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Texas Water Resources Institute TR-440
May 2013

Environmental Flows in Water Availability Modeling

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Texas Water Resources Institute
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by

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for the

Texas Commission on Environmental Quality
Austin, Texas 78711-3087

under

Contract 582-12-10220

Technical Report No. 440
Texas Water Resources Institute
The Texas A&M University System
College Station, Texas 77843-2118

May 2013

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CHAPTER 1
INTRODUCTION

The Texas Commission on Environmental Quality (TCEQ) Water Availability Modeling (WAM) System supports administration of the state's water rights permit system, regional and statewide planning, and other water management activities. The Texas water management community pursuant to recent legislative mandates is developing recommendations for environmental flow requirements for the river systems of the state. Capabilities provided by the WAM System have been expanded to better support evaluations of instream flow standards and the impacts thereof on water resources management and use. This report describes capabilities provided by the WAM System for modeling and analysis of the integration of environmental flow needs into comprehensive river system management and issues associated therewith.

The Texas Instream Flow Program (TIFP) was authorized by the 77th Texas Legislature in 2001 through Senate Bill 2. The TIFP is jointly administered by the TCEQ, Texas Parks and Wildlife Department (TPWD), and Texas Water Development Board (TWDB) and consists of scientific and engineering studies to determine flow conditions necessary for supporting a sound ecological environment in the river basins of Texas. Senate Bill 3 enacted by the 80th Texas Legislature in 2007 established a new regulatory approach to provide for environmental needs through the use of flow standards developed through a stakeholder process culminating in TCEQ rulemaking. Ongoing activities to establish environmental flow requirements in Texas are summarized in Chapter 2 of this report. The remainder of the report then focuses on describing WRAP/WAM capabilities for evaluating environmental flow requirements and impacts.

WRAP/WAM System

The TCEQ WAM System consists of the generalized Water Rights Analysis Package (WRAP) modeling system, which is applicable for simulating river/reservoir systems located anywhere, and WRAP input datasets for all of the river basins of Texas. Initial versions of WRAP date back to 1988. The Texas WAM System was implemented by the TCEQ and its partner agencies (TWDB and TPWD) and contractors (consulting firms and university research entities) during 1997-2003 pursuant to Senate Bill 1 enacted by the Texas Legislature in 1997.

The WAM System is routinely applied by applicants (or their consultants) in preparing water right permit applications, by TCEQ staff in evaluating permit applications, and by the TWDB and regional planning groups (or their consultants) in regional and statewide planning studies mandated by the 1997 Senate Bill 1. The WAM System is also used by agencies and their consultants to support other local, regional, and statewide planning and management efforts that are not directly associated with the planning and water rights programs administered by the TWDB and TCEQ. The generalized WRAP modeling system continues to be expanded to address a broadening range of applications with updated versions reflecting new and improved capabilities being released periodically. The WAM datasets are periodically updated with new or revised water right permits and refinements in modeling capabilities.

WRAP is documented by *Reference* and *Users Manuals* (Wurbs 2012), a *Fundamentals Manual* (Wurbs 2011), *Hydrology Manual* (Wurbs 2012), *Salinity Manual* (Wurbs 2009), *Programming Manual* (Wurbs and Hoffpauir 2012), and *Daily Manual* (Wurbs and Hoffpauir

2012). The public domain software and documentation are available at the following website which links to the TCEQ WAM website: http://ceprofs.tamu.edu/rwurbs/wrap.htm

The WRAP modeling system consists of the following seven computer programs.

WinWRAP provides an interface for executing the *WRAP* programs within the *Microsoft Windows* environment along with Microsoft programs and *HEC-DSSVue*.

SIM simulates river/reservoir water allocation/management/use systems for input sequences of monthly naturalized streamflows and net reservoir evaporation rates.

SIMD (*D* for daily) is an expanded version of *SIM* designed for detailed daily simulations that include flow forecasting and routing, flow and demand disaggregation, and options for simulating environmental pulse flows and flood control operations.

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 summary tables, volume budgets, data listings, DSS files for plotting, reliability indices, and frequency metrics for organizing, summarizing, and displaying simulation results output by *SIM*, *SIMD*, and *SALT*.

HYD assists in developing monthly naturalized streamflow and reservoir net evaporation rate data for the *SIM* hydrology input files and includes recently developed features for extending hydrologic periods-of-analysis.

DAY assists in developing daily hydrology input for *SIMD* and includes options for flow disaggregation and calibrating routing parameters.

The software package documented by the *Reference* and *Users Manuals* and routinely applied with the TCEQ WAM System consists of *WinWRAP*, *SIM*, and *TABLES* and is based on a computational time step of one month. Likewise, the WRAP input datasets in the TCEQ WAM System are based on a monthly time interval. The WRAP/WAM system has been based on hydrologic periods-of-analyses of greater than a half century and a monthly time step.

The August 2012 version of WRAP incorporates capabilities for performing simulations using a sub-monthly computational time step with the default being daily. Development of the daily modeling system was motivated by the need to expand capabilities for modeling environmental flow requirements and associated water management issues. Programs *SIMD* and *DAY* were added to WRAP to provide the daily time step, flood control, and environmental pulse flow simulation capabilities documented by the *Daily Manual*. *SIMD* includes all of the capabilities of *SIM* plus newer features which are a primary focus of this report.

This report focusing on environmental flows is written based on the premise that readers are familiar with WRAP/WAM basics as documented in the manuals cited above. Chapter 3 of this report summarizes both monthly and new daily WRAP features for evaluating environmental flow considerations. Chapter 4 presents simple examples illustrating these modeling capabilities. Practical complexities are illustrated by the Brazos WAM case study presented in Chapters 5, 6, and 7. Chapter 8 provides summary guidance for evaluating environmental flow requirements within the WRAP/WAM System combining older and newer modeling features.

Brazos WAM Case Study

The TCEQ WAM System dataset for the Brazos River Basin and San Jacinto-Brazos Coastal Basin, called the Brazos WAM, is adopted for the environmental flow modeling case study presented in Chapters 5, 6, and 7. The datasets developed in the case study are not designed for direct implementation by the TCEQ in the water rights permitting process. Rather the purpose of the case study investigation is to develop, test, and demonstrate modeling capabilities that may be useful to the TCEQ and water management community for various types of applications. The case study explores both daily and monthly modeling capabilities.

The Brazos WAM has also served as the case study for endeavors in expanding WRAP modeling capabilities that are documented by four earlier reports (Wurbs and Kim 2008; Wurbs and Lee 2009; Wurbs et al. 2012; and Wurbs and Chun 2012). All datasets in the TCEQ WAM System, including the Brazos WAM, are based on a monthly computational time interval. Wurbs et al. (2012) document the conversion of the monthly Brazos WAM to a daily time step and application of the new capabilities covered in the August 2012 *Daily Manual*. The original Brazos WAM has a hydrologic period-of-analysis of 1940-1997. Wurbs and Chun (2012) demonstrate the new hydrology extension capabilities documented in the November 2012 *Hydrology Manual* by updating the Brazos WAM period-of-analysis to cover 1940-2011.

The Brazos WAM datasets used in the case study include the original and expanded monthly Brazos WAM datasets, an expanded version of the new daily model, and alternative variations thereof. The Brazos WAM is large and complex, providing opportunities to explore a number of issues involved in integrating environmental flow, water supply, flood control, hydropower, multiple-reservoir system operations, and other related water management practices and associated modeling methods. A diverse array of environmental instream flow requirements are considered in the case study.

The Basin and Bay Expert Science Team (BBEST) for the Brazos River Basin submitted its Environmental Flow Regime Recommendation Report to its Basin and Bay Area Stakeholders Committee (BBASC), the Environmental Flows Advisory Group, and TCEQ in March 2012. The BBASC submitted its Environmental Flow Standards and Strategies Recommendations Report to the TCEQ in August 2012. The Brazos River Authority (BRA) submitted a system operations permit to the TCEQ in 2004 which is still under review. The BRA developed a draft water management plan during 2012 in conjunction with the system operations permit application. The Brazos WAM case study presented in Chapters 5, 6, and 7 of this report is independent of these other studies. However, the environmental flow recommendations and other publically available information developed by these studies are used in the case study.

Scope and Organization of this Report

The objectives of this report are to:

- provide guidance in applying the expanded WRAP to model and evaluate environmental flow requirements and the integration of environmental flow needs in comprehensive multiple-purpose water resources management

- support continued testing and improvement of new modeling capabilities

The endeavors mandated by the 2001 Senate Bill 2 and 2007 Senate Bill 3 to address environmental flow needs motivate the effort presented here to improve the decision-support capabilities provided by the WAM System originally implemented pursuant to the 1997 Senate Bill 1. Environmental flows are a priority concern currently being addressed by the Texas water management community.

Environmental flow requirements have been an important consideration in Texas water rights permitting processes for many years and are incorporated in the original TCEQ WAM System datasets and WRAP simulation model. However, environmental flow considerations are currently being greatly expanded. Newer expanded WRAP/WAM modeling capabilities are the focus of this report, but modeling methods applied in the past are also considered. The daily modeling system is the focus, but monthly modeling is also still important.

Environmental flow requirements are an integral part of the WRAP/WAM modeling system. The August 2012 WRAP is documented by seven manuals, with a combined total length of over 1,400 pages, all of which are relevant to modeling environmental flow requirements. This report provides a specific focus on environmental flows and explores key modeling considerations. However, modeling of environmental flow requirements cannot be separated from the overall WRAP/WAM modeling system. This report is written based on the premise that readers are generally familiar with the overall basics of the WRAP/WAM modeling system.

This report is organized as follows.

Chapter 2 provides an overview summary of ongoing endeavors to establish environment flow requirements for the river systems of Texas. These activities motivated the development of expanded modeling capabilities explored in this report.

Chapter 3 summarizes WRAP and WAM capabilities focusing specifically on modeling and analysis of environmental flow requirements.

Chapter 4 provides a set of simple examples illustrating the modeling methods covered in Chapter 3. These examples are designed for explaining the basic concepts and logistics of applying the various options provided by the modeling system.

Chapters 5, 6, and 7 present the Brazos WAM case study. The Brazos River Basin, Brazos WAM, and existing and recommended new environmental flow requirements are described in Chapter 5. Environmental flow requirements are added to the datasets and simulation results are presented in Chapter 6. Key issues are investigated in Chapter 7 based on comparative analyses of the results of alternative simulations.

Chapter 8 summarizes modeling strategies and methodologies, study conclusions, and guidance for incorporation of environmental flow requirements into WRAP/WAM modeling and the capabilities provided for analyzing instream flow requirements and their impacts from the perspective of integrated multiple-purpose water resources development, allocation, and management.

References are cited throughout this report and listed at the end of the report.

CHAPTER 2
ENVIRONMENTAL INSTREAM FLOWS

The term *environmental flow* refers to water flowing in rivers, streams, lakes, and reservoirs, and includes freshwater inflows to bays and estuaries as well as flow in inland stream systems. Environmental flow requirements are defined in terms of the magnitude, frequency, timing, duration, spatial distribution, and water quality of the flows required to sustain freshwater and estuarine ecosystems and the quality of life of humans that depend on these ecosystems.

Water resources development and management has altered the natural flow of rivers around the world. Water managers throughout the world are concerned with the challenges of providing reliable and affordable water supplies for growing populations while preserving the vitality of ecosystems and environmental resources. The scientific literature related to environmental flows is extensive. However, O'Keefe (2012) and many other authors note that despite the global recognition of the need to use natural resources sustainably, implementation of policies and practices to protect environmental flows has lagged far behind the intention.

Protection of environmental instream flows in the river systems of Texas has been a concern in water resources planning, allocation, and management historically, particularly since the 1980's. Efforts of the state agencies (TCEQ, TPWD, TWDB), water managers, stakeholder groups, environmental organizations, and science and engineering community in establishing improved and expanded environmental instream flow standards have intensified pursuant to Senate Bill 2 enacted by the Texas Legislature in 2001 and Senate Bill 3 enacted in 2007.

Water Allocation in Texas

The water allocation systems for the 15 major river basins and eight coastal basins of Texas simulated within the TCEQ Water Availability Modeling (WAM) System include:

- the water rights permit system administered by the TCEQ which includes about 8,000 active permits with the allocation mechanisms for the Lower Rio Grande being significantly different than for the remainder of the state
- 1903 and 1944 Treaties between Mexico and the United States allocating the waters of the Rio Grande between the two nations and agreements implementing the treaties
- five interstate compacts with neighboring states with different allocation mechanisms
- water supply storage contracts between the U.S. Army Corps of Engineers and one or more nonfederal entities for conservation storage capacity in each of 32 federal multiple-purpose reservoirs
- various other agreements between water management entities

The approximately 8,000 water right permits are represented in the WAM datasets by about 10,400 water right *WR* records, 700 instream flow *IF* records, and auxiliary records supporting each of the *WR* and *IF* records. The water right permits include storage in about 3,450 reservoirs.

In Texas like elsewhere, water resources are shared by many people who use the water for a variety of purposes. Water right systems serve to equitably apportion water resources among users; protect existing water users from having their supplies diminished by new users; govern the sharing of limited water during droughts when supplies are inadequate to meet all needs; and facilitate efficient water use. Effective water allocation becomes particularly important as demands exceed reliable supplies. As demands on limited resources increase, water right systems and other institutional water allocation mechanisms are expanded and refined.

The laws enacted by the Texas Legislature listed in Table 2.1 represent milestones in the development of the Texas water rights system. Establishment of the current water rights permit system pursuant to the Lower Rio Grande Court Case and the Water Rights Adjudication Act of 1967 are summarized in the following section. The other legislative acts listed in Table 2.1 are discussed in subsequent sections of this chapter.

Table 2.1
Milestone Legislative Acts in the Evolution of Water Rights in Texas

1967	Water Rights Adjudication Act of 1967 created an adjudication process to merge diverse water rights into a permit system.
1985	Texas Water Code was revised to incorporate environmental flow requirements in the water rights permit system.
1997	Senate Bill 1 authorized creation of the WAM System and the current regional and statewide planning process.
2001	Senate Bill 2 created the Texas Instream Flow Program.
2007	Senate Bill 3 created the current process for establishing environmental flow requirements.

Historical Evolution of Water Rights in Texas

The Texas water rights system evolved over several centuries. The riparian doctrine was introduced in Texas during the rule of Spain and later Mexico and after independence in 1836, in a somewhat different form by the Republic of Texas. In 1840, the state of Texas adopted the common law of England with another variation of riparian water rights. The prior appropriation doctrine was adopted by legislative acts in 1889 and 1895. After 1895, public lands which transferred into private ownership no longer carried riparian water rights. Land already privately owned kept its riparian rights. At first, appropriation simply involved water users filing sworn statements with county clerks describing their use. Since 1913, more strictly administered procedures have been followed based on a statewide appropriation system administered by a centralized state agency, though that agency has since changed or been renamed several times.

All appropriation statutes recognized existing riparian rights. Riparian landowners could also acquire appropriative water rights. In 1926, the courts divided streamflow into *ordinary normal flow* and *flood flow*. Riparian rights were limited to normal flow and therefore are not applicable to flood waters impounded by reservoirs. This distinction was the basis for correlating riparian and appropriative rights from 1926 until the riparian rights were merged into the appropriative system pursuant to the Water Rights Adjudication Act of 1967.

Thus, an unmanageable system evolved, with various conflicting rights and many rights being unrecorded (Wurbs 2004). The severe drought during 1951-1957 motivated a massive lawsuit in the Lower Rio Grande which demonstrated the impracticality of a purely judicial adjudication of water rights statewide. Thus, the Water Rights Adjudication Act was enacted by the Texas legislature in 1967, with the stated purpose being to require a recording of all claims for water rights, to limit the exercise of those claims to actual use, and to provide for the adjudication and administration of water rights. All riparian water rights were merged into the prior appropriation system, creating the present permit system applicable to all of Texas except the Lower Rio Grande. The water rights adjudication process required for transition to the permit system was initiated in 1968 and completed during the late 1980's.

The Lower Rio Grande Valley Case resulted in a water rights system for the Lower Rio Grande which is different from the otherwise statewide system. The Texas share of the waters of the Rio Grande below Fort Quitman was allocated among numerous water right holders in conjunction with this massive lawsuit. The lawsuit was filed in 1956, the trial was held in 1964-1966, and the final judgment of the appellate court was filed in 1969. In 1971, the Texas Water Rights Commission adopted rules and regulations implementing the court decision. Assorted versions of riparian and appropriative rights were combined into a permit system. The lawsuit resulted in rights being divided into three categories. Municipal rights have the highest priority. Irrigation rights are divided into Class A and Class B rights, with Class A rights receiving more storage in Lakes Falcon and Amistad storage accounts in the allocation procedure (Wurbs 2004).

The existing water rights permit system has been in place since completion of the adjudication process in the 1980's. Water rights are granted by a state license, or permit, which allows the holder to divert a specified amount of water annually at a specific location, for a specific purpose, and to store water in reservoirs of specified capacity. Any organization or person may submit an application to the TCEQ for a new water right or to change an existing water right at any time. The TCEQ will approve the permit application if unappropriated water is available, a beneficial use of the water is contemplated, water conservation will be practiced, existing water rights are not impaired, and the water use is not detrimental to the public welfare. Proposed actions reflected in permit applications must be consistent with regional water plans. Priorities are based on the date specified in the permits. During the 1967-1980's adjudication process, priority dates were established based on historical water use. Since then, priorities are based on the dates that the permits are administratively approved.

The water authorized to be appropriated under the terms of the particular permit is not subject to further appropriation unless the permit is canceled. A permit may be canceled if water is not used during a 10-year period. Special term permits may also be issued allowing water use for specified periods of time. The Rio Grande and segments of other rivers are over-appropriated with no new rights for additional water use being granted. However, unappropriated water is still available for appropriation in some regions of the state. A permit holder has no actual title of ownership of the water but only a right to use the water. However, a water right can be sold, leased, or transferred to another person. The Lower Rio Grande Valley has been the only region of Texas with an active water market historically.

Environmental Flow Procedures without the 2007 Senate Bill 3 Changes

For water right permits issued or revised since 1985, the TCEQ has used special permit conditions to implement the Texas Water Code provisions that require consideration of instream uses, freshwater inflows, water quality, and fish and wildlife habitat. However, few of the several thousand permits issued before 1985 address environmental flows. The provisions noted below affect only applications for new permits or amendments to existing permits.

The Texas Legislature enacted a suite of environmental flow protection provisions in 1985 (Bradsby 2009). Texas Water Code Section 11.147 was amended to provide the TCEQ authority, for permits for projects located within 200 river miles of the coast, to include permit conditions considered necessary to maintain beneficial inflows to any affected bay and estuary system. Sections 11.147(d) & (e) were added to require the TCEQ to consider the effect, if any, of the issuance of a water right permit on the existing instream uses and water quality of the stream and on fish and wildlife habitats. Texas Water Code Section 11.152 requires reasonable actions to mitigate adverse impacts on fish and wildlife for permits in excess of 5,000 acre-feet. The TCEQ implemented the 1985 provisions by including special conditions in new and amended permits. This practice was further clarified in 2003 when Texas Water Code Section 11.147 was further amended with specific directions for permits to include, to the extent practical when considering all public interests, conditions to maintain existing instream uses and water quality, and fish and wildlife habitats.

When processing an application for a permit to store and/or divert water, the TCEQ performs a technical review of the proposed action and assesses its environmental impacts (Science Advisory Committee 2004). The investigation may rely upon existing data and literature or may require site-specific studies. If available and applicable, studies of freshwater inflow, instream flow, and water quality are considered in the technical review. The TCEQ determines the level of required protection using the best available science and information and imposes permit conditions consistent with the needed protection. A typical special condition limits diversion of water by requiring that a certain quantity of water or flow rate occur at a reference or diversion site before the permittee may divert water. This is called a streamflow restriction. Factors that lead to a streamflow restriction may include the perennial nature of the stream, aquatic life uses and biological integrity, water quality, threatened or endangered species, and existing recreational use. Special permit conditions are customized to address the specific impacts of a particular water project.

Permit applications supported by site-specific studies have been rare in the past. Therefore, the majority of environmental flow protection permit conditions have been developed through the use of hydrologic analysis based methodologies. The Lyons and Consensus Criteria methods, discussed later in this chapter, have been routinely used by the TCEQ to determine minimum flows that must be maintained before the permitted diversion or storage is allowed.

Under pre-Senate Bill 3 practices, participation in the development of special conditions to protect environmental flows has been limited. For uncontested water right applications, the participants are the applicant and the TCEQ. For contested applications, parties admitted to a contested case hearing may also participate. The TCEQ considers recommendations of the TPWD, but the TPWD has no decision-making authority (Bradsby 2009).

Texas Instream Flow Program Created by 2001 Senate Bill 2

Senate Bill 2 passed into law by the 77th Texas Legislature in 2001 established the Texas Instream Flow Program (TIFP) which is jointly administered by the Texas Parks and Wildlife Department (TPWD), Texas Commission on Environmental Quality (TCEQ), and Texas Water Development Board (TWDB) in collaboration as appropriate with other entities. The 2001 Senate Bill 2 directed the agencies

- to jointly establish and continuously maintain an instream flow data collection and evaluation program and
- to conduct studies and analyses to determine appropriate methodologies for determining flow conditions in the state rivers and streams necessary to support a sound ecological environment.

The TWDB maintains the TIFP website at which relevant reports and information are compiled for convenient access.

http://www.twdb.state.tx.us/instreamflows/index.html

The goal of the TIFP is to identify appropriate flow regimes (quantity and timing of flow) that are adequate to maintain an ecologically sound environment, conserving fish and wildlife resources while also providing sustained benefits for other human uses of water resources. TIFP studies consider a wide range of environmental variables such as habitat, hydrology, biology, geomorphology, water quality, and stream system connectivity, dictating a multiple-disciplinary collaboration. The three agencies have developed a technical report (TCEQ, TPWD, TWDB 2008) providing an overview of methods proposed for performing environmental instream flow studies. The process of developing these methods included a detailed review by the *Committee on Review of Methods for Establishing Instream Flows for Texas Rivers* performed through the National Research Council, which is documented by a technical report (National Research Council 2005). Stakeholders and other scientists in Texas also contributed to the process of reviewing, adapting, and developing methodologies for performing environmental flow studies.

Priority studies under the TIFP to determine environmental flow needs for the following selected river reaches are to be completed by December 2016: lower San Antonio River, lower Guadalupe River, lower and middle Brazos River, middle Trinity River, and lower Sabine River. However, these selected priority reaches represent only a small portion of the rivers and tributary stream systems of Texas. Many years will be required to perform detailed studies for all reaches of all of the rivers and streams of the state.

Recognizing the need to more expeditiously determine appropriate amounts of water to set aside for the environment, the Texas Legislature enacted Senate Bill 3 in 2007, creating an accelerated process for establishing instream flow requirements for selected priority river systems using existing information and the best available science. Schedules set by the Senate Bill 3 process do not allow completion of new, more detailed studies before developing recommended instream flow standards. However, an adaptive management component allows for periodic refinement of flow recommendations at least every ten years. Results of more detailed studies, such as those completed by the Texas Instream Flow Program, can facilitate future refinements of environmental flow standards.

Protection of Environmental Flows Pursuant to the 2007 Senate Bill 3

A new regulatory strategy for protecting environmental flows in Texas was introduced with enactment in 2007 by the 80th Texas Legislature of Article 1 of Senate Bill 3. The 2007 Senate Bill 3 broadens the range of participants involved in establishing environmental flow requirements. Senate Bill 3 will require many years to fully implement statewide. Water right permits in effect prior to the effective date of September 1, 2007 are not impacted. Only new water rights and water right amendments that are submitted after this date are subject to the new requirements established pursuant to Senate Bill 3.

Procedures for protecting environmental flows that were already being applied prior to enactment of the 2007 Senate Bill 3 are discussed earlier in this chapter. These old policies and practices continue to be applied along with incorporating new procedures. The new and different practices added pursuant to Senate Bill 3 are outlined in this section as follows.

The products of the expanded regulatory process mandated by Senate Bill 3 are establishment of environmental flow requirements and set-asides to satisfy the environmental flow requirements. *Set-asides* refer to volumes of unappropriated water set aside by the TCEQ in administration of the water rights permit process to meet specified environmental flow standards. Environmental flow requirements (standards) for particular locations in particular stream systems are defined in terms of flow regimes. Senate Bill 3 defines an environmental flow regime as:

> *A schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies.*

Senate Bill 3 recognizes the need for specified timeframes and prompt action to protect environmental flows, the need for additional enforcement and more effective water rights administration, the need for improved science and technical tools, and the need for adaptive management. Texas Water Code Section 11.0235(d-5) reproduced below highlights the need for continuing evaluation of environmental flow requirements along with other water needs on a site specific basis.

> *The legislature finds that the management of water to meet instream flow and freshwater inflow needs should be evaluated on a regular basis and adapted to reflect both improvements in science related to environmental flows and future changes in projected human needs for water. In addition, the development of management strategies for addressing environmental flow needs should be an ongoing, adaptive process that considers and addresses local issues.*

EFAG, SAC, BBASCs, and BBESTs

The regulatory system mandated by Senate Bill 3 generates a sequence of recommendations regarding environmental flow regimes that ultimately lead to the adoption by rulemaking by the TCEQ of environmental flow standards and set-asides. Senate Bill 3 greatly expands the number of people and groups that contribute to the regulatory process. The decision-making procedures are based on a combination of regional public participation, statewide agency oversight, and technical support of the science and engineering community. Local stakeholders and technical experts develop recommendations regarding the appropriate environmental regime for particular river basin and bay systems (Bradsby 2009).

The three agencies (TCEQ, TPWD, TWDB) provide administrative leadership and technical support for the Senate Bill 3 process. As discussed below, the committees listed in Table 2.2 are responsible for specified components of the process. Announcements, records, technical reports, and other information created and/or used by these committees are available at the following resources website shown below and the TCEQ websites noted in Table 2.2. A wealth of information about environmental flows can be found at these websites.

http://www.tceq.texas.gov/permitting/water_supply/water_rights/eflows/resources.html

Table 2.2
Committees Created to Implement the Senate Bill 3 Process

Environmental Flows Advisory Group (EFAG) http://www.tceq.texas.gov/permitting/water_supply/water_rights/eflows/group.html
Science Advisory Committee (SAC) http://www.tceq.texas.gov/permitting/water_rights/eflows/txenvironmentalflowssac.html
Basin and Bay Area Stakeholder Committees (BBASC) http://www.tceq.texas.gov/permitting/water_rights/eflows
Basin and Bay Expert Science Teams (BBEST) http://www.tceq.texas.gov/permitting/water_rights/eflows

The Environmental Flows Advisory Group (EFAG) provides general oversight of the statewide Senate Bill 3 process including investigating public policy implications of options to protect environmental flows and overseeing appointment of the SAC and BBASCs. The EFAG is comprised of nine members: three members appointed by the governor including one each from the TCEQ, TWDB, and TPWD, three members of the Senate appointed by the Lieutenant Governor, and three members of the House of Representatives appointed by the Speaker of the House of Representatives.

The Science Advisory Committee (SAC) provides technical assistance to the EFAG and direction to the committees and agencies involved in conducting environmental flow studies. Senate Bill 3 specifies that the SAC be comprised of between five and nine members appointed by the EFAG with diverse experience in hydrology, hydraulics, water resources, biology, geomorphology, geology, water quality, computer modeling, and other technical areas pertinent to the evaluation of environmental flows. The SAC is currently comprised of nine scientists and engineers from consulting firms and universities.

A Basin and Bay Area Stakeholder Committee (BBASC) is appointed by the EFAG for each river basin and bay system specified in the Texas Water Code as being a priority system. Each BBASC must consist of at least 17 members and must reflect a fair and equitable balance of interest groups concerned with the particular river basin and bay system. A BBASC must establish a Basin and Bay Expert Science Team (BBEST) within six months of creation of the BBASC. The BBASC is responsible for evaluating the instream flow regime recommendations developed by the BBEST along with considering other factors such as present and future needs for water for other human uses within the framework of comprehensive integrated water resources management. Each Stakeholders Committee (BBASC) develops a recommendations report proposing environmental flow standards and strategies for achieving the flow standards. BBASC recommendations must be based on achieving a consensus among the members of the committee. The BBASC recommendations reports are submitted to the TCEQ and EFAG.

Each Basin and Bay Expert Science Team (BBEST) is responsible for developing a recommended flow regime for the particular river basin system for which the team is established considering only environmental needs without regard to needs for human water uses. The Science Teams are charged by Senate Bill 3 with application of a scientifically derived process for predicting the response of ecosystems to changes in instream flows or freshwater inflows. BBEST recommendations must be based solely on best available science. The recommended flow regime developed by consensus of the Science Team (BBEST) members is submitted in a technical recommendations report to the BBASC, EFAG, and TCEQ.

Each BBEST develops a proposed flow regime based solely on environmental needs. A BBASC reviews the BBEST report and develops an environmental flow regime based on a comprehensive consideration of all water needs including human as well as ecosystem needs. The Science Team and Stakeholder Committee may work together and interact in various ways.

BBEST and BBASC Recommendations Reports and Work Plans

The TCEQ maintains websites for each Basin and Bay Expert Science Team (BBEST) and Basin and Bay Area Stakeholder Committee (BBASC) that contain various information generated during the process of the committees performing their work as well as their final recommendations reports. These websites may be accessed through the website listed in Table 2.2. The BBEST environmental flow regime recommendations reports, BBASC environmental flow standards and strategies recommendations reports, and BBASC work plan reports that were available at the TCEQ website as of March 2013 are listed in Table 2.3.

The reports noted in Table 2.3 can be downloaded from the TCEQ website as PDF files. The dates of the reports and number of pages in the PDF files of the main reports are noted in Table 2.3. In addition to the main reports, several of the reports include lengthy appendices as separate PDF documents that are not included in the page counts in Table 2.3.

The BBEST recommendations reports document analyses and supporting rationale and present the environmental flow requirements proposed by the BBEST considering only environmental needs. The BBASC recommendations reports present the environmental flow requirements recommended by consensus of the BBASC considering human needs for water as well as the recommendations and supporting information provided by the BBEST.

Table 2.3
River Systems with Completed BBEST and BBASC Recommendation Reports

River Basin and Bay System	BBEST Report	BBASC Report	Work Plan	TCEQ Standards
Sabine and Neches Rivers and Sabine Lake Bay	Nov 2009 1215 pages	May 2010 66 pages	Dec 2010 29 pages	May 2011 page 11
Trinity and San Jacinto Rivers and Galveston Bay	Nov 2009 671 pages	May 2010 35 pages	Apr 2012 73 pages	May 2011 9 pages
Colorado and Lavaca Rivers and Matagorda and Lavaca Bays	Mar 2011 497 pages	Aug 2011 346 pages	Jun 2012 46 pages	Aug 2012 35 pages
Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, San Antonio bays	Mar 2011 427 pages	Sep 2011 152 pages	May 2012 56 pages	Aug 2012 25 pages
Nueces River and Corpus Christi and Baffin Bays	Oct 2011 285 pages	Aug 2012 522 pages	Nov 2012 56 pages	Sep 2013 scheduled
Brazos River and Associated Bay and Estuary System	Mar 2012 198 pages	Sep 2012 103 pages		Sep 2013 scheduled
Rio Grande, Rio Grande Estuary, and Lower Laguna Madre				Sep 2013
Lower Rio Grande BBEST	Jul 2012			scheduled
Upper Rio Grande BBEST	Jul 2012			

The BBASCs are also charged under the Senate Bill 3 process with developing work plans to facilitate adaptive management of the environmental flow standards adopted by the TCEQ. Work plans are prepared as directed by Texas Water Code Section 11.02362(p) which is reproduced below.

In recognition of the importance of adaptive management, after submitting its recommendations regarding environmental flow standards and strategies to meet the environmental flow standards to the commission, each basin and bay area stakeholders committee, with the assistance of the pertinent basin and bay expert science team, shall prepare and submit for approval by the advisory group a work plan. The plan must:

(1) establish a periodic review of the basin and bay environmental flow analyses and environmental flow regime recommendations, environmental flow standards, and strategies, to occur once every ten years;

(2) prescribe specific monitoring, studies, and activities, and

(3) establish a schedule for continuing the validation or refinement of the basin and bay environmental flow analyses and environmental regime recommendations, the environmental flow standards adopted by the commission, and the strategies to achieve those standards.

TCEQ Adoption of Environmental Flow Standards and Set-Asides

The TCEQ is charged by the 2007 Senate Bill 3 with adopting flow standards for each river basin and bay system in Texas that are adequate to support a sound ecological environment, to the maximum extent reasonable considering other public interests and other relevant factors. The flow standards are adopted through TCEQ rule-making procedures. Proposed flow regimes are recommended to the TCEQ by the Science Teams (BBESTs) and Stakeholder Committees (BBASCs). TCEQ evaluation of these recommended plans include public review and comment.

The Texas Water Code Section 11.1471(a) requires the TCEQ to establish an amount of unappropriated water, if available, to set aside to satisfy environmental flow standards to the maximum extent reasonable when considering human water needs. With the exception of the middle and lower Rio Grande, a set-aside is to be assigned a priority date corresponding to the date the TCEQ receives the environmental flow regime recommendations from the applicable BBEST. Each set-aside is to be included in the Water Availability Modeling (WAM) System.

The Senate Bill 3 process is based on incorporating environmental flow protection conditions in water right permits issued or amended on or after September 1, 2007. The TCEQ may not issue a permit for a new appropriation or amendment to an existing water right permit that increases the amount of water authorized to be stored, taken, or diverted if any environmental flow set-aside would be impaired. With respect to an amended permit, this restriction applies only to the increase in amount of water to be stored, taken, or diverted.

The TCEQ has either published or is scheduled to publish the environmental flow standards for the river basin and bay systems listed in Table 2.3 as Subchapters B through H of Texas Administrative Code Chapter 298 entitled *Environmental Flow Standards for Surface Water*. Subchapter A of Chapter 298 is *General Provisions*. The actual past or future scheduled effective dates of the subchapters are listed in the last column of Table 2.3. The length in pages of the individual subchapter of Chapter 298 for each river and bay system is also shown.

Components of an Environmental Flow Regime

Environmental flow standards adopted by the TCEQ consist of a set of flow metrics and rules that vary seasonally or by hydrologic condition and by location that govern decisions to curtail junior rights to divert and/or store streamflows. Environmental flow requirements or standards are defined in terms of flow regimes which describe the magnitude, frequency, duration, timing, and rate of change of streamflows required to maintain a sound ecology.

In the past, environmental flow requirements typically have been specified as a minimum instream flow target that may vary by month and location. However, the Texas Instream Flow Program (TIFP) and Senate Bill 3 strategy is based on flow regimes with multiple components. Scientists recognize that various characteristics of flow variability are important determinants of aquatic community structure and stability. Ecosystems are adapted to hydrologic patterns reflecting flow variability for a full range of flows, not just low flows.

The Senate Bill 3 process has adopted a framework recommended by studies performed pursuant to the Senate Bill 2 TIFP that defines an instream flow regime that includes four components: subsistence flows, base flows, within-bank high flow pulses, and overbank high pulse flows. The magnitude, frequency, duration, timing, and rate of change of streamflows are considered for each component. Flow ranges defining the four components and primary objectives addressed are presented in Table 2.4, which is reproduced from the TIFP technical studies report (TCEQ, TPWD, TWDB 2008).

Table 2.4
Instream Flow Regime Components

Subsistence Flows
Definition: Infrequent, seasonal periods of low flows.
Objectives: Maintain water quality criteria.

Base Flows
Definition: Normal flow conditions between storm events.
Objectives: Ensure adequate habitat conditions, including variability, to support the natural biological community.

High Flow Pulses
Definition: Short-duration, in-channel, high flows following storm events.
Objectives: Maintain important physical habitat features.
Provide longitudinal connectivity along the channel.

Overbank Flows
Definition: Infrequent high flow events that exceed the normal channel.
Objectives: Maintain riparian areas. Provide lateral connectivity between the river channel and active floodplain.

Subsistence flows occur during drought or very dry conditions. The primary objective of subsistence flow standards is to maintain water quality. Other objectives include ensuring that species populations are able to recolonize the river system after normal base flow rates return.

Base flows represent the range of average or normal flow conditions without the effects of recent rainfall. A primary objective of base flow standards is to ensure adequate habitat conditions, including variability, to support the natural biological community of the river system.

High flow pulses are short duration, high magnitude but still within channel, flow events that occur during and immediately following rainfall storms. High flow standards are designed to maintain physical habitat features and longitudinal connectivity along the river channel.

Overbank flows are infrequent, high magnitude flow events that exceed channel banks resulting in water entering the floodplain. The primary objectives of overbank flow requirements are to maintain riparian areas and provide lateral connectivity to the floodplain. Other objectives may include transporting organic matter to the main channel, providing life cycle cues for various species, and maintaining the balance of species in aquatic and riparian communities.

Quantitative Definition of Instream Flow Requirements

The primary water management practices for satisfying instream flow requirements are to restrict water supply diversions and modify reservoir operations. Strategies for altering reservoir operations to provide for instream flow needs may be limited to restricting refilling of depleted storage capacity or could include changing operating rules that control releases from storage.

Optimizing reservoir operations may include multiple-reservoir system operations and interactions between multiple purposes that could include environmental instream flows, water supply diversions, return flows, hydroelectric energy generation, lake and river recreation, and flood control. However, in administering the water rights system in the past, instream flows have been protected typically by simply restricting water supply diversions and restricting refilling of depleted reservoir storage capacity. Reservoir owners may be required to make releases for downstream environmental flow needs, but release requirements are usually limited to the magnitude of the stream inflows into the reservoir.

The Texas water rights system is based on the prior appropriation doctrine, meaning that existing water users are protected from having their supplies diminished by newer water users. Seniority or priorities are based on dates specified in the water right permits. For permit applications approved with permits issued after completion of the adjudication process mandated by the Water Rights Adjudication Act of 1967, priorities are based on the dates that the permits were administratively approved. During the 1967-1980’s adjudication process, priority dates were established based on historical water use. Water rights with earlier priority dates are senior to other more recent (junior) water rights.

Environmental flow requirements have commonly in the past been specified as a minimum instream flow target at a location on a stream that may vary by month and location and in some case vary with hydrologic condition. The metric is the specified minimum flow rate. In the TCEQ Water Availability Modeling (WAM) System, diversion and storage rights that are junior to the instream flow requirements are curtailed as necessary to protect the instream flow requirements. The minimum instream flow limit expressed as an instantaneous flow rate, in cubic feet per second, must be approximated as a monthly volume, in acre-feet/month, in the monthly time step WAM System. In the model and in the real world, the amount of streamflow available for appropriation by new water right permits may be reduced by the instream flow requirements. During drought or emergency conditions, curtailment actions may be activated through the TCEQ water rights administration process in actual water management and use.

The terms *flow standard* or *regime* refer to the environmental instream flow requirements (needs for flow) that are specified to be satisfied or at least to be protected from junior water rights. Diversion and/or storage rights that are junior to the specified instream flow standard may be curtailed as necessary to prevent or minimize violation of an instream flow standard. A flow standard is a set of specifications consisting of flow metrics and rules for applying the metrics. The metrics and rules defining environmental flow standards developed by the Senate Bill 3 process are much more complex than those adopted in the past.

The new Senate Bill 3 strategy is based on defining a flow regime that includes multiple metrics for subsistence, base, high pulse, and overbank flows that may include flow magnitude, frequency, duration, timing, and rate of change. This approach is much more complicated than the conventional past practice of defining environmental instream flow standards solely in terms of minimum flow limits. Conceptually in the future, physical mechanisms for achieving the flow standards may also involve more innovative integrated water management strategies.

Each of the individual flow regime components (subsistence, base, high pulse, and overbank), particularly the higher flows, may include various metrics quantifying flow magnitude, duration, timing, frequency, and rate of change. The metrics may vary with climatic or hydrologic conditions such as dry, average, and wet periods. Varying hydrologic conditions can be considered in different ways. Triggers for defining dry, average, and wet or other categories of conditions could be based on reservoir storage contents or an index such the Palmer hydrology drought index. Different sets of metrics are activated depending on hydrologic condition. Long-term attainment frequencies may be considered as well as current conditions.

The adopted instream flow standards will be incorporated in the WAM System to allow modeling of their impacts on water availability for other water users as well as evaluating capabilities for satisfying the environmental instream flow needs. Water Rights Analysis Package (WRAP) capabilities have been greatly expanded to deal with the increased complexities of modeling environmental flow requirements. Additional improvements to the modeling system will be made if and as needed.

Environmental Flow Literature

The published literature dealing with scientific and resource management aspects of environmental flows is interdisciplinary and massive. Hydrology, biology, ecology, geomorphology, water quality, fish and wildlife management, water resources engineering, and water resources systems planning and management all overlap with environmental flow science. The several publications cited below provide a general starting point for exploring the extensive literature dealing with environmental flow science and associated integrated water management.

During 1981 and again in 1986, Reiser et al. (1989) surveyed legislation and practices in throughout the United States and Canada and found that a wide array of methods for quantifying environmental flow needs had been proposed, though effective implementation of management strategies was lacking. Poff and Zimmerman (2009) review the literature dealing with the response of ecosystems to altered flow regimes. Lake (2011) explores the effects of droughts on aquatic ecosystems. Tharme (2003), Acreman and Dunbar (2004) and O'Keefe (2012) provide international perspectives on methods for assessing and managing environmental flow allocation. A few of the numerous papers that propose strategies and methodologies for establishing instream flow requirements at locations throughout the United States and world include Mathews and Richter (2007), Richter (2009), Richter et al. (1996), Richter et al. (1997), Richter et al. (2006), and Sanderson et al. (2012). These publications reference many other publications.

Publications including Annear et al. (2004, 2009) available from the Instream Flow Council (http://www.instreamflowcouncil.org/) compile the experiences of state and provincial fish and wildlife agency scientists in the United States and Canada in investigating and managing environmental flows and establishing flow standards. Previously cited technical reports (National Research Council 2005; TCEQ, TPWD, TWDB 2008) prepared under the auspices of the Texas Instream Flow Program provide reviews of the published literature as well as themselves being major new contributions to the published literature.

Hundreds of assessment methodologies, computer models, and computational techniques for assessing environmental flow needs are proposed in the published literature including:

- hydrologic methodologies that rely upon streamflow statistics using streamflow as an indicator for ecological and biological health
- hydraulic models that correlate streamflow with available habitat based on river channel geometry
- habitat evaluation methodologies that combine target species data and hydraulic data to determine optimal habitat
- complex holistic strategies for comprehensive ecosystem assessments
- methodologies for determining appropriate inflows to bays and estuaries required to maintain salinity gradients and otherwise preserve healthy bay and estuarine fisheries and ecosystems
- and various other auxiliary supporting models and data compilation methods

Some tools are designed to directly produce instream flow requirements as their computed result. Many tools do not directly generate flow requirements but rather produce flow statistics and/or other information useful in evaluating alternative proposed flow standards. Many techniques have been explored by researchers but not actually adopted in practical decision-support applications. Other methodologies have been used by agencies in real-world applications.

Recognizing the importance that the ecological soundness of the state's riverine and bay and estuarine systems has on the economy, health, and well-being of the state, the Texas Legislature enacted Senate Bill 1639 during the 78th Legislative Session (2003-2004) that established the Study Commission on Water for Environmental Flows. A report prepared for the Study Commission by the Science Advisory Committee (1) describes hydrologic conditions of the major river basins of Texas and freshwater inflow patterns for major bay and estuary systems, (2) evaluates the analytical tools and procedures for assessing requirements for preservation, maintenance, or enhancement of aquatic resources and riparian habitat, (3) identifies ecological parameters to be considered in determining environmental flow needs, and (4) outlines strategies that could be implemented to protect and enhance environmental flows. Chapter 6 of this *Report on Water for Environmental Flows* (Science Advisory Committee 2004) provides a comparative review critiquing analytical tools that have been used or are available for use in environmental flow studies in Texas.

Environmental flows include both (1) instream flows in rivers and streams needed to preserve healthy riverine ecosystems and (2) freshwater inflows to bays and estuaries needed to maintain the productivity of economically important and ecologically characteristic sport or commercial fish and shellfish species and the estuarine life upon which such species are dependent. Although daily fluctuates may also be important, monthly or seasonal time intervals are commonly considered appropriate in analyzing freshwater inflows to bays and estuaries. Daily flow fluctuations are much more important in analyzing effects on riverine ecosystems.

Assessments of Freshwater Inflows to the Bays and Estuaries of Texas

The Science Advisory Committee (2004) *Report on Water for Environmental Flows* includes descriptions and critiques of analytical methods for determining appropriate bay and estuary inflows. An estuary is defined as a transitional watercourse in which freshwater and seawater intermix. The downstream reach of a river affected by tides and salinity from seawater is an estuary. Coastal bays into which streams flow and mix with seawater are also estuaries. The seven major bay and estuary systems of Texas are Sabine Lake, Galveston Bay, Matagorda Bay, San Antonio Bay, Aransas-Copano Bay, Corpus Christi Bay, and the Laguna Madre.

The TWDB and TPWD have been studying the bays and estuaries of Texas and their needs for freshwater inflows since the 1960's. The TWDB has: (1) assembled data bases of water budgets for the Texas bays, their water quality and physiography, and commercial harvests of key species which are used as a measure of ecological health; (2) developed mathematical models of various aspects of the Texas bays, including inflows due to ungaged runoff, circulation, and salinity distribution; and (3) sponsored investigations of various aspects of the ecology of the bays and estuaries. The TPWD has conducted intensive biological sampling activities in the Texas bays, dating back to the 1950's for some of the bays. The two agencies have been coordinating their programs since about 1985 in response to legislative directives.

The Science Advisory Committee (2004) summarizes the series of data analyses, calculations, and computer modeling studies that comprise the *State Methodology* for determining the patterns of monthly freshwater inflows to a bay or estuary that are required to maintain the estuarine ecosystem. Ecological health is measured by the abundance of several key species, such as brown shrimp, blue crab, and red drum, as estimated by commercial harvests or by biological data collection programs. Statistical relations are developed between harvest and seasonal inflows. Statistical relations are also developed between measured salinities at key locations and monthly inflows. A predicted total abundance is determined that depends upon seasonal inflow quantities. An optimization model is then applied to determine the distribution of monthly inflows that either minimizes or maximizes some variable defined by a specific management goal. Several management goals are typically evaluated with the two most important being maximizing the harvest or minimizing inflow defined as follows.

- The total annual harvest of the selected species is maximized subject to constraints that the monthly inflows be bounded by the lowest decile and median period-of-record flows for each month.
- Total annual inflow is minimized subject to the constraint that total annual harvest is no lower than 80% of its period-of-record average.

Since 1990, the TWDB has applied this general methodology to establish monthly beneficial inflows for several management goals for each of the seven major bays of the Texas coast.

Tools for Using Hydrologic Data to Quantify Environmental Instream Flow Requirements in Texas

Design of environmental flow standards is based on work performed both in the office and in the field compiling information at sites on rivers and streams. Field studies significantly improve the validity of flow standards but require time, expertise, and funds. Decisions often are based on analyses and computations performed in the office based on available information without the expense of site-specific field studies. The term "*desktop methods*" is sometimes used to refer to relatively simple techniques applied in the office without benefit of site-specific field studies. The following discussion focuses on desktop methods that have been applied to establish environmental flow requirements in Texas. Though also relevant to freshwater inflows to bays and estuaries, these methods are designed primarily for establishing flow requirements for riverine ecosystems.

The discussion here focuses on hydrologic standard-setting methods as contrasted with biological, geomorphological, and water quality analysis methods and more complex comprehensive ecosystem assessment strategies. Streamflow is considered to be a "*master variable*" in environmental flow studies, meaning relevant biological, chemical, and physical processes relate directly to streamflow. Streamflows representing current conditions of river basin development, historical conditions, or natural conditions are often assumed to represent conditions conducive to a healthy ecosystem that should be protected and preserved in the future.

The TCEQ created a Technical Review Group to review available instream flow assessment tools with a focus on simple "*desktop*" methods applicable to Texas river and stream conditions. The Technical Review Group (2008) review provided a compilation of information regarding alternative tools and several conclusions/recommendations, two of which are as follows: "*(1) In the absence of any further information and primarily for the sake of continuity with past practices, we reluctantly recommend that the TCEQ continue to apply the Lyons Method as a desk-top approach for permitting purposes. (5) We recommend that any future detailed studies undertaken by the State agencies and/or water rights applicants be designed for validating and/or refining an appropriate desk-top method for the State.*"

The following discussion consists of brief descriptions of the Lyons, CCEFN, IHA, HEFR, TX-HAT, and IFIM methods, which deal with environmental flow needs of riverine ecosystems. The Lyons and CCEFN are alternative sets of criteria that are applied to set minimum instream flow limits based on streamflow statistics. The IHA, HEFR, and TX-HAT are computer-based methods for computing an array of streamflow statistics that are useful in quantifying instream flow requirements. The IFIM is a much more comprehensive approach using field studies and a set of multiple modeling and analysis tools.

- The Lyons Method is routinely applied by the TCEQ in water rights permitting.
- The Consensus Criteria for Environmental Flow Needs (CCEFN) was developed by the TWDB, in collaboration with the TPWD, TCEQ, and others, for planning studies and is also occasionally used by the TCEQ for water right permitting.
- The Indicators of Hydrologic Alteration (IHA) developed by the Nature Conservancy has been applied throughout the world over many years. Concepts and tools from the IHA are incorporated in the HEFR methodology developed specifically for application in Texas.
- The Hydrology-Based Environmental Flow Regime (HEFR) was recently developed by the TPWD in collaboration other Texas entities.

- The Texas Hydrologic Assessment Tool (TX-HAT) is a customized version of the Hydrologic Assessment Tool HAT which is a component of the U.S. Geological Survey (USGS) Hydroecological Integrity Process (HIP).
- The Instream Flow Incremental Methodology (IFIM) developed by the U.S. Fish and Wildlife Service has been applied over many years for river systems throughout the United States and other countries including several studies in Texas. The IFIM is much more complex than the other tools listed above.

Lyons Method

TCEQ routinely applies a modified version of the Lyons method in evaluating applications for new water right permits and amendments to existing permits, when site-specific field studies are not available and cannot be performed. Minimum flow limits computed with the Lyons method have been incorporated as special conditions in a number of water right permits. The Lyons method simply assigns minimum daily instream flow targets (in units of cubic feet per second) for each of the 12 months of the year as a percentage of the median of gaged daily flows in each of the 12 months as follows.

minimum flow limit = 40% of median daily flows by month for October through February
minimum flow limit = 60% of median daily flows by month for March through September

The TCEQ modifications to the Lyons method include adopting a flow target equal to the 7Q2 if the value derived from the Lyons method is less than the 7Q2 flow. The 7Q2 is defined as the lowest mean streamflow during seven consecutive days that has an annual recurrence interval of two years. The 7Q2 is a minimum flow limit associated with protecting water quality. The Lyons method results in a different minimum instream flow target for each of the 12 months of the year. The TCEQ may group or average similar monthly values to reduce the number of monthly target values to less than 12.

The Lyons method for Texas (Bounds and Lyons 1979) was derived from the Tenant (1976) method which was originally developed for Montana and other western states. The basic objective of the general approach is to determine minimum flow targets that maintain a healthy stream under normal base flow conditions. This minimum flow should result in a longitudinally connected wetted stream bed containing pools, riffles, and other essential habitat features that ensure short-term maintenance of fish populations. The flow percentages (60% and 40% of median flows) are weighted to be more protective of river ecosystems during the Spring and Summer which are considered most critical to the warm-water fisheries found in Texas.

The Lyons Method was validated with measurements of wetted channel perimeter versus flow rate at two sites on the Guadalupe River downstream of Canyon Dam in February 1977 with releases from the dam manipulated to provide a range of streamflow rates. Based on these very limited data, flow limit criteria were adopted for application to streams throughout Texas.

The Lyons method provides minimum flow limits that are analogous to the base flow component of a flow regime. However, the method is not relevant to the subsistence, high pulse, and overbank flow components. The Lyons method also does not differentiate between different hydrologic conditions such as dry, average, and wet.

Consensus Criteria for Environmental Flow Needs (CCEFN)

The Consensus Criteria for Environmental Flows Needs (CCEFN) methodology was developed during the mid-1990's based on the collaborative judgment of scientists and engineers from the TWDB, TPWD, and TCEQ along with representatives from universities and consulting firms and informed citizens. The CCEFN were developed for use by the TWDB and regional planning groups in planning studies for evaluating water supply development strategies, when site-specific field studies are not available or feasible during the planning studies. The TCEQ also applies the CCEFN occasionally in water rights permitting. The objective of the minimum flow limits derived from the criteria is to protect the long-term health of the aquatic environment.

The CCEFN are typically applied in planning studies and permit application studies by incorporation in the monthly WAM System. Instream flow requirements are assigned for the following three zones, with the zones being defined differently depending on whether flow restrictions are being applied to a run-of-river diversion right (no reservoir) or to a water right that includes reservoir storage.

Zone 1, wetter than normal: Flow exceeds median of naturalized streamflow or reservoir storage contents exceeds 80% of conservation storage capacity.

Zone 2, normal: Naturalized flow is between 75% exceedance frequency flow and median (50% frequency) flow or storage is between 50% and 80% of capacity.

Zone 3, drought: Naturalized flow is less than 75% exceedance frequency flow (no reservoir) or storage is less than 50% of capacity (for rights with reservoirs).

As water rights are considered in priority sequence in each month of a WRAP/WAM simulation, the minimum instream flow limit is assigned as follows depending on which of the three zones are in effect.

Zone 1: Minimum instream flow limit is set at the median of the naturalized flows.

Zone 2: Minimum instream flow limit is set at the 75% exceedance naturalized flow.

Zone 3: Minimum instream flow limit is set at a specified threshold such the 7Q2 that is considered necessary to maintain a continuous flow and protect water quality.

Indicators of Hydrologic Alteration (IHA)

The Indicators of Hydrologic Alteration (IHA) is a statistical software package available from the Nature Conservancy that is designed for performing ecologically-meaningful statistical analyses of daily streamflows (www.Nature.org, http:conserveonline.org/workspaces/iha, Richter et al. 1997). Although the statistical methods may be applied to any hydrologic variable, typical applications consist of analyzing historical gaged daily flows. The computer program is designed to support assessment of hydrologic impacts of human activities by analyzing changes in flow statistics over time. The statistical analyses may also be used to support development of environmental flow recommendations. IHA does not directly generate instream flow requirements, but rather provides information to support instream flow studies.

IHA has a feature called the Environmental Flow Components (EFC) in which each day is assigned one of five flow regime categories: extreme low flow, low flow, high flow pulses, small floods, and large floods. An algorithm parses the input hydrograph accordingly based on user defined parameters and then generates summary statistics corresponding to each flow regime component.

IHA computes statistics derived from daily hydrologic data that may include the complete data series or the days that fall within each of the five flow regimes. For example, the IHA software can determine the magnitude and timing of greatest and smallest flow in each year and calculate the mean and variance of the annual series of maximum and minimum daily flows over specified periods of years. The results can be used to analyze changes over time. An array of different statistics can be computed and different types of statistical analyses performed.

The IHA software has been applied in locations around the world. Kiesling (2003) describes a collaborative investigation by the U.S. Geological Survey (USGS) and TCEQ of the potential usefulness of the IHA for studies in Texas. Hersh and Maidment (2006), under the sponsorship of the TWDB, compared the IHA and USGS's HAT from the perspective of their potential application to instream flow studies in Texas. Concepts and computation procedures from the IHA have been adopted in development of the HEFR methodology described next.

Hydrology-based Environmental Flow Regime (HEFR)

The Hydrology-based Environmental Flow Regime (HEFR) methodology is described in a report prepared by the TPWD for the Senate Bill 3 Science Advisory Committee for Environmental Flows (2011). HEFR was developed relatively recently by the TPWD in collaboration with other organizations. HEFR has been used by BBESTs including the Brazos River Basin BBEST in developing flow regime recommendations. HEFR was also applied in studies supporting a systems operation permit application submitted by the Brazos River Authority in 2004 that is contested and as of March 2013 still pending.

The HEFR methodology consists of statistical analyses for individual flow regime components. Either the Environmental Flow Components (EFC) algorithm in the Indicators of Hydrologic Alteration (IHA) software described in the preceding section or the Modified Base Flow Index with Threshold (MBFIT) implemented in a Microsoft Excel spreadsheet may be applied to parse a hydrograph into individual flow regime components. Excel is then used to develop summary statistics. Alternatively, other software tools could be used for either or both of these steps.

In applying HEFR, the EFC methodology from the IHA software has been typically adopted in the BBEST studies rather than the MBFIT to divide flows into the four components of the flow regime. The IHA methodology is applied within the HEFR methodology to separate flows into subsistence, base, pulse, and overbank flows using the following six parameters. The IHA also includes a large flood flow component which has not been adopted in Texas.

subsistence flow limit: Flows below this magnitude are subsistence flows.

minimum flow for pulse flows: Flows below this limit cannot be pulse or overbank flows.

maximum flow for base flows: Flows above this limit are pulse or overbank flows and cannot be base or subsistence flows.

percent increase that changes base flow to pulse flow: This parameter applies if the flow in the previous day is base or subsistence flow and if flows are between the minimum and maximum defined above. This parameter is the percent increase in flow that will change a base/subsistence flow to a pulse/overbank flow. If the flow decreases or the increase is less than this value, the flow remains a base or subsistence flow.

percent decrease below which pulse flow changes to base flow: This parameter applies if the flow in the previous day is pulse or overbank flow and if the current day flow is between the maximum base and minimum pulse flow. The current flow is base or subsistence if the percent decrease is less than this value. If the decrease is greater than this value or if the flow increases, the flow remains a pulse or overbank flow.

overbank flow limit: Flows above this value are overbank flows.

The Senate Bill 3 Science Advisory Committee for Environmental Flows (2011) outlines a general framework for developing instream flow recommendations based on hydrologic data within which the HEFR statistical computations provide supporting information. The basic concept of this general strategy for determining flow recommendations is to identify certain desired flow characteristics of the historical flow regime and associated statistical metrics and create a set of flow recommendations based on those flow characteristics and metrics.

HEFR is an add-in for Microsoft Excel that is available at the TCEQ environment flow resources website. HEFR is designed with its statistical analysis options and results organized for convenient use in environmental flow studies. The statistical analyses are based on observed daily flows at a selected stream gaging station. A flow separation algorithm is applied to categorize the flow in each day as falling within one of the flow ranges defined for the subsistence, base flow, high flow pulse, and overbank flow components of the flow regime based on user-supplied input parameters. Pertinent statistics are computed for flows in a selected range including flow-frequency and flow-duration metrics and volume versus peak flow regressions.

Texas Hydrologic Assessment Tool (TX-HAT)

The U.S. Geological Survey (USGS) Hydroecological Integrity Assessment Process (HIP) is based on a suite of software tools used for stream classification, addressing instream flow needs and assessing hydrologic alterations on streamflow and/or other ecosystem components (www.fort.usgs.gov/Resources/Research_Briefs/HIP.asp). The Hydrologic Assessment Tool (HAT) is a key computational component of the HIP. TX-HAT is a version of HAT customized for Texas by the USGS under contract with the TCEQ. HAT and TX-HAT provide the same statistical computations.

HAT has many of the same statistical analysis options as the previously discussed Indicators of Hydrologic Alteration (IHA) and other options not included in the IHA software. However, HAT does not sparse the hydrograph into flow regimes. Hersh and Maidment (2006) performed a comparative review of HAT and IHA for the TWDB. HAT or TX-HAT has not been applied in Texas studies to actually develop instream flow requirements.

Instream Flow Incremental Methodology (IFIM)

The Instream Flow Incremental Methodology (IFIM) developed by the U.S. Fish and Wildlife Service (Bovee 1982) has been applied extensively throughout the United States and abroad. The IFIM has been applied to establish flow requirements for protecting aquatic resources for several proposed water projects in Texas including O. H. Ovie Reservoir, Little Cypress Creek Reservoir, Lake Bosque, Paluxy Reservoir, Canyon Reservoir (hydropower), and several sites on the Colorado River (Science Advisory Committee 2004).

The IFIM relies upon field studies and a set of modeling and analysis tools dealing with habitat, water quality, sediment transport, and hydrology. Physical habitat sites are described using transects set across stream channels and measurements are made of velocity, depth, substrate, and vegetative cover. Estimates of suitable and unsuitable habitat available at different flow levels are developed based on a model that simulates hydraulic depth-flow relationships combined with data describing how habitat is used by fish and other organisms.

TCEQ Water Availability Modeling System

The remainder of this report deals with the WRAP/WAM System which combines water resources development, allocation, management, regulation, and use with river system hydrology. Various interconnections that may occur between applying the methods discussed in Chapter 2 for establishing environmental flow standards and the WRAP/WAM System include the following.

- In administering the water rights permit system, the instream flow standards developed with the methods discussed in Chapter 2 are incorporated in the WAM System to properly assess stream flow availability for new permit applications for water supply diversions and/or storage. Likewise, in planning studies, the instream flow needs quantified with the tools described in Chapter 2 are incorporated in the WAM models to simulate their impacts on existing and future new water users.

- Sequences of monthly or daily naturalized flows or regulated flows for a specified water development and use scenario from the WAM System may be used as input for the tools discussed in Chapter 2.

- Design of instream flow standards can benefit from evaluations of the effectiveness of alternative proposed standards in protecting environmental flows based on WAM simulation results and associated flow frequency analyses. Likewise, design of instream flow standards can also benefit from WAM evaluations of the impacts of alternative proposed instream flow standards on water supply reliability and availability for agricultural, municipal, industrial, and other water uses.

Instream flow standards are incorporated in the WAM System to allow modeling of their impacts on water availability for other water users as well as evaluating capabilities for satisfying the environmental instream flow needs. WRAP capabilities have been greatly expanded to deal with the increased complexities of modeling environmental flow requirements. Selected WAM datasets are being converted from monthly to daily and otherwise refined. Additional improvements to the modeling system will continue be made as needed.

As discussed in this chapter, environmental flow protection and enhancement endeavors being accomplished in Texas pursuant to the 2001 Senate Bill 2 and 2007 Senate 3 address both (1) freshwater inflows to bays and estuaries and (2) environmental flows for riverine ecosystems. A third related area of environmental concern that appears to be receiving lesser attention is fluctuations in reservoir storage levels that may include severe draw-downs.

The WRAP/WAM system is designed for analyzing flow-frequency relationships for naturalized and regulated streamflows and storage-frequency relationships for reservoir storage contents along with water supply reliability metrics. The monthly modeling system is relevant for evaluating freshwater water inflows to bays and estuaries, instream flows in rivers and streams, reservoir storage level fluctuations, and impacts on water supply availability and reliability for agricultural, municipal, industrial, and other uses. The new daily modeling system significantly improves assessment capabilities, particularly in regard to daily flows requirements for riverine ecosystems.

The improvements in accuracy achieved by converting from a monthly to daily WAM simulation vary between the subsistence, base, pulse, and overbank components of the flow regime outlined in Table 2.4. As discussed in Chapter 3, regulated flow variations are more pronounced in a daily model. A monthly model averages out daily variations within the month. Environmental flow requirements for high pulse flows, either within banks or overbank flows, are defined as a function of regulated flows. A small computational time step is very important in modeling pulse flows. Subsistence and base flow limits may be defined as pre-specified constant flow targets that vary only with season of the year, not as a function of regulated flow. Alternatively, subsistence and base flow targets may also be defined as a function of regulated flow. Subsistence and base flows are modeled more accurately in a daily than monthly simulation, particularly if the minimum flow targets are formulated to vary with regulated flow.

Instream flow requirements are reflected in a WAM simulation from two perspectives.

1. The instream flow targets at each pertinent control point in each time period of the simulation are computed and adopted as minimum limits on regulated flows which represent quantities of appropriated stream flows.
2. The effects of the minimum instream flow limits are reflected in the computation of stream flow availability for other more junior water rights.

The improvements in accuracy resulting from shifting from a monthly to daily simulation differ between these two aspects of the simulation as well as between subsistence, base, within bank pulse, and overbank pulse flow components of the flow regime. Daily variability is lost in a monthly simulation from the perspective of the second task noted above. However, in the first task, in many cases, a daily base or subsistence flow target may be defined as a constant daily quantity for the duration of a month. The monthly target volume is set simply and accurately by summing the daily target volumes. Conversely, pulse flow targets are defined as a function of actual flows in the real world and regulated flows in the model, which vary from day to day. Thus, a daily simulation is needed to compute pulse flow targets.

CHAPTER 3
WRAP INSTREAM FLOW MODELING CAPABILITIES

The Texas Water Availability Modeling (WAM) System includes the generalized Water Rights Analysis Package (WRAP) and WRAP input datasets for the river basins of Texas. The WAM System has been applied to support water rights permitting and regional and statewide planning since its initial implementation in 1997-2002. WRAP and the WAM System employ a monthly step time and will continue to employ a monthly time step. However, the August 2012 version of WRAP also includes optional features for daily simulations. The Brazos WAM case studies documented by Wurbs et al. (2012) and Chapters 5, 6, and 7 of the present report represent an inaugural application of the daily modeling system. Daily WRAP input datasets are currently being developed for the Colorado and Trinity River Basins. Instream flow requirements have been included in the monthly WAM System since its inception. Capabilities for modeling and analysis of environmental instream flow requirements have been greatly expanded with the August 2012 daily WRAP modeling system which includes the following additional features designed for use with a daily computational time step.

- disaggregation of monthly naturalized flows to daily flows
- flow routing and flow forecasting
- disaggregation of diversion, hydropower, and instream flow targets
- simulation of pulse flow environmental flow requirements
- simulation of reservoir flood control operations
- additional frequency analysis capabilities

WRAP is documented by the seven manuals cited on page 1 of Chapter 1 and listed in the list of references at the end of this report. The monthly modeling system is documented in detail by the *Reference* and *Users Manuals*. The tutorial *Fundamentals Manual* covers the basics of the monthly modeling system. The daily modeling system is documented by the *Daily Manual*.

The WAM System, including adopted instream flow standards, supports administration of the water rights permit system, regional and statewide planning, and various other water management applications. The WAM System is designed to support assessments of hydrologic and institutional water availability for all existing water right permit holders and applicants for new and amended permits. Instream flow standards are incorporated to simulate their impacts on water availability for water supply diversions and/or reservoir storage. Likewise, in planning studies, instream flow requirements are incorporated in the WAM models to simulate their impacts on existing and future new water users. The WAM System can also be used as follows in the development of environmental instream flow standards.

- WAM System naturalized flows or sequences of regulated flows for a specified water use scenario may be used as input for the methodologies used to develop instream flow standards. Standard-setting methods have commonly been based on historical gaged flows. The WAM System may solve non-homogeneity problems associated with gaged flows.

- Decision processes for developing many types of management strategies are commonly based on testing many alternative trial plans with a simulation model. The effects on stream flows of alternative variations of proposed instream flow standards can be evaluated based on WAM simulation results and associated flow frequency analyses.

Water Availability Modeling (WAM) System

Senate Bill 1, Article VII of the 75th Texas Legislature in 1997 directed the Texas Natural Resource Conservation Commission (renamed the TCEQ in 2002) to develop water availability models for the 22 river basins of the state, excluding the Rio Grande. Models for six river basins were to be completed by January 2000, and the 16 others completed by January 2002. Subsequent legislation authorized modeling of the Rio Grande Basin. The WAM System was developed collaboratively by the TCEQ (as lead agency), TWDB, TPWD, consulting firms, and university researchers, in coordination with the water management community. The resulting WAM System includes database management systems, the generalized WRAP, input datasets, and simulation results for all of Texas (Wurbs 2005; Martin and Chenoweth 2009). WAM information including WRAP input datasets are available at the TCEQ WAM website.

http://www.tceq.state.tx.us/permitting/water_supply/water_rights/wam.html

Texas has 15 major river basins and eight coastal basins lying between the lower reaches of the major river basins. The WAM System includes 21 WRAP input datasets for the 23 river basins. Three of the datasets combine two river basins, and one basin is divided into two datasets. The water rights in the datasets are updated as the TCEQ approves applications for new permits or revisions to existing permits. Other aspects of the datasets also continue to be refined. Information describing authorized use scenario datasets as of July 2011 is tabulated in Table 3.1. The map number in the first column of Table 3.1 refers to the river basins shown in Figure 3.1.

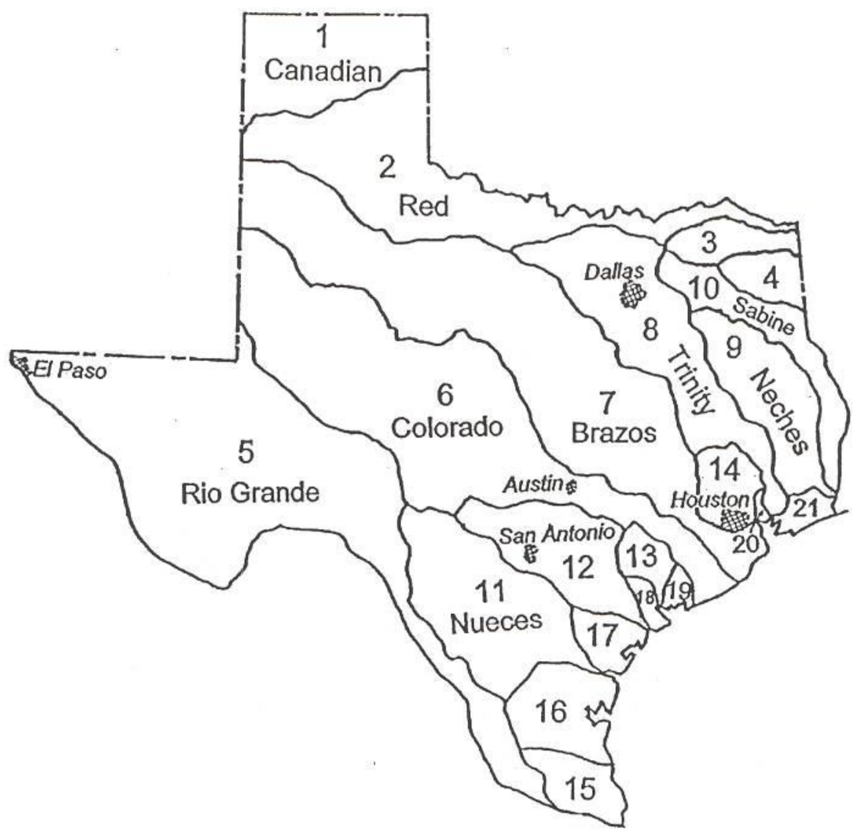

Figure 3.1 Water Availability Modeling (WAM) System River Basins

Table 3.1
WAM System Models

Map ID	Major River Basin or Coastal Basin	Period of Analysis	Number of Primary Control Points	Total Control Points	WR Record Rights	IF Record Rights	Model Reser-voirs	Reservoir Storage Capacity (acre-feet)	Mean Natural Flow (ac-ft/yr)
1	Canadian River Basin	1948-98	12	85	56	0	47	966,000	190,000
2	Red River Basin	1948-98	47	447	494	101	245	4,124,000	11,049,000
3	Sulphur River Basin	1940-96	8	83	85	10	57	753,000	2,498,000
4	Cypress Bayou Basin	1948-98	10	147	163	1	91	902,000	1,748,000
5	Rio Grande Basin	1940-00	55	957	2,584	4	113	23,918,000	3,724,000
6	Colorado River Basin and Brazos-Colorado Coastal	1940-98	45	2,395	1,922	86	511	4,763,000	2,999,000
7	Brazos River and San Jacinto-Brazos Coastal	1940-97	77	3,842	1,634	122	678	4,695,000	6,357,000
8	Trinity River Basin	1940-96	40	1,343	1,027	35	700	7,504,000	6,879,000
9	Neches River Basin	1940-96	20	306	328	19	180	3,904,000	6,235,000
10	Sabine River Basin	1940-98	27	376	310	21	207	6,401,000	6,887,000
11	Nueces River Basin	1934-96	41	542	373	30	121	1,040,000	868,000
12	Guadalupe and San Antonio River Basins	1934-89	46	1,338	848	200	238	808,000	2,101,000
13	Lavaca River Basin	1940-96	7	185	72	30	22	235,000	943,000
14	San Jacinto River Basin	1940-96	17	412	150	15	114	637,000	2,207,000
15	Lower Nueces-Rio Grande	1948-98	16	119	70	6	42	101,700	249,000
16	Upper Nueces-Rio Grande	1948-98	13	81	34	2	22	11,000	342,000
17	San Antonio-Nueces	1948-98	9	53	12	2	9	1,480	565,000
18	Lavaca-Guadalupe Coast	1940-96	2	68	10	0	0	0	134,000
19	Colorado-Lavaca Coastal	1940-96	1	111	27	4	8	7,230	142,000
20	Trinity-San Jacinto	1940-96	2	94	24	0	13	4,880	181,000
21	Neches-Trinity Coastal	1940-96	4	245	138	9	31	58,000	607,000
	Total		499	13,229	10,361	697	3,449	60,834,290	56,905,000

The 21 authorized use scenario datasets as of July 2011 contained 10,361 water right *WR* records and 697 instream flow *IF* records (11,058 total model water rights) representing about 8,000 permits. Multiple water rights in the model may represent a single complex water right permit. These counts change as the TCEQ adds new water rights and otherwise refines the datasets. The hydrologic period-of-analysis is at least 50 years for all of the basins, with the longest being 1940-2000. The datasets contain 13,229 control points, including 499 primary control points, usually representing gaging stations, with naturalized flows included in the WRAP-SIM input. The datasets model the approximately 3,449 reservoirs for which a water right permit has been issued. Over 90 percent of the total capacity of the 3,449 reservoirs is contained in the approximately 200 reservoirs that have conservation capacities ranging between 5,000 acre-feet and over 4 million acre-feet. Storage capacities for the reservoirs are cited in their water right permits. Most of the larger reservoirs have undergone sediment surveys since construction. In developing the WAM datasets, elevation-storage-area tables for most of the major reservoirs having conservation storage capacities of at least 5,000 acre-feet were assembled for both permitted and estimated year 2000 conditions of sedimentation. Generalized storage-area relationships were adopted in each river basin for the numerous smaller reservoirs.

Several of the river systems are shared with neighboring states. The Rio Grande is shared with Mexico. For the interstate and international river basins, hydrology and water management in neighboring states and Mexico are considered to the extent necessary to assess water availability in Texas. The models reflect two international treaties and five interstate compacts as well as the two Texas water rights systems administered by the TCEQ. As discussed in Chapter 2, the water rights system allocating the Texas share of the waters of the lower Rio Grande is significantly different from the water rights system for the rest of Texas.

The following two water use scenarios are routinely adopted for both water right permit applications and planning studies. Variations of WRAP input datasets representing a variety of other water use scenarios have been developed by the three agencies, planning groups, river authorities, consulting firms, and university researchers for various applications.

- The authorized use scenario 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 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 year 2000 conditions of sedimentation.
  4. Term permits are included.

The WAM System is applied by water management agencies and their consultants in preparation of water right permit applications. TCEQ staff applies the modeling system in evaluating the permit applications. The TWDB, regional planning groups, and their consultants apply the modeling system in regional and statewide planning studies also established by the 1997 Senate Bill 1. The TPWD, river authorities, and other entities use the modeling system in various other types of studies as well. Water management strategies and projects of interest are inserted into the datasets to serve the purposes of the particular application.

Water Rights Analysis Package (WRAP) Modeling System

WRAP consists of the seven computer programs listed on page 2 of Chapter 1 and seven manuals cited on page 1. The computer programs perform the tasks outlined in Table 3.2. The latest version of the software and manuals are available at the following website:

http://ceprofs.tamu.edu/rwurbs/wrap.htm

WinWRAP is an interface for connecting programs and data files. The programs are each individual executable files that can be executed either within *WinWRAP* or independently of *WinWRAP*. The Fortran programs are designed to facilitate adding new features and options as needs arise.

Table 3.2
Organization of the WRAP Modeling System

1. Development of Hydrology Input Data for the Simulation Model

   Program *HYD* documented by the *Hydrology Manual* is used to develop and extend (update) *SIM* input FLO and EVA files containing monthly naturalized streamflows and net reservoir evaporation-precipitation rates.

   Program *DAY* documented by the *Daily Manual* is used to calibrate routing parameters and otherwise compile input data for *SIMD*.

2. Simulation of the River/Reservoir System

   Program *SIM* performs a monthly simulation as described in detail by the *Reference* and *Users Manuals* and summarized by the *Fundamentals Manual*.

   Program *SIMD* performs a daily simulation as described in the *Daily Manual*.

3. Tracking Salinity through the River/Reservoir System

   SALT performs a salinity simulation as described in the *Salinity Manual*.

4. Post-Simulation Analyses of Simulation Results

   Program *TABLES* reads *SIM*, *SIMD*, and *SALT* simulation results, performs an assortment of frequency and reliability analyses, and creates a variety of tables to organize, summarize, and display simulation results as described by the *Reference*, *Users*, *Fundamentals*, *Daily*, and *Salinity Manuals*.

