TEXAS A&M AGRILIFE RESEARCH | EXTENSION

TEXAS A&M UNIVERSITY

Texas Water Resources Institute TR-389, 2nd Edition
August 2012

Application of Expanded WRAP Modeling Capabilities to the Brazos WAM

Ralph A. Wurbs, Richard J. Hoffpauir and Spencer T. Schnier
Texas A&M University

Texas Water Resources Institute
make every drop count

Application of Expanded WRAP Modeling Capabilities to the Brazos WAM

Ralph A. Wurbs, Richard J. Hoffpauir,
and Spencer T. Schnier

Texas A&M University

for the

Texas Commission on Environmental Quality
Austin, Texas 78711-3087

and

Brazos River Authority
Waco, Texas 76714-7555

Technical Report No. 389
Texas Water Resources Institute
Texas A&M University System

Second Edition
August 2012

TABLE OF CONTENTS

FIGURES

FIGURES (Continued)

FIGURES (Continued)

FIGURES (Continued)

TABLES

TABLES (Continued)

TABLES (Continued)

TABLES (Continued)

TABLES (Continued)

TABLES (Continued)

TABLES (Continued)

CHAPTER 1
INTRODUCTION

The Water Rights Analysis Package (WRAP) has been applied since 1997 in the Texas Commission on Environmental Quality (TCEQ) Water Availability Modeling (WAM) System. However, the Brazos River Basin studies documented by this report represent inaugural applications of the following expanded WRAP modeling capabilities:

- conditional reliability modeling to determine short-term storage and flow frequencies and supply reliabilities conditioned on preceding reservoir storage contents
- capabilities added to allow simulations to be performed with sub-monthly (daily) time steps, including methods for disaggregating monthly naturalized flows to daily time intervals, routing flow changes occurring during the simulation, forecasting flow availability over a user-specified forecast period, setting daily water supply diversion and environmental instream flow targets, and other daily modeling features
- simulation of reservoir operations for flood control

These expanded modeling capabilities were developed, tested, and improved by application to the Brazos River Basin. The new features include complex sets of user-specified options. The Brazos WAM studies presented in this report provide a data and experience base for evaluating, demonstrating, and developing guidance for applying the new WRAP modeling capabilities. This report also includes a comparative evaluation of *JD* record *ADJINC* options for dealing with negative incremental naturalized flows, including old as well as new recently added alternatives.

This is the third in a set of three Texas Water Resources Institute (TWRI) technical reports (http://twri.tamu.edu/publications/reports) documenting application of expanded WRAP modeling capabilities the Brazos River Basin. The two other companion reports [1, 2] are as follows. [Note that numbers in brackets refer to the list of references at the end of this report.]

> *Extending and Condensing the Brazos River Basin Water Availability Model*, by Wurbs and Kim, TWRI TR-340, December 2008.
>
> *Salinity Budget and WRAP Salinity Simulation Studies of the Brazos River/Reservoir System*, by Wurbs and Lee, TWRI TR-352, July 2009.

The extended hydrologic period-of-analysis and condensed dataset introduced in TR-340 are used in the studies covered in Chapters 3, 4, 5, and 6 of the present TR-389.

Objectives and Scope of this Report

The studies documented by this report provide a better understanding of both water management in the Brazos River Basin and the WRAP/WAM modeling system. The simulation studies of water resources development, regulation, allocation, management, and use in the Brazos River Basin are designed to provide an enhanced understanding of water availability in the basin for alternative water management strategies and modeling premises. The Brazos WAM case study also supports development of new WRAP modeling methodologies and software and development of guidelines for applying the new modeling methodologies and software.

The objectives of the studies presented in this report are as follows.

1. develop modeling and analysis capabilities that can be applied to address a variety of water management issues in the Brazos River Basin both current and future
2. test, evaluate, improve, and demonstrate new generalized modeling capabilities of WRAP including: short-term conditional reliability modeling capabilities; an array of methodologies required to convert to a daily time step; and features for simulating reservoir operations for flood control
3. develop an experience base in applying the new methods, perform experimental sensitivity testing of the various options associated with the new methods, and develop guidelines with supporting information for applying the new modeling capabilities that are applicable in general to simulation studies of any river basin

This introductory Chapter 1 describes the scope of the studies documented by this report, the WRAP/WAM modeling system, water resources development and management in the Brazos River Basin, and previous studies applying WRAP to the Brazos River Basin. Chapters 2 and 3 describe the TCEQ Brazos WAM (Bwam) datasets and the Brazos River Authority Condensed (BRAC) datasets, respectively, that are used in the studies presented in the subsequent chapters. Alternative versions of the Bwam and BRAC datasets are described in Chapters 2 and 3 and applied in Chapters 4, 5, 6, 7, 8, 9, and 10.

Short-term conditional reliability modeling (CRM) studies are presented in Chapters 4 and 5. The CRM analyses for the Brazos River Authority (BRA) system are performed with the WRAP programs *SIM* and *TABLES* using the monthly BRAC dataset with a 1900-2007 hydrologic period-of-analysis. The various CRM options are outlined in Chapters 4 and 5 and demonstrated by application to the case study focusing on developing short-term storage-frequency tables conditioned on preceding reservoir storage contents. Chapters 4 and 5 cover the equal-weight and probability array CRM approaches, respectively.

Chapter 6 summarizes the results of conventional monthly simulations using *SIM* and *TABLES* with the authorized use scenario and current use scenario Brazos WAM datasets with 1940-1997, 1940-2007, and 1900-2007 hydrologic periods-of-analysis and *ADJINC* option 5.

Chapter 7 is a comparative evaluation of the alternative negative incremental naturalized flow options activated by *ADJINC* on the *JD* record based on monthly *SIM* simulations. New variations of the *ADJINC* options were developed in conjunction with this study.

Simulation studies using the WRAP programs *DAY*, *SIMD*, and *TABLES* based on a daily time step are presented in Chapters 8, 9, and 10. The Brazos WAM authorized use scenario dataset with the official 1940-1997 period-of-analysis is adopted for these studies. Development of the additional input data required for daily time step simulations is described in Chapter 8. Simulation results are presented in Chapter 9 without consideration of flood control operations. Flood control operations are added in Chapter 10.

This August 2012 report has evolved from December 2010 and September 2011 editions. The primary enhancements since 2011 have been multiple refinements of the daily simulations of Chapters 8, 9, and 10 in support of development of the daily modeling system capabilities.

Water Rights Analysis Package (WRAP) Modeling System

WRAP is a generalized river/reservoir system simulation model providing flexible capabilities for analyzing water resources development, management, allocation, and control. WRAP is documented by the following manuals [3, 4, 5, 6, 7] and other publications [8, 9, 10] included in the list of references at the end of this report.

> *Water Rights Analysis Package (WRAP) Modeling System Reference and Users Manuals*, TWRI TR-255 and TR-256, 9th Edition, August 2012. (*Reference Manual* and *Users Manual*)
>
> *Fundamentals of Water Availability Modeling with WRAP*, TWRI TR-283, 6th Edition, September 2011. (*Fundamentals Manual*)
>
> *Water Rights Analysis Package (WRAP) River System Hydrology*, TWRI TR-431, August 2012. (*Hydrology Manual*)
>
> *Salinity Simulation with WRAP*, TWRI TR-317, July 2009. (*Salinity Manual*)
>
> *Water Rights Analysis Package (WRAP) Daily Modeling System*, TWRI TR-430, August 2012. (*Daily Manual*)

The TCEQ Water Availability Modeling (WAM) System includes the generalized WRAP and WRAP input datasets for the river basins of the state. The *Reference* and *Users Manuals* cited above cover the WRAP capabilities that are reflected in the current as of September 2011 TCEQ WAM System datasets. The *Fundamentals Manual* is a condensed version of the *Reference* and *Users Manuals*. The *Salinity Manual* deals specifically with water quality simulation capabilities, which are not included in the TCEQ WAM System.

The Brazos WAM simulation studies reported here focus on the conditional reliability modeling (CRM) covered in Chapter 7 of the *Reference Manual* and the modeling capabilities documented by the *Daily Manual*. All WRAP applications require basic capabilities described by the *Reference* and *Users Manuals*. Thus, the Brazos River Basin studies also illustrate WRAP simulation capabilities in general though focusing on recently added features. The basic methodologies outlined in the *Reference* and *Users Manuals* are fundamental to understanding the expanded CRM and daily modeling methodologies addressed by this report.

WRAP consists of the following seven computer programs.

WinWRAP facilitates execution of the *WRAP* programs within the *Microsoft Windows* environment along with Microsoft programs and *HEC-DSSVue*.

SIM simulates the river/reservoir water allocation/management system for input sequences of monthly naturalized stream flows and net evaporation rates.

SIMD (*D* for daily) is an expanded version of *SIM* that includes sub-monthly time step and flood control features along with all of the simulation capabilities of *SIM*.

SALT reads the main *SIM* or *SIMD* output file and a salinity input file and tracks salt constituents through the river/reservoir/use system.

TABLES develops tables, data listings, and reliability/frequency indices for organizing, summarizing, and displaying simulation results.

HYD assists in developing and periodically updating monthly naturalized stream flow and reservoir net evaporation rate data for the *SIM* hydrology input files.

DAY assists in developing sub-monthly (daily) time step hydrology input for *SIMD* including disaggregating monthly flows to sub-monthly time intervals and calibrating routing parameters.

The software package documented by the *Reference and Users Manuals* and routinely applied with the Texas WAM System consists of *WinWRAP*, *SIM*, and *TABLES*. Programs *SIMD* and *DAY* were added to the package to provide the sub-monthly time step and flood control simulation capabilities documented by the *Daily Manual*. *SIMD* includes all of the capabilities of *SIM* plus newer features which are the focus of this report. *HYD* and *SALT* described in the *Hydrology* and *Salinity Manual* are the only WRAP programs that are not applied in the Brazos WAM studies presented in this report. The *WinWRAP* user interface program is designed to execute the newer programs *SIMD*, *DAY*, and *SALT* as well as the older *SIM*, *TABLES*, and *HYD*. The post-simulation program *TABLES* has been expanded to organize simulation results from the newer *SIMD* and *SALT* as well as continuing to organize the simulation results from *SIM*. Conditional reliability modeling capabilities are incorporated in *SIM* (and thus *SIMD*) and *TABLES.*

WRAP-SALT and associated salinity features of *TABLES* covered in the *Salinity Manual* are not addressed in the Brazos River Basin studies covered by this particular report but are covered by the Brazos River Basin salinity report [2] mentioned earlier. New features added to program *HYD* for condensing and extending datasets are covered by the other companion report [1].

Brazos River Basin

Figure 1.1 is a map of the major rivers of Texas including the Brazos River. The Brazos River Basin is delineated in Figure 1.2. The basin has a total area of 45,600 square miles, with about 43,000 square miles in Texas and the remainder in New Mexico. The extreme upper end of the basin in and near New Mexico is an arid flat area that rarely contributes to stream flow. The climate, hydrology, and geography of the basin vary greatly across Texas from New Mexico to the Gulf of Mexico. Mean annual precipitation varies from 19 inches in the upper basin which lies in the High Plains to 45 inches in the lower basin in the Gulf Coast region. The Brazos River flows in a meandering path about 920 miles from the confluence of the Salt Fork and Double Mountain Fork to the City of Freeport at the Gulf of Mexico. In its upper reaches, the Brazos River is a gypsum-salty intermittent stream. Toward the coast it is a rolling river flanked by levees, agricultural fields, and hardwood bottoms. The 2010 population of the Brazos River Basin is about 2,440,000 people [11].

The TCEQ WAM System combines the Brazos River Basin and San-Jacinto-Brazos Coastal Basin in the same dataset. The San Jacinto-Brazos Coastal Basin lies south of Houston between the lower Brazos Basin and Galveston Bay as shown in Figure 1.2. This adjoining coastal basin has a watershed drainage area of 1,145 square miles and mean annual precipitation of 46.3 inches. The small streams that drain into Galveston Bay and the Gulf of Mexico include Clear Creek, Oyster Creek, and Dickinson, Mustang, Chocolate, and Bastrop Bayous.

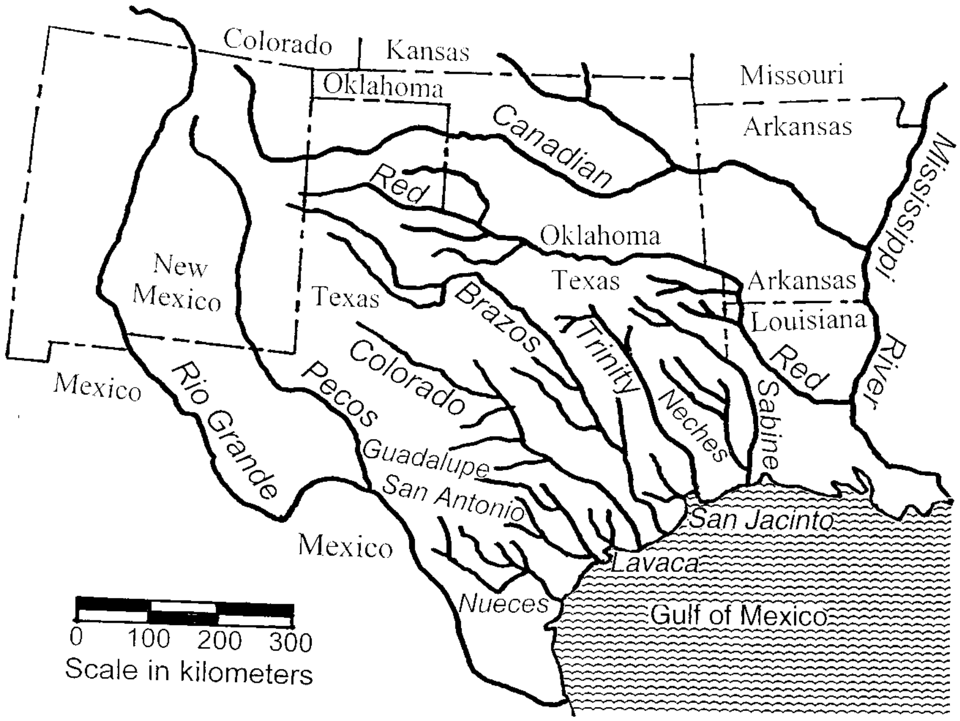

Figure 1.1 Major Texas Rivers including the Brazos River

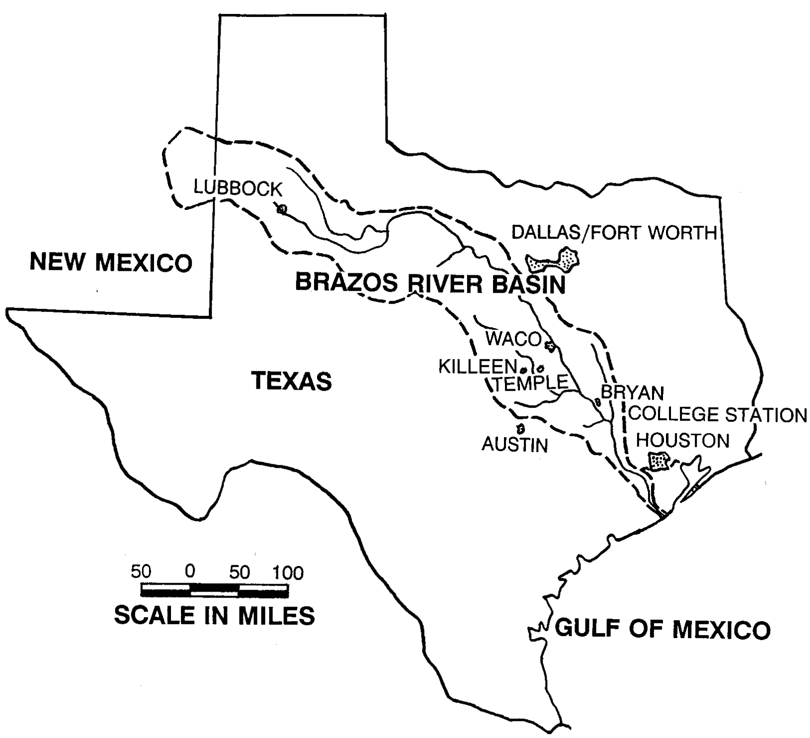

Figure 1.2 Brazos River Basin

Reservoirs in the Brazos River Basin

The Brazos River Basin contains over 700 reservoirs cited in water right permits. Forty-three of these permitted reservoirs have conservation storage capacities of 5,000 acre-feet or greater. The 16 reservoirs listed in Table 1.1 and included on the map of Figure 1.3 are the only reservoirs in the Brazos River Basin that have a combined conservation and flood control storage capacity of greater than 75,000 acre-feet. There are no reservoirs of this size in the San Jacinto-Brazos Coastal Basin. These 16 reservoirs contain about 80 percent of the conservation storage capacity and 100 percent of the controlled (gated) flood control storage capacity in the basin. The conservation storage capacities shown in Table 1.1 are from the water right permits.

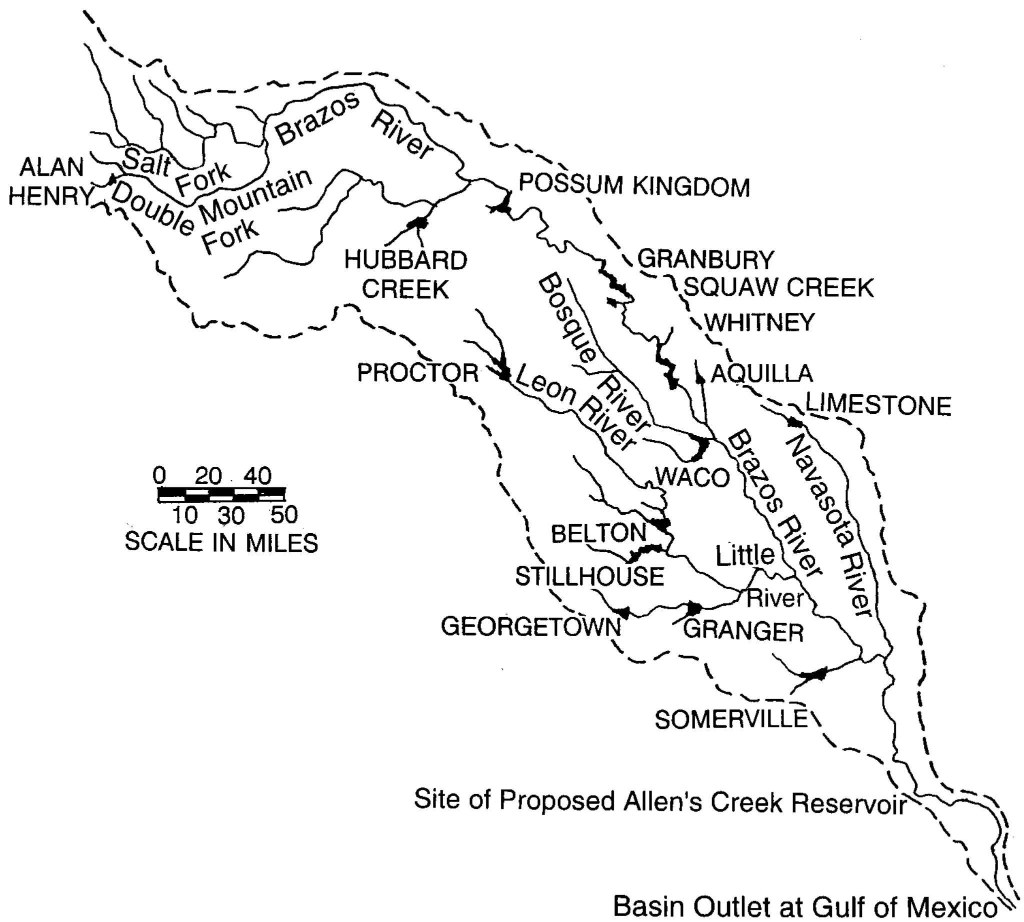

Figure 1.3 Brazos River Basin and its Largest Reservoirs

A system of nine multiple-purpose reservoirs is operated by the U.S. Army Corps of Engineers (USACE) Fort Worth District. The Brazos River Authority (BRA) has contracted for the conservation storage in the nine federal reservoirs and owns three other reservoirs. The City of Waco has water right permits for Lake Waco, and the BRA holds permits for the 11 other reservoirs. The BRA holds a water right permit jointly with Houston and the TWDB for Allen′s Creek Reservoir which has not yet been constructed. Two other municipal water supply reservoirs and a thermal-electric power plant cooling reservoir are included in Table 1.1 and Figure 1.3.

Table 1.1
Largest Reservoirs in the Brazos River Basin

Reservoir	Stream	Initial Impound-ment	Storage Capacity Conservation (acre-feet)	Storage Capacity Flood Control (acre-feet)
		Brazos River Authority and U.S. Army Corps of Engineers		
Possum Kingdom	Brazos River	1941	724,739	–
Granbury	Brazos River	1969	155,000	–
Whitney	Brazos River	1951	636,100	1,372,400
Aquilla	Aquilla Creek	1983	52,400	86,700
Waco	Bosque River	1965	206,562	553,300
Proctor	Leon River	1963	59,400	310,100
Belton	Leon River	1954	457,600	640,000
Stillhouse Hollow	Lampases River	1968	235,700	390,660
Georgetown	San Gabriel	1980	37,100	87,600
Granger	San Gabriel	1980	65,500	162,200
Limestone	Navasota River	1978	225,400	–
Somerville	Yequa Creek	1967	160,110	337,700
Allen′s Creek	Allen′s Creek	proposed	145,533	–
		City of Lubbock		
Alan Henry	Double Mountain	1993	115,937	–
		West Central Texas Municipal Water District		
Hubbard Creek	Hubbard Creek	1962	317,750	–
		Texas Utilities Services (cooling water for Comanche Peak Power Plant)		
Squaw Creek	Squaw Creek	1977	151,500	–

Conservation capacity is used to store water for municipal, industrial, and agricultural water supply, hydroelectric power generation, and other beneficial uses. Flood control storage capacity is maintained empty except during and immediately following flood events. Flood control operations occur whenever lake levels rise above the top of conservation pool elevation. The bottom of the flood control pool is the top of the conservation pool.

Flood control pools may be controlled by gated outlet structures operated by people or may consist of surcharge storage behind ungated structures. All of the controlled (gated) flood control storage capacity in the Brazos River Basin is contained in the nine reservoirs listed in Table 1.1 that are operated by the USACE Fort Worth District. The storage capacities of the designated flood control pools are tabulated in the last column of Table 1.1.

Possum Kingdom Lake has the largest conservation storage capacity in the Brazos River Basin, and Lake Whitney has the second largest conservation storage capacity. Considering the combined total of both flood control and conservation storage capacity, Lake Whitney is the largest reservoir in the Brazos River Basin and the seventh largest reservoir in Texas. Lakes Whitney, Granbury, and Possum Kingdom are the only major storage reservoirs on the main stream of the Brazos River. All other major reservoirs in the Brazos River Basin are on tributaries.

The system of nine reservoirs operated by the USACE Fort Worth District contains a little over 40 percent of the conservation storage capacity and all of the flood control storage capacity in the Brazos River Basin. The federal Whitney, Aquilla, Waco, Proctor, Belton, Stillhouse Hollow, Georgetown, Granger, and Somerville Reservoirs are the only reservoirs in Table 1.1 and Figure 1.3 with flood control pools. The Corps of Engineers constructed, owns, and maintains the federal multiple-purpose reservoir system and is responsible for flood control operations.

Hydroelectric power is generated at Whitney Reservoir and until recently was generated at Possum Kingdom Reservoir. Hydropower generation at Possum Kingdom was recently terminated. The Southwest Power Administration is responsible for marketing hydroelectric power generated at Lake Whitney, which it sells to the Brazos Electric Power Cooperative. Hydropower is generated by excess flows (spills) and releases for downstream water supply diversions. The inactive pool at Lake Whitney provides dead storage for hydropower. No water rights exist specifically for hydropower at the two Brazos River reservoir/hydropower projects.

In addition to releases for water supply diversions from the lower Brazos River, Possum Kingdom and Granbury Reservoirs supply water as needed to maintain constant operating levels in Lakes Squaw Creek, Tradinghouse Creek, and Lake Creek which are owned and operated by utility companies for steam-electric power plant cooling. The BRA operates a desalting water treatment plant that allows use of water from Lake Granbury to supplement the water supply for the City of Granbury and other water users in Johnson and Hood Counties. The BRA holds a water right permit to impound 50,000 acre-feet of storage in Lake Whitney between elevations 520 feet (387,024 acre-feet) and 533 feet (642,179 acre-feet) to supply a diversion of 18,336 acre-feet/year for municipal use. The BRA has a water supply contract with the Corps of Engineers for the 50,000 acre-feet of storage capacity in Lake Whitney.

Allen′s Creek Reservoir is the only proposed but not yet constructed project in Table 1.1. The BRA, City of Houston, and Texas Water Development Board jointly hold a water right permit for the proposed project. A water right permit was initially issued to Houston Lighting and Power (Reliant Energy) to construct a cooling lake for a nuclear power plant. The electric power plant was abandoned during the 1980s, and the City of Houston and BRA acquired the site for a municipal water supply storage project. The reservoir site is on Allen′s Creek, a tributary of the lower Brazos River, in Austin County near the towns of Wallis and Simonton.

Lake Alan Henry in the upper basin is the most recently constructed of the 16 largest reservoirs listed in Table 1.1. The Brazos River Authority was responsible for the initial planning for the Alan Henry Reservoir project and held the original water right permit. Lake Alan Henry is now owned and operated by the City of Lubbock for municipal water supply. The West Central Texas Municipal Water District operates Hubbard Creek Reservoir to supply the cities of Abilene, Albany, Anson, and Breckenridge and other water users.

Squaw Creek Reservoir owned by Texas Utilities Services Company provides cooling water for the Comanche Peak Nuclear Power Plant. The lake is located between the cities of Glen Rose and Granbury on Squaw Creek which flows into the Brazos River between Lakes Granbury and Whitney. The BRA supplies water from Lakes Possum Kingdom and Granbury as needed to maintain a constant water level in Squaw Creek Reservoir.

Previous WRAP Simulation Studies of the Brazos River Basin

Several versions of the modeling system have been applied to the Brazos River Basin as WRAP has evolved over the past 25 years. These studies are briefly noted as follows.

Early Studies

WRAP originated during a 1986-1988 study sponsored by the cooperative research program of the Texas Water Resources Institute with federal funds from the U.S. Department of the Interior and non-federal matching funds from the Brazos River Authority. This study is documented in detail by a two 1988 TWRI technical reports [12, 13] and summarized by two journal papers [14, 15]. Water rights data were obtained from the Texas Water Commission (TNRCC/TCEQ predecessor). Sequences of naturalized monthly flows for 1900-1988 were compiled for the sites of 23 U.S. Geological Survey (USGS) stream gaging stations. Reliability and firm yield analyses were performed with HEC-3 and HEC-5 for the 12-reservoir BRA/USACE system along with Hubbard Creek Reservoir which was also included due to its large size. However, HEC-3 and HEC-5 did not allow consideration of the effects of the numerous other water rights in the basin. Thus, TAMUWRAP was developed.

The following generalized models were obtained from the USACE Hydrologic Engineering Center: *HEC-3 Reservoir System Analysis for Conservation* and *HEC-5 Simulation of Flood Control and Conservation Purposes*. An initial version of WRAP, then called the Texas A&M University Water Rights Analysis Program (TAMUWRAP), was developed that could simulate any number of individual reservoirs but did not include capabilities for modeling multiple-reservoir system operations. A procedure was developed in which stream flows available to the twelve BRA/USACE reservoirs and Hubbard Creek Reservoir were adjusted for the impacts of the numerous other water rights in the basin using TAMUWRAP. The adjusted inflows were input to HEC-3 and HEC-5 which were used to simulate multiple-reservoir system operations. The study quantified the effects of the numerous water rights in the basin on firm yields and yield-reliability relationships for the BRA/USACE reservoirs. The study also demonstrated the benefits of multiple-reservoir system operating strategies.

TAMUWRAP was later replaced with WRAP2, and then WRAP3 was developed by adding features for simulation of hydropower and multiple-reservoir system operations. This eliminated the need for HEC-3 and HEC-5. Salinity simulation capabilities were also added. These versions of WRAP were developed and applied in conjunction with a study of the Brazos River Basin documented by 1994 TWRI technical report [16]. The water rights and hydrology datasets developed in the 1986-1988 studies continued to be used in these 1990-1994 studies. Multiple-reservoir system operations, storage reallocations, and related strategies were investigated in greater detail.

TCEQ Water Availability Modeling (WAM) System

The WAM System was developed by the Texas Natural Resource Conservation Commission (renamed TCEQ in 2003), its partner agencies, and contractors pursuant to the comprehensive water management plan enacted the Texas Legislature as its 1997 Senate Bill 1 [10]. WRAP water rights and hydrology input datasets for the 15 major river basin and eight coastal basins were prepared by consulting engineering firms under contract with the TNRCC (TCEQ). Simulations were performed for specified water use scenarios. Modeling of the Brazos River Basin and San Jacinto-Brazos Coastal Basin is documented by reports [17, 18] prepared by HDR Engineering, Inc., and Freeze and Nichols, Inc. for the TCEQ.

The WAM System WRAP input datasets for alternative water use scenarios for the Brazos River Basin and adjoining San Jacinto-Brazos Coastal Basin, referred to in this report as the Brazos WAM, are discussed in detail in the next chapter and used in the studies presented in subsequent chapters. The TCEQ updates the WAM input datasets over time to reflect new and modified water right permits and refinements in modeling capabilities. Model users modify the datasets for their particular applications to reflect proposed water management strategies and analysis premises of interest. The Brazos WAM has been modified and applied by HDR Engineering for the Region G Planning Group in regional planning studies. The BRA and its consultants, including Freese and Nichols, Inc., developed a modified dataset for a system operations permit application. The datasets continue to be adjusted for various applications including the studies presented in this report.

WRAP modeling methodologies and software have continued to be expanded and improved from 1997 through the present in support of the TCEQ WAM System. The WRAP/WAM System is applied in support of regional and statewide planning studies, administration of the water waters permitting system, and a growing range of other activities.

Companion TWRI Reports

This is the third in a set of three recent TWRI reports documenting WRAP simulation studies of the Brazos River Basin. Technical Report 340 [1] addresses two different tasks: condensing WAM System WRAP input datasets and extending the hydrologic period-of-analysis covered by the datasets. New features were added to the WRAP programs *HYD* and *SIM* to perform these tasks. Brazos River Authority Condensed (BRAC) input datasets were developed that dramatically reduce the size and complexity of the model while preserving the effects of all water rights. The hydrologic period-of-analysis for the full Brazos WAM datasets and BRAC condensed datasets was extended from 1940-1997 to 1900-2007. These datasets are described in Chapter 3 and applied in the studies presented in subsequent chapters of this report.

TWRI Technical Report 352 [2] deals with natural salt pollution in the upper Brazos River Basin and its impacts on water supply capabilities of the BRA/USACE reservoir system. Much of the salt load in the Brazos River is from primary salt source areas in the watersheds of the Salt Fork and Double Mountain Fork of the Brazos River in the upper basin. Salt loads decrease in the lower Brazos River with inflows from low-salinity tributaries. Use of water from Possum Kingdom, Granbury, and Whitney Reservoirs is constrained by high salinity concentrations. The objectives of the studies reported in TR-352 are (1) to better understand the occurrence, transport, and impacts of salinity in the Brazos River and Lakes Possum Kingdom, Granbury, and Whitney and (2) to improve salinity simulation capabilities of the WRAP modeling system. Water volume and TDS load budgets are presented for five river reaches covering about 400 miles of the upper Brazos River. WRAP is applied to model the river basin for alternative modeling premises and water management scenarios. The impacts of salinity and salinity control measures on water supply capabilities are assessed.

CHAPTER 2
TCEQ WATER AVAILABILITY MODELING SYSTEM DATASETS

The Texas Water Availability Modeling (WAM) System is comprised of the generalized WRAP simulation model, *WRAP-SIM* input datasets for the river basins of the state, geographical information system (GIS) tools, and other auxiliary software and databases [10]. WRAP is generalized for application to river/reservoir systems located anywhere, with input data files being developed for particular river basins of concern. WRAP input datasets for all the Texas river basins were developed during 1997-2003 pursuant to the 1997 Senate Bill 1 by the Texas Commission on Environmental Quality (TCEQ), which prior to 2003 was called the Texas Natural Resources Conservation Commission (TNRCC), its partner agencies (Texas Water Development Board and Texas Parks and Wildlife Department), and contractors (consulting engineering firms and university research entities). The TCEQ continues to maintain, refine, and update the WAM System datasets.

Organization of WAM System Datasets

The WAM System datasets for the individual river basins consist of input files for the WRAP simulation program *SIM*. The input files store the following data.

- Hydrology data consisting of sequences of monthly naturalized stream flow volumes and net reservoir evaporation-precipitation depths covering the hydrologic period-of-analysis at relevant control points are typically stored in files with filename extensions FLO and EVA, which are called the FLO and EVA files.
- Control point selections and watershed parameters used in computing naturalized flows at ungaged (unknown-flow) control points, called secondary control points, based on naturalized flows at gaged (known-flow) control points, called primary control points, are stored in a flow distribution DIS file with filename extension DIS.
- Water rights data describe water use requirements, reservoirs and other water-control infrastructure, water right permits and other institutional arrangements for allocating water among multiple users, and river/reservoir system operating rules and practices. These data are stored in a data DAT file with filename extension DAT.

Alternative versions of the water rights data (DAT) files contained in the TCEQ WAM System datasets represent alternative scenarios reflecting combinations of premises regarding water use, return flows, reservoir sedimentation, and term permits. (Unlike regular water right permits which are issued for perpetuity, temporary term permits are issued for a fixed period of time.) Several specified scenarios were simulated by the TCEQ contractors during 1997-2003 for each of the river basins in conjunction with implementation of the WAM System. The following two scenarios are routinely adopted for water right permit applications and planning studies.

- The authorized use scenario (run 3) is based on the following premises.
  1. Water use targets are the full amounts authorized by the permits.
  2. Full reuse with no return flow is assumed.
  3. Reservoir storage capacities are those specified in the permits, which typically reflect no sediment accumulation.
  4. Term permits are not included.

- The current use scenario (run 8) is based on the following premises.
  1. The water use target for each right is based on the maximum annual amount used in any year during a recent ten year period.
  2. Best estimates of actual return flows are adopted.
  3. Reservoir storage capacities and elevation-area-volume relations for major reservoirs reflect then current (year 2000) conditions of sedimentation.
  4. Term permits are included.

Input data are referenced to control points, reservoirs, and water rights. The spatial configuration of the river/reservoir/use system is defined by control points. Control point (*CP*) input records include the next downstream control point for each control point, which defines spatial connectivity. The locations of stream flows, reservoirs, diversions, return flows, and other system components are defined by their assigned control points. Reservoirs, pipelines, hydropower plants, water use targets, environmental instream flow requirements, operating rules, water right permits, and all other aspects of water resources development, allocation, control, management, and use are defined in terms of water rights (*WR*, *IF*, and supporting records in the DAT file).

WAM Datasets for the Brazos River Basin and San Jacinto-Brazos Coastal Basin

The TCEQ WAM System WRAP-SIM input dataset for the authorized use scenario and the corresponding dataset for the current use scenario for the combined Brazos River Basin and San Jacinto-Brazos Coastal Basin are called the Brazos WAM throughout this report. The Brazos WAM files for the authorized use scenario (run 3) and current use scenario (run 8) have the filename roots Bwam3 and Bwam8, respectively. As noted in Chapter 1, the original Brazos WAM datasets were developed by HDR Engineering, Inc., and Freese and Nichols, Inc., during 1998-2001 under contract with the TCEQ [17, 18]. The TCEQ periodically updates and refines the datasets.

WRAP-SIM prints a listing to its message file of the number of various system components. The *SIM* counts for the Brazos WAM in Table 2.1 are from the August 2007 version used in earlier studies and the September 2008 update which is the latest available version as of August 2010.

Table 2.1
Number of System Components in Brazos WAM Datasets

Latest Update of Datasets Water Use Scenario Filename	Aug 2007 Authorized Bwam3	Aug 2007 Current Bwam8	Sep 2008 Authorized Bwam3	Sep 2008 Current Bwam8
total number of control points	3,830	3,834	3,842	3,852
number of primary control points	77	77	77	77
control points with evaporation-precip rates	67	67	67	67
number of reservoirs as counted by *SIM*	670	711	678	719
number of *WR* record water rights	1,634	1,725	1,643	1,734
number of instream flow *IF* record rights	122	144	122	145
number of *FD* records in DIS file	3,138	3,141	3,152	3,157

Control Points and Hydrology Data

Primary control points are locations at which naturalized flows are provided in a *WRAP-SIM* input dataset. Naturalized flows at all other control points (called *secondary* control points) are computed within the *SIM* simulation based on the naturalized flows provided at the primary control points and watershed parameters provided on DIS file flow distribution *FD* and water parameter *WP* records and/or DAT file control point *CP* records.

The Brazos WAM has 77 primary control points for which January 1940 through December 1997 naturalized flows are provided on inflow *IN* records in the FLO file. Naturalized flows are synthesized during execution of *SIM* for the over 3,000 secondary control points based on information provided a DIS file. The combined drainage area ratio and channel loss factor method (*CP* record *INMETHOD* option 6) is used in the Brazos WAM for distributing flows to secondary control points. The drainage area method with or without channel losses is the standard option adopted in the TCEQ WAM System for the various river basins, though the DIS files contain the curve number and precipitation data required to switch to *CP* record INMETHOD options 4, 5, or 8.

All but three of the 77 primary control points are U.S. Geological Survey (USGS) gaging stations located on the Brazos River and its tributaries. Control point BRGM73 represents the site at which the Brazos River flows into the Gulf of Mexico. Control points SJGBC3 and SJCMC4 represent locations at which coastal basin streams flow into Galveston Bay and the Gulf of Mexico. The other 74 control points are USGS gaging stations. *IN* record naturalized flows at the gaged control points were computed by adjusting observed flows. In cases of periods of missing data during 1940-1997, the missing naturalized flows at the gaged sites were filled in using regression.

The 77 primary control points for which naturalized flows are provided as *IN* records in the Bwam3.FLO and Bwam8.FLO files are listed in Table 2.2 with the six-character identifiers used in the data files. The first 73 control points listed in Table 2.2 are located in the Brazos River Basin, and the last four are in the San Jacinto-Brazos Coastal Basin. Their spatial configuration is shown schematically (not to scale) in Figure 2.1. The watershed drainage areas shown in Tables 2.2 and 2.4 are from the DIS file *WP* records and do not include non-contributing areas of the upper basin.

The Bwam3.EVA and Bwam8.EVA files contain *EV* records with 1940-1997 sequences of monthly net reservoir surface evaporation less precipitation depths at the 67 control points listed in Table 2.3, none of which are primary control points listed in Table 2.2. Texas is divided into quadrangles for purposes of compiling evaporation and precipitation data. The location of control points are indicated in Table 2.3 either by quadrangle number or by a major reservoir with its control point identifier assigned to the net evaporation data. The EVA file evaporation-precipitation depths are applied to reservoirs located at these 67 control points and other nearby control points.

The 678 reservoirs in the Bwam3 dataset and 719 reservoirs in the Bwam8 dataset are each assigned January 1940 through December 1997 sequences of monthly net evaporation-precipitation depths in feet/month read from *EV* records in the EVA file that are connected to one of the control points listed in Table 2.3. The first 20 control points listed in Table 2.3 serve as location identifiers for the one degree quadrangles that cover the Brazos River, which are shown on the Figure 2.2 map. The other control points in Table 2.3 are locations of reservoirs. The 1940-1997 means of the net monthly net evaporation-precipitation depths are shown in the table.

Table 2.2
Primary Control Points in the Brazos WAM Datasets

WAM CP ID	Stream	Nearest City	USGS Gage No.	Watershed Area	1940-1997 Mean Nat Flow
				(sq miles)	(ac-ft/year)
RWPL01	Running Water Draw	Plainview	08080700	295	2,469
WRSP02	White River Reservoir	Spur	08080910	689	16,730
DUGI03	Duck Creek	Girard	08080950	300	10,078
SFPE04	Salt Fork Brazos River	Peacock	08081000	2,007	53,686
CRJA05	Croton Creek	Jayton	08081200	293	12,399
SFAS06	Salt Fork Brazos River	Aspermont	08082000	2,504	77,052
BSLU07	Buffalo Spring Lake	Lubbock	08079550	245	16,918
DMJU08	Double Mountain Fork	Justiceburg	08079600	265	22,230
DMAS09	Double Mountain Fork	Aspermont	08080500	1,891	108,367
NCKN10	North Croton Creek	Knox City	08082180	250	12,941
BRSE11	Brazos River	Seymour	08082500	5,996	250,096
MSMN12	Millers Creek	Munday	08082700	106	5,806
CFRO13	Clear Fork Brazos	Roby	08083100	266	7,221
CFHA14	Clear Fork Brazos	Hawley	08083240	1,456	45,162
MUHA15	Mulberry Creek	Hawley	08083245	208	7,780
CFNU16	Clear Fork Brazos	Nugent	08084000	2,236	95,668
CAST17	California Creek	Stamford	08084800	476	27,572
CFFG18	Clear Fork Brazos	Fort Griffin	08085500	4,031	174,974
HCAL19	Hubbard Creek	Albany	08086212	612	57,538
BSBR20	Big Sandy Creek	Breckenridge	08086290	289	23,348
HCBR21	Hubbard Creek	Breckenridge	08086500	1,092	97,181
CFEL22	Clear Fork Brazos	Eliasville	08087300	5,738	308,856
BRSB23	Brazos River	South Bend	08088000	13,171	656,260
GHGH24	Lake Graham	Graham	08088400	224	35,827
CCIV25	Big Cedar Creek	Ivan	08088450	97	13,452
SHGR26	Brazos River	Graford	08088600	14,093	793,483
BRPP27	Brazos River	Palo Pinto	08089000	14,309	810,380
PPSA28	Palo Pinto Creek	Santo	08090500	574	64,126
BRDE29	Brazos River	Dennis	08090800	15,733	1,003,749
BRGR30	Brazos River	Glen Rose	08091000	16,320	1,118,978
PAGR31	Paluxy River	Glen Rose	08091500	411	58,474
NRBL32	Nolan River	Blum	08092000	282	67,304
BRAQ33	Brazos River	Aquilla	08093100	17,746	1,379,053
AQAQ34	Aquilla Creek	Aquilla	08093500	307	89,186
NBHI35	North Bosque River	Hico	08094800	360	44,879
NBCL36	North Bosque River	Clifton	08095000	977	162,919
NBVM37	North Bosque River	Valley Mills	08095200	1,158	202,937
MBMG38	Middle Bosque River	McGregor	08095300	77	55,164
HGCR39	Hog Creek	Crawford	08095400	181	25,735
BOWA40	Bosque River	Waco	08095600	1,660	356,832

Table 2.2 Continued
Primary Control Points in the Brazos WAM Datasets

WAM CP ID	Stream	Nearest City	USGS Gage No.	Watershed Area	1940-1997 Mean Nat Flow
				(sq miles)	(ac-ft/year)
BRWA41	Brazos River	Waco	08096500	20,065	1,942,324
BRHB42	Brazos River	Highbank	08098290	20,900	2,331,139
LEDL43	Leon River	De Leon	08099100	267	56,375
SADL44	Sabana River	De Leon	08099300	476	35,079
LEHS45	Leon River	Hasse	08099500	1,283	141,273
LEHM46	Leon River	Hamilton	08100000	1,928	166,469
LEGT47	Leon River	Gatesville	08100500	2,379	257,793
COPI48	Cowhouse Creek	Pidcoke	08101000	455	77,373
LEBE49	Leon River	Belton	08102500	3,579	505,257
LAKE50	Lampasas River	Kempner	08103800	817	119,776
LAYO51	Lampasas River	Youngsport	08104000	1,240	208,870
LABE52	Lampasas River	Belton	08104100	1,321	233,258
LRLR53	Little River	Little River	08104500	5,266	846,554
NGGE54	North Fork San Gabriel	Georgetown	08104700	248	57,922
SGGE55	South Fork San Gabriel	Georgetown	08104900	132	36,173
GAGE56	San Gabriel River	Georgetown	08105000	404	104,317
GALA57	San Gabriel River	Laneport	08105700	737	189,268
LRCA58	Little River	Cameron	08106500	7,100	1,318,302
BRBR59	Brazos River	Bryan	08109000	30,016	4,027,961
MYDB60	Middle Yegua Creek	Dime Box	08109700	235	39,362
EYDB61	East Yegua Creek	Dime Box	08109800	239	43,189
YCSO62	Yegua Creek	Somerville	08110000	1,011	223,399
DCLY63	Davidson Creek	Lyons	08110100	195	47,485
NAGR64	Navasota River	Groesbeck	08110325	240	83,472
BGFR65	Big Creek	Freestone	08110430	97	32,237
NAEA66	Navasota River	Easterly	08110500	936	322,578
NABR67	Navasota River	Bryan	08111000	1,427	421,304
BRHE68	Brazos River	Hempstead	08111500	34,374	5,358,943
MCBL69	Mill Creek	Bellville	08111700	377	149,586
BRRI70	Brazos River	Richmond	08114000	35,454	5,850,224
BGNE71	Big Creek	Needville	08115000	46	25,631
BRRO72	Brazos River	Rosharon	08116650	35,775	6,112,278
BRGM73	Brazos River	Gulf of Mexico	–	36,027	6,105,239
CLPEC1	Clear Creek	Pearland	08077000	38.8	28,734
CBALC2	Chocolate Bayou	Alvin	08078000	87.7	76,372
SJGBC3	Coastal Basin	Galveston Bay	–	415	345,148
SJGMC4	Coastal Basin	Gulf of Mexico	–	1,004	834,204

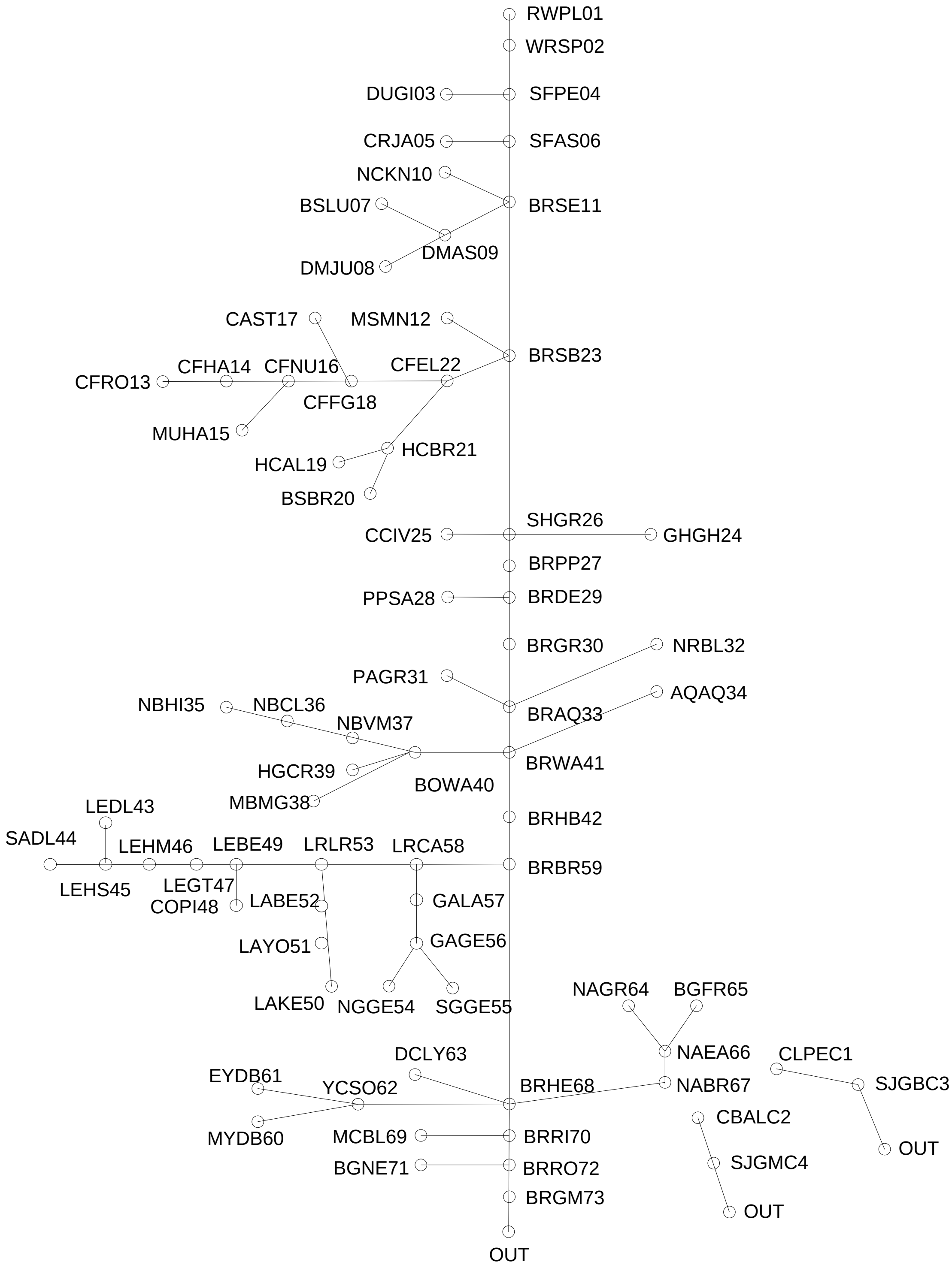

Figure 2.1 Schematic of Primary Control Points (Not to Scale)

Table 2.3
Control Points Assigned to Reservoir Net Evaporation-Precipitation Depth Input

Control Point	Quadrangle or Major Reservoir	Mean Rate feet/month
366631	305	0.3216
368131	306	0.3120
370431	405	0.3216
368931	406	0.3053
341131	407	0.3184
341331	408	0.2815
344801	409	0.2262
371431	506	0.3411
372031	507	0.3022
413331	508	0.2785
220131	509	0.2364
227031	510	0.1912
225331	609	0.0308
228731	610	0.1818
406331	611	0.1422
299231	710	0.1519
375931	711	0.0888
531531	712	0.0131
401041	812	-0.0047
516841	813	-0.0144
414231	Abilene	0.2985
4146P1	Alan Henry	0.3109
527231	Alcoa	0.1354
292531	Allen Creek	0.0392
515831	Aquilla	0.1658
293631	Belton	0.1437
532842	Brazoria	0.0512
526831	Bryan Utilities	0.1011
370631	Buffalo Springs	0.3104
530131	Camp Creek	0.0848
421131	Cisco	0.1945
421431	Daniel	0.2521
344031	Davis	0.2913
549231	Eagle Nest	0.0320

Control Point	Quadrangle or Major Reservoir	Mean Rate feet/month
416131	Fort Phantom Hill	0.2866
516231	Georgetown	0.1243
531131	Gibbons Creek	0.0673
345831	Graham	0.2473
515631	Granbury	0.1808
516331	Granger	0.1432
421331	Hubbard Creek	0.2557
415031	Kirby	0.2924
434531	Lake Creek	0.1611
347031	Leon	0.2235
516531	Limestone	0.1109
435533	Marlin City	0.1455
528731	Mexia	0.1480
344431	Millers Creek	0.2709
403931	Mineral Wells	0.2047
403131	Lake Palo Pinto	0.2183
410631	Pat Cleburne	0.1751
515531	Possum Kingdom	0.2324
371131	Post	0.4469
515931	Proctor	0.1734
554032	Sandow Surface Mine	0.1354
532531	Smithers	0.0043
516431	Somerville	0.0787
409731	Squaw Creek	0.1768
417931	Stamford	0.2911
516131	Stillhouse Hollow	0.1382
413031	Sweetwater	0.3014
434231	Tradinghouse Creek	0.1611
529831	Twin oaks	0.1274
231531	Waco	0.1709
369331	White River	0.3106
515731	Whitney	0.1709
532841	William Harris	0.0294

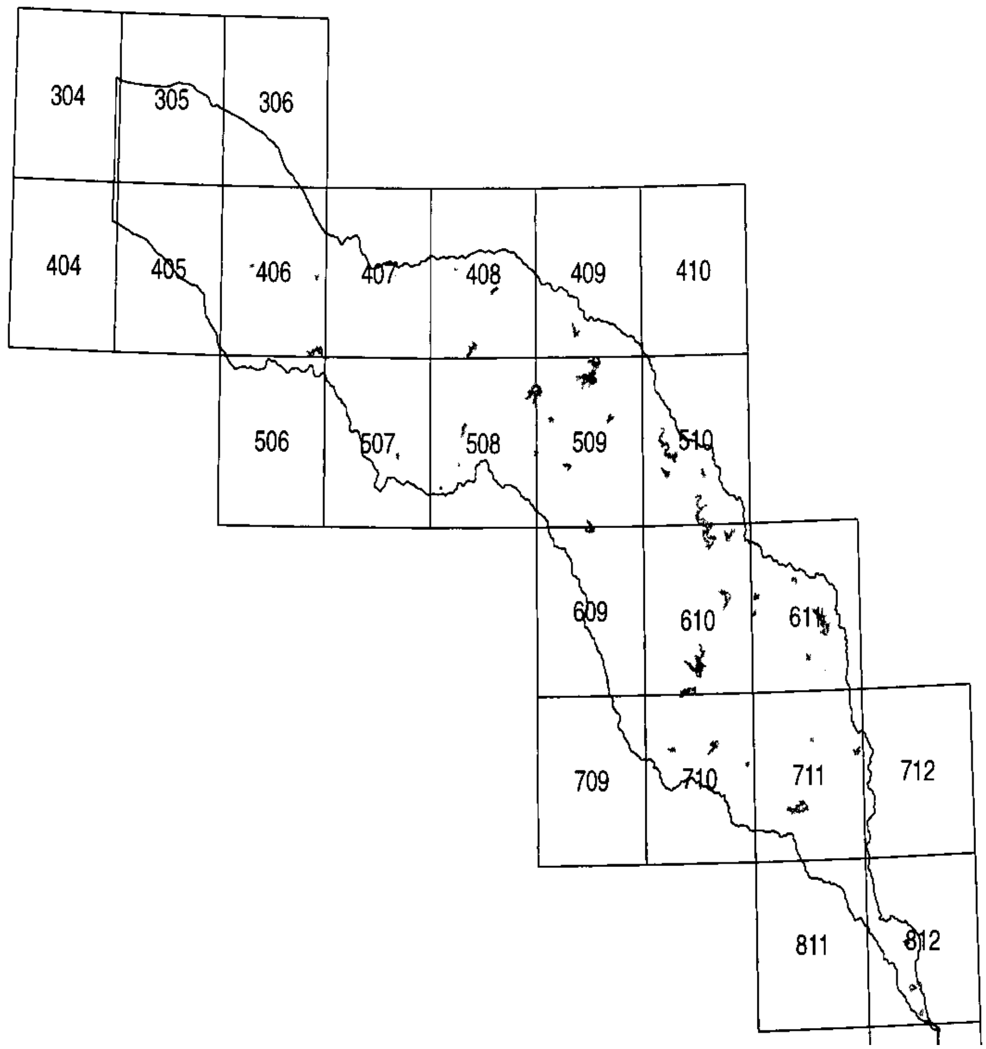

Figure 2.2 Quadrangles for TWDB Evaporation and Precipitation Data

Several key control points that are referenced frequently throughout this report are shown in Figure 2.3 and listed in Table 2.4 with their control point identifiers from the Brazos WAM (Bwam) input files and the streams on which they are located. Table 2.4 and Figure 2.3 include seven of the 77 primary control points and 13 secondary control points. The seven primary control points include six USGS stream gaging stations and the outlet of the Brazos River at the Gulf of Mexico. The secondary control points are the sites of Hubbard Creek Reservoir and the 12 BRA/USACE reservoirs, which are described in Chapter 1. The control points of these major on-stream reservoirs represent the locations of the dams. Control points for off-channel storage reservoirs and run-of-river diversion rights are the locations at which water is diverted from the stream.

The Brazos River Basin and the much smaller adjoining San Jacinto-Brazos Coastal Basin are delineated in Figure 1.2 of Chapter 1. The dry flat upper basin in and near New Mexico, which contributes little or no flow to the river system, is omitted from the following Figure 2.3 map of the Brazos River Basin showing the control points listed in Table 2.4.

Table 2.4
Selected Control Points

Control Point ID	Reservoir or Gage	Stream	Watershed Area (square miles)
	USGS Stream Gaging Stations		
BRSE11	Seymour Gage	Brazos River	5,996
BRSB23	Southbend Gage	Brazos River	13,171
LRCA58	Cameron Gage	Little River	7,100
BRBR59	Bryan Gage	Brazos River	30,016
BRHE68	Hempstead Gage	Brazos River	34,374
BRRI70	Richmond Gage	Brazos River	35,454
	Outlet of the Brazos River at the Gulf of Mexico		
BRGM73	Gulf of Mexico	Brazos River	36,027
	Reservoirs		
421331	Hubbard Creek Lake	Hubbard Creek	1,087
515531	Possum Kingdom Lake	Brazos River	14,093
515631	Granbury Lake	Brazos River	16,181
515731	Whitney Lake	Brazos River	17,690
515831	Aquilla Lake	Aquilla Creek	254
509431	Waco Lake	Bosque River	1,655
516531	Limestone Lake	Navasota River	678
515931	Proctor Lake	Leon River	1,280
516031	Belton Lake	Leon River	3,568
516131	Stillhouse Hollow Lake	Lampases R.	1,313
516231	Georgetown Lake	San Gabriel R.	247
516331	Granger Lake	San Gabriel R.	726
516431	Somerville Lake	Yequa Creek	1,008

Hydrologic Period-of-Analysis

River basin hydrology is represented in the WRAP/WAM modeling system by sequences of monthly naturalized stream flows and net reservoir surface evaporation less precipitation depths covering a specified hydrologic simulation period. Naturalized flow volumes and evaporation-precipitation depths are provided in the FLO and EVA input files, and the *SIM* simulation is performed for each month of the hydrologic period-of-analysis. The Brazos WAM has a hydrologic period-of-analysis extending from January 1940 through December 1997. However, as discussed next, alternative FLO and EVA files are available that cover the period from January 1900 through December 2007.

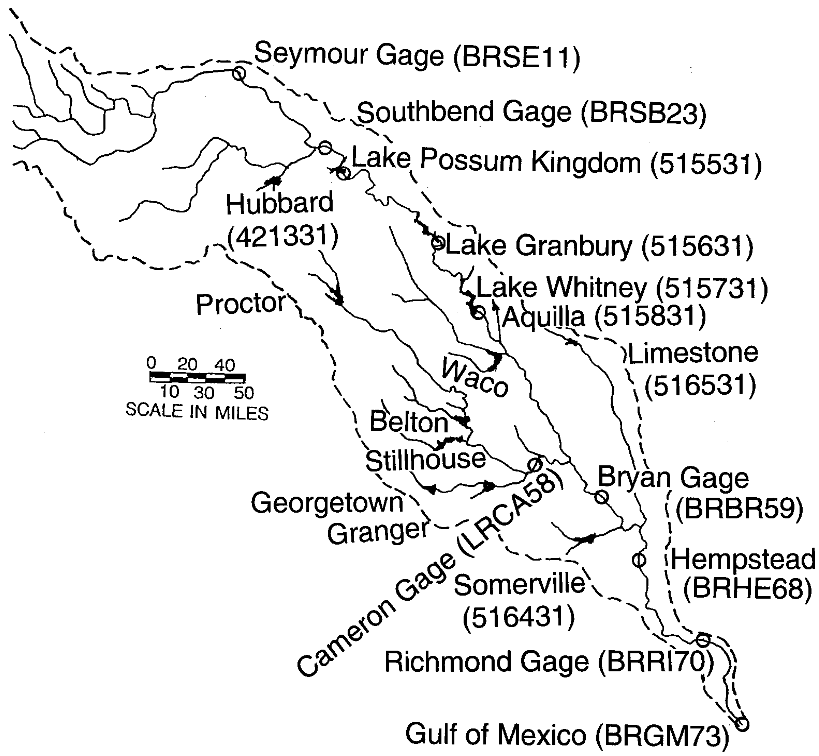

Figure 2.3 Selected Brazos River Basin Control Points

Extension of the Hydrologic Period-of-Analysis

Wurbs and Kim [1] extended the Brazos WAM sequences of naturalized flows and evaporation-precipitation depths from 1940-1997 to 1900-2007. The methodology adopted for the 1998-2007 and 1900-1939 extensions are documented in detail in TWRI Technical Report 340 [1].

The procedure for extending naturalized monthly flows forward to cover 1998-2007 is based on creating a DAT file dataset representing actual water management/use during the 1998-2007 extension period by modifying the current use scenario WAM System dataset. The results of *SIM* simulations with the actual use dataset are used to convert gaged 1998-2007 monthly stream flows to naturalized flows. Application of this procedure to the Brazos WAM is described in TR-340 [1].

The naturalized flows compiled in the studies during 1986-1994 described in TWRI TR-144 [12] and TR-165 [16] were adopted for the simulation period 1900-1939. These are gaged flows with minimal naturalization adjustments combined with flows synthesized by regression for the extensive gaps in recorded observations. The process of converting gaged flows to naturalized flows is much simpler for 1900-1939 because water resources development and use were much less during this time period than later years. Rapid population and economic growth in Texas began in the 1950s. Most of the reservoir projects in Texas were constructed during the 1950s through 1970s. The 1900-1939 extension deals primarily with synthesizing flows at many ungaged as well as gaged sites based on limited available gaged flow data [1]. The naturalized stream flows for 1900-1939 are significantly less accurate than later flows due to the small number of stream gaging stations in operation during the earlier years. However, WRAP simulations with the exceptionally long 108 years of hydrology provide interesting insights.

The official TCEQ Brazos WAM still has a hydrologic period-of-analysis of 1940-1997. However, the total extended hydrologic period-of-analysis covers January 1900 through December 2007. Three alternative periods-of-analysis were adopted in the studies documented by this report: 1940-1997, 1940-2007, and 1900-2007. FLO and EVA files are available for each alternative simulation period. The DAT files are not affected.

Natural Stream Flow Variability

The future, not the past, is of concern in water resources planning and management. However, since the future is unknown, historical naturalized stream flows and net evaporation-precipitation rates are adopted as being representative of the statistical characteristics of natural river basin hydrology. The period-of-analysis should be long enough to capture the full spectrum of hydrologic conditions including the extremes of infrequent major floods and severe droughts.

Monthly naturalized flows for 1900-2007 at the South Bend, Waco, and Richmond gages on the Brazos River and Cameron gage on the Little River (locations shown in Figure 2.3) are plotted in Figures 2.4, 2.5, 2.6, and 2.7. Similar plots for each of the 77 primary control points are found in Appendix A of TWRI TR-340 [1]. These plots illustrate the tremendous natural temporal and spatial variability of stream flows in the Brazos River Basin and throughout Texas. The most hydrologically severe drought during 1900-2007 at these four sites began gradually during 1950-1951 and ended with a major flood in March-May 1957. Several other severe droughts during this period-of-record have had drier individual years but shorter durations than the 1950-1957 drought.

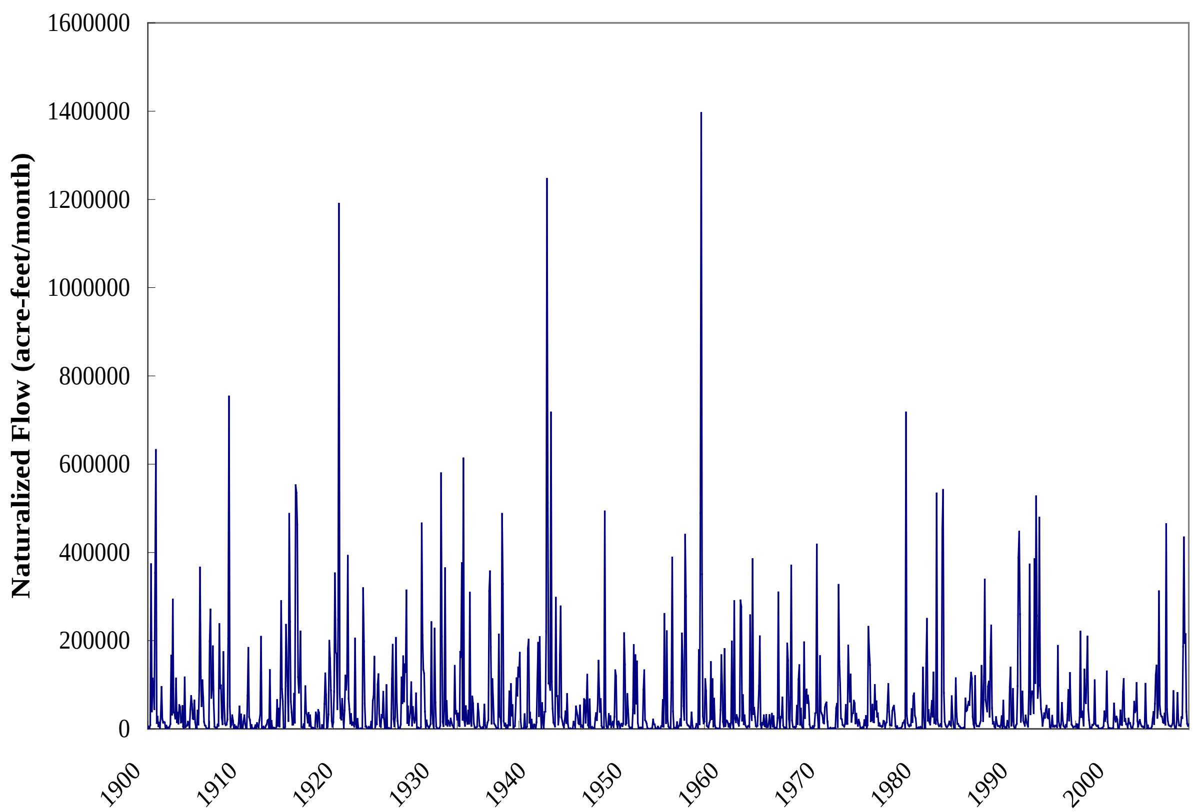

Figure 2.4 Monthly Naturalized Flow of Brazos River at South Bend (BRSB23)

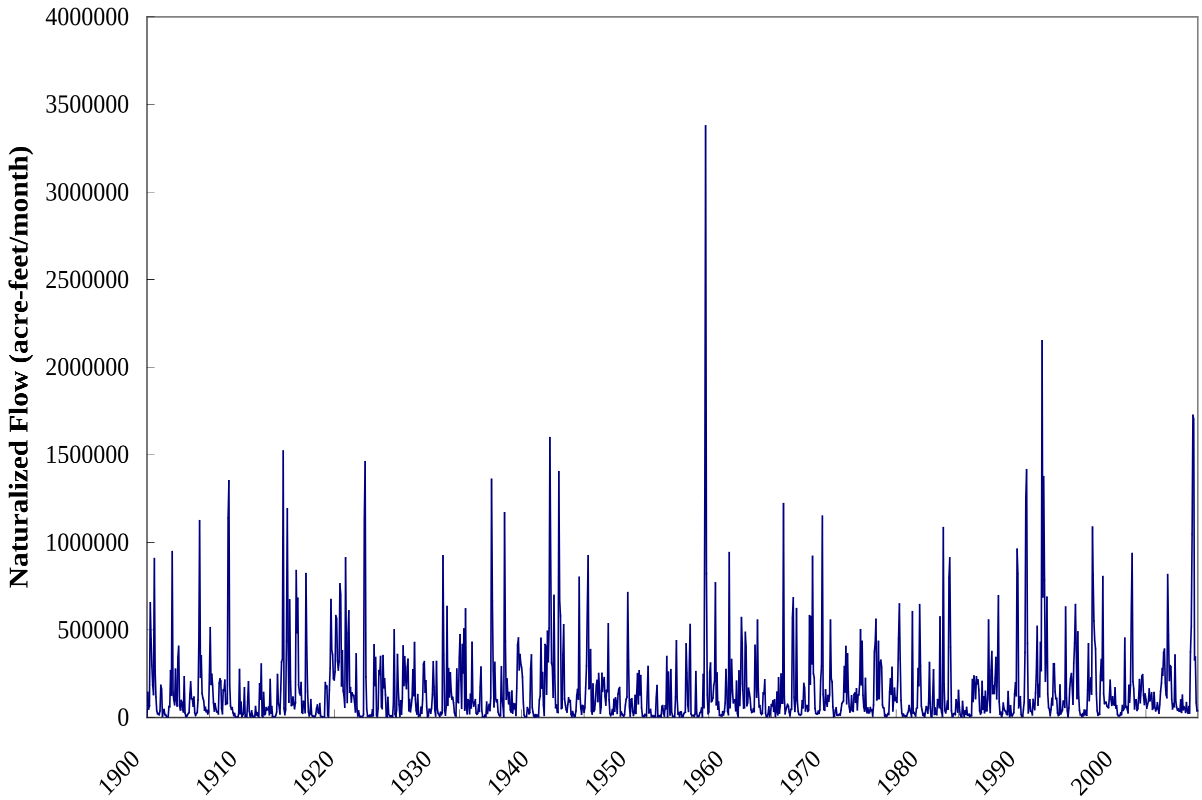

Figure 2.5 Monthly Naturalized Flow of Brazos River at Waco (BRWA41)

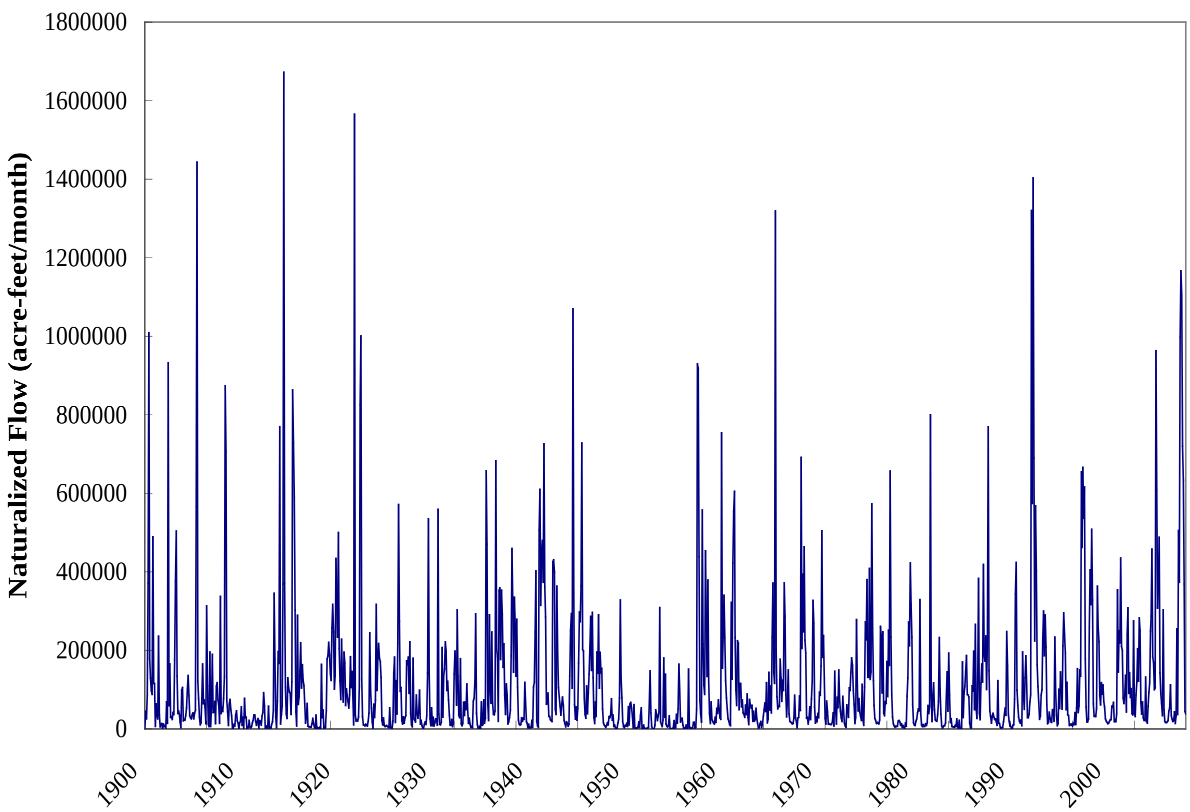

Figure 2.6 Monthly Naturalized Flow of Little River at Cameron (LRCA58)

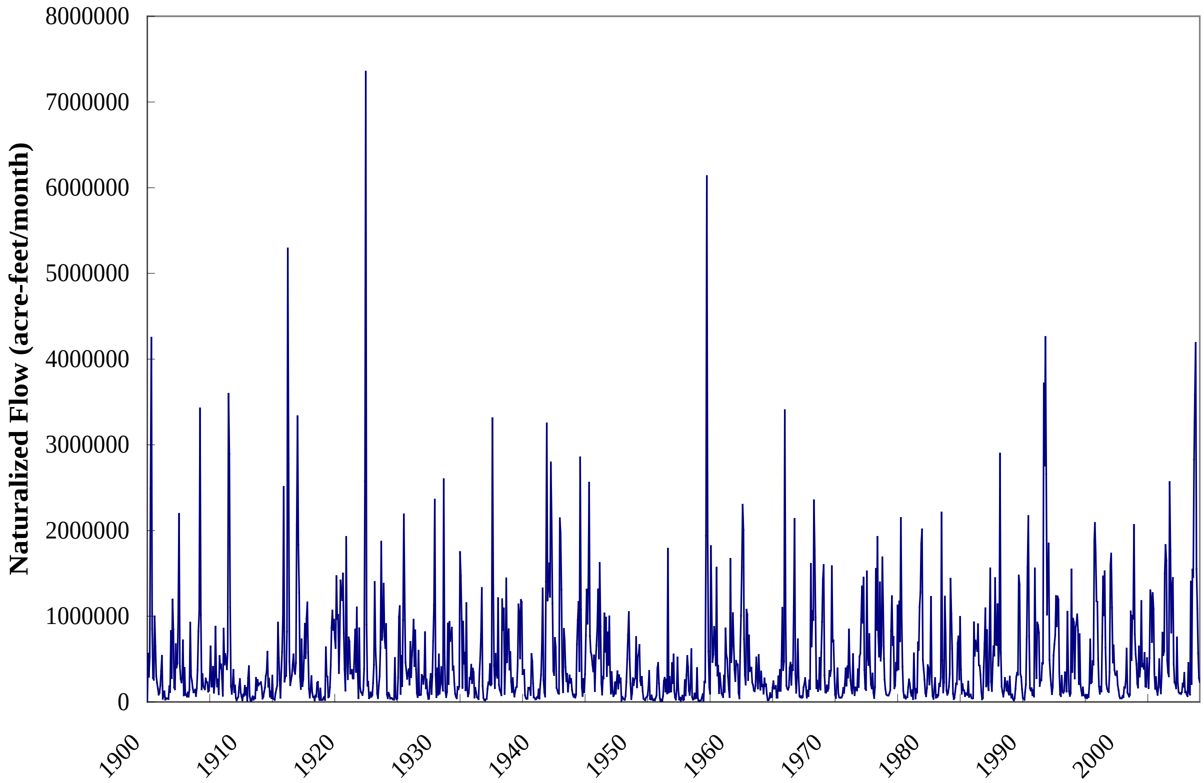

Figure 2.7 Monthly Naturalized Flow of Brazos River at Richmond (BRRI70)

Reservoirs

The number of control points, reservoirs, and other system components in the authorized use scenario (Bwam3) and current use scenario (Bwam8) versions of the Brazos WAM are tabulated in Table 2.1 for the August 2007 version of the datasets used in previous studies [1, 2] and the September 2008 version used in the studies presented in this report. The 77 primary control points and all the major reservoirs with greater than 5,000 acre-feet storage capacity are the same in both versions. However, the September 2008 updated dataset contains eight more small reservoirs than the datasets as last updated in August 2007.

Table 2.1 shows the total *WRAP-SIM* counts of 678 and 719 reservoirs in the September 2008 Bwam3 and Bwam8 data files. These are model reservoirs. The *WRAP-SIM* simulation model includes an option to divide a reservoir into multiple components in order to model storage capacity allocated to multiple owners. The Bwam3 and Bwam8 datasets contain 673 and 714 actual reservoirs. The following tables reflect the 673 and 714 actual reservoirs rather than 678 and 719 model reservoirs shown in Table 2.1. The difference of five reservoirs in these counts is due to sub-dividing Whitney and Waco Reservoirs into component reservoirs in the model to reflect multiple owners, as shown in Table 2.5. In the 678 and 719 reservoir count of Table 2.1, Whitney Reservoir is counted as three model reservoirs, and Waco Reservoir is counted as the four reservoirs shown in Table 2.5.

The authorized use dataset, as of September 2008, contains 673 reservoirs with conservation storage capacities totaling 4,698,652 acre-feet (excluding flood control storage capacity). The current use dataset contains 714 reservoirs with conservation storage capacities totaling 4,015,865 acre-feet. The range in conservation storage capacity is shown in Table 2.6. The Bwam3 and Bwam8 datasets have 249 and 269 reservoirs, respectively, that have less than 50 acre-feet of storage capacity and 12 and 11 reservoirs, respectively, that each contain over 100,000 acre-feet of conservation storage capacity. Although there are numerous smaller reservoirs, most of the total reservoir storage capacity in the Brazos River Basin is contained in a relatively few large reservoirs.

Table 2.5
Whitney and Waco Component Reservoirs

	Storage Capacity (acre-feet)	
Reservoir ID	Bwam3	Bwam8
	Whitney Reservoir	
WHITNY	387,024	311,998
BRA	50,000	50,000
CORWHT	199,076	199,076
Total	636,100	561,074
	Waco Reservoir	
LKWACO	39,100	39,100
WACO2	65,000	65,000
WACO4	88,062	88,062
WACO5	14,400	14,400
Total	206,562	206,562

Table 2.6
Reservoirs in the Brazos WAM

	Authorized Use (Bwam3)		Current Use (Bwam8)	
Range of Conservation Storage Capacity (acre-feet)	Number of Reservoirs	Total Capacity (acre-feet)	Number of Reservoirs	Total Capacity (acre-feet)
less than 50	249	4,510	269	4,974
50 to 99	83	5,920	90	6,407
100 to 499	197	45,373	210	48,246
500 to 999	49	35,503	51	36,841
1,000 to 4,999	46	96,572	51	110,980
5,000 to 9,999	12	94,479	10	76,849
10,000 to 49,999	18	463,298	19	511,698
50,000 to 99,999	7	421,066	3	174,621
100,000 to 499,999	10	2,171,092	9	1,943,444
greater than 500,000	2	1,360,839	2	1,113,087
Total	673	4,698,652	714	4,015,865

Table 2.7
Reservoirs with Authorized Storage Capacities Exceeding 10,000 acre-feet

Reservoir	Stream	County	Storage (acre-feet)	Diversion (ac-ft/yr)	Owner
Abilene	Elm Creek	Taylor	11,868	1,675	City of Abilene
Alan Henry	SF Double Mountain	Garza	115,937	35,000	City of Lubbock
Alcoa Lake	Sandy Creek	Milan	15,650	14,000	ALCOA Company
Allens Creek	Allens Creek	Austin	145,533	99,650	Brazos River Authority
Aquilla	Aquilla Creek	Hill	52,400	13,896	Corps of Engineers
Belton	Leon River	Bell	457,600	100,257	Corps of Engineers
Brazoria	Off-Channel	Brazoria	21,700	75,656	Dow Chemical
Bryan Utilities	Unnamed Tributary	Brazos	15,227	850	City of Bryan
Cisco	Sandy Creek	Eastland	45,000	2,027	City of Cisco
Cleburne	Nolan Creek	Johnson	25,600	6,000	City of Cleburne
Daniel	Gonzales Creek	Stephens	11,400	2,100	City of Breckenridge
Eagles Nest	Vamers Creek	Brazoria	11,315	1,800	T.L Smith Trust
Fort Phantom Hill	Elm Creek	Jones	73,960	33,190	City of Abilene
Georgetown	NF San Gabriel River	Williamson	37,100	13,610	Corps of Engineers
Gibbons Creek	Gibbons Creek	Grimes	32,084	9,740	Tex Mun Power Agency
Graham/Eddlerman	Flint Creek	Young	52,386	20,000	City of Graham
Granbury	Brazos River	Hood	155,000	64,712	Brazos River Authority
Granger	San Gabriel River	Williamson	65,500	19,840	Corps of Engineers
Harris	Off-Channel	Brazoria	10,200	230,000	Dow Chemical
Hubbard Creek	Hubbard Creek	Stephens	317,750	56,000	West Central Tex MWD
Leon	Leon River	Eastland	28,000	6,301	Eastland Co. WSD
Limestone	Navasota River	Robertson	225,400	65,074	Brazos River Authority
Millers Creek	Millers Creek	Baylor	30,696	5,000	North Central Tex MWD
Palo Pinto	Palo Pinto Creek	Palo Pinto	44,100	13,480	Palo Pinto MWD
Possum Kingdom	Brazos River	Palo Pinto	724,739	230,750	Brazos River Authority
Post	NF Double Mountain	Garza	57,420	10,600	White River MWD
Proctor	Leon River	Comanche	59,400	19,658	Corps of Engineers
Smithers	Smithers Creek	Fort Bend	18,750	34,300	Houston L&P Company
Somerville	Yegua Creek	Washington	160,110	48,000	Corps of Engineers
Squaw Creek	Squaw Creek	Somervell	151,500	23,180	Texas Utilities Electric
Stamford	Paint Creek	Haskell	60,000	10,000	City of Stamford
Stillhouse Hollow	Lampasas River	Bell	235,700	67,768	Corps of Engineers
Tradinghouse	Tradinghouse Creek	McLennan	37,800	15,000	Texas Utilities Electric
Twin Oaks	Duck Creek	Robertson	30,319	13,200	Texas Utilities Electric
Waco	Bosque River	McLennan	206,562	79,870	Corps of Engineers
White River	White River	Crosby	44,897	6,000	White River MWD
Whitney	Brazos River	Hill	50,000	18,336	Corps of Engineers
			----------	----------	
Total			3,838,603	1,466,520	

The authorized reservoir storage capacities in the Bwam3 dataset are the storage capacities stated in the water right permits. For most of the reservoirs, this is the capacity at the time of construction, prior to occurrence of reservoir sedimentation. The data for some permits are updated by sediment surveys. Reservoir storage capacity is diminished over time due to accumulation of sediment. The storage capacities in the current use Bwam8 dataset includes adjustments reflecting estimated year 2000 conditions of reservoir sedimentation.

The 37 reservoirs in the Brazos River Basin with water right permits that authorize storage capacities exceeding 10,000 acre-feet are listed in Table 2.7. The proposed Allens Creek Reservoir is included along with 36 actual existing reservoirs. These 37 reservoirs contain about 94.0 percent of the authorized storage capacity in the basin reflected in all of the water right permits. With the notable exception of Lake Whitney, the authorized storage capacities tabulated in Table 2.7 are the capacities included in the Bwam3 dataset. However, of the total Lake Whitney conservation storage capacity of 636,100 acre-feet shown in Table 2.6, only 50,000 acre-feet is authorized in a water right permit and thus tabulated in Table 2.7. Pertinent information for the 16 largest reservoirs is provided in Table 1.1 and accompanying discussion in Chapter 1.

Water Rights

The Bwam3 authorized use scenario input data file with filename extension DAT contains 1,643 water right *WR* records and 122 instream flow *IF* records. The Bwam8 current use scenario DAT file contains 1,734 *WR* records and 145 *IF* records. In many cases, a single *WR* record represents a single actual water right permit. However, in some cases, multiple *WR* and *IF* records are used to model a particular water right permit. For example, separate *WR* records are included for municipal, industrial, and agricultural water use authorized by the same water right permit.

The Bwam3 and Bwam8 datasets model the authorized use and current use scenarios described earlier in this chapter. The differences between the Bwam3 authorized use scenario and Bwam8 current use scenario models are as follows.

- The Bwam3 water supply diversion targets are based on the authorized amounts specified in the water right permits. The Bwam8 dataset models the current use scenario. Diversion targets were adopted based on the maximum annual water use associated with each individual water right permit during any year during 1988 through 1997. The Bwam8 diversion targets are generally significantly smaller than the Bwam3 diversion targets.

- The Bwam3 authorized use dataset has no return flows associated with the authorized diversions. Bwam8 includes estimated return flows. The Bwam8 return flows significantly increase water availability.

- The Bwam3 reservoir storage capacities are authorized volumes from the water right permits which typically reflect conditions at the time of initial impoundment prior to accumulation of sediment deposits. The Bwam8 storage capacities are adjusted to reflect estimated year 2000 conditions of reservoir sedimentation. The total storage capacity in the Bwam8 dataset is smaller than the storage capacity in Bwam3.

- Bwam8 includes term permits which are issued for fixed relatively short-term periods of time as well as regular water right permits. Bwam3 does not. Thus, Bwam8 has more water rights. However, the term permits generally involve relatively small storage and diversion volumes.

The authorized diversions associated with the 37 reservoirs with conservation storage capacities greater than 10,000 acre-feet are tabulated in Table 2.7. The storage volumes and annual diversion volumes in Table 2.7 are the amounts specified in the water right permits which are modeled by Bwam3. The authorized diversion amounts associated with these 37 reservoirs represent about 60.2 percent of the total of the authorized diversion targets in the Bwam3 dataset.

Diversion targets from the water right *WR* records of the Bwam3 and Bwam8 DAT files are summarized in Tables 2.8 and 2.9, respectively. The diversion targets for the water rights in the Bwam3 and Bwam8 input data DAT files sum to 2,437,338 and 1,496,568 acre-feet/year.

Table 2.8
Water Rights Summary for Bwam3 Authorized Use Scenario

Water Use Type Identifier on *UC* and *WR* Records (Type of Use and Region)	Number of WR Records	Total of Diversion Targets	Total Storage Capacity	Priorities Range from	to
		(ac-ft/yr)	(acre-feet)		
MUN1 municipal, region 1	39	165,493	2,339,399	Jun 1914	Oct 1981
MUN2 municipal, region 2	85	329,774	15,974,008	Oct 1914	88888888
MUN3 municipal, region 3	31	159,377	1,850,580	Mar 1914	Feb 2000
MUN4 municipal, region 4	34	677,752	355,367	0	Jun 2001
IRR1 irrigation, region 1	157	25,875	490,764	Dec 1914	Jun 1996
IRR2 irrigation, region 2	570	81,869	3,373,950	Dec 1889	Apr 2002
IRR3 irrigation, region 3	225	53,248	883,133	Dec 1883	Apr 2002
IRR4 irrigation, region 4	71	101,554	39,884	Jun 1914	Jun 2000
IND1 industrial, region 1	20	19,691	707,547	Mar 1925	Oct 1981
IND2 industrial, region 2	24	251,692	4,176,287	Oct 1915	Mar 1986
IND3 industrial, region 3	50	148,368	1,651,012	Jun 1914	Oct 2004
IND4 industrial, region 4	21	269,902	74,232	Jun 1914	Jan 1997
MIN1 mining, region 1	24	23,133	523,695	Jul 1926	Jul 2000
MIN2 mining, region 2	13	21,040	2,900,952	Dec 1919	Oct 2000
MIN3 mining, region 3	17	547	717,644	Dec 1963	Oct 1976
MIN4 mining, region 4	3	54,300	0	Feb 1939	Jul 2000
HYD2 PK hydropower	1	3,600	724,739	Apr 1934	Apr 1934
WHIT1, Whitney municipal	4	18,336	349,076	Aug 1982	99999999
UNIFO uniform distribution	181	543	1,126,539	Jun 1914	99999999
other individual water rights	73	31,244	1,685,440	Jun 1914	99999999
Total	1,643	2,437,338			

The water use type identifier connecting the *WR* records to monthly water use distribution factor *UC* records are shown in the first column of Tables 2.8 and 2.9. The following four regions of the river basin cited in the first column are considered in specifying *UC* record sets of 12 monthly water use distribution factors as well as the type of use.

- Region 1 is the upper basin upstream of Possum Kingdom reservoir. Alan Henry and Hubbard Creek Reservoirs are located in Region 1.
- Region 2 is the upper middle basin between Regions 1 and 3. Possum Kingdom, Granbury, Aquilla, Waco, Proctor, and Belton Reservoirs are in Region 2.

- Region 3 is the lower middle basin below Whitney Dam that includes the Little River and Navasota River subbasins. Stillhouse Hollow, Georgetown, Granger, Limestone, Somerville Reservoirs are located in Region 3.
- Region 4 in the lower basin below the confluence of the Navasota River with the Brazos River. The proposed Allens Creek Reservoir will be located in Region 4.

Table 2.9
Water Rights Summary for Bwam8 Current Use Scenario

Water Use Type Identifier on *UC* and *WR* Records (Type of Use and Region)	Number of WR Records	Total of Diversion Targets	Total Storage Capacity	Priorities Range from	to
		(ac-ft/yr)	(acre-feet)		
MUN1 municipal, region 1	39	50,702	2,284,300	Jun 1914	Oct 1981
MUN2 municipal, region 2	89	167,868	14,217,771	Oct 1914	88888888
MUN3 municipal, region 3	31	101,701	1,742,405	Mar 1914	Feb 2000
MUN4 municipal, region 4	32	484,515	64,301	0	Jun 2001
IRR1 irrigation, region 1	158	14,385	495,565	Dec 1914	Jun 1996
IRR2 irrigation, region 2	626	71,722	2,811,547	Dec 1889	Apr 2002
IRR3 irrigation, region 3	244	37,316	835,443	Dec 1883	Apr 2002
IRR4 irrigation, region 4	72	83,674	39,884	Jun 1914	Jun 2000
IND1 industrial, region 1	20	5,354	621,846	Mar 1925	Oct 1981
IND2 industrial, region 2	27	94,951	3,419,223	Oct 1915	Mar 1986
IND3 industrial, region 3	51	82,572	1,560,971	Jun 1914	Oct 2004
IND4 industrial, region 4	21	250,480	73,257	Jun 1914	Jan 1997
MIN1 mining, region 1	23	3,199	432,243	Jul 1926	Jul 2000
MIN2 mining, region 2	13	13,336	2,320,575	Dec 1919	Oct 2000
MIN3 mining, region 3	19	338	675,950	Dec 1963	Oct 1976
MIN4 mining, region 4	3	3,957	0	Feb 1939	Jul 2000
HYD2 PK hydropower	1	3,600	552,013	Apr 1934	Apr 1934
WHIT1 Whitney municipal	3	0	4,380	40000101	99999999
UNIFO uniform distribution	185	426	1,036,091	Jun 1914	99999999
other individual water rights	77	26,472	1,769,002	Jun 1914	99999999
Total	1,734	1,496,568			

Several water supply diversion rights held by the Brazos River Authority and other permit holders are authorized for multiple types of use but included in the WAM dataset as municipal use. Since reservoirs supply multiple types of use, the storage capacities in Tables 2.8 and 2.9 reflect counting the same reservoirs more than once.

The Bwam3 DAT file contains 122 *IF* records specifying instream flow requirements. The Bwam8 dataset has 145 *IF* records. All instream flow rights require junior rights to pass inflows through reservoirs if necessary to meet the minimum instream flow targets. However, most of the *IF* record rights do not require release of additional water from reservoir storage to meet the instream flow targets. The exceptions are the following three relatively small instream flow rights that do require releases from reservoir storage if necessary to satisfy instream flow targets.

- *IF* record right IFC4097_1 sets a target of 1,086 acre-feet/year distributed uniformly over the 12 months of the year at control point 409702. Releases are made as necessary from Squaw Creek Reservoir.
- *IF* record right IFC5158_1 sets a target of 362 acre-feet/year distributed uniformly over the 12 months of the year at control point 515831. Releases are made as necessary from Aquilla Reservoir.
- *IF* record right IFC4355_1 sets a target of 72 acre-feet/year distributed uniformly over the 12 months of the year at control point 435533. Releases are made as necessary from Brushy Creek Reservoir.

Water Rights Associated with the 16 Largest Reservoirs

The locations of the 16 largest reservoirs in the basin previously listed in Table 1.1 of Chapter 1 are shown in Figure 1.3 which is reproduced below as Figure 2.8. The annual diversion targets for the Bwam3 authorized use scenario and Bwam8 current use scenario are tabulated in Table 2.10 for water rights associated with these 16 reservoirs. The totals for the entire dataset are shown at the bottom of Table 2.10. The diversion targets associated with the 16 largest reservoirs account for about 39.7 percent and 31.7 percent of the total authorized diversion amounts for the Bwam3 and Bwam8 datasets.

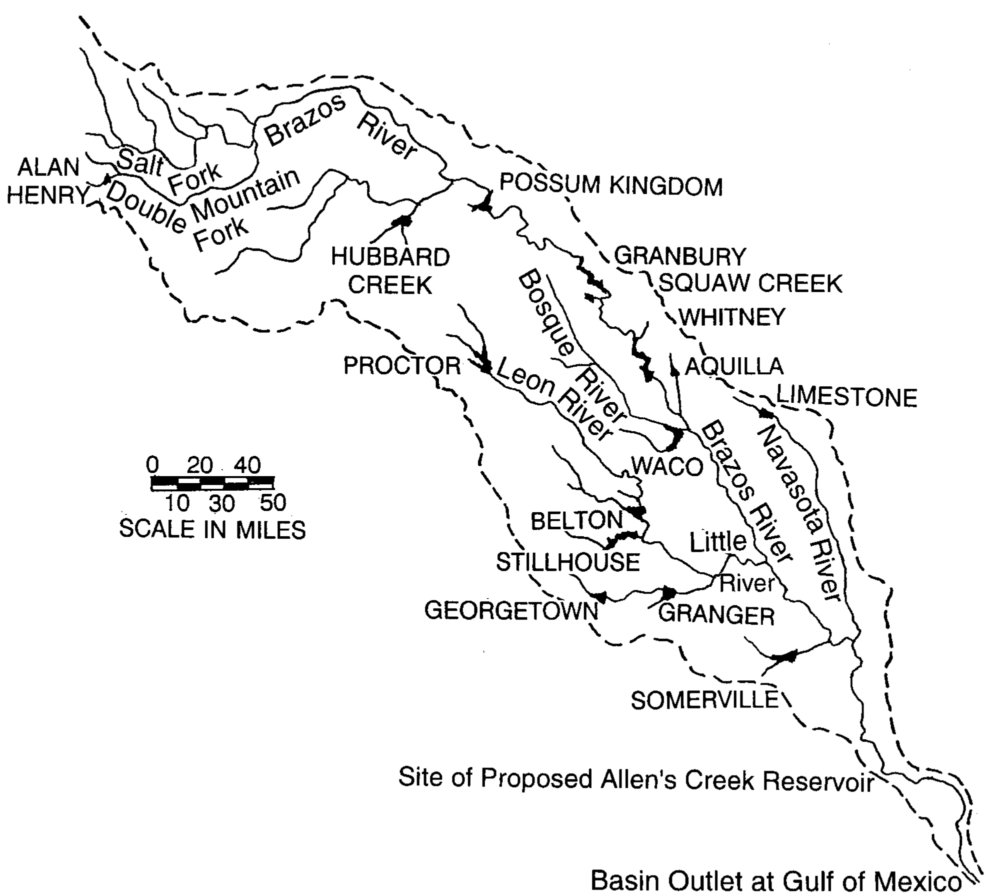

Figure 2.8 Sixteen Largest Reservoirs in the Brazos River Basin

Table 2.10
Brazos WAM Water Rights

Reservoir	Reservoir Identifier	Control Point	Storage (acre-feet) Bwam3	Storage (acre-feet) Bwam8	Diversion (ac-ft/year) Bwam3	Diversion (ac-ft/year) Bwam8
Brazos River Authority System						
Possum Kingdom	POSDOM	515531	724,739	552,013	230,750	59,482
Granbury	GRNBRY	515631	155,000	132,821	64,712	36,025
Whitney	WHITNY	515731	387,024	311,998	0	0
	BRA	515731	50,000	50,000	18,336	18,336
	CORWHT	515731	199,076	199,076	0	0
Aquilla	AQUILA	515831	52,400	41,700	13,896	2,394
Waco	LKWACO	509431	39,100	39,100	39,100	37,448
	WACO2	509431	65,000	65,000	20,000	900
	WACO4	509431	88,062	88,062	20,777	0
	WACO5	509431	14,400	14,400	0	0
Proctor	PRCTOR	515931	59,400	54,702	19,658	14,068
Belton	BELTON	516031	457,600	432,978	112,257	107,738
Stillhouse Hollow	STLHSE	516131	235,700	224,279	67,768	67,768
Georgetown	GRGTWN	516231	37,100	36,980	13,610	11,943
Granger	GRNGER	516331	65,500	50,540	19,840	2,569
Limestone	LMSTNE	516531	225,400	208,017	65,074	39,337
Somerville	SMRVLE	516431	160,110	154,254	48,000	48,000
Allens Creek	ALLENS	292531	145,533	−	99,650	−
City of Lubbock						
Alan Henry	ALANHN	4146P1	115,937	115,773	35,000	288
West Central Texas Municipal Water District						
Hubbard Creek	HUBBRD	421331	317,750	317,750	56,000	9,924
Texas Utilities Services (cooling water for an electric power plant)						
Squaw Creek	SQWCRK	409702	151,500	151,015	23,180	17,536
Water Right Totals						
Total for the 16 reservoirs listed above			3,746,331	3,240,458	967,608	473,756
Percentage of basin total			(79.7%)	(80.7%)	(39.7%)	(31.7%)
All other water rights			952,321	775,407	1,469,730	1,022,812
Total for the entire river basin			4,698,652	4,015,865	2,437,338	1,496,568

For most of the 1,643 water right *WR* records in the Bwam3 DAT file or 1,734 *WR* records in the Bwam8 DAT file, each individual *WR* record represents a particular water right permit. In most cases, a water right permit is modeled with a single *WR* record and associated reservoir storage WS record. However, the water right permits governing the water supplied by the larger reservoirs are more complex. Several *WR* records may be used to model a single water right permit.

Table 2.11
Bwam3 and Bwam8 Water Right *WR* Records Connected to the 16 Largest Reservoirs

Water Right	Control Point	Bwam3 Diversion (ac-ft/yr)	Bwam8 Diversion (ac-ft/yr)	Use Type	Priority	Return Flow CP	Water Right Permit Holder
Possum Kingdom Reservoir (POSDOM) with Storage Capacity of 724,739 and 552,013 acre-feet							
C5155_1	515531	1,000	1,000	MUN2	19380406	27891	Brazos River Authority
C5155_2	515531	237	237	MUN2	19380406		Brazos River Authority
C5155_3	515531	1,200	1,200	MUN2	19380406	101102	Brazos River Authority
C5155_4	515531	315	315	MUN2	19380406	106271	Brazos River Authority
C5155_5	515531	473	473	MUN2	19380406	104101	Brazos River Authority
C5155_6	515531	2,051	2,051	MUN2	19380406	105685	Brazos River Authority
C5155_7	515531	3,549	3,549	MUN2	19380406	103751	Brazos River Authority
C5155_8	515531	1,499	1,499	MUN2	19380406	101731	Brazos River Authority
C5155_9	515531	40,753	1,999&50	MUN2	19380406		Brazos River Authority
C5155_10	515531	5240	264	MUN2	19380406		Brazos River Authority
C5155_11	515531	168	13.9	IND2	19380406		Brazos River Authority
C5155_12	515531	107,447	8,864.4	IND2	19380406		Brazos River Authority
C5155_13	515531	371	30.6	IND2	19380406		Brazos River Authority
C5155_14	515531	31,538	2,601.9	IND2	19380406		Brazos River Authority
C5155_15	515531	1273	1,918.3	IRR2	19380406		Brazos River Authority
C5155_16	515531	840	1,275.8	IRR2	19380406		Brazos River Authority
C5155_17	515531	10,099	15,218.2	IRR2	19380406		Brazos River Authority
C5155_18	515531	18,924	13,201.4	MIN2	19380406		Brazos River Authority
C5155_19	515531	158	110.2	MIN2	19380406		Brazos River Authority
C5155_20	515531	15	10.5	MIN2	19380406		Brazos River Authority
C5155_21	515531	3,600	3,600	HYD2	19380406	515551	Brazos River Authority
Granbury Reservoir (GRNBRY) Storage Capacity of 155,000 (Bwam3) and 132,821 (Bwam8) ac-ft							
C5156_1	515631	1,557	397	MUN2	19640213		Brazos River Authority
C5156_2	515631	2,600	624	MUN2	19640213		Brazos River Authority
C5156_3	515631	6,705	1,652.8	MUN2	19640213	101782	Brazos River Authority
C5156_4	515631	1,475	363.6	MUN2	19640213		Brazos River Authority
C5156_5	515631	1,073	264.5	MUN2	19640213		Brazos River Authority
C5156_6	515631	2	1.3	IND2	19640213		Brazos River Authority
C5156_7	515631	3,748	2,472.2	IND2	19640213		Brazos River Authority
C5156_8	515631	40,000	26,384	IND2	19640213		Brazos River Authority
C5156_9	515631	4,544	2,326.1	IRR2	19640213		Brazos River Authority
C5156_10	515631	2,806	1,436.4	IRR2	19640213		Brazos River Authority
C5156_11	515631	200	102.4	IRR2	19640213		Brazos River Authority
C5156_12	515631	2	1.0	MIN2	19640213		Brazos River Authority
Whitney Reservoir (WHITNY) Storage Capacity of 387,024 (Bwam3) and 311,998 (Bwam8) ac-ft							
USACE_WHIT	515731	0	0		88888888		Corps of Engineers
EVAP1	515731	0	0		99999999		Corps of Engineers
Whitney Reservoir (BRA) Storage Capacity of 50,000 acre-feet (both Bwam3 and Bwam8)							
C5157_2	515731	18,336	18,336	WHIT1	19820830		Brazos River Authority
C5157_3	515731	0	0	WHIT1	40000101		Brazos River Authority
EVAP2	515731	0	0		99999999		
Whitney Reservoir (CORWHT) Storage Capacity of 199,076 acre-feet (both Bwam3 and Bwam8)							
FILLWHT	515731	0	0	WHIT1	99999999		Brazos River Authority
EVAP3	515731	0	0		99999999		Brazos River Authority
Aquilla Reservoir (AQUILLA) Storage Capacity of 52,400 (Bwam3) and 41,700 (Bwam8) acre-feet							
C5158_1	515831	12,246	2,110	MUN2	19761025		Brazos River Authority
C5158_2	515831	1,650	284.3	MUN2	19761025	106301	Brazos River Authority

C5158_3	515831	0	0	IND2	19761025		Brazos River Authority
C5158_4	515831	0	0	MIN2	19761025		Brazos River Authority
C5158_5	515831	0	0	UNIFO	19761025		Brazos River Authority

Waco Reservoir with Total Storage Capacity of 155,000 (Bwam3) and 132,821 (Bwam8) acre-feet

Waco Reservoir (LKWACO) Storage Capacity of 39,100 acre-feet (both Bwam3 and Bwam8)

C2315_1	509431	39,100	37,448	MUN2	19290110	110711	City of Waco
C2315_4	509431	0	0		99999999		City of Waco

Waco Reservoir (WACO2) Storage Capacity of 65,000 acre-feet (both Bwam3 and Bwam8)

C2315_2	509431	19,100	0	MUN2	19580416	110711	City of Waco
C2315_3	509431	900	900	IRR21	19790221		City of Waco

Waco Reservoir (WACO2) Storage Capacity of 39,100 acre-feet (both Bwam3 and Bwam8)

C2315_5	509431	0	0		99999999		

Waco Reservoir (WACO4) Storage Capacity of 88,062 acre-feet (both Bwam3 and Bwam8)

P5094_1	509431	20,089	0	MUN2	19860912	110711	City of Waco
P5094_2	509431	688	0	MUN2	19880121	110711	City of Waco
P5094_4	509431	0	0		99999999		

Waco Reservoir (WACO5) Storage Capacity of 14,400 acre-feet (both Bwam3 and Bwam8)

P5094_3	509431	0	0		88888888		City of Waco
P5094_3	509431	0	0		99999999		City of Waco

Proctor Reservoir (PRCTOR) Storage Capacity of 59,400 (Bwam3) and 54,702 (Bwam8) acre-feet

C5159_1	515931	2,685	1,343	MUN2	19631216		Brazos River Authority
C5159_2	515931	735	367.6	MUN2	19631216		Brazos River Authority
C5159_3	515931	1,147	573.7	MUN2	19631216		Brazos River Authority
C5159_4	515931	1,772	886.4	MUN2	19631216		Brazos River Authority
C5159_5	515931	1,671	835.8	MUN2	19631216		Brazos River Authority
C5159_6	515931	0	0.0	IND2	19631216		Brazos River Authority
C5159_7	515931	5,948	5137.9	IRR2	19631216		Brazos River Authority
C5159_8	515931	5,700	4,923.7	IRR2	19631216		Brazos River Authority
C5159_9	515931	0	0.0	MIN2	19631216		Brazos River Authority
C5159_10	515931	0	0.0	INIFO	19631216		Brazos River Authority

Belton Reservoir (BELTON) Storage Capacity of 10,000 acre-feet (both Bwam3 and Bwam8)

C2936_1	516031	10,000	7,483	MUN2	19530824		US Department of Army

Belton Reservoir (BELTON) Storage Capacity of 12,000 acre-feet (both Bwam3 and Bwam8)

C2936_2	516031	2,000	0	MUN2	19540823		US Department of Army

Belton Reservoir (BELTON) Storage Capacity of 457,600 (Bwam3) and 387,024 (Bwam8) acre-feet

C5160_1	516031	7,056	4,944.1	MUN2	19631216	102191	Brazos River Authority
C5160_2	516031	1,245	872.4	MUN2	19631216		Brazos River Authority
C5160_3	516031	3,432	2,404.8	MUN2	19631216	101761	Brazos River Authority
C5160_4	516031	2,016	1,412.6	MUN2	19631216	101741	Brazos River Authority
C5160_5	516031	27,735	19,433.9	MUN2	19631216	103513	Brazos River Authority
C5160_6	516031	7,745	5,426.9	MUN2	19631216	103512	Brazos River Authority
C5160_7	516031	540	378.4	MUN2	19631216		Brazos River Authority
C5160_8	516031	1,758	1,231.8	MUN2	19631216	100451	Brazos River Authority
C5160_9	516031	4,549	3,187.5	MUN2	19631216	100455	Brazos River Authority
C5160_10	516031	1,758	1,231.8	MUN2	19631216	100451	Brazos River Authority
C5160_11	516031	5,424	3,801.0	MUN2	19631216	101551	Brazos River Authority
C5160_12	516031	17,484	12,251.0	MUN2	19631216	113181	Brazos River Authority
C5160_13	516031	10,469	7,335.6	MUN2	19631216	104702	Brazos River Authority
C5160_14	516031	5,411	3,791.5	MUN2	19631216		Brazos River Authority
C5160_15	516031	200	140.1	MUN2	19631216		Brazos River Authority
C5160_16	516031	2,365	16,843.0	IND2	19631216		Brazos River Authority
C5160_17	516031	1,070	15,568.0	IRR2	19631216		Brazos River Authority

Stillhouse Hollow (STLHSE) Storage Capacity of 235,700 (Bwam3) and 224,279 (Bwam8) acre-feet

C5161_1	516131	6,973	6,973	MUN3	19631216	102051	Brazos River Authority
C5161_2	516131	2,092	2,092	MUN3	19631216		Brazos River Authority

C5161_3	516131	4,880	4,880	MUN3	19631216		Brazos River Authority
C5161_4	516131	53,823	53,823	MUN3	19631216		Brazos River Authority

Georgetown Reservoir (GRGTWN) Storage Capacity of 37,100 (Bwam3) and 36,980 (Bwam8) ac-ft

C5162_1	516231	4,764	4,130.9	MUN3	19680212	104893	Brazos River Authority
C5162_2	516231	2,041	1,769.8	MUN3	19680212	104892	Brazos River Authority
C5162_3	516231	3,198	2,773.0	MUN3	19680212	102641	Brazos River Authority
C5162_4	516231	3,607	3,127.6	MUN3	19680212	102642	Brazos River Authority
C5162_5	516231	0	0.3	IND3	19680212		Brazos River Authority
C5162_6	516231	0	141.8	MIN3	19680212		Brazos River Authority
C5162_7	516231	0	0.0	IRR3	19680212		Brazos River Authority

Granger Reservoir (GRNGER) Storage Capacity of 65,500 (Bwam3) and (Bwam8) acre-feet

C5163_1	516331	6,566	1,175.9	MUN3	19680212		Brazos River Authority
C5163_2	516331	6,721	1,203.1	MUN3	19680212	102991	Brazos River Authority
C5163_3	516331	5,659	0	IND3	19680212		Brazos River Authority
C5163_4	516331	0	0	IND3	19680212		Brazos River Authority
C5163_5	516331	20	0	MIN3	19680212		Brazos River Authority
C5163_6	516331	874	190	IRR3	19680212		Brazos River Authority

Limestone Reservoir (LMSTNE) Storage Capacity of 217,494 (Bwam3) and 208,017 (Bwam8) ac-ft

C5165_1	516531	28,415	54	MUN3	19740506		Brazos River Authority
C5165_2	516531	200	1	MUN3	19740506		Brazos River Authority
C5165_3	516531	21,602	23,271.8	IND3	19740506		Brazos River Authority
C5165_4	516531	11,255	12,125	IND3	19740506		Brazos River Authority
C5165_5	516531	3,600	3,878.3	IND3	19740506		Brazos River Authority
C5165_6	516531	0	0	IRR3	19740506		Brazos River Authority
C5165_7	516531	2	7.0	MIN3	19740506		Brazos River Authority
C5165_8	516531	0	0	UNIFO	19790904		Brazos River Authority

Somerville Reservoir (SMRVLE) Storage Capacity of 160,110 (Bwam3) and (Bwam8) ac-ft

C5164_1	516431	4,619	4,619	MUN3	19631216	103881	Brazos River Authority
C5164_2	516431	6,658	6,658	IND3	19631216		Brazos River Authority
C5164_3	516431	23,763	23,763	IND3	19631216		Brazos River Authority
C5164_4	516431	0	0	IRR3	19631216		Brazos River Authority
C5164_5	516431	12,928	12,928	IRR3	19631216		Brazos River Authority
C5164_6	516431	32	32	MIN3	19631216		Brazos River Authority
C5164_7	516431	0	0	UNIFO	19631216		Brazos River Authority

Proposed Allens Creek Reservoir (ALLENS) with Storage Capacity of 145,533 acre-feet (Bwam3)

ALLENS_1	292531	99,650	−	MUN4	19990901		Brazos River Authority

Alan Henry Reservoir (ALANHN) Storage Capacity of 115,937 (Bwam3) and 115,773 (Bwam8) ac-ft

P4146_1	4146P1	35,000	88	MUN1	19811005		City of Lubbock
P4146_2	4146P1	0	−	IRR1	19811005		City of Lubbock
P4146_3	4146P1	0	200.4	IND1	19811005		City of Lubbock

Hubbard Creek Reservoir (HUBBRD) Storage Capacity of 317,750 ac-ft (both Bwam3 and Bwam8)

C4213_1	421331	21,008	3,349	MUN1	19570528		West Central Texas MWD
C4213_2	421331	17,362	2,768	MUN1	19570528	103341	West Central Texas MWD
C4213_3	421331	1,882	300	MUN1	19570528		West Central Texas MWD
C4213_4	421331	2,061	329	MUN1	19570528		West Central Texas MWD
C4213_5	421331	2,487	396	MUN1	19570528	100401	West Central Texas MWD
C4213_6	421331	2,000	1,026.3	D&L1	19720814		West Central Texas MWD
C4213_7	421331	1,200	0	IND1	19570528		West Central Texas MWD
C4213_8	421331	6,000	1,013.2	MIN1	19570528		West Central Texas MWD
C4213_9	421331	2,000	742	IRR1	19720814		West Central Texas MWD

Squaw Creek Reservoir (SQWCRK) Capacity of 151,500 (Bwam3) and 151,015 (Bwam8) acre-feet

C4097_1	409732	23,180	17,536	IND2	19730425		Texas Utilities Electric Co

Information from the 133 *WR* records in the Bwam3 DAT file connected to the 16 largest reservoirs is tabulated in Table 2.11. Each of the 133 model water rights listed in Table 2.11 corresponds to a *WR* record in the Bwam3 DAT file. The water right identifier and corresponding control point identifier for the right are tabulated in the first two columns of Table 2.11. The annual diversion target in acre-feet/year for the water right is shown in the third column. The use type in the fourth column connects the annual diversion target to a set of 12 monthly water use distribution factors entered on water use coefficient *UC* records.

Bwam3 has zero return flows for all water rights. However, the Bwam3 and Bwam8 data files are designed to contain essentially the same records with entries in certain fields being different as appropriate for the authorized and current use scenarios. Thus, the files are designed so that return flows are conveniently activated in Bwam8 and set at zero in Bwam3. Return flows may be specified on the *WR* record as a constant fraction of monthly diversion volumes, or alternatively, a set of 12 monthly varying fractions may be specified. Both of these alternative options are incorporated in the water rights listed in Table 2.11. The identifier of the control point at which Bwam8 diversion return flows return to the river system is tabulated in the sixth column of Table 2.11. The default is for return flows to enter the river at the control point located immediately downstream of the diversion. The sixth column is blank for the majority of the water rights in Table 2.11 indicating adoption of the default next downstream control point option.

There are no water right permits for hydroelectric power generation at Lakes Whitney and Possum Kingdom. Most of the water that flows through the hydroelectric power turbines at these reservoirs consists of spills from full conservation pools or releases for downstream water supply diversions. Water right C5155_21 at Possum Kingdom Reservoir has an annual diversion target of 3,600 acre-feet/year and return flow factor of 100 percent. Water right C5155_21 represents the contribution of hydropower releases in meeting an instream flow requirement set by the Federal Energy Regulatory Commission.

The conservation pool of Lake Whitney serves largely to provide recreation and head for hydropower. Lake Whitney is an abnormality in the reservoir storage capacity inventory in that most of its conservation storage capacity, though included in both the Bwam3 and Bwam8 datasets, is not specified in any water right permit. The total conservation storage capacity of Lake Whitney is 636,100 and 561,074 acre-feet in the Bwam3 and Bwam8 datasets as shown in Table 2.5. The Lake Whitney storage capacity authorized by a water right permit is 50,000 acre-feet between elevation 520 feet above mean sea level (387,024 ac-ft storage level) and 523 feet (642,179 ac-ft).

The nine USACE reservoirs contain flood control pools with large storage capacities, which are tabulated in Table 1.1. There are no water right permits for the flood control pools.

Modifications to the WAM Datasets

The original TCEQ WAM System WRAP input datasets for alternative water use scenarios for the Brazos River Basin and adjoining San Jacinto-Brazos Coastal Basin, referred to in this report as the Brazos WAM, were developed by HDR Engineering, Inc., and Freese and Nichols, Inc., during 1998-2001 under contract with the TCEQ [17, 18]. The TCEQ updates the WAM input datasets over time to reflect new and modified water right permits and improvements in the WRAP software and expanded modeling capabilities.

The official TCEQ Brazos WAM authorized and current use scenario datasets with latest update dates of August 2007 and September 2008 are compared in Table 2.1. The September 2008 updates of the Bwam3 and Bwam8 datasets have 9 more *WR* records and 8 more reservoirs than the August 2007 versions, with essentially no change in diversion targets and minimal changes in storage capacity. The studies documented by the companion TWRI Technical Reports 340 and 352 [1, 2] used the August 2007 version of the Brazos WAM datasets. The condensed datasets described in the following Chapter 3 and applied in Chapters 4 and 5 were developed from the August 2007 WAM datasets. Studies documented in Chapters 6, 7, 8, and 9 of this report use the September 2008 update of the Brazos WAM datasets.

Model users modify the WRAP input datasets from the TCEQ WAM System for their particular applications to reflect proposed water management strategies and analysis premises of interest. The Brazos WAM has been modified and applied by HDR Engineering for the Region G Planning Group in regional planning studies. The Texas Water Development Board is developing WAM datasets for the river basins of the state modeling future water use scenarios for application in planning studies. The BRA and its consultants, including Freese and Nichols, Inc., has developed a modified dataset for a system operations permit application. The datasets continue to be adjusted for various applications including the studies presented in this report.

The hydrologic period-of-analysis is 1940-1997 for the official TCEQ WAM. However, as discussed earlier in this and the preceding chapters, TCEQ-sponsored studies documented by TWRI TR-340 [1] included developing methodologies for extending hydrologic periods-of-analysis and applied the methodologies to extend the Brazos WAM simulation period to include 1998-2007 and 1900-1939. Thus, FLO and EVA files covering 1900-2007 are available and 1900-2007 or any sub-period thereof can be readily adopted for particular applications.

FLO and EVA files storing monthly stream flow volumes and net evaporation-precipitation depths are standard text files but can also be easily converted to DSS files with the data stored in the binary format of the USACE Hydrologic Engineering Center (HEC) Data Storage System (DSS). Simulation results can also be optionally written as DSS files to be read with HEC-DSSVue [19].

CHAPTER 3
BRAZOS RIVER AUTHORITY CONDENSED DATASETS

The Brazos River Authority Condensed (BRAC) authorized use scenario (BRAC3) and current use scenario (BRAC8) input datasets were developed by condensing the August 2007 version of the Brazos WAM Bwam3 and Bwam8 datasets described in the preceding Chapter 2. Development of the BRAC3 and BRAC8 datasets is documented in detail by TWRI Technical Report 340 [1]. The 14 largest existing reservoirs in the basin are included in the BRAC3 and BRAC8 DAT files, and the proposed Allen's Creek Reservoir is also included in the BRAC3 DAT file. The effects of the numerous other reservoirs and water rights in the river basin that are omitted from the BRAC3 and BRAC8 DAT files are incorporated in the stream flow inflows at the 48 selected control points included in the BRAC3 and BRAC8 FLO files while properly maintaining the priority system reflected in the water right permits. The size of the BRAC and Bwam datasets are compared below in Table 3.1.

Table 3.1
Size of Brazos WAM and Condensed Datasets

Complete WAM versus Condensed	Brazos WAM		Condensed	
Water Use Scenario	Authorized	Current	Authorized	Current
Filename	Bwam3	Bwam8	BRAC3	BRAC8
number of primary control points	77	77	48	48
number of secondary control points	3,753	3,757	0	0
number of WR record water rights	1,634	1,725	114	112
number of instream flow rights	122	144	0	0
number of reservoirs	670	711	15	14

The BRAC datasets were developed and applied along with the full WAM model in the investigation documented by TR-340 [1]. Both the Brazos WAM and condensed BRAC datasets were applied and results compared in the salinity studies reported by TR-352 [2]. The condensed BRAC models are also applied in the following Chapters 3 and 4 of this report. The complete Brazos WAM datasets are applied in the studies presented in Chapters 6, 7, and 8 of this report.

Conceptual Basis of Condensed Datasets

The primary reason for developing condensed datasets is to provide a much simpler model that can be conveniently and effectively applied in studies dealing with a particular river/reservoir water management system. Condensed datasets also provide a mechanism for allocating water between a primary system of concern and all of the other water rights in the river basin that can be useful in certain types of modeling applications. Alternative operating plans for the primary system are investigated based on a fixed allocation of water to the secondary system water rights.

The larger TCEQ WAM System datasets such as the Brazos WAM contain hundreds of water rights, control points, and reservoirs. These large complex datasets are essential for the water right permitting and regional and statewide planning applications for which the WAM System was developed. However, simplification of datasets is beneficial for other applications that focus on a particular water management system while still considering interactions between that system and other water management entities in the river basin.

The objective of a condensed dataset is to facilitate studying or providing decision support for a particular reservoir/river water management system. WRAP input datasets and corresponding simulation results with dramatically fewer control points, water rights, and reservoirs are much more manageable to use in modeling studies. However, the interactions between the numerous water users and water control facilities in a river basin should be preserved in the model. The condensed model allows alternative operating plans for the primary water management system to be simulated based on the premise of assuring appropriate protection of all other water rights. In developing a condensed dataset, selected water rights, control points, and reservoirs are removed with their effects retained in the adopted stream inflow input data for the condensed dataset.

DAT, FLO, and EVA Files

A condensed *WRAP-SIM* input dataset (DAT, FLO, and EVA files) is created by reducing the number of control points, water rights, and reservoirs in a TCEQ WAM System dataset and thus simplifying the modeling system for certain applications. The effects of water rights, control points, and reservoirs are removed with their effects incorporated in the stream inflow input data (FLO file) for the condensed dataset. A *SIM* water rights DAT file for the particular river/reservoir water management and use system of interest, called the primary system, is developed along with a FLO file containing river system inflows that have been adjusted to reflect all other water rights in the original complete WAM dataset, which are referred to as secondary water rights. The condensed dataset also includes an EVA file containing the same net reservoir evaporation-precipitation rates as used with the complete WAM dataset with the same adjustments.

The accuracy achieved in the development of a condensed dataset is checked by comparing *SIM* simulation results with the condensed versus original complete dataset. The water supply reliabilities computed for the diversions included in the condensed model should be the same as in the simulation with the original complete dataset. Likewise, the sequences of monthly storage volumes at the common reservoirs and unappropriated stream flows at the common control points will be the same. Near perfect correspondence between simulation results with the condensed versus complete datasets should be expected.

The methodology is based on developing flows at selected control points that represent stream inflow amounts available to the selected system, called the primary system, that reflect the impacts of all of the water rights and accompanying reservoirs, called the secondary system, that are removed from the original complete dataset. These river flows represent flows available to the primary system modeled in the water right DAT input file considering the effects of all the other water rights in the river basin contained in the original complete DAT file that are not included in the condensed DAT file. The river system inflows in the FLO file for a condensed dataset include stream flow depletions made for the selected water rights less return flows plus unappropriated flows. Hydropower releases and reservoir releases made specifically to meet instream flow requirements are also properly incorporated in the flows. Summation and cascading operations, including channel losses, are applied in developing the FLO input file.

The methodology presented in TR-340 [1] for developing the sequences of monthly stream flow volumes and net evaporation-precipitation depths (FLO and EVA files) for a condensed dataset is outlined as follows.

1. The WRAP simulation program *SIM* is executed with the original complete dataset.
2. Program *HYD* is used to retrieve the adjusted net evaporation-precipitation depths from the *SIM* output file and store them in an EVA file for the condensed dataset.
3. *HYD* is applied to read stream flow depletions, return flows, unappropriated flows, and any other pertinent variables from the *SIM* output file and combine these variables as required to develop the stream flow FLO file for the condensed dataset. Combining the time sequences of flow volumes includes summations and cascading operations that may include channel losses.

The accuracy of the procedure is confirmed by reproducing the sequences of monthly water supply diversions, reservoir storage contents, unappropriated flows, and other pertinent variables contained in the *SIM* simulation results associated with the primary system reservoirs, diversions, and control points. These *SIM* simulation results should be same with the condensed dataset versus the original complete dataset. The primary system reservoirs and diversions must be operated the same in both the condensed and complete datasets for the comparison simulations. After completing the comparison to confirm that the dataset is correct, the condensed dataset can be used to simulate alternative river/reservoir system operating rules and water management and use scenarios for the primary system.

Regulated-Unappropriated Flow (RUF) File

With the exception of naturalized and regulated flows, all the variables in the *SIM* input and simulation results are defined the same in condensed and complete models. However, the regulated flows computed by *SIM* are defined differently. The optional RUF file described below is needed only for those applications in which knowing the actual regulated flows is important.

The unappropriated stream flows computed by *SIM* are the same with either a condensed or complete WAM input dataset. However, the naturalized and regulated flows are defined differently. The stream flows in the FLO file of the original WAM dataset are naturalized flows. The stream flows in the FLO file of the condensed dataset are flows reflecting the effects of all of the water rights in the river basin that are not included in the DAT file of the condensed dataset. With a complete dataset, the regulated flows computed by *SIM* represent the actual flows at a site on a river. With a condensed input dataset, the regulated flows computed by *SIM* represent the flows unaffected by the water rights omitted from the DAT file.

The basic condensed dataset methodology focuses on unappropriated river flows rather than regulated flows. However, a regulated-unappropriated flow (RUF) file with filename extension RUF may be created using program *HYD* that contains deviations between regulated and unappropriated flows from the simulation results for the original dataset that are used within a *SIM* simulation with a condensed dataset to estimate regulated flows based on adjusting unappropriated flows. The RUF file and accompanying flow adjustment options are not needed in various applications in which regulated flows are not of concern. However, the estimates of regulated flows provided by the RUF options may be required in applications that involve environmental instream flow requirements, flood control operations, or salinity simulation, or may be useful simply to provide general information regarding river flows.

The regulated-unappropriated flow RUF file contains the differences between the regulated flows less unappropriated flows from the simulation results of the original complete dataset. These data are used to perform flow adjustments that allow conventionally-defined regulated flows to be included in the *SIM* simulation results for the condensed dataset.

Incorporation of regulated flows, as normally defined in *WRAP-SIM* simulations, into a condensed model using the RUF file feature is complicated by the differences between regulated and unappropriated flows being caused by both secondary (FLO file) and primary system (DAT file) water rights. The RUF file feature is necessarily approximate in certain situations due to the combined effects of secondary and primary water rights on river flows. *SIM* includes a set of options for creating and applying the RUF file adjustments in different situations. These computations have no affect on any simulation result variables other than regulated flows.

Brazos River Authority System Condensed Model

The Brazos River Authority sponsored development of the Brazos River Authority Condensed (BRAC) datasets designed to provide a much simpler model that facilitates operational planning studies and other decision support endeavors for the BRA reservoir system [1]. Alternative versions of the BRAC model were developed for the authorized use and current use scenarios with hydrologic periods-of-analysis of 1900-2007 and 1940-2007 by condensing the August 2007 version of the TCEQ WAM System authorized use and current use datasets for the Brazos River Basin and San Jacinto-Brazos Coastal Basin, referred to here as the Brazos WAM.

The condensed datasets designed to focus on operation of the BRA reservoir system include the 15 largest reservoirs in the river basin and associated water rights. The 15 reservoirs include one proposed (Allen's Creek Reservoir) and 12 existing BRA reservoirs and two other reservoirs (Hubbard Creek and Squaw Creek Reservoirs). The proposed Allen's Creek Reservoir is included in the authorized use scenario but is not included in the current use scenario. The 12 BRA reservoirs include Lakes Possum Kingdom, Granbury, and Limestone owned by the BRA and nine federal multiple-purpose reservoirs owned by the U.S. Army Corps of Engineers for which the BRA has contracted for the water supply storage capacity. These 15 reservoirs include all of the reservoirs in Table 1.1 and Figure 1.3 of Chapter 1 except Lake Alan Henry.

The condensed dataset has 48 primary control points and no secondary control points. With no secondary control points, there is no flow distribution DIS file. The impacts of the 655 reservoirs and numerous water rights removed from the Brazos WAM dataset are reflected in the FLO file river flows developed for the condensed SIM input dataset.

The condensed datasets were developed using the WRAP programs *SIM* and *HYD* as outlined in TR-340 [1]. The resulting BRAC datasets consist of *SIM* input files with filename extensions DAT, FLO, EVA, and RUF which are called DAT, FLO, EVA, and RUF files. Four versions of the datasets were developed representing authorized use and current use scenarios of water resources development and management and 1900-2007 and 1940-2007 hydrologic periods-of-analysis. The *SIM* input files comprising the condensed datasets are described as follows.

- The authorized use and current use DAT files contain water rights and related information for 15 and 14 reservoirs, respectively, and associated water supply diversions. This information was excerpted from the Brazos WAM DAT files. All but 48 of the original over 3,800 control point *CP* records are omitted. Thus, the next downstream control point identifiers and channel loss factors are modified for the adopted 48 control points.

- FLO files with alternative 1940-2007 and 1900-2007 sets of monthly flows at 48 control points represent conditions of river system development that include all of the water rights and associated reservoirs in the original complete Brazos WAM DAT files except the 15 reservoirs and associated diversions contained in the condensed DAT files.

- EVA files contain alternative 1940-2007 and 1900-2007 sets of monthly net evaporation-precipitation depths for the 15 reservoirs. Adjusted net evaporation-precipitation depths are obtained from the *SIM* output OUT file.

- RUF files contain alternative 1940-2007 and 1900-2007 sets of differences between the regulated flows less unappropriated flows from the *SIM* output file for complete Brazos WAM simulation. The optional RUF files allow conventionally-defined regulated flows to be included in the BRAC simulation results.

The DAT files for the condensed datasets were developed by excerpting pertinent water rights and associated data records from the original DAT file, excerpting pertinent records providing reservoir data, and modifying remaining control point *CP* records to reflect removal of many of the control points. With removal of control points, channel loss factors for the stream reaches removed were aggregated for the combined longer reaches between the remaining control points. Various other organizational refinements were made that have no effect on simulation results.

A number of the water rights included in the BRAC datasets have diversion return flows that are returned back to the river in the Brazos WAM dataset at control points that have been removed in the BRAC datasets. The return flows are returned in the BRAC dataset at the next downstream control point that was not removed. Channel losses associated with the return flows may be affected. The decrease in channel loss could be offset by increasing the return flow factor. However, this ploy was not applied for the Brazos since the impacts on channel losses of reassigning return flow locations were negligible.

The condensed dataset adopts the same net evaporation-precipitation depths for the 15 reservoirs as used in the original complete dataset *SIM* simulation. *SIM* includes a routine for adjusting net evaporation-precipitation depths for the precipitation runoff from the portion of the watershed inundated by the reservoir. Therefore, net evaporation-precipitation depths were obtained from the output file for the complete simulation rather than using the original evaporation-precipitation depth input dataset.

River flows developed with *HYD* for the 48 BRAC control points consist of 1940-2007 or 1900-2007 sequences of monthly volumes of the following variables obtained by *HYD* from the simulation results output file created by *SIM* with the original complete input dataset.

- Stream flow depletions made by each of the water rights associated with the 15 reservoirs are included in the flows developed. These flow volumes are placed at the control point of the stream flow depletion and at all downstream control points. Channel losses are considered in cascading the stream flow depletions downstream.

- Return flows from the diversion component of the stream flow depletions are subtracted from the flows. These flow volumes are placed at the control point at which the return flow is returned to the stream and at all downstream control points. Channel losses are considered in cascading the return flows downstream.

- Unappropriated flows at each of the control points are added to the flows. Since unappropriated flows are cumulative total flows, these flows are not cascaded downstream.

- Any releases from the 15 selected reservoirs made specifically for instream flow requirements are subtracted at the control point of the reservoir and cascaded downstream in the normal manner which includes consideration of channel losses.

The BRAC inflows are the portion of the naturalized flows still available to the primary system water rights after the secondary water rights have appropriated their appropriate quantities of the stream flow. Naturalized flows are the same in the authorized use and current use scenario versions of the complete WAM dataset but differ in the condensed datasets. The 1940-1997 means are compared in Table 3.2 for three control points at gaging stations locations shown in Figure 3.1. The 1940-1997 means of the Brazos WAM naturalized flows at the three control points are tabulated in acre-feet/year. The corresponding 1940-1997 means of the inflows in the FLO files of the condensed inflows are shown in Table 3.2 as a percentage of the Brazos WAM naturalized flows. At the Richmond gage control point, the mean FLO file inflows for the authorized use and current use scenarios are 77.8 and 78.2 percent of naturalized flows.

Table 3.2
Comparison of Means of Flows in FLO Input Files

Control Point at USGS Gaging Station	Brazos WAM	Condensed Datasets	
		Authorized	Current Use
	(ac-ft/yr)		
Cameron gage on Little River (LRCA58)	1,318,302	81.5%	83.9%
Waco gage on Brazos River (BRWA41)	1,942,324	85.6%	87.5%
Richmond gage on Brazos River (BRRI70)	5,850,224	77.8%	78.2%

Mean annual inflows for the 48 control points are tabulated in Table 3.3 for the BRAC3 and BRAC8 FLO files covering 1940-1997, 1940-2007, and 1900-2007 simulation periods along with the 1940-1997 means for the original Brazos WAM (Bwam) naturalized flows. The Bwam inflows are naturalized flows. The BRAC inflows are the portion of the naturalized flows still available to the primary system water rights after the secondary water rights have appropriated their appropriate quantities of the stream flow. Naturalized flows are the same in the Bwam3 and Bwam8 datasets. Inflows are different in the BRAC3 versus BRAC8 datasets. Further more detailed comparisons of the input and output of the Brazos WAM and condensed BRAC models are presented in TR-340.

Table 3.3
Mean Annual Inflow Comparison

Control Point	Naturalized 1940-1997 (ac-ft/yr)	Mean BRAC3 Inflow (acre-feet/year) 1940-1997	1940-2007	1900-2007	Mean BRAC8 Inflow (acre-feet/year) 1940-1997	1940-2007	1900-2007
DMAS09	108,367	44,460	41,448	49,049	74,326	68,686	79,680
BRSE11	250,096	132,042	122,291	141,209	178,075	166,901	191,777
BRSB23	656,260	325,207	300,013	316,583	436,956	411,960	445,290
BRPP27	810,380	645,899	618,490	634,695	624,593	598,655	630,120
BRDE29	1,003,749	792,955	752,373	754,209	798,957	762,134	784,013
BRGR30	1,118,978	932,062	892,731	886,416	925,180	890,778	905,673
BRAQ33	1,379,053	1,218,568	1,190,268	1,166,997	1,243,201	1,221,944	1,220,284
BRWA41	1,942,324	1,663,149	1,686,947	1,611,069	1,699,166	1,718,093	1,636,573
BRHB42	2,331,139	1,918,534	1,954,664	1,870,094	1,986,461	2,016,233	1,925,858
LEHM46	166,469	113,636	121,634	116,585	122,293	129,868	123,882
LEGT47	257,793	184,085	195,392	181,646	189,827	200,320	186,520
LEBE49	505,257	446,925	482,795	444,228	470,944	507,651	469,555
LABE52	233,258	218,704	247,270	226,516	225,028	253,680	233,184
LRLR53	846,554	710,551	781,485	781,592	725,859	797,499	803,633
GALA57	189,268	175,267	191,160	180,741	177,635	193,089	182,689
LRCA58	1,318,302	1,074,595	1,180,248	1,113,263	1,105,941	1,212,400	1,149,826
BRBR59	4,027,961	3,145,590	3,314,460	3,167,977	3,287,679	3,453,651	3,300,320
NAEA66	322,578	287,078	303,274	299,981	297,182	312,739	307,926
NABR67	421,304	361,504	371,745	367,370	381,092	390,210	383,597
BRHE68	5,358,943	3,757,219	4,009,383	3,846,009	4,172,630	4,434,926	4,251,048
BRRI70	5,850,224	4,551,922	4,804,536	4,642,490	4,576,835	4,833,041	4,668,702
BRRO72	6,112,278	5,339,820	5,612,354	5,438,737	5,521,223	5,802,469	5,630,372
515531	793,475	637,768	611,703	629,482	614,423	589,726	622,464
515631	1,093,872	915,523	875,206	871,428	906,356	871,360	887,845
515731	1,366,866	1,209,580	1,181,021	1,159,217	1,233,376	1,211,836	1,212,006
515831	73,769	69,596	79,049	74,773	70,125	80,386	76,996
509431	357,464	353,635	387,189	353,050	352,265	386,751	357,087
515931	144,846	107,035	108,691	103,453	113,572	114,667	108,241
516031	502,986	447,362	483,252	444,651	471,037	507,624	469,570
516131	230,861	217,295	243,987	224,285	223,474	250,244	230,835
516231	57,558	54,078	57,940	58,489	55,307	59,222	60,091
516331	186,622	173,350	188,890	178,838	175,398	190,528	180,403
516531	232,793	214,648	226,470	224,267	221,471	232,922	229,746
516431	222,869	214,876	233,114	235,218	220,247	238,278	240,595
516031	502,986	447,362	483,252	444,651	471,037	507,624	469,570
421331	97,210	74,124	70,032	66,820	86,166	81,529	79,944
409732	14,098	13,221	15,210	18,821	13,533	15,694	19,485
CON036	662,147	328,374	302,938	319,657	441,183	415,942	449,570
CON063	1,199,051	991,691	954,815	946,991	988,825	957,236	973,188
CON070	1,561,064	1,368,216	1,356,724	1,316,082	1,404,556	1,393,169	1,360,303
433901	1,931,926	1,665,658	1,689,118	1,612,877	1,701,747	1,720,326	1,638,278
CON096	845,754	711,975	783,051	783,143	727,315	799,098	805,230
CON108	1,317,498	1,075,127	1,180,788	1,113,803	1,106,360	1,212,825	1,150,250
CON111	3,912,185	3,141,016	3,305,400	3,155,638	3,300,309	3,461,937	3,303,293
CON130	4,431,340	3,490,079	3,701,680	3,545,080	3,826,467	4,031,679	3,862,690
CON147	5,208,345	3,781,114	4,031,695	3,869,617	4,201,584	4,461,015	4,277,781
CON234	5,840,577	4,579,370	4,833,506	4,670,484	4,604,430	4,862,180	4,696,849
BRGM73	6,105,239	5,265,884	5,533,323	5,360,813	5,467,242	5,744,583	5,573,062

Brazos River Authority Condensed (BRAC) Datasets

The Brazos River Authority Condensed (BRAC) dataset (DAT, FLO, EVA, and RUF files) created by reducing the size of the Brazos WAM dataset has 48 control points. The BRAC3 authorized use and BRAC8 current use versions of the condensed dataset have 15 and 14 reservoirs, respectively. The permitted but not yet constructed Allen's Creek Reservoir is included in the Bwam3 and BRAC3 datasets but is not included in the Bwam8 and BRAC8 datasets. Net evaporation-precipitation depths are provided in the EVA file for the reservoir control points. River flows are included in the BRAC3 and BRAC8 versions of the FLO file for all of the 48 control points. Thus, there is no flow distribution DIS file. Only water rights associated with the 15 or 14 reservoirs are included in the two versions of the BRAC DAT file. RUF files facilitate modeling regulated flows. The impacts of the over 650 reservoirs and numerous water rights removed from the Brazos WAM are reflected in the *IN* record river flows developed for the condensed dataset.

The control points, reservoirs, and water rights included in the condensed DAT file are called the *primary* system. The control points, reservoirs, and water rights that are not included in the primary system comprise the secondary system. The effects of the secondary water rights on stream flows available to the primary water rights are reflected in the FLO file inflow *IN* record stream flows. The condensed model allows alternative operating plans to be modeled based on the premise of allowing no impacts on the numerous secondary rights.

With completion of the work reported in TR-340 [1], the BRAC datasets are available to simulate alternative river/reservoir system operating rules and water management and use scenarios for the system of 15 reservoirs and associated diversions at the 48 control points. The primary system is modeled by the DAT file with secondary water rights reflected in the FLO file. The primary system may be modified in any manner without altering the FLO file. However, changes to the secondary water rights would require repeating the TR-340 procedure for developing the BRAC FLO file. The optional RUF file is also modified any time the FLO file is changed.

Reservoirs in the BRAC Datasets

Figure 3.1 is a map showing the locations of the 15 BRAC reservoirs and 11 of the 22 USGS stream gaging stations included in the BRAC control points. Information describing the reservoirs is provided in Tables 1.1 and 3.5. The primary objective of the BRAC datasets is to model operations of the BRA system composed of the nine federal reservoirs for which BRA partners with the USACE and the three BRA owned reservoirs. Nine of the 15 BRAC reservoirs are USACE multiple-purpose projects for which the BRA has contracted for most of the conservation storage capacity. Lakes Possum Kingdom, Granbury, and Limestone are owned and operated by the BRA for water supply and other purposes. The BRA, City of Houston, and TWDB jointly hold a water right permit for the proposed Allen's Creek Reservoir, which has not yet been constructed. Allen's Creek Reservoir is included in the authorized use Bwam3 and BRAC3 but is not included in the current use Bwam8 and BRAC8 datasets.

Squaw Creek Reservoir at the Comanche Peak Nuclear Power Plant is owned by Texas Utilities Services which purchases water from the BRA to maintain constant levels in the large cooling reservoir. Hubbard Creek Reservoir is owned and operated by the West Central Texas Municipal Water District. The BRA is not directly involved in its operation. However, the conservation storage capacity of Hubbard Creek Reservoir is the fourth largest in the Brazos River Basin and thus a major feature of the river basin.

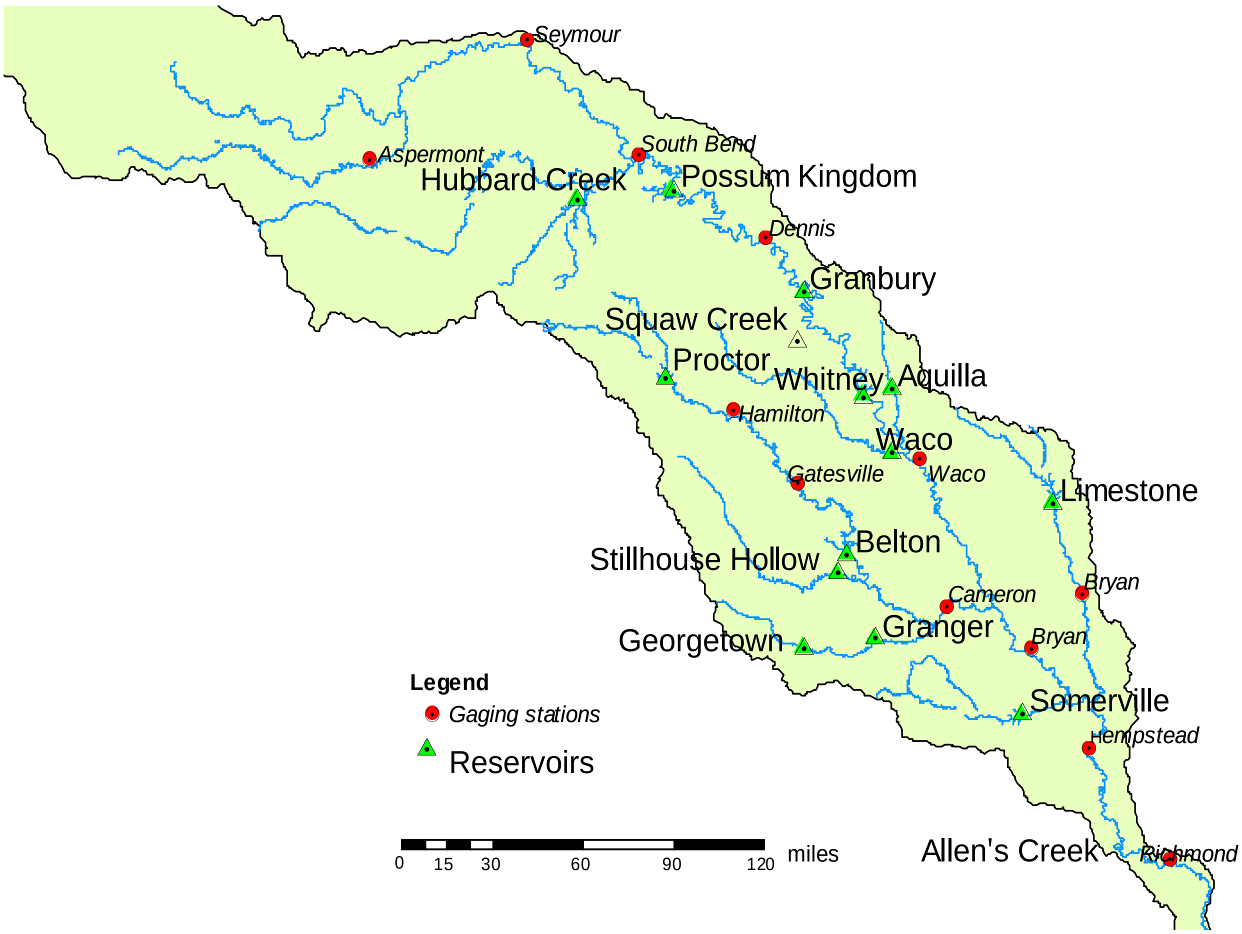

Figure 3.1 Brazos River Authority Condensed (BRAC) Model Reservoirs

Control Points in the BRAC Datasets

The 48 control points included in the BRAC dataset are listed in Tables 3.4, 3.5, 3.6, and 3.7. Channel loss factors are tabulated in Table 3.4. The 15 control points in Table 3.5 are locations of reservoir projects. The 11 control points in Table 3.6 represent stream confluences and the basin outlet. The 22 control points in Table 3.7 are locations of stream gaging stations. The control points are referenced by the six-character identifiers originally assigned in the Brazos WAM data files and continued in the BRAC datasets. The six-character WAM reservoir identifiers are shown in parenthesis under the control point identifiers in the Figure 3.2 schematic.

The WRAP term *primary control point* refers to locations at which stream flows are provided as input on *IN* records stored in a FLO file. The Brazos WAM dataset has 77 primary control points which are listed in Table 2.3 of Chapter 2. The locations of the 77 Brazos WAM primary control points are shown on the schematic of Figure 2.2. The 48 BRAC control points includes 42 of the 77 Bwam primary control points and 16 of the Bwam secondary control points.

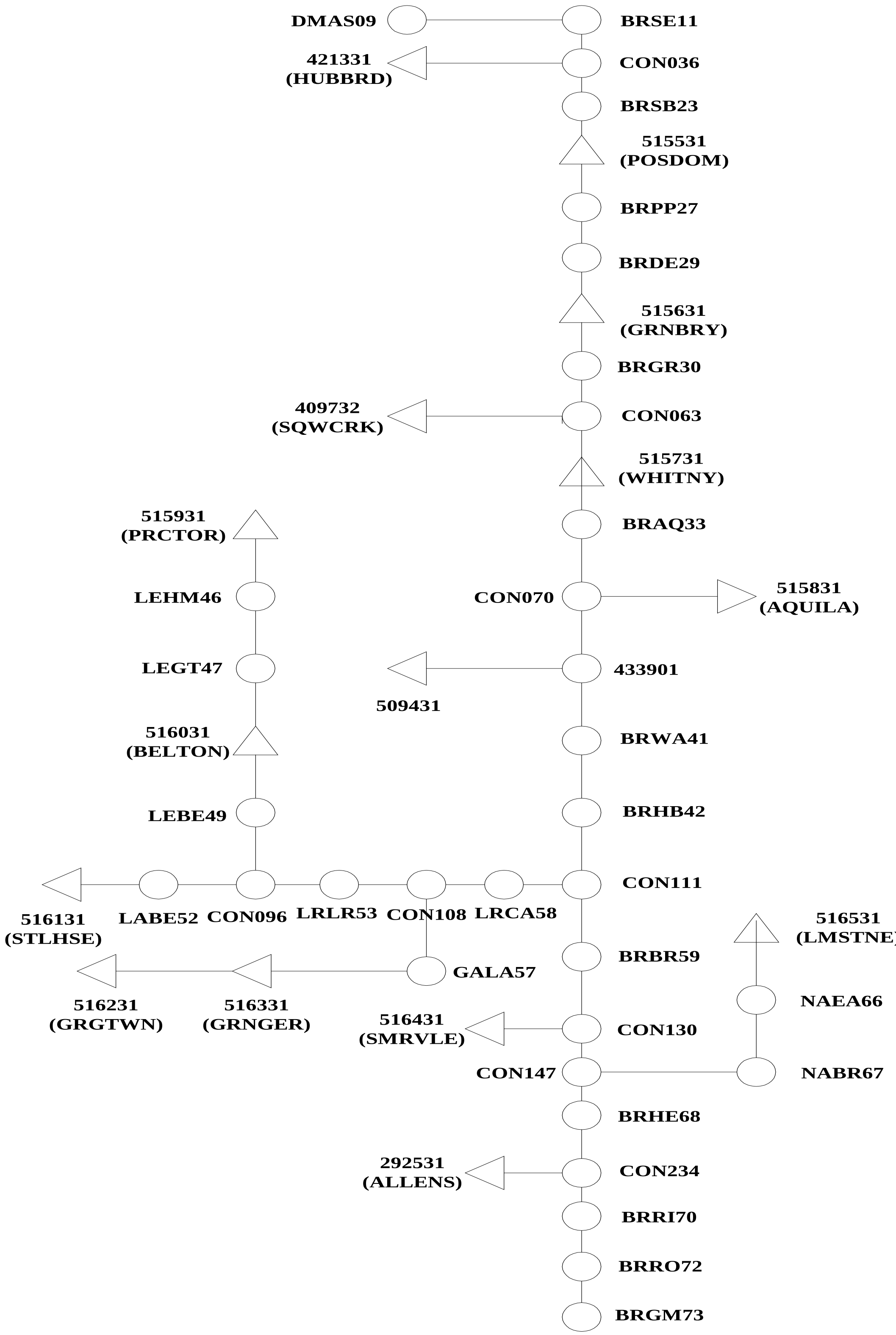

Figure 3.2 BRAC Control Point Schematic (Not to Scale)

The 22 BRAC gaging station control points listed in Table 3.7 are included in the 77 primary control points in the Brazos WAM. All 48 control points are primary control points in the BRAC dataset. River flows for all 48 control points computed as outlined in TR-340 [1] are stored as *IN* records in the FLO files of the BRAC3 and BRAC8 datasets. The corresponding regulated less unappropriated flow adjustments are recorded in *UR* records in RUF files. The BRAC3 and BRAC8 DAT files include *CP* records for each of the 48 control points. The EVA file contains evaporation-precipitation depths for the 15 reservoir control points.

Table 3.4
Channel Loss Factors for Reaches Between the 48 Control Points

	Control Points		Loss		Control Points		Loss
	Upstream	Downstream	Factor		Upstream	Downstream	Factor
1	DMAS09	BRSE11	0.4918	25	LEBE49	CON096	0.0040
2	BRSE11	CON036	0.4146	26	516131	LABE52	0.0010
3	421331	CON036	0.2275	27	LABE52	CON096	0.0020
4	CON036	BRSB23	0.0100	28	CON096	LRLR53	0.0020
5	BRSB23	515531	0.0179	29	LRLR53	CON108	0.0208
6	515531	BRPP27	0.0050	30	516231	516331	0.0080
7	BRPP27	BRDE29	0.0198	31	516331	GALA57	0.0060
8	BRDE29	515631	0.0119	32	GALA57	CON108	0.0139
9	515631	BRGR30	0.0060	33	CON108	LRCA58	0.0020
10	BRGR30	CON063	0.0010	34	LRCA58	CON111	0.0267
11	409732	CON063	0.0000	35	CON111	BRBR59	0.0100
12	CON063	515731	0.0198	36	BRBR59	CON130	0.0119
13	515731	BRAQ33	0.0000	37	516431	CON130	0.0110
14	BRAQ33	CON070	0.0050	38	CON130	CON147	0.0040
15	515831	CON070	0.0050	39	516531	NAEA66	0.0050
16	CON070	433901	0.0020	40	NAEA66	NABR67	0.0100
17	509431	433901	0.0199	41	NABR67	CON147	0.0296
18	433901	BRWA41	0.0020	42	CON147	BRHE68	0.0090
19	BRWA41	BRHB42	0.0100	43	BRHE68	CON234	0.0177
20	BRHB42	CON111	0.0040	44	292531	CON234	0.0040
21	515931	LEHM46	0.3795	45	CON234	BRRI70	0.0060
22	LEHM46	LEGT47	0.0119	46	BRRI70	BRRO72	0.0100
23	LEGT47	516031	0.0252	47	BRRO72	BRGM73	0.0169
24	516031	LEBE49	0.0010	48	BRGM73	OUT	0.0000

Water Rights in the BRAC Datasets

The BRAC3 and BRAC8 DAT files include only those water rights from the Brazos WAM dataset that are associated with the 15 and 14 reservoirs, respectively. Water rights associated with Allen′s Creek Reservoir are included in the authorized use scenario BRAC3 but are not included in the current use BRAC8 version. *WR* record water rights in the BRAC3 and BRAC8 DAT files refill storage in the 15 or 14 reservoirs and supply water supply diversion requirements with withdrawals and releases from the reservoirs. The BRAC water rights are listed in Table 3.8 with their storage capacities and annual diversion targets for the BRAC3 and BRAC8 versions of the condensed datasets. The main portion of the water right identifiers is tabulated in Table 3.8 A complete listing of water rights with their full identifiers is provided in Table 2.11 of Chapter 2.

