table 4.12.

Missing flows at control points NEAL and NEDI are synthesized by multiplying the F_{NNI} by the ratios of the mean of available flows at NEAL and NEDI to the means of the F_{NNI} for the corresponding time periods. The ratios of mean naturalized flows during corresponding periods of known observed flows are 0.812704 and 1.02109 (Table 4.12).

Missing flows at control point ANAL during January 1940 through September 1979 are computed based on the ratio (0.779335 in Table 4.12) of the means of flows during corresponding sub-periods of January 1940 through September 1979 at control points ANAL and ANLU. Missing flows at control point ANAL during October 1979 through December 2019 are computed based on the ratio 0.519124 of the means of available flows during corresponding sub-periods of March 1959 through December 2019 of flows at control point ANAL and the NNI flows. The F_{ANAL} are used in filling in gaps at five other control points listed in Table 4.12.

Naturalized Flows at Control Point NEBA

Control points NEEV, VIKO, and PISL define the downstream limits for which the naturalized flows adopted as described in this report are computed directly by adjusting observed flows. Naturalized flows at control points NEBA and NESL, located further downstream, are synthesized based on naturalized flows at NEEV, VIKO, and PISL. The majority of the surface water use supplied by the Neches Basin is through diversions from the lower Neches River and Pine Island Bayou at sites downstream of control points NEEV, VIKO, and PISL. The wateshed area above these three control points represents 90.91 percent of the total area of the Neches River Basin above its outlet at ungaged control point NESL and and 92.75 percent of the watershed above gaged control point NEBA. There is no stream flow gage at control point NESL. Control point NEBA represents the USGS gage on the Neches River at the salt water barrier at Beaumont, which has a period-of record of June 2003 to present with multiple periods of one to several days of missing data.

The adopted modeling strategy addresses both the lack of observed flow data at control points NEBA and NESL and the situation with the largest water supply diversions in the basin occurring downstream of control points NEEV, VIKO, and PISL. With naturalized flows at control points NEBA and NESL derived from naturalized flows at upstream control points NEEV, VIKO, and PISL, the removal of the effects of water supply diversions downstream of NEEV, VIKO, and PISL are indirectly reflected in the monthly naturalized flows at NEBA and NESL.

Two alternative sequences of naturalized flows were computed for control point NEBA for comparison. The second alternative daily naturalized flow time series developed as described below was actually adopted.

1. The alternative flows not adopted were compiled in essentially the same manner as the daily naturalized flows at control points NETB and NEEV. USACE 1940-2011 unregulated daily flows were combined with 2003-2019 daily adjusted observed flows, with adjustments limited to the previously discussed upstream reservoirs.
2. The adopted 1940-2019 naturalized flows at NEBA were synthesized from daily and monthly naturalized at control points NEEV, VIKO, and PISL.

Referencing Table 4.12, the 1940-2019 daily and monthly naturalized flows F_{NEBA} at control point NEBA are computed with following equation.

$$F_{NEBA} = 1.09128\ (F_{NEEV} + F_{VIKO} + F_{PISL})$$

Information for the relevant control points is tabulated in Table 4.13. The watershed area above control point NEBA is 1.07812 of the total combined watershed area above control points NEEV, VIKO, and PISL. The ratio of the mean of 1940-1996 naturalized flow at NEBA from the original WAM to the summation of the corresponding mean flows at NEEV, VIKO, and PISL is 1.09128. Either of these two ratios could be reasonably applied in the flow synthesis. Either choice is approximate. The ratio of mean naturalized flow was actually adopted.

Table 4.13
Watershed Areas and 1940-1996 Mean Naturalized Flow

CP	Location	Drainage Area	Naturalized Flow
		(sq miles)	(ac-ft/year)
NEEV	Neches River at Evadale	7,885	4,576,252
VIKO	Village Creek near Kountze	861	639,756
PISL	Pine Island Bayou bear Sour Lake	368	323,123
Total		9,114	5,539,131
NEBA	Neches River at Beaumont	9,826	6,044,722
Ratio		1.07812	1.09128

The equation from Table 4.12 replicated above was used to synthesize both 1940-2019 daily naturalized flows and 1997-2019 monthly naturalized flows at NEBA. Daily flows at NEEV, VIKO, and PISL are used to synthesize initial daily flows at NEBA. Monthly flows at NEEV, VIKO, and PISL are used to synthesize monthly and daily flows at NEBA. The computational procedure is discussed further in Chapter 5.

Dealing with Negative Naturalized Flows

Naturalization adjustments at several control points and computation of F_{NNI} incrementals result in negative naturalized stream flows for some days. The negative values for computed stream flows may be caused by inaccuracies in the naturalization adjustments, inaccuracies in modeling the lag between control points NENE and NERO for the F_{NNI}, and/or other factors.

Adjustments to remove negative quantities include both daily and monthly flows. The number of negative values in 1940-2019 series of 960 monthly summations of daily flows is much smaller than the number of negative values in 1940-2019 series of 29,220 daily flows. In most months, the monthly summation is positive even though one or several days have negative flows.

The following strategy for removing negative values for naturalized flows was applied for all of the control points at the completion of the process of filling in gaps of missing flow data.

1. Daily flows were summed to monthly prior to removing the negative daily values.
2. Negative values were changed to zero in both the monthly and daily flows.
3. The monthly flows were then distributed to daily within *SIMD* using the daily flows as input *DF* record pattern hydrographs while maintaining the monthly volumes. The daily naturalized flows from the *SIMD* simulation results were adopted as the final *DF* record daily naturalized flows.

Additional adjustments were employed for naturalized flows at control points NENE, NERO, and ANAL, and the NERO-NENE incremental flows (F_{NNI}) due to and prior to their use in filling in gaps of missing flows at other control points. The following computations to remove negative flow values were performed with *HEC-DSSVue* and *SIMD*.

1. F_{NENE}, F_{NERO}, and F_{NNI} series of 1940-2019 daily naturalized flows were summed to monthly totals prior to adjusting negative daily values. Negative monthly flows were then changed to an arbitrary very small non-zero number (10.00 acre-feet/month), which still preserves the daily distribution in the *SIMD* simulation described below as the third task for months with some but all days of zero flows. For the monthly F_{NNI} summations, flows in adjoining months were decreased by the volume of the negative adjustment to maintain the original long-term mean flow, based on the premise that the negative values were due largely to inaccuracies associated with lag. The resulting monthly flows were stored as *IN* records in a *SIMD* hydrology DSS input file for use in the second task described below.
2. Negative daily flows were changed to zero and the flows were stored as *DF* records in a *SIMD* hydrology DSS input file. *SIMD* was employed to disaggregate the monthly flows from the first task listed above in proportion to the daily pattern flows while preserving the monthly totals. The daily naturalized flows recorded in the *SIMD* simulation results were adopted for use in filling in gaps of missing flows at other control points.
3. A large recorded November 25, 1988 Lake Palestine storage increase and corresponding decrease the next day appeared unrealistic and were removed in the naturalization process. The F_{ANAL} computed as shown in Table 4.12 had small negative values in several days, which were changed to zero prior to the using the F_{ANAL} to synthesize flows at other control points.

Daily Pattern Hydrographs and Daily and Monthly Naturalized Flows

The final adopted *DF* record daily naturalized flows differ from the initial daily flows compiled as outlined in the preceding sections of the chapter as follows.

1. The initial 1940-2019 daily naturalized flow series include some days with negative flows as discussed in the preceding section. All negative values of daily naturalized flows are set to zero on the final *DF* records.
2. The original WAM 1940-1996 monthly naturalized flows were adopted without modification. The final adopted daily naturalized flows sum to the monthly naturalized flows. The initial 1940-1996 daily naturalized flows did not necessarily sum to the original WAM 1940-1996 monthly naturalized flows.

The 1940-2017 daily flows at 17 control points are stored as *DF* records in the *SIMD* hydrology input DSS file. The *DF* record daily flows are employed in the *SIMD* simulation as pattern hydrographs for disaggregating monthly naturalized flow volumes in acre-feet/month to daily volumes in acre-feet/day at the over 300 control points in the Neches WAM. *SIMD* distributes monthly naturalized flow volumes to daily volumes in proportion to the flows in daily pattern hydrographs while maintaining the monthly volumes. Although monthly and daily flow volumes in a *SIMD* simulation are in units of acre-feet, flow rates in cfs or other units can be used for the *DF* record pattern hydrographs since only relative, not absolute, quantities are relevant. However, the *DF* record daily flows are the daily naturalized flows also found in the *SIMD* simulation results.

The 1940-2019 monthly naturalized flows at the 20 primary control points are compiled as described in Chapter 5. The original 1940-1996 monthly naturalized flows are adopted without modification. Monthly summations of 1997-2019 daily naturalized flows are used in the compilation of 1997-2019 monthly naturalized flows.

The 1940-2019 daily naturalized flows at 17 control points compiled as described in the preceding sections of the chapter were further modified through a *SIMD* simulation. The *SIMD* simulation results includes daily naturalized flow volumes in acre-feet/day, which for each month sum to the monthly naturalized flow volume in acre-feet/month. These daily naturalized flows in acre-feet/day were adopted for the final set of *DF* records included in the *SIMD* hydrology input DSS file. Thus, the daily naturalized flows input on *DF* records sum to the monthly naturalized flows in each month from the *IN* records.

Hydrology and Daily Flow DSS Files

This report is accompanied by the following DSS files as well as the Neches WAM text (non-DSS) input files. The first two DSS files are described in this final section of Chapter 4. The other two DSS files are described in Chapters 5 and 6. The last file is described in Chapter 9.

NechesHYD.DSS	Neches WAM *SIM/SIMD* hydrology input file.
NechesDailyFlows.DSS	Daily flow data covered in Chapters 3 and 4.
NechesMonthlyFlows.DSS	Monthly flow data covered in Chapters 3 and 5.
NechesEvapPrecip.DSS	Monthly evaporation and precipitation rates in Chapter 6.
NechesSimulationResults.DSS	Selected simulation results from Chapters 9 and 10.

USACE Hydrologic Engineering Center (HEC) Data Storage System (DSS)

HEC-DSS and its *HEC-DSSVue* interface are documented in detail in the *HEC-DSSVue User's Manual* [8]. WRAP applications of DSS files and *HEC-DSSVue* are explained in Chapter 6 of the WRAP *Users Manual* [2]. Data is stored in a DSS file in a binary format that can be created and/or accessed only by *HEC-DSSVue*, WRAP programs, or other software containing the necessary DSS library routines. When a DSS file is created or read with *HEC-DSSVue*, an auxiliary catalog file with filename extension DSC is automatically created to catalog the data records, which requires no action by users but can be read with text file editing programs such as WordPad. *HEC-DSSVue* includes options for importing data from Microsoft Excel spreadsheets to DSS files and copying data from DSS files to Excel files.

DSS pathnames illustrated in Tables 4.14 and 4.16 are designed to facilitate convenient data series identification, organization, and access. DSS pathnames are defined with six components called Parts A, B, C, D, E, and F [2, 8]. Pathname Parts A, B, C, and F can be named and renamed applying *HEC-DSSVue* editor options. Pathname Part D contains the range of the data blocks, which is determined automatically by the DSS routines in *SIM*, *SIMD*, or *HEC-DSSVue* for a given start date and period-of-analysis. The range is based on complete standard block lengths, which are one year for daily and one decade for monthly data. The range encompasses the data, but the data does not necessarily fill the entire block. Pathname Part E is reserved for the time interval, such 1DAY, 1MON, or 1YEAR. Daily and monthly interval data are assigned the time 24:00 hours (midnight) at the end of the time interval, for example 1 January 1940, 24:00 for daily flows and 31 January 1940, 24:00 for monthly flows.

SIM and *SIMD* allow the simulation period set by the parameters YRST and NYRS on the *JD* record to be any sub-period of the period covered by the hydrology input data sequences. *HEC-DSSVue* also has a time window option for selecting a sub-period of the DSS data records.

Flows in cfs are assigned the DSS type "PER AVER", meaning average during the daily, monthly, or other time interval. Flow volumes in acre-feet and precipitation-evaporation depths in inches or feet are labeled type "PER-CUM", meaning cumulative during the time period.

SIM/SIMD Hydrology Input File

The Neches WAM hydrology input file shared by *SIM* and *SIMD* is labeled with the filename NechesHYD.DSS. The *HYD* appended to the filename root distinguishes the *SIM/SIMD* input file from the simulation results DSS output file with filename Neches.DSS. DSS pathname conventions for input and output files are described in the WRAP *Users Manual* [2]. The following standard format for the pathnames for the *SIM* and *SIMD* hydrology input file is generally required.

Part A is the filename root of the hydrology input file without the appended HYD.

Part B is the WAM control point identifier.

Part C differentiates between daily flows (DF), monthly flows (IN), and monthly net evaporation-precipitation depths (EV) by the standard identifiers DF, IN, and EV.

Part D is either the start date or the range of the data blocks.

Part E is 1DAY for daily data or 1MON for monthly data.

Part F is blank in the pathnames of *SIM/SIMD* hydrology input records.

The DSS pathname conventions for the *SIM/SIMD* hydrology input file for the Neches WAM are illustrated by Table 4.14. The pathnames are for 1940-2020 series of daily and monthly flows at control point NERO (Neches River at Rockland) and 1940-2019 monthly net reservoir evaporation-precipitation rates labeled with control point identifier 3256N in pathname part B. The same pathname conventions are applied to identify the DSS records for the *DF* record daily flows for 17 control points (Chapter 4), *IN* record monthly naturalized flows for 20 control points (Chapter 5), *EV* record net evaporation-precipitation depths for 12 control points (Chapter 6), and *TS* record SB3 EFS targets for two scenarios for five control points (Chapters 9 and 10).

Table 4.14
Pathnames for *SIM/SIMD* Hydrology Input File NechesHYD.DSS

Part A	Part B	Part C	Part D / range	Part E	Part F
NECHES	NERO	DF	01JAN1940-01JAN2019	1DAY	
NECHES	NERO	IN	01JAN1940-01JAN2019	1MON	
NECHES	3256N	EV	01JAN1940-01JAN2019	1MON	
NECHES	ANERO	TS	01JAN1940-01JAN2019	1MON	
NECHES	CNERO	TS	01JAN1940-01JAN2019	1MON	

Daily Flow DSS File for Data Discussed in Chapters 3 and 4

Daily flow datasets compiled as described in Chapters 3 and 4 are stored in a DSS file with the filename NechesDailyFlow.DSS. The primary final product of the work presented in Chapter 4 is the *DF* record daily naturalized flows stored in the *SIM/SIMD* hydrology input file. However, the observed flows and other flow datasets discussed in Chapters 3 and 4 provide insight regarding stream flow characteristics and modeling methods as well as document development of the *DF* record daily naturalized flow dataset. Datasets in DSS files are conveniently stored, accessed, inventoried, organized, compared, analyzed, and manipulated with *HEC-DSSVue*.

The daily naturalized flows are summed to monthly flows. As discussed further in Chapter 5, the *IN* record monthly naturalized flows are the 1940-1996 monthly flows from the original Neches WAM extended through 2019 with the monthly summations of daily flows.

The DSS file with filename NechesDailyFlows.DSS was created in conjunction with analyzing, synthesizing, and verifying daily simulation *SIMD DF* record input daily flow pattern hydrographs and contains the datasets of daily flow sequences outlined in Tables 4.15 and 4.16. The DSS file contains 107 records. The following discussion of these DSS records is organized by the pathname part C groups listed in Table 4.15 with the number of records contained in each group. One example pathname is listed in Table 4.16 for each of the ten sets of daily time series data sequences listed in Table 4.15.

As previously noted, pathname parts D and E are reserved for providing time period information in a standard format. The other pathname parts are arbitrary labeling information that can be changed in the *HEC-DSSVue* editor. The units for the daily time series quantities in this DSS file are either cubic feet per second (cfs), with DSS data type "period average", or acre-feet per day (ac-ft), with type "period cumulative". The units of "CFS" or "AC-FT" are included for general information in the labels devised for pathname part C.

Table 4.15
Groups of Records in the File with Filename NechesDailyFlows.DSS

Dataset	Pathname Part C	Number of Records
1	FLOW-USGS (CFS)	16 control points
2	FLOW RELEASES (CFS)	1 Sam Rayburn releases
3	FLOW-USACE (CFS)	5 control points
4	FLOW-USACE (AC-FT)	5 control points
5	FLOW-SWAT (CFS)	20 control points
6	OBSERVED FLOW (AC-FT)	17 control points
7	FLOW ADJUSTMENTS (AC-FT)	8 reservoirs
8	INCREMENTAL FLOW (AC-FT)	1 NNI incrementals
9	NATURALIZED FLOW (AC-FT)	17 control points
10	DF	17 daily flow *DF* records
	Total Number of DSS Records	107 records

Table 4.16
DSS Pathnames for the File with Filename NechesDailyFlows.DSS

Part A	Part B	Part C	Part D / range	Part E	Part F
NECHES RV	ROCKLAND, TX	FLOW-USGS (CFS)	01JAN1903-01JAN2020	1DAY	NERO
SAM RAYBURN OUTFLOW	SAM RAYBURN DAM	FLOW RELEASES (CFS)	01JAN1996-01JAN2019	1DAY	ANSR
USACE UNREGULATED	NECHES RV, ROCKLAND	FLOW-USACE (CFS)	01JAN1929-01JAN2011	1DAY	NERO
USACE UNREGULATED	NECHES RV, ROCKLAND	FLOW-USACE (AC-FT)	01JAN1929-01JAN2011	1DAY	NERO
SWAT FLOWS	ROCKLAND, TX	FLOW-SWAT (CFS)	01JAN1940-01JAN2013	1DAY	NERO
NECHES RV	ROCKLAND, TX	OBSERVED FLOW (AC-FT)	01JAN1940-01JAN2019	1DAY	NERO
LAKE PALESTINE ADJUSTMENT	3256N1 EP & STORAGE	FLOW ADJUSTMENTS (AC-FT)	01JAN1940-01JAN2019	1DAY	PALESTINE ADJUST
NERO-NENE INCREMENTALS	NNI INCREMENTALS	INCREMENTAL FLOW (AC-FT)	01JAN1940-01JAN2019	1DAY	SIMD OUTPUT
NECHES RIVER ROCKLAND	NERO	NATURALIZED FLOW (AC-FT)	01JAN1940-01JAN2019	1DAY	SIMD OUTPUT
NECHES	NERO	DF	01Jan 1940-01JAN2019	1DAY	

The first dataset listed in Table 4.15 consists of period-of-record daily flows in cfs at 16 gages downloaded from the National Water Information System (NWIS) website maintained by the U.S. Geological Survey (USGS). These USGS gages represented by 16 of the 20 primary control points are listed in Table 4.1 and their locations are shown in Figure 4.1. The complete pathname for the daily observed flows at the gage on the Neches River near Rockland (control point NERO) is included in Table 4.16 as an example illustrating the pathname organization adopted to label the DSS record data series. The DSS pathname labels automatically assigned in the *HEC-SSP* [17] download from the NWIS website was adopted for the USGS observed flows, except parts C and F were changed from FLOW and USGS to FLOW-USGS (CFS) and the WAM control point identifier.

The second dataset consists of observed daily reservoir releases in cfs from Sam Rayburn Reservoir obtained from the USACE Fort Worth District (FWD) water management website. These outflows converted to units of acre-feet/day are included in the sixth dataset consisting of observed flows at 16 USGS gages and observed releases from Sam Rayburn Reservoir. The releases from Sam Rayburn Reservoir serve as observed flows at WAM control point ANSR.

The third and fourth datasets listed in Table 4.15 consist of the 1929-2011 daily unregulated flows in cfs at five sites generated by the USACE Fort Worth District (FWD) modeling system. These five sites are included in the 20 WAM primary control points. The USACE FWD furnished the daily unregulated flows in units of cfs (third dataset in Table 4.15), which were multiplied by the conversion factor of 1.98347107 to create the fourth dataset in acre-feet/day. The 1940-1996 sub-period of the unregulated flows at control points ANSR, NETB, NEEV, and NEBA were adopted for the use in developing *DF* record daily flow pattern hydrographs.

The fifth dataset in Table 4.15 consists of 1940-2013 daily flows in cfs generated using the Soil and Water Assessment Tool (SWAT) for the 20 WAM primary control points. The flows synthesized with the SWAT watershed rainfall-runoff model described in Chapter 3 were used in comparative evaluations but were not included the final adopted Neches WAM input data.

The sixth dataset consists of the complete set of observed daily flows in acre-feet/day adopted for use in developing the naturalized flows. The observed flows consist of period-of-record flows at the 16 USGS gages listed in Table 4.1 and Sam Rayburn Reservoir releases measured by the USACE FWD which were adopted as observed flows at control point ANSR.

The seventh dataset consists of daily adjustments in acre-feet/day associated with the eight reservoirs listed in Tables 4.8 and 4.9 that were used to convert observed flows to naturalized flows at the downstream control points listed in Table 4.10. *Microsoft Excel* and *HEC-DSSVue* were combined to develop the daily flow adjustment quantities.

The eighth dataset listed in Table 4.15 consists of the NERO-NENE incremental (NNI) daily naturalized flows in acre-feet/day that was created for use in synthesizing flows to fill in gaps of missing daily naturalized flows at several other control points as outlined in Table 4.12.

The ninth dataset consists of 1940-2019 daily naturalized flows in acre-feet/day at 17 control points. A preceding initial dataset of naturalized flows included gaps of missing data as indicated in Table 4.11 that were filled as outlined in Table 4.12. The ninth dataset listed in Table 4.15 is complete with all gaps of missing data filled based on naturalized flows at other control points. For these 17 records, pathname part B is the control point identifier and part F is used for descriptive notations. Pathname part F of ten of the records has a notation that gaps of missing records have been filled. Control point ANSR (part B) has a part F notation that 1940-1996 USACE unregulated flows are combined with 1997-2019 adjusted Sam Rayburn Reservoir outflows. Combinations of USACE unregulated flows and adjusted USGS observed flows are also noted for control points NEEV, NETB, and NEBA. The naturalized flows at control points NENE and NERO used to develop the NNI and fill gaps at other control points are noted in pathname part F to be *SIMD* simulation results with all negative values removed.

The tenth dataset consists of the 1940-2019 sequences of daily naturalized flows adopted as the final *DF* records incorporated in the *SIMD* hydrology input dataset. A *SIMD* simulation was employed to convert the ninth dataset to the tenth dataset as discussed further in the next chapter. The tenth dataset listed in Table 4.15 is the first dataset listed in Table 4.14.

CHAPTER 5
MONTHLY STREAM FLOW

Chapter 5 is a continuation of the Chapters 3 and 4 coverage of naturalized stream flow. The final adopted 1940-2019 monthly naturalized flows at the 20 primary control points are presented in Chapter 5. The original WAM 1940-1996 monthly naturalized flows were adopted without modification for the June 2020 daily/monthly Neches WAM. The 1997-2019 monthly naturalized flows were compiled based on monthly summations of the daily naturalized flows developed as described in the preceding Chapter 4. Chapters 4 and 5 are closely interconnected. Daily naturalized flows are used to develop monthly 1997-2019 naturalized flows. Monthly naturalized flows for the entire 1940-2019 hydrologic period-of-analysis are employed in *SIMD* simulations in the development of 1940-2019 daily naturalized stream flows.

Computational Procedures for Developing Naturalized Flows

Monthly naturalized stream flows at the 20 primary control points stored in the *SIM/SIMD* hydrology input DSS file as *IN* records (Table 4.14) are distributed to the over 300 secondary control points within the simulation. Daily naturalized stream flows at the 17 control points with observed flows are provided in the hydrology DSS input file as *DF* records (Table 4.14). The daily naturalized flows serve as pattern hydrographs employed within the *SIMD* simulation to disaggregate monthly naturalized flows to daily at the over 300 control points. The hydrologic period-of-analysis is January 1940 through December 2019.

The 20 Neches WAM primary control points at the locations shown in Figures 4.1, 4.2, and 4.3 are listed with relevant information in Tables 4.1, 4.2, 4.3, and 4.5. Sixteen of the 20 primary control points represent USGS gage sites. Observed daily stream flows were compiled as described in Chapters 3 and 4 for these 16 control points. Measured releases from Sam Rayburn Reservoir provide observed stream flows for control point ANSR. Monthly naturalized flows at the remaining three primary control points (NEPA, MUTY, NESL) are synthesized based on naturalized flows at the other control points as explained in this chapter.

Monthly naturalized flows for 1940-1996 from the original Neches WAM [9] are adopted for the June 2020 WAM. Monthly naturalized flows for 1997-2019 are computed as described in this chapter based on summing the daily naturalized flows developed as explained in Chapter 4 and further discussed here in Chapter 5.

Data management and computational procedures employed in developing the stream flow input data for the June 2020 daily/monthly Neches WAM were performed with *HEC-DSSVue*. *SIMD* was employed to disaggregate monthly naturalized flows to daily quantities at several steps in the process of compiling the *IN* and *DF* record *SIM/SIMD* input dataset. Abbreviated *SIMD* input files without unnecessary data were compiled for the intermediate monthly-to-daily disaggregation computations.

Component Tasks in the Development of Monthly and Daily Naturalized Flows

Compilation of the *IN* record monthly and *DF* record daily naturalized flows included the following tasks.

1. The original 1940-1996 monthly naturalized flows at the 20 primary control points were developed during 1999-2001 based on adjusting observed flows as documented by the 2001 WAM report [9]. The 1940-1996 monthly naturalized flows and net evaporation-precipitation rates are adopted for the June 2020 daily/monthly WAM without revision.

2. The 1940-2019 daily naturalized flows at 16 control points were developed by adjusting observed flows as described in the preceding Chapter 4. This work covered in Chapter 4 included compiling and naturalizing observed daily flow data (Tables 4.6, 4.7, 4.8, 4.9) and filling gaps of missing daily naturalized flows using flows from other control points (Tables 4.10, 4.11, 4.12). The NERO-NENE incremental (NNI) naturalized flows were computed for use in filling in gaps at several other control points (Table 4.12).

3. As discussed in Chapter 4, *SIMD* was employed to refine the daily flows at control points NERO and NENE and the NNI incrementals prior to using these data to fill in gaps of missing data at other control points. The daily flows were aggregated to monthly within *HEC-DSSVue*. Days and months of negative values for daily versus monthly flows were removed differently as described later. *SIMD* was employed to disaggregate monthly summations back to daily quantities at control points NERO and NENE and the NNI incrementals. The resulting flows were used to fill gaps of missing daily naturalized flows at other control points (Table 4.12).

4. The 1940-2019 daily naturalized flows at 16 control points with no gaps of missing data were summed to monthly prior to changing negative values of daily flows to zero. Although the monthly summations removed most of the daily negatives, the resulting monthly naturalized flows still included some months with negative monthly flows. The negative monthly flows were changed to zero and flows in adjacent months were reduced correspondingly.

5. A set 16 *IN* records of 1940-2019 monthly naturalized flows were compiled by combining 1940-1996 flows from Task 1 above with 1997-2019 flows from Task 4. A set of 16 *DF* records with daily naturalized was developed as noted above but with all negative daily flows changed to zero. *SIMD* was executed with these sets of 16 *IN* records and 16 *DF* records provided as input for the sole purpose of disaggregating the 1940-2019 monthly naturalized flows to daily. The monthly flows were disaggregated to daily in proportion to the *DF* record daily flows while preserving the monthly volumes. The resulting *SIMD* computed daily naturalized flows were abstracted from the *SIMD* simulation results DSS output file. These 1940-2019 daily flows sum identically to the monthly flow for each individual month.

6. The 16 control points of Task 5 above do not include control point NEBA for reasons explained in Chapter 4. Daily naturalized flows at control point NEBA were computed from daily flows at control points NEEV, VIKO, and PISL using the last equation listed in Table 4.12. Monthly flows at control point NEBA were computed from monthly flows at control points NEEV, VIKO, and PISL using the same equation from Table 4.12. *SIMD* was employed to disaggregate monthly flows to daily, assuring that the final adjusted daily flows at NEBA summed to the final adjusted monthly flows.

7. Primary control points NEPA, MUTY, and NESL have no observed flows. Monthly naturalized flows for 1940-1996 from the original WAM dataset were adopted for all primary control points. Monthly naturalized flows for 1997-2019 were synthesized for control points NEPA, MUTY, and NESL from the flows at other control points as described on the next page.

Removing Negative Values for Monthly and Daily Flows

The adjustments described in Chapter 4 for converting observed daily flows to naturalized daily flows results in negative values for naturalized flows in some days. The negative flows were converted to zeros as follows, with monthly flows being handled differently than daily flows. Summation of daily flows to monthly removes ("averages out") daily negatives, but the monthly summations still had months of negative flow values at some control points.

Monthly flows were created by summing 1940-2019 daily flows for each day prior to removing negative values for daily flows. Resulting negative values for monthly naturalized flows were adjusted as follows. The negative monthly values are changed to zero. The flow in the adjacent month just before or after the month with a negative value was decreased by the amount of the removed negative value. This preserves the long-term total or mean of the daily flows with negatives. The larger of the flow before or after the negative month was selected for the balancing adjustment. For cases of multiple adjacent negative values or larger negative values, the adjustments involved reducing flows at multiple control points. This methodology reflects the premise that negative values for daily naturalized flows are probably related largely to inaccuracies in reflecting the propagation time (lag) of upstream flow adjustments on downstream flows.

The negative values remain in the daily flows for the summation of daily quantities to monthly. However, after the monthly summations, the negative values of the preliminary daily flows were simply changed to zero without any balancing adjustments prior to applying *SIMD* to disaggregate monthly flows to final daily flows based on these preliminary daily flows.

Naturalized Flows at Ungaged Control Points NEPA, MUTY, and NESL

The original through the latest versions of the Neches WAM include *IN* record monthly naturalized flows at 20 primary control points. *DF* record daily flow pattern hydrographs at 17 of these control points are added as described in this report. *DF* records are not included for the three ungaged control points (NEPA, MUTY, NESL).

The 1940-1996 monthly naturalized flows at all 20 primary control points, including NEPA, MUTY, and NESL, are adopted without modification. The 1997-2019 monthly naturalized flows at ungaged primary control points NEPA, MUTY, and NESL are computed as a function of naturalized flows at control points NENE, MUJA, and NEBA with the following equations, where F_{NEPA}, F_{NENE}, F_{MUTY}, F_{MUJA}, F_{NESL}, and F_{NEBA} are 1940-1996 naturalized stream flows.

$$F_{NEPA} = 0.65833\ F_{NENE}$$
$$F_{MUTY} = 0.29783\ F_{MUJA}$$
$$F_{NESL} = 1.03143\ F_{NEBA}$$

Pertinent information for these six control points is tabulated in Table 5.1. The watershed areas in square miles and 1940-1996 mean annual naturalized flow in acre-feet/year for the six control points are included in Table 5.1. Drainage area ratios and 1940-1996 mean naturalized flow ratios are also shown. Either of these two ratios could be reasonably applied in the flow synthesis. Either choice is approximate. Both choices yield similar results. The ratio of mean naturalized flow was actually adopted. The mean flow ratios are incorporated in the three equations above.

Table 5.1
Watershed Areas and 1940-1996 Mean Naturalized Flow

Control Point	Location	Drainage Area	Naturalized Flow
		(sq miles)	(ac-ft/year)
NEPA	Neches River below Lake Palestine	837	367,859
MUTY	Mud Creek below Lake Tyler	114	60,352
NESL	Neches River at Sabine Lake	10,025	6,234,720
NENE	Neches River near Neches	1,145	558,775
MUJA	Mud Creek near Jacksonville	376	202,637
NEBA	Neches River at Beaumont	9,826	6,044,722
	Ratio of NEPA/NENE means	0.7310	0.65833
	Ratio of MUTY/MUJA means	0.3032	0.29783
	Ratio of NESL/NEBA means	1.0203	1.03143

Monthly Flow DSS File

The last section of Chapter 4 entitled "*Hydrology and Daily Flow DSS Files"* describes the use of DSS and *HEC-DSSVue*. Data records in the hydrology and daily flow DSS files are outlined in Tables 4.14, 4.15, and 4.16. Similarly, data records in the monthly flow DSS file are described in Tables 5.2 and 5.3. These DSS files were created in conjunction with analyzing, synthesizing, and verifying *SIM/SIMD* simulation *IN* and *DF* record monthly and daily stream flows. The DSS files serve as appendices to this report, document computational procedures, and facilitate convenient graphical, tabular, and statistical comparisons of the datasets that provide insights into the methods employed and the characteristics of river system hydrology.

The following discussion of the records in the monthly DSS file is organized by the pathname part C groups listed in Table 5.2 with the number of DSS records and WAM control points contained in each group. One example pathname is listed in Table 5.3 for each of the nine datasets listed in Table 5.2. All quantities are daily or monthly flow volumes in acre-feet at one of the 20 primary control points. The DSS file contains a total of 148 time series records.

The first set of DSS records listed in Table 5.2 (Dataset 1) consist of the 1940-2019 daily naturalized flows at 17 control points developed as described in the preceding Chapter 4. The DSS pathname for naturalized flows at control point NERO is replicated as the first example pathname in Table 5.3 to illustrate the format of pathname labels for these 17 time series. This first dataset in Table 5.2 is identical to the ninth dataset in Table 4.15 except the flows at control point NEBA are added. The naturalized flows at control point NEBA are computed as outlined in Table 4.12 and discussed in both Chapters 4 and 5. The 1940-2019 monthly naturalized flows in the fourth dataset of Table 5.2 consists of the monthly summations of the daily volumes in the first dataset.

Dataset 2 with pathname part C of "DF - INITIAL" consists of *DF* record daily naturalized flows at 17 control points. Dataset 2 is the same as Dataset 1 with the exception of negative values. Dataset 1 includes days with negative flows. These negative values are changed to zero in the second dataset. The second dataset serves as preliminary *DF* records that were provided as input to a *SIMD* simulation that generated the third dataset in Table 5.2, with pathname part C of "DF".

Table 5.2
Groups of Records in the File with Filename NechesMonthlyFlows.DSS

Dataset	Pathname Part C	Number of Records
	<u>Daily Naturalized Flow in acre-feet/day</u>	
1	NATURALIZED FLOW (AC-FT)	16 records (16 control points)
2	DF – INITIAL	17 records (17 control points)
3	DF	17 records (17 control points)
	<u>Monthly Naturalized Flow in acre-feet/month</u>	
4	NATURALIZED FLOW (AC-FT)	16 records (16 control points)
5	IN – ORIGINAL	20 records (20 control points)
6	IN	20 records (20 control points)
	<u>Auxiliary Monthly Flow Datasets (feet/month)</u>	
7	OBSERVED FLOW (AC-FT)	17 records (17 control points)
8	FLOW-USACE (AC-FT)	5 records (5 control points)
9	IN - HYD SYNTHESIZED	20 records (20 control points)

Table 5.3
DSS Pathnames for the File with Filename NechesMonthly.DSS

Part A	Part B	Part C	Part D / range	Part E	Part F
NECHES RV ROCKLAND	NERO	NATURALIZED FLOW (AC-FT)	01JAN1940-01JAN2019	1DAY	SIMD OUTPUT
NECHES	NERO	DF – INITIAL	01JAN1940-01JAN2016	1DAY	BEFORE REMOVING NEGATIVES
AA – FINAL DF RECORDS	NERO	DF	01JAN1940-01JAN2019	1DAY	
NECHES RV ROCKLAND	NERO	NATURALIZED FLOW (AC-FT)	01JAN1940-01JAN2010	1MON	INITIAL 1940-2019 MONTHLY
NECHES3	NERO	IN – ORIGINAL	01JAN1940-01JAN2010	1MON	ORIGINAL WAM 1940-1996 NAT
AA – FINAL IN RECORDS	NERO	IN	01JAN1940-01JAN2010	1MON	
NECHES RV	ROCKLAND, TX	OBSERVED FLOW (AC-FT)	01JAN1940-01JAN2010	1MON	NERO
USACE UNREGULARED	NECHES, ROCKLAND	FLOW-USACE (AC-FT)	01JAN1940-01JAN2010	1MON	NERO
WRAP-HYD MODEL	NERO	IN – HYD SYNTHESIZED	01JAN1940-01JAN2010	1MON	DESCRIBED IN CHAPTER 3

The third dataset listed in Table 5.2 (Dataset 3) consists of the adopted final *DF* record 1940-2019 daily naturalized flows at 17 control points. The third dataset in Table 5.2 is the same as the first dataset in Table 4.14 and the last (tenth) dataset in Table 4.15. The daily flows in this dataset sum identically to the monthly flows of the adopted final set of *IN* records listed as the sixth dataset in Table 5.2.

The "AA" in pathname part A of "AA – Final DF Records" and "AA – Final IN Records" assigned to the records in Datasets 1 and 6 results in these final 17 *DF* and *20 IN* records being listed first in *HEC-DSSVue* when the 148 records are listed in alphabetical order by pathname part A. These are the records that are included in the *SIM/SIMD* hydrology input file.

Dataset 4 in Table 5.2 consists of 1940-2019 monthly naturalized flows at the 17 control points computed by summing the daily naturalized flows before changing negative values of daily flows to zero. The fourth dataset is the monthly summation of the quantities in the first dataset. This monthly dataset includes months with negative values for flow volumes.

Dataset 5 listed in Table 5.2 consists of the original WAM 1940-1996 monthly naturalized flows [9]. Dataset 6 includes these Dataset 5 monthly flows for 1940-1996 combined with monthly flows for 1997-2019 developed from monthly summations of daily naturalized flows.

Dataset 6 consists of the final 1940-2019 monthly naturalized flows adopted for the June 2020 *SIM/SIMD* hydrology input file. The sixth dataset in Table 5.2 is the second dataset in Table 4.14. The final set of *IN* records consists of the original WAM 1940-1996 monthly naturalized flows (Dataset 5) extended through 2019 with the 1997-2019 subset of monthly flows from Dataset 4 adjusted to remove negative values.

Dataset 7 in Table 5.2 is the monthly summations of the observed daily flows in the sixth dataset of Table 4.15. These are monthly totals of observed flows at 16 USGS gages and measured releases from Sam Rayburn Reservoir.

Dataset 8 is the monthly summations of 1929-2011 daily unregulated daily flows for five control points from the USACE modeling system stored as the third dataset listed in Table 4.15. USACE 1940-1996 daily unregulated flows were adopted for inclusion in the *DF* record flows for four control points. Monthly summations of the USACE daily unregulated flows were not used in developing *IN* records for the WAM but are included in the DSS file for comparative analyses.

Dataset 9 in Table 5.2 consists of 1940-2019 monthly naturalized flows at the 20 primary control points synthesized with the WRAP program *HYD* hydrologic model discussed in Chapter 3. Monthly naturalized flows are related to monthly precipitation and evaporation. The model was calibrated using the original 1940-1996 naturalized flows and corresponding 1940-1996 monthly precipitation and evaporation. The *HYD* generated monthly naturalized flows were explored in comparative analysis but were not selected for inclusion in the June 2020 Neches WAM.

Analyses of the Final 1940-2019 Monthly Naturalized Stream Flows

The 1940-2019 monthly naturalized flows at the 20 primary control points are plotted in Figures 5.1 through 5.20. The annual means of the 1940-1996 and 1940-2019 naturalized flows are included in Table 4.1 of Chapter 4. Frequency metrics are presented in Table 5.4. Means for each of the 12 months and annual means are tabulated in Table 5.5. Linear trend analyses are presented in Tables 5.6 and 5.7. The time series plots, frequency statistics, and linear tread analysis metrics are discussed in the following sub-sections of this final section of Chapter 5.

Stream flow variability and stationarity are both important considerations. The time series plots and frequency metrics for the monthly naturalized flows demonstrate the tremendous temporal variability of stream flow in the Neches River Basin, which is characteristic of stream flow throughout Texas. The purpose of the flow naturalization process is to remove non-stationarities. The 1940-2019 naturalized stream flows are shown to be essentially stationary with no evident long-term trends or permanent changes in flow characteristics.

Plots of 1940-2019 Monthly Naturalized Flows at 20 Control Points

The time series plots of Figures 5.1 through 5.20 are presented in upstream-to-downstream sequence. The plots demonstrate extreme variability and apparent stationarity. Any long-term trends or permanent changes that may have occurred are hidden by the great continuous variability.

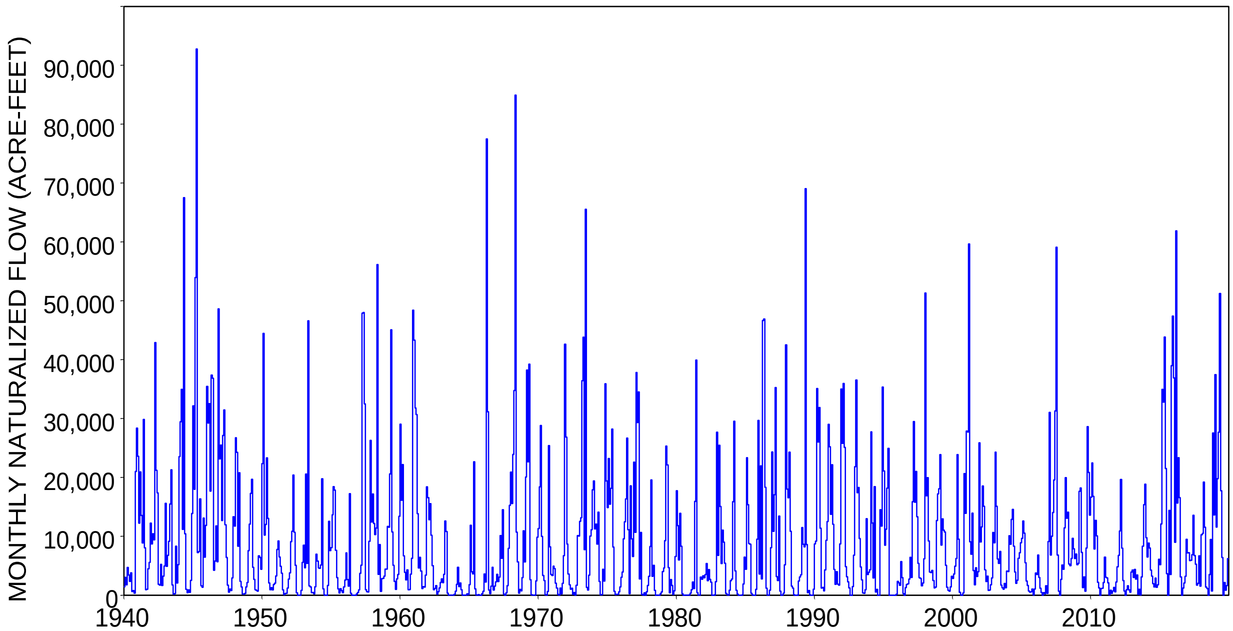

Figure 5.1 Monthly Naturalized Flow of the Neches River near Brownsboro (Control Point KIBR)

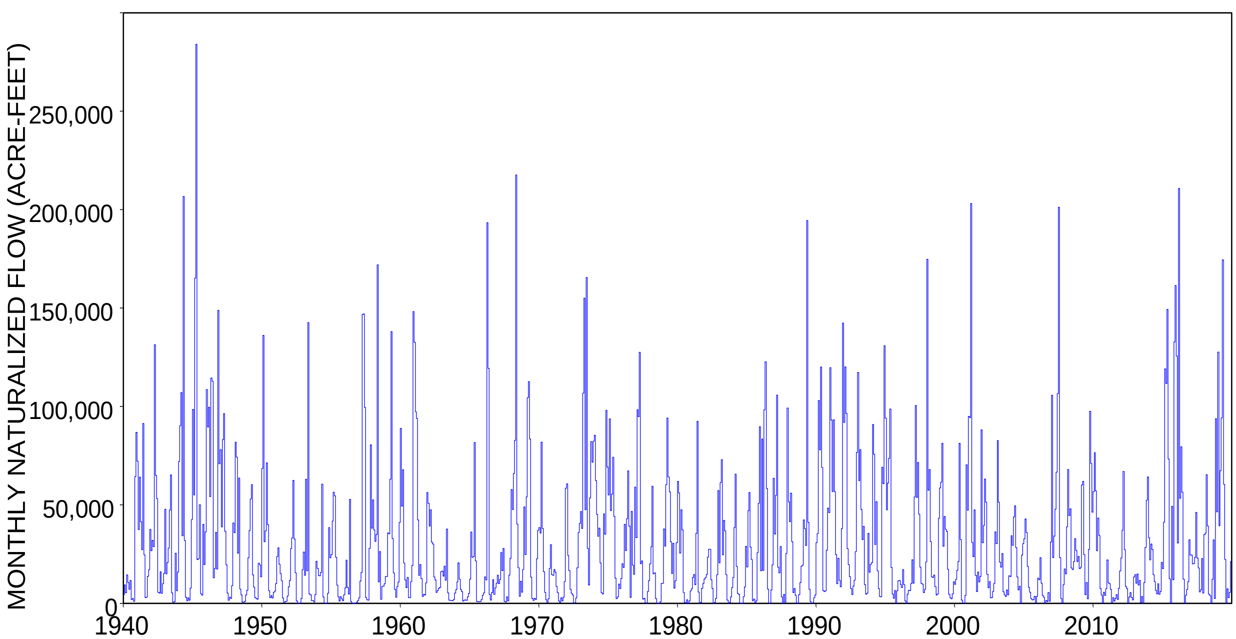

Figure 5.2 Monthly Naturalized Flow of the Neches River at Lake Palestine (Control Point NEPA)

The plots replicated here in this report were prepared with *HEC-DSSVue*. Plots of any time series in any DSS file or modifications thereto, including the groups of datasets listed in Tables 4.14, 4.15, 5.2, and 6.8 can be conveniently prepared and viewed within *HEC-DSSVue* either with or without copying to a document. Plots are quickly prepared and viewed on the computer monitor.

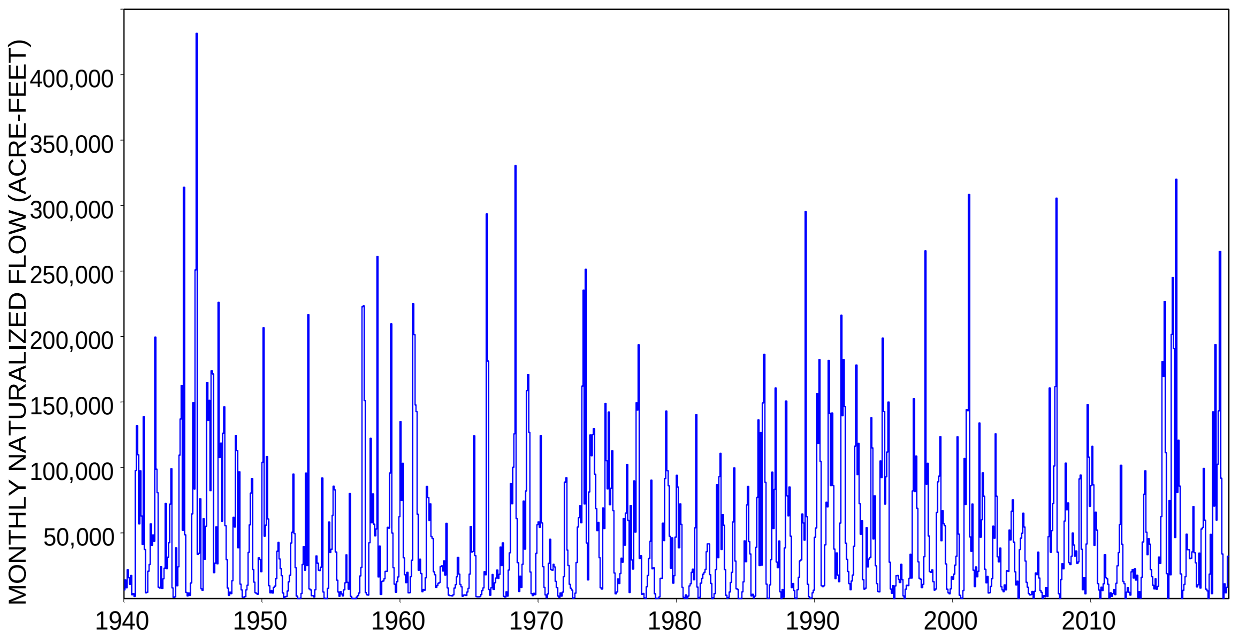

Figure 5.3 Monthly Naturalized Flow of the Neches River near Neches
(Control Point NENE)

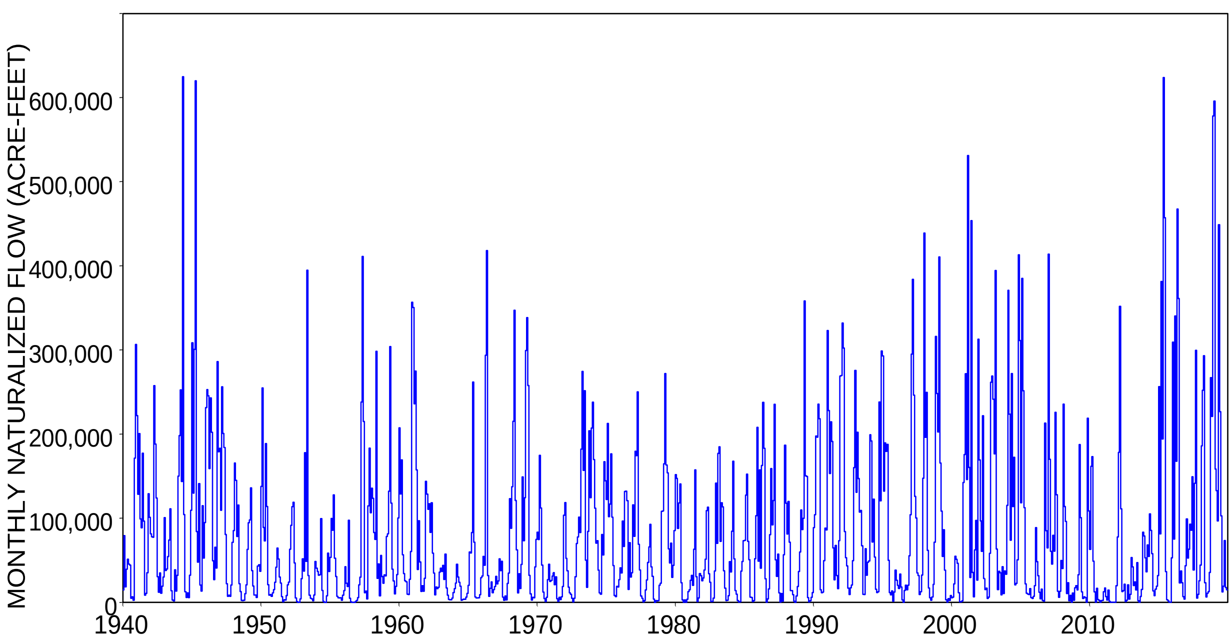

Figure 5.4 Monthly Naturalized Flow of the Neches River near Alto
(Control Point NEAL)

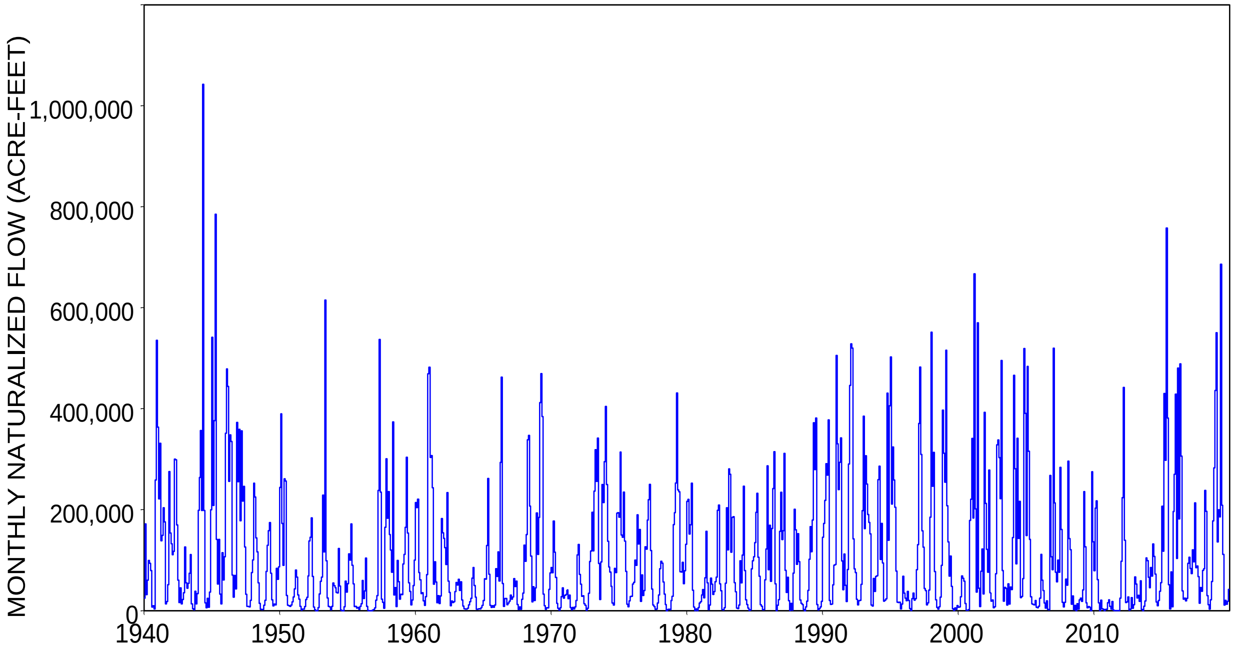

Figure 5.5 Monthly Naturalized Flow of the Neches River near Diboll
(Control Point NEDI)

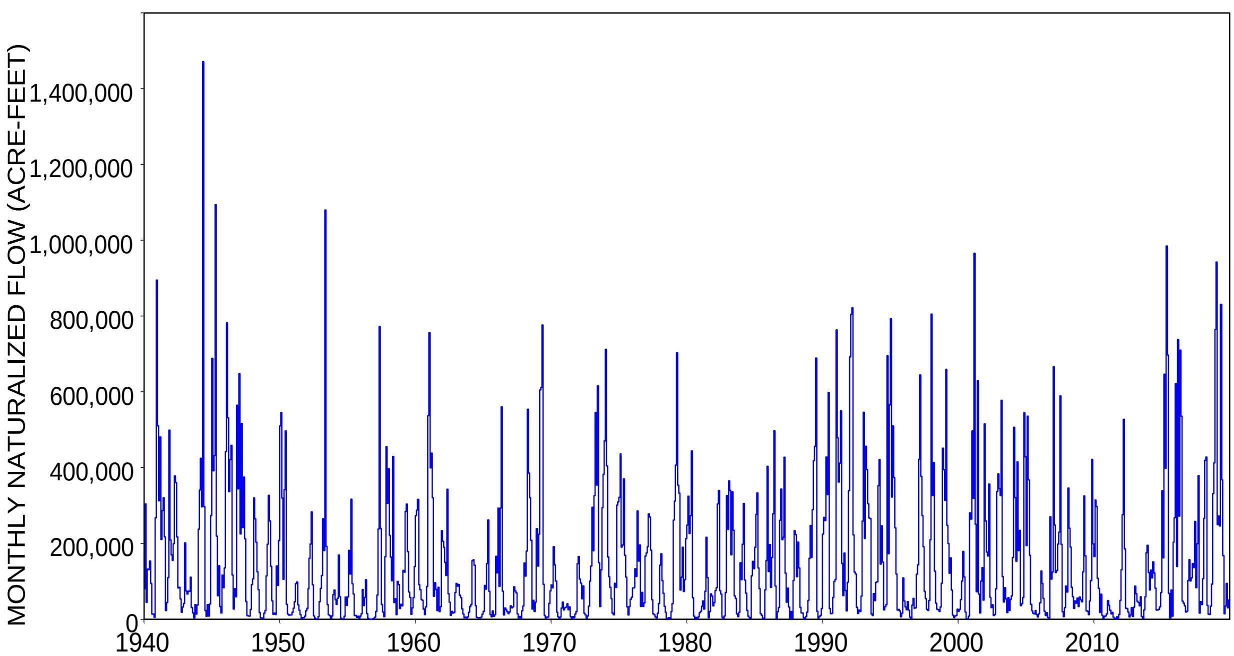

Figure 5.6 Monthly Naturalized Flow of the Neches River near Rockland
(Control Point NERO)

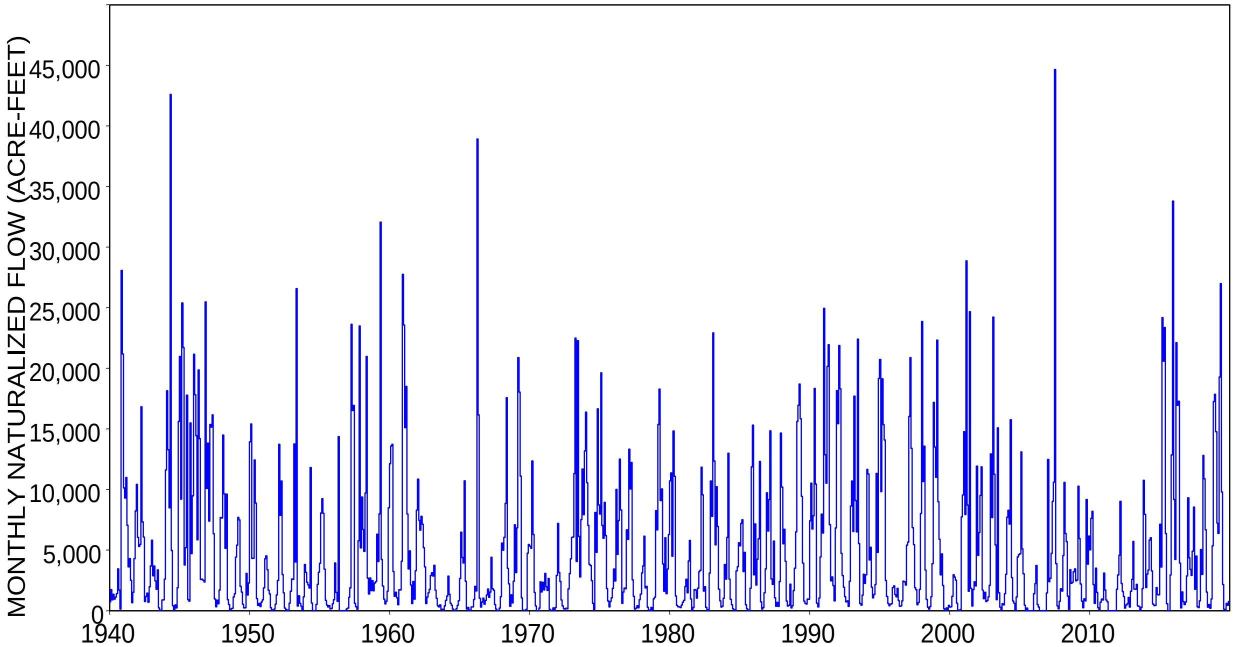

Figure 5.7 Monthly Naturalized Flow of Mud Creek at Lakes Tyler and Tyler East
(Control Point MUTY)

