Daily Water Availability Model for the Trinity River Basin

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CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

CHAPTER 1
INTRODUCTION

The Texas Commission on Environmental Quality (TCEQ) Water Availability Modeling (WAM) System consists of the Water Rights Analysis Package (WRAP), WRAP input datasets for all of the river basins of Texas, and related information. The TCEQ WAM System input dataset for a particular river basin combined with the generalized WRAP modeling system is called a water availability model (WAM). The water availability model for the Trinity River Basin is called the Trinity WAM. This report documents the following additions to the full authorization and current use scenario versions of the Trinity WAM.

- A daily WAM is created by expanding the monthly WAM to include monthly-to-daily disaggregation of naturalized flows, routing daily flow changes, and forecasting.
- Daily *SIMD* features are employed to incorporate flood control operations of the eight U.S. Army Corps of Engineers (USACE) reservoirs in the WAM.
- New expanded WRAP capabilities for simulating Senate Bill 3 (SB3) environmental flow standards (EFS) are implemented with the daily *SIMD* simulation model.
- The USACE Hydrologic Engineering Center (HEC) Data Storage System (DSS) is fully employed in creating and applying the WAM.
- Available data are compiled to update the original 1940-1996 hydrologic period-of-analysis for the monthly and daily WAMs to extend through December 2018.
- 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 for the Daily WAM

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 Trinity 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 environmental flow standards 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 environmental flow targets for the monthly *SIM* employed routinely for applications of interest.

The monthly WAMs have been routinely applied in administration of the water rights permit system and in regional and statewide planning since 2002. The TCEQ has sponsored

research at Texas A&M University (TAMU) over the past several years that has included development of a daily WRAP modeling system and daily versions of selected datasets, including the Brazos and Trinity WAMs. Developmental test status daily modeling features introduced in the August 2015 WRAP are greatly improved in the May 2019 WRAP [1, 2, 3, 4, 5, 6]. The new modeling capabilities were tested and demonstrated in conjunction with developing a daily Brazos WAM [7]. Numbers in brackets refer to the list of references at the end of this report.

TCEQ sponsored research and development at TAMU has also included expanding capabilities for compiling and updating WAM hydrology input datasets. The WRAP programs *HYD* [5] and *DAY* [4] provide capabilities for compiling, synthesizing, and updating monthly and daily hydrology input data for the WRAP monthly *SIM* and daily *SIMD* simulation models. *HYD* and *DAY* methods have been significantly expanded and improved since the August 2015 WRAP. *HYD* includes features designed for detailed extensions of monthly hydrology datasets. *HYD* also includes options designed for expedient preliminary updates of hydrology datasets that can be performed between less frequent but more detailed updates. These preliminary methods are employed with the daily Brazos [7] and Trinity WAM hydrology extensions.

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.

Trinity WAM Hydrology

The original Trinity WAM in the TCEQ WAM System has a hydrologic period-of-analysis extending from January 1940 through December 1996 [9]. The validity and accuracy of frequency and reliability estimates derived from the WAMs are enhanced by periodically updating the hydrologic periods-of-analysis to extend to near the present. The updated 1940-2018 hydrology compiled as described in this report also facilitates comparisons of more recent periods of drought such as 2010-2012 with the 1950-1957 drought, which is the most hydrologically severe drought-of-record for the Trinity River Basin and most of the state.

Primary control points are defined as sites for which monthly naturalized flows are provided in a *SIM/SIMD* input dataset as *IN* records in a FLO or DSS file. Naturalized monthly flows at secondary control points are synthesized during the simulation performed by the WRAP programs *SIM* or *SIMD* using parameters read from a flow distribution DIS input file. Monthly net evaporation less precipitation rates used by *SIM* and *SIMD* for computing reservoir surface net evaporation-precipitation volumes are stored on *EV* input records in an EVA file or DSS file.

The monthly 1940-1996 Trinity WAM hydrology includes naturalized flows (*IN* records) at 40 control points and net reservoir surface evaporation less precipitation depths (*EV* records) assigned to 50 control points. The monthly 1940-1996 naturalized flows and net evaporation-precipitation rates in the TCEQ WAM dataset are adopted without revision in the development of the new daily WAM presented in this report. These monthly time series input data are updated to extend through December 2018 as described in Chapters 7 and 8.

The daily Trinity WAM has a *SIMD* input file with *DF* record 1940-2018 daily flows at 49 control points, which are used within *SIMD* as pattern hydrographs for about 1,400 WAM control points. Daily flow data compilation and synthesis methods are described in Chapter 6.

SIM/SIMD channel loss factors recorded on *CP* records in the DAT file and *SIMD* lag and attenuation routing parameters stored on *RT* records in the DIF file are also related to hydrology. Channel loss factors are input for only a few control points in the original WAM and are not reinvestigated or modified in the December 2019 expanded WAM. A routing parameter calibration methodology is employed to develop lag and attenuation parameters for 39 river reaches as discussed in Chapter 3.

Scope of Work

The work reported here consists of employing expanded WRAP capabilities to develop updated and expanded daily and monthly versions of the full authorization and current use scenario versions of the Trinity WAM. Improvements in modeling Senate Bill 3 (SB3) environmental flow standards (EFS) are a central motivating objective, but the expanded WAM capabilities are relevant to a broad range of applications. The tasks accomplished in the work documented by this report are outlined in Table 1.1.

Table 1.1
Tasks Performed in Expanding the Trinity WAM

1. Preliminary update of 1940-1996 monthly Trinity WAM period-of-analysis to 1940-2018 and conversion of the time series from FLO and EVA files to a single DSS file.

   Compilation of monthly naturalized flow volumes on *IN* records for 40 control points.

   Compilation of evaporation-precipitation depths on *EV* records for 50 control points.

2. Creation of a new daily Trinity WAM by converting the monthly WAM to daily.

   Evaluation and selection of strategies and options for various modeling tasks.

   Addition of 1940-2018 sequences of daily flows at 49 control points used as pattern hydrographs for disaggregating monthly naturalized flows to daily at 40 primary and about 1,360 secondary control points.

   Addition of daily lag and attenuation routing parameters for 39 river reaches.

   Addition of flood control operations for eight multiple-purpose reservoirs operated by the U.S. Army Corps of Engineers (USACE) Fort Worth District (FWD).

3. Simulation of Senate Bill 3 (SB3) environmental flow standards (EFS) at four control points using the new features introduced in the May 2019 version of *SIMD*.

4. Execution of daily *SIMD* simulations to compute daily targets for the SB3 EFS that are summed to monthly quantities and incorporated as target series *TS* records in the DSS input file to be read as input for monthly *SIM* simulations.

5. Analyses of simulation results to explore modeling issues and compare the monthly versus daily WAMs. A simulation study is presented in Chapters 9 and 10.

Versions of WRAP and the Trinity WAM *SIM* and *SIMD* Input Datasets

WRAP daily modeling capabilities have been greatly expanded and improved over the past several years with evolving developmental versions of *SIMD* and the other WRAP programs replacing preceding versions. The Brazos [7] and Trinity WAMs served as case study datasets for developing and testing daily modeling capabilities. The version of WRAP documented by the May 2019 manuals [1, 2, 3, 4, 5] was used to create the daily Trinity WAM and perform the simulations presented in this report. The May 2019 WRAP reflects major additions and improvements since preceding versions [6]. The September 2019 versions of *SIM* and *SIMD* were used for the simulations. However, the only modifications between the May 2019 and September 2019 versions of *SIM* and *SIMD* are refinements to the routines controlled by the hydrologic condition *HC* record HCV(wr) options. These *HC* record options are not applicable to the Trinity WAM.

Alternative versions of the monthly WAMs for all of the river basins of the state have been developed in the past for various alternative scenarios reflecting combinations of premises regarding water use, return flows, and reservoir sedimentation. Full authorization and current use datasets are available at the TCEQ WAM website. In the full authorization scenario, water use targets are the full amounts authorized by water right permits and full reuse with no return flow is assumed. In the current use scenario, water use targets for each right is based on the maximum annual amount used in any year during a recent ten-year period, best estimates of actual return flows are adopted, and storage capacities for large reservoirs are adjusted for sedimentation.

Full authorization (run 3) and current use (run 8) *SIM* water rights input DAT files for the Trinity WAM have been periodically revised and updated by the TCEQ since their creation in 2002 [9]. The work reported here expands the latest versions of the datasets downloaded from the TCEQ WAM website in October 2019. The two datasets are each composed of four files with the following filenames. The dates for the latest revisions are shown in parenthesis.

- trin3.dat (10/7/2014), trin3.dis (9/12/2014), trin3.eva (2/25/2011), trin3.flo (4/2/2013)
- trin8.dat (10/26/2012), trin8.dis (8/21/2012), trin8.eva (10/25/2011), trin8.flo (10/24/2007)

The authorized and current use DAT files with filenames trin3.dat and trin8.dat are expanded as described by this report to create both daily and revised monthly WAMs.

The December 2019 full authorization and current use daily DAT files described by this report were created by adding input records to the monthly full authorization DAT file with filename trin3.dat last updated by the TCEQ on 10/7/2014 and current use DAT file with filename trin8.dat last updated by the TCEQ on 10/26/2012. The additions described by the chapters of this report were inserted into copies of these two DAT files downloaded from the TCEQ WAM website in October 2019. The resulting December 2019 full authorization daily Trinity WAM DAT file replaces several preceding developmental test versions of the daily *SIMD* input DAT file. The December 2019 current use daily Trinity WAM is the first version of a current use daily WAM.

The flow distribution files with filename trin3.dis and trin8.dis and the accompanying FLO and EVA files were downloaded from the TCEQ WAM website in October 2019 along with the DAT files. The DIS files are adopted without change for the daily WAM. The hydrology files were replaced as discussed later in this report. The monthly and daily Trinity WAMs are described in Chapter 2.

Data Files Accompanying and Described by this Report

This report describes the files listed in Table 1.2 and procedures employed in developing them. The expanded monthly and daily Trinity WAM input dataset is composed of the first eight files listed in the table. Selected monthly *SIM* and daily *SIMD* simulation results are stored in the ninth file. The last three DSS files listed in Table 1.2 were created in the process of developing the expanded Trinity WAM. These last three DSS files listed are also useful, independently of WRAP/WAM modeling, in exploring characteristics of stream flow and river system hydrology. Organization and content of the data files discussed in this report are summarized in Chapter 11.

The terms run 3 and run 8 were adopted during 1998-2002 during the original development of the statewide WAMs to refer to the authorized use (full authorization) scenario and current use scenario versions of the WAMs. The numerals 3 and 8 are retained in the filenames to refer to the full authorization and current use versions of the WAMs.

The expanded Trinity WAM for the authorized or current use scenarios with either a daily or monthly time step consists of *SIM* or *SIMD* and the relevant input files listed in Table 1.2. The 1940-1996 hydrology dataset routinely employed by the TCEQ in monthly *SIM* simulations is adopted without modification. The 1997-2018 hydrology extension was compiled from available data that were developed differently than the original 1940-1996 hydrology as explained in Chapters 7 and 8. The 1997-2018 extension can be easily switched on or off in simulation studies. With the hydrology input data covering 1940-2018, a simulation for 1940-2018, 1940-1996, or any sub-period of years between 1940 and 2018 can be performed by setting *YRST* and *NYRS* on the *JD* record in the DAT file.

The daily flows (*DF* records) at 49 control points, monthly naturalized flows (*IN* records) at 40 control points and net evaporation-precipitation depths (*EV* records) assigned to 50 control point identifiers are stored in the same single DSS input file, but alternatively can be stored in optional DIF, FLO, and EVA files. Monthly summations of daily targets for SB3 environmental flow standards computed by *SIMD* are also stored in the same DSS file (rather than TSF file) for input to a monthly *SIM* simulation. Selected results from both daily and subsequent monthly simulations (Chapters 9 and 10) are recorded in the ninth file listed in Table 1.2.

A monthly simulation can be performed with the WRAP program *SIM* with a DAT file containing input records for a daily simulation, such as the file Trinity3D.DAT. Program *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. The WRAP program *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, but only with a DAT file with no daily-only records.

This report is also accompanied by the last three DSS files listed in Table 1.2, which were compiled along with expanding the Trinity WAM as described in Chapters 6, 7, 8, 9, 10, and 11 of this report. These three other auxiliary files are read with *HEC-DSSVue* but are not designed to be read by *SIM* or *SIMD*. The datasets contained in these three other DSS files serve the following purposes. The DSS files compile data relevant to the improved and updated 1940-2018 hydrology for the Trinity WAM. Model-users can access and explore the DSS datasets with *HEC-DSSVue* to develop a better understanding of Trinity WAM hydrology. The DSS files can be used in future

updates of the WAM hydrology. The datasets in the DSS files can support other research independently of the WRAP/WAM *SIM* and *SIMD* simulation models involving comparative analyses of stream flow characteristics and exploring river system hydrology. *HEC-DSSVue* provides flexible comprehensive capabilities for organizing, managing, and analyzing time series data, which includes convenient graphical and tabular displays and statistical analyses of the DSS files of time series datasets listed in Table 1.2.

Table 1.2
Data Files Accompanying and Described by this Report

Trinity WAM Files

Trinity3M.DAT and Trinity8M.DAT – monthly *SIM/SIMD* input file with information regarding water development, allocation, and use including *IF* and *TS* records at four control points that reference *TS* records in the DSS input file with Senate Bill 3 (SB3) environmental flow standard (EFS) targets.

Trinity3D.DAT and Trinity8D.DAT – daily *SIMD* input file with information regarding water development, allocation, and use including *IF*, *ES*, and *PF* records modeling SB3 environmental flow standards at four control points and *FR*, *FF*, *FV*, and *FQ* records modeling reservoir operations during floods at eight reservoirs.

Trinity3(M/D).DIS and Trinity8(M/D).DIS – parameters governing *SIM/SIMD* distribution of monthly naturalized flows from 40 primary to about 1,360 secondary control points. These are the original authorized and current use flow distribution files without modification and are applicable to both daily and monthly simulations.

Trinity(3/8)D.DIF – *SIMD* lag and attenuation routing parameters for 39 control points and other daily simulation data. The data in the daily input DIF file is the same for both the full authorization and current use daily WAMs but the filename root must be either Trinity3D.DIF or Trinity8D.DIF for consistency with the other files.

TrinityHYD.DSS – monthly and daily 1940-2018 *SIM* and/or *SIMD* time series input including monthly naturalized flows (*IN* records) in acre-feet/month at 40 control points, 50 sets of net evaporation-precipitation depths (*EV* records) in feet/month, monthly SB3 EFS targets (*TS* records) in acre-feet/month at four control points, and daily flows (*DF* records) in acre-feet/day at 49 control points.

TrinitySimulationResults.DSS –Selected *SIM* monthly and *SIMD* daily and monthly simulation results for both the full authorization and current use scenario simulations.

Other DSS Files

TrinityDailyFlows.DSS – gaged and computed daily flow data compiled in the process of analyzing and synthesizing *SIMD* daily flow pattern hydrographs (Chapter 6).

TrinityMonthlyFlows.DSS – monthly observed and naturalized stream flow data compiled in the process of compiling and analyzing monthly flows (Chapter 7).

TrinityEvapPrecip.DSS – monthly precipitation rates, reservoir evaporation rates, and net reservoir evaporation less precipitation rates (Chapter 8).

CHAPTER 2
TRINITY RIVER BASIN AND TRINITY WAM

The following maps show the major rivers and largest cities of Texas (Figure 2.1), major river basins of Texas (Figure 2.2), and the Trinity River Basin (Figure 2.3).

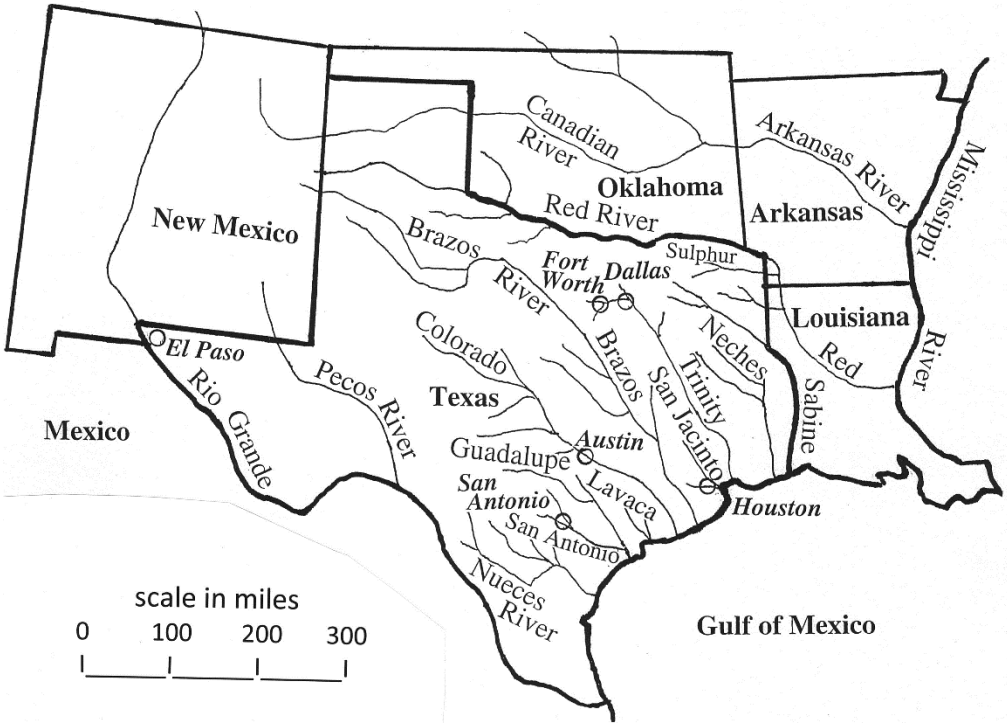

Figure 2.1 Major Rivers and Largest Cities of Texas

Figure 2.2 Major River Basins of Texas

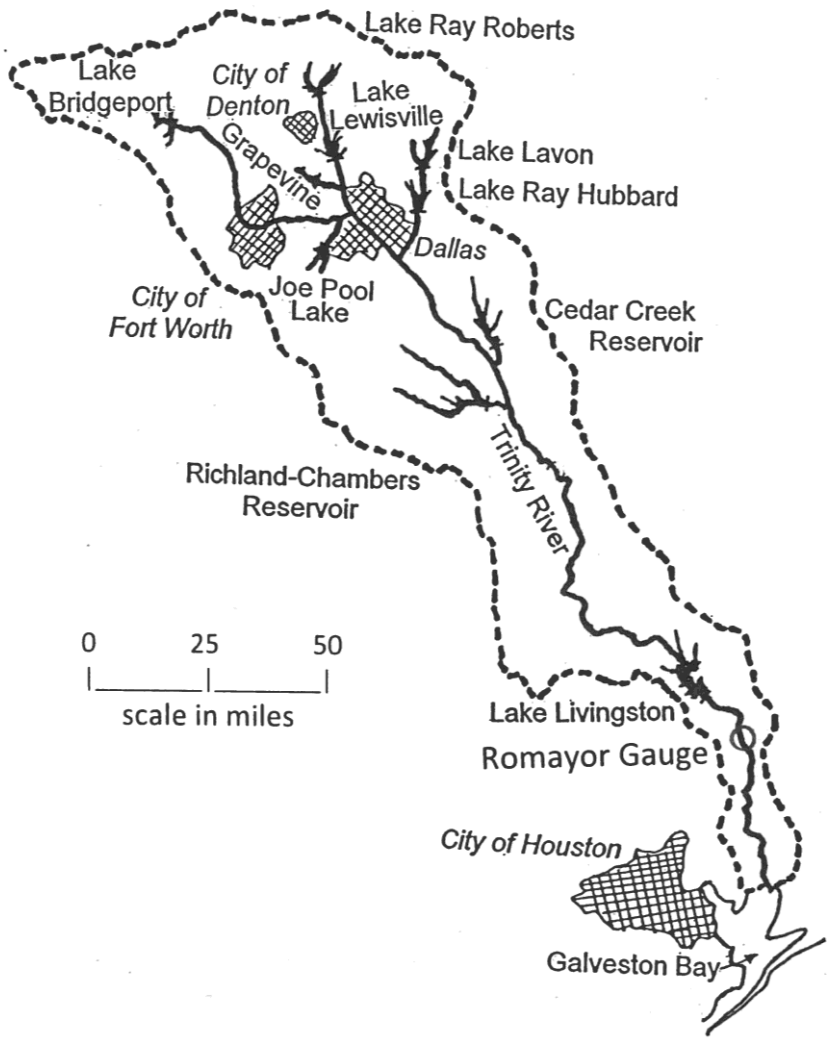

Figure 2.3 Trinity River Basin

The Trinity River Basin is bordered by the Brazos, Red, Sabine, Neches, and San Jacinto River Basins and discharges into Galveston Bay east of Houston. The basin encompasses an area of approximately 18,000 square miles that transitions from western rolling plains, through central Texas prairies and East Texas piney woods, into the gulf coastal prairies. Most of the population of the Trinity River Basin reside in the Dallas-Fort Worth (DFW) metropolitan area. The DFW metropolitan area has a 2019 population of about 6.8 million people, which is about a fourth of the population of Texas. Dallas and Fort Worth have 2019 populations of 1,350,000 and 550,000. Seventy other cities in the DFW metropolitan area have populations exceeding 10,000 people.

Mean annual rainfall increases from west to east from less than 30 inches at the northwestern extreme of the basin to over 50 inches at the southeastern-most point of the basin. Major tributaries include the West Fork, Elm Fork, and East Fork of the Trinity River, Cedar Creek, Chambers Creek, and Richland Creek. Mean daily flows recorded at the U.S. Geological Survey (USGS) gage on the Trinity River near the city of Romayor (Figure 2.3) located 20 miles below Livingston Dam are plotted in Figure 2.4 in units of cubic feet per second (cfs). Figure 2.4 illustrates the tremendous variability that is characteristic of streamflow throughout the basin.

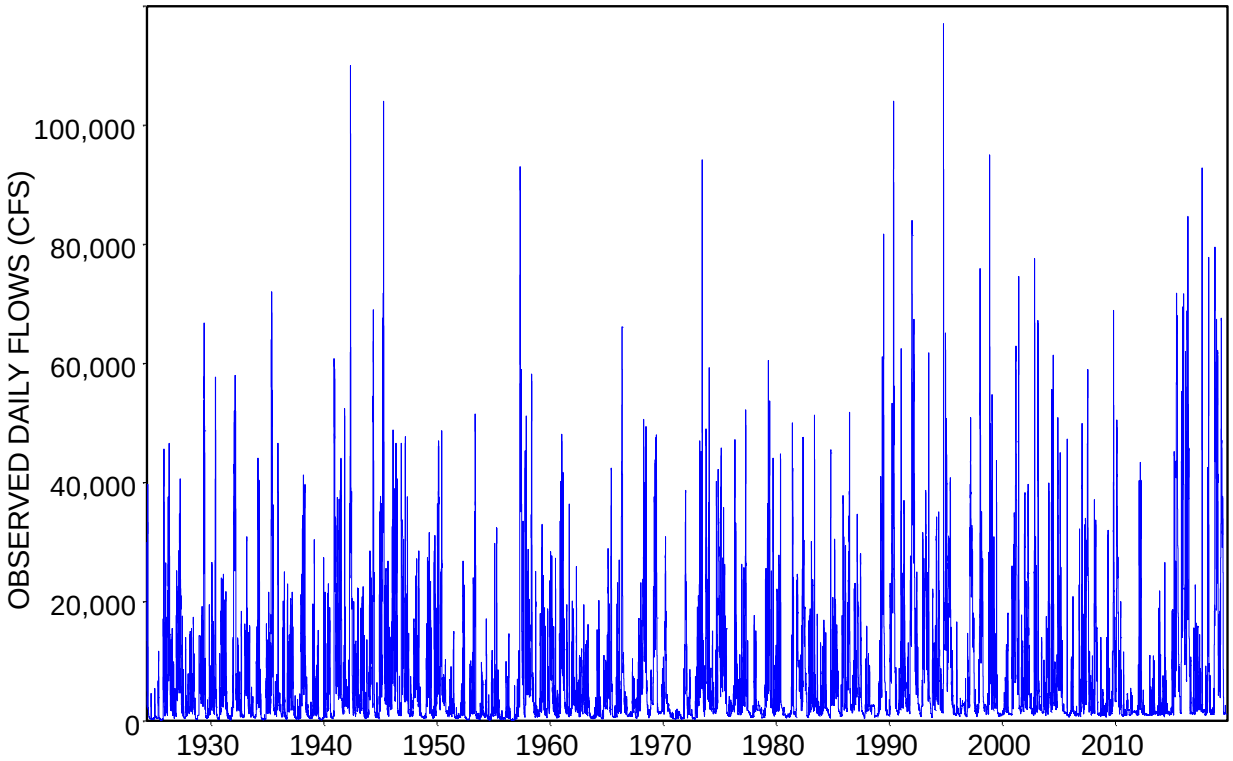

Figure 2.4 Mean Daily Flows Observed at the USGS Gage on the Trinity River near Romayor from May 1, 1924 through October 9, 2019

Trinity WAM System Components

Table 2.1 is a tabulation of input record counts recorded in the *SIM* message file for the latest (October 2012 and October 2014) updated versions of the full authorization and current use versions of the Trinity WAM input DAT and DIS files available at the TCEQ WAM website as of December 2019. The original records modeling the Senate Bill 3 (SB3) environmental flow standards (EFS) are removed in the work reported here as explained later in this chapter.

Table 2.1
Counts of Number of Input Records in Trinity WAM Datasets

Latest Update of Datasets	Oct 2014 Authorized		Oct 2012 Current Use	
Water Use Scenario	Original	SB3 EFS	Original	SB3 EFS
With or Without SB3 EFS	SB3 EFS	Removed	SB3 EFS	Removed
total number of control point *CP* records	1,403	1,356	1,418	1,405
number of primary control points	40	40	40	40
control points with evaporation-precip rates	50	50	50	50
number of reservoirs as counted by *SIM*	697	697	700	700
number of *WR* record water rights	1,057	1,013	1,067	1,023
number of instream flow *IF* record rights	71	35	89	53
number of *FD* records in DIS file	1,251	1,251	1,247	1,247

The original Trinity WAM [9] modeled 552 water right permits with authorized annual diversions totaling 5,322,610 acre-feet/year, with 57.7% municipal, 35.4% industrial, and 6.5% agricultural irrigation, and 0.2% other uses. The *WR* record counts in Table 2.1 are much greater than the number of water right permits since multiple *WR* records are used in the WAM to model a single water right permit. The largest water right holders are Dallas Water Utilities, North Texas Municipal Water District, Tarrant Regional Water District, and Trinity River Authority.

Reservoirs

The major reservoirs listed in Table 2.2 include the 31 reservoirs with permitted storage capacities exceeding 5,000 acre-feet and a 32th with almost 5,000 acre-feet. The numbers in the first column of Table 2.2 refer to the reservoir labels on the map of Figure 2.5. The reservoirs are listed in Table 2.2 in descending order of permitted (authorized) water supply storage capacity.

The conservation storage capacities from the full authorization and current use WAM datasets are listed in the last two columns of Table 2.2. The authorized storage capacities are from the water right permits. The current use scenario dataset includes adjustments of storage capacities for sedimentation. The full authorization dataset includes permitted but not yet constructed reservoirs; the current use dataset does not. The current use dataset includes term permits; the full authorization dataset does not.

The total permitted conservation storage capacity of 7,445,687 acre-feet of the 32 major reservoirs account for 98.0 percent of the total storage capacity of 7,596,675 acre-feet in the 697 model reservoirs in the full authorization WAM. The total storage capacity of 7,188,849 acre-feet of these 32 reservoirs account for 97.7 percent of the total storage capacity of 7,356,202 acre-feet in the 700 model reservoirs in the current use WAM.

Flood control storage capacity is not included in the water right permits and monthly WAM. However, the following flood control pool storage capacities for the eight USACE reservoirs are added to the daily WAM: Lakes Lewisville (340,770 acre-feet), Lavon (291,700), Ray Roberts (265,000), Grapevine (244,400), Navarro Mills (148,900), Joe Pool (127,100), Bardwell (85,100), and Benbrook (76,550 acre-feet). Addition of reservoir flood control operations to the daily WAM is covered in Chapter 4.

Lake Livingston owned and operated by the Trinity River Authority under contract with the City of Houston and located on the lower Trinity River is the largest reservoir in the basin. Water is transported by pipeline from Lake Livingston through a regional water supply system to Houston in the adjoining San Jacinto River Basin and water users in the lower Trinity Basin. The Trinity River Authority supplies its customers in the upper and middle Trinity Basin from Lakes Bardwell, Navarro Mills, and Joe Pool, owned by the USACE.

Richland-Chambers, Cedar Creek, Bridgeport, and Eagle Mountain, which are ranked among the nine largest water supply reservoirs in the basin, are owned and operated by Tarrant Regional Water District to supply water to Fort Worth and other cities. Lakes Bridgeport and Eagle Mountain are operated as a system, along with Lake Worth which is located immediately below Eagle Mountain Lake. Lake Worth is operated by the City of Fort Worth as a pass-through reservoir and is used for recreation and water supply. Tarrant Regional Water District also supplies

water to the cities of Fort Worth, Weatherford, and Benbrook from Lake Benbrook which is owned by the U.S. Army Corps of Engineers (USACE) Fort Worth District (FWD).

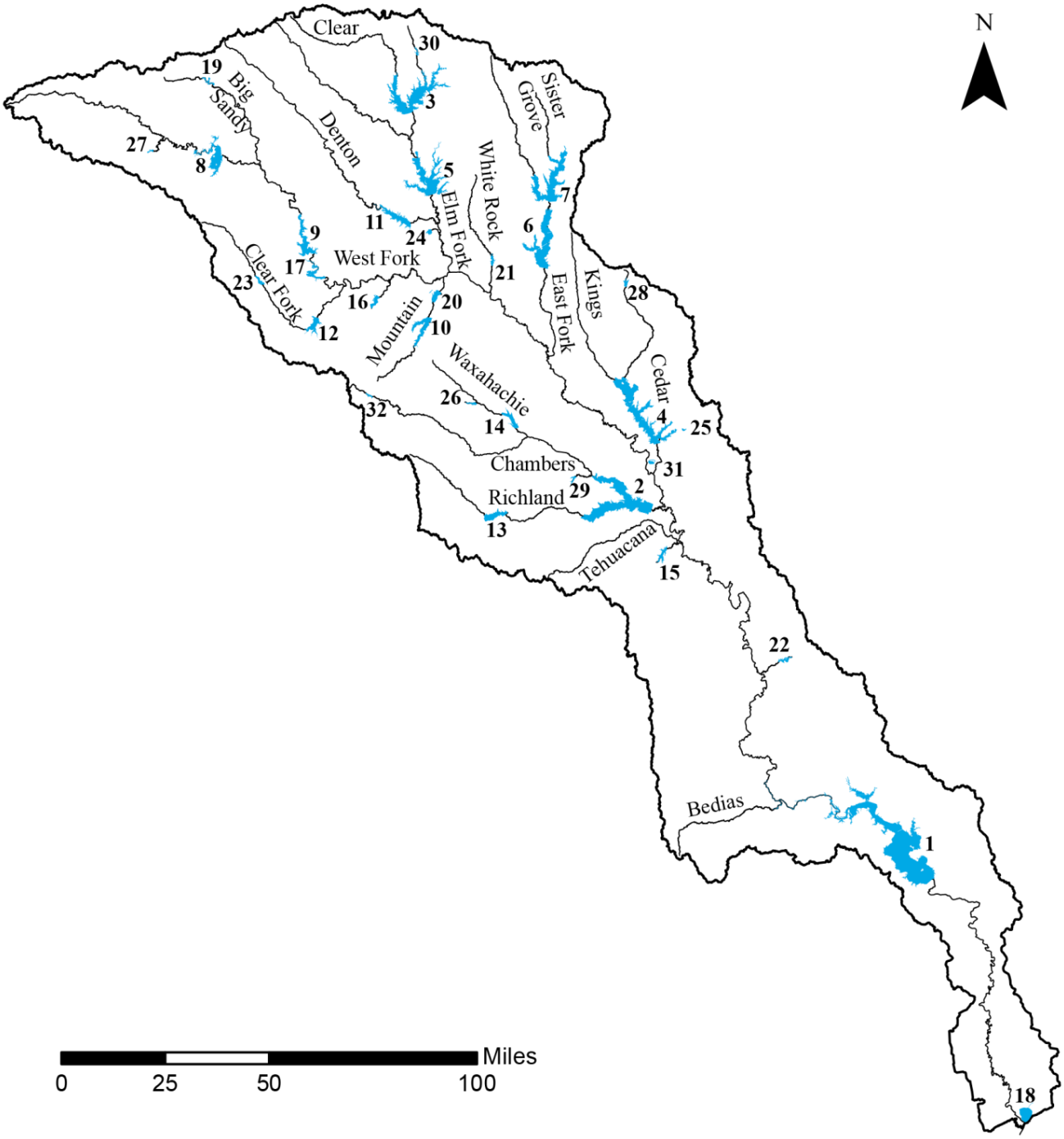

Figure 2.5 Major Tributaries and the 32 Largest Reservoirs

The City of Dallas (Dallas Water Utilities) supplies water to about 30 cities in addition to Dallas from Lakes Ray Roberts, Lewisville, and Grapevine owned by the USACE and Lake Ray Hubbard and White Rock Lake owned by the City of Dallas. The North Texas Municipal Water

District supplies its customers from Lavon Lake under a water supply storage contract with the USACE. The other major reservoirs are owned by various cities and electric power companies.

Lake Lewisville is currently the only reservoir in the Trinity River Basin with capabilities for hydropower energy generation. A low-head run-of-river hydropower unit located in the river below the dam operates using water supply releases through the dam. Recreation is popular at most of the lakes in the basin.

Table 2.2
Major Reservoirs in the Trinity River Basin

Map ID	Reservoir	Reservoir Identifier	WAM CP ID	Initial Impound	Storage Capacity Authorized (acre-feet)	Storage Capacity Current (acre-feet)
1	Lake Livingston	LIVSTN	B4248B	1969	1,750,000	1,739,743
2	Richland-Chambers	RICHCH	B5035A	1987	1,135,000	1,109,368
3	Ray Roberts Lake	Table 2.3	B2335A	1987	799,600	796,474
4	Cedar Creek Lake	CEDAR	B4976A	1965	678,900	630,550
5	Lewisville Lake	Table 2.3	B2456A	1954	618,400	613,957
6	Lake Ray Hubbard	HUBBRD	B2462A	1968	490,000	484,495
7	Lavon Lake	Table 2.3	B2410A	1953	456,500	421,028
8	Lake Bridgeport	BRIDGE	B3808A	1932	387,000	370,468
9	Eagle Mountain Lake	EGLMTN	B3809A	1934	210,000	195,941
10	Joe Pool Lake	JOPOOL	B3404A	1986	176,900	172,678
11	Grapevine Lake	Table 2.3	B2362A	1952	162,500	162,500
12	Benbrook Lake	Table 2.3	B5157P	1952	88,250	85,568
13	Navarro Mills Lake	NAVARO	B4992A	1963	63,300	41,335
14	Bardwell Lake	BARDWL	B5021A	1965	54,900	44,199
15	Fairfield Lake	FAIRFD	B5040A	1969	50,600	43,884
16	Lake Arlington	ARLING	B3391A	1957	45,710	37,792
17	Lake Worth	WORTH	B3340A	1914	38,124	37,077
18	Lake Anahuac	ANAHUA	B4279C	1914	35,300	25,781
19	Lake Amon G. Carter	CARTER	B3320B	1956	28,589	20,050
20	Mountain Creek Lake	MTNCRK	B3408A	1937	22,840	22,840
21	White Rock Lake	WHITER	B2461A	1911	21,345	7,937
22	Houston County Lake	HOUCTY	B5097A	1966	19,500	17,561
23	Lake Weatherford	WTHRFD	B3356A	1957	19,470	18,630
24	North Lake	NORTH	B2365A	1957	17,100	16,985
25	Forest Grove	FOREST	B4983A	1976	16,348	16,348
26	Lake Waxahachie	WAXAHC	B5018A	1956	13,500	11,790
27	Lost Creek Reservoir	LOSTCK	B3313B	1990	11,961	11,882
28	New Terrell City Lake	TERREL	B4972A	1955	8,712	8,512
29	Lake Halbert	HALBRT	B5030A	1921	7,357	5,982
30	Lake Kiowa	KIOWA	B2334A	1970	7,000	6,513
31	Trinidad Lake	TRINDD	B4970A	1925	6,200	6,200
32	Alvarado Park Lake	B5001	B5001A	1966	4,781	4,781

The USACE Fort Worth District owns and operates eight of the 14 largest reservoirs (Ray Roberts, Lewisville, Lavon, Joe Pool, Grapevine, Benbrook, Navarro Mills, and Bardwell). The eight multiple-purpose reservoirs are operated by the USACE for flood control. Nonfederal sponsors hold contracts for the water supply storage capacity. The nonfederal water supply sponsors for the eight federal reservoirs include the Trinity River Authority, Tarrant Regional Water District, North Texas Municipal Water District, Dallas, Fort Worth, and other cities.

Lakes Ray Roberts, Lewisville, Lavon, Grapevine, and Benbrook owned and operated by the USACE are modeled in the Trinity WAM input DAT file using the component reservoirs listed in Table 2.3. The conservation storage capacities of these federal reservoirs are divided between multiple nonfederal water supply sponsors. The Cities of Denton and Dallas have contracted separately with the USACE for the water supply storage of both Lake Ray Roberts and Lake Lewisville. Lake Grapevine is shared by the Dallas County Park Cities (a group of several communities) and the cities of Grapevine and Dallas. The conservation pool of Lake Benbrook is also modeled as a multiple-owner reservoir in the monthly Trinity WAM. Recognizing that Ray Roberts, Lewisville, Lavon, Grapevine, and Benbrook are five actual reservoirs rather than 20 component reservoirs reduces the number of reservoirs in Table 2.1 from 697 to 682 for the full authorization dataset and from 700 to 685 for the current use dataset.

Table 2.3
Conservation Storage Capacity (acre-feet) of Component Reservoirs Used to Model Multiple-Owner Lakes Ray Roberts, Lewisville, Grapevine, Benbrook, and Lavon

Ray Roberts		Lewisville		Grapevine		Benbrook		Lavon	
				Full Authorization					
ROBDAL	591,704	LEWDA1	214,000	GPVDAL	85,000	BENBRK	15,750	LAVON0	12,700
ROBDEN	207,896	LEWDA2	201,000	GPVDPC	50,000	BENBR1	7,250	LAVON1	100,000
Total	799,600	LEWDA3	134,976	GPVGP1	1,250	BENBR2	7,250	LAVON2	280,000
		LEWDE1	21,000	GPVGP2	26,250	BENBR3	9,210	LAVON3	63,800
		LEWDE2	47,424	Total	162,500	BENBR4	48,790	Total	456,500
		Total	618,400			Total	88,250		
				Current Use					
ROBDAL	589,237	LEWDA1	214,000	GPVDAL	85,000	BENBRK	13,068	LAVON0	7,772
ROBDEN	207,237	LEWDA2	201,000	GPVDPC	50,000	BENBR1	7,250	LAVON1	100,000
Total	796,474	LEWDA3	131,025	GPVGP1	1,250	BENBR2	7,250	LAVON2	280,000
		LEWDE1	21,000	GPVGP2	26,250	BENBR3	9,210	LAVON3	41,028
		LEWDE2	46,932	Total	162,500	BENBR4	48,790	Total	421,028
		Total	613,957			Total	85,568		

Addition of flood control pools and flood control operations is covered in Chapter 4. A flood control pool in each of the five actual reservoirs in Table 2.3 is combined with only one of the component reservoirs of that actual reservoir in the daily WAM. The flood control pool in each of the five reservoirs is set on top of a single component reservoir conservation pool as described in Chapter 4. All component reservoirs should be full in order to store water in the flood control pool. However, with the selected component reservoir full and stream flows at flood levels, all component reservoirs are expected to be full or essentially full to capacity in the *SIMD* simulation.

WAM Primary Control Points and Corresponding USGS Gaging Stations

Primary control points are locations at which monthly naturalized flows are provided in a *SIM* or *SIMD* input dataset. Naturalized flows at all other control points, called secondary control points, are computed within the *SIM/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.

INMETHOD(cp) option 7 is entered in *CP* record field 6 for most of the secondary control points. The naturalized flows are distributed from primary to secondary control points based on specifications for defining incremental watersheds read from flow distribution *FD* records and incremental watershed drainage areas on watershed parameter *WP* records in the DIS file.

The Trinity WAM has 40 primary control points, which are listed in Table 2.4 with locations and connectivity shown in Figures 2.6 and 2.7. Monthly naturalized flows are provided in the FLO file. Naturalized flows are synthesized during execution of *SIM* for the about 1,360 secondary control points based on sub-watershed delineations and areas provided in the DIS file. The 40 primary control points are the sites of USGS stream gaging stations, with the exception of control point 8TRGB, the outlet of the Trinity River at Galveston Bay. Daily stream flow data is available at 38 of the USGS gaging stations for varying periods of record, as shown in Table 2.9.

The last three columns of Table 2.4 show the 1940-1996 median and mean naturalized flow in acre-feet/month and mean flow in cubic feet per second (cfs). The mean of the daily gaged flows in cfs during the period-of-record is tabulated in the last column of Table 2.5. For the observed flows used in the analyses presented in this report, the term *present* in the Table 2.5 period-of-record refers to September 8, 2019, the last day of data available when the data were downloaded from the USGS National Water Information System (NWIS) website. The beginning and end of the period-of-record for daily flows for each gage is shown in the third column of Table 2.5. The number of days with missing recorded flows is tabulated in the fourth column. The periods-of-record have the following days of missing data.

Big Sandy Creek near Bridgeport (control point 8BSBR): 3,289 days during 1995-2004.
West Fork of the Trinity River at Grand Prairie (8WTGP): 13 days during April and May 1925.
Mountain Creek at Grand Prairie (8MCGP): 731 days during September 1999 – September 2001.
Elm Fork Trinity near Lewisville (8ELLE): 365 days during September 1992 – September 1993.
Denton Creek at Grapevine (8DNGR): 4,391 days during June 1991 through July 2003.
White Rock Creek at Greenville Avenue (8WRDA): 2,738 days during 1980-1984, 1992-1994, and 1999-2001.
East Fork of the Trinity River at McKinney (8ETMK): 12,496 days during 1975-2009.
East Fork Trinity River near Forney (8ETFO): 367 days during September 1999 – September 2000.
Trinity River at Rosser (8TRRS): 4,810 days during October 1925 through December 1938.
Cedar Creek at Kemp (8CEKE): 5,480 days during October 1987 through September 2002.
Richland Creek near Dawson (8RIDA): 365 days during October 1992 – September 1993.
Tehuacana Creek near Streetman (8TEST) has 367 missing days, 1999-2000.
Trinity River near Crockett (8TCR): 4,754 days during September 1988 – September 2001.
Trinity River at Riverside (8TRRI): two days, 24 August 1944 and 23 May 1961.

The 2002 WAM Report [9] indicates that control point 8RIFA is the site of USGS gaging station 08064600 on Richland Creek near Fairfield. However, this gage is no longer included in the NWIS website maintained by the USGS. The gage was probably terminated in conjunction with construction of the Richland-Chambers Reservoir.

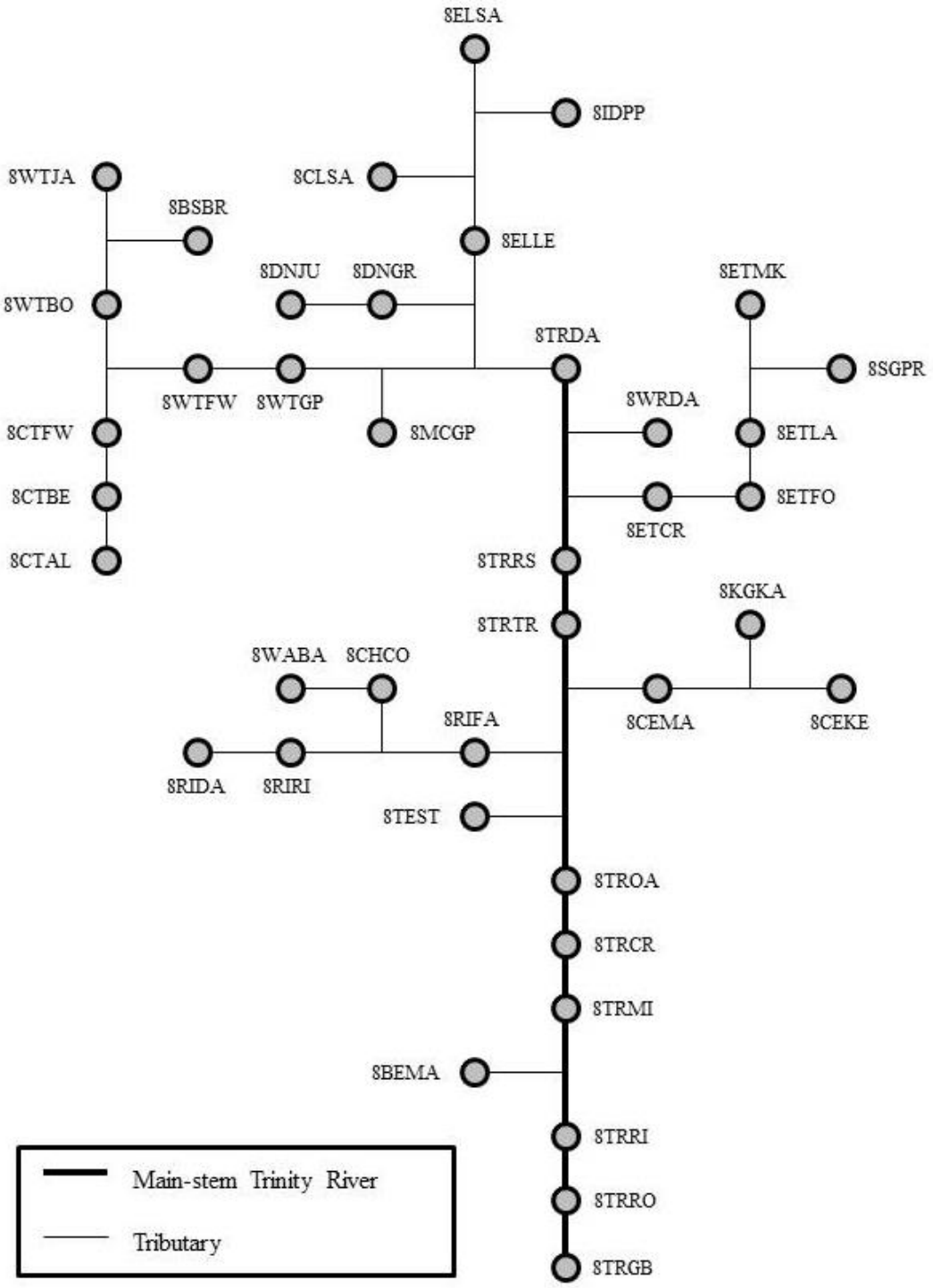

Figure 2.6 Schematic of Primary Control Points in the Trinity WAM

Table 2.4
Primary Control Points in the Trinity WAM

WAM CP	USGS Gage	Location	Basin Area	1940-1996 Naturalized Flow Median	Mean	Mean
			(mile^2)	(ac-ft/m)	(ac-ft/m)	(cfs)
8WTJA	08042800	West Fork Trinity River near Jacksboro	683	1,055	6,031	100.0
8BSBR	08044000	Big Sandy Creek near Bridgeport	333	844	4,794	79.5
8WTBO	08044500	West Fork Trinity River near Boyd	1,725	4,220	19,183	318.0
8CTAL	08046000	Clear Fork Trinity River near Aledo	251	893	3,370	55.9
8CTBE	08047000	Clear Fork Trinity River near Benbrook	431	1,713	6,953	115.2
8CTFW	08047500	Clear Fork Trinity River at Fort Worth	518	2,801	9,493	157.3
8WTFW	08048000	West Fork Trinity River at Fort Worth	2,615	11,433	35,920	595.4
8WTGP	08049500	West Fork Trinity River at Grand Prairie	3,065	18,600	47,838	792.9
8MCGP	08050100	Mountain Creek at Grand Prairie	298	1,882	8,046	133.4
8ELSA	08050500	Elm Fork Trinity River near Sanger	381	2,410	11,179	185.3
8IDPP	08051000	Isle Du Bois Creek near Pilot Point	266	1,807	8,677	143.8
8CLSA	08051500	Clear Creek near Sanger	295	1,350	6,173	102.3
8ELLE	08053000	Elm Fork Trinity River near Lewisville	1,673	12,646	49,131	814.4
8DNJU	08053500	Denton Creek near Justin	400	1,294	6,550	108.6
8DNGR	08055000	Denton Creek near Grapevine	705	2,595	13,337	221.1
8TRDA	08057000	Trinity River at Dallas	6,106	47,236	132,318	2193
8WRDA	08057200	White Rock Creek at Greenville Ave	66	1,514	3,372	55.9
8ETMK	08059000	East Fork Trinity River near McKinney	190	2,318	8,273	137.1
8SGPR	08059500	Sister Grove Creek near Princeton	113	1,487	4,968	82.3
8ETLA	08061000	East Fork Trinity River near Lavon	773	7,656	30,890	512.0
8ETFO	08061750	East Fork Trinity River near Forney	1,118	13,615	47,947	794.7
8ETCR	08062000	East Fork Trinity River near Crandall	1,256	15,200	52,456	869.5
8TRRS	08062500	Trinity River near Rosser	8,146	82,132	203,983	3,381
8TRTR	08062700	Trinity River at Trinidad	8,538	89,298	220,148	3,649
8CEKE	08062800	Cedar Creek near Kemp	189	3,109	11,198	185.6
8KGKA	08062900	Kings Creek near Kaufman	233	2,166	8,101	134.3
8CEMA	08063000	Cedar Creek near Mabank	733	7,242	26,706	442.7
8RIDA	08063100	Richland Creek near Dawson	333	1,478	6,066	100.5
8RIRI	08063500	Richland Creek near Richland	734	6,532	28,066	465.2
8WABA	08063800	Waxahachie Creek near Bardwell	178	1,777	11,181	185.3
8CHCO	08064500	Chambers Creek near Corsicana	963	4,264	25,147	416.8
8RIFA	08064600	Richland Creek near Fairfield	1,957	13,581	58,942	977.0
8TEST	08064700	Tehuacana Creek near Streetman	142	623	5,350	88.7
8TROA	08065000	Trinity River near Oakwood	12,833	150,299	342,785	5,682
8TRCR	08065350	Trinity River near Crockett	13,911	182,567	386,254	6,402
8TRMI	08065500	Trinity River near Midway	14,450	192,293	406,067	6,731
8BEMA	08065800	Bedias Creek near Madisonville	321	3,885	12,629	209.3
8TRRI	08066000	Trinity River at Riverside	15,589	218,349	451,127	7,478
8TRRO	08066500	Trinity River at Romayor	17,186	254,206	503,149	8,340
8TRGB	no gage	Trinity River at Galveston Bay	17,949	411,977	549,103	9,102

Table 2.5
Periods-of-Record and Mean Gaged Flows for the USGS Gaging Stations
(Missing days counts and mean flows are for gage period-of-record through September 8, 2019.)

WAM CP	USGS Gage Location	Period-of Record	Missing Days	Mean Flow (cfs)
8WTJA	West Fork Trinity River near Jacksboro	Mar 1956-present	0	106.3
8BSBR	Big Sandy Creek near Bridgeport	Oct 1936-present	3,289	78.2
8WTBO	West Fork Trinity River near Boyd	Jan 1947-present	0	264.1
8CTAL	Clear Fork Trinity River near Aledo	Aug 1947-Oct 1975	0	40.7
8CTBE	Clear Fork Trinity River near Benbrook	Jul 1947-present	0	96.9
8CTFW	Clear Fork Trinity River at Fort Worth	Mar 1924-present	0	131.6
8WTFW	West Fork Trinity River at Fort Worth	Oct 1920-present	0	413.9
8WTGP	West Fork Trinity River at Grand Prairie	Mar 1925-present	13	717.7
8MCGP	Mountain Creek at Grand Prairie	Oct 1960-present	731	145.1
8ELSA	Elm Fork Trinity River near Sanger	May 1949-Dec 1984	0	156.7
8IDPP	Isle Du Bois Creek near Pilot Point	May 1949-Dec 1984	0	120.0
8CLSA	Clear Creek near Sanger	Mar 1949-present	1	107.6
8ELLE	Elm Fork Trinity River near Lewisville	Mar 1949-present	365	737.1
8DNJU	Denton Creek near Justin	Oct 1949-present	0	113.2
8DNGR	Denton Creek near Grapevine	Oct 1947-present	4,391	208.8
8TRDA	Trinity River at Dallas	Oct 1903-present	0	1,813.1
8WRDA	White Rock Creek at Greenville Ave	Aug 1961-present	2,738	89.2
8ETMK	East Fork Trinity River near McKinney	Sep 1949-present	12,496	119.5
8SGPR	Sister Grove Creek near Princeton	Sep 1949-Jan 1975	0	71.2
8ETLA	East Fork Trinity River near Lavon	Oct 1953-Sep 1989	0	338.3
8ETFO	East Fork Trinity River near Forney	Jan 1973-present	367	713.3
8ETCR	East Fork Trinity River near Crandall	Jul 1949-present	0	727.5
8TRRS	Trinity River near Rosser	Aug 1924-present	4,810	3,331
8TRTR	Trinity River at Trinidad	Oct 1964-present	0	4,664
8CEKE	Cedar Creek near Kemp	Jan 1963-present	5,480	120.2
8KGKA	Kings Creek near Kaufman	Jan 1963-Sep 1987	0	153.7
8CEMA	Cedar Creek near Mabank	Oct 1938-Feb 1966	0	413.2
8RIDA	Richland Creek near Dawson	Oct 1960-present	365	165.1
8RIRI	Richland Creek near Richland	Apr 1939-Jun 1989	0	363.3
8WABA	Waxahachie Creek near Bardwell	Oct 1963-present	4	96.7
8CHCO	Chambers Creek near Corsicana	Apr 1939-Sep 1984	0	421.1
8RIFA	Richland Creek near Fairfield	Gage is missing from NWIS.		-
8TEST	Tehuacana Creek near Streetman	Apr 1968-present	367	92.6
8TROA	Trinity River near Oakwood	Oct 1923-present	0	5,480
8TRCR	Trinity River near Crockett	Jan 1964-present	4,754	6,078
8TRMI	Trinity River near Midway	Apr 1939-Nov 1970	0	5,716
8BEMA	Bedias Creek near Madisonville	Oct 1967-present	0	230.5
8TRRI	Trinity River at Riverside	Oct 1923-Sep 1968	2	6,333
8TRRO	Trinity River at Romayor	May 1924-present	0	8,114
8TRGB	Trinity River at Galveston Bay	no gage	-	-

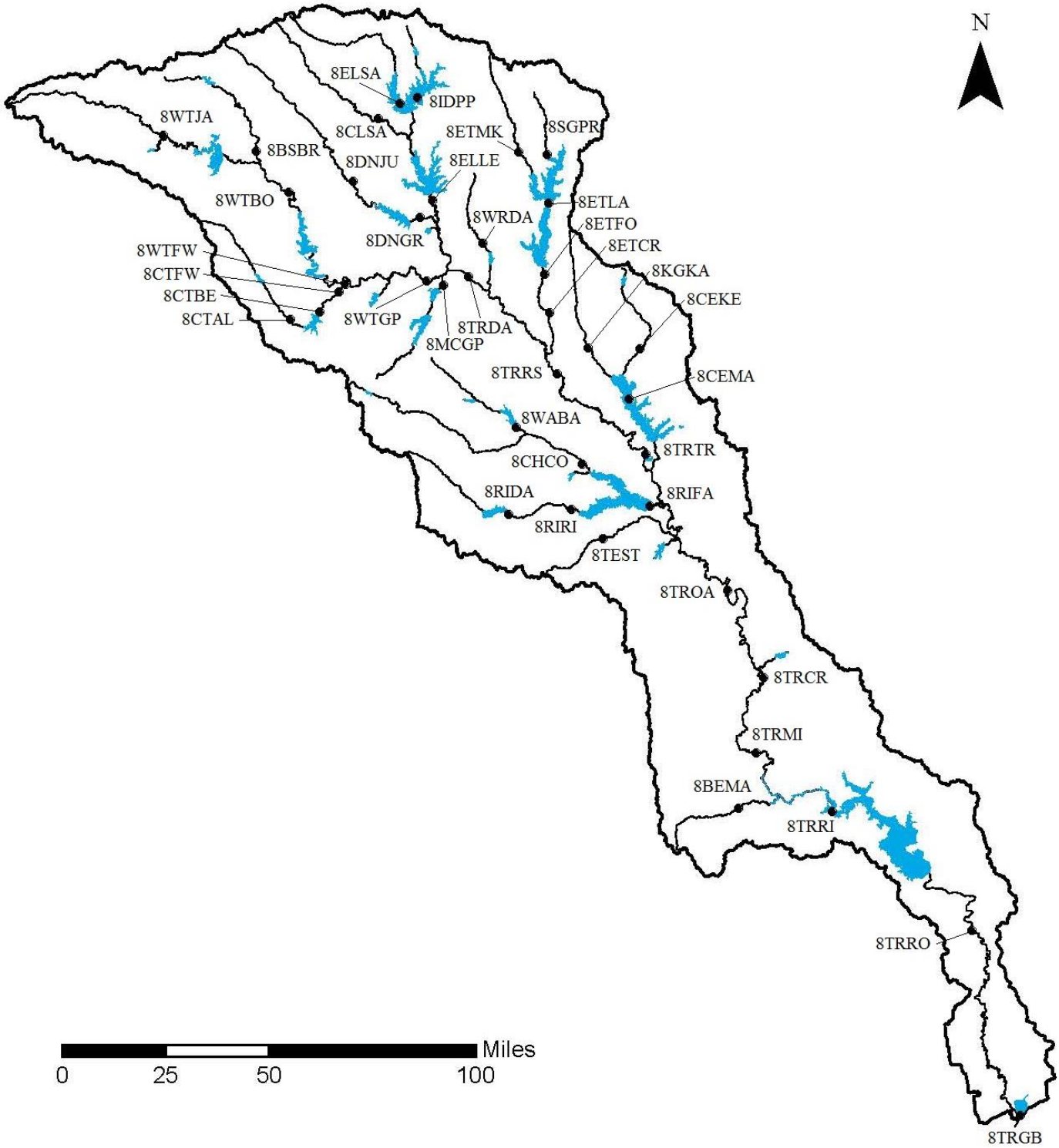

Figure 2.7 Map of Primary Control Points in the Trinity WAM

The 40 primary control points with naturalized flows provided as *IN* records in the *SIM* and *SIMD* input dataset have five-character identifiers that begin with the numeral 8.

Water Rights

The October 2014 full authorization Trinity WAM has 1,057 water right *WR* records and 71 instream flow *IF* records (Table 2.1). The 1,057 *WR* records have annual water supply diversion targets (AMT in *WR* record field 3) totaling 6,987,694 acre-feet/year. The 71 *IF* records have annual instream flow targets (AMT in *IF* record field 3) totaling 6,795,905 acre-feet/year. Program *TABLES* 1SUM water rights summary tables by control point are replicated as Tables 2.6 and 2.7. Table 2.6 includes the 70 *WR* records with annual diversion amounts of 10,000 acre-feet/year or greater, which account for 95.8 percent of the total annual diversion amount for the 1,057 *WR* records. Diversion amounts are in the third column. Table 2.7 includes all of the 71 *IF* records.

Table 2.6
Control Point Summary of 70 *WR* Record Water Rights in Full Authorization DAT File with Annual Diversions of 10,000 acre-feet or Greater

Control Point	Number of Rights	Annual Amount (ac-ft/yr)	Number of Reservoirs	Reservoir Storage (acre-feet	Priorities Range From	To
B3808A	1	78000	1	387000	19260706	19260706
B3809A	1	158495	80	224648	19250713	19250713
B3340A	1	12143	59	109275	19140627	19140627
B3404A	2	31760	6	199797	19590922	19760120
B2335A	2	799600	2	799600	19751124	19751124
B2456A	5	608400	6	619650	19240125	19751124
B2362A	3	160000	87	199156	19460211	19740422
B2457D	2	59380	11	519318	19140422	19920402
B2410A	7	363070	12	458741	19530908	20050131
B2462A	1	78700	19	46814	19550202	19550202
B4976A	2	172500	13	702436	19560528	19560528
B4992A	2	37700	43	1287524	19541017	19571004
B5035A	2	215000	13	2807	19520623	19541018
B5040A	2	28300	130	195305	19590922	19671218
B4248B	6	358750	30	1752304	19590923	19590923
B4277A	1	33000	1	150	19130702	19130702
B4261A	10	1064300	84	13114	19131230	19590923
B5271P	1	27500	0	0	19590923	19590923
B4261D	2	73334	0	0	19060414	19140212
B4279C	1	30000	71	33189	19711111	19711111
801	1	30000	1	35300	19140626	19140626
FAKE01	4	886554	0	0	20091201	20091201
FKWF02	1	28964	0	0	20091201	20091201
FKTD02	1	38039	0	0	20091201	20091201
FKTD06	1	40000	0	0	20091201	20091201
FKTK02	1	235471	0	0	20091201	20091201
FKTK04	1	18000	0	0	20091201	20091201
FKTK06	1	130000	0	0	20091201	20091201
FKTK08	1	23000	0	0	20091201	20091201
FKTM02	1	584080	0	0	20091201	20091201
FKTM04	1	80000	0	0	20091201	20091201
FKTM06	1	150000	0	0	20091201	20091201
FKTM08	1	60000	28	10548	20091201	20091201
TOTALS	70	6694040	697	7596675	19060414	20091201

Table 2.7
IF Record Water Rights by Control Point in Full Authorization DAT File

Control Point	Number of Rights	Annual Amount (ac-ft/yr)	Number of Reservoirs	Reservoir Storage (acre-feet)	Priorities Range From	To
586407	1	20	0	0	20050304	20050304
B5153A	2	362	0	0	20010816	20010816
8CTBE	1	723	0	0	19590518	19590518
B3365B	1	1146	0	0	19590518	19590518
B3368A	1	362	0	0	19771219	19771219
B5589P	1	55504	0	0	19970606	19970606
B5688P	1	55504	0	0	20000626	20000626
B3778Q	1	0	0	0	19970818	19970818
WFSUBS	1	15947	0	0	20091201	20091201
WFBASE	1	28964	0	0	20091201	20091201
WFLPUL	7	26600	0	0	20091201	20091201
B5151P	1	0	0	0	19870729	19870729
B5599P	1	724	0	0	19970813	19970813
B3404A	1	2011	0	0	19760120	19760120
838	1	3620	0	0	19760120	19760120
B2457C	1	56948	0	0	19920402	19920402
B2457D	1	18095	0	0	19920402	19920402
8TRDA	1	154892	0	0	19920402	19920402
TDSUBS	1	18124	0	0	20091201	20091201
TDBASE	1	38039	0	0	20091201	20091201
TDLPUL	7	104000	0	0	20091201	20091201
B5642P	1	3017	0	0	19991213	19991213
B2462B	3	28960	0	0	19550202	19951116
B2416A	1	0	0	0	19970818	19970818
8ETFO	1	31123	0	0	20021110	20021110
8TRRS	3	926458	0	0	19911003	20060329
B5704P	1	310220	0	0	20000920	20000920
B5153P	1	145	1	2980	20010816	20010816
506132	1	305	0	0	20021004	20021004
8TROA	3	1902557	0	0	19540201	20070301
TKSUBS	1	82394	0	0	20091201	20091201
TKBASE	1	235471	0	0	20091201	20091201
TKLPUL	7	342000	0	0	20091201	20091201
TMSUBS	1	294285	0	0	20091201	20091201
TMBASE	1	584080	0	0	20091201	20091201
TMLPUL	7	580000	0	0	20091201	20091201
B4261A	4	893305	0	0	19140626	20040225
TOTALS	71	6795905	1	2980	19140626	20091201

The October 2012 current use Trinity WAM has 1,067 water right *WR* records and 89 instream flow *IF* records (Table 2.1). The 1,067 *WR* records have annual water supply diversion targets (AMT in *WR* record field 3) totaling 4,648,894 acre-feet/year. The 89 *IF* records have annual instream flow targets (AMT in *IF* record field 3) totaling 8,435,299 acre-feet/year. Program *TABLES* 1SUM water rights summary tables by control point are replicated as Tables 2.8 and 2.9. Table 2.8 includes all of the 89 *IF* records. Table 2.9 includes the 46 *WR* records with annual diversion amounts of 10,000 acre-feet/year or greater, which account for 95.1 percent of the total annual diversion amount for the 1,067 *WR* records.

Table 2.8
IF Record Water Rights by Control Point in Current Use DAT File

Control Point	Number of Rights	Annual Amount (ac-ft/yr)	Number of Reservoirs	Reservoir Storage (acre-feet)	Priorities Range From	To
586407	1	20	0	0	20050304	20050304
B5153A	2	362	0	0	20010816	20010816
8CTBE	2	15,371	0	0	19590518	20030115
B3365B	1	1,146	0	0	19590518	19590518
B3368A	1	362	0	0	19771219	19771219
8CTFW	4	20,516	0	0	19791001	20000717
8WTFW	1	24,270	0	0	20030115	20030115
B5589P	1	55,504	0	0	19970606	19970606
B5688P	1	55,504	0	0	20000626	20000626
B3778Q	1	615	0	0	19970818	19970818
B3399B	1	1,713	0	0	19970629	19970629
WFSUBS	1	15,947	0	0	20091201	20091201
WFBASE	1	28,964	0	0	20091201	20091201
WFLPUL	7	26,600	0	0	20091201	20091201
B5151P	1	150,585	0	0	19870729	19870729
B5136A	3	210,056	0	0	19870529	19880622
B3404A	1	2,011	0	0	19760120	19760120
838	1	3,620	0	0	19760120	19760120
B2457C	1	56,948	0	0	19920402	19920402
B2457D	1	18,095	0	0	19920402	19920402
8TRDA	2	330,774	0	0	19920402	20011205
TDSUBS	1	18,124	0	0	20091201	20091201
TDBASE	1	38,039	0	0	20091201	20091201
TDLPUL	7	104,000	0	0	20091201	20091201
B5642P	1	3,017	0	0	19991213	19991213
B2462B	2	14,480	0	0	19550202	19550202
B2416A	1	350	0	0	19970818	19970818
8ETFO	1	31,123	0	0	20021110	20021110
B2410F	1	18,720	0	0	20051003	20051003
B5535P	1	173	0	0	20070112	20070112
8TRRS	3	926,458	0	0	19911003	20060329
B5704P	1	310,220	0	0	20000920	20000920
8TRTR	3	506,776	0	0	19590922	20000907
B5153P	1	145	1	2,980	20010816	20010816
506132	1	305	0	0	20021004	20021004
8TROA	3	1,902,557	0	0	19540201	20070301
TKSUBS	1	82,394	0	0	20091201	20091201
TKBASE	1	235,471	0	0	20091201	20091201
TKLPUL	7	342,000	0	0	20091201	20091201
B5061S	1	1,448	0	0	20040218	20040218
B5061Q	1	2,896	0	0	20040218	20040218
B5061P	2	1,810	0	0	19860521	20040218
TMSUBS	1	294,285	0	0	20091201	20091201
TMBASE	1	584,080	0	0	20091201	20091201
TMLPUL	7	580,000	0	0	20091201	20091201
B4261A	4	1,417,445	0	0	19140626	20040225
TOTALS	89	8,435,299	1	2,980	19140626	20091201

Table 2.9
Control Point Summary of 46 *WR* Record Water Rights in Current Use
DAT File with Annual Diversions of 10,000 acre-feet or Greater

Control Point	Number of Rights	Annual Amount (ac-ft/yr)	Number of Reservoirs	Reservoir Storage (acre-feet	Priorities Range From	To
B3808A	1	78,000	1	370,468	19260706	19260706
B3809A	1	124,207	78	210,589	19250713	19250713
B3340A	1	12,143	65	295,045	19140627	19140627
B2335A	2	136,028	2	796,474	19751124	19751124
B2456A	2	243,275	7	641,457	19240125	19481124
B2362A	2	99,712	83	172,042	19460211	19480706
B2457D	2	51,469	11	500,404	19140422	19920402
B2410A	7	363,070	12	431,041	19530908	20050131
B2462A	1	86,894	21	38,254	19550202	19550202
B4976A	1	59,082	61	771,972	19560528	19560528
B5035A	1	133,951	141	1,300,971	19541018	19541018
B4248A	1	10,662	1	0.00	19590923	19590923
B4248B	2	40,249	29	2,304	19590923	19590923
B4277A	1	32,540	1	150	19130702	19130702
B4261A	4	605,143	84	13,008	19131230	19590923
B4261D	2	71,169	73	58,790	19060414	19140212
FAKE01	4	886,554	0	0.00	20091201	20091201
FKWF02	1	28,964	0	0.00	20091201	20091201
FKTD02	1	38,039	0	0.00	20091201	20091201
FKTD06	1	40,000	0	0.00	20091201	20091201
FKTK02	1	235,471	0	0.00	20091201	20091201
FKTK04	1	18,000	0	0.00	20091201	20091201
FKTK06	1	130,000	0	0.00	20091201	20091201
FKTK08	1	23,000	0	0.00	20091201	20091201
FKTM02	1	584,080	0	0.00	20091201	20091201
FKTM04	1	80,000	0	0.00	20091201	20091201
FKTM06	1	150,000	0	0.00	20091201	20091201
FKTM08	1	60,000	29	1,750,252	20091201	20091201
TOTALS	46	4,421,702	699	7,353,220	19060414	20091201

Removal of SB3 Environmental Flow Standards

The new environmental standard *ES* record and associated input records and features have been added to *SIM* and *SIMD* with the May 2019 version of WRAP. The October 2014 full authorization and October 2012 current use versions of the Trinity WAM include Senate Bill 3 (SB3) environmental flow standards (EFS) modeled using the old *SIM* features available before the expanded May 2019 version of WRAP. The original *SIM* input records simulating the SB3 EFS were removed as noted here in Chapter 2 and replaced with new *SIM/SIMD* features described in Chapter 5 that employ the new capabilities added with the May 2019 WRAP.

Counts of the number of *SIM* input records are tabulated in Table 2.1 for the full authorization and current use scenario versions of the monthly WAM last updated in October 2014 and October 2012, respectively. The counts in Table 2.1 include DAT file records before and after

removal of the SB3 EFS. Forty-four *WR* records and 36 *IF* records along with associated *CP*, *CI*, *UC*, *WS*, *TO*, *PX*, and *FS* records model the SB3 EFS at four USGS gage sites represented by four primary control points. These input records were removed as discussed in the present Chapter 2 and replaced with the records described in Chapter 5 in the December 2019 monthly and daily WAMs. Water rights summary tables by control point created with the WRAP program *TABLES* 1SUM record with the original *SIM* input datasets are presented earlier as Tables 2.6, 2.7, 2.8, and 2.9. The corresponding summary tables created after removing the SB3 EFS are replicated as the following Tables 2.10, 2.11, 2.12, and 2.13.

Table 2.10
IF Record Water Rights in Full Authorization DAT File After Removing SB3 IFS

Control Point	Number of Rights	Annual Amount (ac-ft/yr)	Number of Reservoirs	Reservoir Storage (acre-feet)	Priorities Range From	To
586407	1	20	0	0	20050304	20050304
B5153A	2	362	0	0	20010816	20010816
8CTBE	1	723	0	0	19590518	19590518
B3365B	1	1146	0	0	19590518	19590518
B3368A	1	362	0	0	19771219	19771219
B5589P	1	55504	0	0	19970606	19970606
B5688P	1	55504	0	0	20000626	20000626
B3778Q	1	0	0	0	19970818	19970818
B5151P	1	0	0	0	19870729	19870729
B5599P	1	724	0	0	19970813	19970813
B3404A	1	2011	0	0	19760120	19760120
838	1	3620	0	0	19760120	19760120
B2457C	1	56948	0	0	19920402	19920402
B2457D	1	18095	0	0	19920402	19920402
8TRDA	1	154892	0	0	19920402	19920402
B5642P	1	3017	0	0	19991213	19991213
B2462B	3	28960	0	0	19550202	19951116
B2416A	1	0	0	0	19970818	19970818
8ETFO	1	31123	0	0	20021110	20021110
8TRRS	3	926458	0	0	19911003	20060329
B5704P	1	310220	0	0	20000920	20000920
B5153P	1	145	1	2980	20010816	20010816
506132	1	305	0	0	20021004	20021004
8TROA	3	1902557	0	0	19540201	20070301
B4261A	4	893305	0	0	19140626	20040225
TOTALS	35	4446001	1	2980	19140626	20070301

Table 2.11
IF Record Water Rights in Current Use DAT File After Removing SB3 IFS

Control Point	Number of Rights	Annual Amount (ac-ft/yr)	Number of Reservoirs	Reservoir Storage (acre-feet)	Priorities Range From	To
586407	1	20	0	0	20050304	20050304
B5153A	2	362	0	0	20010816	20010816

8CTBE	2	15371	0	0	19590518	20030115
B3365B	1	1146	0	0	19590518	19590518
B3368A	1	362	0	0	19771219	19771219
8CTFW	4	20516	0	0	19791001	20000717
8WTFW	1	24270	0	0	20030115	20030115
B5589P	1	55504	0	0	19970606	19970606
B5688P	1	55504	0	0	20000626	20000626
B3778Q	1	615	0	0	19970818	19970818
B3399B	1	1713	0	0	19970629	19970629
B5151P	1	150585	0	0	19870729	19870729
B5136A	3	210056	0	0	19870529	19880622
B3404A	1	2011	0	0	19760120	19760120
838	1	3620	0	0	19760120	19760120
B2457C	1	56948	0	0	19920402	19920402
B2457D	1	18095	0	0	19920402	19920402
8TRDA	2	330774	0	0	19920402	20011205
B5642P	1	3017	0	0	19991213	19991213
B2462B	2	14480	0	0	19550202	19550202
B2416A	1	350	0	0	19970818	19970818
8ETFO	1	31123	0	0	20021110	20021110
B2410F	1	18720	0	0	20051003	20051003
B5535P	1	173	0	0	20070112	20070112
8TRRS	3	926458	0	0	19911003	20060329
B5704P	1	310220	0	0	20000920	20000920
8TRTR	3	506776	0	0	19590922	20000907
B5153P	1	145	1	2980	20010816	20010816
506132	1	305	0	0	20021004	20021004
8TROA	3	1902557	0	0	19540201	20070301
B5061S	1	1448	0	0	20040218	20040218
B5061Q	1	2896	0	0	20040218	20040218
B5061P	2	1810	0	0	19860521	20040218
B4261A	4	1417445	0	0	19140626	20040225
TOTALS	53	6085395	1	2980	19140626	20070301

Table 2.12
Control Point Summary of 55 *WR* Record Water Rights in Full Authorization DAT File with Annual Diversions of 10,000 acre-feet or Greater After Removal of SB3 EFS

Control Point	Number of Rights	Annual Amount (ac-ft/yr)	Number of Reservoirs	Reservoir Storage (acre-feet	Priorities Range From	To
B3808A	1	78000	1	387000	19260706	19260706
B3809A	1	158495	80	224648	19250713	19250713
B3340A	1	12143	59	109275	19140627	19140627
B3404A	2	31760	6	199797	19590922	19760120
B2335A	2	799600	2	799600	19751124	19751124
B2456A	5	608400	6	619650	19240125	19751124
B2362A	3	160000	87	199156	19460211	19740422
B2457D	2	59380	11	519318	19140422	19920402
B2410A	7	363070	12	458741	19530908	20050131
B2462A	1	78700	19	46814	19550202	19550202
B4976A	2	172500	13	702436	19560528	19560528
B4992A	2	37700	43	1287524	19541017	19571004
B5035A	2	215000	13	2807	19520623	19541018

B5040A	2	28300	130	195305	19590922	19671218
B4248B	6	358750	30	1752304	19590923	19590923
B4277A	1	33000	1	150	19130702	19130702
B4261A	10	1064300	84	13114	19131230	19590923
B5271P	1	27500	0	0	19590923	19590923
B4261D	2	73334	0	0	19060414	19140212
B4279C	1	30000	71	33189	19711111	19711111
801	1	30000	1	35300	19140626	19140626
TOTALS	55	4419933	697	7596675	19060414	20050131

Table 2.13
Control Point Summary of 31 *WR* Record Water Rights in Current Use DAT File with Annual Diversions of 10,000 acre-feet or Greater After Removal of SB3 EFS

Control Point	Number of Rights	Annual Amount (ac-ft/yr)	Number of Reservoirs	Reservoir Storage (acre-feet	Priorities Range From	To
B3808A	1	78000	1	370468	19260706	19260706
B3809A	1	124207	78	210589	19250713	19250713
B3340A	1	12143	65	295045	19140627	19140627
B2335A	2	136028	2	796474	19751124	19751124
B2456A	2	243275	7	641457	19240125	19481124
B2362A	2	99712	83	172042	19460211	19480706
B2457D	2	51469	11	500404	19140422	19920402
B2410A	7	363070	12	431041	19530908	20050131
B2462A	1	86894	21	38254	19550202	19550202
B4976A	1	59082	61	771972	19560528	19560528
B5035A	1	133951	141	1300971	19541018	19541018
B4248A	1	10662	1	0	19590923	19590923
B4248B	2	40249	29	2304	19590923	19590923
B4277A	1	32540	1	150	19130702	19130702
B4261A	4	605143	84	13008	19131230	19590923
B4261D	2	71169	73	58790	19060414	19140212
TOTALS	31	2147594	699	7353220	19060414	20050131

Annual water right diversion targets are tabulated in the third column of Table 2.13. The 1,013 and 1,023 *WR* records (Table 2.1) in the authorized and current use DAT files have diversion targets (AMT in *WR* record field 3) totaling 4,688,286 and 2,349,486 acre-feet/year. The rights reflected in Tables 2.12 and 2.13 account for 94.28% and 91.41% of these totals.

Subordination Agreements

Subordination agreements have been executed in various river basins of Texas that allow selected upstream junior rights to access stream flow that should otherwise be passed through to a downstream senior water right. The objective of a subordination agreement, and modeling thereof, is to circumvent the water rights priority system. The difficulty in both the real-world and the simulation model is that these water management agreements may have unintended interactions with third party water rights holders that are not included in the subordination agreements. Schemes for implementing and/or modeling agreements that achieve the intended subordination without affecting and/or being affected by other third-party water rights may not be possible.

The Trinity River Basin and Trinity WAM contain multiple subordination agreements. Senior water rights at three major reservoirs are subordinated to junior upstream water rights. The three downstream reservoirs in the subordination agreements are Richland-Chambers, Ray Hubbard, and Livingston. The Lake Livingston subordination is the most complex of the three. Figure 2.8 is a schematic of control points and information relevant to the subordination agreements. Several primary control points are included in Figure 2.8 shown as darkened circles. Control points of reservoirs and water rights are shown as triangles. Upstream and subordinated downstream rights included in the subordination modeling schemes are located at reservoirs.

Water rights at Richland-Chambers Reservoir, with priority dates in the years 1950, 1952, 1954, and 1970, are subordinated to junior water rights at Bardwell and Navarro Mills Reservoirs pursuant to certificate of adjudication 08-5035. Relevant control points are shown as green triangles in Figure 2.2. Richland-Chambers Reservoir is located at control point B5035A.

Water rights at Lake Ray Hubbard at control point B2462A, with priority 19550202 (February 2, 1955), are subordinated to junior water rights at Lake Lavon located upstream at control point B2410A. Lake Lavon has multiple rights with priorities of 19530908 and 19650802. Lakes Ray Hubbard and Lavon are shown as blue triangles in Figure 2.8.

Water rights at Lake Livingston at control point B4248B, with priority 19590924, are subordinated to junior water rights at Lakes Joe Pool, Forest, Navarro Mills, Alvarado, Bardwell, Fairfield, and Houston County and at locations at or above Lakes Lewisville, Grapevine, Ray Hubbard, and Worth. The control points of Lake Livingston and the lakes to which it is subordinated are shown as red triangles in Figure 2.8. Triangles with a white letter U indicate that Lake Livingston is subordinated to all water rights located upstream of those control points.

Lake Livingston on the lower Trinity River (Figure 2.7) is the largest reservoir in the Trinity River Basin (Table 2.2). Lake Livingston is owned and operated by the Trinity River Authority and city of Houston to supply water to Houston in the adjoining San Jacinto River Basin and other water users in the lower Trinity River Basin. Storage refilling and water supply diversions from Lake Livingston have a priority date of September 23, 1959 (19590923), which is senior to many water rights in the river basin above Lake Livingston and junior to many other water rights. The objective of the subordination strategy is to allow specified junior rights to appropriate stream flow at upstream sites without being constrained by senior water rights that would otherwise protect inflows to Lake Livingston.

Lake Livingston water rights have been subordinated to other upstream junior rights that include storage and diversion of water in Lakes Joe Pool, Forest, Navarro Mills, Alvarado, Bardwell, Fairfield, and Houston County and at locations at or above Lakes Lewisville, Grapevine, Ray Hubbard, and Worth, which includes Lakes Ray Roberts and Lavon and other reservoirs. Richland-Chambers and Cedar Creek, which are the second and fourth largest reservoirs in the basin (Table 2.2), are not subordinated to Lake Livingston. Most of the other reservoirs listed in Table 2.2 are located in the river basin at sites for which the downstream Lake Livingston is specified as being subordinate. However, many of the water rights at these sites have priority dates that are senior to the priority date of September 23, 1959 assigned to the water rights at Lake Livingston. The subordination agreement is not relevant for these senior rights. Many other rights throughout the basin affect or are affected by the rights associated with the subordination.