Whitney and Waco Reservoirs are modeled in the Brazos WAM and BRAC datasets as sets of component reservoirs with the evaporation allocation *EA* record option activated. The storage capacity and diversion target of the water rights associated with each component reservoir are shown in parenthesis in Table 3.8.

BRAC dataset totals are compared with Brazos WAM dataset totals at the bottom of Table 3.8. The 15 reservoirs in the authorized use scenario BRAC3 dataset account for 77.3 percent of the total reservoir storage capacity in the 665 reservoirs in the Bwam3 dataset. The 14 reservoirs in the current use scenario BRAC8 dataset account for 77.7 percent of the total reservoir storage capacity in the 706 reservoirs in the Bwam8 dataset. The diversion targets for the water rights in the BRAC3 and BRAC8 datasets are 38.3 and 31.6 percent of the of the total diversion targets in the Bwam3 and Bwam8 datasets.

Table 3.5
BRAC Control Points for Reservoirs

Control Point	Reservoir	Reservoir Identifier	Storage (acre-feet) BRAC3	Storage (acre-feet) BRAC8	Diversion (ac-ft/year) BRAC3	Diversion (ac-ft/year) BRAC8
	Brazos River Authority and Corps of Engineers					
515531	Possum Kingdom	POSDOM	724,739	552,013	230,750	59,482
515631	Granbury	GRNBRY	155,000	132,821	64,712	36,025
515731	Whitney	WHIT	636,100	561,074	18,336	18,336
515831	Aquilla	AQUILA	52,400	41,700	13,896	2,394
509431	Waco	WACO	206,562	206,562	79,877	38,348
515931	Proctor	PRCTOR	59,400	54,702	19,658	14,068
516031	Belton	BELTON	457,600	432,978	112,257	107,738
516131	Stillhouse Hollow	STLHSE	235,700	224,279	67,768	67,768
516231	Georgetown	GRGTWN	37,100	36,980	13,610	11,943
516331	Granger	GRNGER	65,500	50,540	19,840	2,569
516531	Limestone	LMSTNE	225,400	208,017	65,074	39,337
516431	Somerville	SMRVLE	160,110	154,254	48,000	48,000
	Proposed by BRA and City of Houston but Not Yet Constructed					
292531	Allen's Creek	ALLENS	145,533	–	99,650	–
	West Central Texas Municipal Water District					
421331	Hubbard Creek	HUBBRD	317,750	317,750	56,000	9,924
	Comanche Peak Nuclear Power Plant					
409732	Squaw Creek	SQWCRK	151,500	151,015	23,180	17,536

Table 3.6
BRAC Control Points for Stream Confluences and the Basin Outlet

Control Point	Location
CON036	Confluence of Hubbard Creek and Brazos River
CON063	Confluence of Squaw Creek and Brazos River
CON070	Confluence of Aquilla Creek and Brazos River
433901	Confluence of Bosque and Brazos River
CON096	Confluence of Lampasas and Little River
CON108	Confluence of Little River and San Gabriel
CON111	Confluence of Little River and Brazos River
CON130	Confluence of Yegua Creek and Brazos River
CON147	Confluence of Navasota River and Brazos River
CON234	Confluence of Allen′s Creek and Brazos River
BRGM73	Brazos River Outlet at the Gulf of Mexico

Table 3.7
BRAC Control Points for USGS Gaging Stations

WAM CP ID	River	Nearest City	USGS Gage No.	Period-of Record	Watershed Area (square miles)
DMAS09	Double Mountain Fork	Aspermont	08080500	1923–present	265
BRSE11	Brazos River	Seymour	08082500	1923–present	5,996
BRSB23	Brazos River	South Bend	08088000	1938–present	13,171
BRPP27	Brazos River	Palo Pinto	08089000	1924–present	14,309
BRDE29	Brazos River	Dennis	08090800	1968–present	15,733
BRGR30	Brazos River	Glen Rose	08091000	1923–present	16,320
BRAQ33	Brazos River	Aquilla	08093100	1938–present	17,746
BRWA41	Brazos River	Waco	08096500	1898–present	20,065
BRHB42	Brazos River	Highbank	08098290	1965–present	20,900
LEHM46	Leon River	Hamilton	08100000	1925–present	1,928
LEGT47	Leon River	Gatesville	08100500	1950–present	2,379
LEBE49	Leon River	Belton	08102500	1923–present	3,579
LABE52	Lampasas River	Belton	08104100	1963–present	1,321
LRLR53	Little River	Little River	08104500	1923–present	5,266
GALA57	San Gabriel River	Laneport	08105700	1965–present	737
LRCA58	Little River	Cameron	08106500	1916–present	7,100
BRBR59	Brazos River	Bryan	08109000	1899–1993	30,016
NAEA66	Navasota River	Easterly	08110500	1924–present	936
NABR67	Navasota River	Bryan	08111000	1951–1997	1,427
BRHE68	Brazos River	Hempstead	08111500	1938–present	34,374
BRRI70	Brazos River	Richmond	08114000	1903–present	35,454
BRRO72	Brazos River	Rosharon	08116650	1967–present	35,775

Table 3.8
BRAC Water Rights Summary

Reservoir	Reservoir Identifier	Control Point	Water Right	Storage (acre-feet) BRAC3	Storage (acre-feet) BRAC8	Diversion (ac-ft/year) BRAC3	Diversion (ac-ft/year) BRAC8
Brazos River Authority System							
Possum Kingdom	POSDOM	515531	C5155	724,739	552,013	230,750	59,482
Granbury	GRNBRY	515631	C5156	155,000	132,821	64,712	36,025
Whitney		515731		636,100	561,074	18,336	18,336
	WHITNY		USACE	(387,024)	(311,998)	0	0
	BRA		C5157	(50,000)	(50,000)	(18,336)	(18,336)
	CORWHT		EVAP3	(199,076)	(199,076)	0	0
Aquilla	AQUILA	515831	C5158	52,400	41,700	13,896	2,394
Waco		509431		206,562	206,562	79,877	38,388
	LKWACO		C2315	(39,100)	(39,100)	(39,100)	(37,448)
	WACO2		C2315	(65,000)	(65,000)	(20,000)	(900)
	WACO4		P5094	(88,062)	(88,062)	(20,777)	0
	WACO5		P5094	(14,400)	(14,400)	0	0
Proctor	PRCTOR	515931	C5159	59,400	54,702	19,658	14,068
Belton	BELTON	516031	C2936	457,600	432,978	112,257	107,738
Stillhouse Hollow	STLHSE	516131	C5161	235,700	224,279	67,768	67,768
Georgetown	GRGTWN	516231	C5162	37,100	36,980	13,610	11,943
Granger	GRNGER	516331	C5163	65,500	50,540	19,840	2,569
Limestone	LMSTNE	516531	C5165	225,400	208,017	65,074	39,337
Somerville	SMRVLE	516431	C5164	160,110	154,254	48,000	48,000
Allen's Creek	ALLENS	292531	ALLENS	145,533	−	99,650	−
West Central Texas Municipal Water District							
Hubbard Creek	HUBBRD	421331	C4213	317,750	317,750	56,000	9,924
Texas Utilities Services							
Squaw Creek	SQWCRK	409732	C4097	151,500	151,015	23,180	17,536
Water Right Totals							
Total for the 15 reservoirs listed above				3,630,394	3,124,685	932,608	473,468
Percentage of basin total				(77.3%)	(77.7%)	(38.3%)	(31.6%)
All other water rights				1,064,457	898,665	1,504,730	1,022,963
Total for the entire river basin				4,694,851	4,023,350	2,437,338	1,496,431

Actual Water Use Supplied by the BRA System During 2008

The Brazos WAM (Bwam) and Brazos River Authority Condensed (BRAC) datasets are modified in various ways for particular applications. The BRAC datasets are modified to reflect actual water use supplied by the Brazos River Authority system during 2008 for the salinity simulation studies presented in TR-352 [2] and conditional reliability modeling studies presented in the following Chapter 4 of this report. The BRAC2008 DAT file is used in these studies with BRAC3 or BRAC8 FLO, EVA, and RUF files to more accurately represent current water use from the perspective of diversion amounts and locations and multiple-reservoir system operations.

The BRAC2008 DAT file is a modified version of the BRAC8 DAT file revised to reflect actual water use by Brazos River Authority customers during 2008. The year 2008 was relatively dry with below normal stream flows and high water supply demands. The 2008 water use data are adopted as a reasonable representation of current water use conditions. These data are used to partially update the current use scenario reflected in the Bwam8 and BRAC8 DAT files. In the BRAC2008 DAT file, BRA diversions in the BRAC3 or BRAC8 DAT files are replaced with actual measured water supply diversions for BRA customers during the year 2008. The BRAC3 or BRAC8 FLO, EVA, and RUF files are not changed.

The authorized use scenario Bwam3 and BRAC3 datasets include the annual water use demands specified in the water right permits. The current use scenario Bwam8 and BRAC8 datasets adopt the largest actual annual water use for each individual water right permit during any year of the ten-year period 1988-1997. The Bwam8 and BRAC8 datasets treat all diversions supplied by reservoirs as lakeside diversions at the reservoirs. In reality, a major portion of the water supplied by the Brazos River Authority reservoirs for municipal, industrial, and agricultural water supply is diverted from the river at locations significant distances downstream of the dams. Diversions for Brazos River Authority customers from the lower Brazos River and Little River are supplied by releases from multiple reservoirs as well as unregulated flows at the diversion sites. The diversions are placed in the BRAC2008 model at control points approximating actual diversion locations reflecting actual year 2008 BRA system diversions.

The annual diversion amounts for the Brazos River Authority water rights (*WR* records) are replaced in the BRAC2008 dataset with the quantities tabulated in Table 3.9 representing actual water use during the representative year 2008. The diversion targets are placed at the control points shown in the table. Diversions located at a particular reservoir are treated as a lakeside diversion supplied by that reservoir. Diversions at non-reservoir control points are supplied by available stream flow supplemented as necessary by releases from reservoirs located upstream.

The BRAC2008 DAT file contains the BRAC8 diversions at Lake Waco (38,348 ac-ft/yr), Lake Hubbard Creek (9,924 ac-ft/yr), and Squaw Creek Reservoir (17,536 ac-ft/yr), which are associated with water right permits not held by the BRA.

Lakes Waco and Whitney are modeled as multiple owner reservoirs in the Bwam and BRAC DAT files but are simplified in the BRAC2008 DAT files, as adopted for the salinity simulations of TR-352 and conditional reliability modeling simulations of Chapter 2, by removing the multiple-component differentiation. The dual simulation feature connected to Waco and Whitney Reservoirs in the Bwam and BRAC DAT files is also deactivated.

Table 3.9
Water Supply Diversions by BRA Customers During 2008

Water Supply Diversion Location	Control Point	Indus-trial	Irri-gation	Mining	Muni-cipal	Total
		2008 Annual Diversion (acre-feet/year)				
Lake Possum Kingdom	515531	1,016	321	1,229	1,401	3,968
Brazos River at Palo Pinto gage	BRPP27	0	0	277	0	277
Brazos River at Dennis gage	BRDE29	0	112	2,045	0	2,157
Lake Granbury	515631	51,196	3,091	1,077	6,912	62,276
Brazos River at Glen Rose gage	BRGR30	0	103	1,001	0	1,103
Lake Whitney	515731	1,046	786	30	13	1,875
Lake Aquilla	515831	0	0	0	5,716	5,716
Brazos River at Waco gage	BRWA41	0	333	0	325	658
Brazos River at Highbank gage	BRHB42	0	1,977	0	0	1,977
Lake Proctor	515931	0	4,438	0	2,695	7,134
Leon River at Belton	LEBE49	0	204	0	6,268	6,472
Lake Belton	516031	0	0	0	43,212	43,212
Lake Stillhouse Hollow	516131	0	56	0	26,774	26,830
Lake Georgetown	516231	0	0	0	13,440	13,440
Lake Granger	516331	0	1	0	2,803	2,804
Little River at Little River gage	LRLR53	0	93	0	0	93
Confluence of San Gabriel & Little R.	CON108	2,606	0	8	0	2,614
Confluence of Little and Brazos Rivers	CON111	0	120	13	0	133
Lake Somerville	516431	0	0	0	3,499	3,499
Lake Limestone	516531	32,391	0	5	181	32,577
Navasota River at Easterly gage	NAEA66	3,665	0	0	0	3,665
Brazos River at Hempstead gage	BRHE68	35,938	30	0	0	35,968
Brazos River at Rosharon gage	BRRO72	0	232	0	0	232
Totals		127,858	11,897	5,685	113,239	258,680

Possum Kingdom, Granbury, Aquilla, Limestone, Somerville, Belton, Stillhouse Hollow, Granger, and Georgetown Reservoirs are operated in the BRAC2008 model to supply diversions at downstream sites as well as lakeside diversions. Multiple-reservoir system release decisions are based on balancing as evenly as possible the storage contents of system reservoirs expressed as a percentage of storage capacity.

Lake Waco is not included in the BRA system with respect to multiple-reservoirs releasing to supply common downstream diversion requirements. The BRA holds a water supply storage contract with the USAC E for the conservation pool in the federal Lake Waco, but the City of Waco holds the water right permit. The Lake Waco water supply storage is committed totally to supplying the City of Waco. Likewise, Lake Proctor is committed to lakeside diversions and downstream diversions above Lake Belton that cannot be supplied by any other reservoir. Only 50,000 acre-feet of Lake Whitney is permitted for water supply. Lake Whitney is also limited to supplying lakeside diversions in the BRAC2008 model.

CHAPTER 4
CONDITIONAL RELIABILITY MODELING
BASED ON THE EQUAL-WEIGHT METHODOLOGY

WRAP was originally designed for long-term planning studies and preparation and evaluation of water right permit applications. Conditional reliability modeling (CRM) features expand WRAP capabilities to support short-term drought management and operational planning activities in which consideration of preceding reservoir storage levels is important. The terms *conditional* and *short-term* modeling are used here interchangeably. Using CRM, the likelihood of meeting reservoir storage, water supply diversion, instream flow, and hydroelectric power generation targets during the next month, next several months, next year, or perhaps next several years is assessed as a function of the amount of water currently in storage along with all the other information otherwise reflected in WRAP. In the short-term, storage and flow frequencies and water supply reliabilities are conditioned on preceding reservoir storage contents.

The equal-weight and probability array options are two alternative CRM approaches. This chapter focuses on applying the equal-weight method. Chapter 5 repeats the CRM analyses using the probability array approach and explores conditions under which the optional probability array methods could potentially improve the accuracy of CRM results.

The difference between the equal-weight and probability array methodologies is the approach adopted within *TABLES* for assigning probabilities to each hydrologic sequence and corresponding CRM simulation for use in the frequency and reliability analysis computations. The Brazos River Basin CRM analyses of Chapters 4 and 5 use 107 annual hydrologic sequences derived from a 1900-2007 period-of-analysis. With the equal-weight method, each of the 107 simulations are weighted the same in the frequency and reliability analyses, which is equivalent to assigning a probability of 1/107 to each of the 107 simulations. The probability array option is based on assigning varying probabilities to the 107 simulations. The probability array option adds complexity but may improve the accuracy of the probability estimates under certain conditions.

Conditional Reliability Modeling (CRM) Features of *SIM* and *TABLES*

CRM is described in Chapter 7 of the *Reference Manual* [3]. CRM is based on dividing a long hydrologic period-of-analysis into many shorter simulation sequences. The simulation is repeated for each hydrologic sequence with the same initial storage condition. Storage and flow frequency relationships and water supply reliability indices are developed from the simulation results. The WRAP programs *SIM* or *SIMD* perform the multiple short-term simulations with the specified starting storage contents. Routines in the program *TABLES* read the simulation results and perform frequency and reliability analyses.

The multiple short-term simulations are performed within either *SIM* or *SIMD*. The *SIMD* version of the simulation model provides the option of performing the simulation computations using a daily time interval and then aggregating the daily results to monthly totals for use in the *TABLES* CRM analyses. Otherwise, a CRM analysis is performed in the same manner with either *SIM* or *SIMD*. *SIM* rather than *SIMD* is used for the CRM simulations reported in this report. *SIM* is switched to the CRM mode by entering a conditional reliability *CR* record in the input file. The *CR* record is the only *SIM* input record that is used solely for CRM. The *CR* record sets the time parameters that control the subdivision of the hydrologic period-of-analysis into multiple short-term sequences. Without a *CR* record, the model performs a conventional single hydrologic period-of-analysis simulation. Simulation results are stored in the main *SIM* output file with filename extension OUT or CRM which is read by *TABLES*.

Program *TABLES* provides alternative approaches for assigning probabilities to each of the CRM hydrologic sequences. With the default equal-weight option, the *TABLES* input records are the same as with a conventional non-CRM analysis, with the exception of adding a *5CRM* record. The *5CRM* record, which has no actual input data, is used to switch *TABLES* from the conventional to CRM mode of analysis. A set of optional *5CR1* and *5CR2* records activates probability array options as discussed in Chapter 5.

Brazos River Basin *SIM* Dataset

The CRM analyses presented in Chapters 4 and 5 focus on the Brazos River Authority (BRA) reservoir system. The following *SIM* input files described in Chapter 3 are combined.

- BRA Condensed (BRAC3) FLO and EVA files for the authorized use scenario for a hydrologic period-of-analysis of January 1900 through December 2007.
- BRAC2008 DAT file reflecting actual water use supplied by the BRA System during 2008 as described in the last section of Chapter 3

Adoption of the BRAC3 FLO file means that stream flow accessible to the BRA system is limited to the flow amounts legally available assuming that other permit holders in the basin use the full amounts specified in their water right permits. The accuracy of the CRM analyses is enhanced by the extended 108-year 1900-2007 hydrologic period-of-analysis which is much longer than the original Brazos WAM 58-year 1940-1997 period-of-analysis. The BRAC2008 DAT file provides a realistic representation of actual operations of the BRA system during a relatively dry year.

CRM may be performed using various variations of the Bwam3 and Bwam8 datasets described in Chapter 2 and BRAC3 and BRAC8 datasets described in Chapter 3. CRM modeling procedures are basically the same regardless of the dataset adopted. However, all simulation results presented in this report are based on the *SIM* input dataset noted in the preceding paragraph, consisting of the BRAC2008 DAT file and BRAC3 FLO and EVA files described in Chapter 3.

Schnier [20] used other variations of the BRAC3 and BRAC8 datasets to investigate a broad range of modeling issues and also performed a CRM case study based on storage and water use during the 2009 drought. The CRM analyses of BRA reservoirs and Hubbard Creek Reservoir presented by Schnier [20] addresses a broader spectrum of issues than the more focused presentation of Chapters 4 and 5 of this report. Though similar, the CRM simulations included in this report are different than any of the alternative simulations covered by Schnier [20].

The CRM analyses of the BRA reservoirs focus on developing frequency tables for storage levels three, six, nine, and twelve months later, given specified preceding storage levels at the beginning of April or July. The analyses are repeated with the equal-weight (Chapter 4) and probability array (Chapter 5) options provided by the WRAP program *TABLES*.

Brazos River Basin CRM Analyses

CRM analyses are presented for a system of 12 reservoirs owned and operated by the U.S. Army Corps of Engineers (USACE) Fort Worth District and Brazos River Authority (BRA). The 12 reservoirs contain storage capacities as listed in Table 1.1 and are located as shown in Figure 1.3. The BRA owns three of the reservoirs and has contracted for water supply storage capacity in the nine USACE reservoirs. The City of Waco holds water right permits for Lake Waco, and the BRA has the water right permits for the 11 other reservoirs.

The purpose of Chapters 4 and 5 is to illustrate CRM. Conditional reliability modeling of the BRA reservoir system can be performed with a massive array of alternative variations of *SIM* input datasets and *TABLES* CRM options reflecting a spectrum of water management strategies and modeling premises. The CRM analyses presented in this report are limited to a particular set of data, modeling options, and premises. The CRM analyses could be repeated for an essentially unlimited number of combinations of variations of *SIM* input datasets and *TABLES* CRM options. The generalized WRAP modeling system is designed to be routinely executed to address specific water management issues and modeling applications. Variations of the modeling studies presented in this report can be repeated in the future to address particular concerns as they arise.

Voluminous modeling results can be generated with *SIM* and *TABLES*. Essentially all of the types of simulation output generated in conventional long-term WRAP simulation studies are also available with short-term CRM analyses. This chapter focuses on developing storage-frequency tables which, though fundamental, are certainly not the only results generated by a CRM study.

SIM Simulations

The *SIM* simulations are performed with the BRAC2008 DAT file combined with the BRAC3 FLO and EVA files, which are described in Chapter 3. The hydrologic period-of-analysis extends from January 1900 through December 2007.

The BRAC2008 DAT file contains the following 14 reservoirs for which information is provided in Figure 3.1, Table 3.5, and accompanying discussion in Chapter 3.

- 11 BRA/USACE reservoirs associated with BRA water right permits
- USACE/BRA Waco Reservoir for which the City of Waco holds the water right permits
- Hubbard Creek Reservoir owned by the West Central Texas Municipal Water District
- Squaw Creek Reservoir which provides cooling water for the Comanche Peak Power Plant

The *SIM* dataset adopted for the CRM analyses reflects the following premises.

1. Water supply needs associated with the BRA permits as listed in Table 3.9 are supplied by 11 reservoirs in the BRAC2008 DAT file as outlined in the last section of Chapter 3. Thus, the BRA water rights are modeled based on actual water use during 2008 which was a relatively dry year. The objective is to reflect realistic demands on the BRA system.

2. Waco, Hubbard Creek, and Squaw Creek Reservoirs are modeled in the DAT file with data from the current use Bwam8 and corresponding BRAC8 DAT files. Again, the objective is to reflect realistic demands on these three large reservoirs.

3. The BRAC3 FLO and EVA files are adopted. Thus, holders of all water right permits other than those incorporated in the BRAC2008 DAT file are assumed to appropriate the full amounts of water to which they are legally entitled. The BRA has access only to the water to which it is legally entitled. This provides a conservative representation of the effects of the numerous other water users in the basin on the water available to the BRA system.

The annual cycle option described in the *Reference Manual* is adopted for the Brazos River Basin study rather the monthly cycle option. The 1900-2007 hydrologic period-of-analysis provides a relatively large number of annual sequences, which supports use of the annual cycle option. Seasonal characteristics of flow are important and are captured with the annual cycle option.

The results presented in this report are based on eight alternative *SIM* simulations. The CRM mode is activated in *SIM* by addition to the DAT file of one of the eight versions of the conditional reliability *CR* record shown in Table 4.1. The annual cycle option using a simulation period of 12 months is activated by setting the parameter CR1 on the CR record equal to 12. The starting month for the annual cycle is April (CR=4) in four of the simulations and July (CR2=7) in the other four simulations. The *SIM* simulations are repeated with the initial storage contents of each of the 14 reservoirs in the DAT file set alternatively at 100%, 75%, 50%, and 25% of their conservation storage capacity.

Table 4.1
Alternative Versions of the *SIM CR* Record

CR	12	4	1.00
CR	12	4	0.75
CR	12	4	0.50
CR	12	4	0.25
CR	12	7	1.00
CR	12	7	0.75
CR	12	7	0.50
CR	12	7	0.25

TABLES CRM Analyses

Versions of the *TABLES* input TIN file reproduced as Table 4.2 were used with the results of each of the eight *SIM* simulations to develop the storage frequency statistics summarized in Tables 4.4 through 4.31. The *TABLES* 2FRE record frequency analysis results are condensed and reorganized as Tables 4.4–4. 31. Storage-frequency relationships are presented for selected individual reservoirs and groups of reservoirs for specified initial storage conditions as of the beginning of either April or July. The tables show storage content, as a percentage of storage capacity, at the end of either June, September, December, or March corresponding to defined exceedance frequencies. The mean and maximum of the 107 simulated storage contents at the end of the specified month are shown at the top and bottom of each column in the tables, in acre-feet.

Storage-frequency tables are presented for the multiple-reservoir systems and individual reservoirs listed in Table 4.3. A single storage-frequency relationship is developed for the total combined storage contents of Lakes Possum Kingdom and Granbury. Likewise, the storage volumes in Lakes Belton, Stillhouse Hollow, Granger, and Georgetown are summed for purposes of developing storage-frequency relationships. The conservation storage capacities for the 14 reservoirs in the BRAC2008 DAT file are listed in Tables 2.1 and 3.5. Conservation storage capacities are included in Table 4.3 for the two groups of reservoirs and five individual reservoirs for which storage-frequency tables are developed.

Storage content volumes of each of the 14 reservoirs contained in the BRAC2008 DAT file are fixed in the eight *SIM* simulations at the beginning of either April or July at a specified percentage (either 100%, 75%, 50%, and 25%) of the reservoir storage capacity. The same eight *SIM* simulations are adopted with both the equal-weight based CRM analyses of this chapter and probability array based CRM analyses covered in the next chapter. The last two columns of Table 4.3 list the tables containing the results of applying the equal-weight option (Chapter 4) and probability-array option (Chapter 5), respectively, which can be compared.

Table 4.2
TABLES TIN File for Developing the
Equal-Weight Option Storage Frequency Statistics

```
5CRM
****
2FRE   6   6   2   4
IDEN  POSDOM  GRNBRY
2FRE   6   9  -2   4
2FRE   6  12  -2   4
2FRE   6   3  -2   4
****
2FRE   6   6   4   4
IDEN  BELTON  STLHSE  GRGTWN  GRNGER
2FRE   6   9  -4   4
2FRE   6  12  -4   4
2FRE   6   3  -4   4
****
2FRE   6   9   5   4
IDEN  PRCTOR  AQUILA  SMRVLE  LMSTNE  LKWACO
2FRE   6   9  -5   4
2FRE   6  12  -5   4
2FRE   6   3  -5   4
****
ENDF
```

Conditional Reliability Modeling Results

Adoption of the annual cycle option with the 1900-2007 hydrologic period-of-analysis results in 107 twelve-month long hydrologic sequences. The 107 annual simulations are repeated within an execution of *SIM* with each starting at the beginning of either April or July, with specified initial storage contents of either 100, 75, 50, or 25 percent of storage capacity. The storage volumes equaled or exceeded at specified frequencies determined with *TABLES* are storage contents at the end of either June, September, December, or March which represent periods of 3 months, 6 months, 9 months, and 12 months after initiating the simulations at the beginning of either April or July. Frequency-storage results are presented in the tables of Chapters 4 and 5 listed in Table 4.3.

Table 4.3
Listing of Storage-Frequency Tables

Multiple-Reservoir System or Individual Reservoir	Storage Capacity (acre-feet)	Initial Storage Contents	Tables for Options Equal Weight	Tables for Options Prob Array
Lakes Possum Kingdom and Granbury on Brazos River	684,834	100%	4.4	5.18
		75%	4.11	5.25
		50%	4.18	5.32
		25%	4.25	5.39
Belton, Stillhouse Hollow, Granger, and Georgetown in Little River Sub-Basin	744,777	100%	4.5	5.19
		75%	4.12	5.26
		50%	4.19	5.33
		25%	4.26	5.40
Lake Proctor on Leon River	54,702	100%	4.6	5.20
		75%	4.13	5.27
		50%	4.20	5.34
		25%	4.27	5.41
Lake Aquilla on Aquilla Creek	41,700	100%	4.7	5.21
		75%	4.14	5.28
		50%	4.21	5.35
		25%	4.28	5.42
Somerville on Yequa Creek	154,254	100%	4.8	5.22
		75%	4.15	5.29
		50%	4.22	5.36
		25%	4.29	5.43
Limestone on Navasota River	208,017	100%	4.9	5.23
		75%	4.16	5.30
		50%	4.23	5.37
		25%	4.22	5.44
Lake Waco on Bosque River	206,562	100%	4.10	5.24
		75%	4.17	5.31
		50%	4.30	5.38
		25%	4.31	5.45

The storage-frequency tables presented in Chapters 4 and 5 are grouped by initial storage content (100%, 75%, 50%, or 25% of capacity). The tables are in the following format.

- Each column begins with the mean end-of-month storage content in acre-feet at the end of the specified month in each of the 107 simulations. The mean is the average of 107 end-of-specified-month storage volumes in acre-feet.

- The second quantity in each column is the minimum end-of-specified-month storage volume of all of the 107 simulations. The minimum storage volume is expressed in the tables as a percentage of corresponding conservation storage capacity. The minimum storage contents is equaled or exceeded in 100% of the 107 simulations.

- End-of-specified-month storage volume expressed as a percentage of storage capacity is tabulated for exceedance frequencies of 99%, 98%, 95%, 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, and 10%. With the equal-weight option, these are simply storage volumes that are equaled or exceeded during the specified percentage of the 107 simulations. The probability array option provides more sophisticated methods for assigning probabilities to the 107 simulations. With either modeling option, the resulting storage-frequency tables are viewed as representing estimated future exceedance probabilities, likelihood, or percent-of-time.

- The maximum end-of-specified-month storage volume of all of the 107 annual simulations is shown as the last quantity in each column in acre-feet.

- The left side of each table contains statistics for CRM simulations with the initial storage contents specified for the beginning of April (end of March). The left side of each table reflects initial storage contents being specified for the beginning of July (end of June).

For example, Tables 4.4, 4.11, 4.18, and 4.25 present storage-frequency statistics for the combined Lakes Possum Kingdom and Granbury on the Brazos River for initial storage contents of 100%, 75%, 50%, and 25%, respectively, of capacity at alternatively either the beginning of April or beginning of July. The Bwam8 conservation storage capacities of Possum Kingdom and Granbury are 552,013 and 132,821 acre-feet (Tables 2.10 and 3.5) for a total of 684,834 acre-feet. Frequency analyses for the individual Lakes Possum Kingdom and Granbury are not presented in this report. Rather results are presented for a frequency analysis performed with *TABLES* for the 107 summations of end-of-month storage contents of both Lakes Possum Kingdom and Granbury.

Referring to Table 4.4, based on all of the modeling methodologies, premises, approximations, and assumptions reflected in the *WRAP-SIM/TABLES* programs and dataset, with Possum Kingdom and Granbury Reservoirs full to capacity at the beginning of April, the estimated probability of both lakes being full at the end of March, 12 months later, is 60% or 0.60. There is an estimated probability of 99% or 0.99 that, under these specified conditions, the total combined storage contents of the two lakes 12 months later will be at least 83.67 of their combined capacity.

In Table 4.11, with the 14 reservoirs in the DAT file assigned an initial storage volume of 75% of capacity at the beginning of April, the 80% exceedance frequency total storage contents of the combined Possum Kingdom and Granbury Reservoirs at the end of June, September, December, and March are 86.90%, 89.53%, 95.08%, and 97.05% of the storage capacity of 684,834 acre-feet. The combined storage of Lakes Possum Kingdom and Granbury at the end of 12 months (end of March) equals or exceeds 97.05% of capacity in 80% of the 107 simulations. Thus, based on the information and premises reflected in the model, if Possum Kingdom and Granbury are at 75% capacity at the beginning of April, the estimated probability of the storage being at or above 97.05% capacity 12 months later (end of March) is 80% or 0.80.

The interpretation of conditional reliability modeling results is further illustrated as follows. The left half of Table 4.26 is a tabulation of frequency statistics for the combined storage contents of Lakes Belton, Stillhouse Hollow, Georgetown, and Granger at the end of June, September, December, and March given that the four reservoirs (actually all 14 reservoirs) are each 25% full at the beginning of April. The right half of Table 4.26 is a tabulation of frequency statistics for the total storage volume of the four reservoirs at the end of September, December, March, and June given that the storage content is 25% of capacity at the beginning of July. The frequencies are for the combined total end-of-month storage volume in the four reservoirs. Program *TABLES* sums the four end-of-month storage volumes in each of the 107 months used in the frequency analysis.

In Table 4.26, with the reservoirs at 25% capacity at the beginning of July, the probability of reaching 48.53% of the storage capacity of the four reservoirs three months later at the end of September is estimated to be 10% or 0.10. Ten percent of the 107 hydrologic sequences result in end-of-September storage volumes in the four reservoirs that total to 48.53% of their combined capacity or greater. The September storage equals or exceeds 24.87% capacity in 50% of the 107 simulations. The largest end-of-September total 4-reservoir storage volume during the 107 simulations is 476,478 acre-feet. The smallest end-of-September total storage volume in the four reservoirs during the 107 simulations is 18.70% of the 744,777 acre-feet storage capacity which is 139,273 acre-feet. The average of the 107 end-of-September storage volumes is 215,390 acre-feet.

Concluding Remarks

The equal-weight option is simple to apply and interpret. The storage frequency statistics developed based on the equal-weight method and presented in Tables 4.4 through 4.31 provide valid estimates of the likelihood of various storage levels being equaled or exceeded in the future given preceding storage levels. These estimates, like all modeling results, are of course approximate, but CRM results based on the equal-weight option are considered to be reasonably accurate. However, the next chapter focuses on the probability array option which is designed to address the potential short-coming of the equal-weight method described in the following paragraph.

With the equal-weight option, the probabilities associated with the 107 hydrologic sequences in the program *TABLES* computations are the same regardless of whether initial reservoir storage levels are specified to be 100%, 75%, 50%, or 25% of capacity. However, the concept of hydrologic persistence implies that dry hydrologic conditions are more likely to follow past dry conditions than past wet conditions. Reservoir storage levels of 25% of capacity indicate drier previous hydrologic conditions than does storage levels at 75% capacity. Therefore, the set of probabilities associated with the 107 hydrologic sequences perhaps should be different in CRM with different initial reservoir storage conditions. The degree of correlation between naturalized stream flow and preceding storage is a key consideration affecting the accuracy of the equal-weight versus probability array options. Correlation analyses presented in Chapter 5 demonstrate some relatively small correlation between naturalized flow and simulated preceding reservoir storage. Conditions under which the accuracy of the frequency analyses may be enhanced by applying the optional probability array methodology are explored in the following Chapter 5.

Notes for Tables 4.4−4.31: The mean storage volume and maximum storage volume at the top and bottom, respectively, of each column are in units of acre-feet. Exceedance frequencies are listed in the first column. The reservoir storage volumes associated with the specified exceedance frequencies are expressed as a percentage of storage capacity.

Table 4.4
Storage-Frequency Relationship for Combined Lakes Possum Kingdom and Granbury
For Initial Storage Contents of 100% of 684,834 acre-feet Capacity

	100% Full at Beginning of April (Month 4)				100% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	683,021	670,160	672,884	674,530	671,076	673,281	674,708	680,870
Min	92.29	83.33	82.23	80.49	87.64	84.35	82.56	89.10
99%	95.85	85.83	86.16	83.67	88.31	86.19	83.70	90.40
98%	97.40	86.52	87.31	84.45	89.88	87.65	84.91	92.30
95%	97.70	90.11	88.13	91.53	90.76	88.76	91.53	94.39
90%	99.48	92.28	93.94	95.56	92.37	93.94	95.56	99.35
80%	100.00	95.85	97.53	97.85	95.85	97.53	97.85	100.00
70%	100.00	97.88	99.30	99.21	97.88	99.32	99.21	100.00
60%	100.00	99.18	99.84	100.00	99.18	99.84	100.00	100.00
50%	100.00	99.99	100.00	100.00	99.99	100.00	100.00	100.00
40%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
30%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
20%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Max	684,834	684,834	684,834	684,834	684,834	684,834	684,834	684,834

Table 4.5
Storage-Frequency Relationship for Lakes Belton, Stillhouse Hollow, Granger, and Georgetown
For Initial Storage Contents of 100% of 744,777 acre-feet Capacity

	100% Full at Beginning of April (Month 4)				100% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	739,920	709,628	713,585	720,327	713,612	716,553	722,231	731,782
Min	94.21	85.21	82.27	79.37	89.74	84.91	81.22	82.35
99%	94.99	86.23	83.05	82.22	90.02	86.64	86.73	84.30
98%	95.04	86.43	83.46	85.17	90.32	87.00	86.96	86.83
95%	96.27	89.19	86.64	87.00	91.07	87.86	87.62	89.60
90%	98.00	90.49	87.82	89.01	92.03	89.42	89.34	94.87
80%	98.99	92.02	91.20	93.12	92.42	91.52	93.31	97.77
70%	99.58	93.35	93.11	95.40	93.93	94.40	95.54	99.05
60%	99.96	94.26	96.15	99.06	94.68	96.16	99.06	99.89
50%	100.00	95.74	98.30	99.95	95.94	98.54	99.97	100.00
40%	100.00	97.23	99.59	100.00	97.32	99.68	100.00	100.00
30%	100.00	97.95	100.00	100.00	98.07	100.00	100.00	100.00
20%	100.00	99.24	100.00	100.00	99.35	100.00	100.00	100.00
10%	100.00	99.80	100.00	100.00	99.83	100.00	100.00	100.00
Max	744,777	744,777	744,777	744,777	734,319	744,777	744,777	744,777

Table 4.6
Storage-Frequency Relationship for Lake Proctor for
Initial Storage Contents of 100% of 54,702 acre-feet Capacity

End of Month	100% Full at Beginning of April (Month 4) 6 Jun	9 Sep	12 Dec	3 Mar	100% Full at Beginning of July (Month 7) 9 Sep	12 Dec	3 Mar	6 Jun
Mean	53,524	47,390	47,299	47,842	48,331	48,244	48,512	50,323
Min	84.45	68.02	66.61	64.97	78.32	71.87	68.79	58.10
99%	85.75	71.75	68.02	66.73	78.51	74.69	68.91	60.20
98%	87.44	74.35	69.00	67.68	79.73	74.81	70.12	62.74
95%	91.94	76.56	72.06	69.55	81.12	76.68	73.00	68.11
90%	94.12	78.18	74.19	71.51	82.68	77.52	76.01	70.59
80%	95.67	81.10	77.32	75.03	83.96	80.94	77.72	78.22
70%	96.16	82.64	78.93	77.80	84.86	81.07	78.28	94.55
60%	98.78	84.04	81.14	82.26	85.00	81.87	84.04	96.11
50%	100.00	84.99	83.72	87.29	85.05	85.31	89.22	99.51
40%	100.00	87.63	89.65	97.72	88.17	91.57	97.72	100.00
30%	100.00	90.43	96.39	100.00	90.43	96.85	100.00	100.00
20%	100.00	92.23	100.00	100.00	93.29	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Max	54,702	54,702	54,702	54,702	54,702	54,702	54,702	54,702

Table 4.7
Storage-Frequency Relationship for Lake Aquilla for
Initial Storage Contents of 100% of 41,700 acre-feet Capacity

End of Month	100% Full at Beginning of April (Month 4) 6 Jun	9 Sep	12 Dec	3 Mar	100% Full at Beginning of July (Month 7) 9 Sep	12 Dec	3 Mar	6 Jun
Mean	40,930	36,808	37,930	38,897	37,437	38,283	39,151	40,351
Min	88.27	73.61	68.94	67.95	79.68	72.24	67.95	70.36
99%	89.05	74.79	69.83	68.96	79.86	73.79	73.73	71.42
98%	90.72	75.12	72.32	70.30	80.71	75.23	74.68	73.37
95%	93.74	78.12	74.61	73.95	82.79	77.88	76.79	82.24
90%	94.68	81.47	77.74	75.85	84.27	79.97	78.59	92.77
80%	96.06	83.36	80.54	84.40	86.08	82.56	84.84	95.52
70%	97.09	84.97	84.18	90.41	86.49	85.01	91.10	96.69
60%	98.75	86.44	88.26	98.11	86.85	88.99	98.38	98.15
50%	100.00	87.43	95.93	100.00	88.15	95.93	100.00	100.00
40%	100.00	88.93	100.00	100.00	90.27	100.00	100.00	100.00
30%	100.00	92.50	100.00	100.00	93.56	100.00	100.00	100.00
20%	100.00	94.26	100.00	100.00	94.83	100.00	100.00	100.00
10%	100.00	97.21	100.00	100.00	97.24	100.00	100.00	100.00
Max	41,700	41,700	41,700	41,700	41,700	41,700	41,700	41,700

Table 4.8
Storage-Frequency Relationship for Lake Somerville for
Initial Storage Contents of 100% of 154,254 acre-feet Capacity

	100% Full at Beginning of April (Month 4)				100% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	153,047	147,257	150,137	152,476	148,208	150,675	152,764	152,529
Min	93.54	83.00	79.91	79.29	87.46	82.55	81.92	80.06
99%	94.01	85.13	80.95	85.86	87.70	85.40	85.97	90.26
98%	94.97	85.48	83.64	90.53	88.70	86.45	92.25	91.25
95%	95.91	86.74	86.57	93.25	89.92	87.83	94.02	95.12
90%	97.30	89.48	90.91	95.19	91.42	91.02	97.10	96.51
80%	98.79	92.28	94.54	99.30	93.03	95.03	99.30	98.69
70%	99.25	93.33	97.33	100.00	93.53	98.77	100.00	99.24
60%	100.00	94.59	100.00	100.00	95.14	100.00	100.00	99.99
50%	100.00	96.15	100.00	100.00	96.21	100.00	100.00	100.00
40%	100.00	97.52	100.00	100.00	97.64	100.00	100.00	100.00
30%	100.00	98.89	100.00	100.00	100.00	100.00	100.00	100.00
20%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Max	154,254	154,254	154,254	154,254	154,254	154,254	154,254	154,254

Table 4.9
Storage-Frequency Relationship for Lake Limestone for
Initial Storage Contents of 100% of 208,017 acre-feet Capacity

	100% Full at Beginning of April (Month 4)				100% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	203,216	184,250	192,936	198,044	188,459	195,772	199,437	199,009
Min	87.87	74.32	68.74	67.36	82.33	76.49	75.07	67.76
99%	89.24	76.48	73.17	73.02	82.81	78.58	76.04	73.53
98%	89.36	77.37	73.94	75.23	83.55	80.21	79.41	73.67
95%	91.17	78.78	76.66	77.12	85.56	81.83	81.75	76.21
90%	92.66	80.04	81.01	81.77	86.67	84.77	84.47	87.02
80%	95.45	83.88	85.68	87.30	87.91	86.67	88.73	93.00
70%	97.02	86.40	87.02	97.01	88.12	89.10	98.06	96.20
60%	97.78	87.60	91.99	99.74	88.83	93.93	100.00	97.31
50%	99.69	88.26	96.91	100.00	89.24	97.98	100.00	98.62
40%	100.00	89.10	100.00	100.00	90.69	100.00	100.00	100.00
30%	100.00	91.21	100.00	100.00	91.94	100.00	100.00	100.00
20%	100.00	93.20	100.00	100.00	93.52	100.00	100.00	100.00
10%	100.00	96.99	100.00	100.00	97.50	100.00	100.00	100.00
Max	208,017	208,017	208,017	208,017	208,017	208,017	208,017	208,017

Table 4.10
Storage-Frequency Relationship for Lake Waco for
Initial Storage Contents of 100% of 206,562 acre-feet Capacity

	100% Full at Beginning of April (Month 4)				100% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	204,998	192,500	194,805	199,011	193,645	195,789	199,510	203,157
Min	94.42	81.93	78.85	80.97	85.00	81.43	81.44	80.32
99%	95.71	83.29	79.95	81.36	85.59	82.24	81.94	85.51
98%	96.02	84.46	80.55	81.46	87.02	82.78	82.38	86.24
95%	96.39	86.59	83.17	84.13	87.27	83.83	85.10	89.86
90%	96.99	87.46	85.03	86.82	88.71	86.15	87.12	95.89
80%	98.49	89.66	88.71	89.81	90.89	89.94	90.92	97.08
70%	99.38	90.93	90.87	97.67	91.78	91.25	98.49	99.03
60%	100.00	91.98	93.11	100.00	92.24	93.29	100.00	100.00
50%	100.00	92.55	96.87	100.00	93.17	97.30	100.00	100.00
40%	100.00	93.58	99.95	100.00	93.76	99.95	100.00	100.00
30%	100.00	94.92	100.00	100.00	95.37	100.00	100.00	100.00
20%	100.00	99.12	100.00	100.00	99.12	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Max	206,562	206,562	206,562	206,562	206,562	206,562	206,562	206,562

Table 4.11
Storage-Frequency Relationship for Combined Lakes Possum Kingdom and Granbury
For Initial Storage Contents of 75% of 684,834 acre-feet Capacity

	75% Full at Beginning of April (Month 4)				75% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	645,666	652,230	663,014	668,220	584,868	619,201	635,721	669,534
Min	68.42	60.82	68.52	67.05	64.55	62.55	61.21	68.04
99%	73.31	71.80	74.20	79.34	65.68	63.71	61.79	70.04
98%	73.86	72.31	77.04	82.47	66.71	64.67	62.45	70.85
95%	77.90	80.79	83.92	86.19	67.31	66.08	68.99	81.93
90%	80.59	84.72	87.88	91.03	68.38	73.95	75.86	95.63
80%	86.90	89.53	95.08	97.05	74.20	79.04	85.12	99.53
70%	91.53	95.34	97.95	98.83	76.97	86.04	90.46	100.00
60%	97.32	97.95	99.38	99.79	79.87	89.39	96.96	100.00
50%	99.47	99.44	100.00	100.00	85.01	96.07	99.32	100.00
40%	100.00	99.99	100.00	100.00	89.87	99.55	100.00	100.00
30%	100.00	100.00	100.00	100.00	96.72	100.00	100.00	100.00
20%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Max	684,834	684,834	684,834	684,834	684,834	684,834	684,834	684,834

Table 4.12
Storage-Frequency Relationship for Lakes Belton, Stillhouse Hollow, Granger, and Georgetown
For Initial Storage Contents of 75% of 744,777 acre-feet Capacity

	75% Full at Beginning of April (Month 4)				75% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	678,886	656,674	673,186	691,196	570,116	613,049	646,024	692,729
Min	69.68	61.82	59.21	57.64	65.83	61.43	57.97	59.10
99%	70.53	62.55	61.12	59.29	67.04	63.08	62.94	60.70
98%	70.55	64.03	62.18	63.37	67.29	63.34	63.22	63.72
95%	72.88	69.16	67.82	72.91	67.94	64.07	64.05	65.85
90%	76.99	71.91	72.09	74.87	68.75	65.24	65.55	75.03
80%	80.27	75.73	75.98	85.69	69.05	67.67	70.10	87.29
70%	84.05	82.19	87.89	91.40	70.57	70.81	75.39	93.60
60%	91.48	89.46	92.62	95.27	71.22	76.93	83.93	97.99
50%	96.88	91.89	95.84	99.25	74.27	80.88	91.21	99.51
40%	98.91	95.51	98.24	100.00	76.63	88.94	99.81	100.00
30%	99.99	97.29	99.96	100.00	80.36	94.20	100.00	100.00
20%	100.00	98.34	100.00	100.00	88.31	99.03	100.00	100.00
10%	100.00	99.75	100.00	100.00	95.77	100.00	100.00	100.00
Max	744,777	744,777	744,777	744,777	734,319	744,777	744,777	744,777

Table 4.13
Storage-Frequency Relationship for Lake Proctor for
Initial Storage Contents of 75% of 54,702 acre-feet Capacity

	75% Full at Beginning of April (Month 4)				75% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	43,782	38,113	39,102	41,247	34,188	35,088	38,269	41,221
Min	61.57	47.96	46.67	43.43	56.27	51.26	48.11	39.76
99%	62.60	49.30	46.77	44.01	56.38	53.18	48.41	41.40
98%	63.38	50.53	46.93	45.26	56.97	53.30	48.92	41.46
95%	65.38	51.14	48.24	47.19	58.11	53.72	51.07	43.23
90%	66.22	52.56	49.35	48.23	59.11	54.63	52.00	46.35
80%	67.33	54.69	51.60	49.47	60.11	56.08	54.14	48.98
70%	67.91	55.11	52.04	52.66	60.78	57.71	55.16	49.47
60%	68.17	55.33	53.48	64.72	61.35	57.95	55.29	59.31
50%	69.31	59.05	69.07	80.05	61.41	58.01	55.87	80.69
40%	83.61	72.50	81.06	89.57	61.49	58.10	63.90	96.08
30%	97.53	84.88	90.29	99.75	61.54	59.05	89.58	100.00
20%	100.00	90.05	96.93	100.00	62.77	66.67	100.00	100.00
10%	100.00	100.00	100.00	100.00	64.92	100.00	100.00	100.00
Max	54,702	54,702	54,702	54,702	54,702	54,702	54,702	54,702

Table 4.14
Storage-Frequency Relationship for Lake Aquilla for
Initial Storage Contents of 75% of 41,700 acre-feet Capacity

	75% Full at Beginning of April (Month 4)				75% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	38,353	34,564	36,502	37,965	29,067	32,776	35,250	38,718
Min	64.97	52.52	51.60	51.99	57.97	51.49	47.67	49.34
99%	65.64	56.26	53.18	53.35	58.12	52.73	52.48	50.75
98%	67.76	58.60	55.33	57.07	58.78	53.84	53.02	51.27
95%	70.17	61.08	60.27	61.81	60.51	56.74	55.17	62.52
90%	73.24	63.61	63.15	71.64	61.59	57.86	56.32	75.30
80%	80.41	72.71	75.00	78.67	63.03	60.03	62.18	88.83
70%	90.01	79.07	81.12	90.19	63.36	62.29	70.24	94.91
60%	94.61	82.52	86.70	96.09	63.87	66.51	85.39	97.37
50%	97.74	85.01	92.41	99.88	65.13	75.51	96.85	99.16
40%	100.00	87.41	99.62	100.00	68.68	89.17	100.00	100.00
30%	100.00	90.99	100.00	100.00	71.48	99.88	100.00	100.00
20%	100.00	94.10	100.00	100.00	74.37	100.00	100.00	100.00
10%	100.00	96.05	100.00	100.00	90.76	100.00	100.00	100.00
Max	41,700	41,700	41,700	41,700	41,700	41,700	41,700	41,700

Table 4.15
Storage-Frequency Relationship for Lake Somerville for
Initial Storage Contents of 75% of 154,254 acre-feet Capacity

	75% Full at Beginning of April (Month 4)				75% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	140,948	136,717	143,243	148,874	118,637	133,640	143,980	147,777
Min	69.96	60.67	58.76	58.43	64.33	60.10	59.63	58.20
99%	70.13	63.08	59.24	68.65	64.52	62.56	63.18	67.28
98%	70.96	64.18	64.01	72.85	65.38	63.48	68.72	68.51
95%	73.64	67.44	67.22	76.21	66.45	64.72	71.15	76.26
90%	75.48	70.61	74.90	85.26	67.79	67.32	74.40	83.05
80%	80.84	75.36	83.95	97.25	69.04	71.00	84.68	95.43
70%	84.95	85.24	93.02	100.00	69.72	77.29	93.09	98.33
60%	89.27	90.80	98.93	100.00	71.20	82.83	99.71	99.30
50%	97.87	93.19	100.00	100.00	74.30	90.64	100.00	100.00
40%	100.00	95.69	100.00	100.00	76.03	99.02	100.00	100.00
30%	100.00	97.54	100.00	100.00	78.55	100.00	100.00	100.00
20%	100.00	99.87	100.00	100.00	83.12	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	97.36	100.00	100.00	100.00
Max	154,254	154,254	154,254	154,254	154,254	154,254	154,254	154,254

Table 4.16
Storage-Frequency Relationship for Lake Limestone for
Initial Storage Contents of 75% of 208,017 acre-feet Capacity

End of Month	75% Full at Beginning of April (Month 4) 6 Jun	9 Sep	12 Dec	3 Mar	75% Full at Beginning of July (Month 7) 9 Sep	12 Dec	3 Mar	6 Jun
Mean	181,433	164,993	179,197	189,874	142,365	165,079	181,413	188,169
Min	63.99	52.12	47.24	45.95	59.43	54.31	52.98	45.82
99%	65.24	53.87	51.34	50.57	59.83	56.02	53.41	50.88
98%	65.35	54.92	51.81	54.76	60.44	57.36	56.45	51.07
95%	66.86	56.48	55.58	58.60	62.27	58.76	58.25	54.41
90%	68.49	58.80	61.04	63.30	63.12	61.32	60.97	65.21
80%	73.83	65.78	68.08	81.19	64.10	62.95	66.22	78.69
70%	77.93	68.52	79.28	93.57	64.22	65.22	79.49	93.64
60%	83.46	76.41	87.71	98.86	64.91	70.14	90.95	95.69
50%	90.73	83.55	94.94	100.00	65.28	76.48	98.53	97.77
40%	95.99	87.07	100.00	100.00	66.84	84.40	100.00	100.00
30%	100.00	88.95	100.00	100.00	68.48	95.92	100.00	100.00
20%	100.00	93.07	100.00	100.00	69.89	100.00	100.00	100.00
10%	100.00	96.16	100.00	100.00	80.51	100.00	100.00	100.00
Max	208,017	208,017	208,017	208,017	208,017	208,017	208,017	208,017

Table 4.17
Storage-Frequency Relationship for Lake Waco for
Initial Storage Contents of 75% of 206,562 acre-feet Capacity

End of Month	75% Full at Beginning of April (Month 4) 6 Jun	9 Sep	12 Dec	3 Mar	75% Full at Beginning of July (Month 7) 9 Sep	12 Dec	3 Mar	6 Jun
Mean	190,757	180,084	185,261	192,740	154,886	166,006	181,115	194,597
Min	71.35	60.79	56.60	62.07	61.24	57.75	58.36	57.32
99%	71.87	62.20	58.59	62.77	61.87	58.90	58.55	61.75
98%	72.10	62.91	61.25	64.66	63.13	59.03	58.67	63.03
95%	72.68	66.70	64.96	65.82	63.31	60.07	61.33	67.56
90%	75.30	69.83	69.13	76.07	64.66	62.59	63.53	73.99
80%	82.04	76.71	80.07	85.01	66.69	65.91	67.25	90.93
70%	88.46	82.87	85.11	91.89	67.47	67.40	78.47	98.29
60%	95.16	87.46	91.17	99.96	67.99	69.57	90.06	99.47
50%	99.30	90.46	94.04	100.00	69.13	75.85	99.79	100.00
40%	100.00	92.09	98.22	100.00	70.09	88.92	100.00	100.00
30%	100.00	94.00	100.00	100.00	73.38	98.05	100.00	100.00
20%	100.00	97.25	100.00	100.00	91.74	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Max	206,562	206,562	206,562	206,562	206,562	206,562	206,562	206,562

Table 4.18
Storage-Frequency Relationship for Combined Lakes Possum Kingdom and Granbury
For Initial Storage Contents of 50% of 684,834 acre-feet Capacity

	50% Full at Beginning of April (Month 4)				50% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	548,945	589,079	617,260	633,358	455,019	524,333	557,992	635,975
Min	44.57	38.20	47.43	46.36	41.41	40.62	39.36	46.82
99%	48.88	49.96	52.56	56.79	42.98	41.15	39.70	48.78
98%	49.76	50.09	55.39	61.25	43.23	41.42	40.25	49.51
95%	53.69	58.39	61.31	64.96	43.76	43.33	45.84	59.77
90%	56.36	61.47	67.91	71.58	44.70	50.30	52.76	74.52
80%	63.07	69.03	77.88	85.91	50.69	55.75	62.88	88.03
70%	70.99	79.79	86.66	92.00	53.06	63.15	68.23	98.13
60%	75.47	86.29	94.28	97.82	56.49	66.97	75.92	100.00
50%	79.73	92.02	99.41	99.75	62.04	72.88	88.98	100.00
40%	88.59	97.33	100.00	100.00	66.18	88.02	98.43	100.00
30%	95.80	99.83	100.00	100.00	74.90	100.00	100.00	100.00
20%	100.00	100.00	100.00	100.00	90.82	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	99.62	100.00	100.00	100.00
Max	684,834	684,834	684,834	684,834	684,834	684,834	684,834	684,834

Table 4.19
Storage-Frequency Relationship for Lakes Belton, Stillhouse Hollow, Granger, and Georgetown
For Initial Storage Contents of 50% of 744,777 acre-feet Capacity

	50% Full at Beginning of April (Month 4)				50% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	561,298	552,536	590,050	628,075	394,611	469,711	539,628	619,327
Min	45.21	38.71	36.52	35.08	47.93	38.19	35.03	36.14
99%	46.10	38.94	37.95	36.61	48.10	39.75	38.90	37.16
98%	46.15	40.35	38.71	39.51	48.30	39.79	39.76	39.95
95%	48.37	45.24	44.21	49.32	48.89	40.34	40.16	42.83
90%	52.42	48.11	48.74	51.65	49.53	41.07	41.92	52.08
80%	55.94	52.43	53.07	64.45	49.98	43.50	47.02	64.99
70%	59.90	58.07	67.71	74.68	51.39	47.23	51.70	72.54
60%	67.78	67.76	76.82	89.22	52.34	53.14	61.17	83.19
50%	75.05	75.52	87.85	95.39	55.637	57.82	71.48	93.69
40%	83.03	85.35	94.40	99.56	58.22	66.77	87.64	99.81
30%	92.70	92.05	96.95	100.00	62.61	72.73	96.62	100.00
20%	98.81	97.04	99.82	100.00	71.37	86.35	100.00	100.00
10%	100.00	99.13	100.00	100.00	82.81	98.97	100.00	100.00
Max	744,777	744,777	744,777	744,777	655,617	744,777	744,777	744,777

Table 4.20
Storage-Frequency Relationship for Lake Proctor for
Initial Storage Contents of 50% of 54,702 acre-feet Capacity

	50% Full at Beginning of April (Month 4)				50% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	30,683	26,032	26,483	30,544	21,275	22,101	26,479	31,818
Min	40.13	28.73	27.32	23.79	35.63	31.64	28.98	22.03
99%	40.79	29.61	27.35	24.57	35.70	32.99	29.24	23.21
98%	41.21	30.07	27.43	24.70	36.09	33.08	29.62	23.27
95%	42.18	30.91	27.83	25.92	36.84	33.37	31.13	24.52
90%	42.93	31.41	28.47	27.18	37.49	34.00	31.59	26.60
80%	43.51	32.35	29.73	28.42	38.12	34.84	32.90	28.23
70%	43.96	33.36	30.75	28.87	38.55	35.98	33.74	28.69
60%	44.17	33.61	30.95	29.45	38.91	36.15	33.95	28.88
50%	44.33	33.70	31.11	36.71	38.97	36.20	34.00	35.22
40%	44.42	34.38	32.48	58.76	39.02	36.24	34.13	87.71
30%	45.35	37.45	44.43	89.60	39.05	36.43	37.92	99.06
20%	80.13	84.76	88.91	99.90	39.45	37.83	91.29	100.00
10%	100.00	98.90	100.00	100.00	40.54	44.10	100.00	100.00
Max	54,702	54,702	54,702	54,702	23,262	54,702	54,702	54,702

Table 4.21
Storage-Frequency Relationship for Lake Aquilla for
Initial Storage Contents of 50% of 41,700 acre-feet Capacity

	50% Full at Beginning of April (Month 4)				50% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	33,403	30,027	33,456	35,726	19,855	26,002	30,066	35,823
Min	41.72	31.50	30.46	30.01	38.30	30.80	27.45	28.38
99%	42.22	34.72	32.20	32.38	38.42	31.73	31.27	28.79
98%	43.85	36.92	33.48	35.36	38.92	32.50	31.44	30.56
95%	46.69	39.35	38.10	41.23	40.34	35.05	33.09	41.62
90%	49.22	41.20	42.78	52.63	41.09	35.72	34.63	53.96
80%	56.19	50.99	56.83	70.80	42.23	37.24	39.57	68.38
70%	66.06	58.10	72.07	81.20	42.45	39.55	48.46	80.29
60%	75.09	65.42	81.76	88.99	43.22	43.15	62.87	95.40
50%	89.18	76.30	87.16	98.56	43.91	53.05	74.26	97.66
40%	96.20	84.27	92.75	100.00	47.48	66.45	98.52	100.00
30%	100.00	87.89	100.00	100.00	50.14	83.51	100.00	100.00
20%	100.00	93.23	100.00	100.00	53.64	100.00	100.00	100.00
10%	100.00	95.04	100.00	100.00	72.86	100.00	100.00	100.00
Max	41,700	41,700	41,700	41,700	39,563	41,700	41,700	41,700

Table 4.22
Storage-Frequency Relationship for Lake Somerville for
Initial Storage Contents of 50% of 154,254 acre-feet Capacity

	50% Full at Beginning of April (Month 4)				50% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	120,685	118,251	130,120	141,212	85,600	109,272	128,767	137,514
Min	45.98	38.53	36.98	36.97	41.32	37.85	37.56	36.58
99%	46.21	40.73	37.55	46.64	41.48	39.89	40.51	43.53
98%	46.94	41.33	41.65	50.46	42.16	40.65	44.87	46.50
95%	49.14	44.26	44.28	52.84	43.07	41.74	47.62	53.85
90%	51.13	47.39	51.37	62.23	44.23	43.76	50.64	59.69
80%	56.25	52.04	60.19	78.48	45.08	47.30	61.13	72.56
70%	60.36	61.43	75.54	99.06	45.75	53.27	69.17	94.54
60%	64.81	70.32	91.03	100.00	47.23	59.09	85.84	98.67
50%	82.35	80.46	98.89	100.00	50.16	66.67	99.69	99.53
40%	95.96	93.17	100.00	100.00	51.78	76.29	100.00	100.00
30%	100.00	95.83	100.00	100.00	54.24	95.28	100.00	100.00
20%	100.00	98.87	100.00	100.00	59.20	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	93.46	100.00	100.00	100.00
Max	154,254	154,254	154,254	154,254	154,254	154,254	154,254	154,254

Table 4.23
Storage-Frequency Relationship for Lake Limestone for
Initial Storage Contents of 50% of 208,017 acre-feet Capacity

	50% Full at Beginning of April (Month 4)				50% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	147,852	134,272	156,101	173,591	93,590	126,657	156,249	171,720
Min	40.22	30.23	26.16	24.97	36.75	32.41	30.82	24.24
99%	41.33	31.48	29.20	28.24	37.06	33.69	31.35	28.46
98%	41.46	32.24	30.43	32.28	37.52	34.72	33.67	28.56
95%	42.66	33.62	33.09	36.68	39.12	35.88	34.98	31.92
90%	44.96	35.45	38.16	40.65	39.67	37.94	37.27	42.52
80%	49.68	42.40	44.75	60.73	40.32	39.60	42.69	56.06
70%	53.37	45.10	56.05	78.69	40.52	41.73	55.81	76.58
60%	58.88	52.84	69.22	93.96	41.07	46.15	67.94	94.73
50%	66.15	62.48	85.27	99.55	41.41	52.74	82.90	96.94
40%	77.09	74.22	95.25	100.00	42.97	60.80	99.81	99.46
30%	93.43	85.33	100.00	100.00	44.49	72.45	100.00	100.00
20%	100.00	89.01	100.00	100.00	45.86	93.29	100.00	100.00
10%	100.00	93.43	100.00	100.00	56.77	100.00	100.00	100.00
Max	208,017	208,017	208,017	208,017	208,017	208,017	208,017	208,017

Table 4.24
Storage-Frequency Relationship for Lake Waco for
Initial Storage Contents of 50% of 206,562 acre-feet Capacity

	50% Full at Beginning of April (Month 4)				50% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	163,975	155,891	165,137	178,951	109,499	120,043	155,200	179,850
Min	46.81	37.66	33.83	38.66	37.91	34.50	35.15	34.96
99%	47.41	38.96	35.74	39.70	38.56	35.60	35.35	38.42
98%	47.69	39.29	38.88	41.86	39.40	36.19	36.08	40.41
95%	48.53	43.09	41.51	43.74	39.77	36.79	37.81	45.10
90%	50.88	46.38	46.15	53.10	41.03	39.16	39.97	51.15
80%	57.54	53.26	56.44	66.24	42.70	42.08	43.83	67.70
70%	63.80	58.99	67.25	83.64	43.45	43.65	54.48	85.58
60%	70.49	66.16	79.57	94.37	44.00	45.74	66.80	98.19
50%	82.54	85.09	90.10	100.00	45.10	52.30	79.42	99.72
40%	98.28	90.26	95.72	100.00	46.42	65.14	99.88	100.00
30%	100.00	92.51	100.00	100.00	49.37	75.91	100.00	100.00
20%	100.00	95.78	100.00	100.00	68.20	95.49	100.00	100.00
10%	100.00	100.00	100.00	100.00	85.82	100.00	100.00	100.00
Max	206,562	206,562	206,562	206,562	206,562	206,562	206,562	206,562

Table 4.25
Storage-Frequency Relationship for Combined Lakes Possum Kingdom and Granbury
For Initial Storage Contents of 25% of 684,834 acre-feet Capacity

	25% Full at Beginning of April (Month 4)				25% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	422,401	490,691	544,033	574,319	302,326	404,918	455,414	579,636
Min	21.12	17.14	26.15	25.47	18.24	17.99	17.01	26.82
99%	24.40	27.31	30.71	36.55	19.30	18.77	19.45	27.75
98%	25.62	27.76	33.47	39.25	19.61	18.88	20.02	28.28
95%	29.42	35.68	38.40	44.66	20.27	20.96	24.29	39.71
90%	32.21	38.10	45.56	49.14	21.55	26.74	29.63	53.23
80%	38.93	46.47	54.99	64.34	26.94	32.52	40.25	65.81
70%	46.54	57.81	66.16	73.17	29.15	39.55	45.07	78.86
60%	50.99	63.70	75.42	90.92	32.92	43.43	54.25	93.42
50%	56.26	71.78	88.52	96.89	38.35	50.62	66.19	99.53
40%	64.07	80.13	99.06	99.60	42.38	65.99	78.57	100.00
30%	73.92	98.56	100.00	100.00	52.18	83.14	91.55	100.00
20%	92.26	99.99	100.00	100.00	66.82	97.08	100.00	100.00
10%	100.00	100.00	100.00	100.00	79.64	100.00	100.00	100.00
Max	684,834	684,834	684,834	684,834	684,834	684,834	684,834	684,834

Table 4.26
Storage-Frequency Relationship for Lakes Belton, Stillhouse Hollow, Granger, and Georgetown
For Initial Storage Contents of 25% of 744,777 acre-feet Capacity

End of Month	25% Full at Beginning of April (Month 4)				25% Full at Beginning of July (Month 7)			
	6 Jun	9 Sep	12 Dec	3 Mar	9 Sep	12 Dec	3 Mar	6 Jun
Mean	420,208	422,160	476,026	538,402	215,350	311,078	411,926	527,269
Min	20.84	15.45	14.38	13.57	18.70	15.19	12.58	13.88
99%	21.76	15.89	14.71	14.65	18.78	16.16	14.98	14.17
98%	21.79	16.87	16.31	16.06	18.88	16.49	16.00	16.57
95%	23.92	21.35	20.83	25.87	19.23	16.77	16.67	20.26
90%	27.92	24.32	24.95	28.73	19.54	17.50	18.63	28.77
80%	31.56	29.02	30.26	41.96	19.94	19.70	23.56	41.95
70%	35.19	34.56	45.02	53.20	21.14	23.21	27.94	51.34
60%	42.99	45.16	54.97	68.77	22.11	29.01	38.24	60.71
50%	50.96	52.12	67.06	82.85	24.87	34.23	49.28	80.56
40%	59.02	62.50	78.81	92.68	27.07	42.82	68.10	94.24
30%	69.53	74.14	87.53	97.58	31.11	49.45	79.73	99.89
20%	89.89	91.99	99.22	100.00	38.38	64.79	96.51	100.00
10%	100.00	97.57	100.00	100.00	48.53	81.54	100.00	100.00
Max	744,777	744,777	744,777	744,777	476,478	744,777	744,777	744,777

Table 4.27
Storage-Frequency Relationship for Lake Proctor for
Initial Storage Contents of 25% of 54,702 acre-feet Capacity

End of Month	25% Full at Beginning of April (Month 4)				25% Full at Beginning of July (Month 7)			
	6 Jun	9 Sep	12 Dec	3 Mar	9 Sep	12 Dec	3 Mar	6 Jun
Mean	17,773	14,260	15,180	18,947	8,529	9,441	12,746	20,826
Min	17.46	8.03	6.63	4.37	13.59	10.55	8.57	3.25
99%	17.87	8.62	6.71	4.75	13.62	11.34	8.73	3.91
98%	18.14	8.83	6.75	4.83	13.86	11.43	8.89	3.95
95%	18.76	9.33	6.95	5.28	14.32	11.61	9.79	4.68
90%	19.23	9.69	7.36	5.56	14.73	12.01	10.09	5.70
80%	19.59	10.27	7.95	6.46	15.10	12.49	10.83	6.60
70%	19.88	10.86	8.48	6.96	15.37	13.17	11.29	6.89
60%	19.99	10.94	8.73	7.10	15.61	13.29	11.45	7.01
50%	20.10	11.06	8.82	7.21	15.64	13.32	11.53	7.12
40%	20.16	11.14	8.92	9.72	15.67	13.35	11.57	30.50
30%	20.54	11.69	11.13	60.30	15.69	13.38	11.84	76.38
20%	30.18	49.64	67.35	95.29	15.93	13.96	14.40	100.00
10%	100.00	89.29	100.00	100.00	16.59	15.94	75.14	100.00
Max	54,702	54,702	54,702	54,702	9,769	54,702	54,702	54,702

Table 4.28
Storage-Frequency Relationship for Lake Aquilla for
Initial Storage Contents of 25% of 41,700 acre-feet Capacity

	25% Full at Beginning of April (Month 4)				25% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	27,126	24,424	29,276	32,545	10,430	18,239	24,224	32,541
Min	18.48	10.60	9.38	8.09	15.51	10.23	7.42	6.75
99%	18.80	13.15	10.99	11.46	15.60	10.81	9.78	7.77
98%	19.87	14.62	11.83	13.47	15.90	11.22	10.25	10.02
95%	22.81	17.03	16.25	20.57	16.78	12.95	10.79	20.66
90%	25.21	19.12	22.38	31.28	17.34	13.56	12.55	32.67
80%	31.98	29.13	35.57	51.08	18.03	14.64	17.24	47.53
70%	42.13	35.65	51.29	63.03	18.12	17.01	26.67	58.65
60%	50.81	44.51	67.46	82.40	18.66	21.19	40.35	93.58
50%	65.19	57.65	82.42	97.25	19.45	30.15	51.78	97.12
40%	81.15	75.48	88.85	100.00	22.55	43.39	78.95	98.73
30%	97.42	84.90	98.66	100.00	25.71	59.88	100.00	100.00
20%	100.00	89.98	100.00	100.00	29.31	81.24	100.00	100.00
10%	100.00	95.04	100.00	100.00	48.42	100.00	100.00	100.00
Max	41,700	41,700	41,700	41,700	39,563	41,700	41,700	41,700

Table 4.29
Storage-Frequency Relationship for Lake Somerville for
Initial Storage Contents of 25% of 154,254 acre-feet Capacity

	25% Full at Beginning of April (Month 4)				25% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	95,345	96,151	113,687	130,697	51,984	82,692	109,933	125,357
Min	22.12	17.18	16.14	16.47	18.84	16.41	16.37	15.99
99%	22.24	17.54	16.73	25.50	18.94	17.86	18.45	20.08
98%	22.55	19.03	19.81	28.51	19.39	18.27	21.09	25.07
95%	24.60	21.53	21.46	29.91	20.06	19.29	24.38	31.75
90%	27.13	24.33	27.92	38.68	20.91	20.62	27.84	36.05
80%	31.66	28.67	36.61	56.32	21.36	23.36	37.89	50.21
70%	35.81	37.75	51.94	87.27	22.00	30.30	45.98	71.26
60%	40.66	47.00	71.42	98.31	23.39	35.67	62.08	97.32
50%	57.65	56.86	92.78	100.00	26.51	43.24	86.87	99.36
40%	72.42	80.69	100.00	100.00	27.97	52.53	99.13	100.00
30%	97.03	93.63	100.00	100.00	29.91	72.63	100.00	100.00
20%	100.00	97.58	100.00	100.00	35.44	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	76.61	100.00	100.00	100.00
Max	154,254	154,254	154,254	154,254	154,254	154,254	154,254	154,254

Table 4.30
Storage-Frequency Relationship for Lake Limestone for
Initial Storage Contents of 25% of 208,017 acre-feet Capacity

	25% Full at Beginning of April (Month 4)				25% Full at Beginning of July (Month 7)			
End of Month	6 Jun	9 Sep	12 Dec	3 Mar	9 Sep	12 Dec	3 Mar	6 Jun
Mean	109,088	98,149	125,893	151,686	44,891	84,419	125,601	152,378
Min	16.80	9.30	6.28	5.24	14.73	11.43	9.28	3.74
99%	17.72	9.87	7.92	6.71	14.93	12.16	10.40	5.91
98%	17.87	9.98	9.82	10.07	15.21	12.77	11.21	6.82
95%	18.68	11.76	10.86	15.12	16.15	13.55	12.10	10.37
90%	20.61	12.85	15.87	18.54	16.70	14.79	14.21	20.16
80%	25.87	19.30	21.76	38.24	16.91	16.26	19.55	33.83
70%	28.88	22.19	32.97	56.54	17.10	18.58	32.48	53.83
60%	34.37	29.45	46.16	79.25	17.56	22.54	44.70	86.76
50%	41.63	39.20	63.33	89.18	17.77	29.33	59.71	95.45
40%	52.52	50.95	82.74	99.05	19.43	37.61	85.12	97.28
30%	70.10	66.50	91.84	100.00	20.70	49.19	97.91	100.00
20%	96.57	87.56	100.00	100.00	22.04	69.83	100.00	100.00
10%	100.00	91.96	100.00	100.00	33.23	97.84	100.00	100.00
Max	208,017	208,017	208,017	208,017	174,152	208,017	208,017	208,017

Table 4.31
Storage-Frequency Relationship for Lake Waco for
Initial Storage Contents of 25% of 206,562 acre-feet Capacity

	25% Full at Beginning of April (Month 4)				25% Full at Beginning of July (Month 7)			
End of Month	6 Jun	9 Sep	12 Dec	3 Mar	9 Sep	12 Dec	3 Mar	6 Jun
Mean	131,087	126,782	140,096	160,179	60,919	86,877	124,511	160,618
Min	22.33	14.65	11.19	15.44	14.67	11.34	11.82	12.68
99%	22.82	15.46	12.90	16.85	15.35	12.32	12.33	15.19
98%	23.57	16.18	16.17	18.91	15.72	12.75	12.68	17.78
95%	24.42	19.88	18.23	22.12	16.08	13.82	14.63	22.41
90%	26.56	23.06	23.86	30.26	17.35	15.56	16.57	28.56
80%	33.14	30.35	33.97	43.09	18.78	18.33	20.38	44.60
70%	39.24	35.61	43.46	64.59	19.54	20.02	30.60	62.66
60%	45.93	42.67	56.36	85.74	20.17	22.12	42.87	86.76
50%	58.07	61.52	79.19	98.03	21.17	28.59	55.81	98.57
40%	76.25	81.82	91.07	100.00	22.85	41.36	83.00	100.00
30%	98.07	91.72	98.03	100.00	25.47	51.86	100.00	100.00
20%	100.00	94.56	100.00	100.00	44.26	71.52	100.00	100.00
10%	100.00	100.00	100.00	100.00	61.35	100.00	100.00	100.00
Max	206,562	206,562	206,562	206,562	206,562	206,562	206,562	206,562

CHAPTER 5
CONDITIONAL RELIABILITY MODELING
BASED ON THE PROBABILITY ARRAY METHODOLOGY

The CRM analyses presented in the preceding Chapter 4 are based on the WRAP equal-weight option. These same analyses are repeated in Chapter 5 using the probability array option. The objective of Chapter 5 is to investigate opportunities for improving the accuracy of CRM results by switching from the default equal-weight methodology to probability array based methods.

The CRM analyses of Chapters 4 and 5 use the same *SIM* input dataset. As described in Chapter 4, the Brazos River Authority Condensed BRAC2008 DAT file is combined with the BRAC8 FLO and EVA files. The CRM analyses of the 12 BRA reservoirs focus on developing frequency tables for storage levels three to 12 months later for individual reservoirs and multiple-reservoir sub-systems for specified initial storage contents at the beginning of either April or July.

<u>Conditional Reliability Modeling (CRM) Options</u>

Choices in applying CRM are outlined in Table 5.1 which is a slightly condensed version of Table 2.25 found in Chapter 7 of the *Reference Manual* [3]. Choosing between the equal-weight and probability array options is a key consideration in WRAP CRM. The probability array option adds complexity but may improve the accuracy of the probability estimates. The Brazos River Basin CRM analyses are repeated with the equal-weight (Chapter 4) and probability array (Chapter 5) options and compared in Chapter 5.

Table 5.1
Outline of CRM Computational Options

1. Equal-Weight Option
    * choice of annual or monthly cycle options (*SIM CR* record)
2. Probability Array Option (*CR* record, *5CR1* and *5CR2* records)
    - Flow-Frequency (FF) Relationship Option
        * choice of annual or monthly cycle options
        * selection of control points for naturalized flows
        * upper and lower limits defining reservoir storage range
        * log-normal distribution or Weibull relative frequency
    - Storage-Flow-Frequency (SFF) Relationship Option
        * choice of annual or monthly cycle options
        * selection of control points for storages and flows
        * upper and lower limits defining reservoir storage range
        * choice of regression equation
        * log-normal distribution or Weibull relative frequency

The annual cycle option is adopted for the Brazos River Basin study rather the monthly cycle option in both the equal-weight analyses of Chapter 4 and probability array analyses of Chapter 5. The 1900-2007 hydrologic period-of-analysis provides a relatively large number of annual sequences, which supports use of the annual cycle option. Seasonal characteristics of flow are important and are captured with the annual cycle option.

Water supply, hydroelectric power, and environmental instream flow reliabilities and reservoir storage levels over the next several months depend on both the:

1. amount of water currently available in reservoir storage
2. hydrology that occurs over the next several-month period of interest as represented by naturalized flows and net reservoir evaporation rates

Beginning reservoir storage and naturalized stream flow represent the two sources of available water. The relative importance of these two sources in determining supply reliabilities and storage frequencies depends upon their relative magnitude. With both the equal-weight and probability array methods, initial storage conditions are specified by the model-user, and *SIM/TABLES* analyses are based on dividing the hydrologic period-of-analysis into multiple hydrologic sequences.

The difference between the equal-weight and probability array modeling strategies is the approach adopted within *TABLES* for assigning probabilities to each hydrologic sequence. For example, the Brazos River Basin CRM analyses presented in this report use 107 annual hydrologic sequences derived from a 1900-2007 period-of-analysis. With the equal-weight method, each of the 107 simulations are weighted the same in the frequency and reliability analyses, which is equivalent to assigning a probability of 1/107 to each of the 107 simulations. The probability array option is based on assigning varying probabilities to the 107 simulations.

The equal-weight method is a valid CRM approach which can be expected to provide reasonably accurate, useful modeling results. However, under certain circumstances, the probability array based methods may improve the accuracy of CRM results. The following two key issues are addressed in adopting probability array options to enhance CRM accuracy.

1. finite length of the hydrologic period-of-analysis
2. hydrologic persistence which may be viewed in terms of the relationship between preceding reservoir storage contents and the likelihood of stream flow volumes

The accuracy of CRM increases with length of the hydrologic period-of-analysis. Brazos River Basin CRM studies have been enhanced by extending the original TCEQ WAM System period-of-analysis of 1940-1997 (58 years) to 1900-2007 (108 years). A 108-year period-of-analysis should provide more dependable CRM results than a 58-year period-of-analysis. There is a trade-off in that flows and net-evaporation rates for 1900-1939 are less accurate than later years because data had to be synthesized due to a much smaller number of gaging stations in earlier years [1].

Referring to Table 5.1, either the log-normal probability distribution or relative frequency sub-options are available with either the FF array or SFF array sub-options of the probability array option. These methods are explained in Chapter 7 of the *Reference Manual* [3]. The relative frequency (equal-weight) based concept reflected in the Weibull formula was adopted for the Brazos River Basin CRM because of the relative large number (107) of annual hydrologic sequences provided by the 1900-2007 hydrologic period-of-analysis. The advantages of the alternative of applying the log-normal probability distribution would have increased if only the 1940-1997 hydrology was available. Flow characteristics are best represented by a long record of flows. However, modeling flows with the log-normal distribution, though approximate, provides additional information that becomes even more pertinent if the length of flow record is shorter.

The SFF array option is adopted for the Brazos River Basin study rather than the FF array option. Unlike the FF array option, the SFF relationship approach is based on relating flow frequencies to preceding storage. The FF array option allows adoption of the log-normal distribution without relating flow frequencies to preceding storage.

The relationship between stream flow and preceding storage is the second modeling issue noted above. Low reservoir storage levels result from past dry conditions which imply a higher likelihood of continued dry conditions than does higher present reservoir storage levels. Likewise, future high flows are logically more likely if reservoirs are presently at high storage levels. The storage-flow-frequency (SFF) array sub-option of the probability array option deals with this relationship between naturalized stream flow and preceding storage. This is a major focus of discussion throughout Chapter 5.

The SFF array is developed from the results of a conventional long-term *SIM* simulation using the same input dataset, exclusive of *CR* record, used in the CRM. Frequency-storage statistics from the long-term *SIM* simulation are developed in the next section which provides insight in the applicability of the SFF option in CRM. The correlation between naturalized flow and preceding storage is also important in exploring CRM options. Storage-flow correlation statistics are also presented prior to repeating the CRM analysis of Chapter 4 using the probability array method in place of the equal-weight method.

Storage Frequency Statistics for the Conventional Long-Term Simulation

The SIM input dataset used in Chapters 4 and 5 consists of the BRAC2008 DAT file in combination with the BRAC8 FLO and EVA files. Storage frequency statistics for the conventional long-term *SIM* simulation are presented in Tables 5.2 through 5.7. Tables 5.2, 5.4, and 5.6 provide frequency statistics considering all 1,296 months of the 1900-2007 hydrologic period-of-analysis. Tables 5.3, 5.5, and 5.7, based on 108 annual sequences, shows the frequency or likelihood of reservoir storage levels at the beginning of April and July (end of March and June) dropping to various levels, such as the 100%. 75%, 50%, and 25% of capacity adopted in the CRM analyses.

The storage-flow-frequency-frequency (SFF) array developed in the CRM methodology is based on simulation results from this conventional long-term *SIM* simulation. Long-term simulation results used to develop the SFF array should include storage levels covering the entire range of storage levels generated in the CRM simulations. As discussed later, this is a key issue in the Brazos River Basin CRM study. The storage levels in some of the reservoirs do not drop low enough or low storage levels do not occur frequently enough during the long-term simulation to generate adequate data to develop an accurate SFF relationship for the CRM analyses that specify initial storage conditions of 25% or 50% of capacity or perhaps even 75% of capacity in some cases.

Table 5.2
Storage Frequency Statistics for All Months

Reservoir	P.K.	Granbury	Total
Mean	548,017	126,060	674,077
Minimum	83.99	24.93	72.80
99%	90.57	50.79	83.80
98%	92.53	58.29	86.54
95%	95.33	70.35	91.25
90%	97.67	82.3	94.81
80%	99.38	91.5	97.74
70%	99.94	97.71	99.32
60%	100.00	100.00	99.99
50%	100.00	100.00	100.00
40%	100.00	100.00	100.00
30%	100.00	100.00	100.00
20%	100.00	100.00	100.00
10%	100.00	100.00	100.00
Maximum	552,013	132,821	684,834

Table 5.3
Storage Frequency Statistics for the End of March and June

	Storage at End of March			Storage at End of June		
Reservoir	P.K.	Granbury	Total	P.K.	Granbury	Total
Mean	548,061	126,081	674,142	550,890	129,409	680,299
Minimum	84.60	26.66	73.36	94.17	29.54	81.63
99%	89.53	49.64	83.67	94.61	60.65	89.32
98%	92.25	53.86	84.54	95.74	62.83	91.93
95%	97.06	73.18	91.69	99.41	80.77	94.48
90%	98.22	82.57	95.66	99.93	96.75	99.36
80%	99.33	93.15	97.88	100.00	100.00	100.00
70%	99.73	98.47	99.25	100.00	100.00	100.00
60%	100.00	100.00	100.00	100.00	100.00	100.00
50%	100.00	100.00	100.00	100.00	100.00	100.00
40%	100.00	100.00	100.00	100.00	100.00	100.00
30%	100.00	100.00	100.00	100.00	100.00	100.00
20%	100.00	100.00	100.00	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00	100.00
Maximum	552,013	132,821	684,834	552,013	132,821	684,834

Table 5.4
Storage Frequency Statistics for All Months

Reservoir	Belton	Stillhouse	Georgetown	Granger	Total
Mean	414,610	215,725	31,727	48,507	710,568
Minimum	70.90	61.04	0.00	48.85	65.91
99%	74.48	74.30	0.78	59.80	72.86
98%	76.75	77.22	11.54	71.12	76.14
95%	82.06	83.06	40.78	82.18	80.81
90%	87.17	87.68	57.15	86.86	86.22
80%	91.87	92.40	74.60	91.84	91.32
70%	94.36	95.78	84.07	96.05	94.52
60%	97.02	98.11	90.03	99.85	96.67
50%	99.07	100.00	95.02	100.00	98.30
40%	100.00	100.00	100.00	100.00	99.61
30%	100.00	100.00	100.00	100.00	100.00
20%	100.00	100.00	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00
Maximum	432,978	224,279	36,980	50,540	744,777

Table 5.5
Storage Frequency Statistics for the End of March and June

	Storage at End of March					Storage at End of June				
	Belton	Stillhouse	Georgetown	Granger	Total	Belton	Stillhouse	Georgetown	Granger	Total
Mean	415,111	216,552	32,001	49,070	712,735	424,200	219,883	33,471	49,603	727,157
Min	70.90	61.04	0.00	48.85	65.91	80.03	76.39	0.00	70.85	82.35
99%	74.61	77.23	0.69	60.86	71.04	81.84	83.09	23.35	72.34	82.67
98%	76.17	79.66	7.16	73.03	78.56	82.61	83.43	26.31	86.54	83.02
95%	81.15	84.37	39.81	81.16	81.04	87.11	86.59	53.62	88.40	85.20
90%	87.09	88.20	60.53	90.35	87.08	92.17	92.04	62.30	94.87	89.62
80%	91.15	91.99	72.04	97.42	91.15	98.28	98.27	84.35	97.70	96.47
70%	94.87	97.17	84.16	100.00	95.18	99.58	100.00	96.32	100.00	99.06
60%	99.16	99.69	96.11	100.00	98.52	100.00	100.00	99.77	100.00	99.91
50%	100.00	100.00	100.00	100.00	99.78	100.00	100.00	100.00	100.00	100.00
40%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
30%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
20%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Max	432,978	224,279	36,980	50,540	744,777	432,978	224,279	36,980	50,540	744,777

Notes for Tables: The mean storage volume and maximum storage volume at the top and bottom, respectively, of each column are in units of acre-feet. Exceedance frequencies are listed in the first column. The reservoir storage volumes associated with the specified exceedance frequencies are expressed as a percentage of storage capacity.

Table 5.6
Storage Frequency Statistics for All Months

Reservoir	Proctor	Aquilla	Somerville	Limestone	Waco	Total
Mean	43,248	37,983	150,005	189,059	195,805	616,101
Minimum	0.00	43.16	71.87	37.48	64.49	56.90
99%	0.00	52.76	75.81	43.80	73.71	63.81
98%	0.00	54.62	82.19	50.05	76.87	69.65
95%	18.54	69.08	87.38	63.78	81.13	75.49
90%	39.20	76.41	91.74	76.13	85.20	81.24
80%	63.32	83.26	94.58	84.43	89.56	87.08
70%	76.73	87.21	96.83	88.03	92.39	90.43
60%	81.73	91.48	99.16	91.81	95.02	93.02
50%	86.87	95.46	100.00	95.23	97.81	95.25
40%	93.05	99.01	100.00	98.51	100.00	96.96
30%	98.86	100.00	100.00	100.00	100.00	98.48
20%	100.00	100.00	100.00	100.00	100.00	99.70
10%	100.00	100.00	100.00	100.00	100.00	100.00
Maximum	54,702	41,700	154,254	208,017	206,562	665,235

Table 5.7
Storage Frequency Statistics for the End of March and June

	Storage at End of March					Storage at End of June				
	Proctor	Aquilla	Somerville	Limestone	Waco	Proctor	Aquilla	Somerville	Limestone	Waco
Mean	42,867	38,450	152,065	194,146	197,817	46,787	39,988	152,269	196,694	202,335
Min	0.00	43.76	75.80	43.83	72.10	0.00	63.08	80.06	49.54	79.78
99%	0.00	50.50	82.23	47.41	74.36	2.03	65.08	86.29	55.73	84.79
98%	0.90	53.76	82.81	57.04	77.70	9.19	69.15	89.48	60.59	85.20
95%	14.54	70.17	91.12	69.73	81.12	28.48	72.43	93.90	71.36	89.15
90%	37.57	75.42	94.88	76.83	85.18	45.98	90.02	96.44	82.83	92.40
80%	63.10	84.46	99.32	85.99	89.12	70.87	95.55	98.50	92.47	96.71
70%	76.35	90.32	100.00	95.78	95.69	91.57	96.68	99.24	95.91	98.72
60%	79.85	97.85	100.00	99.17	100.00	95.49	98.04	99.98	97.21	99.80
50%	85.91	100.00	100.00	100.00	100.00	98.79	100.00	100.00	98.45	100.00
40%	97.04	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
30%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
20%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Max	54,702	41,700	154,254	208,017	206,562	54,702	41,700	154,254	208,017	206,562

Each column of Tables 5.2−5.7, other than the first column, begins with the mean storage in acre-feet and ends with the maximum of the 1,296 (Tables 5.2, 5.4, 5.6) or 108 (Tables 5.3, 5.5, 5.7) storage volumes in acre-feet. The second quantity in each column is the minimum of the 1,296 or 108 storage volumes expressed as a percentage of reservoir storage capacity. End-of-month storage volume expressed as a percentage of storage capacity is tabulated for the 12 exceedance frequencies tabulated in the first column.

The storage frequency statistics tabulated in Tables 5.2 through 5.7 are from the same long-term *SIM* simulation used to develop the SFF array used in the probability array CRM computations presented later in this chapter. All of the frequency tables in Chapters 4 and 5 were developed using the *TABLES* 2FRE record with format set by option 4 for parameter TABLE in 2FRE field 5. The total column in *TABLES* frequency tables are not the summation of the previous columns of the table. Rather, *TABLES* sums storage volumes in each month, and performs the frequency computations for the resulting dataset. For example, the total column of Table 5.2 is for a dataset of 1,286 summations of end-of-month storage in Lakes Possum Kingdom and Granbury.

Storage frequency statistics for the 1,296 months of the 1900-2007 hydrologic period-of-analysis are presented in Table 5.2 for Possum Kingdom Reservoir, Granbury Reservoir, and the total storage in the combined Possum Kingdom and Granbury Reservoirs. The combined total end-of-month storage during the 1,296 months of the *SIM* simulation range from 72.80% to 100.00% of capacity. The reservoirs are full to capacity 60 percent of the time.

End-of-March (beginning-of-April) and end-of-June (beginning-of-July) storage frequency statistics for the 108 years of the 1900-2007 hydrologic period-of-analysis are presented in Table 5.3 for Possum Kingdom Reservoir, Granbury Reservoir, and the total storage in the combined Possum Kingdom and Granbury Reservoirs. The combined total end-of-March storage during the 108 years of the *SIM* simulation range from 73.36% to 100% of capacity. The reservoirs are full to capacity at the end of March during 60 percent of the 108 years.

Similarly, storage frequency statistics for Lakes Belton, Stillhouse Hollow, Georgetown, and Granger are tabulated in Tables 5.4 and 5.5, and storage statistics for Lakes Proctor, Aquilla, Somerville, Limestone, and Waco are provided in Tables 5.6 and 5.7. All of the reservoirs are full to capacity much of the time. The majority of the reservoirs are full to capacity at least half of the time. Five of the 12 reservoirs never drop to below 60% of their storage capacity during the 1900-2007 simulation. Lakes Proctor and Georgetown are empty in at least one month and display a full range of storage levels ranging from full to empty.

Correlation between Naturalized Flow Volume and Preceding Storage Volume

The relative advantage of adopting the equal-weight option versus probability array option depends upon the degree of correlation between naturalized flow volume and preceding reservoir storage volume. With negligible correlation, the equal-weight option is probably more accurate than the probability array option. A significant degree of correlation implies that the more complex probability array approach is likely worthwhile. If the probability array option is adopted, a decision is required regarding the number of months of naturalized flow volume to sum in relating naturalized flow volume to preceding storage volume. Correlation statistics reflecting levels of storage-flow correlation are relevant for this decision as well.

Definition of Correlation Coefficients

Correlation coefficients relating naturalized flow volumes during a specified period of months to the preceding reservoir storage volume are developed with *TABLES* using the 5COR record. The correlation coefficients are also automatically included in the information developed with a 5CR1 record. The 5COR record facilitates focusing solely on computing correlation coefficients without dealing with the other features included with the 5CR1 record. The naturalized flow volumes at any number of control points may be summed in *TABLES* for any number of months. The storage volume in any number of reservoirs may be summed.

The standard linear correlation coefficient and Spearman rank correlation coefficient defined by Equations 7.17 and 7.18 of the *Reference Manual* are computed by *TABLES*. The Spearman rank correlation coefficient is the linear correlation coefficient computed for the relative ranks of the storage and flow volumes rather than the actual volumes. The linear correlation coefficient equation found in all statistics textbooks and reproduced as Equation 7.17 of the *Reference Manual* is as follows.

$$r = \frac{n\Sigma x_i y_i - (\Sigma x_i)(\Sigma y_i)}{\sqrt{n\Sigma x_i^2 - (\Sigma x_i)^2}\sqrt{n\Sigma y_i^2 - (\Sigma y_i)^2}} \qquad (5.1)$$

The correlation coefficient r provides a measure of the degree of linear correlation between the variables x and y. In the present analyses, x is preceding storage volume and y is naturalized flow volume. Values of the correlation coefficient can range between –1.0 and 1.0.

$$-1.0 \le r \le 1.0$$

A value for r of 1.0 indicates a perfect linear correlation. A plot of x versus y would be a perfect straight line, increasing with increasing magnitudes of x and y. A value for r of –1.0 indicates that x and y are inversely correlated with y decreasing with increasing x. A value for r of 0.0 indicates no linear correlation between x and y. With r near zero, a plot of x versus y would show either random scatter or a highly nonlinear relationship.

The Spearman rank correlation coefficient r_r provides a measure of the degree of linear correlation between the ranks of the variables x and y. The 107 storage and flow volumes (n values of x and y) are ranked from 1 to 107. The linear correlation coefficient of the ranks, rather than the actual quantities, are computed. The rank correlation coefficient, like the standard correlation coefficient, ranges from −1.0 to 1.0 [$-1.0 \le r_r \le 1.0$].

Correlation Coefficients for Naturalized Flow and Preceding Storage Volume

The *SIM* simulation results for a conventional long-term 1900-2007 simulation using the same *SIM* input dataset used throughout this chapter provides the storage and flow volumes for the *TABLES* correlation analyses. The range of reservoir storage volumes covered by this dataset is described by the previous Tables 5.2−5.7 and accompanying discussion. Correlation coefficients computed using the *TABLES* 5COR record are tabulated in the following Tables 5.8−5.11. The x and y variables are the preceding storage volume in the individual reservoir or groups of reservoirs listed in the first column of the tables and the naturalized flow volumes at the control point listed in the second column.

Table 5.8
Linear Correlation Coefficient for Beginning-of-April Storage Versus Naturalized Flow

Reservoirs	Control Point	Total Number of Months for Naturalized Flow Volume 1	2	3	6	9	12
Proctor	515931	0.1575	0.1173	0.1095	0.1216	0.1272	0.1739
Aquilla	515831	0.0473	0.1438	0.1544	0.1521	0.1371	0.1076
Somerville	516431	0.0623	0.1243	0.1198	0.1409	0.1171	0.0981
Limestone	516531	0.0782	0.0184	0.0607	0.1000	0.0888	0.1260
Waco	509431	0.1801	0.2093	0.0654	0.0109	0.0201	0.1265
PK and Granbury	BRDE29	0.1411	0.1310	0.1618	0.1076	0.0878	0.0898
	515531	0.1249	0.1153	0.1497	0.0749	0.0633	0.0747
	515631	0.0142	0.1213	0.1523	0.0938	0.0726	0.0766
Belton, Stillhouse, Granger, Georgetown	LRCA58	0.1792	0.1951	0.2073	0.2309	0.1943	0.1748

Table 5.9
Spearman Correlation Coefficient for Beginning-of-April Storage Versus Naturalized Flow

Reservoirs	Control Point	Total Number of Months for Naturalized Flow Volume 1	2	3	6	9	12
Proctor	515931	0.2939	0.1420	0.1375	0.1813	0.1649	0.2223
Aquilla	515831	0.1887	0.2425	0.2223	0.1927	0.1725	0.1526
Somerville	516431	0.3325	0.3374	0.2938	0.3236	0.2882	0.2265
Limestone	516531	0.2842	0.1680	0.1887	0.2378	0.2025	0.1937
Waco	509431	0.3161	0.2726	0.2391	0.2393	0.2081	0.1577
PK and Granbury	BRDE29	0.2702	0.1659	0.2324	0.0666	0.0129	−0.0011
	515531	0.2084	0.0922	0.1499	−0.0250	−0.0274	−0.0294
	515631	0.2621	0.1489	0.2080	0.0495	0.0033	−0.0251
Belton, Stillhouse, Granger, Georgetown	LRCA58	0.3846	0.3494	0.3640	0.4024	0.3296	0.2638

Beginning-of-April storage volumes are analyzed in Tables 5.8 and 5.9, and beginning-of-July storage volumes are analyzed in Tables 5.10 and 5.11. The correlation statistics reflect the range of storage levels covered in the *SIM* simulation results as described by the previous Tables 4.25 through 4.30. The naturalized flow volumes are summed totals for the one-, two-, three-, six-, nine-, and twelve-month periods following the beginning-of-April or beginning-of-July.

For the five reservoirs Proctor, Aquilla, Somerville, Limestone, and Waco, the storage in each individual reservoir is correlated with naturalized flows at its control point. The combined total storage in the four Little River Sub-Basin reservoirs (Belton, Stillhouse, Granger, Georgetown) is correlated with naturalized flows at the Cameron gage (control point LRCA58) which is located downstream of the four reservoirs. The combined total storage in Possum Kingdom and Granbury Reservoirs is correlated with naturalized flows at the Dennis gage on the Brazos River (control point BRDE29) which is located between the two reservoirs. However, due to the weak correlation, the correlation coefficients for the combined storage in Lakes Possum Kingdom and Granbury and naturalized flows at their control points are also shown in the tables.

Table 5.10
Linear Correlation Coefficient for Beginning-of-July Storage Versus Naturalized Flow

Reservoirs	Control Point	Total Number of Months for Naturalized Flow Volume 1	2	3	6	9	12
Proctor	515931	0.1131	0.1214	0.1554	0.1694	0.1450	0.1196
Aquilla	515831	0.0848	0.0902	0.0933	0.1102	0.0669	0.0602
Somerville	516431	0.1470	0.1633	0.1956	0.1588	0.1764	0.1284
Limestone	516531	0.1114	0.1265	0.1451	0.1704	0.1565	0.0284
Waco	509431	0.0818	0.0766	0.0863	0.1169	0.0189	−0.1801
PK and Granbury	BRDE29	−0.0469	−0.1996	−0.0919	−0.0455	−0.0446	−0.0255
	515531	−0.0887	−0.2609	−0.1279	−0.0799	−0.0657	−0.0403
	515631	−0.0405	0.1849	−0.0975	−0.0531	−0.0536	−0.0428
Belton, Stillhouse, Granger, Georgetown	LRCA58	0.1820	0.1682	0.1814	0.2112	0.0935	0.1118

Table 5.11
Spearman Correlation Coefficient for Beginning-of-July Storage Versus Naturalized Flow

Reservoirs	Control Point	Total Number of Months for Naturalized Flow Volume 1	2	3	6	9	12
Proctor	515931	0.4401	0.4255	0.4145	0.2894	0.2507	0.1063
Aquilla	515831	0.4179	0.4350	0.3867	0.2064	0.1655	0.1268
Somerville	516431	0.4943	0.4791	0.4928	0.3584	0.2681	0.1779
Limestone	516531	0.1265	0.5201	0.4075	0.2876	0.1597	0.0706
Waco	509431	0.3472	0.2935	0.2235	0.2335	0.1331	−0.0134
PK and Granbury	BRDE29	0.2808	0.0206	0.0391	0.0328	−0.0062	−0.0213
	515531	0.2788	0.0095	0.0183	−0.0044	−0.0395	−0.0452
	515631	0.2686	0.0179	0.0362	0.0343	−0.0049	−0.0411
Belton, Stillhouse, Granger, Georgetown	LRCA58	0.6116	0.5846	0.5682	0.3362	0.1199	0.1203

With the exception of the combined Possum Kingdom and Granbury Reservoirs, the correlation coefficients in Tables 5.8, 5.9, 5.10, and 5.11 are similar for all of the reservoirs. The correlation coefficients are small positive numbers indicating a noticeable though relatively small correlation between naturalized flow and preceding storage volume. Correlation coefficients are negative or near zero for the beginning-of-July storage volumes in Possum Kingdom and Granbury Reservoirs, indicating no correlation between preceding storage and naturalized flow. Correlation coefficients computed using three alternative control points [Dennis gage (BRDE29), Possum Kingdom (515531), and Granbury (515631)] similarly indicate no correlation between naturalized flow in the Brazos River and preceding storage volume in Lakes Possum Kingdom and Granbury.

CRM analyses based of the probability array option using storage-frequency-flow (SFF) relationship are presented later in this chapter. For purposes of developing SFF relationships as well as performing frequency analyses, reservoirs are grouped as shown in the first column of Table 4.3 of Chapter 4 and associated with naturalized flows at the control points shown in the second column of Table 4.3. The SFF option feature allows storage volume in any number of reservoirs be summed in *TABLES*. The naturalized flow volumes at any number of control points to may be summed in *TABLES* for any number of months. Three months was selected essentially subjectively, based largely on a review of the correlation coefficients presented in Tables 5.8 −5.11 for one, two, three, six, nine, and twelve months.

<u>Plots of Storage Volume versus 3-Month Naturalized Flow Volume</u>

Naturalized flow volumes during April through June of each of the 108 years of the 1900-2007 *SIM* simulation are plotted versus the corresponding end-of-March (beginning-of-April) reservoir storage volumes in Tables 5.1, 5.3, and 5.5. Naturalized flow volumes during July through September of each of the 108 years of the 1900-2007 *SIM* simulation are plotted versus the corresponding end-of-June (beginning-of-July) storage volumes in Tables 5.2, 5.4, and 5.6.

- Naturalized flows at the Dennis gaging station (control point BRDE29) on the Brazos River versus the sum of the storage in the combined Possum Kingdom and Granbury Reservoirs are plotted in Tables 5.1 and 5.2.
- Naturalized flows the Cameron gaging station (control point BRCA58) on the Little River versus the total storage in Belton, Stillhouse Hollow, Georgetown, and Granger Reservoirs are plotted in Tables 5.3 and 5.4.
- Naturalized flows at the control point of the reservoir versus storage in the individual reservoir are plotted in Tables 5.5−5.14 of each of the reservoirs Proctor, Aquilla, Somerville, Limestone, and Waco.

Naturalized flows vary greatly at all of the sites. However, the simulated storage contents are at or near capacity most of the time. Proctor Reservoir exhibits the most significant variation in storage contents, ranging from full to empty. Aquilla and Limestone Reservoirs also have a greater range of storage draw-downs than the other reservoirs. Draw-downs in Georgetown Reservoir are also significant, but Georgetown is combined with the three other Little River reservoirs in the analyses presented in this report. The storage versus flow plots also show considerable scatter over the range of draw-downs that do occur in the simulation. With the exception of Proctor Reservoir, fitting a regression equation, as discussed in the next section, and developing an accurate SFF array is significantly constrained by the reservoirs being at or near capacity during many of the months of the 1900-2007 *SIM* simulation.

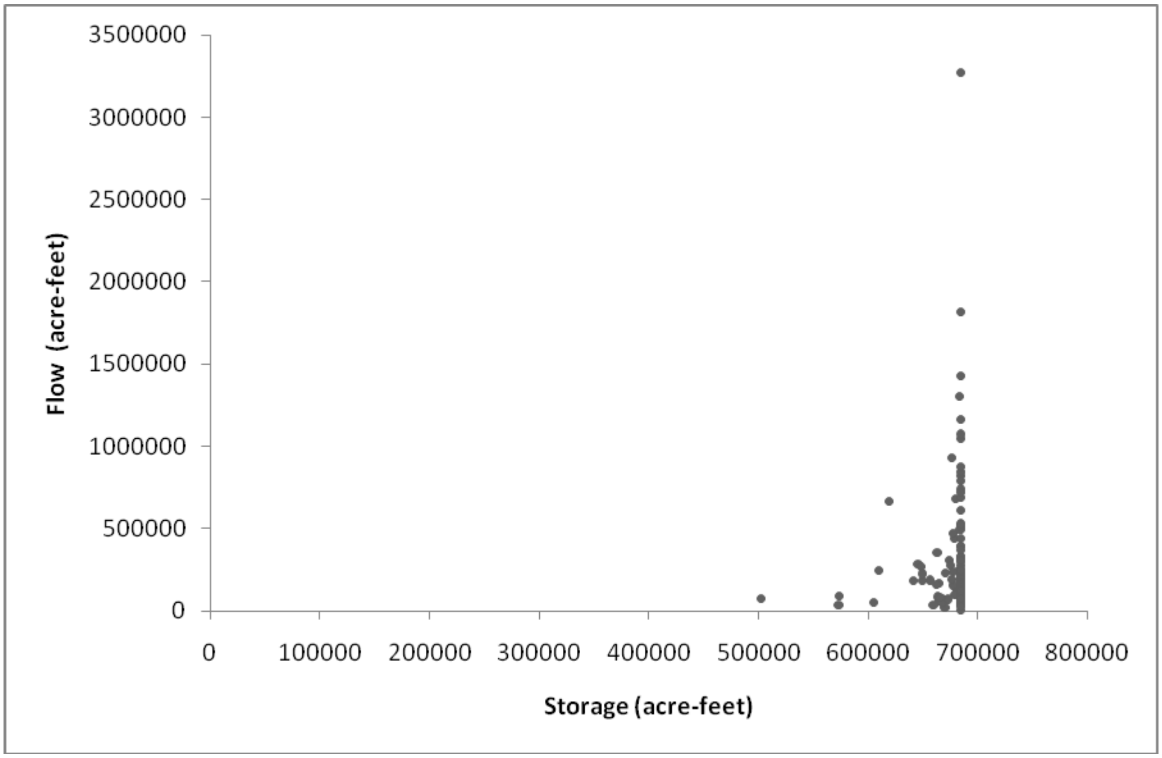

Figure 5.1 End-of-March Storage in Possum Kingdom and Granbury Reservoirs versus April-June Naturalized Flow Volume at Dennis Gage (Control Point BRDE29)

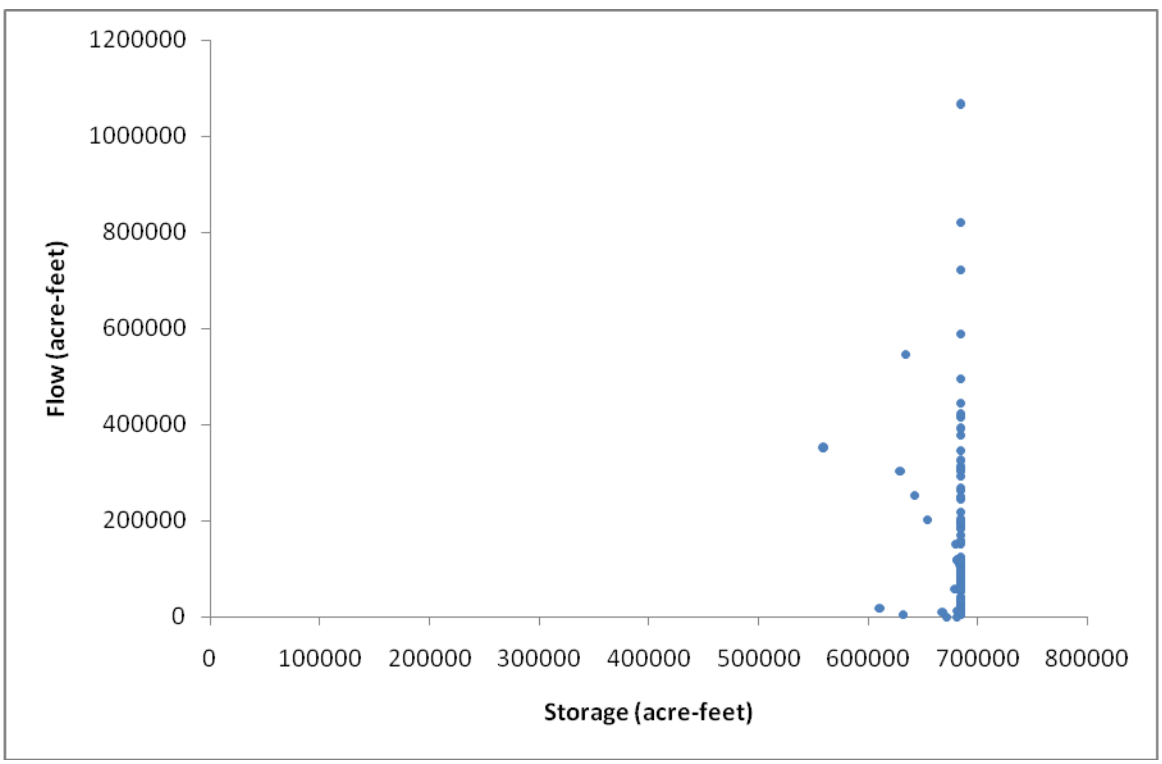

Figure 5.2 End-of-June Storage in Possum Kingdom and Granbury Reservoirs versus July-September Naturalized Flow Volume at Dennis Gage (Control Point BRDE29)

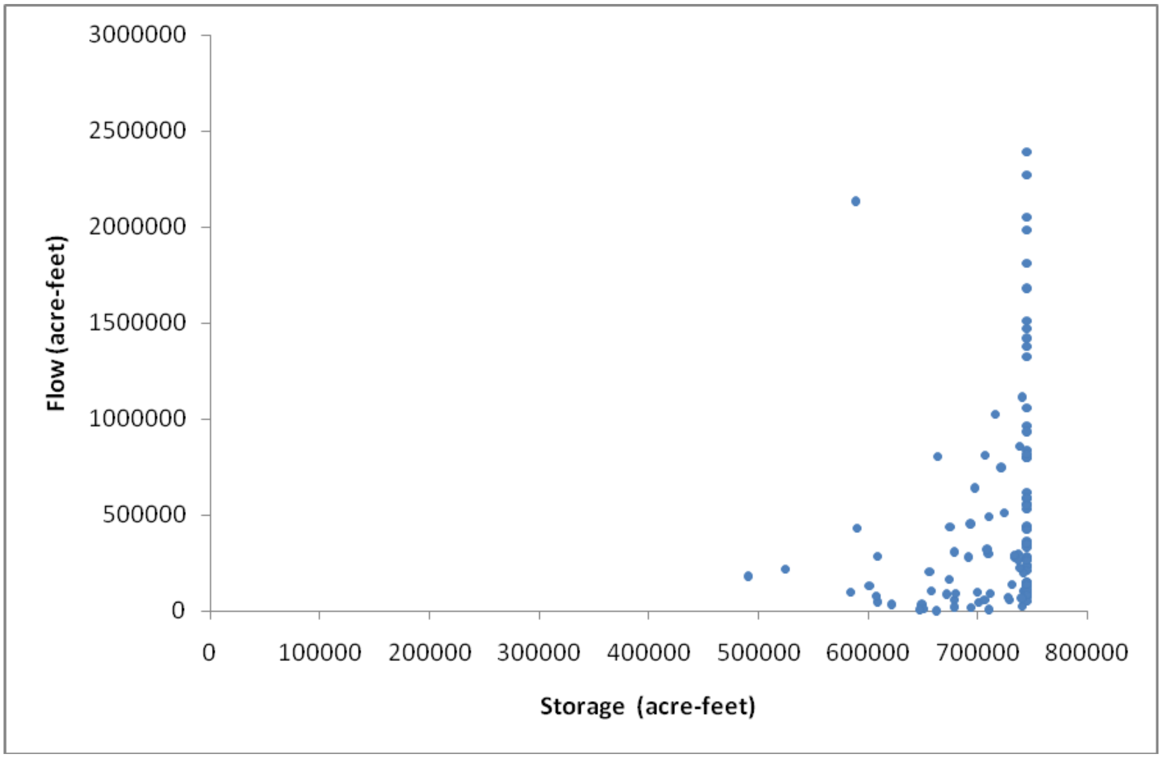

Figure 5.3 End-of-March Storage in Belton, Stillhouse, Georgetown, and Granger versus April-June Naturalized Flow Volume at Cameron Gage (Control Point BRCA58)

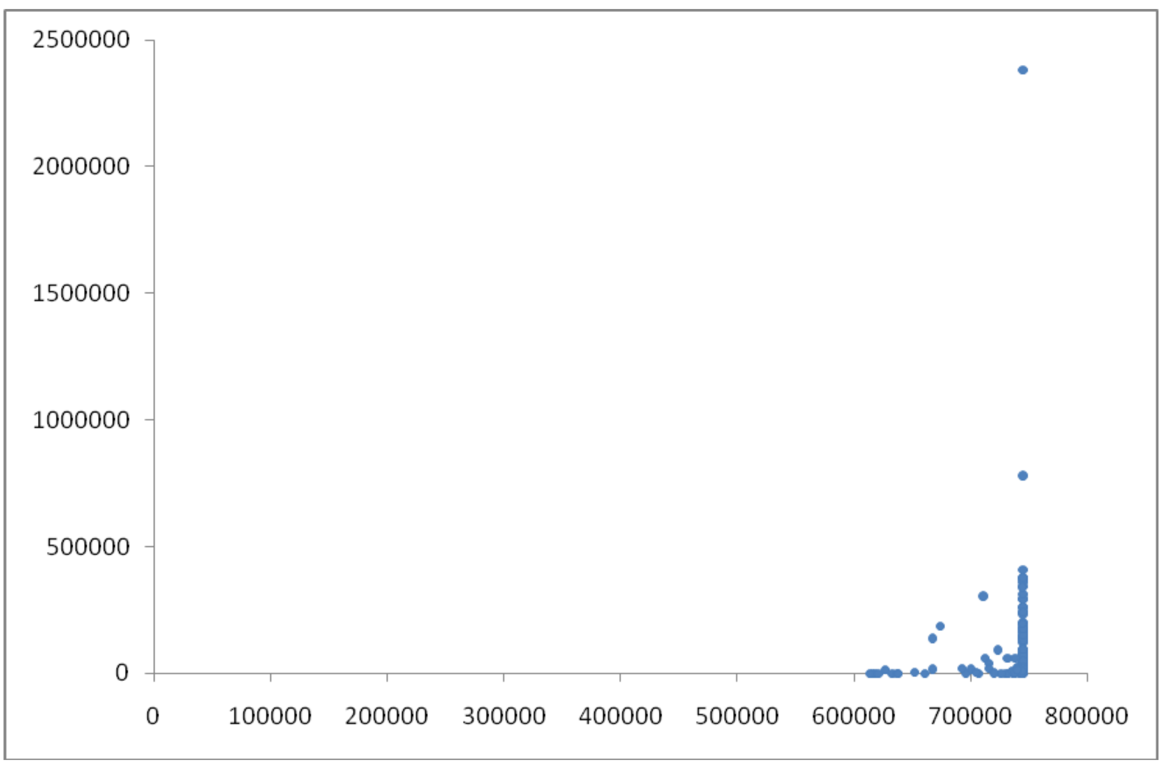

Figure 5.4 End-of-June Storage in Belton, Stillhouse, Georgetown, and Granger versus July-September Naturalized Flow Volume at Cameron Gage (Control Point BRCA58)

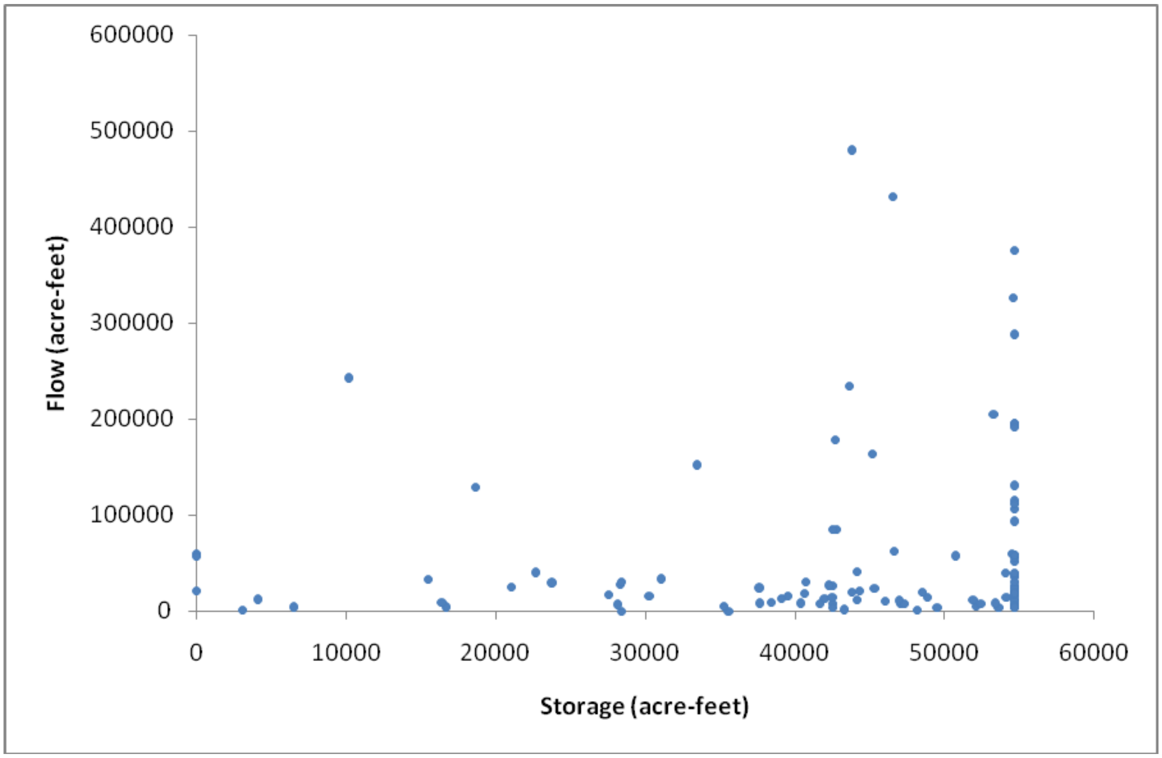

Figure 5.5 End-of-March Storage in Proctor Reservoir versus
April-June Naturalized Flow Volume

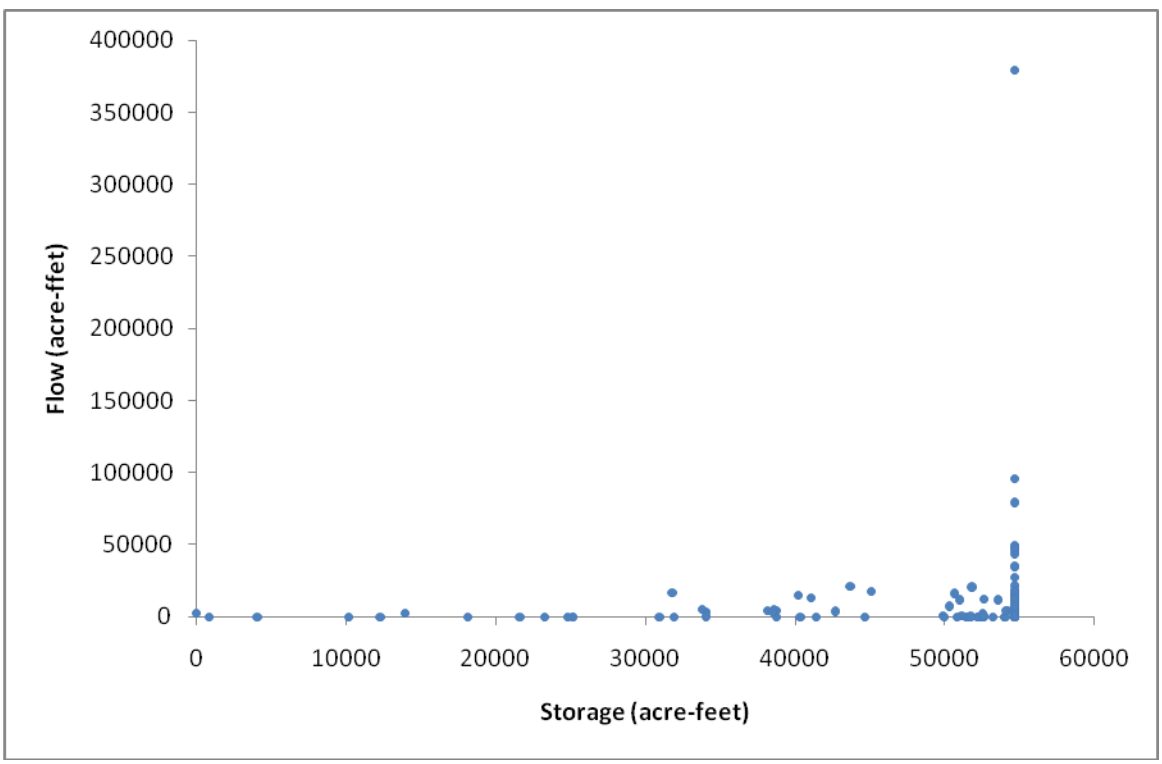

Figure 5.6 End-of-June Storage in Proctor Reservoir versus
July-September Naturalized Flow Volume

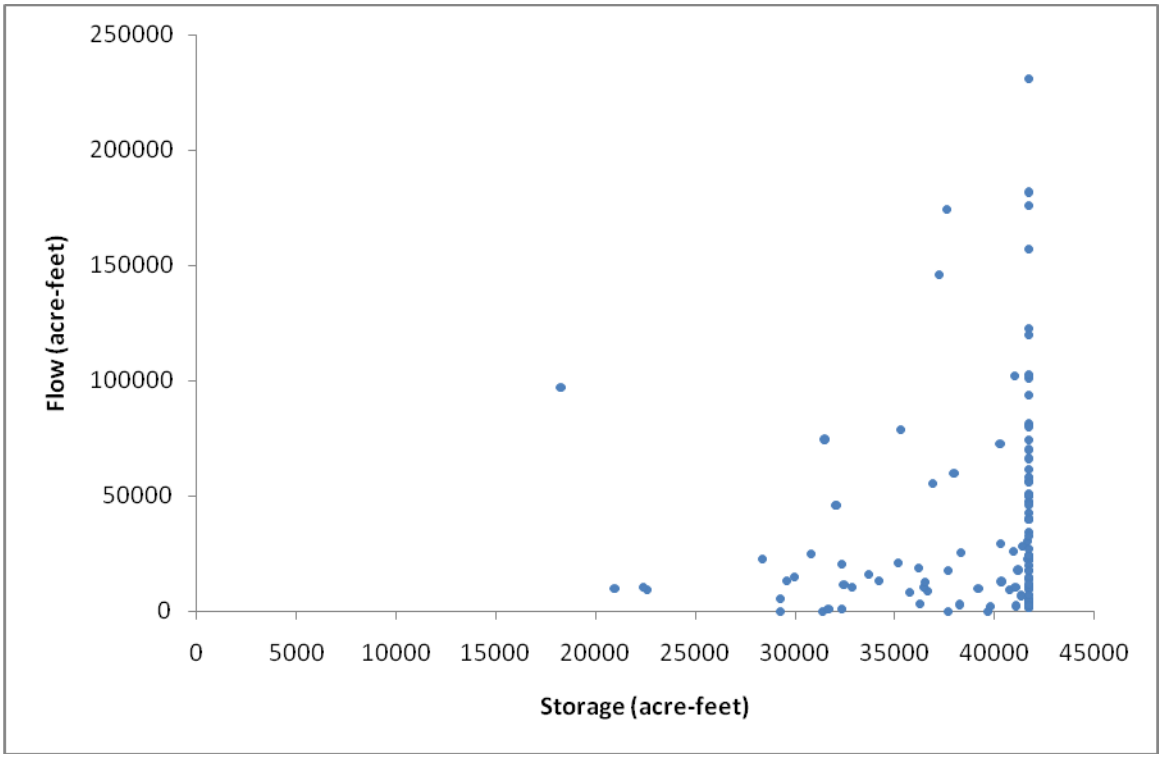

Figure 5.7 End-of-March Storage in Aquilla Reservoir versus April-June Naturalized Flow Volume

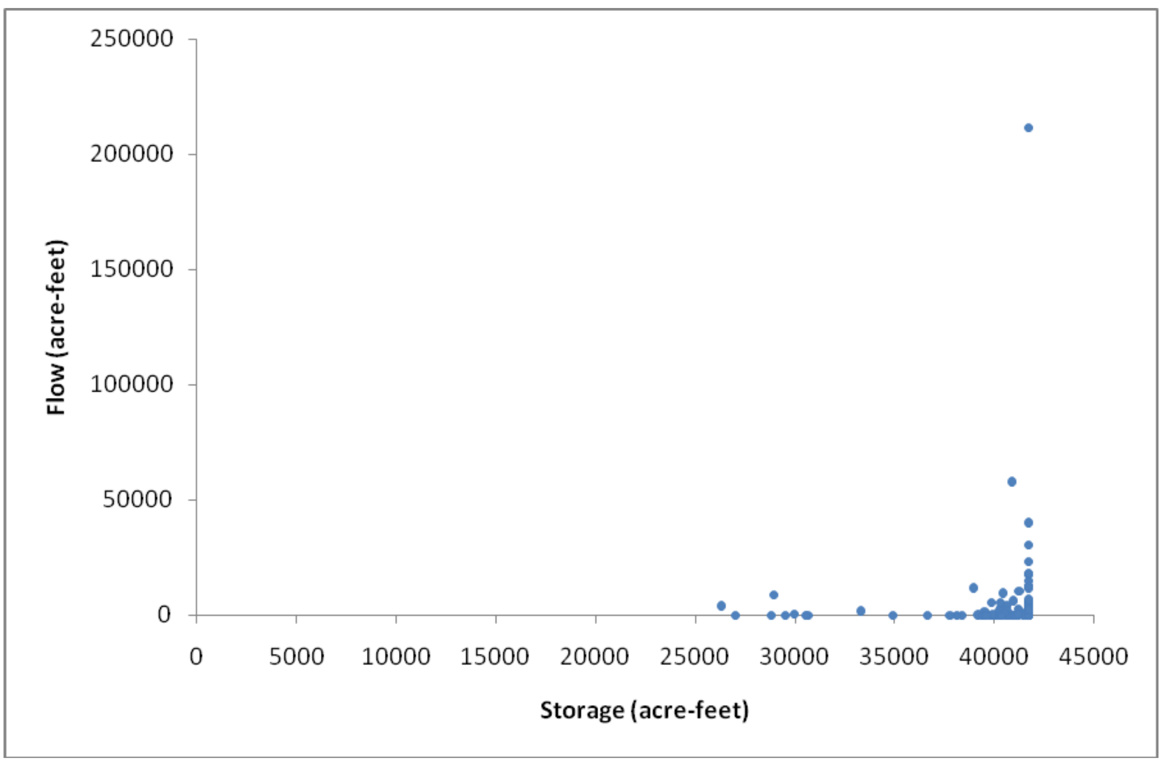

Figure 5.8 End-of-June Storage in Aquilla Reservoir versus July-September Naturalized Flow Volume

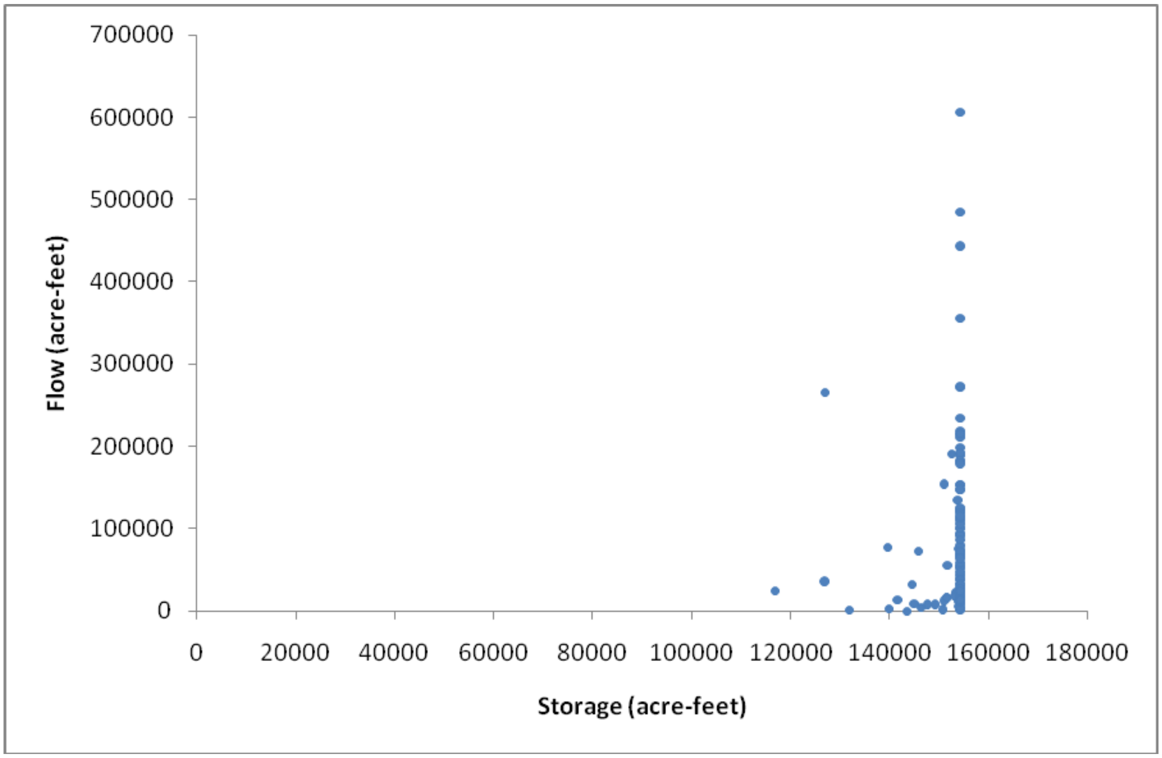

Figure 5.9 End-of-March Storage in Somerville Reservoir versus
April-June Naturalized Flow Volume

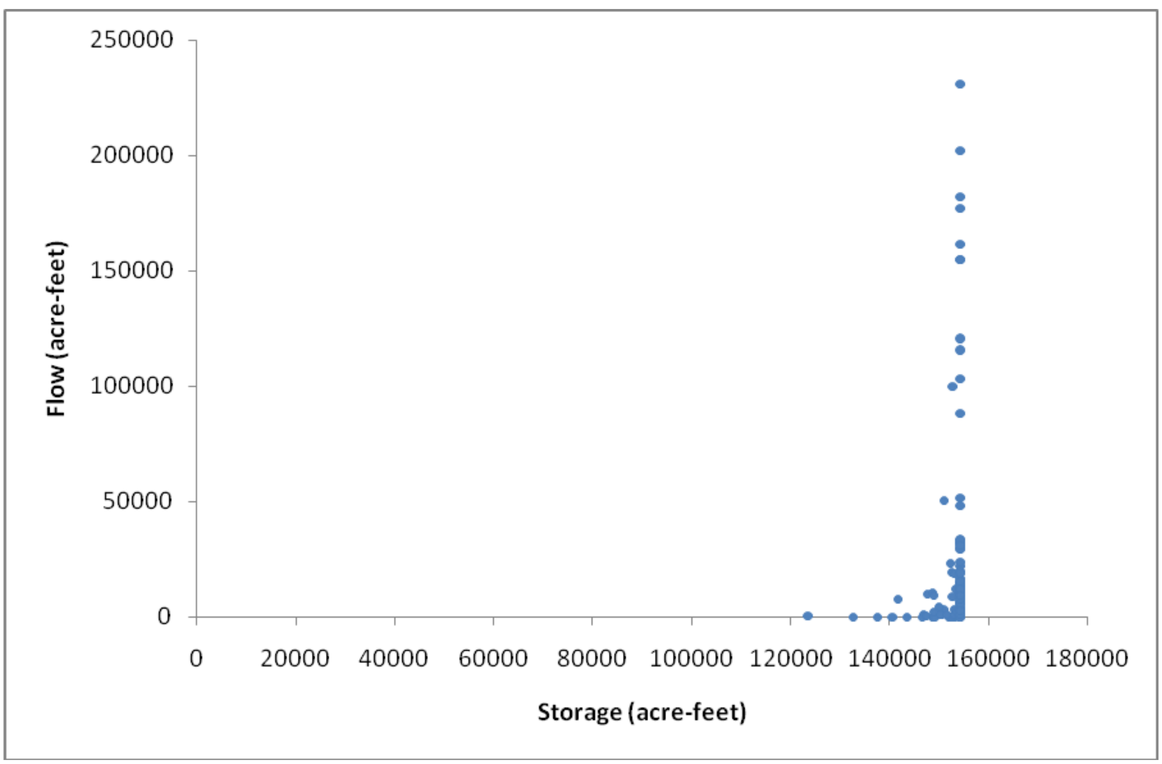

Figure 5.10 End-of-June Storage in Somerville Reservoir versus
July-September Naturalized Flow Volume

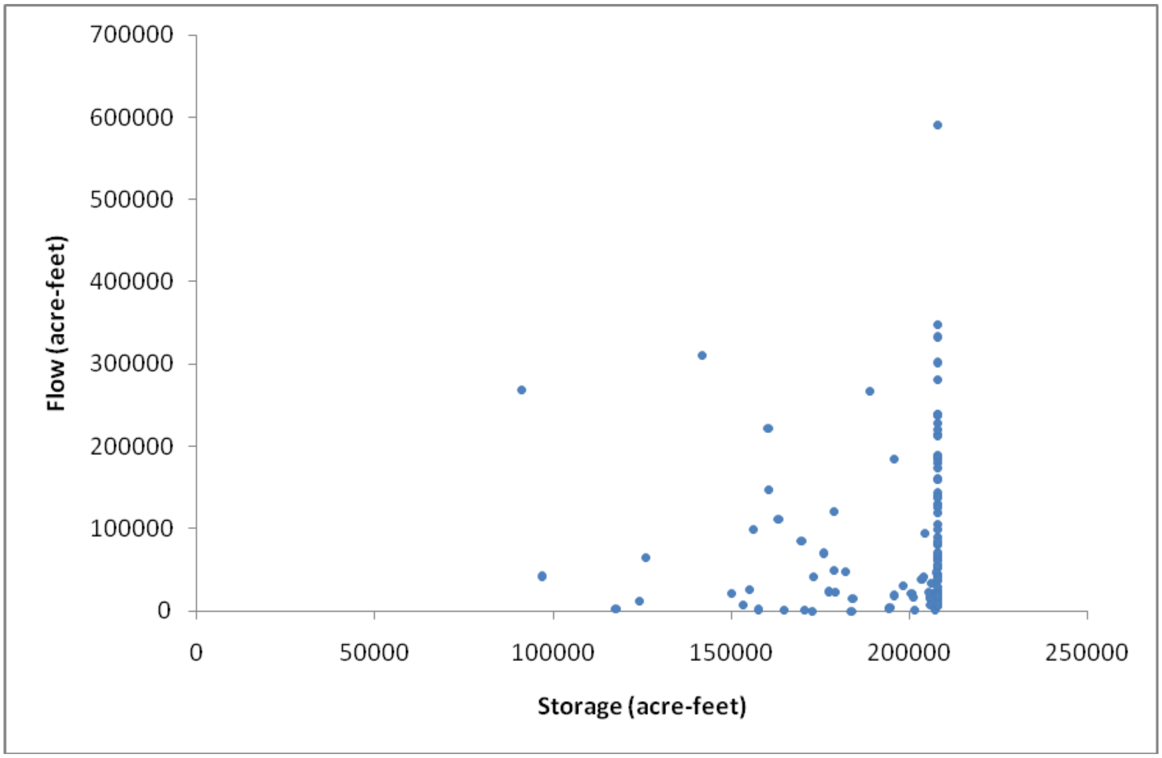

Figure 5.11 End-of-March Storage in Limestone Reservoir versus
April-June Naturalized Flow Volume

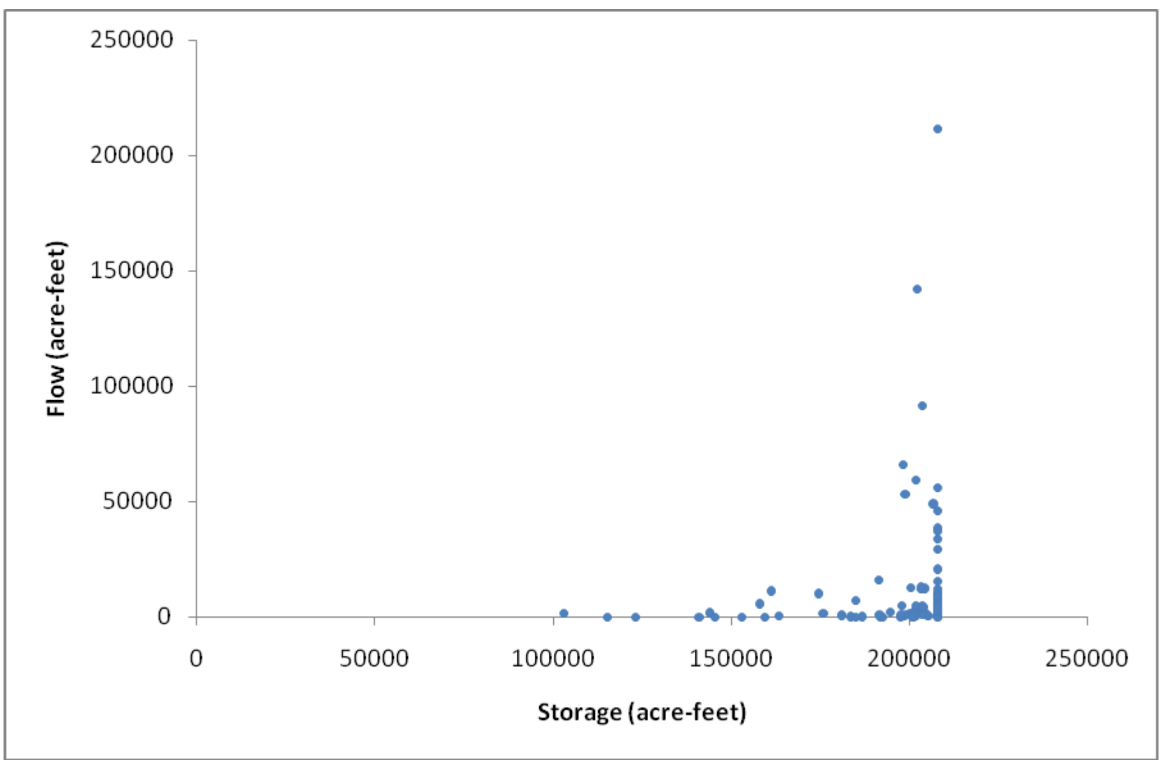

Figure 5.12 End-of-June Storage in Limestone Reservoir versus
July-September Naturalized Flow Volume

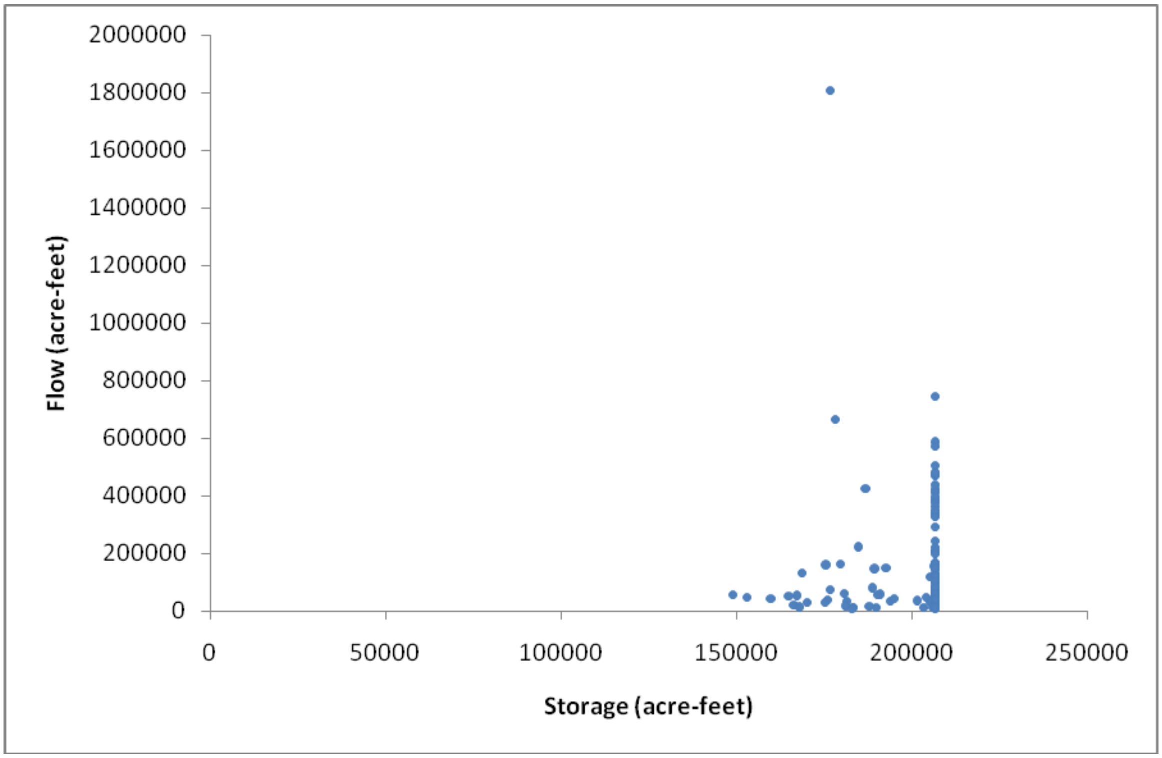

Figure 5.13 End-of-March Storage in Waco Reservoir versus
April-June Naturalized Flow Volume

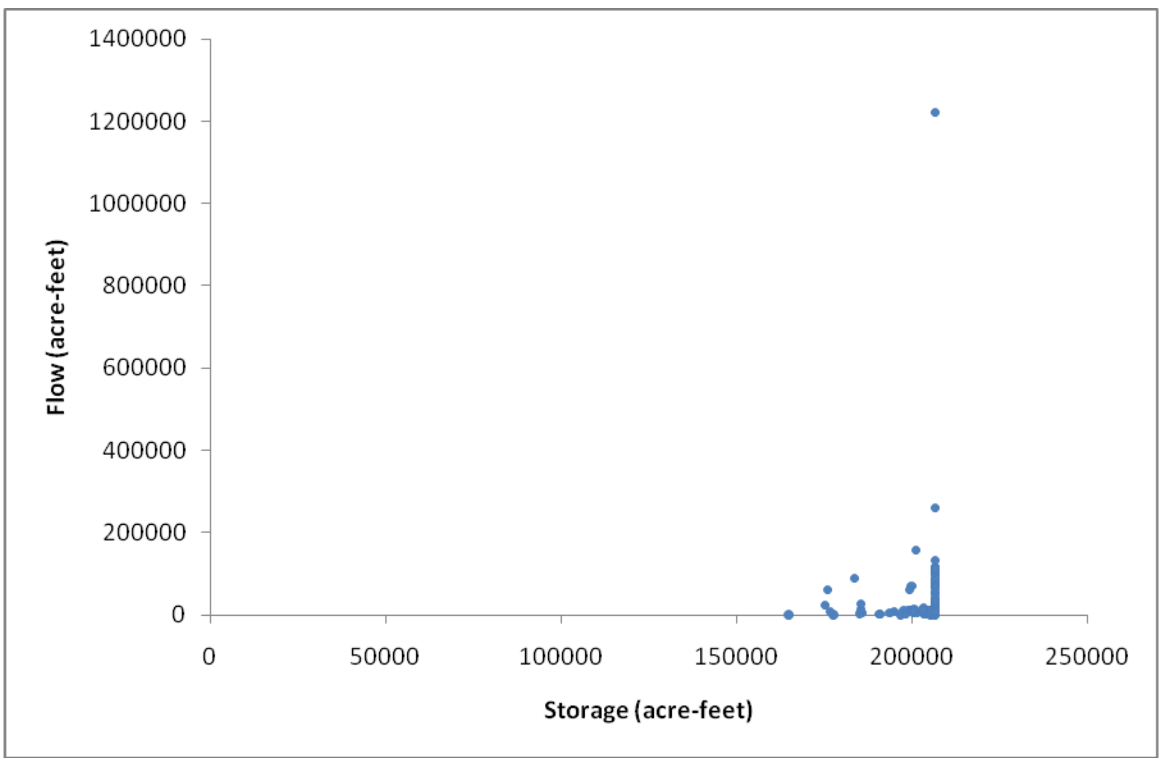

Figure 5.14 End-of-June Storage in Waco Reservoir versus
July-September Naturalized Flow Volume

CRM Analyses Based on the Probability Array Option

The CRM analyses for the BRA reservoirs previously performed using the equal-weight option are repeated using the probability array methodology as outlined in Table 4.3 of Chapter 4. The eight variations of the *CR* record controlling the *SIM* CRM simulations are shown in Table 4.1. The eight *SIM* simulations are the same for the equal-weight based CRM analyses of Chapter 4 and the probability array based CRM analyses of Chapter 5.

Probability Array Modeling Options

CRM options are outlined in Table 5.1 of this chapter and Chapter 7 of the *Reference Manual*. The following options are adopted in the analyses reported here.

- probability array option
- storage-frequency-flow (SFF) option
- annual cycle option
- no upper or lower limits on reservoir storage
- exponential regression option
- Weibull formula relative frequency option

The storage-frequency-flow (SFF) option allows the naturalized flow volumes at any number of control points to be summed in *TABLES* for any number of months. The storage volume in any number of reservoirs may be summed. For purposes of developing SFF relationships as well as performing frequency analyses, reservoirs are grouped as shown in the first column of Table 4.3 of Chapter 4 and associated with naturalized flows at the control points shown in the second column of Table 4.3. Seven sets of eight SFF relationships are developed as outlined in Table 4.3. All of the SFF arrays are based on summing naturalized flows over three months. The correlation coefficients presented in Tables 5.8−5.11 for one, two, three, six, nine, and twelve months do not vary dramatically between time periods. Three months was selected basically subjectively.

The SFF option for assigning probabilities to each of the multiple simulation sequences as a function of preceding reservoir storage is based on the SFF relationship which relates exceedance probabilities to the random variable $Q_{\%}$ as described in the *Reference Manual*. Equation 7.8 of the *Reference Manual* is reproduced as Eq. 5.2 below.

$$Q_{\%} = \frac{Q}{Q_S}\ 100\% \qquad (5.2)$$

where Q is the naturalized flow volume over one or more months observed in the *SIM* CRM simulation results, and Q_S is the corresponding expected value of the naturalized flow volume determined from a regression equation reflecting preceding storage volume. The naturalized flow volume is the total summed for the months specified by the parameter FM on the 5CR1 record which is three months for the studies presented here.

The flow $Q_{\%}$ is the naturalized flow volume observed in the model as a percentage of the flow volume expected from relating flow to preceding storage. The magnitude of $Q_{\%}$ expresses the deviation of the flow volume from the expected value of the flow volume conditioned on preceding storage volume as modeled by a regression equation.

<u>*Regression Equations*</u>

The parameter FIT on the 5CR1 and 5CR2 records allows a choice between four alternative regression equations. The exponential regression equation activated by FIT option 1 was selected for the Brazos Basin CRM analyses based on the 5CR1 record correlation analyses presented in Tables 5.12 and 5.13. The correlation coefficients in Tables 5.12−5.13 for nonlinear regression equations are computed by *TABLES* based on applying linear regression (Equation 5.1) to the transformed variables associated with each nonlinear regression equation as described in the *Reference Manual*. The selected exponential regression equation (FIT=1) has the highest correlation coefficient for all of the comparisons presented in Tables 5.12 and 5.13.

Table 5.12
Correlation Coefficient for Beginning-of-April Storage Versus Flow Ratio

Reservoirs	Control Point	FIT = 1 Exponential	FIT = 2 Combined	FIT = 3 Linear	FIT = 4 Power
Proctor	515931	0.1430	0.0469	0.1095	0.0137
Aquilla	515831	0.1922	0.1758	0.1584	0.1658
Somerville	516431	0.2363	−	0.1198	0.2244
Limestone	516531	0.1518	0.0709	0.0607	0.1214
Waco	509431	0.2118	0.0622	0.0654	0.2087
PK and Granbury	BRDE29	0.2143	0.1756	0.1618	0.2114
Belton, Stillhouse, Granger, Georgetown	LRCA58	0.2846	0.2387	0.2073	0.2671

Table 5.13
Correlation Coefficient for Beginning-of-July Storage Versus Flow Ratio

Reservoirs	Control Point	FIT = 1 Exponential	FIT = 2 Combined	FIT = 3 Linear	FIT = 4 Power
Proctor	515931	0.3675	0.1360	0.1554	0.1315
Aquilla	515831	0.2641	−	0.0933	0.2477
Somerville	516431	0.4057	−	0.1956	0.3952
Limestone	516531	0.4887	−	0.1451	0.4716
Waco	509431	0.1993	−	0.0863	0.1978
PK and Granbury	BRDE29	0.0181	0.0920	0.0919	0.0130
Belton, Stillhouse, Granger, Georgetown	LRCA58	0.5693	−	0.1814	0.5691

Note that the correlation coefficients are not provided in the tables for the combined regression option (FIT=2) for several of the cases. The computations for the combined regression option will not work for certain data sets with too much scatter or nonlinearity, which are flagged by a *TABLES* error message, for which there is essentially no fit.

