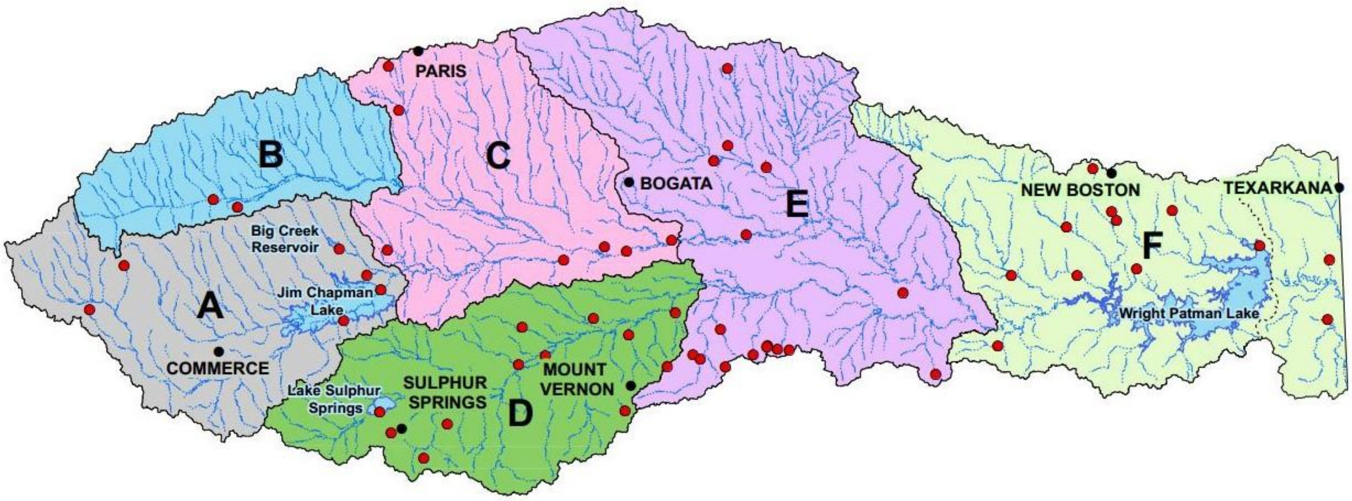
# FINAL REPORT

# *Extension of Naturalized Streamflows and Update of Run 3 and Run 8 Versions of Sulphur River Basin WAM*




**prepared for**

**Riverbend Water Resources District**
**New Boston, Texas**

**in coordination with**

**Texas Commission on Environmental Quality**
**Austin, Texas**

**August 31, 2019**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# EXECUTIVE SUMMARY

## 2019 UPDATE AND EXTENSION OF SULPHUR RIVER BASIN WATER AVAILABILITY MODEL

### Introduction

Pursuant to Senate Bill 1 passed by the 75th Texas Legislature in 1997, the Texas Natural Resource Conservation Commission (TNRCC, now the Texas Commission on Environmental Quality, TCEQ) developed, with contractor assistance, river basin models that simulated the available water supply for all water rights in the State of Texas subject to applicable laws and regulations stipulated in the Texas Water Code. Under contract with TNRCC, R. J. Brandes Company of Austin, Texas developed the water availability model and performed the required water availability analyses for the Sulphur River Basin, which was completed in 1999. This work involved the development of naturalized[1] streamflows at strategic locations within the Sulphur River Basin and the application of the Texas A&M University "Water Rights Analysis Package, WRAP" to develop the original water availability model (WAM) for the Sulphur Basin. With this WAM, the behavior of all water rights in the basin could be simulated to determine their available water supplies.

Since the original development of the WAM for the Sulphur River Basin (Sulphur WAM), there have been a variety of additions, changes and amendments of water rights in the basin, and the WAM has been routinely updated by the TCEQ to reflect these modifications, as well as to incorporate improvements in the WRAP modeling procedures. However, the hydrology reflecting 1940-1996 actual flow conditions that was included in the original Sulphur WAM has never been updated to include the more recent drought and flood periods that have occurred throughout the basin. Some of these have been extreme, particularly the 2005-2006 and 2011 droughts, and exclusion of these more recent hydrologic conditions from the Sulphur WAM data base has called into question the suitability and appropriateness of the water availability results, especially for water supply planning purposes.

The Riverbend Water Resources District (Riverbend or District) is actively engaged in water-related activities in northeast Texas, including representing the water supply interests of numerous communities and industries in the vicinity of the City of Texarkana that rely on Wright Patman Lake for their source of supply. With the need to develop additional future water supplies, Riverbend has recognized the importance of having reliable water availability information from the Sulphur WAM, and in this regard, has undertaken this effort to update and extend the existing

[1] Naturalized flows are used as the basic hydrologic input to the water availability models, and they represent historical flows with the effects of man's surface water-related activities such as streamflow diversions, wastewater discharges, and reservoir flow depletions removed from the flow records, thus leaving "naturalized" flows.

WAM to include hydrologic data reflecting conditions since 1996. For this work, Riverbend has contracted with Robert J. Brandes Consulting of Austin, Texas.

It should be noted that for purposes of this report, references to the "original" Sulphur WAM mean the original WAM as produced in 1999, either Run 3 or Run 8. The term "existing" WAM refers to the Run 3 version of the Sulphur WAM as currently maintained by the TCEQ and as downloaded from the TCEQ web site on August 21, 2018. This existing Sulphur WAM has provided the starting point for the revisions and modifications made in this current study. References to either the "updated" or the "extended" or the "updated and extended" or the "updated-extended" Sulphur WAM all mean the revised and modified Run 3 or Run 8 versions of the Sulphur WAM as produced in this current study, including the revised WRAP data input files and the revised naturalized flow workbooks that extend the WAMs' period of record to include 1997-2017.

**Sulphur River Basin**

The Sulphur River Basin lies within 11 counties (Bowie, Cass, Delta, Fannin, Franklin, Hopkins, Hunt, Lamar, Morris, Red River, and Titus) in northeast Texas and drains an area of approximately 3,600 square miles within Texas. From the state line, the Sulphur River flows into Arkansas and eventually joins with the Red River, a tributary of the Mississippi River. Figure 1-1 presents a general map of the Sulphur River Basin and shows its location in northeast Texas.

The South and North Sulphur Rivers originate in southern Fannin County and flow eastward 50 to 60 miles to their confluence on the boundary of eastern Delta and Lamar Counties. In the late 1920's, the U. S. Army Corps of Engineers initiated extensive channelization of these streams, particularly the North Sulphur River, for flood control purposes, and the confluence of the rectified channels was moved some distance west of where the natural confluence existed. This confluence forms the Sulphur River, which flows eastward an additional 75 miles to the Texas-Arkansas state line. White Oak Creek is the largest tributary of the Sulphur River, and it drains about 500 square miles in the southern part of the basin, including the city of Sulphur Springs. Ground elevations in the basin range from about 700 feet above sea level at the headwaters down to about 190 feet at the state line.

There are 57 individual existing water rights located within the Sulphur River Basin that authorize the diversion and/or storage of surface water. All of these water rights are accounted for and represented with regard to their individual features in the updated Sulphur WAM. The total amount of authorized diversions for these water rights is approximately 445,000 acre-feet per year (ac-ft/yr). Approximately 50 percent of the total authorized diversion volume is for municipal use and about 41 percent is for industrial purposes. The remainder is for irrigation (~9 percent) and other uses. Wright Patman, Jim Chapman, Ralph Hall and Sulphur Springs reservoirs are permitted by the State for diversions of 381,320 acre-feet per year, about 83 percent of the total.

There are 50 reservoirs, or groups of reservoirs, authorized by existing water rights in the Sulphur River Basin. The total storage capacity of these authorized impoundments is about 940,000 acre-feet. Of the total, there are 15 reservoirs, or groups of reservoirs, that are authorized to store 1,000 acre-feet or more, and these impoundments represent 99 percent of the total authorized reservoir storage capacity in the basin. Wright Patman Lake (formerly Lake Texarkana), located on the Sulphur River about seven miles upstream of the Texas-Arkansas state line with 386,900 acre-feet of authorized storage capacity, was constructed in the mid-1950's and provides water supply, flood control, and recreational benefits. It is the source of supply for the city of Texarkana and for a number of smaller communities in the area, as well as major industries in the region. Jim Chapman Lake (formerly Cooper Lake), located on the South Sulphur River near the city of Cooper in the western part of the basin with 310,000 acre-feet of authorized storage capacity, began impoundment in 1991 and provides supplemental water supplies for the City of Irving, the North Texas Municipal Water District, and by contract with the Sulphur River Municipal Water District or the City of Commerce to the City of Cooper, the City of Sulphur Springs, and the Upper Trinity Regional Water District. Both Wright Patman Lake and Jim Chapman Lake are owned and operated by the U. S. Army Corps of Engineers (Corps). Lake Sulphur Springs on White Oak Creek, the next largest existing reservoir with 17,838 acre-feet of authorized storage capacity, is owned by and supplies municipal water to the City of Sulphur Springs. Lake Ralph Hall, owned by the Upper Trinity Regional Water District on the North Sulphur River with an authorized storage capacity of 180,000 acre-feet, is not yet constructed but is scheduled to begin providing up to 45,000 acre-feet per year of water to customers of the District around 2024.

## Study Approach

Because the TCEQ has routinely updated the Sulphur WAM to include changes and additions of water rights as they have occurred since the original development of the WAM in 1999, this current effort has not been primarily focused on incorporating new water rights into the WAM but rather on extending the WAM hydrologic data base to include conditions since 1996, the last year included in the existing data base, through 2017, the last full calendar year with available historical data records. This work has involved primarily developing naturalized flows at selected streamflow gage locations and using these to compile complete 1997-2017 records of naturalized flows for the six primary control points that are used for representing flow conditions in the Sulphur WAM. This process of developing naturalized flows for the 1997-2017 period has required historical monthly information for actual water rights diversions, wastewater return flow discharges, and reservoir storage and releases and rainfall and evaporation amounts.

With these naturalized flows developed for the 1997-2017 period, the existing WAM data input files have been revised to include the new information to produce a complete 1940-2017 hydrologic data set. First, these extended naturalized flows and reservoir rainfall and evaporation data were added to the data input files for the Run 3 version of the Sulphur WAM. This version of the WAM is used as the primary tool for evaluating water availability for existing and new water rights under conditions with all existing water rights fully exercised in accordance with stipulations in their permits or certificates of adjudication and without any wastewater discharges represented in the model. Then, for the Run 8 current conditions version of the Sulphur WAM, the historical diversion and wastewater discharge data for the most recent years have been analyzed to establish current values, and these have been incorporated into the Run 8 data input files for all existing water rights and for all wastewater discharges with a flow rate greater than one million gallons per day. The Run 8 version of the Sulphur WAM also has been updated to include the 1997-2017 naturalized flows.

**Naturalized Streamflows**

Naturalized streamflows are the fundamental driver for the WAM. By definition, naturalized streamflows represent historical streamflow conditions, including typical wet, dry and normal flow periods, without the influence of man's activities as they relate to water rights and water use. For example, the construction and operation of reservoirs, the diversion of surface waters, and the discharge of wastewater discharges are all activities of man related to water rights and water use that can impact historical streamflows. In the determination of naturalized streamflows, the historical effects of these types of activities must be removed from those portions of the historical streamflow records when such activities actually occurred. The resulting historical trace of naturalized streamflows then represents streamflow conditions uninfluenced by man's water rights or water use activities, and these are the flows that are required for water availability modeling.

These analyses have been performed for monthly historical flows from four strategically located streamflow gages in the Sulphur River Basin for the 1997-2017 period. Because gages do not exist in the lower part of the basin with records for this period, the historical inflows to Wright Patman Lake have been calculated, or deduced, using a water balance approach based on measured monthly values of historical reservoir storage, diversions, releases, rainfall and evaporation. These deduced inflows then have been used in the naturalized flow process to reflect hydrologic conditions in the lower basin. The end result of this overall effort has been six sets of 1997-2017 monthly naturalized flows for the six subwatersheds that are used to specify naturalized flows in the WAM. These sets of naturalized flows have been added to the six existing sets of naturalized flows in the WAM to produce complete records for the 1940-2017 period that is used in the extended WAM. The monthly and annual magnitudes and variations in the 1997-2017 naturalized flows generally are similar to those exhibited by the previous 1940-1996 naturalized flows; although, based on comparison of these two periods, it appears that some of the drought conditions during the latter period were somewhat worse than those during the earlier 1940-1996 period.

**Run 3 WAM Update and Extension**

For updating the Run 3 version of the Sulphur WAM, the most recent data sets for the model were obtained from the TCEQ. These data sets were reviewed, and comparisons of the water rights included in the model were made with specifications in the TCEQ's most recent water rights masterfile and in permits for recent water rights. Modifications to the Run 3 data sets were made to update the model to reflect currently existing water rights and to incorporate the extended 1997-2017 monthly naturalized flows and associated net evaporation rates. Simulations then were made with the updated and extended Run 3 version of the model to assess water right reliabilities, to examine diversions for major water rights with reservoirs and for selected run-of-river water rights, to analyze storage variations in the major reservoirs, to determine firm annual yields for the major reservoirs, and to evaluate potential unappropriated water at selected locations.

As with results from the original Run 3 WAM for the Sulphur Basin, the diversion reliabilities for water rights simulated with the updated model with the extended 1997-2017 naturalized flows are relatively high, with the reliability for very few water rights less than 75 percent. Many are at 100 percent, particularly those with reservoirs. As expected, the run-of-river water right diversions exhibit considerable variation with wet and dry periods. Time-series graphs of the storage variations of the major reservoirs indicate that two significant droughts on the order of the severe drought of the 1950s drought occurred during the 1997-2017 period of the extended naturalized flows. The calculated firm annual yields of the major reservoirs, as summarized in the following table from both the existing Run 3 WAM with 1940-1996 naturalized flows and from the updated Run 3 WAM with extended 1940-2017 naturalized flows, confirm that these more recent droughts were more severe than the previous droughts, with the exception of Lake Ralph Hall. This reservoir is located in the upper end of the Sulphur Basin, and under its fully authorized conditions, the more recent droughts apparently as analyzed with the Run 3 WAMs are not more severe than the reservoir's original drought of record and do not significantly affect its firm annual yield.

**Table ES-1 Comparison of Firm Annual Yields for Major Reservoirs from Existing and Updated-Extended Run 3 WAMs**

| (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|
| **RESERVOIR** | **AUTH.** | **BASED ON 1940-1996 NAT. FLOWS USED IN EXISTING RUN 3 WAM** | | **BASED ON 1940-2017 NAT. FLOWS USED IN UPDATED RUN 3 WAM** | |
| | **DIVERSION AMOUNT (ac-ft/yr)** | **FIRM YIELD** | **DROUGHT PERIOD (Spill to Spill)** | **FIRM YIELD (ac-ft/yr)** | **DROUGHT PERIOD (Spill to Spill)** |
| Jim Chapman Lake | 146,520 | 128,830 | June 1953 - May 1957 | 124,510 | April 2010 - May 2015 |
| Lake Sulphur Springs | 9,800 | 11,525 | May 1955 - April 1957 | 7,725 | April 2003 - July 2007 |
| Wright Patman Lake | 180,000 | 469,290 | Feb. 1972 - December 1972 | 354,000 | April 2005 - December 2006 |
| Lake Ralph Hall | 45,000 | 40,620 | July 1942 - June 1969 | 40,620 | July 1942 - June 1969 |

Notes: [1] The conservation storage capacity for Wright Patman Lake represents the maximum under the Ultimate Rule Curve.
[2] All firm annual yield values were determined using the FY Record in the WAM data files.

## Run 8 WAM Update and Extension

As stipulated by TCEQ, the Run 8 version of the WAM is intended to reflect current conditions with respect to diversions, wastewater discharges, and reservoir operations and storage conditions. In this regard, updated values for these quantities reflecting recent years have been determined for the 1997-2017 period and incorporated into the existing Run 8 version of the Sulphur WAM, along with the extended naturalized flows and net evaporation quantities for the 1997-2017 period. For developing the current conditions data inputs to the model, historical records were examined to determine the current annual diversion amounts (maximum annual for the last ten years) for all water rights and the current monthly return flow quantities (minimum for each month for the last five years) for all permitted wastewater discharges. Storage and area relationships for all major reservoirs in the basin also have been modified to reflect projected 2020 storage and sedimentation conditions. Simulations have been made with this updated and extended Run 8 version of the WAM to assess water right reliabilities, to examine diversions and storage variations for major water rights, and to determine the firm annual yields for the major reservoirs in the basin. These results generally show more water available than those from the updated-extended Run 3 version of the WAM because of the reduced water right demands reflecting current usage.

Results from operating the updated-extended Run 8 version of the Sulphur WAM to determine the firm annual yield for Wright Patman Lake, Jim Chapman Lake, and Lake Sulphur Springs, the three largest existing reservoirs in the basin used for municipal and industrial purposes, are summarized in Table ES-2 below. For these analyses, the Current Rule Curve and 221.5 feet msl minimum storage level have been engaged for Wright Patman Lake, which means, as described in Section 4.3 of the report, it has a maximum of only 134,326 acre-feet of storage capacity for making diversions. For each of the other two reservoirs, it has been assumed that they can be drawn down to near zero for purposes of calculating firm annual yield. Even though the storage capacities of these reservoirs have been reduced in the updated-extended Run 8 WAM to represent 2020 sedimentation conditions, the firm annual yields for Jim Chapman Lake and Lake Sulphur Springs are slightly higher than those from the updated-extended Run 3 WAM, a reflection of the overall lower water right demands in the Run 8 model. The Wright Patman yield is significantly lower than the Run 3 yield because of the substantially reduced storage capacity under current operating conditions.

## Closure

Development of the updated and extended Run 3 and Run 8 versions of the Sulphur WAM has been undertaken using standard procedures that have been applied in previous WAM development work and that have been approved and accepted by the TCEQ. The resulting naturalized flows for the 1997-2017 period appear to be consistent with the original 1940-1996 naturalized flows in terms of magnitudes and monthly and annual variations. Overall, the updated-extended Run 3 and Run 8 versions of the Sulphur WAM are fully operational and are considered to effectively represent water rights conditions to support water availability technical studies and water rights permitting activities.

**Table ES-2 Firm Annual Yields for Major Reservoirs from Updated-Extended Run 8 WAM**

| (1) RESERVOIR | (2) PRIORITY DATE | (3) AUTH. DIVERSION AMOUNT (ac-ft/yr) | (4) CONSERV. STORAGE CAPACITY (ac-ft) | (5) FIRM ANNUAL YIELD (ac-ft/yr) | (6) CRITICAL DROUGHT PERIOD (Spill to Spill) |
|---|---|---|---|---|---|
| Jim Chapman Lake | 11/19/1965 | 146,520 | 291,650 | 126,010 | April 2010 - May 2015 |
| Lake Sulphur Springs | 7/24/1951 | 9,800 | 17,086 | 9,336 | April 2003 - July 2007 |
| Wright Patman Lake | 3/5/1951 | 180,000 | 134,326 [1] | 99,373 | May 2005 - March 2006 |

Notes: [1] The top of the conservation pool for Wright Patman Lake varies monthly according to the Current Rule Curve (Table 4-3), with the maximum storage capacity occuring in June at 248,892 acre-feet. However, the bottom of the conservation pool is fixed at Elevation 221.5 feet msl, or 114,566 acre-feet. Therefore, maximum volume of storage available for making diversions is only 134,326 acre-feet.

[2] All firm annual yield values were determined using the FY Record in the WAM data files.

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**2019 UPDATE OF SULPHUR RIVER BASIN WATER AVAILABILITY MODEL**

# 1.0 INTRODUCTION

## 1.1 Background

Pursuant to Senate Bill 1 passed by the 75th Texas Legislature in 1997, the Texas Natural Resource Conservation Commission (TNRCC, now the Texas Commission on Environmental Quality, TCEQ) developed, with contractor assistance, river basin models that simulated the available water supply for all water rights in the State of Texas subject to applicable laws and regulations stipulated in the Texas Water Code. Under contract with TNRCC, R. J. Brandes Company of Austin, Texas developed the water availability model and performed the required water availability analyses for the Sulphur River Basin (Brandes, 1999). This work involved the development of naturalized[2] streamflows at strategic locations within the Sulphur River Basin and the application of the Texas A&M University "Water Rights Analysis Package, WRAP" (Wurbs, et al, 1996, 1998) to model all water rights in the basin and to determine their available water supplies in accordance with the requirements of Senate Bill 1.

Since the original development of the Sulphur River Basin water availability model (WAM), there have been a variety of additions, changes and amendments of water rights in the basin, and the WAM has been routinely updated by the TCEQ to reflect these modifications, as well as to incorporate improvements in the WRAP modeling procedures. However, the hydrology reflecting 1940-1996 actual flow conditions that was included in the original Sulphur WAM has never been extended to include the more recent drought and flood periods that have occurred throughout the basin. Some of these have been extreme, particularly the 2005-2006 and 2011 droughts, and exclusion of these more recent hydrologic conditions from the Sulphur WAM data base has called into question the suitability and appropriateness of the water availability results, especially for water supply planning purposes.

The Riverbend Water Resources District (Riverbend or District) is actively engaged in water-related activities in northeast Texas, including representing the water supply interests of numerous communities and industries in the vicinity of the City of Texarkana that rely on Wright Patman Lake for their source of supply. With the need to develop additional future water supplies, Riverbend has recognized the importance of having reliable water availability information from the Sulphur WAM, and in this regard, has undertaken this effort to update the existing WAM to include hydrologic data reflecting conditions since 1996. For this work, Riverbend has contracted with Robert J. Brandes Consulting of Austin, Texas.

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## 1.2 Sulphur River Basin

The Sulphur River Basin lies within 11 counties (Bowie, Cass, Delta, Fannin, Franklin, Hopkins, Hunt, Lamar, Morris, Red River, and Titus) in northeast Texas and drains an area of approximately 3,600 square miles within Texas. From the state line, the Sulphur River flows into Arkansas and eventually joins with the Red River, a tributary of the Mississippi River. Figure 1-1 presents a general map of the Sulphur Basin and shows its location in northeast Texas.

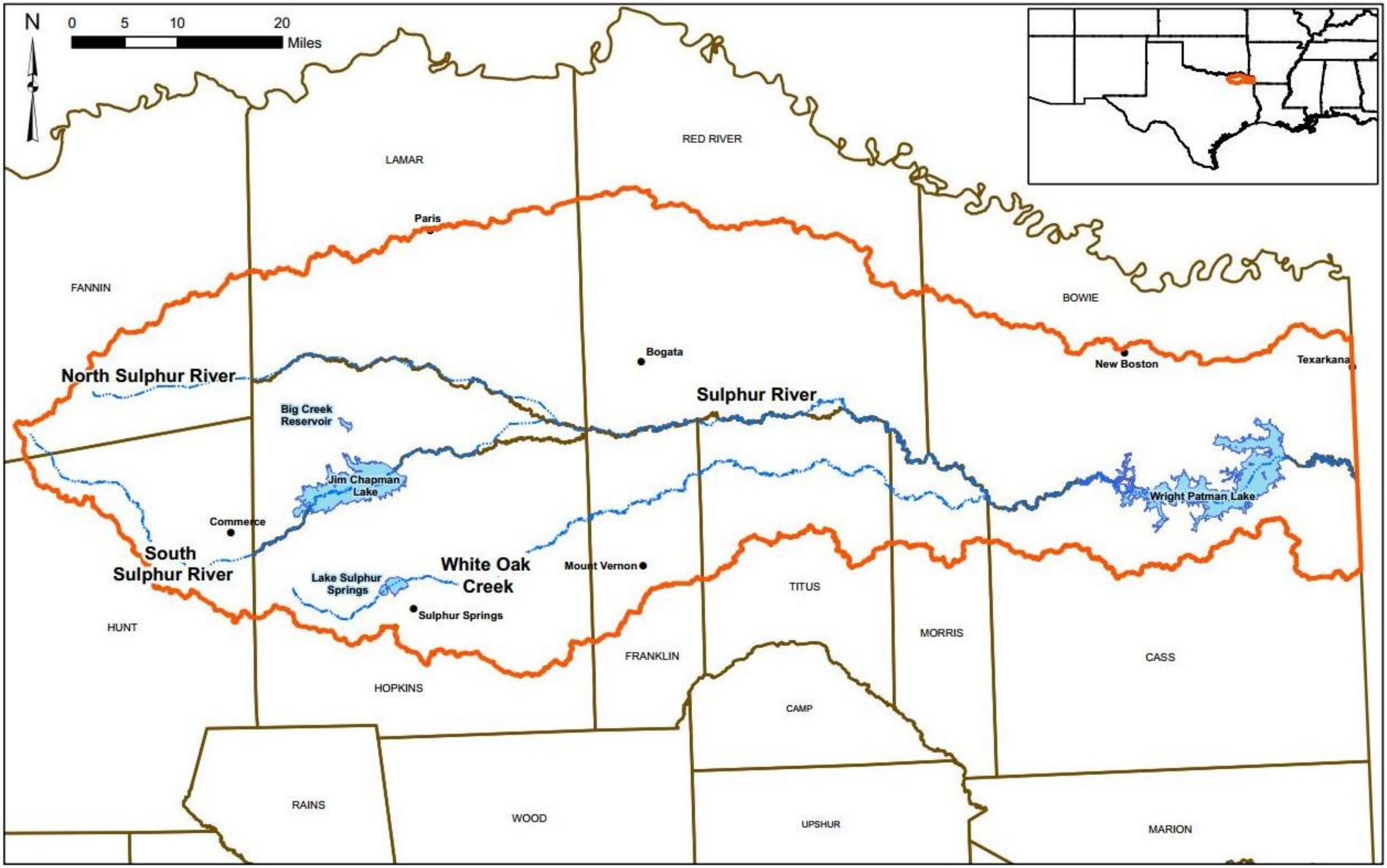
The South and North Sulphur Rivers originate in southern Fannin County and flow eastward 50 to 60 miles to their confluence on the boundary of eastern Delta and Lamar Counties. In the late 1920's, the U. S. Army Corps of Engineers initiated extensive channelization of these streams, particularly the North Sulphur River, for flood control purposes, and the confluence of the rectified channels was moved some distance west of where the natural confluence existed. This confluence forms the Sulphur River, which flows eastward an additional 75 miles to the Texas-Arkansas state line. White Oak Creek is the largest tributary of the Sulphur River, and it drains about 500 square miles in the southern part of the basin, including the city of Sulphur Springs. Ground elevations in the basin range from about 700 feet above sea level at the headwaters down to about 190 feet at the state line.

The climate of the basin is classified as humid subtropical. Rainfall is high, and average annual precipitation ranges from approximately 40 inches in the western portion of the basin to approximately 47 inches at the state line. The mean annual gross lake evaporation rate within the basin is approximately 50 inches, nearly the lowest in the state. The low evaporation rates are the result of the low wind speeds and high average relative humidity that characterize the region.

The Sulphur Basin is largely rural in nature and lies in the Coastal Plain geographic province. Overall relief is low. The western part of the basin lies in the Blackland Prairie belt and generally is comprised of open rolling prairies with small tracts of woodlands. Pasture and cropland are the predominant land uses. The eastern part of the basin lies in the Forested Coastal Plain and is typically forested, with a smaller amount of cropland and pasture. Since the 1940's, land use has changed from primarily cropland (mostly cotton) to a predominance of pastureland. Oil and gas, timber, and tourism are important industries that have developed in the basin in the last 30 to 40 years.

The Sulphur Basin is characterized by a prolific water resource, primarily because of the high annual rainfall. Average runoff is estimated to range from about 14 inches per year (750 acre-feet per square mile) in the eastern portion of the basin to about 10 inches per year (550 acre-feet per square mile) at the headwaters. Surface water resources supply more than 90 percent of the water used for all purposes in the basin, with groundwater supplying the remainder.

**Figure 1-1 General Location Map of Sulphur River Basin**



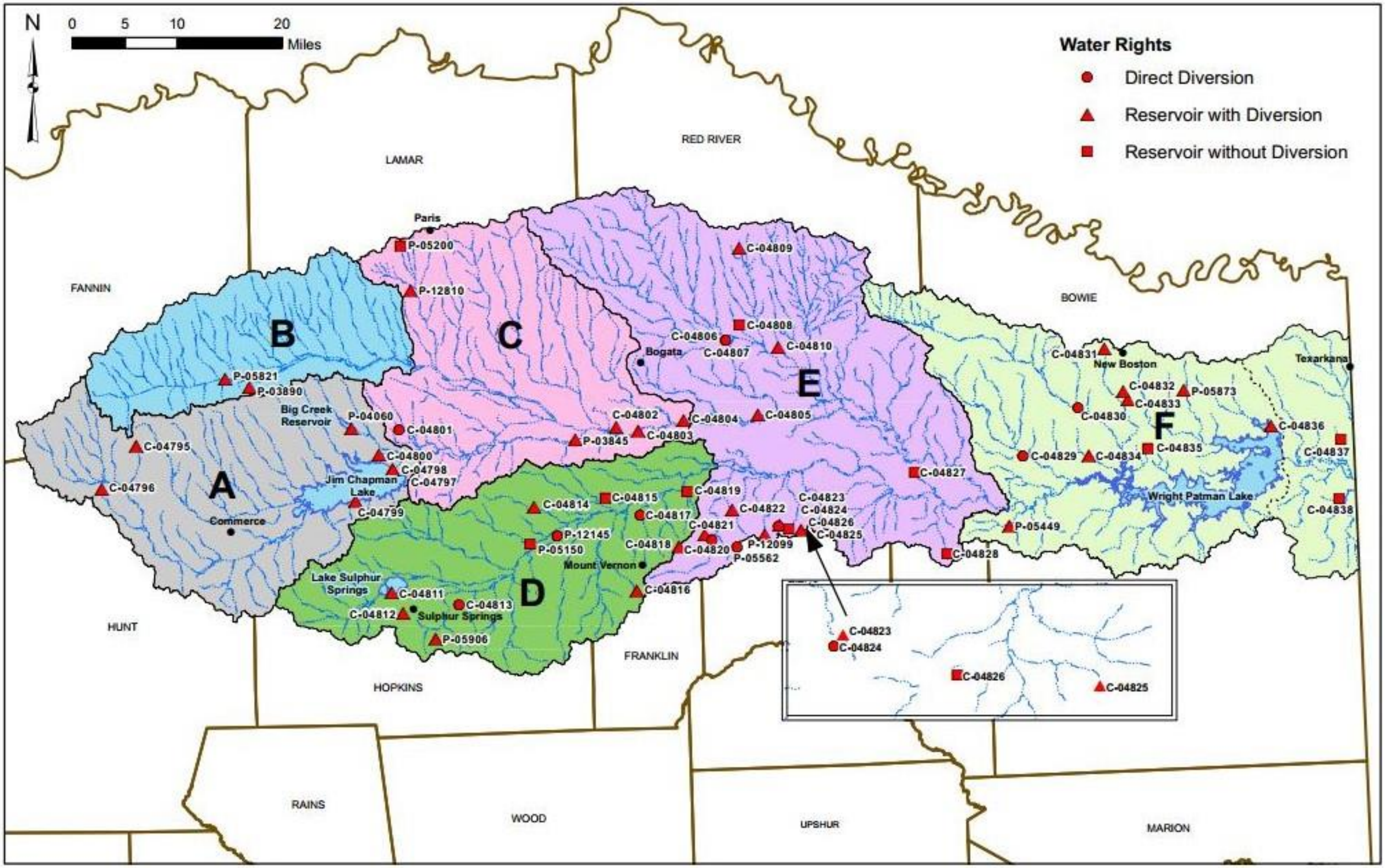
## 1.3 Existing Water Rights

The locations of existing water rights in the Sulphur River Basin are identified on the map in Figure 1-2, and they are listed individually in Table 1-1 by water right number, with a "C" designating a certificate of adjudication and a "P" designating a permit. This list was compiled based on the TCEQ's water rights masterfile as of September 7, 2018. There are 57 individual existing water rights located within the Sulphur Basin that authorize the diversion and/or storage of surface water. All of these water rights are accounted for and represented with regard to their individual features in the updated Sulphur WAM.

The total amount of authorized diversions for these water rights is approximately 445,000 acre-feet per year (ac-ft/yr). Approximately 50 percent of the total authorized diversion volume is for municipal use and about 41 percent is for industrial purposes. The remainder is for irrigation (~9 percent) and other uses. Wright Patman, Jim Chapman, Ralph Hall and Sulphur Springs reservoirs are permitted by the State for diversions up to 381,320 acre-feet of water per year, about 83 percent of the total. Wright Patman Lake, which was constructed in the mid-1950's, is the water supply source for the city of Texarkana and for a number of smaller communities in the area, as well as major industries in the region. Jim Chapman Lake, which began impoundment in 1991, provides supplemental water supplies for the City of Irving, the North Texas Municipal Water District, and by contract with the Sulphur River Municipal Water District or City of Commerce to the City of Cooper, the City of Sulphur Springs, and the Upper Trinity Regional Water District. Lake Sulphur Springs, the next largest existing reservoir, supplies municipal water primarily to the City of Sulphur Springs. Lake Ralph Hall is not yet constructed but is scheduled to begin providing water to customers of the Upper Trinity Regional Water District around 2024.

There are 50 reservoirs, or groups of reservoirs, authorized by existing water rights in the Sulphur River Basin. The total storage capacity of these authorized impoundments is about 940,000 acre-feet. Of the total, there are 15 reservoirs, or groups of reservoirs, that are authorized to store 1,000 acre-feet or more, and these impoundments represent 99 percent of the total authorized reservoir storage capacity in the basin. Wright Patman Lake (formerly Lake Texarkana), covering approximately 20,000 acres and located on the Sulphur River about seven miles upstream of the Texas-Arkansas state line, and Jim Chapman Lake (formerly Cooper Lake), covering about 19,000 acres and located on the South Sulphur River near the city of Cooper in the western part of the basin, are the two largest reservoirs, with 386,900 acre-feet and 310,000 acre-feet, respectively, of authorized storage capacity. These reservoirs are owned and operated by the U. S. Army Corps of Engineers (Corps), and they provide water supply, flood control, and recreational benefits. Lake Ralph Hall is proposed for construction on the North Sulphur River in the western part of the basin. It is authorized to impound 180,000 acre-feet and will cover approximately 8,000 acres. Lake Sulphur Springs (sometimes referred to as White Oak Reservoir), is owned by the City of Sulphur Springs and covers approximately 1,600 acres on White Oak Creek in Hopkins County. This reservoir is authorized to impound 17,838 acre-feet.

**Figure 1-2 Existing Water Rights in Sulphur River Basin**



## Table 1-1 Existing Water Rights in Sulphur River Basin

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | WATER RIGHT NO. [1] | WATER RIGHT OWNER | SUB WATER-SHED | PRIORITY DATE | DIVERSION AMOUNT (ac-ft/yr) | TYPE OF USE [2] | STREAM | RESERVOIR | |
| | | | | | | | | CAPACITY (ac-ft) | NAME |
| (1) | C 4795 | City of Wolfe City | A | 12/31/1925 | 68.5 | Mun | East Fork Turkey Creek | 425 | Wolfe City Reservoir |
| (2) | C 4795 | City of Wolfe City | A | 8/12/1957 | 231.5 | Mun | East Fork Turkey Creek | 430 | Wolfe City Reservoir |
| (3) | C 4796 | Webb Hill Country Club | A | 3/11/1968 | 80 | Irr | Trib of S Sulphur River | 60 | |
| (4) | C 4797 | Commerce/Sulphur R MWD | A | 11/19/1965 | 26,960 | Mun | South Sulphur River | 81,470 | Jim Chapman Lake |
| (5) | C 4797 | Sulphur River MWD | A | 11/19/1965 | 11,560 | Ind | South Sulphur River | - - | |
| (6) | C 4797 | City of Commerce | A | 11/19/1965 | 11,274 [3] | Mun | | - - | |
| (7) | C 4797 | City of Commerce | A | 11/19/1965 | 4,832 [3] | Ind | | - - | |
| (8) | C 4798 | North Texas MWD | A | 11/19/1965 | 54,000 | Mun | South Sulphur River | 114,265 | Jim Chapman Lake |
| (9) | C 4799 | City of Irving | A | 11/19/1965 | 44,820 | Mun | South Sulphur River | 114,265 | Jim Chapman Lake |
| (10) | C 4799 | City of Irving | A | 11/19/1965 | 9,180 | Ind | South Sulphur River | - - | |
| (11) | C 4800 | City of Cooper | A | 1/3/1977 | 273 | Mun | Cedar Creek | 164 | City Lake |
| (12) | C 4801 | Delta Country Club | C | 7/2/1979 | 5 | Irr | Trib of Brushy Creek | - - | |
| (13) | C 4802 | Alexander Frick et al | C | 12/31/1955 | 278 | Irr | Trib of Sulphur River | 300 | |
| (14) | C 4803 | Helmut Hermann et al | C | 6/19/1978 | 1,000 | Irr | Trib of Sulphur River | 328 | Terry Lake |
| (15) | C 4803 | Jimmie, Kate & Terry Brown | C | 6/19/1978 | - - | D&L | | | |
| (16) | C 4803 | Helmut Hermann et al | C | 11/15/1982 | 900 | Irr | Trib of Sulphur River | | |
| (17) | C 4804 | Luminant Generation Co LLC | C | 3/5/1952 | 10,000 | Ind | Sulphur River | 7,100 | River Crest Lake |
| (18) | C 4805 | E P Land and Cattle Inc | E | 1/5/1981 | 3,000 | Irr | Trib of Sulphur River | 2,063 | Multiple Reservoirs |
| (19) | C 4806 | Laura E Vaughan et al | E | 9/22/1969 | 8.4 | Irr | Bernard Draw | - - | |
| (20) | C 4807 | Mary Margaret Vaughan | E | 9/22/1969 | 21.6 | Irr | Bernard Draw | - - | |
| (21) | C 4808 | Red River Country Club | E | 1/6/1975 | 0 | Rec | Pickett Creek | 670 | South Lake |
| (22) | C 4809 | Red River County WCID 1 | E | 1/20/1964 | 1,119.5 | Mun | Langford Creek | 1,225 | Langford Creek Lake |
| (23) | C 4809 | Red River County WCID 1 | E | 1/20/1964 | 0.5 | Ind | Langford Creek | - - | |
| (24) | C 4810 | Donelson Family, LTD | E | 4/4/1960 | 200 | Irr | Sand Branch | 200 | Magic Valley Lake |
| (25) | C 4811 | City of Sulphur Springs | D | 7/24/1951 | 2,000 | Mun | White Oak Creek | 17,838 | Lake Sulphur Springs |
| (26) | C 4811 | City of Sulphur Springs | D | 11/25/1968 | 7,800 | Mun | White Oak Creek | | |
| (27) | C 4812 | City of Sulphur Springs | D | 12/1/1975 | 408 | Mun | Trib of White Oak Creek | 408 | Lake Coleman |
| (28) | C 4813 | Sulphur Springs Country Club | D | 12/15/1975 | 113 | Irr | Trib of Rock Creek | - - | |
| (29) | C 4814 | Jerry N Jordan Trustee et al | D | 7/16/1959 | 30 | Irr | Trib of Wolfpen Creek | 26 | |
| (30) | C 4815 | Charles and Lewis Helm | D | 3/28/1976 | 0 | Rec | Trib of Mitchell Creek | 760 | |
| (31) | C 4816 | City of Mount Vernon | D | 3/1/1976 | 188 | Mun | Denton Creek | 434 | |

## Table 1-1 continued

| | (1) WATER RIGHT NO. [1] | (2) WATER RIGHT OWNER | (3) SUB WATER-SHED | (4) PRIORITY DATE | (5) DIVERSION AMOUNT (ac-ft/yr) | (6) TYPE OF USE [2] | (7) STREAM | (8) RESERVOIR CAPACITY (ac-ft) | (9) RESERVOIR NAME |
|---|---|---|---|---|---|---|---|---|---|
| (32) | C 4816 | City of Mount Vernon | D | 11/22/1982 | 212 | Mun | | | |
| (33) | C 4817 | Hans & Waltraud Weiss | D | 6/30/1964 | 333.3 | Irr | Bear Pen Creek | - - | |
| (34) | C 4818 | Robert & Dewitta Campbell | D | 12/31/1964 | 10.5 | Irr | Trib of Campbell Creel | 24 | |
| (35) | C 4819 | WOCR Holding, LLC | D | 3/18/1974 | 0 | Rec | Lick Creek | 2,360 | Lake Romal |
| (36) | C 4820 | Joe R. Menefee | E | 12/31/1964 | 22 | Irr | Ripley Creek | - - | |
| (37) | C 4821 | Anna Pearl Lewis | E | 12/31/1953 | 1.2 | Ind | Trib of Ripley Creek | 1 | |
| (38) | C 4822 | Bernice Ann Baldwin | E | 7/31/1967 | 100 | Irr | Trib of McCullough Creek | 196 | |
| (39) | C 4823 | Ardelia Gauntt | E | 6/1/1965 | 22.5 | Irr | Trib of Piney Creek | 24 | |
| (40) | C 4824 | Walter W. Lee | E | 6/1/1965 | 7.5 | Irr | Trib of Piney Creek | - - | |
| (41) | C 4825 | Robert Crooks et al | E | 12/31/1963 | 20 | Irr | East Piney Creek | 30 | |
| (42) | C 4825 | Robert Crooks et al | E | 12/31/1965 | 0.04 | Ind | East Piney Creek | | |
| (43) | C 4826 | Elles-Kelly Lake Club | E | 1/8/1973 | 0 | Rec | East Piney Creek | 151 | |
| (44) | C 4827 | Broventure Company Inc | E | 10/18/1974 | 0 | Rec | Murphy Branch | 1,455 | |
| (45) | C 4828 | Glass Club Lake Inc. | E | 1/29/1973 | 0 | Rec | Trib of Village Creek | 500 | |
| (46) | C 4829 | Estate of E D Simms et al | F | 4/30/1940 | 4 | Irr | Eds Creek | - - | |
| (47) | C 4830 | Estate of E D Simms et al | F | 4/30/1940 | 378 | Irr | Unnamed Trib | - - | |
| (48) | C 4831 | City of New Boston | F | 6/30/1914 | 31 | Mun | Trib of Rice Creek | 259 | |
| (49) | C 4832 | City of New Boston | F | 8/29/1944 | 325 | Mun | Holly Branch | 8 | |
| (50) | C 4833 | H C Prange Jr | F | 1/31/1956 | 7.9 | Ind | Trib of Moss Creek | 13.8 | |
| (51) | C 4834 | Estate of E D Simms et al | F | 4/30/1940 | 39 | Irr | Brooks Creek | 15 | |
| (52) | C 4835 | Khalid Malik | F | 12/31/1948 | 0 | Rec | Trib of Moss Creek | 78 | |
| (53) | C 4836 | City of Texarkana | F | 3/5/1951 | 14,572 | Mun | Sulphur River | 386,900 | Wright Patman Lake |
| (54) | C 4836 | City of Texarkana | F | 2/17/1957 | 10,428 | Mun | Sulphur River | - - | |
| (55) | C 4836 | City of Texarkana | F | 2/17/1957 | 35,000 | Ind | Sulphur River | - - | |
| (56) | C 4836 | City of Texarkana | F | 9/19/1967 | 20,000 | Mun | Sulphur River | - - | |
| (57) | C 4836 | City of Texarkana | F | 9/19/1967 | 100,000 | Ind | Sulphur River | - - | |
| (58) | C 4837 | Leon S Kennedy Jr | F | 6/30/1962 | 0 | Rec | Crutchers Creek | 550 | Kennedy Lake |
| (59) | C 4837 | Henry Maddox Jr, et ux | F | 6/30/1962 | 80 | Irr | Crutchers Creek | - - | |
| (60) | C 4838 | International Paper Company | F | 11/17/1975 | 0 | Rec | Grassy Creek | 52 | Supervisors Club Reservoir |
| (61) | C 3845 | Sulphur Bluff Land | C | 9/14/1981 | - - | Irr | Old Chan, S Sulphur River | 26 | |
| (62) | P 3845 | Sulphur Bluff Land | C | 9/14/1981 | 2,828 | Irr | Off-Channel Reservoir | 3,849 | |

## Table 1-1 continued

| | (1) WATER RIGHT NO. [1] | (2) WATER RIGHT OWNER | (3) SUB WATER-SHED | (4) PRIORITY DATE | (5) DIVERSION AMOUNT (ac-ft/yr) | (6) TYPE OF USE [2] | (7) STREAM | (8) RESERVOIR CAPACITY (ac-ft) | (9) RESERVOIR NAME |
|---|---|---|---|---|---|---|---|---|---|
| (63) | P 3845 | Sulphur Bluff Land | C | 11/7/1984 | 5,500 | Irr | Off-Channel Reservoir | 3,623 | |
| (64) | P 3845 | Sulphur Bluff Land | C | 4/11/1997 | 11,312 | Irr | Off-Channel Reservoir | 2,925 | |
| (65) | P 3890 | City of Pecan Gap | B | 4/26/1982 | 102 | Mun | Trib of Sulphur River | 152 | |
| (66) | P 4060 | City of Cooper | A | 9/6/1983 | 1,518 | Mun | Big Creek | 4,890 | Big Creek |
| (67) | P 5150 | Larry Miles et al | D | 7/28/1987 | 0 | D&L | Unnamed Trib | 269 | Cross Timbers Rch Lake #1 |
| (68) | P 5200 | Gordon Country Club | C | 11/1/1988 | 0 | Rec | Cottonwood Branch | 394 | Gordon Lake |
| (69) | P 5449 | Texas Parks & Wildife Dept | F | 2/18/1993 | 863 | Oth | Toyah Creek | 504 | Multiple Reservoirs |
| (70) | P 5562 | Luminant Mining Co LLC | E | 11/19/1996 | 125 | Ind | Tribs of Ripley/Dorsey Ck | - - | |
| (71) | P 5821 | Upper Trinity Reg Water Dist | B | 8/13/2004 | 45,000 | Multi | North Sulphur River | 180,000 | Lake Ralph Hall |
| (72) | P 5873 | TexAmericas Center | F | 6/16/2005 | 1,032 | Mun | Caney Creek | 1,340 | Reservoir No. 1 |
| (73) | P 5873 | TexAmericas Center | F | 6/16/2005 | 1,928 | Mun | Elliot Creek | 2,734 | Reservoir No. 2 |
| (74) | P 5906 | Luminant Mining Co LLC | D | 2/27/2006 | 220 [4] | Min | Trib of Rock Creek | - - | |
| (75) | P 5906 | Luminant Mining Co LLC | D | 2/27/2006 | - - | D&L | Trib of Rock Creek | 217 | Pond B-15 |
| (76) | P 5906 | Luminant Mining Co LLC | D | 2/27/2006 | - - | D&L | Trib of Rock Creek | 248 | Pond B-18 |
| (77) | P 5906 | Luminant Mining Co LLC | D | 2/27/2006 | - - | D&L | Trib of Rock Creek | 537 | Pond D-03 |
| (78) | P 12099 | Luminant Mining Co LLC | E | 1/3/2007 | 200 [4] | Min | Piney Creek and Tribs | - - | |
| (79) | P 12099 | Luminant Mining Co LLC | E | 1/3/2007 | - - | D&L | Piney Creek and Tribs | 513.11 | Reservoirs M-1 ,J-2, L-1, L-2, L-4 |
| (80) | P 12145 | Los Senderos Cattle/Ranch Co | E | 4/24/2007 | 35 | Irr | White Oak Creek | 8.6 | Off-Channel Reservoir |
| (81) | P 12810 | Daisy Farms LLC | C | 4/12/2013 | 17,500 [5] | Multi | Auds Creek | - - | |
| (82) | P 12810 | Daisy Farms LLC | C | 4/12/2013 | 245 | Multi | Tribs of Auds Creek | - - | |
| (83) | P 12810 | Daisy Farms LLC | C | 4/12/2013 | - - | | Tribs of Auds Creek | 1,368 | Existing Ponds 1-6 |
| (84) | P 12810 | Daisy Farms LLC | C | 4/12/2013 | - - | | Tribs of Auds Creek | 4,179 | Prop Ponds 1-2, Sump, Williams |

NOTES:

[1] C = Certificate of Adjudication and P = Permit

[2] Mun = Municipal, Ind = Industrial, Irr = Irrigation, Min = Mining, Rec = Recreation, Oth = Other, Multi = Municipal, Industrial, Irrigation and/or Recreation, D&L = Domestic and Livestock

[3] These diversion authorizations for the City of Commerce are stipulated in Amendment A as contractual commitments of the base diversion amounts authorized for the Sulphur River MWD.

[4] The authorization to divert water for mining purposes in this permit apparently has expired because mining activities essentially have ceased, a condition of the permit. For this reason, these water rights are not included in the WAMs.

[5] The diversion amount of 17,500 ac-ft/yr from Auds Creek is authorized to be stored in the Sump and Williams Pond, with subsequent diversions limited to 15,000 ac-ft/yr.

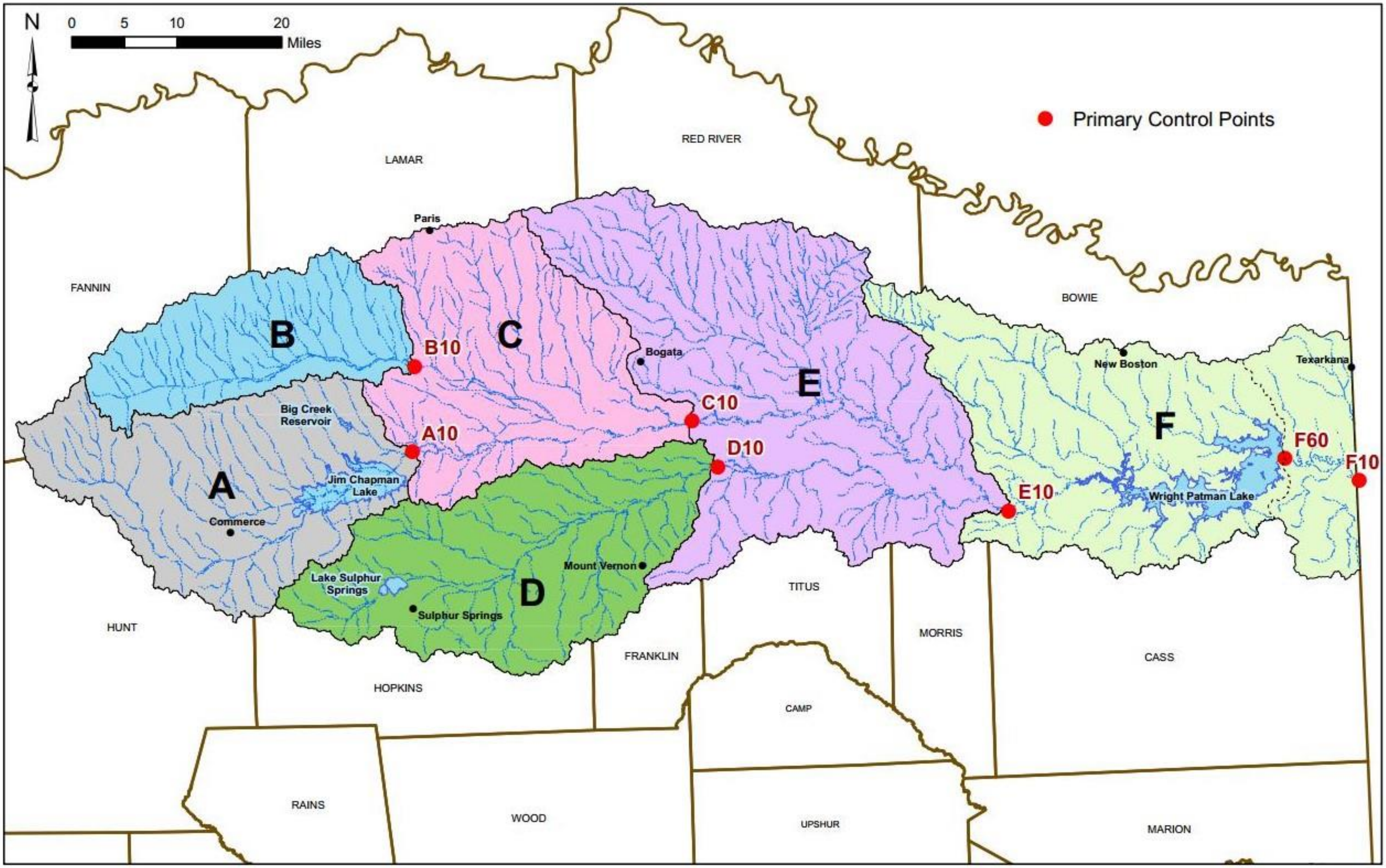
## 1.4 Study Approach

Because the TCEQ has routinely updated the Sulphur WAM to include changes and additions of water rights as they have occurred since the original development of the WAM in 1999, this current effort to update the model has not been focused on incorporating new water rights into the WAM but rather on updating the WAM hydrologic data base to include conditions since 1996, the last year included in the existing data base, through 2017, the last full calendar year with available historical data records. This work has involved primarily developing naturalized flows at selected streamflow gage locations and at Wright Patman Lake dam and using these to compile complete 1997-2017 records of naturalized flows for the primary control points that are used in the Sulphur WAM. This process of developing naturalized flows for the 1997-2017 period has required, in addition to streamflow data, historical monthly information for actual water rights diversions, wastewater return flow discharges, and reservoir storage and releases and rainfall and evaporation amounts. The primary control points and subwatersheds considered in this process are identified on the map of the basin in Figure 1-3.

It should be noted that for Subwatersheds E and F, streamflow gage data are not available at the downstream end of these subwatersheds for the 1997-2017 period; therefore, deduced historical monthly inflows to Wright Patman Lake were calculated for this period. Deduced means that these inflows were calculated each month using a mass balance approach whereby all monthly inflows to Wright Patman Lake (primarily wastewater discharges and rainfall but not the watershed inflows) and outflows from Wright Patman Lake (diversions, releases and evaporation losses) were known and used in a water balance equation with monthly changes in storage to solve for monthly volumes of watershed inflow. The resulting deduced historical inflows to Wright Patman Lake then were naturalized and translated using drainage area ratios to the downstream ends of Subwatersheds E and F.

With these naturalized flows developed for the 1997-2017 period, the existing WAM data input files have been revised to include the new information to produce complete 1940-2017 hydrologic data sets. First, these extended naturalized flows and reservoir rainfall and evaporation data were added to the data input files for the Run 3 version of the Sulphur WAM. This version of the WAM is used as the primary tool for evaluating water availability for existing and new water rights under conditions with all existing water rights fully exercised in accordance with stipulations in their permits or certificates of adjudication and without any wastewater discharges represented in the model. Then, for the Run 8 current conditions version of the Sulphur WAM, the historical diversion and return flow data for the most recent years have been analyzed to establish current values, and these values have been incorporated into the Run 8 data input files for all existing water rights and for all wastewater discharges with a flow rate greater than one million gallons per day. The Run 8 version of the Sulphur WAM also has been revised to include the extended 1997-2017 naturalized flows and current area-capacity data for the major reservoirs.

**Figure 1-3 Subwatersheds and Primary Control Points Used in Updated-Extended Sulphur WAM**



## 2.0 NATURALIZED STREAMFLOW ANALYSES

### 2.1 Streamflow Naturalization Methodology

By definition, naturalized streamflows represent historical streamflow conditions, including typical wet, dry and normal flow periods, without the influence of man's activities as they relate to water rights and water use. For example, the construction and operation of reservoirs, the diversion of surface waters, and the discharge of wastewater are all activities related to water rights and water use that can impact historical streamflows. In the determination of naturalized streamflows, the historical effects of these types of activities must be removed from those portions of the historical streamflow records when such activities actually occurred. The resulting historical trace of naturalized streamflows then represents streamflow conditions uninfluenced by man's water rights or water use activities, and these are the flows that are used for water availability modeling.

For the 1997-2017 period adopted for extension of the hydrologic data set for the Sulphur WAM, the following general equation has been used to derive the monthly naturalized streamflows at locations where historical streamflow records are available:

| | | |
|---|---|---|
| Naturalized Streamflow | = | Historical Streamflow |
| | + | Historical Upstream Diversions |
| | – | Historical Upstream Wastewater Discharges |
| | + | Historical Changes in Upstream Reservoir Storage |
| | + | Historical Upstream Reservoir Evaporation Loss |

In this equation, the terms Historical Upstream Diversions and Historical Upstream Wastewater Discharges refer to the monthly sums of these quantities that occur upstream of the location where the Historical Streamflow is being naturalized. Similarly, the term Historical Changes in Upstream Reservoir Storage refers to the monthly sum of the changes in reservoir storage that occur upstream of the gage location where the Historical Streamflow is being naturalized. In this analysis of naturalized streamflows, the effects of reservoir storage and evaporation losses have only been considered for reservoirs with conservation storage capacities greater than 1,000 acre-feet, as these effects from smaller reservoirs are considered to not be significant.

The term referred to as "Historical Upstream Reservoir Evaporation Loss" in the streamflow naturalization equation has a special meaning that is unique to the naturalization process. First of all, it actually means "net evaporation loss", which is defined as the net loss of water across a reservoir’s surface area due to the difference between the evaporation and the precipitation that occurs during any given month. On the average in the Sulphur Basin, the total or gross annual evaporation from the water surface of a reservoir (outflow) exceeds the annual precipitation that falls on the surface of the reservoir (inflow); therefore, the net evaporation term for most months usually is positive, although it certainly can be negative during wet periods. Second, the Historical

Upstream Reservoir Evaporation Loss term also includes an additional adjustment for the amount of runoff that would have occurred, and appeared at the downstream gage, if all upstream reservoirs had not been in place. By simply taking the difference between the gross evaporation and the amount of precipitation that fell on the surface of a reservoir during a given month to define the net evaporation loss in the streamflow naturalization equation, the effect of precipitation in the evaporation adjustment term is overstated by the amount of precipitation that actually would have occurred as runoff from the reservoir area (in the absence of the reservoir) and eventually as streamflow at the downstream gage. To account for this local runoff effect, the monthly evaporation amount that has been used for calculating the Historical Upstream Reservoir Evaporation Loss in the streamflow naturalization equation has been defined by the following relationship and is referred to as the "Adjusted Net Reservoir Evaporation":

| | | |
|---|---|---|
| Adjusted Net Reservoir Evaporation | = | Gross Reservoir Evaporation |
| | – | Rainfall on the Reservoir Surface |
| | + | Runoff from Reservoir Area in Absence of Reservoir |

The last term of the above equation can be expressed as the Runoff Coefficient times Rainfall, and when combined with the second term, the equation becomes:

| | | |
|---|---|---|
| Adjusted Net Reservoir Evaporation | = | Gross Reservoir Evaporation |
| | – | (1 – Runoff Coefficient) x Rainfall |

The term (1 – Runoff Coefficient) is referred to as the Effective Rainfall Factor, and the product of this term and Rainfall is called the Effective Rainfall. While estimates of historical monthly rainfall amounts generally are available from existing records, the estimation of the associated runoff from a reservoir site can involve a number of complex factors regarding the local reservoir watershed without the reservoir in place, including soil types, vegetative cover, land use, and antecedent soil moisture conditions. For purposes of deriving naturalized streamflows, however, an exact accounting for these factors in not essential considering the accuracy of the overall streamflow naturalization process itself and the relative magnitude of the runoff term compared to total precipitation (usually less than 20 percent). The process of evaluating runoff for a given amount of precipitation at a reservoir site during a given month can be simplified by applying the Runoff Coefficient to the rainfall amount, and this is the approach that was used for the Sulphur Basin during the original development of the WAM. Runoff Coefficients previously were obtained from the 1971 Hydrologic Data Refinement Study conducted by the Texas Water Development Board. Results from this study indicated that a value of 0.15 would be appropriate as a general approximation of the Runoff Coefficient for the Sulphur Basin, which by definition equates to a value of 0.85 for the Effective Rainfall Factor, and this is the value that has been used for purposes of calculating Adjusted Net Reservoir Evaporation, except for Wright Patman Lake.

For updating the hydrologic data set for the Sulphur WAM to include the 1997-2017 period, the streamflow naturalization process was conducted in an upstream-to-downstream mode. In other words, naturalized flows were calculated for an upstream gage (primary control point), incremental naturalized flows were calculated for the intervening drainage area between the upstream primary control point and the next downstream primary control point, and then the incremental naturalized flows were added to the cumulative upstream naturalized flows. Referring to the subwatershed map in Figure 1-3, this means that naturalized flows were determined first for the primary control points at Subwatersheds A, B and D since these are all upstream subwatersheds. Then, the incremental naturalized flows for the primary control point at the lower end of Subwatershed C were calculated and subsequently added to the total naturalized flows for Subwatersheds A and B to arrive at the total naturalized flows for Subwatershed C. As noted previously in Section 1.4, since streamflow gage data are not available at the downstream ends of Subwatersheds E and F, deduced historical monthly inflows to Wright Patman Lake were calculated for the 1997-2017 period, and these deduced inflows then were naturalized and translated using drainage area ratios to the lower ends of Subwatersheds E and F.

The primary difficulty in the streamflow naturalization process is the availability of reliable data regarding historical diversions, wastewater discharges, and reservoir storage and evaporation for the entire 1997-2017 period. Following multiple inquiries at TCEQ, extensive research of TCEQ files, and contacts with individual water users and wastewater dischargers, it appears that some data records simply do not exist. While the data that have been developed for naturalizing flows in this study very likely do not always fully and accurately reflect actual historical diversions, wastewater discharges, and reservoir storage and evaporation, they are believed to represent reasonable estimates of these quantities that probably could not be significantly refined or improved upon without the availability of additional data records. Still, the data that have been developed in this study for purposes of the streamflow naturalization process are believed to be adequate and satisfactory for purposes of updating the hydrologic data base for the Sulphur WAM.

Occasionally, the calculation of incremental naturalized flows between primary control points has yielded a negative incremental flow value. While this is a physical impossibility, it can be caused by a variety of factors, such as inaccuracies in streamflow data or reservoir contents or spills, incorrect or unreported diversions or wastewater discharges, or reservoir seepage losses, and commonly by travel time effects due to high flow events that overlap monthly data. In the latter case, a flood near the end of a month at an upstream control point could result in a higher monthly total discharge at the upstream control point than the downstream control point, because the full effects of the flood are not recorded downstream until the following month. This would result in not only a negative incremental flow at the downstream control point for that month, but also a disproportionately large incremental flow for the following month. In this analysis, negative incremental flows have been set to zero for the month in which they occur, with the flow for an adjacent month, or months, reduced by the amount of the negative value.

## 2.2 Gage Location Considerations

While the same basic streamflow naturalization methodology has been used throughout the Sulphur Basin, it has been applied to two different types of drainage areas depending on the location of a particular streamflow or reservoir storage gage relative to other gages being used in the naturalization process. For those gages without any other gages located upstream, the entire drainage area upstream of the downstream gage where streamflows are being naturalized has been considered in the naturalization process. Hence, all historical diversions, wastewater discharges, and reservoir depletions within this drainage area have been accounted for in the adjustment of the historical gaged streamflows. The resulting naturalized streamflows then reflect the total flows for the entire drainage area upstream of the gage. In this case, if the calculations resulted in negative values for the total naturalized flows, the negative values were set to zero with no offset of adjacent months as described above for the incremental negative flow case.

Alternatively, for those gages that do have other gages located upstream within their drainage areas, only the intervening or incremental drainage area between the downstream gage where streamflows are being naturalized and the other upstream gages (which will already have been naturalized) have been considered in the naturalization process, to the extent that these gages have common periods of record. The resulting naturalized streamflows for the intervening drainage area then have been added to the sum of the naturalized streamflows for the upstream gages to arrive at the total naturalized streamflows at the downstream gage. In this naturalization process, the intervening observed streamflows have been determined by subtracting the sum of the observed flows at the upstream gages from the observed flows at the downstream gage where the naturalized streamflows are being calculated. Once the intervening observed flows have been determined, they have been naturalized using the same basic procedures as those applied for the case with no upstream gages. Of course, this streamflow naturalization process has only been applied for those periods of time when the downstream and upstream gages have common periods of record.

The procedure that has been employed for naturalizing streamflows using intervening drainage areas is summarized by the following equations:

Historical Intervening Streamflow = Downstream Historical Streamflows
– Upstream Historical Streamflows

Naturalized Intervening Streamflow = Historical Intervening Streamflow
+ Intervening Diversions
– Intervening Wastewater Discharges
+ Historical Changes in Intervening Reservoir Storage
+ Historical Intervening Reservoir Evaporation Loss

| | | |
|---|---|---|
| Total Naturalized Flow | = | Naturalized Intervening Streamflow |
| | + | Naturalized Upstream Streamflows |

Each of the gages where streamflows have been naturalized has been evaluated to formulate the most appropriate procedure for determining naturalized streamflows for specific periods of time. This has included an examination of other proximate gages and their periods of record, as well as an evaluation of the difficulties associated with applying various alternative procedures for determining the naturalized streamflows. The resulting streamflow naturalization procedures that have been adopted and applied for each of the subwatersheds in the Sulphur Basin are summarized in Section 2.9. As noted, these procedures have encompassed both total and incremental drainage area naturalization analyses depending on whether gages existed upstream of individual naturalization locations.