   HEC-DSSVue reads *SIM*, *SIMD*, and *SALT* simulation results DSS files and DSS files created by *TABLES* and prepares plots and computes statistics.

   The *WRAP Display Tool* functions as a toolbar within the ArcMap component of ArcGIS to spatially display *SIM* and *SIMD* simulation results.

The *SIM* simulation model is an accounting system for tracking streamflow sequences, subject to reservoir storage and operating rules; water supply diversion, hydroelectric power, and instream flow requirements; and priority-based water allocation rules. Water balance computations are performed in each month of the simulation considering water rights in priority order. The simulation is based on combining

- a repetition of historical hydrology represented by input sequences of monthly naturalized flows and net reservoir evaporation-precipitation rates with
- a specified scenario of river system development infrastructure, water use demands, reservoir system operating rules, and water allocation rules.

A broad spectrum of hydrologic and water management scenarios may be simulated. Numerous optional features have been incorporated into the generalized modeling system to model the complexities in the diverse ways that water resources in river/reservoir systems are developed, allocated, managed, regulated, and used.

SIMD (D for daily) contains all of the capabilities of the monthly *SIM*, plus options related to environmental instream pulse flow requirements, reservoir operations for flood control, flow forecasting and routing, sub-monthly targets, and synthesizing sub-monthly time step naturalized streamflows. Although any sub-monthly time interval may be used, *SIMD* is called the daily version of *SIM* since the day is the default expected to be adopted most often. Simulation results can be output as daily values as computed. Alternatively, *SIMD* can perform a simulation using a daily or other sub-monthly time step for the computations with the results optionally being aggregated to monthly quantities.

The WRAP program *TABLES* provides a flexible array of options for performing frequency and reliability analyses and organizing simulation results as sets of tables in a variety of user-specified optional formats. *TABLES* works with either monthly or daily simulation results. Two other programs for analyzing simulation results are listed in Table 3.2. *HEC-DSSVue* deals with time series data. The *WRAP Display Tool* displays simulation results spatially using GIS.

The Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers has a suite of generalized hydrologic, hydraulic, and water management simulation models that are applied extensively by numerous agencies and consulting firms throughout the United States and abroad. The HEC-DSS (Data Storage System) is used routinely with HEC models and with other non-HEC models as well. Multiple simulation models share the same graphics and data management software and a set of basic statistical and arithmetic routines. The HEC-DSS Visual Utility Engine (HEC-DSSVue) is a graphical user interface program for viewing, editing, and manipulating data in HEC-DSS files (Hydrologic Engineering Center 2009). The public domain HEC-DSSVue software and documentation may be downloaded from the HEC website: http://www.hec.usace.army.mil/

WRAP programs include options for writing *SIM*, *SIMD*, or *SALT* simulation results as HEC-DSS files or reading hydrology input data stored as a DSS file. The results of *TABLES* manipulations of simulation results may also optionally be stored as DSS files. HEC-DSSVue provides convenient and flexible capabilities for graphical displays of WRAP simulation results. HEC-DSSVue mathematical and statistical computational routines may also be pertinent to analysis of WRAP simulation results. The HEC-SSP Statistical Software Package (Hydrologic Engineering Center 2009) is another companion program that can be used with WRAP.

The WRAP Display Tool functions as a toolbar within the ArcMap component of ArcGIS. Ranges of water supply reliabilities, flow and storage frequencies, and other simulation results are displayed by control point locations as a color coded map. Time series graphs of *SIM* output variables can also be plotted. Customization capabilities as well as standard output data features are provided (Center for Research in Water Resources, University of Texas at Austin 2012). The WRAP Display Tool is available at the TCEQ WAM website.

WRAP/WAM Streamflows

A *WRAP-SIM* simulation combines sequences of naturalized streamflows and reservoir net evaporation-precipitation rates representing river basin hydrology with water rights information representing the manner in which water resources are developed, regulated, allocated, and used. A simulation starts with known naturalized flows at primary control points, synthesizes flows at ungaged sites, and then computes regulated flows and unappropriated flows at all control points.

Simulation input is divided into two categories of data: (1) river system hydrology data files and (2) a water rights data file containing information describing reservoirs and other constructed facilities, water use demands, and priority-based water allocation rules. A *SIM* or *SIMD* simulation begins each month or day with streamflow volumes at each control point representing natural hydrology or some other specified condition of river basin development. These streamflows typically represent unregulated natural historical hydrology and are called *naturalized flows*. The naturalized flows provided as input to *SIM* or *SIMD* conceptually represent the flows that would have occurred without the human activity reflected in the information provided in the water rights input file. As each water right is simulated in priority order, streamflows available to the water right and streamflow depletions incurred by the water right are computed. The simulation for each time step results in *regulated* and *unappropriated flows* at each control point.

Regulated flows represent the actual physical streamflow at a control point location after accounting for all of the water rights. Given all of the water right requirements and other premises reflected in the model, the regulated flows are the streamflow volumes in each computational time step that would be measured by a gaging station at the control point location.

Unappropriated flows represent the streamflow volumes still available for appropriation after considering all water rights requirements. In a particular month, the unappropriated flow at a control point may be less than the regulated flow because a portion or all of the flow may have been committed to meet instream flow requirements at that control point or for use further downstream. The unappropriated flow is the portion of the regulated flow that is not appropriated to meet the water rights requirements included in the simulation. Unappropriated flows represent water available for additional new water right applicants.

The future is of concern, rather than the past. However, future hydrology is unknown. Historical streamflows and reservoir evaporation less precipitation rates are adopted as being representative of the hydrologic characteristics of a river basin that can be expected to continue into the future. The hydrologic periods-of-analysis of the WAM datasets are tabulated in Table 3.1. These simulation periods include the 1950-1957 most severe drought-of-record as well as a full range of fluctuating wet and dry periods. Water resources are extremely variable and highly stochastic (random), subject to extremes of droughts and floods as well as continuous less extreme fluctuations. Major droughts typically involve long periods with sequences of many months of low flows. A basic premise of the conventional modeling approach is that historical naturalized streamflows and evaporation-precipitation rates for an adequately long period-of-analysis capture the essential statistical characteristics of river basin hydrology.

<u>Naturalized Streamflows</u>

A simulation begins with homogeneous sequences of monthly streamflow volumes (naturalized flows) covering the hydrologic period-of-analysis at all control points. For each control point, streamflows must be either provided as input to *SIM/SIMD* or computed within *SIM/SIMD* from flows at one or more other control points using techniques described in the *Reference Manual*. Table 3.1 indicates that as of July 2011, the TCEQ WAM System WRAP input datasets contained a total of 13,229 control points. The datasets include naturalized monthly flow sequences at 499 primary control points, most of which are gaging stations. The term primary refers to sites at which naturalized streamflows are provided in the input datasets.

The naturalized flows in the simulation model are established in the following stages.

1. The monthly naturalized flows in the WAM datasets at about 500 primary datasets were compiled during 1997-2002 by consulting firms working under contract with the TCEQ. These flows are read by *SIM* or *SIMD* from input files.

2. Methods for updating the flow sequences to extend to near the present are being investigated. The Brazos WAM case study presented in this report has the hydrologic period-of-analysis updated from 1940-1997 to 1940-2011 using a methodology described in the *Hydrology Manual*. The *SIM* input file is updated with the longer flow sequences.

3. Naturalized flows at ungaged secondary control point are synthesized within the *SIM* or *SIMD* simulation using methods described in the *Reference Manual* based upon the naturalized flows at primary control points and watershed areas, channel loss factors, and perhaps other watershed parameters depending upon flow distribution options adopted.

4. A *SIMD* daily simulation begins with disaggregation of monthly naturalized flows to daily volumes using disaggregation methods described in the *Daily Manual*. The disaggregation will typically be based on replicating observed daily flow patterns provided as an input file while preserving the monthly volumes from the WAM datasets. Alternatively, *SIMD* can optionally directly adopt naturalized daily flows read from an input file.

The *WRAP-SIM* input datasets in the WAM System were compiled during 1997-2002 by consulting firms working for the TCEQ. Developing naturalized monthly flows accounted for a major portion of the effort required for creating the datasets. The naturalized streamflows in the *SIM* input datasets represent flows unaffected by the reservoirs, diversions, return flows, and other water management practices and water use reflected in the *SIM* water rights input dataset. The objective of the streamflow naturalization process is to develop a homogeneous set of flows representing natural river basin hydrology. Historical observed flows were adjusted to remove nonhomogeneities caused by human activities. Upon completion of the naturalized flow sequences, statistical trend analyses were performed to demonstrate that long-term trends had been removed.

The extent to which observed historical flows were naturalized involved judgment. In extensively developed river basins, quantifying and removing all effects of human activities is not possible. For sites with relatively undeveloped watersheds, little or no adjustments may be necessary. Sequences of monthly flows representing historical natural hydrology were developed by adjusting recorded flows at gaging stations to remove the past impacts of upstream major reservoirs, water supply diversions, return flows from surface and ground water sources, and in some cases other factors such as land use changes (Sulphur River Basin) and changes in spring flows due to changes in groundwater use (Nueces, San Antonio, Guadalupe Basins). In the major river basins, numerous smaller reservoirs have been constructed over many decades, but most of the storage capacity is contained in a relatively few large reservoirs. Decisions were required regarding which reservoirs to include in the adjustments. Major water supply diversions and return flows were included in the flow adjustments but smaller water users were often omitted.

Streamflow Homogeneity

Environmental flow requirements in the *SIM* or *SIMD* simulation model are restrictions that protect simulated regulated flows. However, the flow requirements established using the methods discussed in Chapter 2 may be based on historical observed gaged flows or perhaps adjusted naturalized flows. Homogeneity is a key issue in investigating environmental flow needs.

Homogeneity of streamflow sequences is a fundamental concept of the WRAP modeling system. Homogeneous flow sequences represent a specified uniform condition of river system development, long-term climate, and water use. The intention is that naturalized, regulated, and unappropriated flows at least approximately represent homogeneous conditions of development. Homogeneous naturalized streamflow sequences represent natural conditions without human water resources development. Homogeneous regulated and unappropriated flow sequences represent the water use scenario that is being simulated within *SIM* or *SIMD*. Historical natural flows are relevant only from the perspective of representing river basin hydrology while not knowing actual future flows. Historical natural flows are assumed to represent relevant characteristics of future flows that would occur under conditions without human water resources development and use.

Homogeneity or non-homogeneity of streamflow sequences is viewed somewhat differently in the methods for establishing environmental instream flow recommendations that are discussed in Chapter 2. The methods may be based on historical flows or may be based on natural flows. In some cases, historical flows occurring before the time that significant development occurred are adopted as representing natural conditions. Conceptually, flow recommendations may be based alternatively on preserving either ecosystems accustomed to current flow characteristics or the ecosystems that would exist under natural undeveloped conditions. For some streams, development may be minimal, observed flows may closely represent natural flows, and this discussion of homogeneity may be irrelevant. At other locations, human activity has significantly altered flows. Protection of an existing healthy ecosystem is also different than restoration of an ecosystem that has been damaged by flow alterations resulting from human development.

Population growth in Texas has increased at a significant rate since before the 1940's and is projected to continue to increase in the future. Most of the major reservoirs in the state were constructed during the 1940's through the 1970's. Non-homogeneities in historical gaged stream flows are typically caused primarily by construction of reservoir projects, growth or changes in water use, and other changes in water management practices over time. However, watershed land use changes, climate changes, and other factors may also affect the homogeneity of recorded stream flow measurements. The potential impacts of climate change on future hydrology adds even more uncertainty to the great variability and uncertainty already inherent in water management. The online water and climate change bibliography maintained by the Pacific Institute references over 3,000 publications (http://www.pacinst.org/topics/global_change/water_bibliography/).

Long-term trends in flow alterations occurring in the past are hidden by the extreme natural variability characteristic of rivers and streams throughout Texas. Multiple-year droughts such as the 1950-1957 hydrologically most severe drought on record are important as well as the great seasonal and annual variability. Flows from major rainfall events may vary dramatically over days or hours.

Environmental Flow Requirements in a Monthly Simulation

The entire WRAP modeling system is relevant to evaluating capabilities for meeting instream flow needs and evaluating the impacts of instream flow standards on other water rights. Environmental flow standards are an integral component of the overall *SIM* or *SIMD* simulation.

However, the *SIM* features that deal specifically with instream flow requirements are summarized in this section. These *SIM* features are also applied in the daily *SIMD*. Additional capabilities provided by the daily *SIMD* are summarized later in the chapter. Post-simulation analyses of *SIM* and *SIMD* simulation results are covered in the last section of this chapter.

All features of *SIM* can be categorized as dealing with either hydrology or water rights. River system hydrology in *SIM* is explained in Chapter 3 of the *Reference Manual*. *SIM* capabilities for modeling water resources development, allocation, management, and use systems are described in chapter 4 of the *Reference Manual*. Constructed facilities, water use requirements, allocation rules, and river/reservoir system operating practices are referred to generically as *water rights* in WRAP. All input files and input records for *SIM* are described in the *Users Manual*.

In WRAP terminology, a water right is a set of water management/use requirements associated with either a water right *WR* record or an instream flow *IF* record. *UC*, *UP*, *DI*, *IS*, *IP*, *RF*, *WS*, *OR*, *HP*, *SO*, *ML*, *TO*, *LO*, *FS*, *CV*, *TS*, and *PX* records are connected to a *WR* or *IF* record to provide additional information regarding water management and use specifications. Refilling reservoir storage, water supply diversions, and hydroelectric energy generation are specified as *WR* record rights. Environmental instream flow requirements are specified as *IF* record rights. The number of rights counted by *SIM* is simply the number of *WR* and *IF* records in the input file. The total number of rights (*WR* and *IF* records) counted by the model typically does not correspond to the number of actual water right permits. A key aspect of applying WRAP is ingenuity in combining water right *WR*, instream flow *IF*, and supporting input records to model a particular water management situation. The simulation model provides considerable flexibility in defining water management/use requirements and capabilities.

Instream flow requirement features of *SIM* are described on pages 101-111 of Chapter 6 of the *Reference Manual*. Instream flow targets are set in the same manner as water supply diversion or hydroelectric energy generation targets, using a flexible set of target building options that range from simple to complex. An instream flow requirement activated by an *IF* record is a target minimum regulated flow rate, in acre-feet/month, at a control point location. Instream flow *IF* record rights add constraints limiting water availability based on regulated flow targets. The objective is to maintain regulated flows equal to or greater than the monthly instream flow targets. Two types of actions may occur in the simulation in order to prevent or minimize failures (shortages) in meeting the instream flow requirements.

1. Constraints placed on the amount of streamflow available to diversion and storage rights, that are junior to an instream flow requirement, may result in these rights being curtailed to minimize shortages in meeting the instream flow target. Only releases equal to inflows are passed through reservoirs with no additional releases from storage.
2. Releases from any number of reservoirs identified by storage *WS* records associated with the *IF* record may be made specifically to meet instream flow requirements.

Any number of *IF* records may be input for a particular control point, with the next more junior instream flow target replacing the latest more senior target or optionally the largest or smallest controlling at different priorities. Thus, the stringency of flow limits may be increased in the priority sequence. Junior diversion and storage rights are curtailed as necessary to prevent or minimize violation of senior instream flow rights.

Setting Instream Flow Targets

Instream flow targets are specified in a *SIM* input file using an instream flow *IF* record and optional supporting *UC*, *DI/IS/IP/IM*, *TO*, *SO*, *CV*, *FS*, *HI*, and/or *TS* records. An *IF* record is required for each instream flow requirement. The auxiliary records activate various options. Most of the instream flow requirements in the existing WAM datasets are simply monthly minimum flow limits that vary over the 12 months of the year. However, the optional auxiliary records allow instream flow targets to be specified as functions of flexible combinations of:

- month of the year (water use coefficient *UC* record)
- beginning-of-each-month or beginning-of-multiple-month-season storage contents of any number of specified reservoirs (drought index *DI*, *IS*, *IP*, and *IM* records)
- arithmetic combinations of naturalized flow, regulated flow, unappropriated flow, reservoir storage, reservoir drawdown, streamflow depletions, withdrawal from storage, diversions, other instream flow targets, or instream flow shortages at selected control points or for selected water rights (target options *TO* records)
- monthly, seasonal, or annual limits (supplemental options *SO* records)
- arithmetic functions of the total cumulative volume over a specified number of preceding months of naturalized, regulated, and unappropriated flows at a specified control point, or diversions, targets, or shortages for specified *IF* or *WR* record rights (cumulative volume *CV* records)
- switches that completely or partially turn targets on-or-off depending on the total volume of a selected switch variable (same variable options as *CV* record) that has accumulated during a specified number of preceding months (flow switch *FS* records)
- a hydrologic index such as the Palmer hydrologic drought index used in arithmetic operations controlled by *TO*, *CV*, and/or *FS* records (hydrologic index *HI* records)
- flow sequences entered on input records (target series *TS* records)

The instream flow target is built by *SIM* in each month of the simulation using options listed above as explained in the *Reference* and *Users Manuals*. Each input record type cited above provides an array of options that can be applied in various combinations. The resulting target is a minimum limit for regulated flows at specified control point locations for that month of the simulation. Likewise, as discussed later, the instream flow targets computed during each day of a daily simulation are minimum limits on regulated flows for that day at specified sites.

Applying Instream Flow Targets

For a given time step (month) of the *SIM* simulation, each water right is considered in priority order of seniority. The target for each *IF* record water right is set at its specified priority in the priority sequence and then applied throughout the remainder of the priority sequence for that month. The details of both setting and applying the target depend upon options activated on the instream flow *IF* record and in some cases options activated on the job *JD* and *JO* records. Options controlling the details of applying instream flow targets are summarized as follows.

By default, each *IF* record instream flow right is applied at a single control point. However, an option activated by parameter CP2 on the *IF* record allows the same computed target to be applied at all control points located within a defined stream reach.

By default, each *IF* record instream flow target is applied as a minimum limit on total regulated flow. An option activated on the *IF* record allows the limit to be applied to regulated flows excluding reservoir releases made for use at downstream locations.

Multiple *IF* records with different priorities may set any number of targets at the same control point. The default is for each junior *IF* record target to replace the preceding senior target in the priority sequence. An option activated on the *IF* record allows either the largest or smallest *IF* target to be adopted at the specified priorities in the priority sequenced simulation.

All water rights with junior priorities curtail diversions if and as required to protect the minimum flow limits. Junior rights with reservoirs likewise curtail refilling of depleted storage capacity. Optionally, releases from any number of reservoirs specified on water right storage *WS* records may be made to achieve the instream flow target. The full array of reservoir operation options provided by *WS* and operating rules *OR* records may be employed. The parameter IFMETH on the *IF* record controls whether releases from reservoir storage, in excess of inflows, are made specifically to satisfy instream flow targets.

With the default IFMETH option 1, junior rights pass inflows but do not make releases exceeding inflows to meet downstream senior instream flow targets. With IFMETH options 3 and 4, releases from reservoirs identified on one or more *WS* records attached to the *IF* record occur if and as needed to meet minimum instream flow targets. Operating rules *OR* records may optionally be used for specifying non-default multiple-reservoir operating rules. Also, by default, reservoir releases contribute to regulated flows only at control points located at and downstream of the reservoir. Parameter SN2 on the *OR* record removes this constraint, allowing pump and pipeline conveyance to any location as well as gravity flows to downstream sites.

IF record IFMETH options 2 and 4 and *JO* record PASS2 option 2 activate a *second pass* option that causes the water rights simulation to be performed a second time in some or all months. The *second pass* option dates back to 1997 and should no longer be applied or applied only for specific modeling situations, with caution. The second pass greatly complicates various combinations of new WRAP features added since 1997. The sole purpose of the second pass option is to partially mitigate the problems of (1) senior *WR*-record rights not having access to water made available by junior *WR*-record rights through either same-month diversion return flows or hydropower releases and (2) reservoir releases by junior water rights not being credited in meeting senior instream flow targets at intermediate control points. The first problem is now routinely solved by the alternative means of adopting the next-month return flow and next-month hydropower options which are very straight-forward to apply.

Instream flow targets and shortages for each *IF* record right and for each control point are included in the simulation results output file. For multiple *IF* records with different priorities at the same control point, the output recorded for the control point is the target at the junior end of the priority sequence. Job control *JD* record ICHECK option 12 writes intermediate instream flow target results in the message file.

SIMD Daily Simulation Model

The WRAP daily modeling system was developed by expanding *SIM* (to *SIMD*) and *TABLES* to incorporate additional features and creating the new auxiliary program *DAY*. *SIMD* includes all of the capabilities of *SIM* plus additional features either required for or made feasible by a daily computational time step. All of the features described in the preceding section are applicable with either a daily or monthly time step. The *Daily Manual* supplements the *Reference* and *Users Manuals*. S*IMD* incorporates the following features needed to perform a daily simulation: (1) options for disaggregating monthly naturalized flows to daily volumes (or reading daily flows as input), (2) flow routing and forecasting, and (3) development of daily diversion, hydropower, and instream flow targets. With the computations performed at a daily interval, addition of features for simulating pulse flow environmental flow requirements and reservoir operations for flood control are feasible and have been added to *SIMD*.

Basic Conceptual Differences between Daily and Monthly Simulation Models

Fundamental differences between daily and monthly simulation models are as follows.

- The smaller computational time interval improves the preciseness of the simulation. The increased level of preciseness is particularly relevant in simulating instream flow requirements and flood control operations. The effects of changing the size of the computational time step are diminished by reservoir storage and thus tend to be least pronounced on water supply rights with large reservoir storage capacities.

- In a monthly model, the effects of reservoir releases and water management/use actions on streamflows at downstream locations are assumed to propagate through the river system within the same month, precluding flow forecasting and routing computations. However, flow forecasting and routing are important in typical modeling applications based on a daily time step.

- Input data compilation, including developing naturalized flows, routing parameters, and diversion and instream flow requirements, is much simpler for a monthly model.

Flow rates that vary continuously over time in the real world are modeled as volumes occurring during discrete time intervals. Comparisons of rates in the model are based on total volumes during finite time intervals rather than instantaneous rates at instances in time. Figure 3.1 illustrates why the time interval selected may significantly affect the accuracy and validity of simulation results.

A hydrograph of instantaneous regulated flow rates at a location on a river over a six-month period is plotted in Figure 3.1. A constant target minimum instream flow rate and the channel capacity discharge rate above which flow enters the floodplain are also shown. The river discharge hydrograph, instream flow target, and channel capacity are instantaneous flow rates in ft^3/s. The flow volume during any month, day, or any other specified time interval is represented by the area under the flow plot. The total river flow during the six-month period is represented by the area under the streamflow hydrograph during January through June. Likewise, the total volume of the minimum flow target during the six-month period is represented by the rectangular area under the plot of the instantaneous target flow rate.

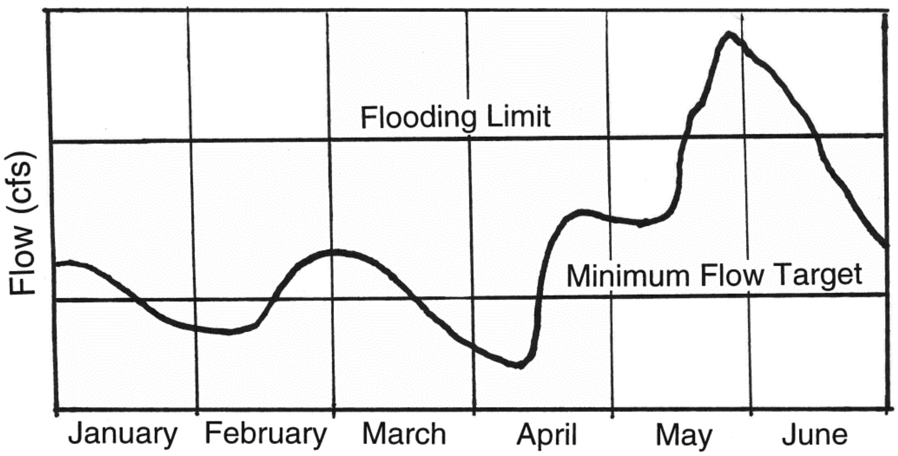

Figure 3.1 Streamflow Hydrograph, Channel Capacity, and Instream Flow Target

If a monthly computational time interval is adopted, both the instream flow target and streamflow are expressed in terms of flow volume in each month, typically in units of acre-feet/month. The streamflow volume exceeds the instream flow target in each of the six months, with no failures to meet the target. However, results change significantly if a daily time step is adopted. Failures to meet the instream flow target occur during the last 15 days of January and first 15 days of February and during the last 14 days of March and first 15 days of April. With a monthly time interval, the instream flow target is satisfied 100 percent of the time during this six-month period. With a daily model, the flow target is satisfied 67 percent of the time.

The flooding limit shown in Figure 3.1 is the river flow level above which the channel capacity is exceeded and water flows into the floodplain. With a monthly time interval, the mean streamflow rate each month is less than the channel capacity for each of the six months. A monthly time interval indicates no floodplain flows. With a daily computational time step, the channel capacity is exceeded during 30 days during May through June.

The Figure 3.1 example illustrates the approximations involved in averaging flow rates over a monthly time interval. Flow averaging over longer time intervals tends to over-estimate capabilities for meeting requirements for environmental instream flow, water supply diversions, hydroelectric power, and flood control. River flows may fall well below minimum instream flow requirement limits for several days even though higher flows in other days of the month result in the mean monthly streamflow being above the instream flow target.

Reservoir storage plays a significant role in mitigating the effects of alternative choices of time interval. The effects on water supply reliability and firm yield estimates of changing between monthly and daily models would normally be expected to be relatively minimal for water rights with large reservoir storage capacity. The critical draw-downs that empty large reservoirs occur over long periods of many months. Choice of time interval tends to affect reliability estimates for run-of-river diversion and instream flow targets much more.

Although this discussion focuses on monthly versus daily time intervals, flow fluctuations during a day may also be significant. Flows in response to a major rainfall storm may vary greatly over a period of several hours, an hour, or minutes. However, the day and month are probably the two alternative time intervals that are most pertinent for most typical WRAP applications. The impacts of the choice of computational time interval on the accuracy of the model depend on the circumstances of the modeling application.

Flow routing and forecasting are the key computational tasks that make the internal computations performed by *SIMD* much more complicated than the simulation computations performed within *SIM*. In a real-world river system, time is required for the effects of diversions, return flows, and reservoir refilling and releases at an upstream location to propagate to downstream locations. River flows diverted or stored by a particular water user today may diminish the flows available to other water users located further downstream tomorrow or several days in the future. Likewise, flow travel times for reservoir releases or diversion return flows to reach other downstream locations may be several days, perhaps a week or longer. Thus, water supply capabilities are affected by earlier upstream activities. Flood control reservoir operations are based on making no releases that contribute to flows exceeding maximum non-damaging flow limits at downstream gages that may be located several days of flow travel time below the dam. Water supply and flood control operations affect instream flows.

The timing and attenuation of flow changes cascading downstream through a river system are reflected in flow forecasting and flow routing. These effects are typically not explicitly addressed in modeling with a monthly computational time step but may be very significant with daily time steps. Pertinent effects of streamflow depletions and inflows propagating through a river/reservoir system typically occur over time scales of less than a month. Translating effects of actions occurring late in one month to the early part of the next month is not possible if the model is based on lumped monthly volumes. *SIM* has no explicit features for either forecasting future streamflows or modeling timing (lag) and attenuation effects. *SIMD* provides optional capabilities for streamflow routing and forecasting for use with daily time steps.

Converting WAM System Datasets from Monthly to Daily

The Texas WAM System datasets listed in Table 3.1 are based on a monthly time interval. The Brazos WAM case study documented by Wurbs et al. (2012) and Chapters 5, 6, and 7 of the present report represent the first endeavor to convert a WAM System monthly dataset set to a daily model. A preliminary dataset with less testing has also been developed for the much smaller Neches River Basin WAM (Hoffpauir and Wurbs 2012). Daily WRAP input datasets are currently being developed for the Colorado and Trinity River Basins. Daily versions of WAM datasets for other river basins are expected to follow.

The daily modeling system is designed to supplement, not replace, the monthly models. Monthly WRAP modeling applications will remain important. The objective is to expand modeling and analysis capabilities to facilitate daily along with monthly applications.

Additional Input Data Needed for a Daily Model

SIMD allows each of the 12 months of the year to be divided into an integer number of time steps. With the default daily time step, each month is subdivided into 31, 30, 29 (leap year February), or 28 days. All simulation result variables are computed by *SIMD* for each time step, but the sub-monthly (daily) amounts may be summed to monthly values. *TABLES* organizes

SIMD simulation results and develops frequency and reliability tables using either daily or other sub-monthly computational time step *SIMD* results or aggregated monthly amounts. *DAY* is a pre-simulation program providing options for calibrating routing parameters and developing certain other *SIMD* input data. The WRAP daily modeling system is documented by the *Daily Manual* (Wurbs and Hoffpauir 2012) along with the *Reference* and *Users Manuals*.

A conventional monthly time step simulation may be performed with *SIMD* with the same input datasets used with *SIM*, with *SIMD* and *SIM* yielding identically the same results. Supplemental input is added to apply the *SIMD* sub-monthly (daily) features. As a minimum, a *SIM* monthly dataset can be modified for a *SIMD* daily simulation by simply adding to the DAT file a *JT* record with all fields blank. The *JT* record will activate defaults that allow a daily simulation to be performed using only the data provided by the *SIM* input files developed for a monthly simulation. However, the default settings will probably not achieve an acceptable level of accuracy for most applications. Other options requiring additional input data are adopted to improve the validity and accuracy of the model. Tradeoffs between necessary effort versus model accuracy and validity, requiring professional judgment, are necessary in selecting modeling options and compiling input data.

All of the input data contained in the *SIM* input files are used with a daily *SIMD* simulation without modification. The additional input data for a daily simulation are divided between the DAT file shared with *SIM* and a DCF input file used only by *SIMD*. These records and their placement in the DAT and DCF files are explained in Appendix A of the *Daily Manual*.

Most of the additional data compiled to convert a monthly WAM dataset to a daily *SIMD* model deals with: (1) naturalized flow disaggregation, (2) flow routing parameters, and (3) disaggregation of diversion and instream flow requirements. These data are discussed in the following paragraphs. Optional new *SIMD* features for simulating flood control operations and environmental pulse flow requirements require a daily time step and thus have never been included in the monthly *SIM*. Flood control and pulse flows are discussed later in this chapter.

In addition to the *SIMD* input data discussed in the following paragraphs, the input also includes selections between various options, most of which have defaults that are activated if input record fields are left blank. A daily interval is activated by default if other sub-monthly intervals are not specified on a *JT* record. Negative increment flow option 7 (*JD* record *ADJINC*) is designed to be the standard any time routing and forecasting are activated. Several options, all with defaults, are activated by entries on the daily job options *JU* record. Forecasting is essentially automated and is normally controlled by default parameters but can optionally be deactivated or changed. The default routing option is the lag and attenuation method. Monthly simulation results can be massive, and daily simulation results much more massive. *C2*, *C3*, *W2*, *G2*, and *R2* records control selections of daily *SIMD* simulation results to include in the output.

<u>Disaggregation of Monthly Naturalized Flows to Daily Amounts</u>

Alternative options for disaggregating monthly naturalized flows to daily range in complexity from a linear interpolation routine that requires no additional input data to methodologies that reproduce the daily variability patterns exhibited by sequences of daily flows provided as model input. *SIMD* can also directly use daily flows read as input without needing monthly flows. The method that is expected be adopted most often with the TCEQ WAM System is based on disaggregating the monthly flows from the WAM System datasets based on patterns from inputted daily flows while maintaining the original monthly volumes.

Daily flow *DF* records in a DCF file may contain either sub-monthly naturalized flow volumes or amounts that are used to define daily flow patterns. In the case of flow amounts defining patterns, only the relative amounts, not the actual amounts, are relevant. The monthly volumes in the FLO file are preserved. Each set of *DF* record daily flow sequences may be repeated for any number of control points. The *DF* input records do not have to include data covering the entire period-of-analysis. The daily pattern flows on the *DF* records are repeated as necessary within the *SIMD* simulation to extend over the hydrologic period-of-analysis.

Compiling daily flows for use as flow patterns is a major component of the effort of converting a WAM dataset to daily. The daily flows in the Brazos WAM case study presented in this report are unregulated flows developed by the U.S. Army Corps of Engineers Fort Worth District in conjunction with their modeling system used to support their reservoir operations. The Corps of Engineers has models of parts of some, but not all, of the Texas river systems. Observed gaged daily flows are a primary potential source for *SIMD* pattern flows. Daily flow patterns could conceivably also be synthesized with precipitation-runoff (watershed) models.

Flow Routing

The lag and attenuation method described in the *Daily Manual* was developed specifically for *SIMD* as its standard though not only routing option. A set of control points defining a system of routing reaches are selected and the lag and attenuation parameters are determined for each reach in conjunction with creating a daily *SIMD* input dataset. Program *DAY* provides routines for calibrating routing parameters based on the input daily flow hydrographs at the upstream and downstream control points defining the routing reaches.

Routing in *SIMD* propagates flow changes through river reaches connecting control points. Water supply diversions and return flows and reservoir releases and storage refilling at a control point result in changes in streamflows at downstream control points. Routing in *SIMD* refers to the downstream propagation of changes resulting from an upstream change to streamflow. Routing simulates the storage effects (lag and attenuation) of a river reach on the relative timing of reach outflows and inflows. Reverse routing replicates the effects of routing in the procedure for forecasting flow availability for *WR* and *IF* record rights.

Routing parameters are entered on a *RT* record for the control point defining the upstream end of each routing reach. Different parameter values may be entered for flow changes associated with flood control *FR* record reservoir operations and flow changes for *WR* record water rights. If routing parameters are assigned for a control point, routing computations are performed resulting in lag and attenuation of flow changes originating at or passing through the control point. If routing parameters are not specified for a particular control point, flow changes originating at or passing through the control point are passed through the reach below the control point instantaneously without routing computations and thus without lag or attenuation. Without routing, outflow from a river reach equals the inflow in the time step less channel losses. Channel losses are computed similarly in both monthly *SIM* and daily *SIMD* simulations.

The larger river basins in the Texas WAM System have hundreds of control points, many of which are too closely spaced for meaningful routing. For complex datasets with numerous closely spaced control points, lag and attenuation effects may be aggregated to selected reaches. Converting a monthly WAM dataset to daily requires both designing the configuration of control points that define routing reaches and calibrating parameters for each routing reach.

Water Supply Diversion and Instream Flow Requirements

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 as described in detail in the *Reference*, *Users*, and *Daily Manuals*.

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*, cumulative volume *CV*, flow switch *FS*, drought index *DI*, hydrologic index *HI*, and other supporting records.

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.

   - With the uniform option, monthly targets are evenly divided into daily amounts.

   - Options activated by parameters *ND* and *SHORT* are based on meeting the monthly target earlier in the month if adequate streamflow is available. For example, a target could be defined such that up to a specified limit, for example 20%, of the monthly target is supplied in each day subject to streamflow availability. Portions of the monthly target not supplied to date due to limited available flow, up to 20% of the monthly total, is supplied in each subsequent day of the month until the total monthly target is supplied.

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*, *CV*, *FS*, and *DI* record monthly target setting options noted in step 1 above. Pulse flow *PF* and *PO* records are considered only on a daily basis as explained in the next section.

For most modeling applications, daily targets will be set for most water rights (*WR* and *IF* records) by combining options from the first two sets of options listed above. However, the third set of options is also available as needed. Judgments based on available information regarding water management/use practices are required in regard to selecting among these options for each water right or groups of water rights in the process of converting a monthly model to daily.

The features for defining environmental instream flow standards, called *IF* record water rights in WRAP terminology, described above set minimum regulated flow limits which are relevant to the subsistence and base flow components of the flow regime outlined in Table 2.4. Monthly or seasonal variations in subsistence and base flow requirements are modeled using *UC* records that vary the minimum target regulated flow limit over the 12 months of the year. As discussed in Chapter 2, environmental flow limits may also vary depending upon hydrologic conditions such as wetter than normal, normal, and drought. Variation of subsistence and base flow requirements with hydrologic conditions can be simulated with:

- drought indices (*DI*, *IS*, *IP*, and *IM* records) that set the minimum flow limit based on the storage contents of any number of reservoirs at the beginning of the day, month, or specified multiple-month season
- hydrologic indices (*HI* records) such as the Palmer hydrologic drought index used in the Brazos WAM case study discussed later
- rules specified by combinations of target options *TO*, supplemental options *SO*, cumulative volume *CV*, flow switch *FS*, and target series *TS* records that define the hydrologic conditions upon on which the minimum flow limits depend as arithmetic functions of combinations of streamflow, storage, diversion, and/or other variables in the current time period or accumulated over multiple periods.

SIMD daily simulation capabilities can significantly improve accuracy in capturing streamflow variability and the response of water management decisions to this variability. Minimum flow limits for subsistence and base flow components of the flow regime are defined similarly in the daily *SIMD* and monthly *SIM* models with certain refinements in the daily model. The *SIMD* pulse flow features described next deal with high flow responses to major rainfall events that cannot be addressed in the monthly *SIM*.

Environmental Pulse Flow Requirements

High flow pulses are characterized by rainfall-runoff events with high flow rates which may include flooding conditions. The rising limb of a typical high flow pulse hydrograph climbs quickly to a peak, after which flows recede more slowly back to base flow levels. High flow pulses are considered to be events typically with durations measured in days.

Capabilities for modeling pulse flow requirements are explained in Chapter 8 of the *Daily Manual* (Wurbs and Hoffpauir 2012) along with illustrative examples. The pulse flow *PF* and pulse flow options *PO* records are described in Appendix A of the *Daily Manual*. These options are designed for modeling the high flow pulse and overbank flow components of the flow regime outlined in Table 2.4 of the preceding Chapter 2. The pulse flow feature requires a daily time step and is included only in *SIMD*, not *SIM*. Therefore, the original monthly WAM System datasets incorporate no pulse flow requirements. The pulse flow feature is not used in the Brazos WAM daily case study reported by Wurbs et al. (2012) but is used in the expanded Brazos WAM case study presented in Chapters 5, 6, and 7 of the present report.

The *SIMD* pulse flow feature activated with the *PF* and *PO* records is designed for a daily simulation. However, instream flow targets for high flow pulses can be computed in a daily *SIMD* simulation and provided as input to the monthly *SIM*. The computed daily targets are summed to monthly target volumes within *SIMD*. The resulting sequences of monthly target volumes are provided as input to *SIM* as target series *TS* records. A new target series TSF input file was recently added to *SIM* for *TS* record target sequences. A new option on the *TS* record placed in the DAT file following a water right *WR* or *IF* allows the target series *TS* records with the monthly instream flow targets to be stored in either the DAT file or the new TSF file.

General Framework for Modeling Instream Flow Requirements

The daily pulse flow targets computed by the *PF* and *PO* record routine in *SIMD* are minimum regulated flow limits that are observed to the extent possible by curtailing junior diversion and storage refilling rights in the same way as for instream flow targets determined using any other target-setting records. Optionally, reservoir releases can be specified for all *SIM/SIMD* instream flow *IF* record targets. *PF/PO* records can be combined with the other target-setting records discussed in the preceding section to set minimum flow limits at a control point for any days of the *SIMD* simulation, with the minimum flow limits varying between days.

The general framework for creating instream flow targets along with diversion, hydropower, and storage targets is outlined, and the target-setting options provided by *DI*, *TO*, *SO*, *CV*, *FS*, *TS*, and *HI* records are explained in detail in the *Reference* and *Users Manual*. Daily target-building options added by the *DW* and *DO* records and *PF* and *PO* records, for application within the established framework, are covered in the *Daily Manual*.

Like most aspects of WRAP, pulse flow *PF* and pulse options *PO* records are generalized for a variety of applications that depend upon the creative ingenuity of the model user in combining various options activated by various input records. *PF* and *PO* records are inserted with the other target-setting records following an *IF* or *WR* record in the DAT input file. The optional *PO* record is placed after its *PF* record. Any number of *PF/PO* records may be assigned to the same *IF* or *WR* record. Targets set by *IF* and *WR* records can be used as the variable selected for use by target options *TO*, flow switch *FS*, cumulative volume *CV*, and pulse flow *PF* records. This allows for connectivity between *IF* and *WR* records.

In WRAP modeling terminology, a water right is a *WR* or *IF* record and its auxiliary records that control various functions such as target setting and reservoir operations. A *IF* record water right sets a minimum instream flow limit. *WR* record water right types 1, 2, 3, and 4 deal with water supply diversions and reservoir storage. *WR* record types 5 and 6 deal with hydroelectric energy generation and reservoir storage. Type 7 deals only with setting storage targets. A *WR* record with type 8 activated does nothing but set a target, which may then be used for target setting operations with other rights. For example, any number of *WR* records designated as type 8 could be used to create targets for different components of an environmental flow regime which are then combined for the same *IF* record water right.

Modeling High Pulse Flows

The following terms are used in describing *PF/PO* record pulse flow operations.

Initiate: The decision to declare that a pulse event is engaged is based on regulated flow exceeding the trigger criterion and satisfaction of optional initiation criteria.

Engaged: A pulse event is engaged when it has been initiated and is being tracked. An engaged pulse may set daily pulse targets.

Terminate: The decision to declare that a pulse event is no longer engaged is based on satisfaction of either the total event volume or maximum duration parameter or satisfaction of other optional termination criteria.

Daily Pulse Target: Targets are developed each day during a pulse flow event. Daily pulse targets are less than or equal to the daily regulated flow measured at the priority of the *IF* record (or *WR* record) to which the *PF* record is attached. Daily pulse targets are not used to set a final target for the *PF* record if the frequency criterion has already been met.

PF Record Target: The minimum flow limit for each day of the pulse flow event governed by the *PF* record may be either the complete final target or a component of the target-building process for the instream flow *IF* record water right to which the *PF* record is attached.

Target Setting Event: The flow pulse used in setting daily targets is defined by *PF* record parameters. The frequency parameter limits the number of pulse events meeting the specified criteria during the tracking period that are adopted as target setting events.

Excess Pulse Event: Excess pulse events are those not used to set targets. When the number of pulse events exceeds the frequency parameter, events are tracked but otherwise do not set *PF* record targets. Excess pulse events are tracked only if specified by a *PO* record option.

Seasonal Tracking: Pulse events are only initiated and considered for meeting the frequency criterion between specified starting and ending months. An optional number of the previous seasons may be considered together for meeting the frequency.

Continuous Tracking: Pulse events are initiated and considered for meeting the frequency criterion over the previous number of time steps equal to the WINDOW parameter on the *PF* record.

Table 3.3
PF Record Variables

PF record variable	Description	*PF* record variable	Description
PFV	Pulse flow variable, default regulated flow	SEASON END	Month to end season for counting pulse events, default 12
PFCP	Alternate control point for flow variable	SEASON COUNT	Number of seasons for counting pulses, default is 1
TRIGGER	Daily flow threshold that initiates a pulse event	REGFLOW	Options for considering regulated flow within priority sequence
VOLUME	Terminate pulse event after total volume observed	TARGET LIMIT	Options for limiting the size of the target set by the *PF* record
DURATION	Terminate pulse event after a maximum number of days	PFTAR	Target setting options
FREQ	Number of pulse events per window or season	PFSMM	SMM file output options
WINDOW	Number of previous days to count pulse events	PFWR1	Optional water right ID for defining pulse flow variable
SEASON START	Month to begin season for counting pulse events, default 1	PFID	Optional identifier for *PF* record used by *PO* records or SMM file

Table 3.4
PO Record Variables

PO record variable	Description	*PO* record variable	Description
PREVIOUS EVENT	Options for initiating new pulse event after previous	VOLUME CREDIT	Event volume for smaller pulse events credited to larger events
DELAY	Number of days between previous and new pulse	EXCESS EVENTS	Options for counting excess pulse events towards frequency
LARGER EVENTS	Larger pulse events block initiation of smaller pulses	EVENT VOLUME	Exclusion of pulse events failing volume criterion from count
PREVIOUS FLOW	Regulated flow of previous day considered for initiation	PFWR2	*WR/IF/PF* identifier for optional initiation criteria
LOWER	Lower threshold for terminating pulse event	PFWR3	*WR/IF/PF* identifier for optional initiation criteria
UPPER	Upper threshold and rate of change used together for terminating pulse event	PFWR4	*WR/IF/PF* identifier for optional termination criteria
CHANGE	Rate of change used with UPPER for terminating a pulse event	PFWR5	*WR/IF/PF* identifier for optional termination criteria
SEASON TERMINATE	Termination of pulse events at the end of seasons		

The pulse flow feature of *SIMD* is designed for simulating the high pulse flow and overbank flow components of an environmental flow regime. The parameters entered on *PF* and *PO* records and listed in Tables 3.3 and 3.4 initiate, track, and terminate high flow pulse events.

Pulse flow targets are set based on tracking a pulse flow variable, which by default is regulated flow. A pulse event is defined as the consecutive days between and including the days in which flows satisfy the initiation and termination criteria specified on the *PF* and *PO* records. Once the pulse flow event is initiated, daily targets are set as specified in accordance with the *PF/PO* record specifications until the termination criteria are met. The daily minimum instream flow target is computed as the lesser of the following: (1) the daily regulated flow, (2) remaining volume to satisfy the total event volume criterion, or (3) value of the trigger criterion if the *PO* record target limit option is activated. The daily target either equals or is less than the total daily regulated flow. Daily pulse targets are not used to set a final target for the *PF* record unless the frequency criterion is still unmet.

SIMD performs the following computations in the target building process. If more than one pair of *PF* and *PO* records is assigned to an *IF* or *WR* record water right, the computations are repeated. The computations for each *PF* and *PO* record pair are independent of any other *PF* and *PO* records assigned to the same *IF* or *WR* record.

1. The computations are performed for every time step if continuous tracking is selected. The seasonal tracking option checks whether the month is within the specified season.
2. A variable for defining pulse flow events is selected from a list of 12 options. The default is to track regulated flow at the control point and priority of the *IF* or *WR* record water right.
3. A new pulse flow event is initiated if all of the initiation criteria are satisfied. The initiation criteria include items a and b below plus any combination of options c, d, e, and f.
   a. This *PF* record is not currently tracking a pulse flow event.
   b. The regulated flow is in excess of the trigger criterion.
   c. The number of pulse flow events during the tracking period has not exceeded the frequency criteria. This criterion is ignored if the excess pulse event option is selected.
   d. An optional number of days has occurred since termination of the previous pulse event.
   e. A pulse flow event with a larger trigger criterion is not currently engaged at the same location according to the LARGER EVENTS option.
   f. Regulated flow for the previous day was less than the trigger criterion.
4. A pulse flow event is terminated prior to setting a *PF* record target if the optional *PO* record termination criteria are met. These termination criteria include:
   a. A target has been set by the water right indicated by PFWR3.
   b. Regulated flow is less than the lower threshold.
   c. Regulated flow is less than the upper threshold and has decreased since the previous time step by less than the change variable.
5. If the pulse flow event is terminated by the criteria in step 4, and if the pulse event has failed to achieve the total event volume criterion, the event is eliminated from consideration to satisfy the frequency criterion.
6. If a pulse event is engaged, the total volume of the event is updated. The parameter VOLUME CREDIT allows the total event volume to date of smaller pulses at the same control point that were still engaged when the larger pulse was initiated to be credited towards the larger pulse.
7. If a pulse is engaged, the number of pulse events engaged during the continuous tracking window or seasonal tracking period is updated for comparison with the frequency criterion.
8. The daily pulse target is computed to be equal the lesser of the following:
   a. Daily regulated flow.
   b. Remaining volume to satisfy the total event volume criterion.
   c. Value of trigger criterion if the *PO* record target limit option is selected.
9. A *PF* record target is set equal to the daily pulse target if all of the following criteria are met.
   a. A pulse event is currently engaged.
   b. The number of pulse events during the continuous tracking window or the seasonal tracking period is less than or equal to the frequency criterion.

c. A target has not been set in the current time step by the optional water right indicated by PFWR2 from the *PO* record.

10. If multiple intermediate targets are computed within the overall target setting process for an *IF* or *WR* record water right, the *PF* record target is combined with the preceding intermediate target as specified by the PFTAR option selected on the *PF* record.
11. The pulse event is terminated after setting a *PF* record target if the total volume of the pulse event has exceeded the total event volume criterion.
12. If the pulse flow event has been engaged for the maximum duration number of days, the pulse event is terminated. If the event has failed to satisfy the total event volume criterion, the terminated event is eliminated from consideration to satisfy the frequency criterion according to *PO* record option EVENT VOLUME.
13. The pulse event is terminated if the current day is the last day of a seasonal tracking period. *PO* record option SEASON TERMINATE may allow pulse events to continue past the last day of the season until terminated by other criteria.
14. Optional daily computations are written to the sub-monthly message SMM file.
15. If this is the last day of the last month of a seasonal tracking period, the number of excess flow events, if chosen for consideration, are computed and saved for consideration in the next seasonal tracking period. If more than one seasonal tracking period is to be considered for meeting the frequency criterion, all target setting and excess pulse events in the current season are saved for consideration in future seasonal tracking periods as set by *PF* record option SEASON COUNT.

Regulated flow that is computed at the priority of the water right with the *PF*/*PO* records may not necessarily be the same as the regulated flow at the end of the priority sequence due to the impacts of upstream *WR* record water rights that are junior to the pulse flow target setting right. Steps 11 through 14 are repeated to adjust the total event volume at the end of the time step if the default regulated flow is activated as the pulse flow variable and *PO* record option REGFLOW is selected.

A flow regime recommendation may identify pulses of different trigger magnitudes, event volumes, frequencies, and seasons at the same control point location. The *PO* record LARGER EVENTS option default is to block the initiation of pulse events if another *PF* record at the same location and at any position in the water rights priority sequence has engaged a pulse event with a larger magnitude trigger. Smaller pulses may continue to be tracked if they are initiated prior to the larger magnitude pulse initiation. After the larger magnitude pulse has terminated, the smaller magnitude pulses may resume checking regulated flow for possible pulse event initiation. Multiple *PF* records assigned to the same *WR/IF* record right are processed in the order in which the records appear in the DAT file. Sequencing of *PF* records under a single water right should be considered when using the LARGER EVENTS option.

Total event volume of smaller pulses may be credited towards meeting larger pulse events with *PO* record option VOLUME CREDIT. If a smaller pulse is located at the same control point of a larger pulse requirement, and the smaller pulse is still engaged on the day the larger pulse is initiated, the option VOLUME CREDIT allows the smaller pulse volume to date to be credited towards meeting the larger pulse total event volume. If more than one smaller pulse is engaged at the same control point, the largest to date event volume is selected for crediting to the larger pulse.

The required and optional variables on the *PF* and *PO* records can address a wide range of initiation, termination, and target setting aspects for modeling the high pulse and overbank flow components within a flow regime. Tables 3.3 and 3.4 list the variable names and provide a brief description of each variable. Additional details necessary for developing input records are provided in Appendix A of the *Daily Manual*. Values are assigned to the trigger, volume, duration, and frequency variables and a selection between continuous or discrete seasonal tracking periods is made on the *PF* record. Other variables on the *PF* record are optional or have default values. If a *PO* record is not provided after a *PF* record, all *PO* record defaults are activated. *Daily Manual* Chapter 8 details various considerations in modeling pulse flows.

Examples of applying *PF* and *PO* records are included in *Daily Manual* Chapter 8. Other simple examples are provided in the following Chapter 4 of this report. Environmental pulse flow requirements are included in the Brazos WAM case study presented later in this report.

<u>Reservoir Operations for Flood Control</u>

Although *SIMD* may be applied in studies focused specifically on flood control, simulation of reservoir flood control operations with *SIMD* is most likely to address integrated river system management dealing with interactions between multiple purposes. Flood control operations affect storage capabilities for supplying diversion and low flow needs. Flood control and surcharge pools also affect downstream flows that meet environmental pulse flow needs.

Simulation of reservoir operations for flood control is covered in Chapter 5 of the *Daily Manual* (Wurbs and Hoffpauir 2012) along with illustrative examples. The flood control reservoir *FR*, flood flow *FF*, flood volume *FV*, and flood outflow *FQ* records described in Appendix A of the *Daily Manual* are the only *SIMD* input records designed specifically for flood control. These input record types are applicable in *SIMD* but not *SIM*. The Brazos WAM case study includes simulation of the operation of the flood control pools of nine Corps of Engineers multiple-purpose reservoirs.

Flood control reservoir operations are treated in *SIMD* as a type of water right. In WRAP terminology, a water right is a set of water management requirements and associated reservoir storage and operating rules. Flood control rights activated by pairs of *FR* and *WS* records are simulated along with all the other water rights activated by *WR* and *IF* records. Any number of *FR*, *WR*, or *IF* record rights may be associated with the same reservoir with the use of *WS* records. The auxiliary records that may be attached to the *WR* and *IF* records to activate target setting options are also applicable to setting the *FF* record flood flow target.

Reservoirs with designated flood control pools controlled by gated outlet structures are modeled in *SIMD* as *FR* and *FF* record water rights. Operation of multiple-reservoir systems with any number of reservoirs may be based on flood flow limits at any number of downstream control points. Releases from flood control and surcharge pools are also limited by the flow capacity of the spillway and other outlet structures at the dam, as modeled by a pair of *FV* and

FQ records. *FV* and *FQ* records defining a storage-outflow relationship are provided along with a *FR* record to model (1) surcharge storage in a reservoir with no intentional flood control, (2) surcharge above a flood control pool, and/or (3) limits on releases from a flood control pool.

End-of-month storage contents never exceed conservation storage capacity in *SIM*. The monthly model is based on the premise that monthly outflows equal inflows for reservoir surcharge and flood control pools that may exist above the top of conservation pool.

Multiple-Purpose Reservoir Operations

In the real-world, reservoirs may be operated solely for conservation purposes, for only flood control, or for both flood control and conservation. Conservation purposes include municipal and industrial water supply, agricultural irrigation, hydroelectric power, recreation, and environmental protection or enhancement. Multiple-purpose operations are based on dividing the storage capacity into conservation and flood control pools separated by a designated top of conservation pool elevation as illustrated by Figure 3.2. The top of the conservation pool is the bottom of the flood control pool. The allocation of storage capacity between pools may be constant or vary seasonally. The conservation pool storage contents are maintained as close to capacity as inflows and water demands allow. The flood control pool remains empty except during and following flood events.

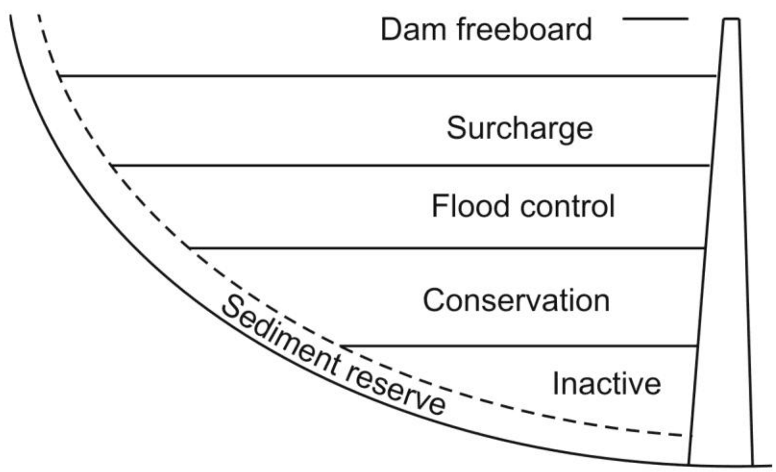

Figure 3.2 Reservoir Pools

Flood releases from reservoirs occur through spillways and other outlet structures that may be either uncontrolled with no gates or controlled by people opening and closing gates. Flood control pools may be controlled by gated spillways. Alternatively, uncontrolled spillways with a crest elevation at the top of the controlled storage may pass extreme flood flows while other gated outlet works are used for controlled releases from the conservation and flood control pools. *SIMD* can simulate either gated or ungated structures. Without gate operations, outflows are governed by the stage-discharge characteristics of the outlet structures, which are modeled in *SIMD* with *FV* and *FQ* records. Designated flood control pools controlled with gated outlet structures are modeled with *FR* and *FF* records. A *FV*/*FQ* record storage-outflow relationship may also provide maximum release limits (outflow capacity) for *FR/FF* record gate operations.

Water supply reservoirs with no designated flood control storage capacity typically have uncontrolled surcharge storage above the normal top of conservation storage that provides incidental attenuation of flood flows. During high flow events, with the controlled conservation storage full to capacity, inflows exceed the outflow capacity of outlet structures resulting in surcharge storage below the top of dam but above the top of conservation pool which often coincides with the crest elevation of an ungated overflow spillway. Surcharge storage in some cases may significantly affect whether instream flow requirements are met at locations downstream of dams. Backwater effects extend upstream in the streams flowing into the reservoir. Surcharge storage can be modeled in *SIMD* with *FV* and *FQ* records

Inactive pools provide head for hydroelectric energy generation or lakeside water supply diversion structures. Lake and river recreation is also a major consideration in reservoir operations. Reservoir pool level fluctuations also affect lake fisheries and ecosystems.

The rivers of Texas are controlled by numerous dams with a variety of outlet structure configurations. Most of the designated flood control pool storage capacity in Texas controlled by gated outlet structures is contained in 32 large reservoirs owned by the U.S. Army Corps of Engineers, of which all but two also have conservation pools, and Amistad and Falcon Reservoirs on the Rio Grande operated by the International Boundary and Water Commission. The Corps of Engineers is responsible for flood control operations of its multiple-purpose reservoirs, and the conservation storage capacity is contracted to non-federal water supply sponsors. The Natural Resource Conservation Service has constructed numerous flood control dams with ungated outlet structures in rural watersheds. Numerous small stormwater detention structures constructed by local entities in urban areas are also ungated.

Corps of Engineers flood control operations are based on minimizing the risk and consequences of making releases that contribute to downstream flooding. Maximum allowable flow rates at downstream control points are established based on bank-full river flow capacities, stages at which significant damages occur, environmental considerations, and/or constraints such as inundation of road crossings. Releases are made to empty flood control storage capacity as quickly as possible without contributing to streamflows exceeding specified maximum allowable flow levels at the downstream gaging stations. When a flood occurs, the spillway and outlet works gates are closed. The gates remain closed until a determination is made that the flood has crested and flows are below the target levels specified for each of the gaged control points. The gates are then operated to empty the flood control pool as quickly as possible without exceeding the allowable flows at the downstream locations. The pool is emptied in preparation for the next storm producing flood inflows which will occur at some unknown time in the future.

Reservoir operations are based on flow limits at downstream locations as long as the flood control pool is not overtopped. During extreme flood events exceeding the flood storage capacity, flood waters may encroach into surcharge storage. With the flood control pool capacity exceeded, releases causing damages downstream are required to prevent the reservoir stage from exceeding a maximum design water surface level set based on protecting the structural integrity of the dam. If flood waters are expected to rise above the top of flood control pool, emergency operating procedures are activated with releases determined based on inflows and storage levels.

In many cases, the allowable non-damaging channel capacity at a given river location is constant regardless of the volume of water in storage. However, operating rules for some reservoirs are formulated with the allowable flow rates at one or more operational control points varying depending upon the volume of water currently stored in the flood control pools. This allows stringently low flow levels to be maintained at certain locations as long as only a relatively small portion of the flood control storage capacity is occupied, with the flows increased to a higher level, at which minor damages could occur, as the reservoirs fill.

A reservoir may have one or more operational control points that are related only to that reservoir and several other control points that are shared with other reservoirs. For example, in Figure 3.3, gaging station 3 is used as a control point for both Reservoirs A and B, and gage 4 controls releases from all three reservoirs. Multiple-reservoir release decisions are typically based on maintaining some specified relative balance between the percentage of flood-control storage capacity utilized in each reservoir. For example, if unregulated flows are below the maximum allowable flow rates at all the control points, the reservoir with the greatest amount of water in storage, expressed as a percentage of flood control storage capacity, might be selected to release water. Various balancing criteria may be adopted. Flows at downstream control points depend upon releases from all reservoirs and runoff from uncontrolled watershed areas below the dams.

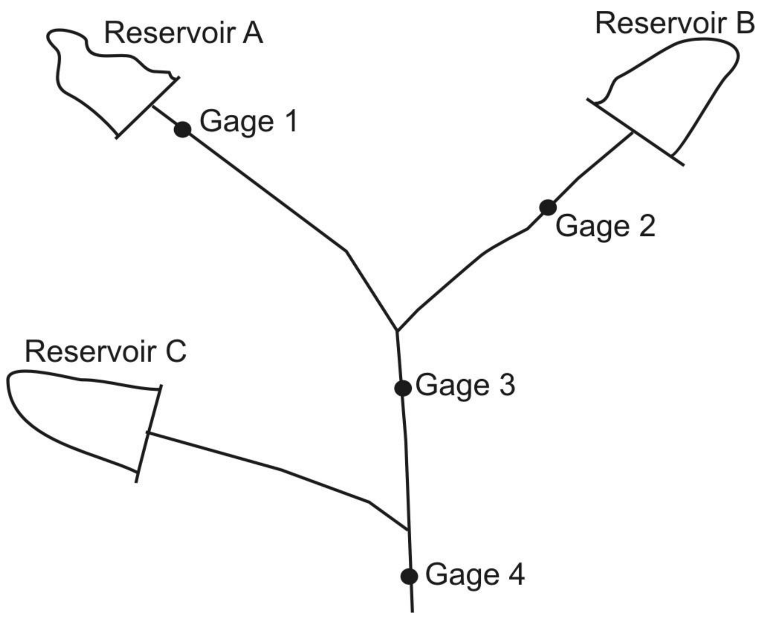

Figure 3.3 Multiple-Reservoir System Flood Control Operations

<u>*SIMD* Simulation of Reservoir Flood Control</u>

In *SIMD*, a reservoir consists of any or all of the four pools shown in Figure 3.2. *SIM* includes only the conservation and inactive pools. In either *SIM* or *SIMD*, inactive and conservation pool storage capacities are specified on storage *WS* records associated with water right *WR* records. Additionally, *SIMD* allows controlled and uncontrolled flood storage to be specified by *FR* and *WS* record pairs. Multiple-reservoir operating rules are defined on *OR* records. Each reservoir in a *SIMD* simulation may include either, both, or neither of the following two types of flood control operations.

1. *FR* and *FF* records control reservoir release decisions based on streamflows at downstream control points. Releases from *FR* record reservoirs are based on emptying controlled flood control pools as quickly as possible without contributing to flows exceeding maximum limits specified by *FF* records within the forecast period at the control point of the reservoir and at any number of downstream control points. Reservoirs may be operated individually or as one or more multiple-reservoir systems. The *FR/FF* record options simulate reservoirs with gated outlet structures with releases controlled by people operating gates.

2. A *FR* record and pair of *FV* and *FQ* records simulate a fixed storage volume versus outflow rate relationship. The volume released from the reservoir in a given day depends solely on the mean storage volume during that day determined by linear interpolation of the *FV/FQ* record storage-outflow table. Ungated outlet structures, fixed gate openings, or maximum outlet capacities are modeled.

Controlled *FR*/*FF* record pools can be operated as individual reservoirs or multiple-reservoir systems. Uncontrolled *FR*/*FV*/*FQ* record storage pools always function individually without multiple-reservoir system interconnections. A particular reservoir may include either or both types of flood storage. Reservoirs may be operated in *SIMD* for conservation purposes only, solely for flood control, or may include both conservation and flood control features.

Most post-simulation analysis options are applicable to flood control along with *SIMD* simulation results in general. *SIMD* also creates an optional output file with the filename extension AFF with annual series of peak flood 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* or the *HEC-SSP Statistical Software Package* to perform flood frequency analyses.

Post-Simulation Analyses

The organization of the WRAP modeling system is outlined in Table 3.2. Post-simulation analyses of *SIM* and *SIMD* are performed with the WRAP program *TABLES* and other auxiliary software packages including HEC-DSSVue, HEC-SSP Statistical Software Package, WRAP Display Tool, and Microsoft Excel. Post-simulation analyses include time series plots, streamflow and storage frequency analyses, water supply reliability analyses, other summary statistics, various tables and tabulations summarizing and displaying simulation results, spatial displays, and other computational manipulations of simulation results.

Simulation results are recorded in a *SIM* or *SIMD* monthly output file with filename extension OUT or *SIMD* daily output file with filename SUB. The OUT and SUB files contain hydrologic period-of-analysis sequences of monthly or daily quantities for 40 variables computed by *SIM* or *SIMD*. These 40 variables and six others developed within *TABLES* by combining variables are listed in Table 5.1 of the *Reference Manual*, Table 4.10 of the *Users Manual*, and Table 6.3 of the *Daily Manual*. Simulation results variables that are of particular interest in environmental flow studies include the following.

- naturalized streamflows at control points (2NAT, 6NAT)
- regulated streamflows at control points (2REG, 6REG)
- instream flow targets by water right or by control point (2IFT, 6IFT)
- instream flow shortages by water right or by control point (2IFS, 6IFS)

TABLES time series record identifiers are noted above in parenthesis, where types 2 and 6 refer to monthly and daily, respectively. An instream flow shortage is the difference between the target and regulated flow in time periods during which the target exceeds the regulated flow.

Instream flow targets and shortages for each *IF* record water right and for each control point may be included in the simulation results. For multiple *IF* records with different priorities at the same control point, the results recorded for the control point are at the completion of the priority sequence. *WR* records with water right type 8 may be used to compute individual components of an instream flow target. These component targets are recorded in the output file as diversion targets and shortages for the *WR* record rights. *JD* record ICHECK option 12 activates an option for tracking intermediate results in the message MSS file.

Program *TABLES*

The WRAP program *TABLES* is designed for organizing, summarizing, analyzing, and displaying *SIM*, *SIMD*, and *SALT* simulation results. Although dealing primarily with simulation results, simulation input data such as naturalized flows are also included in the *TABLES* data tabulations and analyses. *TABLES* provides a flexible array of routines for creating various types of tables with user-specified optional contents and formats that may be based on monthly or sub-monthly (daily) simulation results. *TABLES* is documented by Chapter 5 of the *Reference Manual*, Chapter 4 of the *Users Manual*, and Chapter 6 and Appendix C of the *Daily Manual*.

Of the array of different types of tables that can be created with *TABLES*, time series tables and frequency tables are perhaps most useful for analyses of instream flows and capabilities for meeting environmental flow requirements. Frequency tables are discussed later in this chapter. As explained in the *Users* and *Daily Manuals*, time series records:

- read *SIM* or *SIMD* monthly or daily simulation results
- alternatively access arrays created with a DATA record
- multiply by a constant, add a constant, compute moving averages or moving totals, or sum monthly or daily data to annual totals or annual means
- create tables of the original simulation results or quantities computed from the simulation results in user-selected alternative formats
- record the data noted above in a binary DSS file to be read by HEC-DSSVue

Using DATA Records to Create New Data Series

TABLES reads monthly simulation results from the *SIM* or *SIMD* output OUT file and reads sub-monthly (daily) simulation results from the *SIMD* sub-monthly output SUB file. For most applications, the routines in *TABLES* work directly with simulation results variables read from the OUT and SUB files. However, other datasets may also be derived within *TABLES* from the datasets read from the OUT and SUB files using DATA records. Although the DATA record has broad general applicability, environmental instream flow studies based on daily *SIMD* simulation results provide the primary motivation for its inclusion in *TABLES*.

The DATA record is introduced in Chapter 5 of the *Reference Manual* and further explained in Chapter 4 of the *Users Manual* and Chapter 6 of the *Daily Manual*. The sole purpose of the DATA record is to transform *SIM* or *SIMD* simulation results to other time series variables of interest to be accessed as input by *TABLES* frequency analysis or time series record routines. All of the simulation results time series variables from the *SIM* OUT or SIMD SUB output files can be read with DATA records and manipulated to create other datasets consisting of daily or monthly quantities or annual totals, minima, or maxima covering a specified number of time periods defining a season of the year. The new dataset is treated by *TABLES* just like the original simulation results.

For example, an annual series containing the minimum 7-day flow volume of naturalized or regulated flows for each year may be created from a daily flow series using a DATA record. A frequency analysis of this derived annual series using the 6FRE record results in a frequency table that includes the 7Q2, which is the 7-day low flow volume associated with a 2 year recurrence interval (50% annual exceedance frequency).

The DATA record performs the following tasks in the sequential order listed below.

<u>Step 1</u>: *SIM* monthly or *SIMD* daily simulation results are read from an OUT or SUB file. Only data that falls within the season (months) specified on the DATA record are read.

<u>Step 2</u>: The following equation with factors *XF* and *AF* from the DATA record, with defaults of *XF*=1.0 and *AF*=0.0, converts the original data series X1 to a new series X2.

$$X2 = (XF)(X1) + AF$$

<u>Step 3</u>: Optionally, either moving averages or moving totals of the quantities at the completion of step 2 in the current and preceding specified number of time steps (months for *SIM* or days for *SIMD*) may be computed.

<u>Task 4</u>: Optionally, the monthly or daily dataset at the completion of step 3 may be converted to an annual series consisting of either the total, minimum, or maximum for each year.

<u>Task 5</u>: The resulting annual data array and/or monthly (*SIM*) or daily (*SIMD*) data array are stored in memory for subsequent use by time series and/or frequency analysis records. Thus, the final product of a DATA record is either one or two datasets (annual and/or monthly or daily) stored in computer memory as arrays.

<u>Task 6</u>: An option allows the arrays to be written to the message file for general information.

Data are read and manipulated for only the months in the specified season, which may range from one to 12 months. The default season is the entire year (months 1-12). In creating an annual series, the year is always defined as months 1 through 12 which are typically though not necessarily January through December. The season specified on the DATA record may fall within a single year or may encompass parts of two years. For example, a 6-month long season defined as months 5 through 10 (May-October) falls totally within the year. A 4-month season defined as months 11 through 2 (November through February) is split between years.

The DATA options listed above as steps 2 and 3 are also options in the time series and frequency records. The computations are identical with either of the record types. The steps 2 and 3 options can be applied to the original simulation results by a DATA record and then to the resulting dataset by time series or frequency records. Moving totals are the summation of amounts for a specified number of time steps (months or days) that include the current and preceding time steps. Moving averages are moving totals summed over the specified number of time steps divided by the number of time steps.

Frequency Analyses

The results of a *SIM*, *SIMD*, or *SALT* simulation are viewed from the perspective of frequency, probability, percentage-of-time, and reliability metrics associated with streamflows, reservoir storage, water supply diversions, hydroelectric energy production, and salinity concentrations. These metrics for estimating and communicating likelihood are covered in various chapters of the *Reference, Users*, *Salinity*, and *Daily Manuals*. Chapter 6 of the *Daily Manual* summarizes those features that are covered elsewhere in the WRAP manuals as well as introducing additional features that are not covered elsewhere. Frequency analysis examples are presented in Chapter 7 of the *Daily Manual*. The frequency analysis capabilities discussed in Chapter 6 of the *Daily Manual* are particularly relevant to investigating environmental flows.

Post-simulation frequency and reliability analyses may serve the two different purposes of (1) evaluating capabilities for the river system to provide the flow regimes needed for the environment and (2) evaluating the impact of environmental flow standards on municipal, industrial, agricultural, and other water uses. Water supply reliability metrics are important for assessing the impacts of environmental flow requirements on other water users. Flow frequency metrics are useful in assessing effectiveness in meeting instream flow requirements.

The 2FRE, 2FRQ, 6FRE, and 6FRQ records are used to perform frequency analyses of *SIM* and *SIMD* simulation results. These *TABLES* records allow frequency analyses to be performed alternatively based on either relative frequency or the normal or log-normal probability distributions. The default relative frequency counting approach is typically adopted for most applications. However, as discussed in *Reference Manual* Chapter 5, the alternative of applying a probability distribution function may offer improvements in the accuracy of frequency estimates under appropriate circumstances.

The 2FRE and 2FRQ record frequency tables for monthly quantities may be based on considering all months or alternatively be developed for a specified month of the year such as May or August. Likewise, the 6FRE and 6FRQ record frequency analyses of daily quantities may consider all days of the year or alternatively be developed for only those days falling within a specified month of the year. Optionally, frequency analysis may be performed for moving averages or moving accumulative totals of the data computed for a user-specified number of months or days. The data may be adjusted by a multiplier factor, which may be a unit conversion factor or serve other purposes. The data may be added or subtracted from a constant.

2FRE (monthly data) and 6FRE (daily data) records compute volumes for specified exceedance frequencies which are tabulated in tables that may be in alternative column or row formats. The 2FRQ and 6FRQ records develop frequency tables for the same variables as the 2FRE and 6FRE records, but exceedance frequencies are computed for user-specified quantities.

Exceedance frequency tables may be created with *TABLES* 2FRE, 6FRE, 2FRQ, and 6FRQ records for the following variables without using a DATA record:

- naturalized flow, regulated flow, unappropriated flow, instream flow shortage, and reservoir storage volume for specified control points
- instream flow shortages and reservoir storage volume for specified water rights
- reservoir storage volume and water surface elevation for specified reservoirs
- other variables such as reservoir draw-downs or deviations of regulated flows from a specified constant computed from these variables

Most applications of 2FRE/6FRE and 2FRQ/6FRQ frequency analysis capabilities deal with the variables listed above without needing a DATA record. The DATA record allows frequency analyses to be performed for other daily, monthly, or annual time series developed from the *SIM* or *SIMD* simulation results. The 2FRE/6FRE and 2FRQ/6FRQ record routines can be applied to any data series created with a DATA record.

TABLES Flood Frequency Analyses

SIMD has an option, activated by parameter AFF on the *JT* record, to write annual series of maximum naturalized flows, regulated flows, and reservoir storages to an output file with the filename extension AFF. The peak daily flow and storage volumes are listed for each year of the *SIMD* simulation at specified control points. These series of annual peak daily volumes are input data for the 7FFA record routine in *TABLES* which performs flood frequency analyses based on the log-Pearson type III probability distribution, which with a zero skew coefficient reduces to the log-normal distribution. The 7FFA record flood frequency analysis is described in Chapter 6 and Appendix C of the *Daily Manual*.

Hydrologic Engineering Center (HEC) Statistical Software Package (SSP)

The Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE) has a suite of widely applied generalized modeling systems that include auxiliary supporting software that is also useful with WRAP. The HEC-SSP Statistical Software Package (Hydrologic Engineering Center 2010, http://www.hec.usace.army.mil/) provides a set of flexible capabilities for performing flood frequency analyses, frequency analyses for other hydrologic variables, and other statistical analyses. HEC-SSP is oriented toward flood frequency analyses but also provides flow duration, general frequency analysis for any random variable, and basic statistical capabilities.

HEC-SSP will reproduce the results obtained with the *TABLES* 7FFA record routine. HEC-SSP also computes confidence limits and expected probability adjustments which are not provided with the 7FFA record and plots the frequency analysis results. The flexible plotting routines generate report-quality frequency graphs.

HEC-DSS Visual Utility Engine (HEC-DSSVue)

The HEC-DSS (Data Storage System) was developed by the USACE Hydrologic Engineering Center for use with HEC generalized hydrologic, hydraulic, and water management simulation models. The HEC-DSS can also be used with other non-HEC modeling systems. The WRAP Fortran programs are linked during compilation to DSS routines from a static library file provided by the Hydrologic Engineering Center that allows creation and use of DSS files. The WRAP executable programs include options for writing the *SIM*, *SIMD*, or *SALT* simulation results as DSS files and reading and writing hydrology data from DSS files. Data is stored in a binary format that is accessible only by HEC-DSSVue and programs such as HEC simulation models and WRAP programs that incorporate DSS routines from the HEC-DSS library in the computer code.

HEC-DSSVue is documented in detail by a users manual (Hydrologic Engineering Center 2009) which is available along with the public domain software from the HEC website. The program is designed for working with time series data read from a DSS file. HEC-DSSVue provides flexible capabilities for plotting times series, tabulating time series, comparing time series, basic arithmetic operations, computing alternative versions of moving averages, annual aggregations, time functions such as finding minimum or maximum, statistical computations, and regression analyses. The derived time series can be plotted as well as tabulated.

The purpose for storing WRAP simulation results as DSS files is to allow application of HEC-DSSVue, primarily to develop time series plots. HEC-DSSVue provides convenient capabilities for plotting *SIM*, *SIMD*, and *SALT* simulation results or hydrology input data. In addition to graphics, HEC-DSSVue also provides an array of data management and computation options. HEC-DSSVue statistical analyses and mathematical operations can be applied to the WRAP time series data. The WRAP programs *SIM*, *SIMD*, and *SALT* have options for recording simulation results as records in a DSS files. *TABLES* also includes options for writing essential any of the *SIM* and *SIMD* simulation results and TABLES manipulations thereof as DSS records.