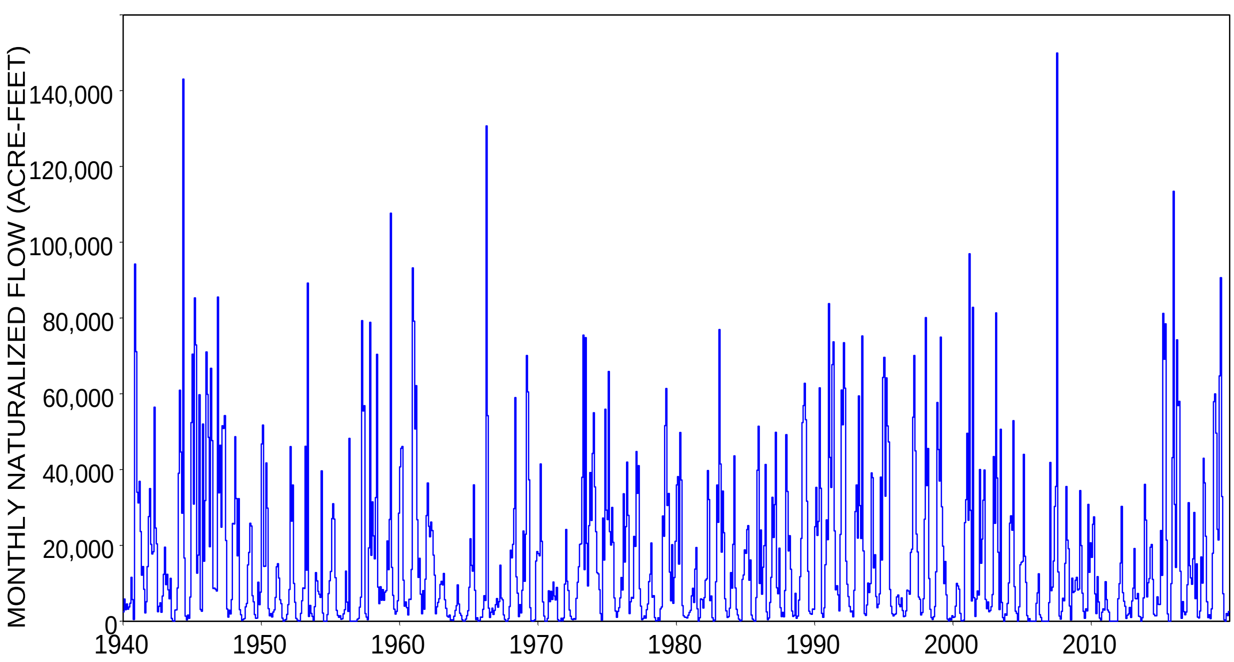

Figure 5.8 Monthly Naturalized Flow of Mud Creek near Jacksonville
(Control Point MUJA)

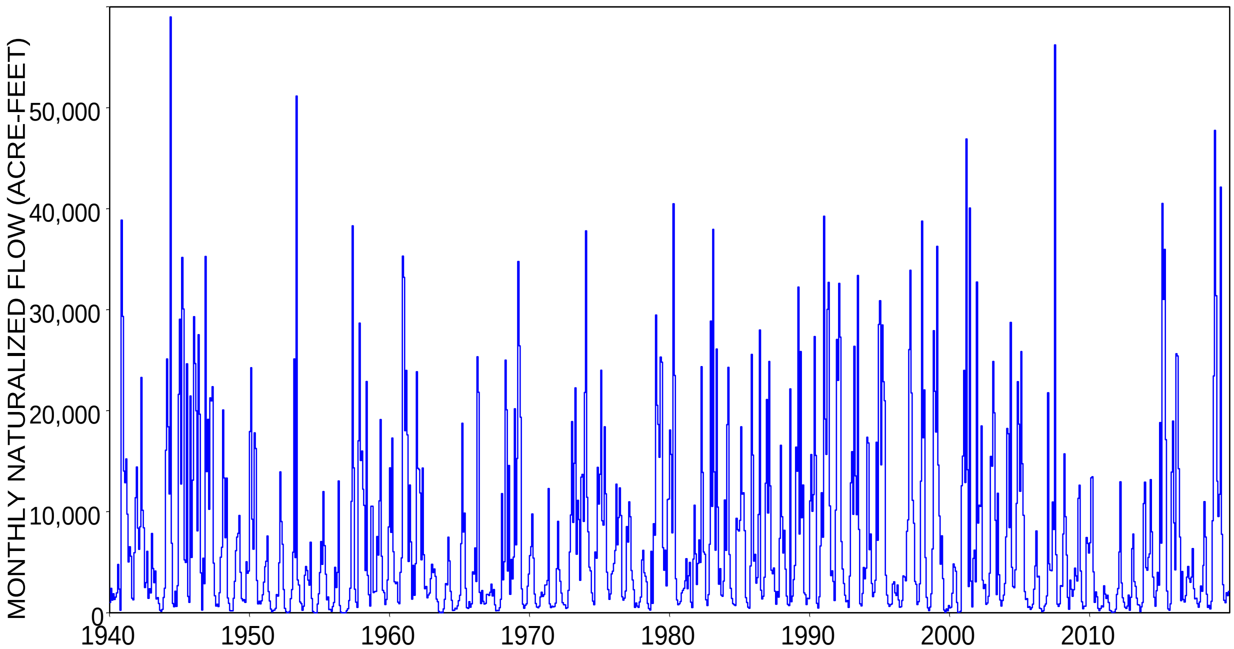

Figure 5.9 Monthly Naturalized Flow of East Fork of Angelina River near Cushing
(Control Point EFACU)

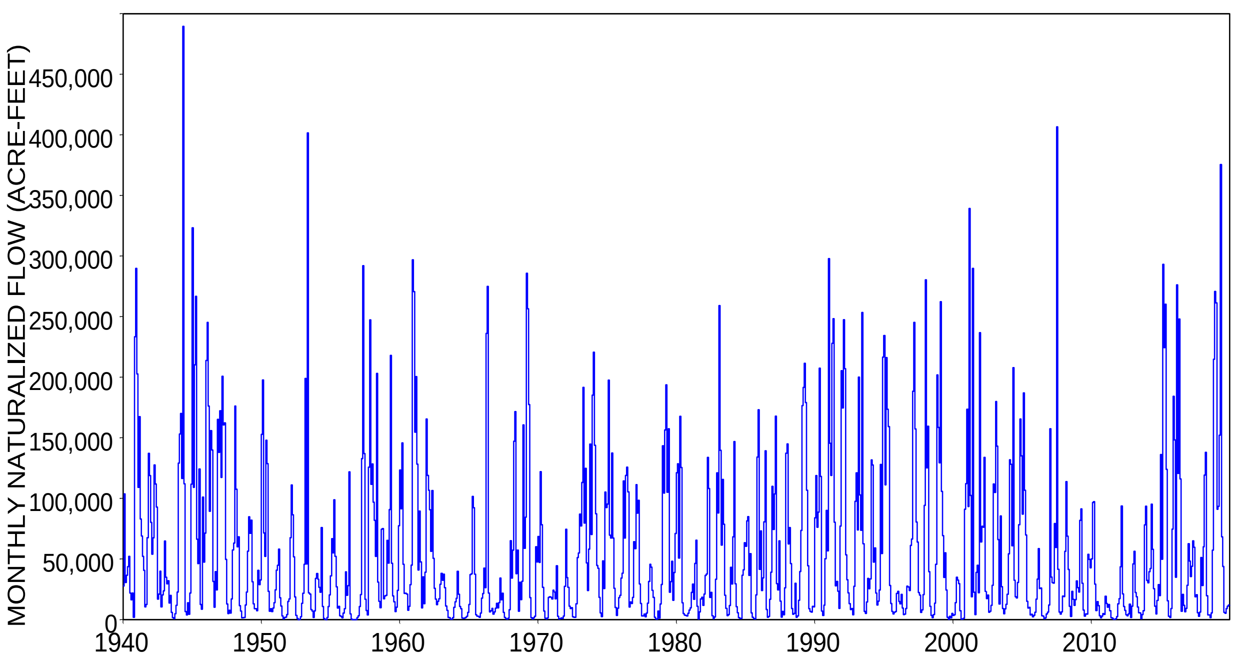

Figure 5.10 Monthly Naturalized Flow of Angelina River near Alto
(Control Point ANAL)

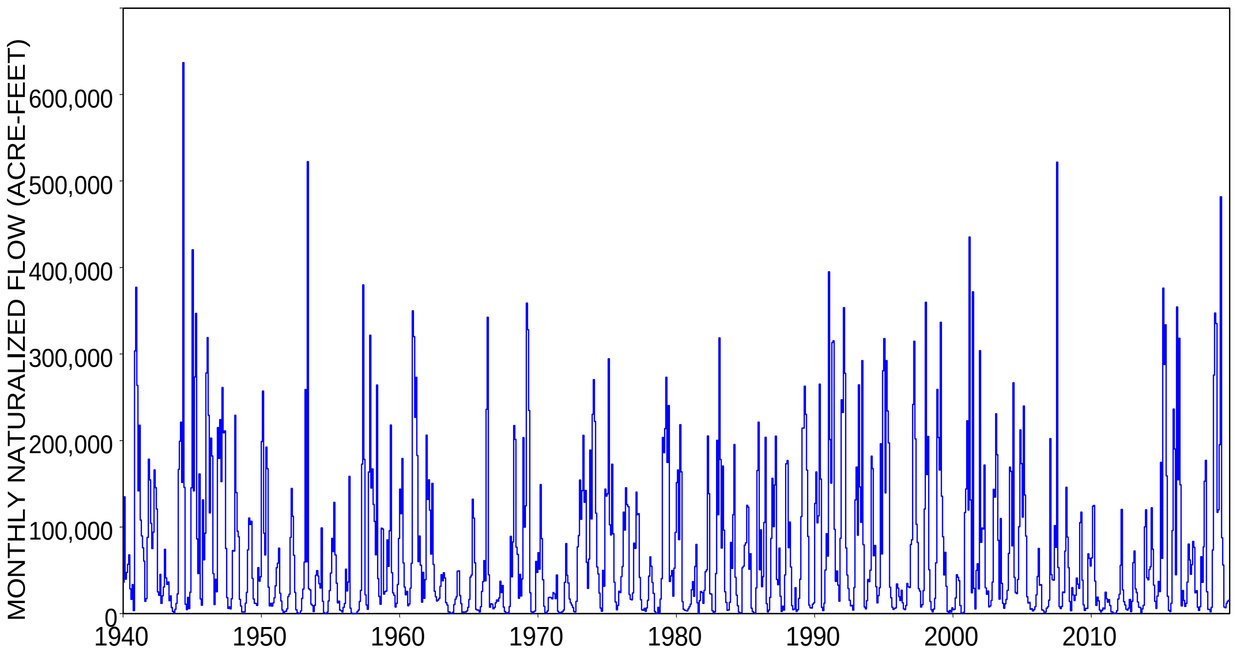

Figure 5.11 Monthly Naturalized Flow of Angelina River near Lufkin
(Control Point ANUL)

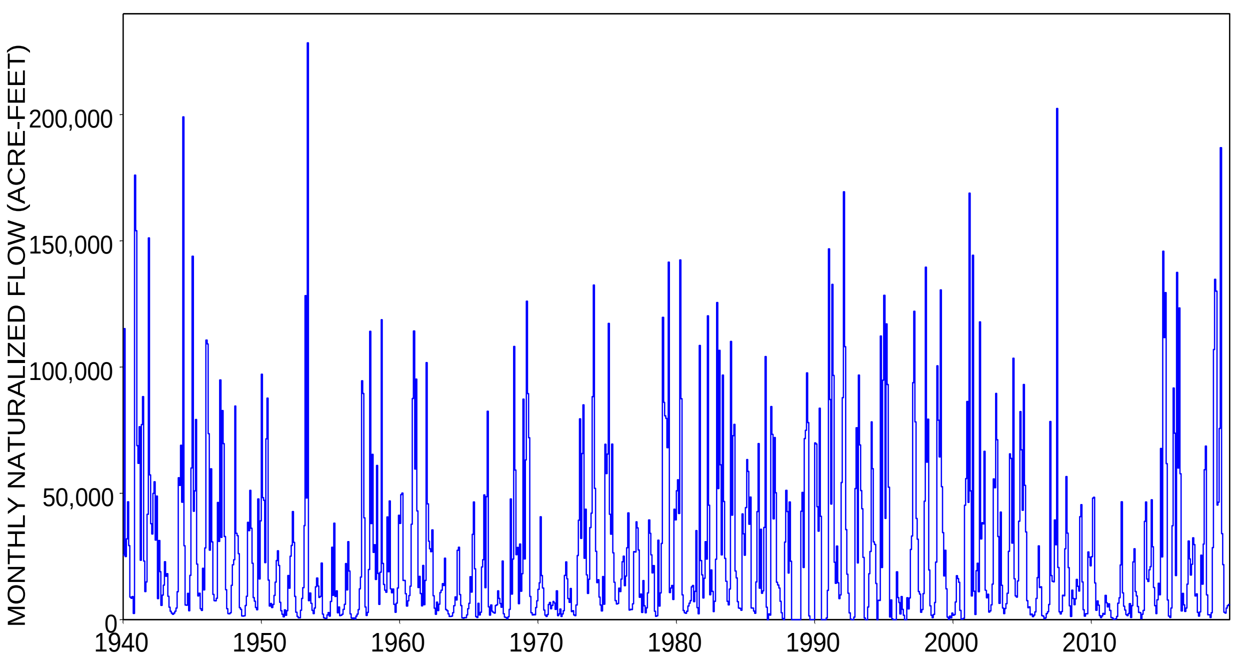

Figure 5.12 Monthly Naturalized Flow of Attoyac Bayou near Chireno
(Control Point ATCH)

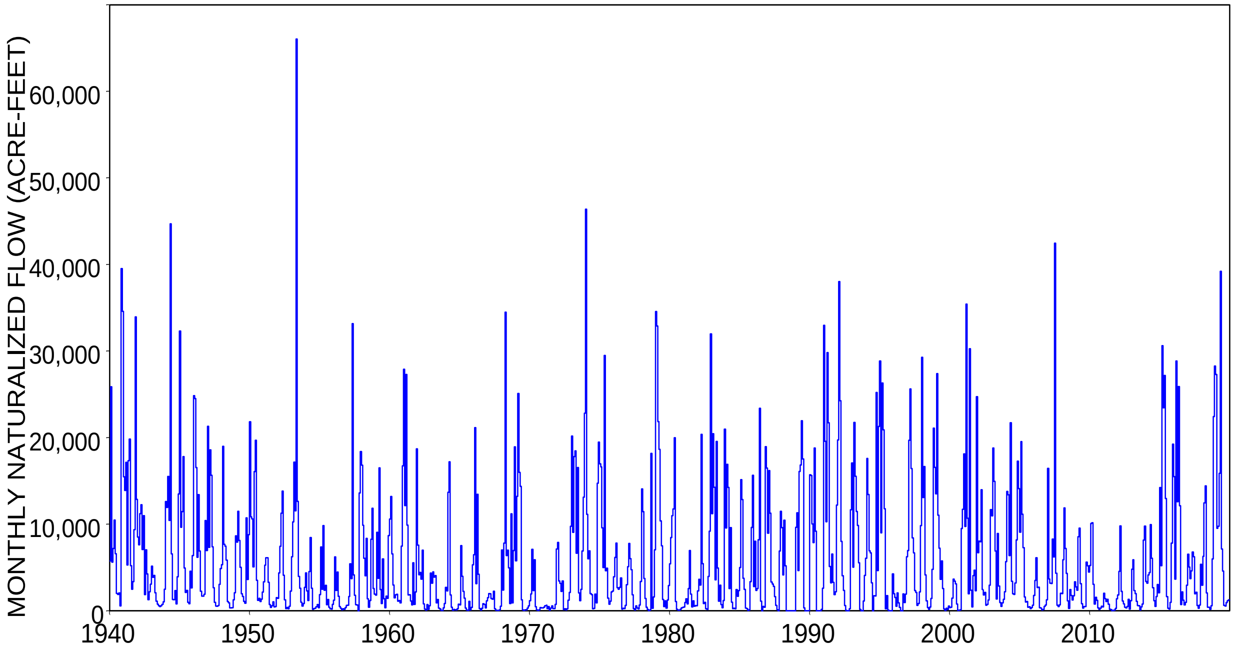

Figure 5.13 Monthly Naturalized Flow of Ayish Bayou near San Augustine (Control Point AYSA)

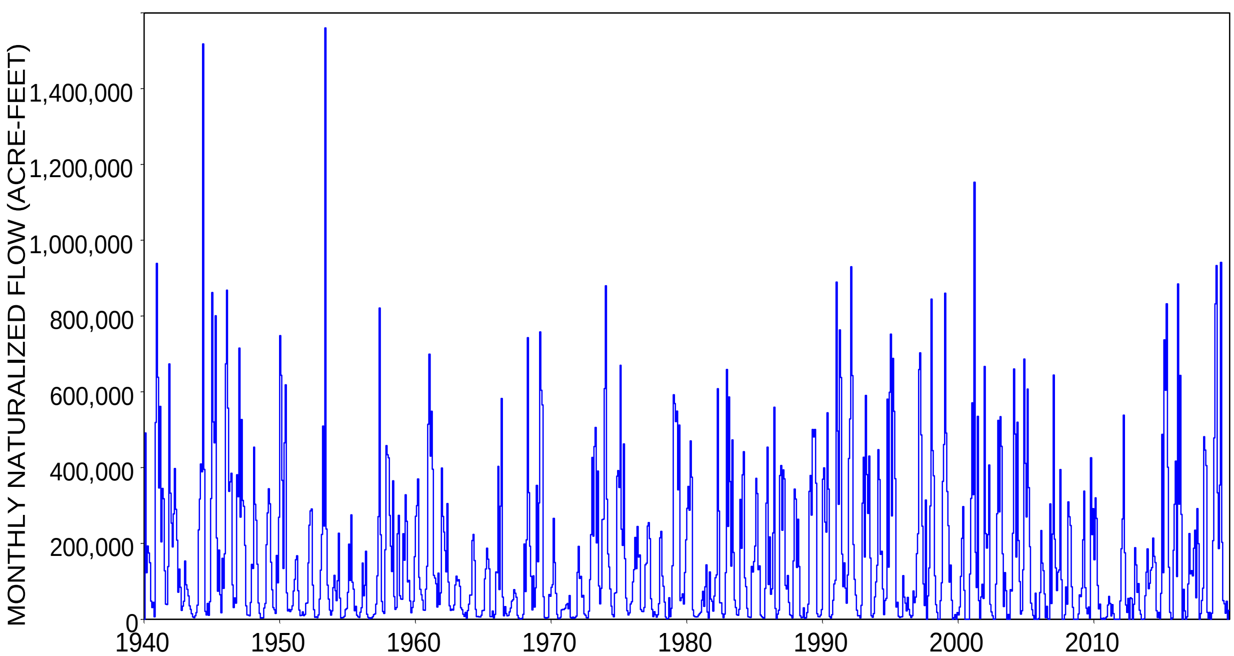

Figure 5.14 Monthly Naturalized Flow of Angelina River at Sam Rayburn Dam (Control Point ANSR)

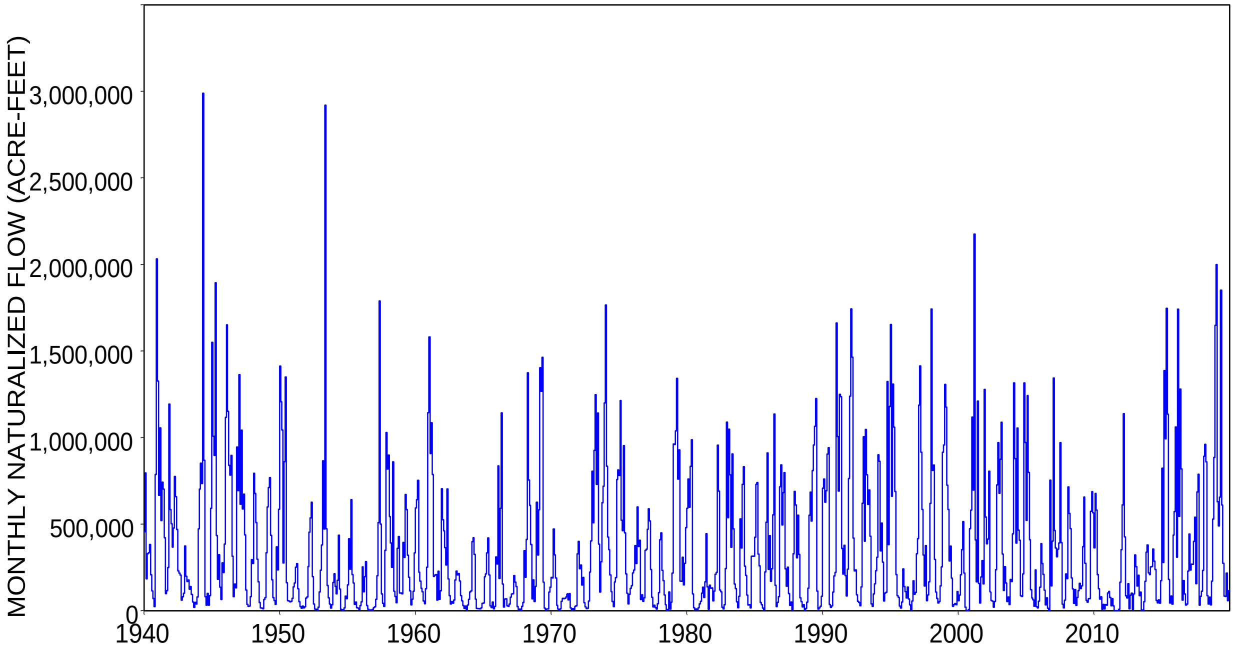

Figure 5.15 Monthly Naturalized Flow of the Neches River near Town Bluff
(Control Point NETB)

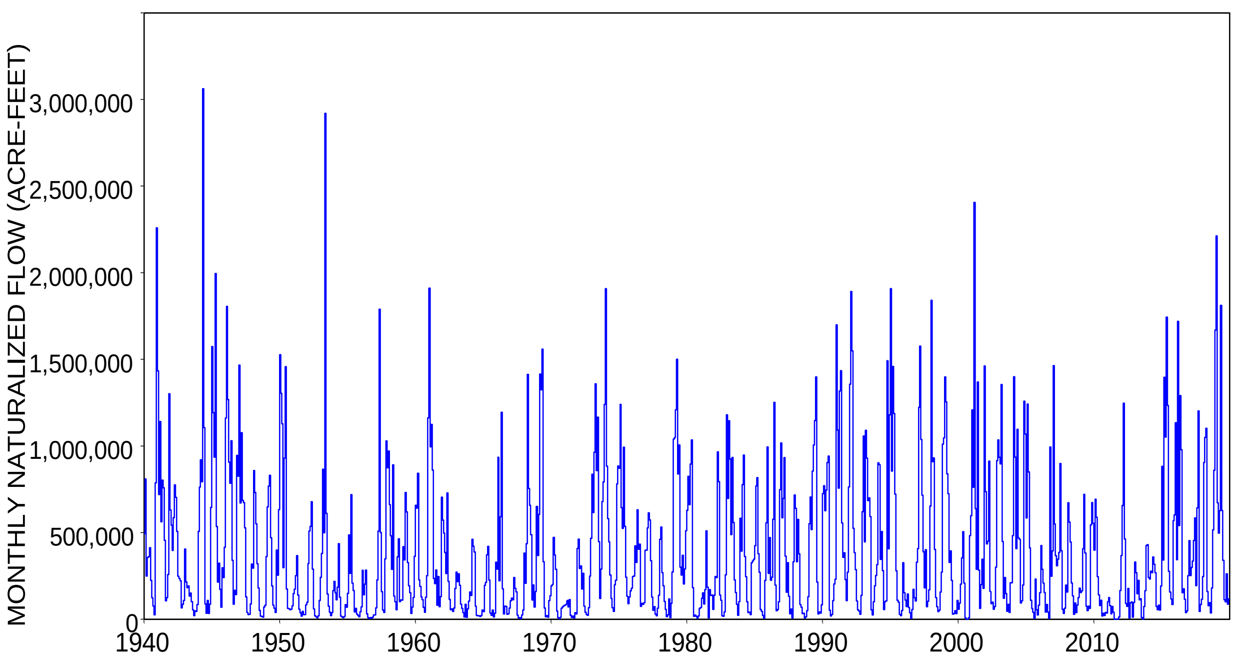

Figure 5.16 Monthly Naturalized Flow of the Neches River at Evadale
(Control Point NEEV)

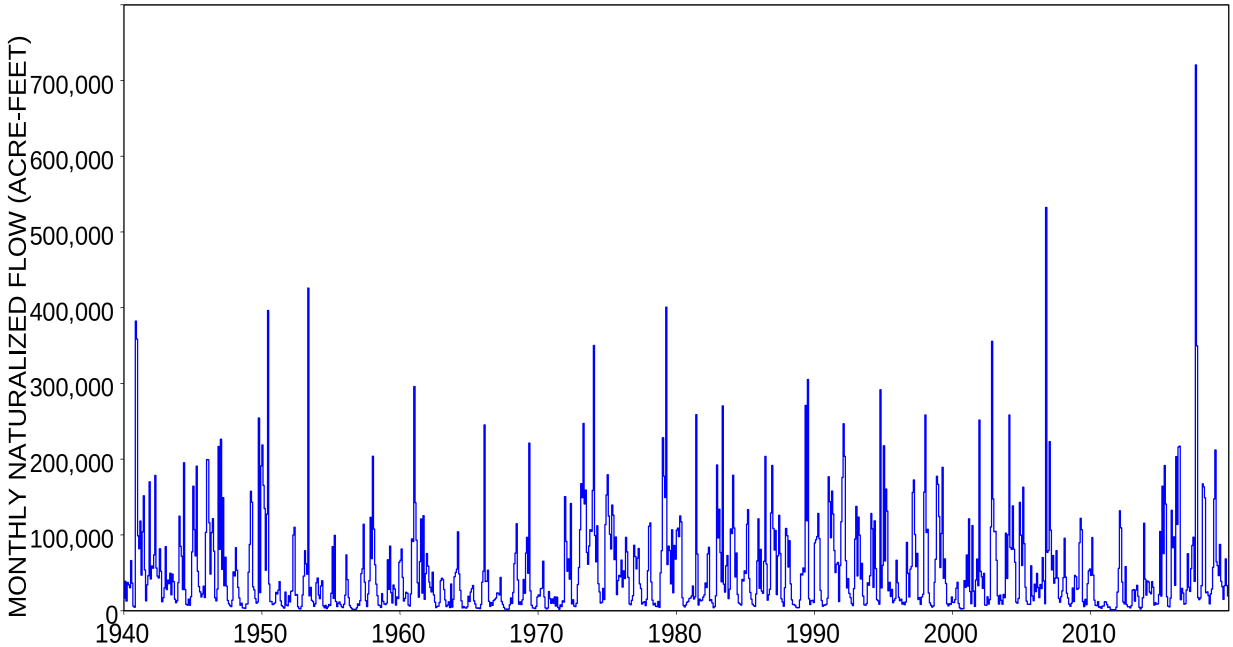

Figure 5.17 Monthly Naturalized Flow of Village Creek near Kountze
(Control Point VIKO)

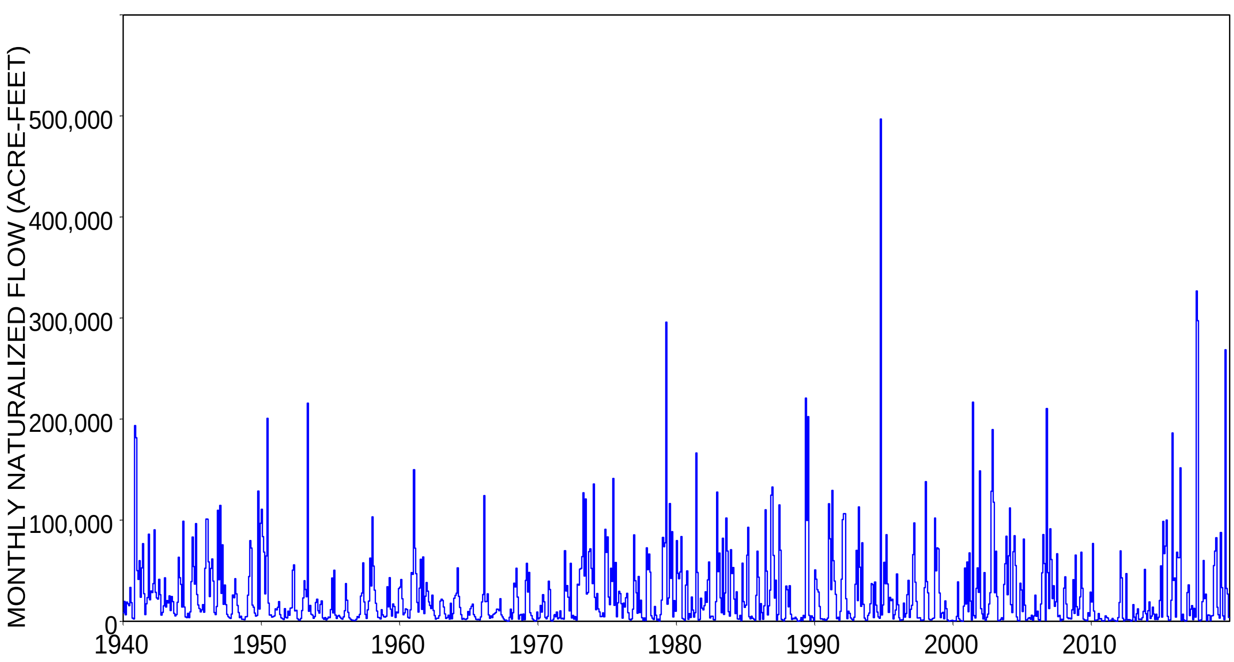

Figure 5.18 Monthly Naturalized Pine Island Bayou near Sour Lake
(Control Point PISL)

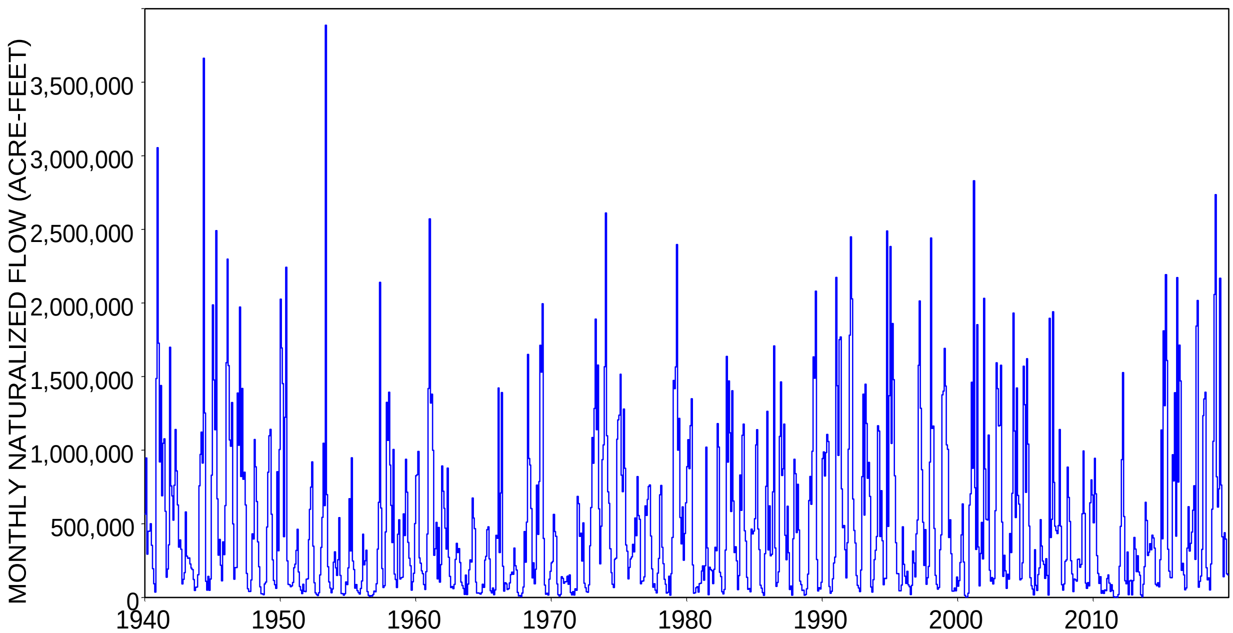

Figure 5.19 Monthly Naturalized Flow of the Neches River at Beaumont (Control Point NEBA)

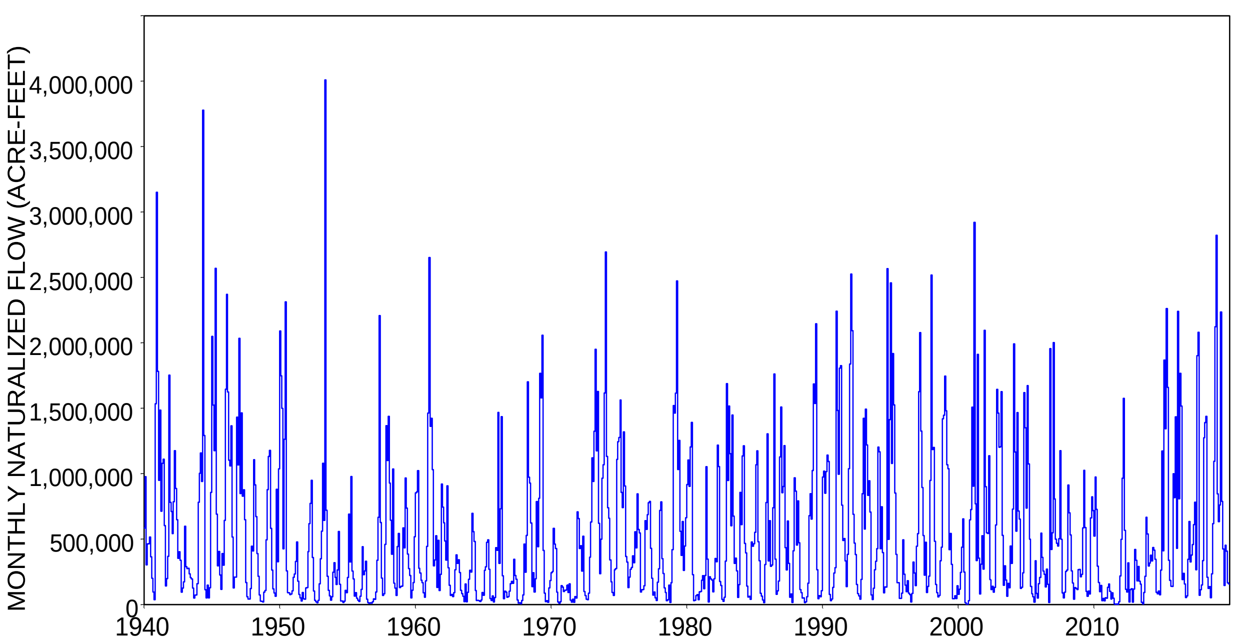

Figure 5.20 Monthly Naturalized Flow of the Neches River at Sabine Lake (Control Point NESL)

USGS gage measurements are recorded as mean daily flows in cubic feet per second (cfs) or daily volumes in second-foot-day (sfd), where a sfd is a volume equivalent to one cfs flowing for one day. Flow rates in SB3 environmental flows standards are also expressed in cfs. Flow quantities in WRAP/WAM simulation computations and output files are volumes per month or volumes per day in acre-feet. The monthly naturalized flows plotted in Figures 5.1-5.20 are in acre-feet/month. Relevant conversion factors are as follows.

one acre-feet per day = 0.50416667 cubic feet per second (cfs)
one cfs = 1.983471 acre-feet/day
one acre-feet = 43,560 cubic feet
one sfd = (1.0 ft^3/s)×(1.0 day) (86,400 seconds/day) = 86,400 cubic feet

Actual stream flow rates vary instantaneously and continuously. Daily means are aggregated to monthly means or volumes. Daily or monthly means or volumes can be aggregated to annual quantities. Variability is reduced with a larger averaging time interval. Flood peaks are lowered and minimum flows during low flow periods increase with an increase in the size of the measurement or computational time interval from instantaneous to daily to monthly to annual.

Monthly Naturalized Flow Statistics

The 1940-2019 monthly naturalized flows in acre-feet/month for the 20 primary control points are stored as *IN* records in the Neches WAM hydrology input DSS file with filename NechesHYD.DSS (Table 4.14). The statistics presented in this section were computed with *HEC-DSSVue* [8] and the WRAP programs *TABLES* and *HYD* [1, 2, 4] based on reading the *IN* records from the hydrology DSS file. *TABLES* and *HYD* as well as *SIM* and *SIMD* read and create DSS files. The frequency metrics of Table 5.4 were developed with the 2FRE record feature of the WRAP program *TABLES* from the data read from the *IN* records in the hydrology DSS file.

Annual means in acre-feet/year of the 1940-1996 and 1940-2019 naturalized flows for the 20 primary control points are compared in Table 4.1 of Chapter 4. The *TABLES* 2FRE frequency metrics in acre-feet/month for the 1940-2019 monthly naturalized flows tabulated in Table 5.4 include the mean and standard deviation for the 960 months of the 1940-2019 period-of-analysis, the minimum and maximum values in the 960-month time series, and the naturalized flow quantities that are equaled or exceeded during specified percentages of the 960 months

The metrics in Tables 5.5, 5.6, and 5.7 were computed from the DSS file *IN* record data with program *HYD* using hydrologic series *HS* record options. The entire *HYD* input HIN file that was used to read the hydrology DSS file and create Table 5.5 is replicated below.

```
HS  1940    2019   4   0         IN              2   2   0
SI    20    KIBR    NEPA    NENE    NEAL    NEDI    NERO    MUTY    MUJA   EFACU    ANAL
SI          ANLU    ATCH    AYSA    ANSR    NETB    NEEV    VIKO    PISL    NEBA    NESL
ED
```

The *HS* record option selection input parameters STAT and SERIES are changed to create Tables 5.6 and 5.7. Parameter SERIES allows the monthly series to be directly analyzed (option 1) or converted to an annual series of monthly totals or means (options 2 and 3), or converted to an annual series of the minima of maxima of the moving averages for any specified number on months between 1 and 12 (options 4 and 5). STAT specifies computation of basic statistics (option 1), linear regression trend analysis illustrated by Tables 5.6 and 5.7 (option 2), monthly and annual means as illustrated by Table 5.5 (option 3), or monthly or annual tabulations (option 4).

Seasonality is illustrated by the monthly means for the each of the 12 months of the year tabulated in Table 5.5. This *HYD HS* table also includes the means of the 80 annual flow volumes.

Table 5.4
Frequency Statistics for Monthly Naturalized Flows in acre-feet/month

CP	KIBR	NEPA	NENE	NEAL	NEDI	NERO	MUTY	MUJA	EFACU	ANAL
Mean	9,142	30,665	46,580	80,606	107,681	152,787	4,961	16,659	7,423	56,700
Stand Dev	12,136	37,177	56,472	99,748	131,140	187,261	6,289	21,117	9,064	69,362
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99.50%	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	96.0
99%	0.0	0.0	0.0	5.7	10.2	199.2	0.0	0.0	21.5	262.1
98%	0.0	2.8	4.2	8.1	99.6	1,363	0.0	0.0	96.8	455.4
95%	2.0	281.1	427	1,202	2,092	3,444	21.2	71.0	244.0	1,394
90%	100.0	1,435	2,180	3,132	4,679	7,478	162.0	544.0	531.0	2,723
85%	390.0	2,712	4,119	5,858	8,009	12,057	306.5	1,029	787.0	4,335
80%	802.0	3,996	6,069	8,836	11,528	16,931	465.2	1,562	1,005	6,300
75%	1,116	5,202	7,902	12,107	15,839	22,957	676.9	2,273	1,300	9,081
70%	1,543	6,836	10,385	15,790	20,414	30,371	911.1	3,059	1,624	11,128
60%	2,745	11,440	17,378	26,885	34,446	49,404	1,602	5,380	2,412	18,764
50%	4,322	16,608	25,228	40,052	56,705	79,360	2,400	8,058	3,713	27,877
40%	6,803	24,528	37,259	61,785	82,674	115,921	3,602	12,094	5,464	42,737
30%	10,479	35,926	54,572	96,439	125,856	179,937	5,795	19,456	8,216	66,036
25%	12,435	42,131	63,997	113,742	157,125	219,095	7,050	23,671	10,457	80,273
20%	15,478	52,560	79,839	137,721	194,675	272,079	8,540	28,675	12,817	102,753
15%	19,396	62,452	94,864	174,194	234,797	325,574	10,701	35,931	15,604	123,992
10%	24,916	81,299	123,493	218,848	291,118	403,285	13,826	46,421	20,975	154,643
5%	34,961	105,719	160,587	292,978	381,549	545,266	18,308	61,472	27,058	206,975
2%	46,842	146,944	223,208	384,764	501,025	732,501	23,554	79,085	35,242	265,747
1%	57,306	174,547	265,136	450,666	544,869	811,739	26,736	89,769	39,572	292,375
0.50%	67,799	203,786	309,550	581,486	670,828	969,117	32,405	108,802	47,061	346,369
Maximum	92,747	283,992	431,382	624,597	1,042,078	1,470,738	44,641	149,888	58,976	489,405

CP	ANLU	ATCH	AYSA	ANSR	NETB	NEEV	VIKO	PISL	NEBA	NESL
Mean	73,421	27,743	5,909	167,496	355,203	389,112	54,163	27,143	513,358	529,493
Stand Dev	89,757	34,605	7,860	206,737	408,481	434,337	67,457	41,527	564,079	581,808
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	810.3	59.2	1,220	1,258
99.50%	124.8	0.0	0.0	0.0	0.0	0.0	1,542	172.8	4,004	4,130
99%	310.7	0.0	0.0	0.0	2,284	4,199	2,000	286.9	9,479	9,777
98%	491.2	0.0	0.0	0.0	5,414	7,229	2,737	390.4	14,612	15,071
95%	1,736	615.0	60.5	1,776	10,087	15,651	4,184	812.3	25,418	26,217
90%	3,369	1,511	201.0	4,782	21,707	28,374	5,939	1,339	43,125	44,481
85%	5,265	2,269	317.0	9,115	33,349	41,668	7,692	1,934	63,325	65,315
80%	7,684	3,190	480.0	13,334	47,780	57,907	9,076	2,632	86,393	89,109
75%	10,902	4,332	644.3	22,051	62,491	74,127	11,543	3,454	103,581	106,837
70%	14,258	5,692	944	28,575	80,665	93,430	13,854	4,237	128,588	132,629
60%	23,939	9,185	1,668	50,221	126,511	145,459	19,958	6,789	202,749	209,121
50%	36,379	13,323	2,471	83,115	197,437	224,228	29,637	11,644	305,100	314,689
40%	53,771	21,373	4,140	130,639	282,260	329,052	41,605	18,601	431,717	445,286
30%	86,718	30,980	6,696	199,405	421,100	468,575	59,599	27,649	621,267	640,793
25%	105,543	38,891	8,157	245,782	522,279	576,099	74,981	35,675	749,049	772,592
20%	132,160	46,584	10,275	303,377	641,327	685,855	89,560	42,904	899,074	927,332
15%	163,769	59,242	13,076	369,581	768,583	842,341	106,876	55,116	1,072,490	1,106,199
10%	203,252	77,280	16,722	457,905	915,508	1,005,375	128,968	69,701	1,369,807	1,412,860
5%	264,968	106,624	21,741	604,020	1,206,873	1,268,335	178,714	100,878	1,691,417	1,744,579
2%	341,239	132,696	30,166	761,946	1,532,635	1,575,164	253,697	147,156	2,161,912	2,229,861
1%	376,387	148,518	34,563	881,449	1,753,880	1,897,119	349,705	205,591	2,464,354	2,541,809
0.50%	444,436	178,188	40,103	938,979	2,005,136	2,221,473	397,161	273,990	2,754,538	2,841,113
Maximum	636,666	228,359	66,033	1,559,985	2,988,493	3,061,346	720,413	496,794	3,886,068	4,008,207

Table 5.5
Monthly Mean (acre-feet/month) and Annual Mean (acre-feet/year) Naturalized Flows

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
KIBR	12,684	13,423	16,686	15,133	16,784	8,566	2,860	974	1,819	3,008	6,446	11,327	109,709
NEPA	43,206	43,722	55,623	49,252	53,491	29,212	11,088	3,906	7,823	10,959	22,968	36,729	367,980
NENE	65,629	66,414	84,492	74,813	81,253	44,372	16,842	5,933	11,883	16,647	34,889	55,792	558,959
NEAL	121,041	122,020	143,906	119,742	135,601	80,403	30,745	12,154	18,193	31,338	57,806	94,329	967,276
NEDI	166,640	165,213	192,338	157,057	181,061	106,921	45,532	15,297	20,317	38,674	79,175	123,941	1,292,166
NERO	244,619	232,500	266,895	222,115	256,358	158,213	67,966	24,317	32,667	53,200	104,303	170,289	1,833,442
MUTY	7,067	7,895	8,980	7,887	7,931	4,509	1,922	714	867	1,720	3,880	6,164	59,538
MUJA	23,729	26,510	30,151	26,482	26,631	15,139	6,455	2,398	2,912	5,775	13,028	20,696	199,905
EFACU	11,138	11,324	13,069	10,424	11,791	6,173	3,309	1,511	1,790	2,992	6,090	9,471	89,081
ANAL	87,081	88,261	103,429	85,018	94,783	50,344	21,945	8,003	10,896	19,644	40,956	70,040	680,399
ANLU	113,160	117,331	133,774	110,086	122,376	64,703	28,400	10,239	13,342	25,047	52,483	90,114	881,055
ATCH	44,984	44,318	47,832	40,736	41,197	23,509	10,714	5,047	8,091	9,349	21,968	35,173	332,919
AYSA	10,218	9,925	10,439	8,514	8,978	4,642	2,112	882	1,321	1,800	4,357	7,718	70,907
ANSR	287,296	289,438	306,124	251,160	262,430	138,249	49,125	27,678	28,968	56,094	107,375	206,012	2,009,945
NETB	579,344	569,766	622,578	517,194	561,547	334,300	142,521	70,644	81,507	127,682	237,290	418,068	4,262,438
NEEV	632,470	615,233	676,845	569,388	598,862	375,788	170,546	82,982	96,875	143,894	255,708	450,753	4,669,344
VIKO	87,042	81,247	74,657	64,888	68,797	50,778	29,833	24,076	23,336	31,144	47,796	66,367	649,960
PISL	40,067	35,641	31,170	28,654	29,154	30,872	17,746	12,331	18,206	22,511	27,750	31,611	325,713
NEBA	828,914	798,949	854,113	723,442	760,418	499,192	238,035	130,286	151,052	215,581	361,491	598,820	6,160,291
NESL	854,966	824,060	880,958	746,180	784,318	514,882	245,517	134,381	155,800	222,356	372,852	617,641	6,353,912

Linear Regression Trend Analyses

As discussed in the preceding Chapter 4, the purpose of the stream flow naturalization process is to remove non-stationarities. Stationarity refers to constant conditions (homogeneity) over time. Population growth and associated increased water use, construction of dams and other water resources development projects, land use changes, and climatic changes can result in long-term modifications (non-stationarities) in stream flow and other hydrologic variables that may or may not be big enough to significantly affect water availability modeling. Time series plots such as Figures 5.1-5.20 are useful in investigating trends and permanent changes or lack thereof. The WRAP program *HYD* also provides *HS* record linear regression trend analysis methods designed to detect and analyze non-stationarity as explained in Chapter 2 of the *Hydrology Manual* [4].

Standard least squares linear regression metrics [4] for the 960 monthly flows and the 80 annual flows are tabulated on the left and right sides, respectively, of Table 5.6. For example, the 80 annual naturalized flow volumes at the basin outlet (control point NESL) have a mean of 6,353,912 acre-feet/year and increasing slope of 8,569 ac-ft/year per year. Regression metrics for the annual series of the minimum and maximum flow volumes during any two consecutive months of each of the 80 years are presented in Table 5.7. A horizon line representing absolutely no trend would conceptually have a slope of zero and the intercept would be equal to the mean. A negative slope indicates decreasing and positive slope increasing trends.

Tables 5.6 and 5.7 contain 32 negative slopes and 48 positive slopes for the four time series variables at 20 sites. None of the slopes are large enough to demonstrate apparent trends. The 1940-2019 naturalized flows at the 20 sites appear to be reasonably stationary.

Table 5.6
Linear Regression Trend Analyses of Monthly and Annual Naturalized Flow Volumes

Site	Regression of Monthly Flows (acre-feet/month)					Regression of Annual Flows (acre-feet/year)				
	Mean	Intercept	Slope	Intercept % Mean	Slope % Mean	Mean	Intercept	Slope	Intercept % Mean	Slope % Mean
KIBR	9,142	9,914	-1.60660	108.4439	-0.01757	109,709	118,152	-208.47	107.696	-0.19003
NEPA	30,665	30,462	0.42265	99.3377	0.00138	367,980	362,525	134..69	98.518	0.03660
NENE	46,580	46,271	0.64217	99.3376	0.00138	558,959	550,673	204.60	98.518	0.03660
NEAL	80,606	67,732	26.79291	84.0286	0.03324	967,277	802,810	4,060.90	82.997	0.41983
NEDI	107,681	101,805	12.22750	94.5438	0.01136	1,292,166	1,209,571	2,039.38	93.608	0.15783
NERO	152,787	141,426	23.64314	92.5645	0.01547	1,833,443	1,679,084	3,811.33	91.581	0.20788
MUTY	4,962	5,152	-0.39685	103.8434	-0.00800	59,538	61,358	-44.95	103.058	-0.07549
MUJA	16,659	17,299	-1.33248	103.8434	-0.00800	199,905	206,017	-150.92	103.058	-0.07549
EFACU	7,423	7,275	0.30831	98.0044	0.00415	89,081	86,609	61.04	97.225	0.06852
ANAL	56,700	58,815	-4.40251	103.7309	-0.00776	680,399	700,195	-488.78	102.909	-0.07184
ANLU	73,421	76,028	-5.42545	103.5507	-0.00739	881,055	904,933	-589.59	102.710	-0.06692
ATCH	27,743	27,362	0.79276	98.6270	0.00286	332,918	325,563	181.61	97.791	0.05455
AYSA	5,909	6,095	-0.38781	103.1536	-0.00656	70,907	72,533	-40.15	102.294	-0.05663
ANSR	167,496	169,288	-3.73003	101.0700	-0.00223	2,009,947	2,012,131	-53.92	100.109	-0.00268
NETB	355,203	343,165	25.05423	96.6108	0.00705	4,262,438	4,078,092	4,551.76	95.675	0.10679
NEEV	389,112	373,992	31.46659	96.1143	0.00809	4,669,343	4,444,411	5,553.89	95.183	0.11894
VIKO	54,163	49,798	9.08571	91.9398	0.01677	649,961	593,182	1,401.94	91.264	0.21570
PISL	27,143	25,038	4.37998	92.2462	0.01614	325,712	299,087	657.43	91.825	0.20184
NEBA	513,358	489,797	49.03397	95.4104	0.00955	6,160,295	5,823,816	8,308.14	94.538	0.13487
NESL	529,493	505,191	50.57566	95.4104	0.00955	6,353,912	6,006,850	8,569.42	94.538	0.13487

Table 5.7
Linear Regression Trend Analyses of
Annual 2-Month Minimum and Annual 2-Month Maximum Naturalized Flow Volumes

Site	Annual 2-Month Volume (acre-feet/two months)					Annual 2-Month Maximum (acre-feet/two months)				
	Mean	Intercept	Slope	Intercept % Mean	Slope % Mean	Mean	Intercept	Slope	Intercept % Mean	Slope % Mean
KIBR	6,952	7,598	-15.9308	109.2802	-0.22914	23,288	26,751	-85.4838	114.8662	-0.36707
NEPA	22,941	23,458	-12.762	102.2530	-0.05563	72,325	77,050	-116.6894	106.5343	-0.16134
NENE	34,847	35,632	-19.3842	102.2529	-0.05563	109,860	117,039	-177.2461	106.5342	-0.16134
NEAL	63,704	49,254	356.7906	77.3170	0.56007	191,838	150,072	1031.2576	78.2286	0.53757
NEDI	86,145	78,407	191.0747	91.0169	0.22181	252,792	233,157	484.8145	92.2327	0.19178
NERO	121,506	114,846	164.4323	94.5192	0.13533	359,682	349,471	252.1378	97.1609	0.07010
MUTY	4,106	4,228	-3.0289	102.9879	-0.07378	12,192	12,576	-9.4706	103.1460	-0.07768
MUJA	13,785	14,197	-10.1699	102.9879	-0.07377	40,937	42,224	-31.7984	103.1459	-0.07768
EFACU	6,006	5,650	8.7991	94.0667	0.14650	17,599	16,429	28.8825	93.3533	0.16411
ANAL	46,256	49,499	-80.0570	107.0095	-0.17307	133,906	138,225	-106.6511	103.2257	-0.07965
ANLU	61,313	66,058	-117.1647	107.7393	-0.19109	173,653	179,004	-132.1155	103.0812	-0.07608
ATCH	23,403	24,485	-26.7211	104.6243	-0.11418	66,521	65,257	31.2235	98.0990	0.04694
AYSA	5,152	5,651	-12.3186	109.6844	-0.23912	14,982	15,886	-22.3255	106.0351	-0.14902
ANSR	148,941	151,663	-67.2021	101.8274	-0.04512	408,869	410,156	-31.7738	100.3147	-0.00777
NETB	299,368	289,626	240.5392	96.7459	0.08035	814,596	810,174	109.1931	99.4571	0.01340
NEEV	326,217	319,900	155.9884	98.0634	0.04782	878,304	871,363	171.3820	99.2097	0.01951
VIKO	44,616	42,505	52.1302	95.2679	0.11684	131,453	118,052	330.8797	89.8058	0.25171
PISL	18,931	21,467	-62.6028	113.3928	-0.33069	69,690	57,454	302.1334	82.4417	0.43354
NEBA	426,794	418,904	194.8240	98.1512	0.04565	153,958	1,134,485	480.8143	98.3125	0.04167
NESL	440,208	432,071	200.9330	98.1514	0.04564	190,226	1,170,141	495.9367	98.3125	0.04167

CHAPTER 6
RESERVOIR EVAPORATION AND PRECIPITATION RATES

The original 1940-1996 *SIM* simulation input monthly naturalized flows and net evaporation-precipitation rates developed as described in the 2001 WAM report [9] have not been changed. Extension of the monthly evaporation-precipitation rates through 1997-2012 employing the WRAP program *HYD* features for manipulating the TWDB precipitation and evaporation datasets is described in the 2014 hydrology extension report [10]. The same methodology is applied as described in this chapter to extend the monthly net evaporation-precipitation rates through 1997-2019. The monthly precipitation and reservoir evaporation data discussed in this chapter also provide insight regarding the hydrologic characteristics of the Neches River Basin.

Extension of the *SIM/SIMD* simulation input *EV* records through December 2019 is a primary focus of Chapter 6. The *EV* record monthly evaporation less adjusted precipitation rates are also used in the stream flow naturalization computations described in Chapter 4. The stream flow naturalization computations were completed prior to the TWDB adding January-December 2019 data to the database described below in May 2020. The 1940-2018 means for each of the 12 months of the year were used for 2019 in the Chapter 4 stream flow naturalization adjustments.

Texas Water Development Board
Evaporation and Precipitation Datasets

The Texas Water Development Board (TWDB) maintains annually updated datasets of monthly precipitation and evaporation depths in inches for the 92 one-degree latitude by one-degree longitude quadrangles shown in Figure 6.1 that cover the state of Texas. The Neches River Basin is also delineated in Figure 6.1. The TWDB monthly reservoir surface evaporation rates extend back to January 1954. The precipitation data start in January 1940. The datasets are updated each Spring to add January through December of the preceding year. The monthly precipitation and evaporation rates and related information are available at the TWDB website.

https://waterdatafortexas.org/lake-evaporation-rainfall

The statewide TWDB datasets are converted at Texas A&M University to WRAP program *HYD* input files with filenames Precipitation.PPP and Evaporation.EEE and also combined using a *HYD* option into a DSS file with filename PrecipEvap.DSS. Chapter 2 of the *Hydrology Manual* [4] explains *HYD* options for working with the TWDB evaporation and precipitation datasets and presents statistical analyses for each of the 92 quadrangles and statewide averages. Linear tread analysis metrics for monthly, annual total, annual minimum two-month, and annual maximum two-month precipitation and evaporation are included in the *Hydrology Manual* [4] presentation.

Time series plots of the monthly precipitation and evaporation rates averaged over each of the 92 quads and over the entire state demonstrate extreme temporal and spatial variability [4]. Precipitation and evaporation exhibit great variability seasonally, between years, and continuously. Annual variability is much greater for precipitation than evaporation. Seasonality is much more evident for evaporation than precipitation. No long-term trends or permanent changes in precipitation or evaporation characteristics are evident from the time series plots and statistical regression analyses. Any long-term trends, if they exist, are hidden by the great continuous monthly and annual variability in precipitation and evaporation [4].

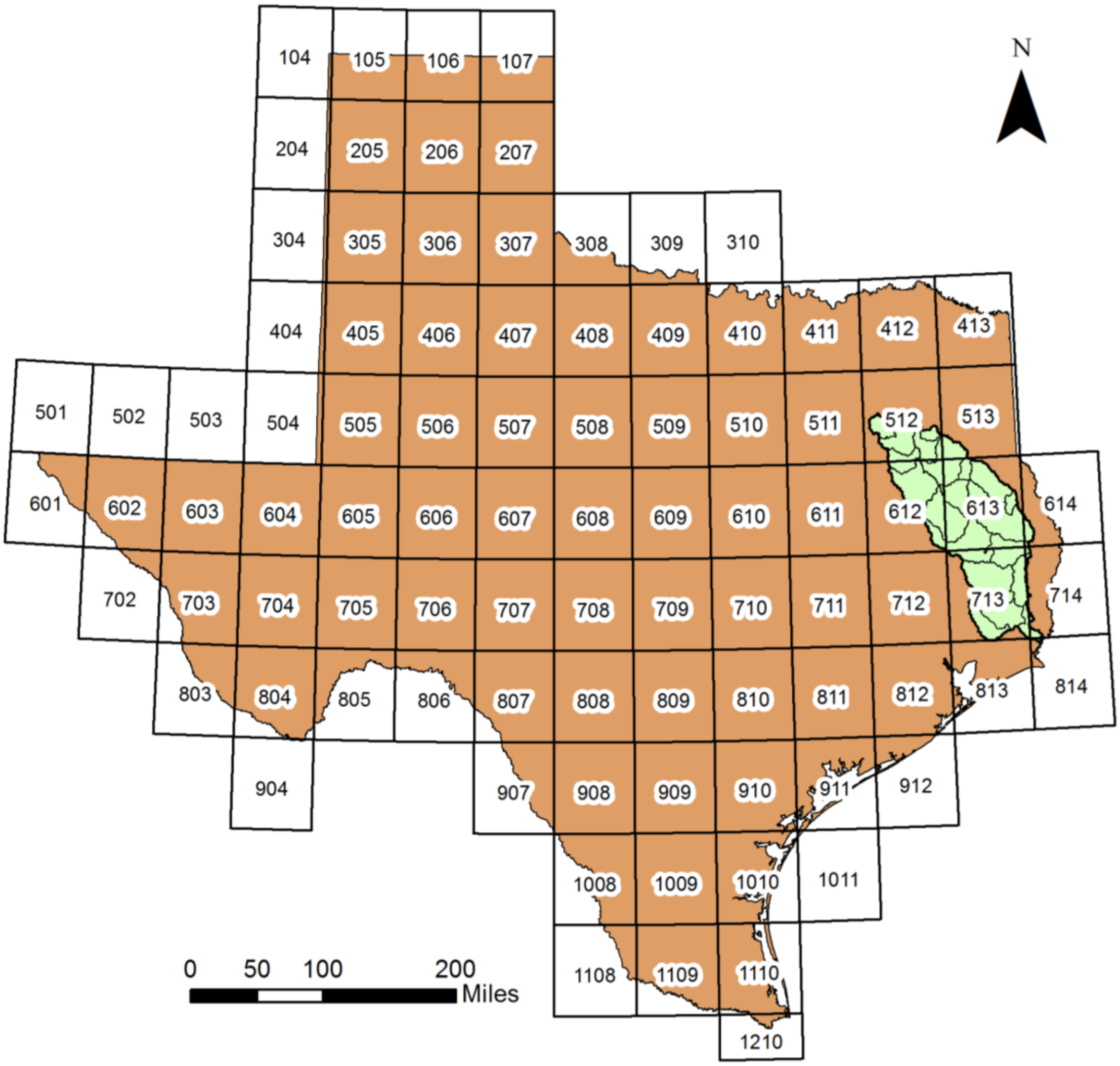

Figure 6.1 Quadrangles for TWDB Monthly Evaporation and Precipitation Databases

<u>Precipitation and Evaporation in the Neches River Basin</u>

The TWDB database was employed in the original [9] and updated compilations of *EV* record net evaporation-precipitation rates for the Neches WAM. The Neches River Basin is encompassed by the TWDB-defined quadrangles shown in Figures 6.1 and 6.2. The WAM control point identifiers assigned to net evaporation-precipitation rate sequences as well as the TWDB integer quadrangle identifiers are included on the basin map of Figure 6.2.