## 2.3 Historical Streamflow Data

For developing the naturalized streamflows for the Sulphur Basin, historical streamflow data have been used from actual streamflow gage records and from deduced reservoir inflows. The U. S. Geological Survey streamflow gages in the Sulphur Basin which have historical streamflow data available and which have been used in the streamflow naturalization process for the 1997-2017 period are identified in Table 2-1, along with their respective periods of record and drainage areas. As shown, several of these gages were used in the original development of the naturalized flows for the existing Sulphur WAM. All of these gage locations are shown on the map of the basin in Figure 2-1. Those gaging stations that define the downstream end of the individual subwatersheds where primary control points are located are identified by subwatershed letter.

It should be noted that during the period from May 1997 to December 2016, Gage No. 7343200, Sulphur River near Talco TX at the downstream end of Subwatershed C, was temporarily moved downstream to accommodate bridge construction at U.S. Highway 271. During this time, a temporary gage was located downstream of the Highway 271 crossing of the Sulphur River; thus, there are three entries in Table 2-1 for this gage: one for the initial permanent gage location from October 1956 to May 1997, one for the temporary gage location from May 1997 to December 2016, and finally one again for the permanent gage location from December 2016 through December 2017. The drainage areas corresponding to these different gage locations are indicated in Table 2-1, and both gage locations are shown on the map in Figure 2-1.

In addition to the streamflow gage records, historical inflows to Wright Patman Lake also have been used in the streamflow naturalization process. This has been necessary because there is no streamflow gage on the Sulphur River at the lower end of Subwatershed F at the state line, and there also is no longer a gage at the downstream end of Subwatershed E. The historical inflows to Wright Patman Lake are not measured, but they can be calculated, or deduced, using monthly

**Table 2-1 Streamflow Gages and Other Locations Used in Development of Naturalized Flows for 1997-2017 Extension of Hydrologic Data Set**

| USGS GAGE NO. | GAGE OR LOCATION NAME | SUB-WATERSHED | WAM DRAINAGE AREA Sq. Miles | PERIOD OF RECORD | | | |
|---|---|---|---|---|---|---|---|
| | | | | Original WAM Naturalized Flows | | Updated WAM Naturalized Flows | |
| | | | | Beginning | Ending | Beginning | Ending |
| 7342500 | S Sulphur River near Cooper, TX [1] | A | 521.3 | Jun-42 | Dec-96 | Jan-97 | Dec-17 |
| 7343000 | N Sulphur River near Cooper, TX [1] | B | 304.6 | Oct-49 | Dec-96 | Jan-97 | Dec-17 |
| 7343200 | Sulphur River near Talco, TX [1] | C | 1,353.2 | Oct-56 | Dec-96 | Jan-97 | May-97 |
| 7343200 | Sulphur River near Talco, TX [2] | - - | 1,393.4 | - - | - - | May-97 | Dec-16 |
| 7343200 | Sulphur River near Talco, TX [2] | C | 1,353.2 | - - | - - | Dec-16 | Dec-17 |
| 7343500 | White Oak Creek near Talco, TX [1] | D | 538.0 | Dec-49 | Dec-96 | Jan-97 | Dec-17 |
| 7344000 | Sulphur River near Darden [3] | E | 2,790.7 | Oct-23 | Dec-56 | n/a | n/a |
| - - | Wright Patman Lake Dam [4] | - - | 3,412.5 | Jul-53 | Dec-96 | Jan-97 | Dec-17 |

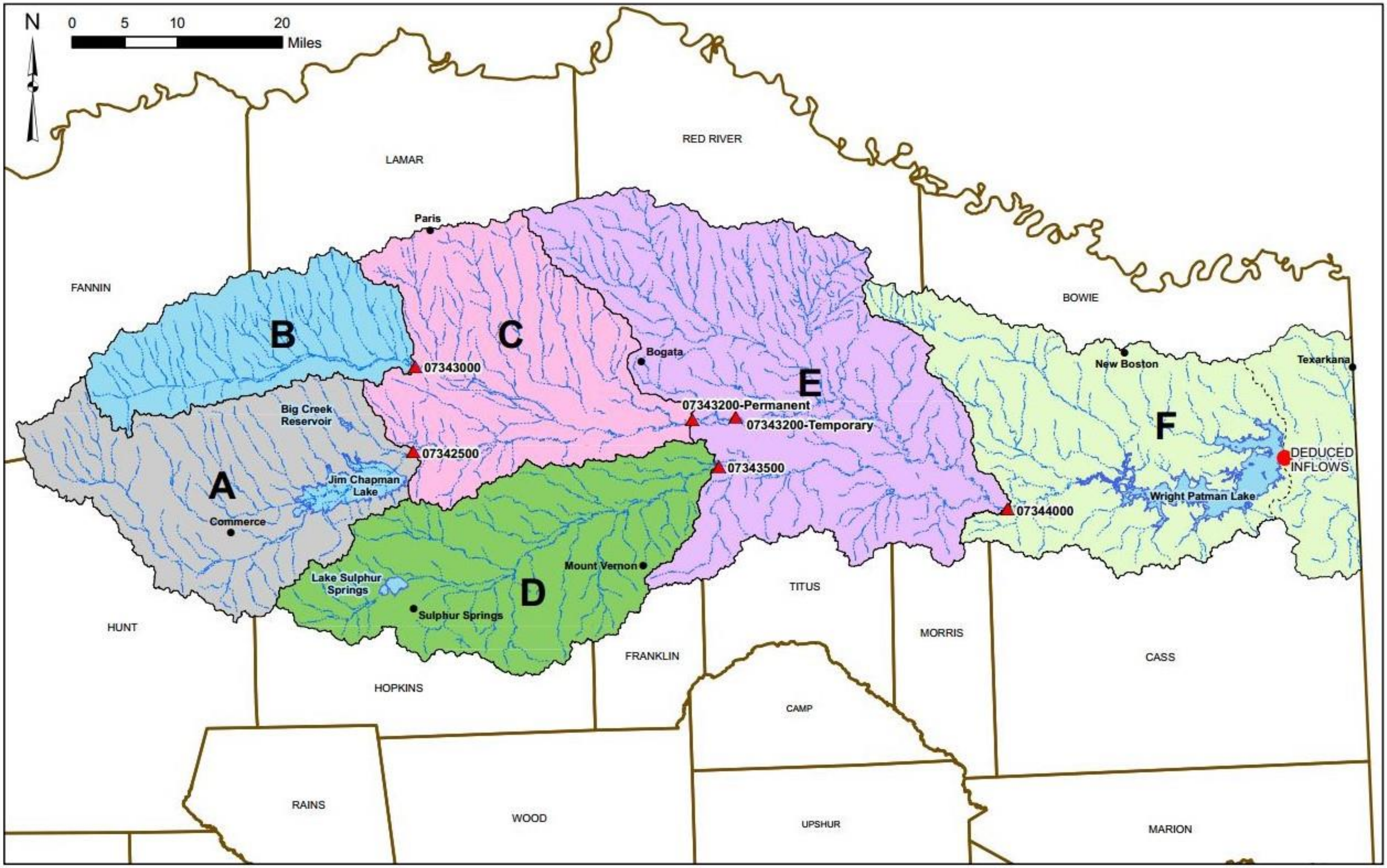
[1] Streamflow data or deduced inflows were used in the original WAM naturalized flow analysis.

[2] Gage was temporarily moved downstream; streamflow data from both locations have been used in current naturalized flow analysis.

[3] Streamflow data were used in original WAM naturalized flow analysis, but only the gage location used in current naturalized flow analysis.

[4] This location is used to calculate deduced inflows to Wright Patman Lake and to provide corresponding naturalized flows for the WAM.

## Figure 2-1 USGS Streamflow Gages Used in 1997-2017 Streamflow Naturalization Process



water balance analyses with historical reservoir operations data obtained primarily from the Corps of Engineers Fort Worth District. This deduced inflow calculation process has involved applying the following mass balance equation which relates the monthly inflow to the reservoir to the change in the amount of water stored in the reservoir during the month, adjusted for corresponding evaporation losses from the reservoir's surface, direct rainfall on the reservoir, and diversions and releases of water from the reservoir, including any uncontrolled spills of floodwater:

$$QI_i = (ST_i - ST_{i-1}) + (EV_i * AR_i) - (PE_i * AR_i) + DV_i + RL_i$$

where:
- $QI_i$ = Historical inflow to the reservoir during Month i
- $ST_i$ = Storage in reservoir at end of Month i
- $ST_{i-1}$ = Storage in reservoir at end of Month i-1
- $EV_i$ = Gross reservoir evaporation rate during Month i
- $AR_i$ = Average surface area of reservoir during Month i
- $PE_i$ = Effective rainfall on reservoir during Month i
- $DV_i$ = Total diversions from reservoir during Month i
- $RL_i$ = Total releases from reservoir during Month i

It should be noted that Effective Rainfall in the above equation, PE, is the same as that previously defined for use in the calculation of the Adjusted Net Reservoir Evaporation that is used in the determination of the Historical Upstream Reservoir Evaporation Loss in the basic Naturalized Streamflow equation in Section 2.1. For Wright Patman Lake, the Effective Rainfall Factors that have been used for the 1997-2017 reservoir inflow simulations are the same as those previous applied in the original development of the naturalized flows for the Sulphur WAM. These are listed below in Table 2-2.

**Table 2-2 Effective Rainfall Factors for Wright Patman Lake**

| MONTH | FACTOR |
|---|---|
| January | 0.55 |
| February | 0.70 |
| March | 0.45 |
| April | 0.62 |
| May | 0.61 |
| June | 0.70 |
| July | 0.86 |
| August | 0.95 |
| September | 0.98 |
| October | 0.96 |
| November | 0.90 |
| December | 0.76 |

## 2.4 Reservoir Elevation-Area-Capacity Relationships

Each reservoir is unique in terms of the relationship between its water surface elevation or stage and the corresponding surface area and storage content. Data relating reservoir surface area to storage content are included for each reservoir in the Run 3 version of the WAM for the Sulphur Basin, and these data represent conditions as the reservoirs were originally constructed and authorized by their respective water rights. Over time, sediment transported with inflows have been deposited and accumulated in the reservoirs, typically causing both their surface area and storage content to decrease with water surface elevation. For TCEQ's existing Run 8 version of the WAM for the Sulphur Basin, these sedimentation effects were accounted for in the major reservoirs with adjusted area-capacity data that reflected year-2000 conditions. These adjusted area-capacity data were derived by applying historical sedimentation rates either for individual reservoirs, or for the region, to the most recent survey data for a reservoir prior to 2000.

In this current study, reservoir elevation-area-capacity data are necessary for calculating reservoir streamflow depletions for the 1997-2017 period that are used in the streamflow naturalization process. As noted previously, these calculations have been limited to only those reservoirs with conservation storage capacities greater than 1,000 acre-feet. In some cases, only the elevation-area or area-storage relationships have been required and for others complete elevation-area-storage relationships have been used. Elevation-area-capacity data and relationships for the reservoirs included in the naturalized flow process are discussed in the sections below. Area-capacity data for the updated-extended Run 8 model also have been developed to represent 2020 storage and area conditions for the major reservoirs. Again, historical sedimentation rates either for individual reservoirs, or for the region, have been applied to the most recent survey data for the major reservoirs to derive area-capacity data sets for 2020 conditions.

### 2.4.1 Wright Patman Lake

As discussed above in Section 2.3, for purposes of the streamflow naturalization process, historical monthly inflows to Wright Patman Lake for the 1997-2017 period have been calculated, or deduced, which has required the use of historical monthly values of both reservoir storage and surface area. For Wright Patman Lake, these data are available for the 1997-2017 period directly from the Corps' data base; therefore, it has not been necessary to use elevation-area-capacity data for determining the historical monthly storage and surface area values based on measured water surface elevations. However, current elevation-area-capacity data still are required for updating the Run 8 version of the WAM.

The Texas Water Development Board (TWDB) conducted volumetric surveys of Wright Patman Lake in 1997 and in 2010. The Corps of Engineers, owner and operator of Wright Patman Lake, used results from these surveys and other information to develop extended elevation-area-capacity tables that have been used by the Corps for reporting historical daily storage and surface area data for the reservoir. Whereas the TWDB surveys include some data above the conservation pool of Wright Patman Lake (above elevation 220.6 feet above mean sea level, msl), the Corps tables provide elevation-area-capacity information for the reservoir up to elevation 290.0 feet msl, which is substantially above the level of the reservoir when it is in typical flood stage. These elevation-area-capacity tables have been obtained from the Corps, and these data are plotted as curves on the graph in Figure 2-2 up to elevation 260.0 feet msl. It should be noted that up to elevation 226.0 feet msl, the Corps data are the same as the TWDB 2010 survey data. This is the highest elevation included in the TWDB 2010 survey. Based on the TWDB 2010 survey, the conservation storage capacity of Wright Patman Lake at elevation 220.6 was determined to be 97,927 acre-feet, with the corresponding surface area at 18,247 acres.

Also plotted on the graph in Figure 2-2 are the original elevation-area-capacity data for Wright Patman Lake that correspond to the authorized conditions when the reservoir was constructed. These are the data used in the original Run 3 version of the Sulphur WAM, and they are still used in the updated-extended version of the model.

In 2018, Riverbend contracted with Arroyo Environmental Consultants, LLC, in association with Aqua Strategies, Inc., to perform a new survey of Wright Patman Lake to acquire current elevation-area-capacity data. This survey was conducted during July and August of 2018, and the report summarizing these data was produced in January of 2019 (Arroyo, 2019). In this survey, the conservation storage capacity of Wright Patman Lake was determined to be 96,430 acre-feet (about 1.5 percent less than in 2010) and the surface area was measured at 17,907 acres. The Arroyo 2018 elevation-area-capacity data are plotted on the graph in Figure 2-3 along with the TWDB 2010 survey data up to elevation 226.0 feet msl and the Corps extended data up to elevation 230 feet msl. As shown, there is very little discernable difference between the TWDB 2010 data and the Arroyo 2018 data, indicating that sedimentation effects on reservoir storage capacity and surface area have been relatively insignificant over the eight-year period. For purposes of updating the Run 8 version of the WAM, the Arroyo 2018 data (up to elevation 224 feet msl) have been used directly to represent 2020 conditions for Wright Patman Lake since it is evident from comparison of the 2010 and 2018 data sets that sedimentation is not likely to appreciably alter the surface area and storage conditions of the reservoir by 2020. From elevation 224 feet msl up to elevation 226 feet msl, the TWDB 2010 data have been used, and above elevation 226 feet msl, the Corps 2018 extended data have been used up to elevation up to elevation 230 feet msl.

### 2.4.2 Jim Chapman Lake

Jim Chapman Lake was surveyed by the TWDB in 2005 when the reservoir was several feet below its conservation pool level and then again in 2007 after the reservoir had risen to near the top of its conservation pool in response to spring and early summer floods. At that time, the conservation storage capacity of the reservoir below elevation 440.0 feet msl was determined to be 298,930 acre-feet, and the corresponding surface area was 17,958 acres.

**Figure 2-2 Elevation-Area-Capacity Curves for Wright Patman Lake from Original Survey and from 2018 Corps of Engineers Fort Worth District**

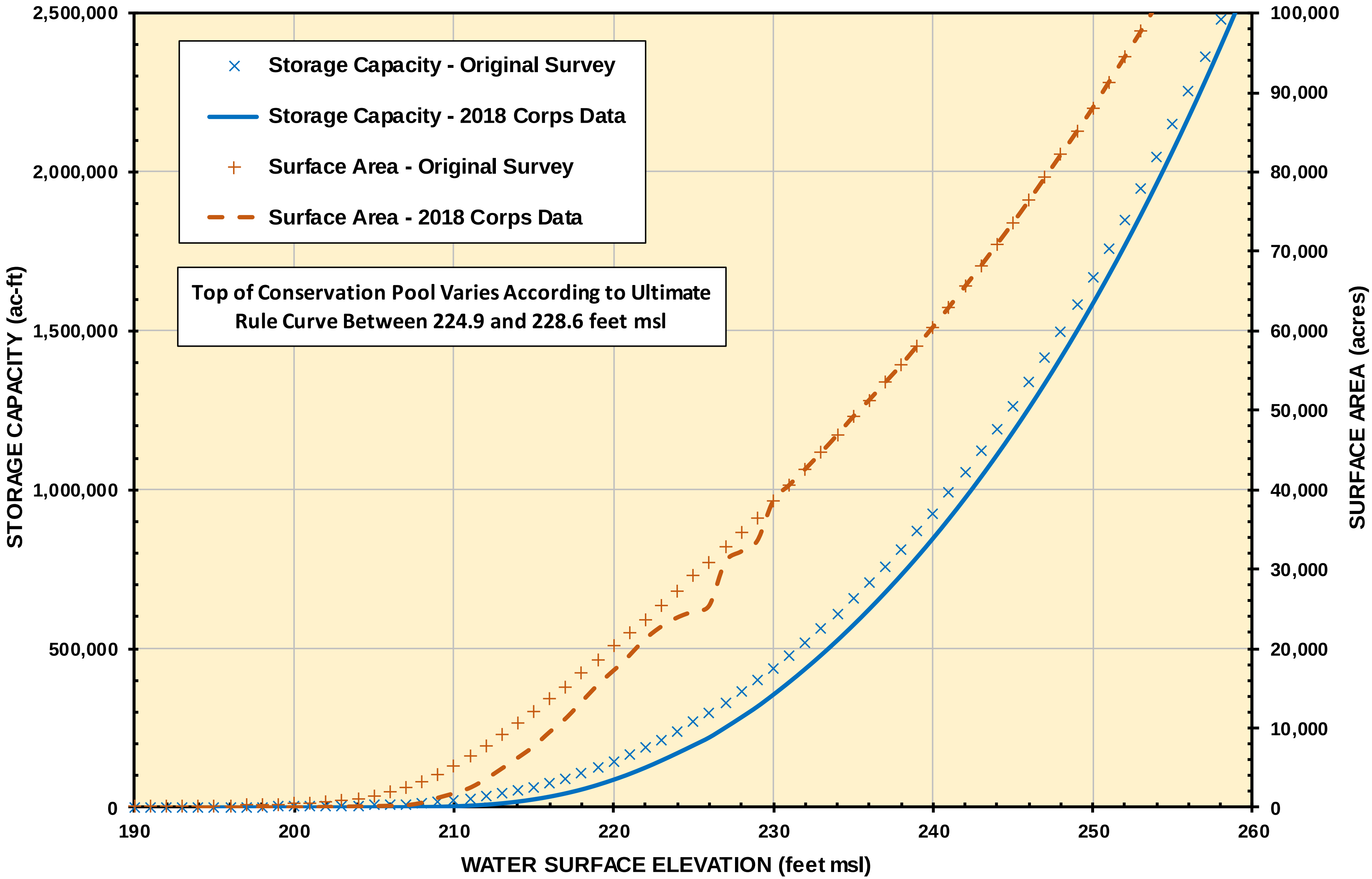
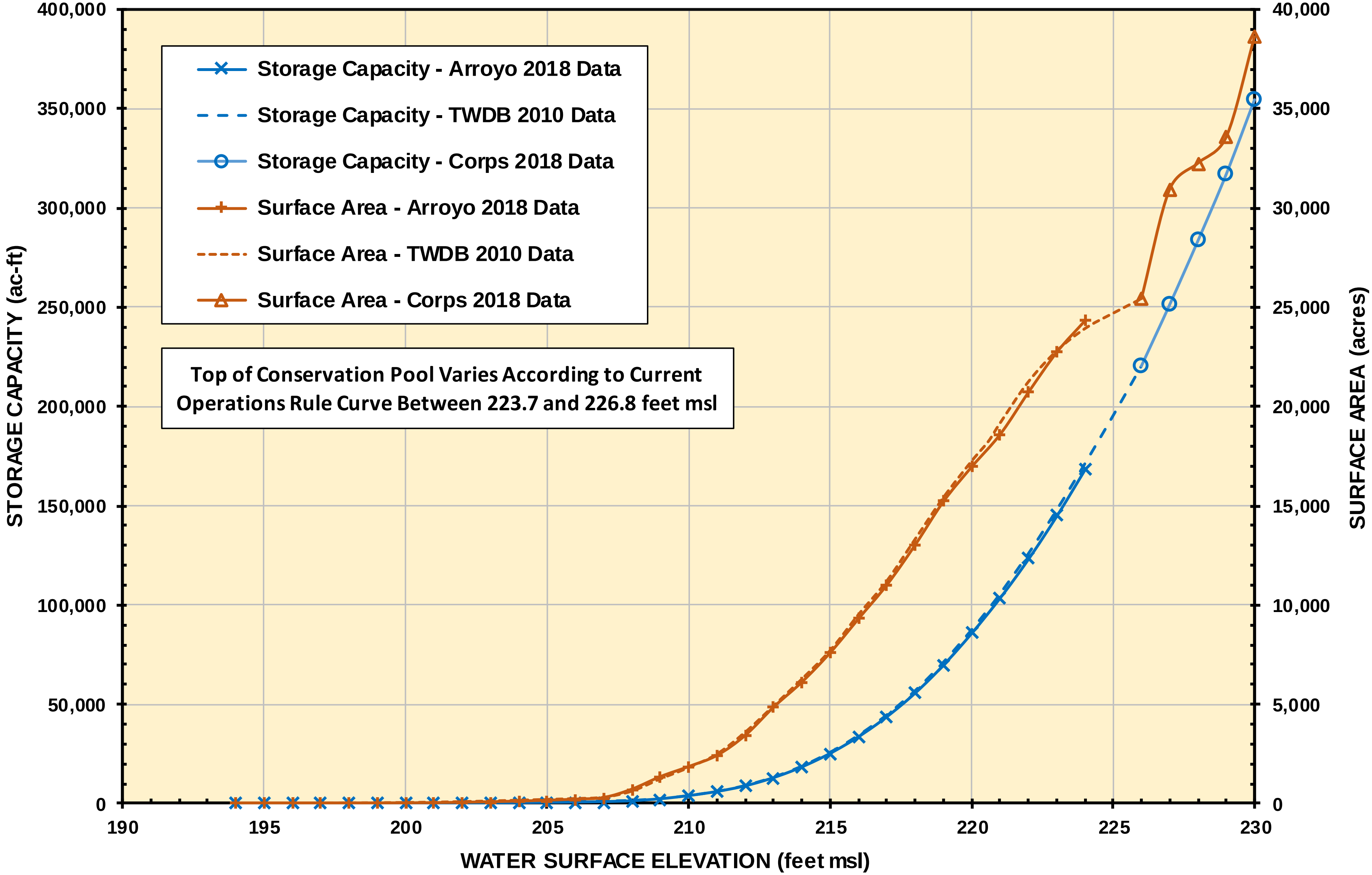


**Figure 2-3 Updated-Extended WAM Run 8 Elevation-Area-Capacity Curves for Wright Patman Lake from Arroyo 2018 Survey and from TWDB 2010 Survey with Corps Extension**



The Fort Worth District of the Corps of Engineers used the results from the 2005 and 2007 TWDB surveys and other information to develop extended elevation-area-capacity tables above the top of the conservation pool that currently are used by the Corps for reporting historical daily stage and storage data for the reservoir. These tables have been obtained from the Corps and have been used in the naturalized flow process for calculating monthly streamflow depletions (changes in storage and net evaporation losses) for Jim Chapman Lake for the 1997-2017 period. These elevation-area-capacity curves are plotted on the graph in Figure 2-4. Also shown on the graph are the elevation-area-capacity curves corresponding to the original as-built conditions for Jim Chapman Lake. These are the data used in the original Run 3 version of the Sulphur WAM, and they are also used in the updated-extended version of the Run 3 model.

For estimating 2020 storage condition for Jim Chapman Lake for use in the extended Run 8 version of the WAM, the same sedimentation rate used in the original 1999 WAM study has been applied. This value of 560 acre-feet of sediment per year was based on a sediment delivery rate of 1.17 acre-feet per square mile per year, which was obtained from the Corps' General Design Memorandum No. 1 for the Cooper Reservoir project. Application of the sedimentation rate of 560 acre-feet per year to the 13-year period from 2007 to 2020 produces a value of 7,250 acre-feet of sediment that has accumulated in the reservoir below the top of the conservation pool (440.0 feet msl) since 2007. Deducting this sediment volume from the 2007 conservation storage capacity of the reservoir produced a 2020 storage capacity of 291,680 acre-feet, and this conservation storage capacity was distributed over the depth of the reservoir proportional to the 2007 storage.

A similar procedure was applied to the obtain the 2020 surface area conditions for Jim Chapman Lake except the change in area from 2007 to 2020 was based on the incremental change that occurred between 1990, when the reservoir was last surveyed prior to the 2007 survey, and 2007. Over this 17-year period, the surface area of the reservoir decreased by 1,347 acres, or 17.2 acres per year, and this annual incremental change was applied to the 2007-2020 period to derive the 2020 surface area at the top of the conservation pool (16,928 acres). This 2020 surface area then was distributed over the depth of the reservoir proportional to the 2007 surface area distribution.

The 2020 surface area and storage capacity curves for Jim Chapman Lake are plotted on the graph in Figure 2-5 along with the corresponding curves based on the TWDB 2007 survey data. As shown, these curves extend only up to elevation 440.0 feet msl, the top of the conservation pool.

### 2.4.3 Lake Sulphur Springs

The only elevation-area-capacity data available for Lake Sulphur Springs are those from the original survey done around the time the reservoir was constructed in the early 1970s. These data were obtained during the development of the original Sulphur WAM, and, at that time, they were extended from their original 1973 condition to the year-2000 condition based on a sediment delivery rate of 0.3 acre-feet per square mile of drainage area per year, or 16 acre-feet per year.

**Figure 2-4 Elevation-Area-Capacity Curves for Jim Chapman Lake from Original 1990 Survey and from 2018 Corps of Engineers Fort Worth District**

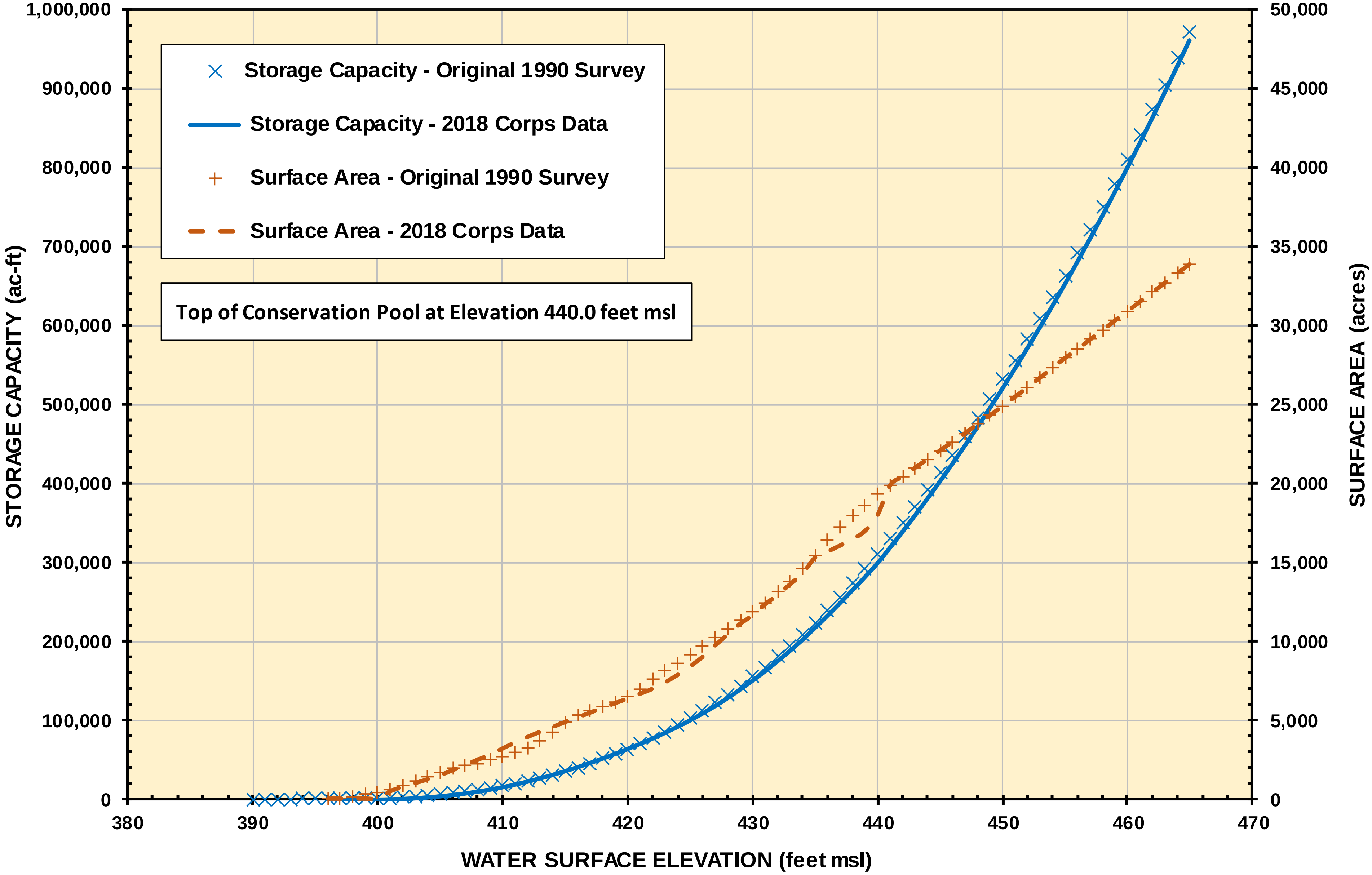
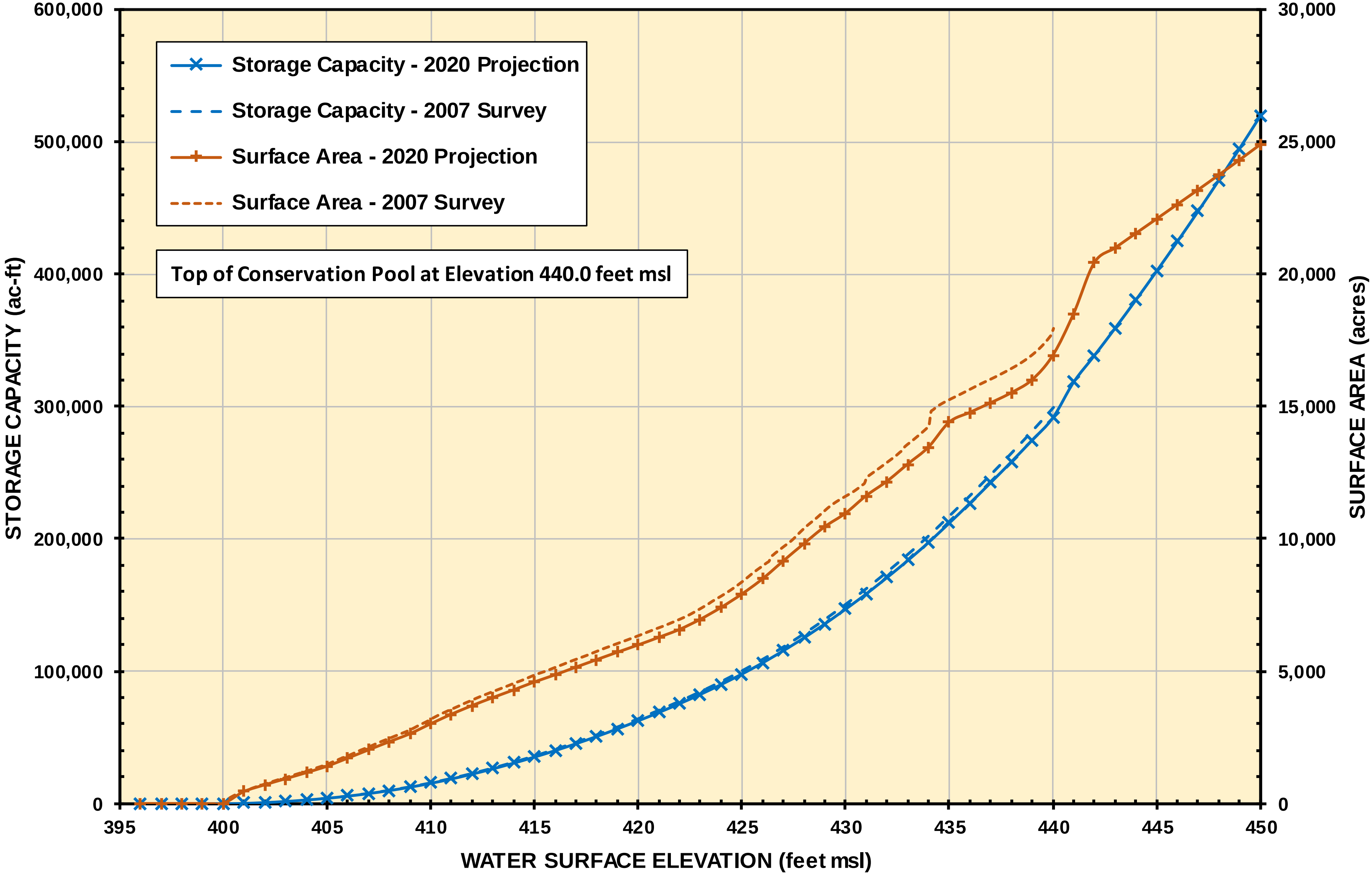


**Figure 2-5 Updated-Extended WAM Run 8 Elevation-Area-Capacity Curves for Jim Chapman Lake for Projected 2020 Conditions Compared to TWDB 2007 Survey**



This sediment delivery rate was considered reasonable based on information for other reservoirs in the Blackland Prairies physiographical region where Lake Sulphur Springs is located. Over the 27-year period from 1973 to 2000, the sedimentation rate of 16 acre-feet per year results in a reduction in the conservation storage capacity of Lake Sulphur Springs of only 432 acre-feet. With this adjustment, the projected year-2000 elevation-area-capacity curves are not appreciably different from the original 1973 curves. Therefore, in this study, the year-2000 elevation-area-capacity curves have been considered adequate and sufficiently representative of 1997-2017 reservoir conditions for purposes of determining the historical streamflow depletions for Lake Sulphur Springs for the streamflow naturalization process.

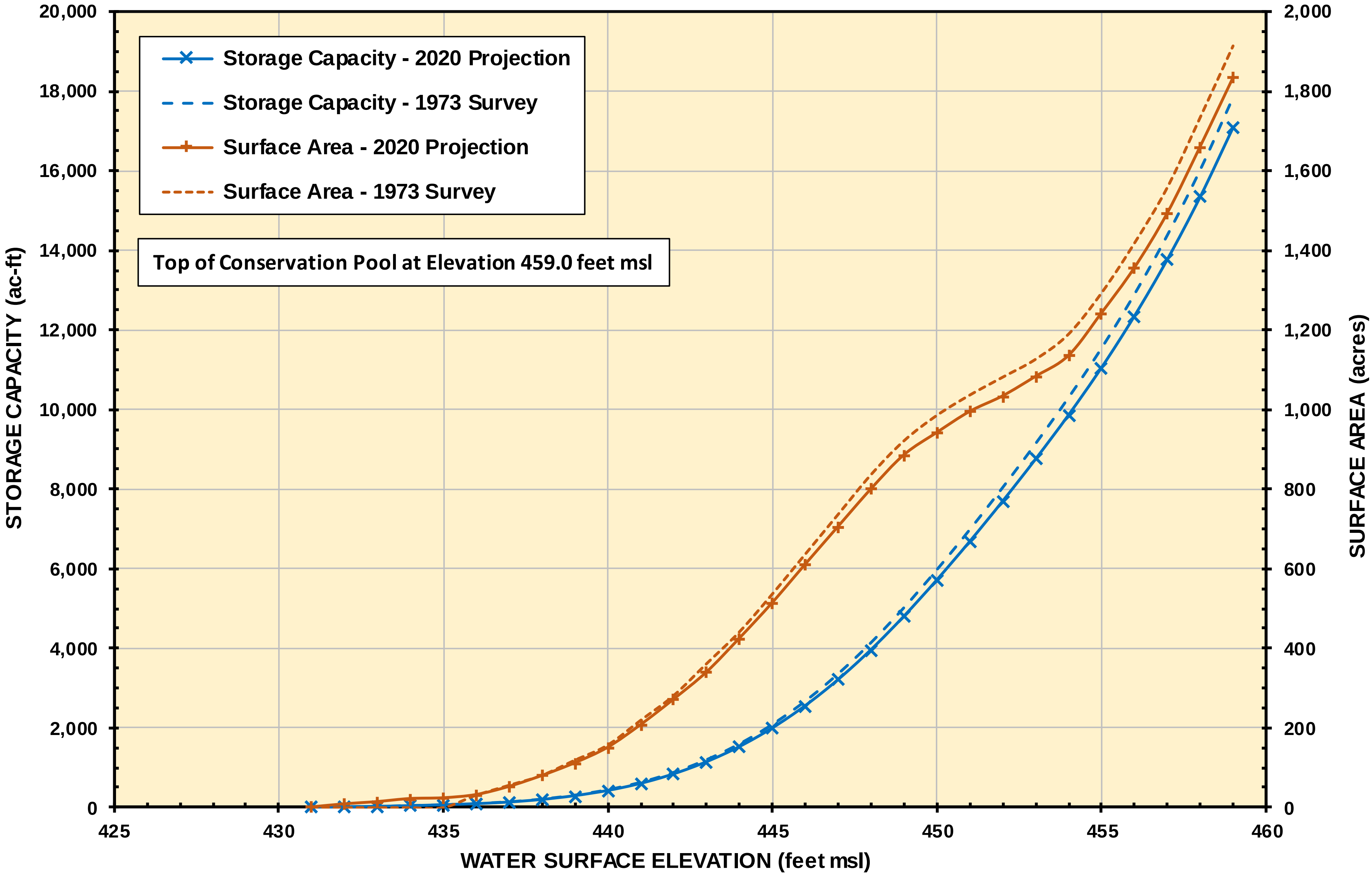
For estimating the 2020 storage condition for Lake Sulphur Springs for use in the updated-extended Run 8 version of the WAM, the same sedimentation rate used for determining the year-2000 storage condition has been applied. This value has been applied to the 47-year period from 1973 to 2020 to estimate the total volume of sediment that has accumulated in the reservoir below the top of the conservation pool (459.0 feet msl). This additional sediment volume (752 acre-feet) then was deducted from the 1973 conservation storage capacity of the reservoir, and the resulting conservation storage capacity (17,086 acre-feet) was distributed over the depth of the conservation pool proportional to the 1973 storage distribution. Values of the surface area of the reservoir over its depth then were calculated based on the incremental change in storage volume between successive increments of water surface elevation, which produced 1,833 acres at the top of the conservation pool. The 2020 surface area and storage capacity curves for Lake Sulphur Springs that have been used in the updated-extended Run 8 version of the WAM are plotted on the graph in Figure 2-6 along with the corresponding curves from the original 1973 survey which are used in the Run 3 version of the WAM. These curves do not deviate appreciably due to the relatively low sedimentation rate.

### 2.4.4 Big Creek Reservoir

Based on information provided by the City of Cooper, no volumetric surveys of the Big Creek Reservoir have been conducted since the original survey when the reservoir was impounded in 1987; consequently, the projected year-2000 elevation-area-capacity curves developed during the original 1999 WAM study have been adopted for this study as being representative of 1997-2017 conditions for purposes of determining historical streamflow depletions for Big Creek Reservoir. These year-2000 data were developed using the same sediment delivery rate as was applied for Jim Chapman Lake to develop its year-2000 elevation-area-capacity curves. This is considered reasonable because of the close proximity of the two reservoirs.

For estimating the 2020 storage condition for Big Creek Lake for use in the updated-extended Run 8 version of the WAM, the same sedimentation rate used for determining the year-2000 storage condition has been applied to the 33-year period from 1987 to 2020 to estimate the additional volume of sediment that has accumulated in the reservoir. This additional volume of sediment

**Figure 2-6 Updated-Extended WAM Run 8 Elevation-Area-Capacity Curves for Lake Sulphur Springs for Projected 2020 Conditions Compared to Original 1973 Survey**



(462 acre-feet) then was deducted from the 1987 conservation storage capacity of the reservoir, and the resulting conservation storage capacity (4,428 acre-feet) was distributed over the depth of the conservation pool proportional to the 1987 storage distribution. Values of the surface area of the reservoir at specified elevations then were calculated based on ratios of the 1987 area at different depths to the maximum area multiplied times the 2020 maximum surface area of the reservoir. The 2020 maximum area was determined by adjusting the 1987 area by the ratio of the 2020-to-1987 maximum storage amounts. Values of the storage capacity and surface area above the conservation pool were set equal to the original 1987 surveyed values. The 2020 surface area and storage capacity curves for Big Creek Lake that have been used in the updated-extended Run 8 version of the WAM are plotted on the graph in Figure 2-7 along with the corresponding curves from the original 1987 survey which are used in the Run 3 version of the WAM. As was the case for Jim Chapman Lake and Lake Sulphur Springs, these curves do not deviate appreciably due to the relatively low sedimentation rate.

### 2.4.5 Lake Ralph Hall

Lake Ralph Hall is the newest major reservoir authorized for the Sulphur River Basin. This project is being implemented by the Upper Trinity Regional Water District (UTRWD) in Fannin County on the North Sulphur River, with construction scheduled to be completed by 2024. The reservoir is authorized under Permit No. 5821 to impound 180,000 acre-feet of water, and the total authorized diversion from the reservoir is 45,000 acre-feet per year. Water from the project will be used to meet local needs in the Sulphur River Basin and the demands of water users within the service area of the UTRWD in the Dallas and Fort Worth metroplex in the Trinity River Basin. Diversions from Lake Ralph Hall will be conveyed via a new pipeline from the reservoir to Jim Chapman Lake, and then transferred to the UTRWD’s service area through the existing City of Irving pipeline.

Elevation-area-capacity data for Lake Ralph Hall have been developed by the UTRWD based on surveys of the reservoir site, and these curves are presented on the graph in Figure 2-8. The reservoir is represented in the updated-extended Run 3 version of the WAM with these data. Once Lake Ralph Hall is constructed and in operation, it will be added to the current-conditions Run 8 version of the WAM.

### 2.4.6 Other Reservoirs

For other reservoirs considered in the naturalized flow process, i.e., those with conservation storage capacities greater than 1,000 acre-feet (see Table 2-3 on page 34), neither recent nor updated elevation-area-capacity tables are available. Therefore, for Lake Romal, Langford Creek Lake, and the multiple E. P. Land and Cattle reservoirs, the same elevation-area-capacity data used in the existing Run 8 version of the Sulphur WAM corresponding to current conditions (i.e., year

## Figure 2-7 Updated-Extended WAM Run 8 Elevation-Area-Capacity Curves for Big Creek Lake for Projected 2020 Conditions Compared to Original 1987 Survey

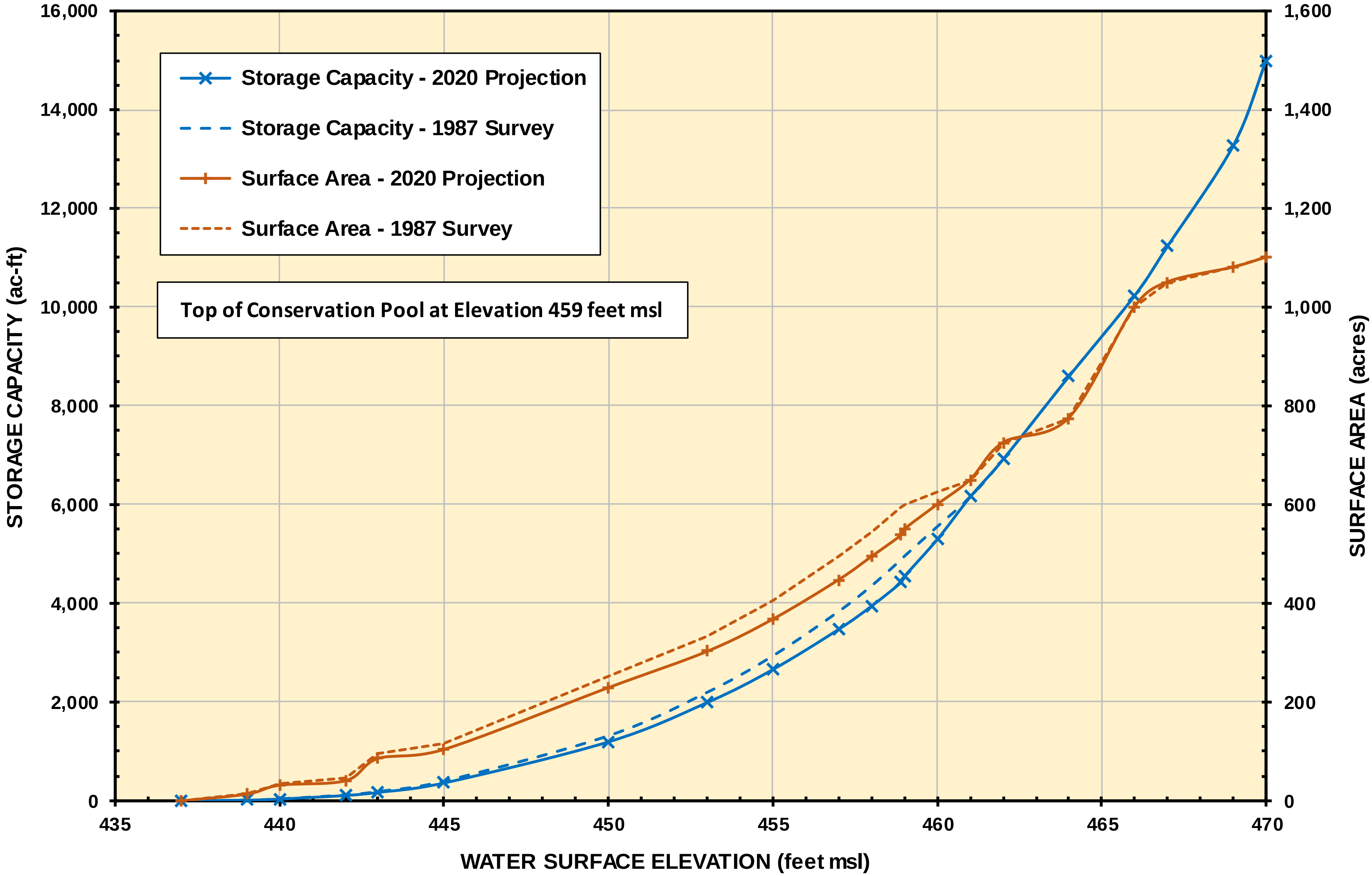
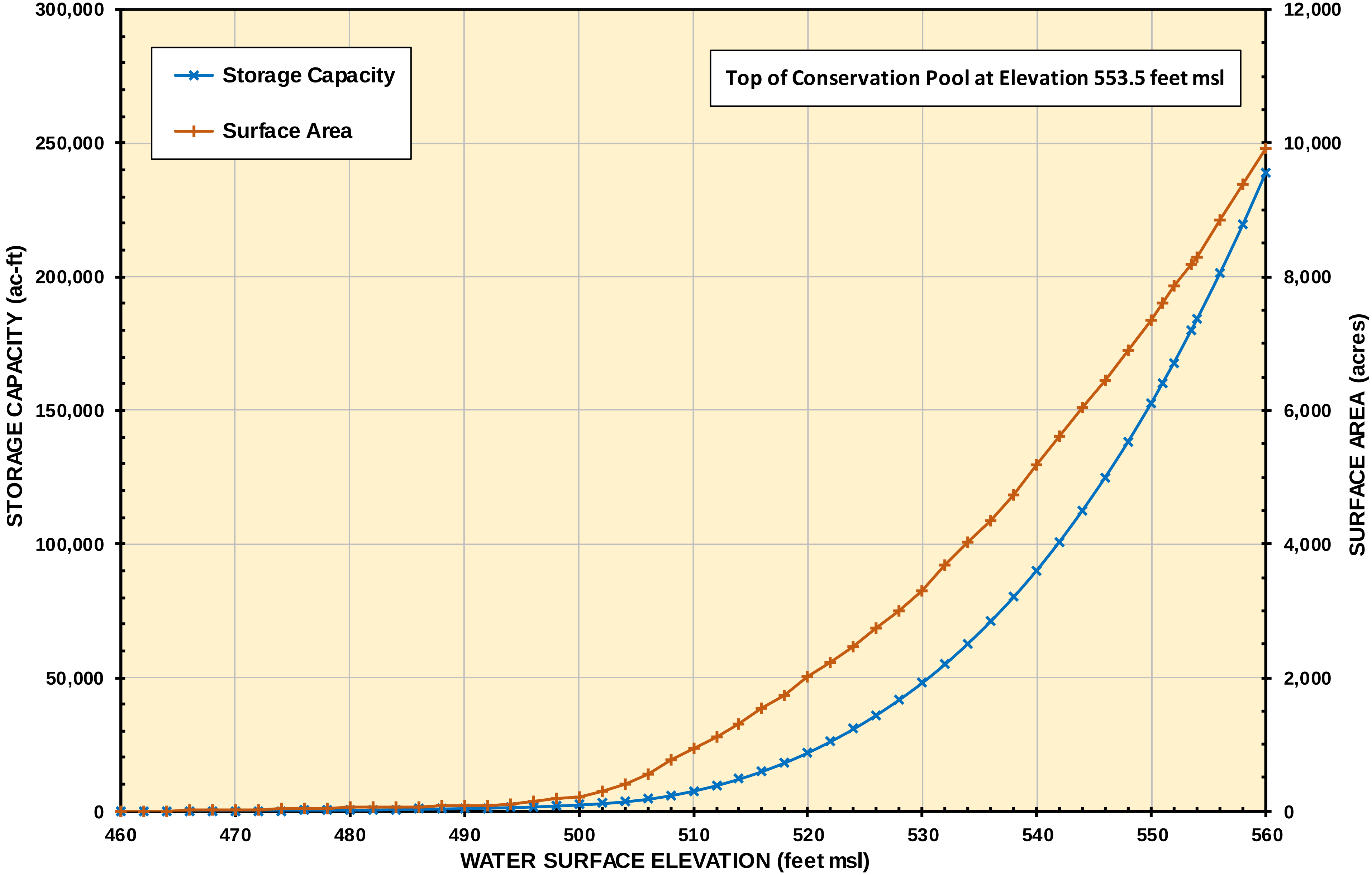


**Figure 2-8 Current Elevation-Area-Capacity Curves for Lake Ralph Hall**



2000) have been used in this study for the analysis of 1997-2017 streamflow depletions. For Langford Creek Lake, these data were based on actual elevation-area-capacity measurements at the time of reservoir construction (1966), adjusted for sedimentation to 2000. For Lake Romal and the multiple E. P. Land and Cattle reservoirs, the previous Run 8 elevation-area-capacity data were based on the standardized equation that was developed as part of the previous 1999 Sulphur WAM study for small reservoirs with known maximum storage capacities but without specific measured elevation-area-capacity data for smaller capacities. This equation, which was derived from analyzing actual data for several small reservoirs in the Sulphur Basin, including Langford Creek Lake, is expressed as follows:

$$\text{Area} = a\,(\text{Capacity})^{b} + c$$

where: $a = 0.8136$

$b = 0.7505$

$c = 0$

Current elevation-area-capacity data have not been found for the two TexAmericas reservoirs authorized under Permit No. 5873; however, elevation-area-capacity curves dated 1941 for the Caney Creek Reservoir were provided by Riverbend. These curves were considered to be too old to reasonably represent recent reservoir conditions, but comparison of this original data with the standardized area-capacity curve based on the above equation indicates that they are similar in shape. Therefore, for purposes of this study, this standardized equation has been used, with maximum authorized storage capacities, to derive applicable area-capacity tables for the TexAmericas reservoirs. The area-capacity relationships for Langford Creek Lake based on the original Run 8 data and for Lake Romal, the multiple E. P. Land and Cattle reservoirs, and the TexAmericas reservoirs based on the standardized equation are plotted on the graph in Figure 2-9. These curves reflect the area-capacity data that have been used both for calculating reservoir depletions for the naturalized flow analysis and for representing these reservoirs in the updated-extended Run 3 and Run 8 versions of the WAM.

## 2.5 Historical Reservoir Evaporation and Rainfall Data

Monthly values of historical reservoir gross evaporation and rainfall amounts, expressed in inches, have been derived by the Texas Water Development Board for all of Texas based on available evaporation and rainfall data. These historical gross evaporation and rainfall values are provided at the center of each one-degree quadrangle covering the state. The boundaries of these one-degree quadrangles covering the Sulphur River Basin are shown on a map in Figure 2-10. Monthly gross evaporation and rainfall data for the 1997-2017 period for these quadrangles have been obtained from the TWDB web site and used in this study for the calculation of reservoir inflows and the analysis of reservoir depletions. The assignment of these data by the TWDB quadrangle numbers to individual reservoirs is indicated in Table 2-3 in Section 2.6. As shown, for some reservoirs, the average of the monthly values for two adjacent quadrangles has been used.

**Figure 2-9 Area-Capacity Relationships Used for Other Small Reservoirs**

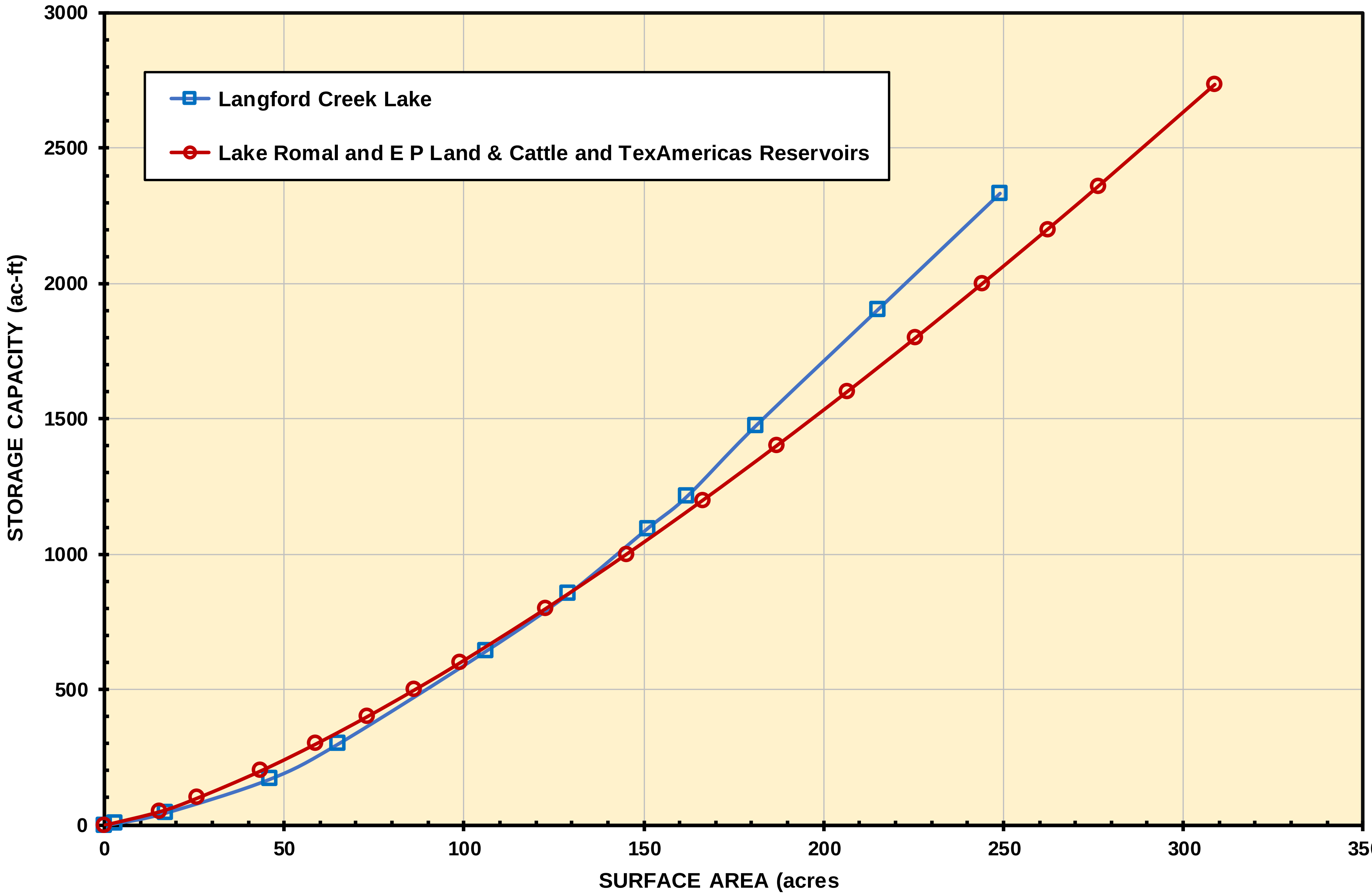
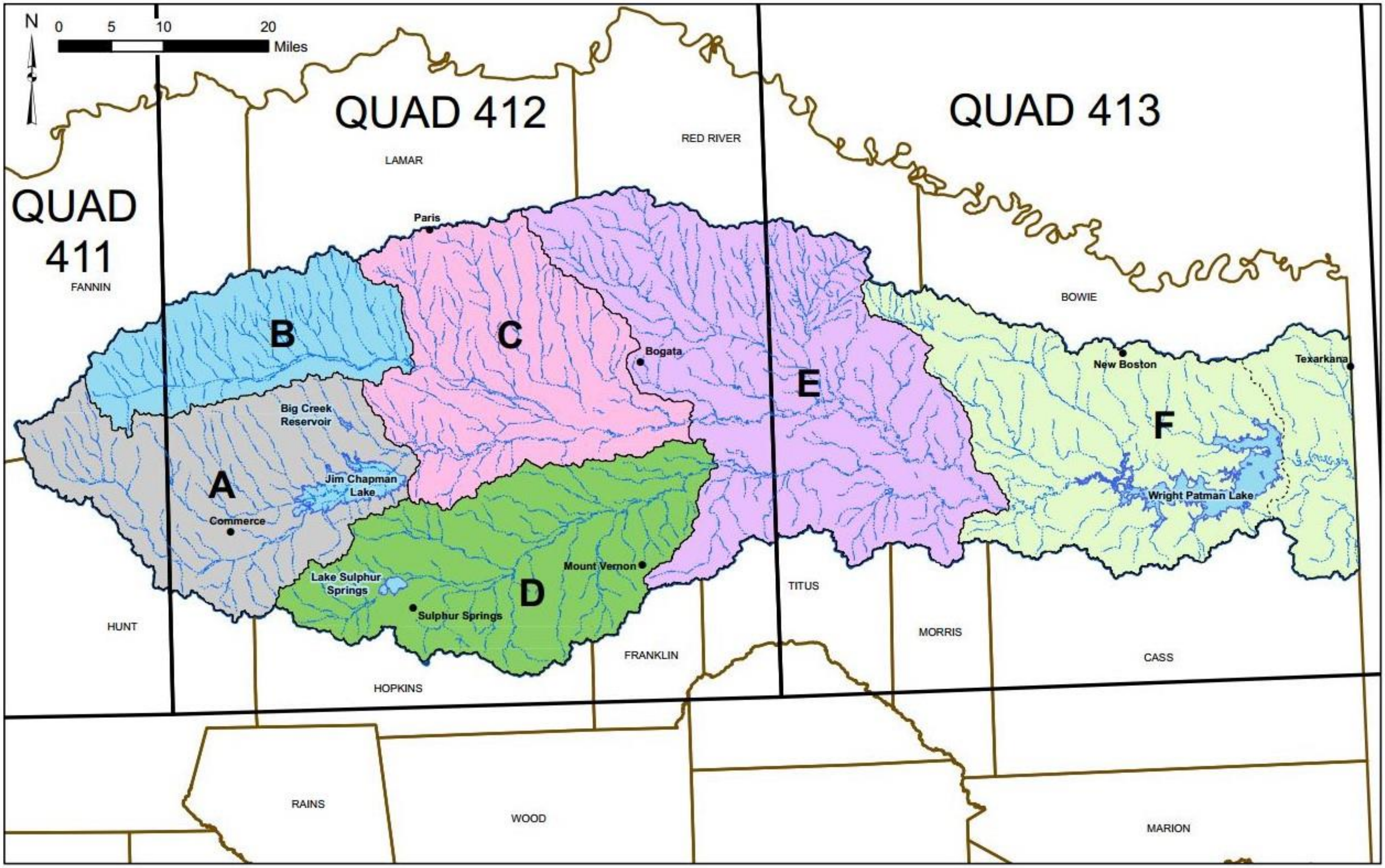


**Figure 2-10 Quadrangle Delineations for TWDB Evaporation and Rainfall Data**



## 2.6 Historical Reservoir Streamflow Depletions

As described above in Section 2.1, the general equation for naturalizing streamflows requires adjustments for the effects of upstream reservoirs with regard to their historical reduction of streamflows, often referred to as reservoir streamflow depletions. In the standard naturalized flow equation, these effects are represented by the monthly changes in the historical storage of the reservoirs and their monthly net evaporation losses.

For purposes of the 1997-2017 naturalized flow process for the Sulphur Basin, only reservoirs with a conservation storage capacity greater than 1,000 acre-feet have been considered. The reservoirs that meet this criterion in the Sulphur Basin are listed along with pertinent descriptive information in Table 2-3, and they are shown on the map in Figure 2-11. Parameters presented in Table 2-3 include those that are required for the calculations that are fundamental to the streamflow naturalization process as described below. The code included in Column 6 identifies for each of the reservoirs the approach used in the flow naturalization process.

It should be noted that in the original development of naturalized flows for the Sulphur WAM in 1999, all reservoirs with storage capacities greater than 200 acre-feet were accounted for with respect to streamflow depletions in the streamflow naturalization process. Because of the small magnitude of the streamflow depletions for these smaller reservoirs, these adjustments were relatively insignificant compared to those for the larger reservoirs, as well as to the overall magnitude of the naturalized flows. For this reason, as stated above, only reservoirs with storage capacities greater than 1,000 acre-feet have been considered in this current analysis of naturalized flows. It is apparent from the comparisons of the previously derived reservoir streamflow depletions for 1940-1996 to those developed in this study for 1997-2017 that the higher limit on reservoir storage capacity does not make any appreciable difference.

For the Sulphur Basin, complete records of 1997-2017 historical monthly reservoir stage and storage are available from the Corps of Engineers Fort Worth District for Wright Patman and Jim Patman Lakes. For Lake Sulphur Springs, these records are available from the U.S. Geological Survey (USGS) beginning in March 1999 and extending through 2017. All of these data were obtained directly from the agency web sites and organized for use in the flow naturalization process. As described previously in Section 2.3, streamflow depletions have not been calculated for Wright Patman Lake for 1997-2017; instead, historical inflows have been calculated directly using water balance analyses with storage data from the Corps and corresponding monthly values of diversions, releases, wastewater discharges, and net evaporation losses.

For Jim Chapman Lake, the 1997-2017 historical monthly streamflow depletions have been calculated as the sum of the historical monthly changes in storage and the net evaporation losses based on the actual historical data. The monthly net evaporation losses were calculated by multiplying monthly values of the reservoir surface area times the corresponding Adjusted Net

**Table 2-3 Descriptive Information for Reservoirs Accounted for in 1997-2017 Streamflow Naturalization Process**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WATER RIGHT NO. [1] | RESERVOIR NAME | OWNER'S NAME | AUTH. CAPACITY (ac-ft) | DRAIN. AREA [2] (sq mi) | NAT FLOW CODE [3] | GAGE USED FOR INFLOW | | | | TWDB EVAP/RAIN QUAD(S) | E-A-C TABLE SOURCE [4] |
| | | | | | | | USGS NO. | GAGE NAME | DRAIN. AREA [2] | | | |
| | | | | | | | | | Sq Mi | Ratio | | |
| (1) | C 4836 | Wright Patman Lake | Corps of Engineers | 386,900 | 3,413 | INFLOW | None | None | n/a | None | 413 | NONE |
| (2) | [5] | Jim Chapman Lake | Corps of Engineers | 310,000 | 483 | DATA | None | None | n/a | None | Avg 411,412 | COE 2018 |
| (3) | C 4811 [6] | Lake Sulphur Springs | City of Sulphur Springs | 17,838 | 70 | CALC | 7343500 | White Oak Ck nr Talco | 467 [7] | 0.1504 | 412 | WAM 2000 |
| (4) | C 4811 [6] | Lake Sulphur Springs | City of Sulphur Springs | 17,838 | 70 | DATA | None | None | n/a | None | 412 | WAM 2000 |
| (5) | P 4060 | Big Creek Reservoir | City of Cooper | 4,890 | 11.8 | CALC | 7343000 | N Sulphur Rv nr Cooper | 305 | 0.3870 | 412 | WAM 2000 |
| (6) | C 4819 | Lake Romal | WOCR Holding LLC | 2,360 | 5.9 | CALC | 7343500 | White Oak Ck nr Talco | 467 [7] | 0.0126 | 412 | WAM 2019 |
| (7) | C 4809 | Langford Creek Lake | Red River Cty WCID 1 | 1,225 | 2.9 | CALC | 7343500 | Patman Deduced Inflow | 1,521 [8] | 0.00190 | Avg 412,413 | WAM 2000 |
| (8) | C 4805 | E.P. Land & Cattle #2,3 & 4 | E.P. Land & Cattle Co. | 2,063 | 0.63 | CALC | 7343500 | White Oak Ck nr Talco | 1,521 [8] | 0.000414 | Avg 412,413 | WAM 2000 |
| (9) | P 5873 | Reservoir No. 1 (Caney Ck) | TexAmericas Center | 1,340 | 7.1 | CALC | n/a | Patman Deduced Inflow | 1,521 [8] | 0.00467 | 413 | WAM 2019 |
| (10) | P 5873 | Reservoir No. 2 (Elliot Ck) | TexAmericas Center | 2,734 | 8.5 | CALC | n/a | Patman Deduced Inflow | 1,521 [8] | 0.00561 | 413 | WAM 2019 |

Notes:

[1] C = Certificate of Adjudication and P = Permit

[2] Drainage areas are from Sulphur WAM data files, except for Wright Patman Lake which is GIS measured.