The SFF array is developed from the results of a long-term *SIM* simulation with the same input dataset, exclusive of *CR* record, used in the CRM analyses. The correlation coefficients in Tables 5.12 and 5.13 are developed with the *TABLES* 5CR1 record based on *SIM* simulation results consisting of 108 end-of-March (beginning-of-April) or end-of-June (beginning-of-July) storage volumes and the corresponding April-June or July-August naturalized flow volumes. These sets of 108 storage-flow pairs cover the range of storage volumes reflected in Tables 5.3, 5.5, and 5.7.

The exponential regression equations for the individual reservoirs and groups of reservoirs are applied in the CRM analyses for a range of storage volumes that exceed the range from which the coefficients of the regression equations are developed. The equations are applied in the CRM analyses to storage volumes that are smaller than any of storage volumes in the long-term simulation results. Thus, the regression equations serve to extrapolate as well as interpolate. Applying regression equations for predictions too far outside the range of data for which the coefficients of the equation are fitted results in inaccurate predictions. This is a significant modeling issue.

TABLES TIN, SFF, and TOU Files

The *TABLES* input file reproduced as Table 5.14 results in the information contained in the remaining tables of this chapter. The 5CR1 records in Table 5.14 reflects hydrologic sequences that begin in April (month 4). 5CR1 record field 4 is changed to month 7 for analyses with hydrologic sequences that begin in July. This is the only change required to the TIN file of Table 5.14 to generate the storage-frequency relationships of Tables 5.18 through 5.45. The left side of Tables 5.18–5.45 reflects simulations beginning in April, and the right side reflects simulations beginning in July. The information in each field of the 5CR1 and 5CR2 records is described in Appendix C of the *Reference Manual*. The 2FRE records are described in the *Users Manual*. 2FRE records are applicable to both conventional long-term simulations and CRM. 2CR1 and 2CR2 records are used only for applying the probability array option in CRM.

The SFF array created with a 5CR1 record and the incremental probability array created with a 5CR2 record may optionally be written to a SFF file. The main *TABLES* results are recorded in the TOU output file. The SFF array and incremental probability array from a SFF file are shown in Tables 5.15 and 5.16. Results from a TOU file are reproduced in Table 5.17. Tables 5.15, 5.16, and 5.17 are from the CRM analysis of the combined total storage in Belton, Stillhouse Hollow, Georgetown, and Granger Reservoirs.

An SFF array, as illustrated by Table 5.15, is a tabulation of the flow percentage defined by Equation 5.2 and corresponding exceedance frequency which ranges from 0.0 to 1.0. An incremental probability array, as illustrated by Table 5.16, is the flow percentage defined by Equation 5.2 and corresponding assigned probability for each of the 107 hydrologic sequences. The 107 probabilities sum to 1.0.

Table 5.14
TABLES Input TIN File

```
**   TABLES Input File BCRM.TIN
**   Chapter 4 CRM
**       1         2         3         4         5
**  567890123456789012345678901234567890123456789012
****---!---!---!---!---!---!---!---!---!---!---!---!
****  Possum Kingdom and Granbury
5CR1   1   2   4   3   1   1
5CR1FLOW  BRDE29
5CR1STRE  POSDOM  GRNBRY
5CR2   1   2   1   3   1   1   0
5CR2FLOW  BRDE29
5CR2STRE  POSDOM  GRNBRY
2FRE   6   6   2   4
IDEN  POSDOM  GRNBRY
2FRE   6   9  -2   4
2FRE   6  12  -2   4
2FRE   6   3  -2   4
****  Belton, Stillhouse Hollow, Georgetown, Granger
5CR1   1   4   4   3   1   1
5CR1FLOW  LRCA58
5CR1STRE  BELTON  STLHSE  GRGTWN  GRNGER
5CR2   1   4   1   3   1   1   0
5CR2FLOW  LRCA58
5CR2STRE  BELTON  STLHSE  GRGTWN  GRNGER
2FRE   6   6   4   4
IDEN  BELTON  STLHSE  GRGTWN  GRNGER
2FRE   6   9  -4   4
2FRE   6  12  -4   4
2FRE   6   3  -4   4
****   Proctor
5CR1   1   1   4   3   1   1
5CR1FLOW  515931
5CR1STRE  PRCTOR
5CR2   1   1   1   3   1   1   0
5CR2FLOW  515931
5CR2STRE  PRCTOR
2FRE   6   6   1   4
IDEN  PRCTOR
2FRE   6   9  -1   4
2FRE   6  12  -1   4
2FRE   6   3  -1   4
****   Aquilla
5CR1   1   1   4   3   1   1
5CR1FLOW  515831
5CR1STRE  AQUILA
5CR2   1   1   1   3   1   1   0
5CR2FLOW  515831
5CR2STRE  AQUILA
2FRE   6   6   1   4
IDEN  AQUILA
2FRE   6   9  -1   4
2FRE   6  12  -1   4
2FRE   6   3  -1   4
```

Table 5.14 (Continued)
TABLES Input TIN File

```
****   Somerville
5CR1   1   1   4   3   1   1
5CR1FLOW  516431
5CR1STRE  SMRVLE
5CR2   1   1   1   3   1   1   0
5CR2FLOW  516431
5CR2STRE  SMRVLE
2FRE   6   6   1   4
IDEN  SMRVLE
2FRE   6   9  -1   4
2FRE   6  12  -1   4
2FRE   6   3  -1   4
****   Limestone
5CR1   1   1   4   3   1   1
5CR1FLOW  516531
5CR1STRE  LMSTNE
5CR2   1   1   1   3   1   1   0
5CR2FLOW  516531
5CR2STRE  LMSTNE
2FRE   6   6   1   4
IDEN  LMSTNE
2FRE   6   9  -1   4
2FRE   6  12  -1   4
2FRE   6   3  -1   4
****   Waco
5CR1   1   1   4   3   1   1
5CR1FLOW  509431
5CR1STRE  LKWACO
5CR2   1   1   1   3   1   1   0
5CR2FLOW  509431
5CR2STRE  LKWACO
2FRE   6   6   1   4
IDEN  LKWACO
2FRE   6   9  -1   4
2FRE   6  12  -1   4
2FRE   6   3  -1   4
****
ENDF
```

Table 5.15
SFF Array for Combined
Lakes Belton, Stillhouse Hollow, Georgetown, and Granger
for Starting Month of April and Simulation Period of 3 Months

Flow Percent	Exceedance Frequency	Flow Percent	Exceedance Frequency	Flow Percent	Exceedance Frequency
4226.176	0.000000	200.444	0.339450	52.141	0.678899
2522.726	0.009174	191.539	0.348624	50.361	0.688073
819.258	0.018349	188.310	0.357798	48.940	0.697248
779.139	0.027523	182.350	0.366972	48.117	0.706422
702.473	0.036697	178.264	0.376147	48.074	0.715596
679.716	0.045872	151.279	0.385321	47.344	0.724771
620.227	0.055046	150.236	0.394495	43.938	0.733945
576.132	0.064220	146.970	0.403670	40.392	0.743119
525.096	0.073394	146.438	0.412844	38.560	0.752294
518.819	0.082569	145.852	0.422018	36.413	0.761468
505.146	0.091743	142.491	0.431193	36.233	0.770642
504.898	0.100917	142.188	0.440367	32.344	0.779817
487.403	0.110092	135.205	0.449541	32.080	0.788991
472.904	0.119266	124.200	0.458716	31.889	0.798165
465.829	0.128440	121.730	0.467890	30.580	0.807339
454.537	0.137615	120.878	0.477064	29.731	0.816514
442.104	0.146789	119.608	0.486239	28.530	0.825688
430.063	0.155963	118.426	0.495413	28.346	0.834862
395.898	0.165138	113.673	0.504587	27.741	0.844037
377.340	0.174312	109.129	0.513761	27.526	0.853211
362.779	0.183486	108.939	0.522936	25.972	0.862385
330.216	0.192661	103.321	0.532110	25.647	0.871560
321.265	0.201835	99.919	0.541284	24.854	0.880734
320.323	0.211009	96.243	0.550459	24.393	0.889908
308.602	0.220183	95.851	0.559633	23.992	0.899083
308.501	0.229358	94.910	0.568807	22.719	0.908257
287.798	0.238532	91.270	0.577982	21.249	0.917431
287.653	0.247706	82.006	0.587156	17.820	0.926606
280.166	0.256881	81.289	0.596330	11.748	0.935780
274.808	0.266055	78.782	0.605505	9.490	0.944954
273.677	0.275229	78.372	0.614679	9.163	0.954128
260.887	0.284404	72.533	0.623853	6.382	0.963303
234.811	0.293578	72.212	0.633027	5.188	0.972477
222.055	0.302752	68.895	0.642202	3.367	0.981651
211.419	0.311927	53.495	0.651376	0.229	0.990826
206.531	0.321101	53.411	0.660550	0.000	1.000000
202.855	0.330275	53.061	0.669725		

Table 5.16
Incremental Probability Array for Combined
Lakes Belton, Stillhouse Hollow, Georgetown, and Granger
for Starting Month of April and Simulation Period of 3 Months

Flow Percent	Probability	Flow Percent	Probability	Flow Percent	Probability
2134.963	0.000377	924.034	0.000200	109.167	0.010681
105.45	0.012026	120.572	0.015521	449.557	0.00594
463.026	0.013546	798.745	0.005301	40.336	0.060514
210.577	0.005475	154.881	0.007032	1260.002	0.000161
209.802	0.003001	307.618	0.011258	683.141	0.008118
2977.349	0.00097	1991.002	0.001069	1227.206	0.000108
228.394	0.007727	1674.491	0.001082	10.505	0.025968
192.459	0.019449	112.343	0.006206	1219.777	4.42E-05
2272.575	0.00084	2071.453	0.000388	447.785	0.004646
65.821	0.03113	1446.441	0.000371	1210.791	4.32E-05
83.243	0.014875	658.078	0.000615	394.148	0.0102
72.859	0.014429	317.716	0.017181	294.49	0.02324
115.39	0.013997	131.175	0.002618	0.523	0.034601
646.848	0.001267	654.668	0.000866	220.595	0.007657
3412.852	0.004939	158.711	0.000785	638.239	0.009525
3077.032	0.000614	50.473	0.0289	1403.107	0.00043
359.208	0.011234	272.285	0.026496	135.776	0.003898
30.47	0.056942	427.47	0.003832	480.916	0.013071
149.395	0.008747	13.282	0.040374	1122.714	0.000636
838.995	0.000143	327.555	0.011223	437.128	0.007031
345.088	0.003056	199.472	0.014083	1589.075	0.00036
421.57	0.000894	3205.264	0.000904	824.851	0.002399
2716.769	0.001222	662.647	0.002359	337.518	0.003459
420.81	0.000784	138.581	0.002567	888.561	0.000124
518.739	0.014728	78.056	0.018706	11.194	0.003684
50.841	0.021733	415.733	0.000706	2523.622	0.001196
1198.784	0.000218	129.825	0.002975	497.922	0.015787
544.033	0.010169	87.992	0.023845	159.501	0.001723
141.674	0.021034	249.078	0.010983	147.71	0.022091
962.75	0.000535	2211.595	0.000371	523.915	0.005008
739.485	0.007785	878.001	0.000134	168.847	0.017425
139.683	0.002032	83.753	0.002352	124.164	0.008103
529.482	0.002565	1203.737	3.23E-05	1286.935	0.000385
121.512	0.010214	767.456	0.004614	207.378	0.012745
415.554	0.002141	399.786	0.003072	101.235	0.026297
1540.912	0.000384	26.836	0.062468	Sum	1.000000

Table 5.17
Sample of Results from *TABLES* Output TOU File
Storage Frequency Statistics for Lakes Belton, Stillhouse Hollow, Georgetown, and Granger
for Starting Month of April and Simulation Period of 3 Months

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 6

CONDITIONAL RELIABILITY MODELING: Probability Array Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 3 months.
Initial storage multiplier (CR4) = 0.750

Res	BELTON	STLHSE	GRGTWN	GRNGER	TOTAL
Mean	358143.34	185078.17	29524.06	42468.55	615214.12
Minimum	70.32	70.29	62.75	66.10	69.68
99%	70.32	70.29	62.75	66.10	69.68
98%	70.32	70.29	63.45	66.10	69.68
95%	70.45	70.76	63.72	66.61	70.53
90%	70.87	71.73	63.76	69.29	70.66
80%	72.72	72.81	64.72	71.93	72.60
70%	75.19	75.94	67.92	73.21	74.58
60%	77.21	76.27	72.82	79.50	77.46
50%	79.01	79.92	75.38	84.43	79.50
40%	82.98	81.66	82.25	87.30	83.32
30%	87.91	89.26	91.07	94.89	88.39
20%	95.45	95.69	100.00	100.00	93.30
10%	100.00	99.79	100.00	100.00	99.00
Maximum	432978.00	224279.00	36980.00	50540.00	744777.00

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 9

CONDITIONAL RELIABILITY MODELING: Probability Array Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 3 months.
Initial storage multiplier (CR4) = 0.750

Res	BELTON	STLHSE	GRGTWN	GRNGER	TOTAL
Mean	353161.56	179942.05	26249.18	40194.31	599547.12
Minimum	62.16	63.60	47.32	54.13	61.82
99%	62.16	63.60	47.32	54.13	61.82
98%	62.16	63.60	48.38	56.17	61.82
95%	63.67	64.02	48.66	56.61	62.46
90%	64.66	64.47	49.35	56.74	63.72
80%	69.46	69.07	51.91	69.48	69.03
70%	71.88	69.70	58.25	69.92	71.15
60%	73.84	72.85	61.74	73.65	75.32
50%	80.60	76.56	66.91	77.43	78.92
40%	84.08	82.36	76.35	81.90	83.72
30%	92.25	89.32	84.96	90.21	90.07
20%	95.36	97.88	90.58	96.26	93.77
10%	98.07	100.00	97.08	100.00	97.67
Maximum	432978.00	224279.00	36980.00	50540.00	744777.00

Table 5.17 (Continued)
Sample of Results from *TABLES* Output TOU File

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 12

CONDITIONAL RELIABILITY MODELING: Probability Array Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 3 months.
Initial storage multiplier (CR4) = 0.750

Res	BELTON	STLHSE	GRGTWN	GRNGER	TOTAL
Mean	366539.97	188331.06	27424.64	44191.45	626487.12
Minimum	58.68	60.07	38.19	50.24	59.21
99%	58.68	60.07	38.19	50.24	59.21
98%	58.68	60.07	38.19	50.24	59.21
95%	62.15	62.06	39.03	52.54	61.08
90%	66.50	65.06	43.00	58.27	65.55
80%	69.97	67.63	49.56	68.94	69.31
70%	72.79	72.21	60.43	82.32	74.79
60%	78.21	79.96	65.05	92.24	75.54
50%	87.67	87.05	72.39	97.50	87.64
40%	95.63	90.75	82.03	100.00	94.62
30%	100.00	97.63	93.52	100.00	95.95
20%	100.00	100.00	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00
Maximum	432978.00	224279.00	36980.00	50540.00	744777.00

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 3

CONDITIONAL RELIABILITY MODELING: Probability Array Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 3 months.
Initial storage multiplier (CR4) = 0.750

Res	BELTON	STLHSE	GRGTWN	GRNGER	TOTAL
Mean	379516.06	196947.34	29126.88	45963.23	651553.50
Minimum	57.74	56.94	30.34	47.37	57.64
99%	57.74	56.94	30.34	47.37	57.64
98%	57.74	56.94	30.34	47.37	57.64
95%	61.54	63.43	35.11	56.47	59.03
90%	64.03	64.85	42.28	64.19	62.78
80%	72.31	71.62	53.74	79.57	74.21
70%	81.17	81.80	63.34	94.55	76.66
60%	84.91	87.01	71.68	100.00	86.84
50%	94.71	92.68	90.64	100.00	93.07
40%	100.00	100.00	100.00	100.00	98.59
30%	100.00	100.00	100.00	100.00	100.00
20%	100.00	100.00	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00
Maximum	432978.00	224279.00	36980.00	50540.00	744777.00

Storage-Frequency Relationships from CRM Results

Storage frequency relationships based on the equal-weight option and probability array option are presented as Tables 4.4–4.24 and 5.18−5.45, respectively, as outlined in Table 4.3 of Chapter 4. Tables 4.4–4.24 based on the equal-weight method and Tables 5.18−5.45 based on the probability array method are all in the same format. Each column begins with the mean storage in acre-feet and ends with the maximum of the 107 storage volumes in acre-feet. The second quantity in each column is the minimum of the 107 storage volumes expressed as a percentage of reservoir storage capacity. End-of-specified-month storage volume expressed as a percentage of storage capacity is tabulated for exceedance frequencies of 99%, 98%, 95%, 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, and 10%. Though the computations performed within *TABLES* are different, as summarized in the following paragraph, Tables 5.18−5.45 are interpreted and applied in the same manner as Tables 4.4 −4.24 which are explained in Chapter 4.

With the equal-weight option, the storage volumes associated with the specified exceedance frequencies are computed simply as the storage volumes that are equaled or exceeded during the specified percentage of the 107 simulations. With the probability array option, an incremental probability array is developed as specified by a 5CRM record using a SSF array developed as specified by a 5CR1 record. The incremental probability array is used in the frequency analysis routine activated by a 2FRE record. With the equal-weight option, the mean storage is the arithmetic average of 107 end-of-specified-month storage volumes in acre-feet. With the probability array option, the mean storage is a probability-weighted average based on the statistical concept of expected value.

Table 5.18
Storage-Frequency Relationship for Combined Lakes Possum Kingdom and Granbury
For Initial Storage Contents of 100% of 684,834 acre-feet Capacity

	100% Full at Beginning of April (Month 4)				100% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	683,377	671,438	675,454	676,295	671,140	673,156	674,421	681,094
Min	92.29	83.33	82.23	80.49	87.64	84.35	82.56	89.10
99%	92.29	83.33	86.08	83.80	87.64	86.08	83.66	90.25
98%	97.40	89.73	87.55	89.36	88.20	87.62	84.34	92.29
95%	99.18	89.93	91.46	90.36	90.61	88.45	90.36	93.75
90%	99.99	92.47	95.97	96.31	92.12	92.88	94.87	99.38
80%	100.00	96.30	98.27	98.26	95.85	97.40	97.80	100.00
70%	100.00	98.25	99.32	99.71	97.87	99.30	99.04	100.00
60%	100.00	99.37	100.00	100.00	99.19	99.85	100.00	100.00
50%	100.00	99.99	100.00	100.00	99.99	100.00	100.00	100.00
40%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
30%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
20%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Max	684,834	684,834	684,834	684,834	684,834	684,834	684,834	684,834

Table 5.19
Storage-Frequency Relationship for Lakes Belton, Stillhouse Hollow, Granger, and Georgetown
For Initial Storage Contents of 100% of 744,777 acre-feet Capacity

	100% Full at Beginning of April (Month 4)				100% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	741,227	715,188	720,033	725,773	718,545	721,304	727,637	733,460
Min	94.21	85.21	82.27	79.37	89.74	84.91	81.22	82.35
99%	94.21	86.23	83.04	82.01	90.00	86.61	86.72	82.35
98%	95.04	86.26	83.15	84.98	90.69	87.06	86.94	86.79
95%	96.28	89.33	87.32	87.29	91.25	87.99	88.06	90.41
90%	98.34	90.98	89.53	91.16	92.37	90.39	91.13	95.05
80%	98.99	92.94	92.74	94.49	93.60	93.10	95.33	98.34
70%	99.51	94.32	96.15	97.22	93.98	95.56	98.16	99.44
60%	99.94	95.67	97.37	99.41	95.69	97.84	99.49	100.00
50%	100.00	97.21	99.54	100.00	97.17	99.16	100.00	100.00
40%	100.00	97.82	100.00	100.00	97.95	99.54	100.00	100.00
30%	100.00	98.41	100.00	100.00	98.92	100.00	100.00	100.00
20%	100.00	99.45	100.00	100.00	99.90	100.00	100.00	100.00
10%	100.00	99.81	100.00	100.00	100.00	100.00	100.00	100.00
Max	744,777	744,777	744,777	744,777	734,319	744,777	744,777	744,777

Table 5.20
Storage-Frequency Relationship for Lake Proctor for
Initial Storage Contents of 100% of 54,702 acre-feet Capacity

	100% Full at Beginning of April (Month 4)				100% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	53,751	47,569	47,123	47,733	49,174	49,024	49,267	50,831
Min	84.45	68.02	66.61	64.97	78.32	71.87	68.79	58.10
99%	85.65	68.02	66.61	66.97	78.43	74.69	68.83	60.04
98%	89.67	71.57	67.97	66.67	80.59	74.74	69.93	62.28
95%	93.47	75.01	70.24	69.30	81.17	76.88	74.15	67.40
90%	94.60	77.89	74.03	70.98	82.69	78.67	77.29	70.88
80%	95.98	80.62	75.86	74.03	83.97	80.98	77.81	82.45
70%	97.79	81.64	78.46	77.76	84.97	81.14	81.88	94.70
60%	100.00	84.06	81.25	82.56	85.05	82.92	88.03	96.19
50%	100.00	84.89	83.01	86.55	87.62	89.60	90.48	98.79
40%	100.00	88.12	89.60	95.28	90.13	96.43	98.90	100.00
30%	100.00	91.08	95.77	100.00	93.43	99.38	100.00	100.00
20%	100.00	93.43	100.00	100.00	100.00	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Max	54,702	54,702	54,702	54,702	54,702	54,702	54,702	54,702

Table 5.21
Storage-Frequency Relationship for Lake Aquilla for
Initial Storage Contents of 100% of 41,700 acre-feet Capacity

	100% Full at Beginning of April (Month 4)				100% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	40,968	36,933	37,203	39,188	37,554	38,294	39,127	40,363
Min	88.27	73.61	68.94	67.95	79.68	72.24	67.95	70.36
99%	88.93	74.77	72.24	67.95	79.79	73.70	73.66	71.32
98%	90.56	75.33	72.24	70.16	80.71	74.88	74.57	72.87
95%	93.66	78.56	74.34	74.68	83.54	78.14	76.83	79.85
90%	94.84	80.73	77.84	76.90	84.56	80.15	78.71	90.56
80%	96.54	83.45	82.04	86.96	86.23	82.78	84.27	95.10
70%	97.44	84.99	85.45	91.02	86.51	85.83	90.34	96.68
60%	98.79	86.44	90.11	98.45	87.27	90.11	97.92	98.30
50%	100.00	87.40	96.03	100.00	88.60	92.62	99.87	99.58
40%	100.00	89.43	99.52	100.00	90.62	99.26	100.00	100.00
30%	100.00	92.99	100.00	100.00	93.70	100.00	100.00	100.00
20%	100.00	94.34	100.00	100.00	94.87	100.00	100.00	100.00
10%	100.00	98.29	100.00	100.00	96.75	100.00	100.00	100.00
Max	41,700	41,700	41,700	41,700	41,700	41,700	41,700	41,700

Table 5.22
Storage-Frequency Relationship for Lake Somerville for
Initial Storage Contents of 100% of 154,254 acre-feet Capacity

	100% Full at Beginning of April (Month 4)				100% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	153,188	147,408	150,274	152,697	148,119	151,578	152,954	152,817
Min	93.54	83.00	79.91	79.29	87.46	82.55	81.92	80.06
99%	94.95	85.10	80.75	85.51	89.82	86.41	92.13	90.20
98%	95.10	85.46	83.52	90.52	90.02	88.14	92.13	91.14
95%	96.46	86.62	86.41	93.70	90.73	90.98	93.70	95.10
90%	97.42	89.16	90.98	96.76	93.02	93.01	94.99	97.42
80%	98.82	92.31	94.52	99.66	94.59	96.49	99.83	99.00
70%	99.32	93.23	97.20	100.00	95.86	100.00	100.00	99.32
60%	100.00	94.59	100.00	100.00	96.68	100.00	100.00	100.00
50%	100.00	96.19	100.00	100.00	98.37	100.00	100.00	100.00
40%	100.00	97.54	100.00	100.00	100.00	100.00	100.00	100.00
30%	100.00	99.35	100.00	100.00	100.00	100.00	100.00	100.00
20%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Max	154,254	154,254	154,254	154,254	107,022	154,254	154,254	154,254

Table 5.23
Storage-Frequency Relationship for Lake Limestone for
Initial Storage Contents of 100% of 208,017 acre-feet Capacity

	100% Full at Beginning of April (Month 4)				100% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	203,534	184,904	192,678	198,290	190,060	198,260	200,882	199,684
Min	87.87	74.32	68.74	67.36	82.33	76.49	75.07	67.76
99%	87.87	76.41	73.12	72.87	83.67	80.67	75.79	73.52
98%	90.01	77.70	74.74	75.13	83.67	80.01	79.70	74.27
95%	91.89	79.11	77.16	77.17	85.28	83.48	83.09	81.10
90%	93.61	80.85	80.95	81.59	86.66	85.95	85.02	87.32
80%	95.56	83.97	85.81	86.61	88.02	88.19	94.08	95.10
70%	96.85	86.55	87.00	98.04	88.12	91.00	98.93	95.53
60%	97.79	87.91	91.94	100.00	88.23	97.42	100.00	96.85
50%	100.00	88.67	95.48	100.00	88.96	100.00	100.00	97.90
40%	100.00	90.45	100.00	100.00	90.48	100.00	100.00	100.00
30%	100.00	91.44	100.00	100.00	91.44	100.00	100.00	100.00
20%	100.00	93.12	100.00	100.00	93.09	100.00	100.00	100.00
10%	100.00	95.94	100.00	100.00	100.00	100.00	100.00	100.00
Max	208,017	208,017	208,017	208,017	208,017	208,017	208,017	208,017

Table 5.24
Storage-Frequency Relationship for Lake Waco for
Initial Storage Contents of 100% of 206,562 acre-feet Capacity

	100% Full at Beginning of April (Month 4)				100% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	205,329	192,945	194,881	199,378	194,714	197,140	199,317	202,515
Min	94.42	81.93	78.85	80.97	85.00	81.43	81.44	80.32
99%	95.69	83.21	79.91	81.35	85.00	81.43	81.44	80.32
98%	95.98	84.37	80.50	81.63	87.00	83.47	81.98	85.99
95%	96.47	86.68	83.47	85.25	87.48	84.77	83.72	88.84
90%	97.09	87.81	85.06	86.91	90.13	87.10	86.91	94.42
80%	98.91	90.11	88.74	88.68	91.04	90.34	91.34	96.65
70%	100.00	91.11	90.88	98.74	91.88	91.97	97.58	98.63
60%	100.00	92.04	92.80	100.00	92.66	94.81	100.00	100.00
50%	100.00	92.71	95.75	100.00	93.49	98.20	100.00	100.00
40%	100.00	93.73	99.94	100.00	94.26	100.00	100.00	100.00
30%	100.00	94.94	100.00	100.00	96.85	100.00	100.00	100.00
20%	100.00	99.76	100.00	100.00	100.00	100.00	100.00	100.00
10%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Max	206,562	206,562	206,562	206,562	206,562	206,562	206,562	206,562

Table 5.25
Storage-Frequency Relationship for Combined Lakes Possum Kingdom and Granbury
For Initial Storage Contents of 75% of 684,834 acre-feet Capacity

	75% Full at Beginning of April (Month 4)				75% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	568,016	614,480	646,526	662,202	564,989	608,764	625,120	665,648
Min	68.42	60.82	68.52	67.05	64.55	62.55	61.21	68.04
99%	68.42	60.82	68.52	67.05	64.55	62.55	61.21	69.99
98%	68.42	60.82	74.04	79.12	65.60	63.64	61.93	70.75
95%	68.42	60.82	80.85	85.33	66.81	65.03	67.06	72.93
90%	73.33	72.05	80.85	90.90	67.64	69.38	72.66	93.00
80%	73.33	83.01	86.64	91.60	71.94	75.98	79.78	97.03
70%	77.58	83.27	94.12	97.48	74.48	79.63	88.19	99.99
60%	79.06	86.97	98.64	99.79	75.20	89.29	90.81	100.00
50%	79.73	95.27	98.81	99.79	79.53	94.02	98.80	100.00
40%	82.94	99.37	99.36	100.00	84.72	99.75	100.00	100.00
30%	87.01	99.82	99.61	100.00	91.51	100.00	100.00	100.00
20%	89.98	99.99	100.00	100.00	95.79	100.00	100.00	100.00
10%	99.53	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Max	684,834	684,834	684,834	684,834	684,834	684,834	684,834	684,834

Table 5.26
Storage-Frequency Relationship for Lakes Belton, Stillhouse Hollow, Granger, and Georgetown
For Initial Storage Contents of 75% of 744,777 acre-feet Capacity

	75% Full at Beginning of April (Month 4)				75% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	615,214	599,547	626,487	651,553	538,813	564,212	603,599	685,818
Min	69.68	61.82	59.21	57.64	65.89	61.43	57.97	59.10
99%	69.68	61.82	59.21	57.64	65.89	61.43	57.97	60.49
98%	69.68	61.82	59.21	57.64	65.89	61.43	57.97	63.51
95%	70.53	62.46	61.08	59.03	66.08	63.07	62.92	65.37
90%	70.66	63.72	65.55	62.78	66.65	63.41	63.24	73.03
80%	72.60	69.03	69.31	74.21	67.16	64.26	66.29	83.79
70%	74.58	71.15	74.79	76.66	67.80	65.26	69.03	89.65
60%	77.46	75.32	75.54	86.84	68.02	67.19	72.14	96.43
50%	79.50	78.92	87.64	93.07	68.04	71.37	75.31	98.65
40%	83.32	83.72	94.62	98.59	69.19	73.76	88.13	99.97
30%	88.39	90.07	95.95	100.00	71.17	79.86	97.06	100.00
20%	93.30	93.77	100.00	100.00	76.00	90.27	100.00	100.00
10%	99.00	97.67	100.00	100.00	87.68	99.59	100.00	100.00
Max	744,777	744,777	744,777	744,777	734,318	744,777	744,777	744,777

Table 5.27
Storage-Frequency Relationship for Lake Proctor for
Initial Storage Contents of 75% of 54,702 acre-feet Capacity

End of Month	75% Full at Beginning of April (Month 4) 6 Jun	9 Sep	12 Dec	3 Mar	75% Full at Beginning of July (Month 7) 9 Sep	12 Dec	3 Mar	6 Jun
Mean	43,467	37,702	38,361	39,626	33,552	33,171	37,606	40,118
Min	61.57	47.96	46.67	43.43	56.27	51.26	48.11	39.76
99%	62.54	47.96	46.67	43.43	56.34	53.18	48.80	41.40
98%	63.33	50.52	46.76	43.43	56.34	53.29	49.66	41.76
95%	65.33	51.06	47.54	46.16	58.00	53.99	51.40	43.12
90%	65.86	52.54	48.56	47.11	59.14	55.08	52.61	46.17
80%	67.45	54.06	50.98	49.08	59.64	56.48	54.54	48.97
70%	67.72	54.79	51.89	49.67	60.69	57.84	55.22	49.47
60%	67.96	55.18	52.18	54.48	61.35	57.95	55.34	53.47
50%	68.24	56.67	64.19	72.38	61.43	57.99	56.10	71.70
40%	81.87	68.58	80.95	80.06	61.50	58.06	63.41	94.53
30%	94.87	84.88	85.38	98.90	61.53	58.10	82.14	98.75
20%	100.00	89.44	98.33	100.00	61.96	58.94	100.00	100.00
10%	100.00	100.00	100.00	100.00	63.63	67.95	100.00	100.00
Max	54,702	54,702	54,702	54,702	54,702	54,702	54,702	54,702

Table 5.28
Storage-Frequency Relationship for Lake Aquilla for
Initial Storage Contents of 75% of 41,700 acre-feet Capacity

End of Month	75% Full at Beginning of April (Month 4) 6 Jun	9 Sep	12 Dec	3 Mar	75% Full at Beginning of July (Month 7) 9 Sep	12 Dec	3 Mar	6 Jun
Mean	36,947	33,276	35,273	37,413	26,805	29,209	31,728	38,176
Min	64.97	52.52	51.60	51.99	57.97	51.49	47.67	49.34
99%	64.97	52.52	51.60	51.99	57.97	51.49	47.67	49.34
98%	65.49	56.08	51.60	53.08	58.07	52.66	52.45	50.74
95%	68.21	58.70	53.02	57.50	60.02	55.80	53.80	57.83
90%	71.02	61.18	59.79	68.06	61.05	56.92	55.16	67.21
80%	72.37	66.25	72.90	75.48	62.28	59.13	57.31	85.46
70%	81.69	75.81	74.93	84.58	62.99	59.42	61.59	93.24
60%	87.40	79.06	81.84	93.93	63.32	60.91	61.59	94.89
50%	92.76	82.84	87.03	99.29	63.44	62.97	72.20	97.46
40%	96.68	85.11	93.88	100.00	63.44	62.98	75.98	100.00
30%	100.00	86.75	100.00	100.00	63.69	73.84	98.39	100.00
20%	100.00	92.11	100.00	100.00	64.63	89.29	100.00	100.00
10%	100.00	94.45	100.00	100.00	65.45	100.00	100.00	100.00
Max	41,700	41,700	41,700	41,700	41,700	41,700	41,700	41,700

Table 5.29
Storage-Frequency Relationship for Lake Somerville for
Initial Storage Contents of 75% of 154,254 acre-feet Capacity

	75% Full at Beginning of April (Month 4)				75% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	119,582	112,708	122,245	137,652	104,990	128,769	140,420	147,761
Min	69.96	60.67	58.76	58.43	64.33	60.10	59.63	73.20
99%	69.96	60.67	58.76	58.43	64.33	60.10	59.63	73.20
98%	69.96	60.67	58.76	68.35	64.33	60.10	59.63	73.20
95%	69.96	60.67	58.76	68.35	64.33	60.10	59.63	73.20
90%	70.07	64.15	63.99	72.73	64.46	62.49	72.11	75.86
80%	70.91	66.78	64.70	75.10	65.62	64.59	75.75	95.27
70%	73.28	67.52	70.26	81.42	69.01	71.64	86.42	100.00
60%	75.04	68.57	73.78	86.46	69.04	75.89	93.72	100.00
50%	75.37	69.10	76.90	95.18	69.04	79.84	100.00	100.00
40%	76.35	73.63	77.11	100.00	69.04	99.13	100.00	100.00
30%	80.47	74.39	82.90	100.00	69.04	99.13	100.00	100.00
20%	82.20	77.32	100.00	100.00	69.04	99.13	100.00	100.00
10%	87.15	91.44	100.00	100.00	69.04	99.13	100.00	100.00
Max	154,254	154,254	154,254	154,254	107,022	154,254	154,254	154,254

Table 5.30
Storage-Frequency Relationship for Lake Limestone for
Initial Storage Contents of 75% of 208,017 acre-feet Capacity

	75% Full at Beginning of April (Month 4)				75% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	174,216	156,321	167,140	180,755	133,628	156,222	178,983	184,375
Min	63.99	52.12	47.24	45.95	59.43	54.31	52.98	45.82
99%	63.99	53.79	51.33	50.28	59.43	54.31	52.98	50.88
98%	65.24	54.85	51.51	54.52	59.79	55.92	57.01	52.25
95%	66.68	55.30	51.51	56.28	60.55	58.93	58.07	57.55
90%	68.03	55.39	53.64	57.06	62.53	61.74	61.15	57.55
80%	70.10	59.32	63.04	64.29	62.53	62.30	61.15	65.47
70%	72.18	62.59	67.68	79.47	63.17	63.26	70.15	92.60
60%	77.37	68.48	70.51	95.34	64.04	64.35	91.44	95.56
50%	81.38	72.73	83.54	100.00	64.14	69.14	98.04	97.75
40%	88.98	82.05	91.80	100.00	64.20	79.34	100.00	97.75
30%	97.17	87.55	98.96	100.00	64.21	79.34	100.00	100.00
20%	100.00	90.67	100.00	100.00	64.40	91.80	100.00	100.00
10%	100.00	93.80	100.00	100.00	65.47	100.00	100.00	100.00
Max	208,017	208,017	208,017	208,017	208,017	208,017	208,017	208,017

Table 5.31
Storage-Frequency Relationship for Lake Waco for
Initial Storage Contents of 75% of 206,562 acre-feet Capacity

End of Month	75% Full at Beginning of April (Month 4) 6 Jun	9 Sep	12 Dec	3 Mar	75% Full at Beginning of July (Month 7) 9 Sep	12 Dec	3 Mar	6 Jun
Mean	179,966	166,889	173,461	187,690	134,449	140,343	181,135	193,374
Min	71.35	60.79	56.60	62.07	61.24	57.75	58.36	57.32
99%	71.35	60.79	56.60	62.07	61.24	57.75	58.36	57.32
98%	71.35	60.79	56.60	62.74	61.24	57.75	58.36	57.32
95%	71.35	62.58	60.97	64.57	61.77	58.90	61.96	67.15
90%	71.85	62.58	62.97	72.00	61.77	58.90	64.96	79.48
80%	73.56	67.00	64.88	76.38	61.77	59.71	66.86	89.07
70%	77.45	71.56	72.47	86.91	63.12	59.71	85.95	95.69
60%	82.40	77.07	83.00	97.96	63.23	59.90	90.27	95.69
50%	87.64	84.14	88.03	99.75	63.23	63.17	90.27	99.70
40%	92.27	87.28	92.35	100.00	63.49	67.36	100.00	99.70
30%	100.00	90.25	99.55	100.00	65.28	75.81	100.00	99.70
20%	100.00	92.28	100.00	100.00	67.64	75.81	100.00	100.00
10%	100.00	94.64	100.00	100.00	69.09	77.05	100.00	100.00
Max	206,562	206,562	206,562	206,562	206,562	206,562	206,562	206,562

Table 5.32
Storage-Frequency Relationship for Combined Lakes Possum Kingdom and Granbury
For Initial Storage Contents of 50% of 684,834 acre-feet Capacity

End of Month	50% Full at Beginning of April (Month 4) 6 Jun	9 Sep	12 Dec	3 Mar	50% Full at Beginning of July (Month 7) 9 Sep	12 Dec	3 Mar	6 Jun
Mean	335,261	391,068	517,232	606,831	389,099	482,756	513,623	614,283
Min	44.57	38.20	47.43	46.36	41.41	40.62	39.36	46.82
99%	44.57	38.20	52.37	62.69	41.41	40.62	39.36	46.82
98%	44.57	38.20	57.65	62.69	41.41	40.62	39.36	46.82
95%	44.57	38.20	57.65	68.48	42.96	41.13	39.36	49.47
90%	44.57	38.20	58.30	68.48	43.26	42.83	44.52	58.30
80%	44.57	38.20	75.84	78.50	44.47	49.60	52.85	74.82
70%	44.57	38.20	75.84	78.50	47.71	53.99	61.01	90.28
60%	44.57	38.20	75.84	78.50	50.67	63.70	67.71	99.99
50%	48.85	59.26	75.84	100.00	51.60	66.65	71.12	100.00
40%	48.85	61.39	75.84	100.00	53.01	72.35	82.46	100.00
30%	48.85	77.47	76.77	100.00	62.18	85.37	100.00	100.00
20%	53.34	77.47	76.77	100.00	69.53	100.00	100.00	100.00
10%	55.28	77.47	77.77	100.00	74.15	100.00	100.00	100.00
Max	684,834	684,834	684,834	684,834	684,834	684,834	684,834	684,834

Table 5.33
Storage-Frequency Relationship for Lakes Belton, Stillhouse Hollow, Granger, and Georgetown
For Initial Storage Contents of 50% of 744,777 acre-feet Capacity

	50% Full at Beginning of April (Month 4)				50% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	369,103	366,367	430,898	509,450	361,461	405,561	475,183	601,961
Min	45.21	38.71	36.52	35.08	42.19	38.19	35.03	36.14
99%	45.21	38.71	36.52	35.08	42.19	38.19	35.03	36.97
98%	45.21	38.71	36.52	35.08	42.19	38.19	35.03	39.68
95%	45.21	38.71	36.52	36.44	42.33	39.75	38.84	42.22
90%	45.21	38.86	37.93	36.44	42.75	39.83	39.89	50.36
80%	46.15	38.86	37.93	43.10	43.21	40.71	42.41	60.53
70%	46.17	40.00	41.61	51.19	43.63	41.10	45.43	68.04
60%	46.17	42.53	47.39	62.51	43.75	43.41	48.67	81.26
50%	47.32	44.96	51.58	69.64	43.77	47.21	51.50	84.68
40%	48.62	47.32	51.67	71.88	44.77	49.74	65.47	94.03
30%	50.72	49.98	72.05	88.16	47.00	56.25	79.96	100.00
20%	52.68	59.70	85.65	89.58	51.75	67.42	99.83	100.00
10%	55.40	64.80	92.60	100.00	63.63	87.23	100.00	100.00
Max	744,777	744,777	744,777	744,777	655,617	744,777	744,777	744,777

Table 5.34
Storage-Frequency Relationship for Lake Proctor for
Initial Storage Contents of 50% of 54,702 acre-feet Capacity

	50% Full at Beginning of April (Month 4)				50% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	30,825	25,068	25,021	28,173	21,086	19,943	22,911	28,114
Min	40.13	28.73	27.32	23.79	35.63	31.64	28.98	22.03
99%	40.76	28.73	27.32	24.56	35.67	32.99	29.53	23.50
98%	40.76	30.53	27.35	24.65	36.09	33.07	30.13	24.21
95%	42.90	30.88	27.40	25.00	36.77	33.07	30.13	24.21
90%	43.13	31.20	28.22	26.21	37.08	33.66	32.22	26.51
80%	43.54	32.17	29.19	27.22	37.83	34.76	33.02	28.33
70%	43.95	32.23	29.20	27.94	37.83	36.13	33.63	28.82
60%	44.12	33.36	30.73	28.87	42.39	36.19	33.83	29.17
50%	44.27	33.64	30.96	29.01	38.93	36.21	34.00	31.62
40%	44.40	33.80	31.12	40.26	39.00	36.24	34.04	42.47
30%	44.95	36.21	35.73	78.23	39.03	36.24	34.04	63.86
20%	73.73	63.96	80.95	98.00	39.05	36.27	34.65	98.79
10%	100.00	90.93	100.00	100.00	40.10	38.16	75.77	100.00
Max	54,702	54,702	54,702	54,702	23,262	54,702	54,702	54,702

Table 5.35
Storage-Frequency Relationship for Lake Aquilla for
Initial Storage Contents of 50% of 41,700 acre-feet Capacity

	50% Full at Beginning of April (Month 4)				50% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	25,293	22,948	28,065	32,609	16,700	20,136	23,683	34,136
Min	41.72	31.50	30.46	30.01	36.34	30.80	27.45	28.38
99%	41.72	31.50	30.46	30.01	36.34	30.80	27.45	28.38
98%	41.72	31.50	30.46	30.01	36.41	31.69	31.30	28.68
95%	43.73	34.55	32.13	30.01	36.93	33.80	32.88	37.59
90%	44.60	36.89	33.09	37.72	38.58	35.22	33.82	54.36
80%	46.80	39.71	39.03	50.34	39.29	36.38	37.10	69.71
70%	48.25	41.05	50.27	68.01	40.07	37.11	38.98	82.74
60%	51.89	44.29	54.79	74.54	40.26	38.77	38.98	82.74
50%	55.33	52.15	65.13	84.57	40.27	40.18	38.98	82.74
40%	60.67	55.52	73.76	100.00	40.35	40.18	53.08	93.76
30%	64.21	63.75	90.33	100.00	40.35	40.18	70.79	98.30
20%	74.46	69.36	100.00	100.00	40.35	57.50	100.00	100.00
10%	88.91	84.45	100.00	100.00	40.38	88.61	100.00	100.00
Max	41,700	41,700	41,700	41,700	39,563	41,700	41,700	41,700

Table 5.36
Storage-Frequency Relationship for Lake Somerville for
Initial Storage Contents of 50% of 154,254 acre-feet Capacity

	50% Full at Beginning of April (Month 4)				50% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	74,511	68,462	99,879	109,130	76,199	91,212	115,704	131,051
Min	45.98	38.53	36.98	36.97	41.32	37.85	37.56	36.58
99%	45.98	38.53	36.98	46.37	41.32	37.85	37.56	45.97
98%	45.98	38.53	36.98	46.37	41.32	37.85	37.56	51.42
95%	45.98	40.69	37.25	46.37	41.32	37.85	37.56	51.42
90%	45.98	41.27	44.58	50.33	41.43	39.84	49.24	53.41
80%	46.16	43.65	44.58	52.14	42.35	41.65	51.05	57.08
70%	48.51	43.65	44.58	52.14	43.75	44.79	59.16	71.78
60%	48.51	43.65	50.88	52.14	45.07	47.62	65.33	93.68
50%	48.51	43.65	50.88	52.14	45.08	53.22	69.71	98.29
40%	49.05	44.84	53.16	77.65	45.08	55.85	81.54	100.00
30%	49.05	44.84	100.00	100.00	46.99	62.02	100.00	100.00
20%	49.05	44.84	100.00	100.00	51.69	74.96	100.00	100.00
10%	49.05	50.50	100.00	100.00	58.93	100.00	100.00	100.00
Max	154,254	154,254	154,254	154,254	154,254	154,254	154,254	154,254

Table 5.37
Storage-Frequency Relationship for Lake Limestone for
Initial Storage Contents of 50% of 208,017 acre-feet Capacity

End of Month	50% Full at Beginning of April (Month 4) 6 Jun	9 Sep	12 Dec	3 Mar	50% Full at Beginning of July (Month 7) 9 Sep	12 Dec	3 Mar	6 Jun
Mean	116,604	102,003	121,048	142,144	81,266	114,758	151,041	173,077
Min	40.22	30.23	26.16	24.97	36.75	32.41	30.82	24.24
99%	40.22	30.23	26.16	24.97	36.75	32.41	31.19	28.45
98%	40.22	30.23	26.16	24.97	36.75	32.41	31.19	28.45
95%	41.77	32.36	30.26	32.18	37.03	33.62	34.43	34.16
90%	42.74	33.59	31.48	32.18	37.51	34.64	35.53	39.61
80%	44.07	34.46	32.32	35.58	37.62	38.26	37.40	48.43
70%	45.21	35.86	35.02	38.83	37.62	40.02	68.95	92.60
60%	46.19	37.61	42.46	56.04	39.11	40.02	68.95	95.14
50%	49.55	42.95	46.52	65.19	39.46	40.02	68.95	95.14
40%	53.71	49.02	57.18	86.01	39.47	41.66	98.04	95.14
30%	61.81	56.69	73.14	100.00	39.47	55.67	100.00	97.75
20%	68.23	62.05	96.40	100.00	40.33	99.14	100.00	100.00
10%	77.40	79.87	100.00	100.00	40.39	100.00	100.00	100.00
Max	208,017	208,017	208,017	208,017	208,017	208,017	208,017	208,017

Table 5.38
Storage-Frequency Relationship for Lake Waco for
Initial Storage Contents of 50% of 206,562 acre-feet Capacity

End of Month	50% Full at Beginning of April (Month 4) 6 Jun	9 Sep	12 Dec	3 Mar	50% Full at Beginning of July (Month 7) 9 Sep	12 Dec	3 Mar	6 Jun
Mean	117,560	106,333	118,913	150,438	81,335	78,512	147,357	175,565
Min	46.81	37.66	33.83	38.66	37.91	34.50	35.15	34.96
99%	46.81	37.66	33.83	38.66	37.91	34.50	35.30	34.96
98%	46.81	37.66	33.83	38.66	37.91	34.50	35.30	34.96
95%	46.81	37.66	33.83	41.83	37.91	34.50	35.30	34.96
90%	46.81	38.95	38.79	41.83	37.91	34.50	35.30	34.96
80%	46.81	38.95	40.59	49.28	38.50	35.55	43.55	56.66
70%	47.40	38.95	40.59	53.75	39.40	36.25	44.22	95.69
60%	48.15	42.78	40.59	74.70	39.40	36.25	44.22	99.70
50%	51.96	44.53	41.93	74.70	39.51	36.25	68.02	100.00
40%	52.89	48.61	55.64	74.70	39.73	36.39	100.00	100.00
30%	58.09	53.44	68.61	94.55	39.73	37.20	100.00	100.00
20%	65.81	62.17	80.06	100.00	39.73	37.20	100.00	100.00
10%	77.16	73.88	100.00	100.00	39.73	41.23	100.00	100.00
Max	206,562	206,562	206,562	206,562	206,562	206,562	206,562	206,562

Table 5.39
Storage-Frequency Relationship for Combined Lakes Possum Kingdom and Granbury
For Initial Storage Contents of 25% of 684,834 acre-feet Capacity

	25% Full at Beginning of April (Month 4)				25% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	148,792	150,061	372,286	600,955	202,409	313,215	369,041	528,562
Min	21.12	17.14	26.15	25.47	18.24	17.99	17.01	26.82
99%	21.12	17.14	36.97	45.66	18.24	17.99	17.01	26.82
98%	21.12	17.14	53.66	55.67	18.24	17.99	17.01	27.72
95%	21.12	17.14	53.66	55.67	19.55	18.87	19.41	29.30
90%	21.12	17.14	53.66	55.67	20.01	18.98	20.10	30.34
80%	21.12	17.14	54.47	92.53	20.34	22.53	27.40	51.03
70%	21.12	17.14	54.47	92.53	21.84	27.37	33.57	59.61
60%	21.12	17.14	54.47	92.53	24.31	33.64	41.18	71.16
50%	21.12	17.14	54.47	92.53	26.79	39.87	44.22	95.15
40%	21.12	17.14	54.47	92.53	27.41	43.69	54.41	99.99
30%	21.12	17.14	54.47	92.53	31.46	56.93	76.38	100.00
20%	21.12	17.14	54.47	92.53	38.32	63.02	91.57	100.00
10%	24.34	54.02	54.47	92.53	43.07	84.18	94.13	100.00
Max	684,834	684,834	684,834	684,834	684,834	684,834	684,834	684,834

Table 5.40
Storage-Frequency Relationship for Lakes Belton, Stillhouse Hollow, Granger, and Georgetown
For Initial Storage Contents of 25% of 744,777 acre-feet Capacity

	25% Full at Beginning of April (Month 4)				25% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	163,262	149,000	216,273	353,385	182,583	239,093	329,703	497,510
Min	20.84	15.45	14.38	13.57	18.70	15.19	12.58	13.88
99%	20.84	15.45	14.38	14.58	18.70	15.19	12.58	14.01
98%	20.84	15.45	14.38	14.58	18.70	15.19	12.58	16.34
95%	20.84	15.45	14.38	14.58	18.78	16.14	14.91	19.02
90%	20.84	15.45	14.38	14.58	19.02	16.65	16.29	27.36
80%	20.84	15.45	14.61	40.69	19.43	16.96	18.70	37.63
70%	20.84	15.45	14.61	40.69	19.56	17.51	21.67	45.27
60%	21.78	15.85	14.61	40.69	19.61	19.49	25.20	60.32
50%	21.78	16.45	29.33	50.84	19.62	23.20	27.59	62.30
40%	21.78	16.45	29.33	50.84	20.64	25.76	42.52	81.22
30%	21.78	16.45	29.33	50.84	22.66	33.08	56.03	98.57
20%	21.87	20.89	29.33	50.84	27.67	44.13	80.27	100.00
10%	22.97	35.86	63.47	74.47	39.40	65.46	97.64	100.00
Max	744,777	744,777	744,777	744,777	476,478	744,777	744,777	744,777

Table 5.41
Storage-Frequency Relationship for Lake Proctor for
Initial Storage Contents of 25% of 54,702 acre-feet Capacity

End of Month	25% Full at Beginning of April (Month 4) 6 Jun	9 Sep	12 Dec	3 Mar	25% Full at Beginning of July (Month 7) 9 Sep	12 Dec	3 Mar	6 Jun
Mean	15,432	11,067	11,567	14,843	8,322	7,201	7,882	10,920
Min	17.46	8.03	6.63	4.37	13.59	10.55	8.57	3.25
99%	17.46	8.03	6.63	4.75	13.60	11.33	8.84	3.97
98%	17.85	8.60	6.71	4.75	13.60	11.43	9.22	4.38
95%	19.08	9.32	6.77	5.22	13.92	11.43	9.22	4.38
90%	19.34	9.59	7.27	5.70	14.29	11.67	9.99	4.71
80%	19.61	10.16	7.77	6.17	14.93	12.36	10.91	6.77
70%	19.89	10.23	8.07	6.52	14.93	13.30	11.43	6.96
60%	19.98	10.88	8.65	6.98	14.93	13.32	11.45	6.99
50%	20.04	10.99	8.78	7.15	15.13	13.32	11.54	7.01
40%	20.12	11.09	8.86	7.23	15.61	13.32	11.54	8.61
30%	20.16	11.15	8.93	10.11	15.68	13.37	11.54	8.61
20%	20.55	11.75	11.37	60.97	15.69	13.37	11.58	8.61
10%	60.69	70.31	73.52	100.00	15.69	13.57	12.50	72.57
Max	54,702	54,702	54,702	54,702	9,769	54,702	54,702	54,702

Table 5.42
Storage-Frequency Relationship for Lake Aquilla for
Initial Storage Contents of 25% of 41,700 acre-feet Capacity

End of Month	25% Full at Beginning of April (Month 4) 6 Jun	9 Sep	12 Dec	3 Mar	25% Full at Beginning of July (Month 7) 9 Sep	12 Dec	3 Mar	6 Jun
Mean	11,859	10,728	17,190	25,217	7,053	10,914	15,536	28,672
Min	18.48	10.60	9.38	8.09	14.72	10.23	7.42	6.75
99%	18.48	10.60	9.38	9.09	14.72	10.23	7.42	6.75
98%	18.48	10.60	9.38	8.09	14.77	10.79	10.20	7.60
95%	18.73	13.05	9.38	8.09	15.09	11.09	10.55	9.98
90%	19.77	13.05	10.97	8.09	15.83	12.91	12.15	32.71
80%	20.99	14.48	11.28	16.57	16.48	13.63	15.57	48.32
70%	22.24	16.99	15.41	29.95	17.06	14.80	16.37	60.89
60%	23.88	17.29	19.21	46.73	17.17	17.39	16.37	60.89
50%	24.14	19.18	34.12	52.83	17.19	17.39	16.37	60.89
40%	26.95	21.82	42.42	82.42	17.27	17.39	16.80	60.89
30%	28.71	22.81	49.13	100.00	17.27	17.39	47.93	97.18
20%	33.04	31.84	69.65	100.00	17.27	34.88	81.84	100.00
10%	38.87	46.60	100.00	100.00	17.27	66.00	100.00	100.00
Max	41,700	41,700	41,700	41,700	39,563	41,700	41,700	41,700

Table 5.43
Storage-Frequency Relationship for Lake Somerville for
Initial Storage Contents of 25% of 154,254 acre-feet Capacity

	25% Full at Beginning of April (Month 4)				25% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	36,939	31,865	111,385	115,537	41,457	60,163	91,183	115,907
Min	22.22	17.18	16.14	25.27	18.84	16.41	16.37	15.99
99%	22.48	20.24	21.05	28.56	18.84	16.41	16.37	24.57
98%	23.78	20.24	21.05	28.56	18.84	16.41	16.37	30.47
95%	23.78	20.24	21.05	28.56	18.84	16.41	16.37	30.47
90%	23.78	20.24	21.05	28.56	18.91	17.83	26.99	31.45
80%	23.78	20.24	21.05	28.56	19.51	19.26	28.49	33.46
70%	23.78	20.24	21.05	28.56	20.65	20.99	35.48	49.33
60%	23.78	20.24	100.00	100.00	21.35	23.84	43.69	70.60
50%	23.78	20.24	100.00	100.00	21.35	31.22	45.93	96.94
40%	23.78	20.24	100.00	100.00	21.35	32.10	57.70	100.00
30%	24.32	21.40	100.00	100.00	23.24	38.29	87.03	100.00
20%	24.32	21.40	100.00	100.00	27.87	51.16	100.00	100.00
10%	24.32	21.40	100.00	100.00	35.21	100.00	100.00	100.00
Max	37,517	41,428	154,254	154,254	154,254	154,254	154,254	154,254

Table 5.44
Storage-Frequency Relationship for Lake Limestone for
Initial Storage Contents of 25% of 208,017 acre-feet Capacity

	25% Full at Beginning of April (Month 4)				25% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	54,700	40,935	61,966	105,329	32,650	44,917	99,834	159,168
Min	16.80	9.30	6.28	5.24	14.73	11.43	9.28	3.74
99%	16.80	9.30	6.28	5.24	14.73	11.43	10.34	6.81
98%	16.80	9.87	7.78	6.46	14.73	11.43	10.34	6.81
95%	17.71	9.92	9.78	9.98	14.73	11.43	10.34	6.81
90%	17.95	10.90	10.05	9.98	14.91	12.12	12.17	20.00
80%	18.80	11.94	10.21	15.08	15.20	12.69	14.31	23.78
70%	20.35	12.73	12.14	21.22	15.29	13.45	17.18	93.60
60%	20.62	12.88	14.56	31.08	15.29	17.59	47.21	93.60
50%	22.37	13.80	19.57	39.90	15.29	18.13	47.21	93.60
40%	22.92	17.83	22.53	61.56	15.29	18.13	47.21	93.60
30%	28.86	22.34	24.44	83.62	16.15	18.13	47.21	93.60
20%	31.74	26.06	45.72	94.47	16.34	18.13	91.47	100.00
10%	36.57	28.73	79.42	100.00	16.84	18.13	100.00	100.00
Max	208,017	208,017	208,017	208,017	174,152	208,017	208,017	208,017

Table 5.45
Storage-Frequency Relationship for Lake Waco for
Initial Storage Contents of 25% of 206,562 acre-feet Capacity

	25% Full at Beginning of April (Month 4)				25% Full at Beginning of July (Month 7)			
End of	6	9	12	3	9	12	3	6
Month	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
Mean	53,957	42,996	54,337	106,988	32,208	26,760	107,546	161,005
Min	22.33	14.65	11.19	15.44	14.67	11.34	11.82	12.68
99%	22.33	14.65	11.19	16.70	14.67	11.34	12.32	12.68
98%	22.33	14.65	11.19	16.70	14.67	11.34	12.32	12.68
95%	22.33	14.65	11.19	19.23	14.67	11.34	12.32	12.68
90%	22.33	15.43	16.05	19.23	14.67	11.34	12.32	12.68
80%	22.33	15.43	17.44	25.99	14.67	11.34	12.32	12.68
70%	22.33	15.43	17.44	51.56	15.72	12.69	21.37	100.00
60%	22.33	15.43	17.44	51.56	15.72	12.69	21.37	100.00
50%	22.33	15.43	17.44	51.56	15.72	12.69	21.37	100.00
40%	22.77	15.95	17.44	51.56	15.98	12.69	88.28	100.00
30%	24.38	19.54	17.44	51.56	15.98	12.69	88.28	100.00
20%	28.32	24.37	28.17	51.56	15.98	14.39	88.28	100.00
10%	33.08	31.21	59.57	100.00	15.98	14.39	88.28	100.00
Max	206,562	206,562	206,562	206,562	206,562	206,562	206,562	206,562

Notes for Tables 5.18−5.45: The mean storage volume and maximum storage volume at the top and bottom, respectively, of each column are in units of acre-feet. The mean storage volume is a probability-weighted average. Exceedance frequencies are listed in the first column. The reservoir storage volumes associated with the specified exceedance frequencies are expressed as a percentage of storage capacity.

Comparative Assessment of the Equal-Weight versus Probability Array Options

The only difference between the equal-weight option and probability array option is the approach adopted within *TABLES* for assigning probabilities to each hydrologic sequence and corresponding CRM simulation for use in the frequency and reliability analysis computations. The probability array option assigns varying probabilities to the 107 simulations in the Brazos River Basin CRM analyses. The sub-option of the probability array option (Table 5.1) adopted for the Brazos study bases the estimation of probabilities for each hydrologic sequence on a storage-flow-frequency (SFF) relationship developed by *TABLES* based on naturalized flow volumes and preceding reservoir storage volumes from the *SIM* simulation results for a long-term simulation.

Key Modeling Issues

The objective of the probability array option is to improve the accuracy of the frequency analyses over the simpler relative frequency methodology of the equal-weight option. Hydrologic persistence is a key issue addressed by the probability-array option. For example, alternative initial storage contents of 100%, 75%, 50%, and 25% of capacity are specified in the CRM analyses of this report. Current storage contents of 100% imply that preceding months are wetter with higher stream flows than would be implied by current storage contents of 25% capacity. Continued high stream flows are more likely to follow preceding high flows. Likewise, low flows are more likely to follow low flows than to follow high flows. The probabilities associated with the 107 hydrologic sequences should be different for different specified initial storage conditions. The storage-flow-frequency (SFF) array methodology addresses this modeling issue.

The sub-option of the probability array option (Table 5.1) adopted for the Brazos River Basin study bases the estimation of probabilities for each hydrologic sequence on a SFF array developed by *TABLES* based on naturalized flow volumes and preceding storage volumes from the *SIM* simulation results for the long-term simulation.

The range of storage levels covered in the *SIM* simulation results from which the SFF array is developed is an important issue in applying the SFF array to model the storage-flow relationship. The following two ranges of reservoir storage contents reflected in the CRM analyses must be reasonably consistent.

1. The SFF array is developed from 108 pairs (assuming a 1900-2007 hydrologic period of analysis) of naturalized flow volume and preceding storage contents from the results of a long-term *SIM* simulation that uses the same *SIM* input dataset, exclusive of *CR* record, as the CRM simulations.
2. The *SIM* CRM simulations, with *CR* record, are based on analyst specified initial storage conditions, which for this study were arbitrarily set at 100%, 75%, 50%, and 25% of the storage capacity. These model-user specified initial storage levels greatly affect the range of storage levels that occur in the *SIM* CRM simulations.

The SFF array should be developed from the results of a long-term simulation with storage draw-downs that are reasonably representative of the draw-downs that occur in the CRM simulations.

As previously discussed, the draw-downs reflected in Tables 5.2−5.7 and Figures 5.1−5.14 are not severe enough to adequately develop accurate SFF relationships for all of the cases covered in the Brazos River Basin CRM analyses. For the majority of the reservoirs, with low initial CRM storage levels specified, the storage in the CRM simulations falls significantly below the lowest storage level occurring during the long-term simulation used to develop the SFF arrays. The reservoirs are full to capacity in many months of the long-term simulations.

The scatter in the storage-flow data is another related modeling issue. The improvement in accuracy of the frequency analyses to be achieved by adopting the probability array option depends on the degree of correlation between naturalized flows and preceding storage. The correlation coefficients in Tables 5.8, 5.9, 5.10, and 5.11 are generally small positive numbers, which implies that the probability array option should be somewhat, though not dramatically, more accurate than the equal-weight option, in those cases in which a truly representative SFF relationship can be developed. The exception is the beginning-of-July storage versus flow relationship associated with Lakes Possum Kingdom and Granbury. Correlation coefficients are negative or near zero for the beginning-of-July storage volumes in Possum Kingdom and Granbury Reservoirs, indicating little or no correlation exists between preceding storage and naturalized flow. In this case, the equal-weight option is probably more accurate.

Comparison of CRM Results

The CRM analyses outlined in Table 4.3 with results summarized in Tables 4.4–4.24 and Tables 5.18−5.45 were repeated using both the equal-weight option methodology (Chapter 4) and probability array methodology (Chapter 5). Tables 4.4–4.24 (equal-weight option) and Tables 5.18−5.45 (probability array option) can be compared in their entirety. However, the sample results reproduced in Table 5.46 are representative of the complete storage frequency relationships of Tables 4.4–4.24 and Tables 5.18−5.45. The more concise Table 5.46 is designed to make the comparison a little more convenient. All of the data in Table 5.46 are reproduced directly from Tables 4.4−4.24 and 5.18−5.45.

The storage contents associated with an exceedance frequency of 90% in Tables 4.4–4.24 and Tables 5.18–5.45 are reproduced in Table 5.46. Initial beginning-of-April and beginning-of-July storage contents are shown in column 1 as a percentage of capacity. The corresponding end of June, September, December, and March storage contents, as a percentage of capacity, are reproduced in Table 5.46 as two lines for each of the seven reservoir groups or individual reservoirs.

- The first (top) line consists of the storage volumes from Tables 4.4−4.24 computed based on the equal-weight option.
- The second (bottom) line consists of the storage volumes from Tables 5.18−5.45 computed based on the probability array option.

For example, Table 5.46 begins with CRM results for the combined Possum Kingdom and Granbury Reservoirs. With the reservoirs full at 100% of capacity at the beginning of April, there is an estimated 90% chance that storage contents will be at or above 99.48% of storage capacity at the end of June based on the equal-weight method. The 90% exceedance frequency end-of-June storage contents is 99.99% of storage capacity based on the probability array method. With Possum Kingdom and Granbury Reservoirs at 100% of capacity at the beginning of April, the storage volume with a 90% probability of being equaled or exceeded at the end of June is 32.21% and 21.12% of capacity based on the equal-weight and probability array options, respectively.

Table 5.46 includes only the 90% exceedance frequency simulated storage volumes. These storage volumes have a 90% chance of being equaled or exceeded. The probability is 10% that the storage at the end of the specified months will be below the storage level tabulated in Table 5.46.

With the initial storage contents set at 100% of capacity, the future storage volumes computed based on the equal-weight option storage are generally slightly smaller than the storage volumes computed with the probability array option. The pattern is logically to be expected. The initial storage volume of 100% of capacity is the maximum storage contents possible in the model. Thus, the probability array option assigns higher probabilities to high flows than does the equal-weight option. This results in higher storage volumes for any particular exceedance frequency, including the 90% exceedance frequency storage volumes included in Table 5.46.

The equal-weight option, in essence, assigns the same probability of 1/107 to each of the 107 hydrologic sequences regardless of user-specified initial storage conditions. The probability array option is designed to model hydrologic persistence as reflected in the initial storage contents. With the initial storage contents set at 100% of capacity, the probability array option assigns higher probabilities to high flows and lower probabilities to low flows than does the equal-weight option. Conversely, with the initial storage contents set at 25% of capacity, the probability array option assigns higher probabilities to low flows and lower probabilities to high flows than does the equal-weight option. Higher flows result in higher future storage levels, and lower flows result in lower future storage levels.

As the arbitrarily set initial storage contents is lowered to 75%, 50%, and 25% of capacity, the storage volumes in Table 5.46 computed based on the equal-weight option storage become larger than the storage volumes computed with the probability array option. The difference between the larger equal-weight storage volumes and smaller probability storage volumes in Table 5.46 increases with decreases in the specified initial storage contents. With the initial storage contents set at only 25% of capacity, the future storage volumes computed based on the equal-weight option are much larger than the corresponding storage volumes computed based on the probability array option. This is because, with a low initial storage, the probability array option assigns higher probabilities to the lower flows than does the equal-weight option.

With the initial storage contents set at 100% of capacity, the results are almost the same with the equal-weight and probability array methodologies. With the initial storage contents set at 25% of capacity, the differences are significant.

The CRM analyses for Proctor Reservoir are significantly different than for the other reservoirs. The CRM results behave exactly as they logically should for Proctor Reservoir. The consistent results are due to the full range of storage draw-downs experienced by Proctor Reservoir in the long-term *SIM* simulation. The CRM results for Proctor Reservoir are almost the same with either the equal-weight or probability array options. With the initial storage contents set at 100% of capacity, the 90% storage levels in Table 8.45, as well as the other storage levels in Tables 4.4−4.24 and Tables 5.18−5.45, for Proctor Reservoir simulated based on the equal-weight option are slightly smaller than the storage volumes computed with the probability array option. The reverse occurs with an initial storage contents of 25%.

The CRM results for Aquilla and Limestone Reservoirs behave similarly as Proctor, but the differences between results from the two alternative options are greater that at Proctor. Storage draw-downs in Aquilla and Limestone Reservoirs in the long-term simulation are less severe than at Proctor but more severe than most of the other reservoirs.

In general, plots of naturalized flow volumes versus preceding storage volumes exhibit considerable scatter. Correlation coefficients are low. Thus, hydrologic persistence is relatively minimal. The equal-weight results should be reasonably valid even though hydrologic persistence is ignored in the methodology.

The extreme case of negative or near zero correlation coefficients occur with beginning-of-July storage volumes in the combined Possum Kingdom and Granbury Reservoirs. With little or no correlation between preceding storage and naturalized flow, the equal-weight option is probably more accurate than the probability array option in the combined Possum Kingdom and Granbury Reservoirs. Proctor Reservoir represents the other extreme where the probability array option is most valid. However, both of the alternative methods yield similar results for Proctor Reservoir.

The initial storage contents of 100%, 75%, 50%, and 25% are set arbitrarily. The storage levels simulated in the long-term SIM simulation represent reality. With the exception of Proctor Reservoir, 25% of capacity is unrealistically low. The accuracy of both the equal-weight and probability options is low for the CRM analyses with initial storage set at 25% of capacity. The CRM analyses with initial storage of 50% capacity are similarly suspect for some of the reservoirs.

Table 5.46
Comparison of 90% Exceedance Frequency Storage Contents
Estimated with Equal-Weight Versus Probability Array Options
(Equal-weight is on top followed by probability array below.)

	Starts at Beginning of April (Month 4)				Starts at Beginning of July (Month 7)			
Initial	6	9	12	3	9	12	3	6
Storage	Jun	Sep	Dec	Mar	Sep	Dec	Mar	Jun
	Possum Kingdom and Granbury Reservoirs							
100%	99.48	92.28	93.94	95.56	92.37	93.94	95.56	99.35
	99.99	92.47	95.97	96.31	92.12	92.88	94.87	99.38
75%	80.59	84.72	87.88	91.03	68.38	73.95	75.86	95.63
	73.33	72.05	80.85	90.90	67.64	69.38	72.66	93.00
50%	56.36	61.47	67.91	71.58	44.70	50.30	52.76	74.52
	44.57	38.20	58.30	68.48	43.26	42.83	44.52	58.30
25%	32.21	38.10	45.56	49.14	21.55	26.74	29.63	53.23
	21.12	17.14	53.66	55.67	20.01	18.98	20.10	30.34
	Belton, Stillhouse Hollow, Georgetown, and Granger Reservoirs							
100%	98.00	90.49	87.82	89.01	92.03	89.42	89.34	94.87
	98.34	90.98	89.53	91.16	92.37	90.39	91.13	95.05
75%	76.99	71.91	72.09	74.87	68.75	65.24	65.55	75.03
	70.66	63.72	65.55	62.78	66.65	63.41	63.24	73.03
50%	52.42	48.11	48.74	51.65	49.53	41.07	41.92	52.08
	45.21	38.86	37.93	36.44	42.75	39.83	39.89	50.36
25%	27.92	24.32	24.95	28.73	19.54	17.50	18.63	28.77
	20.84	15.45	14.38	14.58	19.02	16.65	16.29	27.36
	Proctor Reservoir							
100%	94.12	78.18	74.19	71.51	82.68	77.52	76.01	70.59
	94.60	77.89	74.03	70.98	82.69	78.67	77.29	70.88
75%	66.22	52.56	49.35	48.23	59.11	54.63	52.00	46.35
	65.86	52.54	48.56	47.11	59.14	55.08	52.61	46.17
50%	42.93	31.41	28.47	27.18	37.49	34.00	31.59	26.60
	43.13	31.20	28.22	26.21	37.08	33.66	32.22	26.51
25%	19.23	9.69	7.36	5.56	14.73	12.01	10.09	5.70
	19.34	9.59	7.27	5.70	14.29	11.67	9.99	4.71

Table 5.46 (Continued)
Comparison of 90% Exceedance Frequency Storage Contents

Initial Storage	Starts at Beginning of April (Month 4) 6 Jun	9 Sep	12 Dec	3 Mar	Starts at Beginning of July (Month 7) 9 Sep	12 Dec	3 Mar	6 Jun
				Aquilla Reservoir				
100%	94.68	81.47	77.74	75.85	84.27	79.97	78.59	92.77
	94.84	80.73	77.84	76.90	84.56	80.15	78.71	90.56
75%	73.24	63.61	63.15	71.64	61.59	57.86	56.32	75.30
	71.02	61.18	59.79	68.06	61.05	56.92	55.16	67.21
50%	49.22	41.20	42.78	52.63	41.09	35.72	34.63	53.96
	44.60	36.89	33.09	37.72	38.58	35.22	33.82	54.36
25%	25.21	19.12	22.38	31.28	17.34	13.56	12.55	32.67
	19.77	13.05	10.97	8.09	15.83	12.91	12.15	32.71
				Somerville Reservoir				
100%	97.30	89.48	90.91	95.19	91.42	91.02	97.10	96.51
	97.42	89.16	90.98	96.76	93.02	93.01	94.99	97.42
75%	75.48	70.61	74.90	85.26	67.79	67.32	74.40	83.05
	70.07	64.15	63.99	72.73	64.46	62.49	72.11	75.86
50%	51.13	47.39	51.37	62.23	44.23	43.76	50.64	59.69
	45.98	41.27	44.58	50.33	41.43	39.84	49.24	53.41
25%	27.13	24.33	27.92	38.68	20.91	20.62	27.84	36.05
	23.78	20.24	21.05	28.56	18.91	17.83	26.99	31.45
				Limestone Reservoir				
100%	92.66	80.04	81.01	81.77	86.67	84.77	84.47	87.02
	93.61	80.85	80.95	81.59	86.66	85.95	85.02	87.32
75%	68.49	58.80	61.04	63.30	63.12	61.32	60.97	65.21
	68.03	55.39	53.64	57.06	62.53	61.74	61.15	57.55
50%	44.96	35.45	38.16	40.65	39.67	37.94	37.27	42.52
	42.74	33.59	31.48	32.18	37.51	34.64	35.53	39.61
25%	20.61	12.85	15.87	18.54	16.70	14.79	14.21	20.16
	17.95	10.90	10.05	9.98	14.91	12.12	12.17	20.00
				Waco Reservoir				
100%	96.99	87.46	85.03	86.82	88.71	86.15	87.12	95.89
	97.09	87.81	85.06	86.91	90.13	87.10	86.91	94.42
75%	75.30	69.83	69.13	76.07	64.66	62.59	63.53	73.99
	71.85	62.58	62.97	72.00	61.77	58.90	64.96	79.48
50%	50.88	46.38	46.15	53.10	41.03	39.16	39.97	51.15
	46.81	38.95	38.79	41.83	37.91	34.50	35.30	34.96
25%	26.56	23.06	23.86	30.26	17.35	15.56	16.57	28.56
	22.33	15.43	16.05	19.23	14.67	11.34	12.32	12.68

Option to Model the SFF Array with the Log-Normal Probability Distribution

The parameter DIST in field 6 of the 5CR1 provides two options for assigning exceedance probabilities to the flow ratio defined by Equation 5.2. The default option 1 is based on relative frequency as expressed by the Weibull formula. Option 2 uses the log-normal probability distribution. The relative frequency approach based on the Weibull formula (option 1) was adopted for developing the SFF arrays in the CRM analyses presented in this report. The log-normal probability distribution provides an approximate model of the probability distribution of the flow ratio defined by Equation 5.2. The fit is better in some cases than others but is never perfect. The 1900-2007 hydrologic period-of-analysis provides 107 annual April-May or July-June sequences. The 107 hydrologic sequences is judged to be a large enough number of sequences to adequately define the frequency distribution without resorting to using the log-normal probability distribution.

Program *TABLES* is easily executed with the parameter DIST on the 5CR1 records switched to the log-normal distribution option. The change in CRM results varies between reservoirs and between the April versus July starting months. CRM results with the log-normal distribution option activated for Lake Proctor are shown in Table 5.47. The choice of DIST option in 5CR1 record field 6 is the only difference in the CRM analyses reflected in Table 5.47 versus Table 5.27. The storage frequency statistics of Table 5.47 can also be compared with the equal-weight CRM results of Table 4.13.

Table 5.47
Storage-Frequency Relationship for Lake Proctor for
Initial Storage Contents of 75% of 54,702 acre-feet Capacity
Log-Normal Distribution Activated by 5CR1 Field 6 DIST Option 2
For Comparison with Tables 4.13, 5.27, and 5.46

	75% Full at Beginning of April (Month 4)				75% Full at Beginning of July (Month 7)			
End of Month	6 Jun	9 Sep	12 Dec	3 Mar	9 Sep	12 Dec	3 Mar	6 Jun
Mean	43,896	38,147	38,790	39,626	37,227	30,468	36,144	37,253
Min	61.57	47.96	46.67	43.43	61.57	47.96	46.67	43.43
99%	61.57	47.96	46.67	43.43	61.57	47.96	46.67	45.11
98%	61.57	49.21	46.76	43.93	61.57	47.96	46.67	45.11
95%	63.33	51.06	47.91	46.16	61.57	47.96	46.67	45.11
90%	66.23	51.42	48.56	47.11	61.57	47.96	46.67	45.11
80%	67.45	52.93	50.73	48.51	61.57	50.52	46.83	45.11
70%	67.88	54.72	51.91	49.62	62.54	50.52	47.91	46.16
60%	68.11	55.26	52.18	54.48	62.54	51.11	48.08	46.91
50%	68.24	56.67	66.87	75.80	65.86	51.20	51.48	49.43
40%	84.40	74.24	81.10	80.65	65.86	51.20	67.97	78.23
30%	97.88	84.88	91.26	94.88	66.88	52.91	92.12	100.00
20%	100.00	90.46	95.34	100.00	68.12	55.11	92.12	100.00
10%	100.00	100.00	100.00	100.00	90.74	78.24	92.12	100.00
Max	54,702	54,702	54,702	54,702	54,702	54,702	54,702	54,702

Summary, Conclusions, and Guidance in Applying CRM

Conditional reliability modeling (CRM) is a decision support tool for water management during drought, operational planning studies, developing reservoir system operating plans, and administration of water right permits systems and water supply contracts, for which assessments of short-term water supply reliabilities and storage frequencies are important. CRM in an extension of WRAP modeling capabilities which requires only minimal modifications to existing WRAP input datasets. CRM is described in Chapter 7 of the *Reference Manual* [3]. Instructions for preparing *TABLES* CRM input records are included in Chapter 4 of the *Users Manual* [4].

The CRM analyses of the Brazos River Authority reservoirs combine the BRAC2008 DAT file with the BRAC8 FLO and EVA files. The BRAC2008 DAT file reflects actual operations of the BRA system during the relatively dry year 2008. Stream flow accessible to the 12-reservoir BRA system, along with Hubbard Creek and Squaw Creek Reservoirs, is limited in the *SIM* simulation to the flow amounts legally available assuming that other permit holders in the basin use the full amounts specified in their water right permits. The CRM analyses of the BRA reservoirs focus on developing frequency tables for storage levels three, six, nine, and twelve months later, given specified preceding storage levels at the beginning of either April or July. The analyses are repeated with the *TABLES* equal-weight (Chapter 4) and probability array (Chapter 5) options.

The purpose of Chapters 4 and 5 is to illustrate CRM. WRAP is designed to be routinely applied to address specific water management issues and modeling applications. Variations of the modeling studies presented in this report can be repeated in the future to address particular concerns as they arise. Modeling of individual BRA reservoirs or multiple-reservoir systems can be performed with an extensive array of alternative variations of *SIM* input datasets and *TABLES* CRM options reflecting a spectrum of water management strategies and modeling premises.

The remainder of this chapter is a comparative summary review of the CRM options outlined in Table 5.1. Experience acquired from the Brazos River Basin CRM studies provides a basis for the following guidance on applying CRM.

CRM Simulations with Monthly Cycle versus Annual Cycle Hydrologic Sequences

CRM is based on dividing a long hydrologic period-of-analysis into many shorter simulation sequences. *SIM* automatically repeats the simulation for each hydrologic sequence with the same initial storage condition. Storage and flow frequency relationships and water supply reliability indices are developed with program *TABLES* from the *SIM* simulation results.

The accuracy of CRM increases with the number of hydrologic sequences. The Brazos River Basin CRM studies presented in this report have been enhanced by extending the original TCEQ WAM System 1940-1997 period-of-analysis to January 1900 through December 2007 [1]. The 108-year 1900-2007 hydrologic period-of-analysis allows 107 annual April-March or July-June simulations which should provide more dependable CRM results than 57 annual simulations based on 1940-1997 hydrology. The naturalized flows and net-evaporation rates for 1900-1939 are less accurate than later years because data had to be synthesized since a much smaller number of gaging stations were in operation during earlier years. Thus, a tradeoff occurs as the number of annual hydrologic sequences is increased, but the additional sequences are more approximate.

The annual cycle option is adopted for the Brazos River Basin study rather the monthly cycle option in both the equal-weight analyses of Chapter 4 and probability array analyses of Chapter 5. The primary advantage of the monthly cycle option over the annual cycle option is the generation of many more hydrologic sequences and corresponding CRM simulations. However, seasonality is lost with the monthly cycle option. The 107 CRM sequences provided by the 1900-2007 period-of-analysis is a relatively large number, which supports use of the annual cycle option. Seasonal characteristics of hydrology are important and are captured with the annual cycle option.

CRM Analyses Based on the Equal-Weight versus Probability Array Options

The equal-weight and probability array options are two alternative CRM approaches, which differ only in the methodology incorporated in *TABLES* for assigning probabilities to each hydrologic sequence and corresponding CRM simulation for use in the frequency and reliability analysis computations. The Brazos River Basin CRM analyses of Chapters 4 and 5 use 107 annual hydrologic sequences derived from a 1900-2007 period-of-analysis. With the equal-weight method adopted in Chapter 4, each of the 107 simulations are weighted the same in the frequency analyses, which is equivalent to assigning a probability of 1/107 to each of the 107 simulations. The probability array option is based on assigning varying probabilities to the 107 simulations. The CRM analyses are repeated in Chapter 5 using the probability array approach, and conditions under which probability array methods may improve the accuracy of CRM results are explored.

The equal-weight option is simple to understand and apply. Unlike applying the probability array methodology, in applying the equal-weight method, the model-user does not choose between a myriad of modeling options, all of which affect the CRM results. The storage frequency statistics developed based on the equal-weight method and presented in Tables 4.4 through 4.31 provide valid estimates of probabilities of various storage volumes being equaled or exceeded in the future given preceding storage levels. All models are necessarily approximate, but CRM results based on the equal-weight option are considered to represent reasonably accurate estimates. However, hydrologic persistence is a key issue which is addressed by shifting to the probability array option.

With the equal-weight option, the probabilities associated with the 107 hydrologic sequences in the frequency computations are the same regardless of whether initial reservoir storage levels are set at 100%, 75%, 50%, or 25% of capacity. However, the concept of hydrologic persistence implies that dry hydrologic conditions are more likely to follow past dry conditions than past wet conditions. Reservoir storage levels of 25% of capacity indicate much drier previous hydrologic conditions than does storage levels at 75% capacity. Therefore, the set of probabilities associated with the 107 hydrologic sequences perhaps should be different in CRM with different initial reservoir storage conditions. The storage-flow-frequency sub-option of the probability array option is designed to model hydrologic persistence.

The degree of correlation between naturalized stream flow and preceding simulated storage is fundamental in considering the accuracy of the equal-weight versus probability array options. Correlation analyses presented in Chapter 5 demonstrate some relatively small correlation between naturalized flow and preceding reservoir storage. Storage-flow plots exhibit considerable scatter. Though correlation coefficients are not high at any of the reservoirs, the degree of correlation varies significantly between reservoirs. The equal-weight option is deemed to be generally adequate, but improvements in accuracy are possible in some cases by switching to the probability array option.

Initial Storage Conditions

The following discussion is based on the premise that the specified initial storage conditions are representative of preceding hydrologic conditions. However, CRM applications could possibly involve situations in which the model-user specified initial storage contents are not related to preceding hydrology. For example, a reservoir might be drained to 25% of capacity for purposes of performing maintenance or rehabilitation construction on the dam or outlet structures. In this case, the equal-weight option, not probability array option, should be adopted for CRM analyses.

Consistency between the general range of storage volumes reflected in the CRM simulations as compared with the long-term simulation is a significant modeling issue in applying either the equal-weight or probability array options. The long-term *SIM* simulation represents actual storage levels that would occur if 1900-2007 historical hydrology is repeated with current conditions of water resources development, management, and use. Storage levels in five of the eleven reservoirs included in the CRM analyses never drop below 50 percent of capacity during the 1900-2007 long-term simulation. Only three of the eleven reservoirs experience storage volumes of less than 25 percent of capacity during the long-term simulation. Six of the reservoirs are full to capacity at least 50 percent of the time. All are full to capacity at least 20 percent of the time.

The alternative initial storage contents of 100%, 75%, 50%, and 25% of capacity adopted for the CRM analyses of this report were selected arbitrarily to cover the full range from full to severely drawn-down. These specified initial storage levels greatly affect the range of storage levels that occur in the *SIM* CRM simulations. With initial storage set at 25% of capacity, several of the reservoirs experience draw-downs during the CRM simulations that are much more severe than the greatest draw-downs occurring during the 1900-2007 long-term simulation. Initial storage of 25% capacity represents a drought much more severe than any drought occurring during 1900-2007.

Both the equal-weight option CRM analyses of Chapter 4 and the probability array option CRM analyses of Chapter 5 are most valid for initial storage conditions of 100% capacity and least valid for initial storage conditions of 25% capacity. The CRM analyses for Proctor Reservoir covering the full range of initial storage contents (100%, 75%, 50%, 25%) are more valid than the corresponding CRM analyses for the other reservoirs because Proctor exhibits the most complete range of storage levels in the long-term simulation.

The equal-weight option, in essence, assigns the same probability of 1/107 to each of the 107 hydrologic sequences regardless of user-specified initial storage conditions. The probability array option is designed to model hydrologic persistence as reflected in the initial storage contents. With initial storage set at 100% of capacity, the probability array option assigns higher probabilities to high flows and lower probabilities to low flows than does the equal-weight option. Conversely, with the initial storage at 25% of capacity, the probability array option assigns higher probabilities to low flows and lower probabilities to high flows than does the equal-weight option. Higher flows result in higher future storage levels, and lower flows result in lower future storage levels.

Equal-weight option predictions of future storage levels associated with given exceedance frequencies are generally conservatively low for high initial storage contents such as 100% of capacity. Conversely, with relatively low initial storage contents such as 25% of capacity specified, predictions of future storage volumes based on the equal-weight option are generally too large.

The purpose of the probability array option with the SFF array sub-option is to better deal with hydrologic persistence. The SFF array should be developed from the results of a long-term simulation with storage draw-downs that are reasonably representative of the draw-downs that occur in the CRM simulations.

Probability Array Based CRM Options

CRM computational options are outlined in Table 5.1 at the beginning of this chapter. The CRM methodologies are described and compared in Chapter 7 of the *Reference Manual*. The equal-weight option and probability array options are compared in the preceding discussions.

Referring to Table 5.1, the probability array option may employ either a flow-frequency (FF) relationship or a storage-flow-frequency (SFF) relationship. As discussed throughout this chapter, the SFF relationship option was adopted for the Brazos River Basin CRM investigation presented in this report. The FF option offers no significant advantages with the Brazos River Basin dataset. The FF array option develops a probability array without considering storage. The FF array random variable is naturalized flow volume rather than the Equation 5.2 flow ratio. The FF array replaces the SFF array with the probability option computations otherwise being the same. The FF array option is different from the equal-weight option in that the log-normal distribution can be used to model naturalized flows, and naturalized flows may be limited to only those flows associated with a specified range of reservoir storage. Persistence can be modeled by using only naturalized flows that follow a range of relatively low storage levels to develop the FF array if the specified initial CRM storage content is relatively low, and vice versa for high initial storage.

The log-normal probability distribution is used in multiple different *TABLES* options. A 2FRE record frequency option allows application of the log-normal or normal probability distributions to a random variable of interest. These probability distributions fit stream flow, but typically do not fit reservoir storage well because of the limit imposed by storage capacity. Thus, this 2FRE record option is not applicable to the CRM analyses of this chapter. 5CR1 record options allow the naturalized flows of the FF array or flow ratios of the SFF array to be modeled with the log-normal distribution. The log-normal probability distribution provides a smooth exceedance frequency curve that provides information to supplement a limited sample size and also facilitates extrapolation. However, the 107 sequences were considered to be a large enough sample size for the Brazos River Basin CRM analyses. Thus, the alternative relative frequency option was adopted.

Development of a 5CR1 record SFF array is based on correlating the sum of naturalized flow volumes at any number of control points covering a defined number of months with the sum of the preceding reservoir storage volume at any number of reservoirs. Correlation coefficients supplemented by storage-flow plots provide information that is useful in choosing time periods and control points. These choices also involve subjective judgment regarding river basin hydrology. Sensitivity analyses may be performed to evaluate the effects of various choices on CRM results. Three-month flow volumes were adopted for developing the SFF arrays for the CRM studies of this chapter. Beginning of April or July storage was related to April-June or July-September naturalized flows at the control point of the reservoir for each of the five individual reservoirs. Preceding total storage was related to 3-month naturalized flow volumes at control point LRCA58 (Cameron gage) for the 4-reservoir Little River Subbasin system and at control point BRDE29 (Dennis gage) for the combined Lakes Possum Kingdom and Granbury.

CHAPTER 6
CONVENTIONAL LONG-TERM MONTHLY SIMULATION

Results of conventional long-term monthly *SIM* simulations for the Brazos WAM authorized and current use scenarios with alternative hydrologic periods-of-analysis of 1940-1997, 1900-2007, and 1940-2007 are presented in Chapter 6. The authorized use scenario and a 1940-1997 period-of-analysis are adopted to support a comparative evaluation of negative incremental flow options in Chapter 7. Simulation results with a daily time step presented in Chapters 8, 9, and 10 can be compared with the corresponding monthly simulations in Chapters 6 and 7.

SIM Input Datasets

The TCEQ WAM System *SIM* input datasets for the authorized use scenario and current use scenario for the combined Brazos River Basin and San Jacinto-Brazos Coastal Basin, called the Brazos WAM in this report, are described in Chapter 2. The water rights in the Brazos WAM are summarized in Table 2.10. The Brazos WAM files for the authorized use scenario (run 3) and current use scenario (run 8) have the filename roots Bwam3 and Bwam8, respectively.

The hydrologic period-of-analysis is 1940-1997 for the official TCEQ Brazos WAM. Wurbs and Kim [1] extended the Brazos WAM sequences of naturalized stream flows and reservoir evaporation-precipitation depths from 1940-1997 to 1900-2007. The *SIM* simulations in this chapter were repeated with the authorized use scenario input files (with filenames Bwam3.DAT, Bwam3.FLO, Bwam3.EVA, and Bwam3.DIS) and current use scenario input files (Bwam8.DAT, Bwam8.FLO, Bwam8.EVA, and Bwam8.DIS) with alternative hydrologic periods-of-analysis of 1940-1997, 1900-2007, and 1940-2007. The Bwam3 dataset with a 1940-1997 period-of-analysis was adopted for the comparative evaluation of *ADJINC* options presented in Chapter 7 and the daily simulations of Chapters 8, 9, and 10.

The simulation results presented in the remainder of this report, including this chapter, are based on the September 2008 version of the Brazos WAM datasets. Counts from the *SIM* message files are reproduced in Table 6.1. The simulation results presentations in Chapter 6 as well as in Chapters 7, 8, 9, and 10 focus on the control points included in Table 6.2 and Figure 6.1.

Table 6.1
Number of System Components in Brazos WAM Datasets

Water Use Scenario Filename	Authorized Bwam3	Current Bwam8
total number of control points	3,842	3,852
number of primary control points	77	77
control points with evaporation-precip rates	67	67
number of reservoirs as counted by *SIM*	678	719
number of *WR* record water rights	1,643	1,734
number of instream flow *IF* record rights	122	145
number of *FD* records in DIS file	3,152	3,157

Table 6.2
Selected Control Points

Control Point ID	Reservoir or Gage	Stream	Watershed Area (square miles)
421331	Hubbard Creek Lake	Hubbard Creek	1,087
515531	Possum Kingdom Lake	Brazos River	14,093
515631	Granbury Lake	Brazos River	16,181
515731	Whitney Lake	Brazos River	17,690
515831	Aquilla Lake	Aquilla Creek	254
509431	Waco Lake	Bosque River	1,655
516531	Limestone Lake	Navasota River	678
515931	Proctor Lake	Leon River	1,280
516031	Belton Lake	Leon River	3,568
516131	Stillhouse Hollow Lake	Lampases R.	1,313
516231	Georgetown Lake	San Gabriel R.	247
516331	Granger Lake	San Gabriel R.	726
516431	Somerville Lake	Yequa Creek	1,008
BRSE11	Seymour Gage	Brazos River	5,996
BRSB23	Southbend Gage	Brazos River	13,171
LRCA58	Cameron Gage	Little River	7,100
BRBR59	Bryan Gage	Brazos River	30,016
BRHE68	Hempstead Gage	Brazos River	34,374
BRRI70	Richmond Gage	Brazos River	35,454
BRGM73	Outlet at Gulf of Mexico	Brazos River	36,027

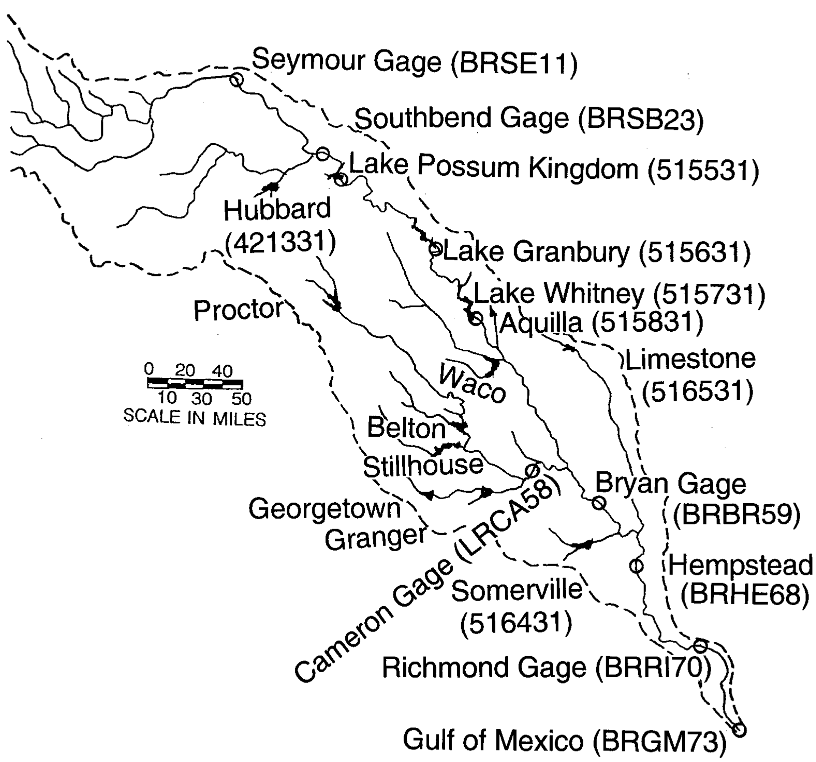

Figure 6.1 Selected Brazos River Basin Control Points

Simulation Results for Alternative Scenarios and Simulation Periods

Although the simulations were originally performed with the July 2010 version of *SIM*, the results presented here are from simulations rerun with the March 2011 *SIM*. Without activation of the new *ADJINC* options discussed later in this chapter, the only difference in Brazos WAM simulation results between the March 2011 and July 2010 versions of *SIM* are due to January 2011 *SIM* modifications that affect combinations of *PX* and *BU* record features used to model water rights at Lakes Waco and Whitney.

The *SIM* simulations summarized in this section were repeated with the authorized use and current use scenario input files with alternative hydrologic periods-of-analysis of 1940-1997, 1900-2007, and 1940-2007. The TCEQ Brazos WAM has a 1940-1997 hydrologic period-of-analysis. The methodology adopted for the 1998-2007 and 1900-1939 extensions are documented in detail in TWRI Technical Report 340 [1]. Naturalized monthly flows during 1900-2007 at four of the control points in Figure 6.1 are plotted in Chapter 2 as Figures 2.4, 2.5, 2.6, and 2.7. HEC-DSSVue plots of 1940-2007 end-of-month storage contents for the 13 reservoirs in Figure 6.1 are presented as Figures 6.2 through 6.27. *SIM* simulation results organized with *TABLES* are presented as Tables 6.3 through 6.7.

The basin summaries in Table 6.3 are from 2SBA record tables developed with program *TABLES* from the results of *SIM* simulations with six alternative variations of the Brazos WAM dataset. The naturalized and unappropriated stream flows in 2SBA record basin summary tables represent the maximum flow at any control point in a given month, based on comparing all control points. All other quantities are the sum of the values at all control points. Mean annual flows are in units of acre-feet/year, and mean end-of-month reservoir storage contents are in acre-feet. Volume reliabilities in percent [R_V=(target/actual diversion)100%] are added as the last line of Table 6.3.

Table 6.3
Basin Summaries from 2SBA Tables
(Mean annual flows are in acre-feet/year and mean storage volume in acre-feet.)

Simulation Period	1940-1997		1900-2007		1940-2007	
Scenario	Authorized	Current	Authorized	Current	Authorized	Current
naturalized flow	7,735,888	7,735,885	9,723,938	9,723,937	8,516,062	8,516,058
return flow	99,889	308,863	100,863	308,873	102,218	309,561
stream flow depletion	2,590,734	1,855,110	2,613,916	1,874,509	2,600,621	1,864,807
unappropriated flow	5,545,604	6,258,923	5,945,928	6,867,140	5,946,352	6,660,921
end-of-month storage	3,446,850	3,396,398	3,487,372	3,480,553	3,447,116	3,412,309
net evaporation	397,396	432,195	407,447	445,623	396,581	435,647
diversion target	2,452,789	1,518,643	2,458,931	1,519,742	2,459,278	1,520,775
diversion	2,207,638	1,427,606	2,212,258	1,429,899	2,212,581	1,431,145
diversion shortage	245,152	91,038	246,673	89,843	246,697	89,630
volume reliability	90.01	94.01%	89.97%	94.09%	89.97%	94.11%

The Brazos WAM authorized and current use scenario DAT files are combined with alternative versions of the FLO and EVA files reflecting hydrologic periods-of-analysis of 1940-

1997, 1900-2007, and 1940-2007 in the six *SIM* simulations of Table 6.3. In general, frequency metrics for naturalized flows and simulation results are similar for the three periods-of-analysis though means of naturalized flows for 1900-1939 and 1998-2007 are higher than for 1940-1997. The accuracy of naturalized flows for the period before 1940, particularly before 1924, is uncertain due to the small number of gaging stations in operation during these early years. Variations in simulation results with the alternative periods-of-analyses are explored further in TWRI TR-340 [1].

Reservoir storage is a meaningful variable for comparing the results of alternative simulations. Frequency statistics are tabulated in Table 6.4 for the total end-of-month storage contents of the 13 reservoirs listed in Table 6.2 and shown in Figure 6.1. The 13 reservoirs include Hubbard Creek Reservoir, the nine Corps of Engineers reservoirs, and three BRA reservoirs. These 13 reservoirs have a total Bwam3 conservation storage capacity of 3,333,361 acre-feet which is 71 percent of the capacity of the 678 reservoirs in Bwam3. The 13 reservoirs have a Bwam8 capacity of 2,973,670 acre-feet which is 74 percent of the total capacity of the 719 reservoirs in Bwam8.

Table 6.4
Storage Frequencies from 2FRE Tables

Simulation Period	1940-1997		1900-2007		1940-2007	
Scenario	Authorized	Current	Authorized	Current	Authorized	Current
			Storage Volume (acre-feet)			
Mean	2,777,001	2,707,108	2,791,439	2,740,229	2,793,062	2,720,159
Standard Deviation	437,280	264,420	408,261	233,332	411,652	248,812
Minimum	1,256,266	1,694,924	1,256,249	1,694,922	1,256,266	1,694,924
99%	1,370,180	1,791,358	1,376,642	1,888,405	1,375,332	1,822,406
98%	1,480,920	1,890,432	1,537,729	2,010,631	1,526,506	1,908,902
95%	1,802,142	2,099,240	1,864,526	2,256,403	1,875,672	2,158,939
90%	2,196,914	2,372,287	2,241,749	2,430,122	2,260,453	2,420,459
85%	2,354,474	2,470,063	2,406,952	2,533,448	2,396,955	2,507,231
80%	2,505,448	2,553,726	2,568,166	2,601,432	2,558,426	2,587,704
75%	2,598,783	2,603,491	2,656,439	2,649,296	2,642,879	2,628,542
70%	2,682,814	2,641,913	2,723,411	2,696,368	2,682,814	2,673,579
60%	2,808,930	2,732,440	2,828,727	2,772,524	2,822,896	2,753,412
50%	2,889,989	2,794,260	2,904,315	2,813,668	2,894,560	2,799,714
40%	2,970,278	2,842,250	2,969,661	2,851,127	2,969,215	2,834,978
30%	3,050,239	2,880,223	3,028,143	2,888,689	3,028,158	2,877,145
25%	3,085,253	2,895,720	3,057,352	2,906,546	3,074,914	2,888,454
20%	3,110,509	2,915,460	3,086,558	2,922,922	3,100,836	2,906,660
15%	3,163,485	2,932,010	3,121,701	2,937,640	3,144,646	2,929,979
10%	3,223,741	2,950,080	3,189,920	2,951,524	3,223,741	2,948,322
5%	3,284,360	2,958,888	3,259,774	2,958,851	3,275,401	2,958,350
1%	3,332,029	2,962,531	3,325,767	2,962,490	3,331,947	2,962,530
Maximum	3,333,349	2,962,534	3,333,361	2,962,534	3,333,349	2,962,534

The frequency and reliability tables of Tables 6.5, 6.6, and 6.7 were developed with *TABLES* 2FRE and 2REL records from the Brazos WAM simulation results for the 1940-1997 hydrologic period-of-analysis. Naturalized flows (Table 6.5) are the same in both the Bwam3 and Bwam8 datasets. *TABLES* output files for the authorized use (Bwam3) and current use (Bwam8)

SIM simulations are reproduced as Tables 6.6 and 6.7, respectively. Program *TABLES* provides options for developing frequency and reliability tables in optional formats for any number of either control points, reservoirs, or water rights. The 20 control points listed in Table 6.2 and shown in Figure 6.1 are included in the flow frequency tables. The control points of the 13 reservoirs are included in the storage frequency and diversion reliability tables. The aggregate of all diversions at the 13 control points represent the BRA water rights described in Tables 2.10 and 2.11 of Chapter 2.

TCEQ Brazos WAM datasets and the simulations of Tables 6.3-6.7 and Figures 6.2-6.27 adopt *ADJINC* option 5. The remainder of this chapter explores the alternative *ADJINC* options.

The frequency tables include the control points in Table 6.2 and Figure 6.1 which are listed again by control point identifier as follows. These control points represent the location of six USGS gaging stations, the outlet of the Brazos River at the Gulf of Mexico, and 13 reservoirs.

BRSE11	Seymour Gage on Brazos River	515731	Whitney Reservoir
BRSB23	Southbend Gage on Brazos River	515831	Aquilla Reservoir
LRCA58	Cameron Gage on Little River	509431	Waco Reservoir
BRBR59	Bryan Gage on Brazos River	516531	Limestone Reservoir
BRHE68	Hempstead Gage on Brazos	515931	Proctor Reservoir
BRRI70	Richmond Gage on Brazos River	516031	Belton Reservoir
BRGM73	Brazos Outlet at Gulf of Mexico	516131	Stillhouse Hollow Res.
421331	Hubbard Creek Reservoir	516231	Georgetown Reservoir
515531	Possum Kingdom Reservoir	516331	Granger Reservoir
515631	Granbury Reservoir	516431	Somerville Reservoir

Table 6.5
Brazos WAM Naturalized Monthly Flow Frequency Table for 1940-1997

FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRSE11	20841.3	42817.	0.0	0.0	52.0	266.2	621.2	1711.0	3082.	5042.	8026.	18500.	57693.	414811.
BRSB23	54688.3	116203.	0.0	64.8	119.4	785.0	2082.8	4889.0	9258.	13817.	23707.	52133.	145077.	1395822.
LRCA58	109858.4	170466.	0.0	494.4	1249.0	2706.4	5440.0	15032.0	28988.	44799.	65294.	130473.	290433.	1403136.
BRBR59	335663.5	483897.	0.0	6558.6	11161.7	17707.0	28172.8	60717.0	107622.	158629.	232671.	402271.	810073.	4704312.
BRHE68	446578.6	588542.	1634.0	13817.1	17422.0	30122.4	44643.0	89698.0	157333.	229331.	306815.	581968.	1153505.	5723482.
BRRI70	487518.7	613002.	0.0	18382.7	25401.7	39521.8	53887.8	111204.0	184723.	257456.	358553.	653272.	1230723.	6135975.
BRGM73	508769.8	634290.	4.0	18771.8	25991.5	42893.2	59767.2	121025.0	199329.	269220.	376386.	676536.	1272971.	6254466.
421331	8100.9	23078.	0.0	0.0	0.0	0.1	1.5	26.6	629.	1231.	2165.	5152.	22071.	264176.
515531	66122.9	137150.	0.0	0.0	0.1	284.1	2186.9	6882.7	12816.	18404.	30992.	64389.	166332.	1794484.
515631	91156.0	178785.	0.0	39.5	781.5	2047.9	4459.1	10227.7	19707.	29493.	48833.	95565.	237433.	2653863.
515731	113905.5	203559.	7.5	323.7	1767.3	3507.6	6777.5	16134.5	28423.	46037.	65333.	130424.	277592.	2962997.
515831	6147.4	11987.	0.0	0.0	0.0	0.0	0.0	37.2	472.	988.	2017.	6582.	19446.	102561.
509431	29788.7	53352.	0.0	1.0	9.3	39.1	468.0	2859.5	5978.	9933.	15244.	34692.	80535.	530557.
516531	19399.4	34018.	0.0	0.0	0.0	32.9	100.9	614.1	1824.	3970.	7964.	21035.	62911.	240424.
515931	12070.5	28547.	0.0	0.0	0.0	0.4	56.4	495.3	1307.	2450.	3799.	10841.	33218.	327284.
516031	41915.5	75191.	0.0	0.0	0.1	2.3	485.7	3335.9	7744.	12710.	22290.	47382.	112448.	627569.
516131	19238.4	34306.	27.8	135.3	147.7	486.0	718.5	2122.1	3912.	5988.	9237.	20984.	53075.	309090.
516231	4796.5	8418.	0.0	0.0	0.0	19.7	85.3	343.8	880.	1416.	2333.	5510.	14484.	74909.
516331	15551.8	24898.	0.0	1.2	5.7	172.5	473.9	1772.8	3581.	5412.	8432.	19756.	44908.	210085.
516431	18572.4	33188.	0.0	0.0	0.0	1.5	4.5	764.2	2329.	3895.	7369.	18888.	60673.	250982.

Table 6.6
Frequency and Reliability Tables Created with 2FRE and 2 REL Records
from Bwam3 Authorized Use 1940-1997 Simulation Results with *ADJINC* Option 5

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRSE11	19438.1	40217.	0.0	0.0	28.2	224.7	587.5	1680.4	2998.	4812.	7904.	17278.	51071.	408040.
BRSB23	45868.7	100430.	0.0	31.8	82.5	541.7	1768.0	4500.5	8812.	12714.	20182.	41706.	113693.	1217333.
LRCA58	83222.6	157642.	0.0	85.5	579.4	1190.1	1260.8	5832.4	12459.	18935.	31839.	87682.	235472.	1399450.
BRBR59	256140.5	437586.	284.6	3277.2	5624.8	9756.4	14565.8	30415.3	55396.	81896.	129194.	285334.	658089.	4221430.
BRHE68	353138.3	534097.	1918.9	10965.6	13208.9	20946.0	27216.3	53875.9	85854.	130756.	197911.	442982.	959488.	5081234.
BRRI70	383849.2	562148.	306.6	13296.9	17713.9	27683.5	35325.9	61420.5	94907.	147048.	233610.	474542.	1043177.	5486716.
BRGM73	351369.8	581999.	0.0	0.0	0.1	0.4	1.9	8911.5	47701.	105094.	188987.	455947.	1049934.	5543116.
421331	2284.3	8610.	0.0	0.0	0.0	0.0	0.0	0.0	0.	6.	376.	1389.	4714.	150843.
515531	32066.0	111095.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	10995.	80923.	1594131.
515631	49696.1	150740.	0.0	0.0	0.0	0.0	0.0	2.7	1545.	3926.	7462.	28664.	138320.	2445679.
515731	76097.7	179597.	0.0	0.0	0.0	230.2	1603.0	4921.4	9600.	13754.	24284.	69167.	213926.	2722565.
515831	4409.5	10945.	27.8	27.8	27.8	29.8	29.8	30.8	31.	31.	31.	2347.	15453.	100103.
509431	20790.9	50780.	0.0	0.0	0.0	0.0	0.0	0.0	0.	43.	732.	15924.	68601.	529220.
516531	11352.1	27354.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	4420.	45229.	215300.
515931	8519.9	26634.	0.0	0.0	0.0	0.0	0.0	3.2	60.	267.	831.	3356.	21873.	316032.
516031	28048.2	68102.	0.0	0.0	0.0	0.0	463.0	1997.5	2672.	3186.	4002.	16874.	80844.	547284.
516131	12315.9	31856.	0.0	0.0	0.0	0.0	0.0	0.0	0.	145.	989.	7661.	39269.	302801.
516231	3513.6	7909.	0.0	0.0	0.0	0.0	0.0	0.0	0.	149.	464.	2707.	12223.	73211.
516331	11945.8	23657.	0.0	0.0	0.0	0.0	0.0	0.0	623.	1670.	3882.	12324.	38739.	208215.
516431	13218.3	30277.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7106.	52326.	247494.

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

CONTROL		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRSE11	10944.3	36337.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	849.	29447.	408040.
BRSB23	22895.3	87308.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	229.	57996.	1210603.
LRCA58	67368.4	152305.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	6311.	66984.	206394.	1392119.
BRBR59	190250.5	415452.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2404.	39466.	207403.	564431.	4163632.
BRHE68	231146.0	480003.	0.0	0.0	0.0	0.0	0.0	0.0	0.	9282.	52478.	262209.	763779.	4808310.
BRRI70	290053.4	527607.	0.0	0.0	0.0	0.0	0.0	0.0	8390.	51158.	124555.	374445.	914599.	5158283.
BRGM73	351369.8	581999.	0.0	0.0	0.1	0.4	1.9	8911.5	47701.	105094.	188987.	455947.	1049934.	5543116.
421331	745.9	7160.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	150843.
515531	25250.3	99200.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	66200.	1594131.
515631	42600.2	143394.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	16449.	127295.	2445679.
515731	59520.5	175424.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	32.	33062.	172990.	2722565.
515831	4042.5	10931.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	379.	15014.	100072.
509431	19931.3	50956.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	12647.	68567.	529220.
516531	10628.2	26851.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	374.	42099.	215300.
515931	6556.6	25518.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	12824.	274816.
516031	24634.2	67887.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	5052.	77271.	546730.
516131	11525.6	31703.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1932.	39269.	302801.
516231	3227.8	7880.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1695.	12124.	73211.
516331	10866.7	23876.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	11443.	37936.	208215.
516431	12833.1	30215.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	6203.	52326.	247494.

Table 6.6 (Continued)
Frequency and Reliability Tables Created with 2FRE and 2 REL Records
from Bwam3 Authorized Use 1940-1997 Simulation Results with *ADJINC* Option 5

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
421331	109112.	101612.	0.	0.	0.	0.	0.	17864.	56306.	81915.	107867.	181809.	284991.	317750.
515531	668617.	75339.	269773.	341224.	471791.	525815.	570176.	637163.	679689.	697336.	713063.	724739.	724739.	724739.
515631	137376.	24940.	47383.	57132.	63444.	81949.	98357.	128033.	142679.	149634.	155000.	155000.	155000.	155000.
515731	609486.	36230.	449616.	465804.	506696.	528104.	556371.	598048.	616624.	624599.	631543.	636069.	636100.	636100.
515831	44477.	9747.	2101.	8567.	14295.	21449.	33209.	40306.	45084.	47181.	49751.	52400.	52400.	52400.
509431	180280.	32196.	63311.	74270.	86560.	109323.	132292.	166832.	182980.	191698.	200782.	206012.	206298.	206561.
516531	185777.	47944.	15880.	26577.	41128.	73743.	118487.	170405.	189288.	201282.	211861.	225400.	225400.	225400.
515931	47414.	13462.	1801.	8426.	9950.	18675.	27773.	41235.	46457.	51342.	55737.	59400.	59400.	59400.
516031	385149.	99289.	20722.	42474.	64956.	142858.	242322.	364109.	401778.	420980.	439201.	457600.	457600.	457600.
516131	192477.	63266.	0.	0.	7435.	24385.	76472.	180125.	209744.	220573.	228310.	235700.	235700.	235700.
516231	29662.	9696.	0.	0.	120.	7351.	15725.	25103.	31326.	33783.	36079.	37100.	37100.	37100.
516331	55876.	14494.	0.	3034.	9892.	23174.	35190.	51230.	58931.	63273.	65500.	65500.	65500.	65500.
516431	131299.	35645.	0.	10194.	32424.	58124.	75571.	115392.	136254.	144425.	151718.	160110.	160110.	160110.
Total	2777001.	437280.	1256266.	1370180.	1480920.	1802142.	2196914.	2598782.	2808930.	2889989.	2970278.	3085252.	3223740.	3333348.

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	+++++++++ PERCENTAGE OF MONTHS +++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS ---------- PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
421331	56000.0	8804.43	82.76	84.28	82.8	83.0	83.0	83.5	84.2	84.5	85.1	69.0	69.0	70.7	70.7	77.6	84.5	98.3
515531	230750.0	0.02	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18945.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	80394.4	303.54	98.56	99.62	98.6	98.6	98.6	98.6	100.0	100.0	100.0	96.6	96.6	96.6	98.3	100.0	100.0	100.0
516531	65074.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	19658.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	112257.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	367.19	98.85	99.46	98.9	99.0	99.0	99.3	99.4	99.6	99.6	94.8	94.8	96.6	96.6	100.0	100.0	100.0
516231	13610.0	229.43	98.13	98.31	98.1	98.1	98.1	98.1	98.3	98.4	98.6	93.1	94.8	94.8	94.8	98.3	98.3	100.0
516331	19840.0	53.35	99.57	99.73	99.6	99.6	99.6	99.6	99.6	99.7	99.9	96.6	96.6	98.3	98.3	100.0	100.0	100.0
516431	48000.0	189.42	99.14	99.61	99.1	99.1	99.1	99.1	99.3	99.4	99.6	96.6	96.6	96.6	98.3	100.0	100.0	100.0
Total	810904.8	9947.39		98.77														

Control Points

- BRSE11 Seymour Gage on Brazos River
- BRSB23 Southbend Gage on Brazos River
- LRCA58 Cameron Gage on Little River
- BRBR59 Bryan Gage on Brazos River
- BRHE68 Hempstead Gage on Brazos
- BRRI70 Richmond Gage on Brazos River
- BRGM73 Brazos Outlet at Gulf of Mexico
- 421331 Hubbard Creek Reservoir
- 515531 Possum Kingdom Reservoir
- 515631 Granbury Reservoir
- 515731 Whitney Reservoir
- 515831 Aquilla Reservoir
- 509431 Waco Reservoir
- 516531 Limestone Reservoir
- 515931 Proctor Reservoir
- 516031 Belton Reservoir
- 516131 Stillhouse Hollow Res.
- 516231 Georgetown Reservoir
- 516331 Granger Reservoir
- 516431 Somerville Reservoir

Table 6.7
Frequency and Reliability Tables Created with 2FRE and 2REL Records from Bwam8 Current Use 1940-1997 Simulation Results with *ADJINC* Option 5

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRSE11	20148.8	42076.	4.7	11.7	63.6	271.9	625.9	1719.4	2957.	4938.	7752.	17604.	53869.	414568.
BRSB23	48220.1	109064.	63.1	270.9	398.2	1009.6	2179.7	4613.2	8064.	12301.	19242.	42590.	120369.	1386043.
LRCA58	91178.1	161813.	1111.6	1229.8	2580.3	3475.0	5051.6	9829.7	16948.	23989.	40617.	98849.	248450.	1406391.
BRBR59	286636.4	464577.	2857.4	7901.2	10023.0	14649.6	19811.7	39344.4	66580.	105220.	161175.	334559.	727885.	4612182.
BRHE68	388107.5	564312.	8572.3	16469.7	18366.2	25034.8	34131.1	62274.2	106286.	159144.	236201.	502942.	1080568.	5575021.
BRRI70	427439.5	591144.	6308.9	17376.3	23061.2	31307.9	41031.3	80972.1	129696.	188074.	279051.	567504.	1143579.	5986648.
BRGM73	404034.8	611674.	0.0	0.2	0.8	123.3	620.4	39748.9	92869.	158423.	254344.	530884.	1141362.	6047678.
421331	3487.0	16402.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	698.	4200.	239879.
515531	49389.1	128364.	0.0	0.0	0.0	0.0	0.0	0.0	0.	4290.	12641.	42733.	134058.	1782594.
515631	69607.8	169974.	0.0	0.0	0.0	0.0	0.0	743.1	4495.	10119.	22884.	67573.	196689.	2633908.
515731	90075.5	195067.	0.0	0.0	0.0	351.9	1626.8	5545.6	12418.	19301.	38002.	91922.	253892.	2907663.
515831	5377.0	11742.	27.8	27.8	27.8	29.8	29.8	30.8	31.	31.	665.	5077.	17879.	101155.
509431	24545.1	52867.	0.0	0.0	0.0	0.0	0.0	0.0	37.	1527.	6871.	26351.	76003.	532891.
516531	13940.3	30940.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	49.	10258.	52027.	229076.
515931	9170.1	27290.	0.0	0.0	0.0	0.0	0.0	0.0	63.	200.	690.	4623.	23727.	320050.
516031	29203.8	70978.	0.0	209.0	251.2	277.3	569.7	952.9	1241.	1465.	1798.	22707.	87149.	610564.
516131	12952.1	32625.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2.	1090.	9340.	41868.	306237.
516231	3623.4	8038.	0.0	0.0	0.0	0.0	0.0	0.0	0.	34.	509.	3063.	13012.	73401.
516331	13881.4	24488.	0.0	0.0	0.0	0.0	0.0	666.0	1989.	3837.	6606.	16426.	41647.	210617.
516431	13381.7	30605.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7415.	53138.	248174.

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRSE11	14756.2	37536.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	2094.	9980.	46129.	414568.
BRSB23	33111.3	96856.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	2935.	24730.	95078.	1386043.
LRCA58	74633.4	156928.	0.0	0.0	0.0	0.0	0.0	0.0	0.	4539.	18895.	79526.	219856.	1399060.
BRBR59	228946.9	442410.	0.0	0.0	0.0	0.0	0.0	0.0	8669.	34403.	88387.	269728.	641850.	4469454.
BRHE68	294222.9	526202.	0.0	0.0	0.0	0.0	0.0	0.0	19800.	53333.	138958.	384033.	892377.	5302097.
BRRI70	329065.9	558187.	0.0	0.0	0.0	0.0	0.0	0.0	37512.	83943.	173923.	434145.	986386.	5658216.
BRGM73	404034.8	611674.	0.0	0.2	0.8	123.3	620.4	39748.9	92869.	158423.	254344.	530884.	1141362.	6047678.
421331	2920.8	16254.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	239879.
515531	38674.6	113176.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	3138.	29453.	114830.	1782594.
515631	59027.7	159736.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2.	13893.	49078.	179984.	2633908.
515731	78549.1	194855.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2.	18415.	68044.	237193.	2907663.
515831	5044.5	11746.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	3849.	16786.	101125.
509431	23526.5	53130.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	1963.	24106.	75979.	532891.
516531	13366.4	30570.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	8888.	51619.	229076.
515931	7518.7	26811.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	17534.	320050.
516031	27337.4	70836.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	18600.	86424.	610564.
516131	12348.3	32438.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	8000.	41868.	306237.
516231	3435.0	8048.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	2477.	12635.	73401.
516331	12786.1	24837.	0.0	0.0	0.0	0.0	0.0	0.0	0.	1163.	4482.	15006.	41246.	210617.
516431	13277.6	30633.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7146.	53138.	248174.

Table 6.7 (Continued)
Frequency and Reliability Tables Created with 2FRE and 2REL Records
from Bwam8 Current Use 1940-1997 Simulation Results with *ADJINC* Option 5

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
421331	257187.	50799.	100323.	122805.	144840.	170857.	184729.	219914.	246412.	265145.	285284.	304169.	317382.	317750.
515531	542987.	19363.	427013.	457053.	475756.	500629.	521689.	543054.	551983.	551996.	552013.	552013.	552013.	552013.
515631	127102.	10381.	86366.	91815.	93218.	101165.	109717.	125643.	132748.	132821.	132821.	132821.	132821.	132821.
515731	530880.	28291.	402941.	421573.	439511.	466197.	490543.	523663.	538626.	544210.	548233.	549788.	549788.	549788.
515831	38904.	3689.	26620.	27409.	28017.	30884.	33545.	36950.	39530.	40644.	41700.	41700.	41700.	41700.
509431	198223.	11767.	139450.	160522.	165167.	173302.	180709.	193351.	200754.	204249.	205987.	206471.	206553.	206562.
516531	185539.	29670.	72713.	82390.	96284.	115075.	143984.	176010.	188714.	196611.	203925.	208017.	208017.	208017.
515931	46994.	9131.	12684.	16845.	22974.	27758.	34627.	41801.	46600.	49913.	53913.	54702.	54702.	54702.
516031	380470.	72070.	133432.	144358.	155500.	201724.	265947.	360653.	391029.	409711.	425979.	432978.	432978.	432978.
516131	191496.	48162.	31006.	43950.	50302.	67857.	111869.	179293.	204674.	214769.	220741.	224429.	224429.	224429.
516231	31664.	7055.	4811.	6498.	9827.	17159.	22119.	28029.	32817.	34881.	36632.	36980.	36980.	36980.
516331	48930.	3282.	31677.	34559.	37836.	41781.	45000.	48640.	50540.	50540.	50540.	50540.	50540.	50540.
516431	126731.	34133.	0.	10736.	32624.	55907.	73999.	112342.	131338.	139860.	146493.	154254.	154254.	154254.
Total	2707108.	264420.	1694924.	1791358.	1890432.	2099240.	2372287.	2603491.	2732440.	2794260.	2842250.	2895720.	2950080.	2962534.

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	VOLUME (%)	+++++++++ PERCENTAGE OF MONTHS +++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS ---------- PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
421331	9923.5	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515531	59482.2	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	36025.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18784.5	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	2394.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	38725.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516531	39337.1	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	14068.1	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	107737.5	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516231	11943.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516331	2569.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516431	48000.0	121.14	99.43	99.75	99.4	99.4	99.4	99.4	99.4	99.6	99.9	96.6	96.6	96.6	100.0	100.0	100.0	100.0
Total	456758.5	121.15		99.97														

Authorized and Current Use Scenario 1940-2007 End-of-Month Storage Plots

The 1940-2007 end-of-month reservoir storage contents in Figures 6.2 through 6.27 were plotted with HEC-DSSVue from *SIM* simulation results. The simulations begin with all reservoirs full to capacity. Figures 6.2 through 6.27 show the significant difference in reservoir storage levels between the authorized use (Bwam3) and current use (Bwam8) scenarios. The plots of Figures 6.2 through 6.27 also provide a comparison of the 1940-1997 versus extended 1940-2007 simulation periods. The simulation from January 1940 through December 1997 is identical to the simulation from which the frequency tables of Tables 6.6 and 6.7 were developed.

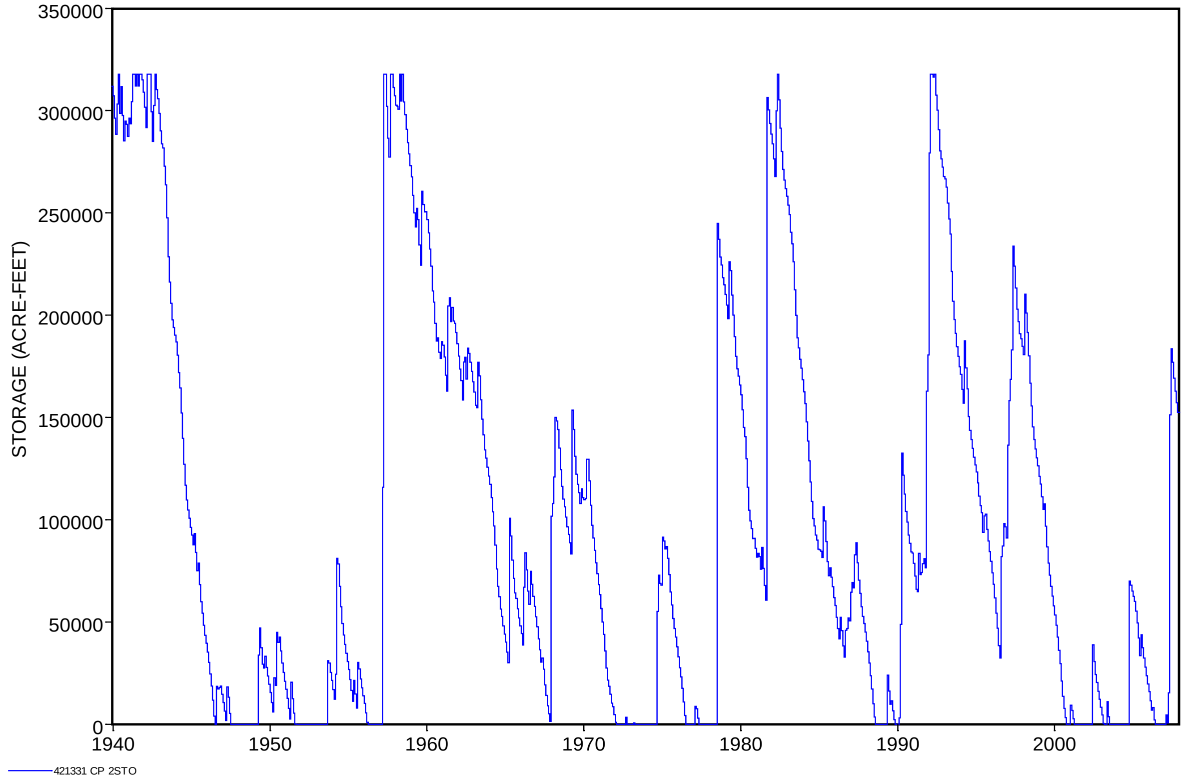

Figure 6.2 Authorized Use Scenario (Bwam3) Storage Contents of Hubbard Creek Reservoir

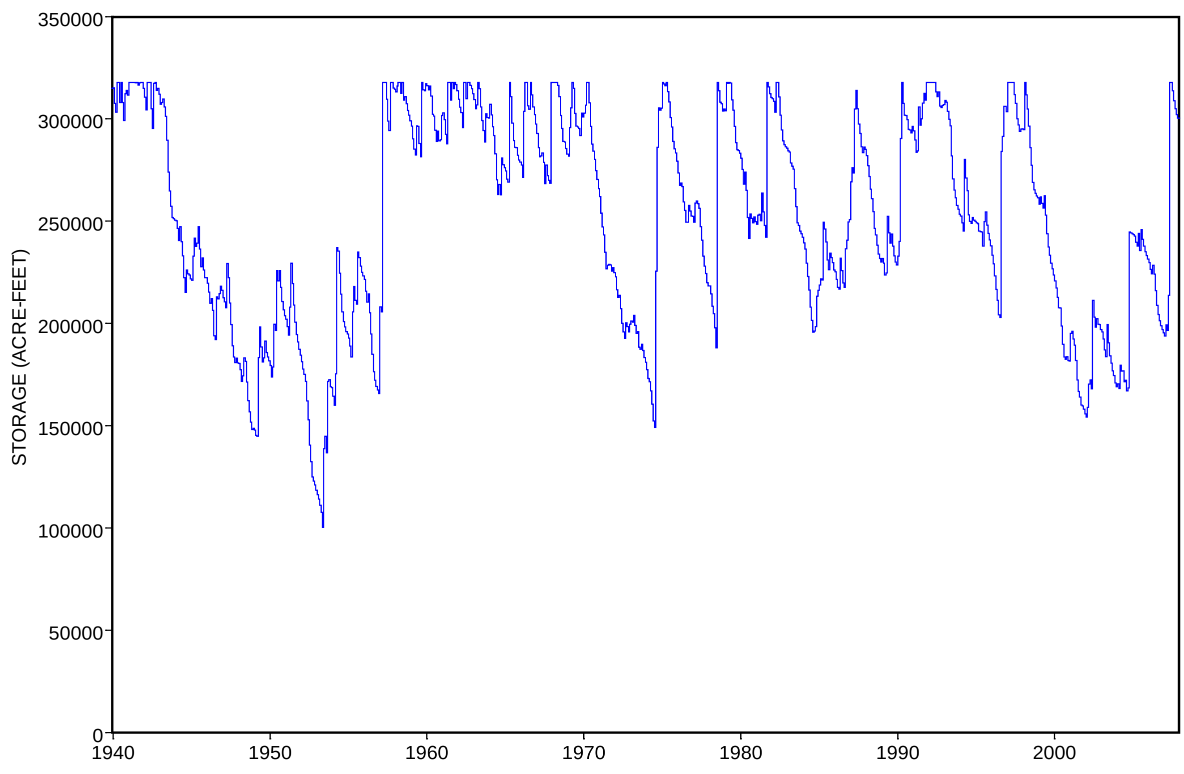

Figure 6.3 Current Use Scenario (Bwam8) Storage Contents of Hubbard Creek Reservoir

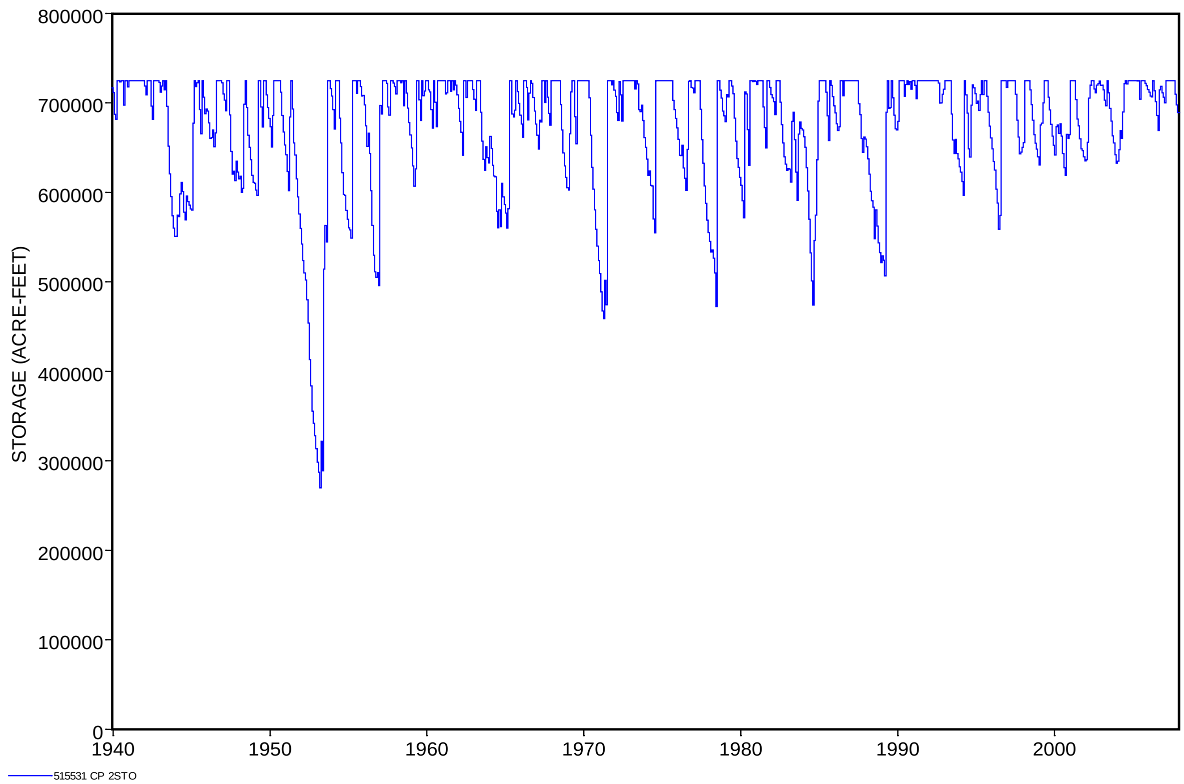

Figure 6.4 Authorized Use Scenario (Bwam3) Storage Contents of Possum Kingdom Reservoir

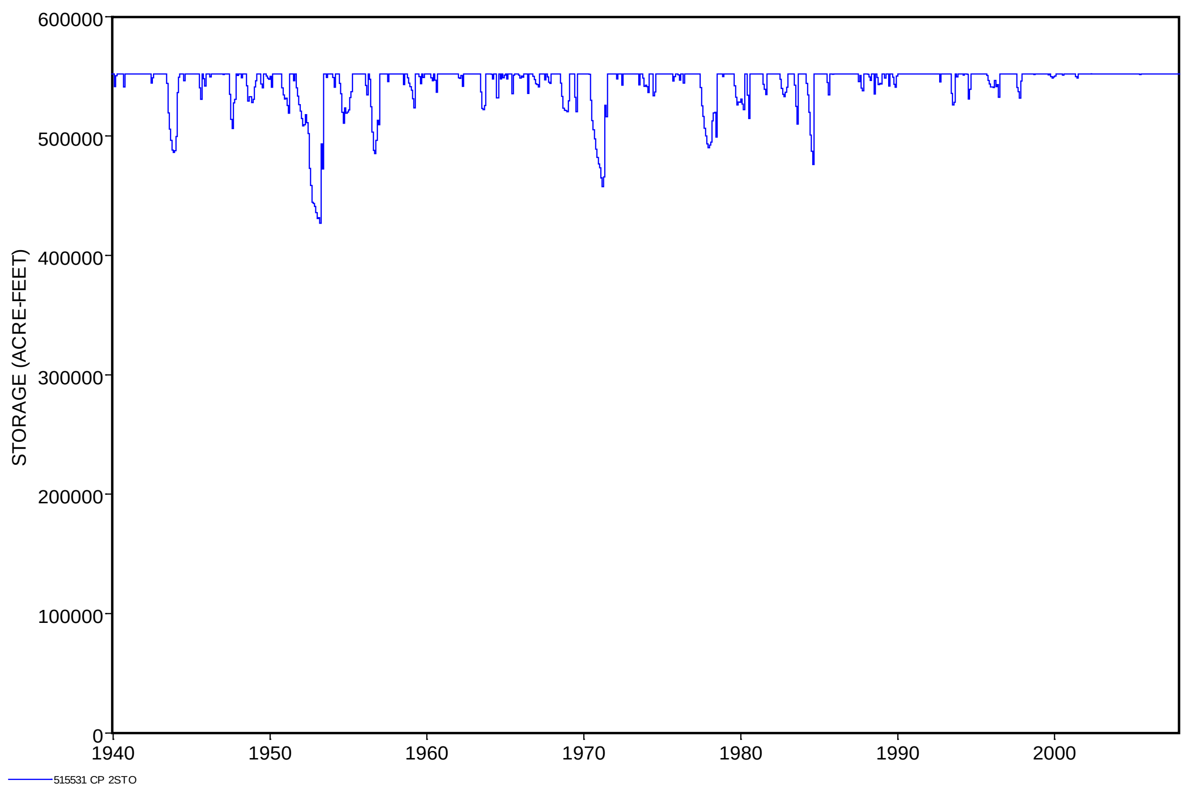

Figure 6.5 Current Use Scenario (Bwam8) Storage Contents of Possum Kingdom Reservoir

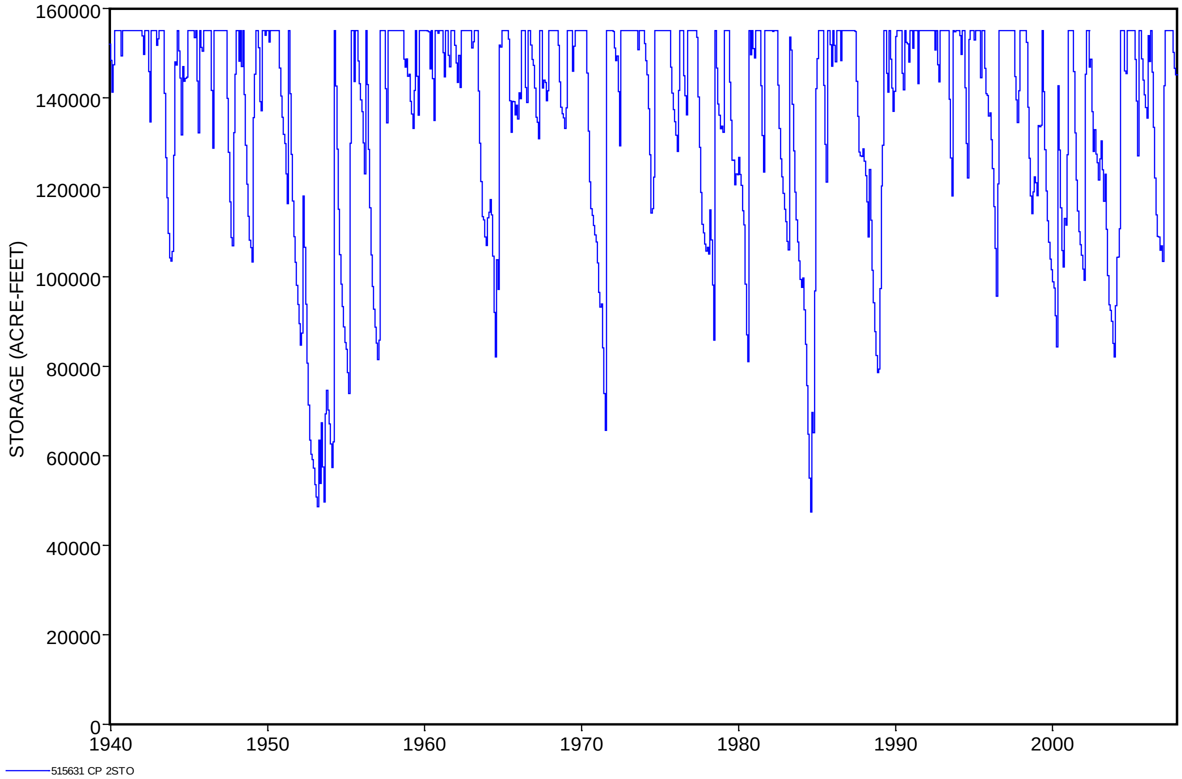

Figure 6.6 Authorized Use Scenario (Bwam3) Storage Contents of Granbury Reservoir

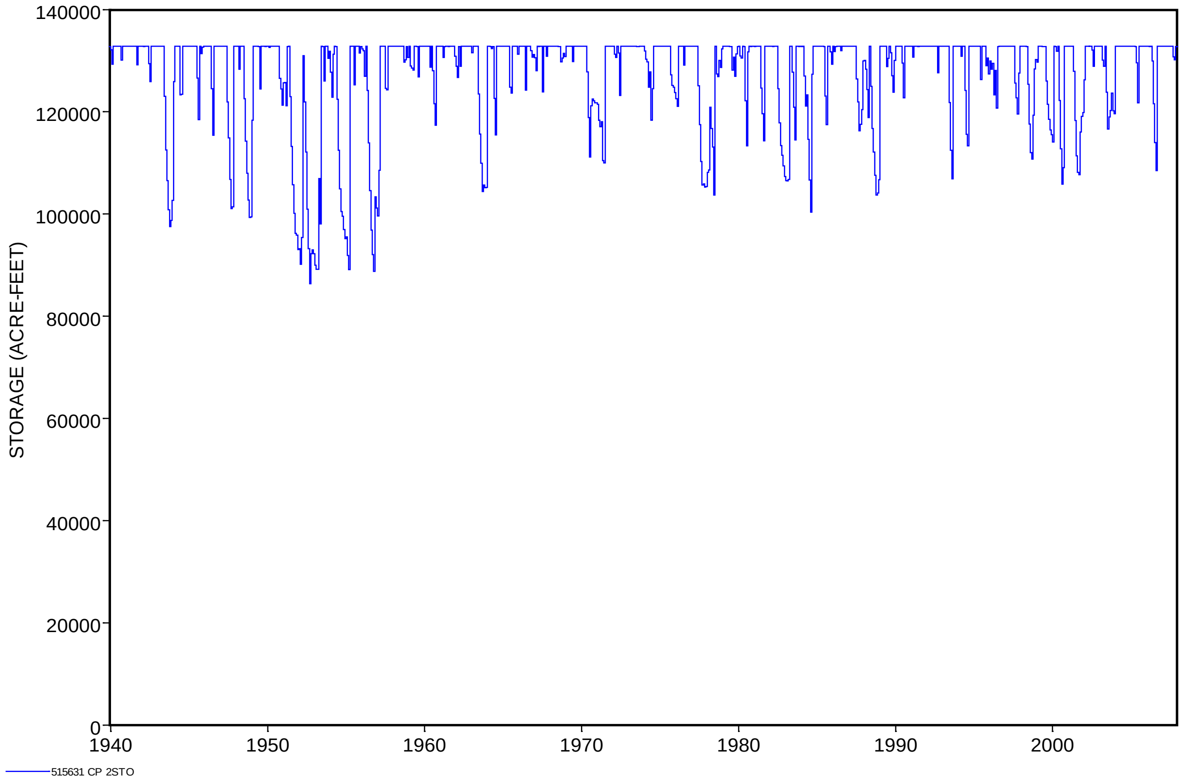

Figure 6.7 Current Use Scenario (Bwam8) Storage Contents of Granbury Reservoir

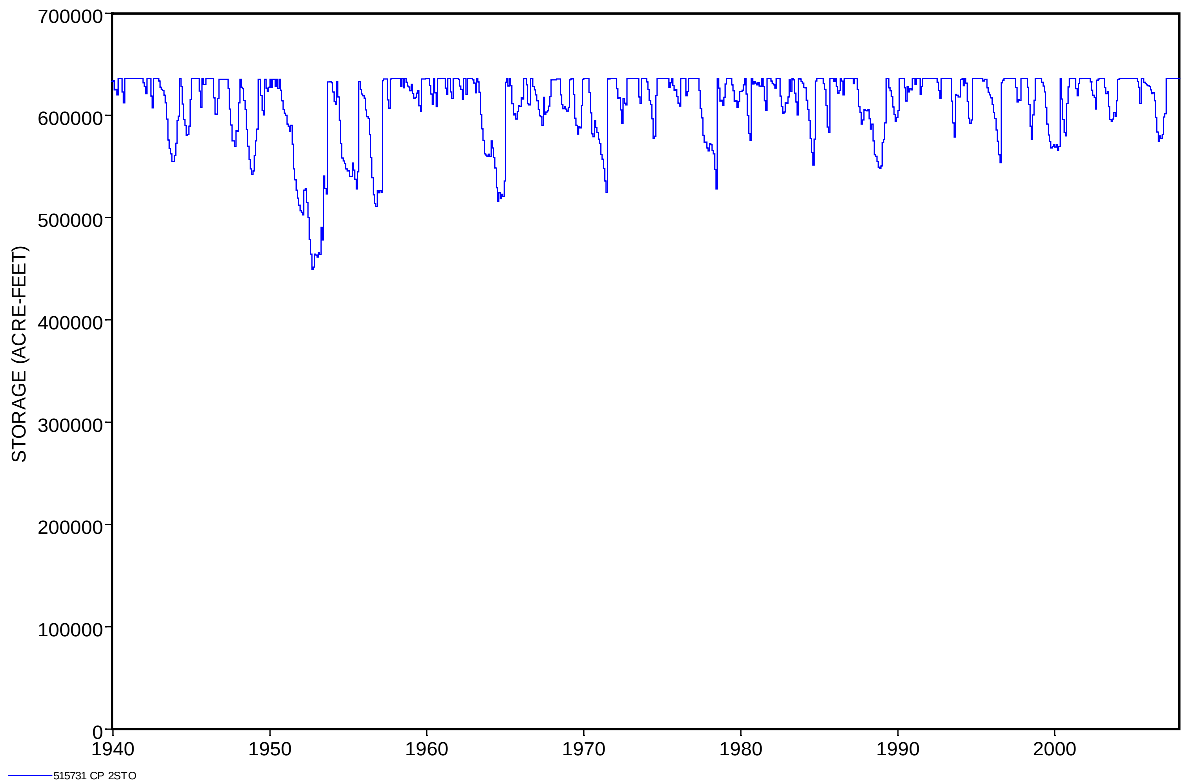

Figure 6.8 Authorized Use Scenario (Bwam3) Storage Contents of Whitney Reservoir

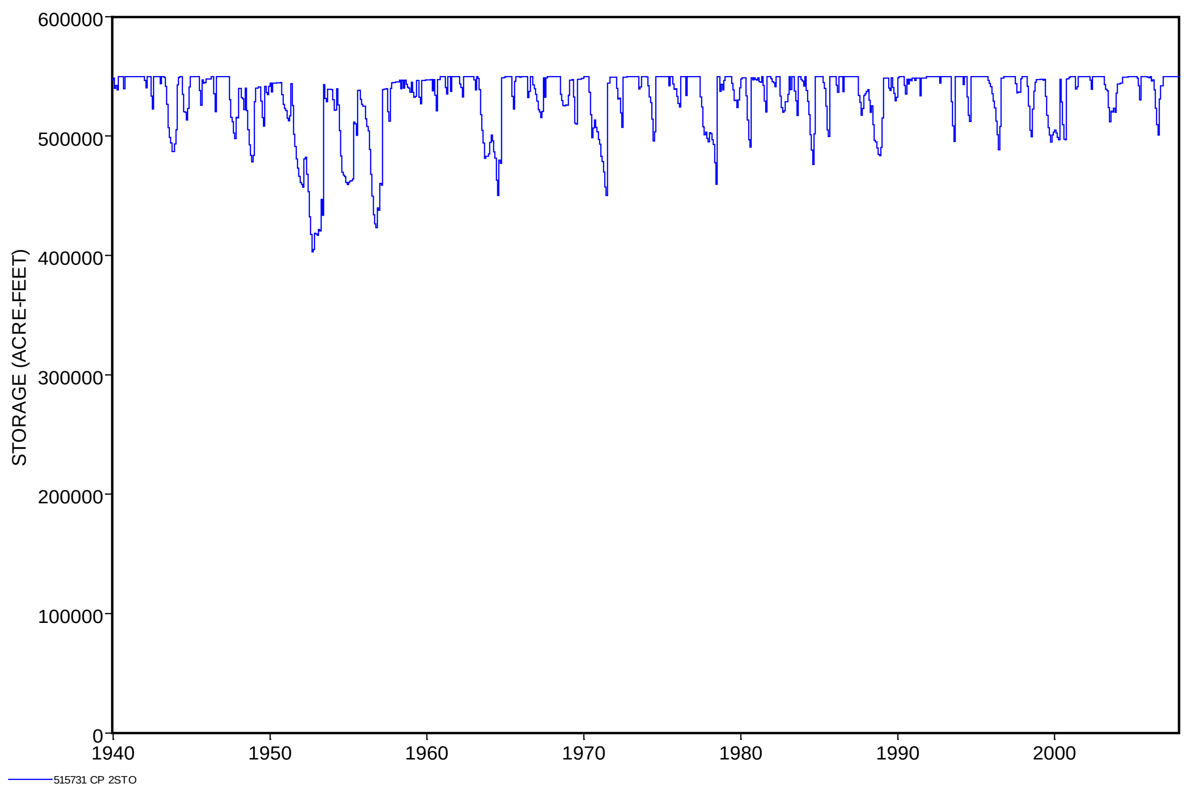

Figure 6.9 Current Use Scenario (Bwam8) Storage Contents of Whitney Reservoir

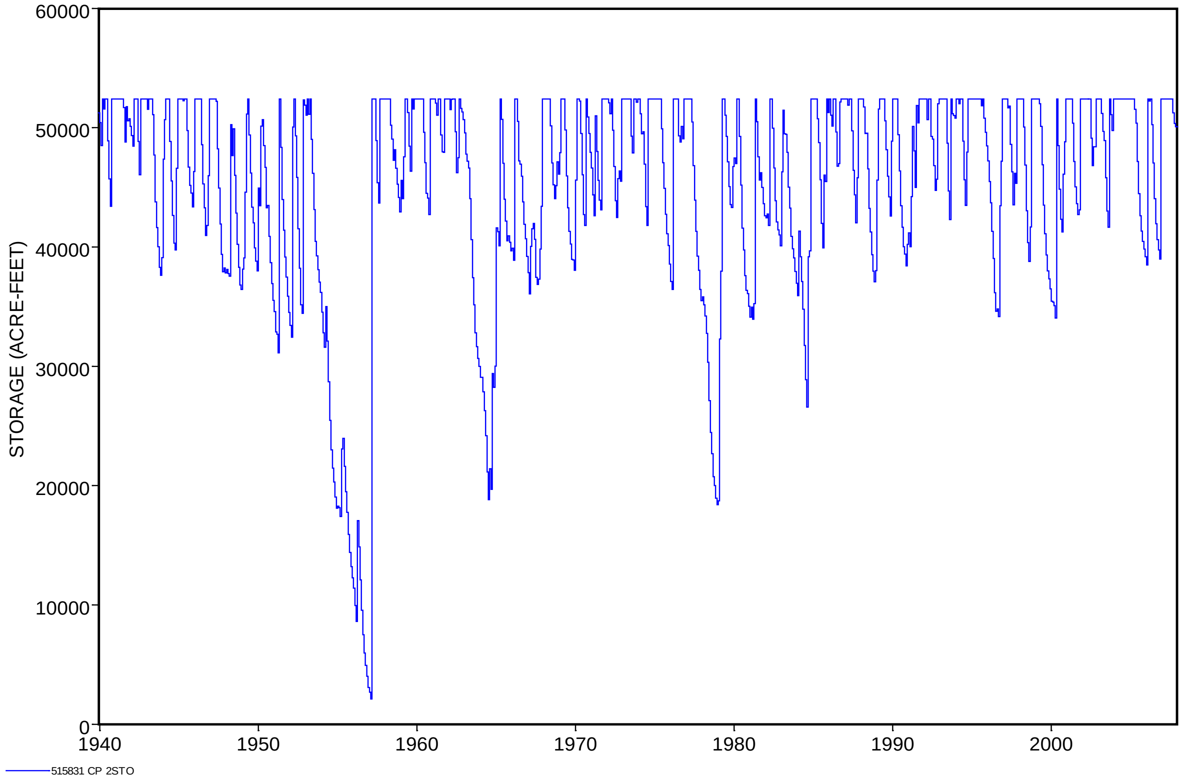

Figure 6.10 Authorized Use Scenario (Bwam3) Storage Contents of Aquilla Reservoir