Means of the 1940-2019 monthly precipitation, 1954-2019 evaporation, and 1954-2019 net evaporation less precipitation rates in inches/month for each of the 12 months of the year from the TWDB database are tabulated in Table 6.1 for the ten quads delineated in Figure 6.2. The means of the annual totals in inches/year are also included in Table 6.1. These quantities reflect spatial averaging over the quadrangle land area and temporal averaging over 1954-2019 or 1940-2019.

Figure 6.2 *EV* Record Control Points and TWDB Quadrangles for the Neches River Basin

Table 6.1
Means of Monthly and Annual Evaporation, Precipitation, and Evaporation-Precipitation

Quad	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
						Means of 1954-2019 Reservoir Evaporation (inches)							
512	2.05	2.51	3.94	4.60	4.95	6.33	7.37	7.27	5.70	4.63	3.09	2.32	54.77
513	1.86	2.25	3.56	4.30	4.79	5.85	6.50	6.37	5.06	3.98	2.64	2.05	49.20
612	2.26	2.58	3.82	4.50	4.96	6.11	6.90	6.61	5.31	4.36	3.03	2.32	52.77
613	1.94	2.30	3.47	4.19	4.77	5.65	6.02	5.85	4.69	3.85	2.64	1.97	47.34
614	2.03	2.37	3.70	4.31	4.86	5.83	6.19	5.90	4.75	3.94	2.70	2.15	48.72
712	2.18	2.42	3.57	4.41	4.96	5.92	6.31	6.05	4.87	4.16	2.87	2.23	49.94
713	1.89	2.19	3.31	4.07	4.63	5.40	5.74	5.52	4.45	3.80	2.53	1.95	45.49
714	1.92	2.25	3.48	4.15	4.70	5.53	5.89	5.66	4.54	3.88	2.61	1.99	46.59
813	2.07	2.28	3.37	4.12	4.68	5.35	5.56	5.29	4.43	3.96	2.73	2.16	45.99
814	1.94	2.20	3.35	4.12	4.62	5.35	5.67	5.37	4.47	3.92	2.68	2.01	45.69
						Means of 1940-2019 Precipitation (inches)							
512	3.11	3.51	3.82	4.31	5.02	3.89	2.46	2.40	3.27	4.18	3.85	3.87	43.68
513	3.84	3.92	4.30	4.59	5.00	4.13	3.02	2.82	3.48	3.94	4.29	4.48	47.82
612	3.45	3.35	3.61	3.92	4.86	4.10	2.72	2.84	3.56	3.99	4.02	3.82	44.24
613	4.32	4.03	4.02	4.23	5.03	4.34	3.17	3.23	3.79	3.98	4.52	4.66	49.32
614	4.88	4.64	4.67	4.65	5.19	4.53	3.88	3.57	3.65	3.93	4.66	5.24	53.48
712	3.68	3.38	3.24	3.85	4.89	4.51	3.25	3.49	4.07	4.20	4.31	4.02	46.90
713	4.44	4.07	3.83	4.37	5.16	5.30	4.37	4.27	4.56	4.60	4.79	4.99	54.72
714	4.93	4.19	4.01	4.40	5.16	5.47	5.28	4.80	4.79	4.11	4.67	5.26	57.07
813	3.75	2.94	3.03	3.32	4.18	4.91	4.53	5.00	5.73	4.14	3.81	4.08	49.43
814	4.85	3.56	3.43	3.85	4.53	5.57	6.64	6.16	5.67	4.15	4.40	4.59	57.38
						Means of 1954-2019 Differences in Evaporation Minus Precipitation (inches)							
512	-1.003	-0.993	0.198	0.435	0.128	2.451	4.965	4.937	2.328	0.246	-0.638	-1.539	11.515
513	-1.860	-1.686	-0.695	-0.247	0.014	1.586	3.468	3.598	1.441	-0.169	-1.624	-2.437	1.388
612	-1.161	-0.709	0.240	0.676	0.323	1.883	4.173	3.696	1.640	0.134	-0.851	-1.469	8.576
613	-2.312	-1.637	-0.520	0.049	0.099	1.234	2.876	2.566	0.731	-0.303	-1.759	-2.673	-1.647
614	-2.782	-2.197	-1.003	-0.156	-0.001	1.262	2.342	2.249	0.987	-0.156	-1.907	-3.127	-4.490
712	-1.417	-0.855	0.417	0.762	0.216	1.373	3.177	2.526	0.581	-0.272	-1.284	-1.677	3.545
713	-2.500	-1.856	-0.516	-0.095	-0.293	-0.001	1.480	1.161	-0.323	-0.988	-2.172	-3.014	-9.118
714	-3.045	-1.916	-0.432	-0.001	-0.156	-0.012	0.738	0.720	-0.472	-0.467	-1.980	-3.272	-10.295
813	-1.838	-0.660	0.325	0.786	0.475	0.224	1.071	0.144	-1.716	-0.442	-1.108	-1.944	-4.684
814	-3.055	-1.324	-0.012	0.315	0.125	-0.426	-0.753	-1.061	-1.283	-0.460	-1.578	-2.558	-12.071

The three tables combined in Table 6.1 were developed with the *HYD* hydrologic series *HS* record statistical analysis capabilities described in Chapter 2 of the *Hydrology Manual* [4] using the *HYD* input HIN file shown below, with PE options 1, 2, 3 activated in alternative runs.

```
HS  1940     2019   6   0                   3        3
SI    10      512      513      612      613      614      712      713      714      813      814
ED
```

HEC-DSSVue plots of the 1940-2019 monthly precipitation, 1954-2019 evaporation, and 1954-2019 net evaporation less precipitation for quadrangle 613 are plotted in Figures 6.3, 6.4, and 6.5. Quadrangle 613 in the middle of the Neches Basin includes Sam Rayburn Reservoir and several small reservoirs. The monthly rates are expressed as depths in inches per month.

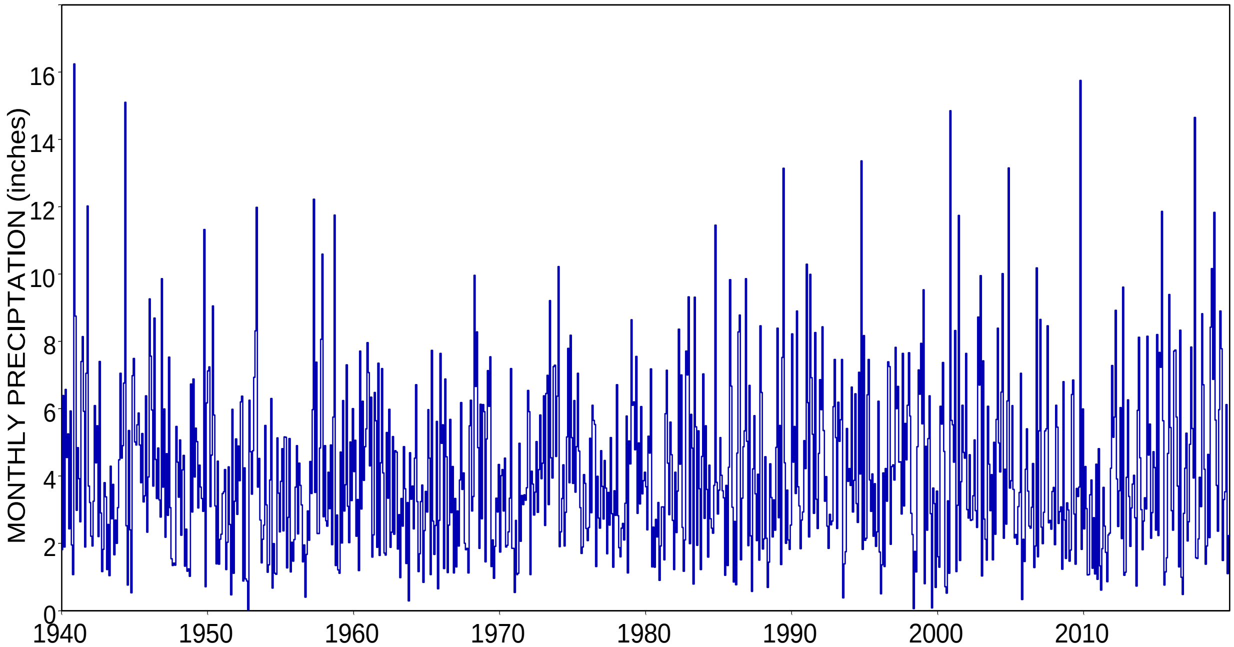

Figure 6.3 1940-2019 Monthly Precipitation from TWDB Database for Quadrangle 613

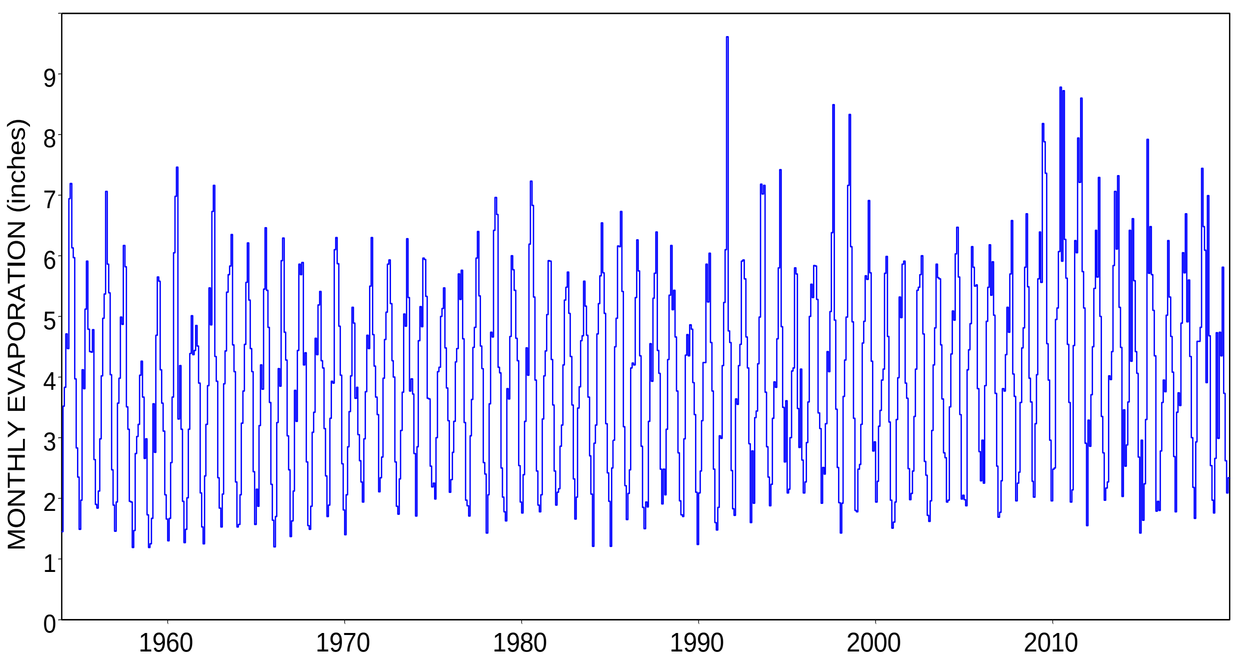

Figure 6.4 1954-2019 Monthly Lake Evaporation from TWDB Database for Quadrangle 613

Monthly precipitation and reservoir evaporation rates (depth/time) are recorded in the TWDB database in units of inches per month. Monthly net evaporation less precipitation rates are recorded on *SIM/SIMD* input *EV* records in feet per month.

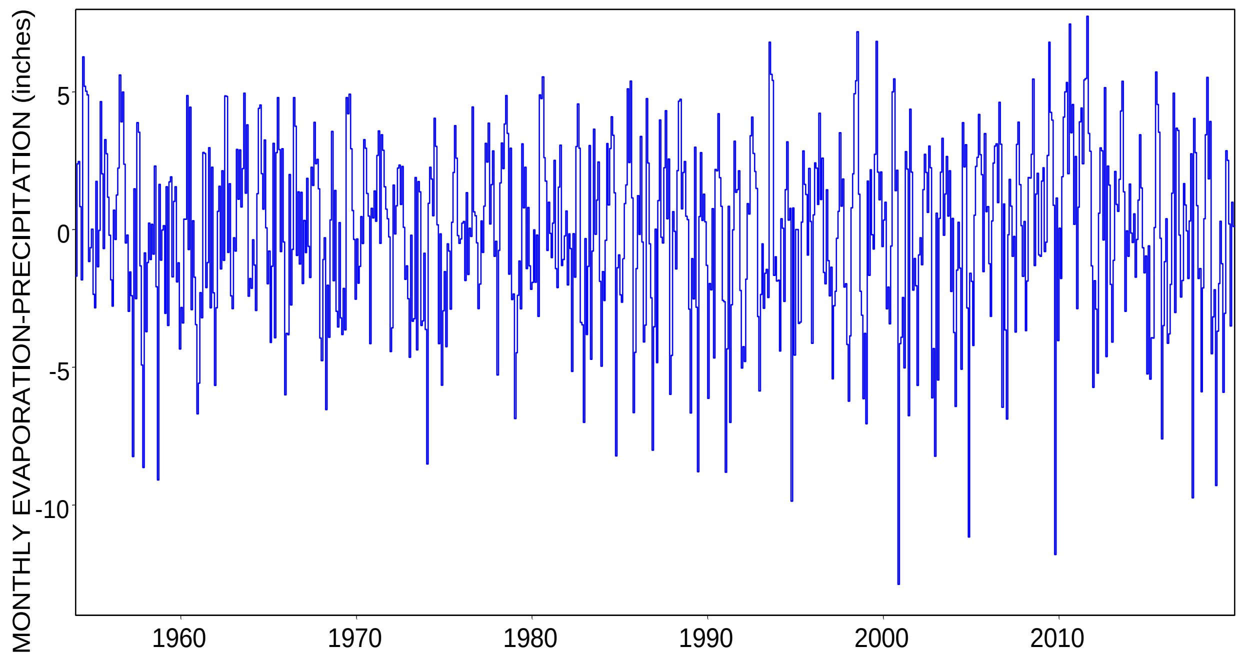

Figure 6.5 1954-2019 Monthly Net Evaporation-Precipitation for Quadrangle 613

<u>WAM Monthly Net Evaporation Less Adjusted Precipitation Depths</u>

Net evaporation-precipitation volumes in units of feet/month are computed within the *SIM* or *SIMD* simulation by multiplying the reservoir water surface area in acres by net evaporation-precipitation rates in feet provided as input on *EV* records stored in an EVA file or hydrology DSS input file. Evaporation from a reservoir and precipitation falling directly on the reservoir water surface are combined as an evaporation minus adjusted precipitation depth. The *EV* record quantities are negative if the adjusted precipitation exceeds evaporation and positive if evaporation exceeds adjusted precipitation. The precipitation is adjusted for the rainfall runoff reflected in the naturalized flow. As discussed in the next sub-section, without the reservoir, a portion of rainfall is lost through infiltration and evapotranspiration and a portion reaches the stream system.

The WRAP program *HYD* is an assortment of routines designed to facilitate developing and updating the net evaporation-precipitation rates and naturalized stream flows included in *SIM/SIMD* simulation input datasets. The *HYD* methodology described in Chapters 5 and 8 of the *Hydrology Manual* [4] was adopted previously to extend the net evaporation-precipitation rates to cover 1997-2012 [10] and later to cover 1997-2015 [12]. The same methodology is applied as reported here to extend the evaporation-precipitation rates through December 2019.

The 12 control points to which reservoir surface net evaporation-precipitation rates are assigned are listed in Table 6.2 and shown in Figure 6.2. The *EV* record control points correspond to the locations of large reservoirs. Beginning with the original WAM [9] and continuing with this extension, evaporation-precipitation depths at the reservoirs are determined using weighted values from adjacent TWDB quadrangles. The quadrangle weighting equations are shown in Table 6.2. In the original dataset, precipitation depths at reservoirs were determined using weighted values from nearby National Oceanic and Atmospheric Administration (NOAA) rainfall gages [9]. In subsequent extensions, both precipitation and evaporation depths were computed using the TWDB datasets and the weighting equations listed in Table 6.2.

Table 6.2
EV Record Control Points, Reservoirs, Quadrangles, and Weighting Factors

Control Point	Reservoir	TWDB Quadrangle(s)
3256N	Lake Athens	0.180 (511) + 0.130 (611) + 0.510 (512) + 0.180 (612)
3254N1	Lake Palestine	0.680 (512) + 0.320 (612)
3274N2	Lake Jacksonville	0.250 (512) + 0.350 (612) + 0.190 (513) + 0.210 (613)
4853A	Lake Tyler (West)	0.380 (512) + 0.190 (612) + 0.260 (513) + 0.170 (613)
4537A	Lake Columbia	0.320 (512) + 0.250 (513) + 0.230 (612) + 0.200 (613)
4847A	Lake Striker	0.230 (512) + 0.240 (612) + 0.260 (513) + 0.270 (613)
4864A	Lake Nacogdoches	0.130 (512) + 0.220 (612) + 0.150 (513) + 0.500 (613)
4393A1	Lake Kurth	0.210 (612) + 0.790 (613)
5585A	Lake Naconiche	0.140 (512) + 0.190 (513) + 0.170 (612) + 0.500 (613)
4404A	Pinkston Lake	0.190 (513) + 0.460 (613) + 0.160 (514) + 0.200 (614)
4411A1	Sam Rayburn Reservoir	0.470 (613) + 0.150 (713) + 0.200 (614) + 0.180 (714)
4411N2	B.A. Steinhagen Lake	0.240 (613) + 0.320 (713) + 0.200 (614) + 0.240 (714)

Adjustments for Precipitation Runoff at Reservoir Sites

Naturalized stream flows reflect natural conditions without construction of reservoir projects and thus conceptually include a portion but not all of the rain falling on the reservoir site. Precipitation depths are commonly adjusted in the WAMs for reservoir site runoff that is reflected in the naturalized stream flows. Without a reservoir, the runoff from the land area of the non-existent reservoir contributes to stream flow. However, without the reservoir, only a portion of the precipitation falling at the reservoir site contributes to stream flow. The remainder is lost through infiltration, evapotranspiration, and other hydrologic abstractions. With the reservoir in place, all of the precipitation falling on the water surface is inflow to the reservoir.

Evapotranspiration also occurs at a reservoir site even before the land is inudated by the reservoir. The difference between evaporation or evapotranspiration with versus without a reservoir is normally not included in the WAM data compilation or analysis. This evaporation difference is not considered in the Neches WAM hydrology update.

SIM and *SIMD* have an option activated by parameters EPADJ in *JD* record field 11 and EWA(cp) in *CP* record field 9 which is designed to account for the fact that a portion of the precipitation falling on the reservoir water surface is also reflected in the naturalized stream flows [1, 2]. The adjustment computations are performed during the *SIM/SIMD* simulation based on the watershed area from the DIS file and simulated reservoir water surface areas. However, this *SIM/SIMD* option is not employed in the Neches WAM. Rather, the net evaporation-precipitation rates on the *EV* records are adjusted during compilation of the *SIM* input dataset of *EV* records. This approach was adopted for several of the other WAMs as well the Neches during the initial development of the TCEQ WAM System.

Evaporation from a reservoir and a portion of the precipitation falling directly on the reservoir water surface are combined in the Neches WAM hydrology dataset as a net evaporation minus precipitation depth recorded on *EV* records in units of feet/month. Net evaporation less precipitation volumes are computed within the *SIM* or *SIMD* simulation by multiplying the reservoir water surface area by the appropriate net evaporation-precipitation rates.

The adjustment for precipitation falling on the reservoir surface is determined by multiplying a runoff coefficient by precipitation [10]. The first equation presented below describes the strategy used to compute adjusted net evaporation-precipitation in the original EVA file of 1940-1996 monthly quantities [9]. The second equation is an alternate form of the first equation used to compute adjusted net evaporation-precipitation for the 1997-2019 extension. The multiplier factor in the second equation is equivalent to one minus the runoff coefficient in the first equation. The multipliers used for the extension are tabulated in Table 6.3.

Adjusted Net Evaporation-Precipitation = Evaporation – Precipitation + (Precipitation × Runoff Coefficient)

Adjusted Net Evaporation-Precipitation = Evaporation – (Precipitation × Multiplier Factor)

Table 6.3
Precipitation Multiplier Factors for the 1997-2019 Extension

CP ID	January	Feb	March	April	May	June	July	August	Sept	October	Nov	Dec
3256N	0.5855	0.6580	0.6509	0.6234	0.7285	0.7173	0.6358	0.8411	0.9341	0.9704	0.7727	0.7195
3254N1	0.6590	0.6759	0.6634	0.6773	0.7246	0.7126	0.7497	0.8912	0.9443	0.9131	0.7971	0.7360
3274N2	0.7114	0.6534	0.6499	0.6862	0.7118	0.8194	0.8089	0.8834	0.9255	0.8491	0.8307	0.6881
4853A	0.5919	0.6300	0.5933	0.5866	0.6953	0.6775	0.8045	0.8720	0.9032	0.8845	0.8015	0.6833
4537A	0.2874	0.2167	0.2909	0.3254	0.4305	0.5448	0.5853	0.9958	0.8144	0.7981	0.6270	0.5662
4847A	0.6060	0.5669	0.6020	0.6275	0.7033	0.7902	0.8007	0.9274	0.8227	0.8264	0.7198	0.6475
4864A	0.5730	0.5025	0.5060	0.6158	0.6043	0.6907	0.9524	0.9001	0.9951	0.8068	0.7892	0.7679
4393A1	0.5877	0.4709	0.5473	0.5884	0.6515	0.7476	0.8528	0.8707	0.9032	0.8234	0.8075	0.7990
5585A	0.1927	0.1954	0.1972	0.2311	0.4325	0.6254	0.7185	0.9330	0.8479	0.8141	0.6674	0.5626
4404A	0.5551	0.5867	0.5715	0.5800	0.6398	0.6892	0.6761	0.8533	0.8616	0.5973	0.7404	0.7322
4411A1	0.6546	0.5921	0.5722	0.6158	0.7158	0.8296	0.8953	0.8234	0.8296	0.7695	0.8859	0.7527
4411N2	0.6407	0.5372	0.5866	0.6295	0.7946	0.8598	0.7407	0.7532	0.8664	0.7238	0.8202	0.7442

The basic premise is that the naturalized flows reflect conditions without the reservoir, which means the naturalized flows should contain some but not all of the rainfall actually falling on the reservoir water surface. The precipitation multiplier factors (F_P) in Table 6.3 represent the fraction of the monthly precipitation that would have been lost through infiltration and other hydrologic abstractions without the reservoir. The remaining fraction ($1.0 - F_P$) of the precipitation would contribute to precipitation even if the reservoir did not exist.

The original factors developed for the original 1940-1996 dataset are not documented in detail in the original 2001 WAM report [9]. The multiplier factors shown in Table 6.3 are derived algebraically using known values of adjusted 1940-1996 net evaporation-precipitation from the original EVA file and computed values of precipitation and evaporation from the TWDB datasets and quadrangle weighting equations. The monthly multipliers listed in Table 6.3 are averages of the unique multipliers derived each year of the period-of-analysis [10].

Extending the *EV* Records of Net Evaporation-Precipitation Depths

A DSS file and/or EVA file with 1940-2019 net evaporation-precipitation rates is created by executing *HYD* with the input HIN file replicated as Table 6.4. The *HYD* input HIN file contains the information tabulated in Tables 6.2 and 6.3. The input parameters are explained in detail in the *Hydrology Manual* [4]. The HIN file of Table 6.4 is accompanied by the other files with evaporation, precipitation, and net evaporation-precipitation data listed below. *HYD* also includes an option to combine the Evaporation.EEE and Precipitation.PPP files into a single DSS file that replaces the EEE and PPP files in the list below.

HIN file controlling the 1997-2019 evaporation-precipitation extension
EVA file from Neches WAM with 1940-1996 evaporation-precipitation rates
Evaporation.EEE file with TWDB statewide 1954-2019 evaporation data
Precipitation.PPP file with TWDB statewide 1940-2019 precipitation data

The datasets can be manipulated in various ways to obtain identically the same extended *EV* records of monthly net evaporation less adjusted precipitation depths. The *EV* records were extended in two alternative ways, yielding identically the same results.

1. The approach described in the preceding paragraph is controlled by a HIN file with filename NechesEV.HIN that is reproduced as Table 6.4. The twelve sets of *EV* records of 1940-1996 sequences of evaporation-precipitation depths are read by *HYD* from the original WAM EVA file. The 1997-2019 extension is based on 1997-2019 evaporation and precipitation data from the TWDB database read by *HYD* from the DSS file NechesEV.DSS previously created with *HYD* or alternatively from the text files Evaporation.EEE and Precipitation.PPP.

2. An alternative approach consists of modifying the HIN file to compute 1997-2019 (or 1954-2019) *EV* records with *HYD* which are combined within *HEC-DSSVue* with the original 1940-1996 EV records read by *HEC-DSSVue* from a DSS file.

For purposes of comparative analyses, a dataset of 1954-2019 net evaporation less adjusted precipitation depths was created using *HYD* with a modified version of the HIN file of Table 6.4 without using the original EVA file *EV* records as noted in the second option listed above. The factors from Tables 6.2 and 6.3 recorded on the *QA* and *EX* records of Table 6.4 were applied to the TWDB evaporation and precipitation data for the entire 1954-2019 period. The resulting dataset of twelve 1954-2019 sequences of monthly evaporation-precipitation depths is included in the file with filename NechesEvapPrecip.DSS discussed in the last section of this chapter.

Creation of the program *HYD* routines, EEE and PPP files, and *HYD* input HIN input file required significant time and effort. However, updates of the WAM net evaporation-precipitation simulation input data using the same updated HIN file are readily performed after updating the Evaporation.EEE and Precipitation.PPP files each year after the TWDB completes the annual update of the quadrangle precipitation and evaporation databases available for download from the TWDB website.

Table 6.4
HYD Input File NechesEV.HIN for Extending *EV* Records

```
**       1         2         3         4         5         6         7         8         9
**34567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456
JC  1940  57   1   0   1                            6
CP 3256N
CP3254N1
CP3274N2
CP 4853A
CP 4537A
CP 4847A
CP 4864A
CP4393A1
CP 5585A
CP 4404A
CP4411A1
CP4411N2
EE 3256N            1997    2019   1   7.0833333
EX0.5855  0.6580  0.6509  0.6234  0.7285  0.7173  0.6358  0.8411  0.9341  0.9704  0.7727  0.7195
QD     4     511     611     512     612
QA     3   0.180   0.130   0.510   0.180
EE3254N1            1997    2019   1   7.0833333
EX0.6590  0.6759  0.6634  0.6773  0.7246  0.7126  0.7497  0.8912  0.9443  0.9131  0.7971  0.7360
QD     2     512     612
QA     3   0.680   0.320
EE3274N2            1997    2019   1   7.0833333
EX0.7114  0.6534  0.6499  0.6862  0.7118  0.8194  0.8089  0.8834  0.9255  0.8491  0.8307  0.6881
QD     4     512     612     513     613
QA     3   0.250   0.350   0.190   0.210
EE 4853A            1997    2019   1   7.0833333
EX0.5919  0.6300  0.5933  0.5866  0.6953  0.6775  0.8045  0.8720  0.9032  0.8845  0.8015  0.6833
QD     4     512     612     513     613
QA     3   0.380   0.190   0.260   0.170
EE 4537A            1997    2019   1   7.0833333
EX0.2874  0.2167  0.2909  0.3254  0.4305  0.5448  0.5853  0.9958  0.8144  0.7981  0.6270  0.5662
QD     4     512     513     612     613
QA     3   0.320   0.250   0.230   0.200
EE 4847A            1997    2019   1   7.0833333
EX0.6060  0.5669  0.6020  0.6275  0.7033  0.7902  0.8007  0.9274  0.8227  0.8264  0.7198  0.6475
QD     4     512     612     513     613
QA     3   0.230   0.240   0.260   0.270
EE 4864A            1997    2019   1   7.0833333
EX0.5730  0.5025  0.5060  0.6158  0.6043  0.6907  0.9524  0.9001  0.9951  0.8068  0.7892  0.7679
QD     4     512     612     513     613
QA     3   0.130   0.220   0.150   0.500
EE4393A1            1997    2019   1   7.0833333
EX0.5877  0.4709  0.5473  0.5884  0.6515  0.7476  0.8528  0.8707  0.9032  0.8234  0.8075  0.7990
QD     2     612     613
QA     3   0.210   0.790
EE 5585A            1997    2019   1   7.0833333
EX0.1927  0.1954  0.1972  0.2311  0.4325  0.6254  0.7185  0.9330  0.8479  0.8141  0.6674  0.5626
QD     4     512     513     612     613
QA     3   0.140   0.190   0.170   0.500
EE 4404A            1997    2019   1   7.0833333
EX0.5551  0.5867  0.5715  0.5800  0.6398  0.6892  0.6761  0.8533  0.8616  0.5973  0.7404  0.7322
QD     4     513     613     514     614
QA     3   0.190   0.460   0.160   0.200
EE4411A1            1997    2019   1   7.0833333
EX0.6546  0.5921  0.5722  0.6158  0.7158  0.8296  0.8953  0.8234  0.8296  0.7695  0.8859  0.7527
QD     4     613     713     614     714
QA     3   0.470   0.150   0.200   0.180
EE4411N2            1997    2019   1   7.0833333
EX0.6407  0.5372  0.5866  0.6295  0.7946  0.8598  0.7407  0.7532  0.8664  0.7238  0.8202  0.7442
QD     4     613     713     614     714
QA     3   0.240   0.320   0.200   0.240
ED
```

Extended *EV* Record 1940-2019 Monthly Net Evaporation-Precipitation Depths

The *SIM/SIMD* hydrology DSS input file with filename NechesHYD.DSS is discussed throughout this report and is illustrated by Table 4.14 of Chapter 4. The twelve *EV* record sequences incorporated in the hydrology DSS input file consists of the 1940-2019 monthly net evaporation less adjusted precipitation depths developed as described in this chapter. The evaporation-precipitation depths are read by *SIM* or *SIMD* from either an EVA text file or the hydrology DSS file.

The WRAP program *HYD* includes options for compiling, computationally manipulating, and recording monthly evaporation rates, precipitation rates, and/or net evaporation less adjusted or unadjusted precipitations rates either as DSS records in a DSS file or records in alternative optional organizational formats in a text file (EVA file). *HYD* also includes options for creating summary tables of basic statistics or linear regression trend analyses metrics. Time series tabulations and plots of the DSS file data are prepared and viewed with *HEC-DSSVue*.

Means of the *EV* record 1940-2019 monthly net evaporation less adjusted precipitation depths in feet for each of the 12 months of the year are tabulated in Table 6.5. The table also includes the means of the annual summations of the monthly depths. The *HYD* input HIN file employed in reading the *EV* records from a DSS file and creating Table 6.5 is reproduced as Table 6.6. The quantities in Table 6.5 are converted to inches in Table 6.7 for convenient comparison with the 1954-2019 means of evaporation-precipitation without the precipitation adjustments and the evaporation and precipitation means tabulated in Table 6.1.

Table 6.5
Means of 1940-2019 Monthly and Annual *EV* Record Evaporation Precipitation Depths in feet

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
3256N	0.027	0.022	0.123	0.153	0.101	0.285	0.476	0.425	0.227	0.056	0.023	-0.020	1.898
3254N1	-0.010	0.006	0.110	0.129	0.098	0.262	0.419	0.394	0.195	0.055	-0.011	-0.049	1.599
3274N2	-0.051	-0.005	0.081	0.110	0.094	0.197	0.356	0.324	0.155	0.055	-0.053	-0.054	1.209
4853A	-0.022	-0.003	0.099	0.130	0.099	0.242	0.357	0.360	0.177	0.054	-0.036	-0.065	1.391
4537A	0.067	0.126	0.207	0.225	0.223	0.296	0.385	0.315	0.198	0.081	0.032	-0.005	2.151
4847A	-0.026	0.015	0.092	0.115	0.097	0.195	0.357	0.316	0.182	0.063	-0.012	-0.049	1.344
4864A	-0.026	0.026	0.118	0.114	0.140	0.223	0.298	0.298	0.124	0.065	-0.047	-0.092	1.243
4393A1	-0.041	0.027	0.099	0.120	0.122	0.197	0.285	0.271	0.122	0.046	-0.070	-0.116	1.060
5585A	0.092	0.126	0.223	0.237	0.214	0.254	0.331	0.290	0.174	0.072	0.002	-0.008	2.007
4404A	-0.058	-0.031	0.067	0.099	0.097	0.190	0.286	0.243	0.119	0.059	-0.066	-0.119	0.886
4411A1	-0.086	-0.031	0.078	0.092	0.075	0.117	0.195	0.215	0.102	0.040	-0.113	-0.125	0.559
4411N2	-0.084	-0.019	0.071	0.088	0.045	0.097	0.221	0.217	0.079	0.051	-0.105	-0.136	0.524

Table 6.6
HYD Input HIN File Used to Create Table 6.5

```
HS  1940    2019   4   0          EV       0       3
SI    12   3256N  3254N1  3274N2   4853A   4537A   4847A   4864A  4393A1   5585A   4404A  4411A1  4411N2
ED
```

Table 6.7
Means of 1940-2019 Monthly and Annual Evaporation Precipitation Depths in inches

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
3256N	0.324	0.264	1.476	1.836	1.212	3.420	5.712	5.100	2.724	0.672	0.276	-0.240	22.78
3254N1	-0.120	0.072	1.320	1.548	1.176	3.144	5.028	4.728	2.340	0.660	-0.132	-0.588	19.19
3274N2	-0.612	-0.060	0.972	1.320	1.128	2.364	4.272	3.888	1.860	0.660	-0.636	-0.648	14.51
4853A	-0.264	-0.036	1.188	1.560	1.188	2.904	4.284	4.320	2.124	0.648	-0.432	-0.780	16.69
4537A	0.804	1.512	2.484	2.700	2.676	3.552	4.620	3.780	2.376	0.972	0.384	-0.060	25.81
4847A	-0.312	0.180	1.104	1.380	1.164	2.340	4.284	3.792	2.184	0.756	-0.144	-0.588	16.13
4864A	-0.312	0.312	1.416	1.368	1.680	2.676	3.576	3.576	1.488	0.780	-0.564	-1.104	14.92
4393A1	-0.492	0.324	1.188	1.440	1.464	2.364	3.420	3.252	1.464	0.552	-0.840	-1.392	12.72
5585A	1.104	1.512	2.676	2.844	2.568	3.048	3.972	3.480	2.088	0.864	0.024	-0.096	24.08
4404A	-0.696	-0.372	0.804	1.188	1.164	2.280	3.432	2.916	1.428	0.708	-0.792	-1.428	10.63
4411A1	-1.032	-0.372	0.936	1.104	0.900	1.404	2.340	2.580	1.224	0.480	-1.356	-1.500	6.71
4411N2	-1.008	-0.228	0.852	1.056	0.540	1.164	2.652	2.604	0.948	0.612	-1.260	-1.632	6.29

The 1940-2019 monthly evaporation-precipitation rates in feet/month stored on the *EV* records for control points 3254N1 and 4411A1, which represent Lakes Palestine and Sam Rayburn, are plotted in Figures 6.6 and 6.7. Positive values of evaporation depths minus adjusted precipitation depths indicate that the evaporation depth exceeds the adjusted precipitation depth. Negative values mean the adjusted precipitation exceeds the evaporation. The minimum net evaporation-precipitation depth in Figure 6.7 for control point 4411A1 representing Sam Rayburn Reservoir is −1.01 feet in August 2017, which reflects the extreme rainfall occurring during Hurricane Harvey concurrently with little evaporation.

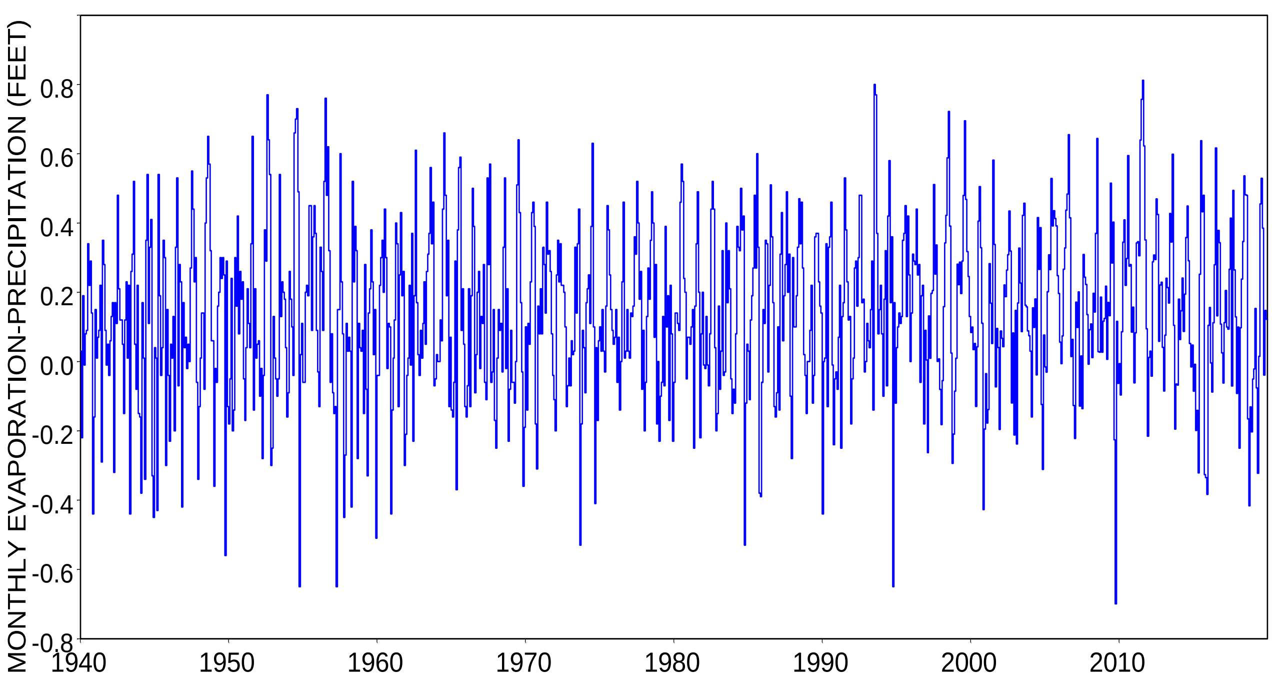

Figure 6.6 Monthly Net Evaporation-Precipitation for Lake Palestine (Control Point 3254N1)

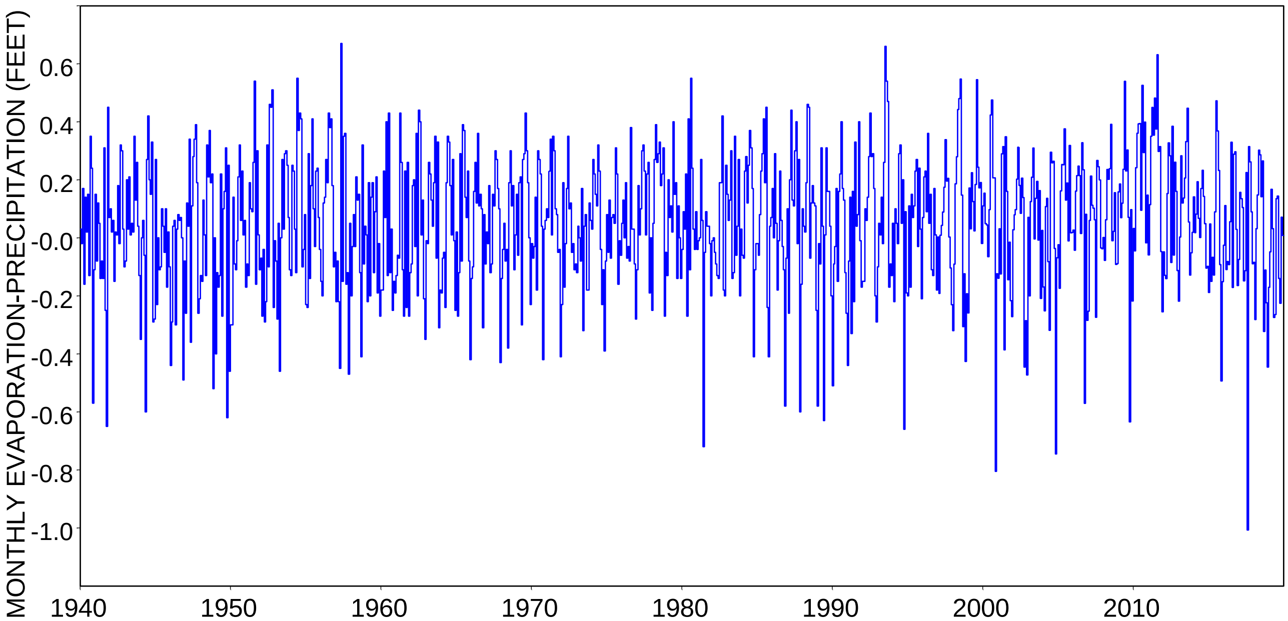

Figure 6.7 Monthly Net Evaporation-Precipitation for Sam Rayburn Reservoir (4411A1)

<u>DSS File with Evaporation, Precipitation, and Net Evaporation-Precipitation Datasets</u>

Datasets discussed in Chapters 1, 3, 4, 5, 6, 9, 10, and 11 are stored in DSS files with the following filenames that accompany this report.

NechesHYD.DSS (*SIM/SIMD* hydrology input file)
NechesDailyFlows.DSS (Chapters 3 and 4)
NechesMonthlyFlows.DSS (Chapters 3 and 5)
NechesEvapPrecip.DSS (Chapter 6)
NechesSimulationResults.DSS (Chapters 9 and 10)

These DSS files are organized as outlined in Tables 4.14, 4.15, 4.16, 5.2, 5.3, 6.8, 9.15, and 9.16. The data storage system (DSS) and *HEC-DSSVue* methods and conventions are described in detail in the *HEC-DSSVue* and WRAP users manuals [2, 8] and discussed throughout the WRAP manuals.

The DSS file prepared in conjunction with the compilation of net reservoir evaporation less adjusted precipitation depths covered in this chapter has the filename NechesEvapPrecip.DSS and contains the following datasets. TWDB quadrangle 613 and WAM control point 4411A1 defined in Figure 6.2 and Table 6.2 are used in Table 6.8 to illustrate the pathnames adopted for the DSS data records in each dataset.

1. Ten 1954-2019 sequences of monthly reservoir evaporation depths in inches for the quadrangles delineated in Figure 6.2.

2. Ten 1940-2019 sequences of monthly precipitation depths in inches for the quadrangles delineated in Figure 6.2.

3. Ten 1954-2019 sequences of net evaporation less precipitation depths in inches for the quadrangles delineated in Figure 6.2 computed with *HYD* by subtracting precipitation depths from evaporation depths.

4. Twelve 1954-2019 sequences of monthly reservoir evaporation less adjusted precipitation depths in inches which are assigned the control point identifiers listed in Table 6.2. The original WAM 1940-1996 *EV* record quantities are not incorporated in this dataset.

5. Twelve sequences of 1940-2019 monthly net evaporation less adjusted precipitation depths in inches compiled as *EV* records adopted for inclusion in the *SIM/SIMD* hydrology input file. This final adopted dataset consists of the original WAM 1940-1996 *EV* record quantities combined with 1997-2019 quantities from dataset 4 listed above.

Table 6.8
DSS Pathnames for the File NechesEvapPrecip.DSS

	Part A	Part B	Part C	Part D / range	Part E	Part F
1	NECHES TWDB	613	EVAPORATION	31Jan1954-31Dec2019	1MON	INCHES
2	NECHES TWDB	613	PRECIPITATION	31Jan1940-31Dec2019	1MON	INCHES
3	NECHES TWDB	613	EVAP-PRECIP	31Jan1954-31Dec2019	1MON	INCHES
4	TWDB-WAM	4411A1	EVAP-ADJUSTED PRECIP	31Jan1954-31Dec2019	1MON	FEET WITHOUT ORIGINAL
5	NECHES	4411A1	EV	31Jan1940-31Dec2019	1MON	FEET FINAL EV RECORDS

The WRAP program *HYD* was employed to read the TWDB evaporation and precipitation data from the files Evaporation.EEE and Precipitation.PPP or alternatively the *HYD*-created file PrecipEvap.DSS and to create the five datasets listed above. The first three datasets are monthly depths in inches. The last two datasets are monthly depths in feet.

The first three datasets are computed directly, without adjustment, from the TWDB monthly evaporation and/or precipitation data in inches for the ten TWDB-delineated quadrangles. The quadrangle identifiers are assigned to pathname part B as illustrated in Table 6.8.

The fourth dataset is computed from the TWDB monthly evaporation and precipitation data incorporating the adjustments reflected in Tables 6.2, 6.3, and 6.4. The fifth dataset consists of the original 1940-1996 monthly *EV* record net evaporation less adjusted precipitation depths combined with 1997-2019 monthly net evaporation less adjusted precipitation depths from the fourth dataset. The 1940-2019 monthly net evaporation-precipitation depths in feet in these last two datasets are for the ten reservoirs listed in the second column of Table 6.2 and are assigned the WAM control point identifiers listed in the first column of Table 6.2. These control point identifiers are assigned to DSS pathname Part B as shown in Table 6.8.

The last (5th) dataset listed in Table 6.8 consists of the original 1940-1996 monthly *EV* record net evaporation less adjusted precipitation depths combined with the corresponding 1997-2019 quantities from the fourth dataset described above. This is the final dataset of *EV* records of 1940-2019 monthly net evaporation less adjusted precipitation depths in feet adopted for the June 2020 Neches WAM and incorporated in the *SIM/SIMD* input file NechesHYD.DSS (Table 4.14).

CHAPTER 7
ENVIRONMENTAL FLOW STANDARDS

The daily version of the Neches WAM is designed to improve capabilities for modeling Senate Bill 3 (SB3) environmental flow standards (EFS) and their interactions with other water rights. Two alternative approaches have been adopted for modeling the SB3 EFS in the monthly Neches WAM. The TCEQ incorporated the SB3 EFS directly into the 2012 version of the monthly Neches WAM without using a daily model. The alternative approach described in this chapter combines the daily and monthly models. The SB3 EFS are incorporated into the daily version of the Neches 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.

Other Instream Flow Requirements

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. The input records previously added to the monthly *SIM* DAT files to simulate SB3 EFS are removed in the conversion to a daily model. New daily *SIMD* features designed specifically for modeling SB3 EFS are employed instead.

The *WR* record and *IF* record water rights contained in the Neches WAM are discussed in Chapter 2. Tables 2.5 and 2.7 are summary listings of the 20 and 23 instream flow *IF* record rights in the full authorization and current use scenario, respectively, DAT files excluding the *IF* record rights that model the SB3 EFS. These instream flow requirements maintain instream flows for the protection of senior rights or other purposes. The additional 55 *IF* records and associated supporting records included in the 2012 full authorization and current use DAT files to model the subsistence, base, and high pulse flow components of the SB3 EFS are removed in the June 2020 version of the DAT files and replaced with the input records discussed in this chapter.

Monthly instream flow targets for the other pre-SB3 EFS instream flow requirements are established using *IF* records in combination with use coefficient *UC* records. Annual instream flow targets are distributed uniformly over the 12 months of the year for most of these other non-SB3 EFS *IF* record rights. One of the *IF* record rights uses target options *TO* record specifications in the computation of instream flow targets. None of the other *IF* records are assigned to the control point locations of the five SB3 EFS.

Environmental Flow Standards Established Pursuant to Senate Bill 3 Process

A process for establishing environmental flow standards was created by Senate Bill 3 enacted by the Texas Legislature in 2007. 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 [15].

https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/eflows

https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/eflows/rulemaking

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 [15]. The priority date used for water availability modeling is November 30, 2009, corresponding to the date that the BBEST Report was received by the TCEQ.

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 [15]. 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 7.1.

Table 7.1
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

Subsistence, Base, and High Pulse Flow Components of EFS

The instream flow standards consist of seasonal subsistence flows, base flows, and high flow pulses. Four seasons are defined as shown in Table 7.2.

Table 7.2
Months Included in Each Season Defined by EFS

Season	Months
Winter	January, February, March
Spring	April, May, June
Summer	July, August, September
Fall	October, November, December

The flow limits in cfs for the subsistence flow standards for the five sites are shown on the left side of Table 7.3. 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 7.3. If the flow at a site is greater than the applicable base flow standard and less than the applicable pulse flow trigger level (Table 7.4), water right holders may divert flow as long as the stream is at or above the base flow criterion.

Table 7.3
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 7.4
High Flow Pulse Standards

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

High pulse flow criteria are outlined in Table 7.4. The high flow pulse standards 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.

The SB3 EFS criteria are presented in Tables 7.3 and 7.4 for all five sites. The numerical criteria for the site of USGS gage 08032000 on the Neches River at Neches are repeated in Table 7.5 in the format found in the Texas Water Code [15]. The SB3 EFS criterion metrics for each of the five individual locations are published in the Texas Water Code in the format of Table 7.5

Table 7.5
SB3 EFS at Control Point NEEV

Season	Subsistence	Base	Pulse
Winter	51 cfs	196 cfs	1 per season Trigger: 833 cfs Volume: 19,104 acre-feet Duration: 10 days1
Spring	21 cfs	96 cfs	2 per season Trigger: 820 cfs Volume: 20,405 acre-feet Duration: 12 days
Summer	12 cfs	46 cfs	1 per season Trigger: 113 cfs Volume: 1,339 acre-feet Duration: 4 days
Fall	13 cfs	80 cfs	2 per season Trigger: 345 cfs Volume: 5,391 acre-feet Duration: 8 days

Water Right Permit Exemptions for High Pulse Flows

Water right permits issued after the effective date of the SB3 EFS with an authorization to divert 10,000 acre-feet or less per year are not required to protect the high flow pulse standards. However, the input records corresponding for the SB3 EFS in the Neches WAM DAT file are not configured to allow these smaller junior water right exemptions from honoring downstream senior instream flow requirements.

Modeling the Senate Bill 3 Environmental Flow Standards

Senate Bill 3 (SB3) environmental flow standards (EFS) are based on a flow regime that includes subsistence, base, and high pulse flows as explained in the WRAP *Reference and Daily Manuals* [1, 5]. Environmental standard *ES*, pulse flow *PF*, and pulse flow supplemental options *PO* 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]. Hydrologic condition *HC* records are employed in the daily Brazos WAM [13] but 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. An example of modeling SB3 EFS is presented in Chapter 8 of the *Daily Manual* [5]. The general daily simulation methodology employing *ES* and *PF* records employed in modeling SB3 EFS in the Neches WAM was also recently applied for the Brazos and Trinity WAMs [13, 14].

Simulation results of daily and monthly instream flow targets for *IF* record rights representing SB3 EFS are presented in Chapter 9 of this report for the authorized use and current use scenario versions of the Neches WAM. The sets of records presented later in this chapter are inserted in both the current and authorized use DAT files used in the simulations of Chapter 9.

<u>*IF* Record Water Rights Representing SB3 EFS</u>

The two alternative sets of *SIMD* DAT file input records reproduced as Tables 7.6 and 7.7 control the computation of daily instream flow targets representing the SB3 EFS at the five control points. The only difference between these datasets is whether or not the high pulse flow component is separated from the subsistence and base flow components for purposes of recording simulation results in the *SIMD* output file. The simulation computations are the same with either alternative.

The alternative sets of *IF*, *ES*, and *PF* records replicated in Tables 7.6 and 7.7 are inserted in the DAT files of both the full authorization and current use versions of the WAM. In the dataset of Table 7.6 and simulations of Chapters 9 and 10, 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/base flow targets. The following water rights are included in Table 7.6: IF-NENE-ES, IF-NENE-PF, IF-NERO-ES, IF-NERO-PF, IF-ANAL-ES, IF-ANAL-PF, IF-NEEV-ES, IF-NEEV-PF, IF-VIKO-ES, and IF-VIKO-PF. Alternatively, the ten *IF* record water rights can be combined into five water rights (IF-NENE, IF-NERO, IF-ANAL, IF-NEEV, and IF-VIKO) as shown in Table 7.7, with the only difference in simulation results being that combined rather that separate water right targets and target shortages are recorded in the *SIMD* simulation results output file [2, 5]. Combined daily targets are summed to monthly for the monthly WAM.

Options controlled by *IF* record field 3 and *PF* record field 15 create tables in the MSS and SMM message files that provide additional supplemental information that facilitates tracking the *ES* and *PF* record computations. These message file options are not activated in the datasets of Tables 7.6 and 7.7.

<u>Multiple Instream Flow Targets or Target Components at the Same Control Point</u>

The table on page 47 of the WRAP *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 quantities are listed in the first column of Table 7.8. The second column of Table 7.8 refers to the *OF* record labels listed on page 47 of the *Users Manual* [2] that are 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 7.8. The DSS pathname part C labels in the third column are adopted in the following discussion for referring to the quantities listed in Table 7.8.

Table 7.6

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

(*ES* and *PF* Record Components as Separate *IF* Record Rights)

```
**       1         2         3         4         5         6         7         8         9        10
**34567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890121234
**     !       !       !       !       !       !       !       !       !       !       !       !       !
**
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
```

Table 7.7

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

(*ES* and *PF* Record Components Combined as a Single *IF* Record Right)

```
**       1         2         3         4         5         6         7         8         9        10
**3456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
IF  NENE     -9.        20091130   2           IF-NENE
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.
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 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.
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 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.
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 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.
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 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.
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
```

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 based on the options listed in Table 7.9. SB3 EFS are modeled as a set of *IF*, *HC*, *ES*, and *PF* records as explained in the *Daily and Users Manuals* [2, 5]. Pulse flow *PF* and subsistence/base flow *ES* records can be combined as a single *IF* record instream flow water right at a control point (Table 7.7). With *PF* and *ES* records for the same *IF* record right, the instream flow targets are combined as specified in *PF* record field 14. The options for combining consecutive *PF* record targets for a single *IF* record right are also listed in Table 7.9. Alternatively, a SB3 EFS can be modeled as two separate *IF* record rights at the same control point with the *ES* records included with one *IF* record and the *PF* records included with a different *IF* record (Table 7.6).

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.

Table 7.8
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

Table 7.9
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

The computation of a SB3 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 is adopted. The two targets may be computed as a single *IF* record water right target as shown in Table 7.7. A daily time single time series of targets consisting of the larger of the two targets in each day is recorded in the *SIMD* simulation results output files. The primary reason for separating subsistence and base flow (*ES* record) targets and pulse flow (*PF* record) targets into two *IF* record water rights as shown in Table 7.6 is to generate separate targets in the output for information purposes. The actual simulation computations are not otherwise affected.

Both alternative sets of records in Tables 7.6 and 7.7 are applied in the simulation studies of Chapters 9 and 10. Monthly IFT-WR output for water rights IF-NENE, IF-NERO, IF-ANAL, IF-NEEV, and IF-VIKO (Table 7.7) from the daily WAM are adopted for the monthly WAM following the procedure outlined in the next section of this chapter. Pulse flow targets are plotted and otherwise viewed separately from TIF-WR output (Table 7.6).

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 dataset for a monthly WAM is outlined on the last section of Chapter 6 of the *Daily Manual* [5]. The methodology is illustrated in an example in Chapter 8 of the *Daily Manual* [5]. The methodology is implemented for the current use and full authorization versions of the Neches WAM as described in Chapters 9 and 10 of this report.

Daily instream flow targets in acre-feet/day for SB3 EFS computed in the 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 7.10 and 7.12. The *TS* records in the DSS file are referenced by *TS* records in the DAT file which are replicated in Tables 7.11 and 7.13.

Table 7.10
Pathnames for *TS* Records for the SB3 EFS for the Authorized Use Scenario
in the *SIM* and *SIMD* Shared Hydrology Input DSS File of the Neches WAM

Part A	Part B	Part C	Part D	Part E
NECHES	ANENE	TS	01Jan1940-31Dec2019	1MON
NECHES	ANERO	TS	01Jan1940-31Dec2019	1MON
NECHES	AANAL	TS	01Jan1940-31Dec2019	1MON
NECHES	ANEEV	TS	01Jan1940-31Dec2019	1MON
NECHES	AVIKO	TS	01Jan1940-31Dec2019	1MON

Table 7.11
Instream Flow Rights that Model the SB3 EFS in the DAT File of the
Monthly Authorized Use Scenario Version of the Neches WAM

```
IF NENE                     20091130   2             IF-NENE
TS       DSS  ANENE
IF NERO                     20091130   2             IF-NERO
TS       DSS  ANERO
IF ANAL                     20091130   2             IF-ANAL
TS       DSS  AANAL
IF NEEV                     20091130   2             IF-NEEV
TS       DSS  ANEEV
IF VIKO                     20091130   2             IF-VIKO
TS       DSS  AVIKO
```

Daily SB3 EFS targets are computed in the *SIMD* simulation based on regulated flows. Regulated flows differ significantly between the authorized and current use scenario versions of the WAM. Consequently, the SB3 EFS vary between the current and authorized versions of the WAM. The *TS* records for both versions are stored in the same single hydrology DSS input file. A single time series input file is used for all simulations including daily and monthly and current use and full authorization. The labels in DSS record pathname part B and *TS* record field 3 are used to differentiate between authorized use (A) and current use (C) instream flow targets.

Table 7.12
Pathnames for *TS* Records for the SB3 EFS for the Current Use Scenario
in the *SIM* and *SIMD* Hydrology Input DSS File of the Neches WAM

Part A	Part B	Part C	Part D	Part E
NECHES	CNENE	TS	01Jan1940-31Dec2019	1MON
NECHES	CNERO	TS	01Jan1940-31Dec2019	1MON
NECHES	CANAL	TS	01Jan1940-31Dec2019	1MON
NECHES	CNEEV	TS	01Jan1940-31Dec2019	1MON
NECHES	CVIKO	TS	01Jan1940-31Dec2019	1MON

Table 7.13
Instream Flow Rights that Model the SB3 EFS in the DAT Files of the
Monthly Current Use Scenario Version of the Neches WAM

```
IF NENE                     20091130   2              IF-NENE
TS      DSS   CNENE
IF NERO                     20091130   2              IF-NERO
TS      DSS   CNERO
IF ANAL                     20091130   2              IF-ANAL
TS      DSS   CANAL
IF NEEV                     20091130   2              IF-NEEV
TS      DSS   CNEEV
IF VIKO                     20091130   2              IF-VIKO
TS      DSS   CVIKO
```

A daily *SIMD* simulation is performed with the set of *IF*, *ES*, and *PF* records replicated in Table 7.7 inserted in the DAT file to control computation of IFT and TIF (Table 7.8) daily instream flow targets for the SB3 EFS at the five 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 and the pathnames are revised using *HEC-DSSVue*.