[3] INFLOW means that historical inflows to the reservoir were calculated (deduced) with water balance analyses and then naturalized using standard procedures. No E-A-C data for the reservoir were required.
DATA means that historical stage and storage data are available for the reservoir and have been used for directly calculating historical reservoir depletions.
CALC means that historical stage and storage values are not available for the reservoir and were simulated with water balance analyses and then used to calculate the historical reservoir depletions.

[4] COE 2018 refers to elevation-area-capacity data currently used and provided by the Corps of Engineers Fort Worth District in 2018.
WAM 2000 refers to year-2000 elevation-area-capacity data that were projected during the original development of the Sulphur Basin WAM in 1999.
WAM 2019 refers to elevation-area-capacity data included in the TCEQ's most recent 2019 version of the Sulphur Basin WAM.

[5] Multiple entities own water rights for storage capacity in Jim Chapman Lake as follows:*

| | |
|---|---|
| C 4797 | 81,470 ac-ft |
| C 4798 | 114,265 ac-ft |
| C 4799 | 114,265 ac-ft |
| Total | 310,000 ac-ft |

* Proportionate shares of the dedicated sediment reserve of 37,000 ac-ft are included.

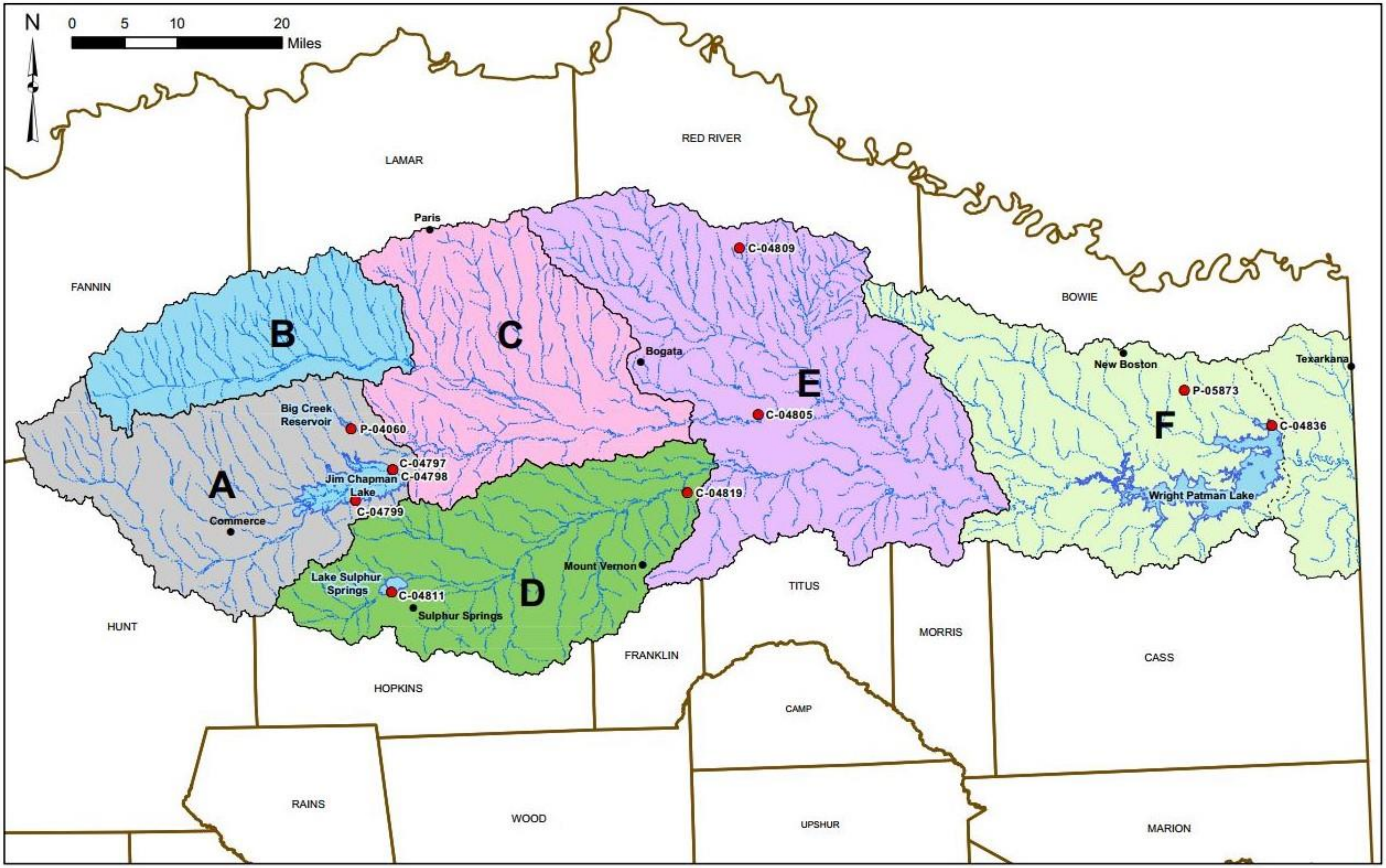
[6] For January 1997 - February 1999, streamflow depletions for Lake Sulphur Springs were calculated using the CALC method because historical data for reservoir storage were not available, whereas the DATA method was used for March 1999 - December 2017 when historical storage data were available.

[7] This drainage area represents the incremental drainage area from Gage No. 7343500, White Oak Creek near Talco, upstream to Lake Sulphur Springs Dam.

[8] This drainage area represents the incremental drainage area from Wright Patman Lake Dam upstream to Gage No. 7343200, Sulphur River near Talco, and to Gage No. 7343500, White Oak Creek near Talco.

**Figure 2-11 Reservoirs with Streamflow Depletions Accounted for in 1997-2017 Streamflow Naturalization Process**

**(Water right numbers are labeled at each reservoir location with "C" for Certificate of Adjudication and "P" for Permit)**



Reservoir Evaporation, as defined in Section 2.1, derived from historical monthly evaporation and rainfall data from the Texas Water Development Board (see Section 2.5 and Table 2-3 for quadrant delineations). Historical monthly values of the surface area of the reservoir were determined for the 1997-2017 period using the reported data for monthly reservoir stage and the Corps' stage-area relationship as presented in Section 2.4.2. The result of this process was a complete set of historical monthly streamflow depletions for Jim Patman Lake for the entire 1997-2017 period.

It should be noted that during the course of developing the streamflow depletions for Jim Chapman Lake, a discrepancy was observed regarding how these calculations were made during the original development of the WAM. It appears that the depletions were not correctly accounted for when the total naturalized flows for Subwatershed C were calculated. Since this only occurred during the time when Jim Chapman Lake was in existence, corrections to the original naturalized flows only needed to be made for the period from October 1991 through December 1996. In this current study, the correct adjustments for these streamflow depletions for Jim Chapman Lake have been made directly to the original naturalized flows for Subwatershed C, with these revised naturalized flows then reflected in the final naturalized flow values for Subwatersheds E and F.

The same procedure described above for Jim Chapman Lake also has been used for calculating Lake Sulphur Springs reservoir depletions for the period from March 1999 through December 2017 when historical stage and storage data were available for the reservoir from the U. S. Geological Survey. For the period prior to March 1999 when no data were available for Lake Sulphur Springs and for the entire 1997-2017 period for those reservoirs without any data (designated by CALC in Column 6 of Table 2-3), the monthly storage changes and monthly net evaporation losses have been simulated using a water balance Excel spreadsheet model. For each of these reservoirs, the spreadsheet water balance model was applied to perform a time-series simulation (using monthly time steps) of reservoir storage changes using the following revised form of the same basic equation described previously for simulating the historical inflows to Wright Patman Lake in Section 2.3.

$$\text{Change-in-Storage} = (ST_i - ST_{i-1}) = QI_i - (EV_i * AR_i) + (PE_i * AR_i) - DV_i - RL_i$$

And for the corresponding net evaporation loss:

$$\text{Net Evaporation Loss} = (EV_i * AR_i) - (PE_i * AR_i)$$

For these reservoir simulations, monthly inflows to the reservoirs were estimated from historical monthly flow records for streamflow gages considered to exhibit generally similar watershed and streamflow characteristics. The gage used for estimating inflows to each reservoir is identified in Table 2-3. The ratio of the drainage area of each reservoir to the drainage area of its assigned streamflow gage has been used to translate the monthly gaged streamflows to each reservoir site. Monthly TWDB evaporation and rainfall data were determined for each reservoir according to the appropriate quadrant assignments shown in Table 2-3 (see Figure 2-10 for quadrant delineations), and the Effective Rainfall Factor of 0.15 was applied to the monthly rainfall amounts to derive Effective Rainfall. During the simulation process for each of these reservoirs, the monthly surface area was determined based on the appropriate area-capacity relationship presented in Section 2.4.

It should be noted that historical streamflow depletions by the two reservoirs owned by TexAmericas Center, referred to as Reservoir No. 1 (Caney Creek) and Reservoir No. 2 (Elliot Creek) in Table 2-3, were not accounted for in the streamflow naturalization process during the original development of the Sulphur WAM. At that time, these reservoirs, both of which are located in Subwatershed F above Wright Patman Lake, were not authorized by an existing water right, and therefore, their effects on naturalized flows were not accounted for. However, since then, they have been authorized under Permit No. 5873 with diversions for municipal use at a priority date of June 16, 2005. Furthermore, based on an elevation-area-capacity chart for one of these reservoirs that was dated December 1941 (as provided by Riverbend), it appears that these reservoirs have been in existence since the early 1940s. Therefore, as part of this current effort to extend the naturalized flows for the WAM to include the 1997-2017 period, the historical streamflow depletions due to these two reservoirs prior to 1997 also have been determined and accounted for in the original naturalized flows. For this purpose, monthly streamflow depletions for both reservoirs have been calculated using the water balance Excel spreadsheet model beginning in 1942, and corresponding adjustments in the 1942-1996 original monthly naturalized flows for Subwatershed F have been made to account for the effects of these streamflow depletions. It should be noted that these adjustments have not been incorporated into the calculations in the original naturalized flow workbooks; instead, they have been applied directly to the original monthly values of the Subwatershed F naturalized flows.

Annual reservoir streamflow depletions for the 1997-2017 period are plotted on bar charts along with previously determined annual depletions for 1940-1996 (as adjusted herein) in Figures 2-12 through 2-17 for Subwatersheds A through F, respectively. The streamflow depletions for Subwatershed F represent only those for reservoirs located upstream of Wright Patman Lake, since this is the only portion of the entire subwatershed that was considered when the deduced inflows to the reservoir were naturalized for the 1997-2017 period.

As shown by the bars on these plots, the magnitude of the streamflow depletions varies significantly from year to year within subwatersheds as reservoir behavior is influenced by changing climatic and hydrologic conditions and, as expected, it varies among the subwatersheds in accordance with relative reservoir sizes and capacities. Subwatershed A has by far the largest values of reservoir depletions reflecting the significant effects on streamflows of Jim Chapman Lake, which was completed on the South Sulphur River in 1991. For the 1997-2017 period, no reservoir depletions are shown for Subwatersheds B and C because there are no reservoirs in these subwatersheds that meet the storage capacity criterion of greater than 1,000 acre-feet that has been adopted for use in this study for reservoir depletions. The depletions for reservoirs in Subwatersheds D and E for the 1997-2017 period generally are consistent with those originally determined for the earlier 1940-1996 period.

**Figure 2-12 Historical Annual Reservoir Streamflow Depletions for Subwatershed A**

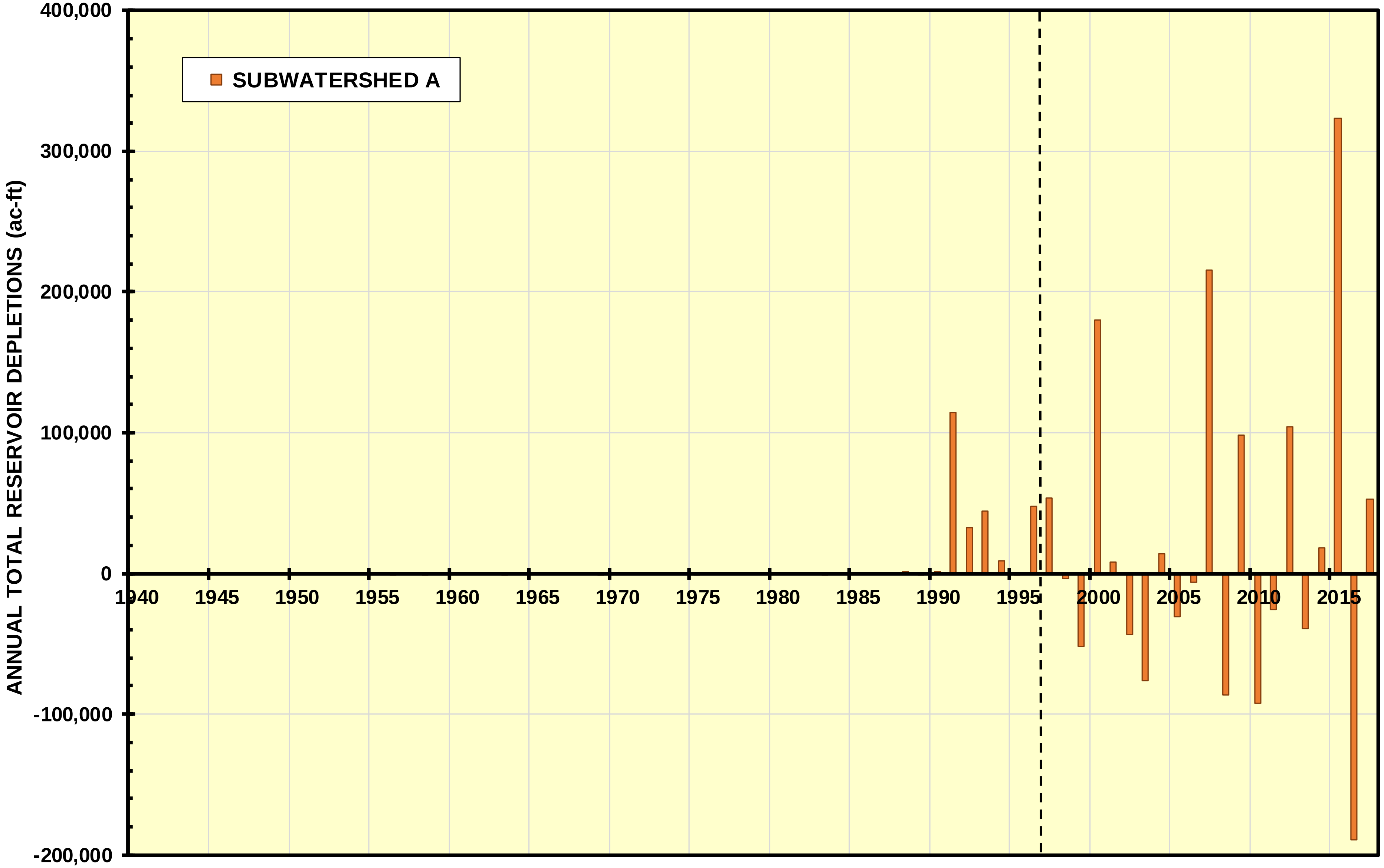


**Figure 2-13 Historical Annual Reservoir Streamflow Depletions for Subwatershed B**

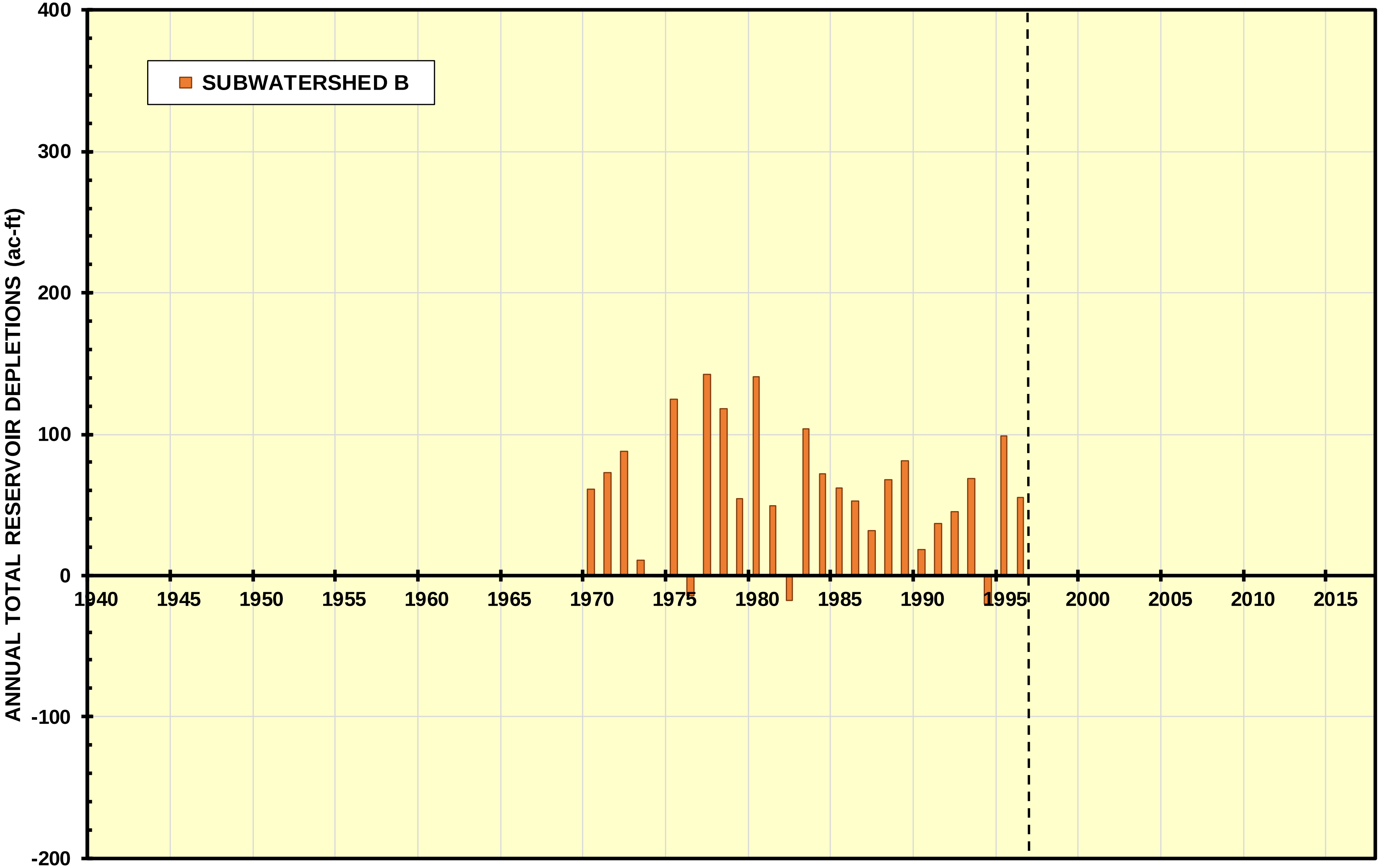


**Figure 2-14 Historical Annual Reservoir Streamflow Depletions for Subwatershed C**

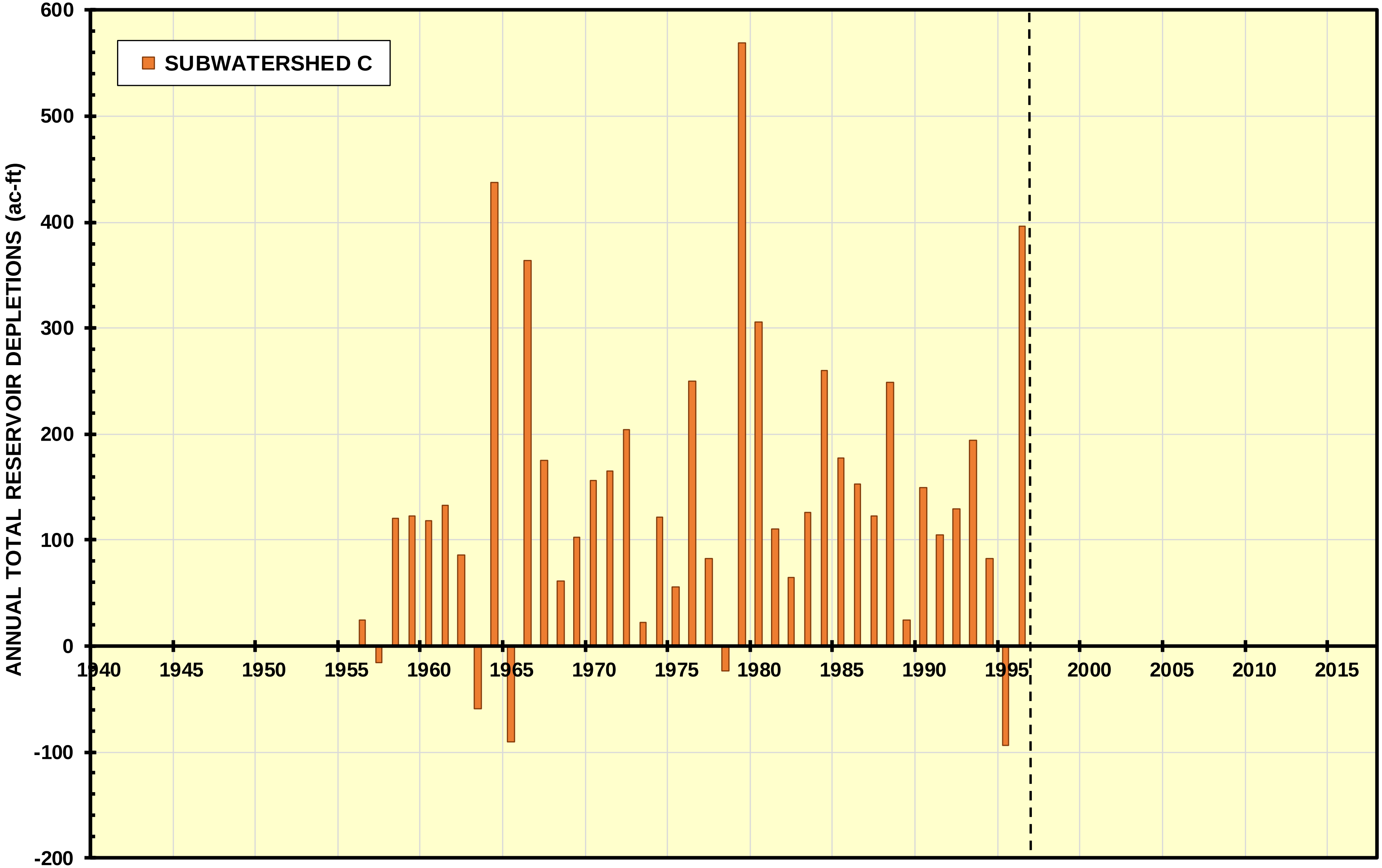


**Figure 2-15 Historical Annual Reservoir Streamflow Depletions for Subwatershed D**

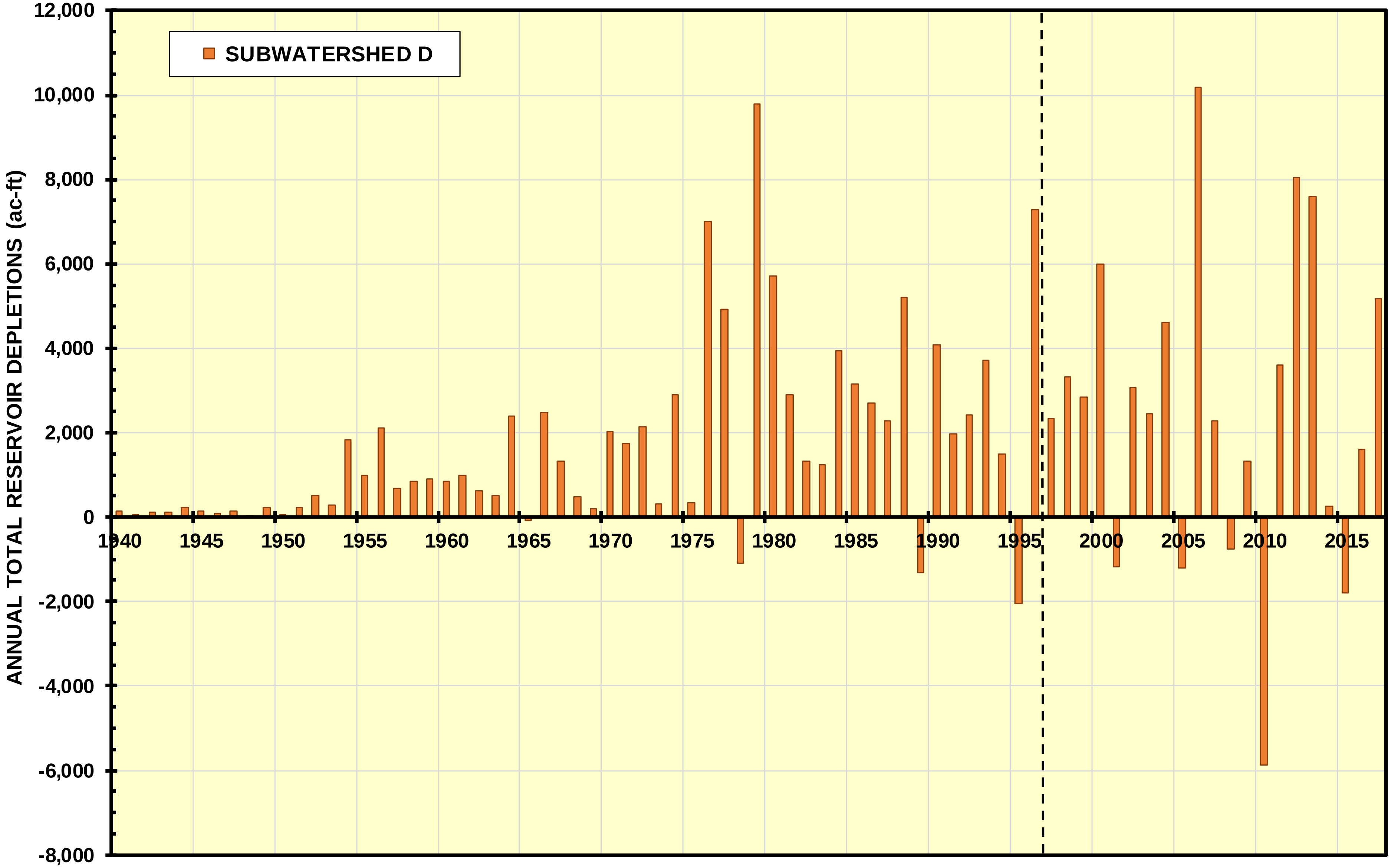


**Figure 2-16 Historical Annual Reservoir Streamflow Depletions for Subwatershed E**

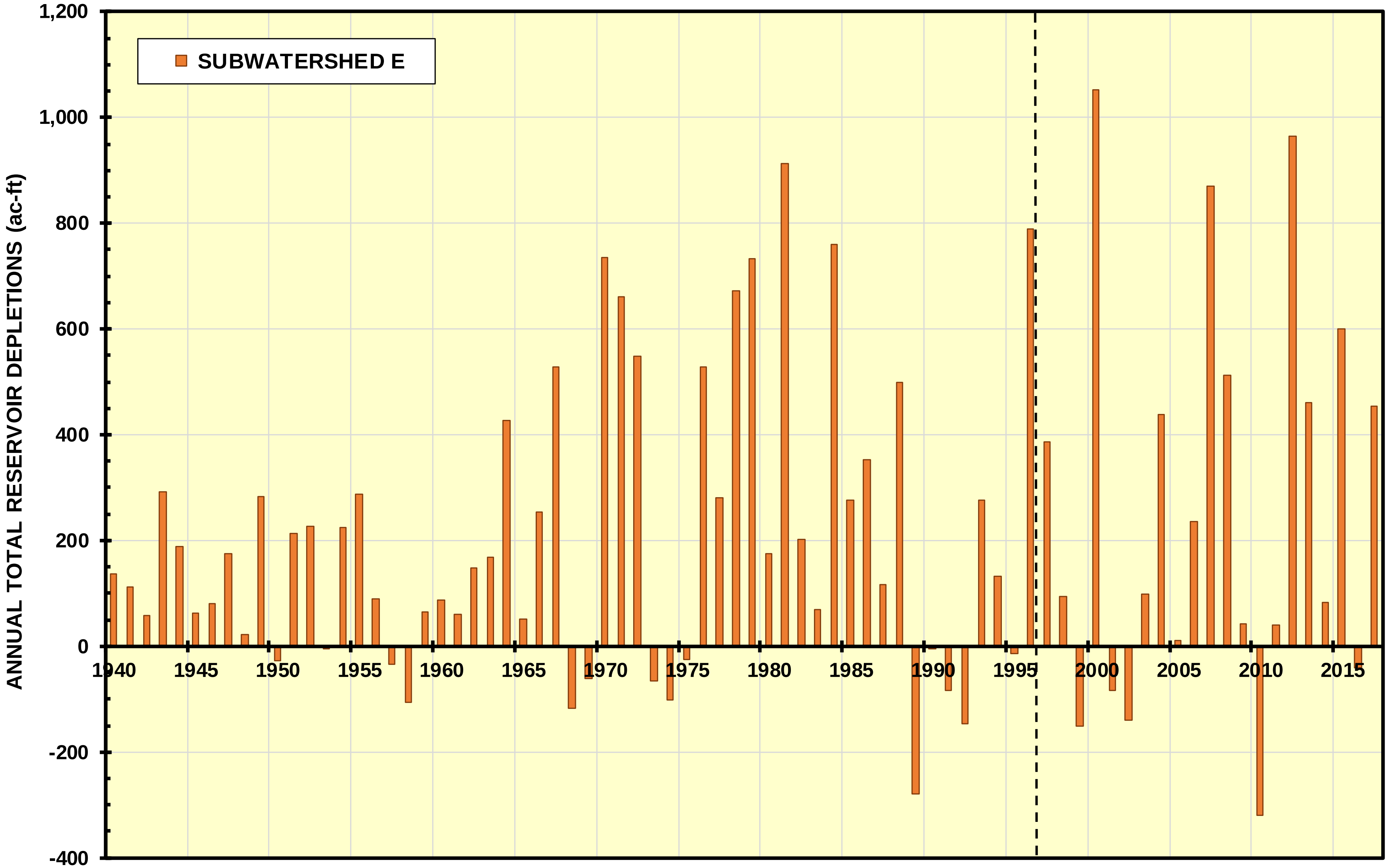
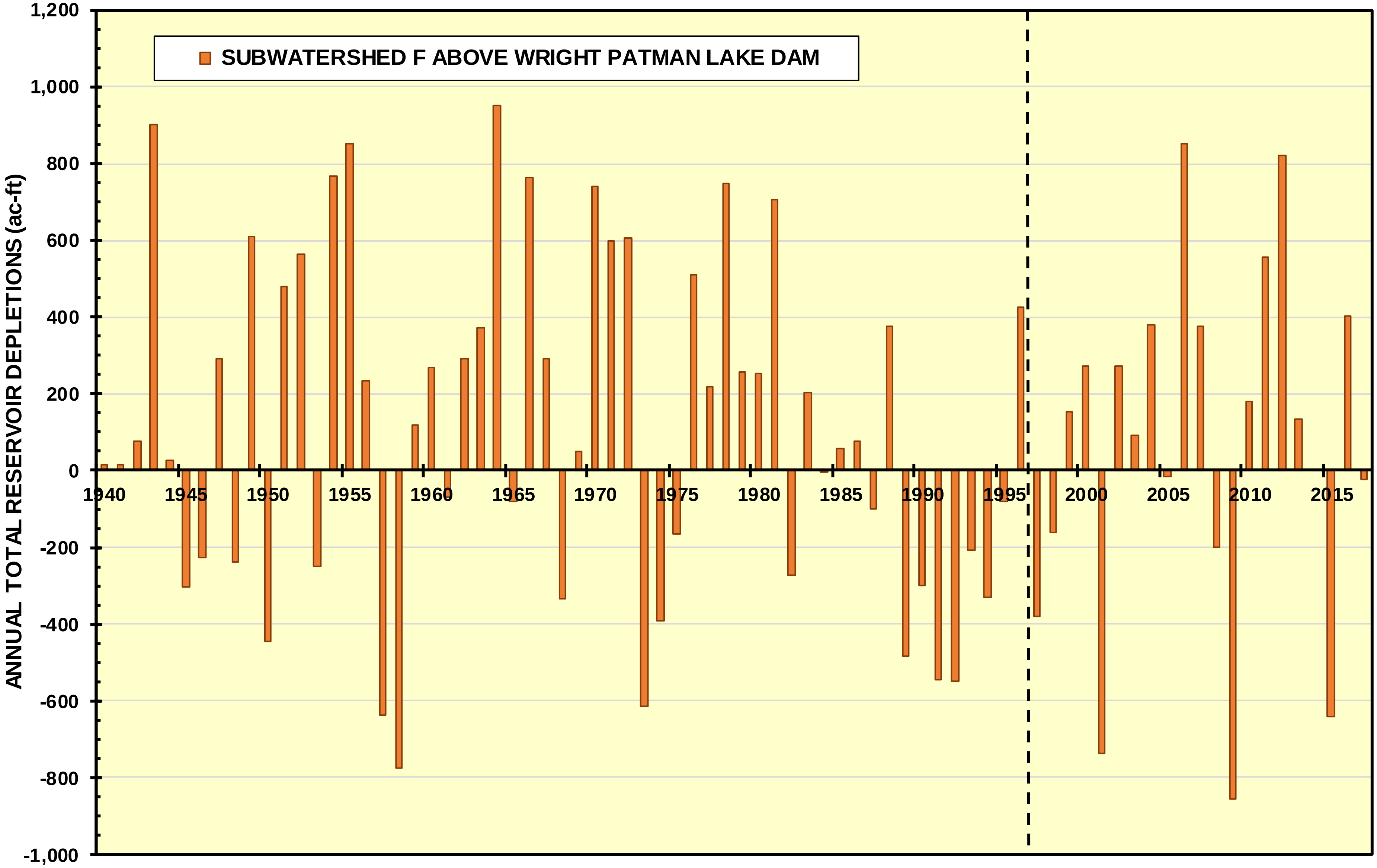


**Figure 2-17 Historical Annual Reservoir Streamflow Depletions for Subwatershed F above Wright Patman Lake**



In Figure 2-17, the reservoir depletions shown are only for reservoirs located in the portion of Subwatershed F upstream of Wright Patman Lake because this is the only portion of Subwatershed F for which naturalized flows were calculated. The effects of the two TexAmericas Center reservoirs that were permitted in 2006 but have been in existence since the early 1940s are apparent beginning in 1942. Even with these reservoirs, the total streamflow depletions caused by reservoirs generally are less than 1,000 acre-feet per year and are relatively insignificant with regard to the magnitude of the total naturalized flows for Subwatershed F.

## 2.7 Historical Diversions and Water Use

Fundamental to the streamflow naturalization process is the adjustment of historical gaged streamflows for the historical amounts of water that were diverted by upstream users. To make these adjustments, information describing these upstream diversions for the entire 1997-2017 analysis period, by month, either has been compiled from existing records or estimated from available data. The basic source of diversion information that has been relied upon has been the TCEQ's electronic records of historical monthly water use as reported by individual water rights holders. Many of these records as provided by TCEQ included complete or near-complete monthly values for water use for the 1997-2017 period. However, there also were numerous records that included only partial or periodic data, indicating that either the diverter only operated part of the time or may have started or ended diverting some time during the 1997-2017 period, or may not have reported all diversions for every month or every year. Also, some records appeared to reflect erroneous or inconsistent data, and in several cases, all reported water use values were zero.

Because of these problems, extensive effort has been expended in reviewing previous data used in the original naturalized flow development and comparing these older data with the newer data to verify magnitudes and trends. In some cases, individual water rights holders were contacted to discuss their historical water usage and verify diversion patterns. For some diverters, actual paper copies of the TCEQ water use reports were examined for additional information, and diversion data issues also were discussed and reviewed with TCEQ staff. The TCEQ Central Records files also were reviewed for some water rights to assess diversion operations.

In the end, practically all of the missing or zero records of water use for municipal and industrial users either were justified according to how individual diverters actually made their diversions or were filled in using existing data from adjacent months and years to establish appropriate values and indicated trends. In a few cases, the reported water use data for some small municipal and industrial water users were accepted as being correct even though some questions remained that could not be resolved. The impact of these types of issues on the resulting naturalized flows is not considered to be significant. For irrigation water use by individual water rights holders, the reported data from TCEQ generally were accepted and used directly in the naturalized flow process. For months when historical diversions for irrigation use could not be specifically quantified, zeros have been assumed.

Table 2-4 lists all water rights in the Sulphur River Basin with authorized diversions during the 1997-2017 period and indicates which of those have been used in the streamflow naturalization process. The locations of these water rights are shown on the map in Figure 1-2. Also indicated in the table is the extent to which individual records were complete or reported as all zeros and whether some missing data were filled.

The annual total amounts of diversions and water use by water right holders in each subwatershed are illustrated on the bar charts in Figures 2-18 through 2-23. These charts cover the entire period from 1940 through 2017, and provide comparisons of the previous 1940-1996 diversions with those for the extended 1997-2017 period. These quantities vary considerably among the subwatersheds depending on the individual water users, and they demonstrate annual variations resulting from changes in users and use. In some cases, new water rights have been authorized since 1996, and these account for the increases in recent diversions. It should be noted for Subwatershed F, the diversions plotted do not include those from Wright Patman Lake under the City of Texarkana's water right No. C-4836 because naturalized streamflows were calculated only for the portion of Subwatershed F located upstream of Wright Patman Lake. Naturalized streamflows for the remainder of Subwatershed F were determined using drainage area ratios. Also, it should be noted that there were no reported diversions for the TexAmericas Center reservoirs (water right P-5873) for the 1942-1996 period so no adjustments had to be made.

Following are specific notes regarding what appear to be irregularities or inconsistencies in the water use data for the different subwatersheds:

1) The annual diversions for Subwatershed A in Figure 2-18 increase dramatically during the 1997-2017 period, but these are after Jim Chapman Lake was completed in 1991 with increased water use under water rights and/or water supply contracts owned by the North Texas Municipal Water District, the City of Irving, the City of Sulphur Springs, and the Upper Trinity Regional Water District.
2) The diversions shown for Subwatershed B in Figure 2-19 terminate after 1997, but this is because there are no reported diversions in TCEQ's data base or in Central Records for the City of Pecan Gap under water right No. C-3890. However, these are very small diversions and do not significantly affect the final naturalized flow values.
3) Diversions for Subwatershed C in Figure 2-20 in 1998, 1999 and 2000 are significantly higher than those for any other years. These are reported diversions by Luminant (formerly Texas Utilities) under water right No. C-4804, and these are the only diversions reported for that water right during the 1997-2017 period. This water right authorizes diversions from the Sulphur River into an off-channel reservoir (River Crest Lake) for a steam-electric power plant that was retired in early 2005. Contacts with Luminant personnel have not provided any explanation as to why the diversions in 1998, 1999 and 2000 were so much higher than those in other years, but since they were reported, they have been used.

## Table 2-4 Water Use Information for Water Rights Used in 1997-2017 Streamflow Naturalization Process

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| | WATER RIGHT NO. [1] | WATER RIGHT OWNER | SUB WATER-SHED | AUTH. DIVERSION (ac-ft/yr) | TYPE OF USE [2] | STREAM | TCEQ WATER USE DATA | | | |
| | | | | | | | Provided Yes or No | Complete Yes or No | Filled Yes or No | Used Yes or No |
| (1) | C 4795 | City of Wolfe City | A | 300 | Mun | East Fork Turkey Creek | Yes | Unknown | No | **Yes** |
| (2) | C 4796 | Webb Hill Country Club | A | 80 | Irr | Trib of S Sulphur River | Yes | Yes | No | **Yes** |
| (3) | C 4797 | Sulphur River MWD | A | 26,960 | Mun/Ind | South Sulphur River | Yes | Almost | Some | **Yes** |
| (4) | C 4798 | North Texas MWD | A | 54,000 | Mun | South Sulphur River | Yes | Yes | No | **Yes** |
| (5) | C 4799 | City of Irving | A | 54,000 | Mun/Ind | South Sulphur River | Yes | Yes | No | **Yes** |
| (6) | C 4800 | City of Cooper | A | 273 | Mun | Cedar Creek | Yes | [3] | No | **No** |
| (7) | C 4801 | Delta Country Club | C | 5 | Irr | Trib of Brushy Creek | Yes | Yes | No | **Yes** |
| (8) | C 4802 | Alexander Frick et al | C | 278 | Irr | Trib of Sulphur River | Yes | [4] | No | **No** |
| (9) | C 4803 | Helmut Hermann et al | C | 1,900 | Irr | Trib of Sulphur River | Yes | Zeros | No | **Yes** |
| (10) | C 4804 | Luminant Generation Co LLC | C | 10,000 | Ind | Sulphur River | Yes | Yes | No | **Yes** |
| (11) | C 4805 | E P Land and Cattle Inc | E | 3,000 | Irr | Trib of Sulphur River | Yes | Zeros | No | **Yes** |
| (12) | C 4806 | Laura E Vaughan et al | E | 8.4 | Irr | Bernard Draw | Yes | Zeros | No | **Yes** |
| (13) | C 4807 | Mary Margaret Vaughan | E | 21.6 | Irr | Bernard Draw | Yes | Zeros | No | **Yes** |
| (14) | C 4809 | Red River County WCID 1 | E | 1,120.0 | Mun | Langford Creek | Yes | Yes | No | **Yes** |
| (15) | C 4810 | Donelson Family, LTD | E | 200 | Irr | Sand Branch | Yes | Zeros | No | **Yes** |
| (16) | C 4811 | City of Sulphur Springs | D | 9,800 | Mun | White Oak Creek | Yes | Unknown | No | **Yes** |
| (17) | C 4812 | City of Sulphur Springs | D | 408 | Mun | Trib of White Oak Creek | Yes | Zeros | No | **Yes** |
| (18) | C 4813 | Sulphur Springs Country Club | D | 113 | Irr | Trib of Rock Creek | Yes | Yes | No | **Yes** |
| (19) | C 4814 | Jerry N Jordan Trustee et al | D | 30 | Irr | Trib of Wolfpen Creek | Yes | Zeros | No | **Yes** |
| (20) | C 4816 | City of Mount Vernon | D | 400 | Mun | Denton Creek | Yes | Zeros | No | **Yes** |
| (21) | C 4817 | Hans & Waltraud Weiss | D | 333.3 | Irr | Bear Pen Creek | Yes | Zeros | No | **Yes** |
| (22) | C 4818 | Robert & Dewitta Campbell | D | 10.5 | Irr | Trib of Campbell Creel | Yes | Zeros | No | **Yes** |
| (23) | C 4820 | Joe R. Menefee | E | 22 | Irr | Ripley Creek | Yes | Zeros | No | **Yes** |
| (24) | C 4821 | Anna Pearl Lewis | E | 1.2 | Ind | Trib of Ripley Creek | Yes | Zeros | No | **Yes** |
| (25) | C 4822 | Bernice Ann Baldwin | E | 100 | Irr | Trib of McCullough Creek | Yes | Yes | No | **Yes** |
| (26) | C 4823 | Ardelia Gauntt | E | 22.5 | Irr | Trib of Piney Creek | Yes | Zeros | No | **Yes** |
| (27) | C 4824 | Walter W. Lee | E | 7.5 | Irr | Trib of Piney Creek | Yes | Zeros | No | **Yes** |
| (28) | C 4825 | Robert Crooks et al | E | 20 | Irr | East Piney Creek | Yes | Zeros | No | **Yes** |
| (29) | C 4829 | Estate of E D Simms et al | F2 [8] | 4 | Irr | Eds Creek | Yes | Zeros | No | **Yes** |
| (30) | C 4830 | Estate of E D Simms et al | F2 | 378 | Irr | Unnamed Trib | Yes | Zeros | No | **Yes** |

## Table 2-4 continued

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| | WATER RIGHT NO. [1] | WATER RIGHT OWNER | SUB WATER-SHED | AUTH. DIVERSION (ac-ft/yr) | TYPE OF USE [2] | STREAM | TCEQ WATER USE DATA | | | |
| | | | | | | | Provided Yes or No | Complete Yes or No | Filled Yes or No | Used Yes or No |
| (31) | C 4831 | City of New Boston | F2 | 31 | Mun | Trib of Rice Creek | Yes | Zeros | No | **Yes** |
| (32) | C 4832 | City of New Boston | F2 | 325 | Mun | Holly Branch | Yes | Zeros | No | **Yes** |
| (33) | C 4833 | H C Prange Jr | F2 | 7.9 | Ind | Trib of Moss Creek | Yes | Only 2016 | No | **Yes** |
| (34) | C 4834 | Estate of E D Simms et al | F2 | 39 | Irr | Brooks Creek | Yes | Zeros | No | **Yes** |
| (35) | C 4836 | City of Texarkana | FPat [8] | 180,000 | Mun | Sulphur River | Yes | Yes | No | **Yes** |
| (36) | C 4837 | Henry Maddox Jr, et ux | F1 [8] | 80 | Irr | Crutchers Creek | Yes | Zeros | No | **Yes** |
| (37) | C 4838 | International Paper Co | F1 | [5] | Ind | Grassy Creek | Yes | Only 1998 | No | **No** |
| (38) | P 3845 | Sulphur Bluff Land | C | 8,328 | Irr | Old Chan, S Sulphur River | Yes | Yes | No | **Yes** |
| (39) | P 3845 | Sulphur Bluff Land | C | 11,312 | Irr | Old Chan, S Sulphur River | - - | - - | - - | **- -** |
| (40) | P 3890 | City of Pecan Gap | B | 102 | Mun | Trib of Sulphur River | Yes | Ends 1998 | No | **Yes** |
| (41) | P 4060 | City of Cooper | A | 1,518 | Mun | Big Creek | Yes | Yes | No | **Yes** |
| (42) | P 5285 | Texas Utilities Mining Co | E | [6] | Ind | | Yes | Unknown | No | **Yes** |
| (43) | P 5392 | Paul A Pfiefer Et Ux | D | 341 [7] | Irr | | Yes | Zeros | Yes | **Yes** |
| (44) | P 5449 | Texas Parks & Wildife Dept | F2 | 1,726 | Oth | Toyah Creek | Yes | Almost | Yes | **Yes** |
| (45) | P 5562 | Luminant Mining Co LLC | E | 125 | Ind | Tribs of Ripley/Dorsey Ck | Yes | Unknown | No | **Yes** |
| (46) | P 5821 | Upper Trinity Reg Water Dist | B | 45,000 | Multi | North Sulphur River | Yes | Zeros | No | **Yes** |
| (47) | P 5873 | TexAmericas Center | F2 | 2,960 | Mun | Caney & Elliot Creeks | Yes | Zeros | No | **Yes** |
| (48) | P 5906 | Luminant Mining Co LLC | D | 220 | Min | Trib of Rock Creek | Yes | Unknown | No | **Yes** |
| (49) | P 12099 | Luminant Mining Co LLC | E | 200 | Min | Piney Creek and Tribs | Yes | Zeros | No | **Yes** |
| (50) | P 12145 | Los Senderos Cattle/Rch Co | D | 35 | Irr | White Oak Creek | Yes | Zeros | No | **Yes** |
| (51) | P 12810 | Daisy Farms LLC | C | 17,500 | Multi | Auds Creek | Yes | Zeros | No | **Yes** |
| (52) | P 12810 | Daisy Farms LLC | C | 245 | Multi | Tribs of Auds Creek | No | n/a | n/a | **n/a** |

NOTES:

[1] C = Certificate of Adjudication and P = Permit

[2] Mun = Municipal, Ind = Industrial, Irr = Irrigation, Min = Mining, Rec = Recreation, Oth = Other, Multi = Municipal, Industrial and Other Uses, D&L = Domestic and Livestock

[3] Diversions reported for this water right are also reported for the City of Cooper's Permit No. 4060; therefore, these reported diversions are not used.

[4] Diversions reported for this water right are well in excess of the authorized diversion amount and must be in error; therefore, these reported diversions are not used.

[5] No diversion is authorized for this water right but historical diversions are reported in the TCEQ water use database.

[6] No diversion is authorized for this water right but historical diversions are reported in the TCEQ water use database. Water right was cancelled on July 16, 2008.

[7] Water right was cancelled on December 31, 2002.

[8] For purposes of the naturalized flow process, Subwatershed F has been divided into three parts:
F1 - portion of Subwatershed F watershed downstream of Wright Patman Lake.
F2 - portion of Subwatershed F watershed upsteam of Wright Patman Lake.
FP - at Wright Patman Lake.

Figure 2-18   Historical Annual Diversions and Water Use for Subwatershed A

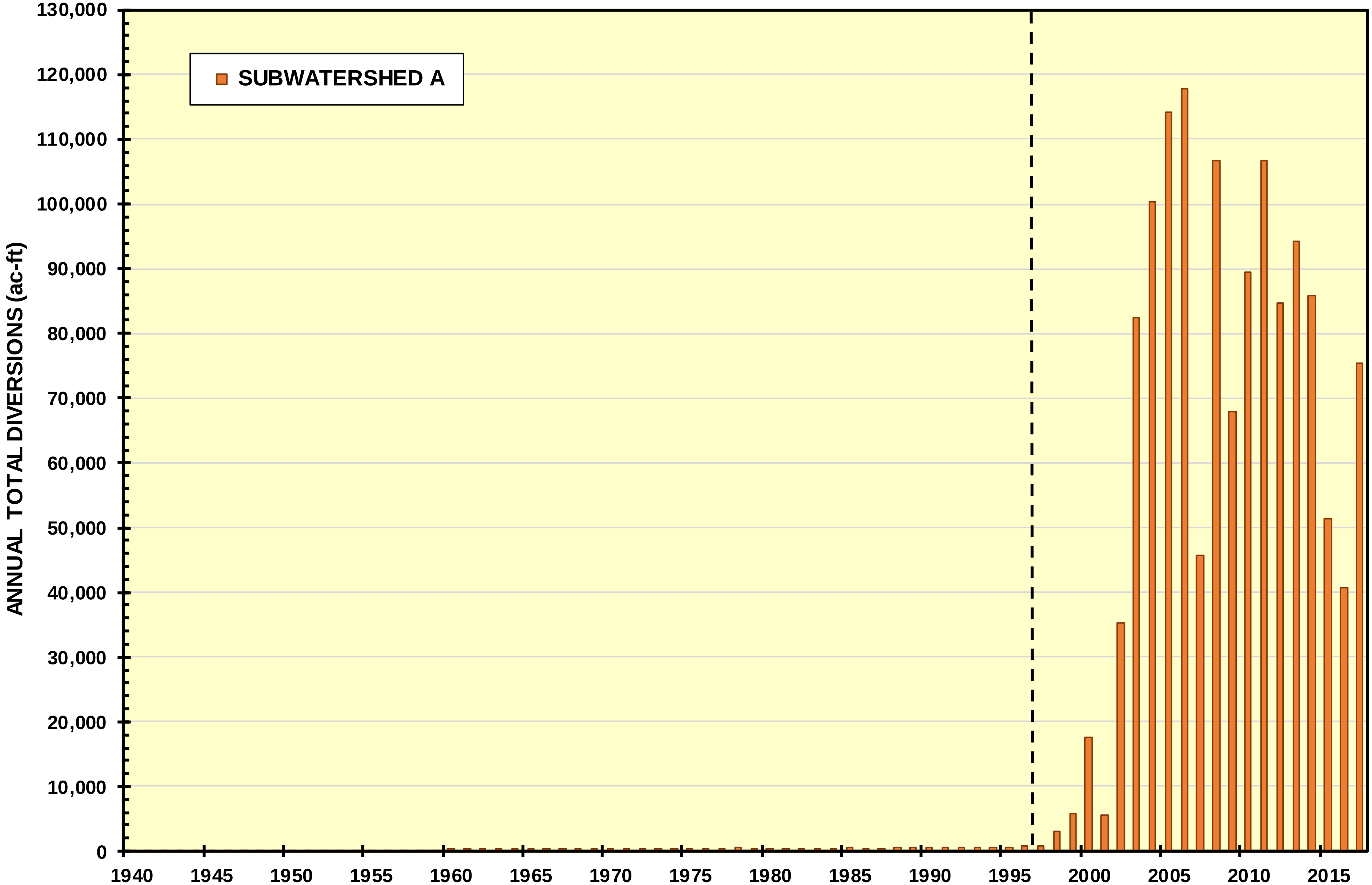


**Figure 2-19   Historical Annual Diversions and Water Use for Subwatershed B**

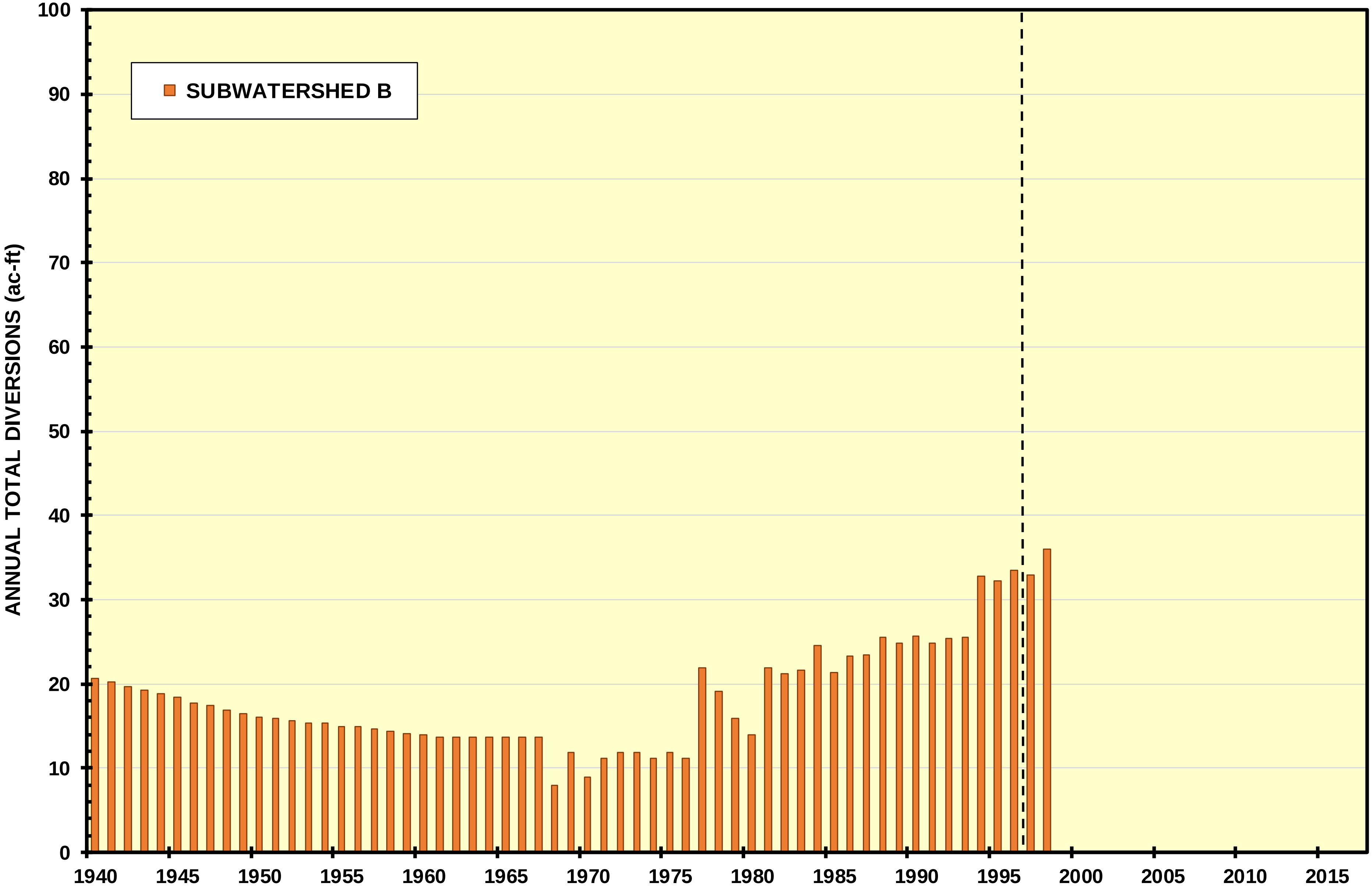


**Figure 2-20 Historical Annual Diversions and Water Use for Subwatershed C**

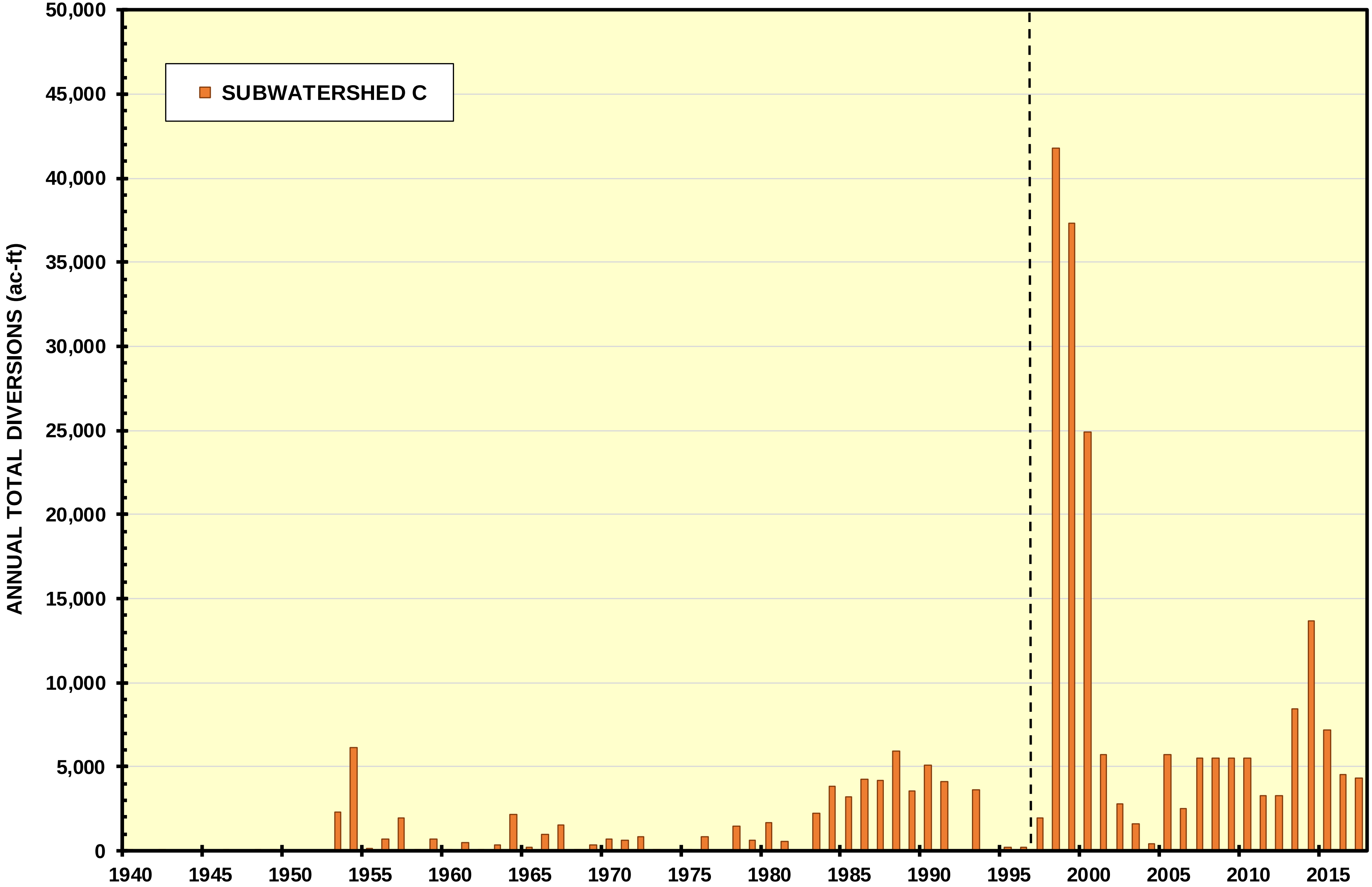


**Figure 2-21 Historical Annual Diversions and Water Use for Subwatershed D**

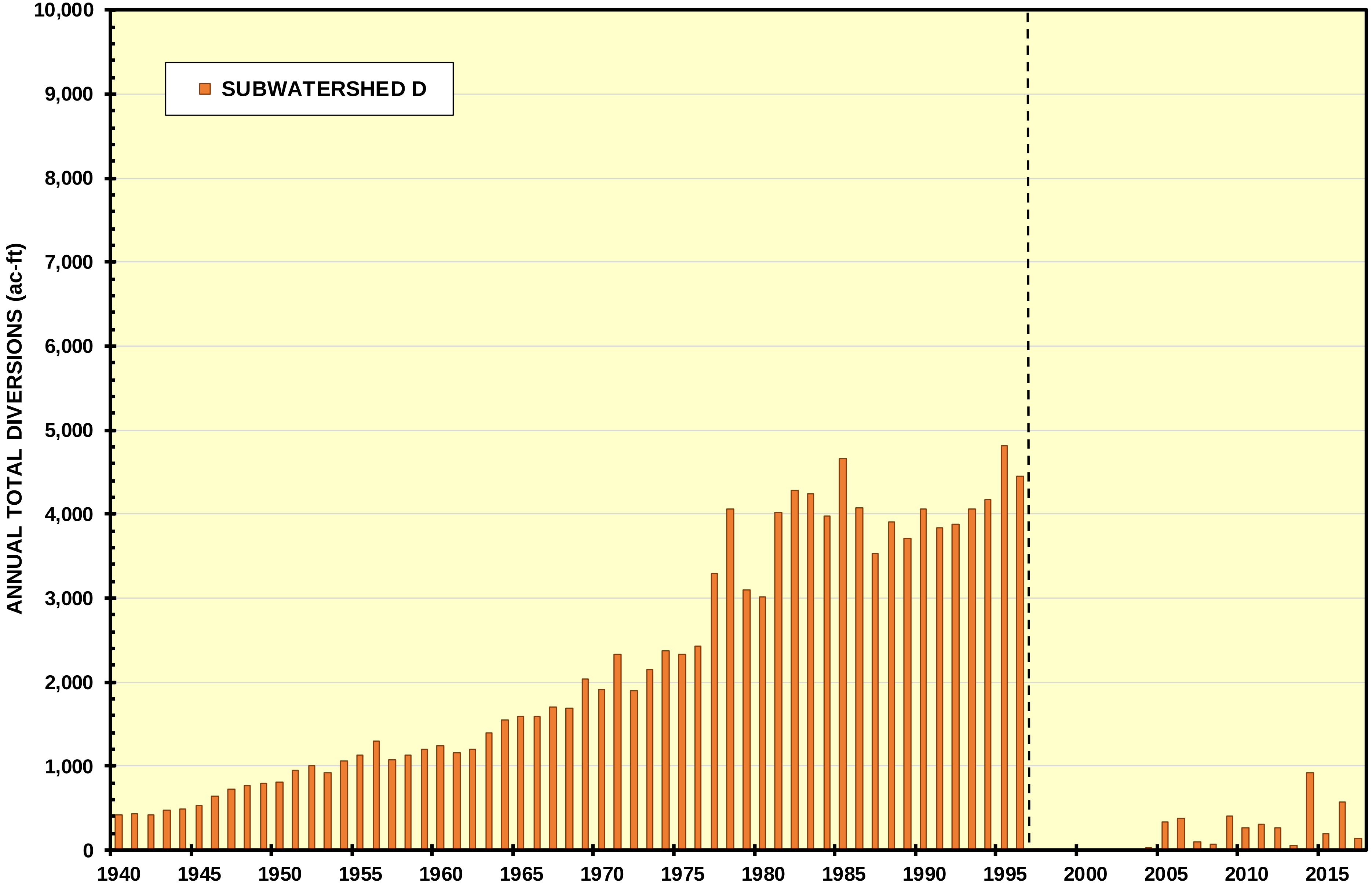


**Figure 2-22   Historical Annual Diversions and Water Use for Subwatershed E**

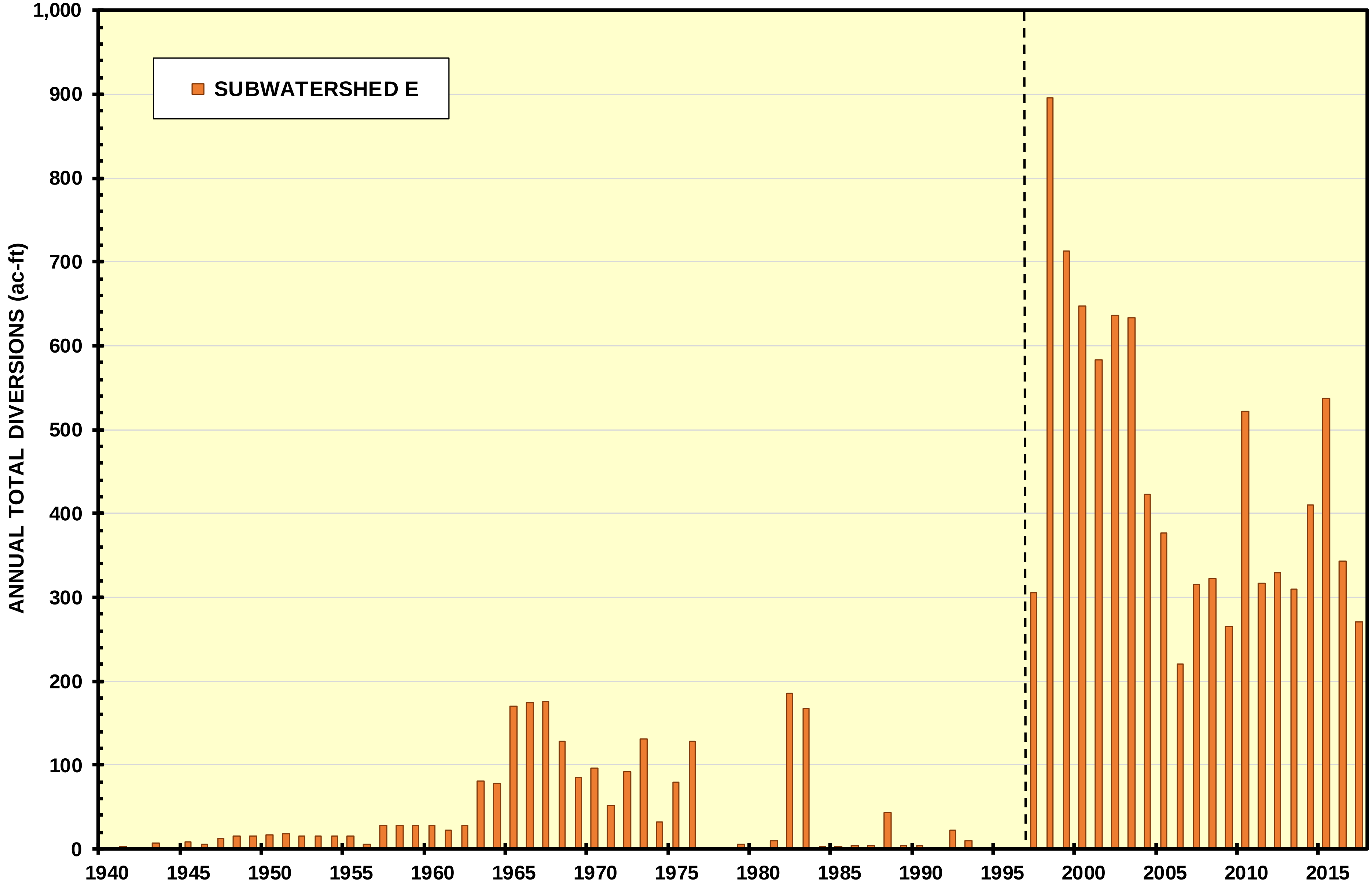
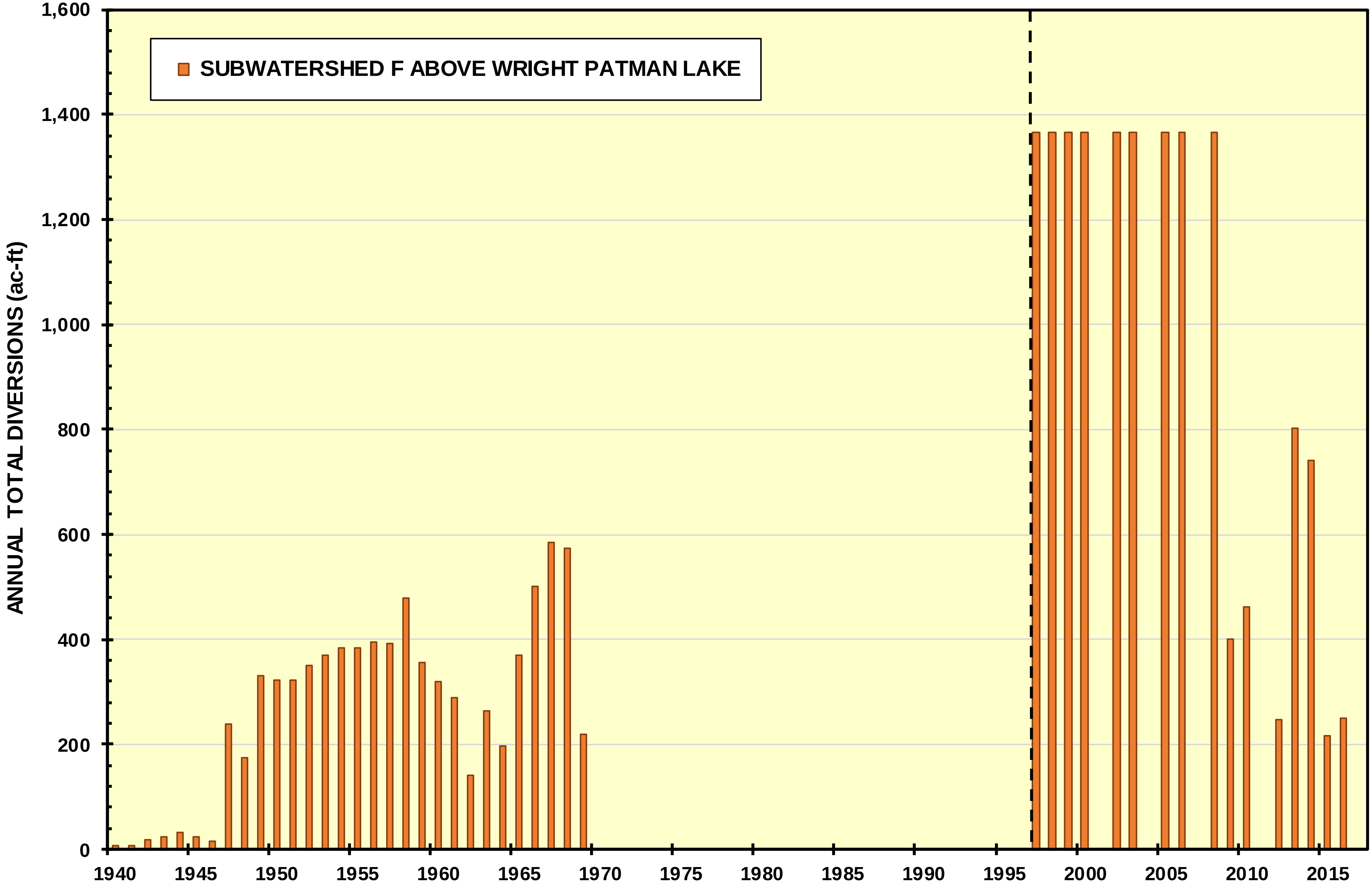


Figure 2-23 Historical Annual Diversions and Water Use for Subwatershed F above Wright Patman Lake



4) The diversions for Subwatershed D plotted in Figure 2-21 abruptly end beginning in 1997. Actually, this appears to be correct since the City of Sulphur Springs essentially ended diverting water under water right No. C-4811 from Lake Sulphur Springs around that time and started diverting water from Jim Chapman Lake under a contractual arrangement with the Sulphur River Municipal Water District, owner of water right No. C-4797 that authorizes diversions from Jim Chapman Lake up to 38,520 acre-feet/year.