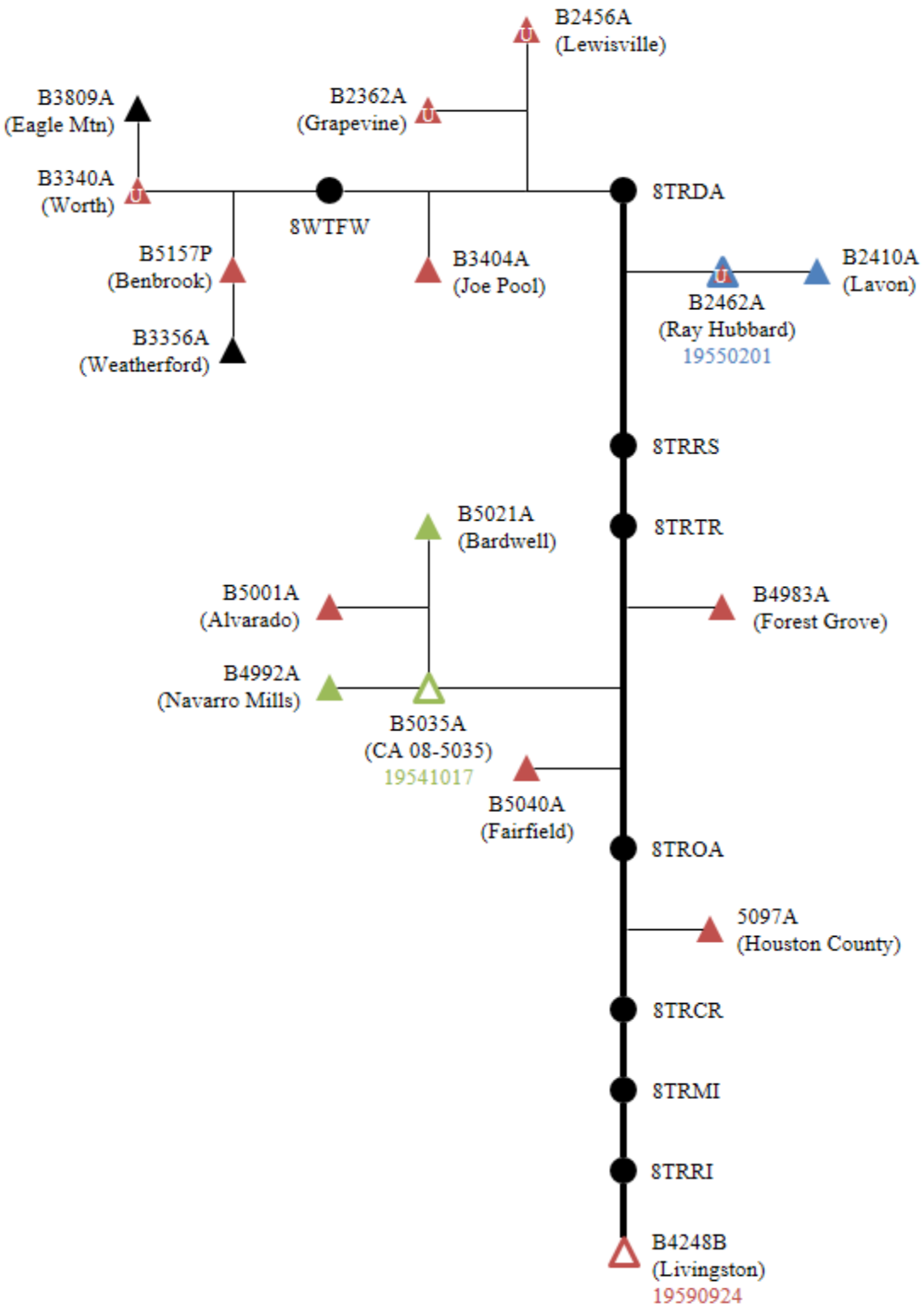

Figure 2.8 Schematic of Subordination Agreements

A modeling scheme is employed in the Trinity WAM that constrains the amount of stream flow available to water rights at Lakes Livingston, Richland-Chambers, and Ray Hubbard to reflect their subordination to water rights at the specified upstream reservoirs. All regulated flow at the

control points of the upstream reservoirs is removed by diverting to an imaginary accounting control point by imaginary water rights assigned a priority just senior to the downstream reservoir being subordinated. Thus, stream flow originating at upstream control points is not available to the subordinated reservoir water rights. The streamflow removed at the upstream control points is returned by imaginary water rights assigned a priority just junior to the rights at the downstream reservoir being subordinated, making the stream flow available to other third-party water rights that are not involved in the subordination agreements.

The modeling scheme works as follows for the Lake Livingston subordination. All water rights at Lake Livingston have a priority of 19590923. "Imaginary" water rights are added that divert the total regulated flows at the control points of the relevant upstream water rights with a priority of 19590922. This prevents access by the water rights at Lake Livingston to stream flows originating above these upstream sites. Other water rights are added that return the flows to their original control points with an assigned priority of 19590924. The extra accounting control points are named with control point identifiers beginning with ″IM″ signifying ″imaginary″.

The entire regulated flow in each month at each of the upstream control points shown in Figure 2.8 are diverted to imaginary accounting control points that have no other control points located downstream. The streamflow depletions propagate downstream through all immediate control points to the outlet at control point 8TRGB. Likewise, the corresponding monthly return flows later in the priority sequence simulation computations propagate downstream to the outlet.

This computational strategy for simulating subordination is more complex in a daily *SIMD* simulation with routing and forecasting. The streamflow depletions and return flows reach different downstream control points in different future days in the routing computations. Complexities of routing and forecasting and related issues such as negative incremental flow adjustments are explained in the *Daily Manual* [5] and explored in the *Daily Brazos WAM Report* [7]. The subordination scheme adds to the complexity of the *SIMD* flow availability computations in the daily WAM. The Lake Livingston subordination is much more complex than the Richland-Chambers Reservoir and Lake Ray Hubbard subordination agreements.

An alternative strategy for modeling Lake Livingston subordination explored in the next section is based on XCP(px) option 1 activated in *PX* record field 4. Control point 8TRRI is entered for XCPID in *PX* record field 5. New *PX* records are added or entries are inserted in existing *PX* records for each of the water rights to which Lake Livingston rights are subordinated. These rights are protected from the streamflow depletion effects of senior rights at Lake Livingston by the XCP(px) option 1 feature activated by their *PX* records.

Flow availability is always computed in the water rights priority simulation considering the control point of the water right and all downstream control points. With *PX* record XCP(px) option 1 activated, the water availability computations do not consider control point 8TRRI and control points downstream of 8TRRI. Thus, stream flow depletions at Lake Livingston do not affect water availability for water rights at the identified upstream control points. The problem is that upstream junior water rights may incorrectly appropriate stream flow that has already been appropriated by senior rights at Lake Livingston. However, this potential double appropriation of the same stream flow volume is an inaccuracy that may be advantageous relative to inaccuracies associated with combining the original monthly strategy with daily routing and forecasting.

Simulated Reservoir Storage for Alternative Versions of the Monthly WAM

Reservoir storage contents provide a meaningful metric for a comparative summary of simulation results. Series of January 1940 through December 2018 end-of-month storage volumes from the following four monthly simulations are plotted in Figures 2.9 through 2.18 for the four largest reservoirs and the total summations of storage for the 28 other reservoirs in Table 2.2. Means of the 948 storage volumes and the 1940-2018 minima are shown in Tables 2.14 and 2.15.

A1 − Authorized use dataset last updated by the TCEQ in October 2014 with the SB3 EFS removed in 2019. The SB3 EFS are junior to almost all other water rights and have no effect on the storage volumes presented here.

A2 − Authorized use dataset last updated by the TCEQ in October 2014 with the SB3 EFS and Lake Livingston subordination completely removed.

A2 − Authorized use dataset last updated by the TCEQ in October 2014 with the SB3 EFS removed and the original Lake Livingston subordination replaced with the *PX* record XCP(px) option.

C1 − Current use dataset last updated by the TCEQ in October 2012 with the SB3 EFS removed in 2019. Removal of the SB3 EFS does not affect the simulated storage.

Table 2.14
Mean and Minimum Storage Contents from Authorized Use Simulation

Reservoir or Summation for 28 Reservoirs	Mean Storage (acre-feet)			Minimum Storage (acre-feet)		
	Original	No Liv Sub	XCP(px)	Original	No Liv Sub	XCP(px)
	A1	A2	A3	A1	A2	A3
Livingston	1,490,231	1,524,322	1,524,305	0.0	0.0	0.0
Richland-Chambers	997,005	994,755	996,945	112,474	98,030	112,565
Ray Roberts	25,443	25,149	25,420	0.0	0.0	0.0
Cedar Creek	588,689	588,023	588,024	164,521	164,460	164,521
Summation 28 Others	1,923,576	1,848,054	1,887,172	124,463	101,427	130,855

Table 2.15
Mean and Minimum Storage Contents from Authorized Use Simulation and Capacities

Reservoir or Summation for 28 Reservoirs Reservoir or	Current Use Scenario (C1)		Current Storage Capacity (acre-feet)	Authorized Storage Capacity (acre-feet)
	Mean Storage (acre-feet)	Minimum Storage (acre-feet)		
Livingston	1,706,968	1,313,172	1,739,743	1,750,000
Richland-Chambers	1,034,770	514,093	1,109,368	1,135,000
Ray Roberts	323,195	0.0	796,474	799,600
Cedar Creek	604,388	441,686	630,550	678,900
Summation 28 Others	2,260,697	274,908	2,912,714	3,082,187

Premises Reflected in the Alternative Variations of the WAM

The original Trinity WAM January 1940 through December 1996 hydrologic period-of-analysis monthly naturalized flows and net reservoir evaporation less precipitation rates are extended through December 2018 as described in Chapters 7 and 8. The simulations presented here adopt the complete 1940-2018 hydrology. The 1940-1996 portions of the plots of Figures 2.9-2.18 reflect the original WAM naturalized flows and evaporation-precipitation rates without modification. The hydrology update covers 1997-2018.

The *SIM* input records added to the current use and full authorization DAT files by the TCEQ in 2012 and 2014 to model the SB3 EFS were removed in 2019 and replaced with the new methodology described in Chapter 5. The simulations presented here in Chapter 2 have no SB3 EFS. However, the SB3 EFS are junior to essentially all other water rights in the WAM and have no effect on the simulated reservoir storage volumes plotted in Figures 2.9-2.18. The 1940-2018 end-of-month storage volumes of all of the reservoirs are the same with or without the SB3 EFS in all of the simulations discussed here. Of course, the SB3 EFS reduce unappropriated flows and may affect new more junior water rights that may be added to the WAM in the future.

Simulations A1, A2, and A3 employ the full authorization version of the WAM with and without the Lake Livingston subordination. Simulation C1 models the current use scenario, which includes the subordination. The authorized use simulations A1, A2, and A3 are compared in each of Figures 2.9, 2.11, 2.13, 2.15 and 2.17. The current use simulation C1 results are plotted in Figures 2.10, 2.12, 2.14, 2.16, and 2.18. Information regarding the water rights in full authorization simulations is tabulated in Table 2.14. The corresponding data for the water rights in the current use scenario simulation is provided in Table 2.15.

Conservative storage capacities of the 32 largest reservoirs are included in Table 2.2 for both the authorized and current use versions of the WAM. The 697 model reservoirs in the full authorization WAM have a total storage capacity of 7,596,675 acre-feet of which 7,445,687 acre-feet is contained in the 32 largest reservoirs in Table 2.2. The 700 model reservoirs in the current use WAM have storage capacities totaling 7,356,202 acre-feet, with the 32 largest reservoirs accounting for 7,188,849 acre-feet. Storage capacities for some of the major reservoirs are less in the current use dataset than in the full authorization version due to adjustments for sedimentation.

The full authorization and current use DAT files have diversion targets (*WR* record AMT) totaling 4,688,286 and 2,349,486 acre-feet/year. Annual diversion targets for the full authorization WAM are from the water right permits. Annual diversion targets for each right in the current use scenario was set as the maximum estimated actual use for any year of 1990-1999.

Return flows are important to water supply capabilities in the Trinity River Basin. Municipal and industrial wastewater return flows in the Dallas-Fort Worth metropolitan area in the upper basin are a significant component of inflows to Lake Livingston, particularly during low-flow periods. Return flows are included in the current use WAM but are not included in the full authorization WAM.

The full authorization scenario includes the premise of full reuse of all wastewater since the water right permits do not require return flows. The current use DAT file simulates return flows

from groundwater and some surface diversions as constant inflow on *CI* records. The constant inflow *CI* record flows enter the river system at the beginning of the water rights priority sequence simulation computations. Other return flows are computed as a fraction of water right diversions specified on *WR* records and returned within the priority sequence.

Subordination Agreements

Subordination agreements are a complicating issue in the monthly Trinity WAM and become an even greater complexity when combined with routing, forecasting, negative incremental flow adjustments, and other aspects of a daily *SIMD* simulation. Subordination is explored here in Chapter 2 from a monthly modeling perspective to support later investigations presented in Chapters 9 and 10 in the development of the daily version of the WAM.

As discussed earlier in this chapter, the Lake Livingston subordination to multiple upstream reservoirs is significantly more complicated than the Richmond-Chambers subordination to Bardwell and Navarro Mills Reservoirs and the Lake Ray Hubbard subordination to Lake Lavon. The subordination discussion presented in this last section of Chapter 2 focuses specifically on the Lake Livingston subordination in the full authorization WAM.

In a monthly simulation, upstream stream depletions reach Lake Livingston in the same month. In a daily simulation with routing, upstream streamflow depletions may reach Lake Livingston in during future days. Likewise, reverse routing in forecasting may span multiple days. With a few exceptions, channel loss factors are not provided for most river reaches in the Trinity WAM. Modeling of subordination is based on the premise that upstream stream flow depletions propagate to Lake Livingston with minimal or no modification by channel losses.

Subordination agreements are approximate and complex in the real-world due to interactions between many water rights that include third-part water rights not specifically considered in the subordination agreements. Modeling approximations result from approximations in the real-world that is being modeled.

All water rights at Lake Livingston have a priority of September 23, 1959 (19590923). Subordination of water rights at Lake Livingston to junior water rights at upstream control points is modeled by diverting the total regulated flows at the control points of the relevant upstream water rights with a priority of 19590922 and returning the flows to their original control points with an assigned priority of 19590924. This prevents access by the water rights at Lake Livingston to these stream flows originating upstream. However, as an unintended consequence, other third-party water rights may appropriate the flows saved from Lake Livingston water rights, reducing water available to the upstream rights that the agreements are designed to enhance.

Simulation C3 reflects an alternative strategy for modeling Lake Livingston subordination based on the XCP(px) option 1 activated in *PX* record field. Control point 8TRRI is assigned for XCID in *PX* record field 5. New *PX* records are added or parameters are added to existing *PX* records for each of the water rights to which Lake Livingston rights are subordinated. These *PX* record rights are protected from the effects of senior rights at Lake Livingston. The existing records implementing the original subordination scheme are removed.

The *SIM* simulation is based on computing streamflow availability for each water right in the priority sequence considering the control point of the water right and all downstream control points. With *PX* record XCP(px) option 1 activated, the water availability computations do not consider control point 8TRRI and control points downstream of 8TRRI. Thus, stream flow depletions at Lake Livingston do not affect water availability for water rights at the identified upstream control points. The approximation or modeling inaccuracy is that upstream junior water rights may appropriate stream flow that has already been appropriated by senior rights at Lake Livingston. The double appropriation of the same stream flow is an inaccuracy in the simulation. However, this approximation may be preferable to inaccuracies associated with the employing the original monthly strategy with daily *SIMD* routing and forecasting.

Simulated 1940-2018 End-of-Month Storage Contents

The 32 largest reservoirs in the Trinity River basin are listed with pertinent information in Table 2.2. Their locations are shown in Figure 2.5. Simulated storage contents are plotted for each of the four reservoirs with the largest authorized storage capacities (Livingston, Richland-Chambers, Ray Roberts, Cedar Creek) in Figures 2.9-2.16. The summation of storage in the other 28 reservoirs listed in Table 2.2 are plotted in Figures 2.17 and 2.18. Averages of the storage volumes for the 948 months of the simulation and the minimum storage contents during the 1940-2018 hydrologic period-of-analysis simulations are tabulated in Tables 2.14 and 2.15 on page 29. Reservoir storage capacities from Table 2.2 are also included in Table 2.15.

The following legend is adopted for the storage plots for the four simulations previously defined on page 29.

———	blue solid line:	simulations A1 and C1
••••••	red dotted line:	simulation A2
-------	green dashed line:	simulation A3

The Lake Livingston subordination is the only input that varies between the three full authorization simulation simulations A1, A2, and A3. The following alternative approaches for modeling the Lake Livingston subordination are compared: the original modeling scheme (A1), removal of subordination (A2), and use of the *PX* record XCP(px) option 1 (A3). However, the storage plots are very close in some cases so as to be indistinguishable between the alternative simulations.

Figure 2.9 consists of storage plots for Lake Limestone for authorized use simulations A1 (blue solid plot), A2 (red dotted plot), and A3 (red dotted line). However, the 1940-2018 monthly storage volumes from simulations A2 and A3 are essentially identically the same, with averages of 1,490,231 ac-ft, 1,524,322 ac-ft, and 1,524,305 ac-ft (Table 2.14). This indicates that employing the *PX* record XCP(px) option with the upstream water rights has the same effect on water rights at Lake Livingston as entirely removing the Lake Livingston subordination.

Figure 2.11 consists of storage plots for Richland-Chambers Reservoir for simulations A1, A2, and A3. All three plots are almost the same. The means of the 1940-2018 end-of-month storage contents shown in Table 2.14 are 997,005 acre-feet, 994,755 acre-feet, and 996,945 acre-feet for the three alternative simulations. The Lake Livingston subordination has minimal or no effect on water rights at Richland-Chambers Reservoir. Richland-Chambers Reservoir has its own subordination to Bardwell and Navarro Mills but is not included in the Livingston subordination.

Figure 2.13 storage plots for Ray Roberts Reservoir exhibit extreme continuous drawdowns. The mean storage volumes for the 948 months of the 1940-2018 hydrologic period-of-analysis are 25,443 acre-feet, 25,149 acre-feet, and 25,149 acre-feet for simulations A1, A2, and A3 for a reservoir with a storage capacity of 799,600 acre-feet. The cities of Dallas and Denton have contracted as nonfederal sponsors for conservation storage capacity of the federal USACE multiple-purpose Ray Roberts Reservoir. As indicated in Table 2.3, Dallas and Denton have 591,704 acre-feet and 207,896 acre-feet, respectively, of the 799,600 acre-feet conservation pool. Ray Roberts Reservoir is a component of a system of several lakes operated by Dallas Water Utilities to supply water to about 31 cities in the eastern half of the Dallas-Fort Worth metropolitan area. Physical connections provide some degree of flexibility for balancing draw-downs between the several reservoirs of the system. However, multiple-reservoir system operations have not been incorporated in these versions of the Trinity WAM input datasets. WRAP includes options for modeling multiple-reservoir system operations not employed in these versions of the WAM.

The three storage plots for Cedar Creek Reservoir in Figure 2.15 are almost identical. Water rights at Cedar Creek Reservoir are affected only minimally if at all by the Lake Livingston subordination agreements.

The simulated storage contents of Livingston, Richland-Chambers, Ray Roberts, and Cedar Creek Reservoirs for the current use version of the WAM are plotted in Figures 2.10, 2.12, 2.14, and 2.16. The drawdowns for Livingston, Richland-Chambers, and Cedar Creek Reservoirs are relatively small, much less than drawdowns for the full authorization simulations. Storage depletions in Ray Roberts are dramatic for the current use scenario, but much less drastic than in the full authorization simulations.

The summations of the January 1940 through December 2018 end-of-month storage contents of the other 28 reservoirs listed in Table 2.2 (excluding the four largest) from the simulation results of the full authorization and current use versions of the Trinity WAM are plotted in Figures 2.17 and 2.18. Storage contents remain much higher during the hydrologic period-of-analysis for the current use scenario than for the authorized use scenario. However, the differences between the current and authorized use scenarios are much less for the summation of these 28 reservoirs than for Livingston, Richland-Chambers, and Cedar Creek Reservoirs.

Time series plots of simulated reservoir storage contents provide an insightful drought index. Reoccurring major droughts can be identified in the storage plots of Figures 2.9 through 2.18. The 1950-1957 drought is clearly the most hydrologically severe drought since 1940 for the Trinity River Basin. Observed stream flow at USGS gages with long records and other information indicate that the last drought more hydrologically severe than 1950-1957 for much of Texas including the Trinity River Basin dates back to before 1900, perhaps long before 1900. The water management community and citizens of the Trinity River Basin have never experienced a drought as hydrologically severe as 1950-1957 combined with present conditions of development and water demands.

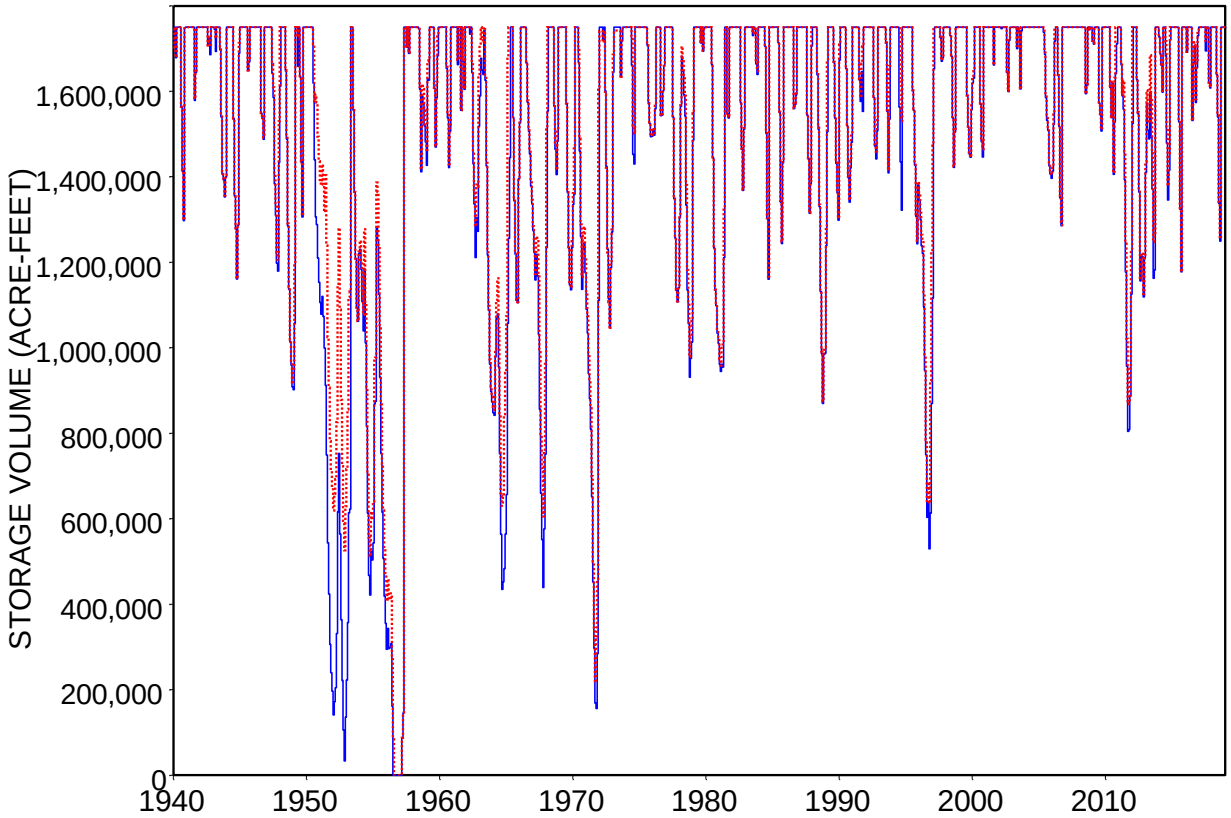

Figure 2.9 Lake Livingston Storage from Authorized Use Simulations

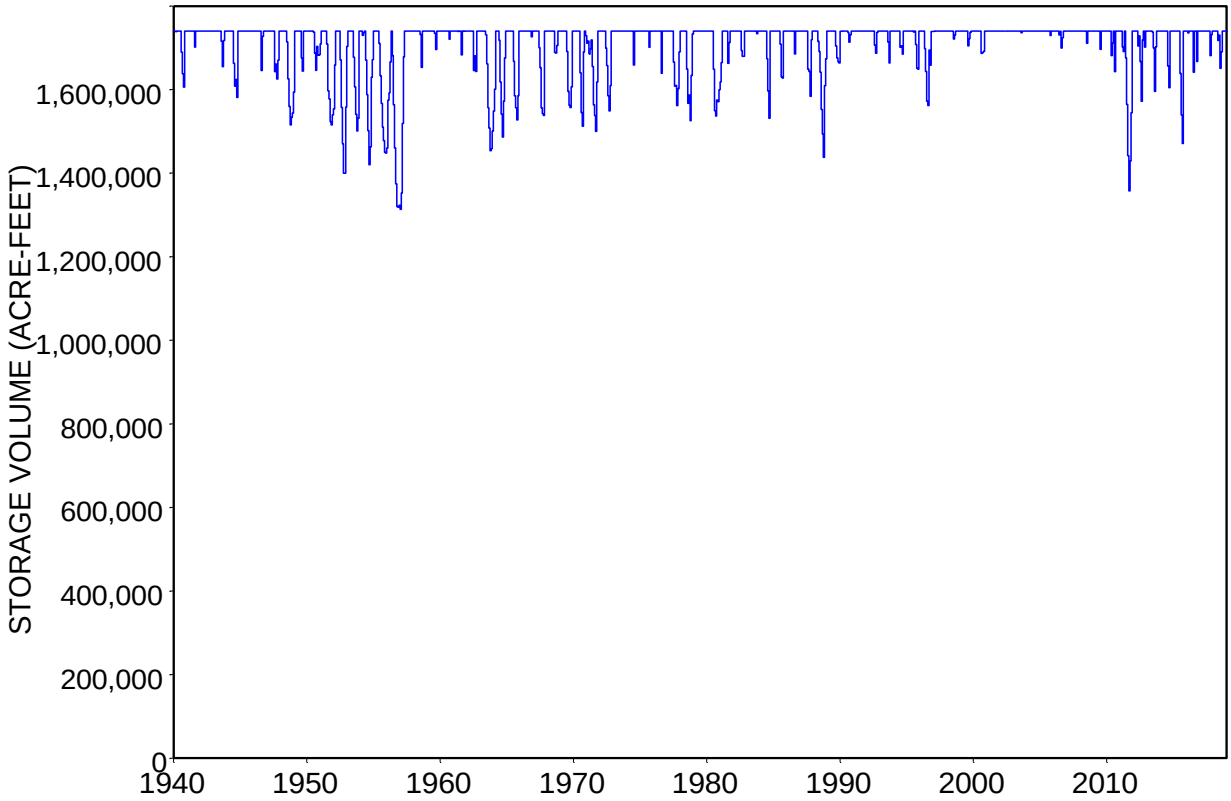

Figure 2.10 Lake Livingston Storage from Current Use Simulation

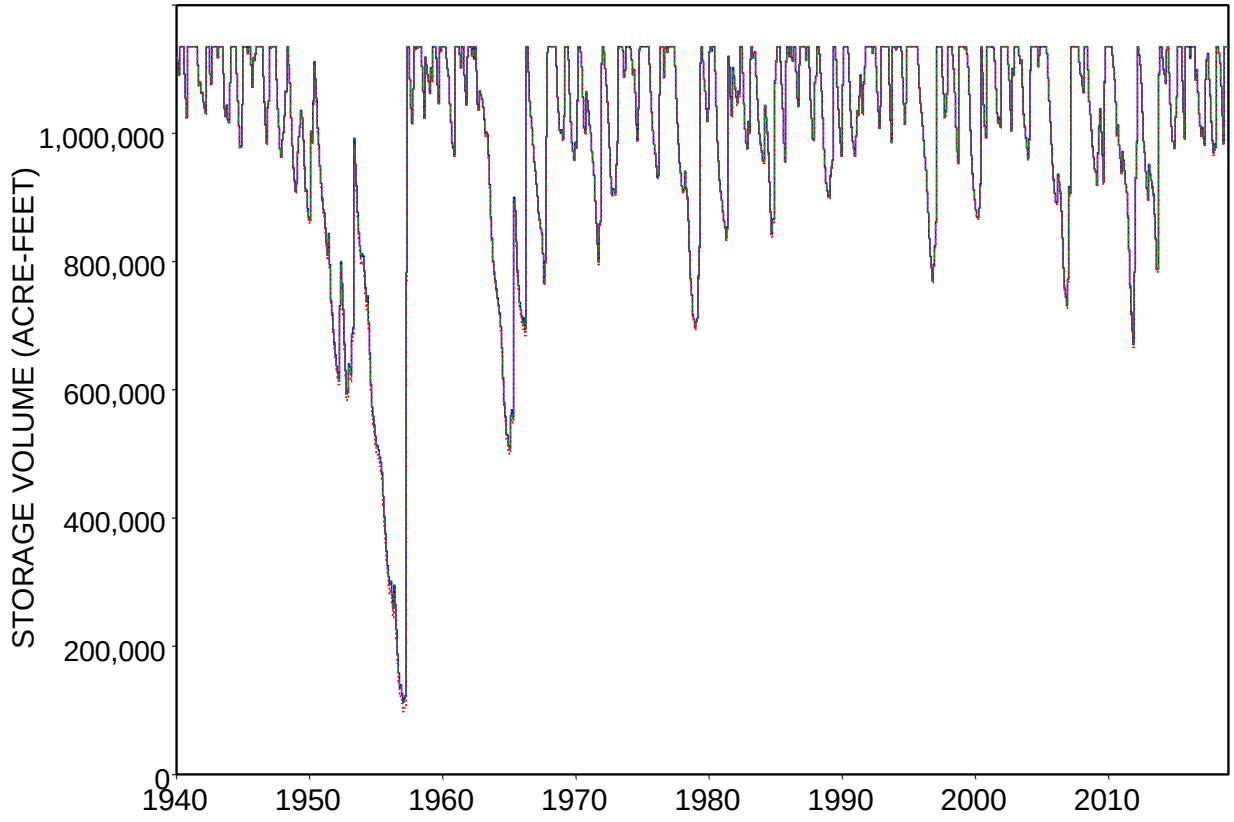

Figure 2.11 Richland-Chambers Reservoir Storage from Authorized Use Simulations

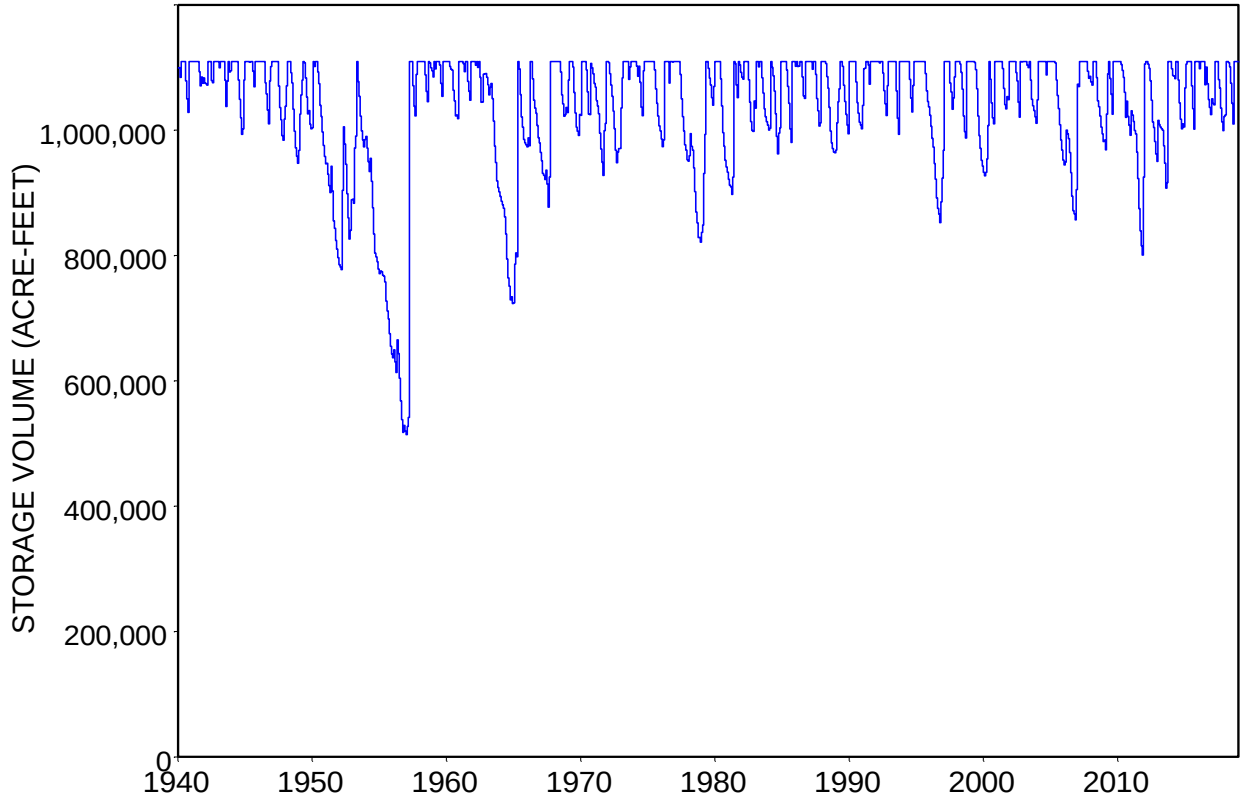

Figure 2.12 Richland-Chambers Reservoir from Current Use Simulation

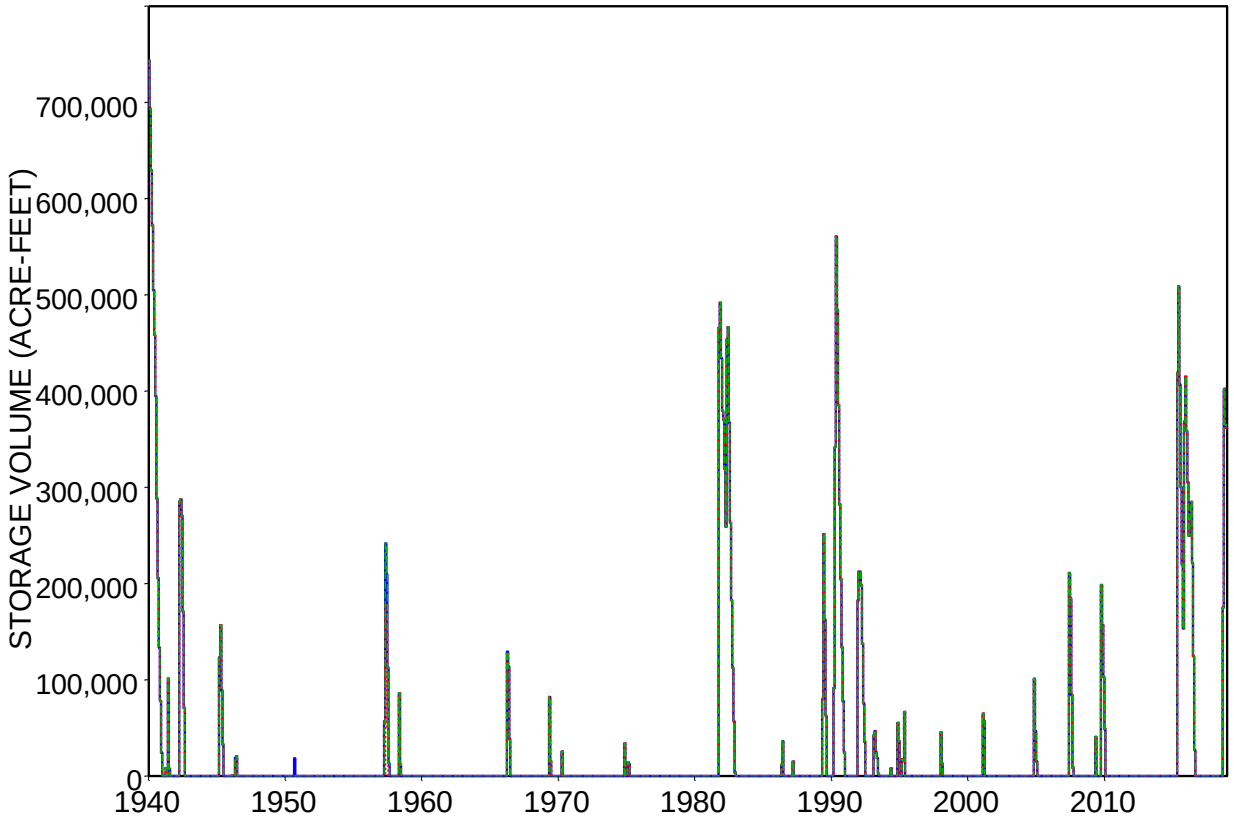

Figure 2.13 Ray Roberts Reservoir Storage from Authorized Use Simulations

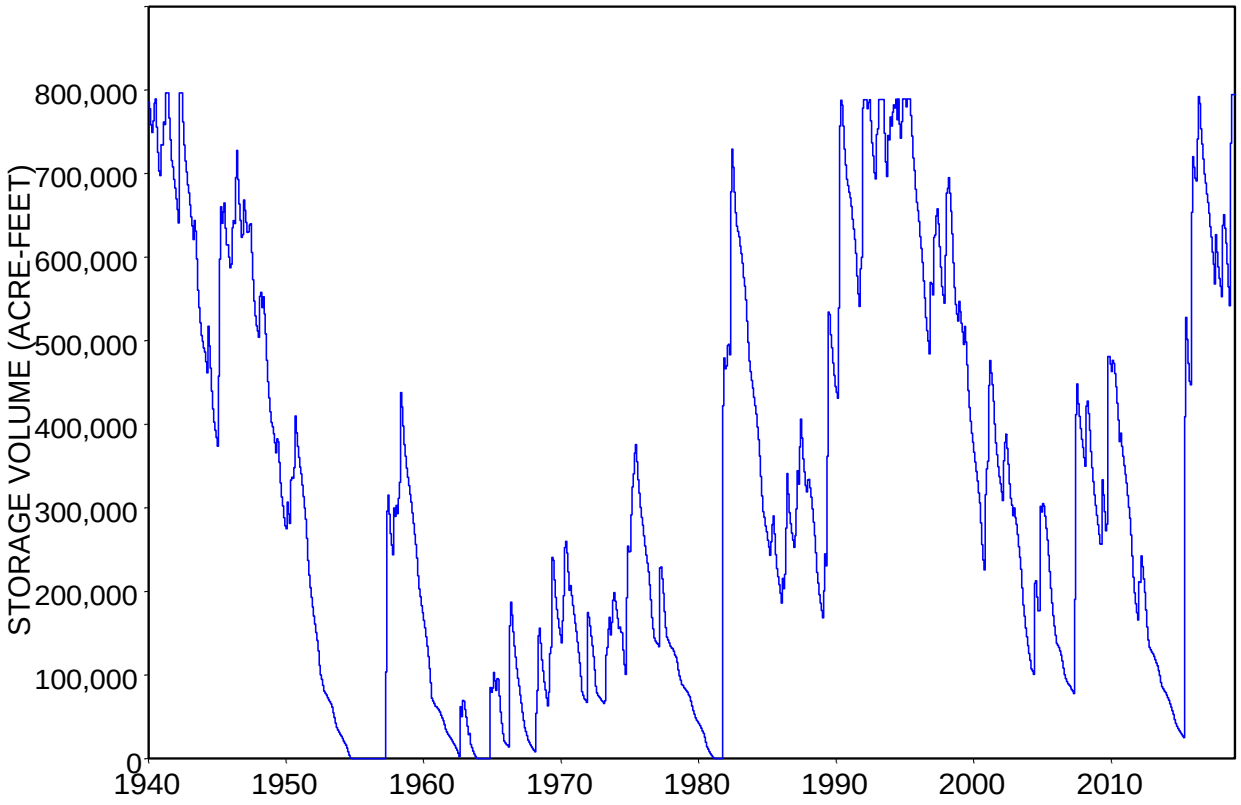

Figure 2.14 Ray Roberts Reservoir from Current Use Simulation

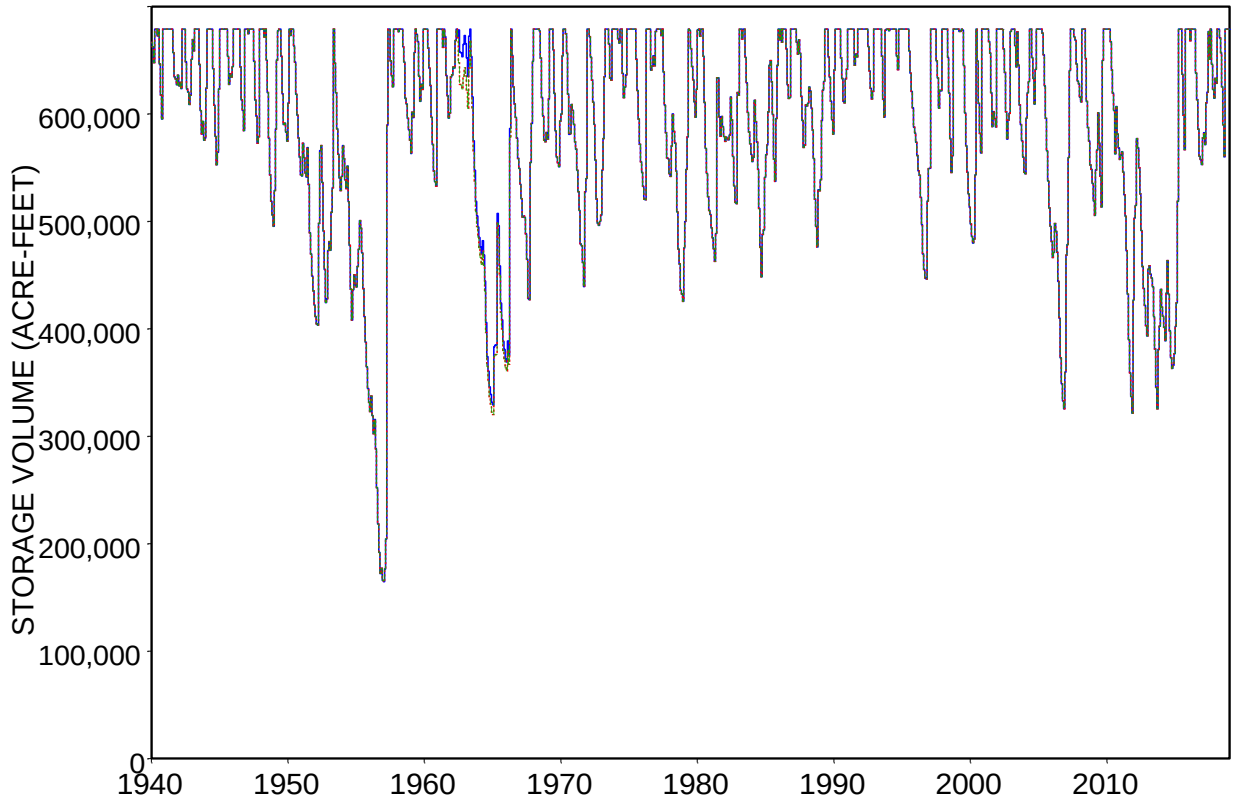

Figure 2.15 Cedar Creek Reservoir Storage from Authorized Use Simulations

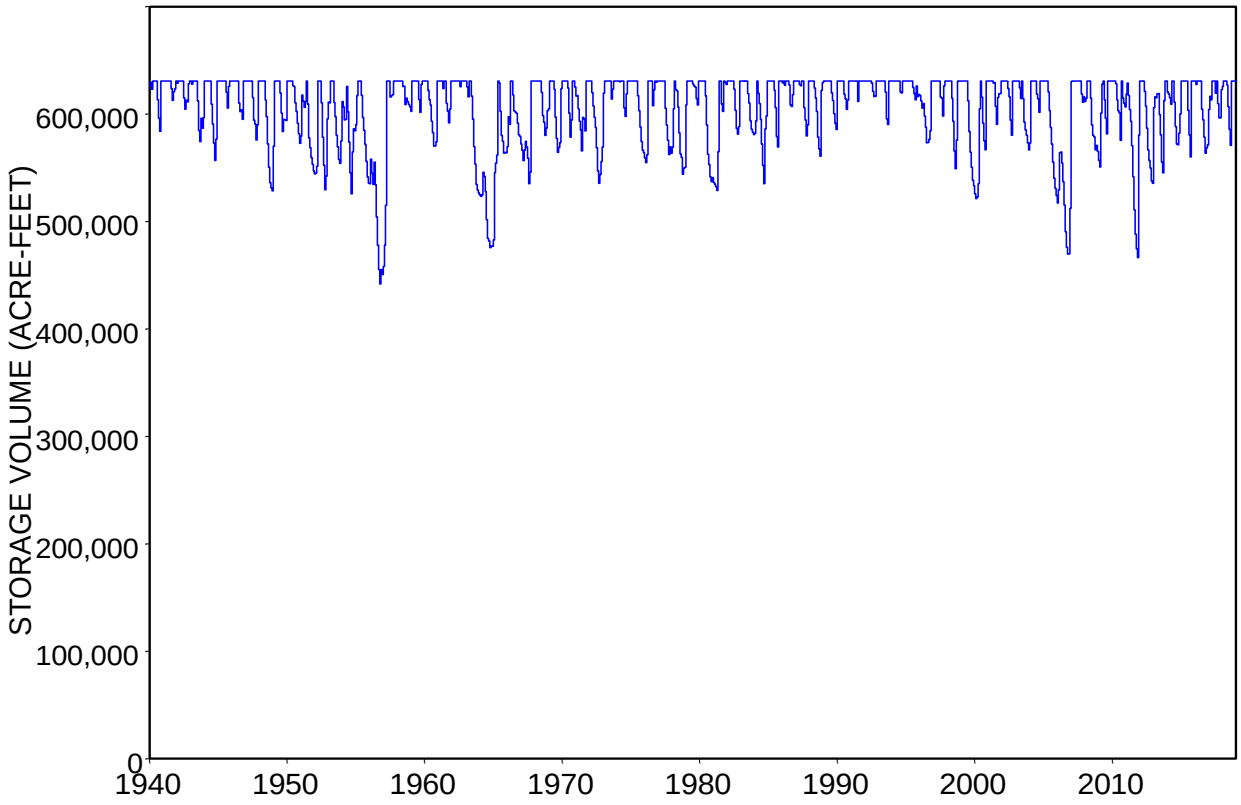

Figure 2.16 Cedar Creek Reservoir from Current Use Simulation

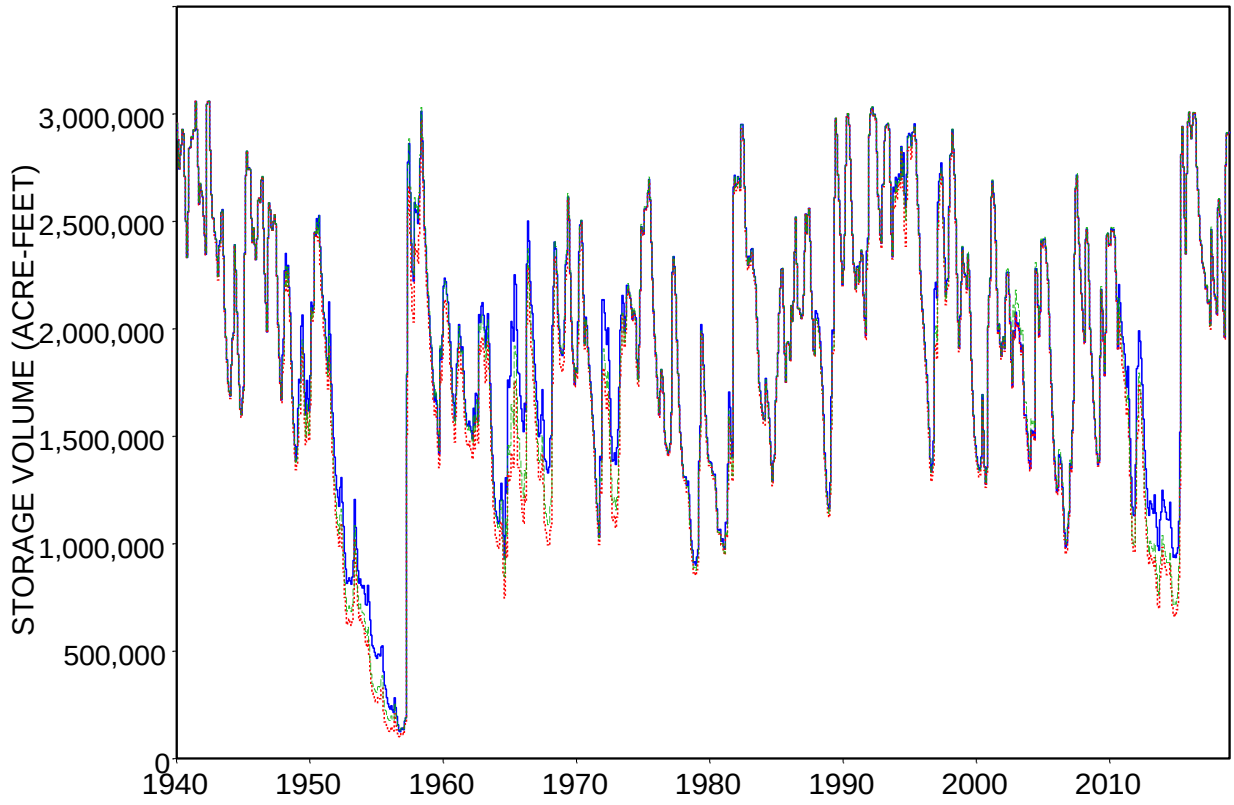

Figure 2.17 Summation of Storage Contents of 28 Reservoirs from Authorized Use Simulations

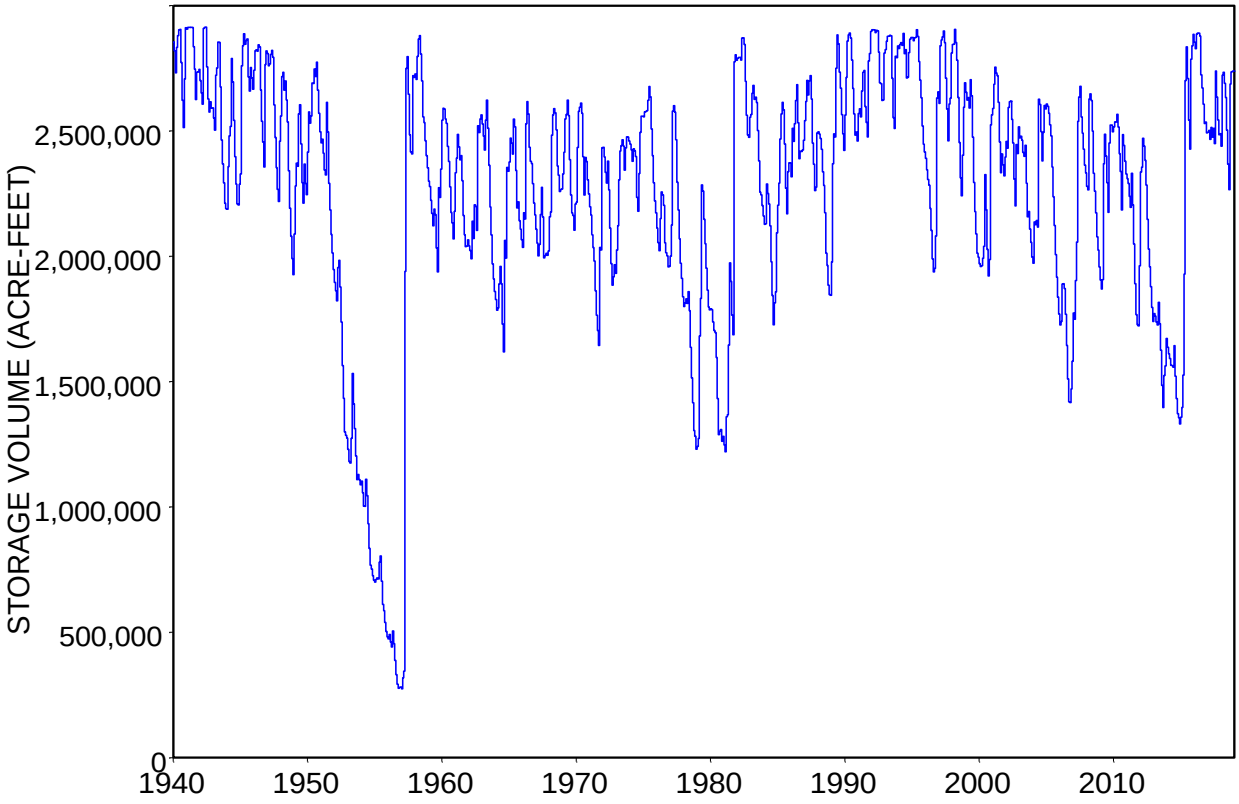

Figure 2.18 Summation of Storage Contents of 28 Reservoirs from Current Use Simulation

CHAPTER 3
DAILY AND MODIFIED MONTHLY VERSIONS OF THE TRINITY WAM

The December 2019 expanded Trinity WAM consists of the files described in Table 1.2 and includes both monthly and daily versions. Conversion of the full authorization WAM dataset last updated by the TCEQ in October 2014 and current use dataset last updated by the TCEQ in October 2012 (Table 2.1) to full authorization and current use versions of a December 2019 daily WAM included the following additions and other modifications.

1. The 1940-1996 monthly naturalized flows (*IN* records) and monthly net evaporation-precipitation depths (*EV* records) are extended to cover 1940-2018. The data are stored in the hydrology input DSS file. The 1940-2018 *IN* and *EV* records are applicable to both the monthly and daily WAMs. Updating the *IN* and *EV* records is described in Chapters 7 and 8.
2. Compilation of daily flow *DF* records stored in the DSS hydrology input file is described in Chapter 6. *DF* record 1940-2018 daily flows serve as pattern hydrographs in the *SIMD* flow disaggregation computations.
3. Calibrated lag and attenuation parameters are added on routing *RT* records in a new daily input DIF file. Development of routing parameters is covered in the present Chapter 3.
4. Flood control operations of eight USACE reservoirs is modeled by adding *FR* and *FF* records to the DAT file as explained in Chapter 4. Other records are revised to accommodate addition of reservoir flood control pools and operations.
5. Senate Bill 3 (SB3) environmental flow standards (EFS) are modeled by adding instream flow *IF*, environmental standard *ES*, and pulse flow *PF* records as described in Chapter 5. Records added to the monthly WAM in 2014 to model SB3 EFS are removed and replaced.
6. Alternative strategies and methods for performing various aspects of the simulation are evaluated and the optimal options are selected.

The 1940-1996 hydrologic period-of-analysis was extended to cover 1940-2018. The same hydrology DSS input file with filename TrinityHYD.DSS is employed in both *SIM* monthly and *SIMD* daily simulations with both full authorization and current use DAT files.

The completed daily WAM is used to compute daily instream flow targets for SB3 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 as time series *TS* records which are used by *IF* record instream flow rights in the monthly *SIM* simulation model.

Daily *SIMD* Simulation Input Dataset

With the exception of the monthly *IF/TS* record targets for SB3 EFS noted in the preceding paragraph, all of the *SIM* input files and input records in the monthly Trinity WAM dataset are also included in the daily Trinity WAM dataset to be 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 3.1 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 3.1 are employed in the daily Trinity WAM. The following daily records are included in the daily Trinity WAM: *JT* and *JU* (simulation options), *W2* and *C2* (output control), *FR* and *FF* (flood control), *RT* (routing), *DF* (daily flows), and *PF* (pulse flow component of SB3 environmental flow standards).

Table 3.1
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.
	DSS File
DF	Daily flows.

The daily Trinity 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 Trinity3D.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.

DAT File Input Records with Simulation Control Option Parameters

The records replicated as Table 3.2 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*.

Table 3.2
SIMD DAT File Input Records for Controlling Simulation Options

```
**       1         2         3         4         5         6         7         8
**345678901234567890123456789012345678901234567890123456789012345678901234567890
**-----!-------!-------!-------!-------!-------!-------!-------!-------!-------!
JD    79    1940       1       0       0               7                      13
JO     6                   0                                                   3
JT     0   0   0   0   0   0   0   0   0   0   0   1
JU     1   0   0   0   0
OF     1   0   2                                       Trinity
DF         8WTJA   8BSBR   8WTBO   8CTAL   8CTFW   8WTFW   8WTGP   8MCGP   8ELSA
DF         8IDPP   8CLSA   8DNJU   8TRDA   8WRDA   8ETMK
DF         8SGPR   8ETCR   8TRRS   8TRTR   8CEKE   8KGKA   8CEMA   8RIRI   8CHCO
DF         8TEST   8TROA   8TRMI   8BEMA   8TRRI   8TRRO
DF        B3808A  B3809A  B3349A  B5157P  B3404A  B5136A  B2335A  B2456A    B304
DF        B2362A  B2457C  B2462A  B2410A  B4976A  B4992A
DF        B5021A  B5035A  B4248A  B4248B
C2         8WTGP   8TRDA   8TROA   8TRRO
```

The following options activated on the records shown in Table 3.2 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 *Daily Manual* Chapter 3. *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 to 13 from the default of 12. The *SV* and *SA* records are extended to encompass the flood control pools of the eight USACE reservoirs.
- 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.
- DUALD in *JO* record field 16 (column 80) sets the default dual option that is replaced for individual water rights by DUAL(wr) in *PX* record field 2.
- 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 Trinity 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 3.2. 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 49 control points listed on the DAT file *DF* records in Table 3.2.
- 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 Trinity 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 eight USACE reservoirs are modeled as described in Chapter 4 by adding *FR* and *FF* records to the DAT file. Senate Bill 3 (SB3) environmental flow standards (EFS) at four sites are modeled by adding *IF*, *ES*, and *PF* records as described in Chapter 5.

The creation of the full authorization and current use scenario versions of the daily WAM began with the monthly full authorization and current use DAT files last updated by the TCEQ in October 2014 and October 2012, respectively. The SB3 EFS had been added to the monthly DAT files by the TCEQ using the original WRAP capabilities available prior to the expanded May 2019 WRAP. The SB3 EFS at four USGS gage sites were originally modeled in the monthly *SIM* input DAT files as 44 *WR* record and 36 *IF* record rights defined with many *UC*, *WS*, *TO*, *PX*, *FS*, *CI*, and *CP* records. These records were removed in 2019 prior to adding the *IF*, *ES*, and *PF* records described in Chapter 5 of this report.

The current use scenario DAT file last updated by the TCEQ in October 2012 contains several target series *TS* records used to model certain return flows that contained the year 1996 in an input field. The 1996 was changed to 2018 in the December 2019 update.

The *SV/SA* record tables in the DAT file are extended to include flood control pools in the eight USACE reservoirs. The *IS/IP* records for *DI* record drought indices for Lakes Benbrook and Lavon were extended to include the flood control pools.

Lag and attenuation routing coefficients developed as described later in this chapter are recorded on *RT* records stored in a DIF file. Daily flow *DF* records developed as explained in Chapter 6 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.

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 input flow pattern hydrographs. Daily stream flow is extremely variable as illustrated Figure 2.4 of Chapter 2. All other monthly time series input data including *EV* record net evaporation-precipitation depths and computed diversion targets in the daily Trinity WAM are uniformly disaggregated from monthly to daily.

Monthly naturalized flows are disaggregated to daily at most control points in the WAM using 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 8TRRO with REPEAT and DFMETHOD options 2 and 4 activated. Control point 8TRRO is the Trinity River outlet.

```
DC 8TRGB    2    4    8TRRO
```

Flows at computational accounting control points not encompassed within the actual stream system are disaggregated uniformly by the default DFMETH option 1 in *JU* record field 2.

Monthly naturalized stream flows at about 1,400 Trinity WAM control points are disaggregated to daily using 1940-2018 daily flows at 49 control points which are stored as *DF* records in the hydrology 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* [4]. The automated procedure consists of using flows at the nearest downstream control point if available, otherwise finding flows at the nearest upstream control point, and lastly if necessary using flows from another tributary.

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 Trinity WAM version presented in this report. 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 environmental flow standards based on *HC*, *ES*, and *PF* record specifications for the 2019 daily Trinity WAM as explained in Chapter 5, 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 Trinity 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, streamflow changes propagate to the outlet in the same day that they originate, with no lag, in a daily *SIMD* simulation. 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 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 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 Trinity WAM with over 1,400 control points includes routing parameters at 39 control points. Routing is not necessarily required at all.

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.

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. 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 Trinity WAM [10]. The lag parameters LAG and LAGF in days and attenuation parameters ATT and ATTF in days 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 water right operations and flood control operations, respectively [5].

The routing parameters for the 39 reaches defined by the 40 primary control points in the Trinity WAM are contained on *RT* records in the DIF file and tabulated in Table 3.3 [10]. The calibration study resulted in ATT and ATTF values of 1.0 day for all of the 39 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. The LAG and LAGF for each of the 39 selected reaches are tabulated in the third and fourth columns of Table 3.3. The daily input DIF file is replicated as Table 3.4.

Table 3.3
Lag Parameters and Related Metrics

Upstream Control Point	Down-Stream CP	Normal LAG (days)	High Flow LAGF (days)	Reach Length (miles)	Normal Lag/mile (days/mile)	High Flow Lag/mile (days/mile)	Normal Speed (miles/day)	High Flow Speed (miles/day)
8WTJA	8WTBO	6.36	5.74	63	0.101	0.091	9.9	11.0
8WTBO	8WTFW	2.07	2.28	46	0.045	0.050	22.2	20.2
8WTFW	8WTGP	0.99	1.03	39	0.025	0.026	39.4	37.9
8WTGP	8TRDA	0.35	0.37	14	0.025	0.026	40.0	37.8
8TRDA	8TRRS	2.00	3.04	47	0.043	0.065	23.5	15.5
8TRRS	8TRTR	1.04	3.15	58	0.018	0.054	55.8	18.4
8TRTR	8TROA	1.96	4.05	76	0.026	0.053	38.8	18.8
8TROA	8TRCR	1.00	3.86	47	0.021	0.082	47.0	12.2
8TRCR	8TRMI	1.00	3.83	32	0.031	0.120	32.0	8.4
8TRMI	8TRRI	1.08	4.79	66	0.016	0.073	61.1	13.8
8TRRI	8TRRO	2.00	3.05	69	0.029	0.044	34.5	22.6
8TRRO	8TRGB	2.52	3.85	87	0.029	0.044	34.5	22.6
8BSBR	8WTBO	1.82	1.64	18	0.101	0.091	9.9	11.0
8CTAL	8CTBE	1.11	1.00	11	0.101	0.091	9.9	11.0
8CTBE	8CTFW	0.91	0.82	9	0.101	0.091	9.9	11.0
8CTFW	8WTFW	0.10	0.11	2.3	0.043	0.050	23.0	20.9
8MCGP	8TRDA	0.25	0.26	10	0.025	0.026	40.0	38.5
8ELSA	8ELLE	2.10	2.40	35	0.060	0.069	16.7	14.6
8ELLE	8TRDA	2.14	1.99	33	0.065	0.060	15.4	16.6
8IDPP	8ELLE	2.84	2.82	36	0.079	0.078	12.7	12.8
8CLSA	8ELLE	2.11	2.40	35	0.060	0.069	16.6	14.6
8DNJU	8DNGR	3.23	2.92	32	0.101	0.091	9.9	11.0
8DNGR	8TRDA	2.02	1.87	31	0.065	0.060	15.3	16.6
8WRDA	8TRRS	3.63	3.75	58	0.063	0.065	16.0	15.5
8ETMK	8ETLA	1.25	1.28	19	0.066	0.067	15.2	14.8
8ETLA	8ETFO	1.45	1.48	22	0.066	0.067	15.2	14.9
8ETFO	8ETCR	0.99	1.01	15	0.066	0.067	15.2	14.9
8ETCR	8TRRS	1.05	1.96	20	0.053	0.098	19.0	10.2
8SGPR	8ETLA	0.85	0.88	13	0.065	0.067	15.3	14.8
8CEKE	8CEMA	1.32	1.35	20	0.066	0.067	15.2	14.8
8CEMA	8TROA	3.40	5.35	94	0.036	0.057	27.6	17.6
8KGKA	8CEMA	1.38	1.41	21	0.066	0.067	15.2	14.9
8RIDA	8RIRI	0.98	1.09	22	0.045	0.050	22.4	20.2
8RIRI	8RIFA	1.30	1.44	29	0.045	0.050	22.3	20.1
8RIFA	8TROA	1.63	3.36	63	0.026	0.053	38.7	18.8
8WABA	8CHCO	2.00	1.16	18	0.111	0.064	9.0	15.5
8CHCO	8RIFA	2.82	1.86	31	0.091	0.060	11.0	16.7
8TEST	8TROA	3.88	4.49	63	0.062	0.071	16.2	14.0
8BEMA	8TRRI	1.49	2.49	40	0.037	0.062	26.8	16.1

The 39 river reaches with their upstream and downstream control points (USGS gage sites) are delineated in the map of Figure 3.1. Estimates of the approximate length of each reach is

tabulated in the fifth column of Table 3.3. The normal lag LAG per mile (day/mile) is tabulated in the sixth column of Table 3.3 and shown by color-code in Figure 3.1 [10].

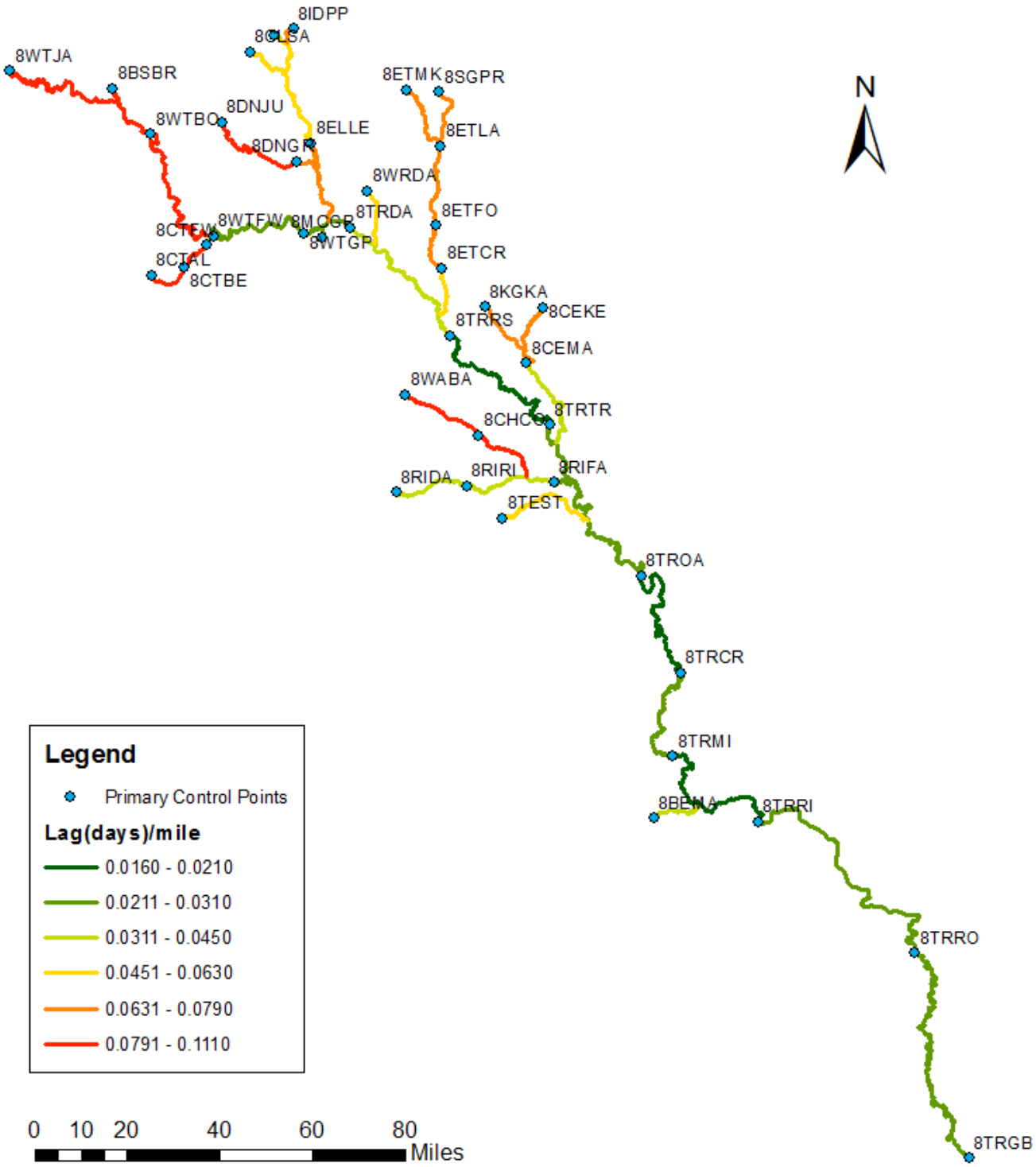

Figure 3.1 Lag in Days/Mile for River Reaches in Table 3.3 [10]

Table 3.4
SIMD Daily Input DIF File

```
**                NORMAL FLOWS          HIGH FLOWS
**                 LAG     ATT          LAG     ATT
RT 8WTJA   1    6.36    1.00   1    5.74    1.00
RT 8WTBO   1    2.07    1.00   1    2.28    1.00
RT 8WTFW   1    0.99    1.00   1    1.03    1.00
RT 8WTGP   1    0.35    1.00   1    0.37    1.00
RT 8TRDA   1    2.00    1.00   1    3.04    1.00
RT 8TRRS   1    1.04    1.00   1    3.15    1.00
RT 8TRTR   1    1.96    1.00   1    4.05    1.00
RT 8TROA   1    1.00    1.00   1    3.86    1.00
RT 8TRCR   1    1.00    1.00   1    3.83    1.00
RT 8TRMI   1    1.08    1.00   1    4.79    1.00
RT 8TRRI   1    2.00    1.00   1    3.05    1.00
RT 8TRRO   1    2.52    1.00   1    3.85    1.00
RT 8BSBR   1    1.82    1.00   1    1.64    1.00
RT 8CTAL   1    1.11    1.00   1    1.00    1.00
RT 8CTBE   1    0.90    1.00   1    0.82    1.00
RT 8CTFW   1    0.10    1.00   1    0.11    1.00
RT 8MCGP   1    0.25    1.00   1    0.26    1.00
RT 8ELSA   1    2.10    1.00   1    2.40    1.00
RT 8ELLE   1    2.14    1.00   1    1.99    1.00
RT 8IDPP   1    2.84    1.00   1    2.82    1.00
RT 8CLSA   1    2.11    1.00   1    2.40    1.00
RT 8DNJU   1    3.23    1.00   1    2.92    1.00
RT 8DNGR   1    2.02    1.00   1    1.87    1.00
RT 8WRDA   1    3.63    1.00   1    3.75    1.00
RT 8ETMK   1    1.25    1.00   1    1.28    1.00
RT 8ETLA   1    1.45    1.00   1    1.48    1.00
RT 8ETFO   1    0.99    1.00   1    1.01    1.00
RT 8ETCR   1    1.05    1.00   1    1.96    1.00
RT 8SGPR   1    0.85    1.00   1    0.88    1.00
RT 8CEKE   1    1.32    1.00   1    1.35    1.00
RT 8CEMA   1    3.40    1.00   1    5.35    1.00
RT 8KGKA   1    1.38    1.00   1    1.41    1.00
RT 8RIDA   1    0.98    1.00   1    1.09    1.00
RT 8RIRI   1    1.30    1.00   1    1.44    1.00
RT 8RIFA   1    1.63    1.00   1    3.36    1.00
RT 8WABA   1    2.00    1.00   1    1.16    1.00
RT 8CHCO   1    2.82    1.00   1    1.86    1.00
RT 8TEST   1    3.88    1.00   1    4.49    1.00
RT 8BEMA   1    1.49    1.00   1    2.49    1.00
**
DC 8TRGB   2   4   8TRRO
ED
```

Control Points and Routing Reaches

The 39 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 3.3, 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 Trinity WAM. The control point identifiers in the first column of Table 3.3 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 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 3.3. 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 shown in Table 3.4 are the control points listed in the first column of Table 3.3.

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. The lags in Table 3.3 were determined based on statistical analyses of many identified flow fluctuations between USGS gaging stations [4, 10]. Lag estimates are highly variable and approximate.

Travel speeds (wave celerity) in miles/day corresponding to the lags are tabulated in Table 3.3 for general information. The travel speeds in Table 3.3 are 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 longest continuous sequence of river reaches extends through control points 8WTJA, 8WTBO, 8WTFW, 8WTGP, 8TRDA, 8TRRS, 8TRTR, 8TROA, 8TRCR, 8TRMI, 8TRRI, 8TRRO, and 8TRGB and has an estimated total length of 644 miles, total normal lag of 22.37 days, and flood lag of 39.04 days. This 644 mile reach extends from the USGS gage on the West Fork of the Trinity near Jacksboro (8WTJA) to the outlet of the Trinity River at Galveston Bay (8TRGB). The reach between the USGS gage on the Trinity River at Dallas (control point 8TRDA) and the Trinity River near Richland (control point 8TRRI) just upstream of Lake Livingston has an estimated total length of 340 miles, total normal lag of 8.43 days, and flood lag of 23.09 days.

LAGF may be longer or shorter than LAG. The flood lag LAGF for many reaches in Table 3.3 is shorter than the normal lag LAG, presumably due to average flow rates through overbank flood plains being slower than average flows in a main channel. High flows in a channel normally have greater mean velocities than low flows. The metrics in Table 3.3 exhibit great variability.

Water Rights

Flood control operations of the eight USACE reservoirs are modeled as *FR* record water rights as explained in Chapter 4. SB3 EFS at four sites are modeled as instream flow *IF* record water rights as described in Chapter 5. Addition of flood control and SB3 EFS are the primary water rights related modifications involved in the creation of the daily Trinity WAM. Other miscellaneous water right related modifications and considerations are noted as follows.

The *SIMD DW* and *DO* records listed in Table 3.1 and explained in the *Users Manual* [2] provide options for non-uniform monthly-to-daily distribution of diversion targets. The *JU* record input parameters DND and DSHORT also activate options for non-uniform disaggregation of monthly diversion targets to daily quantities. These options are not applied in the daily Trinity WAM. Monthly diversion targets are uniformly disaggregated to daily.

The *IS/IP* records for *DI* record drought indices for Lakes Benbrook and Lavon were extended to include the flood control pool. The *SV/SA* record tables in the DAT file are extended to include flood control pools in the eight USACE reservoirs.

The current use scenario DAT file last updated by the TCEQ in October 2012 contains several target series *TS* records used to model certain return flows that contained the year 1996 in an input field. The 1996 was changed to 2018 in the December 2019 update.

The dual simulation options are activated by the input parameters DUALD on the *JO* record and DUAL on the *PX* record for several water rights in the Trinity WAM. Alternative dual simulation options were investigated for the daily WAM. However, the dual simulation was concluded to not be an issue in the monthly-to-daily conversion. The dual simulation options in the original monthly WAM remain the same in the daily WAM.

Subordination agreements are explored in Chapter 2, particularly the Lake Livingston subordination. Subordination was investigated as a potential issue in the monthly-to-daily conversion but concluded to not be a major problem. The schemes for modeling subordination agreements in the original monthly WAM remain the same in the daily WAM.

The parameters WRMETH and WRFCST entered on the *JU* record control the next-day placement of routed flow changes in the water rights priority sequence. These options affect the impacts of water right actions in a particular day on stream flow availability for other rights in future days. The default of placing flow changes at the beginning of the water rights priority sequence is adopted for all of the simulations presented in this report.

CHAPTER 4
RESERVOIR FLOOD CONTROL OPERATIONS

Converting the monthly Trinity 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 such as the Trinity. Accurate modeling of small systems may require hourly or smaller time steps not available in *SIMD*. Operation of gate-controlled flood control pools based on flows at downstream gage sites 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. Operation of the flood control pools of the eight multiple-purpose reservoirs in the Trinity River Basin owned and operated by the U.S. Army Corps of Engineers (USACE) Fort Worth District (FWD) is incorporated in the daily WAM as described in this chapter.

Of the major reservoirs in the Trinity River Basin with storage capacities of 5,000 acre-feet or greater, the eight USACE FWD reservoirs are the only reservoirs with designated flood control pools. *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 Trinity 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.

Flood Control Reservoir Operations in the Trinity River Basin

Pertinent data sheets, flood control operating criteria, historical water surface elevations, and other data for USACE FWD reservoirs are found at: http://www.swf-wc.usace.army.mil. The eight USACE multiple-purpose reservoirs in the Trinity River Basin are listed in Table 4.1 with their designated top of conservation and flood control pool elevations and corresponding cumulative storage capacities from the USACE information. The storage capacities include sediment reserves. The flood control storage capacity in the last column of Table 4.1 are computed as the difference between the preceding two columns. Information from the USACE FWD reservoir website is also reproduced as Table 4.2 and Figures 4.1 through 4.8.

Flood control operating criteria are outlined in Table 4.2. Whenever the actual water surface level is above the top of conservation pool elevation and below the top of flood control pool elevation in the reservoirs, operation is based on emptying the flood control pools as expeditiously as feasible without contributing to flows exceeding the maximum allowable rates shown in Table 4.2. The allowable flow rates at downstream gages are tabulated in cubic feet per second (cfs). The maximum allowable flow rates of 15,000 cfs and 24,000 cfs at USGS gages on the Trinity River near the cities of Rosser and Oakwood constrain flood releases from all eight of the reservoirs. Other gages are below one or some but not all of the reservoirs.

Observed water levels in the eight reservoirs from their initial impoundment through October 2019 are plotted in Figures 4.1 through 4.8. Reservoir water surface elevations are expressed in units of feet above a mean sea level datum. Figures 4.1 through 4.8 trace encroachments into the flood control pools throughout the history of the reservoirs.