The DSS file pathnames for the target series *TS* records are listed in Tables 7.10 and 7.12. The *TS* records in the monthly *SIM* DAT file replicated in Table 7.11 and 7.13 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. Simulation results for daily and monthly simulations are presented in Chapters 9 and 10 for the full authorization and current use WAMs. The simulation results presented in Chapters 9 and 10 include daily and aggregated monthly instream flow targets for the SB3 EFS.

CHAPTER 8
DAILY AND MODIFIED MONTHLY VERSIONS OF THE NECHES WAM

The June 2020 Neches WAM incorporates hydrology data described in Chapters 4, 5, and 6, Senate Bill 3 (SB3) environmental flow standards (EFS) described in Chapter 8, and other daily modeling features added as explained in the present Chapter 7. The monthly version of the WAM includes SB3 EFS instream flow targets developed in the simulations of Chapters 9 and 10.

SIM and *SIMD* Input Files

The June 2020 new daily and modified monthly full authorization scenario and current use scenario versions of the Neches WAM consist of the following files. The integers 3 and 8 are included in the filenames to refer to the authorized use scenario (also called full authorization or run 3) and the current use scenario (run 8). The letters D and M in the filenames denote daily or monthly. The four versions of the *SIM/SIMD* input DAT files are labeled 3D, 8D, 3M, and 8M.

Authorized Use	Current Use
Neches3D.DAT	Neches8D.DAT
Neches3M.DAT	Neches8M.DAT
Neches3.DIS	Neches8.DIS

Shared by Two (DIF) or Four (DSS) Versions

Neches.DIF
NechesHYD.DSS

The daily WAM is used to compute daily instream flow targets for Senate Bill 3 (SB3) environmental flow standards (EFS) modeled with *IF*, *ES*, and *PF* records that are summed to monthly targets within the *SIMD* simulation. The monthly instream flow targets are stored in the shared DSS input file (NechesHYD.DSS) as time series *TS* records which are used by *IF* record instream flow rights in the monthly *SIM* simulation model. This strategy for combining daily and monthly modeling capabilities is demonstrated in the simulations presented in Chapters 9 and 10.

The June 2020 daily authorized and current use DAT files expand the monthly DAT files last updated by the TCEQ in 2012 by replacing the original records modeling SB3 EFS with sets of *IF*, *ES*, and *PF* records implementing recently added WRAP features, adding flood control operations of Sam Rayburn Reservoir, and adding input records controlling disaggregation of monthly naturalized flows to daily and other daily features.

The June 2020 modified monthly authorized use and current use DAT files reflect the following modifications to the 2012 versions of the DAT files. Records added to the DAT files by the TCEQ in 2012 to model SB3 EFS are removed and replaced with target series *TS* records of instream flow targets computed in a daily simulation and stored in the *SIM/SIMD* hydrology (time series) DSS input file referenced by five sets of *IF* and *TS* records in the DAT file (Tables 7.10, 7.11, 7.12, and 7.13).

The authorized and current use scenario versions of the flow distribution DIS file contains the flow distribution *FD* and watershed parameter *WP* records used by *SIM* and *SIMD* to distribute monthly naturalized flows at the 20 primary control points to the over 300 secondary control points. The DIS files are employed the same with the daily versus monthly versions of the WAM. No changes were required to the DIS files in developing the June 2020 expanded/updated WAM.

Daily routing parameters for 19 routing reaches between the 20 primary control points developed as explained in this chapter and the *DC* record described in this chapter are stored in the daily input DIF file. A daily *SIMD* simulation can be performed optionally with or without routing. The DIF file is not relevant in a monthly simulation and is optional in a daily simulation.

A single hydrology DSS file with filename NechesHYD.DSS is used with all versions of the June 2020 WAM (authorized or current use combined with daily or monthly). Relevant data are read from this shared file in a particular simulation. The *hydrology* DSS file can also be called the *time series* DSS file since other time series such as *TS* record instream flow targets can also be included with the hydrology time series. The NechesHYD.DSS file includes January 1940 through December 2019 sequences of *IN* record monthly naturalized flows for 20 control points, *EV* record monthly evaporation-precipitation depths for 12 control points, *DF* record daily flows for 17 control points, and *TS* record SB3 EFS targets for five control points.

Daily *SIMD* Simulation Input Dataset

With the exception of the new monthly *IF/TS* record targets for the SB3 EFS, all of the *SIM* input files and input records in the monthly WAM are also included in the daily dataset read by *SIMD*. Additional "daily-only" input records are added in the conversion of the monthly WAM to daily. The daily-only *SIMD* input records listed in Table 8.1 are explained in Chapter 4 of the *Users Manual* [2]. The only record required to switch a monthly WAM to daily is the *JT* record. The other records are all optional, with defaults activated for blank fields or missing records.

Some but not all of the records listed in Table 8.1 are employed in the daily Neches WAM. The following daily records are used: *JT* and *JU* (simulation options), *W2* and *C2* (output control), *PF* (pulse flow SB3 EFS), *FR*, *FF*, and *FV/FQ* (flood control), *RT* (routing), and *DF* (daily flows).

Table 8.1
SIMD Input Records for Daily Simulations [2]

	DAT File
JT, *JU*	Simulation job control options.
W2, *C2*, *C3*, *G2*, *R2*	Simulation results output control.
DW, *DO*, *PF*, *PO*	Daily water right data.
FR, *FF*, *FV*, *FQ*	Reservoir operations for flood control.
	DIF File
DW/SC, *DO/SC*	Optional placement of *DW* and *DO* records.
RT, *DC*	Routing and disaggregation parameters.
	Hydrology DSS File
DF	Daily flows.

The daily Neches WAM *SIMD* input dataset is composed of DAT, DIS, DIF, and DSS files. The authorized and current use versions of the old flow distribution DIS file (*FD* and *WP* records) are used without modification in both the expanded monthly and daily versions of the WAM. The DSS hydrology input file is shared by both the expanded monthly and daily versions of the WAM. The DIF file is relevant only with the daily *SIMD*. *SIMD* will execute without the DIF file. With no DIF file, the routing and flow distribution options controlled by the DIF file records are not activated. A warning message in the MSS file indicates that no DIF file was found.

A monthly simulation can be performed with *SIM* with a DAT file containing input records for a daily simulation, such as the file Neches3D.DAT. *SIM* skips over daily input records in the DAT file, does not read the DIF file, and ignores the *DF* records in the DSS time series input file. However, *SIMD* has no option for skipping over the daily-only records in the DAT file, other than manually commenting (**) them out. *SIMD* can perform a monthly simulation if and only if no daily-only records are included in the input dataset.

<u>DAT File Input Records with Simulation Control Option Parameters</u>

The records replicated as Table 8.2 are found at the beginning of the 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*. *SIMD* input records applicable only in a daily *SIMD* simulation are explained in Chapter 4 of the *Users Manual*. Although *OF* record field 4 entry DSS(3) has options that are relevant only to a daily simulation, the file options *OF* record is described in Chapter 3 of the *Users Manual* [2].

Table 8.2
SIMD DAT File Input Records for Controlling Simulation Options

```
**      1       2       3       4       5       6       7       8
**345678901234567890123456789012345678901234567890123456789012345678901234
**-----!-------!-------!-------!-------!-------!-------!-------!-------!-------!
JD    80    1940       1       0       0               7                    13
JO     6
JO     6                                       1                             3
JT     0   0   0   0   0   0   0   0   0   0   0   1
JU     1   0   0   0   0
OF     1   0   2                                         Neches
DF      KIBR    NEPA    NENE    NEAL    NEDI    NERO    MUTY    MUJA   EFACU    ANAL
DF      ANLU    ATCH    AYSA    ANSR    NETB    NEEV    VIKO    PISL    NEBA    NESL
```

The following options activated on the records shown in Table 8.2 contribute to the conversion of the monthly WAM to daily.

- ADJINC option 7 selected in *JD* record field 8 (column 56) is the recommended standard negative incremental flow adjustment option for daily simulations with forecasting as explained in Chapter 3 of the *Daily Manual* [5]. *JO* record *ADJINC* options 4 or 6 are the recommended standards for monthly simulations or daily simulations without forecasting.

- TL of 13 is entered in *JD* record field 11 (column 80) to increase the number of entries allowed in the *SV/SA* record storage-area table for Sam Rayburn Reservoir to 13 from the default of 12. The *SV* and *SA* records are extended to encompass the flood control pool.
- INEV option 6 in *JO* record field 2 (column 8) instructs *SIM* and *SIMD* to read *IN* and *EV* records from a DSS input file.
- DSS(3) option 2 is selected in *OF* record field 4 (column 16) to instruct *SIMD* to record daily and monthly simulation results in a DSS output file. A blank *OF* record field 4 (column 20, DSS(4)=0) means that a default subset of variables will be included in the simulation results.
- The DSS input filename root Neches is entered in *OF* record field 12 for DSSROOT. 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 *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.
- Entries for OUTCP2 and OUTWR2 in *JT* record fields 2 and 3 in combination with *C2*, *R2*, and *W2* records control selection of control points and water rights to include in the daily simulation results output in the same manner that OUTCP and OUTWR on the *JD* record in combination with *CO*, *RO*, and *WO* records control output of monthly simulation results.
- Fields 8, 9, 10, 11, and 12 are blank (or zero) on the *JT* record in Table 8.2. These fields allow optional output tables to be created in the annual flood frequency AFF and message SMM files. An entry of 1 for SUBFILE in field 13 (column 52) activates the daily output SUB file.
- The *JU* record controls disaggregation and forecasting options. The blank (or zero) *JU* record field 3 (column 12) activates the default DFFILE option 1, meaning daily flow *DF* records are read from the DSS file for the 20 control points listed on the DAT file *DF* records in Table 8.2.
- 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 (Table 3.4) with REPEAT and DFMETHOD options 2 and 4 activate disaggregation option 4 based on *DF* record pattern hydrographs for all control points on the Neches River and its tributaries that have actual naturalized flows.
- Options for placing routed flow changes at the beginning or within the priority sequenced simulation computations are controlled by entries for WRMETH and WRFCST in *JU* record fields 4 and 5 (columns 16 and 20). Blank fields mean defaults are adopted.
- Forecasting is activated by FCST option 2 in *JU* record field 6 (column 24). The forecast period FPRD set in *JU* record field 7 can be easily set or changed. If FCST=2 is entered in *JU* record field 6 and field 7 is blank, the forecast period FPRD is automatically computed within *SIMD*.

<u>Other Groups of Input Records</u>

Flood control operations of Sam Rayburn Reservoirs are modeled as described later in this chapter by adding flood control reservoir *FR* and flood flow *FF* records and pairs of storage volume versus outflow (*FV/FQ*) records to the DAT file. The *SV/SA* record table for Sam Rayburn Reservoir in the DAT file is extended to include the flood control pool. TL on the *JD* record increases the limit for the number of volumes and surface areas allowed on the SV and SA records.

The creation of the full authorization and current use scenario versions of the daily WAM DAT file began with the monthly full authorization and current use DAT files last updated by the TCEQ in 2012. The SB3 EFS had been added to the monthly DAT files by the TCEQ in 2012 using the original WRAP capabilities available prior to the expanded May 2019 WRAP. The SB3 EFS at five USGS gage sites were originally modeled in the monthly *SIM* input DAT files as *WR* record and *IF* record rights defined with many *UC*, *WS*, *TO*, *PX*, *FS*, *CI*, and *CP* records as previously noted in Chapter 2. These records were removed in conjunction with development of the June 2020 WAM prior to adding the *IF*, *ES*, and *PF* records described in Chapter 7 of this report to model the SB3 EFS.

Daily flow *DF* records developed as explained in Chapter 4 are stored in the DSS input file along with the *IN*, *EV*, and *TS* records for use within *SIMD* for disaggregating monthly naturalized stream flows to daily. Lag and attenuation routing coefficients developed as described later in this chapter are recorded on *RT* records stored in a DIF file.

Monthly-to-Daily Disaggregation

A daily WAM is based on performing the *SIMD* simulation computations with a daily time step. Naturalized flow volumes in acre-feet/month are distributed to daily volumes in acre-feet/day in proportion to the daily flows of flow pattern hydrographs input on *DF* records. Daily stream flow is extremely variable. All other monthly time series input data including *EV* record net evaporation-precipitation depths and computed diversion targets in the daily Neches WAM are uniformly disaggregated from monthly to daily.

Monthly naturalized flows are disaggregated to daily at most control points in the WAM using the default DFMETHOD(cp) option 4 based on daily flow pattern hydrographs input on *DF* records stored in the DSS input file. Monthly volumes are distributed to daily volumes in proportion to daily flows while maintaining monthly volumes. The procedure described in the following 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 1940-2019 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 on page 28 of 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.

Monthly water supply diversion targets are uniformly disaggregated to daily. Daily diversion targets in acre-feet/day are computed by dividing monthly diversion target volumes by the number of days in the month. *SIMD* includes options for non-uniformly disaggregating monthly diversion targets to daily, activated by input parameters on *JU*, *DW*, and *DO* records, but these options are not employed in the daily Neches WAM. Releases from flood control pools and targets for SB3 EFS are computed on a daily basis.

SIMD directly computes daily *IF* record instream flow targets for SB3 EFS based on *ES* and *PF* record specifications for the June 2020 daily Neches WAM, rather than disaggregating computed monthly targets to daily. However, for other *IF* record instream flow requirements, computed monthly target volumes are uniformly sub-divided to daily volumes. Non-uniform *IF* target distribution options provided by *SIMD JU*, *DW*, and *DO* records are not employed in the Neches WAM.

Routing and Forecasting

Streamflow depletions for diversions and refilling reservoir storage, reservoir releases, and return flows result in stream flow changes that propagate through river reaches to downstream control points. The monthly *SIM* simulation has no routing; flow changes are assumed to propagate to the river system outlet within the current month. The daily *SIMD* routing computations consist of lag and attenuation adjustments to the flow changes that occur as each of the water rights is considered in the priority-based simulation computations. Without routing in a daily *SIMD* simulation, streamflow changes propagate to the outlet in the same day they originate, with no lag. Forecasting is designed to mitigate the effects of routing on the water right priority system and on flood control operations controlled by maximum allowable flow limits at downstream gages.

Forecasting of Water Availability and Flood Control Flow Capacity

Forecasting is relevant only if routing is employed. Forecasting should not be activated unless routing is employed. Forecasting and accompanying reverse routing, as explained in Chapter 3 of the *Daily Manual* [5], are designed specifically to deal with the effects of *WR* and *FR* record water right actions in a particular time step on downstream stream flows in future time steps, as reflected in routing computations. Due to routing (lag and attenuation), stream flow depletions, return flows, and reservoir releases in the current time step can affect both (1) stream flow availability for downstream senior water rights in future time periods and (2) flood flow capabilities for releases from flood control pools. Forecasting serves the two purposes of: (1) protecting water rights from the lag effects associated with stream flow depletions of junior water rights located upstream and (2) facilitating reservoir flood control operations by preventing releases from flood control pools that contribute to flooding in future time steps.

Forecasting is switched on or off with input parameter FCST in *JU* record field 6. The forecast period FPRD is entered in *JU* record field 7, with a blank field 7 activating a *SIMD* routine that automatically computes a forecast period. Forecasting greatly increases computer execution time and can be switched off with a blank *JU* field 6 to reduce execution time.

Routing Flow Changes

Routing of flow changes through downstream control points is incorporated in a *SIMD* simulation by a DIF file with routing parameters on *RT* records. Routing can be switched off simply by deactivating the *RT* records in the DIF file or, with no *DC* or other DIF file records, removing the DIF file. Routing is not required. Without routing, streamflow changes propagate to the outlet in the same day that they originate in a daily *SIMD* simulation, analogously to streamflow changes propagating to the outlet in the same month in a monthly simulation.

The lag and attenuation routing method and calibration of routing parameters are described in Chapters 3 and 4 of the *Daily Manual* [5]. Routing *RT* records are described in Chapter 4 of the *Users Manual* [2]. Lag and attenuation routing is activated as RTYPE(cp) option 1 in *RT* record field 3. Lag (LAG and LAGF) and attenuation (ATT and ATTF) routing parameters in units of days are provided on *RT* records in a DIF file. Separate values for lag and attenuation are provided for normal water right operations (LAG and ATT) and flood control operations (LAGF and ATTF). The parameters are for the river reach below the control point in *RT* record field 2.

The routing computations are performed at the control points specified on the *RT* records but conceptually represent changes occurring gradually along river reaches. Routing parameters are not necessarily required for all control points. The daily Neches WAM with over 300 control points includes routing parameters at 19 control points.

Routing is very approximate with inherent simplifications, uncertainties, inaccuracies, and variabilities. However, in general, this may not be a major concern if simulation results are not overly sensitive to routing. In many typically situations, reasonable simulation results can be obtained without routing and, with routing, results vary only minimally with significant changes to routing parameter values. Various aspects of routing inaccuracies include the following.

Flows fluctuate continuously. Mean daily or monthly flow rates or volumes are adopted in simulation models to represent instantaneous flows that actually may vary over any non-instantaneous time interval. The timing of the daily flow fluctuations are affected by the methods adopted in Chapter 4 for filling in gaps of missing daily flows a site based on flows at another site. The timing of lags is not necessarily transferred accurately with the flow quantity transfers.

Calibrating routing parameters and performing routing computations in the *SIMD* simulation for the river reaches between all control points is not feasible. Routing parameters are determined for only selected river reaches defined by stream flow gages. The routing computations are performed for only a sub-reach of each of the selected calibrated reaches.

Observed actual lag and attenuation characteristics of flow changes in actual gaged river reaches exhibit great apparently random variability that is difficult to describe or explain [5, 21]. Calibrated values for lag and attenuation parameters for the *SIMD* routing algorithm also exhibit great unexplained variability and associated uncertainty.

The routing algorithm incorporated in the *SIMD* simulation is a very simplistic model of a very complex phenomena. However, adding greater complexity to the model would likely not improve the accuracy of the model.

The routing algorithm simulates lag and attenuation of flow changes in free flowing stream reaches, not reservoirs. However, surcharge storage in reservoirs can be modeled in the flood control routines using *FV/FQ* record reservoir storage volume versus outflow tables.

Lag and Attenuation Routing Parameters

Two alternative strategies for calibrating routing parameters are explained in Chapter 4 of the *Daily Manual* [5]. An optimization-based calibration procedure was initially developed for the daily WRAP modeling system. A more recently developed calibration procedure based on statistical analysis of fluctuations in observed flows between two gage sites was applied in determining routing parameters for the daily Neches WAM [21]. The lag parameters LAG and LAGF in days and attenuation parameters ATT and ATTF in days for normal and flood (high) flows are calibrated based on observed flow fluctuations between gaging stations for normal flows and high flows, respectively, and applied in the *SIMD* simulation routing algorithm for normal *WR* record water right operations and *FR* record flood control operations, respectively [5].

The routing parameters for the 19 reaches defined by the 20 primary control points in the Neches WAM are contained on *RT* records in the DIF file and tabulated in Table 8.3 [21]. The normal flow and flood flow lag (LAG and LAGF) for each of the 19 selected reaches are tabulated in the fourth and sixth columns of Table 8.3. The calibration study resulted in normal and flood flow attenuation (ATT and ATTF) values of 1.0 day for all of the 19 reaches. 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.

Table 8.3
Lag and Attenuation Parameters

Upstream Control Point	Down-stream CP	Reach Length (miles)	Normal Flow LAG (days)	Normal Flow ATT (days)	High (Flood) Flow LAGF (days)	High (Flood) Flow ATTF (days)
KIBR	NEPA	31	2.06	1.0	2.14	1.0
NEPA	NENE	20	1.33	1.0	1.38	1.0
NENE	NEAL	61	4.07	1.0	4.22	1.0
NEAL	NEDI	75	4.04	1.0	5.07	1.0
NEDI	NERO	47	3.00	1.0	4.23	1.0
NERO	NETB	45	2.52	1.0	3.61	1.0
NETB	NEEV	53	1.96	1.0	3.00	1.0
NEEV	NEBA	25	1.14	1.0	2.13	1.0
NEBA	NESL	28	1.03	1.0	1.58	1.0
MUTY	MUJA	26	2.72	1.0	1.56	1.0
MUJA	ANAL	47	4.93	1.0	2.82	1.0
ANAL	ANLU	41	2.55	1.0	3.65	1.0
ANLU	ANSR	83	5.50	1.0	4.35	1.0
ANSR	NETB	38	2.14	1.0	2.04	1.0
EFACU	ANAL	44	4.61	1.0	2.64	1.0
ATCH	ANSR	64	6.71	1.0	3.84	1.0
AYSA	ANSR	35	3.67	1.0	2.1	1.0
VIKO	NEBA	37	2.61	1.0	3.01	1.0
PISL	NEBA	31	2.48	1.0	2.48	1.0

Lags and reach lengths are tabulated in Table 8.3. The normal lag (LAG) per mile of reach length is shown by color-code in Figure 8.1 [21]. The lag/mile decreases gradually from upstream reaches to downstream reaches.

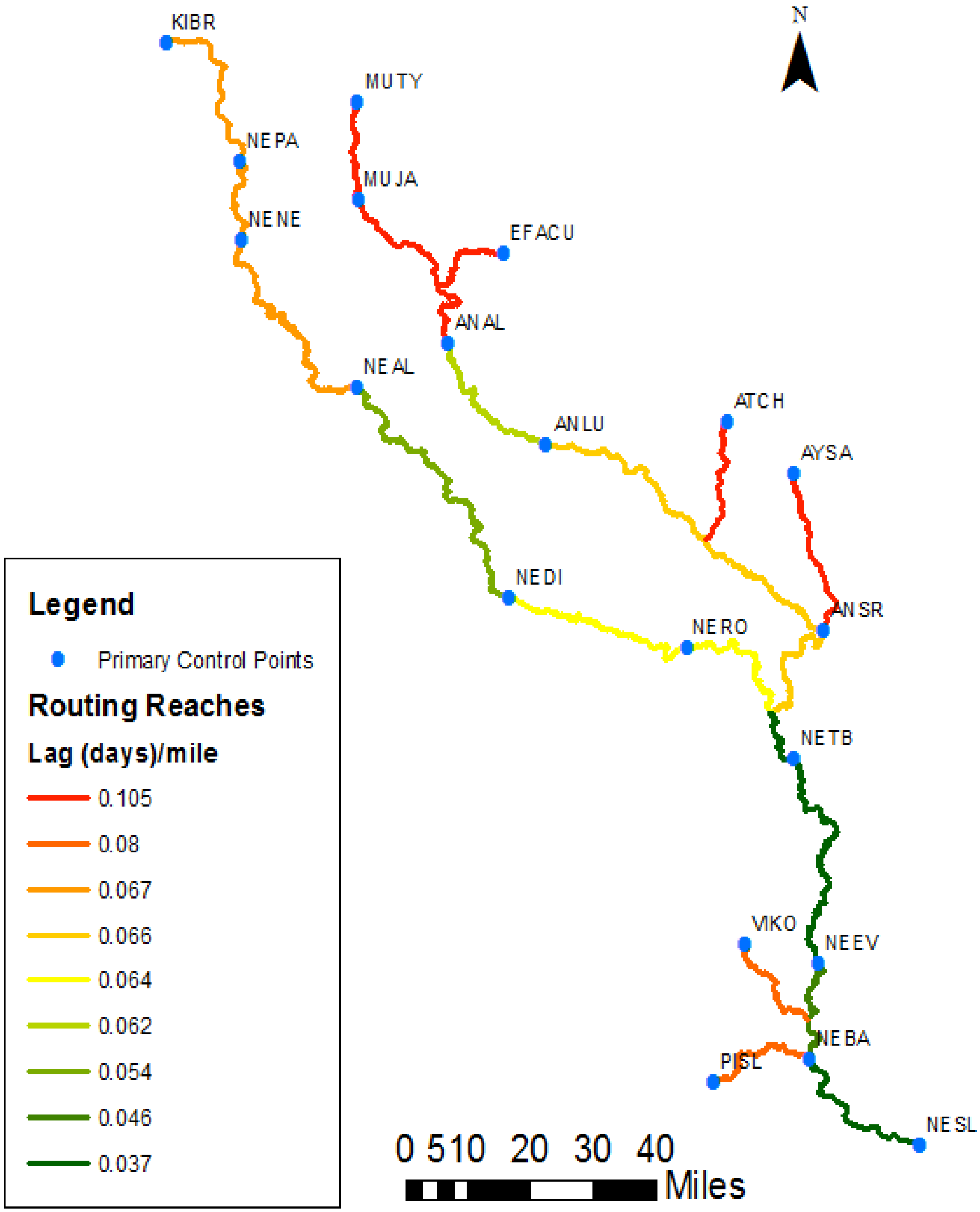

Figure 8.1 Lag in Days/Mile for Normal Flow in the River Reaches Defined in Table 8.3 [21]

Control Points and Routing Reaches

The 19 reaches for which lag and attenuation parameters were calibrated are defined by the upstream and downstream control points listed in the first and second columns of Table 8.3, which are sites of USGS gaging stations and WAM primary control points. Multiple other control points are located within the reaches used for the parameter calibration. The routing computations occur at one selected control point within each of the calibration reaches. The routing parameters and calibration computations are assigned to the upstream control points in the Neches WAM. The control point identifiers in the first column of Table 8.3 are entered in field 2 of the *RT* records.

Selection of control points at which to apply the calibrated routing parameters is an issue. The *SIMD* input lag parameters LAG and LAGF are calibrated for the river reaches between the upstream and downstream control points (gaging stations) listed in the first and second columns of Table 8.3. The routing algorithm in *SIMD* performs computations at a specified control point to model the lag occurring between that control point and the adjacent control point located immediately downstream. The river reach for which the LAG and LAGF are applied is a sub-reach of the reach for which the LAG and LAGF are calibrated. Return flows occur at locations downstream of the corresponding streamflow depletions for water supply diversion rights.

Conceptually, perhaps the *SIMD* routing sub-reach should be near the center of the calibration reach but conceivably could be anyplace within the calibration reach. The upstream end of the routing reaches somewhat arbitrarily adopted on the *RT* records are the control points listed in the first column of Table 8.3.

Travel Times and Distances

Lag is the time in days required for flow fluctuations at a control point to propagate through a river reach to a downstream control point. A volume of return flow at a wastewater treatment plant discharged into a river during a particular day reaches downstream sites some periods of time (lags) later. Likewise, the effects of depleting streamflow to refill reservoir storage propagate downstream over time. Lag represents a wave celerity, not a mean velocity. Flow velocities vary at points across a river cross-section. The mean velocity (ft/s) is the flow discharge rate (ft^3/s) divided by cross-section flow area (ft^2). Wave celerity is normally faster than mean velocity. Estimates of travel speed (wave celerity) in miles/day can be computed by dividing reach length in miles by lag time in days. Travel speeds provide insight on river flow characteristics and whether estimates of lag appear to be reasonably valid.

The lags in Table 8.3 were determined based on statistical analyses of many identified flow fluctuations between USGS gaging stations [5, 21]. Lag estimates are highly variable and approximate. Measurements of flow path lengths (reach lengths in river miles) are also approximate and vary with flow discharge rate/stage.

The longest continuous sequence of river reaches extends from control point KIBR through NEPA, NENE, NEAL, NEDI, NERO, NETB, NEEV to control point NESL and has an estimated total length of 385 miles, normal lag of 21.2 days, flood lag of 27.4 days, and corresponding mean travel speeds of 1.11 and 0.86 ft/s. This 385 mile reach extends from the USGS gage on Kickapoo Creek near Brownsboro (KIBR) to the outlet of the Neches River at Sabine Lake (NESL).

The lag (LAGF) during high flow conditions may generally be either longer or shorter than the lag (LAG) during normal flow conditions. The flood lag LAGF for many reaches in Table 8.3 is longer than the normal lag LAG, presumably due to average flow rates through overbank flood plains being slower than average flows in a main channel. For other reaches, the LAGF are smaller than the LAG presumably influenced by high flows in a channel normally have greater mean velocities than low flows.

Simulation of Flood Control Operations of Sam Rayburn Reservoir

Converting the monthly Neches WAM to daily allows incorporation of reservoir flood control operations. Relatively small computational time steps are required to accurately simulate reservoir operations during floods due to the great fluctuations in flow rates over short time spans that occur during flood events. A daily time step is adequate for modeling flood control operations of large river and reservoir systems. Accurate modeling of small systems may require hourly or smaller time steps not available in *SIMD*. Operation of flood control pools with gated outlet structures based on flows at downstream gages is simulated with flood reservoir *FR* and flood flow *FF* records combined with use of *FV* and *FQ* records to model outlet structure outflow capacities.

FV/FQ record reservoir storage volume versus outflow tables can also be used to model surcharge storage above the conservation pool of water supply reservoirs that have no designated flood control pool. However, this modeling strategy is not employed in the daily Neches WAM. Information required to model outlet structure hydraulics is not readily available for the many water supply reservoirs that have no designated flood control pools.

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 8.4. 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 possible 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 8.4.

Table 8.4
U.S. Army Corps of Engineers Flood Control Operation Criteria

Reservoir	Reservoir Surface Elevations (feet msl)	% Flood Storage Volume	Neches River Turbine (cfs)	Neches River Evadale (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.

One or more flood control rights consisting of sets of *FR*, *FV/FQ*, and *FF* records may be inserted any place in the DAT file grouping of all water right records. The input records for operating Sam Rayburn Reservoir for flood control are inserted in the DAT file as the last group of water right input records in the DAT file before the reservoir storage volume and surface area *SV/SA* tables. These records modeling flood control operations of Sam Rayburn Reservoir are replicated below as Tables 8.5 and 8.6.

Table 8.5
FR and *WS* Records for Flood Control Operation of Sam Rayburn Reservoir

```
**       1         2         3         4         5         6         7         8         9        10
**3456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678
**     |       |       |       |       |       |       |       |       |       |               |

FR4411A19100000092000000        2  20000. 3997600         2898200                RAYBURN-STOR    RAYBURN-REL
WSRAYBRN
```

Table 8.6
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.     0.0     0.0
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 entry of 2 for parameter *FCDEP* in *FR* record field 6 allows flood control reservoir operations to ignore conventional *WR* record stream flow availability computations when storing flood flows in the flood control pool in accordance with downstream maximum allowable flow limits. This *FCDEP* option allows the flood control reservoir to store flood flows even if stream flow available to downstream senior water rights in the current and future days is adversely affected in the routing and forecasting computations.

Since no value for FCGATE is entered in *FR* record field 9, the most restrictive of the *FF* record 20,000 cfs limit and *FV/FQ* record capacities control in each day. In the simulation study presented in Chapter 9, the *FF* record flow was found to control in most days of the simulated floods.

CHAPTER 9
SIMULATION RESULTS FOR THE AUTHORIZED USE SCENARIO

Simulation results from the full authorization and current use versions of the June 2020 Neches WAM are summarized in Chapters 9 and 10, respectively. Selected simulation results are accessible from the DSS file described in the last section of this chapter. Results from daily and monthly simulations with the full authorization scenario are presented in this chapter as follows.

1. Reservoir storage contents are plotted in Figures 9.1 through 9.8 in a comparative analysis of the effects of converting the WAM from monthly to daily and employing routing and forecasting. A daily modeling strategy without routing and forecasting is adopted for purposes of simulating the Senate Bill 3 (SB3) environmental flow standards (EFS).
2. Observed, naturalized, regulated, and unappropriated flows and SB3 EFS instream flow targets and target shortages at the five SB3 EFS sites are explored and compared. Time series plots (Figures 9.9-9.13) and summary tables of statistical metrics are presented.
3. Monthly SB3 EFS instream flow targets are developed as described on pages 107-108 of Chapter 7. Monthly summations of daily targets from the daily *SIMD* simulation are recorded on target series *TS* records for inclusion in the monthly *SIM* input dataset. The daily and monthly instream flow targets for the SB3 EFS are plotted in Figures 9.14–9.28.

Storage Contents for Alternative Simulations With and Without Routing and Forecasting

Major reservoirs in the Neches River Basin are described in Chapter 2. Simulated reservoir storage contents for the USACE Sam Rayburn and B. A. Steinhagen Reservoirs and Lake Palestine and summations of the storage contents of the other ten reservoirs listed in Tables 2.8 and 2.9 resulting from alternative modeling premises are compared in Figures 9.1 through 9.8 and Tables 9.2, 9.3, and 9.4. The one monthly and five daily alternative simulations selected for inclusion in the comparative analyses presented here are defined below and in Table 9.1.

- M1 Monthly *SIM* simulation with the original dataset last updated in October 2012 described in Chapter 2 with the hydrologic period-of-analysis extended through 2019.
- D1 Daily *SIMD* simulation with no routing and no forecasting.
- D2 Daily *SIMD* simulation with routing and but no forecasting.
- D3 Daily *SIMD* simulation with routing and a forecast period of 3 days.
- D4 Daily *SIMD* simulation with routing and a forecast period of 10 days.
- D5 Daily *SIMD* simulation with routing and the default forecast period of 57 days.

The 1940-2019 end-of-month storage volumes for simulation M1 and end-of-day volumes for the daily simulations for Sam Rayburn, B. A. Steinhagen, and Palestine Reservoirs are plotted in Figures 9.1 through 9.3. The summations of the storage contents of the other ten reservoirs in Table 2.8 are plotted in Figure 9.4. The means of the 960 end-of-month storage volumes from simulation M1 and the 29,220 end-of-day storage volumes from simulations D1, D2, D3, D4, and D5 are tabulated in Table 9.2. The median quantities equaled or exceeded during 50 percent of the 960 months of simulation M1 or the 29,220 days of the daily simulations are shown in Table 9.3. The minimum end-of-month (M1) or end-of-day (D1, D2, D3, D4, D5) storage contents during each of the five 1940-2019 hydrologic period-of-analysis simulations are presented in Table 9.4.

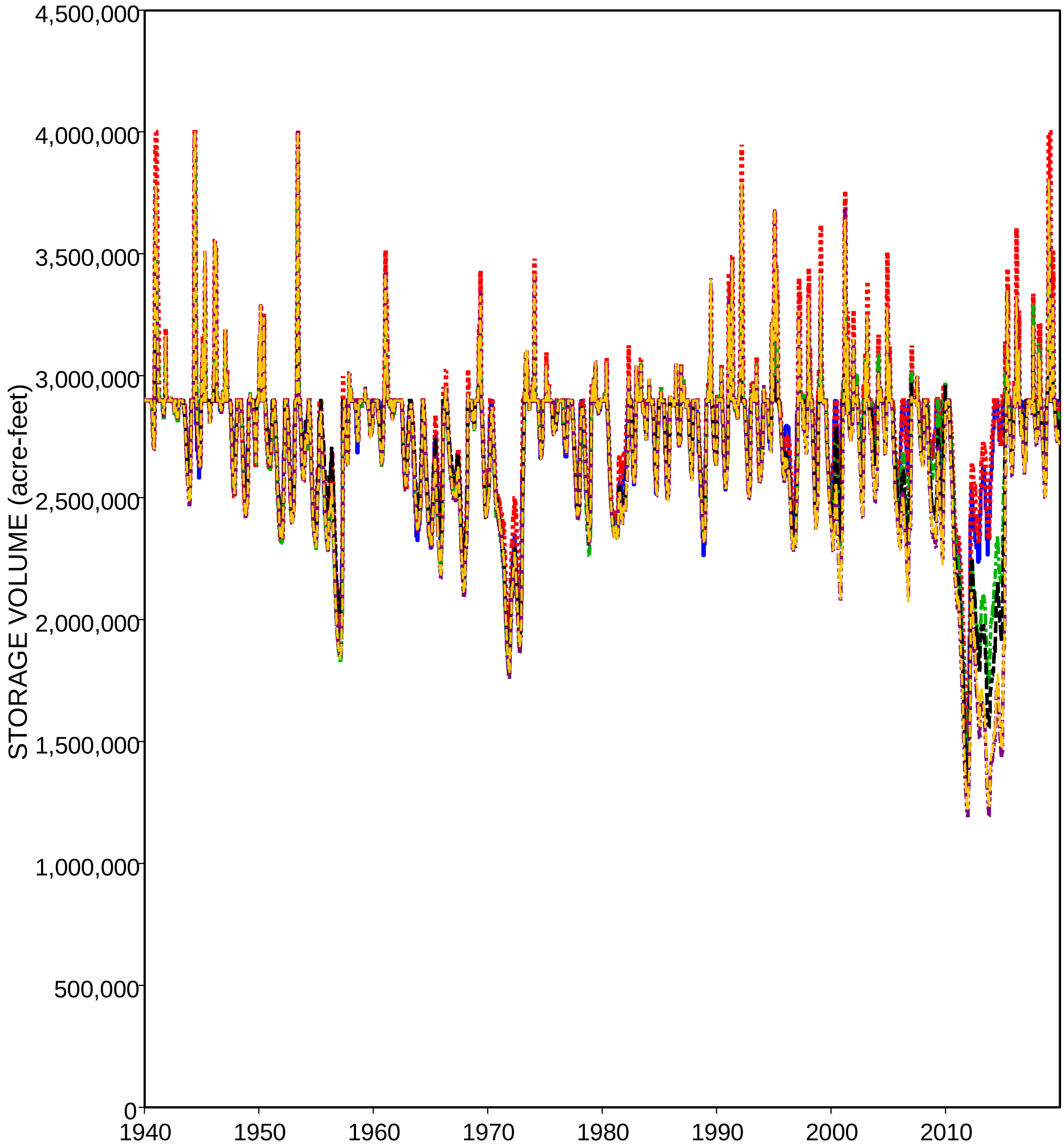

Figure 9.1 Sam Rayburn Reservoir Storage for Alternative 1940-2019 Simulations

M1	Original monthly WAM		blue solid line
D1	No routing and no forecasting		red dotted line
D2	Routing but no forecasting		green dashes and dots
D3	Routing and 3-day forecast		black dashed line
D4	Routing and 10-day forecast		purple dashes and dots
D5	Routing and 57-day forecast		orange dashed line

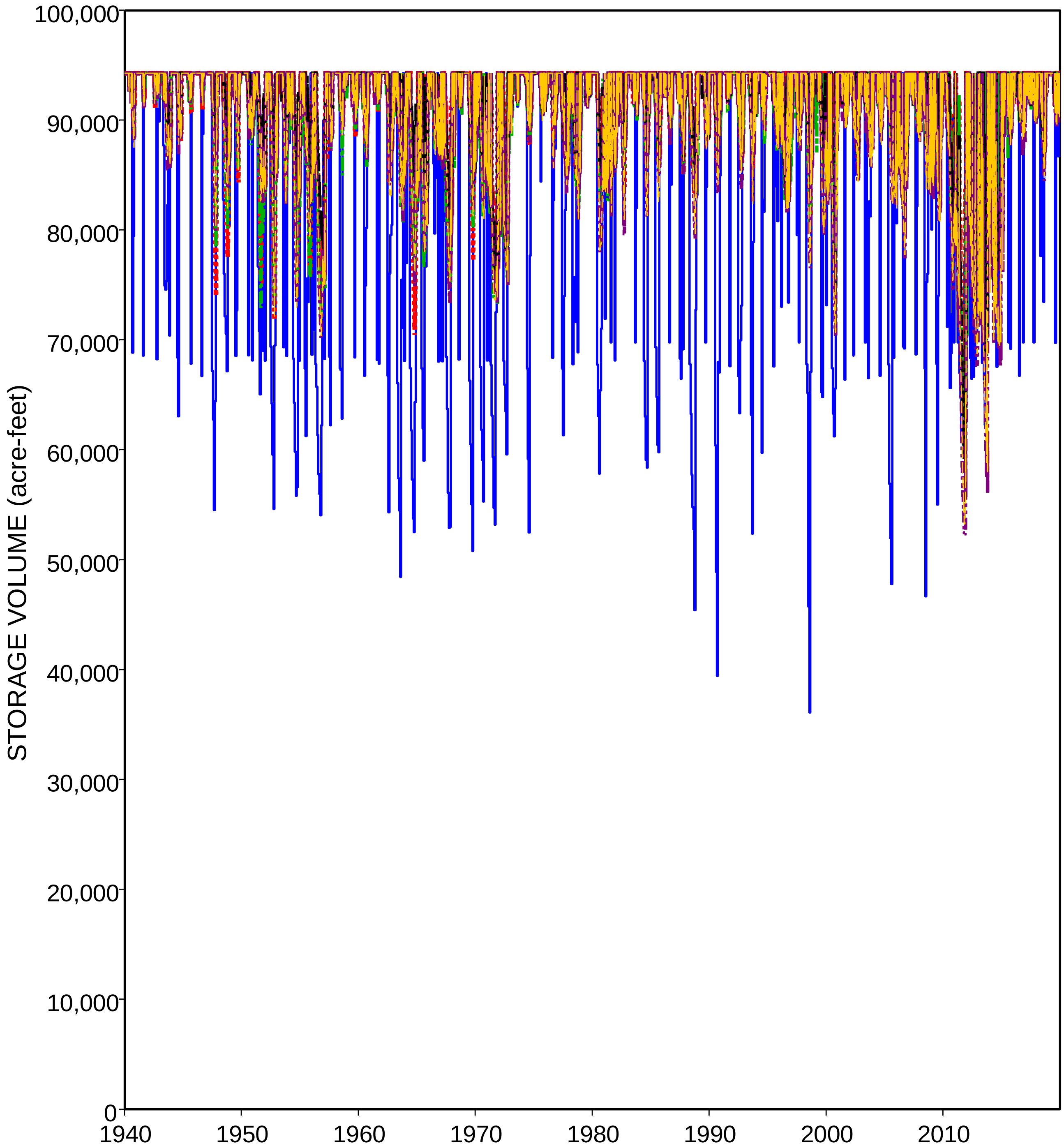

Figure 9.2 B. A. Steinhagen Reservoir Storage Contents for Alternative 1940-2019 Simulations

M1	Original monthly WAM		blue solid line
D1	No routing and no forecasting		red dotted line
D2	Routing but no forecasting		green dashes and dots
D3	Routing and 3-day forecast		black dashed line
D4	Routing and 10-day forecast		purple dashes and dots
D5	Routing and 57-day forecast		orange dashed line

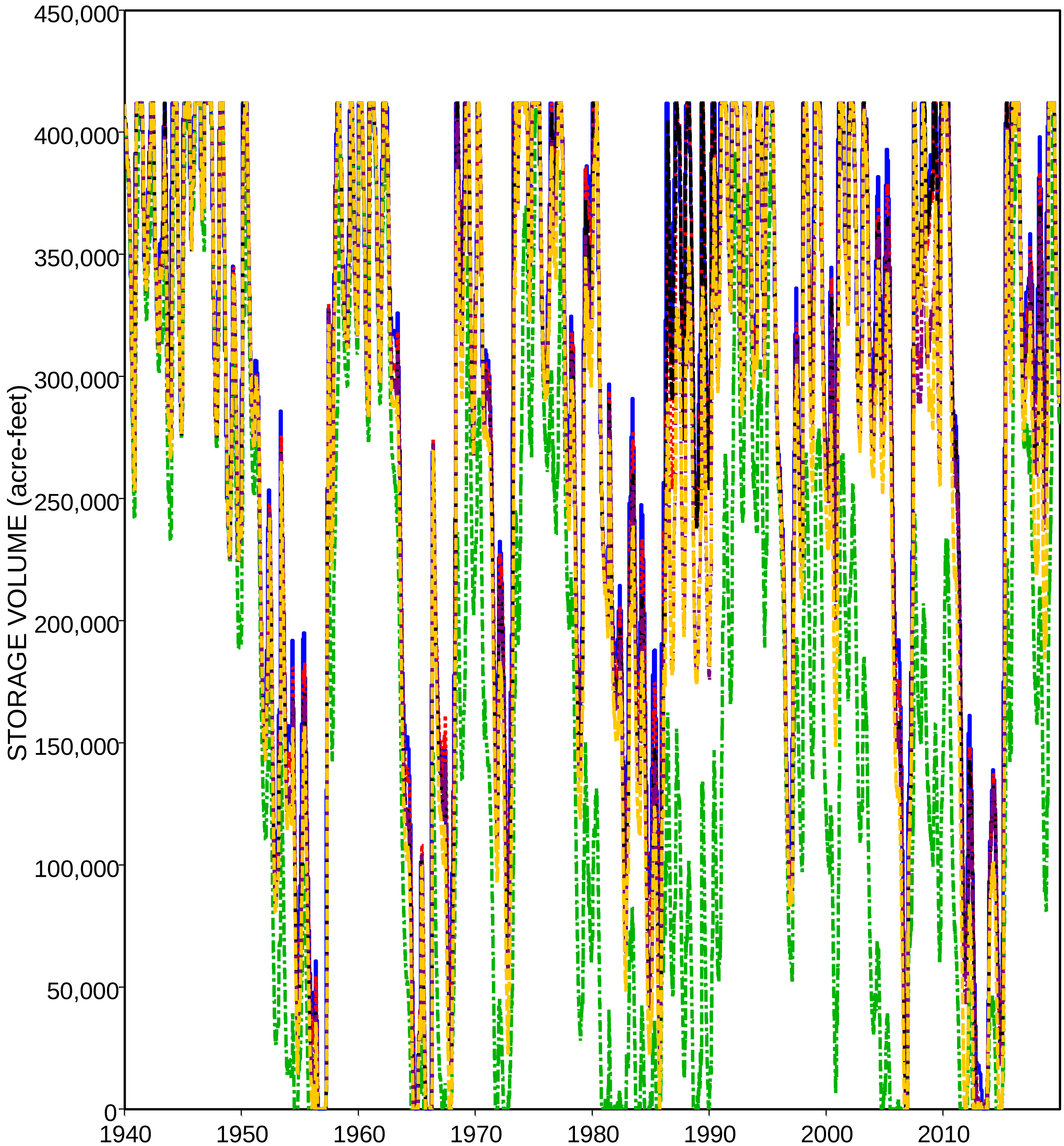

Figure 9.3 Lake Palestine Storage Contents for Alternative 1940-2019 Simulations

M1	Original monthly WAM	blue solid line
D1	No routing and no forecasting	red dotted line
D2	Routing but no forecasting	green dashes and dots
D3	Routing and 3-day forecast	black dashed line
D4	Routing and 10-day forecast	purple dashes and dots
D5	Routing and 57-day forecast	orange dashed line

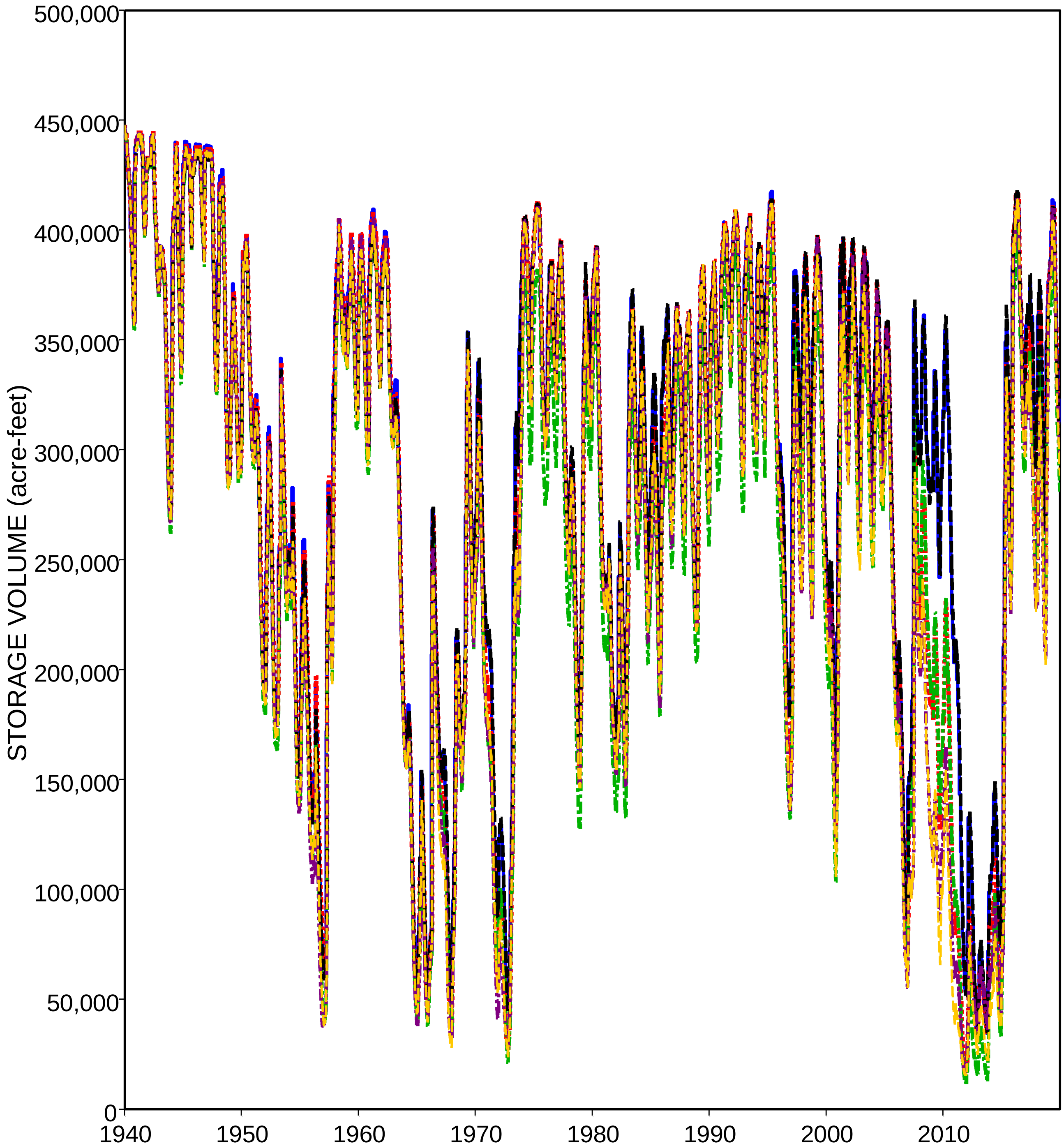

Figure 9.4 Summation of Storage in Ten Reservoirs for Alternative 1940-2019 Simulations

M1	Original monthly WAM	blue solid line
D1	No routing and no forecasting	red dotted line
D2	Routing but no forecasting	green dashes and dots
D3	Routing and 3-day forecast	black dashed line
D4	Routing and 10-day forecast	purple dashes and dots
D5	Routing and 57-day forecast	orange dashed line

Table 9.1
Alternative Authorized Use (Chapter 9) and Current Use (Chapter 10) Scenario Simulations

Label	Routing and Forecasting Options	Negative Incremental Flow Option	Simulation Model
M1	No routing and no forecasting	Option 5	Monthly *SIM*
D1	No routing and no forecasting	Option 4	Daily *SIMD*
D2	Routing but no forecasting	Option 4	Daily *SIMD*
D3	Routing and 3-day forecast	Option 7	Daily *SIMD*
D4	Routing and 10-day forecast	Option 7	Daily *SIMD*
D5	Routing and 57-day forecast	Option 7	Daily *SIMD*

Table 9.2
Average Reservoir Storage Contents in acre-feet for Authorized Use Scenario

Reservoir or	Storage	Alternative Simulations					
10-Reservoir Total	Capacity	M1	D1	D2	D3	D4	D5
Sam Rayburn	2,898,200	2,734,516	2,775,487	2,706,272	2,695,440	2,670,862	2,674,662
B. A. Steinhagen	94,250	85,958	91,713	90,722	91,446	89,986	90,020
Palestine	411,840	286,992	279,899	170,950	275,321	267,268	258,805
Other ten Reservoirs	447,870	292,223	278,812	262,397	290,184	266,722	265,097

Table 9.3
Median (50% Exceedance) Reservoir Storage Contents in acre-feet for Authorized Use Scenario

Reservoir or	Storage	Alternative Simulations					
10-Reservoir Total	Capacity	M1	D1	D2	D3	D4	D5
Sam Rayburn	2,898,200	2,864,670	2,852,810	2,805,512	2,813,308	2,780,424	2,782,870
B. A. Steinhagen	94,250	94,250	94,245	93,172	93,774	92,716	92,769
Palestine	411,840	317,528	309,158	158,271	306,466	297,365	289,897
Other ten Reservoirs	447,870	318,145	303,828	285,796	314,972	291,402	291,168

Table 9.4
Minimum Reservoir Storage Contents in acre-feet for Authorized Use Scenario

Reservoir or	Storage	Alternative Simulations					
10-Reservoir Total	Capacity	M1	D1	D2	D3	D4	D5
Sam Rayburn	2,898,200	1,451,752	1,525,113	1,399,915	1,326,013	1,192,655	1,220,317
B. A. Steinhagen	94,250	36,087	63,423	60,745	59,128	52,317	53,194
Palestine	411,840	0.0	0.0	0.0	0.0	0.0	0.0
Other ten Reservoirs	447,870	32,554	17,889	12,227	32,542	17,262	15,544

Description of Options Reflected in the Selected Alternative Simulations

Many simulations were performed to explore the effects of various alternative modeling options and input quantities on simulation results. Results of several selected authorized use and current use scenario simulations are summarized in Chapters 9 and 10, respectively. The selected simulations listed in Table 9.1 support the following discussion of alternative modeling options.

Simulation M1 of Figures 9.1-9.4 and Tables 9.1-9.5 employs the original monthly full authorization DAT and DIS files last updated by the TCEQ in October 2012 combined with the original 1940-1996 WAM hydrology updated to extend through December 2019 as described in the preceding chapters of this report. Simulations D1, D2, D3, D4, and D5 are alternative variations of the daily WAM developed as described in the preceding Chapter 8.

With an assigned priority number of 20091130 (November 30, 2009), the SB3 EFS are junior to essentially all other water rights in the WAM. The SB3 EFS affect unappropriated flows and may affect water rights added in the future with more junior priorities. However, the simulated reservoir storage quantities presented in this report are the same with or without the SB3 EFS.

The selection parameter NEGINC on the *JD* record specifies negative incremental flow adjustment options as explained in the *Reference* and *Users Manuals* [1, 2]. Results of a monthly *SIM* simulation may vary significantly with choice of NEGINC option. Daily *SIMD* simulation results are even more sensitive to the choice of negative incremental flow adjustment option. The standard recommended options are 4 or 6 for monthly simulations and daily simulations without forecasting and option 7 for daily simulations with forecasting [1, 5, 13, 14].

The NEGINC option employed in each of the five simulations is shown in the third column of Table 9.1. The Neches daily WAM results, like the Brazos and Trinity daily Trinity WAM (13, 14] results, were found to be sensitive to the choice negative incremental flow adjustment option. Option 5 is used in the original Neches WAM. The standard options 4 and 7 are adopted for the daily simulations without and with forecasting.

The monthly simulation labeled M1 and five daily simulations labeled D1, D2, D3, D4, and D5 were selected for inclusion in the tables and figures presented here for comparison. The plot for simulation M1 consists of 960 end-of-month storage volumes in acre-feet. The plots for simulations D1, D2, D3, D4, and D5 consist of 29,220 end-of-day storage volumes in acre-feet. The daily simulations generate monthly as well as daily storage contents. The 960 end-of-month volumes are a subset of the 29,220 end-of-day volumes. Monthly and daily plots from the same daily simulation are almost the same, with the most significant differences being flood peaks.

Daily *SIMD* simulations D1, D2, D3, D4, and D5 include flood control operations of Sam Rayburn Reservoir and SB3 EFS at five sites as described in Chapters 7 and 8. The only difference between these five daily simulations is the handling of routing and forecasting.

Senate Bill 3 (SB3) environmental flow standards (EFS) are a major focus of the simulations presented in Chapters 9 and 10. The monthly *SIM* simulation and five alternative daily simulations all include the SB3 EFS. Monthly simulation M1 reflects initial 2012 methods for modeling SB3 EFS. The daily simulations incorporate the new methods discussed in Chapter 7.

Sam Rayburn and B. A. Steinhagen Reservoir System Operations

Sam Rayburn is the only reservoir in the Neches WAM that includes flood control operations. The total storage capacity of Sam Rayburn below the top of flood pool is 3,030,128 acre-feet and below the top of conservation pool is 2,898,200 acre-feet. Flood control storage is evident in the storage plot of Figure 9.1. Flood control operations of Sam Rayburn Reservoir are described in the last section of Chapter 8. Releases from the Sam Rayburn flood control pool during each day of the simulation are the lesser of the release computed based on *FF* record specified downstream channel capacity and the outlet capacity at the dam specified by the *FV/FQ* records replicated in Table 8.6. The *FF* record flood flow limit was found in the simulation study to control in most of the days that had water stored in the flood control pool.

The monthly *SIM* simulation is based on outflow equaling inflow anytime the conservation pool storage capacity is exceeded. Likewise, in a daily *SIMD* simulation, for reservoirs without a *FR* record flood control pool, outflow equals inflow if the conservation pool is full.

As discussed in Chapter 2, the USACE Fort Worth District operates Sam Rayburn and B.A. Steinhagen Reservoirs as a system. The primary purpose of B. A. Steinhagen Reservoir is to re-regulate hydroelectric power and flood control releases from Sam Rayburn Reservoir to facilitate water supply diversions from the lower Neches River by the Lower Neches Valley Authority (LNVA). LNVA water rights are subordinated to other upstream water rights.

SIM/SIMD simulation of the Steinhagen re-regulation of Rayburn releases is complex. Steinhagen and Sam Rayburn Reservoirs are modeled in the Neches WAM DAT file as a multiple-reservoir system using multiple *WR* and *WS* records with auxiliary operating rule *OR*, backup *BU*, and priority circumvention *PX* records. This scheme in the October 2012 DAT file was not modified in the recent conversion of the monthly WAM to daily. The same basic operating rules for B. A. Steinhagen Reservoir are applied in all of the simulations without modification.

As illustrated by Figures 9.1-9.4 and Tables 9.2-9.5, the daily *SIMD* simulation results differ from the monthly *SIM* simulation results for B. A. Steinhagen Reservoir much more than the monthly-versus-daily simulation results differences for the other reservoirs.

Reservoir Storage Plots and Statistics

Reservoir storage content provides a meaningful measure of water availability and fluctuations thereof. Figures 9.1-9.3 are *HEC-DSSVue* plots of 1940-2019 hydrologic period-of-analysis end-of-month storage contents in acre-feet of Sam Rayburn, B. A. Steinhagen, and Palestine Reservoirs for the monthly *SIM* simulation M1 and end-of-day volumes for the five alternative *SIMD* daily simulations. The summations of the 1940-2019 end-of-month (simulation M1) and end-of-day (simulations D1, D2, D3, D4, D5) storage volume in acre-feet of the other ten reservoirs listed in Tables 2.2 and 2.9 of Chapter 2 are plotted in Figure 9.4. These time series datasets are stored in the simulation results DSS file discussed in the last section of this chapter.

The reservoir storage plots illustrate the sensitivity of simulation results to alternative modeling premises. The time series plots for the six alternative simulations are similar enough that they tend to blend together in the figures presented in this report. The similarities and differences between the simulated time series of reservoir storage contents can be compared in greater detail with better clarity by viewing selected plots on the computer monitor directly within *HEC-DSSVue*. The number of plots included and time window are easily varied in *HEC-DSSVue*.

The means and minima of the 960 end-of-month storage volumes from simulation M1 and the 29,220 end-of-day storage volumes from simulations D1, D2, D3, D4, and D5 are tabulated in Tables 9.2 and 9.4 from the *HEC-DSSVue* basic statistics table. The median quantities equaled or exceeded during 50 percent of the 960 months of simulation M1 or the 29,220 days of simulations D1, D2, D3, D4, and D5 shown in Table 9.3 are from frequency tables produced with the *HEC-DSSVue* duration analysis feature. A single table with a full range of storage exceedance metrics for all six simulations viewed within *HEC-DSSVue* provides a more detailed comparison. The authorized reservoir conservation storage capacities are included in Tables 9.2-9.4.