5) While the total annual diversions for Subwatershed E shown on the plot in Figure 2-22 are relatively small (< 900 acre-feet/year), the diversions during the 1997-2017 period are significantly greater than those prior to that time. These increases appear to be due to some water rights now having reported water use and others becoming active after 1996. For example, water right No. P-5285, owned by Texas Utilities Mining, reported no water use prior to 1997 but it has reported annual diversions of 100 to 300 acre-feet/year since that time – this water right was cancelled on July 16, 2008 with no diversions since. Water right No. P-5562, owned by Luminant Mining Company, was issued in March 1997 and now has reported annual diversions of about 100 acre-feet/year. There are also additional diversions reported for water right No. C-4809, which is owned by Red River County WCID No. 1 and authorizes diversions from Langford Creek Lake. Although this water right has a priority date of January 20, 1964, apparently either diversions were not made or diversions were not reported for the 1940-1996 period; consequently, none were considered in the original development of the 1940-1996 naturalized flows. However, now there are reported diversions throughout the 1997-2017 period on the order of 200 to 400 acre-feet/year.

6) The annual diversions for Subwatershed F plotted on the graph in Figure 2-23 for the 1997-2017 period represent only those diversions made upstream of Wright Patman Lake since this is the only portion of the entire subwatershed for which naturalized flows have been calculated. As shown, these annual diversions vary considerably over the 1940-2017 period; however, most of these changes can be explained. The diversions prior to 1970 were primarily by the City of New Boston under its own water rights (C-4831 and C-4832, see Table 1-1), but around 1970 the City began using water from Wright Patman Lake under contract with the City of Texarkana. So since then, these diversions have been reported under the City of Texarkana's water right authorizing municipal diversions from the reservoir (C-4836), and these diversions are not included on the bar chart in Figure 2-23, which only presents diversions above Wright Patman Lake. In the mid-1990s, the Texas Parks and Wildlife Department was issued a water right permit (P-5449, see Table 1-1) that authorized the diversion of a total of 1,726 acre-feet per year from Toyah Creek for maintaining four off-channel reservoirs. The diversions under this water right make up the large majority of the total annual diversions shown after the mid-1990s on the bar chart in Figure 2-23. As with the reservoir depletions for this portion of Subwatershed F, the magnitude of the annual diversions is relatively insignificant compared to the annual values of the naturalized flows for Subwatershed F.

## 2.8 Historical Municipal and Industrial Wastewater Discharges

As with diversions, data for historical wastewater discharges from municipal and industrial wastewater treatment facilities also are required for the development of naturalized streamflows. For this study, a list of current wastewater discharge permits for the Sulphur Basin was compiled from the GIS records of the TCEQ, and this list then was used to obtain the historical monthly discharge records for these permits from the TCEQ for the 1997-2017 period.

Table 2-5 lists these current wastewater discharge permits in the Sulphur River Basin. The locations of the outfalls associated with these permits are shown on the map in Figure 2-24. Permit numbers and other related information included in the table for each permit were extracted from the GIS data base. The Yes/No entries in Column 8 of Table 2-5 indicate whether discharge data were available from the TCEQ; for some of the permits, no discharge records were provided and were assumed to be unavailable. The reported maximum flow rate for each discharge permit is indicated in Column 9 in units of million gallons per day (mgd). Initially, discharges with flow rates less than 1.0 mgd (about 1,120 acre-feet/year) were considered too small to be significant with regard to the development of naturalized flows; however, since some of these smaller discharges had complete or nearly complete data sets for the 1997-2017 period, they were included in the naturalized flow process. The Yes/No entries in Column 10 of the table indicate whether a particular discharge was used for the naturalized flow calculations.

The annual total amounts of wastewater discharges in each subwatershed as used in the naturalized flow process are illustrated on the bar charts in Figures 2-25 through 2-30. These charts cover the entire period from 1940 through 2017, and provide comparisons of the previous wastewater discharges accounted for in the naturalized flow process for the 1940-1996 period with those compiled for the extended 1997-2017 period in this current study. As expected, these quantities vary considerably among the subwatersheds depending on the magnitude of individual wastewater discharges, and they demonstrate annual variations resulting from changes in discharge conditions. In some cases, new discharge permits have been issued since 1996, and these account for some of the increases in recent discharges. For Subwatershed F in Figure 2-30, only those wastewater discharges discharged upstream of Wright Patman Lake are plotted since this is the only portion of the subwatershed for which naturalized streamflows have been calculated.

It should be noted that none of the subwatersheds exhibit significant quantities of wastewater discharges relative to typical annual flows in the Sulphur River, with maximum discharge amounts less than 4,000 acre-feet per year – even river flows in the upper basin average several hundred thousand acre-feet per year. For this reason, wastewater discharges are not considered a major factor with regard to the quantification of naturalized streamflows. Still, there are what appear to be some inconsistencies in the wastewater discharge data for some of the subwatersheds that are addressed below.

## Table 2-5 Information for Permitted Wastewater Discharges Used in 1997-2017 Streamflow Naturalization Process

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| | **PERMITTEE** | **PERMIT NO.** | **NPDES NO.** | **OUT-FALL** | **STATUS** | **COUNTY** | **SUB WATER-SHED** | **DISCHARGE DATA AVAILABLE Yes or No** | **MAXIMUM REPORTED FLOW mgd** | **USED FOR NATURALIZED FLOWS Yes or No** |
| (1) | City of Bailey | 13584-001 | 0107719 | 001 | Current | Fannin | A | Yes | 0.07 | **No** |
| (2) | City of Commerce | 10555-001 | 0020591 | 001 | Current | Hunt | A | Yes | 2.10 | **Yes** |
| (3) | City of Cooper | 10449-001 | 0027936 | 001 | Current | Delta | A | Yes | 1.18 | **Yes** |
| (4) | City of Ladonia | 14673-001 | 0057011 | 001 | Current | Fannin | A | Yes | 0.71 | **No** |
| (5) | City of Wolfe City | 10383-001 | 0023558 | 001 | Current | Hunt | A | Yes | 0.29 | **Yes** |
| (6) | City of Wolfe City | 10383-002 | 0124192 | 001 | Current | Hunt | A | No | n/a | **No** |
| (7) | Delta County MUD | 10744-001 | 0020192 | 001 | Current | Delta | A | Yes | 0.15 | **No** |
| (8) | Texas Parks & Wildlife Dept | 13613-001 | 0108499 | 001 | Current | Hopkins | A | Yes | 0.27 | **No** |
| (9) | City of Roxton | 10204-001 | 0053538 | 001 | Current | Lamar | B | Yes | 0.31 | **Yes** |
| (10) | Petty Water Sup/Sew Svc | 12305-001 | 0085707 | 001 | Current | Lamar | B | Yes | 0.02 | **No** |
| (11) | City of Bogata | 10065-001 | 0022322 | 001 | Current | Red River | C | Yes | 0.31 | **No** |
| (12) | City of Deport | 10741-002 | 0136930 | 001 | Current | Lamar | C | No | n/a | **No** |
| (13) | Kimberly Clark Corp | 02648-000 | 0093416 | 001 | Current | Lamar | C | Yes | 0.20 | **No** |
| (14) | Lamar Power Partners | 04846-000 | 0130125 | 001 | Current | Lamar | C | No | n/a | **No [4]** |
| (15) | Lamar Power Partners | 04127-000 | 0119288 | 002 | Current | Lamar | C | Yes | 0.91 | **Yes** |
| (16) | Lamar Power Partners | 04127-000 | 0119288 | 001 | Current | Lamar | C | Yes | 0.91 | **Yes** |
| (17) | Prairiland ISD | 14473-001 | 0126136 | 001 | Current | Lamar | C | No | n/a | **No** |
| (18) | Rivercrest ISD | 11204-001 | 0116556 | 001 | Current | Red River | C | Yes | 0.01 | **No** |
| (19) | Turner Industries Group LLC | 00300-000 | 0000108 | 001 | Current | Lamar | C | Yes | 0.70 | **No** |
| (20) | City of Mount Vernon | 11122-001 | 0075540 | 001 | Current | Franklin | D | Yes | 0.10 | **No** |
| (21) | City of Mount Vernon | 11122-002 | 0063096 | 001 | Current | Franklin | D | Yes | 0.54 | **Yes** |
| (22) | City of Sulphur Springs | 10372-001 | 0058955 | 001 | Current | Hopkins | D | Yes | 4.69 | **Yes** |
| (23) | Luminant Mining Co | 04122-000 | 0071081 | 001 | Current | Hopkins | D | Yes | 51.67 | **No [3]** |
| (24) | City of Annona | 14255-001 | 0022705 | 001 | Current | Red River | E | Yes | 0.10 | **Yes** |
| (25) | City of Blossom | 10715-002 | 0075957 | 001 | Current | Lamar | E | Yes | 0.40 | **Yes** |
| (26) | City of Clarksville | 10148-001 | 0058106 | 001 | Current | Red River | E | Yes | 1.69 | **Yes** |
| (27) | City of Detroit | 10724-001 | 0055581 | 001 | Current | Red River | E | Yes | 0.13 | **Yes** |
| (28) | City of Talco | 10869-001 | 0021105 | 001 | Current | Titus | E | Yes | 0.11 | **Yes** |
| (29) | Ervin Don Crutcher | 04828-000 | 0129542 | 001 | Current | Red River | E | No | n/a | **No** |
| (30) | Luminant Mining Co | 02697-000 | 0068357 | 001 | Current | Titus | E | Yes | 27.07 | **No [3]** |

**Table 2-5 continued**

| | (1) PERMITTEE | (2) PERMIT NO. | (3) NPDES NO. | (4) OUT-FALL | (5) STATUS | (6) COUNTY | (7) SUB WATER-SHED | (8) DISCHARGE DATA AVAILABLE Yes or No | (9) MAXIMUM REPORTED FLOW mgd | (10) USED FOR NATURALIZED FLOWS Yes or No |
|---|---|---|---|---|---|---|---|---|---|---|
| (31) | Alumax Mill Products Inc | 02742-000 | 0097055 | 002 | Current | Bowie | F | Yes | 0.12 | **No [2]** |
| (32) | City of De Kalb | 10062-002 | 0069671 | 001 | Current | Bowie | F | Yes | 0.79 | **Yes** |
| (33) | City of Domino | 15332-001 | 0136123 | 001 | Pending | Cass | F | No | n/a | **No [2]** |
| (34) | City of Maud | 14025-001 | 0117498 | 001 | Current | Bowie | F | Yes | 0.35 | **Yes** |
| (35) | City of New Boston | 10482-002 | 0136409 | 001 | Pending | Bowie | F | No | n/a | **No** |
| (36) | City of New Boston | 10482-001 | 0026018 | 001 | Current | Bowie | F | Yes | 2.88 | **Yes** |
| (37) | City of Queen City | 11225-001 | 0034797 | 001 | Current | Cass | F | Yes | 0.45 | **No [2]** |
| (38) | City of Redwater | 10926-001 | 0056251 | 001 | Current | Bowie | F | Yes | 0.87 | **Yes** |
| (39) | City of Texarkana | 10374-005 | 0101800 | 001 | Current | Bowie | F | Yes | 18.39 | **No [2]** |
| (40) | City of Texarkana | 10374-007 | 0099287 | 001 | Current | Bowie | F | Yes | 3.10 | **No [2]** |
| (41) | International Paper Co | 01339-000 | 0000167 | 001 | Current | Cass | F | Yes | 157.04 | **No [2]** |
| (42) | Nalco Company | 02955-000 | 0102822 | 001 | Current | Bowie | F | Yes | 0.33 | **No [2]** |
| (43) | TexAmericas Center | 04664-000 | 0126098 | 001 | Current | Bowie | F | Yes | 2.67 | **Yes** |
| (44) | US Dept of the Army | 04978-000 | 0133370 | 005 | Current | Bowie | F | No | n/a | **No** |

NOTES:

[1] Downloaded from web site of Texas Commission on Environmental Quality on April 30, 2018.

[2] Discharge is located downstream of Wright Patman Lake and is not needed for streamflow naturalization.

[3] Discharge is only for stormwater FLOWS.

[4] Inactive permit.

**Figure 2-24 Permitted Wastewater Discharges for Sulphur River Basin (NPDES IDs)**

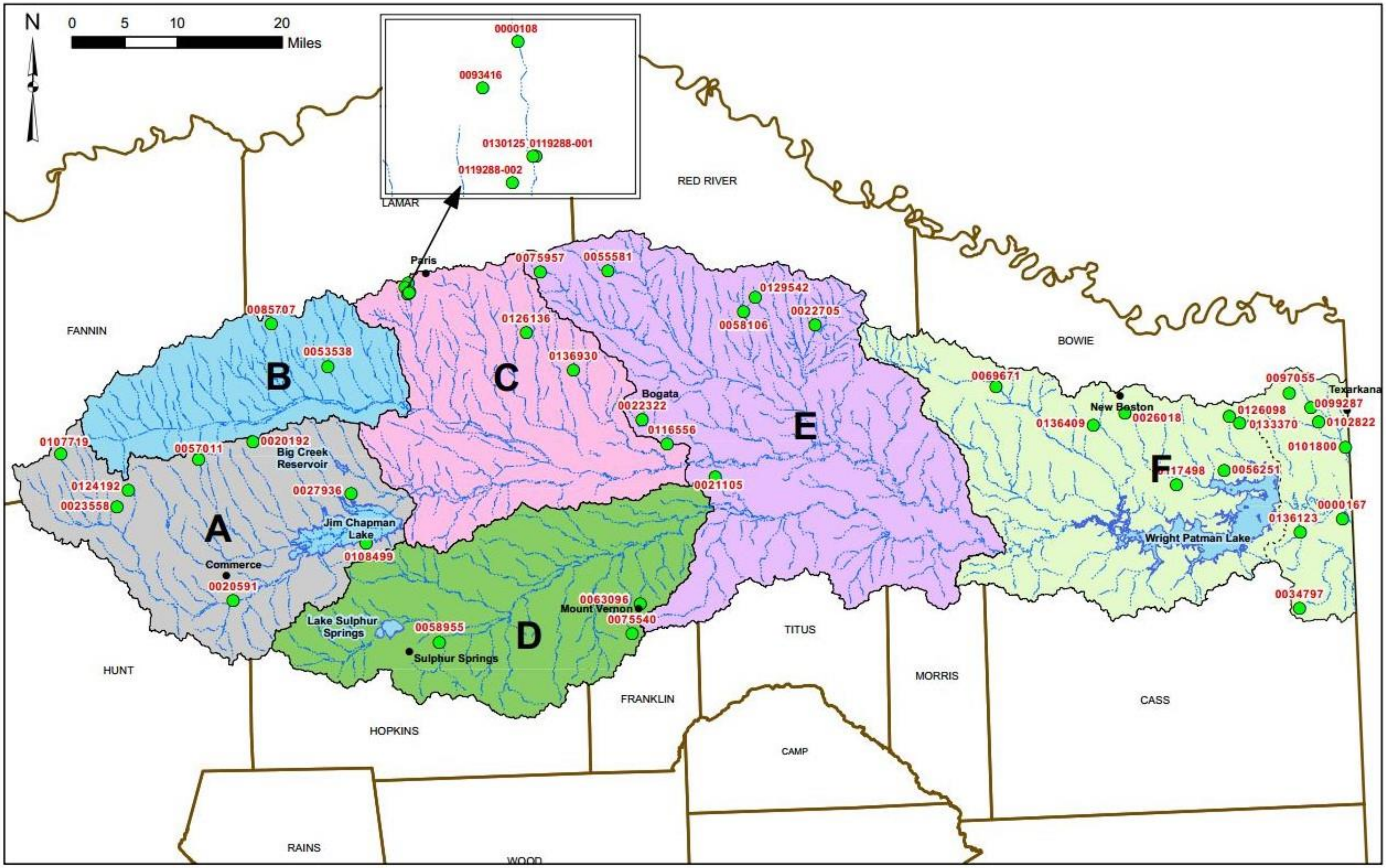


**Figure 2-25 Historical Annual Wastewater Discharges for Subwatershed A**

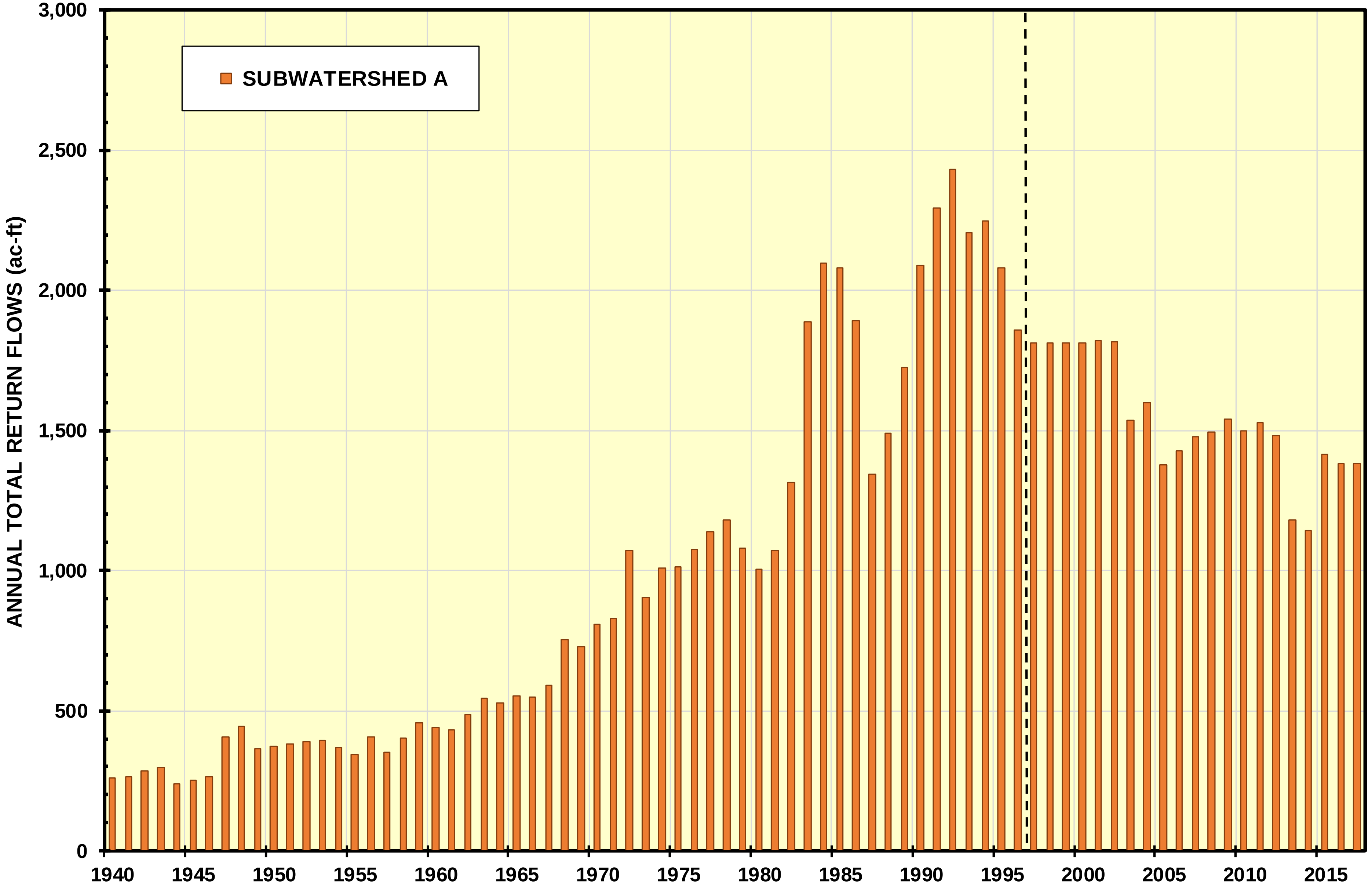


**Figure 2-26   Historical Annual Wastewater Discharges for Subwatershed B**

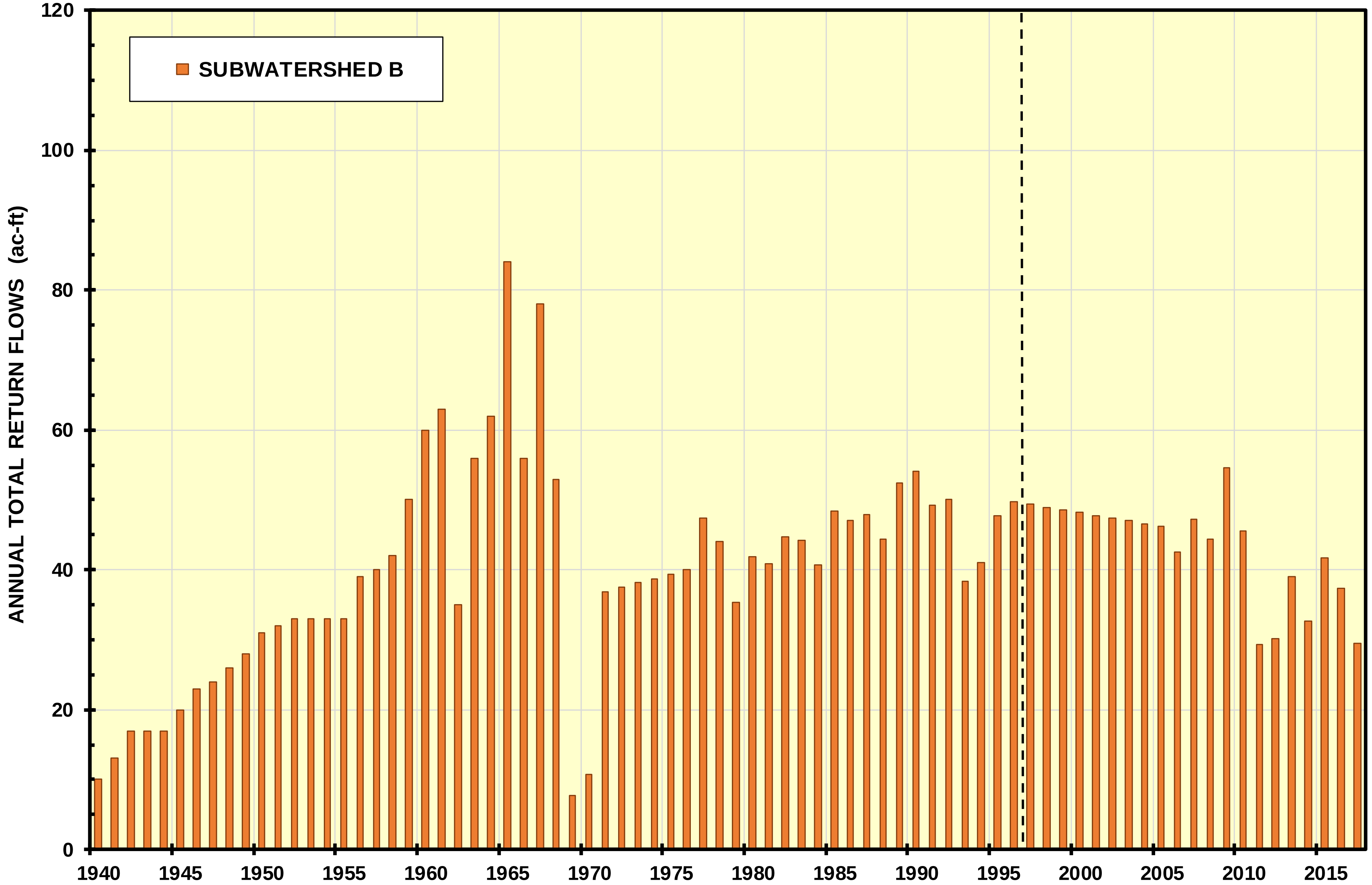


**Figure 2-27 Historical Annual Wastewater Discharges for Subwatershed C**

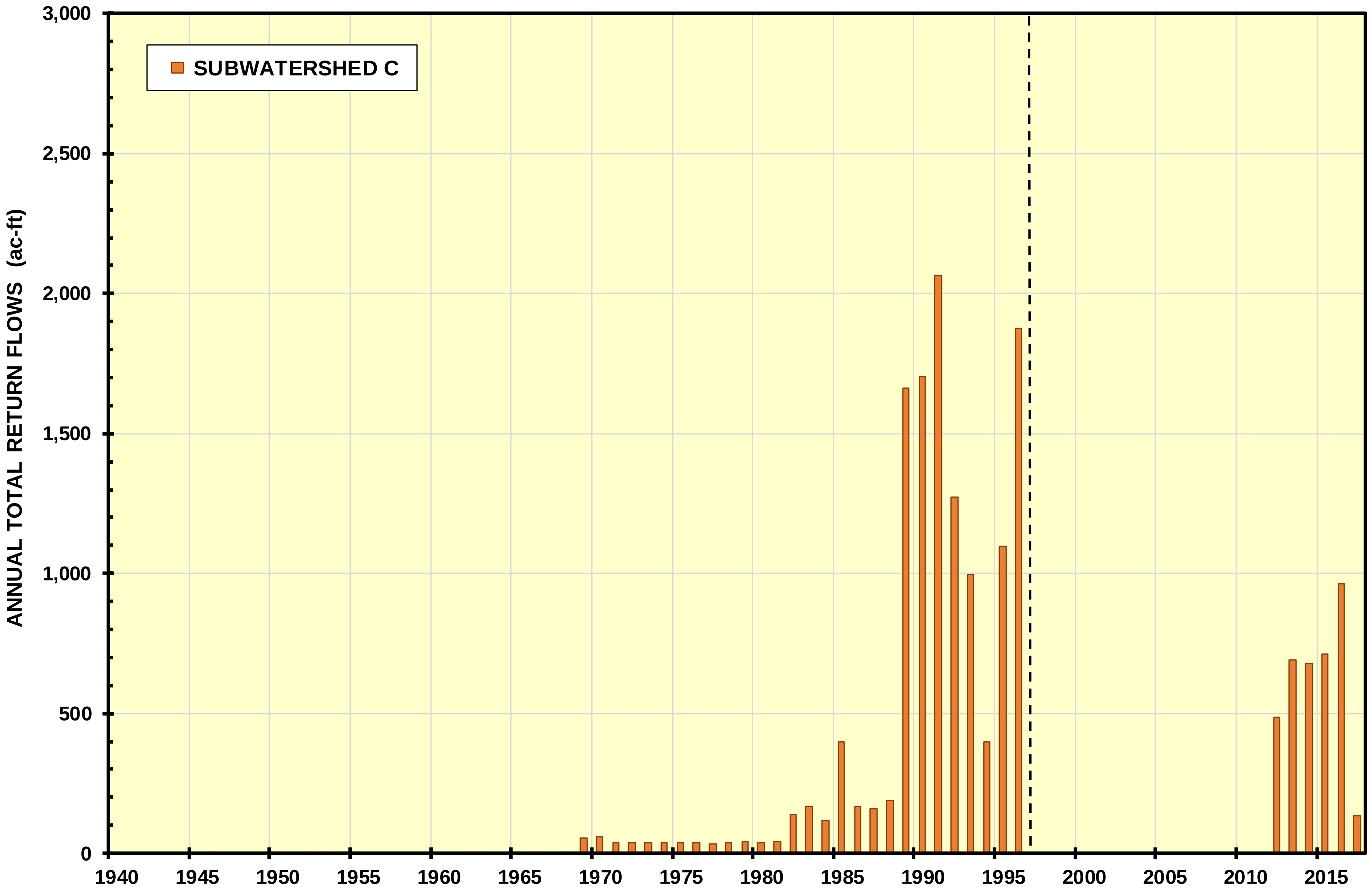


**Figure 2-28 Historical Annual Wastewater Discharges for Subwatershed D**

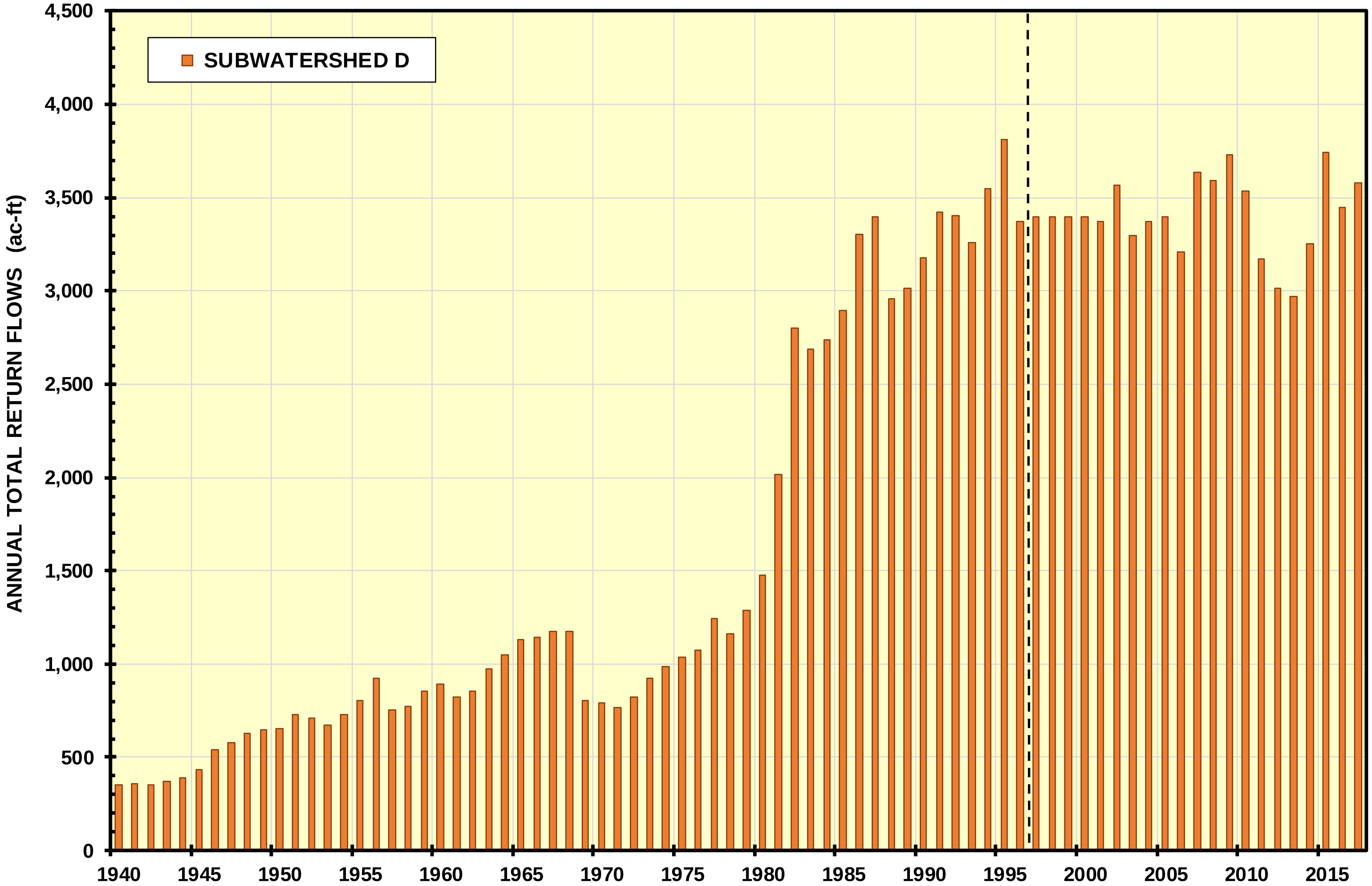


**Figure 2-29 Historical Annual Wastewater Discharges for Subwatershed E**

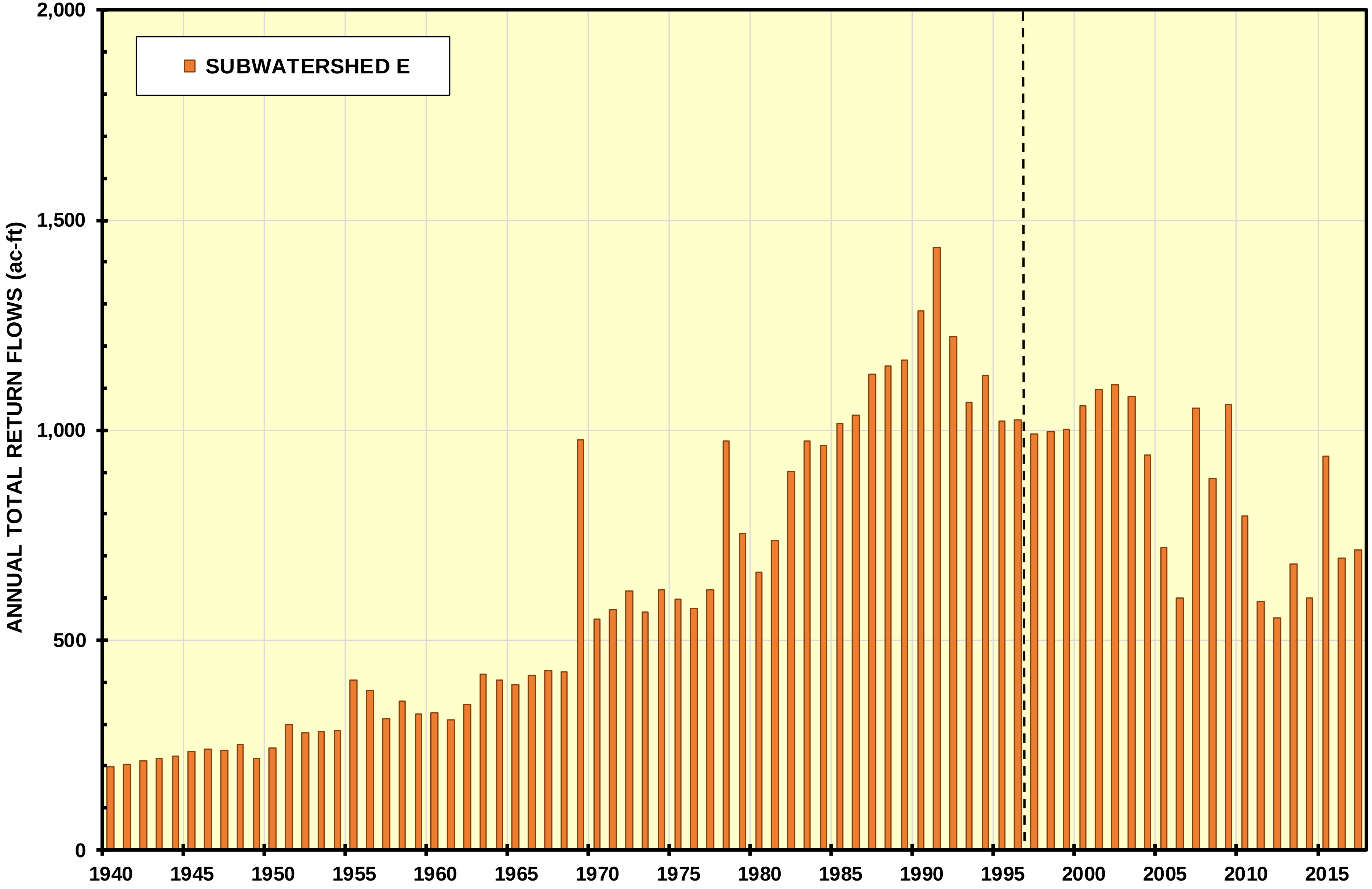
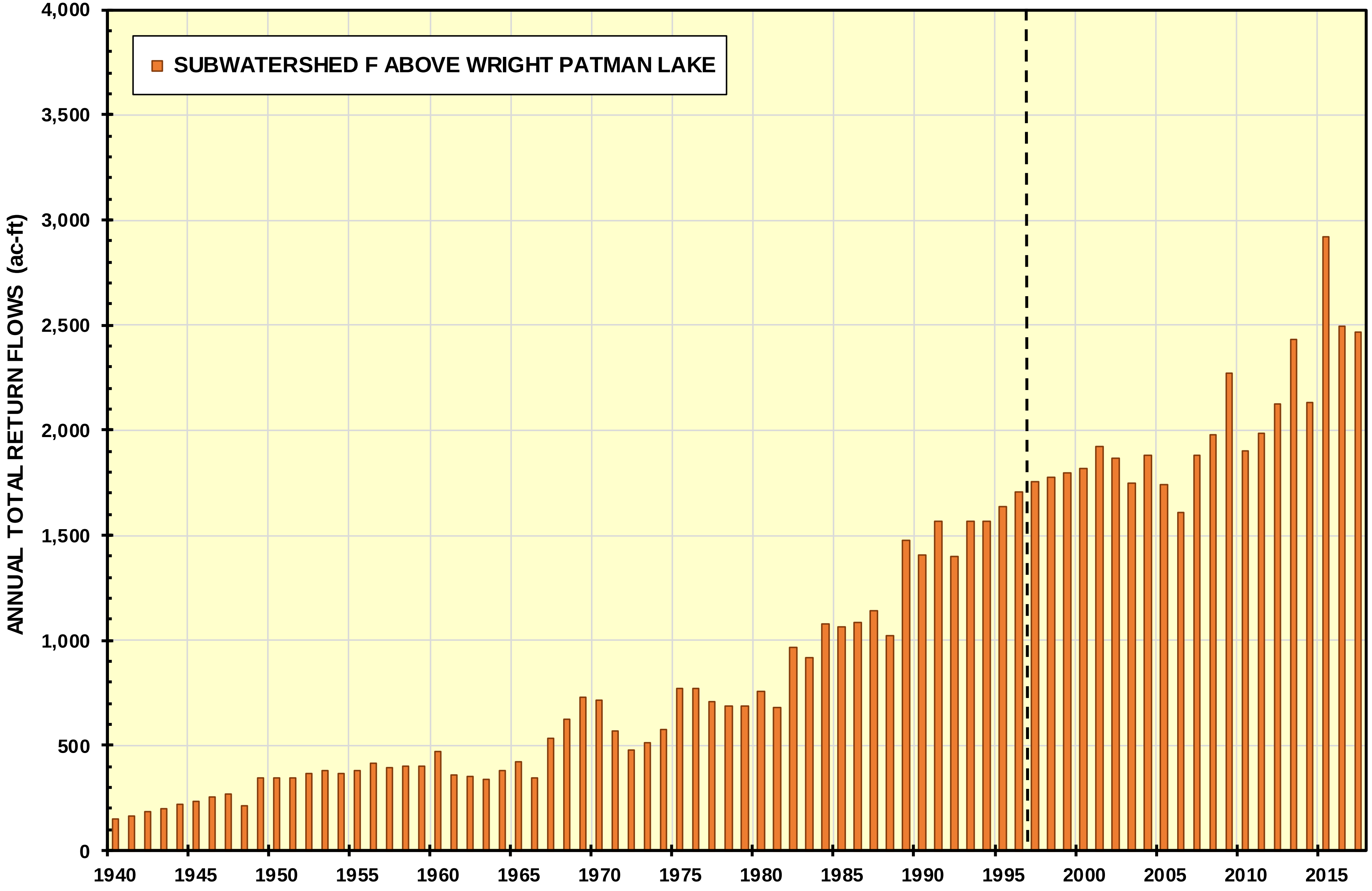


**Figure 2-30 Historical Annual Wastewater Discharges for Subwatershed F above Wright Patman Lake**



1) The annual wastewater discharges for both Subwatersheds A and E show decreasing trends beginning in the early 1990s and extending through 2017; however, these appear to be explained with population data for the cities in these subwatersheds that also show declining trends that average on the order of 20 percent since 1990.

2) The zero annual wastewater discharges shown for Subwatershed C after 1996 are the result of having only limited data reported for the wastewater discharges located in this subwatershed, even though they apparently had significant discharge quantities prior to 1997. One of these discharges, permitted to Kimberly Clark Corporation (NPDES No. 0093416) near Paris, Texas, has reported data prior to 1997 (ranging from 200 to 1,800 acre-feet/year) and every year after 2003 with some missing months (ranging from only 50 to 170 acre-feet/year), but none for the 1997-2003 period. This discharge has not been accounted for in the streamflow naturalization process for 1997-2017 because the values reported after 2003 are substantially less than 1.0 mgd. Another discharger, Lamar Power Partners (NPDES No. 0119288), apparently owned and operated a power plant near Paris that was constructed around 2000 and subsequently acquired by Luminant in 2016. For this permit, discharges are reported beginning in 2012 and continuing into 2017, and these discharges (which range from about 500 to 1,000 acre-feet/year) have been accounted for in the 1997-2017 naturalized flow process. It is also relevant to note that Texas Utilities (now Luminant) also had reported discharges in Subwatershed C prior to 1997 (maximum of about 1,800 acre-feet/year, then zeros after 1993), but no discharges reported since 1996. These discharges appear to be for a power plant that was located on River Crest Lake in Titus County which was retired in February 2005 – so there should have been no discharges after that time. The reported earlier discharges were either cooling water circulated through the power plant and back into River Crest Lake, which should not have been considered in the previous naturalized process since River Crest Lake is an off-channel reservoir, or discharges into the Sulphur River as periodic blow-down discharges which would explain their variability. Again, the relatively small magnitude of any discrepancies in these combined discharges for Subwatershed C is not likely to significantly affect the resulting naturalized flows for Subwatershed C, which average over 900,000 acre-feet/year.

## 2.9 Streamflow Naturalization by Subwatershed

Outlined below are the specific procedures and steps that have been applied to derive the final sets of 1997-2017 monthly naturalized streamflows for the six subwatersheds of the Sulphur Basin.

Subwatershed A - South Sulphur River (CP A10)

1. Naturalize the monthly historical streamflows for Gage No. 7342500 at the downstream end of Subwatershed A for the period January 1997 – December 2017 using the general naturalized flow equation from Section 2.1. Set any resulting negative value of the

monthly naturalized flows to zero.

Subwatershed B - North Sulphur River (CP B10)

1. Naturalize the monthly historical streamflows for Gage No. 7343000 at the downstream end of Subwatershed B for the period January 1997 – December 2017 using the general naturalized flow equation from Section 2.1. Set any resulting negative value of the monthly naturalized flows to zero.

Subwatershed C – Upper Sulphur River (CP C10)

1. Apply the drainage area ratio of 0.971 (1,353.24/1,393.36) to the monthly historical streamflows for temporary Gage No. 7343200 (Sulphur River near Talco) to estimate the monthly historical streamflows for the permanent Gage No. 7343200 at the downstream end of Subwatershed C for the period May 1997 - December 2016.

2. Incorporate the estimated monthly historical streamflows for the permanent Gage No. 7343200 (Sulphur River near Talco) from Step 1 for the period May 1997 - December 2016 into the monthly historical streamflow record for the permanent Gage No. 7343200 to obtain the complete set of monthly historical streamflows at the downstream end of Subwatershed C for the period January 1997 - December 2017.

3. Subtract the sum of the monthly historical streamflows for Gage No. 7342500 (South Sulphur River near Cooper) and Gage No. 7343000 (North Sulphur River near Cooper) from the monthly historical streamflows for the permanent Gage No. 7343200 (Sulphur River near Talco) from Step 2 to obtain the monthly historical incremental streamflows for Subwatershed C for the period January 1997 - December 2017.

4. Naturalize the monthly historical incremental streamflows from Step 3 for Subwatershed C for the period January 1997 - December 2017 using the general naturalized flow equation from Section 2.1. Set any negative incremental naturalized flows to zero and offset the extent of these flow adjustments from the naturalized flows in adjacent months.

5. Compute the total monthly naturalized streamflows at the downstream end of Subwatershed C (Gage No. 7343200) for the period January 1997 - December 2017 by combining the monthly incremental naturalized streamflows for Subwatershed C from Step 4 with the sum of the monthly naturalized streamflows for Subwatersheds A and B for the period January 1997 - December 2017.

Subwatershed D - Upper White Oak Creek (CP D10)

1. Naturalize the monthly historical streamflows for Gage No. 7343500 for the period January 1997 – December 2017 using the general naturalized flow equation from Section

2.1. Set any resulting negative value of the monthly naturalized flows to zero.

Subwatershed E - Middle Sulphur River (CP E10)

1. Calculate the monthly historical deduced inflows to Wright Patman Lake using the mass balance equation in Section 2.3 with available historical reservoir storage, evaporation, rainfall, diversion, and release data for the period January 1997 - December 2017. Set any resulting negative deduced inflows to zero.

2. Compute the monthly incremental historical streamflows for Subwatershed E plus the portion of Subwatershed F above Wright Patman Lake Dam by subtracting the sum of the total monthly historical streamflows at the downstream ends of Subwatershed C (Gage No. 7343200) and Subwatershed D (Gage No. 7343500) from the monthly historical deduced inflows to Wright Patman Lake from Step 1 for the period January 1997 - December 2017.

3. Naturalize the monthly incremental historical streamflows for Subwatershed E plus the portion of Subwatershed F above Wright Patman Lake Dam from Step 2 for the period January 1997 - December 2017 by adjusting for historical diversions, wastewater discharges and reservoir depletions in the corresponding incremental watershed, i. e., Subwatershed E and the portion of Subwatershed F above Wright Patman Lake Dam. Set any negative incremental naturalized flows to zero and offset the extent of these flow adjustments from the incremental naturalized flows in adjacent months.

4. Adjust the monthly incremental naturalized streamflows for Subwatershed E plus the portion of Subwatershed F above Wright Patman Lake Dam (1,521 square miles) for the period January 1997 - December 2017 from Step 3 to represent only the incremental naturalized streamflows for Subwatershed E (899 square miles) by applying the drainage area ratio of 0.591 (899/1,521 = 0.591).

5. Compute the total monthly naturalized streamflows at the downstream end of Subwatershed E (Gage No. 7344000, Sulphur River near Darden) by combining the monthly incremental naturalized streamflows for Subwatershed E from Step 4 with the total monthly naturalized streamflows at the downstream ends of Subwatershed C (Gage No. 7343200) and Subwatershed D (Gage No. 7343500) for the period January 1997 - December 2017.

Subwatershed F - Lower Sulphur River (CP F10)

1. Adjust the monthly incremental naturalized streamflows for Subwatershed E plus the portion of Subwatershed F above Wright Patman Lake Dam (1,521 square miles) for the period January 1997 - December 2017 from Step 3 above to represent the incremental naturalized streamflows for all of Subwatershed F (756 square miles) by applying the drainage area ratio of 0.497 (756/1,521 = 0.497).

2. Compute the total monthly naturalized streamflows for Subwatershed F by combining the monthly incremental streamflows for Subwatershed F from Step 1 with the total monthly naturalized streamflows at the downstream end of Subwatershed E for the period January 1997 - December 2017.

Primary Control Points Within Subwatershed F at Arkansas State Line

Within Subwatershed F as represented in the original WAM for the Sulphur Basin, there are two small watersheds associated with creeks that were originally determined to drain directly into Arkansas at the state line apart from the Sulphur River. These two small watersheds had the following primary control points assigned at the intersection of their respective watercourses with the state line, with naturalized flows associated with each:

- Primary Control Point F20 – on Days Creek, which lies north of the Sulphur River and drains part of the city of Texarkana

- Primary Control Point F30 – on Cypress Slough, which lies immediately south of the Sulphur River where it enters Arkansas. Water right No. C-4838, owned by International Paper Company, authorizes a small reservoir on a tributary of Cypress Slough called Grassy Creek, and naturalized flows at the primary control point F30 were used in the original WAM to estimate the naturalized flows at the location for this water right.

For structuring and operating the updated-extended Sulphur WAM, there appears to be no need for having these two primary control points since their naturalized flows have to be estimated anyway based on the incremental naturalized flows for Subwatershed F. Furthermore, any naturalized flows that may be required at control points downstream of Wright Patman Lake can easily be determined from the naturalized flows for Subwatershed F at its primary control point F10. For this reason, no naturalized flows have been developed for the 1997-2017 period for either of the control points F20 or F30, and the updated-extended Sulphur WAM has been reconfigured to use the incremental naturalized flows for Subwatershed F (CP F10) to estimate the naturalized flows for any control points located downstream of Wright Patman Lake for the entire period of record 1940-2017.

It should be noted that pursuant to locating and creating new control points for wastewater discharges as part of updating the Run 8 version of the Sulphur WAM, the TCEQ determined that only Days Creek, on which control point F20 is located, actually flows into Arkansas at the state line apart from the Sulphur River. Cypress Slough, on which control point F30 is located, does actually flow into the Sulphur River just upstream of the state line. Therefore, while both of these control points still are included in the updated-extended Sulphur WAM network, only one is on the state line (F20), and the other is at the Cypress Slough-Sulphur River confluence (F30).

## 2.10 Naturalized Streamflow Results

Application of the procedures outlined in Section 2.9 has produced total monthly naturalized streamflows for the period 1997 through 2017 at the downstream end of each of the six subwatersheds as defined for purposes of the Sulphur WAM in Figure 1-3. These naturalized flows have been combined with the original 1940-1996 naturalized flows to produce the complete 1940-2017 extended hydrologic data set. The final total monthly naturalized streamflows for the complete 1940-2017 period for each of the six primary control points used in the extended Sulphur WAM are listed in tables in Appendix A of this report. These are the values of naturalized streamflows that now have been incorporated into the WAM to extend the ending year of its hydrologic data base from 1996 to 2017. Thus, the WAM now is capable of simulating 78 years, or 936 months, of water availability, instead of the previous 57 years, or 684 months.

To facilitate evaluation and comparison of the extended naturalized streamflows, the annual quantities of the flows for each of Subwatersheds A through F are plotted as time series bar charts in Figures 2-31 through 2-36, respectively. None of the 1997-2017 annual naturalized flows presented on the charts in these figures exhibit magnitudes or trends appreciably different from those that were originally developed for the 1940-1996 period, which suggests that hydrologic conditions appear to have remained generally consistent across the Sulphur Basin. It is significant to note, however, that the 1997-2017 annual naturalized flows for each one of the subwatersheds do include two distinct drought periods, one generally covering 2003-2006 and a second generally covering 2011-2014. The occurrence of these low-flow conditions is consistent with observed rainfall and other climatic parameters during these periods.

The two new drought periods during 1997-2017 are even more evident on the graph shown in Figure 2-37, which is a time series plot of the four-year running average of the naturalized flows for Subwatersheds A, B, and F. The four-year running average flows provide a better indication of extended drought conditions for each of the subwatersheds and are more indicative of critical drought periods for most reservoirs in the Sulphur Basin. The curves for Subwatersheds A and B depict potential drought inflows to Jim Chapman Lake and Lake Ralph Hall during the 2003-2009 and 2011-2015 periods, and the significance of these low flows is apparent when compared to other severe drought periods, like during the mid-1950s and the mid-1960s. Similarly, the four-year running average naturalized flow curve for Subwatershed F provides an indication of potential drought inflows to Wright Patman Lake, and in this case, the significance of the 2003-2009 and 2011-2015 low-flow conditions is even more pronounced when compared to the other previous droughts, suggesting that these later periods may represent a new drought of record determining the firm annual yield the reservoir. The actual meaning of these low-flow conditions, and the overall 1940-2017 extended hydrologic data set, with respect to water availability for individual water rights and for the firm yield of specific reservoirs, is addressed in Section 3.0 based on results from the updated-extended Run 3 version of the Sulphur WAM with the new extended hydrology.