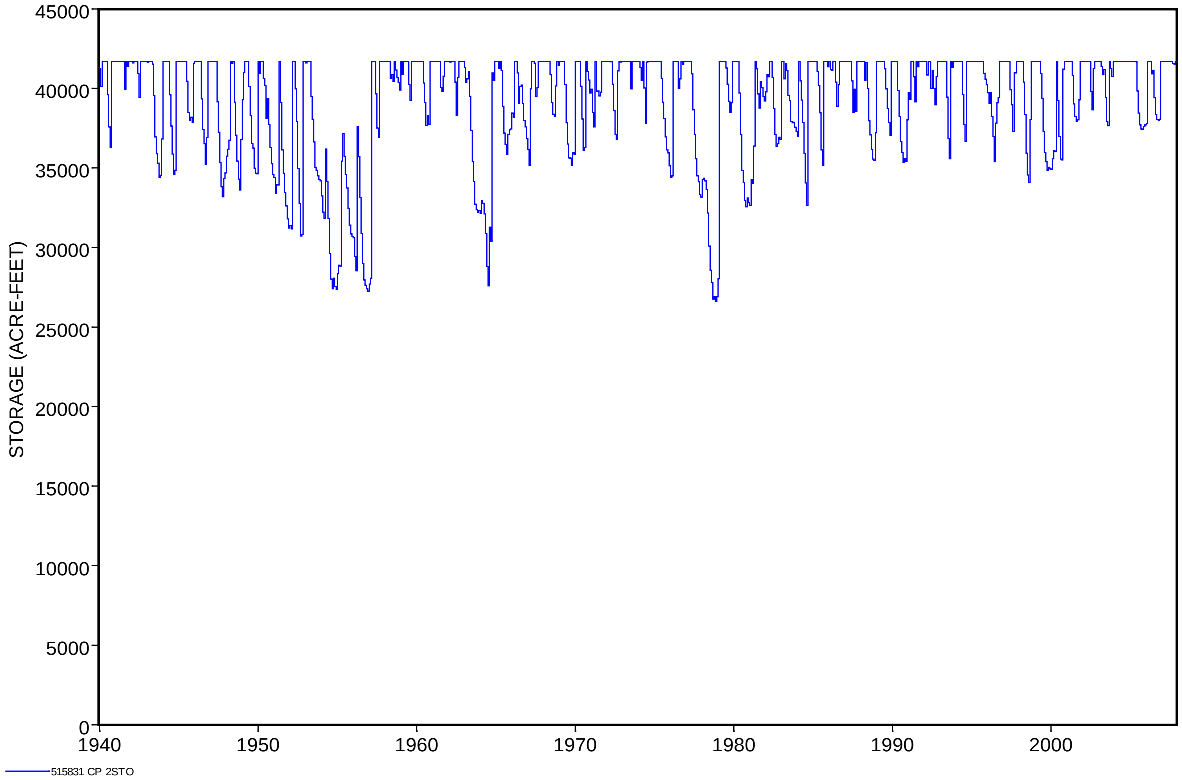

Figure 6.11 Current Use Scenario (Bwam8) Storage Contents of Aquilla Reservoir

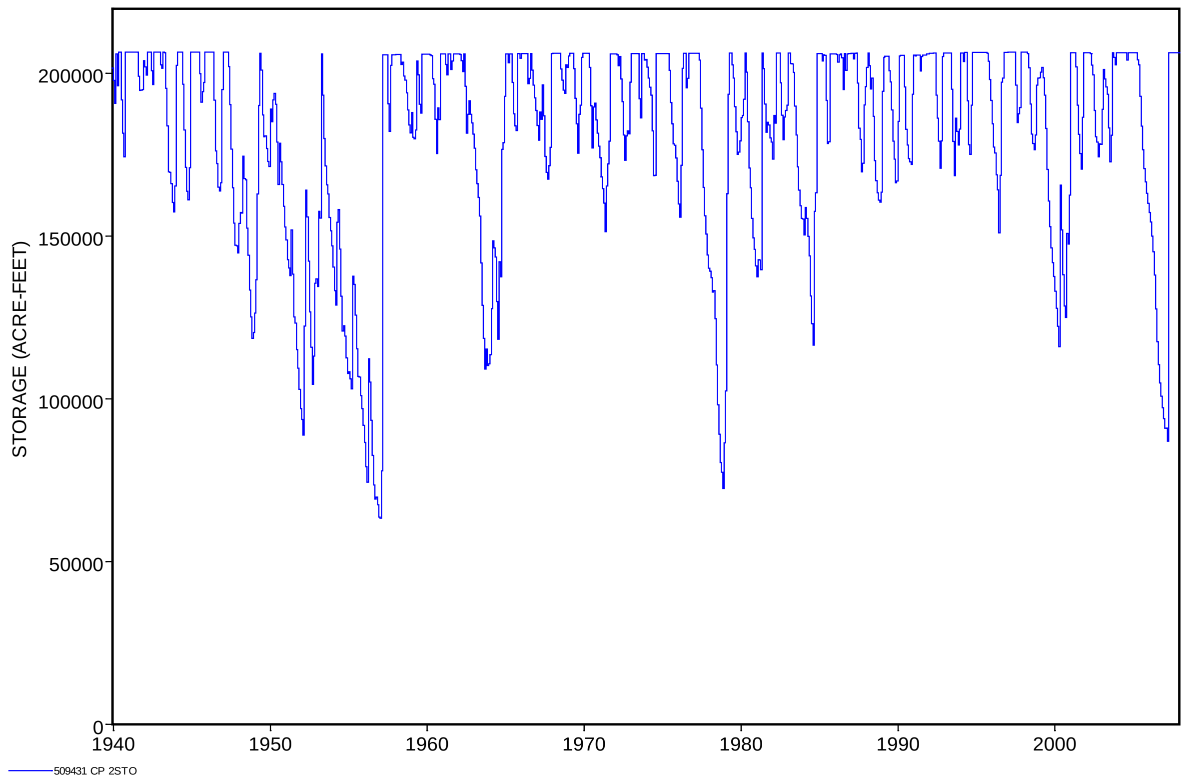

Figure 6.12 Authorized Use Scenario (Bwam3) Storage Contents of Waco Reservoir

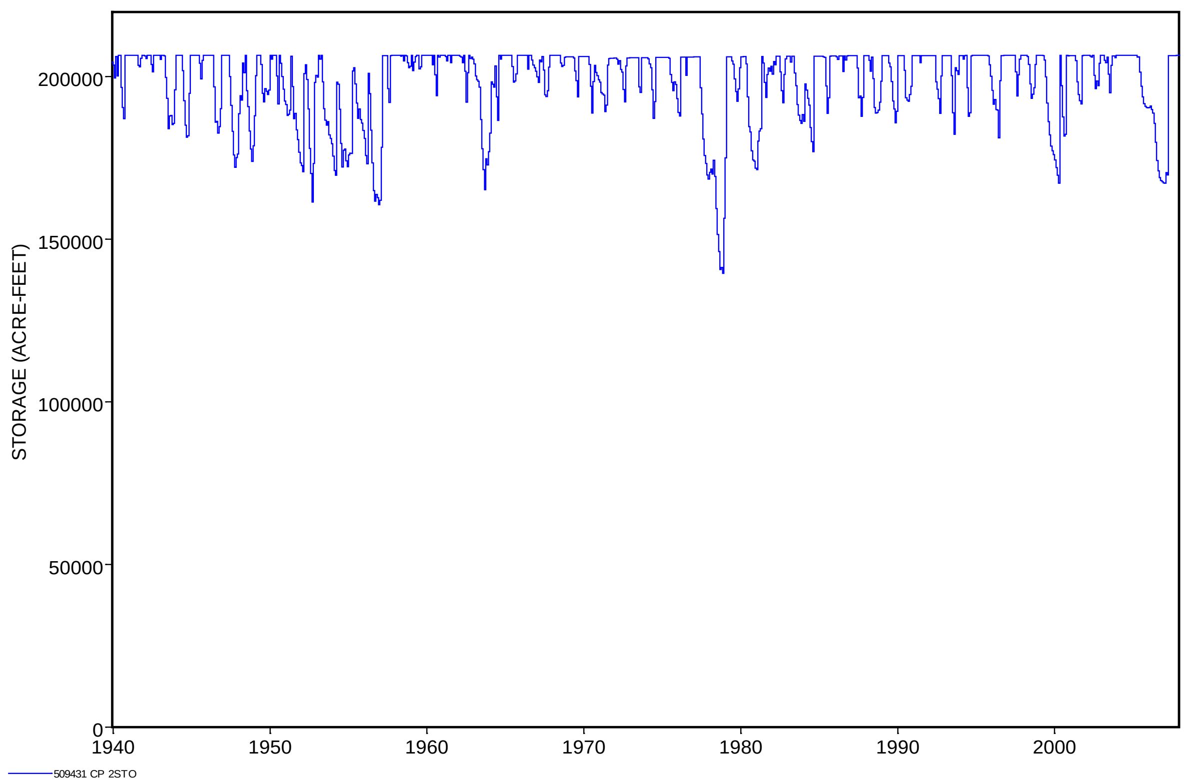

Figure 6.13 Current Use Scenario (Bwam8) Storage Contents of Waco Reservoir

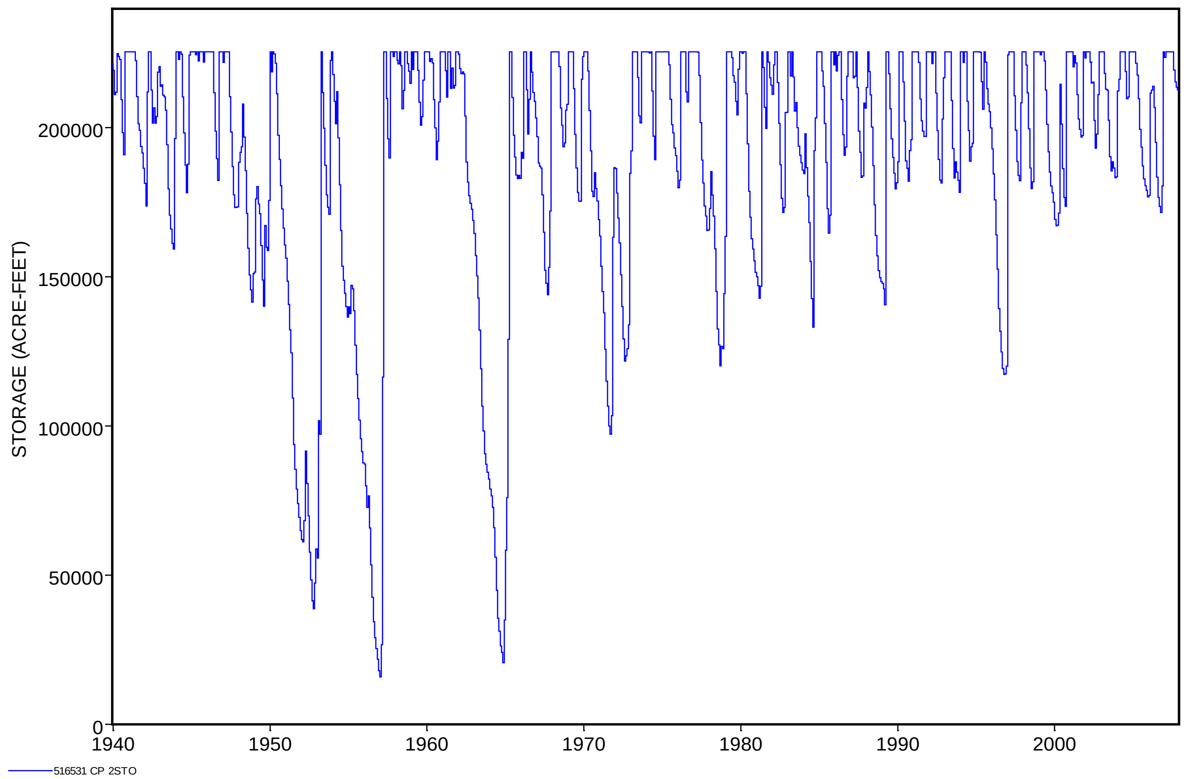

Figure 6.14 Authorized Use Scenario (Bwam3) Storage Contents of Limestone Reservoir

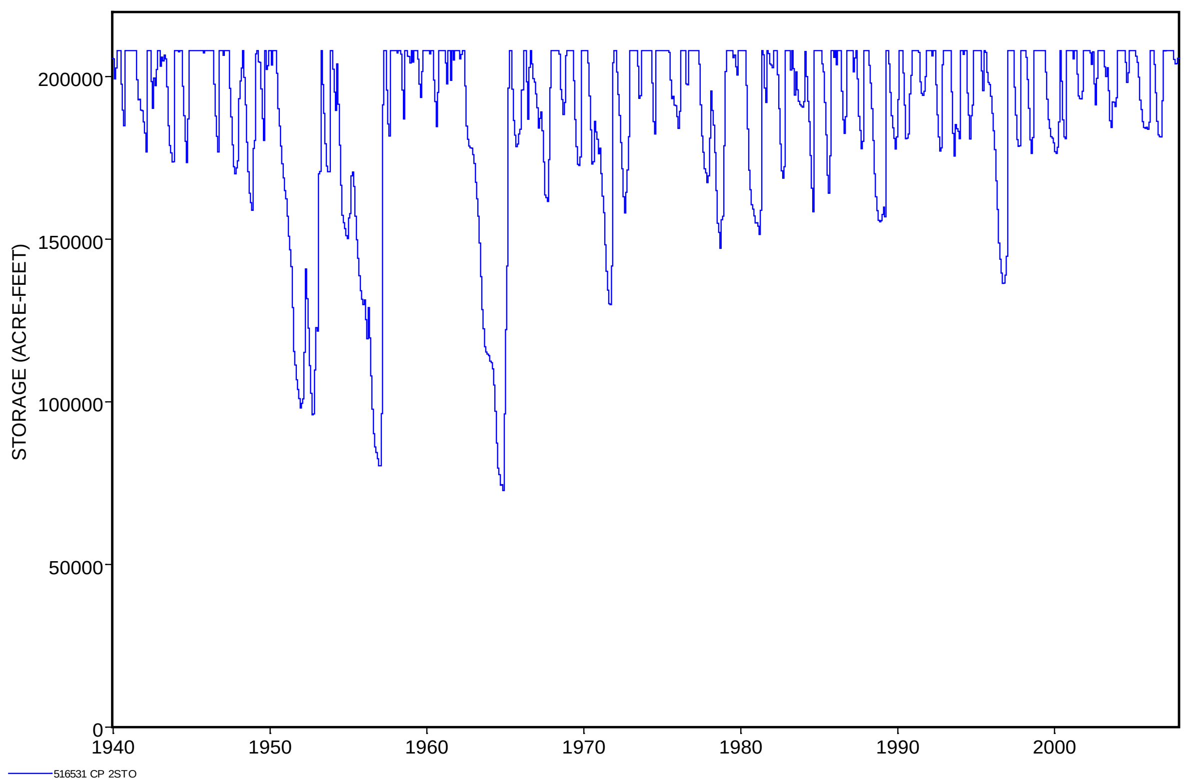

Figure 6.15 Current Use Scenario (Bwam8) Storage Contents of Limestone Reservoir

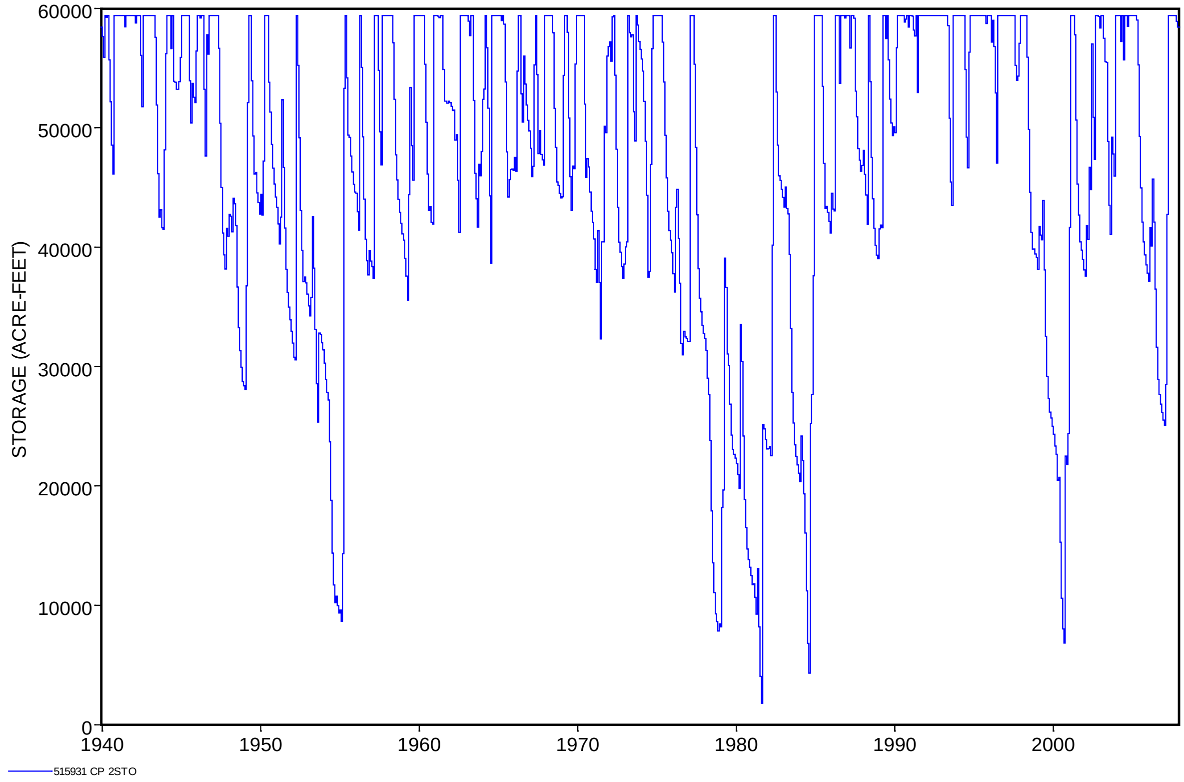

Figure 6.16 Authorized Use Scenario (Bwam3) Storage Contents of Proctor Reservoir

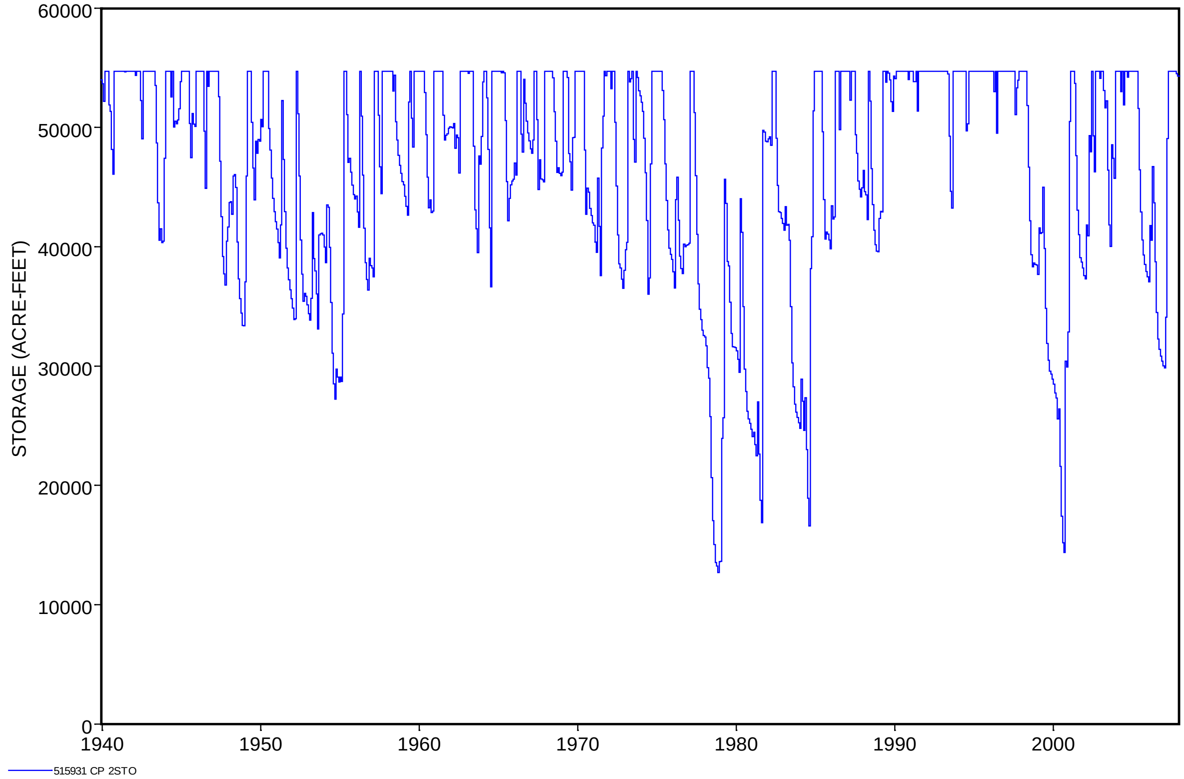

Figure 6.17 Current Use Scenario (Bwam8) Storage Contents of Proctor Reservoir

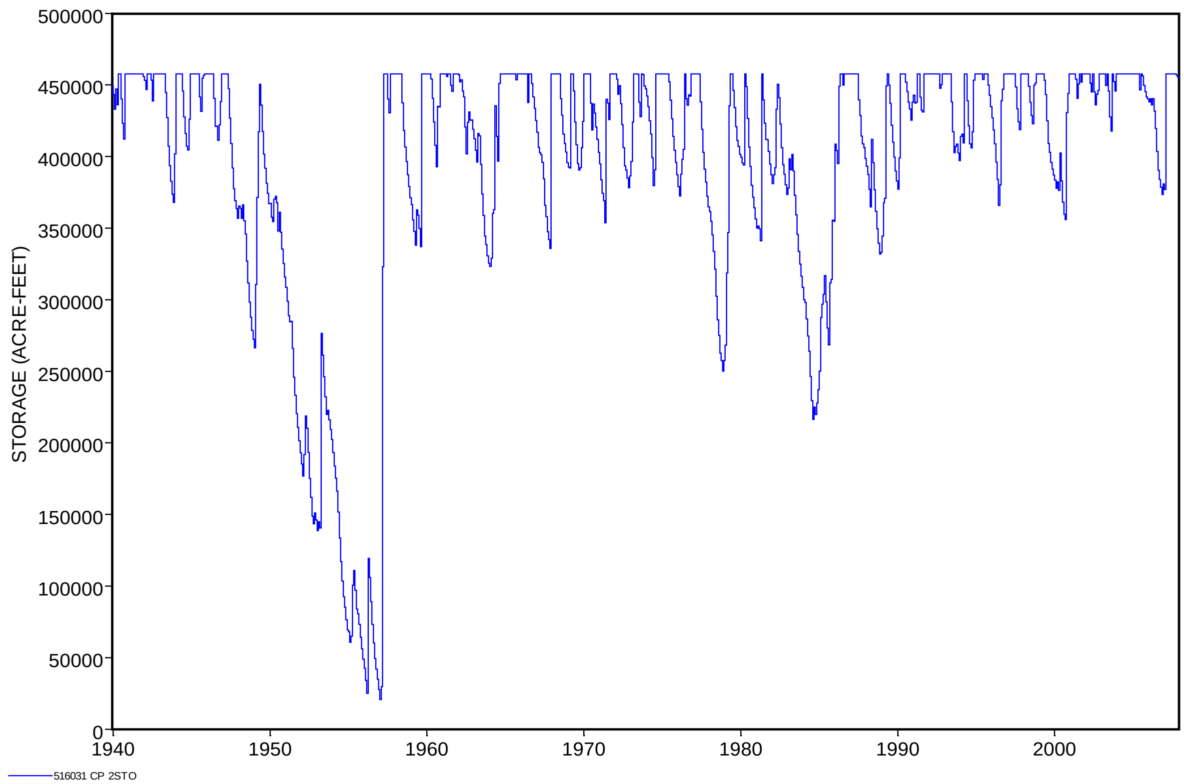

Figure 6.18 Authorized Use Scenario (Bwam3) Storage Contents of Belton Reservoir

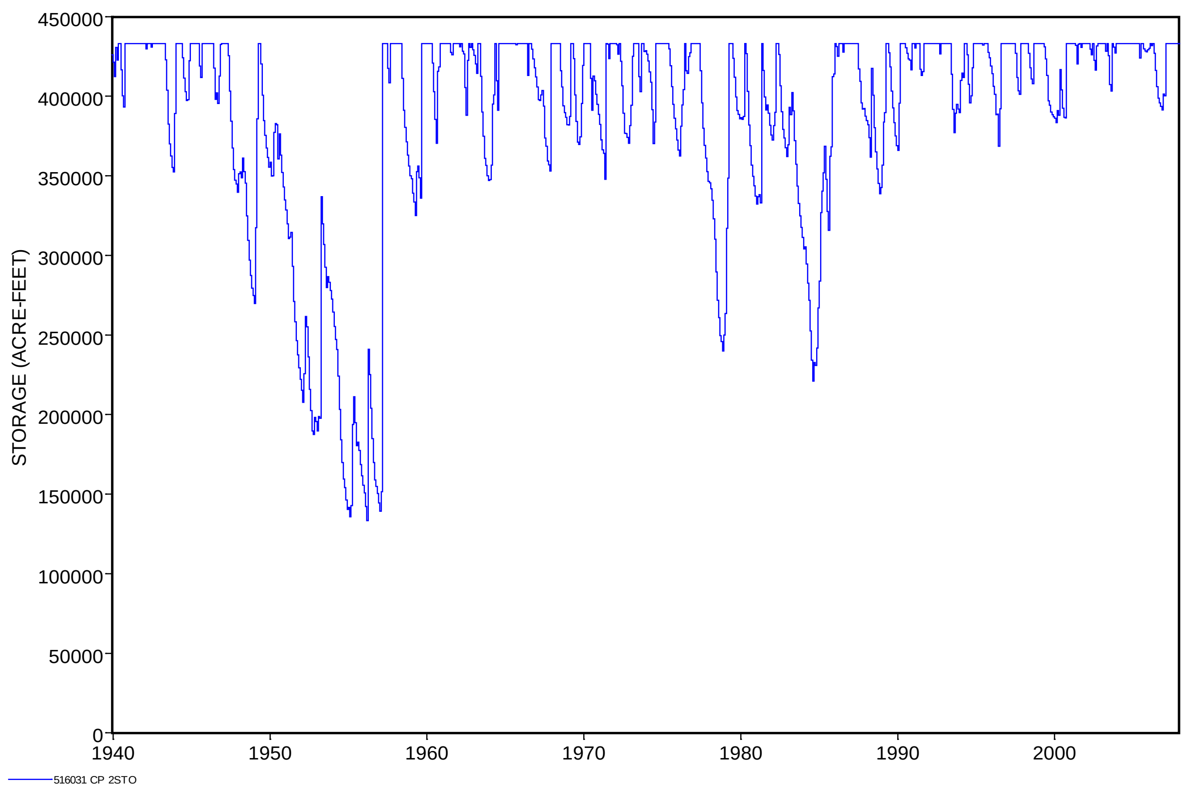

Figure 6.19 Current Use Scenario (Bwam8) Storage Contents of Belton Reservoir

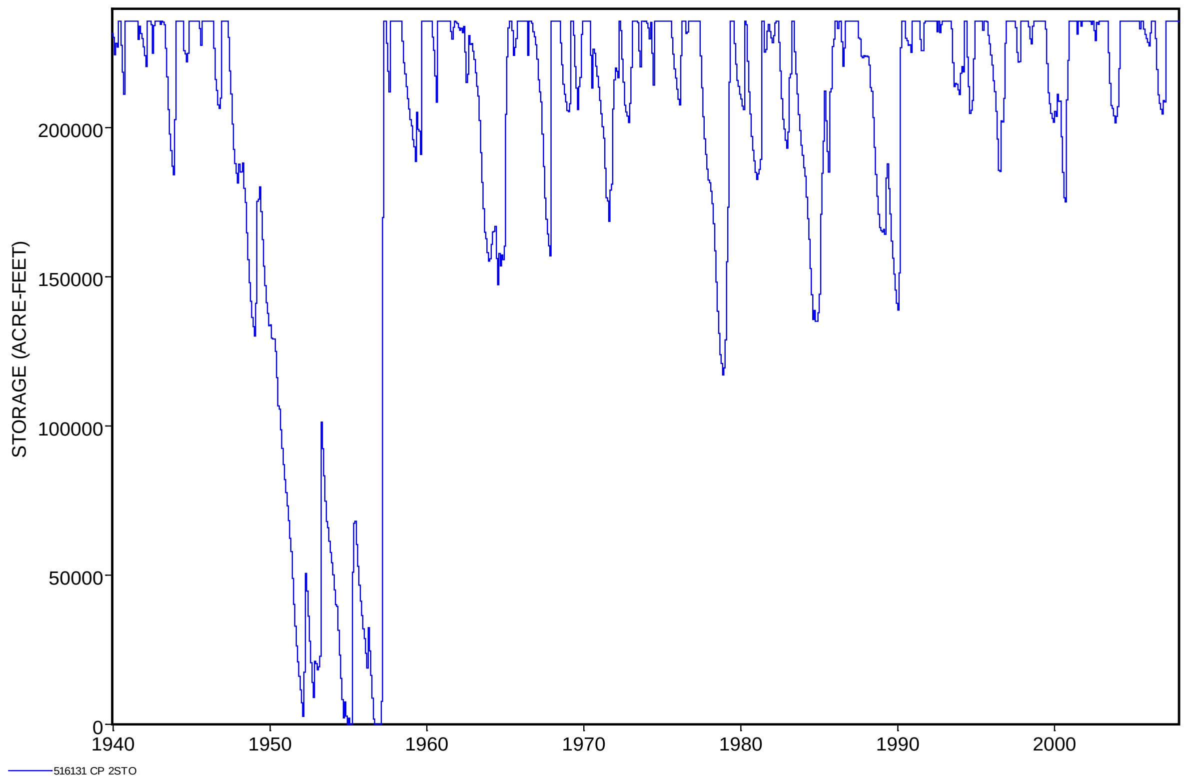

Figure 6.20 Authorized Use Scenario (Bwam3) Storage Contents of Stillhouse Hollow Reservoir

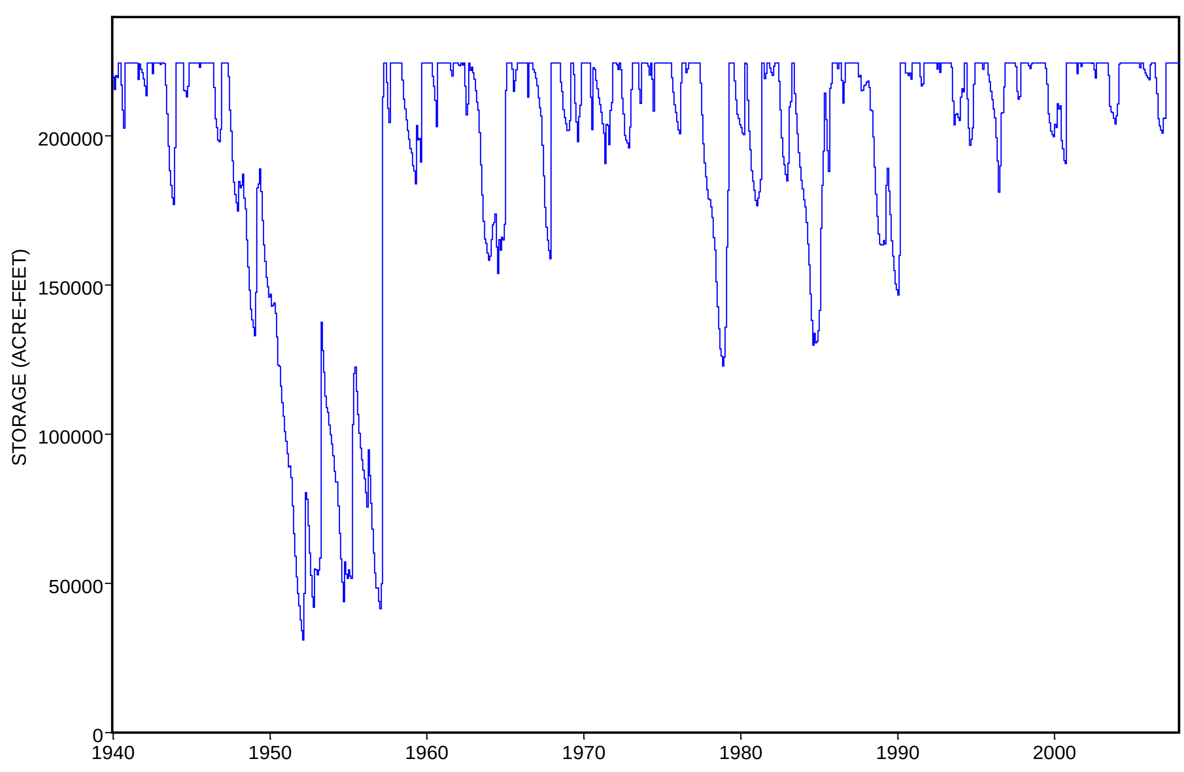

Figure 6.21 Current Use Scenario (Bwam8) Storage Contents of Stillhouse Hollow Reservoir

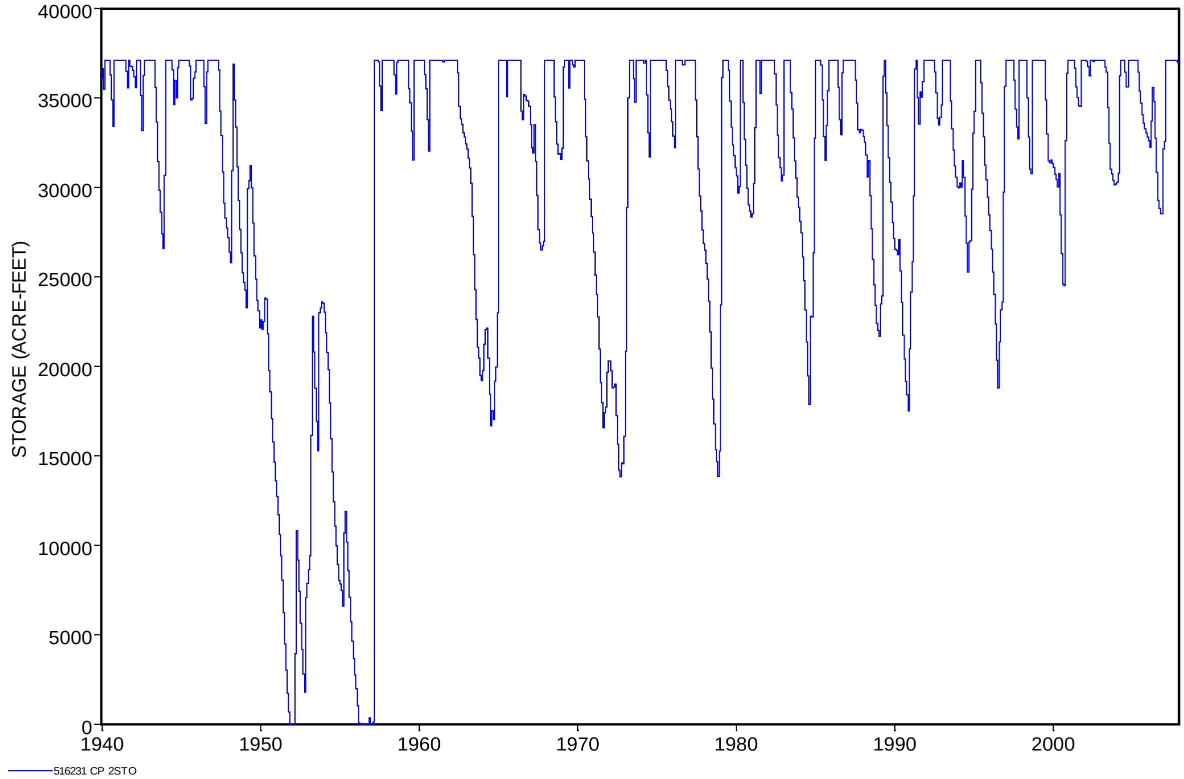

Figure 6.22 Authorized Use Scenario (Bwam3) Storage Contents of Georgetown Reservoir

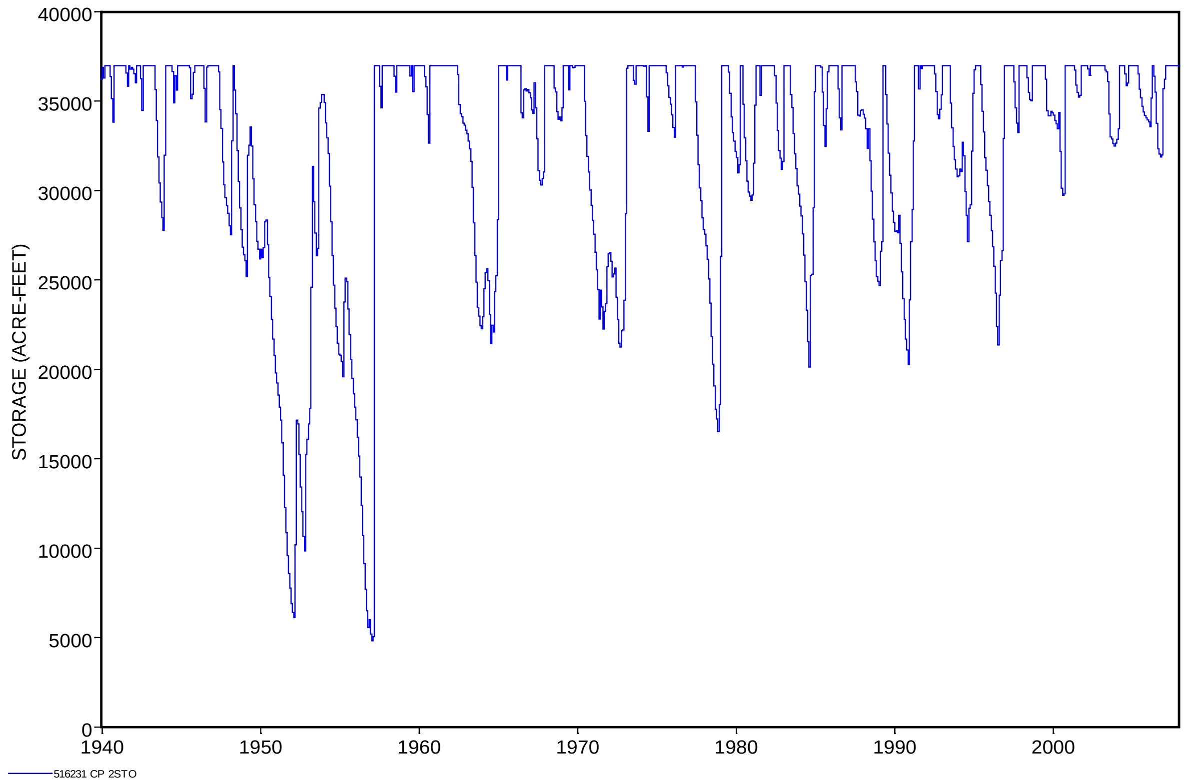

Figure 6.23 Current Use Scenario (Bwam8) Storage Contents of Georgetown Reservoir

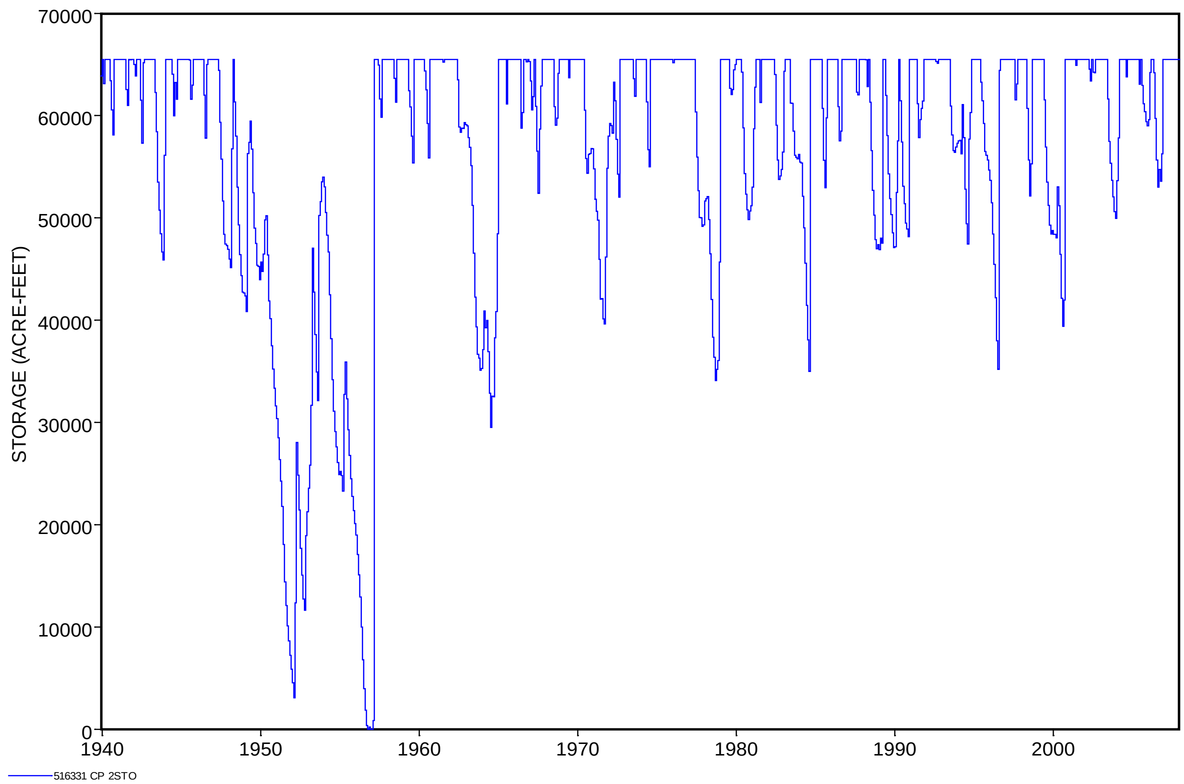

Figure 6.24 Authorized Use Scenario (Bwam3) Storage Contents of Granger Reservoir

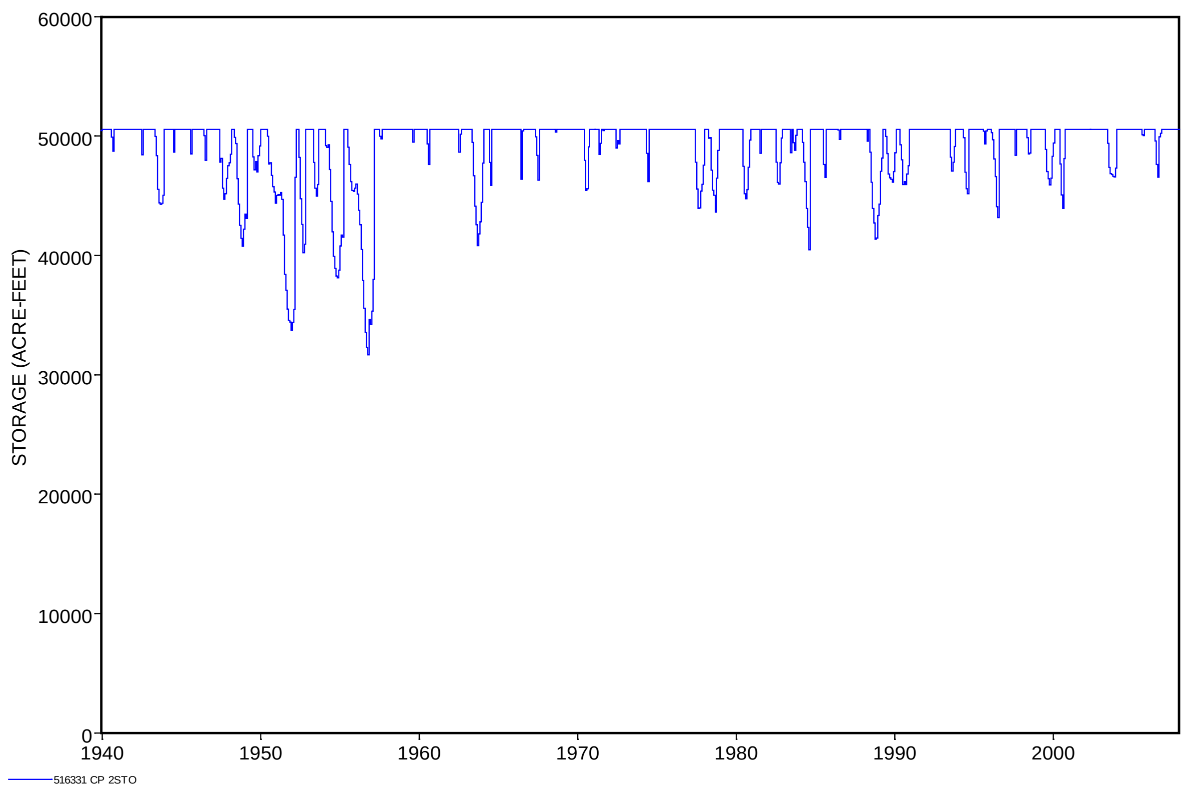

Figure 6.25 Current Use Scenario (Bwam8) Storage Contents of Granger Reservoir

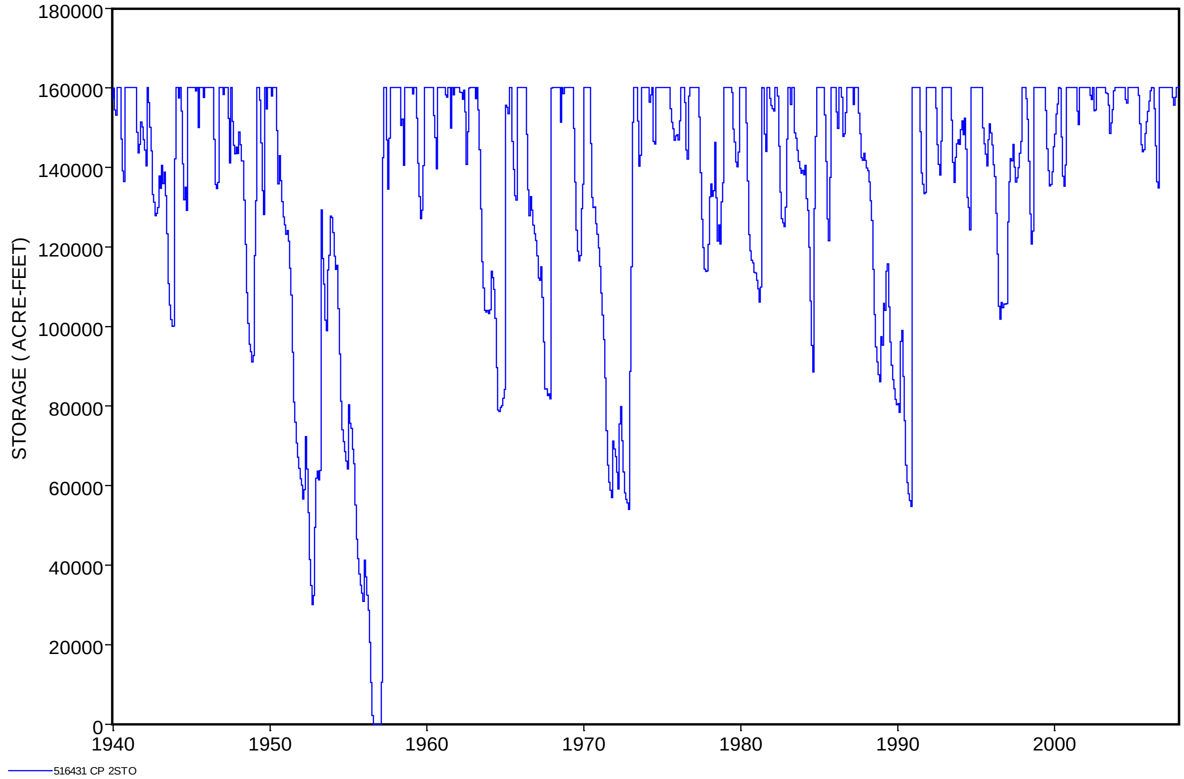

Figure 6.26 Authorized Use Scenario (Bwam3) Storage Contents of Somerville Reservoir

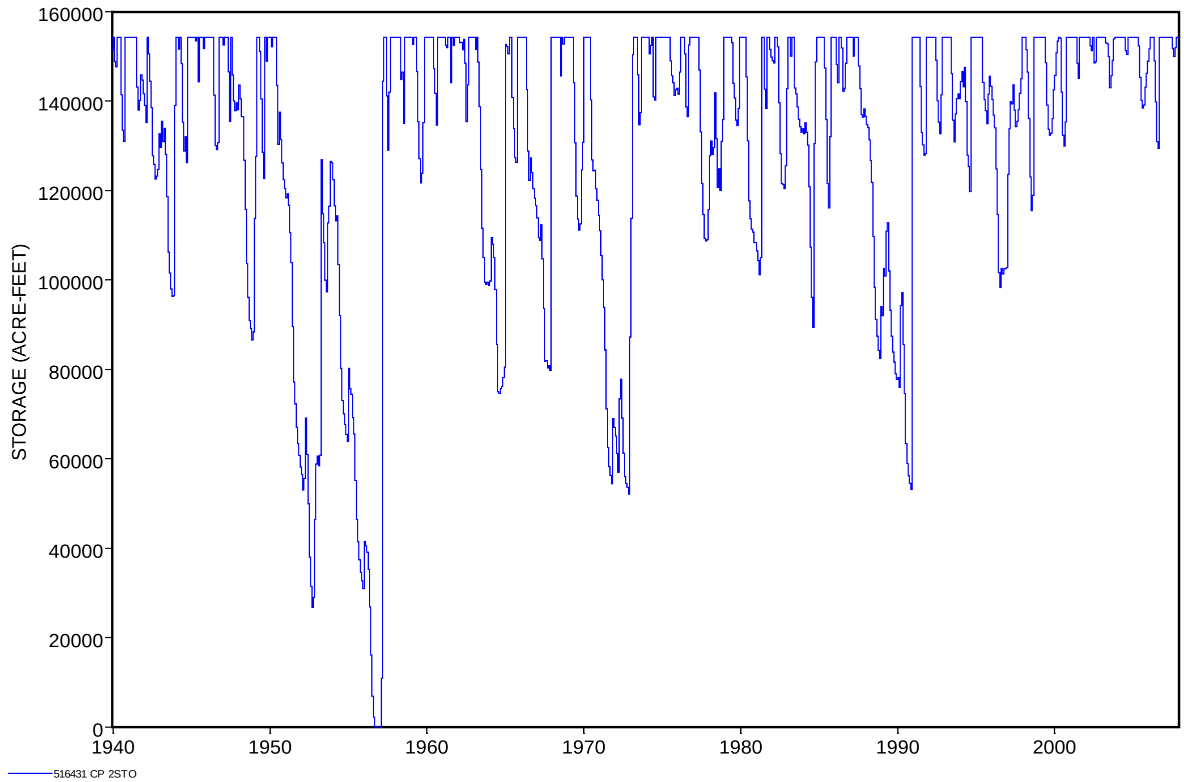

Figure 6.27 Current Use Scenario (Bwam8) Storage Contents of Somerville Reservoir

CHAPTER 7
NEGATIVE INCREMENTAL FLOW OPTIONS

ADJINC in *JD* record field 8 is a switch for selecting between options associated with the impacts of flows at downstream control points on the determination of the amount of stream flow available to each water right during each time step. *ADJINC* options 1, 2, 3, -3, 4, -4, and 5 are described in the *Reference* and *Users Manuals* from the perspective of a monthly *SIM* simulation. Though also applicable for a *SIM* monthly simulation, options 6, 7, and 8 were added during 2011 in conjunction with development of *SIMD* daily capabilities and are described in the *Daily Manual*. These ten options represent alternative approaches for dealing with the effects of downstream senior rights and negative incremental flows in determining the amount of stream flow available to each water right. Options 2, 3, -3, 4, and -4 develop negative incremental flow adjustments, but the other options do not develop flow adjustments. The options also differ in the selection of downstream control points to include in the flow availability computations.

CPFLOW Array Based Water Accounting

The *SIM* or *SIMD* simulation steps through time. At each time step, computations are performed for each water right in priority order. With either a daily or monthly simulation, as each water right is considered in the priority sequence, the tasks described in Table 7.1 are performed. All of the *ADJINC* options affect Task 1 of Table 7.1, and option 5 also affects Task 4.

Table 7.1
Computations Repeated for Each Water Right at Each Time Step

Task 1: Flow Availability Determination. – The amount of stream flow available to the water right is the minimum of the control point flow *CPFLOW* array available flows at the control point of the water right and at relevant control points located downstream, adjusted for channel losses (monthly or daily simulation) and/or routing (daily simulation). In *SIMD* simulation of flood control operations, the amount of channel flood flow capacity below maximum allowable non-damaging limits is determined considering the control point of the flood control right and pertinent downstream control points.

Task 2: Target Set. – The water supply diversion target, hydroelectric power generation target, minimum instream flow limit, or non-damaging flood flow limit is set.

Task 3: Water Right Simulation. – For the water right being considered, decisions are made and actions are taken regarding reservoir storage and releases, water supply diversions, and other water management/use requirements. Net evaporation volumes are determined. Water balance accounting computations are performed.

Task 4: Flow Adjustment. – The control point flow availability *CPFLOW* array is adjusted at the control point of the water right and downstream control points for the effects of the Task 3 water management, control, and use actions associated with that particular water right.

A *control point flow CPFLOW array* is created in a *SIM* or *SIMD* simulation. The *CPFLOW* array elements represent available stream flow volumes at that computational step in the water right priority-based simulation sequence considering each control point location individually. At the beginning of a simulation time step, the *CPFLOW* array is populated with the naturalized flows plus *CI* record constant inflows and next-period return flows from the preceding time period. The amounts in the *CPFLOW* array at the control point of the water right and downstream control points are adjusted (Task 4 in Table 7.1) in the water rights computational loop nested within the time step loop to reflect the impacts of each right. The *CPFLOW* array is used to determine flow availability (Task 1 in Table 7.1) for each right in the priority sequence. At the end of the simulation time step, the *CPFLOW* array is used to determine regulated and unappropriated flows.

Negative Incremental Naturalized Stream Flows

Naturalized, regulated, and unappropriated flow volumes, and *SIM/SIMD* algorithms are all based on cumulated total flows at each control point, rather than incremental local flows between control points. However, with a monthly simulation interval (with no routing), the term *negative incremental flow* is applied to describe situations in which the naturalized flow volume for a particular time step at a control point is less than concurrent flows at control points located upstream. Negative incremental means the flow is decreasing in a downstream direction in that time interval. With a monthly time step, by definition, negative incrementals do not exist in a naturalized flow dataset if flows in each time step always increase going downstream.

Negative incremental naturalized flows can be defined either looking downstream or upstream. *ADJINC* option 2 is based on *downstream* negative incremental flows. The *downstream* negative incremental flow for a control point is the greatest negative difference between the naturalized flow at the control point and any other control point located downstream. *ADJINC* options 3 and 4 are based on *upstream* negative incremental flows. With *ADJINC* options 3 and 4, negative incremental flow adjustments at a control point represent the amount that must be added to the naturalized flow at that control point to remove all negative incremental flows occurring at all control points located upstream. *JD* record *NEGINC* writes either downstream or upstream negative incremental naturalized flows to the message file for each month at each control point.

A daily simulation is complicated by routing which extends the concept of negative incremental flows across multiple time steps. With routing, incremental flows at a particular control point are viewed conceptually as total naturalized flows originating from the current and previous days routed from one or more (multiple-tributary) adjacent upstream control points less the total naturalized flow at the particular control point. These incremental flows are usually positive but may be negative. Though simulation computations are based on total rather than incremental flows, the concept of negative incremental flows is fundamental to daily as well as monthly simulations.

Relevant Control Points Considered in the Determination of Available Flow

In Task 1 of Table 7.1, the stream flow available to a water right is determined by *SIM* or *SIMD* as the minimum of the *CPFLOW* array flows at the control point of the right and at control points located downstream. Without *SIMD* routing and forecasting, only *CPFLOW* array available flows in the current period are considered. With *SIMD* routing and forecasting, *CPFLOW* flows in the current day and each day of the forecast are considered. For a particular water right, the set of control points included in determining flow availability includes the control point of the water right and those additional control points that meet all three of the following criteria:

1. located downstream of the control point of the water right
2. identified in the *SIMD* routing and reverse routing (not applicable for *SIM*)
3. location of senior water rights if either *ADJINC* option 5, 6, or 7 is activated

The amount of stream flow available to a water right in Task 1 of Table 7.1 is the minimum *CPFLOW* array available flows in the current and forecast days at the control point of the water right and selected downstream control points. Flow at downstream control points may be the minimum in the *CPFLOW* array comparison and thus limit the amount of flow available to the water right located upstream only if one or more of the following conditions occur:

1. junior rights decrease the flows at one or more of the downstream control points
2. senior rights decrease the flows at one or more of the downstream control points
3. negative incremental flow situations affect the flow availability computations

The priority-based simulation is designed to protect senior rights from junior rights reducing the amount of stream flow available to them. In a *SIMD* daily simulation, forecasting is adopted to prevent junior rights from reducing the stream flow available to senior water rights in future days. Therefore, with senior rights protected from junior rights, the above list of factors affecting flow available to a particular right is reduced to the effects of senior rights and negative incremental flows. *ADJINC* options 5, 6, and 7 limit the search for the constraining minimum *CPFLOW* flow to the control points of the water right being simulated and downstream senior rights.

CP and PX Record Options

The *CP* and *PX* record options noted here also affect the selection of downstream control points to be considered in Task 1 of Table 7.1. Although having effects similar to the *ADJINC* options, these *CP* and *PX* record options are not addressed in the discussions of this chapter. Parameter *INMETHOD* entered in control point *CP* record field 6 specifies the option used for obtaining naturalized flows at the control point. With *INMETHOD* option 9, no flows are input and the control point is ignored in determining flow availability in Task 1 of Table 7.1. Downstream control point flow availability options governed by *XCP* and *XCPID* in *PX* record fields 4 and 5 circumvent or modify the consideration of *CPFLOW* array flows at specified downstream control points in Task 1 of Table 7.1.

Options Activated by *ADJINC* in *JD* Record Field 8

A *SIM* or *SIMD* simulation requires selection of one of the following options with the entry for *ADJINC* in *JD* record 8.

Option 1: All downstream control points are considered and there are no negative incremental flow adjustments. (*ADJINC* = 1)

Option 2: Downstream negative incremental flow adjustments defined in the *Reference Manual* are applied at all control points at the beginning of the simulation. (*ADJINC* = 2)

Option 3: Upstream negative incremental flow adjustments defined in the *Reference Manual* are applied at all control points at the beginning of the simulation. (*ADJINC* = 3)

Option −3: Variation of option 3 in which incremental flow adjustments are applied only at primary control points, not control points with synthesized flows. (*ADJINC* = −3)

Option 4: As flow availability is determined for each water right at each time step during the simulation, upstream negative incremental flow adjustments are applied at the downstream control points but not at the control point of the right. (*ADJINC* = 4)

Option −4: Variation of option 4 in which incremental flow adjustments are applied only at primary control points, not control points with synthesized flows. (*ADJINC* = −4)

Option 5: The simulation algorithms for Tasks 1 and 4 in Table 7.1 are modified as discussed later for option 5. Whereas options 2, 3, and 4 involve computation of an array of flow adjustments, there are no negative incremental flow adjustments with option 5.

Option 6: Option 6 is same as option 4 except the downstream control points used in selecting the minimum flow from the *CPFLOW* array are limited to sites of senior rights that appropriate stream flow which excludes types 3, 4, and 6 defined by *WR* record field 6.

Option 7: Option 7 is same as option 1 except the downstream control points used in selecting the minimum flow from the *CPFLOW* array are limited to sites of senior rights that appropriate stream flow which excludes types 3, 4, and 6 defined by *WR* record field 6.

Option 8: Option 8 ignores all downstream control points. The *CPFLOW* array flow at the control point of the water right is assumed to be the flow available to the water right.

Negative incremental naturalized flows are discussed and the *ADJINC* options are described in detail in Chapter 3 of the *Reference Manual*. The *ADJINC* options discussed further in the *Daily Manual* from the perspective of a *SIMD* daily simulation. *ADJINC* options 2, 3, and 4 were developed in conjunction with early versions of WRAP and focus on negative incremental flow adjustments. Option 5 was added during about 1999 with a somewhat difference conceptual basis. Options 6, 7, and 8 were added during January-March 2011 along with with development of *SIMD* daily capabilities but are also applicable for a *SIM* monthly simulation.

Any of the *ADJINC* options can be adopted in *SIM* or *SIMD* monthly or *SIMD* daily simulations, except option 5 is not allowed in a daily simulation. Option 5 has been commonly used for monthly simulations. Option 4 has been the recommended standard for a monthly simulation. The new option 6 yields identically the same simulation results as option 4, but the computer runtime is reduced. Option 7 is recommended whenever routing is adopted, which is typically the case in a daily simulation. Option 1 restricts the flow amount available to water rights more than option 6 but is also applicable with routing. Options 2, 3, −3, and −4 have been seldom if ever used.

Option 1 considers all downstream control points in selecting the minimum flow quantity from the *CPFLOW* array and applies no incremental flow adjustments. Option 1 constrains the amount of stream flow available to water rights more severely than the other seven options and thus represents the most conservative (most restricting) extreme.

Without routing and forecasting, option 4 or 6 is the standard recommended option for a daily simulation as well as a monthly simulation. Since the negative incremental flows are defined in either *SIM* or *SIMD* by concurrent upstream and downstream flows in the same time step, options 4 and 6 are generally not applicable for a *SIMD* daily simulation that includes routing. As explained in Chapter 3 of the *Reference Manual*, option 6 involves a flow adjustment defined as the minimum amount of flow that must be added to the naturalized flow at a control point to alleviate all negative incrementals. *SIMD* computes and applies negative incremental flow adjustments for a daily time step in the same manner as the monthly *SIM*. *SIMD* first determines daily naturalized flows at all control points and then computes daily negative incremental flow adjustments. *SIMD* applies daily negative incremental flow adjustments in the same manner that *SIM* applies monthly adjustments. In determining stream flow available for *WR* record water rights and filling *FR* record flood control reservoir storage at a particular control point, the adjustment amounts are added to control point flows at downstream control points but not at the control point of the water right.

Option 5 is a modified version of the algorithms for Tasks 1 and 4 in Table 7.1. Incremental flows are not computed, and there is no negative flow adjustment array developed prior to the simulation like in options 2, 3, and 4. Option 5 is the only option that includes a modification to Task 4 of Table 7.1. The other options are reflected only in Task 1. Option 5 consists of the following components.

- In Task 1 described in Table 7.1, *CPFLOW* array flows at downstream control points are considered only at control points of senior rights. Furthermore, no control points located downstream of a discontinuity of flow (control point with zero flow) are considered regardless of senior rights. If a zero flow occurs in the *CPFLOW* array at a control point, regardless of whether a senior right is located at the zero-flow control point, no other control points located downstream are considered.
- In Task 4 described in Table 7.1, option 5 limits the flow adjustment to not exceed the minimum of the regulated flows at any of the intermediate control points between the current upstream water right being simulated and downstream senior rights. The Task 4 adjustments stop if a control point with zero regulated flow is encountered.

Option 7 is designed to be the standard *ADJINC* option to be adopted whenever routing and forecasting are employed, but can also be used in a monthly or daily simulation without routing and forecasting. The downstream control points identified in the *SIMD* reverse routing are further constrained to only those control points at which relevant senior rights are located. Flows at downstream control points not affected by senior rights have no effect on water availability for the junior right. Therefore, negative incremental flows at a downstream control point affect the amount of flow available to a particular water right only if senior rights also reduce the flows at the downstream control point. Option 7 is option 1 with the limitation to senior right control points added. Option 7 is similar to option 6 without the option 6 flow adjustments.

Options 6 and 4 should always yield the same simulation results though option 4 is more conservative in assuring that flow cannot be over-appropriated. Whereas option 4 considers all downstream control points in searching for the constraining site, option 6 limits consideration to only control points at which senior rights are located. However, the control points with senior rights should be the constraining sites. Option 6 also includes other features to reduce computer runtime.

Option 8 ignores downstream control points in Task 1 of Table 7.1. Thus, junior water rights can erroneously appropriate stream flow that has already been appropriated by senior rights. This *double-taking* of the same water introduces errors in the simulation. Thus, option 8 should normally not be adopted except for experimentation. Option 8 is designed for experimentation. The effects of junior rights not passing inflows to protect downstream senior rights can be explored.

With the water rights priority system, water rights must pass stream flows as necessary to meet the requirements of senior rights located downstream. The *SIM/SIMD* simulation strategy outlined in Table 7.1 is designed to protect senior water rights from having their water taken by junior water rights located upstream. The *SIMD* daily simulation with routing is more complicated in this regard than the *SIM* monthly simulation since senior rights must be protected from the actions of junior rights occurring in preceding days as well as in the current day. Incremental naturalized flows representing net inflows less outflows in the stream reaches between control points are not directly incorporated in the simulation computations, except as negative incremental flow adjustments for certain *ADJINC* options. However, the concept of negative increment naturalized flows is an important issue for both *SIM* monthly and *SIMD* daily simulations. The ten *ADJINC* options differ in the degree to which they penalize or do not penalize water rights for the effects of downstream negative incremental naturalized flows.

Negative Incremental Naturalized Monthly Flow Volumes

Negative incremental characteristics of the Brazos WAM naturalized flows are investigated here prior to the comparative assessment of *SIM* simulation results with alternative *ADJINC* options presented later in this chapter. Negative incremental flows are numerous for the Brazos WAM with its 3,842 control points and 696-month 1940-1997 hydrologic period-of-analysis. Negative incremental naturalized monthly flow volumes occur in many months at many control points.

Unlike the *ADJINC* options, *JD* record *NEGINC* options do not affect simulation results but rather simply record selected information in the message file. Negative incremental flows may be defined looking downstream, as with *ADJINC* option 2 and *NEGINC* option 2, or looking upstream, as with *ADJINC* options 3 and 4 and *NEGINC* options 3, 4, and 5. The default *NEGINC* option 1 writes nothing. *NEGINC* options 2 and 3, which date back to early versions of the model, list in the message file all of the negative flow adjustments for each month at all control points.

The new *NEGINC* options 4 and 5 were added in conjunction with the study reported here. Option 5 lists all control points that have one or more negative incremental flows along with the number of negative incremental flows as well as the option 4 summary table. Option 4 provides just a summary table. Summary statistics are provided by *NEGINC* options 4 and 5 for flow adjustments defined looking upstream as applied in *ADJINC* options 3 and 4. The flow adjustments are defined as the minimum additional monthly volume that must be added at each control point to remove all negative incrementals in the set of all naturalized flows at all control points.

The *NEGINC* option 4 summary table for the Brazos WAM is reproduced as Table 7.2. Negative incremental flows occur in one or more of the 696 months of the simulation at 1,163 of the 3,842 control points. With 696 months of flows at 3,842 control points, there are 2,674,032 naturalized flows which have an average volume of 49,756 acre-feet/month. Negative incrementals are reflected in 555,838 of the 2,674,032 naturalized flows. The monthly flow adjustments required to remove the 555,838 negative incrementals average 121,863 acre-feet, with a maximum of 7,108,469 acre-feet. 253,110 of the 555,838 *ADJINC* option 3 or 4 flow adjustments are 10,000 acre-feet or greater. The number of months in which negative incrementals occur averages 478 months for the 1,163 control points with one or more negative incrementals. Thirty-seven of the control points have negative incremental flows in all 696 months of the 1940-1997 simulation. 526 control points have negative incremental flows in 90 percent or more of the 696 months.

Table 7.2
NEGINC Option 4 Negative Incremental Naturalized Flow Summary

Negative Incremental Flow Summary for NEGINC Option 4 and 5

Number of months in simulation:	696
Total number of control points:	3,842
Control points with negative incrementals:	1,163
Total number of naturalized flows:	2,674,032
Mean of 2,674,032 naturalized flows:	49,756.3
Negative incrementals of 0.0001 or more:	555,838
Negative incrementals of 1.0 or greater:	542,931
Negative incrementals of 10 or greater:	514,104
Negative incrementals of 100 or greater:	459,756
Negative incrementals of 10,000 or more:	253,110
Mean of negative incremental flows:	121,862.6
Maximum negative incremental volume:	7,108,469.0

Control points with negative incrementals in all months of the simulation: 37
Control points with negative incrementals in 90% or more of the months: 526

Table 7.3
Negative Incremental Naturalized Flow Summary for the *Fundamentals Manual* Example

Negative Incremental Flow Summary for NEGINC Options 4 and 5

Number of months in simulation:	696
Total number of control points:	11
Control points with negative incrementals:	7
Total number of naturalized flows:	7,656
Mean of 7656 naturalized flows:	139,284.7
Negative incrementals of 0.0001 or more:	500
Negative incrementals of 1.0 or greater:	500
Negative incrementals of 10 or greater:	498
Negative incrementals of 100 or greater:	491
Negative incrementals of 10,000 or more:	153
Mean of negative incremental flows:	14,509.5
Maximum negative incremental volume:	289,017.0

NEGINC Option 5 Listing of Control Points with Number of Negative Incrementals of 0.0001 or Greater

Whit	58
WacoG	141
High	95
Grang	12
Camer	7
Bryan	126
Hemp	61

The Brazos WAM dataset includes many more control points than are necessary. Multiple control points are included in the dataset that represent the same reservoir or site on a river. For example, separate control points are assigned to various diversion rights and storage rights at the same reservoir. These control points representing the same or closely spaced control points result in many incremental flows. Artificial or *dummy* control points created to model complex water right situations also result in extra control points causing large negative incremental naturalized flows.

Negative Incremental Flows for the Example in the Fundamentals Manual

The *Fundamentals Manual* uses a simplified example based on the Brazos WAM which is further expanded to create several examples in the *Daily Manual*. The naturalized flows in the FLO input file for the example in the *Fundamentals Manual* consists of 1940-1997 monthly naturalized flows from the Brazos WAM dataset for the eleven control points shown in Figure 7.1 that include sites of six reservoirs and five USGS gaging stations. The dataset of naturalized flows at 11 control points in the *Fundamentals Manual* example is a subset of the naturalized flows at 77 primary control points included in the FLO input file of the Brazos WAM dataset. The negative incremental flows generated by the 11 control point dataset are much different than the naturalized flows generated by the Brazos WAM dataset with its 77 primary control points and 3,765 secondary control points. The *NEGINC* option 5 summary table for the example in the *Fundamental Manual* is reproduced as Table 7.3.

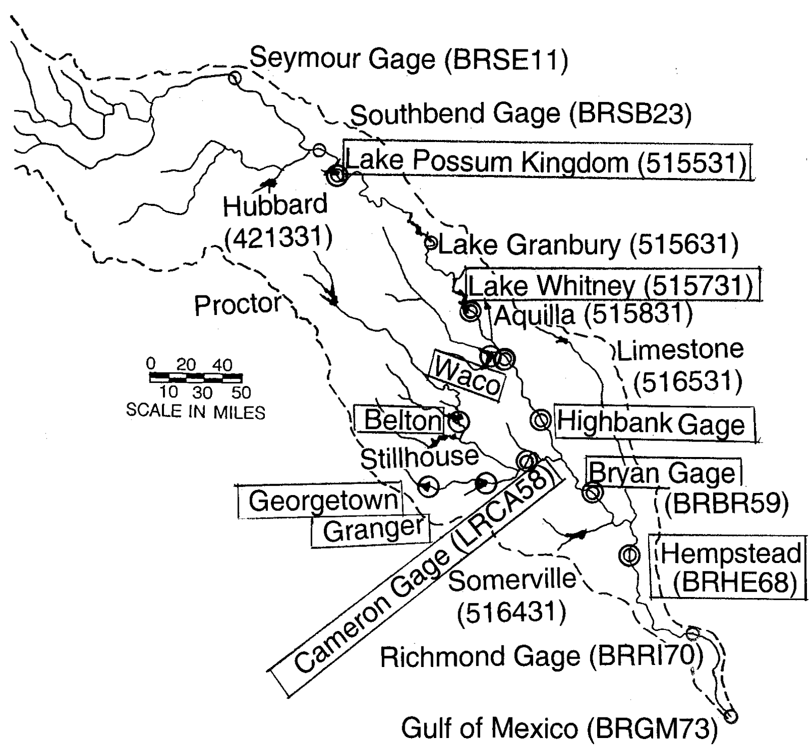

Figure 7.1 Brazos WAM Control Points in *Fundamentals Manual* Example

The 11 control points in the *Fundamentals Manual* include four gaging stations on the Brazos River at Hempstead, Bryan, Highbank, and Waco, the gaging station on the Little River at Cameron, and Lakes Possum Kingdom, Whitney, Waco, Belton, Georgetown, and Granger. There are no control points located upstream of the Possum Kingdom, Waco, Belton, and Georgetown control points, and thus no incremental flows and no negative incremental flows. Negative incremental flows occur at the seven other control points. Table 7.3 indicates that the largest number of negative incrementals is the 141 months of negative incrementals at the Waco gage on the Brazos River. With 696 months of flows at each of 11 control points, there is a total of 7,656 naturalized flows of which 500 reflect negative incrementals. 153 of the negative incrementals are of magnitude 10,000 acre-feet/month or larger, with the largest being 289,017 acre-feet/month.

Reasons for Negative Incremental Naturalized Flows

In general, flow rates tend to increase with increases in watershed area and tributary inflows as a stream flows downstream. However, flow at a downstream site may be less than concurrent upstream flow in the same period. In the monthly *SIM* simulation, the term negative incremental flow refers to a situation with upstream flow exceeding concurrent downstream flow in the same month. Reasons for negative incremental flows include the following.

1. Timing effects of runoff from a rainfall event reaching an upstream control point late in a particular month but reaching a downstream control point during the next month.
2. Permanent channel losses over and above those modeled with the channel loss coefficients included in the input dataset and associated *SIM* computational routines.
3. Channel losses over and above those modeled in *SIM* where bank storage or underflow may reenter the stream at a downstream location and/or during a future time period.
4. Inaccuracies and impreciseness in stream flow measurements and in the computations performed to convert gaged flows to naturalized flows.
5. Modeling peculiarities in creating and assigning control points and flows in the *SIM* input dataset such as multiple control points at the same physical location or artificial or dummy control points that are not necessarily representing a specific location.

The combination of factors and relative extent to which each factor contributes to causing naturalized flows to have negative incrementals may vary between months and between control points. The uncertainties associated with the factors listed above are inherent in the model even if all incremental flows are positive. Negative incremental flows result in the effects being more evident. Without negative incrementals, simulation results are not affected by which *ADJINC* option is adopted. With negative incrementals, the choice of *ADJINC* option affects simulation results.

All of the causative factors noted above are probably reflected to some extent in the negative incremental flows in the Brazos WAM in some months at some control points. However, modeling peculiarities (fifth factor listed above) in the input dataset is a key factor. The 526 control points in the Brazos WAM with negative incremental flows in 90 percent or more of the 696 months of the simulation reflect multiple control points at the same site and dummy control points.

The eleven Brazos WAM control points included in the *Fundamental Manual* example represent specific locations at or near USGS gaging stations. Unlike the full Brazos WAM, there are no modeling peculiarities in this simplified example dataset. The negative incrementals in the *Fundamental Manual* example appear to be due largely to timing effects (first factor listed above).

<u>Simulation Results with the Ten Alternative *ADJINC* Options</u>

The effects of the alternative *ADJINC* options on simulation results are explored in Chapter 7 from the perspective of monthly *SIM* simulations. However, this Chapter 7 investigation is also relevant to understanding the *ADJINC* option aspects of the *SIMD* daily simulation study presented in Chapters 8, 9, and 10. The Brazos WAM authorized use scenario dataset with a 1940-1997 hydrologic period-of-analysis is adopted for the simulation study summarized by the remainder of this chapter. The TCEQ Brazos WAM datasets adopt *ADJINC* option 5. The remainder of this chapter explores the ten alternative *ADJINC* options. Results from ten *SIM* simulations with the Brazos WAM authorized use dataset with a 1940-1997 period-of-analysis are presented. The only difference between the ten simulations is the *ADJINC* option selected in *JD* record field 8.

<u>*Computer Execution Times*</u>

Computer run times, in minutes and seconds, for *SIM* executions are recorded in Table 7.4 for two sets of ten simulations. These times are from the start and end times recorded in the *SIM* message file. The only difference between the two sets of simulations is the amount of output data recorded in the simulation results OUT and message MSS output files.

- The first set of ten simulations of Table 7.4 included writing simulation results in the output OUT file for all 3,842 control points, 1,765 *WR* and *IF* record water rights, and 678 reservoirs. *ICHECK* option 1 error and warning checks were performed with corresponding messages written to the message MSS file.
- The second set of ten simulations of Table 7.4 included recording no simulation results in the output OUT file. *ICHECK* was switched to zero, minimizing warning and error checks and messages recorded in the MSS file.

The Brazos WAM dataset is large, and the dual simulation option is activated meaning the entire simulation is performed twice. The simulations were performed on an older desktop computer. Thus, these execution times are relatively large for a monthly *SIM* simulation.

Table 7.4 shows that the amount of simulation results written to the output file greatly affects the execution time of a *SIM* simulation. The difference in runtime with no output is much less than with maximum levels of output recorded in the OUT file. Table 7.4 also shows significant differences in execution times with the ten alternative *ADJINC* options activated. Table 7.4 provides insight regarding the extent of the computations associated with the *ADJINC* options. For example, with no output written to the OUT file, the *SIM* simulation runs 44 seconds with option 5 compared to one minute and 25 seconds with option 4, and 52 seconds with option 7.

Table 7.4
Execution Times for *SIM* Simulations (minutes:seconds)

ADJINC Options									
1	2	−3	3	−4	4	5	6	7	8
3:25	4:20	5:34	3:32	5:34	3:35	2:14	3:09	2:49	2:50
1:15	2:11	3:25	1:24	3:25	1:25	0:44	1:09	0:52	1:01

Simulation Results Summaries

The basin summaries in Table 7.5 are developed with program *TABLES* from the results of the ten *SIM* simulations. The naturalized and unappropriated stream flows in 2SBA record basin summary tables represent the maximum flow at any control point in a given month, based on comparing all control points. All other quantities are the sum of the values at all control points. Mean annual flows are in units of acre-feet/year, and mean end-of-month reservoir storage contents are in acre-feet. Volume reliabilities in percent [R_V=(target/actual diversion)100%] are added as the last line of Table 7.5. The *ADJINC* option 5 basin summary in Table 7.5 corresponds to the basin summary in Table 6.3 for the authorized use scenario and 1940-1997 hydrologic period-of-analysis.

Table 7.5
Basin Summaries from 2SBA Tables
(Mean annual flows are in acre-feet/year, and storage volumes are in acre-feet.)

ADJINC Option	1	2	−3	3	−4
naturalized flow	7,735,888	6,210,782	7,788,434	10,488,288	7,735,888
return flow	99,592	99,593	99,489	107,773	99,583
stream flow depletion	2,350,131	2,350,191	2,384,464	2,664,910	2,383,783
unappropriated flow	4,387,398	4,387,404	4,531,511	8,486,713	4,376,213
end-of-month storage	3,115,274	3,115,513	3,122,705	3,618,069	3,120,102
net evaporation	351,377	351,393	351,630	413,099	351,328
diversion target	2,491,699	2,491,690	2,491,301	2,449,070	2,491,679
Diversion	2,016,891	2,016,935	2,050,849	2,264,494	2,050,468
diversion shortage	474,808	474,754	440,452	184,576	441,212
volume reliability (%)	80.94%	80.95%	82.32%	92.46%	82.29%

ADJINC Option	4	5	6	7	8
naturalized flow	7,735,888	7,735,888	7,735,888	7,735,888	7,735,888
return flow	102,305	99,889	102,305	99,781	107,201
stream flow depletion	2,608,251	2,590,734	2,608,251	2,559,510	2,701,886
unappropriated flow	4,465,180	5,545,604	4,465,180	4,437,015	6,805,851
end-of-month storage	3,488,539	3,446,850	3,488,539	3,386,375	3,670,238
net evaporation	406,959	397,396	406,959	387,540	430,878
diversion target	2,450,824	2,452,789	2,450,824	2,455,259	2,444,369
Diversion	2,214,363	2,207,638	2,214,363	2,186,959	2,282,558
diversion shortage	236,462	245,152	236,462	268,300	161,810
volume reliability (%)	90.35%	90.01	90.35%	89.07	93.38%

The mean annual naturalized stream flows in Table 7.5 represent the summation for all months of the maximum naturalized flow at any control point in each month determined based on comparing all control points. The monthly naturalized flows reflected in the mean annual naturalized flow totals in Table 7.5 occur often but not always at the basin outlet. The 1940-1997 Brazos River Basin mean annual naturalized flow volume in Table 7.5 is 7,735,888 acre-feet/year with either of the *NEGINC* options except options 2, −3, and 3 which adjust the naturalized flows at the beginning of the *SIM* execution prior to the simulation. As previously noted, *ADJINC* options 2 and 3 are based on defining negative incremental flows looking downstream and upstream, respectively. With option 3, the basin total mean annual naturalized flows are 10,488,288 acre-feet/year which is 135% of the 7,735,888 acre-feet/year mean without adjustments for negative incrementals. Thus, negative incrementals are quite substantial on a total basin basis. The means of negative incremental flows are a much greater percentage of the means of naturalized flows at many of the individual control points located throughout the basin.

Basinwide simulation results over the 1940-1997 hydrologic period-of-analysis can also be viewed in terms of reservoir storage. *TABLES 2FRE* frequency statistics in Table 7.6 are for the *SIM* simulated total end-of-month storage contents of the 13 reservoirs included in Figure 6.1 and Table 6.2. These reservoirs have a total conservation capacity of 3,333,361 acre-feet which is 71 percent of the total capacity of the 678 reservoirs in the Bwam3 dataset. The storage-frequency statistics for the simulation with *ADJINC* option 5 are included in both Tables 6.4 and 7.6.

<u>Frequency and Reliability Tables for ADJINC Options 4, 5, 6, and 7</u>

A *TABLES* 2FRE frequency table for naturalized flows at 20 control points is presented as Table 6.5 in Chapter 6. Plots of naturalized flow at four control points are provided in Chapter 2 as Figures 2.4, 2.5, 2.6 and 2.7. Naturalized flows are the same in both the Bwam3 and Bwam8 datasets. With the exception of options 2, −3, and 3 which adjust naturalized flows at the beginning of the simulation, the naturalized flows are the same regardless of the *ADJINC* option selected for a simulation.

Tables 7.7, 7.8, and 7.9 were developed with *TABLES* 2FRE and 2REL records from *SIM* simulations with *ADJINC* options 4 or 7, 5, and 6, respectively. Since simulation results are the same for options 4 and 6, Table 7.7 applies to both options 4 and 6. The frequency and reliability tables for the *SIM* simulation with *ADJINC* option 5 presented as Table 7.8 are also included in Chapter 6 as Table 6.6.

Although *ADJINC* option 4 has been selected in earlier version of the official Brazos WAM, the September 2008 version uses *ADJINC* option 5. Thus, the SIM simulation results presented earlier in Tables 6.3-6.7 and Figures 6.2-6.27 reflect *ADJINC* option 5.

The flow frequency tables include the 20 control points listed in Table 6.2 and shown in Figure 6.1. The control points of the 13 reservoirs are included in the storage frequency and diversion reliability tables. The aggregate of all diversions at the 13 control points represent the BRA water rights described in Tables 2.10 and 2.11.

The daily *SIMD* simulations of Chapters 8, 9, and 10 are based on *ADJINC* option 6. The daily simulation results can be compared with the option 7 monthly results of Table 7.9.

Table 7.6
Frequency Statistics for Total Storage Volume (acre-feet) in 13 Reservoirs

ADJINC Option	1	2	−3	3	−4
Mean	2,587,277	2,587,441	2,589,521	2,898,061	2,587,434
Standard Deviation	548,731	548,709	547,118	318,739	548,728
Minimum	776,042	776,043	778,356	1,722,080	775,988
99%	973,210	973,210	978,585	1,890,540	973,138
98%	1,044,254	1,044,253	1,050,692	1,984,457	1,044,292
95%	1,346,240	1,346,212	1,356,003	2,225,363	1,346,182
90%	1,757,593	1,757,591	1,761,368	2,471,850	1,757,550
85%	2,148,214	2,148,101	2,152,309	2,589,961	2,148,932
80%	2,236,795	2,236,792	2,237,891	2,669,723	2,236,840
75%	2,327,597	2,327,595	2,341,417	2,735,789	2,327,582
70%	2,437,747	2,437,905	2,438,209	2,797,155	2,437,813
60%	2,620,511	2,621,297	2,623,239	2,898,116	2,620,490
50%	2,731,282	2,731,245	2,733,047	2,972,962	2,732,903
40%	2,823,241	2,823,241	2,823,963	3,030,161	2,823,255
30%	2,933,905	2,933,761	2,935,165	3,080,955	2,934,711
25%	2,986,506	2,986,194	2,987,252	3,117,953	2,986,526
20%	3,028,024	3,028,128	3,028,063	3,159,333	3,028,058
15%	3,067,141	3,067,158	3,067,149	3,199,313	3,067,184
10%	3,134,764	3,134,774	3,134,979	3,250,390	3,134,753
5%	3,246,159	3,246,189	3,246,733	3,296,334	3,246,166
1%	3,320,771	3,320,772	3,320,777	3,332,798	3,320,773
Maximum	3,333,349	3,333,348	3,333,349	3,333,361	3,333,348

ADJINC Option	4	5	6	7	8
Mean	2,786,551	2,777,001	2,786,551	2,759,398	2,886,459
Standard Deviation	440,930	437,280	440,930	451,081	355,712
Minimum	1,318,165	1,256,266	1,318,165	1,208,330	1,611,808
99%	1,409,559	1,370,180	1,409,559	1,303,566	1,719,401
98%	1,535,413	1,480,920	1,535,413	1,437,321	1,830,186
95%	1,830,647	1,802,142	1,830,647	1,752,641	2,107,685
90%	2,164,058	2,196,914	2,164,058	2,165,437	2,404,914
85%	2,352,811	2,354,474	2,352,811	2,339,524	2,547,117
80%	2,486,469	2,505,448	2,486,469	2,477,074	2,644,525
75%	2,591,134	2,598,783	2,591,134	2,574,365	2,735,630
70%	2,668,894	2,682,814	2,668,894	2,658,565	2,791,217
60%	2,821,138	2,808,930	2,821,138	2,790,903	2,894,655
50%	2,909,241	2,889,989	2,909,241	2,876,085	2,983,263
40%	2,989,132	2,970,278	2,989,132	2,963,722	3,045,662
30%	3,054,568	3,050,239	3,054,568	3,033,418	3,105,348
25%	3,106,156	3,085,253	3,106,156	3,077,727	3,141,245
20%	3,138,609	3,110,509	3,138,609	3,104,693	3,171,230
15%	3,176,613	3,163,485	3,176,613	3,156,113	3,217,432
10%	3,240,816	3,223,741	3,240,816	3,222,177	3,254,075
5%	3,288,052	3,284,360	3,288,052	3,284,359	3,295,690
1%	3,332,096	3,332,029	3,332,096	3,332,001	3,332,796
Maximum	3,333,348	3,333,349	3,333,348	3,333,348	3,333,361

Table 7.7
Frequency and Reliability Tables with *ADJINC* Options 4 and 6

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRSE11	19276.7	40280.	0.0	0.0	28.0	216.1	546.5	1613.3	2945.	4539.	7405.	16860.	51049.	406951.
BRSB23	45116.9	100873.	0.0	0.0	0.0	322.6	1580.2	3866.8	7928.	11719.	19000.	40071.	115983.	1216770.
LRCA58	82940.7	158828.	0.0	5.5	570.0	1189.9	1229.8	4009.7	11105.	17633.	30417.	86682.	236627.	1399448.
BRBR59	244094.5	438608.	0.0	0.0	1248.7	5463.0	9621.5	24289.0	42427.	71037.	111249.	263948.	656606.	4301495.
BRHE68	341097.4	537145.	0.0	7809.4	9553.8	14834.7	21998.3	46765.9	77207.	116411.	180788.	434946.	958948.	5236141.
BRRI70	372070.1	565488.	0.0	10482.2	14122.6	20314.9	28301.3	53914.7	84381.	133546.	219903.	461447.	1041647.	5633054.
BRGM73	341526.2	584486.	0.0	0.0	0.0	0.0	0.0	2461.5	36869.	85479.	173384.	450712.	1013601.	5689008.
421331	1765.2	7964.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	642.	3156.	150934.
515531	32457.3	111939.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	10993.	81423.	1599164.
515631	49124.2	151550.	0.0	0.0	0.0	0.0	0.0	0.0	0.	1454.	5723.	28433.	133780.	2450764.
515731	64237.5	173295.	0.0	0.0	0.0	0.0	0.0	1681.4	4748.	9206.	15772.	42358.	170255.	2728846.
515831	4409.4	10931.	27.8	27.8	27.8	29.8	29.8	30.8	31.	31.	31.	2245.	15453.	100103.
509431	20826.7	50722.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	1195.	15956.	68509.	529226.
516531	11344.5	27698.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	2764.	45576.	215300.
515931	8450.2	26941.	0.0	0.0	0.0	0.0	0.0	0.0	0.	37.	396.	3137.	21842.	320839.
516031	27991.3	69704.	0.0	0.0	0.0	0.0	0.0	0.0	187.	1498.	2981.	20497.	83931.	549161.
516131	12327.7	31839.	0.0	0.0	0.0	0.0	0.0	0.0	0.	222.	1039.	7661.	39269.	305240.
516231	3513.9	7909.	0.0	0.0	0.0	0.0	0.0	0.0	0.	150.	488.	2699.	12223.	73211.
516331	11948.4	23648.	0.0	0.0	0.0	0.0	0.0	0.0	611.	1730.	3869.	12464.	39255.	208215.
516431	13203.3	30339.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7106.	52326.	247496.

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRSE11	9529.5	34781.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	23250.	406951.
BRSB23	22242.5	90474.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	47035.	1215727.
LRCA58	66799.9	153109.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	2921.	63569.	205292.	1392117.
BRBR59	182953.9	415430.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	19754.	189894.	564398.	4243696.
BRHE68	224277.6	481542.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2000.	35979.	231199.	746387.	4963217.
BRRI70	282052.4	529459.	0.0	0.0	0.0	0.0	0.0	0.0	1039.	36245.	105383.	365343.	894380.	5304621.
BRGM73	341526.2	584486.	0.0	0.0	0.0	0.0	0.0	2461.5	36869.	85479.	173384.	450712.	1013601.	5689008.
421331	791.7	7258.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	150934.
515531	24238.1	103197.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	49440.	1599164.
515631	39762.4	145981.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7575.	103879.	2450764.
515731	52677.1	170810.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	18913.	156665.	2728846.
515831	4031.3	10907.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	365.	15014.	100072.
509431	19737.2	50944.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	10320.	68509.	529226.
516531	10843.2	27300.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	701.	43874.	215300.
515931	6616.4	25522.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	12384.	259583.
516031	25499.1	69409.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7041.	81885.	549161.
516131	11456.8	31701.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1462.	39269.	305240.
516231	3222.5	7907.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1551.	11938.	73211.
516331	10794.5	23914.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	10993.	38739.	208215.
516431	12894.0	30273.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	6198.	52326.	247496.

Table 7.7 (Continued)
Frequency and Reliability Tables with *ADJINC* Options 4 and 6

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
421331	122429.	100512.	0.	0.	0.	0.	0.	37035.	75435.	99357.	134373.	196911.	288305.	317750.
515531	668900.	74978.	271009.	342493.	472525.	530473.	571645.	637247.	679602.	697424.	713905.	724739.	724739.	724739.
515631	136235.	25563.	30631.	46554.	59945.	79936.	102904.	126190.	140340.	147316.	155000.	155000.	155000.	155000.
515731	593202.	54977.	366468.	379891.	410324.	472914.	517743.	578233.	601339.	610734.	621917.	635185.	636100.	636100.
515831	44579.	9682.	2011.	9034.	14788.	22103.	33203.	40452.	45197.	47339.	49886.	52400.	52400.	52400.
509431	179641.	32301.	63246.	74191.	86419.	109288.	132372.	165062.	182368.	191120.	200043.	205766.	206146.	206561.
516531	186786.	46721.	19773.	31734.	43996.	78038.	121425.	171559.	190030.	201445.	211766.	225400.	225400.	225400.
515931	47931.	13163.	2993.	8897.	11370.	18961.	28032.	41725.	47551.	52109.	56101.	59400.	59400.	59400.
516031	397450.	84760.	91488.	113204.	125201.	183613.	263842.	380235.	412035.	430234.	446259.	457600.	457600.	457600.
516131	191992.	63789.	0.	0.	4329.	22162.	74014.	181269.	209389.	219386.	228262.	235700.	235700.	235700.
516231	29736.	9550.	0.	0.	114.	7351.	16070.	25232.	31286.	33653.	35676.	37100.	37100.	37100.
516331	55843.	14300.	0.	4507.	10558.	23372.	35121.	51387.	58420.	62444.	65500.	65500.	65500.	65500.
516431	131827.	35010.	0.	11259.	35492.	59650.	76495.	116463.	136297.	145590.	152028.	160110.	160110.	160110.
Total	2786551.	440930.	1318165.	1409559.	1535413.	1830646.	2164058.	2591134.	2821138.	2909240.	2989132.	3106156.	3240816.	3333348.

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	VOLUME (%)	+++++++++ PERCENTAGE OF MONTHS +++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS ---------- 100%	98%	95%	90%	75%	50%	1%
421331	56000.0	5871.98	87.64	89.51	87.6	87.8	87.8	88.4	88.8	89.8	91.4	74.1	74.1	74.1	79.3	87.9	89.7	100.0
515531	230750.0	0.02	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18886.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	80371.8	302.04	98.56	99.62	98.6	98.6	98.6	98.6	100.0	100.0	100.0	96.6	96.6	96.6	98.3	100.0	100.0	100.0
516531	65074.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	19658.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	112257.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	438.04	98.85	99.35	98.9	99.0	99.1	99.3	99.3	99.3	99.6	93.1	94.8	94.8	96.6	100.0	100.0	100.0
516231	13610.0	237.10	97.99	98.26	98.0	98.1	98.1	98.1	98.3	98.3	98.4	94.8	94.8	94.8	94.8	98.3	98.3	100.0
516331	19840.0	66.35	99.43	99.67	99.4	99.4	99.4	99.6	99.6	99.6	99.6	96.6	96.6	96.6	98.3	100.0	100.0	100.0
516431	48000.0	51.99	99.71	99.89	99.7	99.7	99.7	99.7	99.9	99.9	100.0	98.3	98.3	98.3	100.0	100.0	100.0	100.0
Total	810823.1	6967.54		99.14														

<u>Control Points</u>

BRSE11	Seymour Gage on Brazos River
BRSB23	Southbend Gage on Brazos River
LRCA58	Cameron Gage on Little River
BRBR59	Bryan Gage on Brazos River
BRHE68	Hempstead Gage on Brazos
BRRI70	Richmond Gage on Brazos River
BRGM73	Brazos Outlet at Gulf of Mexico
421331	Hubbard Creek Reservoir
515531	Possum Kingdom Reservoir
515631	Granbury Reservoir
515731	Whitney Reservoir
515831	Aquilla Reservoir
509431	Waco Reservoir
516531	Limestone Reservoir
515931	Proctor Reservoir
516031	Belton Reservoir
516131	Stillhouse Hollow Res.
516231	Georgetown Reservoir
516331	Granger Reservoir
516431	Somerville Reservoir

Table 7.8
Frequency and Reliability Tables with *ADJINC* Option 5

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
			100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRSE11	19438.1	40217.	0.0	0.0	28.2	224.7	587.5	1680.4	2998.	4812.	7904.	17278.	51071.	408040.
BRSB23	45868.7	100430.	0.0	31.8	82.5	541.7	1768.0	4500.5	8812.	12714.	20182.	41706.	113693.	1217333.
LRCA58	83222.6	157642.	0.0	85.5	579.4	1190.1	1260.8	5832.4	12459.	18935.	31839.	87682.	235472.	1399450.
BRBR59	256140.5	437586.	284.6	3277.2	5624.8	9756.4	14565.8	30415.3	55396.	81896.	129194.	285334.	658089.	4221430.
BRHE68	353138.3	534097.	1918.9	10965.6	13208.9	20946.0	27216.3	53875.9	85854.	130756.	197911.	442982.	959488.	5081234.
BRRI70	383849.2	562148.	306.6	13296.9	17713.9	27683.5	35325.9	61420.5	94907.	147048.	233610.	474542.	1043177.	5486716.
BRGM73	351369.8	581999.	0.0	0.0	0.1	0.4	1.9	8911.5	47701.	105094.	188987.	455947.	1049934.	5543116.
421331	2284.3	8610.	0.0	0.0	0.0	0.0	0.0	0.0	0.	6.	376.	1389.	4714.	150843.
515531	32066.0	111095.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	10995.	80923.	1594131.
515631	49696.1	150740.	0.0	0.0	0.0	0.0	0.0	2.7	1545.	3926.	7462.	28664.	138320.	2445679.
515731	76097.7	179597.	0.0	0.0	0.0	230.2	1603.0	4921.4	9600.	13754.	24284.	69167.	213926.	2722565.
515831	4409.5	10945.	27.8	27.8	27.8	29.8	29.8	30.8	31.	31.	31.	2347.	15453.	100103.
509431	20790.9	50780.	0.0	0.0	0.0	0.0	0.0	0.0	0.	43.	732.	15924.	68601.	529220.
516531	11352.1	27354.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	4420.	45229.	215300.
515931	8519.9	26634.	0.0	0.0	0.0	0.0	0.0	3.2	60.	267.	831.	3356.	21873.	316032.
516031	28048.2	68102.	0.0	0.0	0.0	0.0	463.0	1997.5	2672.	3186.	4002.	16874.	80844.	547284.
516131	12315.9	31856.	0.0	0.0	0.0	0.0	0.0	0.0	0.	145.	989.	7661.	39269.	302801.
516231	3513.6	7909.	0.0	0.0	0.0	0.0	0.0	0.0	0.	149.	464.	2707.	12223.	73211.
516331	11945.8	23657.	0.0	0.0	0.0	0.0	0.0	0.0	623.	1670.	3882.	12324.	38739.	208215.
516431	13218.3	30277.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7106.	52326.	247494.

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
			100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRSE11	10944.3	36337.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	849.	29447.	408040.
BRSB23	22895.3	87308.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	229.	57996.	1210603.
LRCA58	67368.4	152305.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	6311.	66984.	206394.	1392119.
BRBR59	190250.5	415452.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2404.	39466.	207403.	564431.	4163632.
BRHE68	231146.0	480003.	0.0	0.0	0.0	0.0	0.0	0.0	0.	9282.	52478.	262209.	763779.	4808310.
BRRI70	290053.4	527607.	0.0	0.0	0.0	0.0	0.0	0.0	8390.	51158.	124555.	374445.	914599.	5158283.
BRGM73	351369.8	581999.	0.0	0.0	0.1	0.4	1.9	8911.5	47701.	105094.	188987.	455947.	1049934.	5543116.
421331	745.9	7160.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	150843.
515531	25250.3	99200.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	66200.	1594131.
515631	42600.2	143394.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	16449.	127295.	2445679.
515731	59520.5	175424.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	32.	33062.	172990.	2722565.
515831	4042.5	10931.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	379.	15014.	100072.
509431	19931.3	50956.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	12647.	68567.	529220.
516531	10628.2	26851.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	374.	42099.	215300.
515931	6556.6	25518.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	12824.	274816.
516031	24634.2	67887.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	5052.	77271.	546730.
516131	11525.6	31703.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1932.	39269.	302801.
516231	3227.8	7880.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1695.	12124.	73211.
516331	10866.7	23876.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	11443.	37936.	208215.
516431	12833.1	30215.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	6203.	52326.	247494.

Table 7.8 (Continued)
Frequency and Reliability Tables with *ADJINC* Option 5

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
421331	109112.	101612.	0.	0.	0.	0.	0.	17864.	56306.	81915.	107867.	181809.	284991.	317750.
515531	668617.	75339.	269773.	341224.	471791.	525815.	570176.	637163.	679689.	697336.	713063.	724739.	724739.	724739.
515631	137376.	24940.	47383.	57132.	63444.	81949.	98357.	128033.	142679.	149634.	155000.	155000.	155000.	155000.
515731	609486.	36230.	449616.	465804.	506696.	528104.	556371.	598048.	616624.	624599.	631543.	636069.	636100.	636100.
515831	44477.	9747.	2101.	8567.	14295.	21449.	33209.	40306.	45084.	47181.	49751.	52400.	52400.	52400.
509431	180280.	32196.	63311.	74270.	86560.	109323.	132292.	166832.	182980.	191698.	200782.	206012.	206298.	206561.
516531	185777.	47944.	15880.	26577.	41128.	73743.	118487.	170405.	189288.	201282.	211861.	225400.	225400.	225400.
515931	47414.	13462.	1801.	8426.	9950.	18675.	27773.	41235.	46457.	51342.	55737.	59400.	59400.	59400.
516031	385149.	99289.	20722.	42474.	64956.	142858.	242322.	364109.	401778.	420980.	439201.	457600.	457600.	457600.
516131	192477.	63266.	0.	0.	7435.	24385.	76472.	180125.	209744.	220573.	228310.	235700.	235700.	235700.
516231	29662.	9696.	0.	0.	120.	7351.	15725.	25103.	31326.	33783.	36079.	37100.	37100.	37100.
516331	55876.	14494.	0.	3034.	9892.	23174.	35190.	51230.	58931.	63273.	65500.	65500.	65500.	65500.
516431	131299.	35645.	0.	10194.	32424.	58124.	75571.	115392.	136254.	144425.	151718.	160110.	160110.	160110.
Total	2777001.	437280.	1256266.	1370180.	1480920.	1802142.	2196914.	2598782.	2808930.	2889989.	2970278.	3085252.	3223740.	3333348.

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	VOLUME (%)	100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%
					+++++++++ PERCENTAGE OF MONTHS +++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING							---------- PERCENTAGE OF YEARS ---------- PERCENTAGE OF TARGET DIVERSION AMOUNT						
421331	56000.0	8804.43	82.76	84.28	82.8	83.0	83.0	83.5	84.2	84.5	85.1	69.0	69.0	70.7	70.7	77.6	84.5	98.3
515531	230750.0	0.02	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18945.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	80394.4	303.54	98.56	99.62	98.6	98.6	98.6	98.6	100.0	100.0	100.0	96.6	96.6	96.6	98.3	100.0	100.0	100.0
516531	65074.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	19658.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	112257.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	367.19	98.85	99.46	98.9	99.0	99.0	99.3	99.4	99.6	99.6	94.8	94.8	96.6	96.6	100.0	100.0	100.0
516231	13610.0	229.43	98.13	98.31	98.1	98.1	98.1	98.1	98.3	98.4	98.6	93.1	94.8	94.8	94.8	98.3	98.3	100.0
516331	19840.0	53.35	99.57	99.73	99.6	99.6	99.6	99.6	99.6	99.7	99.9	96.6	96.6	98.3	98.3	100.0	100.0	100.0
516431	48000.0	189.42	99.14	99.61	99.1	99.1	99.1	99.1	99.3	99.4	99.6	96.6	96.6	96.6	98.3	100.0	100.0	100.0
Total	810904.8	9947.39		98.77														

Control Points

BRSE11	Seymour Gage on Brazos River	515731	Whitney Reservoir
BRSB23	Southbend Gage on Brazos River	515831	Aquilla Reservoir
LRCA58	Cameron Gage on Little River	509431	Waco Reservoir
BRBR59	Bryan Gage on Brazos River	516531	Limestone Reservoir
BRHE68	Hempstead Gage on Brazos	515931	Proctor Reservoir
BRRI70	Richmond Gage on Brazos River	516031	Belton Reservoir
BRGM73	Brazos Outlet at Gulf of Mexico	516131	Stillhouse Hollow Res.
421331	Hubbard Creek Reservoir	516231	Georgetown Reservoir
515531	Possum Kingdom Reservoir	516331	Granger Reservoir
515631	Granbury Reservoir	516431	Somerville Reservoir

Table 7.9
Frequency and Reliability Tables with *ADJINC* Option 7

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
BRSE11	19869.8	41106.	0.0	0.0	51.8	265.9	618.3	1708.0	3038.	4855.	7931.	17278.	52174.	402288.
BRSB23	46264.5	100790.	0.0	34.6	104.5	639.8	1901.2	4519.6	8809.	12714.	20402.	42028.	114807.	1213901.
LRCA58	83224.6	157626.	0.0	85.5	626.4	1190.1	1260.8	5832.4	12543.	18923.	31839.	87682.	235472.	1399450.
BRBR59	254101.2	436040.	284.6	4225.3	5624.8	9756.4	14565.8	30248.6	54797.	80838.	127153.	281978.	658096.	4212604.
BRHE68	351067.0	532589.	1940.6	11130.8	13208.6	20946.0	27184.4	53730.3	85557.	130056.	197910.	442981.	947032.	5067959.
BRRI70	381820.4	560677.	299.4	13296.9	17713.6	27681.1	35140.2	61300.7	94421.	146871.	232073.	469628.	1042751.	5473725.
BRGM73	349444.9	580550.	0.0	0.0	0.1	0.4	1.8	8911.5	46163.	104743.	188762.	455938.	1023771.	5530442.
421331	2326.4	8625.	0.0	0.0	0.0	0.0	0.0	0.0	0.	26.	393.	1399.	4852.	150813.
515531	32450.5	111207.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	12671.	82318.	1590506.
515631	50443.7	151511.	0.0	0.0	0.0	0.0	0.0	0.0	1519.	4077.	8377.	26707.	138530.	2439763.
515731	73982.7	178418.	0.0	0.0	0.0	74.0	1412.3	4707.6	8997.	13349.	23694.	61645.	209064.	2715296.
515831	4409.5	10945.	27.8	27.8	27.8	29.8	29.8	30.8	31.	31.	31.	2347.	15453.	100103.
509431	20789.6	50770.	0.0	0.0	0.0	0.0	0.0	0.0	12.	53.	732.	15923.	68601.	529218.
516531	11356.3	27188.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	47.	4689.	45224.	215300.
515931	8520.5	26630.	0.0	0.0	0.0	0.0	0.0	3.4	63.	272.	831.	3356.	21873.	315934.
516031	28048.5	68081.	0.0	0.0	0.0	0.0	463.0	1997.5	2672.	3186.	4002.	16874.	80844.	547262.
516131	12315.9	31855.	0.0	0.0	0.0	0.0	0.0	0.0	0.	145.	989.	7661.	39269.	302801.
516231	3513.6	7909.	0.0	0.0	0.0	0.0	0.0	0.0	0.	149.	464.	2699.	12223.	73211.
516331	11946.0	23657.	0.0	0.0	0.0	0.0	0.0	0.0	624.	1611.	3930.	12324.	38739.	208215.
516431	13215.5	30270.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	3.	7106.	52326.	247435.

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
BRSE11	6922.6	28731.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	15782.	402288.
BRSB23	16071.1	78373.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	30755.	1207149.
LRCA58	67300.6	152271.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	6306.	66984.	206394.	1392119.
BRBR59	188454.9	413974.	0.0	0.0	0.0	0.0	0.0	0.0	0.	878.	37572.	197595.	560577.	4154806.
BRHE68	229322.2	478411.	0.0	0.0	0.0	0.0	0.0	0.0	0.	9275.	49466.	262183.	761575.	4795035.
BRRI70	288264.7	526005.	0.0	0.0	0.0	0.0	0.0	0.0	8368.	51158.	122803.	373235.	899494.	5145292.
BRGM73	349444.9	580550.	0.0	0.0	0.1	0.4	1.8	8911.5	46163.	104743.	188762.	455938.	1023771.	5530442.
421331	647.5	6884.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	150813.
515531	17923.3	90069.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	35878.	1590506.
515631	31494.4	132863.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	638.	73246.	2439763.
515731	57731.2	174196.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	30909.	164809.	2715296.
515831	4039.9	10931.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	365.	15014.	100072.
509431	19858.3	50902.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	12647.	68567.	529218.
516531	10539.5	26702.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	42099.	215300.
515931	6555.3	25514.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	12824.	274661.
516031	24630.0	67867.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	5052.	77271.	546708.
516131	11520.5	31703.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1932.	39269.	302801.
516231	3226.3	7880.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1695.	12124.	73211.
516331	10860.2	23878.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	11443.	37936.	208215.
516431	12824.2	30211.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	6203.	52326.	247435.

Table 7.9 (Continued)
Frequency and Reliability Tables with *ADJINC* Option 7

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
421331	107852.	101864.	0.	0.	0.	0.	0.	14407.	54216.	80501.	106808.	180486.	284991.	317750.
515531	667686.	77038.	256115.	327227.	466099.	523770.	569627.	636687.	679689.	697213.	713063.	724739.	724739.	724739.
515631	124522.	37702.	0.	0.	0.	32893.	73917.	112579.	126027.	135843.	145064.	155000.	155000.	155000.
515731	608199.	38324.	434682.	450821.	489625.	523946.	555271.	596337.	615040.	623817.	630804.	636061.	636100.	636100.
515831	44472.	9746.	2101.	8567.	14295.	21449.	33209.	40306.	44999.	47181.	49751.	52400.	52400.	52400.
509431	179862.	32618.	63284.	74091.	86091.	108137.	130704.	166317.	182806.	191516.	200661.	205963.	206250.	206561.
516531	185216.	48473.	11109.	24209.	38602.	71604.	116793.	170405.	188681.	200769.	211500.	225400.	225400.	225400.
515931	47409.	13466.	1801.	8426.	9950.	18675.	27730.	41235.	46457.	51342.	55737.	59400.	59400.	59400.
516031	384887.	99889.	18877.	40352.	62712.	140186.	240496.	364100.	401771.	420980.	439183.	457600.	457600.	457600.
516131	192473.	63267.	0.	0.	7418.	24385.	76472.	180125.	209736.	220560.	228310.	235700.	235700.	235700.
516231	29655.	9691.	0.	0.	120.	7351.	15725.	25103.	31326.	33783.	35992.	37100.	37100.	37100.
516331	55870.	14494.	0.	3033.	9875.	23152.	35190.	51230.	58931.	63238.	65500.	65500.	65500.	65500.
516431	131297.	35649.	0.	10194.	32424.	58013.	75567.	115392.	136254.	144425.	151718.	160110.	160110.	160110.
Total	2759398.	451081.	1208330.	1303566.	1437321.	1752640.	2165436.	2574365.	2790902.	2876085.	2963722.	3077727.	3222177.	3333348.

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	+++++++++ PERCENTAGE OF MONTHS +++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS ---------- PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
421331	56000.0	9010.99	82.18	83.91	82.2	82.5	82.6	83.0	83.9	84.2	84.6	67.2	67.2	70.7	70.7	75.9	84.5	98.3
515531	230750.0	0.02	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	1518.08	97.27	97.65	97.3	97.3	97.3	97.3	97.4	97.7	98.0	94.8	94.8	94.8	94.8	98.3	98.3	98.3
515731	19126.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	80416.6	302.91	98.56	99.62	98.6	98.6	98.6	98.7	100.0	100.0	100.0	96.6	96.6	96.6	98.3	100.0	100.0	100.0
516531	65074.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	19658.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	112257.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	367.50	98.85	99.46	98.9	99.0	99.0	99.3	99.4	99.6	99.6	94.8	94.8	96.6	96.6	100.0	100.0	100.0
516231	13610.0	229.43	98.13	98.31	98.1	98.1	98.1	98.1	98.3	98.4	98.6	93.1	94.8	94.8	94.8	98.3	98.3	100.0
516331	19840.0	53.59	99.57	99.73	99.6	99.6	99.6	99.6	99.6	99.7	99.9	96.6	96.6	98.3	98.3	100.0	100.0	100.0
516431	48000.0	189.42	99.14	99.61	99.1	99.1	99.1	99.1	99.3	99.4	99.6	96.6	96.6	96.6	98.3	100.0	100.0	100.0
Total	811107.9	11671.94		98.56														

<u>Control Points</u>

BRSE11	Seymour Gage on Brazos River	515731	Whitney Reservoir
BRSB23	Southbend Gage on Brazos River	515831	Aquilla Reservoir
LRCA58	Cameron Gage on Little River	509431	Waco Reservoir
BRBR59	Bryan Gage on Brazos River	516531	Limestone Reservoir
BRHE68	Hempstead Gage on Brazos	515931	Proctor Reservoir
BRRI70	Richmond Gage on Brazos River	516031	Belton Reservoir
BRGM73	Brazos Outlet at Gulf of Mexico	516131	Stillhouse Hollow Res.
421331	Hubbard Creek Reservoir	516231	Georgetown Reservoir
515531	Possum Kingdom Reservoir	516331	Granger Reservoir
515631	Granbury Reservoir	516431	Somerville Reservoir

Comparative Evaluation of Alternative *ADJINC* Options

ADJINC options 4, 5, 6, and 7 are viable alternatives for application in actual assessments of water availability.

- Option 4 has been the standard *ADJINC* option recommended in the *Reference Manual* since the initial versions of WRAP. Option 4 has been routinely applied in the past in TCEQ WAM System datasets including early versions of the Brazos WAM.
- With its reduction in computer execution time, option 6 should now be viewed as the recommended standard option for a monthly simulation or sub-monthly (daily) simulation without routing. Option 6 yields the same simulation results as option 4 but is more computationally efficient with reduced computer execution time.
- Option 7 is the recommended option for a sub-monthly (daily) simulation with routing.
- Option 5 provides an alternative viable methodology for application with a monthly simulation but is not available within *SIMD* for a sub-monthly (daily) simulation. Option 5 is currently activated in the official TCEQ WAM dataset as well as various other TCEQ WAM System datasets.

Options 1, 2, −3, 3, −4, and 8 are generally not good options for use in actual assessments of water availability. However, these *ADJINC* options provide opportunities for experimentation in simulation studies. Alternative simulations with these options provide insight on the effects of various premises on simulation results.

The ten options are compared here conceptually as well as from the perspective of the Brazos WAM case study. Options 1, 2, −3, 3, −4, and 8, which are not recommended for actual water availability modeling studies, are covered first prior to exploring options 4, 5, 6, and 7.

ADJINC Options 1, 2, −3, 3, −4, and 8

Options 1 and 8 represent the two extremes of the *ADJINC* options. With option 1, all downstream control points are considered and no flow adjustments are applied in determining the amount of stream flow available to each water right. The rights are subject to being penalized for negative incremental naturalized flows at any downstream control points. On the other extreme, option 8 ignores downstream control points, invalidating the simulation. The amount of stream flow available to junior rights does not reflect deductions for the amounts appropriated by senior rights located downstream, and negative incremental flows occurring downstream have no impact.

The 1940-1997 mean annual naturalized flow volume is 7,735,888 with either option 1 or 8. The volume reliability for the aggregation of all diversion rights are 80.94% and 93.38%, respectively, with options 1 and 8. Volume reliabilities fall between these two extremes of 80.94% and 93.38% with each of the other *ADJINC* options activated. The storage contents of the 678 reservoirs average 3,115,274 acre-feet with option 1 and 3,670,238 acre-feet with option 8. The average storage contents range between these lower and upper extremes with the other options.

Options 2 and 3 replicate older traditional practices in which naturalized flows are adjusted to remove negative incrementals prior to providing the flows as input to the simulation model.

Modelers have in the past adjusted naturalized flows to remove negative incrementals in the process of compiling input datasets for *WRAP-SIM* or other simulation models. Options 2 and 3 perform the flow adjustment computations at the beginning of the *SIM* execution in conceptually the same manner as traditional methods for adjusting the naturalized flows outside of the simulation model.

The Brazos WAM simulations demonstrate the wide variation in simulation results as well as naturalized flow input between *ADJINC* options 2 and 3. The mean annual basin naturalized flow of 7,735,888 acre-feet/year is reduced to 6,210,782 acre-feet/year with option 2 and increased to 10,488,288 acre-feet/year with option 4. The downstream (option 2) and upstream (option 3) approaches for defining negative incremental flows are described earlier in this chapter as well as in the *Reference Manual.* Options 2 and 3 represent opposite extremes in defining negative incremental flows and adjusting naturalized flows to remove the negative incrementals.

The Brazos WAM has 77 primary control points and 3,765 secondary control points. Options –3 and −4 show the effects of developing flow adjustments based on only the 77 primary control points and applying the adjustments at only the 77 primary control points. Options –3 and −4 have not and should not be used except for experimentation.

Comparison of Brazos WAM Simulation Results with ADJINC Options 4, 5, 6, and 7

Brazos WAM simulation results are reasonably close for these alternative *ADJINC* options from an overall river basin perspective. From Table 7.5, volume reliabilities for the aggregation of all diversion rights are 90.35%, 90.01%, 89.07%, and 90.35%, respectively, with options 4, 5, 6, and 7. Average total storage contents of the 678 reservoirs are 3,488,539 ac-ft, 3,446,850 ac-ft, 3,386,375 ac-ft, and 3,488,539 ac-ft, respectively, with options 4, 5, 6, and 7. From Table 7.6, the mean, median (50% exceedance frequency), minimum, and maximum total storage contents (acre-feet) of the 13 large reservoirs are as follows based on simulations with the four options.

Table 7.10
Comparison of Storage in 13 Reservoirs Simulated with Alternative ADJINC Options

ADJINC Option	4	5	6	7
mean	2,786,551	2,777,001	2,786,551	2,759,398
median	2,909,241	2,889,989	2,909,241	2,876,085
minimum	1,318,165	1,256,266	1,318,165	1,208,330
maximum	3,333,348	3,333,349	3,333,348	3,333,348

From Tables 7.7, 7.8, and 7.9, volume reliabilities for the aggregation of all diversion rights at the 13 reservoirs are 99.34%, 98.77%, and 98.56%, respectively, with options 4/6, 5, and 7. The regulated and unappropriated flow frequency tables for the 20 individual control points are also reasonably similar for the alternative *NEGINC* options. For example, the mean regulated flow at the Brazos River outlet at the Gulf of Mexico is 341,526 acre-feet/month (Table 7.7), 351,370 ac-ft/month (Table 7.8), and 349,445 ac-ft/month (Table 7.9), respectively, with options 4/6, 5, and 7.

The simulation results are consistent with the conceptual premises reflected in the four alternative *ADJINC* options. Results are identical for options 4 and 6. Options 4 and 6 do not penalize water rights for negative incremental flows occurring downstream and thus, in general, result in higher water supply reliabilities and reservoir storage contents and lower regulated flows. Of the four options, option 6 most severely penalizes water rights for negative incremental flows occurring downstream and thus, in general, results in lower reliabilities and storage volumes.

Comparison of ADJINC Options 4, 5, 6, and 7 for a SIM or SIMD Monthly Simulation

Options 6 and 4 are designed to yield identically the same simulation results. Option 6 is designed for efficiency in reducing computer execution time. Option 4 considers all downstream control points in Task 1 described in Table 7.1 without identifying which of the control points are sites of senior water rights. Option 6 limits consideration to only control points at which senior rights are located. However, the control points with senior rights should be the constraining sites. Option 6 also stops the search for the control point with minimum *CPFLOW* array flow whenever a flow of zero is found; option 4 always searches the current and all downstream control points.

The negative incremental flow adjustments are developed and applied the same by options 4 versus 6. Flow adjustments are computed for each control point at the beginning of the *SIM* simulation and applied during each time step of the simulation. The negative incremental flow adjustments at a control point represent the minimum amount that must be added to the naturalized flow at that control point to remove all negative incremental flows occurring at all control points located upstream. The negative incremental flow adjustments at a control point are computed by comparing the naturalized flow at that control point with concurrent naturalized flows at all control points located upstream of that control point.

In Task 1 described in Table 7.1, the volume of stream flow available to a water right is the minimum of the *CPFLOW* array flow at the control point of the water right and at control points located downstream adjusted for channel losses. With *ADJINC* options 4 and 6, the *CPFLOW* array flows at the downstream control points are increased by the amount of the negative incremental flow adjustments as well as being adjusted for channel losses. However, the flow adjustments are not applied to the *CPFLOW* array flow at the control point of the right.

Option 5 requires significantly less run time than the other options. In Task 1 of Table 7.1, *CPFLOW* array flows at downstream control points are considered only at control points of senior rights with option 5 as well as with options 6 and 7. However, unlike options 6 and 7, no control points located downstream of an intermediate control point with zero flow are considered with option 5 regardless of senior rights. Option 5 is the only option to include a modification of Task 4 of Table 7.1. The other options are reflected only in Task 1. Option 5 limits the flow adjustment in Task 4 to not exceed the minimum of the regulated flows at any of the intermediate control points between the current upstream water right being simulated and downstream senior rights. The Task 4 adjustments stop if a control point with zero regulated flow is encountered.

Option 7 is simpler than options 4, 5, and 6. Option 7 is identical to option 1 except only control points at which senior water rights are located are considered in the Table 7.1 Task 1 determination of flow availability for a water right.

The conceptual similarities and difference between ADJINC options 4, 5, 6, and 7 are compared as follows. All four of the options deal with the determination of the volume of stream flow available to each water right in each month of Task 1 described in Table 7.1. Option 5 is the only option that also modifies the CPFLOW available flow array adjustments of Task 4 described in Table 7.1.

In the Task 1 determination of stream flow availability for a water right, with either of the four *ADJINC* options, the amount of stream flow available to a water right is the lesser of:

1. the amount of flow physically available at the control point at which the right is located
2. available flows at downstream control points as affected by senior water rights and negative incrementals in the naturalized flows as well as simulated channel losses

In many months at many control points, the amount of flow available to a water right will be governed by the flow at the control point of the water right. In this case, the four *ADJINC* options are the same, yielding the same simulation results. The four *ADJINC* options are also the same in regard to not allowing a water right to appropriate stream flow that has already been appropriated by other senior water rights located downstream. With all four options, rights must pass inflows as required by downstream senior rights. The differences between options 4/6, 5, and 7 are the manner in which they deal with negative incremental flows at the downstream control points.

- Options 4 and 6 do not penalize water rights for negative incremental flows that occur at downstream control points.
- Options 5 and 7 do penalize water rights for negative incremental flows that occur at downstream control points at which senior rights are located.

Whether or not the flow available to a water right should be reduced by the amount of negative incremental flows occurring at downstream control points depends upon the cause of the negative incremental. Negative incremental naturalized flows may result from combinations of the following previously noted factors.

1. Timing effects of runoff from a rainfall event reaching an upstream control point late in a particular month but reaching a downstream control point during the next month.
2. Permanent channel losses over and above those modeled with the channel loss coefficients included in the input dataset and associated *SIM* computational routines.
3. Channel losses over and above those modeled in *SIM* where bank storage or underflow may reenter the stream at a downstream location and/or during a future time period.
4. Inaccuracies and impreciseness in stream flow measurements and in the computations performed to convert gaged stream flows to naturalized flows.
5. Modeling peculiarities in creating and assigning control points and flows in the *SIM* input dataset such as multiple control points at the same physical location or artificial (dummy) control points that are not necessarily representing a specific location.

For causative factors 1, 4, and 5 listed above, water rights normally should not be penalized for downstream negative incremental naturalized flows. Thus, *ADJINC* options 4 and 6 would be most appropriate in these situations. However, with channel losses in addition to those modeled in *SIM* (factors 2 and 3) causing the negative incrementals, options 5 or 7 may be more appropriate assuming that junior rights must pass sufficient flows to cover these losses as well as provide for the diversion, storage, and instream flow requirements of senior rights.

Channel losses estimated within *SIM* using channel loss factors provided on control point *CP* records in the input file are reflected in the computations of Tasks 1 and 2 of Table 7.1. Conceptually, if the negative incremental flows are due strictly to channel losses, and the *SIM* linear channel loss equation accurately models channel losses, negative incrementals are handled automatically within *SIM* and are not a concern. *NEGINC* options 4 and 6 would be conceptually correct. However, the channel loss computations in *SIM* are approximate. Negative incremental naturalized flows could reflect additional channel losses not included in the *SIM* simulation.

The preceding discussion addresses Task 1 of Table 7.1. Option 5 is the only *ADJINC* option to also include a modification of Task 4 of Table 7.1. Task 4 consists of adjusting flows at downstream control points for the stream flow depletion and/or return flow associated with a water right. The depletion and/or return flow are adjusted for channel losses as they cascade downstream. Option 5 limits the stream flow adjustment for a flow depletion in Task 4 to not exceed the minimum of the regulated flows at any of the intermediate control points between the current upstream water right being simulated and downstream senior rights. The Task 4 adjustments stop if a control point with zero regulated flow is encountered. Options 4, 6, and 7 are more conservation in this regard in that stream flow depletions and return flows, with adjustments for channel losses, always cascade all of the way downstream to the outlet. The channel loss computations may significantly reduce the volume of a flow change (adjustment) as it cascades downstream.

ADJINC Options SIMD for a Sub-Monthly (Daily) Simulation

SIMD includes all of the *ADJINC* options except option 5. Without routing, *ADJINC* option 7 is recommended for a *SIMD* sub-monthly simulation. With routing, *ADJINC* option 7 is recommended. However, *ADJINC* option 7 is applied in the context of the *SIMD* reverse routing procedure. The addition of *ADJINC* option 7 was motivated by the development of *SIMD* sub-monthly (daily) modeling capabilities.

A *SIMD* daily simulation will normally include routing and forecasting which extends the concept of negative incremental naturalized flows across multiple time steps. A *SIMD* simulation based on a daily or other sub-monthly time step does not necessarily have to include activation of the routing and forecasting features. Forecasting will typically not be activated without routing. Without routing, handling of negative incremental flows in a sub-monthly time step *SIMD* simulation is similar to a *SIM* monthly simulation. Thus, *ADJINC* option 6 is applicable.

The negative incremental flow adjustments developed for *ADJINC* options 2, 3, 4, and 6 are developed from naturalized flows occurring in the same time period at multiple control points. These flows adjustments do not reflect routing and should normally not be applied in a *SIMD* simulation that includes routing.

SIMD incorporates routing in Task 4 of Table 7.1 and reverse routing in Task 1 of Table 7.1 as explained in the *Daily Manual*. *ADJINC* option 7 is applied in conjunction with the reverse routing in Task 1. *ADJINC* option 1 may also be applied within the reverse routing procedure, resulting in typically more severe limits on stream flow availability than option 7.

CHAPTER 8
DAILY SIMULATION FEATURES AND ASSOCIATED INPUT DATA

The conventional WRAP modeling system based on a monthly computational time step is documented by the *Reference* and *Users Manuals*. The *Daily Manual* documents additional features incorporated in the WRAP programs *SIMD*, *TABLES*, and *DAY* for adopting a sub-monthly computational time step. *SIMD* allows each of the 12 months of the year to be subdivided into multiple time intervals with the default being daily. A conventional monthly time step simulation may be performed with *SIMD* with the same input datasets used with *SIM*. Supplemental *SIMD* input is added to apply the daily modeling features.

Options are provided in the post-simulation program *TABLES* for developing frequency relationships using either daily time step simulation results or aggregated monthly results. Program *DAY* contains routines for calibration of flow routing parameters for use in *SIMD* and the same flow disaggregation methods as *SIMD* for developing sequences of naturalized flows or flow patterns for input to *SIMD*.

The Water Availability Modeling (WAM) System dataset for the Brazos River Basin and San Jacinto-Brazos Coastal Basin, called the Brazos WAM (Bwam) in this report, was modified for simulations based on a daily time step. The additional options and input data used in *SIMD* are presented in this chapter. The results of the daily Bwam simulation study are presented and compared with conventional monthly Bwam simulations in Chapter 9. Incorporation in the *SIMD* simulation of operations of the flood control storage pools of nine multiple-purpose Corps of Engineers reservoirs is described in Chapter 10. The simulation results with inclusion of flood control are compared in Chapter 10 with the daily simulation results without flood control. Hoffpauir [21] provides further elaboration on the daily time step WRAP Bwam case study.

WRAP Features for Modeling with Daily Time Steps

Datasets used in *SIM* can be modified to simulate in daily time steps in *SIMD* with only the addition of the *JT* record in the DAT file. The settings on a blank *JT* record will apply to all aspects of the daily modeling features such as the disaggregation of monthly naturalized flows into daily flows and the calculation of daily demand targets. While the default settings allow for easy conversion from monthly to daily simulation, most rivers have hydrologic characteristics and water management practices that are unlikely to be adequately represented without additional input data and application of additional water management features within *SIMD*. The steps taken to convert the Bwam dataset to a daily time interval are likely to be similar for any river basin with high daily flow variability, multiple-day travel times to the outlet, and many water users governed by a priority order based water management system.

Features of DAY

A significant portion of the effort in constructing a monthly simulation dataset for *SIM* is typically devoted to developing naturalized flows. Similarly, much of the effort in developing additional data for daily *SIMD* simulations is likely to be related to naturalized flows. Daily flows used directly or as patterns in *SIMD* should be representative of the expected flows in the absence of the water management scenario being simulated. Therefore in most cases, the daily flows should be as representative of naturalized conditions as possible. The daily flows are provided as input to *SIMD* in the form of *DF* records. *DAY* can be used to facilitate testing of monthly to daily flow patterns as well as organization of daily flows into *DF* record format.

DAY also can be used to calibrate stream flow routing parameters between one or more upstream gages and a common downstream gage. Unlike monthly time steps, simulation of a stream network with daily time steps requires the consideration of timing differences between the occurrence of a change in flow and the effects of that change at downstream locations. *DAY* calibrates the routing parameters from the daily flows used as *DF* record input for *SIMD*. The calibrated routing parameters are likewise used as input in *SIMD* on *RT* records. However, *SIMD* does not apply the routing parameters to the flows from the *DF* records. Routing within *SIMD* is only applied to changes in flow. *DAY* can calibrate, and *SIMD* will apply, the values of lag and attenuation or the Muskingum *K* and *X* for the two alternative routing methods.

Routing parameters are calibrated in *DAY* for the period-of-analysis represented by the *DF* records. *SIMD* uses the period-of-analysis routing parameters to rout changes to flow caused by *WR* record water rights. *SIMD* can also use the period-of-analysis routing parameters to rout the changes to flow caused by *FR* record flood control rights. Alternatively, *DAY* can be used to calibrate routing parameters for those time steps in the *DF* period-of-analysis which correspond to flood flow conditions. The flood flow routing parameters can be used by *SIMD* to rout changes to flow caused by the *FR* record flood control rights.

Features of SIMD

Features of *SIMD* used exclusively for daily simulation include:

- routines for setting the number of daily computational time steps contained in each month and subdividing monthly naturalized flow volumes into daily time steps
- options for setting and varying diversion, hydropower, and instream flow targets over the daily time steps within each month
- option for reading daily naturalized flows from an input file
- alternative options for disaggregating naturalized monthly flows to daily time intervals
- option for determining current day available stream flow for *WR* record water rights based on a forecast simulation over a future forecast period
- forecasting of remaining channel capacity for *FF*/*FR* record flood control operations
- alternative methods for routing of stream flow adjustments
- aggregation of daily simulation results to monthly values and recording of simulation results at daily and/or monthly time steps

The inputs for daily simulation in *SIMD* are divided between the common DAT input file shared with *SIM* and a DCF input file utilized only by *SIMD*. These records and their placement in the respective input files are detailed in Appendix A of the *Daily Manual*. The DAT file contains records specifying daily job control, water right daily target setting and building options and flood control operations. The DCF file contains routing parameters, disaggregation methods, daily flow records and optional placement of the water right daily target records.

Brazos Water Availability Model (Bwam) Input Files

The Bwam dataset was modified by adding the *JT* and *JU* records at the beginning of the DAT file. The *JT* record flags *SIMD* to initiate a daily Bwam simulation using default parameters. The *JU* record provides a disaggregation option to be used if no *DC* records are provided in the DCF file to override the *JT* record value. The *JT* record also sets the method for placing changes to flow before the daily water rights loop. Table 8.1 shows an example of the *JU* and *JT* records used in the Bwam with primarily default inputs. Simulation results presented in Chapter 9 may utilize other values on the *JT* record.

Table 8.1
Example of Daily Job Control Records Used in the Bwam DAT File

```
**
JT      0   0   0     0   0      0   0   0   0   0   0   0
**
JU      1     0.0     0.0   0    0   0   0   0   0   0
**
```

The only additional *SIMD* records added to the Bwam DAT file pertain to resetting *TO* record target building options from monthly to daily consideration. A target options *TO* record connected to water right *WR* record is also paired with a daily options *DO* record which sets a value of 16 in *DO* record field 3. As discussed in the *Daily Manual*, this *DO* record setting causes *TO* record options to be considered in step 16 of the target building process. There are no other *SIMD* records added to the DAT file to produce the results of Chapter 9. The flood control records added to the DAT file are discussed in Chapter 10.

The Bwam DCF file was populated with routing parameters, monthly to daily disaggregation information for each control point of the Bwam DAT file, and the daily flow patterns. This information is contained in *RT*, *DC* and *DF* records, respectively. The development of the routing parameters and a description of the daily flow patterns is the subject of subsequent sections in this chapter.

Features of TABLES

Program *TABLES* includes options for summarizing and tabulating simulation results and developing reliability and frequency statistics for sub-monthly (such as daily) as well as monthly simulations. *TABLES* reads and processes *SIMD* input and output files using the routines available for processing conventional monthly *SIM* input and output files. *SIMD* can aggregate daily simulation results into monthly amounts that are written to a *SIMD* OUT file that is identical in format to a *SIM* OUT file. *TABLES* also provides options to process the *SIMD* daily simulation results output SUB file and the annual flood frequency AFF file. *TABLES* job 6 routines are identical to the job 2 routines, except that the SUB file is used as input instead of the OUT or DSS file. *TABLES* job 7 routines process the AFF file. These *TABLES* features are covered in detail in Chapters 3 and 5 and Appendix C of the *Daily Manual*.

Monthly to Daily Disaggregation of Naturalized Flows

The Texas WAM System contains datasets of monthly naturalized flows. Disaggregation options are adopted when applying daily time steps. Selecting and applying the disaggregation options is a subjective process of making optimal use of available monthly and daily flow data. Historical gaged daily flow records and daily data related to past water management are required to convert gaged flows to naturalized or unregulated flows, but may be limited in availability. The effects of lag and attenuation on flow can complicate the process of naturalizing gaged flows and transferring them to ungaged sites. Converting gaged daily flows to naturalized daily flows at pertinent locations is difficult for extensively developed river basins.

SIMD reads monthly flow volumes from *IN* records or DSS records for primary control points and distributes the flows to secondary control points using DIS file parameters in the exact same manner as *SIM*. These monthly flows are then disaggregated to daily amounts in *SIMD*. The alternative disaggregation methods all convert sequences of monthly naturalized flow volumes into daily flow volumes that preserve the monthly amounts. The option of preserving the monthly WAM naturalized flows and disaggregating with a *DF* record flow pattern was adopted for the Bwam dataset as discussed below.

USACE SUPER Daily Unregulated Flow Dataset

SUPER is a computer modeling system developed by the USACE Southwestern Division (SWD) and applied by the Fort Worth District and other districts in the SWD [22]. SUPER is designed for simulating multiple-purpose reservoir systems over a long period-of-record using a daily time step. Unregulated flows in SUPER are analogous to naturalized flows in WRAP. Unregulated flows for SUPER, as well as the WAM naturalized flows, have been developed by adjusting gaged flows to remove the effects of major reservoirs and other water control facilities. Development and application of SUPER have been motivated largely by flood control operations of Corps of Engineers multiple-purpose reservoir systems. Whereas low flows have been a key consideration in developing WRAP naturalized flows for the TCEQ WAM System, flood flows have been a greater concern in developing unregulated flows for the USACE SUPER modeling system. Thus, different river control and water use activities may have been included or excluded in the SUPER versus WAM adjustments of gaged flows.

A dataset of daily unregulated flow volumes provided by the USACE Fort Worth District from their SUPER modeling system are used as flow patterns in the disaggregation of the Bwam monthly naturalized flow volumes to daily volumes. The SUPER flow data cover the period from 1940 through 1997 at locations along the main stem of the Brazos River at and downstream of Possum Kingdom Lake and on major tributaries contributing inflows to the Brazos River below Whitney Dam. The Bwam control point locations of the SUPER flow data are listed in Table 8.2. Figure 8.1 shows the map locations of the SUPER flow data. Figure 8.2 shows the relative locations of Bwam control points with SUPER flow data and their connectivity.

The SUPER flow data do not include streams in the San Jacinto-Brazos Coastal Basin. The Bwam control points in the San Jacinto-Brazos Coastal Basin utilize the disaggregation method set on the *JU* record to develop daily flows from the WAM monthly naturalized flows. No routing parameters were calibrated for the San Jacinto-Brazos Coastal Basin.

Table 8.2
USACE SUPER Unregulated Flow Series with
Corresponding Bwam Control Points

Name Assigned by USACE to the SUPER Unregulated Flow Time Series	Brazos WAM Information		
	Control Point Identifier	Watershed Drainage Area (sq miles)	Stream Length to Outlet (miles)
Possum Kingdom Outflow	515531	14,093	706
Granbury Outflow	515631	16,181	559
Whitney Outflow	515731	17,690	462
Aquilla Outflow	515831	254	458
Bosque Outflow	227901	710	490
Waco Outflow	509431	1,655	428
Proctor Outflow	515931	1,280	639
Belton Outflow	516031	3,568	442
Stillhouse Outflow	516131	1,313	441
South Fork Outflow	SGGE55	132	430
Georgetown Outflow	516231	247	432
Granger Outflow	516331	726	399
Somerville Outflow	516431	1,008	271
Limestone Outflow	516531	675	351
Dennis	BRDE29	15,733	605
Glen Rose	BRGR30	16,320	527
Elm Mott	CON070	18,313	434
Clifton	NBCL36	977	468
Waco (Brazos)	BRWA41	20,065	418
Highbank	BRHB42	20,900	358
Gatesville	LEGT47	2,379	519
Lampasas Mouth	CON095	1,511	426
Little River	LRLR53	5,266	419
Georgetown	GAGE56	404	427
Rockdale	CON102	1,357	373
Cameron	LRCA58	7,100	357
Bryan (Brazos)	BRBR59	30,016	290
Yegua Mouth	CON129	1,302	257
Washington	CON147	33,930	234
Easterly	NAEA66	936	334
Bryan (Navasota)	NABR67	1,427	300
Navasota Mouth	CON231	2,241	240
Hempstead	BRHE68	34,374	202
Richmond	BRRI70	35,454	97

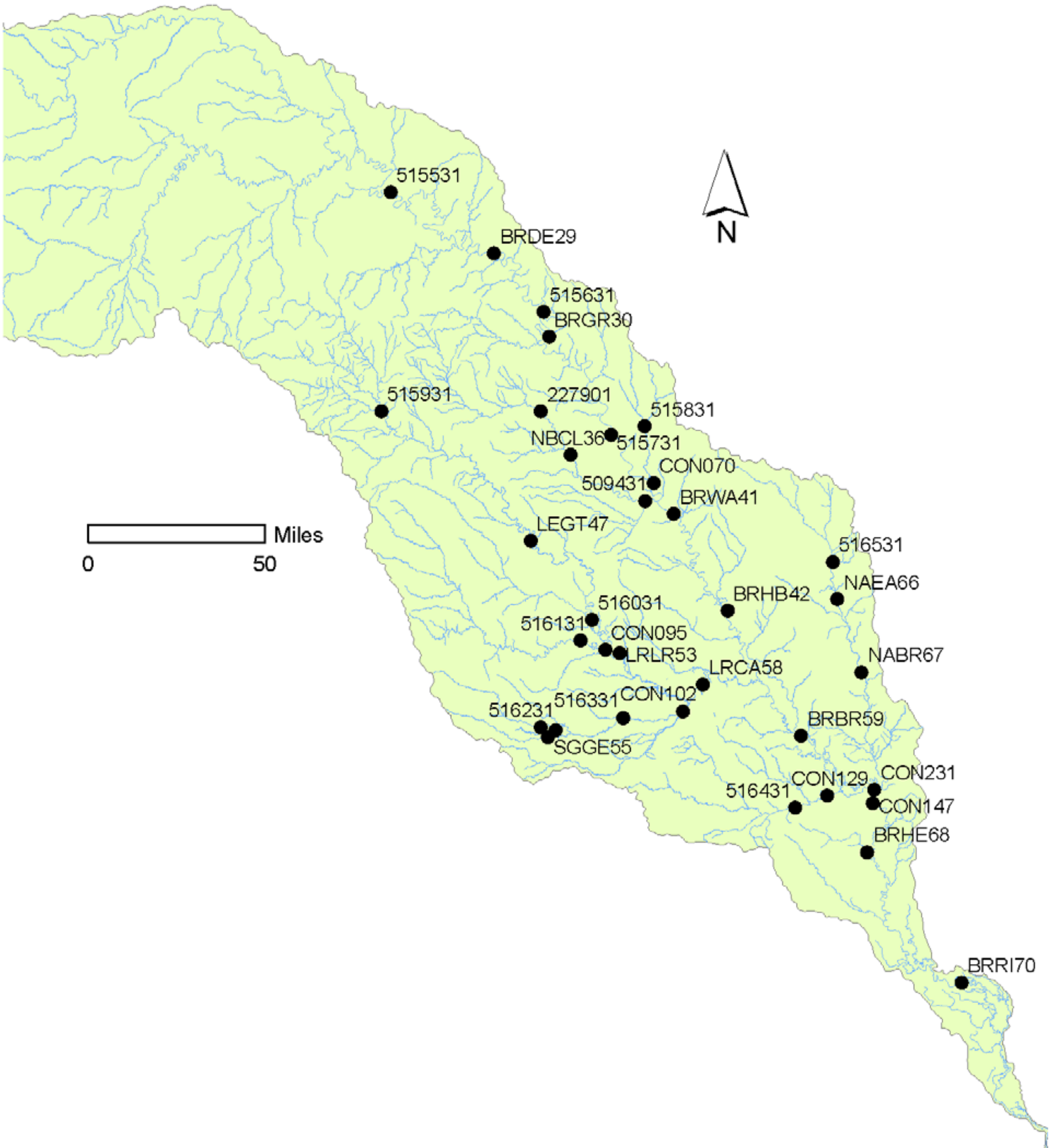

Figure 8.1 Bwam Control Points at which SUPER Flow Data Are Located

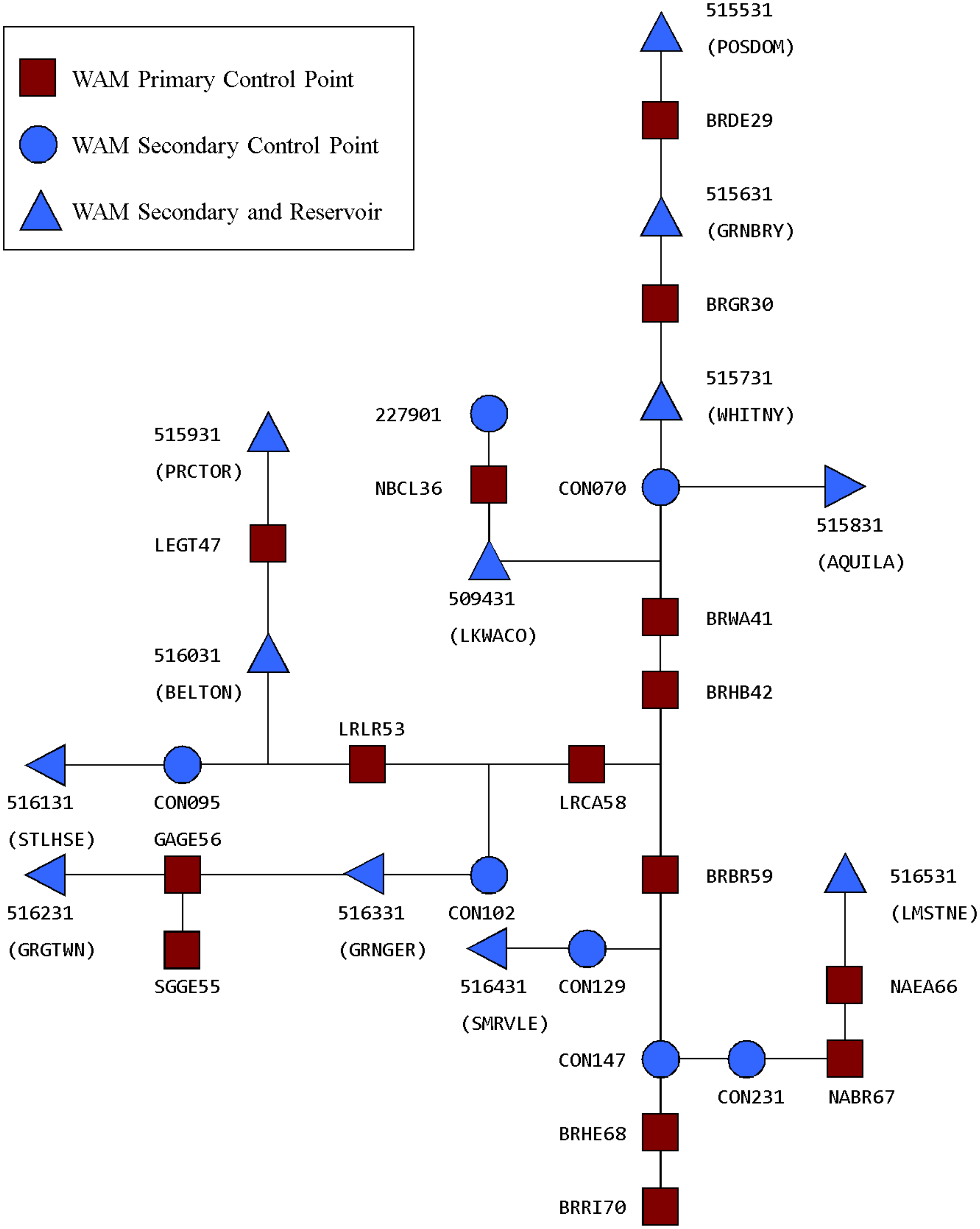

Figure 8.2 Connectivity of WAM Control Points Corresponding to Locations of SUPER Flow Data (figure not to scale)

Table 8.3
WAM Monthly Naturalized Flows and SUPER Monthly Aggregated Flows
at WAM Primary Control Points (USGS gages), acre-feet per month

Bwam Control Point	Data Source	Mean	Standard Deviation	Percentage of Months with Flows Equaling or Exceeding Values Shown in the Table 100%	98%	90%	75%	50%	25%	10%	Max
SGGE55	WAM	3,014	5,397	0	11	60	241	946	3,497	8,301	50,622
	SUPER	2,977	5,325	0	3	61	239	938	3,496	8,241	50,622
	Difference	38	72	0	8	-1	2	8	1	60	0
GAGE56	WAM	8,693	15,106	0	27	204	751	2,754	10,232	25,510	140,494
	SUPER	8,251	14,236	0	11	218	658	2,532	9,461	25,422	123,179
	Difference	443	870	0	16	-15	93	222	771	88	17,315
NBCL36	WAM	13,577	31,085	0	0	166	771	2,594	11,722	40,586	450,470
	SUPER	13,629	31,060	0	0	183	840	2,647	11,847	40,559	449,932
	Difference	-52	25	0	0	-17	-69	-53	-125	27	538
LEGT47	WAM	21,483	41,916	0	0	383	1,361	5,793	21,255	56,294	383,340
	SUPER	23,652	47,879	0	0	401	1,392	5,898	23,656	59,491	430,910
		-2,169	-5,963	0	0	-18	-31	-105	-2,401	-3,197	-47,570
NAEA66	WAM	26,882	46,900	0	0	125	848	5,743	28,826	87,562	332,958
	SUPER	27,735	46,688	0	37	279	1,410	6,912	29,619	89,413	326,639
	Difference	-854	212	0	-37	-154	-562	-1,169	-793	-1,851	6,319
NABR67	WAM	35,109	57,655	0	0	295	1,759	8,530	40,035	109,997	384,272
	SUPER	38,486	58,709	0	98	810	3,127	10,764	47,633	125,002	379,429
	Difference	-3,378	-1,054	0	-98	-515	-1,368	-2,234	-7,598	-15,005	4,843
LRLR53	WAM	70,546	120,022	30	562	3,418	8,225	25,741	80,406	190,524	950,933
	LRLR53	75,044	121,634	15	677	4,759	10,778	29,744	89,071	196,687	995,412
	Difference	-4,498	-1,612	15	-115	-1,341	-2,553	-4,003	-8,665	-6,163	-44,479
BRDE29	WAM	83,646	165,799	0	529	3,713	9,442	27,265	87,622	211,034	2,450,046
	SUPER	83,787	168,037	33	1,960	5,809	11,004	27,736	79,860	211,820	2,528,313
	Difference	-142	-2,238	-33	-1,431	-2,095	-1,562	-471	7,762	-786	-78,267
BRGR30	WAM	93,248	182,476	0	528	4,598	10,445	30,585	96,926	242,476	2,710,228
	SUPER	94,663	184,820	0	1,958	6,782	12,299	31,856	96,854	243,134	2,833,811
	Difference	-1,415	-2,344	0	-1,430	-2,184	-1,854	-1,271	72	-658	-123,583
LRCA58	WAM	109,858	170,466	0	1,249	5,440	15,032	44,799	130,473	290,433	1,403,136
	SUPER	114,664	177,292	122	1,385	6,568	17,166	47,182	136,409	294,857	1,446,929
	Difference	-4,805	-6,826	-122	-136	-1,128	-2,134	-2,383	-5,936	-4,424	-43,793
BRWA41	WAM	161,860	266,253	0	3,434	10,364	24,749	68,642	183,578	422,755	3,376,485
	SUPER	164,614	271,325	1,471	4,575	12,831	27,669	69,098	182,415	422,385	3,475,462
	Difference	-2,753	-5,072	-1,471	-1,142	-2,467	-2,920	-456	1,163	370	-98,977

Table 8.3 (Continued)
WAM Monthly Naturalized Flows and SUPER Monthly Aggregated Flows
at WAM Primary Control Points (USGS gages), acre-feet per month

Bwam Control Point	Data Source	Mean	Standard Deviation	Percentage of Months with Flows Equaling or Exceeding Values Shown in the Table							Max
				100%	98%	90%	75%	50%	25%	10%	
BRHB42	WAM	194,262	300,104	1,251	6,378	14,726	31,658	89,483	232,892	488,252	3,599,269
	SUPER	192,089	298,898	1,890	5,943	17,370	33,843	86,146	220,430	471,991	3,659,795
	Difference	2,173	1,206	-639	435	-2,645	-2,185	3,337	12,462	16,261	-60,526
BRBR59	WAM	335,664	483,897	0	11,162	28,173	60,717	158,629	402,271	810,073	4,704,312
	SUPER	343,562	501,143	2,661	12,738	31,917	63,917	166,181	414,285	854,640	5,091,260
	Difference	-7,898	-17,246	-2,661	-1,576	-3,745	-3,200	-7,552	-12,014	-44,567	-386,948
BRHE68	WAM	446,579	588,542	1,634	17,422	44,643	89,698	229,331	581,968	1,153,505	5,723,482
	SUPER	445,071	602,300	5,498	18,236	45,310	90,235	218,495	567,780	1,113,301	6,237,132
	Difference	1,507	-13,758	-3,864	-814	-667	-537	10,836	14,188	40,204	-513,650
BRRI70	WAM	487,519	613,002	0	25,402	53,888	111,204	257,456	653,272	1,230,723	6,135,975
	SUPER	479,525	633,801	4,468	22,451	48,924	101,488	249,022	607,449	1,227,600	6,713,006
	Difference	7,994	-20,799	-4,468	2,950	4,964	9,716	8,434	45,823	3,123	-577,031

Table 8.4
WAM Monthly Naturalized Flows and SUPER Monthly Aggregated Flows
at WAM Secondary (Ungaged) Control Points, acre-feet per month

Bwam Control Point	Data Source	Mean	Standard Deviation	Percentage of Months with Flows Equaling or Exceeding Values Shown in the Table							Max
				100%	98%	90%	75%	50%	25%	10%	
516231	WAM	4,797	8,418	0	0	85	344	1,416	5,510	14,484	74,909
	SUPER	5,274	9,072	0	0	123	406	1,555	5,990	15,411	72,646
	Difference	-477	-654	0	0	-38	-62	-139	-480	-927	2,263
515831	WAM	6,147	11,987	0	0	0	37	988	6,582	19,446	102,561
	SUPER	7,185	13,855	0	0	20	234	1,344	7,344	21,786	124,101
	Difference	-1,038	-1,868	0	0	-20	-197	-356	-762	-2,340	-21,540
227901	WAM	9,653	21,769	0	0	121	538	1,870	8,331	28,445	302,330
	SUPER	9,949	22,708	0	0	134	620	1,929	8,564	29,668	329,012
	Difference	-296	-939	0	0	-14	-82	-59	-233	-1,223	-26,682
515931	WAM	12,071	28,547	0	0	56	495	2,450	10,841	33,218	327,284
	SUPER	11,494	27,093	0	0	87	652	2,300	10,189	31,331	326,715
	Difference	576	1,454	0	0	-31	-157	150	652	1,887	569
516331	WAM	15,552	24,898	0	6	474	1,773	5,412	19,756	44,908	210,085
	SUPER	16,258	25,212	0	119	740	2,207	5,841	19,985	45,384	208,010
	Difference	-706	-314	0	-113	-266	-434	-429	-229	-476	2,075

Table 8.4 (Continued)
WAM Monthly Naturalized Flows and SUPER Monthly Aggregated Flows
at WAM Secondary (Ungaged) Control Points, acre-feet per month

Bwam Control Point	Data Source	Mean	Standard Deviation	Percentage of Months with Flows Equaling or Exceeding Values Shown in the Table 100%	98%	90%	75%	50%	25%	10%	Max
516431	WAM	18,572	33,188	0	0	5	764	3,895	18,888	60,673	250,982
	SUPER	20,245	34,435	0	0	190	1,525	5,204	22,125	63,996	248,272
	Difference	-1,672	-1,247	0	0	-185	-761	-1,309	-3,237	-3,323	2,710
516131	WAM	19,238	34,306	28	148	719	2,122	5,988	20,984	53,075	309,090
	SUPER	18,567	33,557	0	49	678	2,009	5,527	20,705	52,037	310,738
	Difference	671	749	28	99	40	113	461	279	1,038	-1,648
516531	WAM	19,399	34,018	0	0	101	614	3,970	21,035	62,911	240,424
	SUPER	20,448	34,643	0	3	176	837	5,281	21,740	66,553	240,850
	Difference	-1,048	-625	0	-3	-75	-223	-1,311	-705	-3,642	-426
CON095	WAM	24,263	41,021	0	430	1,445	3,363	8,124	27,288	66,398	351,724
	SUPER	24,099	39,495	0	391	1,664	3,544	9,193	27,413	68,566	350,683
	Difference	164	1,526	0	39	-219	-181	-1,069	-125	-2,168	1,041
CON129	WAM	25,966	43,479	0	0	619	2,066	7,069	27,509	84,897	322,760
	SUPER	31,286	46,377	0	341	1,229	3,786	11,137	37,245	102,195	358,204
	Difference	-5,320	-2,898	0	-341	-610	-1,720	-4,068	-9,736	-17,298	-35,444
509431	WAM	29,789	53,352	0	9	468	2,860	9,933	34,692	80,535	530,557
	SUPER	28,906	53,160	0	91	915	2,842	9,542	30,462	79,278	499,977
	Difference	883	192	0	-81	-447	18	391	4,230	1,257	30,580
CON102	WAM	30,113	47,637	0	0	712	3,143	11,462	37,003	82,590	385,711
	SUPER	30,047	47,547	0	153	1,161	3,526	10,242	35,400	82,697	360,454
	Difference	67	90	0	-153	-449	-383	1,220	1,603	-107	25,257
516031	WAM	41,916	75,191	0	0	486	3,336	12,710	47,382	112,448	627,569
	SUPER	45,630	79,832	0	54	1,706	4,897	16,191	49,194	118,788	638,998
	Difference	-3,715	-4,641	0	-54	-1,221	-1,561	-3,481	-1,812	-6,340	-11,429
CON231	WAM	64,512	88,128	0	0	3,753	8,560	25,420	82,017	187,854	624,252
	SUPER	60,855	85,095	41	543	2,785	8,120	24,408	78,602	182,699	685,211
	Difference	3,657	3,033	-41	-543	969	440	1,012	3,415	5,155	-60,959
515531	WAM	66,123	137,150	0	0	2,187	6,883	18,404	64,389	166,332	1,794,484
	SUPER	66,259	134,668	0	830	4,052	8,598	20,808	63,683	166,345	1,806,223
	Difference	-136	2,482	0	-830	-1,865	-1,715	-2,404	706	-13	-11,739
515631	WAM	91,156	178,785	0	782	4,459	10,228	29,493	95,565	237,433	2,653,863
	SUPER	93,144	182,692	0	1,844	6,695	11,902	31,148	94,187	239,468	2,792,087
	Difference	-1,988	-3,907	0	-1,062	-2,236	-1,674	-1,655	1,378	-2,035	-138,224
515731	WAM	113,906	203,559	8	1,767	6,778	16,135	46,037	130,424	277,592	2,962,997
	SUPER	116,093	208,401	297	2,804	9,789	18,739	45,363	125,234	287,669	3,006,321
	Difference	-2,187	-4,842	-290	-1,037	-3,012	-2,605	674	5,190	-10,077	-43,324
CON070	WAM	130,089	222,662	0	2,454	7,920	20,524	56,178	144,695	342,884	3,096,309

	SUPER	132,601	225,994	585	3,186	11,371	22,899	57,929	149,793	342,029	3,124,326
	Difference	-2,512	-3,332	-585	-732	-3,451	-2,375	-1,751	-5,098	855	-28,017
CON147	WAM	434,029	579,775	1,424	16,028	42,367	85,443	223,684	566,908	1,126,324	5,562,412
	SUPER	385,886	537,742	4,083	15,249	38,061	75,026	186,755	472,948	951,539	5,418,890
	Difference	48,143	42,033	-2,659	780	4,306	10,417	36,929	93,960	174,785	143,522

Tables 8.3 and 8.4 compare the WAM monthly naturalized flows and the SUPER unregulated flows aggregated from daily to monthly volumes. Flow differences for low flows tend to be a greater percentage of the WAM naturalized monthly flow than for high flows. Percent differences in high flows are generally smaller than the percent differences of low flows. For low flows, the SUPER flows are higher than the WAM flows at most of the control points. The WAM naturalization process and the SUPER process for computing unregulated flows reflect various differences in adjusting for diversions and return flows and the timing effects of flow routing. The monthly naturalized flow volumes in *SIMD* are set as the WAM monthly naturalized flow volumes. Only the daily pattern of flow is set by the SUPER flow data.