Table 4.1
USACE FWD Flood Control Reservoirs
http://www.swf-wc.usace.army.mil/pertdata/TRINITY.htm

Reservoir	Stream Location of Dam	Drainage Area (sq miles)	Pool Elevation (feet) Conservation	Pool Elevation (feet) Flood Control	Storage Capacity (acre-feet) Top of Conservation	Storage Capacity (acre-feet) Top of Flood Control	Storage Capacity (acre-feet) Flood Control
Benbrook	Clear Fork	429	694.0	710.0	88,250	164,800	76,550
Joe Pool	Mountain Creek	232	522.0	536.0	176,900	304,000	127,100
Ray Roberts	Elm Fork	692	632.5	640.0	799,600	1,064,600	265,000
Lewisville	Elm Fork	1,660	522.0	532.0	640,990	981,760	340,770
Grapevine	Denton Creek	695	535.0	560.0	181,100	425,500	244,400
Lavon	East Fork	770	492.0	503.5	456,500	748,100	291,600
Navarro Mills	Richland Creek	320	424.5	443.0	63,300	212,200	148,900
Bardwell	Waxahachie Ck	178	421.0	439.0	54,900	140,000	85,100

Table 4.2
USACE FWD Flood Control Operations Criteria for the Trinity River Basin

Reservoir	Water Surface Elevation (feet)	Percent Flood Storage	Clear Fork Trinity River	West Fork Trinity Fort Worth	West Fork Trinity Grand Prairie	Mountain Creek Grand Prairie	Denton Creek	Elm Fork Trinity Above L. Lewisvil	Elm Fork Trinity near Carrollton	Trinity River near Dallas	East Fork Trinity near Crandall	Trinity River near Rosser	Trinity River near Oakwood
Benbrook	694.0 - 696.0	0 - 10	600		6,000					13,000		15,000	24,000
	696.0 - 697.1	10 -16		3,000	6,000					13,000		15,000	24,000
	697.1 - 710.0	16 - 100			6,000					13,000		15,000	24,000
Joe Pool	522.0 - 523.0	0 - 6			6,000	1,200				13,000		15,000	24,000
	523.0 - 527.0	6 - 30			6,000	2,400				13,000		15,000	24,000
	527.0 - 536.0	30 - 100			6,000	4,000				13,000		15,000	24,000
Ray	632.5 - 633.5	0 - 11						2,000	4,000	13,000		15,000	24,000
Roberts	633.5 - 636.0	11 - 41						4,000	5,500	13,000		15,000	24,000
	636.0 - 640.5	41 - 100						6,000	7,000	13,000		15,000	24,000
Lewisville	533.1 - 533.6	0 -							4,000	13,000		15,000	24,000
	533.6 - 534.1								5,500	13,000		15,000	24,000
	534.1 - 571.1	-100							7,000	13,000		15,000	24,000
Grapevine	535.0 - 538.2	0 - 10					2,000		4,000	13,000		15,000	24,000
	538.2 - 542.0	10 - 23					2,000		5,500	13,000		15,000	24,000
	542.0 - 560.0	23 - 100					2,000		7,000	13,000		15,000	24,000
Lavon	492.0 - 503.5	0 - 100									8,000	15,000	24,000

Reservoir	Water Surface Elevation	Percent Flood Storage	Richland Creek at Dawson	Waxahachie Creek at Bardwell	Chambers Creek at Rice	Trinity River at Oakwood
Navarro Mills	424.5 - 427.0	0 - 10	1,200		5,000	24,000
	427.0 - 435.5	10 - 50	2,000		5,000	24,000
	435.5 - 443.0	50 - 100	2,000		5,000	24,000
Bardwell	421.0 - 423.3	0 - 10		Inflow+600	4,000	24,000
	423.3 - 427.4	10 - 30		Inflow+1200	4,000	24,000
	427.4 - 439.0	30 - 100		2,000	4,000	24,000

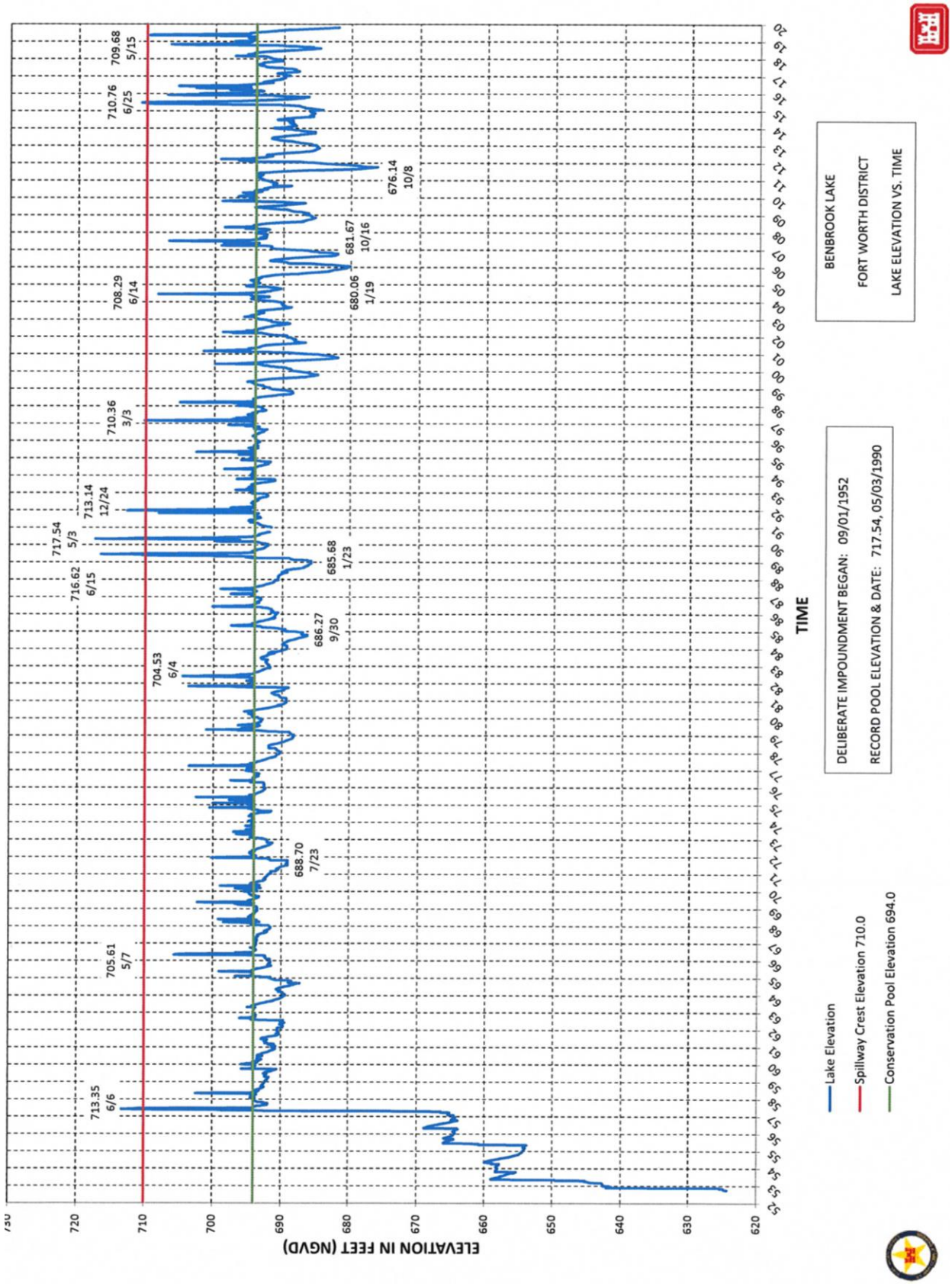

Figure 4.1 Benbrook Lake Levels (USACE FWD)

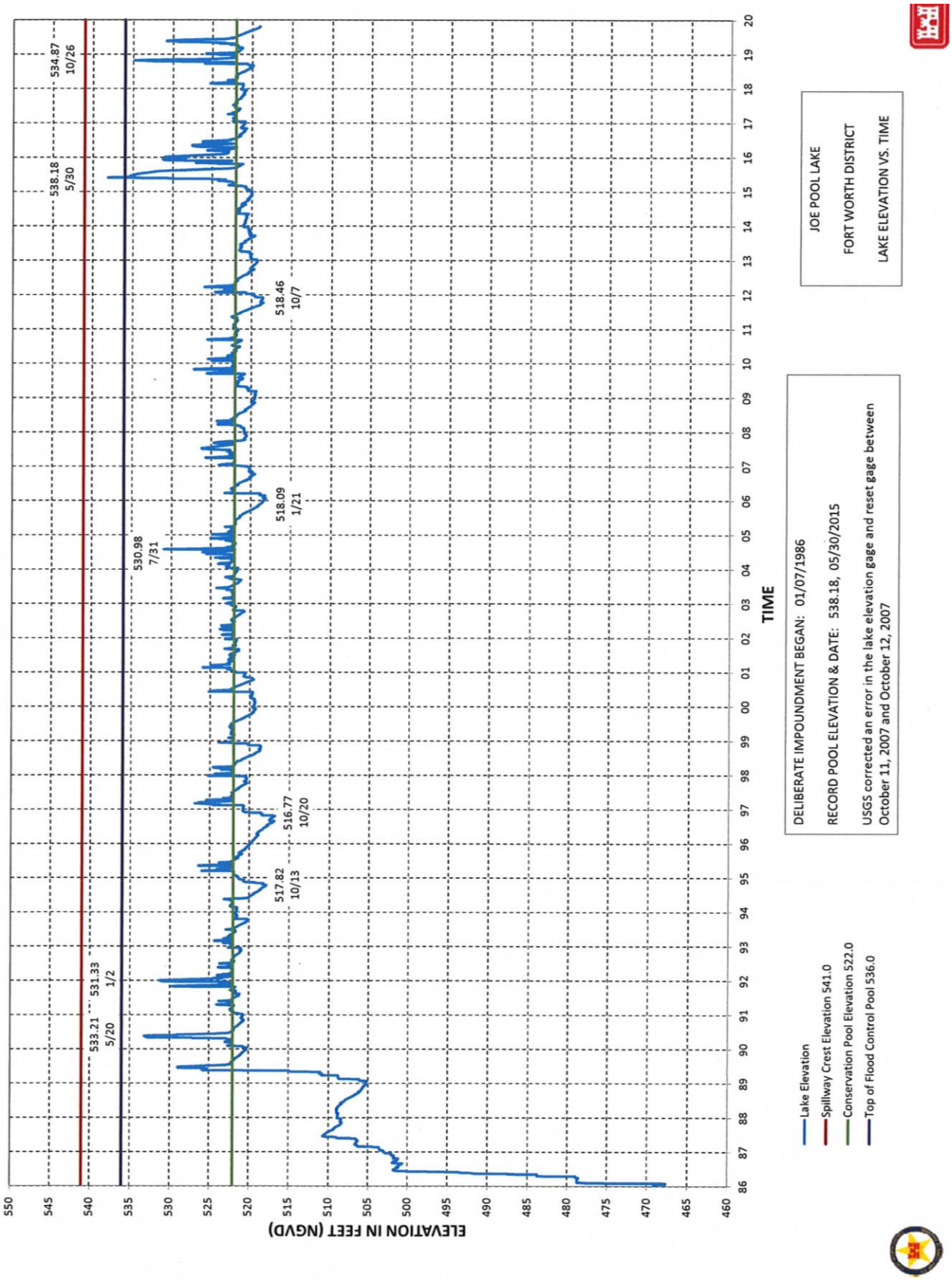

Figure 4.2 Joe Pool Lake Levels (USACE FWD)

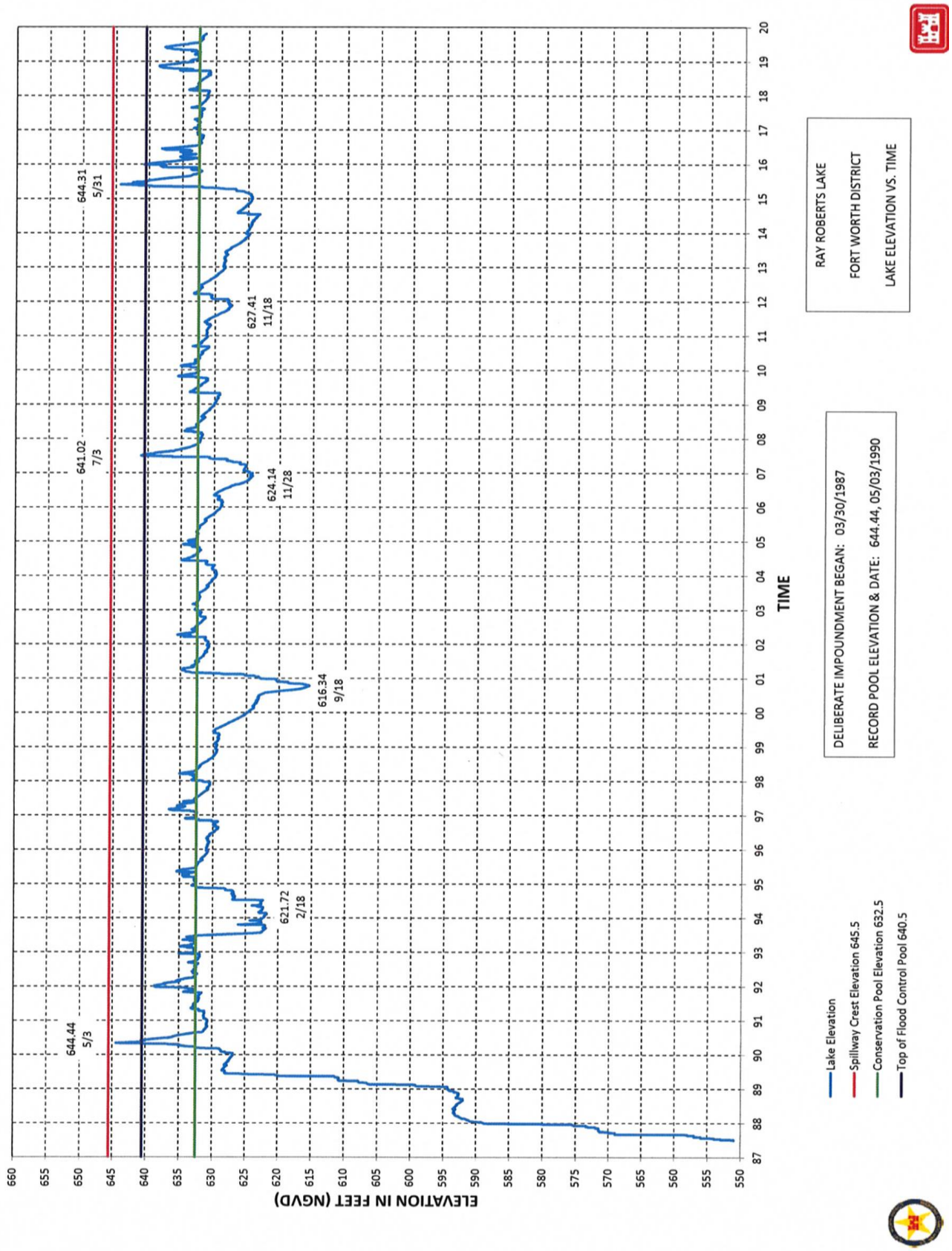

Figure 4.3 Ray Roberts Lake Levels (USACE FWD)

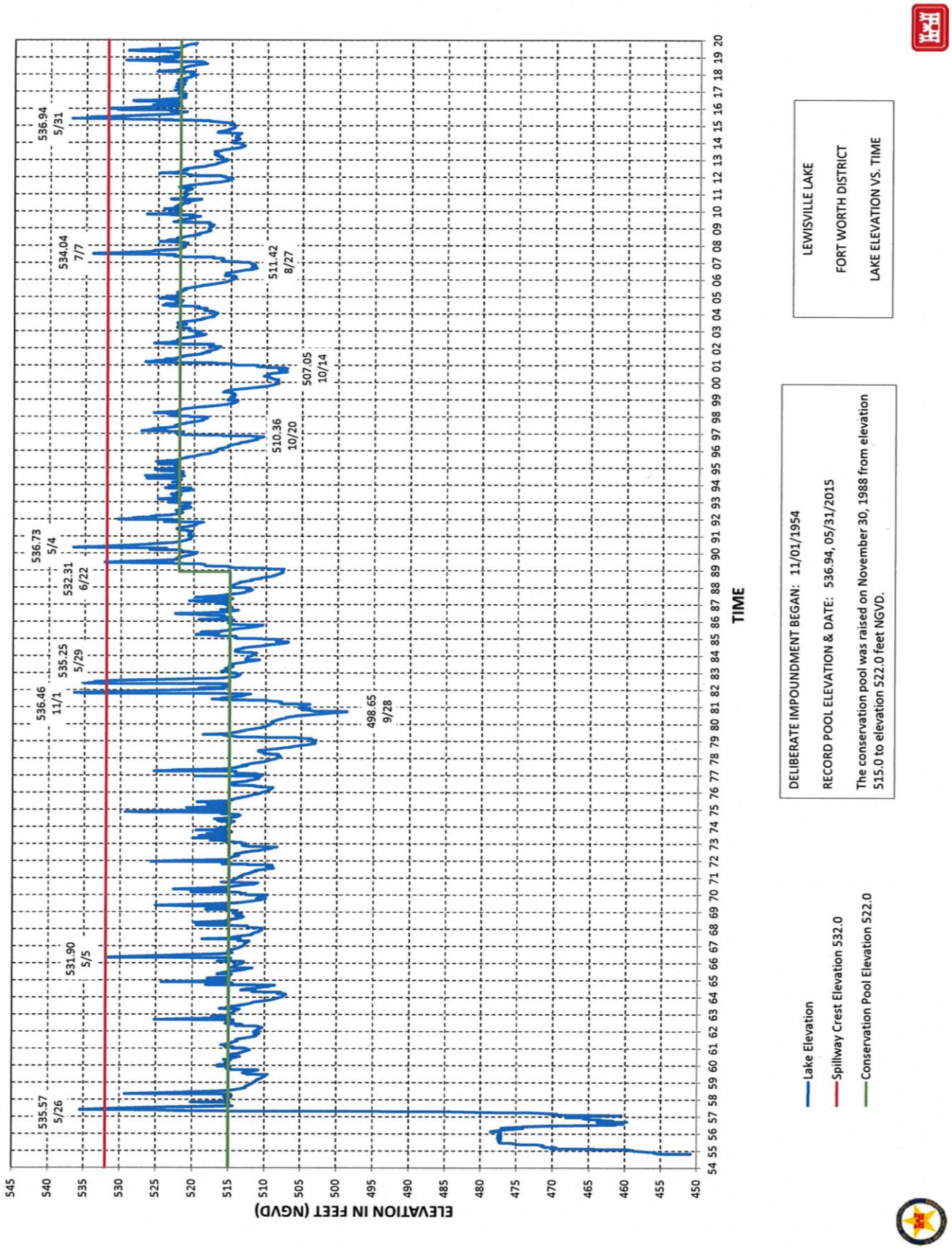

Figure 4.4 Lewisville Lake Levels (USACE FWD)

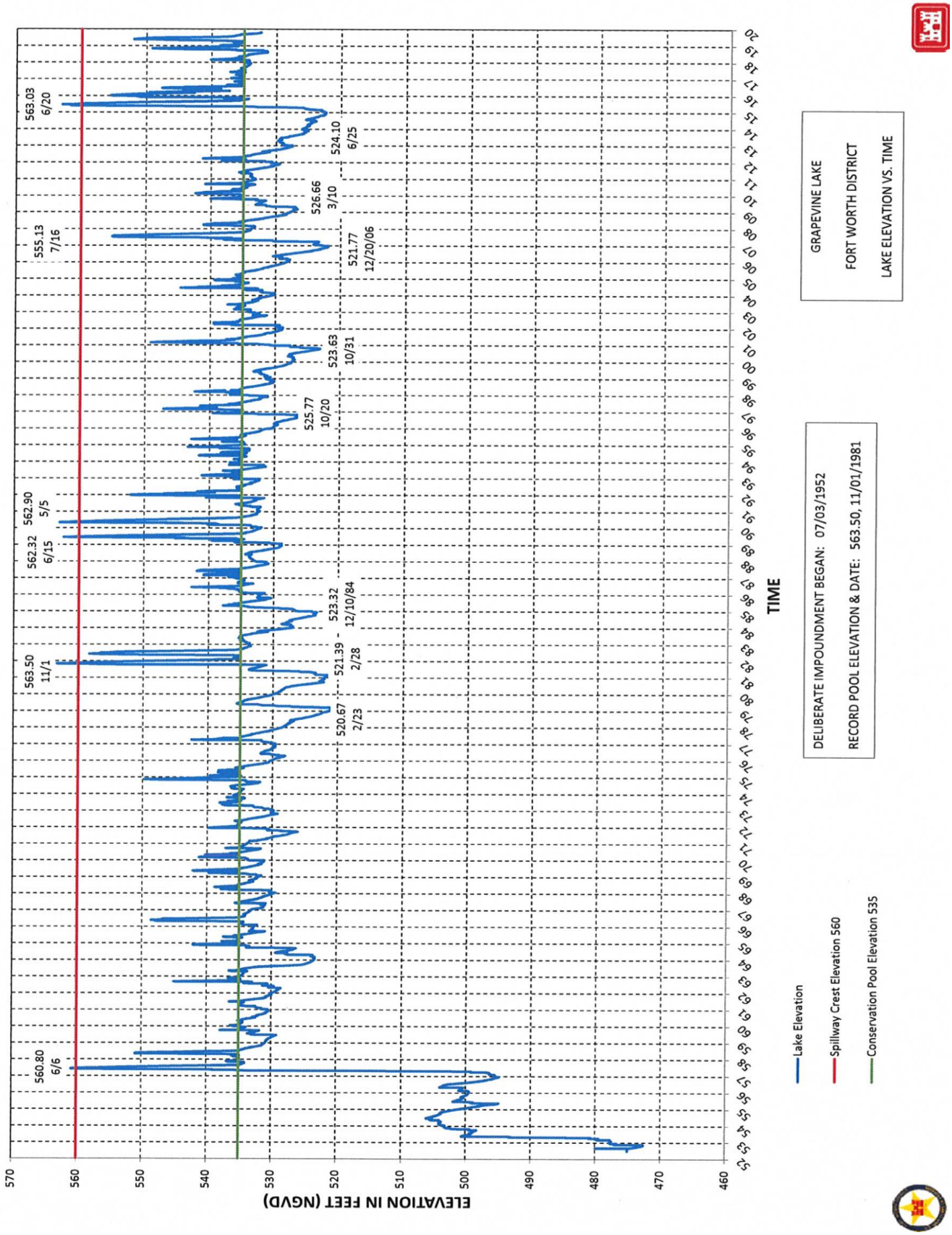

Figure 4.5 Grapevine Lake Levels (USACE FWD)

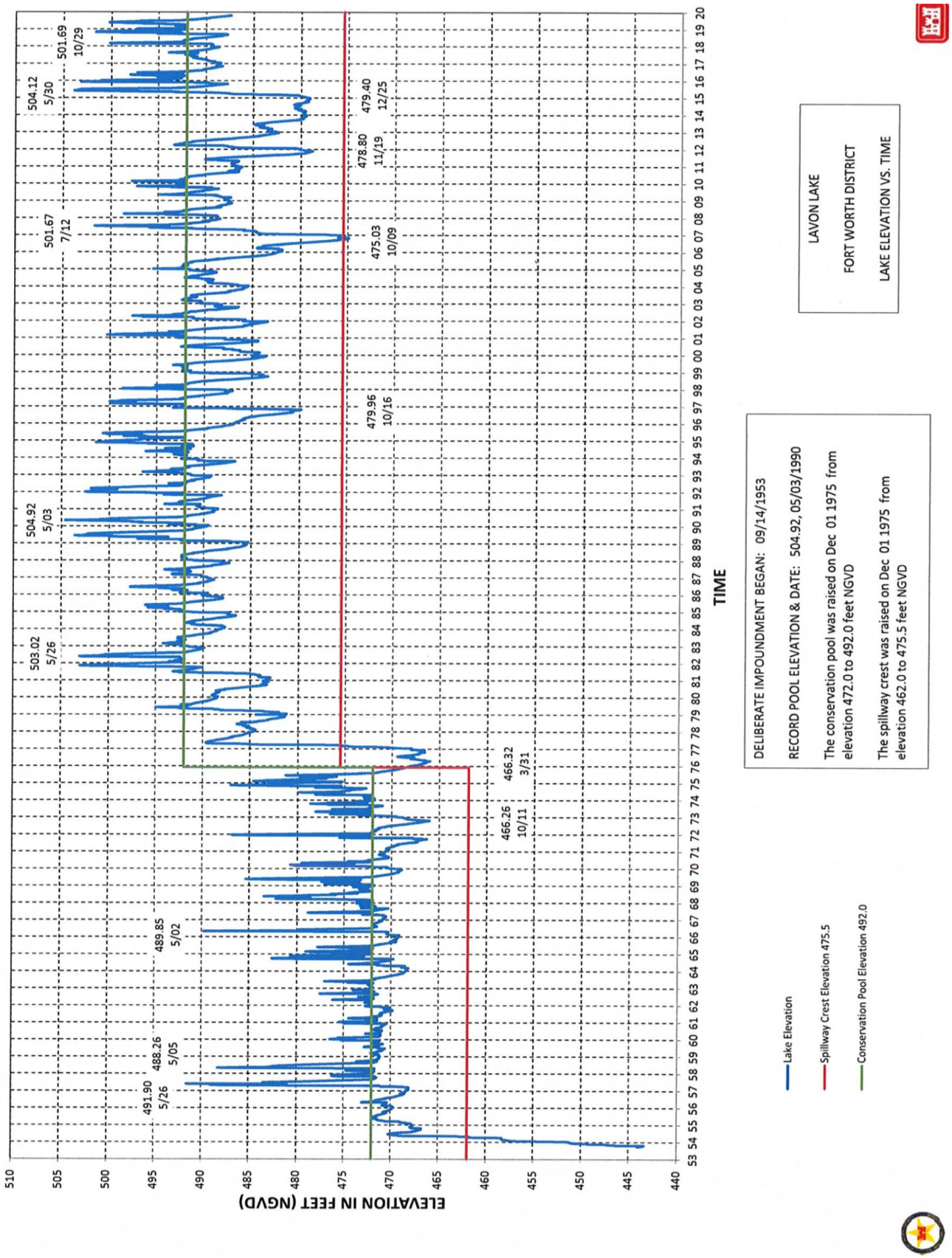

Figure 4.6 Lavon Lake Levels (USACE FWD)

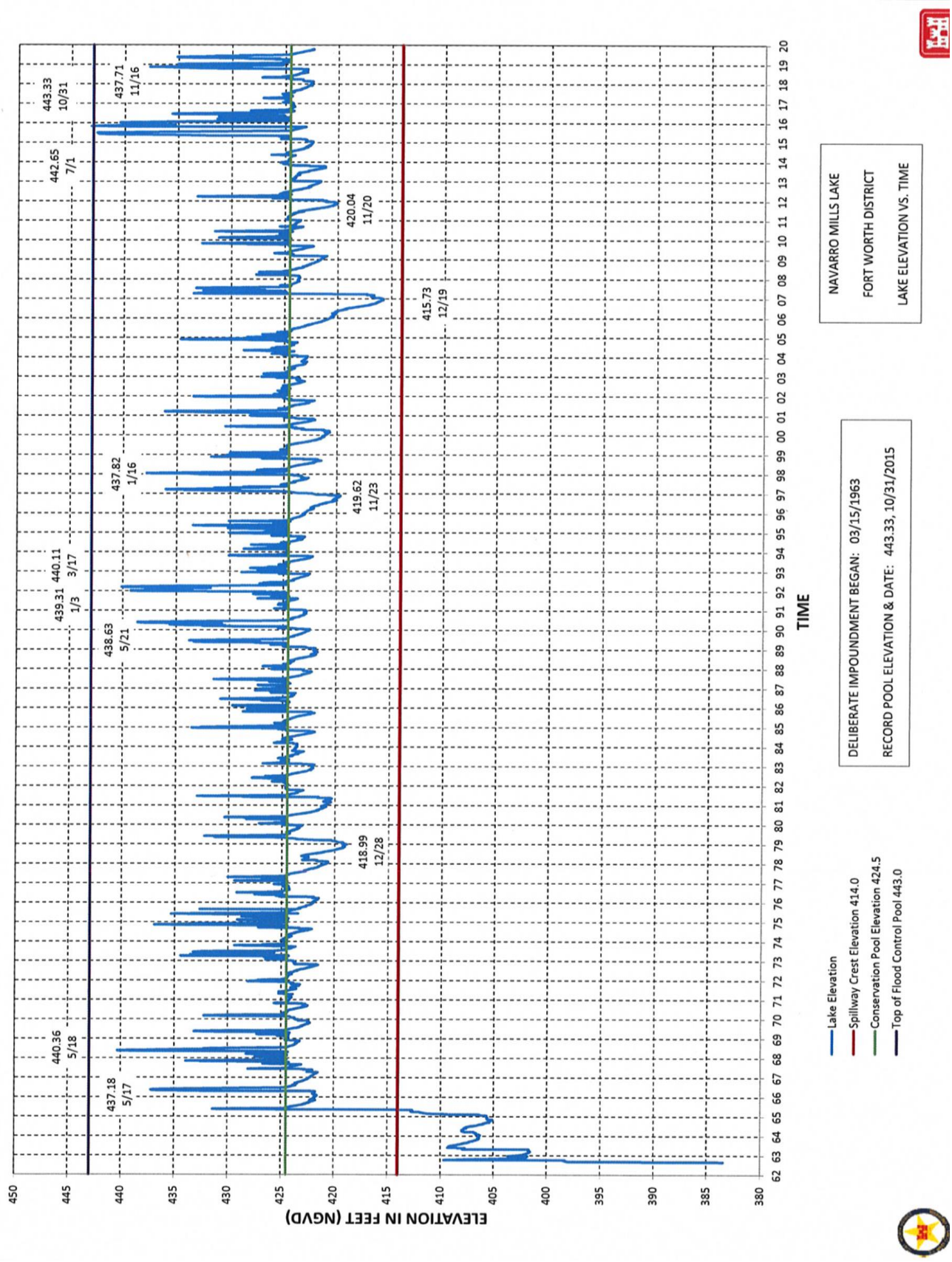

Figure 4.7 Navarro Mills Lake Levels (USACE FWD)

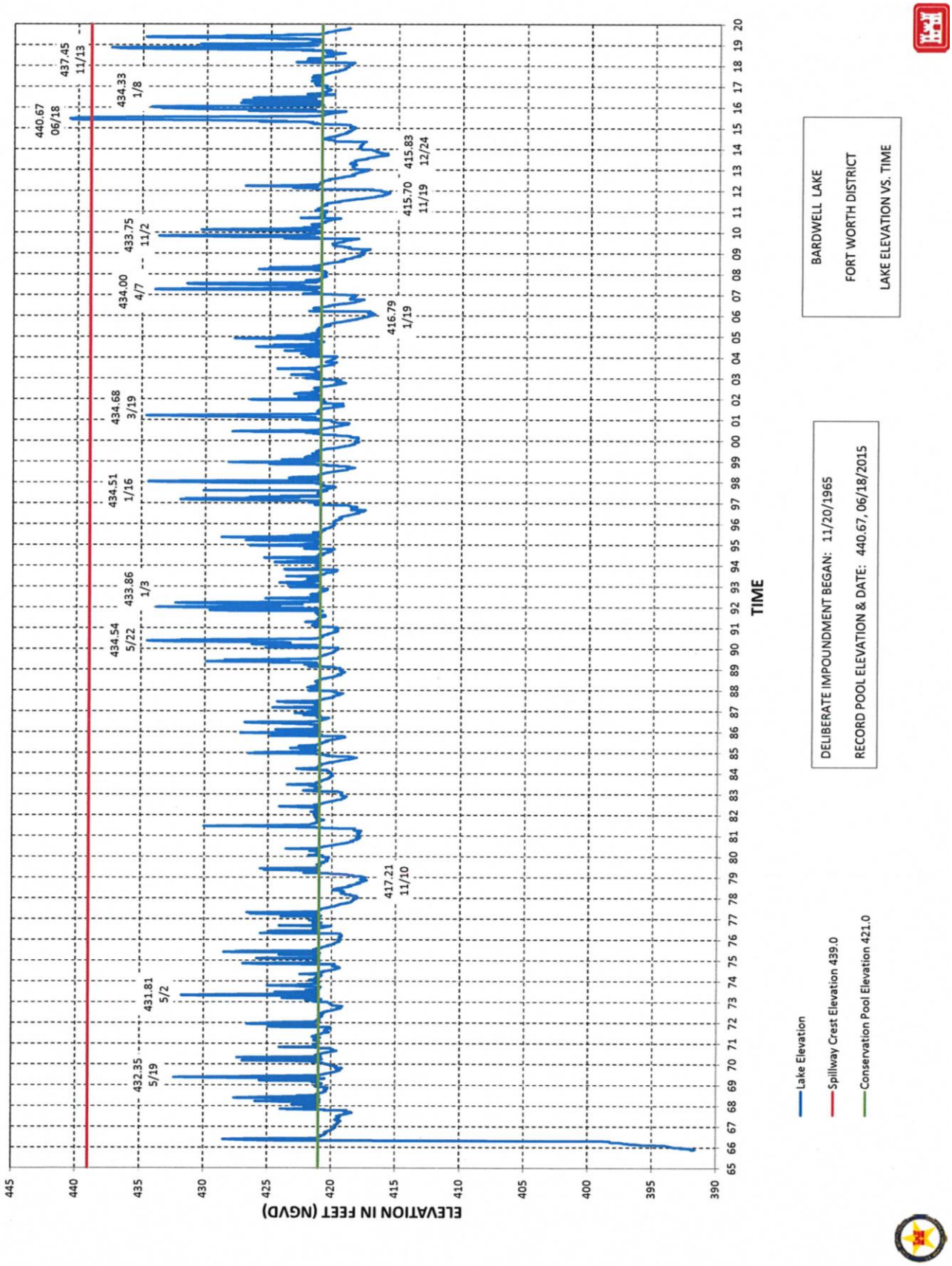

Figure 4.8 Bardwell Lake Levels (USACE FWD)

Flood Control Operation Procedures and Criteria

Flood control operations are guided by two sets of operating rules: regular operations and emergency operations. Regular operations are based on the criteria tabulated in Table 4.2. Maximum allowable discharge rates are specified at the dams and at USGS stream gaging stations located downstream of the dams. The allowable flow limits at some gages vary with storage contents of an upstream reservoir. If the flood control pool capacity is exceeded, emergency operations are activated to protect the dam following release rules that assure that the designated maximum design water surface is never overtopped, even though the releases contribute to downstream flooding. The emergency operating rules are not included in the WAM or this report.

As an example of the operating criteria shown in Table 4.2, if the water surface in Benbrook Reservoir is between 694.0 and 710.0 feet above mean sea level (within the flood control pool), releases through outlet conduits are made to draw the storage contents down to the top of conservation pool (elevation 694.0 feet) expeditiously, subject to making no release that would contribute to flow exceeding the allowable non-damaging flow rates at downstream gages shown in Table 4.2. With the water surface above elevation 710.0 feet, spills may contribute to flooding.

Lake Benbrook has an uncontrolled (ungated) ogee spillway with a crest elevation of 724.0 feet, which has a notch with a crest elevation of 710.0 feet. With the water surface above elevation 710.0 feet, water spills through the ungated spillway. The top of dam elevation of 747.0 feet was set during preconstruction design to assure that the dam is never overtopped. Lavon and Navarro Mills Reservoirs have gated spillways with crest elevations below the top of conservation pool with large release capacities. The other six reservoirs have ungated spillways with crest elevations at or above the top of flood control pool. Assuming the flood control storage capacity is not exceeded, releases from the flood control pool are made through conduits through the dams. For the six dams with uncontrolled emergency spillways, release capacities limited to flows through the conduits are much less than the large gated spillways at Lavon and Navarro Mills Reservoirs accessible for non-emergency and emergency flood control operations.

The reservoirs are operated by the USACE Fort Worth District (FWD) office as a multiple reservoir system to reduce downstream flood flows. The operating objective is to empty the flood control pools as expeditiously as possible without making releases that contribute to river flows exceeding the allowable flow limits at the downstream sites shown in Table 4.2. Releases may also be constrained by the outlet structure discharge capacities. Regular operations continue as long as flood control pool storage capacities are not exceeded. Regular operations are modeled in *SIMD* with flood reservoir *FR* and flood flow *FF* records. Outlet structure capacities can be specified with storage/outflow *FV/FQ* records and/or FCMAX on the *FR* record.

During rare extreme flood events that exceed the controlled (gated) flood control storage capacity, larger releases are based on protecting the dam from overtopping or otherwise structurally failing rather than the downstream allowable flood flow limits. The emergency operating plans can be modeled in *SIMD* with *FV* and *FQ* records based on information regarding the hydraulic characteristics of the outlet structures and the release rules that have been established. However, the emergency operating plans are not incorporated in the Trinity WAM. If the flood control pool is overtopped in the model, the excess flows pass through the reservoir without storage attenuation.

***SIMD* Capabilities for Simulating Reservoir Operations During Floods**

Flood control reservoir operations are treated as a type of water right in *SIMD*. Within WRAP, a water right is a set of water control requirements, reservoir facilities, and operating rules. Flood control rights are activated by *FR* records and are simulated along with all other *WR* and *IF* record water rights. 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 volume and outflow *FV/FQ* record pair are the only *SIMD* input records specifically for flood control. These records are described in Chapter 4 of the *Users Manual* [2]. *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 environmental instream flow requirements.

FV and *FQ* records and/or FCMAX on the *FR* record can be used to model outlet structure capacities for flood control operations. *FV* and *FQ* records can also be used to model the lag and attenuation effect of river flows through the outlet structures of a water supply reservoir with no flood control pool when the conservation pool is full to capacity and overflowing. The *FV/FQ* table of reservoir storage volume versus outflow represents the hydraulics of the outlet structures. The routing methodology based on parameters on *RT* records covered in the preceding Chapter 3 model the lag and attenuation (temporary storage) of flows through river reaches. Analogously, the *FV/FQ* record routing feature models flows over spillways and through outlet conduits of dams. Surcharge storage above the top of a full conservation pool occurs when reservoir inflow exceeds outflow due to limited spillway outflow capacity.

SIMD creates an optional output file with the filename extension AFF with annual series of peak flows and storages. The maximum naturalized flow, regulated flow, and storage volume are listed for each year of the simulation at specified control points. The *SIMD* AFF file is read by *TABLES* to perform flood frequency and damage analyses specified by a 7FFA record.

Reservoir Pools

In *SIMD*, a reservoir consists of any or all of the four pools shown in Figure 4.9. *SIM* includes only the bottom two pools. In either *SIM* or *SIMD*, inactive and conservation pool storage capacities are specified on storage *WS* records associated with water right *WR* records. *SIMD* allows controlled and uncontrolled flood control storage to be specified by *FR* records. A flood control pool defined by *FR* record fields 8 and 10 may include zones defined by *FR* record field 9 with outflows through either gated or ungated outlet structures. Pools with flood releases controlled by a gates operated by people based on downstream stream flows are referred to in *SIMD* as controlled flood control pools. Pools with releases governed by an ungated spillway or specified rules based only on storage are called uncontrolled flood control pools in *SIMD*.

The division of the flood control pool between controlled and uncontrolled storage pools is defined by input parameter FCGATE in *FR* record field 9. Both portions of the flood control pool are optional. Releases from the lower controlled portion of the flood control pool are constrained by stream flow limits entered on *FF* records. Releases from the upper uncontrolled pool are defined completely by the *FV/FQ* record storage-outflow table.

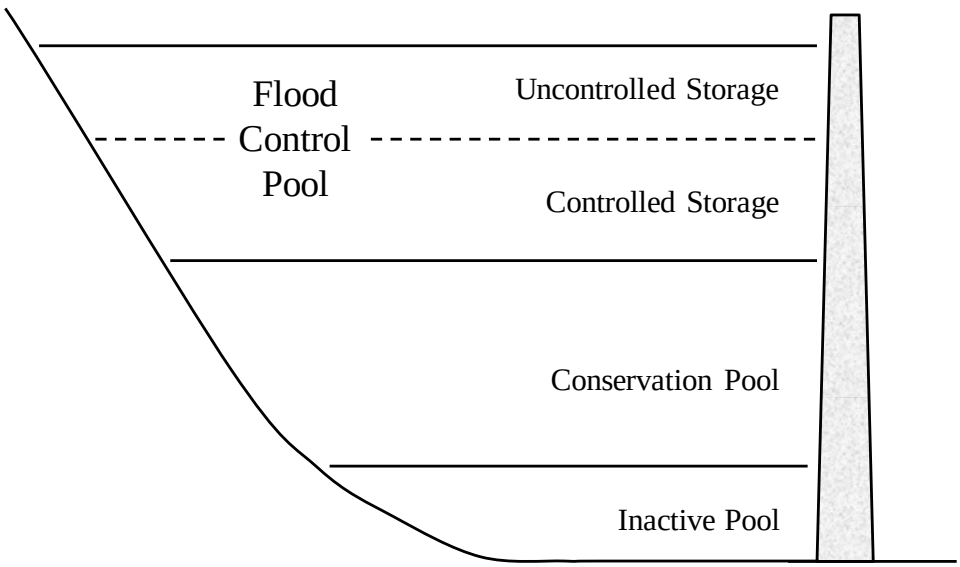

Figure 4.9 Reservoir Pools Defined by *SIMD WS* and *FR* Records

Storage Capacities and Reservoir Outlet Gate Operations

Reservoir operations for either flood control or conservation storage purposes in *SIMD* consist of storing inflows and making releases. *WR* record rights fill storage to the top of the conservation pool only. *FR* record rights can fill storage to the top of the flood control pool. However, if the conservation pool is not full when a *FR* record stores inflows, the empty conservation space is filled as the storage level rises into the flood control pool. The optional *FR* record parameter *FCDEP* controls whether downstream control points are considered in computing the amount of stream flow available for filling flood control pools. With the default *FCDEP* option, the control point flow availability computation is applied in the conventional manner and all relevant downstream control points are considered. The alternative *FCDEP* option is to store all regulated flow at the control point of the dam with the exception of releases from conservation storage to downstream water rights. Releases from the controlled flood control pool are governed by operating rules defined by parameters entered on the *FR* and *FF* records.

Outlet Structure Capacities

FV/*FQ* record tables of reservoir storage volume versus outflow rates model the flow capacity of the outlet structures for fully-opened gates or a specified fixed gate opening. Outflow over spillway crests and through outlet conduits increase with increasing head as the reservoir water surface rises. For a *FR* record reservoir with both *FF* and *FV*/*FQ* records, releases each day are constrained to the lesser of: (1) the release specified by one or more *FF* records, (2) the release set by the *FV*/*FQ* records, or (3) the maximum release FCMAX entered in *FR* record field 7. FCMAX and *FF* records are used in the Trinity WAM, but *FV*/*FQ* records are not used.

For reservoirs with designated flood control pools, uncontrolled outflows from surcharge storage above the top of flood control pool can be modeled with *FV* and *FQ* records. The same *FV* and *FQ* records can be used to model outlet structure outflow discharge capacities for storage levels above the top of conservation pool and below the top of flood control pool.

In the daily Trinity WAM, the modeling features activated by *FR* and *FF* records are applied only to flood control operations of the eight USACE reservoirs, which contain flood control pools. Surcharge storage above the controlled flood control pool is not modeled. The *SIMD* simulation sets outflow equal to inflow whenever storage exceeds the top of the flood control pool.

FR, *FV*, and *FQ* records (without *FF* records) can also be used to model surcharge storage above the top of conservation (water supply or hydropower) pool for reservoirs that contain no flood control storage capacity. Surcharge storage occurs when the conservation storage is full to capacity and stream inflows exceed the discharge capacity of the outlet structures as modeled by *FV/FQ* records. Surcharge storage may be negligible in a reservoir with a large gated overflow spillway with a crest elevation below the top of conservation pool. Development of a *FV/FQ* record storage-outflow tables requires information regarding the hydraulics of the overflow spillway and outlet conduit structures. Surcharge storage is not modeled in the daily Trinity WAM. *SIMD* sets outflow equal to inflow when storage contents exceed the conservation storage capacity.

Forecasting of Future Flows

The *SIMD* forecast simulation computes downstream future water availability for use with curtailing current day water availability for *WR* record rights. The forecast simulation also records future regulated flow in the absence of future depletions and releases from controlled flood control storage at the location of the *FF* record rights. Forecasted regulated flow at the location of the *FF* record rights is used in conjunction with the *FR* record operating rules to begin impounding stream flow in controlled flood control storage. Forecasting can also reduce the amount of water released from controlled flood control storage. Due to approximations related to forecasting and routing, water may be stored in greater quantities and longer than absolutely necessary. However, future days extending past the forecast period are not considered in reservoir operating decisions. Routed reservoir releases could contribute to flooding at downstream control points in future days after the end of the forecast period. Approximations related to imperfect forecasting and routing are an issue in modeling of reservoir operations as well as in actual real-world reservoir operations.

Trinity WAM Simulation of Reservoir Flood Control Operations

Flood control operations in the eight USACE multiple-purpose reservoirs both in actual reality and in the *SIMD* simulation model are based on maintaining empty flood control pools except during and immediately following flood events. The flood control pools are emptied as expeditiously as feasible without contributing to regulated flows exceeding specified maximum allowable flows at downstream gaging stations. Actual metrics employed in the operating rules are tabulated in Tables 4.1 and 4.2. Though not identically the same, the metrics adopted in the Trinity WAM *SIMD* input DAT file tabulated in Tables 4.4 and 4.5 represent the real-world metrics in Tables 4.1 and 4.2. Reservoir operations are simplified somewhat in the model.

Flood Control Operating Rules and Criteria

The total storage capacities in the full authorization and current use versions of the daily WAM below the top of conservation pool and top of flood control pool are tabulated in Tables 2.2 and 4.3. Conservation storage capacities are from the full authorization and current use versions of the monthly TCEQ WAM. The same USACE flood control pool storage capacities from Table

4.1 are adopted for both versions of the daily model. The full authorization conservation storage capacities from the Trinity WAM in Tables 2.2 and 4.3 are the same as from the USACE information in Table 4.1, except for Lewisville and Grapevine Reservoirs.

Table 4.3
Flood Control Reservoirs in the Trinity WAM

Reservoir	Full Authorization Storage Capacity at Top of Conservation	Full Authorization Storage Capacity at Top of Flood Control	Current Use Scenario Storage Capacity at Top of Conservation	Current Use Scenario Storage Capacity at Top of Flood Control	Outlet Capacity
	(acre-feet)	(acre-feet)	(acre-feet)	(acre-feet)	(cfs)
Benbrook	88,250	164,800	88,250	164,800	3,310
Joe Pool	176,900	304,000	172,678	299,778	3,880
Ray Roberts	799,600	1,064,600	796,474	1,061,474	6,900
Lewisville	618,400	959,170	618,400	959,170	11,000
Grapevine	162,500	406,900	162,500	406,900	7,200
Lavon	456,500	748,100	456,500	748,100	–
Navarro Mills	63,300	212,200	41,335	190,235	–
Bardwell	54,900	140,000	44,199	129,299	3,120

Flood control operations in the *SIMD* simulation are based on the metrics in Tables 4.4 and 4.5. Flood control operations are activated whenever the storage level in one or more of the reservoirs is in the flood control pool, defined as above the top of conservation pool storage volume and below the top of flood control storage volume. With the flood control pool full to capacity, outflows are set equal to inflows.

Table 4.4
Flood Control Reservoir *FR* Record Input Parameters

Reservoir	Reservoir Identifier	Control Point	Full Authorization FCBOTTOM	Full Authorization FCTOP	Current Use Scenario FCBOTTOM	Current Use Scenario FCTOP	Limit FCMAX
			(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(cfs)
Benbrook	BENBR4	B5157P	48,790	125,340	48,790	125,340	3,310
Joe Pool	JOPOOL	B3404A	176,900	304,000	172,678	299,778	3,880
Ray Roberts	ROBDAL	B2335A	591,704	856,704	589,237	854,237	6,000
Lewisville	LEWDA1	B2456A	214,000	554,770	214,000	554,770	7,000
Grapevine	GPVDAL	B2362A	85,000	329,400	85,000	329,400	7,000
Lavon	LAVON2	B2410A	280,000	571,600	280,000	571,600	8,000
Navarro Mills	NAVARO	B4992A	63,300	212,200	41,335	190,235	2,000
Bardwell	BARDWL	B5021A	54,900	140,000	44,199	129,299	2,000

The cumulative storage capacity at the top of conservation pool and top of flood control pool in Table 4.4 are entered as input parameters FCBOTTOM and FCTOP in *FR* record fields 10 and 8 [2]. The maximum limit on daily release rates from the flood control pool FCMAX in the last column of Table 4.4 is entered in *FR* record field 7.

Table 4.5
Maximum Allowable Flood Flow Limits at USGS Stream Gaging Stations

Control Point	Stream	Nearest City	Drainage Area	Flood Flow Limit
			(sq miles)	(cfs)
8WTGP	West Fork of Trinity River	Grand Prairie	3,065	6,000
8MCGP	Mountain Creek	Grand Prairie	298	4,000
8DNGR	Denton Creek	Grapevine	705	2,000
839	Elm Fork of Trinity River	Lake Lewisville	1,086	6,000
B2457C	Elm Fork of Trinity River	Carrolton	2,460	7,000
8TRDA	Trinity River	Dallas	6,106	13,000
8ETCR	East Fork of Trinity River	Crandall	1,256	8,000
8TRRS	Trinity River	Rosser	8,146	15,000
8RIDA	Richland Creek	Dawson	333	2,000
8WABA	Waxahachie Creek	Bardwell	178	2,000
B5023A	Chambers Creek	Rice	807	5,000
8TROA	Trinity River	Oakwood	12,833	24,000

The USACE Ray Roberts, Lewisville, Lavon, Grapevine, and Benbrook Reservoirs are modeled as multiple-owner reservoirs with conservation pools divided into component reservoirs for each of the different nonfederal water supply sponsors as discussed in Chapter 2. These five actual reservoirs are modeled as 20 component reservoirs in the monthly WAM as shown in Table 2.3. Flood control pools are added in the conversion to a daily WAM. Each of the five reservoirs is modeled in the daily WAM by adding a flood control pool on top of a single component conservation pool. The reservoir identifier in the second column of Table 4.4 and the FCBOTTOM conservation storage capacities in the fourth and sixth columns of Table 4.4 are for selected component reservoirs from Table 2.3.

The maximum outlet discharge capacity in cubic feet per second (cfs) in the last column of Table 4.3 is the capacity of the outlet works with the water surface at the top of flood control pool for the six reservoirs with uncontrolled (ungated) spillways. Lavon and Navarro Mills have gated spillways with very large discharge capacities that are too great to limit releases in the model. The maximum release rates FCMAX in the last column of Table 4.4 are the lesser of the outlet capacities in Table 4.3 and the maximum allowable flow rates in Table 4.5 at the nearest gage below the dams.

Releases from the flood control pools that are constrained by outlet structure discharge capacities with outflows increasing with increasing storage levels can be modeled with *FV* and *FQ* records. However, this option is not employed in the Trinity WAM.

Maximum allowable flow limits at downstream gages are tabulated in Tables 4.2 and 4.5. Reservoir operations in the *SIMD* simulation are based on making no releases from flood control pools that contribute to flows exceeding the flow limits shown in the last columns of Tables 4.4 and 4.5, which are generated from the actual USACE operating criteria outlined in Tables 4.1 and 4.2. The flow limits from Table 4.5 are input on the flood flow *FF* records in Table 4.7.

Flow limits at several gages in Table 4.2 vary with upstream reservoir storage contents. More stringent flood flow limits at downstream gaging stations are applied for smaller encroachments into the reservoir flood control pools, with the maximum allowable flow limits increasing with higher flood pool levels. Drought indices with *DI*, *IS*, and *IP* records can be used to model *FF* record flood flow limits that vary with upstream reservoir storage. This option was not employed with the Trinity WAM.

Daily simulation computations combining routing, forecasting, and reservoir flood control operations are complex. Selected simplification of the flood control operations in the daily WAM was judged to be worthwhile. The WAM dataset can be modified to model flood control operations in greater detail if warranted by future modeling applications.

Multiple Reservoir System Operations

Flexible options for defining multiple-reservoir operating rules are provided in *SIMD* and explained in the *Daily Manual*. However, actual flood control operations necessarily depend somewhat on operator judgments that cannot be precisely modeled. In both real-world operations and the simulation model, the balance of storage contents between reservoirs can vary significantly depending on choices regarding which reservoirs release at different times. The allocation of storage contents between the flood control pools of multiple-reservoir systems in both actual reality and *SIMD* simulation results can vary significantly with variations in specified operating rules, even though the alternative variations in operating rules may represent equally valid real-world operating practices and operator judgments or modeling approximations thereof.

FR/FF record flood control operating decisions are based on the following criterion. Releases from a flood control pool are not allowed in any day of the simulation in which the allowable flow rate at the dam or one or more of the downstream gaging station control points equals or exceeds the allowable flow rate in that day or during the forecast period. Releases are made each day to empty or draw-down the flood control pool to the extent possible subject to the constraint of making no release that contributes to flows exceeding of the maximum flow limit at any control point during the current day or forecast period.

Storage and release priorities are entered on the *FR* record as two separate parameters. Priorities control the sequential order in which rights (sets of water control facilities and operating practices) are considered in the simulation computations in each day. The flood release priority for a particular reservoir is always junior to its flood storage priority. Multiple reservoirs with the same storage priorities or same release priorities are operated as a multiple-reservoir system based on balancing flood pool storage expressed as a percentage of capacity. If the percentage storage contents of the reservoirs are the same, the order of *FR* records in the DAT file controls.

Additions to the *SIMD* Input Dataset to Model Flood Control Operations

Flood control operations of the eight U.S. Army Corps of Engineers (USACE) Fort Worth District (FWD) reservoirs are incorporated into the daily *SIMD* input dataset developed in the preceding Chapter 3 as described in the present Chapter 4. The following information is added to the *SIMD* input files. With the exception of LAGF and ATTF on *RT* records in the DIF file, the additional input data are inserted in the DAT file.

- Two sets of lag (LAG and LAGF) and attenuation (ATT and ATTF) routing parameters are input on routing *RT* records in the DIF file as discussed in the preceding Chapter 3. The second set (LAGF and ATTF) are for routing releases from *FR* record flood control pools and reverse routing in determination of remaining flood flow channel capacity.
- *SV/SA* record reservoir storage volume versus area tables are extended to encompass the flood control storage pools above the top of conservation pools.
- *FR* and *FF* records are added to model operation of the flood control pools of the eight USACE reservoirs based on flows at downstream gaging station and outlet structure discharge capacities. *WS* records are used with *FR* records to provide reservoir identifiers. Any number of reservoirs can be operated based on flows at any number of downstream gages.
- Though not used for the Trinity WAM, storage or drought index *DI/IS/IP* records can be employed with a *FF* record to model the variation of maximum allowable stream flow limits with reservoir storage capacity.
- *FV* and *FQ* records can be employed to model outlet structure flow capacity and flow capacity of the stream reach below a dam that is relevant to single individual reservoirs rather than systems of two or more reservoirs. FCMAX is a constant release limit entered on a *FR* record that can be used to model either outlet structure discharge capacity or the maximum flood flow limit of the river reach immediately downstream of a dam. FCMAX is used for the Trinity WAM. *FV* and *FQ* records are not used in the Trinity WAM.

With the exception of the flood routing parameters on the *RT* records in the DIF file, all of the additional *SIMD* input data compiled specifically to model flood control operations are contained in the DAT file. Routing parameters are described in Chapter 3, tabulated in Table 3.3, and stored on *RT* records in the DIF file. The routing parameters LAGF and ATTF are employed in the *SIMD* simulation to route releases from the flood control pools of *FR* record reservoirs and perform reverse routing in determining available channel capacity associated with *FF* record flow limits. The parameters LAG and ATT are applied for all other routed flow changes.

The *SV* and *SA* record tables of storage volume versus surface area were extended to the top of flood control pool for the eight reservoirs using data available from the USACE website. The parameter TL in *JD* record field 11 is increased to 13 to accommodate the *SV/SA* record extension. A water supply drought index defined by drought index *DI*, reservoir storage *IS*, and index percentage adjustment *IP* records is also extended as necessary to cover a flood control pool.

Flood Reservoir *FR* and Flood Flow *FF* Records in the DAT File

Operating rules are based on specified maximum allowable flow rates at the dams and downstream gaging stations. Reservoir flood control operation specifications are adapted to *SIMD* input *FR* and *FF* records, which are explained in Chapter 5 of the *Daily Manual* [5] and Chapter 4 of the *Users Manual* [2]. Forecasting of remaining flow capacity is controlled by *JU* record parameters FCST and APRD. A blank *FF* record field 4 defaults to the remaining flood control channel capacity forecasting period APRD set on the *JU* record. The *FR* and *WS* records in the daily full authorization WAM DAT file are replicated as Table 4.6. Storage capacities differ between the authorized and current use scenarios as shown in Table 4.4. The *FF* records replicated as Table 4.7 are the same in both the full authorization and current use daily Trinity WAMs.

Table 4.6
FR and *WS* Records for Full Authorization Daily WAM

```
**      1         2         3         4         5         6         7         8         9        10
**345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678
**     |       |       |       |       |       |       |       |       |       |               |
FRB5157P9100000092000000       2   3310. 125340.          48790.                BENBR4-FRSTOR   BENBRK-FRREL
WSBENBR4
FRB3404A9100000092000000       2   3380. 304000.         176900.                JOPOOL-FRSTOR   JOPOOL-FRREL
WSJOPOOL
FRB2335A9100000092000000       2   6000. 856704.         591704.                ROBDAL-FRSTOR   ROBDEN-FRREL
WSROBDAL
FRB2456A9100000092000000       2   7000. 554770.         214000.                LEWDA1-FRSTOR   LEWDE1-FRREL
WSLEWDA1
FRB2362A9100000092000000       2   7000. 329400.          85000.                GPVDA1-FRSTOR   GPVGP1-FRREL
WSGPVDAL
FRB2410A9100000092000000       2   8000. 571600.         280000.                LAVON2-FRSTOR   LAVON0-FRREL
WSLAVON2
FRB4992A9100000092000000       2   2000. 212200.          63300.                NAVARO-FRSTOR   NAVARO-FRREL
WSNAVARO
FRB5021A9100000092000000       2   2000. 140000.          54900.                BARDWL-FRSTOR   BARDWL-FRREL
WSBARDWL
```

Table 4.7
Flood Flow Limit *FF* Records

```
**        1         2         3         4
**345678901234567890123456789012345678901234
**     |       |       |       |       |
FF 8WTGP   6000.                FFLIM- 8WTGP
FF 8MCGP   4000.                FFLIM- 8MCGP
FF 8DNGR   2000.                FFLIM- 8DNGR
FF   839   6000.                FFLIM-   839
FFB2457C   7000.                FFLIM-B2457C
FF 8TRDA  13000.                FFLIM- 8TRDA
FF 8ETCR   8000.                FFLIM- 8ETCR
FF 8TRRS  15000.                FFLIM- 8TRRS
FF 8RIDA   2000.                FFLIM- 8RIDA
FF 8WABA   2000.                FFLIM- 8WABA
FFB5023A   4000.                FFLIM-B5023A
FF 8TROA  24000.                FFLIM- 8TROA
```

SIMD provides considerable flexibility for modeling flood control operations. The actual USACE criteria for flood control operations outlined in Tables 4.1 and 4.2 provide a general framework that allows a significant degree of flexibility for operator judgement during flood events. Various alternative strategies for employing *FR*, *FF*, and other auxiliary records for modeling the flood control operations were explored in the *SIMD* simulation study. The strategy finally adopted is outlined in this chapter. The simulations discussed in Chapters 9 and 10 employ the input records described in the present Chapter 4.

Flood flow *FF* records are added immediately after the other water right records in the DAT file. The *FF* records set daily targets equal to the flow rates shown in Table 4.7 with the exception that the instantaneous flow rates in cfs are converted into volumes of acre-feet per day.

Flood control reservoir *FR* records are replicated in Table 4.6. The priority numbers for flood control storage and release are junior to essentially all other water rights in the Trinity WAM. One of the several *WR* record water rights at Benbrook Lake at control point B5157P has a priority of 99999999, zero diversion, and storage capacity of 13,068 acre-feet. All eight *FR* records are assigned the same set of priorities in *FR* record fields 3 and 4, approximately balancing the flood pool storage contents expressed as a percentage of capacity.

FCDEP option 2 is selected in *FR* record field 6 (column 32) for all flood control reservoirs. The default *FCDEP* means that downstream control points are not considered in the determination of stream flow available for storage in flood control pools.

Reservoir storage volume (*SV* record) versus surface area (*SA* record) tables for the eight flood control reservoirs for the full authorization dataset are reproduced in Table 4.8. The *SV*/*SA* tables were modified by an additional entry consisting of the total reservoir volume and surface area at the top of the flood control pool. *JD* record field 11 was changed from the default value of zero to 13 to allow the expanded table entries to be read. The *SV* and *SA* records quantities in the current use scenario dataset, not replicated here, reflect adjustments for sedimentation.

Table 4.8
Storage Volume – Surface Area *SV*/*SA* Records for Flood Control Reservoirs
In the Full Authorization DAT File

SVROBDEN	0	5000	20000	65000	110000	210000	340000	380000	480000	630000	730000	799600	1064601
SAROBDEN	0	800	2500	4900	7400	11000	14500	16500	20000	24000	28000	29350	36900
SVLEWDE1	0	510	3824	39399	86203	138752	206931	291014	358343	441620	537846	648418	981764
SALEWDE1	0	100	1400	4630	7750	9740	12850	15920	18170	22630	25500	29700	39168
SVGPVGP1	0	104	515	1421	3441	7990	15986	28203	45537	77128	129291	181259	425501
SAGPVGP1	0	30	86	216	537	979	1686	2420	3358	4518	5901	7190	12710
SVLAVON0	0	1520	5660	12700	41100	72800	115900	171900	240400	321500	415200	456500	748201
SALAVON0	0	910	1810	2870	5190	7470	9970	12500	15000	17500	20000	21400	29450
SVJOPOOL	0	2500	5160	11180	24620	37620	54460	75260	100100	129000	162300	176900	304001
SAJOPOOL	0	430	650	1170	2230	2990	3760	4560	5360	6220	7110	7470	10940
SVNAVARO	0	2370	6960	12900	17100	22100	27900	34600	42400	51300	60800	63300	212201
SANAVARO	0	530	1070	1950	2310	2690	3100	3610	4200	4570	4600	5070	11700
SVBARDWL	0	1077	3074	7270	23467	35867	54900	140001					
SABARDWL	0	215	610	1082	2201	2800	3570	6040					
SVBENBRK	0	145	696	1400	6200	9911	15750	32400	44169	59800	73897	88251	164801
SABENBRK	0	28	102	270	720	1050	1360	2120	2520	2960	3400	3770	5820

CHAPTER 5
SENATE BILL 3 ENVIRONMENTAL FLOW STANDARDS

The following topics are covered in this chapter.

1. The environmental flow standards (EFS) at four gaging stations adopted by the TCEQ in 2011 pursuant to the 2007 Senate Bill 3 (SB3) are described.
2. Addition of the SB3 EFS to the daily Trinity WAM is explained.
3. A procedure is applied in which daily *IF* record instream flow targets for the SB3 EFS computed in a daily *SIMD* simulation are summed to monthly totals and incorporated in the monthly *SIM* input dataset for the Trinity WAM.

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

Senate Bill 3 enacted by the 80th Texas Legislature in 2007 established a new regulatory approach to provide for environmental needs for certain stream flow conditions through the use of standards developed through a stakeholder process culminating in TCEQ rulemaking. Water right permits in effect prior to the effective date of September 1, 2007 are not impacted. Only new water rights and water right amendments that are submitted after this date are subject to the new requirements established pursuant to the 2007 Senate Bill 3.

Information regarding Senate Bill 3 (SB3) environmental instream flow standards (EFS) can be found at the following TCEQ website.

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

This website provides access to the EFS that have been adopted to date, which are published as Subchapters B through F of Chapter 298 of Title 30 of the Texas Administrative Code. Rules for the different river systems are published as individual subsections of Chapter 298. Modifications to these existing standards and establishment of standards for additional regions and river reaches are expected in the future. The EFS relevant to the Trinity WAM are found in "*Subchapter B: Trinity and San Jacinto Rivers and Galveston Bay*" [11] which was adopted April 20, 2011 and became effective on May 15, 2011. The priority date for the EFS and set-asides to be incorporated in the WAM is December 1, 2009.

The expanded regulatory process created by the 2007 Senate Bill 3 results in determination of environmental flow needs and establishment of set-asides to satisfy the environmental flow needs. *Set-asides* refer to commitment of previously unappropriated water in the TCEQ Water Availability Modeling (WAM) System to meet specified environmental flow standards. Environmental flow standards (requirements, needs, or targets) for particular locations in particular stream systems are defined in terms of flow regimes. SB3 defines an environmental flow regime as: *A schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies.* SB3 EFS are based on a flow regime that includes subsistence flows, base flows, within-bank high pulse flows, and overbank high pulse flows.

SB3 EFS at Four USGS Gaging Stations in the Trinity River Basin

The geographic area covered by "*Subchapter B: Trinity and San Jacinto Rivers and Galveston Bay* " of Chapter 298 of Title 30 of the Texas Administrative Code [11] consists of the Trinity and San Jacinto Rivers, their associated tributaries, Galveston Bay, and associated estuaries. Environmental instream flow recommendations are developed for freshwater inflows to Galveston Bay, instream flows at four stream gaging stations on the Trinity River and its tributaries, and instream flows at two gaging stations in the San Jacinto River Basin (East Fork of Jan Jacinto River near Cleveland and West Fork of the Trinity River near Conroe). However, only the EFS for the four gaging stations on the Trinity River and its tributaries are incorporated in the daily Trinity WAM by the work documented by this report. Both the Trinity and San Jacinto Basins contribute freshwater inflows into Galveston Bay but are modeled as separate WAMs. Combining the two WAMs or allocating instream flow requirements between them is not addressed.

The four USGS gage sites in the Trinity Basin at which SBS EFS have been established are listed in Table 5.1. Their locations are shown on the maps of Figures 2.7 and 5.1. Watershed areas in square miles and the means of the 1940-1996 and 1940-2018 naturalized flows are included in Table 5.1. The period-of-record for observed flows at the USGS gaging stations are also shown. The USGS gage numbers and other information for all of the primary control points in the Trinity WAM including these four are also included in Tables 2.4 and 2.5 of Chapter 2.

Table 5.1
Trinity WAM Control Point Locations for SB3 Environmental Flow Standards

Control Point	River	Nearest City	Watershed Area	USGS Gage Period-of-Record	Mean Natural Flow 1940-1996	Mean Natural Flow 1940-2018
			(mile^2)		(cfs)	(cfs)
8WTGP	West Fork	Grand Prairie	3,065	April 1925 to present	792.9	856.1
8TRDA	Trinity	Dallas	6,106	October 1903 to present	2,193	2,424
8TROA	Trinity	Oakwood	12,833	October 1923 to present	5,682	6,280
8TRRO	Trinity	Romayor	17,186	May 1924 to present	8,340	9,114

Table 5.2
Subsistence and Base Flow Limits for SB3 Environmental Flow Standards

Control Point	Gauge Site Nearest City	Subsidence Flow Limits (cfs)				Base Flow Limits (cfs)			
		Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
8WTGP	Grand Prairie	19	25	23	21	45	45	35	35
8TRDA	Dallas	26	37	22	15	50	70	40	50
8TROA	Oakwood	120	160	75	100	340	450	250	260
8TRRO	Romayor	495	700	200	230	875	1,150	575	625

The SB3 EFS are based on the natural flow regime paradigm adopted by the Texas Instream Flow Program that considers magnitude, frequency, duration, timing, and rate of change in flow

within the framework of the following flow regime components: subsidence, base, within-bank high pulse, and overbank high pulse flows [5]. Subsistence and base flow limits and high pulse flow metrics are tabulated in Tables 5.2 and 5.3. The Trinity EFS and the WAMs in general do not distinguish between within-bank versus overbank high pulse flows.

Table 5.3
Metrics for High Flow Pulse Components of Environmental Flow Standards

CP	Site	Criteria	Winter	Spring	Summer/Fall
8WTGP	West Fork of Trinity River at Grand Prairie	Trigger (cfs)	300	1,200	300
		Volume (acre-feet)	3,500	8,000	1,800
		Duration (days)	4	8	3
8TRDA	Trinity River at Dallas	Trigger (cfs)	700	4,000	1,000
		Volume (acre-feet)	3,500	40,000	8,500
		Duration (days)	3	9	5
8TROA	Trinity River at Oakwood	Trigger (cfs)	3,000	7,000	2,500
		Volume (acre-feet)	18,000	130,000	23,000
		Duration (days)	5	11	5
8TRRO	Trinity River at Romayor	Trigger (cfs)	8,000	10,000	4,000
		Volume (acre-feet)	80,000	150,000	60,000
		Duration (days)	7	9	5

Seasons are defined as follows for the EFS for the Trinity River system: Winter (December, January, February), Spring (March, April, May), Summer (June, July, August), Fall (September, October, November). Unlike the EFS established for other river basins, hydrologic conditions are not specified for the Trinity EFS.

The applicable subsistence flow standard varies with seasons of the year as shown in Table 5.2. For a water right holder to which an EFS applies, the water right holder may not store or divert water unless the stream flow at the gage is above the subsistence flow limit shown in Table 5.2. If the flow at the gage is above the subsistence flow limit but below the base flow limit, the water right holder may divert or store water as long as the flow at the gage does not fall below the subsistence flow limit. If the flow is above the base flow limit, the water right holder may store or divert stream flow as long as the flow does not fall below the base flow standard.

The quantities used to set high flow pulse targets are tabulated in Table 5.3. A qualifying pulse event is initiated when the flow exceeds the prescribed peak trigger flow tabulated in Table 5.3. A pulse flow event is terminated when either the volume limit (in acre-feet in Table 5.3) or the duration limit in days is reached. Pulse flow events initiated in a particular season or year continue into the following season or year if and as necessary to meet the volume and/or duration termination criteria. Pulse flow events are tracked in the WRAP/WAM modeling system to set minimum instream flow targets for each day of the tracked flow event. The daily pulse flow target in acre-feet/day is computed as the lesser of the (1) daily regulated flow, (2) peak trigger flow rate shown in Table 5.3 in cfs converted to acre-feet/day, or (3) remaining volume that will satisfy the volume criterion. The daily minimum instream flow target is the greater of the subsistence and base flow target and high pulse target.

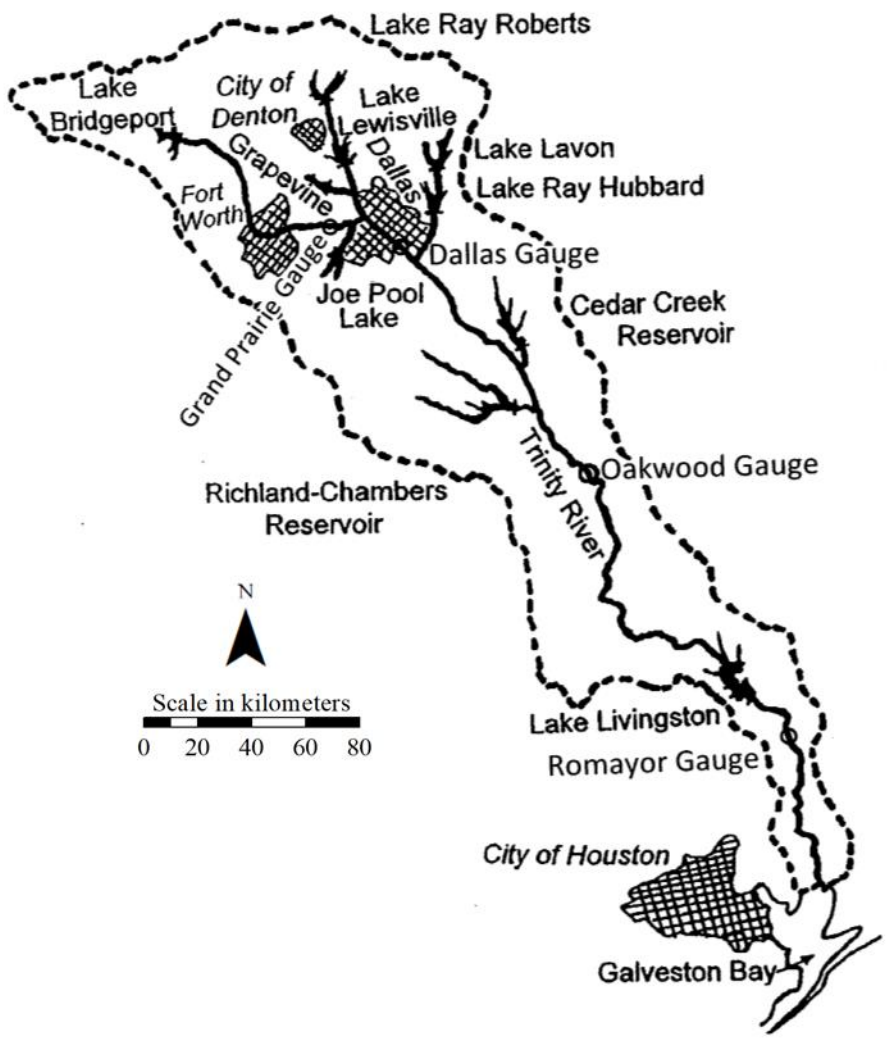

Figure 5.1 USGS Gage Locations for Four SB3 EFS

Modeling SB3 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 Chapter 4 of the *Reference Manual* [1] and illustrated by the Trinity EFS described on the preceding pages of this chapter. Hydrologic condition *HC* records are employed in the daily Brazos WAM but are not needed for the Trinity WAM since hydrologic condition is not used as a parameter in defining EFS for the Trinity River system. 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]. An example of modeling SB3 environmental flow standards is presented in Chapter 8 of the *Daily Manual* [5].

Daily and monthly instream flow targets for *IF* record rights representing SB3 EFS are presented in Chapters 9 and 10 for current use and authorized use versions of the Trinity WAM. The records replicated in Table 5.4 are inserted in both the current and authorized use DAT files

IF Record Water Rights Representing SB3 EFS

The alternative sets of *SIMD* DAT file input records reproduced as Tables 5.4 and 5.5 control the computation of daily instream flow targets at the four control points representing the SB3 EFS. These instream flow targets are managed in the same manner as all water right targets within the *SIMD* simulation computations and output files. Options controlled by *IF* record field 3 and *PF* record field 15 create tables in the MSS and SMM message files that provide additional supplemental information that facilitates tracking the *ES* and *PF* record computations. These message file options are not activated in the datasets of Tables 5.4 and 5.5.

Table 5.4
Instream Flow Rights that Model the SB3 EFS in the Daily Trinity WAM DAT File
(*ES* and *PF* Record Components as Separate *IF* Record Rights)

```
**       1         2         3         4         5         6         7         8         9        10
**3456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
**     !       !       !       !       !       !       !       !       !       !       !       !       !
IF 8WTGP     -9.        20091201   2            IF-WTGP-ES
ES SUBS      19.     19.     25.     25.     25.     23.     23.     23.     21.     21.     21.     19.
ES BASE      45.     45.     45.     45.     45.     35.     35.     35.     35.     35.     35.     45.
IF 8WTGP     -9.        20091201   2            IF-WTGP-PF
ES PFES
PF   1 0    300.   3500.   4   2      12   2           2
PF   1 0   1200.   8000.   8   2       3   5           2
PF   1 0    300    1800.   3   2       6   8           2
PF   1 0    300    1800.   3   2       9  11           2
IF 8TRDA    -9.        20091201   2            IF-TRDA-ES
ES SUBS      26.     26.     37.     37.     37.     22.     22.     22.     15.     15.     15.     26.
ES BASE      50.     50.     70.     70.     70.     40.     40.     40.     50.     50.     50.     50.
IF 8TRDA     -9.        20091201   2            IF-TRDA-PF
ES PFES
PF   1 0    700.   3500.   3   2      12   2           2
PF   1 0   4000.  40000.   9   2       3   5           2
PF   1 0   1000    8500.   5   2       6   8           2
PF   1 0   1000    8500.   5   2       9  11           2
IF 8TROA     -9.        20091201   2            IF-TROA-ES
ES SUBS     120.    120.    160.    160.    160.     75.     75.     75.    100.    100.    100.    120.
ES BASE     340.    340.    450.    450.    450.    250.    250.    250.    260.    260.    260.    340.
IF 8TROA     -9.        20091201   2            IF-TROA-PF
ES PFES
PF   1 0   3000.  18000.   5   2      12   2           2
PF   1 0   7000. 130000.  11   2       3   5           2
PF   1 0   2500   23000.   5   2       6   8           2
PF   1 0   2500   23000.   5   2       9  11           2
IF 8TRRO     -9.        20091201   2            IF-TRRO-ES
ES SUBS     495.    495.    700.    700.    700.    200.    200.    200.    230.    230.    230.    495.
ES BASE     875.    875.   1150.   1150.   1150.    575.    575.    575.    625.    625.    625.    875.
IF 8TRRO     -9.        20091201   2            IF-TRRO-PF
ES PFES
PF   1 0   8000.  80000.   7   2      12   2           2
PF   1 0  10000. 150000.   9   2       3   5           2
PF   1 0   4000   60000.   5   2       6   8           2
PF   1 0   4000   60000.   5   2       9  11           2
```

The set of *IF*, *ES*, and *PF* records replicated in Table 5.4 are inserted in the DAT file of the current use and full authorization DAT files employed in the daily *SIMD* simulations presented in Chapters 9 and 10. In the dataset of Table 5.4 and simulation studies 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 5.4: IF-WTGP-ES, IF-WTGP-PF, IF-TRDA-ES, IF-TRDA-PF, IF-TROA-ES, IF-TROA-PF, IF-TRRO-ES, and IF-TRRO-PF. Alternatively, the eight *IF* record water rights can be combined into four water rights (IF-WTGP, IF-TRDA, IF-TROA, IF-TRRO) as shown in Table 5.5, with the only difference in simulation results being that combined rather that separate water right targets and target shortages are recorded in the output file [2, 5].

Table 5.5
Instream Flow Rights that Model the SB3 EFS in the Daily Trinity 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
**345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
IF 8WTGP     -9.        20091201   2            IF-WTGP
ES SUBS      19.     19.     25.     25.     25.     23.     23.     23.     21.     21.     21.     19.
ES BASE      45.     45.     45.     45.     45.     35.     35.     35.     35.     35.     35.     45.
PF   2 0    300.   3500.   4   2      12   2           2
PF   2 0   1200.   8000.   8   2       3   5           2
PF   2 0    300    1800.   3   2       6   8           2
PF   2 0    300    1800.   3   2       9  11           2
IF 8TRDA     -9.        20091201   2            IF-TRDA
ES SUBS      26.     26.     37.     37.     37.     22.     22.     22.     15.     15.     15.     26.
ES BASE      50.     50.     70.     70.     70.     40.     40.     40.     50.     50.     50.     50.
PF   2 0    700.   3500.   3   2      12   2           2
PF   2 0   4000.  40000.   9   2       3   5           2
PF   2 0   1000    8500.   5   2       6   8           2
PF   2 0   1000    8500.   5   2       9  11           2
IF 8TROA     -9.        20091201   2            IF-TROA
ES SUBS     120.    120.    160.    160.    160.     75.     75.     75.    100.    100.    100.    120.
ES BASE     340.    340.    450.    450.    450.    250.    250.    250.    260.    260.    260.    340.
PF   2 0   3000.  18000.   5   2      12   2           2
PF   2 0   7000. 130000.  11   2       3   5           2
PF   2 0   2500   23000.   5   2       6   8           2
PF   2 0   2500   23000.   5   2       9  11           2
IF 8TRRO     -9.        20091201   2            IF-TRRO
ES SUBS     495.    495.    700.    700.    700.    200.    200.    200.    230.    230.    230.    495.
ES BASE     875.    875.   1150.   1150.   1150.    575.    575.    575.    625.    625.    625.    875.
PF   2 0   8000.  80000.   7   2      12   2           2
PF   2 0  10000. 150000.   9   2       3   5           2
PF   2 0   4000   60000.   5   2       6   8           2
PF   2 0   4000   60000.   5   2       9  11           2
```

Other *IF* Record Rights in Addition to the SB3 EFS

The SB3 EFS are modeled as *IF* record water rights. A total of 35 other more senior *IF* record rights are located at the 25 control points listed in Table 2.10 for the full authorization DAT file. A total of 53 other more senior *IF* record rights are located at the 34 control points listed in Table 2.11 for the current use input dataset. The SB3 EFS are the only *IF* record rights at control points 8WTGP and 8TRRO. However, the following additional *IF* record rights are found at control points 8TRDA and 8TROA.

The following *IF* record water right at control point 8TRDA in the full authorization DAT file has an annual instream flow targets of 154,892 acre-feet/year (213.9 cfs or 424 acre-feet/day) uniformly distributed over the 12 months of the year and uniformly within each month.

```
IF 8TRDA  154892   IFCON19920402       1                  IF5414C
```

The current use DAT file includes the following *IF* record water rights at control point 8TRDA with instream flow targets of 175,882 and 154,892 acre-feet/year (242.8 cfs and 213.9 cfs) that are uniformly distributed over the 12 months of the year and within each month.

```
IF 8TRDA  175882   IFCON20011205       1                 DALRUIF
IF 8TRDA  154892   IFCON19920402       1                 IF5414C
```

Both the full authorization and current use datasets contain the following *IF* record rights at control point 8TROA that have an instream flow target of 951,278.4 acre-feet/year (1,313 cfs) distributed non-uniformly over the 12 months of the year and uniformly within each month.