**Figure 2-31 Naturalized Streamflows for Subwatershed A**

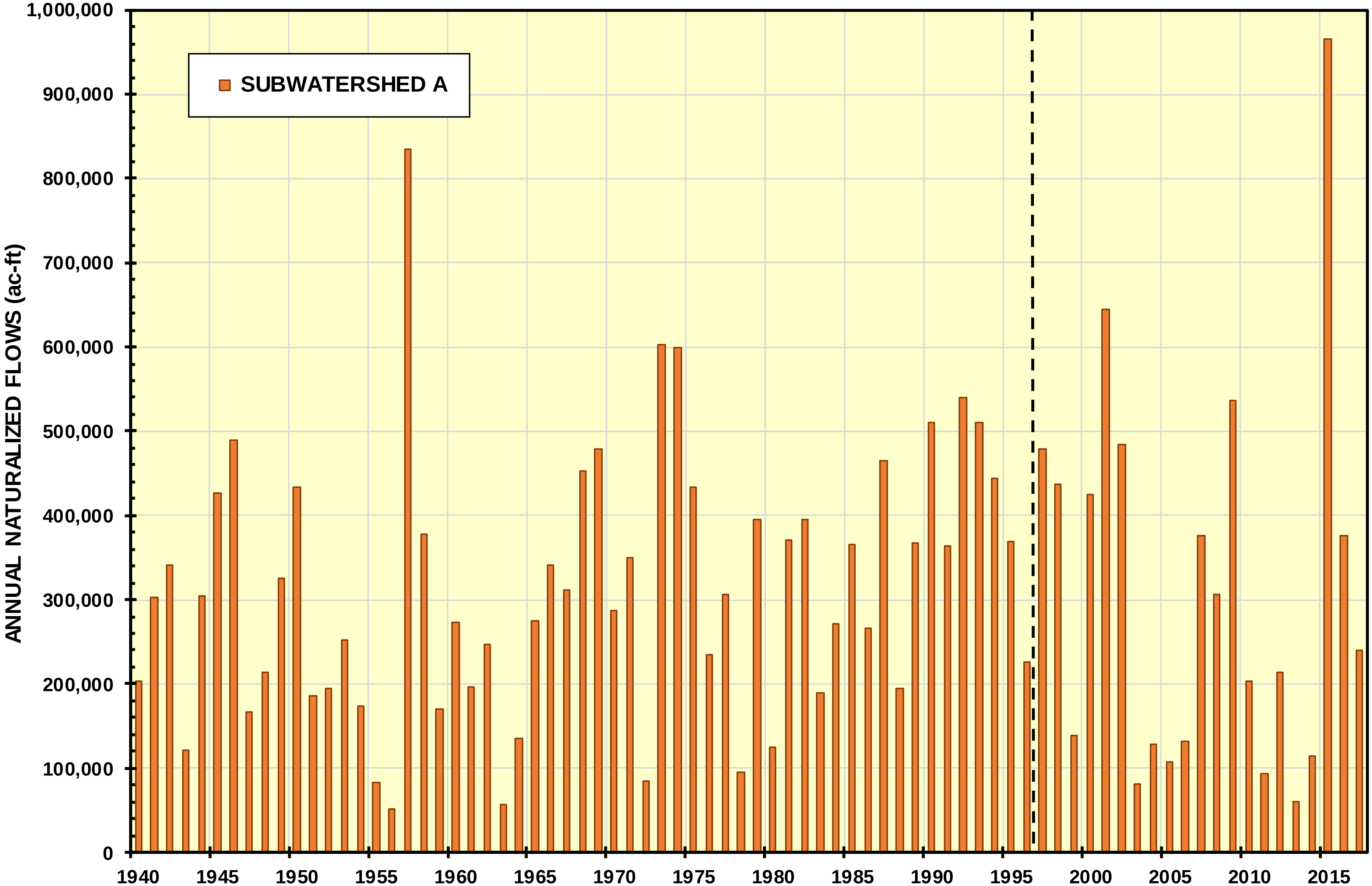


**Figure 2-32 Naturalized Streamflows for Subwatershed B**

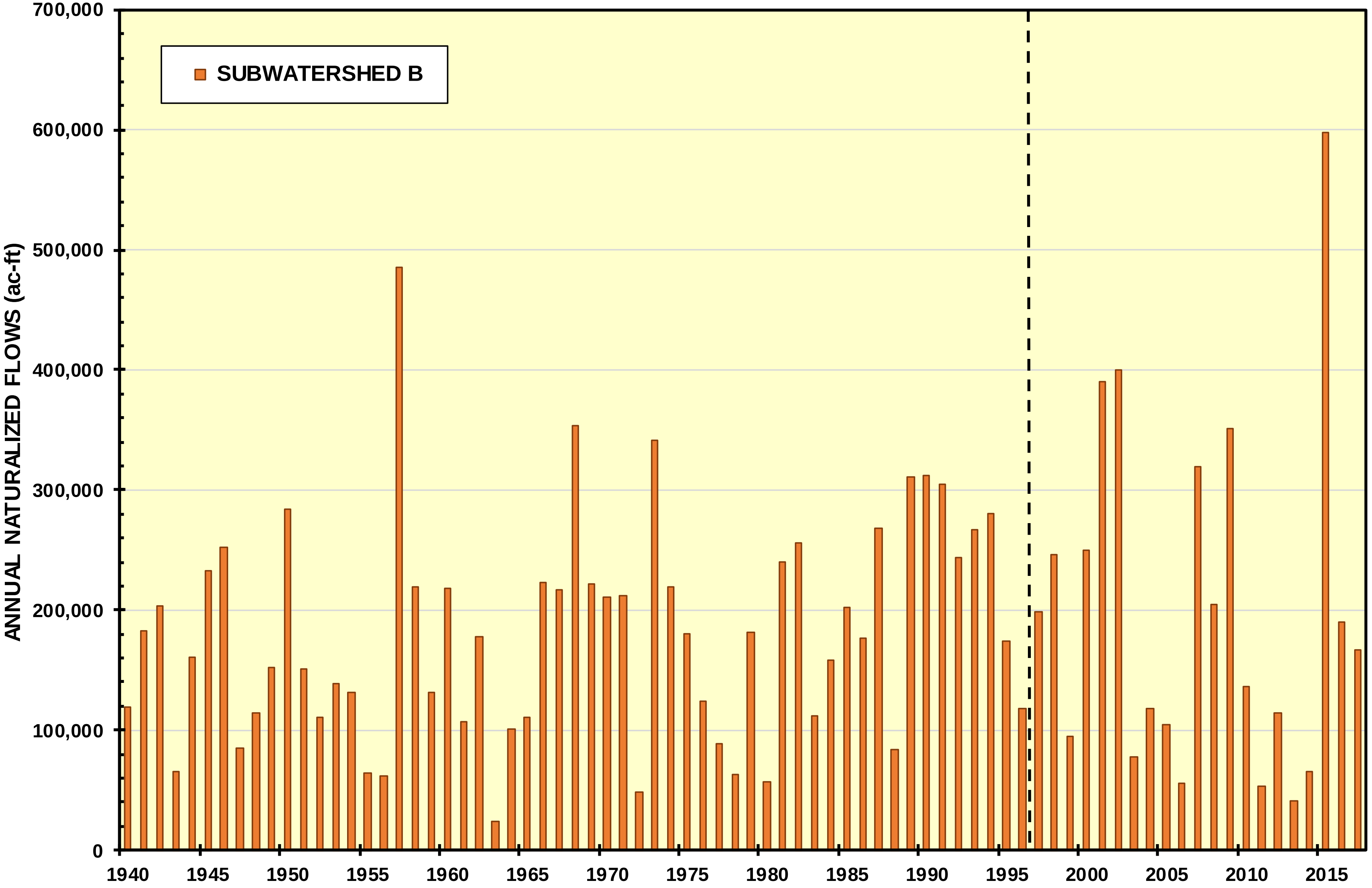


**Figure 2-33 Naturalized Streamflows for Subwatershed C**

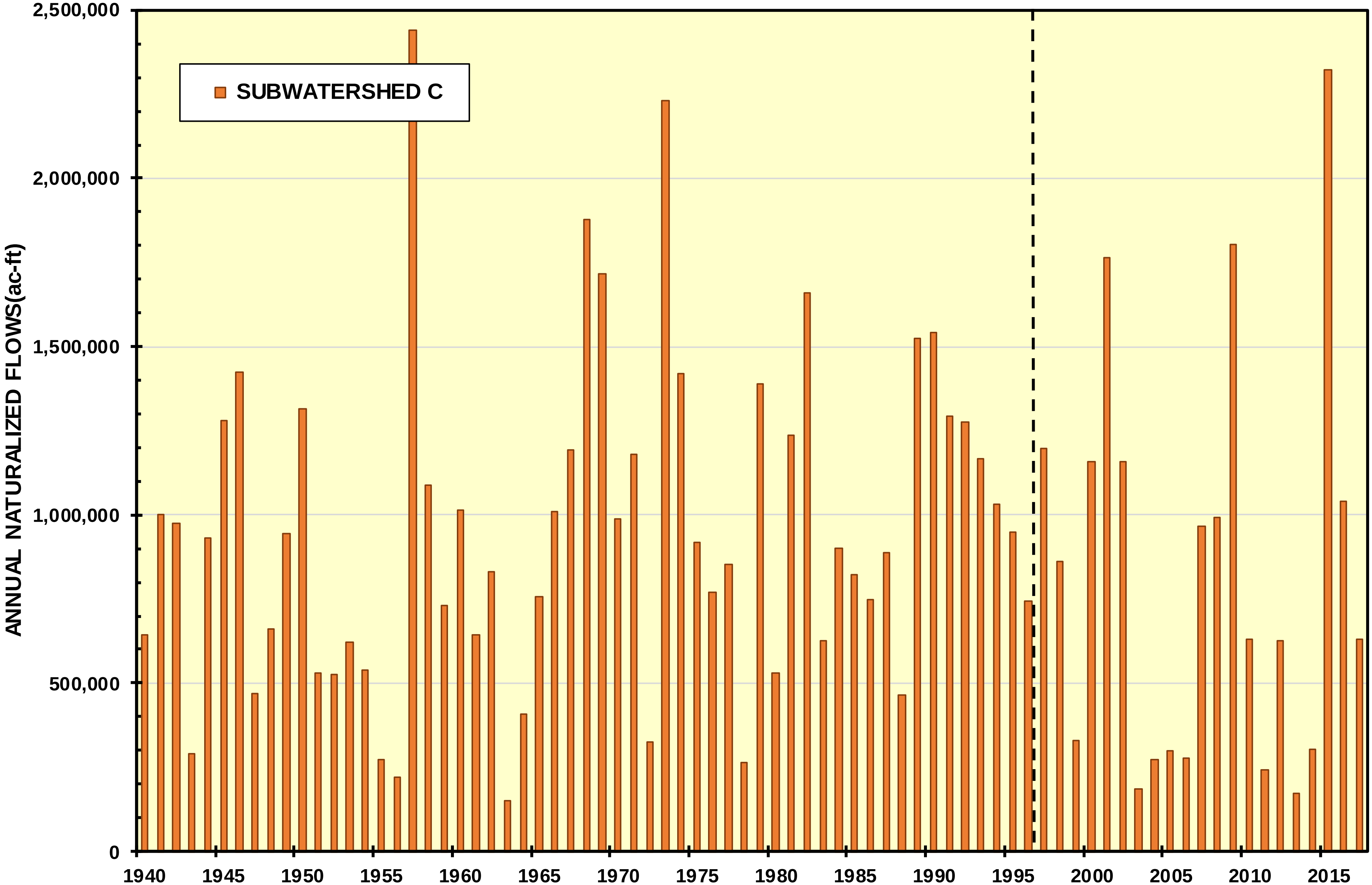


**Figure 2-34 Naturalized Streamflows for Subwatershed D**

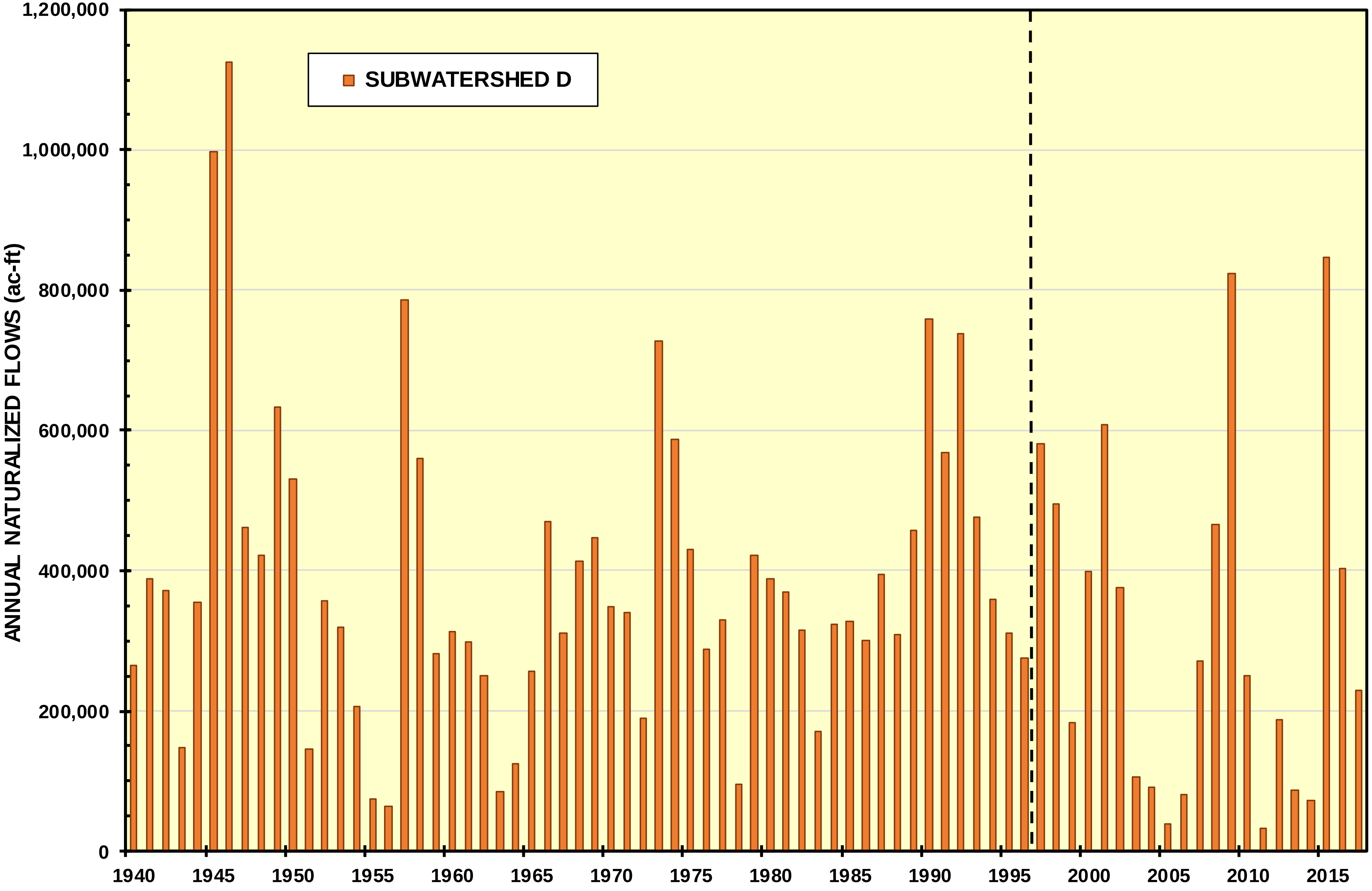


**Figure 2-35 Naturalized Streamflows for Subwatershed E**

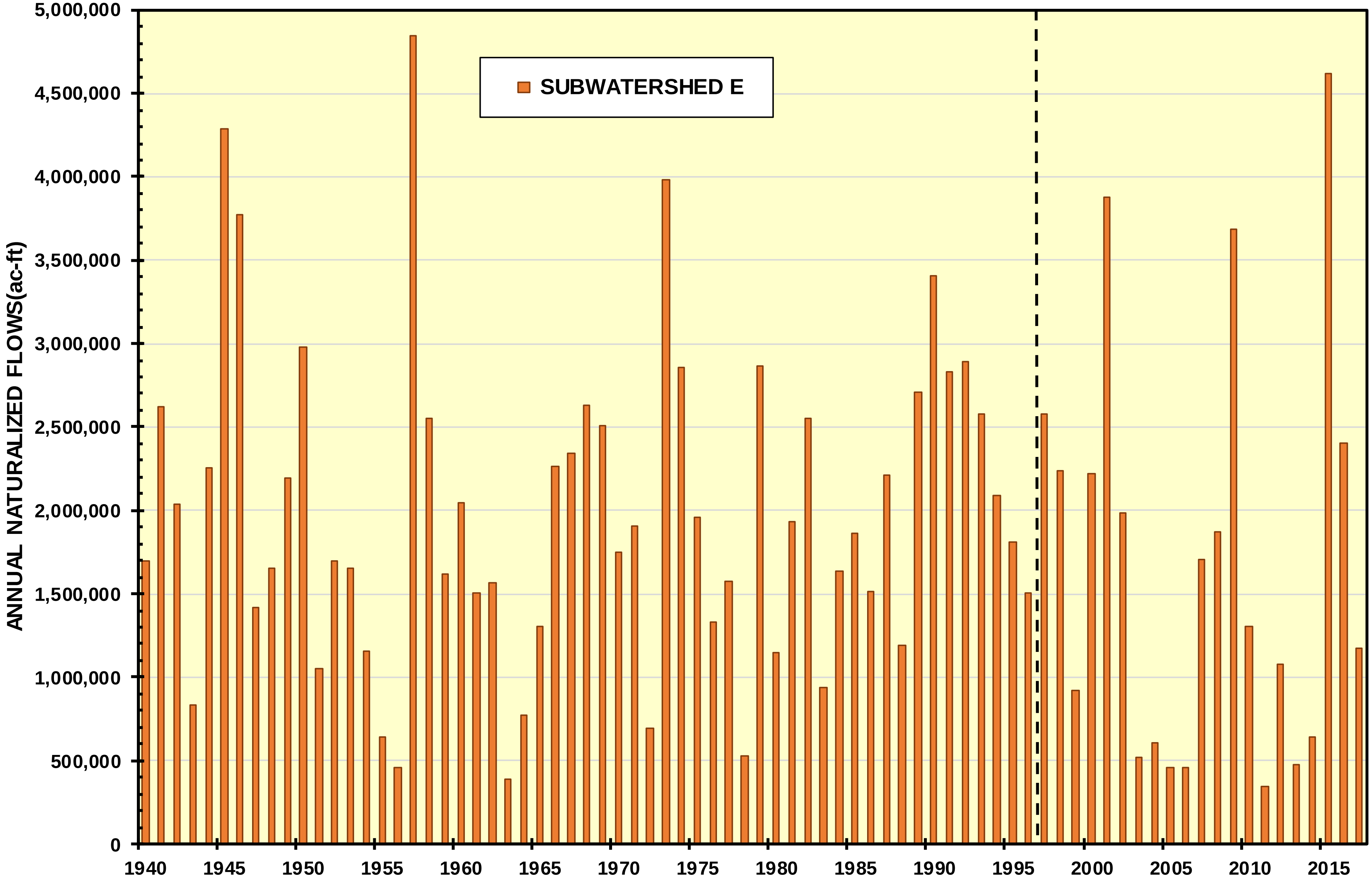


**Figure 2-36   Naturalized Streamflows for Subwatershed F**

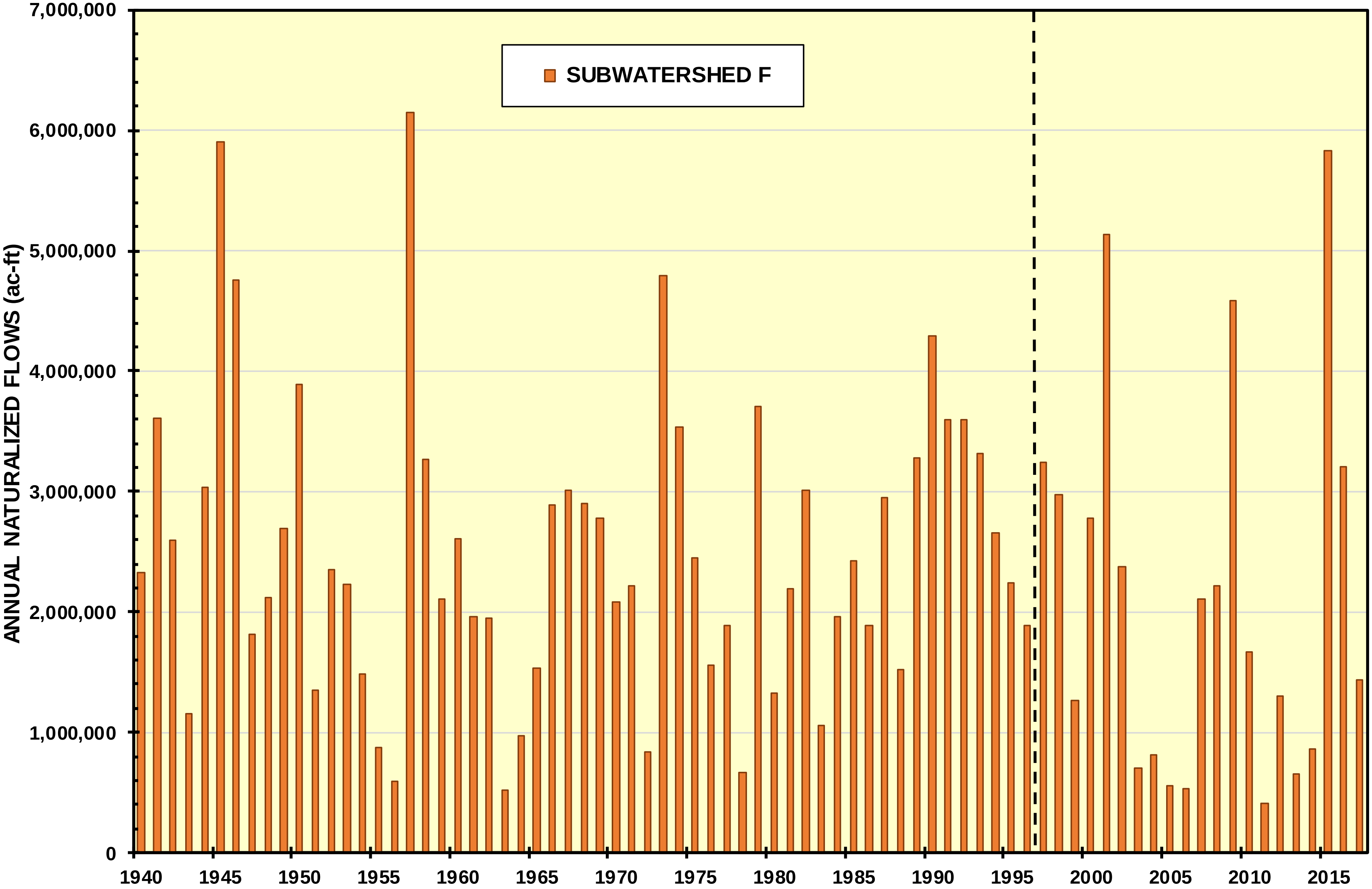
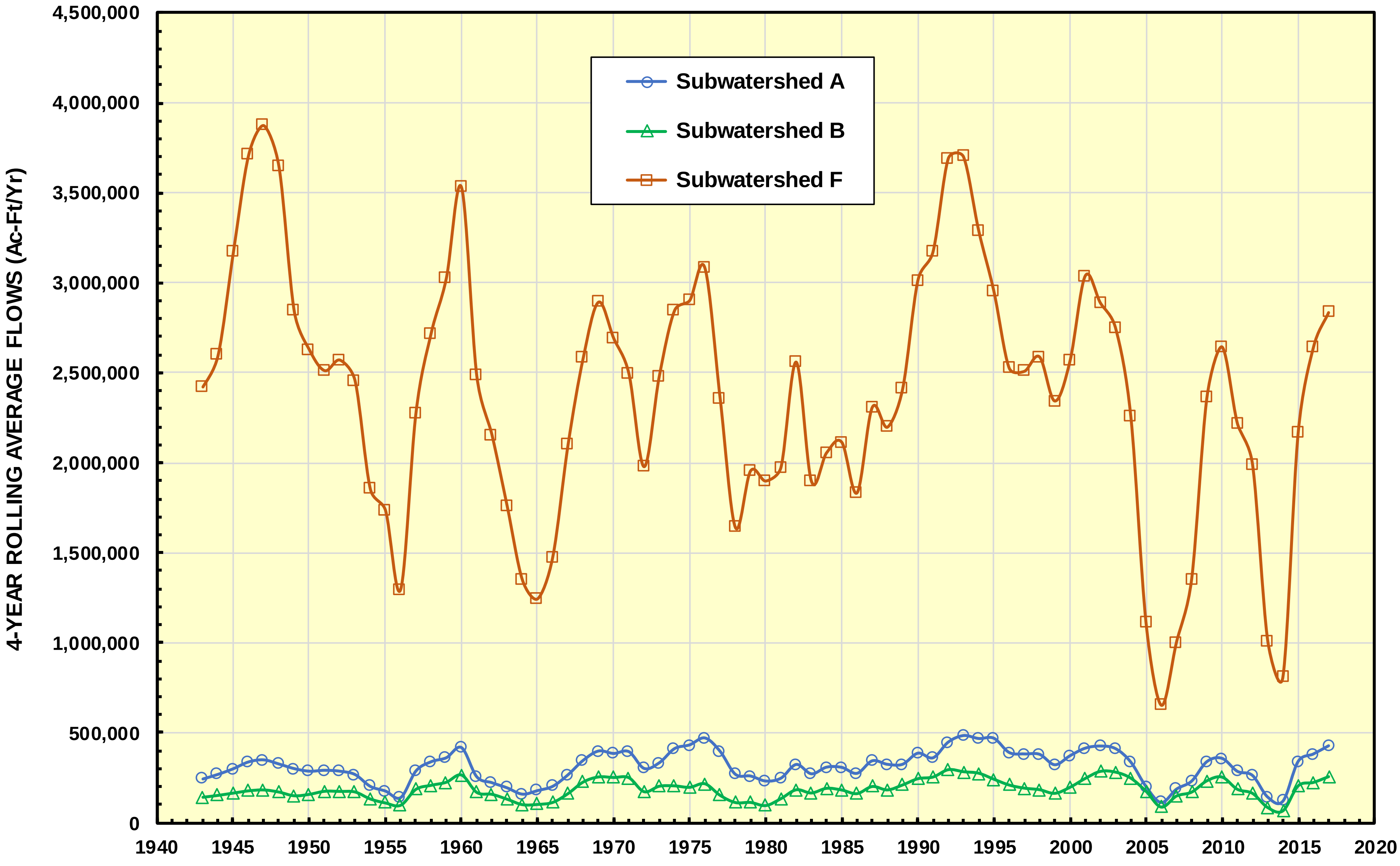


Figure 2-37 Four-Year Running Average Naturalized Streamflows for Subwatersheds A, B, and F



It should also be noted that since 2015, the annual naturalized flows plotted in Figures 2-31 through 2-36 appear to exhibit a downward trend for 2016 and 2017, potentially indicating the beginning of a new drought. However, with the wet conditions that have occurred during 2018 and 2019, the current (July 2019) storage levels in Jim Chapman, Wright Patman, and Lake Sulphur Springs are 100 percent full, and thus the threat of the beginning of a new drought is not imminent.

In overview, the naturalized streamflows developed in this study for the 1997-2017 period for each subwatershed appear to be generally consistent with the previous corresponding naturalized flows for 1940-1996 in terms of annual variations and patterns, and they reflect known trends in observed climatic and hydrologic conditions that have occurred across the basin during this time. The resulting 1997-2017 set of naturalized streamflows is considered to be appropriate and satisfactory for extending the hydrologic data base of the Sulphur WAM.

## 3.0 UPDATED AND EXTENDED RUN 3 VERSION OF SULPHUR WAM

For updating the existing Run 3 version of the Sulphur WAM, the most recent data sets for the model were obtained from the TCEQ on August 21, 2018. These data sets were reviewed, and comparisons of the water rights included in the model were made with specifications in the TCEQ's most recent water rights masterfile. Modifications to the Run 3 data sets were made as described below to update the model to reflect current water rights and to incorporate the extended 1997-2017 monthly naturalized flows and associated net evaporation rates. Simulations then were made with the updated-extended Run 3 version of the model to assess water right reliabilities, to examine diversions and storage for major water rights, to determine firm annual yields for the major reservoirs in the basin, and to evaluate potential unappropriated water at selected locations within the Sulphur Basin.

### 3.1 Modifications to Original Run 3 Version of WAM

The most fundamental changes that have been made to the Run 3 version of the WAM relate to the extension of the hydrologic data base through the year 2017. The extended 1997-2017 monthly naturalized flows for all six of the primary control points in the model (corresponding to Subwatersheds A, B, C, D, E and F) have been incorporated into the WAM data input files. The two control points (F20 and F30) below Wright Patman Lake in Subwatershed F have been eliminated as primary control points as described in Section 2.9. The extended hydrologic data base in the WAM now includes significant new drought periods that occurred since 1996, the last year of the original WAM data base.

It should be noted that as part of updating the Run 8 version the Sulphur WAM to incorporate additional wastewater discharge outfalls, the TCEQ created a number of new control points and modified the connectivity of the control point network. This also resulted in some minor changes to the drainage areas for many of the existing control points in the WAM. To maintain consistency, all of these control point changes have been made in both the updated-extended Run 3 and updated-extended Run 8 versions of the WAM, even though the control points for wastewater discharges are not needed for the Run 3 model. Table 3-1 provides a current list of all control points included in the updated-extended WAM, with associated water rights or wastewater discharges identified and with drainage areas, authorized diversion and storage amounts listed. The locations of these control points are shown on the map of the basin in Figure 3-1.

The existing WAM data input files for historical monthly net evaporation quantities have been extended to include new data for the 1997-2017 period. Reservoir evaporation and precipitation data were extracted from TWDB records for Quads 411, 412 and 413 (see Figure 2-10), and then organized and assigned in the WAM data base to represent net evaporation conditions for each reservoir simulated in the WAM. It should be noted that since the original development of the reservoir evaporation data, the TWDB, in an effort to improve the accuracy of reported monthly reservoir evaporation rates, revised its procedures for determining monthly reservoir evaporation from available evaporation pan data and posted revised monthly values in some cases dating back to 1954 for all quadrangles across the state. These revised evaporation data for Quads 411, 412 and 413 have been compared to the original evaporation data used in the existing Sulphur WAM. The deviations of the revised data from the original data are very small, and based on this analysis, it has been determined that there is no need to replace the 1954-1996 net evaporation data used in developing the original Sulphur WAM with the revised data from the TWDB.

All existing water rights in the Sulphur Basin already were incorporated into TCEQ's existing version of Run 3 of the WAM, so no additional water rights had to be added as part of this study. All water rights are represented in the model in accordance with their authorized diversion and reservoir storage specifications and any stipulated special conditions. It should be noted, however, that one of the diversion amounts for water right P-12810, owned by Daisy Farms LLC, was specified in the existing Run 3 data file as 645 acre-feet/year, but this value is incorrect based on the permit and should be 245 acre-feet/year. This change has been made in the updated-extended Run 3 data file. As with the original Run 3 version of the Sulphur WAM, the area-capacity relationships for reservoirs in the updated-extended Run 3 model reflect authorized maximum storage amounts as specified in their respective water rights, with these typically corresponding to original as-built reservoir conditions.

For Wright Patman Lake, the conservation pool capacity is specified in accordance with the Ultimate Rule Curve that is stipulated in the City of Texarkana's Certificate of Adjudication No. 03-4836 (COA 4836). With this curve, the top of the conservation pool varies monthly in stepwise fashion from a minimum elevation of 224.9 feet msl (265,300 acre-feet of storage capacity) for January through March up to a maximum elevation of 228.6 feet msl (386,900 acre-feet of storage capacity) in June. In the updated-extended Run 3 version of the WAM, the minimum storage capacity below which the City of Texarkana cannot make diversions is specified as zero. While this appears contrary to provisions in contracts between the City and the Corps of Engineers that

## Table 3-1 Summary of Control Points Used in Updated-Extended Sulphur WAM

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| | CONTROL POINT NO. | WAM WATER RIGHT ID | WATER RIGHT NO. [1] | CONTROL POINT DESCRIPTION [2] | PRIORITY DATE | DRAINAGE AREA (sq miles) | AUTHORIZED DIVERSION (ac-ft/yr) | RESERVOIR NAME | AUTHORIZED STORAGE (ac-ft) | NOTES |
| (1) | 121451 | 12145_1 | P 12145 | WR - LOS SENDEROS C & R CO | 04/24/07 | 274.17 | 35.0 | - - | 8.6 | [3 ,5] |
| (2) | 158211 | 15821F | P 5821 | WR - UPPER TRINITY REG WATER DIST | 08/13/04 | 99.69 | 45,000.0 | LK RALPH HALL | 180,000 | |
| (3) | 587301 | 5873_1 | P 5873 | WR - TEXAMERICAS CENTER | 06/16/05 | 7.11 | 1,032.0 | RESERV. NO. 1 | 1,340 | |
| (4) | 587302 | 5873_2 | P 5873 | WR - TEXAMERICAS CENTER | 06/16/05 | 8.51 | 1,928.0 | RESERV. NO. 2 | 2,734 | |
| (5) | A10 | - - | - - | SUBWATERSHED A PRIMARY CP | - - | 521.31 | - - | - - | - - | |
| (6) | A20 | 4800 | C 4800 | WR - CITY OF COOPER | 01/03/77 | 1.48 | 273.0 | CITY LAKE | 164 | |
| (7) | A30 | 4395 | P 4060 | WR - CITY OF COOPER | 09/06/83 | 11.84 | 1,518.0 | BIG CREEK | 4,890 | |
| (8) | A40 | 4797AM_1 | C 4797 | WR - SULPHUR R MWD & COMMERCE | 11/19/65 | 483.24 | 38,520.0 | J CHAPMAN LK | 81,470 | |
| (9) | A40 | 4798_1 | C 4798 | WR - NORTH TEXAS MWD | 11/19/65 | 483.24 | 54,000.0 | J CHAPMAN LK | 114,265 | |
| (10) | A40 | 4799M_1 | C 4799 | WR - CITY OF IRVING | 11/19/65 | 483.24 | 54,000.0 | J CHAPMAN LK | 114,265 | |
| (11) | A41 | - - | - - | WW - CITY OF COOPER | - - | 0.88 | - - | - - | - - | |
| (12) | A42 | - - | - - | WW - TEXAS PARKS & WILDLIFE DEPT | - - | 0.61 | - - | - - | - - | |
| (13) | A43 | - - | - - | WW - DELTA COUNTY MUD | - - | 0.00 | - - | - - | - - | |
| (14) | A50 | - - | - - | Special Purpose or No Longer Used | - - | 109.12 | - - | - - | - - | |
| (15) | A51 | - - | - - | WW - CITY OF LADONIA | - - | 1.31 | - - | - - | - - | |
| (16) | A60 | - - | - - | Special Purpose or No Longer Used | - - | 206.33 | - - | - - | - - | |
| (17) | A61 | - - | - - | WW - CITY OF COMMERCE | - - | 4.69 | - - | - - | - - | |
| (18) | A62 | - - | - - | WW - CITY OF WOLFE CITY | - - | 1.13 | - - | - - | - - | |
| (19) | A64 | - - | - - | WW - CITY OF BAILEY | - - | 0.35 | - - | - - | - - | |
| (20) | A70 | 4795_1 | C 4795 | WR - CITY OF WOLFE CITY | 12/31/25 | 0.91 | 69.0 | WOLFE CITY RES. | 425.0 | |
| (21) | A70 | 4795_2 | C 4795 | WR - CITY OF WOLFE CITY | 08/12/57 | 0.91 | 232.0 | WOLFE CITY RES. | 855.0 | |
| (22) | A80 | 4796_1 | C 4796 | WR - WEBB HILL COUNTRY CLUB INC | 03/11/68 | 0.06 | 80.0 | - - | 39.0 | |
| (23) | A80 | 4796_2 | C 4796 | WR - WEBB HILL COUNTRY CLUB INC | 04/18/83 | 0.06 | - - | - - | 60.0 | |
| (24) | AUDCRK | - - | - - | Special Purpose or No Longer Used | - - | 39.92 | - - | - - | - - | |
| (25) | B10 | - - | - - | SUBWATERSHED B PRIMARY CP | - - | 304.64 | - - | - - | - - | |
| (26) | B11 | - - | - - | WW - CITY OF ROXTON | - - | 3.81 | - - | - - | - - | |
| (27) | B12 | - - | - - | WW - PETTY WTER SUPPLY | - - | 0.54 | - - | - - | - - | |
| (28) | B20 | 4205 | P 3890 | WR - CITY OF PECAN GAP | 04/26/82 | 0.65 | 102.0 | - - | 152.0 | |
| (29) | B30 | - - | - - | Special Purpose or No Longer Used | - - | 0.74 | - - | - - | - - | |

## Table 3-1 continued

| | (1) CONTROL POINT NO. | (2) WAM WATER RIGHT ID | (3) WATER RIGHT NO. [1] | (4) CONTROL POINT DESCRIPTION [2] | (5) PRIORITY DATE | (6) DRAINAGE AREA (sq miles) | (7) AUTHORIZED DIVERSION (ac-ft/yr) | (8) RESERVOIR NAME | (9) AUTHORIZED STORAGE (ac-ft) | (10) NOTES |
|---|---|---|---|---|---|---|---|---|---|---|
| (30) | C10 | - - | - - | SUBWATERSHED C PRIMARY CP | - - | 1,353.25 | - - | - - | - - | |
| (31) | C100 | 5200 | P 5200 | WR - GORDON COUNTRY CLUB | 11/01/88 | 1.44 | 0.0 | - - | 394.0 | |
| (32) | C110 | 4801 | C 4801 | WR - DELTA COUNTRY CLUB | 07/02/79 | 0.20 | 5.0 | - - | 34.0 | |
| (33) | C20 | 4804 | C 4804 | WR - LUMINANT GENERATION CO LLC | 03/05/52 | 1,351.76 | 10,000.0 | - - | 7,100 | [3, 5] |
| (34) | C21 | - - | - - | WW - RIVERCREST ISD | - - | 0.00 | - - | - - | - - | |
| (35) | C22 | - - | - - | Special Purpose or No Longer Used | - - | 7.42 | - - | - - | - - | |
| (36) | C30 | 4803_1 | C 4803 | WR - HELMUT HERMANN ET AL | 06/19/78 | 3.33 | 1,000.0 | - - | 328.0 | |
| (37) | C40 | 4803_2 | C 4803 | WR - HELMUT HERMANN ET AL | 06/19/78 | 1,275.66 | 0.0 | - - | - - | |
| (38) | C30 | 4803_3 | C 4803 | WR - HELMUT HERMANN ET AL | 11/15/82 | 3.33 | 900.0 | - - | - - | |
| (39) | C40 | 4803_4 | C 4803 | WR - HELMUT HERMANN ET AL | 11/15/82 | 1,275.66 | 0.0 | - - | - - | |
| (40) | C41 | - - | - - | Special Purpose or No Longer Used | - - | 0.04 | - - | - - | - - | |
| (41) | C50 | 4802 | C 4802 | WR - ALEXANDER FRICK ET AL | 12/31/55 | 1.78 | 278.0 | - - | 300.0 | |
| (42) | C60 | 3845_3 | P 3845 | WR - SULPHUR BLUFF LAND LLC | 04/11/1997 | 1,147.87 | 11,312.0 | - - | 2,925.0 | [3,5] |
| (43) | C70 | 3845_1 | P 3845 | WR - SULPHUR BLUFF LAND LLC | 09/14/1981 | 51.37 | - - | - - | 26.0 | |
| (44) | C70 | 3845_1 | P 3845 | WR - SULPHUR BLUFF LAND LLC | 09/14/1981 | 51.37 | 2,828.0 | - - | 3,849.0 | [3] |
| (45) | C80 | 3845_2 | P 3845 | WR - SULPHUR BLUFF LAND LLC | 11/07/1984 | 29.61 | 5,500.0 | - - | 3,623.0 | [3,5] |
| (46) | C90 | - - | - - | Special Purpose or No Longer Used | - - | 469.30 | - - | - - | - - | |
| (47) | C91 | - - | - - | WW - LAMAR POWER PARTNERS | - - | 1.28 | - - | - - | - - | |
| (48) | C92 | - - | - - | Special Purpose or No Longer Used | - - | 1.11 | - - | - - | - - | |
| (49) | C93 | - - | - - | Special Purpose or No Longer Used | - - | 1.11 | - - | - - | - - | |
| (50) | C94 | - - | - - | WW - KIMBERLY CLARD | - - | 0.14 | - - | - - | - - | |
| (51) | C95 | - - | - - | WW - TURNER INDUSTRIES | - - | 0.46 | - - | - - | - - | |
| (52) | D10 | - - | - - | SUBWATERSHED D PRIMARY CP | - - | 538.00 | - - | - - | - - | |
| (53) | D100 | 4813 | C 4813 | WR - SULPHUR SPGS COUNTRY CLUB | 12/15/75 | 0.53 | 113.0 | - - | 127.0 | |
| (54) | D101 | - - | - - | WW - CITY OF SULPHUR SPRINGS | - - | 29.28 | - - | - - | - - | |
| (55) | D110 | 4812_1 | C 4812 | WR - CITY OF SULPHUR SPRINGS | 12/01/75 | 0.56 | - - | LAKE COLEMAN | 408.0 | |
| (56) | D110 | 4812_2 | C 4812 | WR - CITY OF SULPHUR SPRINGS | 02/12/85 | 0.56 | 408.0 | - - | - - | |
| (57) | D120 | 4811_1 | C 4811 | WR - CITY OF SULPHUR SPRINGS | 07/24/51 | 70.58 | 2,000.0 | L SULPHUR SPGS | 2,100 | |
| (58) | D120 | 4811_2 | C 4811 | WR - CITY OF SULPHUR SPRINGS | 11/25/68 | 70.58 | 7,800.0 | - - | 14,000 | |

## Table 3-1 continued

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| | CONTROL POINT NO. | WAM WATER RIGHT ID | WATER RIGHT NO. [1] | CONTROL POINT DESCRIPTION [2] | PRIORITY DATE | DRAINAGE AREA (sq miles) | AUTHORIZED DIVERSION (ac-ft/yr) | RESERVOIR NAME | AUTHORIZED STORAGE (ac-ft) | NOTES |
| (59) | D120 | 4811_3 | C 4811 | WR - CITY OF SULPHUR SPRINGS | 11/30/70 | 70.58 | - - | - - | 16,260 | |
| (60) | D120 | 4811_4 | C 4811 | WR - CITY OF SULPHUR SPRINGS | 09/26/83 | 70.58 | - - | - - | 17,838 | |
| (61) | D20 | 4819 | C 4819 | WR - WOCR HOLDING, LLC | 02/18/74 | 5.89 | 0.0 | Romal | 2,360.0 | |
| (62) | D30 | 4818 | C 4818 | WR - ROBERT & DEWATTA CAMPBELL | 12/31/64 | 0.16 | 11.0 | - - | 24.0 | |
| (63) | D40 | 4817 | C 4817 | WR - HANS & WALTRAUD WEISS | 06/30/64 | 460.82 | 333.0 | - - | - - | |
| (64) | D50 | - - | - - | Special Purpose or No Longer Used | - - | 0.28 | - - | - - | - - | |
| (65) | D59 | - - | - - | WW - CITY OF MOUNT VERNON | - - | 0.86 | - - | - - | - - | |
| (66) | D60 | 4816_1 | C 4816 | WR - CITY OF MOUNT VERNON | 03/01/76 | 0.85 | 188.0 | - - | 434.0 | |
| (67) | D60 | 4816_2 | C 4816 | WR - CITY OF MOUNT VERNON | 11/22/82 | 0.85 | 212.0 | - - | - - | |
| (68) | D70 | 4815 | C 4815 | WR - CHARLES & LEWIS HELM | 03/01/76 | 1.69 | 0.0 | - - | 760.0 | |
| (69) | D80 | 4814 | C 4814 | WR - JERRY N JORDAN TRUSTEE ET AL | 07/16/59 | 0.66 | 30.0 | - - | 26.0 | |
| (70) | D90 | 5150 | P 5150 | WR - LARRY MILES ET AL | 07/28/87 | 1.04 | 0.0 | - - | 269.0 | |
| (71) | DIVERT | 2AUDSWATER | P 12810 | WR - DAISY FARMS LLC | 04/12/13 | 31.34 | 17,500.0 | - - | - - | |
| (72) | DSYPE1 | DAISYEX_1 | P 12810 | WR - DAISY FARMS LLC | 04/12/13 | 0.03 | 0.0 | - - | 29.0 | |
| (73) | DSYPE2 | DAISYEX_2 | P 12810 | WR - DAISY FARMS LLC | 04/12/13 | 0.04 | 0.0 | - - | 10.0 | |
| (74) | DSYPE3 | DAISYEX_3 | P 12810 | WR - DAISY FARMS LLC | 04/12/13 | 0.06 | 0.0 | - - | 10.0 | |
| (75) | DSYPE4 | DAISYEX_4 | P 12810 | WR - DAISY FARMS LLC | 04/12/13 | 0.09 | 0.0 | - - | 31.0 | |
| (76) | DSYPE5 | DAISYEX_5 | P 12810 | WR - DAISY FARMS LLC | 04/12/13 | 0.16 | 0.0 | - - | 43.0 | |
| (77) | DSYPE6 | DAISYEX_6 | P 12810 | WR - DAISY FARMS LLC | 04/12/13 | 0.06 | 0.0 | - - | 16.2 | |
| (78) | DSYPP1 | DAISYPR_1 | P 12810 | WR - DAISY FARMS LLC | 04/12/13 | 0.80 | 245.0 | - - | 76.5 | |
| (79) | E10 | - - | - - | SUBWATERSHED E PRIMARY CP | - - | 2,790.69 | - - | - - | - - | |
| (80) | E100 | - - | - - | Special Purpose or No Longer Used | - - | 1.24 | - - | - - | - - | |
| (81) | E110 | - - | - - | Special Purpose or No Longer Used | - - | 0.40 | - - | - - | - - | |
| (82) | E120 | 4822 | C 4822 | WR - BERNICE ANN BALDWIN | 07/31/67 | 0.29 | 100.0 | - - | 196.0 | |
| (83) | E130 | 4821 | C 4821 | WR - ANNA PEARL LEWIS | 12/31/53 | 0.05 | 1.0 | - - | 1.0 | |
| (84) | E140 | 5562_1 | P 5562 | WR - LUMINANT MINING CO LLC | 11/19/96 | 0.21 | 9.0 | - - | - - | |
| (85) | E150 | 5562_2 | P 5562 | WR - LUMINANT MINING CO LLC | 11/19/96 | 1.28 | 79.0 | - - | - - | |
| (86) | E160 | 4820 | C 4820 | WR - JOE R MENEFEE | 12/31/64 | 21.97 | 22.0 | - - | - - | |
| (87) | E170 | 5562_3 | P 5562 | WR - LUMINANT MINING CO LLC | 11/19/96 | 0.50 | 37.0 | - - | - - | |

## Table 3-1 continued

| | (1) CONTROL POINT NO. | (2) WAM WATER RIGHT ID | (3) WATER RIGHT NO. [1] | (4) CONTROL POINT DESCRIPTION [2] | (5) PRIORITY DATE | (6) DRAINAGE AREA (sq miles) | (7) AUTHORIZED DIVERSION (ac-ft/yr) | (8) RESERVOIR NAME | (9) AUTHORIZED STORAGE (ac-ft) | (10) NOTES |
|---|---|---|---|---|---|---|---|---|---|---|
| (88) | E180 | - - | - - | Special Purpose or No Longer Used | - - | 364.53 | - - | - - | - - | |
| (89) | E190 | 4810 | C 4810 | WR - DONELSON FAMILY LTD | 04/04/60 | 1.96 | 200.0 | MAGIC VALLEY LK | 200.0 | |
| (90) | E191 | - - | - - | WW - CITY OF ANNONA | - - | 0.51 | - - | - - | - - | |
| (91) | E192 | - - | - - | WW - CITY OF CLARKSVILLE | - - | 10.44 | - - | - - | - - | |
| (92) | E20 | - - | - - | Special Purpose or No Longer Used | - - | 799.08 | - - | - - | - - | |
| (93) | E200 | 4809M | C 4809 | WR - RED RIVER COUNTY WCID 1 | 01/20/64 | 2.91 | 1,120.0 | LANGFORD CK LK | 1,225.0 | |
| (94) | E200 | 4809I | C 4809 | WR - RED RIVER COUNTY WCID 1 | 01/20/64 | 2.91 | 1.0 | - - | - - | |
| (95) | E205 | - - | - - | Special Purpose or No Longer Used | - - | 0.52 | - - | - - | - - | |
| (96) | E210 | 4808 | C 4808 | WR - RED RIVER COUNTRY CLUB | 01/06/75 | 3.10 | 0.0 | - - | 670.0 | |
| (97) | E220 | 4807 | C 4807 | WR - MARY MARGARET VAUGHAN | 09/22/69 | 0.29 | 22.0 | - - | 75.0 | |
| (97) | E220 | 4806_1 | C 4806 | WR - LAURA E VAUGHAN ET AL | 09/22/69 | 0.29 | 8.4 | - - | - - | |
| (98) | E221 | - - | - - | WW - CITY OF DETROIT | - - | 2.37 | - - | - - | - - | |
| (99) | E222 | - - | - - | WW - CITY OF BLOSSOM | - - | 4.10 | - - | - - | - - | |
| (100) | E230 | - - | - - | Special Purpose or No Longer Used | - - | 0.34 | - - | - - | - - | |
| (101) | E240 | 4805_1 | C 4805 | WR - E P LAND AND CATTLE CO | 01/05/81 | 0.05 | - - | - - | 186.0 | |
| (102) | E250 | IF4805 | C 4805 | WR - E P LAND AND CATTLE CO | 01/05/81 | 1,448.29 | - - | - - | - - | |
| (103) | E260 | 4805_2 | C 4805 | WR - E P LAND AND CATTLE CO | 01/05/81 | 0.07 | - - | - - | 1,307.0 | |
| (104) | E260 | 4805_3 | C 4805 | WR - E P LAND AND CATTLE CO | 01/05/81 | 0.07 | 2,500.0 | - - | - - | |
| (105) | E270 | 4805_4 | C 4805 | WR - E P LAND AND CATTLE CO | 01/05/81 | 0.52 | 500.0 | - - | 570.0 | |
| (106) | E271 | - - | - - | WW - CITY OF TALCO | - - | 0.02 | - - | - - | - - | |
| (107) | E272 | - - | - - | WW - CITY OF BOGATA | - - | 1.83 | - - | - - | - - | |
| (108) | E30 | 4828 | C 4828 | WR - GLASS CLUB LAKE INC | 01/29/73 | 0.93 | 0.0 | - - | 500.0 | |
| (109) | E40 | 4827_1 | C 4827 | BROVENTURE COMPANY INC | 10/18/74 | 3.83 | 0.0 | - - | 796.0 | |
| (110) | E50 | 4827_2 | C 4827 | BROVENTURE COMPANY INC | 10/18/74 | 1.77 | 0.0 | - - | 659.0 | |
| (111) | E60 | 4825 | C 4825 | WR - ROBERT CROOKS ET AL | 12/31/63 | 0.07 | 20.0 | - - | 30.0 | |
| (112) | E70 | 4826 | C 4826 | ELLIS-KELLY LAKE CLUB | 01/08/73 | 0.68 | - - | - - | 151.0 | |
| (113) | E80 | 4823 | C 4823 | WR - ARDELIA GAUNTT | 06/01/65 | 0.09 | 23.0 | - - | 24.0 | |
| (114) | E90 | 4824 | C 4824 | WR - WALTER W LEE | 06/01/65 | 0.04 | 8.0 | - - | - - | |
| (115) | F10 | - - | - - | SUBWATERSHED F PRIMARY CP | - - | 3,546.52 | - - | - - | - - | |

## Table 3-1 continued

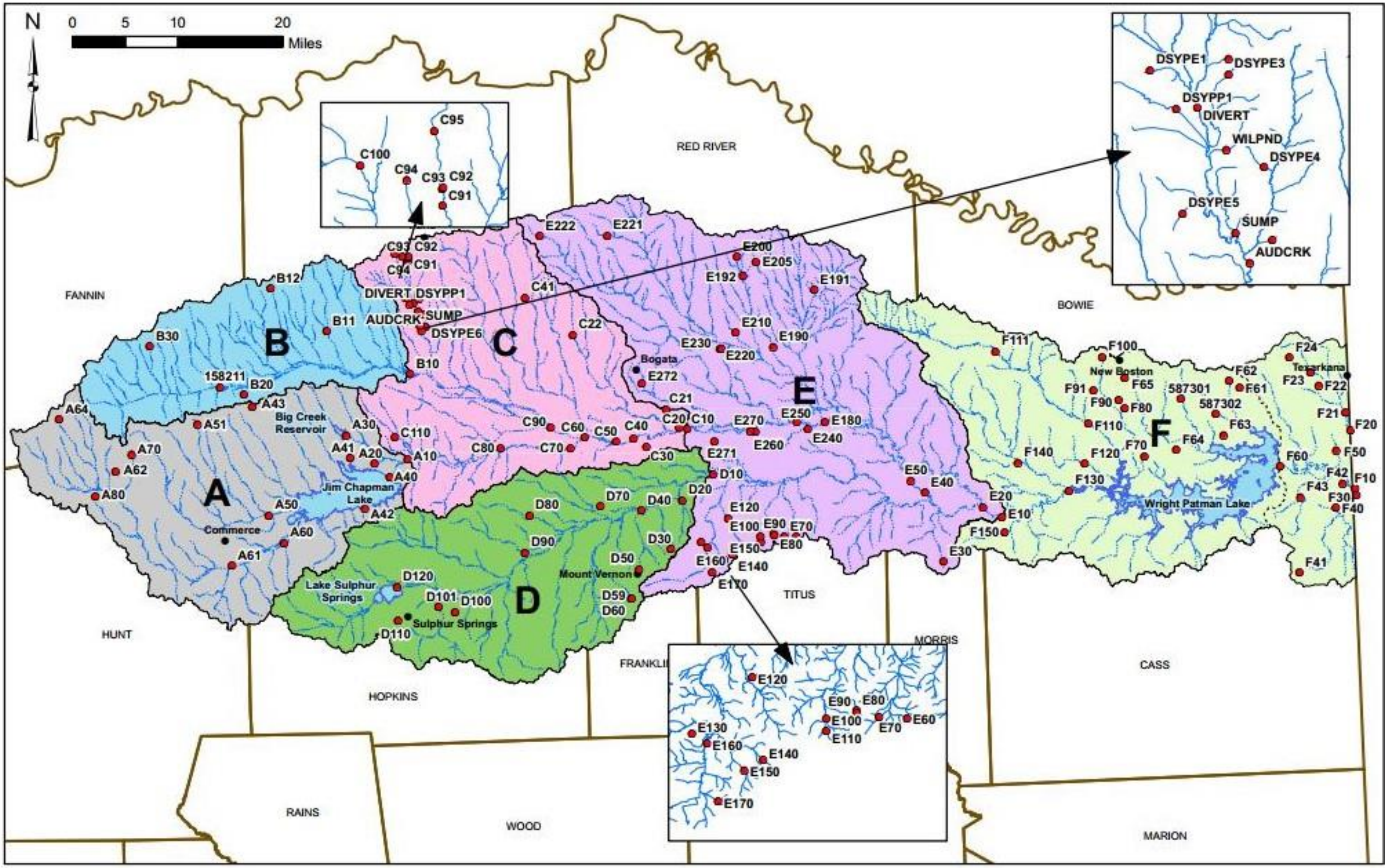
| | (1) CONTROL POINT NO. | (2) WAM WATER RIGHT ID | (3) WATER RIGHT NO. [1] | (4) CONTROL POINT DESCRIPTION [2] | (5) PRIORITY DATE | (6) DRAINAGE AREA (sq miles) | (7) AUTHORIZED DIVERSION (ac-ft/yr) | (8) RESERVOIR NAME | (9) AUTHORIZED STORAGE (ac-ft) | (10) NOTES |
|---|---|---|---|---|---|---|---|---|---|---|
| (116) | F100 | 4831 | C 4831 | WR - CITY OF NEW BOSTON | 06/30/14 | 0.73 | 31.0 | - - | 259.0 | |
| (117) | F110 | 4830 | C 4830 | WR - ESTATE OF E D SIMMS ET AL | 04/30/40 | 101.19 | 378.0 | - - | - - | |
| (118) | F111 | - - | - - | WW - CITY OF DE KALB | - - | 50.23 | - - | - - | - - | |
| (119) | F120 | 4834 | C 4834 | WR - ESTATE OF E D SIMMS ET AL | 04/30/40 | 17.53 | 39.0 | - - | 15.0 | [3, 5] |
| (120) | F130 | - - | - - | Special Purpose or No Longer Used | - - | 2,937.07 | - - | - - | - - | |
| (121) | F140 | 4829 | C 4829 | WR - ESTATE OF E D SIMMS ET AL | 04/30/40 | 8.13 | 4.0 | - - | - - | |
| (122) | F150 | 5449ON | P 5449 | WR - TEXAS PARKS & WILDLIFE DEPT | 02/18/93 | 9.93 | - - | - - | 504.0 | |
| (123) | F151 | 5449OC | P 5449 | WR - TEXAS PARKS & WILDLIFE DEPT | 02/18/93 | 9.93 | 863.0 | - - | 863.0 | [3, 4] |
| (124) | F20 | - - | - - | Special Purpose or No Longer Used | - - | 41.71 | - - | - - | - - | |
| (125) | F21 | - - | - - | WW - CITY OF TEXARKANA | - - | 37.18 | - - | - - | - - | |
| (126) | F22 | - - | - - | WW - NALCO COMPANY | - - | 0.84 | - - | - - | - - | |
| (127) | F23 | - - | - - | WW - CITY OF TEXARKANA | - - | 1.03 | - - | - - | - - | |
| (128) | F24 | - - | - - | WW - ALUMAX MILL | - - | 0.13 | - - | - - | - - | |
| (129) | F30 | - - | - - | Special Purpose or No Longer Used | - - | 45.57 | - - | - - | - - | |
| (130) | F40 | 4838 | C 4838 | INTERNATIONAL PAPER COMPANY | 11/17/75 | 0.40 | - - | - - | 52.0 | |
| (131) | F41 | - - | - - | WW - CITY OF QUEEN CITY | - - | 0.60 | - - | - - | - - | |
| (132) | F42 | - - | - - | WW - INTERNATIONAL PAPER | - - | 4.00 | - - | - - | - - | |
| (133) | F43 | - - | - - | Special Purpose or No Longer Used | - - | 4.46 | - - | - - | - - | |
| (134) | F50 | 4837 | C 4837 | WR - LEON KENNEDY & H MADDOX | 06/30/62 | 3.26 | 80.0 | - - | 550.0 | |
| (135) | F60 | 4836M1 | C 4836 | WR - CITY OF TEXARKANA | 03/05/51 | 3,412.54 | 14,572.0 | W PATMAN LK | 386,900 | |
| (136) | F61 | - - | - - | Special Purpose or No Longer Used | - - | 0.25 | - - | - - | - - | |
| (137) | F62 | - - | - - | WW - TEXAMERICA | - - | 1.34 | - - | - - | - - | |
| (138) | F63 | - - | - - | WW - CITY OF REDWATER | - - | 0.14 | - - | - - | - - | |
| (139) | F64 | - - | - - | WW - CITY OF MAUD | - - | 1.10 | - - | - - | - - | |
| (140) | F65 | - - | - - | WW - CITY OF NEW BOSTON | - - | 0.01 | - - | - - | - - | |
| (141) | F70 | 4835 | C 4835 | WR - KHALID MALIK | 12/31/48 | 0.34 | 0.0 | - - | 78.0 | |
| (142) | F80 | 4833_1 | C 4833 | WR - H C PRANGE JR | 02/01/56 | 0.01 | - - | - - | 1.0 | |

## Table 3-1 continued

| | (1) CONTROL POINT NO. | (2) WAM WATER RIGHT ID | (3) WATER RIGHT NO. [1] | (4) CONTROL POINT DESCRIPTION [2] | (5) PRIORITY DATE | (6) DRAINAGE AREA (sq miles) | (7) AUTHORIZED DIVERSION (ac-ft/yr) | (8) RESERVOIR NAME | (9) AUTHORIZED STORAGE (ac-ft) | (10) NOTES |
|---|---|---|---|---|---|---|---|---|---|---|
| (143) | F80 | 4833_2 | C 4833 | WR - H C PRANGE JR | 02/01/56 | 0.01 | 7.9 | - - | 12.8 | [3, 4] |
| (144) | F90 | 4832 | C 4832 | WR - CITY OF NEW BOSTON | 08/29/44 | 0.55 | 325.0 | - - | 8.0 | |
| (145) | F91 | - - | - - | Special Purpose or No Longer Used | - - | 1.29 | - - | - - | - - | |
| (146) | SUMP | 3FILLSUMP | P 12810 | WR - DAISY FARMS LLC | - - | 0.59 | 0.0 | SUMP | 1,229.0 | |
| (147) | WILPND | 4WILLPOND | p 12810 | WR - DAISY FARMS LLC | - - | 0.33 | 0.0 | WILLIAMS POND | 4,102.0 | |

Notes: [1] P means Permit.
C means Certificate of Adjudication.
[2] WR means Water Right with name of Owner.
WW means wastewater discharge with name of Wastewater Discharger.
[3] Off-channel reservoir; drainage area is for diversion into off-channel reservoir
[4] Authorized diversion amount is only annual refill limit.
[5] Authorized diversion amount is both demand and annual refill limit.

**Figure 3-1 Control Points Used in Updated-Extended WAM for Sulphur River Basin**



state the City is entitled to use stored water in the reservoir only above elevation 220.0 feet msl (145,300 acre-feet of storage capacity), there is other language in these contracts that suggests, with the expressed approval of the Corps, stored water below this minimum elevation can be used by the City during critical dry periods. In the original Run 3 version of the Sulphur WAM, the minimum storage capacity also was assumed to be zero.

Jim Chapman Lake is still represented in the updated-extended Run 3 version of the WAM with three conservation pools corresponding to the authorized storage amounts stipulated in the three water rights that have authority to divert water from the reservoir. These are COA 4797 owned by the City of Commerce and the Sulphur River Municipal Water District that has 81,470 acre-feet of authorized storage capacity, COA 4798 owned by the North Texas Municipal Water District that has 114,265 acre-feet of authorized storage capacity, and COA 4799 owned by the City of Irving that has 114,265 acre-feet of authorized storage capacity. Evaporation losses from the reservoir are prorated to each of the pools based on their relative monthly storage amounts, and inflows to the reservoir are allocated to each of the pools in the order that the three water rights are listed in the WAM data input files, i.e., COA 4797 first, then COA 4798, and finally COA 4799, which is arbitrary since all three of these water rights have the same priority date.

### 3.2 Simulated Water Right Reliabilities from Updated-Extended Run 3 WAM

The updated-extended Run 3 version of the WAM has been operated with the extended record of 1940-2017 hydrologic data, and the volume reliabilities of the diversions for all water rights have been determined. These values are presented in Table 3-2 for all water rights listed in order of water right numbers, with certificates of adjudication first, followed by permits. Pertinent descriptive information is also included for each water right. As shown, the volume reliabilities range from 100 percent for water rights with reservoirs, down to less than 50 percent for those with relatively junior priority dates and no reservoir storage capacity. The overall average reliability for the entire basin is 86.3 percent. The reliabilities of the diversions for the water right holders with major reservoirs range from a low of 98.5 percent for the Sulphur River Municipal Water District and the City of Commerce in Jim Chapman Lake up to 100 percent for the City of Texarkana in Wright Patman Lake.

### 3.3 Simulated Reservoir Storage from Updated-Extended Run 3 WAM

Graphs of the monthly variations of storage in the three largest reservoirs in the Sulphur Basin - Wright Patman Lake, Jim Chapman Lake and Lake Ralph Hall - as simulated with the updated-extended Run 3 version of the WAM for the 1940-2017 period are presented in Figures 3-2 through 3-4. A similar graph of the simulated monthly variations of storage in Lake Sulphur Springs and Big Creek Reservoir is presented in Figure 3-5. As shown, all of these reservoirs exhibit storage variations in response wet and dry periods. The cyclic annual pattern of the storage trace for Wright Patman Lake results from use of the Ultimate Rule Curve for top of the conservation pool.

## Table 3-2 Diversion Reliabilities for Water Rights Simulated with Updated-Extended Run 3 Version of Sulphur WAM

| | WATER RIGHT ID | WATER RIGHT OWNER | SUB WATER-SHED | PRIORITY DATE yyyymmdd | AUTHORIZED STORAGE ac-ft | AUTHORIZED DIVERSION ac-ft/year | SIMULATED AVERAGE DIVERSION ac-ft/year | VOLUME RELIABILITY % |
|---|---|---|---|---|---|---|---|---|
| (1) | C 4795 | CITY OF WOLFE CITY | A | 19251231 | 425 | 69.0 | 68.1 | 98.7 |
| (2) | C 4795 | CITY OF WOLFE CITY | A | 19570812 | 430 | 232.0 | 226.2 | 97.5 |
| (3) | C 4796 | WEBB HILL COUNTRY CLUB INC | A | 19680311 | 60 | 80.0 | 20.9 | 26.2 |
| (4) | C 4797 | COMMERCE-SULPHUR RIVER MWD | A | 19651119 | 81,470 | 38,520.0 | 37,930.3 | 98.5 |
| (5) | C 4798 | NORTH TEXAS MUN WATER DIST | A | 19651119 | 114,265 | 54,000.0 | 53,941.2 | 99.9 |
| (6) | C 4799 | CITY OF IRVING | A | 19651119 | 114,265 | 54,000.0 | 52,299.1 | 96.9 |
| (7) | C 4800 | CITY OF COOPER | A | 19770103 | 164 | 273.0 | 250.2 | 91.7 |
| (8) | C 4801 | DELTA COUNTRY CLUB | C | 19790702 | - - | 5.0 | 5.0 | 100.0 |
| (9) | C 4802 | ALEXANDER FRICK ET AL | C | 19551231 | 300 | 278.0 | 266.8 | 96.0 |
| (10) | C 4803 | HERMANN, CHRISTA & HELMUT | C | 19780619 | 328 | 1,000.0 | 863.8 | 86.4 |
| (11) | C 4803 | HERMANN, CHRISTA & HELMUT | C | 19821115 | - - | 900.0 | 666.9 | 74.1 |
| (12) | C 4804 | LUMINANT GENERATION CO LLC | C | 19520306 | 7,100 | 10,000.0 | 9,681.2 | 96.8 |
| (13) | C 4805 | E P LAND AND CATTLE COMPANY | E | 19810105 | 2,063 | 500.0 | 500.0 | 100.0 |
| (14) | C 4805 | E P LAND AND CATTLE COMPANY | E | 19810105 | - - | 2,500.0 | 1,974.4 | 79.0 |
| (15) | C 4806 | LAURA E VAUGHAN ET AL | E | 19690922 | - - | 8.4 | 8.4 | 99.8 |
| (16) | C 4807 | VAUGHAN, MARY MARGARET | E | 19690922 | - - | 22.0 | 22.0 | 99.8 |
| (17) | C 4809 | RED RIVER COUNTY WCID 1 | E | 19640120 | 1,225 | 1,119.0 | 1,023.1 | 91.3 |
| (18) | C 4809 | RED RIVER COUNTY WCID 1 | E | 19640120 | - - | 1.0 | 0.9 | 89.0 |
| (19) | C 4810 | DONELSON FAMILY LTD | E | 19600404 | 200 | 200.0 | 192.4 | 96.2 |
| (20) | C 4811 | CITY OF SULPHUR SPRINGS | D | 19510724 | 17,838 | 2,000.0 | 1,990.0 | 99.5 |
| (21) | C 4811 | CITY OF SULPHUR SPRINGS | D | 19681125 | - - | 7,800.0 | 7,744.3 | 99.3 |
| (22) | C 4812 | CITY OF SULPHUR SPRINGS | D | 19850212 | 408 | 408.0 | 306.8 | 75.2 |
| (23) | C 4813 | SULPHUR SPRINGS COUNTRY CLUB | D | 19751215 | - - | 113.0 | 106.7 | 94.4 |
| (24) | C 4814 | JERRY/LENA JORDAN TRUSTEE | D | 19590716 | 26 | 30.0 | 28.2 | 94.1 |
| (25) | C 4816 | CITY OF MOUNT VERNON | D | 19760301 | 434 | 188.0 | 169.5 | 90.2 |

## Table 3-2 continued

| | WATER RIGHT ID | WATER RIGHT OWNER | SUB WATER-SHED | PRIORITY DATE yyyymmdd | AUTHORIZED STORAGE ac-ft | AUTHORIZED DIVERSION ac-ft/year | SIMULATED AVERAGE DIVERSION ac-ft/year | VOLUME RELIABILITY % |
|---|---|---|---|---|---|---|---|---|
| (26) | C 4816 | CITY OF MOUNT VERNON | D | 19821122 | - - | 212.0 | 185.1 | 87.3 |
| (27) | C 4817 | HANS & WALTRAUD WEISS | D | 19640630 | - - | 333.0 | 243.0 | 73.0 |
| (28) | C 4818 | CAMPBELL, DEWITTA & ROBERT W | D | 19641231 | 24 | 11.0 | 10.9 | 98.8 |
| (29) | C 4820 | MENEFEE, JOE R | E | 19641231 | - - | 22.0 | 12.2 | 55.3 |
| (30) | C 4821 | LEWIS, ANNA PEARL | E | 19531231 | 1 | 1.0 | 1.0 | 96.0 |
| (31) | C 4822 | BALDWIN, BERNICE ANN | E | 19670731 | 196 | 100.0 | 91.8 | 91.8 |
| (32) | C 4823 | GAUNTT, ARDELIA | E | 19650601 | 24 | 23.0 | 19.7 | 85.6 |
| (33) | C 4824 | LEE, WALTER W | E | 19650601 | - - | 8.0 | 1.5 | 19.3 |
| (34) | C 4825 | ROBERT CROOKS ET AL | E | 19631231 | 30 | 20.0 | 18.7 | 93.5 |
| (35) | C 4829 | ESTATE OF A D SIMMS ET AL | F | 19400430 | - - | 4.0 | 2.8 | 69.8 |
| (36) | C 4830 | ESTATE OF A D SIMMS ET AL | F | 19400430 | - - | 378.0 | 256.4 | 67.8 |
| (37) | C 4831 | CITY OF NEW BOSTON | F | 19140630 | 259 | 31.0 | 31.0 | 100.0 |
| (38) | C 4832 | CITY OF NEW BOSTON | F | 19440829 | 8 | 325.0 | 155.6 | 47.9 |
| (39) | C 4833 | H C PRANGE JR | F | 19560131 | 14 | 7.9 | [1] | [1] |
| (40) | C 4834 | ESTATE OF A D SIMMS ET AL | F | 19400430 | 15 | 39.0 | 36.2 | 92.7 |
| (41) | C 4836 | CITY OF TEXARKANA | F | 19510305 | 386,900 | 14,572.0 | 14,572.0 | 100.0 |
| (42) | C 4836 | CITY OF TEXARKANA | F | 19570217 | - - | 10,428.0 | 10,428.0 | 100.0 |
| (43) | C 4836 | CITY OF TEXARKANA | F | 19670919 | - - | 20,000.0 | 20,000.0 | 100.0 |
| (44) | C 4836 | CITY OF TEXARKANA | F | 19570217 | - - | 35,000.0 | 35,000.0 | 100.0 |
| (45) | C 4836 | CITY OF TEXARKANA | F | 19670919 | - - | 100,000.0 | 100,000.0 | 100.0 |
| (46) | C 4837 | MADDOX, HENRY JR ET UX | F | 19620630 | 550 | 80.0 | 80.0 | 100.0 |
| (47) | P 4060 | CITY OF COOPER | A | 19830906 | 4,890 | 1,518.0 | 1,518.0 | 100.0 |
| (48) | P 3845 | SULPHUR BLUFF LAND LLC | C | 19810914 | 7,498 | 2,828.0 | 2,826.4 | 99.9 |
| (49) | P 3845 | SULPHUR BLUFF LAND LLC | C | 19841107 | 2,925 | 5,500.0 | 4,681.1 | 85.1 |
| (50) | P 3845 | SULPHUR BLUFF LAND LLC | C | 19970411 | - - | 11,312.0 | 9,219.0 | 81.5 |

## Table 3-2 continued

| | WATER RIGHT ID | WATER RIGHT OWNER | SUB WATER-SHED | PRIORITY DATE yyyymmdd | AUTHORIZED STORAGE ac-ft | AUTHORIZED DIVERSION ac-ft/year | SIMULATED AVERAGE DIVERSION ac-ft/year | VOLUME RELIABILITY % |
|---|---|---|---|---|---|---|---|---|
| (51) | P 3890 | CITY OF PECAN GAP | B | 19820426 | 152 | 102.0 | 99.5 | 97.6 |
| (52) | P 5449 | TEXAS PARKS & WILDLIFE DEPT | F | 19930218 | - - | 863.0 | [1] | [1] |
| (53) | P 5562 | LUMINANT MINING COMPANY LLC | E | 19961119 | - - | 9.0 | 5.3 | 58.6 |
| (54) | P 5562 | LUMINANT MINING COMPANY LLC | E | 19961119 | - - | 79.0 | 45.6 | 57.7 |
| (55) | P 5562 | LUMINANT MINING COMPANY LLC | E | 19961119 | - - | 37.0 | 21.1 | 57.1 |
| (56) | P 5821 | UPPER TRINITY REG WATER DIST | B | 20040813 | 180,000 | 45,000.0 | 44,400.0 | 98.7 |
| (57) | P 5873 | TEXAMERICAS CENTER | F | 20050616 | 1,340 | 1,032.0 | 1,015.5 | 98.4 |
| (58) | P 5873 | TEXAMERICAS CENTER | F | 20050616 | 2,734 | 1,928.0 | 1,875.2 | 97.3 |
| (59) | P 12145 | LOS SENDEROS CATTLE & RANCH CO | D | 20070424 | 8.6 | 35.0 | 28.5 | 81.3 |
| (60) | P 12810 | DAISY FARMS LLC | C | 20130412 | 1,368 | 245.0 | 200.2 | 81.7 |
| (61) | P 12810 | DAISY FARMS LLC | C | 20130412 | 4,179 | 17,500.0 | 13,958.3 | 79.8 |

Note: [1] Both Water Right No. C-4833 and No. P-5447 authorize refilling of an off-channel with maximum annual diversion limits, but there is no annual target diversion amount. Therefore, the diversion reliabilities for these water rights cannot be calculated.