Daily flows during the drought year 1952 for control point BRBR59 at the USGS gage on the Brazos River near Bryan are plotted in Figures 8.3 and 8.4. The WAM naturalized daily flows are so close to the SUPER daily flows that the differences are almost indistinguishable in Figure 8.3. Figure 8.4 shows the lower portion of the 1952 hydrograph to more clearly illustrate the differences between the WAM and SUPER flows, which are most pronounced for low flows. Differences during September 1952 are significant.

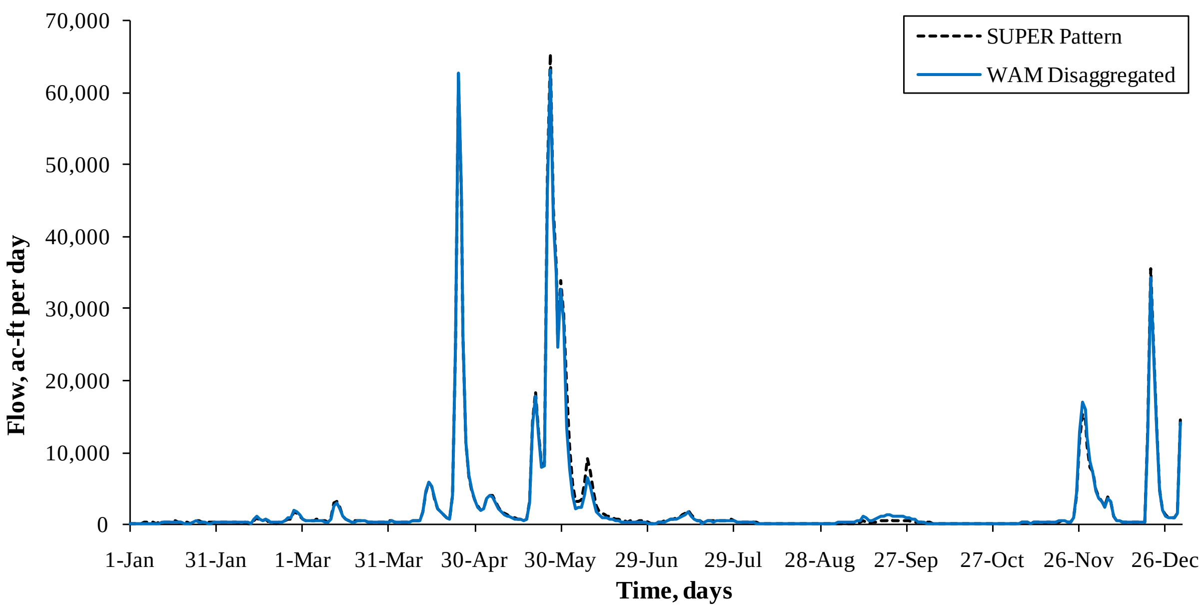

Figure 8.3 SUPER Flows and WAM Disaggregated Naturalized Flows
at Bwam Control Point BRBR59 for Year 1952, ac-ft per day

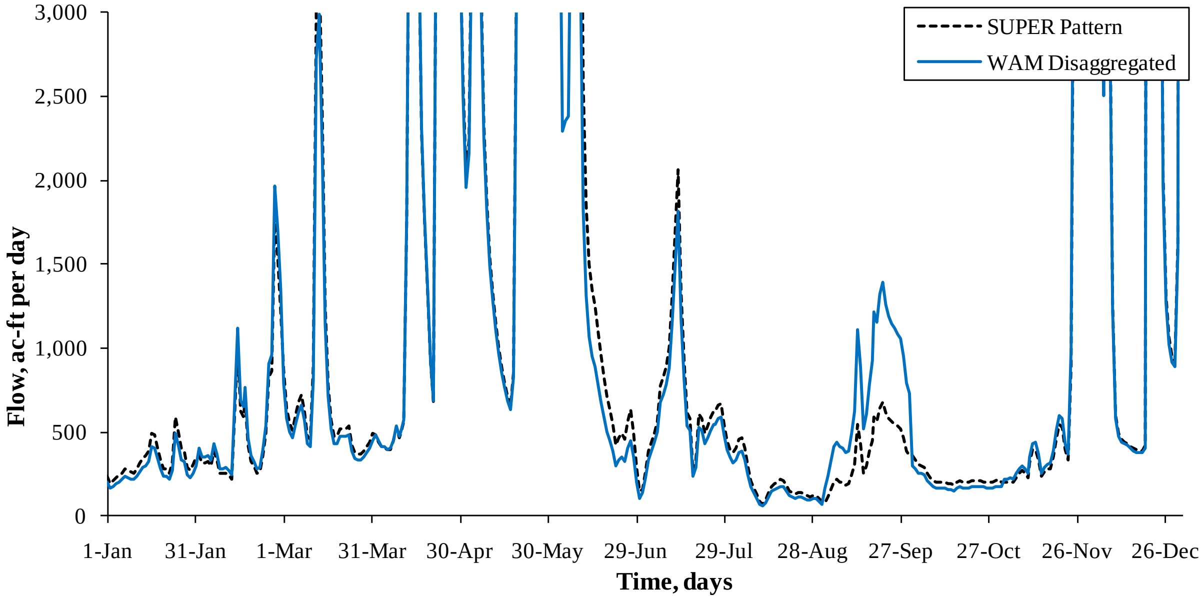

Figure 8.4 SUPER Flows and WAM Disaggregated Naturalized Flows
at Bwam Control Point BRBR59 for Year 1952, acre-feet per day

DC Record Development

All control points in the Bwam are assigned monthly naturalized flows either through direct *IN* record input in the FLO file, or by transferring flows from gaged (primary) to ungaged (secondary) control points. The drainage area ratio method with consideration of channel losses is used to transfer flows from gaged to ungaged control points in the Bwam DAT file. The monthly naturalized flows for every control point are disaggregated using the SUPER daily flows and thereby maintain the same monthly naturalized volume at every control point as utilized in the conventional monthly simulation.

The SUPER flows were provided by the USACE as daily mean flows in units of cubic feet per second which is equivalent to daily flow volumes in second-foot-day. These values were not changed when the SUPER flows were formatted into *DF* records for the *SIMD* DCF file. The daily flow patterns on the *DF* records are not utilized as direct daily flow input. Instead the *DF* record flows are used by *SIMD* to compute sets of daily normalized coefficients in a process which is analogous to disaggregating *WR* record annual targets into monthly values using normalized coefficients computed from *UC* record values. Each set of daily normalized coefficients are computed from one monthly set of *DF* record values. The monthly naturalized flow at the control point is multiplied by the daily normalized coefficients to obtain the daily disaggregated naturalized flow. Therefore, units of the values of flow on the *DF* records do not affect the computation of the normalized coefficients used in this disaggregation method.

Each *DF* record set was assigned the control point identifier of a Bwam control point that matches the location of SUPER flow data. Matches between Bwam control point identifiers and SUPER flow locations are given in Table 8.2.

DC records specify the disaggregation method to be applied to flows at specified control points. A single *DC* record with field 3 option -4 was assigned to the control point location just upstream of the outlet of the Brazos River. Option -4 is described in Chapter 3 and Appendix A of the *Daily Manual*. This option automatically matches all control points in the basin with the first DF record pattern encountered downstream. If no downstream pattern is available, the first upstream DF record pattern is selected. Finally, if no downstream or upstream pattern is available, the nearest DF record pattern that shares a common downstream confluence is matched with the control point in need of a disaggregation pattern. No DF record patters are provided for the San Jacinto-Brazos Coastal Basin. All control points in the costal basin are assigned the default uniform disaggregation method that was specified on the *JU* record.

Table 8.5 shows the single *DC* record for the control point located immediately upstream of the Brazos River outlet to the Gulf of Mexico. This *DC* record has parameters in fields 5 through 8 that specify the entire period of record for the WAM simulation. All control points upstream of BRGM73 are assigned field 3 option -4 and the same parameters for fields 5 through 8. The *DF* record set identifier is left blank in field 4. The process of automatically pairing control points with *DF* record sets is described in the preceding paragraph.

Figure 8.5 shows a conceptual example of the *DF* record set assignment process for most control points in the Brazos River Basin. Only those control points below the last DF record set, located at the Rosharon control point BRRO72, will not be paired with a downstream pattern. These control points are automatically assigned the upstream pattern at BRRO72.

Table 8.5
DC Record for the Bwam Dataset

```
**
DCBRGM73      -4             1940       1     1997      12
**
```

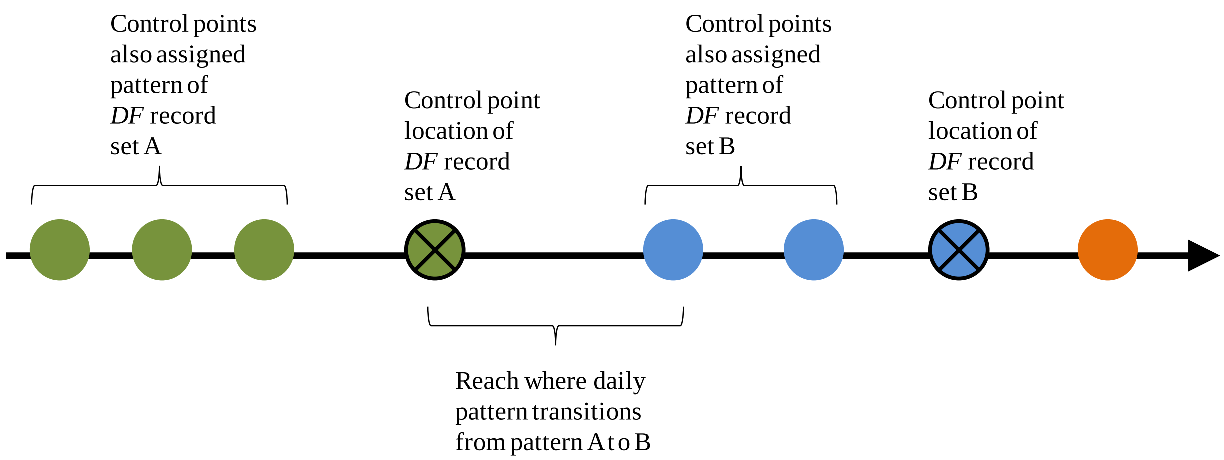

Figure 8.5 Example of Downstream *DF* Record Assignment

Alternative Disaggregation Methods

The SUPER daily unregulated flow volumes are used as a source of flow patterns to disaggregate WAM monthly naturalized flow volumes into daily quantities. There are no SUPER flow data for the San Jacinto-Brazos Coastal Basin. The uniform method of flow disaggregation was used to develop daily flows for the Bwam control points in the coastal basin. The uniform and linear interpolation methods of disaggregation are also applied to all control points in Chapter 9 as a comparison to the simulation with the SUPER daily flow patterns. The uniform and linear interpolation methods tend to smooth out the extreme variability often exhibited by naturalized or unregulated river flows.

The uniform distribution option consists of computing daily flow volumes by simply dividing the monthly naturalized flow volume by the number of sub-intervals in the month. This option produces the least daily flow variability. For a location with no available information on flow variability, or a location with known low variability in flow, the uniform disaggregation option may be adequate as a default disaggregation option until actual daily flow data or information about flow variability at the location can be collected.

Linear spline interpolation may be applied to a sequence of monthly naturalized flows to obtain non-uniform daily amounts. The methodology is illustrated graphically in Figure 8.6. Instantaneous flows at the beginning, middle, and end of each month of the series are defined based on the flow volumes in the preceding, current, and subsequent months. The straight lines connecting these points are called linear splines. The splines represent instantaneous flow rates at points in time, and the areas under the splines represent flow volumes during intervals of time. The splines define areas representing monthly flow volumes which are dissected at sub-monthly intervals to disaggregate the monthly volumes into sub-monthly volumes.

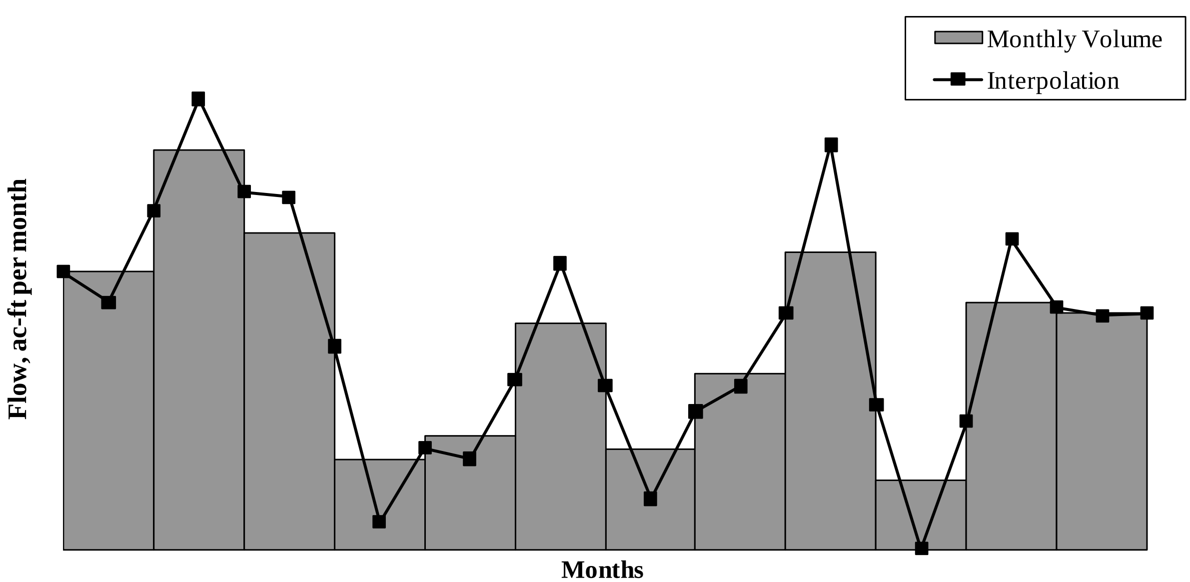

Figure 8.6 Example of the Linear Spline Interpolation Method of Disaggregation

The shaded bars in Figure 8.6 represent the monthly naturalized flow volumes that are to be disaggregated. The linear interpolation splines connect the beginning, middle, and ending points of each month. The end of one month is the beginning of the next month. The spline flows at the beginning and end of each month are set as the average of the mean instantaneous flow rates associated with the monthly volumes of adjoining months. Middle-of-month flow points are then set based on conserving the total monthly flow volume. The middle-of-month flow point is selected such that the monthly flow volume being disaggregated is represented by the area under the two linear splines spanning that month.

In some cases, with beginning/end-of-month flow points set as averages of adjacent mean monthly flows, the preservation of the monthly volume by defining a single middle-of-month point may result in negative middle-of-month flow rates. When such a negative flow occurs, two zero-flow points are set within the month defining a period of zero flow during the middle of the month that results in preservation of the total volume for the month without creating negative flows. A zero monthly volume results in a zero instantaneous flow rate for the entire month.

The linear interpolation method for disaggregating monthly flows to daily volumes results in smoother and more serially correlated daily flow sequences than the actual observed daily flows. Thus, the method may be best applied to streams that are baseflow dominated with rare high flow pulses. In streams with high variability, the linear interpolation method may have better results for the low variability base flow periods than for flood flows periods.

Flow-frequency relationships for daily naturalized flow at key stream flow gages and major reservoirs in the Bwam dataset are tabulated in Tables 8.6, 8.7, and 8.8. These tables contain flow-frequency statistics for daily naturalized flows developed based on the uniform, linear interpolation and flow pattern disaggregation options. The control points are the same as those listed in Table 2.4 of Chapter 2 excluding the Seymour and Southbend stream flow gages and Hubbard Creek Reservoir as these locations are above Possum Kingdom Reservoir.

Table 8.6
Uniform Flow Disaggregation Method
Flow-Frequency Statistics for Daily Naturalized Stream Flows, acre-feet per day

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	3609.23	30971.6	0.00	12.35	36.58	84.37	178.53	485.00	946.9	1484.0	2164.1	4319.3	9470.4	48384.0
BRBR59	11027.70	87717.8	0.00	208.19	360.19	592.80	911.03	1957.52	3517.6	5295.3	7589.1	13305.5	26782.3	151752.0
BRHE68	14671.64	106706.7	52.71	423.07	566.00	972.71	1464.74	2903.32	5146.3	7615.1	10090.4	19220.0	37804.3	184628.5
BRRI70	16016.66	111100.2	0.00	545.55	789.26	1282.57	1786.16	3675.33	5964.3	8500.7	11761.1	21358.3	39861.4	197934.7
BRGM73	16714.84	114966.0	0.13	556.37	827.47	1364.45	1918.39	3974.07	6425.5	8999.7	12368.3	22127.8	41621.7	201757.0
515531	2172.36	24761.9	0.00	0.00	0.00	8.00	68.27	223.70	422.2	608.5	1000.2	2146.2	5404.2	57886.6
515631	2994.79	32270.9	0.00	0.00	23.41	66.12	148.95	330.84	641.2	969.0	1596.6	3123.1	7723.2	85608.5
515731	3742.19	36763.3	0.25	3.58	48.93	108.57	220.13	528.09	943.0	1489.0	2119.5	4223.7	9418.4	95580.5
515831	201.96	2173.3	0.00	0.00	0.00	0.00	0.00	1.07	15.3	32.1	67.2	209.6	623.0	3308.4
509431	978.66	9674.1	0.00	0.00	0.22	1.20	15.11	88.78	191.0	325.2	495.6	1120.7	2616.0	17114.8
516531	637.34	6168.5	0.00	0.00	0.00	0.99	3.20	19.85	58.1	128.6	259.9	691.4	1990.5	7755.6
515931	396.56	5179.9	0.00	0.00	0.00	0.01	1.78	16.21	43.1	79.0	125.0	348.8	1090.8	10909.5
516031	1377.07	13642.9	0.00	0.00	0.00	0.07	15.62	111.02	251.5	411.9	730.8	1533.5	3668.9	20244.2
516131	632.05	6231.6	0.90	3.80	4.70	16.08	23.81	68.98	125.7	194.4	302.5	686.0	1741.7	9970.7
516231	157.58	1533.9	0.00	0.00	0.00	0.61	2.69	11.09	28.6	45.8	75.9	177.8	469.4	2496.9
516331	510.93	4536.9	0.00	0.04	0.18	5.18	15.48	58.08	116.5	179.7	274.7	644.1	1488.6	7002.8
516431	610.17	6029.1	0.00	0.00	0.00	0.05	0.14	24.07	75.3	127.9	237.4	609.3	2021.8	8654.6

Table 8.7
Linear Interpolation Disaggregation Method
Flow-Frequency Statistics for Daily Naturalized Stream Flows, acre-feet per day

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	3609.23	33098.2	0.00	1.80	7.43	43.31	120.15	415.67	848.6	1329.2	2057.1	4216.2	9779.3	71863.0
BRBR59	11027.70	93695.8	0.00	28.33	75.46	282.73	620.03	1656.13	3270.8	4949.7	7127.1	13291.5	28211.5	203605.2
BRHE68	14671.64	113466.7	0.29	68.95	175.37	521.84	1016.59	2521.61	4801.5	6944.0	10055.6	18766.1	37675.1	241718.9
BRRI70	16016.66	117537.1	0.00	85.14	284.08	770.09	1401.50	3216.28	5680.3	7940.2	11470.4	20527.8	40550.3	262967.8
BRGM73	16714.84	121654.7	0.01	105.02	319.90	808.90	1501.20	3497.15	5977.1	8342.6	11990.8	21573.2	42544.1	267816.1
515531	2172.36	26908.7	0.00	0.00	0.00	1.12	21.66	146.54	342.8	544.6	914.5	2097.8	5375.3	76829.3
515631	2994.79	34747.4	0.00	0.00	2.18	17.71	64.77	254.77	535.6	872.7	1464.4	3095.6	7605.5	118275.1
515731	3742.19	39435.2	0.00	2.24	6.14	32.59	114.06	417.48	842.4	1319.8	2065.2	4078.4	9631.6	130674.7
515831	201.96	2401.7	0.00	0.00	0.00	0.00	0.00	0.33	8.4	24.9	53.3	196.6	635.4	5996.3
509431	978.66	10414.5	0.00	0.00	0.09	0.70	4.87	62.10	163.4	274.5	472.1	1044.7	2660.5	27989.9
516531	637.34	6775.6	0.00	0.00	0.00	0.19	1.16	11.56	41.6	99.4	218.4	664.0	2051.3	13499.6
515931	396.56	5628.7	0.00	0.00	0.00	0.01	0.43	9.38	33.1	63.8	113.0	309.7	1053.1	17201.5
516031	1377.07	14590.9	0.00	0.00	0.00	0.05	4.24	83.41	211.5	379.6	678.7	1431.4	3791.2	30209.2
516131	632.05	6655.2	0.00	0.40	1.24	5.68	16.78	54.93	113.3	185.0	289.8	656.4	1740.7	16817.6
516231	157.58	1646.2	0.00	0.00	0.00	0.11	1.60	8.44	23.2	41.8	67.9	174.0	466.7	4467.0
516331	510.93	4859.3	0.00	0.02	0.08	2.23	9.32	46.47	106.2	170.2	259.2	614.9	1453.9	11700.6
516431	610.17	6604.3	0.00	0.00	0.00	0.03	0.13	13.85	52.9	104.6	207.4	601.5	1941.5	11630.1

Table 8.8
Flow Pattern Disaggregation Method
Flow-Frequency Statistics for Daily Naturalized Stream Flows, acre-feet per day

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	3609.23	52884.7	0.00	5.25	15.60	40.40	86.35	309.13	608.8	941.4	1505.3	3120.1	8211.2	289749.2
BRBR59	11027.70	136251.4	0.00	173.59	235.31	400.05	623.20	1309.30	2293.0	3328.5	4970.3	10061.4	26679.6	719015.3
BRHE68	14671.64	154395.5	4.72	303.04	407.49	640.35	988.37	2049.15	3464.8	5018.9	7618.8	15116.6	38178.6	759900.8
BRRI70	16016.66	157058.8	0.00	347.82	502.13	803.53	1199.23	2463.31	4149.3	5975.9	8980.2	17174.1	40730.7	645000.9
BRGM73	16714.84	161331.9	0.01	362.81	530.45	862.16	1286.37	2675.55	4472.3	6389.1	9582.4	17925.0	42078.3	586041.8
515531	2172.36	41586.8	0.00	0.00	0.00	0.00	0.00	62.92	219.9	365.6	564.0	1256.1	4078.0	192249.2
515631	2994.79	50689.1	0.00	0.00	1.20	33.00	77.03	233.16	430.5	614.3	894.8	1856.5	6112.8	178772.0
515731	3742.19	56352.8	0.00	1.78	16.16	62.19	124.25	340.67	626.6	904.9	1313.9	2681.5	8381.6	193611.7
515831	201.96	6493.0	0.00	0.00	0.00	0.00	0.00	0.00	2.9	7.1	15.9	49.0	197.2	44240.4
509431	978.66	20698.6	0.00	0.00	0.00	0.48	3.59	34.17	96.8	168.4	284.3	630.5	1940.0	219455.4
516531	637.34	13890.4	0.00	0.00	0.00	0.00	0.00	5.30	18.1	36.8	72.3	211.3	1303.4	72246.6
515931	396.56	12970.0	0.00	0.00	0.00	0.00	0.00	2.55	13.6	28.8	56.1	138.7	685.9	200315.7
516031	1377.07	23458.8	0.00	0.00	0.00	0.00	0.76	43.41	133.2	250.3	447.7	1038.6	3157.8	165626.0
516131	632.05	13367.1	0.00	0.00	0.00	2.68	9.75	32.88	71.7	116.2	197.1	501.7	1461.6	120489.0
516231	157.58	3569.7	0.00	0.00	0.00	0.00	1.11	6.13	17.4	30.6	49.7	124.3	340.8	26837.0
516331	510.93	9253.5	0.00	0.00	0.00	1.34	6.76	33.23	77.1	114.8	184.6	433.6	1094.2	61175.3
516431	610.17	13080.9	0.00	0.00	0.00	0.00	0.00	4.20	20.7	45.5	89.5	265.6	1245.9	98735.3

Differences in flow-frequency quantities are most evident in the low and high magnitude flows. In particular, locations with the highest daily flow variability exhibit the greatest differences in flow-frequency statistics according to the disaggregation method. For example, the outlets of relatively small drainage basins like those for Lakes Aquilla and Limestone are located at control points 5151831 and 516531, respectively. The watershed area of Aquilla Lake is 254 square miles, and the watershed area of Limestone Lake is 678 square miles. Comparison of either the uniform or the linear disaggregation method to the flow pattern disaggregation method shows a dramatic difference in the flow-frequency tables. In general, the flow-frequencies at all control point locations are sensitive to change from the uniform or linear interpolation method to the flow pattern disaggregation method.

Figure 8.7 shows the flow-exceedance frequency curves at the location of Aquilla Lake for the uniform, linear interpolation and flow pattern methods of disaggregating naturalized flow. All days in the Bwam period-of-analysis are represented in the figure. The flow-exceedance curve for the flow pattern method of disaggregation crosses the uniform and linear interpolation method flow-exceedance curves at 3.1% exceedance. Smoothing high flow events across adjacent time steps in the uniform and linear interpolation methods of disaggregation results in flow-exceedance values which are higher than the flow pattern method for all values of exceedance greater than 3.1%. Large distortions in flow-frequency due to smoothing high flows across lower flow time steps are more likely where flows regimes can be characterized by high flow pulse or flash flooding events.

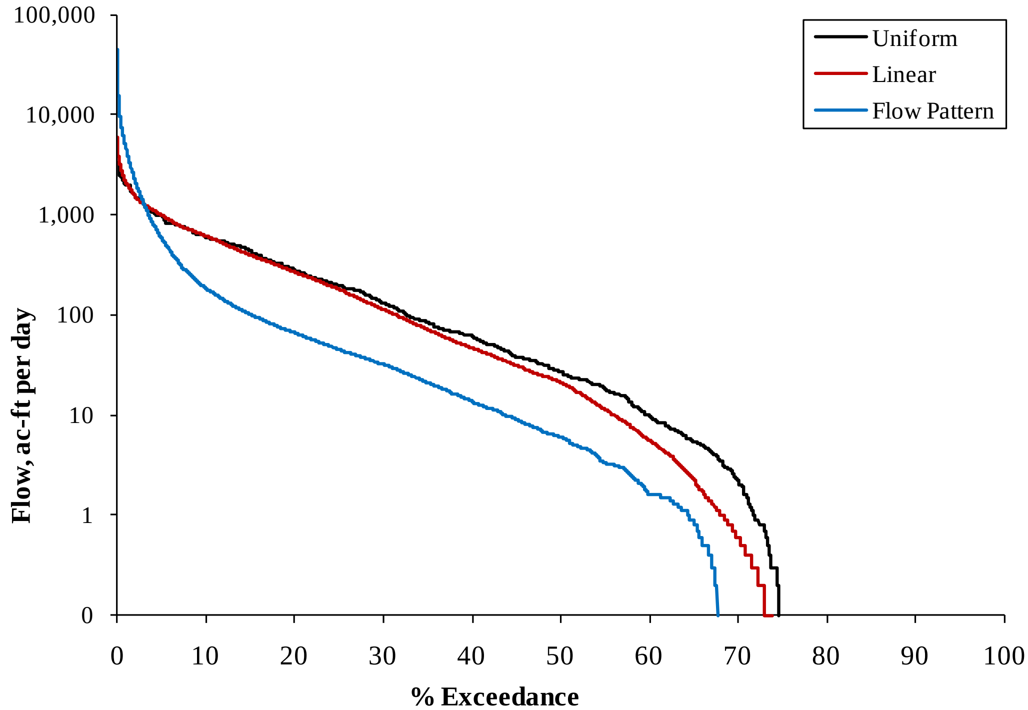

Figure 8.7 Daily Naturalized Flow Volume versus Exceedance Frequency at Aquilla Lake for the Uniform, Linear Interpolation and Flow Pattern Disaggregation Methods

Figure 8.8 shows the flow-exceedance frequency curves at the location of the Richmond gage for the uniform, linear interpolation and flow pattern methods of disaggregating naturalized flow. All days in the Bwam period-of-analysis are represented in the figure. The watershed area above the Richmond gage is 35,454 square miles. Unlike the relatively small drainage area upstream of the location of Aquilla Lake, the flow events at the Richmond gage may have a larger percentage of baseflow contribution and can be comprised of attenuated pulse flows from distant upstream tributaries. The flow-exceedance curves at the Richmond gage are different for the three methods of disaggregation, though not as visually different as those presented in Figure 8.7 for the location of Aquilla Lake. The flow-exceedance curve for the flow pattern method of disaggregation crosses the uniform and linear interpolation method flow-exceedance curves for flows below 10.0% exceedance. The flow-exceedance curve for the linear interpolation method crosses under the flow pattern curve at 90.1%. As will be shown in Figure 8.11 and 8.12, the linear interpolation method occasionally draws interpolation splines that dip below the flows that are generated in the uniform or flow pattern methods of disaggregation.

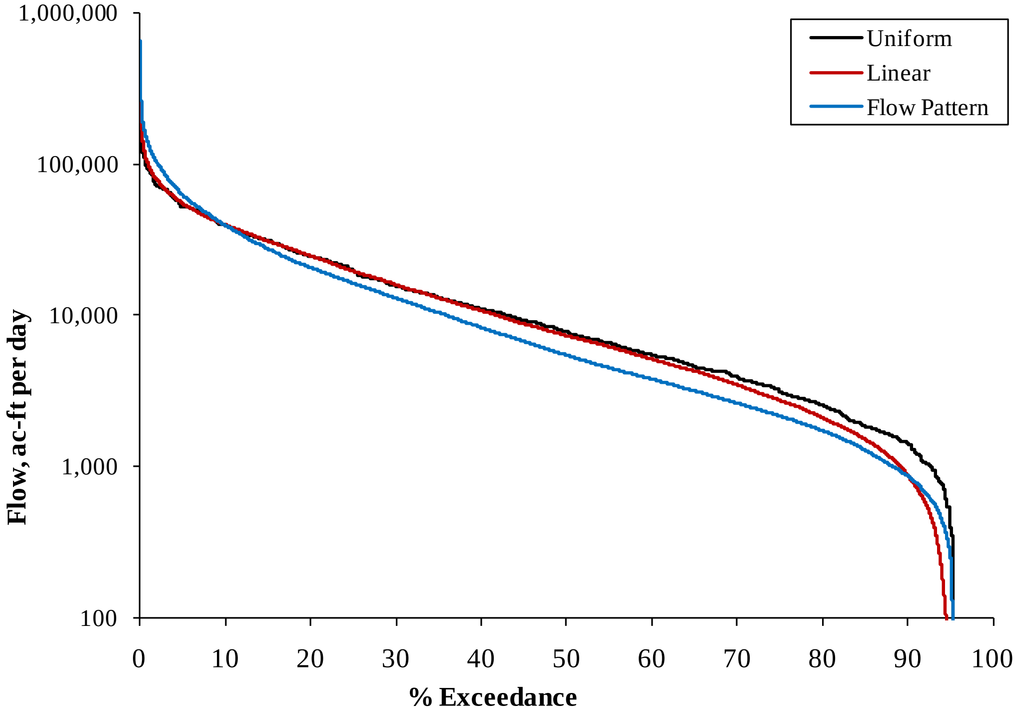

Figure 8.8 Daily Naturalized Flow Volume versus Exceedance Frequency at the Richmond Gage for the Uniform, Linear Interpolation and Flow Pattern Disaggregation Methods

Figures 8.9 shows a portion of the Bwam period-of-analysis daily disaggregated naturalized flow at the location of Aquilla Lake. Figure 8.10 is the same sequence of flows at Aquilla Lake, but with a different scale on the ordinate axis to make the lower flow magnitudes visible. Figures 8.11 and 8.12 show the same period of flows, but at the Richmond gage.

The uniform and linear interpolation methods of disaggregation match reasonably with the low flow period in Figure 8.12 in January, 1952 and September through October, 1952. These periods were characterized by relatively uniform flows from day to day. Whenever the flow pattern is characterized by rapidly rising and falling flow rates, there is a larger divergence between the flow pattern method and the uniform and linear interpolation methods of disaggregation. The effect on water availability of these differences are examined in Chapter 9.

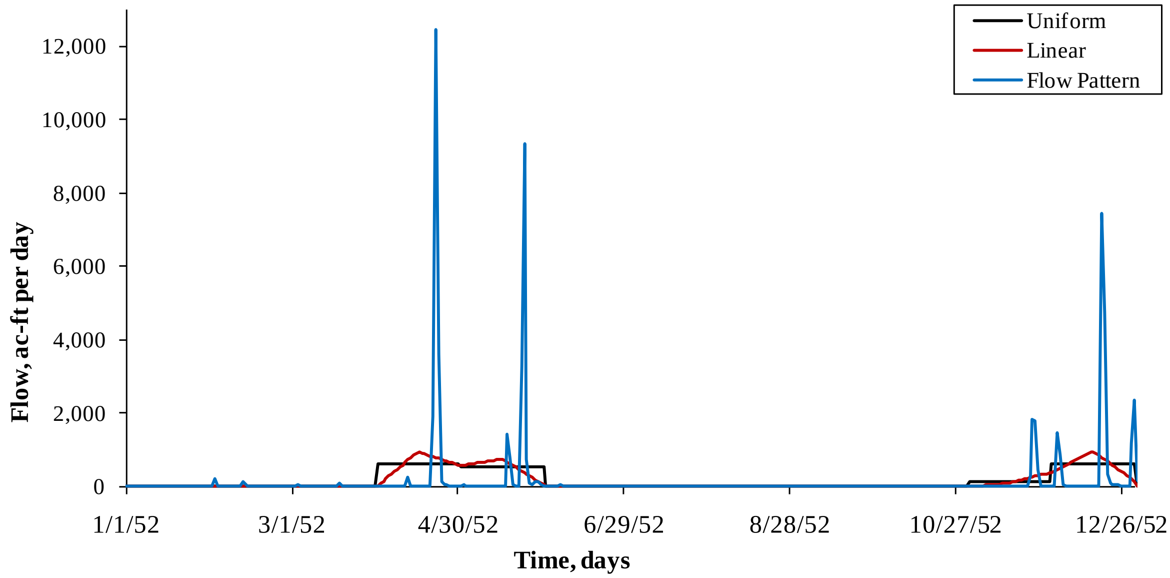

Figure 8.9 Example of Daily Naturalized Flows at Aquilla Lake for the Uniform, Linear Interpolation and Flow Pattern Disaggregation Methods

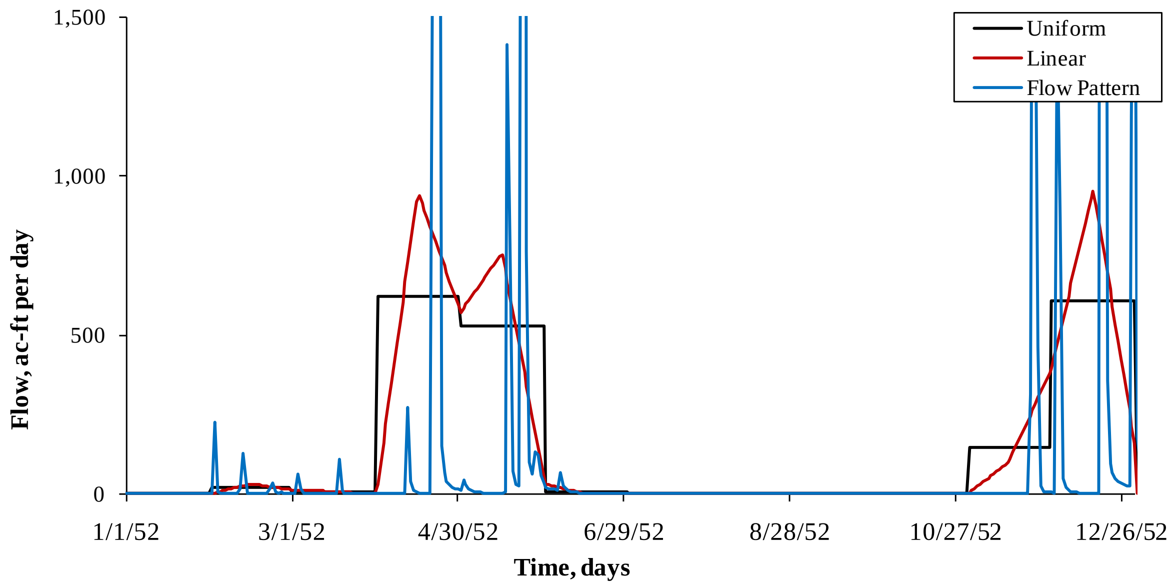

Figure 8.10 Example of Daily Naturalized Flows at Aquilla Lake for the Uniform, Linear Interpolation and Flow Pattern Disaggregation Methods

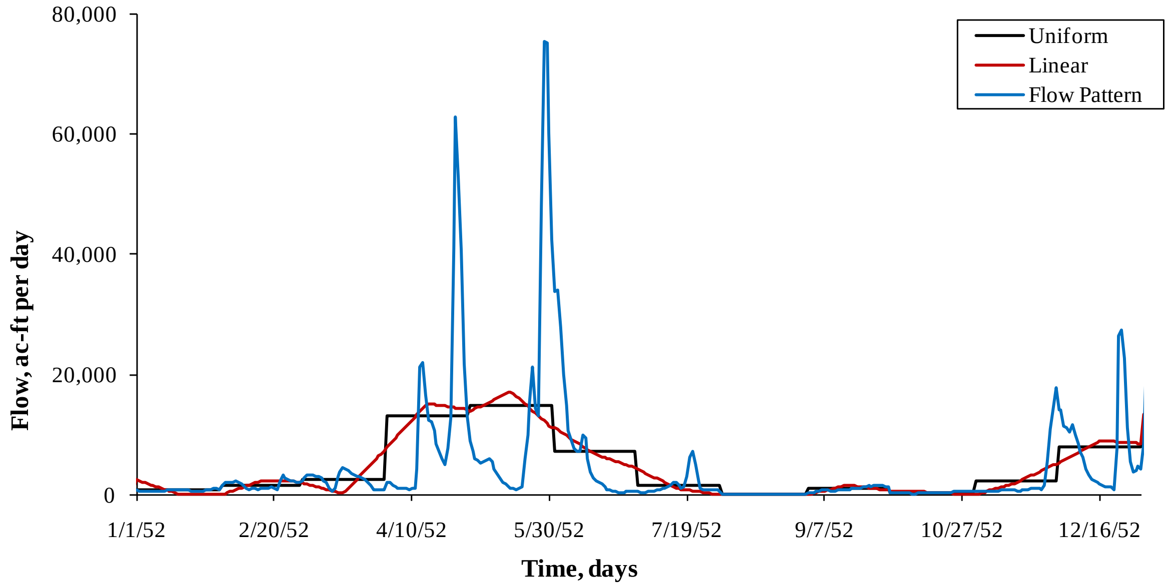

Figure 8.11 Example of Daily Naturalized Flows at the Richmond Gage for the Uniform, Linear Interpolation and Flow Pattern Disaggregation Methods

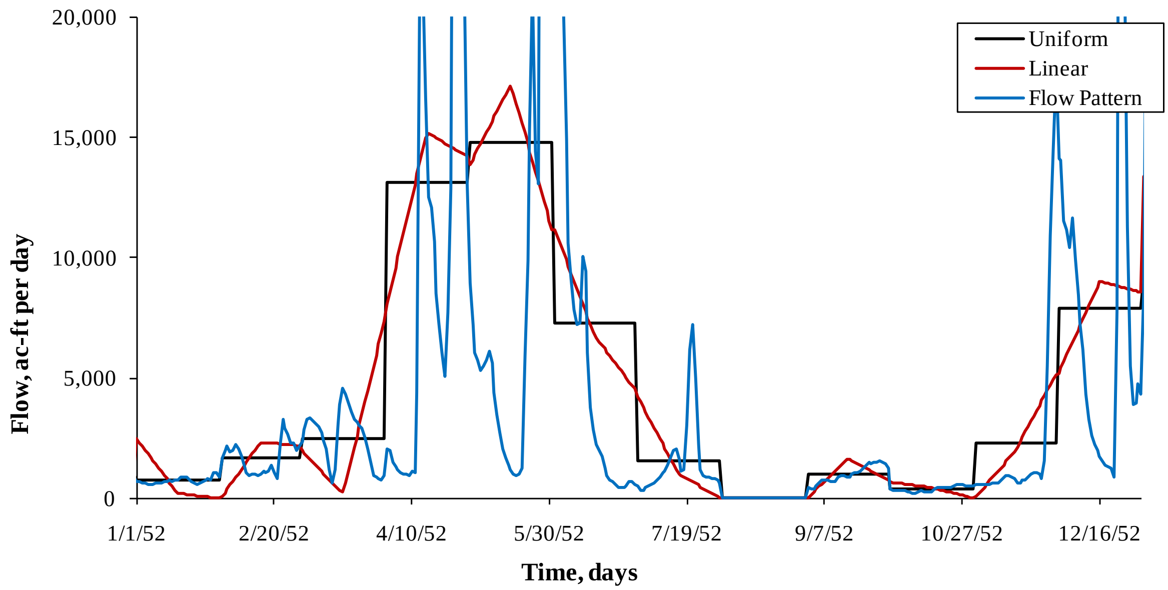

Figure 8.12 Example of Daily Naturalized Flows at the Richmond Gage for the Uniform, Linear Interpolation and Flow Pattern Disaggregation Methods

Flow Routing Parameters

Daily simulation time steps necessitate consideration of the travel time of changes to flow in the *SIMD* simulation. The naturalized and regulated flows at each control point in a *SIM* or *SIMD* simulation represent the total stream flow, rather than incremental flow, at each location. Changes to total flows resulting from water management actions are cascaded downstream through the control point network in the simulation computations. In large river basins, the travel time to the outlet from various points in the basin may range up to several days or perhaps many days.

Travel time and the effects of attenuation are characterized with flow routing parameters in *SIMD*. Routing occurs between two control points if and only if routing parameters are provided for the upstream control point of the river reach. In the absence of routing parameters for a river reach, the routing methods in *SIMD* are not activated during the simulation. On reaches without routing, changes to flow entering the upstream end of the reach will equal the changes to flow exiting the downstream end of the reach each day less any channel losses.

SIMD incorporates two alternative approaches for routing changes to flow, the lag and attenuation method and an adaptation of the Muskingum method. The lag and attenuation method is the generally recommended option for most applications and is the method adopted for the Brazos WAM study reported here. Muskingum routing parameters are also included in this chapter for comparison with the lag and attenuation parameters.

The *Daily Manual* contains a detailed description of the premises and methodologies of the two alternative routing methods. Both methods have analogous input parameters related to travel time and storage attenuation that are best determined through calibration. Different sets of routing parameters may be applied to flow changes associated with *WR* record water rights versus flow changes resulting from flood control operations.

Routing parameters are provided as input on the *RT* records. The *RT* records are placed in the DCF file before the *DF* records. The routing parameters are applied in every time step of the simulation. Therefore, the parameters should be given as a best fit for flow conditions over the entire period of record. The following section describes the calibration of routing parameters using program *DAY* based on the SUPER flow data for the Bwam period of record.

Locations for Routing Reaches

As discussed earlier in this chapter, the control points in the Bwam dataset were assigned the pattern of the first downstream SUPER flow daily flow pattern for disaggregation of monthly to daily flows. The SUPER flows were input as *DF* records in the DCF file. Assignments of the *DF* record daily patterns to each control point in the Bwam dataset were made on the *DC* records. Routing reaches were designated in the Bwam dataset at the same location of each *DF* record pattern set. The only exception was that no routing parameters were needed at the location of the most downstream *DF* record set. Designating routing reaches where the disaggregation transitions from one *DF* record flow pattern to the next ensures that travel time and attenuation between the flow patterns is also being applied to the changes in flow. An example of the transition of daily flow pattern is shown in Figure 8.5.

Calibration Settings in Program DAY

The calibration routine in *DAY* seeks to minimize the value of an objective function selected by the user from five alternative objective functions for use in the calibration of routing parameters. The objective function options are explained in detail in the *Daily Manual*. Objective function 1 computes the root of the mean squared error between the routed hydrograph and the measured hydrograph at the downstream location. Objective function 2 computes the mean absolute error between the routed and measured hydrographs. Objective function 3 computes the mean absolute error in daily lateral inflow volume. Objective function 4 is a weighted average of objective function 1 and objective function 3. Objective function 5 is a weighted average of objective function 2 and objective function 3. Options 5 and 4 were adopted for the Brazos WAM study for *SIMD* normal and flood flow operations, respectively. The default *RTYPES* record attenuation limiting factor, *LF*, was utilized in all calibrations.

Objective function 5 was adopted with a weighting factor of 0.80 for the calibration of the Bwam routing parameters for all flow conditions. Therefore, parameters selected by *DAY* in the calibration routine provided an optimized minimum value of the mean absolute error in lateral inflow volume plus the mean absolute error. Objective function 3 was given a 0.80 weight and objective function 2 was given a weight of 0.20 in the calculation of objective function 5. Objective function 5 was utilized for calibrating routing parameters for all flow conditions because minimizing absolute errors in objective function 3 allows lower flow conditions nearer to the central tendency of the flow regime to contribute meaningfully to the objective function value.

Calibration of the Bwam routing parameters for high flow conditions utilized objective function 4 with a weighting factor of 0.80. Squared errors tend to favor the minimization of the objective function for peak flow events. Therefore, objective functions 1 and 4 are more suited for calibrating routing parameters to be used for high flow conditions. High flow conditions were defined as any time step in which the flow at the upstream end of the reach meets or exceeds a flow criteria. The calibration routine steps through every time step in the input dataset. However, only those time steps which meet the upstream flow threshold are used to compute the objective function value.

High flow conditions for the calibration were defined as any time step with a flow equal to or greater than the 25% exceedance frequency level at the upstream end of the reach. The 25% exceedance level does not correspond to flow conditions which would typically warrant the use of flood control reservoirs to impound water. However, flood control releases in *SIMD* will be made after a flood event and will utilize the same routing parameters as used when the flood flows were impounded. The routing parameters should represent the range of high flow conditions under which both flood control storage and releases are made.

Figure 8.13 shows the daily flow volume versus exceedance frequency curve for the Bryan gage, Bwam control point BRBR59. The curve was developed with the Bwam *DF* record set for the 1940 to 1997 period-of-analysis. A mean daily flow rate of 5,129 cfs or daily flow volume of 5,129 second-foot-day (cfs-day) was equaled or exceeded during 25 percent of the 21,185 days of the 1940-1997 period-of-analysis. The 25% exceedance frequency unregulated flow for the Brazos River gage near Bryan in the SUPER flow dataset is equal to 384,480 cfs.

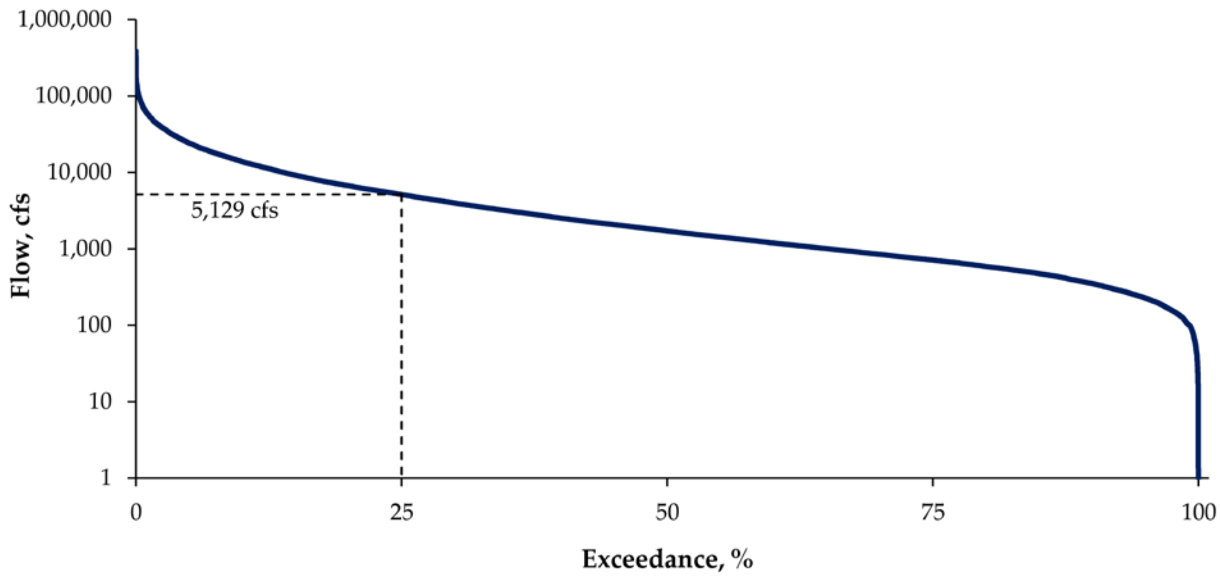

Figure 8.13 Daily Flow versus Exceedance Frequency at Bwam Control Point BRBR59

Calibration of Routing Reaches

The lag and attenuation method was adopted for the *SIMD* simulation studies of Chapters 9 and 10. Unlike the Muskingum method, the lag and attenuation method is able to maintain the water balance for routing reaches with short travel time. Some routing reaches in the Bwam dataset have much less than one-day of travel time under certain flow conditions. These reaches may not be appropriate for calibration of Muskingum routing parameters.

Lag and attenuation method routing parameters for the Bwam *SIMD* input dataset were calibrated with *DAY* for each location of the SUPER flow data which were input as *DF* records. The calibration was performed between an upstream *DF* record set and the next downstream *DF* record set. All control points between *DF* record sets are assigned the pattern of the first downstream *DF* record set. There may be a short real-world spatial distance between a control point which is coincident with a *DF* record set and the next downstream control point that is assigned the *DF* records of the next downstream daily pattern. However, the routing parameters for the routing reach, as conceptually illustrated in Figure 8.6, are intended to simulate the travel time and attenuation effect occurring with the transition in patterns.

DAY was used to calibrate the lag and attenuation parameters between each *DF* record set. The calibrated routing parameters were used as *RT* record inputs at the locations of the upstream *DF* record set. For example, in Figure 8.6 the calibration would be performed with *DF* record set A and B. The routing parameters would be used as *RT* record input for the control point location of *DF* record set A. The *SIMD* simulation would rout flow from the location of *DF* record set A to the next downstream control point. No other routing parameters are encountered until the change in flow is passed to the control point location of *DF* record set B.

Where multiple upstream *DF* record sets have a common downstream *DF* record set, *DAY* can calibrate the routing parameters at each of the upstream locations simultaneously for the outflow hydrograph at the common downstream location. For example, as shown in Figure 8.2, BRHB42 and LRCA58 have a common downstream *DF* record set at BRBR59. Calibrating the routing parameters in *DAY* simultaneously for BRHB42 and LRCA58 improves the mass balance with BRBR59 during the routing process than if either BRHB42 or LRCA58 were calibrated separately.

Calibration of the lag and attenuation routing parameters was conducted for all flow conditions and for high flow conditions separately. The parameters calibrated for all flow conditions are used as input on the *RT* records for routing the changes to flow caused by *WR* record water rights. The high flow routing parameters are used as input on the *RT* records for routing the changes to flow caused by *FR* record flood control rights.

The results of the routing parameter calibrations are presented in Tables 8.9 for all flow conditions and Table 8.10 for high flow conditions. All calibrations utilized the *DF* record sets developed from the SUPER flow dataset. The exception is the routing parameters in Table 8.9 for the Richmond control point. There are no SUPER flows below Richmond. In order to calibrate a set of routing parameters for the Richmond to Rosharon reach, USGS stream flow gaging data were utilized. Routing parameters for all flow conditions were calibrated for the Richmond reach as shown in Table 8.9. These lag and attenuation parameters were used in *DAY* to rout the SUPER time series of flows at control point BRRI70. This produced a time series of flows for use at the Rosharon control point BRRO72 which are based entirely on the SUPER flows at Richmond but routed with the parameters in Table 8.9. Routing during high flows from Richmond to Rosharon in *SIMD* utilizes the same routing parameters.

The final two columns of Tables 8.9 and 8.10 are for comparing values of the routing parameters between control points. The singular value of lag and attenuation per control point in Table 8.9 covers all flow conditions and all seasons over a period-of-analysis with 21,185 daily time steps. Upstream control points contribute varying percentages of flow to their downstream outflow control point. Information regarding river reach conditions such as gradient, channel geometry and vegetation is not presented in the tables. The value of lag and attenuation per control point in Table 8.10 cover a smaller and more consistent subset of flows. The lag parameter can be interpreted as the travel time for the last portion of the receding limb of a hydrograph. However, there is generally a low correlation between travel time and flow rate for reaches in the Brazos River Basin [23].

The lag times in Tables 8.9 and 8.10, expressed as miles/day, can be compared with the results of a U.S. Geological Survey [23] investigation of stream flow wave translatory travel times on the Brazos, Leon, and Little Rivers. The USGS used stream flow records for gages on the Brazos River at Whitney, Waco, Bryan, Hempstead, and Richmond for December 10, 1951 to September 30, 1967. Flow records were used from gages on the Leon River near Belton, Little River near Little River, and Little at Cameron for the period March 8, 1954 to September 30, 1967. The results of the investigation are summarized by the abstract of the USGS report [23] which is reproduced as follows. Wave travel times in miles/day are added in parenthesis in the following quotation for comparison with the lag times expressed in miles/day in Tables 8.9 and 8.10.

Table 8.9
Lag and Attenuation Routing Parameters for All Flow Conditions for SUPER 1940-1997 Period-of-Analysis

River Reach						Calibration Results					
Reach Name	Inflow Control Point	Outflow Control Point	Median Daily Inflow, cfs	Median Daily Outflow, cfs	Reach Length, miles	Lag, days	Att., days	Obj. Func. 5, cfs	Linear Corr. Coef.	Miles per Day of Lag	Miles per Day of Att
Possum Kingdom Outflow	515531	BRDE29	212	298	101	1.54	1.22	71	0.94	65.6	82.8
Dennis	BRDE29	515631	298	330	46	0.27	1.02	43	0.99	170.4	45.1
Grandbury Outflow	515631	BRGR30	330	349	32	0.52	1.05	5	1.00	61.5	30.5
Glen Rose	BRGR30	515731	349	467	65	0.52	1.03	75	0.94	125.0	63.1
Whitney Outflow	515731	CON070	467	565	28	0.31	1.06	31	1.00	90.3	26.4
Aquilla Outflow	515831	CON070	6	565	24	0.31	1.06	*	*	77.4	22.6
Bosque Outflow	227901	NBCL36	18	26	22	0.00	1.00	12	0.97	na	22.0
Clifton	NBCL36	509431	26	80	40	0.51	1.02	54	0.82	78.4	39.2
Lake Waco Outflow	509431	BRWA41	80	726	10	0.05	1.01	18	1.00	200.0	9.9
Elm Mott	CON070	BRWA41	565	726	16	0.41	1.03	*	*	39.0	15.5
Waco (Brazos)	BRWA41	BRHB42	726	889	60	0.82	1.14	103	0.98	73.2	52.6
Proctor Outflow	515931	LEGT47	15	55	120	2.71	1.43	43	0.79	44.3	83.9
Gatesville	LEGT47	516031	55	156	77	1.51	1.08	78	0.72	51.0	71.3
Stillhouse Outflow	516131	CON095	56	96	15	0.30	1.04	18	0.98	50.0	14.4
Lampasas Mouth	CON095	LRLR53	96	323	7	0.29	1.01	19	1.00	24.1	6.9
Belton Outflow	516031	LRLR53	156	323	23	0.39	1.02	*	*	59.0	22.5
Georgetown Outflow	516231	GAGE56	17	29	5	0.17	1.01	0	1.00	29.4	5.0
South Fork Outflow	SGGE55	GAGE56	11	29	3	0.17	1.01	*	*	17.6	3.0
Georgetown	GAGE56	516331	29	66	28	0.52	1.05	27	0.85	53.8	26.7
Granger Outflow	516331	CON102	66	109	26	0.46	1.05	46	0.93	56.5	24.8
Rockdale	CON102	LRCA58	109	504	16	0.02	1.01	44	0.99	800.0	15.8
Little River	LRLR53	LRCA58	323	504	62	1.24	1.29	*	*	50.0	48.1
Cameron	LRCA58	BRBR59	504	1,710	67	0.86	1.07	158	0.99	77.9	62.6
Highbank	BRHB42	BRBR59	889	1,710	68	1.22	1.29	*	*	55.7	52.7
Limestone Outflow	516531	NAEA66	22	48	17	1.46	1.14	27	0.95	11.6	14.9
Easterly	NAEA66	NABR67	48	93	34	2.37	1.59	39	0.96	14.3	21.4
Bryan (Navasota)	NABR67	CON231	93	235	60	5.34	2.33	78	0.91	11.2	25.8
Somerville Outflow	516431	CON129	32	97	14	0.17	1.01	37	0.96	82.4	13.9
Bryan (Brazos)	BRBR59	CON147	1,710	2,058	56	0.64	1.01	191	0.99	87.5	55.4
Yegua Mouth	CON129	CON147	97	2,058	23	0.00	1.00	*	*	na	23.0
Navasota Mouth	CON231	CON147	235	2,058	6	0.00	1.00	*	*	na	6.0
Washington	CON147	BRHE68	2,058	2,490	32	0.59	1.02	289	0.97	54.2	31.4
Hempstead	BRHE68	BRRI70	2,490	2,860	105	1.26	1.28	188	0.99	83.3	82.0
Richmond**	BRRI70	BRRO72	3,490	3,490	38	0.59	1.12	0	1.00	64.4	33.9

* Values are given for the first reach listed in a multiple-upstream inflow site calibration.
** Gaged flow data used for USGS gages 08114000 and 08116650. Concurrent gaged flow period-of-record utilized was January 1968 through September 1980 and May 1984 through December 2008.

Table 8.10
Lag and Attenuation Routing Parameters for High Flow Condition (25% Exceedance Frequency) for SUPER 1940-1997 Period-of-Analysis

River Reach						Calibration Results					
Reach Name	Inflow Control Point	Outflow Control Point	25% Exc Inflow, cfs	Max Inflow, cfs	Reach Length, miles	Lag, days	Att., days	Obj. Func. 4, cfs	Linear Corr. Coef.	Miles per Day of Lag	Miles per Day of Att
Possum Kingdom Outflow	515531	BRDE29	661	90,596	101	0.69	1.09	776	0.91	146.4	92.7
Dennis	BRDE29	515631	834	95,785	46	0.08	1.02	306	0.99	575.0	45.1
Grandbury Outflow	515631	BRGR30	948	88,420	32	0.52	1.10	131	1.00	61.5	29.1
Glen Rose	BRGR30	515731	992	87,279	65	0.07	1.01	687	0.93	928.6	64.4
Whitney Outflow	515731	CON070	1,360	112,782	28	0.18	1.00	379	0.99	155.6	28.0
Aquilla Outflow	515831	CON070	30	27,000	24	0.30	1.07	*	*	80.0	22.4
Bosque Outflow	227901	NBCL36	81	70,664	22	0.18	1.01	132	1.00	122.2	21.8
Clifton	NBCL36	509431	115	92,208	40	0.23	1.04	436	0.82	173.9	38.5
Lake Waco Outflow	509431	BRWA41	298	104,265	10	0.11	1.02	254	1.00	90.9	9.8
Elm Mott	CON070	BRWA41	1,618	146,190	16	0.35	1.05	*	*	45.7	15.2
Waco (Brazos)	BRWA41	BRHB42	2,118	227,752	60	0.69	1.08	676	0.98	87.0	55.6
Proctor Outflow	515931	LEGT47	69	100,817	120	2.38	1.59	378	0.79	50.4	75.5
Gatesville	LEGT47	516031	236	54,270	77	1.19	1.30	644	0.70	64.7	59.2
Stillhouse Outflow	516131	CON095	244	55,900	15	0.26	1.01	126	0.98	57.7	14.9
Lampasas Mouth	CON095	LRLR53	339	52,394	7	0.15	1.03	179	1.00	46.7	6.8
Belton Outflow	516031	LRLR53	579	91,637	23	0.43	1.03	*	*	53.5	22.3
Georgetown Outflow	516231	GAGE56	69	15,665	5	0.17	1.01	2	1.00	29.4	5.0
South Fork Outflow	SGGE55	GAGE56	40	8,435	3	0.17	1.01	*	*	17.6	3.0
Georgetown	GAGE56	516331	112	20,873	28	0.35	1.07	221	0.83	80.0	26.2
Granger Outflow	516331	CON102	229	31,151	26	0.40	1.07	392	0.92	65.0	24.3
Rockdale	CON102	LRCA58	364	46,975	16	0.00	1.00	418	0.99	na	16.0
Little River	LRLR53	LRCA58	1,074	110,331	62	1.11	1.22	*	*	55.9	50.8
Cameron	LRCA58	BRBR59	1,634	157,415	67	0.83	1.10	1305	0.98	80.7	60.9
Highbank	BRHB42	BRBR59	2,593	228,919	68	0.91	1.10	*	*	75.1	61.8
Limestone Outflow	516531	NAEA66	122	36,489	17	0.74	1.09	238	0.95	23.0	15.6
Easterly	NAEA66	NABR67	198	43,584	34	1.80	1.27	249	0.95	18.9	26.8
Bryan (Navasota)	NABR67	CON231	406	37,356	60	3.62	1.89	576	0.81	16.6	31.7
Somerville Outflow	516431	CON129	164	49,900	14	0.13	1.00	202	0.96	107.7	14.0
Bryan (Brazos)	BRBR59	CON147	5,128	384,480	56	0.54	1.04	888	0.99	103.7	53.8
Yegua Mouth	CON129	CON147	364	46,972	23	0.12	1.00	*	*	191.7	23.0
Navasota Mouth	CON231	CON147	922	30,251	6	0.00	1.00	*	*	na	6.0
Washington	CON147	BRHE68	6,032	399,920	32	0.60	1.06	1446	0.96	53.3	30.2
Hempstead	BRHE68	BRRI70	7,469	401,773	105	1.03	1.07	1041	0.98	101.9	98.1

″Travel times of peaks for the 346.4-mile reach of the Brazos River between Whitney and Richmond varied from 213 hours (39.0 miles/day) at 1,000 cfs to 92 hours (90.4 miles/day) at 40,000 cfs, to 168 hours (49.5 miles/day) at 100,000 cfs

Minimum travel times of peaks for the 82-mile reach between Leon River near Belton and Little River at Cameron varied from 57 hours (34.5 miles/day) for initial flow less than 15 cfs at Belton to 42 hours (46.9 miles/day) for initial flow above 200 cfs at Belton.

Minimum travel times of peaks for the 65-mile reach between Little River at Cameron to Brazos River near Bryan varied from 30 hours (52.0 miles/hour) for 1,000 cfs to 22 hours (70.9 miles/day) for 3,500 cfs, to 25 hours (62.4 miles/day) for 65,000 cfs, to 34 hours (44.6 miles/day) for 134,000 cfs.

Travel time was not consistent for any discharge, and was even more inconsistent in the low discharge range. Minimum peak travel time for each channel condition was fairly well defined.″ [23]

Table 8.11
Lag and Attenuation and Muskingum Routing Parameters for
All Flow Conditions in the SUPER Period-of-Analysis January 1940 through December 1997

River Reach					Calibration Results			
Reach Name	Inflow Control Point	Outflow Control Point	Reach Length, miles	Routing Method	Lag or K	Att. or X	Obj. Func. 5, cfs	Linear Corr. Coef.
Glen Rose	BRGR30	515731	65	lag-attenuation	0.52	1.03	75	0.94
				Muskingum	0.50	0.00	75	0.94
Waco (Brazos)	BRWA41	BRHB42	60	lag-attenuation	0.82	1.14	103	0.98
				Muskingum	0.80	0.18	118	0.98
Gatesville	LEGT47	516031	77	lag-attenuation	1.51	1.08	78	0.72
				Muskingum	1.67	0.23	80	0.81
Cameron	LRCA58	BRBR59	67	lag-attenuation	0.86	1.07	158	0.99
				Muskingum	0.97	0.21	228	0.97
Highbank	BRHB42	BRBR59	68	lag-attenuation	1.22	1.29	*	*
				Muskingum	1.11	0.36	*	*
Bryan	NABR67	CON231	60	lag-attenuation	5.34	2.33	78	0.91
				Muskingum	4.94	0.10	101	0.84
Hempstead	BRHE68	BRRI70	105	lag-attenuation	1.26	1.28	188	0.99
				Muskingum	1.21	0.37	296	0.97

Table 8.12
Lag and Attenuation and Muskingum Routing Parameters for
High Flow Conditions (25% Exceedance Frequency)
in the SUPER Period-of-Analysis January 1940 through December 1997

River Reach					Calibration Results			
Reach Name	Inflow Control Point	Outflow Control Point	Reach Length, miles	Routing Method	Lag or K	Att. or X	Obj. Func. 4, cfs	Linear Corr. Coef.
Glen Rose	BRGR30	515731	65	lag-attenuation	0.07	1.01	687	0.93
				Muskingum	0.50	0.00	745	0.93
Waco (Brazos)	BRWA41	BRHB42	60	lag-attenuation	0.69	1.08	676	0.98
				Muskingum	0.63	0.20	746	0.97
Gatesville	LEGT47	516031	77	lag-attenuation	1.19	1.30	644	0.70
				Muskingum	1.30	0.05	623	0.75
Cameron	LRCA58	BRBR59	67	lag-attenuation	0.83	1.10	1,305	0.98
				Muskingum	0.73	0.31	1,747	0.94
Highbank	BRHB42	BRBR59	68	lag-attenuation	0.91	1.10	*	*
				Muskingum	0.83	0.34	*	*
Bryan	NABR67	CON231	60	lag-attenuation	3.62	1.89	576	0.81
(Navasota)				Muskingum	2.45	0.20	643	0.57
Hempstead	BRHE68	BRRI70	105	lag-attenuation	1.03	1.07	1,041	0.98
				Muskingum	0.98	0.43	1,614	0.94

Tables 8.11 and 8.12 compare the calibrated lag and attenuation routing parameters for selected control points in Tables 8.9 and 8.10 to the calibrated values Muskingum *K* and *X*. Similar length reaches above the Hempstead reach were selected, but covering different regions of the basin. Both routing methods give similar values of the objective function during the calibration process with *DAY*, though the Muskingum method tends to give slightly higher values on a consistent basis. Unlike the lag and attenuation method which does not require a minimum distance between inflow and outflow control points, the Muskingum method does not maintain computational stability for values of *K* smaller than 0.50 days. For this reason, Muskingum routing parameters cannot be fit to every routing reach listed in Tables 8.9 and 8.10. Muskingum routing is not utilized as a routing method in the Bwam case study.

Forecasting Period

Forecasting addresses the issue of water control and use decisions today which affect downstream available and regulated flows over the next several days. Some time is required for changes to flow to propagate downstream to the river system outlet. The lag time may range from zero to several or more days. Water supply diversions and return flows and multiple-purpose reservoir operations in the current time step affect downstream available and regulated flows in subsequent time steps. Flow forecasting in *SIMD* is the process of considering future flows over a forecast period in determining water availability for *WR* record rights and available flood flow channel capacity for *FF*/*FR* record flood control rights. As discussed in Chapter 10, reservoir operations for flood control are based on making no release today that contributes to downstream flooding today or during future days.

Flow forecasting in *SIMD* is defined as considering stream flow availability over a future simulation forecast period, F_P, when determining water availability and flood flow capacity for each individual water right in the priority based water rights computation loop. The default is no forecast or $F_P = 0$. Without forecasting, *SIMD* considers only the current time period in determining water availability and flood flow capacity. With forecasting, F_P future days are considered in the examination of available flows at downstream control points. Forecasting is not relevant for water rights at a control point that has no other control points located downstream or a simulation in which routing parameters are not utilized.

Forecasting is activated by setting the forecast option, *FCST*, in field 7 on the *JU* record. The simulation forecast period, F_P, is set by option *FPRD* in field 8 on the *JU* record. Forecasting for flood control is covered in Chapter 10. Water availability forecast periods within the simulation forecast period are selected for *WR* record water rights by *JU* and *DW* record parameters. The value of F_P as set by option *FPRD* must be greater than the global water right availability period, option *APRD* on the *JU* record, or the individual *WR* record right availability period option *APERIOD* on the *DW* record or the channel capacity forecasting period option *CPERIOD* for flood control rights on *FF* records. The value of F_P will be ignored for *IF* records and Type 3, 4, 5 and 6 *WR* record rights which do not diminish downstream water availability and therefore are not assigned a water availability forecast period.

Routing Adjustments

SIM and SIMD monthly simulation computations always maintain volume balances that properly account for all inflows, outflows, and changes in storage. However, due to inaccuracies in forecasting and routing, control point flow availability array values may drop to zero in the *SIMD* computations before all depletions are deducted during the given day. Rather than create negative regulated flows, *SIMD* sets regulated flow equal to zero and postpones consideration of the necessary amount of routed depletions until the next time step. The routed depletions are applied to regulated flows at the start of in the next time steps until regulated flow meets or exceeds the amount of routed depletions. Adjustment of the timing of routed depletion consideration allows stream flows to remain at or above zero and also maintains the long-term volume balance.

WRMETH option 1 does not protect senior rights in the current day from actions of junior rights in previous days. *WRMETH* option 2 protects senior rights from the routed changes to flow from junior rights, but with imperfect routing and imperfect or no flow forecasting, allows senior rights to potentially take stream flow that has already been depleted by junior rights in previous days. Thus, the issue of over appropriation may be increased with *WRMETH* option 2 if forecasting is not applied. Chapter 9 examines the efficacy of forecasting to reduce the incidence of over appropriation and associated need for routing adjustments.

<u>Bwam Forecasting</u>

The Bwam dataset contains over 1,600 individual water rights. Included in these water rights are rights to impound and store water in reservoirs for later use. These water rights are spread over a large river basin and its tributaries and over a large range of priority dates. Some water rights have relatively few to no downstream senior water rights. In other cases, many water rights may be located over a network of tributaries with a common few downstream senior water rights.

Forecasting of future river flows may be considered from the dual perspectives of actual forecasts in the real world and computational forecasts in the *SIMD* model. Both are characterized by uncertainties and inaccuracies. The intent of forecasting for *WR* record rights in *SIMD* is the prevention of upstream junior rights from making depletions of stream flow in the current day which will otherwise be appropriated by downstream senior water rights during the forecast period. The time delay between current day stream flow depletions and the downstream effect on water availability in the future connects the concepts of routing and flow forecasting for water availability and channel capacity.

Strict adherence to the doctrine of prior appropriation would require water rights to curtail their stream flow depletions in junior-to-senior priority order during times of shortage. However, dynamically individualizing a forecasting method and forecasting period for every possible combination of water right location, water right priority date, and tributary flow event during the period of record is not practical. The simulation forecast period, F_p, should be set with option *FPRD* on the *JU* record to a value that is at least equal to the maximum routing period in the basin. The forecasting period is used throughout the period of record.

The results of *SIMD* simulations with the Bwam dataset converted to daily time steps are presented in Chapters 9 and 10. Simulations with and without forecasting are explored. Chapter 9 deals with simulation results from the perspective of water availability. Chapter 10 focuses on the addition of flood control operations to the simulation. The following two cases of forecasting periods are presented in Chapter 9:

- No forecasting
- A simulation forecast period equal to the maximum routing period in the Bwam dataset and automatic *SIMD* assignment of individual *WR* record right water availability forecasting periods within the simulation forecast period

All water rights in the Bwam DAT file are assigned a forecasting period regardless of location. This includes water rights outside of the area covered by the SUPER flow dataset such as those water rights far upstream of Possum Kingdom Lake and in the San Jacinto-Brazos Coastal Basin.

Water Use Targets

Targets for water supply diversions, hydroelectric power generation, and environmental instream flow requirements are set in a *SIMD* daily simulation by combining selected options from the following three sets of target-building options.

1. A monthly target is determined at the beginning of each month in a *SIMD* daily simulation in the same manner as a *SIM* or *SIMD* monthly simulation. *UC* record use coefficients are combined with an annual target from a water right *WR* or instream flow *IF* record. The target may be adjusted further by target options *TO*, supplemental options *SO*, flow switch *FS*, drought index *DI*, and other supporting records as described in the *Reference* and *Users Manuals*.
2. The monthly target set in step 1 above is distributed over the days of the month using one of the following two alternative approaches as specified by parameters on *JU* and *DW* records.
    - uniform distribution
    - specified number of days, *ND*, option with or without shortage recovery, *SHORT*, option
3. The daily target for a *WR* or *IF* record water right optionally may be set or adjusted using options specified on *DW* and *DO* records that are analogous to the *TO*, *SO*, *BU*, *FS*, and *DI* record monthly target setting options noted in step 1 above.

For most modeling applications, daily targets will be set for most water rights by combining options from the first two sets of options listed above. However, the third set of options is also available as needed.

Uniform Distribution and ND/SHORT Options

The monthly target is set at the beginning of the month as specified by a *WR* or *IF* record and accompanying *UC*, *TO*, *SO*, *FS*, *DI*, *TS*, and other optional auxiliary records. The monthly target is distributed over the days of the month based on either a uniform distribution or the features controlled by the *ND* and *SHORT* parameters as follows. A global default daily target distribution option may be set on the *JU* record. This default can be overridden for individual water rights by options activated by the daily water right data *DW* record associated with each individual water right. The *JU* and *DW* record default for the conversion of monthly to daily targets is the uniform distribution option described as follows. Monthly targets may be evenly divided into daily amounts. A monthly target is divided by the number of sub-intervals in each month to obtain amounts for each computational time step. With this option, a shortage occurs any time a daily target is not fully met.

Options activated by the parameters *ND* and *SHORT* entered on the *JU* or *DW* record provide an alternative to the uniform distribution. The *ND* option allocates the monthly target to a specified *ND* number of days each month. The daily target amount during the *ND* days is the monthly target divided by *ND*. The period of *ND* days always begins in the first day of the month. The *ND* option may be combined with the *SHORT* option that allows an attempt at recovering shortages from preceding days in subsequent days of the same month.

The parameter *SHORT* on the *JU* or *DW* record is a switch that activates an option used in combination with the *ND* option that allows diversion, hydropower or instream flow shortages to be supplied in subsequent days of the same month. With the *ND* option, if the target is fully met during each of the first *ND* days of the month, the target is zero for the remainder of the month with or without the *SHORT* option. However, with the *SHORT* option, a failure to meet the full target amount during the first *ND* days results in an attempt to recover shortages in subsequent days of the same month if sufficient water is available.

With the *JU* or *DW* record defaults, all daily water use targets are built with a uniform monthly distribution. The monthly water use targets derived from the *WR*/*IF* and *UC* records are distributed evenly by the number of days in the month. This is an appropriate approach for water rights which require a constant daily target across all days of the month. However, storage capacity and water use characteristics often provide some degree of flexibility in day-to-day timing of water supply diversions. Cities maintain storage tanks to provide flexibility in balancing water supply and demand. Likewise, farmers may have small off-channel storage ponds as well as some flexibility in choosing which days to irrigate. Daily pumping capacities are a relevant issue. The *ND* and *SHORT* options are designed to model day-to-day flexibility in matching supply availability and water use.

Bwam Water Use Targets

The Bwam dataset contains numerous water rights which reflect a diversity of types of water use and water management/use situations. The choice of *ND* is subjective without detailed knowledge of the specific manner in which water suppliers and users implement individual water rights or the authorized daily diversion rates of the underlying water rights. Two cases regarding application the *ND* option are presented in Chapter 9. The first case consists of *ND* being set to zero for all water rights. This results in uniform water use targets across all days of the month. The second case consists of applying a common value of *ND* for all water rights along with activation of the *SHORT* feature, based on water use types as specified on the *UC* records assigned to the water right *WR* records. The *ND* option is not applied to the instream flow *IF* record rights in the Bwam dataset.

Summary, Conclusions, and Guidance for Developing Data for *SIMD* Simulations

A *SIMD* input dataset based on a daily or other sub-monthly computational time step can be developed from scratch without an existing *SIM* dataset. *SIMD* can read daily flows as direct input for representing the naturalized flows at each primary control point. However, this report focuses on converting existing TCEQ WAM System datasets from monthly to daily. Existing *SIM* datasets can be converted from monthly to sub-monthly time steps for use with *SIMD* by the addition of a single *JT* record in the DAT file. However, additional *SIMD* features will typically be employed to more realistically capture the variability associated with a daily time step.

The following features of *SIMD* are designed for use exclusively in simulations employing sub-monthly (such as daily) computational time steps.

- routines for setting the number of daily computational time steps contained in each month and subdividing monthly naturalized flow volumes into daily time steps

- options for setting and varying diversion, hydropower, and instream flow targets over the daily time steps within each month
- option for reading daily naturalized flows from an input file
- alternative options for disaggregating naturalized monthly flows to daily
- option for determining current day available stream flow for *WR* record water rights based on a forecast simulation over a future forecast period
- forecasting of remaining channel capacity for *FF*/*FR* record flood control operations
- alternative methods for routing of stream flow adjustments
- aggregation of daily simulation results to monthly values and recording of simulation results at daily and/or monthly time steps

SIMD is designed to allow each of the 12 months of the year to be subdivided into any integer number of time intervals with the default being daily. Programs *DAY* and *TABLES* support and time step adopted for *SIMD*. A daily time step is adopted for the Brazos WAM studies presented in this report. The day is considered to be the most logical sub-monthly time step for most applications of *SIMD* anticipated for modeling realistic variability in water management scenarios. Gaged stream flow data and other types of data are available at a daily interval. A daily time step reasonably captures stream flow variability for major river systems for most anticipated WRAP modeling applications.

The most data-intensive tasks in converting a conventional monthly *SIM/SIMD* input dataset to a daily computational time step are disaggregating the monthly flows to daily flows and calibrating routing parameters that can be paired with the disaggregated daily flows. Other features of *SIMD*, such as forecasting and target building, can also greatly affect the simulation results and should be implemented after consideration of sensitivity analyses. Chapters 9 and 10 examine the effect on simulation output of choices for various input parameters available in *SIMD*.

Disaggregation of Naturalized Stream Flows from Monthly to Daily

Daily naturalized flows may be provided directly in a *SIMD* input DCF file without monthly flows. Alternatively, monthly naturalized flow volumes may be disaggregated to daily naturalized flows. Most *SIMD* daily simulation studies in Texas will likely build upon the TCEQ WAM System datasets, with the monthly naturalized flows being disaggregated to daily flows within the *SIMD* simulation. The Brazos WAM studies reported here represent an inaugural application of *SIMD* and are based on converting the Bwam dataset to a daily time step.

Daily flows provided by the USACE Fort Worth District from their SUPER model are used in the Brazos case study to define flow patterns while preserving monthly TCEQ WAM System naturalized flow volumes. Flow disaggregation is based on the flow pattern option. Daily unregulated flows at 34 locations in the Brazos River Basin from the USACE SUPER model are used to disaggregate the Bwam monthly naturalized flows. The daily flows computed in the flow disaggregation algorithm for each month sum to the original TCEQ WAM System monthly naturalized flows.

Daily flows at primary control points in a *SIMD* input dataset consist of either

- observed gage flows without adjustments
- observed gage flows with adjustments to remove the effects of water resources development and use
- simulated flows developed with a watershed precipitation-runoff model or other means

Observed gaged stream flows may be used directly without adjustments for sites on stream with relatively little watershed development and stream regulation. However, observed flows at many gaging stations are significantly affected by human development. Converting gaged flows to naturalized or unregulated flows is much more complex at a daily time step than monthly.

The USACE Fort Worth District has extensive experience in modeling most of the major Texas river basins at a daily time step using primarily their SUPER modeling system but, more recently, also HEC-ResSim and RiverWare [14]. Development of Corps of Engineers modeling capabilities has been motivated primarily by multiple-purpose reservoir system operations with a particular focus on flood control operations. Thus, the motivation in developing SUPER unregulated daily flows has been somewhat different than the motivation in developing the TCEQ WAM System monthly naturalized flows. Modeling approximations may differ. However, in both cases the general objective has been to develop flows representing natural conditions without water resources development/use and river regulation. The unregulated flows provided by the Corps of Engineers appear to be an excellent database for defining flow patterns for disaggregating TCEQ WAM System monthly naturalized flows.

The choice of flow disaggregation method for most applications of *SIMD* will depend primarily on the availability of daily flow data representative of natural conditions. WRAP provides flexible options to design flow disaggregation strategies for a broad range of situations ranging from having extensive daily flow data available to having no daily flow data. Chapter 9 demonstrates the significant impact that the selection of the disaggregation method has on *SIMD* simulation results. Available daily flow data should be used to the fullest extent practical in the disaggregation of monthly naturalized flow volumes to the daily time interval.

Ideally, the daily flows used to define flow patterns should cover the entire monthly naturalized flow period-of-analysis. Fortunately, the SUPER unregulated flows adopted for the Brazos WAM covered the entire 1940-1997 period-of-analysis. *SIMD* does include features for repetition of daily flow patterns that are shorter than the monthly naturalized flow period-of-analysis. However, repeating a daily pattern over the monthly period of record can result in mismatches of high and low flow conditions between the daily pattern and the monthly volumes. Mismatched flow conditions will have implications for water availability, regulated flow patterns, and flood control operations. With available SUPER unregulated flows covering the entire 1940-1997 period-of-analysis, this issue is not addressed in the Brazos case study.

The locations of the daily naturalized flows used to establish flow patterns ideally should widely distributed spatially over the river basin and cover both the main stem of the river and all of the major tributaries. Spatial distribution of the daily flow patterns should cover the diverse flow characteristics throughout the basin without leaving large distances between pattern locations. Fortunately, as illustrated in Figures 8.1 and 8.2, this objective was reasonably well achieved in the Brazos WAM case study.

Routing of Flow Changes and Calibration of Routing Parameters

A daily flow dataset is required for both calibration of routing parameters and disaggregation of monthly naturalized flows. Thus, the discussion of daily flow datasets in the preceding section on disaggregation is also relevant to routing parameter calibration.

The lag and attenuation routing method was developed specifically for routing flow changes in *SIMD* and is the recommended option for most WRAP applications. The lag and attenuation parameters can be calibrated for a reach of any length and with any average travel time. An adaptation of the Muskingum method is also included in the WRAP modeling system. However, Muskingum may not be appropriate for reaches of short length and travel time. Program *DAY* provides a set of options for calibration of parameters for either routing method, which is covered in the *Daily Manual*. Calibrated routing parameters will be reflective of all time steps selected for inclusion in the calculation of the objective function. Therefore, selection of the objective function in *DAY* and selection of valid time steps for the calibration will influence the value of the calibrated parameters.

Forecasting

The effects on *SIMD* simulation results of forecasting are demonstrated in Chapters 9 and 10. Overall reliabilities for essentially all water rights may be affected by the utilization of forecasting. Conversely, senior rights may not be protected from junior rights if forecasting is not utilized. The effects on simulation results due to forecasting are dependent on choices related to the other *SIMD* features described in this chapter such as routing, placement of routed changes to flow, and water use target settings. The different modeling features are interconnected through common access to the stream network.

Stream flow forecasting can be applied to protect water availability for senior rights from past upstream junior water right actions and to reduce the incidence of over appropriation when the routing option *WRMETH* 1 is used. If *WRMETH* 2 is used, forecasting is used to protect the water balance from over appropriation. All water rights can be automatically assigned a water availability forecasting period within the global simulation forecasting period, F_p. Automatic assignment of a water availability forecasting period is based on routing time to the basin outlet. Alternatively the user can set an availability forecast period that is shorter than the routing time for each water right or groups of water rights.

User selection of the simulation forecast period, F_p, should include consideration of the maximum routing period to the basin outlet. The simulation forecast period should be set to a value that is at least equal to the maximum routing period unless the user has specific reasons to consider fewer future days in the forecasts of future downstream flow. Extending the simulation forecast period beyond the number of days computed as the maximum routing period may produce different results for some water rights, though extending the forecasting period may not necessarily improve simulation results for all water rights. Uncertainty in future flow increases with the number of days in the forecasting period beyond the current real day. The *SIMD* forecasting algorithm repeats future days after each real day of the simulation is completed and thereby compensates for future uncertainty.

Water Right Target Building

The 22 steps in the target setting process in SIMD are described in the *Daily Manual*. Converting a monthly simulation into a daily simulation requires review of the intended water right target setting options. For example, backup water rights can be simulated as attempting to recover the shortage of the primary water right on a day-to-day shortage basis, or can be simulated as attempting to recover the total monthly shortage from the previous month. If the primary water right is utilizing a positive value of *ND* and *SHORT*, the day-to-day shortages may not be actual shortages prior to the end of the month. In such cases, the backup water right should use the option to recover the total monthly shortage for the previous month. The target setting options on the *TO* record also require examination. For example, *TO* records in the monthly model which build a target based on the reservoir drawn down in the previous month, *TOTARGET* option -3, could be set to build targets in *SIMD* according to the previous day's reservoir draw down or the end-of-month reservoir draw down in the previous month. Choice of the previous day reservoir draw down can result in very large total monthly targets being set.

In the Bwam dataset, all backup water rights are assigned to recover the primary water right's total monthly shortage in the previous month. All *TO* record options are set to operate on a total prior monthly basis unless otherwise required by the water right.

Monthly-to-Daily Disaggregation of Water Right Targets

Options activated by the input parameters *ND* and *SHORT* provide an alternative to the uniform distribution of diversion, instream flow, and hydropower targets from monthly to daily. If *ND* is greater than zero, the monthly target is distributed evenly over the first *ND* days of the month. After the first *ND* days of the month, any shortage in meeting the target demand in the preceding days can be reapplied to the daily target building process if the *SHORT* parameter option is activated. Use of *ND* and *SHORT* enables a water right to attempt to meet the monthly target demand sooner in the month depending on variations in water availability conditions. The use of *ND* and *SHORT* can increase the reliability at which the monthly target associated with a water right is supplied.

The *SIMD* feature controlled by the parameters *ND* and *SHORT* is designed to model day-to-day flexibility in water demand characteristics and water control facilities such as storage tanks or ponds and pumping and conveyance facilities. Information regarding this day-to-day flexibility is not typically available in the TCEQ WAM System datasets. Thus, judgment and knowledge of water right permitting conditions are required in selecting appropriate values of *ND*.

The various features of the *SIMD* simulation model addressed in this chapter are all interrelated. *SIMD* simulation results are affected by the interactions of the combination of disaggregation, forecasting, routing, priority sequencing, target building, and target distribution options selected as well as the individual options. The target distribution feature controlled by the *ND* and *SHORT* parameters, in addition to allowing better representation of real-world water use, provides a degree of flexibility for balancing the imperfections in forecasting, routing, and target setting. For example, flexibility in water supply target disaggregation can mitigate approximations in the variability of stream flow availability associated with imperfect routing.

CHAPTER 9
DAILY WATER AVAILABILITY SIMULATION STUDY

The TCEQ Water Availability Modeling (WAM) System WRAP input dataset for the Brazos River Basin and San Jacinto-Brazos Coastal Basin, called the Brazos WAM (Bwam) in this report, is described in Chapter 2. Flow disaggregation, routing, flow forecasting, and target distribution methods and associated *SIMD* input data developed to convert the Bwam dataset to a daily time step are described in the preceding Chapter 8. The discussions of Chapter 8 are applicable to either the authorized use scenario (Bwam3) or current use scenario (Bwam8) versions of the dataset. The simulation study described in Chapter 9 focuses on the authorized use scenario (Bwam3) though current use scenario (Bwam8) simulations are also included to examine the effect of time step on return flows. Flood control is added in Chapter 10.

Chapter 9 presents simulation results and comparisons for various alternative choices regarding modeling methods and associated input data. Frequency statistics for reservoir storage, regulated flows, and unappropriated flows at the major reservoirs and selected stream gages and reliabilities for selected water right groups provide a basis for comparison. Simulation results are organized to facilitate a comparative evaluation of the following aspects of modeling.

- Monthly versus daily simulation time step size
- Methods for disaggregating naturalized flow from monthly to daily values
- Placement of routed changes to flow in the priority sequence
- Usage of flow forecasting for water availability
- Daily water right target distribution
- Negative incremental options

Input parameters are adjusted to examine these aspects of the simulation. Guidelines and recommendations for applying the new WRAP modeling capabilities are presented based on the study results. Applications of *SIMD* in other river basins will differ somewhat from the Brazos WAM case study. However, WRAP is generalized to accommodate a wide range of applications.

Simulation Scenarios and Output Reporting

The control points at which monthly simulation results are presented in Chapter 2 are also adopted in this chapter to report results, excluding the Seymour and South Bend gages and Hubbard Creek Lake which are located upstream of the area covered by the SUPER flow data used in the flow disaggregation. All control points upstream of Possum Kingdom Lake are assigned the same daily flow pattern as the control point for Possum Kingdom. No routing parameters are calibrated for control points above Possum Kingdom Lake because the flow pattern is the same. All control points in the San Jacinto-Brazos Coastal Basin are simulated with a uniform daily flow distribution, without developing flow pattern data.

SIMD daily simulation capabilities do not support *JD* record negative incremental *ADJINC* option 5. Option 5 is adopted in the monthly TCEQ Bwam dataset for which results are presented in Chapter 6. Negative incremental options 1 and 7 are used for Chapter 9 monthly as well as daily *SIMD* simulations to facilitate comparisons between results of daily versus monthly simulations. Option 7 is used with daily simulations that employ routing. Simulations with no routing considerations use option 1 except for the final daily simulation listed in Table 9.1 that is presented for comparative purposes. The monthly TCEQ Bwam3 simulation with option 5 is repeated from Chapter 6 for comparison puposes with a daily simulation using option 7.

This chapter presents comparative analyses of *SIMD* results for 15 simulation scenarios representing alternative sets of input parameter choices. The 14 simulation scenarios are assigned numerical identifiers listed in Table 9.1. The scenario identifier begins with the chapter number followed by a decimal which is incremented for each simulation parameter set. Each section of this chapter considers only a select number of these scenarios. The scenarios being considered in each section are listed at the beginning of the section. Simulation results are reported for the groups of water rights defined in Table 9.2 and the control points listed in Table 9.3.

Execution times measured in hours for each simulation are also provided in Table 9.1. The same daily output was generated for each simulation with a daily time step. All simulations delivered the same monthly output to the OUT file. The simulation execution times are given for comparative purposes and illustrate the effect on the number of computations of the various daily simulation parameter settings. The computer used for these simulations is equipped with an Intel Xeon W5580 central processing unit. Execution times will vary according to central processing unit capability and according to the amount of output chosen.

The simulation forecast period is listed in terms of the value of option *FPRD* on the *JU* record. Daily simulations without forecasting are listed with a *FPRD* value of 0 days. The assignment of 14 days to the simulation forecast period is discussed later in this chapter and is expanded beyond 14 days in Chapter 10. Monthly time step simulations do not use forecasting.

Table 9.1
Parameters per Simulation Scenario

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, *WRMETH*	Disaggregation Option, *DFMETHOD*	Target Distribution Option, *ND*	Flow Forecasting, *FPRD*	Negative Increntals, *ADJINC*	Execution Time, hours
9.01	month	Bwam3	*na*	*na*	*na*	*na*	*na*	1	0.01
9.02	month	Bwam8	*na*	*na*	*na*	*na*	*na*	1	0.01
9.03	day	Bwam3	none	*na*	uniform	uniform	0 days	1	0.22
9.04	day	Bwam8	none	*na*	uniform	uniform	0 days	1	0.25
9.05	day	Bwam3	none	*na*	linear interp	uniform	0 days	1	0.26
9.06	day	Bwam3	none	*na*	daily pattern	uniform	0 days	1	0.24
9.07	day	Bwam3	lag-att	1	uniform	uniform	0 days	7	0.26
9.08	day	Bwam3	lag-att	1	daily pattern	uniform	0 days	7	0.24
9.09	day	Bwam3	lag-att	2	daily pattern	uniform	0 days	7	0.46
9.10	day	Bwam3	lag-att	1	daily pattern	uniform	14 days	7	3.63
9.11	day	Bwam3	lag-att	2	daily pattern	uniform	14 days	7	6.92
9.12	day	Bwam3	lag-att	1	daily pattern	7 days	14 days	7	3.54
9.13	day	Bwam3	lag-att	1	daily pattern	1 day	14 days	7	3.52
9.14	day	Bwam3	lag-att	1	daily pattern	uniform	14 days	1	5.19
9.15	month	Bwam3	*na*	*na*	*na*	*na*	*na*	5	0.01

Table 9.2
Bwam3 Selected Run-of-River Water Rights for Reliability Computations

Groups of Water Rights Defined by Priority and Type of Use	Number of Water Rights	Total Annual Target, acre-feet per year
December 31, 1929 and senior priority, all uses	45	120,722
January 1, 1930 to December 31, 1939, all uses	14	75,550
January 1, 1940 to December 31, 1949, all uses	25	191,981
January 1, 1950 to December 31, 1959, all uses	117	112,238
January 1, 1960 to December 31, 1969, all uses	231	125,777
January 1, 1970 to December 31, 1979, all uses	16	4,692
January 1, 1980 and junior priority, municipal use	1	75,000
January 1, 1980 and junior priority, non-municipal	53	84,261
All Selected Water Rights	502	790,221

Table 9.3
Selected Control Points for Which Simulation Results are Presented

Control Point ID	Reservoir or Gage	Stream	Watershed Area (square miles)
	USGS Stream Gaging Stations		
LRCA58	Cameron Gage	Little River	7,100
BRBR59	Bryan Gage	Brazos River	30,016
BRHE68	Hempstead Gage	Brazos River	34,374
BRRI70	Richmond Gage	Brazos River	35,454
	Outlet of the Brazos River at the Gulf of Mexico		
BRGM73	Gulf of Mexico	Brazos River	36,027
	Reservoirs		
515531	Possum Kingdom Lake	Brazos River	14,093
515631	Granbury Lake	Brazos River	16,181
515731	Whitney Lake	Brazos River	17,690
515831	Aquilla Lake	Aquilla Creek	254
509431	Waco Lake	Bosque River	1,655
516531	Limestone Lake	Navasota River	678
515931	Proctor Lake	Leon River	1,280
516031	Belton Lake	Leon River	3,568
516131	Stillhouse Hollow Lake	Lampases R.	1,313
516231	Georgetown Lake	San Gabriel R.	247
516331	Granger Lake	San Gabriel R.	726
516431	Somerville Lake	Yegua Creek	1,008

Frequency statistics for storage, regulated flow and unappropriated flow are presented for the control points listed in Table 9.3. Reliabilities are reported for the water right groups defined in Table 9.2 that met the following criteria and the water rights at the reservoir control points listed in Table 9.2. Only water rights that fit the following selection criteria are included in the groups listed in Table 9.2, along with the number of rights that fit the criteria out of the 1,643 *WR* record rights in the Bwam3 DAT file.

- Not located within the San Jacinto-Brazos Coast Basin
- Not located upstream of Possum Kingdom Lake
- No access to primary or secondary reservoir storage
- Target demands are not modified by water right backups, *TO* or *DI*/*IS*/*IP* records

Presenting reliabilities for the water right groups defined in Table 9.2 allow comparisons of water availability at various levels within the priority order. Selection based on target setting options ensures that the water rights within each group have a consistent annual target regardless of the changes made to the *SIMD* simulation parameters. Only water rights located within the area covered by the SUPER flow data are included in these groups.

Daily Versus Monthly Simulation Time Step Size

In this section, time step is isolated as the only difference between simulation scenarios. The daily *SIMD* simulation is performed with the default simulation settings which include no routing, uniform monthly to daily flow disaggregation, and uniform daily target demands. The *SIM* and *SIMD* simulations differ only in their respective time steps. The *SIM* simulation has 696 monthly time steps, and the *SIMD* simulation has 21,185 daily time steps over the 1940 to 1997 Bwam hydrologic period-of-analysis. The monthly *SIM* and daily *SIMD* simulations are performed with *JD* record negative incremental option 1. Chapter 6 presents simulation results for the unaltered TCEQ Bwam input dataset which uses negative incremental option 5.

Table 9.4
Parameters per Simulation Scenario Being Considered Scenario

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, *WRMETH*	Disaggregation Option, *DFMETHOD*	Target Distribution Option, *ND*	Flow Forecasting, *FPRD*	Negative Increntals, *ADJINC*	Execution Time, hours
9.01	month	Bwam3	*na*	*na*	*na*	*na*	*na*	1	0.01
9.02	month	Bwam8	*na*	*na*	*na*	*na*	*na*	1	0.01
9.03	day	Bwam3	none	*na*	uniform	uniform	0 days	1	0.22
9.04	day	Bwam8	none	*na*	uniform	uniform	0 days	1	0.25

The flow frequency statistics of the monthly aggregated naturalized flows are the same for all scenarios considered in this chapter. Only the daily naturalized flow frequency statistics vary with the *SIMD* option for monthly-to-daily naturalized flow disaggregation. Flow disaggregation is examined in the next section of this chapter.

Table 9.5
Flow Frequency Statistics for Monthly Naturalized Flows for the
Period-of-Analysis for All Scenarios in Chapter 9
(Flows are in acre-feet per month.)

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	109858.4	170466.	0.0	494.4	1249.0	2706.4	5440.0	15032.0	28988.	44799.	65294.	130473.	290433.	1403136.
BRBR59	335663.5	483897.	0.0	6558.6	11161.7	17707.0	28172.8	60717.0	107622.	158629.	232671.	402271.	810073.	4704312.
BRHE68	446578.6	588542.	1634.0	13817.1	17422.0	30122.4	44643.0	89698.0	157333.	229331.	306815.	581968.	1153505.	5723482.
BRRI70	487518.7	613002.	0.0	18382.7	25401.7	39521.8	53887.8	111204.0	184723.	257456.	358553.	653272.	1230723.	6135975.
BRGM73	508769.8	634290.	4.0	18771.8	25991.5	42893.2	59767.2	121025.0	199329.	269220.	376386.	676536.	1272971.	6254466.
515531	66122.9	137150.	0.0	0.0	0.1	284.1	2186.9	6882.7	12816.	18404.	30992.	64389.	166332.	1794484.
515631	91156.0	178785.	0.0	39.5	781.5	2047.9	4459.1	10227.7	19707.	29493.	48833.	95565.	237433.	2653863.
515731	113905.5	203559.	7.5	323.7	1767.3	3507.6	6777.5	16134.5	28423.	46037.	65333.	130424.	277592.	2962997.
515831	6147.4	11987.	0.0	0.0	0.0	0.0	0.0	37.2	472.	988.	2017.	6582.	19446.	102561.
509431	29788.7	53352.	0.0	1.0	9.3	39.1	468.0	2859.5	5978.	9933.	15244.	34692.	80535.	530557.
516531	19399.4	34018.	0.0	0.0	0.0	32.9	100.9	614.1	1824.	3970.	7964.	21035.	62911.	240424.
515931	12070.5	28547.	0.0	0.0	0.0	0.4	56.4	495.3	1307.	2450.	3799.	10841.	33218.	327284.
516031	41915.5	75191.	0.0	0.0	0.1	2.3	485.7	3335.9	7744.	12710.	22290.	47382.	112448.	627569.
516131	19238.4	34306.	27.8	135.3	147.7	486.0	718.5	2122.1	3912.	5988.	9237.	20984.	53075.	309090.
516231	4796.5	8418.	0.0	0.0	0.0	19.7	85.3	343.8	880.	1416.	2333.	5510.	14484.	74909.
516331	15551.8	24898.	0.0	1.2	5.7	172.5	473.9	1772.8	3581.	5412.	8432.	19756.	44908.	210085.
516431	18572.4	33188.	0.0	0.0	0.0	1.5	4.5	764.2	2329.	3895.	7369.	18888.	60673.	250982.

Net Evaporation-Precipitation Volume

In the monthly simulation, net evaporation less precipitation is computed for the average of the beginning and ending reservoir surface areas each month. All target demands for the month are met in one time step and the end of the month reservoir storage volume is computed. Beginning and end of month surface areas are computed from a *SV*/*SA* record pair or by an equation specified on the *WS* record. In a daily simulation, there are between 28 and 31 beginning and end of period storages within the month. Reservoir net evaporation-precipitation is computed at each intermediate sub-monthly time step.

Due to the nonlinearity of reservoir surface area versus storage volume relationships, daily versus monthly computational time steps result in differences in total monthly evaporation-precipitation volumes even if daily inflows and withdrawals from reservoir storage are uniform throughout the month. Reservoir surface area versus conservation storage volume curves are typically convex as illustrated by the plot of the Bwam *SV/SA* record table for Belton Lake in Figure 9.1. Computation of surface area from such a nonlinear storage-area relationship for 28 to 31 daily time steps can result in a greater total monthly evaporation-precipitation volume than computations at a single monthly time step.

A larger draw-down of reservoir storage in a daily simulation due to a convex storage-area relationship causes slightly lower storage volume, which reduces surface area and thus reduces the draw on storage of net evaporation-precipitation in the subsequent month. The increased daily simulation draw-down due to increased net evaporation-precipitation may therefore be self-limiting due to negative feedback. Slight differences in storage volume in all 719 reservoirs in the Bwam3 data set cause small differences in the sequence of water availability between the *SIM* and *SIMD* simulations over the hydrologic period-of-analysis.

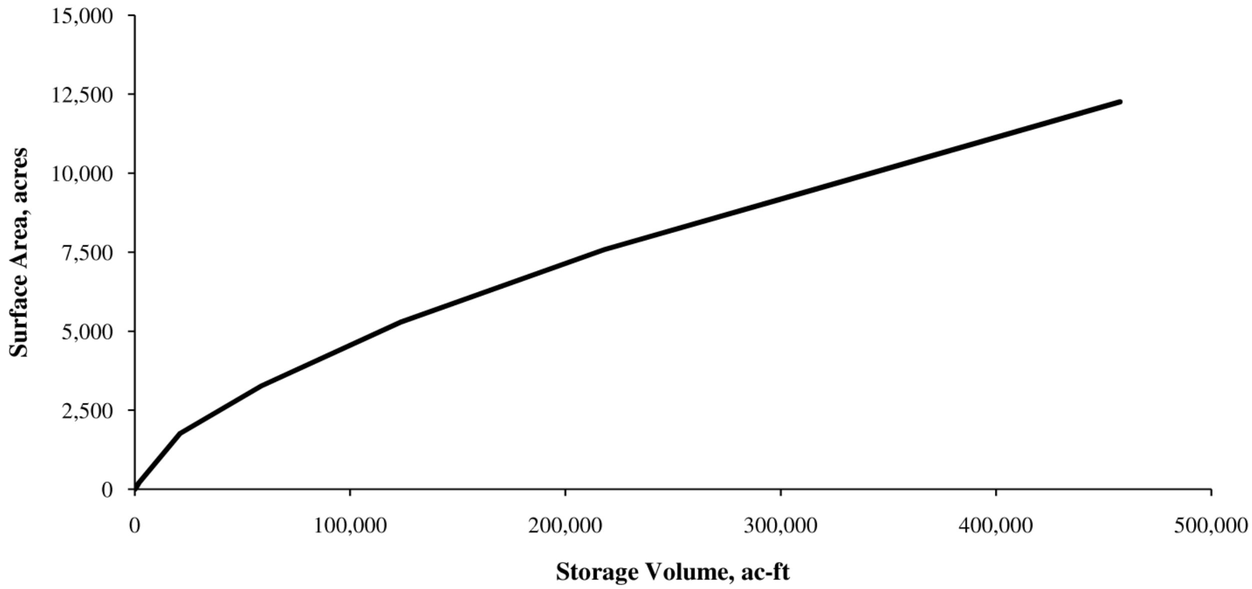

Figure 9.1 Surface Area versus Storage Volume for Belton Lake

Figure 9.2 shows the slight differences in reservoir storage in Belton Lake with respect to time step size. The differences are most evident during the peak drought months of the 1950s. The differences in storage contents between *SIM* and *SIMD* are returned to zero when the reservoir refills to the top of conservation capacity in both simulation scenarios. Figure 9.3 shows the differences in total annual net evaporation-precipitation volume for Belton Lake. Again, the differences are most evident during the peak drought months.

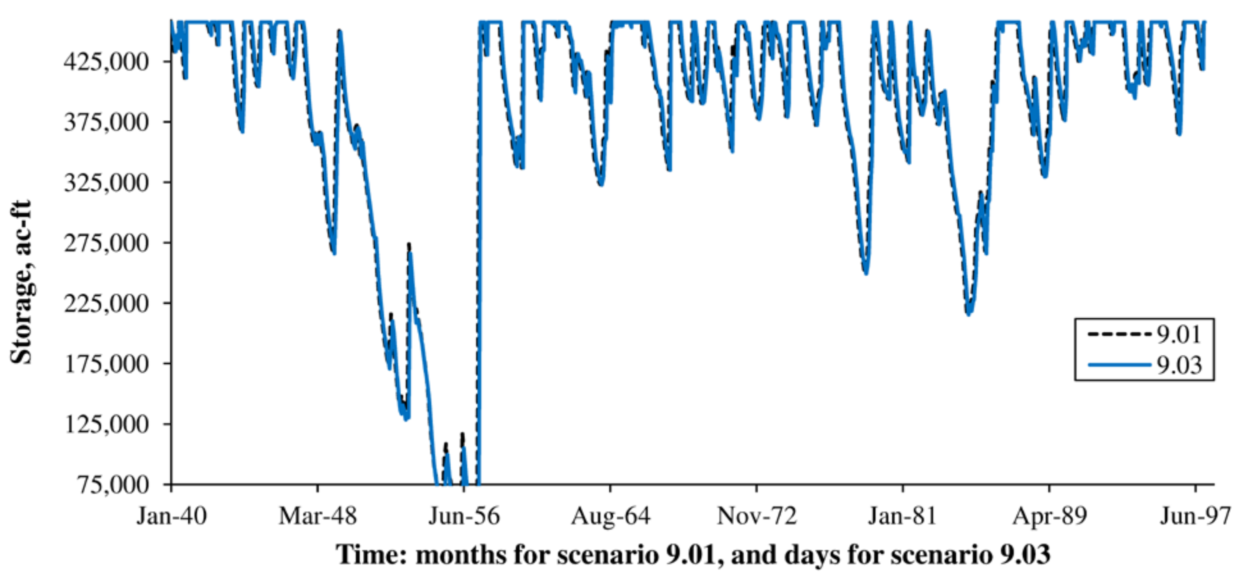

Figure 9.2 Storage in Belton Lake

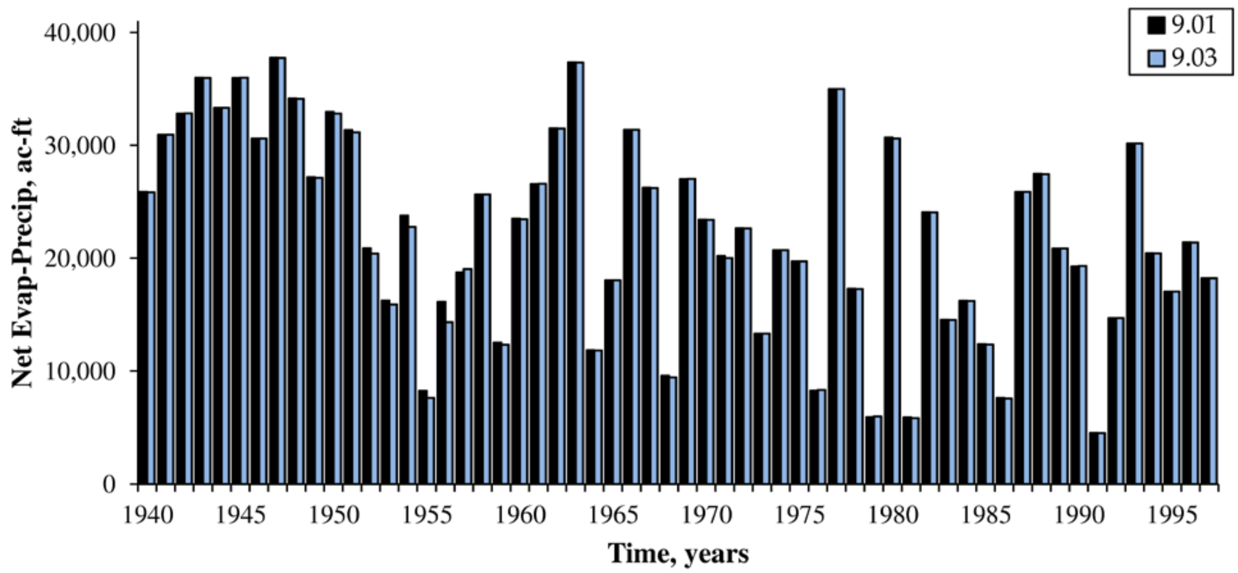

Figure 9.3 Net Evaporation-Precipitation for Belton Lake

Figure 9.4 shows the daily net evaporation-precipitation volume and storage volumes for Belton Lake in years 1955 and 1956. The difference at Belton in net evaporation-precipitation between the monthly and daily time step scenarios is greatest in 1956. The daily net evaporation-precipitation volumes are higher at the beginning of the month than at the end of the month as the reservoir is drawn down. This is particularly noticeable for July, August, and September 1956 at Belton. Net evaporation-precipitation depths are entered on the *EV* record in the EVA file and are distributed uniformly over the number of days in the month. The uniform distribution of the *EV* record data gives the stair-step appearance to the net evaporation-precipitation volume. The *EV* depths can be negative, as shown for May 1955 at Belton.

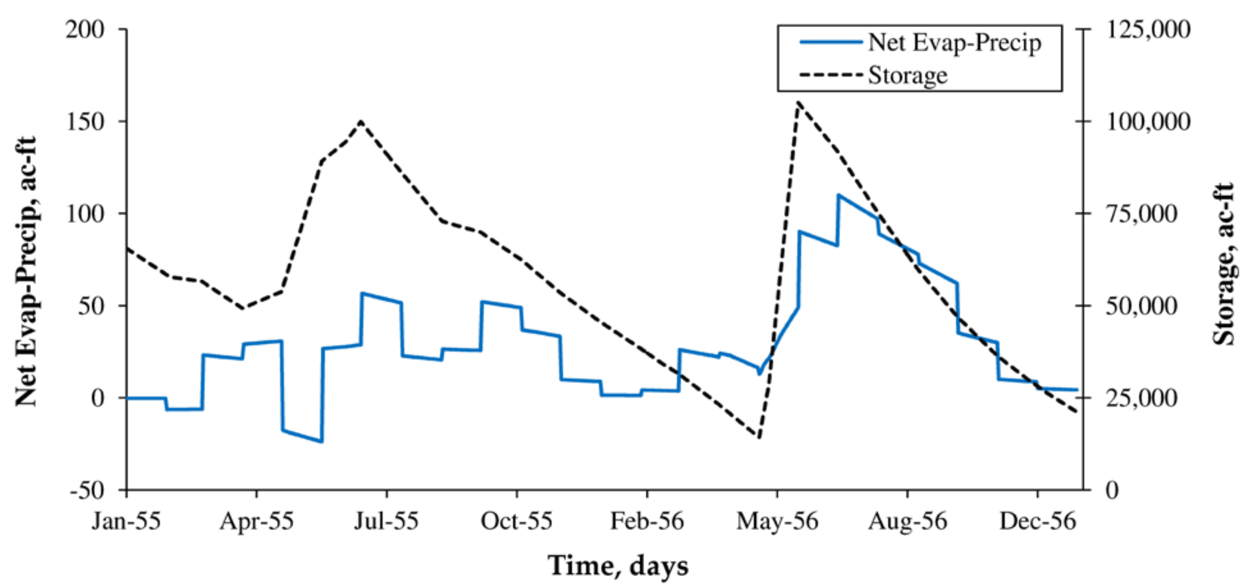

Figure 9.4 Belton Lake Net Evaporation-Precipitation and Storage, Scenario 9.03

Return Flows

Ordinary return flows are not included under the full authorization conditions of Bwam3. Return flows are simulated in the current condition scenario Bwam8. Differences occur between the monthly and daily simulations when the *WR* record return flow option *RFMETH* is set to place return flows in the stream at the beginning of the next time step. Bwam8 uses next-period placement of return flows. In the monthly simulation, the entire monthly return flows are placed into the stream at the beginning of the next monthly time step. In the daily simulation, the return flows from day 1 of the month are placed into the stream at the beginning of day 2 of the same month. The next-period placement occurs within the same month in the daily simulation until the last day of the month. The differences in return flow timing between the monthly and daily simulation scenarios creates a difference in the sequence of water availability over the entire period-of-analysis.

Figure 9.5 shows the monthly total return flows entering the stream in Bwam8 at control point 100455 resulting from a municipal use water right on Belton Lake. Both sets of return flows sum to 1,780 ac-ft/yr in every year of the period-of-analysis.

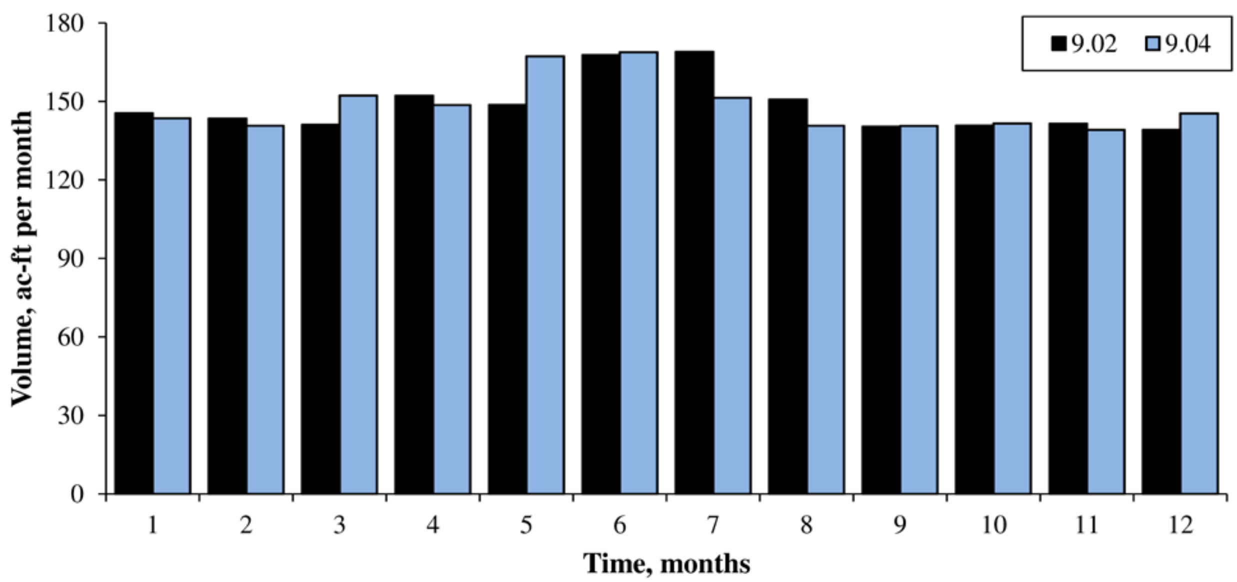

Figure 7.5 Monthly Total Return Flow Entering Control Point 100455

The monthly *SIM* return flow *RF* records could be adjusted for use in a daily *SIMD* simulation. The existing *RF* records in the Bwam8 DAT file could be recomputed to ensure that the monthly aggregate pattern of return flow discharge for next-period placement is the same as the monthly pattern achieved in *SIM*. Adjustment of the *RF* records is not performed in the simulation reported here.

Table 9.6

End of Month Storage-Frequency for Scenarios 9.01, 9.02, 9.03 and 9.04, acre-feet

End of Month Storage-Frequency, Scenario 9.01, Monthly Bwam3 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
515531	556283.	171951.	0.	4131.	74084.	175212.	315909.	466570.	559106.	602901.	647227.	696310.	724739.	724739.
515631	118224.	42660.	0.	0.	0.	11425.	54186.	104966.	122269.	130659.	140773.	155000.	155000.	155000.
515731	607508.	38591.	433580.	449718.	488367.	522742.	554612.	595478.	614214.	623142.	629845.	635738.	636100.	636100.
515831	44434.	9791.	2101.	8567.	14295.	21320.	33209.	40244.	44988.	47181.	49751.	52400.	52400.	52400.
509431	179735.	32613.	63171.	73954.	85957.	107976.	130643.	166096.	182731.	191158.	200381.	205857.	206141.	206561.
516531	185104.	48616.	10986.	24066.	38591.	70421.	116365.	170405.	188559.	200769.	211500.	225400.	225400.	225400.
515931	47408.	13468.	1800.	8426.	9950.	18675.	27730.	41235.	46456.	51342.	55737.	59400.	59400.	59400.
516031	384875.	99890.	18873.	40347.	62706.	140180.	240465.	364100.	401771.	420980.	439183.	457600.	457600.	457600.
516131	192127.	63183.	0.	0.	7205.	24382.	76454.	180102.	209288.	219910.	227714.	235700.	235700.	235700.
516231	29572.	9739.	0.	0.	120.	7351.	15322.	25103.	31326.	33670.	35619.	37100.	37100.	37100.
516331	55550.	14914.	0.	1766.	8031.	21545.	34159.	50681.	58717.	63099.	65500.	65500.	65500.	65500.
516431	130786.	35970.	0.	8694.	32287.	57120.	74456.	114644.	135824.	143983.	151601.	160110.	160110.	160110.
Total	2531606.	505154.	774469.	971202.	1043853.	1344362.	1755938.	2326150.	2598324.	2690449.	2768308.	2907646.	3002783.	3015598.

End of Month Storage-Frequency, Scenario 9.03, Daily Bwam3 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
515531	555287.	172202.	0.	3341.	73231.	174497.	313798.	465015.	558931.	602857.	646547.	695905.	724739.	724739.
515631	118109.	42672.	0.	0.	0.	11773.	53775.	104856.	122074.	130659.	140876.	154240.	154982.	155000.
515731	609836.	37756.	434412.	449092.	489354.	528806.	560592.	598733.	618097.	626543.	632286.	636100.	636100.	636100.
515831	44241.	9885.	1381.	7745.	13426.	20653.	32878.	40087.	44871.	47031.	49560.	52181.	52309.	52399.
509431	179921.	32246.	63464.	75749.	86678.	109526.	130898.	167183.	183216.	191523.	200186.	205718.	206330.	206513.
516531	185025.	48741.	10466.	23226.	38542.	69686.	116309.	170325.	188563.	200611.	211500.	225235.	225400.	225400.
515931	47025.	13452.	1697.	8336.	9722.	18666.	27213.	40317.	45929.	50696.	55185.	58762.	59400.	59400.
516031	381051.	103468.	1376.	24773.	46799.	124672.	230302.	358460.	399110.	418362.	437582.	450097.	457409.	457600.
516131	190788.	63756.	0.	0.	4850.	22423.	70984.	178486.	208452.	219387.	227368.	232642.	235566.	235700.
516231	29107.	9912.	0.	0.	0.	6092.	14460.	24281.	31009.	33487.	35333.	36620.	37004.	37096.
516331	55073.	15410.	0.	945.	6252.	18728.	33600.	50115.	58240.	62720.	65126.	65461.	65477.	65500.
516431	130738.	36026.	0.	8357.	31909.	57084.	74284.	114478.	135825.	143983.	151563.	160110.	160110.	160110.
Total	2526202.	508895.	753575.	946782.	1023283.	1340664.	1736897.	2319538.	2594344.	2686721.	2768350.	2896245.	2992688.	3015463.

LRCA58	Cameron Gage on Little River
BRBR59	Bryan Gage on Brazos River
BRHE68	Hempstead Gage on Brazos
BRRI70	Richmond Gage on Brazos River
BRGM73	Brazos Outlet at Gulf of Mexico
515531	Possum Kingdom Reservoir
515631	Granbury Reservoir
515731	Whitney Reservoir
515831	Aquilla Reservoir
509431	Waco Reservoir
516531	Limestone Reservoir
515931	Proctor Reservoir
516031	Belton Reservoir
516131	Stillhouse Hollow Res.
516231	Georgetown Reservoir
516331	Granger Reservoir
516431	Somerville Reservoir

Table 9.6 (continued)
End of Month Storage-Frequency for Scenarios 9.01, 9.02, 9.03 and 9.04, acre-feet

End of Month Storage-Frequency, Scenario 9.02, Monthly Bwam8 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
515531	530529.	32016.	377207.	401457.	433717.	462811.	485126.	520833.	537700.	545897.	551983.	552013.	552013.	552013.
515631	118546.	23717.	3254.	13499.	36328.	61693.	94988.	113262.	124057.	128883.	132779.	132821.	132821.	132821.
515731	529070.	29912.	393237.	411853.	434874.	459602.	487861.	521761.	535175.	541169.	547024.	549785.	549788.	549788.
515831	38890.	3715.	26620.	27261.	27816.	30866.	33503.	36939.	39530.	40644.	41700.	41700.	41700.	41700.
509431	198072.	11883.	139234.	160387.	165149.	172694.	180400.	193300.	200658.	204182.	205884.	206400.	206549.	206562.
516531	185126.	30205.	72124.	78982.	95449.	113916.	142589.	175523.	188168.	196471.	203844.	208017.	208017.	208017.
515931	46940.	9199.	12684.	16842.	22974.	27146.	34260.	41710.	46600.	49913.	53913.	54702.	54702.	54702.
516031	380359.	72310.	131496.	142651.	153544.	201479.	265540.	360653.	391029.	409647.	425979.	432978.	432978.	432978.
516131	191131.	48214.	31006.	43154.	49447.	67261.	111304.	179293.	203655.	213001.	220149.	224429.	224429.	224429.
516231	31623.	7102.	4443.	6395.	9827.	17111.	21818.	27825.	32769.	34819.	36607.	36980.	36980.	36980.
516331	48898.	3289.	31677.	34559.	37836.	41752.	44742.	48548.	50540.	50540.	50540.	50540.	50540.	50540.
516431	126293.	34424.	0.	10685.	32117.	55195.	72486.	111147.	131075.	138892.	146322.	154254.	154254.	154254.
Total	2425478.	253759.	1485395.	1600063.	1641408.	1838090.	2064421.	2329087.	2455281.	2510358.	2559027.	2617790.	2644060.	2644782.

End of Month Storage-Frequency, Scenario 9.04, Daily Bwam8 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
515531	530387.	32303.	377039.	399201.	433444.	461546.	485054.	520859.	537171.	545885.	552006.	552013.	552013.	552013.
515631	118617.	23726.	2814.	13271.	36292.	61656.	95555.	113496.	124165.	129615.	132764.	132821.	132821.	132821.
515731	530228.	29556.	396022.	413593.	436999.	462356.	488388.	523493.	537632.	543749.	548272.	549788.	549788.	549788.
515831	38878.	3723.	26617.	27219.	27807.	31024.	33483.	36924.	39514.	40618.	41699.	41700.	41700.	41700.
509431	198100.	11841.	139580.	160166.	164867.	173017.	180552.	193479.	201147.	204403.	205778.	206347.	206402.	206479.
516531	185082.	30297.	72103.	78822.	94763.	113814.	142102.	175474.	188169.	196471.	203844.	208017.	208017.	208017.
515931	46810.	9189.	12696.	17029.	23005.	26993.	33923.	41518.	46415.	49741.	53791.	54692.	54702.	54702.
516031	379106.	72824.	128485.	139581.	150390.	197997.	264835.	357249.	390547.	408830.	425268.	432926.	432978.	432978.
516131	190041.	48622.	28620.	42843.	48225.	65200.	108596.	178271.	202996.	212181.	219679.	223197.	224429.	224429.
516231	31542.	7151.	4194.	6139.	9568.	16832.	21663.	27758.	32744.	34753.	36527.	36909.	36959.	36980.
516331	48884.	3327.	31597.	34125.	37712.	41706.	44698.	48548.	50540.	50540.	50540.	50540.	50540.	50540.
516431	126293.	34436.	0.	10747.	32140.	55200.	72566.	111167.	131109.	138894.	146323.	154254.	154254.	154254.
Total	2423969.	254282.	1480218.	1596430.	1634045.	1837380.	2057241.	2328940.	2455739.	2511000.	2557604.	2615317.	2642355.	2644650.

LRCA58	Cameron Gage on Little River
BRBR59	Bryan Gage on Brazos River
BRHE68	Hempstead Gage on Brazos
BRRI70	Richmond Gage on Brazos River
BRGM73	Brazos Outlet at Gulf of Mexico
515531	Possum Kingdom Reservoir
515631	Granbury Reservoir
515731	Whitney Reservoir
515831	Aquilla Reservoir
509431	Waco Reservoir
516531	Limestone Reservoir
515931	Proctor Reservoir
516031	Belton Reservoir
516131	Stillhouse Hollow Res.
516231	Georgetown Reservoir
516331	Granger Reservoir
516431	Somerville Reservoir

Table 9.7
Monthly Regulated Flow-Frequency for Scenarios 9.01, 9.02, 9.03 and 9.04
(Flows are in acre-feet per month.)

Monthly Regulated Flow-Frequency, Scenario 9.01, Monthly Bwam3 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	83111.8	157495.	0.0	370.9	733.9	1190.1	1260.8	5832.4	12543.	18923.	31916.	87682.	235472.	1399450.
BRBR59	249517.2	427660.	284.6	4225.3	5624.7	9655.6	14555.7	29878.3	53023.	80081.	123253.	273602.	655387.	3954605.
BRHE68	346533.6	525048.	1940.6	11130.8	13025.8	20944.7	27077.8	52368.2	84316.	129252.	193841.	436410.	937304.	4816218.
BRRI70	377431.2	553621.	299.4	13296.9	17705.3	27542.7	35140.2	60205.6	92744.	145832.	229234.	469303.	1038609.	5227913.
BRGM73	345192.9	573761.	0.0	0.0	0.1	0.4	1.8	8714.7	43633.	104269.	182159.	448020.	1021423.	5291176.
515531	36695.2	115267.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	2543.	14042.	94145.	1425792.
515631	54289.3	152007.	0.0	0.0	0.0	0.0	0.0	0.0	1199.	4147.	8525.	31538.	153852.	2168298.
515731	69443.7	169157.	0.0	0.0	0.0	57.3	1380.6	4664.9	8699.	13184.	22117.	50994.	192675.	2449524.
515831	4409.8	10939.	27.8	27.8	27.8	29.8	29.8	30.8	31.	31.	31.	2347.	15453.	100103.
509431	20682.1	50671.	0.0	0.0	0.0	0.0	0.0	0.0	19.	59.	699.	14967.	68488.	529232.
516531	11364.3	27088.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	103.	4749.	44970.	215300.
515931	8520.3	26629.	0.0	0.0	0.0	0.0	0.0	3.4	63.	272.	833.	3356.	21873.	315934.
516031	28048.5	68078.	0.0	0.0	0.1	2.3	463.0	1997.5	2672.	3186.	4008.	16874.	80844.	547262.
516131	12322.0	31775.	0.0	0.0	0.0	0.0	0.0	0.0	49.	270.	1166.	7251.	39269.	302253.
516231	3514.0	7900.	0.0	0.0	0.0	0.0	0.0	0.0	0.	154.	503.	2699.	12223.	73211.
516331	11954.8	23609.	0.0	0.0	0.0	0.0	0.0	0.0	651.	1778.	3981.	12324.	38739.	208215.
516431	13227.6	30191.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2.	256.	6899.	52326.	247435.

Monthly Regulated Flow-Frequency, Scenario 9.03, Daily Bwam3 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	83198.8	157241.	0.0	371.1	735.5	1229.8	1741.4	5859.8	12799.	19147.	31951.	87682.	235287.	1399331.
BRBR59	250085.5	428393.	281.9	4328.6	5624.7	9662.5	14898.6	29529.1	53558.	79732.	121424.	280304.	660710.	3933625.
BRHE68	347102.3	525614.	1940.6	11265.0	13025.9	20964.8	27435.5	52165.8	84019.	127906.	194732.	442401.	948639.	4797424.
BRRI70	377964.5	554337.	294.2	13297.3	17746.8	27543.7	35565.6	58106.5	89406.	145995.	229234.	472660.	1037276.	5209746.
BRGM73	345775.4	574464.	0.0	0.0	0.1	1.4	17.2	6916.0	42523.	102612.	186561.	451416.	1021418.	5274451.
515531	37148.6	115081.	0.0	0.0	0.0	0.0	0.0	0.0	0.	165.	2587.	15194.	94410.	1421014.
515631	54753.6	151910.	0.0	0.0	0.0	0.0	0.0	25.0	1465.	4457.	8619.	32114.	155168.	2162849.
515731	69896.6	169538.	0.0	0.0	0.0	219.7	1209.3	4671.5	8874.	13325.	22109.	50528.	201284.	2442042.
515831	4412.1	10936.	27.8	27.8	27.8	29.8	29.8	30.8	31.	31.	65.	2245.	15453.	100103.
509431	20717.7	50668.	0.0	0.0	0.0	0.0	0.0	0.0	29.	78.	874.	15559.	68517.	529435.
516531	11369.2	27074.	0.0	0.0	0.0	0.0	0.0	0.0	0.	6.	127.	4748.	44933.	215300.
515931	8551.1	26596.	0.0	0.0	0.0	0.0	0.0	11.7	103.	343.	903.	3460.	21817.	315174.
516031	28097.4	67867.	0.0	0.0	0.1	2.3	463.0	2058.0	2745.	3365.	4172.	17039.	81190.	547037.
516131	12340.3	31711.	0.0	0.0	0.0	0.0	0.0	14.6	145.	440.	1245.	7064.	39227.	299954.
516231	3521.2	7891.	0.0	0.0	0.0	0.0	0.0	0.0	72.	178.	505.	2699.	12222.	73211.
516331	11973.2	23554.	0.0	0.0	0.0	0.0	0.0	113.6	750.	1803.	3984.	12321.	38735.	207952.
516431	13239.7	30182.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2.	274.	6899.	52324.	246373.

LRCA58	Cameron Gage on Little River
BRBR59	Bryan Gage on Brazos River
BRHE68	Hempstead Gage on Brazos
BRRI70	Richmond Gage on Brazos River
BRGM73	Brazos Outlet at Gulf of Mexico
515531	Possum Kingdom Reservoir
515631	Granbury Reservoir
515731	Whitney Reservoir
515831	Aquilla Reservoir
509431	Waco Reservoir
516531	Limestone Reservoir
515931	Proctor Reservoir
516031	Belton Reservoir
516131	Stillhouse Hollow Res.
516231	Georgetown Reservoir
516331	Granger Reservoir
516431	Somerville Reservoir

Table 9.7 (Continued)
Monthly Regulated Flow-Frequency for Scenarios 9.01, 9.02, 9.03 and 9.04
(Flows are in acre-feet per month.)

Monthly Regulated Flow-Frequency, Scenario 9.02, Monthly Bwam8 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	91083.9	161743.	1111.6	1229.8	2590.1	3480.8	5063.6	9829.7	16774.	23930.	40613.	98849.	248366.	1406391.
BRBR59	282404.1	459894.	2856.5	7656.8	9982.9	14459.6	19811.7	38316.1	66123.	101155.	154305.	328063.	725385.	4500617.
BRHE68	383853.2	559946.	8572.3	16459.2	18098.7	24980.5	34091.4	61051.0	105488.	154881.	234604.	497405.	1063419.	5461411.
BRRI70	423285.4	587244.	5890.6	17366.1	22800.0	31307.9	40498.2	78609.8	126295.	187162.	276832.	555073.	1135186.	5875715.
BRGM73	400019.2	608002.	0.0	0.2	0.8	121.3	563.5	39233.8	90376.	157648.	247919.	526430.	1140365.	5939702.
515531	50506.9	128599.	0.0	0.0	0.0	0.0	0.0	0.0	1646.	5217.	12716.	42733.	130107.	1661772.
515631	70701.0	169430.	0.0	0.0	0.0	0.0	0.0	572.1	4877.	10393.	23517.	65950.	198005.	2516516.
515731	85851.4	189838.	0.0	0.0	0.0	344.8	1469.1	4825.0	10685.	16851.	33448.	84121.	238897.	2793222.
515831	5377.2	11741.	27.8	27.8	27.8	29.8	29.8	30.8	31.	31.	665.	5077.	17879.	101155.
509431	24488.8	52838.	0.0	0.0	0.0	0.0	0.0	0.1	52.	1421.	6942.	26099.	75876.	532815.
516531	13940.3	30698.	0.0	0.0	0.0	0.0	0.0	0.0	0.	5.	283.	10258.	52027.	229076.
515931	9170.9	27287.	0.0	0.0	0.0	0.0	0.0	0.0	67.	200.	690.	4623.	23727.	320049.
516031	29205.3	70973.	0.0	209.0	251.2	277.3	569.7	952.9	1241.	1467.	1870.	22707.	87149.	610564.
516131	12954.6	32563.	0.0	0.0	0.0	0.0	0.0	0.0	5.	132.	1174.	9253.	41466.	306237.
516231	3623.6	8035.	0.0	0.0	0.0	0.0	0.0	0.0	0.	49.	514.	3063.	13012.	73401.
516331	13882.2	24481.	0.0	0.0	0.0	0.0	0.0	652.6	2004.	3837.	6570.	16426.	41647.	210617.
516431	13391.9	30531.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	60.	7415.	53138.	248174.

Monthly Regulated Flow-Frequency, Scenario 9.04, Daily Bwam8 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	91120.3	161752.	1111.6	1229.8	2766.9	3475.4	5045.3	9711.5	16871.	24135.	40493.	98909.	248457.	1406332.
BRBR59	282356.4	459471.	2636.7	7815.1	9747.5	14341.6	19855.0	38145.0	66252.	101237.	155443.	327516.	725732.	4475658.
BRHE68	383827.2	559546.	7161.0	15896.1	17824.7	24471.5	33792.8	60814.8	104268.	153545.	234164.	497572.	1064336.	5437516.
BRRI70	423264.0	586807.	5033.6	16810.4	22532.5	31397.6	40682.3	78846.0	125816.	187505.	276752.	555098.	1135282.	5852380.
BRGM73	400044.6	607550.	0.0	0.4	1.2	37.9	678.4	37811.3	89772.	157932.	247318.	526317.	1140248.	5916996.
515531	50608.9	127885.	0.0	0.0	0.0	0.0	0.0	0.0	1996.	5621.	13077.	43752.	130529.	1636740.
515631	70812.0	168659.	0.0	0.0	0.0	0.0	0.0	721.0	5326.	10546.	24119.	66988.	195648.	2491574.
515731	85758.7	189151.	0.0	0.0	0.0	364.4	1395.3	4666.1	10724.	17111.	33468.	84181.	237407.	2769028.
515831	5377.6	11738.	27.8	27.8	27.8	29.8	29.8	30.8	31.	34.	675.	5078.	17880.	101158.
509431	24509.4	52829.	0.0	0.0	0.0	0.0	0.0	4.2	68.	1523.	6766.	26335.	75858.	532825.
516531	13944.0	30688.	0.0	0.0	0.0	0.0	0.0	0.0	0.	20.	311.	10258.	52029.	229058.
515931	9204.6	27218.	0.0	0.0	0.0	0.0	0.0	0.0	70.	210.	755.	4755.	24454.	319891.
516031	29237.1	70905.	0.0	191.1	241.0	271.0	558.3	955.6	1244.	1482.	2022.	22698.	87017.	606992.
516131	12960.5	32570.	0.0	0.0	0.0	0.0	0.0	0.0	23.	150.	1207.	9248.	41299.	305822.
516231	3624.1	8035.	0.0	0.0	0.0	0.0	0.0	0.0	0.	58.	518.	3056.	13012.	73401.
516331	13883.8	24477.	0.0	0.0	0.0	0.0	0.0	709.8	2064.	3803.	6514.	16432.	41650.	210662.
516431	13406.6	30539.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	84.	7443.	53136.	248026.

LRCA58	Cameron Gage on Little River
BRBR59	Bryan Gage on Brazos River
BRHE68	Hempstead Gage on Brazos
BRRI70	Richmond Gage on Brazos River
BRGM73	Brazos Outlet at Gulf of Mexico
515531	Possum Kingdom Reservoir
515631	Granbury Reservoir
515731	Whitney Reservoir
515831	Aquilla Reservoir
509431	Waco Reservoir
516531	Limestone Reservoir
515931	Proctor Reservoir
516031	Belton Reservoir
516131	Stillhouse Hollow Res.
516231	Georgetown Reservoir
516331	Granger Reservoir
516431	Somerville Reservoir

Table 9.8
Monthly Unappropriated Flow-Frequency for Scenarios 9.01, 9.02, 9.03 and 9.04
(Flows are in acre-feet per month.)

Monthly Unappropriated Flow-Frequency, Scenario 9.01, Monthly Bwam3 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	66802.6	151868.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	6306.	63957.	205500.	1392119.
BRBR59	184398.5	406029.	0.0	0.0	0.0	0.0	0.0	0.0	0.	646.	36492.	194437.	550651.	3896806.
BRHE68	225326.8	470961.	0.0	0.0	0.0	0.0	0.0	0.0	0.	8990.	49169.	253542.	749110.	4543294.
BRRI70	284147.7	518865.	0.0	0.0	0.0	0.0	0.0	0.0	7210.	51158.	117997.	363843.	888534.	4899480.
BRGM73	345192.9	573761.	0.0	0.0	0.1	0.4	1.8	8714.7	43633.	104269.	182159.	448020.	1021423.	5291176.
515531	14628.9	82845.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	13848.	1425792.
515631	27582.6	122537.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	59951.	2168298.
515731	53721.8	164864.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	27533.	154334.	2449524.
515831	4034.9	10925.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	305.	15014.	100072.
509431	19489.9	50339.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	12128.	68299.	529232.
516531	10501.2	26607.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	42099.	215300.
515931	6522.8	25377.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	12806.	274660.
516031	24581.9	67816.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	5052.	77271.	546708.
516131	11288.2	31531.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1462.	37535.	302253.
516231	3178.8	7842.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1553.	11644.	73211.
516331	10680.3	23751.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	11206.	37535.	208215.
516431	12763.9	30148.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	6197.	52326.	247435.

Monthly Unappropriated Flow-Frequency, Scenario 9.03, Daily Bwam3 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	67733.6	151574.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	8216.	67411.	205474.	1392000.
BRBR59	201203.8	414158.	0.0	0.0	0.0	0.0	0.0	0.0	0.	11012.	62620.	229012.	568159.	3875826.
BRHE68	255643.7	486455.	0.0	0.0	0.0	0.0	0.0	0.0	541.	26329.	92336.	323119.	783318.	4524500.
BRRI70	285299.3	519213.	0.0	0.0	0.0	0.0	0.0	0.0	5507.	53335.	122142.	368586.	893633.	4881313.
BRGM73	345775.4	574464.	0.0	0.0	0.1	1.4	17.2	6916.0	42523.	102612.	186561.	451416.	1021418.	5274451.
515531	14931.6	81606.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	20621.	1381468.
515631	28174.8	122377.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	67405.	2162849.
515731	57640.6	167538.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	127.	37009.	159578.	2442042.
515831	4043.8	10910.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	410.	15014.	100072.
509431	19872.2	50724.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	12371.	68270.	529435.
516531	10604.2	26618.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	887.	42886.	215300.
515931	6233.9	23781.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	12666.	237486.
516031	24721.5	67605.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	8004.	78177.	546483.
516131	11305.4	31479.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1907.	37535.	299954.
516231	3179.9	7825.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1553.	11644.	73211.
516331	10711.9	23683.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	10993.	37535.	207952.
516431	12965.4	30242.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	6711.	52324.	246373.

LRCA58	Cameron Gage on Little River
BRBR59	Bryan Gage on Brazos River
BRHE68	Hempstead Gage on Brazos
BRRI70	Richmond Gage on Brazos River
BRGM73	Brazos Outlet at Gulf of Mexico
515531	Possum Kingdom Reservoir
515631	Granbury Reservoir
515731	Whitney Reservoir
515831	Aquilla Reservoir
509431	Waco Reservoir
516531	Limestone Reservoir
515931	Proctor Reservoir
516031	Belton Reservoir
516131	Stillhouse Hollow Res.
516231	Georgetown Reservoir
516331	Granger Reservoir
516431	Somerville Reservoir

Table 9.8 (Continued)
Monthly Unappropriated Flow-Frequency for Scenarios 9.01, 9.02, 9.03 and 9.04
(Flows are in acre-feet per month.)

Monthly Unappropriated Flow-Frequency, Scenario 9.02, Monthly Bwam8 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	74441.4	156901.	0.0	0.0	0.0	0.0	0.0	0.0	0.	3930.	18748.	79151.	219785.	1399060.
BRBR59	225229.4	437702.	0.0	0.0	0.0	0.0	0.0	0.0	7255.	31009.	82896.	265098.	637389.	4357889.
BRHE68	290485.3	521750.	0.0	0.0	0.0	0.0	0.0	0.0	18888.	52384.	136401.	368670.	889961.	5188487.
BRRI70	325346.3	554068.	0.0	0.0	0.0	0.0	0.0	0.0	36362.	83046.	167086.	433552.	976451.	5547282.
BRGM73	400019.2	608002.	0.0	0.2	0.8	121.3	563.5	39233.8	90376.	157648.	247919.	526430.	1140365.	5939702.
515531	26222.0	99550.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	5468.	69053.	1661772.
515631	42548.5	144470.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	22373.	124847.	2516516.
515731	74882.8	189411.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	13749.	63356.	227370.	2793222.
515831	5040.3	11746.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	3849.	16786.	101125.
509431	23431.6	53102.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	1487.	23882.	75753.	532815.
516531	13283.3	30352.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	8762.	51619.	229076.
515931	7515.8	26810.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	17534.	320049.
516031	27311.8	70830.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	18600.	86424.	610564.
516131	12105.6	32263.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	6455.	41086.	306237.
516231	3385.6	7994.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	2470.	12303.	73401.
516331	12533.4	24754.	0.0	0.0	0.0	0.0	0.0	0.0	0.	429.	3976.	14184.	41198.	210617.
516431	13220.1	30577.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7053.	53138.	248174.

Monthly Unappropriated Flow-Frequency, Scenario 9.04, Daily Bwam8 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	74432.0	156797.	0.0	0.0	0.0	0.0	0.0	0.0	0.	4632.	18426.	79199.	219687.	1399000.
BRBR59	225179.7	437092.	0.0	0.0	0.0	0.0	0.0	0.0	7367.	33414.	85136.	262079.	637646.	4332930.
BRHE68	290522.1	521266.	0.0	0.0	0.0	0.0	0.0	0.0	19210.	52454.	136222.	368746.	889886.	5164593.
BRRI70	325360.1	553589.	0.0	0.0	0.0	0.0	0.0	0.0	35807.	82104.	168196.	432886.	975235.	5523946.
BRGM73	400044.6	607550.	0.0	0.4	1.2	37.9	678.4	37811.3	89772.	157932.	247318.	526317.	1140248.	5916996.
515531	25802.1	98244.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	6189.	68590.	1636740.
515631	42224.0	143251.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	21484.	124412.	2491574.
515731	74824.4	188631.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	13887.	64072.	227179.	2769028.
515831	5005.4	11720.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	3870.	16516.	101127.
509431	23392.8	53057.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	1640.	23983.	75736.	532825.
516531	13254.3	30318.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	8888.	51620.	229058.
515931	7198.0	25511.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	255.	16693.	271441.
516031	27371.6	70744.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	18752.	85790.	606992.
516131	12112.5	32266.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	6387.	41058.	305822.
516231	3390.4	7991.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	2470.	12303.	73401.
516331	12522.9	24743.	0.0	0.0	0.0	0.0	0.0	0.0	0.	548.	3899.	14156.	41218.	210662.
516431	13230.3	30583.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7063.	53136.	248026.