```
IF 8TROA951278.4  2388IF19540201       1                  2388F1
IF 8TROA       0  2388IF19540201       1                  2388F2
IF 8TROA951278.4  2388IF20070301       1                  2388F3

UC2388IF     756    1128    2034    1884    3450    2094
UC           735     735     735     735     735     735
```

These instream flow rights are senior to the SB3 EFS rights. Their instream flow targets are much larger than the base flow components of the SB3 EFS but much smaller than the pulse flow components (Tables 5.2 and 5.3). The largest target in each day controls.

Multiple Instream Flow Targets or Target Components at the Same Control Point

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 instream flow targets and shortage quantities are listed in the first column of Table 5.6 below. The second column of Table 5.6 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 5.6. The DSS pathname part C labels in the third column are adopted in the following discussion for referring to the quantities listed in Table 5.6.

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.

With two or more *IF* record rights at the same control point, the target for a junior right is combined with the target from the preceding senior right as specified by IFM(IF,2) in *IF* record field 7. The IF record IFM(IF,2) target combining options are listed in Table 5.7.

Table 5.6
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 5.7
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

SB3 EFS standards are modeled as a set of *IF*, *HC*, *ES*, and *PF* records as explained in the *Daily and Users Manuals* [2, 4]. 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 5.5). With pulse flow *PF* and subsistence/base flow *ES* records for the same *IF* record right, the instream flow targets are combined as specified in *PF* record field 14. The options for combining consecutive *PF* record targets for a single *IF* record right are also listed in Table 5.7. 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 5.4).

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 5.5. 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 5.4 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 5.4 and 5.5 are applied in the simulation studies of Chapters 9 and 10. Monthly IFT-WR output for water rights IF-WTGP, IF-TRDA, IF-TROA, IF-TRRO (Table 5.5) from the daily WAM are adopted for the monthly WAM. Pulse flow targets are plotted from TIF-WR output (Table 5.4). *IF* record IFM(IF,2) option 2 is activated to select the largest target at 8TRDA and 8TROA considering the other *IF* records as well as the SB3 EFS.

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 Trinity 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 5.8 and 5.10. The *TS* records in the DSS file are referenced by *TS* records in the DAT file which are replicated in Tables 5.9 and 5.11. The instream flow rights in Tables 5.9 and 5.11 model the SB3 EFS at control points 8WTGP, 8TRDA, 8TROA, and 8TRRO.

Table 5.8
Pathnames for *TS* Records for the SB3 EFS for the Current Use Scenario in the Shared Single Hydrology Input DSS File of the Trinity WAM

Part A	Part B	Part C	Part D	Part E
TRINITY	C8WTGP	TS	01Jan1940-31Dec2018	1MON
TRINITY	C8TRDA	TS	01Jan1940-31Dec2018	1MON
TRINITY	C8TROA	TS	01Jan1940-31Dec2018	1MON
TRINITY	C8TRRO	TS	01Jan1940-31Dec2018	1MON

Table 5.9
Instream Flow Rights that Model the SB3 EFS in the DAT File of the Monthly Current Use Scenario Version of the Trinity WAM

```
IF 8WTGP                20091201   2            IF-WTGP
TS      DSS  C8WTGP
IF 8TRDA                20091201   2            IF-TRDA
TS      DSS  C8TRDA
IF 8TROA                20091201   2            IF-TROA
TS      DSS  C8TROA
IF 8TRRO                20091201   2            IF-TRRO
TS      DSS  C8TRRO
```

Daily SB3 EFS are computed in the *SIMD* simulation based on regulated stream flows. Regulated flows differ significantly between the current use and authorized 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 current use (C) and authorized use (A) instream flow targets. Tables 5.8 and 5.9 are replicated as Tables 9.5 and 9.6 in Chapter 9. Tables 5.10 and 5.11 are replicated as Tables 10.10 and 10.11 in Chapter 10.

Table 5.10
Pathnames for *TS* Records for the SB3 EFS for the Full Authorization Scenario in the Shared Single Hydrology Input DSS File of the Trinity WAM

Part A	Part B	Part C	Part D	Part E
TRINITY	A8WTGP	TS	01Jan1940-31Dec2018	1MON
TRINITY	A8TRDA	TS	01Jan1940-31Dec2018	1MON
TRINITY	A8TROA	TS	01Jan1940-31Dec2018	1MON
TRINITY	A8TRRO	TS	01Jan1940-31Dec20180	1MON

Table 5.11
Instream Flow Rights that Model the SB3 EFS in the DAT Files of the Monthly Authorized Use Scenario Version of the Trinity WAM

```
IF 8WTGP                20091201   2            IF-WTGP
TS      DSS  A8WTGP
IF 8TRDA                20091201   2            IF-TRDA
TS      DSS  A8TRDA
IF 8TROA                20091201   2            IF-TROA
TS      DSS  A8TROA
IF 8TRRO                20091201   2            IF-TRRO
TS      DSS  A8TRRO
```

A daily *SIMD* simulation is performed with the set of *IF*, *ES*, and *PF* records replicated in Table 5.5 inserted in the DAT file to control computation of IFT and TIF (Table 5.6) daily instream flow targets for the SB3 EFS at the four 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 5.8 and 5.10. The *TS* records in the monthly *SIM* DAT file replicated in Table 5.9 and 5.11 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, respectively. The simulation results presented in Chapters 9 and 10 include daily and aggregated monthly instream flow targets for the SB3 EFS.

CHAPTER 6
DAILY STREAM FLOW PATTERN HYDROGRAPHS

The 1940-2018 sequences of daily flows at 49 control points stored as *DF* records in the Trinity WAM hydrology input DSS file were developed in two steps as follows.

1. Initial 1940-2018 pattern hydrographs of daily mean flow rates in cfs at the 49 control points were developed as described in this chapter and stored as *DF* records in a DSS file. Many of the 1940-2018 sequences reflect combinations of flows from different sources and/or sites.

2. Daily flow volumes in acre-feet/day at the 49 sites were computed with *SIMD* by combining monthly naturalized flow volumes with the initial daily flow pattern hydrographs in cfs from the first step described above. These final *DF* record daily flows represent 1940-2018 daily naturalized flow volumes, rather than just flow patterns, and have units of acre-feet/day.

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

In addition to the Trinity WAM files, Table 1.2 in Chapter 1 lists three other DSS files compiled for use in exploring river system hydrology in general as well as supporting development and future updates of the WAM input files. The organization of these auxiliary DSS files are summarized in Chapter 11. The DSS file with filename TrinityDailyFlows.DSS was created in conjunction with compiling, analyzing, and verifying daily simulation *SIMD* daily flow pattern hydrographs and contains five datasets of daily flow sequences described in the present Chapter 6.

Disaggregation of Monthly Naturalized Flows to Daily

Disaggregation of monthly naturalized flow volumes in acre-feet/month to daily volumes in acre-feet/day at the approximately 1,400 control points in the Trinity WAM is controlled by the input parameters (Table 6.1) on the *JO* and *JU* records found in the DAT file and *DC* record in the DIF file along with the 49 daily flow pattern hydrographs stored on *DF* records in the DSS file.

INEV option 6 in *JO* record field 2 specifies that the naturalized monthly flows on *IN* records at the primary control points are read from the DSS hydrology input file along with other time series input data. The blank *JU* record field 3 results in the default DFFILE option 1 of reading the *DF* record daily flow pattern hydrographs from the DSS file. The *DF* records in the DAT file lists the 49 control point identifiers for the *DF* records read from the DSS file.

DFMETH option 1 in *JU* record field 2 sets uniform as the default for distributing monthly naturalized flows to daily. This default is applied at all control points for which another flow distribution option is not specified. For the Trinity WAM, the default is applied only to special control points that have no flows. Disaggregation DFMETHOD(cp) option 4 is applied at all regular control points with flows as specified by the DIF file *DC* record shown in Table 6.1. Option 4 is applied to all control points located above the Trinity River outlet (control point 8TRGB).

Table 6.1
SIMD DAT and DIF File Input Parameters that Control Naturalized Flow Disaggregation

DAT File

```
JO     6
JU     1

DF         8WTJA   8BSBR   8WTBO   8CTAL   8CTFW   8WTFW   8WTGP   8MCGP   8ELSA   8IDPP
DF         8CLSA   8DNJU   8TRDA   8WRDA   8ETMK
DF         8SGPR   8ETCR   8TRRS   8TRTR   8CEKE   8KGKA   8CEMA   8RIRI   8CHCO   8TEST
DF         8TROA   8TRMI   8BEMA   8TRRI   8TRRO
DF        B3808A  B3809A  B3349A  B5157P  B3404A  B5136A  B2335A  B2456A    B304  B2362A
DF        B2457C  B2462A  B2410A  B4976A  B4992A  B5021A  B5035A  B4248A  B4248B
```

DIF File