**Figure 3-2 Storage in Wright Patman Lake**
**Simulated with Updated-Extended Run 3 Version of Sulphur WAM**

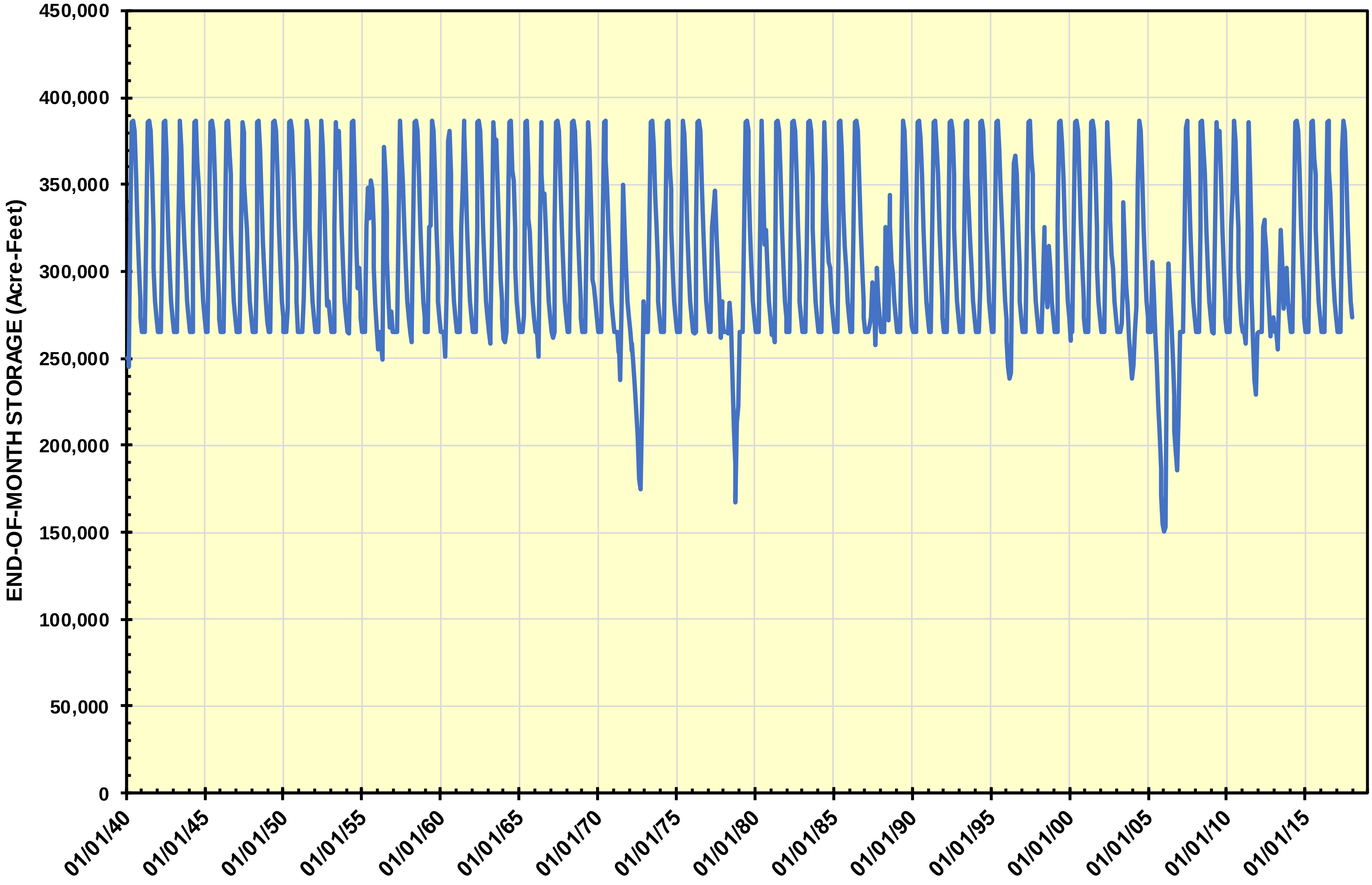


**Figure 3-3 Storage in Jim Chapman Lake**
**Simulated with Updated-Extended Run 3 Version of Sulphur WAM**

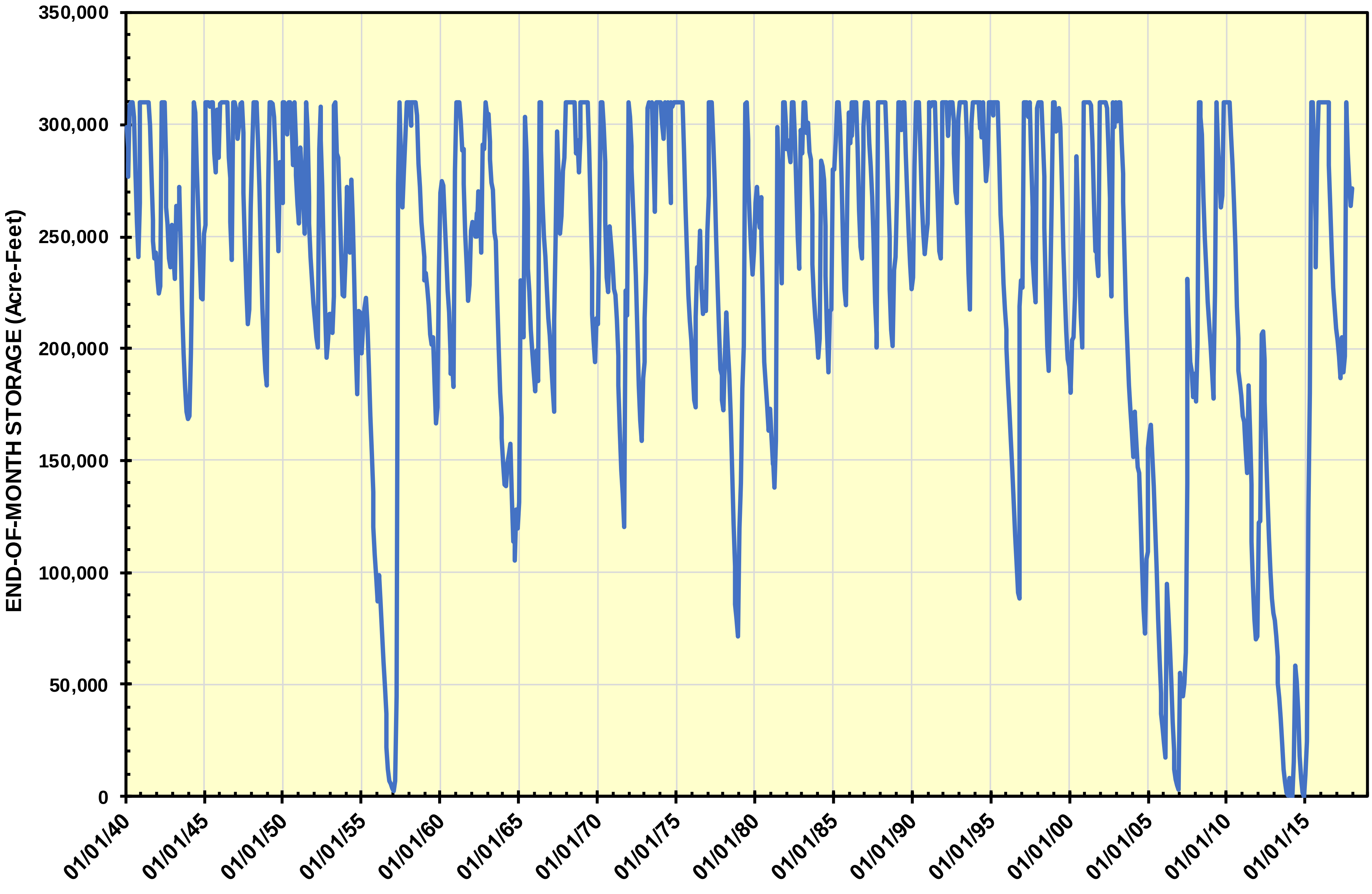


**Figure 3-4 Storage in Lake Ralph Hall**
**Simulated with Updated-Extended Run 3 Version of Sulphur WAM**

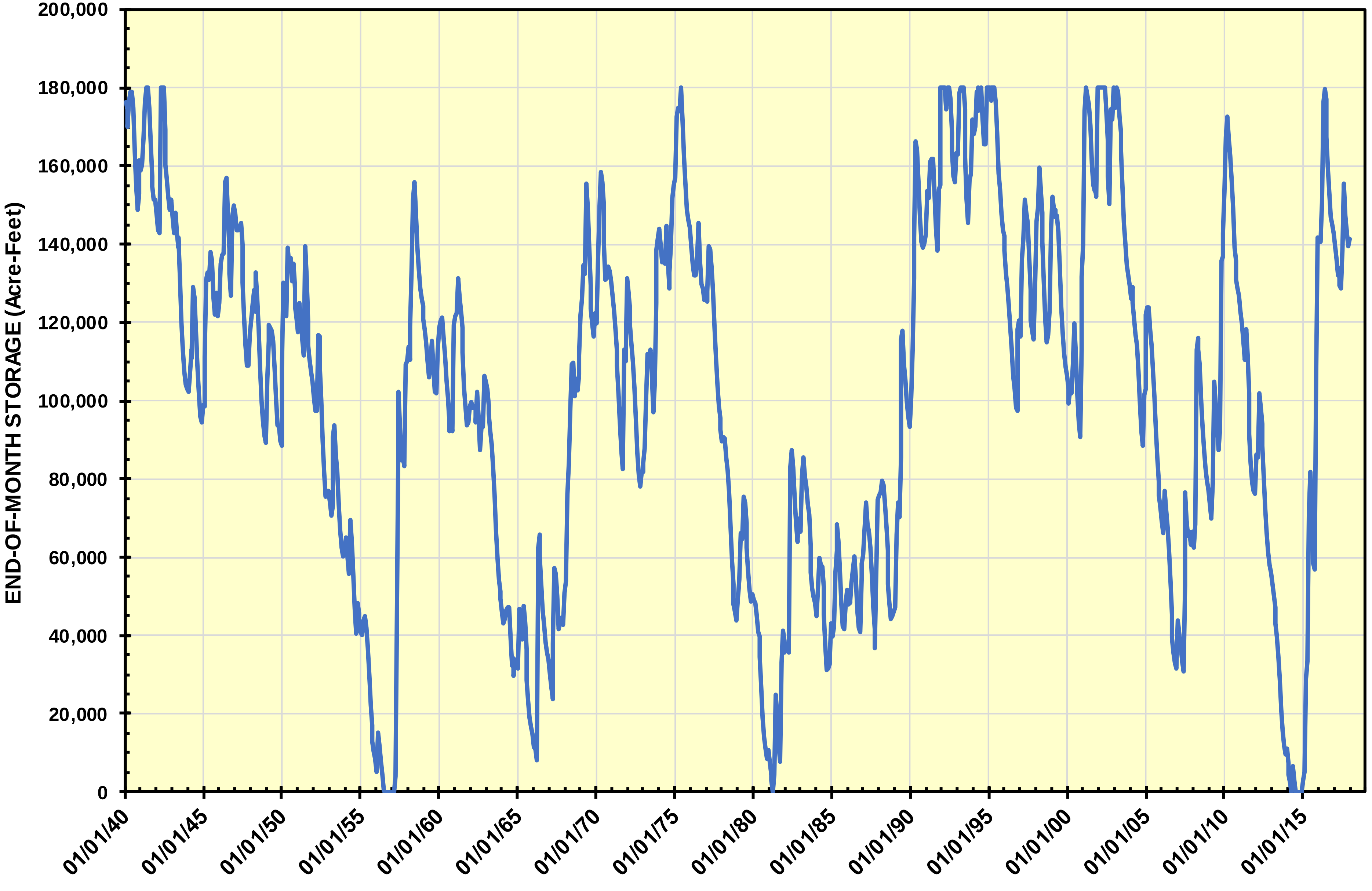
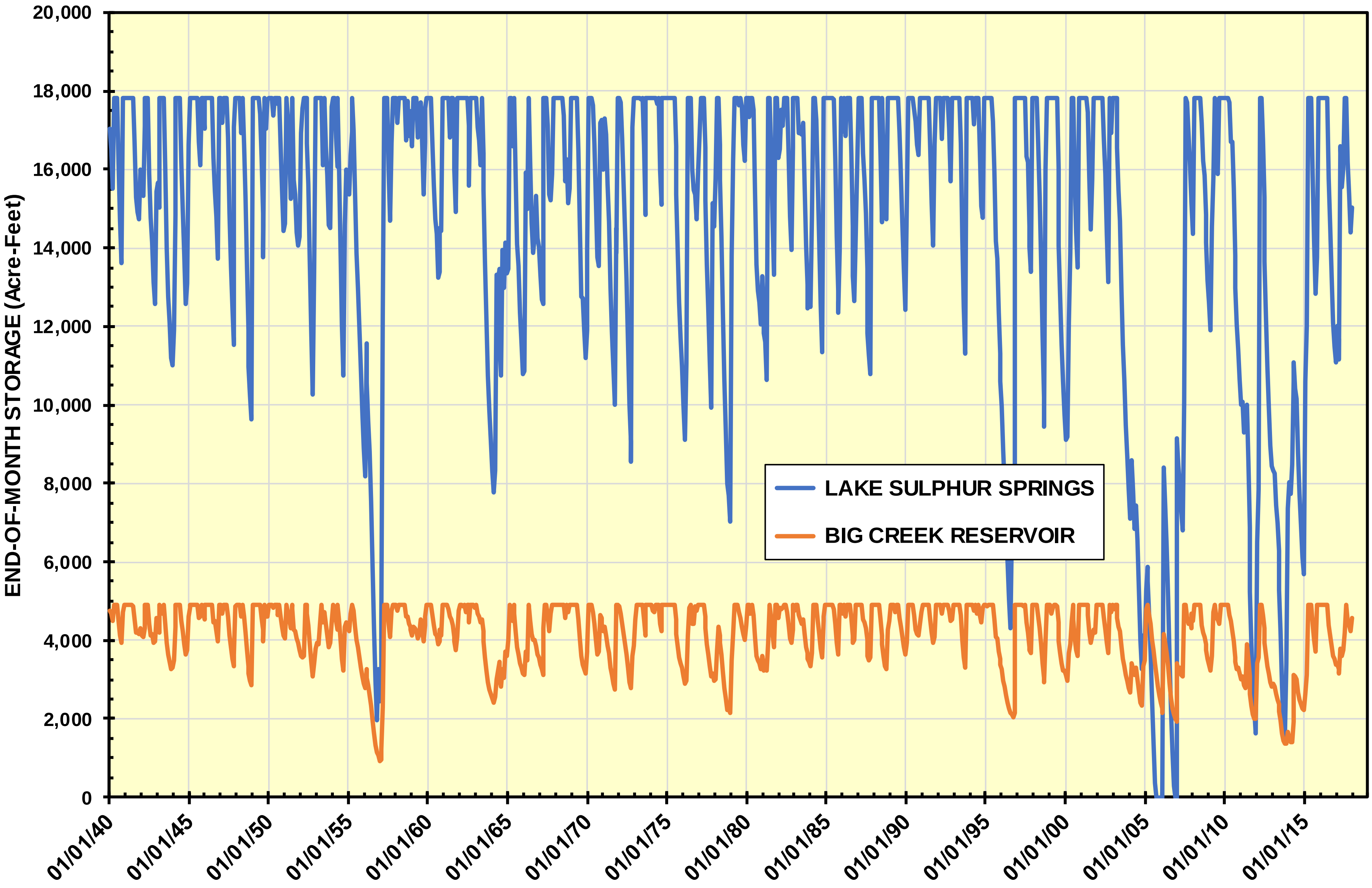


**Figure 3-5 Storage in Lake Sulphur Springs and Big Creek Reservoir**
**Simulated with Updated-Extended Run 3 Version of Sulphur WAM**



With the Ultimate Rule Curve, the top of the conservation pool changes in monthly steps, from a low of 265,300 acre-feet in the winter months up to 386,900 acre-feet in June.

The occurrence of significant droughts during the of the 1997-2017 period of extended naturalized flows for the Sulphur WAM is apparent on the storage graphs for all of the reservoirs, with the droughts centered around 2006 and 2014 potentially being more severe than the historical drought of the 1950s. The storage trace for Lake Ralph Hall in Figure 3-4 exhibits considerable drawdown below the top of its conservation pool over long periods; however, it is important to note that while the water right for this reservoir authorizes storage up to 180,000 acre-feet and a maximum diversion of 45,000 acre-feet per year, the intent of the Upper Trinity Regional Water District is to initially only impound water up to 160,235 acre-feet and to make overdrafting withdrawals from the reservoir on an as needed basis to supplement the District's other sources of water supply.

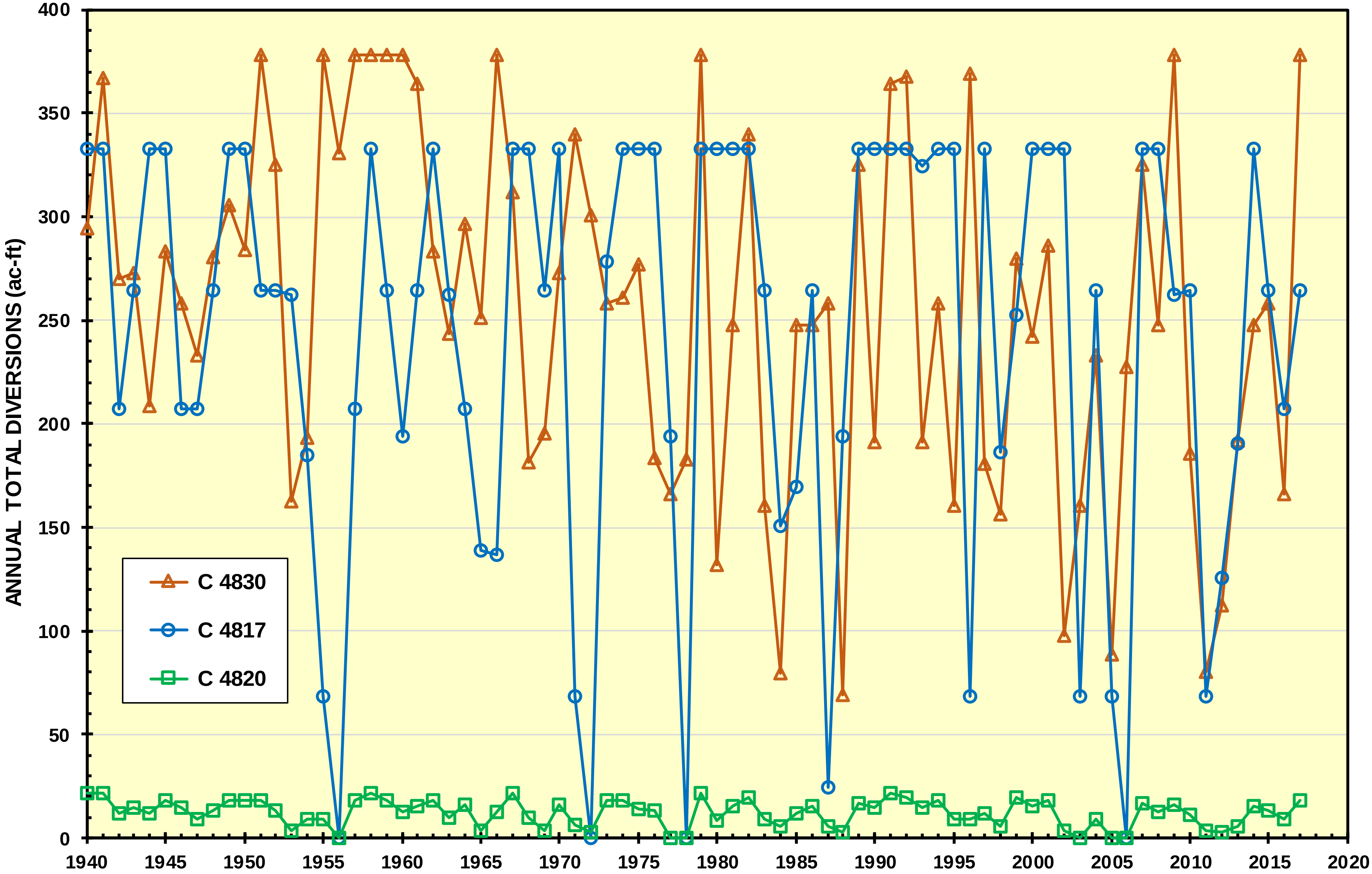
### 3.4 Simulated Diversions from Updated-Extended Run 3 WAM

A time series graph of the annual diversions from the major reservoirs in the Sulphur Basin - Wright Patman Lake, Jim Chapman Lake, Lake Ralph Hall and Lake Sulphur Springs - as simulated with the updated-extended Run 3 version of the WAM for the 1940-2017 period is presented in Figure 3-6. Consistent with the high reliabilities for these diversions as noted in Table 3-2, the annual simulated diversions for each of these reservoirs generally track their authorized diversion amounts, except during the severe drought periods that occur around 1956, 2006 and 2014. As shown, the diversion for Wright Patman Lake is 100 percent firm, which reflects the assumption in the updated-extended Run 3 model that the available pool for meeting water supply demands is at the bottom of the reservoir. Different results will likely be produced with the updated-extended Run 8 model with a higher minimum pool reflecting actual intake conditions. The curve for Jim Chapman Lake represents the sum of the diversions by all three water rights authorized to divert from the reservoir (C-4797 - Sulphur River Municipal Water District and the City of Commerce, C-4798 - North Texas Municipal Water District, and C-4799 - City of Irving), and the fact that the total diversion is slightly less in 2013 than in 1956 suggests that this later period may represent a more critical drought for the reservoir with respect to its firm annual yield.

Simulated annual diversions by selected run-of-river water rights in the Sulphur Basin are plotted on the graph in Figure 3-7. These water rights include C-4830 (Estate of E D Simms et al with an April 30, 1940 priority date), C-4817 (Hans and Waltraud Weiss with a June 30, 1964 priority date), and C-4820 (Joe R Menefee with a December 31, 1964 priority date). Although these water rights have different authorized diversion amounts and priority dates, they all exhibit highly variable annual diversions. The effect of not having a reservoir for storage of flows during high flow periods to extend the water supply during dry periods is demonstrated by the extreme variations in the annual diversions for all three of the water rights.

**Figure 3-6 Annual Diversions from Major Reservoirs**
**Simulated with Updated-Extended Run 3 Version of Sulphur WAM**

**Figure 3-7 Annual Diversions by Selected Run-of-River Water Rights**
**Simulated with Updated-Extended Run 3 Version of Sulphur WAM**



### 3.5 Firm Annual Yield of Major Reservoirs from Updated-Extended Run 3 WAM

The firm annual yield of a reservoir is defined as the maximum annual amount of water that can be withdrawn from the reservoir without a shortage during the critical drought of record. The Run 3 version of the updated-extended Sulphur WAM provides a useful tool for determining the firm annual yield of reservoirs, particularly with the new naturalized flows extended through 2017. This model has been used to determine the firm annual yield for Wright Patman Lake, Jim Chapman Lake, Lake Ralph Hall, and Lake Sulphur Springs, the four largest reservoirs in the basin used for municipal and industrial purposes. Special records, known as FY records, were inserted into the WAM data input files for each of these reservoirs to facilitate the actual model iteration process that is required to determine the firm annual yield. For these analyses, it has been assumed that the storage in each of these reservoirs can be drawn down to near zero for purposes of calculating firm annual yield. Results from this firm yield exercise are summarized in Table 3-3.

As noted in the table, the firm annual yield for all of these reservoirs, with the exception of Wright Patman Lake, is somewhat less than the authorized diversion amount. For Wright Patman Lake, the firm yield is substantially greater than the authorized diversion amount because the available conservation storage capacity used for the yield determination represents the full storage capacity of the reservoir. The authorized diversion value of 180,000 acre-feet per year stipulated in the Texarkana C-4836 water right likely reflects a lower conservation storage capacity more in line with the minimum storage levels stipulated in storage-use contracts between the City of Texarkana and the Corps of Engineers.

**Table 3-3 Firm Annual Yields for Major Reservoirs from Updated-Extended Run 3 Sulphur WAM Based on 1940-2017 Naturalized Flows**

| (1) RESERVOIR | (2) PRIORITY DATE | (3) AUTH. DIVERSION AMOUNT (ac-ft/yr) | (4) CONSERV. STORAGE CAPACITY (ac-ft) | (5) FIRM ANNUAL YIELD (ac-ft/yr) | (6) CRITICAL DROUGHT PERIOD (Spill to Spill) |
|---|---|---|---|---|---|
| Jim Chapman Lake | 11/19/1965 | 146,520 | 310,000 | 124,510 | April 2010 - May 2015 |
| Lake Sulphur Springs | 7/24/1951 | 9,800 | 17,838 | 7,725 | April 2003 - July 2007 |
| Wright Patman Lake | 3/5/1951 | 180,000 | 369,900 [1] | 354,000 | April 2005 - December 2006 |
| Lake Ralph Hall | 8/13/2004 | 45,000 | 180,000 | 40,620 | July 1942 - June 1969 |

Notes: [1] The conservation storage capacity for Wright Patman Lake represents the maximum under the Ultimate Rule Curve
[2] All firm annual yield values were determined using the FY Record in the WAM data files.

It is significant to note that, with the exception of Lake Ralph Hall, the critical drought periods that determine the firm annual yields for the reservoirs occur during the 1997-2017 period when the data base, including the naturalized flows, was extended for the Sulphur WAM. This means that these are new droughts of record for these reservoirs, and, with respect to the specific assumptions embedded in the updated-extended Run 3 version of the Sulphur WAM, these new firm yield values likely represent reductions from firm yield values that may have been determined based on the 1940-1996 naturalized flows in the original Sulphur WAM. While firm annual yields were not determined for reservoirs during the 1999 original development of the Sulphur WAM, analyses using a modified version of the updated-extended Run 3 WAM have been made in this current study to determine firm yields based only on the original 1940-1996 flow conditions. These results are summarized in Table 3-4 for Wright Patman Lake, Jim Chapman Lake, and Lake Sulphur Springs. This modified firm yield analysis has not been necessary for Lake Ralph Hall since its critical drought period as determined with the updated-extended Run 3 WAM using 1940-2017 data base occurs during the original 1940-1996 period. Comparison of the firm annual yields from this analysis based only on 1940-1996 naturalized flows in Table 3-4 with those derived using the entire 1940-2017 hydrologic data base in Table 3-3 clearly shows that the firm annual yields of these reservoirs have been reduced as a result of the new droughts included in the extended hydrologic data. The magnitudes of these changes are listed Table 3-4, as well as the earlier critical drought periods.

**Table 3-4 Firm Annual Yields for Major Reservoirs from Updated-Extended Run 3 Sulphur WAM Based on Original 1940-1996 Naturalized Flows**

| (1) RESERVOIR | (2) PRIORITY DATE | (3) AUTH. DIVERSION AMOUNT (ac-ft/yr) | (4) FIRM ANNUAL YIELD (ac-ft/yr) | (5) REDUCTION DUE TO NEW DROUGHT (ac-ft/yr) | (6) CRITICAL DROUGHT PERIOD (Spill to Spill) |
|---|---|---|---|---|---|
| Jim Chapman Lake | 11/19/1965 | 146,520 | 128,830 | 4,320 | June 1953 - May 1957 |
| Lake Sulphur Springs | 7/24/1951 | 9,800 | 11,525 | 3,800 | May 1955 - April 1957 |
| Wright Patman Lake | 3/5/1951 | 180,000 | 469,290 | 115,290 | February 1972 - December 1972 |

Note: [1] All firm annual yield values were determined using the FY Record in the WAM data files.

## 3.6 Unappropriated Water from Updated-Extended Run 3 WAM

Results produced with the updated-extended Run 3 version of the Sulphur WAM include the amount of unappropriated water that is potentially available at locations within the Sulphur River Basin. Values of unappropriated water at the downstream end of each of the six subwatersheds in the Sulphur Basin as simulated with the updated-extended Run 3 model are listed in Table 3-5. In the table, average annual, maximum annual, and minimum annual values expressed in acre-feet per year are presented. As shown, there is a considerable amount of unappropriated water throughout the Sulphur Basin. Theoretically, the unappropriated water as simulated with the WAM at a location on a particular stream is available for appropriation through the TCEQ's water rights permitting process, subject to certain restrictions involving reliability, environmental flow requirements, and other factors. The values presented in Table 3-5 are intended to provide general information regarding the availability of unappropriated water, and they are presented here merely for informational purposes. Further analyses and discussions with TCEQ would be required to establish the extent to which unappropriated water actually may be available at a particular location for water rights permitting.

**Table 3-5 Unappropriated Water from Updated-Extended Run 3 Sulphur WAM**

| (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|
| **SUB-WATERSHED** | **WAM CONTROL POINT** | **UNAPPROPRIATED WATER (ac-ft/yr)** | | |
| | | **AVERAGE ANNUAL** | **MAXIMUM ANNUAL** | **MINIMUM ANNUAL** |
| A | A10 | 132,037 | 476,927 | 1,162 |
| B | B10 | 117,820 | 401,148 | 6,337 |
| C | C10 | 563,603 | 1,707,890 | 17,439 |
| D | D10 | 329,628 | 1,085,330 | 9,193 |
| E | E10 | 1,521,960 | 4,123,879 | 56,014 |
| F | F10 | 1,905,665 | 5,313,559 | 67,012 |

## 4.0 UPDATED AND EXTENDED RUN 8 VERSION OF SULPHUR WAM

As stipulated by TCEQ, the Run 8 version of the WAM is intended to reflect current conditions with respect to diversions, wastewater discharges, and reservoir operations and storage conditions. In this regard, updated values for these quantities reflecting recent years have been determined for the 1997-2017 period and incorporated into the existing Run 8 version of the Sulphur WAM, along with the extended naturalized flows and net evaporation quantities for the 1997-2017 period. Simulations then were made with this updated-extended Run 8 version of the model to assess water right reliabilities, to examine diversions and storage variations for major water rights, and to determine the firm annual yields for the major reservoirs in the basin.

### 4.1 Development of Updated-Extended Run 8 Version of WAM

For developing the current conditions updated-extended Run 8 version of the Sulphur WAM, historical records were examined to determine the current annual diversion amounts (maximum annual for the last ten years) for all water rights and the current monthly return flow quantities (minimum for each month for the last five years) for all permitted wastewater discharges. Storage and area relationships for all major reservoirs in the basin also have been modified to reflect projected 2020 storage and sedimentation conditions. Details regarding the Run 8 modifications are described in the following sections.

### 4.1.1 Updated Water Rights Information

Except for annual diversion amounts and reservoir storage capacities and certain reservoir operating procedures, water rights in the updated-extended Run 8 version of the WAM are represented essentially the same as those in the updated-extended Run 3 version. There are no additional water rights, such as temporary rights, included in the Run 8 version of the model. As directed by TCEQ staff, the annual diversion amounts for all water rights in the Run 8 model have been set equal to the maximum annual amount diverted during the last 10 years as reported on annual water use reports submitted to the TCEQ by individual water rights holders – limited to authorized diversion amounts. These current annual diversion amounts are listed in Table 4-1 for all water rights in the basin with authorized diversions, along with their authorized diversion amounts, associated control point, priority date, and type of use.

As shown in the table, based on the TCEQ annual water use reports, diversions for many water rights have been reported to be zero in the last 10 years. Others are substantially less than their authorized diversion amounts. These current annual diversion amounts have been incorporated into the updated-extended Run 8 data files, and they have been distributed to monthly values using the same distribution factors included and applied in the Run 3 version of the model.

Also, for the currently-permitted wastewater discharges in the Sulphur Basin shown on the map in Figure 2-24, available historical discharge records have been compiled and analyzed to determine the minimum amount of discharge during each month of the last five years. These monthly amounts have been aggregated into an annual set of monthly discharges for each permitted discharge, and these annual amounts are listed in Table 4-2 for those permitted discharges with reported data. Permit numbers, assigned control points, and associated subwatersheds also are listed in the table. The monthly values for each of these wastewater discharges have been incorporated into the updated-extended Run 8 data files using CI records.

It should be noted that International Paper Company (IPC), now Graphic Packaging International (GPI), has a NPDES permit for discharging treated paper mill wastewater into a remnant channel of Baker Slough that flows directly into the Sulphur River just downstream of the Wright Patman Lake Dam. As per conditions in this permit, the flow rate for these wastewater discharges is controlled and limited for dilution purposes by the concurrent flow of the Sulphur River just below the dam; consequently, these discharges can vary substantially by month or even by season of the year. The IPC paper mill has been in operation since the 1970s; however, TCEQ's water use records for the 1997-2017 period either do not contain annual reports for many years or show zero discharges, except for three months during 2008 and 2009. Through contacts with GPI personnel during this current study, monthly discharge data for the 2015-2018 period have been acquired,

## Table 4-1 Current Diversion Amounts for Updated-Extended Run 8 Version of Sulphur WAM

| | (1) WATER RIGHT NO. [1] | (2) WATER RIGHT OWNER | (3) CONTROL POINT | (4) PRIORITY DATE | (5) TYPE OF USE [2] | (6) AUTHORIZED DIVERSION (ac-ft/yr) | (7) CURRENT DIVERSION (ac-ft/yr) |
|---|---|---|---|---|---|---|---|
| (1) | C 4795 | City of Wolfe City | A70 | 12/31/1925 | Mun | 68.5 | 45 |
| (2) | C 4795 | City of Wolfe City | A70 | 8/12/1957 | Mun | 231.5 | 175 |
| (3) | C 4796 | Webb Hill Country Club | A80 | 3/11/1968 | Irr | 80 | 80 |
| (4) | C 4797 | Commerce/Sulphur R MWD | A40 | 11/19/1965 | Mun | 26,960 | 18,573 |
| (5) | C 4797 | Sulphur River MWD | A40 | 11/19/1965 | Ind | 11,560 | - - |
| (6) | C 4797 | City of Commerce | A40 | 11/19/1965 | Mun | 11,274 [3] | - - |
| (7) | C 4797 | City of Commerce | A40 | 11/19/1965 | Ind | 4,832 [3] | - - |
| (8) | C 4798 | North Texas MWD | A40 | 11/19/1965 | Mun | 54,000 | 54,000 |
| (9) | C 4799 | City of Irving | A40 | 11/19/1965 | Mun | 44,820 | 42,260 |
| (10) | C 4799 | City of Irving | A40 | 11/19/1965 | Ind | 9,180 | - - |
| (11) | C 4800 | City of Cooper | A20 | 1/3/1977 | Mun | 273 | 0 |
| (12) | C 4801 | Delta Country Club | C110 | 7/2/1979 | Irr | 5 | 5 |
| (13) | C 4802 | Alexander Frick et al | C50 | 12/31/1955 | Irr | 278 | 0 |
| (14) | C 4803 | Helmut Hermann et al | C30 | 6/19/1978 | Irr | 1,000 | 0 |
| (15) | C 4803 | Helmut Hermann et al | C30 | 11/15/1982 | Irr | 900 | 0 |
| (16) | C 4804 | Luminant Generation Co LLC | C20 | 3/5/1952 | Ind | 10,000 | 0 |
| (17) | C 4805 | E P Land and Cattle Inc | C260, C270 | 1/5/1981 | Irr | 3,000 | 0 |
| (18) | C 4806 | Laura E Vaughan et al | E220 | 9/22/1969 | Irr | 8.4 | 0 |
| (19) | C 4807 | Mary Margaret Vaughan | E220 | 9/22/1969 | Irr | 21.6 | 0 |
| (20) | C 4809 | Red River County WCID 1 | E200 | 1/20/1964 | Mun | 1,119.5 | 521 |
| (21) | C 4809 | Red River County WCID 1 | E200 | 1/20/1964 | Ind | 0.5 | 1 |
| (22) | C 4810 | Donelson Family, LTD | E190 | 4/4/1960 | Irr | 200 | 0 |
| (23) | C 4811 | City of Sulphur Springs | D120 | 7/24/1951 | Mun | 2,000 | 796 |
| (24) | C 4811 | City of Sulphur Springs | D120 | 11/25/1968 | Mun | 7,800 | - - |
| (25) | C 4812 | City of Sulphur Springs | D110 | 12/1/1975 | Mun | 408 | 0 |
| (26) | C 4813 | Sulphur Springs Country Club | D100 | 12/15/1975 | Irr | 113 | 113 |
| (27) | C 4814 | Jerry N Jordan Trustee et al | D80 | 7/16/1959 | Irr | 30 | 0 |
| (28) | C 4816 | City of Mount Vernon | D60 | 3/1/1976 | Mun | 188 | 0 |
| (29) | C 4816 | City of Mount Vernon | D60 | 11/22/1982 | | 212 | 0 |
| (30) | C 4817 | Hans & Waltraud Weiss | D40 | 6/30/1964 | Irr | 333.3 | 0 |
| (31) | C 4818 | Robert & Dewitta Campbell | D30 | 12/31/1964 | Irr | 10.5 | 0 |
| (32) | C 4820 | Joe R. Menefee | E160 | 12/31/1964 | Irr | 22 | 0 |
| (33) | C 4821 | Anna Pearl Lewis | E130 | 12/31/1953 | Ind | 1.2 | 0 |
| (34) | C 4822 | Bernice Ann Baldwin | E120 | 7/31/1967 | Irr | 100 | 100 |
| (35) | C 4823 | Ardelia Gauntt | E80 | 6/1/1965 | Irr | 22.5 | 0 |
| (36) | C 4824 | Walter W. Lee | E90 | 6/1/1965 | Irr | 7.5 | 0 |
| (37) | C 4825 | Robert Crooks et al | E60 | 12/31/1963 | Irr | 20 | 0 |
| (38) | C 4825 | Robert Crooks et al | E60 | 12/31/1965 | Ind | 0.04 | 0 |
| (39) | C 4829 | Estate of E D Simms et al | F140 | 4/30/1940 | Irr | 4 | 0 |
| (40) | C 4830 | Estate of E D Simms et al | F110 | 4/30/1940 | Irr | 378 | 0 |
| (41) | C 4831 | City of New Boston | F100 | 6/30/1914 | Mun | 31 | 0 |
| (42) | C 4832 | City of New Boston | F100 | 8/29/1944 | Mun | 325 | 0 |
| (43) | C 4833 | H C Prange Jr | F80 | 1/31/1956 | Ind | 7.9 | 0 |
| (44) | C 4834 | Estate of E D Simms et al | F120 | 4/30/1940 | Irr | 39 | 0 |
| (45) | C 4836 | City of Texarkana | F60 | 3/5/1951 | Mun | 14,572 | 12,863 |
| (46) | C 4836 | City of Texarkana | F60 | 2/17/1957 | Mun | 10,428 | - - |
| (47) | C 4836 | City of Texarkana | F60 | 2/17/1957 | Ind | 35,000 | 35,000 |
| (48) | C 4836 | City of Texarkana | F60 | 9/19/1967 | Mun | 20,000 | - - |
| (49) | C 4836 | City of Texarkana | F60 | 9/19/1967 | Ind | 100,000 | 29,812 |

## Table 4-1 continued

| | (1) WATER RIGHT NO. [1] | (2) WATER RIGHT OWNER | (3) CONTROL POINT | (4) PRIORITY DATE | (5) TYPE OF USE [2] | (6) AUTHORIZED DIVERSION (ac-ft/yr) | (7) CURRENT DIVERSION (ac-ft/yr) |
|---|---|---|---|---|---|---|---|
| (50) | C 4837 | Henry Maddox Jr, et ux | F50 | 6/30/1962 | Irr | 80 | 0 |
| (51) | P 3845 | Sulphur Bluff Land | C70 | 9/14/1981 | Irr | 2,828 | 2,828 |
| (52) | P 3845 | Sulphur Bluff Land | C80 | 11/7/1984 | Irr | 5,500 | 5,500 |
| (53) | P 3845 | Sulphur Bluff Land | C60 | 4/11/1997 | Irr | 11,312 | 5,338 |
| (54) | P 3890 | City of Pecan Gap | B20 | 4/26/1982 | Mun | 102 | 34 |
| (55) | P 4060 | City of Cooper | A30 | 9/6/1983 | Mun | 1,518 | 784 |
| (56) | P 5200 | Gordon Country Club | C100 | 11/1/1988 | Rec | 0 | 0 |
| (57) | P 5449 | Texas Parks & Wildife Dept | F150, F151 | 2/18/1993 | Oth | 863 | 0 |
| (58) | P 5562 | Luminant Mining Co LLC | E140 | 11/19/1996 | Ind | 9 | 9 |
| (59) | P 5562 | Luminant Mining Co LLC | E150 | 11/19/1996 | Ind | 79 | 79 |
| (60) | P 5562 | Luminant Mining Co LLC | E170 | 11/19/1996 | Ind | 37 | 7 |
| (61) | P 5821 | Upper Trinity Reg Water Dist | 158211 | 8/13/2004 | Multi | 45,000 | 0 |
| (62) | P 5873 | TexAmericas Center | 587301 | 6/16/2005 | Mun | 1,032 | 0 |
| (63) | P 5873 | TexAmericas Center | 587302 | 6/16/2005 | Mun | 1,928 | 0 |
| (64) | P 12145 | Los Senderos Cattle/Ranch Co | 121451 | 4/24/2007 | Irr | 35 | 1 |
| (65) | P 12810 | Daisy Farms LLC | 2AUDSWATER | 4/12/2013 | Multi | 17,500 | 0 |
| (66) | P 12810 | Daisy Farms LLC | DAISYPR_1 | 4/12/2013 | Multi | 245 | 0 |

NOTES:

[1] C = Certificate of Adjudication and P = Permit

[2] Mun = Municipal, Ind = Industrial, Irr = Irrigation, Min = Mining, Rec = Recreation, Oth = Other, Multi = Municipal, Industrial, Irrigation and/or Recreation, D&L = Domestic and Livestock

[3] These diversion authorizations for the City of Commerce are stipulated in Amendment A as contractual commitments of the base diversion amounts authorized for the Sulphur River MWD.

## Table 4-2 Current Wastewater Discharges for Updated-Extended Run 8 Version of Sulphur WAM

| | (1) PERMITTEE | (2) PERMIT NO. | (3) NPDES NO. | (4) SUB WATER-SHED | (5) CONTROL POINT | (6) MINIMUM 5-YEAR DISCHARGE (ac-ft/yr) |
|---|---|---|---|---|---|---|
| (1) | Alumax Mill Products Inc | 02742-000 | 0097055 | F | F24 | 0.00 |
| (2) | City of Annona | 14255-001 | 0022705 | E | E191 | 1.8 |
| (3) | City of Bailey | 13584-001 | 0107719 | A | A64 | 0.0 |
| (4) | City of Blossom | 10715-002 | 0075957 | E | E222 | 85.8 |
| (5) | City of Bogata | 10065-001 | 0022322 | C | E272 | 0.0 |
| (6) | City of Clarksville | 10148-001 | 0058106 | E | E192 | 361.1 |
| (7) | City of Commerce | 10555-001 | 0020591 | A | A61 | 808.0 |
| (8) | City of Cooper | 10449-001 | 0027936 | A | A41 | 141.4 |
| (9) | City of De Kalb | 10062-002 | 0069671 | F | F111 | 156.5 |
| (10) | City of Detroit | 10724-001 | 0055581 | E | E221 | 20.5 |
| (11) | City of Ladonia | 14673-001 | 0057011 | A | A51 | 0.0 |
| (12) | City of Maud | 14025-001 | 0117498 | F | F64 | 118.4 |
| (13) | City of Mount Vernon | 11122-002 | 0063096 | D | D59 | 206.7 |
| (14) | City of New Boston | 10482-001 | 0026018 | F | F65 | 1,213.8 |
| (15) | City of Queen City | 11225-001 | 0034797 | F | F41 | 115.0 |
| (16) | City of Redwater | 10926-001 | 0056251 | F | F63 | 56.0 |
| (17) | City of Roxton | 10204-001 | 0053538 | B | B11 | 24.2 |
| (18) | City of Sulphur Springs | 10372-001 | 0058955 | D | D101 | 2,598.2 |
| (19) | City of Talco | 10869-001 | 0021105 | E | E271 | 23.1 |
| (20) | City of Texarkana | 10374-005 | 0101800 | F | F21 | 1,436.9 |
| (21) | City of Texarkana | 10374-007 | 0099287 | F | F23 | 7,089.7 |
| (22) | City of Wolfe City | 10383-001 | 0023558 | A | A62 | 46.2 |
| (23) | Delta County MUD | 10744-001 | 0020192 | A | A43 | 0.0 |
| (24) | International Paper Co | 01339-000 | 0000167 | F | F42 | 31,093.0 |
| (25) | Kimberly Clark Corp | 02648-000 | 0093416 | C | C94 | 0.0 |
| (26) | Lamar Power Partners | 04127-000 | 0119288 | C | C91 | 546.5 |
| (27) | Nalco Company | 02955-000 | 0102822 | F | F22 | 27.7 |
| (28) | Petty Water Sup/Sew Svc | 12305-001 | 0085707 | B | B12 | 0.0 |
| (29) | Rivercrest ISD | 11204-001 | 0116556 | C | C21 | 0.0 |
| (30) | TexAmericas Center | 04664-000 | 0126098 | F | F62 | 337.5 |
| (31) | Texas Parks & Wildlife Dept | 13613-001 | 0108499 | A | A42 | 0.0 |
| (32) | Turner Industries Group LLC | 00300-000 | 0000108 | C | C95 | 0.0 |

and these data have been analyzed to establish the monthly discharge values required for the updated-extended Run 8 version of the WAM. Because of the extreme monthly and seasonal variability of these discharges, the minimum monthly values for the 2015-2018 period significantly underestimate annual discharge values compared to the actual annual discharges. For this reason, the average monthly discharges for the 2015-2018 period have been used, and these values produce an annual discharge quantity (34,624 acre-feet/year) that is more in line with the annual values for the 2015-2018 period that range from around 30,000 acre-feet/year up to about 42,000 acre-feet/year. This annual sum of the average monthly discharges is the value listed for the IPC discharges in Table 4-2.

### 4.1.2 Year-2020 Reservoir Area-Capacity Data

As described in Section 2.4, for purposes of the updated-extended Run 8 version of the Sulphur WAM, reservoir sedimentation and storage conditions corresponding to the year 2020 have been assumed for the major reservoirs. Elevation-area-capacity data for each of these reservoirs have been developed for the year 2020 by extending previously surveyed data using either reservoir-specific or reported sedimentation rates and corresponding calculated area changes.

These year-2020 elevation-area-capacity data have been presented as curves on the plots in Figures 2-3, 2-5, 2-6, 2-7 and 2-8 for Wright Patman Lake, Jim Chapman Lake, Lake Sulphur Springs, Big Creek Reservoir, and Lake Ralph Hall, respectively, and these are the data that have been incorporated into the updated-extended Run 8 version of the Sulphur WAM. For other reservoirs with maximum authorized storage capacities greater than 1,000 acre-feet, the same area-capacity data corresponding to year-2000 conditions as used in the existing Run 8 version of the Sulphur WAM have been adopted and used for the updated-extended Run 8 model. These data are plotted on the graph in Figure 2-9 for Lake Romal, Langford Creek Lake, the multiple E. P. Land and Cattle reservoirs, and the two TexAmericas reservoirs now authorized under Permit No. 5873.

### 4.1.3 Revised Operating Rule Curve for Wright Patman Lake

Based on an existing contract dated September 16, 1968, between the City of Texarkana, the entity authorized to divert water from Wright Patman Lake, and the Corps of Engineers, the owner of the reservoir, the City is entitled to use conservation storage capacity in the reservoir for water supply in accordance with what is referred to as the Interim Rule Curve. The Interim Rule Curve is structured similar to the Ultimate Rule Curve described in Section 3.1 above, except that it allows somewhat less conservation storage capacity to be used by the City, with the top of the conservation pool varying by month from a minimum water surface elevation of 220.6 feet msl for November through March up to a maximum water surface elevation of 227.5 feet msl at the end of May. The bottom of the conservation pool is set at elevation 220.0 feet msl. At the time the original Run 8 version of the WAM was developed, the Interim Rule Curve was considered to be appropriate for use in the model because of its stipulation in the City-Corps contract.

Although the Interim Rule Curve provides the contractual basis for defining the conservation storage capacity in Wright Patman Lake that is available to the City of Texarkana, the actual operation of the reservoir by the Corps over the last 15 years or so suggests that the Interim Rule Curve has not necessarily been followed when the reservoir is not in a flood condition. Instead, the reservoir generally has been operated at levels higher than those specified by the Interim Rule Curve for the winter, early spring and late fall months. This means, under current operating procedures, that the City has access to more stored water for its supply than what would be available if the Interim Rule Curve was strictly followed.

The curves in Figure 4-1 depict the actual daily traces of the water surface elevation of Wright Patman Lake for all of the non-flood years since 2002, with non-flood years being defined for purposes of this analysis as those years without any daily water surface elevations greater than 229.0 feet msl (which is well above even the maximum elevation stipulated by the Ultimate Rule Curve). Also plotted on the graph are the Interim and Ultimate Rule Curves. As shown, the lower water surface elevations of the Interim Rule Curve during the winter, early spring and late fall months have always been exceeded by the actual water surface elevations during the non-flood years, typically by two to three feet. The higher actual water surface elevations during the summer months generally track the Interim Rule Curve. After discussions with TCEQ staff, the monthly averages of the water surface elevations for the non-flood years have been adopted for use in the updated-extended Run 8 WAM to provide a more realistic representation of current reservoir operations for Wright Patman Lake, and these values have been used to define the 2020 Current Rule Curve shown as the bold black line on the graph in Figure 4-1. The water surface elevation and the projected year-2020 surface area and storage capacity associated with each of the monthly steps of this Current Rule Curve are listed in Table 4-3.

For purposes of updating the Run 8 version of the Sulphur WAM, the bottom elevation assumed to be the minimum level of Wright Patman Lake below which diversions from the reservoir cannot be made has been set at 221.5 feet msl. This minimum elevation has been established through discussions with Riverbend personnel who are familiar with the operation of Lake Wright Patman and the City of Texarkana's diversion facilities. Elevation 221.5 feet msl generally represents the lowest level of the reservoir below which pumping water by the City of Texarkana becomes impractical due to cavitation and sediment problems. The year-2020 storage capacity of Wright Patman Lake at elevation 221.5 feet msl is 113,566 acre-feet, which means that the maximum volume of storage available for making diversions from the reservoir is 135,326 acre-feet (248,892 – 113,566 = 135,326). This occurs during the month of June since this is the month with the highest conservation pool level and storage capacity based on the Current Rule Curve data presented in Table 4-3. As was the case for the updated-extended Run 3 version of the Sulphur WAM, the minimum storage level for making diversions has been assumed to be zero for <u>all other reservoirs</u> in the updated-extended Run 8 version of the WAM.

**Figure 4-1 Historical Daily Water Levels and Reservoir Operating Rule Curves for Wright Patman Lake**

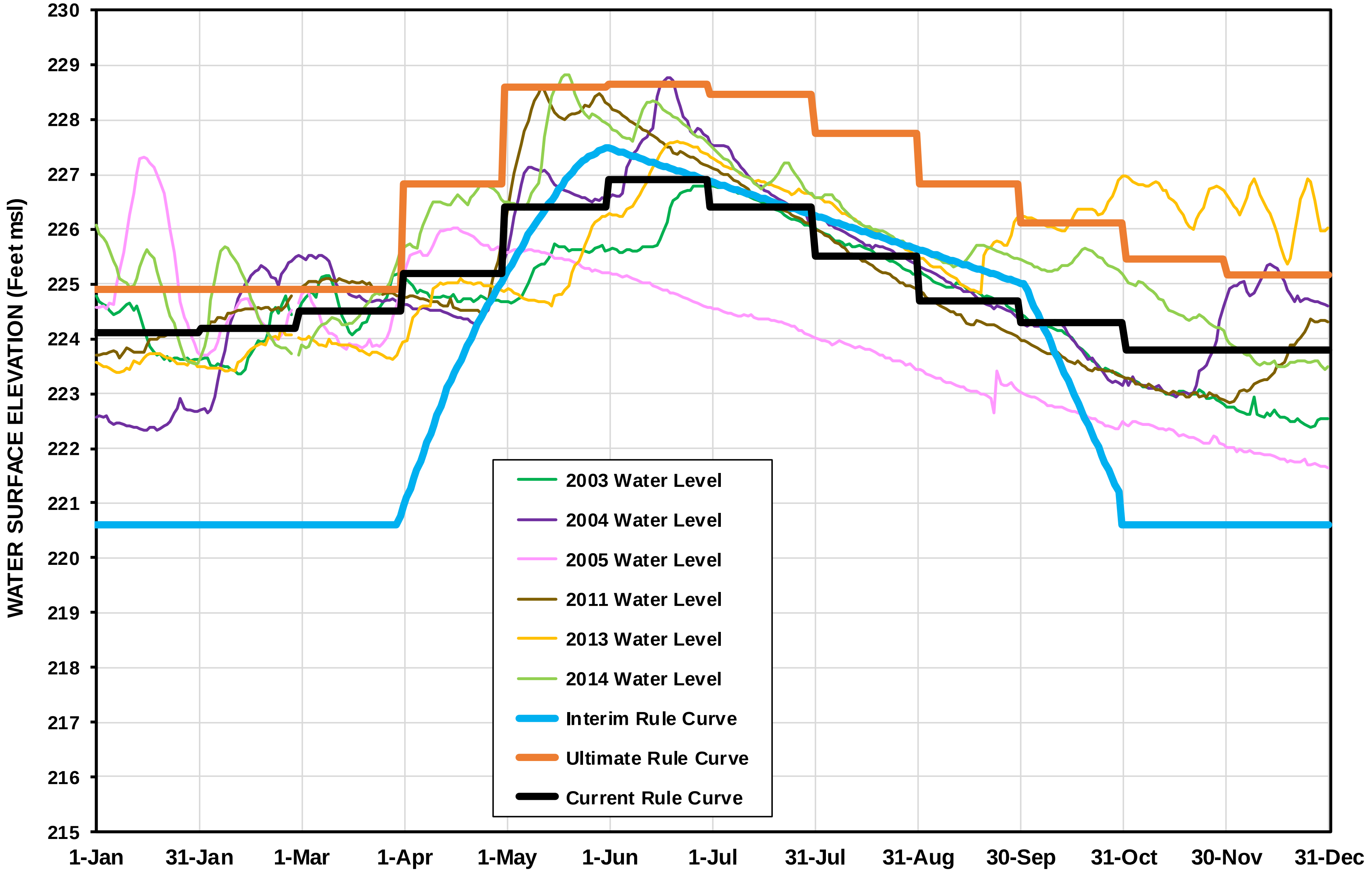


**Table 4-3 Current Operating Rule Curve Data for Wright Patman Lake Used in Updated-Extended Run 8 Version of Sulphur WAM**

| Month | Water Surface Elevation feet msl | Surface Area acres | Storage Capacity acre-feet |
|---|---|---|---|
| January | 224.1 | 24,379 | 171,402 |
| February | 224.2 | 24,415 | 174,068 |
| March | 224.5 | 24,524 | 182,067 |
| April | 225.2 | 24,998 | 199,773 |
| May | 226.4 | 26,457 | 229,941 |
| June | 226.9 | 28,501 | 248,892 |
| July | 226.4 | 26,457 | 229,941 |
| August | 225.5 | 25,162 | 207,533 |
| September | 224.7 | 24,596 | 187,399 |
| October | 224.3 | 24,415 | 174,068 |
| November | 223.8 | 24,024 | 164,024 |
| December | 223.8 | 24,024 | 164,024 |

## 4.2 Simulated Water Right Reliabilities from Updated-Extended Run 8 WAM

The updated-extended Run 8 version of the WAM has been operated with the extended record of 1940-2017 hydrologic data, and the volume reliabilities of the diversions for all water rights that had reported diversions during the past ten years (see Table 4-1) have been determined. These values are presented in Table 4-4 for these water rights, listed in order of water right numbers, with certificates of adjudication first, followed by permits. The current maximum diversion amount and the current conservation storage capacity as developed for purposes of the updated-extended Run 8 WAM also are included for each water right, as well as the priority date.

As with the volume reliabilities produced with the updated-extended Run 3 WAM, these volume reliabilities range from 100 percent for many of the water rights down to the lowest reliability of 32 percent. Most of these water rights have reservoir storage, so that is a contributing factor to the high reliabilities, as well as, of course, the fact that most of the time there are abundant flows in the Sulphur Basin. Comparison of the Run 8 reliabilities with those in Table 3-2 from the updated-extended Run 3 WAM indicate that generally these Run 8 reliabilities are higher because of the reduced water right diversions in the Run 8 model.

**Table 4-4 Diversion Reliabilities for Water Rights Simulated with Updated-Extended Run 8 Version of Sulphur WAM**

| | (1) WATER RIGHT ID | (2) WATER RIGHT OWNER | (3) SUB WATER-SHED | (4) PRIORITY DATE yyyymmdd | (5) CURRENT STORAGE ac-ft | (6) CURRENT DIVERSION ac-ft/year | (7) SIMULATED AVERAGE DIVERSION ac-ft/year | (8) VOLUME RELIABILITY % |
|---|---|---|---|---|---|---|---|---|
| (1) | C 4795 | CITY OF WOLFE CITY | A | 19251231 | 425 | 45.0 | 44.95 | 99.9 |
| (2) | C 4795 | CITY OF WOLFE CITY | A | 19570812 | 430 | 175.0 | 174.36 | 99.9 |
| (3) | C 4796 | WEBB HILL COUNTRY CLUB INC | A | 19680311 | 60 | 80.0 | 25.62 | 32.0 |
| (4) | C 4797 | COMMERCE-SULPHUR RIVER MWD | A | 19651119 | 76,648 | 18,573.0 | 18,573.00 | 100.0 |
| (5) | C 4798 | NORTH TEXAS MUN WATER DIST | A | 19651119 | 107,501 | 54,000.0 | 53,437.66 | 99.9 |
| (6) | C 4799 | CITY OF IRVING | A | 19651119 | 107,501 | 42,260.0 | 42,260.00 | 100.0 |
| (7) | C 4801 | DELTA COUNTRY CLUB | C | 19790702 | - - | 5.0 | 5.0 | 100.0 |
| (8) | C 4809 | RED RIVER COUNTY WCID 1 | E | 19640120 | 1,225 | 521.0 | 521.00 | 100.0 |
| (9) | C 4809 | RED RIVER COUNTY WCID 1 | E | 19640120 | - - | 1.0 | 1.00 | 100.0 |
| (10) | C 4811 | CITY OF SULPHUR SPRINGS | D | 19510724 | 17,086 | 796.0 | 796.00 | 100.0 |
| (11) | C 4813 | SULPHUR SPRINGS COUNTRY CLUB | D | 19751215 | - - | 113.0 | 107.97 | 95.6 |
| (12) | C 4822 | BALDWIN, BERNICE ANN | E | 19670731 | 196 | 100.0 | 92.9 | 92.9 |
| (13) | C 4836 | CITY OF TEXARKANA | F | 19510305 | 135,326 [1] | 12,863.0 | 12,863.00 | 100.0 |
| (14) | C 4836 | CITY OF TEXARKANA | F | 19670919 | - - | 29,812.0 | 29,812.00 | 100.0 |
| (15) | C 4836 | CITY OF TEXARKANA | F | 19570217 | - - | 35,000.0 | 35,000.0 | 100.0 |
| (16) | P 3845 | SULPHUR BLUFF LAND LLC | C | 19810914 | 7,498 | 2,828.0 | 2,826.51 | 99.9 |
| (17) | P 3845 | SULPHUR BLUFF LAND LLC | C | 19841107 | 2,925 | 5,500.0 | 4,776.12 | 86.8 |
| (18) | P 3845 | SULPHUR BLUFF LAND LLC | C | 19970411 | - - | 5,338.0 | 5,020.38 | 94.1 |
| (19) | P 3890 | CITY OF PECAN GAP | B | 19820426 | 152 | 34.0 | 34.00 | 100.0 |
| (20) | P 4060 | CITY OF COOPER | A | 19830906 | 4,890 | 784.0 | 784.0 | 100.0 |

## Table 4-4 continued

| | (1) WATER RIGHT ID | (2) WATER RIGHT OWNER | (3) SUB WATER-SHED | (4) PRIORITY DATE yyyymmdd | (5) CURRENT STORAGE ac-ft | (6) CURRENT DIVERSION ac-ft/year | (7) SIMULATED AVERAGE DIVERSION ac-ft/year | (8) VOLUME RELIABILITY % |
|---|---|---|---|---|---|---|---|---|
| (21) | P 5562 | LUMINANT MINING COMPANY LLC | E | 19961119 | - - | 9.0 | 5.79 | 64.3 |
| (22) | P 5562 | LUMINANT MINING COMPANY LLC | E | 19961119 | - - | 79.0 | 49.73 | 63.0 |
| (23) | P 5562 | LUMINANT MINING COMPANY LLC | E | 19961119 | - - | 7.0 | 4.65 | 66.4 |
| (24) | P 12145 | LOS SENDEROS CATTLE & RANCH CO | D | 20070424 | 8.6 | 1.0 | 1.0 | 100.0 |

Note: [1] The top of the conservation pool for Wright Patman Lake varies monthly according to the Current Rule Curve (Table 4-3), with the maximum storage capacity occuring in June at 248,892 acre-feet. However, the bottom of the conservation pool is fixed at Elevation 221.5 feet msl, or 113,566 acre-feet. Therefore, the maximum volume of storage available for making diversions is only 135,326 acre-feet.

## 4.3 Simulated Reservoir Storage from Updated-Extended Run 8 WAM

Graphs of the monthly variations of storage in the two largest existing reservoirs in the Sulphur Basin - Wright Patman Lake and Jim Chapman Lake - as simulated with the updated-extended Run 8 version of the WAM for the 1940-2017 period are presented in Figures 4-2 and 4-3. A similar graph of the monthly variations of storage in Lake Sulphur Springs and Big Creek Reservoir is presented in Figure 4-4. These storage variations are similar to those produced with the updated-extended Run 3 WAM, except they reflect lower conservation storage capacities due to sedimentation as projected for year-2020 conditions for the updated-extended Run 8 model. Also, with the lower current-conditions maximum diversions, there is less demand on the reservoirs, which translates to generally higher storage conditions.

As described above, the available storage capacity for making diversions from Wright Patman Lake in this updated-extended Run 8 WAM is limited on the top by the Current Rule Curve depicted on the graph in Figure 4-1 (and Table 4-3) and on the bottom by the minimum withdrawal level at elevation 221.5 feet msl, which corresponds to 113,566 acre-feet of storage under current conditions. At the highest level of the Current Rule Curve in the month of June, the current-conditions storage capacity of the reservoir is 248,892 acre-feet, which means that the volume of available storage capacity is only 135,326 acre-feet. However, even with this limited amount of storage capacity in Wright Patman Lake under current conditions, the current demand on the reservoir (77,675 acre-feet/year in Table 4-1) still is satisfied 100 percent of the time.