LRCA58	Cameron Gage on Little River
BRBR59	Bryan Gage on Brazos River
BRHE68	Hempstead Gage on Brazos
BRRI70	Richmond Gage on Brazos River
BRGM73	Brazos Outlet at Gulf of Mexico
515531	Possum Kingdom Reservoir
515631	Granbury Reservoir
515731	Whitney Reservoir
515831	Aquilla Reservoir
509431	Waco Reservoir
516531	Limestone Reservoir
515931	Proctor Reservoir
516031	Belton Reservoir
516131	Stillhouse Hollow Res.
516231	Georgetown Reservoir
516331	Granger Reservoir
516431	Somerville Reservoir

Table 9.9
Reliability Summaries for Scenarios 9.01, 9.02, 9.03 and 9.04

Control Point Reliability, Scenario 9.01, Monthly Bwam3 Simulation

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	++++++++ PERCENTAGE OF MONTHS ++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS ---------- PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	230750.0	988.25	99.14	99.57	99.1	99.1	99.1	99.4	99.4	99.6	99.9	96.6	96.6	96.6	96.6	100.0	100.0	100.0
515631	64712.0	1905.32	96.41	97.06	96.4	96.4	96.6	96.6	96.7	97.0	97.0	91.4	91.4	91.4	93.1	96.6	98.3	98.3
515731	19126.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	80425.1	303.04	98.56	99.62	98.6	98.6	98.6	98.7	100.0	100.0	100.0	96.6	96.6	96.6	98.3	100.0	100.0	100.0
516531	65074.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	19658.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	112257.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	371.47	98.85	99.45	98.9	99.0	99.0	99.3	99.4	99.6	99.6	94.8	94.8	96.6	96.6	100.0	100.0	100.0
516231	13610.0	229.43	98.13	98.31	98.1	98.1	98.1	98.1	98.3	98.4	98.6	93.1	94.8	94.8	94.8	98.3	98.3	100.0
516331	19840.0	78.24	99.43	99.61	99.4	99.4	99.4	99.4	99.4	99.6	99.7	96.6	96.6	96.6	96.6	100.0	100.0	100.0
516431	48000.0	211.36	99.14	99.56	99.1	99.1	99.1	99.1	99.1	99.3	99.6	96.6	96.6	96.6	98.3	100.0	100.0	100.0
Total	755116.1	4087.11		99.46														

Control Point Reliability, Scenario 9.03, Daily Bwam3 Simulation

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	++++++++ PERCENTAGE OF MONTHS ++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS ---------- PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	230750.0	1001.12	99.14	99.57	99.1	99.1	99.1	99.4	99.4	99.6	99.9	96.6	96.6	96.6	96.6	100.0	100.0	100.0
515631	64712.0	1917.01	96.41	97.04	96.4	96.6	96.6	96.6	96.6	97.0	97.0	91.4	91.4	91.4	91.4	96.6	98.3	98.3
515731	19132.9	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	80557.9	127.35	99.14	99.84	99.1	99.3	99.3	99.3	100.0	100.0	100.0	96.6	96.6	98.3	100.0	100.0	100.0	100.0
516531	65074.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	19658.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	112257.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	471.34	97.99	99.30	98.0	98.0	98.4	99.0	99.4	99.4	99.6	91.4	91.4	93.1	96.6	100.0	100.0	100.0
516231	13610.0	282.48	97.27	97.92	97.3	97.3	97.6	97.6	97.8	98.1	98.1	93.1	93.1	93.1	94.8	98.3	98.3	100.0
516331	19840.0	109.15	98.99	99.45	99.0	99.0	99.3	99.3	99.4	99.4	99.4	96.6	96.6	96.6	98.3	100.0	100.0	100.0
516431	48000.0	215.89	99.14	99.55	99.1	99.1	99.1	99.1	99.1	99.3	99.6	96.6	96.6	96.6	98.3	100.0	100.0	100.0
Total	755255.7	4124.32		99.45														

Control Point Reliability, Scenario 9.02, Monthly Bwam8 Simulation

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	++++++++ PERCENTAGE OF MONTHS ++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS ---------- PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	59482.2	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	36025.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18972.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	2394.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	38743.2	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516531	39337.1	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	14068.1	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	107737.5	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516231	11943.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516331	2569.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516431	48000.0	138.26	99.28	99.71	99.3	99.3	99.3	99.3	99.4	99.6	99.7	96.6	96.6	96.6	100.0	100.0	100.0	100.0
Total	447040.9	138.26		99.97														

Table 9.9 (Continued)
Reliability Summaries for Scenarios 9.01, 9.02, 9.03 and 9.04

Control Point Reliability, Scenario 9.04, Daily Bwam8 Simulation

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	++++++++ PERCENTAGE OF MONTHS ++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS ---------- PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	59482.2	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	36025.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18985.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	2394.3	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	38773.5	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516531	39337.1	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	14068.1	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	107737.5	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516231	11943.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516331	2569.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516431	48000.0	142.57	99.28	99.70	99.3	99.3	99.3	99.3	99.3	99.6	99.7	96.6	96.6	96.6	100.0	100.0	100.0	100.0
Total	447084.0	142.58		99.97														

<u>Control Points</u>

515531 Possum Kingdom Reservoir
515631 Granbury Reservoir
515731 Whitney Reservoir
515831 Aquilla Reservoir
509431 Waco Reservoir
516531 Limestone Reservoir
515931 Proctor Reservoir
516031 Belton Reservoir
516131 Stillhouse Hollow Res.
516231 Georgetown Reservoir
516331 Granger Reservoir
516431 Somerville Reservoir

Water rights with access to the Brazos River Authority conservation storage in Whitney Lake are modeled with a drought index *DI*/*IS*/*IP* record set to alter monthly target demands based on the state of conservation storage. The water right targets at Whitney's control point, 515731, are different between scenarios due to differences in storage.

The differences in Tables 9.6 through 9.9 are small, but can be traced to the effect of time step size on the simulation computations. Slightly lower storage-frequencies in the Bwam3 scenarios due to the computation of net evaporation-precipitation with a non-linear surface area versus storage volume relationship causes reservoir refilling to be slightly higher. This results in slightly lower regulated and unappropriated flow volumes for specified exceedance frequencies. Reliabilities of water rights at the major conservation reservoirs are not materially affected. Water availability in the Bwam8 scenarios is higher overall due to the combination of lower water right demands and the presence of return flows. Reservoirs that are more frequently full in the monthly and daily simulations experience less divergence in their net evaporation-precipitation volumes.

Methods for Disaggregating Naturalized Flow

SIMD has several alternative methods available to disaggregate monthly naturalized flows into daily naturalized flows. The user may also enter daily naturalized flows directly as input in lieu of selecting a disaggregation method. The uniform, linear interpolation, and flow pattern disaggregation methods are examined in this section. Flow disaggregation methods are discussed in Chapter 8 of this report and in detail in the *Daily Manual*. The focus of this section is to examine the effects of the naturalized flow disaggregation method on simulation output. The SUPER flow data presented in Chapter 8 are used as the basis for the flow pattern disaggregation method in this chapter.

Table 9.10
Parameters per Simulation Scenario Being Considered

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, *WRMETH*	Disaggregation Option, *DFMETHOD*	Target Distribution Option, *ND*	Flow Forecasting, *FPRD*	Negative Increntals, *ADJINC*	Execution Time, hours
9.03	day	Bwam3	none	*na*	uniform	uniform	0 days	1	0.22
9.05	day	Bwam3	none	*na*	linear interp	uniform	0 days	1	0.26
9.06	day	Bwam3	none	*na*	daily pattern	uniform	0 days	1	0.24
9.07	day	Bwam3	lag-att	1	uniform	uniform	0 days	7	0.26
9.08	day	Bwam3	lag-att	1	daily pattern	uniform	0 days	7	0.24

The SUPER daily flow patterns were used to develop routing parameters. The daily flow patterns and the associated routing parameters are both used in Scenario 9.08. Scenario 9.07 uses routing parameters only as a basis for comparison with Scenario 9.08. The alternative method for placing routed flow changes in the priority sequence is examined in the next section.

The monthly naturalized flows are the same for all Bwam simulations in this chapter. Accordingly, the monthly naturalized flow-frequencies shown in Table 9.5 are the same for all scenarios. The flow-frequency computed from daily naturalized flows will differ according to the method of disaggregation applied to the monthly naturalized flows. Table 9.11 shows the daily naturalized flow-frequencies for the uniform, linear interpolation and flow pattern disaggregation methods used in the scenarios of this section.

The values of mean naturalized flow are the same for all methods of disaggregation. Flow variability is, however, significantly different. Differences in flow frequency statistics are most evident in the low and high exceedance frequencies. In particular, locations with the highest daily flow variability exhibit the greatest differences in flow frequency statistics between different disaggregation methods. For example, outlets of the relatively small drainage basins for Lakes Aquilla and Limestone are located at control points 5151831 and 516531, respectively. The watershed area of Aquilla Lake is 254 square miles, and the watershed area of Limestone Lake is 678 square miles. Switching from uniform or linear disaggregation to the flow pattern disaggregation method produces a dramatic difference in the flow frequency tables. In general, the flow frequency analysis computations at all control point locations exhibit sensitivity to the disaggregation method.

Table 9.11
Flow Frequency Statistics for Daily Naturalized Stream Flows for the
Uniform, Linear Interpolation, and Flow Pattern Methods of Disaggregation
(Flows are in acre-feet/day.)

Daily Naturalized Flow-Frequency, Scenarios 9.03 and 9.07, Uniform Disaggregation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	3609.22	5609.9	0.00	12.35	36.58	84.37	178.53	485.00	946.9	1484.0	2164.1	4319.3	9470.4	48384.0
BRBR59	11027.70	15888.3	0.00	208.19	360.19	592.80	911.03	1957.52	3517.6	5295.3	7589.1	13305.5	26782.3	151752.0
BRHE68	14671.70	19327.7	52.71	423.07	566.00	972.71	1464.74	2903.32	5146.3	7615.1	10090.4	19220.0	37804.3	184628.5
BRRI70	16016.62	20123.4	0.00	545.55	789.26	1282.57	1786.16	3675.33	5964.3	8500.7	11761.1	21358.3	39861.4	197934.7
BRGM73	16714.85	20823.7	0.13	556.37	827.47	1364.45	1918.39	3974.07	6425.5	8999.7	12368.3	22127.8	41621.7	201757.0
515531	2172.37	4485.1	0.00	0.00	0.00	8.00	68.27	223.70	422.2	608.5	1000.2	2146.2	5404.2	57886.6
515631	2994.79	5845.2	0.00	0.00	23.41	66.12	148.95	330.84	641.2	969.0	1596.6	3123.1	7723.2	85608.5
515731	3742.18	6658.9	0.25	3.58	48.93	108.57	220.13	528.09	943.0	1489.0	2119.5	4223.7	9418.4	95580.5
515831	201.96	393.7	0.00	0.00	0.00	0.00	0.00	1.07	15.3	32.1	67.2	209.6	623.0	3308.4
509431	978.66	1752.3	0.00	0.00	0.22	1.20	15.11	88.78	191.0	325.2	495.6	1120.7	2616.0	17114.8
516531	637.34	1117.3	0.00	0.00	0.00	0.99	3.20	19.85	58.1	128.6	259.9	691.4	1990.5	7755.6
515931	396.55	938.2	0.00	0.00	0.00	0.01	1.78	16.21	43.1	79.0	125.0	348.8	1090.8	10909.5
516031	1377.07	2471.1	0.00	0.00	0.00	0.07	15.62	111.02	251.5	411.9	730.8	1533.5	3668.9	20244.2
516131	632.05	1128.7	0.90	3.80	4.70	16.08	23.81	68.98	125.7	194.4	302.5	686.0	1741.7	9970.7
516231	157.58	277.8	0.00	0.00	0.00	0.61	2.69	11.09	28.6	45.8	75.9	177.8	469.4	2496.9
516331	510.93	821.8	0.00	0.04	0.18	5.18	15.48	58.08	116.5	179.7	274.7	644.1	1488.6	7002.8
516431	610.17	1092.0	0.00	0.00	0.00	0.05	0.14	24.07	75.3	127.9	237.4	609.3	2021.8	8654.6

Daily Naturalized Flow-Frequency, Scenario 9.05, Linear Interpolation Disaggregation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	3609.23	5970.3	0.00	2.60	9.48	49.99	129.04	420.21	853.6	1327.1	2071.9	4190.8	9797.6	71863.0
BRBR59	11027.70	16916.0	0.00	35.89	103.25	322.20	658.80	1652.83	3268.6	4946.9	7122.9	13324.1	28198.6	203605.2
BRHE68	14671.64	20535.4	0.35	95.05	228.74	578.72	1071.12	2501.74	4788.4	6963.2	9985.0	18794.4	37605.3	241718.9
BRRI70	16016.66	21248.3	0.00	138.16	394.79	861.48	1466.18	3194.71	5670.2	7960.8	11405.5	20625.1	40549.4	262967.8
BRGM73	16714.85	21966.7	0.01	161.81	441.49	898.78	1570.66	3475.65	5965.3	8347.7	11863.8	21523.8	42386.7	267816.1
515531	2172.36	4879.5	0.00	0.00	0.00	1.30	23.90	147.93	343.2	549.4	915.0	2094.8	5371.0	76829.3
515631	2994.79	6302.5	0.00	0.00	2.26	20.88	73.93	256.67	531.8	878.4	1471.6	3073.0	7598.2	118275.1
515731	3742.19	7144.5	0.00	2.19	6.32	37.28	118.60	417.20	847.2	1319.3	2058.8	4075.5	9628.9	130674.7
515831	201.96	434.5	0.00	0.00	0.00	0.00	0.00	0.32	8.5	25.0	53.8	197.5	633.9	5996.3
509431	978.66	1877.6	0.00	0.00	0.08	0.72	5.24	64.84	164.9	275.1	478.5	1044.3	2659.3	27989.9
516531	637.34	1224.8	0.00	0.00	0.00	0.20	1.25	12.38	41.6	97.5	218.2	664.0	2036.0	13499.6
515931	396.56	1019.1	0.00	0.00	0.00	0.01	0.48	9.69	33.8	63.9	112.9	311.6	1053.1	17201.5
516031	1377.07	2637.4	0.00	0.00	0.00	0.05	4.91	87.21	214.0	380.8	681.8	1427.8	3799.5	30209.2
516131	632.05	1202.6	0.00	0.49	1.54	6.64	18.07	56.59	112.1	186.6	294.8	652.5	1747.5	16817.6
516231	157.58	297.1	0.00	0.00	0.00	0.15	1.82	8.73	23.8	42.1	68.6	172.7	467.9	4467.0
516331	510.93	876.2	0.00	0.02	0.10	2.69	10.06	49.01	105.4	170.5	260.6	614.3	1460.2	11700.6
516431	610.17	1205.6	0.00	0.00	0.00	0.03	0.14	14.38	53.3	104.2	205.4	595.3	1964.2	14283.5

LRCA58 Cameron Gage on Little River
BRBR59 Bryan Gage on Brazos River
BRHE68 Hempstead Gage on Brazos
BRRI70 Richmond Gage on Brazos River
BRGM73 Brazos Outlet at Gulf of Mexico
515531 Possum Kingdom Reservoir
515631 Granbury Reservoir
515731 Whitney Reservoir

515831 Aquilla Reservoir
509431 Waco Reservoir
516531 Limestone Reservoir
515931 Proctor Reservoir
516031 Belton Reservoir
516131 Stillhouse Hollow Res.
516231 Georgetown Reservoir
516331 Granger Reservoir
516431 Somerville Reservoir

Table 9.11 (continued)
Flow Frequency Statistics for Daily Naturalized Stream Flows for the
Uniform, Linear Interpolation, and Flow Pattern Methods of Disaggregation
(Flows are in acre-feet/day.)

Daily Naturalized Flow-Frequency, Scenarios 9.06 and 9.08, Flow Pattern Disaggregation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	3609.23	9579.0	0.00	5.25	15.60	40.40	86.35	309.13	608.8	941.4	1505.3	3120.1	8211.2	289749.2
BRBR59	11027.70	24679.1	0.00	173.59	235.31	400.05	623.20	1309.30	2293.0	3328.5	4970.3	10061.4	26679.6	719015.3
BRHE68	14671.63	27965.5	4.72	303.04	407.49	640.35	988.36	2049.15	3464.8	5018.9	7618.8	15116.6	38178.6	759900.8
BRRI70	16016.66	28447.9	0.00	347.82	502.13	803.53	1199.23	2463.31	4149.3	5975.9	8980.2	17174.1	40730.7	645000.9
BRGM73	16714.85	29220.0	0.01	363.07	530.46	862.15	1286.39	2676.40	4471.7	6386.6	9589.5	17932.2	42033.5	586092.1
515531	2172.37	7532.6	0.00	0.00	0.00	0.00	0.00	62.92	219.9	365.6	564.0	1256.1	4078.0	192249.2
515631	2994.79	9181.3	0.00	0.00	1.20	33.00	77.02	233.16	430.5	614.3	894.8	1856.5	6112.8	178772.0
515731	3742.19	10207.1	0.00	1.78	16.16	62.18	124.25	340.67	626.6	904.9	1313.9	2681.5	8381.6	193611.7
515831	201.96	1176.1	0.00	0.00	0.00	0.00	0.00	0.00	2.9	7.1	15.9	49.0	197.2	44240.4
509431	978.66	3749.1	0.00	0.00	0.00	0.48	3.59	34.17	96.8	168.4	284.3	630.5	1940.0	219455.4
516531	637.34	2516.0	0.00	0.00	0.00	0.00	0.00	5.30	18.1	36.8	72.3	211.3	1303.4	72246.6
515931	396.56	2349.2	0.00	0.00	0.00	0.00	0.00	2.55	13.6	28.8	56.2	138.7	685.9	200315.6
516031	1377.07	4249.1	0.00	0.00	0.00	0.00	0.76	43.41	133.2	250.3	447.7	1038.6	3157.8	165626.0
516131	632.05	2421.2	0.00	0.00	0.00	2.68	9.75	32.88	71.7	116.2	197.1	501.7	1461.6	120489.0
516231	157.58	646.6	0.00	0.00	0.00	0.00	1.11	6.13	17.4	30.6	49.7	124.3	340.8	26837.0
516331	510.93	1676.1	0.00	0.00	0.00	1.34	6.76	33.23	77.1	114.8	184.6	433.6	1094.2	61175.3
516431	610.17	2369.4	0.00	0.00	0.00	0.00	0.00	4.20	20.7	45.5	89.5	265.6	1245.9	98735.3

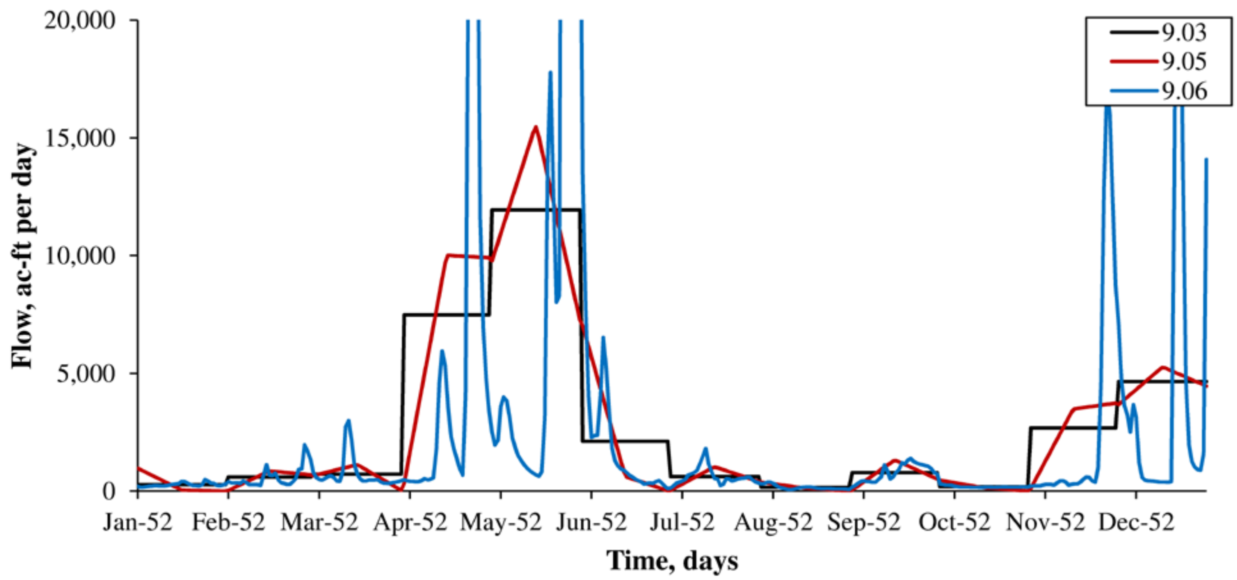

Figure 9.6 Naturalized Flow at the Bryan Gage

The linear interpolation method has lower values of flow in the high exceedance percentages at locations where baseflow comprises a larger component of the flow regime. The linear interpolation method occasionally sets the end points of the interpolation splines below baseflow levels. An example of the interpolation spline method is shown in Figure 8.6.

Figure 9.6 shows daily disaggregated naturalized flow the Bryan gage for 1952. The visual appearance of the uniform and linear interpolation methods is most different where there are large intra-month changes in flow. Months with lower intra-month flow rate variability, such as September through November, 1952, do not have as much difference in flow between the three methods of disaggregation. Lower intra-month flow variability allows the uniform and linear interpolation methods to create a more comparable set of disaggregated flows to the flow pattern method for that particular month.

Table 9.12
End of Day Storage-Frequency for the Scenarios 9.03, 9.05, 9.06 and 9.08
(Flows are in acre-feet/day.)

End of Day Storage-Frequency, Scenarios 9.03, Uniform Disaggregation

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
515531	556144.	171916.	0.	3364.	66354.	167542.	313286.	465609.	560215.	602283.	647913.	698153.	724739.	724739.
515631	118458.	42609.	0.	0.	0.	12233.	52914.	105486.	121988.	131283.	141274.	154198.	155000.	155000.
515731	610470.	37463.	434412.	449038.	490071.	531003.	560856.	599990.	618579.	627601.	632642.	636100.	636100.	636100.
515831	44389.	9831.	1381.	8084.	12985.	20915.	33216.	40374.	44862.	47381.	49799.	52226.	52400.	52400.
509431	180503.	32117.	63464.	75979.	87428.	109723.	131137.	167741.	183850.	192155.	200663.	206294.	206562.	206562.
516531	185448.	48535.	10466.	22943.	39466.	69840.	116848.	169727.	189767.	201856.	212331.	224260.	225400.	225400.
515931	47229.	13421.	1697.	8494.	10039.	18168.	27266.	40579.	46493.	51032.	55595.	59107.	59400.	59400.
516031	381796.	103482.	887.	26150.	47475.	124659.	227554.	359243.	400270.	418634.	438191.	454206.	457600.	457600.
516131	191178.	63778.	0.	0.	4561.	23527.	69646.	179068.	208923.	219876.	227505.	233713.	235700.	235700.
516231	29219.	9939.	0.	0.	0.	6009.	14464.	24560.	31000.	33660.	35468.	36913.	37100.	37100.
516331	55204.	15364.	0.	866.	6150.	18692.	33637.	50211.	58695.	63063.	65328.	65500.	65500.	65500.
516431	131024.	35876.	0.	4889.	32010.	57552.	74685.	114527.	136125.	144370.	152642.	160110.	160110.	160110.
Total	2531062.	508265.	753575.	949755.	1029271.	1325221.	1742334.	2315939.	2597348.	2694461.	2773403.	2903588.	2996147.	3015611.

End of Day Storage-Frequency, Scenario 9.05, Linear Interpolation Disaggregation

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
515531	519425.	188724.	0.	0.	23316.	121460.	255702.	397345.	505680.	570615.	621900.	680102.	723208.	724739.
515631	113681.	43990.	0.	0.	0.	4247.	46842.	97529.	114292.	124662.	136083.	151674.	155000.	155000.
515731	610287.	37069.	434948.	452459.	488383.	532682.	561823.	599795.	618443.	626373.	632029.	635985.	636100.	636100.
515831	43746.	10395.	0.	3857.	8720.	19822.	31658.	39534.	44134.	46705.	49244.	52069.	52400.	52400.
509431	178364.	33158.	61462.	72698.	83620.	104894.	127147.	164644.	180821.	189464.	198156.	205771.	206562.	206562.
516531	182655.	50069.	2502.	17408.	31927.	64376.	114449.	165367.	186348.	198636.	209472.	222528.	225400.	225400.
515931	46051.	13888.	1046.	6834.	8357.	17054.	25667.	39461.	44767.	48490.	53971.	58900.	59400.	59400.
516031	378294.	104677.	0.	19424.	41948.	116519.	226448.	354871.	396412.	413753.	432358.	452604.	457600.	457600.
516131	187629.	64086.	0.	0.	2434.	21121.	67075.	174660.	206067.	214097.	221642.	232041.	235700.	235700.
516231	28749.	10235.	0.	0.	0.	3606.	13373.	24061.	30519.	33058.	34865.	36897.	37100.	37100.
516331	54260.	16479.	0.	0.	1808.	13519.	29408.	49662.	58171.	61875.	64795.	65500.	65500.	65500.
516431	129279.	36601.	0.	3623.	29478.	55169.	70167.	112424.	133095.	141840.	150585.	160040.	160110.	160110.
Total	2472423.	525448.	708698.	899376.	976128.	1250489.	1646322.	2230264.	2505979.	2630046.	2722630.	2873082.	2982184.	3015611.

Table 9.12 (continued)

End of Day Storage-Frequency, Scenario 9.06, Flow Pattern Disaggregation without Routing

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
515531	348048.	242186.	0.	0.	0.	0.	0.	108924.	263675.	380923.	446172.	557032.	676333.	724739.
515631	116272.	42679.	0.	0.	0.	8956.	49714.	101628.	119350.	128606.	137604.	151187.	155000.	155000.
515731	607628.	37559.	447120.	455612.	480538.	528052.	556102.	595977.	613563.	622213.	629430.	635029.	636100.	636100.
515831	29617.	17331.	0.	0.	0.	0.	0.	15650.	28545.	33567.	37873.	44223.	50876.	52400.
509431	158006.	54897.	549.	5346.	9805.	24593.	67277.	139322.	165857.	176066.	186970.	200434.	206437.	206562.
516531	114014.	72774.	0.	0.	0.	0.	5678.	53993.	89196.	112337.	140692.	176513.	218596.	225400.
515931	30727.	22496.	0.	0.	0.	0.	0.	6440.	21211.	35602.	42756.	52285.	59324.	59400.
516031	349481.	133789.	0.	0.	0.	366.	112456.	318877.	378847.	400617.	420289.	448744.	457600.	457600.
516131	156186.	74675.	0.	0.	0.	0.	0.	111644.	159436.	178531.	197796.	216916.	233557.	235700.
516231	25254.	12733.	0.	0.	0.	0.	246.	16393.	27136.	31122.	33150.	36043.	36922.	37100.
516331	48816.	20748.	0.	0.	0.	0.	10953.	39359.	52775.	58213.	62025.	65202.	65500.	65500.
516431	118471.	45975.	0.	0.	0.	13898.	41692.	96966.	123851.	133980.	142911.	157950.	160110.	160110.
Total	2102520.	659915.	496375.	514615.	550490.	659408.	1008103.	1747753.	2111300.	2271091.	2413321.	2614586.	2801920.	3015611.

End of Day Storage-Frequency, Scenario 9.08, Flow Pattern Disaggregation with Routing

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
515531	613531.	102465.	197891.	269496.	325440.	424888.	471354.	553291.	612117.	645157.	669083.	698226.	713525.	724739.
515631	113854.	43075.	0.	0.	0.	3287.	45297.	96784.	116899.	125716.	135265.	149445.	154889.	155000.
515731	598018.	46975.	406161.	424352.	448585.	483037.	534812.	586278.	604271.	612760.	621615.	632112.	636100.	636100.
515831	37777.	15612.	0.	0.	0.	0.	8155.	33190.	40320.	42984.	45573.	49856.	52015.	52400.
509431	155002.	57104.	453.	784.	4515.	15790.	60127.	134735.	163374.	173908.	186049.	200163.	205144.	206562.
516531	177604.	51916.	0.	11259.	27751.	59308.	101115.	158405.	181506.	193319.	204748.	218816.	224612.	225400.
515931	37834.	19091.	0.	0.	0.	0.	8095.	23294.	36976.	41672.	47285.	55994.	59351.	59400.
516031	362293.	124635.	0.	0.	0.	23073.	171856.	336641.	389830.	408302.	427730.	449720.	457600.	457600.
516131	178138.	71117.	0.	0.	0.	0.	27572.	160656.	195008.	207033.	216912.	229507.	235222.	235700.
516231	26756.	11513.	0.	0.	0.	0.	6876.	20182.	28086.	31696.	34016.	36009.	36940.	37100.
516331	52384.	18005.	0.	0.	0.	7869.	24901.	46404.	56055.	60973.	64132.	65444.	65500.	65500.
516431	128784.	37132.	0.	279.	24051.	53763.	67699.	111780.	133896.	141556.	149326.	159722.	160110.	160110.
Total	2481974.	519504.	843201.	916578.	1020846.	1285734.	1607640.	2271998.	2545968.	2647156.	2737996.	2877579.	2965380.	3015611.

Table 9.13
Daily Regulated Flow-Frequency for the Scenarios 9.03, 9.05, 9.06 and 9.08 (ac-ft per day)

Daily Regulated Flow-Frequency, Scenario 9.03, Uniform Disaggregation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	2733.36	5238.9	0.00	2.86	23.75	39.67	39.67	188.33	389.5	614.3	1002.5	2824.5	7729.2	48362.9
BRBR59	8216.14	14186.7	0.00	109.48	179.20	305.29	482.01	979.61	1701.6	2555.4	3948.4	9021.7	21879.4	143162.5
BRHE68	11403.51	17377.3	62.60	371.20	416.95	664.49	909.66	1710.12	2701.4	4106.8	6544.0	14125.9	30566.3	175552.5
BRRI70	12417.48	18320.6	9.47	420.56	569.62	882.38	1147.19	1787.13	2825.1	4656.0	7494.2	15686.1	33401.9	188363.1
BRGM73	11359.87	18972.2	0.00	0.00	0.00	0.01	0.06	184.70	1218.2	3252.9	6057.0	14840.5	33458.6	189994.6
515531	1220.46	3799.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	75.0	458.1	3288.4	50731.1
515631	1798.84	5051.3	0.00	0.00	0.00	0.00	0.00	0.00	28.5	124.2	267.3	989.5	5164.3	78303.9
515731	2296.34	5665.2	0.00	0.00	0.00	0.00	7.36	132.40	268.1	417.2	668.0	1611.8	6602.1	87731.0
515831	144.96	370.4	0.96	0.96	0.99	0.99	0.99	0.99	1.0	1.0	1.0	46.9	528.8	3308.3
509431	680.65	1696.5	0.00	0.00	0.00	0.00	0.00	0.00	0.2	1.2	3.6	466.7	2268.0	17141.1
516531	373.52	949.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1.9	79.2	1514.7	7585.4
515931	280.93	886.7	0.00	0.00	0.00	0.00	0.00	0.04	1.1	5.3	17.6	101.2	711.7	10860.7
516031	923.09	2304.3	0.00	0.00	0.00	0.07	14.74	65.08	85.8	102.2	122.7	400.6	2748.2	20143.2
516131	405.42	1072.0	0.00	0.00	0.00	0.00	0.00	0.00	0.4	4.6	24.3	184.5	1306.6	10010.5
516231	115.68	267.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	2.3	11.6	83.1	415.5	2496.6
516331	393.36	791.4	0.00	0.00	0.00	0.00	0.00	0.00	16.2	51.3	119.2	399.1	1281.7	7046.0
516431	434.97	1021.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	4.2	200.3	1750.0	8569.3

Daily Regulated Flow-Frequency, Scenario 9.05, Linear Interpolation Disaggregation

CONTROL		STANDARD	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	2740.93	5519.2	0.00	0.00	0.57	25.91	39.67	163.24	361.5	602.0	1011.9	2650.4	8284.3	71338.9
BRBR59	8273.18	14954.7	0.00	10.14	31.87	149.51	351.46	861.44	1647.8	2553.6	4069.9	8715.2	23044.8	195788.8
BRHE68	11462.63	18311.0	0.00	41.84	127.32	376.77	713.57	1518.67	2693.2	3987.0	6264.0	13960.6	31571.8	220013.1
BRRI70	12477.89	19199.1	8.61	98.86	277.47	577.39	955.10	1785.15	2634.2	4513.0	7068.2	15557.9	34198.2	241057.6
BRGM73	11477.00	19839.0	0.00	0.00	0.00	0.00	0.03	41.39	1087.7	3042.8	5754.4	14769.7	33820.0	244064.0
515531	1254.97	4114.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	32.0	122.2	512.5	3001.4	63833.0
515631	1837.47	5382.2	0.00	0.00	0.00	0.00	0.00	0.00	49.8	138.3	302.6	1076.3	4947.3	105079.8
515731	2338.65	5987.8	0.00	0.00	0.00	0.00	5.12	107.34	270.1	438.1	720.2	1732.4	6106.1	116413.9
515831	145.31	408.1	0.02	0.96	0.99	0.99	0.99	0.99	1.0	1.0	1.0	35.4	495.2	5917.0
509431	681.89	1804.7	0.00	0.00	0.00	0.00	0.00	0.00	0.3	1.6	7.7	379.7	2262.7	27947.9
516531	374.35	1027.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.1	3.7	68.4	1372.6	13283.1
515931	281.94	956.6	0.00	0.00	0.00	0.00	0.00	0.06	1.4	6.4	19.6	92.9	669.0	16868.2
516031	925.97	2439.0	0.00	0.00	0.00	0.05	3.60	58.80	83.9	100.5	122.1	379.8	2883.0	29926.0
516131	407.31	1127.9	0.00	0.00	0.00	0.00	0.00	0.00	1.3	10.2	35.8	194.1	1247.7	16692.8
516231	116.02	283.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	3.5	11.7	70.0	411.5	4410.4
516331	394.66	839.6	0.00	0.00	0.00	0.00	0.00	0.00	15.8	49.0	109.8	383.7	1268.9	11638.3
516431	435.82	1122.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.1	6.6	126.3	1609.0	13991.3

Daily Regulated Flow-Frequency, Scenario 9.06, Flow Pattern Disaggregation without Routing

CONTROL		STANDARD	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	2804.81	8612.2	0.00	0.00	0.27	18.97	39.67	134.30	313.0	501.1	805.4	1920.1	6517.0	288362.0
BRBR59	8509.46	21337.1	0.00	73.26	120.67	217.63	358.16	754.08	1368.6	1864.5	2899.4	6728.8	21238.1	688249.7
BRHE68	11748.52	24277.1	0.00	208.80	294.60	460.79	690.59	1349.42	2256.0	3256.1	5095.2	11240.4	31257.8	727197.6
BRRI70	12755.44	25365.1	0.00	200.09	295.88	488.23	776.67	1586.00	2252.6	3360.1	5716.0	12618.5	33776.5	619377.1
BRGM73	11807.46	26261.4	0.00	0.00	0.00	0.01	0.03	0.67	564.5	1769.8	4212.7	11458.6	33745.1	559755.8
515531	1402.45	6210.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	42.7	146.2	485.0	2096.9	192249.2
515631	1979.51	7560.3	0.00	0.00	0.00	0.00	0.00	26.42	102.5	195.0	346.0	852.7	3526.7	178772.0
515731	2486.56	8304.8	0.00	0.00	0.00	0.00	14.66	100.29	235.2	377.6	597.8	1332.0	5055.4	178156.4
515831	154.77	1070.9	0.00	0.00	0.00	0.00	0.99	0.99	1.0	1.0	1.0	5.0	80.4	37727.5
509431	699.15	3557.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	3.7	30.1	210.0	1278.4	219431.6
516531	415.82	2241.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1.4	17.1	507.3	72183.0
515931	304.96	2236.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	2.6	7.9	43.6	430.7	197122.6
516031	960.52	3752.3	0.00	0.00	0.00	0.00	0.00	3.57	36.9	69.6	122.1	387.5	2180.3	137414.1
516131	429.93	2195.1	0.00	0.00	0.00	0.00	0.00	0.00	11.4	22.1	41.5	128.5	932.9	120480.1
516231	119.29	628.0	0.00	0.00	0.00	0.00	0.00	0.00	1.8	5.2	10.6	45.8	263.9	26836.5
516331	402.91	1588.2	0.00	0.00	0.00	0.00	0.00	5.37	21.0	42.7	78.5	237.5	899.3	61175.3
516431	445.41	2079.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	1.9	11.4	84.2	757.2	97585.1

Daily Regulated Flow-Frequency, Scenario 9.08, Flow Pattern Disaggregation with Routing

CONTROL		STANDARD	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	2772.99	8546.8	0.00	0.00	0.70	19.30	39.67	125.99	290.6	466.6	770.5	1896.7	6486.0	286640.9
BRBR59	8263.17	21346.7	0.00	23.42	99.25	201.54	329.90	708.90	1238.9	1753.4	2680.5	6216.2	20488.3	710468.4
BRHE68	11457.17	24262.5	0.00	86.45	241.42	404.20	633.05	1266.74	2079.7	2945.4	4627.0	10753.4	30852.6	750363.7
BRRI70	12473.39	24906.5	8.25	107.84	253.63	469.51	746.22	1572.02	2243.5	3246.8	5379.7	12216.3	33477.3	636108.2
BRGM73	11543.97	25628.5	0.00	0.00	0.00	0.01	0.05	10.74	700.1	1740.8	4009.9	11190.7	32883.8	575309.6
515531	1167.47	5799.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	235.0	1786.3	152071.0
515631	1754.61	7209.6	0.00	0.00	0.00	0.00	0.00	6.72	62.0	131.0	249.3	683.9	3003.8	156232.5
515731	2265.59	8068.1	0.00	0.00	0.00	0.00	5.81	74.62	187.9	305.1	500.3	1152.4	4333.9	188629.4
515831	149.92	1039.9	0.00	0.00	0.00	0.96	0.99	0.99	1.0	1.0	1.0	6.7	101.0	37727.5
509431	698.84	3446.7	0.00	0.00	0.00	0.00	0.00	0.00	1.1	15.6	55.8	260.5	1331.1	219374.0
516531	376.45	2017.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	10.4	342.0	67259.6
515931	293.05	2149.3	0.00	0.00	0.00	0.00	0.00	0.00	0.2	4.6	14.1	64.3	439.7	200270.0
516031	944.37	3742.3	0.00	0.00	0.00	0.00	0.00	2.87	36.1	71.9	132.4	431.2	2113.4	164041.7
516131	419.20	2126.3	0.00	0.00	0.00	0.00	0.00	0.00	10.2	20.6	39.5	134.5	995.6	120479.8
516231	117.48	571.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	3.5	9.8	48.8	272.2	23854.5
516331	397.46	1534.9	0.00	0.00	0.00	0.00	0.00	1.34	16.7	39.0	76.5	256.6	890.8	57765.2
516431	436.43	2153.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	20.2	684.6	97722.0

Table 9.14
Daily Unappropriated Flow-Frequency for the Scenarios 9.03, 9.05, 9.06 and 9.08
(Flows are in acre-feet/day.)

Daily Unappropriated Flow-Frequency, Scenario 9.03, Uniform Disaggregation

CONTROL		STANDARD	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	2225.28	5064.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	240.8	2185.6	6898.2	48110.1
BRBR59	6610.24	13739.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	204.4	1928.0	7584.6	18967.0	141298.0
BRHE68	8398.77	16118.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	720.6	2887.6	10450.9	26046.7	166748.5
BRRI70	9373.06	17175.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	1483.6	4072.9	12101.2	28955.3	177768.5
BRGM73	11359.87	18972.2	0.00	0.00	0.00	0.01	0.06	184.70	1218.2	3252.9	6057.0	14840.5	33458.6	189994.6
515531	490.56	2740.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	203.2	50731.1
515631	925.64	4111.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1936.9	78303.9
515731	1893.69	5608.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	963.2	5623.3	87731.0
515831	132.85	369.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	504.8	3307.4
509431	652.87	1697.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	279.8	2250.6	17141.1
516531	348.38	935.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1414.5	7585.4
515931	204.80	824.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	395.6	10839.6
516031	812.19	2294.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	2667.6	20121.1
516131	371.42	1063.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1299.7	10010.5
516231	104.47	265.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	16.3	383.5	2496.6
516331	351.92	795.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	344.0	1225.4	7046.0
516431	425.96	1023.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	150.7	1750.0	8569.3

Daily Unappropriated Flow-Frequency, Scenario 9.05, Linear Interpolation Disaggregation

CONTROL		STANDARD	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	2182.48	5344.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	32.5	1812.0	7209.6	69315.7
BRBR59	6521.58	14372.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1349.2	6759.4	20547.8	176041.6
BRHE68	8417.49	16939.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	221.7	2465.6	9983.5	26496.0	211209.1
BRRI70	9485.62	18031.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	1159.2	3774.0	11725.6	28981.9	230463.0
BRGM73	11477.00	19839.0	0.00	0.00	0.00	0.00	0.03	41.39	1087.7	3042.8	5754.4	14769.7	33820.0	244064.0
515531	412.90	2646.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	63833.0
515631	840.27	4173.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1258.5	105079.8
515731	1824.09	5827.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	709.3	5168.1	116413.9
515831	128.54	405.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	429.2	5916.0
509431	629.49	1798.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	2178.7	27944.3
516531	329.95	996.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1224.1	13283.1
515931	192.45	861.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	292.9	14348.1
516031	789.41	2421.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	2647.2	29926.0
516131	356.00	1115.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1202.9	16692.8
516231	99.51	279.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	372.8	4410.4
516331	336.47	839.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	223.3	1214.0	11638.3
516431	419.36	1124.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1597.9	13991.3

LRCA58 Cameron Gage on Little River
BRBR59 Bryan Gage on Brazos River
BRHE68 Hempstead Gage on Brazos
BRRI70 Richmond Gage on Brazos River
BRGM73 Brazos Outlet at Gulf of Mexico
515531 Possum Kingdom Reservoir
515631 Granbury Reservoir
515731 Whitney Reservoir
515831 Aquilla Reservoir
509431 Waco Reservoir
516531 Limestone Reservoir
515931 Proctor Reservoir
516031 Belton Reservoir
516131 Stillhouse Hollow Res.
516231 Georgetown Reservoir
516331 Granger Reservoir
516431 Somerville Reservoir

Table 9.14 (continued)

Daily Unappropriated Flow-Frequency, Scenario 9.06, Flow Pattern Disaggregation without Routing

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	1464.83	5095.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	509.0	3813.4	165999.8
BRBR59	4875.68	14705.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	196.8	2931.2	13138.3	477784.4
BRHE68	7755.23	20254.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	816.4	5473.6	23182.1	468841.8
BRRI70	9601.90	23618.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	169.4	2037.9	8214.7	28498.7	569417.2
BRGM73	11807.46	26261.4	0.00	0.00	0.00	0.01	0.03	0.67	564.5	1769.8	4212.7	11458.6	33745.1	559755.8
515531	186.08	2068.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	65532.0
515631	503.18	3610.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	334.4	124209.2
515731	1070.66	5178.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1796.5	129752.6
515831	21.41	216.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	8136.0
509431	292.76	1417.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	477.5	32896.5
516531	47.21	375.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	9316.5
515931	78.56	568.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	19265.3
516031	498.74	2117.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1057.8	66303.8
516131	191.41	880.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	213.8	33376.1
516231	62.51	301.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	193.3	14942.4
516331	197.07	821.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	576.2	27439.9
516431	243.20	1193.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	304.7	44318.8

Daily Unappropriated Flow-Frequency, Scenario 9.08, Flow Pattern Disaggregation with Routing

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	1640.36	5527.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	677.7	4354.2	176738.8
BRBR59	5020.52	14973.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	297.9	3032.7	13518.8	494096.0
BRHE68	7705.26	20038.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	815.8	5433.7	23657.2	485019.7
BRRI70	9392.63	23109.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	278.1	1903.1	7922.4	27916.5	585389.1
BRGM73	11543.97	25628.5	0.00	0.00	0.00	0.01	0.05	10.74	700.1	1740.8	4009.9	11190.7	32883.8	575309.6
515531	336.47	2581.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	67305.9
515631	657.46	4099.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	599.0	112881.9
515731	1173.26	5457.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	11.5	2075.6	129415.0
515831	52.40	393.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	20.0	14156.4
509431	362.09	1664.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	693.8	51367.8
516531	160.45	803.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	56.5	22167.8
515931	95.88	654.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	18.5	27378.3
516031	564.83	2265.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1330.7	70955.3
516131	267.35	1170.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	734.2	68814.9
516231	81.84	365.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	241.5	14969.7
516331	268.87	1068.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	44.0	718.0	32890.8
516431	398.50	1928.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	605.9	59205.6

Storage, regulated flow, and unappropriated flow frequency statistics exhibit sensitivity to the disaggregation method used to create the input naturalized flow. The flow pattern method creates higher peak flows and lower base and low flows than the uniform and linear interpolation methods. This naturalized flow skewness of the flow pattern method was shown in the flow frequency curves of Figures 8.7 and 8.8. Table 7.14 shows that unappropriated flows are generally more concentrated in the higher magnitude flows for the flow pattern method of disaggregation.

Figure 9.7 shows the daily storages at Belton Lake for scenarios with uniform, linear interpolation and flow pattern disaggregation. The uniform and linear interpolation methods generally produce the same storages for Belton. However, the flow pattern method results in substantially less storage during the peak of the 1950's drought. Belton's conservation storage is used as backup for 112,257 acre-feet per year of target demands. Belton can refill up to the top of conservation with a December 16, 1963 priority date.

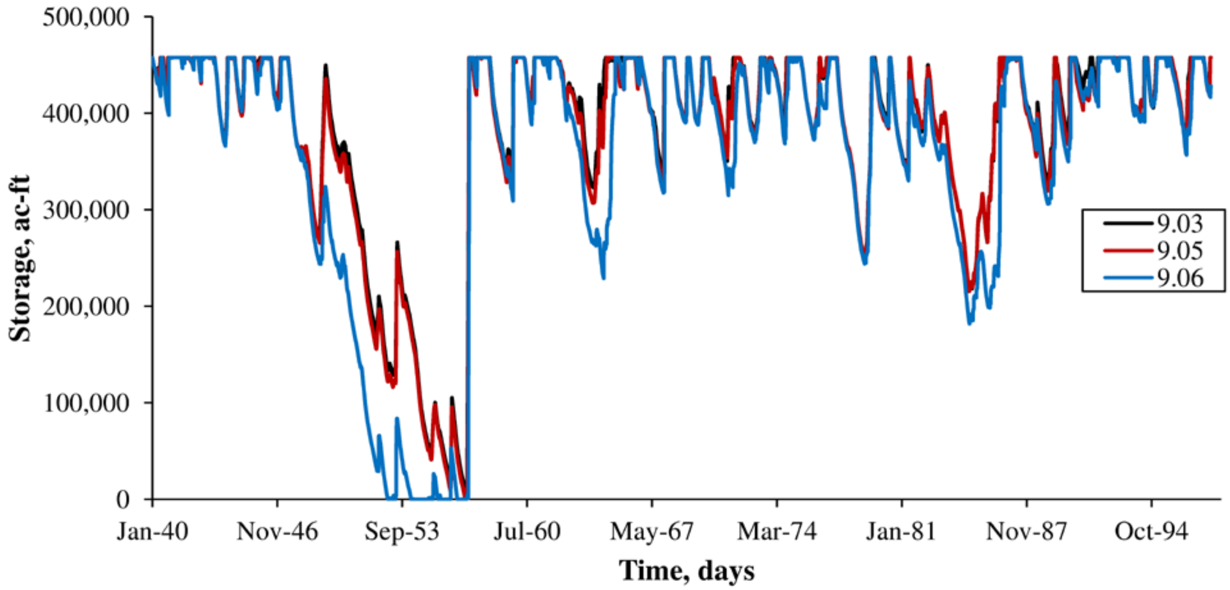

Figure 9.7 Storage in Belton Lake

Figure 9.8 shows the daily storages at Waco Lake for scenarios with uniform, linear interpolation and flow pattern disaggregation. Like Belton, the uniform and linear interpolation methods of disaggregation produce very similar storage results for Waco Lake. The largest differences between the uniform and linear interpolation methods and the flow pattern methods occur during the peak of the 1950's drought. Waco's conservation storage is used as backup for 97,335 ac-ft per year of target demands. Unlike Belton, Waco has multiple priorities dates for refilling pools. The senior most pool in Waco Lake has 39,100 ac-ft of conservation storage and can refill with a priority of January 10, 1929. The top most pool in Waco Lake has 14,400 ac-ft of conservation storage and refills with the junior most priority date in the basin. Figure 9.8 shows that the junior most pool in Waco Lake often cannot completely refill when the method of flow disaggregation changes to the flow pattern method even outside of drought periods.

Daily regulated flow for 1952 at the Bryan gage is shown in Figure 9.9. Like the naturalized flow shown in Figure 9.6, there are large differences in flows between the uniform and linear interpolation methods and the flow pattern method as a function of intra-month flow variability. Regulated flows in Figure 9.9 for Scenario 9.06 tend to abruptly move towards zero and rebound. Scenario 9.06 was conducted with flow pattern disaggregation, but without routing parameters. Without routing parameters, changes to flow are able to travel from the top of the basin to the outlet, regardless of distance, at the moment the changes are made each day. Mismatches will exist between the speed at which the changes to flow can travel to the outlet and the speed at which the flow event waves are propagating downstream. The flow pattern method of disaggregation uses real-world flows which have travel time embedded in their hydrographs. Therefore, routing parameters should always be used when using the flow pattern method of disaggregation so changes to flow can track downstream at the same rate as the underlying flow event which produced the upstream water availability.

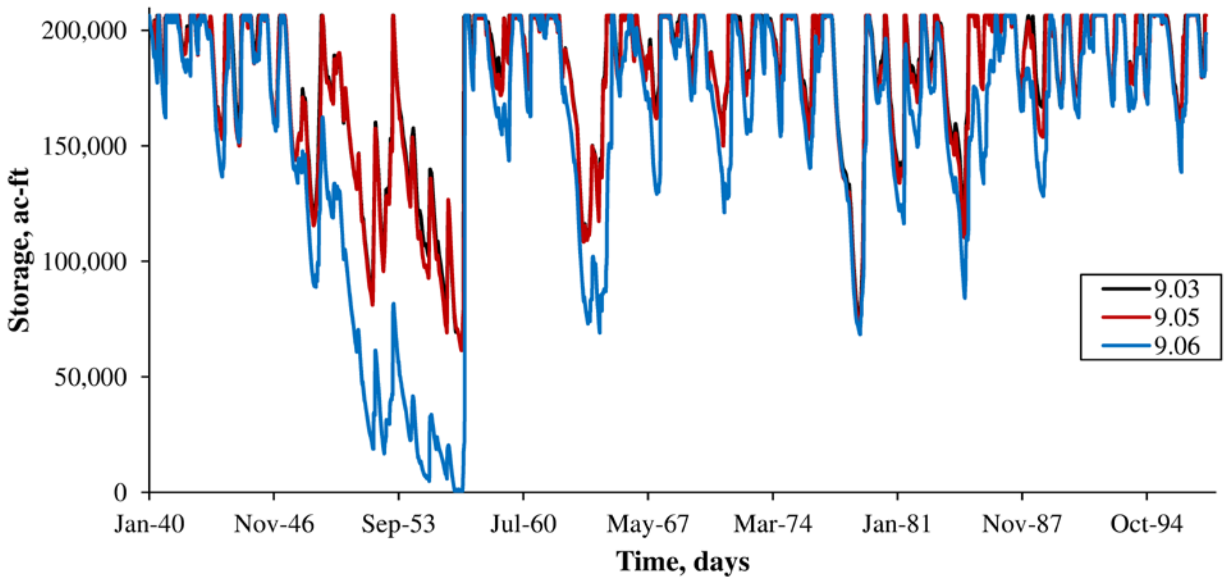

Figure 9.8 Storage in Waco Lake

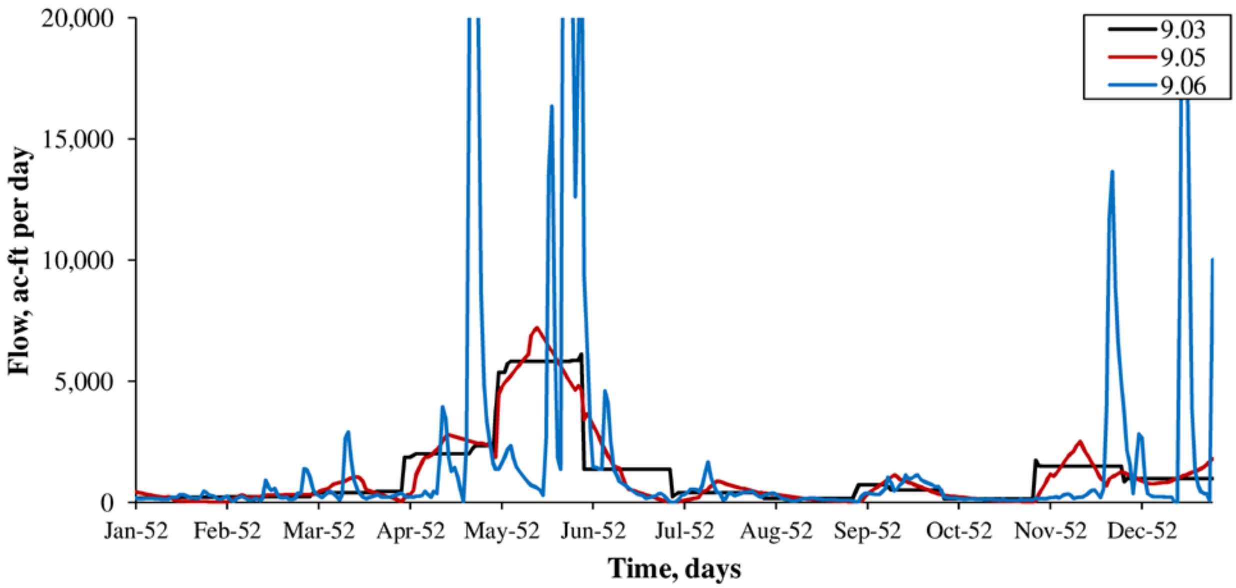

Figure 9.9 Regulated Flow at the Bryan Gage

Figure 9.10 shows daily naturalized flow at the location of Whitney Lake and the Bryan and Richmond stream flow gages as disaggregated by the flow pattern method. The embedded travel time in the flow events can be seen. The hydrograph at Whitney tends to peak two or three days before the hydrograph at Bryan which peaks two or three days before the hydrograph at Richmond. The time lag and attenuation of flows is represented in the routing parameters shown in Chapter 8.

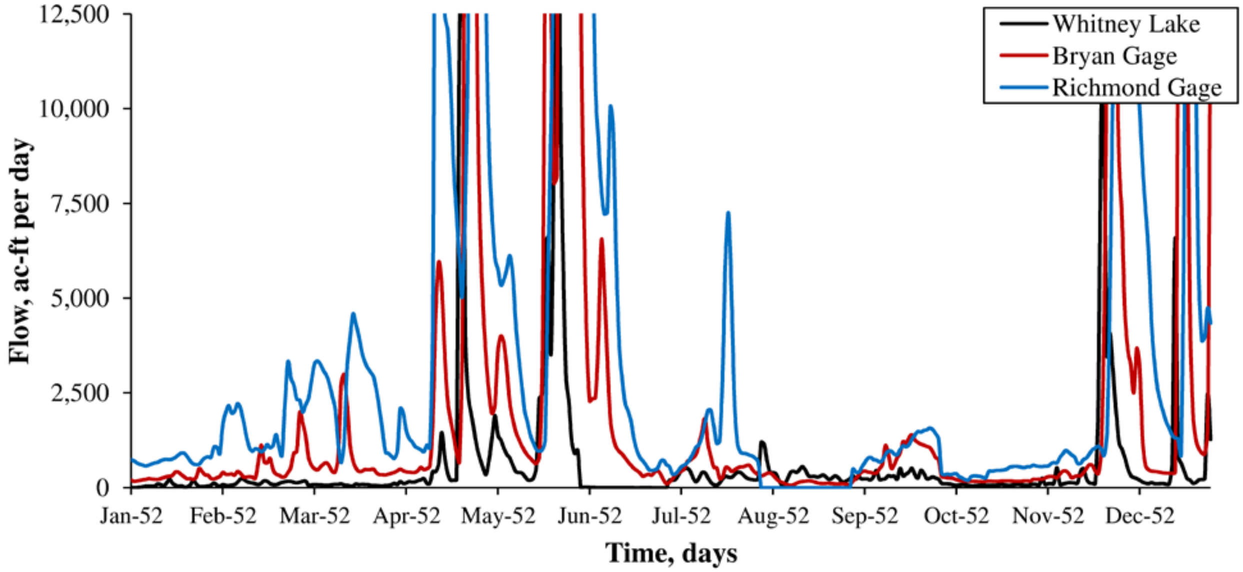

Figure 9.10 Naturalized Flow at Several Locations on the Main Stem Brazos River

Routing parameters are used in Scenario 9.08 along with the flow pattern method of disaggregation. The regulated and unappropriated flows in Tables 9.13 and 9.14 for scenarios 9.06 and 9.08 show differences across tables. Differences in the near-zero and peak event regulated flows are visible in Figure 9.11. The addition of routing parameters to the simulation to accompany the flow pattern disaggregation method allows changes to flow to realistically track downstream with the underlying flow events.

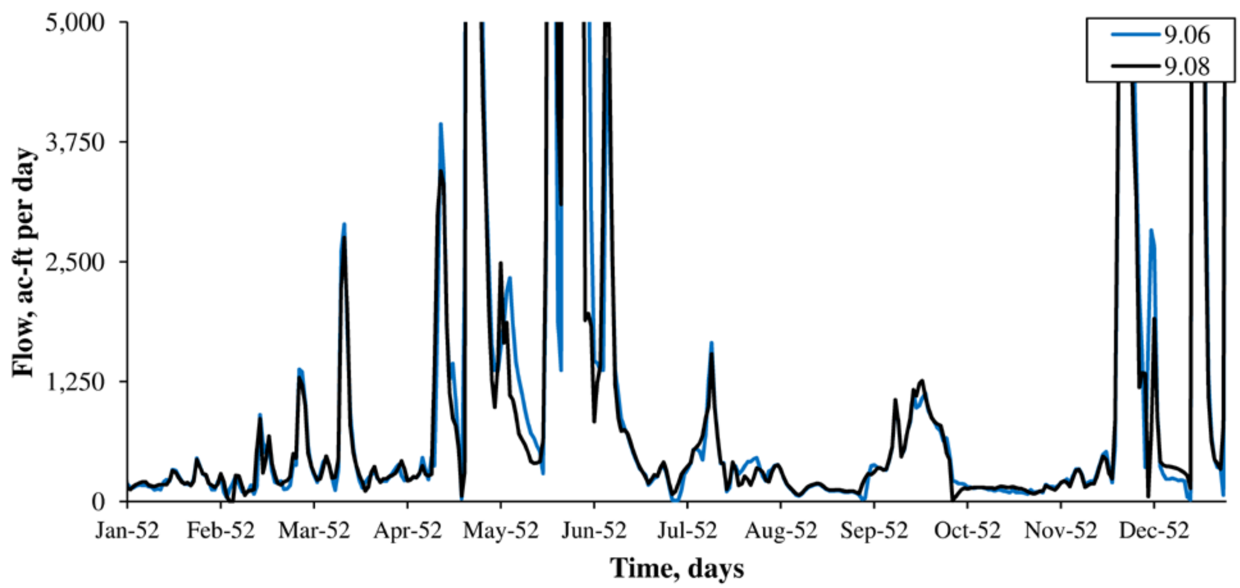

Figure 9.11 Regulated Flow at the Bryan Gage

Routing parameters were also added to the simulation using the uniform flow disaggregation method. Scenario 9.07 is the identifier of the simulation with uniform flow disaggregation and routing parameters. Intra-month flow events are smoothed by the uniform and linear interpolation disaggregation methods, so there is no violation in flow event tracking by allowing changes in flow to move through every control point to the outlet of the basin at the moment the change to flow is made.

Figure 9.12 shows regulated flow at the Bryan gage for the uniform flow disaggregation scenarios with and without routing parameters. There is a peak upward in regulated flow at the beginning of months where the uniform naturalized flow increases over the previous month's amount. Regulated flows decrease at the beginning of the month where the uniform naturalized flows are below the previous month's amount. Each month new daily target demand amounts are set. The changes to flow made by upstream water rights require time to propagate downstream and reduce regulated flow for the scenario with routing parameters. Once the changes to flow propagate downstream, the upstream water right's water availability is reduced and stream flow depletions are reduced. This causes a reversal of the regulated flow in Figure 9.12 for Scenario 9.07 after the beginning of the month. Regulated flows for Scenario 9.07 oscilate around or converge toward a steady state in the middle of the month as water rights and early month depletions begin to accumulate in downstream reaches.

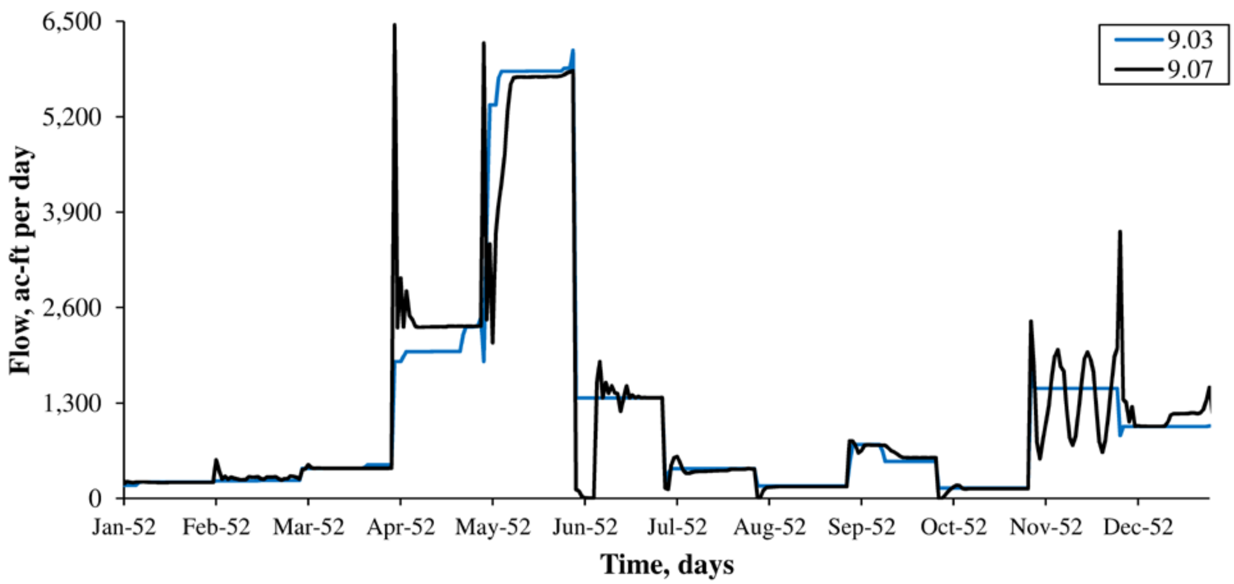

Figure 9.12 Regulated Flow at the Bryan Gage

Regulated flow at the Bryan gage for the uniform and linear interpolation disaggregation scenarios without routing are compared to the flow pattern disaggregation scenario with routing in Figures 9.13 and 9.14. The figures cover the same period of time, but the y-axis of Figure 9.14 is reduced in scale to highlight lower flow values. There are large differences in regulated flow based on the selected method of naturalized flow disaggregation.

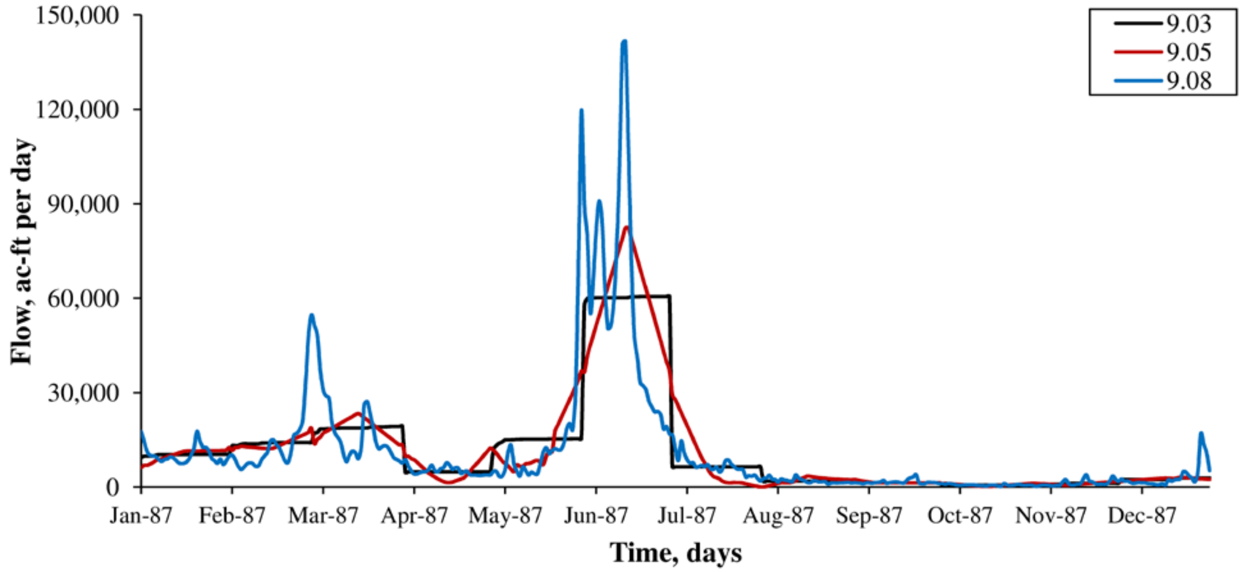

Figure 9.13 Regulated Flow at the Bryan Gage

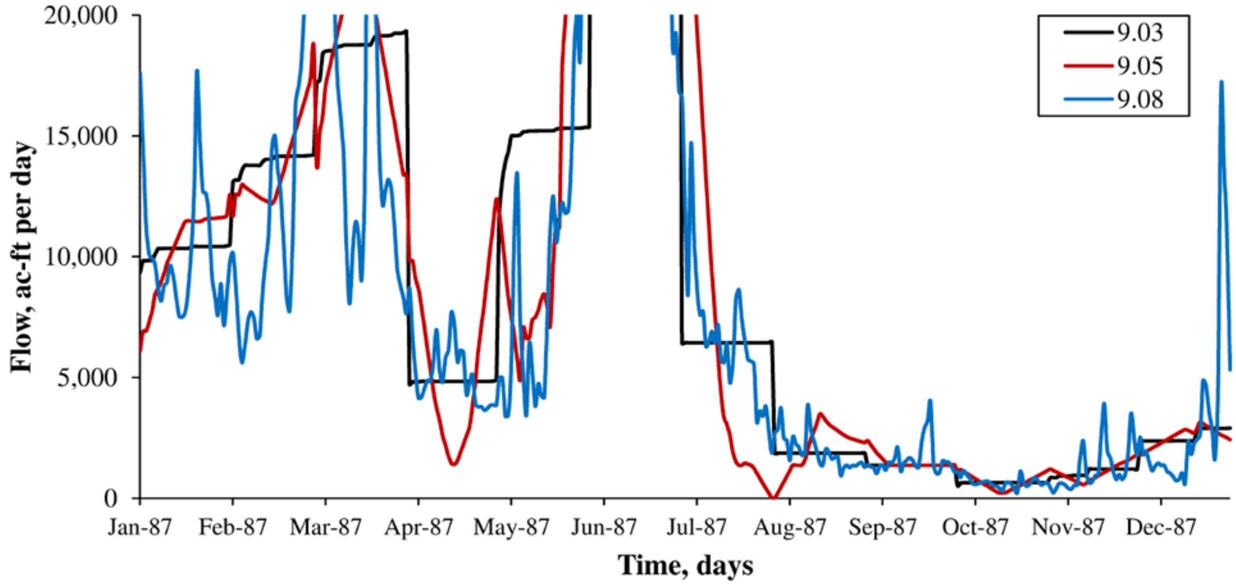

Figure 9.14 Regulated Flow at the Bryan Gage

Figure 9.15 and 9.16 show the daily storages in Belton and Waco Lakes, respectively, for Scenario 9.08. The entire simulation time series is not shown in either figure. The time series is stopped in 1964 to center the drought of the 1950's where the greatest differences in storage with respect to disaggregation method occur. The drought storages are affected with the addition of routing parameters and the corresponding change to the negative incremental flow option. The particular affect of the negative incremental flow option is explored later in this chapter.

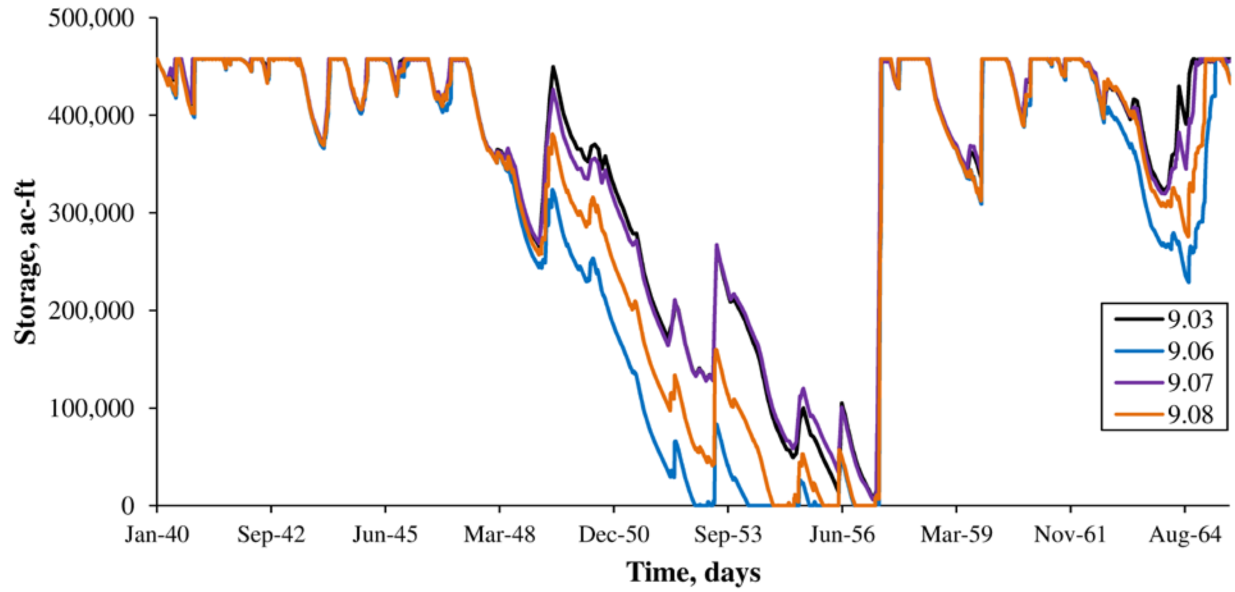

Figure 9.15 Storage in Belton Lake

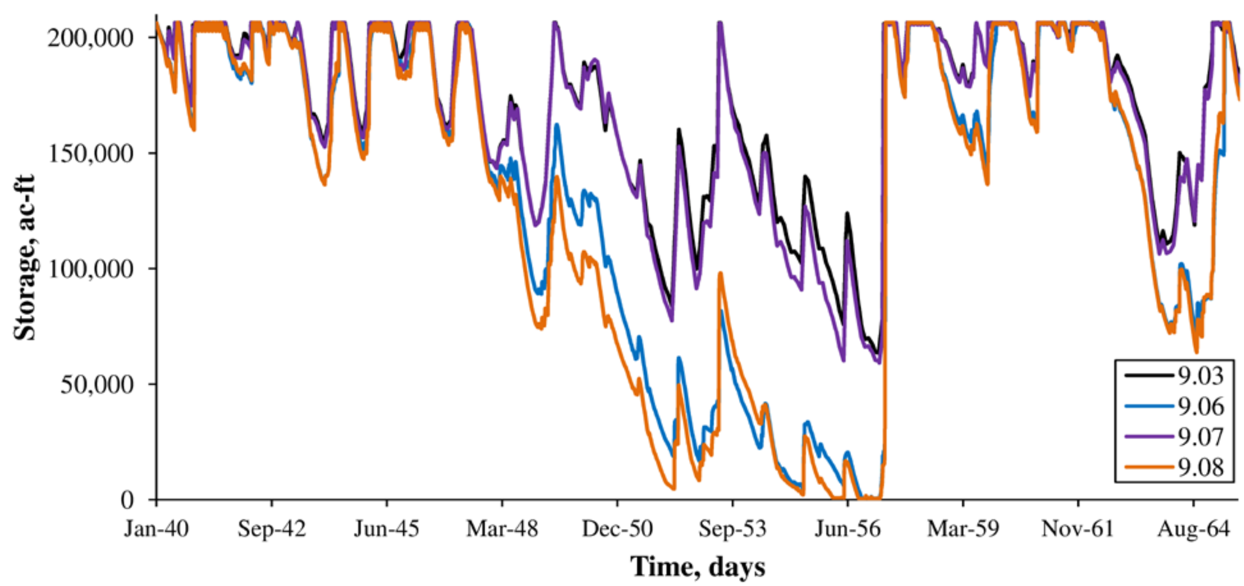

Figure 9.16 Storage in Waco Lake

Daily naturalized, regulated and unappropriated flows for Scenario 9.08 are shown in Figures 9.17 and 9.18 at the Bryan gage for 1952 and 1987, respectively. A wetter year was chosen for Figure 9.17. Unappropriated flow at Bryan is nearly zero throughout 1952 as water rights make depletions to meet target demands and to refill storage. Some unappropriated flow exists, however, in the high flow events of 1952 when flow increases rapidly. Water rights have monthly target demands and are not able to capture all water contained in pulse flow events, and instead will experience shortages before and after the pulse flow event.

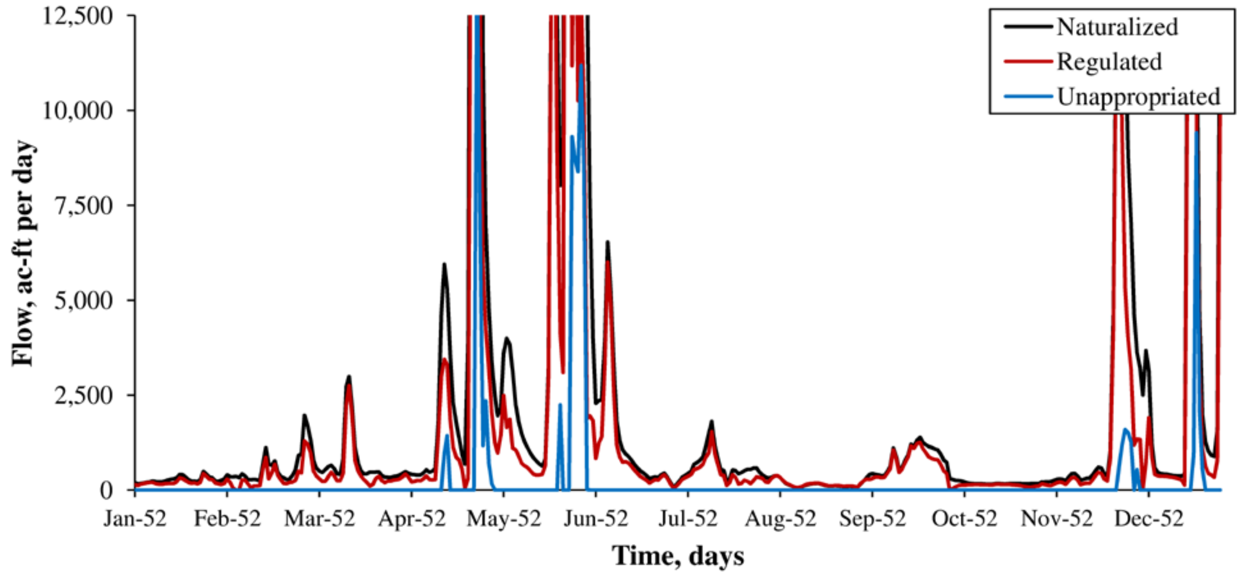

Figure 9.17 Flow at the Bryan Gage for Scenario 9.08

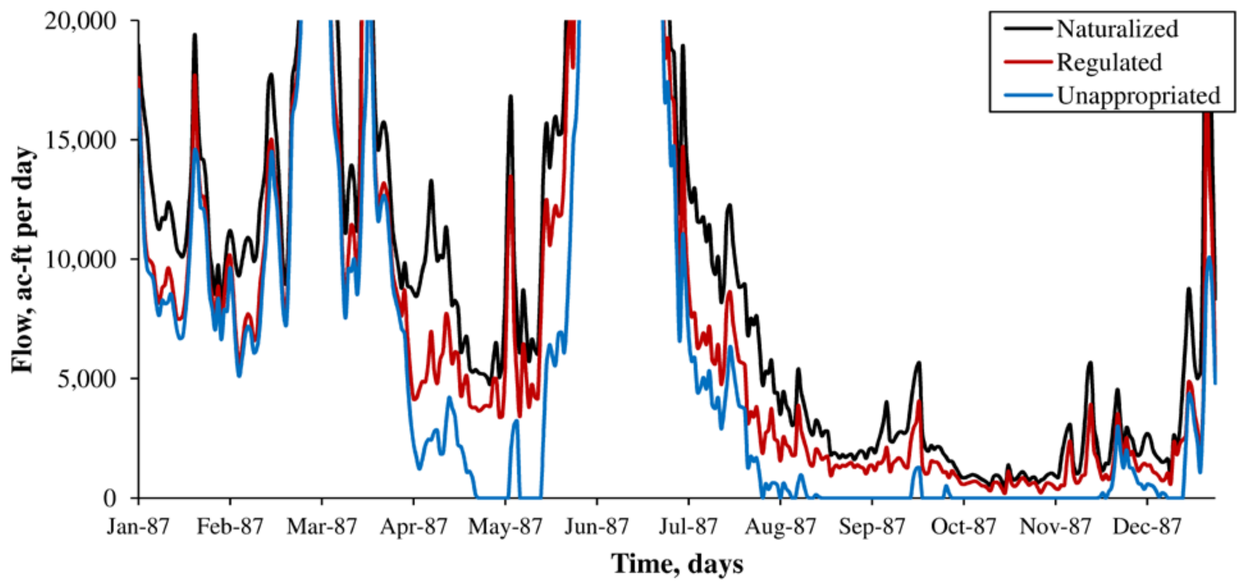

Figure 9.18 Flow at the Bryan Gage for Scenario 9.08

Unappropriated flow at the Bryan gage is compared between scenarios using the uniform, linear interpolation and flow pattern methods of disaggregation in Figures 9.19 and 9.20. Unappropriated flow is zero throughout 1952 for the scenarios using the uniform and linear interpolation methods of disaggregation. Because pulse flow events are distributed across the entire month in the uniform and linear interpolation methods, water rights can apply target demands against these events in every day of the month, even though the events are occurring over fewer days as represented in the flow pattern scenario.

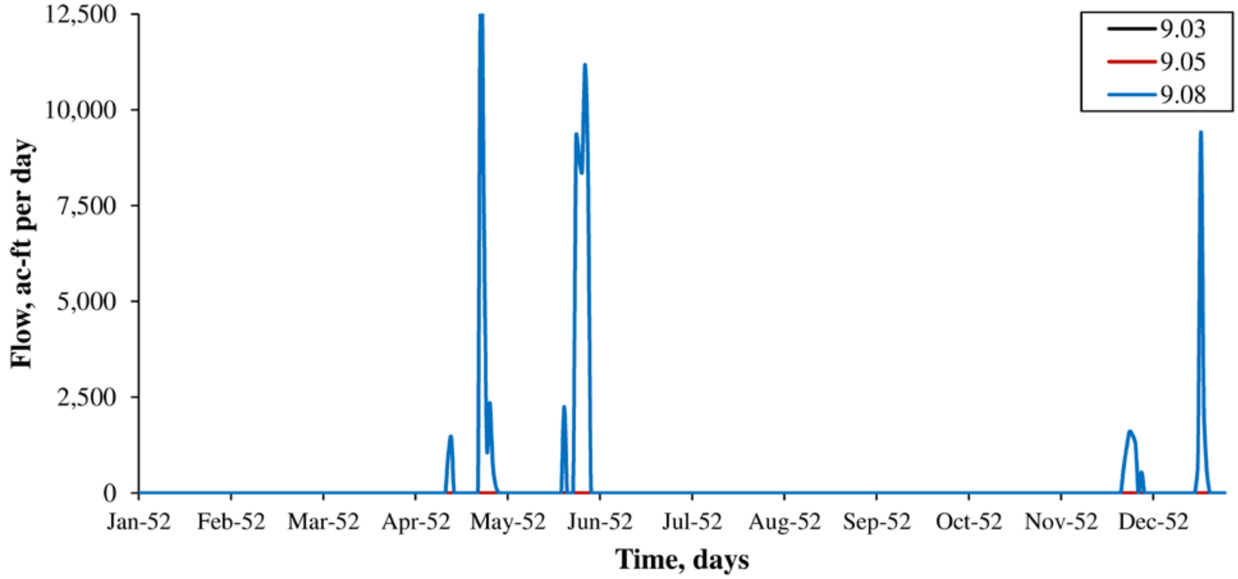

Figure 9.19 Unappropriated Flow at the Bryan Gage

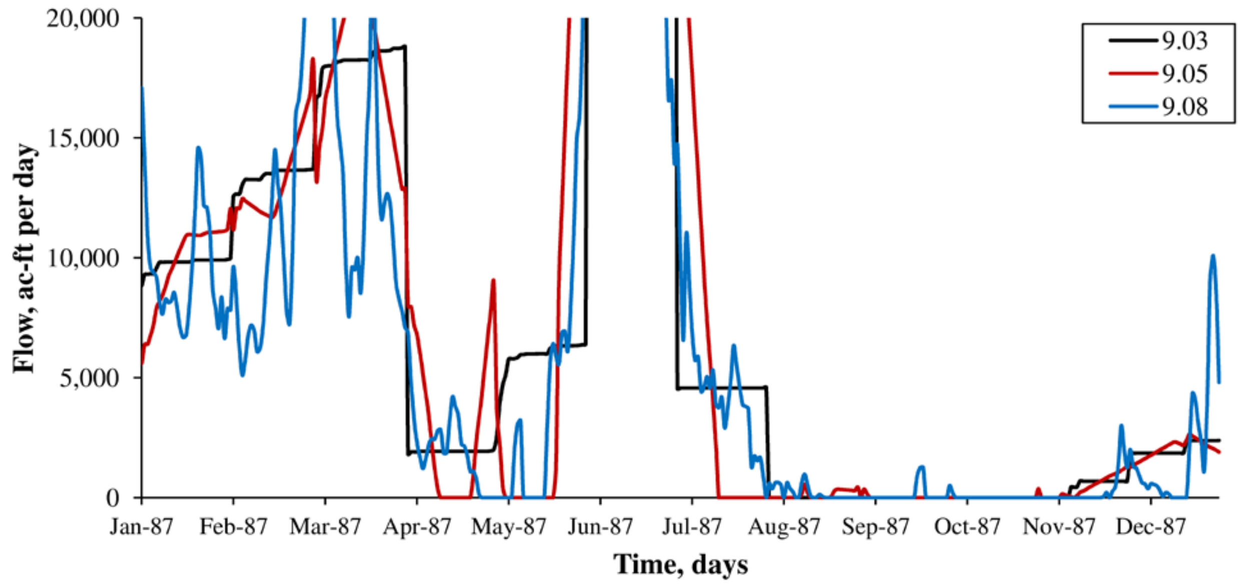

Figure 9.20 Unappropriated Flow at the Bryan Gage

Water right reliability at the locations of the major reservoirs are shown in Table 9.15 with respect to the different disaggregation methods. Reservoir storage-frequency is higher with the uniform and linear interpolation disaggregation methods. Consequently, volume reliability is slightly higher in these scenarios than in the scenarios utilizing the flow pattern disaggregation method. Reservoir storage is non-zero through the majority of the simulation. Non-zero reservoir storage leads to insensitivity of reliabilities at these locations with respect to the methods of disaggregation. Water rights without access to reservoir storage as a backup source of water, however, can be expected to exhibit sensitivity to stream flow variability caused by the choice of disaggregation method. The addition of routing and the accompanying negative incremental option to Scenario 9.08 improves water availability and reservoir storage over Scenario 9.06.

Table 9.15
Reliability Summaries for Scenarios 9.03, 9.05, 9.06 and 9.08

Control Point Reliability, Scenario 9.03, Uniform Disaggregation Method

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	VOLUME (%)	+++++++++ PERCENTAGE OF MONTHS +++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS ---------- PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	230750.0	1001.12	99.14	99.57	99.1	99.1	99.1	99.4	99.4	99.6	99.9	96.6	96.6	96.6	96.6	100.0	100.0	100.0
515631	64712.0	1917.01	96.41	97.04	96.4	96.6	96.6	96.6	96.6	97.0	97.0	91.4	91.4	91.4	91.4	96.6	98.3	98.3
515731	19132.9	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	80557.9	127.35	99.14	99.84	99.1	99.3	99.3	99.3	100.0	100.0	100.0	96.6	96.6	98.3	100.0	100.0	100.0	100.0
516531	65074.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	19658.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	112257.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	471.34	97.99	99.30	98.0	98.0	98.4	99.0	99.4	99.4	99.6	91.4	91.4	93.1	96.6	100.0	100.0	100.0
516231	13610.0	282.48	97.27	97.92	97.3	97.3	97.6	97.6	97.8	98.1	98.1	93.1	93.1	93.1	94.8	98.3	98.3	100.0
516331	19840.0	109.15	98.99	99.45	99.0	99.0	99.3	99.3	99.4	99.4	99.4	96.6	96.6	96.6	98.3	100.0	100.0	100.0
516431	48000.0	215.89	99.14	99.55	99.1	99.1	99.1	99.1	99.1	99.3	99.6	96.6	96.6	96.6	98.3	100.0	100.0	100.0
Total	755255.7	4124.32		99.45														

Control Point Reliability, Scenario 9.05, Linear Interpolation Disaggregation Method

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	VOLUME (%)	+++++++++ PERCENTAGE OF MONTHS +++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS ---------- PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	230750.0	2543.19	98.28	98.90	98.3	98.4	98.4	98.4	98.9	99.3	99.4	96.6	96.6	96.6	96.6	98.3	100.0	100.0
515631	64712.0	2176.53	95.11	96.64	95.1	95.3	95.5	96.0	96.4	96.8	97.6	91.4	91.4	91.4	93.1	96.6	96.6	100.0
515731	19102.5	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	47.84	99.28	99.66	99.3	99.3	99.3	99.3	99.6	99.9	99.9	96.6	96.6	98.3	98.3	100.0	100.0	100.0
509431	80587.5	88.07	99.28	99.89	99.3	99.3	99.6	99.6	100.0	100.0	100.0	96.6	98.3	98.3	100.0	100.0	100.0	100.0
516531	65074.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	19658.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	112257.0	119.85	99.71	99.89	99.7	99.7	99.7	99.9	99.9	99.9	100.0	98.3	98.3	98.3	100.0	100.0	100.0	100.0
516131	67768.0	744.40	97.56	98.90	97.6	97.7	97.7	98.1	99.0	99.1	99.4	91.4	91.4	91.4	93.1	100.0	100.0	100.0
516231	13610.0	373.83	96.55	97.25	96.6	96.6	96.6	96.7	97.1	97.1	97.7	91.4	91.4	91.4	91.4	98.3	98.3	100.0
516331	19840.0	264.57	98.13	98.67	98.1	98.1	98.1	98.4	99.0	99.0	99.0	94.8	94.8	94.8	98.3	98.3	98.3	100.0
516431	48000.0	242.52	98.85	99.49	98.9	99.0	99.0	99.1	99.1	99.3	99.4	96.6	96.6	96.6	98.3	100.0	100.0	100.0
Total	755255.0	6600.80		99.13														

Table 9.15 (continued)
Reliability Summaries for Scenarios 9.03, 9.05, 9.06 and 9.08

Control Point Reliability, Scenario 9.06, Flow Pattern Disaggregation Method with Routing

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	230750.0	22819.72	86.35	90.11	86.4	86.5	86.6	87.4	89.5	91.2	95.0	77.6	77.6	77.6	79.3	86.2	89.7	100.0
515631	64712.0	1812.24	95.98	97.20	96.0	96.0	96.0	96.3	96.7	97.6	98.4	91.4	91.4	91.4	93.1	96.6	98.3	100.0
515731	19018.4	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	1419.57	88.22	89.78	88.2	88.4	88.8	89.1	89.5	90.1	93.0	84.5	84.5	84.5	84.5	86.2	91.4	98.3
509431	80732.0	3375.74	89.22	95.82	89.2	89.2	89.4	89.5	95.7	99.4	100.0	86.2	86.2	86.2	87.9	91.4	96.6	100.0
516531	65074.0	4698.77	90.37	92.78	90.4	90.5	90.7	91.2	92.7	93.8	95.5	82.8	84.5	86.2	86.2	89.7	93.1	100.0
515931	19658.0	3143.71	81.61	84.01	81.6	82.0	82.0	82.5	83.8	85.2	87.2	74.1	75.9	75.9	75.9	81.0	82.8	100.0
516031	112257.0	5004.24	94.40	95.54	94.4	94.4	94.4	94.5	95.0	96.0	97.1	89.7	89.7	89.7	89.7	94.8	94.8	100.0
516131	67768.0	6611.64	88.94	90.24	88.9	88.9	88.9	89.2	89.7	90.5	94.3	86.2	86.2	86.2	86.2	89.7	89.7	98.3
516231	13610.0	1268.83	89.51	90.68	89.5	89.8	89.8	89.9	90.4	91.1	93.2	82.8	84.5	86.2	86.2	89.7	91.4	98.3
516331	19840.0	1215.04	92.53	93.88	92.5	92.5	92.7	93.0	93.7	94.3	95.4	87.9	87.9	87.9	91.4	93.1	93.1	98.3
516431	48000.0	1429.29	96.12	97.02	96.1	96.1	96.3	96.4	96.7	97.1	98.3	93.1	93.1	93.1	93.1	96.6	96.6	100.0
Total	755315.4	52798.78		93.01														

Control Point Reliability, Scenario 9.08, Flow Pattern Disaggregation Method without Routing

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	230750.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	2522.32	94.83	96.10	94.8	95.0	95.1	95.3	95.8	96.3	98.0	89.7	89.7	89.7	91.4	96.6	96.6	100.0
515731	18990.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	717.56	94.11	94.84	94.1	94.1	94.1	94.3	94.4	94.8	96.7	89.7	89.7	89.7	89.7	93.1	94.8	100.0
509431	80694.4	3692.21	87.79	95.42	87.8	87.8	87.8	89.2	96.8	98.7	99.7	84.5	84.5	84.5	84.5	91.4	98.3	100.0
516531	65074.0	205.33	99.43	99.68	99.4	99.4	99.4	99.4	99.7	99.7	99.9	96.6	96.6	98.3	98.3	100.0	100.0	100.0
515931	19658.0	920.37	93.68	95.32	93.7	93.7	93.8	94.3	95.1	95.8	97.1	87.9	87.9	87.9	87.9	94.8	96.6	100.0
516031	112257.0	2830.08	96.41	97.48	96.4	96.4	96.6	96.7	97.1	97.6	98.3	93.1	93.1	93.1	93.1	94.8	100.0	100.0
516131	67768.0	4061.63	92.96	94.01	93.0	93.0	93.0	93.2	93.7	94.5	96.3	87.9	87.9	87.9	89.7	91.4	93.1	100.0
516231	13610.0	752.07	93.39	94.47	93.4	93.7	93.7	93.7	93.7	94.5	96.6	89.7	89.7	89.7	89.7	91.4	94.8	100.0
516331	19840.0	448.26	97.27	97.74	97.3	97.3	97.3	97.3	97.3	98.1	98.4	93.1	93.1	93.1	94.8	98.3	98.3	100.0
516431	48000.0	318.81	98.85	99.34	98.9	98.9	98.9	98.9	99.0	99.3	99.7	96.6	96.6	96.6	96.6	100.0	100.0	100.0
Total	755250.1	16468.65		97.82														

Control Points

515531 Possum Kingdom Reservoir
515631 Granbury Reservoir
515731 Whitney Reservoir
515831 Aquilla Reservoir
509431 Waco Reservoir
516531 Limestone Reservoir
515931 Proctor Reservoir
516031 Belton Reservoir
516131 Stillhouse Hollow Res.
516231 Georgetown Reservoir
516331 Granger Reservoir
516431 Somerville Reservoir

Mean annual shortage and volume reliability for selected water rights are shown in Table 9.16. The number and total annual targets of these water right groupings are given in Table 9.2. These water right grouping include water rights without access to reservoir storage as a backup source of water. Consequently, there are overall greater shortages and lower reliabilities for these water rights than illustrated in Table 9.15 for water rights with access to reservoir storage.

Table 9.16
Mean Shortage and Volume Reliability for Selected Water Rights

Selected Water Rights	Scenario Mean Shortage, ac-ft per year			
	9.03	9.05	9.06	9.08
Dec. 31, 1929 and Senior, all uses	2,654	6,585	5,441	8,572
Jan. 1, 1930 to Dec. 31, 1939, all uses	1,823	4,464	5,211	5,754
Jan. 1, 1940 to Dec. 31, 1949, all uses	16,167	24,188	30,353	32,910
Jan. 1, 1950 to Dec. 31, 1959, all uses	15,887	21,446	25,980	27,221
Jan. 1, 1960 to Dec. 31, 1969, all uses	20,272	25,097	32,032	34,345
Jan. 1, 1970 to Dec. 31, 1979, all uses	1,150	1,340	1,560	1,484
Jan. 1, 1980 and Junior, municipal use	13,834	16,650	20,418	19,609
Jan. 1, 1980 and Junior, non-municipal use	25,126	27,592	32,663	31,185
All Selected Water Rights	96,912	127,363	153,657	161,081

Selected Water Rights	Scenario Volume Reliability, %			
	9.03	9.05	9.06	9.08
Dec. 31, 1929 and Senior, all uses	97.8	94.5	95.5	92.9
Jan. 1, 1930 to Dec. 31, 1939, all uses	97.6	94.1	93.1	92.4
Jan. 1, 1940 to Dec. 31, 1949, all uses	91.6	87.4	84.2	82.9
Jan. 1, 1950 to Dec. 31, 1959, all uses	85.8	80.9	76.9	75.7
Jan. 1, 1960 to Dec. 31, 1969, all uses	83.9	80.0	74.5	72.7
Jan. 1, 1970 to Dec. 31, 1979, all uses	75.5	71.4	66.8	68.4
Jan. 1, 1980 and Junior, municipal use	81.6	77.8	72.8	73.9
Jan. 1, 1980 and Junior, non-municipal use	70.2	67.3	61.2	63.0
All Selected Water Rights	87.7	83.9	80.6	79.6

Placement of Routed Flow Changes in the Priority Sequence

The propagation of changes to flow may require several days to weeks to completely travel to the outlet of the basin. This is particularly relevant in the Brazos River Basin where tributaries extend for several hundred miles upstream of the Gulf of Mexico. Changes to flow from previous days can be routed at the beginning of each daily time step using *JU* record option *WRMETH* 1. This allows the previous changes to flow to affect water availability for all water rights in the basin until the changes to flow exit the basin's outlet. The alternative option, *WRMETH* 2, is to rout the changes to flow at the priority order in which the original depletion was made. Only the water right making the depletion and all junior water rights will experience a direct impact to water availability as the changes to flow travel to the outlet. This section examines the effect produced by the choice of placement of routed changes to flow at the beginning or within the priority order. Forecasting for water availability reduces the incidence of over appropriation and routing adjustments.

Over appropriation occurs when upstream depletions in past days are routed downstream and encounter drier downstream future stream flow conditions. The primary cause is a mismatch in routing parameter values with the particular flow event under which the original depletion was made. *WRMETH* 2 also allows for over appropriation when senior rights make stream flow depletions of water which was appropriated by upstream juniors in previous days. Over appropriation is also discussed in Chapter 8 of this report and in the *Daily Manual*.

Table 9.17
Parameters per Simulation Scenario Being Considered

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, *WRMETH*	Disaggregation Option, *DFMETHOD*	Target Distribution Option, *ND*	Flow Forecasting, *FPRD*	Negative Increntals, *ADJINC*	Execution Time, hours
9.08	day	Bwam3	lag-att	1	daily pattern	uniform	0 days	7	0.24
9.09	day	Bwam3	lag-att	2	daily pattern	uniform	0 days	7	0.46
9.10	day	Bwam3	lag-att	1	daily pattern	uniform	14 days	7	3.63
9.11	day	Bwam3	lag-att	2	daily pattern	uniform	14 days	7	6.92

Tables 9.18 through 9.22 present the simulation results for Scenarios 9.08 and 9.09. Storage and flow-frequencies are slightly different with the change in routing placement. The slight change in storage-frequency is accompanied by only a slight change in reliability for water rights with access to the reservoirs. The run-of-river rights considered in Table 9.22 exhibit some sensitivity in reliability to the choice of *WRMETH*. In particular, water right reliability tends to improve at more senior priorities, and decrease at more junior priorities. Layering routed changes to flow within the priority sequence via *WRMETH* 2 shields the more senior rights from the routed changes to flow connected with junior rights.

Placing routed changes to flow at the beginning of the priority order ensures that all water rights factor past stream flow depletions into their respective calculations of available water. Present day depletions can be limited by stream flow depletions from past days as they propagate downstream. This self-limiting feedback from the use of *WRMETH* 1 reduces the likelihood of over appropriation of the stream. Table 9.23 shows the aggregated monthly amount of routing adjustments that occurs at the listed control points. Routing adjustments are applied on a daily basis during the simulation to adjust the stream flow availability array for routed stream flow depletions in previous time steps. *WRMETH* 2 results in greater need for routing adjustments as a result of over appropriation. Tables 9.23 and 9.25 show the aggregated monthly amount of routing adjustments for all time steps in the 58 year period-of-analysis from 1940 to 1997. The total amount of routing adjustment is also presented as a percentage of the total naturalized flow for the period-of-analysis. Over appropriation and the need for routing adjustment is more likely when the regulated flows are low. The 29 years with the lowest naturalized flow at each control point are selected from the period-of-analysis. Routing adjustments during these lowest flow years are reported separately in Tables 9.23 and 9.25.

Table 9.18

End of Day Storage-Frequency for Scenarios 9.08 and 9.09, acre-feet

End of Day Storage-Frequency, Scenario 9.08, *WRMETH* 1

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
515531	613531.	102465.	197891.	269496.	325440.	424888.	471354.	553291.	612117.	645157.	669083.	698226.	713525.	724739.
515631	113854.	43075.	0.	0.	0.	3287.	45297.	96784.	116899.	125716.	135265.	149445.	154889.	155000.
515731	598018.	46975.	406161.	424352.	448585.	483037.	534812.	586278.	604271.	612760.	621615.	632112.	636100.	636100.
515831	37777.	15612.	0.	0.	0.	0.	8155.	33190.	40320.	42984.	45573.	49856.	52015.	52400.
509431	155002.	57104.	453.	784.	4515.	15790.	60127.	134735.	163374.	173908.	186049.	200163.	205144.	206562.
516531	177604.	51916.	0.	11259.	27751.	59308.	101115.	158405.	181506.	193319.	204748.	218816.	224612.	225400.
515931	37834.	19091.	0.	0.	0.	0.	8095.	23294.	36976.	41672.	47285.	55994.	59351.	59400.
516031	362293.	124635.	0.	0.	0.	23073.	171856.	336641.	389830.	408302.	427730.	449720.	457600.	457600.
516131	178138.	71117.	0.	0.	0.	0.	27572.	160656.	195008.	207033.	216912.	229507.	235222.	235700.
516231	26756.	11513.	0.	0.	0.	0.	6876.	20182.	28086.	31696.	34016.	36009.	36940.	37100.
516331	52384.	18005.	0.	0.	0.	7869.	24901.	46404.	56055.	60973.	64132.	65444.	65500.	65500.
516431	128784.	37132.	0.	279.	24051.	53763.	67699.	111780.	133896.	141556.	149326.	159722.	160110.	160110.
Total	2481974.	519504.	843201.	916578.	1020846.	1285734.	1607640.	2271998.	2545968.	2647156.	2737996.	2877579.	2965380.	3015611.

End of Day Storage-Frequency, Scenario 9.09, *WRMETH* 2

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
515531	632146.	96721.	202515.	268370.	358885.	453322.	503757.	580965.	637978.	664556.	686063.	708148.	721944.	724739.
515631	112777.	40286.	0.	0.	0.	22201.	53832.	96073.	112887.	121922.	131738.	146540.	153627.	155000.
515731	595272.	49150.	387990.	410315.	445196.	473814.	532368.	584181.	600357.	610419.	620605.	630217.	635798.	636100.
515831	37868.	15563.	0.	0.	0.	0.	8477.	33194.	40407.	43067.	45800.	49921.	52167.	52400.
509431	157030.	54171.	579.	4623.	12119.	26986.	66414.	137262.	164560.	174844.	186402.	200032.	204689.	206562.
516531	177517.	51771.	0.	11228.	27718.	59372.	101652.	158380.	181164.	193092.	204656.	218611.	224294.	225400.
515931	38007.	19210.	0.	0.	0.	268.	7895.	22487.	37217.	42280.	47992.	56748.	59036.	59400.
516031	361169.	126102.	0.	0.	0.	19727.	157514.	334082.	389446.	408140.	427814.	449843.	457600.	457600.
516131	178421.	71067.	0.	0.	0.	0.	27668.	162457.	195507.	206881.	217430.	229518.	235541.	235700.
516231	26328.	11720.	0.	0.	0.	0.	5630.	19324.	27746.	31308.	33738.	35732.	37019.	37100.
516331	51705.	18388.	0.	0.	0.	6471.	23411.	45302.	55186.	60477.	63682.	65166.	65500.	65500.
516431	129004.	36822.	0.	390.	25161.	54700.	69179.	112106.	133825.	141507.	149375.	159722.	160110.	160110.
Total	2497244.	513814.	871610.	937464.	1040147.	1298797.	1634802.	2290852.	2564591.	2663596.	2752993.	2883749.	2969979.	3015544.

Table 9.19

Daily Regulated Flow-Frequency for Scenarios 9.08 and 9.09, ac-ft per day

Daily Regulated Flow-Frequency, Scenario 9.08, *WRMETH* 1

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	2772.99	8546.8	0.00	0.00	0.70	19.30	39.67	125.99	290.6	466.6	770.5	1896.7	6486.0	286640.9
BRBR59	8263.17	21346.7	0.00	23.42	99.25	201.54	329.90	708.90	1238.9	1753.4	2680.5	6216.2	20488.3	710468.4
BRHE68	11457.17	24262.5	0.00	86.45	241.42	404.20	633.05	1266.74	2079.7	2945.4	4627.0	10753.4	30852.6	750363.7
BRRI70	12473.39	24906.5	8.25	107.84	253.63	469.51	746.22	1572.02	2243.5	3246.8	5379.7	12216.3	33477.3	636108.2
BRGM73	11543.97	25628.5	0.00	0.00	0.00	0.01	0.05	10.74	700.1	1740.8	4009.9	11190.7	32883.8	575309.6
515531	1167.47	5799.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	235.0	1786.3	152071.0
515631	1754.61	7209.6	0.00	0.00	0.00	0.00	0.00	6.72	62.0	131.0	249.3	683.9	3003.8	156232.5
515731	2265.59	8068.1	0.00	0.00	0.00	0.00	5.81	74.62	187.9	305.1	500.3	1152.4	4333.9	188629.4
515831	149.92	1039.9	0.00	0.00	0.00	0.96	0.99	0.99	1.0	1.0	1.0	6.7	101.0	37727.5
509431	698.84	3446.7	0.00	0.00	0.00	0.00	0.00	0.00	1.1	15.6	55.8	260.5	1331.1	219374.0
516531	376.45	2017.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	10.4	342.0	67259.6
515931	293.05	2149.3	0.00	0.00	0.00	0.00	0.00	0.00	0.2	4.6	14.1	64.3	439.7	200270.0
516031	944.37	3742.3	0.00	0.00	0.00	0.00	0.00	2.87	36.1	71.9	132.4	431.2	2113.4	164041.7
516131	419.20	2126.3	0.00	0.00	0.00	0.00	0.00	0.00	10.2	20.6	39.5	134.5	995.6	120479.8
516231	117.48	571.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	3.5	9.8	48.8	272.2	23854.5
516331	397.46	1534.9	0.00	0.00	0.00	0.00	0.00	1.34	16.7	39.0	76.5	256.6	890.8	57765.2
516431	436.43	2153.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	20.2	684.6	97722.0

Daily Regulated Flow-Frequency, Scenario 9.09, *WRMETH* 2

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	2773.56	8507.4	0.00	0.00	0.00	9.95	36.91	130.74	300.9	488.3	785.1	1915.2	6452.3	285262.4
BRBR59	8246.28	21327.1	0.00	5.52	64.72	189.70	324.82	693.82	1211.9	1737.7	2660.9	6149.7	20318.6	709714.4
BRHE68	11440.93	24263.5	0.00	47.77	223.90	397.08	620.49	1252.85	2046.8	2937.0	4602.6	10760.7	30773.4	748850.8
BRRI70	12456.78	24907.9	0.00	9.47	219.14	453.64	727.41	1548.61	2241.4	3239.2	5387.2	12202.0	33441.3	635018.9
BRGM73	11529.57	25630.7	0.00	0.00	0.00	0.00	0.00	6.54	678.5	1736.0	3995.8	11172.0	32811.2	574066.0
515531	1152.45	5838.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	168.3	1658.3	152022.1
515631	1739.11	7265.9	0.00	0.00	0.00	0.00	0.00	6.51	55.4	120.5	236.6	647.1	2812.4	156339.2
515731	2251.73	8113.6	0.00	0.00	0.00	0.00	0.92	70.85	179.8	296.9	480.8	1101.4	4156.9	188265.0
515831	149.68	1037.2	0.00	0.00	0.00	0.99	0.99	0.99	1.0	1.0	1.0	8.1	97.9	37727.5
509431	693.92	3446.1	0.00	0.00	0.00	0.00	0.00	0.00	0.1	9.0	43.3	247.4	1311.9	219372.6
516531	376.46	2046.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	10.5	331.7	67454.3
515931	291.78	2150.0	0.00	0.00	0.00	0.00	0.00	0.00	1.0	5.2	15.2	63.4	441.7	200272.9
516031	943.69	3684.2	0.00	0.00	0.00	0.00	0.00	3.27	39.6	75.9	136.4	432.9	2109.7	164565.7
516131	418.93	2122.1	0.00	0.00	0.00	0.00	0.00	0.00	10.5	21.2	40.0	140.2	1000.2	120477.4
516231	117.84	566.8	0.00	0.00	0.00	0.00	0.00	0.00	0.3	4.5	11.1	51.0	273.9	23854.5
516331	398.45	1528.8	0.00	0.00	0.00	0.00	0.00	2.16	18.7	42.9	81.3	258.0	893.0	57288.6
516431	436.43	2155.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	19.4	684.6	97636.3

LRCA58 Cameron Gage on Little River
BRBR59 Bryan Gage on Brazos River
BRHE68 Hempstead Gage on Brazos
BRRI70 Richmond Gage on Brazos River
BRGM73 Brazos Outlet at Gulf of Mexico
515531 Possum Kingdom Reservoir
515631 Granbury Reservoir
515731 Whitney Reservoir
515831 Aquilla Reservoir
509431 Waco Reservoir
516531 Limestone Reservoir
515931 Proctor Reservoir
516031 Belton Reservoir
516131 Stillhouse Hollow Res.
516231 Georgetown Reservoir
516331 Granger Reservoir
516431 Somerville Reservoir

Table 9.20
Daily Unappropriated Flow-Frequency for Scenarios 9.08 and 9.09, ac-ft per day

Daily Unappropriated Flow-Frequency, Scenario 9.08, *WRMETH* 1

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	1640.36	5527.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	677.7	4354.2	176738.8
BRBR59	5020.52	14973.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	297.9	3032.7	13518.8	494096.0
BRHE68	7705.26	20038.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	815.8	5433.7	23657.2	485019.7
BRRI70	9392.63	23109.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	278.1	1903.1	7922.4	27916.5	585389.1
BRGM73	11543.97	25628.5	0.00	0.00	0.00	0.01	0.05	10.74	700.1	1740.8	4009.9	11190.7	32883.8	575309.6
515531	336.47	2581.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	67305.9
515631	657.46	4099.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	599.0	112881.9
515731	1173.26	5457.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	11.5	2075.6	129415.0
515831	52.40	393.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	20.0	14156.4
509431	362.09	1664.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	693.8	51367.8
516531	160.45	803.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	56.5	22167.8
515931	95.88	654.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	18.5	27378.3
516031	564.83	2265.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1330.7	70955.3
516131	267.35	1170.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	734.2	68814.9
516231	81.84	365.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	241.5	14969.7
516331	268.87	1068.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	44.0	718.0	32890.8
516431	398.50	1928.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	605.9	59205.6

Daily Unappropriated Flow-Frequency, Scenario 9.09, *WRMETH* 2

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	1640.04	5536.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	667.1	4344.2	176580.3
BRBR59	5023.94	15020.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	279.6	3000.3	13471.5	492683.9
BRHE68	7702.23	20068.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	795.3	5402.2	23463.2	484502.6
BRRI70	9383.64	23118.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	245.3	1893.8	7890.8	27852.5	584114.1
BRGM73	11529.57	25630.7	0.00	0.00	0.00	0.00	0.00	6.54	678.5	1736.0	3995.8	11172.0	32811.2	574066.0
515531	346.69	2636.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	67415.6
515631	665.77	4157.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	576.2	115232.0
515731	1180.36	5511.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.6	2083.7	129172.1
515831	51.98	392.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	18.7	14156.4
509431	365.26	1672.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	717.0	51367.1
516531	160.78	803.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	62.0	21933.3
515931	96.04	654.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	8.4	27373.5
516031	569.53	2283.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1344.7	70654.0
516131	268.46	1172.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	739.4	70512.8
516231	81.33	364.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	239.9	14969.7
516331	266.71	1068.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	17.2	713.3	32864.0
516431	398.66	1926.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	610.7	59205.5

LRCA58 Cameron Gage on Little River
BRBR59 Bryan Gage on Brazos River
BRHE68 Hempstead Gage on Brazos
BRRI70 Richmond Gage on Brazos River
BRGM73 Brazos Outlet at Gulf of Mexico
515531 Possum Kingdom Reservoir
515631 Granbury Reservoir
515731 Whitney Reservoir
515831 Aquilla Reservoir
509431 Waco Reservoir
516531 Limestone Reservoir
515931 Proctor Reservoir
516031 Belton Reservoir
516131 Stillhouse Hollow Res.
516231 Georgetown Reservoir
516331 Granger Reservoir
516431 Somerville Reservoir

Table 9.21
Control Point Reliability Summaries for Scenarios 9.08 and 9.09

Control Point Reliability, Scenario 9.08, *WRMETH* 1

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	230750.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	2522.32	94.83	96.10	94.8	95.0	95.1	95.3	95.8	96.3	98.0	89.7	89.7	89.7	91.4	96.6	96.6	100.0
515731	18990.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	717.56	94.11	94.84	94.1	94.1	94.1	94.3	94.4	94.8	96.7	89.7	89.7	89.7	89.7	93.1	94.8	100.0
509431	80694.4	3692.21	87.79	95.42	87.8	87.8	87.8	89.2	96.8	98.7	99.7	84.5	84.5	84.5	84.5	91.4	98.3	100.0
516531	65074.0	205.33	99.43	99.68	99.4	99.4	99.4	99.4	99.7	99.7	99.9	96.6	96.6	98.3	98.3	100.0	100.0	100.0
515931	19658.0	920.37	93.68	95.32	93.7	93.7	93.8	94.3	95.1	95.8	97.1	87.9	87.9	87.9	87.9	94.8	96.6	100.0
516031	112257.0	2830.08	96.41	97.48	96.4	96.4	96.6	96.7	97.1	97.6	98.3	93.1	93.1	93.1	93.1	94.8	100.0	100.0
516131	67768.0	4061.63	92.96	94.01	93.0	93.0	93.0	93.2	93.7	94.5	96.3	87.9	87.9	87.9	89.7	91.4	93.1	100.0
516231	13610.0	752.07	93.39	94.47	93.4	93.7	93.7	93.7	93.7	94.5	96.6	89.7	89.7	89.7	89.7	91.4	94.8	100.0
516331	19840.0	448.26	97.27	97.74	97.3	97.3	97.3	97.3	97.3	98.1	98.4	93.1	93.1	93.1	94.8	98.3	98.3	100.0
516431	48000.0	318.81	98.85	99.34	98.9	98.9	98.9	98.9	99.0	99.3	99.7	96.6	96.6	96.6	96.6	100.0	100.0	100.0
Total	755250.1	16468.65		97.82														

Control Point Reliability, Scenario 9.09, *WRMETH* 2

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	230750.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	2011.43	96.41	96.89	96.4	96.4	96.4	96.7	96.8	97.0	97.4	93.1	93.1	93.1	93.1	96.6	98.3	98.3
515731	18922.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	660.65	94.54	95.25	94.5	94.5	94.5	94.5	94.7	95.3	96.8	89.7	89.7	89.7	89.7	94.8	94.8	100.0
509431	80714.7	2985.67	88.94	96.30	88.9	89.1	89.4	89.8	97.6	99.4	100.0	86.2	86.2	86.2	86.2	93.1	98.3	100.0
516531	65074.0	204.07	99.43	99.69	99.4	99.4	99.4	99.4	99.7	99.7	99.9	96.6	96.6	98.3	98.3	100.0	100.0	100.0
515931	19658.0	854.31	94.40	95.65	94.4	94.5	94.7	94.8	95.4	95.8	97.0	87.9	87.9	87.9	87.9	94.8	96.6	100.0
516031	112257.0	2793.41	96.55	97.51	96.6	96.7	96.8	96.8	97.0	97.7	98.4	91.4	93.1	93.1	93.1	94.8	98.3	100.0
516131	67768.0	3967.37	92.96	94.15	93.0	93.0	93.0	93.1	93.8	94.7	96.0	87.9	87.9	87.9	89.7	91.4	93.1	100.0
516231	13610.0	818.39	92.82	93.99	92.8	93.2	93.2	93.2	93.4	94.0	95.3	87.9	87.9	87.9	89.7	91.4	94.8	98.3
516331	19840.0	551.22	96.55	97.22	96.6	96.6	96.6	96.7	96.8	97.4	97.7	93.1	93.1	93.1	93.1	94.8	98.3	100.0
516431	48000.0	305.47	98.85	99.36	98.9	98.9	98.9	98.9	99.0	99.3	99.7	96.6	96.6	96.6	96.6	100.0	100.0	100.0
Total	755202.3	15152.00		97.99														

Table 9.22
Mean Shortage and Volume Reliability for Selected Water Rights

Selected Water Rights	Mean Shortage, ac-ft/yr Scenario ID 9.08	Mean Shortage, ac-ft/yr Scenario ID 9.09	Volume Reliability, % Scenario ID 9.08	Volume Reliability, % Scenario ID 9.09
Dec. 31, 1929 and Senior, all uses	8,572	7,387	92.9	93.9
Jan. 1, 1930 to Dec. 31, 1939, all uses	5,756	5,916	92.4	92.2
Jan. 1, 1940 to Dec. 31, 1949, all uses	32,910	32,082	82.9	83.3
Jan. 1, 1950 to Dec. 31, 1959, all uses	27,225	27,654	75.7	75.4
Jan. 1, 1960 to Dec. 31, 1969, all uses	34,355	34,024	72.7	72.9
Jan. 1, 1970 to Dec. 31, 1979, all uses	1,484	1,557	68.4	66.8
Jan. 1, 1980 and Junior, municipal use	19,614	19,945	73.8	73.4
Jan. 1, 1980 and Junior, non-municipal use	31,186	32,003	63.0	62.0
All Selected Water Rights	161,101	160,568	79.6	79.7

Table 9.23
Routing Adjustments at Selected Control Points, Scenario 9.08, *WRMETH* 1

Bwam Control Point Identifier	Control Point Location Name	Routing Adjustments, All 58 Years		Routing Adjustments, Driest 29 Years	
		Average, ac-ft per year	% Naturalized Flow	Average, ac-ft per year	% Naturalized Flow
BRBR59	Bryan Gage	2,879.9	0.07	5,569.8	0.27
BRHE68	Hempstead Gage	2,726.8	0.05	4,804.0	0.17
BRRI70	Richmond Gage	2,419.5	0.04	4,257.0	0.14
LRCA58	Cameron Gage	401.3	0.03	404.2	0.07
BRGM73	Gulf Outlet	2,068.1	0.03	3,698.7	0.11
515531	Possum Kingdom Lake	65.9	0.01	110.0	0.03
515631	Granbury Lake	4,552.9	0.42	5,011.3	0.86
515731	Whitney Lake	2,565.6	0.19	3,604.5	0.47
515831	Aquilla Lake	0.0	0.00	0.0	0.00
509431	Waco Lake	0.4	0.00	0.4	0.00
516531	Limestone Lake	101.8	0.04	74.7	0.07
515931	Proctor Lake	1.8	0.00	2.6	0.00
516031	Belton Lake	172.5	0.03	260.6	0.14
516131	Stillhouse Lake	14.1	0.01	28.2	0.03
516231	Georgetown Lake	0.0	0.00	0.0	0.00
516331	Granger Lake	6.0	0.00	8.4	0.01
516431	Somerville Lake	8.3	0.00	9.7	0.01

Routing Adjustments at Selected Control Points, Scenario 9.09, *WRMETH* 2

Bwam Control Point Identifier	Control Point Location Name	Routing Adjustments, All 58 Years		Routing Adjustments, Driest 29 Years	
		Average, ac-ft per year	% Naturalized Flow	Average, ac-ft per year	% Naturalized Flow
BRBR59	Bryan Gage	7,474.1	0.19	13,929.5	0.67
BRHE68	Hempstead Gage	7,474.2	0.14	12,960.4	0.45
BRRI70	Richmond Gage	7,424.8	0.13	12,637.8	0.40
LRCA58	Cameron Gage	1,222.0	0.09	1,616.7	0.30
BRGM73	Gulf Outlet	22,613.3	0.37	36,525.1	1.11
515531	Possum Kingdom Lake	72.8	0.01	118.9	0.03
515631	Granbury Lake	12,580.4	1.15	14,332.9	2.46
515731	Whitney Lake	7,554.6	0.55	11,448.7	1.51
515831	Aquilla Lake	0.0	0.00	0.0	0.00
509431	Waco Lake	671.2	0.19	688.0	0.44
516531	Limestone Lake	102.0	0.04	75.0	0.07
515931	Proctor Lake	1.9	0.00	2.8	0.01
516031	Belton Lake	385.7	0.08	530.2	0.28
516131	Stillhouse Lake	14.2	0.01	28.4	0.03
516231	Georgetown Lake	0.0	0.00	0.0	0.00
516331	Granger Lake	10.5	0.01	13.9	0.02
516431	Somerville Lake	8.4	0.00	10.0	0.01

Flow forecasting is used with either *WRMETH* option to protect the water availability of downstream senior water rights. The simulation forecasting period, *FPRD*, and water right availability periods, *APRD*, are set on the JU record in both Scenarios 9.10 and 9.11 for all water rights. *FPRD* is set equal to the maximum routing period of 14 days and *APRD* is set to the *SIMD* default value for automatic calculation. The simulation results are examined for the affects of flow forecasting in the following section of this chapter.

Downstream senior rights can be affected directly by the routed changes to flow of junior rights in previous days with *WRMETH* 1. Flow forecasting also helps to reduce the incidence of routing adjustments which can result in reduced water availability for all water rights. Flow forecasting, therefore, can be viewed as having a dual role to protect the prior appropriation system and to reduce the incidence of over appropriation with the use of *WRMETH* 1. Flow forecasting is used with *WRMETH* 2 primarily to reduce the incidence of over appropriation. Since senior water rights are not directly affected by the routed changes to flow from previous days, flow forecasting is a necessary option for use with *WRMETH* 2.

Scenario 9.10 uses *WRMETH* 1 and flow forecasting. Scenario 9.11 uses *WRMETH* 2 and flow forecasting as well. Shortages and reliabilities are presented in Table 9.24 for Scenarios 9.10 and 9.11. Compared with the shortages and reliabilities in Table 9.22, the scenarios generally show increased reliability in most water right groupings when flow forecasting is added to the simulation.

Table 9.25 shows the routing adjustments for the scenarios which use flow forecasting. Less routing adjustment is required with either *WRMETH* option after the application of forecasting, as compared to the results of Table 9.23. Reduced routing adjustment improves water availability for all water rights, and especially for senior rights in the case of *WRMETH* 2.

Table 9.24
Mean Shortage and Volume Reliability for Selected Water Rights

Selected Water Rights	Mean Shortage, ac-ft per year		Volume Reliability, %	
	Scenario ID		Scenario ID	
	9.10	9.11	9.10	9.11
Dec. 31, 1929 and Senior, all uses	8,339	7,335	93.1	93.9
Jan. 1, 1930 to Dec. 31, 1939, all uses	5,653	5,913	92.5	92.2
Jan. 1, 1940 to Dec. 31, 1949, all uses	32,481	31,738	83.1	83.5
Jan. 1, 1950 to Dec. 31, 1959, all uses	26,997	27,445	75.9	75.5
Jan. 1, 1960 to Dec. 31, 1969, all uses	34,079	33,933	72.9	73.0
Jan. 1, 1970 to Dec. 31, 1979, all uses	1,472	1,544	68.6	67.1
Jan. 1, 1980 and Junior, municipal use	19,445	19,806	74.1	73.6
Jan. 1, 1980 and Junior, non-municipal use	31,076	31,795	63.1	62.3
All Selected Water Rights	159,542	159,508	79.8	79.8

Table 9.25
Routing Adjustments at Selected Control Points, Scenario 9.10, *WRMETH* 1

Bwam Control Point Identifier	Control Point Location Name	Routing Adjustments, All 58 Years		Routing Adjustments, Driest 29 Years	
		Average, ac-ft per year	% Naturalized Flow	Average, ac-ft per year	% Naturalized Flow
BRBR59	Bryan Gage	1,675.9	0.04	3,242.1	0.16
BRHE68	Hempstead Gage	1,557.4	0.03	2,618.6	0.09
BRRI70	Richmond Gage	1,364.6	0.02	2,353.5	0.08
LRCA58	Cameron Gage	178.3	0.01	112.0	0.02
BRGM73	Gulf Outlet	1,177.3	0.02	2,113.9	0.06
515531	Possum Kingdom Lake	66.6	0.01	111.5	0.03
515631	Granbury Lake	4,559.9	0.42	5,099.9	0.88
515731	Whitney Lake	1,993.1	0.15	2,886.2	0.38
515831	Aquilla Lake	0.0	0.00	0.0	0.00
509431	Waco Lake	0.2	0.00	0.4	0.00
516531	Limestone Lake	102.2	0.04	75.4	0.07
515931	Proctor Lake	1.7	0.00	2.5	0.00
516031	Belton Lake	48.1	0.01	73.2	0.04
516131	Stillhouse Lake	14.0	0.01	27.9	0.03
516231	Georgetown Lake	0.0	0.00	0.0	0.00
516331	Granger Lake	5.2	0.00	7.1	0.01
516431	Somerville Lake	8.5	0.00	9.7	0.01

Routing Adjustments at Selected Control Points, Scenario 9.11, *WRMETH* 2

Bwam Control Point Identifier	Control Point Location Name	Routing Adjustments, All 58 Years		Routing Adjustments, Driest 29 Years	
		Average, ac-ft per year	% Naturalized Flow	Average, ac-ft per year	% Naturalized Flow
BRBR59	Bryan Gage	6,549.0	0.16	12,325.7	0.59
BRHE68	Hempstead Gage	7,349.8	0.14	13,088.1	0.46
BRRI70	Richmond Gage	7,280.8	0.12	12,595.5	0.40
LRCA58	Cameron Gage	576.4	0.04	567.4	0.11
BRGM73	Gulf Outlet	19,058.4	0.31	30,240.3	0.92
515531	Possum Kingdom Lake	72.8	0.01	119.2	0.03
515631	Granbury Lake	12,552.3	1.15	14,424.2	2.48
515731	Whitney Lake	6,183.9	0.45	9,378.5	1.24
515831	Aquilla Lake	0.0	0.00	0.0	0.00
509431	Waco Lake	666.9	0.19	684.4	0.44
516531	Limestone Lake	102.3	0.04	75.7	0.07
515931	Proctor Lake	1.9	0.00	2.8	0.01
516031	Belton Lake	118.1	0.02	153.9	0.08
516131	Stillhouse Lake	14.3	0.01	28.5	0.03
516231	Georgetown Lake	0.0	0.00	0.0	0.00
516331	Granger Lake	5.9	0.00	8.0	0.01
516431	Somerville Lake	8.3	0.00	9.8	0.01

Flow Forecasting for Water Availability

The application of flow forecasting for adjusting water availability is described in Chapter 8 of this report and in the *Daily Manual*. A simulation with flow forecasting is compared to a simulation without flow forecasting in this section for the pertinent effects on storage frequency, water right reliability, and water balance maintenance. Forecasting is applied to all water rights with options *FPRD* and *APRD* on the *JU* record. The total number of future days in the simulation forecast period is set with option *FPRD* as the longest number of future days to rout changes to flow from an upstream routing control point to the basin outlet. Within the forecast simulation, individual water rights will consider a subset of the future days for determining current day water availability. Option *APRD* is set to automatically compute the individual water right periods according to the number of future days between the water right location and the basin outlet. Reverse routing of future downstream flows and reuse and revision of forecasting data are utilized in simulations with forecasting. Simulations without forecasting data only utilize downstream current day flow data without reverse routing for the purposes of determining water availability.

Table 9.26
Parameters per Simulation Scenario Being Considered

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, *WRMETH*	Disaggregation Option, *DFMETHOD*	Target Distribution Option, *ND*	Flow Forecasting, *FPRD*	Negative Increntals, *ADJINC*	Execution Time, hours
9.08	day	Bwam3	lag-att	1	daily pattern	uniform	0 days	7	0.24
9.10	day	Bwam3	lag-att	1	daily pattern	uniform	14 days	7	3.63

Scenario 9.10 uses flow forecasting with a simulation forecast period set by option *FPRD* according to the longest number of future days to rout changes to flow from an upstream routing control point to the basin outlet. The routing parameters shown in Table 8.9 and 8.10 are used by *SIMD* to compute a routing factor array, RFA. The routing factor array is an array of the multipliers used to convert an upstream change to flow into a downstream value in future days. RFA entries are computed from each routing reach to the basin outlet. The routing reach with the longest number of future days to the basin outlet is used as the forecast simulation period, *FPRD*. For the Bwam dataset, the longest routing period in the RFA occurs at location of Limestone Lake, control point 516531, for routing parameters calibrated to all flow conditions as listed in Table 8.9. Though the total distance to the outlet from Possum Kingdom Lake is approximately twice that of the distance to the outlet from Limestone Lake, the calibrated routing parameters along the tributary below Limestone Lake result in a longer routing period. The routing period from Possum Kingdom Lake to the outlet is 12 days beyond the current day. The routing period from Limestone Lake to the outlet is 14 days. The RFA values for Possum Kingdom Lake and Limestone Lake are given in Table 9.27.

Scenario 9.10 uses a simulation forecast period of 14 days beyond the current day as indicated by the longest number of future days in the RFA. Selecting the maximum routing period for the simulation forecast period will ensure that all downstream control points are included in water availability computations for water rights located at or above the reach with the maximum routing period. In the Bwam dataset, the water rights at or above the location of Limestone Lake require 14 days beyond the current day to consider water availability at control points located below the last routing reach in the basin. However, water availability within the forecast simulation at the location of Limestone Lake is still dependent upon downstream conditions 14 days into the future. This creates a situation where the water availability in day 14 of the forecast simulation is dependent on routing that occurs in future days 15 through 28 beyond the current day. Extending the simulation forecast period beyond the maximum routing period of 14 days is addressed in Chapter 10.

Table 9.27
Routing Factor Array Values for Selected Routing Control Points

Possum Kingdom Lake to the Outlet

CONTROL POINT ID		515531	BRDE29	515631	BRGR30	515731	CON070	BRWA41	BRHB42	BRBR59	CON147	BRHE68	BRRI70	OUTLET
DELIVERY FACTOR		1.000	0.975	0.988	0.994	0.979	0.995	0.996	0.990	0.986	0.984	0.991	0.976	0.973
CUMULATIVE DF		1.000	0.975	0.963	0.957	0.937	0.933	0.929	0.920	0.907	0.893	0.885	0.864	0.841
LAG or MUSKINGUM K		1.536	0.269	0.524	0.515	0.306	0.413	0.821	1.220	0.636	0.594	1.257	0.594	
ATT or MUSKINGUM X		1.223	1.019	1.046	1.032	1.056	1.032	1.144	1.292	1.005	1.023	1.283	1.121	
ROUTING	DAY 0	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FACTOR	1	0.000	0.547	0.398	0.197	0.096	0.068	0.040	0.011	0.000	0.000	0.000	0.000	0.000
ARRAY (RFA)	2	0.000	0.427	0.453	0.423	0.304	0.243	0.172	0.077	0.013	0.000	0.000	0.000	0.000
	3	0.000	0.000	0.111	0.281	0.344	0.331	0.294	0.204	0.072	0.039	0.019	0.000	0.000
	4	0.000	0.000	0.000	0.055	0.164	0.215	0.261	0.282	0.184	0.111	0.066	0.016	0.008
	5	0.000	0.000	0.000	0.000	0.027	0.074	0.125	0.220	0.262	0.209	0.151	0.056	0.033
	6	0.000	0.000	0.000	0.000	0.000	0.000	0.034	0.098	0.221	0.243	0.221	0.132	0.089
	7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.113	0.178	0.214	0.202	0.161
	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.082	0.137	0.209	0.200
	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.027	0.057	0.147	0.175
	10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.070	0.108
	11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.027	0.046
	12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016

Limestone Lake to the Outlet

CONTROL POINT ID		516531	NAEA66	NABR67	CON147	BRHE68	BRRI70	OUTLET
DELIVERY FACTOR		1.000	0.995	0.990	0.970	0.991	0.976	0.973
CUMULATIVE DF		1.000	0.995	0.985	0.955	0.947	0.925	0.900
LAG or MUSKINGUM K		1.462	2.366	5.340	0.594	1.257	0.594	
ATT or MUSKINGUM X		1.135	1.589	2.327	1.023	1.283	1.121	
ROUTING	DAY 0	1.000	0.000	0.000	0.000	0.000	0.000	0.000
FACTOR	1	0.000	0.589	0.000	0.000	0.000	0.000	0.000
ARRAY (RFA)	2	0.000	0.405	0.081	0.000	0.000	0.000	0.000
	3	0.000	0.000	0.423	0.000	0.000	0.000	0.000
	4	0.000	0.000	0.386	0.000	0.000	0.000	0.000
	5	0.000	0.000	0.092	0.000	0.000	0.000	0.000
	6	0.000	0.000	0.000	0.033	0.014	0.000	0.000
	7	0.000	0.000	0.000	0.208	0.106	0.013	0.000
	8	0.000	0.000	0.000	0.347	0.264	0.088	0.053
	9	0.000	0.000	0.000	0.259	0.307	0.228	0.150
	10	0.000	0.000	0.000	0.093	0.188	0.289	0.250
	11	0.000	0.000	0.000	0.013	0.066	0.204	0.243
	12	0.000	0.000	0.000	0.000	0.000	0.081	0.143
	13	0.000	0.000	0.000	0.000	0.000	0.018	0.050
	14	0.000	0.000	0.000	0.000	0.000	0.000	0.010

Tables 9.28 and 9.29 present water right reliabilities at control points with major reservoir conservation storage and for groups of run-of-river rights, respectively. As compared with Scenario 9.08, the results of the scenario using flow forecasting do not show significant changes in reliability at control points with reservoir storage. Table 9.29 shows an overall trend for slight improvements in run-of-river reliability. Improvements in reliability are likely the result of protection of downstream senior rights through better enforcement of priority order and through reductions in the occurrence of routing adjustments. Reducing the frequency of downstream senior water right shortages should benefit upstream junior water right reliability.

Daily storage frequency statistics are given in Table 9.30. As compared with Scenario 9.08, the scenario using flow forecasting shows a slight decrease in the mean reservoir storage content. The basin total mean reservoir storage decreases from 2,494,034 to 2,468,922 ac-ft between Scenarios 9.08 and 9.10, respectively. Reservoirs with a more senior priority, such as Possum Kingdom Lake, show an increase in mean storage with the use of flow forecasting. The frequency of days with zero storage contents is relatively the same between two scenarios. Water right reliabilities for the water rights located at the control points of the reservoirs are generally controlled by to the number of zero storage days for their respective reservoirs.

Table 9.31 presents the routing adjustments for each scenario. As compared with the scenario without forecasting, the scenarios using flow forecasting reduces the amount of over appropriation and routing adjustment that occurs during the simulation. As mentioned in conjunction with the discussion of water right reliability, reducing the occurrence of over appropriation may contribute to improvements water right reliability.

Table 9.28
Control Point Reliability Summaries for Scenarios 9.08 and 9.10

Control Point Reliability, Scenario 9.08, No Flow Forecasting

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT: 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT: 100%	98%	95%	90%	75%	50%	1%
515531	230750.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	2522.32	94.83	96.10	94.8	95.0	95.1	95.3	95.8	96.3	98.0	89.7	89.7	89.7	91.4	96.6	96.6	100.0
515731	18990.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	717.56	94.11	94.84	94.1	94.1	94.1	94.3	94.4	94.8	96.7	89.7	89.7	89.7	89.7	93.1	94.8	100.0
509431	80694.4	3692.21	87.79	95.42	87.8	87.8	87.8	89.2	96.8	98.7	99.7	84.5	84.5	84.5	84.5	91.4	98.3	100.0
516531	65074.0	205.33	99.43	99.68	99.4	99.4	99.4	99.4	99.7	99.7	99.9	96.6	96.6	98.3	98.3	100.0	100.0	100.0
515931	19658.0	920.37	93.68	95.32	93.7	93.7	93.8	94.3	95.1	95.8	97.1	87.9	87.9	87.9	87.9	94.8	96.6	100.0
516031	112257.0	2830.08	96.41	97.48	96.4	96.4	96.6	96.7	97.1	97.6	98.3	93.1	93.1	93.1	93.1	94.8	100.0	100.0
516131	67768.0	4061.63	92.96	94.01	93.0	93.0	93.0	93.2	93.7	94.5	96.3	87.9	87.9	87.9	89.7	91.4	93.1	100.0
516231	13610.0	752.07	93.39	94.47	93.4	93.7	93.7	93.7	93.7	94.5	96.6	89.7	89.7	89.7	89.7	91.4	94.8	100.0
516331	19840.0	448.26	97.27	97.74	97.3	97.3	97.3	97.3	97.3	98.1	98.4	93.1	93.1	93.1	94.8	98.3	98.3	100.0
516431	48000.0	318.81	98.85	99.34	98.9	98.9	98.9	98.9	99.0	99.3	99.7	96.6	96.6	96.6	96.6	100.0	100.0	100.0
Total	755250.1	16468.65		97.82														

Table 9.28 (continued)

Control Point Reliability, Scenario 9.10, With Flow Forecasting

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	+++++++++ PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING +++++++++ 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS ---------- PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	230750.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	3270.73	93.68	94.95	93.7	93.7	93.7	94.3	94.7	95.3	97.4	87.9	87.9	87.9	89.7	93.1	96.6	100.0
515731	18949.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	726.25	93.97	94.77	94.0	94.0	94.0	94.1	94.4	94.8	96.6	89.7	89.7	89.7	89.7	93.1	94.8	100.0
509431	80706.5	3666.69	87.79	95.46	87.8	87.8	87.8	89.1	96.8	98.7	99.9	84.5	84.5	84.5	86.2	91.4	98.3	100.0
516531	65074.0	203.10	99.43	99.69	99.4	99.4	99.4	99.4	99.7	99.7	99.9	96.6	96.6	98.3	98.3	100.0	100.0	100.0
515931	19658.0	1493.43	90.80	92.40	90.8	90.9	91.2	91.8	93.2	94.3	95.3	81.0	82.8	86.2	87.9	89.7	89.7	100.0
516031	112257.0	3859.70	94.68	96.56	94.7	95.0	95.4	95.7	96.3	96.7	97.7	89.7	89.7	89.7	91.4	94.8	96.6	100.0
516131	67768.0	4081.75	93.25	93.98	93.2	93.2	93.2	93.2	93.4	94.4	96.1	87.9	87.9	89.7	89.7	91.4	91.4	100.0
516231	13610.0	802.65	93.10	94.10	93.1	93.1	93.2	93.4	93.5	94.1	95.8	89.7	89.7	89.7	89.7	91.4	94.8	98.3
516331	19840.0	468.36	96.98	97.64	97.0	97.0	97.0	97.0	97.0	98.1	98.4	93.1	93.1	93.1	94.8	96.6	98.3	100.0
516431	48000.0	330.68	98.85	99.31	98.9	98.9	98.9	98.9	98.9	99.3	99.7	96.6	96.6	96.6	96.6	98.3	100.0	100.0
Total	755221.2	18903.35		97.50														

Control Points

515531 Possum Kingdom Reservoir
515631 Granbury Reservoir
515731 Whitney Reservoir
515831 Aquilla Reservoir
509431 Waco Reservoir
516531 Limestone Reservoir
515931 Proctor Reservoir
516031 Belton Reservoir
516131 Stillhouse Hollow Res.
516231 Georgetown Reservoir
516331 Granger Reservoir
516431 Somerville Reservoir

Table 9.29
Mean Shortage and Volume Reliability for Selected Water Rights

Selected Water Rights	Mean Shortage, acre-feet per year		Volume Reliability, %	
	Scenario ID		Scenario ID	
	9.08	9.10	9.08	9.10
Dec. 31, 1929 and Senior, all uses	8,572	8,339	92.9	93.1
Jan. 1, 1930 to Dec. 31, 1939, all uses	5,754	5,653	92.4	92.5
Jan. 1, 1940 to Dec. 31, 1949, all uses	32,910	32,481	82.9	83.1
Jan. 1, 1950 to Dec. 31, 1959, all uses	27,221	26,997	75.7	75.9
Jan. 1, 1960 to Dec. 31, 1969, all uses	34,345	34,079	72.7	72.9
Jan. 1, 1970 to Dec. 31, 1979, all uses	1,484	1,472	68.4	68.6
Jan. 1, 1980 and Junior, municipal use	19,609	19,445	73.9	74.1
Jan. 1, 1980 and Junior, non-municipal use	31,185	31,076	63.0	63.1
All Selected Water Rights	161,081	159,542	79.6	79.8

Table 9.30

End of Day Storage-Frequency for Scenarios 9.08 and 9.10, ac-ft

End of Day Storage-Frequency, Scenario 9.08, No Forecasting

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
515531	613531.	102465.	197891.	269496.	325440.	424888.	471354.	553291.	612117.	645157.	669083.	698226.	713525.	724739.
515631	113854.	43075.	0.	0.	0.	3287.	45297.	96784.	116899.	125716.	135265.	149445.	154889.	155000.
515731	598018.	46975.	406161.	424352.	448585.	483037.	534812.	586278.	604271.	612760.	621615.	632112.	636100.	636100.
515831	37777.	15612.	0.	0.	0.	0.	8155.	33190.	40320.	42984.	45573.	49856.	52015.	52400.
509431	155002.	57104.	453.	784.	4515.	15790.	60127.	134735.	163374.	173908.	186049.	200163.	205144.	206562.
516531	177604.	51916.	0.	11259.	27751.	59308.	101115.	158405.	181506.	193319.	204748.	218816.	224612.	225400.
515931	37834.	19091.	0.	0.	0.	0.	8095.	23294.	36976.	41672.	47285.	55994.	59351.	59400.
516031	362293.	124635.	0.	0.	0.	23073.	171856.	336641.	389830.	408302.	427730.	449720.	457600.	457600.
516131	178138.	71117.	0.	0.	0.	0.	27572.	160656.	195008.	207033.	216912.	229507.	235222.	235700.
516231	26756.	11513.	0.	0.	0.	0.	6876.	20182.	28086.	31696.	34016.	36009.	36940.	37100.
516331	52384.	18005.	0.	0.	0.	7869.	24901.	46404.	56055.	60973.	64132.	65444.	65500.	65500.
516431	128784.	37132.	0.	279.	24051.	53763.	67699.	111780.	133896.	141556.	149326.	159722.	160110.	160110.
Total	2481974.	519504.	843201.	916578.	1020846.	1285734.	1607640.	2271998.	2545968.	2647156.	2737996.	2877579.	2965380.	3015611.

End of Day Storage-Frequency, Scenario 9.10, With Flow Forecasting

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
515531	619206.	100910.	200123.	271542.	332451.	432596.	479218.	562019.	620852.	650513.	673809.	702491.	715640.	724739.
515631	103554.	44363.	0.	0.	0.	0.	32962.	77423.	104218.	113059.	123986.	141574.	151517.	155000.
515731	598754.	45952.	411790.	429054.	457749.	488429.	532998.	587077.	604227.	613133.	622508.	632992.	636100.	636100.
515831	37426.	15471.	0.	0.	0.	0.	8460.	32474.	39772.	42399.	45025.	49514.	51764.	52400.
509431	154738.	56846.	480.	825.	4890.	15881.	60926.	135045.	163077.	173637.	185703.	199607.	204582.	206562.
516531	177710.	51852.	0.	11429.	27923.	59692.	101338.	158591.	181604.	193441.	204834.	218902.	224627.	225400.
515931	34862.	20436.	0.	0.	0.	0.	1390.	17123.	33827.	39813.	45616.	54356.	58273.	59400.
516031	347369.	127868.	0.	0.	0.	6671.	119593.	316555.	373235.	392282.	414139.	436433.	451008.	457600.
516131	178420.	71345.	0.	0.	0.	0.	26490.	161872.	196120.	207326.	217281.	229849.	235341.	235700.
516231	26436.	11665.	0.	0.	0.	0.	5018.	19528.	27828.	31369.	33919.	35649.	36976.	37100.
516331	52457.	17974.	0.	0.	0.	6971.	25753.	46339.	56050.	61047.	64214.	65478.	65500.	65500.
516431	128632.	37384.	0.	204.	23213.	52660.	67210.	111506.	133907.	141619.	149343.	159722.	160110.	160110.
Total	2459563.	521748.	829911.	906565.	1015273.	1265676.	1570247.	2235172.	2519890.	2622480.	2714290.	2862868.	2951975.	3015544.

Control Points

515531	Possum Kingdom Reservoir	515931	Proctor Reservoir
515631	Granbury Reservoir	516031	Belton Reservoir
515731	Whitney Reservoir	516131	Stillhouse Hollow Res.
515831	Aquilla Reservoir	516231	Georgetown Reservoir
509431	Waco Reservoir	516331	Granger Reservoir
516531	Limestone Reservoir	516431	Somerville Reservoir

Table 9.31
Routing Adjustments at Selected Control Points, Scenario 9.08, No Forecasting

Bwam Control Point Identifier	Control Point Location Name	Routing Adjustments, All 58 Years		Routing Adjustments, Driest 29 Years	
		Average, ac-ft per year	% Naturalized Flow	Average, ac-ft per year	% Naturalized Flow
BRBR59	Bryan Gage	2,879.9	0.07	5,569.8	0.27
BRHE68	Hempstead Gage	2,726.8	0.05	4,804.0	0.17
BRRI70	Richmond Gage	2,419.5	0.04	4,257.0	0.14
LRCA58	Cameron Gage	401.3	0.03	404.2	0.07
BRGM73	Gulf Outlet	2,068.1	0.03	3,698.7	0.11
515531	Possum Kingdom Lake	65.9	0.01	110.0	0.03
515631	Granbury Lake	4,552.9	0.42	5,011.3	0.86
515731	Whitney Lake	2,565.6	0.19	3,604.5	0.47
515831	Aquilla Lake	0.0	0.00	0.0	0.00
509431	Waco Lake	0.4	0.00	0.4	0.00
516531	Limestone Lake	101.8	0.04	74.7	0.07
515931	Proctor Lake	1.8	0.00	2.6	0.00
516031	Belton Lake	172.5	0.03	260.6	0.14
516131	Stillhouse Lake	14.1	0.01	28.2	0.03
516231	Georgetown Lake	0.0	0.00	0.0	0.00
516331	Granger Lake	6.0	0.00	8.4	0.01
516431	Somerville Lake	8.3	0.00	9.7	0.01

Routing Adjustments at Selected Control Points, Scenario 9.10, With Flow Forecasting

Bwam Control Point Identifier	Control Point Location Name	Routing Adjustments, All 58 Years		Routing Adjustments, Driest 29 Years	
		Average, ac-ft per year	% Naturalized Flow	Average, ac-ft per year	% Naturalized Flow
BRBR59	Bryan Gage	1,675.9	0.04	3,242.1	0.16
BRHE68	Hempstead Gage	1,557.4	0.03	2,618.6	0.09
BRRI70	Richmond Gage	1,364.6	0.02	2,353.5	0.08
LRCA58	Cameron Gage	178.3	0.01	112.0	0.02
BRGM73	Gulf Outlet	1,177.3	0.02	2,113.9	0.06
515531	Possum Kingdom Lake	66.6	0.01	111.5	0.03
515631	Granbury Lake	4,559.9	0.42	5,099.9	0.88
515731	Whitney Lake	1,993.1	0.15	2,886.2	0.38
515831	Aquilla Lake	0.0	0.00	0.0	0.00
509431	Waco Lake	0.2	0.00	0.4	0.00
516531	Limestone Lake	102.2	0.04	75.4	0.07
515931	Proctor Lake	1.7	0.00	2.5	0.00
516031	Belton Lake	48.1	0.01	73.2	0.04
516131	Stillhouse Lake	14.0	0.01	27.9	0.03
516231	Georgetown Lake	0.0	0.00	0.0	0.00
516331	Granger Lake	5.2	0.00	7.1	0.01
516431	Somerville Lake	8.5	0.00	9.7	0.01

Daily Water Right Target Distribution

Monthly target demands are established by the annual *WR* record target demand and the associated *UC* record set. The monthly demand is distributed uniformly over each day of the month by default. *SIMD* offers the option to set the number of days, *ND*, in which the target demand can be met. If *ND* is greater than zero, the monthly target demand will be distributed in the first *ND* days of the month. After the first *ND* days of the month, any shortage in meeting the target demand in the preceding days can be reapplied to the daily target building process if the *SHORT* parameter option is activated. Use of *ND* and *SHORT* enables a water right to attempt to meet the month's target demand sooner in the month or later in the month if water availability conditions improve.

The simulation scenarios examined in this section are given in Table 9.32. Scenarios 9.12 and 9.13 reduce the number days for setting the monthly target demand to 7 and 1 days, respectively. The *ND* parameter for each water right is set globally for all water rights using the *JU* record option *DND* in simulation scenarios 9.12 and 9.13. The ability to recover shortages that occur in the first *ND* number of days of each month is activated with the *JU* record option *DSHORT*. Fewer days for recovering shortages occur the closer the value of *ND* is to the actual number of days in the month.

Table 9.32
Parameters per Simulation Scenario Being Considered

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, *WRMETH*	Disaggregation Option, *DFMETHOD*	Target Distribution Option, *ND*	Flow Forecasting, *FPRD*	Negative Increntals, *ADJINC*	Execution Time, hours
9.10	day	Bwam3	lag-att	1	daily pattern	uniform	14 days	7	3.63
9.12	day	Bwam3	lag-att	1	daily pattern	7 days	14 days	7	3.54
9.13	day	Bwam3	lag-att	1	daily pattern	1 day	14 days	7	3.52

Table 9.33 shows that mean shortages are significantly decreased for run-of-river rights with the utilization of the *ND* and *SHORT* parameters in Scenario 9.12. Shortages are decreased further for the run-of-river rights when the number of target setting days is reduced to 1 day in Scenario 9.13. Table 9.34 indicates that reservoir storage-frequency is decreased on average with the utilization of the *ND* and *SHORT* options. Decreases in reservoir storage are a result of increases in run-of-river water right reliability. The enhanced ability to capture stream flow by all run-of-river rights decreases the ability to refill reservoir storage. Table 9.34 shows the number of days with zero storage content expands with the utilization of *ND* and *SHORT*. Table 9.35 shows that routing adjustments increases with the utilization of *ND* and *SHORT*. As water rights place larger daily demands on stream flow, the potential for over-appropriation and routing mismatches increases. This results in increases in routing adjustments.

The utilization of *ND* and *SHORT* improves the reliability of all run-of-river water right groups shown in Table 9.33. Caution should be exercised, however, when applying the non-uniform target setting features. While shortening the length of time for a water right to divert its entire monthly target and allowing shortages to be recovered prior to the end of the month improves the simulated ability to meet the monthly target, this may result in an unrealistic water management scenario for many water rights. For example, municipal water rights are unlikely to have pump, treatment, or storage capacity or operational policies that justify significant modification of their daily target demands. Agricultural users may have pumping and storage capacity to capture their entire monthly demand within a shorter period of time. However, actual knowledge of the individual water right holder's infrastructure should be considered. Furthermore, many water rights may not be legally authorized to exceed a certain maximum daily or instantaneous pump rate. Knowledge of the individual water right authorizations should be considered prior to utilization of *ND* and *SHORT*. Simulation scenarios 9.12 and 9.13 are presented in this section only as a demonstration example of these options.