```
DC 8TRGB   2   4
```

The *DC* record in the DIF file is assigned to control point 8TRGB, which is the Trinity River outlet to the Galveston Bay. Disaggregation DFMETHOD(cp) option 4 in *DC* record field 4 is 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 from *DF* record pattern hydrographs while maintaining the monthly volumes.

REPEAT option 2 in field 3 of the *DC* record repeats the DSS file *DF* record daily flow pattern hydrographs input for 49 control points for disaggregating flows at over 1,400 control points. 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.

DFMETHOD(cp) option 4 is applied at all regular control points in the Trinity WAM as explained above. The default DFMETH option 1 in *JU* record field 2 is applicable only to control points that are not upstream of the outlet at control point 8TRGB, which includes control points used only for *EV* records or imaginary accounting control points. These special purpose control points are not assigned actual naturalized stream flows.

Compilation of Daily Flows

SIMD disaggregates monthly naturalized flow volumes to daily volumes in proportion to the flows in daily pattern hydrographs while preserving the monthly volumes. The Trinity WAM includes daily flow pattern hydrographs stored in the *SIMD* input data for 49 control points and repeated within the *SIMD* simulation for over 1,300 other control points.

The daily flows include both observed flows from U.S. Geological Survey (USGS) gage records and unregulated flows from a U.S. Army Corps of Engineers (USACE) Fort Worth District (FWD) modeling system. Daily observed flows at USGS stream gaging stations were downloaded from the National Water Information System (NWIS) website maintained by the USGS.

USACE FWD Unregulated Flows

Unregulated daily flows for the Brazos and Trinity Basins covering periods of 1940-1997 and 1940-2009, respectively, were obtained from the USACE FWD office in 2013 early in the process of developing daily WRAP/WAM modeling capabilities.

The 24 reservoirs in Texas owned and operated by the USACE FWD include 8 reservoirs in the Trinity River Basin and 9 reservoirs in the Brazos River Basin. The USACE FWD has a daily modeling system designed to support operations of their multiple-purpose reservoirs, particularly flood control operations. A river/reservoir system simulation model called SUPER was applied for many years and later replaced with RiverWare [13]. The modeling system includes incremental daily unregulated flows that are accumulated to obtain total daily unregulated flows at each control point. Unregulated daily flows from the USACE modeling system are analogous to WAM monthly naturalized flows. USACE unregulated flows are similarly developed by adjusting gaged flows to remove the effects of major reservoirs and water users. Although computational details are different, both USACE daily unregulated and WAM monthly naturalized flows are based on adjustments to observed flows.

Sources of Daily Flows at the WAM Control Points

WAM primary control points are defined as sites with monthly naturalized flows stored in a *SIM* or *SIMD* simulation input file. Secondary control points are sites at which monthly flows are synthesized within the monthly *SIM* or daily *SIMD* simulation. The input files of the daily Trinity WAM include daily flow pattern hydrographs at 30 primary control points and 19 secondary control points which are used within the *SIMD* simulation to disaggregate monthly flows to daily at 40 primary and over 1,350 secondary control points.

The map of Figure 6.1 and schematic of Figure 6.2 show the locations of the WAM control points relevant to the discussion of daily flows. Daily flows are provided in the *SIMD* input data at most but not all of these control points. All of the control points in Figures 6.1 and 6.2 were considered in the process of assigning daily pattern hydrographs, but determinations were made to omit *DF* record flows at some of the control points from the final adopted *SIMD* input dataset.

The 40 primary control points in the Trinity WAM are listed in Tables 2.4, 2.5, and 6.2. The periods-of-record of the 38 primary control points with recorded daily flows from USGS gaging stations are listed in the third column of Table 6.2. The number of days during the period-of-record for which flows are missing from the recorded data is tabulated in the fourth column.

The 16 primary control points with 1940-2009 USACE unregulated daily flows are labeled with "1940-2009" in the last column of Table 6.2. The USACE daily unregulated flows cover the period from January 1940 through December 2009. USGS gaged flows are adopted to extend the USACE flows through 2010-2018.

Thirty of the 40 primary control points are assigned daily flows on *DF* records in the *SIMD* input dataset (Tables 6.4 and 6.5). The other ten primary control points are assigned daily flows from other control points within the *SIMD* simulation (Table 6.6). The sources of daily flow pattern hydrographs for the primary control points are shown in Table 6.3.

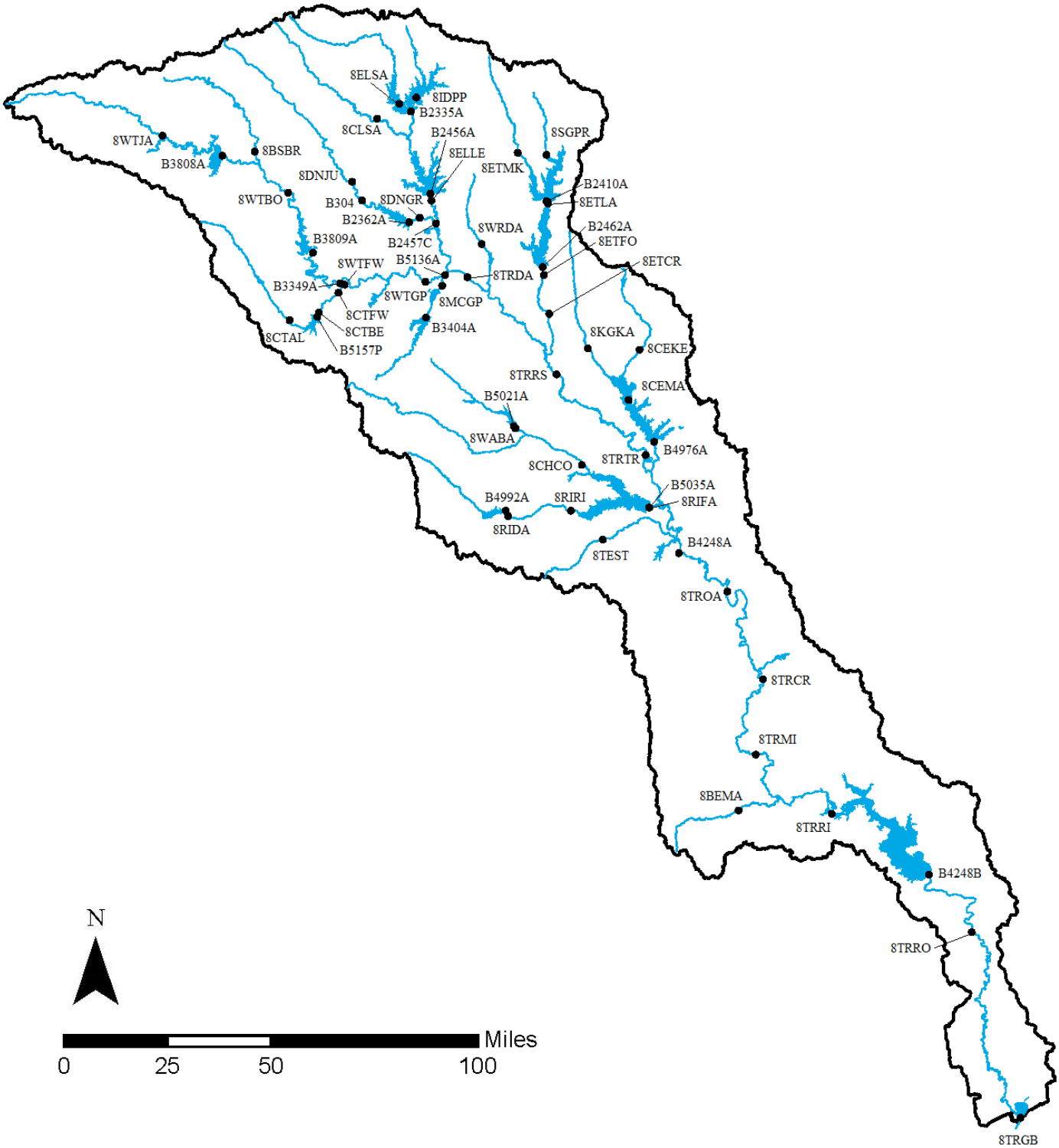

Figure 6.1 Map of Trinity WAM Control Points Relevant to Daily Flows

The five-character identifiers for primary control points begin with the numeral 8. The control point identifiers for the 19 secondary control points begin with the letter B.

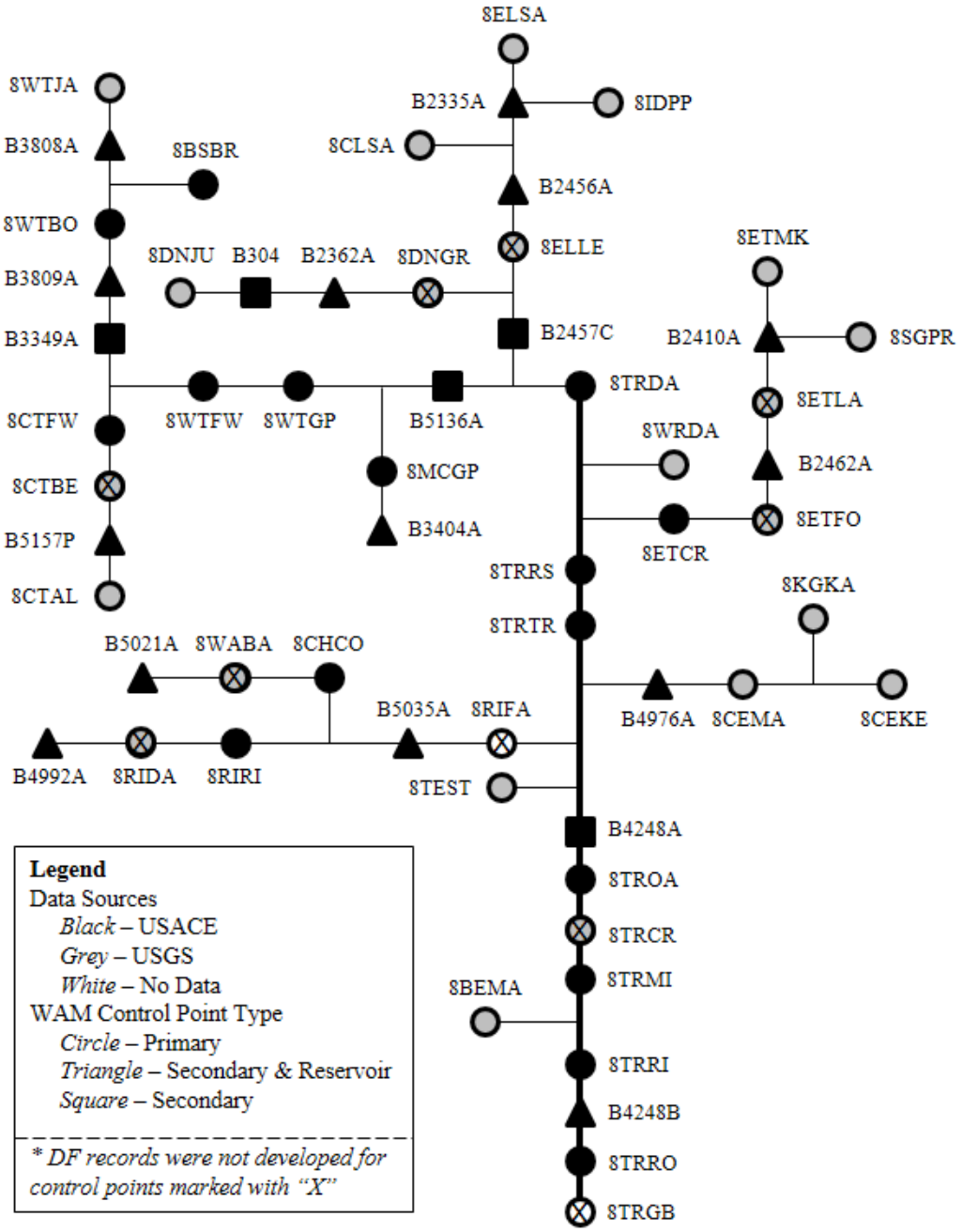

Figure 6.2 Schematic of Trinity WAM Control Points Relevant to Daily Flows

Daily Flows Included in *SIMD* Simulation Input File

Daily flows are provided in the *SIMD* input dataset for the 49 control points listed in Tables 6.4 and 6.5. The 16 primary and 19 secondary control points listed in Table 6.3 have January 1940 through December 2009 daily flows from the USACE modeling system. Extensions of the daily flows from January 2010 through December 2018 are based on USGS gaged flows. The 1940-2018 daily flows for the 14 primary control points listed in Table 6.4 are based on USGS gaged flows. Most of the USGS gaging stations have subperiods with no recorded data during 1940-

2018. Flows at a nearby gage with similar flow characteristics are substituted for missing data at a particular gage.

Table 6.2
Periods-of-Record of USGS Gaged Flows and USACE Unregulated Flows
at the 40 WAM Primary Control Points

WAM CP	Location	USGS Period-of Record	Missing Days	USACE Flows
8WTJA	West Fork Trinity River near Jacksboro	Mar 1956-present	0	–
8BSBR	Big Sandy Creek near Bridgeport	Oct 1936-present	3,288	1940-2009
8WTBO	West Fork Trinity River near Boyd	Jan 1947-present	0	1940-2009
8CTAL	Clear Fork Trinity River near Aledo	Aug 1947-Oct 1975	0	–
8CTBE	Clear Fork Trinity River near Benbrook	Jul 1947-present	0	–
8CTFW	Clear Fork Trinity River at Fort Worth	Mar 1924-present	0	1940-2009
8WTFW	West Fork Trinity River at Fort Worth	Oct 1920-present	0	1940-2009
8WTGP	West Fork Trinity River at Grand Prairie	Mar 1925-present	13	1940-2009
8MCGP	Mountain Creek at Grand Prairie	Oct 1960-present	0	1940-2009
8ELSA	Elm Fork Trinity River near Sanger	May 1949-Dec 1984	0	–
8IDPP	Isle Du Bois Creek near Pilot Point	May 1949-Dec 1984	0	–
8CLSA	Clear Creek near Sanger	Mar 1949-present	0	–
8ELLE	Elm Fork Trinity River near Lewisville	Mar 1949-present	0	–
8DNJU	Denton Creek near Justin	Oct 1949-present	0	
8DNGR	Denton Creek near Grapevine	Oct 1947-present	4,391	
8TRDA	Trinity River at Dallas	Oct 1903-present	0	1940-2009
8WRDA	White Rock Creek at Greenville Ave	Aug 1961-present	1,279	–
8ETMK	East Fork Trinity River near McKinney	Sep 1949-present	12,496	–
8SGPR	Sister Grove Creek near Princeton	Sep 1949-Jan 1975	0	–
8ETLA	East Fork Trinity River near Lavon	Oct 1953-Sep 1989	0	–
8ETFO	East Fork Trinity River near Forney	Jan 1973-present	0	–
8ETCR	East Fork Trinity River near Crandall	Jul 1949-present	0	1940-2009
8TRRS	Trinity River near Rosser	Aug 1924-present	4,807	1940-1996
8TRTR	Trinity River at Trinidad	Oct 1964-present	0	1940-2009
8CEKE	Cedar Creek near Kemp	Jan 1963-present	5,480	–
8KGKA	Kings Creek near Kaufman	Jan 1963-Sep 1987	0	–
8CEMA	Cedar Creek near Mabank	Oct 1938-Feb 1966	0	–
8RIDA	Richland Creek near Dawson	Oct 1960-present	0	–
8RIRI	Richland Creek near Richland	Apr 1939-Jun 1989	0	1940-2009
8WABA	Waxahachie Creek near Bardwell	Oct 1963-present	0	–
8CHCO	Chambers Creek near Corsicana	Apr 1939-Sep 1984	0	1940-2009
8RIFA	Richland Creek near Fairfield	Gage is missing from NWIS.		–
8TEST	Tehuacana Creek near Streetman	Apr 1968-present	1	–
8TROA	Trinity River near Oakwood	Oct 1923-present	0	1940-2009
8TRCR	Trinity River near Crockett	Jan 1964-present	0	–
8TRMI	Trinity River near Midway	Apr 1939-Nov 1970	0	1940-2009
8BEMA	Bedias Creek near Madisonville	Oct 1967-present	0	–
8TRRI	Trinity River at Riverside	Oct 1923-Sep 1968	2	1940-2009
8TRRO	Trinity River at Romayor	May 1924-present	0	1940-2009
8TRGB	Trinity River at Galveston Bay	There is no gage.	–	–

Table 6.3
Sources of Daily Flow Pattern Hydrographs for the 40 Primary Control Points

CP	Location	USGS	USACE Site Identification
8WTJA	West Fork Trinity River near Jacksboro	08042800	
8BSBR	Big Sandy Creek near Bridgeport	08044000	Big Sandy Dam Site
8WTBO	West Fork Trinity River near Boyd	08044500	Boyd Dam Site
8CTAL	Clear Fork Trinity River near Aledo	08046000	
*8CTBE	Clear Fork Trinity River near Benbrook	~~08047000~~	
8CTFW	Clear Fork Trinity River at Fort Worth	08047500	Fort Worth on Clear Fork
8WTFW	West Fork Trinity River at Fort Worth	08048000	Fort Worth
8WTGP	West Fork Trinity River at Grand Prairie	08049500	Grand Prairie above Mountain Creek
8MCGP	Mountain Creek at Grand Prairie	08050100	Grand Prairie on Mountain Creek
8ELSA	Elm Fork Trinity River near Sanger	08050500	
8IDPP	Isle Du Bois Creek near Pilot Point	08051000	
8CLSA	Clear Creek near Sanger	08051500	
*8ELLE	Elm Fork Trinity River near Lewisville	~~08053000~~	
8DNJU	Denton Creek near Justin	08053500	
*8DNGR	Denton Creek near Grapevine	~~08055000~~	
B2457C	Elm Fork Trinity River near Carrollton		Carrollton
8TRDA	Trinity River at Dallas	08057000	Dallas
8WRDA	White Rock Creek at Greenville Ave	08057200	
8ETMK	East Fork Trinity River near McKinney	08059000	
8SGPR	Sister Grove Creek near Princeton	08059500	
*8ETLA	East Fork Trinity River near Lavon	~~08061000~~	
*8ETFO	East Fork Trinity River near Forney	~~08061750~~	
8ETCR	East Fork Trinity River near Crandall	08062000	Crandall
8TRRS	Trinity River near Rosser	08062500	Rosser
8TRTR	Trinity River at Trinidad	08062700	Trinidad
8CEKE	Cedar Creek near Kemp	08062800	
8KGKA	Kings Creek near Kaufman	08062900	
8CEMA	Cedar Creek near Mabank	08063000	
*8RIDA	Richland Creek near Dawson	~~08063100~~	
8RIRI	Richland Creek near Richland	USACE	Richland
*8WABA	Waxahachie Creek near Bardwell	~~08063800~~	
8CHCO	Chambers Creek near Corsicana	08064500	Corsicana
*8RIFA	Richland Creek near Fairfield	None	
8TEST	Tehuacana Creek near Streetman	08064700	
8TROA	Trinity River near Oakwood	08065000	Oakwood
*8TRCR	Trinity River near Crockett	~~08065350~~	
8TRMI	Trinity River near Midway	08065500	Midway
8BEMA	Bedias Creek near Madisonville	08065800	
8TRRI	Trinity River at Riverside	08066000	Riverside
8TRRO	Trinity River at Romayor	08066500	Romayor
*8TRGB	Trinity River at Galveston Bay	None	

* USGS gage numbers for eight control points are marked with a strike-through in Table 6.3. Control points 8RIFA and 8TRGB have no gage. These ten control points are assigned daily flows in the *SIMD* simulation based on daily flows at the control points identified in Table 6.6.

Table 6.4
Control Points with 1940-2009 USACE Daily Unregulated Flows in *SIMD* Input File

16 Primary Control Points		19 Secondary Control Points	
8BSBR	Big Sandy Creek near Bridgeport	B3808A	West Fork Trinity River, Lake Bridgeport
8WTBO	West Fork Trinity River near Boyd	B3809A	West Fork Trinity R, Eagle Mountain Lake
8CTFW	Clear Fork Trinity River at Fort Worth	B3349A	West Fork Trinity River above Clear Fork
8WTFW	West Fork Trinity River at Fort Worth	B5157P	Clear Fork Trinity River, Benbrook Lake
8WTGP	West Fork Trinity River at Grand Prairie	B3404A	Mountain Creek, Joe Pool Lake
8MCGP	Mountain Creek at Grand Prairie	B5136A	West Fork Trinity R below Mountain Creek
8TRDA	Trinity River at Dallas	B2335A	Elm Fork Trinity River, Ray Roberts Lake
8ETCR	East Fork Trinity River near Crandall	B2456A	Elm Fork Trinity River, Lewisville Lake
8TRRS	Trinity River near Rosser	B304	Denton Creek near Roanoke
8TRTR	Trinity River at Trinidad	B2362A	Denton Creek, Grapevine Lake
8RIRI	Richland Creek near Richland	B2457C	Elm Fork Trinity River near Carrollton
8CHCO	Chambers Creek near Corsicana	B2462A	East Fork Trinity River, Lake Ray Hubbard
8TROA	Trinity River near Oakwood	B2410A	East Fork Trinity River, Lake Lavon
8TRMI	Trinity River near Midway	B4976A	Cedar Creek, Cedar Creek Reservoir
8TRRI	Trinity River at Riverside	B4992A	Richland Creek, Navarro Mills Lake
8TRRO	Trinity River at Romayor	B5021A	Waxahachie Creek, Bardwell Lake
		B5035A	Richland Creek, Richland-Chambers Lake
		B4248A	Trinity River near Tennessee Colony
		B4248B	Trinity River, Lake Livingston

The ten primary control points listed in 6.6 are assigned flows from control points listed in Table 6.4. Daily flows for these ten control points are automatically assigned within the *SIMD* simulation by repeating flows from the control points listed in the last column of Table 6.6. Control points 8RIFA and 8TRGB have no gaged flows. 8TRGB has no gage. Old gage records for the terminated gage at 8RIFA are not found in the NWIS at the USGS website. The other eight primary control points are each located near a secondary control point, identified in the last column of Table 6.6, for which USACE flows are available and more appropriately adopted. Methods for assigning daily flows for each of the 40 primary control points are summarized in Table 6.12.

Median flows are presented in Table 6.7 to provide general information characterizing the relative magnitude of flows at the different sites. The median flows in cfs are the daily flows that are exceeded in 50 percent of the days of 1940-2009 for the USACE unregulated flows or the period-of-record for USGS gaged flows. The median values of 1940-2009 USACE flows are shown in Table 6.7 for 16 primary and 19 secondary control points of Table 6.4. The median values for the period-of-record of USGS gaged flows are tabulated in Table 6.7 for 22 primary control points which include the 14 control points of Table 6.5 and eight control points from Table 6.6. The median flows are computed using the duration analysis feature of *HEC-DSSVue*.

Filling in Missing Flows

Complete 1940-2018 sequences of daily flows at 49 control points are provided in the DSS input file to be read by *SIMD*. The USACE flows cover 1940-2009 but not 2010-2018. The USGS gaging stations have different periods-of-record, most of which do not cover all of 1940-2018. The

12 primary control points listed in Table 6.8 have USACE unregulated flows for 1940-2009 and USGS gaged flows for all of 2010-2018, which are adopted. The 1940-2009 USACE and 2010-2018 USGS flows were combined within *HEC-DSSVue* to create the necessary records for these 12 control points listed in Table 6.8. Subperiods of missing data for the other 37 control points were handled as described in this section.

Table 6.5
14 Primary Control Points with 1940-2018 USGS Gaged Daily Flows in *SIMD* Input File

WAM CP	Location	USGS Period-of Record	Missing Days
8WTJA	West Fork Trinity River near Jacksboro	Mar 1956-present	0
8CTAL	Clear Fork Trinity River near Aledo	Aug 1947-Oct 1975	0
8ELSA	Elm Fork Trinity River near Sanger	May 1949-Dec 1984	0
8IDPP	Isle Du Bois Creek near Pilot Point	May 1949-Dec 1984	0
8CLSA	Clear Creek near Sanger	Mar 1949-present	0
8DNJU	Denton Creek near Justin	Oct 1949-present	0
8WRDA	White Rock Creek at Greenville Ave	Aug 1961-present	1,279
8ETMK	East Fork Trinity River near McKinney	Sep 1949-present	12,496
8SGPR	Sister Grove Creek near Princeton	Sep 1949-Jan 1975	0
8CEKE	Cedar Creek near Kemp	Jan 1963-present	5,480
8KGKA	Kings Creek near Kaufman	Jan 1963-Sep 1987	0
8CEMA	Cedar Creek near Mabank	Oct 1938-Feb 1966	0
8TEST	Tehuacana Creek near Streetman	Apr 1968-present	1
8BEMA	Bedias Creek near Madisonville	Oct 1967-present	0

Table 6.6
Ten Primary Control Points Assigned Daily Flows within *SIMD* Simulation

WAM CP	Location	USGS Period-of Record	Missing Days	Flow CP
8CTBE	Clear Fork Trinity River near Benbrook	Jul 1947-present	0	B5157P
8ELLE	Elm Fork Trinity River near Lewisville	Mar 1949-present	0	B2456A
8DNGR	Denton Creek near Grapevine	Oct 1947-present	4,391	B2362A
8ETLA	East Fork Trinity River near Lavon	Oct 1953-Sep1989	0	B2410A
8ETFO	East Fork Trinity River near Forney	Jan 1973-present	0	B2462A
8RIDA	Richland Creek near Dawson	Oct 1960-present	0	B4992A
8WABA	Waxahachie Creek near Bardwell	Oct 1963-present	0	B5021A
8TRCR	Trinity River near Crockett	Jan 1964-present	0	8TRMI
8RIFA	Richland Creek near Fairfield	Records missing.	-	B5035A
8TRGB	Trinity River at Galveston Bay	There is no gage.	-	8TRRO

The 18 primary control points for which gaps of missing daily flows are filled by substituting flows at other control points are listed in both Tables 6.9 and 6.10. Daily flows at all

of the 19 ungaged secondary control points in Table 6.11 are assigned to the 3,287 days of 2010-2018 based on gaged flows at the selected primary control points listed in the last column of Table 6.11.

The daily flows in the *SIMD* input file serve solely as pattern hydrographs used to disaggregate monthly naturalized flows to daily. Within the daily *SIMD* simulation, for each individual month of the hydrologic period-of-analysis, the naturalized flow volume for that month is distributed between the 28, 29, 30, or 31 days in proportion to the daily flow pattern while preserving the total volume for the month. Thus, in developing daily flow pattern hydrographs, only the relative pattern of flows within each individual month, not the absolute magnitude of the daily flows, affect the *SIMD* simulation.

Table 6.7
Median (50% Exceedance Frequency) of Daily Flows in cfs

CP	Location	Median (cfs)
USACE Flows at 16 Primary Control Points		
8BSBR	Big Sandy Creek Bridgeport	5.00
8WTBO	West Fork Trinity River Boyd	65.7
8CTFW	Clear Fork Trinity Fort Worth	28.0
8WTFW	West Fork Trinity River Fort Worth	213.0
8WTGP	West Fork Trinity Grand Prairie	264.3
8MCGP	Mountain Creek at Grand Prairie	5.20
8TRDA	Trinity River at Dallas	625.0
8ETCR	East Fork Trinity River Crandall	329.1
8TRRS	Trinity River near Rosser	1,180
8TRTR	Trinity River at Trinidad	1,530
8RIRI	Richland Creek near Richland	32.51
8CHCO	Chambers Creek near Corsicana	50.57
8TROA	Trinity River near Oakwood	2,255
8TRMI	Trinity River near Midway	3,071
8TRRI	Trinity River at Riverside	3,627
8TRRO	Trinity River at Romayor	4,315
USGS Flows at 14 Primary Control Points		
8WTJA	West Fork Trinity Jacksboro	0.60
8CTAL	Clear Fork Trinity River Aledo	5.4
8ELSA	Elm Fork Trinity River Sanger	16.0
8IDPP	Isle Du Bois Creek Pilot Point	1.9
8CLSA	Clear Creek near Sanger	11.0
8DNJU	Denton Creek near Justin	11.0
8WRDA	White Rock Creek Greenville	24.0
8ETMK	East Fork Trinity McKinney	10.0
8SGPR	Sister Grove Creek Princeton	9.8
8CEKE	Cedar Creek near Kemp	2.8
8KGKA	Kings Creek near Kaufman	5.1
8CEMA	Cedar Creek near Mabank	10.0
8TEST	Tehuacana Creek Streetman	1.4
8BEMA	Bedias Creek Madisonville	7.9

CP	Location	Median (cfs)
USACE Flows at 19 Secondary Control Pts		
B3808A	Lake Bridgeport	32.95
B3809A	Eagle Mountain Lake	127.0
B3349A	West Fork Trinity River	166.1
B5157P	Benbrook Lake	20.00
B3404A	Joe Pool Lake	4.20
B5136A	West Fork Trinity River	301.3
B2335A	Ray Roberts Lake	37.10
B2456A	Lewisville Lake	165.7
B304	Denton Creek Roanoke	21.70
B2362A	Grapevine Lake	30.77
B2457C	Elm Fork Trinity Carrollton	242.6
B2462A	Lake Ray Hubbard	199.3
B2410A	Lake Lavon	109.0
B4976A	Cedar Creek Reservoir	75.90
B4992A	Navarro Mills Lake	14.00
B5021A	Bardwell Lake	16.00
B5035A	Richland-Chambers Res	147.1
B4248A	Trinity Tennessee Colony	165.7
B4248B	Lake Livingston	3,993
USGS Flows at 8 Primary Control Points		
8CTBE	Clear Fork Trinity Benbrook	8.5
8ELLE	Elm Fork Trinity, Lewisville	231
8DNGR	Denton Creek, Grapevine	58.0
8ETLA	East Fork Trinity, Lavon	0.5
8ETFO	East Fork Trinity, Forney	68.0
8RIDA	Richland Creek, Dawson	12.0
8WABA	Waxahachie Creek Bardwell	0.6
8TRCR	Trinity River, Crockett	2,160

Table 6.8
12 Primary Control Points with 1940-2009 USACE Unregulated Flows
and 2010-2018 USGS Gaged Flows with no Missing Flows

WAM CP	Location	USGS Period-of Record	Missing Days	USACE Flows
8BSBR	Big Sandy Creek near Bridgeport	Oct 1936-present	3,288	1940-2009
8WTBO	West Fork Trinity River near Boyd	Jan 1947-present	0	1940-2009
8CTFW	Clear Fork Trinity River at Fort Worth	Mar 1924-present	0	1940-2009
8WTFW	West Fork Trinity River at Fort Worth	Oct 1920-present	0	1940-2009
8WTGP	West Fork Trinity River at Grand Prairie	Mar 1925-present	13	1940-2009
8MCGP	Mountain Creek at Grand Prairie	Oct 1960-present	0	1940-2009
8TRDA	Trinity River at Dallas	Oct 1903-present	0	1940-2009
8ETCR	East Fork Trinity River near Crandall	Jul 1949-present	0	1940-2009
8TRRS	Trinity River near Rosser	Aug 1924-present	4,807	1940-1996
8TRTR	Trinity River at Trinidad	Oct 1964-present	0	1940-2009
8TROA	Trinity River near Oakwood	Oct 1923-present	0	1940-2009
8TRRO	Trinity River at Romayor	May 1924-present	0	1940-2009

Table 6.9
18 Primary Control Points with Gaps Reconstituted with Flows from Other Control Points

WAM CP	Location	USGS Period-of Record	Missing Days	USACE Flows
8WTJA	West Fork Trinity River near Jacksboro	Mar 1956-present	0	–
8CTAL	Clear Fork Trinity River near Aledo	Aug 1947-Oct 1975	0	–
8ELSA	Elm Fork Trinity River near Sanger	May 1949-Dec 1984	0	–
8IDPP	Isle Du Bois Creek near Pilot Point	May 1949-Dec 1984	0	–
8CLSA	Clear Creek near Sanger	Mar 1949-present	0	–
8DNJU	Denton Creek near Justin	Oct 1949-present	0	–
8WRDA	White Rock Creek at Greenville Ave	Aug 1961-present	1,279	–
8ETMK	East Fork Trinity River near McKinney	Sep 1949-present	12,496	–
8SGPR	Sister Grove Creek near Princeton	Sep 1949-Jan 1975	0	–
8CEKE	Cedar Creek near Kemp	Jan 1963-present	5,480	–
8KGKA	Kings Creek near Kaufman	Jan 1963-Sep 1987	0	–
8CEMA	Cedar Creek near Mabank	Oct 1938-Feb 1966	0	–
8RIRI	Richland Creek near Richland	Apr 1939-Jun 1989	0	1940-2009
8CHCO	Chambers Creek near Corsicana	Apr 1939-Sep 1984	0	1940-2009
8TEST	Tehuacana Creek near Streetman	Apr 1968-present	1	–
8TRMI	Trinity River near Midway	Apr 1939-Nov 1970	0	1940-2009
8BEMA	Bedias Creek near Madisonville	Oct 1967-present	0	–
8TRRI	Trinity River at Riverside	Oct 1923-Sep 1968	2	1940-2009

Flows at the control points listed in the last column of Tables 6.10 and 6.11 are substituted into the gaps of missing flows during the periods tabulated in the third column at the control points listed in the first column. The tabular edit cut and paste feature of HEC-DSSVue was used to fill

in the gaps of missing flows by combining flows at two different sites. The combined flows are assigned to the control points listed in the first column of Tables 6.10 and 6.11.

The daily flow pattern hydrographs were developed by combining daily flows at the control points listed in the first and last columns of Tables 6.10 and 6.11 without otherwise adjusting the flows to represent the same control point location. An alternative approach not adopted would be to adjust flows using either regression or simply ratios of drainage area, median flow, or mean flow. However, these adjustments would not affect the relative pattern and thus would not affect the *SIMD* simulation results. However, in viewing the daily flows or using them for other purposes, the viewer/user should be aware that, in the final *SIMD* input file, the flows assigned to the control points listed in the first column of Tables 6.10 and 6.11 combine flows at two different locations.

The 1940-2018 sequences of *DF* record daily flows at 49 control points were developed in two steps as follows. Initial 1940-2018 pattern hydrographs of daily mean flow rates in cfs were developed as described in this chapter and stored as *DF* records in a DSS file. Many of the 1940-2018 sequences reflect combinations of flows from different sources and/or sites. Daily flow volumes in acre-feet/day were then computed with *SIMD* by combining monthly naturalized flow volumes with the initial daily flow pattern hydrographs in cfs. These final *DF* record daily flows represent 1940-2018 daily naturalized flow volumes, rather than just flow patterns, and have units of acre-feet/day. Flows are consistent throughout 1940-2018 even if derived for multiple sites.

Table 6.10
18 Primary Control Points with Gaps Reconstituted with Flows from Other Control Points

WAM CP	Location	Period of Missing Data	Data Source
8WTJA	West Fork Trinity, Jacksboro	Jan 1940-Feb 1956	8BSBR
8CTAL	Clear Fork Trinity, Aledo	1/40-7/49&10/75-12/15	8BSBR
8ELSA	Elm Fork Trinity River near Sanger	1/40-4/49&1/85-12/15	B2335A
8IDPP	Isle Du Bois Creek near Pilot Point	1/40-4/49&1/85-12/15	B2335A
8CLSA	Clear Creek near Sanger	Jan 1940-Feb 1949	8BSBR
8DNJU	Denton Creek near Justin	Jan 1940-Sep 1949	8BSBR
8WRDA	White Rock Creek, Greenville Av	1/40-8/61&10/80-Mar84	8BSBR
8ETMK	East Fork Trinity, McKinney	1/40-8/49&10/79-12/09	8BSBR
8SGPR	Sister Grove Creek, Princeton	1/40-8/49&1/76-12/15	8BSBR
8CEKE	Cedar Creek near Kemp	1/40-12/62&10/87-9/02	8CHCO
8KGKA	Kings Creek near Kaufman	1/40-12/62&10/87-12/15	8CHCO
8CEMA	Cedar Creek near Mabank	Mar 1966-Dec 2018	8CHCO
8RIRI	Richland Creek near Richland	Jan 2010-Dec 2018	8RIDA
8CHCO	Chambers Creek near Corsicana	Jan 2010-Dec 2018	8WABA
8TEST	Tehuacana Creek, Streetman	Mar 1967--Dec 2018	8RIRI
8TRMI	Trinity River near Midway	Jan 2010-Dec 2018	8TRCR
8BEMA	Bedias Creek near Madisonville	Jan 1940-Sep 1967	8TRMI
8TRRI	Trinity River at Riverside	Jan 2010-Dec 2018	8TRCR

Table 6.11
19 Secondary Control Points with 1940-2009 USACE Flows Extended through 2010-2018

WAM CP	Location	Missing Data	Data Source
B3808A	West Fork Trinity River, Lake Bridgeport	2010-2018	8BSBR
B3809A	West Fork Trinity River, Eagle Mountain Lake	2010-2018	8WTBO
B3349A	West Fork Trinity River above Clear Fork	2010-2018	8WTBO
B5157P	Clear Fork Trinity River, Benbrook Lake	2010-2018	8BSBR
B3404A	Mountain Creek, Joe Pool Lake	2010-2018	8BSBR
B5136A	West Fork Trinity River below Mountain Creek	2010-2018	8WTGP
B2335A	Elm Fork Trinity River, Ray Roberts Lake	2010-2018	8BSBR
B2456A	Elm Fork Trinity River, Lewisville Lake	2010-2018	8BSBR
B304	Denton Creek near Roanoke	2010-2018	8BSBR
B2362A	Denton Creek, Grapevine Lake	2010-2018	8DNGR
B2457C	Elm Fork Trinity River near Carrollton	2010-2018	8TRDA
B2462A	East Fork Trinity River, Lake Ray Hubbard	2010-2018	8ETFO
B2410A	East Fork Trinity River, Lake Lavon	2010-2018	8BSBR
B4976A	Cedar Creek, Cedar Creek Reservoir	2010-2018	8TROA
B4992A	Richland Creek, Navarro Mills Lake	2010-2018	8RIDA
B5021A	Waxahachie Creek, Bardwell Lake	2010-2018	8WABA
B5035A	Richland Creek, Richland-Chambers Reservoir	2010-2018	8TROA
B4248A	Trinity River near Tennessee Colony	2010-2018	8TROA
B4248B	Trinity River, Lake Livingston	2010-2018	8TROA

The input files of the daily Trinity WAM include daily flow pattern hydrographs at 30 of the 40 primary control points and 19 secondary control points that are used within the *SIMD* simulation to disaggregate monthly flows to daily at 40 primary and over 1,300 secondary control points. The 19 secondary control points with daily flows in the *SIMD* input file are listed in Table 6.11. The 40 primary control points are listed in Table 6.11 along with their sources of daily flow pattern hydrographs. Table 6.12 summarizes information presented in Tables 6.6, 6.8, and 6.12.

The ten primary control points that have no daily flows in the *SIMD* input file are listed in Table 6.6 and are identified in Table 6.12 by control point identifiers within parenthesis in the third and fourth columns. The flows at the source control points shown in parenthesis are automatically adopted within *SIMD* for these ten control points. Daily flows for the 30 other primary control points are provided in the *SIMD* input file. Flows for the periods of missing data shown in Table 6.10 are filled in with flows from the control points listed in the last column of Table 6.12.

Plots of Observed and Naturalized Daily Flows at the Four SB3 EFS Sites

The four USGS gage sites at which SB3 EFS have been established are listed in Table 5.1 of Chapter 5. Their locations are shown in the maps of Figures 2.7 and 5.1. Period-of-record observed mean daily flow rates in cubic feet per second (cfs) at these gaging stations are plotted in Figures 6.3, 6.4, 6.5, and 6.6. Naturalized daily flow volumes in acre-feet/day for these locations are plotted in Figures 6.7, 6.8, 6.9, and 6.10. The great flow variability at these sites is characteristic of river flows throughout the Trinity River Basin and other river basins of Texas.

Table 6.12
Daily Flows at Primary Control Points in the
December 2019 Version of the Daily Trinity WAM

Control Point	Location	Data Source for 1940-2009	Data Source for 2010-2018	Substitute for Missing Data
8WTJA	West Fork Trinity River near Jacksboro	gaged	gaged	8BSBR
8BSBR	Big Sandy Creek near Bridgeport	USACE	gaged	–
8WTBO	West Fork Trinity River near Boyd	USACE	gaged	–
8CTAL	Clear Fork Trinity River near Aledo	gaged	gaged	8BSBR
8CTBE	Clear Fork Trinity River near Benbrook	(B5157P)*	(B5157P)*	–
8CTFW	Clear Fork Trinity River at Fort Worth	USACE	gaged	–
8WTFW	West Fork Trinity River at Fort Worth	USACE	gaged	–
8WTGP	West Fork Trinity River Grand Prairie	USACE	gaged	–
8MCGP	Mountain Creek at Grand Prairie	USACE	gaged	–
8ELSA	Elm Fork Trinity River near Sanger	gaged	B2335A	B2335A
8IDPP	Isle Du Bois Creek near Pilot Point	gaged	B2335A	B2335A
8CLSA	Clear Creek near Sanger	gaged	gaged	8BSBR
8ELLE	Elm Fork Trinity River near Lewisville	(B2456A)*	(B2456A)*	–
8DNJU	Denton Creek near Justin	gaged	gaged	8BSBR
8DNGR	Denton Creek near Grapevine	(B2362A)*	(B2362A)*	–
8TRDA	Trinity River at Dallas	USACE	gaged	–
8WRDA	White Rock Creek at Greenville Ave	gaged	gaged	8BSBR
8ETMK	East Fork Trinity River near McKinney	gaged	gaged	8BSBR
8SGPR	Sister Grove Creek near Princeton	gaged	gaged	8BSBR
8ETLA	East Fork Trinity River near Lavon	(B2410A)*	(B2410A)*	–
8ETFO	East Fork Trinity River near Forney	(B2462A)*	(B2462A)*	–
8ETCR	East Fork Trinity River near Crandall	USACE	gaged	–
8TRRS	Trinity River near Rosser	USACE	gaged	–
8TRTR	Trinity River at Trinidad	USACE	gaged	–
8CEKE	Cedar Creek near Kemp	gaged	gaged	8CHCO
8KGKA	Kings Creek near Kaufman	gaged	gaged	8CHCO
8CEMA	Cedar Creek near Mabank	gaged	gaged	8CHCO
8RIDA	Richland Creek near Dawson	(B4992A)*	(B4992A)*	–
8RIRI	Richland Creek near Richland	USACE	gaged	8RIDA
8WABA	Waxahachie Creek near Bardwell	(B5021A)*	(B5021A)*	–
8CHCO	Chambers Creek near Corsicana	USACE	gaged	8WABA
8RIFA	Richland Creek near Fairfield	(B5035A)*	(B5035A)*	–
8TEST	Tehuacana Creek near Streetman	gaged	gaged	8RIRI
8TROA	Trinity River near Oakwood	USACE	gaged	–
8TRCR	Trinity River near Crockett	(8TRMI)*	(8TRMI)*	–
8TRMI	Trinity River near Midway	USACE	gaged	8TRCR
8BEMA	Bedias Creek near Madisonville	gaged	gaged	8TRMI
8TRRI	Trinity River at Riverside	USACE	gaged	8TRCR
8TRRO	Trinity River at Romayor	USACE	gaged	–
8TRGB	Trinity River at Galveston Bay	(8TRRO)*	(8TRRO)*	–

* The flows at the control points shown in parenthesis are automatically adopted within *SIMD* for the ten primary control points with no DF record daily flows in the input file.

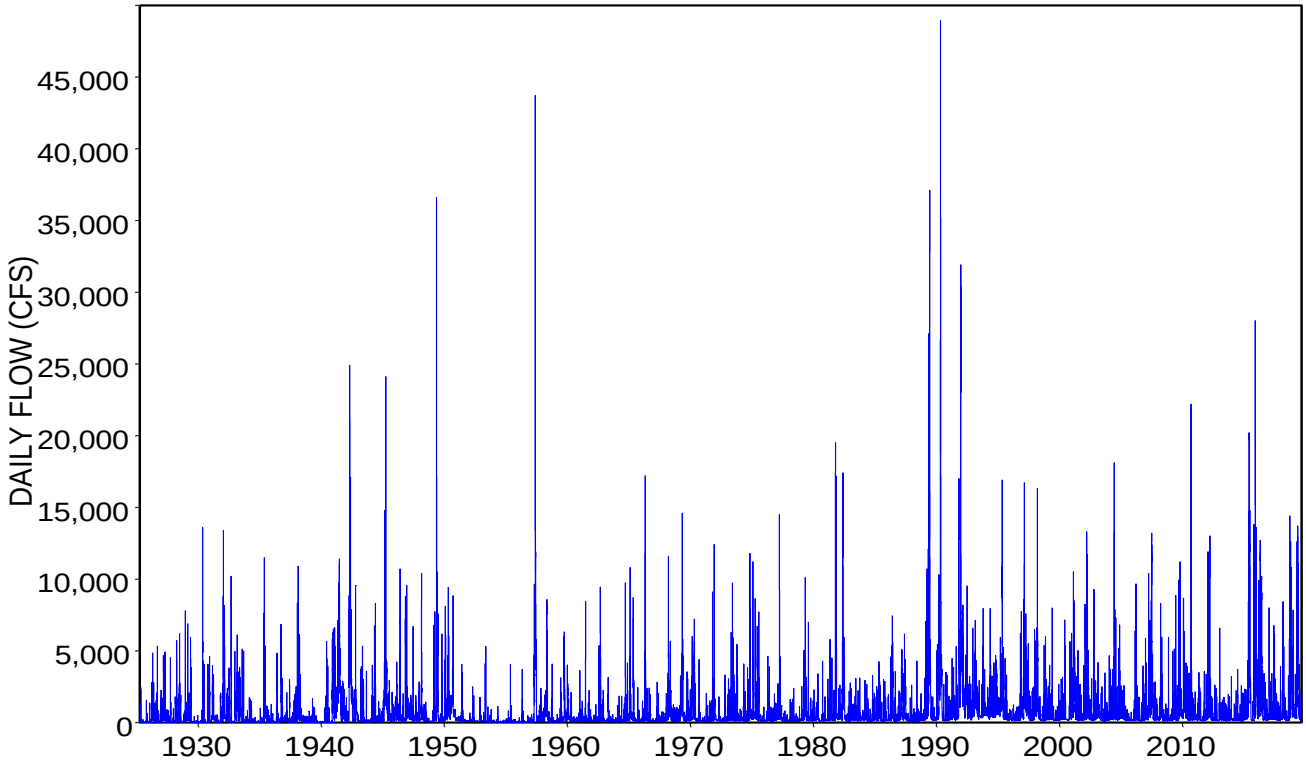

Figure 6.3 Observed Daily Flows during 27 March 1925 through 8 September 2019 of the West Fork of Trinity River at Grand Prairie (8WTGP)

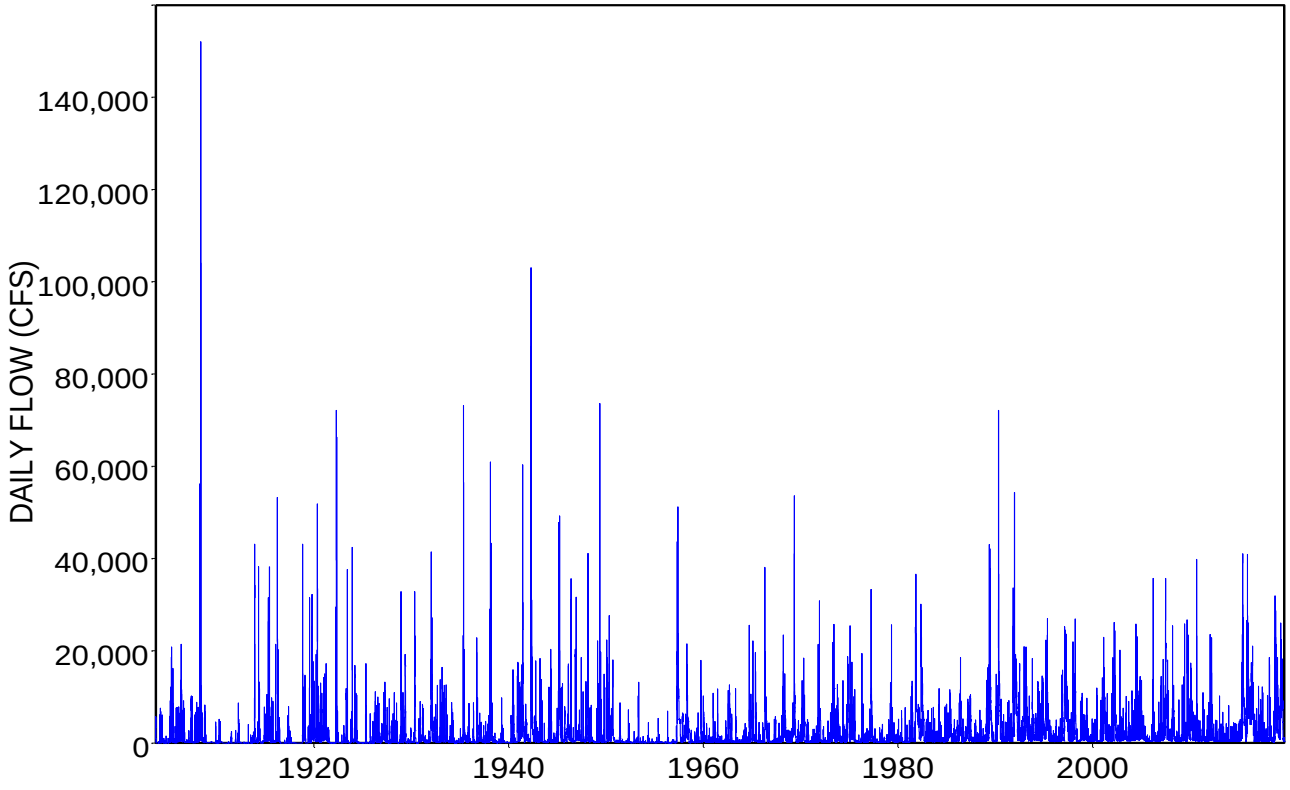

Figure 6.4 Observed Daily Flows during 1 October 1903 through 8 September 2019 of the Trinity River at Dallas (8TRDA)

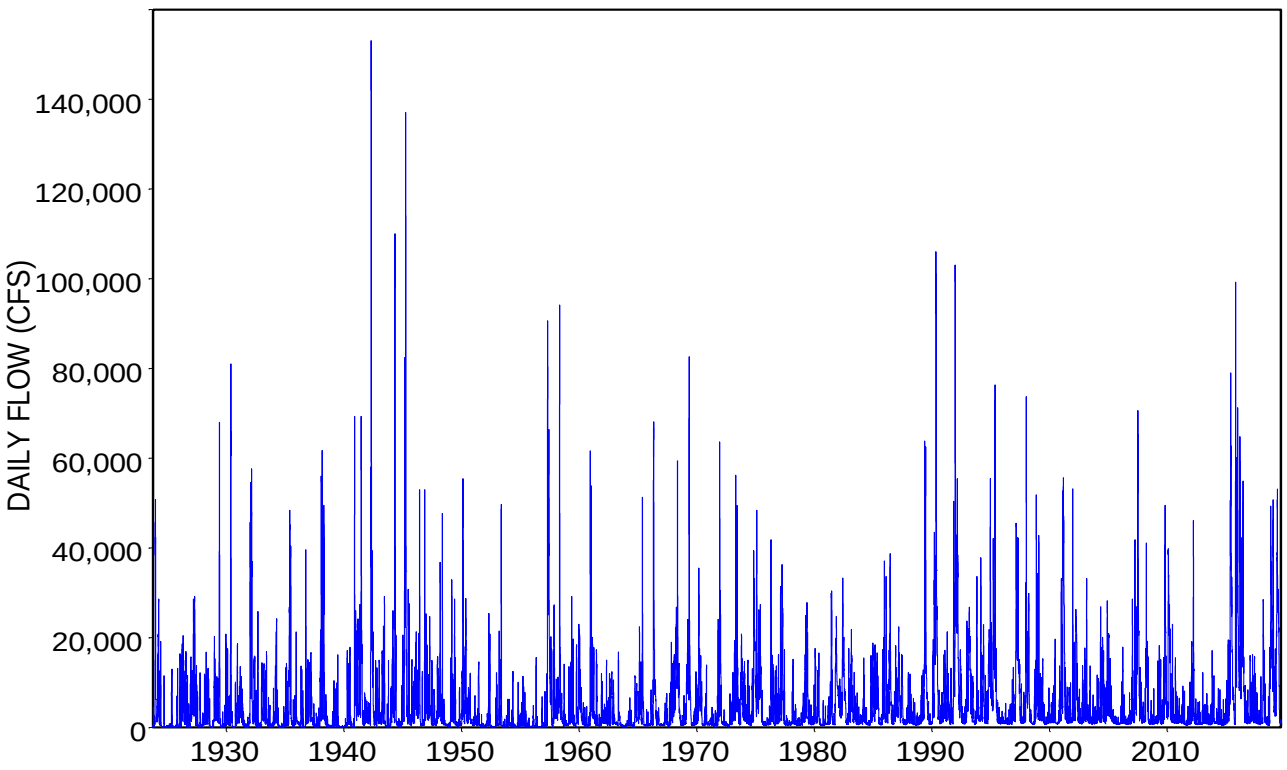

Figure 6.5 Observed Daily Flows during 1 October 1923 through 8 September 2019 of the Trinity River at Oakwood (8TROA)

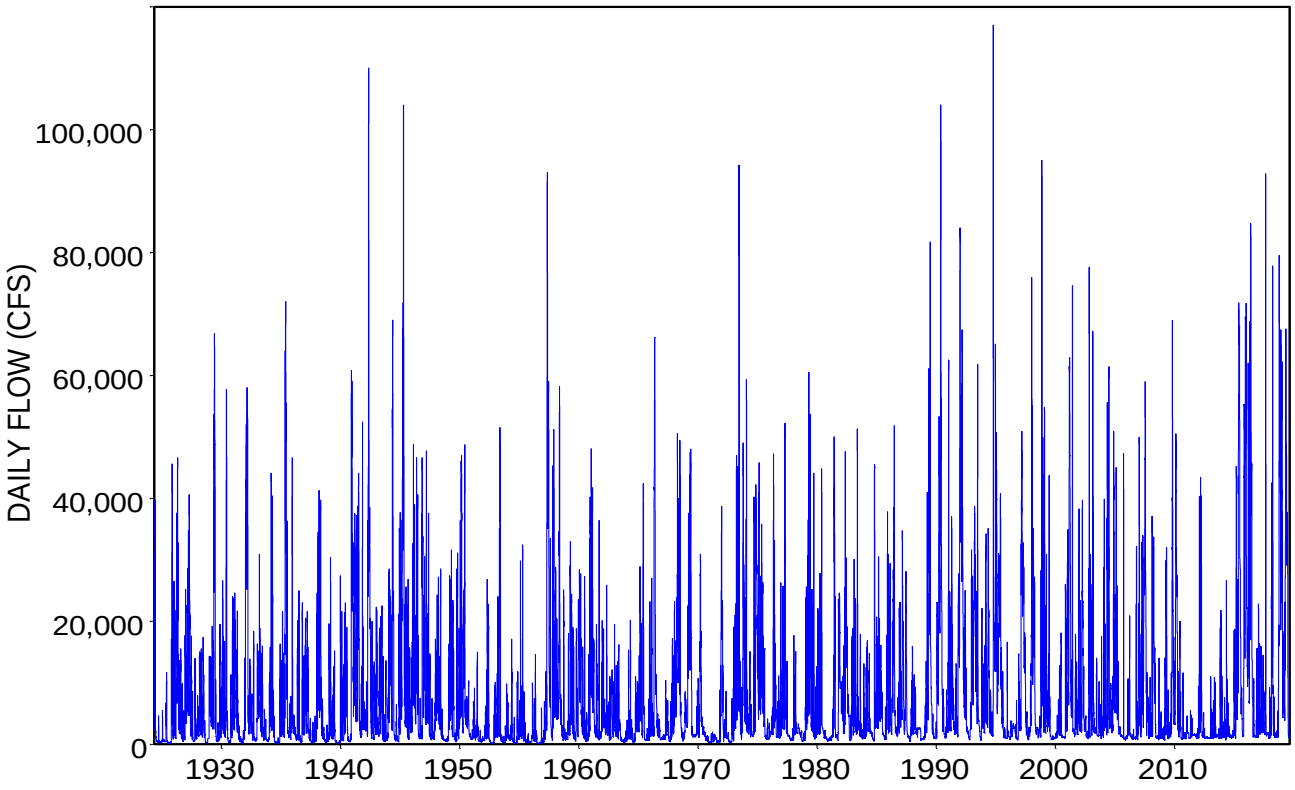

Figure 6.6 Observed Daily Flows during 1 May 1924 through 8 September 2019 of the Trinity River at Romayor (8TRRO)

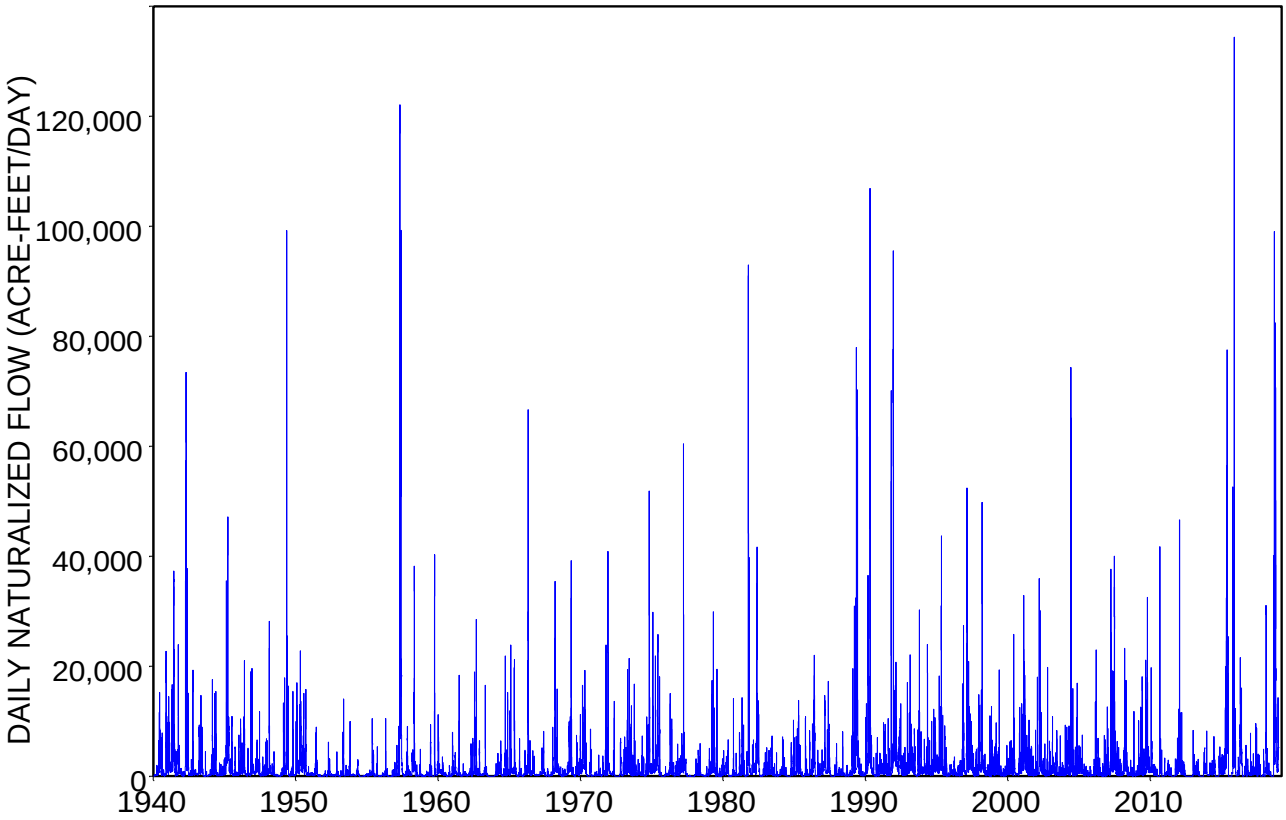

Figure 6.7 Daily Naturalized Flow of West Fork of Trinity River at Grand Prairie (8WTGP)

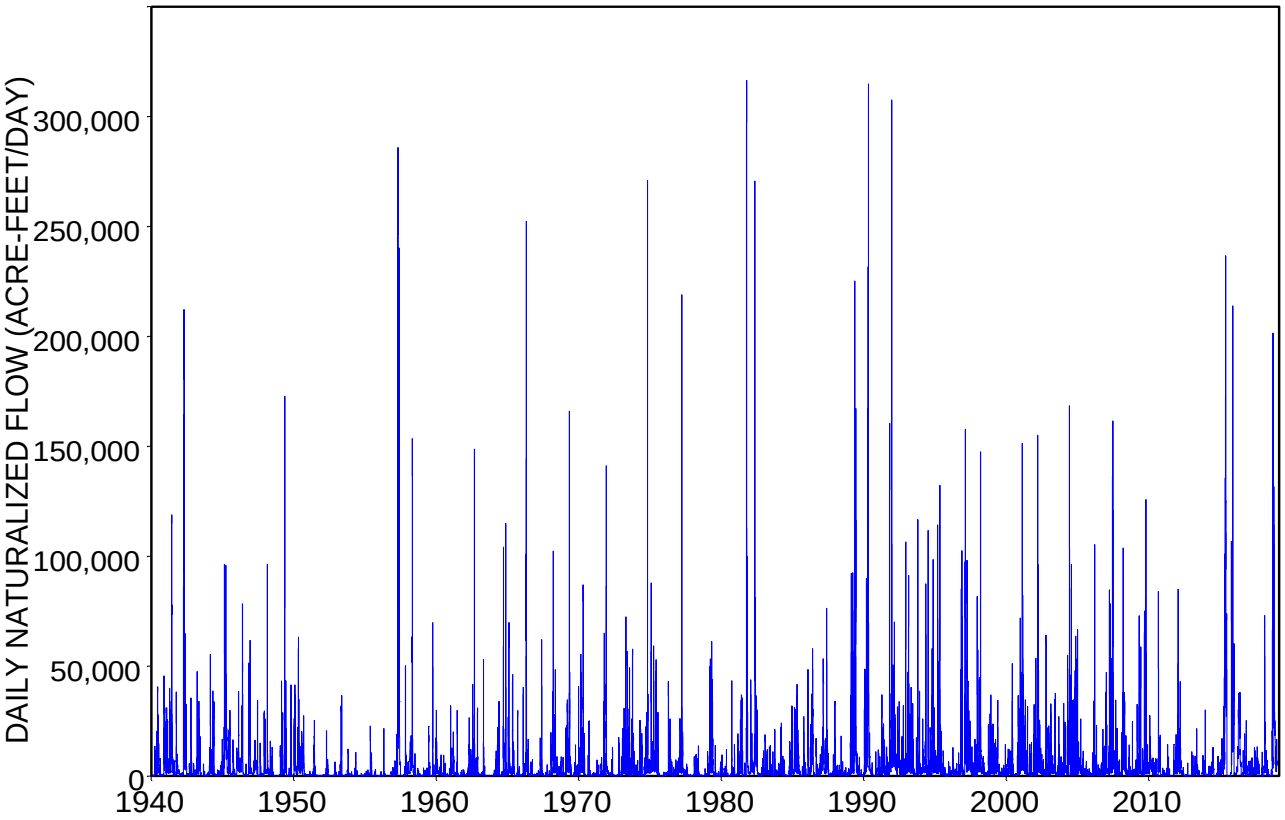

Figure 6.8 Daily Naturalized Flow of Trinity River at Dallas (8TRDA)

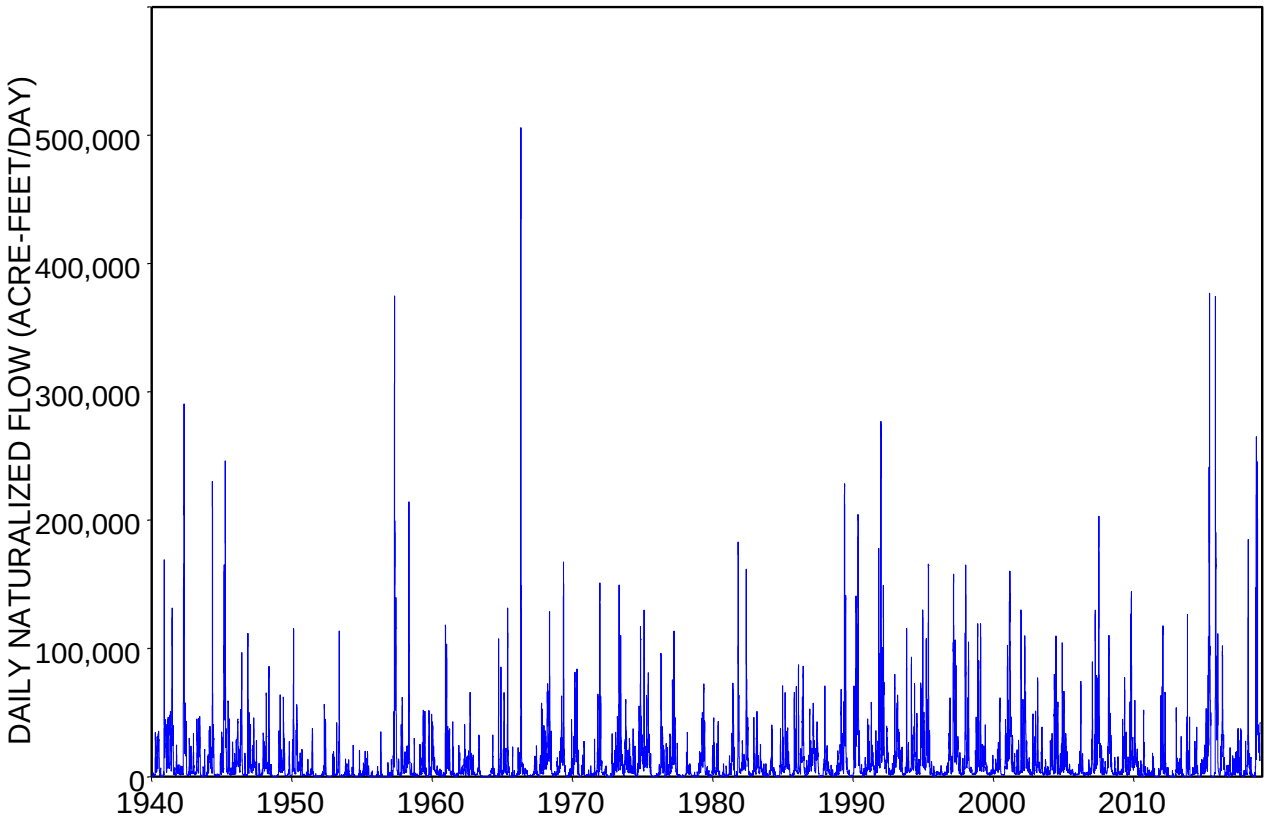

Figure 6.9 Daily Naturalized Flow of Trinity River at Oakwood (8TROA)

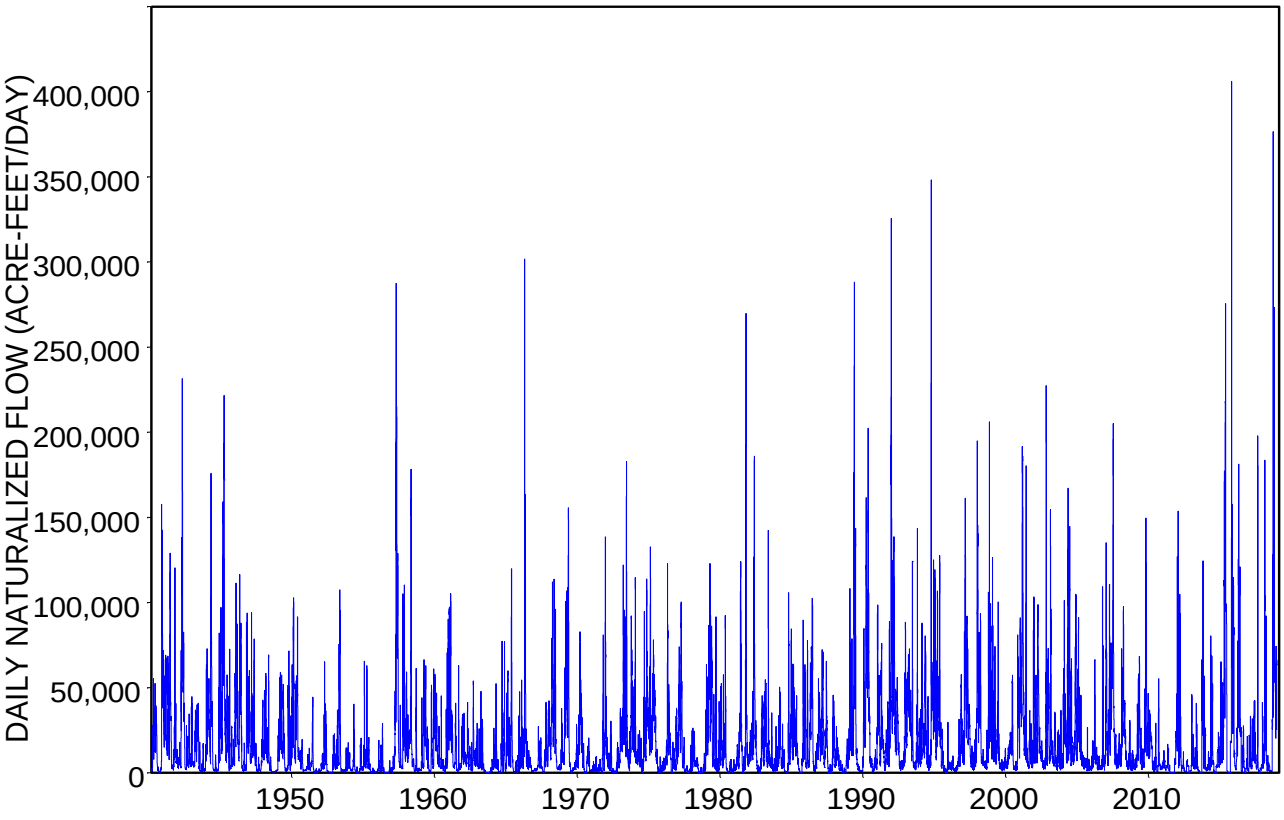

Figure 6.10 Daily Naturalized Flow of Trinity River at Romayor (8TRRO)

CHAPTER 7
MONTHLY NATURALIZED FLOWS

The Trinity WAM contains monthly naturalized flows at the 40 control points listed in Tables 2.4 and 2.5 which are located at the sites shown in Figures 2.6 and 2.7. The original January 1940 through December 1996 monthly naturalized flow sequences continue to be adopted without change. The update consists of extending the naturalized flows through December 2018.

Alternative Sources of Monthly Naturalized Flows

The following sources of monthly flows are relevant in the compilation of 1940-2018 sequences of monthly naturalized flows.

- Daily observed flows at USGS gages downloaded from the National Water Information System (NWIS) website maintained by the USGS are aggregated to monthly flows.
- Daily unregulated flows for 1940-2009 at the 35 control points listed in Table 6.3 were provided by the USACE FWD in 2013 in response to a request from TAMU in support of the effort to develop daily WRAP modeling capabilities as discussed in Chapter 6. The daily unregulated flows are aggregated to monthly flows.
- The original 1940-1996 monthly naturalized flows were developed by adjusting gaged flows as discussed below.
- A hydrologic model in the WRAP program *HYD* relates monthly naturalized flows to monthly precipitation and reservoir evaporation rates.

In the future, the 1940-1996 monthly naturalized may be extended to near the present by adjusting flows observed at USGS gages since 1997 in essentially the same manner as employed in compiling the original 1940-1996 naturalized flows. However, considerable effort would be required to compile the necessary water use, reservoir storage, and other data and perform the adjustment computations. Observed flows are available after 1996 for 27 of the 40 primary control points. Readily available data are employed as discussed in this chapter to efficiently extend the hydrologic period-of-record. More accurate data possibly may be compiled in the future to replace these preliminary estimates of 1997-2018 naturalized flows at some or all of the control points.

Original 1940-1996 Monthly Naturalized Flows

Development of the original hydrology dataset is documented by the 2002 WAM Report [9]. The original sequences of monthly naturalized flows for 1940-1996 at 39 primary control points were developed by adjusting actual observed flows to remove the effects of human activities as follows.

$$\text{Naturalized Flow} = \text{Historical Gaged Flow} + \text{Upstream Diversions} - \text{Upstream Return Flows} + \text{Changes in Upstream Reservoir Storage} + \text{Upstream Reservoir Evaporation}$$

Historical gaged flow was determined using available USGS stream flow data. For many control point locations, USGS flow data was not available for the entire 1940-1996 period-of-analysis. Missing data was estimated based on data from nearby gages using double mass curves, scatter plots, and linear regression equations.

Upstream diversions were estimated using a variety of methods for municipal, industrial, and agricultural water rights. For municipal water rights, water use records from the Texas Natural Resource Conservation Commission (TCEQ predecessor) were used to determine historical diversions. Gaps in the available data were filled in by contacting individual water right holders or making estimates on a per capita basis using population data. Water use estimates for industrial and agricultural water rights were made using historical water use patterns for individual rights or rights with similar uses and diversion amounts. Historical water use was estimated to be zero for water rights for which good estimates could not be determined.

Historical return flows were estimated for municipal and industrial users and neglected for agricultural users. TNRCC return flow data was available for municipal and industrial sites for the period from 1978 to 1996. Return flow data for the remaining time period was determined using records from individual users or estimates based on information from individual users.

Historical changes in reservoir storage were determined using USGS data, information from alternative sources, or estimates of storage content changes. Historical reservoir evaporation was estimated by multiplying the net evaporation rate by the average reservoir surface area. The net evaporation rate was computed by subtracting precipitation from evaporation using TWDB data. Values of evaporation and precipitation for each reservoir were computed using the sum of weighted values from adjacent TWDB quadrangles.

Flow losses in stream channels due to seepage and evapotranspiration complicate the flow adjustments. Modeling the downstream propagation of gains and losses associated with diversion and storage depletions from stream flows, return flows from surface and groundwater supplies, and reservoir storage, releases, and evaporation are necessarily very approximate.

Hydrologic Model Relating Monthly Naturalized Flows to Precipitation and Evaporation

Program *HYD* consists of various routines for developing and updating net evaporation-precipitation rates and naturalized flows in *SIM* simulation input datasets [4]. 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 for the 92 one-degree latitude by one-degree longitude quadrangles encompassing Texas that are shown in Figure 8.1 in the next chapter. The same TWDB databases are used to extend both net evaporation-precipitation rates (Chapter 8) and the naturalized flows.

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. Calibration analyses requires significant time and effort. However, after the model has been calibrated for each relevant control point, the extension of naturalized flows is quick and easy. 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 program *HYD* hydrologic model was used to extend the naturalized flows through December 2018 using a previously calibrated set of parameters [12]. The *HYD* flow extension model has been calibrated for each of the 40 primary control points using the original 1940-1996

naturalized flows along with concurrent TWDB precipitation and evaporation depths for relevant quadrangles [12]. The previously calibrated flow extension model was used to compute naturalized flows for the period from January 1997 through December 2018 using 1997-2018 TWDB precipitation and reservoir evaporation depths as input. Comparative analyses of extended flows and observed flows were performed. Based on these analyses, the flows extended using the hydrologic model were adopted at some control points for some periods, but USACE unregulated flows and actual observed flows were used instead of the synthesized flows in some cases.

Summary Comparison of Approaches for Extending Monthly Naturalized Flows

The original sequences of monthly naturalized flows for January 1940 through December 1996 at 40 primary control points are adopted without modification for the updated hydrology dataset reported here. Methods adopted for extending the monthly flows through December 2018 are described in this chapter. Development of daily flows is covered in the preceding Chapter 6.

The 1940-2009 USACE daily unregulated flows discussed in Chapter 6 were obtained from the USACE for use as pattern hydrographs employed in disaggregating monthly naturalized flows to daily. However, in the update documented by this report, the USACE daily flows are also aggregated to monthly quantities for adoption in some cases as 1997-2009 naturalized flows.

The original 1940-1996 WAM monthly naturalized flows and 1940-2009 USACE daily unregulated flows are based on adjustments to gaged flows to remove the effects of water resources development/use and reservoir system regulation of river flows. Thirty-nine of the 40 primary control points are located at USGS gaging stations with periods-of-record that include all or a portion of 1940-1996. Twenty-seven of these 39 gaging stations have periods-of-record that extend later than 1996. The other 12 gages have no data recorded after 1989.

As indicated by Table 2.2, initial impoundment for the 32 largest reservoirs in the Trinity River Basin occurred between 1911 and 1987. No large reservoirs have been constructed in the basin since 1987. Adjustments to river flows to remove the effects of reservoir storage and evaporation, water supply diversions, inter-basin transports, return flows from ground and surface water sources, and other factors are complicated by historical data availability and accuracy, flow lag and attenuation, channel losses, reservoir seepage, multiple reservoir system operations, land use changes, and various other considerations.

The *HYD* calibrated precipitation-streamflow regression model was employed to extend the naturalized flows to cover 1997-2018 at the 40 primary control points. However, these synthesized monthly naturalized flows are adopted only in cases in which other flows deemed more accurate are not available. The *HYD* generated flows replicate statistical characteristics of flows reasonably well but may be significantly high or low in individual months. Based on analyses discussed in the remainder of this chapter, monthly summations of gaged daily flows are considered to be the most accurate representation of natural conditions in some cases.

Synthesizing monthly flow sequences at 1,400 sites based on flows observed during all or portions of 1940-2018 at 39 gaging stations is necessarily approximate. Flow distribution from gaged to ungaged sites as well as flow naturalization methodologies involves inaccuracies.

Extension of Monthly Naturalized Flows through December 2018

The Trinity WAM dataset contains monthly naturalized flows at the 40 control points listed in Tables 2.4, 2.5, and 7.1 which are located at the sites shown in Figures 2.6 and 2.7. The original January 1940 through December 1996 naturalized flow sequences are adopted without modification. Naturalized flows are extended through December 2018. The following datasets are used to extend the monthly flows stored in the hydrology DSS or FLO files from January 1997 through December 2018 as shown in Table 7.1.

- Monthly summations in acre-feet of the daily USGS gaged flows.
- Monthly summations in acre-feet of the daily USACE unregulated flows.
- Monthly flows in acre-feet synthesized with the WRAP program *HYD* by relating monthly flow volumes to the TWDB quadrangle monthly precipitation and reservoir evaporation depths described in Chapter 8.

Thirty-nine of the 40 primary control points are located at USGS stream flow gaging stations with periods-of-record that include all or a portion of 1940-1996. Twenty-seven of these gaging stations have periods-of-record that extend later than 1996. The other 12 gages have been discontinued and have no data recorded after 1989. Control point 8TRGB represents the outlet which has no gage.

The naturalized flows adopted for the sub-periods 1997-2009 and 2010-2018 or the entire 1997-2018 consist of USACE unregulated flows, *HYD* synthesized flows, or USGS gaged flows as shown in Table 7.1. Naturalized flows for the sub-period 1997-2009 consist of:

- USACE unregulated flows for 17 control points
- HYD synthesized flows for 17 control points
- USGS gaged flows for 6 control points

Naturalized flows for the sub-period 2010-2018 consist of:

- HYD synthesized flows for 32 control points
- USGS gaged flows for 8 control points

The USACE flows are adopted for all WAM primary control points for which they are available. The USGS gaged flows are adopted for sites with relatively small unregulated watersheds. Gaged flows at these sites are almost identical to WAM naturalized and USACE unregulated flows. The *HYD* synthesized flows are used for the remaining sites.

The December 2019 Trinity WAM has 40 primary control points, with 1940-2018 monthly naturalized flow sequences stored in a DSS or FLO file, and over 1,350 secondary control points for which naturalized flows are synthesized during the *SIM* simulation based on the flows at the primary control points and information provided on *CP* records in the DAT file and *FD* and *WP* records in the flow distribution DIS file. Flow distribution option 7 based on drainage area ratios are employed for synthesizing flows at most of the secondary control points in the original and 2019 versions of the Trinity WAM.

Table 7.1
Flows Adopted for the Trinity WAM Monthly Naturalized Flow Dataset

CP	USGS Gage Location	USACE	HYD	USGS
8WTJA	West Fork Trinity River near Jacksboro	-	-	1997-2018
8BSBR	Big Sandy Creek near Bridgeport	1997-2009	-	2010-2018
8WTBO	West Fork Trinity River near Boyd	1997-2009	-	2010-2018
8CTAL	Clear Fork Trinity River near Aledo	-	1997-2018	-
8CTBE	Clear Fork Trinity River near Benbrook	-	1997-2018	-
8CTFW	Clear Fork Trinity River at Fort Worth	1997-2009	2010-2018	-
8WTFW	West Fork Trinity River at Fort Worth	1997-2009	2010-2018	-
8WTGP	West Fork Trinity River at Grand Prairie	1997-2009	2010-2018	-
8MCGP	Mountain Creek at Grand Prairie	1997-2009	2010-2018	-
8ELSA	Elm Fork Trinity River near Sanger	-	1997-2018	-
8IDPP	Isle Du Bois Creek near Pilot Point	-	1997-2018	-
8CLSA	Clear Creek near Sanger	-	-	1997-2018
8ELLE	Elm Fork Trinity River near Lewisville	-	1997-2018	-
8DNJU	Denton Creek near Justin	-	-	1997-2018
8DNGR	Denton Creek near Grapevine	-	1997-2018	-
8TRDA	Trinity River at Dallas	1997-2009	2010-2018	-
8WRDA	White Rock Creek at Greenville Ave	-	-	1997-2018
8ETMK	East Fork Trinity River near McKinney	-	1997-2018	-
8SGPR	Sister Grove Creek near Princeton	-	1997-2018	-
8ETLA	East Fork Trinity River near Lavon	-	1997-2018	-
8ETFO	East Fork Trinity River near Forney	-	1997-2018	-
8ETCR	East Fork Trinity River near Crandall	1997-2009	2010-2018	-
8TRRS	Trinity River near Rosser	1997-2009	2010-2018	-
8TRTR	Trinity River at Trinidad	1997-2009	2010-2018	-
8CEKE	Cedar Creek near Kemp	-	1997-2018	-
8KGKA	Kings Creek near Kaufman	-	1997-2018	-
8CEMA	Cedar Creek near Mabank	-	1997-2018	-
8RIDA	Richland Creek near Dawson	-	1997-2018	-
8RIRI	Richland Creek near Richland	1997-2009	2010-2018	
8WABA	Waxahachie Creek near Bardwell	-	1997-2018	-
8CHCO	Chambers Creek near Corsicana	1997-2009	2010-2018	-
8RIFA	Richland Creek near Fairfield	-	1997-2018	-
8TEST	Tehuacana Creek near Streetman	-	-	1997-2018
8TROA	Trinity River near Oakwood	1997-2009	2010-2018	-
8TRCR	Trinity River near Crockett	-	1997-2018	-
8TRMI	Trinity River near Midway	1997-2009	2010-2018	-
8BEMA	Bedias Creek near Madisonville	-	-	1997-2018
8TRRI	Trinity River at Riverside	1997-2009	2010-2018	-
8TRRO	Trinity River at Romayor	1997-2009	2010-2018	-
8TRGB	Trinity River at Galveston Bay	-	1997-2018	-

Monthly and Annual Observed and Naturalized Flows at the Four SB3 EFS Sites

The four USGS gaging stations at which SB3 EFS have been established are listed in Table 5.1. Their locations are shown on the maps of Figures 2.7 and 5.1. Frequency metrics for observed and naturalized monthly flows are compared in Table 7.2. The mean and monthly flow rates in acre-feet/month that are exceeded during specified percentages of the 948 months of the 1940-2018 period-of-analysis are tabulated in Table 7.2.

Daily observed and naturalized flows at these sites are plotted in Figures 6.3 through 6.10 of Chapter 6. Monthly flow rates in acre-feet/month of observed and naturalized flows at these four control points are plotted in the following Figures 7.1, 7.2, 7.3, and 7.3. Annual flow volumes in acre-feet/year of observed and naturalized flows at these four control points are plotted in Figures 7.5, 7.6, 7.7, and 7.8.

Table 7.2
Frequency Metrics for Monthly Observed and Naturalized Flows in acre-feet/month

	Grand Prairie 8WTGP		Dallas 8TRDA		Oakwood 8TROA		Romayor 8TRRO	
	Gaged	Naturalized	Gaged	Naturalized	Gaged	Naturalized	Gaged	Naturalized
Mean	45,835	51,676	121,023	146,320	339,501	379,150	500,336	550,243
Maximum	843,312	955,627	1,724,628	2,630,490	3,446,281	4,801,544	3,910,017	5,020,073
0.20	726,547	852,951	1,621,109	2,117,249	2,792,390	3,832,698	3,822,010	4,605,226
0.50	514,391	742,624	975,788	1,819,709	2,534,211	3,273,069	3,632,975	3,945,974
1.00	425,845	597,500	870,231	1,573,707	2,445,620	2,911,122	2,921,554	3,418,785
2.00	302,049	376,859	669,025	1,035,245	1,889,454	2,167,377	2,589,223	2,692,261
5.00	185,901	199,047	505,240	576,025	1,296,496	1,466,956	1,704,387	1,905,612
10.00	108,115	124,453	345,045	372,132	892,919	988,625	1,312,066	1,415,991
15.00	71,249	88,654	247,997	264,994	646,008	735,097	1,074,654	1,125,677
20.00	55,097	64,708	182,031	194,689	526,116	594,182	844,721	921,483
30.00	35,107	41,988	102,643	125,545	345,350	382,711	546,169	640,157
40.00	25,773	27,719	67,343	84,964	225,017	244,545	375,281	424,912
50.00	20,477	20,393	49,000	55,193	145,388	173,954	239,385	282,629
60.00	15,800	14,302	37,498	37,907	102,367	117,753	169,408	202,119
70.00	12,694	9,071	29,431	23,601	76,368	75,439	119,940	136,355
80.00	9,687	5,532	21,388	13,016	54,859	42,694	79,563	84,213
85.00	8,185	3,352	16,337	8,141	45,909	29,048	66,842	54,867
90.00	6,678	791	12,787	3,257	37,777	17,461	56,206	35,102
95.00	4,431	0.0	7,952	0.0	24,370	2,584	37,609	16,058
98.00	3,392	0.0	5,044	0.0	16,653	0.0	26,868	3,568
99.00	2,729	0.0	4,250	0.0	11,056	0.0	18,803	0.0
99.50	1,378	0.0	3,678	0.0	8,090	0.0	12,640	0.0
99.80	1,152	0.0	3,115	0.0	6,845	0.0	9,630	0.0
Minimum	1,010	0.0	3,088	0.0	6,206	0.0	7,864	0.0

Legend for Figures 7.1 through 7.8

observed flow blue solid line
naturalized flow red dotted line

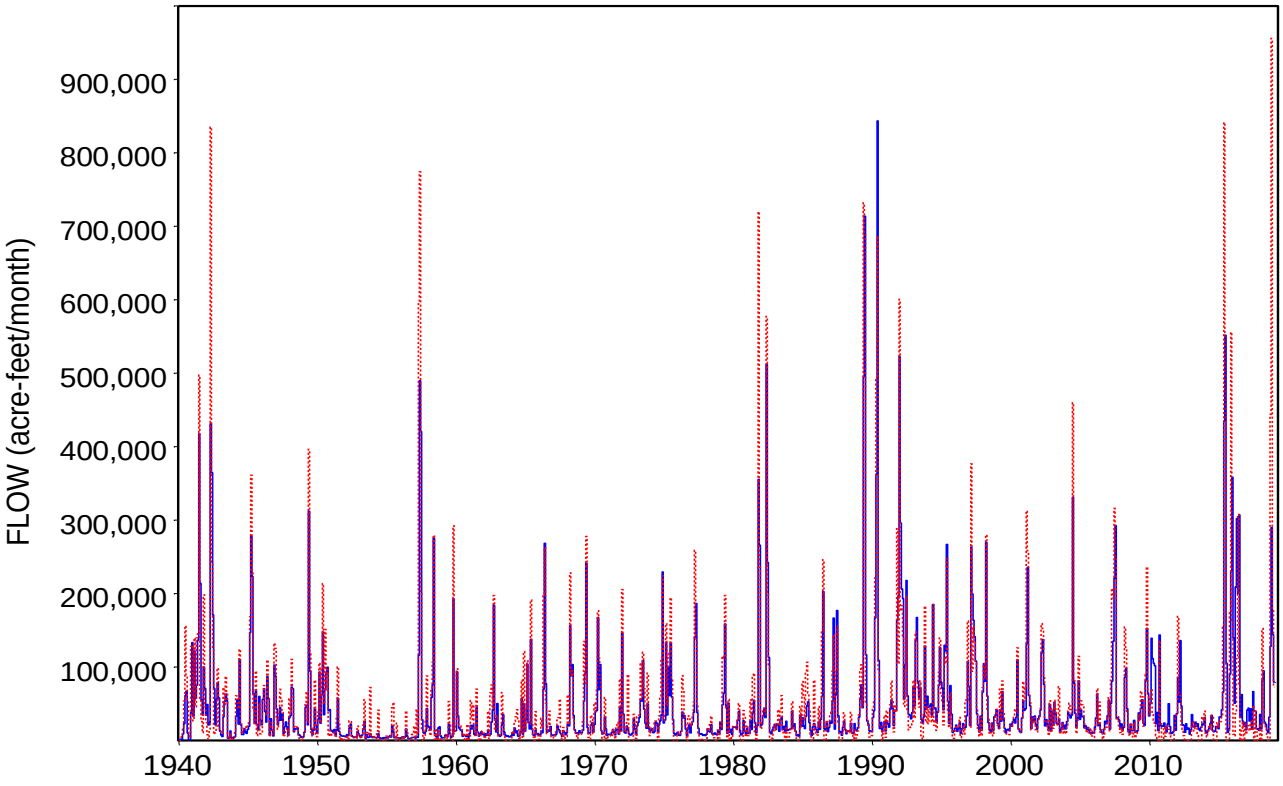

Figure 7.1 Observed (blue solid) and Naturalized (red dots) Monthly Flows of the West Fork of the Trinity River at Grand Prairie (8WTGP)

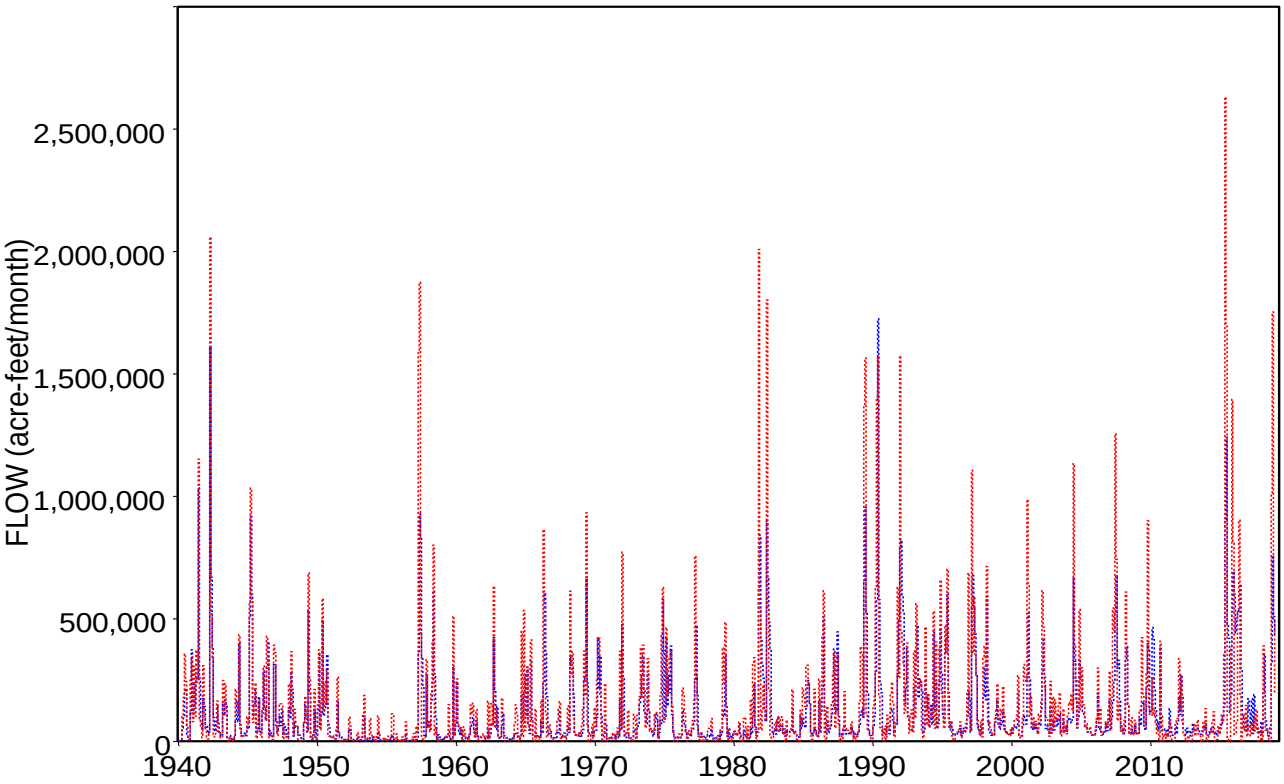

Figure 7.2 Observed and Naturalized Monthly Flows of the Trinity River at Dallas (8TRDA)

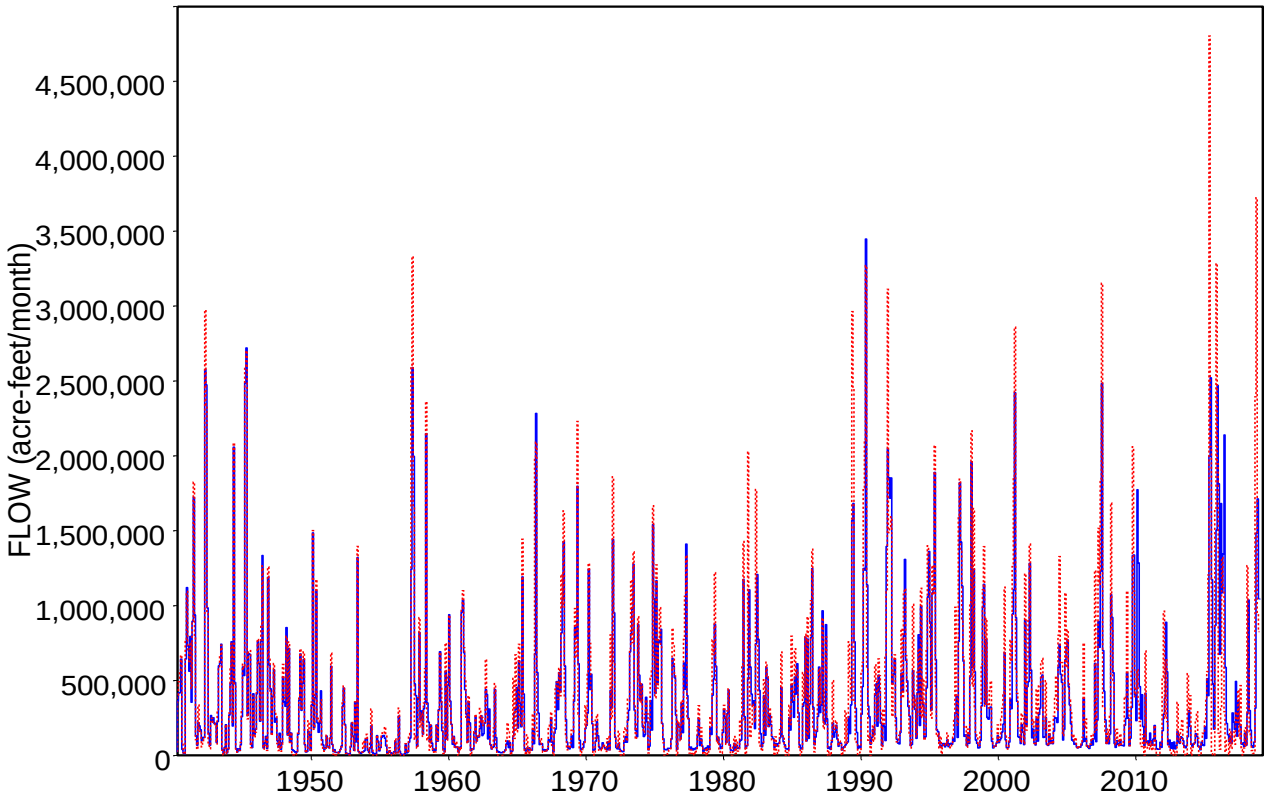

Figure 7.3 Observed and Naturalized Monthly Flows of the Trinity River at Oakwood (8TROA)

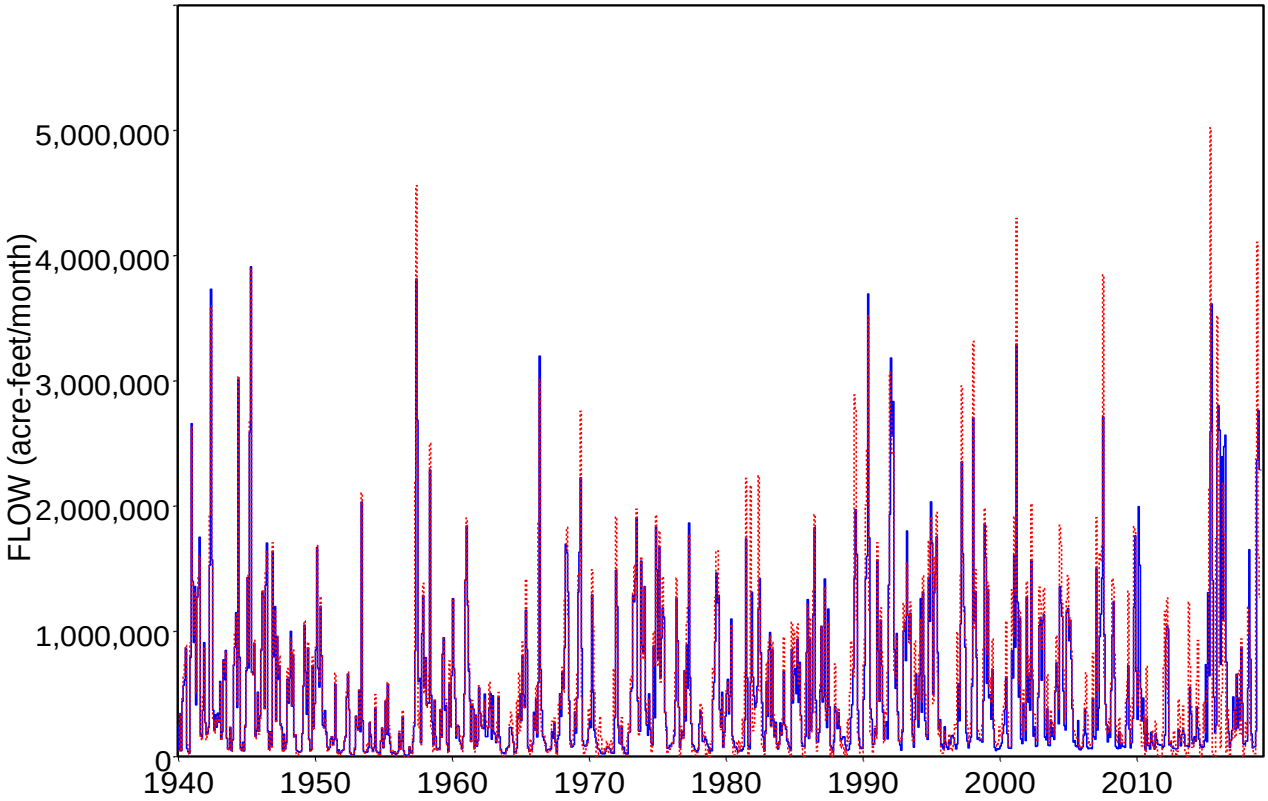

Figure 7.4 Observed and Naturalized Monthly Flows of the Trinity River at Romayor (8TRRO)

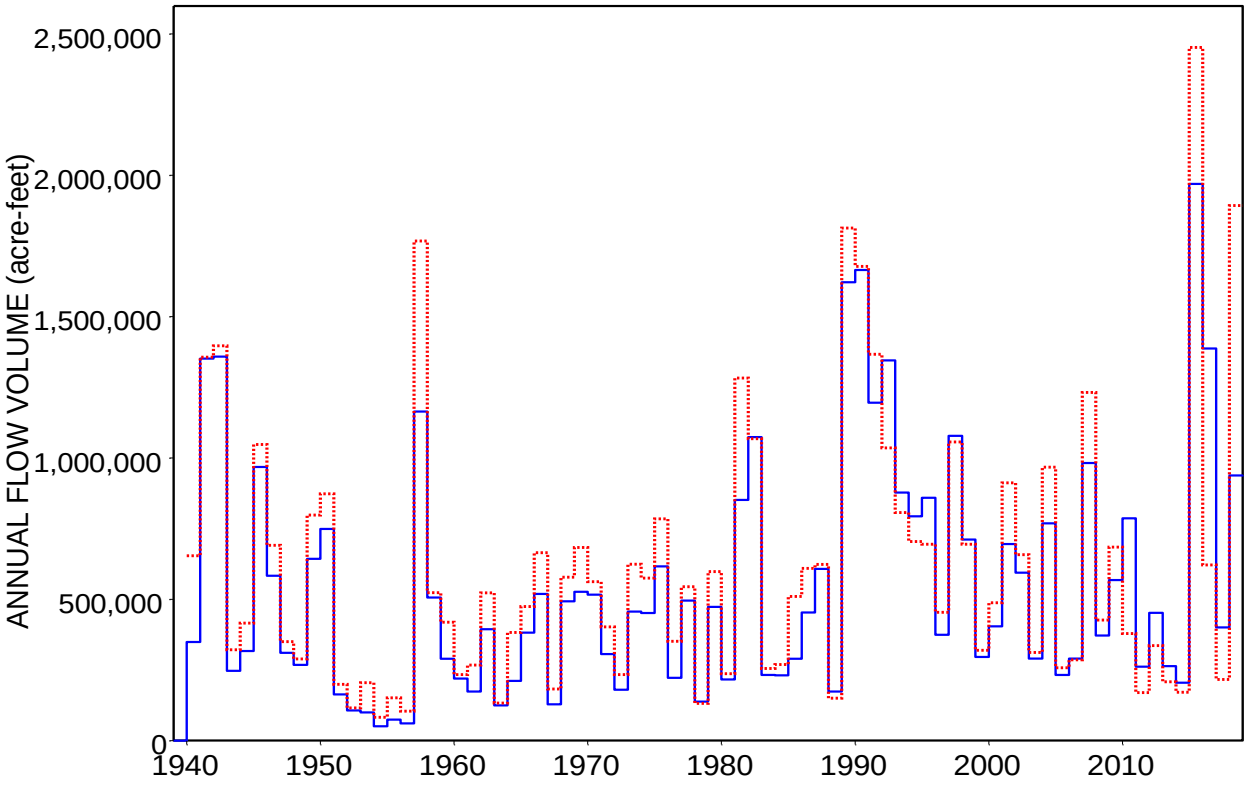

Figure 7.5 Observed (blue solid) and Naturalized (red dots) Annual Flow of the West Fork of the Trinity River at Grand Prairie (8WFGP)

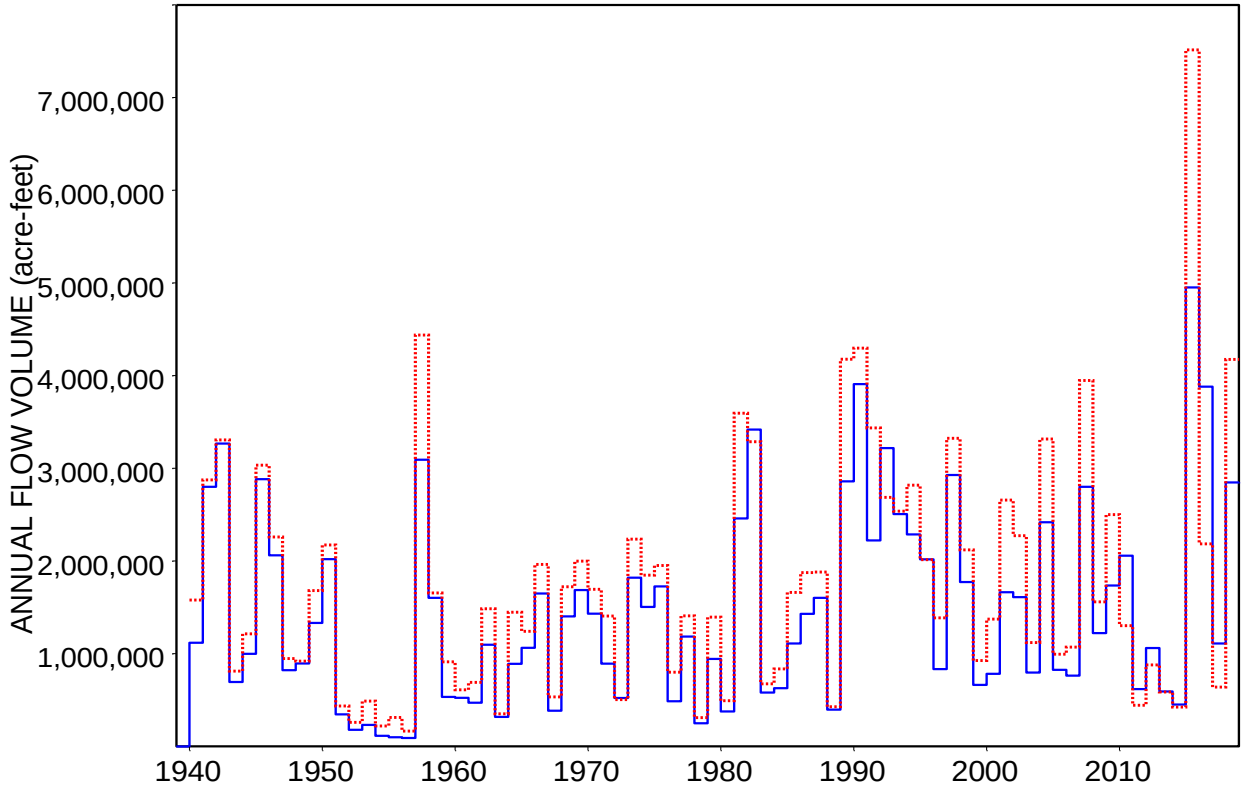

Figure 7.6 Observed and Naturalized Annual of the Trinity River at Dallas (8TRDA)

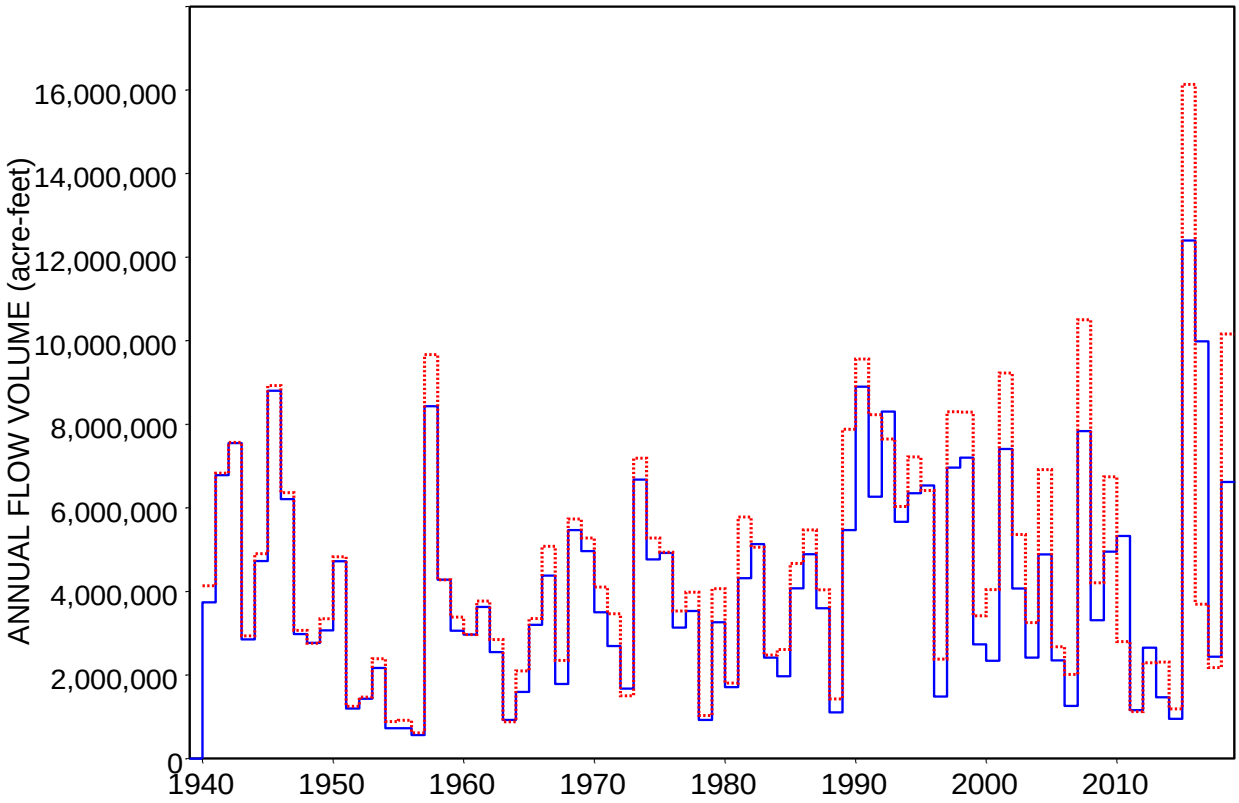

Figure 7.7 Observed and Naturalized Annual Flow of Trinity River at Oakwood (8TRAO)

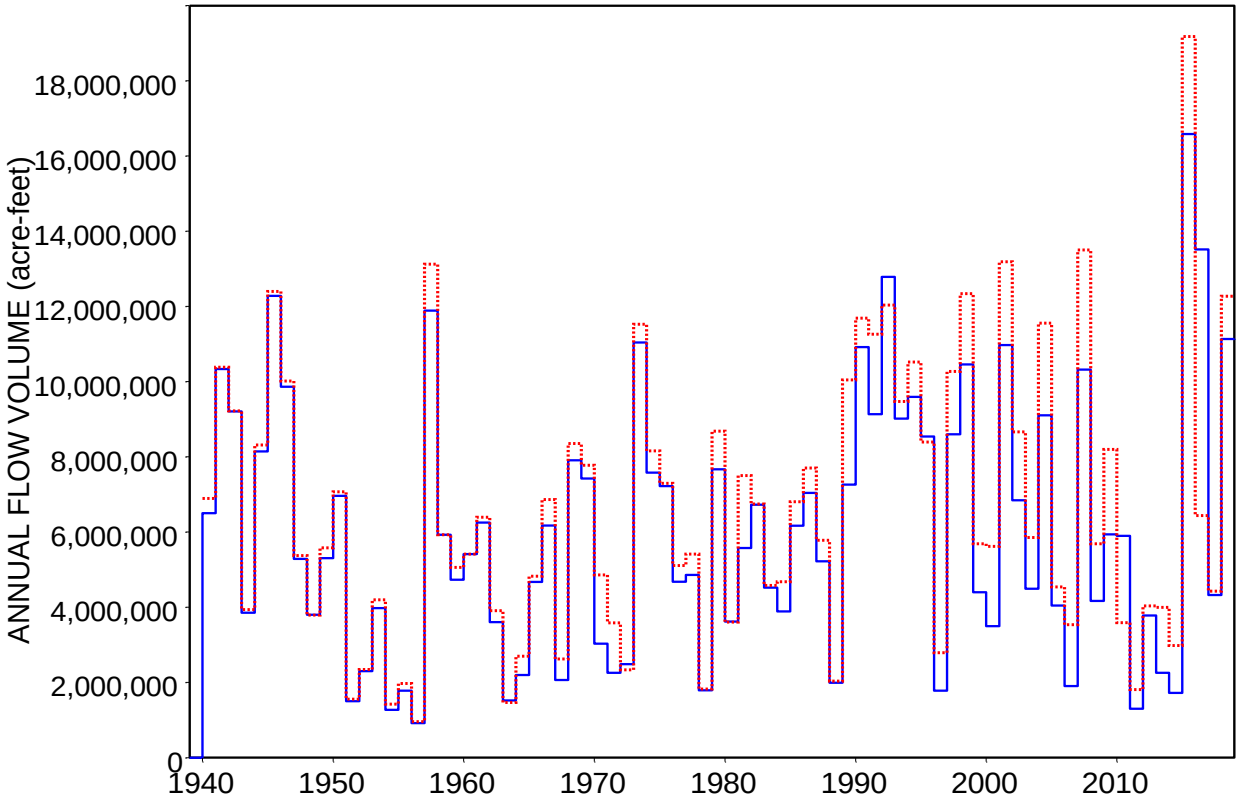

Figure 7.8 Observed and Naturalized Annual Flow of Trinity River at Romayor (8TRRO)

CHAPTER 8
EVAPORATION, PRECIPITATION, AND NET EVAPORATION-PRECIPITATION RATES

The original 1940-1996 hydrology developed as described in the 2002 WAM report [9] was not modified in the process of extending the period-of-analysis through December 2018. Extension of the monthly net evaporation-precipitation rates through 1997-2012 is described a 2013 hydrology extension report [12]. The same *HYD* based methodology using the Texas Water Development Board (TWDB) precipitation and evaporation datasets is applied to extend the monthly net evaporation-precipitation rates from January 1997 through December 2018.

Texas Water Development Board Evaporation and Precipitation Database

The TWDB maintains annually updated datasets of monthly precipitation and reservoir evaporation depths for the 92 one-degree latitude by one-degree longitude quadrangles shown in Figure 8.1 that cover the state of Texas. The Trinity River Basin is also delineated in Figure 8.1.

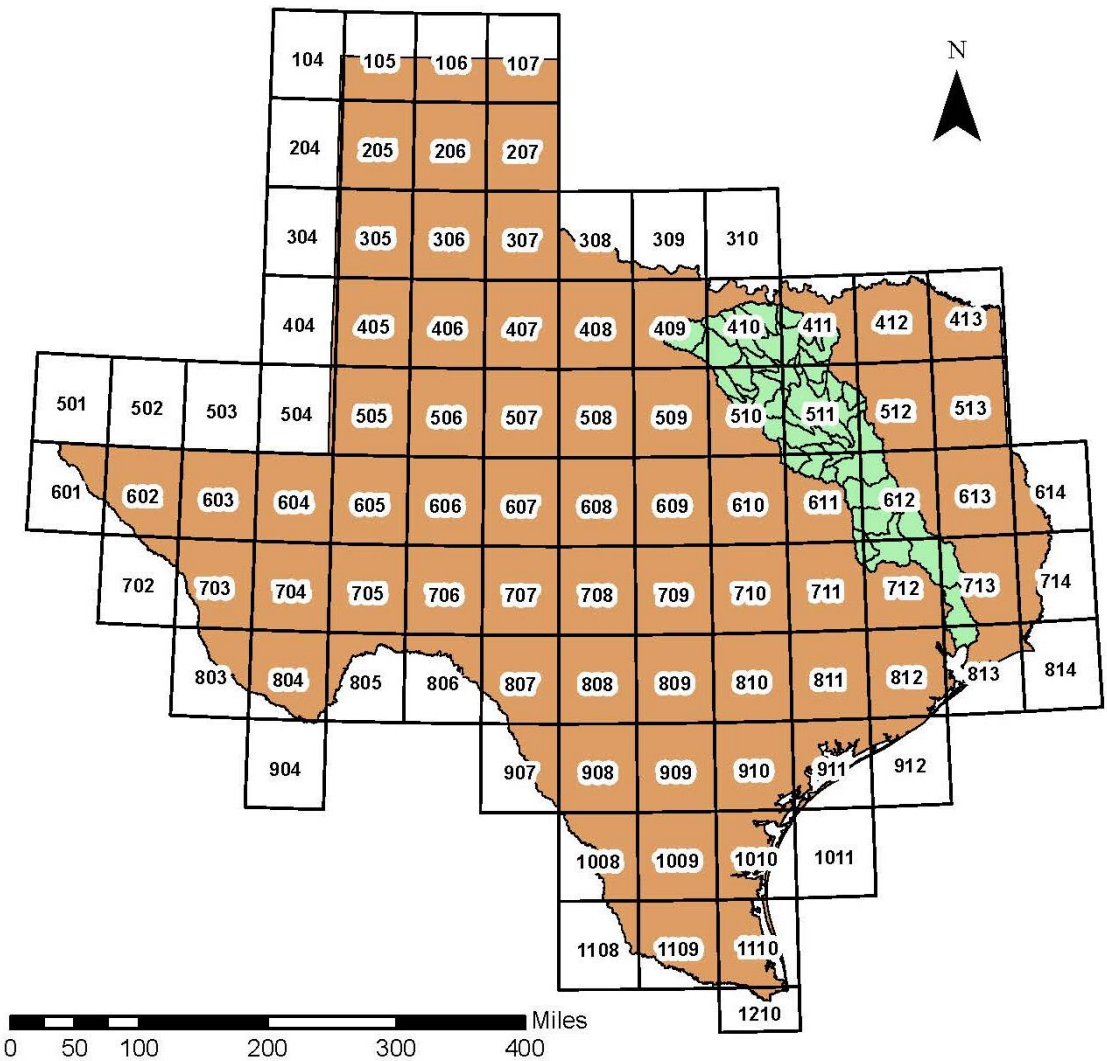

Figure 8.1 Quadrangles Encompassing Texas and the Trinity River Basin

The identifiers assigned by the TWDB for each of the quadrangles are shown in Figure 8.1. The Trinity River Basin is also delineated in Figure 8.1. The Trinity River Basin is encompassed by quadrangles 409, 410, 411, 510, 511, 611, 612, 711, 712, 713, and 813.

The TWDB evaporation and precipitation data are converted at Texas A&M University to WRAP program *HYD* input files with filenames Precipitation.PPP and Evaporation.EEE [4]. The program *HYD* consists of an assortment of routines designed to facilitate developing and updating the net evaporation-precipitation rates and naturalized flows included in *SIM* simulation input datasets. The *HYD* methodology described in Chapters 4 and 7 of the *Hydrology Manual* [4] was adopted previously [12] to extend the Trinity WAM evaporation-precipitation rates to cover 1997-2012 and again during late 2019 to extend the hydrologic period-of-analysis through 2018.

Annual means computed with *HYD* for the 1940-2018 precipitation depths and 1954-2018 reservoir evaporation depths for each of the 92 quadrangles are shown in Figure 8.2. The top number in each cell of Figure 8.2 is the mean annual precipitation in inches/year. The bottom number is the mean annual evaporation depth in inches/year. The statewide averages of the monthly precipitation and evaporation depths are plotted in Figures 8.3 and 8.4 [4].

			16.9	17.8	18.7	21.0	24.1						
			60.2	67.3	67.1	64.5	59.9						
			16.8	18.4	20.4	24.0	27.8						
			63.4	66.1	66.2	64.0	59.3						
			16.7	18.3	20.7	22.2	26.0	30.9					
			63.0	63.7	65.8	66.0	64.4	59.2					
			16.0	18.1	22.8	23.0	25.5	29.8	34.6	40.9	46.2	49.0	51.1
			63.8	65.6	68.1	70.0	64.8	60.9	55.5	53.5	52.7	43.5	39.8
			15.5	17.2	20.7	22.7	26.4	30.2	33.9	38.8	43.6	47.8	50.8
			68.2	71.2	70.2	65.7	63.4	59.4	57.6	57.0	54.8	49.3	45.7
10.9	14.5	14.8	11.7	13.5	18.1	21.4	24.8	29.1	33.2	38.5	44.2	49.3	53.4
69.7	70.4	64.9	68.1	70.9	68.6	66.0	65.8	56.7	56.5	59.1	52.8	47.5	49.0
9.29	15.7	13.8	15.0	13.7	19.0	22.6	25.5	30.5	33.2	40.0	46.7	54.6	56.8
70.0	62.6	55.7	58.1	63.1	63.0	61.9	57.2	54.2	52.4	53.8	49.9	45.5	46.7
		20.2	14.7	11.8	16.9	24.6	26.8	31.5	34.6	41.8	47.6	49.2	57.2
		56.0	55.8	65.5	68.9	67.0	56.8	53.6	52.7	49.9	47.1	46.1	45.8
						20.9	22.1	25.5	35.2	39.8	44.4		
						67.1	59.4	57.1	52.9	50.3	48.4		
							20.5	24.1	29.5	34.8			
							65.2	63.6	59.1	54.6			
							17.9	21.8	26.0				
							64.8	61.3	61.9				
									26.2				
									60.8				

Figure 8.2 Mean Annual Precipitation and Reservoir Evaporation Depths in inches/year for Each of 92 Quadrangles from the TWDB Database

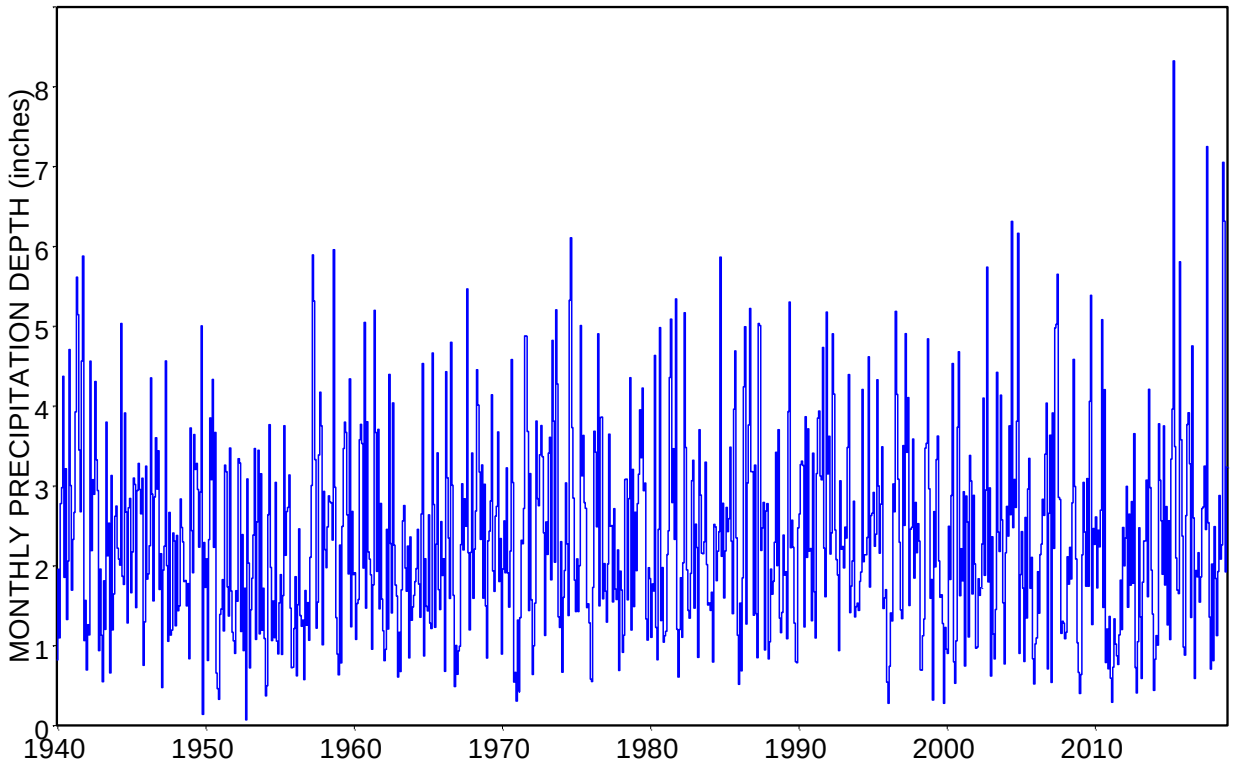

Figure 8.3 Statewide Mean 1940-2018 Monthly Precipitation Depths in inches/month

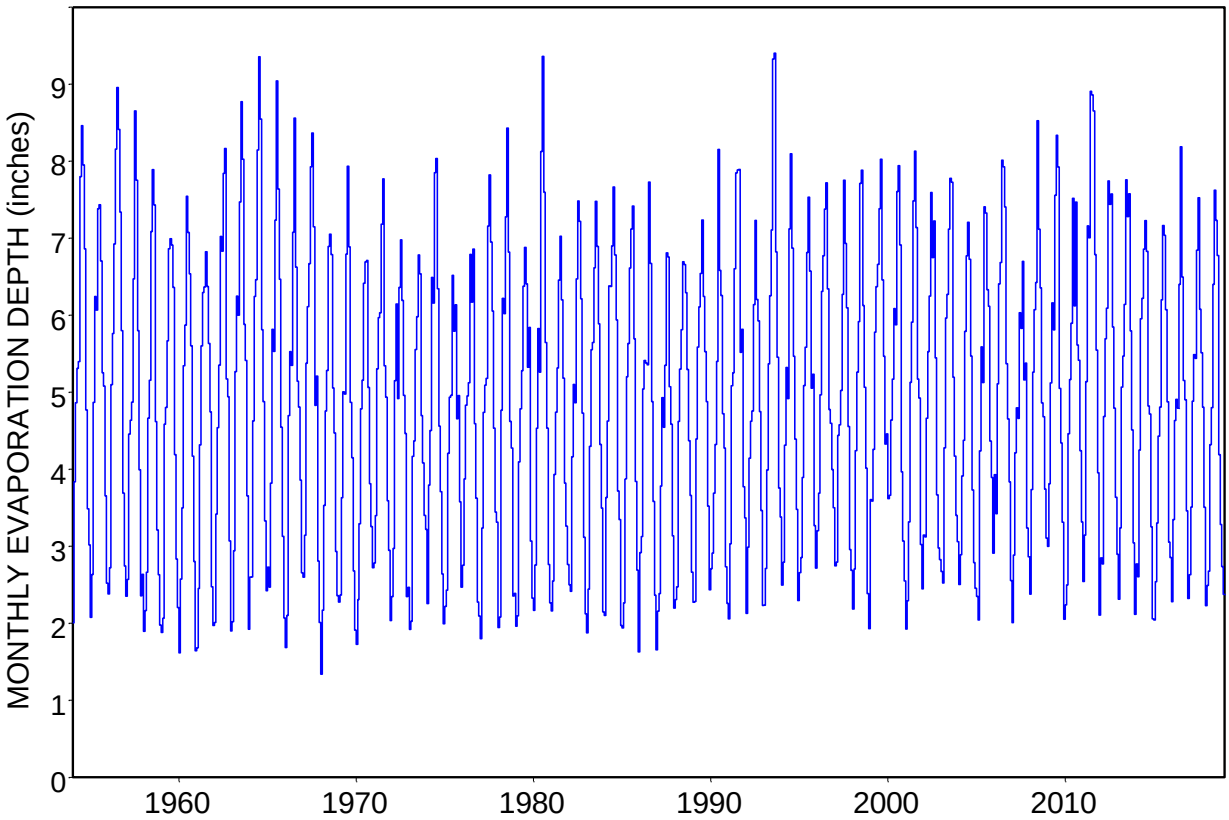

Figure 8.4 Statewide Mean 1954-2018 Monthly Reservoir Evaporation Depths in inches/month

Evaporation-Precipitation Depths Assigned to 50 Control Point Identifiers

Evaporation from a reservoir and precipitation falling directly on the reservoir water surface are combined as a net evaporation minus precipitation. Net evaporation less precipitation volumes are computed within the *SIM* or *SIMD* simulation by multiplying the simulated reservoir water surface area in acres by net evaporation-precipitation rates in units of feet/month provided as input. Monthly net evaporation less precipitation depths are assigned to 50 control point identifiers as explained in the original 2002 WAM report [9] and 2013 hydrology extension report [12]. Nineteen of the 50 control point identifiers reference the 19 quadrangles shown in Figure 8.5 and listed in Table 8.1 with their control point identifiers.

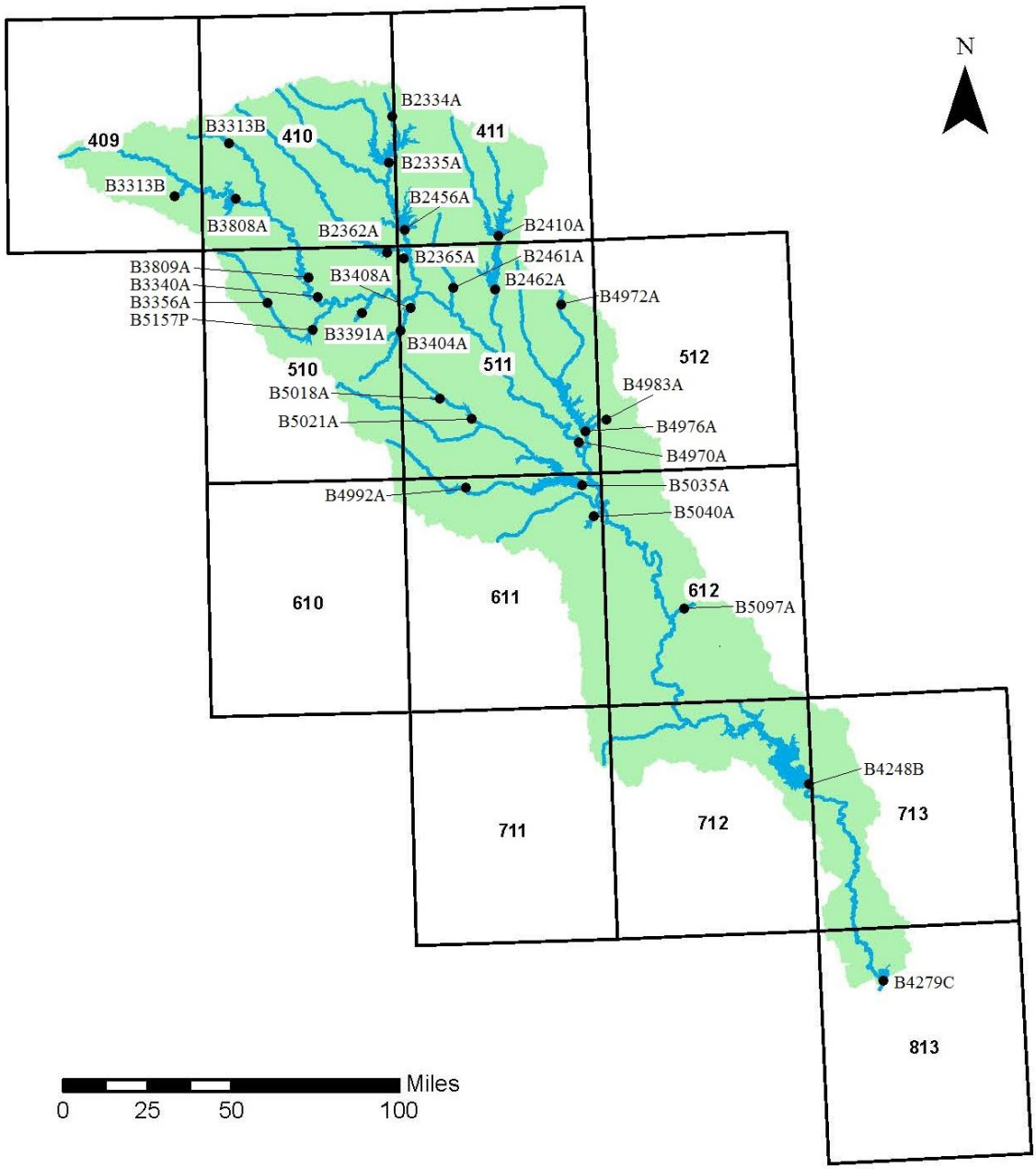

Figure 8.5 Reservoir Evaporation-Precipitation Control points and Quadrangles

Table 8.1
Control Points and Associated TWDB Quadrangles

Control Point	TWDB Quadrangle
EV409	409
EV410	410
EV411	411
EV412	412
EV509	509
EV510	510
EV511	511
EV512	512
EV610	610
EV611	611
EV612	612
EV613	613
EV711	711
EV712	712
EV713	713
EV714	714
EV812	812
EV813	813
EV814	814

The monthly evaporation-precipitation depths assigned to the 19 control point identifiers listed in Table 8.1 are applied to over 650 reservoirs in the WAM simulation. The other 31 control points refer to the large reservoirs listed in Table 8.2. Evaporation and precipitation depths for the 31 reservoirs are computed using weighting factors for multiple quadrangles, which are tabulated in Table 8.2.

Adjustments for Reservoir Site Rainfall Runoff Reflected in Naturalized Flows

Precipitation depths are adjusted 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, only a portion of this precipitation contributes to stream flow. The remainder is lost through infiltration and other hydrologic abstractions. With the reservoir in place, all of the precipitation falling on the water surface is inflow to the reservoir.

The WRAP simulation models *SIM* and *SIMD* include an option activated by parameters on the *JD* and *CP* records designed to account for the fact that a portion of the rain falling on the reservoir water surface is also reflected in the naturalized flows. The adjustment computations are performed during the *SIM/SIMD* simulation based on computed reservoir water surface area. However, this option is not employed in the Trinity WAM. Rather, the net evaporation-precipitation rates are adjusted during the process of creating the input data file [9]. The modified methodology for performing these adjustments is explained in the 2013 extension report [12]. The adjustment consists of applying the multiplier factors in Tables 8.3 and 8.4 to the precipitation depths in the process of extending the monthly net evaporation-precipitation depths past 1996.

Table 8.2
Control Points and Associated Reservoirs and Weighting Equations

CP ID	Reservoir	Quadrangle Weighting Equation
B3320B	Lake Amon G. Carter	0.419 (409) + 0.581 (410)
B4279C	Lake Anahuac	0.161 (712) + 0.227 (713) + 0.205 (812) + 0.407 (813)
B3391A	Lake Arlington	0.175 (410) + 0.147 (411) + 0.448 (510) + 0.230 (511)
B5021A	Bardwell Lake	0.185 (510) + 0.508 (511) + 0.131 (610) + 0.175 (611)
B5157P	Benbrook Lake	1.000 (510)
B3808A	Lake Bridgeport	0.256 (409) + 0.367 (410) + 0.174 (509) + 0.203 (510)
B3809A	Eagle Mountain Lake	0.384 (410) + 0.616 (510)
B5040A	Fairfield Lake	0.204 (511) + 0.194 (512) + 0.316 (611) + 0.286 (612)
B2362A	Grapevine Lake	0.269 (410) + 0.226 (411) + 0.274 (510) + 0.231 (511)
B5030A	Lake Halbert	0.574 (511) + 0.426 (611)
B5097A	Houston County Lake	0.123 (611) + 0.695 (612) + 0.079 (711) + 0.103 (712)
B3404A	Joe Pool Lake	0.157 (410) + 0.155 (411) + 0.347 (510) + 0.340 (511)
B2334A	Lake Kiowa	0.528 (410) + 0.472 (411)
B2410A	Lavon Lake	0.561 (411) + 0.439 (511)
B2456A	Lewisville Lake	0.277 (410) + 0.286 (411) + 0.216 (510) + 0.221 (511)
B4248B	Lake Livingston	0.181 (612) + 0.164 (613) + 0.382 (712) + 0.273 (713)
B3408A	Mountain Creek Lake	0.159 (410) + 0.179 (411) + 0.312 (510) + 0.350 (511)
B4992A	Navarro Mills Lake	0.193 (510) + 0.268 (511) + 0.212 (610) + 0.327 (611)
B2365A	North Lake	0.250 (410) + 0.250 (411) + 0.250 (510) + 0.250 (511)
B2462A	Lake Ray Hubbard	0.366 (411) + 0.634 (511)
B2335A	Ray Roberts Lake	0.402 (410) + 0.309 (411) + 0.147 (510) + 0.142 (511)
B5035A	Richland-Chambers Reservoir	0.281 (511) + 0.207 (512) + 0.300 (611) + 0.212 (612)
B4972A	New Terrell City Lake	0.185 (411) + 0.417 (511) + 0.156 (412) + 0.242 (512)
B5018A	Lake Waxahachie	0.240 (510) + 0.456 (511) + 0.141 (610) + 0.163 (611)
B3356A	Lake Weatherford	0.145 (409) + 0.192 (410) + 0.201 (509) + 0.463 (510)
B2461A	White Rock Lake	0.167 (410) + 0.221 (411) + 0.211 (510) + 0.400 (511)
B3340A	Lake Worth	0.306 (410) + 0.694 (510)
B4970A	Trinidad Lake	0.314 (511) + 0.256 (512) + 0.229 (611) + 0.202 (612)
B4976A	Cedar Creek Reservoir	0.415 (511) + 0.252 (512) + 0.179 (611) + 0.155 (612)
B4983A	Forest Grove Reservoir	0.289 (511) + 0.340 (512) + 0.181 (611) + 0.190 (612)
B3313B	Lost Creek Reservoir	0.386 (409) + 0.247 (410) + 0.197 (509) + 0.171 (510)

Extending the Net Evaporation-Precipitation Depths

An EVA or DSS file with 1940-2018 net evaporation-precipitation rates is created by executing *HYD* with the following input files. The *HYD* input HIN file (filename extension HIN) contains the information tabulated in Tables 8.1 through 8.4. *HYD* also includes options for recording evaporation rates and precipitation rates as well as net evaporation-precipitations rates in a DSS file using these input files.

HIN file controlling the 1997-2018 evaporation-precipitation update.
EVA file from Trinity WAM with 1940-1996 evaporation-precipitation rates.
Evaporation.EEE file with TWDB statewide 1940-2018 evaporation data.
Precipitation.PPP file with TWDB statewide 1940-2018 precipitation data.

A file with filename TrinityEvapPrecip.DSS is included in the set of DSS files that accompany this report. The file TrinityEvapPrecip.DSS contains fifty sequences of 1954-2018 monthly evaporation rates and fifty sequences of 1940-2018 monthly precipitation rates from the TWDB datasets (in inches) as well as the fifty 1940-2018 sequences of net evaporation less precipitation depths (in feet). The fifty 1954-2018 evaporation and 1940-2018 precipitation sequences include quantities read directly from the TWDB database for the 19 quadrangles encompassing the Trinity River Basin listed in Table 8.1 and weighted averages for the 31 control points listed in Table 8.2. Time series plots are created and statistical analyses are performed for these datasets using *HEC-DSSVue*. *HYD* also includes options for computing statistics.

The 50 sequences of 1940-2018 monthly net evaporation-precipitation rates are also stored in a hydrology DSS file read by *SIM* or *SIMD* along with the monthly naturalized flows and daily pattern flows. The evaporation-precipitation depths can be read by *SIM* or *SIMD* from either an EVA text file or binary hydrology DSS file. The original 1940-1996 WAM evaporation-precipitation rates are adopted without change and extended through 1997-2018 as described here.

Creation of the program *HYD* input HIN input file required significant time and effort [12]. However, future updates of the WAM net evaporation-precipitation data using the same HIN file can be readily performed after updating the Evaporation.EEE and Precipitation.PPP files following TWDB completion of the update of the quadrangle precipitation and evaporation files each year.

Table 8.3
Precipitation Multiplier Factors Applied in the
HYD Evaporation-Precipitation Extension for 19 Quadrangles

Control Point	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
EV409	0.8382	0.9301	0.9179	0.9238	0.8562	0.8848	0.9651	0.9881	0.9808	0.9411	0.8982	0.9484
EV410	0.9086	0.8750	0.8773	0.8768	0.8320	0.8691	0.9438	0.9790	0.9813	0.9656	0.9022	0.8944
EV411	0.6791	0.6389	0.6774	0.6946	0.6854	0.7617	0.8921	0.9805	0.9507	0.9120	0.8324	0.7435
EV412	0.8069	0.7629	0.7837	0.8112	0.7479	0.8209	0.9455	0.9835	0.9593	0.9167	0.8817	0.8370
EV509	0.9331	0.9290	0.9154	0.9301	0.8949	0.9117	0.9566	0.9663	0.9774	0.9865	0.9586	0.9625
EV510	0.8433	0.9071	0.8732	0.8649	0.8291	0.8916	0.9702	0.9779	0.9809	0.9433	0.9441	0.9053
EV511	0.7910	0.7404	0.7717	0.7616	0.7524	0.8219	0.9760	0.9753	0.9724	0.9223	0.8638	0.8005
EV512	0.6301	0.6429	0.6563	0.6974	0.7418	0.8270	0.9168	0.9727	0.9706	0.9521	0.8603	0.7664
EV610	0.8347	0.7975	0.8298	0.7977	0.7869	0.8274	0.8131	0.9532	0.9682	0.8908	0.8626	0.8726
EV611	0.8274	0.7488	0.7851	0.8318	0.7205	0.8527	0.9680	0.9784	0.9640	0.9364	0.8954	0.8247
EV612	0.6854	0.6839	0.6749	0.7103	0.7464	0.8112	0.7842	0.9623	0.9761	0.9484	0.8928	0.8272
EV613	0.5805	0.5697	0.5782	0.5903	0.7186	0.8009	0.8624	0.9324	0.9193	0.8963	0.8337	0.7485
EV711	0.8758	0.8602	0.8889	0.8852	0.8752	0.8914	0.9479	0.9905	0.9773	0.9137	0.9425	0.9171
EV712	0.6666	0.6638	0.7222	0.7445	0.7972	0.8301	0.9005	0.9529	0.9417	0.8972	0.8209	0.8017
EV713	0.5497	0.5411	0.5321	0.6624	0.7199	0.8015	0.8417	0.9054	0.9041	0.8647	0.8042	0.7339
EV714	0.5843	0.5330	0.5754	0.6530	0.6951	0.7938	0.8811	0.9177	0.9052	0.8131	0.7920	0.7391
EV812	0.6096	0.6635	0.7557	0.6919	0.6409	0.5039	0.5451	0.6430	0.6356	0.4161	0.7179	0.7188
EV813	0.3301	0.2078	0.2417	0.4543	0.5475	0.6967	0.7008	0.8929	0.8905	0.7513	0.6477	0.5756
EV814	0.5824	0.3838	0.2298	0.5444	0.6485	0.7347	0.8237	0.9149	0.9041	0.7333	0.7359	0.6594

Table 8.4
Precipitation Multiplier Factors Applied in the *HYD* Evaporation-Precipitation Extension for the Individual Large Reservoirs Listed in Table 8.2

Control Point	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
B3320B	0.9310	0.8948	0.8911	0.8867	0.8427	0.8725	0.9579	0.9682	0.9773	0.9176	0.9266	0.8954
B4279C	0.5163	0.4835	0.5201	0.6356	0.6697	0.7073	0.7463	0.8565	0.8475	0.7617	0.7313	0.6834
B3391A	0.8183	0.8125	0.8102	0.8131	0.7836	0.8456	0.9710	0.9770	0.9759	0.9251	0.9006	0.8456
B5021A	0.8183	0.7710	0.7952	0.7941	0.7618	0.8368	0.9279	0.9733	0.9670	0.9228	0.8908	0.8284
B5157P	0.8433	0.9071	0.8732	0.8649	0.8291	0.8916	0.9702	0.9779	0.9809	0.9433	0.9441	0.9053
B3808A	0.9131	0.9158	0.8986	0.8850	0.8484	0.8829	0.9591	1.0012	0.9766	0.9753	0.9233	0.9302
B3809A	0.9118	0.9015	0.8714	0.8627	0.8293	0.8828	0.9466	0.9969	0.9796	0.9667	0.9314	0.8935
B5040A	0.7326	0.7078	0.7188	0.7471	0.7373	0.8225	0.8598	0.9700	0.9688	0.9291	0.8768	0.8054
B2362A	0.8066	0.7891	0.8017	0.8009	0.7724	0.8327	0.9056	0.9699	0.9689	0.9343	0.8772	0.8350
B5030A	0.8019	0.7370	0.7732	0.7865	0.7399	0.8297	0.9631	0.9811	0.9655	0.9280	0.8824	0.8090
B5097A	0.7083	0.6963	0.7047	0.7390	0.7538	0.8252	0.8311	0.9565	0.9676	0.9441	0.8880	0.8292
B3404A	0.8228	0.7861	0.8016	0.7956	0.7739	0.8404	0.9737	0.9790	0.9714	0.9208	0.8852	0.8347
B2334A	0.7608	0.7376	0.7697	0.7820	0.7544	0.8163	0.8974	0.9853	0.9694	0.9197	0.8665	0.8091
B2410A	0.7240	0.6868	0.7172	0.7248	0.7116	0.7811	0.9313	0.9840	0.9510	0.8987	0.8420	0.7648
B2456A	0.7872	0.7742	0.7886	0.7892	0.7646	0.8235	0.9557	0.9826	0.9665	0.9263	0.8793	0.8250
B4248B	0.6216	0.6146	0.6374	0.6925	0.7524	0.8160	0.8660	0.9397	0.9321	0.8968	0.8331	0.7734
B3408A	0.8153	0.7842	0.7951	0.7956	0.7712	0.8319	0.9437	0.9718	0.9698	0.9115	0.8869	0.8313
B4992A	0.8344	0.7831	0.8025	0.8092	0.7582	0.8408	0.9495	0.9843	0.9687	0.9291	0.8964	0.8384
B2365A	0.7924	0.7738	0.7817	0.7894	0.7636	0.8226	0.9369	0.9758	0.9673	0.9102	0.8748	0.8199
B2462A	0.7412	0.6975	0.7370	0.7338	0.7219	0.7899	0.9370	0.9785	0.9634	0.9136	0.8481	0.7750
B2335A	0.7994	0.7733	0.7932	0.8011	0.7692	0.8279	0.9513	0.9708	0.9628	0.9315	0.8819	0.8367
B5035A	0.7371	0.7079	0.7260	0.7449	0.7378	0.8294	0.8755	0.9711	0.9667	0.9225	0.8713	0.8067
B4972A	0.7313	0.6975	0.7222	0.7401	0.7345	0.8110	0.9320	0.9777	0.9643	0.9131	0.8559	0.7858
B5018A	0.8269	0.7825	0.7914	0.7960	0.7660	0.8389	0.9435	0.9728	0.9731	0.9146	0.8928	0.8301
B3356A	0.8617	0.9125	0.8843	0.8832	0.8472	0.8920	0.9649	0.9958	0.9800	0.9347	0.9328	0.9018
B2461A	0.7986	0.7660	0.7816	0.7811	0.7595	0.8280	0.9112	0.9877	0.9702	0.9206	0.8698	0.8145
B3340A	0.9171	0.9065	0.8764	0.8674	0.8304	0.8849	0.9670	0.9856	0.9769	0.9425	0.9367	0.9294
B4970A	0.7210	0.6997	0.7148	0.7384	0.7424	0.8263	0.8702	0.9719	0.9685	0.9358	0.8795	0.7995
B4976A	0.7311	0.7059	0.7158	0.7365	0.7411	0.8218	0.8847	0.9783	0.9667	0.9277	0.8730	0.7987
B4983A	0.7121	0.6899	0.7076	0.7361	0.7401	0.8232	0.8708	0.9766	0.9718	0.9361	0.8668	0.7948
B3313B	0.8536	0.9344	0.9038	0.8980	0.8548	0.8843	0.9636	1.0339	0.9787	0.9007	0.9074	0.9457

Example of Net Evaporation-Precipitation Depths

Fifty 1940-2018 sequences of monthly net evaporation less precipitation depths are stored as *EV* records in the hydrology DSS file read by *SIM* and *SIMD*. The *EV* records are labeled with the control point identifiers listed in Tables 8.1 and 8.2. EV511 representing quadrangle 511 shown in Figure 8.5 and Table 8.1 is adopted here as an example. Monthly precipitation and evaporation depths in inches from the TWDB database are plotted in Figures 8.6 and 8.7. Figure 8.8 is Figure 8.6 less Figure 8.7. The *EV* records from the *SIM/SIMD* input file in feet plotted in Figure 8.9 reflect the adjustment factors of Table 8.3. The EV511 net evaporation-precipitation depths are assigned to 153 *CP* records for use with the reservoirs located at the 153 control points.

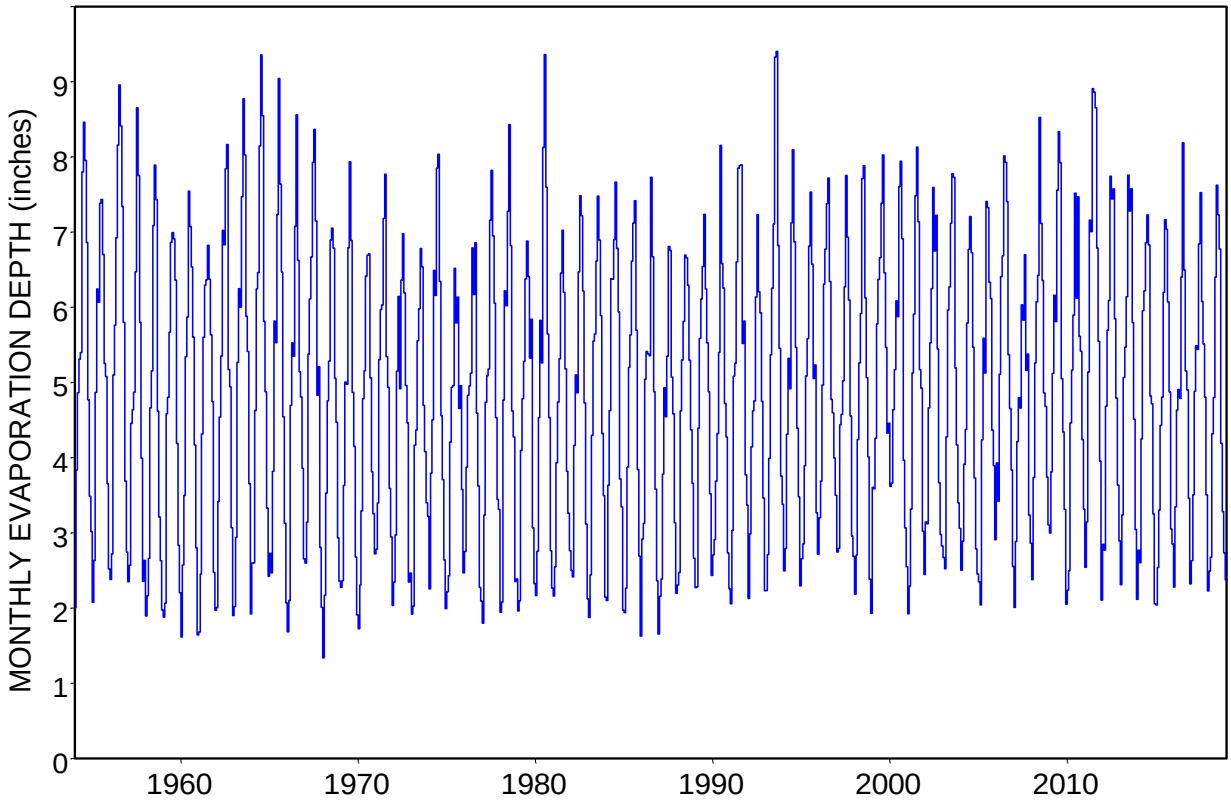

Figure 8.6 TWDB 1940-2018 Monthly Evaporation Depths (inches) for Quad 511

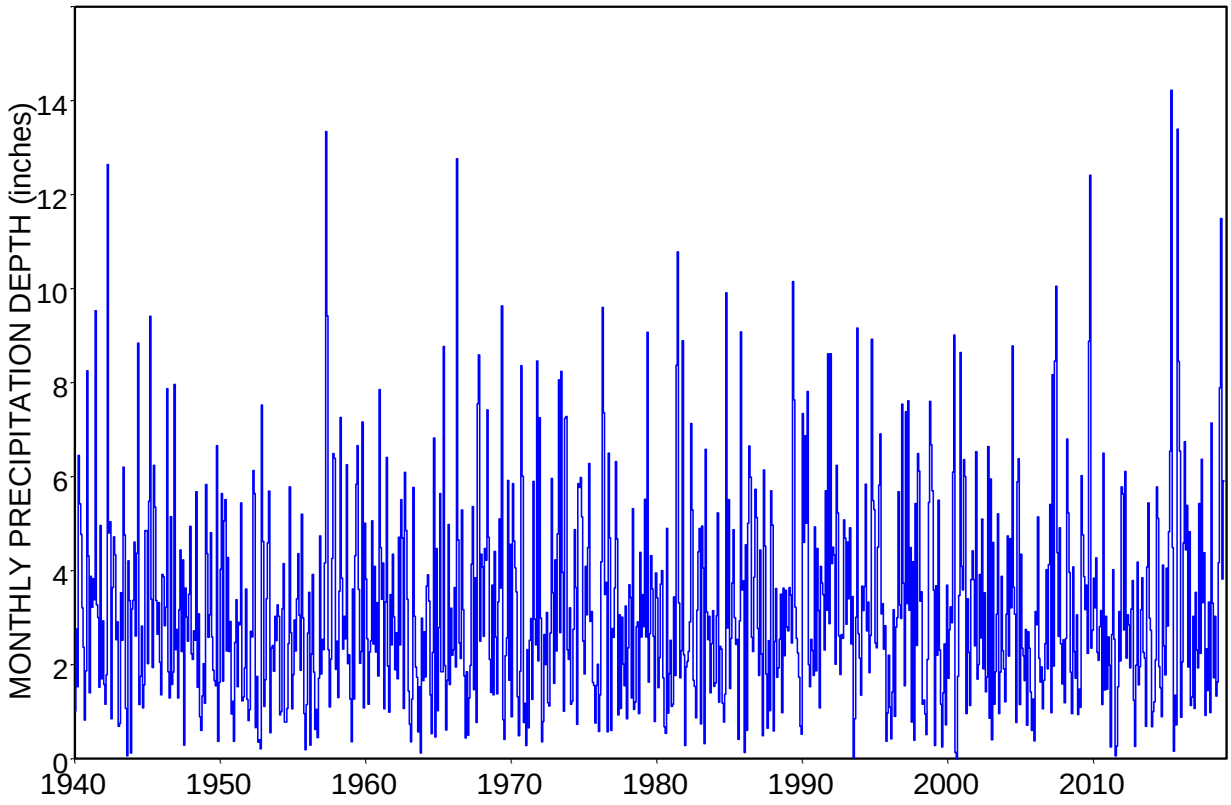

Figure 8.7 TWDB 1954-2018 Monthly Precipitation Depths (inches) for Quad 511

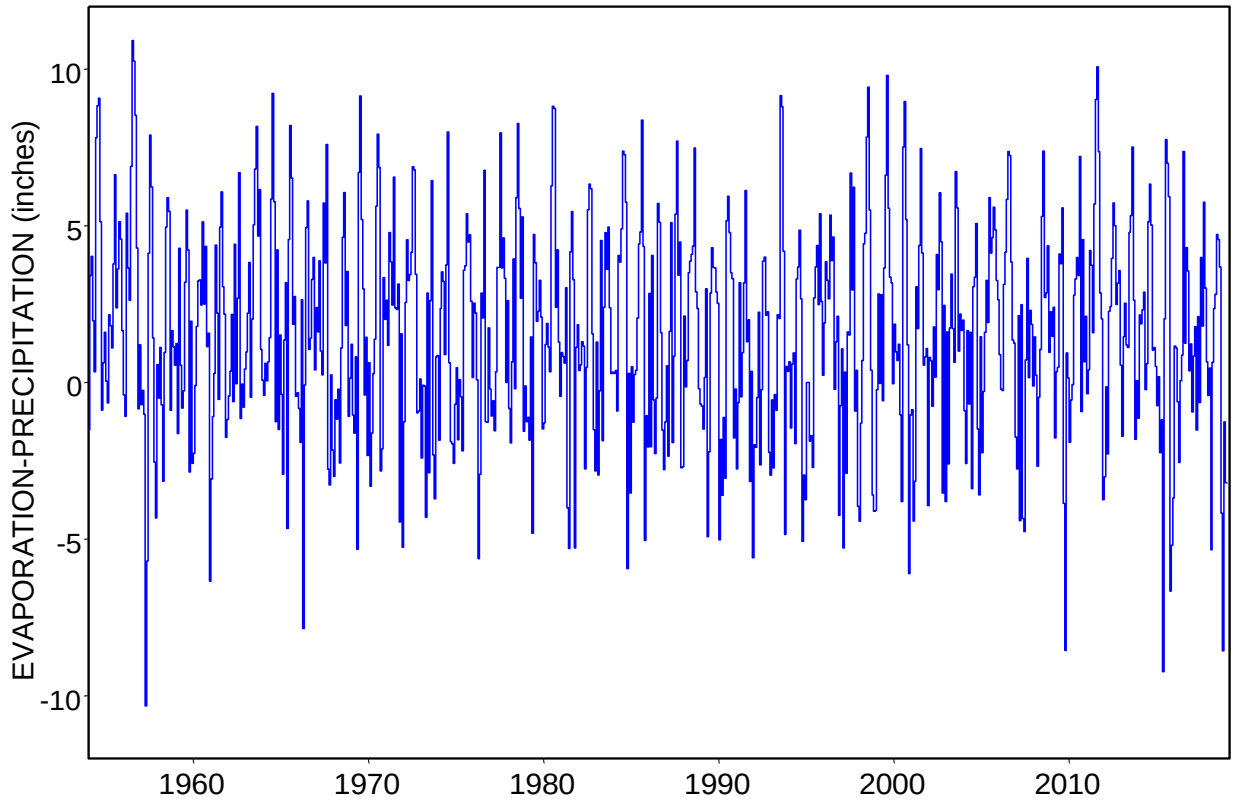

Figure 8.8 TWDB 1954-2018 Monthly Evaporation-Precipitation Depths (inches) for Quad 511

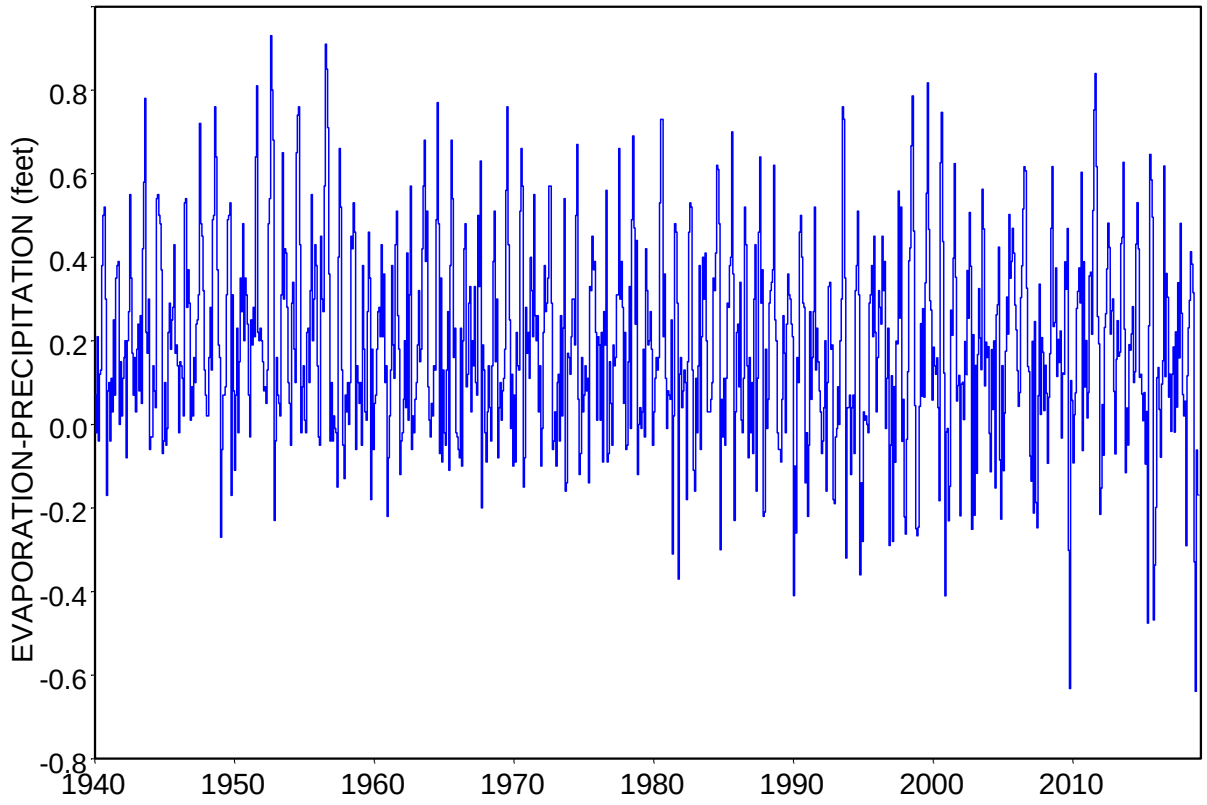

Figure 8.9 EV Record 1940-2018 Adjusted Evaporation-Precipitation Depths (feet) for EV511

CHAPTER 9
SIMULATION RESULTS FOR CURRENT USE SCENARIO

Simulation results from the current use and full authorization versions of the December 2019 Trinity WAM are summarized in Chapters 9 and 10, respectively. 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 9.1 through 9.10 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. Daily instream flow targets for the SB3 EFS are plotted in Figures 9.11 through 9.18.
3. Monthly instream flow targets for the SB3 EFS are developed as described in Chapter 5 (page 79). 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 monthly summations of daily instream flow targets for the SB3 EFS are plotted in Figures 9.19–9.21.

The following *SIM* and *SIMD* input files are employed in the simulations presented in this chapter: trin8.DAT (original DAT file last updated by TCEQ in October 2012), Trinity8DIS (same as trin8.DIS), Trinity8D.DAT, Trinity8D.DIF, TrinityHYD.DSS, and Trinity8M.DAT.

Storage Contents for Alternative Simulations
With and Without Routing and Forecasting

January 1940 through December 2010 hydrologic period-of-analysis simulated end-of-month or end-of-day reservoir storage content is adopted as a meaningful metric for comparative analyses of simulation results in Chapter 2 (Figures 2.9 – 2.18), the present Chapter 9 (Figures 9.1 – 9.10), and Chapter 10 (Figures 10.1 – 10.10). The 32 largest reservoirs in the Trinity River Basin are listed with pertinent information in Table 2.2. Their locations are shown in Figure 2.5. The storage volumes for each of the four largest reservoirs (Livingston, Richland-Chambers, Ray Roberts, Cedar Creek) are plotted in Figures 9.1 through 9.8. The summation of the storage contents of the other 28 reservoirs in Table 2.2 is plotted in Figures 9.9 and 9.10. The one monthly (M1) and four daily (D1, D2, D3, D4) alternative simulations selected for inclusion in the reservoir storage plots are defined in Table 9.1.

Table 9.1
Alternative Current Use Scenario Simulations

	Routing and Forecasting	Negative Incremental	Figures 9.1–9.10 Legend
M1	Original monthly WAM	Option 5	——— blue solid line
D1	No routing and no forecasting	Option 4	•••••• red dotted line
D2	Routing but no forecasting	Option 4	------- green dashed line
D3	Routing and 3-day forecast	Option 7	— •• — black dashes and dots
D4	Routing and 10-day forecast	Option 7	•••••• purple dotted line

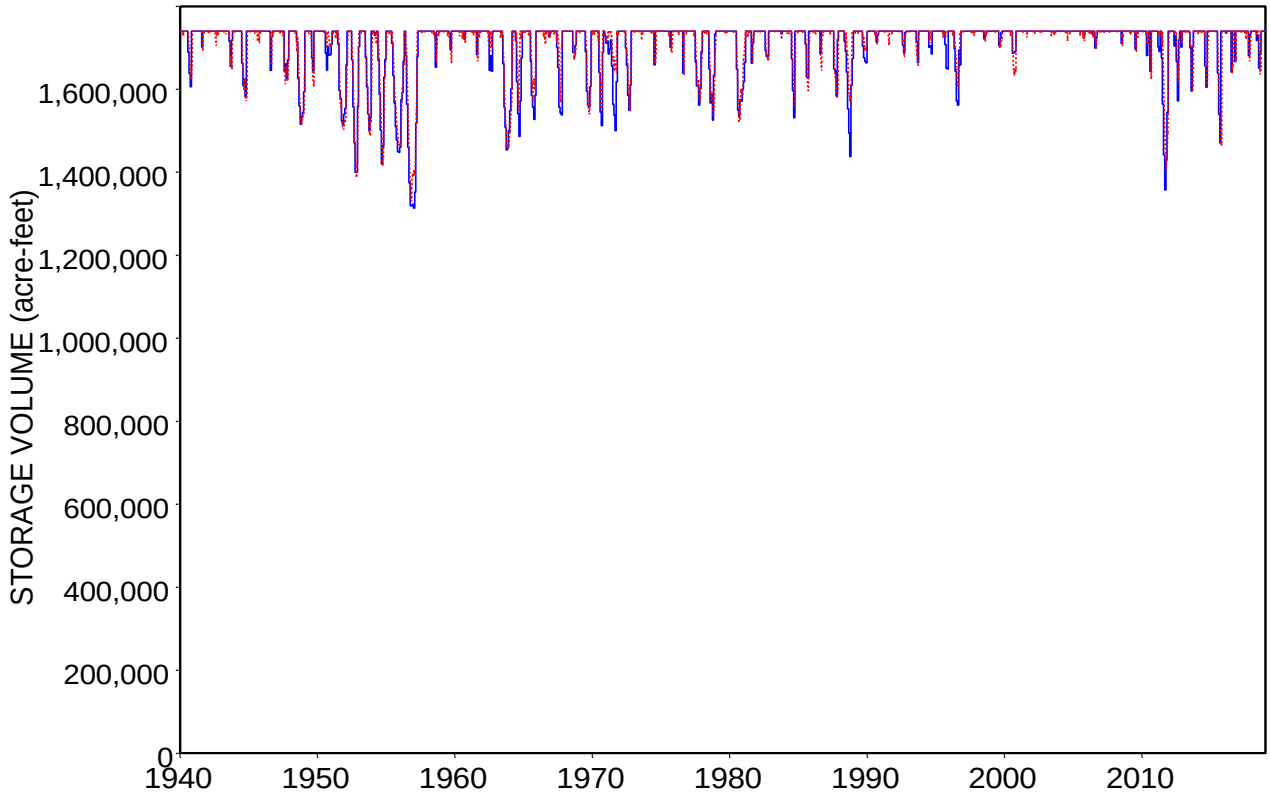

Figure 9.1 Lake Livingston Storage Contents for Simulations M1 (blue solid) and D1 (red dots)

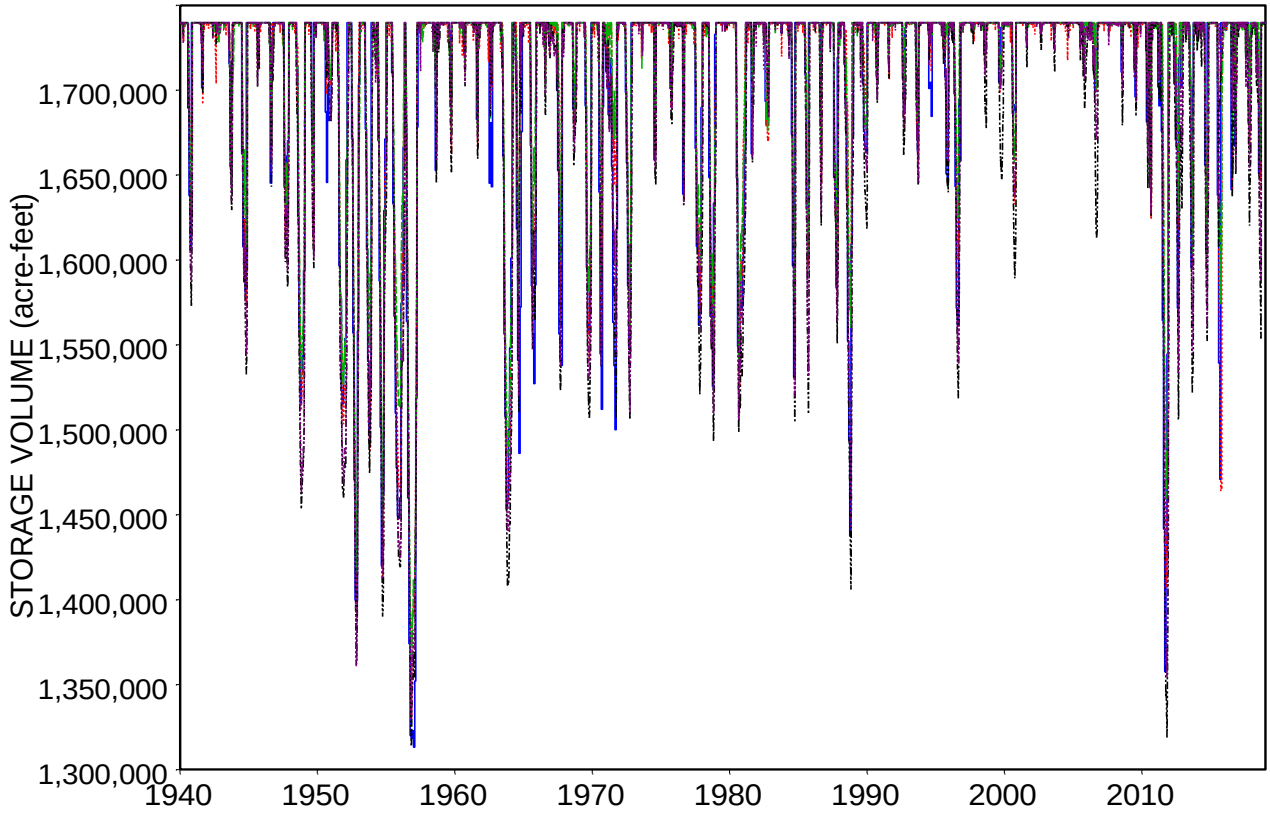

Figure 9.2 Lake Livingston Storage Contents for Simulations M1, D1, D2, D3, and D4

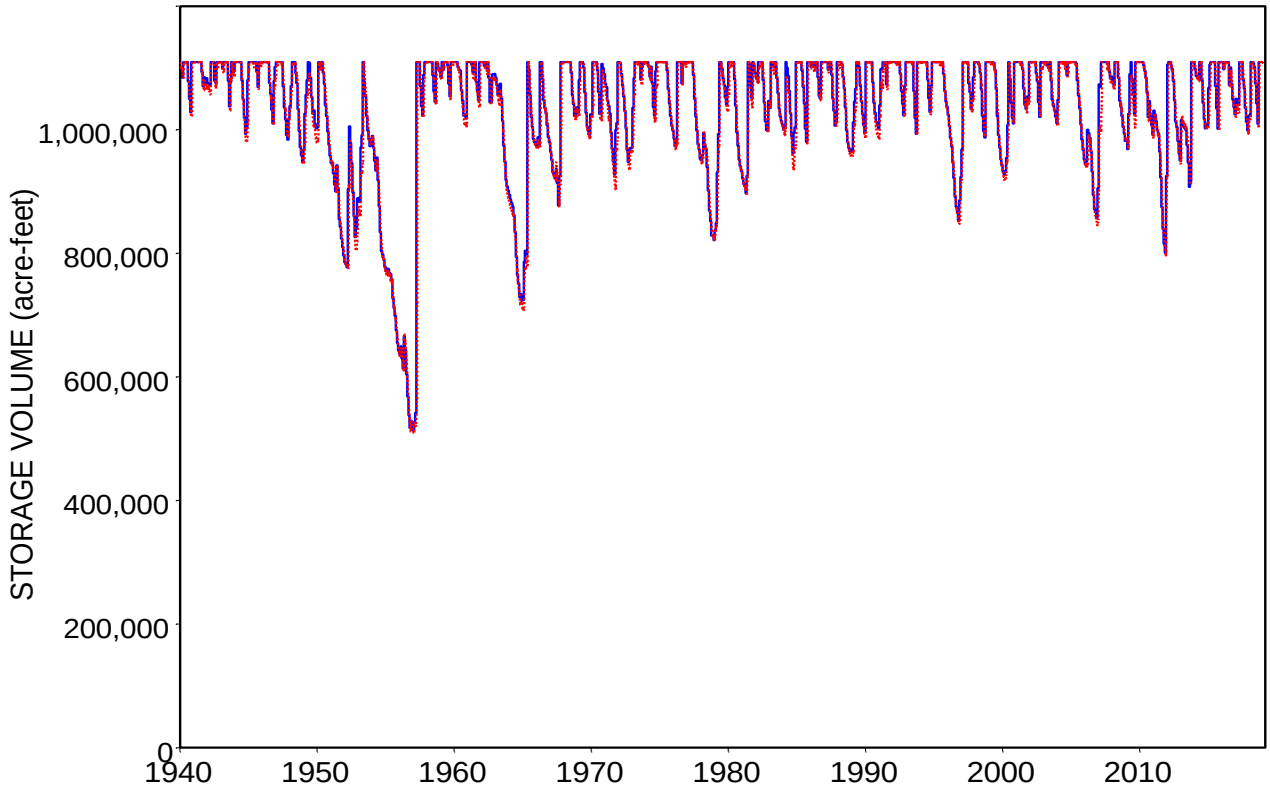

Figure 9.3 Richland-Chambers Reservoir Storage Contents for Simulations M1 and D1

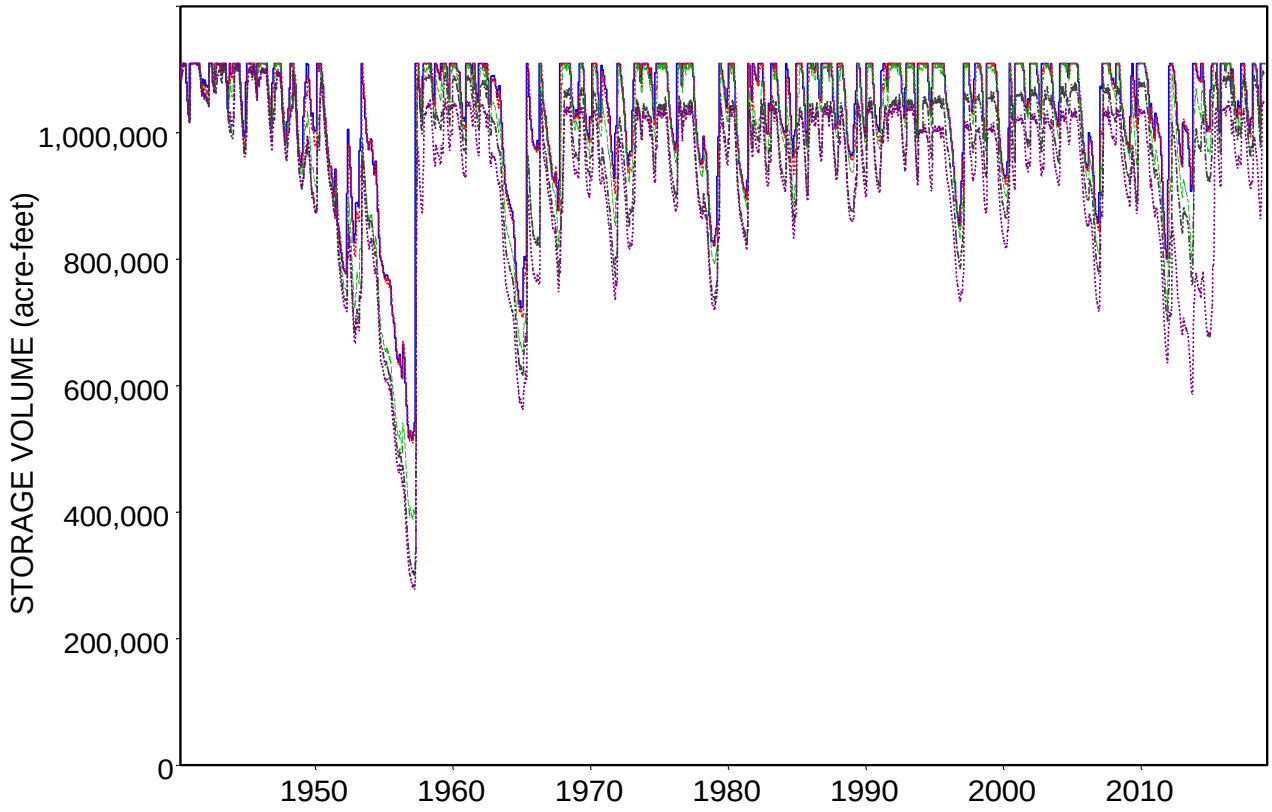

Figure 9.4 Richland-Chambers Storage Contents for Simulations M1, D1, D2, D3, and D4

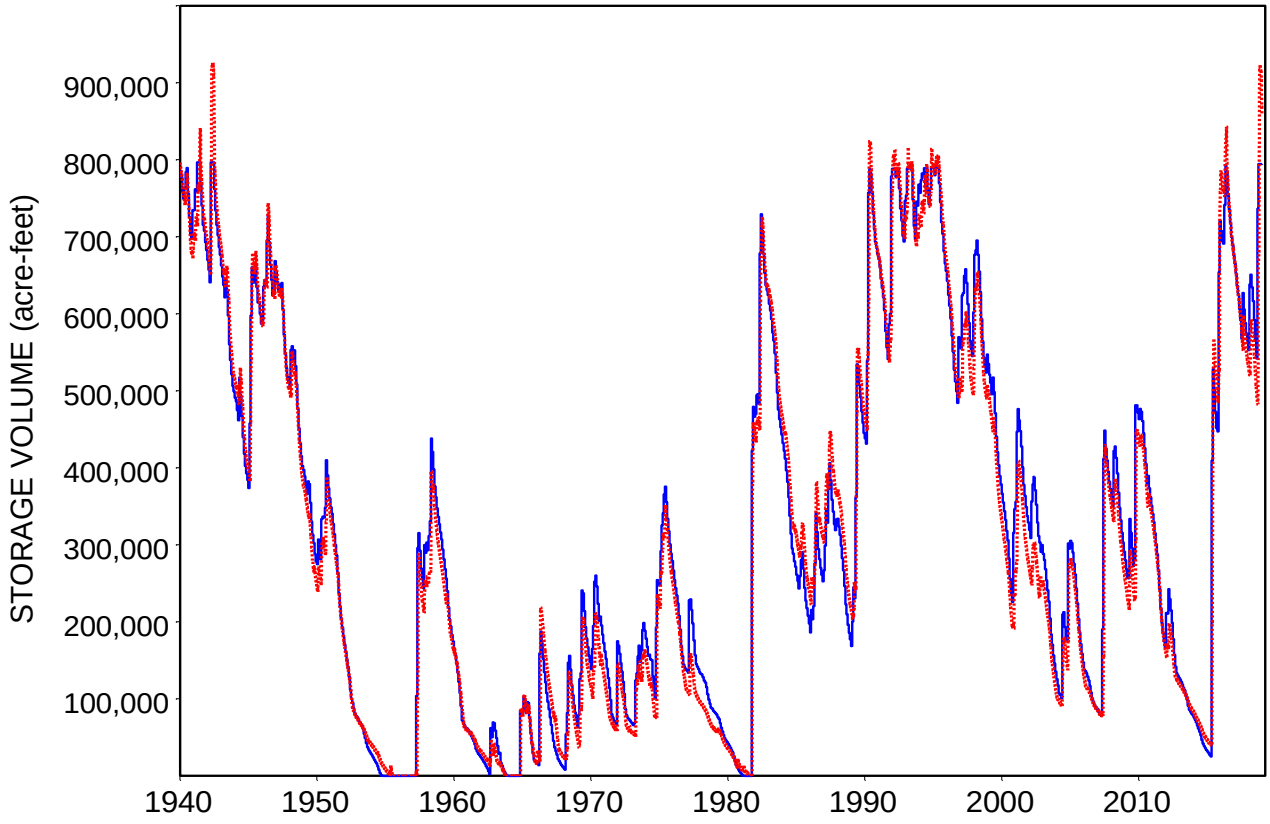

Figure 9.5 Ray Roberts Storage Contents for Simulations M1 (blue solid) and D1 (red dots)

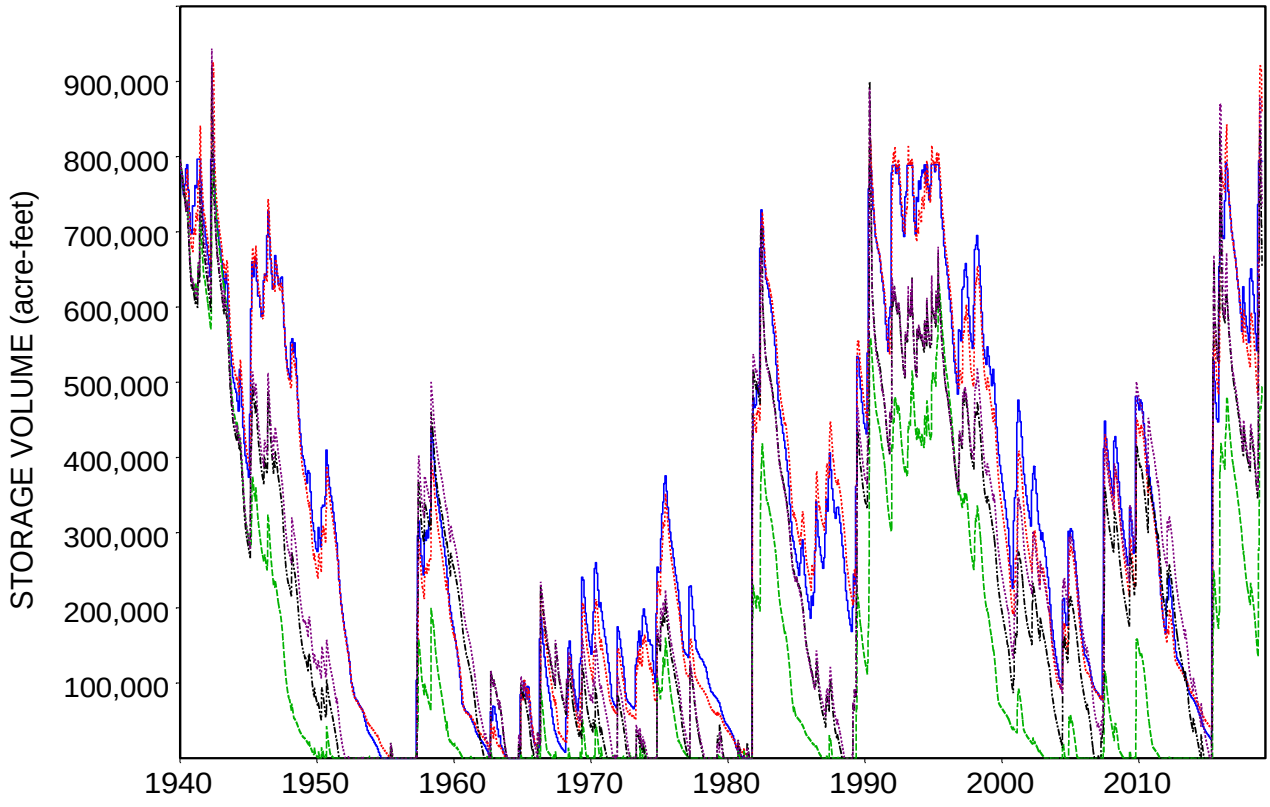

Figure 9.6 Ray Roberts Storage Contents for Simulations M1, D1, D2, D3, and D4

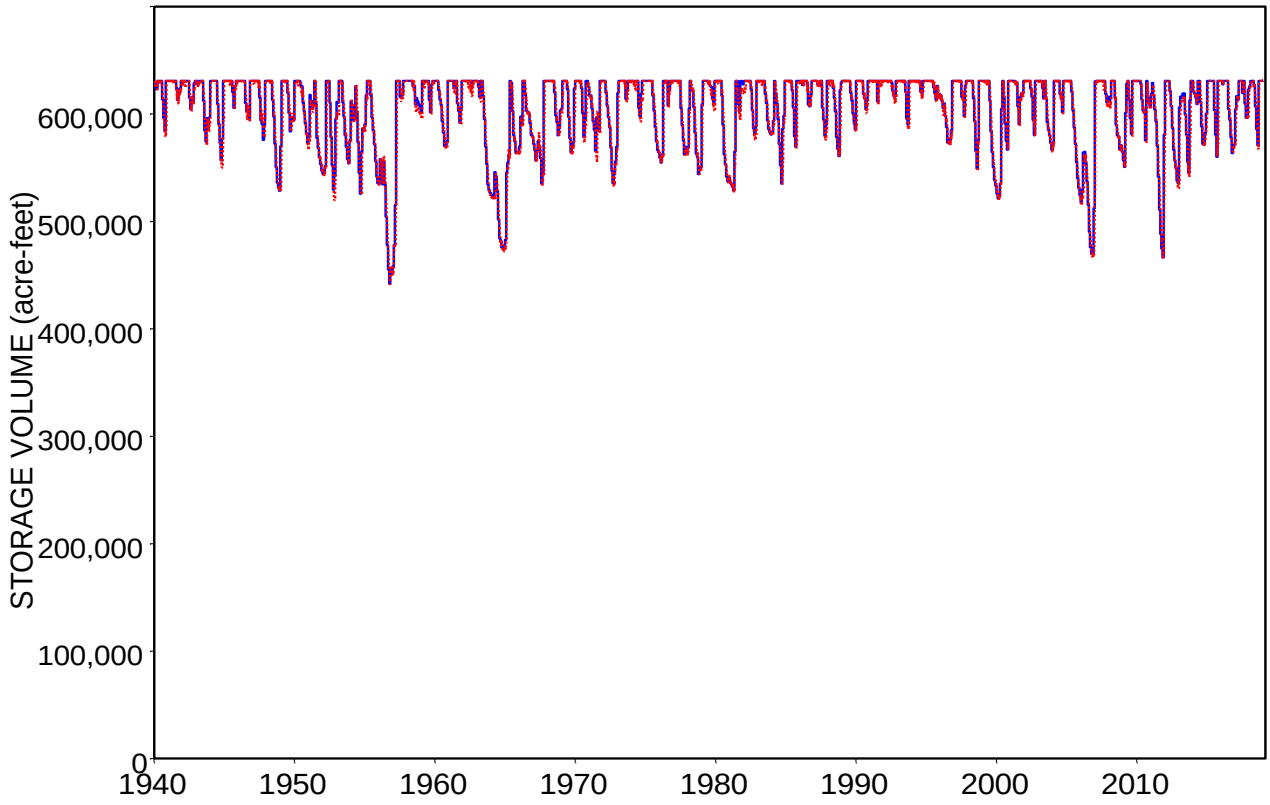

Figure 9.7 Cedar Creek Reservoir Storage Contents for Simulations M1 and D1

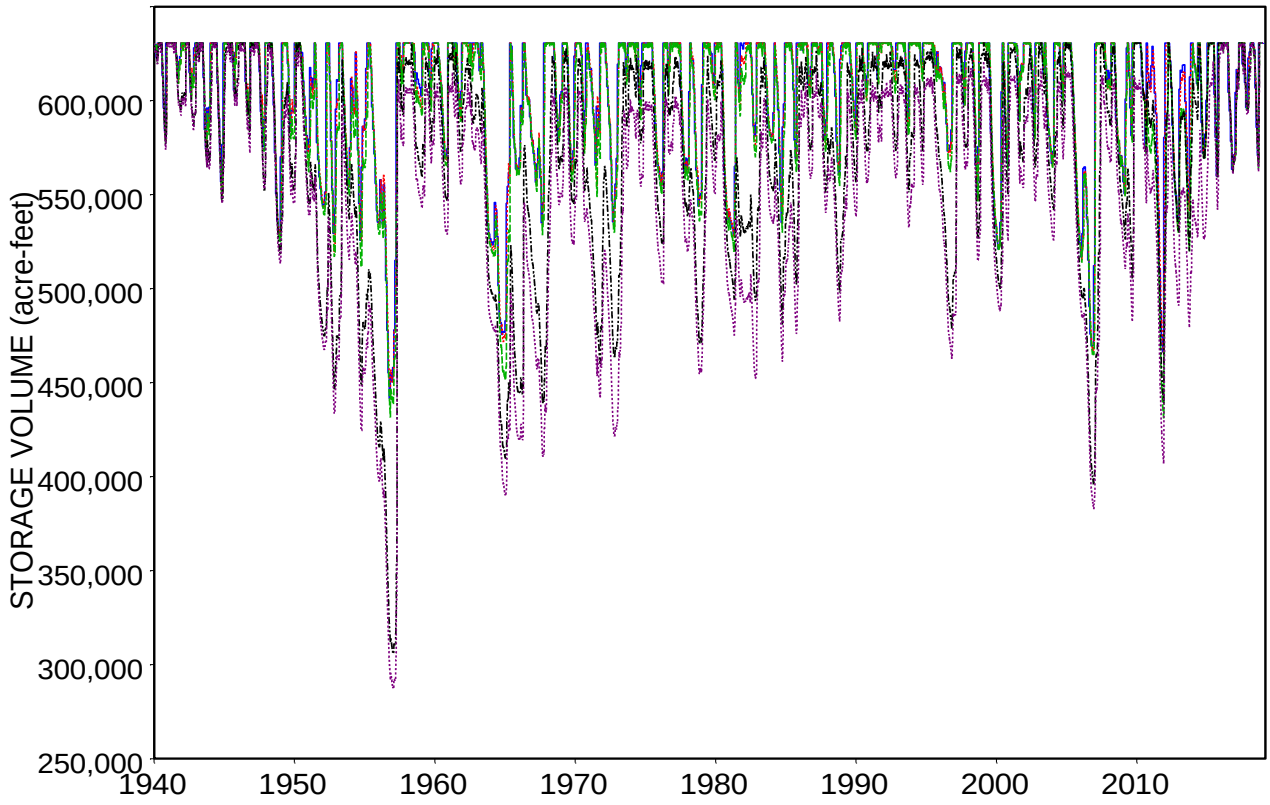

Figure 9.8 Cedar Creek Lake Storage Contents for Simulations M1, D1, D2, D3, and D4

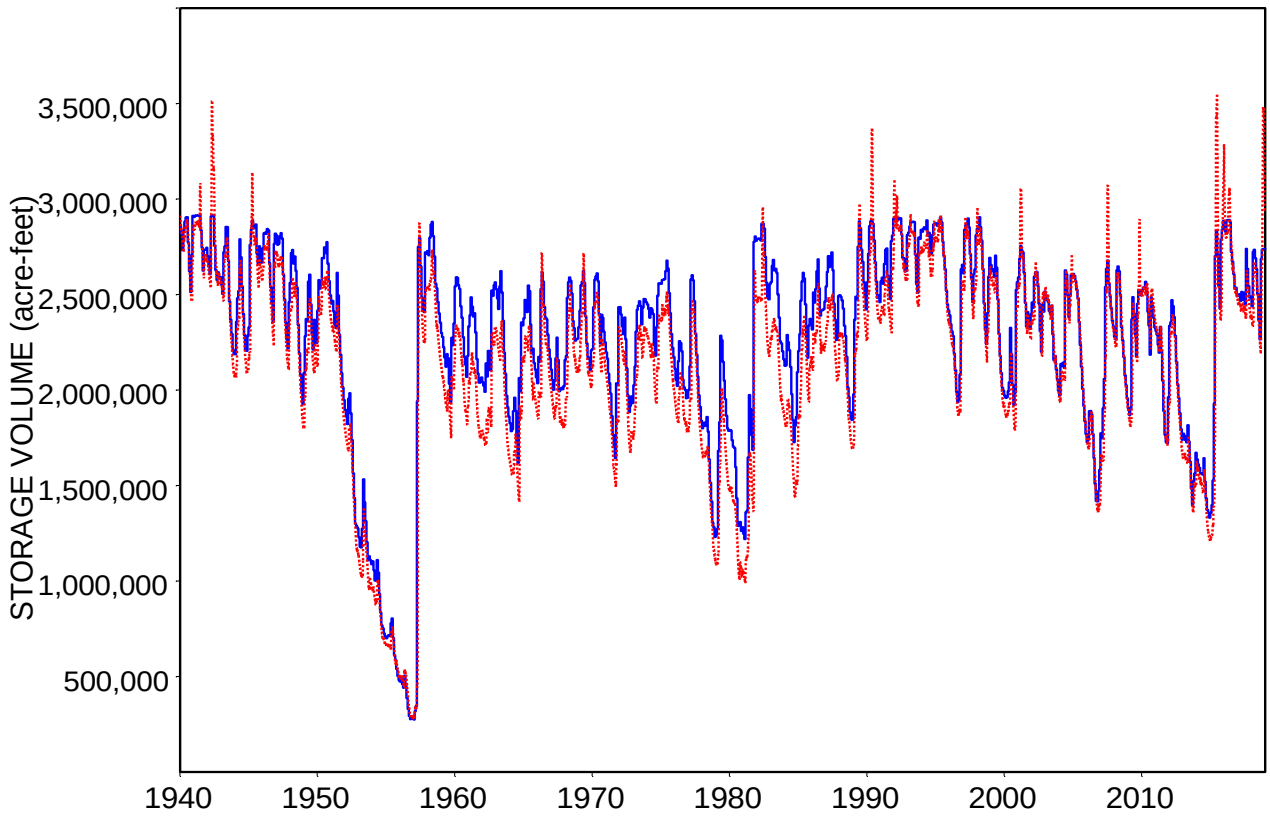

Figure 9.9 Summation of Storage in 28 Reservoirs for Simulations M1 (blue) and D1 (red dots)

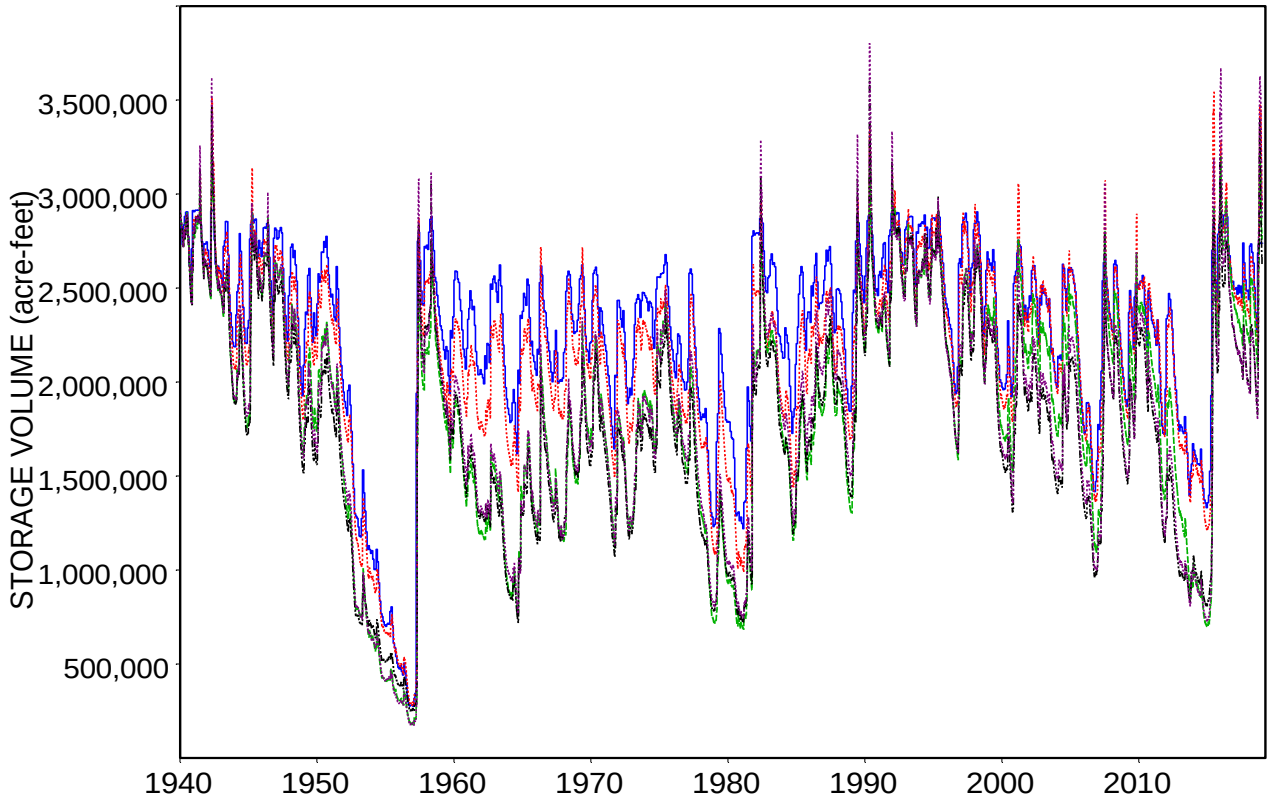

Figure 9.10 Summation of Storage in 28 Reservoirs for Simulations M1, D1, D2, D3, and D4

Simulations Included in Tables 9.1-9.3 and Figures 9.1-9.10

The means of the 948 end-of-month storage volumes from simulation M1 and the 28,885 end-of-day storage volumes from simulations D1, D2, D3, and D4 are tabulated in Table 10.2. The minimum end-of-month or end-of-day storage contents during each of the 1940-2018 simulations are shown in Table 9.3.

Table 9.2 Average Reservoir Storage Contents in acre-feet

Reservoir	Capacity	M1	D1	D2	D3	D4
Livingston	1,739,743	1,706,968	1,711,066	1,714,379	1,700,526	1,705,106
Richland-Chambers	1,199,368	1,034,770	1,029,434	1,001,810	961,488	926,653
Ray Roberts	796,474	323,195	312,551	131,002	226,491	250,552
Cedar Creek	630,550	604,388	603,218	599,713	567,753	549,881
Other 28 Reservoirs	2,912,714	2,260,697	2,140,787	1,841,798	1,780,211	1,838,445

Table 9.3 Minimum Reservoir Storage Contents in acre-feet

Reservoir	M1	D1	D2	D3	D4
Livingston	1,313,172	1,329,137	1,364,024	1,314,330	1,329,039
Richland-Chambers	514,093	509,009	387,470	298,798	277,775
Ray Roberts	0.0	0.0	0.0	0.0	0.0
Cedar Creek	441,686	441,266	430,851	306,230	287,238
Other 28 Reservoirs	274,908	280,366	178,913	250,378	175,947

M1 Monthly *SIM* simulation with the original dataset last updated in October 2012.
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.

Many simulations were performed to explore the effects of various input choices on simulation results. A monthly simulation labeled M1 and four daily simulations labeled D1, D2, D3, and D4 were selected for inclusion in the tables and figures for comparison. The plot for simulation M1 consists of 948 end-of-month storage volumes in acre-feet. The plots for simulations D1, D2, D3, and D4 consist of 28,885 end-of-day storage volumes in acre-feet. The daily simulations generate monthly as well as daily storage contents. The 948 end-of-month volumes are a subset of the 28,885 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.

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 here are the same with or without the SB3 EFS.

Negative incremental flow adjustment options are selected by the parameter NEGINC in *JD* record field 10. NEGINC options are 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 NEGINC [5, 7]. 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].

The negative incremental flow adjustment option activated in each of the four simulations is shown in the third column of Table 9.1. Daily Trinity WAM results were found to be sensitive to NEGINC negative incremental flow adjustments. Option 5 is used in the original Trinity WAM. The standard options 4 and 7 are adopted for the daily simulations without and with forecasting.

Simulation M1 employs the original monthly current use scenario WAM last updated by the TCEQ in October 2012. Storage plots comparing this version of the current use WAM with the monthly full authorization version are presented in Figures 2.9 through 2.18 in the last section of Chapter 2.

Daily *SIMD* simulations D1, D2, D3, and D4 include the flood control operations and SB3 EFS described in Chapters 4 and 5. The only difference between these four daily simulations is the handling of routing and forecasting. Simulation D1 has no routing and no forecasting. Simulations D2, D3, and D4 employ the lag and attenuation parameters shown in Tables 3.3 and 3.4 of Chapter 3. Simulation D2 includes routing but no forecasting. D3 and D4 have forecast periods of three days and ten days, respectively.

Routing and forecasting are discussed in Chapter 3. The default forecast period of 81 days automatically computed by *SIMD* as twice the lag time for the longest lag flow path is excessive. Forecast periods of 3 and 10 days are reflected in the alternative simulations presented here. From zero to ten days is considered to be perhaps a reasonable timeframe for predicting future flows.

Daily Simulation D1 Selected for Determining SB3 EFS Targets

In general, a daily simulation is expected to tend to result in greater constraints on stream flow availability for filling reservoirs and thus somewhat greater storage draw-downs than a monthly simulation for reasons discussed in the *Daily Manual* [5]. Uncertainties and inaccuracies associated with routing and forecasting are discussed in Chapter 3. Routing and forecasting may improve accuracy in some cases but this Trinity simulation study as well as the Brazos study [7] indicate that forecasting tends to reduce accuracy due to over-constraining stream flow availability.

Daily simulation D1 with no routing or forecasting closely replicates the original monthly simulation M1 with slightly greater storage draw-downs. Simulations D2, D3, and D4 result in significantly greater storage draw-downs. The storage plots for simulations M1 and D1 are generally relatively close. The storage plots for simulations D2, D3, and D3 are generally close to each other but significantly lower than the storage contents for M1 and D1. The remainder of this chapter focuses on SB3 EFS instream flow targets computed in simulation D1.

Daily Instream Flow Targets for SB3 EFS

Senate Bill 3 (SB3) environmental flow standards (EFS) are described in Chapter 5. The metrics for the SB3 EFS are tabulated in Tables 5.2 and 5.3 with flows in units of cubic feet per second (cfs). Flows input on the *ES* and *PF* records replicated as Table 5.4 are also in units of cfs. However, flows are in units of acre-feet/day in the *SIMD* simulation computations and recorded results. Tables 9.4 and 9.5 are repeats of Tables 5.2 and 5.3 with flows converted from units of cfs to acre-feet/day. Seasons are defined as follows: Winter (December, January, February), Spring (March, April, May), Summer (June, July, August), Fall (September, October, November).

Table 9.4
Subsistence and Base Flow Limits for SB3 Environmental Flow Standards

Control Point	Gauge Site Nearest City	Subsidence Flow Limits (af/day)				Base Flow Limits (af/day)			
		Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
8WTGP	Grand Prairie	37.69	49.59	45.62	41.65	89.26	89.26	69.42	69.42
8TRDA	Dallas	51.57	73.39	43.64	29.75	99.17	138.84	79.34	99.17
8TROA	Oakwood	238.0	317.4	148.8	198.4	674.4	892.6	495.9	515.7
8TRRO	Romayor	981.8	1,388	396.79	456.2	1,735	2,281	1,140	1,240

Table 9.5
Metrics for High Flow Pulse Components of SB3 Environmental Flow Standards

CP	Site	Criteria	Winter	Spring	Summer/Fall
8WTGP	West Fork of Trinity River at Grand Prairie	Trigger (ac-ft/day)	595.0	2,380	595.0
		Volume (acre-feet)	3,500	8,000	1,800
		Duration (days)	4	8	3
8TRDA	Trinity River at Dallas	Trigger (ac-ft/day)	1,388	7,934	1,983
		Volume (acre-feet)	3,500	40,000	8,500
		Duration (days)	3	9	5
8TROA	Trinity River at Oakwood	Trigger (ac-ft/day)	5,950	13,884	4,959
		Volume (acre-feet)	18,000	130,000	23,000
		Duration (days)	5	11	5
8TRRO	Trinity River at Romayor	Trigger (cfs)	15,868	19,835	7,934
		Volume (acre-feet)	80,000	150,000	60,000
		Duration (days)	7	9	5

All four of the daily simulations (labeled D1, D2, D3, and D4) described in the preceding section all include the flood control operations described in Chapter 4 and the SB3 EFS described in Chapter 5. The remainder of this chapter focuses on the *IF* record instream flow targets included in the results of daily *SIMD* simulation D1, which has no routing and no forecasting.

The SB3 EFS are the only *IF* record water rights at control points 8WTGP and 8TRRO. Other *IF* record rights described in Chapter 5 are located at control points 8TRDA and 8TROA in

addition to the SB3 EFS. Multiple rights at the same control point are combined with the option of adopting the largest instream flow volume for each day (Table 5.7). Components of the targets for multiple *IF* record rights at the same control point are recorded in the *SIMD* output file using the options outlined in Table 5.6.

The means of the 1940-2018 sequences of naturalized, regulated, and unappropriated flows and SB3 EFS targets and shortages are compared in Table 9.6. The combined subsistence and base flow targets are the TIF-WR targets defined in Table 5.6 for the water rights IF-WTGP-ES, IF-TRDA-ES, IF-TROA-ES, and IF-TRRO-ES in Table 5.4. The pulse flow targets are the TIF-WR targets for the water rights IF-WTGP-PF, IF-TRDA-PF, IF-TROA-PF, and IF-TRRO-PF in Table 5.4. The final SB3 EFS targets are the IFT-WR (Table 5.6) targets for water rights IF-WTGP, IF-TRDA, IF-TROA, and IF-TRRO in Table 5.5. The targets considering all *IF* record rights at control points 8TRDA and 8TROA differ from the SB3 EFS targets due to other *IF* record rights being located at these two control points. There are no other *IF* record rights at control points 8WTGP and 8TRRO.

Table 9.6
Means of Daily Flow Quantities in acre-feet/day (af/d) and cubic feet per second (cfs)

Control Point	8WTGP	8TRDA	8TROA	8TRRO	8WTGP	8TRDA	8TROA	8TRRO
	(af/d)	(af/d)	(af/d)	(af/d)	(cfs)	(cfs)	(cfs)	(cfs)
Naturalized flow	1,698	4,807	12,457	18,078	856.1	2,424	6,280	9,114
Regulated flow	1,119	2,741	9,199	14,200	564.2	1,382	4,638	7,159
Unappropriated	360.4	1,067	5,786	11,712	181.7	538	2,917	5,905
Flow Targets								
subsistence/base	60.43	88.39	530.2	1,314	30.47	44.56	267.3	662.5
pulse flow	43.63	167.3	521.4	921.2	22.00	84.35	262.9	464.4
SB3 EFS	100.8	249.9	1,016	2,137	50.82	126.0	512.2	1,077
all *IF* rights	100.8	619.8	2,917	2,137	50.82	312.5	1,471	1,077
Target Shortages								
before pulse	0.00	122.1	874.9	2.386	0.00	61.56	441.1	1.203
with pulse flow	17.57	176.9	1,019	347.1	8.86	89.19	513.7	175.0

Table 10.9 in Chapter 10 is a full authorization simulation version of Table 9.6. The SB3 EFS targets computed in the *SIMD* full authorization simulation (Table 10.9) are smaller than the SB3 EFS targets in the current use simulation (Table 9.6) because the regulated flows are smaller.

The *IF* record daily instream flow targets for the SB3 EFS computed in *SIMD* simulation D1 are plotted in Figures 9.11 through 9.18. The combined subsistence and base flow components of the SB3 EFS defined on *ES* records are plotted in Figures 9.11, 9.13, 9.15, and 9.17. The final daily targets for the complete SB3 EFS including the pulse flow components defined on *PF* records as well the *ES* record subsistence and base flow components are plotted in Figures 9.12, 9.14, 9.16, and 9.18. The final computed SB3 EFS instream flow target for each of the 28,885 days of the 1940-2018 hydrologic period-of-analysis the is larger of the combined subsistence and base flow target (*ES* record) or pulse flow target (*PF* record).

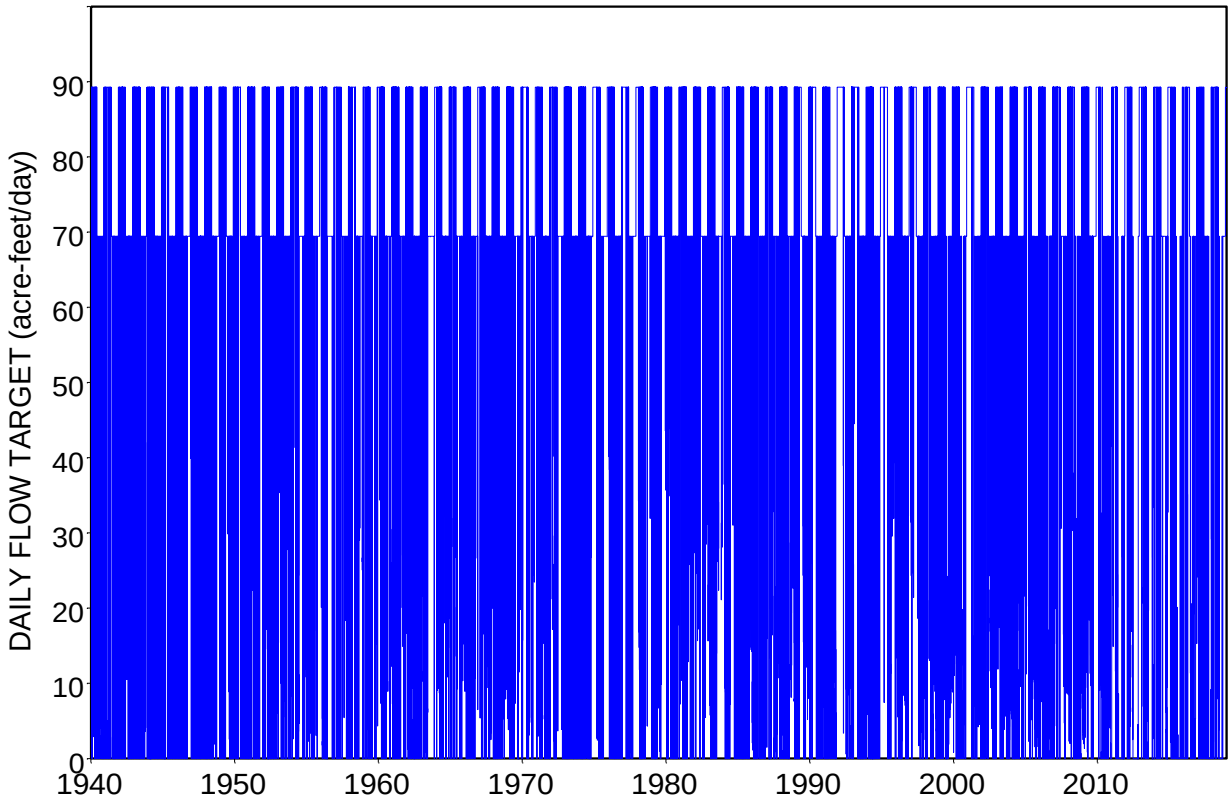

Figure 9.11 Daily Flow Targets for Subsistence and Base Flow Components of EFS at 8WTGP

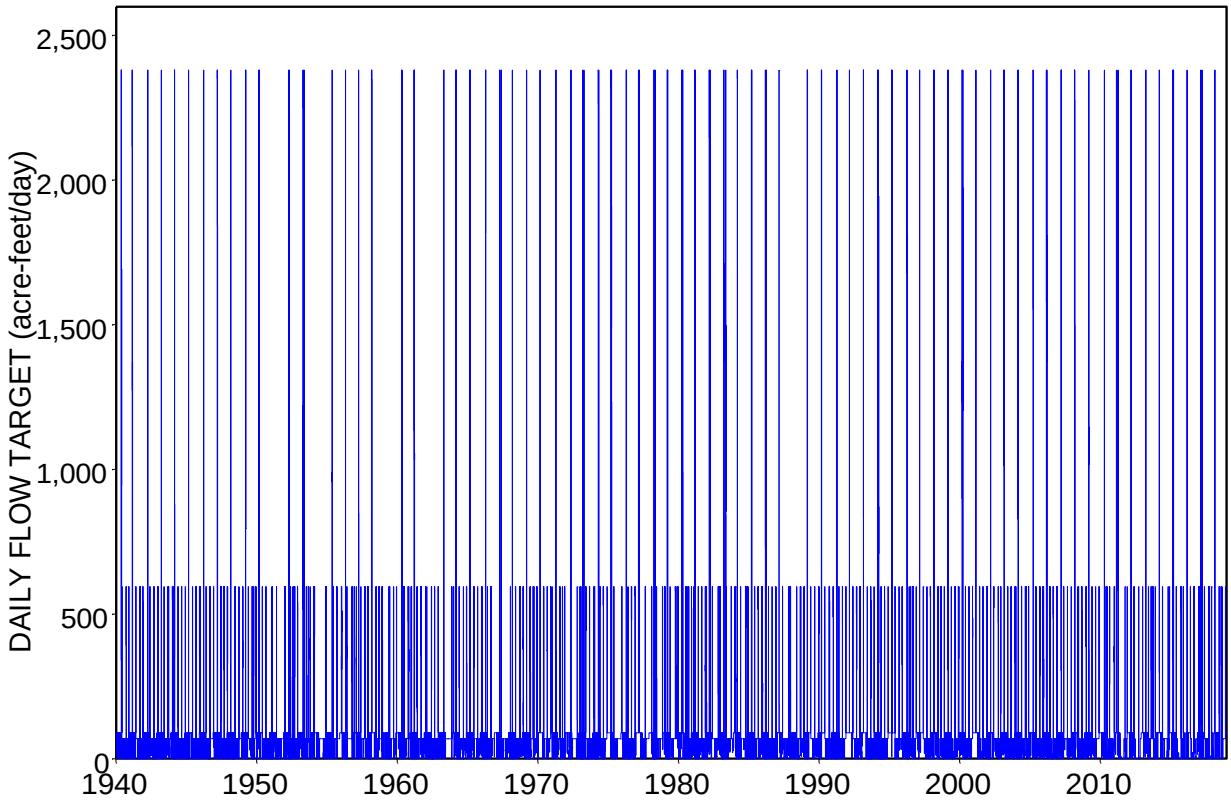

Figure 9.12 Final Daily Instream Flow Targets for SB3 EFS at 8WTGP (Grand Prairie)

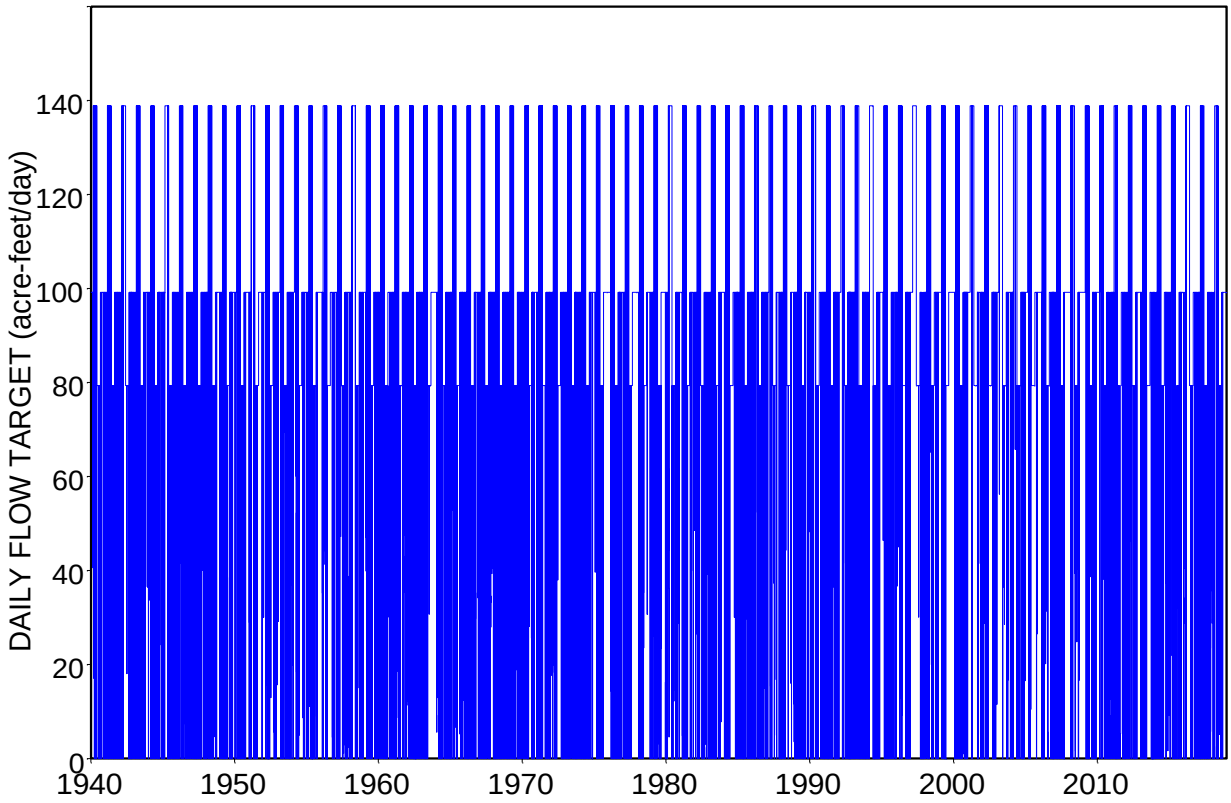

Figure 9.13 Daily Flow Targets for Subsistence and Base Flow Components of EFS at 8TRDA

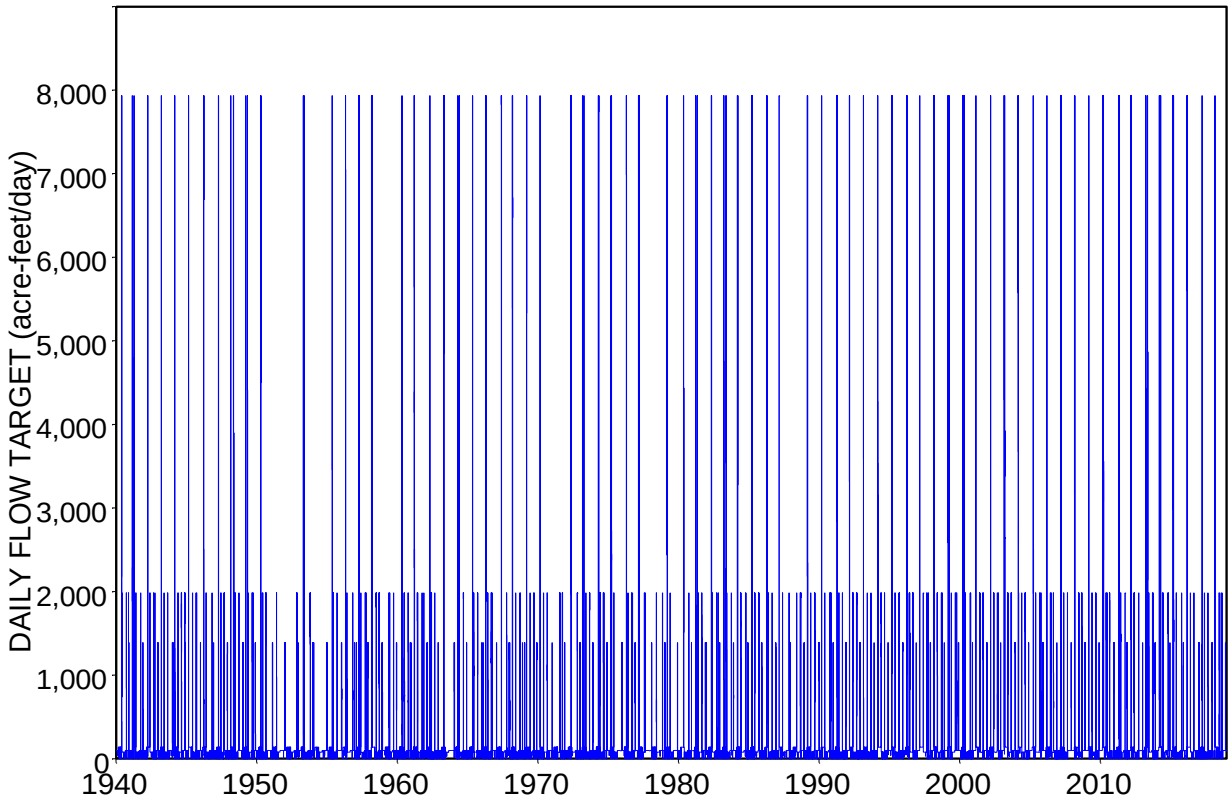

Figure 9.14 Final Daily Instream Flow Targets for SB3 EFS at 8TRDA (Dallas)

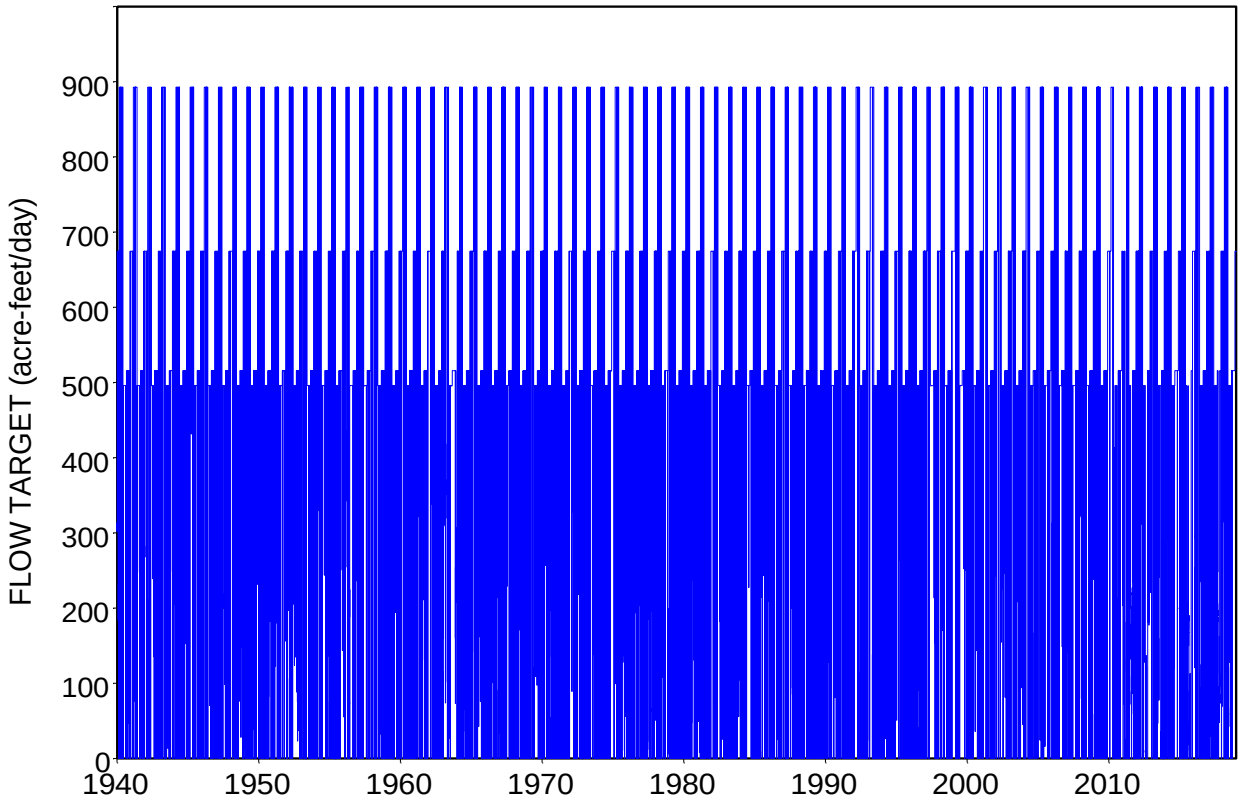

Figure 9.15 Daily Flow Targets for Subsistence and Base Flow Components of EFS at 8TROA

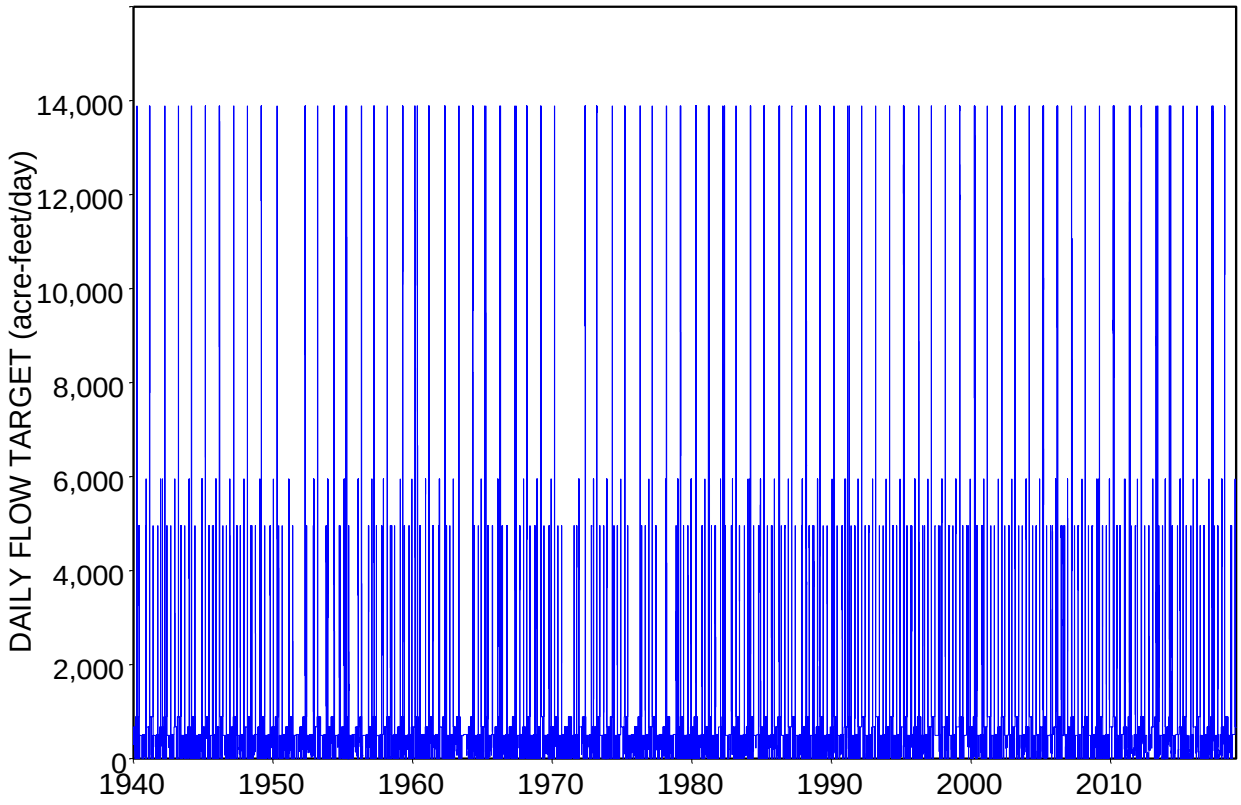

Figure 9.16 Final Daily Instream Flow Targets for SB3 EFS at 8TROA (Oakwood)

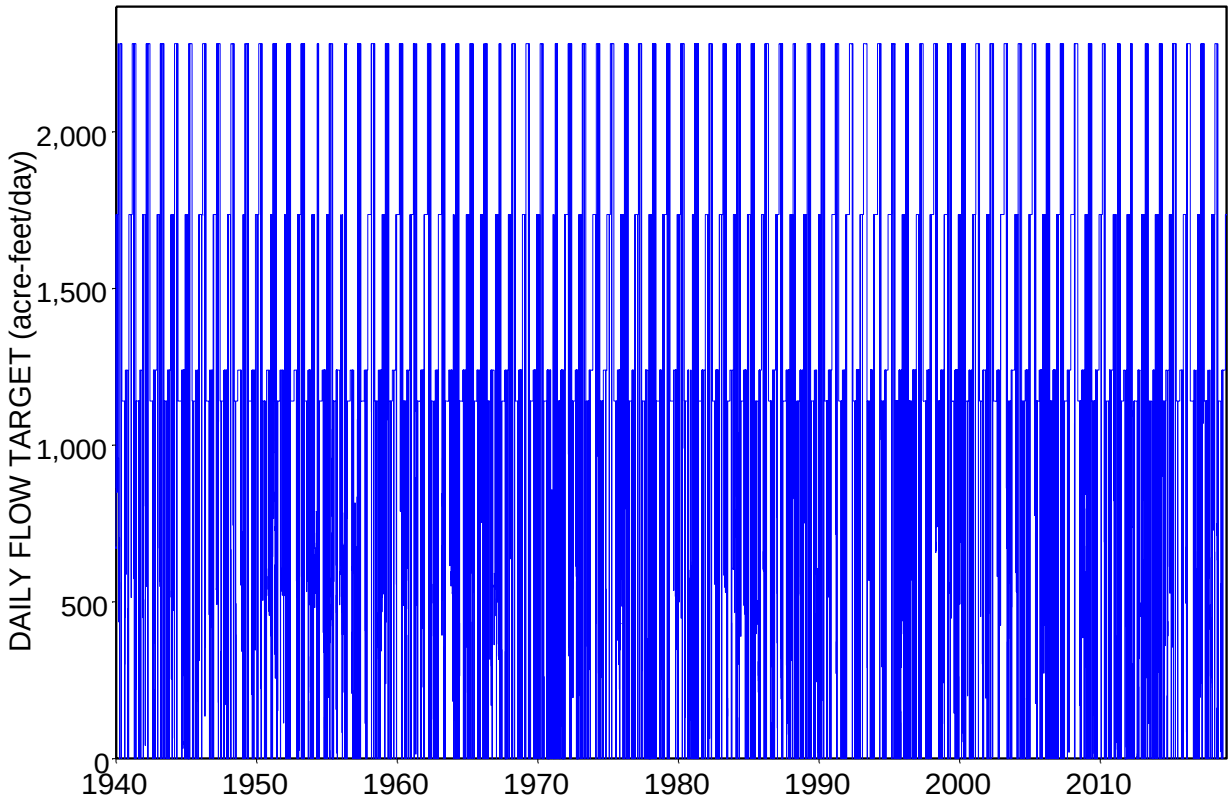

Figure 9.17 Daily Flow Targets for Subsistence and Base Flow Components of EFS at 8TRRO

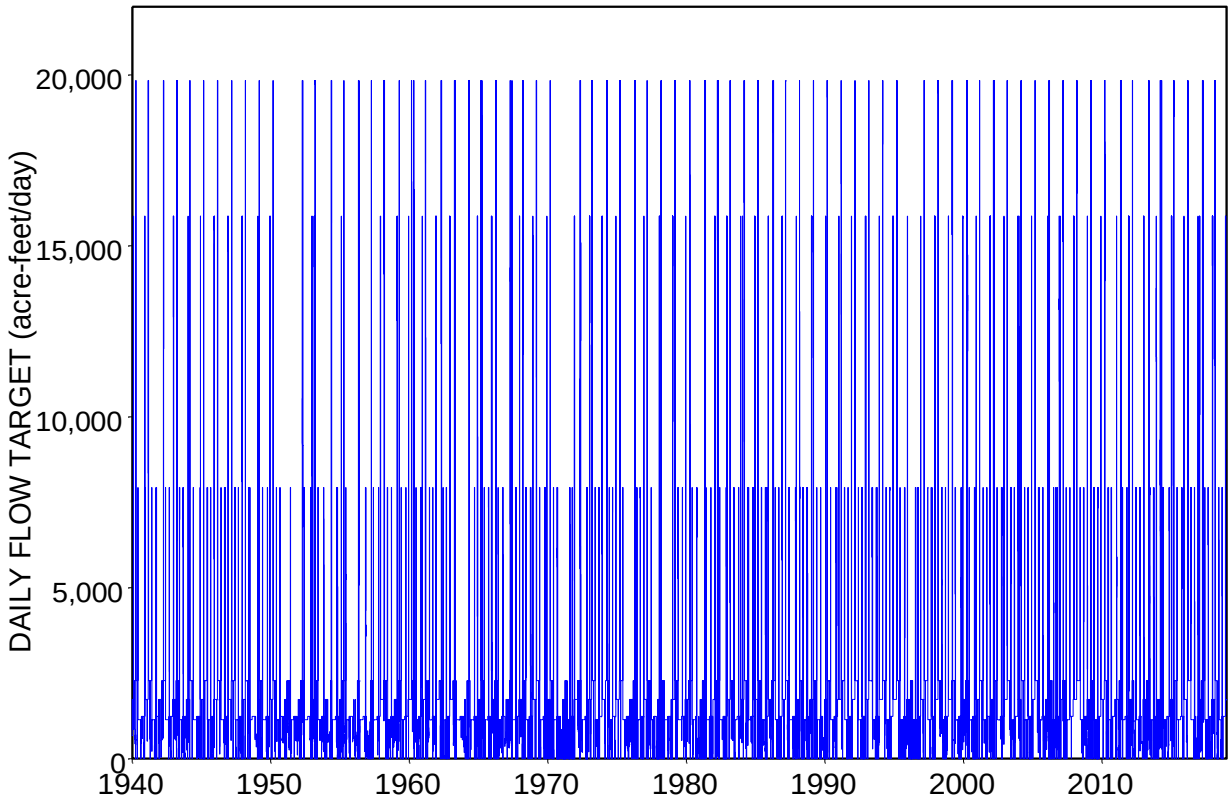

Figure 9.18 Final Daily Instream Flow Targets for SB3 EFS at 8TRRO (Romayor)

Monthly Instream Flow Targets for SB3 EFS from Daily SIMD Simulation

The final daily SB3 EFS plotted in Figures 9.12, 9.14, 9.16, and 9.18 are summed to monthly totals in each of the 948 months within the *SIMD* simulation. The monthly targets are plotted in Figures 9.20, 9.21, 9.22, and 9.23.

The SB3 EFS instream flow targets are computed in the *SIMD* current use scenario daily simulation D1 (Table 9.1), which has no routing and no forecasting. The final daily SB3 EFS instream flow targets in acre-feet/day consist of the larger of the *ES* record subsistence and base flow target or the *PF* record pulse flow target in each of the 28,885 days of the simulation. The monthly SB3 EFS targets in acre-feet/month are the total of the daily targets in each of the 948 months of the simulation.

The procedure for incorporating the monthly SB3 EFS targets generated in the daily *SIMD* simulation into the monthly WAM is described in Chapter 5 (pages 76-77). 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 5.8 which is replicated below as Table 9.7. The *IF* record water rights shown in Table 5.9 and 9.8 are inserted in the monthly WAM DAT file.

Table 9.7
Pathnames for *TS* Records for the SB3 EFS for the Current Use Scenario
in the Shared Single Hydrology Input DSS File of the Trinity WAM

Part A	Part B	Part C	Part D	Part E
TRINITY	C8WTGP	TS	01Jan1940-31Dec2018	1MON
TRINITY	C8TRDA	TS	01Jan1940-31Dec2018	1MON
TRINITY	C8TROA	TS	01Jan1940-31Dec2018	1MON
TRINITY	C8TRRO	TS	01Jan1940-31Dec2018	1MON

Table 9.8
Instream Flow Rights that Model the SB3 EFS in the DAT File of the
Monthly Current Use Scenario Version of the Trinity WAM