## 4.4 Simulated Diversions from Updated-Extended Run 8 WAM

A time series graph of the annual diversions from the two largest reservoirs in the Sulphur Basin - Wright Patman Lake and Jim Chapman Lake - as simulated with the updated-extended Run 8 version of the WAM for the 1940-2017 period is presented in Figure 4-5. Consistent with the diversion reliabilities in Table 4-4, the current-conditions demand for Wright Patman Lake (City of Texarkana, C-4836) as plotted in Figure 4-5 is fully satisfied every year. For Jim Chapman Lake, the current-conditions demand curve indicates that there are a few years with shortages. This also is consistent with the diversion reliabilities for Jim Chapman Lake in Table 4-4, which show that the Commerce-Sulphur River MWD (C 4797) and the City of Irving (C 4799) current-conditions demands are 100 percent satisfied every year but the demand for the North Texas Municipal Water District (C 4798) is only 99.9 percent satisfied. This occurs because the allocated storage pool for the North Texas Municipal Water District in Jim Chapman Lake is reduced under current conditions due to sedimentation, but the current-conditions demand for the District remains at the fully authorized amount due to high usage in the last 10 years. This results in demand shortages in a few dry years as illustrated on the graph in Figure 4-5. While the allocated storage pools for Commerce-Sulphur River MWD (C 4797) and the City of Irving (C 4799) also have been reduced due to sedimentation, their current-conditions demands also are significantly lower, thus allowing them to be fully satisfied.

**Figure 4-2 Storage in Wright Patman Lake**
**Simulated with Updated-Extended Run 8 Version of Sulphur WAM**

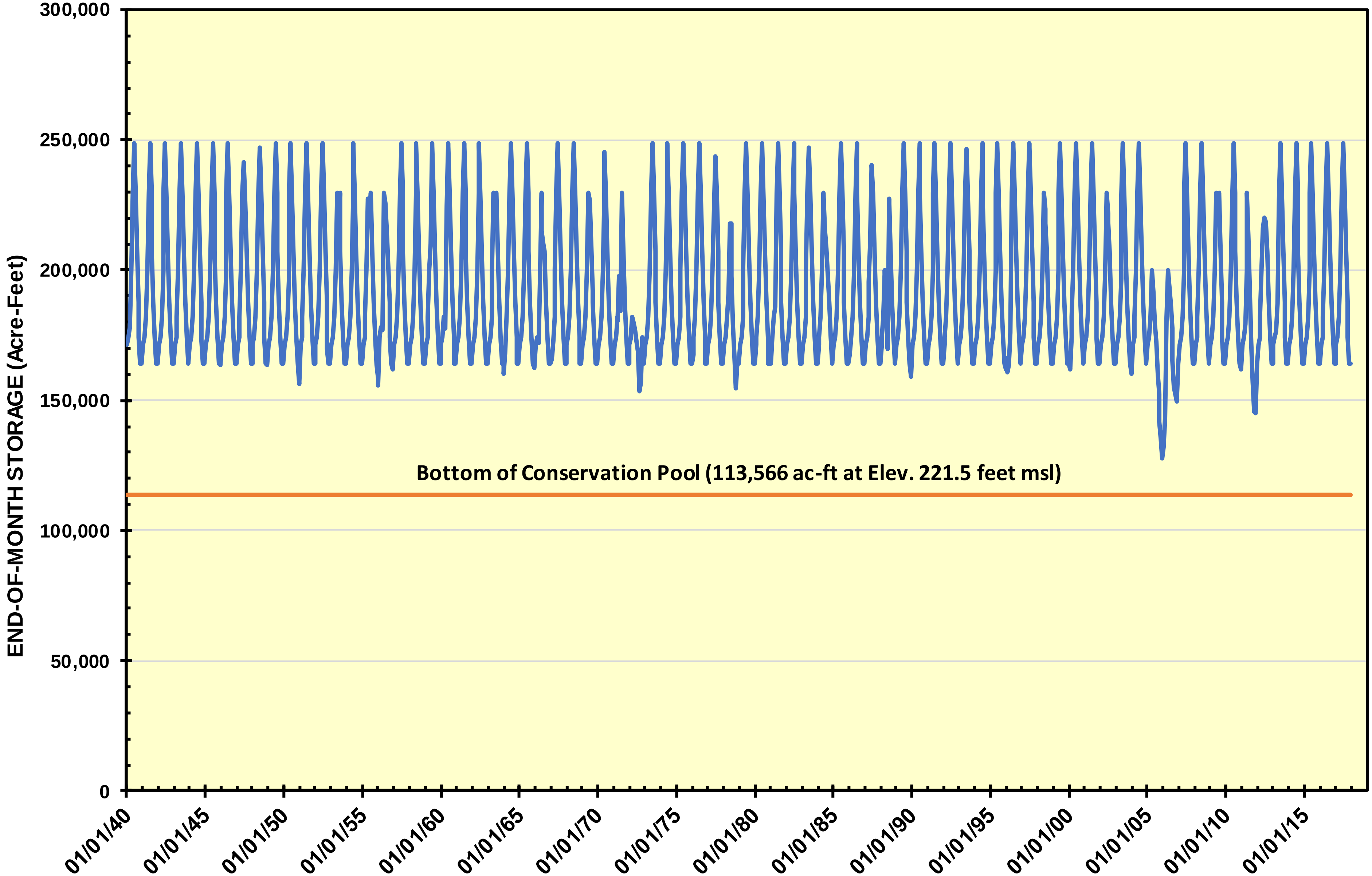


**Figure 4-3 Storage in Jim Chapman Lake**
**Simulated with Updated-Extended Run 8 Version of Sulphur WAM**

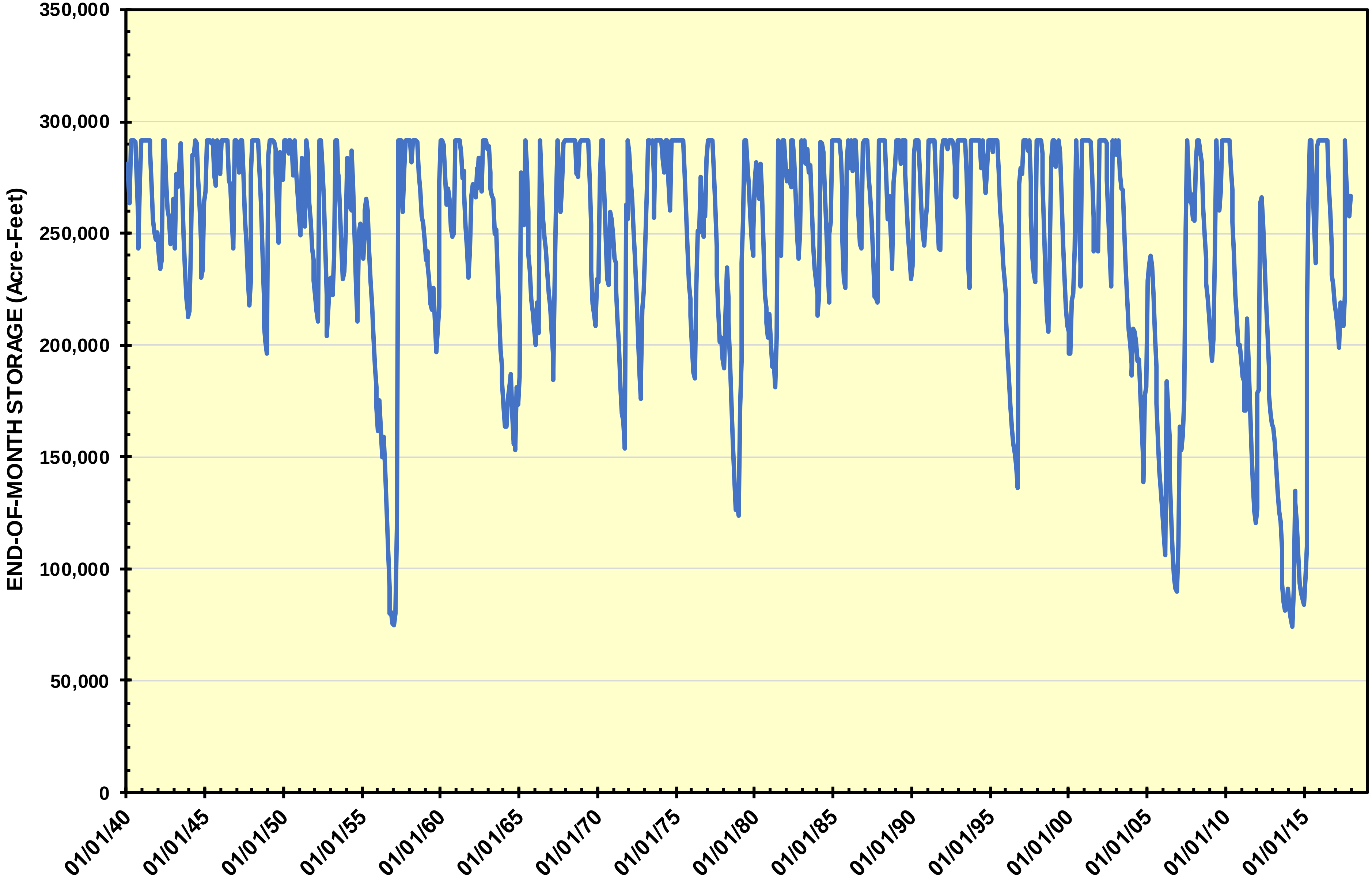


**Figure 4-4 Storage in Lake Sulphur Springs and Big Creek Reservoir**
**Simulated with Updated-Extended Run 8 Version of Sulphur WAM**

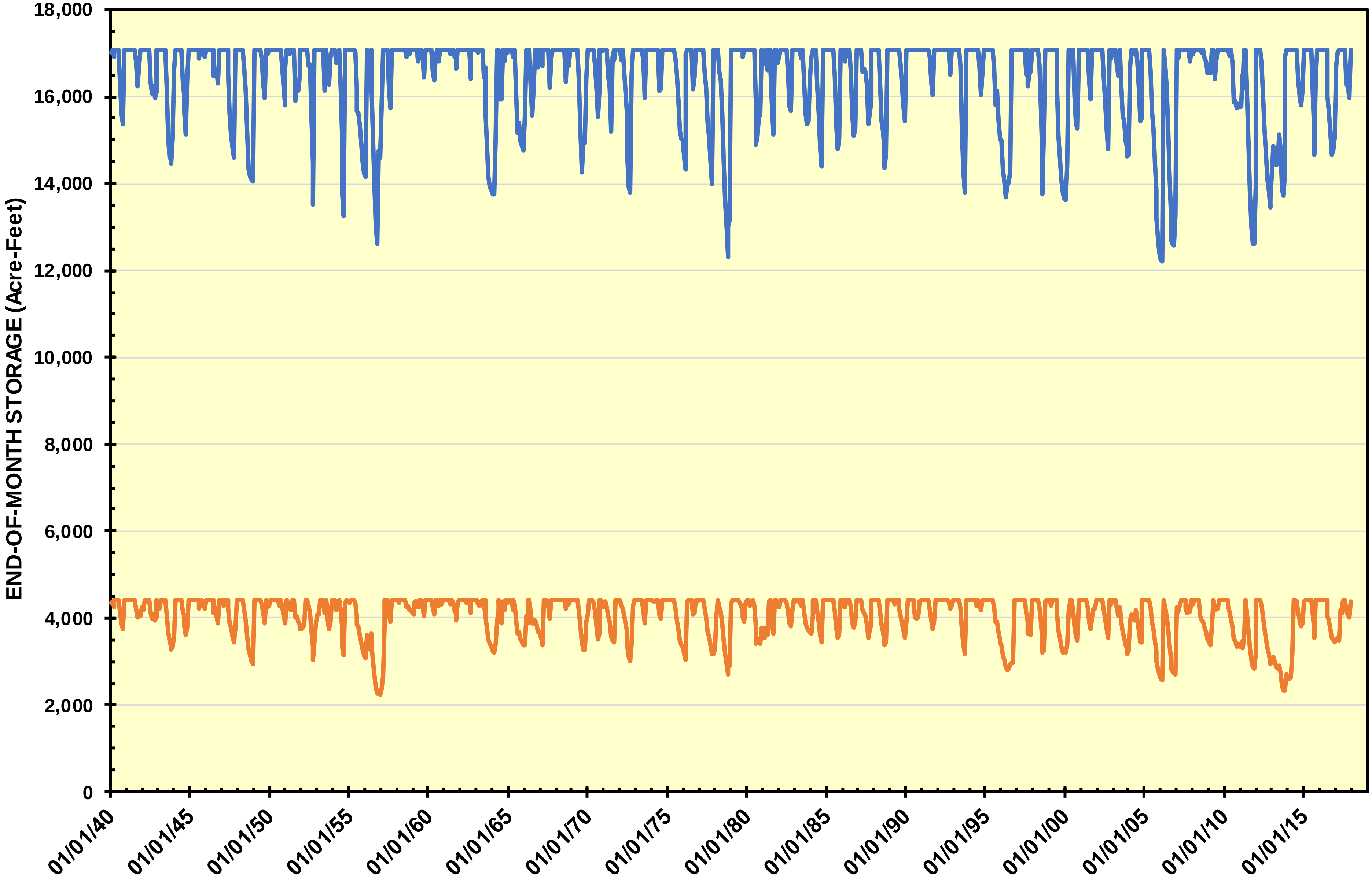
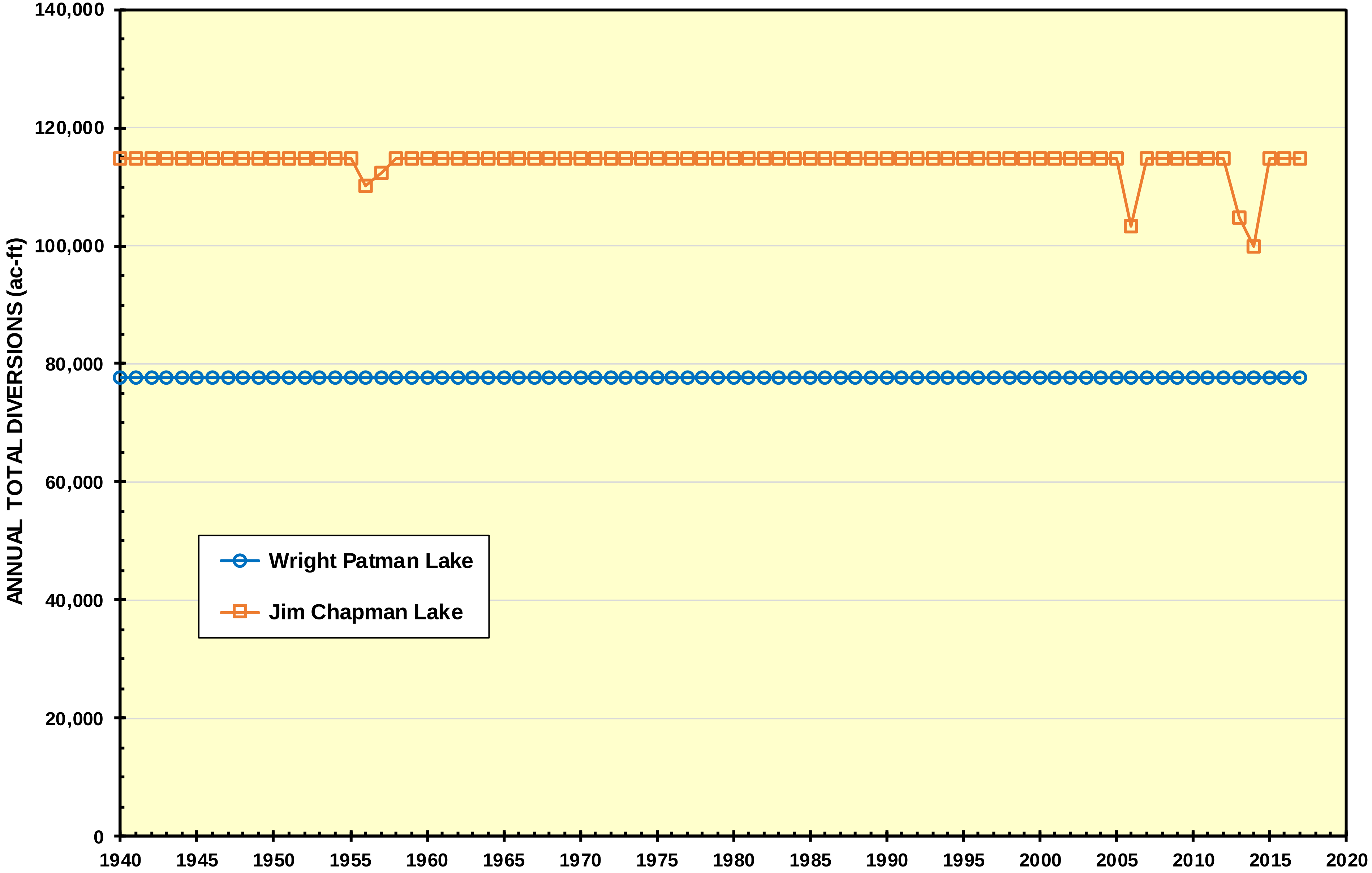


**Figure 4-5 Annual Diversions from Wright Patman and Jim Chapman Lakes**
**Simulated with Updated-Extended Run 8 Version of Sulphur WAM**



A similar graph is presented in Figure 4-6 for the diversions from Lake Sulphur Springs and Big Creek Reservoir, and again these current-conditions demands are fully satisfied. The graph in Figure 4-7 presents a plot of the simulated annual diversions by two components of Luminant's water right P-5562. This is a run-of-the-river water right without the support of any reservoir storage capacity, which accounts for the extreme variations in the annual diversion amounts.

## 4.5 Firm Annual Yields of Major Reservoirs from Updated-Extended Run 8 WAM

The updated-extended Run 8 version of the Sulphur WAM has been operated to determine the firm annual yield for Wright Patman Lake, Jim Chapman Lake, and Lake Sulphur Springs, the three largest existing reservoirs in the basin used for municipal and industrial purposes. For these analyses, the Current Rule Curve and 221.5 feet msl minimum storage level have been engaged for Wright Patman Lake, which means, as described in Section 4.3, it has a maximum storage capacity of only 134,326 acre-feet. For each of the other two reservoirs, it has been assumed that they can be drawn down to near zero storage for purposes of calculating firm annual yield.

Results from this exercise are summarized in Table 4-5. Compared to the updated-extended Run 3 firm annual yields presented in Table 3-3, the Run 8 firm yields for Jim Chapman Lake and Lake Sulphur Springs are slightly higher, a reflection of the overall lower water right demands in the Run 8 model. The Wright Patman yield from the Run 8 model is significantly lower than the Run 3 yield because of the substantially reduced storage capacity available for making diversions.

**Table 4-5 Firm Annual Yields for Major Reservoirs from Updated-Extended Run 8 WAM**

| (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|
| **RESERVOIR** | **PRIORITY DATE** | **AUTH. DIVERSION AMOUNT (ac-ft/yr)** | **CONSERV. STORAGE CAPACITY (ac-ft)** | **FIRM ANNUAL YIELD (ac-ft/yr)** | **CRITICAL DROUGHT PERIOD (Spill to Spill)** |
| Jim Chapman Lake | 11/19/1965 | 146,520 | 291,650 | 126,010 | April 2010 - May 2015 |
| Lake Sulphur Springs | 7/24/1951 | 9,800 | 17,086 | 9,336 | April 2003 - July 2007 |
| Wright Patman Lake | 3/5/1951 | 180,000 | 135,326 [1] | 99,373 | May 2005 - March 2006 |

Notes: [1] The top of the conservation pool for Wright Patman Lake varies monthly according to the Current Rule Curve (Table 4-3), with the maximum storage capacity occuring in June at 248,892 acre-feet. However, the bottom of the conservation pool is fixed at Elevation 221.5 feet msl, or 113,566 acre-feet. Therefore, the maximum volume of storage available for making diversions is only 135,326 acre-feet.

[2] All firm annual yield values were determined using the FY Record in the WAM data files.

**Figure 4-6 Annual Diversions from Lake Sulphur Springs and Big Creek Reservoir Simulated with Updated-Extended Run 8 Version of Sulphur WAM**

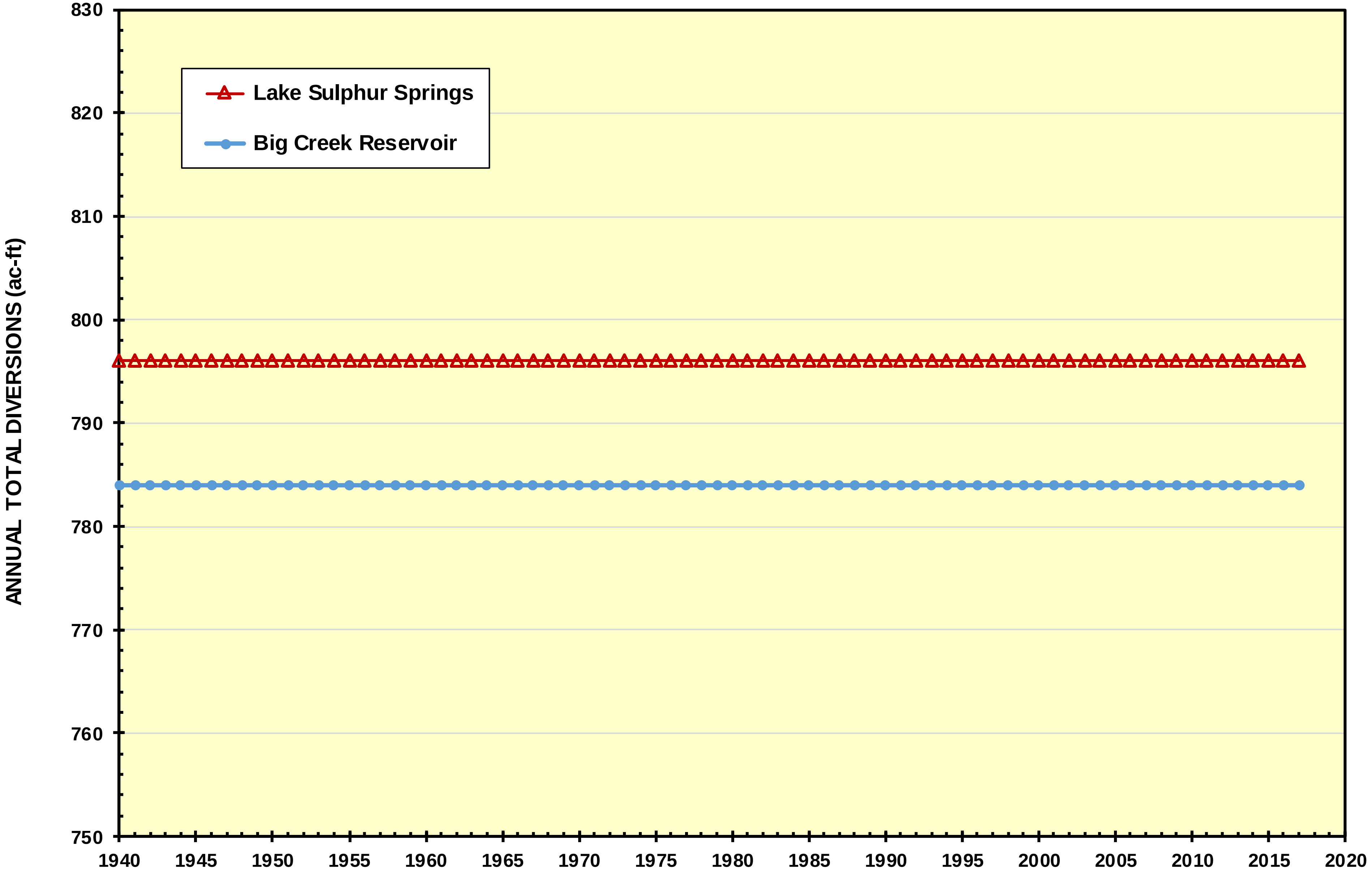
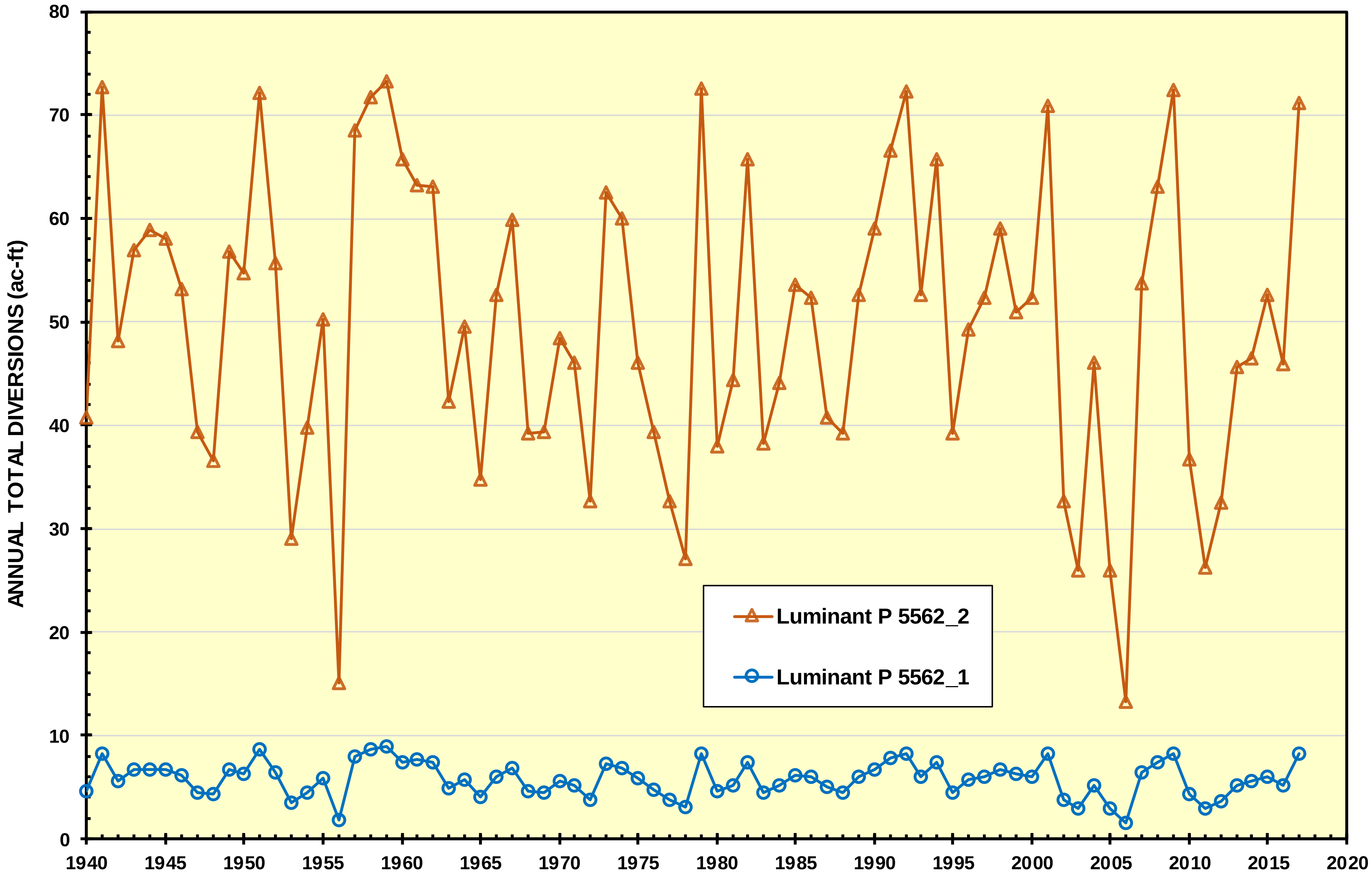


**Figure 4-7 Annual Diversions by Luminant's P-5562 Run-of-River Water Right Simulated with Updated-Extended Run 8 Version of Sulphur WAM**



# APPENDIX A

# 1940-2017 NATURALIZED STREAMFLOWS

# TABULATED BY SUBWATERSHED

# NATURALIZED FLOWS FOR SUBWATERSHED A

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940 | 170 | 2,809 | 2,376 | 44,621 | 26,170 | 22,500 | 14,608 | 276 | 586 | 47 | 31,054 | 57,673 | 202,890 |
| 1941 | 16,241 | 23,605 | 63,490 | 57,131 | 83,575 | 30,013 | 9,076 | 2,378 | 809 | 562 | 4,512 | 10,955 | 302,347 |
| 1942 | 1,797 | 5,127 | 16,651 | 194,648 | 31,741 | 39,004 | 2,150 | 2,957 | 10,748 | 430 | 8,166 | 27,396 | 340,815 |
| 1943 | 173 | 2,344 | 46,310 | 6,530 | 20,869 | 39,251 | 176 | 0 | 0 | 69 | 1,233 | 4,771 | 121,726 |
| 1944 | 12,478 | 38,458 | 55,915 | 14,052 | 118,503 | 17,096 | 1,122 | 3,245 | 569 | 0 | 5,374 | 38,479 | 305,291 |
| 1945 | 16,546 | 84,798 | 126,755 | 36,106 | 14,370 | 59,486 | 29,659 | 99 | 8,578 | 46,419 | 3,182 | 24 | 426,022 |
| 1946 | 36,394 | 79,591 | 31,619 | 24,006 | 110,323 | 41,046 | 490 | 14,243 | 233 | 183 | 124,377 | 27,658 | 490,163 |
| 1947 | 8,587 | 393 | 17,482 | 22,125 | 30,314 | 5,632 | 2 | 6,557 | 331 | 227 | 18,346 | 56,154 | 166,150 |
| 1948 | 39,349 | 35,760 | 41,720 | 17,233 | 70,981 | 3,010 | 3,911 | 52 | 0 | 19 | 0 | 2,150 | 214,185 |
| 1949 | 102,558 | 69,636 | 43,659 | 16,511 | 16,664 | 10,898 | 5,059 | 1,435 | 973 | 54,241 | 248 | 3,252 | 325,134 |
| 1950 | 58,877 | 160,465 | 7,533 | 7,942 | 91,105 | 19,303 | 8,967 | 1,400 | 77,697 | 134 | 5 | 23 | 433,451 |
| 1951 | 836 | 45,357 | 622 | 288 | 4,361 | 122,161 | 10,076 | 0 | 0 | 760 | 1,199 | 294 | 185,954 |
| 1952 | 3,933 | 1,869 | 5,124 | 105,706 | 33,714 | 5,941 | 0 | 0 | 0 | 0 | 15,544 | 22,328 | 194,159 |
| 1953 | 11,883 | 1,134 | 28,199 | 104,260 | 55,564 | 6 | 11,898 | 533 | 4 | 118 | 8,545 | 29,456 | 251,600 |
| 1954 | 43,353 | 6,665 | 110 | 12,005 | 44,063 | 3,899 | 0 | 0 | 0 | 50,745 | 12,087 | 552 | 173,479 |
| 1955 | 1,300 | 22,925 | 23,157 | 18,001 | 8,833 | 49 | 2,494 | 3,280 | 831 | 1,540 | 0 | 0 | 82,410 |
| 1956 | 0 | 21,622 | 10 | 390 | 23,789 | 1,449 | 0 | 0 | 0 | 0 | 2,504 | 2,030 | 51,794 |
| 1957 | 6,719 | 15,815 | 50,928 | 259,718 | 207,674 | 69,708 | 395 | 4,250 | 30,544 | 30,169 | 148,671 | 11,001 | 835,592 |
| 1958 | 34,431 | 828 | 54,281 | 94,839 | 141,913 | 29,493 | 15,985 | 61 | 3,267 | 565 | 831 | 715 | 377,209 |
| 1959 | 1,078 | 12,722 | 8,025 | 6,719 | 2,229 | 9,075 | 20,983 | 1,554 | 1,394 | 21,160 | 18,296 | 67,584 | 170,819 |
| 1960 | 49,620 | 16,475 | 10,809 | 2,218 | 15,937 | 22,873 | 11,680 | 1,621 | 7,917 | 20,083 | 749 | 112,806 | 272,788 |
| 1961 | 53,228 | 18,293 | 40,051 | 9,718 | 1,059 | 14,254 | 3,700 | 1,396 | 4,660 | 44 | 14,998 | 34,122 | 195,523 |
| 1962 | 13,584 | 10,461 | 5,625 | 25,701 | 7,260 | 35,874 | 19,976 | 3,392 | 68,832 | 10,042 | 41,060 | 4,734 | 246,541 |
| 1963 | 12,904 | 203 | 5,995 | 8,113 | 12,236 | 1,153 | 16,646 | 22 | 0 | 0 | 0 | 0 | 57,272 |
| 1964 | 0 | 73 | 9,383 | 23,028 | 18,012 | 24,323 | 0 | 0 | 22,279 | 420 | 35,912 | 1,188 | 134,618 |
| 1965 | 24,547 | 117,799 | 1,378 | 564 | 119,658 | 3,609 | 19 | 0 | 6,086 | 18 | 685 | 0 | 274,363 |
| 1966 | 700 | 27,548 | 860 | 201,997 | 97,921 | 44 | 481 | 2,365 | 6,490 | 1,851 | 52 | 664 | 340,973 |
| 1967 | 168 | 67 | 1,984 | 55,701 | 48,037 | 77,874 | 1,181 | 74 | 23,443 | 36,837 | 20,817 | 44,646 | 310,829 |
| 1968 | 35,017 | 16,451 | 102,163 | 54,819 | 81,486 | 40,900 | 27,268 | 4,255 | 21,152 | 2,921 | 25,796 | 40,088 | 452,316 |
| 1969 | 62,469 | 101,604 | 70,229 | 23,620 | 180,559 | 2,504 | 0 | 0 | 0 | 5,667 | 2,440 | 29,118 | 478,210 |
| 1970 | 10,306 | 58,973 | 87,912 | 60,530 | 6,263 | 3,499 | 0 | 0 | 8,986 | 45,313 | 4,414 | 1,575 | 287,771 |
| 1971 | 1,093 | 8,379 | 3,870 | 34 | 49 | 72 | 265 | 10,370 | 1,842 | 128,074 | 797 | 195,267 | 350,112 |
| 1972 | 4,923 | 673 | 5,743 | 222 | 737 | 795 | 0 | 0 | 165 | 13,982 | 39,393 | 17,385 | 84,018 |
| 1973 | 32,048 | 34,232 | 88,360 | 107,696 | 13,725 | 36,055 | 703 | 204 | 75,665 | 78,215 | 98,529 | 37,106 | 602,538 |
| 1974 | 76,516 | 3,928 | 9,252 | 86,054 | 14,499 | 112,847 | 51 | 502 | 74,074 | 9,477 | 143,372 | 67,950 | 598,522 |
| 1975 | 16,559 | 140,249 | 62,274 | 45,444 | 80,255 | 86,869 | 1,734 | 179 | 0 | 0 | 0 | 153 | 433,716 |
| 1976 | 0 | 37 | 5,642 | 57,365 | 36,275 | 13,523 | 39,511 | 425 | 4,432 | 23,764 | 3,532 | 50,562 | 235,068 |
| 1977 | 28,495 | 60,311 | 138,015 | 51,104 | 1,887 | 16,782 | 259 | 3,401 | 834 | 0 | 5,101 | 820 | 307,009 |
| 1978 | 4,889 | 36,391 | 33,799 | 2,166 | 5,120 | 7,137 | 0 | 0 | 0 | 0 | 3,468 | 2,656 | 95,626 |
| 1979 | 64,369 | 31,535 | 57,276 | 35,090 | 132,708 | 46,117 | 2,337 | 5,164 | 424 | 107 | 344 | 19,583 | 395,054 |
| 1980 | 33,966 | 21,742 | 202 | 8,968 | 27,617 | 907 | 0 | 0 | 4,775 | 5,904 | 134 | 20,794 | 125,009 |
| 1981 | 69 | 43 | 16,617 | 1,302 | 32,522 | 172,596 | 1,582 | 36 | 0 | 100,763 | 44,352 | 798 | 370,680 |
| 1982 | 1,170 | 14,460 | 8,590 | 10,264 | 233,227 | 42,359 | 7,447 | 316 | 489 | 0 | 12,756 | 64,899 | 395,977 |
| 1983 | 1,808 | 86,319 | 54,053 | 4,032 | 16,103 | 3,152 | 22,847 | 50 | 0 | 410 | 801 | 318 | 189,893 |
| 1984 | 306 | 20,183 | 99,899 | 14,479 | 6,075 | 222 | 0 | 0 | 0 | 38,437 | 13,929 | 77,745 | 271,275 |
| 1985 | 12,245 | 21,873 | 84,269 | 48,423 | 71,766 | 9,225 | 292 | 0 | 0 | 3,842 | 65,700 | 47,731 | 365,366 |
| 1986 | 91 | 46,789 | 265 | 51,412 | 17,802 | 53,970 | 4,917 | 0 | 3,947 | 6,971 | 60,878 | 19,174 | 266,216 |
| 1987 | 26,094 | 27,367 | 89,786 | 694 | 11,180 | 12,581 | 264 | 0 | 11,303 | 9,708 | 156,814 | 118,574 | 464,365 |
| 1988 | 25,673 | 21,868 | 17,582 | 23,318 | 6 | 96 | 39,096 | 0 | 2,248 | 5,124 | 43,235 | 15,735 | 193,981 |
| 1989 | 41,713 | 74,280 | 31,321 | 4,670 | 67,077 | 94,048 | 51,478 | 1,799 | 996 | 80 | 219 | 43 | 367,724 |
| 1990 | 12,074 | 65,099 | 136,238 | 86,334 | 138,642 | 35,281 | 0 | 1,483 | 509 | 3,114 | 15,317 | 15,374 | 509,465 |
| 1991 | 60,513 | 27,249 | 13,301 | 58,193 | 44,823 | 23,156 | 151 | 0 | 0 | 5,092 | 59,641 | 71,375 | 363,494 |
| 1992 | 48,139 | 44,369 | 93,531 | 9,752 | 121,797 | 81,762 | 63,140 | 19,666 | 1,530 | 2,876 | 2,384 | 50,324 | 539,270 |
| 1993 | 23,546 | 93,040 | 50,761 | 76,542 | 18,993 | 2,261 | 3,816 | 4,459 | 3,035 | 102,773 | 34,818 | 96,586 | 510,630 |
| 1994 | 17,035 | 34,798 | 46,030 | 13,463 | 85,353 | 5,339 | 56,214 | 5,782 | 7,504 | 22,300 | 88,360 | 62,333 | 444,511 |
| 1995 | 60,128 | 4,695 | 57,291 | 56,182 | 144,048 | 35,060 | 3,102 | 2,620 | 3,653 | 0 | 2,026 | 0 | 368,805 |
| 1996 | 4,213 | 2,208 | 3,915 | 6,898 | 2,263 | 6,019 | 5,777 | 5,958 | 2,472 | 12,609 | 152,089 | 22,097 | 226,518 |

## NATURALIZED FLOWS FOR SUBWATERSHED A, continued

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | 10,249 | 168,008 | 57,211 | 96,647 | 6,983 | 33,102 | 0 | 388 | 0 | 860 | 928 | 104,365 | 478,741 |
| 1998 | 98,605 | 41,526 | 38,786 | 8,968 | 2,297 | 2,014 | 1,602 | 0 | 4,496 | 52,818 | 55,052 | 130,032 | 436,196 |
| 1999 | 69,486 | 0 | 12,133 | 17,336 | 22,521 | 9,485 | 0 | 0 | 0 | 0 | 0 | 8,166 | 139,127 |
| 2000 | 2,333 | 10,989 | 36,323 | 14,559 | 30,352 | 84,728 | 0 | 0 | 0 | 0 | 136,922 | 108,446 | 424,652 |
| 2001 | 52,083 | 162,749 | 138,655 | 59,429 | 12,521 | 280 | 456 | 873 | 14,331 | 12,224 | 2,791 | 188,747 | 645,139 |
| 2002 | 38,872 | 46,128 | 102,664 | 95,339 | 11,445 | 0 | 973 | 0 | 0 | 142,813 | 1,507 | 43,564 | 483,305 |
| 2003 | 7,119 | 31,230 | 16,678 | 9,131 | 6,173 | 10,896 | 0 | 0 | 0 | 0 | 0 | 0 | 81,227 |
| 2004 | 5,107 | 30,828 | 12,562 | 6,594 | 2,607 | 10,106 | 0 | 0 | 0 | 1,860 | 44,509 | 14,221 | 128,394 |
| 2005 | 61,185 | 18,290 | 17,862 | 9,515 | 0 | 0 | 0 | 0 | 0 | 180 | 0 | 713 | 107,745 |
| 2006 | 1,297 | 3,266 | 95,762 | 1,192 | 0 | 0 | 0 | 0 | 0 | 835 | 1,100 | 28,349 | 131,801 |
| 2007 | 68,020 | 1,666 | 10,906 | 19,969 | 25,164 | 97,421 | 119,804 | 3,012 | 0 | 9,877 | 0 | 20,516 | 376,355 |
| 2008 | 0 | 39,915 | 191,740 | 56,216 | 3,478 | 8,775 | 0 | 484 | 1,633 | 0 | 2,107 | 1,300 | 305,648 |
| 2009 | 564 | 1,554 | 20,884 | 52,178 | 144,786 | 0 | 5,231 | 5,351 | 15,697 | 228,656 | 31,624 | 29,449 | 535,974 |
| 2010 | 66,566 | 80,302 | 44,249 | 282 | 2,597 | 567 | 935 | 0 | 0 | 0 | 4,426 | 2,894 | 202,818 |
| 2011 | 3,393 | 8,103 | 1,138 | 10,374 | 55,236 | 0 | 451 | 773 | 130 | 0 | 1,970 | 11,158 | 92,726 |
| 2012 | 65,489 | 11,931 | 102,538 | 16,275 | 9,469 | 1,984 | 340 | 1,341 | 611 | 0 | 1,103 | 2,195 | 213,276 |
| 2013 | 8,149 | 2,792 | 2,756 | 5,736 | 6,176 | 8,697 | 1,317 | 660 | 1,613 | 72 | 3,747 | 18,138 | 59,853 |
| 2014 | 773 | 1,636 | 6,517 | 29,293 | 59,380 | 7,809 | 4,258 | 0 | 0 | 2,346 | 0 | 2,850 | 114,862 |
| 2015 | 23,039 | 26,309 | 122,186 | 70,409 | 164,955 | 56,471 | 0 | 0 | 0 | 69,428 | 232,266 | 200,977 | 966,040 |
| 2016 | 16,983 | 14,384 | 79,893 | 166,944 | 24,953 | 68,371 | 0 | 2,862 | 0 | 2,442 | 0 | 0 | 376,832 |
| 2017 | 5,166 | 4,724 | 2,424 | 28,005 | 2,497 | 11,842 | 24,312 | 143,715 | 0 | 0 | 2,255 | 15,542 | 240,482 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Average | 22,051 | 33,719 | 38,039 | 41,560 | 53,504 | 29,020 | 9,175 | 2,068 | 8,883 | 15,863 | 28,054 | 29,944 | 311,881 |
| 1997-2017 Average | 28,785 | 33,635 | 53,041 | 36,876 | 28,266 | 19,645 | 7,604 | 7,593 | 1,834 | 24,972 | 24,872 | 44,363 | 311,485 |
| 1940-2017 Average | 23,864 | 33,696 | 42,078 | 40,299 | 46,709 | 26,496 | 8,752 | 3,555 | 6,985 | 18,316 | 27,197 | 33,826 | 311,775 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Maximum | 102,558 | 160,465 | 138,015 | 259,718 | 233,227 | 172,596 | 63,140 | 19,666 | 77,697 | 128,074 | 156,814 | 195,267 | 835,592 |
| 1997-2017 Maximum | 98,605 | 168,008 | 191,740 | 166,944 | 164,955 | 97,421 | 119,804 | 143,715 | 15,697 | 228,656 | 232,266 | 200,977 | 966,040 |
| 1940-2017 Maximum | 102,558 | 168,008 | 191,740 | 259,718 | 233,227 | 172,596 | 119,804 | 143,715 | 77,697 | 228,656 | 232,266 | 200,977 | 966,040 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Minimum | 0 | 37 | 10 | 34 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 51,794 |
| 1997-2017 Minimum | 0 | 0 | 1,138 | 282 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 59,853 |
| 1940-2017 Minimum | 0 | 0 | 10 | 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 51,794 |

# NATURALIZED FLOWS FOR SUBWATERSHED B

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940 | 60 | 1,490 | 1,239 | 28,468 | 16,798 | 18,382 | 10,871 | 109 | 477 | 50 | 14,593 | 26,946 | 119,483 |
| 1941 | 5,748 | 12,522 | 33,118 | 36,449 | 53,646 | 24,520 | 6,755 | 935 | 658 | 608 | 2,120 | 5,119 | 182,198 |
| 1942 | 636 | 2,720 | 8,686 | 124,186 | 20,374 | 22,687 | 994 | 1,153 | 5,076 | 302 | 3,842 | 12,969 | 203,625 |
| 1943 | 92 | 1,226 | 23,081 | 3,920 | 11,357 | 22,830 | 81 | 0 | 0 | 48 | 580 | 2,259 | 65,474 |
| 1944 | 6,624 | 20,119 | 27,869 | 8,436 | 64,487 | 9,943 | 518 | 1,265 | 269 | 0 | 2,528 | 18,216 | 160,274 |
| 1945 | 8,784 | 44,361 | 63,176 | 21,677 | 7,820 | 34,600 | 13,709 | 39 | 4,051 | 32,609 | 1,497 | 11 | 232,334 |
| 1946 | 19,322 | 41,638 | 15,759 | 14,412 | 60,036 | 23,874 | 226 | 5,555 | 110 | 129 | 58,520 | 13,093 | 252,674 |
| 1947 | 4,559 | 206 | 8,713 | 13,283 | 16,496 | 3,276 | 1 | 2,557 | 156 | 159 | 8,632 | 26,583 | 84,621 |
| 1948 | 20,891 | 18,708 | 20,794 | 10,346 | 38,626 | 1,751 | 1,807 | 20 | 0 | 13 | 0 | 1,018 | 113,974 |
| 1949 | 54,449 | 36,429 | 21,760 | 9,912 | 9,068 | 6,339 | 2,338 | 560 | 460 | 6,739 | 76 | 3,488 | 151,618 |
| 1950 | 72,069 | 82,363 | 1,435 | 2,619 | 64,671 | 3,827 | 20,153 | 2,207 | 34,158 | 340 | 98 | 160 | 284,100 |
| 1951 | 286 | 31,319 | 817 | 2,430 | 7,311 | 102,593 | 2,032 | 34 | 356 | 3,361 | 586 | 69 | 151,194 |
| 1952 | 243 | 239 | 9,280 | 71,228 | 11,863 | 3,631 | 29 | 0 | 0 | 0 | 10,309 | 4,275 | 111,097 |
| 1953 | 3,316 | 574 | 16,369 | 66,837 | 22,590 | 39 | 9,962 | 1,441 | 530 | 520 | 4,463 | 12,442 | 139,083 |
| 1954 | 18,866 | 9,951 | 270 | 7,668 | 52,375 | 4,174 | 0 | 0 | 8 | 34,664 | 3,144 | 549 | 131,669 |
| 1955 | 1,459 | 6,520 | 21,405 | 16,935 | 5,145 | 683 | 7,237 | 1,797 | 712 | 1,801 | 0 | 0 | 63,694 |
| 1956 | 321 | 39,137 | 621 | 2,610 | 16,059 | 459 | 0 | 0 | 0 | 22 | 2,160 | 371 | 61,760 |
| 1957 | 1,040 | 2,546 | 20,230 | 144,216 | 146,404 | 50,812 | 486 | 3,849 | 19,197 | 5,459 | 83,644 | 8,042 | 485,925 |
| 1958 | 20,638 | 1,511 | 34,182 | 56,571 | 70,015 | 33,534 | 2,020 | 75 | 442 | 51 | 321 | 338 | 219,698 |
| 1959 | 243 | 1,759 | 2,503 | 214 | 355 | 26,526 | 35,492 | 4,102 | 3,931 | 10,766 | 4,660 | 40,816 | 131,367 |
| 1960 | 26,650 | 14,622 | 13,925 | 2,211 | 7,197 | 17,755 | 5,787 | 5,547 | 11,184 | 23,873 | 615 | 89,140 | 218,506 |
| 1961 | 18,090 | 10,462 | 38,241 | 4,833 | 3,502 | 1,609 | 1,187 | 210 | 2,681 | 26 | 7,638 | 17,969 | 106,448 |
| 1962 | 13,991 | 5,843 | 10,018 | 13,277 | 2,786 | 33,493 | 2,964 | 259 | 29,531 | 14,642 | 48,799 | 2,362 | 177,965 |
| 1963 | 6,235 | 521 | 4,688 | 8,688 | 1,430 | 278 | 2,403 | 18 | 0 | 0 | 0 | 21 | 24,282 |
| 1964 | 5 | 164 | 10,721 | 19,803 | 14,327 | 15,807 | 21 | 18 | 18,658 | 90 | 18,773 | 1,922 | 100,309 |
| 1965 | 9,866 | 56,300 | 3,336 | 854 | 34,509 | 1,337 | 9 | 41 | 4,685 | 1 | 177 | 39 | 111,154 |
| 1966 | 81 | 7,267 | 534 | 179,508 | 22,736 | 539 | 65 | 4,998 | 4,619 | 1,568 | 71 | 715 | 222,701 |
| 1967 | 228 | 489 | 4,593 | 55,368 | 68,781 | 12,513 | 3,027 | 90 | 19,696 | 17,807 | 2,772 | 31,021 | 216,385 |
| 1968 | 17,160 | 12,968 | 75,180 | 37,380 | 54,417 | 50,906 | 23,680 | 2,092 | 29,684 | 6,207 | 19,714 | 23,694 | 353,082 |
| 1969 | 44,021 | 21,134 | 35,970 | 8,612 | 79,769 | 2,855 | 107 | 37 | 51 | 6,258 | 367 | 22,120 | 221,301 |
| 1970 | 3,031 | 58,994 | 53,845 | 41,585 | 5,149 | 453 | 27 | 34 | 11,748 | 25,298 | 8,205 | 2,674 | 211,043 |
| 1971 | 2,220 | 6,910 | 3,322 | 722 | 2,329 | 74 | 2,594 | 9,821 | 2,237 | 109,731 | 4,185 | 67,282 | 211,427 |
| 1972 | 3,467 | 992 | 1,073 | 181 | 157 | 324 | 58 | 337 | 45 | 17,079 | 18,056 | 6,126 | 47,895 |
| 1973 | 16,072 | 19,920 | 50,645 | 46,040 | 9,652 | 16,941 | 613 | 197 | 34,793 | 75,867 | 52,915 | 17,328 | 340,983 |
| 1974 | 19,929 | 2,725 | 1,502 | 16,677 | 10,490 | 49,617 | 116 | 385 | 23,597 | 30,581 | 47,746 | 15,553 | 218,918 |
| 1975 | 16,956 | 61,129 | 17,312 | 14,019 | 34,357 | 32,306 | 3,600 | 148 | 116 | 41 | 41 | 115 | 180,140 |
| 1976 | 57 | 52 | 2,972 | 10,854 | 7,142 | 30,458 | 53,606 | 689 | 807 | 8,258 | 954 | 8,722 | 124,571 |
| 1977 | 6,804 | 18,520 | 43,250 | 12,911 | 676 | 3,103 | 69 | 146 | 14 | 5 | 2,051 | 611 | 88,160 |
| 1978 | 1,763 | 11,120 | 8,219 | 1,430 | 3,837 | 6,845 | 22 | 16 | 0 | 1 | 14,926 | 14,410 | 62,589 |
| 1979 | 27,510 | 22,860 | 45,203 | 9,012 | 41,703 | 14,236 | 3,782 | 4,733 | 180 | 903 | 331 | 11,440 | 181,893 |
| 1980 | 4,860 | 8,350 | 703 | 1,272 | 7,472 | 77 | 20 | 7 | 18,592 | 2,762 | 271 | 12,301 | 56,687 |
| 1981 | 375 | 702 | 11,454 | 1,857 | 22,702 | 76,487 | 3,043 | 111 | 2,576 | 86,461 | 32,439 | 1,363 | 239,570 |
| 1982 | 7,505 | 15,475 | 7,445 | 10,727 | 151,320 | 25,653 | 8,501 | 1,722 | 325 | 568 | 6,724 | 19,455 | 255,420 |
| 1983 | 1,942 | 53,099 | 25,710 | 1,721 | 8,114 | 4,953 | 15,031 | 33 | 70 | 251 | 960 | 430 | 112,314 |
| 1984 | 669 | 32,433 | 33,455 | 9,298 | 24,379 | 157 | 7 | 0 | 2 | 10,755 | 10,483 | 36,909 | 158,547 |
| 1985 | 12,339 | 16,253 | 51,833 | 29,330 | 32,457 | 5,959 | 591 | 7 | 16 | 7,919 | 26,789 | 18,662 | 202,155 |
| 1986 | 661 | 20,859 | 1,756 | 27,597 | 18,597 | 22,411 | 7,854 | 0 | 3,577 | 7,182 | 50,567 | 15,623 | 176,684 |
| 1987 | 17,727 | 29,324 | 30,969 | 530 | 6,096 | 3,250 | 6,015 | 267 | 31,719 | 13,960 | 66,662 | 61,285 | 267,804 |
| 1988 | 15,675 | 13,069 | 18,758 | 11,310 | 380 | 31 | 3,336 | 18 | 970 | 2,540 | 9,670 | 8,399 | 84,156 |
| 1989 | 11,955 | 67,108 | 33,384 | 5,363 | 54,578 | 106,586 | 25,700 | 1,086 | 4,811 | 147 | 131 | 272 | 311,121 |
| 1990 | 31,386 | 48,025 | 61,570 | 39,107 | 85,708 | 14,229 | 740 | 642 | 424 | 10,259 | 9,125 | 11,015 | 312,230 |
| 1991 | 44,213 | 13,191 | 7,941 | 42,239 | 11,533 | 16,472 | 221 | 856 | 1,162 | 59,432 | 14,151 | 93,902 | 305,313 |
| 1992 | 37,900 | 15,738 | 46,218 | 2,984 | 36,979 | 55,051 | 13,631 | 3,444 | 332 | 129 | 2,184 | 29,146 | 243,736 |
| 1993 | 12,659 | 57,732 | 32,267 | 27,938 | 12,480 | 7,390 | 119 | 27 | 49 | 46,625 | 17,127 | 52,046 | 266,459 |
| 1994 | 1,869 | 16,081 | 43,560 | 13,900 | 62,380 | 13,134 | 30,668 | 3,578 | 661 | 5,631 | 61,802 | 26,599 | 279,863 |
| 1995 | 22,940 | 1,985 | 24,764 | 28,687 | 82,304 | 8,220 | 1,059 | 70 | 3,199 | 138 | 327 | 230 | 173,923 |
| 1996 | 1,873 | 238 | 983 | 908 | 2,609 | 5,767 | 3,054 | 7,874 | 1,352 | 12,082 | 68,322 | 12,495 | 117,557 |

## NATURALIZED FLOWS FOR SUBWATERSHED B, continued

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | 2,559 | 67,026 | 29,245 | 43,675 | 1,270 | 7,348 | 138 | 209 | 8 | 2,754 | 1,476 | 42,462 | 198,170 |
| 1998 | 60,243 | 18,628 | 41,902 | 2,591 | 374 | 62 | 0 | 0 | 8,123 | 17,287 | 26,990 | 69,779 | 245,979 |
| 1999 | 37,712 | 6,937 | 9,521 | 10,719 | 9,974 | 4,930 | 763 | 0 | 115 | 0 | 565 | 13,622 | 94,858 |
| 2000 | 598 | 3,245 | 18,370 | 10,169 | 34,582 | 45,134 | 1,844 | 0 | 0 | 80 | 71,201 | 64,048 | 249,271 |
| 2001 | 37,408 | 116,545 | 65,442 | 10,800 | 9,360 | 1,623 | 278 | 10,140 | 10,095 | 18,950 | 5,861 | 104,059 | 390,561 |
| 2002 | 47,246 | 36,894 | 104,323 | 46,105 | 14,607 | 290 | 2,745 | 5,256 | 2,165 | 87,996 | 7,850 | 45,095 | 400,572 |
| 2003 | 8,316 | 32,965 | 10,258 | 380 | 6,788 | 15,113 | 473 | 60 | 1,378 | 60 | 1,970 | 311 | 78,072 |
| 2004 | 7,652 | 22,685 | 12,873 | 2,560 | 4,285 | 9,658 | 799 | 33 | 11 | 633 | 43,517 | 12,996 | 117,702 |
| 2005 | 68,760 | 16,119 | 12,122 | 6,959 | 266 | 16 | 12 | 0 | 0 | 0 | 0 | 0 | 104,254 |
| 2006 | 11 | 1,072 | 41,213 | 782 | 6 | 0 | 0 | 0 | 0 | 925 | 1,292 | 10,659 | 55,960 |
| 2007 | 47,468 | 294 | 3,320 | 14,539 | 39,464 | 80,205 | 94,000 | 3,311 | 4,635 | 16,092 | 577 | 14,972 | 318,877 |
| 2008 | 728 | 28,270 | 147,979 | 21,838 | 882 | 4,264 | 9 | 0 | 24 | 11 | 28 | 77 | 204,110 |
| 2009 | 123 | 98 | 8,419 | 37,033 | 88,936 | 66 | 2,130 | 4,283 | 29,262 | 142,820 | 14,349 | 23,086 | 350,605 |
| 2010 | 44,742 | 54,650 | 28,006 | 1,707 | 1,886 | 618 | 388 | 0 | 1,805 | 238 | 1,187 | 1,450 | 136,677 |
| 2011 | 1,096 | 1,953 | 277 | 10,730 | 34,283 | 249 | 4 | 0 | 0 | 0 | 21 | 5,072 | 53,685 |
| 2012 | 40,505 | 6,373 | 60,363 | 3,364 | 2,095 | 1,084 | 519 | 72 | 0 | 0 | 0 | 42 | 114,417 |
| 2013 | 2,074 | 1,462 | 2,590 | 1,857 | 13,983 | 7,425 | 113 | 1 | 0 | 209 | 1,744 | 9,450 | 40,908 |
| 2014 | 701 | 294 | 1,875 | 2,064 | 30,265 | 1,381 | 2,378 | 870 | 9,476 | 10,572 | 432 | 5,307 | 65,615 |
| 2015 | 18,681 | 16,068 | 81,944 | 24,292 | 123,280 | 49,435 | 565 | 9 | 22 | 5,169 | 163,058 | 114,751 | 597,274 |
| 2016 | 8,628 | 12,457 | 40,437 | 93,427 | 23,315 | 11,404 | 20 | 207 | 106 | 0 | 39 | 68 | 190,108 |
| 2017 | 3,263 | 2,426 | 2,437 | 14,904 | 1,074 | 10,593 | 51,509 | 71,456 | 291 | 435 | 96 | 8,598 | 167,082 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Average | 12,286 | 19,263 | 20,853 | 24,231 | 30,185 | 18,452 | 5,930 | 1,320 | 5,873 | 12,328 | 14,524 | 15,968 | 181,213 |
| 1997-2017 Average | 20,882 | 21,260 | 34,425 | 17,166 | 20,999 | 11,948 | 7,557 | 4,567 | 3,215 | 14,487 | 16,298 | 25,995 | 198,798 |
| 1940-2017 Average | 14,601 | 19,801 | 24,507 | 22,329 | 27,712 | 16,701 | 6,368 | 2,194 | 5,157 | 12,910 | 15,001 | 18,667 | 185,948 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Maximum | 72,069 | 82,363 | 75,180 | 179,508 | 151,320 | 106,586 | 53,606 | 9,821 | 34,793 | 109,731 | 83,644 | 93,902 | 485,925 |
| 1997-2017 Maximum | 68,760 | 116,545 | 147,979 | 93,427 | 123,280 | 80,205 | 94,000 | 71,456 | 29,262 | 142,820 | 163,058 | 114,751 | 597,274 |
| 1940-2017 Maximum | 72,069 | 116,545 | 147,979 | 179,508 | 151,320 | 106,586 | 94,000 | 71,456 | 34,793 | 142,820 | 163,058 | 114,751 | 597,274 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Minimum | 5 | 52 | 270 | 181 | 157 | 31 | 0 | 0 | 0 | 0 | 0 | 0 | 24,282 |
| 1997-2017 Minimum | 11 | 98 | 277 | 380 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40,908 |
| 1940-2017 Minimum | 5 | 52 | 270 | 181 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24,282 |