Daily Simulation D1 Selected for Determining SB3 EFS Targets

Determining monthly SB3 EFS instream flow targets from a daily *SIMD* simulation for inclusion in a monthly *SIM* input dataset is the primary application of daily modeling employed in this chapter. The daily simulation results presented in the remainder of this chapter were generated by daily *SIMD* simulation D1 defined in Table 9.1, which has no routing and no forecasting. The storage plots of Figures 9.5-9.8 are limited to simulations M1 and D1. The following discussion addresses the differences between the alternative simulations listed in Table 9.1. These differences include: (1) monthly-versus-daily time step, (2) with-versus-without routing and forecasting, and (3) alternative forecast periods.

Routing and forecasting methods are explained in the *Daily Manual* [5]. Uncertainties and inaccuracies associated with routing and forecasting are discussed in the preceding Chapter 8 of this report as well as in the *Daily Manual*. Forecasting is relevant and should be activated only if routing is employed. Routing and forecasting may improve accuracy in some situations, but this Neches WAM simulation study as well as the Brazos WAM [13] and Trinity WAM [14] simulation studies indicate that forecasting tends to adversely affect accuracy due to over-constraining stream flow availability. Routing without forecasting does not maintain the water right priority system.

Routing simulates the physical hydraulic characteristics of changes in stream flow. Inaccuracies, variability, and uncertainty in the routing methodology and parameters are discussed in Chapter 8. The values of the routing parameters replicated in Table 8.3 are stored as *RT* records in the DIF file. Simulations can be performed either with or without routing simply by activating or deactivating the *RT* records. *SIM* and *SIMD* has no routing features for monthly simulations. Flow changes are assumed to propagate through the system within the same month.

Forecasting future stream flow is highly uncertain in real-world water management and results in major modeling complexities and approximations. Interactions between forecasting, negative incremental flow options, and other input selections significantly contribute to modeling complexity. Simulation D5 incorporates the default forecast period of 57 days automatically computed within the *SIMD* simulation as twice the lag time for the longest lag flow path [5]. Forecast periods of 3 days and 5 days incorporated in simulations D3 and D4 are more representation of real-world stream flow forecast capabilities than the default 57 days of D5, but do not fully protect senior water rights.

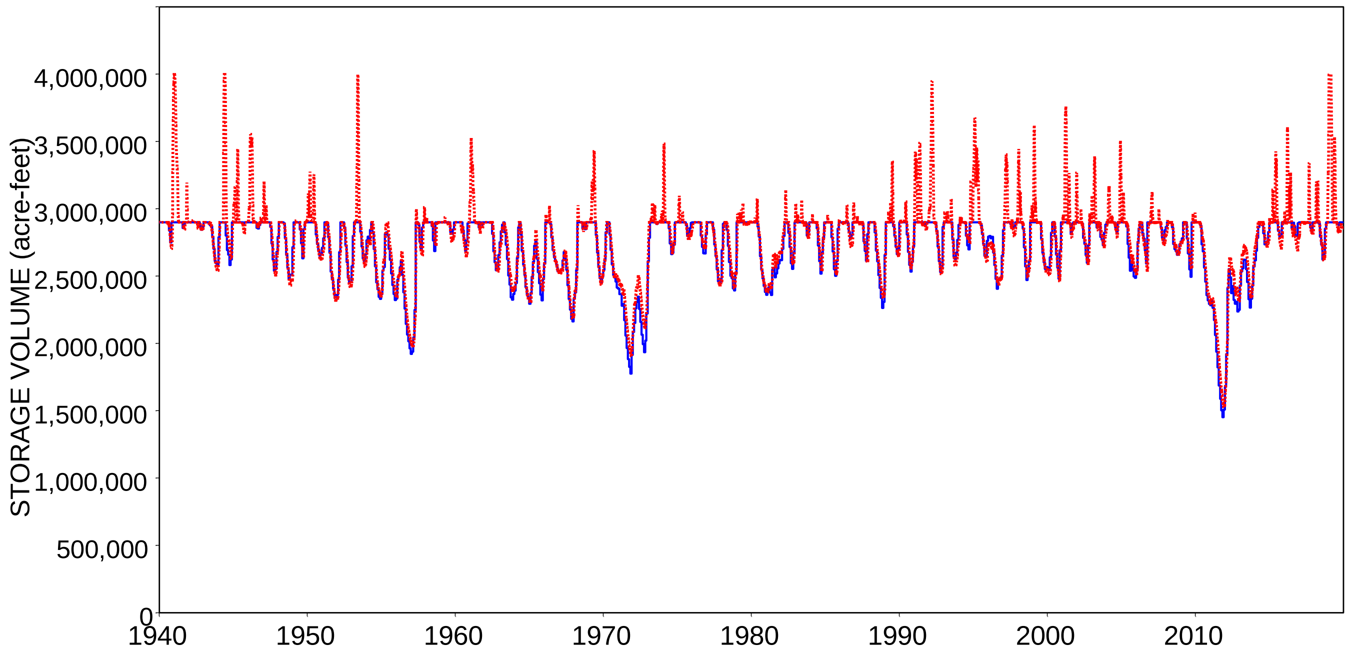

Figure 9.5 Sam Rayburn Reservoir Storage Contents for Simulations
M1 (blue solid) and D1 (red dotted)

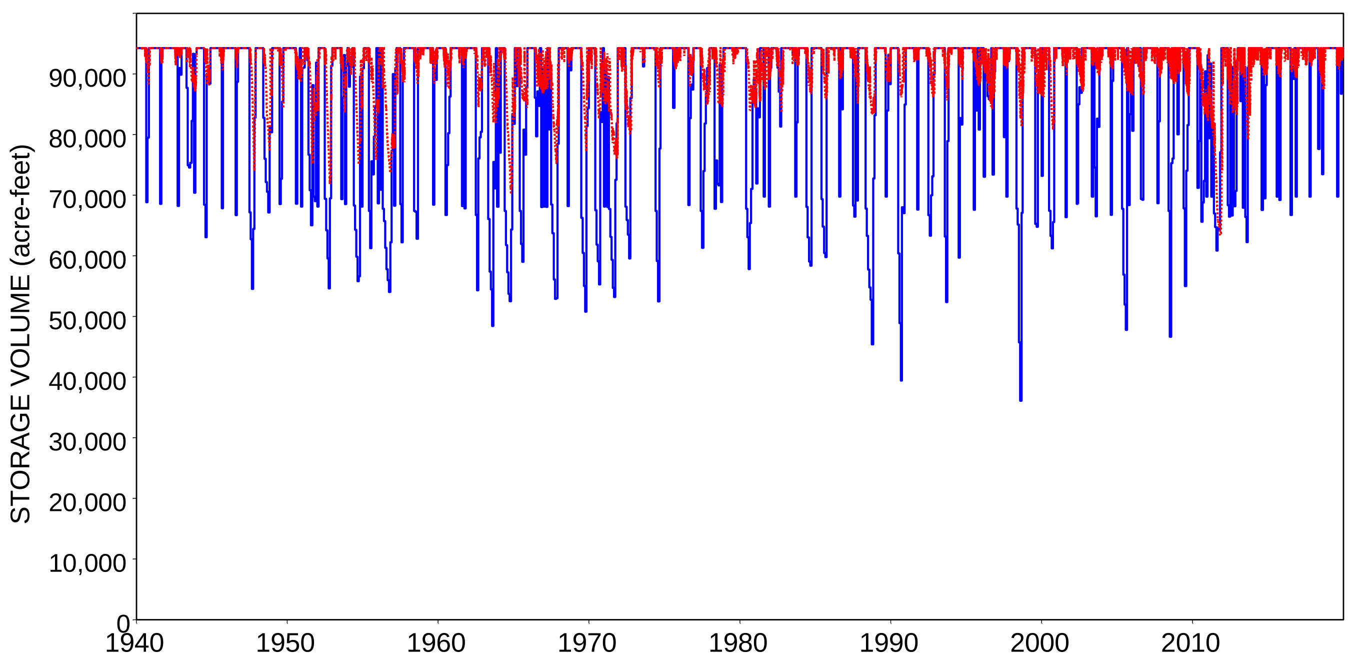

Figure 9.6 B. A. Steinhagen Reservoir Storage Contents for Simulations
M1 (blue solid) and D1 (red dotted)

The only difference between the five daily simulations is the handling of routing and forecasting. Simulation D1 has no routing and no forecasting. Simulations D2, D3, D4, and D5 employ the lag and attenuation parameters shown in Table 8.3 of Chapter 8. Simulation D2 includes routing but no forecasting. D3 and D4 have forecast periods of three days and ten days, respectively. Simulation D5 incorporates the default forecast period of 57 days automatically computed by *SIMD* as twice the lag time for the longest lag flow path. Selection of the optimal forecast period is largely judgmental and depends on the particular modeling application.

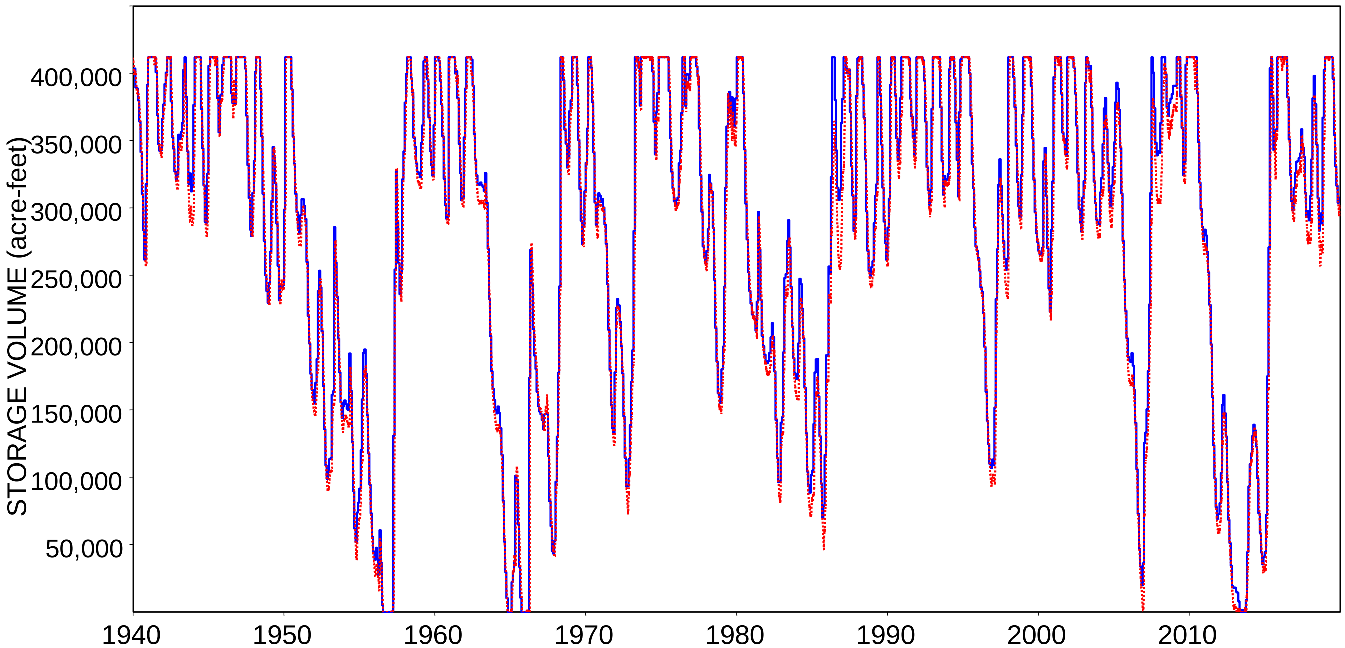

Figure 9.7 Lake Palestine Storage Contents for Simulations M1 (blue solid) and D1 (red dotted)

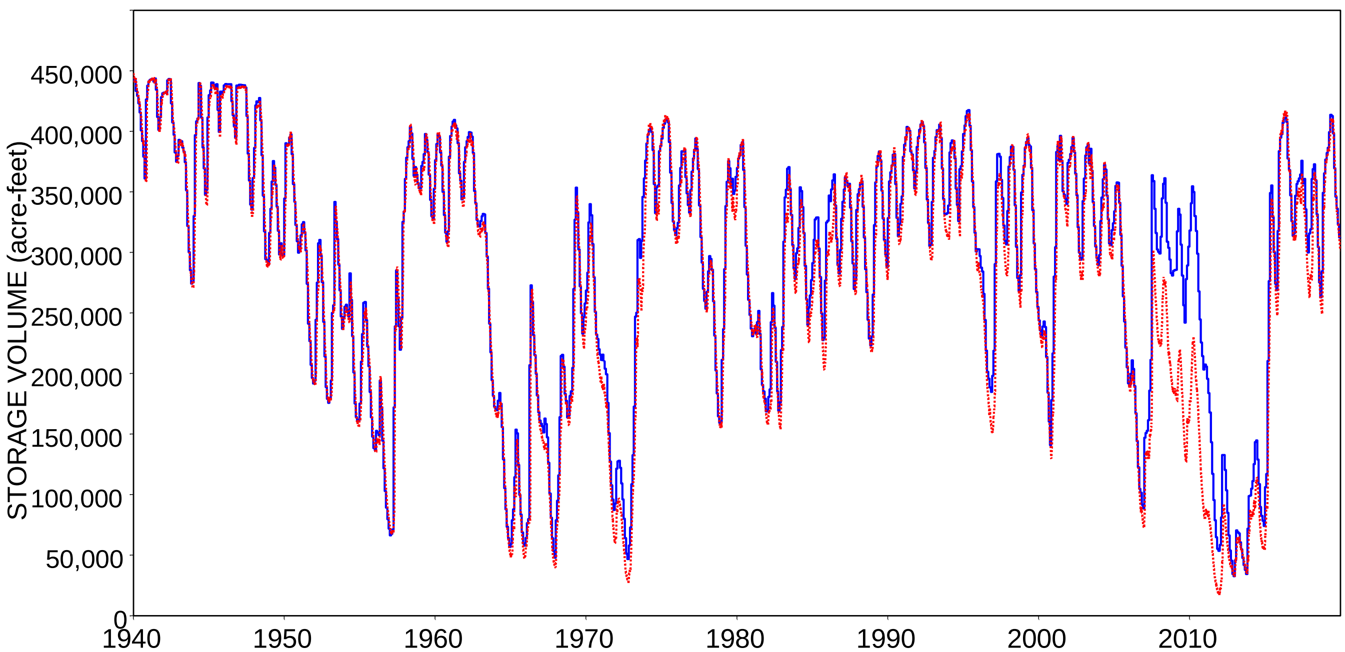

Figure 9.8 Summation of Storage in Ten Reservoirs for Simulations M1 (blue solid) and D1 (red dotted)

With the notable exception of B.A. Steinhagen Reservoir, the storage plots for each of the five daily simulations are generally relatively close to the results for monthly simulation M1. Again with the exception of Steinhagen, daily *SIMD* simulation D1 with no routing or forecasting most closely replicates the monthly *SIM* simulation M1 results. Likewise, a daily simulation without routing and forecasting closely replicates monthly simulation results for the Brazos and Trinity WAMs [13, 14], with significant departures from the monthly simulation results occurring with the addition of routing and forecasting. Routing with no forecasting and routing with longer forecast periods tend to decrease stream flow availability and increase reservoir draw-downs.

The modeling premises reflected in either of the five daily simulations or other variations thereof could reasonably be adopted for various daily modeling applications. Routing and forecasting may improve the accuracy of simulation results to various extents from various application perspectives, but the improvements are difficult to verify. Conversely, routing and forecasting and related modeling options have certain adverse effects on simulation results.

The remainder of this chapter focuses on SB3 EFS flow targets and other simulation results from simulation D1. Selection of the premises reflected in simulation D1, including no routing and forecasting, though perhaps somewhat arbitrary, is considered to be the optimal approach for computing SB3 EFS targets with a daily WAM for incorporation in the monthly WAM. Other applications could warrant activation of routing and forecasting.

Stream Flow at the Five SB3 EFS Sites

The control points representing the USGS gage site locations of the SB3 EFS are listed in Tables 7.1 and 9.5. The locations of these control points are shown in the maps of Figures 4.1 and 4.3. The 1940-2019 averages of the daily observed, naturalized, and simulation D1 regulated and unappropriated stream flows at these five locations are tabulated in Table 9.5 in cubic feet per second (cfs). Frequency metrics including the 1940-2019 mean flow rates, standard deviations of the daily mean flow rates, and the daily mean flow rates exceeded during specified percentages of the 29,220 days of the 1940-2019 period-of-analysis are tabulated in Tables 9.6, 9.7, and 9.8 in units of cfs. Daily regulated flows in cfs from the *SIMD* simulation D1 are plotted in Figures 9.9 through 9.13. (A flow rate of 1.0 cfs is equivalent to 1.98347 acre-feet/day.) These time series of stream flows are accessible with HEC-DSSVue from the simulation results DSS file described in the last section of this chapter.

Table 9.5
Mean Flows in cfs at SB3 EFS Sites

Control Point	Location River and Town	Watershed Area (sq miles)	1940-2019 Means for Stream Flows Observed (cfs)	Naturalized (cfs)	Regulated (cfs)	Unappropr (cfs)
NENE	Neches River at Neches	1,145	730.4	771.6	419.3	175.7
NERO	Neches River near Rockland	3,631	2,492	2,531	2,138	1,587
ANAL	Angelina River near Alto	1,273	830.2	939.2	714.0	320.3
NEEV	Neches River at Evadale	7,885	6,285	6,445	4,632	3,776
VIKO	Village Creek near Kountze	861	897.8	897.2	896.7	668.9

Table 9.6
Frequency Statistics in cfs for Daily Naturalized Flows at SB3 EFS Sites

CP	NENE	NERO	ANAL	NEEV	VIKO
Mean	771.6	2,531	939.2	6,445	897.2
Stand Dev	1,585	3,913	1,632	9,021	2,341
Minimum	0.00	0.00	0.00	0.00	9.81
99%	0.00	0.00	0.00	0.00	28.00
98%	0.00	0.00	0.00	0.00	39.96
95%	0.00	0.00	8.82	0.00	57.93
90%	0.00	28.76	26.39	210.4	82.00
80%	14.67	150.1	73.54	592.6	122.9
70%	66.58	317.8	133.76	1,094	169.0
60%	152.6	563.3	224.2	1,821	238.0
50%	267.8	970.1	354.3	2,934	336.6
40%	444.0	1,601	577.3	4,526	481.4
30%	709.0	2,578	907.0	7,000	711.1
20%	1,112	4,044	1,429	10,546	1,129
10%	1,954	6,928	2,394	17,358	2,140
Maximum	44,013	49,687	42,543	119,018	151,000

Table 9.7
Frequency Statistics in cfs for Daily Regulated Flows at SB3 EFS Sites

CP	NENE	NERO	ANAL	NEEV	VIKO
Mean	419.3	2,138	714.0	4,632	896.7
Stand Dev	1,130	3,616	1,374	7,031	2,341
Minimum	0.00	0.00	0.00	0.00	9.09
99%	0.00	0.00	0.00	0.00	27.90
98%	0.00	0.00	0.00	0.00	39.62
95%	0.00	0.00	7.39	0.00	57.64
90%	8.48	0.53	20.52	0.00	81.44
80%	33.24	77.49	47.33	108.48	121.86
70%	46.61	189.71	83.04	292.64	168.31
60%	62.56	355.6	141.1	536.0	237.7
50%	99.78	655.1	225.0	878.5	335.7
40%	158.1	1,152	371.7	1,918	480.6
30%	259.6	2,013	603.8	4,292	710.8
20%	453.4	3,315	1,027	8,627	1,129
10%	1,008	6,148	1,898	20,000	2,139
Maximum	43,463	49,298	39,366	66,176	151,009

Table 9.8
Frequency Statistics in cfs for Daily Unappropriated Flows at SB3 EFS Sites

CP	NENE	NERO	ANAL	NEEV	VIKO
Mean	175.7	1,587	320.3	3,776	668.9
Std Dev	629.3	3,343	832.1	6,567	2,308
Minimum	0.00	0.00	0.00	0.00	0.00
99%	0.00	0.00	0.00	0.00	0.00
70%	0.00	0.00	0.00	0.00	0.00
60%	0.00	0.00	0.00	0.00	0.00
50%	0.00	0.00	0.00	190.8	94.89
40%	0.00	233.3	0.00	734.0	238.7
30%	22.20	933.3	57.35	2,692	443.6
20%	91.37	2,421	372.6	7,026	789.6
10%	428.7	5,317	1,052	18,019	1,752
Maximum	18,196	39,825	17,904	65,596	150,932

Observed daily, monthly, and annual flows at control points NERO and NEEV are plotted in Figures 4.4-4.7 of Chapter 4. Monthly 1940-2019 naturalized flows at the 20 primary control points are plotted in Figures 5.1-5.20. The following Figures 9.9-9.13 are plots of the mean daily simulated regulated flow rate in cfs for each of the 29,220 days of the 1940-2019 period-of-analysis for *SIMD* simulation D1. Regulated flows computed by *SIMD* in units of acre-feet/day have been converted to cfs within *HEC-DSSVue*. Tables 9.6-9.8 and Figures 9.9-9.13 reflect the previously discussed daily *SIMD* simulation D1 which has no routing and no forecasting.

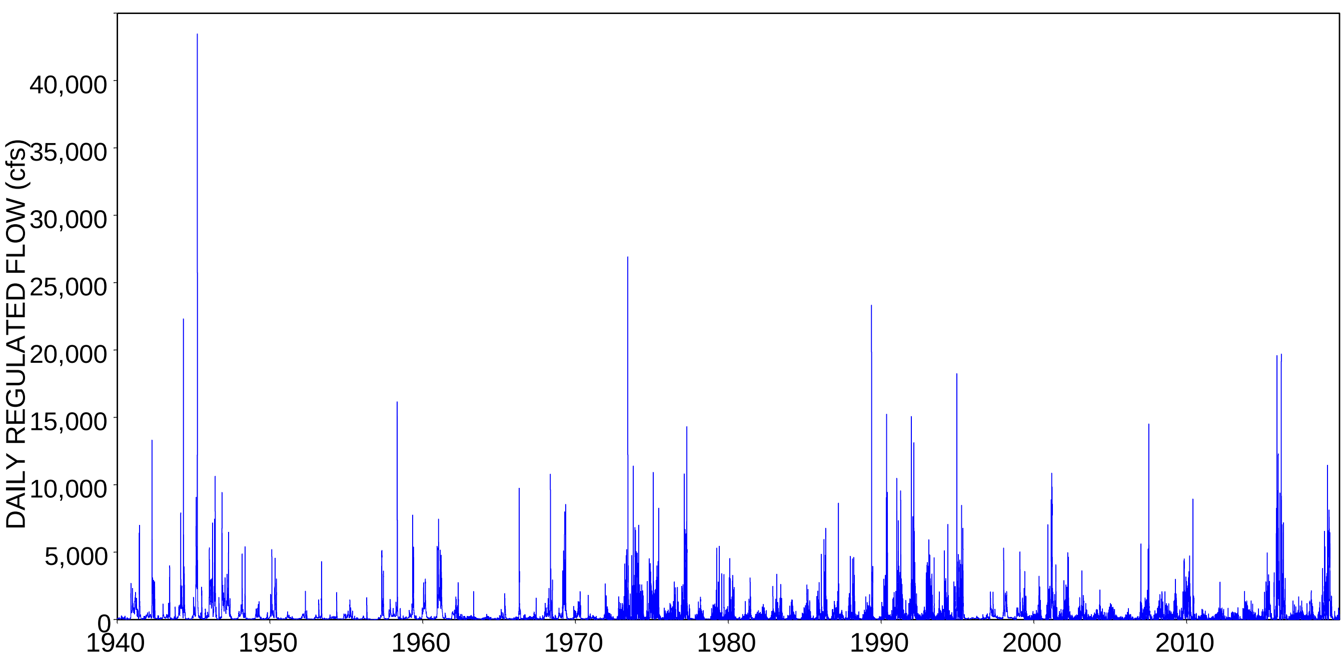

Figure 9.9 Simulated Daily Regulated Flow of the Neches River at Neches
(Control Point NENE)

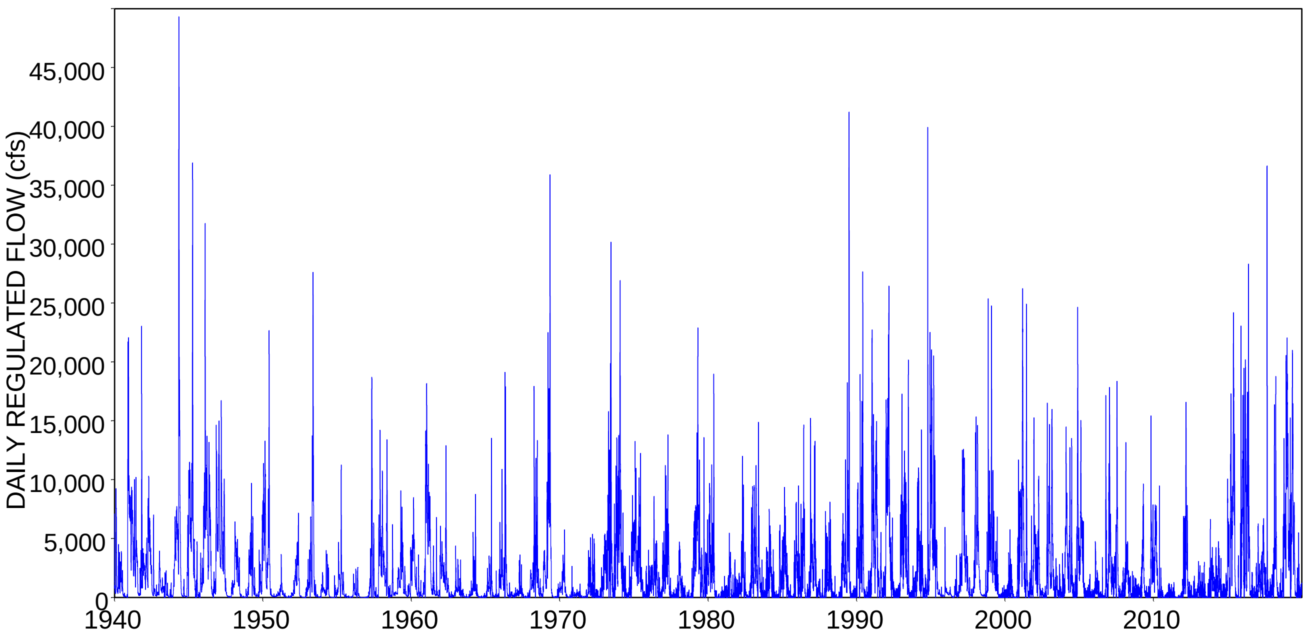

Figure 9.10 Simulated Daily Regulated Flow of the Neches River near Rockland (Control Point NERO)

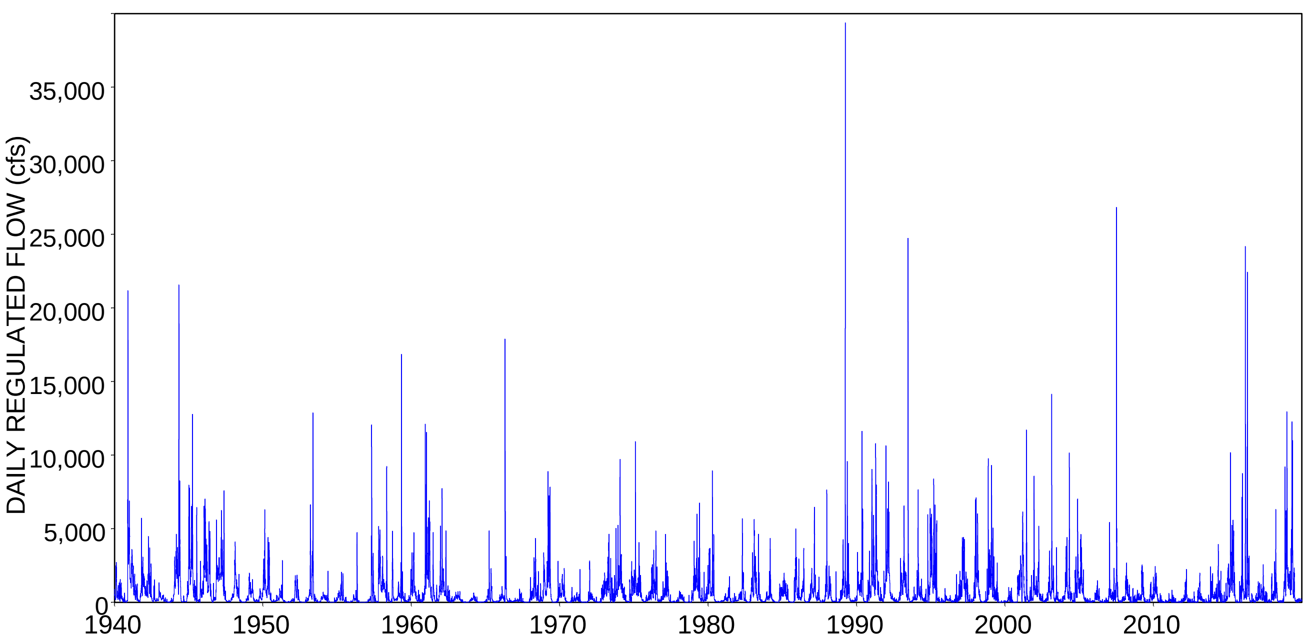

Figure 9.11 Simulated Daily Regulated Flow of the Angelina River near Alto (Control Point ANAL)

Flood control operations of Sam Rayburn Reservoir are evident in the observed daily flows of Figure 4.6 and simulated flows plotted in Figure 9.12. Flood control operations of Sam Rayburn Reservoir are based on making no releases from the flood control pool that would contribute to flows at the gage on the Neches River at Evadale (control point NEEV) exceeding 20,000 cfs. The high flows plotted in Figure 9.12 are often 20,000 cfs. River flows greater than 20,000 cfs result from flood flows entering the river from the watershed not controlled by Sam Rayburn Reservoir.

The vertical scale of the Figure 9.13 graph ranges from zero to 70,000 cfs to more clearly show lower flows. Flows of Village Creek at Kountze (VIKO) exceed 70,000 cfs during three days of Hurricane Harvey flooding. The *SIMD* simulated mean daily regulated flows are 151,009 cfs, 145, 009 cfs, and 89,297 cfs during August 30, 2017, August 31, 2017, and September 1, 2017. The actual observed flows recorded at the USGS gage during these three days are 151,000 cfs, 145,000 cfs, and 89,300 cfs, which are essentially the same as the simulated flows.

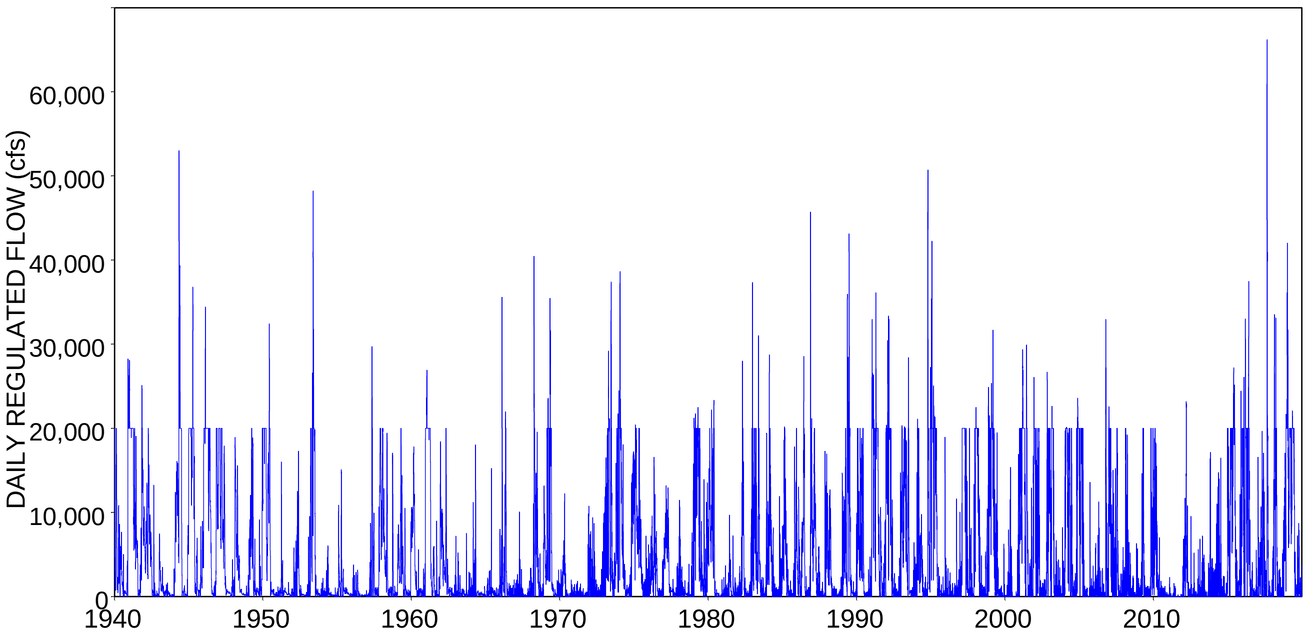

Figure 9.12 Simulated Daily Regulated Flow of the Neches River at Evadale
(Control Point NEEV)

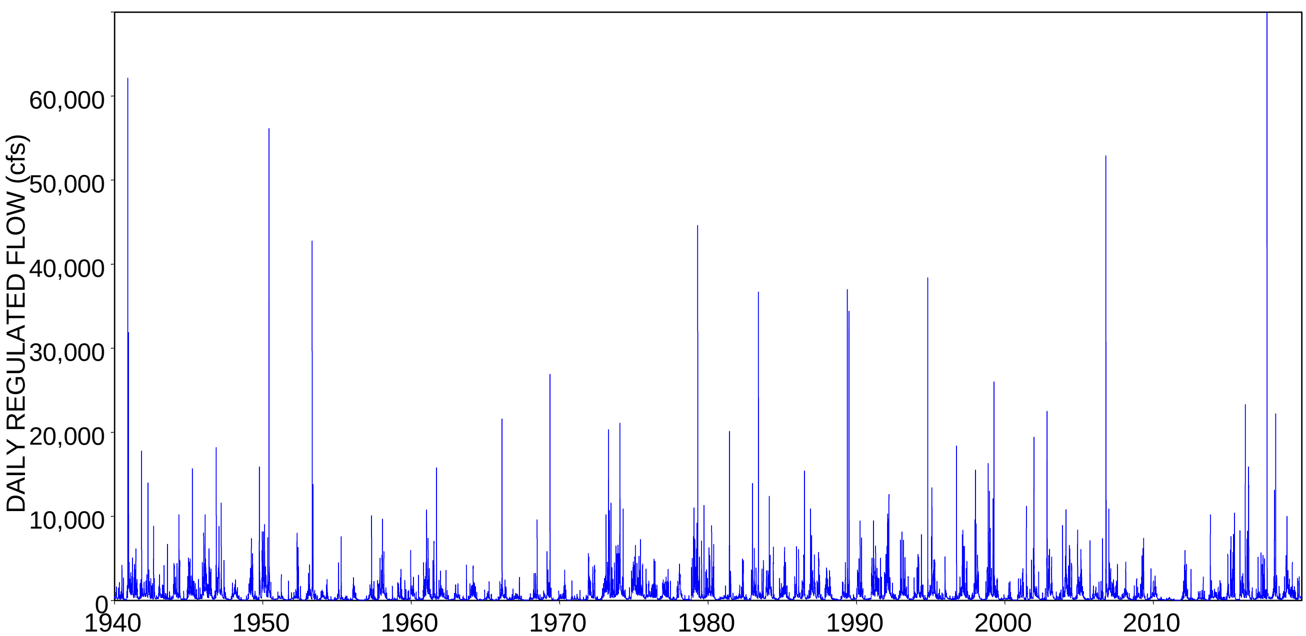

Figure 9.13 Simulated Daily Regulated Flow of Village Creek near Kountze
(Control Point VIKO)

Daily Instream Flow Targets for SB3 EFS

The Senate Bill 3 (SB3) environmental flow standards (EFS) and modeling thereof are explained in Chapter 7. The SB3 EFS are modeled in the *SIMD* simulation as instream flow *IF* record water rights. Daily *IF* record instream flow targets for the SB3 EFS computed in a *SIMD* simulation are summed to monthly for inclusion in the monthly *SIM* input dataset as discussed later in this chapter.

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

SB3 EFS subsistence and base limits are tabulated in Table 9.9. Pulse flow specifications are listed in Table 9.10. SB3 EFS seasons are defined as follows: Winter (December, January, February), Spring (March, April, May), Summer (June, July, August), Fall (September, October, November). One high flow pulse per season is specified for the Winter and Summer and two pulses per season for Spring and Fall for all five sites. Tracking of pulse flow events each season is performed independently of preceding and subsequent seasons.

Table 9.9
Subsistence and Base Flow Limits for SB3 Environmental Flow Standards

Control Point	Units of Flow Limits	Subsidence Flow Limits				Base Flow Limits			
		Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
NENE	cfs	51	21	12	13	196	96	46	80
	acre-feet/day	101.2	41.65	23.80	25.79	388.8	190.4	91.2	158.7
NERO	cfs	67	29	21	21	603	420	67	90
	acre-feet/day	132.9	57.52	41.7	41.7	1,196	833.1	132.9	178.5
ANAL	cfs	55	18	11	16	277	90	40	52
	acre-feet/day	109.1	35.70	21.82	31.74	549.4	178.5	79.3	103.1
NEEV	cfs	228	266	228	228	1,925	1,804	580	512
	acre-feet/day	452.2	527.6	452.2	452.2	3,818	3,578	1,150	1,016
VIKO	cfs	83	49	41	41	264	117	77	98
	acre-feet/day	164.6	97.19	81.32	81.32	523.6	232.1	152.7	194.4

SB3 EFS subsistence and base flow limits and high pulse flow trigger limits are specified in units of cubic feet per second (cfs). Stream flows and instream flow targets in the *SIMD* computations and simulation results are in units of acre-feet per day. These limits are tabulated in both cfs and acre-feet/day in Tables 9.9 and 9.10. A flow rate of 1.0 acre-foot per day is equal to 0.5041667 cubic feet per second.

Simulation of SB3 EFS

The five SB3 EFS are modeled in *SIMD* as instream flow *IF* record water rights with the information in Tables 9.8 and 9.9 provided on the environmental standard *ES* and pulse flow *PF* records replicated in Tables 7.6 and 7.7 as explained in Chapter 7.

Table 9.10
Metrics for High Flow Pulse Components of SB3 Environmental Flow Standards

CP	Site	Criteria	Winter	Spring	Summer	Fall
		Trigger (cfs)	833	820	113	345
NENE	Neches River	Trigger (ac-ft/day)	(1,652)	(1,626)	(224.1)	(684.3)
	at Neches	Volume (acre-feet)	19,104	20,405	1,339	5,391
		Duration (days)	10	12	4	8
		Trigger (cfs)	3,080	1,720	195	515
NERO	Neches River	Trigger (ac-ft/day)	(6,109)	(3,412)	(386.8)	(1,021)
	at Rockland	Volume (acre-feet)	82,195	39,935	1,548	8,172
		Duration (days)	14	12	5	8
		Trigger (cfs)	1,620	1,100	146	588
ANAL	Angelina River	Trigger (ac-ft/day)	(3,213)	(2,182)	(289.6)	(1,166)
	at Alto	Volume (acre-feet)	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	Neches River	Trigger (ac-ft/day)	(4,007)	(7,597)	(3,055)	(3,114)
	at Evadale	Volume (acre-feet)	20,920	68,784	21,605	17,815
		Duration (days)	6	12	9	7
		Trigger (cfs)	2,010	1,380	341	712
VIKO	Village Creek	Trigger (ac-ft/day)	(3,987)	(2,737)	(676)	(1,412)
	at Kountze	Volume (acre-feet)	36,927	23,093	6,159	11,426
		Duration (days)	13	13	8	9

Options for selection of components of instream flow targets to be recorded in the *SIMD* simulation results output file are outlined in Table 7.8 of Chapter 7. The two alternative sets of *IF*, *ES*, and *PF* records used to model the SB3 EFS are replicated in Tables 7.6 and 7.7. Both sets of input records result in the same final instream flow targets. However, the input records in Table 7.6 allow intermediate as well as final targets to be recorded in the *SIMD* output file. The input records in Table 7.7 allow targets for only the final SB3 EFS at each of the five control points to be recorded. The input records in Table 7.6 store the targets for the *ES* and *PF* records components as well as the final SB3 EFS at each of the five control points.

The means of the 1940-2019 sequences of naturalized, regulated, and unappropriated flows and SB3 EFS targets and shortages are compared in Tables 9.11 and 9.12. The combined subsistence and base flow targets are the TIF-WR targets defined in Table 7.8 for the water rights IF-NENE-ES, IF-NERO-ES, IF-ANAL-ES, IF-NEEV-ES, and IF-VIKO-ES in Table 7.6. The pulse flow targets are the TIF-WR targets for the water rights IF-NENE-PF, IF-NERO-PF, IF-ANAL-PF, IF-NEEV-PF, and IF-VIKO-PF in Table 7.6. The final SB3 EFS targets are the IFT-WR targets for pulse flows or combined flows of the IFT-CP targets for control points (Table 7.8).

The shortages in meeting instream flow targets consider all *IF* record rights at a control point including both the subsistence/base components of SB3 EFS and any other more senior *IF* record rights. Since no other *IF* record rights are located at the five control points, the shortages are related only to the SB3 EFS. Water rights are considered in a priority sequence with the pulse flows being most junior.

Table 9.11
Means of 1940-2019 Daily Flow Quantities in acre-feet per day

Control Point	NENE	NERO	ANAL	NEEV	VIKO
	(ac-ft/day)	(ac-ft/day)	(ac-ft/day)	(ac-ft/day)	(ac-ft/day)
Observed flow	1,449	4,943	1,647	12,466	1,781
Naturalized flow	1,530	5,020	1,863	12,783	1,780
Regulated flow	831.7	4,241	1,416	9,187	1,779
Unappropriated	348.5	3,148	635.3	7,490	1,327
<u>Flow Targets</u>					
subsistence/base	138.2	462.7	187.7	1,499	249.0
pulse flow	69.36	249.1	134.7	260.9	142.4
SB3 EFS	192.4	652.1	302.7	1,643	370.0
<u>Target Shortages</u>					
before pulse	0.000	0.000	0.000	0.000	0.000
with pulse flow	1.054	10.20	5.301	39.11	0.000

Table 9.12
Means of 1940-2019 Daily Flow Quantities in cubic feet per second

Control Point	NENE	NERO	ANAL	NEEV	VIKO
	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
Observed flow	730.4	2,492	830.2	6,285	897.8
Naturalized flow	771.6	2,531	939.2	6,445	897.2
Regulated flow	419.3	2,138	714.0	4,632	896.7
Unappropriated	175.7	1,587	320.3	3,776	668.9
<u>Flow Targets</u>					
subsistence/base	69.68	233.3	94.63	755.7	125.5
pulse flow	34.97	125.6	67.91	131.5	71.79
SB3 EFS	97.00	328.8	152.6	828.3	186.5
<u>Target Shortages</u>					
before pulse	0.000	0.000	0.000	0.000	0.000
with pulse flow	0.531	5.143	2.673	19.72	0.000

Daily instream flow targets for the SB3 EFS are computed in the *SIMD* simulation for each day as the maximum of the computed subsistence and base flow target and the pulse flow target. Subsistence and base flow targets are set as minimum flow limits defined on environmental flow *ES* records. Shortages in meeting subsistence and base flow targets are deficits between the targeted minimum flow limits and regulated stream flow at the end of the water right priority sequence simulation for the day. The high pulse flow components of the SB3 EFS controlled by pulse flow *PF* records replicate regulated flows computed within the water rights priority sequence, which differs from the final regulated flow at the completion of the priority sequence. Thus, shortages can also occur in meeting pulse flow targets.

The priorities for the *FR* record flood control operations are set junior to the SB3 EFS *IF* record water rights. However, FCDEP option 2 is activated in *FR* record field 6 which means that storing flood waters is not constrained by water availability at downstream control points. Thus, flood control operations can result in shortages in meeting SB3 EFS targets.

The *IF* record daily instream flow targets for the SB3 EFS computed in the *SIMD* simulation are plotted in Figures 9.14 through 9.18.

- The combined subsistence and base flow components of the SB3 EFS targets defined on *ES* records are plotted as a blue solid line. These are the TIF-WR targets (Table 7.8) for water rights IF-NENE-ES, IF-NERO-ES, IF-ALTO-ES, IF-NEEV-ES, and IF-VIKO-ES.
- The SB3 EFS pulse flow targets defined on *PF* records are plotted in Figures 9.14-9.18 as a red dotted line. These are the TIF-WR targets (Table 7.8) for water rights IF-NENE-PF, IF-NERO-PF, IF-ALTO-PF, IF-NEEV-PF, and IF-VIKO-PF.

The SB3 EFS instream flow target at a control point for each day of the simulation is the larger of the subsistence/base flow target specified by the *ES* records and the pulse flow target specified by the *PF* records.

The pulse flow targets plotted in Figures 9.14-9.18 are much larger than the subsistence/base flow targets. However, the means tabulated in Tables 9.11 and 9.12 are lower for pulse flow targets than subsistence/base flow targets. The pulse flow targets are relatively high during occasional high flow events while the much smaller subsistence/base flow targets are set almost every day of the simulation.

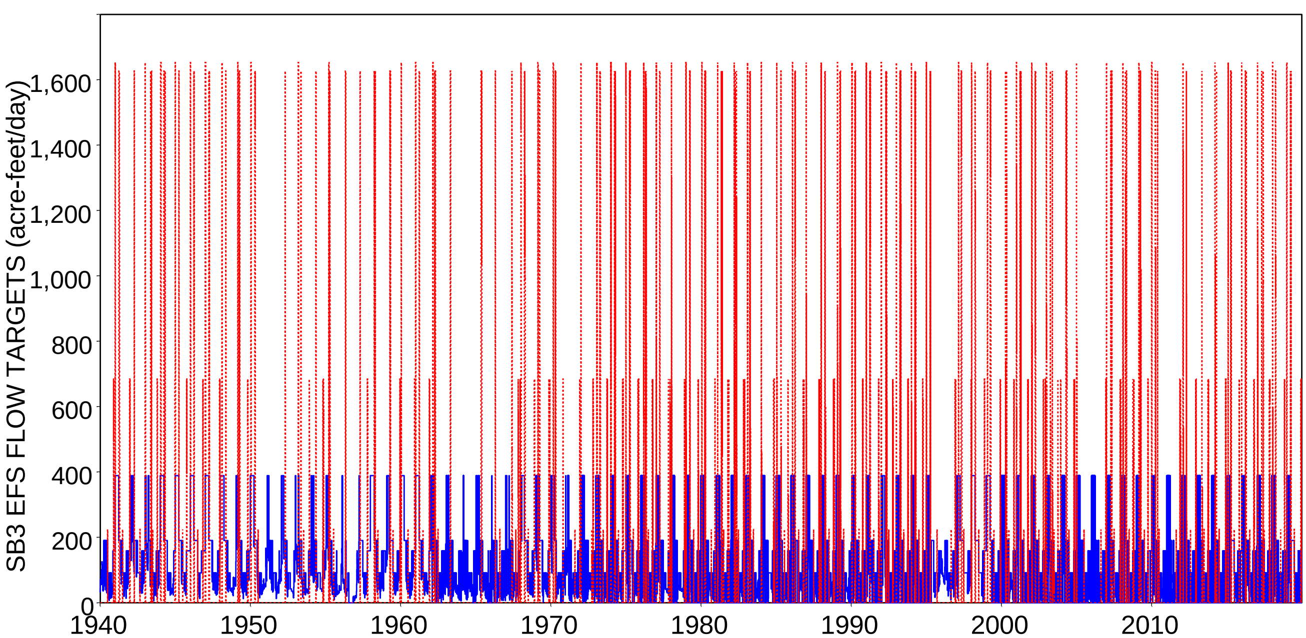

Figure 9.14 Daily Subsistence/Base (blue solid) and Pulse (red dots) Flow Targets at NENE

The final SB3 EFS instream flow target for each individual day is set within the *SIMD* simulation as the greater of the *ES* record subsistence/base target and *PF* record pulse flow target. The final total daily instream flow targets computed by *SIMD* are plotted in Figures 9.19, 9.21, 9.23, 9.25, and 9.27. The monthly summations of the daily targets are plotted in Figures 9.20, 9.22, 9.24, 9.26, and 9.28.

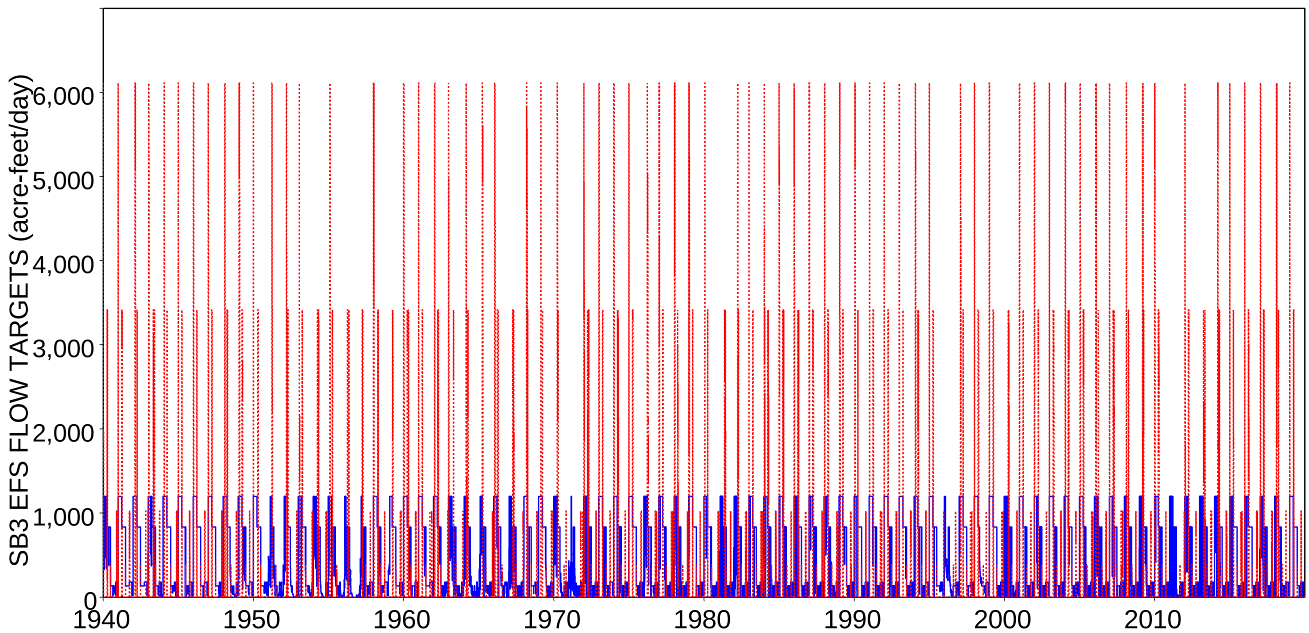

Figure 9.15 Daily Subsistence/Base (blue solid) and Pulse (red dots) Flow Targets at NERO

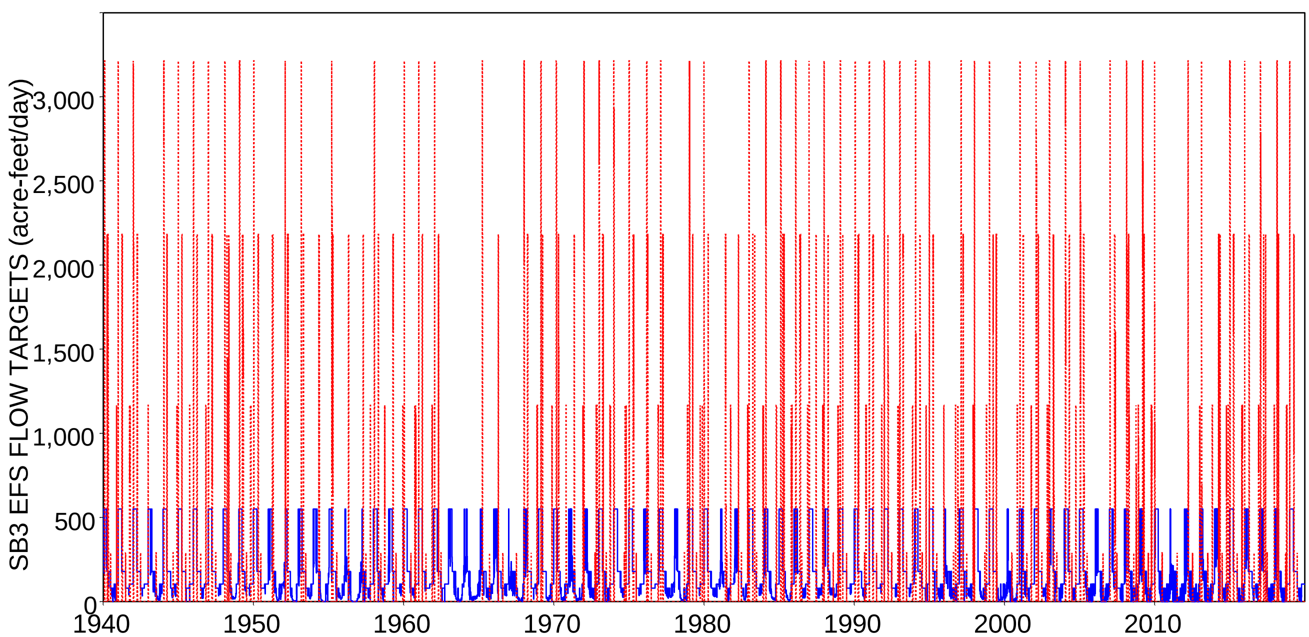

Figure 9.16 Daily Subsistence/Base (blue solid) and Pulse (red dots) Flow Targets at ANAL

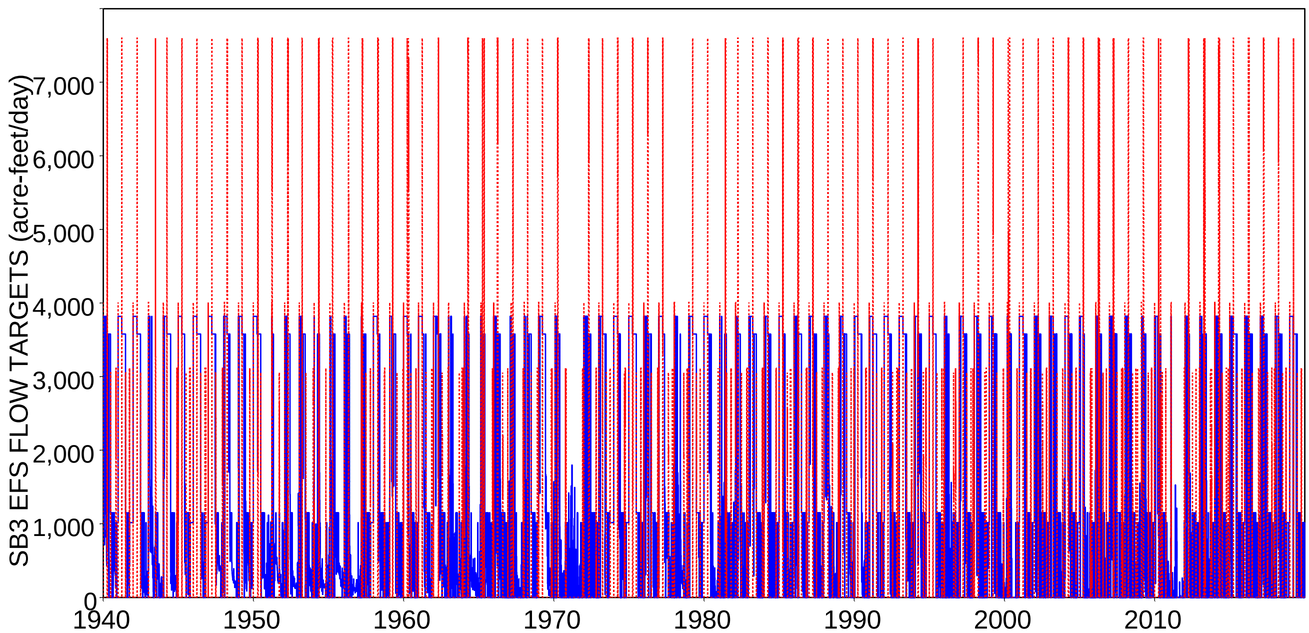

Figure 9.17 Daily Subsistence/Base (blue solid) and Pulse (red dots) Flow Targets at NEEV

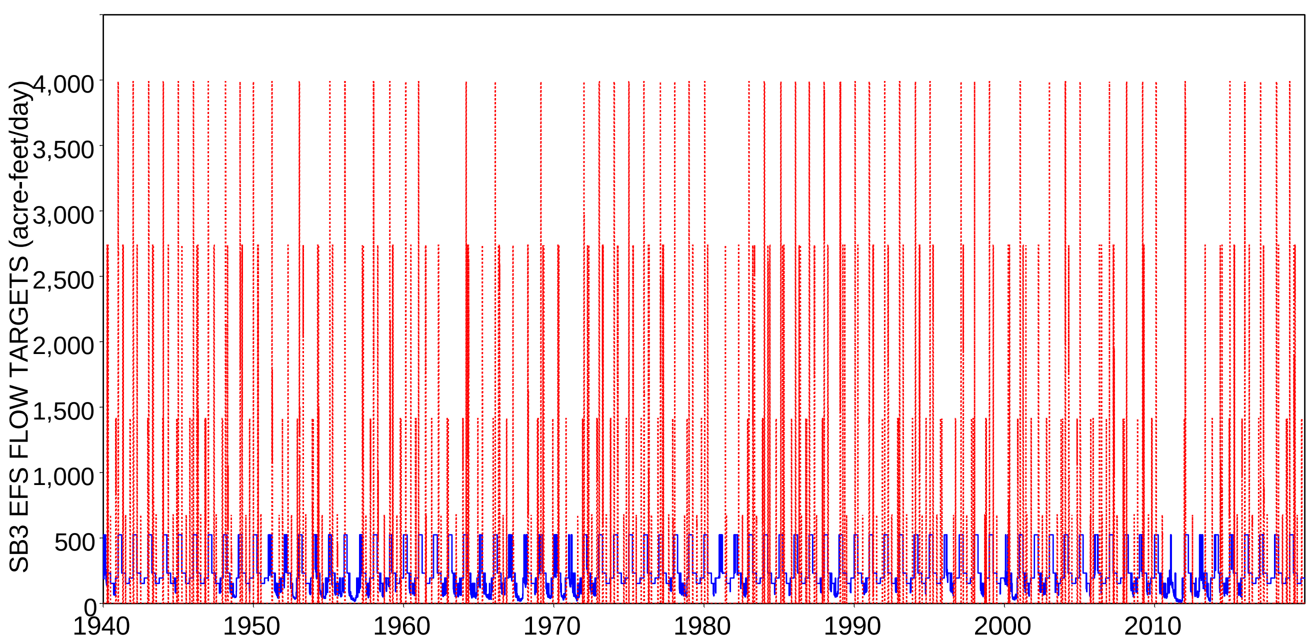

Figure 9.18 Daily Subsistence/Base (blue solid) and Pulse (red dots) Flow Targets at VIKO

Monthly Instream Flow Targets for SB3 EFS from the Daily *SIMD* Simulation

The final daily SB3 EFS instream flow target in acre-feet/day for each of the 29,220 days of the 1940-2019 hydrologic period-of-analysis is the larger of the *ES* record subsistence/base flow target or *PF* record pulse flow target. The final daily SB3 EFS targets in each of the 960 months of 1940-2019 are summed to monthly totals within the *SIMD* simulation. The daily and monthly targets in acre-feet/day and acre-feet/month for simulation D1 are plotted in Figures 9.19-9.28.