```
IF 8WTGP                20091201   2            IF-WTGP
TS      DSS  C8WTGP
IF 8TRDA                20091201   2            IF-TRDA
TS      DSS  C8TRDA
IF 8TROA                20091201   2            IF-TROA
TS      DSS  C8TROA
IF 8TRRO                20091201   2            IF-TRRO
TS      DSS  C8TRRO
```

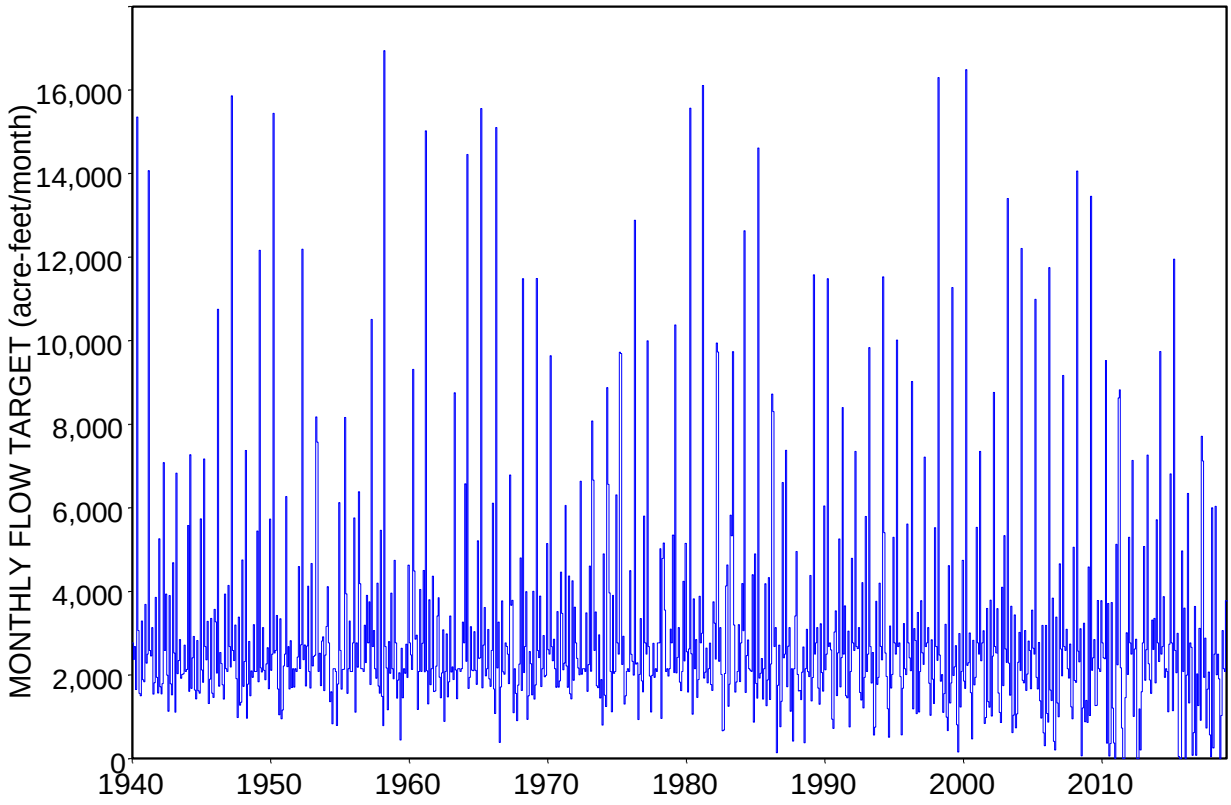

Figure 9.19 SB3 EFS Monthly Instream Flow Targets at 8WTGP (Grand Prairie)

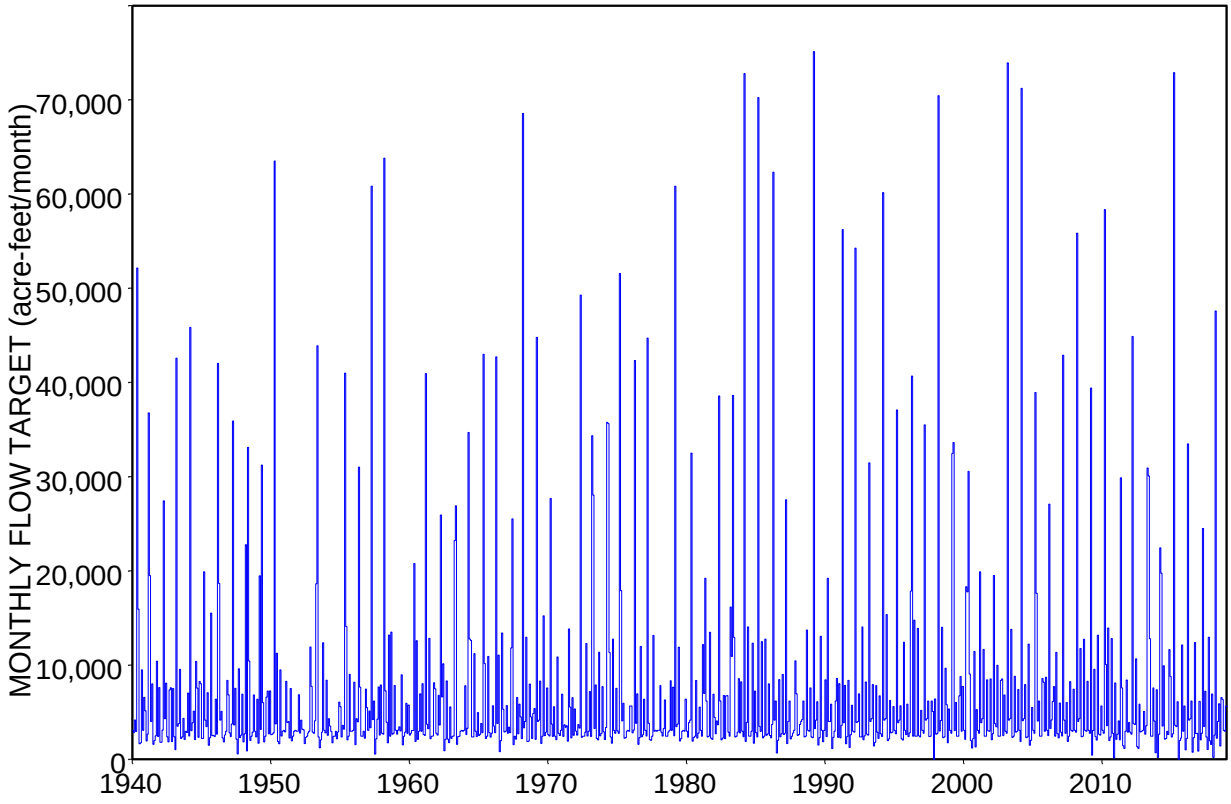

Figure 9.20 SB3 EFS Monthly Instream Flow Targets at 8TRDA (Dallas)

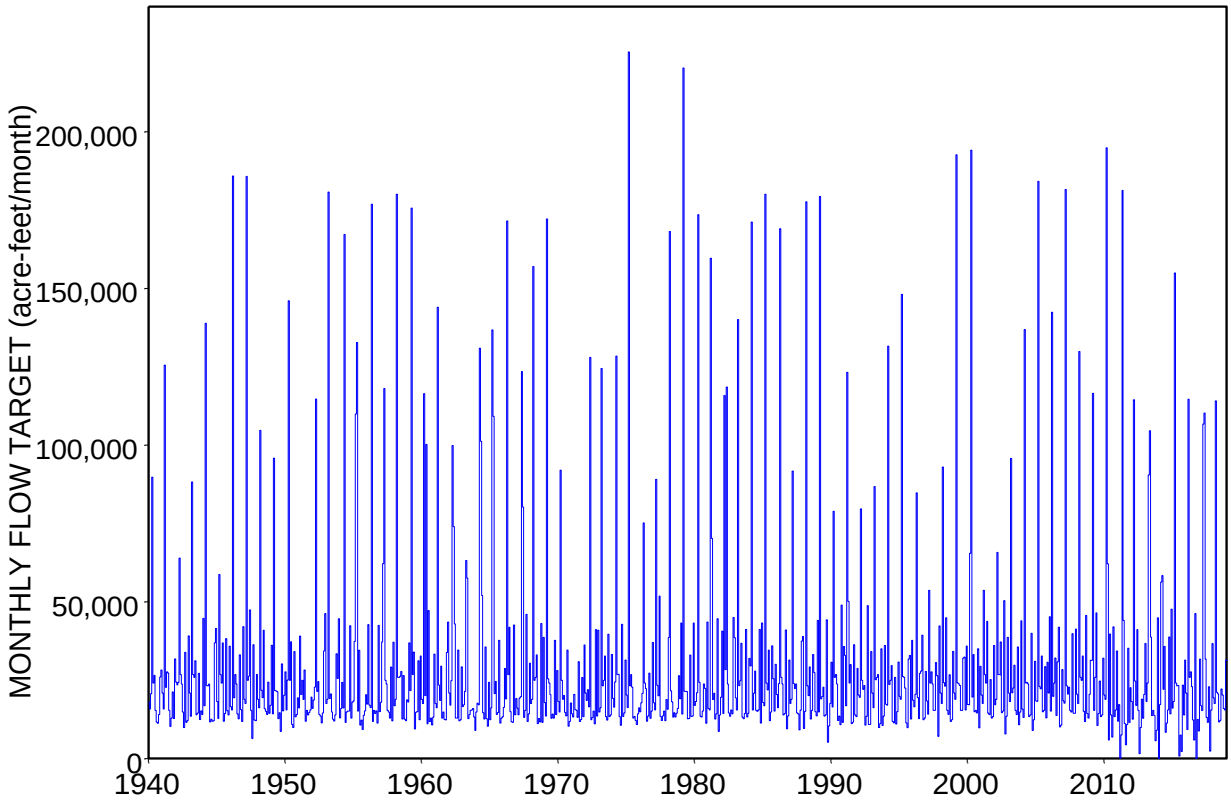

Figure 9.21 SB3 EFS Monthly Instream Flow Targets at 8TROA (Oakwood)

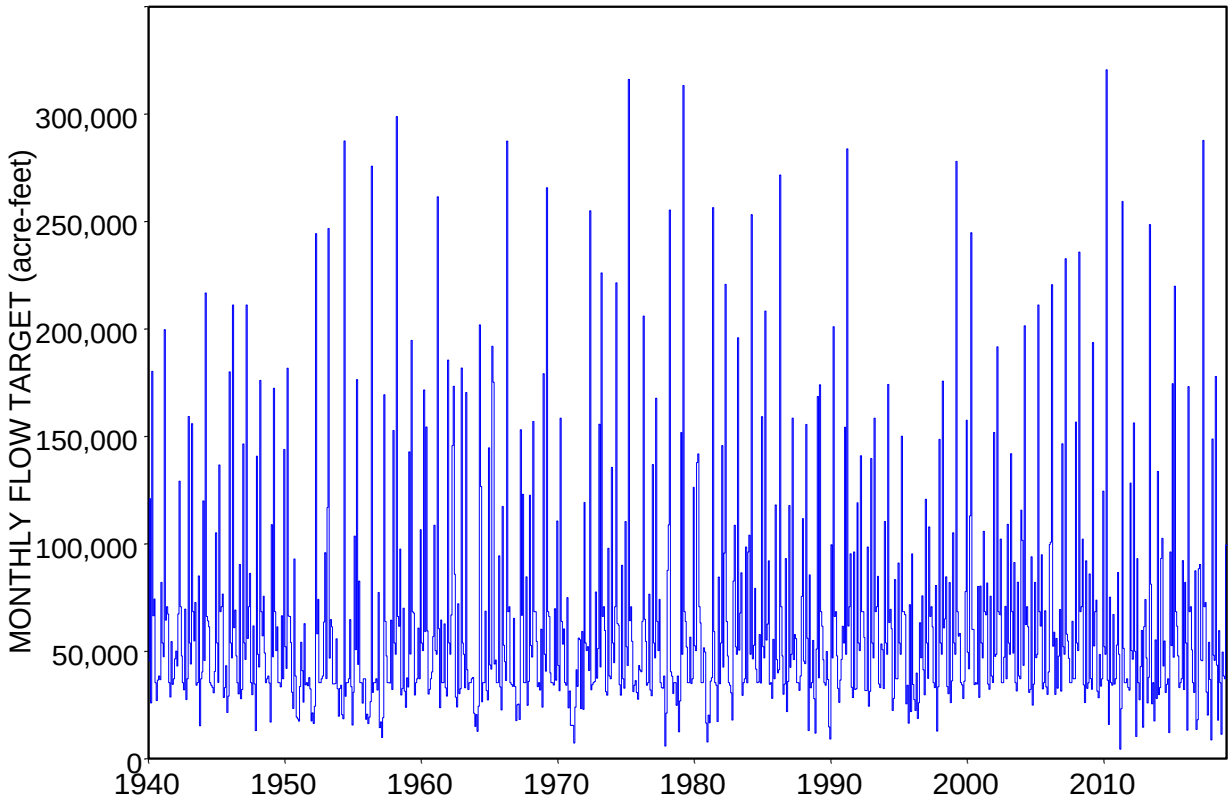

Figure 9.22 SB3 EFS Monthly Instream Flow Targets at 8TRRO (Romayor)

The DAT file with the filename Trinity8M.DAT listed in Tables 1.2 and 12.1 of Chapters 1 and 12 contains the set of *IF* and *TS* records listed in Table 9.8. Selected results from a simulation with this version of the WAM are included in the file with filename TrinitySimulationResults.DSS described in the last section of Chapter 11. Reservoir storage contents computed in this monthly current use WAM simulation replicate the plots of Figures 2.10, 2.12, 2,14, 2.16, and 2.18 of Chapter 2. The TIF (Table 5.6) instream flow targets for *IF* record water rights IF-WTGP, IF-TRDA, IF-TROA, and IF-TRRO in the simulation results replicate the plots of Figures 9.19, 9.20, 9.21, and 9.22.

CHAPTER 10
SIMULATION RESULTS FOR AUTHORIZED USE SCENARIO

Simulation results from the daily full authorization Trinity WAM are summarized in this chapter similarly to the presentation of current use scenario simulation results in the preceding Chapter 9 but in more detail. Chapter 10 progresses through the following topics.

1. Reservoir storage contents are plotted in Figures 10.1 through 10.10 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. Daily and annual SB3 EFS instream flow targets and target shortages and daily and annual naturalized, regulated, and unappropriated flows at the four SB3 EFS sites are explored and compared. Time series plots and summary tables of statistical metrics are presented.
3. Monthly instream flow targets for the SB3 EFS are developed as described in Chapter 5 (page 79). 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 monthly summations of daily instream flow targets for the SB3 EFS are plotted in Figures 10.23–10.26.

Storage Contents for Alternative Simulations With and Without Routing and Forecasting

Simulated reservoir storage contents for each of the four largest reservoirs (Livingston, Richland-Chambers, Ray Roberts, Cedar Creek) and summations of the storage contents of the other 28 reservoirs listed in Table 2.2 resulting from alternative modeling premises are compared in Chapter 2 (Figures 2.9–2.18), the Chapter 9 (Figures 9.1–9.10), and the present Chapter 10 (Figures 10.1–10.10). The one monthly (M1) and four daily (D1, D2, D3, D4) alternative simulations selected for inclusion in the comparative analyses presented here are defined in Table 10.1. The means of the 948 end-of-month storage volumes from simulation M1 and the 28,885 end-of-day storage volumes from simulations D1, D2, D3, and D4 are tabulated in Table 10.2. The minimum end-of-month or end-of-day storage contents during each of the 1940-2018 simulations are shown in Table 10.3. The storage volumes for each of the four largest reservoirs are plotted in Figures 10.1 through 10.8. The summation of the storage contents of the other 28 reservoirs in Table 2.2 is plotted in Figures 10.9 and 10.10. A legend for the plots is provided in Table 10.1.

Table 10.1
Alternative Current Use Scenario Simulations

	Routing and Forecasting	Negative Incremental	Figures 10.1–10.10 Legend
M1	Original monthly WAM	Option 5	——— blue solid line
D1	No routing and no forecasting	Option 4	•••••• red dotted line
D2	Routing but no forecasting	Option 4	------- green dashed line
D3	Routing and 3-day forecast	Option 7	— •• — black dashes and dots
D4	Routing and 10-day forecast	Option 7	•••••• purple dotted line

Table 10.2
Average Reservoir Storage Contents in acre-feet

Reservoir	Capacity	M1	D1	D2	D3	D4
Livingston	1,750,000	1,490,228	1,554,340	1,534,025	1,482,366	1,519,037
Richland-Chambers	1,135,000	997,005	982,396	877,612	831,496	650,289
Ray Roberts	799,600	25,443	16,255	7,265	28,139	35,530
Cedar Creek	678,900	588,689	586,782	558,844	255,298	126,293
Other 28 Reservoirs	3,082,187	1,923,570	1,730,895	1,309,578	1,420,944	1,362,044

Table 10.3
Minimum Reservoir Storage Contents in acre-feet

Reservoir	M1	D1	D2	D3	D4
Livingston	0.0	0.0	0.0	0.0	0.0
Richland-Chambers	112,474	71,005	0.0	0.0	0.0
Ray Roberts	0.0	0.0	0.0	0.0	0.0
Cedar Creek	164,521	161,619	111,029	0.0	0.0
Other 28 Reservoirs	124,454	157,150	58,334	112,114	63,167

M1 Monthly *SIM* simulation with the original dataset last updated in October 2014.
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.

Description of Alternative Simulations

Many simulations were performed to explore the effects of various alternative modeling options and input quantities on simulation results. Results of current use and authorized use scenario simulations are summarized in Chapters 9 and 10, respectively. Simulation M1 employs the original monthly full authorization WAM last updated by the TCEQ in October 2014. Storage plots comparing this version of the full authorization WAM with the monthly current use version are presented in Figures 2.9 through 2.18 of Chapter 2. Storage contents of Lakes Livingston, Richland-Chambers, Ray Roberts, and Cedar Creek are plotted individually. The summation of storage contents of the other 28 reservoirs in Table 2.2 provides a single combined storage plot.

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 repot 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, 7].

The NEGINC option employed in each of the four simulations is shown in the third column of Table 10.1. Daily Trinity WAM results were found to be sensitive to negative incremental flow adjustments. Option 5 is used in the original Trinity WAM. The standard options 4 and 7 are adopted for the daily simulations without and with forecasting.

The monthly simulation labeled M1 and four daily simulations labeled D1, D2, D3, and D4 were selected for inclusion in the tables and figures presented here for comparison. The plot for simulation M1 consists of 948 end-of-month storage volumes in acre-feet. The plots for simulations D1, D2, D3, and D4 consist of 28,885 end-of-day storage volumes in acre-feet. The daily simulations generate monthly as well as daily storage contents. The 948 end-of-month volumes are a subset of the 28,885 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, and D4 include the flood control operations and SB3 EFS described in Chapters 4 and 5. The only difference between these four daily simulations is the handling of routing and forecasting. Simulation D1 has no routing and no forecasting. Simulations D2, D3, and D4 employ the lag and attenuation parameters shown in Tables 3.3 and 3.4 of Chapter 3. Simulation D2 includes routing but no forecasting. D3 and D4 have forecast periods of three days and ten days, respectively.

Routing and forecasting are discussed in Chapter 3. The default forecast period of 81 days automatically computed by *SIMD* as twice the lag time for the longest lag flow path is excessive. Forecast periods of 3 and 10 days are reflected in the alternative simulations presented here. From zero to ten days is considered to be perhaps a reasonable timeframe for predicting future flows.

Daily Simulation D1 Selected for Determining SB3 EFS Targets

Daily simulations are generally expected to tend to exhibit greater storage draw-downs than corresponding monthly simulations due to greater constraints on stream flow availability [5, 7]. Decreases in storage contents of upstream reservoirs in the Trinity WAM are accompanied by increases in storage contents of the downstream Lake Livingston with the conversion from a monthly to daily computational time step. Uncertainties and inaccuracies associated with routing and forecasting are discussed in Chapter 3. Routing and forecasting may improve accuracy in some cases, but this Trinity WAM simulation study as well as the Brazos WAM study [7] indicate that forecasting tends to reduce accuracy due to over-constraining stream flow availability.

Daily simulation D1 with no routing or forecasting reasonably closely replicates the monthly simulation M1. The storage plots for simulations D1 and M1 are generally relatively close. Simulations D2, D3, and D4 result in significantly greater storage depletions. The forecasting algorithm in *SIMD* is shown to severely over-constrain the amount of stream flow available for refilling storage, most notably in Cedar Creek Reservoir. The remainder of this chapter focuses on SB3 EFS flow targets and other simulation results from simulation D1.

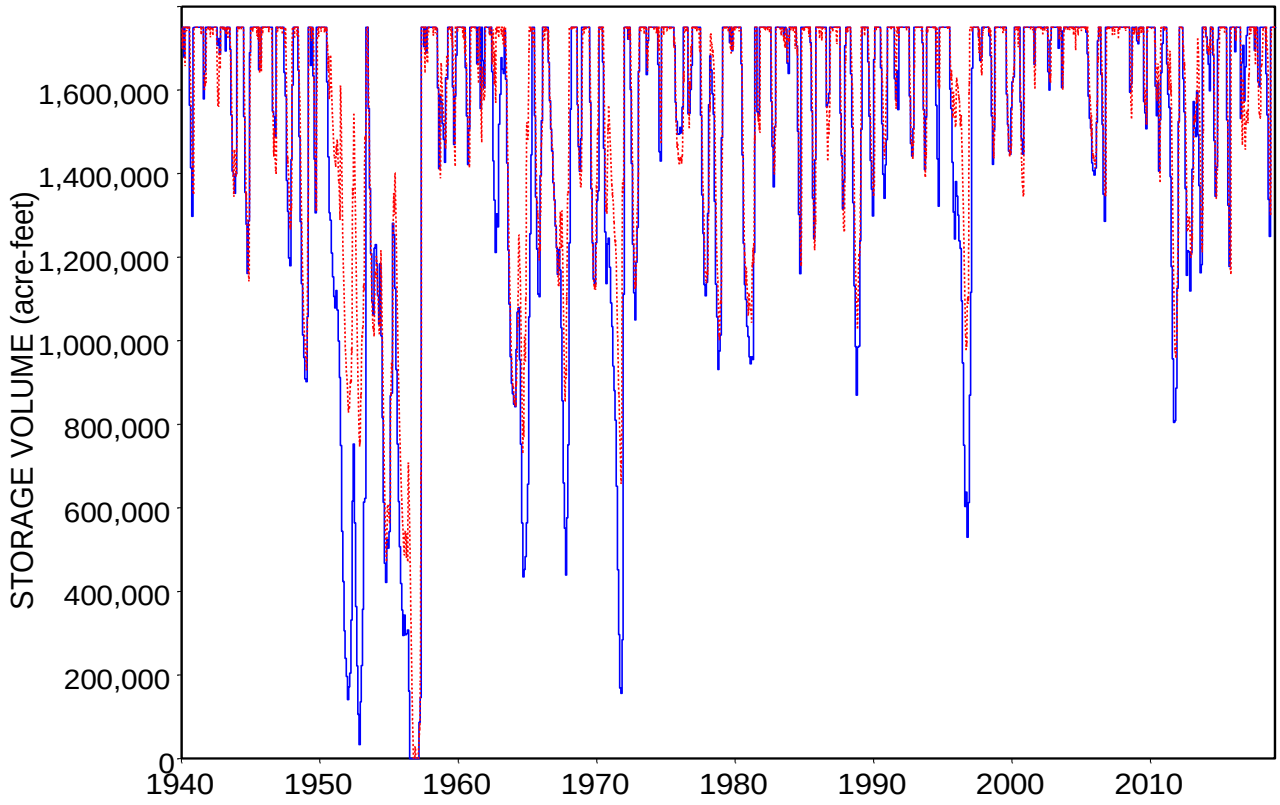

Figure 10.1 Lake Livingston Storage Contents for Simulations M1 (blue solid) and D1 (red dots)

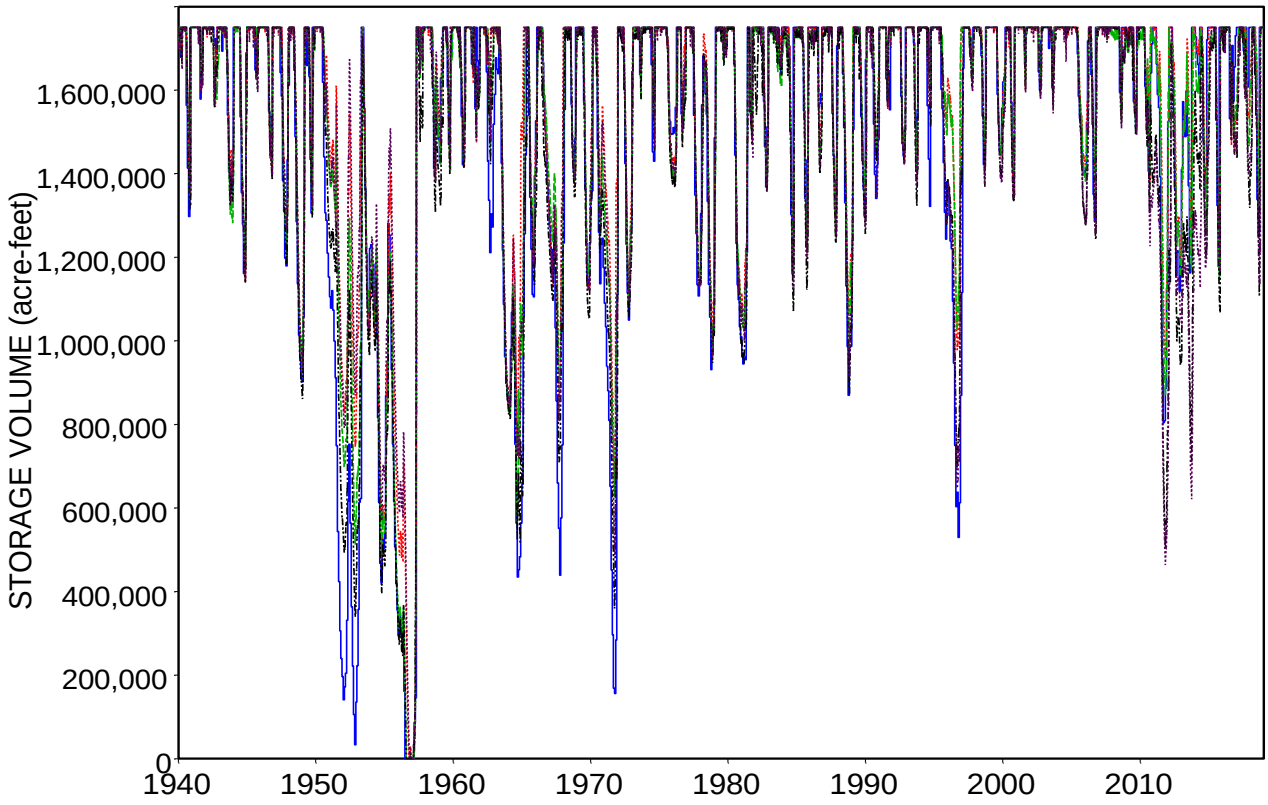

Figure 10.2 Lake Livingston Storage Contents for Simulations M1, D1, D2, D3, and D4

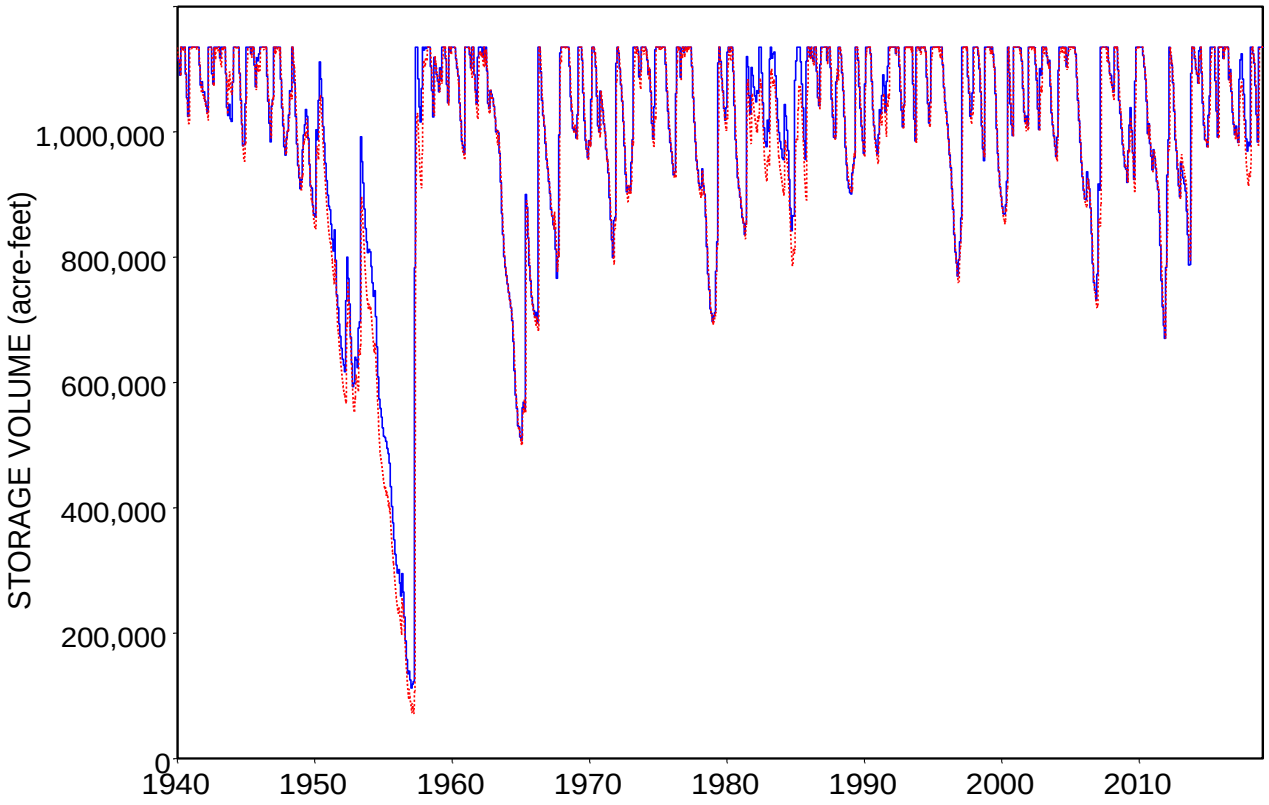

Figure 10.3 Richland-Chambers Storage Contents for Simulations M1 (blue solid) and D1 (red dots)

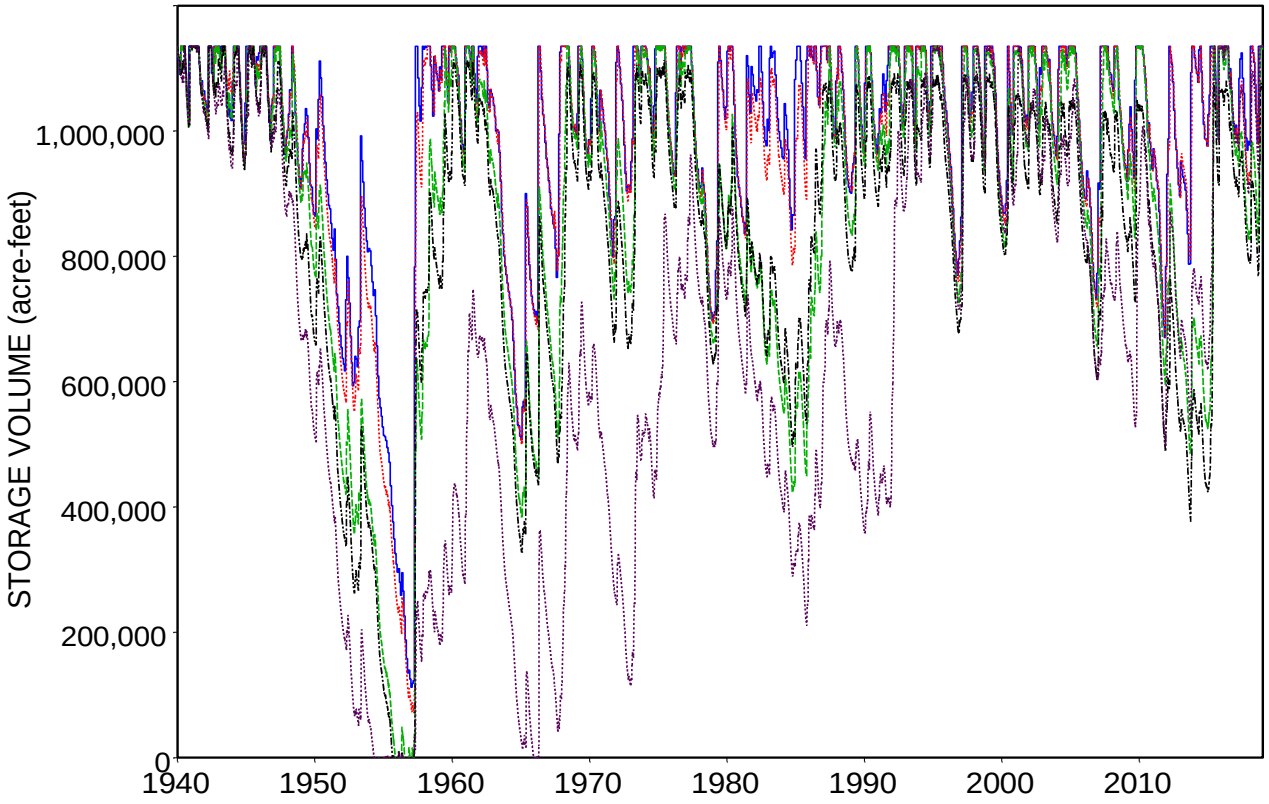

Figure 10.4 Richland-Chambers Reservoir Storage Contents for Simulations M1, D1, D2, D3, and D4

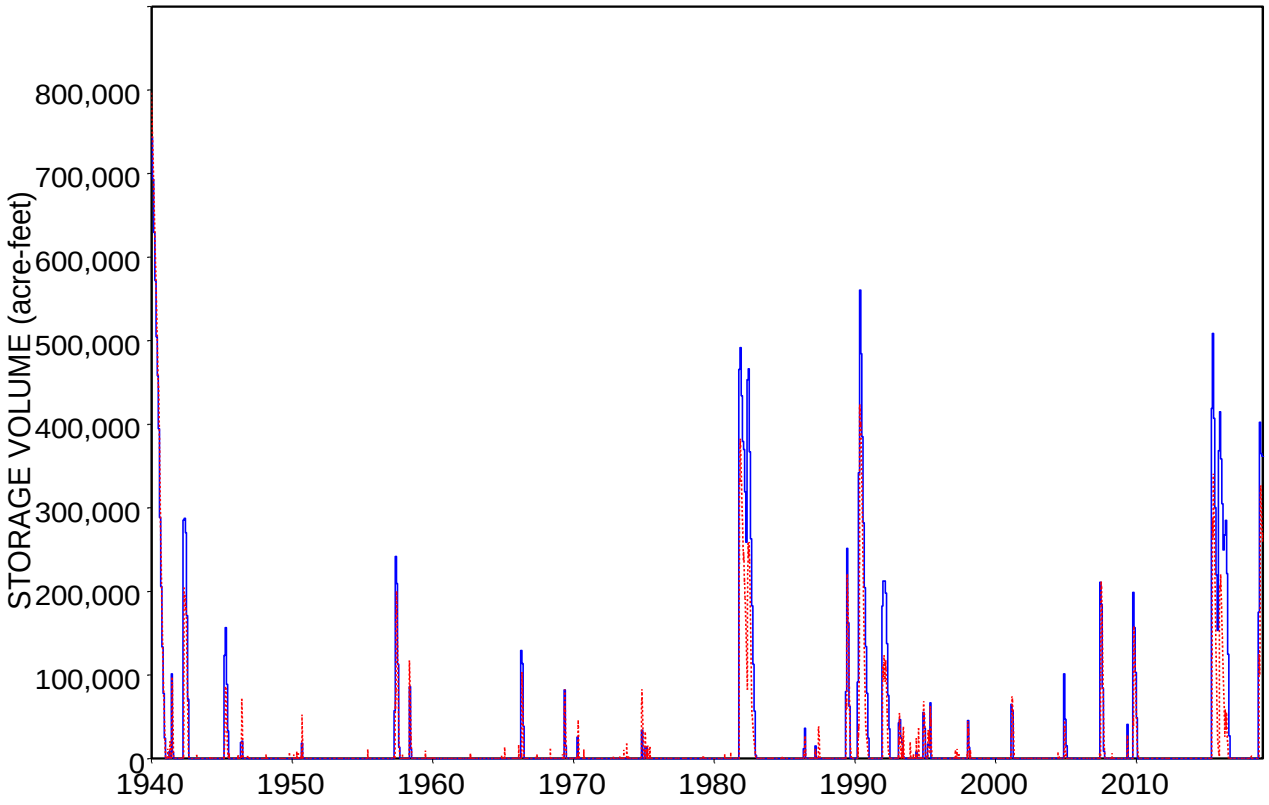

Figure 10.5 Ray Roberts Reservoir Storage Contents for Simulations M1 (blue solid) and D1 (red dots)

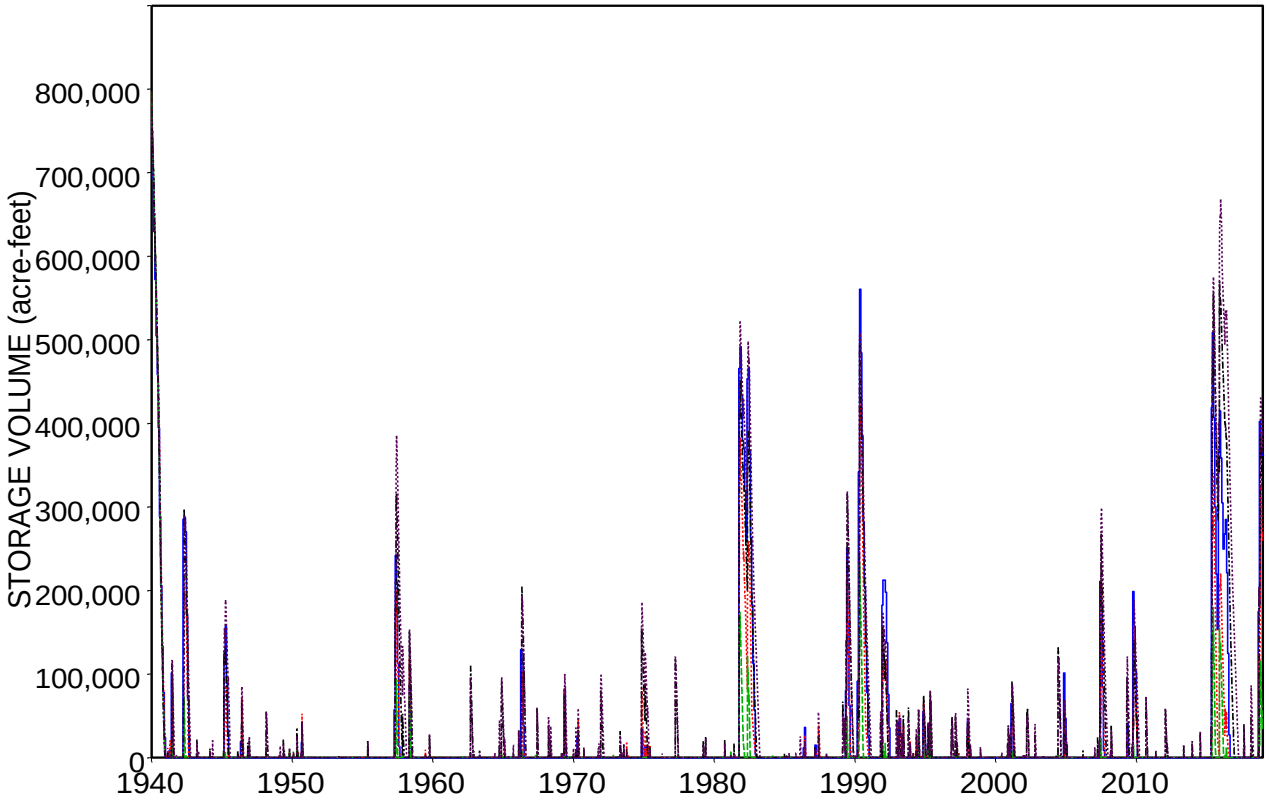

Figure 10.6 Ray Roberts Reservoir Storage Contents for Simulations M1, D1, D2, D3, and D4

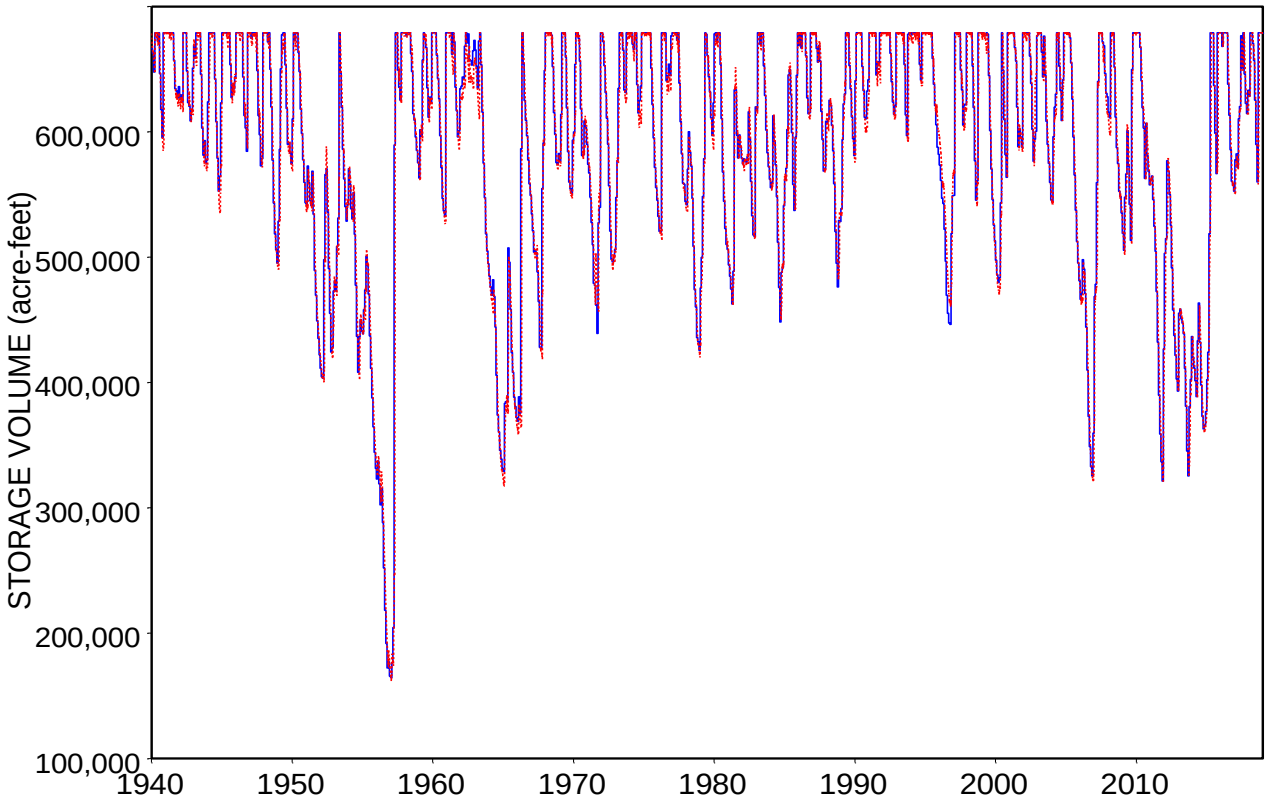

Figure 10.7 Cedar Creek Storage Contents for Simulations M1 (blue solid) and D1 (red dots)

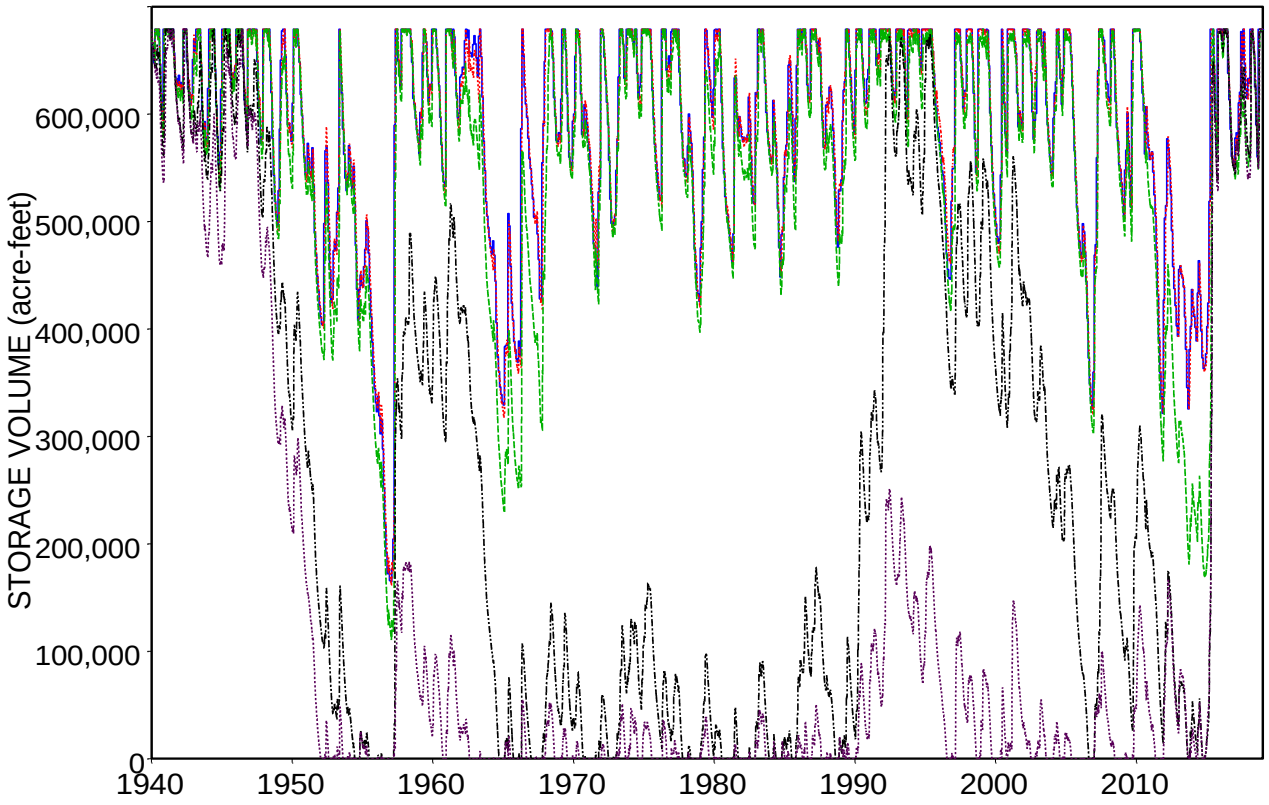

Figure 10.8 Cedar Creek Reservoir Storage Contents for Simulations M1, D1, D2, D3, and D4

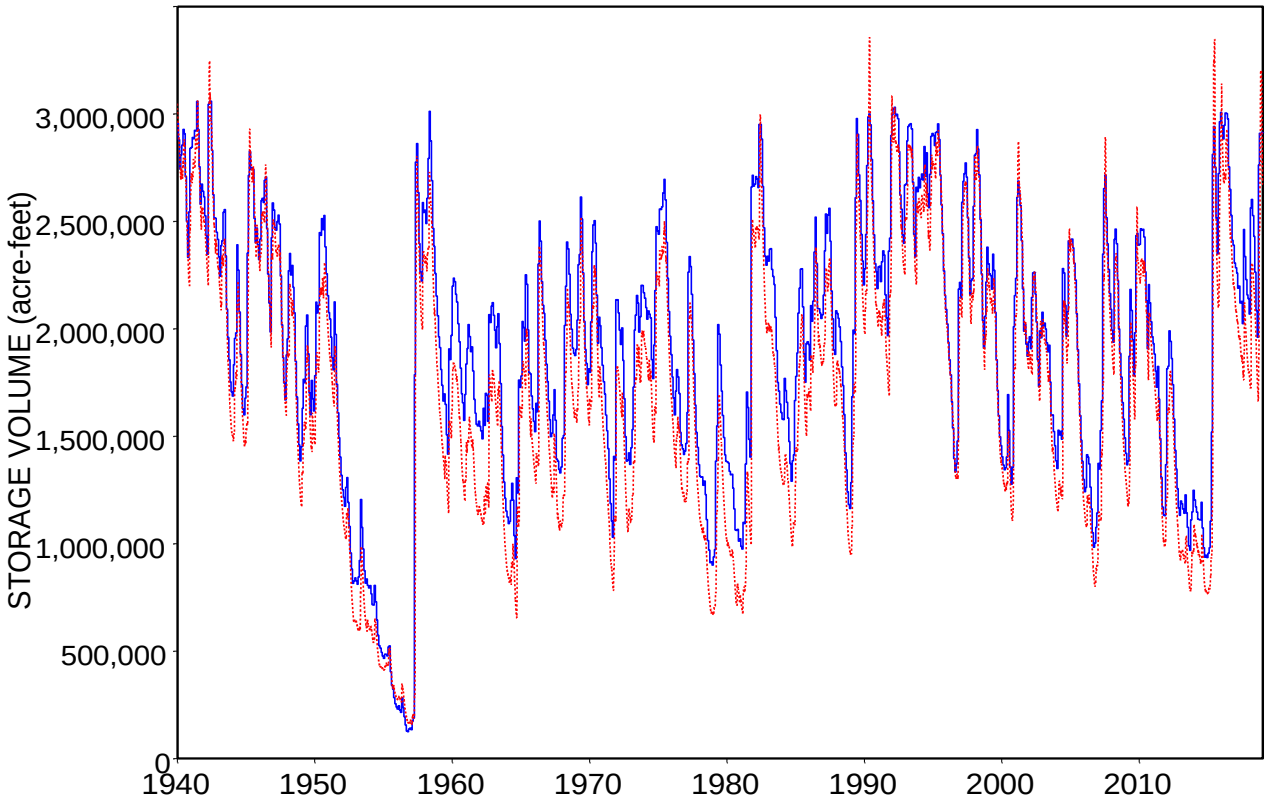

Figure 10.9 Summation of Storage in 28 Reservoirs for Simulations M1 (blue solid) and D1 (red dots)

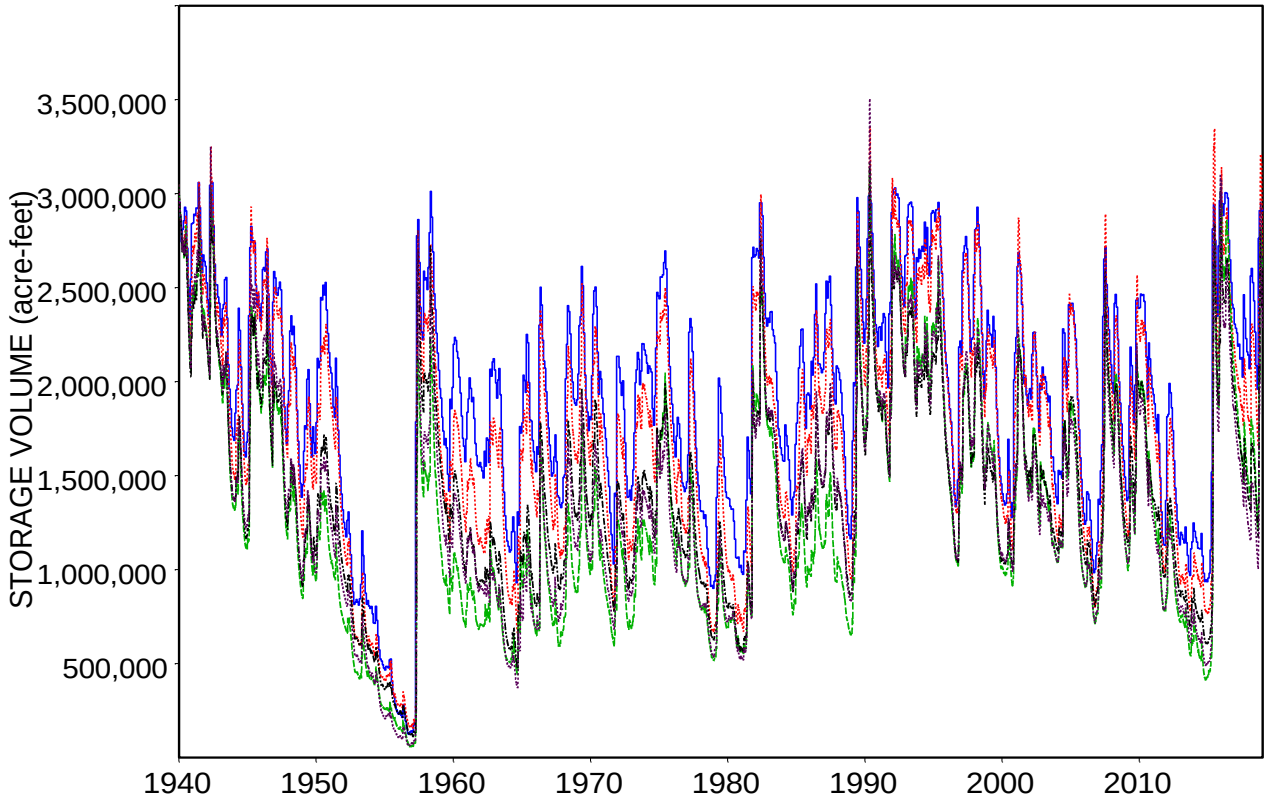

Figure 10.10 Summation of Storage in 28 Reservoirs for Simulations M1, D1, D2, D3, and D4

Stream Flow at the Four SB3 EFS Sites

The control points representing the USGS gage site locations of the SB3 EFS are listed in Table 5.1. The locations of these control points are shown in the maps of Figures 2.7 and 5.1. The 1940-2018 averages of the daily observed, naturalized, simulated regulated, and unappropriated stream flows at these four locations are tabulated in Table 10.4 in cubic feet per second (cfs). Frequency metrics including the 1940-2018 mean and daily means exceeded during specified percentages of the 28,855 days of the 1940-2018 period-of-analysis are tabulated in Tables 10.5 and 10.6 in units of acre-feet/day. [A flow rate of 1.0 cfs is equivalent to 1.98347 acre-feet/day.]

Table 10.4
Trinity WAM Control Point Locations for SB3 Environmental Flow Standards

Control Point	River	Nearest City	Watershed Area	1940-2018 Means for Stream Flows			
				Observed	Naturalized	Regulated	Unappropr
			(mile^2)	(cfs)	(cfs)	(cfs)	(cfs)
8WTGP	West Fork	Grand Prairie	3,065	760	856	426	148
8TRDA	Trinity	Dallas	6,106	2,007	2,424	992	323
8TROA	Trinity	Oakwood	12,833	5,629	6,280	4,172	2,079
8TRRO	Trinity	Romayor	17,186	8,294	9,114	6,204	4,790

Table 10.5
Frequency Metrics in acre-feet/day for Daily Flows at Control Points 8WTGP and 8TRDA

	Flows at 8WTGP (acre-feet/day)			Flows at 8TRDA (acre-feet/day)		
	Naturalized	Regulated	Unapprop	Naturalized	Regulated	Unapprop
mean	1,698	844.5	294.5	4,807	1,968	639.7
maximum	134,353	124,130	61,100	316,352	220,831	114,730
0.1%	71,342	58,277	30,481	181,030	105,308	47,405
0.2%	56,942	42,599	19,159	149,432	78,795	33,693
0.5%	35,532	25,249	11,235	97,800	51,194	21,381
1.0%	22,994	14,834	7,054	67,274	32,401	15,602
2.0%	14,468	8,605	3,895	42,966	20,328	10,018
5.0%	7,016	3,790	1,095	21,656	9,505	2,868
10%	3,550	1,478	125	10,298	3,895	520
15%	2,199	773	0.0	6,277	2,020	0.0
20%	1,514	457	0.0	4,275	1,223	0.0
30%	872	195	0.0	2,370	553	0.0
40%	582	87.9	0.0	1,516	316	0.0
50%	406	34.6	0.0	1,040	137	0.0
60%	290	0.0	0.0	737	32.4	0.0
70%	196	0.0	0.0	494	0.0	0.0
80%	113	0.0	0.0	283	0.0	0.0
85%	70.8	0.0	0.0	187	0.0	0.0
90%	13.5	0.0	0.0	80.2	0.0	0.0
95%	0.0	0.0	0.0	0.0	0.0	0.0

Table 10.6
Frequency Metrics in acre-feet/day for Daily Flows at Control Points 8TROA and 8TRRO

	Flows at 8TROA (acre-feet/day)			Flows at 8TRRO (acre-feet/day)		
	Naturalized	Regulated	Unapprop	Naturalized	Regulated	Unapprop
mean	12,457	8,276	4,123	18,078	12,305	9,501
maximum	505,680	317,684	260,741	405,939	363,176	361,936
0.1%	245,331	203,603	145,625	239,237	204,459	201,302
0.2%	205,566	174,581	124,040	207,460	184,192	181,751
0.5%	162,878	134,164	89,886	174,076	147,609	145,380
1.0%	126,592	101,624	67,435	138,570	119,284	116,700
2.0%	92,692	73,498	46,172	106,437	90,071	87,613
5.0%	53,241	41,814	25,465	70,729	56,057	53,420
10%	31,729	22,394	11,853	47,348	34,400	30,878
15%	22,489	14,428	5,282	35,247	23,516	19,884
20%	16,433	9,527	2,067	27,586	16,508	12,316
30%	9,453	4,670	0.0	17,505	7,391	3,356
40%	5,912	2,505	0.0	11,182	4,725	0.0
50%	3,862	1,349	0.0	7,363	3,751	0.0
60%	2,557	675	0.0	4,971	2,843	0.0
70%	1,757	253	0.0	3,346	2,235	0.0
80%	1,011	0.0	0.0	2,016	1,654	0.0
85%	712	0.0	0.0	1,435	999	0.0
90%	394	0.0	0.0	951	0.0	0.0
95%	83.0	0.0	0.0	446	0.0	0.0
98%	0.0	0.0	0.0	105	0.0	0.0
99%	0.0	0.0	0.0	0.0	0.0	0.0

The four daily simulations described in the preceding section all include the flood control operations described in Chapter 4 and the Senate Bill 3 (SB3) environmental flow standards (EFS) described in Chapter 5. The simulated regulated and unappropriated flows reflected in Tables 10.4-10.6 and Figures 10.11-10.18 and the remainder of this chapter present the results of daily *SIMD* simulation D1, which has no routing and no forecasting.

Daily regulated flows from the *SIMD* simulation are plotted in acre-feet/day in Figures 10.11 through 10.14. Plots of stream flow variables at these four control points are also found in the other chapters of this report as follows.

Figures 6.3-6.6 on pages 95-96 are plots of gage period-of-record daily observed flows in cfs.
Figures 6.7-6.10 on pages 97-98 are plots of 1940-2018 daily naturalized flows in acre-feet/day.
Figures 7.1-7.4 on pages 105-106 are plots of 1940-2018 observed and naturalized monthly flows in acre-feet/month.
Figures 7.5-7.8 on pages 105-106 are plots of 1940-2018 observed and naturalized annual flows in acre-feet/year.
Figures 9.11-9.18 on pages 129-132 are plots of 1940-2018 daily SB3 EFS targets in acre-feet/day generated in a daily *SIMD* current use scenario simulation.
Figures 9.19-9.22 on pages 133-134 are plots of 1940-2018 monthly SB3 EFS targets in acre-feet/month generated in a daily *SIMD* current use scenario simulation.

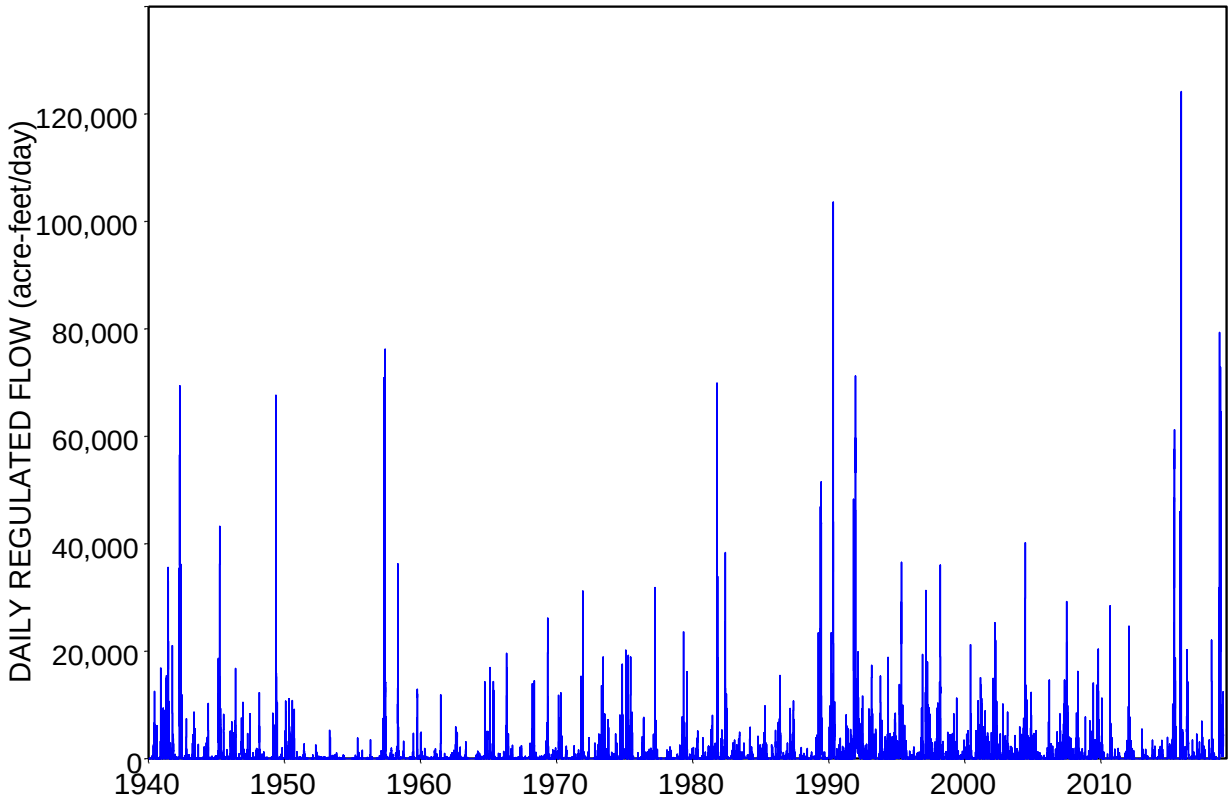

Figure 10.11 Simulated Daily Regulated Flows at Control Point 8WTGP (Grand Prairie)

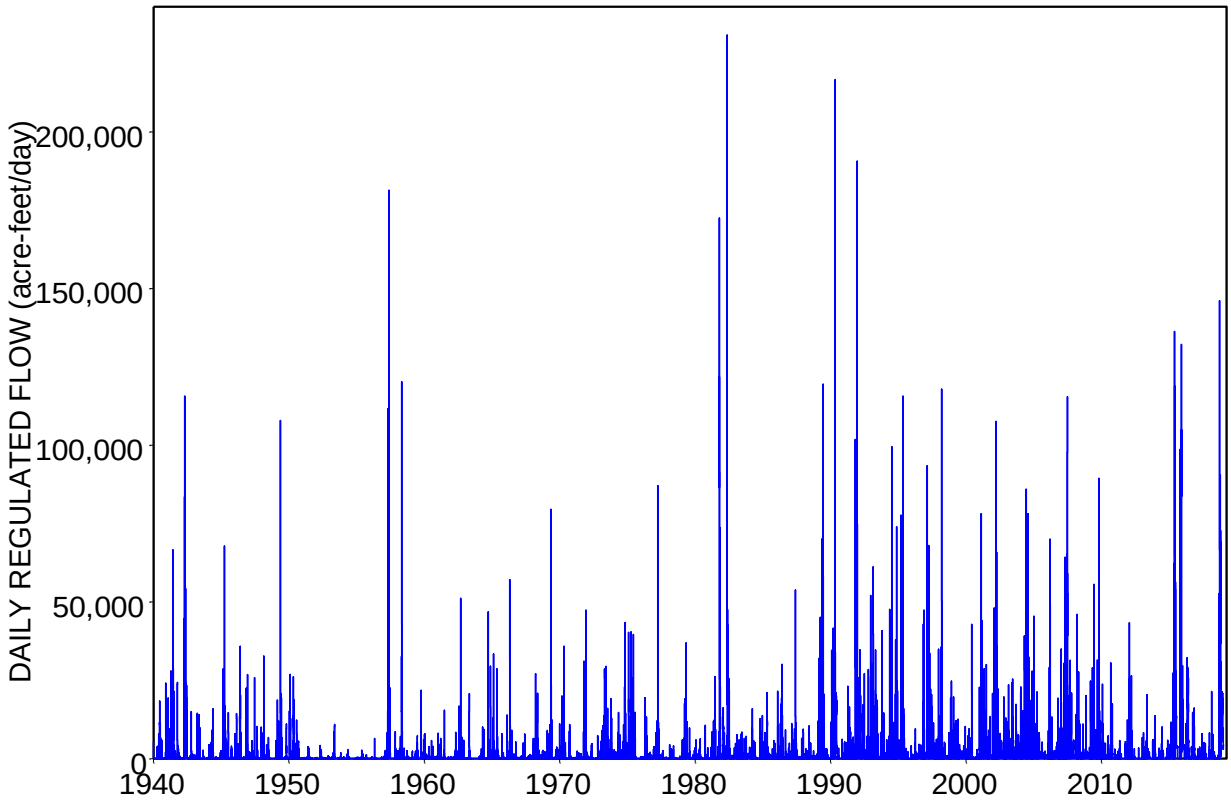

Figure 10.12 Simulated Daily Regulated Flows at Control Point 8TRDA (Dallas)

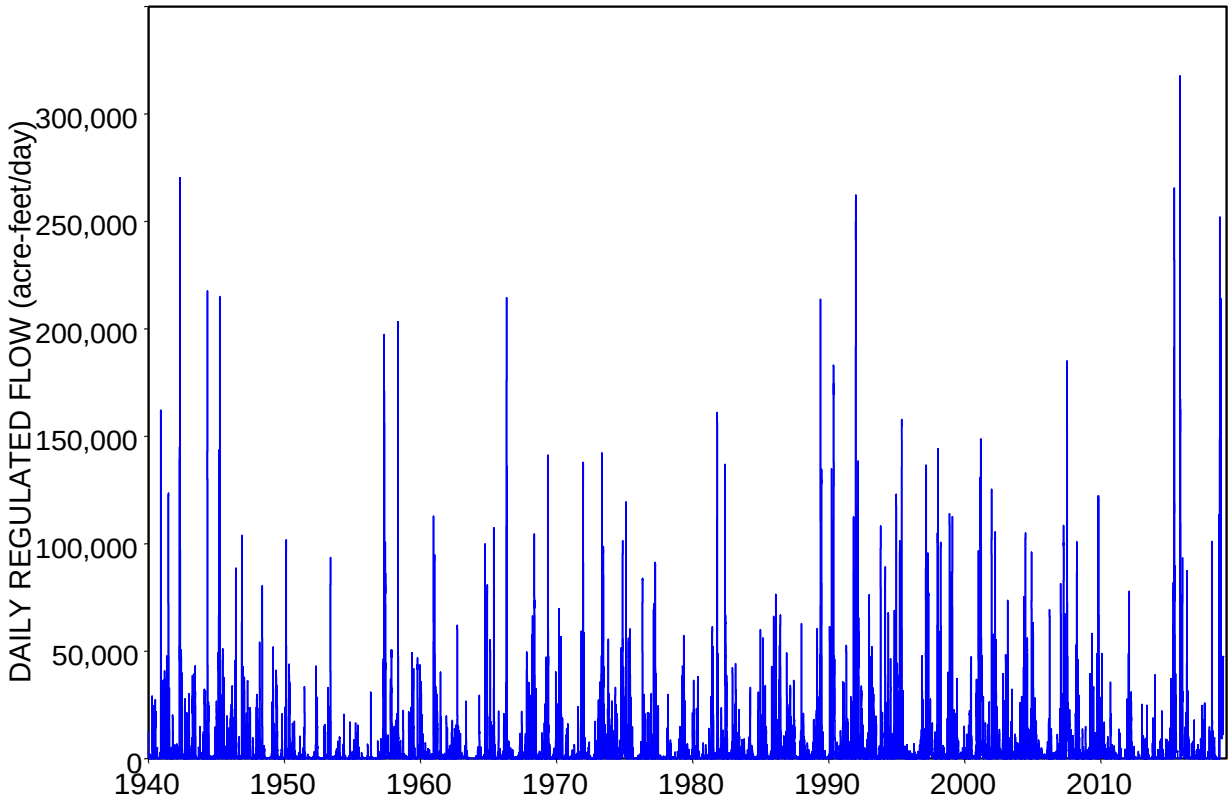

Figure 10.13 Simulated Daily Regulated Flows at Control Point 8TROA (Oakwood)

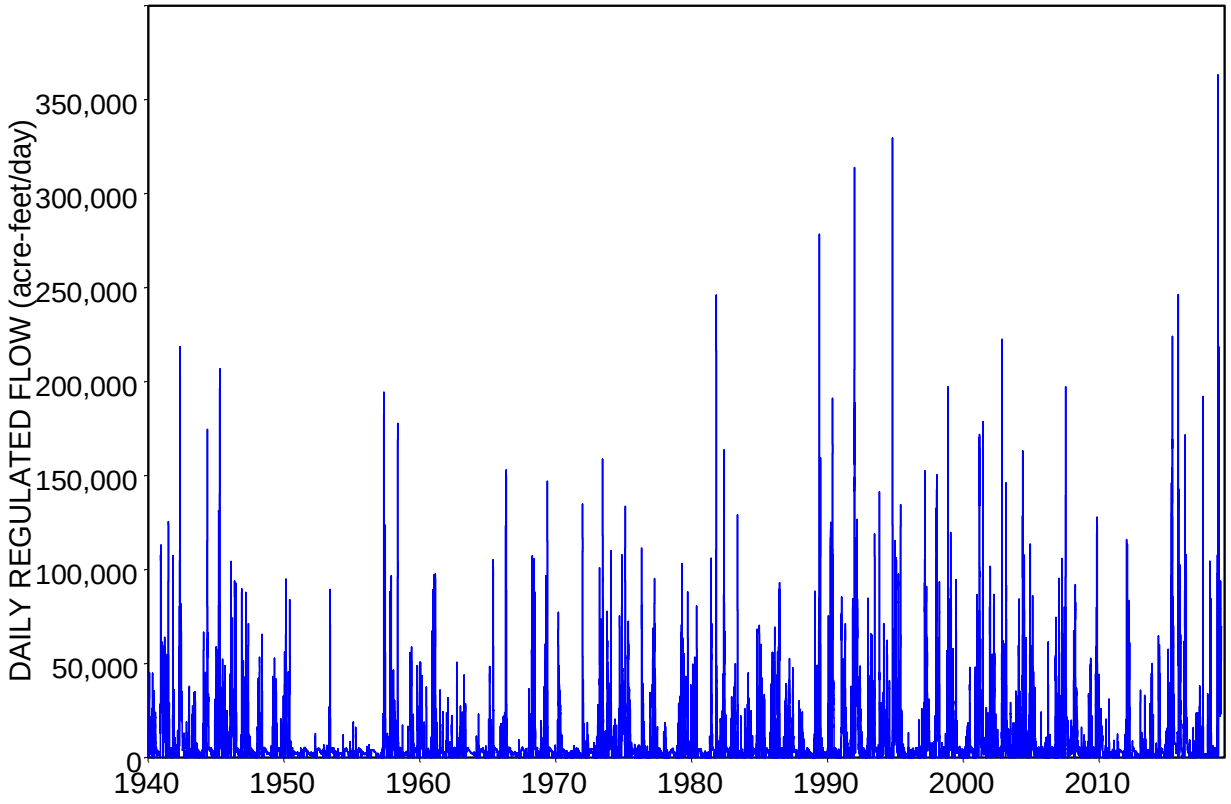

Figure 10.14 Simulated Daily Regulated Flows at Control Point 8TRRO (Romayor)

Daily Instream Flow Targets for SB3 EFS

Stream flows and instream flow targets in the *SIMD* computations and simulation results are in units of acre-feet/day. SB3 EFS subsistence and base limits are tabulated in Table 5.2 of Chapter 2 in cubic feet per second (cfs). Pulse flow specifications are listed in Table 5.3 with trigger levels in cfs. Tables 5.2 and 5.3 are replicated below as Tables 10.7 and 10.8 with flow units converted from cfs to acre-feet/day. SB3 EFS seasons are defined as follows: Winter (December, January, February), Spring (March, April, May), Summer (June, July, August), Fall (September, October, November).

Table 10.7
Subsistence and Base Flow Limits for SB3 Environmental Flow Standards

Control Point	Gauge Site Nearest City	Subsidence Flow Limits (af/day)				Base Flow Limits (af/day)			
		Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
8WTGP	Grand Prairie	37.69	49.59	45.62	41.65	89.26	89.26	69.42	69.42
8TRDA	Dallas	51.57	73.39	43.64	29.75	99.17	138.84	79.34	99.17
8TROA	Oakwood	238.0	317.4	148.8	198.4	674.4	892.6	495.9	515.7
8TRRO	Romayor	981.8	1,388	396.79	456.2	1,735	2,281	1,140	1,240

Table 10.8
Metrics for High Flow Pulse Components of SB3 Environmental Flow Standards

CP	Site	Criteria	Winter	Spring	Summer/Fall
8WTGP	West Fork of Trinity River at Grand Prairie	Trigger (ac-ft/day)	595.0	2,380	595.0
		Volume (acre-feet)	3,500	8,000	1,800
		Duration (days)	4	8	3
8TRDA	Trinity River at Dallas	Trigger (ac-ft/day)	1,388	7,934	1,983
		Volume (acre-feet)	3,500	40,000	8,500
		Duration (days)	3	9	5
8TROA	Trinity River at Oakwood	Trigger (ac-ft/day)	5,950	13,884	4,959
		Volume (acre-feet)	18,000	130,000	23,000
		Duration (days)	5	11	5
8TRRO	Trinity River at Romayor	Trigger (cfs)	15,868	19,835	7,934
		Volume (acre-feet)	80,000	150,000	60,000
		Duration (days)	7	9	5

The two alternative sets of *IF*, *ES*, and *PF* records used to model the SB3 EFS are replicated in Tables 5.4 and 5.5. Both sets of input records result in the same final instream flow targets. However, the input records in Table 5.4 allow intermediate as well as final targets to be recorded in the *SIMD* output file. The input records in Table 5.5 allow only the final SB3 EFS at each of the four control points to be recorded. The input records in Table 5.4 store the *ES* and *PF* records components as well as the final SB3 EFS at each of the four control points to be recorded. Options for selection of components of instream flow targets to be recorded are outlined in Table 5.6.

The SB3 EFS are the only *IF* record water rights at control points 8WTGP and 8TRRO. Other *IF* record rights described in Chapter 5 are located at control points 8TRDA and 8TROA in addition to the SB3 EFS. Multiple rights at the same control point are combined with the option of adopting the largest instream flow volume for each day (Table 5.7). Components of the targets for multiple *IF* record rights at the same control point are recorded in the *SIMD* output file using the options outlined in Table 5.6.

The means of the 1940-2018 sequences of naturalized, regulated, and unappropriated flows and SB3 EFS targets and shortages are compared in Table 10.9. The combined subsistence and base flow targets are the TIF-WR targets defined in Table 5.6 for the water rights IF-WTGP-ES, IF-TRDA-ES, IF-TROA-ES, and IF-TRRO-ES in Table 5.4. The pulse flow targets are the TIF-WR targets for the water rights IF-WTGP-PF, IF-TRDA-PF, IF-TROA-PF, and IF-TRRO-PF in Table 5.4. The final SB3 EFS targets are the IFT-WR (Table 5.6) targets for water rights IF-WTGP, IF-TRDA, IF-TROA, and IF-TRRO in Table 5.5. The targets considering all *IF* record rights at control points 8TRDA and 8TROA differ from the SB3 EFS targets due to other *IF* record rights being located at these two control points. There are no other *IF* record rights at control points 8WTGP and 8TRRO.

Table 10.9
Means of Daily Flow Quantities in acre-feet/day (af/d) and cubic feet per second (cfs)

Control Point	8WTGP	8TRDA	8TROA	8TRRO	8WTGP	8TRDA	8TROA	8TRRO
	(af/d)	(af/d)	(af/d)	(af/d)	(cfs)	(cfs)	(cfs)	(cfs)
Naturalized flow	1,698	4,807	12,457	18,078	856.1	2,424	6,280	9,114
Regulated flow	844.5	1,968	8,276	12,305	425.8	992.2	4,172	6,204
Unappropriated	294.5	639.7	4,123	9,501	148.5	322.5	2,079	4,790
Flow Targets								
subsistence/base	36.75	58.50	427.9	1,293	18.53	29.5	215.7	651.9
pulse flow	40.93	156.2	535.9	893.1	20.64	78.8	270.2	450.3
SB3 EFS	75.15	210.0	928.9	2,100	37.89	105.9	468.3	1058.8
all *IF* rights	75.15	556.7	2,926	2,100	37.89	280.7	1,475	1,059
Target Shortages								
before pulse	9.519	225.9	1,105	0.0	4.799	113.9	557.1	0.0
with pulse flow	19.74	283.3	1,253	408.1	9.952	142.8	631.7	205.8

The shortages in meeting instream flow targets consider all *IF* record rights at control points 8TRDA and 8TROA including both the SB3 EFS and the other more senior *IF* record rights. Since no other *IF* record rights are located at control points 8WTGP and 8TRRO, the shortages reflected in Table 10.9 are related only to the SB3 EFS. Water rights are considered in a priority sequence with the pulse flows being most junior. The shortages averaging 9.519, 225.9, 1,105, and 0.0 occur in the priority sequence prior to consideration of the pulse flow targets.

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 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.

Annual volumes in acre-feet/year of naturalized, regulated, and unappropriated flows and the final total SB3 EFS targets are plotted in Figures 10.15, 10.16, 10.17, and 10.18. The final SB3 EFS instream flow targets in these plots are the annual summations of the daily IFT-WR (Table 5.6) targets for water rights IF-WTGP, IF-TRDA, IF-TROA, and IF-TRRO in Table 5.5. A legend for Figures 10.15 through 10.18 is provided below.

naturalized stream flow	———	blue solid line
regulated stream flow	••••••	red dotted line
unappropriated flow	-------	green dashed line
SB3 EFS target	———	black solid line

The *IF* record daily instream flow targets for the SB3 EFS computed in the *SIMD* simulation are plotted in Figures 10.19 through 10.22.

- The combined subsistence and base flow components of the SB3 EFS targets defined on *ES* records are plotted in these figures as a red dotted line. These are the TIF-WR (Table 5.6) targets for water rights IF-WTGP-ES, IF-TRDA-ES, IF-TROA-ES, and IF-TRRO-ES (Table 5.4).
- The final combined subsistence, base, and pulse flow SB3 EFS targets defined on *ES* and *PF* records are plotted in Figures 10.15-10.18 as a blue solid line. These are the TIF-WR (Table 5.6) targets for water rights IF-WTGP, IF-TRDA, IF-TROA, and IF-TRRO (Table 5.5).

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 10.15-10.18 are much larger than the subsistence/base flow targets. However, their means tabulated in Table 10.9 are much closer. The means of the subsistence/base flow targets at the four sites are 36.75, 58.50, 427.9, and 1,293 acre-feet. The corresponding means of the pulse flow targets are 40.93, 156.2, 535.9, and 893.1 acre-feet/day. 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.

As previously noted, other *IF* record rights described in Chapter 5, in addition to the SB3 EFS, are located at control points 8TRDA and 8TROA. These instream flow rights result in higher targets than the SB3 EFS rights during some days of the simulation as indicated by Table 10.9. The instream flow targets in Figures 10.15 through 10.26 include only targets associated with the SB3 EFS.

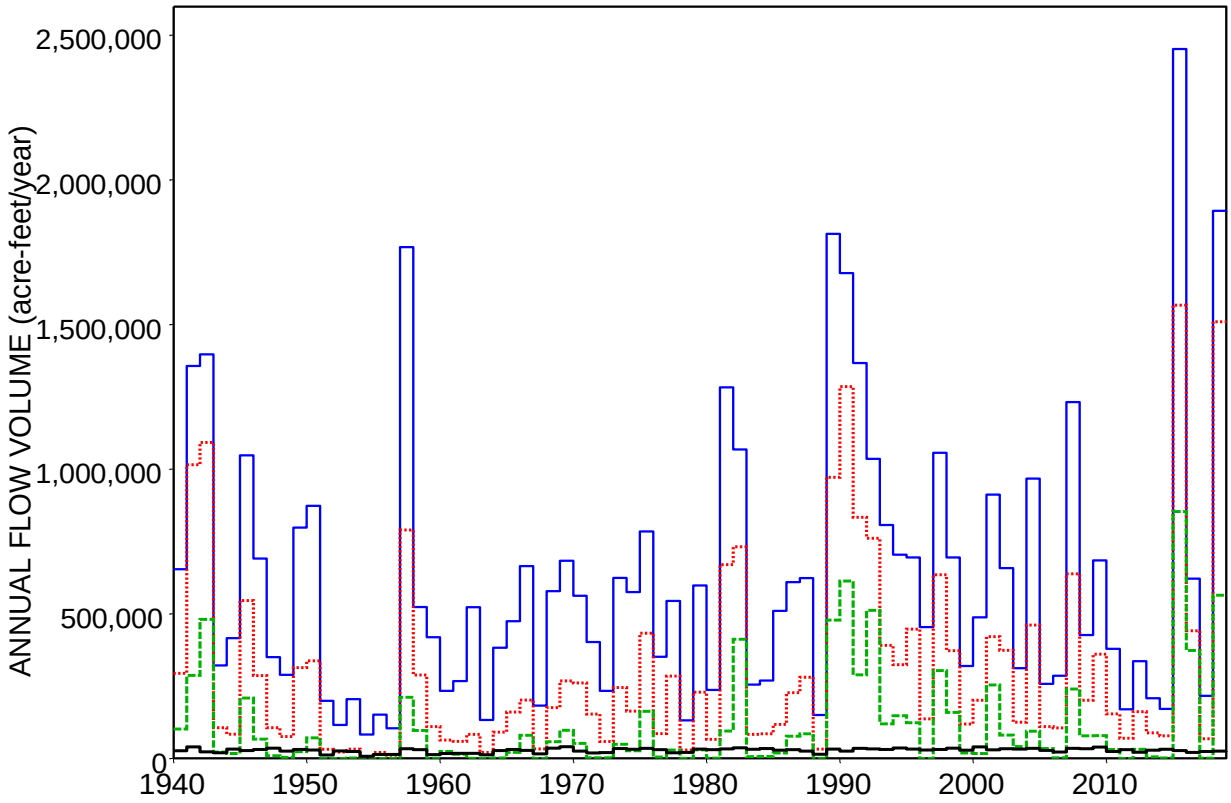

Figure 10.15 Annual Naturalized, Regulated, and Unappropriated Flows and SB3 EFS Targets at 8WTGP (Grand Prairie)

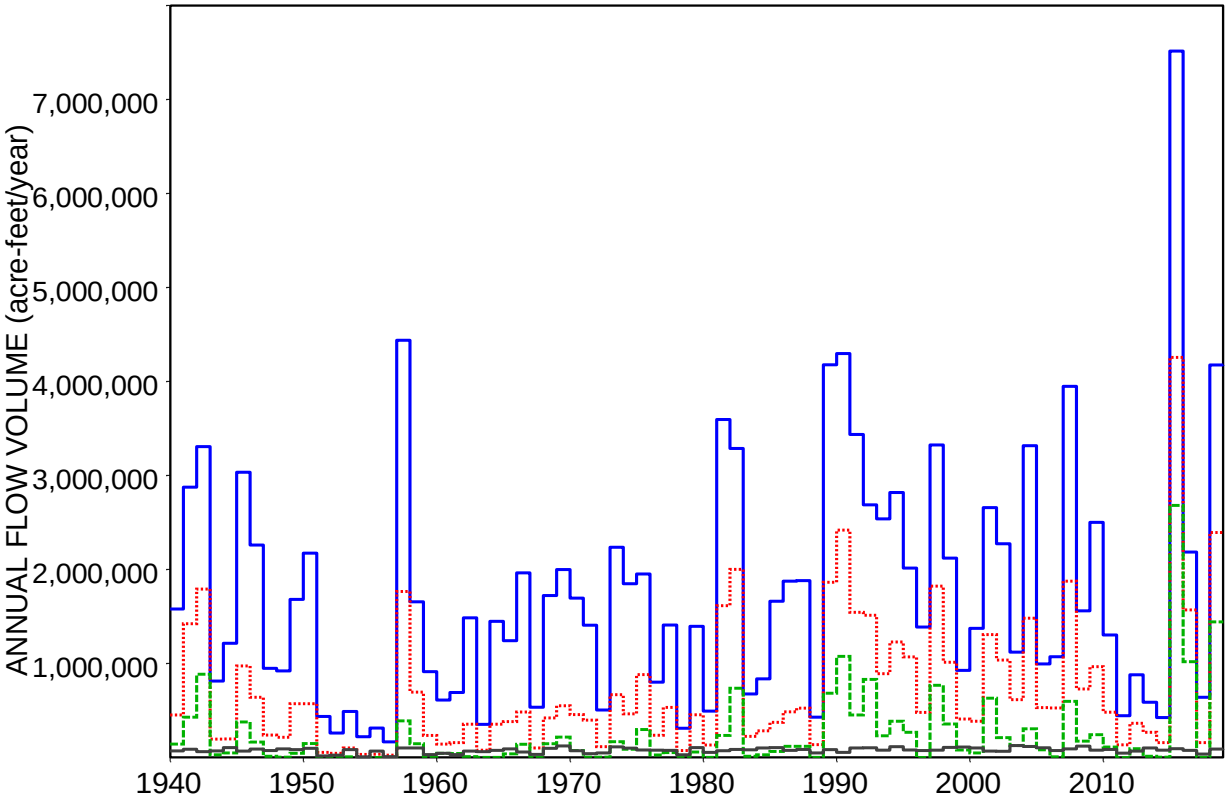

Figure 10.16 Annual Flows and SB3 EFS Targets at 8TRDA (Dallas)

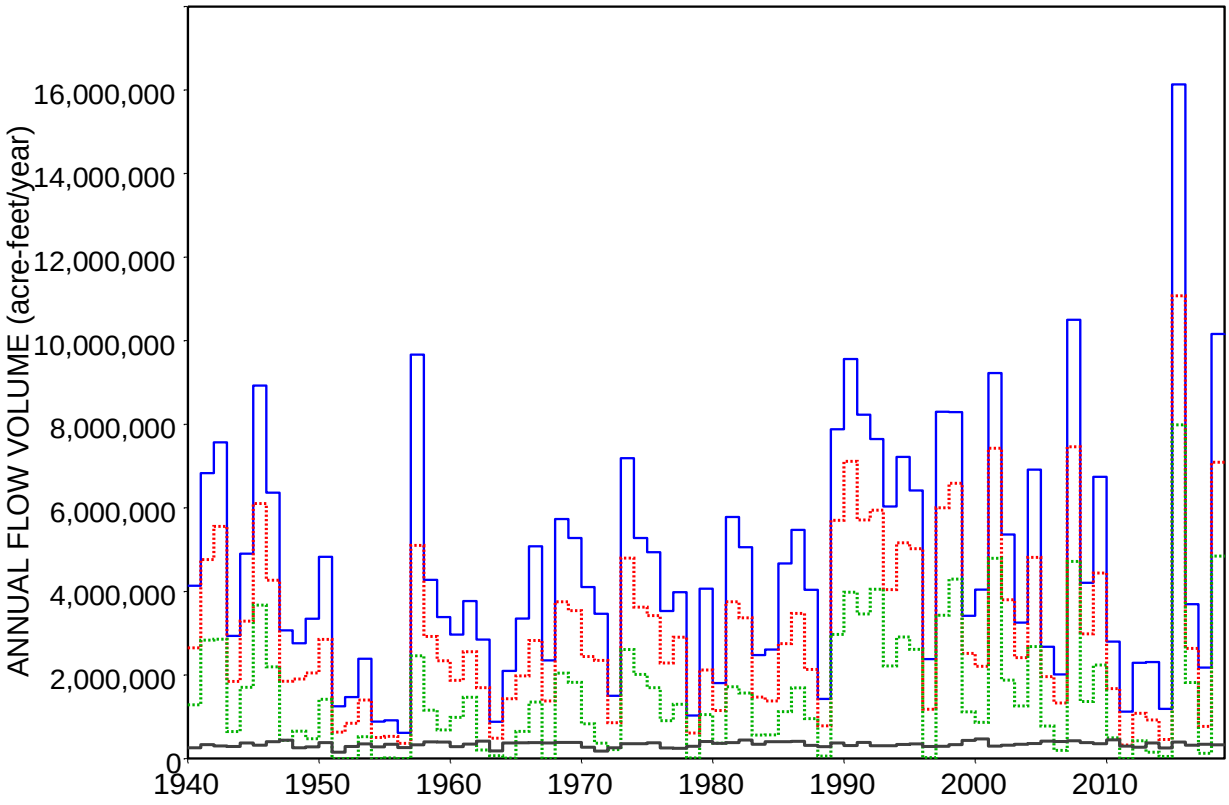

Figure 10.17 Annual Flows and SB3 EFS Targets at 8TROA (Oakwood)

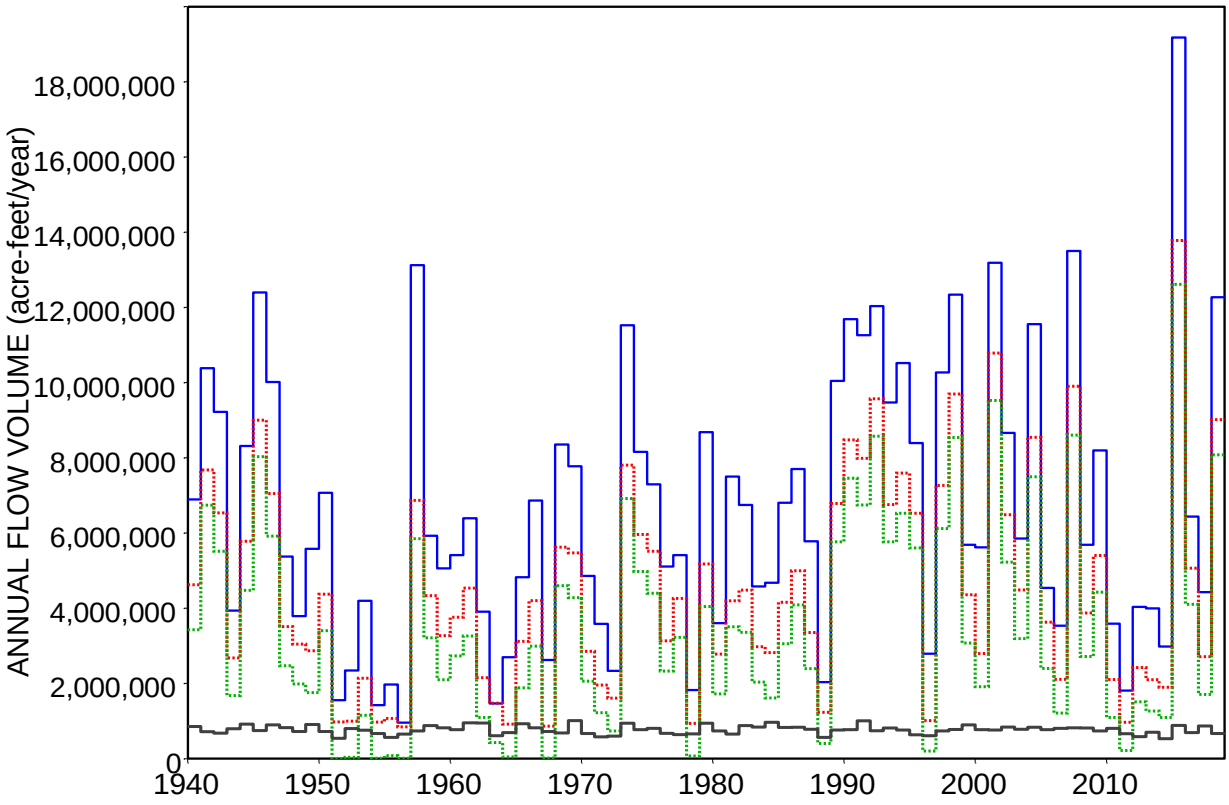

Figure 10.18 Annual Flows and SB3 EFS Targets at 8TRRO (Romayor)

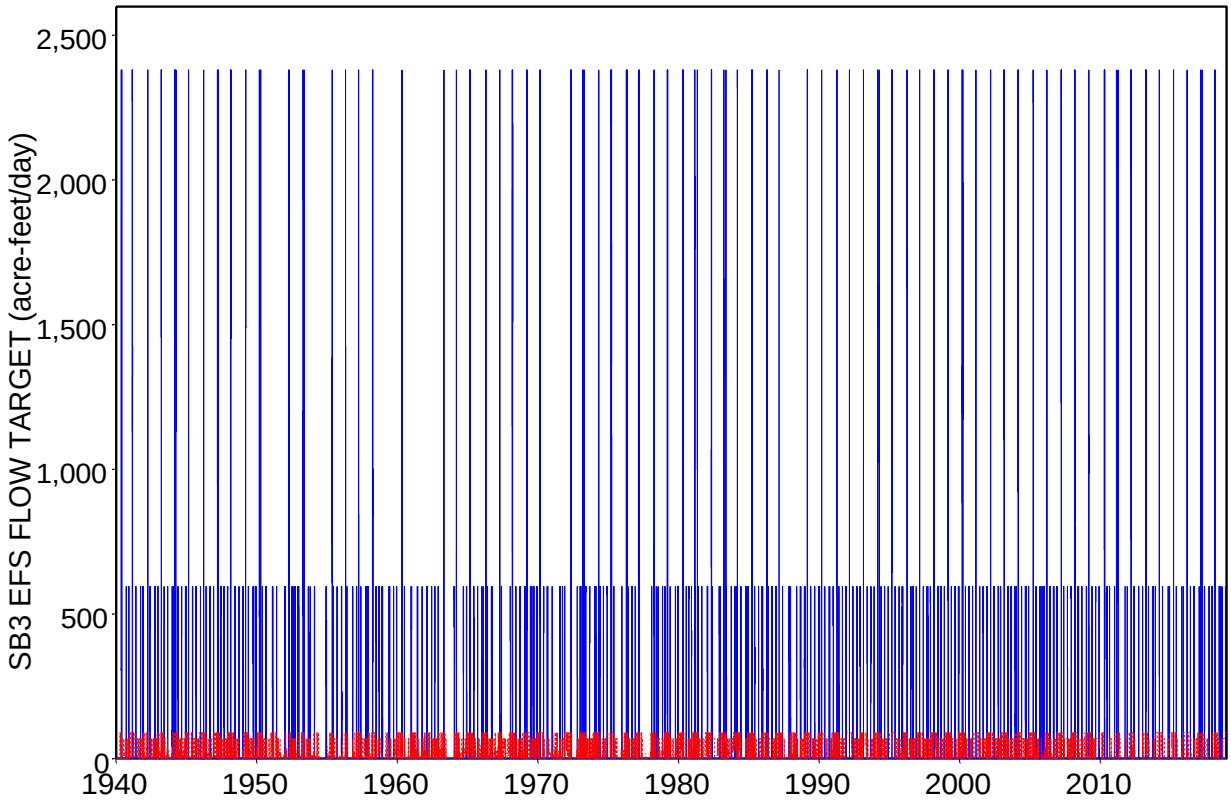

Figure 10.19 Daily Subsistence/Base and Pulse Flow Targets at 8WTGP (Grand Prairie)

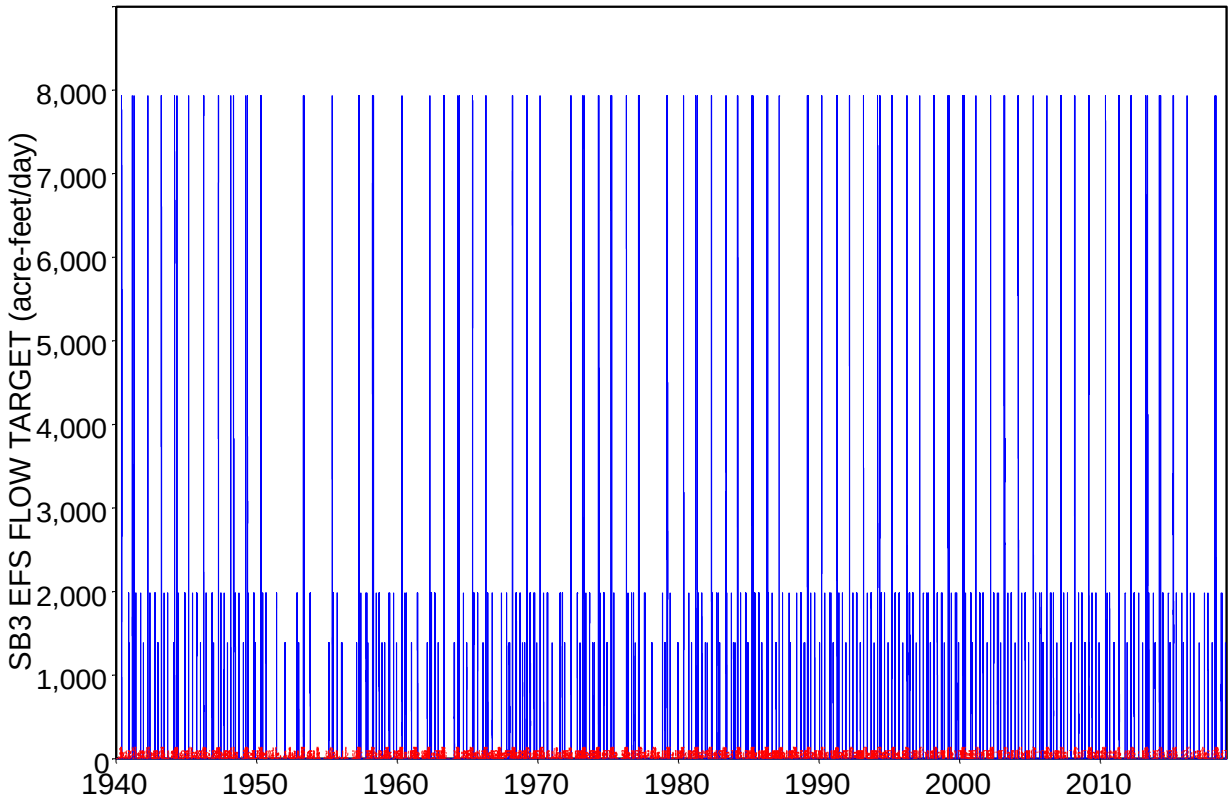

Figure 10.20 Daily Subsistence/Base and Pulse Flow Targets at 8TRDA (Dallas)

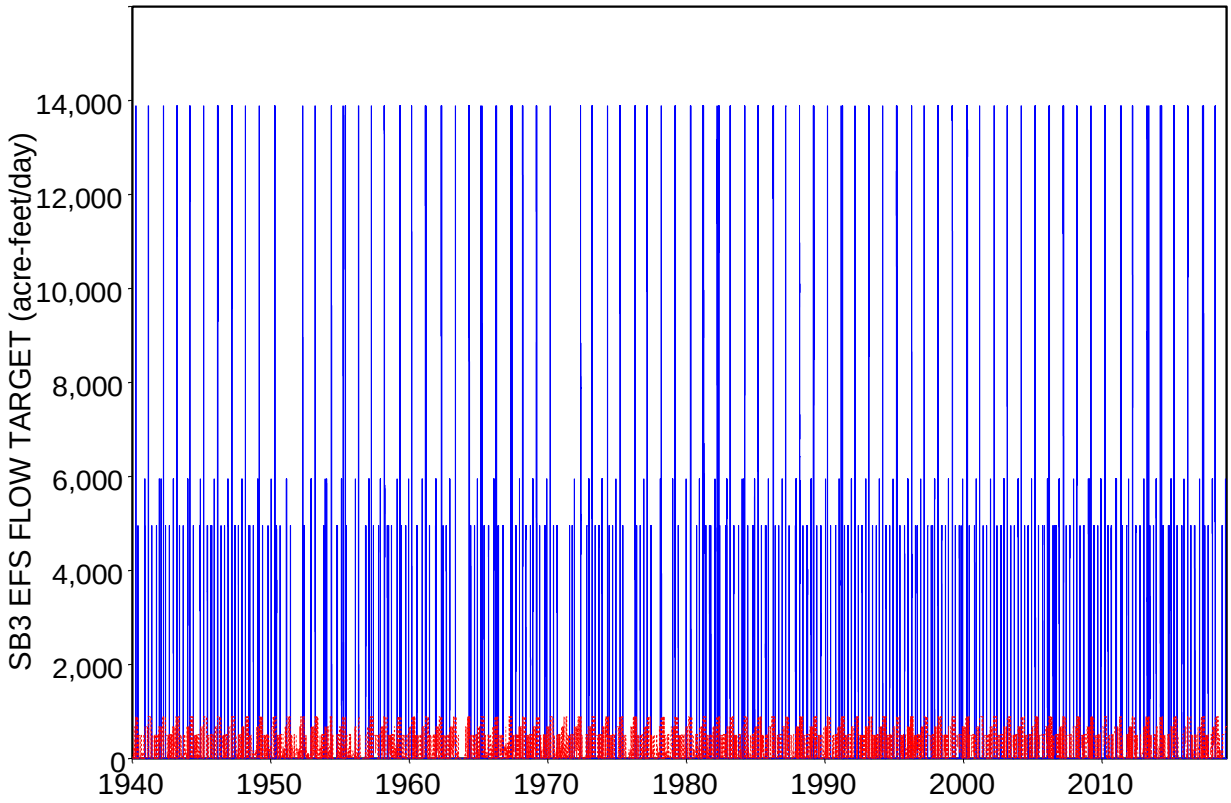

Figure 10.21 Daily Subsistence/Base and Pulse Flow Targets at 8TROA (Oakwood)

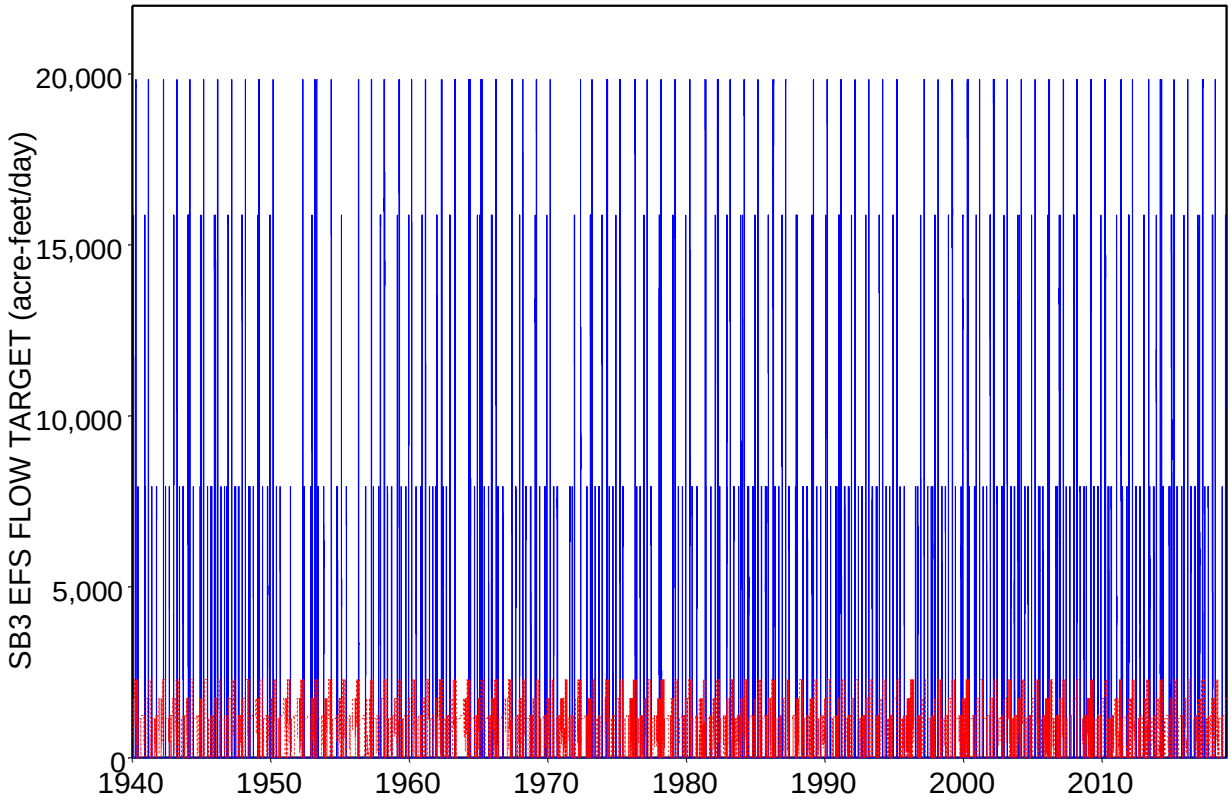

Figure 10.22 Daily Subsistence/Base and Pulse Flow Targets at 8TRRO (Romayor)

Monthly Instream Flow Targets for SB3 EFS from Daily SIMD Simulation

The final daily SB3 EFS instream flow target in acre-feet/day for each of the 28,555 days of the 1940-2018 hydrologic period-of-analysis is the larger of the subsistence/base flow targets or pulse flow targets plotted in Figures 10.19, 10.20, 10.21, and 10.22. The final daily SB3 EFS targets in each of the 948 months are summed to monthly totals within the *SIMD* simulation. The monthly targets in acre-feet/month are plotted in Figures 10.23, 10.24, 10.25, and 10.26.

The procedure for incorporating the monthly SB3 EFS targets generated in the daily SIMD simulation into the monthly WAM is described in Chapter 5 (pages 76-77). 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 5.10 replicated below as Table 10.10. The *IF* record water rights shown in Table 5.11 replicated below as Table 10.11 are inserted in the monthly WAM DAT file.

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 simulations daily and monthly. 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.

Table 10.10
Pathnames for *TS* Records for the SB3 EFS for the Full Authorization Scenario in the Shared Single Hydrology Input DSS File of the Trinity WAM

Part A	Part B	Part C	Part D	Part E
TRINITY	A8WTGP	TS	01Jan1940-31Dec2018	1MON
TRINITY	A8TRDA	TS	01Jan1940-31Dec2018	1MON
TRINITY	A8TROA	TS	01Jan1940-31Dec2018	1MON
TRINITY	A8TRRO	TS	01Jan1940-31Dec2018	1MON

Table 10.11
Instream Flow Rights that Model the SB3 EFS in the DAT File of the Monthly Authorized Use Scenario Version of the Trinity WAM