HEC-DSSVue provides flexible and convenient capabilities for plotting *SIM* and *SIMD* simulation results, which may be very useful in environmental flow studies. Any number of daily or monthly time series generated directly by *SIM* or *SIMD* as simulation results and/or by *TABLES* manipulations thereof can be stored in a DSS file to be read by HEC-DSSVue. For example, hydrologic period-of-analysis sequences of naturalized flows and regulated flows and instream flow targets for alternative instream flow standards can be easily plotted for comparison. The different components of an instream flow regime can be plotted for comparison along with the regulated flows. Several time series plots developed with HEC-DSSVue from *SIMD* simulation results are included in the examples presented in Chapter 4.

CHAPTER 4
WRAP INSTREAM FLOW MODELING EXAMPLES

Chapter 4 consists of a series of six simple examples that illustrate WRAP capabilities covered in Chapter 3 for modeling instream flow requirements. Modeling methods and input record configurations are explained using a basic shared dataset. WRAP programs *SIMD* and *TABLES* are applied in the first five examples. *SIM*, *HYD*, and *TABLES* are used in Example 6. *TABLES* is applied both in developing instream flow targets that are input to the simulation model and for post-simulation analyses. Simulation results are plotted using HEC-DSSVue.

Instream flow requirements can be incorporated in either a daily *SIMD* or monthly *SIMD* or S*IM* simulation. However, as discussed in Chapter 3, instream flow targets specified as a function of regulated flows are modeled much more accurately with a daily rather than monthly time interval. The examples focus on daily *SIMD* simulations. A daily time step is adopted for all of the examples of Chapter 4 except Example 6 which incorporates monthly targets in a monthly *SIM* simulation that are derived from a daily *SIMD* simulation. Instream flow targets can also be modeled directly in a monthly *SIM* simulation, but with a significant loss of accuracy. Pulse flows are particularly difficult to meaningfully model without using a daily simulation. Example 6 introduces an alternative monthly simulation strategy in which instream flow targets are computed in a daily *SIMD* simulation, aggregated to monthly totals within *SIMD*, and then input to *SIM* as monthly volumes on target series *TS* records in a TSF file.

The possible combinations of input records and parameter values on each record that conceivably could be adopted for modeling a diverse range of instream flow requirements and impacts thereof is essentially unlimited. Demonstrating all possible combinations of all modeling options is not feasible in a report of reasonable length. The simple examples of Chapter 4 serve to illustrate basic modeling capabilities in general. A much more complex set of environmental flow regime requirements is modeled in the Brazos case study in Chapters 5, 6, and 7. The Brazos case study builds upon the fundamental concepts and methods of modeling environmental instream flow requirements discussed in Chapter 4.

Appendix B of the *Reference Manual* consists of nine examples of applying the monthly *SIM* and *TABLES*. Five of these nine examples include instream flow requirements, though the instream flow requirements are not the specific focus of the examples. Examples 7.4, 7.5, 8.1, and 8.2 in the *Daily Manual* focus specifically on modeling instream flow requirements.

<u>Description of the Examples and their Shared Dataset</u>

Six examples are presented in this chapter to illustrate WRAP-based methods for modeling and analysis of environmental instream flow requirements. The six examples all include the same basic input dataset with two control points, a single reservoir and water supply diversion, as shown in Figure 4.1, and 1940-1997 hydrology. However, each example adds an additional level of instream flow requirements to the preceding example. Example 5 incorporates multiple levels of environmental instream flow requirements that range from low flows to high flow pulses. Examples 1, 2, 3, 4, and 5 are based on a daily time step. Example 6 is based on a monthly *SIM* simulation with inputted monthly instream flow targets derived from the daily *SIMD* simulation of Example 5. The six examples are described as follows.

- ***Example 1, Baseline***: No instream flow *IF* records are included in Example 1. A frequency analysis of naturalized flows is performed with *TABLES* to develop instream flow requirements to be applied in subsequent examples. Regulated flow frequency and reservoir firm yield are computed for comparison with the subsequent examples.

- ***Example 2, 7Q2 Flow Limits***: Minimum regulated flow limits at the two control points are set at the naturalized flow minimum 7-day volume that has an annual recurrence interval of 2 years. Basic methods for modeling instream flow requirements are covered. An option for recording instream flow information in the message file is demonstrated.

- ***Example 3, Median Flow Limits***: Releases from reservoir storage are employed in meeting the 7Q2-based instream flow requirements. A second pair of minimum instream flow limits based on the median (50% frequency) naturalized flows is activated during wet periods when reservoir storage levels are relatively high. Alternative configurations are presented for modeling the same instream flow requirements.

- ***Example 4, Cumulative Seasonal Flow Volume***: An instream flow requirement with multiple features is added for a flow volume to occur over several consecutive months. Multiple *WR*, *TO*, *FS*, *CV*, *DO*, *DW*, and *DI*/*IS*/*IP*/*IM* records are used to construct an *IF* record instream flow target. The use of a hydrologic index series HIS file is introduced.

- ***Example 5, Pulse Flow Events***: Examples 1, 2, 3, and 4 can be modeled directly with either monthly or daily time steps, though more accurately with a daily time step. Pulse flow *PF* and pulse option *PO* records are used exclusively with daily *SIMD* simulations. Modeling of pulse flow requirements with *PF* and *PO* records and printing pulse flow target building information to the message file are illustrated with Example 5.

- ***Example 6, Monthly Simulation***: Example 5 incorporates several instream flow requirements in a single daily *SIMD* input dataset. In Example 6, the daily instream flow targets computed with *SIMD* are aggregated to monthly volumes within *SIMD* for inclusion in the simulation results. Example 6 uses the aggregated monthly instream flow targets resulting from the daily *SIMD* simulation as input to a monthly *SIM* simulation.

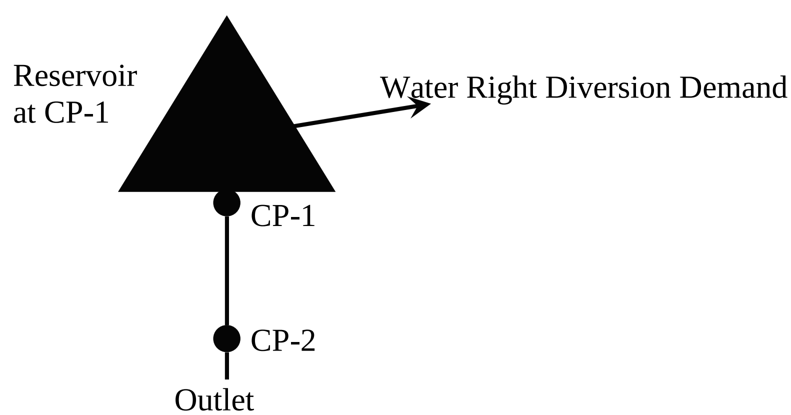

Figure 4.1 System Configuration for the Six Examples

All six examples use the same basic simulation input dataset, with only the instream flow requirements and time interval differing between the examples. Examples 1, 2, 3, 4, and 5 are based on a daily computational time step, and Example 6 is monthly. The system being modeled is represented by two control points, a reservoir at the upstream control point, and a storage and diversion water right at the upstream control point, as shown in Figure 4.1. The hydrologic period-of-analysis extends from January 1940 through December 1997.

The hydrology for the example dataset is derived from the Brazos River Basin WAM dataset. Naturalized flows for control points CP-1 and CP-2 are the naturalized flows in the Brazos WAM dataset at the Hempstead and Richmond gages on the Brazos River. The net evaporation-precipitation EVA file data for CP-1 are derived from a location near Hempstead in the Brazos WAM. Daily unregulated stream flow patterns for Hempstead and Richmond for the 1940-1997 period-of-analysis are derived from the Brazos case study documented by Wurbs et al. (2012). These daily stream flow patterns serve as the basis for disaggregated monthly naturalized flows read by *SIMD* from the FLO file.

The example dataset does not represent actual water rights, reservoirs, or environmental instream flow requirements. The only data from the Brazos WAM dataset used in the examples are the naturalized flows and evaporation-precipitation rates. With adoption of these hydrologic data plus actual Palmer hydrologic drought index data, the examples reflect realistic hydrology.

The *SIMD* DCF input file is used to provide routing parameter *RT* records for the stream reach between CP-1 and CP-2, monthly to daily disaggregation *DC* and *DH* records, and the daily flow pattern *DF* records. The DCF input file is not required if the simulation is run in monthly time step mode with *SIM* or *SIMD*. The DCF file can also be excluded from daily simulations with *SIMD* if no routing or daily disaggregation patterns are required. *SIMD* will utilize default settings when the DCF file is not provided.

The examples also employ a hydrologic index series HIS input file. The hydrologic index *HI* records in the example HIS file provide integer values of 1, 2, or 3 for each month that categorize hydrologic conditions as dry (1), average (2), or wet (3). The three hydrologic index categories are based on drainage area weighted computations using monthly Palmer hydrologic drought index (PHDI) data. The *HI* record data for the example dataset are derived from the Brazos case study locations at Hempstead and Richmond. Development of the *HI* records is explained in Chapter 6 of this report. The HIS file contains only hydrologic index *HI* records with monthly values. Each *HI* record is assigned to a control point but otherwise has no computational connection to that location. The HIS file *HI* record index is used with optional target setting *TO*, *CV*, *FS*, and *PF* records.

Example 1 uses the DAT file shown in Table 4.1 which does not contain instream flow requirements. *IF* and supporting records are added in Examples 2 through 5. The Example 1 DAT file in Table 4.1 sets a 58 year period-of-analysis beginning in 1940. *SIMD JT* and *JU* records are provided to set daily simulation parameters, including stream flow forecasting. Only one water right *WR* record for water supply diversions and reservoir storage is adopted in the examples. Water right WR-1 establishes a single large reservoir, BIGRES, at control point CP-1 and sets an annual water right demand target of 1,095,000 acre-feet/year. With a uniform daily distribution using the NDAYS use coefficient option, the daily demand target is 3,000 ac-ft/ day.

The water right priority number for WR-1 is arbitrarily set at 4444. The instream flow requirements added in Examples 2 through 6 adopt a more senior priority number.

Table 4.1
DAT File for Example 1

```
T1  Environmental Flow Example Dataset
T2  Example 1
**       1         2         3         4         5         6         7
**3456789012345678901234567890123456789012345678901234567890123456789012
**     !       !       !       !       !       !       !       !       !
JD    58    1940       0      -1      -1       0       1
JO     2                                               1
JT     0  -1  -1                               2
JU                                 2
**
**FY        2500000  100000   10000    1000            WR-1
**
CP  CP-1    CP-2                        1
CP  CP-2     OUT                        1           NONE
**
WR  CP-1 1095000   NDAYS    4444   1                           WR-1
WSBIGRES 2000000
**
FF  CP-2        43438650   NDAYS       0
FR  CP-1    8888    9999   0   2  119010 6500000 6000000 2000000
WSBIGRES
FVBIGRES               0         2000000         1000000         7000000
FQ                     0          200000          100000          700000
**
SVBIGRES       0  500000 1000000 2000000 7000000
SA             0   18000   36000   50000  200000
**
ED
```

Reservoir operations for flood control are incorporated into the DAT file of Table 4.1. The conservation capacity of reservoir BIGRES is set at 2.0 million acre-feet by WR-1. Flood reservoir storage *FR* records increase the reservoir capacity by 4.5 million acre-feet. The controlled reservoir storage pool is between cumulative storage capacities of 2.0 and 6.0 million acre-feet. Uncontrolled flood control (surcharge) storage occurs at cumulative capacities between 6.0 and 6.5 million acre-feet. The flood control storage and release priority numbers are 8888 and 9999, respectively, making flood control the most junior water right in the dataset.

Flood releases occur only when the reservoir storage content is above the bottom of flood control pool. Flood releases are the lesser of the two quantities computed by *SIMD* based on *FF* and *FV/FQ* records, respectively. Flood flow limit *FF* records simulate gate operations based on maximum allowable downstream flow levels. The *FF* record in Table 4.1 sets a flood flow limit of 119,010 ac-ft/day (60,000 cfs) at the downstream control point CP-2. A storage volume versus outflow relationship for the controlled and uncontrolled flood control pools defined on the *FR* record is provided on *FV* and *FQ* records. The dam outlet structure rating curve defined by the *FV* and *FQ* records in the example reflects outflow capacities that are very large such that the *FF* record flow limit rather than the *FV/FQ* records always control outflows.

The instream flow requirements in the examples are assigned priorities that are senior to water right WR-1 in order to explore the impacts of the instream flow requirements on the diversion and storage right. Firm yield is used to compare the relative effects on water supply capabilities of increasingly more stringent instream flow requirements. A firm yield *FY* record is provided, though shown deactivated in Table 4.1, to compute the firm yield of WR-1.

The FLO, EVA, and HIS files each cover the 58-year 1940-1997 hydrologic period-of-analysis. The first 10 years of the data are shown in Table 4.2. The HIS file contains integer indices 1, 2, and 3 that specify monthly hydrologic conditions at the respective control points, which are either dry, average, or wet as denoted by the values of 1, 2, and 3, respectively.

Table 4.2
Example FLO, EVA, HIS Files

Naturalized Flow FLO File, acre-feet

**			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
IN	CP-1	1940	27123	132434	23220	202714	370680	650447	1129935	309655	99665	30289	1317627	2574030
IN	CP-1	1941	979344	1216105	1340200	954890	2596453	1862510	1042565	380381	289445	777762	462061	156454
IN	CP-1	1942	103796	82415	78247	2036031	1913727	1186618	178183	113656	873460	745350	361298	238680
IN	CP-1	1943	284155	106189	198874	311912	234715	240949	63066	44856	54392	82258	28796	51855
IN	CP-1	1944	525197	853578	1047781	288339	2765411	1041157	150358	73350	266274	114079	280883	659275
IN	CP-1	1945	1211158	840497	1363974	2484447	788312	584149	541713	166546	284175	550744	113720	429877
IN	CP-1	1946	611402	772182	1080604	466028	1485238	747797	148897	65067	343380	265947	886636	578411
IN	CP-1	1947	906047	251260	751693	415187	1032542	321336	86062	234475	100385	36166	85186	167819
IN	CP-1	1948	86265	224302	245220	143970	293581	183371	336602	34206	30848	27851	24238	22216
IN	CP-1	1949	76972	183268	493695	663072	1076750	559665	148676	40139	122971	253945	169816	179369
IN	CP-2	1940	48144	130776	38191	206386	303905	639837	1260786	294797	93828	49035	1233736	3167111
IN	CP-2	1941	1195933	1288585	1566461	1206907	2824151	2109805	1085878	319796	411954	847959	602873	181237
IN	CP-2	1942	123104	95083	91675	1968772	2047750	1271813	300208	101652	872125	750802	371361	222571
IN	CP-2	1943	340528	114370	198926	334311	197012	247118	102967	60493	41593	86011	47170	82788
IN	CP-2	1944	615308	885077	1186751	362919	2728257	1111625	133134	70256	254939	127094	233966	738543
IN	CP-2	1945	1238867	874238	1340994	2389871	817802	545601	538420	356282	336126	557071	121689	494655
IN	CP-2	1946	615651	800663	1208734	510075	1507750	823683	209349	50693	346744	290622	975059	586286
IN	CP-2	1947	924178	275793	762326	403751	1016578	323989	69713	272602	135298	46805	106373	233156
IN	CP-2	1948	96638	217275	365337	137525	274883	163687	329773	30325	30985	36989	34768	30301
IN	CP-2	1949	69036	168547	497658	658462	1111758	511891	163753	33145	110719	211380	212990	228343

Net Evaporation-Precipitation EVA File, feet

**			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EV	CP-1	1940	0.0350	-0.1360	0.1780	0.0110	0.0980	-0.1330	0.1900	0.4320	0.3620	0.0600	-0.7160	-0.3260
EV	CP-1	1941	0.0010	-0.1190	-0.2350	-0.3050	-0.1220	-0.2380	0.0080	0.3340	-0.2360	-0.3610	0.0860	0.0530
EV	CP-1	1942	0.1240	-0.0170	0.0750	-0.3150	0.1870	0.0720	-0.2340	0.1000	0.0690	0.2030	0.0690	-0.0250
EV	CP-1	1943	-0.0910	0.0800	-0.0820	0.2050	-0.0100	0.2640	-0.0690	0.4530	0.0990	0.2780	-0.2020	-0.1900
EV	CP-1	1944	-0.4670	-0.0470	-0.2940	0.1710	-0.4740	0.3210	0.4730	0.0900	0.1920	0.3680	-0.2730	-0.2550
EV	CP-1	1945	-0.0830	-0.0950	-0.1120	-0.1450	0.1930	0.0920	0.2200	-0.3090	0.3140	-0.0520	0.2060	-0.1820
EV	CP-1	1946	-0.2860	-0.1840	-0.1340	0.0460	-0.3540	-0.1160	0.2540	0.2410	-0.0550	0.0050	-0.4480	0.0320
EV	CP-1	1947	-0.2390	0.1290	-0.0710	0.0960	-0.1660	0.2590	0.3910	0.0490	0.4070	0.2720	-0.0170	-0.2040
EV	CP-1	1948	-0.0590	-0.1610	0.0410	0.0650	0.0570	0.3260	0.3630	0.4020	0.2990	0.3480	-0.0040	0.1240
EV	CP-1	1949	-0.2330	-0.3070	-0.0920	-0.2420	0.2360	0.1780	0.0600	0.3110	0.2100	-0.6180	0.3260	-0.2880

Table 4.2 Continued
Example FLO, EVA, HIS Files

Hydrologic Index Series HIS File, unitless

**			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HI	CP-1	1940	1	1	1	1	1	2	2	2	2	2	3	3
HI	CP-1	1941	3	3	3	3	3	3	3	3	3	3	3	3
HI	CP-1	1942	3	3	3	3	3	3	3	3	3	3	3	3
HI	CP-1	1943	3	2	2	2	2	2	2	1	1	1	1	1
HI	CP-1	1944	2	2	2	2	2	2	2	2	2	2	2	2
HI	CP-1	1945	2	2	3	3	2	2	3	3	3	3	2	2
HI	CP-1	1946	2	2	2	2	2	2	2	2	2	2	2	2
HI	CP-1	1947	2	2	2	2	2	2	2	2	2	1	2	2
HI	CP-1	1948	2	2	2	2	2	2	2	2	1	1	1	1
HI	CP-1	1949	2	2	2	2	2	2	2	2	2	2	2	2
HI	CP-2	1940	1	1	1	1	1	2	2	2	2	2	3	3
HI	CP-2	1941	3	3	3	3	3	3	3	3	3	3	3	3
HI	CP-2	1942	3	3	3	3	3	3	3	3	3	3	3	3
HI	CP-2	1943	3	2	2	2	2	2	2	1	1	1	1	1
HI	CP-2	1944	2	2	2	2	2	2	2	2	2	2	2	2
HI	CP-2	1945	2	2	3	3	2	2	3	3	3	3	2	2
HI	CP-2	1946	2	2	2	2	2	2	2	2	2	2	2	2
HI	CP-2	1947	2	2	2	2	2	2	2	2	2	1	2	2
HI	CP-2	1948	2	2	2	2	2	2	2	2	1	1	1	1
HI	CP-2	1949	2	2	2	2	2	2	2	2	2	2	2	2

Table 4.3 shows the input data that is specific to *SIMD* related to routing parameters, disaggregation methods, and daily flow patterns. Lag and attenuation routing parameters are provided for the single stream reach in the example from CP-1 to CP-2. Both normal flow and flood flow routing parameters are given on the *RT* record corresponding to values for the lag and attenuation method of routing as described in the *Daily Manual*. In the example dataset, the routing for normal flow conditions extends by 1.25 days beyond the current time step. Normal flow routing parameters are used to rout changes to flow by *WR* records. The flood routing parameters in the example dataset extend routing only 1.0 days beyond the current time step. Flood routing parameters are used to rout changes to flow by *FR* records.

Disaggregation of monthly naturalized flow volumes to daily amounts is governed by the *DC* records. The method chosen for the example datasets, as well as the Brazos case study presented in Chapters 5, 6, and 7, is to use daily flow patterns provided on *DF* records. *DF* records for CP-1 and CP-2 are used to disaggregate monthly stream flows throughout the entire period-of-analysis. Only the first two months of *DF* record flow patterns are shown in Table 4.3.

The *DH* records in Table 4.3 select the option of no disaggregation for the *HI* record monthly hydrologic index data. With 8 entered for parameter DHMETHOD on the *DH* record, each monthly value on the *HI* record is used without disaggregation in each day of the month. For example, the *HI* record hydrologic index value at CP-1 for January 1940 is equal to 1. The *DH* record specifies that the hydrologic index is 1 in each daily time step of January.

Table 4.3
Example DCF File

```
RT  CP-1   1   1.250   1.500   1   1.000   1.000
**
DC  CP-2      -4           1940       1    1997      12
**
DHCP-1        8
DHCP-2        8
**
DF CP-1      1940         1         4
   1670.00   1321.00   1010.00    765.00    600.00    479.00    399.00    373.00
    375.00    381.00    382.00    377.00    369.00    360.00    353.00    338.00
    321.00    306.00    293.00    278.00    258.00    242.00    239.00    246.00
    259.00    267.00    272.00    278.00    283.00    289.00    292.00
DF CP-1      1940         2         4
    295.00    297.00    291.00    351.00    890.00   2518.00   3709.00   3664.00
   3479.00   2977.00   2540.00   2506.00   2447.00   2224.00   1870.00   1571.00
   1877.00   2825.00   3275.00   3332.00   3449.00   3401.00   3179.00   2981.00
   2792.00   2485.00   2148.00   1837.00   1559.00


DF CP-2      1940         1         4
   2646.00   2402.00   1972.00   1579.00   1252.00   1111.00    921.00    752.00
    671.00    635.00    613.00    608.00    593.00    588.00    578.00    570.00
    554.00    538.00    509.00    479.00    459.00    452.00    437.00    419.00
    407.00    417.00    423.00    414.00    420.00    419.00    435.00
DF CP-2      1940         2         4
    433.00    436.00    447.00    432.00    278.00    293.00   1004.00   2383.00
   2932.00   2912.00   2720.00   2449.00   2465.00   2557.00   2698.00   2509.00
   2378.00   2797.00   2857.00   3543.00   3574.00   3317.00   3288.00   3036.00
   3186.00   3145.00   2953.00   2642.00   2269.00
```

The six examples illustrate methods for simulation of instream flow requirements, pre-simulation analysis of flow data, and analysis of simulation results. Each example has the same configuration shown in Figure 4.1 and the same input files as shown in Tables 4.1, 4.2, and 4.3. Additional *IF* records and supporting records for modeling instream flow requirements are added to the DAT file shown in Table 4.1 in the various examples. Examples 2, 3, 4, and 5 each adds an additional level of instream flow requirement to the preceding example. Example 5 adopts multiple levels of environmental instream flow requirements that include high flow pulses. Example 6 presents a monthly *SIM* simulation with instream flow targets determined by the daily *SIMD* simulation of Example 5.

Example 1 – Naturalized Flow Frequency Analysis and Baseline Simulation

Example 1 provides a baseline scenario without instream flow requirements. Subsequent examples add instream flow requirements to the baseline DAT file. Regulated flow frequency metrics and reservoir storage plots are compared between the baseline and the subsequent examples. *IF* record requirements added in the other examples are based on a frequency analysis of naturalized flows in Example 1. Naturalized flows are used in Example 1 to establish instream flow requirements, though gaged flows have typically been used in actual real-world applications to establish instream flow requirements. Example 1 covers the following topics.

- Performing frequency analyses of daily naturalized flows at the two control points to determine the annual 7-day low flows that have a recurrence interval of 2 years, which are used in establishing instream flow requirements.
- Establishing a baseline of reservoir storage, regulated flow, and firm yield for comparison to subsequent examples that include *IF* record instream flow targets.

Observed gaged flows have commonly been used in the past in the analyses performed in setting instream flow standards. Alternatively, naturalized flows or simulated regulated flows for a specified scenario may be adopted for the methods used to develop instream flow targets. Naturalized flows are used for setting instream flow requirements in the Chapter 4 examples. Table 4.4 is a daily naturalized flow frequency table produced with *TABLES* using the 6FRE record with columnar format option. The columnar option includes additional exceedance frequencies that are not reported in the row format. Analyzing extreme low and high flow events often requires examination of the tails of the frequency distribution.

Table 4.4
Daily Naturalized Flow Frequency, acre-feet per day

FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS
Daily Data Ranging From January 1940 through December 1997

CP	CP-1	CP-2
Mean	14622.14	15754.02
Std Dev	28080.14	28834.86
Minimum	15.87	13.88
99.5%	245.94	204.29
99%	307.13	285.62
98%	430.40	408.59
95%	652.55	721.98
90%	1013.54	1077.02
85%	1368.57	1477.68
80%	1695.85	1886.28
75%	2058.80	2292.88
70%	2455.52	2764.94
60%	3433.38	3869.74
50%	4939.83	5672.72
40%	7384.43	8477.34
30%	11743.10	13116.67
25%	14817.50	16393.36
20%	19086.87	21088.22
15%	26269.55	28330.38
10%	38207.56	40796.97
5%	61186.05	64023.88
2%	97883.05	105114.55
1%	130696.87	142020.56
0.5%	175782.77	181400.95
Maximum	796904.62	698034.62

Frequency analysis methods incorporated in *TABLES* are covered in Chapter 6 of the *Daily Manual* as well as in the *Reference* and *Users Manuals*. Table 4.4 is based on the relative frequency method. Other options include applying either the log-normal or normal probability distributions. The log-Pearson type III distribution can be applied to annual flood series.

The *TABLES* input DATA record is introduced in Chapter 5 of the *Reference Manual*, further explained in Chapter 4 of the *Users Manual* and Chapter 6 of the *Daily Manual*, and is also discussed in Chapter 3 of this report. The sole purpose of the DATA record is to transform *SIM* or *SIMD* simulation results to other time series variables of interest to be accessed by *TABLES* frequency analysis or time series record routines.

The DATA record is applied in this example to develop a series of the minimum naturalized flow volume occurring during any 7-day period during each year of the simulation. The annual series created by the DATA record is used in a 6FRE record frequency analysis from which the 7Q2 is determined. The 7-day low flow volume associated with a 2 year recurrence interval (50% annual exceedance frequency), called the 7Q2, is commonly used to set minimum instream flow targets for water quality protection.

Table 4.5 presents the 7-day minimum annual volume frequency table and associated *TABLES* input records. Seven-day naturalized flow volumes of 6,507.7 and 6,579.1 acre-feet, respectively, at CP1 and CP-2 have annual exceedance frequencies of 50% which is equivalent to a recurrence interval of 2 years. These 7Q2 volumes can be expressed in terms of mean daily flow volumes of 929.7 and 939.9 acre-feet per day over the seven days.

Table 4.5
Annual Minimum 7-Day Naturalized Flow Frequency

```
VARIABLE 6NAT IN DATA RECORD DATASET
Daily Data Ranging From January 1940 through December 1997

CP              CP-1        CP-2
Mean          7166.53     7420.59
Std Dev       4581.83     5486.54
Minimum        418.50      303.42
  99%          643.94      564.59
  98%          883.67      804.81
  95%         1312.01     1330.08
  90%         2293.62     1777.52
  80%         3506.33     3031.88
  70%         4524.67     4014.08
  60%         5351.28     5753.15
  50%         6507.69     6579.10
  40%         7612.47     7101.97
  30%         9352.80     9338.53
  20%        10858.69    11396.17
  10%        12987.73    14968.40
Maximum      22302.11    29803.59

TABLES Input Records
DATA6NAT   0   0   1   2   7   2
6FRE  11           3
```

A *SIMD* simulation is performed with the DAT file presented in Table 4.1 and the associated hydrology input files of Table 4.2. The daily regulated flow frequency metrics for this simulation, which has no instream flow requirements, is shown in Table 4.6. The naturalized flow frequencies from Table 4.4 are included in Table 4.6 for comparison.

Table 4.6
Example 1 Daily Regulated Flow Frequency Comparison with
Daily Naturalized Flow Frequency, acre-feet per day

FLOW-FREQUENCY FOR NATURALIZED AND REGULATED STREAMFLOWS
Daily Data Ranging From January 1940 through December 1997

	NATURALIZED FLOW		REGULATED FLOW	
CP	CP-1	CP-2	CP-1	CP-2
Mean	14622.14	15754.02	11566.59	12698.63
Std Dev	28080.14	28834.86	23811.30	24987.58
Minimum	15.87	13.88	0.00	0.00
99.5%	245.94	204.29	0.00	0.00
99%	307.13	285.62	0.00	0.00
98%	430.40	408.59	0.00	0.00
95%	652.55	721.98	0.00	0.00
90%	1013.54	1077.02	0.00	0.00
85%	1368.57	1477.68	0.00	84.88
80%	1695.85	1886.28	0.00	204.97
75%	2058.80	2292.88	0.00	311.74
70%	2455.52	2764.94	0.00	419.84
60%	3433.38	3869.74	107.09	761.64
50%	4939.83	5672.72	1101.20	1632.81
40%	7384.43	8477.34	3179.45	4189.16
30%	11743.10	13116.67	7451.30	8906.78
25%	14817.50	16393.36	10702.04	12312.76
20%	19086.87	21088.22	15277.33	17172.81
15%	26269.55	28330.38	22751.18	24885.23
10%	38207.56	40796.97	35884.62	38328.17
5%	61186.05	64023.88	64370.93	68568.21
2%	97883.05	105114.55	109922.12	119009.98
1%	130696.87	142020.56	117524.39	119009.99
0.5%	175782.77	181400.95	119010.00	119009.99
Maximum	796904.62	698034.62	119010.00	119010.02

Low flows are reduced by water supply operations, and high flows are reduced mainly by flood control operations. Streamflow depletions for water right WR-1 at control point CP-1 include fully or partially supplying the diversion target of 3,000 acre-feet/day plus reservoir refilling and evaporation. The regulated flow is zero between 30% and 40% of the time at CP-1 and between 10% and 15% of the time at CP-2. The effect of reservoir flood control storage is seen in the high flow range of the frequency distribution in Table 4.6. Regulated flows at CP-1 and CP-2 do not exceed the flow limit of 119,010 acre-feet/day. The reservoir flood control pool operations control regulated flows at CP-1 and downstream at CP-2. Reservoir storage never exceeds the controlled flood pool capacity during the period-of-analysis.

Reservoir storage contents at CP-1 are shown in Figure 4.2. The reservoir conservation storage capacity is equal to 2.0 million acre-feet. The diversion target is 3,000 acre-feet/day, or an annual volume of 1.095 million acre-feet/year. The lone water right WR-1 has access to the entire regulated flow. The median regulated flow at CP-1 is nearly 5,000 acre-feet/day. This results in simulated reservoir storage never falling below 1.0 million acre-feet during the most severe drought in the hydrologic period-of-analysis. Peaks in reservoir storage above 2.0 million acre-feet are associated with flood control operations. Flood control storage never peaks above the maximum controlled storage capacity of 6.5 million acre-feet.

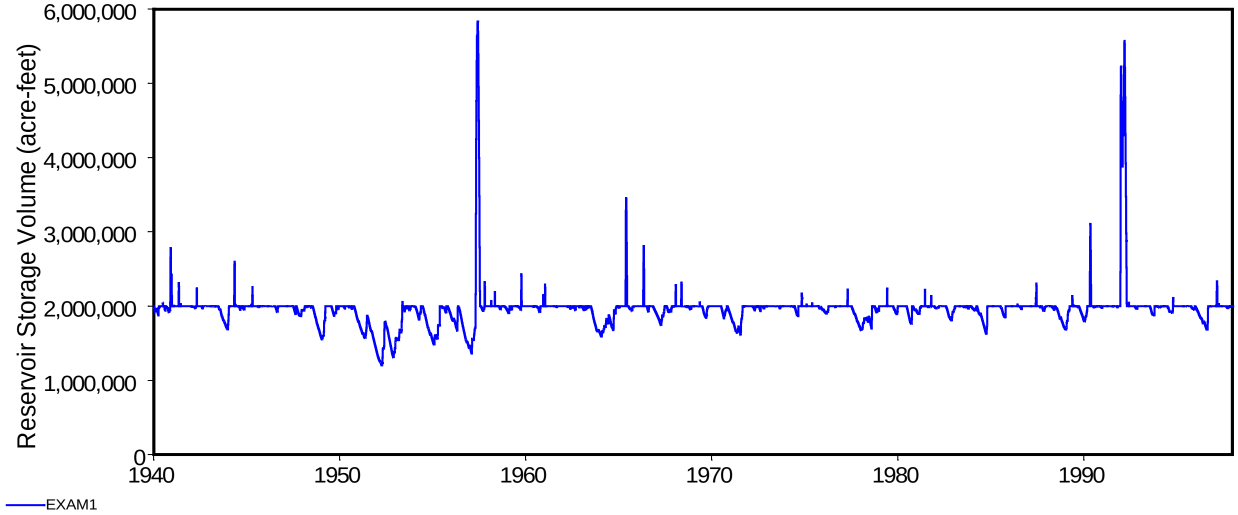

Figure 4.2 Example 1 Reservoir Storage

The water right diversion demand reflected in the regulated flow results in Table 4.6 and the storage plot in Figure 4.2 is equal to 1.095 million acre-feet per year. The same annual demand will be used in each example dataset to generate regulated flow frequencies and instream flow shortages. Firm yield simulations are also performed for these examples in order to further compare the effects of the instream flow requirements on water supply capabilities.

If the *FY* record is activated for Example 1, the firm yield of water right WR-1 is computed by *SIMD* to be 1.731 million acre-feet/year. This is the maximum water right demand, under the conditions reflected in Example 1, which can be supplied with no shortages. Figure 4.3 shows reservoir storages produced by the Example 1 simulation if the diversion demand of WR-1 is changed from 1.095 to 1.731 million acre-feet per year.

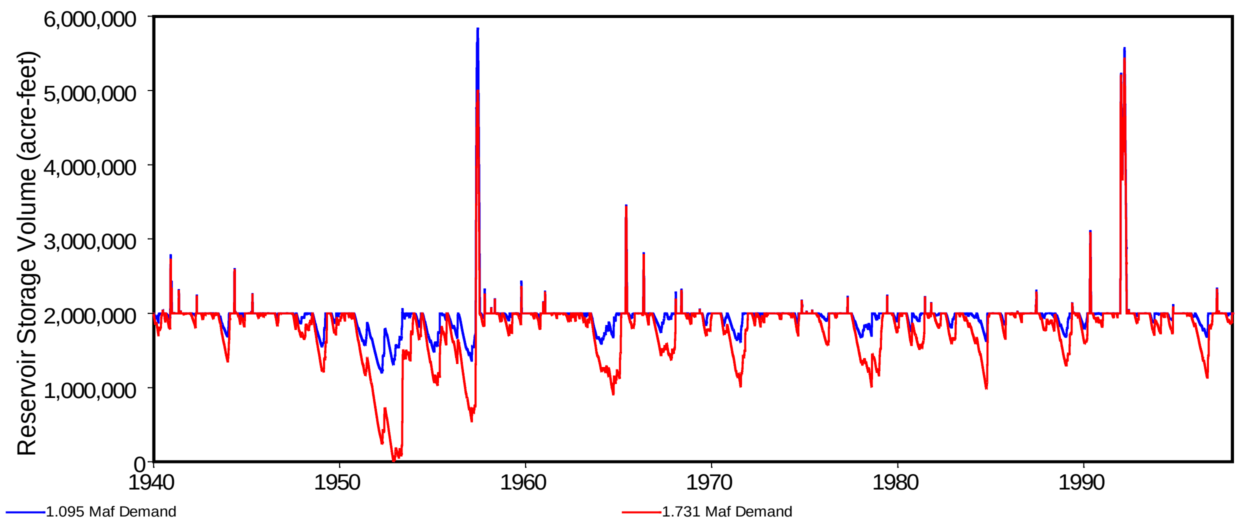

Figure 4.3 Example 1 Reservoir Storage Comparison with the Firm Yield Simulation

Example 2 − Minimum Regulated Flow Limits Based on 7Q2 Naturalized Flows

Example 2 introduces the first instream flow *IF* records to the example dataset. *IF* records are placed at control points CP-1 and CP-2 with instream flow targets equal to the 2-year recurrence interval 7-day low flows, called 7Q2, computed for daily naturalized flows in Example 1. Example 2 illustrates alternative configurations of the same minimum instream flow limit. The instream flow requirements of Example 2 are simple and can be expressed with a single *IF* record water right at each control point. *DW*, *CV*, and *DO* records are employed to activate options in the *IF* record target setting process. Example 2 covers the following topics.

- Basic *IF* record instream flow target construction
- Using *TABLES* for frequency analyses
- Alternative target setting configurations
    1. Annual target and calendar days demand distribution option NDAYS
    2. Directly setting a daily target using the *DW* record option XDAY
    3. Cumulative volume *CV* record
- Optional *CV* record target building information in message MSS file

The naturalized flow 7Q2 computed in Example 1 for CP-1 and CP-2 are volumes of 6,507.7 and 6,579.1 acre-feet over a 7-day period. The mean daily flow over the 7 days is 929.7 and 939.9 ac-ft per day. Converting the daily target into an annual target based on 365 days in a year, the 7Q2 at CP-1 and CP-2 can be expressed as 339,330 and 343,053 acre-feet per year.

The simplest expression of an instream flow requirement is to use a single *IF* record with an annual target and no supplementary records. For the minimum flow requirement in Example 2, the annual target volumes of 339,330 and 343,053 acre-feet/year are combined with the NDAYS use coefficient option. The NDAYS option automatically distributes the annual target to each of the twelve months in proportion to number of calendar days in each month. *SIMD* distributes the monthly volume based on the number of days in each month. This results in 907.5, 929.7, or 939.9 acre-feet per day in each day of the year with the exception of February in leap years. The extra day in February of leap years results in daily targets of 897.6 in February, with daily targets in non-February months being unaffected.

The second alternative *IF* record configuration for Example 2 is to use the *SIMD* option for entering the daily target directly in *IF* record field 3 and using the XDAY option for setting daily targets located in field 3 of the *DW* input record. The *SIMD* XDAY option is analogous to directly setting a monthly target with *WR* or *IF* record field 3 by specifying the XMONTH use coefficient in *WR/IF* record field 4. The daily *IF* record targets at CP-1 and CP-2 can be set to exactly 929.7 and 939.9 acre-feet per day with the XDAY option. The issue of daily targets in February of leap years is avoided.

There are differences in setting a daily or annual target versus maintaining a flow volume of no less than 6,507.7 and 6,579.1 acre-feet at CP-1 and CP-2 for a 7-day rolling window. Regulated stream flow may vary greatly from day to day. If regulated flow is high one day and low during the remaining six days, the 7-day rolling window of regulated flow may still be in excess of the minimum required volume. A daily target *IF* record target set at 929.7 ac-ft/day protects a minimum daily flow volume. The alternative strategy is to not protect the minimum daily volume but rather protect the 7-day minimum volume, where the seven consecutive days included in the 7-day period change each day as the next day is added and the last day drops off.

The third alternative *IF* record configuration for Example 2 involves pairing a *CV* record with the *IF* record. The *CV* record fields are explained in Chapter 3 of the *Users Manual*. The *CV* record sets a daily target according to the cumulative volume of a variable being tracked over a given number of days. For Example 2, the *CV* record is set to track cumulative regulated flow in the previous six consecutive days. This cumulative volume is subtracted from the 7-day total of 6,507.7 and 6,579.1 acre-feet at CP-1 and CP-2. If the difference is positive, the *CV* record passes the difference to the *IF* record to set a daily instream flow requirement.

The three alternative *IF* record configurations for Example 2 are presented in Table 4.7. The three alternative configurations are not added to the example DAT file at the same time. Only one configuration is added and simulation results are produced. The annual and direct daily target configurations will create the same results, except for daily targets in the month of February during leap years. The direct daily and cumulative volume target configurations could be run together to protect both the daily minimum flow and the 7-day cumulative flow.

Table 4.7
Example 2 Alternative Instream Flow Record Configurations

Annual Target

```
IF  CP-1  339330   NDAYS    1111                        MINFLOW1
IF  CP-2  343053   NDAYS    1111                        MINFLOW2
```

Direct Daily Target

```
IF  CP-1  929.67            1111                        MINFLOW1
DW          1
IF  CP-2  939.87            1111                        MINFLOW2
DW          1
```

Cumulative Volume Target

```
IF  CP-1                    1111                        MINFLOW1
CV     1             -1.0 6507.69                          6           3   1
DO                 19
IF  CP-2                    1111                        MINFLOW2
CV     1             -1.0 6579.10                          6           3
DO                 19
```

The direct daily target configuration uses the *DW* record to activate the XDAY option. This sets the daily target equal to the value in *IF* record field 3. Any use coefficient present in *IF* record field 4 is ignored. The other *SIMD* specific record shown in Table 4.7 is the *DO* record. Chapter 2 of the *Daily Manual* describes the 22 target building steps in *SIMD*. The first 12 steps are the same in *SIM* or *SIMD*. The flow switch *FS* and cumulative volume *CV* records are processed in step 8 for once-per-month target building in *SIMD*. However, if the flow switch or cumulative volume is to be evaluated on a daily basis, a *DO* record is required with field 5 set to 19. This moves consideration of the *FS* or *CV* record operations from step 8 to step 19.

The frequency analysis 2FRE and 6FRE records in *TABLES* do not have an option for directly computing the frequency of instream flow targets. However, the DATA record can be used to construct a daily series of instream flow targets that can be used by the 6FRE frequency analysis. Table 4.8 provides the instream flow frequency at CP-1 and CP-2 for the three alternative *IF* record configurations. The *TABLES* input records are at the bottom of Table 4.8.

Table 4.8
Daily Instream Flow Target Frequency, acre-feet per day

	Annual Target		**Direct Daily**		**Cumulative Volume**	
CP	CP-1	CP-2	CP-1	CP-2	CP-1	CP-2
Mean	929.06	939.23	929.72	939.90	605.68	385.25
Std Dev	4.55	4.59	0.02	0.00	1113.62	954.80
Minimum	897.60	907.50	929.70	939.90	0.00	0.00
99.5%	897.60	907.50	929.70	939.90	0.00	0.00
99%	897.60	907.50	929.70	939.90	0.00	0.00
98%	897.60	907.50	929.70	939.90	0.00	0.00
95%	929.70	939.90	929.70	939.90	0.00	0.00
90%	929.70	939.90	929.70	939.90	0.00	0.00
85%	929.70	939.90	929.70	939.90	0.00	0.00
80%	929.70	939.90	929.70	939.90	0.00	0.00
75%	929.70	939.90	929.70	939.90	0.00	0.00
70%	929.70	939.90	929.70	939.90	0.00	0.00
60%	929.70	939.90	929.70	939.90	0.00	0.00
50%	929.70	939.90	929.70	939.90	0.00	0.00
40%	929.70	939.90	929.70	939.90	0.00	0.00
30%	929.70	939.90	929.70	939.90	582.80	0.00
25%	929.70	939.90	929.70	939.90	904.50	0.00
20%	929.70	939.90	929.70	939.90	1232.40	368.60
15%	929.70	939.90	929.70	939.90	1551.10	894.50
10%	929.70	939.90	929.70	939.90	2107.05	1497.95
5%	929.70	939.90	929.70	939.90	3068.40	2558.12
2%	929.70	939.90	929.70	939.90	4240.59	3924.87
1%	929.70	939.90	929.70	939.90	4940.87	4619.52
0.5%	929.70	939.90	929.70	939.90	5442.79	5218.42
Maximum	929.70	939.90	929.70	939.90	6507.70	6579.10

```
TABLES Input Records
DATA6IFT   0   0   2
6FRE  10           2
```

The annual and daily target configurations differ only in the 98% and larger exceedance frequencies. The difference is due solely to the daily targets set in the month of February during leap years. All other frequencies have exactly the same target for the annual and daily *IF* record configurations. The cumulative volume *CV* record configuration has dramatically different targets. The targets set in this configuration are meant to protect the minimum annual 7-day total flow rather than the minimum individual day flow.

The instream flow shortage frequency metrics are shown in Table 4.9 for each alternative configuration. The annual and direct daily target configurations have nearly identical shortages. The minor differences are due to the leap year targets in the annual configuration. The cumulative volume configuration has substantially different shortages due to the difference in instream flow targets.

Table 4.9
Daily Instream Flow Shortage Frequency, acre-feet per day

	Annual Target		**Direct Daily**		**Cumulative Volume**	
CP	CP-1	CP-2	CP-1	CP-2	CP-1	CP-2
Mean	29.473	28.853	29.501	28.875	239.434	199.187
Std Dev	112.662	117.041	112.718	117.051	797.183	758.656
Minimum	0.000	0.000	0.000	0.000	0.000	0.000
99.5%	0.00	0.00	0.00	0.00	0.00	0.00
99%	0.00	0.00	0.00	0.00	0.00	0.00
98%	0.00	0.00	0.00	0.00	0.00	0.00
95%	0.00	0.00	0.00	0.00	0.00	0.00
90%	0.00	0.00	0.00	0.00	0.00	0.00
85%	0.00	0.00	0.00	0.00	0.00	0.00
80%	0.00	0.00	0.00	0.00	0.00	0.00
75%	0.00	0.00	0.00	0.00	0.00	0.00
70%	0.00	0.00	0.00	0.00	0.00	0.00
60%	0.00	0.00	0.00	0.00	0.00	0.00
50%	0.00	0.00	0.00	0.00	0.00	0.00
40%	0.00	0.00	0.00	0.00	0.00	0.00
30%	0.00	0.00	0.00	0.00	0.00	0.00
25%	0.00	0.00	0.00	0.00	0.00	0.00
20%	0.00	0.00	0.00	0.00	0.00	0.00
15%	0.00	0.00	0.00	0.00	0.00	0.00
10%	0.00	0.00	0.00	0.00	602.92	233.96
5%	277.13	233.77	277.13	233.77	2084.73	1473.68
2%	499.27	541.20	499.27	541.19	3398.28	3411.41
1%	624.22	660.21	624.22	660.21	4265.08	4230.69
0.5%	683.73	739.55	683.73	739.55	4768.55	4972.79
Maximum	913.80	939.87	913.80	939.87	6089.19	6275.68

The regulated flow frequencies of each of the three alternative instream flow requirement configurations of Example 2 are presented in Table 4.10. The naturalized flow frequencies are shown for comparison. The annual and direct daily target configurations give nearly identical regulated flow results. The required daily instream flows of 929.9 and 939.9 ac-ft/day at CP-1 and CP-2 are protective of flows down to the 99.5% exceedance level. The minimum regulated flow at CP-2 drops to zero for the annual and direct daily configurations. Daily simulation forecasting at downstream control points protects downstream senior water rights. However, the forecast is not always perfect and protecting a minimum period-of-analysis flow downstream of 13.8 acre-feet/day is within the margin of forecast accuracy. The cumulative volume configuration gives dramatically different regulated flow frequencies. The regulated flow is zero at control point CP-1 up to the 90% exceedance frequency.

Daily reservoir storage is plotted in Figure 4.4. Each simulation uses the same demand target for water right WR-1 of 1.095 million acre-feet per year. The direct daily target and the cumulative volume target configurations are shown for Example 2.

Table 4.10
Daily Naturalized and Example 2 Regulated Flow Frequency, acre-feet per day

	Naturalized		Regulated Flow					
			Annual Target		Direct Daily		Cumulative Volume	
CP	CP-1	CP-2	CP-1	CP-2	CP-1	CP-2	CP-1	CP-2
Mean	14622.1	15754.0	11568.7	12700.7	11568.7	12700.7	11568.3	12700.3
Std Dev	28080.1	28834.8	23412.0	24576.0	23411.6	24575.6	23497.3	24649.5
Minimum	15.8	13.8	15.8	0.0	15.8	0.0	0.0	0.0
99.5%	245.9	204.2	245.9	202.1	245.9	202.1	0.0	0.0
99%	307.1	285.6	307.1	279.6	307.1	279.6	0.0	0.0
98%	430.4	408.5	430.4	398.6	430.4	398.6	0.0	0.0
95%	652.5	721.9	652.5	706.1	652.5	706.1	0.0	210.2
90%	1013.5	1077.0	929.6	939.8	929.6	939.8	0.0	452.2
85%	1368.5	1477.6	929.6	939.8	929.6	939.8	200.3	656.1
80%	1695.8	1886.2	929.6	1003.4	929.6	1003.4	460.1	827.9
75%	2058.8	2292.8	929.6	1122.8	929.6	1123.2	644.6	975.8
70%	2455.5	2764.9	929.6	1246.8	929.6	1247.6	817.1	1138.9
60%	3433.3	3869.7	929.6	1526.0	929.6	1526.7	1194.0	1561.6
50%	4939.8	5672.7	1243.6	2073.9	1243.6	2074.0	1675.8	2210.1
40%	7384.4	8477.3	2710.6	3777.0	2709.8	3773.3	2967.2	3878.1
30%	11743.1	13116.6	6539.7	8085.0	6539.7	8085.0	6723.6	8270.5
25%	14817.5	16393.3	9874.1	11389.2	9874.1	11389.2	10016.1	11565.3
20%	19086.8	21088.2	14292.3	15983.2	14292.3	15983.2	14445.0	16246.8
15%	26269.5	28330.3	21576.4	23454.5	21576.4	23454.5	21826.3	23855.8
10%	38207.5	40796.9	34695.3	37263.3	34695.3	37263.3	34962.9	37500.8
5%	61186.0	64023.8	63467.9	67285.1	63467.9	67285.1	63623.9	67542.7
2%	97883.0	105114.5	109541.4	119009.9	109541.4	119009.9	109593.0	119009.9
1%	130696.8	142020.5	117267.0	119009.9	117267.0	119009.9	117358.1	119009.9
0.5%	175782.7	181400.9	119010.0	119009.9	119010.0	119009.9	119010.0	119009.9
Maximum	796904.6	698034.6	119010.0	119010.0	119010.0	119010.0	119010.0	119010.0

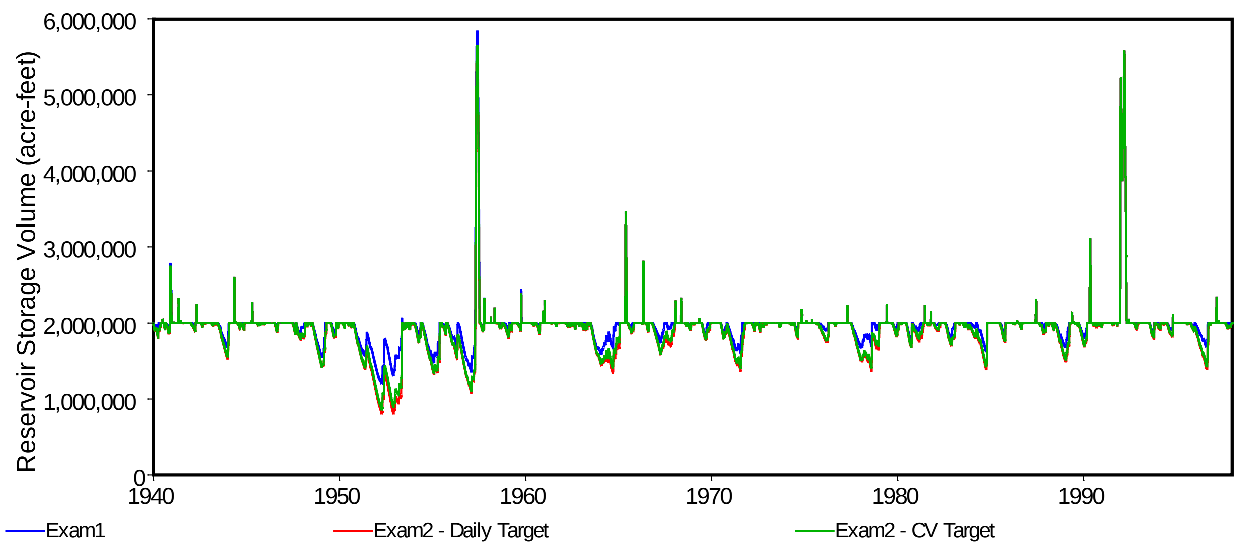

Figure 4.4 Reservoir Storages for Example 1 and Example 2

Firm yields for the water right WR-1 diversion with the three alternative instream flow requirements are tabulated in Table 4.11. The third instream flow target based on the 7-day cumulative volume restricts WR-1 a little less stringently than the other two alternatives.

Table 4.11
Example 2 Firm Yield for WR-1

IF Record Configuration	WR-1 Firm Yield, ac-ft per year
Annual Target	1,490,600
Direct Daily Target	1,490,500
Cumulative Volume Target	1,532,600

An option activated by *CV* record field 15 or *FS* record field 16 writes target setting information in the message MSS file for tracking computations during the simulation. Target setting can involve an unlimited number of optional input records. The *CV* and/or *FS* record optional information in the MSS file is helpful especially when multiple target setting records are involved in setting the final *WR* or *IF* record target. Table 4.12 provides a small selection of the optional MSS output for the *CV* record target setting computations at CP-1.

Table 4.12
Optional *CV* Record Output to the MSS File

```
1940  2  MINFLOW1  CV 1  Preceding Target=  0.0  CVV= 6500.3  Final=    7.4
1940  2  MINFLOW1  CV 1  Preceding Target=  0.0  CVV= 6507.7  Final=    0.0
1940  2  MINFLOW1  CV 1  Preceding Target=  0.0  CVV= 6149.3  Final=  358.4
1940  2  MINFLOW1  CV 1  Preceding Target=  0.0  CVV= 4766.9  Final= 1740.8
1940  2  MINFLOW1  CV 1  Preceding Target=  0.0  CVV= 3586.9  Final= 2920.8
1940  2  MINFLOW1  CV 1  Preceding Target=  0.0  CVV= 5027.3  Final= 1480.4
1940  2  MINFLOW1  CV 1  Preceding Target=  0.0  CVV= 6507.7  Final=    0.0
1940  2  MINFLOW1  CV 1  Preceding Target=  0.0  CVV= 6500.3  Final=    7.4
1940  2  MINFLOW1  CV 1  Preceding Target=  0.0  CVV= 6769.3  Final=    0.0
1940  2  MINFLOW1  CV 1  Preceding Target=  0.0  CVV= 6410.9  Final=   96.8
1940  2  MINFLOW1  CV 1  Preceding Target=  0.0  CVV= 4766.9  Final= 1740.8
1940  2  MINFLOW1  CV 1  Preceding Target=  0.0  CVV= 3586.9  Final= 2920.8
1940  2  MINFLOW1  CV 1  Preceding Target=  0.0  CVV= 5027.3  Final= 1480.4
1940  3  MINFLOW1  CV 1  Preceding Target=  0.0  CVV= 6507.7  Final=    0.0
```

Example 3 – Addition of Median Flow Limits and Reservoir Releases for 7Q2 Limits

The instream flow requirements at CP-1 and CP-2 established in Example 2 based on 7Q2 naturalized flows are modified in Example 3 to employ releases from reservoir storage as necessary to satisfy the minimum regulated flow limits. Additionally, Example 3 introduces instream flow requirements at CP-1 and CP-2 that set minimum regulated flow limits that vary as a function of reservoir storage contents. These minimum limits on regulated flows are based on median (50% exceedance frequency) naturalized flows from Example 1 but are activated only if reservoir storage exceeds a specified level. Example 3 covers the following topics.

- Releases from reservoir storage for meeting instream flow targets
- Setting final *IF* record targets at control points with more than one *IF* record
- Drought index *DI/IS/IP* record modification of *IF* record targets
- MSS file optional output using the *JD* record ICHECK parameter

Example 3 adds reservoir release capabilities to the 7Q2-based minimum flow targets of Example 2 and adds a new median-flow-based target that is activated or deactivated depending on reservoir storage contents. The *IF* records and supporting records added in Example 3 to the DAT file of Table 4.1 are presented in Table 4.13. The first set of *IF* records is carried over from Example 2 to cover 7Q2-based minimum instream flow limits. The second set of *IF* records incorporates minimum regulated flow limits based on median naturalized flows that are in addition to the 7Q2-based minimum flow requirements at the two control points. The third set of *IF* records is an alternative configuration of the median flow requirement. As discussed for Example 2, the modeling system offers the flexibility to develop targets on a once-per-month basis using the first 12 steps in the 22 step *SIMD* target building process. The alternative is to develop daily targets on a day-by-day basis. The last set of records in Table 4.13 is *DI/IS/IP* records used to define a drought index for modifying *IF* record targets.

Table 4.13
Example 3 Input Records

Minimum Flow Limits Based on 7Q2 Flows

```
IF  CP-2  939.87            1111       3         MINFLOW2
WSBIGRES 2000000
DW         1
IF  CP-1  929.67            1111       3         MINFLOW1
WSBIGRES 2000000
DW         1
```

Minimum Flow Limits Based on Median Flows

```
IF  CP-1 1803038   NDAYS    1111   2           1 MEDIAN1
IF  CP-2 2070543   NDAYS    1111   2           1 MEDIAN2
```

Alternative Median Flow Record Configuration

```
IF  CP-1  4939.8            1111   2           1 MEDIAN1
DW         1
DO            18
IF  CP-2  5672.7            1111   2           1 MEDIAN2
DW         1
DO            18
```

Drought Index

```
DI     1       1  BIGRES
IS     4       0 1499999 1500000 7000000
IP             0       0     100     100
```

The minimum flow *IF* records for Example 3 shown in Table 4.13 illustrate the option of using releases from reservoir storage specifically to meet instream flow requirements. In Example 2, the minimum flow limit was met only by the flow available in the stream. As shown in Table 4.10, regulated flow met the instream flow targets as long as the underlying naturalized flows were above targets. Downstream regulated flow at CP-2 was infrequently affected by upstream diversions even when regulated flow was below the senior *IF* record target. This is attributable to the lagging effect of routing changes to stream flow and slight imperfection in forecasting downstream future stream flow conditions. In Example 3, releases from the reservoir specified on the *WS* record supplement flows as necessary to meet the instream flow targets.

Releases from reservoir storage to mitigate instream flow shortages are activated by *IF* record IFMETH options 3 and 4. The minimum flow *IF* records in Table 4.13 call for reservoir releases whenever the regulated flow is below the daily *IF* record target. Water is released from storage in an amount equal to the instream flow shortage adjusted by the cumulative delivery factor which is computed from channel loss factors. The instream flow requirement at CP-2 is intentionally placed before the instream flow requirement at CP-1. If regulated flow is insufficient to meet the daily *IF* record target at CP-2, reservoir storage will be released. The upstream instream flow requirement at CP-1 may incidentally benefit from the release of storage to CP-2. Therefore, making releases to CP-2 prior to checking for shortages at CP-1 may reduce the overall stored water released.

A second set of instream flow *IF* records at CP-1 and CP-2 establishes daily targets equal to the median daily naturalized flow volume. Daily naturalized flow frequency metrics are tabulated in Table 4.4. For purposes of illustrating a second level of instream flow requirements, the 50% exceedance frequency or median daily flow is selected for building daily *IF* record targets. The median daily flows at CP-1 and CP-2 are 4,939.8 and 5,672.7 ac-ft per day. Other alternative quantities could be adopted. As noted in Chapter 2 of this report, the Lyons Method of establishing environmental instream flow requirements involves computation of the daily median flow on a month-by-month basis and multiplying by a specific percentage.

As discussed below, the median flow *IF* record target is set to zero when reservoir storage content is below a specified volume. Since the median flow *IF* records are considered in the priority sequence after the minimum flow *IF* records, the user has a choice of which instream flow target will govern junior water availability at the respective control point. Multiple *IF* records and final target selection options are applied when instream flow requirements are set at different priorities at the same control point.

IF record field 7 offers three target setting options for multiple *IF* records at the same control point. For Example 3, the median flow *IF* record requirements employ field 7 option 2 to adopt the largest *IF* record target at the control point up to that point in the priority sequence. The following *IF* record options are described in the *Users Manual* and *Reference Manual*.

- The junior *IF* record target replaces the preceding senior *IF* record target (default).
- The largest *IF* record target at the control point during the current time step is adopted.
- The smallest *IF* record target at the control point during the current time step is adopted.

The median flow *IF* records shown in Table 4.16 utilize a drought index for modifying the daily target value. *IF* record field 11 connects a set of *DI*, *IS*, and *IP* records to the target building steps. In Example 3, each median flow *IF* record specifies drought index identifier 1 in field 11. The integer index identifier corresponds to *DI* record field 2. Through this connection, the *DI/IS/IP* records are considered in the target building steps to build the *IF* record target.

The median flow *IF* record requirements are used in Example 3 to illustrate a larger instream flow requirement that might be considered under certain conditions. In Example 3, the condition to engage the median flow target is when the reservoir storage content at CP-1 is greater than or equal to 1.5 million acre-feet, which is 75% of the conservation storage capacity. In applying the *DI/IS/IP* record set, *SIMD* computes the total reservoir storage for reservoirs listed on the *DI* record. Given the storage, *SIMD* interpolates the *IS/IP* record table to determine a fraction by which the instream flow target is multiplied. In the example, the multiplier factor from the *IP* record is 1.0 when the reservoir storage contents are greater than or equal to 1.5 million acre-feet and zero otherwise. The *IF* record target is multiplied by the computed drought index factor. Therefore, in Example 3 the median flow *IF* record target is set to zero when reservoir storage at CP-1 is less than 1.5 million acre-feet. However, the final instream flow targets at CP-1 and CP-2 are adopted as the larger of the 7Q2 target or the median flow target.

An alternative configuration of the median flow *IF* record is shown in Table 4.13. As with Example 2, the user may choose to set a daily target based on monthly distribution of the annual target in *IF* record field 3. Alternatively, a daily target may be set directly using the *DW* record option XDAY. With the first annual target configuration, the drought index is evaluated on the first day of the month for the purposes of developing a monthly target using the field 4 use coefficients. The monthly target is then distributed to each day of the month. Alternatively, if the daily target is set directly with *DW* record option XDAY, then consideration of the drought index should be moved to the day-by-day target building step 18. This is accomplished by the entry 18 in *DO* record field 4.

In Example 3, if the annual target setting configuration is selected, the drought index is evaluated once-per-month at the start of the month. Median flow *IF* record requirements are engaged or set to zero for the entire month until the drought index is evaluated on the first day of the next month. If the alternative daily target building configuration is selected, the drought index is evaluated each day of the month. Therefore, in the former configuration, the median flow *IF* record targets can be set throughout the month regardless of intra-month storage contents. The latter configuration allows the median flow *IF* record targets to be set to zero on any day in which reservoir storage at CP-1 falls below 1.5 million acre-feet.

Tables 4.14, 4.15, and 4.16 show Example 3 results for three configurations.

- No median flow *IF* records, only minimum flow requirements with storage backup
- Median flow with an annual target and monthly evaluation of the drought index
- Median flow with daily target setting and daily evaluation of the drought index

Daily reservoir storage contents are shown in Figure 4.5 for Examples 1 and 3. For Example 3, the simulation without median flow instream flow requirements and the simulation with median flow requirements set with an annual target and monthly drought index evaluation are shown. The Example 3 case without median flow requirements differs from Example 2. Example 3 uses reservoir storage to meet daily instream flow shortages up to the daily 7Q2 level.

Regulated flow in Table 4.10 drops below the 7Q2 level in conjunction with low levels of daily naturalized flow. Reservoir releases in Example 3 maintain a minimum regulated flow equal to the daily 7Q2 level at CP-1 and CP-2. Engaging median flow requirements in Example 3 begins to increase regulated flow at the 90% exceedance frequency level.

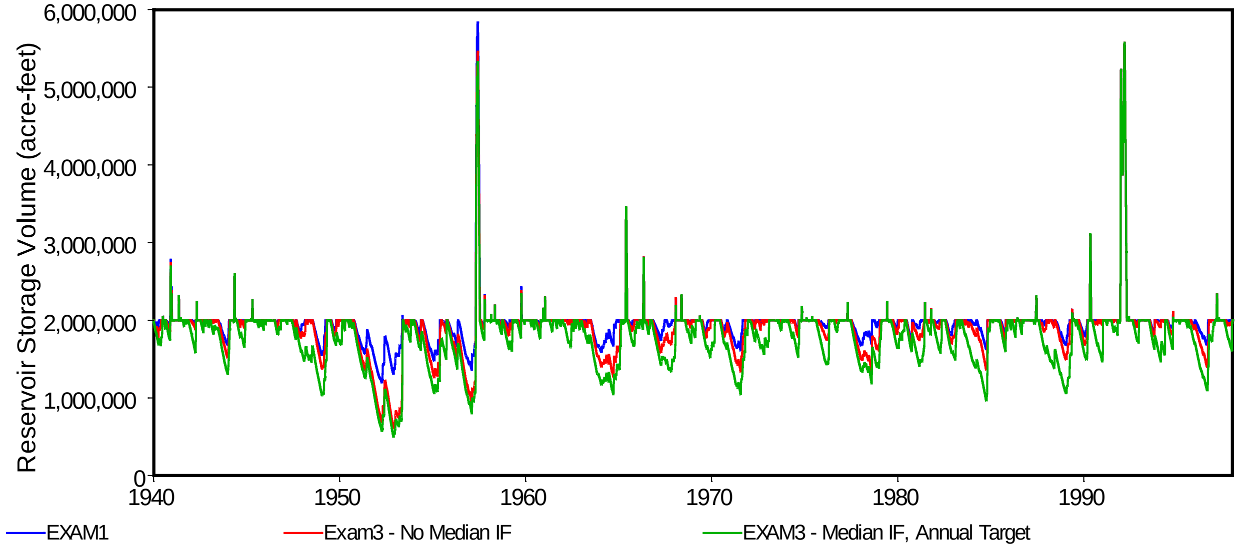

Figure 4.5 Reservoir Storages for Example 1 and Example 3

Table 4.14
Daily Instream Flow Target Frequency, acre-feet per day

	No Median IF		Annual Target Monthly DI		Daily Target Daily DI	
CP	CP-1	CP-2	CP-1	CP-2	CP-1	CP-2
Mean	929.72	939.90	4148.09	4738.25	4127.89	4714.35
Std Dev	0.02	0.00	1593.61	1880.83	1611.55	1901.99
Minimum	929.70	939.90	929.70	939.90	929.70	939.90
99.5%	929.70	939.90	929.70	939.90	929.70	939.90
99%	929.70	939.90	929.70	939.90	929.70	939.90
98%	929.70	939.90	929.70	939.90	929.70	939.90
95%	929.70	939.90	929.70	939.90	929.70	939.90
90%	929.70	939.90	929.70	939.90	929.70	939.90
85%	929.70	939.90	929.70	939.90	929.70	939.90
80%	929.70	939.90	4769.50	5477.10	929.70	939.90
75%	929.70	939.90	4939.80	5672.70	4939.80	5672.70
70%	929.70	939.90	4939.80	5672.70	4939.80	5672.70
60%	929.70	939.90	4939.80	5672.70	4939.80	5672.70
50%	929.70	939.90	4939.80	5672.70	4939.80	5672.70
40%	929.70	939.90	4939.80	5672.70	4939.80	5672.70
30%	929.70	939.90	4939.80	5672.70	4939.80	5672.70
25%	929.70	939.90	4939.80	5672.70	4939.80	5672.70
20%	929.70	939.90	4939.80	5672.70	4939.80	5672.70
15%	929.70	939.90	4939.80	5672.70	4939.80	5672.70
10%	929.70	939.90	4939.80	5672.70	4939.80	5672.70
5%	929.70	939.90	4939.80	5672.70	4939.80	5672.70
2%	929.70	939.90	4939.80	5672.70	4939.80	5672.70
1%	929.70	939.90	4939.80	5672.70	4939.80	5672.70
0.5%	929.70	939.90	4939.80	5672.70	4939.80	5672.70
Maximum	929.70	939.90	4939.80	5672.70	4939.80	5672.70

Table 4.15
Daily Instream Flow Shortage Frequency, acre-feet per day

	No Median IF		Annual Target Monthly DI		Daily Target Daily DI	
CP	CP-1	CP-2	CP-1	CP-2	CP-1	CP-2
Mean	0.00	0.00	877.51	1028.77	823.15	967.45
Std Dev	0.00	0.00	1361.34	1601.39	1323.44	1556.94
Minimum	0.00	0.00	0.00	0.00	0.00	0.00
99.5%	0.00	0.00	0.00	0.00	0.00	0.00
99%	0.00	0.00	0.00	0.00	0.00	0.00
98%	0.00	0.00	0.00	0.00	0.00	0.00
95%	0.00	0.00	0.00	0.00	0.00	0.00
90%	0.00	0.00	0.00	0.00	0.00	0.00
85%	0.00	0.00	0.00	0.00	0.00	0.00
80%	0.00	0.00	0.00	0.00	0.00	0.00
75%	0.00	0.00	0.00	0.00	0.00	0.00
70%	0.00	0.00	0.00	0.00	0.00	0.00
60%	0.00	0.00	0.00	0.00	0.00	0.00
50%	0.00	0.00	0.00	0.00	0.00	0.00
40%	0.00	0.00	0.03	0.03	0.03	0.00
30%	0.00	0.00	1094.87	1272.37	820.15	965.94
25%	0.00	0.00	1807.91	2122.30	1605.60	1908.08
20%	0.00	0.00	2399.03	2784.78	2248.23	2608.24
15%	0.00	0.00	2916.67	3392.20	2791.71	3252.88
10%	0.00	0.00	3368.90	3937.18	3269.72	3818.17
5%	0.00	0.00	3771.84	4470.70	3696.19	4397.34
2%	0.00	0.00	4010.13	4732.83	4009.93	4711.46
1%	0.00	0.00	4010.13	4732.83	4010.13	4732.83
0.5%	0.00	0.00	4010.13	4732.83	4010.13	4732.83
Maximum	0.00	0.00	4010.13	4732.83	4010.13	4732.83

Table 4.16
Daily Regulated Flow Frequency, acre-feet per day

	No Median IF		Annual Target Monthly DI		Daily Target Daily DI	
CP	CP-1	CP-2	CP-1	CP-2	CP-1	CP-2
Mean	11569.2	12701.1	11572.6	12704.5	11572.6	12704.5
Std Dev	23354.7	24522.9	22414.6	23535.6	22372.8	23485.3
Minimum	929.6	939.8	929.6	939.8	929.6	939.8
99.5%	929.6	939.8	929.6	939.8	929.6	939.8
99%	929.6	939.8	929.6	939.8	929.6	939.8
98%	929.6	939.8	929.6	939.8	929.6	939.8
95%	929.6	939.8	929.6	939.8	929.6	939.8
90%	929.6	939.8	929.6	1027.8	929.6	1024.0
85%	929.6	961.7	929.6	1219.8	929.6	1213.5
80%	929.6	1067.5	1130.5	1426.1	1132.5	1408.2
75%	929.6	1173.3	1426.5	1761.9	1441.9	1753.6
70%	929.6	1273.4	1795.0	2138.1	1822.3	2148.0
60%	929.6	1529.9	2735.1	3183.4	2802.6	3252.8
50%	1281.7	2068.2	4076.0	4706.7	4219.8	4850.5
40%	2661.8	3737.2	4939.8	5880.9	4939.8	5944.7
30%	6481.5	8031.7	5781.7	7537.4	5785.1	7593.8
25%	9845.6	11346.5	7746.7	9514.7	7746.7	9531.2
20%	14237.3	15890.7	11444.2	13115.9	11412.8	13074.5
15%	21468.4	23363.4	17787.7	19630.3	17748.6	19473.0
10%	34664.4	37184.4	31313.3	33516.5	31152.8	33375.8

5%	63102.4	67088.3	60237.1	63346.4	60157.7	63171.8
2%	109533.9	119009.9	109018.0	119009.9	108879.8	119009.9
1%	117249.6	119009.9	117187.2	119009.9	117156.8	119009.9
0.5%	119010.0	119009.9	119010.0	119009.9	119010.0	119009.9
Maximum	119010.0	119010.0	119010.0	119010.0	119010.0	119010.0

Firm yield results for WR-1 are presented in Table 4.17 for Example 1, Example 2, and three configurations in Example 3. With each additional instream flow requirement, the firm yield of WR-1 decreases as more regulated flow is required for instream flow purposes, or in Example 3, stored water is released to meet minimum flow requirements. Releasing stored water has almost a 100,000 ac-ft per year effect on firm yield as seen in the comparison between Example 2 and the configuration of Example 3 without the median flow requirement. The addition of the median flow requirement with a drought index and without reservoir storage backup decreases the firm yield by approximately 66,000 acre-feet per year.

Table 4.17
Firm Yield for WR-1

IF Record Configuration		WR-1 Firm Yield, ac-ft per year
Example 1:	No *IF* Records	1,731,000
Example 2:	7Q2 *IF*, No Reservoir	1,490,500
Example 3:	7Q2 *IF*, with Reservoir	1,393,900
	Median *IF*, Annual Target	1,327,500
	Median *IF*, Daily Target	1,327,800

The job control *JD* record at the beginning of the DAT file provides control over period-of-analysis, output files, and default settings and overrides for various simulation methods. The *JD* record field 4 parameter ICHECK has an option for tracking the targets set by instream flow records through the priority sequence. As discussed above, *IF* record field 7 has options for selecting the final instream flow requirement at a control point. As *IF* records are considered through the priority sequence, junior *IF* records can replace or select the maximum or minimum of senior *IF* record targets at the control point. The final instream flow requirements written to the OUT and SUB output files reflect the selection in *IF* record field 7. However, the user may wish to know the target computed by the *IF* record prior to consideration of the *IF* record field 7 option. This is particularly important when field 7 options 2 or 3 are selected to adopt the maximum or minimum of the previous target.

Table 4.18 shows a selection of the period-of-analysis results written to the MSS file for the two configurations of Example 3 that utilize median flow targets. Both median flow *IF* record configurations use *IF* record field 7 option 2. This selects the maximum of the current *IF* record target or the previous *IF* record target at the control point. When the drought index generates a zero factor for multiplication against the *IF* record target, the final instream flow requirement at the control point will equal the minimum flow requirement. However, ICHECK information allows the user to see the days in which the drought index resulted in a zero instream flow target prior to consideration of *IF* record field 7.

Table 4.18
MSS File Output from ICHECK Option 12

Example 3, Median IF with Annual Target and Monthly Drought Index

Targets for Instream Flow Rights in Priority Order

YEAR	MT	DT	MINFLOW2	MINFLOW1	MEDIAN1	MEDIAN2
1948	6	14	939.870	929.670	4939.830	5672.720
1948	6	15	939.870	929.670	4939.830	5672.720
1948	6	16	939.870	929.670	4939.830	5672.720
1948	6	17	939.870	929.670	4939.830	5672.720
1948	6	18	939.870	929.670	4939.830	5672.720
1948	6	19	939.870	929.670	4939.830	5672.720
1948	6	20	939.870	929.670	4939.830	5672.720
1948	6	21	939.870	929.670	4939.830	5672.720
1948	6	22	939.870	929.670	4939.830	5672.720
1948	6	23	939.870	929.670	4939.830	5672.720
1948	6	24	939.870	929.670	4939.830	5672.720
1948	6	25	939.870	929.670	4939.830	5672.720
1948	6	26	939.870	929.670	4939.830	5672.720
1948	6	27	939.870	929.670	4939.830	5672.720
1948	6	28	939.870	929.670	4939.830	5672.720
1948	6	29	939.870	929.670	4939.830	5672.720
1948	6	30	939.870	929.670	4939.830	5672.720
1948	7	1	939.870	929.670	0.000	0.000
1948	7	2	939.870	929.670	0.000	0.000
1948	7	3	939.870	929.670	0.000	0.000
1948	7	4	939.870	929.670	0.000	0.000
1948	7	5	939.870	929.670	0.000	0.000
1948	7	6	939.870	929.670	0.000	0.000
1948	7	7	939.870	929.670	0.000	0.000

Example 3, Median IF with Daily Target and Daily Drought Index

Targets for Instream Flow Rights in Priority Order

YEAR	MT	DT	MINFLOW2	MINFLOW1	MEDIAN1	MEDIAN2
1948	6	14	939.870	929.670	4939.800	5672.700
1948	6	15	939.870	929.670	4939.800	5672.700
1948	6	16	939.870	929.670	4939.800	5672.700
1948	6	17	939.870	929.670	4939.800	5672.700
1948	6	18	939.870	929.670	4939.800	5672.700
1948	6	19	939.870	929.670	4939.800	5672.700
1948	6	20	939.870	929.670	0.000	0.000
1948	6	21	939.870	929.670	0.000	0.000
1948	6	22	939.870	929.670	0.000	0.000
1948	6	23	939.870	929.670	0.000	0.000
1948	6	24	939.870	929.670	0.000	0.000
1948	6	25	939.870	929.670	0.000	0.000
1948	6	26	939.870	929.670	0.000	0.000
1948	6	27	939.870	929.670	0.000	0.000
1948	6	28	939.870	929.670	0.000	0.000
1948	6	29	939.870	929.670	0.000	0.000
1948	6	30	939.870	929.670	0.000	0.000
1948	7	1	939.870	929.670	0.000	0.000
1948	7	2	939.870	929.670	0.000	0.000
1948	7	3	939.870	929.670	4939.800	5672.700
1948	7	4	939.870	929.670	0.000	0.000
1948	7	5	939.870	929.670	4939.800	5672.700
1948	7	6	939.870	929.670	4939.800	5672.700
1948	7	7	939.870	929.670	4939.800	5672.700

Example 4 – Flow Volume During Multiple Consecutive Months

The preceding Examples 2 and 3 illustrate methods for setting daily instream flow limits (7Q2) and then higher daily limits (median flow) that depend on reservoir storage contents. Setting minimum flow limits based on 7Q2, median, or other flow metrics for individual months or days can be associated with establishing subsistence and base flow requirements. As illustrated by the Brazos BBEST and BBASC recommendations described in Chapter 5, base flow requirements can vary as a function of flow rate, season, and hydrologic condition.