# NATURALIZED FLOWS FOR SUBWATERSHED C

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940 | 355 | 7,276 | 7,201 | 127,291 | 105,319 | 92,402 | 28,655 | 438 | 2,792 | 225 | 86,640 | 185,882 | 644,476 |
| 1941 | 33,960 | 76,126 | 192,446 | 162,978 | 336,342 | 123,255 | 17,804 | 3,769 | 3,856 | 2,704 | 12,589 | 35,309 | 1,001,138 |
| 1942 | 3,758 | 16,535 | 50,471 | 555,278 | 127,740 | 108,426 | 6,313 | 4,700 | 16,225 | 1,215 | 12,077 | 70,959 | 973,697 |
| 1943 | 573 | 8,009 | 132,271 | 16,798 | 54,000 | 62,396 | 517 | 0 | 0 | 194 | 2,932 | 14,430 | 292,120 |
| 1944 | 41,220 | 131,441 | 159,704 | 36,148 | 365,321 | 57,890 | 3,293 | 4,510 | 1,366 | 0 | 12,780 | 116,375 | 930,048 |
| 1945 | 54,658 | 289,826 | 362,037 | 92,879 | 44,300 | 201,437 | 76,520 | 302 | 20,602 | 131,207 | 7,567 | 71 | 1,281,406 |
| 1946 | 120,224 | 272,030 | 90,310 | 61,753 | 340,104 | 138,994 | 1,438 | 20,553 | 559 | 518 | 295,793 | 83,650 | 1,425,926 |
| 1947 | 28,366 | 1,344 | 49,931 | 56,915 | 93,451 | 13,670 | 7 | 9,114 | 795 | 640 | 43,631 | 169,833 | 467,697 |
| 1948 | 129,986 | 122,220 | 119,161 | 44,331 | 218,820 | 10,194 | 11,483 | 157 | 0 | 53 | 0 | 6,503 | 662,908 |
| 1949 | 314,642 | 238,003 | 124,700 | 42,472 | 51,373 | 36,903 | 14,855 | 4,369 | 2,337 | 101,874 | 523 | 13,666 | 945,717 |
| 1950 | 248,627 | 461,349 | 17,171 | 16,876 | 311,272 | 43,196 | 29,120 | 8,009 | 177,190 | 793 | 166 | 372 | 1,314,141 |
| 1951 | 2,130 | 145,677 | 2,754 | 4,343 | 23,323 | 316,419 | 24,799 | 75 | 564 | 6,885 | 2,882 | 736 | 530,587 |
| 1952 | 7,929 | 4,003 | 27,580 | 282,722 | 91,072 | 17,875 | 59 | 0 | 0 | 0 | 41,731 | 53,943 | 526,914 |
| 1953 | 28,858 | 3,245 | 85,334 | 221,211 | 156,166 | 85 | 30,817 | 4,384 | 847 | 763 | 17,978 | 73,310 | 622,998 |
| 1954 | 118,136 | 31,569 | 728 | 31,436 | 192,703 | 15,076 | 0 | 0 | 12 | 121,199 | 24,586 | 2,232 | 537,677 |
| 1955 | 5,238 | 55,942 | 85,324 | 55,825 | 27,931 | 1,365 | 19,928 | 11,274 | 2,444 | 5,582 | 0 | 0 | 270,853 |
| 1956 | 610 | 115,436 | 1,208 | 4,793 | 79,625 | 3,564 | 0 | 0 | 0 | 38 | 11,068 | 3,358 | 219,700 |
| 1957 | 18,846 | 49,474 | 134,758 | 618,861 | 718,520 | 337,365 | 881 | 8,099 | 53,716 | 65,956 | 397,149 | 34,839 | 2,438,464 |
| 1958 | 110,564 | 3,280 | 134,832 | 188,099 | 481,569 | 72,322 | 49,885 | 1,144 | 16,981 | 2,470 | 23,732 | 3,519 | 1,088,397 |
| 1959 | 6,954 | 61,075 | 28,335 | 31,179 | 5,965 | 102,275 | 115,029 | 14,033 | 10,993 | 56,212 | 46,493 | 252,328 | 730,871 |
| 1960 | 156,262 | 44,003 | 39,102 | 4,429 | 34,771 | 61,651 | 71,554 | 14,398 | 77,211 | 99,586 | 9,440 | 402,485 | 1,014,892 |
| 1961 | 140,326 | 59,089 | 159,667 | 78,048 | 14,936 | 16,029 | 11,846 | 2,932 | 9,318 | 290 | 47,093 | 105,005 | 644,579 |
| 1962 | 73,350 | 41,238 | 26,898 | 102,450 | 35,474 | 81,464 | 61,016 | 4,233 | 160,049 | 67,139 | 152,822 | 23,526 | 829,659 |
| 1963 | 46,611 | 1,487 | 31,350 | 23,441 | 23,895 | 2,515 | 22,140 | 327 | 49 | 10 | 35 | 72 | 151,932 |
| 1964 | 9 | 1,430 | 39,138 | 113,015 | 32,340 | 58,520 | 97 | 204 | 50,363 | 6,686 | 98,283 | 5,843 | 405,928 |
| 1965 | 71,537 | 335,120 | 10,150 | 4,666 | 303,254 | 17,728 | 144 | 73 | 11,123 | 159 | 862 | 116 | 754,932 |
| 1966 | 1,777 | 84,960 | 2,151 | 482,210 | 380,362 | 1,237 | 574 | 7,363 | 16,691 | 26,520 | 123 | 3,752 | 1,007,720 |
| 1967 | 1,041 | 1,731 | 11,414 | 309,637 | 170,262 | 256,711 | 44,845 | 163 | 46,763 | 74,803 | 103,752 | 173,662 | 1,194,784 |
| 1968 | 115,978 | 68,878 | 384,839 | 238,174 | 333,500 | 234,811 | 59,153 | 18,756 | 78,083 | 15,735 | 123,474 | 206,665 | 1,878,046 |
| 1969 | 134,928 | 479,680 | 297,535 | 84,651 | 613,040 | 10,291 | 627 | 47 | 66 | 11,925 | 8,657 | 76,898 | 1,718,345 |
| 1970 | 50,069 | 194,484 | 299,145 | 211,305 | 29,764 | 8,680 | 338 | 34 | 23,211 | 135,781 | 30,102 | 7,147 | 990,060 |
| 1971 | 5,547 | 23,699 | 11,436 | 756 | 9,369 | 388 | 5,685 | 60,314 | 4,404 | 369,519 | 8,879 | 679,015 | 1,179,011 |
| 1972 | 19,321 | 4,834 | 11,119 | 944 | 1,919 | 2,210 | 472 | 337 | 211 | 31,566 | 173,691 | 77,045 | 323,669 |
| 1973 | 105,140 | 132,443 | 446,010 | 399,777 | 50,277 | 133,381 | 2,009 | 789 | 188,814 | 252,178 | 382,410 | 139,269 | 2,232,497 |
| 1974 | 173,824 | 12,380 | 11,225 | 110,831 | 30,237 | 287,383 | 273 | 887 | 175,361 | 40,058 | 405,784 | 170,465 | 1,418,708 |
| 1975 | 33,515 | 309,116 | 127,864 | 71,410 | 185,108 | 177,405 | 11,268 | 2,004 | 189 | 70 | 154 | 514 | 918,617 |
| 1976 | 233 | 154 | 18,106 | 145,974 | 101,906 | 75,788 | 236,454 | 1,113 | 8,316 | 41,645 | 11,653 | 129,131 | 770,473 |
| 1977 | 82,532 | 174,664 | 318,169 | 228,692 | 6,406 | 22,301 | 1,515 | 4,409 | 849 | 5 | 10,027 | 1,983 | 851,552 |
| 1978 | 12,845 | 63,801 | 104,176 | 7,190 | 17,069 | 13,982 | 22 | 16 | 1 | 1 | 28,667 | 17,067 | 264,837 |
| 1979 | 237,646 | 122,317 | 177,660 | 149,088 | 399,607 | 170,887 | 9,307 | 18,242 | 904 | 1,010 | 1,891 | 99,306 | 1,387,865 |
| 1980 | 124,741 | 104,377 | 2,149 | 49,883 | 114,861 | 7,313 | 35 | 7 | 23,367 | 32,444 | 1,112 | 69,578 | 529,867 |
| 1981 | 715 | 1,277 | 36,271 | 5,736 | 136,679 | 420,365 | 4,884 | 204 | 2,604 | 431,803 | 194,017 | 4,061 | 1,238,616 |
| 1982 | 8,674 | 59,051 | 66,877 | 51,967 | 757,998 | 189,841 | 34,803 | 7,846 | 1,613 | 1,881 | 110,772 | 367,912 | 1,659,235 |
| 1983 | 10,893 | 262,825 | 193,747 | 18,328 | 51,210 | 11,322 | 70,071 | 874 | 122 | 665 | 1,761 | 2,929 | 624,747 |
| 1984 | 2,405 | 87,504 | 351,929 | 37,679 | 82,214 | 1,041 | 352 | 612 | 248 | 106,337 | 45,368 | 185,320 | 901,009 |
| 1985 | 29,183 | 91,364 | 172,800 | 84,816 | 137,559 | 20,090 | 3,651 | 63 | 51 | 11,761 | 120,387 | 149,671 | 821,396 |
| 1986 | 1,314 | 118,585 | 4,531 | 150,167 | 60,375 | 130,015 | 45,355 | 1,111 | 8,820 | 21,523 | 145,596 | 59,243 | 746,635 |
| 1987 | 71,751 | 63,580 | 144,254 | 4,133 | 17,276 | 22,822 | 6,279 | 349 | 43,022 | 38,100 | 259,027 | 215,485 | 886,078 |
| 1988 | 64,403 | 44,431 | 48,797 | 56,222 | 1,196 | 127 | 47,479 | 291 | 3,218 | 7,664 | 154,748 | 38,085 | 466,661 |
| 1989 | 107,286 | 298,378 | 130,494 | 29,645 | 319,956 | 415,926 | 205,696 | 6,524 | 10,227 | 727 | 350 | 316 | 1,525,525 |
| 1990 | 173,922 | 178,326 | 340,673 | 229,517 | 398,593 | 81,843 | 1,644 | 2,659 | 11,547 | 23,255 | 44,072 | 53,722 | 1,539,773 |
| 1991 | 157,553 | 71,859 | 34,999 | 198,779 | 99,851 | 50,429 | 3,118 | 1,086 | 2,387 | 117,959 | 171,635 | 384,251 | 1,293,906 |
| 1992 | 125,604 | 122,498 | 182,009 | 15,806 | 196,571 | 154,314 | 206,069 | 58,229 | 13,635 | 4,221 | 34,896 | 160,023 | 1,273,875 |
| 1993 | 85,023 | 196,812 | 148,435 | 140,670 | 60,207 | 10,028 | 4,051 | 4,611 | 3,093 | 204,973 | 76,848 | 232,310 | 1,167,061 |
| 1994 | 45,463 | 81,516 | 130,033 | 27,363 | 195,553 | 35,951 | 107,919 | 12,112 | 14,677 | 32,006 | 181,940 | 166,345 | 1,030,878 |
| 1995 | 164,221 | 17,759 | 118,669 | 145,976 | 407,473 | 75,117 | 6,078 | 3,091 | 6,852 | 670 | 2,639 | 1,135 | 949,680 |
| 1996 | 7,841 | 2,891 | 6,634 | 11,149 | 28,137 | 26,790 | 8,831 | 37,533 | 19,624 | 51,902 | 442,315 | 100,616 | 744,263 |

## NATURALIZED FLOWS FOR SUBWATERSHED C, continued

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | 22,854 | 443,285 | 170,486 | 277,802 | 20,908 | 57,034 | 1,208 | 597 | 60 | 7,226 | 4,593 | 190,965 | 1,197,018 |
| 1998 | 201,807 | 106,911 | 118,688 | 19,516 | 9,181 | 9,784 | 9,715 | 8,114 | 14,886 | 70,105 | 82,042 | 211,915 | 862,664 |
| 1999 | 108,947 | 16,985 | 47,189 | 42,958 | 38,162 | 27,306 | 12,384 | 9,683 | 2,634 | 141 | 1,120 | 21,788 | 329,297 |
| 2000 | 2,931 | 16,580 | 82,637 | 40,436 | 113,008 | 171,490 | 33,969 | 4,594 | 433 | 177 | 404,879 | 288,618 | 1,159,752 |
| 2001 | 170,896 | 379,021 | 385,988 | 122,268 | 24,064 | 37,341 | 5,836 | 11,013 | 67,046 | 41,791 | 10,344 | 507,124 | 1,762,732 |
| 2002 | 87,208 | 167,964 | 244,077 | 264,685 | 29,729 | 969 | 3,718 | 5,256 | 2,165 | 247,837 | 15,003 | 88,659 | 1,157,270 |
| 2003 | 21,383 | 76,123 | 33,248 | 9,511 | 12,961 | 26,009 | 670 | 152 | 1,378 | 61 | 2,071 | 473 | 184,040 |
| 2004 | 12,758 | 53,513 | 25,435 | 9,154 | 6,892 | 19,764 | 3,164 | 811 | 11 | 2,982 | 96,605 | 40,926 | 272,015 |
| 2005 | 167,529 | 59,961 | 37,717 | 23,153 | 1,295 | 1,681 | 3,557 | 1,026 | 701 | 554 | 120 | 751 | 298,045 |
| 2006 | 1,637 | 5,995 | 221,116 | 5,388 | 1,119 | 152 | 0 | 0 | 88 | 1,760 | 2,392 | 39,008 | 278,655 |
| 2007 | 152,082 | 6,497 | 14,676 | 60,073 | 64,627 | 268,957 | 279,573 | 43,060 | 4,635 | 25,968 | 1,855 | 45,812 | 967,815 |
| 2008 | 3,334 | 113,035 | 610,578 | 209,516 | 18,992 | 23,819 | 3,160 | 1,025 | 4,345 | 1,021 | 2,302 | 1,745 | 992,872 |
| 2009 | 1,054 | 2,490 | 45,260 | 89,211 | 568,927 | 4,379 | 8,478 | 37,400 | 80,027 | 737,381 | 92,257 | 135,315 | 1,802,179 |
| 2010 | 158,932 | 294,685 | 122,969 | 10,775 | 14,525 | 4,812 | 5,420 | 606 | 3,694 | 917 | 6,721 | 4,344 | 628,400 |
| 2011 | 7,844 | 17,310 | 4,068 | 39,927 | 143,210 | 1,100 | 454 | 773 | 130 | 0 | 2,027 | 24,583 | 241,426 |
| 2012 | 172,334 | 45,841 | 315,133 | 54,324 | 21,786 | 9,254 | 2,869 | 1,608 | 629 | 18 | 1,540 | 2,808 | 628,144 |
| 2013 | 14,073 | 8,236 | 5,384 | 14,739 | 30,194 | 22,474 | 1,431 | 661 | 1,613 | 1,876 | 13,318 | 58,307 | 172,306 |
| 2014 | 8,053 | 5,742 | 28,198 | 59,691 | 110,605 | 18,675 | 16,271 | 9,662 | 12,577 | 16,805 | 3,007 | 12,393 | 301,679 |
| 2015 | 95,989 | 62,343 | 371,292 | 126,139 | 447,854 | 161,072 | 5,491 | 226 | 277 | 82,637 | 491,795 | 476,267 | 2,321,382 |
| 2016 | 44,278 | 60,983 | 194,159 | 357,092 | 257,065 | 116,081 | 2,630 | 4,756 | 1,664 | 2,463 | 262 | 224 | 1,041,657 |
| 2017 | 10,791 | 8,026 | 6,648 | 87,275 | 5,894 | 36,685 | 158,444 | 271,154 | 5,705 | 1,516 | 3,468 | 34,598 | 630,204 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Average | 68,756 | 106,182 | 113,100 | 117,135 | 169,546 | 88,453 | 30,299 | 6,470 | 23,305 | 48,440 | 81,151 | 98,794 | 951,632 |
| 1997-2017 Average | 69,844 | 92,930 | 146,902 | 91,602 | 92,428 | 48,516 | 26,592 | 19,627 | 9,748 | 59,202 | 58,939 | 104,125 | 820,455 |
| 1940-2017 Average | 69,049 | 102,614 | 122,201 | 110,261 | 148,784 | 77,701 | 29,301 | 10,012 | 19,655 | 51,338 | 75,171 | 100,230 | 916,315 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Maximum | 314,642 | 479,680 | 446,010 | 618,861 | 757,998 | 420,365 | 236,454 | 60,314 | 188,814 | 431,803 | 442,315 | 679,015 | 2,438,464 |
| 1997-2017 Maximum | 201,807 | 443,285 | 610,578 | 357,092 | 568,927 | 268,957 | 279,573 | 271,154 | 80,027 | 737,381 | 491,795 | 507,124 | 2,321,382 |
| 1940-2017 Maximum | 314,642 | 479,680 | 610,578 | 618,861 | 757,998 | 420,365 | 279,573 | 271,154 | 188,814 | 737,381 | 491,795 | 679,015 | 2,438,464 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Minimum | 9 | 154 | 728 | 756 | 1,196 | 85 | 0 | 0 | 0 | 0 | 0 | 0 | 151,932 |
| 1997-2017 Minimum | 1,054 | 2,490 | 4,068 | 5,388 | 1,119 | 152 | 0 | 0 | 11 | 0 | 120 | 224 | 172,306 |
| 1940-2017 Minimum | 9 | 154 | 728 | 756 | 1,119 | 85 | 0 | 0 | 0 | 0 | 0 | 0 | 151,932 |

# NATURALIZED FLOWS FOR SUBWATERSHED D

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940 | 231 | 3,520 | 3,006 | 54,777 | 34,785 | 27,659 | 21,463 | 351 | 714 | 63 | 40,232 | 78,887 | 265,688 |
| 1941 | 22,107 | 29,577 | 80,323 | 70,134 | 111,088 | 36,895 | 13,335 | 3,016 | 987 | 758 | 5,846 | 14,985 | 389,051 |
| 1942 | 2,446 | 6,424 | 21,066 | 238,952 | 42,191 | 24,109 | 2,092 | 2,170 | 3,234 | 412 | 2,309 | 26,347 | 371,752 |
| 1943 | 9,549 | 2,787 | 28,979 | 7,120 | 12,385 | 79,033 | 815 | 230 | 642 | 3,233 | 202 | 3,446 | 148,421 |
| 1944 | 11,932 | 25,255 | 81,118 | 17,940 | 156,204 | 21,949 | 587 | 373 | 2,588 | 443 | 6,780 | 30,347 | 355,516 |
| 1945 | 41,402 | 89,133 | 301,552 | 121,659 | 31,716 | 156,985 | 110,255 | 2,696 | 2,870 | 122,312 | 14,758 | 2,401 | 997,739 |
| 1946 | 157,064 | 228,289 | 67,430 | 35,123 | 261,382 | 139,772 | 1,921 | 3,725 | 4,727 | 1,191 | 146,535 | 78,681 | 1,125,840 |
| 1947 | 31,483 | 3,197 | 40,028 | 68,868 | 107,935 | 3,005 | 648 | 749 | 2,219 | 719 | 49,078 | 153,603 | 461,532 |
| 1948 | 39,303 | 80,348 | 86,938 | 15,937 | 188,117 | 2,220 | 2,765 | 1,324 | 736 | 1,033 | 1,749 | 1,386 | 421,856 |
| 1949 | 124,601 | 116,956 | 50,376 | 25,771 | 50,772 | 5,073 | 2,431 | 931 | 2,059 | 239,547 | 3,268 | 10,856 | 632,641 |
| 1950 | 71,521 | 199,535 | 39,885 | 9,048 | 114,206 | 10,819 | 11,658 | 9,216 | 63,356 | 698 | 379 | 458 | 530,779 |
| 1951 | 6,288 | 72,649 | 2,945 | 1,468 | 6,715 | 26,574 | 11,694 | 141 | 1,170 | 1,221 | 4,006 | 9,766 | 144,637 |
| 1952 | 26,689 | 10,025 | 14,717 | 167,631 | 38,891 | 2,912 | 3,693 | 136 | 74 | 71 | 28,025 | 64,147 | 357,011 |
| 1953 | 23,999 | 11,790 | 28,579 | 68,939 | 123,140 | 352 | 19,376 | 1,038 | 5,832 | 845 | 4,383 | 30,453 | 318,726 |
| 1954 | 63,471 | 31,678 | 2,476 | 4,542 | 49,437 | 651 | 105 | 64 | 57 | 32,564 | 18,511 | 2,035 | 205,591 |
| 1955 | 4,464 | 12,321 | 12,288 | 35,624 | 1,850 | 375 | 1,055 | 1,664 | 1,602 | 2,042 | 91 | 115 | 73,491 |
| 1956 | 221 | 29,289 | 755 | 260 | 18,452 | 95 | 0 | 0 | 0 | 0 | 14,810 | 76 | 63,958 |
| 1957 | 8,581 | 17,533 | 64,842 | 224,822 | 171,841 | 66,728 | 992 | 1,361 | 18,984 | 37,884 | 157,312 | 14,794 | 785,674 |
| 1958 | 70,703 | 2,554 | 51,713 | 159,289 | 165,207 | 40,376 | 39,911 | 1,906 | 13,391 | 1,777 | 10,061 | 3,941 | 560,829 |
| 1959 | 1,255 | 56,147 | 41,571 | 28,066 | 2,147 | 7,416 | 11,120 | 3,621 | 600 | 15,584 | 13,819 | 99,874 | 281,220 |
| 1960 | 81,947 | 22,621 | 24,336 | 1,691 | 2,327 | 7,023 | 7,617 | 751 | 7,783 | 15,225 | 6,933 | 134,985 | 313,239 |
| 1961 | 54,887 | 37,509 | 55,516 | 33,378 | 1,294 | 19,438 | 14,089 | 3,593 | 3,064 | 785 | 26,760 | 47,559 | 297,872 |
| 1962 | 33,192 | 29,098 | 23,507 | 36,784 | 26,203 | 5,586 | 6,854 | 1,324 | 23,682 | 10,969 | 31,609 | 22,389 | 251,197 |
| 1963 | 20,097 | 1,882 | 5,877 | 8,329 | 38,314 | 5,516 | 3,974 | 272 | 59 | 0 | 0 | 124 | 84,444 |
| 1964 | 82 | 3,500 | 9,359 | 43,181 | 5,978 | 12,557 | 0 | 2,359 | 30,123 | 1,937 | 13,741 | 1,172 | 123,989 |
| 1965 | 5,744 | 94,298 | 7,789 | 3,005 | 121,269 | 20,601 | 43 | 0 | 3,047 | 37 | 63 | 0 | 255,896 |
| 1966 | 4,923 | 42,043 | 3,073 | 216,605 | 164,758 | 903 | 2,728 | 5,046 | 10,169 | 16,808 | 385 | 3,641 | 471,082 |
| 1967 | 3,034 | 3,987 | 7,301 | 54,344 | 56,258 | 56,048 | 4,729 | 286 | 3,887 | 11,050 | 59,592 | 49,516 | 310,032 |
| 1968 | 35,752 | 28,265 | 119,782 | 30,143 | 114,193 | 22,043 | 7,117 | 700 | 9,662 | 310 | 6,489 | 38,393 | 412,849 |
| 1969 | 12,822 | 130,247 | 93,223 | 39,548 | 148,946 | 1,869 | 295 | 0 | 9,160 | 0 | 1,549 | 10,152 | 447,811 |
| 1970 | 21,814 | 45,795 | 101,615 | 113,470 | 8,779 | 5,483 | 3,617 | 1,565 | 4,754 | 33,110 | 7,975 | 1,389 | 349,366 |
| 1971 | 3,093 | 15,825 | 7,310 | 465 | 885 | 300 | 15,291 | 10,230 | 1,041 | 37,958 | 2,259 | 244,775 | 339,432 |
| 1972 | 27,785 | 7,353 | 6,085 | 1,231 | 859 | 4,378 | 385 | 0 | 263 | 17,575 | 70,390 | 53,225 | 189,529 |
| 1973 | 40,883 | 53,987 | 134,412 | 138,306 | 7,755 | 55,190 | 3,642 | 19 | 24,436 | 43,629 | 152,618 | 72,518 | 727,395 |
| 1974 | 100,805 | 10,397 | 11,584 | 64,897 | 7,178 | 71,477 | 578 | 1,290 | 52,865 | 13,627 | 177,515 | 74,813 | 587,026 |
| 1975 | 12,864 | 160,163 | 66,912 | 37,057 | 102,460 | 42,975 | 3,862 | 2,933 | 86 | 70 | 0 | 228 | 429,610 |
| 1976 | 88 | 440 | 19,877 | 79,027 | 60,853 | 12,468 | 90,647 | 239 | 2,606 | 4,022 | 2,536 | 15,858 | 288,661 |
| 1977 | 11,069 | 57,563 | 126,422 | 72,101 | 2,249 | 9,579 | 658 | 1,116 | 76 | 78 | 45,058 | 3,857 | 329,826 |
| 1978 | 14,195 | 25,406 | 45,991 | 3,247 | 3,051 | 1,036 | 19 | 0 | 8 | 0 | 1,008 | 865 | 94,826 |
| 1979 | 57,529 | 22,301 | 43,231 | 66,276 | 106,541 | 21,904 | 8,013 | 22,604 | 7,197 | 387 | 3,900 | 61,906 | 421,789 |
| 1980 | 198,424 | 47,514 | 4,610 | 45,769 | 56,694 | 7,602 | 1,372 | 1,587 | 863 | 5,830 | 2,403 | 16,138 | 388,806 |
| 1981 | 428 | 2,413 | 5,637 | 1,962 | 70,759 | 156,440 | 2,097 | 271 | 151 | 109,052 | 18,488 | 1,075 | 368,773 |
| 1982 | 1,172 | 6,086 | 16,179 | 4,062 | 32,250 | 15,744 | 39,424 | 444 | 0 | 49 | 21,898 | 177,191 | 314,499 |
| 1983 | 11,164 | 51,912 | 56,952 | 9,783 | 9,638 | 8,234 | 15,227 | 0 | 0 | 38 | 1,636 | 7,103 | 171,687 |
| 1984 | 3,786 | 23,443 | 71,634 | 12,221 | 1,170 | 87 | 27 | 0 | 0 | 82,735 | 23,041 | 105,210 | 323,354 |
| 1985 | 12,844 | 57,436 | 50,736 | 45,266 | 39,877 | 10,352 | 1,050 | 43 | 0 | 426 | 15,358 | 95,352 | 328,740 |
| 1986 | 1,624 | 79,086 | 2,042 | 102,025 | 37,177 | 41,879 | 2,397 | 0 | 361 | 281 | 14,997 | 18,934 | 300,803 |
| 1987 | 22,638 | 23,295 | 96,231 | 5,400 | 1,308 | 8,576 | 1,935 | 34 | 1,741 | 3,446 | 94,722 | 134,691 | 394,017 |
| 1988 | 27,809 | 22,963 | 18,180 | 17,529 | 307 | 0 | 42,854 | 680 | 0 | 1,755 | 144,971 | 32,409 | 309,457 |
| 1989 | 31,209 | 111,109 | 47,156 | 28,629 | 109,089 | 94,162 | 30,176 | 5,477 | 713 | 0 | 194 | 81 | 457,995 |
| 1990 | 23,176 | 49,352 | 214,001 | 90,054 | 194,035 | 76,937 | 7,916 | 10,514 | 2,254 | 3,931 | 36,680 | 51,071 | 759,921 |
| 1991 | 69,100 | 72,667 | 17,766 | 79,138 | 46,895 | 12,084 | 4,274 | 500 | 1,398 | 22,764 | 83,957 | 156,854 | 567,397 |
| 1992 | 52,576 | 59,736 | 115,862 | 14,123 | 20,893 | 30,358 | 230,767 | 56,215 | 1,329 | 391 | 44,079 | 111,168 | 737,497 |
| 1993 | 91,581 | 66,707 | 84,805 | 41,535 | 15,418 | 1,534 | 162 | 132 | 15 | 73,368 | 18,717 | 83,031 | 477,005 |
| 1994 | 27,008 | 48,782 | 57,674 | 4,295 | 28,098 | 15,008 | 41,116 | 2,598 | 443 | 3,664 | 43,316 | 86,551 | 358,553 |
| 1995 | 82,574 | 11,558 | 44,677 | 48,511 | 111,720 | 5,546 | 2,358 | 417 | 3,050 | 37 | 0 | 490 | 310,938 |
| 1996 | 1,647 | 170 | 631 | 2,799 | 4,754 | 2,271 | 1,094 | 27,657 | 3,453 | 5,721 | 158,709 | 66,515 | 275,421 |

## NATURALIZED FLOWS FOR SUBWATERSHED D, continued

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | 22,019 | 186,760 | 102,767 | 116,436 | 30,872 | 39,400 | 2,803 | 9,187 | 39 | 1,379 | 584 | 68,350 | 580,596 |
| 1998 | 134,017 | 62,062 | 61,878 | 6,580 | 2,225 | 276 | 160 | 0 | 11,654 | 56,527 | 50,263 | 109,120 | 494,762 |
| 1999 | 23,939 | 19,476 | 47,777 | 23,918 | 52,694 | 14,358 | 157 | 0 | 0 | 0 | 0 | 1,204 | 183,523 |
| 2000 | 339 | 7,470 | 27,524 | 19,639 | 41,551 | 140,263 | 18,495 | 329 | 0 | 0 | 96,470 | 46,826 | 398,906 |
| 2001 | 76,201 | 98,999 | 121,072 | 30,523 | 3,589 | 9,705 | 2,597 | 441 | 15,705 | 46,798 | 7,248 | 195,255 | 608,133 |
| 2002 | 22,300 | 43,048 | 86,993 | 107,486 | 11,897 | 2,703 | 4,761 | 189 | 0 | 63,957 | 952 | 32,351 | 376,637 |
| 2003 | 24,981 | 36,506 | 25,484 | 6,343 | 3,987 | 6,952 | 754 | 268 | 558 | 211 | 52 | 298 | 106,394 |
| 2004 | 500 | 13,348 | 9,227 | 11,985 | 27,350 | 9,417 | 3,402 | 178 | 32 | 614 | 9,977 | 4,482 | 90,512 |
| 2005 | 15,008 | 10,067 | 4,274 | 7,423 | 2,025 | 0 | 719 | 182 | 0 | 0 | 25 | 7 | 39,730 |
| 2006 | 657 | 4,109 | 70,025 | 1,485 | 215 | 0 | 95 | 0 | 0 | 0 | 832 | 3,169 | 80,587 |
| 2007 | 75,216 | 1,216 | 2,697 | 19,616 | 9,258 | 31,028 | 112,598 | 11,941 | 1,482 | 0 | 175 | 5,024 | 270,251 |
| 2008 | 1,179 | 32,767 | 160,326 | 162,454 | 60,785 | 29,419 | 11,166 | 935 | 3,923 | 373 | 1,978 | 448 | 465,753 |
| 2009 | 2,003 | 1,434 | 25,540 | 12,509 | 140,433 | 1,253 | 3,929 | 63,961 | 45,698 | 400,829 | 39,220 | 88,012 | 824,821 |
| 2010 | 26,650 | 139,695 | 53,900 | 7,620 | 7,466 | 13,078 | 1,389 | 255 | 0 | 406 | 189 | 12 | 250,660 |
| 2011 | 1,314 | 6,041 | 2,150 | 8,974 | 6,487 | 280 | 0 | 0 | 0 | 0 | 452 | 6,859 | 32,557 |
| 2012 | 41,860 | 15,763 | 95,823 | 24,686 | 3,711 | 2,821 | 203 | 0 | 0 | 261 | 941 | 1,662 | 187,731 |
| 2013 | 4,178 | 4,606 | 802 | 2,978 | 4,653 | 7,581 | 1,346 | 89 | 873 | 3,156 | 19,760 | 36,621 | 86,643 |
| 2014 | 11,540 | 4,086 | 12,571 | 22,971 | 9,093 | 2,609 | 6,349 | 173 | 0 | 1,136 | 235 | 1,704 | 72,467 |
| 2015 | 43,063 | 16,063 | 126,770 | 59,796 | 112,403 | 25,100 | 220 | 0 | 0 | 11,669 | 123,032 | 328,966 | 847,082 |
| 2016 | 30,033 | 29,845 | 101,625 | 113,421 | 99,129 | 23,571 | 166 | 239 | 0 | 158 | 700 | 3,377 | 402,264 |
| 2017 | 12,447 | 3,523 | 2,832 | 44,428 | 6,100 | 10,294 | 25,052 | 115,375 | 24 | 0 | 200 | 8,718 | 228,993 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Average | 33,661 | 44,841 | 49,799 | 51,792 | 60,503 | 26,600 | 14,988 | 3,432 | 5,887 | 17,254 | 32,556 | 45,751 | 387,065 |
| 1997-2017 Average | 27,116 | 35,090 | 54,384 | 38,632 | 30,282 | 17,624 | 9,351 | 9,702 | 3,809 | 27,975 | 16,823 | 44,879 | 315,667 |
| 1940-2017 Average | 31,899 | 42,215 | 51,034 | 48,249 | 52,367 | 24,183 | 13,470 | 5,120 | 5,328 | 20,140 | 28,320 | 45,517 | 367,842 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Maximum | 198,424 | 228,289 | 301,552 | 238,952 | 261,382 | 156,985 | 230,767 | 56,215 | 63,356 | 239,547 | 177,515 | 244,775 | 1,125,840 |
| 1997-2017 Maximum | 134,017 | 186,760 | 160,326 | 162,454 | 140,433 | 140,263 | 112,598 | 115,375 | 45,698 | 400,829 | 123,032 | 328,966 | 847,082 |
| 1940-2017 Maximum | 198,424 | 228,289 | 301,552 | 238,952 | 261,382 | 156,985 | 230,767 | 115,375 | 63,356 | 400,829 | 177,515 | 328,966 | 1,125,840 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Minimum | 82 | 170 | 631 | 260 | 307 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 63,958 |
| 1997-2017 Minimum | 339 | 1,216 | 802 | 1,485 | 215 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 32,557 |
| 1940-2017 Minimum | 82 | 170 | 631 | 260 | 215 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 32,557 |

# NATURALIZED FLOWS FOR SUBWATERSHED E

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940 | 587 | 10,796 | 10,344 | 283,838 | 257,674 | 263,120 | 236,363 | 1,002 | 3,824 | 401 | 184,327 | 442,653 | 1,694,929 |
| 1941 | 209,629 | 152,921 | 346,204 | 252,706 | 762,226 | 475,578 | 168,120 | 15,260 | 5,002 | 24,433 | 64,399 | 146,119 | 2,622,597 |
| 1942 | 23,247 | 60,457 | 161,421 | 982,219 | 464,442 | 193,321 | 9,225 | 6,870 | 20,437 | 1,628 | 19,930 | 97,306 | 2,040,503 |
| 1943 | 77,984 | 18,902 | 274,899 | 122,478 | 66,341 | 227,764 | 9,462 | 555 | 1,047 | 7,744 | 5,824 | 24,669 | 837,669 |
| 1944 | 84,775 | 199,382 | 539,176 | 166,339 | 754,582 | 223,478 | 3,880 | 4,883 | 20,012 | 443 | 50,523 | 208,313 | 2,255,786 |
| 1945 | 316,135 | 486,481 | 1,145,097 | 1,101,428 | 105,114 | 547,818 | 186,775 | 6,957 | 23,472 | 336,686 | 27,944 | 4,508 | 4,288,415 |
| 1946 | 406,239 | 753,241 | 157,948 | 207,133 | 720,425 | 476,597 | 7,963 | 24,278 | 5,285 | 2,126 | 744,376 | 268,788 | 3,774,399 |
| 1947 | 109,476 | 14,169 | 173,653 | 212,777 | 373,486 | 20,082 | 2,936 | 9,863 | 3,014 | 1,359 | 92,709 | 407,576 | 1,421,100 |
| 1948 | 275,738 | 318,315 | 352,109 | 73,766 | 579,075 | 26,996 | 14,511 | 3,936 | 736 | 1,086 | 1,749 | 7,889 | 1,655,906 |
| 1949 | 439,243 | 442,230 | 384,716 | 150,962 | 180,698 | 64,368 | 17,286 | 7,341 | 5,494 | 393,682 | 61,324 | 48,283 | 2,195,627 |
| 1950 | 469,938 | 1,009,021 | 146,903 | 25,916 | 659,241 | 76,677 | 40,766 | 54,548 | 481,793 | 13,201 | 2,045 | 1,444 | 2,981,493 |
| 1951 | 34,231 | 423,809 | 51,938 | 21,531 | 49,313 | 347,102 | 45,723 | 2,798 | 7,266 | 10,539 | 18,498 | 39,128 | 1,051,876 |
| 1952 | 124,938 | 53,232 | 97,281 | 809,609 | 221,421 | 63,750 | 9,302 | 2,287 | 74 | 71 | 69,756 | 246,305 | 1,698,026 |
| 1953 | 113,199 | 140,516 | 161,353 | 290,080 | 754,065 | 4,670 | 50,193 | 5,423 | 8,719 | 1,608 | 22,361 | 103,763 | 1,655,950 |
| 1954 | 244,990 | 124,543 | 14,186 | 60,005 | 472,615 | 32,096 | 358 | 64 | 69 | 153,763 | 43,097 | 11,018 | 1,156,804 |
| 1955 | 15,624 | 81,069 | 157,645 | 209,304 | 35,619 | 5,314 | 35,512 | 15,968 | 23,566 | 57,720 | 616 | 1,089 | 639,046 |
| 1956 | 1,716 | 277,982 | 7,754 | 5,053 | 124,538 | 4,900 | 1,709 | 1,015 | 791 | 834 | 25,877 | 3,435 | 455,604 |
| 1957 | 44,385 | 108,571 | 309,223 | 1,219,073 | 1,348,323 | 646,263 | 2,728 | 10,634 | 92,371 | 162,033 | 829,464 | 75,736 | 4,848,804 |
| 1958 | 289,002 | 8,834 | 270,265 | 514,615 | 1,018,132 | 155,101 | 151,113 | 5,505 | 53,117 | 7,344 | 61,619 | 12,942 | 2,547,589 |
| 1959 | 14,096 | 204,910 | 120,636 | 103,926 | 12,846 | 172,987 | 185,654 | 27,985 | 16,994 | 105,862 | 92,220 | 560,356 | 1,618,472 |
| 1960 | 376,447 | 96,945 | 96,520 | 7,579 | 49,127 | 92,675 | 131,959 | 22,022 | 141,270 | 175,343 | 29,208 | 823,912 | 2,043,007 |
| 1961 | 274,129 | 149,335 | 320,796 | 238,318 | 32,512 | 62,046 | 51,302 | 8,453 | 15,542 | 3,459 | 73,834 | 277,075 | 1,506,801 |
| 1962 | 192,531 | 178,505 | 169,102 | 187,102 | 107,265 | 105,711 | 67,870 | 8,316 | 183,731 | 101,673 | 201,615 | 60,390 | 1,563,811 |
| 1963 | 94,442 | 9,155 | 93,552 | 52,031 | 97,049 | 9,634 | 33,285 | 599 | 108 | 350 | 35 | 2,257 | 392,497 |
| 1964 | 2,152 | 9,082 | 66,927 | 250,080 | 109,327 | 73,183 | 97 | 8,232 | 90,278 | 17,715 | 112,019 | 35,640 | 774,732 |
| 1965 | 105,670 | 614,918 | 41,658 | 22,464 | 460,745 | 38,328 | 713 | 1,039 | 14,170 | 196 | 925 | 2,583 | 1,303,409 |
| 1966 | 11,803 | 205,980 | 8,525 | 969,694 | 907,665 | 3,483 | 5,677 | 16,760 | 40,429 | 77,462 | 840 | 12,488 | 2,260,806 |
| 1967 | 7,240 | 10,136 | 29,137 | 579,932 | 320,126 | 502,737 | 88,385 | 695 | 57,127 | 112,596 | 282,726 | 349,084 | 2,339,921 |
| 1968 | 209,576 | 133,943 | 597,250 | 268,307 | 574,884 | 256,832 | 70,342 | 19,456 | 88,309 | 16,045 | 152,924 | 245,035 | 2,632,903 |
| 1969 | 196,905 | 704,544 | 442,419 | 192,276 | 821,907 | 12,160 | 922 | 1,633 | 9,226 | 11,925 | 10,206 | 101,555 | 2,505,678 |
| 1970 | 80,799 | 294,538 | 568,906 | 422,074 | 97,457 | 22,262 | 3,955 | 3,431 | 27,965 | 168,890 | 46,258 | 17,031 | 1,753,566 |
| 1971 | 14,965 | 66,851 | 43,105 | 5,615 | 19,679 | 3,298 | 40,865 | 87,453 | 5,445 | 407,477 | 63,377 | 1,150,748 | 1,908,878 |
| 1972 | 107,690 | 12,187 | 25,573 | 6,886 | 6,574 | 6,795 | 5,089 | 945 | 5,953 | 53,356 | 262,265 | 197,738 | 691,051 |
| 1973 | 196,043 | 268,590 | 739,250 | 743,545 | 131,110 | 289,494 | 8,018 | 808 | 213,250 | 319,877 | 738,989 | 328,738 | 3,977,712 |
| 1974 | 426,035 | 70,999 | 38,870 | 175,728 | 109,349 | 503,876 | 851 | 2,831 | 283,799 | 92,083 | 731,506 | 423,583 | 2,859,510 |
| 1975 | 79,659 | 707,763 | 327,889 | 173,683 | 419,613 | 220,380 | 17,637 | 7,047 | 275 | 140 | 3,488 | 2,209 | 1,959,783 |
| 1976 | 6,250 | 8,187 | 108,699 | 225,001 | 256,838 | 173,779 | 327,101 | 1,352 | 17,148 | 47,494 | 14,247 | 147,952 | 1,334,048 |
| 1977 | 115,972 | 329,432 | 564,680 | 431,958 | 25,265 | 33,770 | 2,172 | 5,525 | 925 | 83 | 55,085 | 12,500 | 1,577,367 |
| 1978 | 44,608 | 124,849 | 242,531 | 16,332 | 29,705 | 15,911 | 57 | 16 | 16 | 1 | 39,403 | 18,677 | 532,106 |
| 1979 | 469,030 | 221,628 | 321,973 | 361,596 | 789,448 | 305,955 | 26,863 | 67,328 | 14,508 | 1,730 | 10,187 | 272,385 | 2,862,631 |
| 1980 | 326,252 | 248,866 | 28,371 | 175,234 | 171,552 | 32,059 | 1,407 | 1,594 | 24,230 | 38,274 | 12,466 | 86,619 | 1,146,924 |
| 1981 | 5,718 | 24,525 | 60,727 | 12,743 | 299,725 | 690,867 | 41,651 | 474 | 2,755 | 540,855 | 247,133 | 8,784 | 1,935,957 |
| 1982 | 24,743 | 108,540 | 98,062 | 75,638 | 901,704 | 326,929 | 100,805 | 14,457 | 1,613 | 1,930 | 158,494 | 737,429 | 2,550,344 |
| 1983 | 22,057 | 320,090 | 323,471 | 54,504 | 84,642 | 23,447 | 85,298 | 874 | 122 | 703 | 3,397 | 20,905 | 939,510 |
| 1984 | 13,772 | 117,622 | 427,016 | 140,148 | 83,382 | 1,128 | 379 | 612 | 248 | 259,136 | 183,186 | 407,255 | 1,633,884 |
| 1985 | 78,533 | 254,845 | 416,860 | 258,619 | 254,984 | 58,084 | 5,549 | 106 | 51 | 12,187 | 151,139 | 371,182 | 1,862,139 |
| 1986 | 9,735 | 309,382 | 24,615 | 372,057 | 155,822 | 228,687 | 70,677 | 1,111 | 9,181 | 21,804 | 169,276 | 141,831 | 1,514,178 |
| 1987 | 139,011 | 149,068 | 516,680 | 21,019 | 21,444 | 36,616 | 10,625 | 383 | 44,763 | 44,836 | 460,938 | 765,787 | 2,211,170 |
| 1988 | 197,673 | 123,384 | 125,520 | 116,965 | 1,504 | 127 | 90,333 | 971 | 3,218 | 9,419 | 361,033 | 161,385 | 1,191,532 |
| 1989 | 184,790 | 600,632 | 295,892 | 120,262 | 603,318 | 616,823 | 248,812 | 21,303 | 10,940 | 727 | 544 | 1,857 | 2,705,900 |
| 1990 | 227,078 | 323,695 | 945,620 | 469,991 | 850,732 | 200,340 | 9,560 | 13,173 | 13,800 | 32,874 | 116,808 | 206,677 | 3,410,348 |
| 1991 | 403,211 | 240,128 | 130,747 | 430,699 | 305,844 | 62,979 | 8,603 | 6,174 | 7,312 | 156,325 | 334,513 | 741,594 | 2,828,129 |
| 1992 | 255,214 | 298,521 | 524,994 | 48,709 | 233,804 | 227,981 | 494,741 | 191,279 | 29,980 | 4,613 | 94,386 | 486,222 | 2,890,444 |
| 1993 | 349,415 | 329,161 | 453,054 | 264,397 | 102,959 | 22,079 | 4,213 | 4,743 | 3,108 | 399,791 | 139,582 | 503,512 | 2,576,014 |
| 1994 | 122,895 | 196,809 | 360,746 | 39,307 | 261,003 | 62,120 | 207,247 | 14,710 | 15,119 | 47,203 | 356,253 | 407,721 | 2,091,133 |
| 1995 | 415,033 | 95,267 | 229,148 | 318,395 | 631,841 | 92,701 | 8,436 | 3,508 | 9,902 | 707 | 2,639 | 1,625 | 1,809,202 |
| 1996 | 10,640 | 3,061 | 8,908 | 17,922 | 70,084 | 44,384 | 11,994 | 100,390 | 40,606 | 80,024 | 861,261 | 255,749 | 1,505,023 |

# NATURALIZED FLOWS FOR SUBWATERSHED E, continued

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | 89,976 | 837,651 | 504,299 | 503,282 | 173,862 | 141,898 | 4,009 | 9,785 | 99 | 8,606 | 13,094 | 288,559 | 2,575,120 |
| 1998 | 681,586 | 302,635 | 296,955 | 39,439 | 34,198 | 10,059 | 9,874 | 8,114 | 37,675 | 186,429 | 154,470 | 472,701 | 2,234,135 |
| 1999 | 235,431 | 123,565 | 225,901 | 126,740 | 106,616 | 46,674 | 16,283 | 9,861 | 2,776 | 1,507 | 1,120 | 25,821 | 922,295 |
| 2000 | 3,271 | 30,179 | 162,887 | 125,147 | 280,858 | 457,571 | 132,104 | 4,923 | 433 | 177 | 563,589 | 461,006 | 2,222,145 |
| 2001 | 559,235 | 803,564 | 905,904 | 268,383 | 80,451 | 56,350 | 24,387 | 11,463 | 86,276 | 141,624 | 22,233 | 915,459 | 3,875,329 |
| 2002 | 143,694 | 296,374 | 439,891 | 544,634 | 95,094 | 3,672 | 8,480 | 5,445 | 2,165 | 311,785 | 15,955 | 121,011 | 1,988,200 |
| 2003 | 89,609 | 137,159 | 182,489 | 21,182 | 32,264 | 45,424 | 1,424 | 420 | 1,936 | 272 | 2,123 | 1,007 | 515,309 |
| 2004 | 18,456 | 126,191 | 74,197 | 26,037 | 65,644 | 103,948 | 18,748 | 989 | 43 | 3,597 | 106,580 | 62,242 | 606,672 |
| 2005 | 226,094 | 101,110 | 66,828 | 47,421 | 3,674 | 1,681 | 4,277 | 1,207 | 701 | 554 | 145 | 758 | 454,450 |
| 2006 | 6,223 | 13,110 | 345,191 | 36,989 | 2,197 | 1,736 | 2,971 | 0 | 88 | 1,761 | 3,225 | 42,186 | 455,677 |
| 2007 | 395,765 | 29,804 | 31,084 | 86,030 | 86,344 | 303,367 | 614,561 | 75,397 | 6,117 | 25,961 | 2,029 | 52,679 | 1,709,138 |
| 2008 | 11,255 | 187,869 | 874,004 | 546,338 | 127,837 | 53,238 | 14,323 | 4,743 | 14,712 | 14,239 | 13,586 | 10,970 | 1,873,114 |
| 2009 | 15,370 | 12,706 | 151,900 | 139,938 | 1,020,712 | 10,059 | 42,173 | 129,331 | 140,508 | 1,411,965 | 286,737 | 328,038 | 3,689,437 |
| 2010 | 240,001 | 647,553 | 230,323 | 83,398 | 32,908 | 46,127 | 6,808 | 860 | 3,694 | 1,712 | 9,507 | 4,357 | 1,307,248 |
| 2011 | 17,477 | 31,598 | 12,739 | 48,909 | 192,008 | 1,419 | 454 | 773 | 130 | 0 | 2,479 | 40,668 | 348,654 |
| 2012 | 214,184 | 129,744 | 521,099 | 143,919 | 28,713 | 12,076 | 3,072 | 1,608 | 629 | 279 | 16,434 | 9,946 | 1,081,703 |
| 2013 | 25,031 | 21,465 | 10,160 | 17,718 | 40,009 | 47,015 | 2,777 | 750 | 13,249 | 20,901 | 72,669 | 201,420 | 473,164 |
| 2014 | 58,663 | 57,562 | 79,519 | 154,699 | 168,419 | 37,706 | 23,963 | 9,835 | 12,577 | 17,875 | 3,685 | 17,478 | 641,981 |
| 2015 | 196,342 | 89,791 | 842,521 | 258,334 | 781,414 | 326,438 | 5,711 | 19,849 | 277 | 94,309 | 614,823 | 1,387,144 | 4,616,953 |
| 2016 | 336,716 | 175,032 | 551,892 | 633,459 | 482,849 | 174,117 | 2,797 | 4,890 | 1,979 | 3,207 | 2,777 | 46,782 | 2,416,497 |
| 2017 | 83,710 | 26,397 | 34,290 | 196,875 | 42,908 | 66,695 | 211,986 | 426,566 | 29,396 | 3,484 | 9,054 | 58,730 | 1,190,091 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Average | 159,524 | 225,448 | 257,904 | 264,554 | 339,652 | 166,450 | 60,756 | 14,859 | 38,588 | 79,682 | 156,155 | 219,281 | 1,982,853 |
| 1997-2017 Average | 173,719 | 199,098 | 311,623 | 192,803 | 184,713 | 92,727 | 54,818 | 34,610 | 16,927 | 107,154 | 91,253 | 216,617 | 1,676,062 |
| 1940-2017 Average | 163,346 | 218,354 | 272,367 | 245,236 | 297,938 | 146,601 | 59,157 | 20,177 | 32,756 | 87,078 | 138,682 | 218,564 | 1,900,256 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Maximu | 469,938 | 1,009,021 | 1,145,097 | 1,219,073 | 1,348,323 | 690,867 | 494,741 | 191,279 | 481,793 | 540,855 | 861,261 | 1,150,748 | 4,848,804 |
| 1997-2017 Maximu | 681,586 | 837,651 | 905,904 | 633,459 | 1,020,712 | 457,571 | 614,561 | 426,566 | 140,508 | 1,411,965 | 614,823 | 1,387,144 | 4,616,953 |
| 1940-2017 Maximu | 681,586 | 1,009,021 | 1,145,097 | 1,219,073 | 1,348,323 | 690,867 | 614,561 | 426,566 | 481,793 | 1,411,965 | 861,261 | 1,387,144 | 4,848,804 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Minimu | 587 | 3,061 | 7,754 | 5,053 | 1,504 | 127 | 57 | 16 | 16 | 1 | 35 | 1,089 | 392,497 |
| 1997-2017 Minimu | 3,271 | 12,706 | 10,160 | 17,718 | 2,197 | 1,419 | 454 | 0 | 43 | 0 | 145 | 758 | 348,654 |
| 1940-2017 Minimu | 587 | 3,061 | 7,754 | 5,053 | 1,504 | 127 | 57 | 0 | 16 | 0 | 35 | 758 | 348,654 |

# NATURALIZED FLOWS FOR SUBWATERSHED F

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940 | 587 | 10,796 | 10,454 | 365,387 | 351,884 | 377,755 | 385,603 | 1,172 | 4,079 | 491 | 230,366 | 585,194 | 2,323,768 |
| 1941 | 332,680 | 190,757 | 405,048 | 268,406 | 1,014,476 | 728,334 | 277,885 | 22,051 | 5,129 | 41,236 | 101,231 | 222,905 | 3,610,138 |
| 1942 | 36,889 | 90,484 | 233,441 | 1,132,953 | 700,434 | 242,000 | 9,876 | 6,870 | 21,212 | 1,628 | 24,323 | 97,306 | 2,597,416 |
| 1943 | 132,229 | 25,361 | 365,972 | 201,399 | 66,348 | 296,879 | 15,902 | 813 | 1,368 | 11,164 | 7,955 | 30,051 | 1,155,441 |
| 1944 | 110,036 | 233,658 | 778,284 | 256,323 | 941,437 | 338,491 | 3,880 | 4,883 | 32,735 | 443 | 75,294 | 257,769 | 3,033,233 |
| 1945 | 492,487 | 572,726 | 1,531,191 | 1,812,116 | 128,430 | 699,640 | 186,775 | 10,094 | 23,472 | 403,147 | 32,422 | 6,124 | 5,898,624 |
| 1946 | 509,663 | 955,941 | 158,123 | 295,514 | 815,883 | 635,072 | 11,611 | 24,278 | 5,285 | 2,456 | 986,323 | 354,083 | 4,754,232 |
| 1947 | 149,260 | 21,854 | 240,748 | 282,511 | 511,376 | 22,782 | 4,742 | 9,863 | 3,014 | 1,359 | 92,709 | 474,879 | 1,815,097 |
| 1948 | 361,092 | 411,123 | 469,137 | 84,558 | 717,137 | 38,587 | 14,721 | 5,881 | 736 | 1,086 | 1,749 | 7,889 | 2,113,696 |
| 1949 | 439,243 | 511,973 | 552,729 | 217,261 | 243,580 | 82,299 | 17,286 | 8,959 | 6,365 | 435,554 | 107,366 | 67,340 | 2,689,955 |
| 1950 | 590,053 | 1,288,083 | 218,896 | 25,917 | 846,674 | 94,781 | 40,768 | 84,389 | 675,209 | 22,540 | 3,234 | 1,931 | 3,892,475 |
| 1951 | 54,869 | 588,525 | 88,949 | 34,132 | 64,707 | 350,423 | 53,060 | 4,844 | 11,649 | 12,465 | 27,770 | 62,061 | 1,353,454 |
| 1952 | 197,328 | 84,641 | 141,366 | 1,097,578 | 294,715 | 98,093 | 13,699 | 3,991 | 74 | 71 | 69,756 | 348,779 | 2,350,091 |
| 1953 | 161,579 | 241,058 | 199,388 | 290,091 | 1,134,573 | 8,024 | 50,193 | 5,423 | 10,335 | 1,608 | 22,361 | 103,763 | 2,228,396 |
| 1954 | 295,551 | 173,635 | 22,937 | 79,253 | 657,398 | 45,095 | 558 | 64 | 69 | 153,763 | 43,097 | 16,367 | 1,487,787 |
| 1955 | 20,316 | 91,221 | 205,700 | 303,742 | 40,271 | 8,144 | 47,051 | 18,374 | 39,196 | 97,857 | 1,032 | 1,861 | 874,765 |
| 1956 | 2,419 | 384,764 | 12,374 | 5,053 | 145,700 | 5,882 | 3,064 | 1,818 | 1,418 | 1,463 | 25,877 | 3,435 | 593,267 |
| 1957 | 57,757 | 141,708 | 396,734 | 1,518,672 | 1,713,666 | 839,445 | 3,402 | 11,560 | 108,002 | 208,512 | 1,048,940 | 96,579 | 6,144,977 |
| 1958 | 374,979 | 11,214 | 337,089 | 648,146 | 1,314,369 | 188,941 | 200,020 | 7,494 | 71,286 | 9,817 | 83,863 | 17,305 | 3,264,523 |
| 1959 | 18,787 | 274,909 | 161,084 | 139,563 | 16,610 | 223,458 | 233,119 | 36,145 | 21,256 | 133,020 | 117,668 | 726,452 | 2,102,071 |
| 1960 | 486,775 | 121,151 | 122,882 | 8,729 | 58,623 | 111,773 | 173,980 | 27,450 | 186,159 | 223,608 | 39,429 | 1,052,501 | 2,613,060 |
| 1961 | 337,075 | 191,430 | 405,097 | 339,469 | 45,452 | 83,268 | 71,537 | 9,973 | 18,033 | 5,340 | 73,837 | 376,452 | 1,956,963 |
| 1962 | 261,172 | 264,818 | 263,777 | 225,267 | 143,540 | 120,583 | 67,870 | 10,492 | 183,731 | 120,355 | 215,344 | 71,920 | 1,948,869 |
| 1963 | 116,562 | 13,732 | 138,471 | 68,203 | 124,787 | 10,898 | 38,941 | 599 | 108 | 620 | 35 | 3,883 | 516,839 |
| 1964 | 3,777 | 12,356 | 81,473 | 324,973 | 165,916 | 74,844 | 97 | 12,704 | 98,007 | 24,894 | 112,019 | 58,455 | 969,515 |
| 1965 | 128,337 | 762,967 | 60,573 | 34,193 | 489,673 | 38,328 | 1,129 | 1,801 | 14,170 | 196 | 925 | 4,528 | 1,536,820 |
| 1966 | 15,827 | 268,742 | 11,129 | 1,185,875 | 1,196,817 | 4,542 | 7,552 | 20,191 | 51,139 | 104,642 | 1,102 | 16,592 | 2,884,150 |
| 1967 | 9,741 | 13,650 | 37,397 | 752,231 | 394,871 | 654,214 | 119,279 | 890 | 62,234 | 133,842 | 377,928 | 449,585 | 3,005,862 |
| 1968 | 255,774 | 163,282 | 671,182 | 268,309 | 676,457 | 256,835 | 73,553 | 19,456 | 88,753 | 16,045 | 171,180 | 245,039 | 2,905,865 |
| 1969 | 236,149 | 780,056 | 483,660 | 246,549 | 869,726 | 12,160 | 922 | 2,885 | 9,226 | 11,925 | 10,206 | 112,993 | 2,776,457 |
| 1970 | 87,830 | 337,730 | 703,057 | 499,717 | 144,396 | 28,665 | 3,955 | 4,878 | 27,965 | 168,890 | 52,710 | 23,730 | 2,083,523 |
| 1971 | 19,973 | 88,638 | 62,490 | 9,081 | 27,146 | 5,356 | 56,659 | 100,902 | 5,445 | 407,477 | 104,949 | 1,331,879 | 2,219,995 |
| 1972 | 156,039 | 12,187 | 32,173 | 10,602 | 9,568 | 6,958 | 8,426 | 1,425 | 10,273 | 56,680 | 276,676 | 251,597 | 832,604 |
| 1973 | 235,981 | 334,136 | 866,023 | 907,534 | 189,339 | 370,026 | 9,886 | 808 | 213,250 | 339,071 | 901,746 | 422,052 | 4,789,852 |
| 1974 | 546,881 | 109,436 | 51,624 | 175,728 | 166,685 | 619,594 | 851 | 3,347 | 328,147 | 122,706 | 849,837 | 565,847 | 3,540,683 |
| 1975 | 106,201 | 898,061 | 434,096 | 225,688 | 525,004 | 220,380 | 19,612 | 8,711 | 275 | 140 | 6,117 | 3,367 | 2,447,652 |
| 1976 | 10,926 | 14,175 | 165,055 | 225,001 | 331,883 | 241,995 | 327,101 | 1,352 | 22,057 | 48,935 | 14,292 | 150,288 | 1,553,060 |
| 1977 | 133,812 | 406,984 | 660,516 | 536,559 | 38,430 | 35,260 | 2,172 | 5,525 | 925 | 83 | 55,085 | 17,752 | 1,893,103 |
| 1978 | 58,474 | 153,249 | 316,205 | 20,984 | 37,301 | 16,616 | 69 | 16 | 22 | 1 | 47,073 | 19,265 | 669,275 |
| 1979 | 607,484 | 283,097 | 402,647 | 478,271 | 1,015,441 | 396,167 | 34,497 | 88,404 | 19,615 | 1,993 | 13,669 | 361,076 | 3,702,361 |
| 1980 | 328,767 | 326,200 | 45,591 | 238,704 | 171,553 | 45,673 | 1,407 | 1,594 | 24,230 | 38,274 | 19,524 | 87,331 | 1,328,848 |
| 1981 | 9,327 | 40,959 | 75,650 | 16,721 | 373,415 | 781,872 | 69,274 | 474 | 2,755 | 540,855 | 274,711 | 11,662 | 2,197,675 |
| 1982 | 36,636 | 143,188 | 110,002 | 91,283 | 990,652 | 423,758 | 121,936 | 19,321 | 1,613 | 1,930 | 179,097 | 890,982 | 3,010,398 |
| 1983 | 22,057 | 324,389 | 381,523 | 75,523 | 103,625 | 26,541 | 85,298 | 874 | 122 | 703 | 3,397 | 29,479 | 1,053,531 |
| 1984 | 19,758 | 122,959 | 429,811 | 212,087 | 83,382 | 1,128 | 379 | 612 | 248 | 314,990 | 274,771 | 500,397 | 1,960,522 |
| 1985 | 107,660 | 339,484 | 571,094 | 361,154 | 316,837 | 80,089 | 6,218 | 106 | 51 | 12,187 | 163,290 | 471,843 | 2,430,013 |
| 1986 | 15,103 | 398,519 | 38,959 | 467,722 | 202,304 | 274,001 | 88,855 | 1,111 | 9,181 | 21,804 | 176,210 | 192,647 | 1,886,416 |
| 1987 | 174,608 | 198,748 | 736,999 | 30,092 | 23,699 | 40,736 | 12,527 | 383 | 44,763 | 47,432 | 546,404 | 1,097,466 | 2,953,857 |
| 1988 | 281,781 | 168,058 | 172,226 | 151,391 | 1,504 | 127 | 90,333 | 971 | 3,218 | 9,419 | 409,727 | 233,926 | 1,522,681 |
| 1989 | 221,743 | 753,170 | 390,262 | 169,669 | 742,426 | 702,010 | 259,140 | 28,683 | 10,940 | 727 | 544 | 3,009 | 3,282,323 |
| 1990 | 250,910 | 400,305 | 1,257,586 | 589,986 | 1,056,691 | 233,426 | 9,560 | 13,173 | 13,800 | 37,359 | 145,549 | 288,016 | 4,296,361 |
| 1991 | 544,111 | 316,428 | 192,925 | 552,688 | 432,776 | 63,348 | 9,559 | 9,793 | 10,093 | 168,739 | 397,518 | 901,577 | 3,599,555 |
| 1992 | 316,686 | 391,305 | 706,194 | 63,672 | 246,819 | 262,590 | 540,969 | 252,482 | 42,006 | 4,613 | 106,712 | 657,827 | 3,591,875 |
| 1993 | 487,304 | 381,561 | 628,417 | 329,978 | 124,771 | 30,418 | 4,213 | 4,743 | 3,108 | 496,553 | 174,723 | 653,665 | 3,319,454 |
| 1994 | 163,154 | 249,890 | 498,788 | 45,377 | 290,847 | 70,977 | 253,692 | 14,710 | 15,119 | 56,311 | 460,805 | 531,290 | 2,650,960 |
| 1995 | 549,214 | 147,863 | 281,625 | 417,284 | 721,734 | 102,254 | 8,436 | 3,508 | 9,902 | 707 | 2,639 | 1,625 | 2,246,791 |
| 1996 | 11,549 | 3,061 | 10,203 | 21,056 | 99,465 | 56,621 | 13,671 | 128,478 | 54,608 | 97,904 | 1,068,899 | 326,445 | 1,891,960 |

# NATURALIZED FLOWS FOR SUBWATERSHED F, continued

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | 127,768 | 1,011,803 | 698,450 | 594,913 | 276,449 | 180,105 | 4,011 | 9,784 | 99 | 8,604 | 19,746 | 313,138 | 3,244,870 |
| 1998 | 972,128 | 414,953 | 394,758 | 50,650 | 53,353 | 10,060 | 9,874 | 8,114 | 47,030 | 236,635 | 173,141 | 600,146 | 2,970,842 |
| 1999 | 321,602 | 196,760 | 335,930 | 177,046 | 119,859 | 50,884 | 19,429 | 10,010 | 2,896 | 2,654 | 1,120 | 28,177 | 1,266,367 |
| 2000 | 3,270 | 35,328 | 207,173 | 179,880 | 386,988 | 580,107 | 199,029 | 4,923 | 433 | 177 | 615,909 | 566,527 | 2,779,744 |
| 2001 | 821,485 | 1,077,123 | 1,241,057 | 365,517 | 124,818 | 64,165 | 37,795 | 11,454 | 89,265 | 186,186 | 26,134 | 1,094,507 | 5,139,506 |
| 2002 | 172,411 | 368,085 | 531,311 | 689,543 | 140,041 | 3,672 | 8,479 | 5,445 | 2,165 | 311,793 | 15,955 | 121,011 | 2,369,911 |
| 2003 | 125,977 | 157,750 | 286,460 | 25,646 | 45,129 | 56,349 | 1,425 | 420 | 1,936 | 272 | 2,123 | 771 | 704,258 |
| 2004 | 22,812 | 176,071 | 107,423 | 30,157 | 92,021 | 166,772 | 28,985 | 989 | 43 | 3,596 | 106,582 | 76,392 | 811,843 |
| 2005 | 262,693 | 127,230 | 87,700 | 61,576 | 3,972 | 1,681 | 4,277 | 1,207 | 701 | 554 | 145 | 758 | 552,494 |
| 2006 | 9,525 | 15,635 | 390,549 | 62,296 | 2,922 | 3,067 | 5,388 | 0 | 88 | 1,760 | 3,224 | 42,177 | 536,631 |
| 2007 | 537,251 | 48,368 | 42,601 | 91,364 | 96,813 | 306,216 | 801,436 | 92,535 | 6,117 | 25,968 | 2,029 | 54,387 | 2,105,085 |
| 2008 | 16,912 | 223,204 | 960,636 | 692,858 | 168,227 | 53,239 | 14,325 | 7,133 | 20,137 | 25,039 | 21,406 | 18,341 | 2,221,457 |
| 2009 | 25,718 | 20,086 | 220,034 | 172,068 | 1,282,268 | 13,779 | 67,183 | 152,829 | 152,940 | 1,642,004 | 417,204 | 416,029 | 4,582,142 |
| 2010 | 285,729 | 826,686 | 275,242 | 138,018 | 42,081 | 69,855 | 6,809 | 860 | 3,694 | 2,039 | 11,688 | 4,356 | 1,667,057 |
| 2011 | 24,466 | 38,528 | 18,221 | 48,901 | 227,601 | 1,451 | 454 | 773 | 130 | 0 | 2,479 | 48,416 | 411,420 |
| 2012 | 214,194 | 186,999 | 613,668 | 198,457 | 31,415 | 12,076 | 3,072 | 1,608 | 629 | 279 | 28,167 | 14,548 | 1,305,112 |
| 2013 | 30,726 | 28,711 | 13,495 | 17,717 | 44,326 | 61,258 | 2,777 | 750 | 22,298 | 34,237 | 105,942 | 290,883 | 653,120 |
| 2014 | 91,488 | 97,674 | 112,080 | 215,231 | 209,314 | 51,504 | 25,088 | 9,834 | 12,577 | 17,941 | 4,059 | 20,320 | 867,110 |
| 2015 | 244,488 | 99,360 | 1,131,985 | 319,175 | 967,189 | 444,305 | 5,711 | 36,339 | 277 | 94,306 | 614,827 | 1,876,130 | 5,834,092 |
| 2016 | 555,024 | 243,140 | 764,073 | 767,479 | 586,274 | 201,863 | 2,797 | 4,995 | 1,664 | 2,621 | 962 | 76,909 | 3,207,801 |
| 2017 | 131,661 | 36,329 | 52,154 | 248,851 | 65,994 | 80,599 | 233,206 | 457,062 | 46,455 | 2,174 | 9,949 | 67,763 | 1,432,197 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Average | 205,140 | 284,919 | 333,807 | 340,981 | 427,250 | 207,512 | 73,101 | 18,803 | 46,091 | 90,836 | 190,035 | 278,948 | 2,497,423 |
| 1997-2017 Average | 237,968 | 258,563 | 404,048 | 245,112 | 236,526 | 114,905 | 70,550 | 38,908 | 19,599 | 123,754 | 103,942 | 272,937 | 2,126,812 |
| 1940-2017 Average | 213,978 | 277,823 | 352,718 | 315,170 | 375,901 | 182,579 | 72,414 | 24,216 | 38,958 | 99,698 | 166,856 | 277,330 | 2,397,644 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Maximum | 607,484 | 1,288,083 | 1,531,191 | 1,812,116 | 1,713,666 | 839,445 | 540,969 | 252,482 | 675,209 | 540,855 | 1,068,899 | 1,331,879 | 6,144,977 |
| 1997-2017 Maximum | 972,128 | 1,077,123 | 1,241,057 | 767,479 | 1,282,268 | 580,107 | 801,436 | 457,062 | 152,940 | 1,642,004 | 615,909 | 1,876,130 | 5,834,092 |
| 1940-2017 Maximum | 972,128 | 1,288,083 | 1,531,191 | 1,812,116 | 1,713,666 | 839,445 | 801,436 | 457,062 | 675,209 | 1,642,004 | 1,068,899 | 1,876,130 | 6,144,977 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940-1996 Minimum | 587 | 3,061 | 10,203 | 5,053 | 1,504 | 127 | 69 | 16 | 22 | 1 | 35 | 1,625 | 516,839 |
| 1997-2017 Minimum | 3,270 | 15,635 | 13,495 | 17,717 | 2,922 | 1,451 | 454 | 0 | 43 | 0 | 145 | 758 | 411,420 |
| 1940-2017 Minimum | 587 | 3,061 | 10,203 | 5,053 | 1,504 | 127 | 69 | 0 | 22 | 0 | 35 | 758 | 411,420 |