```
IF 8WTGP                20091201   2            IF-WTGP
TS      DSS  C8WTGP
IF 8TRDA                20091201   2            IF-TRDA
TS      DSS  C8TRDA
IF 8TROA                20091201   2            IF-TROA
TS      DSS  C8TROA
IF 8TRRO                20091201   2            IF-TRRO
TS      DSS  C8TRRO
```

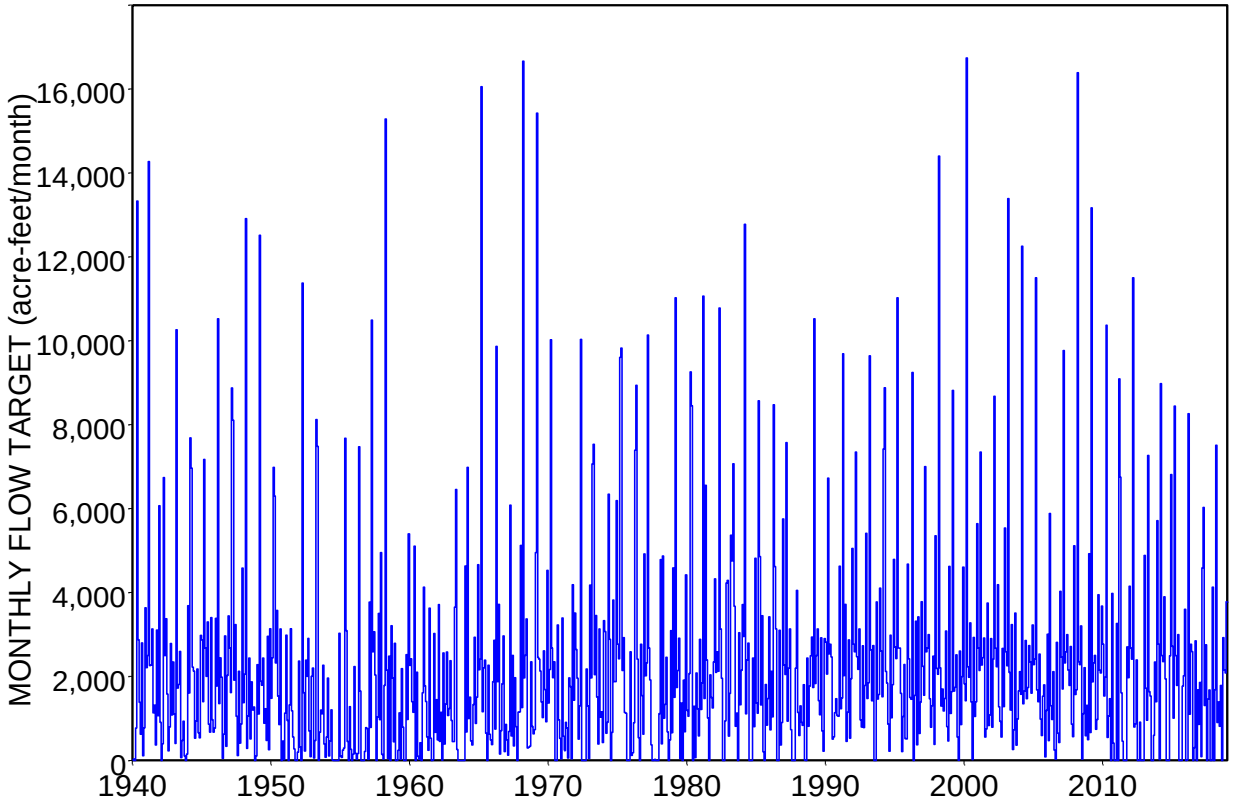

Figure 10.23 Monthly SB3 EFS Targets at Control Point 8WTGP (Grand Prairie)

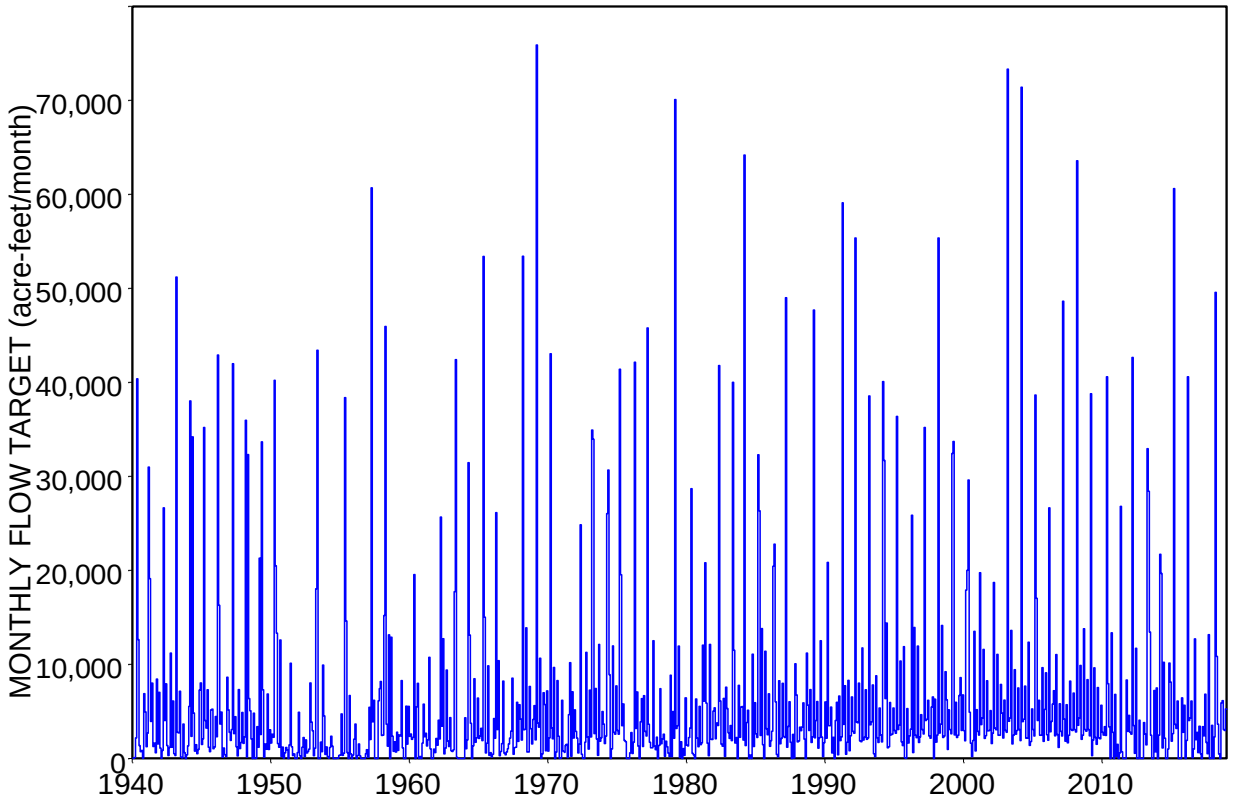

Figure 10.24 Monthly SB3 EFS Targets at Control Point 8TRDA (Dallas)

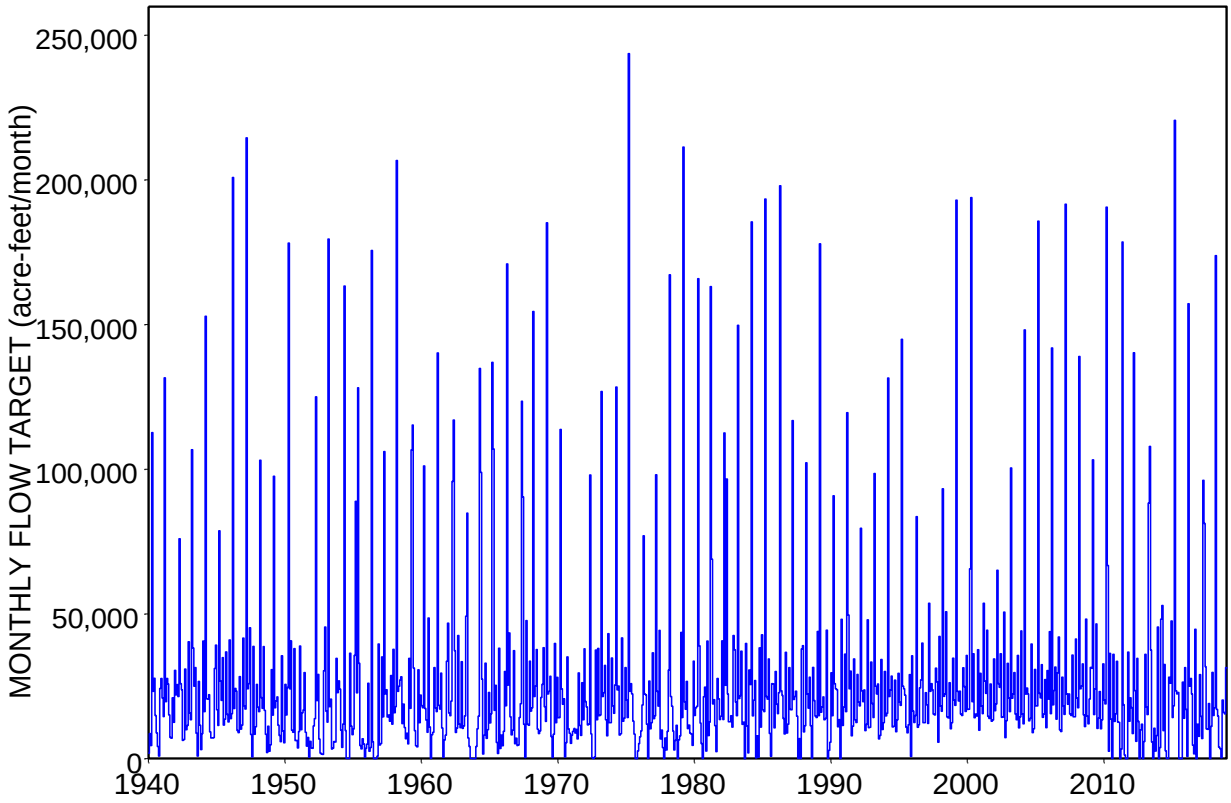

Figure 10.25 Monthly SB3 EFS Targets at Control Point 8TROA (Oakwood)

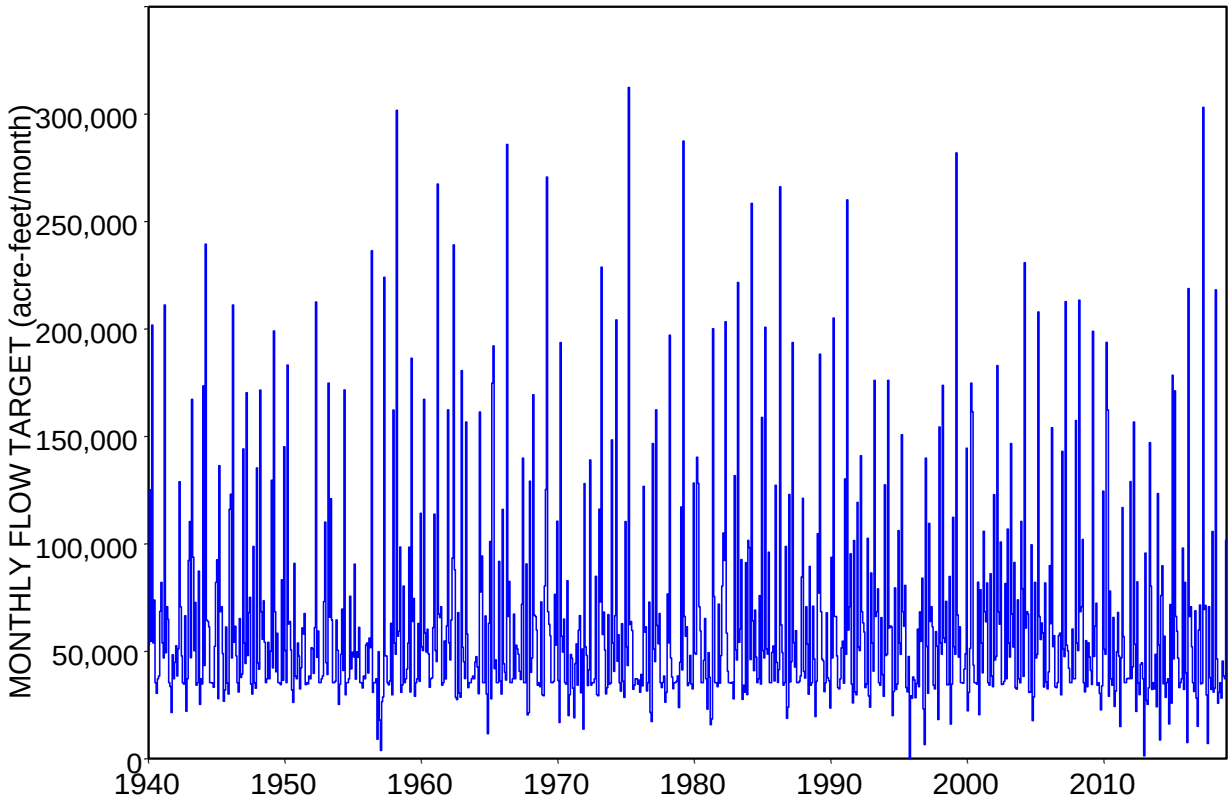

Figure 10.26 Monthly SB3 EFS Targets at Control Point 8TRRO (Romayor)

CHAPTER 11
ORGANIZATION AND CONTENTS OF DSS FILES

WRAP applications of the Hydrologic Engineering Center (HEC) Data Storage System (DSS) and the *HEC-DSSVue* interface component of the DSS are outlined in Chapter 6 of the WRAP *Users Manual* [2] and discussed throughout the WRAP manuals. The *HEC-DSSVue* software and detailed user's manual [8] are readily available for download from the HEC website.

DSS Files Accompanying this Report

This report is accompanied by the following five DSS files.

1. A file with filename TrinityDailyFlows.DSS contains daily stream flow data compiled in the process of compiling and analyzing daily flow sequences to be used as daily pattern hydrographs as described in Chapter 6.
2. A file with filename TrinityMonthlyFlows.DSS contains stream flow data compiled in the process of compiling, analyzing, and synthesizing monthly naturalized flow sequences as described in Chapter 7.
3. A file with filename TrinityEvapPrecip.DSS contains monthly precipitation and reservoir evaporation rates and net reservoir evaporation-precipitation rates described in Chapter 8.
4. The DSS file with filename TrinityHYD.DSS contains the adopted *DF*, *IN*, *EV* record sequences of daily flows, monthly naturalized flows, and evaporation-precipitation depths from the three preceding DSS files designed to serve as the hydrology input file read by *SIM* and *SIMD*. The *TS* records with SB3 EFS monthly instream flow targets described in Chapters 5, 9, and 10 are also stored in the *SIM/SIMD* input DSS file.
5. The DSS file with filename TrinitySimulationResults.DSS contains selected simulation results from the authorized use and current use scenario simulations described in Chapters 9 and 10.

The first three DSS files were used to compile, evaluate, and synthesize data as described by Chapters 6, 7, and 8 of this report. *HEC-DSSVue* was used to create the DSS files, plot the data, perform statistical analyses, and compare and combine datasets. The DSS files are also designed to be appendices to this report, allowing exploration of the datasets using *HEC-DSSVue*.

The fourth DSS file is a *SIM* or *SIMD* simulation input file containing the adopted time series of monthly naturalized flow and evaporation-precipitation rates, daily pattern flows, and monthly SB3 EFS instream flow targets stored as *IN*, *EV*, *DF*, and *TS* records. The same SIM/SIMD hydrology input file is employed with both the full authorization and current use scenario versions of the Trinity WAM. The fifth DSS file contains selected simulation results from the current and authorized use scenario simulations presented in Chapters 9 and 10. These *SIM*/*SIMD* simulation results output files, like all DSS files, can also be read with *HEC-DSSVue*.

Chapter 6 of the WRAP *Users Manual* [2] summarizes DSS methods covered in detail by the *HEC-DSSVue* manual [8]. Data stored in a DSS file is 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.

The DSS pathnames assigned to the data records are designed to facilitate convenient data series identification and comparison. DSS pathnames are defined with six components, called Parts A, B, C, D, E, and F [2, 8]. DSS records are named and renamed applying *HEC-DSSVue* editor options. The following options are recommended for selection in the View menu of HEC-DSSVue: condensed catalog and pathnames searched by parts. Data records can be sorted in alphabetical and numerical order using any of the pathname parts. The list of data records shown on the monitor can be controlled by entries in the search boxes using any combination of the pathname parts.

Pathname Part E is the time interval, which is 1DAY or 1MON for daily and monthly. Part D contains the range of data blocks based on standard block lengths of one year for daily and one decade for monthly data. The range listed on the computer monitor is for complete blocks that encompass the actual range covered by the data. Daily mean flows in cfs are assigned the type "PER AVER". Monthly or daily flow volumes in acre-feet and precipitation-evaporation depths are labeled type "PER-CUM", meaning cumulative during period. 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.

DSS File for Daily Flows (Chapter 6)

The DSS file with filename TrinityDailyFlows.DSS was prepared as discussed in Chapter 6 in conjunction with analyzing, synthesizing, and verifying daily simulation *SIMD* daily flow pattern hydrographs. This file contains the following five datasets containing a total of 220 daily flow sequences. Control point 8TRRO at the USGS gage on the Trinity River at Romayor is used in Table 11.1 to illustrate the pathname naming conventions employed for the DSS data records.

1. Period-of-record observed daily flows in cfs at 38 gages obtained from the USGS National Water Information System (NWIS) website that serve as WAM primary control points.
2. 1940-2009 daily unregulated flows from the modeling system maintained by the USACE Fort Worth District for 16 of the 40 WAM primary control points and 19 secondary control points.
3. 1940-2018 daily flow pattern hydrographs in cfs at 49 Trinity WAM *DF* record control points which were developed by selecting between and combining the two datasets listed above.
4. Daily naturalized flow volumes at the 49 control points in acre-feet/day computed within the *SIMD* simulation by disaggregating monthly flows to daily. This dataset of *DF* records with pathname part F changed to blank is adopted for the *SIMD* hydrology input DSS file and is included in Table 11.4.
5. Daily naturalized flows at the 49 control points, computed with *SIMD* as described above by disaggregating monthly flow volumes to daily, are converted from acre-feet/day to daily flow means in cfs for comparison with the other datasets.

The five datasets in the file TrinityDailyFlows.DSS contain 38 records, 35 records, 49 records, 40 records, and 40 records for a total of 202 DSS records. The fourth dataset listed above consists of *SIMD* generated daily naturalized flow volumes in units of acre-feet/day. The four other datasets consist of daily means of flows in cubic feet per second (cfs). The periods covered by the datasets are encompassed within the data block range shown with Part D. Daily flows have a standard DSS data block length of one year.

Table 11.1
DSS Pathnames for the File with Filename TrinityDailyFlows.DSS

Part A	Part B	Part C	Part D / range	Part E	Part F
GAGE - TRINITY RV	ROMAYOR, TX	FLOW – USGS	01JAN1924-01JAN2019	1DAY	8TRRO
USACE UNREGULATED FLOWS	TRINITY RIVER, ROMAYOR	FLOW – USACE	01JAN1940-01JAN2009	1DAY	8TRRO
WAM DAILY PATTERN FLOWS	8TRRO	FLOW – PATTERN (CFS)	01JAN1940-01Jan2019	1DAY	
TRINITY	8TRRO	DF	01JAN1940-01Jan2018	1DAY	ACRE-FEET
TRINITY	8TRRO	DF (CFS)	01JAN1940-01Jan2018	1DAY	NAT (CFS)

The first dataset consists of daily flows in cfs at 38 USGS gages downloaded in September 2019 directly from the NWIS maintained by the USGS. Identically the same dataset is included in the monthly flow DSS file discussed in the next section.

The second dataset consists of the USACE 1940-2009 daily unregulated flows at 16 of the WAM primary and 19 secondary control points. The USACE provided these daily flows from their modeling system in a Microsoft Excel spreadsheet. The Microsoft Excel spreadsheet was resaved within Excel as a CSV (comma separated values) file which was read with *HEC-DSSVue*.

The third dataset consists of the final 1940-2018 daily pattern hydrographs at 49 control points in cfs. This third dataset was input to *SIMD* as *DF* records with flows in cfs to obtain the fourth dataset of *DF* record flows in acre-feet which is described in the next paragraph.

The fourth dataset in the file TrinityDailyFlows.DSS consists of 1940-2018 daily naturalized flow volumes in acre-feet at the 49 *DF* record control points computed in a *SIMD* simulation by disaggregating monthly flows to daily using the daily flow pattern hydrographs from the third dataset described above read from the hydrology input DSS file. This fourth dataset is identical to the DSS records in the *SIMD* simulation results output file except for pathname part F.

The fifth dataset also consists of daily naturalized flows at the 49 *DF* record control points computed by *SIMD*. However, the daily flow volumes in acre-feet in the *SIMD* simulation results are converted to daily means in cfs, by multiplying by 0.504166667, for consistency in comparing with the other datasets contained in the file TrinityDailyFlows.DSS.

The third, fourth, and fifth datasets provide alternative sets of daily flow patterns that will result in the same *SIMD* simulation results if provided as *SIMD* input. The fourth dataset was actually adopted for the *SIMD* hydrology input DSS file described later in this chapter.

DSS File for Monthly Stream Flows (Chapter 7)

The DSS file prepared in conjunction with compiling, synthesizing, and verifying monthly flows as described in Chapter 7 has the filename TrinityMonthlyFlows.DSS and contains the following five datasets. The five datasets contain 38, 38, 40, 35, and 40 time series data sequences for a total of 191 DSS records. Control point 8TRRO at the USGS gaging station on the Trinity River at Romayor is used in Table 11.2 to illustrate the pathname naming conventions adopted for the DSS records in each of these five datasets. Part F is used for the WAM control point identifier

for all five datasets. The monthly flow DSS file contains a total of 191 DSS records (38, 38, 40, 35, 40 records) in the five datasets listed in Table 11.2 and described below.

1. Period-of-record observed daily flows in cfs obtained from the USGS NWIS website for 38 USGS gages that serve as WAM primary control points. Two other primary control points (8RIFA and 8TRGB) have no flow data in the USGS NWIS.
2. Monthly summations of the daily gaged flows at the 38 sites converted to acre-feet/month.
3. 1940-2018 monthly naturalized flows in acre-feet/month at the 40 primary control points composed of the original 1940-1996 monthly naturalized flows and 1997-2018 extensions synthesized using the hydrologic modeling feature of the WRAP program *HYD* that relates naturalized flows to precipitation and evaporation.
4. Monthly summations of 1940-2009 daily unregulated flows from the USACE Fort Worth District modeling system for 35 sites which include 16 of the 40 WAM primary control points.
5. Final adopted 1940-2018 monthly naturalized flows at the 40 WAM primary control points.

Table 11.2
DSS Pathnames for the File with Filename TrinityMonthlyFlows.DSS

	Part A	Part B	Part C	Part D / range	Part E	Part F
1	GAGE – TRINITY RV	ROMAYOR, TX	FLOW – USGS DAILY	01May1924-08Sep2019	1DAY	8TRRO
2	GAGE – TRINITY RV	ROMAYOR, TX	FLOW – USGS (ACRE-FEET)	31May1924-30Sep2019	1MON	8TRRO
3	WAM&HYD	8TRRO	FLOW – NAT – HYD	31Jan1940-31Dec2018	1MON	8TRRO
4	USACE UNREGULATED	ROMAYOR	FLOW – USACE	31Jan1940-31Dec2009	1MON	8TRRO
5	TRINITY	8TRRO	IN	31Jan1940-31Dec2018	1MON	8TRRO

The first dataset in Table 11.2 consists of daily flows in cubic feet per second (cfs) at 38 USGS gages, which were downloaded from the NWIS. The gage on the Trinity River at Romayor is one of the 38 gages. Pathnames automatically assigned by *HEC-DSSVue* as the datasets downloaded were changed to those illustrated by Table 11.2. Parts B and F of the pathname indicate the site location, Parts C and E indicate the type of data, and Part D indicates the range covered by the data blocks.

The second dataset was created within *HEC-DSSVue* by converting the daily means in cfs to monthly volumes in acre-feet using the following *HEC-DSSVue* option path: Tools – Math Functions – Time Functions – Min/Max/Avg/…over period – Volume for Period – 1MON. The pathname convention for this second dataset is similar to that of the first dataset. Pathname Part A begins with GAGE for the first (daily) and second (monthly) datasets followed by the stream. Part B is the nearest town as assigned in the USGS NWIS.

The third dataset consists of 1940-2018 monthly naturalized flows in acre-feet at the 40 WAM primary control points. The original naturalized flows are adopted without change for 1940-1996. The WRAP program *HYD* hydrologic model that relates naturalized flows to precipitation and evaporation was applied to extend the flows through 2018 [4, 12]. Pathnames for the 40 records of 1940-2018 monthly naturalized flows at the 40 primary control points are assigned as indicated in Table 11.2, which shows only control point 8TRRO. Pathname Part A is WAM&HYD.

The fourth dataset consists of monthly summations in acre-feet of the USACE 1940-2009 daily flows at 35 locations of which 16 sites are at WAM primary control points. The USACE provided the daily flows in cfs in a Microsoft Excel spreadsheet. The Microsoft Excel spreadsheet was resaved within Excel as a CSV (comma separated values) file which was read with *HEC-DSSVue*. The daily flows were summed to monthly volumes within *HEC-DSSVue*.

The fifth dataset consists of the *IN* records of final monthly naturalized flows in acre-feet at the 40 primary control points which are adopted for the daily Trinity WAM. These flow sequences are developed by combining segments of the three other monthly flow sequences as described in Chapter 7. The Edit – Tabular Edit feature of *HEC-DSSVue* was used to combine portions of the data records from the WAM&HYD, USACE, and USGS monthly flow datasets to create the final monthly flow dataset. Part F is blank for the *IN* records in the hydrology file.

Monthly flow volumes in acre-feet and precipitation-evaporation depths in inches or feet are labeled type "PER-CUM". Daily flows in cfs are labeled type "PER-AVER". The monthly data are assigned the time 24:00 hours (midnight) at the end of the month. For example, *HEC-DSSVue* assigns the time 31 January 1940, 24:00 hours to the monthly flow volume during January 1940.

DSS File for Monthly Evaporation and Precipitation Depths (Chapter 8)

The DSS file prepared in conjunction with the compilation of net reservoir evaporation less precipitation depths discussed in Chapter 8 has the filename TrinityEvapPrecip.DSS and contains the following datasets.

1. Thirteen 1954-2018 sequences of monthly reservoir evaporation depths in inches from the TWDB database for the 13 quadrangles shown in Figure 8.5 of Chapter 8.
2. Thirteen 1940-2018 sequences of monthly reservoir evaporation depths in inches from the TWDB database for the 13 quadrangles shown in Figure 8.5.
3. Thirteen 1954-2018 sequences of monthly reservoir evaporation minus precipitation depths in inches for the 13 quadrangles shown in Figure 8.5.
4. Fifty 1940-2018 sequences of *EV* record monthly net evaporation-precipitation depths in feet that are stored in the hydrology DSS file of the Trinity WAM.

Table 11.3
DSS Pathnames for the File TrinityEvapPrecip.DSS

	Part A	Part B	Part C	Part D / range	Part E	Part F
1	TWDB EVAPORATION	511	EVAPORATION	31JAN1954-31DEC2018	1MON	INCHES
2	TWDB PRECIPITATION	511	PRECIPITATION	31JAN1940-31DEC2018	1MON	INCHES
3	TWDB EVAPORATION-PRECIPITATION	511	EVAP-PRECIP	31JAN1954-31DEC2018	1MON	INCHES
4	TRINITY	B4248B	EV	31JAN1940-31DEC2018	1MON	FEET

The first three datasets consist of TWDB data for the 13 quads encompassing the Trinity River Basin. Part B is the quad identifier shown in Figure 8.5. The fourth dataset consists of the *IN* records for the *SIM/SIMD* hydrology input file (Table 11.4) for the 50 control point identifiers listed in Tables 8.1 and 8.2. The net evaporation less precipitation for Lake Livingston illustrates the pathname conventions used for the *EV* records. Part B is control point B4248B in Table 11.3.

***SIM* and *SIMD* Hydrology Input File (Chapters 9 and 10)**

A single combined *SIM/SIMD* time series input file contains *DF*, *IN*, *EV*, and *TS* records with pathnames in the format illustrated by Table 11.4 and discussed in this section. Compilation of the *DF*, *IN*, and *EV* records is covered in Chapters 6, 7, and 8, respectively. The target series *TS* records with SB3 EFS instream flow targets at four sites are explained in Chapters 5, 9, and 10.

The final net evaporation-precipitation depths (*EV* records) for 50 control points, monthly naturalized flows (*IN* records) for 40 control points, and daily flows (*DF* records) for 49 control points developed in the three DSS files described on the preceding sections are copied to a file with filename TrinityHYD.DSS, which is designed to be read by *SIM* and/or *SIMD*. Pathnames are changed a little in the transfer to the *SIM/SIMD* hydrology input file as shown in Table 11.4.

The DSS pathname conventions for the eight *TS* records for the current use and authorized use versions of the Trinity WAM are illustrated in Tables 5.8 and 5.10. The part B identifier for the *TS* records distinguishes between authorized (A) and current (C) use versions as explained in Chapter 5. The daily and monthly full authorization and current use scenario versions of the WAM all employ the same single *SIM/SIMD* time series input file with filename TrinityHYD.DSS.

Table 11.4
DSS Pathnames for *SIM/SIMD* Hydrology Input File TrinityHYD.DSS

Part A	Part B	Part C	Part D / range	Part E	Part F
TRINITY	8TRRO	DF	01Jan1940-31Dec2018	1DAY	
TRINITY	8TRRO	IN	31Jan1940-31Dec2018	1MON	
TRINITY	B2334A	EV	31Jan1940-31Dec2018	1MON	
TRINITY	A8TRRO	TS	31Jan1940-31Dec2018	1MON	
TRINITY	C8TRRO	TS	31Jan1940-31Dec2018	1MON	

JO record INEV option 6 activates the option of reading both monthly evaporation-precipitation rates and naturalized flows from a hydrology DSS file. The default is to read the monthly hydrology from FLO and EVA files. A *SIM/SIMD OF* record option converts existing WAM EVA and FLO files to a hydrology DSS file. With the DSS(5) option on the *OF* record activated, net evaporation-precipitation depths are read from *EV* records in an EVA file and monthly naturalized flows are read from *IN* records in a FLO file and these data are recorded in a hydrology DSS file.

Daily flow pattern hydrographs were recorded on *DF* records in a DCF text file in initial developmental versions of *SIMD*. May 2019 and later versions of *SIMD* read *DF* record daily flows from either the DIF or DSS files. The DSS file option is much more convenient and is the recommended standard. The selection between reading *DF* records from the DSS versus DIF file is controlled by parameter DFFILE in *JU* record field 3. The default DFFILE option 1 is to read the daily flows from the DSS file. Option 2 is to read the daily flows from the DIF file. DFFILE option 3 facilitates converting existing old datasets from option 2 to option 1. The *DF* records for the daily Trinity WAM were developed directly in DSS using *HEC-DSSVue*.

The updated monthly hydrology can be provided alternatively both as updated FLO and EVA files as well as the hydrology DSS file. The updated daily hydrologic data accompanying this report are provided only in the newer hydrology DSS file. The DSS file is proposed as the standard method for storing all time series input data for daily *SIMD* simulations.

DSS pathname conventions for the hydrology input file and simulation results output file are described in Chapter 6 of the *WRAP Users Manual* [2]. The DSS pathname conventions for a *SIM/SIMD* hydrology input file are illustrated by the Trinity WAM pathnames in Table 11.4.

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 HYD (Trinity from TrinityHYD.DSS). The default filename root can be replaced with DSSROOT entered in *OF* record field 13.

Part B is the WAM control point identifier.

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

Part D is 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* time series input records.

By default, *SIM* and *SIMD* automatically set the start month as January of the starting year of the simulation. The starting day is January 1 for daily data and January 31 for monthly data. The default starting month can be overwritten by DSSMONTH entered on the *SIM/SIMD* file options *OF* input record. The ending date is automatically set based on the hydrologic period-of-analysis of the *SIM/SIMD* simulation.

Pathname Part D shown in Table 11.4 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 blocks encompass the data, but the data does not necessarily fill each entire block. The beginning dates of the first and last blocks are shown in Part D of the *HEC-DSSVue* monitor listing, as illustrated in Table 11.4.

The monthly data extends from January 1940 through December 2018. The daily flows extend from January 1, 1940 through December 31, 2018. *SIM* and *SIMD* allow the simulation period set by the *JD* record parameters YRST and NYRS to be any sub-period of complete years of the period covered by the hydrology input data sequences.

Datasets from different sources with 24:00 hours (midnight) defined in DSS as the beginning versus the end of the time interval can result in a one-period shift in a time series. Dataset dates are adjusted for comparison consistency using *HEC-DSSVue* with the following option path: Tools – Math Functions – Time Functions – Shift in Time – Shift to date/time.

***SIM* and *SIMD* Simulation Results DSS Output File (Chapters 9 and 10)**

Thirteen different types of *SIM* and *SIMD* output files are described in the *Reference* and *Users Manuals* [1, 2]. The only *SIM* and/or *SIMD* output files employed in the simulations presented in Chapters 9 and 10 are OUT, SUB, and DSS files. The *SIM/SIMD* OUT and *SIMD* SUB files are read as input files by *TABLES*. The DSS output file is accessed with *HEC-DSSVue*.

Managing the *SIM/SIMD* Simulation Results DSS File

A *SIM* simulation with the input files listed in Table 12.1 of Chapter 12 creates a single DSS output file with the filename Trinity3M.DSS or Trinity8M.DSS that contains the time series of monthly simulation results. A daily *SIMD* simulation with the input files of Table 12.1 creates a single DSS output file with the filename Trinity3D.DSS or Trinity8D.DSS that contains both monthly and/or daily time series of simulation results. The set of DSS files that accompany this report includes a file with filename TrinitySimulationResults.DSS that contains a combination of selected results from multiple different simulations.

Simulation results are conveniently and efficiently managed with DSS files and *HEC-DSSVue*. Simulation results from any number of simulations can be recorded directly by *SIM*, *SIMD*, and/or *TABLES* into the same single DSS file or separate DSS files. Model users can quickly copy selected groups of records between DSS files using the *HEC-DSSVue* editor. The pathnames for selected groups of DSS records are easily renamed using the *HEC-DSSVue* editor.

Selection of time series for inclusion in a *SIMD* simulation results DSS file is illustrated by Table 11.5. The *OF* and auxiliary *OFV* records described on pages 45-47 of the *Users Manual* [2] control selection of any subset of 43 simulation results time series variables associated with either control points, water rights, or reservoirs.

Table 11.5
SIMD DAT File Input Records for Controlling Simulation Results Files