Table 9.33
Mean Shortage and Volume Reliability for Selected Water Rights

Selected Water Rights	Scenario Mean Shortage, ac-ft per year		
	9.10	9.12	9.13
Dec. 31, 1929 and Senior, all uses	8,339	3,090	2,933
Jan. 1, 1930 to Dec. 31, 1939, all uses	5,653	1,864	1,731
Jan. 1, 1940 to Dec. 31, 1949, all uses	32,481	17,461	16,948
Jan. 1, 1950 to Dec. 31, 1959, all uses	26,997	15,392	14,585
Jan. 1, 1960 to Dec. 31, 1969, all uses	34,079	20,315	18,675
Jan. 1, 1970 to Dec. 31, 1979, all uses	1,472	1,085	1,053
Jan. 1, 1980 and Junior, municipal use	19,445	10,752	9,356
Jan. 1, 1980 and Junior, non-municipal use	31,076	19,820	17,746
All Selected Water Rights	159,542	89,781	83,027

Selected Water Rights	Scenario Volume Reliability, %		
	9.10	9.12	9.13
Dec. 31, 1929 and Senior, all uses	93.1	97.4	97.6
Jan. 1, 1930 to Dec. 31, 1939, all uses	92.5	97.5	97.7
Jan. 1, 1940 to Dec. 31, 1949, all uses	83.1	90.9	91.2
Jan. 1, 1950 to Dec. 31, 1959, all uses	75.9	86.3	87.0
Jan. 1, 1960 to Dec. 31, 1969, all uses	72.9	83.8	85.2
Jan. 1, 1970 to Dec. 31, 1979, all uses	68.6	76.9	77.6
Jan. 1, 1980 and Junior, municipal use	74.1	85.7	87.5
Jan. 1, 1980 and Junior, non-municipal use	63.1	76.5	78.9
All Selected Water Rights	79.8	88.6	89.5

Table 9.34
End of Day Storage-Frequency for Scenarios 9.08, 9.18 and 9.19, ac-ft

End of Day Storage-Frequency, Scenario 9.10, Uniform Monthly Target Distribution

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM
			100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	
515531	619206.	100910.	200123.	271542.	332451.	432596.	479218.	562019.	620852.	650513.	673809.	702491.	715640.	724739.
515631	103554.	44363.	0.	0.	0.	0.	32962.	77423.	104218.	113059.	123986.	141574.	151517.	155000.
515731	598754.	45952.	411790.	429054.	457749.	488429.	532998.	587077.	604227.	613133.	622508.	632992.	636100.	636100.
515831	37426.	15471.	0.	0.	0.	0.	8460.	32474.	39772.	42399.	45025.	49514.	51764.	52400.
509431	154738.	56846.	480.	825.	4890.	15881.	60926.	135045.	163077.	173637.	185703.	199607.	204582.	206562.
516531	177710.	51852.	0.	11429.	27923.	59692.	101338.	158591.	181604.	193441.	204834.	218902.	224627.	225400.
515931	34862.	20436.	0.	0.	0.	0.	1390.	17123.	33827.	39813.	45616.	54356.	58273.	59400.
516031	347369.	127868.	0.	0.	0.	6671.	119593.	316555.	373235.	392282.	414139.	436433.	451008.	457600.
516131	178420.	71345.	0.	0.	0.	0.	26490.	161872.	196120.	207326.	217281.	229849.	235341.	235700.
516231	26436.	11665.	0.	0.	0.	0.	5018.	19528.	27828.	31369.	33919.	35649.	36976.	37100.
516331	52457.	17974.	0.	0.	0.	6971.	25753.	46339.	56050.	61047.	64214.	65478.	65500.	65500.
516431	128632.	37384.	0.	204.	23213.	52660.	67210.	111506.	133907.	141619.	149343.	159722.	160110.	160110.
Total	2459563.	521748.	829911.	906565.	1015273.	1265676.	1570247.	2235172.	2519890.	2622480.	2714290.	2862868.	2951975.	3015544.

End of Day Storage-Frequency, Scenario 9.12, 7-Day Target Distribution With Shortage Recovery

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM
			100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	
515531	617904.	106559.	192595.	272641.	332834.	414915.	450170.	562883.	625681.	653678.	676037.	704320.	717893.	724739.
515631	99693.	46157.	0.	0.	0.	0.	18594.	71020.	100148.	110413.	121957.	139992.	149104.	155000.
515731	593783.	53353.	371056.	384108.	421345.	462761.	521229.	580376.	601088.	610760.	620277.	632718.	636100.	636100.
515831	37349.	15680.	0.	0.	0.	0.	9272.	32041.	39677.	42438.	45045.	49647.	52252.	52400.
509431	154185.	56753.	450.	555.	5479.	15432.	60950.	134839.	161770.	173057.	184668.	198379.	204963.	206562.
516531	174092.	54919.	0.	0.	16172.	47343.	90763.	152517.	177956.	189730.	202365.	217790.	225352.	225400.
515931	31603.	21065.	0.	0.	0.	0.	0.	11267.	26174.	37369.	42564.	50796.	57055.	59400.
516031	332933.	134398.	0.	0.	0.	0.	78169.	292813.	356191.	381341.	400767.	433757.	451066.	457600.
516131	175269.	71089.	0.	0.	0.	0.	28223.	153928.	190779.	204273.	213666.	227017.	235614.	235700.
516231	26171.	12317.	0.	0.	0.	0.	2877.	18683.	28411.	31789.	33641.	36481.	37100.	37100.
516331	51234.	18483.	0.	0.	0.	6048.	22341.	44325.	54797.	59488.	62767.	65486.	65500.	65500.
516431	124906.	40316.	0.	0.	1742.	41308.	63882.	103972.	130351.	138900.	147139.	158336.	160110.	160110.
Total	2419122.	547513.	788400.	850700.	956007.	1166368.	1468578.	2179714.	2469832.	2584313.	2688663.	2836634.	2949852.	3014521.

End of Day Storage-Frequency, Scenario 9.13, 1-Day Target Distribution With Shortage Recovery

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM
			100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	
515531	610961.	111018.	193692.	259856.	321826.	396683.	436446.	553300.	617524.	645856.	670426.	700240.	719180.	724739.
515631	86985.	50191.	0.	0.	0.	0.	0.	45033.	82189.	97003.	111898.	127316.	149245.	155000.
515731	589718.	55618.	371968.	386422.	423848.	448330.	514234.	573651.	597672.	607690.	617042.	630840.	636088.	636100.
515831	36192.	15877.	0.	0.	0.	0.	6392.	30059.	38515.	41232.	43925.	48194.	51983.	52400.
509431	152995.	56716.	461.	562.	4418.	15454.	59961.	132897.	160346.	171865.	183069.	196586.	204918.	206562.
516531	168763.	59094.	0.	0.	0.	29430.	75042.	142381.	173994.	186161.	199374.	215553.	225363.	225400.
515931	29374.	21811.	0.	0.	0.	0.	0.	6227.	19087.	34874.	41157.	49948.	56711.	59400.
516031	320435.	138362.	0.	0.	0.	0.	72995.	263703.	334955.	366940.	393004.	433294.	451296.	457600.
516131	170443.	71201.	0.	0.	0.	0.	23368.	143674.	182288.	197684.	208310.	223078.	235457.	235700.
516231	25351.	12689.	0.	0.	0.	0.	240.	16678.	27460.	31120.	32972.	35825.	37084.	37100.
516331	50174.	18700.	0.	0.	0.	5300.	20605.	41443.	53354.	58275.	61958.	65038.	65500.	65500.
516431	122064.	42384.	0.	0.	0.	29577.	58243.	100469.	128137.	135950.	144339.	157084.	160110.	160110.
Total	2363453.	569980.	740443.	829019.	889094.	1068578.	1381918.	2077782.	2391071.	2535227.	2641686.	2809718.	2933416.	3011131.

Table 9.35
Routing Adjustments at Selected Control Points,
Scenario 9.10, Uniform Monthly Target Distribution

Bwam Control Point Identifier	Control Point Location Name	Routing Adjustments, All 59 Years		Routing Adjustments, Driest 29 Years	
		Average, ac-ft per year	% of Naturalized Flow	Average, ac-ft per year	% of Naturalized Flow
BRBR59	Bryan Gage	1,675.9	0.04	3,242.1	0.16
BRHE68	Hempstead Gage	1,557.4	0.03	2,618.6	0.09
BRRI70	Richmond Gage	1,364.6	0.02	2,353.5	0.08
LRCA58	Cameron Gage	178.3	0.01	112.0	0.02
BRGM73	Gulf Outlet	1,177.3	0.02	2,113.9	0.06
515531	Possum Kingdom Lake	66.6	0.01	111.5	0.03
515631	Granbury Lake	4,559.9	0.42	5,099.9	0.88
515731	Whitney Lake	1,993.1	0.15	2,886.2	0.38
515831	Aquilla Lake	0.0	0.00	0.0	0.00
509431	Waco Lake	0.2	0.00	0.4	0.00
516531	Limestone Lake	102.2	0.04	75.4	0.07
515931	Proctor Lake	1.7	0.00	2.5	0.00
516031	Belton Lake	48.1	0.01	73.2	0.04
516131	Stillhouse Lake	14.0	0.01	27.9	0.03
516231	Georgetown Lake	0.0	0.00	0.0	0.00
516331	Granger Lake	5.2	0.00	7.1	0.01
516431	Somerville Lake	8.5	0.00	9.7	0.01

Routing Adjustments at Selected Control Points, Scenario 9.12,
7-Day Target Distribution With Shortage Recovery

Bwam Control Point Identifier	Control Point Location Name	Routing Adjustments, All 59 Years		Routing Adjustments, Driest 29 Years	
		Average, ac-ft per year	% of Naturalized Flow	Average, ac-ft per year	% of Naturalized Flow
BRBR59	Bryan Gage	2,549.0	0.06	5,011.1	0.24
BRHE68	Hempstead Gage	2,182.2	0.04	3,998.9	0.14
BRRI70	Richmond Gage	1,867.3	0.03	3,468.8	0.11
LRCA58	Cameron Gage	161.9	0.01	225.0	0.04
BRGM73	Gulf Outlet	1,583.2	0.03	2,899.1	0.09
515531	Possum Kingdom Lake	67.9	0.01	107.5	0.03
515631	Granbury Lake	4,877.2	0.45	5,265.3	0.91
515731	Whitney Lake	2,297.9	0.17	2,954.2	0.39
515831	Aquilla Lake	0.0	0.00	0.0	0.00
509431	Waco Lake	0.4	0.00	0.5	0.00
516531	Limestone Lake	98.8	0.04	71.8	0.07
515931	Proctor Lake	1.1	0.00	1.2	0.00
516031	Belton Lake	59.4	0.01	97.4	0.05
516131	Stillhouse Lake	20.2	0.01	40.4	0.05
516231	Georgetown Lake	0.0	0.00	0.0	0.00
516331	Granger Lake	5.0	0.00	6.4	0.01
516431	Somerville Lake	5.5	0.00	5.7	0.01

Table 9.35 (continued)

Routing Adjustments at Selected Control Points, Scenario 9.13,
1-Day Target Distribution With Shortage Recovery

Bwam Control Point Identifier	Control Point Location Name	Routing Adjustments, All 59 Years		Routing Adjustments, Driest 29 Years	
		Average, ac-ft per year	% of Naturalized Flow	Average, ac-ft per year	% of Naturalized Flow
BRBR59	Bryan Gage	2,622.0	0.07	5,149.1	0.25
BRHE68	Hempstead Gage	2,162.4	0.04	4,051.8	0.14
BRRI70	Richmond Gage	1,786.6	0.03	3,406.1	0.11
LRCA58	Cameron Gage	272.3	0.02	483.3	0.09
BRGM73	Gulf Outlet	1,908.6	0.03	3,272.8	0.10
515531	Possum Kingdom Lake	66.2	0.01	102.7	0.03
515631	Granbury Lake	4,834.7	0.44	5,101.5	0.88
515731	Whitney Lake	2,272.9	0.17	2,790.1	0.37
515831	Aquilla Lake	0.0	0.00	0.0	0.00
509431	Waco Lake	0.6	0.00	0.6	0.00
516531	Limestone Lake	100.6	0.04	74.2	0.07
515931	Proctor Lake	1.0	0.00	1.1	0.00
516031	Belton Lake	77.5	0.02	119.3	0.06
516131	Stillhouse Lake	23.3	0.01	45.2	0.05
516231	Georgetown Lake	0.0	0.00	0.0	0.00
516331	Granger Lake	4.9	0.00	6.6	0.01
516431	Somerville Lake	5.4	0.00	5.9	0.01

Negative Incremental Flow Options

Chapter 7 of this report discusses the various negative incremental flow options in detail. *ADJINC* in *JD* record field 8 is a switch for selecting between options associated with the impacts of flows at downstream control points on the determination of the amount of stream flow available to each water right during each time step. *ADJINC* options 1, 2, 3, -3, 4, -4, and 5 are described in the *Reference* and *Users Manuals* from the perspective of a monthly *SIM* simulation. Though also applicable for a *SIM* monthly simulation, options 6, 7, and 8 were added during January-March 2011 in conjunction with development of *SIMD* daily capabilities and are described in the *Daily Manual*. These ten options represent alternative approaches for dealing with the effects of downstream senior rights and negative incremental flows in determining the amount of stream flow available to each water right. Options 2, 3, -3, 4, and -4 develop negative incremental flow adjustments, but the other options do not develop flow adjustments. The options also differ in the selection of downstream control points to include in the flow availability computations.

In this section, the effects of two *ADJINC* options are compared. Option 1 considers all downstream control points in selecting the minimum flow quantity from the CPFLOW array and applies no incremental flow adjustments. Option 1 constrains the amount of stream flow available to water rights more severely than the other seven options and thus represents the most conservative (most restricting) extreme. Option 7 is designed to be the standard *ADJINC* option to be adopted whenever routing and forecasting are employed. The downstream control points identified in the *SIMD* reverse routing are further constrained to only those control points at which relevant senior rights are located. Flows at downstream control points not affected by senior rights have no effect on water availability for the junior right. Therefore, negative incremental flows at a downstream control point affect the amount of flow available to a particular water right only if senior rights also reduce the flows at the downstream control point. Option 7 is similar to option 5 but does not include all features of option 5. Option 7 is the same as option 1 with the added limitation to consider only senior right control points.

Table 9.36
Parameters per Simulation Scenario Being Considered

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, *WRMETH*	Disaggregation Option, *DFMETHOD*	Target Distribution Option, *ND*	Flow Forecasting, *FPRD*	Negative Increntals, *ADJINC*	Execution Time, hours
9.10	day	Bwam3	lag-att	1	daily pattern	uniform	14 days	7	3.63
9.14	day	Bwam3	lag-att	1	daily pattern	uniform	14 days	1	5.19

With a monthly time step, by definition, negative incrementals do not exist in a naturalized flow dataset if flows in each time step always increase going downstream. However, a daily simulation is complicated by routing which extends the concept of negative incremental flows across multiple time steps. Routing and reverse routing determines the combinations of future days and control points to be included in the flow availability computations. By selecting only those downstream control points where a senior water right may possibly make stream flow depletions, the concept of negative incrementals in a daily simulation is limited only to consideration of future downstream flow conditions where senior rights may require upstream junior rights to pass inflows in the current day.

Consideration of all downstream control points, as is the case with *ADJINC* options 1 through 5, can unnecessarily constrain current day water availability for upstream rights. This is particularly relevant for refilling of reservoir storage. Reservoirs are typically located on upstream watersheds and tributaries. In the Brazos Basin, all major reservoirs are located on tributaries or on the main stem of the Brazos River above the Waco gage. Many of these reservoirs have relatively senior priorities dating into the 1960's or senior. By requiring the reservoirs to consider all downstream control points, including those with no water rights or junior priority water rights, the upstream senior reservoir refill rights are significantly impaired. Table 9.37 gives the daily storage-frequencies for the major reservoirs for Scenario 9.10 and 9.14. Scenario 9.14 results in overall reduced reservoir storage content.

Table 9.37
End of Day Storage-Frequency for Scenarios 9.10 and 9.14, ac-ft

End of Day Storage-Frequency, Scenario 9.10, *ADJINC* 7

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
			100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
515531	619206.	100910.	200123.	271542.	332451.	432596.	479218.	562019.	620852.	650513.	673809.	702491.	715640.	724739.
515631	103554.	44363.	0.	0.	0.	0.	32962.	77423.	104218.	113059.	123986.	141574.	151517.	155000.
515731	598754.	45952.	411790.	429054.	457749.	488429.	532998.	587077.	604227.	613133.	622508.	632992.	636100.	636100.
515831	37426.	15471.	0.	0.	0.	0.	8460.	32474.	39772.	42399.	45025.	49514.	51764.	52400.
509431	154738.	56846.	480.	825.	4890.	15881.	60926.	135045.	163077.	173637.	185703.	199607.	204582.	206562.
516531	177710.	51852.	0.	11429.	27923.	59692.	101338.	158591.	181604.	193441.	204834.	218902.	224627.	225400.
515931	34862.	20436.	0.	0.	0.	0.	1390.	17123.	33827.	39813.	45616.	54356.	58273.	59400.
516031	347369.	127868.	0.	0.	0.	6671.	119593.	316555.	373235.	392282.	414139.	436433.	451008.	457600.
516131	178420.	71345.	0.	0.	0.	0.	26490.	161872.	196120.	207326.	217281.	229849.	235341.	235700.
516231	26436.	11665.	0.	0.	0.	0.	5018.	19528.	27828.	31369.	33919.	35649.	36976.	37100.
516331	52457.	17974.	0.	0.	0.	6971.	25753.	46339.	56050.	61047.	64214.	65478.	65500.	65500.
516431	128632.	37384.	0.	204.	23213.	52660.	67210.	111506.	133907.	141619.	149343.	159722.	160110.	160110.
Total	2459563.	521748.	829911.	906565.	1015273.	1265676.	1570247.	2235172.	2519890.	2622480.	2714290.	2862868.	2951975.	3015544.

<u>Control Points</u>

515531	Possum Kingdom Reservoir	515931	Proctor Reservoir
515631	Granbury Reservoir	516031	Belton Reservoir
515731	Whitney Reservoir	516131	Stillhouse Hollow Res.
515831	Aquilla Reservoir	516231	Georgetown Reservoir
509431	Waco Reservoir	516331	Granger Reservoir
516531	Limestone Reservoir	516431	Somerville Reservoir

Table 9.37 (continued)

End of Day Storage-Frequency, Scenario 9.14, *ADJINC* 1

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
515531	232271.	226217.	0.	0.	0.	0.	0.	6927.	95603.	177490.	268136.	388556.	596918.	724739.
515631	113393.	38060.	0.	0.	0.	23909.	59513.	98894.	113404.	123085.	131535.	142450.	151988.	155000.
515731	608365.	36372.	460132.	472500.	493233.	529483.	555495.	596631.	614358.	622881.	629599.	635594.	636100.	636100.
515831	36341.	15217.	0.	0.	0.	0.	7268.	31043.	38130.	40919.	43827.	48114.	51092.	52400.
509431	156535.	52003.	5675.	12622.	17788.	34494.	67372.	137038.	162793.	172122.	184825.	197867.	203152.	206562.
516531	130378.	65173.	0.	0.	0.	0.	11088.	88802.	128902.	143624.	160879.	183319.	202962.	225400.
515931	32324.	21281.	0.	0.	0.	0.	0.	11718.	27554.	37137.	42877.	52624.	58030.	59400.
516031	326874.	124633.	0.	0.	0.	8302.	130989.	290184.	340159.	364365.	383396.	414417.	448610.	457600.
516131	159168.	68691.	0.	0.	0.	0.	15531.	127208.	168121.	183637.	195420.	210172.	225534.	235700.
516231	24794.	11802.	0.	0.	0.	0.	2820.	17051.	25974.	29770.	32443.	34209.	35806.	37100.
516331	50623.	17964.	0.	0.	0.	6863.	22475.	43912.	54136.	58920.	61410.	63515.	65279.	65500.
516431	119713.	44867.	0.	0.	0.	18013.	47407.	98803.	125139.	134441.	143457.	158158.	160110.	160110.
Total	1990780.	604784.	528344.	570934.	589108.	715361.	1051422.	1635453.	1930862.	2078595.	2226350.	2438240.	2712898.	3013849.

Reduced reservoir storage content adversely affects water right reliability for the rights located at these reservoirs. Reliability is reduced at all locations, and in particular for the water rights located on Possum Kingdom Lake. Possum Kingdom Lake is located the furthest upstream of those reservoirs listed in Table 9.38, and has one of the most senior refill priority dates. The priority for refilling to the top of conservation in Possum Kingdom is April 6, 1938. By limiting Possum Kingdom's water availability consideration to only those downstream control points where senior rights are located, the reservoir is able to refill on a consistent basis and provide reliable water supply for its respective withdrawal rights.

Water rights without reservoir storage are located throughout the basin. Run-of-river water rights located downstream of the reservoirs can benefit from the reduced refill ability. Table 9.39 shows general improvement in run-of-river water right reliabilties.

Table 9.38
Control Point Reliability Summaries for Scenarios 9.10 and 9.14

Control Point Reliability, Scenario 9.10, *ADJINC* 7

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	230750.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	3270.73	93.68	94.95	93.7	93.7	93.7	94.3	94.7	95.3	97.4	87.9	87.9	87.9	89.7	93.1	96.6	100.0
515731	18949.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	726.25	93.97	94.77	94.0	94.0	94.0	94.1	94.4	94.8	96.6	89.7	89.7	89.7	89.7	93.1	94.8	100.0
509431	80706.5	3666.69	87.79	95.46	87.8	87.8	87.8	89.1	96.8	98.7	99.9	84.5	84.5	84.5	86.2	91.4	98.3	100.0
516531	65074.0	203.10	99.43	99.69	99.4	99.4	99.4	99.4	99.7	99.7	99.9	96.6	96.6	98.3	98.3	100.0	100.0	100.0
515931	19658.0	1493.43	90.80	92.40	90.8	90.9	91.2	91.8	93.2	94.3	95.3	81.0	82.8	86.2	87.9	89.7	89.7	100.0
516031	112257.0	3859.70	94.68	96.56	94.7	95.0	95.4	95.7	96.3	96.7	97.7	89.7	89.7	89.7	91.4	94.8	96.6	100.0
516131	67768.0	4081.75	93.25	93.98	93.2	93.2	93.2	93.2	93.4	94.4	96.1	87.9	87.9	89.7	89.7	91.4	91.4	100.0
516231	13610.0	802.65	93.10	94.10	93.1	93.1	93.2	93.4	93.5	94.1	95.8	89.7	89.7	89.7	89.7	91.4	94.8	98.3
516331	19840.0	468.36	96.98	97.64	97.0	97.0	97.0	97.0	97.0	98.1	98.4	93.1	93.1	93.1	94.8	96.6	98.3	100.0
516431	48000.0	330.68	98.85	99.31	98.9	98.9	98.9	98.9	98.9	99.3	99.7	96.6	96.6	96.6	96.6	98.3	100.0	100.0
Total	755221.2	18903.35		97.50														

Table 9.38 (continued)

Control Point Reliability, Scenario 9.14, *ADJINC* 1

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	230750.0	43782.94	73.85	81.03	73.9	74.1	74.6	76.0	79.3	83.5	93.7	55.2	56.9	56.9	58.6	67.2	82.8	100.0
515631	64712.0	1450.14	96.98	97.76	97.0	97.0	97.0	97.4	97.7	98.3	98.3	93.1	94.8	94.8	94.8	98.3	98.3	100.0
515731	18993.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	752.60	93.97	94.58	94.0	94.0	94.0	94.0	94.3	94.5	96.3	89.7	89.7	89.7	89.7	94.8	94.8	100.0
509431	80708.5	2318.84	90.37	97.13	90.4	90.7	90.9	91.5	98.3	100.0	100.0	86.2	86.2	87.9	89.7	94.8	100.0	100.0
516531	65074.0	4344.13	91.38	93.32	91.4	91.5	91.5	91.8	93.0	94.3	96.4	84.5	84.5	86.2	87.9	91.4	93.1	100.0
515931	19658.0	2035.10	86.49	89.65	86.5	86.8	87.2	88.5	89.9	91.8	94.5	72.4	74.1	77.6	82.8	86.2	89.7	100.0
516031	112257.0	3651.10	95.40	96.75	95.4	95.5	95.7	95.7	96.8	97.3	98.1	91.4	91.4	93.1	93.1	94.8	96.6	100.0
516131	67768.0	4504.21	91.95	93.35	92.0	92.0	92.0	92.2	93.0	94.4	96.1	87.9	87.9	89.7	89.7	91.4	91.4	100.0
516231	13610.0	982.62	91.81	92.78	91.8	91.8	91.8	91.8	92.2	93.1	97.0	87.9	87.9	87.9	87.9	89.7	93.1	100.0
516331	19840.0	541.69	96.55	97.27	96.6	96.6	96.6	96.7	96.7	97.4	98.4	91.4	91.4	93.1	93.1	98.3	98.3	100.0
516431	48000.0	1128.81	97.13	97.65	97.1	97.1	97.4	97.6	97.6	98.0	98.4	94.8	94.8	94.8	94.8	96.6	96.6	100.0
Total	755266.4	65492.19		91.33														

Control Points

- 515531 Possum Kingdom Reservoir
- 515631 Granbury Reservoir
- 515731 Whitney Reservoir
- 515831 Aquilla Reservoir
- 509431 Waco Reservoir
- 516531 Limestone Reservoir
- 515931 Proctor Reservoir
- 516031 Belton Reservoir
- 516131 Stillhouse Hollow Res.
- 516231 Georgetown Reservoir
- 516331 Granger Reservoir
- 516431 Somerville Reservoir

Table 9.39
Mean Shortage and Volume Reliability for Selected Water Rights

Selected Water Rights	Mean Shortage, acre-feet per year, Scenario ID 9.10	Mean Shortage, acre-feet per year, Scenario ID 9.14	Volume Reliability, %, Scenario ID 9.10	Volume Reliability, %, Scenario ID 9.14
Dec. 31, 1929 and Senior, all uses	8,339	7,105	93.1	94.1
Jan. 1, 1930 to Dec. 31, 1939, all uses	5,653	4,384	92.5	94.2
Jan. 1, 1940 to Dec. 31, 1949, all uses	32,481	28,328	83.1	85.2
Jan. 1, 1950 to Dec. 31, 1959, all uses	26,997	24,182	75.9	78.5
Jan. 1, 1960 to Dec. 31, 1969, all uses	34,079	30,169	72.9	76.0
Jan. 1, 1970 to Dec. 31, 1979, all uses	1,472	1,352	68.6	71.2
Jan. 1, 1980 and Junior, municipal use	19,445	16,986	74.1	77.4
Jan. 1, 1980 and Junior, non-municipal use	31,076	29,165	63.1	65.4
All Selected Water Rights	159,542	141,671	79.8	82.1

Figures 9.21 and 9.22 present the daily storages at Possum Kingdom Lake and Belton Lake, respectively. For simulation 9.14, both reservoirs are full at the begging of the simulation and completely refill during the largest flood of record in 1957. By limiting the downstream control points in the water availability computation to only those where senior rights are located, Scenario 9.10 results in an appropriate and more realistic outcome of daily simulated reservoir storage contents.

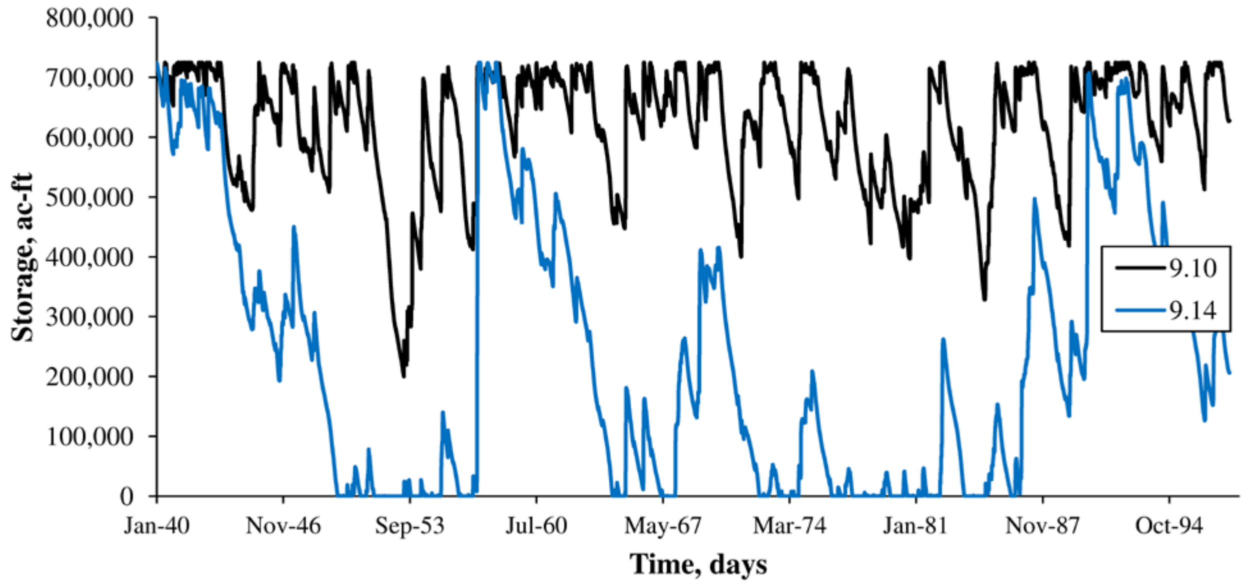

Figure 9.21 End of Day Storage at Possum Kingdom Lake

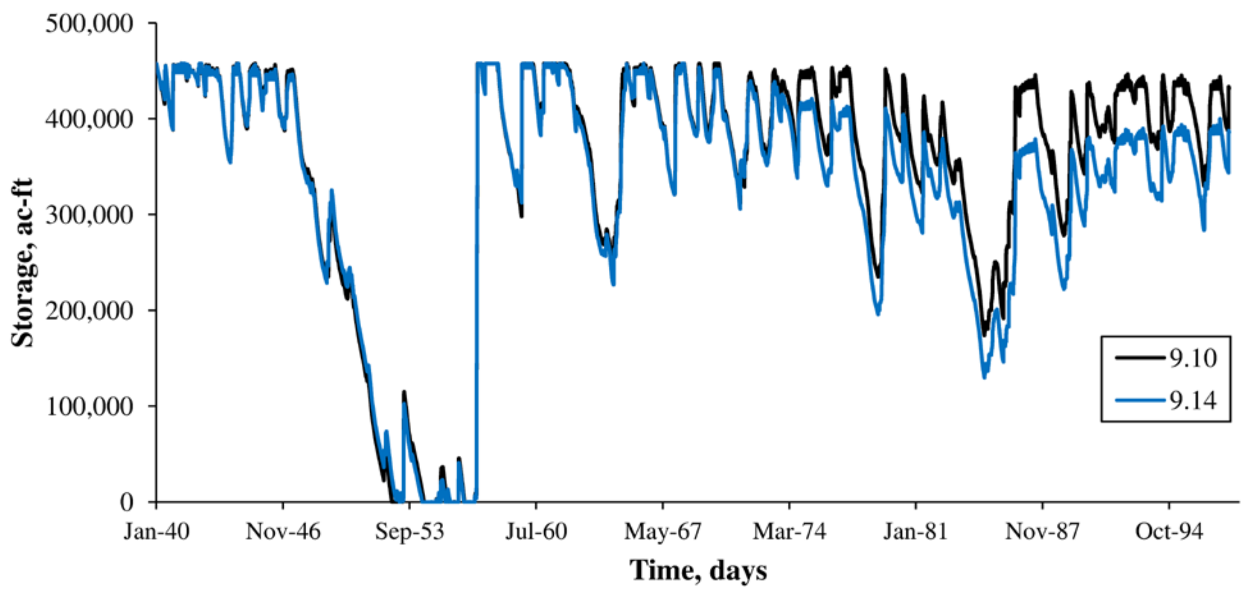

Figure 9.22 End of Day Storage at Belton Lake

Regulated flows generally increase under Scenario 9.14, as shown in Table 9.40, as upstream reservoirs are unable to refill storage contents and downstream run-of-river rights appropriate some of the flows instead. Unappropriated flows increase for the lower basin stream flow gages under Scenario 9.14, but tend to decrease at the locations of the major reservoirs, as shown in Table 9.41, due to an increased frequency of reservoir contents below full capacity and the requirement to consider all downstream control points. Routing adjustments are presented in Table 9.42. Reducing water availability for stream flow depletions reduces the occurrences of over appropriation and routing adjustments in Scenario 9.14.

Table 9.40

Daily Regulated Flow-Frequency for Scenarios 9.10 and 9.14, acre-feet per day

Daily Regulated Flow-Frequency, Scenario 9.10, *ADJINC* 7

CONTROL		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	2780.58	8501.2	0.00	0.00	1.11	19.98	39.67	129.44	298.8	479.8	783.1	1940.2	6555.1	286974.5
BRBR59	8267.18	21273.4	0.00	37.66	105.09	208.24	336.02	718.93	1263.3	1782.9	2711.4	6212.9	20386.6	710685.8
BRHE68	11461.02	24209.9	0.00	123.60	254.00	413.68	638.35	1281.57	2098.4	2987.2	4645.5	10758.0	30930.4	750744.3
BRRI70	12477.02	24859.5	8.56	141.85	271.62	474.86	751.96	1576.70	2247.4	3266.3	5397.2	12207.4	33474.1	636390.9
BRGM73	11544.95	25584.9	0.00	0.00	0.00	0.01	0.05	19.50	703.5	1760.0	4021.7	11193.8	32866.1	575634.4
515531	1158.58	5790.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	219.1	1762.9	152080.3
515631	1752.13	7156.4	0.00	0.00	0.00	0.00	0.00	8.41	70.4	140.7	261.6	696.0	2951.9	156542.1
515731	2262.65	8030.5	0.00	0.00	0.00	0.00	6.78	78.45	195.0	316.0	510.3	1161.3	4263.9	188705.4
515831	150.05	1037.9	0.00	0.00	0.00	0.96	0.99	0.99	1.0	1.0	1.0	7.6	103.9	37727.5
509431	698.89	3446.9	0.00	0.00	0.00	0.00	0.00	0.00	0.9	14.2	52.8	261.9	1331.2	219374.1
516531	376.41	2016.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	10.1	339.4	67260.5
515931	296.37	2134.2	0.00	0.00	0.00	0.00	0.00	0.00	0.6	5.1	15.4	66.5	448.7	195902.8
516031	952.11	3670.7	0.00	0.00	0.00	0.00	0.00	4.10	37.8	74.0	133.9	441.9	2156.3	164722.8
516131	419.22	2053.2	0.00	0.00	0.00	0.00	0.00	0.00	10.7	21.3	40.4	136.4	995.1	120481.6
516231	117.72	568.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	3.5	10.2	50.2	272.3	23854.5
516331	397.73	1534.0	0.00	0.00	0.00	0.00	0.00	1.38	16.9	39.4	77.3	258.0	893.8	57836.4
516431	436.51	2154.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	19.7	683.3	97721.6

Daily Regulated Flow-Frequency, Scenario 9.14, *ADJINC* 1

CONTROL		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
LRCA58	2801.15	8408.4	0.00	0.11	6.18	26.03	39.67	158.19	330.4	522.5	835.0	1979.9	6513.7	260179.7
BRBR59	8579.09	21226.1	0.19	105.31	156.47	261.08	406.39	824.22	1425.1	2017.5	3058.8	6845.8	20925.9	678992.1
BRHE68	11805.57	24097.7	4.91	246.60	328.72	499.13	767.38	1458.19	2350.8	3337.8	5160.2	11336.5	31449.3	722798.4
BRRI70	12811.69	24734.3	0.19	258.67	354.68	559.68	883.13	1748.52	2439.6	3649.0	5976.1	12908.0	33653.7	606808.9
BRGM73	11829.96	25494.4	0.00	0.00	0.00	0.01	0.07	79.09	873.0	2125.2	4564.8	11807.9	33276.3	549237.7
515531	1504.90	6370.8	0.00	0.00	0.00	0.00	0.00	0.00	0.1	91.0	235.5	658.3	2471.4	192226.9
515631	2076.03	7419.1	0.00	0.00	0.00	0.00	0.00	54.82	171.4	285.7	470.0	1064.8	3930.2	178744.4
515731	2571.90	8140.6	0.00	0.00	0.00	0.55	32.58	146.00	307.5	471.3	717.7	1531.9	5338.8	183890.6
515831	150.47	1031.2	0.00	0.00	0.00	0.96	0.99	0.99	1.0	1.0	1.0	9.1	101.7	37727.5
509431	696.08	3423.8	0.00	0.00	0.00	0.00	0.00	0.00	0.5	11.8	50.6	258.8	1323.2	219377.0
516531	407.53	2059.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	3.2	34.5	508.3	71896.3
515931	302.86	2150.0	0.00	0.00	0.00	0.00	0.00	0.00	1.0	5.3	16.4	73.2	465.3	194246.6
516031	960.64	3728.9	0.00	0.00	0.00	0.00	0.00	5.70	43.4	81.8	144.5	455.3	2221.8	164622.0
516131	425.30	2000.4	0.00	0.00	0.00	0.00	0.00	0.00	12.9	24.5	44.6	140.1	1034.6	104874.2
516231	118.54	550.6	0.00	0.00	0.00	0.00	0.00	0.00	1.7	5.0	11.6	52.8	279.6	23854.4
516331	399.47	1513.6	0.00	0.00	0.00	0.00	0.00	4.87	20.6	42.5	78.9	256.0	912.7	54722.9
516431	443.86	2077.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	2.6	14.0	83.0	736.1	97703.4

Table 9.41
Daily Unappropriated Flow-Frequency for Scenarios 9.10 and 9.14, acre-feet per day

Daily Unappropriated Flow-Frequency, Scenario 9.10, *ADJINC* 7

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	1737.80	5921.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	720.2	4591.7	176813.2
BRBR59	5024.92	14960.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	319.3	3048.9	13465.6	494506.1
BRHE68	7708.76	20022.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	848.9	5429.0	23645.5	485237.4
BRRI70	9391.59	23074.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	283.0	1925.1	7907.7	27841.5	585723.2
BRGM73	11544.95	25584.9	0.00	0.00	0.00	0.01	0.05	19.50	703.5	1760.0	4021.7	11193.8	32866.1	575634.4
515531	354.98	2704.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	72196.2
515631	728.82	4547.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	596.6	121642.2
515731	1212.00	5684.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	15.3	2127.1	131980.8
515831	52.26	394.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	23.6	14156.4
509431	362.99	1666.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	706.2	51368.3
516531	160.57	804.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	59.0	22194.9
515931	91.85	653.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	27384.2
516031	584.94	2385.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1377.1	70773.9
516131	272.80	1214.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	738.1	70069.6
516231	83.43	377.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	241.6	14969.7
516331	270.30	1088.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	55.2	716.3	38708.0
516431	398.63	1930.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	603.5	59205.5

Daily Unappropriated Flow-Frequency, Scenario 9.14, *ADJINC* 1

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	1769.94	5924.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	803.3	4724.9	169149.7
BRBR59	5308.04	15104.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	550.0	3589.3	14531.8	475228.1
BRHE68	7954.15	19947.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.8	1208.1	6093.3	23907.0	463475.6
BRRI70	9711.33	23092.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	589.7	2455.3	8651.9	28704.7	558593.8
BRGM73	11829.96	25494.4	0.00	0.00	0.00	0.01	0.07	79.09	873.0	2125.2	4564.8	11807.9	33276.3	549237.7
515531	241.06	2148.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	93605.7
515631	771.10	4226.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1108.4	118715.7
515731	1434.82	5701.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	313.3	3055.6	130085.0
515831	54.56	441.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	18.5	16922.7
509431	386.58	1782.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	746.5	52744.4
516531	123.51	633.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	88.6	12395.5
515931	93.31	691.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	27378.9
516031	594.94	2402.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1392.0	63156.0
516131	262.95	1174.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	693.5	56648.5
516231	84.80	410.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	234.7	14969.7
516331	282.95	1171.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	6.1	769.8	43911.1
516431	293.45	1443.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	380.0	53322.1

Control Points

515531	Possum Kingdom Reservoir	515931	Proctor Reservoir
515631	Granbury Reservoir	516031	Belton Reservoir
515731	Whitney Reservoir	516131	Stillhouse Hollow Res.
515831	Aquilla Reservoir	516231	Georgetown Reservoir
509431	Waco Reservoir	516331	Granger Reservoir
516531	Limestone Reservoir	516431	Somerville Reservoir

Table 9.42
Routing Adjustments at Selected Control Points,
Scenario 9.10, *ADJINC* 7

Bwam Control Point Identifier	Control Point Location Name	Routing Adjustments, All 59 Years: Average, ac-ft per year	Routing Adjustments, All 59 Years: % of Naturalized Flow	Routing Adjustments, Driest 29 Years: Average, ac-ft per year	Routing Adjustments, Driest 29 Years: % of Naturalized Flow
BRBR59	Bryan Gage	1,675.9	0.04	3,242.1	0.16
BRHE68	Hempstead Gage	1,557.4	0.03	2,618.6	0.09
BRRI70	Richmond Gage	1,364.6	0.02	2,353.5	0.08
LRCA58	Cameron Gage	178.3	0.01	112.0	0.02
BRGM73	Gulf Outlet	1,177.3	0.02	2,113.9	0.06
515531	Possum Kingdom Lake	66.6	0.01	111.5	0.03
515631	Granbury Lake	4,559.9	0.42	5,099.9	0.88
515731	Whitney Lake	1,993.1	0.15	2,886.2	0.38
515831	Aquilla Lake	0.0	0.00	0.0	0.00
509431	Waco Lake	0.2	0.00	0.4	0.00
516531	Limestone Lake	102.2	0.04	75.4	0.07
515931	Proctor Lake	1.7	0.00	2.5	0.00
516031	Belton Lake	48.1	0.01	73.2	0.04
516131	Stillhouse Lake	14.0	0.01	27.9	0.03
516231	Georgetown Lake	0.0	0.00	0.0	0.00
516331	Granger Lake	5.2	0.00	7.1	0.01
516431	Somerville Lake	8.5	0.00	9.7	0.01

Routing Adjustments at Selected Control Points,
Scenario 9.14, *ADJINC* 1

Bwam Control Point Identifier	Control Point Location Name	Routing Adjustments, All 59 Years: Average, ac-ft per year	Routing Adjustments, All 59 Years: % of Naturalized Flow	Routing Adjustments, Driest 29 Years: Average, ac-ft per year	Routing Adjustments, Driest 29 Years: % of Naturalized Flow
BRBR59	Bryan Gage	29.0	0.00	19.8	0.00
BRHE68	Hempstead Gage	1.7	0.00	3.3	0.00
BRRI70	Richmond Gage	3.6	0.00	7.3	0.00
LRCA58	Cameron Gage	124.9	0.01	70.9	0.01
BRGM73	Gulf Outlet	6.5	0.00	13.0	0.00
515531	Possum Kingdom Lake	0.0	0.00	0.0	0.00
515631	Granbury Lake	225.2	0.02	233.5	0.04
515731	Whitney Lake	158.0	0.01	149.8	0.02
515831	Aquilla Lake	0.0	0.00	0.0	0.00
509431	Waco Lake	0.0	0.00	0.0	0.00
516531	Limestone Lake	0.0	0.00	0.0	0.00
515931	Proctor Lake	0.0	0.00	0.0	0.00
516031	Belton Lake	23.1	0.00	37.7	0.02
516131	Stillhouse Lake	0.0	0.00	0.0	0.00
516231	Georgetown Lake	0.0	0.00	0.0	0.00
516331	Granger Lake	0.5	0.00	0.9	0.00
516431	Somerville Lake	0.0	0.00	0.0	0.00

Summary, Conclusions, and Guidance for Simulating Water Availability with *SIMD*

A array of optional methods, data, and parameters may be used in a daily *SIMD* simulation. The optional input information can be categorized as either hydrologic or water management. Daily hydrologic inputs include routing parameters, disaggregation methods, and daily flow pattern data. Water management inputs are more numerous, but include flow forecasting and water right target building and monthly distributions. A complete listing and description of *SIMD* inputs can be found in the *Daily Manual*.

The objective of Chapter 9 is to provide simulation results and to make comparisons for various *SIMD* parameterizations. Water right reliability, reservoir storage, regulated and unappropriated flow at the major reservoirs and selected stream gages are provided as a basis for comparison. Development of *SIMD* input data to convert the Brazos WAM dataset from a monthly to daily time step is described in Chapter 8. The focus of the simulation studies reported in Chapter 9 is the full authorization scenario Bwam3.

Simulation results in Chapter 9 are organized to facilitate a comparative investigation of the following aspects of a daily simulation.

- Monthly versus daily simulation time step size
- Methods for disaggregating naturalized flow from monthly to daily values
- Placement of routed changes to flow in the priority sequence
- Usage of flow forecasting for water availability
- Daily water right target distribution
- Negative incremental options

The daily simulations in Chapter 9 do not consider flood control operations. Flood control reservoir operations are addressed in Chapter 10 with the incorporation of flood control operations of the nine major reservoirs in the Brazos River Basin with flood control storage pools. Adding flood control operations to the Bwam dataset affects regulated flows, stream flow availability, reservoir storage, and the other simulation result variables.

Monthly Versus Daily Simulation Time Step Size

The conventional monthly *SIM* simulation was compared with a daily time step simulation in *SIMD* without routing, with uniformly disaggregated monthly to daily naturalized flows, uniformly distributed monthly targets, and no lag/attenuation routing and forecasting. Time step size was the only difference between the two simulations. The objective is to isolate the effects of a daily versus monthly computational time step alone, without the within variations normally activated in a daily simulation. The monthly Bwam simulation covers 696 monthly time steps or 21,185 daily time steps for the 1940-1997 period-of-analysis.

With no within-month variations in naturalized flows and diversion targets and no routing, nearly identical results were obtained for the monthly and daily simulations with respect to reservoir storage, water right reliability, and regulated and unappropriated flows. Slight differences in Bwam3 results between *SIM* and *SIMD* are attributable to the computation of reservoir surface area with a single monthly time step or between 28 and 31 daily time steps.

Total monthly net evaporation-precipitation in *SIMD* is dependent on daily computations of reservoir surface area based on daily average storage volume. Because reservoir surface area is a non-linear function of storage volume, a single monthly time step value of monthly average surface area will differ from the monthly average surface area computed from the daily time steps in the month. Differences in net evaporation-precipitation result in different reservoir draw-downs and stream flow depletions for refilling. Additional differences in with the current conditions scenario Bwam8 dataset are attributable to return flow discharge timing. Return flows in *SIM* are placed in the stream at the beginning of the priority sequence in the next month. Return flows in *SIMD* are returned at the beginning of the priority sequence in the next day.

Methods for Disaggregating Naturalized Flow

Three methods of disaggregating the Bwam monthly naturalized flows to daily naturalized flows are examined in this chapter. The uniform method of disaggregation divides the total monthly naturalized flow by the number of days in the month. The linear interpolation method uses the variation in month to month total naturalized flow to develop an interpolation spline. Monthly flows are divided into daily flows based on the area occupied under the spline. Daily unregulated flow time series at 34 locations at and below the dam site of Possum Kingdom Lake were used as patterns to distribute monthly Bwam naturalized flow. The unregulated flow time series are inputs to the SUPER flood control model of the U.S. Army Corps of Engineers Fort Worth District. The SUPER unregulated flow data are considered to be good approximations of daily naturalized flows.

The greatest difference in *SIMD* simulation output for the various parameterizations examined in this chapter occurs when the daily SUPER flow patterns are used to disaggregate the Bwam monthly naturalized flow. As compared to the uniform or linear interpolation methods of disaggregation, the daily flow pattern method contains significant intra-month stream flow variability. The high degree of intra-month variability reduces the ability of water rights to meet their entire monthly target demands. Increased water right shortages place a greater demand on stored water backup.

Figure 9.23 shows a hypothetical stream flow time series and water right target demand. Stream flows are shown for uniformly disaggregated monthly flow volumes and for daily flow pattern disaggregation. Both stream flow time series have equal monthly total volumes. The water right target is met in all days shown with the uniformly disaggregated flows except in March when stream flow availability is nearly zero. Conversely, the stream flow variability created by the daily flow pattern disaggregation results in frequent shortages in meeting the water right target. If the water right cannot forgo constant daily diversions and recover shortages during periods of greater stream flow, the water right will experience greater shortages with the daily flow pattern method of disaggregation.

Hydrology in the monthly *SIM* model is equivalent to the uniform method of disaggregation in *SIMD*. Monthly mean hydrology versus a daily naturalized flow pattern creates the greatest difference between simulating water availability with a monthly versus daily time step.

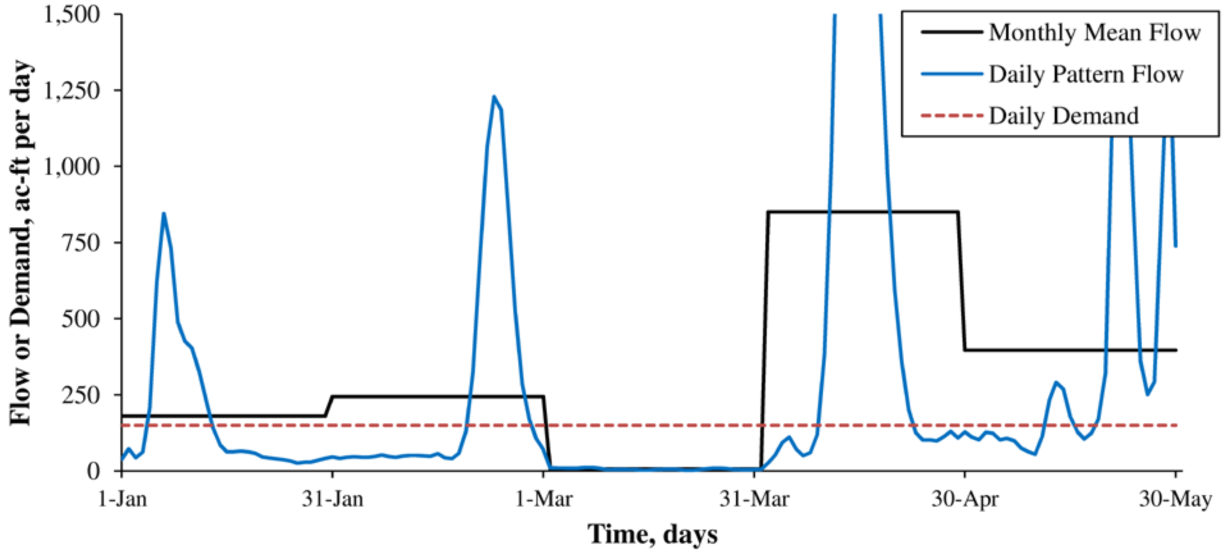

Figure 9.23 Monthly Mean Flow versus Daily Flow

Placement of Routed Changes to Flow

If routing is used in *SIMD*, stream flow depletions and return flows from previous days can be routed downstream each day until they reach the outlet using two alternative methods. Past changes to flow can be routed before the priority sequence. This method allows past junior depletions or returns to directly affect the water availability of all water rights. This method is also the more realistic of the two routing methods. Flow forecasting can reduce the impact on water availability from depletions made by upstream juniors. Alternatively, the changes to flow can be routed within the priority sequence at the priority of the water right which made the depletion or return. This method protects senior water rights from being directly impacted by the changes to flow of junior rights. However, because water availability to senior rights is not reflective of previous junior changes to flow, senior rights may deplete flows which were appropriated by juniors in previous days. The application of flow forecasting is essential if this method of routing is chosen to reduce the occurrence of over appropriation. Over appropriation can lead to artificially elevated water right reliability.

Flow Forecasting for Water Availability

Flow forecasting in *SIMD* is defined as considering stream flow availability over a future forecast period when determining water availability from the stream flow array at downstream control points. The default setting in *SIMD* is no forecasting. Without forecasting, *SIMD* considers only the current time period in determining water availability. With forecasting, future days are considered in the examination of available flows at downstream control points. Forecasting is relevant only if routing is adopted.

Reverse routing is incorporated in the forecasting procedure to account for the lag and attenuation effects of the routing of stream flow changes associated with water rights. Likewise, a reverse accounting for channel losses is incorporated in the forecasting procedure. The assessment of water availability in each future day of the forecast simulation is based upon the proportion of the stream flow depletion or return flow associated with a water right in the current day that travels to downstream control points in the current and future days. In this manner, flow forecasting addresses the complexities of the time lag introduced by routing and apparent current day negative incremental flows that are actually the result of the propagation of flow events though the stream network.

Flow forecasting is useful for the protection of senior water rights from the effects of upstream junior rights. It also serves to protect the water balance from inaccuracies in routing change to flow. Flow forecasting in *SIMD* is a complex algorithm but may be applied with minimal user input on the *JU* record. The simulation forecast period in all simulations in Chapter 9 was set equal to the maximum routing period. In the Bwam dataset, this maximum routing period is equal to 14 days of travel time from Limestone Lake to the basin outlet. Chapter 10 will examine the extension of the simulation forecast period to address water availability computations within the forecast simulation.

Daily Water Right Target Distribution

SIMD offers the option to set the number of days, *ND*, in which the target demand can be met. If *ND* is greater than zero, the monthly target demand will be distributed in the first *ND* days of the month. After the first *ND* days of the month, any shortage in meeting the target demand in the preceding days can be reapplied to the daily target building process if the *SHORT* parameter option is activated. Use of *ND* and *SHORT* enables a water right to attempt to meet the month's target demand sooner in the month or later in the month if water availability conditions improve.

Mean shortages are decreased with the utilization of the *ND* and *SHORT* parameters relative to a simulation scenario with uniform monthly target distribution and no shortage recovery. The use of *ND* and *SHORT* can increase water right reliability. However, judgment must be applied in selecting appropriate values of *ND*. Simulating water rights with a small value of *ND* could unrealistically represent their real-world pumping rates or could violate daily pump rate limitations in their water right permits.

Comparison of SIM and SIMD Output

A monthly *SIM* simulation and a daily *SIMD* simulation of the Bwam3 dataset are presented below. The *SIMD* simulation compared against the *SIM* simulation does not necessarily represent an optimal or recommended set of parameterizations for daily simulation. Rather, Scenario 9.10 represents an application of the default parameter settings on a large number of water rights in the Bwam dataset to protect senior water rights, to reduce occurrences of over appropriation and to represent realistic water uses and interactions of water rights at a daily time step. Alternative parameterizations for individual water rights may be appropriate. The *SIM* simulation presented is the official TCEQ simulation of the Bwam3 dataset which uses *ADJINC* option 5.

Table 9.43
Parameters per Simulation Scenario Being Considered

Scenario ID	Time Step	WAM Dataset	Routing Parameters	Routing Option, *WRMETH*	Disaggregation Option, *DFMETHOD*	Target Distribution Option, *ND*	Flow Forecasting, *FPRD*	Negative Increntals, *ADJINC*	Execution Time, hours
9.10	day	Bwam3	lag-att	1	daily pattern	uniform	14 days	7	3.63
9.15	month	Bwam3	*na*	*na*	*na*	*na*	*na*	5	0.01

Table 9.44
End of Month Storage-Frequency for Monthly vs. Daily Simulations, ac-ft

End of Month Storage-Frequency, Scenario 9.15, Monthly Bwam3 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
515531	668617.	75339.	269772.	341224.	471791.	525815.	570176.	637163.	679689.	697336.	713063.	724739.	724739.	724739.
515631	137376.	24940.	47383.	57132.	63444.	81949.	98357.	128033.	142679.	149634.	155000.	155000.	155000.	155000.
515731	608956.	36458.	449106.	465293.	506114.	526278.	555337.	597118.	615750.	624059.	630630.	635634.	636100.	636100.
515831	44477.	9747.	2101.	8567.	14295.	21449.	33209.	40306.	45084.	47181.	49751.	52400.	52400.	52400.
509431	180057.	32127.	63222.	74164.	86449.	109305.	132180.	166318.	182612.	191606.	200287.	205667.	206030.	206561.
516531	185777.	47944.	15880.	26577.	41128.	73743.	118487.	170405.	189288.	201282.	211861.	225400.	225400.	225400.
515931	47414.	13462.	1801.	8426.	9950.	18675.	27773.	41235.	46457.	51342.	55737.	59400.	59400.	59400.
516031	385149.	99289.	20722.	42474.	64956.	142858.	242322.	364109.	401778.	420980.	439201.	457600.	457600.	457600.
516131	192477.	63266.	0.	0.	7435.	24385.	76472.	180125.	209744.	220573.	228310.	235700.	235700.	235700.
516231	29662.	9696.	0.	0.	120.	7351.	15725.	25103.	31326.	33783.	36079.	37100.	37100.	37100.
516331	55876.	14494.	0.	3034.	9892.	23175.	35190.	51230.	58931.	63273.	65500.	65500.	65500.	65500.
516431	131299.	35645.	0.	10194.	32424.	58124.	75571.	115392.	136254.	144425.	151718.	160110.	160110.	160110.
Total	2667136.	383599.	1253721.	1369648.	1478254.	1791907.	2178923.	2546215.	2710611.	2789685.	2856940.	2954315.	3010398.	3015598.

End of Month Storage-Frequency, Scenario 9.10, Daily Bwam3 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
515531	618322.	99583.	207078.	280267.	348626.	434361.	479314.	562859.	621889.	649835.	673930.	702784.	711093.	720603.
515631	103221.	43921.	0.	0.	0.	0.	33646.	77310.	104217.	112968.	123452.	140992.	150103.	152710.
515731	598800.	45706.	417467.	433409.	459170.	489848.	533591.	587080.	604292.	612973.	621694.	633032.	636056.	636100.
515831	37419.	15412.	0.	0.	0.	0.	9100.	32718.	39706.	42575.	44984.	49545.	51601.	52398.
509431	154541.	56465.	480.	831.	5420.	17346.	62159.	136205.	163453.	173113.	185601.	199614.	202793.	206453.
516531	177750.	51767.	0.	13368.	29135.	61573.	101193.	158803.	181439.	193952.	205200.	219003.	224584.	225400.
515931	34743.	20270.	0.	0.	0.	0.	1525.	17247.	34105.	39783.	45656.	54185.	57935.	59385.
516031	346658.	127190.	0.	0.	0.	7166.	127311.	316261.	374559.	391841.	414493.	433898.	448448.	457514.
516131	178217.	71015.	0.	0.	0.	0.	27747.	162826.	195616.	207859.	216764.	229213.	233754.	235700.
516231	26381.	11571.	0.	0.	0.	0.	5037.	19655.	27947.	31408.	33986.	35404.	36651.	37067.
516331	52429.	17837.	0.	0.	0.	7016.	25951.	46667.	56066.	61108.	64053.	65078.	65475.	65500.
516431	128771.	37372.	0.	3475.	24201.	52438.	68103.	112112.	133846.	141785.	149446.	159917.	160104.	160110.
Total	2457251.	517720.	845117.	911065.	1019383.	1272462.	1594519.	2231065.	2521487.	2622284.	2713391.	2858384.	2944930.	2990679.

Table 9.45
Monthly Regulated Flow-Frequency for Monthly vs. Daily Simulations, ac-ft per month

Monthly Regulated Flow-Frequency, Scenario 9.15, Monthly Bwam3 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	83222.6	157642.	0.0	85.5	579.4	1190.1	1260.8	5832.4	12459.	18935.	31839.	87682.	235472.	1399450.
BRBR59	255898.9	437377.	284.6	3277.2	5624.7	9756.4	14565.8	30415.2	54931.	81562.	128823.	285077.	657526.	4218716.
BRHE68	352903.5	533894.	1918.9	10965.7	13208.9	20946.0	27212.3	53875.8	85854.	130756.	197793.	442980.	959130.	5078586.
BRRI70	383619.9	561958.	306.6	13296.9	17713.9	27683.5	35325.9	61420.5	94907.	147048.	233486.	471835.	1043070.	5484132.
BRGM73	351148.7	581813.	0.0	0.0	0.1	0.3	1.8	8911.5	47700.	105094.	188987.	455947.	1049731.	5540599.
515531	32066.1	111095.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	10995.	80923.	1594131.
515631	49696.1	150740.	0.0	0.0	0.0	0.0	0.0	2.7	1545.	3926.	7462.	28664.	138320.	2445680.
515731	75957.0	179497.	0.0	0.0	0.0	230.2	1539.4	4921.4	9478.	13700.	24254.	67088.	213801.	2720642.
515831	4409.5	10945.	27.8	27.8	27.8	29.8	29.8	30.8	31.	31.	31.	2347.	15453.	100103.
509431	20682.8	50679.	0.0	0.0	0.0	0.0	0.0	0.0	0.	43.	702.	14967.	68488.	529194.
516531	11352.1	27354.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	4420.	45229.	215300.
515931	8519.9	26634.	0.0	0.0	0.0	0.0	0.0	3.2	60.	267.	831.	3356.	21873.	316032.
516031	28048.2	68102.	0.0	0.0	0.0	0.0	463.0	1997.5	2672.	3186.	4002.	16874.	80844.	547284.
516131	12315.9	31856.	0.0	0.0	0.0	0.0	0.0	0.0	0.	145.	989.	7661.	39269.	302801.
516231	3513.6	7909.	0.0	0.0	0.0	0.0	0.0	0.0	0.	149.	464.	2707.	12223.	73211.
516331	11945.8	23657.	0.0	0.0	0.0	0.0	0.0	0.0	623.	1670.	3882.	12324.	38739.	208215.
516431	13218.3	30277.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7106.	52326.	247494.

Monthly Regulated Flow-Frequency, Scenario 9.10, Daily Bwam3 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	84636.0	153587.	0.0	217.6	692.4	1578.7	3062.4	8152.1	15306.	24794.	38426.	89493.	227056.	1398469.
BRBR59	251638.1	417861.	284.9	4792.5	6589.2	10392.8	16084.2	33215.6	58307.	91394.	141846.	281705.	643367.	3766154.
BRHE68	348853.1	512092.	1550.8	9723.3	12668.6	20348.7	30060.1	57195.3	95779.	147692.	205345.	428610.	947358.	4195046.
BRRI70	379777.6	537531.	270.6	13571.8	18725.0	25315.3	34796.8	60441.8	108489.	157319.	233701.	481461.	1034954.	4386256.
BRGM73	351408.3	555867.	0.0	37.8	159.2	752.0	2872.0	20481.1	64008.	119762.	195800.	460399.	1021962.	4402082.
515531	35265.1	108539.	0.0	0.0	0.0	0.0	0.0	507.1	1927.	3853.	6620.	20285.	84725.	1540116.
515631	53331.9	144482.	0.0	74.6	137.8	387.7	1317.8	3536.7	6576.	10473.	17064.	38920.	129990.	2305569.
515731	68871.1	162951.	17.8	230.3	536.6	1613.1	3199.0	7274.6	12752.	19177.	26846.	54369.	165576.	2489619.
515831	4567.0	10389.	0.0	0.0	0.0	29.8	29.8	41.7	236.	528.	1059.	3492.	15069.	100109.
509431	21273.1	48391.	0.0	0.0	4.7	36.5	198.1	1013.8	2384.	3837.	6337.	15225.	64272.	528943.
516531	11457.3	26358.	0.0	0.0	0.0	0.0	0.0	23.1	133.	353.	1184.	6588.	44913.	214840.
515931	9021.0	25460.	0.0	0.0	0.0	0.3	44.3	290.6	688.	1195.	2062.	5549.	21787.	306851.
516031	28980.6	65606.	0.0	0.0	0.0	0.0	459.2	2045.8	3694.	5181.	7861.	21340.	79337.	538587.
516131	12760.4	30004.	0.0	35.6	68.4	167.1	291.8	607.5	1185.	1908.	2994.	9140.	36876.	274336.
516231	3583.2	7792.	0.0	0.0	0.0	0.0	8.4	83.5	225.	397.	687.	2517.	12215.	72205.
516331	12106.2	23282.	0.0	1.2	3.4	57.7	183.0	618.4	1404.	2293.	4025.	12046.	39014.	201942.
516431	13286.6	30091.	0.0	0.0	0.0	0.0	0.0	0.0	75.	284.	779.	8673.	52958.	246883.

Control Points

LRCA58	Cameron Gage on Little River
BRBR59	Bryan Gage on Brazos River
BRHE68	Hempstead Gage on Brazos
BRRI70	Richmond Gage on Brazos River
BRGM73	Brazos Outlet at Gulf of Mexico
515531	Possum Kingdom Reservoir
515631	Granbury Reservoir
515731	Whitney Reservoir
515831	Aquilla Reservoir
509431	Waco Reservoir
516531	Limestone Reservoir
515931	Proctor Reservoir
516031	Belton Reservoir
516131	Stillhouse Hollow Res.
516231	Georgetown Reservoir
516331	Granger Reservoir
516431	Somerville Reservoir

Table 9.46
Monthly Unappropriated Flow-Frequency for Monthly vs. Daily Simulations, ac-ft per month

Monthly Unappropriated Flow-Frequency, Scenario 9.15, Monthly Bwam3 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	67357.8	152306.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	6311.	66984.	206394.	1392119.
BRBR59	190025.2	415254.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2108.	39310.	207191.	563642.	4160918.
BRHE68	230926.3	479813.	0.0	0.0	0.0	0.0	0.0	0.0	0.	8889.	52317.	261908.	763380.	4805662.
BRRI70	289833.8	527416.	0.0	0.0	0.0	0.0	0.0	0.0	7861.	51158.	124470.	374445.	914166.	5155698.
BRGM73	351148.7	581813.	0.0	0.0	0.1	0.3	1.8	8911.5	47700.	105094.	188987.	455947.	1049731.	5540599.
515531	25246.4	99198.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	66200.	1594131.
515631	42585.1	143395.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	16449.	127295.	2445680.
515731	59383.8	175318.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	32446.	172844.	2720642.
515831	4041.2	10931.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	365.	15014.	100072.
509431	19822.4	50854.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	12128.	68464.	529194.
516531	10627.3	26851.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	10.	42099.	215300.
515931	6555.9	25518.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	12824.	274816.
516031	24633.8	67887.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	5052.	77271.	546730.
516131	11525.5	31703.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1932.	39269.	302801.
516231	3227.3	7880.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1695.	12124.	73211.
516331	10866.0	23876.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	11443.	37936.	208215.
516431	12831.8	30215.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	6203.	52326.	247494.

Monthly Unappropriated Flow-Frequency, Scenario 9.10, Daily Bwam3 Simulation

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LRCA58	52895.5	119186.	0.0	0.0	0.0	0.0	0.0	0.0	532.	3219.	9158.	48320.	170181.	1293583.
BRBR59	152949.7	313160.	0.0	0.0	0.0	0.0	0.0	367.6	7518.	22878.	50912.	163905.	459645.	2975692.
BRHE68	234641.1	423754.	0.0	0.0	0.0	0.0	0.0	1381.5	17526.	42128.	86567.	296583.	723441.	3499006.
BRRI70	285863.3	488510.	0.0	0.0	0.0	0.0	0.0	4758.0	37522.	76102.	135762.	377428.	860515.	3979913.
BRGM73	351408.3	555867.	0.0	37.8	159.2	752.0	2872.0	20481.1	64008.	119762.	195800.	460399.	1021962.	4402082.
515531	10805.0	61343.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	2.	13737.	1203475.
515631	22184.0	103414.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	410.	43335.	1917364.
515731	36891.2	128856.	0.0	0.0	0.0	0.0	0.0	0.0	3.	97.	900.	12641.	98280.	2138528.
515831	1590.8	5133.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	1.	23.	4513.	41726.
509431	11048.7	31571.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	2.	286.	36004.	247219.
516531	4887.4	12816.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	181.	16846.	75891.
515931	2795.9	11800.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	2.	3951.	122529.
516031	17804.4	50318.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	8.	2038.	60174.	456030.
516131	8303.5	24044.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	303.	26746.	249958.
516231	2539.6	6409.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	836.	9269.	60746.
516331	8227.4	18576.	0.0	0.0	0.0	0.0	0.0	0.0	0.	3.	118.	7290.	27085.	167794.
516431	12133.7	28177.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7004.	48551.	246883.

Control Points

LRCA58	Cameron Gage on Little River
BRBR59	Bryan Gage on Brazos River
BRHE68	Hempstead Gage on Brazos
BRRI70	Richmond Gage on Brazos River
BRGM73	Brazos Outlet at Gulf of Mexico
515531	Possum Kingdom Reservoir
515631	Granbury Reservoir
515731	Whitney Reservoir
515831	Aquilla Reservoir
509431	Waco Reservoir
516531	Limestone Reservoir
515931	Proctor Reservoir
516031	Belton Reservoir
516131	Stillhouse Hollow Res.
516231	Georgetown Reservoir
516331	Granger Reservoir
516431	Somerville Reservoir

Table 9.47
Reliability Summaries for Monthly vs. Daily Simulations

Control Point Reliability, Scenario 9.15, Monthly Bwam3 Simulation

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	230750.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515731	18945.6	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
509431	80401.2	303.65	98.56	99.62	98.6	98.6	98.6	98.6	100.0	100.0	100.0	96.6	96.6	96.6	98.3	100.0	100.0	100.0
516531	65074.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515931	19658.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516031	112257.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
516131	67768.0	367.19	98.85	99.46	98.9	99.0	99.0	99.3	99.4	99.6	99.6	94.8	94.8	96.6	96.6	100.0	100.0	100.0
516231	13610.0	229.43	98.13	98.31	98.1	98.1	98.1	98.1	98.3	98.4	98.6	93.1	94.8	94.8	94.8	98.3	98.3	100.0
516331	19840.0	53.35	99.57	99.73	99.6	99.6	99.6	99.6	99.6	99.7	99.9	96.6	96.6	98.3	98.3	100.0	100.0	100.0
516431	48000.0	189.42	99.14	99.61	99.1	99.1	99.1	99.1	99.3	99.4	99.6	96.6	96.6	96.6	98.3	100.0	100.0	100.0
Total	754911.8	1143.04		99.85														

Control Point Reliability, Scenario 9.10, Daily Bwam3 Simulation

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515531	230750.0	0.01	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	3270.73	93.68	94.95	93.7	93.7	93.7	94.3	94.7	95.3	97.4	87.9	87.9	87.9	89.7	93.1	96.6	100.0
515731	18949.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	726.25	93.97	94.77	94.0	94.0	94.0	94.1	94.4	94.8	96.6	89.7	89.7	89.7	89.7	93.1	94.8	100.0
509431	80706.5	3666.69	87.79	95.46	87.8	87.8	87.8	89.1	96.8	98.7	99.9	84.5	84.5	84.5	86.2	91.4	98.3	100.0
516531	65074.0	203.10	99.43	99.69	99.4	99.4	99.4	99.4	99.7	99.7	99.9	96.6	96.6	98.3	98.3	100.0	100.0	100.0
515931	19658.0	1493.43	90.80	92.40	90.8	90.9	91.2	91.8	93.2	94.3	95.3	81.0	82.8	86.2	87.9	89.7	89.7	100.0
516031	112257.0	3859.70	94.68	96.56	94.7	95.0	95.4	95.7	96.3	96.7	97.7	89.7	89.7	89.7	91.4	94.8	96.6	100.0
516131	67768.0	4081.75	93.25	93.98	93.2	93.2	93.2	93.2	93.4	94.4	96.1	87.9	87.9	89.7	89.7	91.4	91.4	100.0
516231	13610.0	802.65	93.10	94.10	93.1	93.1	93.2	93.4	93.5	94.1	95.8	89.7	89.7	89.7	89.7	91.4	94.8	98.3
516331	19840.0	468.36	96.98	97.64	97.0	97.0	97.0	97.0	97.0	98.1	98.4	93.1	93.1	93.1	94.8	96.6	98.3	100.0
516431	48000.0	330.68	98.85	99.31	98.9	98.9	98.9	98.9	98.9	99.3	99.7	96.6	96.6	96.6	96.6	98.3	100.0	100.0
Total	755221.2	18903.35		97.50														

Control Points

515531	Possum Kingdom Reservoir	515931	Proctor Reservoir
515631	Granbury Reservoir	516031	Belton Reservoir
515731	Whitney Reservoir	516131	Stillhouse Hollow Res.
515831	Aquilla Reservoir	516231	Georgetown Reservoir
509431	Waco Reservoir	516331	Granger Reservoir
516531	Limestone Reservoir	516431	Somerville Reservoir

Table 9.48
Mean Shortage and Volume Reliability for Selected Water Rights

Selected Water Rights	Mean Shortage, acre-feet per year		Volume Reliability, %	
	Scenario ID		Scenario ID	
	9.15	9.10	9.15	9.10
Dec. 31, 1929 and Senior, all uses	2,460	8,339	98.0	93.1
Jan. 1, 1930 to Dec. 31, 1939, all uses	1,862	5,653	97.5	92.5
Jan. 1, 1940 to Dec. 31, 1949, all uses	15,684	32,481	91.8	83.1
Jan. 1, 1950 to Dec. 31, 1959, all uses	14,775	26,997	86.8	75.9
Jan. 1, 1960 to Dec. 31, 1969, all uses	19,282	34,079	84.7	72.9
Jan. 1, 1970 to Dec. 31, 1979, all uses	1,129	1,472	75.9	68.6
Jan. 1, 1980 and Junior, municipal use	13,283	19,445	82.3	74.1
Jan. 1, 1980 and Junior, non-municipal use	23,293	31,076	72.4	63.1
All Selected Water Rights	91,768	159,542	88.4	79.8

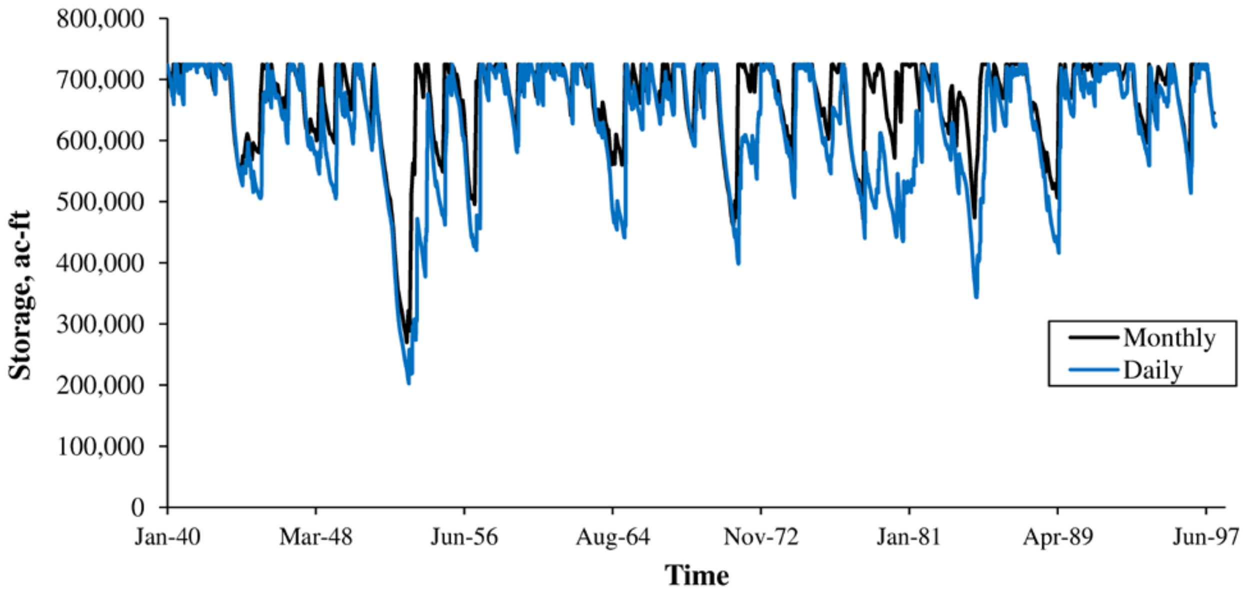

Figure 9.24 Storage in Possum Kingdom Lake

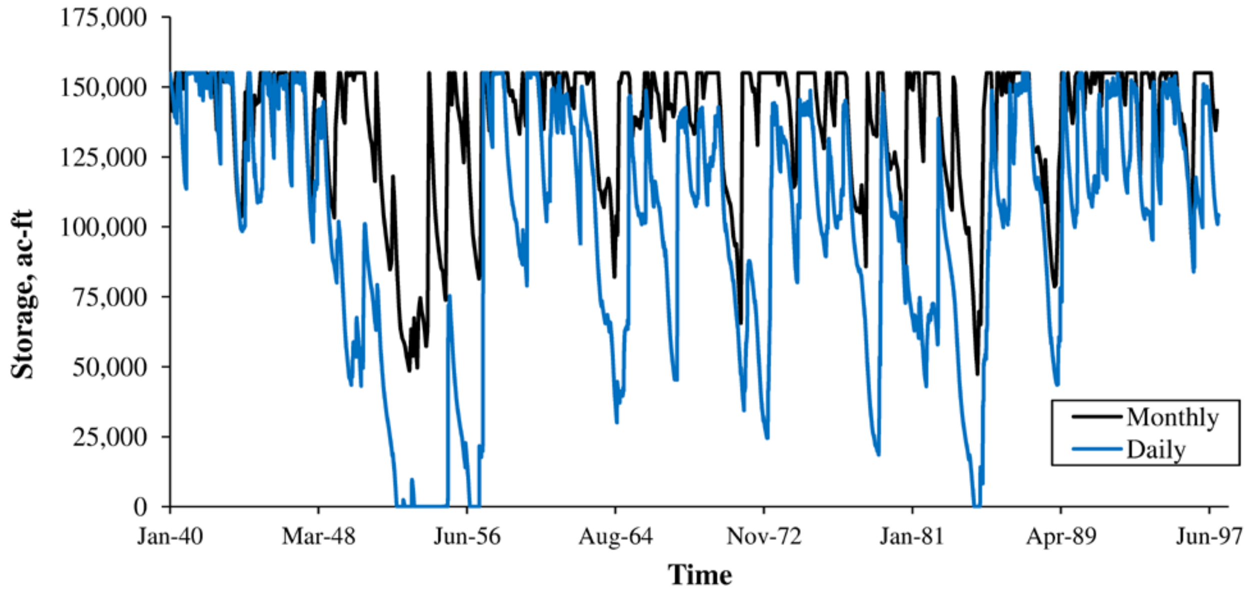

Figure 9.25 Storage in Granbury Lake

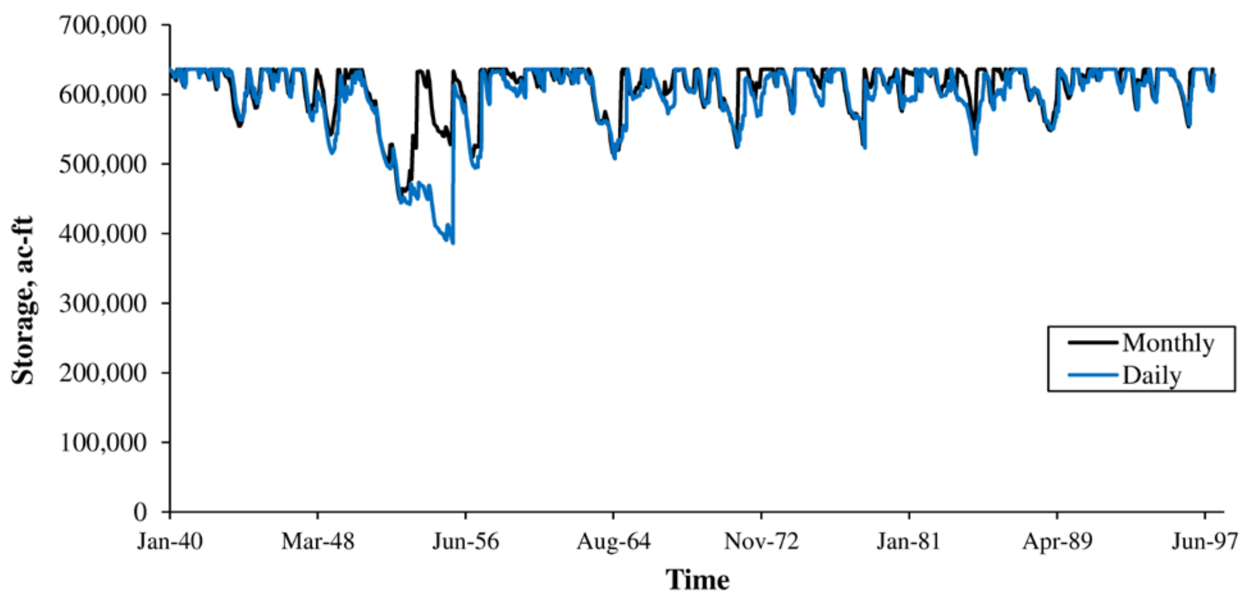

Figure 9.26 Storage in Whitney Lake

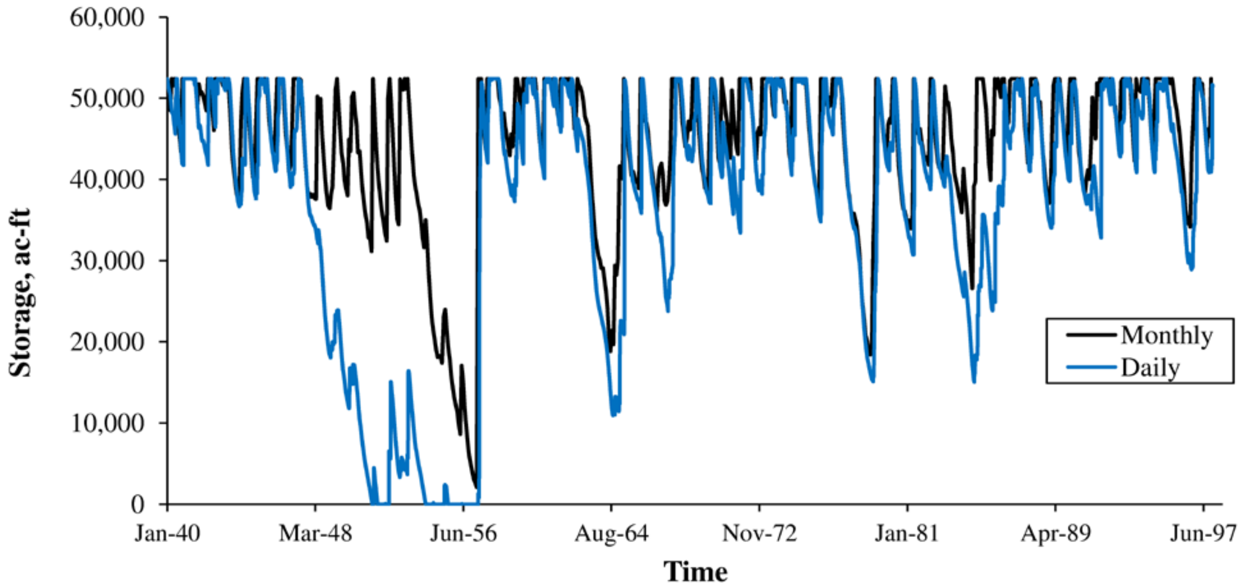

Figure 9.27 Storage in Aquilla Lake

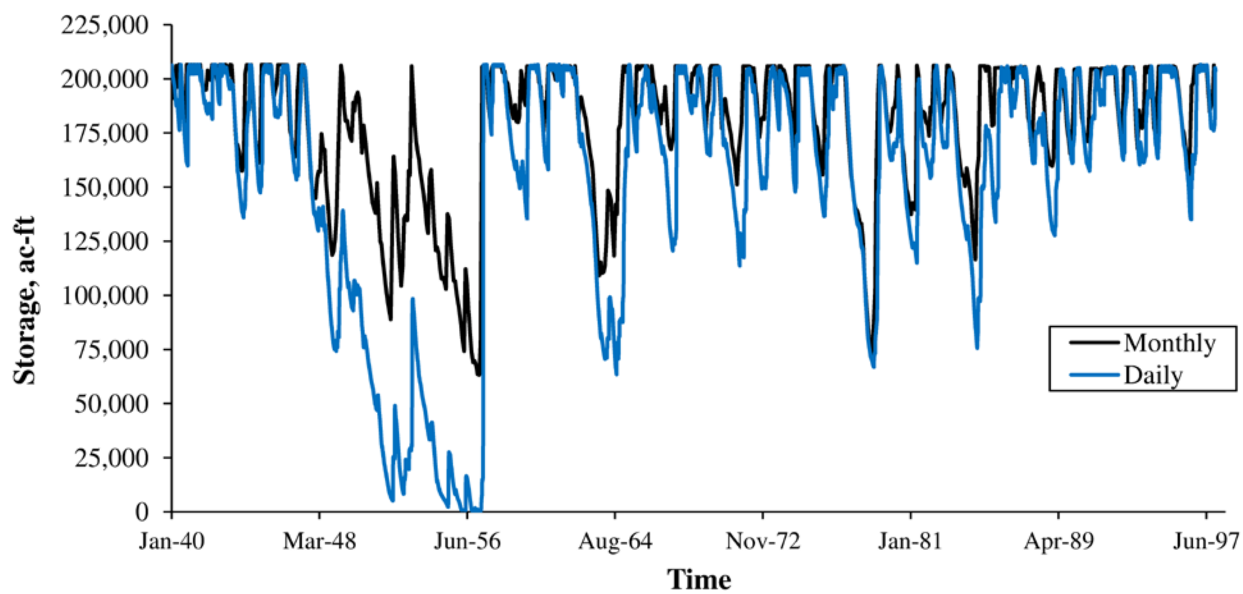

Figure 9.28 Storage in Waco Lake

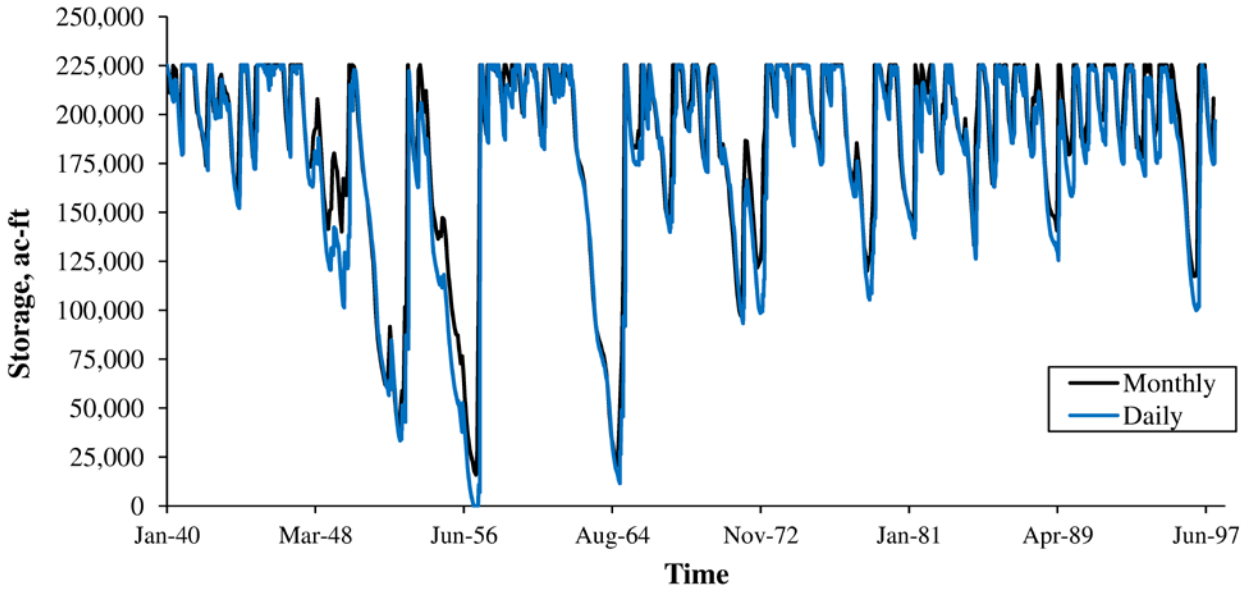

Figure 9.29 Storage in Limestone Lake

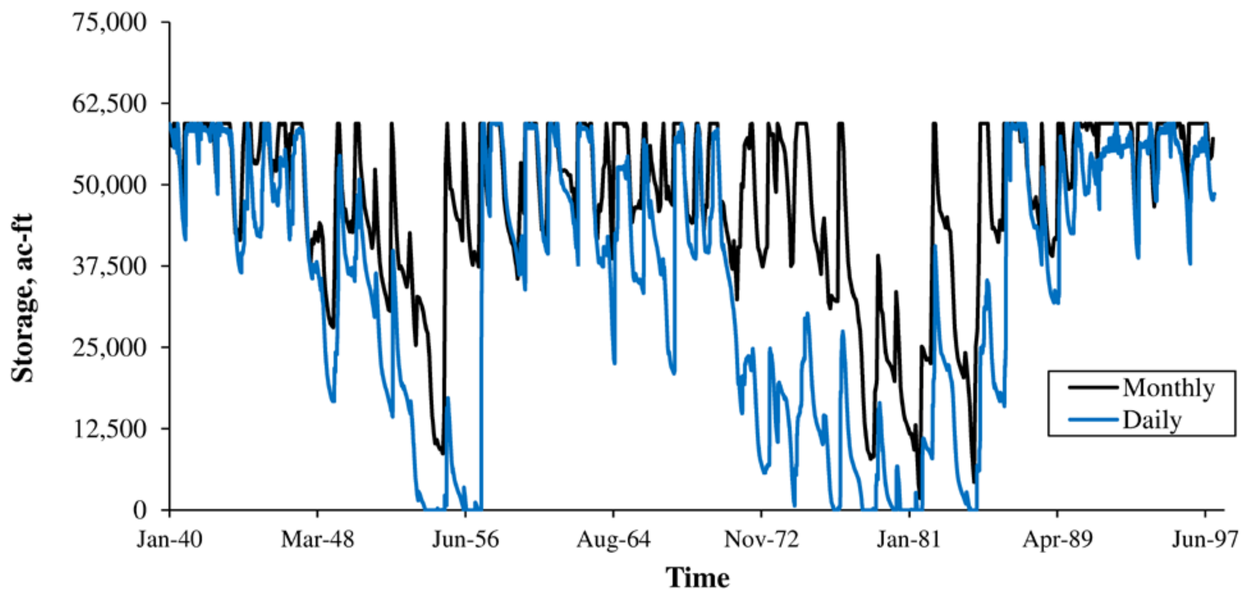

Figure 9.30 Storage in Proctor Lake

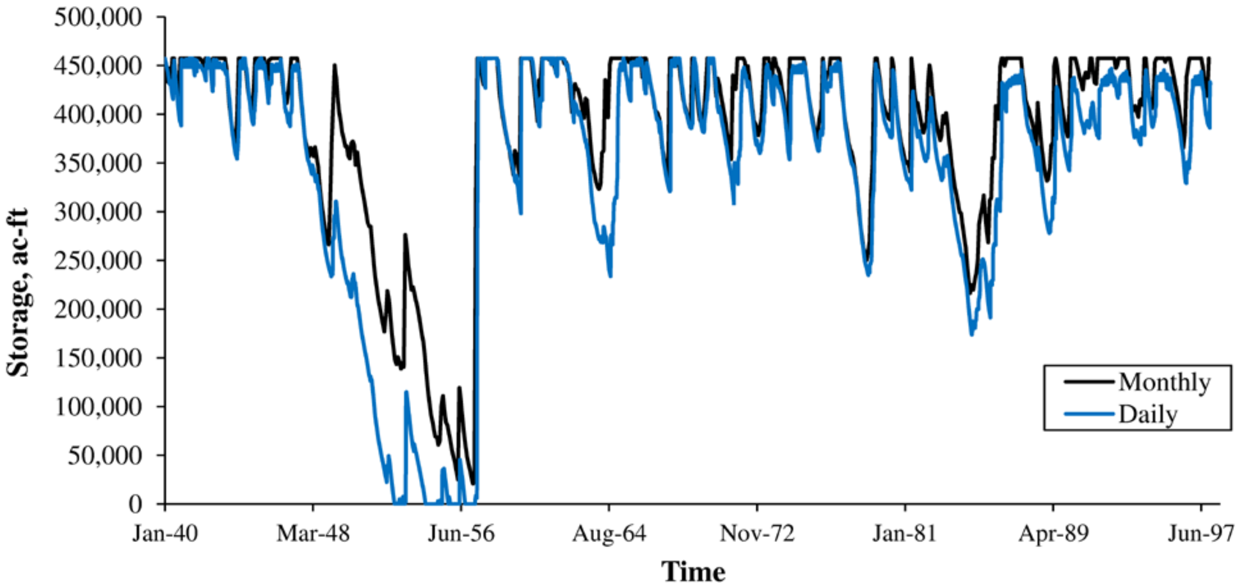

Figure 9.31 Storage in Belton Lake

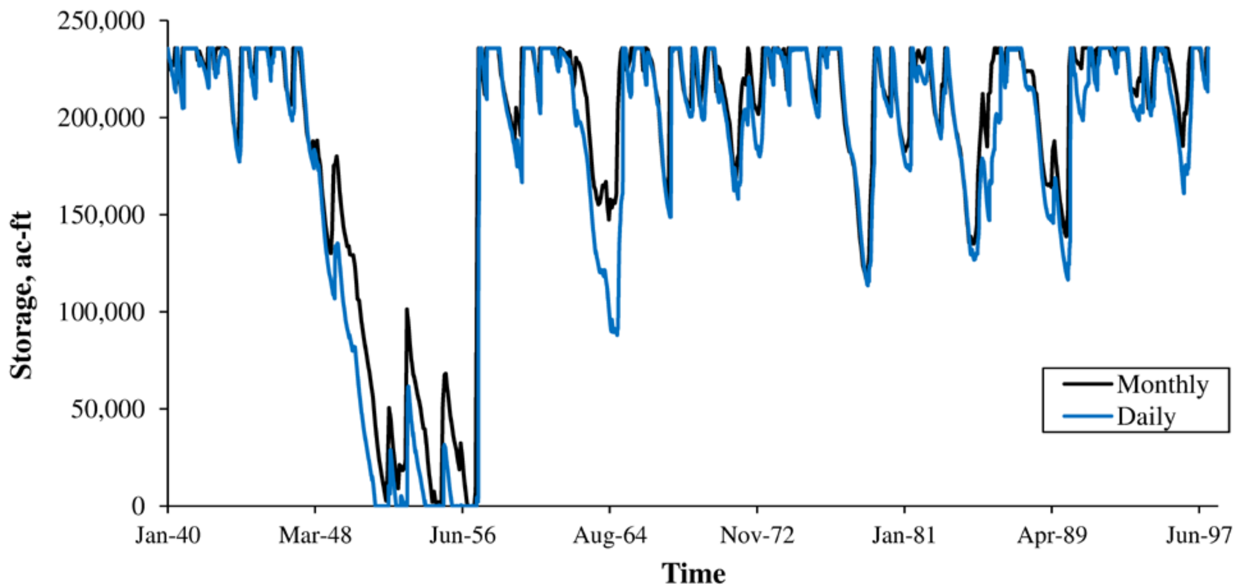

Figure 9.32 Storage in Stillhouse Hollow Lake

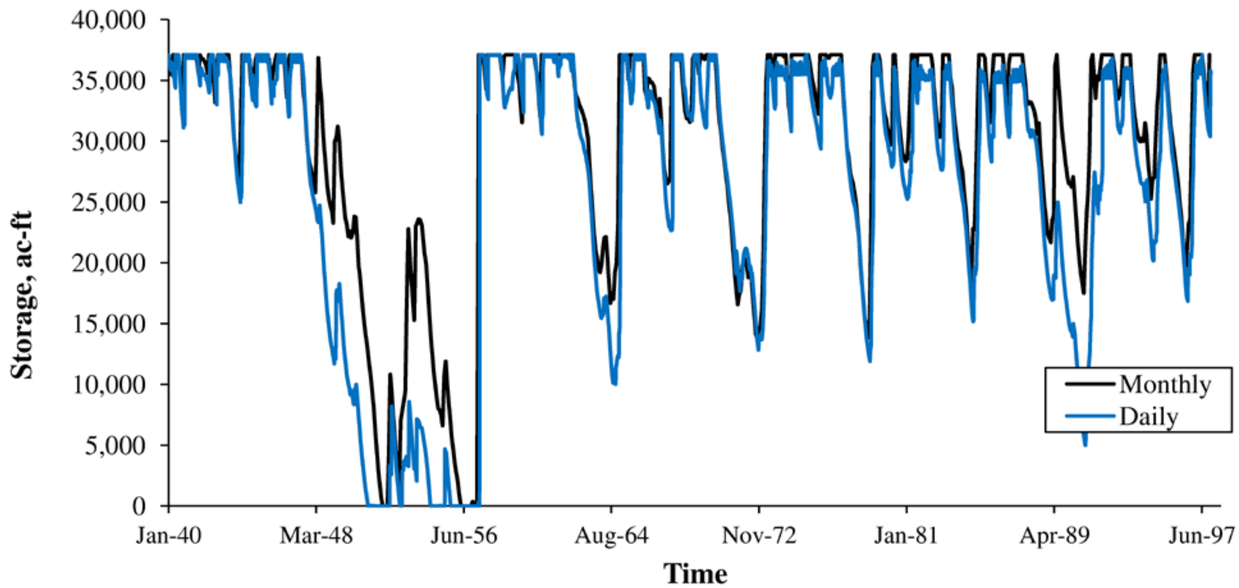

Figure 9.33 Storage in Georgetown Lake

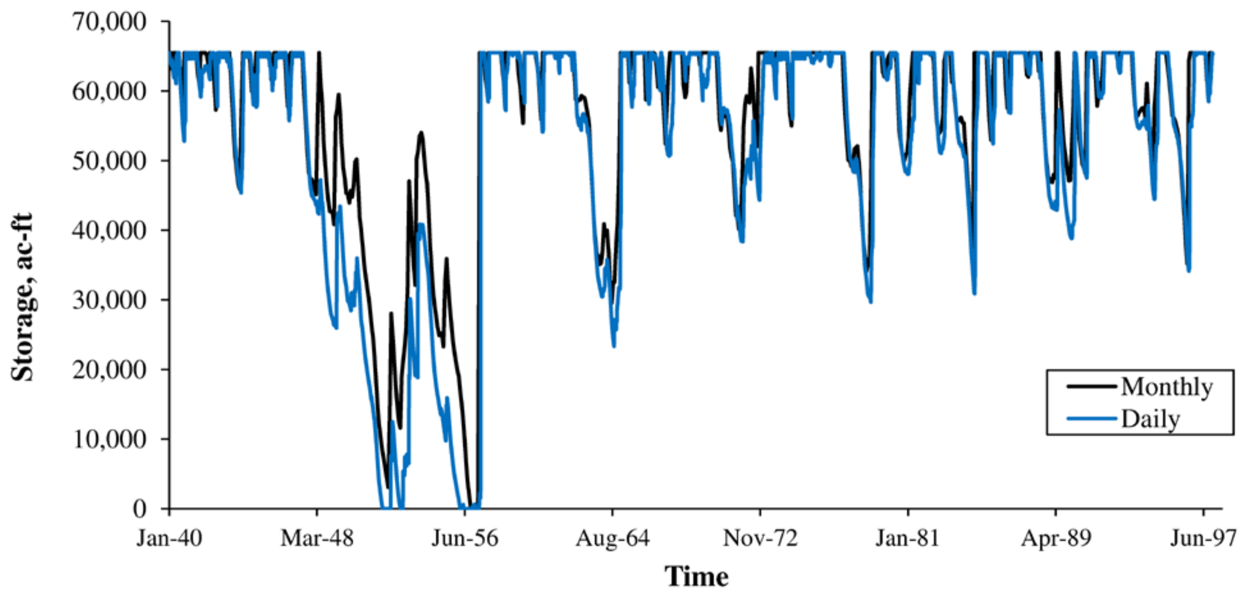

Figure 9.34 Storage in Granger Lake

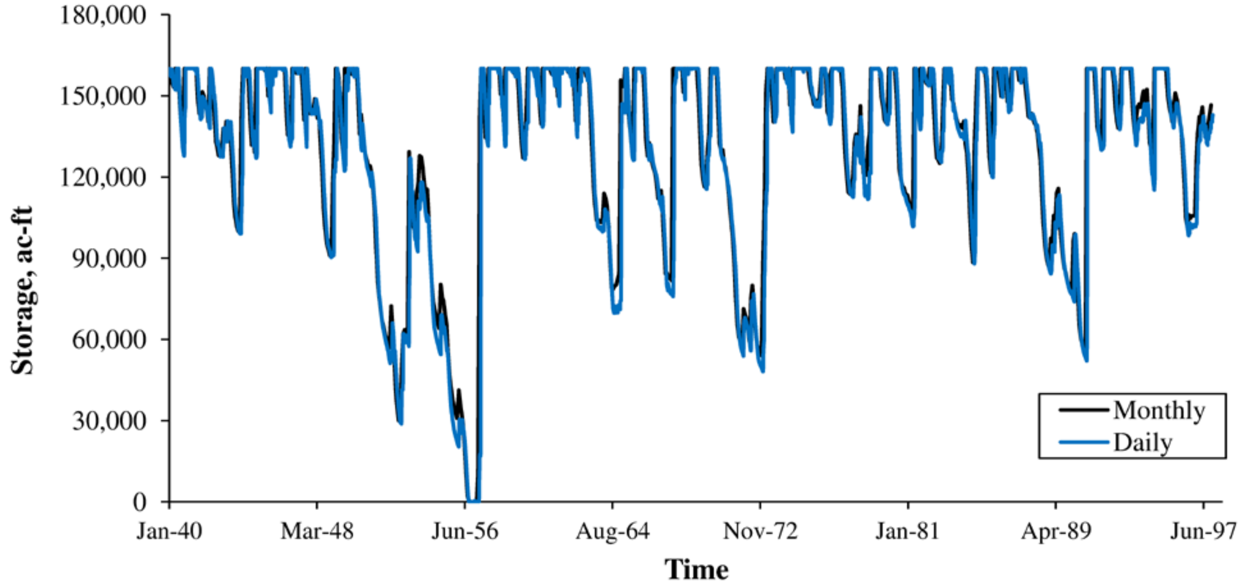

Figure 9.35 Storage in Somerville Lake

CHAPTER 10
DAILY SIMULATIOM STUDY INCORPORATING FLOOD CONTROL

The Brazos River Basin simulation study of Chapters 8 and 9 is expanded in Chapter 10 to incorporate flood control operations of nine Corps of Engineers multiple-purpose reservoirs. The daily time step features of *SIMD* are applied in modeling reservoir operations for flood control. Relatively small computational time steps are required to accurately model flood control operations due to the great fluctuations in flow rates over short time spans that occur during flood events. The day is the smallest time step that can be used in *SIMD*, as currently configured. A daily time step is adequate for modeling flood control operations of large river and reservoir systems such as the Brazos. However, small systems may require hourly or smaller time steps.

SIMD Flood Control Simulation Features

Flood control reservoir operations are treated as a type of water right in *SIMD*. Within WRAP, a water right is a set of water control requirements, reservoir facilities, and operating rules. Flood control rights are activated by *FR* records and are simulated along with all other *WR* and *IF* record water rights. The same reservoir may have any number of *WR* or *IF* record rights, with associated auxiliary records, and any number of *FR* record flood control rights.

The flood control reservoir *FR* record, flood flow *FF* record, and the flood volume and outflow *FV/FQ* record pair are the only *SIMD* input records specifically for flood control. These records are described in the *Daily Manual*. *FR* and FF records are used to model reservoir operations for flood control analogously to applying *WR*, *WS*, *OR*, and *IF* records to model operations for water supply, hydropower and environmental instream flow requirements.

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

Reservoir Pools

In *SIMD*, a reservoir consists of any or all of the four pools shown in Figure 10.1. *SIM* includes only the bottom two pools. In either *SIM* or *SIMD*, inactive and conservation pool storage capacities are specified on storage *WS* records associated with water right *WR* records. *SIMD* allows controlled and uncontrolled flood control storage to be specified by *FR* records. A flood control pool defined by *FR* record fields 8 and 10 may include zones with outflows through either gated or ungated outlet structures. Pools governed by a gated structure in *SIMD* are referred to as controlled flood control pools. Pools governed by an ungated structure in *SIMD* are referred to as uncontrolled flood control pools.

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

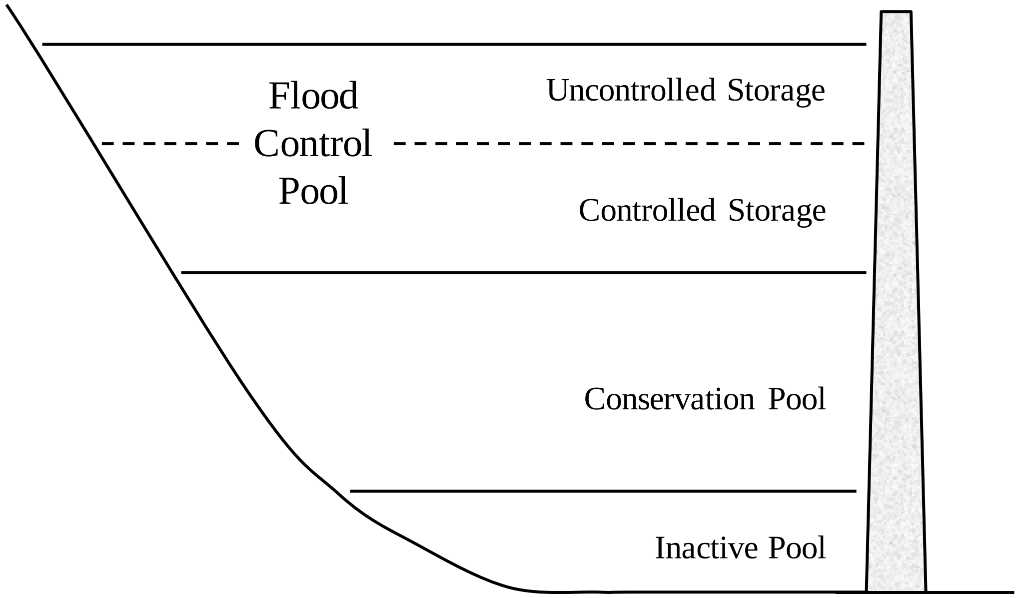

Figure 10.1 Reservoir Pools Defined by *SIMD WS* and *FR* Records

Reservoir Operations

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

Forecasting of Future Flows

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

Brazos River Basin Case Study

A daily Bwam simulation from Chapter 9 is adopted for the Chapter 10 investigation and extended to incorporate the nine federal flood control reservoirs. The nine U.S. Army Corps of Engineers (USACE) multiple-purpose reservoirs in the Brazos River Basin that contain flood control pools are listed in Table 10.1 with their designated top of conservation and flood control pool elevations. Simulations in Chapter 9 only included reservoir capacity up to the top of the conservation pool. Flood control storage capacity for these reservoirs is added to the conservation storage capacity in the Bwam dataset for Chapter 10.

Table 10.1
Reservoir Pool Elevation Data

Reservoir	Elevations, feet above mean sea level		
	Top of Conservation	Top of Flood Control	Top of Dam
Whitney	533.0	571.0	584.0
Aquilla	537.5	556.0	582.5
Waco	462.0	500.0	510.0
Proctor	1,162.0	1,197.0	1,205.0
Belton	594.0	631.0	662.0
Stillhouse	622.0	666.0	698.0
Georgetown	791.0	834.0	861.0
Granger	504.0	528.0	555.0
Somerville	238.0	258.0	280.0

The objectives of Chapter 10 are (1) to model flood control operations and (2) to examine the impacts of flood control operations on *SIMD* simulation results. *SIMD* input records with information describing flood control operations are developed based on flood control operating rules and criteria followed by the USACE, flood control pool elevations, and available storage capacity-area data. Operating rules are based on specified maximum allowable flow rates at downstream gaging stations. Flow forecasting for the purposes of implementing flood control operations is automated in SIMD. Default *SIMD* computation of the flood control forecasting periods is adopted on the *FF* records.

Flood Control Data for *SIMD* Input Records

Changes to flow are routed downstream in *SIMD* using the first set of routing parameters listed on the *RT* records in the DCF file. These routing parameters are applied to changes to stream flow resulting from *WR* or *IF* record rights with storage backup. Changes to flow made by *FR* record flood control reservoirs can be routed using the same routing parameters as used by *WR* and *IF* record rights, or the second set of routing parameters on the *RT* record can be used exclusively for flood control routing. The lag and attenuation parameters for high flow conditions presented in Table 8.10 are used to rout flood control changes to flow for all simulations presented in this chapter.

Top of conservation and flood control pool elevations are listed in Table 10.1. Bwam3 authorized conservation storage capacities and conservation and flood control capacities for estimated year 2010 sedimentation conditions at the nine flood control reservoirs are presented in Table 10.2. The conservation storage capacity of Lake Whitney is the volume between the top of conservation (533.0 feet) and top of inactive (520.0 feet) pools. The conservation storage capacity of the eight other reservoirs is the total volume below the top of conservation elevation listed in Table 10.1. The storage capacities for Lake Waco reflect a recent storage reallocation implemented by raising the top of conservation pool from 455 feet to 462 feet above msl. Flood control capacity is the volume between the top of conservation and flood control pools. A 1988 report [21] provides conservation and flood control storage capacity data projected for year 2010 estimated sedimentation conditions. Elevation, storage capacity, and surface area data from this previous study [21] for the nine flood control reservoirs were adopted for this investigation.

Table 10.2
Reservoir Storage Capacity Data, acre-feet

	Bwam Authorized	Estimated 2010 Sedimentation Conditions	
Reservoir	Conservation	Conservation	Flood Control
Whitney	249,076	227,950	1,364,250
Aquilla	52,400	47,340	91,720
Waco	206,562	157,790	506,410
Proctor	59,400	31,400	310,100
Belton	457,600	372,700	640,200
Stillhouse	235,700	209,700	391,220
Georgetown	37,100	34,540	91,900
Granger	65,500	57,070	173,720
Somerville	160,100	146,140	399,070

Incremental pool storage capacity were taken from the model data presented in [21] and adapted to *FR* records for use in *SIMD*. The incremental flood control pool storage capacities were added to the top of authorized conservation storage capacities from the Bwam3 dataset.

This forms reservoirs with flood control pools with storage capacities equal to year 2010 estimated sedimentation conditions located on top of Bwam3 authorized conservation storage capacities. Whitney and Waco Lakes are the only two flood control reservoirs modeled as separate reservoirs from their respective conservation pools. The Bwam conservation pools for Whitney and Waco Lakes are modeled as separate pools connected by evaporation-allocation *EA* records. The incremental flood control pools of Whitney and Waco Lakes are also connected to their respective separate conservation pools by the shared *EA* records.

Uncontrolled flood control pools are added to the top of the controlled flood control pools on the *FR* records. The uncontrolled flood control pools are formed by the incremental volume above the top of flood control and up to the maximum design water surface.

Incremental pool surface areas versus incremental storage volumes were computed from the previously developed data [13]. The flood control portion of the incremental surface area versus storage volume data were added to the *SV*/*SA* records in the Bwam DAT file. The *SV*/*SA* relationship was extended beyond the top of flood control to account for the storage volume up to the maximum design water surface for the flood control reservoirs. The Bwam *SV*/*SA* records for Belton Lake are shown in Table 10.3. The *SV* and *SA* records are contiguous in the Bwam DAT file, but are presented in Table 10.3 in separate rows to show where the incremental flood control data are added to the existing *SV*/*SA* records.

Table 10.3
SV/SA Records for Belton Lake, acre-feet versus acres

SV/SA Record Data to the Top of Authorized Conservation

SVBELTON	0	40	160	650	1100	1800	20900	58700	123500	218100	304170	457600
SA		17	32	63	110	200	1760	3270	5290	7580	9261	12258

SV/SA Record Data Above the Top of Authorized Conservation to the Top of Flood Control

SV	495550	535400	577400	636650	683800	768700	861400
SA	12903	13618	14293	15298	16128	17688	19428

SV/SA Record Data Above the Top of Flood Control to the Maximum Design Water Surface

SV	1097800	1214900	1464900	1964900
SA	23618	23958	28758	37958

Storage volume versus discharge data are provided for the flood control reservoirs on *FV/FQ* records. These records were developed from maximum conduit and spillway discharge capacity versus elevation data at each reservoir. The elevation data were mapped to the storage capacities developed for the *FR* records and *SV/SA* records. When the flood storage contents exceed the top of controlled flood control pool, the release from the uncontrolled pool is not governed by flood discharge limits at the dam or at downstream flood flow gaging stations. Instead, the daily discharge from the uncontrolled pool is computed only as a function of storage volume using the *FV/FQ* records. Discharge from the controlled flood control pool are computed as the minimum of the discharge according to the *FV/FQ* records or the stream capacity between regulated flows and maximum allowable flood flow limits at the dam or at downstream flood flow gaging stations. Table 10.4 shows the *FV/FQ* records for Belton Lake.

Table 10.4
FV/*FQ* Records for Belton Lake, ac-ft vs. ac-ft per day

```
FV/FQ Records for Maximum Conduit Releases

FVBELTON    0   457600   495550   535400   577400   636650   683800   768700
FQ          0    46811    47604    48199    48992    49984    50579    51769

FV     861400  1097800  1214900  1464900 1964900
FQ      52959    55141    75175   291575  968940
```

USACE maximum allowable discharges for the Brazos River Basin can be found at the website http://www.swf-wc.usace.army.mil/pertdata/BRAZOS.htm. The information from the website is reproduced in Table 10.5. The maximum releases and maximum stream gage discharges are provided for each flood control dam with respect to storage contents as a percentage of the flood control storage capacity. Maximum allowable discharge is provided at downstream stream gaging stations. The flood control information on the USACE website is adapted to *SIMD FR* and *FF* records. Portions of the total flood control storage capacity are represented in *SIMD* by multiple *FR* records per flood control reservoir. The multiple *FR* records per flood control reservoir are used to establish different values of maximum release according to the USACE website.

Table 10.5
USACE Flood Control Operating Criteria
Elevations in feet above MSL, Flow Rate in cubic feet per second

Reservoir	Elevations	% Flood Storage	Maximum Release	Brazos River Turbine	Aquilla Creek Aquilla	Brazos River Down to Bosque R.	Bosque River Near Gage	Brazos River Waco
Whitney	533.0 - 533.5	0 - 1		2200 Min.				60000
	533.5 - 534.0	1 - 2		4400 Min.				60000
	534.0 - 571.0	2 - 100				25000		60000
Aquilla	537.5 - 538.0	0 - 2			3000	25000		60000
	538.0 - 538.5	2 - 4			3000	25000		60000
	538.5 - 539.0	4 - 5			3000	25000		60000
	539.0 - 540.5	5 - 11			3000	25000		60000
	540.5 - 556.0	11 - 100			3000	25000		60000
	556.0 - 564.5	Surcharge			3000	25000		60000
Waco	455.0 - 457.4	0 - 3					3000	60000
	457.4 - 460.0	3 - 7					5000	60000
	460.0 - 465.0	7 - 14					10000	60000
	465.0 - 470.0	14 - 23					20000	60000
	470.0 - 500.0	23 - 100					30000	60000

Table 10.5 (Continued)
USACE Flood Control Operating Criteria
Elevations in feet above MSL, Flow Rate in cubic feet per second

Reservoir	Elevations	% Flood Storage	Maximum Release	Leon River	Leon River	Leon River	Little River	N. Fork San Gabriel Rv	San Gabriel River	Little River	Yegua Creek
				Proctor Gage	Hasse	Gates ville	Little River	George town	Laneport	Cameron	
Proctor	1162.0 - 1168.0	0 - 10		500	2000	5000	3000			10000	
	1168 – 1197	10 - 100		2000	2000	5000	6000			10000	
	1197.0 -			2000	2000	5000	10000			10000	
Belton	594.0 - 596.5	0 - 5					3000			10000	
	596.5 - 610.0	5 - 35					6000			10000	
	610.0 - 631.0	35 - 100					10000			10000	
Stillhouse Hollow	622.0 - 625.0	0 - 5					3000			10000	
	625.0 - 640.0	5 - 34					6000			10000	
	640.0 - 666.0	34 - 100					10000			10000	
Georgetown	791.0 - 792.0	0 - 1	170					3000		10000	
	792.0 - 794.0	1 - 4	250					3000		10000	
	794.0 - 795.0	4 - 6	250					3000		10000	
	795.0 - 796.0	6 - 7	250					6000		10000	
	796.0 - 799.0	7 - 12	1500					6000		10000	
	799.0 - 834.0	12 - 100	3000					6000		10000	
Granger	504.0 - 505.0	0 - 2	150						6000	10000	
	505.0 - 506.0	2 - 5	300						6000	10000	
	506.0 - 507.0	5 - 8	650						6000	10000	
	507.0 - 518.0	8 - 47	3000						6000	10000	
	518.0 - 528.0	47 - 100							6000	10000	
Somerville	238.0 - 243.0	0 - 18									1000
	243.0 - 258.0	18 - 100									2500

Table 10.5 (Continued)
USACE Flood Control Operating Criteria
Elevations in feet above MSL, Flow Rate in cubic feet per second

Reservoir	Elevations	% Flood Storage	Brazos River	Brazos River	Brazos River
			Washington	Hempstead	Richmond
Whitney	533.0 - 533.5	0 - 1	60000	60000	60000
	533.5 - 534.0	1 - 2	60000	60000	60000
	534.0 - 571.0	2 - 100	60000	60000	60000
Aquilla	537.5 - 538.0	0 - 2	60000	60000	60000
	538.0 - 538.5	2 - 4	60000	60000	60000
	538.5 - 539.0	4 - 5	60000	60000	60000
	539.0 - 540.5	5 - 11	60000	60000	60000
	540.5 - 556.0	11 - 100	60000	60000	60000
	556.0 - 564.5	Surcharge	60000	60000	60000
Waco	455.0 - 457.4	0 - 3	60000	60000	60000
	457.4 - 460.0	3 - 7	60000	60000	60000
	460.0 - 465.0	7 - 14	60000	60000	60000
	465.0 - 470.0	14 - 23	60000	60000	60000
	470.0 - 500.0	23 - 100	60000	60000	60000
Proctor	1162.0 - 1168.0	0 - 10	60000	60000	60000
	1168.0 - 1197.0	10 - 100	60000	60000	60000
	1197.0 -		60000	60000	60000
Belton	594.0 - 596.5	0 - 5	60000	60000	60000
	596.5 - 610.0	5 - 35	60000	60000	60000
	610.0 - 631.0	35 - 100	60000	60000	60000
Stillhouse Hollow	622.0 - 625.0	0 - 5	60000	60000	60000
	625.0 - 640.0	5 - 34	60000	60000	60000
	640.0 - 666.0	34 - 100	60000	60000	60000
Georgetown	791.0 - 792.0	0 - 1	60000	60000	60000
	792.0 - 794.0	1 - 4	60000	60000	60000
	794.0 - 795.0	4 - 6	60000	60000	60000
	795.0 - 796.0	6 - 7	60000	60000	60000
	796.0 - 799.0	7 - 12	60000	60000	60000
	799.0 - 834.0	12 - 100	60000	60000	60000
Granger	504.0 - 505.0	0 - 2	60000	60000	60000
	505.0 - 506.0	2 - 5	60000	60000	60000
	506.0 - 507.0	5 - 8	60000	60000	60000
	507.0 - 518.0	8 - 47	60000	60000	60000
	518.0 - 528.0	47 - 100	60000	60000	60000
Somerville	238.0 - 243.0	0 - 18	60000	60000	60000
	243.0 - 258.0	18 - 100	60000	60000	60000

Lakes Whitney and Waco and Lakes Belton and Stillhouse Hollow are operated in *SIMD* as flood control storage and release systems. The storage priority dates and release priority dates on the *FR* records are set equal to each other. This establishes a system for either storing or releasing from the controlled flood control pool for that portion of the controlled flood control capacity defined on the respective *FR* record. Multiple *FR* records are used to establish different values of *FCMAX*. Additionally, multiple *FR* records are used for Whitney, Waco, Belton and Stillhouse Hollow to facilitate balancing flood control storage contents as a percentage of total flood control capacity. As the Whitney-Waco or the Belton-Stillhouse systems impound or release flood water, each reservoir pool in the system will function as a zone to be considered before impounding or releasing from the next priority zone in the system. Multiple system pairings via equal priority numbers on *FR* records increase the likelihood of balancing flood control storage contents across the system pools.

The *FR* and *WS* records for the nine flood control reservoirs are shown in Table 10.6. The conservation pools for Whitney and Waco Lakes are broken into multiple separate *WS* record reservoirs in the Bwam DAT file. The flood control reservoirs for Whitney and Waco Lakes are also modeled as separate reservoirs. Therefore, the *FR* record value for the bottom of flood control for the Whitney and Waco flood control reservoirs is equal to zero storage capacity. All other flood control reservoirs have a value for the bottom of flood control capacity that is equal to the top of the conservation pool capacity.

The priority numbers on the *FR* records were chosen to be the most junior rights in the Bwam DAT file. *WR* record rights in the DAT file with priority numbers equal to 99999999 were renumbered to 88888888. Flood control storage rights are assigned priority numbers equal to 91000000 through 91000071. Flood control release rights are assigned priority numbers equal to 92000900 through 92000990. The priority numbers were chosen to establish a relative storage and release order and to create storage and release systems. *SIMD* allows any priority numbering scheme as long as increases in storage capacity are assigned a junior priority to previously established storage capacities. Flood control storage decisions are prioritized in the following order: Whitney-Waco system, Aquilla, Proctor, Georgetown, Granger, Belton-Stillhouse Hollow system, Somerville. The storage priorities are arranged to generally follow an upstream to downstream order of storage decisions. Flood control release decisions are prioritized in the following order: Proctor, Georgetown, Somerville, Belton-Stillhouse Hollow system, Granger, Aquilla, Whitney-Waco system. The release priorities are arranged to generally follow a downstream to upstream order of storage decisions with the exception of Proctor and Georgetown. These reservoirs make release decisions first because they are located upstream of other flood control reservoirs. Belton should consider Proctor's releases and Granger should consider Georgetown's releases prior to making additional flood control releases.

The *FR* record flood control reservoirs can deplete all flow at their respective control points when regulated flows exceed the value of *FCMAX* at the location of the reservoir or when regulated flows exceed the target set by any of the downstream *FF* record flood flow gages. The option to deplete all flow is set by *FR* record parameter *FCDEP* equal to 2. *FCDEP* equal to 1 will limit depletions for flood control according to the standard water availability calculation which considers all downstream control points.

Table 10.6

FR Record Representation of Flood Control Reservoirs

```
**  CPID   STORE      REL  FF DEP   FCMAX     TOP    GATE  BOTTOM
FR5157319100000092000990   0   2   49588  313780  313780       0
FR5157319100000592000977   0   2   49588  545698          313780
FR5157319100000692000976   0   2   49588  750335          545698
FR5157319100000792000975   0   2   49588  954970          750335
FR5157319100000892000974   0   2   49588 1091395          954970
FR5157319100000992000973   0   2   49588 1159610         1091395
FR5157319100001092000972   0   2   49588 1227820         1159610
FR5157319100001192000971   0   2   49588 1296030         1227820
FR5157319100001292000970   0   2   49588 1544545 1364245 1296030
WSWTNYFC                                                       1       -1
FR5094319100000192000981   0   2    5950   15190   15190       0
FR5094319100000292000980   0   2    9918   35450           15190
FR5094319100000392000979   0   2   19835   70900           35450
FR5094319100000492000978   0   2   39670  116475           70900
FR5094319100000592000977   0   2   59505  202560          116475
FR5094319100000692000976   0   2   59505  278525          202560
FR5094319100000792000975   0   2   59505  354485          278525
FR5094319100000892000974   0   2   59505  405130          354485
FR5094319100000992000973   0   2   59505  430450          405130
FR5094319100001092000972   0   2   59505  455770          430450
FR5094319100001192000971   0   2   59505  481090          455770
FR5094319100001292000970   0   2   59505  665149  506409  481090
WSWACOFC                                                       2       -1
FR5158319100002092000930   0   2    5950  144124           52400
WSAQUILA
FR5159319100003092000901   0   2     990   90410           59400
FR5159319100003192000900   0   2    7934  458000  369500   90410
WSPRCTOR
FR5162319100004092000904   0   2     500   43530           37100
FR5162319100004192000903   0   2    2975   48130           43530
FR5162319100004292000902   0   2    5950  214389  128996   48130
WSGRGTWN
FR5163319100005092000922   0   2    1290   79400           65500
FR5163319100005192000921   0   2    5950  147150           79400
FR5163319100005292000920   0   2   11900  538275  239223  147150
WSGRNGER
FR5161319100006092000919   0   2    5950  255260          235700
FR5161319100006192000918   0   2   11900  368715          255260
FR5161319100006292000917   0   2   19835  431311          368715
FR5161319100006392000916   0   2   19835  470433          431311
FR5161319100006492000915   0   2   19835  509555          470433
FR5161319100006592000914   0   2   19835  548680          509555
FR5161319100006692000913   0   2   19835  568240          548680
FR5161319100006792000912   0   2   19835  587800          568240
FR5161319100006892000911   0   2   19835  607360          587800
FR5161319100006992000910   0   2   19835 1045872  626922  607360
WSSTLHSE
FR5160319100006092000919   0   2    5950  489610          457600
FR5160319100006192000918   0   2   11900  681670          489610
FR5160319100006292000917   0   2   19835  777700          681670
FR5160319100006392000916   0   2   19835  841720          777700
FR5160319100006492000915   0   2   19835  905740          841720
FR5160319100006592000914   0   2   19835  969760          905740
FR5160319100006692000913   0   2   19835 1001770          969760
FR5160319100006792000912   0   2   19835 1033780         1001770
FR5160319100006892000911   0   2   19835 1065790         1033780
FR5160319100006992000910   0   2   19835 1964900 1097800 1065790
WSBELTON
FR5164319100007092000906   0   2    1984  221140          160110
FR5164319100007192000905   0   2    4960  813931  499167  221140
WSSMRVLE
```

The maximum release rate, FCMAX, for Proctor is listed as 7,934 ac-ft per day, or 4,000 cfs, in Table 10.6. This differs from the 2,000 cfs maximum rate shown in Table 8.5. The maximum discharge rate for Proctor was set to 7,934 ac-ft per day to reflect updated operational protocols for flood control releases from the lake.

The *FF* records are shown in Table 10.7. The maximum allowable release of the *FR* record rights and maximum allowable discharge of the *FF* record rights are summarized in Table 10.8. The first three *FF* record rights in Table 10.7 are located at control points corresponding to the Brazos River stream gages near Waco, Bryan and Richmond. These three *FF* records set a maximum allowable discharge target of 119,010 ac-ft per day or 60,000 cfs. Whitney, Waco and Aquilla are upstream of the stream gage near Waco. All flood control reservoirs in the model except Somerville are upstream of the stream gage near Bryan. All flood control reservoirs in the model are upstream of the stream gage near Richmond. The fourth *FF* record right is located at the control point corresponding to the stream gage on the Leon River near Gatesville. The maximum allowable discharge target is set to 9.917.5 ac-ft per day or 5,000 cfs. Proctor Lake is the only flood control reservoir upstream of the Gatesville gage *FF* record right. The fifth *FF* record right is located at the control point corresponding to the stream gage on the Little River near Cameron. The maximum allowable discharge target is set to 19,835 ac-ft per day or 10,000 cfs. All flood control reservoirs in the Little River watershed are located upstream of this *FF* record right. The sixth *FF* record right shown is located at the control point corresponding to the stream gage on the Little River near the town of Little River. The maximum allowable discharge target is set to 19,835 ac-ft per day or 10,000 cfs. Proctor, Belton and Stillhouse are located upstream of this *FF* record right. The maximum allowable discharge is modulated between 5,950.5 ac-ft per day, 11,901 ac-ft per day and 19,835 ac-ft per day. The *FF* record right is connected to a drought index based on the summation of the storage contents in Proctor, Belton and Stillhouse Hollow. The *DO* record shown in Table 10.7 sets consideration of the drought index to a daily basis in the target building steps which are detailed in the *Daily Manual*. The *DI*/*IS*/*IP* records are based on the maximum allowable discharge in Table 10.5 for the Little River near Little River stream gage.

Table 10.7
FF Record Representation of Flood Control Gages

```
**
FFBRWA41       43438650.   NDAYS       0
FFBRBR59       43438650.   NDAYS       0
FFBRRI70       43438650.   NDAYS       0
**
FFLEGT47        3619888.   NDAYS       0
FFLRCA58        7239775.   NDAYS       0
FFLRLR53        7239775.   NDAYS       0       2
DO             15
**
**
DI      2       3  PRCTOR  BELTON  STLHSE
IS      7       0  835280  835281 1423800 1423801 2094222 3468722
IP             30      30      60      60     100     100     100
```

The forecast periods of the *FF* record rights in Table 10.7 are set to adopt the automatically calculated forecasting periods between each flood control reservoir and the control point of each downstream *FF* record. The routing factor array, RFA, for flood control routing parameters is used by *SIMD* to determine the maximum number of future days of routing between each reservoir and each downstream *FF* record. This number of future days is adopted as the forecasting period between the flood control reservoir and the specific downstream *FF* record for the purposes of determining available channel capacity.

Table 10.8
Maximum Allowable Discharge at the Location of the *FF* Record Rights

	Brazos River at Waco, BRWA41	Brazos River at Bryan, BRBR59	Brazos River at Richmond, BRRI70	Leon River at Gatesville, LEGT47	Little River at Little River, LRLR53	Little River at Cameron, LRCA58
ft^3 per second	60,000	60,000	60,000	5,000	10,000	10,000
ac-ft per day	119,010	119,010	119,010	9,918	19,835	19,835

Maximum Allowable Release at *FR* Record Flood Control Reservoirs

	Whitney	Aquilla	Waco	Proctor	Belton	Stillhouse Hollow	Georgetown	Granger	Somerville
ft^3 per second	25,000	3,000	30,000	4,000	10,000	10,000	3,000	6,000	2,500
ac-ft per day	49,588	5,950	59,505	7,934	19,835	19,835	5,950	11,900	4,960

Flood Control Simulation Scenarios

Two simulation scenarios are compared in Chapter 10 to illustrate *SIMD* flood control performance in terms of peaks and frequencies in storage and regulated flow. The simulation parameter options for the scenarios are shown in Table 10.9. Scenario 10.01 is the same as Scenario 9.10 from the previous chapter. It is renumbered here for comparative purposes. Scenario 10.01 contains no flood control reservoir pools. All reservoirs in Scenario 10.01 are defined by capacity up to the top of conservation storage only. Scenario 10.02 contains *FR* record flood control pools and the *FF* record flood flow records described previously in this chapter.

Scenario 10.3 considers the effect of extending the simulation forecast period beyond the maximum routing period. Flood control operations are not simulated during the forecast simulation and therefore do not require channel capacity forecasts beyond the maximum routing period to make current day flood control decisions. However, *WR* record rights are simulated during the forecast simulation and may benefit from an extension of the simulation forecast period. Flood control operations are influenced by the effects of water rights on regulated flows. Scenario 10.3 provides information regarding the effects on water right reliability as well as the effects on flood control operations of an extension of the simulation forecast period.

Table 10.9
Regulated Flow Forecasting Periods per Simulation Scenario

Scenario ID	Time Step	WAM Dataset	Flood Control Reservoirs	Routing Options, *WRMETH, FRMETH*	Disaggregation Option, *DFMETHOD*	Target Distribution Option, *ND*	Flow Forecasting, *FPRD*	Negative Increm., *ADJINC*	Execution Time, hours
10.01	day	Bwam3	no	1, *na*	daily pattern	uniform	14 days	7	3.63
10.02	day	Bwam3	yes	1, 1	daily pattern	uniform	14 days	7	3.88
10.03	day	Bwam3	yes	1, 1	daily pattern	uniform	28 days	7	7.55

Table 10.10
Selected Control Points

Control Point ID	Reservoir or Gage	Stream	Watershed Area (square miles)
	USGS Stream Gaging Stations		
BRWA41	Waco Gage	Brazos River	20,065
BRBR59	Bryan Gage	Brazos River	30,016
BRRI70	Richmond Gage	Brazos River	35,454
LEGT47	Gatesville Gage	Leon River	2,379
LRLR53	Little River Gage	Little River	5,266
LRCA58	Cameron Gage	Little River	7,100
	Reservoirs		
515731	Whitney Lake	Brazos River	17,690
515831	Aquilla Lake	Aquilla Creek	254
509431	Waco Lake	Bosque River	1,655
515931	Proctor Lake	Leon River	1,280
516031	Belton Lake	Leon River	3,568
516131	Stillhouse Hollow Lake	Lampases R.	1,313
516231	Georgetown Lake	San Gabriel R.	247
516331	Granger Lake	San Gabriel R.	726
516431	Somerville Lake	Yegua Creek	1,008

Flood Control Results

Simulation results are given in Tables 10.11 through 10.14 for the first two scenarios listed in Table 10.9. Scenario 10.01 contains reservoirs with conservation storage only. Scenario 10.02 incorporates flood control at the nine major flood control reservoirs in the Brazos River Basin. Both simulations utilize the same number of days in the simulation forecast period.

The results tables show the number of days of exceedance during the simulation. The period of record from January 1, 1940 through December 31, 1997 covers 21,185 days. The numbers of days identified in the tables are small relative to the overall number of days in the simulation, and the differences in the number of days between simulations are even smaller. Therefore, these results are not presented in a decimal frequency percentage format so that the exact number of days can be compared between simulation scenarios.

The numbers of days when regulated flow equals or exceeds the maximum discharge or release rates at the downstream flood gages or at the flood control dam sites, respectively, are shown in Table 10.11 and 10.12. The exceedance of the maximum discharge and release rates are given in the first lines of Tables 10.11 and 10.12 for the daily naturalized flow inputs for comparison purposes. The presence of water rights and reservoir conservation storage has a small effect toward reducing flood conditions. However, the results of Scenario 10.02 show a significant reduction in the incidence of flood flow exceedance at the downstream gages and at the dam sites.

Regulated flow exceedance of the maximum release rate at the flood control reservoirs is shown in Table 10.12. Regulated flow exceeds the maximum release rate only for days during which the flood control pools are filled to capacity. Such simulated events are representative of conditions when reservoir inflows equal outflows through the dam's emergency spillways. Multiple days of exceedance of the top of flood control capacity in Table 10.14 are not indicative of separate events. In all cases, except for Proctor Lake, the simulations result in only one instance where flood control capacity is completely filled. Proctor Lake is simulated as having two events in which flood control capacity is completely filled. However, further adjustment of the flood control system operation code in *SIMD* may reduce the number of filling events at Proctor Lake to one.

Table 10.13 gives the number of days in which the reservoirs are simulated with a storage contents equal to or greater than the top of the conservation pool. Retaining water in the flood control pools for many days, weeks, or months after a flood event will contribute to an increase in the number of days in which storage contents exceed the top of the conservation pool. Allowing flood control operations to refill the depleted conservation storage during a flood event can also increase the number of days in which storage contents exceed the top of conservation storage.

Table 10.11
Number of Days in the Simulation When Regulated Flow
Equals or Exceeds the Maximum Allowable Discharge at *FF* Record Gages

	Brazos River at Waco, BRWA41	Brazos River at Bryan, BRBR59	Brazos River at Richmond, BRRI70	Leon River at Gatesville, LEGT47	Little River at Little River, LRLR53	Little River at Cameron, LRCA58
Naturalized Flow	53	198	307	233	382	721
Scenario 10.01	33	152	230	208	258	578
Scenario 10.02	2	26	51	101	25	197

Table 10.12
Number of Days in the Simulation When Regulated Flow
Equals or Exceeds the Maximum Release at *FR* Record Flood Control Reservoirs

	Whitney	Aquilla	Waco	Proctor	Belton	Stillhouse Hollow	Georgetown	Granger	Somerville
Naturalized Flow	210	158	9	184	188	41	41	82	586
Scenario 10.01	134	122	8	142	122	31	34	74	484
Scenario 10.02	19	0	0	9	7	2	1	3	4

Table 10.13
Number of Days in the Simulation When Storage Contents
Equals or Exceeds the Top of Conservation Storage Capacity

	Whitney	Aquilla	Waco	Proctor	Belton	Stillhouse Hollow	Georgetown	Granger	Somerville
Scenario 10.01	2,703	545	152	435	822	1,762	1,645	4,901	4,321
Scenario 10.02	2,902	2,231	1,580	4,636	4,660	4,546	5,530	6,899	5,327

Table 10.14
Number of Days in the Simulation When Storage Contents
Equals or Exceeds the Top of Flood Control Capacity

	Whitney	Aquilla	Waco	Proctor	Belton	Stillhouse Hollow	Georgetown	Granger	Somerville
Scenario 10.01	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*
Scenario 10.02	25	0	2	40	33	36	9	18	6

Table 10.15
Flood Frequency for Daily Naturalized Stream Flow
at the Selected Control Points, ac-ft per day

Flood Frequencies for Daily Naturalized Stream Flow

	ANNUAL RECURRENCE INTERVAL (YEARS) AND EXCEEDANCE FREQUENCY (%)									
CONTROL POINT	1.01 99%	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%	200 0.5%	500 0.2%	EXPECTED VALUE
BRWA41	12691.	74527.	134428.	181086.	246893.	300369.	357299.	417853.	503679.	94479.
BRBR59	22028.	118974.	214600.	290889.	401093.	492768.	592335.	700351.	856972.	152371.
BRRI70	20820.	124016.	222844.	299039.	405488.	491211.	581781.	677406.	811803.	156185.
LEGT47	613.	12918.	27916.	39222.	53927.	64742.	75210.	85280.	97927.	18353.
LRLR53	2338.	30857.	69973.	104879.	158725.	205528.	257724.	315447.	400442.	49186.
LRCA58	4799.	49760.	102526.	145942.	208828.	260653.	316127.	375206.	458736.	70776.
515731	11046.	53226.	91951.	121810.	163851.	198076.	234641.	273716.	329468.	65454.
515831	909.	10139.	19691.	26751.	36023.	42991.	49905.	56747.	65653.	13227.
509431	1758.	23661.	52375.	77057.	113842.	144808.	178441.	214694.	266556.	36281.
515931	626.	12246.	30170.	46680.	72471.	94978.	120053.	147674.	188055.	21235.
516031	1531.	23705.	52793.	77257.	112799.	141938.	172855.	205405.	250702.	36122.
516131	559.	13421.	34137.	53268.	82963.	108615.	136886.	167656.	211963.	23917.
516231	122.	4161.	10296.	15402.	22510.	28025.	33569.	39082.	46242.	6856.
516331	469.	11062.	24667.	35163.	49031.	59357.	69441.	79216.	91588.	16243.
516431	607.	12357.	30354.	46740.	72025.	93823.	117853.	144048.	181883.	21228.

Statistics for Peak Annual Regulated Streamflow, Log-Pearson Type III Distribution

					Statistics for Logarithms of Annual Peaks				
CONTROL POINT	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION	INPUT SKEW	COMPUTED SKEW	ADOPTED SKEW
BRWA41	93209.	69353.	10551.	417598.	4.8642	0.3117	-0.2000	-0.1428	-0.1569
BRBR59	150573.	117164.	25997.	719015.	5.0722	0.3073	-0.2000	-0.0229	-0.0639
BRRI70	154086.	112704.	24380.	645001.	5.0839	0.3110	-0.2000	-0.1801	-0.1851
LEGT47	17411.	16771.	459.	92376.	4.0594	0.4511	-0.2000	-0.9886	-0.6941
LRLR53	46594.	47333.	2360.	207259.	4.4710	0.4393	-0.2000	-0.2695	-0.2514
LRCA58	67982.	58911.	4635.	289749.	4.6772	0.3913	-0.2000	-0.3400	-0.3022
515731	64857.	42818.	9562.	193612.	4.7226	0.2853	-0.2000	-0.0372	-0.0751
515831	12789.	9663.	578.	44240.	3.9731	0.3750	-0.2000	-0.6795	-0.5287
509431	34593.	35649.	1284.	219455.	4.3508	0.4318	-0.2000	-0.3705	-0.3239
515931	20202.	27943.	418.	200316.	4.0602	0.4913	-0.2000	-0.3929	-0.3396
516031	34423.	34593.	1556.	165626.	4.3446	0.4420	-0.2000	-0.4980	-0.4116
516131	22415.	27011.	397.	120489.	4.0934	0.5143	-0.2000	-0.4840	-0.4022
516231	6276.	6355.	73.	26837.	3.5610	0.5271	-0.2000	-0.9269	-0.6674
516331	15147.	13497.	253.	61175.	3.9905	0.4687	-0.2000	-0.9731	-0.6876
516431	19214.	18453.	1233.	98735.	4.0615	0.4925	-0.2000	-0.4389	-0.3715

Table 10.16
Flood Frequency for Daily Regulated Stream Flow at the
Selected Control Points for Scenarios 10.01 and 10.02, ac-ft per day

Flood Frequencies for Daily Regulated Stream Flow,
Scenario 10.01, Without Flood Control

	ANNUAL RECURRENCE INTERVAL (YEARS) AND EXCEEDANCE FREQUENCY (%)									
CONTROL POINT	1.01 99%	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%	200 0.5%	500 0.2%	EXPECTED VALUE
BRWA41	7916.	58624.	115013.	161890.	231310.	290062.	354565.	425122.	528160.	80901.
BRBR59	16013.	99089.	185725.	256278.	359556.	446316.	541175.	644646.	795470.	131289.
BRRI70	13991.	103493.	196897.	271075.	376577.	462608.	554233.	651567.	789112.	136970.
LEGT47	554.	11353.	25394.	36595.	51932.	63768.	75682.	87580.	103161.	16942.
LRLR53	1390.	21619.	55213.	89121.	147253.	202751.	269515.	348846.	475386.	41071.
LRCA58	4084.	42246.	90412.	132256.	195868.	250669.	311493.	378562.	477155.	63486.
515731	5190.	41240.	77995.	106391.	145707.	176945.	209492.	243333.	289997.	53740.
515831	684.	8466.	17536.	24753.	34826.	42818.	51096.	59626.	71233.	11909.
509431	1138.	19415.	47174.	72962.	113795.	149970.	190837.	236510.	304444.	33469.
515931	467.	8798.	23253.	37937.	63062.	86915.	115414.	149007.	202024.	17272.
516031	782.	16385.	42082.	66750.	106654.	142566.	183571.	229802.	299145.	30172.
516131	336.	9910.	28123.	46782.	78372.	107820.	142302.	182037.	242971.	20764.
516231	64.	3122.	8679.	13756.	21327.	27542.	34059.	40786.	49871.	5945.
516331	326.	9053.	22164.	33355.	49432.	62327.	75681.	89355.	107734.	14973.
516431	71.	8480.	30007.	53106.	91564.	125890.	164061.	205482.	264276.	22146.

Statistics for Peak Annual Regulated Streamflow, Log-Pearson Type III Distribution

					Statistics for Logarithms of Annual Peaks				
CONTROL POINT	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION	INPUT SKEW	COMPUTED SKEW	ADOPTED SKEW
BRWA41	78593.	67406.	9180.	413997.	4.7600	0.3550	-0.2000	-0.1175	-0.1375
BRBR59	129029.	108975.	17206.	710686.	4.9910	0.3287	-0.2000	-0.0582	-0.0916
BRRI70	133466.	105437.	18463.	636391.	5.0020	0.3436	-0.2000	-0.2359	-0.2267
LEGT47	16110.	16680.	459.	91968.	4.0099	0.4606	-0.2000	-0.7833	-0.5914
LRLR53	37782.	43576.	1430.	192938.	4.3260	0.4918	-0.2000	-0.0797	-0.1083
LRCA58	60447.	55261.	3992.	286974.	4.6122	0.4048	-0.2000	-0.2022	-0.2017
515731	52398.	39227.	4905.	188705.	4.5974	0.3456	-0.2000	-0.3545	-0.3125
515831	11315.	8931.	524.	37728.	3.8988	0.4035	-0.2000	-0.5264	-0.4305
509431	31281.	35564.	750.	219374.	4.2660	0.4786	-0.2000	-0.3063	-0.2781
515931	16529.	27206.	346.	195903.	3.9299	0.5145	-0.2000	-0.1594	-0.1694
516031	27967.	32982.	557.	164723.	4.1893	0.5101	-0.2000	-0.3318	-0.2964
516131	18814.	24148.	278.	120482.	3.9672	0.5651	-0.2000	-0.3465	-0.3069
516231	5200.	5392.	38.	23854.	3.4340	0.5886	-0.2000	-0.8319	-0.6196
516331	13582.	12803.	252.	57836.	3.9085	0.5101	-0.2000	-0.7478	-0.5703
516431	17013.	18292.	55.	97722.	3.8552	0.7257	-0.2000	-0.8132	-0.6089

Table 10.16 (continued)
Flood Frequency for Daily Regulated Stream Flow at the
Selected Control Points for Scenarios 10.01 and 10.02, ac-ft per day

Flood Frequencies for Daily Regulated Stream Flow,
Scenario 10.02, With Flood Control

CONTROL POINT	1.01 99%	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%	200 0.5%	500 0.2%	EXPECTED VALUE
	ANNUAL RECURRENCE INTERVAL (YEARS) AND EXCEEDANCE FREQUENCY (%)									
BRWA41	8272.	47898.	80113.	102336.	130555.	151374.	171864.	192079.	218419.	55512.
BRBR59	16614.	77531.	124910.	157702.	199819.	231349.	262832.	294372.	336250.	88165.
BRRI70	14134.	85155.	143106.	182938.	233284.	270241.	306459.	342030.	388144.	98836.
LEGT47	530.	9341.	20633.	29767.	42514.	52559.	62865.	73362.	87430.	13890.
LRLR53	1930.	9757.	18241.	25517.	36741.	46668.	58011.	70939.	90765.	13232.
LRCA58	3382.	28281.	54549.	75195.	104158.	127427.	151880.	177505.	213138.	37615.
515731	5941.	36387.	57229.	69794.	83964.	93310.	101706.	109290.	118245.	39260.
515831	1093.	5004.	7028.	8080.	9135.	9762.	10280.	10712.	11181.	4973.
509431	1314.	11423.	25706.	39526.	62841.	85012.	111764.	143780.	195484.	19030.
515931	221.	2097.	5606.	9735.	18054.	27348.	40176.	57659.	90407.	4764.
516031	895.	7302.	13204.	17419.	22859.	26908.	30907.	34855.	39995.	8972.
516131	329.	5038.	10660.	15060.	21059.	25699.	30393.	35115.	41363.	7150.
516231	56.	1200.	3501.	6083.	10903.	15846.	22137.	30011.	43305.	2786.
516331	289.	3032.	6461.	9414.	13865.	17670.	21866.	26464.	33174.	4521.
516431	331.	2420.	4377.	5817.	7735.	9206.	10697.	12208.	14232.	3006.

Statistics for Peak Annual Regulated Streamflow, Log-Pearson Type III Distribution

					Statistics for Logarithms of Annual Peaks				
CONTROL POINT	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION	INPUT SKEW	COMPUTED SKEW	ADOPTED SKEW
BRWA41	55103.	30572.	9371.	133515.	4.6611	0.2837	-0.2000	-0.4922	-0.4077
BRBR59	88636.	53165.	17227.	336335.	4.8766	0.2580	-0.2000	-0.3355	-0.2990
BRRI70	98228.	57987.	16571.	279689.	4.9095	0.2878	-0.2000	-0.5302	-0.4330
LEGT47	13339.	14336.	459.	85031.	3.9317	0.4471	-0.2000	-0.6686	-0.5220
LRLR53	13170.	13032.	1420.	79097.	3.9958	0.3177	-0.2000	0.2344	0.1230
LRCA58	36340.	26432.	4002.	105926.	4.4337	0.3555	-0.2000	-0.3377	-0.3006
515731	39489.	20949.	4904.	139654.	4.5294	0.2665	-0.2000	-1.0474	-0.7175
515831	5044.	1543.	524.	5950.	3.6669	0.2109	-0.2000	-2.4640	-0.9336
509431	18055.	18041.	750.	59505.	4.0625	0.4148	-0.2000	0.1569	0.0687
515931	4339.	6202.	346.	40911.	3.3498	0.4865	-0.2000	0.5847	0.3481
516031	8885.	6929.	558.	45314.	3.8371	0.3314	-0.2000	-0.6009	-0.4791
516131	6697.	5140.	278.	23136.	3.6648	0.4238	-0.2000	-0.6867	-0.5331
516231	2396.	2523.	38.	9371.	3.0732	0.5579	-0.2000	-0.0219	-0.0631
516331	4260.	3547.	252.	19598.	3.4667	0.4040	-0.2000	-0.2311	-0.2232
516431	2950.	2027.	379.	11587.	3.3636	0.3248	-0.2000	-0.4417	-0.3734

Peak annual flow is reduced across all exceedance frequencies in Table 10.16 when flood control is included in the Bwam simulation. In particular, the maximum value of regulated flow during the simulation is greatly reduced with the inclusion of flood control. The maximum value of regulated flow is presented in the table statistics.

Daily regulated flow-frequencies are given in Table 10.17 for Scenarios 10.01 and 10.02. The inclusion of flood control reduces the maximum value of regulated flow during the simulation. The presence of flood control, however, increases the regulated flows at many control points at levels below the maximum value. The increase in regulated flow is most notable from the 10% to 50% exceedances and is due to flood control releases being made immediately after flood conditions have subsided. The results of Table 10.17 suggest that flood control operations switch from storing to releasing between the 10% exceedance and the maximum value of regulate flow.

Time series of daily regulated flows and end of day reservoir storages are shown to compare the results without and with flood control, respectively. The time series are shown in Figures 10.2 through 10.25. The dashed lines accompanying the regulated flow time series, Figures 10.2 through 10.16, are set at the maximum allowable discharges at the downstream gages and the maximum allowable releases at the dam sites. These maximum values are given in Table 10.8. The flood control reservoirs, however, may have other release rate limits depending on the storage contents in the flood pool. Likewise, the Little River gage has a variable discharge limit with respect to the combined storage in Proctor, Belton and Stillhouse Hollow.

Whitney and Waco Lakes are modeled as separate conservation and flood control reservoirs in order to accommodate the *SIM/SIMD* evaporation-allocation simulation features. Therefore, flood control does not contribute to refilling conservation storage. This is most evident in Figure 10.19 for Waco Lake. The flood event of 1957 fills flood control storage, but does not contribute to recovery in the separate multiple conservation reservoirs.