Example 4 builds on the regulated flow requirements of Example 3, based on the 7Q2 and daily median naturalized flows, and adds a more complex requirement for a seasonal (Spring, March through May) flow volume with monthly and daily limits. The new target is constructed in Example 4 by combining a number of additional records in the DAT file and connecting to hydrologic index *HI* records in a HIS file. Example 4 covers the following topics.

WR record type 8 target setting
FS record flow switch
HI record hydrologic index
IM record monthly switch used with drought index *DI/IS/IP* records
TO records for building *IF* record targets from multiple Type 8 *WR* records

Example 4 demonstrates the concept of setting instream flow requirements to protect a multiple-month volume of stream flow. A practical application of this concept is a requirement for a specified seasonal (over multiple months) volume of freshwater inflow to the bay and estuary system at the outlet of a river basin. Bay and estuary freshwater inflow requirements can be modeled with WRAP using *IF* records placed at the most downstream control point.

Example 4 builds an instream flow target at control point CP-2 centered on a cumulative flow volume during Spring (March through May) by combining *SIMD IF*, *WR*, *FS*, *CV*, *TO*, *DO*, *DW*, *DI*, and *HI* record options as necessary to simulate the following criteria.

- The March through May flow requirement is activated only when the reservoir storage contents at CP-1 is greater than 90% of conservation storage capacity on March 1 and when the hydrologic index at CP-2 on March 1 indicates wet conditions.
- A total flow volume of 1,950,000 acre-feet is required at CP-2 through the months of March, April, and May.
- The cumulative total of the daily targets during March will not exceed 890,000 acre-feet.
- The cumulative total of the daily targets during April will not exceed 820,000 acre-feet.
- The cumulative total of the daily targets during May will not exceed 1,450,000 acre-feet.
- Daily instream flow targets at CP-2 will not exceed 60,000 acre-feet in any month.

The total seasonal flow volume and individual-month limits were selected for illustration purposes based roughly on median monthly naturalized flow volumes. A more comprehensive scientific study of bay and estuary inflow requirements may consider variables such as salinity and duration of salinity reductions due to freshwater inflow events, or key indicator bay species may require certain frequency and volume of freshwater inflow for spawning cues.

Table 4.19 shows the input records added to the DAT file of Table 4.1. The *IF* record minimum flow limits based on 7Q2 flows and the *IF* record water right based on median flows and a *DI/IS/IP* record drought index are developed in Example 3. All other records are new additions to the DAT for modeling the seasonal flow target added in Example 4. The new records are discussed below in their sequential order in Table 4.19.

The water right type is specified in water right *WR* record field 6. A type 8 water right computes an intermediate or final target but does nothing else. Example 4 applies the water right type 8 feature to compute targets for use with *FS* and *CV* records. For a complex target building process, such as that employed by Example 4, building targets in steps may be useful. Example 4 illustrates consideration of conditions in target building such as reservoir storage, hydrologic condition index, daily target limits, monthly total regulated flow volume, and consecutive month regulated flow volume. Considering all conditions with a single *IF* record is not feasible. Multiple calculations must be made in order to build the final *IF* record target. The number of input records in Table 4.19 for the seasonal requirement could be reduced by using multiple *CV* records with a single type 8 *WR* record. However, each *CV* record is assigned to a separate type 8 *WR* record for purposes of tracking and illustrating the computations.

The *WR* record with identifier MARCHSTO is a type 8 target setting water right. Its purpose is to set a daily target of 1 acre-feet/day in the months of March, April, and May when reservoir storage content at CP-1 is greater than or equal to 1.8 million acre-feet. Use coefficient identifier SPRING divides the annual target into monthly volumes according to the number of calendar days in each month. *SIMD* further divides the monthly targets uniformly into 1 acre-feet per day. The daily target size was arbitrarily chosen for accounting purposes. The target of water right MARCHSTO will either equal 0.0 or 1.0.

The second drought index in Table 4.19 is connected to water right MARCHSTO. This drought index uses a monthly switch *IM* record along with the required set of *DI*, *IS*, and *IP* records. The *IM* record allows the drought index factor to be recalculated each month, applying the previous value of the drought index factor, or not applying the factor at all. The *IM* record connected to MARCHSTO is set to recalculate the drought index factor each month except in April and May. The drought index factor computed in March is used again in April and May. This allows water right MARCHSTO to set its targets in March, April, and May based only on the drought index factor computed for March 1.

The *WR* record with identifier MARCHWET is another type 8 target setting water right. Its purpose is to set a daily target of 1 ac-ft per day in the month of March when the hydrologic index is equal to 3 which indicates a wet condition for this example. A flow switch *FS* record is paired with the *WR* record. The *FS* record is similar to the *CV* record in that it tracks the summation of a variable over a specified number of time steps. However, while the *CV* sets a target based on the variable summation, the *FS* record multiplies the previously calculated target by a set of factors if the summation variable is inside or outside of a specified range. The *FS* record in this example is set to read the hydrologic index *HI* record data at CP-2. If in the month of March, the hydrologic index variable is between a value of 2.9 and 3.1, the daily target set by water right MARCHWET is multiplied by 1.0. Otherwise, the target of MARCHWET is multiplied by 0.0. This allows water right MARCHWET to set a daily target throughout the month of March equal to 0.0 or 1.0 based on the March hydrologic index value.

Table 4.19
Example 4 Input Records

Use Coefficient Records

```
UCSPRING       0       0      31      30      31       0
UC             0       0       0       0       0       0
UC MARCH       0       0       1       0       0       0
UC             0       0       0       0       0       0
UC APRIL       0       0       0       1       0       0
UC             0       0       0       0       0       0
UC   MAY       0       0       0       0       1       0
UC             0       0       0       0       0       0
```

Minimum Flow Requirements based on 7Q2 Flows with Reservoir Backup

```
IF  CP-2  939.87            1111       3         MINFLOW2
WSBIGRES 2000000
DW         1
IF  CP-1  929.67            1111       3         MINFLOW1
WSBIGRES 2000000
DW         1
```

Minimum Flow Requirements based on Median Flows with Drought Index 1

```
IF  CP-1 1803038   NDAYS    1111   2           1 MEDIAN1
IF  CP-2 2070543   NDAYS    1111   2           1 MEDIAN2
```

Seasonal (March-May) Flow Requirement

```
WR  CP-2      92  SPRING    1111   8                           2 MARCHSTO
WR  CP-2      31   MARCH    1111   8                             MARCHWET
FS    12             1.0     0.0     2.9     3.1   1           0   3   3   1
WR  CP-2                    1111   8                             SPRINGTOTAL
CV     1            -1.0 1950000                          91   3   5   3
DO                19
WR  CP-2  890000   MARCH    1111   8                             MARCHMAX
CV     1            -1.0  890000                       3  30   3   3   3
DO                19
DW         2
WR  CP-2  820000   APRIL    1111   8                             APRILMAX
CV     1            -1.0  820000                       3  29   4   4   3
DO                19
DW         2
WR  CP-2 1450000     MAY    1111   8                             MAYMAX
CV     1            -1.0 1450000                       3  30   5   5   3
DO                19
DW         2
WR  CP-2                    1111   8                             MONTHMAX
TO    13             SET                                MARCHMAX        CONT
TO    13             MAX                                APRILMAX        CONT
TO    13             MAX                                MAYMAX
DO        16
IF  CP-2                    1111   2             SPRINGEVENT
TO    13             SET                                SPRINGTOTAL     CONT
TO    13             MIN                                MONTHMAX        CONT
TO    15   60000     MIN
FS    10             1.0     0.0     0.9     1.1   1           0   3   5   1 MARCHSTO
FS    10             1.0     0.0     0.9           1          61   3   5   1 MARCHWET
DO        16      19
```

Table 4.19 Continued
Example 4 Input Records

Drought Indices

```
DI     1       1  BIGRES
IS     4       0 1499999 1500000 7000000
IP             0       0     100     100
DI     2       1  BIGRES
IS     4       0 1799999 1800000 7000000
IP             0       0     100     100
IM     1   2   3  -3  -3   6   7   8   9  10  11  12
```

The hydrologic index *HI* records are stored in the hydrologic index series HIS input file. *SIM* and *SIMD* automatically read the HIS file if one or more input records in the DAT file call for the use of *HI* record data. *TO*, *LO*, *CV*, *FS*, and *PF* records access the hydrologic index series at the control point of their respective water right or at a specified alternative control point.

Water rights MARCHSTO and MARCHWET compute monthly targets only. The monthly targets are automatically distributed uniformly into daily targets based on the number of calendar days in each month. Water right MARCHSTO sets targets equal to 0 or 1 ac-ft per day for the months of March, April, and May. This is made possible by the *IM* record which enables the drought index factor for March to be repeated in April and May. The *FS* record does not repeat its multipliers for consecutive months. Each month the summation variable is recomputed and a new target is computed for the water right. Therefore, water right MARCHWET only sets targets of 0 or 1 for the month of March based on the same month value of the hydrologic index, and sets a zero target in all other months and days of the year.

The *WR* record with identifier SPRINGTOTAL is a type 8 target setting *WR* record water right paired with a cumulative volume *CV* record. The *CV* record tracks regulated flow at CP-2 on a daily basis according to the daily target building option *DO* record. Between the days of March 1 and May 31, the *CV* record sums the regulated flow at CP-2 and subtracts the value from 1.95 million acre-feet. As of May 31 each year, the *CV* record is tracking the summation of regulated flow in the previous 91 days at CP-2. If the difference between 1.95 million acre-feet and the summation is positive, the difference is used to set the daily target for water right SPRINGTOTAL. Otherwise, the target for SPRINGTOTAL is set equal to zero.

Water rights MARCHMAX, APRILMAX, and MAYMAX are type 8 target setting rights that function in a similar manner to SPRINGTOTAL with the exception that these three water rights only track cumulative regulated flow for one month. For example, the *CV* record for water right MARCHMAX tracks cumulative daily regulated flow at CP-2 from March 1 to March 31. The cumulative regulated flow is subtracted from 890,000 acre-feet. If the difference is positive, the difference is used to set the daily target for water right MARCHMAX.

Water right *WR* record with identifier MONTHMAX is a type 8 target setting water right paired with three *TO* records and a *DO* record. The three *TO* records select the maximum daily target set by the water rights MARCHMAX, APRILMAX, and MAYMAX. The result is a daily target for MONTHMAX that is zero in months June through February, but positive in March, April, and May according to the targets set by the rights with *CV* records. Water rights MARCHMAX, APRILMAX, and MAYMAX could be eliminated and their respective *CV* records could replace the three *TO* records of MONTHMAX. However, the *CV* records were paired with separate type 8 *WR* records for example purposes. Combining with separate type 8 water rights is also useful for tracking individual computations when initially organizing and checking computations.

The *IF* record with identifier SPRINGEVENT sets the instream flow target. The other *WR* record water rights discussed above perform intermediate computations leading up to setting the *IF* record target. Type 8 *WR* records only set intermediate or final targets but otherwise have no effect on the simulation.

- *IF* record water right SPRINGEVENT sets a daily instream flow target equal to the minimum of the daily targets set by SPRINGTOTAL and MONTHMAX as specified on the first two *TO* records.
- The third *TO* record sets the target equal to the minimum of the preceding target or 60,000 ac-ft per day.
- Finally, the daily target of SPRINGEVENT is multiplied by quantities specified by two *FS* records.
    1. The first *FS* record tracks the daily target set by water right MARCHSTO. If the daily target of MARCHSTO is greater than 0.9 or less than 1.1, then the preceding target is multiplied by 1.0. The preceding target is multiplied by zero for all other cases.
    2. The final *FS* record sums the targets set by MARCHWET for 61 preceding days between March 1 and May 31. Because MARCHWET only sets targets up to March 31, the summation window for the *FS* record must extend from May 31 back to March 31. If the summation of targets set by MARCHWET is greater than 0.9, then the *FS* record multiplies the preceding target by 1.0. The preceding target is multiplied by zero for all other cases.

Daily instream flow targets for specified exceedance frequencies for Example 4 are shown in Table 4.20 for cases without and with the *IF* record right SPRINGEVENT. The only differences between the two simulations reflected in the frequency analysis results of Table 4.20 are the days in which the seasonal March through May (Spring) instream flow requirement at CP-2 is engaged. According to the frequency metrics of Table 4.20, the Spring instream flow target at CP-2 is engaged with an exceedance frequency of less than 5%.

Daily instream flow shortages with specified exceedance frequencies are tabulated in Table 4.21. The instream flow shortages are the same at CP-1. Daily instream flow shortages differ at CP-2 for those time steps in which the spring flow event is engaged. The daily limit on instream flow targets at CP-2 during the spring event is 60,000 acre-feet per day. This is often much greater than the naturalized flow which results in a large instream flow shortage. However, the goal of setting *IF* record targets for water right SPRINGEVENT is not to necessarily increase daily flows to 60,000 ac-ft per day. The overall goal of this exercise is to provide total monthly flow volumes over a 3-month period. Daily instream flow shortages should not be interpreted as a failure to achieve environmental flow protection in this example.

Table 4.20
Daily Instream Flow Target Frequency, acre-feet per day

	No Spring Target		**With Spring Target**	
CP	CP-1	CP-2	CP-1	CP-2
Mean	4148.0	4738.2	4148.0	6533.0
Std Dev	1593.6	1880.8	1593.6	10030.8
Minimum	929.7	939.9	929.7	939.9
99.5%	929.7	939.9	929.7	939.9
99%	929.7	939.9	929.7	939.9
98%	929.7	939.9	929.7	939.9
95%	929.7	939.9	929.7	939.9
90%	929.7	939.9	929.7	939.9
85%	929.7	939.9	929.7	939.9
80%	4769.5	5477.1	4769.5	5477.1
75%	4939.8	5672.7	4939.8	5672.7
70%	4939.8	5672.7	4939.8	5672.7
60%	4939.8	5672.7	4939.8	5672.7
50%	4939.8	5672.7	4939.8	5672.7
40%	4939.8	5672.7	4939.8	5672.7
30%	4939.8	5672.7	4939.8	5672.7
25%	4939.8	5672.7	4939.8	5672.7
20%	4939.8	5672.7	4939.8	5672.7
15%	4939.8	5672.7	4939.8	5672.7
10%	4939.8	5672.7	4939.8	5672.7
5%	4939.8	5672.7	4939.8	5672.7
2%	4939.8	5672.7	4939.8	60000.0
1%	4939.8	5672.7	4939.8	60000.0
0.5%	4939.8	5672.7	4939.8	60000.0
Maximum	4939.8	5672.7	4939.8	60000.0

Table 4.21
Daily Instream Flow Shortage Frequency, acre-feet per day

	No Spring Target		**With Spring Target**	
CP	CP-1	CP-2	CP-1	CP-2
Mean	877.5	1028.7	877.5	2167.8
Std Dev	1361.3	1601.3	1361.3	6964.4
Minimum	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0
99%	0.0	0.0	0.0	0.0
98%	0.0	0.0	0.0	0.0
95%	0.0	0.0	0.0	0.0
90%	0.0	0.0	0.0	0.0
85%	0.0	0.0	0.0	0.0
80%	0.0	0.0	0.0	0.0
75%	0.0	0.0	0.0	0.0
70%	0.0	0.0	0.0	0.0
60%	0.0	0.0	0.0	0.0
50%	0.0	0.0	0.0	0.0
40%	0.0	0.0	0.0	0.0
30%	1094.8	1272.3	1094.8	1814.8
25%	1807.9	2122.3	1807.9	2520.4
20%	2399.0	2784.7	2399.0	3153.7
15%	2916.6	3392.2	2916.6	3718.0
10%	3368.9	3937.1	3368.9	4270.4
5%	3771.8	4470.7	3771.8	4729.4
2%	4010.1	4732.8	4010.1	36525.4
1%	4010.1	4732.8	4010.1	47301.2
0.5%	4010.1	4732.8	4010.1	50277.6
Maximum	4010.1	4732.8	4010.1	56233.3

The daily regulated flow frequency results without and with the SPRINGEVENT instream flow requirement show very minor differences in Table 4.22. The daily regulated flow frequency was computed with *TABLES* for all months of the year. The effects of the SPRINGEVENT instream flow requirement are more evident in Table 4.23. Monthly average regulated flows at CP-2 are greater in March and April in the case containing the spring event requirement. This is a result of the instream flow requirement at CP-2. However, the reservoir at CP-1 must delay refilling storage when the spring event is engaged at CP-2. Refilling storage in subsequent months tends to counter the increased regulated flow that was protected during the spring event.

Table 4.22
Daily Regulated Flow Frequency, acre-feet per day

	No Spring Target		**With Spring Target**	
CP	CP-1	CP-2	CP-1	CP-2
Mean	11572.6	12704.5	11572.6	12704.6
Std Dev	22414.6	23535.6	22293.8	23384.8
Minimum	929.6	939.8	929.6	939.8
99.5%	929.6	939.8	929.6	939.8
99%	929.6	939.8	929.6	939.8
98%	929.6	939.8	929.6	939.8
95%	929.6	939.8	929.6	939.8
90%	929.6	1027.8	929.6	1027.8
85%	929.6	1219.8	929.6	1219.8
80%	1130.5	1426.1	1130.5	1426.1
75%	1426.5	1761.9	1426.5	1761.9
70%	1795.0	2138.1	1795.0	2138.1
60%	2735.1	3183.4	2735.1	3183.4
50%	4076.0	4706.7	4076.0	4706.7
40%	4939.8	5880.9	4939.8	5896.0
30%	5781.7	7537.4	5877.9	7628.6
25%	7746.7	9514.7	8000.5	9794.0
20%	11444.2	13115.9	11664.7	13437.6
15%	17787.7	19630.3	17950.5	19965.2
10%	31313.3	33516.5	31309.5	33598.8
5%	60237.1	63346.4	59840.3	62430.8
2%	109018.0	119009.9	108531.8	119009.9
1%	117187.2	119009.9	117048.7	119009.9
0.5%	119010.0	119009.9	119010.0	119009.9
Maximum	119010.0	119010.0	119010.0	119010.0

Table 4.23
Monthly Average Regulated at CP-2, thousand acre-feet per month

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
No Spring Target	372	396	478	458	864	680	267	119	165	259	238	344
With Spring Target	372	397	485	465	860	672	267	119	165	259	238	342

The firm yield for WR-1 is tabulated in Table 4.24 for the examples covered up to this point of the chapter. The inclusion of the spring instream flow requirement in Example 4 has no effect on the firm yield of WR-1. The spring instream flow requirement is limited only to years in which the March 1 storage at CP-1 is greater than or equal to 1.9 million ac-ft and when the hydrologic index equals 3. The firm yield in this example is governed by the drought that begins in the late 1940's and continues until mid-1957. The conditions for engaging the spring instream flow requirement do not occur during the critical drought period and consequently the inclusion of this instream flow requirement does not affect the firm yield computation for WR-1.

Table 4.24
Firm Yield for Water Right WR-1

IF Record Configuration	WR-1 Firm Yield, ac-ft per year
Example 1: No *IF* Records	1,731,000
Example 2: 7Q2 *IF* requirement No reservoir release for *IF*	1,490,500
Example 3: 7Q2 *IF* with reservoir release Median *IF* without reservoir release	1,327,500
Example 4: 7Q2 *IF* with reservoir release Median *IF* without reservoir release Spring *IF* requirement	1,327,500

Reservoir storage plots for Example 4 with and without the SPRINGEVENT instream flow *IF* record show essentially the same storage through the period-of-analysis. The exceptions are the few years when the event is engaged. In between engagements of the spring in stream flow requirement, the reservoir completely refills its conservation storage to the conservation capacity. When complete refilling occurs, the two reservoir storage series for Example 4 track exactly together. Figure 4.7 selects a smaller portion of the period-of-analysis. It is easier to see the few times when the two reservoir storage series for Example 4 diverge.

Regulated flow and the instream flow target at CP-2 are shown in Figures 4.8, 4.9, and 4.10. There are 13 years in the 58 year period-of-analysis in which the spring instream flow requirement is engaged. During these events, the instream flow target at CP-2 is raised to 60,000 acre-feet per day until the monthly maximum volume requirement is met. The daily target at CP-2 reverts back to median flow target for the remainder of the month of the month that the maximum regulated flow requirement is met. If the total 3-month volume has not been met, and the next day is April 1 or May 1, the daily instream flow target is set again at 60,000 acre-feet per day until the monthly maximum or the total 3-month volume is satisfied. The on-off daily target setting during the month of March is more clearly visible in Figure 4.10. The monthly maximum regulated flow volume requirement of 890,000 acre-feet is satisfied in March. The instream flow target was set again on April 1 because the cumulative regulated flow was less than 1.95 million acre-feet.

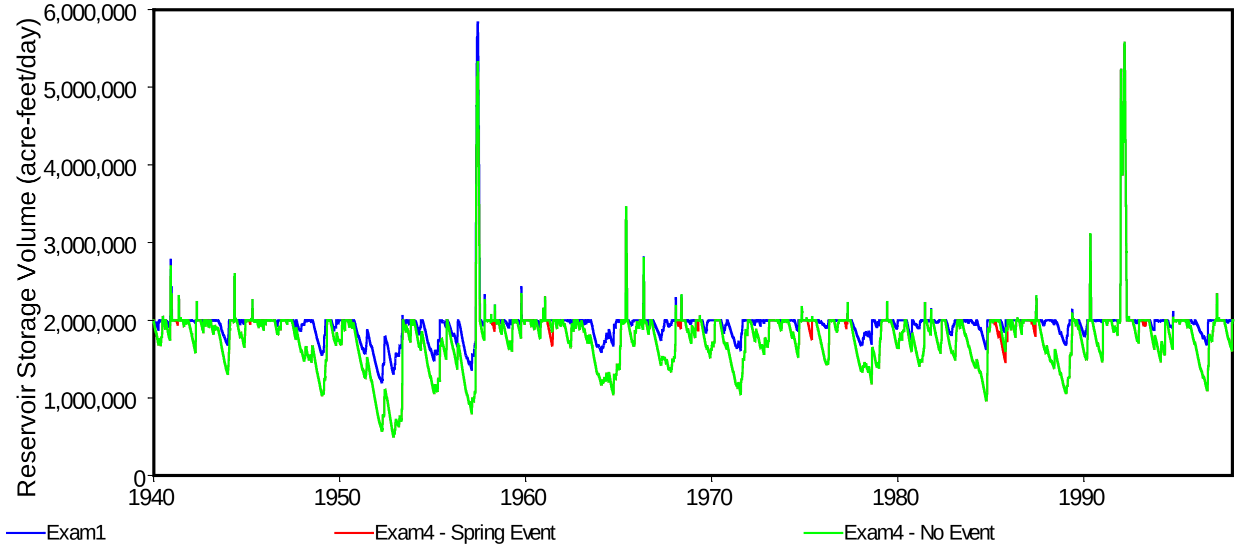

Figure 4.6 Reservoir Storage During 1940-1997 for Example 1 and Example 4

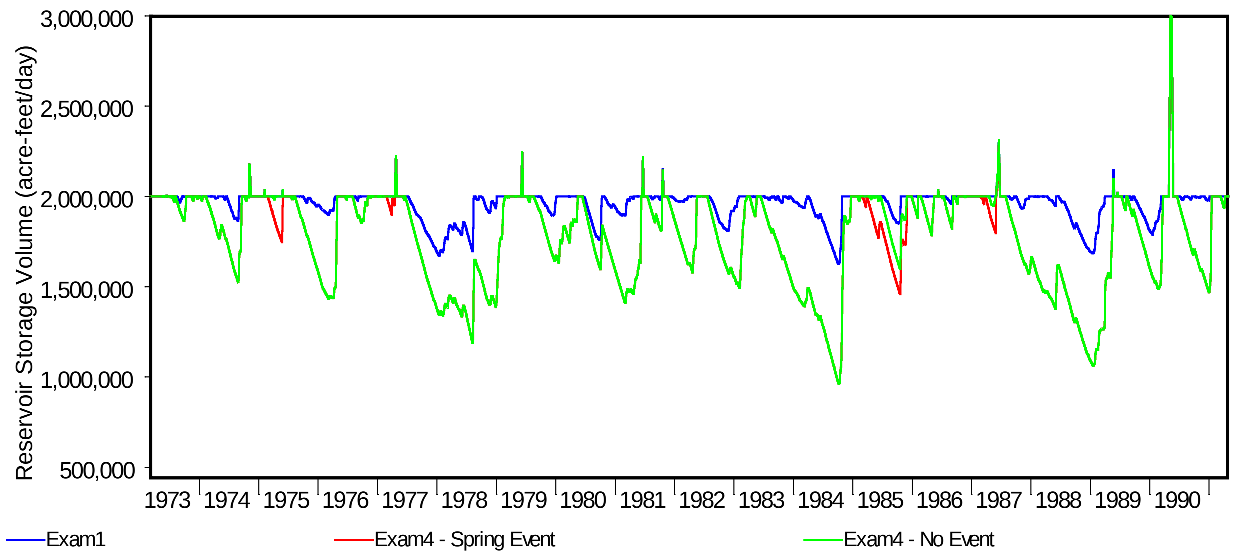

Figure 4.7 Reservoir Storage During 1973-1990 for Example 1 and Example 4

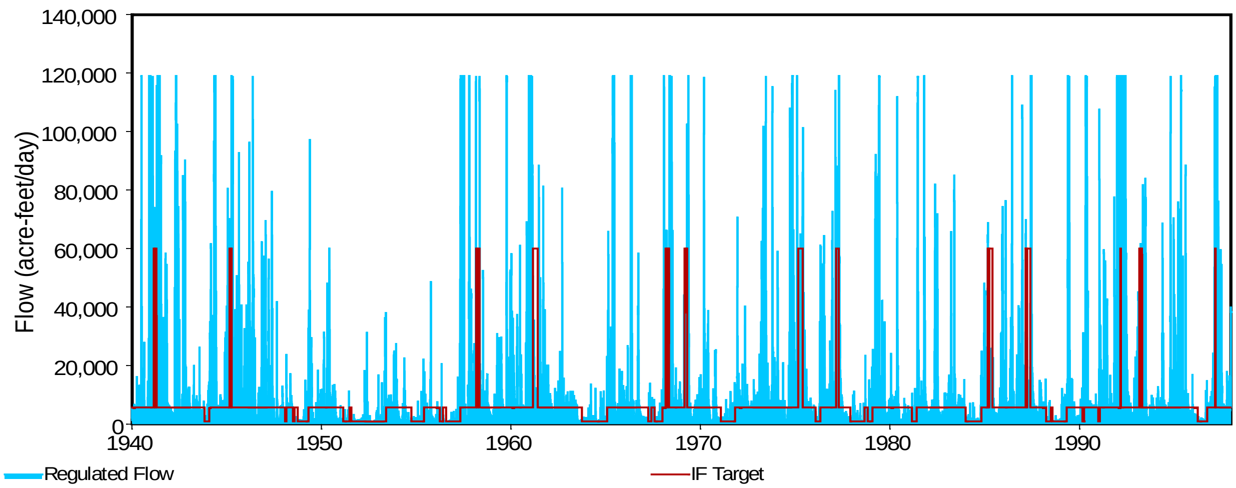

Figure 4.8 Regulated Flow and Instream Flow Target at CP-2 for Example 4 with Spring Target

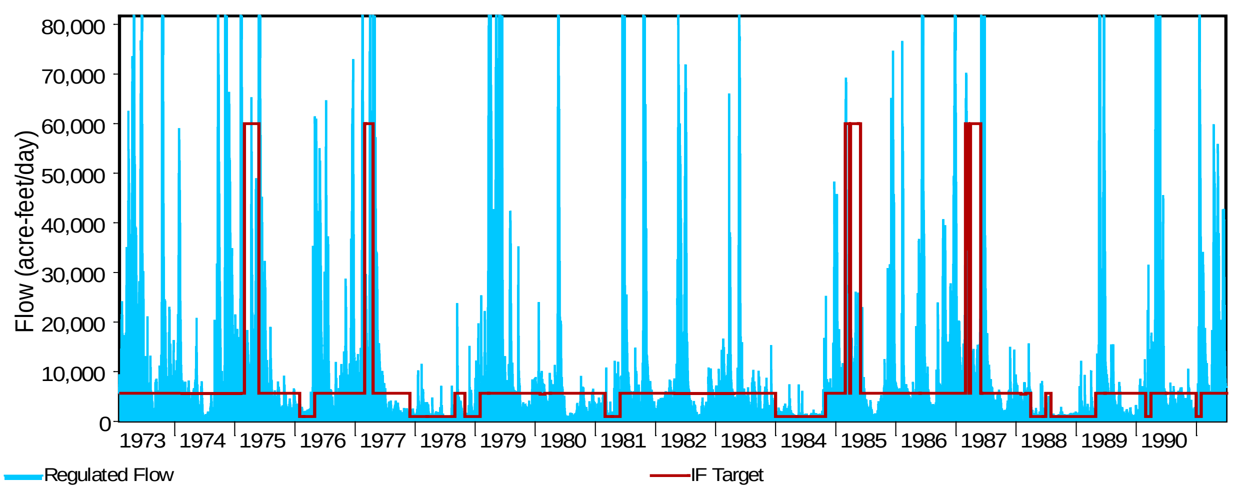

Figure 4.9 Regulated Flow and Instream Flow Target at CP-2 for Example 4 with Spring Target

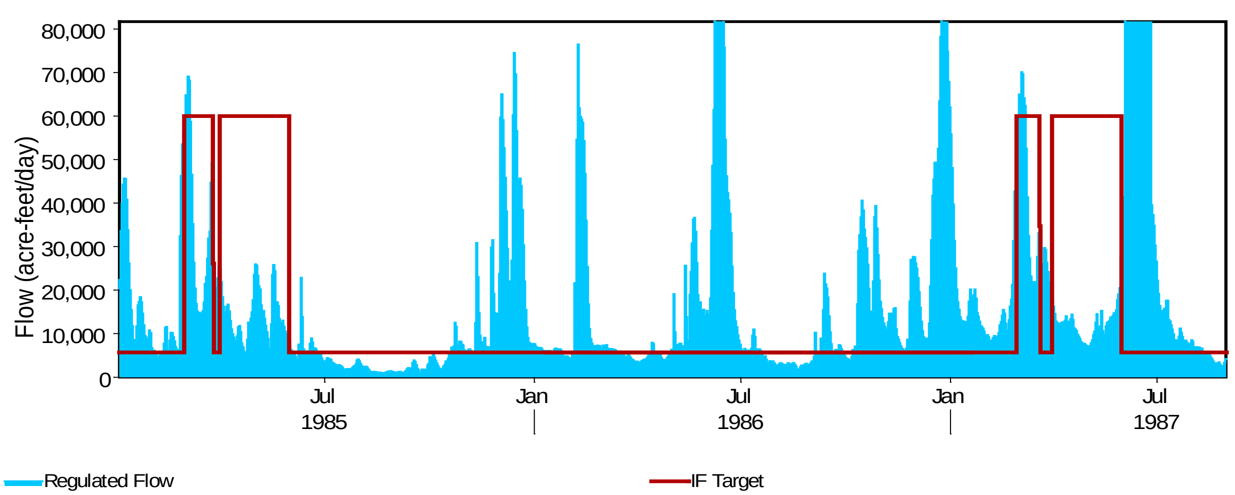

Figure 4.10 Regulated Flow and Instream Flow Target at CP-2 for Example 4 with Spring Target

Example 5 − Pulse Flow Events

Example 5 incorporates the environmental flow requirements developed in the preceding examples and adds a pulse flow requirement to complete an environmental flow regime that ranges from constant minimum flow limits to episodic high flow events. Example 5 covers the following topics.

- Pulse flow *PF* and pulse flow options *PO* records
- *SIMD* message file SMM optional *PF* record target building information and optional pulse flow summary tables

High flow pulses, referred to simply as pulses or pulse flow events, are short-duration, high flows that follow storm events. Stream flow pulses are typically direct runoff responses to rainfall. Pulses are important to the science of environmental flows for their contribution to the maintenance of important physical habitat features, their effect on the life cycle of aquatic and riparian species, and for nutrient and sediment transport in the river system. The inclusion of pulse flow requirements in Texas environmental instream flow standards is discussed in Chapter 2 of this report.

Pulse flow events typically have durations of several days or weeks. Therefore, modeling pulse flows requires a daily time step, or smaller, to correctly capture flow variability associated with these events. For this reason, pulse flow modeling features are included only in *SIMD*, not *SIM*. Capabilities for modeling pulse flow requirements are explained in Chapter 8 of the *Daily Manual* (Wurbs and Hoffpauir 2012) along with illustrative examples. The pulse flow *PF* and pulse flow options *PO* records are described in Appendix A of the *Daily Manual*.

Example 5 adds a set of *IF*, *PF*, and *PO* records to the Example 4 dataset that requires multiple pulses-per-year. The numerical values associated with the pulse flow requirement and additional rules for target setting and pulse termination are given in Table 4.25. The pulse flow requirements are located at CP-2 and are in addition to the 3-month seasonal flow requirement. Locating pulse flow requirements at a dam site, such as CP-1, is not a common practice. The particular values of daily flow rate, event duration, total volume, and frequency are arbitrarily chosen for the purposes of this example. Actual recommendations for pulse flow requirements on the Brazos River are described in Chapter 5 of this report.

The new Example 5 input records added to the Example 4 DAT file are shown in Table 4.26. All of the information given in Table 4.25 is encoded into the *PF* and *PO* records that are combined with the *IF* record. The input records for Example 4 are given in Table 4.19. The complete DAT file for Example 5 is composed of the input records shown in Tables 4.1, 4.19, and 4.25.

The *PF* and *PO* record fields are discussed in Chapter 3 of this report and in greater detail in Chapter 8 and Appendix A of the *Daily Manual*. A pulse flow requirement may consist of only a single *PF* record paired with a *WR* or *IR* record. No additional input records are required to model pulse flow requirements. Without a pulse flow option *PO* record, default settings are automatically adopted by *SIMD*. However, the *PO* record allows encoding of additional rules and target setting or termination features that are often part of pulse flow requirements.

Table 4.25
Example 5 Pulse Flow Requirement at CP-2

Pulse Event Characteristics

Trigger Flow	25,000	acre-feet per day
Total Event Volume	150,000	acre-feet per event
Maximum Event Duration	14	days
Event Occurrence Frequency	6	events per calendar year

Additional Rules

(a) Daily instream flow *IF* record targets are the lesser of regulated flow or the trigger flow rate of 25,000 acre-feet per day.

(b) A new pulse flow event cannot start until one day has lapsed since the end of the previous pulse flow event.

(c) Regulated flow must be less than the trigger flow rate the day prior to engaging a new pulse flow event.

(d) A pulse flow event is considered terminated if the regulated flow is less than 2,000 acre-feet per day.

(e) A pulse flow event will continue to be tracked past December 31 into the next calendar year until it terminates.

Table 4.26
Example 5 Input Records

```
IF  CP-2       0           1111   2            PULSE
PF                 25000  150000  14   6          1  12            2   1   3
PO         1       2    2000                   1
```

Example 5 includes only one pulse flow requirement at CP-2. In actual practice, pulse flow recommendations may include seasonal variations in pulse flow trigger, volume, duration, and frequency. Multiple levels of pulse flows may be required from small events that are slightly in excess of high base flow levels to large events that may include over-bank flow conditions. When multiple pulse flow requirements are specified at the same location, the *PO* record offers options to accommodate rules for coordinating and counting the additional pulse flow requirements on a continuous and simultaneous basis. Common features of the Senate Bill 3 environmental flow standards are rules for crediting smaller pulse flow requirements when a larger pulse flow requirement is engaged. The case study in Chapters 5, 6, and 7 of this report use multiple levels of pulse flow requirements at the same location. Additional *PO* record options are explored in conjunction with the case study.

PF and *PO* records are exclusive to *SIMD* and exclusive to sub-monthly time step simulations. *PF/PO* records are only considered in step 19 of the daily target building sequence.

A *DO* record is only needed for changing the step in the target building sequence for supplemental records that are common to both *SIM* and *SIMD*, such as *BU*, *TO*, *LO*, *DI*, *FS*, and *CV* records. These supplemental records are applied in steps 1 through 12 of the monthly target building sequence. In *SIMD*, these records may optionally be considered on a daily target building basis using the *DO* record.

The pulse flow requirement for Example 5 does not include additional restrictions such as certain values of the hydrologic index at CP-2 or a certain level of upstream reservoir storage at CP-1. These additional restrictions could be modeled in the same manner as shown in Examples 3 and 4. *PF/PO* records can be used in any combination with the other *SIMD* input records used in the other examples shown in this chapter. The only limitation is that *PF/PO* records can only be used in a sub-monthly (typically daily) simulation with *SIMD*.

The values entered on the *PF* record for Example 5 are explained as follows. The first four *PF* record values shown in Table 4.26 correspond to the first four rows in Table 4.25 for trigger, volume, duration, and frequency of pulse flow events. The fifth and sixth entries are the integers 1 and 12 in fields 10 and 11 that set a calendar year seasonal tracking period. The seventh *PF* record entry of 2 in field 14 requires the target limit to be no greater than the trigger flow rate according to rule (a) in Table 4.25. The eighth value adds the target determined by the *PF* record to the preceding target of the *IF* record. The last switch parameter value of 3 in field 16 controls daily target setting information output and end-of-simulation tables to be written to the daily SMM message file. The pulse flow tables contain annual rows and monthly columns of the number of pulse flow events engaged by the *PF* record during the period-of-analysis, and an annual row-monthly column table listing the number of pulse flow events engaged that failed to achieve the recommended total event volume prior to terminating.

The entries shown on the *PO* record in Table 4.26 are explained as follows. The first *PO* record value corresponds to *PO* record field 3. A value of 1 in field 3 requires an additional day to lapse between the last pulse flow event and engagement of a subsequent event according to rule (b) in Table 4.25. The integer 2 in field 5 requires that regulated flow must be less than the trigger flow rate the day prior to engaging a new pulse flow event according to rule (c). The third *PO* record entry sets a minimum flow of 2,000 acre-feet/day according to rule (d). If regulated flow is less than 2,000 ac-ft/day during an engaged pulse flow event, the event is terminated and no pulse flow target is set. The termination occurs without regard to the total event volume and days of duration requirements. The last *PO* record value corresponds to field 9 and allows a pulse flow to continue past the end of the year according to rule (e). For example, if regulated flow increases beyond 25,000 ac-ft/day at the end of December, and there have been five or less pulse flow events in the calendar year, a new pulse flow event is engaged. If the total event volume and number of days of event duration have not been satisfied by December 31, the pulse event will continue to be tracked into the next calendar year and continue to set pulse flow targets until otherwise terminated.

Daily instream flow target frequency relationships from the simulation results of Examples 4 and 5 are compared in Table 4.27. Two differences are noted. In Example 5, the median flow targets at CP-1 and CP-2 are at the 75% exceedance frequency as contrasted to the 80% exceedance frequency in Example 4. The pulse flow requirement in Example 5 tends to reduce reservoir storage content at CP-1 which in turn reduces the frequency of engagement of the median flow requirement. The second difference occurs after the 10% exceedance frequency at CP-2. The daily pulse flow target of 25,000 acre-feet/day occurs in the Example 5 simulation with a frequency of less than 10%.

Table 4.27
Daily Instream Flow Target Frequency, acre-feet per day

	Example 4		**Example 5**	
CP	CP-1	CP-2	CP-1	CP-2
Mean	4148.0	6533.0	3981.7	7211.3
Std Dev	1593.6	10030.8	1707.7	10723.5
Minimum	929.7	939.9	929.7	939.9
99.5%	929.7	939.9	929.7	939.9
99%	929.7	939.9	929.7	939.9
98%	929.7	939.9	929.7	939.9
95%	929.7	939.9	929.7	939.9
90%	929.7	939.9	929.7	939.9
85%	929.7	939.9	929.7	939.9
80%	4769.5	5477.1	929.7	939.9
75%	4939.8	5672.7	4769.5	5672.7
70%	4939.8	5672.7	4939.8	5672.7
60%	4939.8	5672.7	4939.8	5672.7
50%	4939.8	5672.7	4939.8	5672.7
40%	4939.8	5672.7	4939.8	5672.7
30%	4939.8	5672.7	4939.8	5672.7
25%	4939.8	5672.7	4939.8	5672.7
20%	4939.8	5672.7	4939.8	5672.7
15%	4939.8	5672.7	4939.8	5672.7
10%	4939.8	5672.7	4939.8	5672.7
5%	4939.8	5672.7	4939.8	25000.0
2%	4939.8	60000.0	4939.8	60000.0
1%	4939.8	60000.0	4939.8	60000.0
0.5%	4939.8	60000.0	4939.8	60000.0
Maximum	4939.8	60000.0	4939.8	60000.0

Daily instream flow shortage frequency metrics for the simulation results of Examples 4 and 5 are shown in Table 4.28. The mean target at CP-2 increases between Examples 4 and 5 in Table 4.27. However, the mean shortage at CP-2 decreases between Examples 4 and 5. The mean in Table 4.27 is influenced by the large target magnitude increase of the pulse flow requirement. However, pulse flow *PF* records do not set daily targets that are greater than the daily regulated flow. Therefore, no instream flow shortages will result from setting pulse flow targets. Reduced mean Example 5 CP-2 instream flow shortage is attributable to the reduced frequency of the median instream flow targets as a result of reduced reservoir storage content.

Daily regulated flow frequencies are given in Table 4.29 for the simulation results of Examples 4 and 5. The mean regulated flow at CP-1 and CP-2 does not meaningfully change with the addition of the pulse flow requirement. As was seen in the results of Example 4, adding the additional episodic instream flow requirement tends to decrease reservoir storage content while the instream flow requirement is engaged. However, reservoir storage content is refilled in subsequent time steps when the instream flow requirement is lifted. This tends to counter the increased regulated flow that was protected during the pulse flow events.

Table 4.28
Daily Instream Flow Shortage Frequency, acre-feet per day

	Example 4		Example 5	
CP	CP-1	CP-2	CP-1	CP-2
Mean	877.5	2167.8	801.7	2073.0
Std Dev	1361.3	6964.4	1315.0	6968.4
Minimum	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0
99%	0.0	0.0	0.0	0.0
98%	0.0	0.0	0.0	0.0
95%	0.0	0.0	0.0	0.0
90%	0.0	0.0	0.0	0.0
85%	0.0	0.0	0.0	0.0
80%	0.0	0.0	0.0	0.0
75%	0.0	0.0	0.0	0.0
70%	0.0	0.0	0.0	0.0
60%	0.0	0.0	0.0	0.0
50%	0.0	0.0	0.0	0.0
40%	0.0	0.0	0.0	0.0
30%	1094.8	1814.8	653.5	1356.6
25%	1807.9	2520.4	1515.3	2209.0
20%	2399.0	3153.7	2182.7	2908.5
15%	2916.6	3718.0	2759.9	3546.4
10%	3368.9	4270.4	3253.8	4129.5
5%	3771.8	4729.4	3690.2	4690.9
2%	4010.1	36525.4	4002.4	36684.7
1%	4010.1	47301.2	4010.1	47301.2
0.5%	4010.1	50277.6	4010.1	50277.6
Maximum	4010.1	56233.3	4010.1	56233.3

An abbreviation of the daily target setting output to the SMM file is given in Table 4.30. The information written for *PF* records is similar to the MSS file information written for *CV/FS* records as shown in Table 4.12. In each day of the period-of-analysis, the *PF* record variable value is written followed by the target set by the *PF* record. The cumulative event volume of the pulse flow event is recorded along with the count of the number of pulse flow events engaged to date. The final *PF* record target is recorded according to the *PF* record field 15 option.

Field 16 of the *PF* record is used to select the output shown in Tables 4.30 and 4.31. At the end of the simulation, tables with annual rows and monthly columns are written for *PF* records. The tables enumerate the number of pulse flow events that occur in each month of the simulation per *PF* record. The results in Table 4.31 give only the last rows of each table for Example 5. The individual years during the period-of-analysis are not shown here. There are two tables written to the SMM file for Example 5. The first table lists the number of pulse events that were initiated per month by the *PF* record. The second table lists the number of pulse events that were initiated but were terminated before reaching the total event volume criterion. For the pulse flow requirement in Example 5, the pulse flow can be terminated if the number of days has reached the event duration or if the regulated flow falls below 2,000 acre-feet per day.

Six pulse flow events are protected per year. If all six events occur in the 58 years of the period-of-analysis, the total number of pulse flow events engaged would be 348. The actual number of engaged events equals 232, or approximately 67% of the expected frequency. The recommendation of six pulse flow events per calendar year was used only for illustration purposes in Example 5. Careful analyses of stream flow records might result in pulse flow event recommendations that have a greater achievement rate during the period-of-analysis.

Table 4.29
Daily Regulated Flow Frequency, acre-feet per day

	Example 4		**Example 5**	
CP	CP-1	CP-2	CP-1	CP-2
Mean	11572.6	12704.6	11574.1	12706.0
Std Dev	22293.8	23384.8	22210.2	23162.0
Minimum	929.6	939.8	929.6	939.8
99.5%	929.6	939.8	929.6	939.8
99%	929.6	939.8	929.6	939.8
98%	929.6	939.8	929.6	939.8
95%	929.6	939.8	929.6	939.8
90%	929.6	1027.8	929.6	1000.7
85%	929.6	1219.8	929.6	1182.3
80%	1130.5	1426.1	1049.3	1366.6
75%	1426.5	1761.9	1322.9	1662.1
70%	1795.0	2138.1	1676.6	2025.8
60%	2735.1	3183.4	2611.9	3058.5
50%	4076.0	4706.7	3962.9	4567.9
40%	4939.8	5896.0	4939.8	5884.9
30%	5877.9	7628.6	5822.4	7674.0
25%	8000.5	9794.0	8002.4	10056.6
20%	11664.7	13437.6	12035.0	14237.1
15%	17950.5	19965.2	18540.6	21887.8
10%	31309.5	33598.8	32186.4	34047.8
5%	59840.3	62430.8	59772.9	60472.2
2%	108531.8	119009.9	108144.0	118765.0
1%	117048.7	119009.9	116660.1	119009.9
0.5%	119010.0	119009.9	119010.0	119009.9
Maximum	119010.0	119010.0	119010.0	119010.0

Table 4.30
Optional *PF* Record Target Setting Information Written to the SMM File

```
1940  6 19  PFV=   5672.  Target=     0.  Volume=      0.  Count= 0  Final=     0.0
1940  6 20  PFV=   9318.  Target=     0.  Volume=      0.  Count= 0  Final=     0.0
1940  6 21  PFV=  25000.  Target= 25000.  Volume=  25000.  Count= 1  Final= 25000.0
1940  6 22  PFV=  34206.  Target= 25000.  Volume=  59206.  Count= 1  Final= 25000.0
1940  6 23  PFV=  25000.  Target= 25000.  Volume=  84206.  Count= 1  Final= 25000.0
1940  6 24  PFV=  36689.  Target= 25000.  Volume= 120896.  Count= 1  Final= 25000.0
1940  6 25  PFV=  25000.  Target= 25000.  Volume= 145896.  Count= 1  Final= 25000.0
1940  6 26  PFV=  22568.  Target=  4104.  Volume= 168464.  Count= 1  Final=  4104.0
1940  6 27  PFV=   9347.  Target=     0.  Volume=      0.  Count= 0  Final=     0.0
1940  6 28  PFV=   5711.  Target=     0.  Volume=      0.  Count= 0  Final=     0.0
1940  6 29  PFV=   5672.  Target=     0.  Volume=      0.  Count= 0  Final=     0.0
1940  6 30  PFV=  25000.  Target= 25000.  Volume=  25000.  Count= 2  Final= 25000.0
1940  7  1  PFV=  34498.  Target= 25000.  Volume=  59498.  Count= 2  Final= 25000.0
1940  7  2  PFV=  92306.  Target= 25000.  Volume= 151805.  Count= 2  Final= 25000.0
1940  7  3  PFV= 113396.  Target=     0.  Volume=      0.  Count= 0  Final=     0.0
1940  7  4  PFV= 119010.  Target=     0.  Volume=      0.  Count= 0  Final=     0.0
```

Table 4.31
Optional *PF* Record Period-of-Analysis Tables Written to the SMM File

PULSE EVENTS INITIATED PER MONTH

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
21	30	28	33	46	20	10	4	10	15	8	7	232

PULSE EVENTS TERMINATED PER MONTH BEFORE MEETING EVENT VOLUME CRITERION

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
0	0	0	0	0	1	0	1	0	0	0	0	2

The *PF* record in Example 5 allows the six-per-year frequency to be met in any of the months of January through December. Consequently, in years when regulated flow is abundant, the pulse flow events tend to be met in the first half of the year as seen in the monthly totals of Table 4.31. An alternative strategy for setting the pulse flow requirement could be to use multiple *PF* records with shorter seasonal windows. For example, three *PF* records could be used to require two pulse flow events for the months of January through April, two pulse flow events for the months of May through August, and two pulse flow events for the months of September through December. This alternative configuration of *PF* records would more evenly spread the number of pulse flow events engaged per calendar year. Conversely, this alternative configuration would likely result in fewer pulse flow events being engaged overall during the period of record.

Reservoir storage plots for Examples 4 and 5 show similar storage content through the period-of-analysis except during the critical drought period. The pulse flow event requirements in Example 5 are not eased in response to hydrologic condition or reservoir storage. Reservoir refill is reduced during the critical drought period in Example 5. When the reservoir is near full or spilling, there is little difference in the reservoir storage plots between Examples 4 and 5.

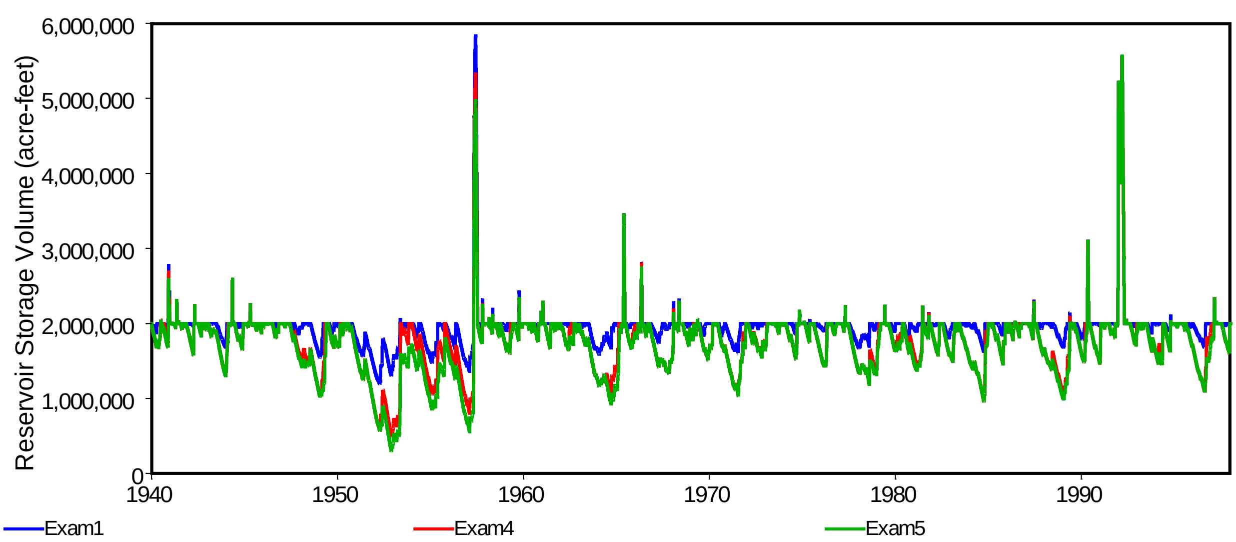

Figure 4.11 Reservoir Storage for Example 1, Example 4, and Example 5

Daily instream flow targets are superimposed on daily regulated flow at CP-2 for Example 5 in Figures 4.12 and 4.13. All four levels of instream flow requirements are visible in the targets set at CP-2. The four levels of environmental flow requirements include minimum levels based on 7Q2 flows and daily median flows, a 3-month flow seasonal volume, and a six-per-year pulse flow event. The 3-month flow volume requirement sets the largest daily targets up to 60,000 ac-ft per day. The pulse flow event sets a maximum target of 25,000 ac-ft per day.

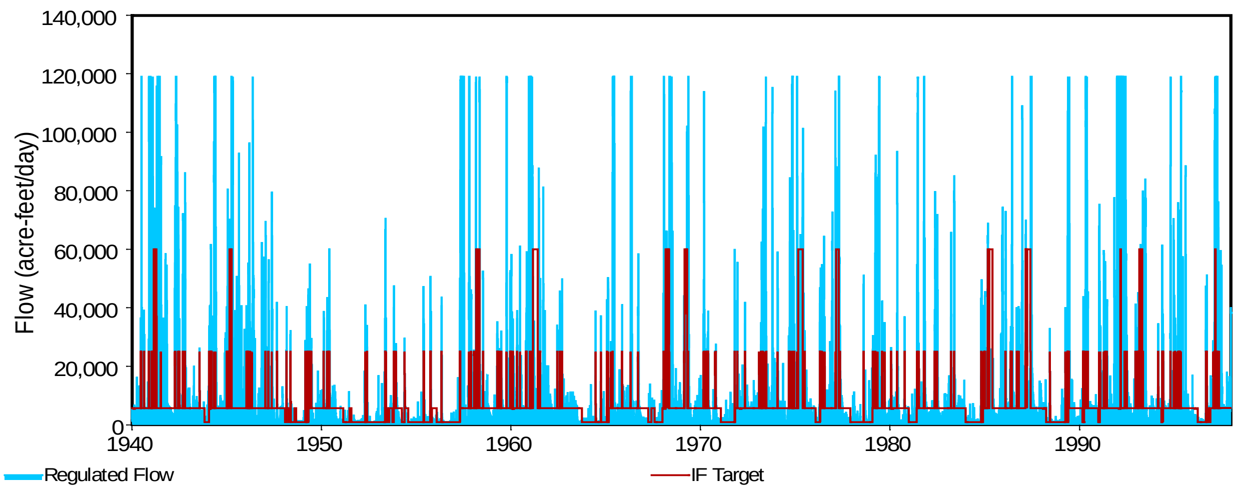

Figure 4.12 Example 5 Regulated Flow and Instream Flow Target at CP-2

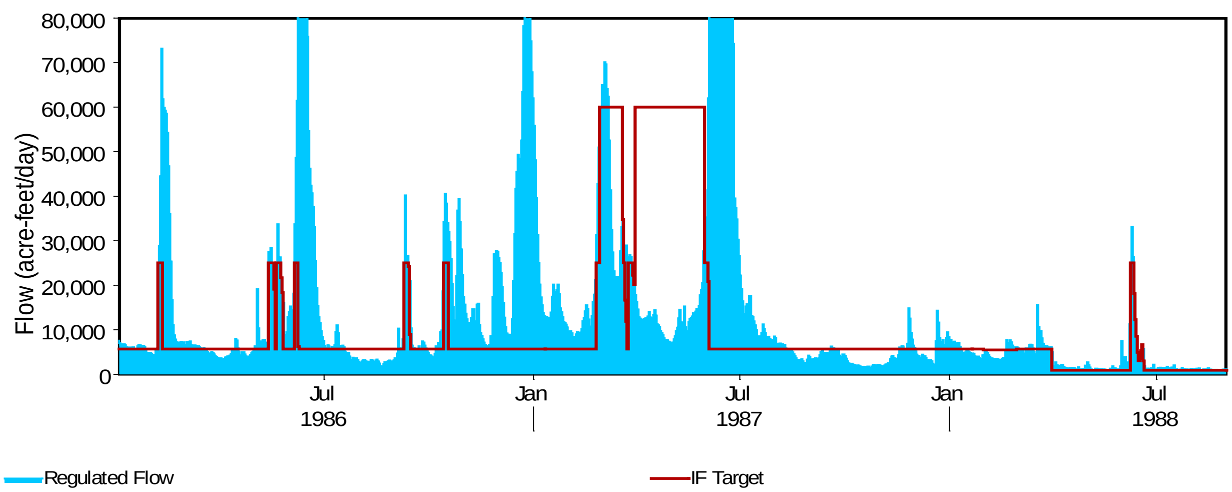

Figure 4.13 Example 5 Regulated Flow and Instream Flow Target at CP-2

Figure 4.14 highlights the pulse flow event occurring in June 1988. The instream flow requirements at CP-2 are senior in priority to the water right and reservoir refill at CP-1. However, the instream flow target is not set by the *PF* record at CP-2 until regulated flow exceeds 25,000 acre-feet/day. If there is travel time between the upstream junior water right and downstream senior pulse flow requirement, as is the case in this example, the upstream junior water right can suppress regulated flow downstream and prevent the pulse flow trigger flow rate from occurring. Example 5 is an extreme example of this behavior because of the size and capacity of the reservoir. Stream flow forecasting can reduce the chances that the upstream junior water right can suppress downstream future regulated flow below the pulse flow trigger. Once the pulse flow event is engaged at CP-2 in June 1988, the stream flow forecasts by the upstream junior water right ensure that regulated flow is not reduced below the trigger flow rate or the amount of naturalized flow until the pulse flow event is terminated on the twelfth day.

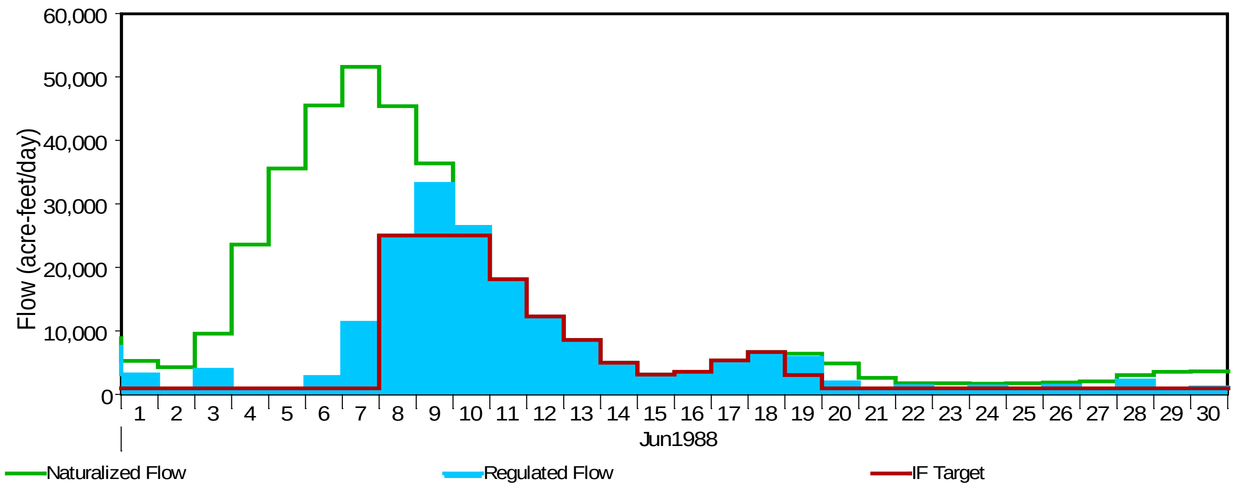

Figure 4.14 Example 5 Regulated Flow and Instream Flow Target at CP-2

Firm yields for the WR-1 diversion from the reservoir with the *SIMD* input datasets developed in the five examples are compared in Table 4.32. The firm yield for Example 5 is compared with the firm yields for Examples 1, 2, 3, and 4 previously presented in Table 4.32.

Table 4.32
Firm Yield for Water Right WR-1

IF Record Configuration	WR-1 Firm Yield, ac-ft per year
Example 1: No *IF* Records	1,731,000
Example 2: 7Q2 *IF* requirement	1,490,500
Example 3: 7Q2 *IF* with reservoir release Median *IF* without release	1,327,500
Example 4: 7Q2 *IF* with reservoir release Median *IF* without release Spring flow requirement	1,327,500
Example 5: 7Q2 *IF* with reservoir release Median *IF* without release Spring flow requirement Pulse flow requirement	1,240,400

Example 6 – Monthly Simulation

Example 6 is the only example in this chapter that uses a monthly computational time step. Monthly totals of daily instream flow targets are computed, examined, and applied. Example 6 illustrates a procedure by which daily instream flow targets computed in a daily *SIMD* simulation are summed within *SIMD* to monthly totals which are transported as input to a monthly *SIM* or *SIMD* simulation. The WRAP program *HYD* is used to convert monthly targets from *SIMD* simulation results to *SIM*/*SIMD* input data. Monthly simulations performed with either *SIM* or *SIMD* provide identically the same results. *SIMD* is required for daily simulations.

The Example 5 daily simulation DAT file shown in Table 4.33 is used in Example 6 to generate monthly minimum regulated flow limits. These flow targets computed in the daily *SIMD* simulation are summed within *SIMD* to monthly quantities and included in the simulation results. The monthly targets computed in the daily *SIMD* simulation are provided as target series *TS* records in a TSF input file for a monthly *SIMD* or *SIM* simulation. Program *HYD* is used with the HIN input file of Table 4.35 to convert the final instream flow targets at the two control points read by *HYD* from the *SIMD* OUT file to target series *TS* records in a TSF file read by *SIM* as input for the monthly simulation controlled by the DAT file shown in Table 4.38. The program *TABLES* is used with the TIN input file shown in Table 4.34 to tabulate the aggregated monthly totals of the instream flow targets in Table 4.39 for information purposes.

The *SIMD* input dataset for the daily simulation includes the DAT file of Table 4.33, FLO, EVA, and HIS files of Table 4.2, and DCF file of Table 4.3. The instream flow targets for the *IF* record water rights are computed during each day of the simulation, summed to monthly totals, and recorded in a *SIMD* monthly output file that has filename extension OUT. The monthly *SIM* input dataset includes the DAT file of Table 4.38, TSF file of Table 4.37, and FLO and EVA files of Table 4.2.

Table 4.33
Daily *SIMD* Input DAT File for Examples 5 and 6

```
T1  Environmental Flow Example 5
JD    58    1940       1      -1      -4       0       1
JO     2                                               1
JT     0  -1  -1                               2
JU                                 2
**
**FY        2500000  100000   10000    1000           WR-1
**
UCSPRING        0       0      31      30      31       0
UC              0       0       0       0       0       0
UC MARCH        0       0       1       0       0       0
UC              0       0       0       0       0       0
UC APRIL        0       0       0       1       0       0
UC              0       0       0       0       0       0
UC   MAY        0       0       0       0       1       0
UC              0       0       0       0       0       0
**
CP  CP-1    CP-2                    1
CP  CP-2     OUT                    1           NONE
**
WR  CP-1 1095000   NDAYS    4444   1                             WR-1
WSBIGRES 2000000
```

Table 4.33 Continued
Daily *SIMD* Input DAT File for Examples 5 and 6

```
**       1         2         3         4         5         6         7         8
**3456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
**     !       !       !       !       !       !       !       !       !       !
**  IF limits are set at minimum 7-day naturalized flow with 2 year recurrence interval.
**  Releases from reservoir storage are made as needed to meet instream flow targets.
**
IF  CP-2  939.87           1111       3         MINFLOW2
WSBIGRES 2000000
DW         1
IF  CP-1  929.67           1111       3         MINFLOW1
WSBIGRES 2000000
DW         1
**
**  IF targets are set at median of naturalized flow when storage content is greater
**  than or equal to 75% capacity. Reservoir storage is not used to meet IF targets.
**  The larger MINFLOW target is adopted when storage is less than 75% capacity.
**
IF  CP-1 1803038   NDAYS    1111   2           1 MEDIAN1
IF  CP-2 2070543   NDAYS    1111   2           1 MEDIAN2
**
**  IF requirement SPRINGEVENT allows 1.95 Maf to pass through CP-2 if storage
**  contents are equal or exceed 90% capacity and the hydrologic index signals
**  wet conditions in March. The volume requirement is for the period March-May.
**
WR  CP-2      92  SPRING    1111   8                           2 MARCHSTO
WR  CP-2      31   MARCH    1111   8                             MARCHWET
FS    12            1.0     0.0     2.9     3.1   1           0   3   3   1
WR  CP-2                    1111   8                             SPRINGTOTAL
CV     1           -1.0 1950000                          91   3   5   3
DO                19
WR  CP-2  890000   MARCH    1111   8                             MARCHMAX
CV     1           -1.0  890000                       3  30   3   3   3
DO                19
DW         2
WR  CP-2  820000   APRIL    1111   8                             APRILMAX
CV     1           -1.0  820000                       3  29   4   4   3
DO                19
DW         2
WR  CP-2 1450000     MAY    1111   8                             MAYMAX
CV     1           -1.0 1450000                       3  30   5   5   3
DO                19
DW         2
WR  CP-2                    1111   8                             MONTHMAX
TO    13            SET                                MARCHMAX        CONT
TO    13            MAX                                APRILMAX        CONT
TO    13            MAX                                MAYMAX
DO        16
IF  CP-2                    1111   2                SPRINGEVENT
TO    13            SET                                SPRINGTOTAL     CONT
TO    13            MIN                                MONTHMAX        CONT
TO    15   60000    MIN
FS    10            1.0     0.0     0.9     1.1   1           0   3   5   1    MARCHSTO
FS    10            1.0     0.0     0.9           1          61   3   5   1    MARCHWET
DO        16      19
**
**  IF requirement is set for 6 pulse flow events per year.
**
IF  CP-2       0            1111   2                PULSE
PF                25000  150000  14   6           1  12           2   1   3
PO         1       2    2000                   1
```

Table 4.33 Continued
Daily *SIMD* Input DAT File for Examples 5 and 6

```
**
**  Flood Flow Limit at CP-2 = 60,000 cfs = 119,010 ac-ft/day = 43,438,650 ac-ft/year.
**  Flood Pool at CP-1 has 4 Maf controlled storage with 119,010 af/day release limit.
**
FF  CP-2        43438650   NDAYS       0
FR  CP-1    8888    9999   0   2  119010 6500000 6000000 2000000
WSBIGRES
FVBIGRES               0          500000         1000000         7000000
FQ                     0           50000          100000          700000
**
SVBIGRES       0  500000 1000000 2000000 7000000
SA             0   18000   36000   50000  200000
**
**  Drought indices for IF record water rights are based on reservoir storage.
**
DI     1       1  BIGRES
IS     4       0 1499999 1500000 7000000
IP             0       0     100     100
DI     2       1  BIGRES
IS     4       0 1799999 1800000 7000000
IP             0       0     100     100
IM     1   2   3  -3  -3   6   7   8   9  10  11  12
ED
```

Table 4.34
TABLES Input TIN File for Tabulating Instream Flow Targets

```
2IFT   1   0   0   1   0   0   0
2IFT   1   0   0   0   0   0   0
ENDF
```

Table 4.35
HYD Input HIN File for Creating *TS* Records in Example 6

```
JC  1940  58   1
OI    18   2  TS
ED
```

The *WR* record water right with identifier WR-1 is a regular type 1 right with reservoir storage and a diversion. The other seven *WR* records in the DAT file of Table 4.33 are type 8 rights that control computations to develop components of the instream flow requirement specified by the *IF* record with water right identifier SPRINGEVENT.

The six *IF* record water rights that control the instream flow requirements in the *SIMD* DAT file of Table 4.33 are listed in Table 4.36. These are the instream flow requirements developed in the preceding examples and incorporated in Example 5. Instream flow targets are computed at control points CP-1 and CP-2 in the *SIMD* daily simulation. The six *IF* record water rights listed in Table 4.36 are each assigned the priority number 1111. With multiple rights with the same priority number, the rights are considered in the simulation in the order that the *IF* records are placed in the DAT file, which is the same order they are listed in Table 4.36.

Table 4.36
Instream Flow Requirements

Water Right Identifier	Control Point	Combining Option	Input Records	Description
MINFLO2	CP-2	−	*IF*, *WS*, *DW*	7Q2 minimum flow limit
MINFLO1	CP-1	−	*IF*, *WS*, *DW*	7Q2 minimum flow limit
MEDIAN1	CP-1	2	*IF*, *DI*, *IS*, *IP*	Median minimum flow limit
MEDIAN2	CP-2	2	*IF*, *DI*, *IS*, *IP*	Median minimum flow limit
SPRINGEVENT	CP-2	2	*IF*,*WR*,*TO*,*FS*,*CV*, *DO*,*DW*,*DI*,*IS*,*IP*,*IM*	March-May flow volume with daily and monthly limits
PULSE	CP-2	2	*IF*, *PF*, *PO*	High pulse flows

IF record field 7 controls the selection between the three options for combining multiple *IF* record instream flow targets at the same control point. Option 2 is selected in all cases, which means the largest target is adopted. Thus, daily instream flow targets developed by *SIMD* for the *IF* record rights listed in Table 4.36 are combined in the daily *SIMD* simulation as follows.

- *IF* record rights MINFLO2 and MINFLO1 at CP-2 and CP-1 are the first two of the six *IF* record rights considered in the *SIMD* simulation priority sequence.
- MEDIAN1 and MEDIAN2 are next in the priority sequence. The target set by MEDIAN1 is the largest of the MINFLO1 or MEDIAN1 intermediate targets. The target set by MEDIAN2 is the largest of the MINFLO2 or MEDIAN2 targets.
- The target set by the *IF* record right with identifier SPRINGEVENT is the largest of the MEDIAN2 and SPRINGEVENT intermediate-computed component targets.
- The target set by PULSE is the largest of the SPRINGEVENT and PULSE targets.

Daily instream flow targets are summed to monthly totals and written to the OUT file for both *IF* record water rights and control points. The combined targets noted above are recorded in the OUT file for the *IF* record rights listed in Table 4.36. With multiple targets at the same control point, the target set by the most junior *IF* record is recorded for the control point. Thus, the final target for MEDIAN1 is recorded in the *SIMD* OUT file for CP-1, and the final target for PULSE is recorded for CP-2. The *TABLES* input TIN file of Table 4.34 develops the tables of instream flow targets reproduced in Table 4.39 for the six *IF* records and the two control points.

Program *HYD* is documented by the *Hydrology Manual*. The *HYD* output-input *OI* input record activates a routine that reads selected monthly time series data from a *SIM* or *SIMD* output OUT file and writes the data in the *HYD* output HOT file in the format of *SIM* input records with a user-specified two-character record identifier. The *OI* record in the *HYD* input HIN file of Table 4.35 reads the monthly instream flow targets for the two control points from the *SIMD* output file and creates a set of *TS* records in the *HYD* output file. The filename is changed to include the extension TSF for use as a *SIM* input file. The first five lines of the TSF file are shown in Table 4.37. With monthly flow targets at two control points provided for the 696 months of the 1940-1997 simulation, the TSF files contains a total of 1,392 *TS* records.

Table 4.37
First Five Target Series *TS* Records in *SIM* Input TSF File for Example 6

```
TS  CP-1    1940153134.7138315.2153134.7148194.9153134.7148194.9153134.7153134.7148194.9153134.7148194.9153134.7
TS  CP-1    1941153134.7138315.2153134.7148194.9153134.7148194.9153134.7153134.7148194.9153134.7148194.9153134.7
TS  CP-1    1942153134.7138315.2153134.7148194.9153134.7148194.9153134.7153134.7148194.9153134.7148194.9153134.7
TS  CP-1    1943153134.7138315.2153134.7148194.9153134.7148194.9153134.7153134.7148194.9153134.7 27890.1 28819.8
TS  CP-1    1944 28819.8138315.2153134.7148194.9153134.7148194.9153134.7153134.7148194.9153134.7148194.9153134.7
TS  CP-1    1945153134.7138315.2153134.7148194.9153134.7148194.9153134.7153134.7148194.9153134.7148194.9153134.7
```

The target series *TS* records for the *IF* records with identifiers IF-1 and IF-2 in the monthly *SIM* input DAT file of Table 4.38 access the TSF file. Target series *TS* records are described in the *Users Manual*. The complete *SIM* input dataset is composed of DAT, TSF, FLO, and EVA files.

Table 4.38
Monthly *SIM* Input DAT File for Example 6

```
T1  Environmental Flow Example 6
JD    58    1940       1      -1       0       0       1
JO     2                                               1
**
**FY       2500000  100000   10000    1000            WR-1
**
CP  CP-1    CP-2                      1
CP  CP-2     OUT                      1             NONE
**
WR  CP-1 1095000   NDAYS    4444   0                           WR-1
WSBIGRES 2000000
**
IF  CP-1                    1111                IF-1
TS       TSF    CP-1
**
IF  CP-2                    1111                IF-2
TS       TSF    CP-2
**
SVBIGRES       0  500000 1000000 2000000 7000000
SA             0   18000   36000   50000  200000
ED
```

Example 6 illustrates the strategy of incorporating into the monthly *SIM* simulation all of the instream flow requirements from the daily *SIMD* simulation as the final targets at each control point. However, alternatively, some of the targets can be transported from *SIMD* simulation results as *TS* records while other targets are modeled directly in the monthly *SIM*. For example, base flows could be modeled directly in the monthly *SIM* while subsistence and pulse flows are modeled as *TS* records derived from a daily *SIMD* simulation. Pulse flow targets will essentially always be computed with a daily *SIMD* simulation.

In Example 6, the total final instream flow targets at control points CP-1 and CP-2 are assigned to *IF* record rights IF-1 and IF-2 in the DAT file of Table 4.38. However, alternatively, instream flow targets could adopted for each of the six individual *IF* record rights listed in Table 4.36. Options on the *HYD* output-input *OI* record convert instream flow targets for either water rights or control points from a *SIMD* OUT file to *TS* records to be read by *SIM* from a TSF file.

Seven *WR* records in the Table 4.33 DAT file are type 8 rights that control computations for intermediate components of the instream flow requirement specified by the *IF* record right SPRINGEVENT. These intermediate component targets can also be written to the *SIMD* output file and converted by *HYD* to *TS* records for input to *SIM*. The *WR* record type 8 targets can be tabulated by *TABLES* as diversion targets.

Comparison of Monthly Instream Flow Targets

The monthly instream flow targets for the six *IF* record rights listed in Table 4.36 are tabulated in Table 4.39. The *TABLES* input TIN file of Table 4.34 is used to develop the tables of Table 4.39 from the daily *SIMD* simulation with the DAT file of Table 4.33. As previously discussed, the targets for control point CP-1 are the targets for *IF* record right MEDIAN1. The targets for control point CP-2 are the targets for *IF* record right PULSE.

Table 4.39
Monthly Instream Flow Targets

Instream Flow Targets (acre-feet) for Water Right MINFLOW2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	29136.	27256.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	343992.
1941	29136.	26316.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	343052.
1942	29136.	26316.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	343052.
1943	29136.	26316.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	343052.
1944	29136.	27256.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	343992.
1945	29136.	26316.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	343052.

Targets for all leap years of the 1940-1997 simulation period are identical, and all non-leap year targets are identical.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1997	29136.	26316.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	343052.
MEAN	29136.	26559.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	343295.

Instream Flow Targets (acre-feet) for Water Right MINFLOW1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	28820.	26960.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	27890.	28820.	340259.
1941	28820.	26031.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	27890.	28820.	339330.
1942	28820.	26031.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	27890.	28820.	339330.
1943	28820.	26031.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	27890.	28820.	339330.
1944	28820.	26960.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	27890.	28820.	340259.
1945	28820.	26031.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	27890.	28820.	339330.

Targets for all leap years of the 1940-1997 simulation period are identical, and all non-leap year targets are identical.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1997	28820.	26031.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	27890.	28820.	339330.
MEAN	28820.	26271.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	27890.	28820.	339570.