```
**       1         2         3         4         5         6         7         8
**345678901234567890123456789012345678901234567890123456789012345678901234567890
JD    79    1940       1       0       0               7                      13
JO     6                   0                                                   3
JT     0   0   0   0   0   0   0   0   0   0   0   1
JU     1   0   0   0   0
OF     1   0   3   5                                       Trinity
OFV    1   2   3  15  16
C2         8WTGP   8TRDA   8TROA   8TRRO
**OF     1   2   3   3                                         Trinity
**OFV   27  28  29
**W2             IF-WTGP         IF-TRDA         IF-TROA         IF-TRRO
```

The entries of 1, 2, 3, 15, and 16 in the *OFV* record of Table 11.5 refers to naturalized flows (NAT), regulated flows (REG), unappropriated flows (UNA), instream flow targets (IFT), and instream flow shortages (IFS) at control points 8WTGP, 8TRDA, 8TROA, and 8TRRO listed on the C2 record. DSS(3) option 3 selected in *OF* record field 4 (column 20) specifies that both monthly and daily results be recorded in the DSS file.

Another optional set of output specifications deactivated by asterisks ** in Table 11.5 can be easily activated by removing the **. These input records specify that the DSS file should include sequences of 1940-2018 daily instream flow *IF* record targets (TIF), combined instream flow *IF* record targets (IFT), and instream flow *IF* record shortages (IFS) for water rights IF-WTGP, IF-TRDA, IF-TROA, and IF-TRRO, which are the SB3 EFS defined in Table 5.5.

Other output options controlled by input parameters on the *JD*, *JO*, *JT*, *JU*, *OF*, *CO*, *WO*, *RO*, *GO*, *C2*, *W2*, *R2*, *G2*, and *C3* records are not activated in the set of records included in Table 11.5. All of the *SIM* and *SIMD* simulation results output options are explained in the *Users Manual*.

Contents of File TrinitySimulationResults.DSS

OF record parameters control selection from among 16 control point variables, 10 *WR* record water right variables, 5 *IF* record water right variables, and 12 reservoir variables [2]. The full authorization daily Trinity WAM has 1,552 control points, 1,041 *WR* records, 43 *IF* records, and 697 reservoirs. Without limiting output with the output selection options, the DSS file created by a single simulation could contain 40,621 sequences of 28,855 daily quantities and 40,621 sequences of 948 monthly quantities covering 1940-2018, which would be massive. The DSS file with filename TrinitySimulationResults.DSS contains 66 daily data sequences and 76 monthly sequences generated by simulations with six different versions of the Trinity WAM, which include daily and monthly computational time steps and authorized and current use scenarios.

The DSS file with filename TrinitySimulationResults.DSS includes:

- storage contents of the four largest reservoirs (Livingston, Richland-Chambers, Ray Roberts, Cedar Creek) and the summation of storage of 28 other major reservoirs
- naturalized, regulated, and unappropriated stream flows at the four control points with SB3 EFS (8TRGP, 8TRDA, 8TROA, 8TRRO)
- SB3 EFS instream flow targets and shortages at the four control points with SB3 EFS

The selected simulation results can be used to replicate plots and statistics presented in Chapters 2, 9, and 10. However, some alternative simulations presented in the report are not included in the summary DSS file. Likewise, some additional quantities are included in the DSS file.

Pathname Conventions for File TrinitySimulationResults.DSS

The DSS file with filename TrinitySimulationResults.DSS contains selected sequences of 1940-2018 daily or monthly quantities from multiple simulations. DSS record pathname conventions adopted for identifying the time series quantities are described in this final section of Chapter 11. Pathname parts D and E are fixed by the characteristics of the time series data. Parts A, B, C, and F are easily revised using the rename feature of the *HEC-DSSVue* editor. DSS record pathname part A is used to identify the following alternative versions of the Trinity WAM.

TRIN3WITHOUTSB3EFS – Original authorized use (run 3) monthly *SIM* input dataset last updated by the TCEQ in October 2014 with the only 2019 modifications being removal of the SB3 EFS and adoption of the updated 1940-2018 hydrology. This simulation is labeled M1 in Chapter 10. DAT filename is Trin3NoSB3EFS.DAT.

TRIN8WITHOUTSB3EFS – Original current use (run 8) monthly *SIM* input dataset last updated by the TCEQ in October 2012 with the only 2019 modifications being removal of the SB3 EFS and adoption of the updated 1940-2018 hydrology. This simulation is labeled M1 in Chapter 9. The DAT file filename is Trin8NoSB3EFS.DAT.

TRINITY3D – December 2019 authorized use (run 3) daily *SIMD* simulation with routing deactivated and no forecasting. This simulation is labeled D1 in Chapter 10.

TRINITY8D – December 2019 current use (run 8) daily *SIMD* simulation with routing deactivated and no forecasting. This simulation is labeled D1 in Chapter 9.

TRINITY3M – December 2019 authorized use (run 3) monthly WAM with SB3 EFS instream flow targets from the daily authorized use WAM noted above. The pathnames for the SB3 EFS targets in the DSS file are replicated in Tables 5.10 and 10.10. The *IF* record rights for the SB3 EFS are replicated in Tables 5.11 and 10.11.

TRINITY8M – December 2019 current use (run 8) monthly WAM with SB3 EFS instream flow targets from the daily current use WAM noted above. The pathnames for the SB3 EFS targets in the DSS file are replicated in Tables 5.8 and 9.7. The *IF* record rights for the SB3 EFS are replicated in Tables 5.9 and 9.9.

Pathname part B is used for control point identifiers defined in the DAT file. *TS* record part B identifiers are modified versions of control point identifiers referenced by *IF* record water rights in the DAT file. Part C defines the variable for which quantities are recorded on the DSS record.

The Senate Bill 3 (SB3) environmental flow standards (EFS) are located at control points 8TRGP (Grand Prairie), 8TRDA (Dallas), 8TROA (Oakwood), and 8TRRO (Romayor) identified in pathname part B of the DSS records. The following stream flow quantities (pathname part C) at these four control points are included in the DSS file: naturalized flows (NAT-CP), regulated flows (REG-CP), and unappropriated flows (UNA-CP). The DSS file includes the forms of SB-3 EFS *IF* record instream flow targets and shortages defined in Table 5.6 of Chapter 5 that have the following pathname part C quantity identifiers: IFT-CP, IFS-CP, IFT-WR, and TIF-WR.

The pathname part C identifier STO-CP refers to the storage contents of Lakes Livingston, Richland-Chambers, Ray Roberts, and Cedar Creek located at control points B4248B, B5035A, B2335A, and B4976A (pathname part B). These are the four largest reservoirs listed in Table 2.2. The pathname part B identifier TOTAL 28 RESERVOIRS refers to the summation of storage contents of the 28 other reservoirs listed in Table 2.2, which are located at the control points tabulated in Table 2.2. The 2STO and 6STO in part C refer to monthly and daily storage contents.

Pathname part D is 01JAN1940-01JAN2010 which defines the data blocks containing the January 1940 through December 2018 monthly or daily time series data sequences. Pathname part E is either 1MON or 1DAY defining the time interval of the monthly or daily data.

Pathname part F for the records in the file with filename TrinitySimulationResults.DSS provides miscellaneous information for various groups of records that includes: water right identifiers IF-WTGP, IF-TRDA, IF-TROA, and IF-TRRO for water right output records; *CP monthly* and *CP daily* for monthly and daily control point output records; or various other descriptive notations such as *SIM AUTHORIZED WITH SIMD EFS*.

CHAPTER 12
SUMMARY AND CONCLUSIONS

This report and accompanying data files and the simulation studies documented by this report serve the following purposes.

1. Daily versions of the full authorization and current use scenario Trinity 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 Senate Bill 3 (SB3) environmental flow standard (EFS) instream flow targets for the monthly WAM.
2. The original 1940-1996 hydrologic period-of-analysis for the monthly Trinity WAM was extended to cover 1940-2018 for both the daily and monthly versions of the WAM. Recently developed techniques for performing preliminary hydrology updates between less frequent more detailed updates were employed.
3. Both the conversion of a monthly WAM to daily and the update of the hydrologic period-of-analysis 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 Trinity WAM 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.

Trinity WAM Input and Output Files

The expanded versions of the Trinity 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 12.1. 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 12.1
SIM/SIMD Simulation Input Files for December 2019 Expanded Trinity WAM

	Authorized Use	Shared	Current Use
Monthly water rights file	Trinity3M.DAT		Trinity8M.DAT
Daily water rights file	Trinity3D.DAT		Trinity8D.DAT
Flow distribution file (*FD*, *WP*)	Trinity3(M/D).DIS		Trinity8(M/D).DIS
Hydrology file (*IN*, *EV*, *DF*, *TS*)		TrinityHYD.DSS	
Daily input file (*RT*, *DC* records)		Trinity3D.DIF/Trinity8D.DIF	

The water right data in the monthly DAT file with filename Trinity3M.DAT includes four *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 Trinity3D.DAT. A single hydrology input DSS file with the filename TrinityHYD.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 12.1 produce DSS output files with the filenames Trinity3D.DSS, Trinity3M.DSS, Trinity8D.DSS, or Trinity8M.DSS. The set of DSS files that accompany this report includes a file with filename TrinitySimulationResults.DSS described in Chapter 11 that combines selected results from multiple different simulations.

The monthly authorized use scenario and current use scenario versions of the Trinity WAM have been assigned the filename roots ″trin3″ and ″trin8″ dating back to their initial creation in 2002. The authorized use Trinity WAM dataset in the TCEQ WAM System consists of the following files: trin3.DAT, trin3.DIS, trin3.FLO, and trin3.EVA. The current use dataset has the following files: trin8.DAT, trin8.DIS, trin8.FLO, and trin8.EVA. The FLO and EVA files were converted to the single combined hydrology DSS file in the work described in this report.

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 introduced in Chapter 1 and explained in Chapters 5, 6, 7, and 8. The organization, format, and content of these files are summarized in Chapter 11.

TrinityDailyFlows.DSS
TrinityMonthlyFlows.DSS
TrinityEvapPrecip.DSS

The datasets stored in these DSS files can be explored with *HEC-DSSVue* to develop a better understanding of Trinity 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 Data Storage System (HEC-DSS) and HEC-DSSVue interface provide comprehensive capabilities for managing, organizing, searching, tabulating, and plotting large time series datasets and performing statistical analyses and mathematical operations.

***SIM* and *SIMD* Hydrology**

The *SIM/SIMD* input file with filename TrinityHYD.DSS contains monthly naturalized flow *IN* records for 40 control points (Chapter 7), evaporation-precipitation *EV* records assigned 50 control point identifiers (Chapter 8), daily flow *DF* records for 49 control points (Chapter 6), and target series *TS* records for four Senate Bill 3 (SB3) environmental flow standard (EFS) instream flow rights (Chapters 5, 9, and 10).

The original monthly Trinity WAM has a hydrologic period-of-analysis of January 1940 through December 1996. The 1997-2018 hydrology extension was compiled from available data that were developed differently than the original 1940-1996 hydrology as explained in Chapters 6, 7, and 8 of this report. The January 1997 through December 2018 extension can be easily switched on or off in simulation studies. With the hydrology input data covering 1940-2018, a simulation for 1940-2018, 1940-1996, or any other sub-period between 1940 and 2018 can be performed by setting *YRST* and *NYRS* on the *JD* record in the DAT file.

The WRAP program *HYD* and *HEC-DSSVue* provide capabilities for extending the hydrologic period-of-analysis to near the present as more years of hydrologic record accumulate. Although *HYD* and *HEC-DSSVue* also provide capabilities for more detailed hydrology updates, the strategy adopted for the Trinity WAM update reported here is designed for expedient preliminary updates of hydrology datasets between less frequent more detailed updates requiring greater time and effort. The procedures outlined and datasets compiled as described in this report could be employed during 2020 to extend the hydrology through December 2019 and repeated again during 2021 to extend the flows through December 2020.

Simulated reservoir storage plots and other metrics presented in Chapters 2, 9, and 10 indicate that the 1950-1957 drought is generally the most hydrologically severe drought to occur during the 1940-2018 hydrologic period-of-analysis in the Trinity River Basin. More recent droughts such as 2010-2012 may be more economically costly due to population and economic growth but not as hydrologically severe in terms of rainfall and stream flow. Thus, extending the 1940-1996 hydrologic period-of-analysis through December 2018 does not affect firm yield estimates for most water rights, though other water supply reliability and storage and flow metrics are affected. The hydrology extension significantly enhances understanding of basin hydrology.

Monthly Naturalized Flows at 40 Primary Control Points on *IN* Records

Monthly naturalized flows at over 1,350 secondary control points are synthesized during the *SIM* or *SIMD* simulation based on the flows at 40 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 Trinity WAM.

The 40 primary control points for which naturalized flows are provided in the hydrology input file are listed in Table 2.4. The original 1940-1996 sequences of monthly naturalized flows at 39 of the 40 primary control points were developed by adjusting actual observed flows recorded at USGS gaging stations as noted in Chapter 7. Gaps in the records at some of the 39 gages were

synthesized by regression analyses using flows at other gages. The one other primary control point represents the outlet where the Trinity River flows into Galveston Bay.

The 1940-1996 monthly naturalized flows in the TCEQ WAM are adopted without modification in the expanded WAM. The flows were extended to cover 1997-2018 by combining the following sets of naturalized flows as explained in Chapter 7.

Period-of-record daily gaged flows were compiled from the National Water Information System (NWIS) website maintained by the U.S. Geological Survey (USGS) as described in Chapter 6. Daily flows were summed to monthly as described in Chapter 7. USGS gage records for 1998-2018 are available at 27 of the 40 primary control points. Gages have been discontinued with no recorded flows for 1998-2018 at 12 of the previously gaged sites.

A hydrologic model in the WRAP program *HYD* relates monthly naturalized flows to monthly precipitation and reservoir evaporation rates. Naturalized flows at the 40 primary control points were synthesized with the calibrated hydrologic model as explained in Chapter 7.

Daily 1940-2009 unregulated flows at the 35 control points (17 primary and 18 secondary control points) were provided by the U.S. Army Corps of Engineers (USACE) Fort Worth District (FWD) in support of the initial development of daily WRAP modeling capabilities as discussed in Chapter 6. Daily unregulated flows at 17 primary control points were aggregated to monthly flows.

The naturalized monthly flows adopted for the sub-periods 1997-2009 and 2010-2018 or the entire 1997-2018 extension consists of USACE unregulated flows, *HYD* synthesized flows, or USGS gaged flows. Naturalized flows for the sub-period 1997-2009 consist of: USACE unregulated flows for 17 control points, *HYD* synthesized flows for 17 control points, and USGS gaged flows for 6 control points. Naturalized flows for the sub-period 2010-2018 consist of: *HYD* synthesized flows for 32 control points, and USGS gaged flows for 8 control points.

The USACE flows are adopted for all WAM primary control points for which they are available. The USGS gaged flows are adopted for sites with relatively small unregulated watersheds. Gaged flows at these sites are almost identical to WAM naturalized and USACE unregulated flows. The *HYD* synthesized flows are used for the remaining sites.

Available data are employed as discussed in Chapter 7 to efficiently extend the hydrologic period-of-record. More accurate data possibly may be compiled in the future to replace these preliminary estimates of 1997-2018 naturalized flows at some or all of the control points. The 1997-2018 flow extensions reported here at some sites could be combined with perhaps more accurate estimates at other sites.

In the future, the 1940-1996 monthly naturalized flows may be extended to near the present by adjusting flows observed at USGS gages since 1997 in essentially the same manner as employed in compiling the original 1940-1996 naturalized flows for those sites for which the necessary observed stream flow, water use, return flow, and other data are available for compilation.

Observed flows are available after 1996 for 27 of the 40 primary control points. Naturalized flows at these 27 gage sites could be developed by adjusting observed flows analogously to the

flows at 39 gage sites in the original dataset 1940-1996 naturalized flows. Expanded WRAP modeling tools may be employed to perform the adjustments more efficiently. However, considerable effort would be required to compile the necessary water use, reservoir storage, and other data and perform the adjustment computations.

Fifty Net Evaporation-Precipitation Depth Sequences on *EV* Records

The original Trinity WAM evaporation EVA input file contains 50 sets of *EV* records with January 1940 through December 1996 sequences of monthly net reservoir surface evaporation-precipitation depths. The WRAP program *HYD* was applied with Texas Water Development Board databases of monthly evaporation and precipitation depths as described in Chapter 8 to extend the sequences of 1998-2017 monthly *EV* record net evaporation-precipitation rates through December 2018. The net evaporation-precipitation rates include adjustments for rainfall at the reservoir sites that is already reflected in the naturalized flows. The *EV* records were converted from EVA file format to DSS file format for incorporation in the input file TrinityHYD.DSS.

Daily Pattern Hydrographs at 49 Control Points on *DF* Records

The monthly naturalized flows at about 1,400 primary and secondary control points are disaggregated to daily in a *SIMD* simulation based on the *DF* record daily flow pattern hydrographs input for 49 control points. The monthly naturalized flow volumes in acre-feet/month are allocated to daily volumes in acre-feet/day for each day of each month while maintaining the same monthly volumes. The flows at 49 control points input on *DF* records are automatically repeated at the about 1,350 other control points using an algorithm activated in *SIMD*.

Initial 1940-2018 pattern hydrographs of daily mean flow rates in cfs at the 49 control points were developed as described in Chapter 6 and stored as *DF* records in a DSS file. Some of the 1940-2018 sequences reflect combinations of flows from different data sources and/or different stream locations. Daily flow volumes in acre-feet/day at the 49 sites were computed with *SIMD* by combining monthly naturalized flow volumes with the initial daily flow pattern hydrographs in cfs from the first step described above. These final *DF* record daily flows represent 1940-2018 daily naturalized flow volumes, rather than just flow patterns, and have units of acre-feet/day.

The compilation of daily flows for the *DF* record pattern hydrographs is documented by Chapter 6. Unregulated daily flows for January 1940 through December 2009 from an USACE modeling system are adopted for 35 control points (16 primary and 19 secondary). Observed flows from USGS gages are adopted for January 2010 through December 2018 for these 16 gaged and 19 ungaged sites. Only relative, not absolute, magnitudes of daily flows within each month are relevant in the initial pattern hydrographs. Thus, months of daily flows from two or more different sources or sites were combined to develop complete 1940-2018 sequences at all relevant sites.

The preceding paragraph covers 35 of the 49 control points with *DF* records. Observed daily flows for 1940-2018 recorded at USGS gaging stations were adopted for the other 14 control points. The 14 WAM control points are located at USGS gage sites. However, gage records for nine of the 14 gages have gaps with missing data that are filled in with flows recorded at other gages. Gage selections are tabulated and explained in Chapter 6.

Daily Modeling System

The daily *SIMD* simulation model includes all 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 auxiliary *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 Trinity WAM

This report, including the following discussion, deals with the Trinity WAM. However, the same issues are addressed in the *Daily Brazos WAM Report* [7]. The Brazos and Trinity WAMs represent the first applications of expanded modeling capabilities incorporated in the May 2019 version of WRAP. Although development of the Brazos and Trinity daily WAMs represent two separate endeavors, basic findings from the two studies are very similar and complementary. The options adopted, lessons learned, and experience base acquired with the Brazos and Trinity WAM studies are also relevant to the future development of daily WAMs for other river basins.

SIMD capabilities outlined in Table 12.2 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 12.3. Multiple alternative approaches are provided in *SIMD* for performing each of these tasks. Methods adopted for the daily Trinity WAM are listed in the second column of Table 12.3. The third column of Table 12.3 lists other options that are not chosen for use with the final daily Trinity WAM. The *Brazos WAM Report* reflects similar choices and conclusions.

Table 12.2
Daily WRAP Modeling System

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 12.3
SIMD Simulation Options Adopted for Trinity WAM

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 effects of computational time step choice on simulation results vary with different water management modeling situations and applications. Flood control reservoir operations, high pulse environmental flow requirements, and the interactions between environmental flow requirements and flood control operations are key aspects of water management that 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.

A monthly computational time step is generally optimal for water availability modeling. The accuracy of modeling water supply capabilities may or may not be improved by converting from a monthly to a daily WAM. A monthly WAM may be more accurate than a daily WAM in accessing water availability for water supply due to: the complexities of streamflow translation and attenuation modeled by routing and forecasting; disaggregation and associated limitations on available stream flow and water use data; and other aspects of daily modeling. Daily modeling requires major additional input data compilation efforts and is significantly driven by data availability. Monthly is generally advantageous over daily modeling of water supply capabilities.

The Texas WAM System is appropriately and effectively constructed based on a monthly computational time step. The month is the optimum time interval for the WAM System. 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.

Stream Flow Variability

The great variability of stream flow is the primary factor responsible for the differences between the 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 Trinity 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 49 control points and employed to disaggregate monthly naturalized flows to daily at the 1,400 control points in the

Trinity WAM are described in Chapter 6. Only relative, not absolute, magnitudes of daily flows within each month are relevant for the daily flow pattern hydrographs. The *DF* record daily flows are a combination of unregulated flows from a USACE Fort Worth District reservoir system operations model and observed flows recorded at USGS gaging stations. In some cases, flows recorded at another gage are used to fill in missing flow records at a particular site.

The flow pattern hydrographs are considered to provide a valid, reasonably accurate representation of stream flow variability at most of the 1,400 individual control points. Since flows at numerous sites are represented by flows developed for only 49 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.

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* [4]. 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 Trinity WAM with about 1,400 control points includes routing parameters at 39 control points representing the 39 river reaches defined by the 40 primary control points.

Development of the normal flow and high flow lag and attenuation parameters at 39 control points is described in Chapter 3. Routing parameter calibration is based on 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 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 Trinity WAM only for modeling gated flood control pools of the USACE reservoirs.

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 Trinity 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 Trinity WAM. The daily Trinity WAM includes the routing parameters described in Chapter 5. 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 significant changes to routing parameter values.

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

Routing and forecasting is not employed in the daily Trinity WAM simulations used to generate monthly SB3 EFS targets. Based on the simulation findings reported in Chapters 9 and 10, forecasting would not be adopted for the final simulations even if routing had been adopted.

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* [4], 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) flood 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 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 simulation studies presented in Chapters 9 and 10 support the following findings.

1. Routing is very approximate, does 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 precise preservation of water right priorities is not required.
2. Forecasting greatly impacts simulation results and adversely affects WAM accuracy and validity. Forecasting is not employed in the final Trinity 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.

The default automatically computed forecast period for the daily Trinity WAM is 81 days, which is computed within *SIMD* as twice the longest flow path measured in lag time plus one day. This option is conceptually based on preventing any impact of actions of junior water rights today on senior water rights in future days. The alternative simulations presented in Chapters 9 and 10 include alternative forecast periods of 3 days and 10 days, which reflect estimates of the number of days into the future during which stream flows can be predicted with reasonable accuracy.

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.

Other Modeling Features that Interact with Routing and Forecasting

Negative incremental naturalized stream flows are a significant issue in monthly *SIM* simulations and have a much greater effect in a daily *SIMD* simulation. Negative incremental flows refer to time periods (days or months) during which the naturalized flow at the downstream end of a river reach are smaller than the flow at the upstream end. The several alternative negative incremental flow adjustment options including the recommended standard options for monthly and daily simulations are explained in Chapter 3 of the *Reference Manual* and Chapter 3 of the *Daily Manual*. Option 4 is generally the best ADJINC option but is not applicable to the future days in the forecast simulation. ADJINC option 7 is employed with forecasting to deal with the future forecast simulation days.

Negative incremental flows during the forecast simulation is a consideration in the determination to not activate forecasting. Deactivating forecasting prevents over-constraining of stream flow availability by negative incremental flows as well as by various other flow conditions.

Most of the array of options for determining monthly water supply diversion targets can be replicated daily in a daily *SIMD* simulation. *SIMD* also has other options for non-uniformly distributing water supply diversion targets over the days of the month. The simulation studies presented in this report adopted the *SIMD* default of uniformly distributing monthly water supply diversion targets over the days of the month.

The Trinity WAM includes several subordination agreements that are investigated in Chapter 2. The most complex involve subordination of water rights at Lake Livingston to other more junior water rights at a number of reservoirs located upstream of Lake Livingston.

The selection parameters WRMETH and WRFCST in *JU* record fields 4 and 5 control the choice of next-day placement of routed flow changes. The simulations presented in this report employ the default option of placing the routed flows at the beginning of the water right priority sequence in the next day of the simulation, rather than within the priority sequence.

Reservoir Flood Control Operations

Flood control operations of the eight USACE Fort Worth District multiple-purpose reservoirs in the Trinity River Basin and *SIMD* simulation thereof are described in Chapter 4. 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 non-flood periods.

The eight USACE reservoirs are operated to control flood flows at multiple downstream control points. The actual operating rules described in Chapter 4 consist of structured criteria with specified maximum flow limits at the downstream gages. However, the operating rules allow considerable flexibility for operator judgment in the continuous gate operation decisions during and after a flood regarding selecting between reservoirs for flood control pool storage and releases. Also, forecasting of flood flows over the next several days or weeks and estimation of flow travel time from the dams to downstream gages are not precise. Likewise, although *SIMD* provides a flexible array of options for simulating flood control operating rules, different reasonable representations of actual operations can yield different simulation results.

Senate Bill 3 Environmental Flow Standards

The work documented by this report 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 four sites are described in Chapter 5. 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 significantly larger than the corresponding targets for the full authorization scenario because the simulated regulated flows are larger.

Monthly instream flow targets for the four 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 5.8 and 5.10 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 5.9 and 5.11.

The 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 due to the basic within-month flow variability issue.

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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