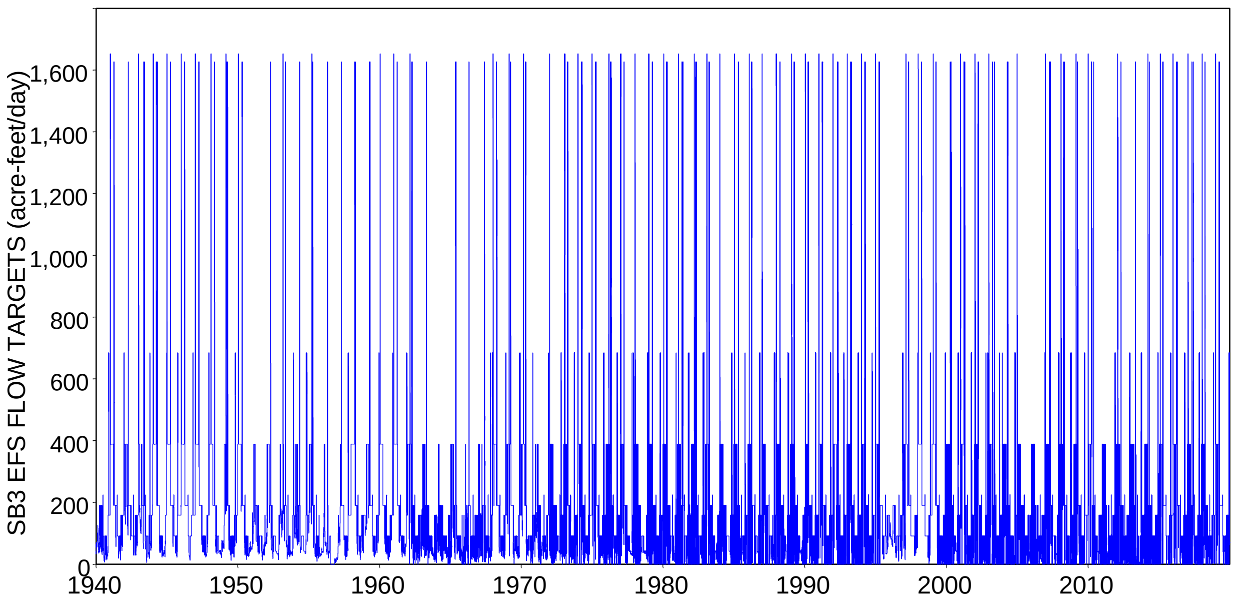

Figure 9.19 Daily SB3 EFS Targets at Control Point NENE

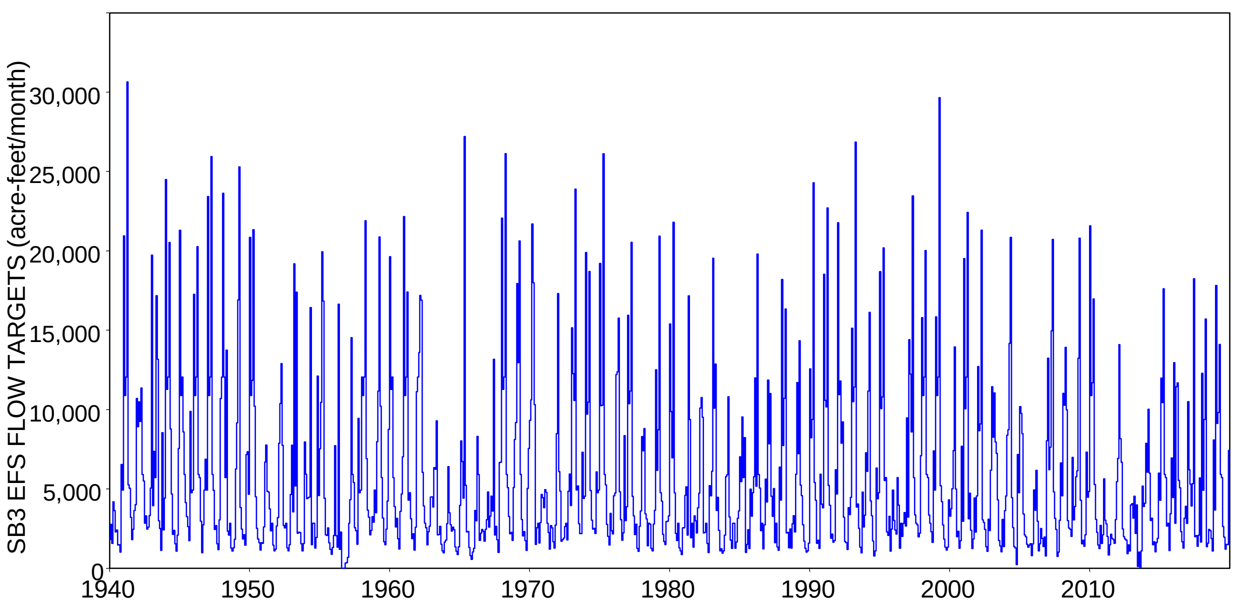

Figure 9.20 Monthly SB3 EFS Targets at Control Point NENE

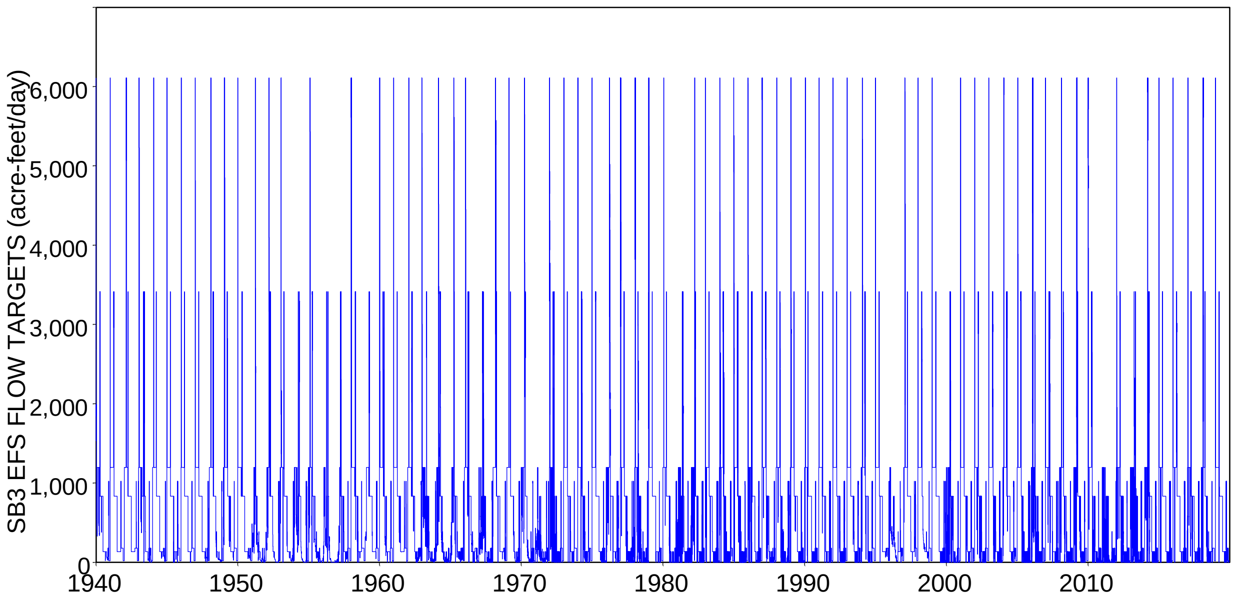

Figure 9.21 Daily SB3 EFS Targets at Control Point NERO

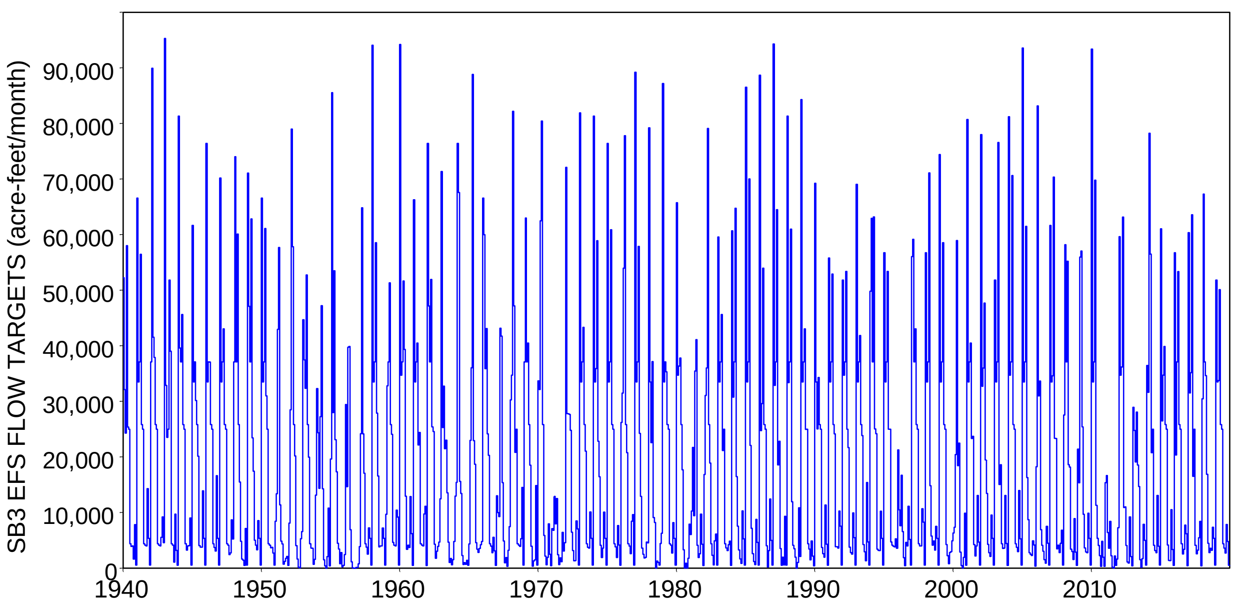

Figure 9.22 Monthly SB3 EFS Targets at Control Point NERO

The procedure for incorporating the monthly SB3 EFS targets generated in the daily *SIMD* simulation into the monthly WAM is described on pages 107-108 of Chapter 5. The monthly instream flow targets in the *SIMD* simulation results DSS output file are converted to time series *TS* records stored in the DSS input file read by *SIM* in monthly simulations. The pathnames for the *TS* records are listed in Table 7.10, which is replicated below as Table 9.13. The *IF* record water rights in presented in Table 7.11 and replicated below as Table 9.14 are inserted in the monthly WAM DAT file. Thus, the monthly SB3 EFS targets computed in the daily *SIMD* simulation are replicated exactly in monthly *SIM* simulations.

Shortages in meeting instream flow targets depend upon regulated flows. Within-month daily variations in the simulated regulated flows are averaged-out in a monthly simulation. Daily shortages in meeting daily instream flow targets are computed by *SIMD* based on daily regulated flows. Monthly shortages for monthly instream flow targets are computed by *SIM* based on monthly regulated flows. Although SB3 EFS monthly instream flow targets are the same in the *SIM* monthly simulation as the daily *SIMD* simulation, shortages in meeting the targets differ greatly between daily and monthly simulations. The total shortages in meeting the SB3 EFS instream flow targets tend to be smaller in a monthly *SIM* simulation than in the daily *SIMD* simulation.

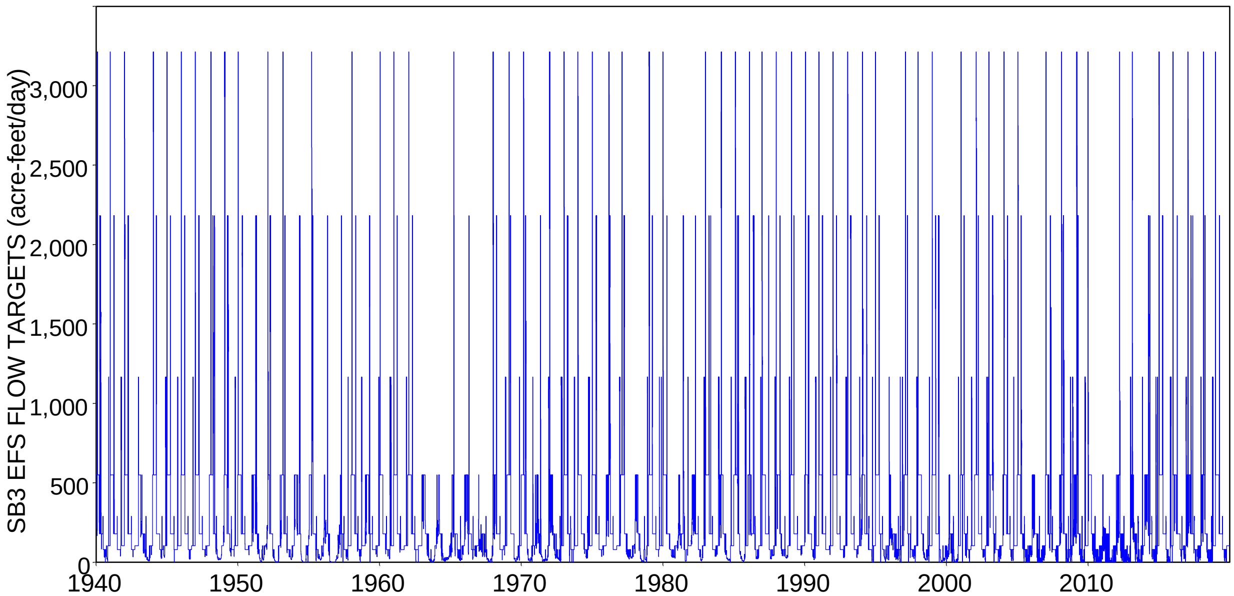

Figure 9.23 Daily SB3 EFS Targets at Control Point ANAL

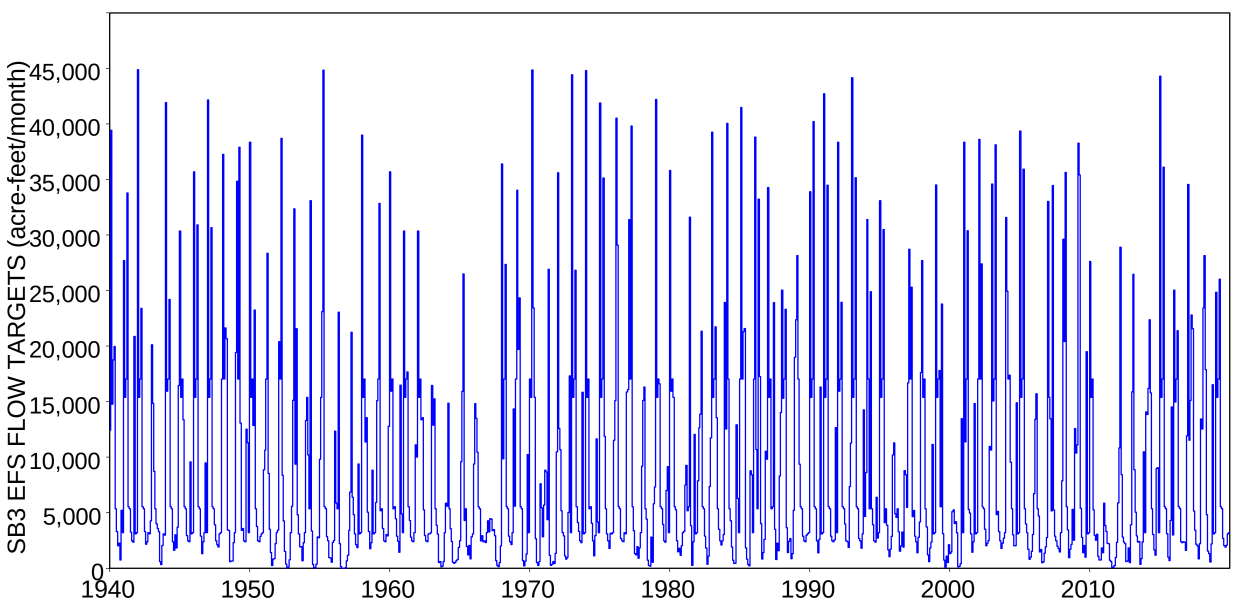

Figure 9.24 Monthly SB3 EFS Targets at Control Point ANAL

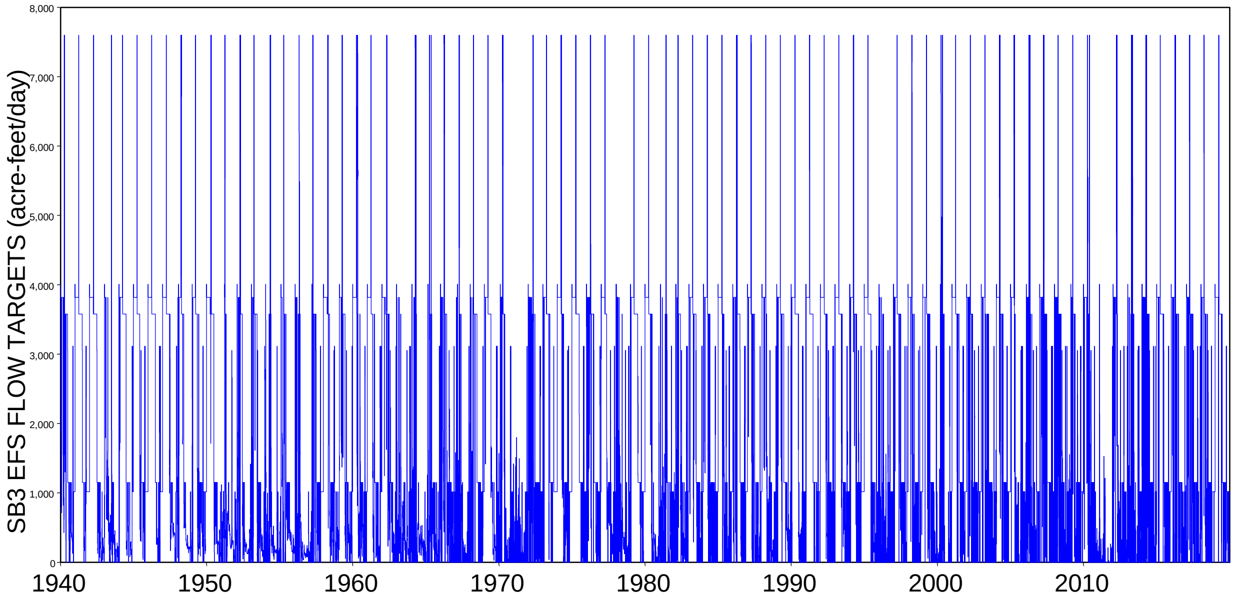

Figure 9.25 Daily SB3 EFS Targets at Control Point NEEV

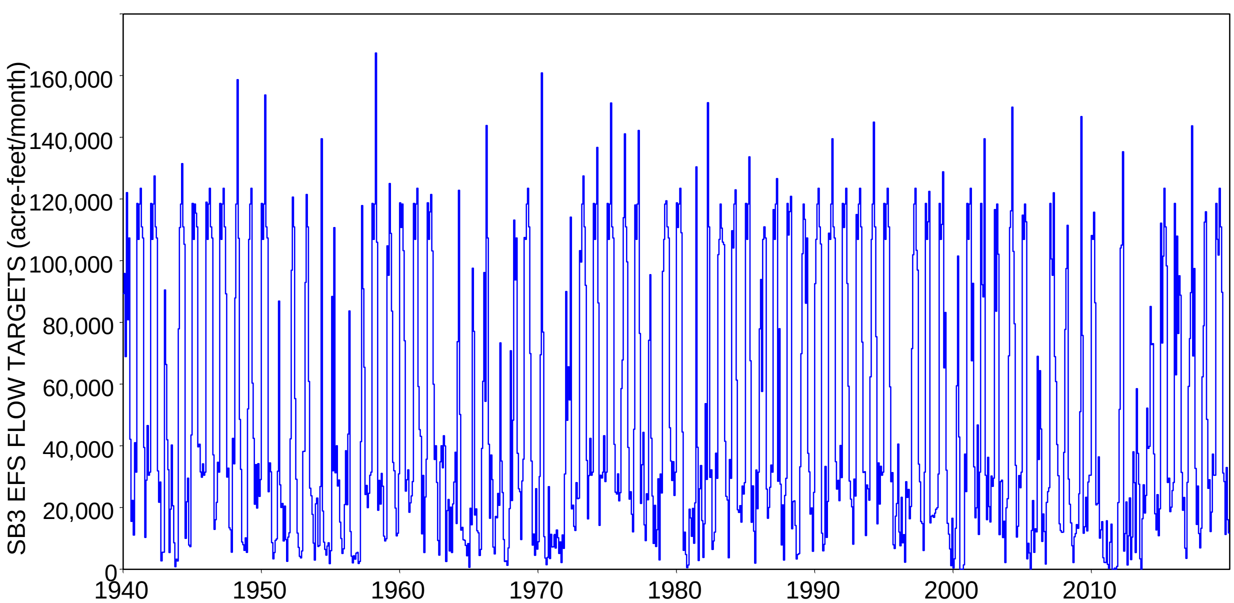

Figure 9.26 Monthly SB3 EFS Targets at Control Point NEEV

The records modeling the SB3 EFS added by the TCEQ in 2012 to the October 2012 version of the Neches WAM DAT file described in Chapter 2 are removed and replaced with the input records shown in Tables 9.13 and 9.14. The DSS records with pathnames listed in Table 9.13 are included in the *SIM* time series input file with filename NechesHYD.DSS introduced in Table 4.14. These DSS records of time series *TS* records of 1944-2019 monthly instream flow targets for the SB3 EFS at the five control points are referenced by the *IF* record instream flow rights replicated in Table 9.14 which are inserted in the monthly DAT file. Input parameter DSSTS in *JO* record field 1 is switched on to indicate that TS records are read from the DSS file.

The identifiers in field 3 of the *TS* records in the DAT file (Table 9.14) reference pathname part B of the *TS* records in the DSS file (Table 9.13). The "A" for authorized added to the control point identifiers distinguishes these *TS* records for the authorized use scenario from the corresponding current use scenario "C" records added to the DSS file as described in Chapter 10.

The reservoir storage plots of Figures 9.1-9.8 include simulation M1 performed with the monthly WAM prior to updating the SB3 EFS modeling methodology. However, the update to the methodology presented here has no effect on the simulated reservoir storage contents. The M1 storage plots are identical to storage results from the final monthly WAM.

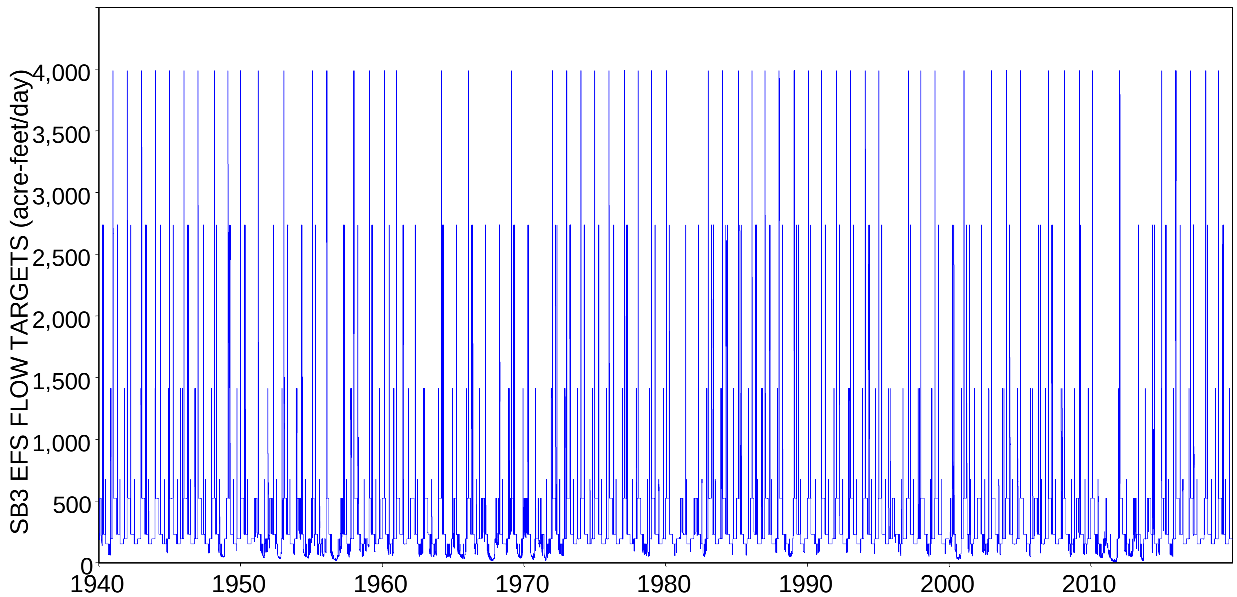

Figure 9.27 Daily SB3 EFS Targets at Control Point VIKO

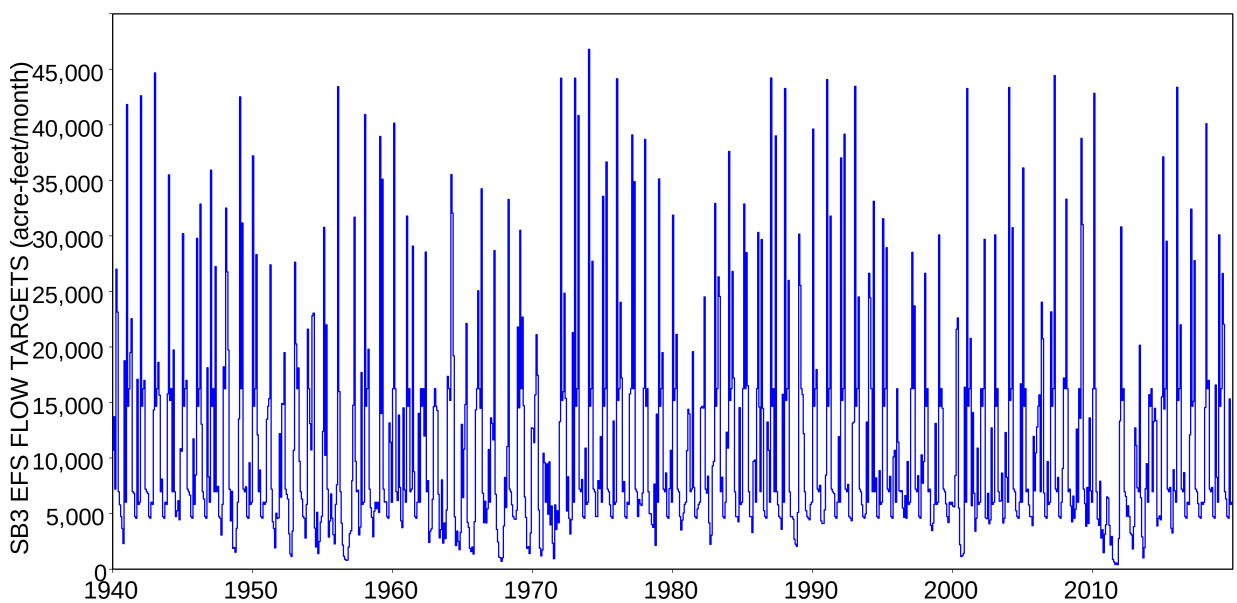

Figure 9.28 Monthly SB3 EFS Targets at Control Point VIKO

Table 9.13
Pathnames for *TS* Records for the SB3 EFS for the Full Authorization Scenario
in the Shared Single Hydrology Input DSS File of the Neches WAM

Part A	Part B	Part C	Part D	Part E
NECHES	ANENE	TS	01Jan1940-31Dec2019	1MON
NECHES	ANERO	TS	01Jan1940-31Dec2019	1MON
NECHES	AANAL	TS	01Jan1940-31Dec2019	1MON
NECHES	ANEEV	TS	01Jan1940-31Dec2019	1MON
NECHES	AVIKO	TS	01Jan1940-31Dec2019	1MON

Table 9.14
Instream Flow Rights that Model the SB3 EFS in the DAT File of the
Monthly Authorized Use Scenario Version of the Neches WAM

```
IF  NENE                    20091201   2            IF-NENE
TS       DSS  ANENE
IF  NERO                    20091201   2            IF-NERO
TS       DSS  ANERO
IF  ANAL                    20091201   2            IF-ANAL
TS       DSS  AANAL
IF  NEEV                    20091201   2            IF-NEEV
TS       DSS  ANEEV
IF  VIKO                    20091201   2            IF-VIKO
TS       DSS  AVIKO
```

DSS File with Selected Simulation Results

The last section of Chapter 4 entitled "*Hydrology and Daily Flow DSS Files"* describes the use of DSS and *HEC-DSSVue* and lists the DSS files that accompany this report. The DSS files are easily and efficiently accessible using *HEC-DSSVue*. These DSS files referenced in Chapters 4, 5, 6, 9, 10, and 12 serve as appendices to this report, document computational procedures, and facilitate convenient graphical, tabular, and statistical comparisons of relevant datasets that provide insights into the modeling and analysis methods employed and the characteristics of river system hydrology and water resources management capabilities.

Selected simulation results from Chapters 9 and 10 are stored in a DSS file with the filename NechesSimulationResults.DSS that accompanies this report. Pathname conventions followed by *SIM* and *SIMD* in recording time series results to the *SIM/SIMD* DSS output file are described in Chapter 6 of the *Users Manual* [2]. Pathnames in existing DSS files are easily modified within the *HEC-DSSVue* editor. However, only minimal post-simulation modifications have been made to the pathnames assigned by *SIM* and *SIMD*. Post-simulation revisions to pathname part F are used to differentiate between simulations M1, D1, D2, D3, D4, and D5 as appropriate. Examples of the pathnames for the 176 records in the simulation results DSS file are provided in Table 9.15. The labels assigned to pathname part A are defined in Table 9.16.

Table 9.15
Examples of DSS Pathnames for the DSS File with Selected Simulation Results

	Part A	Part B	Part C	Part D / range	Part E	Part F
1	NECHES3	3254N1	STO-CP	01JAN1940-31Dec2019	1MON	M1
2	NECHES3D	4411A1	STO-CP	01JAN1940-31Dec2019	1DAY	D1
3	NECHES3D	TOTAL	6STO	01JAN1940-31Dec2019	1DAY	D5
4	NECHES3D	NEEV	NAT-CP	01JAN1940-31Dec2019	1DAY	CPDAILY
5	NECHES3D	NEEV	REG-CP	01JAN1940-31Dec2019	1DAY	CPDAILY
6	NECHES3D	NEEV	REG-CP	01JAN1940-31Dec2019	1DAY	CFS
7	NECHES3D	NEEV	IFT-CP	01JAN1940-31Dec2019	1DAY	CP
8	NECHES3D	NEEV	IFT-CP	01JAN1940-31Dec2019	1MON	CP DAILY
9	NECHES3D	NEEV	IFT-WR	01JAN1940-31Dec2019	1DAY	IF-NEEV-PF
10	NECHES3D	NEEV	IFT-WR	01JAN1940-31Dec2019	1MON	IF-NEEV-PF
11	NECHES3M	NERO	NAT-CP	01JAN1940-31Dec2019	1MON	CP
12	NECHES3M	NERO	REG-CP	01JAN1940-31Dec2019	1MON	CP
13	NECHES3M	NERO	UNA-CP	01JAN1940-31Dec2019	1MON	CP
14	NECHES3M	NERO	IFT-CP	01JAN1940-31Dec2019	1MON	CP
15	NECHES3M	NERO	IFS-CP	01JAN1940-31Dec2019	1MON	CP

Table 9.16
DSS Pathname Part A in the DSS File with Selected Simulation Results

Part A	Description
Neches3	October 2012 monthly authorized use WAM with hydrology through 2019.
Neches3D	June 2020 daily authorized use scenario WAM employed in Chapter 9.
Neches3M	June 2020 monthly authorized use scenario WAM developed in Chapter 9.
Neches8	September 2012 monthly current use WAM with hydrology through 2019.
Neches8D	June 2020 daily current use scenario WAM employed in Chapter 10.
Neches8M	June 2020 monthly current use scenario WAM developed in Chapter 10.

Table 9.15 is in the format of the table viewed on the computer monitor when using *HEC-DSSVue* to select and view data records and manage time series datasets. All DSS records are labeled with pathname with parts A, B, C, D, and E as explained in the *HEC-DSSVue* and WRAP *Users Manuals* [2, 8].

The *SIM* and *SIMD* conventions for assigning labels to DSS records of time series simulation results includes assigning the filename root of the DAT file to pathname part A. The DSS file accompanying this report maintains this convention. Results from the six versions of the WAM listed in Table 9.15 are found in the DSS file. The following versions of the authorized use scenario WAM with pathname part A labels listed in Table 9.15 are covered in Chapter 9: initial monthly WAM with extended hydrology (Neches3), daily (Neches3D), and modified monthly with records from Tables 9.13 and 9.14 (Neches3M). Results from the following corresponding current use scenario versions of the WAM are presented in Chapter 10 and included in this same DSS file: .initial monthly (Neches8), daily (Neches8D), and modified monthly (Neches8M).

SIM and SIMD assign the relevant control point identifier to pathname part B. Fourteen of the 15 pathname examples included in Table 9.15 are for DSS records created by *SIM* or *SIMD*. The third pathname in Table 9.15 is for data created by the *WRAP* program *TABLES* from storage data read from a *SIMD* output SUB file. The pathname part B label *TOTAL* assigned by tables indicates that the daily storage contents (6STO) are the summations for multiple reservoirs.

Options for selecting variables for inclusion in the *SIM*/*SIMD* simulation results DSS output file are provided on the file options *OF* input record described on pages 45-47 of the WRAP *Users Manual* [2]. The 43 time series variables that can be included in the *SIM* or *SIMD* simulation results are listed on page 47 of the *Users Manual* [2] with their definitions and three-character labels. Each of the 43 variables are associated with either control points (CP), water rights (WR), or reservoirs (RE). These identifiers are assigned to DSS pathname part C of the simulation results output file as illustrated by Table 9.16.

Reservoir storage contents for six alternative simulations (M1, D1, D2, D3, D4, D5) defined in Table 9.1 are plotted in Figures 9.1-9.8. These time series are stored in the simulation results DSS file discussed here. Pathname part F has been edited in *HEC-DSSVue* to contain the simulation label. The first pathname in Table 9.16 is for 1940-2019 end-of-month storage contents for Lake Palestine at control point 3254N1 for simulation M1. The second pathname in Table 9.16 references end-of-day storage contents for Sam Rayburn Reservoir at control point 4411A for simulation D1. The third pathname identifies a time series of the summations of 1940-2019 end-of-day storage volumes for ten reservoirs from simulation M5. The DSS file contains 24 records with 1940-2019 storage contents for three individual reservoirs and totals for ten other reservoirs computed in six simulations (M1,. D1, D2, D3, D4, D5).

The simulation results file contains naturalized (NAT-CP), regulated (REG-CP), and unappropriated (UNA-CP) daily flows for control points NENE, NERO, ALTO, NEEV, and VIKO for simulation D1. The pathnames are illustrated by the fourth, fifth, and sixth pathnames in Table 9.15. The regulated daily flows are plotted in Figures 9.5-9.8. Three variables for five control points means DSS records for 15 different 1940-2019 daily time series.

Daily instream flow targets (IFT-CP) for the five SB3-EFS control points and monthly summations thereof are labeled as illustrated by the seventh and eighth example pathnames in Table 9.15. Control point NEEV is used as an example in Table 9.15. The daily instream flow targets and monthly summations thereof are recorded as water right variables (IFT-WR for water right IF-NEEV-PF) labeled as illustrated by the ninth and eighth example pathnames in Table 9.15.

The 11th, 12th, 13th, 14th, and 15th pathnames in Table 9.15 illustrate the format for the pathnames for the final monthly simulation naturalized flows (NAT-CP), regulated flows (REG-CP), unappropriated flows (UNA-CP), instream flow targets (IFT-CP), and instream flow target shortages (IFS-CP) for the fiver SB3 EFS control points. NERO is used as an example.

The example pathnames in Table 9.15 are for Chapter 9 authorized use scenario simulations. Results from the current use simulations of Chapter 10 are also included in the same DSS file.

CHAPTER 10
SIMULATION RESULTS FOR CURRENT USE SCENARIO

The general modeling strategy adopted for simulations with variations of the current use scenario version of the Neches WAM reported in Chapter 10 is essentially the same as for the authorized use scenario simulations of Chapter 9. Only the authorized use scenario version of the WAM is employed in Chapter 9. Chapter 10 employs only the current use scenario. The DSS file of selected simulation results described in the last section of Chapter 9 includes daily and monthly time series results from simulations for variations of both the authorized use (Chapter 9) and current use (Chapter 10) scenario versions of the Neches WAM.

Results from daily and monthly simulations with the current use scenario are presented in this chapter as follows.

1. Reservoir storage contents are plotted in Figures 10.1-10.8 in a continuing comparative analysis of the effects of converting the WAM from monthly to daily and employing routing and forecasting. The daily modeling strategy without routing and forecasting is again adopted for purposes of simulating the Senate Bill 3 (SB3) environmental flow standards (EFS).
2. Observed, naturalized, regulated, and unappropriated flows and SB3 EFS instream flow targets and target shortages at the five SB3 EFS sites are explored and compared. Time series plots (Figures 10.9-10.13) and summary tables of statistical metrics are presented.
3. Monthly SB3 EFS instream flow targets are developed as described on pages 107-108 of Chapter 7. Monthly summations of daily targets from the daily *SIMD* simulation are recorded on target series *TS* records for inclusion in the monthly *SIM* input dataset. The daily and monthly instream flow targets for the SB3 EFS are plotted in Figures 10.14–10.28.

Comparison of Authorized and Current Use Scenario Simulations

Information summarizing simulation results for the current use versus full authorization versions of the Neches WAM are found in the figures and tables listed in Table 10.1. These figures and tables contribute to comparative analyses of the authorized use (full authorization) versus current use versions of the WAM. Various comparative analyses of the data in the simulation results DSS file described in the last section of Chapter 9 are performed using *HEC-DSSVue*.

Table 10.1
Corresponding Figures and Tables for Full Authorization and Current Use Simulations

Simulation Results Presented in Figures and Tables	Authorized Use	Current Use
Reservoir storage plots for six alternative simulations	Figures 9.1-9.8	Figures 10.1-10.8
Reservoir storage statistics for alternative simulations	Tables 9.1-9.4	Tables 9.1-9.4
Stream flow statistics for the five SB3 EFS control points	Tables 9.5-9.8	Tables 10.5-10.8
Simulated regulated flow plots for the SB3 EFS sites	Figures 9.9-.9.13	Figures 10.9-10.13
SB3 EFS information	Tables 9.9-9.12	Tables 10.9-10.10
Plots of SB3 EFS targets	Figures 9.14-9.28	Figures 10.14-10.28
SB3 EFS input records	Tables 9.13-9.14	Tables 10.11-10.12

The authorized use, also called full authorization, scenario models the premise that all water right permit holders use the full amounts authorized by their permits. The current use scenario approximates conditions during the 1990's when the original WAM [9] was developed.

The full authorization and current use scenario versions of the WAM include annual diversion target amounts of 1,730,431 acre-feet/year and 519,666 acre-feet/year, respectively (Tables 2.4 and 2.6). As discussed in Chapter 2, the total permitted conservation storage capacity for the full authorization WAM is 3,904,100 acre-feet in 180 reservoirs. The total conservation storage capacity for the current use WAM is 3,656,259 acre-feet in 203 reservoirs. The current use scenario includes return flows. The authorized use scenario does not include return flows. The current use scenario incorporates term permits as well as regular water right permits. The authorized use scenario simulates only regular water rights; no term permits. Storage capacities of some of the reservoirs have been reduced for sedimentation in the current use scenario. The permitted but not yet constructed Lake Columbia project is included in the authorized use scenario but is not included in the current use scenario.

Water resources in the Neches River Basin are abundant relative to water demand compared to most other river basins in Texas. Demands on water resources in the current use scenario are much less than the permitted water rights modeled in the full authorization version of the Neches WAM. Reservoir storage drawdowns are much less and unappropriated flows are much higher in the current use scenario version of the Neches WAM.

The modeling and analysis methods employed and issues explored in Chapter 9 are also relevant for Chapter 10. As discussed in the next section, the D1 alternative with no routing and forecasting is adopted in both Chapters 9 and 10 for the reasons discussed in Chapter 9.

Storage Contents for Alternative Current Use Scenario Simulations with and without Routing and Forecasting

The major reservoirs with storage capacities of greater than 5,000 acre-feet are described in Chapter 2. Simulated reservoir storage contents for Sam Rayburn and B. A. Steinhagen Reservoirs and Lake Palestine and summations of the storage contents of the other nine reservoirs listed in Table 2.8 resulting from alternative modeling premises are compared in Figures 10.1-10.8 and Tables 10.2-10.4. One monthly (M1) and five daily (D1, D2, D3, D4, D5) alternative simulations are selected for inclusion in the comparative analyses presented in Chapters 9 and 10 are described in Chapter 9, listed in Table 9.1 of Chapter 9, and defined again as follows.

- M1 Monthly *SIM* current use TCEQ WAM with the dataset last updated in September 2012 described in Chapter 2 with the hydrologic period-of-analysis extended through 2019.
- D1 Daily *SIMD* current use simulation with no routing and no forecasting.
- D2 Daily *SIMD* current use simulation with routing and but no forecasting.
- D3 Daily *SIMD* current use simulation with routing and a forecast period of 3 days.
- D4 Daily *SIMD* current use simulation with routing and a forecast period of 10 days.
- D5 Daily *SIMD* simulation with routing and the default forecast period of 57 days.

The 1940-2019 end-of-month storage volumes for the current use scenario version of simulation M1 and end-of-day volumes for the daily current use simulations for Sam Rayburn, B.

A. Steinhagen, and Palestine Reservoirs are plotted in Figures 10.1 through 10.4. The summations of the storage contents of the other nine reservoirs in Table 2.8 are plotted in Figure 10.4. The means of the 960 end-of-month storage volumes from simulation M1 and the 29,220 end-of-day storage volumes from simulations D1, D2, D3, D4, and D5 are tabulated in Table 10.2. The median quantities equaled or exceeded during 50 percent of the 960 months of simulation M1 or the 29,220 days of the daily simulations are shown in Table 10.3. The minimum end-of-month (M1) or end-of-day (D1, D2, D3, D4, D5) storage contents during each of the five 1940-2019 hydrologic period-of-analysis simulations are presented in Table 10.4.

The permitted but not yet constructed Lake Columbia with an authorized storage capacity of 195,600 acre-feet is included in the authorized use but not the current use scenario. Current use storage capacities in Table 2.8 are less than authorized due to estimated reservoir sedimentation. The total permitted conservation storage capacity of 3,852,160 acre-feet of the 13 major reservoirs listed in the tables account for 98.7 percent of the total storage capacity of 3,904,100 acre-feet in the 180 reservoirs in the authorized use scenario dataset. The total conservation storage capacity of 3,601,935 acre-feet of the 12 existing major reservoirs listed in Table 2.8 account for 98.5 percent of the total storage capacity of 3,656,259 acre-feet in the 203 reservoirs in the current use scenario dataset.

Computer execution (run) times are significantly increased by activating forecasting or increasing the forecast period. For example, execution times for a Microsoft Surface Pro laptop computer for the alternative simulations presented here are 1.10 minutes for simulation D1, 1.37 minutes for D2, 5.05 minutes for D3, 11.7 minutes for D4, and 162 minutes for simulation D5.

Simulation D5 employs the default forecast period of 57 days automatically computed by *SIMD* as the twice the total lag time for the longest flow path plus one day [5]. The objective is near-perfect future flow forecasts to protect senior water rights. The totals of the lag times for the longest flow path are 23 days for normal condition lags and 28 days for flood flow lags.

Routing and forecasting methods are explained in the *Daily Manual* [5]. Uncertainties and inaccuracies associated with routing and forecasting are discussed in Chapters 8 and 9 of this report as well as in the *Daily Manual*. Forecasting is relevant and should be activated only if routing is employed [5]. The Brazos [13], Trinity [14], and Neches [this report] WAMs support the conclusion that forecasting and routing may or may not be warranted for various applications.

Determining monthly SB3 EFS instream flow targets from a daily *SIMD* simulation for inclusion in a monthly *SIM* input dataset is the primary application of daily modeling employed in Chapters 9 and 10 of this report. Daily *SIMD* simulation D1 defined in Table 9.1, which has no routing and no forecasting, is adopted for this application in both Chapters 9 and 10 as discussed in greater detail in Chapter 9.

The time series plots of reservoir storage contents presented as Figures 10.1 through 10.4 and the statistics of Tables 10.2-10.4 include monthly simulation M1 and five daily simulations (D1, D2, D3, D4, D5) reflecting alternative premises regarding routing and forecasting. The storage plots of Figures 10.5 through 10.8 are limited to simulations M1 and the selected simulation D1. All of these time series datasets are accessible from the accompanying DSS file with filename NechesSimulationResults.DSS that is described in the last section of Chapter 9.

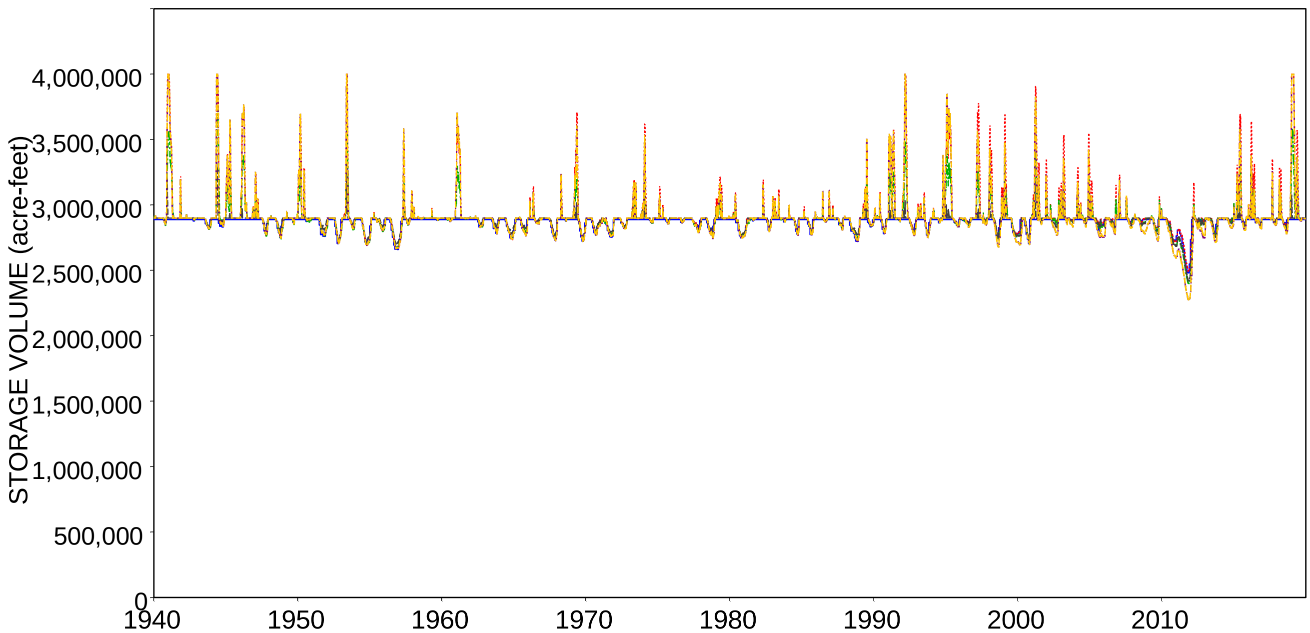

Figure 10.1 Sam Rayburn Reservoir Storage for Alternative 1940-2019 Simulations

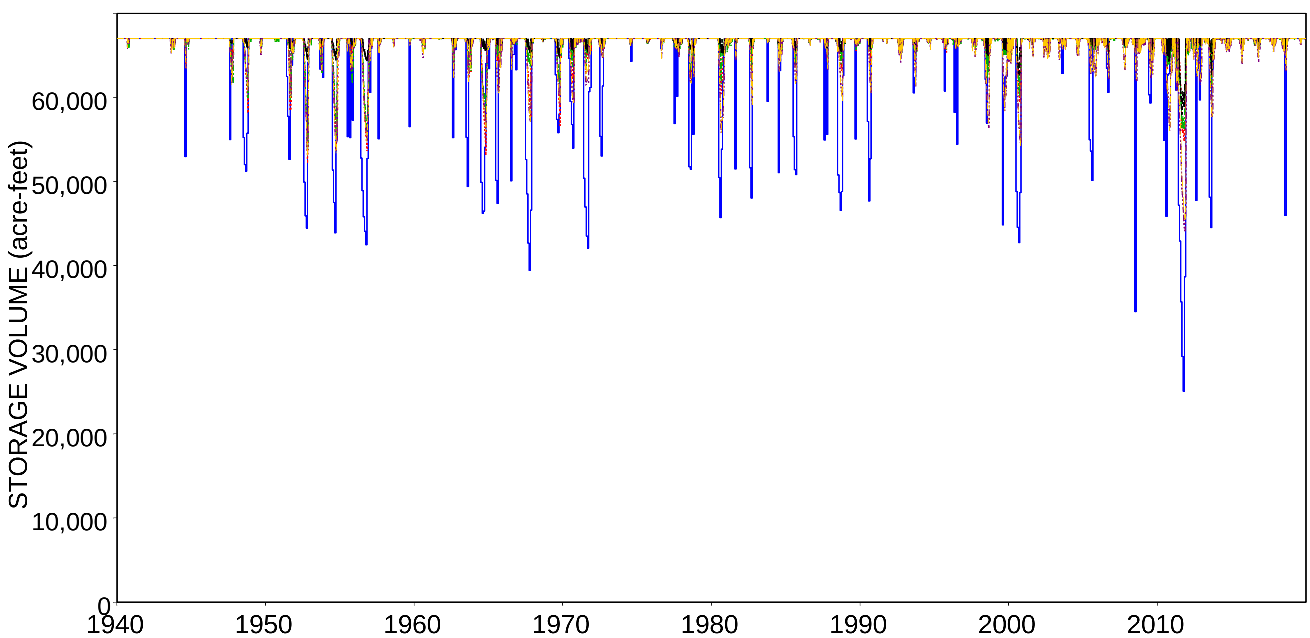

Figure 10.2 B. A. Steinhagen Reservoir Storage for Alternative 1940-2019 Simulations

M1	Original monthly WAM	blue solid line
D1	No routing and no forecasting	red dotted line
D2	Routing but no forecasting	green dashes and dots
D3	Routing and 3-day forecast	black dashed line
D4	Routing and 10-day forecast	purple dashes and dots
D5	Routing and 57-day forecast	orange dashed line

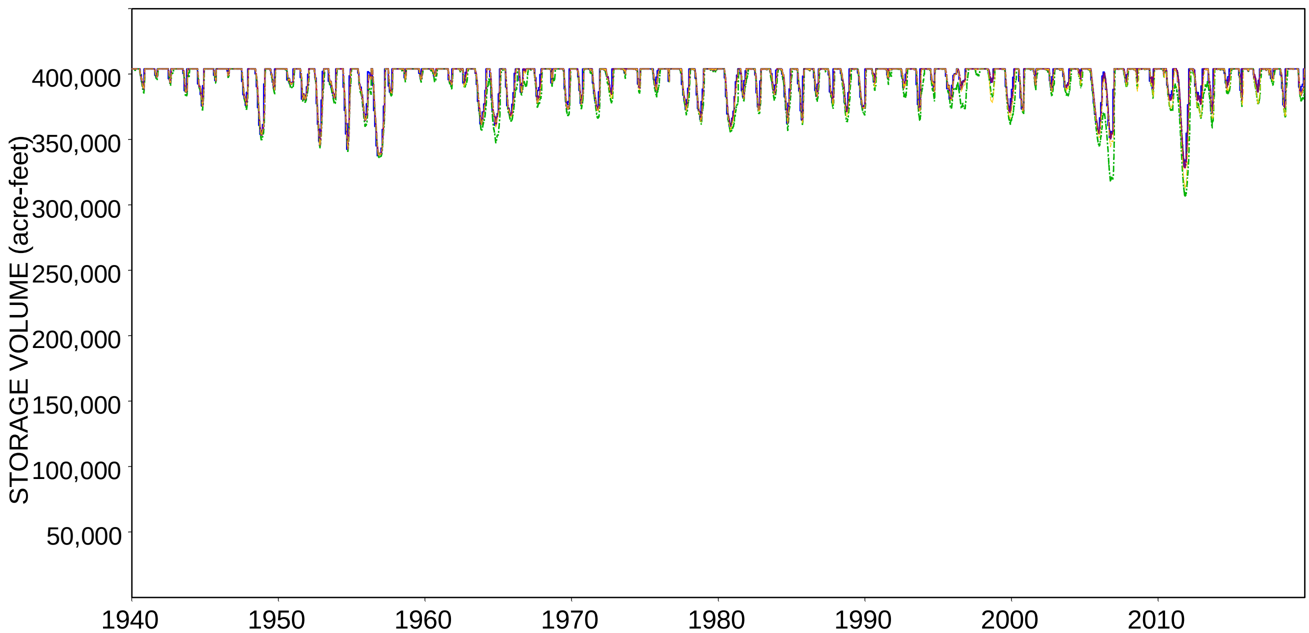

Figure 10.3 Palestine Reservoir Storage for Alternative 1940-2019 Simulations

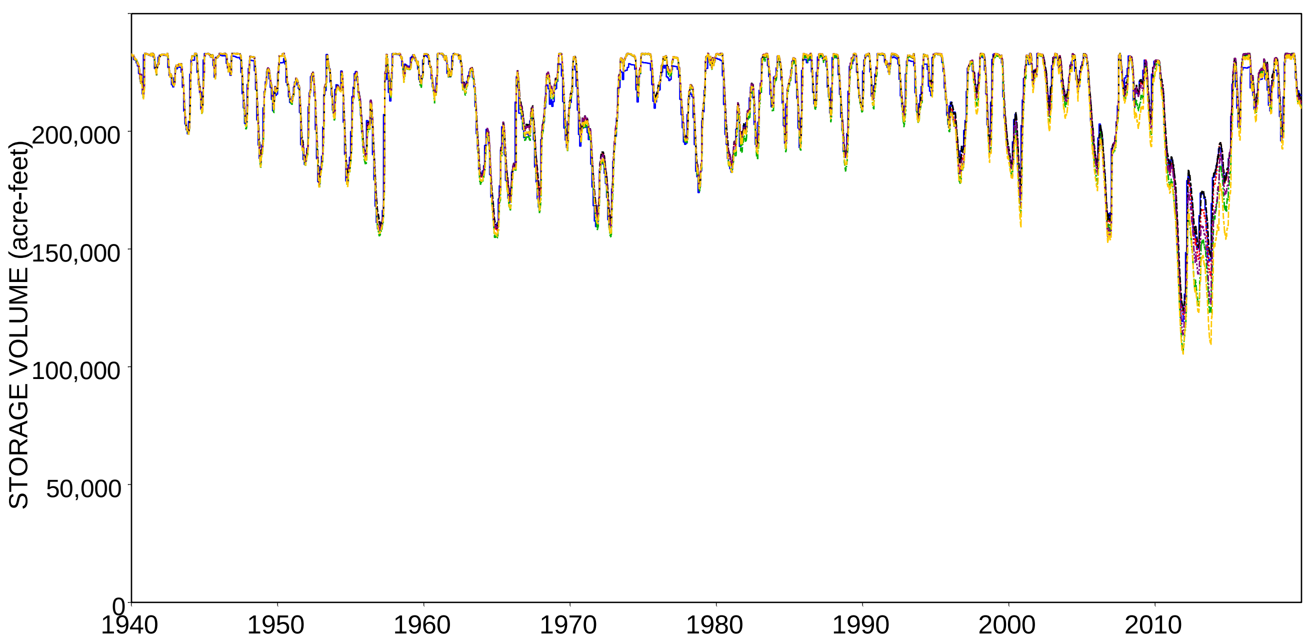

Figure 10.4 Summation of Storage in Nine Reservoirs for Alternative 1940-2019 Simulations

M1	Original monthly WAM	blue solid line
D1	No routing and no forecasting	red dotted line
D2	Routing but no forecasting	green dashes and dots
D3	Routing and 3-day forecast	black dashed line
D4	Routing and 10-day forecast	purple dashes and dots
D5	Routing and 57-day forecast	orange dashed line

Table 10.2
Average Reservoir Storage Contents in acre-feet

Reservoir or	Storage	Alternative Simulations					
9-Reservoir Total	Capacity	M1	D1	D2	D3	D4	D5
Sam Rayburn	2,898,200	2,886,366	2,923,966	2,895,327	2,876,913	2,905,384	2,906,017
B. A. Steinhagen	66,972	64,955	66,517	66,534	66,799	66,121	66,135
Palestine	411,840	396,715	396,305	393,033	396,317	396,316	395,457
Nine Reservoirs	232,938	212,570	213,438	211,224	213,984	212,793	210,747

Table 10.3
Median (50% Exceedance) Reservoir Storage Contents in acre-feet

Reservoir or	Storage	Alternative Simulations					
9-Reservoir Total	Capacity	M1	D1	D2	D3	D4	D5
Sam Rayburn	2,898,200	2,887,736	2,898,200	2,898,199	2,898,200	2,898,200	2,898,200
B. A. Steinhagen	66,972	66,972	66,972	66,972	66,972	66,972	66,972
Palestine	411,840	403,825	403,820	402,488	403,820	403,815	403,756
Nine Reservoirs	232,938	219,340	220,366	219,111	220,615	220,058	218,873

Table 10.4
Minimum Reservoir Storage Contents in acre-feet

Reservoir or	Storage	Alternative Simulations					
9-Reservoir Total	Capacity	M1	D1	D2	D3	D4	D5
Sam Rayburn	2,898,200	2,479,787	2,491,195	2,398,597	2,418,658	2,272,250	2,273,048
B. A. Steinhagen	66,972	25,075	52,153	53,480	57,877	44,102	45,443
Palestine	411,840	329,129	327,555	305,900	328,026	327,992	312,288
Nine Reservoirs	232,938	119,212	121,768	105,925	124,008	113,105	105,405

Simulations M1 and D1

Monthly *SIM* simulation M1 was performed with the authorized use (Chapter 9) or current use (Chapter 10) TCEQ WAM datasets last updated by the TCEQ in 2012 described in Chapter 2, with the only revision being extending the hydrologic period-of-analysis through 2019 as described in Chapters 4, 5, and 6. Simulation M1 contains the original input records inserted during 2012 to model the SB3 EFS. The modified version of the monthly WAM presented later in the present Chapter 10 and all variations of the daily WAM employ the recently developed methods described in Chapter 7 for modeling the SB3 EFS. The authorized use (Chapter 9) and current use (Chapter 10) versions of the daily simulation D1 were performed with the daily *SIMD* input dataset described in Chapter 8 with routing and forecasting deactivated. The simulation D1 model is adopted for the daily modeling applications presented in the remainder of this chapter.