Instream Flow Targets (acre-feet) for Water Right MEDIAN1 and Control Point CP-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1941	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1942	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1943	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	27890.	28820.	1558418.
1944	28820.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1678722.
1945	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1946	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1947	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1948	153135.	26960.	153135.	27890.	28820.	27890.	28820.	153135.	27890.	28820.	27890.	28820.	713204.
1949	28820.	26031.	28820.	27890.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1321818.
1950	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1951	153135.	138315.	28820.	27890.	28820.	27890.	153135.	28820.	27890.	28820.	27890.	28820.	700244.
1952	28820.	26960.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	27890.	28820.	340259.
1953	28820.	26031.	28820.	27890.	28820.	148195.	28820.	153135.	148195.	28820.	148195.	153135.	948874.
1954	153135.	138315.	153135.	27890.	28820.	148195.	153135.	28820.	27890.	28820.	27890.	28820.	944864.
1955	28820.	26031.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	148195.	153135.	583949.
1956	153135.	26960.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	27890.	28820.	464574.
1957	28820.	26031.	28820.	27890.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1321818.
1958	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1959	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1960	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1961	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1962	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1963	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	28820.	27890.	28820.	1434103.
1964	28820.	26960.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	27890.	28820.	340259.
1965	28820.	26031.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1566438.
1966	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1967	153135.	138315.	153135.	27890.	28820.	148195.	153135.	28820.	27890.	28820.	27890.	28820.	944864.
1968	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1969	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1970	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1971	153135.	26031.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	148195.	153135.	708264.
1972	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1973	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1974	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1975	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1976	153135.	26960.	28820.	27890.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1447063.
1977	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	28820.	1678723.
1978	28820.	26031.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	27890.	28820.	339330.
1979	28820.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1678722.
1980	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1981	28820.	26031.	28820.	27890.	28820.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1197504.
1982	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1983	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1984	28820.	26960.	28820.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	27890.	153135.	464574.
1985	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1986	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1987	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1988	153135.	138315.	153135.	27890.	28820.	27890.	28820.	28820.	27890.	28820.	27890.	28820.	700244.
1989	28820.	26031.	28820.	27890.	28820.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1197504.
1990	153135.	138315.	28820.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1678722.
1991	28820.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1678722.
1992	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1993	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1994	153135.	138315.	153135.	148195.	28820.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1678722.
1995	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
1996	153135.	138315.	153135.	27890.	28820.	27890.	28820.	28820.	27890.	153135.	27890.	153135.	948874.
1997	153135.	138315.	153135.	148195.	153135.	148195.	153135.	153135.	148195.	153135.	148195.	153135.	1803038.
MEAN	123128.	109372.	120984.	108785.	116698.	125378.	129558.	127414.	121230.	123128.	121230.	127414.	1454319.

Instream Flow Targets (acre-feet) for Water Right MEDIAN2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1941	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1942	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1943	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	28196.	29136.	1781839.
1944	29136.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1923824.
1945	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1946	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1947	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1948	175854.	27256.	175854.	28196.	29136.	28196.	29136.	175854.	28196.	29136.	28196.	29136.	784147.
1949	29136.	26316.	29136.	28196.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1502601.
1950	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1951	175854.	158836.	29136.	28196.	29136.	28196.	175854.	29136.	28196.	29136.	28196.	29136.	769009.
1952	29136.	27256.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	343992.
1953	29136.	26316.	29136.	28196.	29136.	170182.	29136.	175854.	170182.	29136.	170182.	175854.	1062446.
1954	175854.	158836.	175854.	28196.	29136.	170182.	175854.	29136.	28196.	29136.	28196.	29136.	1057713.
1955	29136.	26316.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	170182.	175854.	631756.
1956	175854.	27256.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	490711.
1957	29136.	26316.	29136.	28196.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1502601.
1958	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1959	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1960	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1961	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1962	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1963	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	29136.	28196.	29136.	1635120.
1964	29136.	27256.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	343992.
1965	29136.	26316.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1791304.
1966	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1967	175854.	158836.	175854.	28196.	29136.	170182.	175854.	29136.	28196.	29136.	28196.	29136.	1057713.
1968	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1969	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1970	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1971	175854.	26316.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	170182.	175854.	778475.
1972	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1973	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1974	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1975	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1976	175854.	27256.	29136.	28196.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1650259.
1977	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	29136.	1923824.
1978	29136.	26316.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	343052.
1979	29136.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1923824.
1980	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1981	29136.	26316.	29136.	28196.	29136.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1355882.
1982	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1983	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1984	29136.	27256.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	175854.	490711.
1985	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1986	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1987	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1988	175854.	158836.	175854.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	769009.
1989	29136.	26316.	29136.	28196.	29136.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1355882.
1990	175854.	158836.	29136.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1923824.
1991	29136.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1923824.
1992	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1993	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1994	175854.	158836.	175854.	170182.	29136.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1923824.
1995	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1996	175854.	158836.	175854.	28196.	29136.	28196.	29136.	29136.	28196.	175854.	28196.	175854.	1062445.
1997	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
MEAN	140440.	124661.	137910.	123669.	132851.	143253.	148028.	145499.	138357.	140440.	138357.	145499.	1658964.

Instream Flow Targets (acre-feet) for Water Right SPRINGEVENT

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1941	175854.	158836.	1027272.	1287956.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	4039734.
1942	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1943	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	28196.	29136.	1781839.
1944	29136.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1923824.
1945	175854.	158836.	1179798.	550473.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	3454777.
1946	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1947	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1948	175854.	27256.	175854.	28196.	29136.	28196.	29136.	175854.	28196.	29136.	28196.	29136.	784147.
1949	29136.	26316.	29136.	28196.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1502601.
1950	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1951	175854.	158836.	29136.	28196.	29136.	28196.	175854.	29136.	28196.	29136.	28196.	29136.	769009.
1952	29136.	27256.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	343992.
1953	29136.	26316.	29136.	28196.	29136.	170182.	29136.	175854.	170182.	29136.	170182.	175854.	1062446.
1954	175854.	158836.	175854.	28196.	29136.	170182.	175854.	29136.	28196.	29136.	28196.	29136.	1057713.
1955	29136.	26316.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	170182.	175854.	631756.
1956	175854.	27256.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	490711.
1957	29136.	26316.	29136.	28196.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1502601.
1958	175854.	158836.	1314436.	1800000.	664800.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	5327890.
1959	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1960	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1961	175854.	158836.	1860000.	1800000.	1860000.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	7068653.
1962	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1963	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	29136.	28196.	29136.	1635120.
1964	29136.	27256.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	343992.
1965	29136.	26316.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1791304.
1966	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1967	175854.	158836.	175854.	28196.	29136.	170182.	175854.	29136.	28196.	29136.	28196.	29136.	1057713.
1968	175854.	158836.	1625996.	1758804.	530843.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	5464296.
1969	175854.	158836.	1837825.	1256728.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	4819059.
1970	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1971	175854.	26316.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	170182.	175854.	778475.
1972	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1973	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1974	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1975	175854.	158836.	1860000.	1800000.	1697018.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	6905672.
1976	175854.	27256.	29136.	28196.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1650259.
1977	175854.	158836.	1860000.	1285064.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	29136.	4722852.
1978	29136.	26316.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	343052.
1979	29136.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1923824.
1980	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1981	29136.	26316.	29136.	28196.	29136.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1355882.
1982	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1983	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1984	29136.	27256.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	175854.	490711.
1985	175854.	158836.	1554473.	1800000.	1860000.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	6763126.
1986	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1987	175854.	158836.	1291456.	1800000.	1860000.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	6500108.
1988	175854.	158836.	175854.	28196.	29136.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	769009.
1989	29136.	26316.	29136.	28196.	29136.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1355882.
1990	175854.	158836.	29136.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1923824.
1991	29136.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1923824.
1992	175854.	158836.	610473.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2505161.
1993	175854.	158836.	1587124.	1431574.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	4743205.
1994	175854.	158836.	175854.	170182.	29136.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	1923824.
1995	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2070542.
1996	175854.	158836.	175854.	28196.	29136.	28196.	29136.	29136.	28196.	175854.	28196.	175854.	1062445.
1997	175854.	158836.	610473.	170182.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2505161.
MEAN	140440.	124661.	412621.	377093.	260739.	143253.	148028.	145499.	138357.	140440.	138357.	145499.	2314987.

Instream Flow Targets (acre-feet) for Water Right PULSE and Control Point CP-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	175854.	158836.	175854.	170182.	175854.	286145.	214509.	272491.	170182.	175854.	239864.	175854.	2391479.
1941	235582.	282157.	1085253.	1326610.	175854.	170182.	233836.	175854.	170182.	175854.	170182.	175854.	4377400.
1942	175854.	158836.	175854.	317132.	175854.	247491.	268184.	175854.	254422.	253163.	170182.	175854.	2548682.
1943	175854.	158836.	175854.	170182.	175854.	170182.	211194.	187041.	170182.	175854.	28196.	29136.	1828365.
1944	53196.	376859.	311145.	170182.	260490.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2385833.
1945	311145.	294127.	1257107.	550473.	175854.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	3802668.
1946	253163.	344779.	327971.	208836.	242594.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2591306.
1947	253163.	158836.	287525.	170182.	253163.	170182.	175854.	269438.	170182.	175854.	170182.	175854.	2430416.
1948	175854.	51316.	251556.	28196.	157641.	28196.	29136.	175854.	28196.	29136.	28196.	29136.	1012414.
1949	29136.	74437.	233342.	143662.	354328.	274778.	175854.	175854.	170182.	175854.	170182.	175854.	2153463.
1950	175854.	255473.	175854.	267423.	279040.	228163.	175854.	175854.	170182.	175854.	170182.	175854.	2425588.
1951	175854.	158836.	29136.	28196.	29136.	28196.	175854.	29136.	28196.	29136.	28196.	29136.	769009.
1952	29136.	27256.	29136.	130536.	161987.	35173.	29136.	29136.	28196.	29136.	28196.	29136.	586160.
1953	29136.	26316.	29136.	28196.	327196.	182707.	29136.	175854.	170182.	77256.	228163.	288280.	1591558.
1954	175854.	158836.	175854.	28196.	165941.	170182.	175854.	29136.	28196.	29136.	28196.	29136.	1194518.
1955	29136.	26316.	29136.	28196.	245677.	62782.	29136.	29136.	28196.	257325.	170182.	175854.	1111072.
1956	175854.	27256.	29136.	28196.	139804.	28196.	29136.	29136.	28196.	29136.	28196.	29136.	601379.
1957	29136.	26316.	29136.	182062.	202223.	170182.	175854.	175854.	170182.	247054.	324800.	175854.	1908652.
1958	285808.	208602.	1314436.	1800000.	664800.	170182.	233836.	175854.	170182.	175854.	170182.	175854.	5545590.
1959	175854.	158836.	175854.	368727.	287818.	208836.	246224.	175854.	170182.	233836.	170182.	240748.	2612952.
1960	272491.	247766.	175854.	189509.	246932.	235990.	175854.	175854.	170182.	380783.	170182.	175854.	2617250.
1961	345822.	216818.	1860000.	1800000.	1860000.	266818.	253163.	175854.	170182.	175854.	170182.	175854.	7470548.
1962	175854.	158836.	175854.	170182.	175854.	275915.	175854.	268120.	250295.	175854.	170182.	175854.	2348656.
1963	175854.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	170182.	29136.	28196.	29136.	1635120.
1964	29136.	27256.	29136.	28196.	29136.	131656.	29136.	29136.	76316.	107477.	28196.	29136.	573913.
1965	146793.	237950.	175854.	258647.	233836.	170182.	175854.	175854.	170182.	175854.	266206.	175854.	2363067.
1966	175854.	158836.	175854.	228163.	175854.	170182.	175854.	175854.	261325.	175854.	170182.	175854.	2219668.
1967	175854.	158836.	175854.	28196.	29136.	170182.	175854.	29136.	28196.	29136.	28196.	29136.	1057713.
1968	253163.	158836.	1683978.	1758804.	588825.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	5657570.
1969	175854.	238830.	1837825.	1256728.	253163.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	4976362.
1970	175854.	178163.	333986.	275485.	377376.	170182.	175854.	175854.	170182.	255708.	170182.	175854.	2634680.
1971	175854.	26316.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	136542.	170182.	253163.	963189.
1972	175854.	158836.	175854.	170182.	272192.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2166880.
1973	175854.	263454.	329346.	228163.	214509.	330940.	175854.	175854.	170182.	175854.	170182.	175854.	2586046.
1974	237206.	158836.	175854.	170182.	175854.	170182.	175854.	175854.	375513.	175854.	266818.	272491.	2530499.
1975	175854.	216818.	1860000.	1800000.	1697018.	170182.	272491.	175854.	170182.	175854.	170182.	175854.	7060289.
1976	175854.	27256.	29136.	219204.	358014.	198234.	340289.	175854.	170182.	175854.	170182.	175854.	2215912.
1977	175854.	216818.	1860000.	1285064.	271161.	170182.	175854.	175854.	170182.	175854.	170182.	29136.	4876141.
1978	29136.	26316.	29136.	28196.	29136.	28196.	29136.	125376.	28196.	29136.	28196.	29136.	439293.
1979	29136.	264217.	237375.	247491.	233836.	170182.	195182.	233836.	259479.	175854.	170182.	175854.	2392623.
1980	285699.	158836.	175854.	170182.	253163.	170182.	175854.	175854.	170182.	275386.	170182.	175854.	2357228.
1981	29136.	26316.	29136.	28196.	29136.	261231.	282342.	175854.	170182.	233836.	228163.	175854.	1669383.
1982	175854.	158836.	175854.	170182.	272491.	247491.	175854.	175854.	170182.	175854.	170182.	175854.	2244488.
1983	175854.	158836.	233836.	170182.	233836.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2186506.
1984	29136.	27256.	29136.	28196.	29136.	28196.	29136.	29136.	28196.	139057.	132177.	266621.	795379.
1985	252598.	228959.	1573800.	1800000.	1860000.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	6929320.
1986	175854.	236145.	175854.	170182.	391944.	228748.	175854.	175854.	269318.	253163.	170182.	175854.	2598954.
1987	175854.	216818.	1436380.	1800000.	1860000.	243311.	175854.	175854.	170182.	175854.	170182.	175854.	6776145.
1988	175854.	158836.	175854.	28196.	29136.	157414.	29136.	29136.	28196.	29136.	28196.	29136.	898227.
1989	29136.	26316.	29136.	149171.	209266.	248813.	175854.	175854.	170182.	175854.	170182.	175854.	1735619.
1990	175854.	158836.	293046.	247491.	175854.	247491.	175854.	175854.	170182.	175854.	170182.	175854.	2342352.
1991	197557.	248078.	175854.	228163.	253163.	247491.	175854.	175854.	170182.	175854.	170182.	175854.	2394087.
1992	175854.	158836.	610473.	170182.	253163.	170182.	279979.	175854.	170182.	175854.	170182.	275386.	2786127.
1993	272491.	339494.	1587124.	1431574.	233836.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	5078481.
1994	175854.	216818.	221690.	170182.	250464.	266818.	175854.	175854.	170182.	272491.	170182.	233836.	2500224.
1995	348722.	185504.	233836.	337931.	233836.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2553791.
1996	175854.	158836.	175854.	28196.	29136.	28196.	29136.	29136.	259938.	175854.	28196.	175854.	1294187.
1997	273539.	224039.	649128.	362481.	253163.	170182.	175854.	175854.	170182.	175854.	170182.	175854.	2976312.
MEAN	170246.	164146.	444931.	413393.	326356.	173740.	163907.	153221.	154377.	164486.	149338.	155836.	2633978.

The instream flow targets tabulated in the preceding tables are summations of daily targets from a *SIMD* simulation. The targets at control points CP-1 and CP-2 are input on target series *TS* records in a TSF file to the monthly *SIM* and serve as minimum limits on regulated flows specified by *IF* record water rights IF-1 and IF-2.

The instream flow targets created by *IF* record water right MINFLO2 at control point 2 are the same each year except for a difference in February of each leap year due to the 29 rather than 28 days. Likewise, the targets at control point 2 determined by *SIMD* for *IF* record water right MINFLO2 are the same each year except for a difference in February of each leap year.

The monthly instream flow targets for *IF* record water right MEDIAN1 are the monthly summations of daily targets consisting of the largest of the targets created by *IF* record water rights MINFLO1 and MEDIAN1. If reservoir storage contents equal or exceed 1,500,000 ac-ft, MEDIAN1 governs the setting of the daily instream flow target. Otherwise, MINFLO1 controls. Likewise, the monthly instream flow targets for *IF* record water right MEDIAN1 are the monthly totals of daily targets consisting of the largest of the targets created by *IF* record water rights MINFLO2 and MEDIAN2, with activation of MEDIAN2 depending on reservoir storage level.

The monthly targets recorded in the *SIMD* simulation results for control point CP-1 are the monthly totals of the final daily targets created by *IF* record water right MEDIAN1. Thus, the targets written to the *SIMD* output OUT file for control point CP-1 and *IF* record water right MEDIAN1 are the same.

The monthly targets for *IF* record water right MEDIAN2 are the monthly totals of daily targets consisting of the largest of the targets created by *IF* record rights MINFLO2 and MEDIAN2. The monthly targets for *IF* record right SPRINGEVENT are the monthly totals of daily targets determined by *SIMD* by selecting the largest of the targets computed by *IF* record water rights SPRINGEVENT and MEDIAN2. Likewise, the monthly targets for *IF* record right PULSE are the monthly aggregation of daily targets determined by *SIMD* by selecting the largest of the targets computed by *IF* record water rights PULSE and SPRINGEVENT.

The monthly targets recorded in the OUT file for control point CP-2 are the monthly totals of the final daily targets established by *IF* record right PULSE. Thus, the targets recorded in the *SIMD* output OUT file for control point CP-2 and *IF* record right PULSE are the same.

<u>Comparison of Reservoir Firm Yields</u>

The four alternative datasets listed below result in the firm yields shown in Table 4.40 for a diversion supplied by water right WR-1 reservoir BIGRES. Firm yields are shown for alternative negative increment flow options consisting of option 1 which is applied consistently throughout the six examples of Chapter 4 and alternatively the recommended options 6 and 7. Table 4.40 provides a comparison of firm yields for monthly versus daily simulations, with and without instream flow requirements, and with alternative negative incremental flow options.

The following four alternative DAT files are applied with associated hydrology files. The preceding discussions of Example 6 deal with the second and third datasets.

- The daily simulation DAT file of Example 1 reproduced as Table 4.1 has no instream flow requirements.
- The daily simulation DAT file of Example 5 reproduced as Table 4.33 incorporates several instream flow requirements into the DAT file of Example 1.
- The DAT file reproduced as Table 4.38 and accompanying target series TSF file are the monthly version of the Example 5 DAT file in Table 4.33.
- With the *IF* and accompanying *TS* records removed, the DAT file reproduced as Table 4.38 is the monthly version of the Example 1 DAT file in Table 4.1.

Table 4.40
Firm Yield Comparison of Example 6

Time Interval	IF Targets	Example	DAT File	Firm Yield NI Option 1	Firm Yield Options 6, 7
				(ac-ft/yr)	(ac-ft/yr)
day	no	1	Table 4.1	1,731,000	1,873,500
day	yes	5	Table 4.33	1,240,400	1,240,400
month	no	6	Table 4.38	1,842,900	1,892,200
month	yes	6	Table 4.38	1,378,600	1,378,600

Options for dealing with negative incremental flows are specified using the parameter ADJINC in *JD* record field 8 and are described in the *Reference*, *Users*, and *Daily Manuals*. A Brazos WAM case study comparison of the alternative negative incremental flow options is presented in Chapter 7 of Wurbs et al. (2012). Naturalized, regulated, and unappropriated flows and *SIM/SIMD* algorithms are based on total flows at each control point rather incremental flows between control points. Negative incremental refers to naturalized flows in a time interval that are greater upstream than downstream. The implications of negative incremental naturalized flows differ between daily and monthly simulations. The recommended standards of option 6 for monthly simulations and option 7 for daily simulations employ flow adjustments that mitigate the effects of negative incremental naturalized flows.

The examples in this chapter activate negative increment flow adjustment ADJINC option 1 which involves no adjustments. The firm yields in the fifth column of Table 4.40 reflect activation of option 1. The sixth column shows firm yields that reflect activation of option 6 for the monthly simulations and option 7 for the daily simulations. In this particular example, the adjustments increase the firm yields for the daily and monthly simulations that have no instream flow requirements but have no effect on the simulations with instream flow requirements.

Based on a monthly simulation, the firm yield of 1,892,200 acre-feet/year with instream flow requirements is 137 percent of the firm yield of 1,378,600 acre-feet/year with instream flow requirements. With a daily simulation, the firm yield of 1,873,500 acre-feet/year without instream flow requirements is 151 percent of the firm yield with instream flow requirements. The firm yield of 1,378,600 acre-feet/year based on a monthly simulation is 111 percent of the firm yield of 1,240,400 acre-feet/year based on a daily simulation.

Concluding Remarks

The examples of this chapter illustrate fundamentals of modeling environmental flow requirements with WRAP from the perspectives both of setting minimum limits on regulated flows and assessing the effects of these flow limits on the other water rights in the model. Various target building features are combined to model instream flow requirements. Pre and post-simulation analyses are accommodated by the WRAP program *TABLES* and WRAP options for storing simulation results in DSS files for plotting and analysis with HEC-DSSVue.

The examples cover the full range of flows relevant to the regime components outlined in Table 2.4 of Chapter 2. Examples 1, 2, and 6 deal with subsistence flows. Examples 1, 3, 4, and 6 are relevant to base flows. Examples 5 and 6 deal with high pulse flows, which may be either within bank or overbank pulse flows.

Most of the instream flow target setting capabilities are applicable for either monthly or daily simulations, with the notable exception of pulse flows which require a *SIMD* daily simulation. A strategy is proposed in this report for incorporating targets computed in a daily *SIMD* simulation into a monthly *SIM* input dataset. This strategy results in the correct monthly instream flow target volumes. However, the precision issue illustrated by Figure 3.1 of Chapter 3 is still inherent in assessing the impacts of instream flow requirements on other water rights.

The daily WRAP modeling system is documented in detail in the *Daily Manual* (Wurbs and Hoffpauir 2012) and explored in the Brazos case study presented by Wurbs et al. (2012). Options for placing routed flow changes either before or within the priority sequence are an example of the array of modeling choices inherent in the daily simulation model. All of the examples in this chapter use the *SIMD* default option to place routed changes to future stream flow at the beginning of the priority sequence. The alternative option is to place the routed changes to future flow within the priority sequence according to the water right making the change. Without routing between control points, the choice of placing routed stream changes before or within the priority sequence does not affect the simulation. Likewise, the effects of forecasting in a daily simulation are dependent on routing. The senior-most right will have access to the full naturalized flow if there is no routing or if the second option for placing changes to flow is adopted in a simulation that contains routing. The examples of this chapter illustrate the effect of a senior downstream instream flow requirement on junior upstream water availability as well as the effect of past junior upstream depletions on future regulated flow for the downstream senior instream flow requirement.

Only a portion of the overall WRAP simulation and analysis capabilities for evaluating environmental instream flow requirements are highlighted in the examples of this chapter. WRAP is a generalized modeling system providing a comprehensive range of features for modeling diverse water management strategies and issues. User creativity and experience with the modeling system enable essentially any environmental instream flow requirement to be modeled. The environmental flow modeling capabilities of WRAP are explored in greater depth in the Brazos WAM case study presented in Chapters 5, 6, and 7. The case study focuses on daily modeling, particularly modeling pulse flow requirements developed through the Senate Bill 3 process, but also employs an alternative monthly *SIM* simulation that incorporates environmental instream flow targets developed with a daily *SIMD* simulation.

CHAPTER 5
BRAZOS WAM CASE STUDY

The TCEQ WAM System dataset for the Brazos River Basin and San Jacinto-Brazos Coastal Basin, called the Brazos WAM, is adopted for the case study presented in Chapters 5, 6, and 7. The datasets used for the case study include the original Brazos WAM monthly dataset with a 1940-1997 period-of-analysis, a new daily model with a 1940-2012 period-of-analysis, and alternative variations thereof. This chapter describes the Brazos River Basin, Brazos WAM, and Brazos BBEST and BBASC recommended environmental flow regimes. Chapter 6 covers the development of expanded *SIM* and *SIMD* datasets. Chapter 7 is a comparative analysis of simulation results that explores key modeling and water management considerations.

Brazos River Basin and Brazos WAM

The Brazos River Basin delineated in Figure 5.1 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 was about 2,440,000 people.

Figure 5.1 Brazos River Basin

The TCEQ WAM System combines the Brazos River Basin and adjoining much smaller San-Jacinto-Brazos Coastal Basin in the same WRAP input dataset. The 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.

The original Brazos WAM completed in 2001 contained 1,216 water rights, all with seniority dates senior to February 2, 2000, which included 1,160 rights in the Brazos River Basin and 56 rights in the San Jacinto-Brazos Coastal Basin (HDR 2001). At least one water right *WR* record is contained in the Brazos WAM dataset for each water right, and many of the water rights are modeled with multiple *WR* records. Excluding hydropower and the portion of thermal electric cooling water returned to streams, diversion rights for municipal, industrial, agricultural irrigation, and other uses account for 47.6%, 30.1%, 18.0%, and 4.3% the total authorized consumptive water use in the Brazos River Basin (95.2%) and adjoining coastal basin (4.8%).

About 120 of the water right permits for diversions contain special conditions requiring that minimum instream flow rates must be maintained in the river or stream. The instream flow requirements are generally specified as flow rates in cubic feet per second (cfs), that may vary seasonally, at the diversion site or a downstream USGS stream gage. These special permit conditions are modeled with instream flow *IF* records and monthly use coefficient *UC* records.

The Brazos WAM is compared with the other river basin WAMs in Table 3.1 and Figure 3.1. 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 TCEQ is revising the Brazos WAM and datasets for other river basins to remove unnecessary control points along with other updates. Future versions of the Brazos WAM will have significantly fewer control points than indicated in Table 5.1. Counts of system components for the August 2007 and September 2008 versions of the Brazos WAM are tabulated in Table 5.1. All of the major reservoirs with greater than 5,000 acre-feet storage capacity are the same in the August 2007 and September 2008 versions, but the September 2008 updated datasets contain eight more small reservoirs than the datasets as last updated in August 2007. The 77 primary control points with *IN* records and the 67 control points with *EV* records are the same in all of the versions of the Bwam datasets.

Table 5.1
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 water right *WR* records	1,634	1,725	1,643	1,734
number of instream flow *IF* records	122	144	122	145
number of *FD* records in DIS file	3,138	3,141	3,152	3,157

Largest Reservoirs in the Brazos River Basin

The Brazos River Basin contains over 700 reservoirs cited in water right permits. Forty-three of these reservoirs have conservation storage capacities of 5,000 acre-feet or greater. The 16 reservoirs listed in Tables 5.2 and 5.3 and included on the map of Figure 5.2 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. The river basin totals of the water right diversions targets and storage capacities for the entire WAM datasets are shown at the bottom of Table 5.2. 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. The storage capacity of the 16 largest reservoirs account for about 79.7 percent and 80.7 percent of the total conservation storage capacity of the 678 and 719 reservoirs in the Bwam3 and Bwam8 datasets.

The 16 reservoirs are listed in both Tables 5.2 and 5.3. The reservoir data in Table 5.2 is from the TCEQ WAM System datasets, which are compiled from the water right permits which exclude flood control storage capacity since no permits have been issued for flood control. Table 5.3 includes the rivers, initial impoundment dates, and flood control storage capacities. The flood control pools of the nine federal reservoirs are included in the daily version of the Brazos WAM.

The U.S. Army Corps of Engineers (USACE) Fort Worth District owns and operates a system of nine multiple-purpose reservoirs. The Brazos River Authority (BRA) has contracted for the conservation storage capacity 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 of the 12-reservoir USACE/BRA system.

All of the controlled (gated) flood control storage capacity in the Brazos River Basin is contained in the nine USACE reservoirs listed in Table 5.3. The storage capacities of the designated flood control pools are tabulated in Table 5.3. These flood pool volumes are included in the daily Brazos WAM model and are based on 2010 sediment conditions, unlike the conservation capacities in Table 5.3 which are from the water right permits. 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.

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 total of both flood control and conservation capacity, Lake Whitney is the largest reservoir in the Brazos River Basin and the seventh largest reservoir in Texas. Whitney, Granbury, and Possum Kingdom are on the Brazos River and the other reservoirs are on tributaries.

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.

Table 5.2
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						
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			(79.8%)	(80.5%)	(39.7%)	(31.7%)
All other water rights			948,520	782,892	1,469,730	1,022,675
Total for the entire river basin			4,694,851	4,023,350	2,437,338	1,496,431

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.

Figure 5.2. Major Tributaries and Largest Reservoirs in the Brazos River Basin

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 (636,100 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.

The system operated by the USACE and BRA includes 12 reservoirs, including nine owned by the USACE and three owned by the BRA. The City of Waco has water right permits for Lake Waco, and the BRA holds water rights permits for the 11 other reservoirs. The BRA supplies customers through lakeside diversions and diversions from the river at downstream locations.

Several major water users divert from the lower reaches of the Brazos River and its tributaries supplied from BRA releases from multiple reservoirs. Water right permits held by the BRA since 1964 facilitate coordination of multiple-reservoir operations. As discussed later in this chapter, a water right application for a system operation permit submitted by the BRA in 2004 and pending TCEQ approval is designed to increase the effectiveness of system operations.

Table 5.3
Largest Reservoirs in the Brazos River Basin

Reservoir	Stream	Initial Impoundment	Storage Capacity Conservation (acre-feet)	Flood Control (acre-feet)	Total (acre-feet)
Brazos River Authority and U.S. Army Corps of Engineers					
Possum Kingdom	Brazos River	1941	724,739	−	724,739
Granbury	Brazos River	1969	155,000	−	155,000
Whitney	Brazos River	1951	636,100	1,363,400	1,999,500
Aquilla	Aquilla Creek	1983	52,400	93,600	146,000
Waco	Bosque River	1965	206,562	519,840	726,400
Proctor	Leon River	1963	59,400	314,800	374,200
Belton	Leon River	1954	457,600	640,000	1,097,600
Stillhouse Hollow	Lampasas River	1968	235,700	394,700	630,400
Georgetown	San Gabriel	1980	37,100	93,700	130,800
Granger	San Gabriel	1980	65,500	178,500	244,000
Somerville	Yequa Creek	1967	160,110	347,290	507,400
Limestone	Navasota River	1978	225,400	−	225,400
Allen′s Creek	Allen′s Creek	proposed	145,533	−	145,533
City of Lubbock					
Alan Henry	Double Mountain	1993	115,937	−	115,937
West Central Texas Municipal Water District					
Hubbard Creek	Hubbard Creek	1962	317,750	−	317,750
Texas Utilities Services (cooling water for Comanche Peak Power Plant)					
Squaw Creek	Squaw Creek	1977	151,500	−	151,500

Allen′s Creek Reservoir is the only proposed but not yet constructed project listed in Tables 5.2 and 5.3. The BRA, City of Houston, and Texas Water Development Board jointly hold a water right permit for this proposed off-channel reservoir 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. 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.

Primary Control Points with Naturalized Streamflows

Primary control points are locations at which naturalized stream flows are provided in a *SIM* input dataset. Naturalized flows at all other 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 watershed 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 in a flow distribution 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.

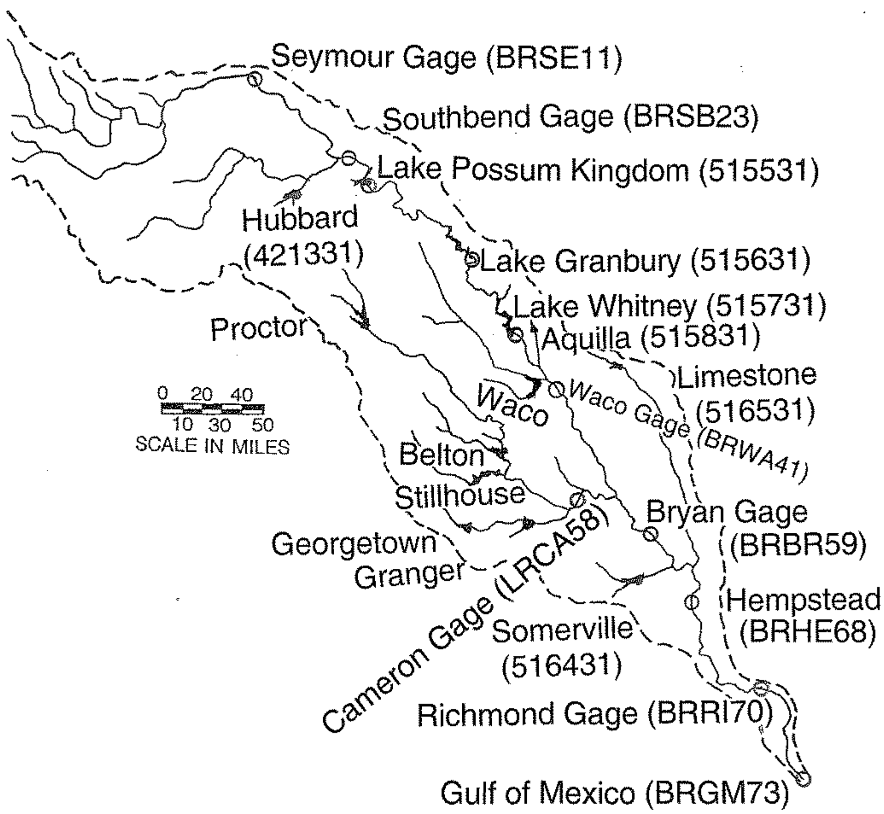

Figure 5.3 Eight of the Primary Control Points and 13 of the Largest Reservoirs

The 77 primary control points with naturalized flows provided as *IN* records in the Brazos WAM dataset are listed in Table 5.4 and shown in the schematic of Figure 5.4 with the six-character identifiers used in the data files. Eight of the primary control points and several reservoir secondary control points are included in Figure 5.3, with identifiers in parenthesis.

Table 5.4
Primary Control Points in the Brazos WAM Datasets

WAM CP ID	Stream	Nearest City	USGS Gage No.	Watershed Area (sq miles)	USGS Period of Record
RWPL01	Running Water Draw	Plainview	08080700	295	1939–present
WRSP02	White River Reservoir	Spur	08080910	689	1964-1976
DUGI03	Duck Creek	Girard	08080950	300	1964-1989
SFPE04	Salt Fork Brazos River	Peacock	08081000	2,007	1950–1986
CRJA05	Croton Creek	Jayton	08081200	293	1959–1986
SFAS06	Salt Fork Brazos River	Aspermont	08082000	2,504	1924–present
BSLU07	Buffalo Spring Lake	Lubbock	–	245	Reservoir releases
DMJU08	Double Mountain Fork	Justiceburg	08079600	265	1961–present
DMAS09	Double Mountain Fork	Aspermont	08080500	1,891	1923–present
NCKN10	North Croton Creek	Knox City	08082180	250	1965–1986
BRSE11	Brazos River	Seymour	08082500	5,996	1923–present
MSMN12	Millers Creek	Munday	08082700	106	1963–present
CFRO13	Clear Fork Brazos	Roby	08083100	266	1962–present
CFHA14	Clear Fork Brazos	Hawley	08083240	1,456	1967–1989
MUHA15	Mulberry Creek	Hawley	08083245	208	1967–1989
CFNU16	Clear Fork Brazos	Nugent	08084000	2,236	1924–present
CAST17	California Creek	Stamford	08084800	476	1962–present
CFFG18	Clear Fork Brazos	Fort Griffin	08085500	4,031	1924–present
HCAL19	Hubbard Creek	Albany	08086212	612	1966–present
BSBR20	Big Sandy Creek	Breckenridge	08086290	289	1962–present
HCBR21	Hubbard Creek	Breckenridge	08086500	1,092	1955–1986
CFEL22	Clear Fork Brazos	Eliasville	08087300	5,738	1915–1982
BRSB23	Brazos River	South Bend	08088000	13,171	1938–present
GHGH24	Lake Graham	Graham	–	224	reservoir releases
CCIV25	Big Cedar Creek	Ivan	08088450	97	1964–1989
SHGR26	Brazos River	Graford	08088600	14,093	1976–1994
BRPP27	Brazos River	Palo Pinto	08089000	14,309	1924–present
PPSA28	Palo Pinto Creek	Santo	08090500	574	1924–1976
BRDE29	Brazos River	Dennis	08090800	15,733	1968–present
BRGR30	Brazos River	Glen Rose	08091000	16,320	1923–present
PAGR31	Paluxy River	Glen Rose	08091500	411	1924–present
NRBL32	Nolan River	Blum	08092000	282	1947–present
BRAQ33	Brazos River	Aquilla	08093100	17,746	1938–present
AQAQ34	Aquilla Creek	Aquilla	08093500	307	1939–2001
NBHI35	North Bosque River	Hico	08094800	360	1994–2003
NBCL36	North Bosque River	Clifton	08095000	977	1923–2008
NBVM37	North Bosque River	Valley Mills	08095200	1,158	1959–present
MBMG38	Middle Bosque River	McGregor	08095300	77	1959–present
HGCR39	Hog Creek	Crawford	08095400	181	1959–present
BOWA40	Bosque River	Waco	08095600	1,660	1959–1982
BRWA41	Brazos River	Waco	08096500	20,065	1898–present
BRHB42	Brazos River	Highbank	08098290	20,900	1965–present
LEDL43	Leon River	De Leon	08099100	267	1960–present
SADL44	Sabana River	De Leon	08099300	476	1960–present
LEHS45	Leon River	Hasse	08099500	1,283	1939–present

Table 5.4 Continued
Primary Control Points in the Brazos WAM Datasets

WAM CP ID	Stream	Nearest City	USGS Gage No.	Watershed Area (sq miles)	USGS Period of Record
LEHM46	Leon River	Hamilton	08100000	1,928	1925–present
LEGT47	Leon River	Gatesville	08100500	2,379	1950–present
COPI48	Cowhouse Creek	Pidcoke	08101000	455	1950–present
LEBE49	Leon River	Belton	08102500	3,579	1923–present
LAKE50	Lampasas River	Kempner	08103800	817	1962–present
LAYO51	Lampasas River	Youngsport	08104000	1,240	1924–1980
LABE52	Lampasas River	Belton	08104100	1,321	1963–present
LRLR53	Little River	Little River	08104500	5,266	1923–present
NGGE54	North Fork San Gabriel	Georgetown	08104700	248	1968–present
SGGE55	South Fork San Gabriel	Georgetown	08104900	132	1967–present
GAGE56	San Gabriel River	Georgetown	08105000	404	1924–1987
GALA57	San Gabriel River	Laneport	08105700	737	1965–present
LRCA58	Little River	Cameron	08106500	7,100	1916–present
BRBR59	Brazos River	Bryan	08109000	30,016	1899–1993
MYDB60	Middle Yegua Creek	Dime Box	08109700	235	1962–present
EYDB61	East Yegua Creek	Dime Box	08109800	239	1962–present
YCSO62	Yegua Creek	Somerville	08110000	1,011	1924–1991
DCLY63	Davidson Creek	Lyons	08110100	195	1962–present
NAGR64	Navasota River	Groesbeck	08110325	240	1978–present
BGFR65	Big Creek	Freestone	08110430	97	1978–present
NAEA66	Navasota River	Easterly	08110500	936	1924–present
NABR67	Navasota River	Bryan	08111000	1,427	1951–1997
BRHE68	Brazos River	Hempstead	08111500	34,374	1938–present
MCBL69	Mill Creek	Bellville	08111700	377	1963–1993
BRRI70	Brazos River	Richmond	08114000	35,454	1903–present
BGNE71	Big Creek	Needville	08115000	46	1947–present
BRRO72	Brazos River	Rosharon	08116650	35,775	1967–present
BRGM73	Brazos River	Gulf of Mexico	–	36,027	–
CLPEC1	Clear Creek	Pearland	08077000	38.8	1944–1994
CBALC2	Chocolate Bayou	Alvin	08078000	87.7	1959–present
SJGBC3	Coastal Basin	Galveston Bay	–	415	–
SJGMC4	Coastal Basin	Gulf of Mexico	–	1,004	–

The first 73 control points listed in Table 5.4 are located in the Brazos River Basin, and the last four are in the San Jacinto-Brazos Coastal Basin. The watershed drainage areas shown in Table 5.4 are from the watershed parameter *WP* records in the DIS file and do not include non-contributing areas of the upper Brazos River Basin in and near New Mexico.

The 77 primary control points in the Brazos WAM include the sites of 72 USGS stream gaging stations, two sites at which reservoir releases have been measured, and three ungaged basin outlets. Table 5.4 shows the beginning and last years of the period-of-record for each gage but does not show the gaps or missing data during the period-of-record that occurs in some of the gage records. Twenty-one of the gages have records that include the 1940-1997 Brazos WAM period-of-analysis. Nineteen gages have records that include 1940 to the present. Forty-nine of the 72 gages have records for 1998 to the present.

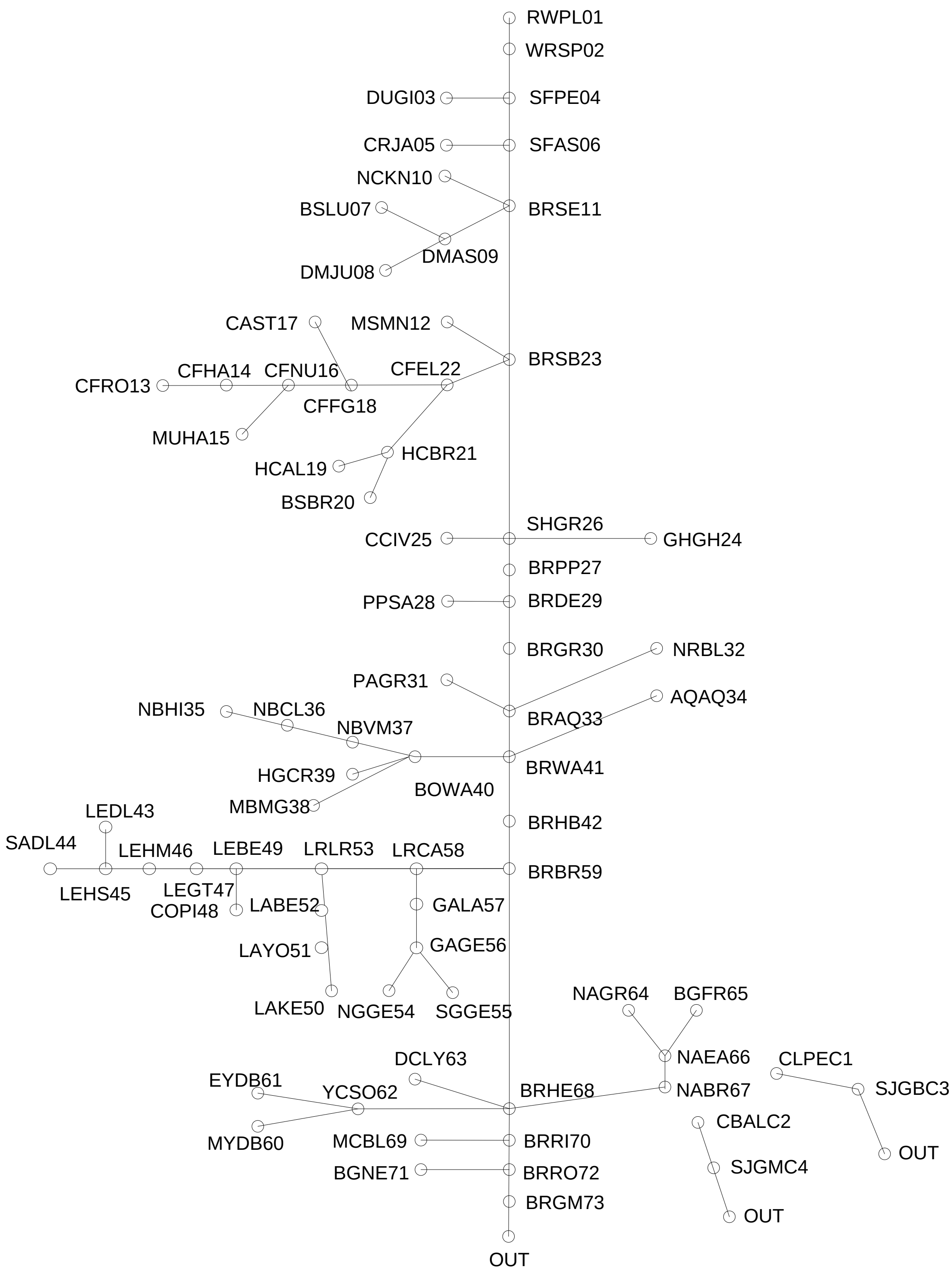

Figure 5.4 Schematic of Primary Control Points (Not to Scale)

Prior Studies and Reports

The development and initial application of the original Brazos WAM datasets is documented by reports prepared for the TCEQ by Freese and Nichols, Inc. (2001) and HDR Engineering (2001). The Brazos River Basin has served as the case study for continuing endeavors in expanding WRAP that are documented by Texas Water Resources Institute technical reports (Wurbs et al. 1988; Wurbs et al. 1994; Wurbs and Kim 2008; Wurbs and Lee 2009; and Wurbs et al. 2012) that are available at: http://twri.tamu.edu/publications/reports/.

All datasets in the TCEQ WAM System, including the Brazos WAM, are based on a monthly computational time interval. Wurbs et al. (2012) document the conversion of the monthly Brazos WAM to a daily time step and application of the new capabilities covered in the August 2012 *Daily Manual*. The original Brazos WAM has a hydrologic period-of-analysis of 1940-1997. Wurbs and Chun (2012) demonstrate the new hydrology extension capabilities documented in the November 2012 *Hydrology Manual* by updating the Brazos WAM period-of-analysis to cover 1940-2011. The present case study builds upon these preceding endeavors.

The Brazos River Authority (BRA) submitted a System Operation Permit to the TCEQ in June 2004 that is still under review pending TCEQ approval. The BRA developed a water management plan during 2012 in conjunction with the water right permit application. On November 28, 2012, the BRA submitted to the TCEQ the proposed Water Management Plan (WMP) and the Technical Report supporting the WMP (Brazos River Authority 2012). The WMP is a regulatory document that, if approved by the TCEQ, will be included as part of the proposed System Operation Permit. The BRA Technical Report expands upon the regulatory document, providing background information designed to assist the TCEQ staff in evaluating the proposed WMP. The Technical Report is a lengthy document that includes seven chapters, 22 appendices, and two accounting plans. The Water Management Plan and Technical Report are available at: http://www.brazos.org/SysOpsWMP.asp

The proposed System Operation Permit will allow the BRA to use naturally occurring flows in the river system and return flows from wastewater treatment plants in conjunction with the water supply from its 11 existing reservoirs. The unregulated flows originating from precipitation runoff entering the rivers downstream of the BRA reservoirs can be used along with, as needed, releases from upstream reservoirs to provide a system firm yield (or yield for a given reliability) that is substantially greater than the sum of individual reservoir yields. The proposed BRA System Operation Permit also implements environmental flow requirements that were developed in cooperation with the TPWD and TCEQ based on mimicking the natural hydrology and includes adaptive management provisions to ensure that the environmental flow criteria can be adjusted to apply with SB-3 requirements and future field and office studies.

The Basin and Bay Expert Science Team (BBEST) for the Brazos River Basin submitted its Environmental Flow Regime Recommendation Report to the Brazos Basin Area Stakeholders Committee (BBASC), Environmental Flows Advisory Group, and TCEQ in March 2012. The BBASC submitted its Environmental Flow Standards and Strategies Recommendations Report to the TCEQ in August 2012. These two reports are available at the following TCEQ website.

http://www.tceq.texas.gov/permitting/water_rights/eflows/brazos-river-and-associated-bay-and-estuary-system-stakeholder-committee-and-expert-science-team

Monthly WAM Simulation Results

The following overview summary of monthly Brazos WAM simulation results provides a general perspective of the relative magnitude of volume budget components and illustrates the dramatic temporal and spatial variability of streamflows. The introductory monthly simulation results presented here in Chapter 5 are based on executing the WRAP simulation model *SIM* with the Brazos WAM authorized use scenario Bwam3 input dataset with the updated 1940-2012 hydrologic period-of-analysis. The locations of the control points and reservoirs referenced in the following discussion are shown in Figure 5.3.

SIM simulation results for a 1940-2012 hydrologic period-of-analysis are summarized and compared in Table 5.5 in terms of mean annual flow and diversion rates in acre-feet/year and mean end-of-month reservoir storage volumes in acre-feet for four alternative periods:

- the 58-years of the original 1940-1997 period-of-analysis
- the 73 years of the entire 1940-2012 period-of-analysis
- the 15 years of the 1998-2012 extension period
- the year 2011 which is the driest single year of 1940-2012

Table 5.5 present the results of a single *SIM* simulation, but the four columns of the table cover different segments of 1940-2012, namely 1940-1997, 1940-2012, 1998-2012, and 2011. The year 2011 has the lowest precipitation on record for the Brazos River Basin and most of Texas. The simulation uses the Brazos WAM authorized use scenario Bwam3 input dataset as last updated in September 2008. Thus, the results for 1940-1997 represent the official TCEQ Brazos WAM. The 1940-2012 simulation uses the Bwam3 DAT file, but the naturalized flow FLO and evaporation EVA files are extended 15 years to include 1998-2011 as described by Wurbs and Chun (2012) plus a later additional one year extension to include 2012.

Mean annual naturalized, regulated, and unappropriated flows at control points LRCA58 on the Little River and BRSE11, BRWA41, and BRRI70 on the Brazos River are tabulated in Table 5.5 along with several summary quantities for the entire Bwam3 model. The quantities in the lower section of Table 5.5 include the means of the 696, 876, 180, and 12 end-of-month total storage contents in acre-feet of the 678 reservoirs, annual means in acre-feet/year of the net evaporation-precipitation volumes for the 678 reservoirs, and annual means in acre-feet/year for the total streamflow depletions, diversion targets, and shortages for all water rights.

The volume reliabilities for the total of all diversion rights are 90.01 and 89.09 percent for simulation periods of 1940-1997 and 1940-2012, respectively. Volume reliabilities for the 180 months of 1998-2012 and the 12 months of 2011, respectively, are 85.85 and 67.76 percent.

The 1940-2012 sequences of monthly and annual flows plotted in Figures 5.5-5.12 show the tremendous temporal and spatial variability characteristic of flows throughout the Brazos River Basin and throughout Texas. Daily flows are characterized by greater variability than monthly flows. Synthesized naturalized flows during the 1998-2012 extension period exhibit extreme variability, ranging from the extremely dry year 2011 to several major floods. Several very wet years during 1998-2012 result in 1998-2012 mean flows being higher than 1940-1997 means at some locations in the Brazos River Basin. However, 2011 was extremely dry, resulting in average flows during 1998-2012 being lower than 1940-1997 means at other locations.

The flow extension methodology explained in the *Hydrology Manual* (Wurbs 2012) can be applied with the Brazos WAM hydrology extension dataset documented by Wurbs and Chun (2012) to expeditiously update the hydrology files annually in the future, which is particularly significant if 2011-2012 drought conditions continue through 2013 into the future.

Table 5.5
Simulation Results Summary

	1940-1997	1940-2012	1998-2012	2011
Annual Flows (acre-feet/year) at the Seymour Gage on the Brazos River (BRSE11)				
naturalized flow	250,100	238,820	195,204	19,242
regulated flow	233,260	222,600	181,380	18,795
unappropriated flow	131,300	122,170	86,870	1,008
Annual Flows (acre-feet/year) at the Cameron Gage on the Little River (LRCA58)				
naturalized flow	1,318,300	1,351,440	1,481,660	574,000
regulated flow	998,670	1,036,020	1,181,840	348,830
unappropriated flow	808,290	826,950	893,450	45,720
Annual Flows (acre-feet/year) at the Waco Gage on the Brazos River (BRWA41)				
naturalized flow	1,942,320	1,882,350	1,675,180	476,010
regulated flow	1,351,620	1,296,590	1,105,020	249,170
unappropriated flow	1,039,280	959,720	672,880	-0-
Annual Flows (acre-feet/year) at the Richmond Gage on the Brazos River (BRRI70)				
naturalized flow	5,850,220	5,822,300	5,757,720	1,609,110
regulated flow	4,603,440	4,588,680	4,572,140	862,140
unappropriated flow	3,478,010	3,328,050	2,770,760	169,800
Mean Storage Volume (acre-feet) and Mean Annual Rates (acre-feet/year)				
reservoir storage	3,510,860	3,486,130	3,417,910	2,812,410
evaporation-precipitation	397,350	396,560	397,150	593,660
streamflow depletion	2,590,280	2,559,090	2,435,960	1,501,040
diversion target	2,452,800	2,457,600	2,472,690	2,520,740
diversion amount	2,207,640	2,189,580	2,122,730	1,708,110
diversion shortage	245,160	268,020	349,960	812,630
volume reliability (percent)	90.01%	89.09%	85.85%	67.76%

End-of-month storage contents 14 of the largest reservoirs for the 876 months of the Bwam3 1940-2012 simulation are plotted in Figures 5.13, 5.14, 5.15, and 5.16. Information about these reservoirs is provided in Tables 5.2 and 5.3. These 14 reservoirs account for 73.5 percent of the total conservation storage capacity and all of the controlled (gated) flood control capacity of the 678 reservoirs in the dataset and are located throughout the river basin.

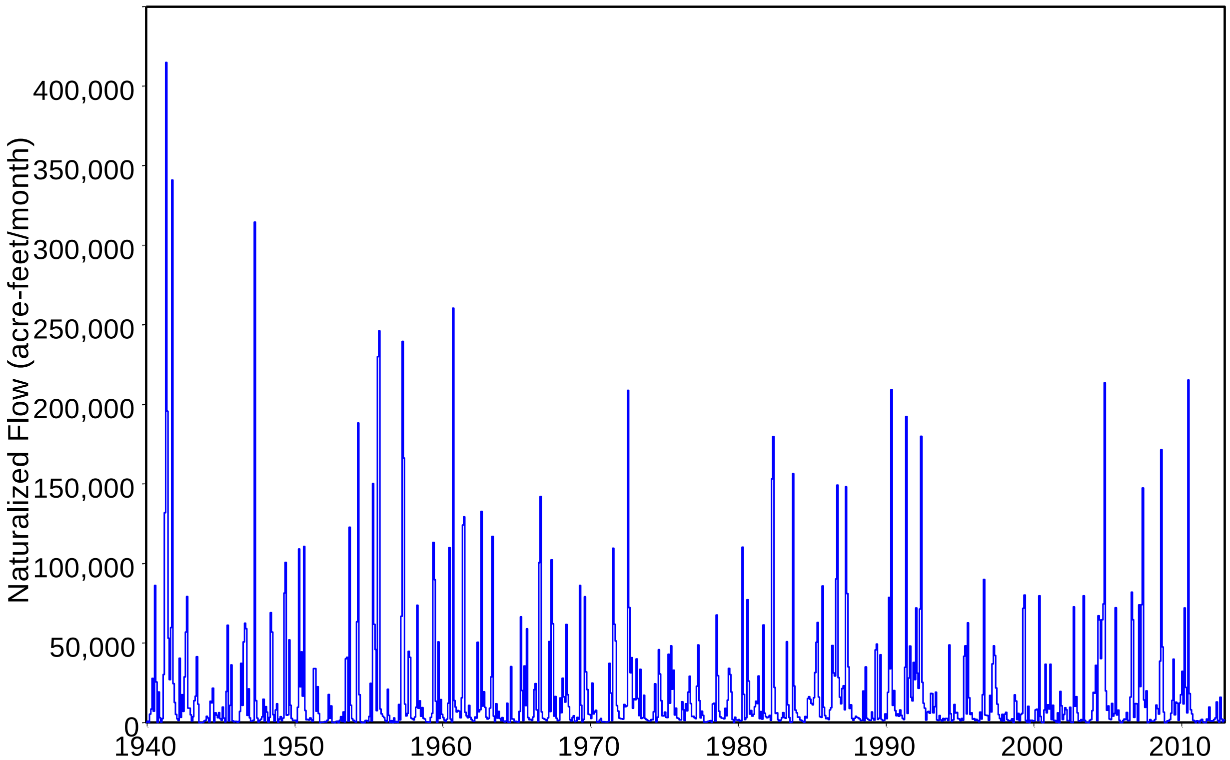

Figure 5.5 Naturalized Monthly Flows for Brazos River at Seymour Gage (BRSE11)

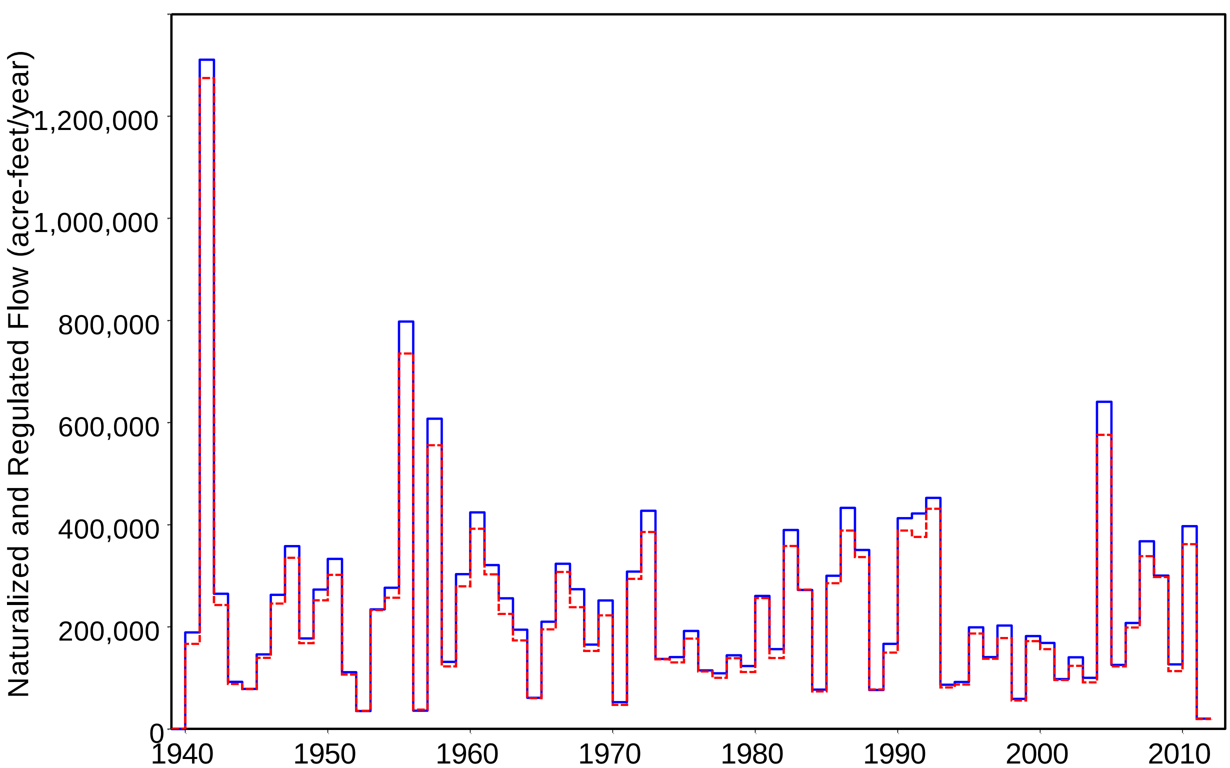

Figure 5.6 Naturalized and Regulated Annual Flows at Seymour Gage (BRSE11)

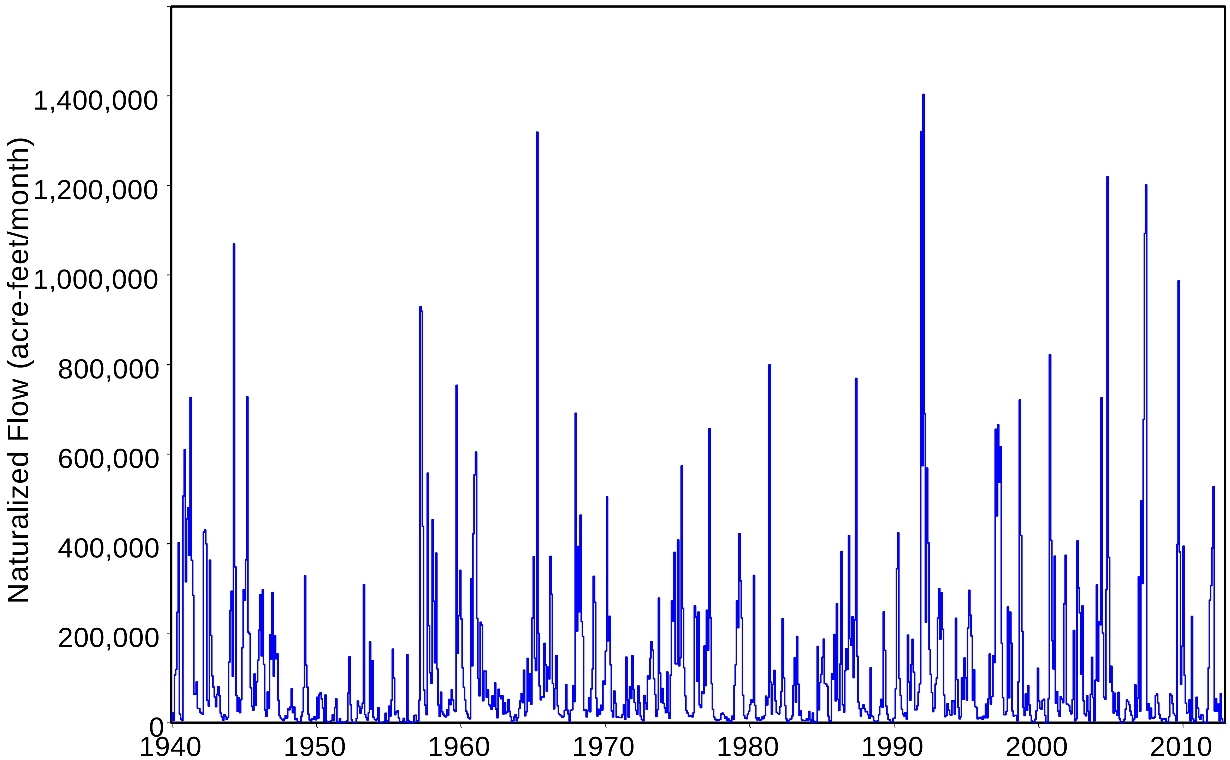

Figure 5.7 Naturalized Monthly Flows for Little River at Cameron Gage (LRCA58)

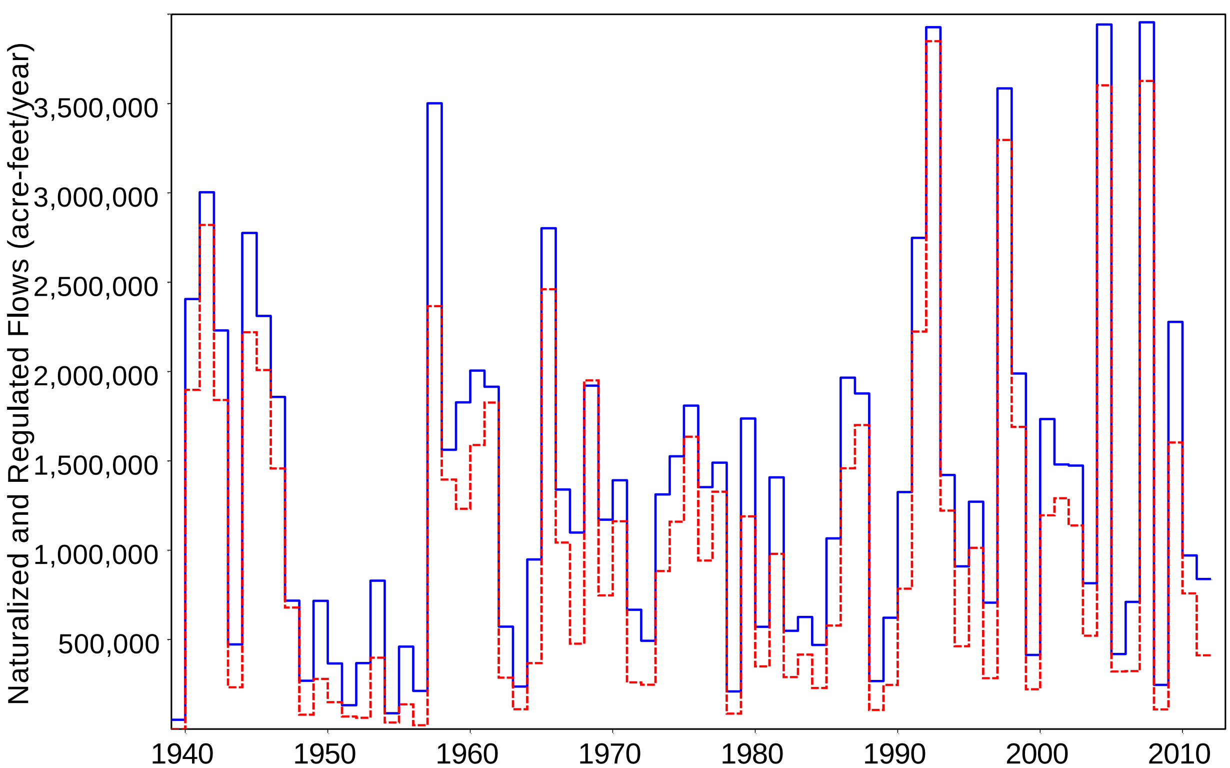

Figure 5.8 Naturalized and Regulated Annual Flows at Cameron Gage (LRCA58)

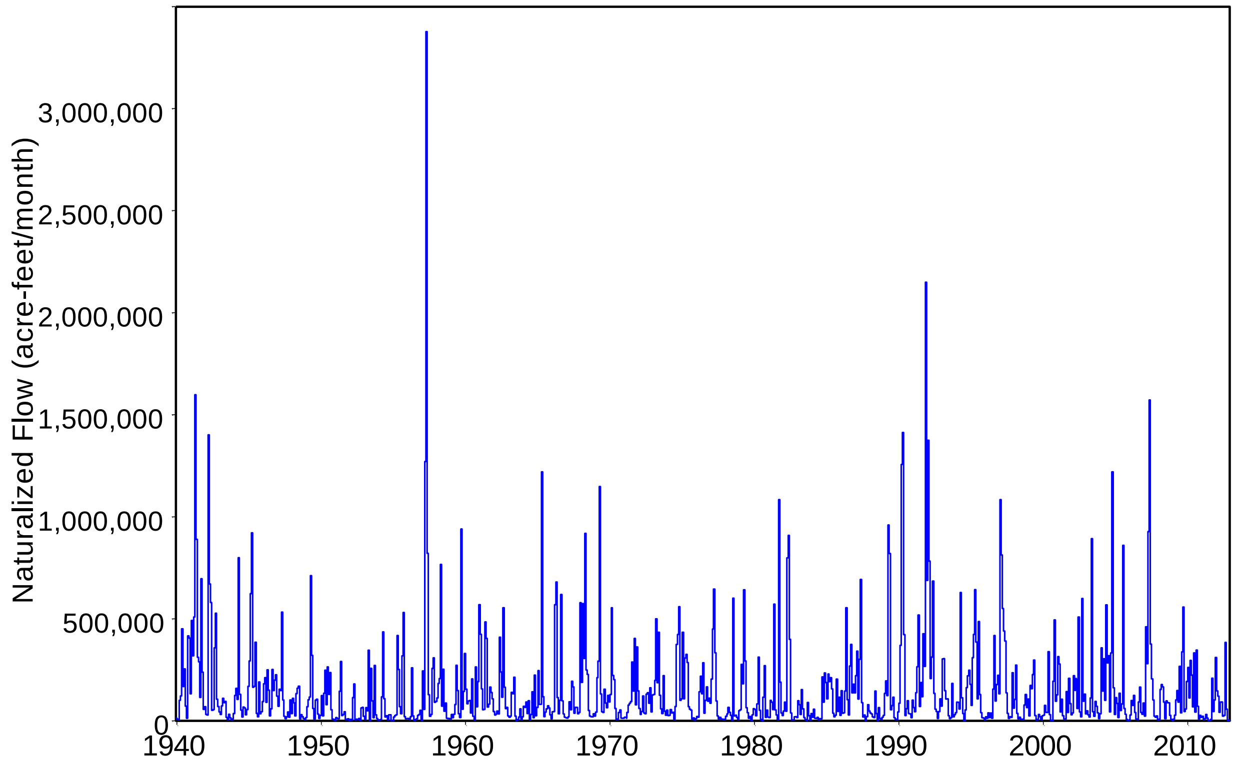

Figure 5.9 Naturalized Monthly Flows for Brazos River at Waco Gage (Control Point BRWA41)

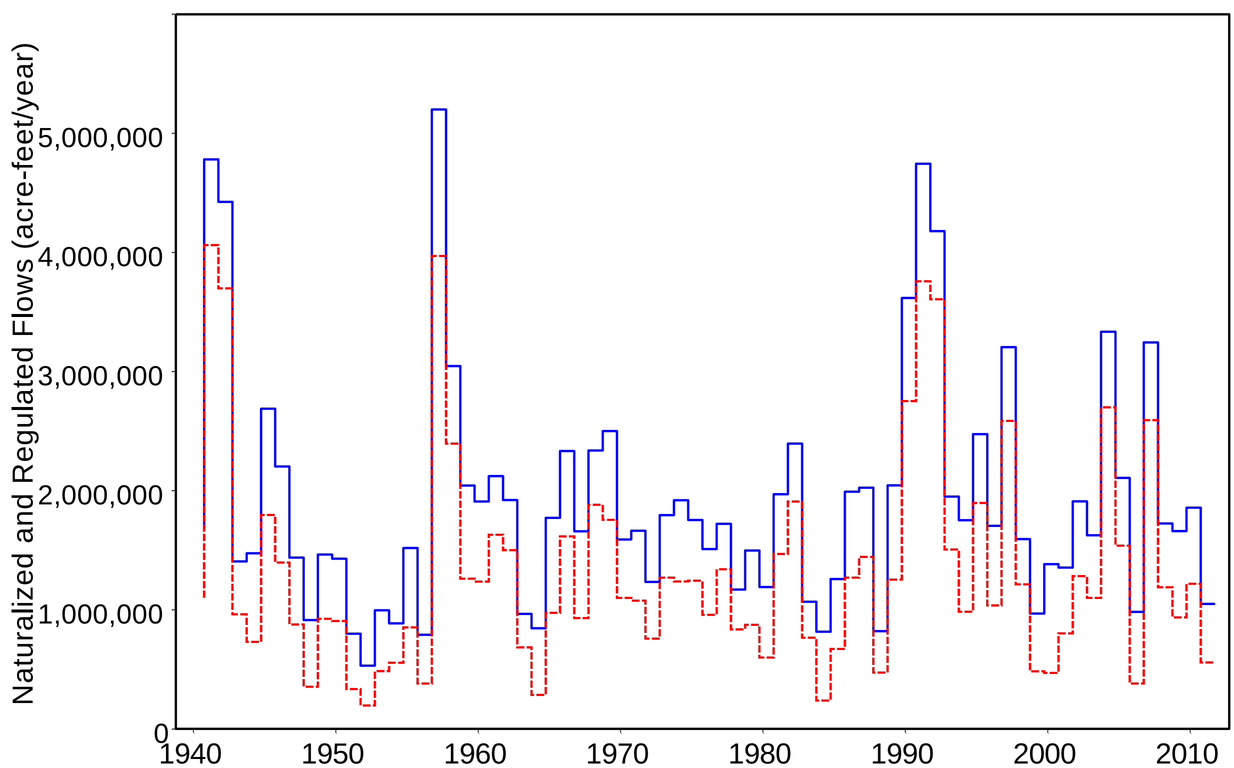

Figure 5.10 Naturalized and Regulated Annual Flows at Waco Gage (BRWA41)

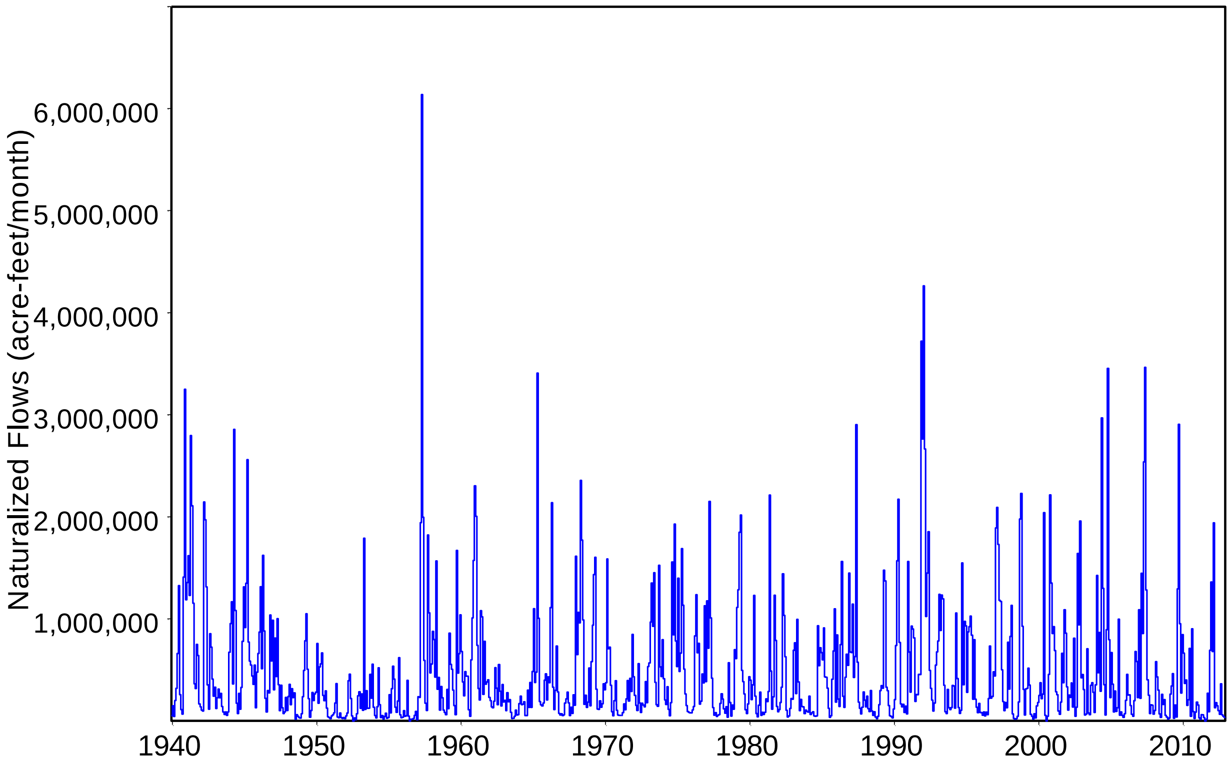

Figure 5.11 Naturalized Flows for Brazos River at Richmond Gage (Control Point BRRI70)

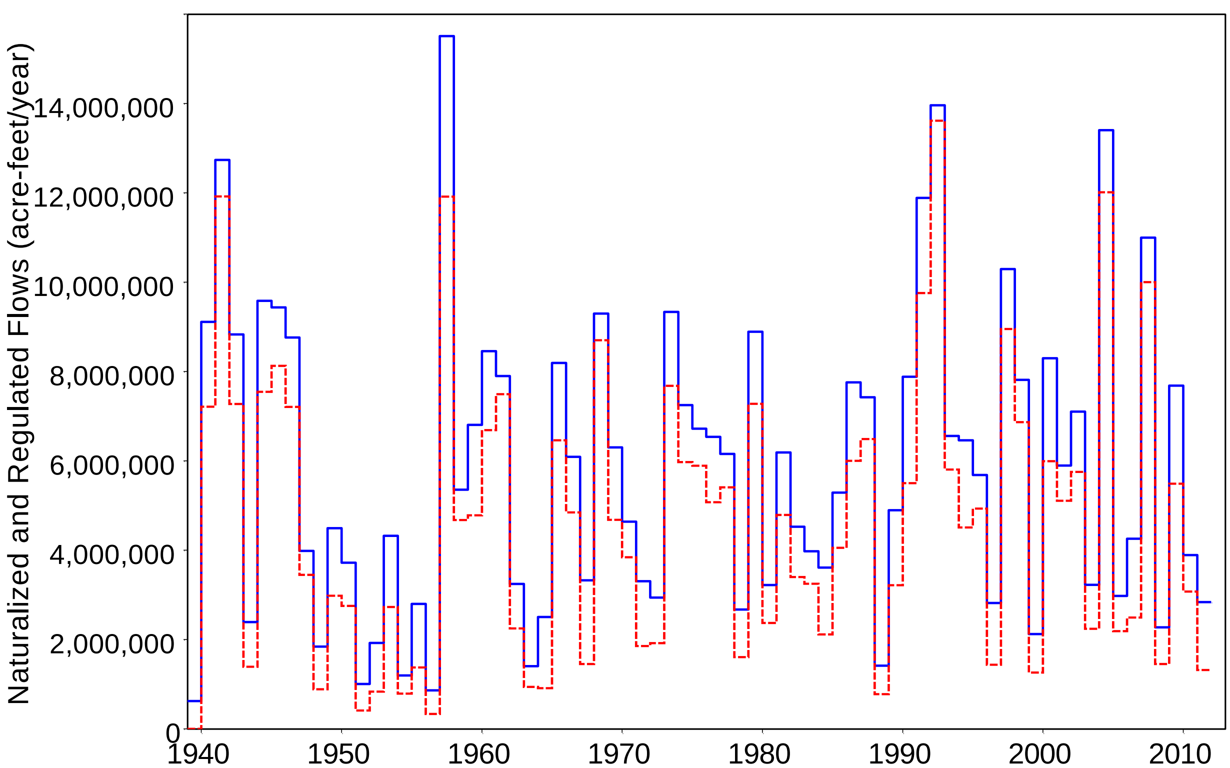

Figure 5.12 Naturalized and Regulated Annual Flows at Richmond Gage (BRRI70)