Table 10.17
Daily Regulated Flow-Frequency for Scenarios 10.01 and 10.02, ac-ft per day

Scenario 10.01, Without Flood Control

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
BRWA41	3495.43	11224.8	0.00	4.65	7.58	19.89	62.35	193.35	371.9	576.7	923.2	2051.5	7353.5	413996.7
BRBR59	8267.18	21273.4	0.00	37.66	105.09	208.24	336.02	718.93	1263.3	1782.9	2711.4	6212.9	20386.6	710685.8
BRRI70	12477.02	24859.5	8.56	141.85	271.62	474.86	751.96	1576.70	2247.4	3266.3	5397.2	12207.4	33474.1	636390.9
LEGT47	631.59	2326.3	0.00	0.00	0.00	0.00	0.24	14.60	42.4	82.8	150.4	378.4	1338.6	91967.7
LRLR53	1640.66	5545.0	0.00	0.00	0.00	5.50	16.31	73.11	146.0	225.7	372.5	956.3	3840.4	192938.4
LRCA58	2780.58	8501.2	0.00	0.00	1.11	19.98	39.67	129.44	298.8	479.8	783.1	1940.2	6555.1	286974.5
515731	2262.65	8030.5	0.00	0.00	0.00	0.00	6.78	78.45	195.0	316.0	510.3	1161.3	4263.9	188705.4
515831	150.05	1037.9	0.00	0.00	0.00	0.96	0.99	0.99	1.0	1.0	1.0	7.6	103.9	37727.5
509431	698.89	3446.9	0.00	0.00	0.00	0.00	0.00	0.00	0.9	14.2	52.8	261.9	1331.2	219374.1
515931	296.37	2134.2	0.00	0.00	0.00	0.00	0.00	0.00	0.6	5.1	15.4	66.5	448.7	195902.8
516031	952.11	3670.7	0.00	0.00	0.00	0.00	0.00	4.10	37.8	74.0	133.9	441.9	2156.3	164722.8
516131	419.22	2053.2	0.00	0.00	0.00	0.00	0.00	0.00	10.7	21.3	40.4	136.4	995.1	120481.6
516231	117.72	568.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	3.5	10.2	50.2	272.3	23854.5
516331	397.73	1534.0	0.00	0.00	0.00	0.00	0.00	1.38	16.9	39.4	77.3	258.0	893.8	57836.4
516431	436.51	2154.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	19.7	683.3	97721.6

Table 10.17 (continued)
Daily Regulated Flow-Frequency for Scenarios 10.01 and 10.02, ac-ft per day

Scenario 10.02, With Flood Control

CONTROL		STANDARD	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRWA41	3501.28	9838.9	0.00	1.78	6.73	15.32	59.24	185.74	356.3	552.8	884.9	1972.1	7625.8	133515.1
BRBR59	8249.02	16606.7	0.00	24.40	102.14	203.88	334.03	723.83	1276.3	1858.4	2923.9	7592.9	22776.7	336335.2
BRRI70	12459.10	20880.9	0.00	107.92	259.99	472.92	755.28	1610.33	2287.5	3475.8	6077.0	13951.1	34401.2	279689.4
LEGT47	626.98	1834.5	0.00	0.00	0.00	0.00	0.05	14.22	42.0	85.6	162.2	499.9	1467.5	85030.7
LRLR53	1618.06	3355.3	0.00	0.00	0.00	2.97	14.15	70.56	146.2	232.1	396.5	1071.0	5950.5	79096.6
LRCA58	2755.12	5654.2	0.00	0.00	0.06	16.10	39.67	128.11	306.1	498.0	832.9	2387.9	8714.5	105925.5
515731	2274.02	7529.2	0.00	0.00	0.00	0.00	1.02	66.98	175.9	285.1	469.7	1060.3	3863.3	139653.6
515831	149.21	758.0	0.00	0.00	0.00	0.00	0.99	0.99	1.0	1.0	1.0	6.4	87.2	5950.0
509431	694.26	2941.6	0.00	0.00	0.00	0.00	0.00	0.00	0.4	10.5	42.1	208.1	1223.6	59505.0
515931	288.61	1133.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	3.7	11.8	59.1	990.0	40910.8
516031	938.97	2436.7	0.00	0.00	0.00	0.00	0.00	0.18	31.4	65.4	123.8	413.7	2947.2	45314.5
516131	409.51	1358.6	0.00	0.00	0.00	0.00	0.00	0.00	5.9	17.2	32.7	106.0	919.9	23135.4
516231	116.20	452.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	3.5	9.4	39.8	500.0	9370.6
516331	394.45	971.4	0.00	0.00	0.00	0.00	0.00	0.76	16.1	38.5	74.3	265.5	1290.0	19598.3
516431	435.25	957.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	63.9	1984.0	11587.4

Control Points

BRWA41	Waco Gage on Brazos River
BRBR59	Bryan Gage on Brazos River
BRRI70	Richmond Gage on Brazos River
LEGT47	Gatesville Gage on Leon River
LRLR53	Little River Gage on Little River
LRCA58	Cameron Gage on Little River
515731	Whitney Reservoir
515831	Aquilla Reservoir
509431	Waco Reservoir
515931	Proctor Reservoir
516031	Belton Reservoir
516131	Stillhouse Hollow Res.
516231	Georgetown Reservoir
516331	Granger Reservoir
516431	Somerville Reservoir

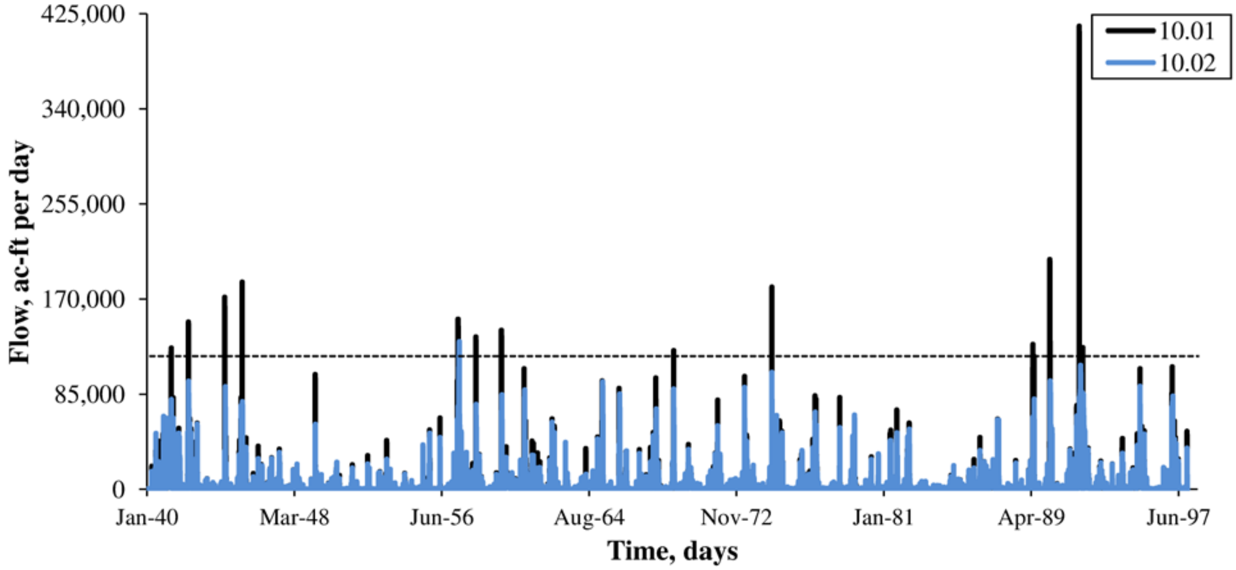

Figure 10.2 Regulated Flow at the Waco Gage on the Brazos River

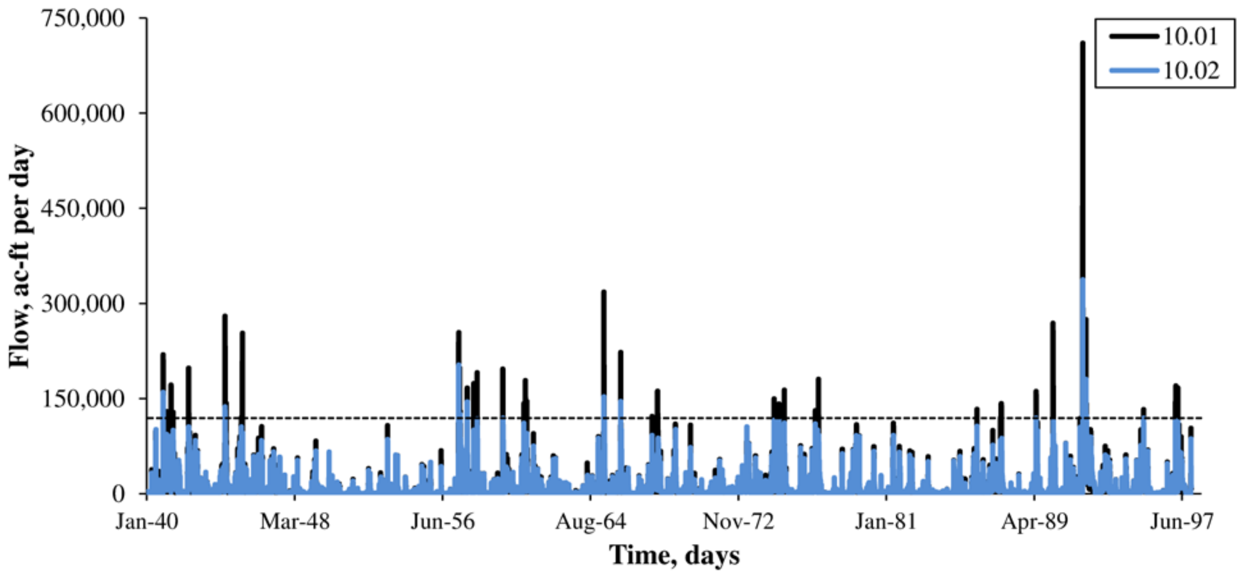

Figure 10.3 Regulated Flow at the Bryan Gage on the Brazos River

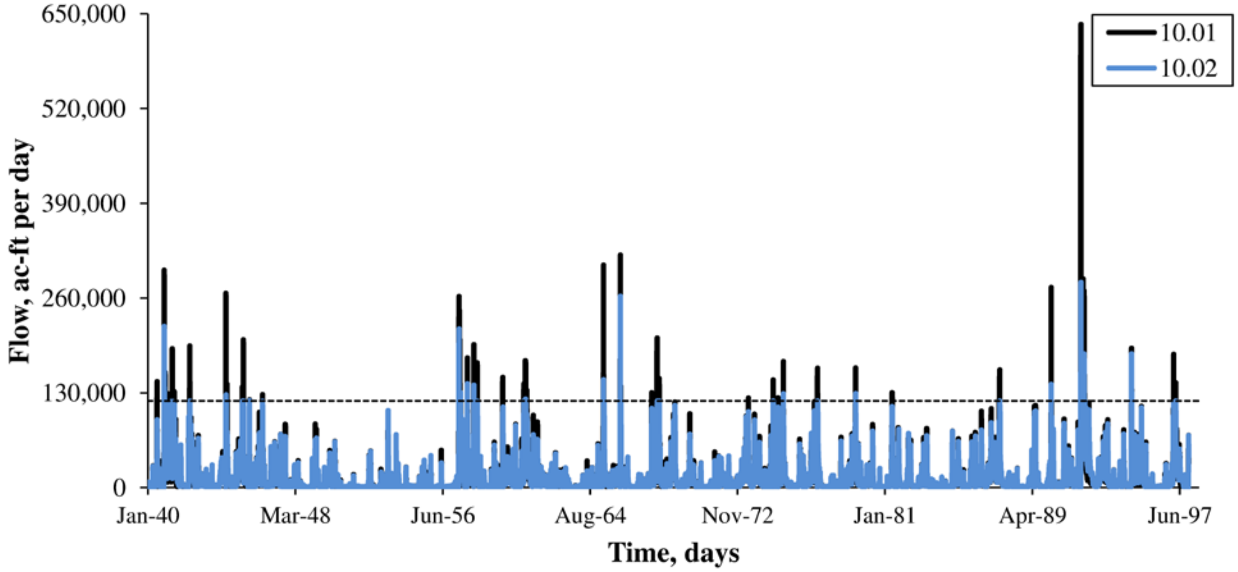

Figure 10.4 Regulated Flow at the Richmond Gage on the Brazos River

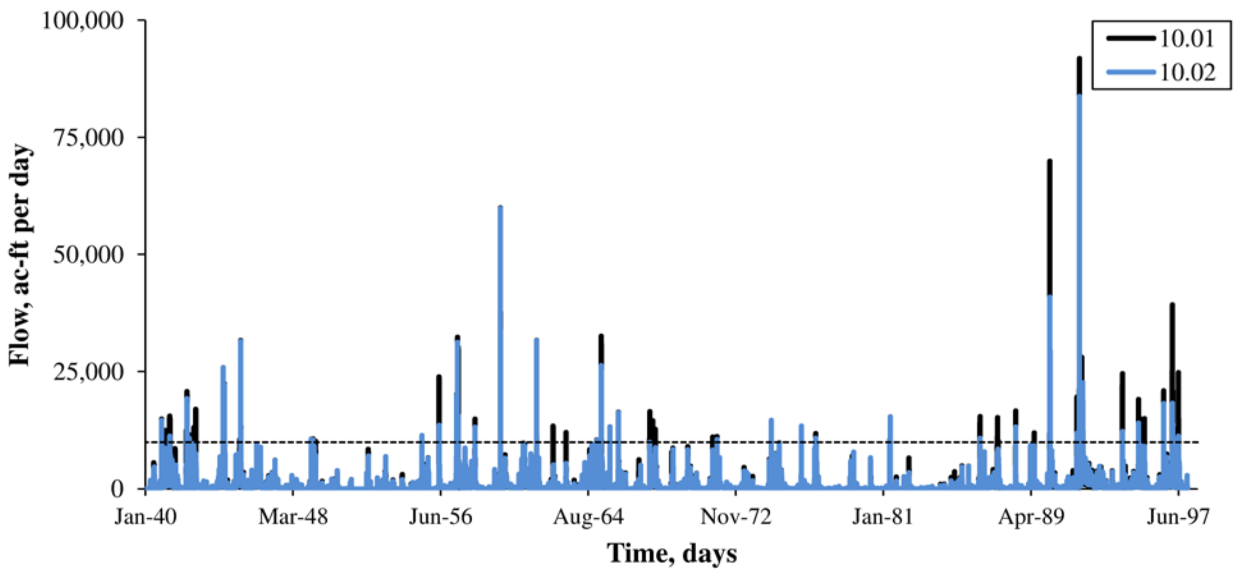

Figure 10.5 Regulated Flow at the Gatesville Gage on the Leon River

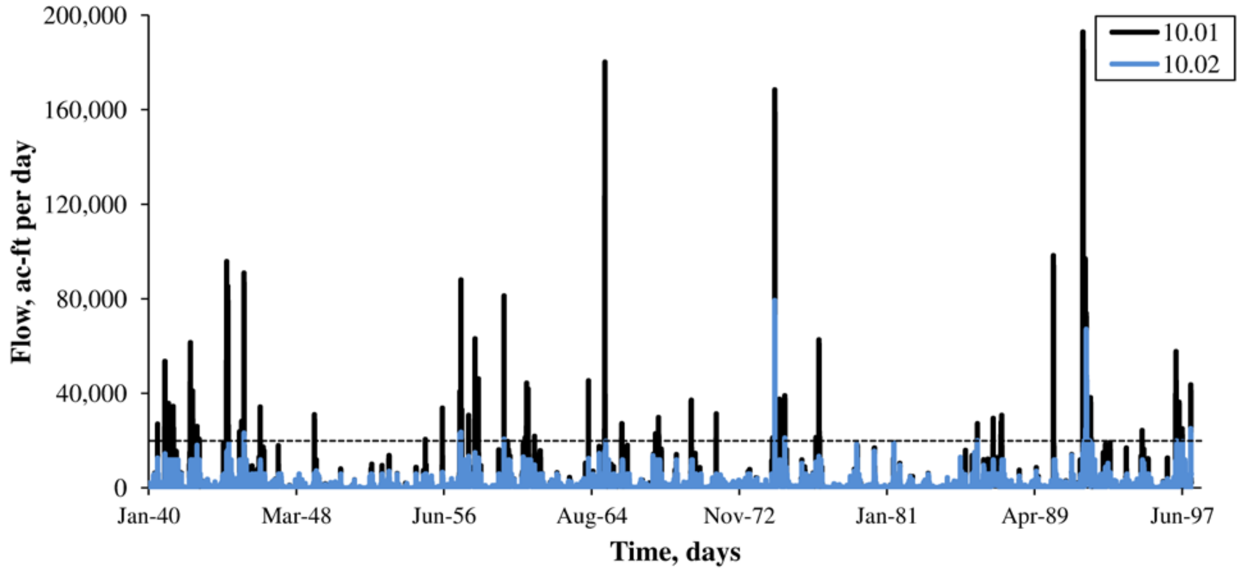

Figure 10.6 Regulated Flow at the Little River Gage on the Little River

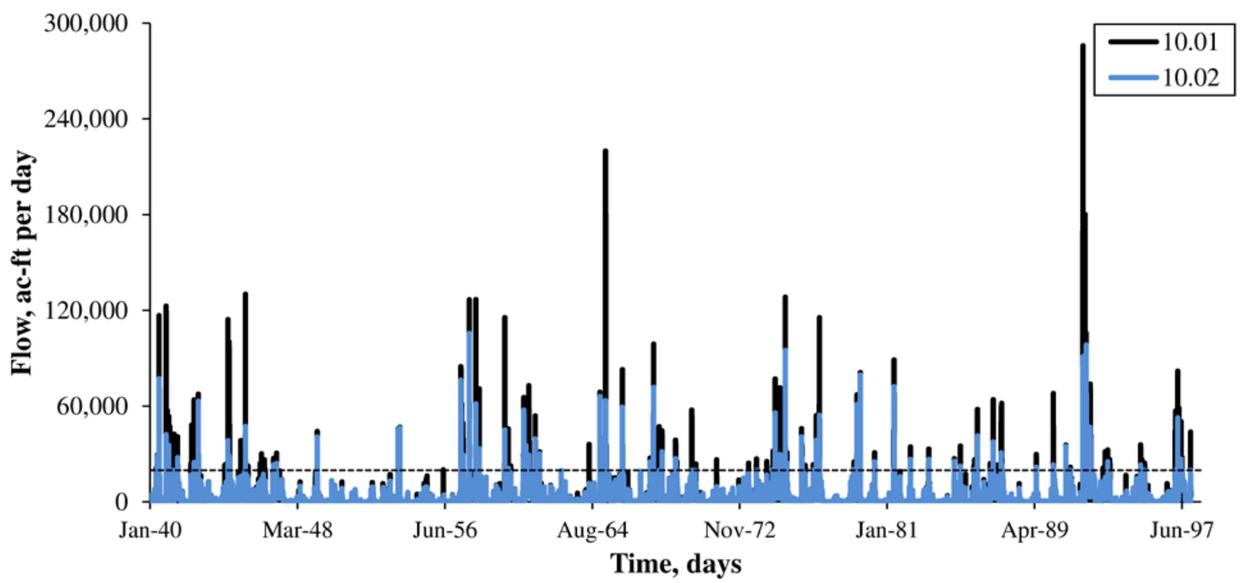

Figure 10.7 Regulated Flow at the Cameron Gage on the Little River

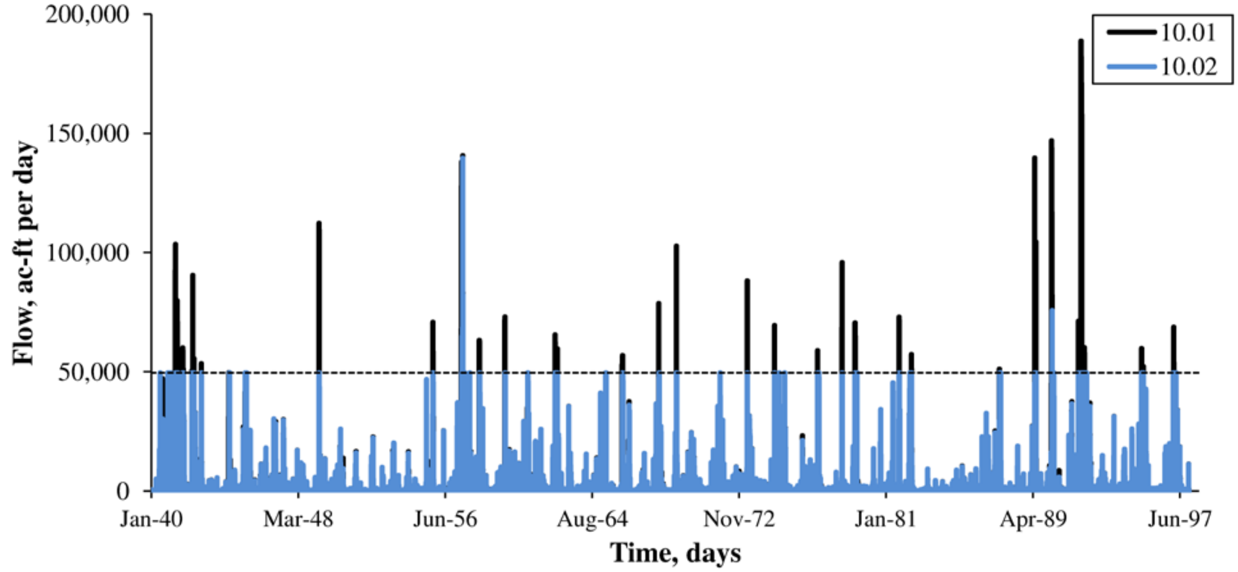

Figure 10.8 Regulated Flow at the Dam of Whitney Lake

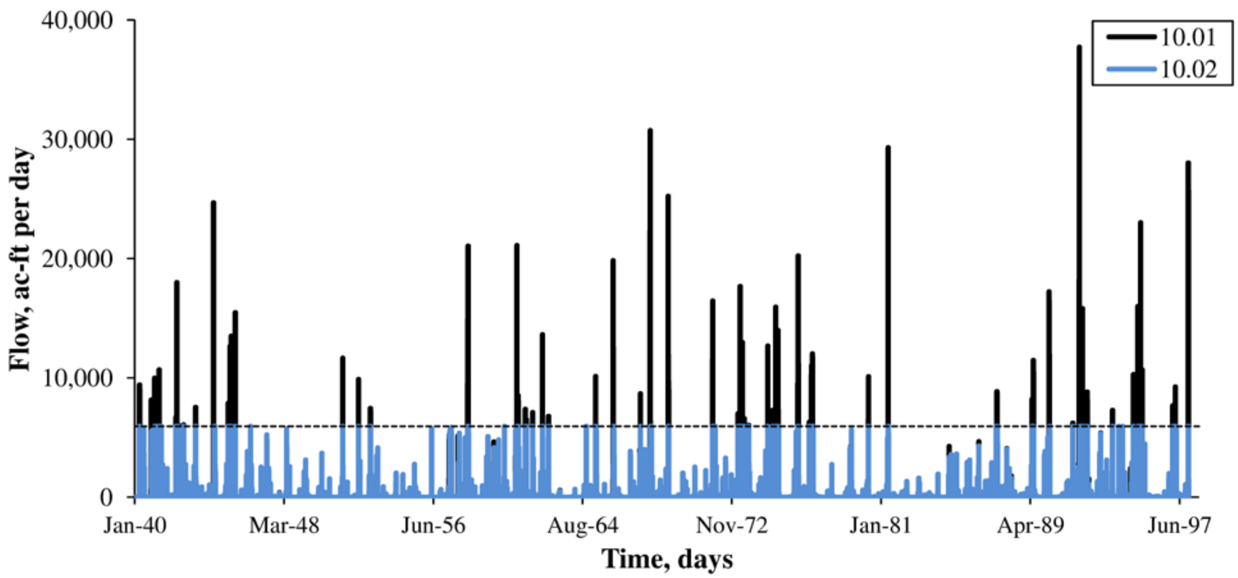

Figure 10.9 Regulated Flow at the Dam of Aquilla Lake

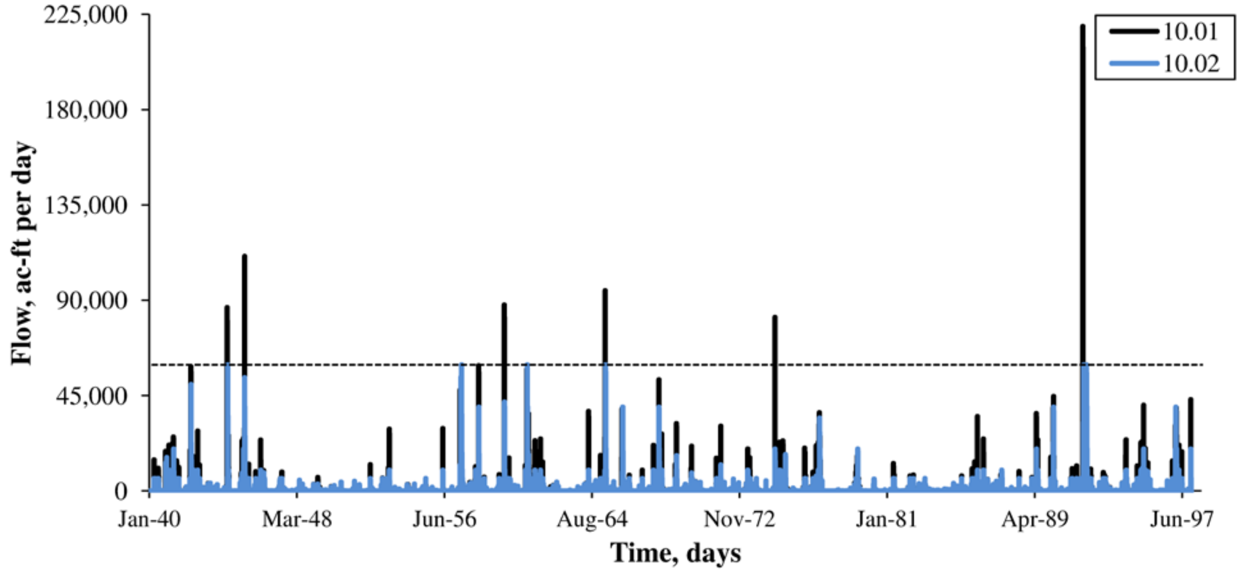

Figure 10.10 Regulated Flow at the Dam of Waco Lake

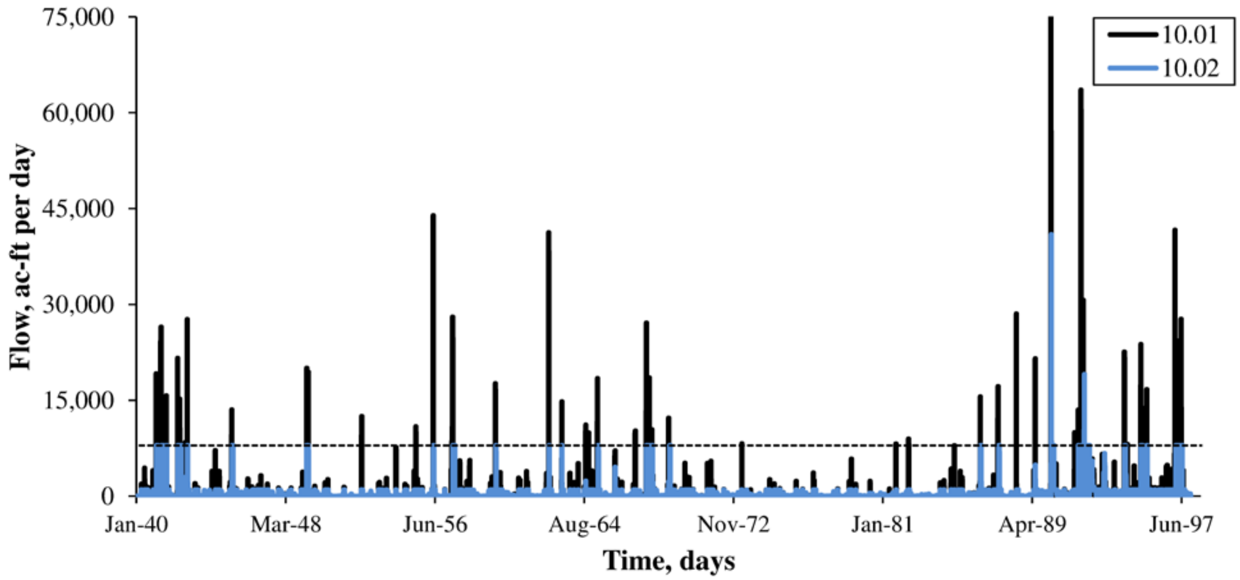

Figure 10.11 Regulated Flow at the Dam of Proctor Lake

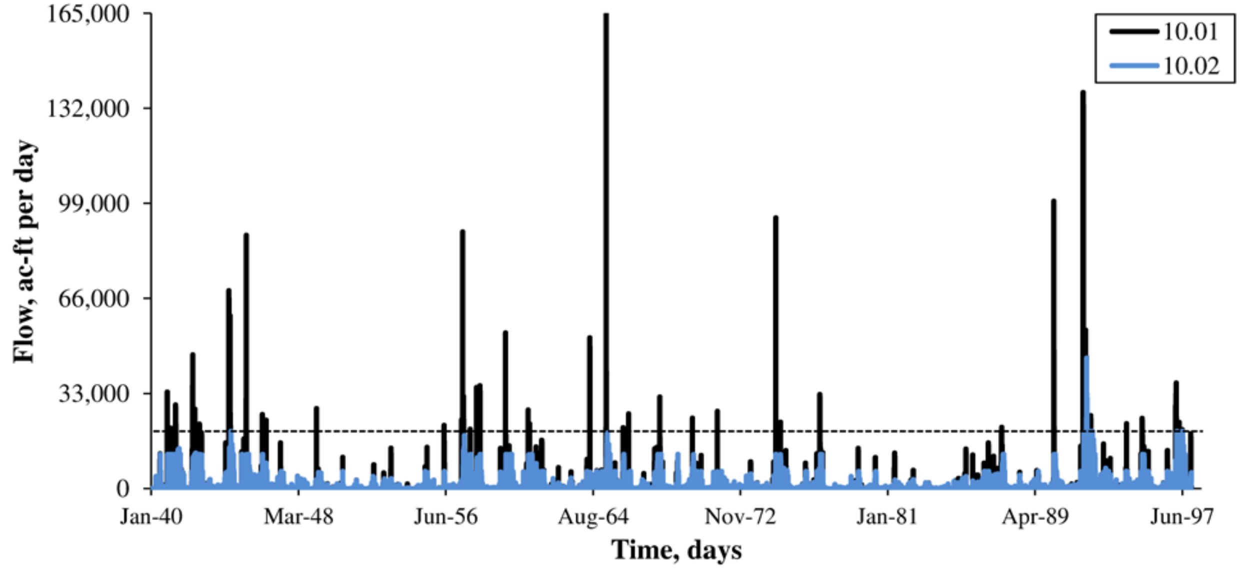

Figure 10.12 Regulated Flow at the Dam of Belton Lake

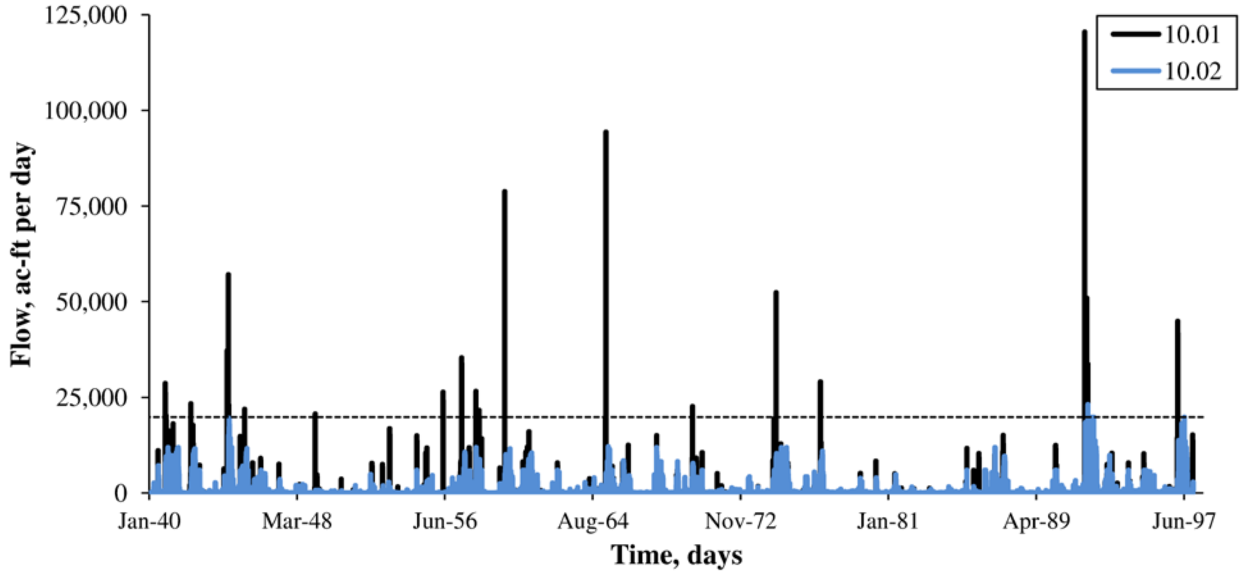

Figure 10.13 Regulated Flow at the Dam of Stillhouse Hollow Lake

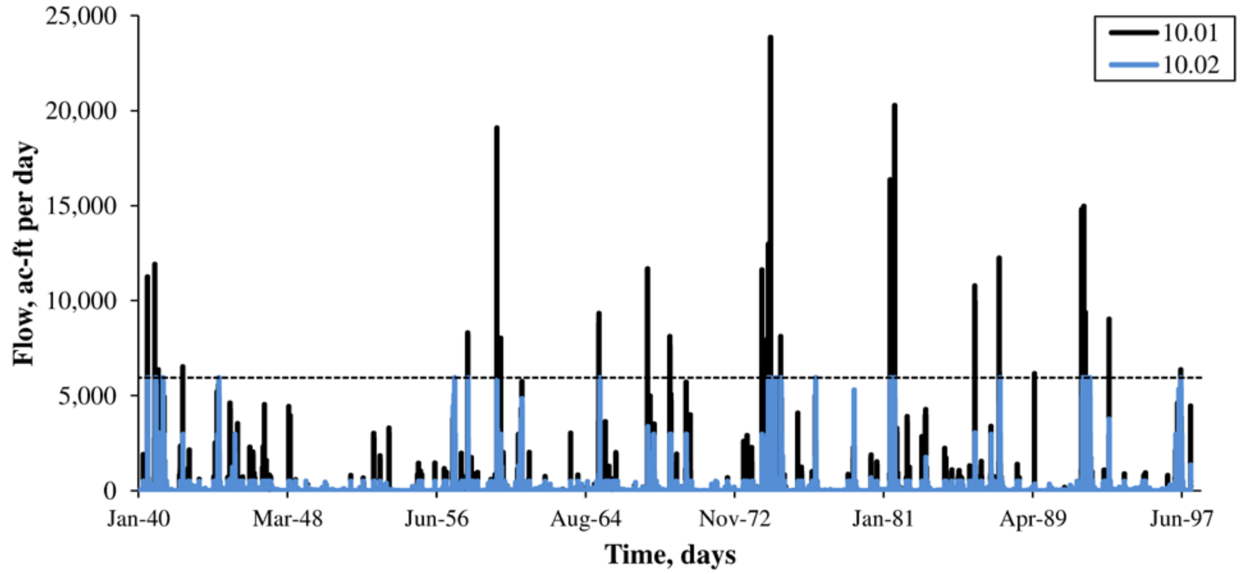

Figure 10.14 Regulated Flow at the Dam of Georgetown Lake

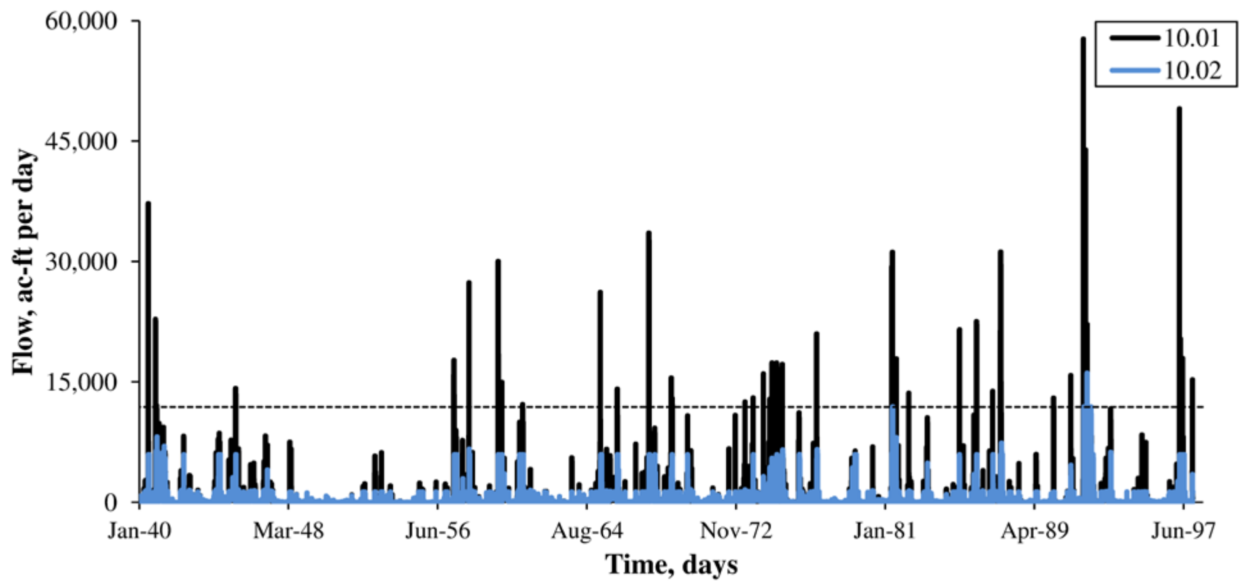

Figure 10.15 Regulated Flow at the Dam of Granger Lake

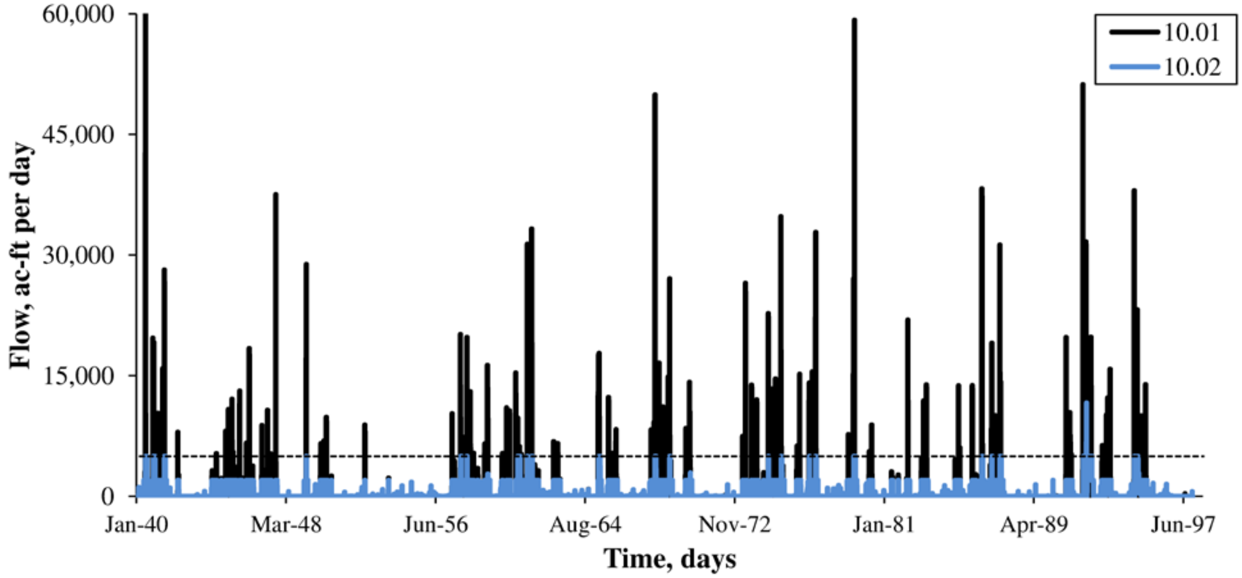

Figure 10.16 Regulated Flow at the Dam of Somerville Lake

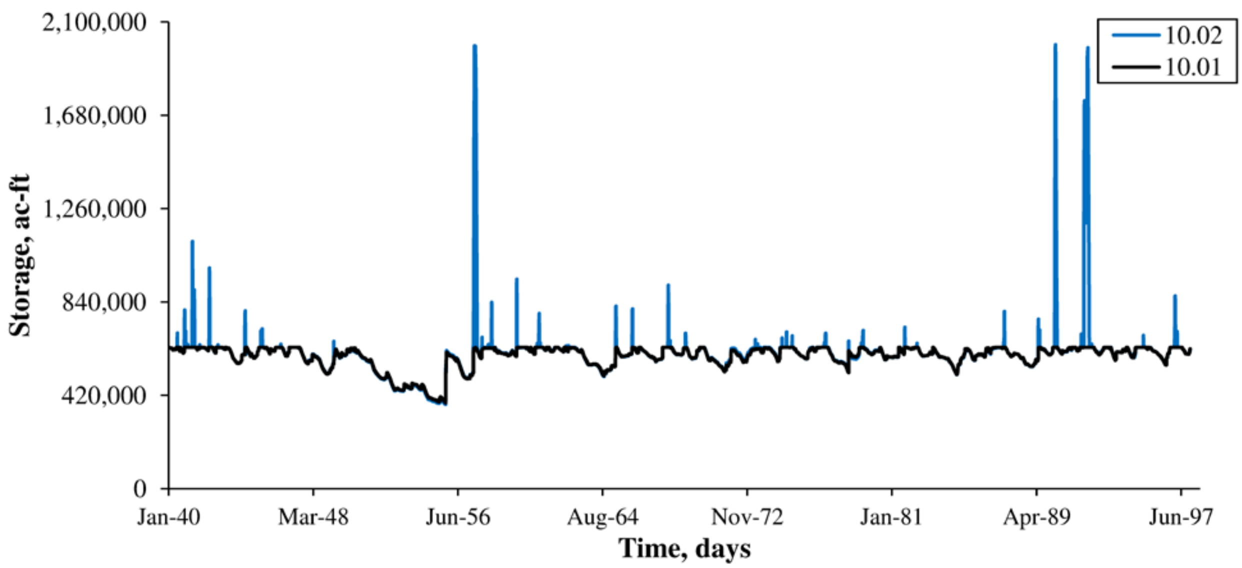

Figure 10.17 Storage in Whitney Lake

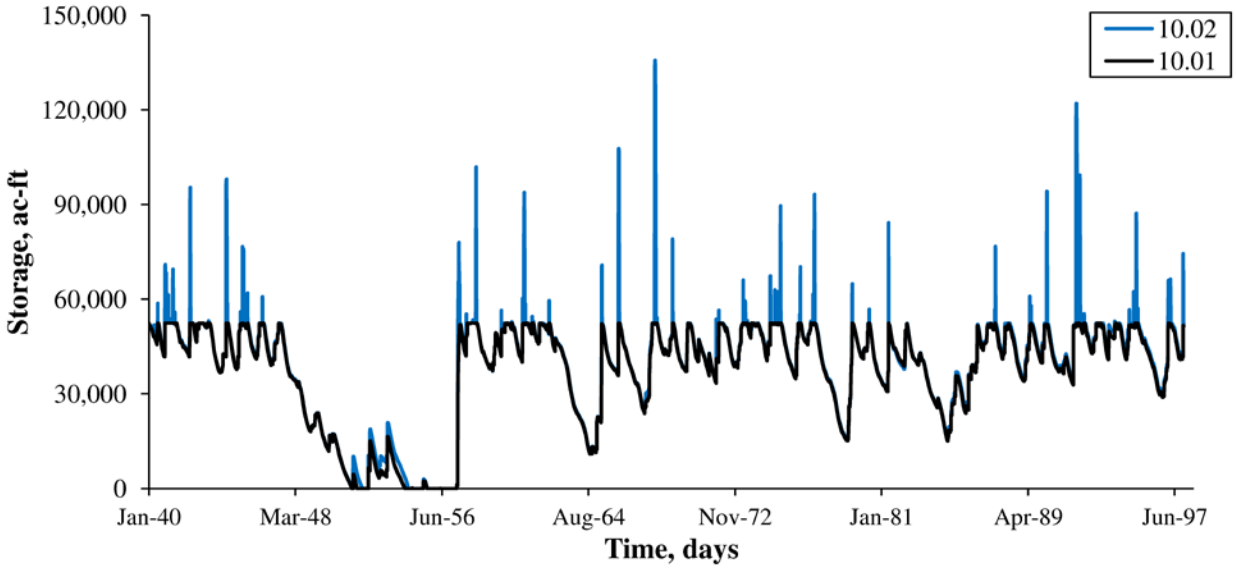

Figure 10.18 Storage in Aquilla Lake

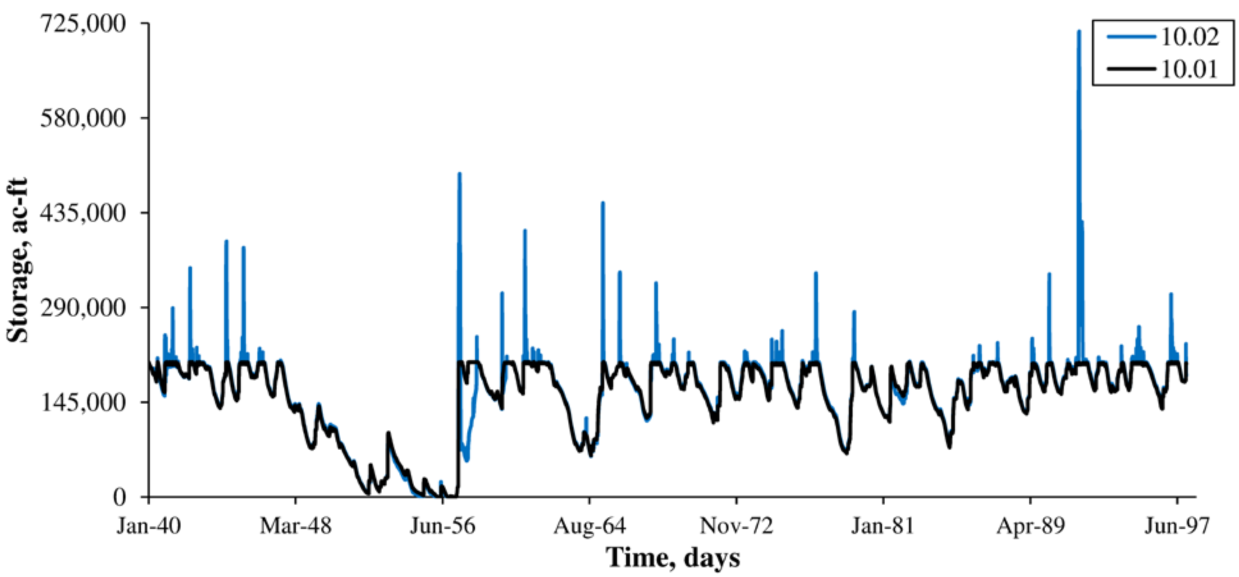

Figure 10.19 Storage in Waco Lake

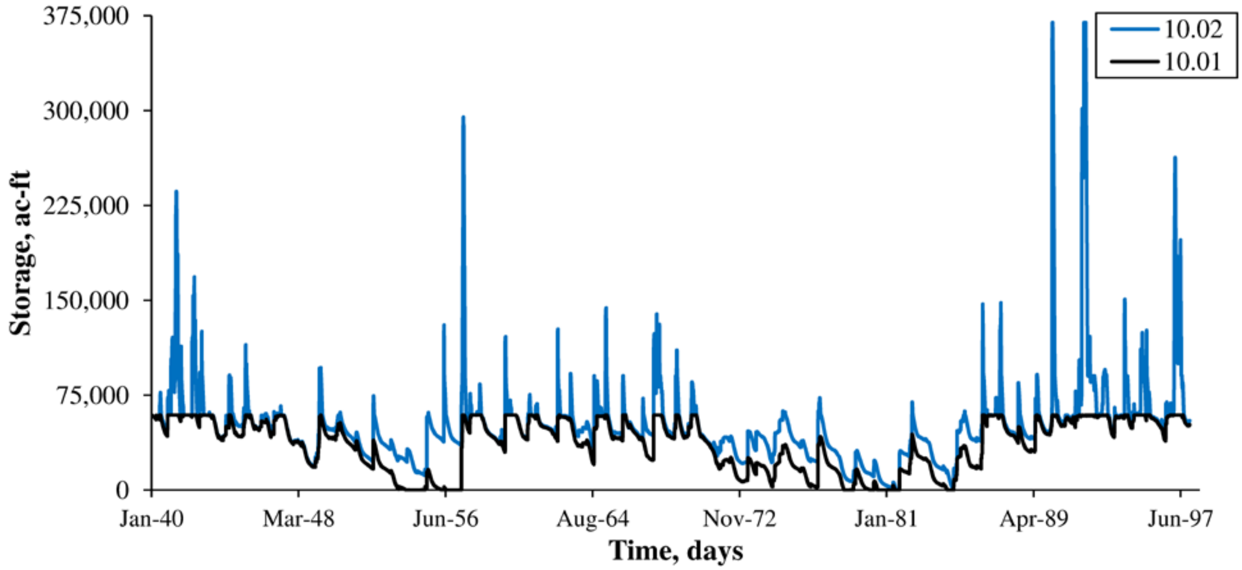

Figure 10.20 Storage in Proctor Lake

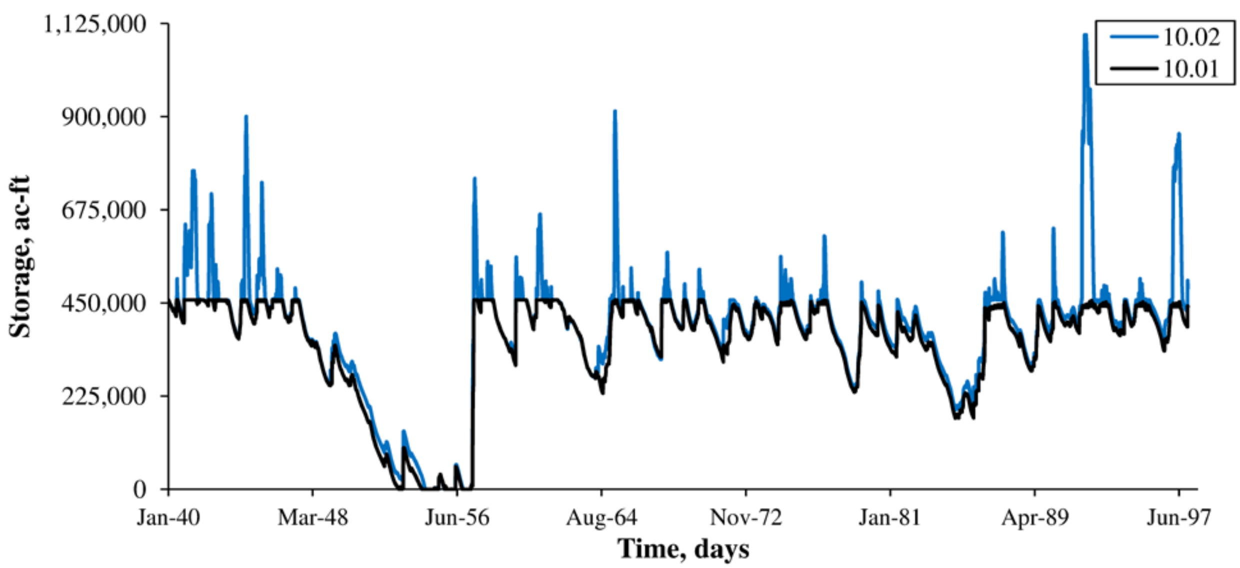

Figure 10.21 Storage in Belton Lake

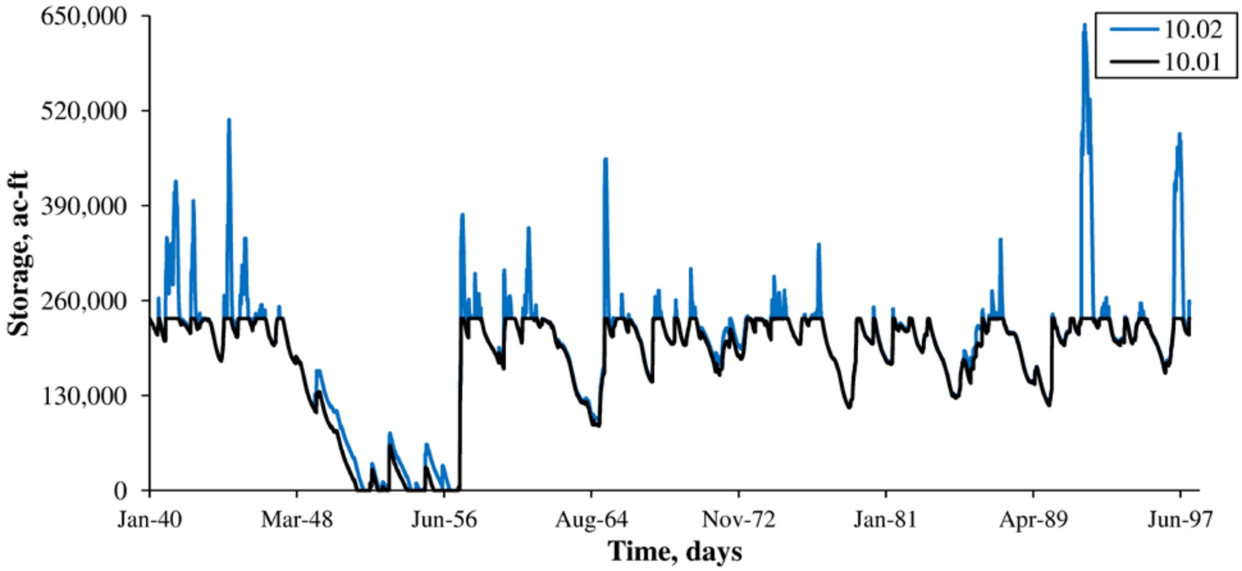

Figure 10.22 Storage in Stillhouse Hollow Lake

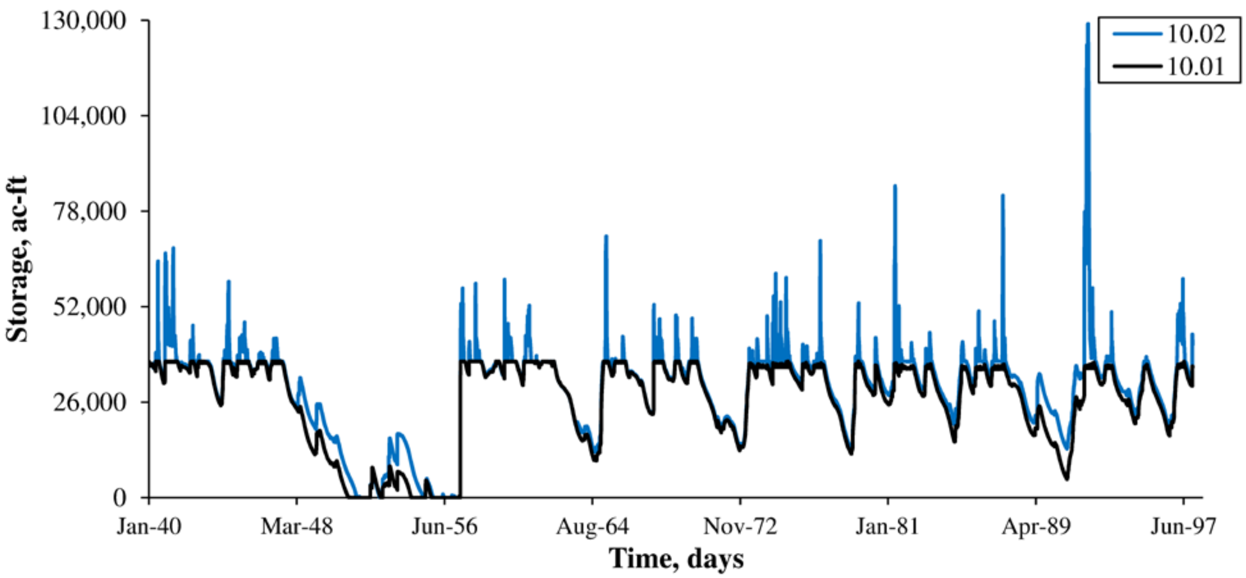

Figure 10.23 Storage in Georgetown Lake

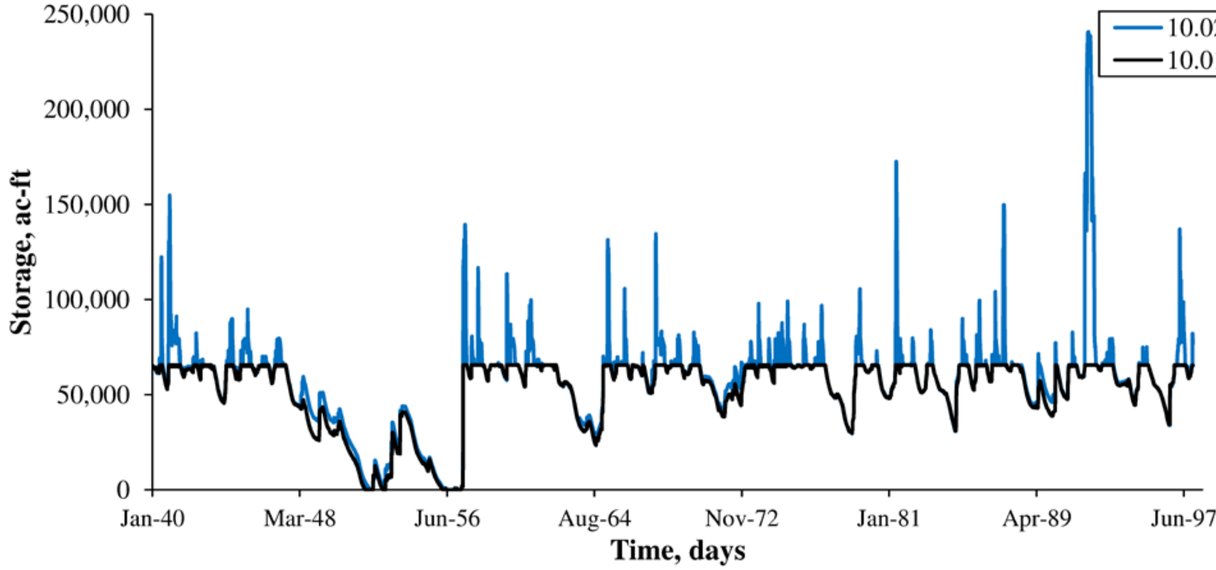

Figure 10.24 Storage in Granger Lake

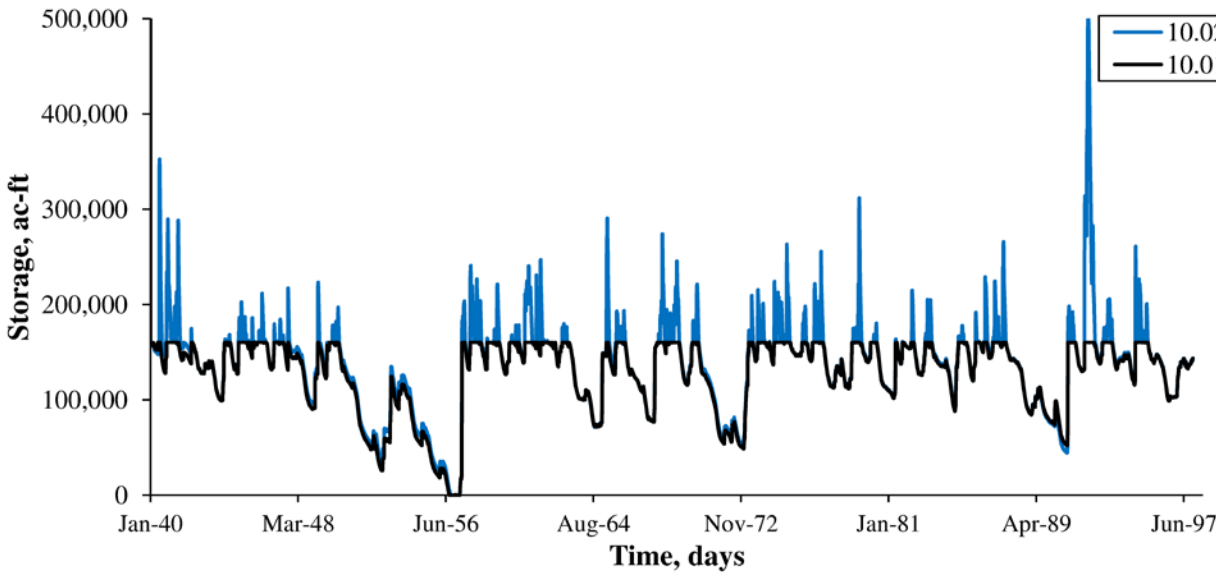

Figure 10.25 Storage in Somerville Lake

Comparison to USGS Gaged Flow

The following section presents the results of Scenario 10.02 at selected locations along the Brazos and Little Rivers. The USGS gaged stream flows at the same locations are plotted for comparison to the *SIMD* naturalized and regulated stream flow. The USGS stream gages are listed in Table 10.18. *SIMD* stream flow units are acre-feet per day. However, all *SIMD* results were converted into daily average cubic feet per second to correspond to the USGS gaged flow. The results are displayed for flood events occurring in 1992 and 1997. Dashed lines on the plots indicate the *FF* record flood flow limits used in the Scenario 10.2. The figures specific to the Little River gage contain three dashed lines which correspond to the *FF* record flood flow limits which vary according to the total storage in Proctor, Belton, and Stillhouse Hollow Lakes.

Differences should be noted between the *SIMD* results presented and the USGS gaged flow. Scenario 10.02 is based on the Bwam3 dataset for full water right authorization. Water rights are simulated as exercising their fully authorized diversion demands without generating return flows. Reservoirs are modeled without conservation pool sedimentation. The USGS gaged flows are indicative of the real-world water right diversion and return flows and reservoir sedimentation conditions which existed at the time of recording. Additionally, *SIMD* operates on a discrete daily time step. Flood control stream flow depletions and releases are carried out over the course of a full day within the simulation. Real-world flood control operations are made on a continuous basis with many storage and release decisions throughout a single day to coordinate the flood control response of the system of reservoirs.

Figures 10.26 through 10.32 cover the major basinwide flood event which began in late 1991 and continued with flood control releases through August, 1992. Figures 10.26 and 10.27 present the naturalized flow used in the *SIMD* simulation. Figures 10.28 through 10.32 present the *SIMD* naturalized flow, *SIMD* regulated flow, and USGS gaged flow at the Waco, Bryan, Richmond, Little River, and Cameron stream gages.

Figures 10.33 through 10.39 cover a smaller flood event that began in February, 1997 and continued with flood control releases through August, 1997. The effects of the flood event were primarily centered downstream of the Waco gage and in the Little River Basin. Figures 10.33 and 10.34 present the naturalized flood used in the *SIMD* simulation. Figures 10.35 through 10.39 present the *SIMD* naturalized flow, *SIMD* regulated flow, and USGS gaged flow at the Waco, Bryan, Richmond, Little River, and Cameron stream gages.

Table 10.18
Selected Control Points and USGS Gages

Control Point ID	USGS Gage Name	USGS Gage Number
BRWA41	Brazos River near Waco	08096500
BRBR59	Brazos River at SH 21near Bryan	08108700
BRRI70	Brazos River near Richmond	08114000
LRLR53	Little River near Little River	08104500
LRCA58	Little River near Cameron	08106500

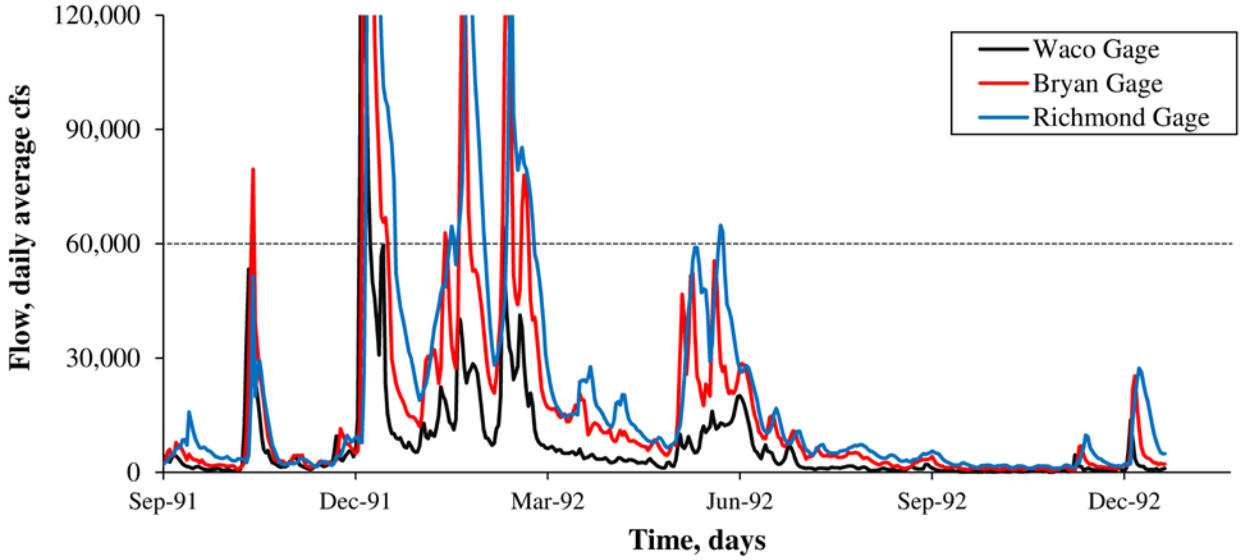

Figure 10.26 *SIMD* Naturalized Flow at the Waco, Bryan, and Richmond Gages

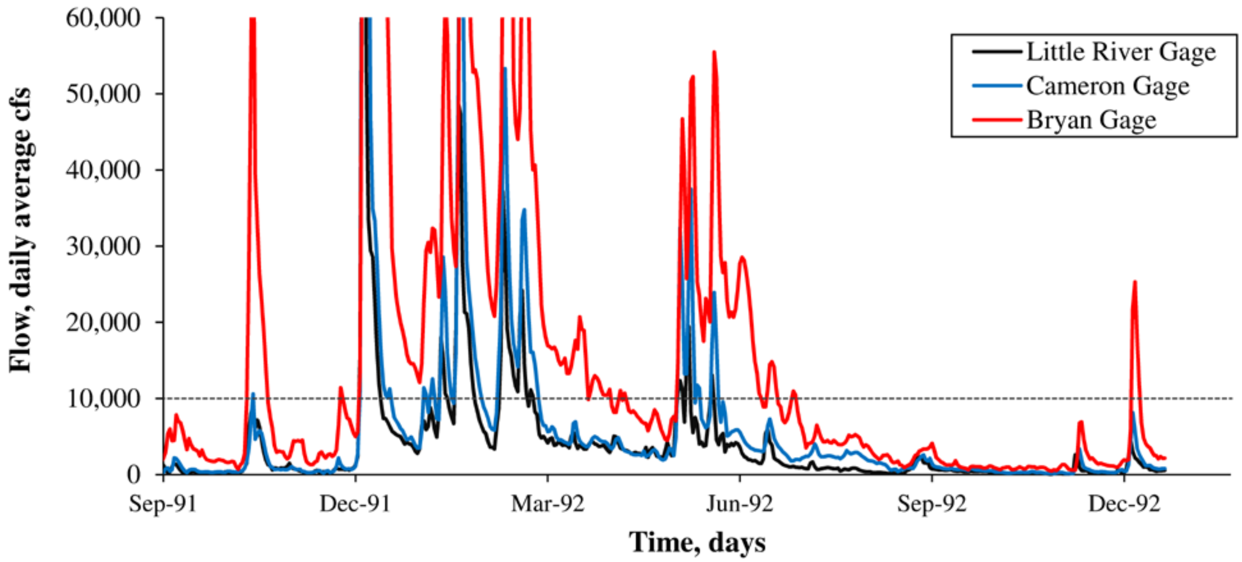

Figure 10.27 *SIMD* Naturalized Flow at the Little River, Cameron, and Bryan Gages

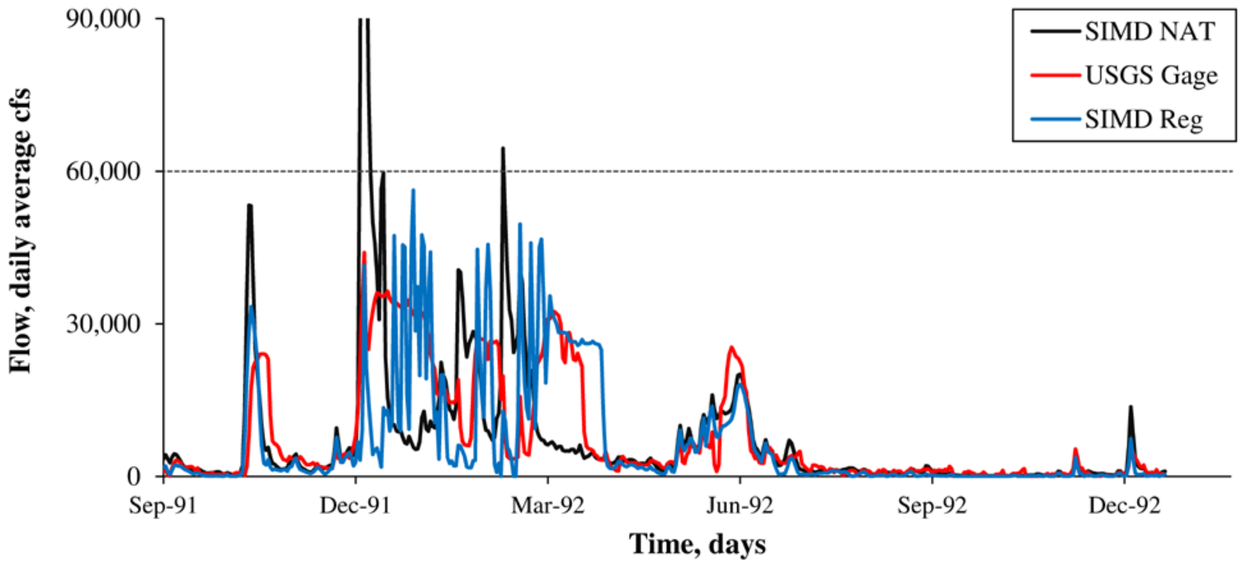

Figure 10.28 Waco Gage *SIMD* Naturalized and Regulated Flow and USGS Gaged Flow

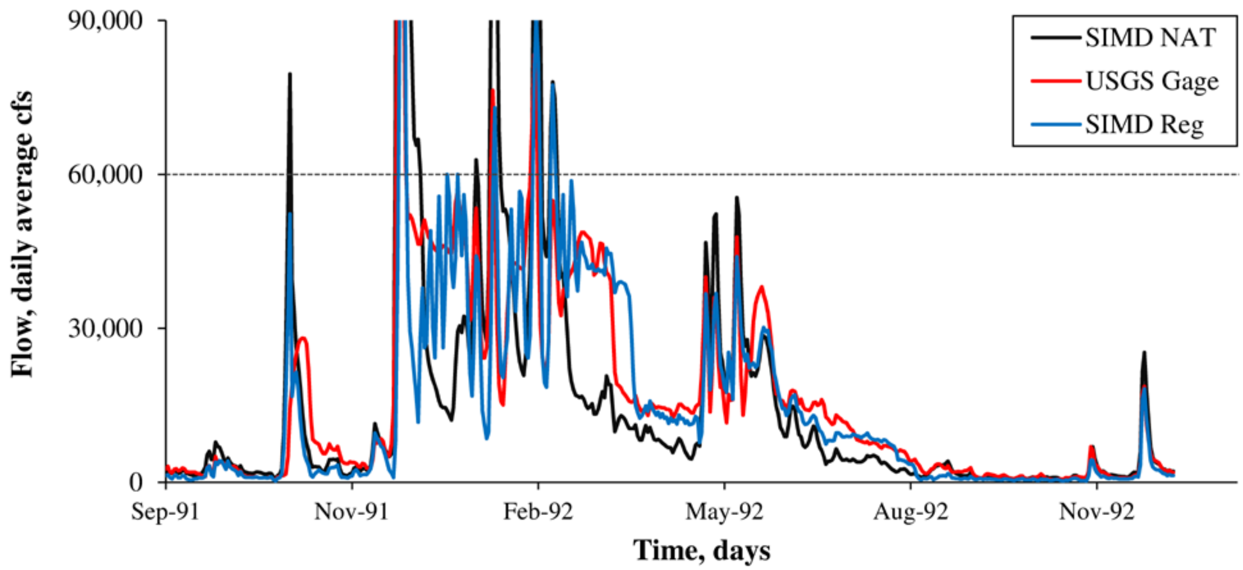

Figure 10.29 Bryan Gage *SIMD* Naturalized and Regulated Flow and USGS Gaged Flow

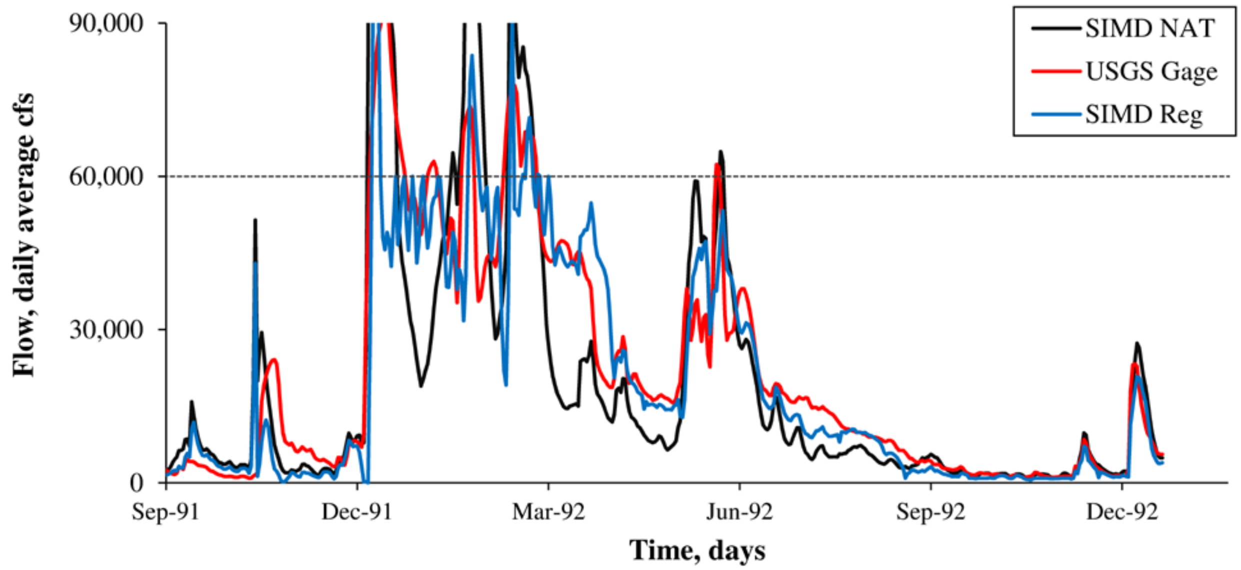

Figure 10.30 Richmond Gage *SIMD* Naturalized and Regulated Flow and USGS Gaged Flow

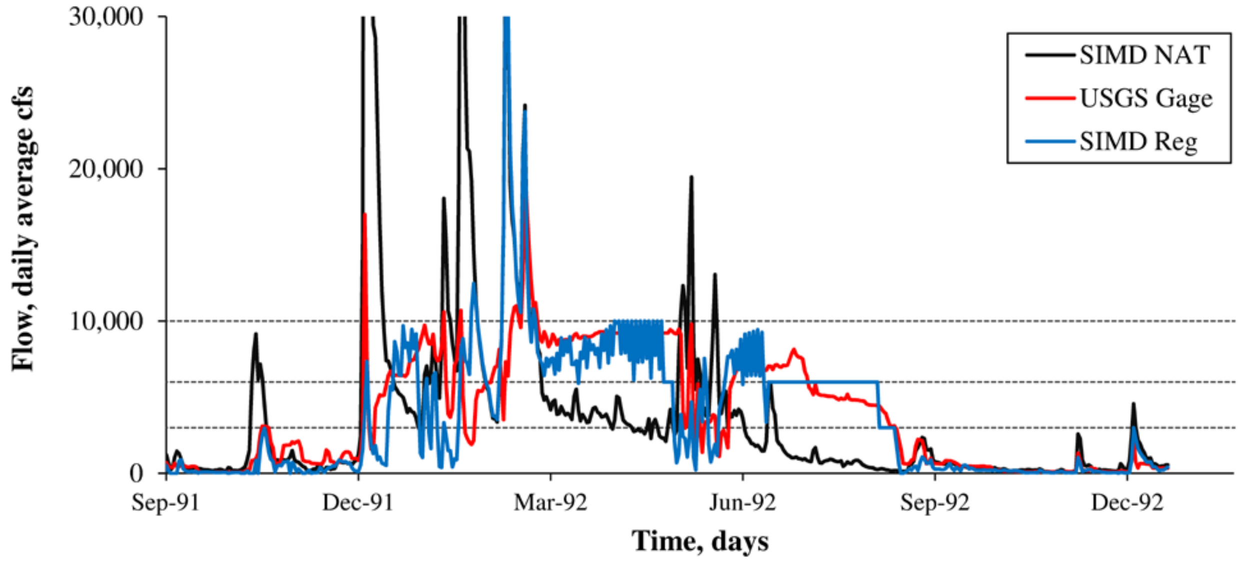

Figure 10.31 Little River Gage *SIMD* Naturalized and Regulated Flow and USGS Gaged Flow

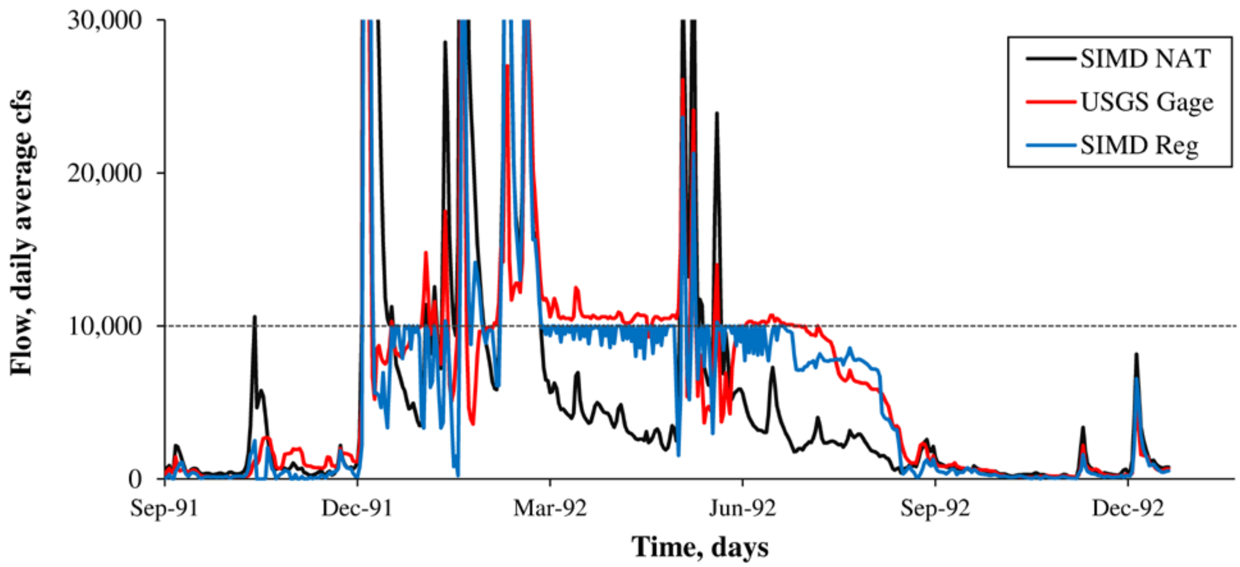

Figure 10.32 Cameron Gage *SIMD* Naturalized and Regulated Flow and USGS Gaged Flow

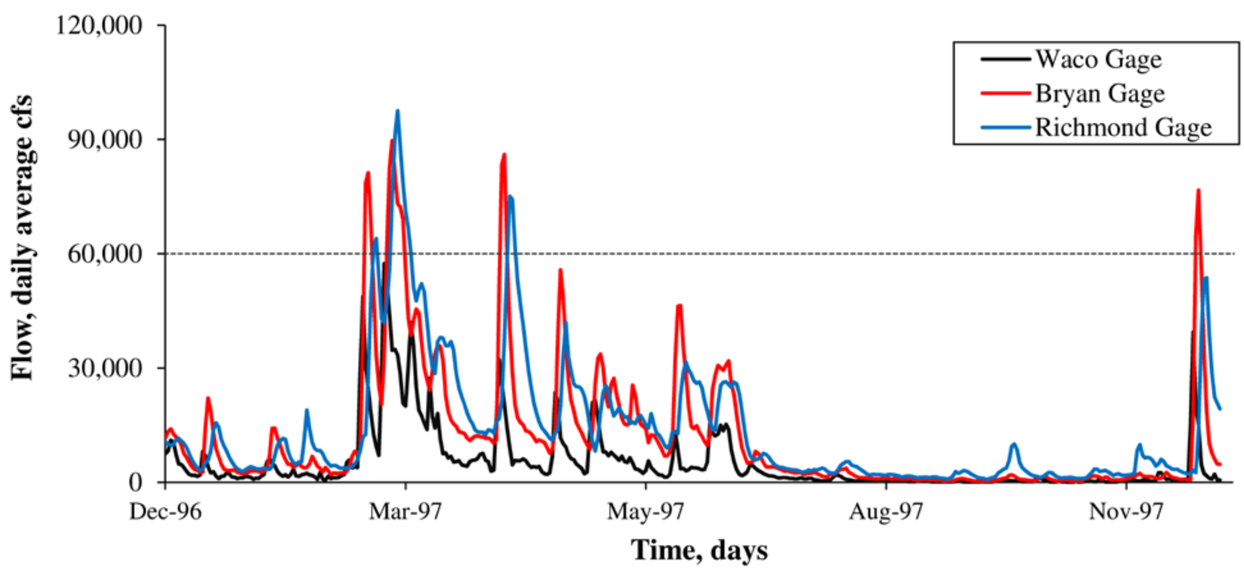

Figure 10.33 *SIMD* Naturalized Flow at the Waco, Bryan, and Richmond Gages

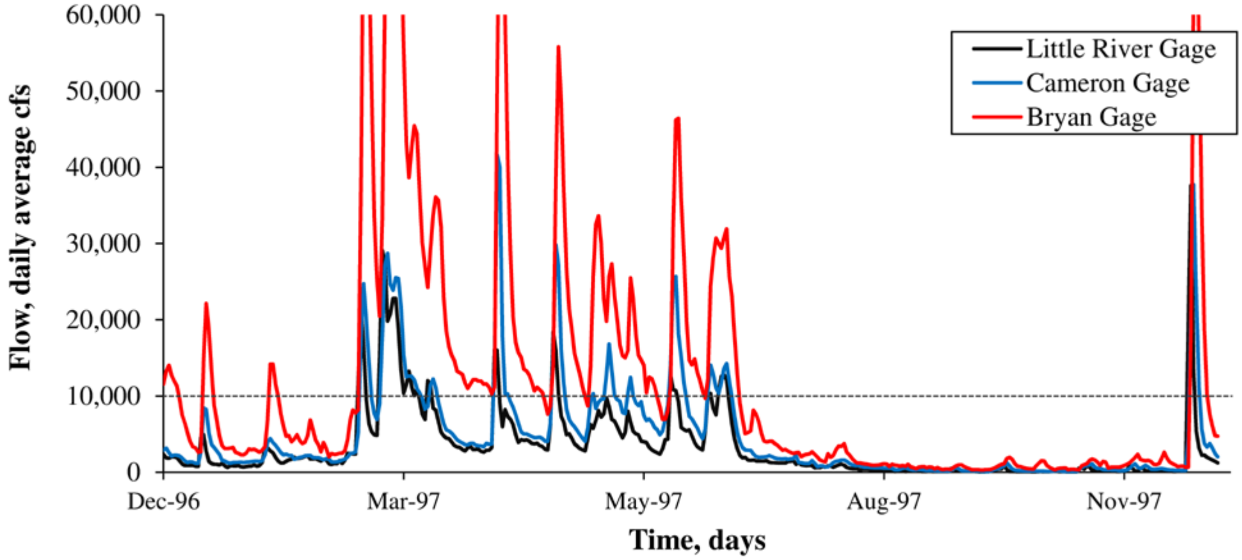

Figure 10.34 *SIMD* Naturalized Flow at the Little River, Cameron, and Bryan Gages

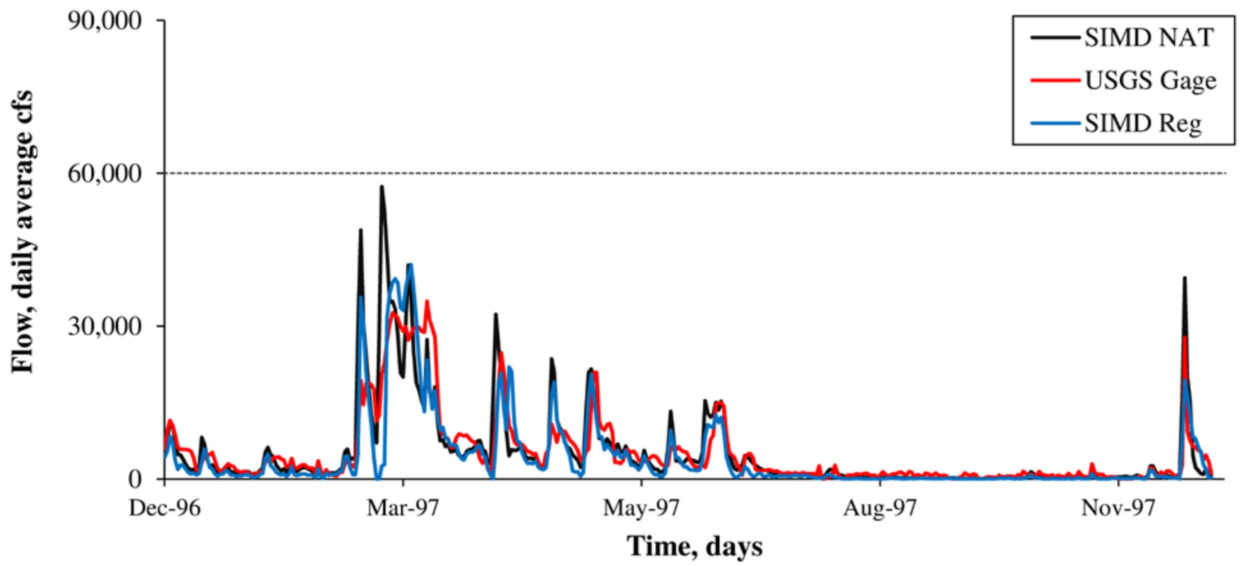

Figure 10.35 Waco Gage *SIMD* Naturalized and Regulated Flow and USGS Gaged Flow

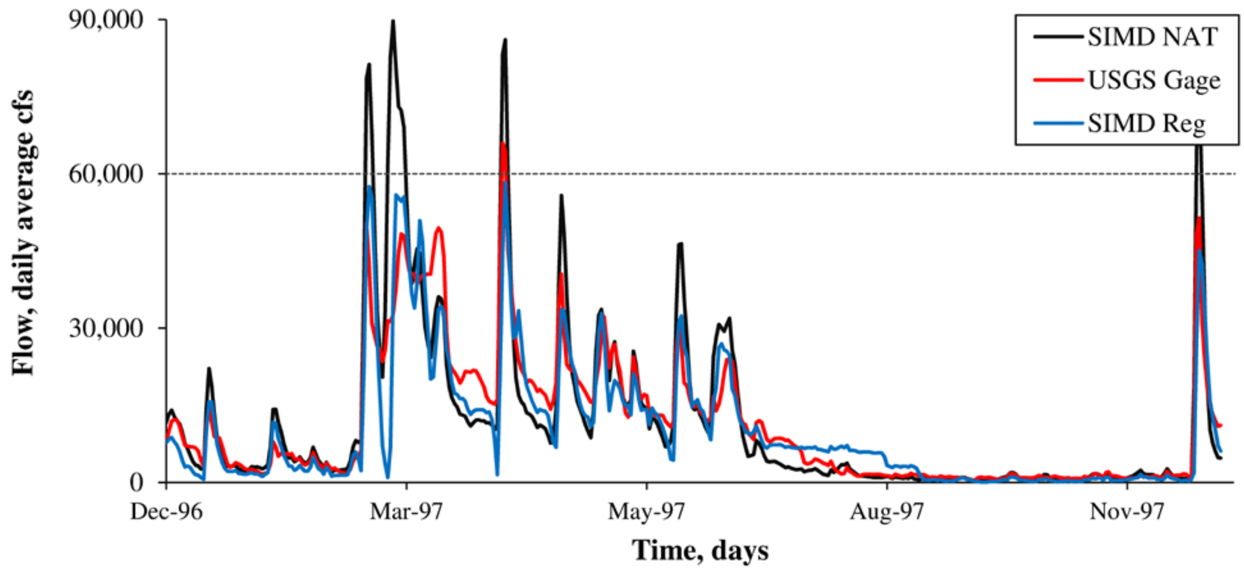

Figure 10.36 Bryan Gage *SIMD* Naturalized and Regulated Flow and USGS Gaged Flow

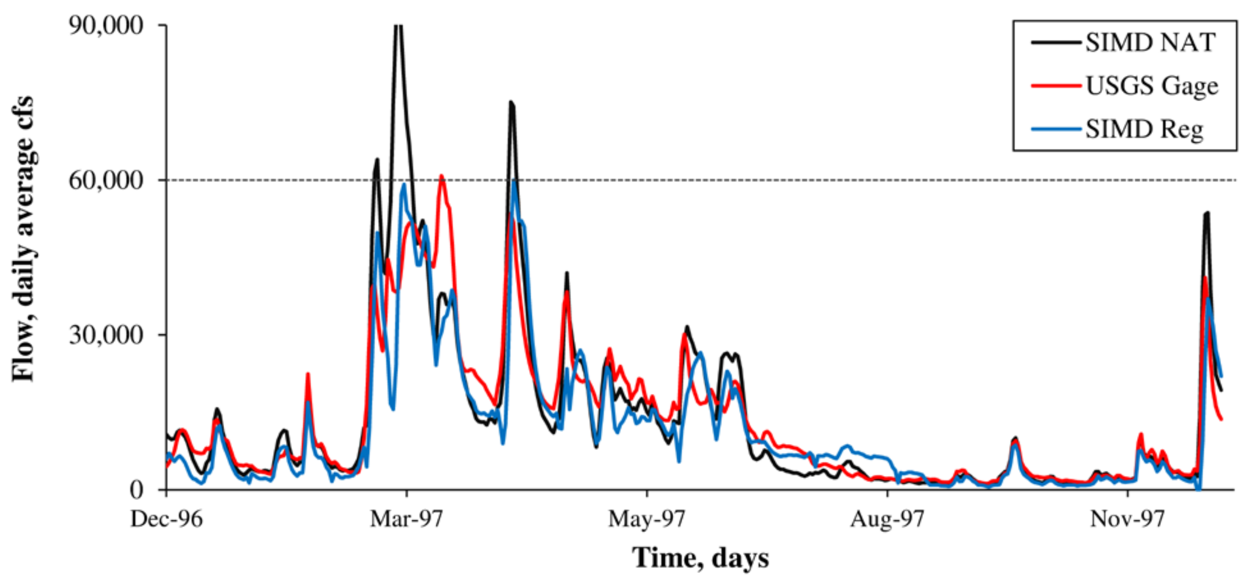

Figure 10.37 Richmond Gage *SIMD* Naturalized and Regulated Flow and USGS Gaged Flow

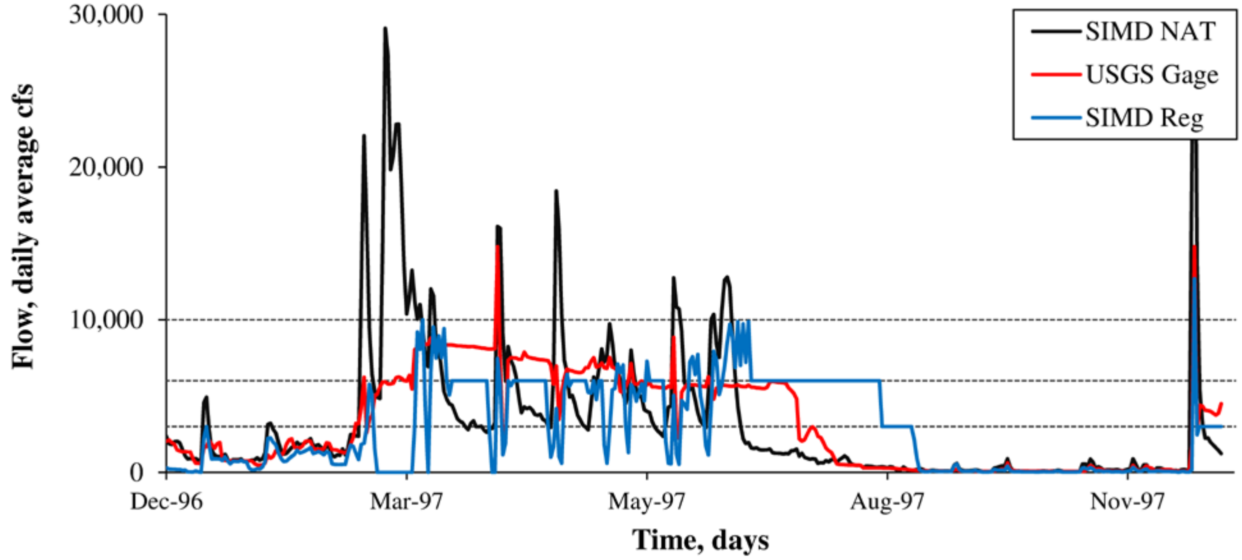

Figure 10.38 Little River Gage *SIMD* Naturalized and Regulated Flow and USGS Gaged Flow

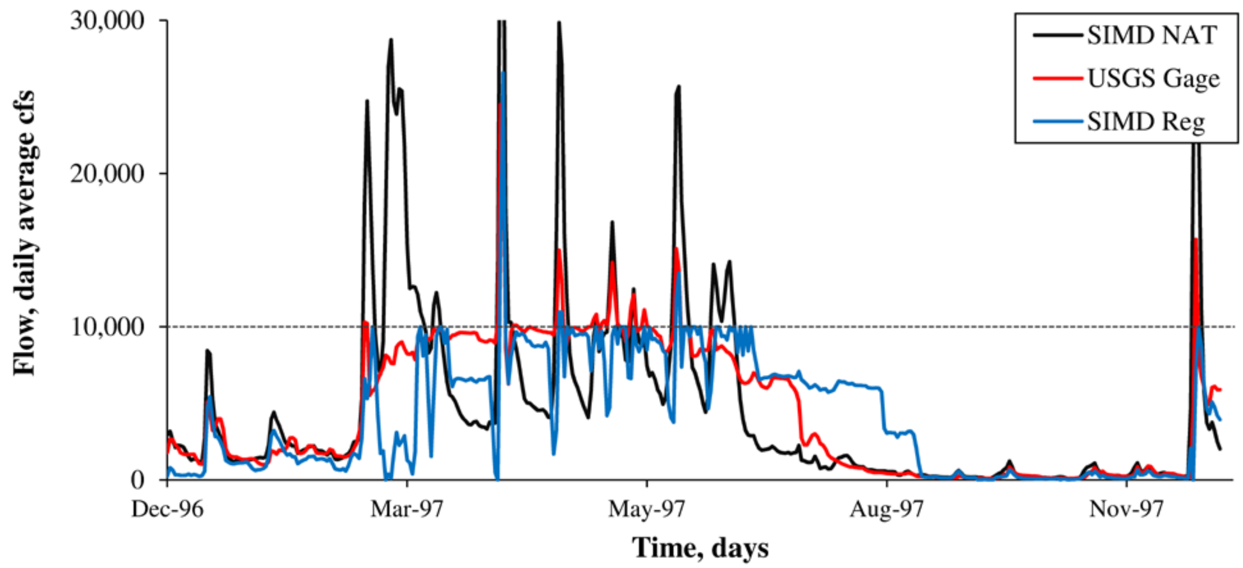

Figure 10.39 Cameron Gage *SIMD* Naturalized and Regulated Flow and USGS Gaged Flow

Water Availability

Flood control in *SIMD* affects water availability for *WR* and *IF* record rights. Flood control pools, when added on top of an existing conservation pool, increase the storage capacity of the underlying reservoir. The type 1 *WR* record rights associated with the conservation pool cannot fill storage above the top of conservation. Flood control rights do not divert stream flow for storage except when regulated flows exceed the maximum allowable discharges at the downstream gages or the maximum allowable release rates at the dam. When flood control rights divert stream flow, conservation storage is filled before the flood control pool. The water right demands on conservation storage can potentially be met by stored water from flood control. Whitney and Waco are modeled as multiple separate conservation and flood control pools which mitigates the connectivity described above between the conservation and flood control pools. Flood control operations can also affect water availability in *SIMD* through flood control releases. The *JU* record parameter *FRMETH* is set to 1 causing flood control depletions and releases to be routed prior to the priority sequence. Flood control releases may occur for many weeks after a major flood event. These releases are placed into the stream and are become part of the available water for any water right in the basin.

Two scenarios are examined in this section for the effect of adding flood control reservoirs to the simulation. The same simulation forecast period is used for both simulations in order to isolate the effects on water availability of the addition of the flood control reservoirs. Extension of the simulation forecast period is examined in the next section of this chapter.

Table 10.19
Parameters per Simulation Scenario Being Considered

Scenario ID	Time Step	WAM Dataset	Flood Control Reservoirs	Routing Options, *WRMETH, FRMETH*	Disaggregation Option, *DFMETHOD*	Target Distribution Option, *ND*	Flow Forecasting, *FPRD*	Negative Increm., *ADJINC*	Execution Time, hours
10.01	day	Bwam3	no	1, *na*	daily pattern	uniform	14 days	7	3.63
10.02	day	Bwam3	yes	1, 1	daily pattern	uniform	14 days	7	3.88

Daily unappropriated flow-frequency is shown in Table 10.20 for Scenarios 10.01 and 10.02. Unappropriated flow is that portion of the regulated flow still available for appropriation after all water rights in the simulation have been considered. Similar to the increase in regulated flow observed for exceedances below the maximum value in Table 10.17, unappropriated flow tends to be greater at exceedances below the maximum value and suggests that flood control operations switch from storing to releasing between the 10% exceedance and the maximum value of unappropriated flow. For example, the 50% exceedance, or median, unappropriated flow at the Richmond gage increases from 280.1 to 468.9 ac-ft per day with the inclusion of flood control in the simulation.

Water right reliabilities at the control points of the nine flood control reservoirs are shown in Table 10.21. Water right reliabilities for the run-of-river rights used in Chapter 9 are shown in Table 10.22. The number and target demands of the run-of-river rights are given in

Table 9.3. The inclusion of flood control in the simulation increases water right reliability and particular for those reservoirs in which flood control reduces the number of days of zero conservation storage. The time series of storage in Proctor Lake is shown in Figure 10.22. Zero storage capacity during the drought of record is eliminated during the 1950's drought. Consequently, volume reliability in Table 10.21 for Proctor increases from 92.41% 99.50%. The run-of-river rights show a slight increase in volume reliability in all decades. However, these water rights have no access to storage. The flood control releases that occur during the wetter portions of the period of record generally do not coincide with the periods of stream flow shortage experienced by these water rights.

Table 10.20
Daily Unappropriated Flow-Frequency for Scenarios 10.01 and 10.02, ac-ft per day

Daily Unappropriated Flow-Frequency, Scenario 10.01, Without Flood Control

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
BRWA41	1792.30	7010.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	389.9	3793.7	165613.1
BRBR59	5024.92	14960.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	319.3	3048.9	13465.6	494506.1
BRRI70	9391.59	23074.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	283.0	1925.1	7907.7	27841.5	585723.2
LEGT47	308.90	1514.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	536.9	53313.8
LRLR53	960.92	3553.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	121.2	2434.7	96318.8
LRCA58	1737.80	5921.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	720.2	4591.7	176813.2
515731	1212.00	5684.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	15.3	2127.1	131980.8
515831	52.26	394.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	23.6	14156.4
509431	362.99	1666.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	706.2	51368.3
515931	91.85	653.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	27384.2
516031	584.94	2385.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1377.1	70773.9
516131	272.80	1214.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	738.1	70069.6
516231	83.43	377.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	241.6	14969.7
516331	270.30	1088.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	55.2	716.3	38708.0
516431	398.63	1930.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	603.5	59205.5

Daily Unappropriated Flow-Frequency, Scenario 10.02, With Flood Control

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
BRWA41	1882.51	7137.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	335.9	3575.6	102656.6
BRBR59	5266.33	12703.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	525.2	4053.6	15995.3	184665.3
BRRI70	9413.14	19388.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	463.7	2592.2	9746.0	29211.5	255249.5
LEGT47	250.33	903.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	641.3	21930.8
LRLR53	1061.52	2794.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	163.6	4749.3	44479.0
LRCA58	1837.33	4295.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	1022.9	6967.8	70381.2
515731	1147.83	5246.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	3.4	1735.7	104673.1
515831	70.24	498.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	9.3	5949.0
509431	411.56	2155.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	486.0	54763.8
515931	106.31	673.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	13083.3
516031	487.86	1600.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1307.8	41853.0
516131	209.97	775.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	495.4	20295.7
516231	87.36	357.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	347.0	7773.2
516331	297.15	862.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	67.3	1229.6	13515.7
516431	404.81	944.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1984.0	11587.4

Table 10.21
Reliability Summaries for Control Points with Flood Control Reservoirs

Control Point Reliability, Scenario 10.01, Without Flood Control

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515731	18949.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	726.25	93.97	94.77	94.0	94.0	94.0	94.1	94.4	94.8	96.6	89.7	89.7	89.7	89.7	93.1	94.8	100.0
509431	80706.5	3666.69	87.79	95.46	87.8	87.8	87.8	89.1	96.8	98.7	99.9	84.5	84.5	84.5	86.2	91.4	98.3	100.0
515931	19658.0	1493.43	90.80	92.40	90.8	90.9	91.2	91.8	93.2	94.3	95.3	81.0	82.8	86.2	87.9	89.7	89.7	100.0
516031	112257.0	3859.70	94.68	96.56	94.7	95.0	95.4	95.7	96.3	96.7	97.7	89.7	89.7	89.7	91.4	94.8	96.6	100.0
516131	67768.0	4081.75	93.25	93.98	93.2	93.2	93.2	93.2	93.4	94.4	96.1	87.9	87.9	89.7	89.7	91.4	91.4	100.0
516231	13610.0	802.65	93.10	94.10	93.1	93.1	93.2	93.4	93.5	94.1	95.8	89.7	89.7	89.7	89.7	91.4	94.8	98.3
516331	19840.0	468.36	96.98	97.64	97.0	97.0	97.0	97.0	97.0	98.1	98.4	93.1	93.1	93.1	94.8	96.6	98.3	100.0
516431	48000.0	330.68	98.85	99.31	98.9	98.9	98.9	98.9	98.9	99.3	99.7	96.6	96.6	96.6	96.6	98.3	100.0	100.0
Total	394685.2	15429.51		96.09														

Control Point Reliability, Scenario 10.02, With Flood Control

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515731	18967.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	603.56	94.83	95.66	94.8	94.8	95.0	95.1	95.1	95.4	97.1	89.7	89.7	89.7	91.4	94.8	96.6	100.0
509431	80684.2	4072.90	86.93	94.95	86.9	86.9	87.1	88.6	95.8	98.4	99.4	84.5	84.5	84.5	86.2	87.9	96.6	100.0
515931	19658.0	99.22	99.28	99.50	99.3	99.3	99.4	99.6	99.7	99.7	99.9	98.3	98.3	98.3	98.3	98.3	100.0	100.0
516031	112257.0	3142.37	96.12	97.20	96.1	96.3	96.3	96.3	96.8	97.4	98.1	93.1	93.1	93.1	93.1	94.8	98.3	100.0
516131	67768.0	1437.38	96.70	97.88	96.7	96.7	96.7	97.1	97.6	98.3	98.7	89.7	89.7	89.7	91.4	98.3	100.0	100.0
516231	13610.0	492.84	95.11	96.38	95.1	95.3	95.4	95.5	96.0	96.7	97.4	91.4	91.4	91.4	91.4	93.1	98.3	100.0
516331	19840.0	340.90	97.84	98.28	97.8	97.8	97.8	98.0	98.1	98.7	98.9	94.8	94.8	94.8	94.8	98.3	98.3	100.0
516431	48000.0	233.48	98.99	99.51	99.0	99.0	99.0	99.0	99.0	99.4	99.9	96.6	96.6	96.6	96.6	100.0	100.0	100.0
Total	394681.0	10422.66		97.36														

Table 10.22
Mean Shortage and Volume Reliability for Selected Water Rights

Selected Water Rights	Mean Shortage, ac-ft per year, Scenario ID 10.01	10.02	Volume Reliability, %, Scenario ID 10.01	10.02
Dec. 31, 1929 and Senior, all uses	8,339	8,405	93.1	93.0
Jan. 1, 1930 to Dec. 31, 1939, all uses	5,653	5,572	92.5	92.6
Jan. 1, 1940 to Dec. 31, 1949, all uses	32,481	32,502	83.1	83.1
Jan. 1, 1950 to Dec. 31, 1959, all uses	26,997	26,335	75.9	76.5
Jan. 1, 1960 to Dec. 31, 1969, all uses	34,079	33,368	72.9	73.5
Jan. 1, 1970 to Dec. 31, 1979, all uses	1,472	1,453	68.6	69.0
Jan. 1, 1980 and Junior, municipal use	19,445	18,942	74.1	74.7
Jan. 1, 1980 and Junior, non-municipal use	31,076	30,183	63.1	64.2
All Selected Water Rights	159,542	156,759	79.8	80.2

Simulation Forecast Period

The application of flow forecasting for adjusting water availability is described in Chapter 8 of this report and in the *Daily Manual*. The total number of future days in the simulation forecast period is set with *JU* record field 8 option *FPRD*. In Chapter 9 and the first two scenarios examined in Chapter 10, the value of *FPRD* is the longest number of future days to rout changes to flow from an upstream routing control point to the basin outlet. Within the forecast simulation, individual water rights will consider a subset of the future days for determining current day water availability. For all daily simulations that use forecasting in this report, the *JU* record field 9 option *APRD* is set to automatically compute the individual water right periods according to the number of future days between the water right location and the basin outlet. Reverse routing of future downstream flows and reuse and revision of forecasting data are utilized as part of the *SIMD* forecasting algorithm. Simulations without forecasting data only utilize downstream current day flow data without reverse routing for the purposes of determining water availability.

The maximum routing period in the Bwam dataset was shown to be 14 days beyond the current day in Chapter 9. The longest routing period is obtained from the longest number of future days in the RFA. Selecting the maximum routing period for the simulation forecast period will ensure that all downstream control points are included in water availability computations for water rights located at or above the reach with the maximum routing period. In the Bwam dataset, the water rights at or above the location of Limestone Lake require 14 days beyond the current day to consider water availability at control points located below the last routing reach in the basin. However, water availability within the forecast simulation at the location of Limestone Lake is still dependent upon downstream conditions 14 days into the future. This creates a situation where the water availability in day 14 of the forecast simulation is dependent on routing that occurs in future days 15 through 28 beyond the current day.

Extending the simulation forecast period beyond the maximum routing period of 14 days is addressed in this section. Water right actions during the forecast simulation depend on the forecast information that was generated during the previous forecast simulation. This information is outdated by one day, but is revised with each pass through the forecast simulation. Water availability calculations during the forecast simulation have decreasing amounts of downstream future flows to consider as the forecast nears the end of the forecast period. This can potentially lead to over appropriation in days near the end of the forecast simulation. For example, junior rights may not have enough future downstream information to curtail their stream flow depletions in a manner that is consistent with the need to pass water for senior rights in future days. If the simulation forecast period is set equal to the maximum routing period, then potential over appropriation during the forecast simulation may influence water availability decisions during the actual real day of the simulation if future flow conditions are inaccurate.

The simulation forecast period is extended to equal twice the maximum routing period in Scenario 10.03. The simulation forecast period is therefore equal to 28 days. An additional 14 days of forecasting will ensure that all water availability calculations in day 14 of the forecast simulation have access to downstream future flows that are fully reflective of water right actions occurring above the longest routing reach.

Table 10.23
Parameters per Simulation Scenario Being Considered

Scenario ID	Time Step	WAM Dataset	Flood Control Reservoirs	Routing Options, *WRMETH, FRMETH*	Disaggregation Option, *DFMETHOD*	Target Distribution Option, *ND*	Flow Forecasting, *FPRD*	Negative Increm., *ADJINC*	Execution Time, hours
10.02	day	Bwam3	yes	1, 1	daily pattern	uniform	14 days	7	3.88
10.03	day	Bwam3	yes	1, 1	daily pattern	uniform	28 days	7	7.55

Flood control operations are not simulated during the forecast simulation. This allows channel capacity in the actual real day of the simulation to be calculated for the effects of future WR record right actions and for the routed actions of flood control from the previous actual day of the simulation. Channel capacity forecasting in the actual day by definition cannot extend beyond the maximum routing period because flood control actions in the current actual real day will only remain in the basin up to the maximum number of days of routing to the outlet. However, *WR* record rights are simulated during the forecast simulation and may have different behavior during a forecast simulation with a different length of forecasting.

Table 10.24 and 10.25 give the daily regulated and unappropriated flow-frequencies, respectively. The extension of the simulation forecast period from 14 to 28 days has a very small effect on the flow-frequencies at all control points. Median regulated flows at the listed stream gages are slightly increased and median flows at the listed dam locations are the same to slightly decreased. The changes are likewise very small in the unappropriated flow frequencies.

Daily storage frequencies are given in Table 10.26 and the water right reliabilities at these reservoirs are given in Table 10.27. Storage frequencies and reservoir water right reliabilities are slightly lower when the simulation forecast period is doubled. The run-of-river right volume reliabilities in Table 10.28 are the same though there is an insignificant increase shown in the mean annual shortage measured in acre-feet per year.

Table 10.29 gives the flood frequency for the daily regulated stream flows. Extension of the simulation forecast period results in no meaningful change in flood control performance.

The most apparent difference between Scenarios 10.02 and 10.03 is computer execution time. Collectively, the results of Tables 10.24 through 10.29 indicate that increasing the simulation forecast period from the maximum routing period to twice the maximum routing period does not significantly change the results in terms of water availability or flood control performance. The results presented here are, however, only for a select number of locations and aggregations of water rights over a long period of record. It is possible that individual water rights for individual flow events may perform differently with increased future flow information during the forecast simulation.

Table 10.24
Daily Regulated Flow-Frequency for Scenarios 10.02 and 10.03, ac-ft per day

Daily Regulated Flow-Frequency, Scenario 10.02, With Flood Control and 14 days of Forecasting

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRWA41	3501.28	9838.9	0.00	1.78	6.73	15.32	59.24	185.74	356.3	552.8	884.9	1972.1	7625.8	133515.1
BRBR59	8249.02	16606.7	0.00	24.40	102.14	203.88	334.03	723.83	1276.3	1858.4	2923.9	7592.9	22776.7	336335.2
BRRI70	12459.10	20880.9	0.00	107.92	259.99	472.92	755.28	1610.33	2287.5	3475.8	6077.0	13951.1	34401.2	279689.4
LEGT47	626.98	1834.5	0.00	0.00	0.00	0.00	0.05	14.22	42.0	85.6	162.2	499.9	1467.5	85030.7
LRLR53	1618.06	3355.3	0.00	0.00	0.00	2.97	14.15	70.56	146.2	232.1	396.5	1071.0	5950.5	79096.6
LRCA58	2755.12	5654.2	0.00	0.00	0.06	16.10	39.67	128.11	306.1	498.0	832.9	2387.9	8714.5	105925.5
515731	2274.02	7529.2	0.00	0.00	0.00	0.00	1.02	66.98	175.9	285.1	469.7	1060.3	3863.3	139653.6
515831	149.21	758.0	0.00	0.00	0.00	0.00	0.99	0.99	1.0	1.0	1.0	6.4	87.2	5950.0
509431	694.26	2941.6	0.00	0.00	0.00	0.00	0.00	0.00	0.4	10.5	42.1	208.1	1223.6	59505.0
515931	288.61	1133.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	3.7	11.8	59.1	990.0	40910.8
516031	938.97	2436.7	0.00	0.00	0.00	0.00	0.00	0.18	31.4	65.4	123.8	413.7	2947.2	45314.5
516131	409.51	1358.6	0.00	0.00	0.00	0.00	0.00	0.00	5.9	17.2	32.7	106.0	919.9	23135.4
516231	116.20	452.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	3.5	9.4	39.8	500.0	9370.6
516331	394.45	971.4	0.00	0.00	0.00	0.00	0.00	0.76	16.1	38.5	74.3	265.5	1290.0	19598.3
516431	435.25	957.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	63.9	1984.0	11587.4

Daily Regulated Flow-Frequency, Scenario 10.03, With Flood Control and 28 days of Forecasting

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRWA41	3501.40	9838.5	0.00	1.76	6.83	16.49	60.10	185.55	357.3	553.4	890.9	1975.1	7625.0	133461.9
BRBR59	8249.55	16604.8	0.00	24.29	101.73	205.46	334.90	726.11	1277.2	1858.9	2930.5	7589.9	22798.1	336358.2
BRRI70	12459.61	20877.3	0.00	109.27	260.94	472.64	755.11	1612.81	2286.0	3481.9	6079.8	13947.6	34299.1	279704.0
LEGT47	626.96	1834.0	0.00	0.00	0.00	0.00	0.05	14.24	41.9	85.7	162.0	500.0	1468.9	85031.1
LRLR53	1618.54	3354.8	0.00	0.00	0.00	3.08	14.36	71.03	146.6	233.6	397.7	1081.6	5950.5	79097.4
LRCA58	2755.57	5653.2	0.00	0.00	0.06	16.09	39.67	128.70	307.3	499.1	838.7	2380.6	8706.2	105925.3
515731	2274.19	7525.3	0.00	0.00	0.00	0.00	1.78	68.62	176.6	289.0	470.7	1072.7	3858.4	139653.8
515831	149.23	757.8	0.00	0.00	0.00	0.00	0.99	0.99	1.0	1.0	1.0	6.4	87.5	5950.0
509431	694.20	2940.8	0.00	0.00	0.00	0.00	0.00	0.00	0.4	10.6	42.6	209.0	1225.9	59505.0
515931	288.62	1132.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	3.7	11.8	59.3	990.0	40910.8
516031	939.44	2439.5	0.00	0.00	0.00	0.00	0.00	0.25	32.2	66.1	126.4	419.6	2915.5	45314.8
516131	409.53	1355.6	0.00	0.00	0.00	0.00	0.00	0.00	5.9	17.1	32.4	104.6	921.2	23135.4
516231	116.18	452.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	3.5	9.2	39.8	500.0	8989.9
516331	394.44	971.2	0.00	0.00	0.00	0.00	0.00	0.75	16.0	38.3	74.1	265.5	1290.0	19387.9
516431	435.24	958.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	63.6	1984.0	11587.8

Control Points

BRWA41 Waco Gage on Brazos River
BRBR59 Bryan Gage on Brazos River
BRRI70 Richmond Gage on Brazos River
LEGT47 Gatesville Gage on Leon River
LRLR53 Little River Gage on Little River
LRCA58 Cameron Gage on Little River
515731 Whitney Reservoir
515831 Aquilla Reservoir
509431 Waco Reservoir
515931 Proctor Reservoir
516031 Belton Reservoir
516131 Stillhouse Hollow Res.
516231 Georgetown Reservoir
516331 Granger Reservoir
516431 Somerville Reservoir

Table 10.25
Daily Unappropriated Flow-Frequency for Scenarios 10.02 and 10.03, ac-ft per day

Daily Unappropriated Flow-Frequency, Scenario 10.02, With Flood Control and 14 days of Forecasting

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRWA41	1882.51	7137.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	335.9	3575.6	102656.6
BRBR59	5266.33	12703.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	525.2	4053.6	15995.3	184665.3
BRRI70	9413.14	19388.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	463.7	2592.2	9746.0	29211.5	255249.5
LEGT47	250.33	903.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	641.3	21930.8
LRLR53	1061.52	2794.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	163.6	4749.3	44479.0
LRCA58	1837.33	4295.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	1022.9	6967.8	70381.2
515731	1147.83	5246.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	3.4	1735.7	104673.1
515831	70.24	498.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	9.3	5949.0
509431	411.56	2155.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	486.0	54763.8
515931	106.31	673.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	13083.3
516031	487.86	1600.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1307.8	41853.0
516131	209.97	775.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	495.4	20295.7
516231	87.36	357.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	347.0	7773.2
516331	297.15	862.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	67.3	1229.6	13515.7
516431	404.81	944.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1984.0	11587.4

Daily Unappropriated Flow-Frequency, Scenario 10.03, With Flood Control and 28 days of Forecasting

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRWA41	1880.51	7120.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	343.9	3566.7	102673.6
BRBR59	5265.72	12698.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	526.1	4058.5	16013.3	184638.6
BRRI70	9413.35	19385.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	466.1	2611.5	9769.9	29195.4	255280.4
LEGT47	250.45	902.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	633.0	21930.9
LRLR53	1060.79	2793.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	170.4	4777.5	44482.5
LRCA58	1837.05	4296.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	1023.1	6979.1	70387.2
515731	1147.90	5241.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	5.1	1732.5	104701.1
515831	70.24	498.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	9.6	5949.0
509431	411.75	2155.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	488.7	54776.9
515931	105.69	670.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	13083.4
516031	486.59	1598.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1303.8	41853.3
516131	210.38	775.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	490.1	20295.6
516231	87.41	357.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	343.1	7457.4
516331	297.29	862.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	67.1	1229.2	13369.5
516431	404.83	945.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1984.0	11587.8

Control Points

BRWA41 Waco Gage on Brazos River
BRBR59 Bryan Gage on Brazos River
BRRI70 Richmond Gage on Brazos River
LEGT47 Gatesville Gage on Leon River
LRLR53 Little River Gage on Little River
LRCA58 Cameron Gage on Little River
515731 Whitney Reservoir
515831 Aquilla Reservoir
509431 Waco Reservoir
515931 Proctor Reservoir
516031 Belton Reservoir
516131 Stillhouse Hollow Res.
516231 Georgetown Reservoir
516331 Granger Reservoir
516431 Somerville Reservoir

Table 10.26
End of Day Storage-Frequency for Scenarios 10.02 and 10.03, ac-ft

End of Day Storage-Frequency, Scenario 10.02, With Flood Control and 14 days of Forecasting

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
515731	609714.	116869.	402731.	417801.	455751.	481177.	532358.	585906.	602726.	613161.	622759.	632988.	636100.	2000345.
515831	38787.	16280.	0.	0.	0.	493.	12181.	33055.	40426.	43097.	46051.	50681.	52400.	135696.
509431	156620.	63849.	461.	757.	1419.	14984.	57721.	134095.	162190.	173488.	185388.	199631.	206467.	712606.
515931	50895.	33918.	0.	2645.	6129.	12885.	20686.	37201.	43519.	47842.	52597.	59162.	75172.	369500.
516031	382714.	155380.	0.	0.	0.	16670.	167831.	339438.	392900.	411151.	432115.	456118.	486209.	1097800.
516131	194842.	85396.	0.	0.	0.	12362.	57136.	167702.	200937.	212481.	223082.	234410.	248543.	637782.
516231	29444.	12738.	0.	0.	0.	1398.	12154.	23007.	30145.	33071.	35052.	37100.	39804.	128996.
516331	57082.	24200.	0.	0.	507.	10577.	29514.	48877.	57361.	62165.	64843.	65500.	75404.	240711.
516431	137040.	47631.	0.	3912.	30153.	55476.	71970.	113884.	135648.	143774.	152260.	160109.	181321.	501965.
Total	1657138.	478985.	497544.	538490.	559252.	675850.	1022671.	1496213.	1662664.	1730358.	1786745.	1871571.	1986006.	5475674.

End of Day Storage-Frequency, Scenario 10.03, With Flood Control and 28 days of

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
515731	609430.	116837.	398950.	415541.	453348.	481188.	531772.	585167.	602549.	612963.	622645.	633194.	636100.	2000345.
515831	38767.	16302.	0.	0.	0.	443.	12160.	33013.	40375.	43093.	46047.	50682.	52400.	135696.
509431	156601.	63838.	469.	769.	1390.	14988.	57832.	134027.	162184.	173523.	185407.	199645.	206470.	712628.
515931	50878.	34042.	0.	2540.	5985.	12736.	20521.	37273.	43525.	47856.	52573.	59154.	75178.	369500.
516031	381891.	156100.	0.	0.	0.	14288.	161404.	338392.	392229.	410955.	431862.	456698.	486172.	1097800.
516131	194882.	85316.	0.	0.	0.	12496.	57306.	167608.	201014.	212588.	223158.	234533.	248449.	637781.
516231	29446.	12724.	0.	0.	0.	1478.	12301.	22999.	30134.	33053.	35050.	37100.	39811.	128996.
516331	57089.	24206.	0.	0.	486.	10675.	29539.	48888.	57330.	62163.	64848.	65500.	75405.	240711.
516431	137074.	47744.	0.	4054.	30318.	55498.	71961.	113885.	135654.	143789.	152260.	160110.	181321.	501965.
Total	1656060.	479922.	495159.	536316.	557011.	672211.	1017607.	1494295.	1660936.	1730023.	1786444.	1871024.	1986757.	5471962.

Reservoir Control Points

515731	Whitney Reservoir	516131	Stillhouse Hollow Res.
515831	Aquilla Reservoir	516231	Georgetown Reservoir
509431	Waco Reservoir	516331	Granger Reservoir
515931	Proctor Reservoir	516431	Somerville Reservoir
516031	Belton Reservoir		

Table 10.27
Reliability Summaries for Control Points with Flood Control Reservoirs

Control Point Reliability, Scenario 10.02, With Flood Control and 14 days of Forecasting

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515731	18967.8	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	603.56	94.83	95.66	94.8	94.8	95.0	95.1	95.1	95.4	97.1	89.7	89.7	89.7	91.4	94.8	96.6	100.0
509431	80684.2	4072.90	86.93	94.95	86.9	86.9	87.1	88.6	95.8	98.4	99.4	84.5	84.5	84.5	86.2	87.9	96.6	100.0
515931	19658.0	99.22	99.28	99.50	99.3	99.3	99.4	99.6	99.7	99.7	99.9	98.3	98.3	98.3	98.3	98.3	100.0	100.0
516031	112257.0	3142.37	96.12	97.20	96.1	96.3	96.3	96.3	96.8	97.4	98.1	93.1	93.1	93.1	93.1	94.8	98.3	100.0
516131	67768.0	1437.38	96.70	97.88	96.7	96.7	96.7	97.1	97.6	98.3	98.7	89.7	89.7	89.7	91.4	98.3	100.0	100.0
516231	13610.0	492.84	95.11	96.38	95.1	95.3	95.4	95.5	96.0	96.7	97.4	91.4	91.4	91.4	91.4	93.1	98.3	100.0
516331	19840.0	340.90	97.84	98.28	97.8	97.8	97.8	98.0	98.1	98.7	98.9	94.8	94.8	94.8	94.8	98.3	98.3	100.0
516431	48000.0	233.48	98.99	99.51	99.0	99.0	99.0	99.0	99.0	99.4	99.9	96.6	96.6	96.6	96.6	100.0	100.0	100.0
Total	394681.0	10422.66		97.36														

Control Point Reliability, Scenario 10.02, With Flood Control and 28 days of Forecasting

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
515731	18966.2	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515831	13896.0	606.29	94.68	95.64	94.7	94.8	95.0	95.0	95.1	95.4	97.1	89.7	89.7	89.7	91.4	94.8	96.6	100.0
509431	80682.1	4038.20	87.07	94.99	87.1	87.2	87.5	88.5	96.0	98.4	99.4	84.5	84.5	84.5	86.2	87.9	96.6	100.0
515931	19658.0	99.77	99.28	99.49	99.3	99.3	99.4	99.6	99.7	99.7	99.9	98.3	98.3	98.3	98.3	98.3	100.0	100.0
516031	112257.0	3285.81	95.69	97.07	95.7	95.8	95.8	96.0	96.8	97.3	98.1	91.4	91.4	91.4	93.1	94.8	98.3	100.0
516131	67768.0	1423.56	96.70	97.90	96.7	97.0	97.0	97.1	97.6	98.3	98.7	89.7	89.7	89.7	91.4	98.3	100.0	100.0
516231	13610.0	488.76	95.26	96.41	95.3	95.3	95.4	95.5	96.0	96.8	97.4	91.4	91.4	91.4	91.4	93.1	98.3	100.0
516331	19840.0	343.07	97.70	98.27	97.7	97.7	97.7	98.0	98.3	98.7	98.9	94.8	94.8	94.8	94.8	98.3	98.3	100.0
516431	48000.0	231.27	98.99	99.52	99.0	99.0	99.0	99.0	99.0	99.4	99.9	96.6	96.6	96.6	96.6	100.0	100.0	100.0
Total	394677.3	10516.73		97.34														

Table 10.28
Mean Shortage and Volume Reliability for Selected Water Rights

Selected Water Rights	Mean Shortage, ac-ft per year		Volume Reliability, %	
	Scenario ID		Scenario ID	
	10.02	10.03	10.02	10.03
Dec. 31, 1929 and Senior, all uses	8,405	8,396	93.0	93.0
Jan. 1, 1930 to Dec. 31, 1939, all uses	5,572	5,579	92.6	92.6
Jan. 1, 1940 to Dec. 31, 1949, all uses	32,502	32,499	83.1	83.1
Jan. 1, 1950 to Dec. 31, 1959, all uses	26,335	26,342	76.5	76.5
Jan. 1, 1960 to Dec. 31, 1969, all uses	33,368	33,363	73.5	73.5
Jan. 1, 1970 to Dec. 31, 1979, all uses	1,453	1,453	69.0	69.0
Jan. 1, 1980 and Junior, municipal use	18,942	18,947	74.7	74.7
Jan. 1, 1980 and Junior, non-municipal use	30,183	30,172	64.2	64.2
All Selected Water Rights	156,759	156,751	80.2	80.2

Table 10.29
Flood Frequency for Daily Regulated Stream Flow at the
Selected Control Points for Scenarios 10.02 and 10.03, ac-ft per day

Flood Frequencies for Daily Regulated Stream Flow,
Scenario 10.02, With Flood Control and 14 days of Forecasting

	ANNUAL RECURRENCE INTERVAL (YEARS) AND EXCEEDANCE FREQUENCY (%)									
CONTROL POINT	1.01 99%	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%	200 0.5%	500 0.2%	EXPECTED VALUE
BRWA41	8272.	47898.	80113.	102336.	130555.	151374.	171864.	192079.	218419.	55512.
BRBR59	16614.	77531.	124910.	157702.	199819.	231349.	262832.	294372.	336250.	88165.
BRRI70	14134.	85155.	143106.	182938.	233284.	270241.	306459.	342030.	388144.	98836.
LEGT47	530.	9341.	20633.	29767.	42514.	52559.	62865.	73362.	87430.	13890.
LRLR53	1930.	9757.	18241.	25517.	36741.	46668.	58011.	70939.	90765.	13232.
LRCA58	3382.	28281.	54549.	75195.	104158.	127427.	151880.	177505.	213138.	37615.
515731	5941.	36387.	57229.	69794.	83964.	93310.	101706.	109290.	118245.	39260.
515831	1093.	5004.	7028.	8080.	9135.	9762.	10280.	10712.	11181.	4973.
509431	1314.	11423.	25706.	39526.	62841.	85012.	111764.	143780.	195484.	19030.
515931	221.	2097.	5606.	9735.	18054.	27348.	40176.	57659.	90407.	4764.
516031	895.	7302.	13204.	17419.	22859.	26908.	30907.	34855.	39995.	8972.
516131	329.	5038.	10660.	15060.	21059.	25699.	30393.	35115.	41363.	7150.
516231	56.	1200.	3501.	6083.	10903.	15846.	22137.	30011.	43305.	2786.
516331	289.	3032.	6461.	9414.	13865.	17670.	21866.	26464.	33174.	4521.
516431	331.	2420.	4377.	5817.	7735.	9206.	10697.	12208.	14232.	3006.

Statistics for Peak Annual Regulated Streamflow, Log-Pearson Type III Distribution

					Statistics for Logarithms of Annual Peaks				
CONTROL POINT	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION	INPUT SKEW	COMPUTED SKEW	ADOPTED SKEW
BRWA41	55103.	30572.	9371.	133515.	4.6611	0.2837	-0.2000	-0.4922	-0.4077
BRBR59	88636.	53165.	17227.	336335.	4.8766	0.2580	-0.2000	-0.3355	-0.2990
BRRI70	98228.	57987.	16571.	279689.	4.9095	0.2878	-0.2000	-0.5302	-0.4330
LEGT47	13339.	14336.	459.	85031.	3.9317	0.4471	-0.2000	-0.6686	-0.5220
LRLR53	13170.	13032.	1420.	79097.	3.9958	0.3177	-0.2000	0.2344	0.1230
LRCA58	36340.	26432.	4002.	105926.	4.4337	0.3555	-0.2000	-0.3377	-0.3006
515731	39489.	20949.	4904.	139654.	4.5294	0.2665	-0.2000	-1.0474	-0.7175
515831	5044.	1543.	524.	5950.	3.6669	0.2109	-0.2000	-2.4640	-0.9336
509431	18055.	18041.	750.	59505.	4.0625	0.4148	-0.2000	0.1569	0.0687
515931	4339.	6202.	346.	40911.	3.3498	0.4865	-0.2000	0.5847	0.3481
516031	8885.	6929.	558.	45314.	3.8371	0.3314	-0.2000	-0.6009	-0.4791
516131	6697.	5140.	278.	23136.	3.6648	0.4238	-0.2000	-0.6867	-0.5331
516231	2396.	2523.	38.	9371.	3.0732	0.5579	-0.2000	-0.0219	-0.0631
516331	4260.	3547.	252.	19598.	3.4667	0.4040	-0.2000	-0.2311	-0.2232
516431	2950.	2027.	379.	11587.	3.3636	0.3248	-0.2000	-0.4417	-0.3734

Table 10.29 (continued)
Flood Frequency for Daily Regulated Stream Flow at the
Selected Control Points for Scenarios 10.02 and 10.03, ac-ft per day

Flood Frequencies for Daily Regulated Stream Flow,
Scenario 10.03, With Flood Control and 28 days of Forecasting

	ANNUAL RECURRENCE INTERVAL (YEARS) AND EXCEEDANCE FREQUENCY (%)									
CONTROL POINT	1.01 99%	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%	200 0.5%	500 0.2%	EXPECTED VALUE
BRWA41	8193.	47857.	80168.	102460.	130759.	151629.	172162.	192410.	218781.	55513.
BRBR59	16474.	77529.	125061.	157940.	200133.	231693.	263178.	294695.	336500.	88201.
BRRI70	14134.	85153.	143120.	182970.	233347.	270334.	306585.	342193.	388362.	98847.
LEGT47	530.	9349.	20644.	29773.	42506.	52534.	62818.	73288.	87312.	13894.
LRLR53	1934.	9773.	18259.	25531.	36742.	46651.	57969.	70862.	90624.	13243.
LRCA58	3363.	28242.	54540.	75224.	104254.	127585.	152110.	177814.	213566.	37606.
515731	5900.	36357.	57280.	69914.	84175.	93590.	102053.	109702.	118740.	39276.
515831	1094.	5004.	7028.	8080.	9135.	9761.	10279.	10712.	11181.	4973.
509431	1315.	11423.	25704.	39523.	62834.	85002.	111751.	143765.	195466.	19029.
515931	220.	2100.	5618.	9755.	18089.	27398.	40242.	57740.	90503.	4773.
516031	899.	7322.	13220.	17422.	22835.	26857.	30824.	34736.	39821.	8981.
516131	332.	5077.	10672.	15009.	20871.	25368.	29888.	34406.	40342.	7142.
516231	56.	1199.	3496.	6067.	10861.	15772.	22014.	29819.	42981.	2778.
516331	290.	3032.	6457.	9403.	13843.	17635.	21815.	26393.	33071.	4517.
516431	331.	2419.	4376.	5818.	7737.	9210.	10704.	12217.	14247.	3006.

Statistics for Peak Annual Regulated Streamflow, Log-Pearson Type III Distribution

					Statistics for Logarithms of Annual Peaks				
CONTROL POINT	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION	INPUT SKEW	COMPUTED SKEW	ADOPTED SKEW
BRWA41	55083.	30600.	9355.	133462.	4.6605	0.2848	-0.2000	-0.4976	-0.4113
BRBR59	88652.	53218.	17234.	336358.	4.8764	0.2589	-0.2000	-0.3432	-0.3046
BRRI70	98234.	57987.	16760.	279704.	4.9095	0.2878	-0.2000	-0.5295	-0.4326
LEGT47	13343.	14330.	459.	85031.	3.9320	0.4470	-0.2000	-0.6707	-0.5232
LRLR53	13183.	13029.	1420.	79097.	3.9965	0.3175	-0.2000	0.2325	0.1217
LRCA58	36320.	26443.	3973.	105925.	4.4331	0.3562	-0.2000	-0.3382	-0.3010
515731	39487.	20978.	4879.	139654.	4.5289	0.2675	-0.2000	-1.0448	-0.7165
515831	5044.	1543.	524.	5950.	3.6670	0.2108	-0.2000	-2.4655	-0.9336
509431	18054.	18041.	750.	59505.	4.0625	0.4148	-0.2000	0.1572	0.0689
515931	4344.	6202.	346.	40911.	3.3503	0.4868	-0.2000	0.5813	0.3461
516031	8896.	6922.	566.	45315.	3.8381	0.3308	-0.2000	-0.6069	-0.4830
516131	6702.	5120.	278.	23135.	3.6672	0.4215	-0.2000	-0.7137	-0.5497
516231	2389.	2504.	38.	8990.	3.0729	0.5574	-0.2000	-0.0248	-0.0654
516331	4256.	3531.	252.	19388.	3.4668	0.4036	-0.2000	-0.2323	-0.2240
516431	2949.	2028.	379.	11588.	3.3635	0.3249	-0.2000	-0.4406	-0.3727

Summary, Conclusions and Guidance for Applying *SIMD* Flood Control

The daily time step features of *SIMD* facilitate modeling reservoir operations for flood control. Relatively small computational time steps are required to accurately model flood control operations due to the great fluctuations in flow rates over short time spans that typically occur during flood events. *SIMD* uses a day as the smallest time step for simulation which can be used for modeling flood control operations of large river and reservoir systems. Smaller systems may require smaller time steps.

Flood control reservoir operations are treated as a type of water right in *SIMD*. Within WRAP, a water right is a set of water control requirements and associated reservoir facilities and operating rules. Flood control rights are activated by *FR* records and are simulated along with all other water rights activated by *WR* and *IF* records. The same reservoir may have any number of *WR* or *IF* record rights with associated *WS* and *OR* records, and any number of *FR* record flood control rights.

Forecasted regulated flow at the location of the *FF* record rights is used in conjunction with the *FR* record operating rules to begin impounding stream flow in controlled flood control storage. Flow forecasting can also reduce the amount of water released from controlled flood control storage.

The objective of Chapter 10 is to examine the performance of the *SIMD* flood control features in reducing regulated flow below maximum allowable release rates at the flood control reservoirs and the maximum allowable discharge rates at downstream flood flow gaging locations. Flood control input records are developed for *SIMD* using USACE flood control limits and flood control pool elevation, capacity and area data. Simulation results are compared in terms of the effect on regulated flood flow-frequency and flood storage-frequency.

Flood control in SIMD was shown to be effective in reducing regulated flows below flood flow limits for the Brazos WAM case study. The following guidelines draw upon the construction of the flood control records for the DAT file and the simulation results of the case study. Other river basins may have unique flood control situations that were not represented in the Brazos WAM case study.

Disaggregation

Flood control simulation deals with infrequent events of high streamflow magnitude. Actual unregulated or naturalized flow patterns provided on the *DF* records can provide the correct magnitude, frequency and timing of the flood events. It is unlikely that using the uniform, linear interpolation or variability adjustment methods of disaggregating monthly naturalized flow into daily flow will generate realistic flow rates or flow frequencies for simulating flood control. The uniform method of disaggregation is equivalent to simulating with a monthly average flow. High flow pulses and overbanking flood events are not well represented with monthly average flows. The linear interpolation and variability adjustment methods introduce more variability to the daily hydrograph. However, flow averaging with these disaggregation methods will tend to underestimate the extreme variability and the upstream to downstream timing of real-world flood events.

SIMD allows *DF* records to be repeated when the *DF* record period is shorter than the monthly naturalized period of record set by the *JD* record. Repeating a sequence of *DF* record over a longer period of record may also result in inaccuracies for simulating flood control. A daily flow pattern with a fairly uniform hydrograph could be paired with a very large naturalized monthly flow. The resulting disaggregated daily naturalized flows for the simulation may not contain a daily flow within that month of sufficient magnitude to trigger flood control operations. Conversely, a daily flow pattern with a highly variable hydrograph could be paired with a low naturalized monthly flow volume. The resulting disaggregated daily naturalized flows for the simulation could contain a daily peak flow with a flow magnitude exceeding flood limits when the real-world flows were otherwise characterized by a hydrograph typical of low variability flows.

The smallest time step available in *SIMD* is 1 day. Daily flows represent the entire volume of flow that passed through the control point for a particular day. Real-world flood control operations are typically triggered by measurements or forecasts of instantaneous flow rates. For example, the maximum allowable discharge at the Richmond gage on the main stem of the Brazos River, as set by the USACE, is 60,000 cubic feet per second. In the Chapter 10 case study, the maximum allowable discharge at Richmond was computed by converting 60,000 cubic feet per second into a daily volume of 119,008.3 ac-ft per day. This daily volume was used for the daily target of the *FF* record at Richmond. The relationship of daily flow volume to daily maximum instantaneous flow, particularly for the rising limb of the hydrograph, may require examination prior to establishing daily targets for the *FF* records. In some instances, the use of daily time steps may mask the achievement of instantaneous flow rates above flood limits. Small streams or basins characterized by extreme flash flow response could have flood conditions develop and dissipate in less than 1 day.

<u>*JU, FR and FF Record Parameter Options*</u>

The *JU* record field 6 parameter, *FRMETH*, governs whether the changes to flow of the flood control pools are placed within the priority sequence or before the priority sequence. If flood control pools are the most junior water rights being simulated, placing their respective changes to flow at their junior priority will result in no affect on the *WR* and *IF* record rights with the exception of increases to reservoir storage. *FR* record flood control reservoirs can fill conservation storage when flood control streamflow depletions occur and the conservation pool level is less than full. Placing the changes to flow made by flood control pools before the priority sequence can affect the water availability of all *WR* and *IF* record rights in the basin. The Chapter 10 case study uses the option to place the changes to flow at the beginning of the priority sequence so the full effect on water availability could be measured.

The amount of flood control streamflow depletions is limited by the remaining storage capacity in the reservoir or the computation of water availability. The *FR* record field 6 parameter, *FCDEP*, can change the computation of water availability. The default *FCDEP* option is to proceed with the conventional water availability method of examining the water availability values at the control point of the depletion and all downstream control points. The alternative *FCDEP* option is to ignore all downstream control points in the conventional water availability method. The alternative option allows maximum flood control streamflow depletions to be made at the expense of potentially depleting streamflows that have already been appropriated by downstream water rights. However, downstream water rights will benefit from the flood control releases being made immediately after flooding conditions subside. Real-world flood control operations will be best replicated in *SIMD* with the alternative *FCDEP* option to ignore downstream control points in determining water availability for streamflow depletions. The Chapter 10 case study uses the *FCDEP* alternative water availability option.

Flood control dams typically have a maximum allowable release rate. Releases through the dam's outlet structures are not allowed to exceed the maximum allowable release rate except during emergency operations. The *FR* record field 8 parameter, *FCMAX*, sets a maximum release rate for the controlled flood control storage defined by *FR* record fields 8, 9 and 10. In the Chapter 10 case study, several flood control reservoirs have differing maximum release rates with respect to the state of storage as a percentage of the flood control pool capacity. Multiple *FR* records can be used for the same flood control pool in *SIMD*. Each *FR* record can have a different value of *FCMAX* to model the increase in maximum allowable release with increasing storage contents.

Automatic calculation of forecast periods between the flood control reservoir and the downstream *FF* flood flow gages is adopted in the Chapter 10 case study. Automatic calculation of the forecast periods for flood control is the recommended option for most applications. No depletions or releases are made from controlled flood control storage during the forecast simulation. Uncontrolled flood control releases may occur during the current day or forecast simulation. Forecasting is an essential simulation feature for the performance of flood control reservoirs in mitigating downstream flooding conditions. The time delay effects of routing necessitate the use of forecasting for making depletions prior to the occurrence of downstream flooding condition as well as for ensuring releases today do not contribute to flooding in the future at downstream locations.

Flood Control Systems

All flood control pools with the same priority are treated as components of a multiple-reservoir system. Each *FR* record right has a priority for storing flood flows and a separate priority for the subsequent release of the stored flood waters. If multiple reservoirs share the same storage priority, these reservoirs are treated as a multiple reservoir system in making storage decisions. If multiple reservoirs share the same release priority, these reservoirs are treated as a multiple reservoir system in making release decisions. At the beginning of each time step, the ordering of reservoirs in a multiple-reservoir system for purposes of operating decisions is based on a ranking index. System reservoirs with a greater available capacity as a percentage of the total capacity are allowed to impound prior to other system reservoirs. System reservoirs with a lower available capacity as a percentage of the total capacity are allowed to release prior to other system reservoirs.

System operation of flood control reservoirs was applied in the Chapter 10 case study to Lakes Whitney and Waco and to Lakes Belton and Stillhouse. These systems were created to improve the ability of the reservoirs in managing flood conditions at their common and nearby downstream flood gages. Lakes Whitney and Waco are upstream of the flood flow gage on the main stem Brazos River at Waco. Aquilla Lake is also upstream of the Waco gage, but was not selected for system operation due to its small relative flood control capacity relative to Lakes

Whitney and Waco. However, Aquilla Lake could be included if so desired. Lakes Belton and Stillhouse are upstream of the flood flow gage on the Little River near the community of Little River. Proctor Lake is also upstream of the Little River gage. However, Proctor Lake was not selected for system operation due a much longer distance upstream from the Little River gage.

Multiple *FR* records per reservoir were created for the Whitney-Waco and Belton-Stillhouse flood control systems and can be seen in Table 10.6. Each *FR* record created for each reservoir was assigned the same storage and release priority as a corresponding *FR* record in the other system reservoir. The records create pools of equal percentages of the total flood control storage capacity and not pools of equal absolute volume. The records were assigned successively junior priorities. Using multiple *FR* records per system reservoir improves the likelihood that the reservoirs will fill and draw down on an equal percentage basis. When a flood even is indicated by the common downstream *FF* record right, each reservoir in the system will fill one pool in the system before proceeding to the consideration of filling the next pool. After flood conditions have subsided, each reservoir in the system will release from the topmost pool containing storage before proceeding to the next pool or until downstream regulated flow capacity has been exhausted for that day.

The priority dates on the *FR* records can be arranged to allow any sequence of storing or releasing from non-system flood control pools. In the Chapter 10 case study, storage priorities were arranged to allow for a general upstream to downstream order of consideration. Release priorities were arranged to allow for a general downstream to upstream order of consideration. The choice of ordering reflects an operational policy to retain flood waters higher in the basin when possible. Flood control capacity lower in the basin is generally reserved until needed.

Water Availability

Flood control in *SIMD* affects water availability for *WR* and *IF* record rights. Flood control pools, when added on top of an existing conservation pool, increase the storage capacity of the underlying reservoir. Flood control rights divert stream flow and conservation storage is filled if the conservation full is not already full. Therefore, water right demands on conservation storage can potentially be met water stored during junior flood control operations. Flood control operations can also affect water availability in *SIMD* through flood control releases if the *JU* record parameter *FRMETH* is set to allow flood control depletions and releases to be routed prior to the priority sequence. Flood control releases may occur for several days or weeks after a major flood event. These releases are placed into the stream and are become part of the available water for any water right in the basin.

Conservation pools that experience periods of zero storage contents when modeled without a flood control pool can potentially experience fewer or no days of zero storage contents when a flood control pool is added to the reservoir. Furthermore, the sequence in which flood control reservoirs are activated during drought conditions can affect the amount of water stored in a particular reservoir. Experimentation with flood control priority numbers may result in different outcomes for drought period conservation storage. Figure 10.20 shows the daily time series of storages for Proctor Lake. The 1950's drought results in many days of zero end-of-day storage contents in Proctor when modeled without a flood control pool. The addition of flood control above the conservation pool eliminates the days of zero storage contents during the

1950's drought. Flood control for Proctor was modeled with the alternative water availability option, FCDEP. Modeling flood control subject to the conventional water availability computation may not result in the same increase in storage for Proctor during the 1950's drought.

Run-of-river rights below flood control reservoirs may experience shortages when flood control reservoirs impound flood waters upstream. The choice of FCDEP on the *FR* records, however, may change whether the downstream water rights experience shortage. Storing flood water typically occurs over a fewer number of days than releasing water completely from flood control storage after the flood event. Downstream run-of-river rights may experience an increase in water availability as the flood control reservoir makes releases from flood control storage for several days to potentially several weeks after the flood event.

Environmental Flows

Table 10.17 presents the daily regulated flow-frequency for simulations with and without flood control. Figures 10.2 through 10.16 show the time series of daily regulated flow for the same control points in Table 10.17. Flood control has a significant effect on peak regulated flows. Regulated flows corresponding to the magnitude of high flow pulses and overbanking flows will likely be affected with the inclusion of flood control in the simulation. High flow event volume will also be affected by flood control. Table 10.17 also illustrates that flood control can increase the magnitude of regulated flows, particularly at flow-frequencies corresponding to the 10% to 50% exceedance. Though flood control reduces high magnitude flow events, the subsequent releases from flood control at lower flow rates will contribute to flows that may be characterized as medium to high baseflow levels or small pulse flow events.

Simulation Forecast Period

Water right actions during the forecast simulation depend on the forecast information that was generated during the previous forecast simulation. This information is outdated by one day, but is revised with each pass through the forecast simulation. Water availability calculations during the forecast simulation have decreasing amounts of downstream future flows to consider as the forecast nears the end of the forecast period. This can potentially lead to over appropriation in days near the end of the forecast simulation. For example, junior rights may not have enough future downstream information to curtail their stream flow depletions in a manner that is consistent with the need to pass water for senior rights in future days. If the simulation forecast period is set equal to the maximum routing period, then potential over appropriation during the forecast simulation may influence water availability decisions during the actual real day of the simulation if future flow conditions are inaccurate.

Extending the simulation forecast period to twice the maximum routing period will ensure that all water availability calculations in actual real day of the simulation are using future flow forecasts that are fully reflective of future water right actions that were too conducted with adequate future information. The prior appropriation system is conservatively protected with the extended forecasting period. The most apparent difference in increasing the simulation forecast period from one to two times the maximum routing period is a doubling of simulation time.

REFERENCES

1. R.A. Wurbs and T.J. Kim, *Extending and Condensing the Brazos River Basin Water Availability Model*, Technical Report 340, Texas Water Resources Institute, December 2008.

2. R.A. Wurbs and C.H. Lee, *Salinity Budget and WRAP Simulation Studies of the Brazos River/Reservoir System*, Technical Report 352, Texas Water Resources Institute, July 2009.

3. R.A. Wurbs, *Water Rights Analysis Package Modeling System (WRAP) Reference Manual*, Technical Report 255, Texas Water Resources Institute, 9th Edition, August 2012.

4. R.A. Wurbs, *Water Rights Analysis Package Modeling System (WRAP) Users Manual*, Technical Report 256, Texas Water Resources Institute, 9th Edition, August 2012.

5. R.A. Wurbs, *Fundamentals of Water Availability Modeling with WRAP*, Technical Report 283, Texas Water Resources Institute, 6th Edition, September 2011.

6. R.A. Wurbs, *Salinity Simulation with WRAP*, TR-317, Texas Water Resources Institute, July 2009.

7. R.A. Wurbs and R.J. Hoffpauir, *Water Rights Analysis Package (WRAP) Daily Modeling System*, Technical Report 430, Texas Water Resources Institute, September 2011.

8. R.A. Wurbs, *Comparative Evaluation of Generalized River/Reservoir System Models*, Technical Report 282, Texas Water Resources Institute, April 2005.

9. R.A. Wurbs, "Chapter 24 Water Rights Analysis Package (WRAP) Modeling System", Watershed Models (V.P. Singh and D.K. Frevert, Editors), CRC Press, 2006.

10. R.A. Wurbs, "Texas Water Availability Modeling System," *Journal of Water Resources Planning and Management*, American Society of Civil Engineers, Vol. 131, No. 4, July 2005.

11. Texas Water Development Board, *Water for Texas 2007*, Document GP-8-1, January 2007.

12. R.A. Wurbs, C.E. Bergman, P.E. Carriere, and W.B. Walls, *Hydrologic and Institutional Water Availability in the Brazos River Basin*, Technical Report 144, Texas Water Resources Institute, August 1988.

13. R.A. Wurbs and P.E. Carriere, *Evaluation of Storage Reallocation and Related Strategies for Optimizing Reservoir System Operations*, Technical Report 145, Texas Water Resources Institute, August 1988.

14. R.A. Wurbs and W.B. Walls, "Water Rights Modeling and Analysis," *Journal of Water Resources Planning and Management*, American Society of Civil Engineers, Vol. 115, No. 4, July 1989.

15. R.A. Wurbs and C.E. Bergman, "Evaluation of Factors Affecting Reservoir Yield Estimates," *Journal of Hydrology*, Elsevier Science Publishers, Vol. 112, 1990.

16. R.A. Wurbs, G. Sanchez-Torres, and D.D. Dunn, *Reservoir/River System Reliability Considering Water Rights and Water Quality*, TR-165, Texas Water Resources Institute, March 1994.

17. Freese and Nichols, Inc., HDR Engineering, Inc., Crespo Consulting Services, Inc., and Densmore and DuFrain Consulting, *Naturalized Flow Estimates for the Brazos River Basin and the San Jacinto-Brazos Coastal Basin*, prepared for the Texas Natural Resource Conservation Commission, TNRCC Contract No. 582-0-820108, October 2001.

18. HDR Engineering, Inc., *Water Availability in the Brazos River Basin and the San Jacinto-Brazos Coastal Basin*, prepared for the Texas Natural Resource Conservation Commission, TNRCC Contract No. 582-0-820108, December 2001.

19. Hydrologic Engineering Center, *HEC-DSSVue Data Storage System Visual Utility Engine*, User's Manual, Version 2.0, CPD-79, U.S. Army Corps of Engineers, Davis, California, July 2009.

20. Spencer T. Schnier, *Issues in Assessing Short-Term Water Supply Capabilities of Reservoir Systems*, Master of Science Thesis, Texas A&M University, May 2010.

21. Richard J. Hoffpauir, *Daily Time Step Simulation within a Priority-Order Based Surface Water Allocation Model*, Ph.D. Dissertation, Texas A&M University, December 2010.

22. Ronald L. Hula, "Southwestern Division Reservoir Regulation Simulation Model," *Proceedings of the National Workshop on Reservoir System Operations* (G.H. Toebes and A.A. Sheppard, Editors), American Society of Civil Engineers, 1981.

23. Willard B. Mills, *Time of Travel of Translatory Waves on the Brazos, Leon, and Little Rivers, Texas*, Texas Water Development Board Report 115, Prepared by the U.S. Geological Survey in Cooperation with the Texas Water Development Board and Brazos River Authority, April 1970.