The 1940-2019 time series of 960 end-of-month simulation M1 reservoir storage contents and 29,220 end-of-day from simulation D1 storage volumes are plotted in Figures 10.5-10.8. With the exception of B. A. Steinhagen Reservoir, the M1 and D1 storage plots are almost the same. The complexities of multiple-reservoir system operations involving Steinhagen re-regulation functions are noted in Chapter 9. Except for the computational time step, Steinhagen re-regulation operations are modeled the same in the monthly and daily simulations. More detailed investigations of system operations incorporating B. A. Steinhagen Reservoir are warranted.

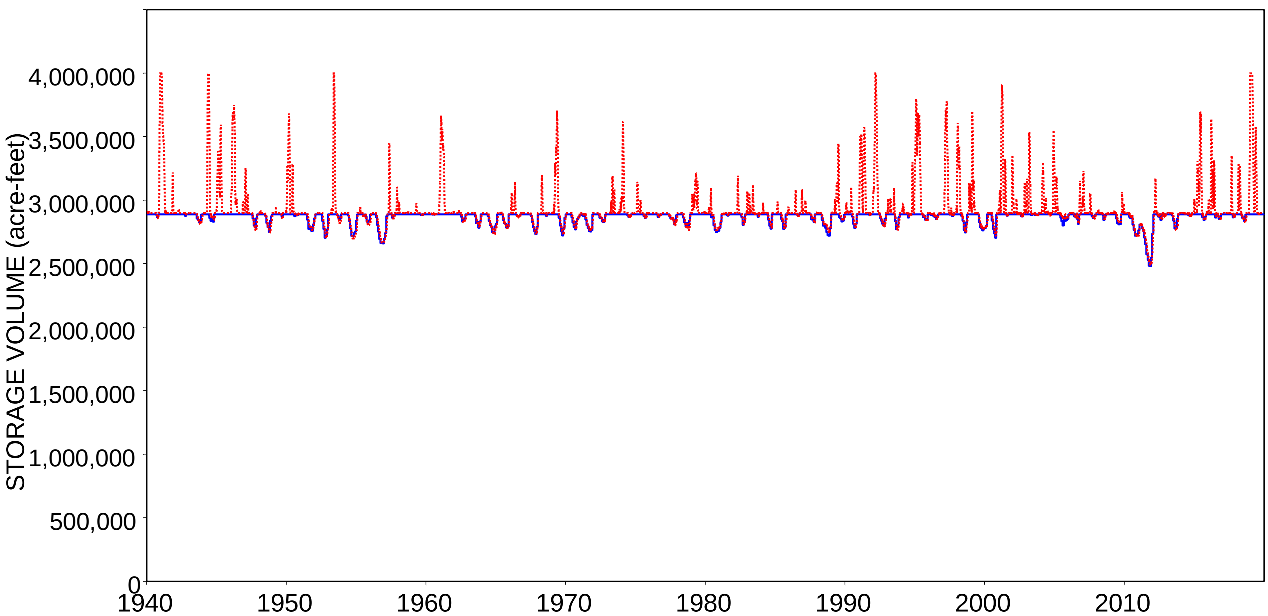

Figure 10.5 Sam Rayburn Reservoir Storage for Simulations M1 (blue solid) and D1 (red dotted)

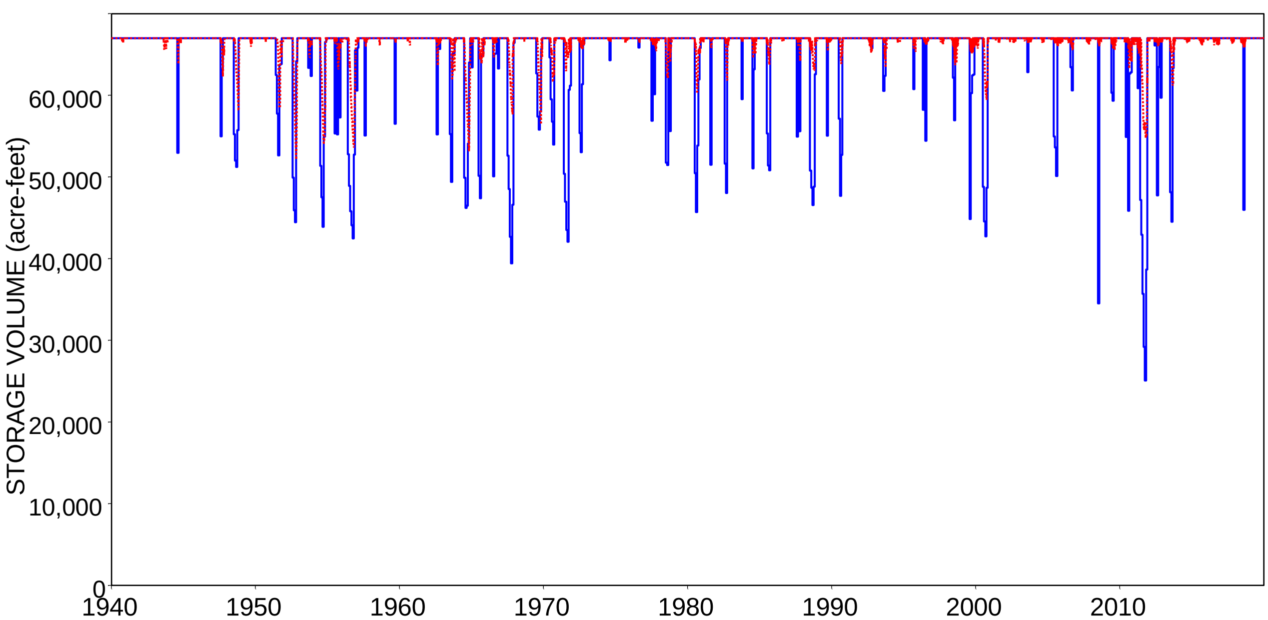

Figure 10.6 B.A. Steinhagen Reservoir Storage Contents for Simulations M1 (blue solid) and D1 (red dotted)

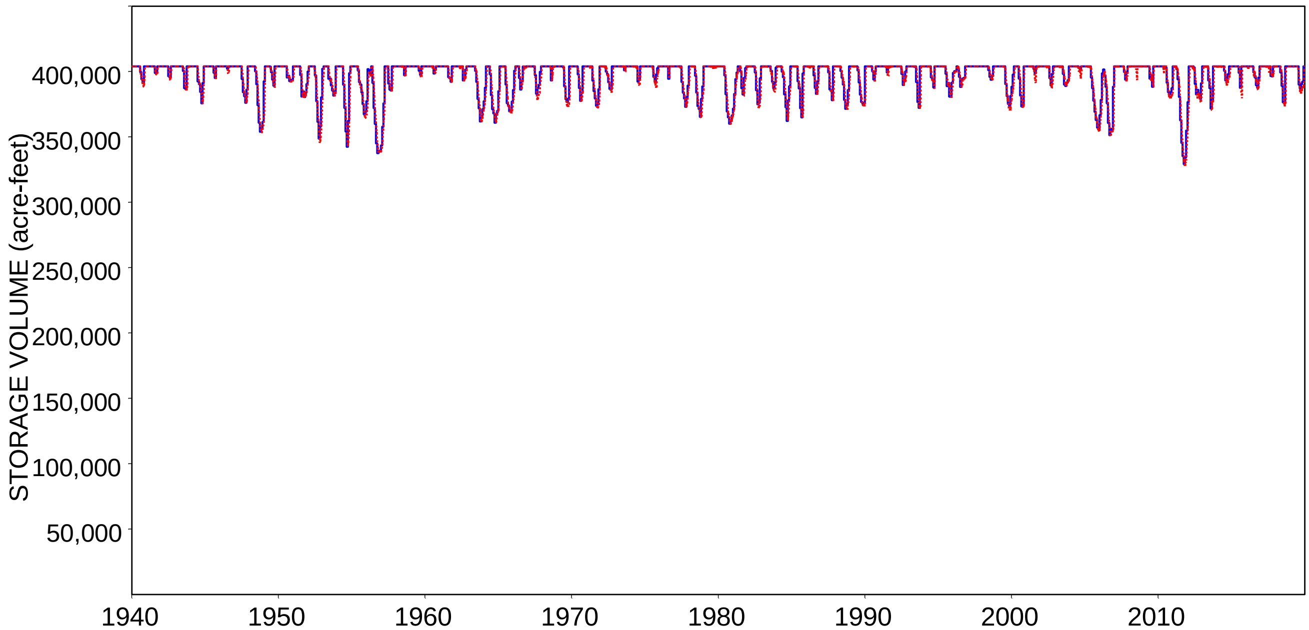

Figure 10.7 Lake Palestine Storage Contents for Simulations
M1 (blue solid) and D1 (red dotted)

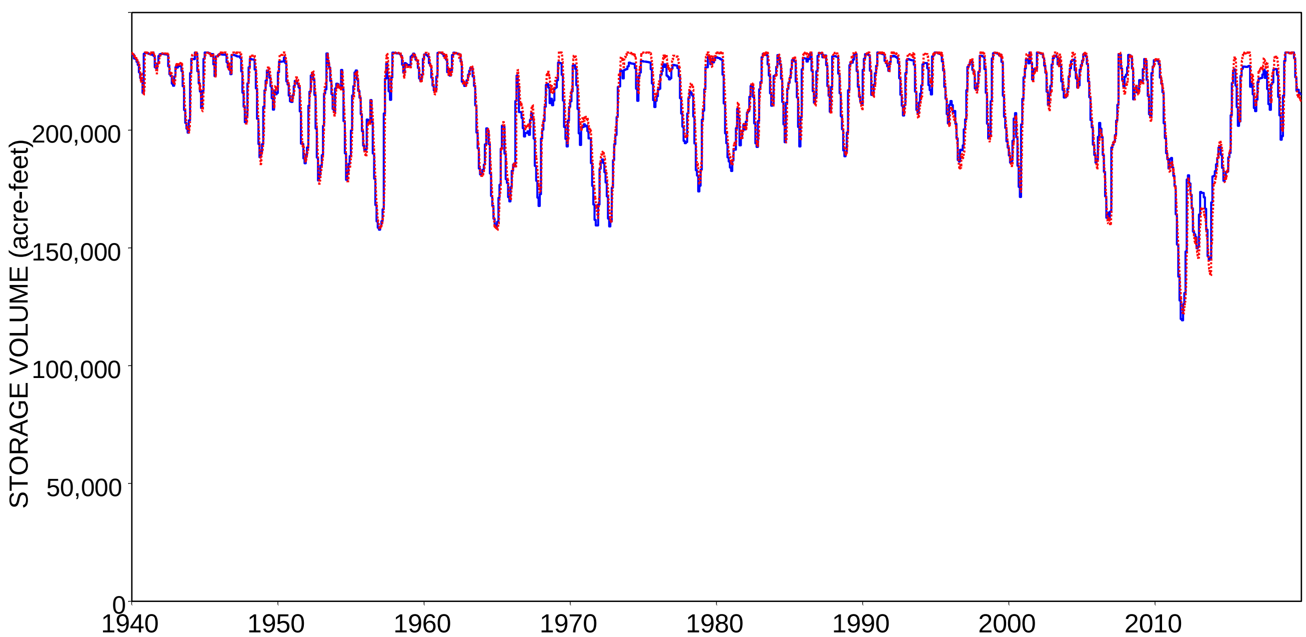

Figure 10.8 Summation of Storage in Nine Reservoirs for Simulations
M1 (blue solid) and D1 (red dotted)

The *SIMD* input dataset used in simulation D1 was employed as explained in the next section to develop daily instream flow targets for the SB3 EFS that were summed to monthly for incorporation in the monthly WAM. The original WAM input records compiled by the TCEQ in 2012 used in simulation M1 were replaced with the simulation D1 instream flow targets.

Stream Flow at the Five SB3 EFS Sites

The control points representing the USGS gage site locations of the Senate Bill 3 (SB3) environmental flow standards (EFS) are listed in Tables 7.1 and 9.5. The locations of these control points are shown in the maps of Figures 4.1 and 4.3. Statistics for daily observed, naturalized, and simulation D1 authorized use scenario regulated and unappropriated stream flows at these five locations are presented in Tables 9.5-9.8 of the preceding Chapter 9. The authorized use scenario version of simulation D1 regulated flows are plotted in Figures 9.9-9.13. Corresponding frequency statistics and time series plots for river flows generated with the current use scenario version of simulation D1 are presented as follows in Tables 10.5-10.8 and Figures 10.9-10.13.

Table 10.5
Means of 1940-2019 Flows in cfs at SB3 EFS Sites

Control Point	Location by River and Town	Watershed Area (sq miles)	1940-2019 Means for Stream Flows Observed (cfs)	Naturalized (cfs)	Regulated (cfs)	Unappropr (cfs)
NENE	Neches River at Neches	1,145	730.4	771.6	696.6	360.3
NERO	Neches River near Rockland	3,631	2,492	2,531	2,459	1,814
ANAL	Angelina River near Alto	1,273	830.2	939.2	897.5	455.0
NEEV	Neches River at Evadale	7,885	6,285	6,445	6,029	4,949
VIKO	Village Creek near Kountze	861	897.8	897.2	897.8	694.6

Table 10.6
Frequency Statistics in cfs for Daily Naturalized Flows at SB3 EFS Sites

CP	NENE	NERO	ANAL	NEEV	VIKO
Mean	771.6	2,531	939.2	6,445	897.2
Stand Dev	1,585	3,913	1,632	9,021	2,341
Minimum	0.00	0.00	0.00	0.00	9.81
99%	0.00	0.00	0.00	0.00	28.00
98%	0.00	0.00	0.00	0.00	39.96
95%	0.00	0.00	8.82	0.00	57.93
90%	0.00	28.76	26.39	210.4	82.00
80%	14.67	150.1	73.54	592.6	122.9
70%	66.58	317.8	133.76	1,094	169.0
60%	152.6	563.3	224.2	1,821	238.0
50%	267.8	970.1	354.3	2,934	336.6
40%	444.0	1,601	577.3	4,526	481.4
30%	709.0	2,578	907.0	7,000	711.1
20%	1,112	4,044	1,429	10,546	1,129
10%	1,954	6,928	2,394	17,358	2,140
Maximum	44,013	49,687	42,543	119,018	151,000

Table 10.7
Frequency Statistics in cfs for Daily Regulated Flows at SB3 EFS Sites

CP	NENE	NERO	ANAL	NEEV	VIKO
Mean	696.5	2,460	897.6	6,051	897.7
Stand Dev	1,575	3,916	1,607	7,583	2,342
Minimum	0.00	0.00	0.00	0.00	10.19
99%	0.00	1.02	14.50	0.00	28.96
98%	0.00	6.79	15.42	0.00	40.65
95%	0.00	11.58	22.17	0.00	58.72
90%	6.30	28.59	36.62	74.48	82.25
80%	8.11	118.4	72.46	301.1	122.7
70%	24.36	243.1	116.9	585.6	169.3
60%	58.33	458.1	191.0	1,244	238.6
50%	131.4	834.4	309.1	2,361	337.1
40%	305.0	1,500	516.9	4,248	481.8
30%	587.3	2,468	834.6	7,211	712.7
20%	1,024	3,946	1,356	12,406	1,130
10%	1,874	6,884	2,316	20,000	2,141
Maximum	43,730	49,854	42,555	68,189	151,011

Table 10.8
Frequency Statistics in cfs for Daily Unappropriated Flows at SB3 EFS Sites

CP	NENE	NERO	ANAL	NEEV	VIKO
Mean	394.0	1,990	498.5	5,040	897.7
Std Dev	930.0	3,634	1,032	7,160	2,342
Minimum	0.00	0.00	0.00	0.00	0.00
99%	0.00	0.00	0.00	0.00	0.00
80%	0.00	0.00	0.00	0.00	0.00
70%	0.00	0.00	0.00	8.22	0.00
60%	0.00	101.1	0.00	431.9	70.16
50%	11.35	288.3	0.00	1,062	147.3
40%	54.76	794.4	153.1	2,767	278.8
30%	236.6	1,729	377.3	5,635	470.5
20%	578.7	3,263	769.6	10,817	816.5
10%	1,245.9	6,240	1,560	18,075	1,767
Maximum	20,556	42,032	18,196	66,693	150,934

The 1940-2019 means in cubic feet per second (cfs) of daily observed, naturalized, and simulation D1 current use scenario regulated and unappropriated stream flows are tabulated in Table 10.5. The frequency metrics in cfs for naturalized flows and simulation D1 current use scenario regulated and unappropriated flows tabulated in Tables 9.6, 9.7, and 9.8 include the 1940-

2019 mean flow rates, standard deviations of the daily mean flow rates, and the daily mean flow rates exceeded during specified percentages of the 29,220 days of the 1940-2019 period-of-analysis. Simulated daily regulated flows in units of cfs are plotted in Figures 10.9 through 10.13. Flow quantities computed by *SIMD* in units of acre-feet/day have been converted to cfs within *HEC-DSSVue*. These time series of stream flows are accessible for further analyses with *HEC-DSSVue* from the simulation results DSS file described in the last section of Chapter 9.

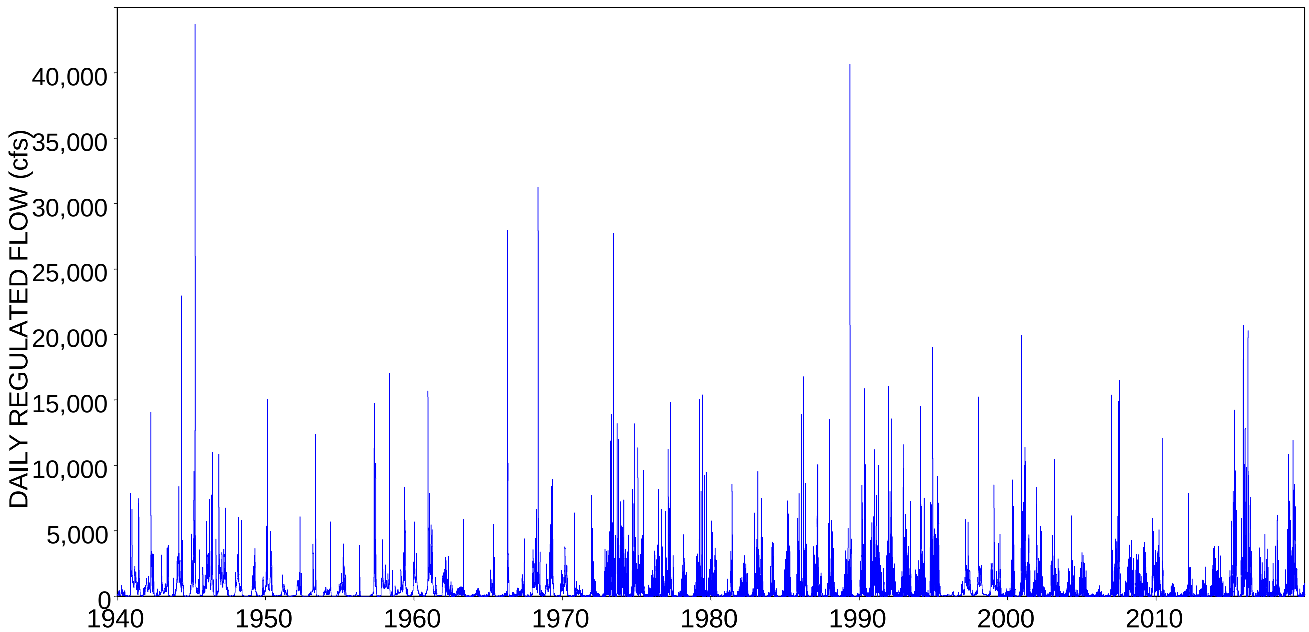

Figure 10.9 Simulated Daily Regulated Flow of the Neches River at Neches (Control Point NENE)

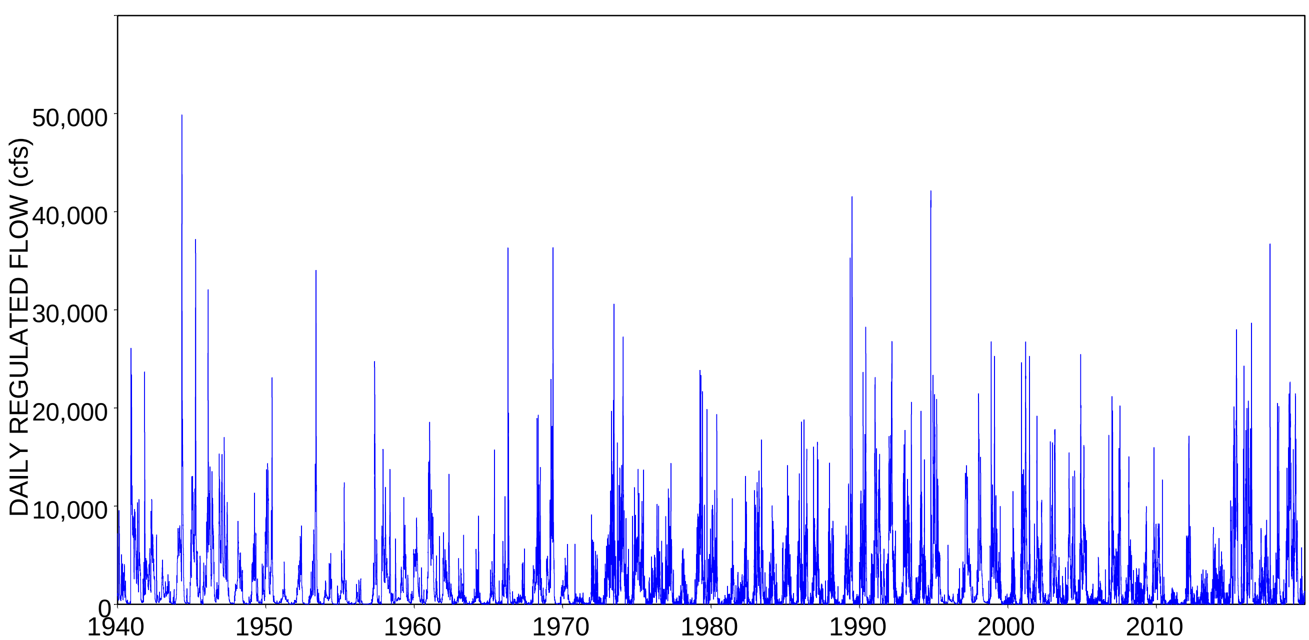

Figure 10.10 Simulated Daily Regulated Flow of the Neches River near Rockland (Control Point NERO)

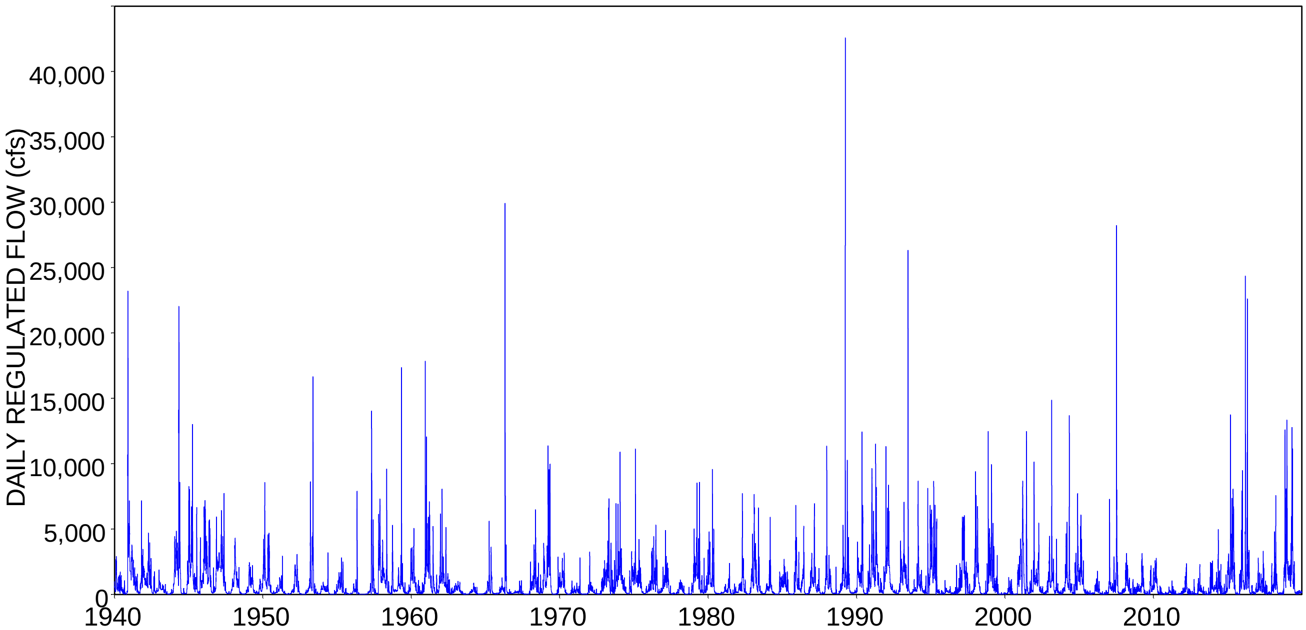

Figure 10.11 Simulated Daily Regulated Flow of the Angelina River near Alto
(Control Point ANAL)

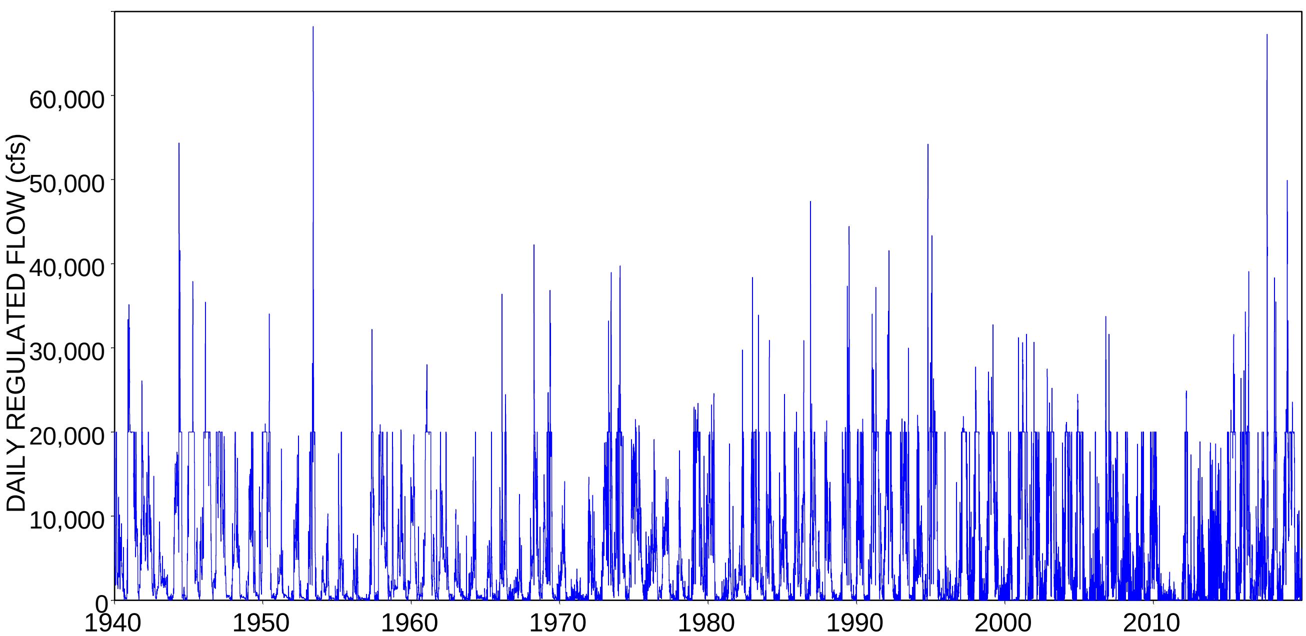

Figure 10.12 Simulated Daily Regulated Flow of the Neches River at Evadale
(Control Point NEEV)

Observed daily, monthly, and annual flows at control points NERO and NEEV are plotted in Figures 4.4-4.7 of Chapter 4. Monthly 1940-2019 naturalized flows at the 20 primary control points are plotted in Figures 5.1-5.20. The following Figures 9.9-9.13 are plots of the mean daily simulated regulated flow rate in cfs for each of the 29,220 days of the 1940-2019 period-of-analysis for *SIMD* simulation D1. Regulated flows computed by *SIMD* in units of acre-feet/day have been converted to cfs within *HEC-DSSVue*. Tables 9.6-9.8 and Figures 9.9-9.13 reflect the previously discussed daily *SIMD* simulation D1 which has no routing and no forecasting.

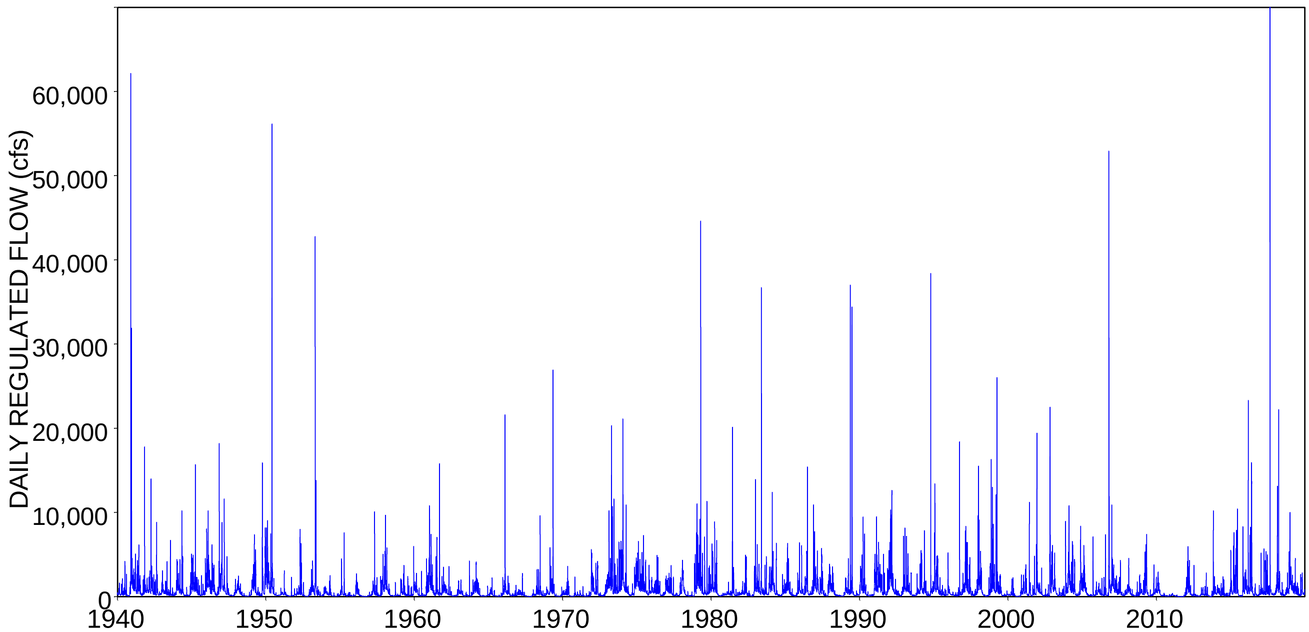

Figure 10.13 Simulated Daily Regulated Flow of Village Creek near Kountze (Control Point VIKO)

Flood control operations of Sam Rayburn Reservoir are evident in the observed daily flows of Figure 4.6 and simulated regulated flows plotted in Figures 9.12 and 10.12. Flood control operations of Sam Rayburn Reservoir are based on emptying the flood control pool as expeditiously as possible without releases that would contribute to flows at the USGS gage on the Neches River at Evadale (control point NEEV) exceeding 20,000 cfs. The high flows plotted in Figure 9.12 are often 20,000 cfs. River flows greater than 20,000 cfs result from flood flows entering the river from the watershed not controlled by Sam Rayburn Reservoir.

The vertical scale of Figure 10.13 extends to only 70,000 cfs. However, the flows of Village Creek at Kountze (control point VIKO) greatly exceed 70,000 cfs during three days of Hurricane Harvey flooding. The *SIMD* simulated mean daily regulated flows for the current use scenario version of simulation D1 are 151,011 cfs, 145, 011 cfs, and 89,298 cfs during August 30, 2017, August 31, 2017, and September 1, 2017. As noted in Chapter 9, the authorized use scenario regulated flows for these three days are 151,009 cfs, 145,009 cfs, and 88,297 cfs. The actual observed flows recorded at the USGS gage during these three days are 151,000 cfs, 145,000 cfs, and 89,300 cfs,which are essentially the same as the simulated flows.

Comparing Tables 9.7 and 10.7, median (50%) regulated flows in cfs for the authorized and current use scenarios are as follows: NENE (99.78, 137.8), NERO (655.1, 832.4), ANAL (225.0, 309.0), NEEV (875.5, 335.7), VIKO (335.7 cfs, 337.0 cfs). From Tables 9.8 and 10.8, authorized and current use scenario median unappropriated flows are: NENE (0.00, 3.53 cfs), NERO (0.00, 271.7), ANAL (0.00, 0.00), NEEV (190.8, 1,000), and VIKO (94.89 cfs, 149.9 cfs).

Daily Instream Flow Targets for SB3 EFS

Time series plots and statistical metrics for river flows at the five sites of Senate Bill 3 (SB3) environmental flow standards (EFS) in the Neches River Basin are presented in the preceding section of this chapter. The SB3 EFS and modeling thereof are explained in Chapter 7. SB3 EFS subsistence flow and base flow limits are tabulated in Table 9.9 of Chapter 9 in units of both cfs and acre-feet/day. Pulse flow specifications are listed in Table 9.10. SB3 EFS seasons are defined as follows: Winter (December, January, February), Spring (March, April, May), Summer (June, July, August), Fall (September, October, November). One high pulse per season is specified for the Winter and Summer and two pulses per season for Spring and Fall for all five sites.

The SB3 EFS are modeled in the *SIMD* simulation as instream flow *IF* record water rights. Daily *IF* record instream flow targets for the SB3 EFS computed in a *SIMD* simulation are summed to monthly for inclusion in the monthly *SIM* input dataset.

The SB3 EFS specifications described in Chapter 7 are incorporated into the Neches WAM in exactly the same manner for both the authorized use and current use versions of the WAM. However, the SB3 EFS instream flow targets are computed in the *SIMD* simulation as a function of regulated flows, which vary significantly between authorized and current use simulations. Regulated flows and SB3 EFS instream flow targets are generally higher for the current use version of the WAM. Thus, separate datasets of SB3 EFS instream flow targets are developed for the current use scenario and full authorization scenarios.

The means of the 1940-2019 sequences of naturalized, regulated, and unappropriated flows and SB3 EFS targets and shortages are compared in Tables 10.9 and 10.10. The combined subsistence and base flow targets are the TIF-WR targets defined in Table 7.8 for the water rights IF-NENE-ES, IF-NERO-ES, IF-ANAL-ES, IF-NEEV-ES, and IF-VIKO-ES in Table 7.6. The pulse flow targets are the TIF-WR targets for the water rights IF-NENE-PF, IF-NERO-PF, IF-ANAL-PF, IF-NEEV-PF, and IF-VIKO-PF in Table 7.6. The final SB3 EFS targets are the IFT-WR targets for pulse flows or combined flows of the IFT-CP targets for control points (Table 7.8).

The quantities in Table 10.9 are tabulated in in units of acre-feet/day and converted to cubic feet per second (cfs) in Table 10.10. A flow rate of 1.0 acre-foot per day is equal to 0.5041667 cubic feet per second. SB3 EFS subsistence and base flow limits and high pulse flow trigger limits are specified in units of cfs. Stream flows and instream flow targets in the *SIMD* computations and simulation results are in units of acre-feet/day.

The shortages in meeting instream flow targets consider all *IF* record rights at a control point including both the subsistence/base components of SB3 EFS and any other more senior *IF* record rights. Since no other *IF* record rights are located at these five control points, the shortages are related only to the SB3 EFS. Water rights are considered in a priority sequence with the pulse flows being most junior.

Daily instream flow targets for the SB3 EFS are computed in the *SIMD* simulation for each day as the maximum of the computed subsistence and base flow target and the pulse flow target. Subsistence and base flow targets are set as minimum flow limits defined on environmental flow *ES* records. Shortages in meeting subsistence and base flow targets are deficits between the targeted minimum flow limits and regulated stream flow at the end of the water right priority sequence simulation for the day. The high pulse flow components of the SB3 EFS controlled by pulse flow *PF* records replicate regulated flows computed within the water rights priority sequence, which differs from the final regulated flow at the completion of the priority sequence. Thus, shortages can also occur in meeting pulse flow targets.

Table 10.9
Means of 1940-2019 Daily Flow Quantities for Current Use Scenario in acre-feet per day

Control Point	NENE	NERO	ANAL	NEEV	VIKO
	(ac-ft/day)	(ac-ft/day)	(ac-ft/day)	(ac-ft/day)	(ac-ft/day)
Observed flow	1,449	4,943	1,647	12,466	1,781
Naturalized flow	1,530	5,020	1,863	12,783	1,780
Regulated flow	1,382	4,877	1,780	11,958	1,781
Unappropriated	714.6	3,598	902	9,816	1,378
<u>Flow Targets</u>					
subsistence/base	141.5	485.6	202.7	1,826	249.4
pulse flow	79.34	249.8	145.8	258.0	142.6
SB3 EFS	204.6	674.9	327.9	1,963	370.7
<u>Target Shortages</u>					
before pulse	0.000	0.000	0.000	0.000	0.000
with pulse flow	0.956	7.811	3.160	25.21	0.000

Table 10.10
Means of 1940-2019 Daily Flow Quantities for Current Use Scenario in cubic feet per second

Control Point	NENE	NERO	ANAL	NEEV	VIKO
	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
Observed flow	730.4	2,492	830.2	6,285	897.8
Naturalized flow	771.6	2,531	939.2	6,445	897.2
Regulated flow	696.6	2,459	897.5	6,029	897.8
Unappropriated	360.3	1,814	455.0	4,949	694.6
<u>Flow Targets</u>					
subsistence/base	71.34	244.8	102.2	920.6	125.7
pulse flow	40.00	125.9	73.51	130.1	71.89
SB3 EFS	103.2	340.3	165.3	989.7	186.9
<u>Target Shortages</u>					
before pulse	0.000	0.000	0.000	0.000	0.000
with pulse flow	0.482	3.938	1.593	12.71	0.000

The priorities for the *FR* record flood control operations are set junior to the SB3 EFS *IF* record water rights. However, FCDEP option 2 is activated in *FR* record field 6 which means that storing flood waters is not constrained by water availability at downstream control points. Thus, flood control operations can result in shortages in meeting SB3 EFS targets.

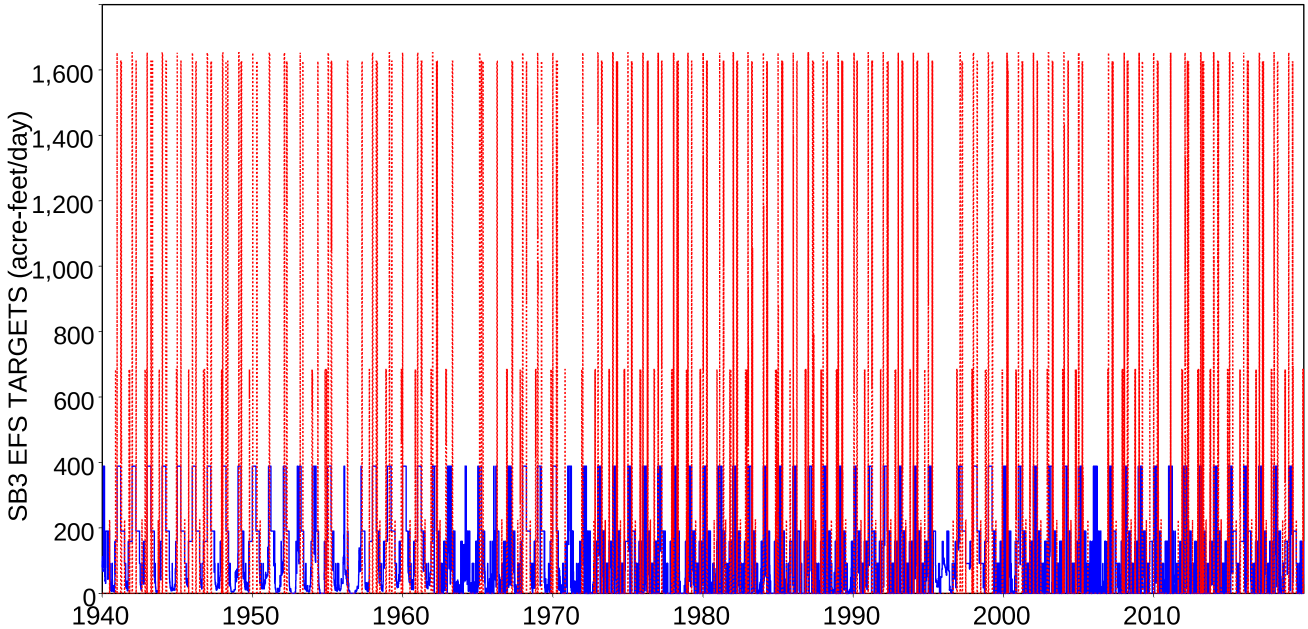

Figure 10.14 Daily Subsistence/Base (blue solid) and Pulse (red dots) Flow Targets at NENE

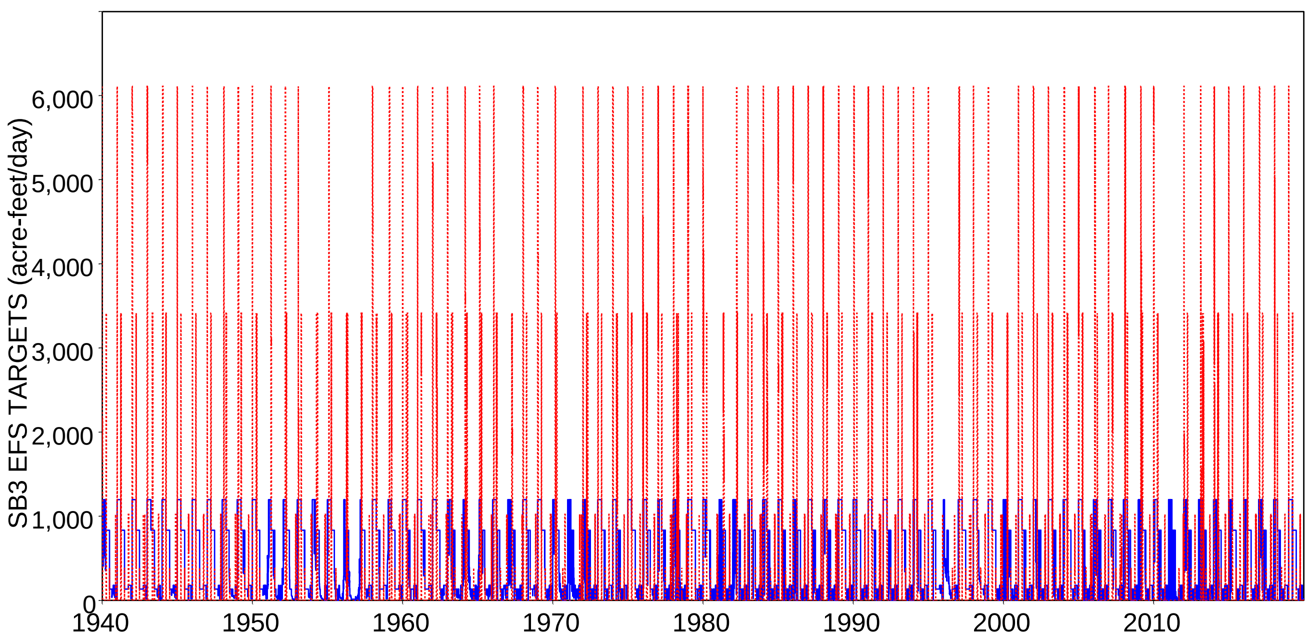

Figure 10.15 Daily Subsistence/Base (blue solid) and Pulse (red dots) Flow Targets at NERO

The *IF* record daily instream flow targets for the SB3 EFS computed in the *SIMD* simulation are plotted in Figures 10.14 through 10.18. The combined subsistence and base flow components of the SB3 EFS targets defined on *ES* records are plotted as a blue solid line. These are the TIF-WR targets (Table 7.8) for water rights IF-NENE-ES, IF-NERO-ES, IF-ALTO-ES, IF-NEEV-ES, and IF-VIKO-ES. The SB3 EFS pulse flow targets defined on *PF* records are plotted in Figures 10.14-10.18 as a red dotted line. These are the TIF-WR targets (Table 7.8) for water rights IF-NENE-PF, IF-NERO-PF, IF-ALTO-PF, IF-NEEV-PF, and IF-VIKO-PF. The SB3 EFS instream flow target at a control point for each day of the simulation is the larger of the subsistence/base flow target specified by the *ES* records and the pulse flow target specified by the *PF* records.

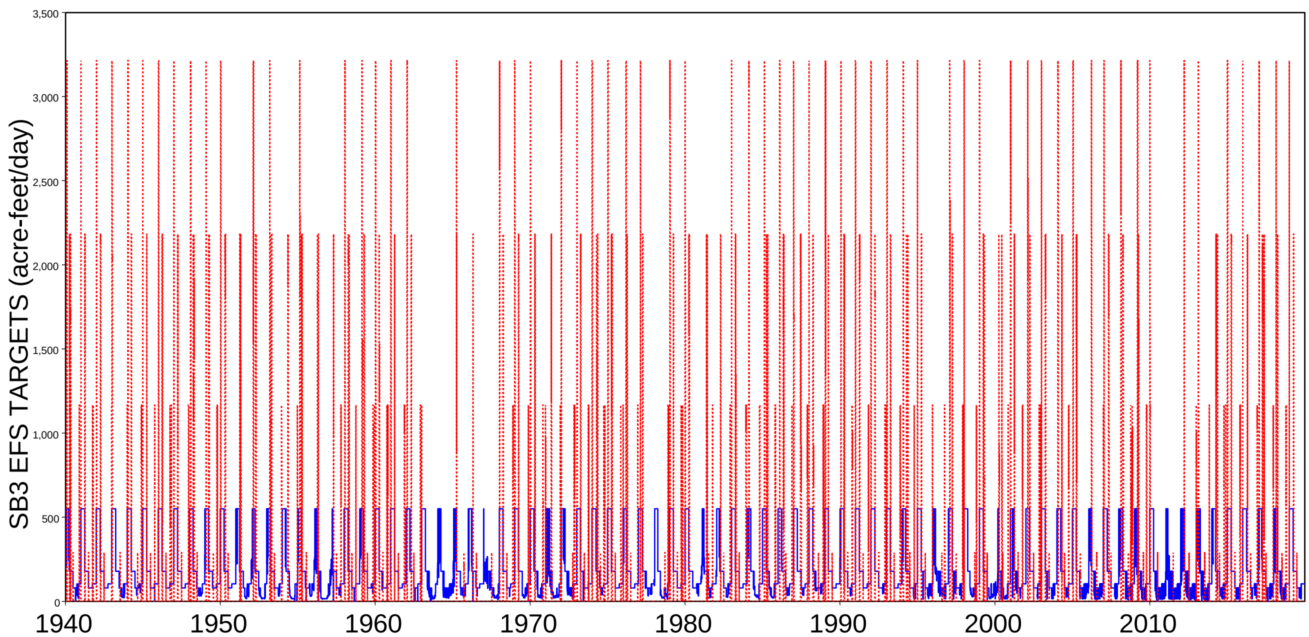

Figure 10.16 Daily Subsistence/Base (blue solid) and Pulse (red dots) Flow Targets at ANAL

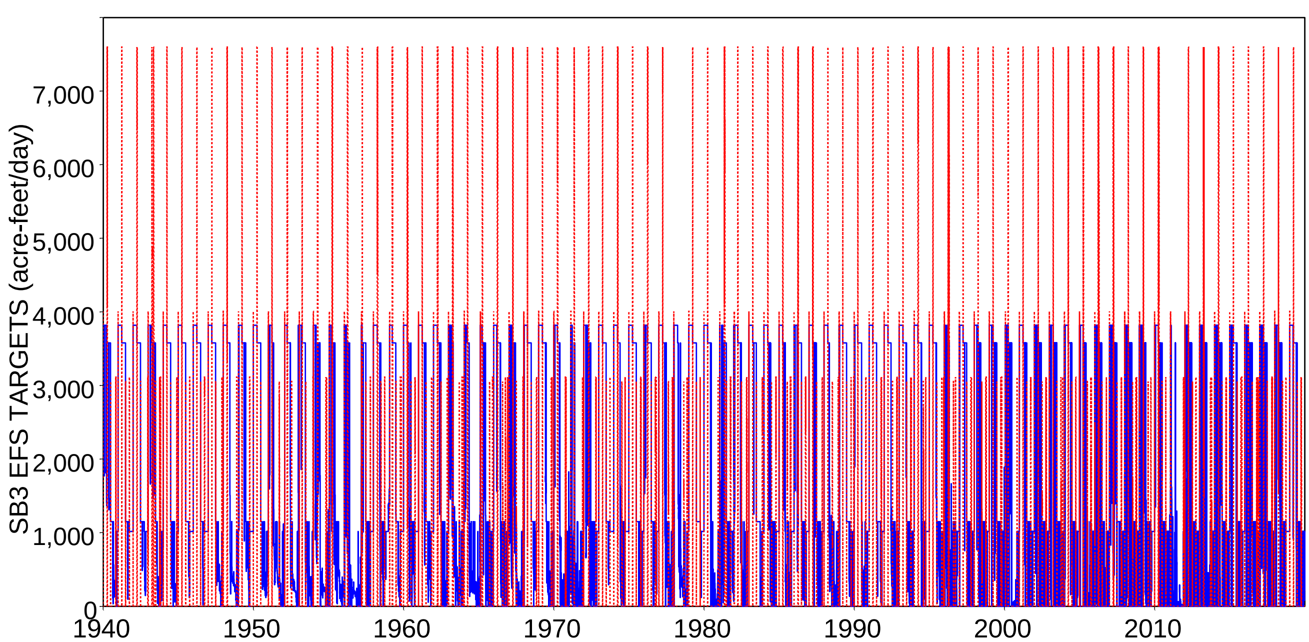

Figure 10.17 Daily Subsistence/Base (blue solid) and Pulse (red dots) Flow Targets at NEEV

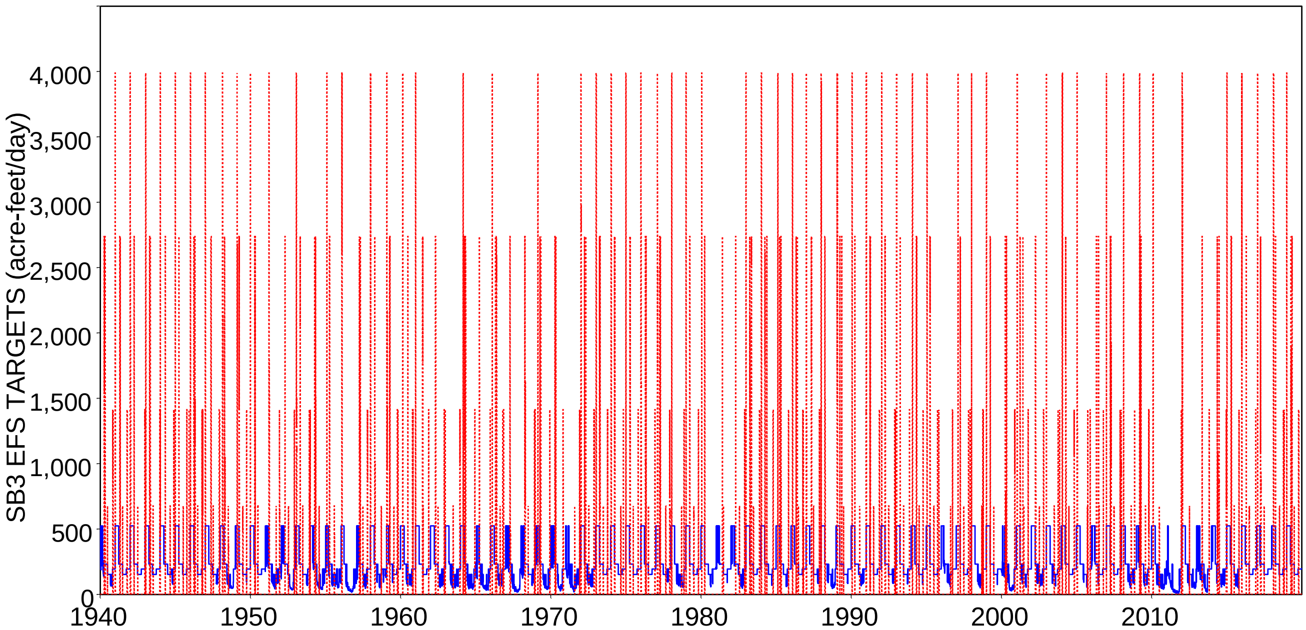

Figure 10.18 Daily Subsistence/Base (blue solid) and Pulse (red dots) Flow Targets at VIKO

The final SB3 EFS instream flow target for each individual day is set within the *SIMD* simulation as the greater of the *ES* record subsistence/base target and *PF* record pulse flow target. The final total daily instream flow targets computed by *SIMD* are plotted in Figures 10.19, 10.21, 10.23, 10.25, and 10.27. The monthly summations of the daily targets are plotted in Figures 10.20, 10.22, 10.24, 10.26, and 10.28.

The pulse flow targets plotted in Figures 10.14-10.18 are much larger than the subsistence/base flow targets. However, the means tabulated in Tables 10.11 and 10.12 are lower for pulse flow targets than subsistence/base flow targets. The pulse flow targets are relatively high during occasional high flow events while the much smaller subsistence/base flow targets are set almost every day of the simulation.

Monthly Instream Flow Targets for SB3 EFS from the Daily *SIMD* Simulation

The same procedure for incorporating the monthly SB3 EFS targets generated in the daily *SIMD* simulation into the monthly WAM is applied to both the authorized use scenario version of the WAM in Chapter 9 and the current use scenario in Chapter 10. The monthly instream flow targets in the *SIMD* simulation results DSS output file are converted to time series *TS* records stored in the DSS input file read by *SIM* in monthly simulations.

The final daily SB3 EFS instream flow target in acre-feet/day for each of the 29,220 days of the 1940-2019 hydrologic period-of-analysis is the larger of the *ES* record subsistence/base flow target or *PF* record pulse flow target plotted in Figures 10.14-10.18. The final daily SB3 EFS targets in each of the 960 months of 1940-2019 are summed to monthly totals within the *SIMD* simulation. The daily and monthly targets in acre-feet/day and acre-feet/month for simulation D1 are plotted in Figures 10.19-10.28.

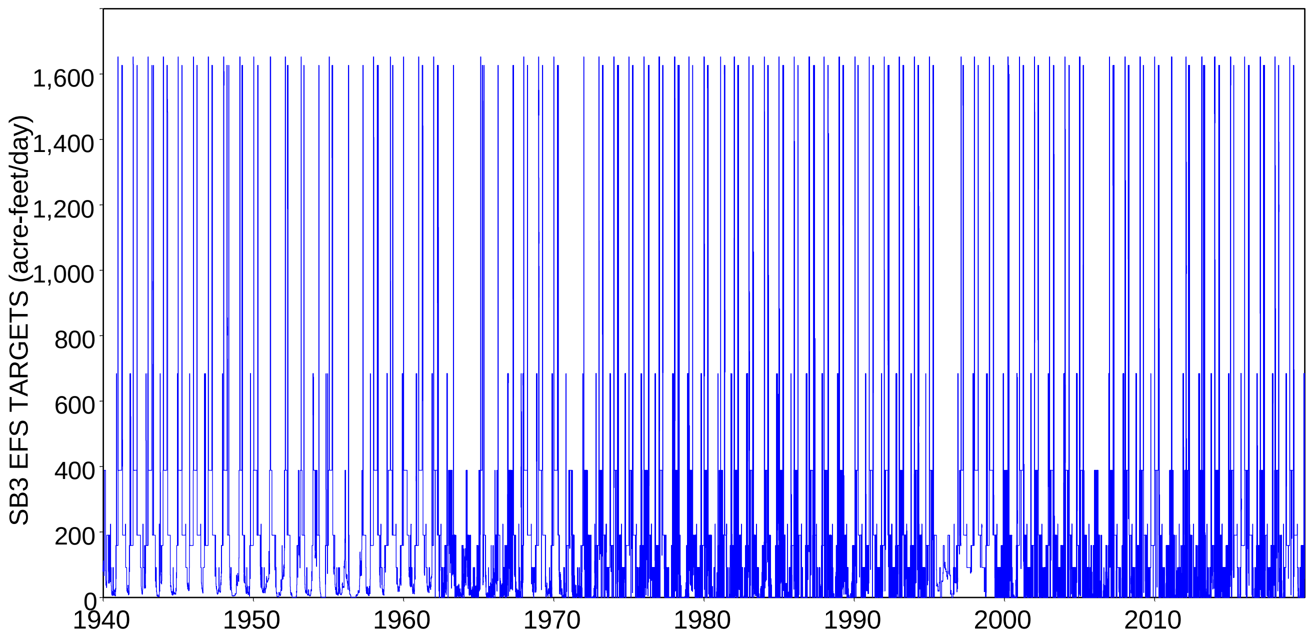

Figure 10.19 Daily SB3 EFS Targets at Control Point NENE

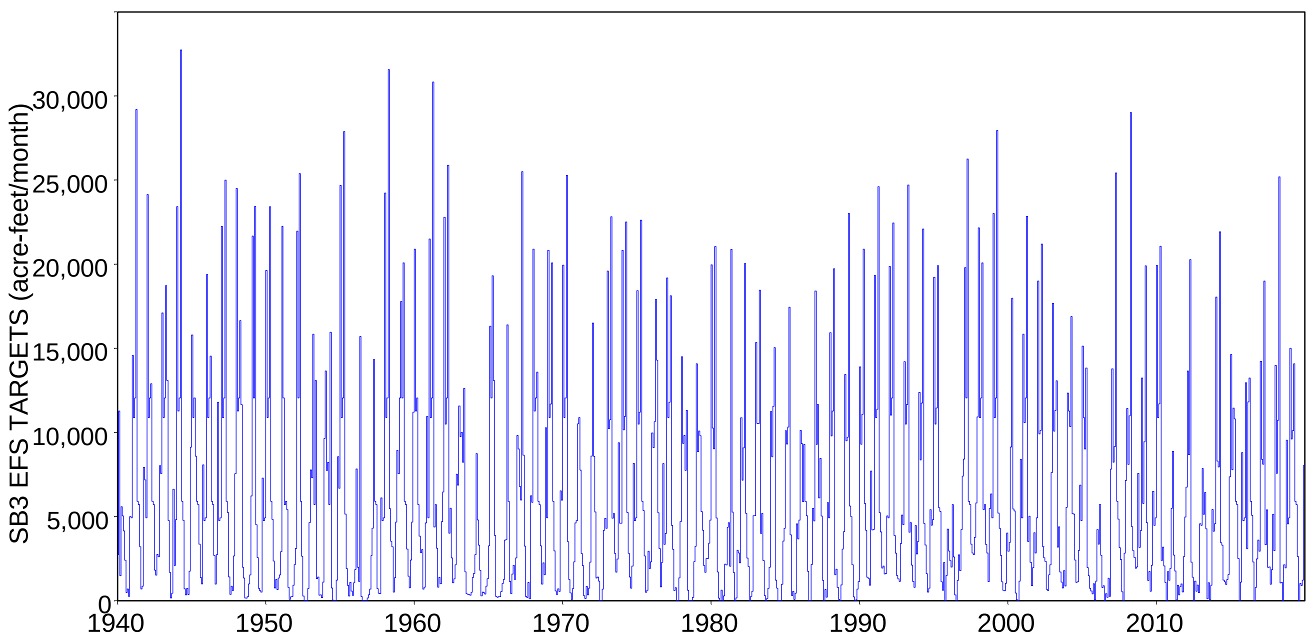

Figure 10.20 Monthly SB3 EFS Targets at Control Point NENE

Shortages in meeting instream flow targets depend upon regulated flows. Within-month daily variations in the simulated regulated flows are averaged-out in a monthly simulation. Daily shortages in meeting daily instream flow targets are computed by *SIMD* based on daily regulated flows. Monthly shortages for monthly instream flow targets are computed by *SIM* based on monthly regulated flows. Although SB3 EFS monthly flow targets are the same in the *SIM* monthly simulation as the daily *SIMD* simulation, shortages in meeting the targets differ greatly between daily and monthly simulations. The total shortages in meeting the SB3 EFS instream flow targets tend to be smaller in a monthly *SIM* simulation than in the daily *SIMD* simulation.