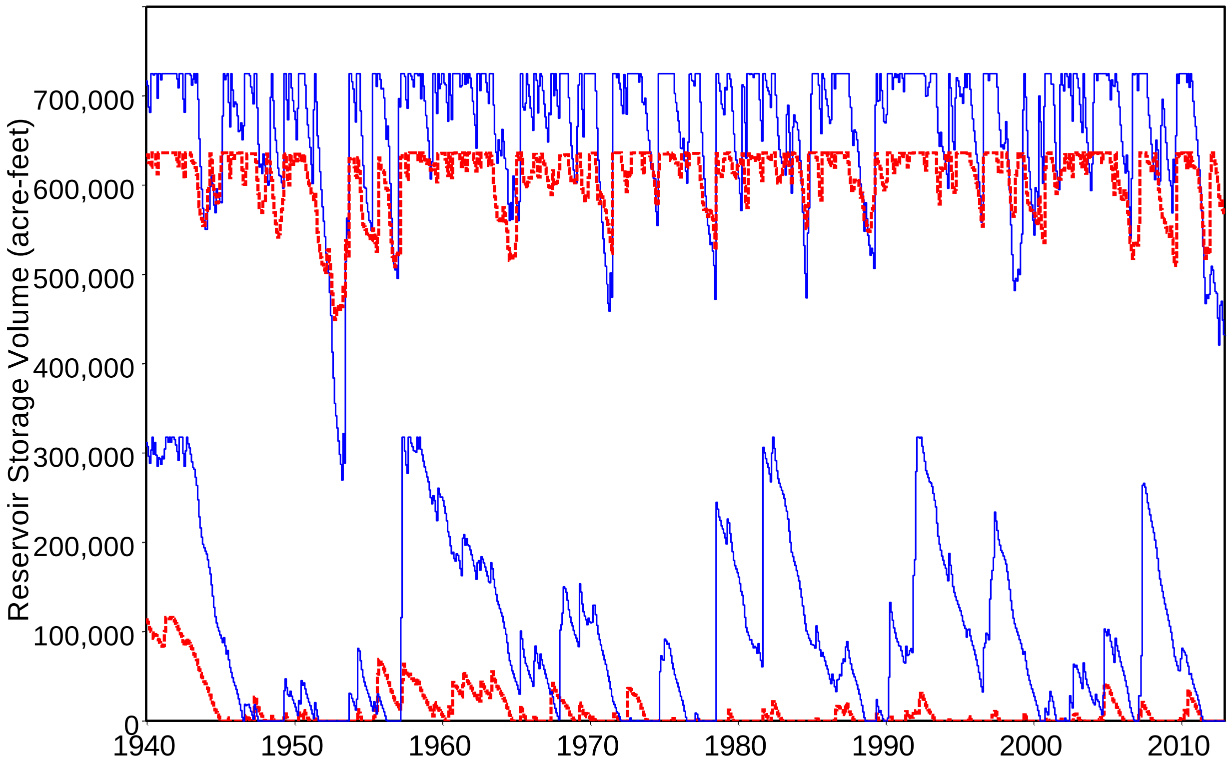

Figure 5.13 Storage Contents for Possum Kingdom (724,739 ac-ft), Whitney (636,100 ac-ft), Hubbard Creek (317,750 ac-ft), and Alan Henry (115,937 ac-ft capacity)

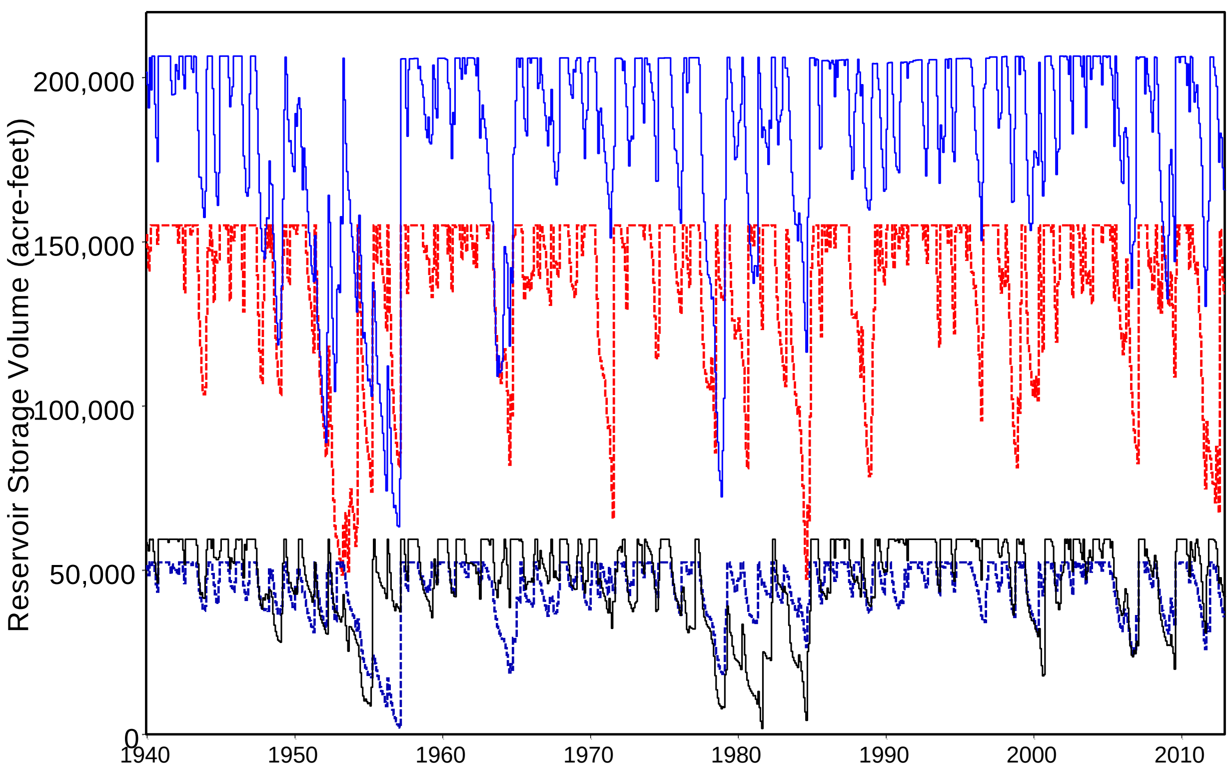

Figure 5.14 Storage Contents for Waco (206,562 ac-ft), Granbury (155,000 ac-ft) Proctor (59,400 ac-ft), and Aquilla (52,400 ac-ft capacity)

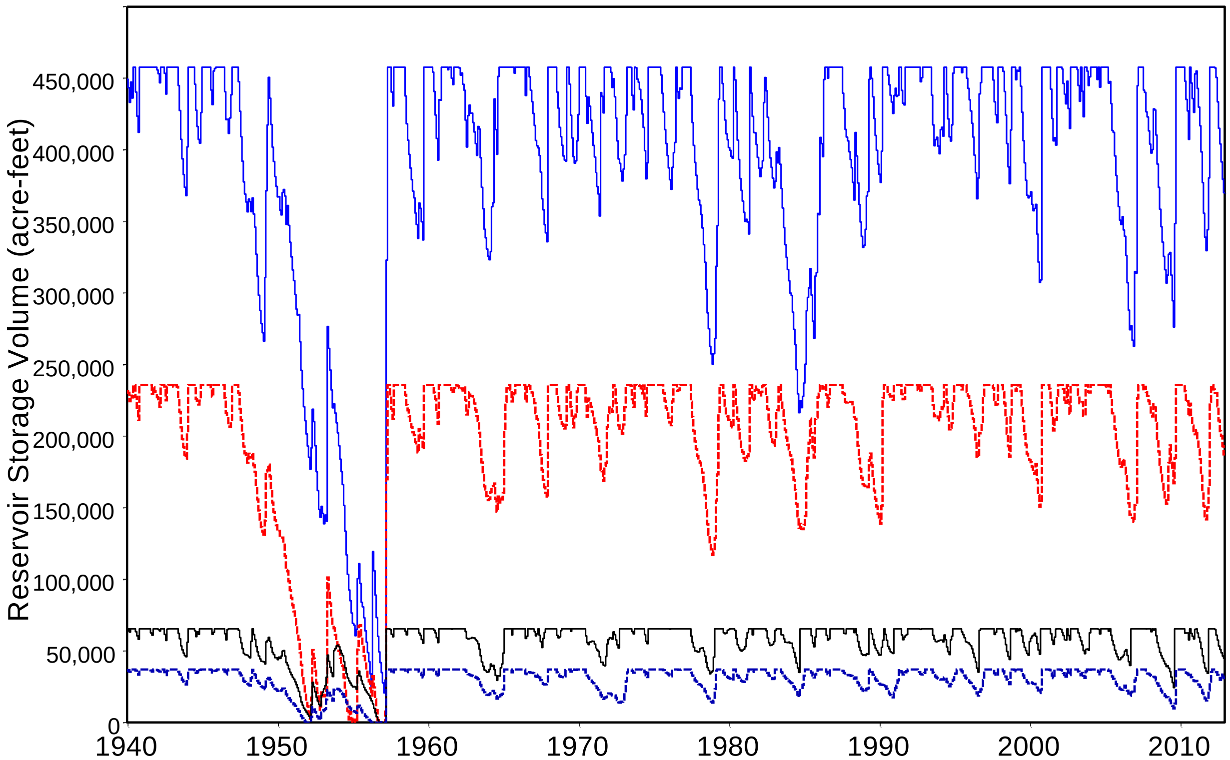

Figure 5.15 Storage Contents for Belton (457,600 ac-ft), Stillhouse Hollow (235,700 ac-ft), Granger (65,500 ac-ft), and Georgetown (37,100 ac-ft capacity)

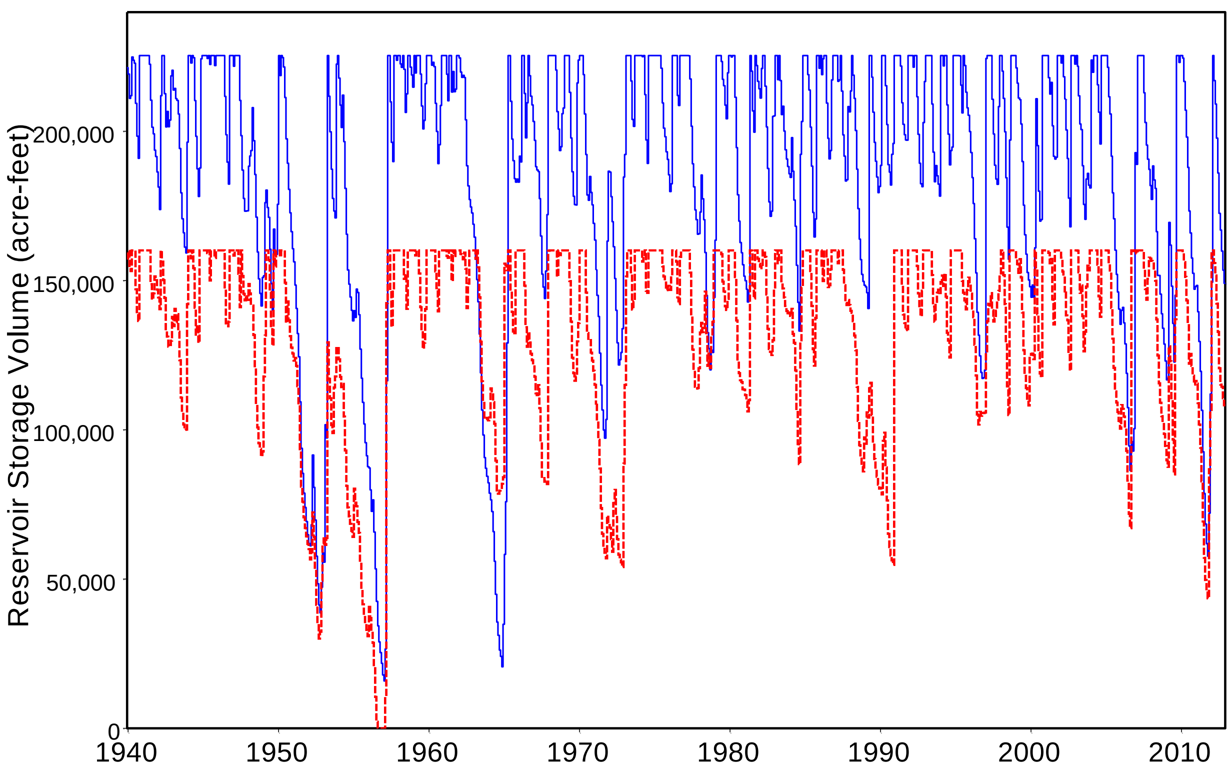

Figure 5.16 Storage Contents for Limestone (225,400 acre-feet capacity) and Somerville (160,110 acre-feet capacity) Reservoirs

The flow and storage plots of Figures 5.5-5.16 prepared with HEC-DSSVue illustrate the tremendous variability that is characteristic of river system hydrology throughout Texas. The plots demonstrate that the 1950-1957 drought is still the hydrologically most severe drought occurring during the extended 1940-2012 simulation period. Extending the hydrologic period-of-analysis through 2012 enhances the validity of the reliability and frequency analyses, but the critical drought period is not yet changed for most of the Brazos River Basin. Regulated and naturalized flows are compared in the annual flow plots in Figures 5.6, 5.8, 5.10, and 5.12.

The selected quantities from the preceding tables compared in Table 5.6 provide a concise perspective of the relative magnitude of streamflows, diversions, and reservoir storage. Most of the conservation storage capacity of the 678 reservoirs is contained in the 16 largest reservoirs. The storage capacity of the flood control pools of the nine federal reservoirs is greater than the conservation pool capacity of the nine reservoirs and is almost as large as the conservation capacity of the 678 reservoirs. Flood control storage is not included in the WAM datasets. However, flood control pools are incorporated in the daily *SIMD* model in Chapter 6, and the effects of flood control operations on environmental flows are investigated in Chapter 7.

Table 5.6
Comparison of Selected Quantities

Summary Comparison Quantity	Table	Amount
Flood control storage capacity of 9 USACE reservoirs	5.3	3,940,660 acre-feet
Bwam3 conservation capacity of 16 largest reservoirs	5.2	3,746,330 acre-feet
Bwam3 conservation storage capacity of 678 reservoirs	5.2	4,694,850 acre-feet
1940-2012 Bwam3 mean storage contents of 678 reservoirs	5.5	3,486,130 acre-feet
total of authorized annual diversion targets	5.5	2,457,600 ac-ft/year
1940-2012 Bwam3 mean annual diversion	5.5	2,189,580 ac-ft/year
1940-2012 Bwam3 mean naturalized flows at Cameron gage	5.5	1,351,440 ac-ft/year
1940-2012 Bwam3 mean regulated flows at Cameron gage	5.5	1,036,020 ac-ft/year
1940-2012 Bwam3 mean naturalized flows at Waco gage	5.5	1,882,350 ac-ft/year
1940-2012 Bwam3 mean regulated flows at Waco gage	5.5	1,296,590 ac-ft/year
1940-2012 Bwam3 mean naturalized flows at Richmond gage	5.5	5,822,300 ac-ft/year
1940-2012 Bwam3 mean regulated flows at Richmond gage	5.5	4,588,680 ac-ft/year

The river system contains a large volume of reservoir storage. Fluctuations in reservoir levels including infrequent severe draw-downs during droughts as well as smaller but more frequent draw-downs can be expected to affect lake ecosystems and the ecosystems of backwater affected reaches of the streams that flow into the lakes as well as downstream flows. The environmental aspects of reservoir fluctuations is not a primary focus of Senate Bill 2 and Senate Bill 3 environmental flow studies to date but may perhaps receive more attention in the future.

The authorized annual diversion target of 2,457,600 acre-feet/year is 52.3% of the total conservation storage capacity of 4,694,850 acre-feet and 42.2% and 53.6% of the mean annual naturalized flow and regulated flow, respectively, at the Richmond gage. The volume reliability is 89.09% for the Bwam3 authorized use scenario total diversion target of 2,457,600 ac-ft/year.

Bwam3 mean regulated flows are 93.2%, 76.7%, 68.9%, and 78.8% of mean naturalized flows at the Seymour, Cameron, Waco, and Richmond gages. However, the effects of human water development/management/use on streamflows vary greatly with location and between low, median, and high flows. A full range of daily flows from ranging from severe droughts to major floods at sites located throughout the river system are investigated in Chapter 6.

Daily Brazos WAM

Conversion of the monthly Brazos WAM to a daily time step and application of the new capabilities covered in the August 2012 *Daily Manual* are documented by Wurbs et al. (2012). The daily Brazos WAM case study supported development of the daily WRAP modeling system. Wurbs et al. (2012) explore various aspects of the daily WRAP modeling system and provide guidance for model users in its application. The daily *SIMD* simulations presented in the following Chapters 6 and 7 of the present report build upon and extend this previous work with a specific focus on environmental instream flow requirements. Refinements to the computer software since the August 2012 version of WRAP and the *Daily Manual* include expanding pulse flow options and routing parameter calibration options and refining the forecasting algorithm. The primary additions to the *SIMD* input dataset for the Brazos WAM since the completion of the preceding Brazos WAM case study report (Wurbs et al. 2012) are described in Chapter 6 and consist of updating the 1940-1997 simulation period to 1940-2012, increasing the number of control points with daily pattern hydrographs, and adding the BBEST and BBASC instream flow requirements, BRA multiple-reservoir system operations, Lake Whitney hydropower operations, and refinements to USACE flood control operations.

Most of the additional data needed to expand a monthly *SIM* input dataset to a daily *SIMD* input dataset deals with (1) naturalized flow disaggregation, (2) calibration flow routing parameters, and (3) disaggregation of diversion and instream flow requirements. The optional new *SIMD* features for simulating flood control operations and environmental pulse flow requirements require a daily time step and thus have never been included in the monthly *SIM*.

A dataset of daily unregulated flow volumes provided by the USACE Fort Worth District from their reservoir modeling system are used as flow patterns in the disaggregation of the Brazos WAM monthly naturalized flows to daily. The USACE 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 entering the Brazos River below Whitney Dam. The daily flows are at 34 control points on the Brazos River and its tributaries, but do not include streams in the San Jacinto-Brazos coastal basin. Monthly naturalized flows for the Brazos WAM control points in the San Jacinto-Brazos coastal basin are disaggregated to daily using an interpolation option which requires no daily pattern flows.

The daily Brazos WAM includes lag and attenuation routing parameters for normal flows and flood flows for the stream reaches between the 34 control points for which daily flows are provided as input for flow patterns. These parameters were calibrated using the WRAP program *DAY*. No routing parameters are provided for the San Jacinto-Brazos coastal basin.

The uniform option was applied to disaggregate monthly instream flow targets to daily. Both uniform and non-uniform disaggregation options were investigated for diversion targets.

Unlike the monthly model, the flood control pools of the nine USACE multiple-purpose reservoirs are included in the daily Brazos WAM. The storage volume versus water surface area relationships defined by the *SV* and *SA* records are extended to include the flood control pools. The system of nine flood control reservoirs are operated in *SIMD* to control flood flows at the damsites and six control points located downstream of the damsites based on *FR* and *FF* records.

Existing Instream Flow Requirements

The version of the Brazos WAM authorized use Bwam3.DAT file last updated by the TCEQ in September 2008 contains the 122 *IF* records listed in Table 5.7. In WRAP terminology, an instream flow *IF* record is a type of water right that sets a minimum instream flow limit that may restrict streamflow depletions of junior *WR* record water rights. The entries in each field of the *IF* records as reproduced in Table 5.7 include:

- the control point location of the instream flow target
- minimum regulated flow limit as an annual flow rate in acre-feet/year
- identifier of the *UC* record containing the 12 distribution coefficients used to disaggregate the annual flow to 12 monthly flows
- priority (seniority) date in the format of year followed by month and day
- water right type 1 or 3 that specifies whether the *IF* record is linked to reservoir storage defined by one or more *WS* records
- water right identifier

Table 5.7
IF Records in Brazos WAM Authorized Use Bwam3.DAT File

	Control Point	Annual Flow (ac-ft/yr)	UC Records	Priority Date	Type	IF Right Identifier
IF	578831	12	IF5788	20020930	1	IFP5788_1
IF	586631	18,095	UNIFO	20050531	1	IFA586631
IF	579101	365	5791IF	20021114	1	IFP5791_1
IF	380934	72	UNIFO	20020429	1	IF3809_1
IF	576701	119,155	5767IF	20020329	1	IF5767_1
IF	BRHE68	1,216,877	5752IF	20011018	1	IF5752_1
IF	575203	2,741	GAVIF	20011018	1	IF5752_2
IF	574432	7,058	5744IF	20010627	1	IF5744_1
IF	565801	94,093	UNIFO	19991018	1	IF5658_1
IF	565801	0	UNIFO	19991018	1	IF5658_2
IF	BRRI70	1,352,902	IF5665	20010621	1	IF5665_1
IF	568601	2,741	IFD129	20000628	1	IFP5686_1
IF	DMAS09	3,367	IFD011	20000719	1	IFP5692_1
IF	41430	12,172	UNIFO	19721218	1	IFC4143_1
IF	413931	21,719	UNIFO	19490803	1	IFC4139_1
IF	418502	362	UNIFO	19750714	1	IFC4185_1
IF	BRRI70	241,987	IFD031	19471114	1	IFC4013_1

Table 5.7 Continued
IF Records in Brazos WAM Authorized Use Bwam3.DAT File

	Control Point	Annual Flow (ac-ft/yr)	UC Records	Priority Date	Type	IF Right Identifier
IF	BRRI70	0	IFD031	19471114	1	IFC4013_2
IF	SADL44	1,448	UNIFO	19710329	1	IFC3532_1
IF	SADL44	1,448	UNIFO	19700504	1	IFC3543_1
IF	408401	3,547	UNIFO	19731119	1	IFC4084_1
IF	408601	10,136	UNIFO	19750902	1	IFC4086_1
IF	409702	1,086	UNIFO	19730425	3	IFC4097_1
IF	228302	12,827	IFLGC	19211231	1	IF4318_ON
IF	228302	0	IFLGC	19211231	1	IF4318_OF
IF	228302	12,827	IFLGC	20010118	1	IF4318_OA
IF	515831	362	UNIFO	19761025	3	IFC5158_1
IF	P41242	3,594	IFD063	19820621	1	IFP4124_1
IF	228101	3,585	IFD065	19600430	1	IFC2281_1
IF	555101	8,172	IFD067	19960403	1	IFP5551_1
IF	555101	15,038	MERID	20050908	1	IF5899
IF	P41351	15,217	IFD068	19830515	1	IFP4135_1
IF	365301	6,901	3653A	20020812	1	IFC3653_1N
IF	281421	8,329	3653B	20020812	1	IFC3653_2N
IF	LEBE49	1,810	UNIFO	19830207	1	IFP4024_1
IF	421812	3,386	IFD074	19841127	1	IFP4218_1
IF	P40121	10,136	UNIFO	19821213	1	IFP4012_1
IF	295811	7,240	IFD081	19760927	1	IFC2958_1
IF	299111	908	2991IF	20020429	1	IF2991_1
IF	LAKE50	16,020	TAYLIF	19660401	1	IF2996_1
IF	LAKE50	0	TAYLIF	19660401	1	IF2996_2
IF	LAKE50	16,020	TAYLIF	20030923	1	IF2996_3
IF	LABE52	4,344	IFD083	19840508	1	IFP4130_1
IF	LABE52	4,344	IFD083	19820920	1	IFC3007_1
IF	LABE52	4,344	IFD083	19860718	1	IFP5076_1
IF	LABE52	4,344	IFD083	19820920	1	IFP4000_1
IF	LABE52	4,344	IFD083	19820920	1	IFP4003_1
IF	LABE52	4,344	IFD083	19820920	1	IFP4002_1
IF	P37631	4,530	IFD08A	19800527	1	IFP3763_1
IF	LRLR53	125,887	IFD085	19990816	1	IFP4095_1
IF	LRLR53	12,377	IFD08B	19800527	1	IFP3762_1
IF	LRCA58	25,103	IFD086	19840228	1	IFP4109_1
IF	LRLR53	22,444	IFD087	19820920	1	IFP4015_1
IF	LRCA58	25,101	IFD086	19850709	1	IFP4279_1
IF	416611	3,403	UNIFO	19840731	1	IFP4166_1
IF	LRCA58	25,103	IFD086	19770829	1	IFC3759_1
IF	LRCA58	25,103	IFD086	19850103	1	IFP4212_1
IF	LRCA58	14,480	UNIFO	19800527	1	IFP3761_1
IF	LRCA58	25,103	IFD086	19860721	1	IFP5077_1
IF	LRCA58	232,926	IFD08D	20000929	1	IFC3775_1
IF	BRWA41	190,763	IFD091	19860814	1	IFP5085_1
IF	BRWA41	130,751	IFD092	19820830	1	IFP3936_1
IF	BRHB42	196,129	IFD098	19830207	1	IFP4042_1
IF	BRHB42	185,856	IFD096	19820922	1	IFP4014_1
IF	BRHB42	185,856	IFD096	19821129	1	IFP4013_1
IF	435533	72	UNIFO	19480401	3	IFC4355_1
IF	BRHB42	185,856	IFD096	19820503	1	IFC4358_1
IF	BRHB42	196,129	IFD098	19830711	1	IFP4063_1
IF	BRHB42	185,856	IFD096	19820503	1	IFC4359_1

Table 5.7 Continued
IF Records in Brazos WAM Authorized Use Bwam3.DAT File

	Control Point	Annual Flow	UC Records	Priority Date	Type	IF Right Identifier
IF	BRHB42	235,583	IFD093	19830906	1	IFP4076_1
IF	BRHB42	235,583	IFD093	19830926	1	IFP4078_1
IF	BRHB42	196,129	IFD098	19830207	1	IFP4023_1
IF	BRHB42	241,653	IFD099	19831031	1	IFC4366_1
IF	BRHB42	235,583	IFD093	19840515	1	IFP4145_1
IF	BRHB42	235,583	IFD093	19830919	1	IFP4080_1
IF	BRHB42	196,129	IFD098	19830207	1	IFC4371_1
IF	BRBR59	435,061	IFD09B	19810309	1	IFC4372_1
IF	BRHB42	235,583	IFD093	19831019	1	IFC4363_1
IF	BRHB42	261,415	IFD09F	19840710	1	IFC4364_1
IF	BRHE68	613,612	IFD09D	19840508	1	IFP4128_1
IF	BRHE68	209,398	IFD111	19821220	1	IFP4017_1
IF	LRCA58	14,480	UNIFO	19511212	1	IFC3758_1
IF	BRBR59	209,398	IFD09E	19511212	1	IFC3758_2
IF	529831	180	IFD103	19740701	1	IFC5298_1
IF	557021	40,905	IFD101	19970117	1	IFP5570_1
IF	531131	362	UNIFO	19770222	1	IFC5311_1
IF	530701	17,022	IFD104	19801215	1	IFC5307_1
IF	556601	35,780	IFD102	19970115	1	IFP5566_1
IF	BRHE68	557,820	IFD111	19821220	1	IFC5285_1
IF	BRHE68	557,820	IFD111	19821220	1	IFP4011_1
IF	BRHE68	557,820	IFD111	19821220	1	IFP4016_1
IF	BRHE68	0	IFD111	19821220	1	IFP4016_2
IF	BRHE68	557,820	IFD111	19821220	1	IFP4016_3
IF	BRHE68	613,616	IFD112	19840313	1	IFP4016_4
IF	BRHE68	613,616	IFD112	19900403	1	IFP5290_1
IF	BRHE68	557,820	IFD111	19830418	1	IFP4009_1
IF	BRRI70	554,696	IFD116	19850806	1	IFP4280_1
IF	2925A	2,604,379	MEDIAN	19990901	1	IFMETESTON
IF	2925A	0	MEDIAN	19990901	1	IFMETESTOF
IF	2925A	1,076,933	25THPT	19990901	1	IF25TESTON
IF	2925A	0	25THPT	19990901	1	IF25TESTOF
IF	2925D	2,604,379	MEDIAN	19990901	1	MEDIAN-REG
IF	2925C	1,076,933	25THPT	19990901	1	25THPT-REG
IF	2925A	531,399	7Q2	19990901	1	7Q2-REG
IF	423204	362	UNIFO	19850409	1	IFP4232_1
IF	BRRI70	721,379	IFD113	19970109	1	IFP5567_1
IF	BRRI70	553,178	IFD114	19960507	1	IFP5552_1
IF	BRRO72	6,655	IFD115	19290208	1	IFC5322_1
IF	BRRI70	553,178	IFD114	19840131	1	IFP4105_1
IF	533811	46,624	UNIFO	19850919	1	IFC5338_1
IF	534401	4,713	IFD121	19840508	1	IFP4201_1
IF	P40101	9,795	IFD122	19850103	1	IFP4221_1
IF	534601	7,254	IFD128	19890829	1	IFP5256_1
IF	CON241	3,989	IFD123	19850103	1	IFP4215_1
IF	P41321	3,808	IFD124	19860527	1	IFP5064_1
IF	534603	3,626	IFD125	19840522	1	IFP4132_1
IF	534602	3,989	IFD123	19840529	1	IFC5349_1
IF	CON241	5,258	IFD126	19860509	1	IFC5343_1
IF	534304	1,597	IFD127	19860509	1	IFC5343_2
IF	CBALC2	72	UNIFO	19681115	1	IFC5355_1
IF	536402	724	UNIFO	19910628	1	IFP5369_1
IF	523001	1,448	UNIFO	19890502	1	IFP5230_1

IF records model instream flow requirements defined in water right permits. About 120 of the approximately 1,200 water right permits modeled in the Brazos WAM contain special conditions regarding minimum instream flow limit requirements. The special conditions attached to the permitted diversion are in the form of minimum instream flow rates, that may vary seasonally, at the diversion site or a downstream stream gaging station. Instantaneous flow limits in ft^3/s for each of the 12 months of the year specified in the permits are modeled as monthly volumes in acre-feet/month using instream flow *IF* records and use coefficient *UC* records. *IF* records restrict streamflow depletions of senior rights at and upstream of their sites.

The term *Hale clause* refers to minimum instream flow limits in the Brazos River Basin that are specified to protect senior water rights. These minimum instream flow requirements incidentally also may benefit the environment. Over half of the 122 *IF* records in Table 5.7, including most of those specifying larger minimum flow rates, represent Hale clause provisions of water right permits. The other *IF* records with typically smaller minimum flow limits represent permit special conditions designed specifically to preserve environmental flows.

The Hale clause provision in diversion/storage permits include language that the special condition makes the instream flow requirement "*exclusive of any releases dedicated by the Brazos River Authority from its conservation storage for subsequent use downstream*." By default, each *IF* record instream flow target is applied as a minimum limit on total regulated flow. An option has been added to the *IF* record that allows the limit to be applied to regulated flows excluding reservoir releases made for use at downstream locations. However, this option had not yet been added when the Brazos WAM dataset was created during 1999-2001 and is not used. The Hale clause exclusion of BRA releases has not been a concern to the TCEQ in the past because all BRA diversion rights are treated as lakeside in the Brazos WAM, even though releases from BRA reservoirs for downstream diversions actually occur in real-world operations. However, this may become an issue as the Brazos WAM is modified to more accurately model actual reservoir system operations, such as in the case study simulations presented in Chapter 6.

The annual flow target in acre-feet/year is tabulated in the third column of Table 5.7. The minimum flow limit target for a month, in acre-feet/month, is computed by *SIM* by multiplying the annual flow volume by a fraction computed using the coefficients on the *UC* records referenced by the identifiers in the fourth column of Table 5.7 The *UC* record contains 12 distribution coefficients that disaggregate the annual flow to 12 monthly flows. For example, a uniform distribution is specified as follows, which is equivalent to the *IF* record NDAYS option.

```
UC UNIFO     31.     28.     31.     30.     31.     30.
UC           31.     31.     30.     31.     30.     31.
```

Of the 122 *IF* record rights, 119 are type 1 and three are type 3. A type 3 *IF* record right includes releases from one or more specified reservoirs as needed to prevent violation of the instream flow target. Type 1 rights have no reservoir storage. With either type, junior *WR* record rights curtail diversions and refilling storage as necessary to maintain the instream flow target. The three *IF* type 3 rights have the identifiers IFC4097_1, IFC5158_1, and IFC4355_1. These *IF* records along with their water right storage *WS* records are reproduced as follows.

IFC4097_1 sets a uniform minimum instream flow target of 1,086 acre-feet/year (2.975 acre-feet/day) at control point 409702 with a seniority date of April 25, 1973. Water is pumped from Squaw Creek Reservoir (identifier SQWCRK) at control point 409732 as necessary to prevent regulated flows from falling below the minimum flow limit at control point 409702. Reservoir SQWCRK has a storage capacity of 151,500 acre-feet. The *OR* record allows water to be conveyed from the reservoir by pump/pipeline rather than gravity flow in the river channel.

```
IF409702   1086.   UNIFO19730425       3             IFC4097_1
WSSQWCRK 151500.
OR409732                              -1
```

With the following *IF*, *WS*, and *OR* records, water right IFC5158_1 sets a monthly uniform minimum regulated flow target equivalent to 362 acre-feet/year at control point 515831. The *IF* record right has a priority of October 25, 1976. Water is released from Aquilla Reservoir (reservoir identifier AQUILA) at control point 515831 as necessary to prevent regulated flows from falling below the minimum flow limit at control point 515831, which is the damsite. The optional *OR* record is actually not necessary in this case and could be removed without affecting simulation results if the *IF/WS* records are placed after the control point location of Aquilla Reservoir is defined by a *WR/WS* water right. Aquilla Reservoir has a capacity of 52,400 acre-feet. This *IF*/*WR/OR* record right models special provisions for environmental flows included in a water right permit for storage and diversions at Aquilla Reservoir located on Aquilla Creek.

```
IF515831    362.   UNIFO19761025       3             IFC5158_1
WSAQUILA  52400.
OR515831                              -1
```

The following *IF*, *WS*, and optional *OR* record set an instream flow target at control point 435533 that is met by releases from Brushy Reservoir and if necessary by curtailing other water rights that are junior to April 1, 1948. This *IF* record right models special provisions in a water right permit held by the city of Marlin.

```
IF435533     72.   UNIFO19480401       3             IFC4355_1
WSBRUSHY   6560.
OR435533                              -1
```

The 119 other *IF* records contained in the Brazos WAM connect to *UC* records but have no *WS* or *OR* records. These are type 1 *IF* rights with no reservoir storage. Junior *WR* record rights curtail diversions and storage refilling as necessary to maintain the instream flow targets. Upstream reservoirs controlled by junior *WR* record water rights make releases to pass inflows but do not otherwise release from storage for the instream flow targets.

The 122 *IF* records listed in Table 5.7 are actively functioning in the version of the Brazos WAM DAT file that is labeled as last updated in September 2008. Other *IF* records have been deactivated (commented out with **) in this version of the Bwam3 DAT file. One of the deactivated *IF* records includes a *WS* record with releases from Lake Limestone specified as a special condition in the Lake Limestone permit to protect downstream senior water rights.

Minimum flow requirements were developed in conjunction with Federal Energy Regulatory Commission (FERC) relicensing of hydropower at Possum Kingdom Lake in about 1990. FERC minimum flows from Possum Kingdom Lake are recaptured for water supply at Lakes Granbury and Whitney whenever storage capacity is available. The BRA has deactivated hydroelectric energy generation at Possum Kingdom Lake and is currently in the process of surrendering its FERC license. However, the BRA has committed to continue the existing FERC minimum flow requirements even after the FERC license has been formally terminated. The WR and WS records modeling the FERC minimum flow requirements are reproduced below.

```
** BRA and Brazos Electric Utilities hold a 3,600 acft/yr contract that represents the firm yield
** lost from Possum Kingdom, Whitney, and Granbury due to FERC instream flow requirements at
** Kingdom.  Downstream releases for hydropower generation and contractual commitments
** will frequently satisfy the FERC requirements.  Because the WAM does not include downstream
** releases to contractual commitments, inflows would be passed through the reservoir more
** frequently solely to satisfy the FERC requirements.  Do not model the FERC requirements.
** Instead, include the 3,600 acft/yr contract as part of the authorized diversions from the
** reservoir with 100% returned immediately downstream.
WR515531   3600.    HYD219380406   1   1  1.0000  515551              C5155_21   C515565155001
WSPOSDOM 724739.                               0
```

Brazos BBEST and BBASC Recommendations Reports

The Brazos River Basin and Bay Expert Science Team (BBEST) submitted its Environmental Flow Regime Recommendation Report to the Basin and Bay Area Stakeholders Committee (BBASC), Environmental Flows Advisory Group, and TCEQ in March 2012. The BBASC submitted its Environmental Flow Standards and Strategies Recommendation Report to the TCEQ in August 2012. The BBASC recommended flow requirements are based upon but differ in some respects from the BBEST recommended flow regime. These instream flow regimes were developed independently of the existing instream flow requirements described in the preceding section. The BBEST and BBASC recommended instream flow requirements are incorporated in the WRAP/WAM simulation study presented later in Chapters 6 and 7.

The geographic area assigned to the Brazos River Basin BBASC and BBEST consists of the entire Brazos Basin in Texas, the Oyster Creek and Austin Creek watersheds in the San Jacinto-Brazos coastal basin to the east, and the San Barnard River Basin which adjoins the lower Brazos Basin to the west. Environmental instream flow recommendations are developed at 19 stream gaging stations on the Brazos River and its tributaries and one gaging station on the San Bernard River. The flow recommendations for the 19 sites in the Brazos River basin are incorporated in the Brazos WAM simulation study presented in Chapters 6 and 7. However, the Brazos WAM does not include the Bernard River, and thus the 20th site is not used in this study. The locations of the 19 in the Brazos River are shown in Figure 13 with their WAM control point identifiers listed in Table 5.8. The USGS discontinued gage 08109000 on the Brazos River near Bryan in 1994 but gage 08108700 installed nearby allowed the two records to be combined to extend the period-of-record to the present.

The Brazos and San Bernard Rivers do not have bays. Their estuaries are classified as riverine in contrast to the lagoon-type estuaries (shallow bays) that dominate the Texas coast. No additional environmental flow requirements are recommended specifically for freshwater inflows to the estuaries. The premise is that instream flow requirements that satisfy the needs of riverine ecosystems will also maintain a sound estuarine ecosystem. After establishing the daily instream flow requirements, the associated monthly flows at the Richmond gage on the Brazos River and the Boling gage on the San Bernard River were compared with historical observed flows to detect potentialities for significant alterations in salinity. This analysis resulted in no further modifications to the recommended instream flow requirements.

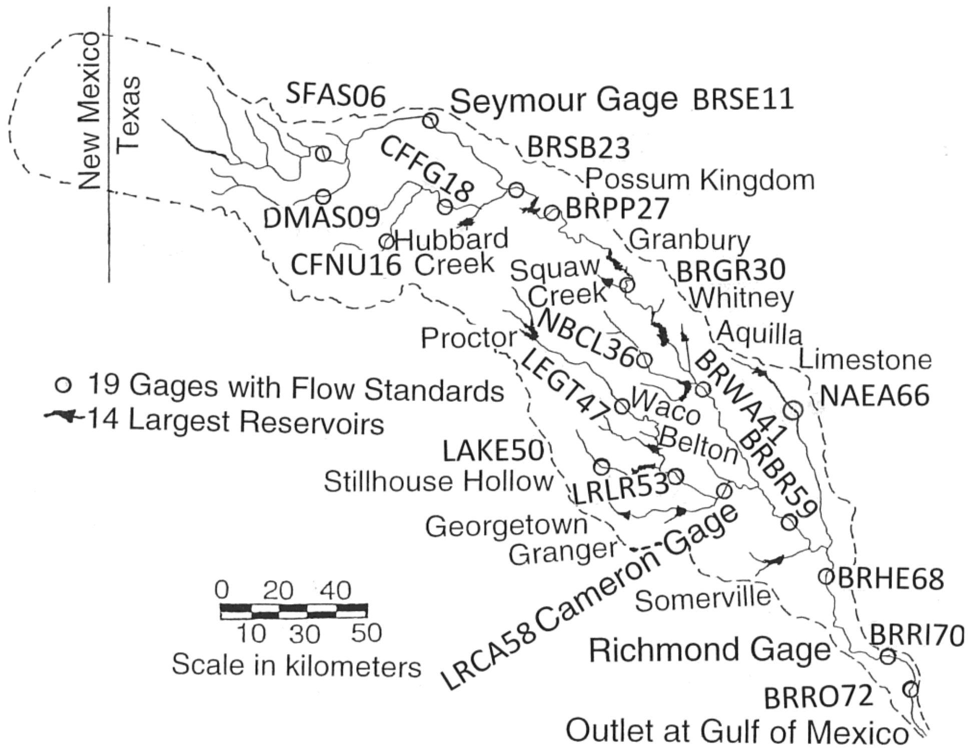

Figure 5.17 Locations for Environmental Flow Requirements

Table 5.8
Brazos WAM Control Point Locations for BBEST Flow Recommendations

WAM CP ID	Stream	Nearest City	USGS Gage No.	Watershed Area (sq miles)	USGS Period of Record
SFAS06	Salt Fork Brazos River	Aspermont	08082000	2,504	1924–present
DMAS09	Double Mountain Fork	Aspermont	08080500	1,891	1923–present
BRSE11	Brazos River	Seymour	08082500	5,996	1923–present
CFNU16	Clear Fork Brazos	Nugent	08084000	2,236	1924–present
CFFG18	Clear Fork Brazos	Fort Griffin	08085500	4,031	1924–present
BRSB23	Brazos River	South Bend	08088000	13,171	1938–present
BRPP27	Brazos River	Palo Pinto	08089000	14,309	1924–present
BRGR30	Brazos River	Glen Rose	08091000	16,320	1923–present
NBCL36	North Bosque River	Clifton	08095000	977	1923–2008
BRWA41	Brazos River	Waco	08096500	20,065	1898–present
LEGT47	Leon River	Gatesville	08100500	2,379	1950–present
LAKE50	Lampasas River	Kempner	08103800	817	1962–present
LRLR53	Little River	Little River	08104500	5,266	1923–present
LRCA58	Little River	Cameron	08106500	7,100	1916–present
BRBR59	Brazos River	Bryan	08109000	30,016	1899–1993
NAEA66	Navasota River	Easterly	08110500	936	1924–present
BRHE68	Brazos River	Hempstead	08111500	34,374	1938–present
BRRI70	Brazos River	Richmond	08114000	35,454	1903–present
BRRO72	Brazos River	Rosharon	08116650	35,775	1967–present
–	San Bernard River	Boling	08117500	727	1955–present

Basin and Bay Expert Science Team (BBEST) Analyses and Recommendations

The Brazos BBEST (2012) environmental flow recommendations are based on the natural flow regime paradigm adopted by the SB 2 Texas Instream Flow Program that considers magnitude, frequency, duration, timing, and rate of change in flow within the framework of the flow regime components (subsidence, base, within-bank high pulse, and overbank high pulse flows) defined in Table 2.4 of Chapter 2. The Brazos BBEST applied the Hydrology-Based Environmental Flow Regime (HEFR) methodology described in Chapter 2 to develop a recommended environmental flow regime. HEFR was developed by the TPWD, is described by the Science Advisory Committee (2011), and is applied in Microsoft Excel.

The historical record of observed gaged daily flows was used within HEFR with the Indicators of Hydrologic Alteration (IHA) flow separation methodology, described in Chapter 2, to define the four regime components of subsistence flows, base flows, within-bank pulse flows, and overbank pulse flows. The flow limits tabulated in columns 7, 8, and 9 of Table 5.9 and the second column of Table 5.10 were adopted by the BBEST for use in categorizing flows. The following parameters are minimum or maximum limits on mean daily flows in units of ft^3/s.

subsistence flow limit	column 2 of Table 5.10	Flows less than this value are classified as subsistence flows.
minimum flow for pulse flows	column 7 of Table 5.9	Flows less than this value are subsistence or base flows.
maximum flow for base flow	column 8 of Table 5.9	Flows greater than this value are in-bank or overbank pulse flows.
overbank flow limit	column 9 of Table 5.9	Flow at and above this value are overbank flows.

The minimum subsistence flow limits adopted for the BBEST recommended flow regime are tabulated in column 2 of Table 5.10. The 5th percentile of all daily flows was adopted for defining subsistence flows in the HEFR analyses. The 5th percentile daily flow is exceeded in 95 percent of the days of the historical flow record. However, the lesser of 1.0 cfs or the 5th percentile daily flow was adopted for the subsistence flow limits in the final recommended flow regime. If the computed 5th percentile flow is less than 1.0 cfs, the subsistence flow was set at 1.0 cfs. The 5th percentile flow at each of the first five gages listed in Table 5.10 is 0.1 cfs, at NBCL36 and LEGT47 is 0.4 cfs, and at NAEA66 is 0.9 cfs. The subsistence flow target was set at 1.0 cfs at these sites. The other computed values are rounded to the nearest cfs.

The effects of low flows on water quality were considered in confirming the validity of the selected subsistence flow targets. Water quality data were compiled and analyzed for variations in selected quality parameters with discharge rates.

The minimum flow rate at which the flow in a particular day is eligible for consideration for classification as a pulse flow is tabulated in column 7 of Table 5.9. The maximum flow rate at which the flow in a particular day is eligible for consideration for classification as a base flow is tabulated in column 8 of Table 5.9. These two parameters shown in columns 7 and 8 define a range in which the flow may be classified as either base or pulse.

Table 5.9
Limits for Categorizing Flows

1	2	3	4	5	6	7	8	9
BBEST Gage	WAM CP ID	Stream	Nearest City	25% PHDI	75% PHDI	Min Pulse	Max Base	Overbank Flow
						(cfs)	(cfs)	(cfs)
2	SFAS06	Salt Fork Brazos River	Aspermont	-1.92	2.19	8	45	3,130
1	DMAS09	Double Mountain Fork	Aspermont	-1. 88	2.21	6	28	31,800
3	BRSE11	Brazos River	Seymour	-1.90	2.21	42	152	11,400
4	CFNU16	Clear Fork Brazos	Nugent	-1.93	2.25	6	29	5,350
5	CFFG18	Clear Fork Brazos	Fort Griffin	-1.84	2.21	6	73	5,980
6	BRSB23	Brazos River	South Bend	-1.79	2.19	115	388	14,200
7	BRPP27	Brazos River	Palo Pinto	-1.78	2.19	169	693	23,500
8	BRGR30	Brazos River	Glen Rose	-1.80	2.21	180	920	29,500
9	NBCL36	North Bosque River	Clifton	-1.96	2.39	24	104	29,200
10	BRWA41	Brazos River	Waco	-1.96	2.22	300	1,960	41,000
11	LEGT47	Leon River	Gatesville	-1.84	2.39	43	225	6,290
12	LAKE50	Lampasas River	Kempner	-1.96	2.23	40	96	23,000
13	LRLR53	Little River	Little River	-1.84	2.31	242	1,110	10,000
14	LRCA58	Little River	Cameron	-1.85	2.32	190	1,730	20,300
15	BRBR59	Brazos River	Bryan	-1.83	2.24	833	5,080	41,200
16	NAEA66	Navasota River	Easterly	-1.84	2.20	27	108	2,090
17	BRHE68	Brazos River	Hempstead	-1.75	2.16	1,200	7,680	60,000
18	BRRI70	Brazos River	Richmond	-1.74	2.14	1,260	8,430	60,000
19	BRRO72	Brazos River	Rosharon	-1.74	2.13	1,310	9,850	52,100
20	−	San Bernard River	Boling	-1.83	2.02	120	367	3,120

The minimum flow rate for classification as a pulse flow is tabulated in column 7 of Table 5.9. The value for this minimum flow limit parameter ranges between the 25th and 50th percentile flow depending upon estimates of flow rates at which flows appear to leave a relatively narrow low flow channel and spread to a wider channel.

> The 25th percentile flow was adopted for this parameter if the low flow channel capacity is less than the 25th percentile flow.
>
> The 50th percentile flow was adopted for this parameter if the low flow channel capacity is greater than the 50th percentile flow.
>
> The low flow channel capacity was adopted for this parameter if the low flow channel capacity is between the 25th and 50th percentile flows.
>
> The 25th percentile flow was adopted for this parameter if the low flow channel capacity is unclear.

The maximum flow rate at which the flow in a particular day is eligible for consideration for classification as a base flow is tabulated in column 8 of Table 5.9. All flows greater than this flow are pulse flows, either in-bank or overbank pulse flows. The BBEST selected the 75th percentile flow (the flow that is exceeded 25% of the time) for this parameter.

Overbank flows are the subset of high flow pulses that are large enough to connect the floodplain to the main river channel. The overbank flow limit is shown in column 9 of Table 5.9. This is the channel capacity or flow level at which flows spill into the floodplain. The non-flooding limits established by the U.S. Army Corps of Engineers Fort Worth District for use in flood control operations of its reservoirs was adopted by the BBEST for the gage sites on the Little River near Cameron, Brazos River near Hempstead, and Brazos River near Hempstead. Discharges at the lowest National Weather Service flood stage were used by the BBEST to establish overbank flows at the other gage sites.

In addition to the four flow limit parameters for categorizing flows discussed above, values of 25% and 5% for the following two flow change parameters were adopted by the BBEST for use in separating the hydrograph between base flows and pulse flows.

- The BBEST selected 25 percent for the flow increase that changes base flow to pulse flow. If the flow in the preceding day is a base or subsidence flow and the flow in the current day is between the limits shown in columns 7 and 8 of Table 5.9, the flow in the current day is a pulse flow if and only if it reflects a 25% or greater increase from the preceding day.
- The BBEST selected 5 percent for the flow decrease below which pulse flow changes to base flow. If the flow in the preceding day is a pulse flow and the flow in the current day is between the limits shown in columns 7 and 8 of Table 5.9, the flow in the current day is a base flow if it is a decrease but less than a 5% decrease from the flow of the preceding day.

The HEFR methodology includes determining the characteristics of high flow pulses that occur with specified exceedance frequencies. The peak of the high flow pulse is defined as the flow peak that has a given exceedance frequency. HEFR analyzes the duration and volume of all pulses that meet frequency requirements defined by peak flows. A range of volume and duration for pulses meeting a peak flow requirement is determined along with a typical value for the volume and duration. The BBEST reviewed the HEFR analysis results of the full range of pulses and selected levels of pulses to include in the recommended flow regime that appeared to have ecological significance based on factors such as differences in magnitude with other pulses and lateral connectivity of aquatic habitats.

Palmer Hydrological Drought Index (PHDI)

The BBEST defined hydrologic conditions as either wet, medium (average), or dry on the basis of the Palmer Hydrological Drought Index (PHDI). The hydrologic conditions defined with PHDI quartile statistics are applicable only to base flows in the BBEST recommendations, but as discussed later, are applied to both high flow pulses and base flows by the BBASC.

The Palmer Hydrological Drought Index (PHDI) uses an arbitrary scale from -6.0 to +6.0 that represents the severity of drought conditions from extremely dry to extremely wet (Guttman 1991 and 1998). The National Weather Service (NWS) has compiled monthly PDHI values for each month since 1895 for the ten climatic divisions of Texas. The monthly PDHI are updated in near real-time. The PHDI data and related information are available at the following websites.

ftp://ftp.ncdc.noaa.gov/pub/data/cirs/drd964x.phdi.txt

ftp://ftp.ncdc.noaa.gov/pub/data/cirs/drought.README

The BBEST superimposed the watersheds above each of the 20 stream gages with the ten climatic divisions. PDHI values for each gage location are computed as a weighted average of the percentage of the drainage area within each climatic division. The BBEST used 1895-2010 sequences of the NWS monthly PDHI to compute the 25% and 75% quartiles in columns 5 and 6 of Table 5.9. The values for the 25% and 75% quartiles can be updated in the future as additional months of the PHDI are accumulated.

The three hydrologic conditions defined with the quartile statistics for the 1895-2010 PHDI tabulated in columns 5 and 6 of Table 5.9, or updated with more recent continuations of the PHDI, are applied in specifying environmental flow targets associated with the base flow component of the flow regime. The upper and lower quartiles represent wet and dry hydrologic conditions. PHDI values between the 25th and 75th percentiles represent average (medium or closer to normal) hydrologic conditions.

low (dry) conditions	PHDI for month falls within lowest 25% PHDI quartile
medium (normal) conditions	PHDI for month falls between 25th and 75th percentiles
high (wet) conditions	PHDI for month falls within highest 75% PHDI quartile

The BBEST Recommendations Report describes the development of the base flow targets presented in Table 5.10. HEFR generates base flow statistics for each of the three seasons from the daily flows falling within the base flow range defined in the flow separation analysis. The BBEST adopted the HEFR default values for low (dry), medium (average), and high (wet) base flows as the 25th, 50th, and 75th percentile flows for each of the three seasons.

Basin and Bay Expert Science Team (BBEST) Environmental Flow Recommendations

The environmental instream flow requirements recommended by the BBEST consist of the quantities tabulated in Tables 5.10 and 5.11 supplemented by columns 7 and 8 of Table 5.9 and the rules for applying these quantities that are described in the following discussion. Subsistence and base flow targets are defined by the parameters in Table 5.10. Pulse flow targets are defined by the parameters in Table 5.11 and columns 7 and 8 of Table 5.9.

In administration of the water rights system during droughts, curtailment operations that protect the instream flow requirements would be implemented based on current and recently observed flows at the gaging stations and estimates of current values of the PHDI for each site. In the daily WRAP/WAM model, the instream flow targets are computed and applied based on computed daily regulated flows and input sequences of an index based on the PHDI along with the rules defined based on the metrics in Tables 5.10 and 5.11 and columns 7 and 8 of Table 5.9.

The BBEST flow regime recommendations are interpreted below in terms of computing instream flow targets each day at each of the 20 locations. The term *instream flow target* as used here has the same meaning as in the WRAP/WAM modeling system and in the discussion earlier in this chapter regarding existing Brazos WAM instream flow requirements. An instream flow target is a minimum streamflow limit at a specified control point location that is activated at a specified seniority in the water rights priority sequence. Upstream junior water rights are required to curtail streamflow depletions (diversions and refilling reservoir storage) as necessary to prevent or minimize violation of the instream flow target.

An instream flow target for a particular day at a particular location is set based on subsistence and base flow requirements (Table 5.10). During any day in which one or more high pulse events are activated, the target is the highest Q_P (Table 5.11) of any of the activated pulse events. With more than one target activated, the target with the highest magnitude controls.

Table 5.10
BBEST and BBASC Recommended Subsistence and Base Flow Limits

Gage and Control Point	Subsist Flow (cfs)	Base Flow (cfs)								
		Winter			Spring			Summer		
		Low	Med	High	Low	Med	High	Low	Med	High
SFAS06	1	1	4	9	1	2	5	1	1	3
DMAS09	1	1	4	15	1	3	8	1	2	7
BRSE11	1	10	25	46	7	19	35	4	13	32
CFNU16	1	5	8	13	3	6	12	1	4	9
CFFG18	1	8	17	34	4	13	27	1	5	20
BRSB23	1	36	73	120	29	60	100	16	46	95
BRPP27	17	40	61	100	39	75	120	40	72	120
BRGR30	16	42	77	160	47	92	170	37	70	160
NBCL36	1	5	12	25	7	16	33	3	8	17
BRWA41	56	120	210	480	150	270	690	140	250	590
LEGT47	1	9	20	52	10	24	54	4	12	27
LAKE50	10	18	27	39	21	29	43	16	23	32
LRLR53	55	82	110	190	95	150	340	84	120	200
LRCA58	32	110	190	460	140	310	760	97	160	330
BRBR59	300	540	860	1,760	710	1,260	2,460	630	920	1,470
NAEA66	1	9	14	23	10	19	29	3	8	16
BRHE68	510	920	1,440	2,890	1,130	1,900	3,440	950	1,330	2,050
BRRI70	550	990	1,650	3,310	1,190	2,140	3,980	930	1,330	2,190
BRRO72	430	1,140	2,090	4,700	1,250	2,570	4,740	930	1,420	2,630
San Bernard	11	23	43	73	32	53	85	64	98	140

Instream Flow Target based on Subsistence and Base Flow Requirements

Subsistence flow and base flow limits are tabulated in Table 5.10. The subsistence flow limit in the second column is a constant for each site. The base flow limits are functions of season and hydrologic condition. The three seasons of the year are defined as follows.

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

As previously discussed, hydrologic conditions are defined as follows.

low (dry) conditions — PHDI for month falls within lowest 25% PHDI quartile
medium (normal) conditions — PHDI for month falls between 25th and 75th percentiles
high (wet) conditions — PHDI for month falls within highest 25% PHDI quartile

The subsistence and base flow limits are applied differently for dry hydrologic conditions than for average and wet hydrologic conditions. A 50% rule is applied if the hydrologic condition is dry as measured by the PHDI being in the lowest quartile. A target for a particular day at a particular location is set based on subsistence and base flow requirements as follows.

- Under average or wet hydrologic conditions, the instream flow target is equal to the base flow limit in Table 5.10 which varies between the three seasons of the year.

- Under dry hydrologic conditions:

  1. If the flow in that day is less than the subsistence flow limit in Table 5.10, then the instream flow target is set equal to the subsistence flow limit.

  2. If the flow equals or exceeds the subsistence flow limit but is less than the base flow limit in Table 5.10, then the instream flow target is equal to the subsistence flow limit plus 50 percent of the difference between the actual flow and the subsistence flow limit.

<u>Instream Flow Target Based on High Flow Pulse Requirements</u>

The quantities used to set high flow pulse targets are tabulated in Table 5.11. The minimum flow for pulse flows tabulated in column 7 of Table 5.9 and the maximum flow for base flows in column 8 of Table 5.9 are also incorporated in the criteria for terminating a pulse.

Each line in Table 5.11 represents a pulse event associated with a specified exceedance frequency. Five to seven pulse events are defined for each location in descending order with the highest magnitude, least frequent pulse listed first. The larger pulses are defined by an annual exceedance frequency (once per five years, once per two years, or once per year). Some of the larger and less frequent pulse events include overbank flows. The smaller and more frequent pulses are defined by seasonal frequency (number of pulses per year occurring in a particular season). The seasons are Winter (November-February), Spring (March-June), and Summer (July-October) for purposes of the BBEST flow regime, including both Tables 5.10 and 5.11. The pulse events are counted in the season or year in which they begin. The quantities in Table 5.11 used in defining a pulse are as follows.

Q_P - The peak daily flow rate (Q_P) in cfs for a high pulse flow event is associated with a specified annual exceedance frequency. Tracking of a pulse is initiated in the day in which the flow rate exceeds the Q_P for a prescribed pulse. The instream flow target is set at the Q_P during the duration of the pulse event.

Freq - The annual exceedance frequency (Freq) may be based on either counting pulse events occurring during the entire calendar year (pulse events/year) or in one of the three four-month seasons of the year (pulse events/season).

Volume - The summation of the daily flow volumes from the day in which tracking of a pulse begins through the current day serves as one of the several criteria for terminating the tracking of a pulse event. Flow volume is in acre-feet

Duration - The prescribed pulse duration in days in Table 5.11 also serves as a criterion for terminating the tracking of a pulse.

Table 5.11
BBEST Recommended High Flow Pulses

WAM Control Point	Winter				Spring				Simmer			
	Qp (cfs)	Freq	Volume (ac-ft)	Duration (days)	Qp (cfs)	Freq	Volume (ac-ft)	Duration (days)	Qp (cfs)	Freq	Volume (ac-ft)	Duration (days)
SFAS06	same throughout year (overbank)				6,040	1/2yr	29,400	26				
	same throughout year (overbank)				3,610	1/yr	17,500	23				
	71	1/s	510	14	1,790	1/s	8,310	16	1,580	1/s	7,680	18
	31	2/s	210	10	670	2/s	3,070	13	520	2/s	2,310	13
	–	–	–	–	300	3/s	1,350	11	260	3/s	1,090	10
	–	–	–	–	160	4/s	720	10	140	4/s	560	8
DMAS09	same throughout year (inbank)				16,300	1/5yr	77,100	31				
	same throughout year (inbank)				9,490	1/2yr	44,900	27				
	same throughout year (inbank)				5,130	1/yr	24,300	23				
	92	1/s	610	12	2,730	1/s	12,500	17	2,540	1/s	11,900	19
	30	2/s	180	8	1,120	2/s	5,120	14	1,040	2/s	4,750	14
	–	–	–	–	570	3/s	2,600	12	480	3/s	2,160	12
	–	–	–	–	280	4/s	1,270	10	230	4/s	990	9
BRSE11	same throughout year (overbank)				16,800	1/2yr	125,000	35				
	same throughout year (inbank)				10,400	1/yr	74,100	29				
	250	1/s	1,560	10	4,730	1/s	30,500	20	4,570	1/s	28,600	21
	97	2/s	490	6	2,000	2/s	12,000	15	1,560	2/s	8,910	14
	–	–	–	–	1,040	3/s	5,870	12	800	3/s	4,290	11
	–	–	–	–	560	4/s	2,960	10	370	4/s	1,870	8
CFNU16	same throughout year (overbank)				7,850	1/5yr	41,700	28				
	same throughout year (inbank)				4,860	1/2yr	23,400	24				
	same throughout year (inbank)				2,390	1/yr	12,300	21				
	110	1/s	710	15	1,290	1/s	6,220	15	980	1/s	4,980	16
	26	2/s	160	9	590	2/s	2,800	12	390	2/s	1,890	12
	–	–	–	–	180	4/s	860	9	100	4/s	460	8
CFFG18	same throughout year (overbank)				8,630	1/yr	53,500	27				
	same throughout year (inbank)				4,970	1/yr	30,700	24				
	240	1/s	1,740	16	2,970	1/s	17,700	18	1,980	1/s	11,900	20
	61	2/s	430	11	1,230	2/s	7,310	15	700	2/s	4,110	16
	–	–	–	–	360	4/s	2,120	12	110	4/s	620	10
BRSB23	same throughout year (overbank)				25,400	1/2yr	228,000	35				
	same throughout year (overbank)				15,800	1/yr	133,000	29				
	960	1/s	6,870	12	9,560	1/s	72,100	21	7,440	1/s	57,200	23
	280	2/s	1,640	7	4,550	2/s	31,100	16	2,560	2/s	17,000	15
	–	–	–	–	2,840	3/s	15,700	13	1,180	3/s	7,050	11
	–	–	–	–	1,260	4/s	7,280	10	580	4/s	3,140	8
BRPP27	same throughout year (overbank)				25,800	1/2yr	301,000	32				
	same throughout year (inbank)				17,500	1/yr	182,000	26				
	1,890	1/s	10,900	8	10,700	1/s	88,000	18	7,440	1/s	61,100	17
	1,390	2/s	7,180	7	3,370	2/s	20,200	10	2,260	2/s	13,000	9
	850	4/s	3,690	5	1,400	4/s	6,600	6	1,230	4/s	5,920	6
BRGR30	same throughout year (overbank)				33,600	1/2yr	327,000	29				
	same throughout year (inbank)				22,200	1/yr	203,000	24				
	3,230	1/s	22,600	13	13,400	1/s	109,000	19	7,760	1/s	62,500	17
	1,700	2/s	10,800	10	6,480	2/s	46,700	14	3,090	2/s	21,200	12
	930	4/s	5,400	8	2,350	4/s	14,300	10	1,320	4/s	7,830	8

Table 5.11 Continued
BBEST Recommended High Flow Pulses

WAM	Winter				Spring				Summer			
Control Point	Qp (cfs)	Freq	Volume (ac-ft)	Duration (days)	Qp (cfs)	Freq	Volume (ac-ft)	Duration (days)	Qp (cfs)	Freq	Volume (ac-ft)	Duration (days)
NBCL36	same throughout year (inbank)				19,800	1/5yr	91,100	30				
	same throughout year (inbank)				13,900	1/2yr	64,300	27				
	same throughout year (inbank)				8,650	1/yr	40,300	24				
	1,490	1/s	8,720	18	5,820	1/s	25,900	19	1,080	1/s	4,300	12
	420	2/s	2,500	13	2,170	2/s	10,100	15	350	2/s	1,380	
	120	3/s	750	10	–	–	–	–	130	3/s	500	6
	–	–	–	–	710	4/s	3,490	12	–	–	–	–
BRWA41	same throughout year (overbank)				42,600	1/2yr	427,000	26				
	same throughout year (inbank)				30,800	1/yr	288,000	22				
	8,450	1/s	61,100	13	23,500	1/s	197,000	18	10,000	1/s	77,900	16
	4,180	2/s	25,700	9	13,600	2/s	102,000	14	4,160	2/s	26,400	10
	2,320	4/s	12,400	7	5,330	4/s	32,700	10	1,980	4/s	10,500	7
LEGT47	same throughout year (overbank)				7,580	1/2yr	80,200	39				
	same throughout year (inbank)				5,300	1/yr	52,300	33				
	same throughout year (inbank)				1,010	1/s	7,160	16				
	280	2/s	1,890	10	1,390	2/s	10,600	18	340	2/s	1,640	9
	100	3/s	540	6	630	3/s	4,050	13	140	3/s	600	6
	–	–	–	–	340	4/s	1,910	10	58	4/s	220	4
LAKE50	same throughout year (overbank)				13,000	1/5yr	77,000	38				
	same throughout year (inbank)				7,960	1/2yr	46,000	32				
	same throughout year (inbank)				4,690	1/yr	26,300	26				
	740	1/s	4,990	18	2,650	1/s	14,000	20	540	1/s	2,040	9
	190	2/s	1,150	11	1,310	2/s	6,860	16	190	2/s	680	6
	78	3/s	430	8	780	3/s	4,020	13	77	3/s	270	4
LRLR53	same throughout year (overbank)				11,700	1/5yr	198000	38				
	same throughout year (inbank)				8,890	1/2yr	134,000	32				
	same throughout year (inbank)				6,740	1/yr	89,800	27				
	2,960	1/s	28,300	17	5,310	1/s	63,400	23	2,470	1/s	20,300	13
	1,600	2/s	11,800	11	3,290	2/s	32,200	17	1,060	2/s	5,890	8
	520	4/s	2,350	5	1,420	4/s	9,760	10	430	4/s	1,560	4
LRCA58	same throughout year (overbank)				29,900	1/2yr	324,000	29				
	same throughout year (overbank)				19,700	1/yr	198,000	24				
	9,550	1/s	85,600	19	12,800	1/s	121,000	20	4,800	1/s	35,300	14
	4,630	2/s	36,700	14	7,550	2/s	65,400	17	2,070	2/s	13,200	10
	2,140	3/s	14,900	10	4,790	3/s	38,400	14	990	3/s	5,550	8
	1,080	4/s	6,680	8	3,200	4/s	23,900	12	560	4/s	2,860	6
BRBR59	same throughout year (overbank)				66,900	1/2yr	989,000	35				
	same throughout year (inbank)				49,400	1/yr	675,000	30				
	22,600	1/s	243,000	20	32,900	1/s	421,000	25	12,100	1/s	114,000	16
	11,200	2/s	100,000	14	17,800	2/s	193,000	18	5,000	2/s	38,100	10
	5,570	3/s	41,900	10	10,400	3/s	97,000	14	2,990	3/s	20,100	8
	3,230	4/s	21,100	7	6,050	4/s	49,000	11	2,060	4/s	12,700	7
NAEA66	same throughout year (overbank)				16,700	1/2yr	142,000	30				
	same throughout year (inbank)				10,800	1/yr	88,500	26				
	4,390	1/s	34,300	21	5,470	1/s	41,100	19	410	1/s	2,340	10
	1,700	2/s	12,300	16	2,380	2/s	16,700	15	120	2/s	580	7
	800	3/s	5,440	12	1,340	3/s	8,990	13	49	3/s	220	5
	260	4/s	1,610	9	720	4/s	4,590	11	–	–	–	–

Table 5.11 Continued
BBEST Recommended High Flow Pulses

WAM Control Point	Winter Qp (cfs)	Winter Freq	Winter Volume (ac-ft)	Winter Duration (days)	Spring Qp (cfs)	Spring Freq	Spring Volume (ac-ft)	Spring Duration (days)	Summer Qp (cfs)	Summer Freq	Summer Volume (ac-ft)	Summer Duration (days)
BRHE68	same throughout year (overbank)				63,900	1/2yr	1,331,000	40				
	same throughout year (overbank)				50,000	1/yr	952,000	35				
	24,800	1/s	368,000	23	34,200	1/s	589,000	29	10,300	1/s	104,000	14
	11,200	2/s	125,000	15	16,800	2/s	219,000	19	5,090	2/s	40,900	9
	5,720	3/s	49,800	10	8,530	3/s	85,000	13	2,620	3/s	17,000	7
BRRI70	same throughout year (inbank)				68,100	1/2yr	1,487,000	41				
	same throughout year (inbank)				51,600	1/yr	1,019,000	35				
	24,600	1/s	383,000	23	35,000	1/s	617,000	15	12,900	1/s	144,000	15
	12,400	2/s	150,000	16	16,300	2/s	215,000	19	5,430	2/s	46,300	10
	6,410	3/s	60,600	11	8,930	3/s	94,000	13	2,460	3/s	16,400	6
BRRO72	same throughout year (overbank)				60,900	1/2yr	1,463,000	42				
	same throughout year (inbank)				51,000	1/yr	1,133,000	38				
	25,700	1/s	415,000	23	33,700	1/s	665,000	31	13,300	1/s	153,000	16
	13,600	2/s	168,000	16	14,200	2/s	184,000	18	4,980	2/s	39,100	9
	9,090	3/s	94,700	12	6,580	3/s	58,500	10	2,490	3/s	14,900	6
San Bernard River at Boling	same throughout year (overbank)				8,820	1/2yr	123,000	32				
	same throughout year (overbank)				6,110	1/yr	79,800	27				
	3,310	1/s	39,400	21	3,220	1/s	36,100	20	2,330	1/s	25,000	19
	1,940	2/s	20,100	16	1,570	2/s	14,900	14	780	2/s	7,250	13
	1,060	3/s	9,370	12	680	3/s	5,300	10	470	3/s	4,050	10
	510	4/s	3,710	8	350	4/s	2,360	7	300	4/s	2,480	9

A pulse event is initiated when the flow exceeds its Q_P, which is tabulated in Table 5.11. During the tracking of this pulse event, flows may increase to a magnitude that exceeds the greater Q_P of a larger pulse in Table 5.11. In this case, the parameters of the higher flow pulse take control of the continued tracking. The higher magnitude pulse event is considered to satisfy any and all lower magnitude events in the same season. For example, if the streamflow during a two-per-season event increases and exceeds the one-per-year event Q_P, then the one-per-year event volume and duration would control the remaining tracking of the pulse. The one-per-year event would also count for one of the smaller two-per-season events.

A qualifying pulse event is initiated when the daily flow exceeds the prescribed peak daily flow Q_P in Table 5.11. The qualifying pulse event continues until terminated by one of the following conditions (termination criteria).

- The prescribed volume shown in Table 5.11 is accumulated.
- The prescribed duration shown in Table 5.11 is reached.
- The mean daily flow recedes to or below the minimum flow for pulse flows tabulated in column 7 of Table 5.9.
- The mean daily flow recedes to or below the maximum flow for base flows tabulated in column 8 of Table 5.9 and decreases by 5 percent or less in a day.

An accounting is maintained of the number of pulses that satisfy the prescribed criteria outlined in Table 5.11. Pulses are used to set instream flow targets only to the extent necessary to satisfy the frequency criteria in Table 5.11. For example, after two pulses that satisfy the two-per-season event criteria are activated for use in target setting, additional pulses occurring in that season are not applied to satisfy that two-per-season frequency criterion.

During each day in which one or more high pulse events are activated, the instream flow target is the highest Q_P of any of the activated pulse events. The pulse-based target-setting procedures are the same for both within-bank and overbank flows. The Q_P in Table 5.11 can be compared with the overbank flow limits in column 9 of Table 5.9.

Basin and Bay Area Stakeholders Committee (BBASC) Recommended Flow Regime

In the Senate Bill 3 process, the BBEST is charged with recommending a flow regime that is based solely on environmental needs. The BBASC reviews the BBEST report and develops an environmental flow regime based on considering all water needs including needs for agricultural, municipal, industrial, and other water uses as well as ecosystem needs. The Brazos BBASC relied upon the studies and recommendations documented in the BBEST report and supporting communications with the BBEST. However, the BBASC performed its own additional analyses and deliberations to develop recommendations based on a comprehensive consideration of all water uses. Upon completion of its analyses and deliberations, the BBASC had adopted the subsistence and low flow limits recommended by the BBEST. However, the final BBASC recommendations for pulse flows differ significantly from the BBEST recommendations. The BBASC also applies the PHDI differently. The BBASC report includes majority and minority recommendations regarding high pulse flows at the gages at SFA06, DMA09, and BRSE11. All other aspects of the flow regime are recommended by consensus.

The subsistence and pulse flow limits tabulated in Table 5.10 are the same in both the BBEST and BBASC recommended flow regimes. The BBEST and BBASC recommended high flow pulses are presented in Tables 5.11 and 5.12, respectively. The BBASC flow pulses in Table 5.12 are significantly different than the BBEST flow pulses in Table 5.11.

The subsistence and base flow quantities of Table 5.10 are applied along with the previously described 50% rule in both the BBASC and BBEST instream flow requirements.

- The 50% rule is applied only under dry hydrologic conditions. If the flow in a day is less than the subsistence flow limit in Table 5.10, then the stream flow target is set equal to the subsistence flow limit. If the flow equals or exceeds the subsistence flow limit but is less than the base flow limit in Table 5.10, then the instream flow target is equal to the subsistence flow limit plus 50 percent of the difference between the actual flow and the subsistence flow limit.

- Under average or wet hydrologic conditions, the instream flow target is equal to the base flow limit in Table 5.10. The smaller subsistence flow limit is redundant.

Hydrologic conditions are defined as follows in both the BBASC and BBEST recommendations based on the Palmer Hydrologic Drought Index (PHDI).

low (dry) conditions	PHDI falls within lowest 25% PHDI quartile
medium (normal) conditions	PHDI falls between 25th and 75th percentiles
high (wet) conditions	PHDI falls within highest 75% PHDI quartile

Differences between the manner in which the PHDI and hydrologic conditions are applied in defining by the BBASC versus BBEST recommended flow regimes are as follows.

- The BBEST applies hydrologic conditions only with base flows. The BBASC applies hydrologic conditions to high pulse flows as well as base flows. The high flow pulses in Table 5.12 recommended by the BBASC vary between hydrologic conditions.
- The BBEST assigns PHDI sequences to each of the 20 individual sites. The BBASC aggregates the PHDI to three drainage regions: (1) the subbasin upstream of Possum Kingdom Dam, (2) the drainage subbasin between Possum Kingdom and Whitney Dams, and (3) the subbasin draining into the Brazos River below Whitney Dam.
- The BBEST updates the PHDI each month for application during the days of that month. The BBBASC adopts a monthly PHDI at the beginning of each season for application to all of the days during that season.

The high pulse flow requirements recommended by the BBASC include fewer in-bank pulses and no overbank flows. The BBASC excluded overbank flows for the following reasons.

- The potential for flood damage to property and human life.
- The Senate Bill 3 process allowed insufficient time to properly analyze overbank flow requirements.
- TCEQ has chosen to not approve overbank components previously recommended for other river basins.
- Overbank flows will occur naturally even if not included in flow standards.

The three seasons of the year are defined as follows in both the BBASC and BBEST recommended regimes: Winter (November, December, January, February), Spring (March, April, May, June), and Summer (July, August, September, October).

A qualifying pulse event is initiated when the flow exceeds the prescribed peak trigger flow Q_P. In regard to the frequency criterion, qualifying pulse events are counted in the season or year in which they begin and continue into the following season or year as necessary to meet the prescribed pulse characteristics. A pulse flow event is terminated if:

- the volume limit is reached,
- the duration limit is reached,
- the mean daily flow decreases to the minimum pulse flow limit in column 7 of Table 5.9 or
- the mean daily flow decreases to the maximum base flow limit in column 8 of Table 5.9 and decreases by 5 percent or less in a day.

The environmental flow regime recommended by the BBASC, as described in the preceding discussion, is modeled in its entirety with WRAP and the expanded Brazos WAM dataset as described in the following Chapters 6 and 7. The exemptions described below are the only feature of the BBASC flow regime that is not included in the model.