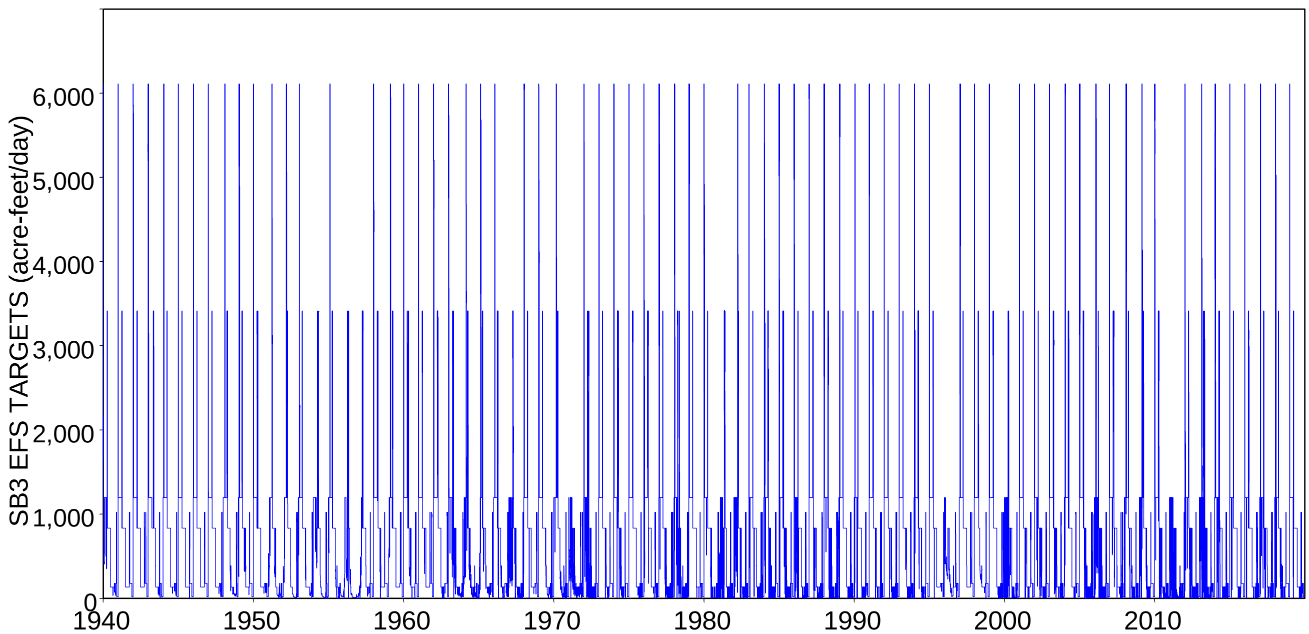

Figure 10.21 Daily SB3 EFS Targets at Control Point NERO

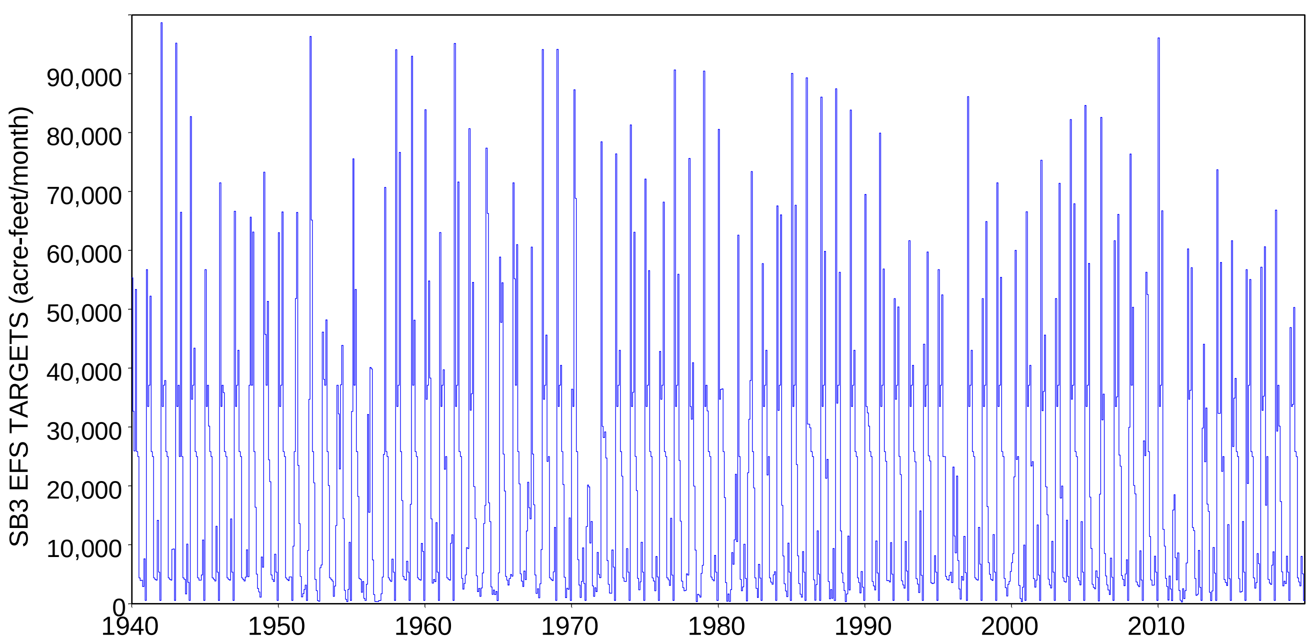

Figure 10.22 Monthly SB3 EFS Targets at Control Point NERO

The records modeling the SB3 EFS added by the TCEQ in 2012 to the October 2012 version of the Neches WAM DAT file described in Chapter 2 are removed and replaced with the input records shown in Tables 10.11 and 10.12. The DSS records with pathnames listed in Table 10.11 are included in the *SIM* time series input file with filename NechesHYD.DSS introduced in

Table 4.14. These DSS records of time series *TS* records of 1944-2019 monthly instream flow targets for the SB3 EFS at the five control points are referenced by the *IF* record instream flow rights replicated in Table 10.12 which are inserted in the monthly DAT file. Input parameter DSSTS in *JO* record field 1 is switched on to indicate that *TS* records are read from the DSS file.

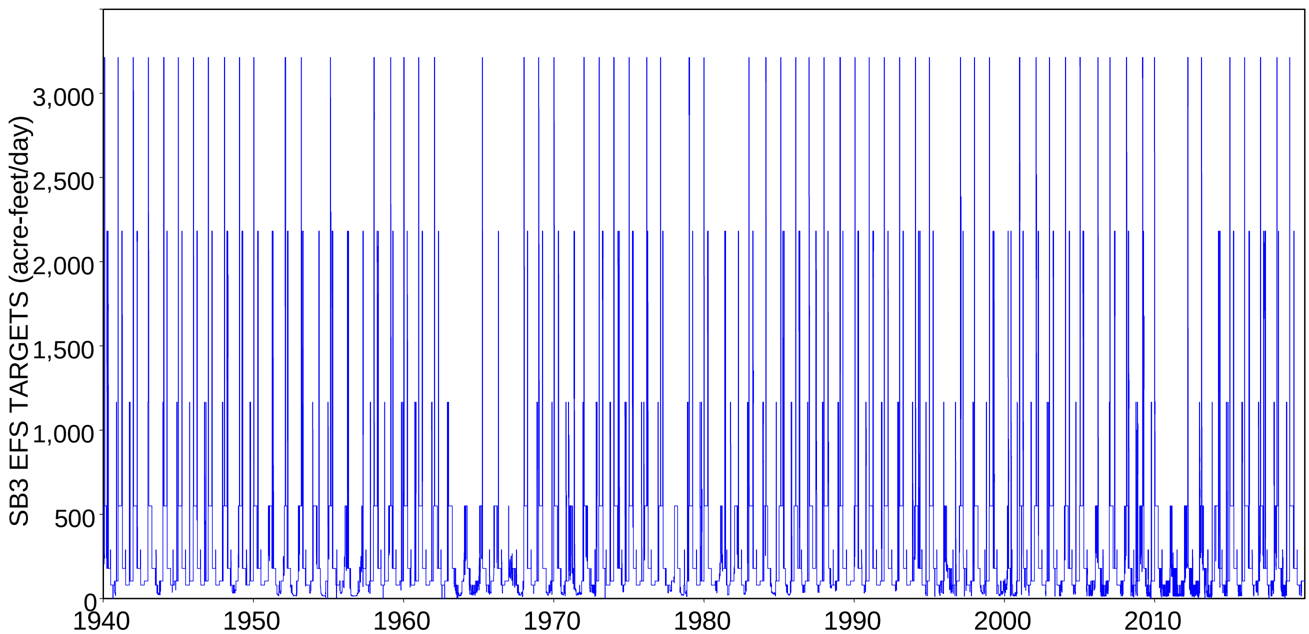

Figure 10.23 Daily SB3 EFS Targets at Control Point ANAL

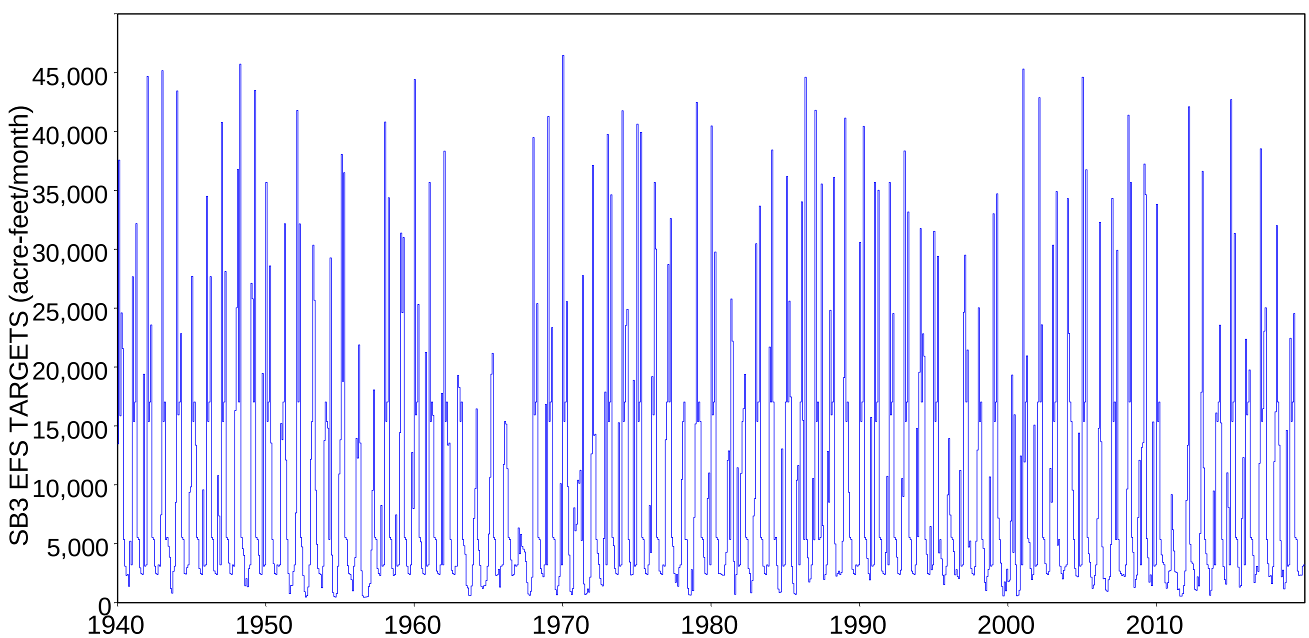

Figure 10.24 Monthly SB3 EFS Targets at Control Point ANAL

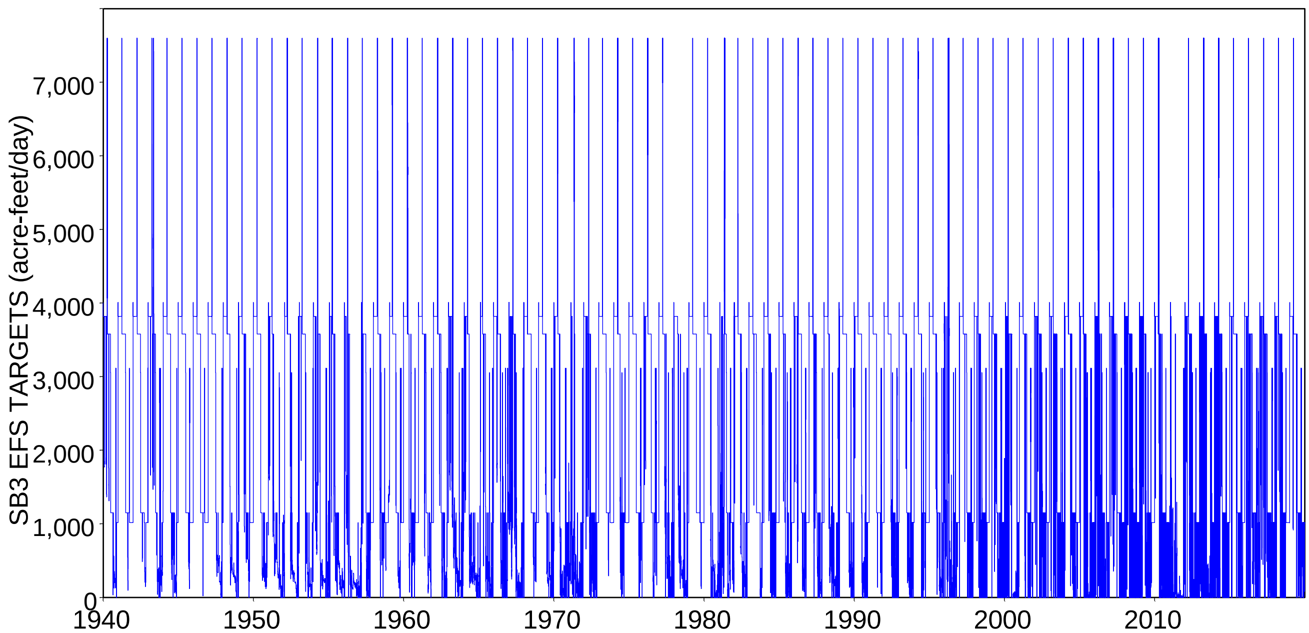

Figure 10.25 Daily SB3 EFS Targets at Control Point NEEV

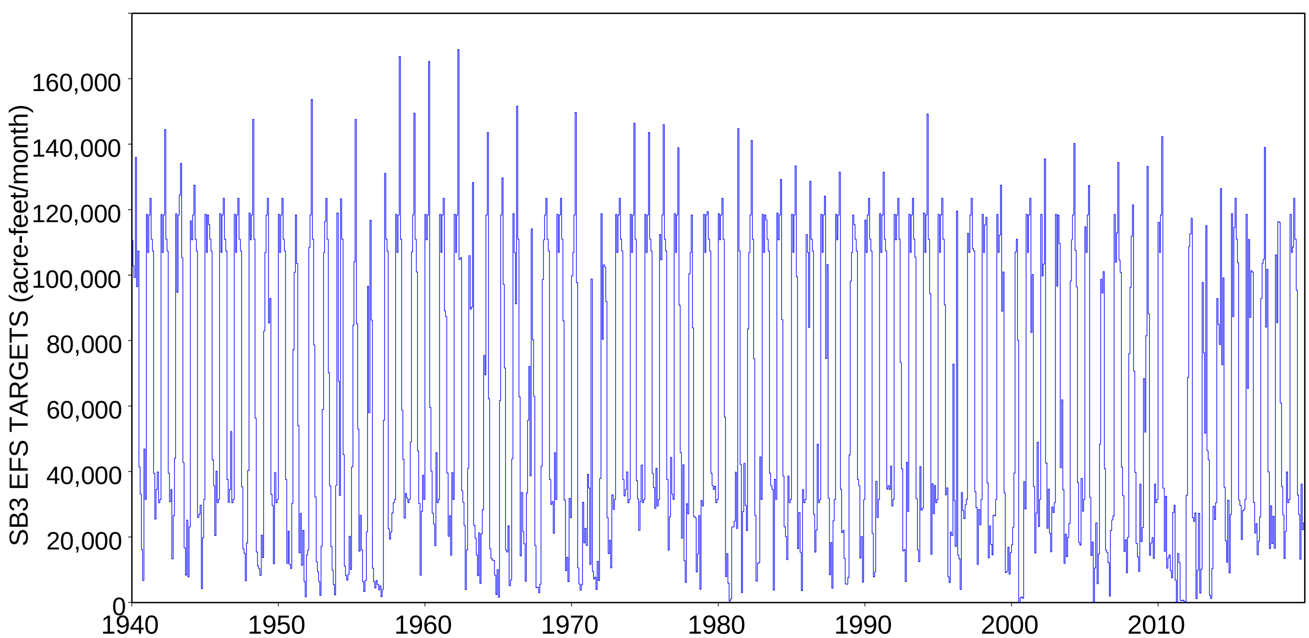

Figure 10.26 Monthly SB3 EFS Targets at Control Point NEEV

The pathnames for the *TS* records are listed in Table 7.10, which is replicated below as Table 10.11. The *IF* record water rights in presented in Table 7.11 and replicated below as Table 10.12 are inserted in the monthly WAM DAT file. Thus, the monthly SB3 EFS targets computed in the daily *SIMD* simulation are replicated exactly in monthly *SIM* simulations.

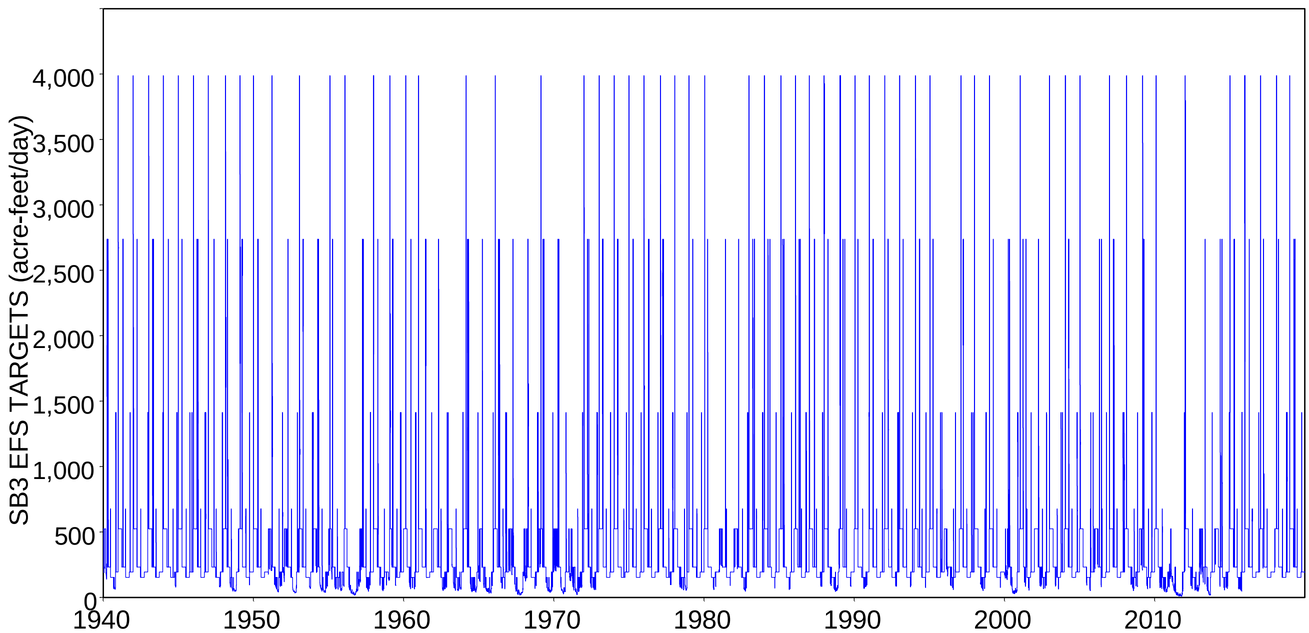

Figure 10.27 Daily SB3 EFS Targets at Control Point VIKO

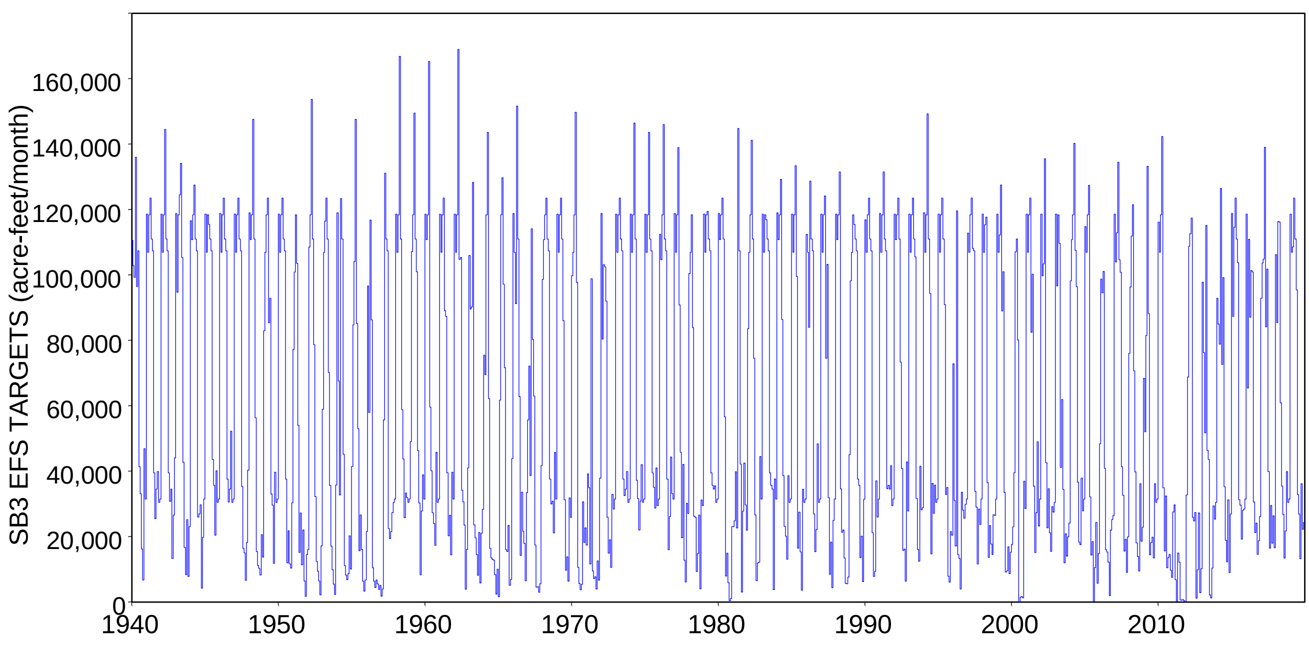

Figure 10.28 Monthly SB3 EFS Targets at Control Point VIKO

The identifiers in field 3 of the *TS* records in the DAT file (Table 10.12) reference pathname part B of the *TS* records in the DSS file (Table 10.11). The "C" for current added to the control point identifiers distinguishes these *TS* records for the current use scenario from the authorized use scenario "A" records added to the DSS file as described in Chapter 9.

Table 10.11
Pathnames for *TS* Records for the SB3 EFS for the Full Authorization Scenario in the Shared Single Hydrology Input DSS File of the Neches WAM

Part A	Part B	Part C	Part D	Part E
NECHES	CNENE	TS	01Jan1940-31Dec2019	1MON
NECHES	CNERO	TS	01Jan1940-31Dec2019	1MON
NECHES	CANAL	TS	01Jan1940-31Dec2019	1MON
NECHES	CNEEV	TS	01Jan1940-31Dec2019	1MON
NECHES	CVIKO	TS	01Jan1940-31Dec2019	1MON

Table 10.12
Instream Flow Rights that Model the SB3 EFS in the DAT File of the Monthly Authorized Use Scenario Version of the Neches WAM

```
IF  NENE                    20091201   2            IF-NENE
TS      DSS  CNENE
IF  NERO                    20091201   2            IF-NERO
TS      DSS  CNERO
IF  ANAL                    20091201   2            IF-ANAL
TS      DSS  CANAL
IF  NEEV                    20091201   2            IF-NEEV
TS      DSS  CNEEV
IF  VIKO                    20091201   2            IF-VIKO
TS      DSS  CVIKO
```

The reservoir storage plots of Figures 10.1-10.8 include simulation M1 performed with the monthly WAM prior to updating the SB3 EFS modeling methodology. However, the update to the methodology presented here has no effect on the simulated reservoir storage contents. The storage contents computed by a simulation with the final monthly WAM with the SB3 EFS modeled as shown in Tables 10.11 and 10.12 are identical to the results from the M1 simulation plotted in Figures 10.1-10.8.

CHAPTER 11
SUMMARY AND CONCLUSIONS

The Water Rights Analysis Package (WRAP) is the generalized modeling system employed in the Water Availability Modeling (WAM) System maintained by the Texas Commission on Environmental Quality (TCEQ). WRAP combined with an input dataset from the TCEQ WAM System for a particular river basin is called a water availability model (WAM). The May 2019 expanded version of WRAP provides significantly expanded capabilities for:

- compiling, analyzing, and updating WAM hydrology input datasets for the WRAP monthly *SIM* and daily *SIMD* simulation models
- incorporating Senate Bill 3 (SB3) environmental flow standards (EFS) in the WAMs

The expanded WRAP modeling capabilities have been employed to develop daily and improved monthly WAMs for the Brazos, Trinity, and Neches River Basins with updated hydrology and significantly improved modeling of SB3 EFS. WRAP input datasets, other auxiliary datasets, and simulation results are documented by a May 2019 Brazos WAM Report [13], December 2019 Trinity WAM Report [14], and this June 2020 Neches WAM Report. These three river basins reflect a broad diversity of hydrologic and water resources development and management conditions. The improved WRAP/WAM modeling capabilities have been demonstrated to work well for these three river basin WAMs and are considered to be similarly applicable to the other river basins of the state.

This report and accompanying data files for the Neches River Basin, similarly to the preceding Brazos and Trinity WAM datasets and reports [13, 14], serve the following purposes.

1. The original 1940-1996 hydrologic period-of-analysis for the monthly Neches WAM was extended to cover 1940-2019 for both the daily and monthly versions of the WAM employing expanded capabilities provided by DSS files, *HEC-DSSVue*, and the WRAP program *HYD*.
2. Daily versions of the full authorization and current use scenario versions of the Neches WAM were developed that may be employed for various types of studies in the future. The work documented by this report focused on using the daily WAM to develop SB3 EFS instream flow targets that are incorporated in the input dataset for the monthly WAM.
3. Both the update of the hydrologic period-of-analysis and the conversion of a monthly WAM to daily employs an array of recently developed input data compilation and computational methodologies implemented in the May 2019 expanded version of the WRAP modeling system. The work in expanding the Neches WAM along with the Brazos and Trinity WAMs facilitated testing, evaluating, comparing, and improving these new modeling capabilities.
4. This report and accompanying data files provide an illustrative example for model-users interested in better understanding WRAP/WAM modeling capabilities and the tasks, data, and choices required in employing the various features of the modeling system.
5. In addition to *SIM/SIMD* input and output files, other relevant datasets were compiled as DSS files that may be used in future WAM updates and various other types of studies.
6. An operational new daily WAM and improved monthly WAM for the Neches River Basin are now available for various future applications.

Neches WAM *SIM* and *SIMD* Input and Output Files

The full authorization and current use Neches WAM datasets in the TCEQ WAM System consist of DAT, DIS, FLO, and EVA files with the filename root Neches3 or Neches8. The FLO and EVA files were converted to a combined hydrology DSS file in the work described here.

The expanded versions of the Neches WAM for the authorized use (run 3) and current use (run 8) scenarios allowing *SIM* and *SIMD* simulations with either daily or monthly computational time steps include the input files listed in Table 11.1. These files accompany this report. The filenames of the authorized use scenario (full authorization) and current use scenario datasets are listed in the second and fourth columns. The filenames of files shared by both the authorized and current use versions of the WAM are listed in the third column. The numerals 3 and 8 refer to the terms run 3 and run 8 adopted during the original 1997-2002 development of the WAM system.

Table 11.1
SIM/SIMD Simulation Input Files for December 2019 Expanded Neches WAM

	Authorized Use	Shared	Current Use
Monthly main water rights file	Neches3M.DAT		Neches8M.DAT
Daily main water rights file	Neches3D.DAT		Neches8D.DAT
Flow distribution file (*FD*, *WP*)	Neches3(M/D).DIS		Neches8(M/D).DIS
Hydrology file (*IN*, *EV*, *DF*, *TS*)		NechesHYD.DSS	
Daily input file (*RT*, *DC* records)		Neches3D.DIF/Neches8D.DIF	

The water right data in the monthly DAT file with filename Neches3M.DAT includes five *IF* record instream flow rights that model SB3 EFS with target series *TS* records derived from daily WAM simulation results using the DAT file with the filename Neches3D.DAT. A single hydrology input DSS file with the filename NechesHYD.DSS is read by both the monthly *SIM* and daily *SIMD*. The daily input DIF file is relevant only for a daily *SIMD* simulation. The same DSS and DIF input files are shared by the authorized and current use versions of the WAM. The daily input DIF file contains *DC* and *RT* records. The *RT* records activate and control routing. The *RT* records are removed to deactivate routing as noted within the DIF file.

Twelve different types of *SIM* and *SIMD* input files and 13 different types of *SIM* and *SIMD* output files are described in the *Reference* and *Users Manuals* [1, 2]. Only DAT, DSS, DIS, and DIF simulation input files and OUT, SUB, and DSS simulation output files are used in the simulations discussed in Chapters 2, 9 and 10 of this report. The *SIM/SIMD* OUT and SUB files are used with *TABLES*. The DSS input and output files are accessed with *HEC-DSSVue* primarily to prepare plots and compute frequency analysis statistics.

SIM and *SIMD* simulations with the input files of Table 11.1 produce DSS output files with the filenames Neches3D.DSS, Neches3M.DSS, Neches8D.DSS, or Neches8M.DSS. The set of DSS files that accompany this report includes a file with filename NechesSimulationResults.DSS that combines selected results from multiple different simulations presented in Chapters 9 and 10. This DSS file containing selected simulation results is described in the last section of Chapter 9.

Auxiliary Data Storage System (DSS) Datasets

In addition to the *SIM/SIMD* input and output files, this report is also accompanied by the following three DSS files which are described in Chapters 4, 5, and 6. The organization, format, and content of these files are summarized in Tables 4.14, 4.15, 4.16, 5.2, 5.3, 6.8, 9.15, and 9.16.

NechesDailyFlows.DSS
NechesMonthlyFlows.DSS
NechesEvapPrecip.DSS

The datasets stored in these DSS files can be explored with *HEC-DSSVue* to develop a better understanding of Neches WAM hydrology and/or used in future updates of the WAM hydrology. The datasets can also support other research or planning studies involving comparative analyses of stream flow characteristics and investigations of river system hydrology independently of the WRAP/WAM *SIM* and *SIMD* simulation models.

The Hydrologic Engineering Center (HEC) Data Storage System (DSS) and *HEC-DSSVue* provide comprehensive capabilities for managing, organizing, searching, tabulating, and plotting large time series datasets and performing statistical analyses and mathematical operations. *DSS* files and *HEC-DSSVue* have been fully integrated into the WRAP modeling system. The resulting greatly expanded modeling and analysis capabilities are demonstrated by this Neches WAM Report and the preceding Brazos and Trinity WAM Reports [13, 14]

SIM and *SIMD* Hydrology Input Datasets

The *SIM/SIMD* input file with filename NechesHYD.DSS contains monthly naturalized flow *IN* records for 20 control points (Chapter 5), evaporation-precipitation *EV* records assigned 12 control point identifiers (Chapter 6), daily flow *DF* records for 17 control points (Chapter 4), and target series *TS* records for five SB3 EFS instream flow rights (Chapters 7, 9, and 10). The DSS file with filename NechesHYD.DSS is called the *hydrology* input file or *time series* input file.

The original monthly Neches WAM has a hydrologic period-of-analysis of January 1940 through December 1996. The January 1997 through December 2019 extension can be easily switched on or off in simulation studies. With the hydrology input data covering 1940-2019, a simulation for 1940-2019, 1940-1996, or any other sub-period between 1940 and 2019 can be performed by setting *YRST* and *NYRS* on the *JD* record in the DAT file.

Alternative Hydrology Time Series Data Compilation and Adjustment Strategies

The Brazos [13], Trinity [14], and Neches [this report] WAMs represent diverse characteristics of natural river system hydrology and a broad diversity of water resources development and management activities that modify river flows. Expanded capabilities provided by DSS files, *HEC-DSSVue*, and the WRAP program *HYD* were employed in the hydrology updates for all three of these WAMs, but different alternative data management and computational strategies and options were adopted with each individual WAM as appropriate.

The extensions of the net evaporation less precipitation rates are designed to replicate basic concepts reflected in the original datasets for the three WAMs. Although the computational details vary between the original hydrologic periods-of-analysis and the extension periods and between the three river basins, the evaporation-precipitation extension methodologies are generally conceptually consistent. Expanded capabilities provided by DSS files, *HEC-DSSVue*, and *HYD* facilitated more efficient data management and computational operations.

Alternative methods for compiling and updating monthly naturalized stream flows (*IN* records) and daily pattern hydrographs (*DF* records) datasets are discussed in Chapter 3. The Neches WAM has been used as a case study to explore various alternative options. The methods for dealing with stream flow input data for the monthly *SIM* and daily *SIMD* simulation models finally adopted for the Neches WAM hydrology update are explained in Chapters 4 and 5.

Alternative methods reflect different levels of accuracy/validity/detail and levels of effort required to develop stream flow datasets. Some data compilation and adjustment strategies are more detailed than others. Techniques for expeditiously performing preliminary hydrology updates between less frequent more detailed updates have been developed as alternatives to the methods adopted during the 1997-2002 compilation of the original statewide WAM datasets.

The Neches WAM naturalized flow (*IN* record) extension methodology documented in this report is significantly different than adopted in the preceding Brazos WAM and Trinity WAM hydrology updates [13, 14]. The 1998-2017, 1997-2018, and 1997-2019 extensions of monthly naturalized flows for the Brazos, Trinity, and Neches WAMs are significantly different than the compilation of the original 1940-1997, 1940-1996, and 1940-1996 datasets. The original WAMs are monthly only with no daily flows (*DF* records).

The Neches WAM hydrology update is designed to develop naturalized monthly flows for the 1997-2019 extension period at a level of detail and accuracy comparable to the original 1940-1996 naturalized flow sequences. The strategies adopted for the Brazos and Trinity WAMs are expedient preliminary updates of hydrology datasets between less frequent more detailed updates requiring greater time and effort. The strategy adopted for the Neches WAM documented in this report required more time and effort, but the results are considered to reflect a higher level of detail and accuracy that is comparable to the methods applied in developing the original WAMs.

The *DF* record daily flows in the June 2020 Neches WAM also reflect much more detailed computational adjustments of observed daily flows than the May 2019 Brazos WAM and December 2019 Trinity WAM. The hydrology update of the June 2020 Neches WAM is also considered to be much improved over earlier developmental versions of the daily Neches WAM.

Stream Flow at WAM Control Points

The full authorization and current use, respectively, versions of the Neches WAM contain 326 and 343 control points. Both versions have the same 20 primary control points. Primary control points are sites at which monthly naturalized flows are provided as *IN* records in a *SIM* or *SIMD* input dataset. Naturalized flows at all other control points, called *secondary* control points, are computed within a *SIM* or *SIMD* simulation based on the naturalized flows provided at the primary control points and watershed parameters provided on flow distribution *FD* and watershed parameter *WP* records in the DIS file and/or control point *CP* records in the DAT file.

Sixteen of the 20 primary control points are USGS stream gage stations. The other four represent three dam sites and the basin outlet. Four of the 16 gage sites contain periods-of-record that include all of 1940 through 1996. Six of the 16 gage sites have periods-of-record that include all of 1997 through 2019. Measured reservoir releases at Sam Rayburn Dam are used as observed flows at a 17th primary control point. Limited periods-of-record of observed flows is a major issue in developing *DF* record daily and *IN* record monthly naturalized stream flow datasets.

DF record sequences of 1940-2019 daily naturalized flows are developed for 17 of the 20 primary control points, which include 16 USGS gage sites and the site of Sam Rayburn Dam. Daily flows at these 17 control points serve as pattern hydrographs used within the *SIMD* simulation to disaggregate monthly naturalized flows to daily at the over 300 control points in the WAM. The 1940-2019 daily flow pattern hydrographs for 17 sites are repeated within a *SIMD* simulation at the over 300 other control points using a standard automatically-applied *SIMD* algorithm.

<u>Daily Naturalized Flows at 17 Control Points (Chapter 4)</u>

Daily naturalized flows at 17 control points were compiled in the Neches WAM hydrology update to serve the following purposes.

1. January 1940 through December 2019 daily flows at 17 control points stored on *DF* records serve as pattern hydrographs used within the *SIMD* simulation to disaggregate monthly naturalized flows to daily at the over 300 control points in the Neches WAM.
2. January 1997 through December 2019 daily naturalized flow volumes are summed to monthly volumes for use in extending the original 1940-1996 monthly naturalized flows through December 2019.

The WRAP daily simulation model *SIMD* disaggregates monthly naturalized flow volumes to daily volumes in proportion to the flows of daily pattern hydrographs input on *DF* records while preserving the monthly volumes. Although monthly and daily flow volumes in a *SIMD* simulation are in acre-feet, flow rates in cfs or other units can be used for the *DF* record flow sequences defining patterns since only relative, not absolute, quantities are relevant. However, the final *DF* record daily flows adopted for the Neches WAM pattern hydrographs are daily naturalized flow volumes in acre-feet/day.

The general strategy adopted for developing a dataset of 1940-2019 daily naturalized flows at 17 control points includes the following tasks.

1. Compilation of observed actual daily flows at the 17 sites for the sub-periods of 1940-2019 for which flow data derived from measurements at gages are available.
2. Conversion of actual daily flows to daily naturalized flows by approximate computational adjustments to remove impacts of upstream reservoir net evaporation-precipitation and storage fluctuations.
3. Filling in gaps of missing daily naturalized flows based on relationships with daily naturalized flows at one or more other sites.
4. Aggregation of daily flows to monthly flows.
5. Adjustment of daily naturalized flows in a *SIMD* simulation to replicate monthly flows.

The computational procedures include additional strategies for dealing with various complications such as negative values for daily naturalized flows. The daily naturalized flows are adjusted to sum to the 1940-1997 monthly naturalized flows from the original WAM and adjusted 1997-2019 summations of 1997-2019 daily naturalized flows. Daily unregulated flows from a USACE Fort Worth District reservoir operations modeling system are adopted for *DF* record daily flows at three control points on the Lower Neches River. Most of the data management and computational tasks were performed using *HYD* and *HEC-DSSVue*.

Monthly Naturalized Flows at 20 Primary Control Points (Chapter 5)

Monthly naturalized flows at over 300 secondary control points are synthesized during the *SIM* or *SIMD* simulation based on the flows at 20 primary control points and information provided on *CP* records in the DAT file and *FD* and *WP* records in the flow distribution file. Flow distribution option 7 based on drainage area ratios is employed for synthesizing monthly naturalized flows at most secondary control points in the Neches WAM.

The original Neches WAM has a hydrologic period-of-analysis of 1940-1996. The January 1940 through December 1996 monthly naturalized flows at the 20 primary control points were adopted without modification for the June 2020 monthly/daily WAM. Daily naturalized flows at 17 control points were used to extend the *IN* record monthly naturalized flows through December 2019. Synthesis of naturalized flows at three ungaged sites from naturalized flows at other control points facilitated dealing with the largest water supply diversions which occur in the lower basin.

The *IN* records of 1940-2019 naturalized monthly flows at 20 control points are stored in the hydrology input file with filename NechesHYD.DSS along with the *DF*, *EV*, and *TS* records. This same single DSS file is accessed by the daily and monthly versions of the authorized use and current use versions of the *SIM* and *SIMD* DAT files.

Stream flow variability and stationarity are both important considerations. Time series plots and frequency statistics for the monthly naturalized flows presented in Chapter 5 demonstrate the great temporal variability of stream flow in the Neches River Basin, which is characteristic of stream flow throughout Texas. The purpose of the flow naturalization process is to remove non-stationarities. The 1940-2019 naturalized stream flows are shown to be essentially stationary with no evident long-term trends or permanent changes in flow characteristics.

Twelve 1940-2019 Monthly Net Evaporation-Precipitation Depth Sequences (Chapter 6)

The original Neches WAM evaporation EVA input file contains 12 sets of *EV* records with January 1940 through December 1996 sequences of monthly net reservoir surface evaporation minus adjusted precipitation depths. The WRAP program *HYD* was applied with Texas Water Development Board databases of monthly evaporation and precipitation depths as described in Chapter 6 to extend the sequences of monthly *EV* record evaporation less adjusted precipitation rates through December 2019. The evaporation-precipitation rates include adjustments for rainfall at the reservoir sites that is already reflected in the naturalized flows. The *EV* records were compiled in DSS file format for incorporation in the *SIM/SIMD* input file with filename NechesHYD.DSS. This single hydrology DSS file replaces the EVA, FLO, and TSF files, though these alternative text files can be quickly created from the DSS file.

Daily Modeling System

The daily *SIMD* simulation model includes all of the modeling capabilities of the monthly *SIM* simulation model, adjusted if and as necessary for a daily computational time step. *SIMD* includes additional 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 pulse flow components of environmental flow standards to the model.

The *SIMD* simulation model is the central component of the daily modeling system. *TABLES* and *HEC-DSSVue* provide a variety of capabilities for managing, organizing, and analyzing either *SIM* or *SIMD* input datasets and simulation results. Methods for calibrating flow routing parameters are implemented in the WRAP program *DAY*. The concepts and methodologies employed in the WRAP modeling system are documented by the *Reference Manual* [2] and *Daily Manual* [5]. The logistics of preparing input records shared by *SIM* and *SIMD* and additional *SIMD*-only records are explained in Chapters 3 and 4, respectively, of the *Users Manual*. Instructions for using *TABLES* and *HEC-DSSVue* with either daily or monthly input or output datasets are found in Chapters 5 and 6 of the *Users Manual*. The daily WRAP program *DAY* is documented in Appendix A of the *Daily Manual*.

Either *SIMD* or *SIM* can be employed to perform a monthly simulation with an input dataset prepared for a monthly simulation that contains no input records that are applicable only to *SIMD*. The monthly *SIM* can also be employed to perform a monthly simulation with an input dataset prepared for a daily simulation that contains input records that are applicable only to *SIMD*. *SIM* simply skips over daily-only *SIMD* records. However, a monthly *SIMD* simulation terminates with an error message if a daily-only *SIMD* input record is found in the DAT file.

Modeling Options Adopted for the Daily Neches WAM

The following discussion deals with the Neches WAM. However, the same issues are addressed in the Trinity and Brazos WAM Reports [13, 14]. The Brazos and Trinity WAMs represent the first applications of expanded modeling capabilities incorporated in the May 2019 version of WRAP. Basic findings from the Brazos and Trinity studies are similar and complementary and provided a foundation for developing the daily Neches WAM. The options adopted, lessons learned, and experience base acquired with the Brazos, Trinity, and Neches daily WAMs are also relevant to the future development of daily WAMs for other river basins.

SIMD capabilities outlined in Table 11.2 replicated from the Trinity WAM Report [14] are a series of optional modeling features that can be added singly or in combination to convert a monthly WAM to daily. Much of the complexity of *SIMD* is due to the model containing multiple optional alternative methods for performing the same tasks. A choice of optional methodology leads to another list of choices of options for implementing that selected methodology. Several *SIMD* modeling tasks are listed in the first column of Table 11.3 [13, 14]. Multiple alternative approaches are provided in *SIMD* for performing each of these tasks. Methods adopted for the daily Brazos, Trinity, and Neches WAMs are listed in the second column of Table 11.3. The third column of Table 11.3 lists other options that are not chosen for use with these three WAMs.

Table 11.2
Daily WRAP Modeling System [14]

Simulation of River/Reservoir Water Management/Use System with *SIMD*

- All *SIM* monthly simulation capabilities are replicated in *SIMD*.
- Additional *SIMD* capabilities that are not available in *SIM*.
  1. Monthly-to-Daily Disaggregation of Naturalized Stream Flows
  2. Monthly-to-Daily Disaggregation of Other Quantities
  3. Routing Flow Changes Caused by Water Rights
  4. Stream Flow Forecasting for Assessing Water Availability
  5. Additional Negative Incremental Flow Option and other Adjustments
  6. Simulation of Reservoir Operations for Flood Control
  7. Tracking High Pulse Flow Events for Environmental Flow Standards

Management/Analysis of *SIMD* Input Datasets with *TABLES* and *HEC-DSSVue*

Management/Analysis of *SIMD* Simulation Results with *TABLES* and *HEC-DSSVue*

Calibration of Routing Parameters Using Program *DAY*

Table 11.3
SIMD Simulation Options Adopted for Neches WAM [14]

Modeling Function	Final Adopted Methods	Other Alternatives Not Adopted
time series input file	DSS file	FLO, EVA, FAD, TSF, HIS files
flow disaggregation	default DFMETH option 4	DFMETH options 1, 2, 3
target disaggregation	Uniform	*JU* and *DW* record DND or ND
other water right options	none adopted	*DW* and *DO* record daily options
routing flow changes	available but not activated	lag and attenuation, Muskingum
routing parameter calibration	*DAY* statistical method	*DAYH* optimization options
negative incremental flows	NEGINC option 4	NEGINC options 1, 2, 3, 5, 6, 7, 8
next month placement	beginning priority sequence	within priority sequence
flow forecasting	no forecasting	wide range of forecast periods

Daily Versus Monthly Simulation Models

Computer simulation models are simplified approximations of real-world systems designed to provide meaningful information for relevant types of modeling and analysis applications. Actual real-world stream flow and other variables simulated in water availability modeling fluctuate continuous over time. Simulation model computations dealing with continuously varying variables are necessarily performed based on fixed computational time intervals. The monthly *SIM* completely ignores within-month variability. Both *SIMD* and *SIM* completely ignore within-day hourly or continuous instantaneous variability which can be relevant for certain modeling applications and situations, such as simulating flood events resulting from intense rainfall on relatively small watersheds.

The Texas WAM System is appropriately and effectively constructed based on a monthly computational time step. A monthly computational time step is generally optimal for water availability modeling. However, 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 pulse flows is represents a particularly significant advantage of daily modeling.

Flood control reservoir operations, high pulse environmental flow requirements, and the interactions between environmental flow requirements and flood control operations are aspects of water management that definitely can be modeled much more accurately with a daily WAM than with a monthly WAM. Daily models are required for modeling both the high flow pulse components of environmental flow standards and reservoir operations during floods due to the extreme variability characteristic of stream flow.

Stream Flow Variability

The tremendous variability of stream flow is the primary consideration responsible for the differences between monthly versus daily simulations. The plots of observed, naturalized, and simulated regulated stream flow found in this report illustrate the continuous variability and occasional extreme fluctuations that are characteristic of river flows throughout the Neches River Basin and throughout Texas. Modeling within-month stream flow variability is the most significant aspect of the daily 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, generally resulting in more stream flow being available for filling reservoir storage and supplying diversion targets, while correspondingly reducing the unappropriated flows leaving the river system at the outlet. Instream flow targets and shortages are significantly affected by stream flow variability. Environmental high flow pulse standards are completely defined by stream flow variability.

The *DF* record daily flow pattern hydrographs compiled for 17 control points and employed to disaggregate monthly naturalized flows to daily at the 326 or 343 control points in the authorized or current use WAM versions are described in Chapter 4. The daily naturalized flows are developed based on adjusting observed daily flows. In cases of gaps of missing gage records, the naturalized daily flows are compiled from flows recorded at another gage site.

The *DF* record daily flow pattern hydrographs are considered to provide a valid, reasonably accurate representation of stream flow variability at most of the many individual control points. However, since flows at over 300 sites are represented by flows developed for only 17 sites, the *DF* record flows do not capture the lag and attenuation effects of the river reaches between the many control points for which the flows are repeated, which is relevant to the following discussion of routing and forecasting.

Routing of Flow Changes

Streamflow depletions for 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. Otherwise, a monthly *SIM* simulation has no routing. 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 week or two of the next month.

The daily *SIMD* routing computations consist of lag and attenuation adjustments to the flow changes that occur as each of the water rights is considered in the priority-based simulation computations. Without routing, streamflow changes propagate to the outlet in the same day that they originate, with no lag, in a daily *SIMD* simulation analogously to a *SIM* monthly simulation.

The lag and attenuation routing method and calibration of routing parameters are described in Chapters 3 and 4 of the *Daily Manual* [5]. The routing parameters are stored on *RT* records in the daily input DIF file and are described in Chapter 4 of the *Users Manual* [2]. The routing computations are performed at the control points specified on the *RT* records but conceptually represent changes occurring gradually along river reaches.

Calibrating routing parameters and performing routing computations in the *SIMD* simulation for the river reaches between all control points is not feasible. Routing parameters are determined for only selected river reaches defined by stream flow gages. The routing computations are performed for only a sub-reach of each of the selected reaches. The daily Neches WAM with overt 300 control points includes routing parameters at 19 control points representing the 19 river reaches defined by the 20 primary control points.

Development of the normal flow and high flow lag and attenuation parameters at 19 control points is described in Chapter 8. Routing parameter calibration for the Brazos, Trinity, and Neches River Basins is based on a recently developed methodology of statistical analyses of flow changes detected in observed flows between USGS gages. Observed actual lag and attenuation characteristics of flow changes in actual gaged river reaches in the Neches River Basin as well as the Brazos and Trinity River Basins were found to exhibit great apparently random variability that is difficult to describe or explain. Calibrated values for the lag and attenuation parameters for the *SIMD* routing algorithm also exhibit great unexplained variability and associated uncertainty.

The *SIMD* routing algorithm simulates lag and attenuation of flow changes in free flowing stream reaches, not reservoirs. However, surcharge storage in reservoirs either with or without flood control pools can be modeled in the flood control routines using *FV/FQ* record reservoir storage volume versus outflow tables. However, *FV/FQ* records are used in the daily Neches WAM only for modeling the gated flood control pool of the USACE Sam Rayburn Reservoir.

The routing algorithm incorporated in the *SIMD* simulation is a very simplistic model of a very complex phenomena. However, adding greater complexity to the model would likely not improve the accuracy of the model. Likewise, further improvements to the recently developed new parameter calibration methodology would likely not further improve the accuracy of the model.

The daily as well as monthly versions of the Neches WAM provide a valid simulation model without employing routing. Routing is very approximate with inherent simplifications, uncertainties, inaccuracies, and variabilities. Routing may or may not improve the accuracy of a simulation depending upon the particular application and circumstances. The effects of routing and variation in routing parameters on improving or worsening model accuracy is difficult to precisely assess. The simulation studies presented in Chapters 9 and 10 indicate reasonable results without routing and perhaps better results without than with routing.

Routing is easily activated or deactivated in the daily Neches WAM. The daily Neches WAM includes the routing parameters described in Chapter 8. In general, simulation results appear to not be overly sensitive to routing strategies and the values of routing parameters. Reasonable simulation results can be obtained with or without routing and, with routing, results vary only minimally with some significant changes to routing parameter values. These conclusions regarding the daily Neches WAM are consistent with the findings of the Brazos and Trinity daily WAM simulation studies [13, 14].

Developing monthly SB3 EFS instream flow targets from daily simulation results is the primary application considered in the report. Based on simulation results discussed in Chapters 9 and 10, routing was not activated in the final simulation adopted for generating the SB3 EFS targets. However, routing could possibly be beneficial in other types of modeling applications.

Forecasting of Future Stream Flows

The *SIMD* forecasting algorithm is applicable only in a daily, not monthly, simulation. Forecasting is relevant only if routing is employed. Forecasting and accompanying reverse routing, as explained in Chapter 3 of the *Daily Manual* [5], are designed specifically to deal with the effects of water right actions in a particular day on downstream stream flows in future days, as reflected in routing computations. Due to routing (lag and attenuation), stream flow depletions, return flows, and reservoir releases in the current day can affect both (1) stream flow availability for downstream senior water rights in future days and (2) channel flow capabilities for releases from flood control pools. The following two purposes are the only purposes served by forecasting in the model.

1. Protecting senior water rights in future days from the lag effects associated with stream flow depletions of junior water rights located upstream in the current day.
2. Prevention of current day releases from flood control pools that contribute to flooding in future days.

The alternative simulations presented in Chapters 9 and 10 include alternative forecast periods of 3 days, 10 days, and 57 days. The default forecast period of 57 days is computed by *SIMD* as twice the total lag time for the longest flow path plus one day and conceptually represents near-perfect protection of senior water rights from the adverse effects of junior streamflow depletions at upstream locations during preceding days. However, routing and forecasting are not employed in the daily Neches WAM simulations used to generate monthly SB3 EFS targets for reasons discussed in the preceding routing section and continued as follows.

The monthly *SIM* and daily *SIMD* simulation algorithms for determining the amount of stream flow available to each water right are based on the minimum of the flows at the control point of the water right and all downstream control points. The reason for considering all downstream control points is to assure that a water right does not appropriate stream flow that has already been appropriated by other more senior water rights. With forecasting in a daily *SIMD* simulation, water availability depends on flows at downstream control points in future days as well as in the current day. The amount of streamflow available for refilling reservoir storage and supplying diversion targets for a water right at a particular control point in a particular day is set as the minimum available flow at that control point and many downstream control points in that day and, with forecasting, during the multiple days of the forecast period. Stream flow variability, routing inaccuracies, and other complexities may result in water availability being over-constrained by the consideration of many downstream control points and additional future days.

A monthly simulation inherently assumes that the effects of water right diversions and refilling reservoir storage on stream flow propagate to the outlet of the river system within the month. Routing and forecasting are relevant in a daily simulation. The effects of reservoir refilling and releases and water supply diversions and return flows during the current day may affect downstream river flows over a number of future days. With routing activated, forecasting serves to protect downstream senior water rights and prevent excessive reservoir flood control pool releases that contribute to exceeding maximum non-damaging flow limits at downstream gages.

The Neches WAM simulation studies presented in Chapters 9 and 10 of this report and the Brazos WAM and Trinity WAM simulation studies documented in previous reports [13, 14] support the following findings.

1. Routing is very approximate, may not dramatically affect simulation results, and may or may not contribute positively to model validity. Routing may be most beneficial without forecasting in situations in which preservation of water right priorities is not required.
2. Forecasting significantly, in some cases greatly, impacts simulation results and adversely affects WAM accuracy and validity. Forecasting is not employed in the final Neches WAM that accompanies this report but can easily be switched on and off in future studies.
3. 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.

JU record parameters WRMETH and WRFCST control selection of next-day placement of routed flow changes within the next day priority sequence. Simulations presented in this report employ the default option of placing routed flows at the beginning of the priority sequence.

Forecasting of future stream flow is highly uncertain in actual real-time water management, with inaccuracies increasing with the length into the future of the forecast period. The selection of a *SIMD* forecast period is largely arbitrary. Routing parameters are inherently highly uncertain and inaccurate. Routing inaccuracies contribute to forecasting inaccuracies. Tradeoffs between dealing with modeling issues inherent in negative incremental flow adjustments, routing, forecasting, and other *SIMD* options may vary between WAMs and between different WAM applications.

Sam Rayburn Reservoir Flood Control Operations

Flood control operations by the USACE Fort Worth District of the multiple-purpose Sam Rayburn Reservoir and *SIMD* simulation thereof are described in Chapter 8. The daily *SIMD* is necessary for WRAP modeling of reservoir flood control operations. In a monthly *SIM* simulation, outflow equals inflow with no flow attenuation (storage) whenever the reservoir is full to the top of conservation storage capacity. *SIMD* includes comprehensive capabilities for modeling the operations of single reservoirs or multiple-reservoir systems with releases controlled by a combination of dam outlet capacities and specified allowable non-damaging flow levels at any number of gaging stations located at downstream sites. Flood control operations greatly affect reservoir storage contents and downstream river flows during high flow periods but generally only minimally during normal and low-flow periods.

Senate Bill 3 Environmental Flow Standards

The work documented by this Neches WAM report and the preceding Brazos and Trinity WAM reports [13, 14] is motivated by the need to improve capabilities for incorporating Senate Bill 3 (SB3) environmental flow standards (EFS) in the TCEQ WAM System. A strategy is demonstrated in which 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 model. The monthly *SIM* simulation model is applied with the SB3 EFS modeled as *IF* record water rights with targets defined as target series *TS* records.

The SB3 EFS at the five sites in the Neches River Basin are described in Chapter 7. Alternative simulations are performed in the simulation studies presented in Chapters 9 and 10 to develop SB3 EFS targets for the full authorization and current use versions of the WAM. The SB3 EFS targets for the current use scenario are larger than the corresponding targets for the full authorization scenario because the simulated regulated flows are larger.

Monthly instream flow targets for the five SB3 EFS are computed and converted to *TS* records, which are copied to the hydrology input file. The *IF* records incorporated in the DAT file for the monthly simulation access the *TS* record targets in the DSS input file. The conversion of *SIMD* simulation results to *SIM* input data is accomplished efficiently within *HEC-DSSVue*. The pathnames for the *TS* records in the DSS file are listed in Tables 9.13 and 10.13 for the current and authorized use versions of the WAM. The *IF* record rights in the current and authorized use DAT files are replicated in Tables 9.14 and 10.14.

This adopted strategy precisely replicates monthly totals of daily SB3 EFS instream flow targets in the monthly WAM. However, shortages in meeting the targets may differ significantly between the monthly and daily simulations. Although the monthly summation of daily *IF* record targets for the SB3 EFS targets are replicated as input to the monthly WAM, monthly regulated flows and associated target shortages are computed within the monthly simulation. The choice between subsistence and base flow targets in each day of the daily *SIMD* simulation is affected by within-month stream flow variability. The determination of high pulse flow targets is totally controlled by within-month stream flow variability. Shortages in meeting instream flow targets are also affected by within month stream flow variability.

Different strategies for employing the expanded WAM will be useful for different types of applications. With the strategy applied in this report, after SB3 EFS targets are established with the daily WAM, routine modeling applications employ the monthly WAM. SB3 EFS set-asides are incorporated in the monthly WAM appropriately reducing the quantities of stream flow available for further appropriation by junior appropriators. This strategy is relevant for evaluating water right permit applications and various types of planning studies. However, as noted in the preceding paragraph, shortages or capabilities for satisfying the instream flow requirements are not accurately modeled in the monthly simulation due to within-month flow variability.

The daily WAM can be employed directly in many other types of studies with input data varied in alternative daily *SIMD* simulations to explore various water management strategies and issues. The daily model can facilitate environmental flow studies in which assessments of capabilities for meeting environmental flow standards are important. Daily simulation modeling capabilities also support studies in which flood control operations are a significant concern.

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