Table 5.12
BBASC Recommended High Flow Pulses

	Winter				Spring				Summer			
	Qp (cfs)	Freq	Volume (ac-ft)	Duration (days)	Qp (cfs)	Freq	Volume (ac-ft)	Duration (days)	Qp (cfs)	Freq	Volume (ac-ft)	Duration (days)
SFAS06	Salt Fork Brazos at Aspermont											
dry	–	–	–	–	160	1	720	10	140	1	560	8
average	–	–	–	–	160	2	720	10	140	2	560	8
wet	–	–	–	–	300	1	1,350	11	260	1	1,090	10
DMAS09	Double Mountain at Aspermont											
dry	–	–	–	–	280	1	1,270	10	230	1	990	9
average	–	–	–	–	280	2	1,270	10	230	2	990	9
wet	–	–	–	–	570	1	2,600	12	480	1	2,160	12
BRSE11	Brazos River at Seymour											
dry	–	–	–	–	560	1	2,960	10	370	1	1,870	8
average	–	–	–	–	560	2	2,960	10	370	2	1,870	8
wet	–	–	–	–	1,040	1	5,870	12	800	1	4,290	11
CFNU16	Clear Fork Brazos at Nugent											
dry	–	–	–	–	180	1	860	9	100	1	460	8
average	–	–	–	–	180	2	860	9	100	2	460	8
wet	26	1	160	9	590	1	2,800	12	390	1	1,890	12
CFFG18	Clear Fork Brazos at Fort Griffin											
dry	–	–	–	–	360	1	2,120	12	110	1	620	10
average	–	–	–	–	360	2	2,120	12	110	2	620	10
wet	61	1	430	11	1,230	1	7,310	15	700	1	4,110	16
BRSB23	Brazos River at South Bend											
dry	–	–	–	–	1,260	1	7,280	10	580	1	3,140	8
average	–	–	–	–	1,260	2	7,280	10	580	2	3,140	8
wet	–	–	–	–	2,480	1	15,700	13	1,180	1	7,050	11
BRPP27	Brazos River at Palo Pinto											
dry	850	2	3,690	5	1,400	2	6,600	6	1,230	2	5,920	6
average	850	4	3,690	5	1,400	4	6,600	6	1,230	4	5,920	6
average	1,390	2	7,180	7	3,370	2	20,200	10	2,260	2	13,000	9
wet	850	4	3,690	5	1,400	4	6,600	6	1,230	4	5,920	6
wet	1,390	3	7,180	7	3,370	3	20,200	10	2,260	3	13,000	9
BRGR30	Brazos River at Glen Rose											
dry	930	2	5,400	8	2,350	2	14,300	10	1,320	2	7,830	8
average	930	4	5,400	8	2,350	4	14,300	10	1,320	4	5,920	6
average	1,700	2	10,800	10	6,480	2	46,700	14	3,090	2	21,200	12
wet	930	4	5,400	8	2,350	4	14,300	10	1,230	4	5,920	6
wet	1,700	3	10,800	10	6,480	3	46,700	14	3,090	3	21,200	12
NBCL36	North Bosque River at Clifton											
dry	–	–	–	–	710	1	3,490	12	–	–	–	–
average	–	–	–	–	710	3	3,490	12	–	–	–	–
wet	120	2	750	10	710	3	3,490	12	130	2	500	6
BRWA41	Brazos River at Waco											
dry	2,320	1	12,400	7	5,330	1	32,700	10	1,980	1	10,500	7
average	2,320	3	12,400	7	5,330	3	32,700	10	1,980	3	10,500	7
wet	4,180	2	25,700	9	13,600	2	102,000	14	4,160	2	26,400	10
LEGT47	Leon River at Gatesville											
dry	–	–	–	–	340	1	1,910	10	58	1	220	4
average	–	–	–	–	340	3	1,910	10	58	3	220	4
wet	100	2	540	6	630	2	4,050	13	140	2	600	6

Table 5.12 Continued
BBASC Recommended High Flow Pulses

	Winter				Spring				Simmer			
	Qp (cfs)	Freq	Volume (ac-ft)	Duration (days)	Qp (cfs)	Freq	Volume (ac-ft)	Duration (days)	Qp (cfs)	Freq	Volume (ac-ft)	Duration (days)
LAKE50	Lampasas River at Kempner											
dry	78	1	430	8	780	1	4,020	13	77	1	270	4
average	78	3	430	8	780	3	4,020	13	77	3	270	4
wet	190	2	1,150	11	1,310	2	6,860	16	190	2	680	6
LRLR53	Little River at Little River											
dry	520	1	2,350	5	1,420	1	9,760	10	430	1	1,560	4
average	520	3	2,350	5	1,420	3	9,760	10	430	3	1,560	4
wet	1,600	2	11,800	11	3,290	2	32,200	17	1,060	2	5,890	8
LRCA58	Little River at Cameron											
dry	1,080	1	6,680	8	3,200	1	23,900	12	560	1	2,860	6
average	1,080	3	6,680	8	3,200	3	23,900	12	560	3	2,860	6
wet	2,140	2	14,900	10	4,790	2	38,400	14	990	2	5,550	8
BRBR59	Brazos River at Bryan											
dry	3,230	1	21,100	7	6,050	1	49,000	11	2,060	1	12,700	7
average	3,230	3	21,100	7	6,050	3	49,000	11	2,060	3	12,700	7
wet	5,570	2	41,900	10	10,400	2	97,000	14	2,990	2	20,100	8
NAEA66	Navasota River at Easterly											
dry	260	1	1,610	9	720	1	4,590	11	–	–	–	–
average	260	3	1,610	9	720	3	4,590	11	–	–	–	–
wet	800	2	5,440	12	1,340	2	8,990	13	49	2	220	5
BRHE66	Brazos River at Hempstead											
dry	5,720	1	5,720	10	8,530	1	85,000	13	2,620	1	17,000	7
average	5,720	3	49,800	10	8,530	3	85,000	13	2,620	3	17,000	7
wet	11,200	2	125,000	15	16,800	2	219,000	19	5,090	2	40,900	9
BRRI70	Brazos River at Richmond											
dry	6,410	1	60,600	11	8,930	1	94,000	13	2,460	1	16,400	6
average	6,410	3	60,600	11	8,930	3	94,000	13	2,460	3	16,400	6
wet	12,400	2	150,000	16	16,300	2	215,000	19	5,430	2	46,300	10
BRRO72	Brazos River at Rosharon											
dry	9,090	1	94,700	12	6,580	1	58,500	10	2,490	1	14,900	6
average	9,090	3	94,700	12	6,580	3	58,500	10	2,490	3	14,900	6
wet	13,600	2	168,000	16	14,200	2	184,000	18	4,980	2	39,100	9
	San Bernard River at Boling											
dry	510	1	3,710	8	350	1	2,360	7	300	1	2,480	9
average	510	3	3,710	8	350	3	2,360	7	300	3	2,480	9
wet	1,060	2	9,370	12	680	2	5,300	10	470	2	4,050	10

The hydrologic conditions are listed in the first column below the WAM control point.

Hydrologic Conditions
low (dry) conditions PHDI within lowest 25% PHDI quartile
medium (average) conditions PDHI between 25th and 75th percentiles
high (wet) conditions PHDI within highest 75% PHDI quartile

Seasons of the Year
Winter: November, December, January, February
Spring: March, April, May, June
Summer: July, August, September, October

Exemptions in the BBASC Pulse Flow Requirements

The BBASC recommendations include a small-user exemption based on the likelihood that the available pumping capacity would not be able to divert enough water to adversely impact the overall pulse event. If the diversion rate for a new water right is less than 20 percent of the pulse flow trigger requirement (peak flow Qp), the new water right will not be required to pass that pulse. Thus, the pulse flow requirements result in curtailment of diversions for only new water rights with diversion rates that are greater than 20 percent of the Qp in Table 5.12. No mention is made of reservoir storage in the BBASC report description of this exemption.

The water right permit system and the WRAP/WAM modeling system are based on the prior appropriation doctrine modeled as a priority (seniority) sequence. Circumventions of the priority system greatly complicate modeling. Also, as discussed below, the interpretation of the 20% rule described above requires additional information for clarity.

Twenty percent of the Qp for the larger high flow pulse events are relatively high flow rates compared to a range of typical authorized water supply diversion rates. For comparison, as indicated by Table 5.2, the over 1,200 water right permits modeled in the Brazos WAM contain authorized diversions totaling 2,437,338 acre-feet/year. The authorized diversions supplied by the 16 largest reservoirs listed in Table 5.2 range from 13,610 acre-feet/year at Georgetown Lake to 230,750 acre-feet/year at Possum Kingdom Lake.

The largest pulse flow trigger Qp in Table 5.12 is 16,800 cfs. Twenty percent of 16,800 cfs is 3,360 cfs which is equivalent to a constant discharge of 2,432,529 acre-feet/year. Over half of the pulse flow peaks Qp in Table 5.12 exceed 1,000 cfs. Twenty percent of 1,000 cfs is equivalent to a constant flow rate of 144,793 acre-feet/year, which would represent a large water supply diversion. It appears likely that most new water rights proposed in the future would be exempt from most of the pulse flow requirements, which may not have been the intent of the BBASC in recommending the exemption.

The 20 percent exception could perhaps be interpreted as applying to flood scalping operations where water supply diversions are limited to flood flows. However, without significant reservoir storage capacity, such diversions would have reliabilities much lower than the conventional agricultural irrigation criterion of supplying at least 75% of the target demand at least 75% of the time. Pumping capacity can be modeled as a maximum limit on the diversion rate. Reservoir storage would need to be addressed to clarify the exemption.

Another pulse flow exemption is specified in the BBASC report for the Palo Pinto Creek Watershed.

> *Requests by an existing permit holder, at the time the environmental flow standards are adopted, in the Palo Pinto Creek watershed to increase authorized storage by up to 15% does not require application of high flow pulse standards on the new application.*

These exemptions are the only aspect of the BBASC environmental flow regime described in this chapter that is not modeled with WRAP and the expanded Brazos WAM dataset described in the following Chapters 6 and 7. Otherwise, the BBASC flow regime is modeled in its entirety.

Comparison of Base Flow Requirements at Three Gages

Table 5.13 compares the BBASC recommended new base flow requirements (Table 5.10) with existing WAM *IF* records (Table 5.7) for two locations on the lower Brazos River and one on the lower Little River, which is the largest tributary of the Brazos River. The locations of control points LRCA58, BRHE68, and BRRI70 are shown in Figure 5.3.

Table 5.13
Instream Flow Comparison

	Little River at Cameron				Brazos River at Hempstead				Brazos River at Richmond			
	Old	Low	Med	High	Old	Low	Med	High	Old	Low	Med	High
	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
Jan	132	110	190	460	1,136	920	1,440	2,890	1,029	990	1,650	3,310
Feb	132	110	190	460	1,516	920	1,440	2,890	1,899	990	1,650	3,310
Mar	474	140	310	760	2,022	1,130	1,900	3,440	1,274	1,190	2,140	3,980
Apr	474	140	310	760	2,304	1,130	1,900	3,440	2,785	1,190	2,140	3,980
May	1020	140	310	760	4,439	1,130	1,900	3,440	5,341	1,190	2,140	3,980
Jun	474	140	310	760	3,299	1,130	1,900	3,440	3,393	1,190	2,140	3,980
Jul	474	97	160	330	1,314	950	1,330	2,050	1,470	930	1,330	2,190
Aug	132	97	160	330	858	950	1,330	2,050	833	930	1,330	2,190
Sep	132	97	160	330	864	950	1,330	2,050	1,418	930	1,330	2,190
Oct	132	97	160	330	734	950	1,330	2,050	882	930	1,330	2,190
Nov	132	110	190	460	734	920	1,440	2,890	962	990	1,650	3,310
Dec	132	110	190	460	952	920	1,440	2,890	1,176	990	1,650	3,310

IF record rights IFC3775_1, IF5752_1, and IF5665_1 in Table 5.7 set the following instream flow targets in the WAM.

LRCA58, Gage on Little River at Cameron:	232,926 acre-feet/year (322 cfs)
BRHE68, Gage on Brazos River at Hempstead:	1,216,877 acre-feet/year (1,681 cfs)
BRRI70, Gage on Brazos River at Richmond:	1,352,902 acre-feet/year (1,869 cfs)

These instream flow targets vary monthly as shown in the 2nd, 6th, and 10th columns of Table 5.13, which are labeled *Old* meaning the existing *IF* records in the Brazos WAM.

The subsistence and base flows recommended by the BBASC (also by the BBEST) are shown in Table 5.10. The base flows for WAM control points LRC58, BRHE68, and BRRI70 are reproduced in Table 5.13. The BBEST/BBASC base flows vary between low (dry), medium (normal), and high (wet) hydrologic conditions and between the three defined seasons. The Table 5.13 columns with the BBEST/BBASC base flows are labeled Low, Med, and High.

With instream flow targets already established by the existing *IF* records, the impacts on water availability simulation results of adding the subsistence and base flow components of the recommended new environmental flow requirements to the WAM, as described in Chapters 6 and 7, are much less than would otherwise be the case. With the proposed new instream flow standards being junior to existing requirements, future even more junior diversion and storage rights affected by the new instream flow standards will also be affected by the existing flow requirements. The largest limit controls. In some cases, the existing limits are larger than the recommended new base flow standards. In some other cases, the recommended new base flow requirements are not much more stringent than the old. Of course, the recommended high pulse flow requirements involve much higher flow rates and will have greater impacts.

Scope of the Brazos River Basin Case Study

The datasets developed in the case study presented in Chapters 5, 6, and 7 are not designed for direct implementation by the TCEQ in the water rights permitting process. Rather the purpose of the case study investigation is to develop and research modeling capabilities that may be useful to the TCEQ and water management community. The actual application of modeling features explored in the case study depend on the policies and practices of the TCEQ and other agencies that will apply the new modeling capabilities in the future.

The purpose of the Brazos case study is to support the TCEQ-sponsored research and development endeavor to improve capabilities for integrating environmental flow standards in the WAM System. The objectives of the case study are to:

- support development and testing of expanded capabilities for incorporating environmental instream flow requirements in water availability modeling
- identify and investigate key issues in modeling instream flow requirements and their impacts on other water rights
- provide an experience base in applying the expanded modeling capabilities that will help guide their future implementation

The monthly Brazos WAM from the TCEQ WAM System and the daily expansion thereof reported by Wurbs et al. (2012) are further expanded as described in Chapter 6. Adding the BBEST and BBASC recommended instream flow requirements described in Chapter 5 is a central focus. Hydrology is also updated and refined in both the daily and monthly datasets. Reservoir operations for flood control are further refined in the daily model. Brazos River Authority multiple-reservoir system operations and Lake Whitney hydroelectric power operations are added to both the monthly and daily models. Chapter 6 describes the addition of these features to the Brazos WAM and presents simulation results with frequency metrics for assessing achievement of the environmental flow requirements.

The proposed new environmental flow requirements are placed in the model at a priority (seniority) that is junior to all of the existing water rights. Thus, existing water rights are not affected by the new environmental flow requirements. However, capabilities provided by the WRAP/WAM modeling system for evaluating effects of environmental flow standards on new water rights proposed in the future are an important concern. Therefore, hypothetical future storage and diversion projects are modeled in Chapter 7 using the models developed in Chapter 6 in order to investigate the effects on proposed new projects and the interactions between environmental flow requirements and integrated multiple-purpose water management. Chapter 7 is a comparative evaluation of simulation results for alternative modeling premises.

CHAPTER 6
ADDITION OF ENVIRONMENTAL FLOW REQUIREMENTS AND SYSTEM OPERATIONS TO THE BRAZOS WAM

The monthly Brazos WAM from the TCEQ WAM System and the daily expansion thereof are further expanded in this chapter by:

- adding the BBEST and BBASC recommended instream flow requirements
- incorporating updated 1940-2012 hydrology
- adding BRA multiple-reservoir system operations
- adding Lake Whitney hydroelectric power operations
- refining reservoir flood control operations in the daily model

Chapter 6 describes the addition of these features to the Brazos WAM and presents selected simulation results. The proposed new environmental flow requirements are placed in the model junior to all of the existing water rights and thus do not affect existing water rights. Hypothetical future storage and diversion projects are added in Chapter 7 to the models developed in Chapter 6 in order to investigate the effects on proposed new projects and the interactions between environmental flow requirements and integrated multiple-purpose water management. As noted in the preceding last section of Chapter 5, the case study datasets of Chapters 6 and 7 are not designed for direct application by the TCEQ in the water right permitting process. The purpose of the case study is to explore modeling capabilities and issues.

Model Description

The monthly *SIM* and daily *SIMD* input datasets discussed in this chapter consist of expanded water right DAT files, updated hydrology FLO and EVA files, an unchanged flow distribution DIS file, and newly created target series TSF and hydrologic index series HIS files. The daily *SIMD* dataset also includes a DCF file. The DAT, TSF, and HIS files reflect environmental flow regimes recommended by either the BBEST or BBASC. Both the monthly and daily DAT files incorporate Whitney hydropower and BRA system operations. The daily model also includes U.S. Army Corps of Engineers (USACE) flood control operations.

Variations of the *SIM* and *SIMD* Input Datasets

The terms EM and ED are adopted to refer to the expanded *SIM* monthly and *SIMD* daily input datasets developed in this chapter. The EM and one of the two versions of the ED incorporate the environmental flow requirements recommended by the BBASC. An alternative version of the ED incorporates the BBEST recommended environmental flow requirements.

- The expanded monthly (EM) model is the Brazos WAM authorized use scenario *SIM* input dataset, last updated by the TCEQ in September 2008, with the hydrologic period-of-analysis updated to 1940-2012 and expanded by addition of the system operations and environmental flow features described in this chapter.

- The expanded daily (ED) model is the Brazos WAM authorized use scenario *SIMD* input dataset described by Wurbs et al. (2012) with the 1940-2012 hydrology update and the added features described in this chapter.

Hydroelectric energy at Whitney Reservoir and BRA multiple-reservoir system operations are modeled by revising and adding DAT file records for both the EM and ED models as described in this chapter. Only the daily model includes flood control. The term *system operations* refers to the combined Whitney hydropower operations, BRA system operations, and USACE flood control operations described in this chapter. These multiple-purpose, multiple-reservoir system operations are the same throughout the simulations discussed in Chapters 6 and 7. However, alternative variations of environmental instream flow requirements are modeled.

Two alternative versions of the daily ED model are developed with the BBASC versus BBEST environmental flow requirements. The BBASC flow requirements are modeled with the monthly EM model. Therefore, three models are discussed in this chapter.

1. daily ED model with BBEST environmental flow requirements
2. daily ED model with BBASC environmental flow requirements
3. monthly EM model with BBASC monthly environmental flow targets
   from the results of a daily simulation

The environmental flow requirements recommended by the BBASC differ from those recommended by the BBEST. Two alternative sets of DAT file records are developed to model the BBEST and BBASC recommended instream flow requirements. The BBEST and BBASC both define hydrologic conditions in terms of the Palmer hydrologic drought index (PHDI). However, the BBEST uses separate PHDI series for each of the 19 gage sites, and the BBASC aggregates the PHDI to three gage sites. Thus, two alternative hydrologic index series HIS files are developed to support the two alternative versions of the DAT file instream flow rights.

<u>Monthly Simulation with Environmental Flow Targets from Daily Simulation</u>

The TCEQ WAM System is built on modeling using a monthly time step. In general, all components of environmental flow regimes can be modeled more accurately with a daily than with a monthly model. However, with a monthly time step, the subsistence and base flow components can be modeled much more accurately than the high pulse flow components. Approximating high pulse flow requirements in a monthly model directly using *IF* and supporting target-building records is perhaps possible but necessarily very approximate.

A strategy is investigated in the case study in which instream flow targets are computed with the daily model and provided as input to the monthly model. The daily targets computed in the daily *SIMD* simulation are summed to monthly target volumes within *SIMD*. The resulting sequences of monthly target volumes from the *SIMD* simulation results are inserted in the monthly *SIM* input dataset as target series *TS* records in a TSF file.

In the case study, environmental flow targets for the complete set of Brazos BBASC recommended flow requirements including subsistence, base, and pulse flows are included in the daily targets computed by *SIMD* and aggregated to monthly totals for input to the monthly *SIM*. The monthly targets on the *TS* records on the TSF file read by *SIM* represent the aggregation of all subsistence, base, and pulse flow requirements.

Pulse flows are the primary component of the environmental flow targets that need to be determined based on a daily rather than monthly simulation. Alternative variations of this modeling strategy could conceivably include computing subsistence and/or base flow targets directly within a monthly *SIM* simulation with only monthly pulse flow and perhaps subsistence flow targets from a daily *SIMD* simulation provided as input on *TS* records. However, computing all targets in a daily model and aggregating to monthly quantities is advantageous, since subsistence, base, and pulse flows are not independent of each other.

Base flows are set independently of regulated flows, and thus specified before the simulation. Pulse flows are computed during the simulation as a function of regulated flows. For the Brazos BBEST and BBASC recommended standards, subsistence flows are computed either independently or as a function of regulated flows depending on hydrologic condition. Intermediate subsistence, base, and pulse flow targets are determined each day in *SIMD*. The actual target set in the simulation is the highest of the computed subsistence, base, and pulse flow targets. Thus, pulse flow targets are not added to base flow targets. The greater of the two targets is adopted in a particular day. This becomes an issue if aggregated monthly pulse flow targets from a daily *SIMD* simulation are combined with base flows determined within a monthly *SIM* simulation. Combining all targets within the daily simulation precludes this problem.

Update of the Hydrologic Period-of-Analysis

The FLO and EVA files in the EM and ED datasets contain 1940-2012 sequences of monthly naturalized flows and net evaporation-precipitation rates. The original Brazos WAM has a 1940-1997 period-of-analysis. The 1998-2011 extension of the monthly hydrology data (Wurbs and Chun 2012) and later update during early 2013 to include 2012 uses methods documented in the recently created *Hydrology Manual* (Wurbs 2012). The 1998-2012 extension of the net evaporation-precipitation depths in the EVA file are performed with *HYD* by directly combining quadrangle evaporation and precipitation depths from the TWDB datasets.

The 1998-2012 extension of monthly naturalized flow sequences is based on the 1940-1997 WAM naturalized flows combined with 1940-2012 monthly precipitation and evaporation rates from datasets maintained by the TWDB. A hydrologic model of rainfall-runoff and base flow processes with numerous data fitting parameters, contained in the WRAP program *HYD*, was calibrated with 1940-1997 data sequences and then applied to synthesize 1998-2012 naturalized flows at the 77 primary control points.

Chapters 5 and 7 include comparisons of simulation results with the 1940-1997 versus 1940-2012 hydrologic period-of-analysis. Although calibration of the *HYD* rainfall-streamflow model for the 77 Brazos WAM primary control points required significant effort, the now available calibrated model for the Brazos WAM can be easily updated each year to add the latest year of record, upon completion by the TWDB of the annual update of the statewide precipitation and evaporation datasets. For example, during April 2013, the Brazos WAM period-of-analysis, previously updated to 1940-2011, was updated to include 2012.

The 1998-2012 hydrology update of the monthly Brazos WAM is also incorporated into the daily model. Since previously compiled daily unregulated flows in the DCF file cover 1940-1997, the monthly 1998-2012 naturalized flows are disaggregated to daily using a *SIMD* option for repeating daily pattern flows. Daily flows for 1940-1954 are repeated for 1998-2012 for use as flow patterns in the disaggregation of the extended monthly flows to daily.

Pattern Hydrographs in the Daily Model

The daily WRAP modeling system is explained in detail by the *Daily Manual* (Wurbs and Hoffpauir 2012). Wurbs et al. (2012) document the expansion of the Brazos WAM to a daily model and addition of flood control operations along with an investigation of issues in developing and applying the daily model. The previous case study report describes the disaggregation of monthly naturalized flows to daily quantities based on daily flow pattern hydrographs at 34 control points. The 34 pattern hydrographs are unregulated daily flows generated by a USACE Fort Worth District modeling system.

Pattern hydrographs at nine additional control points were incorporated in the dataset described in this chapter. Daily unregulated flows from the USACE model were adopted at control points CON137 and CON145 on the Navasota River and AQAQ33 on Aquilla Creek. Observed flows at USGS gaging stations were added for control points SFAS06, DMAS09, BRSE11, CFNU16, CFFG18, and BRSE23 in the upper Brazos River Basin, which are included in the Table 5.8 list of sites adopted by the BBEST and BBASC for recommended flow regimes. Routing parameters for the reaches defined by these sites were also added to the dataset.

Return Flows and Reservoir Sedimentation

The WAM System authorized and current use scenarios are described in Chapter 2. The reservoir storage capacities in the authorized use scenario datasets are from the water right permits, which in most cases reflect conditions at the time of initial impoundment without updates for sediment accumulation. The reservoir storage capacities in the authorized use scenario based EM and ED models are from the water right permits and do not include adjustments for sediment surveys performed in recent years for most of the larger reservoirs.

Return flows from wastewater treatment plants and irrigation returns are included in the current use but are not included in the authorized use scenario WAM System datasets since most water right permits do not have requirements for return flows. The EM and ED models are derived from the authorized use scenario Brazos WAM and do not include return flows. Return flows could be added in future studies to investigate their effects on environmental flows.

Multiple-Purpose, Multiple-Reservoir System Operations

Flood control in the nine USACE reservoirs, hydropower operations at Whitney Reservoir, and multiple-reservoir system operations of nine of the eleven BRA reservoirs are included in the model in order to investigate their interactions with environmental flows. Flood control operations modeled in the previously reported daily Brazos WAM are further refined in the case study documented by this report. Hydropower and multiple-reservoir system operations are added to the monthly *SIM* and daily *SIMD* input datasets.

The water right permits and Brazos WAM do not include flood control and hydropower operations, and all BRA diversions are treated as being lakeside. The multiple-purpose, multiple-reservoir system operations investigated in the case study provide insight into modeling capabilities and water management issues. However, inclusion of these types of operations in the case study in no way implies that they should or ever will be adopted in the TCEQ WAM.

Flood Control Operations

Flood control operations both in actual reality and in the *SIMD* model are based on maintaining essentially empty flood control pools in the nine USACE multiple-purpose reservoirs listed in Table 6.1 except during and immediately following flood events. The flood control pools are emptied as expeditiously as feasible without contributing to regulated flows exceeding the maximum allowable flows listed in Table 6.1 at the nine dams and the maximum flows in Table 6.2 at 12 downstream gaging stations. Releases from the flood control pools of some of the reservoirs are also constrained by outlet structure discharge capacities, with outflows increasing with storage levels. In some cases, more stringent flood flow limits at downstream gaging stations are applied for smaller encroachments into the reservoir flood control pools, with the maximum allowable flow limits increasing with higher flood pool levels.

Table 6.1
Flood Control Reservoirs Owned and Operated by the Corps of Engineers

Control Point	Reservoir	Stream	Drainage Area	Storage Capacity at Top of Conservation	Storage Capacity at Top of Flood Control	Outflow Limit at Dam
			(sq mile)	(acre-feet)	(acre-feet)	(cfs)
515731	Whitney	Brazos River	17,690	636,100	1,999,500	25,000
515831	Aquilla	Aquilla Creek	254	52,400	146,000	2,134 to 2,721
509431	Waco	Bosque River	1,655	206,562	726,400	–
515931	Proctor	Leon River	1,280	59,400	374,200	–
516031	Belton	Leon River	3,568	457,600	1,097,600	24,100 to 28,490
516131	Stillhouse	Lampasas R.	1,313	235,700	630,400	6,200 to 7,400
516231	Georgetown	San Gabriel R.	247	37,100	130,800	–
516331	Granger	San Gabriel R.	726	65,500	244,000	–
516431	Somerville	Yegua Creek	1,008	160,110	507,400	–

Table 6.2
Maximum Allowable Flood Flow Limits at USGS Stream Gaging Stations

Control Point	Stream	Nearest Town	Drainage Area	Flood Flow Limit
			(sq miles)	(cfs)
BRWA41	Brazos River	Waco	20,065	60,000
BRHE68	Brazos River	Hempstead	34,374	60,000
BRRI70	Brazos River	Richmond	35,454	60,000
AQAQ34	Aquilla Creek	Aquilla	307	3,000
BOWA40	Bosque River	Waco	1,660	3,000 to 30,000
LEHS45	Leon River	Hasse	1,283	500-4,000
LEGT47	Leon River	Gatesville	2,379	5,000
LRLR53	Little River	Little River	5,266	3,000 to 10,000
NGGE54	North Fork San Gabriel	Georgetown	248	3,000 to 6,000
SGGE55	South Fork San Gabriel	Georgetown	132	6,000
LRCA58	Little River	Cameron	7,100	10,000
YCSO62	Yegua Creek	Somerville	1,011	1,000 to 2,500

The total storage capacities below the top of conservation pool and below the top of flood control pool are shown in Table 6.1. For Aquilla, Belton, and Stillhouse Hollow Reservoirs, the flow rates in the last column of Table 6.1 are release capacities of the outlet structures when storage levels are at the top of the conservation and flood control pools. For the six other reservoirs, the outlet structure outflow capacities exceed the maximum allowable flood flow limits. The 25,000 cfs for Whitney Reservoir is a maximum flood flow limit just below the dam.

Whitney, Waco, and Proctor Reservoirs have gated spillways with crest elevations at the top of conservation pool and large release capacities. If the flood control storage capacity is not exceeded, reservoir releases from flood control pools are limited in the *SIMD* simulation solely by downstream flood flow limits, not outlet structure capacity. The other six reservoirs have ungated spillways with crest elevations at the top of flood control pool. Assuming the flood control storage capacity is not exceeded, releases from the flood control pool are made through a conduit through the dam. For these six dams with uncontrolled emergency spillways with crest elevations at the top of flood control pool rather than top of conservation pool, release capacities limited to flows through the conduits are much less than the large gated spillways at Whitney, Waco, and Proctor Reservoirs used for routine flood control operations.

The reservoirs are operated by the USACE Fort Worth District as a multiple reservoir system to reduce downstream flood flows. The operating objective is to empty the flood control pools as expeditiously as possible without making releases that contribute to river flows exceeding the allowable flow limits at the downstream gaging stations shown in Table 6.2. Releases may also be constrained by the outlet structure (conduit) discharge capacities shown in Table 6.1. Regular operations continue as long as flood control pool storage capacities are not exceeded. During rare extreme flood events that exceed the flood control storage capacity, larger releases are based on protecting the dam from overtopping or otherwise structurally failing rather than the downstream allowable flood flow limits.

Flood control pool operations for the nine federal reservoirs are modeled in *SIMD* with flood reservoir *FR*, flood flow *FF*, and reservoir volume-outflow *FV/FQ* records in accordance with the guidance provided in the *Daily Manual*. The total storage volumes at the top and bottom of the flood control pools tabulated in Table 6.1 are entered on *FR* records. Outlet structure discharge capacities shown in Table 6.1 for Aquilla, Belton, and Stillhouse Hollow Reservoirs are modeled with storage volume versus discharge relationships defined with *FV* and *FQ* records. The 25,000 cfs flow limit of the river below Whitney Dam is modeled as a maximum release entered on the *FR* record for Whitney.

The maximum allowable flood flow limits at downstream gages tabulated in Table 6.2 are input on *FF* records. The maximum allowable flood flow limits at control points BOWA40, LRLR53, NGGE54, and YCSO62 vary within the ranges shown in Table 6.2 depending on the storage contents of the reservoirs located upstream. These flow limits are modeled in *SIMD* by combining the *FF* record with a set of storage index *DI*, *IP*, and *IS* records.

Flow forecasting and routing are activated. The lag and attenuation parameters for routing changes resulting from flood control operations are different calibrated values than the parameters applied to all other non-flood related flow changes.

Each of the nine reservoirs is operated in the *SIMD* simulation to reduce flows at the dam and each of the control points listed in Table 6.2 that is located downstream of the dam. As shown in Figure 5.3, Control points BRHE68 and BRRI70 on the Brazos River at the Hempstead and Richmond gages are downstream of all nine reservoirs. The other control points in Table 6.2 are located downstream of at least one but not all of the nine reservoirs.

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

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

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

The priorities adopted for the case study are outlined in Table 6.3. The storage capacities of the flood control pools are also shown in Table 6.3.

Table 6.3
Flood Control Operation Priorities in *SIMD* Simulation

Gate Closure Priorities (Capacity of Flood Control Pool)		Reservoir Release Priorities	
Senior Priority	Junior Priority	Senior Priority	Junior Priority
Whitney (1,363,400 ac-ft)	Stillhouse (394,700 ac-ft)	Aquilla	Somerville
Belton (640,000 ac-ft)	Proctor (314,800 ac-ft)	Georgetown	Waco
Waco (519,840 ac-ft)	Granger (178,500 ac-ft)	Granger	Belton
Somerville (347,290 ac-ft)	Georgetown (93,700 ac-ft)	Proctor	Whitney
	Aquilla (93,600 ac-ft)	Stillhouse	

The four large reservoirs (Whitney, Belton, Waco, Somerville) that play the dominant role in controlling flood flows of the lower Brazos River are grouped together as a four-reservoir system with the same storage priority and the same release priority. Operating decisions each day are based on balancing the storage contents of these four reservoirs expressed as a percentage of the flood control pool storage capacity. If more than one of the reservoirs has the same flood pool storage, expressed as a percentage of capacity, priorities are based on the order listed in Table 6.3. With the flood pools all completely empty (zero percent contents), Whitney Reservoir is the first in priority to close its gates at the beginning of a flood event.

The other five smaller reservoirs on more remote tributaries comprise a five-reservoir system with all five reservoirs assigned the same storage priorities and same release priorities. Each of the nine reservoirs contribute to controlling flooding at any and all of the Table 6.2 control points located downstream of that reservoir. However, the priority scheme shown in Table 6.3 is based on placing a greater responsibility on the four larger reservoirs for controlling flood flows at the Hempstead and Richmond gages on the Brazos River.

In the Brazos case study, the modeling features activated by *FR*, *FF*, *FV*, and *FQ* records are applied only to flood control operations of the nine USACE reservoirs that actually contain designated flood control pools. However, *FR*, *FV*, and *FQ* records (without *FF* records) can also be used to model surcharge storage above the top of conservation pool for reservoirs that contain no designated flood control storage. Surcharge storage occurs when the conservation storage is full to capacity and stream inflows exceed the capacity of the outlet structures. Surcharge storage may be negligible in a reservoir with a large gated overflow spillway with a crest elevation below the top of conservation pool. Conversely, ponding above the top of conservation pool may be significant during floods or high flows at reservoirs controlled by releases through ungated or gated conduits with limited discharge capacity. The effects of surcharge storage on environmental pulse flows may or may not be significant in various situations.

Flood control storage capacities are large and can significantly affect river flows. Flood control and/or surcharge storage may impact the within bank pulse flow as well as overbank pulse flow components of environmental flow regimes.

Hydroelectric Power Operations at Whitney Reservoir

As discussed in the preceding Chapter 5, Whitney Reservoir is owned and operated by the USACE for flood control, hydroelectric energy generation, water supply, and recreation. As shown in Table 5.3, in terms of total storage capacity including combined flood and conservation pools, Whitney is the largest reservoir in the Brazos River Basin. However, the only actual water right permit for Whitney Reservoir is held by the Brazos River Authority (BRA) for use of 50,000 acre-feet of the 636,100 acre-feet conservation pool for water supply. Hydroelectric energy generation is not included in the official Brazos WAM. However, hydropower at Whitney Reservoir is included in the model in the case study simulations of Chapters 6 and 7, in order to investigate the effects on river flows and meeting environmental flow requirements.

With the recent deactivation of hydropower production at Possum Kingdom Lake, the only hydroelectric power plant in the Brazos River Basin is at Whitney Lake. There are no water right permits for hydroelectric energy in the Brazos River Basin. Hydropower is not included in the original Brazos WAM. However, storage capacity in Lake Whitney for hydropower is large, and hydropower operations significantly affect the flow of the Brazos River. Therefore, Lake Whitney hydropower operations are incorporated in the EM and ED models.

Hydroelectric power operations at the federal project are governed by a contract between the Southwest Power Administration and Brazos Electric Cooperative. The contract is based on 30,000 kilowatts of Lake Whitney hydroelectric peaking power and provides for annual energy of 1,200 kilowatt-hours per kilowatt of peaking power. The annual energy totals 36 gigawatt-hours/year. The contract places no limits on the maximum amount of energy that the Brazos Electric Cooperative may schedule during any single month or multiple-month period.

The operating agreement between the USACE and Southwest Power Administration limits the Lake Whitney rate of conservation pool drawdown to a maximum of one foot per week, and three feet in any consecutive four week period. There are no formal operating agreements between the Brazos River Authority and either the Southwest Power Administration, Brazos Electric Cooperative, or USACE regarding hydropower operations at Lake Whitney. However, in making multiple-reservoir system release decisions, the BRA considers the amount of water being released through the power turbines. Likewise, Southwest Power Administration and Brazos Electric Cooperative hydropower operations consider the amount of water released from Lakes Possum Kingdom and Granbury for BRA diversions from the lower Brazos River.

The authorized use scenario Brazos WAM incorporates the original storage capacities from the water right permits which date back to a 1959 survey. The TWDB performed a volumetric survey of the lake in June 2005 to update storage capacity data. The updated storage capacities are shown in Table 6.4 to highlight the issue of sedimentation, but all versions of the Brazos WAM datasets used in this case study include the original storage capacities from the water right permits. The flood control capacities for the nine USACE reservoirs, including Whitney, discussed in the preceding section are also from original or old surveys.

Table 6.4
Whitney Reservoir Storage Capacity

Pool Level	Surface Elevation (feet)	Whitney Storage Capacity (acre-feet)			
		WAM (1959 Survey)		2005 Sediment Survey	
		Incremental	Cumulative	Incremental	Cumulative
Top of Flood Control Pool	571		1,999,500		–
		1,363,400		–	
Top of Conservation Pool	533		636,100		554,203
		249,076		233,492	
Bottom of Conservation Pool	520		387,024		320,711

The BRA has a water supply storage contract with the USACE for use of 22.017 percent of the conservation storage capacity between elevations 520.0 feet and 533.0 feet, which has been estimated by the USACE to be 50,000 acre-feet after adjustments for future sedimentation.

The BRA holds a water right permit to divert 18,336 acre-feet/year from Whitney Lake with an August 1982 seniority. This is the only water right permit associated with Whitney Lake.

Whitney Reservoir is modeled in the Brazos WAM as the three component reservoirs shown in Table 6.5. Reservoir WHITNY is the inactive pool. Component reservoir BRA has the only diversions. The TCEQ Brazos WAM includes no hydropower. Component reservoir CORWHT is drawn-down only by evaporation. In the EM and ED models described in this chapter, hydroelectric energy generation is added to component reservoir CORWHT.

Table 6.5
Whitney Lake Component Reservoirs in the Brazos WAM

Reservoir Pool	Component Reservoir	Capacity (acre-feet)
Inactive pool	WHITNY	387,024
BRA component of active conservation pool	BRA	50,000
USACE component of active conservation pool	CORWHIT	199,076
Total conservation pool storage capacity		636,100

The component reservoirs representing allocation of storage capacity to different entities are modeled using an evaporation allocation *EA* record. A drought index (*DI*, *IS*, *IP* records) is used to model the bottom of conservation pool level of 387,024 acre-feet. Hydropower is provided in the model by component reservoir CORWHT without infringing upon component reservoir BRA. Component reservoir BRA in Whitney Reservoir, representing the storage capacity owned by the BRA, supplies the BRA's permitted 18,336 acre-feet/year diversion and also backs up a Somervell County Water District water right.

The *SIM* dual simulation option is activated in conjunction with backup rights at Whitney and Waco Reservoirs. The dual simulation prevents refilling of storage in Lakes Whitney and Waco at the seniority of the BRA and city of Waco rights that has been drawn down backing up the other more junior water rights. The backup right at Lake Whitney models an agreement between the BRA and Somervell County Water District.

Hydroelectric energy generation at Whitney Lake is incorporated in the EM and ED models with a set of *WR*, *WS*, *HP*, *UC*, *PE*, and *PV* records added to the DAT file.

```
UC POWER   2250.   2250.   2250.   2250.   2250.   3000.
           6000.   6000.   3000.   2250.   2250.   2250.

WR515731  36000.   POWER99999999   6   2     1.0  W12422              WhitneyHP
WSCORWHT 199076.                             0.0              1      -1
HP 0.87     440.
WR515731                99999999   1
WSCORWHT 199076.                                              1      -1

PVCORWHT      0.  39444. 144519. 199076. 805000. 1100000 1490000 1999500
PE          520.    523.    530.    533.    540.    550.    560.    571.
```

The monthly energy demands incorporated in the case study model are 6,000,000 kilowatt-hours in July and August, 2,000,000 kilowatt-hours in June and September, and 2,225,000 kilowatt-hours in each of the other eight months, totaling to 36,000,000 kilowatt-hours/year. This approximation of the monthly distribution of the annual energy specified in the federal contract was adopted in an earlier study reported by Wurbs et al. (1994). The hydropower input data also includes an efficiency factor of 0.87 and constant tailwater elevation of 440 feet.

Hydroelectric energy generation and the system operations discussed in the next section affect each other as well as environmental flows. Flows released through the hydropower turbines from storage in Lake Whitney can be diverted for water supply at downstream sites on the Brazos River. Water supply releases from Lakes Possum Kingdom and Granbury for water supply diversions from the lower Brazos River pass through the hydropower turbines at Whitney.

Brazos River Authority (BRA) Multiple-Reservoir System Operations

All BRA diversion rights are modeled in the original Brazos WAM as lakeside diversions at the eleven BRA reservoirs. In actuality, the BRA supplies water from its system of eleven reservoirs through both lakeside diversions and diversions from the Brazos River and its tributaries at various distances downstream of the dams, including major diversions from the lower reach of the Brazos River near Houston. Diversions occur at multiple sites in the river system at significant distances downstream of the dams from releases from multiple reservoirs, contributing to instream flows in the river reaches between dams and downstream diversion sites. BRA system operations are incorporated into the EM and ED models.

As discussed in Chapter 5, an application by the BRA for a system operation permit along with a BRA water management plan are currently under review by the TCEQ that will allow the BRA to use unregulated flows and return flows in coordination with withdrawals and diversions from its reservoirs. Although BRA operations have always included diversions from the lower Brazos River from releases from multiple reservoirs, the water right permits were granted historically over time for individual reservoirs. Water accounting has been based on assigning all water use to permits for the individual reservoirs. An excess flows permit allows multiple-reservoir system operations but does not credit the increased yields provided.

Information regarding the BRA long-term contracts is provided in the water management plan (Brazos River Authority 2012) developed in conjunction with the system operation permit. This information is used to develop an 11-reservoir system water use scenario for the present case study. The long-term commitments, which total 698,759 acre-feet/year, replace the authorized diversions at the 11 reservoirs, which total to 673,900 acre-feet/year, in the case study models. The reservoir storage capacities and water use coefficients remain unchanged.

The annual diversion targets in the EM and ED models are tabulated in Table 6.7. These diversions are located at the eleven reservoir control points and nine downstream control points. The nine downstream control points and the upstream reservoirs from which releases are made to supply the BRA diversions at these control points are listed in Table 6.6. For example, diversions at control point SYS58 are supplied by available stream flow supplemented as necessary by releases from Belton, Stillhouse Hollow, and Granger Reservoirs.

In actual BRA reservoir system operations and in the EM and ED models, water demands supplied by diversions at sites on the rivers located downstream of the dams are supplied by excess flows supplemented as needed by releases from the upstream reservoirs. In the EM and ED models, default multiple-reservoir system operating rules are employed without needing operating rule *OR* records. Multiple-reservoir release decisions are based on balancing storage depletions, expressed as a percentage of storage capacity, in the conservation pools of the multiple reservoirs.

Table 6.6
Control Points and Reservoirs for System Water Rights

New System Control Points	System Reservoirs
SYS27 - Brazos River below Palo Pinto gage (BRPP27)	Possum Kingdom
SYS33 - Brazos River below Aquilla gage (BRAQ33)	Whitney, Granbury, Possum Kingdom
SYS41 - Brazos River below Waco gage (BRWA41)	Possum Kingdom, Granbury, Aquilla
SYS49 - Leon River below Belton gage (LEBE49)	Belton
SYS58 - Little River above Cameron gage (LRCA58)	Belton, Stillhouse Hollow, Granger
SYS59 - Brazos River below Bryan gage (BRBR59)	Possum Kingdom, Granbury, Aquilla, Belton, Stillhouse, Granger
SYS66 - Navasota River below Easterly gage (NAEA66)	Limestone
SYS68 - Brazos River below Hempstead gage (BRHE68)	Possum Kingdom, Granbury, Aquilla, Belton, Stillhouse, Granger, Somerville, Limestone
SYS70 - Brazos River below Richmond gage (BRRI70)	Possum Kingdom, Granbury, Aquilla, Belton, Stillhouse, Granger, Somerville, Limestone

Table 6.7
Long-Term Contract Amounts Adopted as Diversion Rights in the EM and ED

Location	Diversion (ac-ft/yr)	Use Type
Possum Kingdom Lake (Control Point 515531)		
Possum Kingdom Lake	6,809	municipal
Possum Kingdom Lake	66,647	industrial
Possum Kingdom Lake	500	irrigation
Possum Kingdom Lake	1,410	mining
Possum Kingdom Lake Dam to Palo Pinto gage	3,600	other

Table 6.7 Continued
Long-Term Contract Amounts Adopted as Diversion Rights in the EM and ED

Location	Diversion (ac-ft/yr)	Use Type
Lake Granbury (Control Point 515631)		
Lake Granbury	33,740	municipal
Lake Granbury	50,000	industrial
Lake Granbury	4,260	irrigation
Lake Granbury Dam to Glen Rose gage	200	irrigation
Lake Granbury Dam to Glen Rose gage	1,000	mining
Lake Whitney (Control Point 515731)		
Lake Whitney	10,510	municipal
Lake Whitney	1,000	irrigation
Lake Whitney (Downstream Control Point SYS33)		
Lake Whitney Dam to Aquilla Creek/Brazos confluence	6,500	industrial
Lake Aquilla (Control Point 515831)		
Lake Aquilla	11,403	municipal
Lake Proctor (Control Point 515931)		
Lake Proctor	6,437	municipal
Lake Proctor	3,743	irrigation
Lake Proctor Dam to Leon River at Gatesville	2,909	irrigation
Lake Belton (Control Point 516031)		
Lake Belton	76,062	municipal
Lake Belton (Downstream Control Point SYS49)		
Lake Belton Dam to Leon River near Belton	30,453	municipal
Lake Stillhouse Hollow (Control Point 516131)		
Lake Stillhouse Hollow	39,155	irrigation
Stillhouse Hollow Dam to Lampasas River at Belton	108	irrigation
Lake Georgetown (Control Point 516231)		
Lake Georgetown	74,561	municipal
Colorado Basin	21,528	municipal
Lake Granger (Control Point 516331)		
Lake Granger	13,000	municipal
Lake Granger	15	irrigation

Table 6.7 Continued
Long-Term Contract Amounts Adopted as Diversion Rights in the EM and ED

Location	Diversion (ac-ft/yr)	Use Type
Lake Limestone (Control Point 516531)		
Lake Limestone	200	municipal
Lake Limestone	50,675	industrial
Lake Somerville (Control Point 516431)		
Lake Somerville	4,200	municipal
Multiple Reservoirs (Control Point SYS59)		
Leon River near Belton to Little River gage	200	irrigation
Little Brazos confluence to Brazos at Hwy 21 Bryan	200	irrigation
Brazos at Hwy 21 Bryan to Yequa/Brazos confluence	150	irrigation
Possum Kingdom Reservoir (Downstream Control Point SYS27)		
Palo Pinto gage to Dennis gage	50	irrigation
Palo Pinto gage to Dennis gage	1,000	mining
Granbury Reservoir (Control Point 515631)		
Dennis gage to Lake Granbury	44	mining
Dennis gage to Lake Granbury	700	municipal
Dennis gage to Lake Granbury	500	irrigation
Multiple Reservoirs (Control Point SYS41)		
Yegua Brazos confluence to Navasota Brazos confluence	540	irrigation
Aquilla Creek/Brazos River confluence to Highbank gage	2,300	municipal
Multiple Reservoirs (Control Point SYS58)		
Little R/San Gabriel confluence to Little R Cameron gage	5,000	industrial
Multiple Reservoirs (Control Point SYS66)		
Easterly gage to Brazos/Navasota confluence (SYS66)	3,600	industrial
Easterly gage to Brazos/Navasota confluence (SYS66)	4,000	municipal
Multiple Reservoirs (Control Point SYS68)		
Hempstead gage to Richmond gage	50	irrigation
Hempstead gage to Richmond gage	113,020	industrial
Multiple Reservoirs (Control Point SYS70)		
Richmond gage to Rosharon gage	15,820	municipal
Richmond gage to Rosharon gage	25,335	industrial
Richmond gage to Rosharon gage	5,625	irrigation

Modeling Instream Flow Requirements

The original *IF* records already in the Brazos WAM are retained in the case study EM and ED DAT files. The environmental flow requirements for the 19 control points listed in Table 5.8 recommended by the BBEST and BBASC are described in the preceding Chapter 5 and added to the datasets as described in this chapter. The Basin and Bay Expert Science Team (BBEST) and Basin and Bay Area Stakeholders Committee (BBASC) recommended flow requirements are added to the daily ED model. The BBASC recommended environmental flow requirements are incorporated in the EM model based on computing targets in a *SIMD* daily simulation that are input to the *SIM* monthly simulation.

Existing *IF* Records

The 122 instream flow *IF* records in the original WAM DAT file are listed in Table 5.7 and discussed in the preceding Chapter 5. These *IF* record water rights remain unchanged in the expanded monthly EM and expanded daily ED datasets except for activation of an option on the *IF* records to deal with Hale clause instream flow requirements.

The majority of the 122 old *IF* records in the WAM DAT file, including most of those with the larger flow targets, represent Hale clause special conditions of water right permits that are designed to protect senior water rights. The Hale clause provision found in diversion/storage permits includes language that the instream flow requirement is "*exclusive of any releases dedicated by the Brazos River Authority from its conservation storage for subsequent use downstream*." Thus, the Hale clause prevents claiming credit for contributions to stream flow of BRA system reservoir releases when applying the minimum instream flow limit.

The Hale clause exclusion of BRA releases has not been a concern in water right permitting applications of the Brazos WAM in the past because all diversion rights are treated as lakeside in the model even though releases from BRA reservoirs for downstream diversions occur in real-world operations. However, the case study incorporates BRA system operations with diversions from the lower Brazos River and other locations downstream of the dams.

By default, each *IF* record instream flow target is applied as a minimum limit on total regulated flow. An option has been added to the *IF* record that allows the limit to be applied to regulated flows excluding reservoir releases made for use at downstream locations. This option is applied in the EM and ED DAT files to each of the existing *IF* record rights connected to water right permits with Hale clause provisions along with addition of the BRA system operations. This option is not applied to BBEST, BBASC, or other existing *IF* record rights.

Palmer Hydrologic Drought Index (PHDI)

The BBASC and BBEST environmental flow requirements use the Palmer hydrologic drought index (PHDI) to define hydrologic conditions as discussed in Chapter 5. The hydrologic index *HI* record and drought index series HIS file were recently added to *SIM* and *SIMD* to incorporate the PHDI, or other indices, or parameters derived from these indices, in modeling instream flow requirements. *HI* records in a HIS file are incorporated in the EM and ED as described in this chapter. The *HI* records contain 1940-2012 monthly sequences of a hydrologic condition parameter with values of 1, 2, or 3 indicating dry, average, or wet hydrologic conditions. Two HIS files are developed because, as discussed below, the BBEST and BBASC recommended flow regimes differ in the manner in which the PHDI sequences are compiled and applied to specify hydrologic conditions.

Both the BBEST and BBASC recommended environmental flow regimes are based on specifying hydrologic conditions in terms of the PHDI. However, the PHDI sequences are compiled and applied differently in the BBASC versus BBEST flow regimes as follows.

- The BBEST uses hydrologic conditions defined by the PHDI only with base flows. The BBASC uses hydrologic conditions with both high pulse flows and base flows.
- The BBEST uses separate PHDI sequences for each of the 19 control points. The BBASC assigns PHDI sequences to the three subwatersheds of the river basin that drain into the Brazos River: (1) upstream of Possum Kingdom Dam, (2) between Possum Kingdom and Whitney Dams, and (3) below Whitney Dam.
- The BBEST applies the PHDI each month to define the hydrologic condition for all of the days of the next month. The BBASC applies the PHDI at the beginning of each season to define the hydrologic condition for all of the days of that season.

WRAP has always included a drought index feature activated by the drought index *DI* record for setting instream flow and diversion targets as functions of the storage contents of any number of reservoirs. Other *SIM/SIMD* features allow targets to be set as a function of stream flow and other variables. The PHDI and the use of reservoir storage as a drought index both provide the advantage of reflecting the accumulated effects of hydrologic conditions over the preceding several or perhaps many months. The *SIM/SIMD* feature activated by a *DI* record uses simulated storage as the drought index and thus inclusion of index sequences in the input data is not required. Reservoir storage is more closely connected to streamflow than the PHDI. Compiling PHDI sequences on *HI* records requires additional effort. However, the PHDI provides the advantage over the *DI* record drought index of being independent of variables computed within *SIM/SIMD*. Reservoir storage is computed within the simulation and thus is subject to change with changes in the water rights included in the *SIM* or *SIMD* input file.

Hydrologic Index *HI* Records

Table 6.8 and 6.10 show the weighted average of the monthly PHDI index at the Richmond gage using the BBEST and BBASC recommended weighting factors, respectively, for the 10 zones used to report PDHI values. The BBEST recommendations list weighting factors specific for the Richmond gage. The BBASC recommendation lists weighting factors for three locations. The BBASC weighting factors for the lower basin were used for Table 6.10. The PDHI data for the 10 climatic zones of Texas were obtained from the NOAA National Climatic Data Center (NCDC) ftp site listed in Chapter 5.

Tables 6.9 and 6.11 show the final hydrologic index *HI* records developed from the respective weighted average PDHI data in Tables 6.8 and 6.10. Weighted PHDI data falling into the lower quartile, as computed by the BBEST, were assigned a monthly *HI* record input value of

1. Weighted PHDI data above the upper quartile value were assigned a monthly *HI* record input value of 3. All other data within the interquartile range were assigned a value of 2.

The *HI* records for the BBEST recommendations (Table 6.9) are assigned 1, 2, or 3 on a monthly basis according to the weighted average PHDI data. However, *HI* records for the BBASC recommendations (Table 6.11) are only assigned a value of 1, 2, or 3 based on the weighted average of the PHDI data if the month is equal to the start of a season. Months that are not start-of-season are assigned a value of 1, 2, or 3 according to their respective season start months.

PHDI data acquired for this study from the NCDC ftp site correspond to the data used by the BBEST at the time of the BBEST report publication. At that time, data were available for whole calendar years 1895 through 2011. Since the BBEST report publication, the methodology for computing the PHDI data appears to have changed. The new PHDI data are very similar to the previous PHDI dataset. However, small differences exist such that the computation of the BBEST quartiles will be slightly different. Therefore data shown in Tables 6.8 and 6.10 for calendar years 1940-2011 correspond to the same PHDI data used by the BBEST. Data for calendar year 2012 correspond to PHDI data as it exists on the NCDC ftp site at the time of publication of this report. All PHDI data in Tables 6.8 and 6.10 were converted to *HI* record values 1, 2, and 3 using the quartile values as published in the BBEST and BBASC reports.

Table 6.8
BBEST Weighted Average of PHDI Data at Richmond

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1940	-3.077	-2.609	-2.960	-2.210	-2.039	0.359	0.802	1.533	0.917	0.412	2.224	2.813
1941	2.472	3.467	3.506	3.957	4.083	5.038	5.620	6.383	5.636	6.230	5.475	5.001
1942	4.242	3.478	2.792	4.390	3.828	3.435	3.255	3.562	3.732	3.974	3.271	3.124
1943	2.422	1.319	1.516	0.748	0.743	0.461	-0.763	-2.173	-2.099	-2.332	-2.527	-2.003
1944	-1.117	0.110	0.334	0.231	1.714	1.188	0.876	1.209	0.096	-0.421	0.576	1.309
1945	1.407	2.025	2.607	2.761	1.783	1.911	2.682	2.910	2.739	2.666	1.795	0.978
1946	1.444	1.459	1.328	0.866	1.182	0.905	0.348	0.460	0.752	0.322	1.210	1.361
1947	1.464	0.918	1.175	1.084	1.581	1.267	-0.022	-0.520	-1.296	-1.876	-1.543	-1.008
1948	-0.940	0.565	-0.063	-0.852	-0.918	-0.905	-0.811	-1.224	-1.857	-2.067	-2.379	-2.837
1949	-1.553	-0.718	-0.577	0.022	0.167	1.321	1.338	1.262	1.026	1.832	0.885	0.085
1950	0.098	-0.152	-0.718	-0.035	0.135	0.108	1.537	2.194	2.372	1.305	-0.101	-2.187
1951	-2.632	-2.732	-2.759	-3.043	-3.071	-2.590	-2.910	-3.357	-3.185	-3.280	-3.418	-3.879
1952	-4.387	-4.662	-4.360	-3.464	-3.148	-3.952	-4.210	-4.888	-4.962	-5.226	-3.945	-3.243
1953	-3.391	-3.288	-2.975	-2.501	-2.345	-3.025	-2.904	-2.410	-2.817	-2.151	-2.011	-1.880
1954	-1.833	-2.463	-2.849	-2.682	-2.106	-2.530	-3.146	-3.695	-4.265	-3.973	-3.851	-3.906
1955	-3.780	-3.492	-3.497	-3.743	-3.321	-2.829	-2.761	-2.474	-2.251	-2.519	-2.989	-3.378
1956	-3.459	-3.372	-3.805	-4.017	-4.263	-5.062	-5.663	-6.013	-6.509	-6.225	-5.774	-5.374
1957	-5.174	-4.741	-3.832	-1.023	3.555	3.785	3.281	2.296	2.278	2.954	3.984	3.452
1958	3.514	3.348	3.467	3.694	3.223	2.811	2.802	2.499	2.699	2.180	1.630	1.028
1959	-1.169	-1.373	-1.957	-1.934	-2.098	-1.424	-0.714	-0.601	-0.988	1.240	1.130	2.061
1960	2.391	2.384	2.003	1.411	0.665	-0.272	0.300	1.226	0.518	1.104	0.597	1.879
1961	2.440	2.588	2.446	1.562	-0.172	1.632	2.437	2.161	2.230	1.844	2.135	1.844
1962	1.415	0.000	-0.246	0.037	-1.580	-0.701	0.886	0.339	1.195	1.155	1.203	0.972
1963	0.485	-1.159	-1.669	-1.820	-2.027	-2.212	-2.650	-2.990	-3.276	-3.778	-3.265	-3.172
1964	-2.734	-2.444	-2.037	-2.086	-2.396	-2.417	-2.955	-2.489	-1.337	-1.609	0.029	-0.268
1965	-0.111	0.545	0.407	-0.117	0.856	0.604	-0.054	-0.335	-0.217	-0.954	-1.210	-1.255
1966	-1.240	-1.091	-1.444	1.017	0.398	0.135	-1.167	0.790	1.834	1.269	-0.804	-1.702
1967	-2.398	-2.951	-3.345	-3.498	-3.423	-3.905	-3.790	-4.031	-2.687	-2.006	-1.792	-1.420

1968	1.769	2.287	2.689	2.688	2.893	3.136	3.652	3.622	3.396	2.526	2.951	2.531
1969	1.938	2.006	2.635	2.543	2.744	2.314	1.587	1.497	1.307	1.797	1.579	1.843
1970	1.448	1.873	2.399	2.134	1.773	1.143	−0.598	−1.482	0.224	0.445	−0.133	−1.591
1971	−2.280	−2.564	−3.095	−3.322	−3.569	−4.164	−3.826	−2.104	−1.511	0.170	0.067	2.307
1972	2.072	1.316	−0.556	−1.440	−1.500	−1.665	−1.649	−0.665	−0.676	0.084	0.402	0.119
1973	1.685	1.768	2.132	2.686	1.960	2.581	3.484	3.168	3.767	4.172	3.540	2.832
1974	2.527	1.280	0.482	0.120	−1.714	−1.877	−2.356	0.521	2.080	3.570	3.807	3.662
1975	3.303	3.498	3.043	2.746	3.170	3.046	3.547	3.616	3.209	2.395	1.907	1.386
1976	−0.730	−1.906	−1.995	−1.086	−0.742	−1.084	1.263	1.301	1.645	2.630	2.332	2.230
1977	2.332	2.078	2.365	2.793	2.014	1.343	−0.680	−0.662	−1.887	−2.235	−2.330	−3.007
1978	−3.021	−2.564	−2.485	−2.945	−2.874	−3.126	−3.713	−3.081	−2.820	−3.115	−2.296	−2.323
1979	−1.657	−1.310	1.594	1.444	1.906	1.879	2.312	2.873	2.265	1.060	0.510	0.621
1980	0.497	−0.676	−0.743	−0.933	−0.458	−1.151	−2.017	−2.763	−1.538	−1.720	−1.598	−1.158
1981	−1.533	−1.762	−1.254	−1.343	−0.938	1.352	1.592	1.706	1.375	2.982	2.712	2.067
1982	1.902	1.324	0.956	0.713	2.126	3.020	3.165	2.474	1.484	1.084	1.386	1.535
1983	1.480	1.562	1.984	1.284	1.462	1.503	1.457	0.922	0.214	0.897	0.059	−0.202
1984	−0.436	−0.662	−0.426	−1.173	−2.103	−2.399	−2.715	−2.744	−2.936	−1.346	−0.726	2.092
1985	2.113	2.318	2.495	2.334	1.648	2.001	2.075	1.291	1.234	1.904	2.012	1.755
1986	1.019	0.977	−0.487	−1.183	−0.257	0.657	0.623	0.889	1.566	2.381	2.781	3.196
1987	2.981	3.504	3.131	2.044	2.603	3.271	3.450	3.205	2.919	2.010	2.008	2.397
1988	1.869	1.385	1.254	0.727	−1.418	−1.226	−0.898	−1.281	−0.585	−1.150	−1.521	−1.597
1989	−1.449	−0.881	0.127	−0.515	0.028	1.632	1.718	1.971	1.837	1.007	0.187	−0.578
1990	−0.447	−0.057	1.260	2.123	2.190	1.537	1.806	1.635	1.485	1.196	1.341	1.029
1991	1.703	1.311	0.651	0.233	0.153	1.132	1.486	2.396	2.907	3.246	3.002	5.064
1992	5.359	5.822	5.411	4.650	4.731	5.352	5.635	5.460	4.794	3.743	4.012	4.104
1993	4.034	4.237	4.171	3.940	3.510	3.580	2.820	1.986	1.700	2.164	1.898	1.725
1994	1.476	1.257	0.925	0.688	1.264	0.253	0.283	0.095	0.061	0.910	1.466	1.858
1995	1.725	1.104	1.443	1.544	2.353	2.489	2.698	3.450	3.468	2.581	1.812	1.269
1996	0.511	−1.835	−2.379	−2.535	−3.639	−3.886	−3.791	−2.088	−1.130	−1.116	1.320	0.959
1997	0.703	2.709	2.441	3.612	3.317	3.887	3.856	3.839	2.835	2.812	2.546	3.325
1998	3.582	3.727	4.014	3.108	1.598	0.077	−3.164	−3.048	−3.095	−2.089	−1.160	−0.700
1999	0.836	−0.129	0.374	0.189	0.336	1.101	0.886	−0.855	−1.366	−1.686	−2.510	−2.610
2000	−2.805	−3.229	−2.702	−2.587	−2.953	−1.647	−1.967	−2.839	−3.375	−2.639	0.885	1.309
2001	2.732	3.234	3.829	2.768	2.297	1.698	0.054	0.633	0.693	0.417	0.784	0.946
2002	0.723	0.518	1.412	0.969	0.271	0.174	1.457	1.204	0.478	1.807	1.663	2.499
2003	1.955	2.212	1.661	0.899	−1.322	−0.201	−0.444	−0.476	−0.564	−0.771	−1.016	−1.744
2004	−1.562	−0.618	−0.351	0.208	−0.812	1.705	2.371	3.157	2.345	2.644	4.570	4.026
2005	4.024	3.922	3.570	2.590	1.955	1.242	1.051	1.827	−0.315	−0.715	−1.450	−2.169
2006	−3.235	−3.329	−2.778	−3.089	−3.560	−3.991	−4.407	−4.397	−3.982	−3.181	−3.180	−2.597
2007	−1.315	−1.602	0.331	0.570	2.566	4.141	5.342	6.047	5.495	4.533	3.691	3.113
2008	2.260	1.554	2.083	1.978	1.157	−0.115	−1.933	−0.875	−0.913	−0.564	−0.952	−1.851
2009	−2.538	−3.261	−2.841	−2.200	−2.464	−2.813	−2.310	−2.396	−0.157	1.343	1.019	1.282
2010	1.855	2.996	3.103	3.009	2.105	1.548	2.117	1.378	2.204	1.580	0.926	0.428
2011	−0.260	−1.384	−2.332	−2.957	−3.330	−4.194	−5.115	−5.661	−5.878	−5.139	−4.818	−3.771
2012	−2.583	−2.100	0.148	−0.599	−2.427	−2.736	−2.999	−2.780	−2.302	−2.644	−3.324	−3.592

Table 6.9
HI Records for BBEST Environmental Flow Recommendation at Richmond

	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HIBRRI7E	1940	1	1	1	1	1	2	2	2	2	2	3	3
HIBRRI7E	1941	3	3	3	3	3	3	3	3	3	3	3	3
HIBRRI7E	1942	3	3	3	3	3	3	3	3	3	3	3	3
HIBRRI7E	1943	3	2	2	2	2	2	2	1	1	1	1	1
HIBRRI7E	1944	2	2	2	2	2	2	2	2	2	2	2	2
HIBRRI7E	1945	2	2	3	3	2	2	3	3	3	3	2	2
HIBRRI7E	1946	2	2	2	2	2	2	2	2	2	2	2	2
HIBRRI7E	1947	2	2	2	2	2	2	2	2	2	1	2	2
HIBRRI7E	1948	2	2	2	2	2	2	2	2	1	1	1	1
HIBRRI7E	1949	2	2	2	2	2	2	2	2	2	2	2	2

HIBRRI7E	1950	2	2	2	2	2	2	2	3	3	2	2	1
HIBRRI7E	1951	1	1	1	1	1	1	1	1	1	1	1	1
HIBRRI7E	1952	1	1	1	1	1	1	1	1	1	1	1	1
HIBRRI7E	1953	1	1	1	1	1	1	1	1	1	1	1	1
HIBRRI7E	1954	1	1	1	1	1	1	1	1	1	1	1	1
HIBRRI7E	1955	1	1	1	1	1	1	1	1	1	1	1	1
HIBRRI7E	1956	1	1	1	1	1	1	1	1	1	1	1	1
HIBRRI7E	1957	1	1	1	2	3	3	3	3	3	3	3	3
HIBRRI7E	1958	3	3	3	3	3	3	3	3	3	3	2	2
HIBRRI7E	1959	2	2	1	1	1	2	2	2	2	2	2	2
HIBRRI7E	1960	3	3	2	2	2	2	2	2	2	2	2	2
HIBRRI7E	1961	3	3	3	2	2	2	3	3	3	2	2	2
HIBRRI7E	1962	2	2	2	2	2	2	2	2	2	2	2	2
HIBRRI7E	1963	2	2	2	1	1	1	1	1	1	1	1	1
HIBRRI7E	1964	1	1	1	1	1	1	1	1	2	2	2	2
HIBRRI7E	1965	2	2	2	2	2	2	2	2	2	2	2	2
HIBRRI7E	1966	2	2	2	2	2	2	2	2	2	2	2	2
HIBRRI7E	1967	1	1	1	1	1	1	1	1	1	1	1	2
HIBRRI7E	1968	2	3	3	3	3	3	3	3	3	3	3	3
HIBRRI7E	1969	2	2	3	3	3	3	2	2	2	2	2	2
HIBRRI7E	1970	2	2	3	2	2	2	2	2	2	2	2	2
HIBRRI7E	1971	1	1	1	1	1	1	1	1	2	2	2	3
HIBRRI7E	1972	2	2	2	2	2	2	2	2	2	2	2	2
HIBRRI7E	1973	2	2	2	3	2	3	3	3	3	3	3	3
HIBRRI7E	1974	3	2	2	2	2	1	1	2	2	3	3	3
HIBRRI7E	1975	3	3	3	3	3	3	3	3	3	3	2	2
HIBRRI7E	1976	2	1	1	2	2	2	2	2	2	3	3	3
HIBRRI7E	1977	3	2	3	3	2	2	2	2	1	1	1	1
HIBRRI7E	1978	1	1	1	1	1	1	1	1	1	1	1	1
HIBRRI7E	1979	2	2	2	2	2	2	3	3	3	2	2	2
HIBRRI7E	1980	2	2	2	2	2	2	1	1	2	2	2	2
HIBRRI7E	1981	2	1	2	2	2	2	2	2	2	3	3	2
HIBRRI7E	1982	2	2	2	2	2	3	3	3	2	2	2	2
HIBRRI7E	1983	2	2	2	2	2	2	2	2	2	2	2	2
HIBRRI7E	1984	2	2	2	2	1	1	1	1	1	2	2	2
HIBRRI7E	1985	2	3	3	3	2	2	2	2	2	2	2	2
HIBRRI7E	1986	2	2	2	2	2	2	2	2	2	3	3	3
HIBRRI7E	1987	3	3	3	2	3	3	3	3	3	2	2	3
HIBRRI7E	1988	2	2	2	2	2	2	2	2	2	2	2	2
HIBRRI7E	1989	2	2	2	2	2	2	2	2	2	2	2	2
HIBRRI7E	1990	2	2	2	2	3	2	2	2	2	2	2	2
HIBRRI7E	1991	2	2	2	2	2	2	2	3	3	3	3	3
HIBRRI7E	1992	3	3	3	3	3	3	3	3	3	3	3	3
HIBRRI7E	1993	3	3	3	3	3	3	3	2	2	3	2	2
HIBRRI7E	1994	2	2	2	2	2	2	2	2	2	2	2	2
HIBRRI7E	1995	2	2	2	2	3	3	3	3	3	3	2	2
HIBRRI7E	1996	2	1	1	1	1	1	1	1	2	2	2	2
HIBRRI7E	1997	2	3	3	3	3	3	3	3	3	3	3	3
HIBRRI7E	1998	3	3	3	3	2	2	1	1	1	1	2	2
HIBRRI7E	1999	2	2	2	2	2	2	2	2	2	2	1	1
HIBRRI7E	2000	1	1	1	1	1	2	1	1	1	1	2	2
HIBRRI7E	2001	3	3	3	3	3	2	2	2	2	2	2	2
HIBRRI7E	2002	2	2	2	2	2	2	2	2	2	2	2	3
HIBRRI7E	2003	2	3	2	2	2	2	2	2	2	2	2	1
HIBRRI7E	2004	2	2	2	2	2	2	3	3	3	3	3	3
HIBRRI7E	2005	3	3	3	3	2	2	2	2	2	2	2	1
HIBRRI7E	2006	1	1	1	1	1	1	1	1	1	1	1	1
HIBRRI7E	2007	2	2	2	2	3	3	3	3	3	3	3	3
HIBRRI7E	2008	3	2	2	2	2	2	1	2	2	2	2	1
HIBRRI7E	2009	1	1	1	1	1	1	1	1	2	2	2	2
HIBRRI7E	2010	2	3	3	3	2	2	2	2	3	2	2	2
HIBRRI7E	2011	2	2	1	1	1	1	1	1	1	1	1	1
HIBRRI7E	2012	1	1	2	2	1	1	1	1	1	1	1	1

Table 6.10
BBASC Weighted Average of PHDI Data for Locations Below Whitney Dam

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1940	−3.066	−2.626	−2.924	−2.113	−1.838	0.916	1.757	2.334	1.647	1.199	3.331	4.132
1941	3.605	3.993	3.989	4.224	3.927	4.641	5.112	5.639	4.921	5.227	4.531	4.029
1942	3.264	2.571	1.933	3.435	2.981	2.537	2.765	3.207	3.428	3.523	2.841	2.545
1943	1.885	0.641	0.897	−0.017	−0.019	−0.322	−1.326	−2.199	−2.009	−2.178	−2.329	−1.962
1944	−0.904	−0.228	0.324	0.215	2.105	1.459	0.927	1.365	0.147	−0.724	0.440	1.316
1945	1.376	1.976	2.714	2.910	2.061	2.206	2.783	3.185	2.927	2.931	1.973	1.574
1946	2.117	2.187	2.131	1.793	2.299	2.160	1.753	1.952	2.087	1.546	2.548	2.452
1947	2.529	1.844	2.042	1.760	1.679	1.325	−0.089	−0.009	−0.901	−1.741	−1.530	−1.031
1948	−0.867	0.224	−0.506	−0.961	−0.972	−1.048	−1.098	−1.529	−2.043	−2.340	−2.593	−3.087
1949	−2.019	−1.473	−1.224	−0.238	−0.366	0.707	0.827	0.749	0.361	1.736	0.721	−0.020
1950	0.039	0.348	−0.206	0.660	0.654	0.631	1.546	2.038	2.050	1.049	−0.086	−2.400
1951	−2.842	−2.950	−2.910	−3.208	−3.334	−2.830	−3.151	−3.712	−3.289	−3.397	−3.517	−3.977
1952	−4.570	−4.699	−4.328	−3.332	−2.891	−3.464	−3.704	−4.395	−4.454	−4.736	−3.398	−2.656
1953	−2.837	−2.728	−2.532	−2.016	−1.453	−1.980	−2.036	−1.486	−1.880	−1.594	−1.556	−1.346
1954	−1.419	−2.135	−2.577	−2.551	−2.298	−2.767	−3.321	−3.850	−4.330	−3.823	−3.708	−3.926
1955	−3.855	−3.458	−3.530	−3.656	−3.394	−3.075	−2.949	−2.233	−2.150	−2.701	−3.219	−3.619
1956	−3.692	−3.599	−3.974	−4.116	−4.392	−4.983	−5.614	−5.888	−6.382	−6.190	−5.716	−5.354
1957	−5.226	−4.863	−3.769	−0.978	2.683	3.022	2.433	1.526	1.844	2.840	3.927	3.402
1958	3.519	3.369	3.312	3.446	2.781	2.387	2.180	1.984	2.525	2.163	1.629	1.075
1959	−0.710	−0.626	−1.372	−1.208	−1.362	−0.799	−0.166	0.192	−0.205	2.011	1.800	2.156
1960	2.340	2.309	1.904	1.338	0.335	−0.555	−0.142	1.026	0.326	0.878	0.508	1.924
1961	2.465	2.611	2.295	1.440	−0.510	1.409	2.063	1.833	2.036	1.662	1.831	1.548
1962	1.140	−0.435	−0.690	−0.361	−1.392	−0.704	0.356	−0.235	0.439	0.397	0.479	0.323
1963	−0.114	−1.474	−2.049	−2.138	−2.484	−2.742	−3.107	−3.495	−3.689	−4.142	−3.671	−3.558
1964	−3.078	−2.850	−2.332	−2.260	−2.531	−2.595	−3.066	−2.542	−1.289	−1.504	0.140	−0.194
1965	−0.012	0.910	0.780	0.105	1.280	0.957	0.357	−0.102	0.001	−0.921	−1.117	−1.030
1966	−1.011	−0.657	−1.048	1.686	1.277	1.015	−0.432	1.360	1.644	1.139	−1.191	−1.727
1967	−2.421	−2.972	−3.377	−3.515	−3.254	−3.905	−3.886	−3.981	−2.453	−1.432	−1.294	−0.913
1968	2.387	2.226	2.533	2.692	3.004	3.419	3.811	3.570	3.601	2.789	3.070	2.668
1969	1.973	2.144	2.747	2.779	2.835	2.243	1.438	1.198	0.623	1.082	0.914	1.219
1970	0.892	1.455	1.880	1.619	1.546	0.991	−0.722	−1.046	0.913	1.319	0.665	−1.140
1971	−2.016	−2.346	−2.899	−3.134	−3.392	−3.930	−3.558	−2.100	−1.636	−0.886	−0.909	1.888
1972	1.787	1.002	−0.933	−1.301	−1.263	−1.409	−1.354	−0.986	−0.988	−0.234	0.108	−0.166
1973	1.408	1.447	1.626	2.287	1.642	2.605	3.527	3.405	4.043	4.753	4.142	3.449
1974	3.353	2.518	1.653	1.183	−0.653	−0.803	−1.229	1.824	3.179	3.628	4.062	3.849
1975	3.349	3.416	2.941	2.710	3.190	3.072	3.309	3.321	2.793	2.119	1.437	0.873
1976	−1.532	−2.846	−2.733	−1.784	−1.037	−0.598	2.051	2.128	2.416	3.017	2.747	2.828
1977	2.888	2.582	2.866	3.160	2.121	1.303	−0.967	−1.152	−1.908	−2.233	−2.128	−2.957
1978	−2.874	−2.495	−2.390	−2.790	−2.953	−3.126	−3.624	−3.201	−3.022	−3.304	−2.247	−2.224
1979	−1.386	−0.885	1.837	1.805	2.401	2.174	2.697	3.172	2.929	2.181	1.500	1.481
1980	1.294	−0.073	−0.148	−0.344	−0.012	−0.829	−1.640	−2.558	−1.671	−1.818	−1.761	−1.916
1981	−2.279	−2.595	−2.061	−2.299	−1.685	1.230	1.666	1.877	1.618	3.462	3.173	2.485
1982	2.215	1.791	1.315	1.149	2.037	2.604	2.522	1.542	0.619	0.510	0.970	1.303
1983	1.031	1.266	1.898	1.033	1.332	1.373	1.526	1.725	1.164	0.939	−0.068	−0.384
1984	−0.619	−0.864	−0.613	−1.576	−2.090	−2.454	−2.745	−2.924	−3.072	−0.987	−0.555	1.755
1985	1.931	2.140	2.221	1.956	1.203	1.303	1.251	0.331	0.329	1.196	1.514	1.372
1986	0.680	0.568	−1.004	−1.143	−0.014	1.193	1.088	1.128	1.313	2.005	2.404	2.933
1987	2.620	3.093	2.639	1.420	1.749	2.765	2.968	2.641	2.393	1.579	1.852	2.236
1988	1.662	1.143	1.046	0.336	−1.502	−1.392	−1.132	−1.448	−1.317	−1.552	−1.871	−1.929
1989	−1.606	−1.147	0.168	−0.376	0.305	1.636	1.900	2.130	1.760	1.218	0.341	−0.664
1990	−0.518	−0.224	1.048	1.764	1.895	1.142	1.389	1.095	0.966	0.815	0.917	0.587
1991	1.483	1.292	0.683	1.103	0.991	1.322	1.577	2.443	2.715	3.058	2.825	4.884
1992	5.198	5.664	5.367	4.571	4.667	4.915	5.089	4.870	4.306	3.405	3.672	3.855
1993	3.830	3.946	3.978	3.778	3.405	3.645	2.681	1.717	1.457	2.074	1.873	1.702
1994	1.452	1.118	0.854	0.579	1.184	0.691	0.784	0.810	0.650	1.913	2.297	2.869
1995	2.724	2.019	2.360	2.478	2.721	2.627	2.770	3.156	2.957	2.126	1.311	0.862
1996	0.014	−2.543	−2.561	−2.617	−3.655	−3.831	−3.818	−2.074	−0.867	−0.840	1.669	1.326

1997	1.131	2.724	2.727	3.749	3.437	3.805	3.576	3.405	2.418	2.640	2.504	3.234
1998	3.649	3.849	3.930	2.989	1.398	−0.514	−3.298	−2.862	−2.476	−1.006	0.203	0.685
1999	2.129	0.972	1.264	0.738	0.744	0.833	0.741	−0.813	−1.345	−1.732	−2.572	−2.702
2000	−2.894	−3.345	−3.078	−2.933	−2.932	−1.839	−2.143	−2.925	−3.354	−2.772	1.259	1.717
2001	2.725	3.118	3.784	2.677	2.078	1.817	0.654	1.432	1.614	1.436	1.579	1.852
2002	1.446	1.094	1.499	0.833	0.392	0.291	1.468	1.328	0.940	2.132	2.039	2.921
2003	2.297	2.690	2.060	1.104	−1.316	−0.779	−0.812	−0.792	−0.268	−0.392	−0.681	−1.509
2004	−1.317	−0.320	−0.597	−0.029	−0.358	2.064	2.551	3.184	2.346	2.569	4.223	3.637
2005	3.571	3.468	3.108	2.141	1.400	0.586	0.357	0.653	−1.594	−1.969	−2.552	−3.282
2006	−3.558	−3.591	−3.045	−3.341	−3.759	−3.959	−4.121	−4.274	−3.983	−3.114	−3.186	−2.727
2007	−1.084	−1.472	−0.214	0.208	2.302	3.728	5.297	5.806	5.306	4.462	3.655	2.936
2008	2.155	1.459	2.081	1.965	0.988	0.122	−1.882	−0.799	−0.999	−1.190	−1.479	−2.077
2009	−2.849	−3.620	−2.961	−2.103	−2.270	−2.769	−2.362	−2.392	0.094	2.004	1.798	2.071
2010	2.697	3.508	3.542	2.984	1.990	1.123	1.475	0.700	1.722	1.077	0.453	−0.028
2011	−0.055	−1.318	−2.370	−2.904	−3.133	−3.789	−4.718	−5.303	−5.570	−4.958	−4.722	−3.686
2012	−2.433	−1.859	0.734	−0.038	−1.863	−2.211	−2.350	−2.177	−1.847	−2.195	−2.939	−3.261

Table 6.11
HI Records for BBASC Environmental Flow Recommendations Below Whitney Dam

	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HI LOWER	1940	1	1	1	1	1	1	2	2	2	2	2	2
HI LOWER	1941	2	2	3	3	3	3	3	3	3	3	3	3
HI LOWER	1942	3	3	3	3	3	3	3	3	3	3	3	3
HI LOWER	1943	3	3	2	2	2	2	2	2	2	2	1	1
HI LOWER	1944	1	1	2	2	2	2	2	2	2	2	2	2
HI LOWER	1945	2	2	2	2	2	2	3	3	3	3	3	3
HI LOWER	1946	3	3	3	3	3	3	3	3	3	3	2	2
HI LOWER	1947	2	2	2	2	2	2	2	2	2	2	1	1
HI LOWER	1948	1	1	2	2	2	2	2	2	2	2	1	1
HI LOWER	1949	1	1	2	2	2	2	2	2	2	2	2	2
HI LOWER	1950	2	2	2	2	2	2	2	2	2	2	2	2
HI LOWER	1951	2	2	1	1	1	1	1	1	1	1	1	1
HI LOWER	1952	1	1	1	1	1	1	1	1	1	1	1	1
HI LOWER	1953	1	1	1	1	1	1	1	1	1	1	2	2
HI LOWER	1954	2	2	1	1	1	1	1	1	1	1	1	1
HI LOWER	1955	1	1	1	1	1	1	1	1	1	1	1	1
HI LOWER	1956	1	1	1	1	1	1	1	1	1	1	1	1
HI LOWER	1957	1	1	1	1	1	1	3	3	3	3	3	3
HI LOWER	1958	3	3	3	3	3	3	3	3	3	3	3	3
HI LOWER	1959	3	3	2	2	2	2	2	2	2	2	2	2
HI LOWER	1960	2	2	3	3	3	3	2	2	2	2	2	2
HI LOWER	1961	2	2	3	3	3	3	2	2	2	2	2	2
HI LOWER	1962	2	2	2	2	2	2	2	2	2	2	2	2
HI LOWER	1963	2	2	2	2	2	2	1	1	1	1	1	1
HI LOWER	1964	1	1	1	1	1	1	1	1	1	1	2	2
HI LOWER	1965	2	2	2	2	2	2	2	2	2	2	2	2
HI LOWER	1966	2	2	2	2	2	2	2	2	2	2	2	2
HI LOWER	1967	2	2	1	1	1	1	1	1	1	1	2	2
HI LOWER	1968	2	2	3	3	3	3	3	3	3	3	3	3
HI LOWER	1969	3	3	3	3	3	3	3	3	3	3	2	2
HI LOWER	1970	2	2	2	2	2	2	2	2	2	2	2	2
HI LOWER	1971	2	2	1	1	1	1	1	1	1	1	2	2
HI LOWER	1972	2	2	2	2	2	2	2	2	2	2	2	2
HI LOWER	1973	2	2	2	2	2	2	3	3	3	3	3	3
HI LOWER	1974	3	3	3	3	3	3	2	2	2	2	3	3
HI LOWER	1975	3	3	3	3	3	3	3	3	3	3	2	2
HI LOWER	1976	2	2	1	1	1	1	2	2	2	2	3	3
HI LOWER	1977	3	3	3	3	3	3	2	2	2	2	1	1

HI LOWER	1978	1	1	1	1	1	1	1	1	1	1	1	1
HI LOWER	1979	1	1	2	2	2	2	3	3	3	3	3	3
HI LOWER	1980	3	3	2	2	2	2	2	2	2	2	1	1
HI LOWER	1981	1	1	1	1	1	1	2	2	2	2	3	3
HI LOWER	1982	3	3	2	2	2	2	3	3	3	3	2	2
HI LOWER	1983	2	2	2	2	2	2	2	2	2	2	2	2
HI LOWER	1984	2	2	2	2	2	2	1	1	1	1	2	2
HI LOWER	1985	2	2	3	3	3	3	2	2	2	2	2	2
HI LOWER	1986	2	2	2	2	2	2	2	2	2	2	2	2
HI LOWER	1987	2	2	3	3	3	3	3	3	3	3	2	2
HI LOWER	1988	2	2	2	2	2	2	2	2	2	2	2	2
HI LOWER	1989	2	2	2	2	2	2	2	2	2	2	2	2
HI LOWER	1990	2	2	2	2	2	2	2	2	2	2	2	2
HI LOWER	1991	2	2	2	2	2	2	2	2	2	2	3	3
HI LOWER	1992	3	3	3	3	3	3	3	3	3	3	3	3
HI LOWER	1993	3	3	3	3	3	3	3	3	3	3	2	2
HI LOWER	1994	2	2	2	2	2	2	2	2	2	2	2	2
HI LOWER	1995	2	2	2	2	2	2	3	3	3	3	2	2
HI LOWER	1996	2	2	1	1	1	1	1	1	1	1	2	2
HI LOWER	1997	2	2	3	3	3	3	3	3	3	3	3	3
HI LOWER	1998	3	3	3	3	3	3	2	2	2	2	2	2
HI LOWER	1999	2	2	2	2	2	2	2	2	2	2	2	2
HI LOWER	2000	2	2	1	1	1	1	1	1	1	1	1	1
HI LOWER	2001	1	1	3	3	3	3	2	2	2	2	2	2
HI LOWER	2002	2	2	2	2	2	2	2	2	2	2	3	3
HI LOWER	2003	3	3	3	3	3	3	2	2	2	2	2	2
HI LOWER	2004	2	2	2	2	2	2	2	2	2	2	3	3
HI LOWER	2005	3	3	3	3	3	3	2	2	2	2	1	1
HI LOWER	2006	1	1	1	1	1	1	1	1	1	1	1	1
HI LOWER	2007	1	1	2	2	2	2	3	3	3	3	3	3
HI LOWER	2008	3	3	2	2	2	2	2	2	2	2	2	2
HI LOWER	2009	2	2	1	1	1	1	1	1	1	1	2	2
HI LOWER	2010	2	2	3	3	3	3	2	2	2	2	2	2
HI LOWER	2011	2	2	2	2	2	2	1	1	1	1	1	1
HI LOWER	2012	1	1	1	1	1	1	1	1	1	1	1	1

Model Control Points and Priority Dates

New control points are added to the EM and ED to accommodate water right *WR* and instream flow *IF* records associated with the BBEST and BBASC environmental flow recommendations. The new control points are added immediately downstream of the WAM primary control points identified by the BBEST and BBASC. Naturalized flows and daily flow patterns at the primary control points are repeated at the new environmental flow control points. The last alpha-numeric character of the primary control point is changed to "E" to create the control point identifier of the environmental flow control points.

The new environmental flow control points were added because many of the primary control points already have senior instream flow *IF* records assigned to them. In some instances, these senior instream flow requirements exceed the subsistence and base flow recommendations of the BBEST and BBASC. In order to create an end-of-period instream flow requirement at each control point that is reflective of only the BBEST or BBASC recommendation, a separate adjacent control point with the same naturalized flow was added.

The control points for the system water rights are listed in Table 6.6. These control points are listed again in Table 6.12 to illustrate their connectivity to upstream primary and environmental flow control points. The new system control points are added immediately downstream of the environmental flow control points. Naturalized flows and daily flow patterns at the primary control points are repeated at the new system control points.

Table 6.12
Control Points for Environmental Flow Recommendations and System Water Rights

Existing WAM CP ID	Stream	Nearest City	New Downstream Environmental Flow CP ID	New Downstream System CP ID
SFAS06	Salt Fork Brazos River	Aspermont	SFAS0E	-
DMAS09	Double Mountain Fork	Aspermont	DMAS0E	-
BRSE11	Brazos River	Seymour	BRSE1E	-
CFNU16	Clear Fork Brazos	Nugent	CFNU1E	-
CFFG18	Clear Fork Brazos	Fort Griffin	CFFG1E	-
BRSB23	Brazos River	South Bend	BRSB2E	-
BRPP27	Brazos River	Palo Pinto	BRPP2E	SYS27
BRGR30	Brazos River	Glen Rose	BRGR3E	-
NBCL36	North Bosque River	Clifton	NBCL3E	-
BRAQ33	Brazos River	Aquilla	-	SYS33
BRWA41	Brazos River	Waco	BRWA4E	SYS41
LEGT47	Leon River	Gatesville	LEGT4E	-
LAKE50	Lampasas River	Kempner	LAKE5E	-
LEBE49	Leon River	Belton	-	SYS49
LRLR53	Little River	Little River	LRLR5E	-
LRCA58	Little River	Cameron	LRCA5E	SYS58
BRBR59	Brazos River	Bryan	BRBR5E	SYS59
NAEA66	Navasota River	Easterly	NAEA6E	SYS66
BRHE68	Brazos River	Hempstead	BRHE6E	SYS68
BRRI70	Brazos River	Richmond	BRRI7E	SYS70
BRRO72	Brazos River	Rosharon	BRRO7E	-

The new control points for the system water rights are added immediately downstream of the new environmental flow control points to allow reservoirs releases to be counted in the regulated flow of the environmental flow control points. Reservoir releases are made to meet downstream system demands. Past reservoir releases are routed on a daily basis in the ED model through the control point network. Past releases to meet junior system demands will increase present day regulated flow at the environmental flow control points.

Priority order assignments in the WAM, EM, and ED models are shown in Table 6.13. The instream flow *IF* records of the BBEST and BBASC environmental flow recommendations are assigned a priority date equal to the date of the published recommendation reports. The BBEST and BBASC recommendations reports were published on March 1, 2012 and September 17, 2012, respectively.

Table 6.13
Priority Numbers of Water Rights in the WAM, EM, and ED Datasets

Water Right Description	WAM Priority	EM Priority	ED Priority
Existing Water Rights in Brazos Basin WAM	18831231 – 20050908	*unchanged*	*unchanged*
Depletion of Whitney Storage to Recover PX Record Increase in Availability to Somervell County Right	40000101	20120240	20120240
Depletion of Waco Storage to Recover PX Record Increase in Availability to Clifton Right	40050101	20120245	20120245
Refilling of Conservation Storage in Whitney and Waco after PX/BU Depletions	88888888 – 99999999	20120288 – 20120299	20120288 – 20120299
BBEST Environmental Flow IF Records	*na*	*na*	20120301
BBASC Environmental Flow IF Records	*na*	20120917	20120917
BRA System Depletions of Excess Flow and Associated Reservoir Releases	*na*	77777777	66666666
BRA System Reservoir Refill after Releases to Meet System Shortages of Excess Flow	*na*	88888888	77777777
New Hypothetical Project Demands and Storage Reallocations at Proctor and Whitney that will be added later in Chapter 7	*na*	99999999	88888888
Flood Control Storage and Release	*na*	*na*	91000000 – 94000000

The WAM contains water right priority dates 40000101, 40050101, 88888888, and 99999999 as part of the priority circumvention methodology to address subordination agreements associated with storage in Lakes Whitney and Waco and upstream junior water right holders. These existing subordination agreements are assumed to be senior to the Senate Bill 3 environmental flow recommendations. The water rights associated with the subordination agreements are reassigned priority dates in the EM and ED models that are immediately senior to the BBEST and BBASC instream flow *IF* records.

Hypothetical new storage reallocation projects at Lakes Whitney and Proctor are added in Chapter 7 but not included in the Chapter 6 EM and DM. These rights are assigned priorities of 99999999 and 88888888 in the monthly and daily models of Chapter 7.

Flood control pools are not a part of the EM model. The flood control reservoir *FR* records in the ED are assigned priorities of 91000000, 92000000, 93000000, and 94000000. The four priority dates are used to assign flood control system priorities that correspond to the priority groupings listed in Table 6.3.

Control point and priority date assignment in the EM and ED models is intended to limit depletions of stream flow by the new system and flood pool reallocation projects according to the recommendations for environmental flows by the BBEST and BBASC. Additionally, past reservoir releases for system demands and Whitney hydropower will rout through the control point network in the daily model and provide regulated flow enhancement in present and future days. Daily and monthly aggregated instream flow targets computed in the simulation are expected to differ from targets obtained with and without new water rights such as those added in Chapter 7. The effect on regulated flow of new water rights in the daily models of Chapter 7 influences the daily subsistence and pulse flow targets.

Flood control reservoirs in the ED model are modeled with the *FR* record field 6 option 2. Option 2 allows flood control reservoirs to ignore the conventional computation of priority order based water availability. When making stream flow depletions to impound water in flood control storage pools, the flood control reservoirs only consider the regulated flow, minus reservoir releases for water supply purposes, at their respective control points. Placing water into flood control storage at the 91000000 and 92000000 priority dates could impact water availability to downstream senior water rights and regulated flows for downstream environmental flow requirements. However, stream flow depletion for flood control storage only occurs during flood flow conditions and is unlikely to pose a constraint on water availability for water supply or regulated flows for meeting in-bank pulse flow requirements.

Modeling Subsistence and Base Flow Requirements

Under both the BBEST and BBASC recommendations, the subsistence and base flow limits are applied differently for dry hydrologic conditions than for average and wet hydrologic conditions. A 50% rule is applied if the hydrologic condition is dry according to the hydrologic index *HI* record data for the current month. The ED model base flow target for a particular day at a particular location is set based on subsistence and base flow requirements as follows.

- Under average or wet hydrologic conditions, the instream flow target is equal to the base flow limit which varies between the three seasons of the year. No consideration is given to the regulated flow.

- The 50% rule defined as follows is applied under dry hydrologic conditions:

    1. If the regulated flow in that day is less than the subsistence flow limit, then the instream flow target is set equal to the subsistence flow limit.

    2. If the regulated flow equals or exceeds the subsistence flow limit but is less than the dry base flow limit, then the instream flow target is equal to the subsistence flow limit plus 50 percent of the difference between the actual flow and the subsistence flow limit.

    3. If the regulated flow equals or exceeds the dry base flow limit, then the instream flow target is set equal to the dry base flow limit.

Table 6.14 shows the input records that build the daily target for the BBASC subsistence and base flow recommendations at Richmond. Four separate target building water right *WR* records, hereafter referred to as *type 8* water rights according to the option selection in *WR* record field 6, are used to build a target for each of the four recommendations of subsistence flow and dry, average, and wet condition base flow. Finally, type 8 water right BRRI-BASEFLOWS sets a daily target according to the largest of the targets.

Table 6.14
SIMD Input Records for BBASC Subsistence and Base Flow Recommendation at Richmond

```
----------------------------------------------------------------------------------------------------
WRBRRI7E 75213.2  BRRI-W20120917   8                          BRRI-BASE-W
FS    10            1.0     0.0     0.9     1.1   1           0   1  12   1    LOWER-WET-COND
DW         2
DO                 19
WRBRRI7E 40621.5  BRRI-A20120917   8                          BRRI-BASE-A
FS    10            1.0     0.0     0.9     1.1   1           0   1  12   1    LOWER-AVG-COND
DW         2
DO                 19
WRBRRI7E 24674.5  BRRI-D20120917   8                          BRRI-D
DW         2
WRBRRI7E 13090.9  BRRI-S20120917   8                          BRRI-S
DW         2
WRBRRI7E                20120917   8                          BRRI-ONOFF
TO     2                                                              CONT
TO    15     0.1    ADD                                               CONT
TO    13            SUB                                 BRRI-D        CONT
TO    15     0.1    MIN
DO        16
WRBRRI7E                20120917   8                          BRRI-REGSUB
TO     2                                                              CONT
TO    13            ADD                                 BRRI-S        CONT
TO    15     0.5    MUL                                               CONT
TO    13            MAX                                 BRRI-S
DO        16
WRBRRI7E                20120917   8                          BRRI-BASE-D
TO    13                                                BRRI-D
FS    10            1.0     0.0    0.09    0.11   1           0   1  12   1    BRRI-ONOFF
FS    10            1.0     0.0     0.9     1.1   1           0   1  12   1    LOWER-DRY-COND
DO        16       19
WRBRRI7E                20120917   8                          BRRI-SUBSISTENCE
TO    13                                              BRRI-REGSUB
FS    10            0.0     1.0    0.09    0.11   1           0   1  12   1    BRRI-ONOFF
FS    10            1.0     0.0     0.9     1.1   1           0   1  12   1    LOWER-DRY-COND
DO        16       19
**
**  Roll up Base and Subsistence Flow Requirements
**
WRBRRI7E       0        20120917   8                          BRRI-BASEFLOWS
TO    13            MAX                               BRRI-BASE-W     CONT
TO    13            MAX                               BRRI-BASE-A     CONT
TO    13            MAX                               BRRI-BASE-D     CONT
TO    13            MAX                               BRRI-SUBSISTENCE
DO        16
----------------------------------------------------------------------------------------------------
```

Type 8 water rights BRRI-BASE-W and BRRI-BASE-A set targets for the wet and average base flow limit, respectively. Both water rights use a flow switch *FS* record to check the daily target set by type 8 water rights LOWER-WET-COND and LOWER-AVG-COND. If either water right sets a daily target equal to 1.0, then the *FS* record applies the multiplier of 1.0. This ensures that the wet or average targets are set only in days of months with the appropriate hydrologic condition.

Type 8 water rights BRRI-D and BRRI-S set a daily target equal to the dry and subsistence flow limits, respectively. However, these two targets must be modified further to account for the presence of a dry hydrologic condition and to account for the daily value of regulated flow within the framework of the 50% rule.

The priority date is important to the analysis of the final instream flow target set for any of the BBEST or BBASC recommendations. Dry condition subsistence or dry base flow as well as daily pulse flow triggering and target setting are based on regulated flow at the priority date of the instream flow requirement. Routed depletions, return flow, and reservoir releases will influence the regulated flow at the priority date of the instream flow requirement. Flood control storage, while junior in priority, will ignore all downstream instream flow requirements.

Water right BRRI-ONOFF uses four target setting *TO* records. If regulated flow at the priority date of the instream flow requirement is greater than or equal to the dry base flow requirement, then BRRI-ONOFF sets a daily target equal to 0.1. The second *TO* record adds 0.1 to the daily value of regulated flow set by the first *TO* record. This ensures that if regulated flow is exactly equal or slightly greater than the dry base flow limit, the final *TO* record will establish a minimum target of 0.1. Without the addition of 0.1 using the second *TO* record, regulated flow exactly equal to the dry base flow requirement would result in a target setting of zero when the dry base flow limit is subtracted by the third *TO* record. This would result in water right BRRI-ONOFF setting a final target of zero and ultimately the application of the 50% subsistence rule. The addition of 0.1 by the second *TO* record allows upstream junior water rights to reduce regulated flow down to the dry base flow limit without engaging the 50% rule and thereby allowing regulated flow to be reduced down to the subsistence limit.

Water right BRRI-REGSUB adds the subsistence flow limit to a target equal to the regulated flow. The third *TO* record multiplies the target by 0.5 to establish a target equal to 50% of the value of the regulated flow plus the subsistence limit. The final *TO* record takes the maximum of the preceding target and the subsistence limit. If regulated flow is greater than the subsistence limit, the 50% value computed by the third *TO* record will be adopted. Otherwise, the subsistence limit will be adopted as the final daily target by BRRI-REGSUB.

If water right BRRI-ONOFF sets a daily target of 0.1, water right BRRI-BASE-D will set a daily target equal to the dry base flow limit if the hydrologic condition is equal to dry. Otherwise, water right BRRI-BASE-D will set a target equal to zero.

If water right BRRI-ONOFF sets a daily target of 0.0, BRRI-SUBSISTENCE will set a daily target equal to the daily target of water right BRRI-REGSUB if the hydrologic condition is equal to dry. Otherwise, BRRI-SUSSISTENCE will set a daily target equal to zero.

Finally, type 8 right BRRI-BASEFLOWS sets a daily target equal to the maximum value of the preceding water rights that establish the wet, average, dry or subsistence target limits.

The ED model input records shown in Table 6.14 are applicable to the BBASC recommendations for base flow and subsistence flow target setting at Richmond. All other locations throughout the basin have similar input record configuration. Only the values of the base flow and subsistence flow limits are changed accordingly. The relevant hydrologic condition for the lower, middle, or upper basin is applied. The input records for the BBEST base flow and subsistence flow recommendations have the same configuration as well. The primary difference between the BBASC and BBEST recommendations input records is the application of the hydrologic condition. The BBEST recommendations use a separate *HI* record for each of the 19 recommended sites in the Brazos River Basin.

The input records of Table 6.14 implement the subsistence and base flow requirements at the Richmond gage on the Brazos River. The *SIMD* input records for implementing the BBASC and BBEST recommendations are identical except for the flow switch identifier used to designate the name of the hydrologic index information. The BBASC recommended regime provides the hydrologic condition at only 3 locations, whereas the BBEST regime provides similar information at all 19 locations corresponding to environmental flow recommendations. The BBASC and BBEST subsistence and base flow *SIMD* input records for all 19 locations are structured in the same manner as shown in Table 6.14, except the pertinent flow limits are changed according to the values provided in Table 5.10.

Modeling High Flow Pulse Requirements

The BBEST and BBASC high flow pulse recommendations and termination criteria are described in detail in Chapter 5. Numerical values of the BBEST high flow pulse recommendations are provided in Table 5.11. BBASC high flow pulse recommendations are provided in Table 5.12. The BBEST high flow pulse recommendations contain significantly more pulses per location than the BBASC high flow pulse recommendations. The BBEST recommendations provide for up to 3 or 4 of the smallest pulses per season and up through overbanking flood flow events with a frequency as low as 1 per 5 years. The BBEST charge was to make recommendations based on the best available science and consideration only for environmental needs. The BBASC charge was to review and modify the BBEST recommended regime while accounting for human needs for water. As such, the BBASC high flow pulse recommendations eliminated the overbanking flood flow pulses, removed many of the larger inbank pulse flow events, and reduced the number of required smaller pulses per season.

A major difference in the BBEST and BBASC pulse flow recommendations, in addition to the differences in magnitude and frequency of the events, is the application of the hydrologic condition by the BBASC. The BBEST recommendations for high flow pulses are independent of the hydrologic condition. The BBASC recommendation for high flow pulses includes the use of the PHDI hydrologic condition to engage only one set of pulse flow recommendations per season at 17 of the 19 locations. The BBASC recommendations for the Brazos River near Palo Pinto and Glen Rose contain one set of dry PHDI pulses, two sets of average PHDI pulses, and two sets of wet PHDI pulses for the respective hydrologic condition.

Tables 6.15 and 6.16 give the *SIMD* input records for building daily targets according to the high flow pulse recommendations of the BBEST and BBASC, respectively, at the Brazos River near Richmond gage. Only one type 8 water right *WR* record at each of the 19 sites is required to build the pulse flow targets. Alternatively, each pair of pulse flow *PF* and pulse option *PO* records could be connected to separate *WR* records if the user wishes to analyze particular pulses. The *PF* record is required to set a pulse flow target. The *PO* record is optional and offers additional flexibility to model various requirements and conditions.

The first pulse flow *PF/PO* record pair for the BBEST recommended requirements is reproduced below. The *PF* record field entries are interpreted as follows from left to right across the *PF* record. Regulated flow (field 3) as computed at the priority date of the *WR* record is the variable used to engage a pulse flow event. A daily pulse flow event is engaged and a daily target is set when regulated flow exceeds a daily value of 12,714 acre-feet per day (field 5). The pulse flow target continues to be set on a daily basis until the cumulative regulated flow since target setting was initiated equals or exceeds 60,600 acre-feet (field 6), or until a total of 11 days (field 7) have passed since the first pulse flow target was set. After 3 separate pulse flow events (field 8) have been set between the months of November and February (fields 10 and 11), no further pulse events are initiated. Only pulses from the current season (field 12) can be used to meet the 3 per season frequency criterion. End-of-period regulated flow is used as the variable to track cumulative flow volume (field 13), and not the regulated flow as computed at the priority date of the *WR* record. Daily pulse flow targets are limited (field 14) to not exceed the trigger value of 12,714 acre-feet per day. This *PF* record passes the maximum of the daily pulse target or the preceding daily target to the *WR* record (field 15). A table of the number of pulse events per month for this *PF* record is recorded in the daily SMM message file (field 16). Tables recorded in the SMM file for this *PF* record use the identifier of BRRI-WINTER-3 (field 17).

```
PF     0          12714   60600  11   3      0  11   2   1   0   2   4   2            BRRI-WINTER-3
PO     0   1   2   2  2499.2 16720.7    0.05   0   0   0   0        BRRI-SUMMER-3
```

The *PO* record field entries are interpreted as follows from left to right across the *PO* record. New pulse event initiation does not have to wait (field 2) until the entire duration criterion (*PF* field 7) of the previous pulse event has lapsed. However, one additional day must lapse since the termination of the previous pulse before a new pulse can be initiated (field 3). If there are other *PF* records provided at the same control point, then pulse event initiation of this *PF/PO* record pair is blocked (field 4) if another *PF* record with a larger trigger criterion is currently engaged. The regulated flow in the previous day must be less than the *PF* record trigger criterion in order for the current day's regulated flow to be considered for pulse event initiation (field 5). If a pulse event is currently engaged and regulated flow drops below 2,499.2 acre-feet per day, the pulse event is terminated (field 6). If regulated flow is below 16,720.7 acre-feet per day and regulated flow has decreased by 5% or less since the previous day, then the pulse event is terminated (fields 7 and 8). Pulses that are engaged prior to the end of the season are allowed to continue tracking into the next season until other termination criteria are met (default field 9). Smaller pulse events engaged prior to the initiation of this *PF/PO* record pair do not contribute to the total event volume credit (default field 10). Pulse events in excess of the frequency criterion are not considered (default field 11). Pulses events that are terminated prior to reaching their full event volume criterion are still counted towards meeting the frequency criterion (default field 12). Pulse events are blocked from initiation if *PF* record BRRI-SUMMER-3 is currently engaged (field 14).

Pulse event initiation is blocked if a daily target has been set by the *WR*, *IF*, or *PF* record identified in *PO* record field 14. This feature is used in the records shown in Tables 6.15 and

6.16 to prevent pulse events of the same seasonal frequency from simultaneously engaging events. For example, *PO* record field 9 allows a 3 per summer pulse to continue into the winter season until the summer pulse is terminated by other criteria. *PO* record field 14 is used in order to prevent a 3 per winter pulse from being initiated while the 3 per summer pulse is engaged.

Table 6.15
SIMD Input Records for BBEST Pulse Flow Recommendation at Richmond

```
-----------------------------------------------------------------------------------------------------------
WRBRRI7E      0.        20120301   8                            BRRI-PULSES
PF      0            12714   60600  11   3      0  11   2   1   0   2   4   2             BRRI-WINTER-3
PO      0   1   2    2  2499.2 16720.7   0.05   0   0   0   0       BRRI-SUMMER-3
PF      0            17712   94000  13   3      0   3   6   1   0   2   4   2             BRRI-SPRING-3
PO      0   1   2    2  2499.2 16720.7   0.05   0   0   0   0       BRRI-WINTER-3
PF      0             4879   16400   6   3      0   7  10   1   0   2   4   2             BRRI-SUMMER-3
PO      0   1   2    2  2499.2 16720.7   0.05   0   0   0   0       BRRI-SPRING-3
PF      0            24595  150000  16   2      0  11   2   1   0   2   4   2             BRRI-WINTER-2
PO      0   1   2    2  2499.2 16720.7   0.05   0   0   0   0       BRRI-SUMMER-2
PF      0            32331  215000  19   2      0   3   6   1   0   2   4   2             BRRI-SPRING-2
PO      0   1   2    2  2499.2 16720.7   0.05   0   0   0   0       BRRI-WINTER-2
PF      0            10770   46300  10   2      0   7  10   1   0   2   4   2             BRRI-SUMMER-2
PO      0   1   2    2  2499.2 16720.7   0.05   0   0   0   0       BRRI-SPRING-2
PF      0            48793  383000  23   1      0  11   2   1   0   2   4   2             BRRI-WINTER-1
PO      0   1   2    2  2499.2 16720.7   0.05   0   0   0   0       BRRI-SUMMER-1
PF      0            69421  617000  29   1      0   3   6   1   0   2   4   2             BRRI-SPRING-1
PO      0   1   2    2  2499.2 16720.7   0.05   0   0   0   0       BRRI-WINTER-1
PF      0            25587  144000  15   1      0   7  10   1   0   2   4   2             BRRI-SUMMER-1
PO      0   1   2    2  2499.2 16720.7   0.05   0   0   0   0       BRRI-SPRING-1
PF      0           102347 1019000  35   1      0   1  12   1   0   2   4   2             BRRI-1PER-1YEAR
PO      0   1   2    2  2499.2 16720.7   0.05   0   0   0   0
PF      0           135074 1487000  41   1      0   1  12   2   0   2   4   2             BRRI-1PER-2YEARS
PO      0   1   2    2  2499.2 16720.7   0.05   0   0   2   0
-----------------------------------------------------------------------------------------------------------
```

Table 6.16
SIMD Input Records for BBASC Pulse Flow Recommendation at Richmond

```
-----------------------------------------------------------------------------------------------------------
WRBRRI7E                20120917   8                            BRRI-PULSES
PF      0            12714   60600  11   1      0  11   2   1   0   2   4   2              BRRI-WINTER-DRY
PO      0   0   2    0  2499.2 16720.7   0.05   0   0   0   0       BRRI-SUMMER-DRY   LOWER-DRY-COND
PF      0            17712   94000  13   1      0   3   6   1   0   2   4   2              BRRI-SPRING-DRY
PO      0   0   2    0  2499.2 16720.7   0.05   0   0   0   0       BRRI-WINTER-DRY   LOWER-DRY-COND
PF      0             4879   16400   6   1      0   7  10   1   0   2   4   2              BRRI-SUMMER-DRY
PO      0   0   2    0  2499.2 16720.7   0.05   0   0   0   0       BRRI-SPRING-DRY   LOWER-DRY-COND
PF      0            12714   60600  11   3      0  11   2   1   0   2   4   2              BRRI-WINTER-AVG
PO      0   0   2    0  2499.2 16720.7   0.05   0   0   0   0       BRRI-SUMMER-AVG   LOWER-AVG-COND
PF      0            17712   94000  13   3      0   3   6   1   0   2   4   2              BRRI-SPRING-AVG
PO      0   0   2    0  2499.2 16720.7   0.05   0   0   0   0       BRRI-WINTER-AVG   LOWER-AVG-COND
PF      0             4879   16400   6   3      0   7  10   1   0   2   4   2              BRRI-SUMMER-AVG
PO      0   0   2    0  2499.2 16720.7   0.05   0   0   0   0       BRRI-SPRING-AVG   LOWER-AVG-COND
PF      0            24595  150000  16   2      0  11   2   1   0   2   4   2              BRRI-WINTER-WET
PO      0   0   2    0  2499.2 16720.7   0.05   0   0   0   0       BRRI-SUMMER-WET   LOWER-WET-COND
PF      0            32331  215000  19   2      0   3   6   1   0   2   4   2              BRRI-SPRING-WET
PO      0   0   2    0  2499.2 16720.7   0.05   0   0   0   0       BRRI-WINTER-WET   LOWER-WET-COND
PF      0            10770   46300  10   2      0   7  10   1   0   2   4   2              BRRI-SUMMER-WET
PO      0   0   2    0  2499.2 16720.7   0.05   0   0   0   0       BRRI-SPRING-WET   LOWER-WET-COND
-----------------------------------------------------------------------------------------------------------
```

Input records in Tables 6.15 and 6.16 all use *PF* record field 15 option 4 to adopt the larger of the current and preceding targets and *PO* record field 4 option 2 to block pulse initiation if a larger pulse is engaged at the same control point. These options are integral to satisfying the BBEST and BBASC recommendations that a larger pulse controls the daily flow requirement and that the larger pulse counts towards meeting only one of each of the smaller pulses in the same season. In the BBASC recommendations, there are only one set of pulses per season per hydrologic condition except at the Palo Pinto and Glen Rose locations. Thus, *PO* record field 4 option 2 is not necessary at 17 of the 19 locations.

As an example of the use of *PF* record field 15 option 4 and *PO* record field 4 option 2, regulated flow may rapidly increase and initiate a 1 per winter flow event shown in Table 6.15 with a trigger criterion of 48,793 acre-feet per day. In that same day, a 3 per winter and 2 per winter pulse would be initiated as well. The final target set by the *WR* record would be controlled by the larger *PF* record target set by the 1 per winter pulse. The 3 per winter and 2 per winter pulses would receive frequency criterion credit for initiating a pulse, but the daily target would be set according to the 1 per winter pulse. The 3 per winter and 2 per winter pulses would continue to be tracked by *SIMD* for the purposes of generating tables of pulse events for the SMM file. When the 3 per winter and 2 per winter pulse events terminate, these *PF* records cannot initiate new pulses until the larger 1 per winter pulse has terminated. This prevents the protection of regulated flow for a larger 1 per winter pulse event from being used to count towards more than one of the smaller winter pulses.

The Table 6.15 *PO* records for the BBEST recommendation differ from the Table 6.16 *PO* records for the BBASC recommendation with respect to options selected for two fields. The BBEST *PO* records utilize *PO* record field 3 option 1 and field 5 option 2. Field 3 option 1 requires one day to lapse between successive pulse initiations by the same *PF* record. *PO* record field 5 option 2 requires regulated flow in the previous day to be less than the *PF* record trigger criterion in order to consider the regulated flow in the current day for pulse initiation. Neither requirement is specified in the BBEST or BBASC reports. However, the options were used for modeling the BBEST flow recommendations at all 19 locations for the purposes of illustration. The effect of using these two options is to increase the number of days between successive pulse flow events.

The *PO* records in Table 6.16 for the BBASC recommendation utilize field 15. *PO* record field 15 is an optional initiation criterion. If a *WR*, *IF*, or *PF* record does not set a daily target, then the *PF* record does not consider regulated flow in the current day for the purpose of initiating a new pulse flow event. The water right identifier of the *WR* record that signifies the appropriate hydrologic condition is entered into *PO* record field 15. This prevents pulse flow events from initiating except when their respective hydrologic condition is met.

All subsistence flow, base flow, and pulse flow input records examined thus far have been associated with type 8 target setting water rights. The type 8 water rights can be used to build and set a target like any other water right type with the exception that no depletion of stream flow or diversion of stored water is made. A single instream flow *IF* record is required in order to apply the subsistence, base flow, and pulse targets. Table 6.17 illustrates the use of two *TO* records and a *DO* record to set a daily instream flow target. The *IF* records utilize field 7 option 2 to adopt the largest *IF* record target at the control point. However, all of the BBEST and BBASC recommendations are located at new control points that do not have other *IF* records located with them. *DO* record field 3 option 16 allows *TO* records to be considered on a daily basis in step 16 of the target building process described in the *Daily Manual*.

Table 6.17
SIMD Input Records for BBASC Instream Flow Requirement at Richmond

```
-----------------------------------------------------------------------------
IFBRRI7E       0       20120917 0 2            BRRI-ENVIROFLOW
TO    13           MAX                                BRRI-PULSES        CONT
TO    13           MAX                                BRRI-BASEFLOWS
DO       16
-----------------------------------------------------------------------------
```

All *PF* records in the BBEST and BBASC recommendations use field 16 option 2. This option results in tables of annual rows and monthly columns to be written to the end of the *SIMD* daily message SMM file. At least two tables are written for each *PF* record. The first table lists the number of pulse flow events per month that were initiated and counted towards meeting the seasonal frequency criterion. The second table contains the number of pulse events that were terminated each month prior to meeting the *PF* record field 6 event volume criterion. It is possible that some pulse events are initiated in one month and terminated in another month. If *PO* record field 11 option 2 is used, a third table is written to the SMM file that contains the number of pulse flow events that were initiated per month in excess of the required frequency. Excess pulse flow events do not set daily pulse flow targets, but can be used to count towards meeting the frequency criterion in subsequent seasons.

Table 6.18 and 6.19 are a compilation of all SMM tables for the nine *PF* records contained in the BBASC pulse flow recommendation at Richmond as shown in Table 6.16. Each row is a calendar year of results. However, the winter season spans November to February. This results in two winter seasons being represented in each row of the table. The maximum number of pulses in the BBASC recommendation in one cycle of the winter, spring, and summer seasons is 9 high flow pulses if the hydrologic condition is average. However, more than 9 pulses are listed in the annual total in Table 6.18 in some years. The winter pulses listed in January and February actually belong to the winter season that began in the previous year. Therefore, no more than 18 pulses should be listed in Tables 6.18 in any two consecutive calendar years when the hydrologic condition is average throughout the years.

The BBASC recommendations call for up to 3 pulses per cycle of the winter, spring, and summer seasons under dry hydrologic conditions. Every season is not required to meet the per season frequency criterion, and subsequent seasons are not required to make up for pulse shortages in prior seasons. Under average and wet conditions, up to 9 and 6 pulses, respectively, are required per seasonal cycle. The dry and wet hydrologic conditions are designed to occur in 25% of the years each. The average hydrologic condition is designed to occur in the remaining 50% of the years. The theoretical number of pulses for the 73 year simulation period of analysis, assuming every season meets its frequency requirement, is computed as follows:

$$\text{Maximum Richmond BBASC Pulses} = (0.25 \times 73 \times 3) + (0.50 \times 73 \times 9) + (0.25 \times 73 \times 6) = 492.75$$

The theoretical maximum number of pulses is reduced to 492 since a partial pulse is not possible. There are 410 total pulses initiated at Richmond during the 73 year simulation period of analysis according to Table 6.18. This is equal to 83.3% of the theoretical maximum 492 pulses in the BBASC recommendation for this location for a 73 year simulation.

Table 6.18
Number of BBASC Pulses at Richmond Initiated per Month

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0	0	0	1	0	0	3	0	0	0	3	0	7
1941	0	0	2	0	0	0	2	0	0	0	2	0	6
1942	0	0	0	2	0	0	2	0	0	0	0	0	4
1943	0	0	1	1	0	0	2	1	0	0	0	0	5
1944	1	0	3	0	0	0	3	0	0	0	2	1	10
1945	0	0	3	0	0	0	2	0	0	0	0	2	7
1946	0	0	2	0	0	0	2	0	0	0	3	0	7
1947	0	0	3	0	0	0	0	3	0	0	0	0	6
1948	0	1	1	0	1	0	3	0	0	0	0	0	6
1949	0	1	2	1	0	0	3	0	0	0	1	2	10
1950	0	0	0	3	0	0	2	1	0	0	0	0	6
1951	0	0	0	0	0	0	0	0	0	0	0	0	0
1952	0	0	0	1	0	0	0	0	0	0	0	0	1
1953	1	0	0	0	1	0	1	0	0	0	1	2	6
1954	0	0	0	0	1	0	0	0	0	0	0	0	1
1955	0	1	0	1	0	0	1	0	0	0	0	0	3
1956	0	0	0	0	0	0	0	0	0	0	0	0	0
1957	0	0	0	1	0	0	2	0	0	0	2	0	5
1958	0	0	2	0	0	0	2	0	0	0	0	0	4
1959	0	0	0	3	0	0	3	0	0	0	3	0	9
1960	0	0	0	1	0	1	3	0	0	0	3	0	8
1961	0	0	2	0	0	0	3	0	0	0	3	0	8
1962	0	0	0	0	0	1	3	0	0	0	1	2	7
1963	0	0	0	1	0	0	1	0	0	0	0	0	2
1964	0	0	0	0	0	0	0	0	1	0	1	0	2
1965	2	0	1	2	0	0	3	0	0	0	3	0	11
1966	0	0	2	1	0	0	1	2	0	0	0	0	6
1967	0	0	0	0	1	0	1	0	0	0	2	1	5
1968	0	0	2	0	0	0	2	0	0	0	1	1	6
1969	0	0	2	0	0	0	0	0	1	0	0	3	6
1970	0	0	3	0	0	0	2	0	1	0	0	0	6
1971	0	0	0	0	0	0	1	0	0	0	1	2	4
1972	0	0	1	0	2	0	0	0	0	2	2	0	7
1973	1	0	3	0	0	0	2	0	0	0	2	0	8
1974	0	0	0	0	0	0	0	2	1	0	2	0	5
1975	0	0	0	2	0	0	2	0	0	0	0	0	4
1976	0	0	0	1	0	0	3	0	0	0	0	2	6
1977	0	0	1	1	0	0	1	0	0	0	0	0	3
1978	1	0	0	0	0	0	0	1	0	0	1	0	3
1979	0	0	3	0	0	0	2	0	0	0	0	0	5
1980	1	0	1	1	1	0	0	0	1	1	0	0	6
1981	0	0	0	0	0	1	3	0	0	0	2	0	6
1982	0	0	0	2	1	0	2	0	0	0	0	1	6
1983	1	1	3	0	0	0	1	2	0	0	0	0	8
1984	0	0	0	0	0	0	0	0	0	1	3	0	4
1985	0	0	2	0	0	0	0	0	0	3	3	0	8
1986	0	0	0	0	3	0	3	0	0	0	3	0	9
1987	0	0	2	0	0	0	2	0	0	0	1	2	7
1988	0	0	0	0	0	1	0	0	1	0	0	0	2
1989	1	0	1	0	2	0	3	0	0	0	0	0	7

1990	0	1	3	0	0	0	2	0	1	0	0	0	7
1991	3	0	0	3	0	0	3	0	0	0	1	1	11
1992	0	0	2	0	0	0	2	0	0	0	0	2	6
1993	0	0	2	0	0	0	2	0	0	0	0	0	4
1994	0	3	1	0	2	0	1	0	1	1	0	3	12
1995	0	0	3	0	0	0	0	2	0	0	0	1	6
1996	0	0	0	0	0	0	0	1	0	0	0	2	3
1997	1	0	2	0	0	0	2	0	0	0	0	2	7
1998	0	0	2	0	0	0	0	1	1	1	3	0	8
1999	0	0	0	1	1	0	0	1	0	0	0	0	3
2000	0	0	0	0	0	1	1	0	0	0	1	0	3
2001	0	0	1	0	0	0	1	2	0	0	3	0	7
2002	0	0	0	0	2	0	3	0	0	0	2	0	7
2003	0	0	0	0	0	2	2	1	0	0	1	0	6
2004	2	0	2	1	0	0	3	0	0	0	2	0	10
2005	0	0	0	0	0	0	0	3	0	0	0	0	3
2006	0	0	1	0	0	0	0	0	1	0	1	0	3
2007	0	0	3	0	0	0	2	0	0	0	0	0	5
2008	0	0	3	0	0	0	0	3	0	0	0	0	6
2009	0	0	1	0	0	0	1	0	0	0	3	0	5
2010	0	0	0	1	0	0	3	0	0	0	0	0	4
2011	1	1	0	0	0	0	0	0	0	1	0	1	4
2012	0	0	1	0	0	0	1	0	0	0	0	0	2
TOTAL	16	9	75	32	18	7	106	26	10	10	68	33	410

Table 6.19
Number of BBASC Pulses at Richmond Terminated Before Reaching Event Volume Criterion

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0	0	0	1	0	0	0	0	0	0	0	0	1
1941	0	0	0	0	0	0	0	0	0	0	0	0	0
1942	0	0	0	0	0	0	0	0	0	0	0	0	0
1943	0	0	0	1	0	0	0	0	0	0	0	0	1
1944	0	0	0	0	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	0	0	0	0
1947	0	0	0	0	0	0	0	0	0	0	0	0	0
1948	0	0	0	0	1	0	2	0	0	0	0	0	3
1949	0	0	0	1	0	0	0	0	0	0	0	0	1
1950	0	0	0	0	0	0	2	0	0	0	0	0	2
1951	0	0	0	0	0	0	0	0	0	0	0	0	0
1952	0	0	0	0	1	0	0	0	0	0	0	0	1
1953	0	0	0	0	0	0	0	0	0	0	0	0	0
1954	0	0	0	0	0	0	0	0	0	0	0	0	0
1955	0	1	0	0	0	0	1	0	0	0	0	0	2
1956	0	0	0	0	0	0	0	0	0	0	0	0	0
1957	0	0	0	0	0	0	0	0	0	0	0	0	0
1958	0	0	0	0	0	0	0	0	0	0	0	0	0
1959	0	0	0	0	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0	0	0	0	1	1
1963	0	0	0	0	0	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0	0	1	0	1
1965	0	0	0	0	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	1	0	0	0	0	0	1
1967	0	0	0	0	1	0	1	0	0	0	1	0	3
1968	0	0	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	1	0	2	3

1970	0	0	0	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0	0	1	0	1
1972	0	0	1	0	0	0	0	0	0	0	2	0	3
1973	0	0	0	0	0	0	1	0	0	0	0	0	1
1974	0	0	0	0	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	1	0	0	1
1981	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0	0	0	1	1
1983	1	0	0	0	0	0	0	0	0	0	0	0	1
1984	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	1	0	0	0	0	0	0	1	0	0	2
1986	0	0	0	0	0	0	0	0	0	0	3	0	3
1987	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	1	0	0	0	1	0	0	2
1989	0	1	0	0	0	0	2	0	0	0	0	0	3
1990	0	0	1	0	0	0	0	1	0	0	0	0	2
1991	0	0	0	0	0	0	2	0	0	0	1	0	3
1992	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	1	0	1	0	2
1999	0	0	0	0	0	0	0	0	1	0	0	0	1
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	1	0	0	0	0	0	0	0	1
2003	0	0	0	0	0	1	2	0	0	0	0	0	3
2004	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	1	0	0	0	0	0	1
2010	0	0	0	0	1	0	0	0	0	0	0	0	1
2011	0	0	1	0	0	0	0	0	0	0	0	0	1
2012	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	1	2	4	3	5	2	15	1	2	4	10	4	53

There are many factors that can affect achievement of the maximum number of pulses including the simulation assumption of full authorized use. However, the natural variability outside of the simulation assumptions for water supply management likely will always result in less than the theoretical maximum number of pulses being simulated. Some seasons will naturally have zero pulses, while other seasons will have an excess number of pulses that cannot count towards meeting pulse shortages in other seasons. Finally, the BBEST and BBASC recommendations were built using statistical analysis software, HEFR, which produced a frequency based on a central tendency of the number of pulses per season. The actual number of natural pulses in any individual season does not necessarily conform to the recommendation.

The following input records were added to the *SIMD* DAT file to compute the number of days the final instream flow target was set by a base flow or pulse flow target. Subsistence flow targets are included in the number of base flow days for this example. When the ratio of the target set by the pulse flow *WR* record to the target set by the base flow *WR* record exceeds 1.0, the flow switch *FS* records result in a type 8 water rights setting a daily target of 1.0. Monthly aggregation of the daily targets in the OUT output file provides a method to determine the number of days per month the base flow or pulse flow targets controlled the *IF* record target.

```
WRBRRI7E       1        20120917   8                               BRRI-RATIO
TO    13             SET                             BRRI-PULSES     CONT
TO    13             DIV                             BRRI-BASEFLOWS
DO        16
WRBRRI7E       1        20120917   8                               BRRI-BASEDAYS
FS    10             0.0     1.0     1.0         1          0   1  12   1    BRRI-RATIO
DW          1
DO               19
WRBRRI7E       1        20120917   8                               BRRI-PULSEDAYS
FS    10             0.0     1.0             1.0   1          0   1  12   1    BRRI-RATIO
DW          1
DO               19
```

There are 26,664 days in the simulation period of analysis from January 1, 1940 through December 31, 2012. Table 6.20 shows the number of days per month that pulse flow targets control the instream flow target set at Richmond for the BBASC recommendation. Table 6.20 was created using the simulation input records above and generating a *TABLES* time series of monthly targets for water right BRRI-PULSEDAYS. There are 410 pulses set at Richmond during the period of analysis. The BBASC recommendation at Richmond does not contain more than one level of pulse per season. For example, there is no possibility of a larger pulse being set while simultaneously meeting a smaller pulse requirement in the BBASC recommendation at Richmond. Therefore, 410 separate pulses control 1,304 days of *IF* record target setting.

Pulse flow targets may be less than the base flow target when the regulated flow falls below the base flow limit but does not exceed the minimum pulse flow criterion in column 7 of Table 5.9. Such days will not count toward the total number of days in Table 6.20. Table 6.20 only indicates the days when the pulse flow target is larger than the base flow target.

The maximum number of days per pulse is given in *PF* record field 7. The maximum number of day per pulse multiplied by the number of pulse per season can be used to compute the maximum number of days of pulses per cycle of the winter, spring, and summer seasons. For the dry, average, and wet hydrologic conditions, the maximum number of days of pulse flow targets per complete seasonal cycle is 30, 90, and 90 days, respectively. The theoretical number of pulse flow target days for the 73 year simulation period of analysis, assuming every season meets its frequency requirement, is computed as follows:

Max Richmond BBASC Pulses Days = (0.25 x 73 x 30) + (0.50 x 73 x 90) + (0.25 x 73 x 90) = 5,475

Pulse flow targets controlled the final daily *IF* record target for the BBASC recommendation at Richmond for 1,304 days. This is 23.8% of the theoretical maximum pulse flow duration assuming all required pulse flow events were initiated in every season and every pulse flow event set a target in every day of its maximum duration. In reality, and especially with pulse flow events with small trigger flow rate criterion, large natural flow events will initiate and satisfy a small pulse flow requirement in a single day. Likewise, many seasons do not contain any initiated pulse flow events as shown in Table 6.18.

Table 6.20
Number of Days per Month that BBASC Pulse Targets Are Set at Richmond

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0	0	0	9	0	0	3	0	0	0	9	0	21
1941	0	0	9	0	0	0	4	0	0	0	7	0	20
1942	0	0	0	7	0	0	6	0	0	0	0	0	13
1943	0	0	4	8	0	0	3	1	0	0	0	0	16
1944	4	0	7	0	0	0	3	0	0	0	5	2	21
1945	0	0	9	0	0	0	6	0	0	0	0	12	27
1946	0	0	8	0	0	0	7	0	0	0	7	0	22
1947	0	0	10	0	0	0	0	4	0	0	0	0	14
1948	0	1	7	0	6	0	7	0	0	0	0	0	21
1949	0	2	11	5	0	0	3	0	0	0	8	9	38
1950	0	0	0	10	0	0	4	2	0	0	0	0	16
1951	0	0	0	0	0	0	0	0	0	0	0	0	0
1952	0	0	0	6	0	0	0	0	0	0	0	0	6
1953	4	0	0	0	6	0	2	0	0	0	5	6	23
1954	0	0	0	0	8	0	0	0	0	0	0	0	8
1955	0	6	0	5	0	0	3	0	0	0	0	0	14
1956	0	0	0	0	0	0	0	0	0	0	0	0	0
1957	0	0	0	3	0	0	2	0	0	0	11	0	16
1958	0	0	8	0	0	0	5	0	0	0	0	0	13
1959	0	0	0	9	0	0	6	0	0	0	8	0	23
1960	0	0	0	1	6	4	3	0	0	0	6	0	20
1961	0	0	14	0	0	0	3	0	0	0	8	3	28
1962	0	0	0	0	0	9	4	0	0	0	1	12	26
1963	0	0	0	4	0	0	4	0	0	0	0	0	8
1964	0	0	0	0	0	0	0	0	2	0	6	0	8
1965	3	0	4	9	0	0	3	0	0	0	10	0	29
1966	0	0	11	2	0	0	3	3	0	0	0	0	19
1967	0	0	0	0	5	0	1	0	0	0	9	8	23
1968	0	0	11	0	0	0	2	0	0	0	1	12	26
1969	0	0	13	0	0	0	0	0	1	0	0	12	26
1970	0	0	11	0	0	0	6	0	3	0	0	0	20
1971	0	0	0	0	0	0	2	0	0	0	1	7	10
1972	0	0	3	0	7	0	0	0	0	5	4	0	19
1973	4	0	12	0	0	0	5	0	0	0	9	3	33
1974	0	0	0	0	0	0	0	3	1	0	7	0	11
1975	0	0	0	16	0	0	4	0	0	0	0	0	20
1976	0	0	0	2	0	0	6	0	0	0	0	10	18
1977	0	0	1	9	0	0	4	0	0	0	0	0	14
1978	5	0	0	0	0	0	0	2	0	0	3	0	10
1979	0	0	12	0	0	0	7	0	0	0	0	0	19
1980	6	0	2	10	3	0	0	0	1	3	0	0	25
1981	0	0	0	0	0	4	3	0	0	0	6	0	13
1982	0	0	0	6	11	0	4	0	0	0	0	3	24
1983	7	3	10	0	0	0	4	5	0	0	0	0	29
1984	0	0	0	0	0	0	0	0	0	3	6	0	9
1985	0	0	15	0	0	0	0	0	0	3	11	0	29
1986	0	0	0	0	13	0	6	0	0	0	8	0	27
1987	0	0	10	0	0	0	3	0	0	0	4	10	27
1988	1	0	0	0	0	7	0	0	1	0	0	0	9
1989	1	2	2	2	6	0	4	0	0	0	0	0	17
1990	0	6	14	1	0	0	4	0	3	0	0	0	28
1991	6	0	0	11	0	0	6	0	0	0	7	4	34
1992	0	0	5	0	0	0	4	0	0	0	0	10	19

1993	0	0	9	0	0	0	2	0	0	0	0	0	11
1994	0	7	10	0	5	0	3	0	4	2	0	7	38
1995	0	0	7	0	0	0	0	4	0	0	0	5	16
1996	0	0	0	0	0	0	0	3	0	0	0	7	10
1997	4	0	5	0	0	0	4	0	0	0	0	7	20
1998	0	0	5	0	0	0	0	3	2	1	9	0	20
1999	0	0	0	6	7	0	0	1	0	0	0	0	14
2000	0	0	0	0	0	2	4	0	0	0	1	0	7
2001	0	0	5	0	0	0	2	2	0	0	5	0	14
2002	0	0	0	0	10	0	3	0	0	0	7	0	20
2003	0	0	0	0	0	7	6	2	0	0	6	0	21
2004	8	0	9	2	0	0	3	0	0	0	6	0	28
2005	0	0	0	0	0	0	0	4	0	0	0	0	4
2006	0	0	3	0	0	0	0	0	2	0	4	0	9
2007	0	0	6	0	0	0	2	0	0	0	0	0	8
2008	0	0	12	0	0	0	0	4	0	0	0	0	16
2009	0	0	4	1	0	0	2	0	0	0	6	0	13
2010	0	0	0	3	0	0	7	0	0	0	0	0	10
2011	5	2	0	0	0	0	0	0	0	1	0	4	12
2012	0	0	1	0	0	0	3	0	0	0	0	0	4
TOTAL	58	29	299	147	93	33	200	43	20	18	211	153	1304

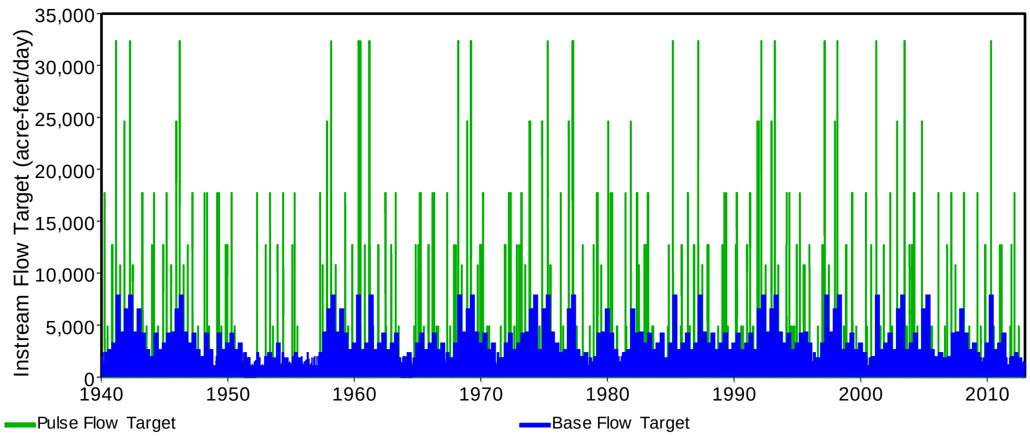

Figure 6.1 Daily BBASC Instream Flow Target at Richmond

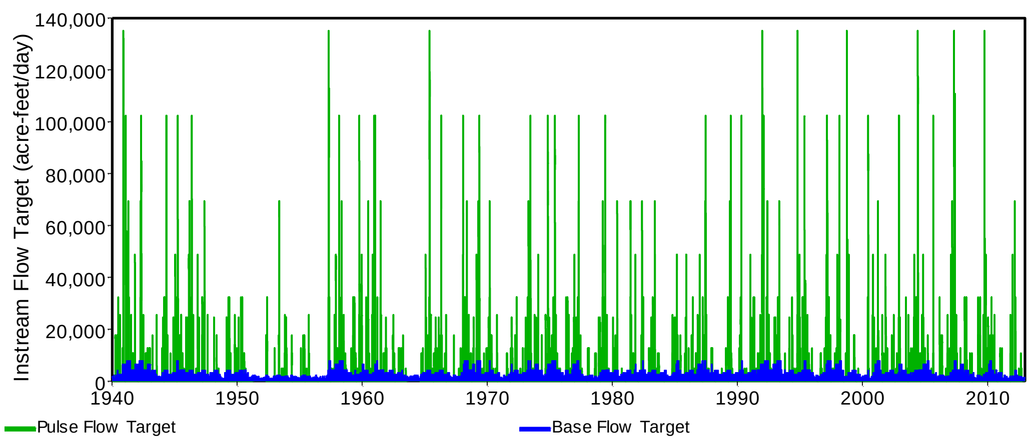

Figure 6.2 Daily BBEST Instream Flow Target at Richmond

Daily instream flow *IF* record targets for the BBASC and BBEST recommendations at Richmond are illustrated in Figures 6.1 and 6.2, respectively. The base flow component of the daily instream flow *IF* record target is shown in blue. The pulse flow component of the daily instream flow *IF* record target is shown in green. Both recommendation figures have a similar blue base flow line. The base flow limits are identical for the BBASC and BBEST recommendations. However, the BBASC utilizes a once per season establishment of the hydrologic condition whereas the BBEST sets the hydrologic condition and corresponding base flow limit each month.

The primary difference between the plots of daily instream flow targets is the smaller magnitude and frequency of pulse flow targets in the BBASC recommendation. The largest pulse target magnitude in the BBASC recommendation at Richmond is 32,331 acre-feet per day for a 2 per spring pulse under wet hydrologic conditions. The largest pulse target magnitude in the BBEST recommendation is 135,074 ac-ft per day for a once per 2 year overbanking event.

Daily regulated flow and daily instream flow *IF* record targets for the BBASC recommendation at the Seymour, Cameron, Waco, and Richmond locations are shown in Figures 6.3 through 6.6. The year 1987 was selected for illustration because it contains an inbank pulse event in March, an overbanking flood event in June, and a low flow period in October and November. The upper basin hydrologic condition is wet throughout 1987 at the Seymour location. The lower basin hydrologic condition is average in the winter months and wet in the spring and summer season months at the Cameron, Waco, and Richmond locations.

No winter pulses are initiated at the locations in January or February. The winter season pulse events were met in November and December 1986. As listed for wet hydrologic conditions in Table 5.12, a one per spring pulse at Seymour is met in March, one of the two per spring pulses is met at Cameron in March, and both two per spring pulses at Waco and Richmond are satisfied. The second spring pulse at Cameron is initiated at the start of the flood event that begins on May 29. No winter pulses are initiated at Seymour in November and December 1987. Two of the three average condition winter pulses are satisfied at Cameron in November and December. One of the three average condition winter pulses is satisfied at Waco in December 1987. All three average condition winter pulses are satisfied at Richmond in November and December 1987.

Base flow targets are set independently of the daily regulated flow. It is expected that instream flow shortages will be incurred when regulated flow falls below the base flow limit, either by natural daily flow variability or by stream flow depletions of upstream senior water rights. Pulse flow targets, however, are set only when the daily regulated flow initiates a pulse event. Pulse targets are set not to exceed either the trigger flow criterion or the magnitude of the regulated flow at the priority of the *WR* or *IF* record associated with the *PF* record. Therefore, no instream flow shortages for targets set by *PF* records will occur unless an upstream junior water right violates the instream flow requirement set by the *IF* record.

The only junior water rights in the ED simulation that do not consider the downstream senior instream flow *IF* records of the BBEST or BBASC recommendations are the flood control reservoir *FR* records. All flood control reservoirs use *FR* field 6 option 2. Option 2 allows for circumvention of the standard water availability computation that considers the passage of flow for downstream senior water rights. With option 2, flood control reservoirs may deplete all regulated flow at their control point except for reservoir releases for water supply purposes.

A flood event begins on May 29, 1987 at the Cameron gage. Regulated flow reaches flood flow limits at the Hempstead and Richmond gages in the first week of June. In response to forecasted flood conditions at Cameron, Hempstead, and Richmond, the flood control reservoirs upstream of Cameron and elsewhere in the basin begin to impound stream flow in flood control storage. The regulated flow at the Cameron gage is reduced to zero by the flood control storages made by flood control operations at Georgetown and Granger on May 29 as a result of the routing factor array providing same day routing effects from these two reservoirs down to the Cameron gage. The *PF* record initiated a high flow pulse event on May 29 and set a daily target. However, the junior flood control operations ignored the downstream instream flow requirement and reduced regulated flow. The instream flow shortage on May 29 at the Cameron location in Figure 6.4 is an example of the only manner in which instream flow shortages can occur for pulse flow events. If flood control reservoirs were not modeled with the option to ignore downstream water availability computations, no pulse flow instream flow shortages would occur.

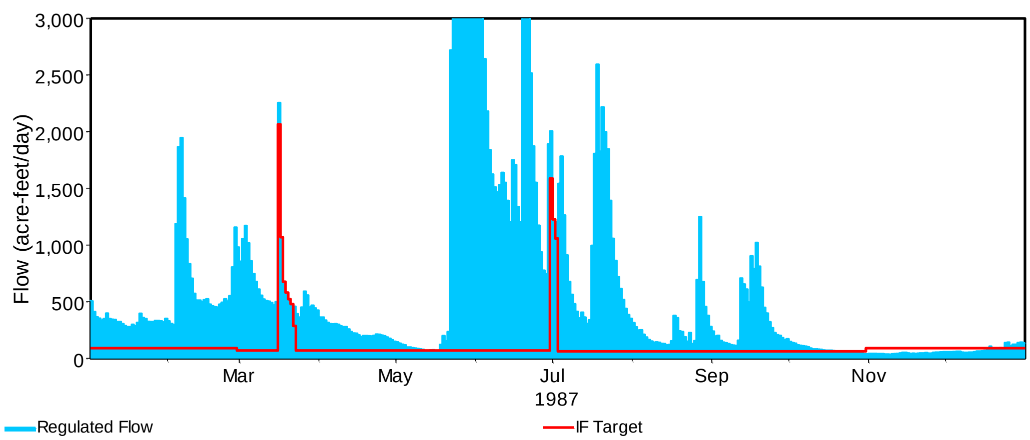

Figure 6.3 Daily Regulated Flow and BBASC Instream Flow Target at Seymour

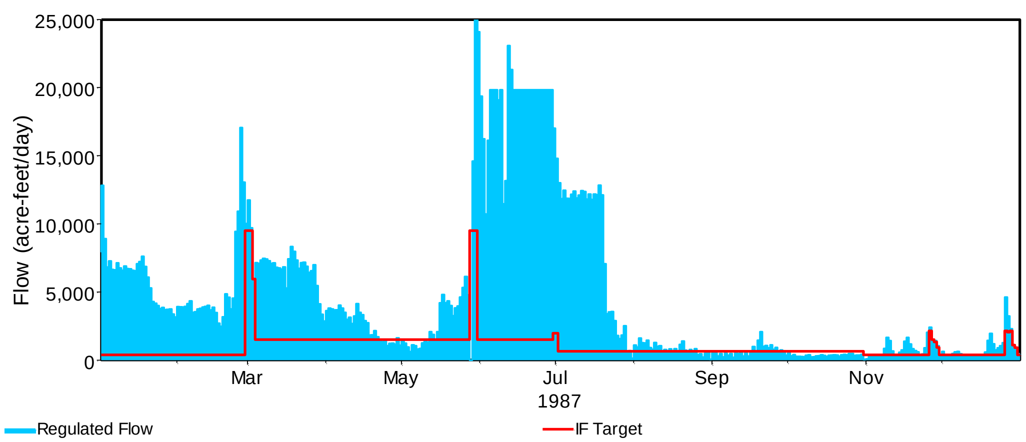

Figure 6.4 Daily Regulated Flow and BBASC Instream Flow Target at Cameron

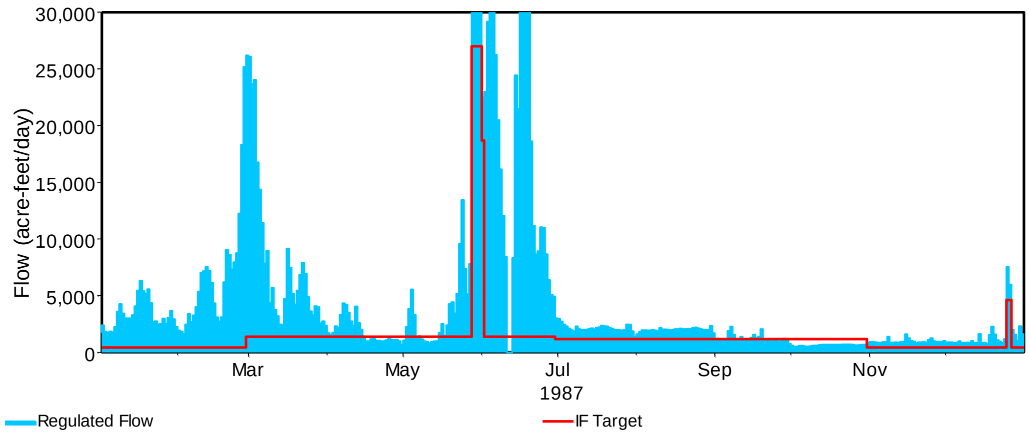

Figure 6.5 Daily Regulated Flow and BBASC Instream Flow Target at Waco

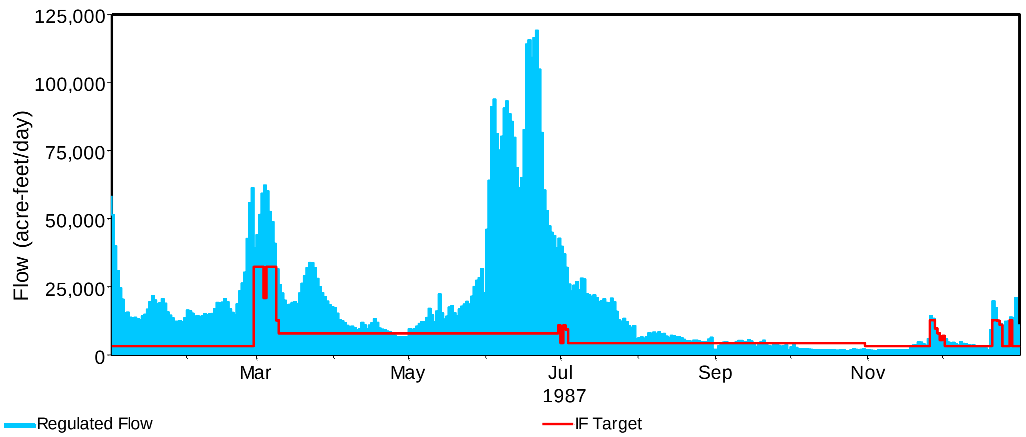

Figure 6.6 Daily Regulated Flow and BBASC Instream Flow Target at Richmond

<u>Daily *SIMD* Monthly Instream Flow Targets As Input to Monthly *SIM*</u>

Capturing variability of regulated flows is important in building pulse flow targets. Base flow targets may be set independently of regulated flow. However, daily fluctuations in regulated flow can result in the difference in setting or not setting subsistence and high flow pulse targets. As such, the ED model is better suited for building daily instream flow targets that reflect the regulated flow variability of the stream reach. The methodology recommended in this report is to use the ED model to build daily instream flow targets at the 19 locations. The monthly aggregated BBASC instream flow targets developed in the ED model are then input as target series *TS* records into the EM model.

Tables 6.21 through 6.24 each contain three time series. The first time series in each table is the total monthly instream flow target developed in the ED model for the BBASC recommendations, which is provided as *TS* record input to the EM model using a target series TSF file. The second time series in each table is the monthly aggregated subsistence and base flow targets. The third time series in each table is the monthly aggregated pulse flow target.

Table 6.21
Brazos River near Seymour
BBASC Instream Flow *IF* Record Targets and Intermediate Base Flow and Pulse Flow Targets

MONTHLY INSTREAM FLOW TARGETS (AC-FT) – BRAZOS RIVER NEAR SEYMOUR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	61.	229.	61.	1274.	291.	399.	3031.	799.	774.	799.	1487.	1537.	10744.
1941	1537.	1388.	6356.	2082.	2152.	2082.	5016.	1969.	1905.	1969.	2736.	2828.	32019.
1942	2828.	2554.	2152.	6940.	2152.	2082.	5261.	1969.	1905.	1969.	2736.	2828.	35374.
1943	2828.	2554.	2152.	6058.	2152.	2082.	3158.	799.	774.	799.	74.	468.	23898.
1944	578.	575.	1168.	1130.	5461.	1130.	2216.	799.	774.	799.	1487.	1537.	17656.
1945	1537.	1388.	3452.	1130.	1168.	3727.	2660.	799.	774.	799.	1487.	1537.	20459.
1946	1537.	1388.	1168.	1130.	2242.	3356.	2216.	799.	774.	799.	1487.	1537.	18434.
1947	1537.	1388.	1168.	1130.	4596.	1130.	799.	799.	774.	799.	440.	615.	15176.
1948	481.	464.	3652.	1130.	3042.	1343.	2924.	799.	774.	799.	1487.	1537.	18434.
1949	1537.	1388.	1168.	1130.	3315.	1130.	799.	799.	2190.	799.	1487.	1537.	17282.
1950	1537.	1388.	1168.	3277.	3315.	1130.	2609.	799.	774.	799.	1487.	1537.	19821.
1951	1537.	1388.	431.	374.	2558.	418.	930.	165.	224.	61.	110.	99.	8295.
1952	156.	245.	174.	209.	1441.	232.	913.	85.	65.	61.	167.	258.	4007.
1953	61.	323.	348.	173.	2179.	84.	909.	245.	169.	233.	595.	615.	5934.
1954	615.	435.	177.	1394.	431.	418.	175.	61.	60.	61.	183.	265.	4274.
1955	425.	371.	2428.	329.	431.	418.	1758.	245.	180.	245.	595.	615.	8039.
1956	615.	575.	431.	371.	1528.	352.	69.	106.	60.	1097.	135.	185.	5524.
1957	103.	493.	369.	2630.	431.	418.	5180.	1969.	1905.	1969.	2736.	2828.	21031.
1958	2828.	2554.	2152.	2082.	6682.	2082.	4876.	1969.	1905.	1969.	1487.	1537.	32122.
1959	1537.	1388.	122.	304.	405.	2612.	1697.	245.	110.	233.	1487.	1537.	11678.
1960	1537.	1438.	2152.	2082.	2152.	2082.	2924.	799.	774.	799.	1487.	1537.	19763.
1961	1537.	1388.	2152.	2082.	4145.	2082.	5016.	1969.	1905.	1969.	2736.	2828.	29809.
1962	2828.	2554.	1168.	2706.	1597.	3846.	2794.	799.	774.	799.	1487.	1537.	22890.
1963	1537.	1388.	2242.	3688.	1168.	1130.	799.	799.	2190.	799.	595.	615.	16951.
1964	576.	575.	1168.	1130.	1168.	5408.	97.	91.	1426.	208.	369.	422.	12639.
1965	415.	289.	1168.	3277.	2242.	1130.	799.	2809.	774.	799.	1487.	1537.	16726.
1966	1537.	1388.	1168.	5073.	1168.	1130.	799.	2290.	774.	799.	1487.	1537.	19152.
1967	1537.	1388.	431.	1515.	431.	418.	971.	245.	237.	245.	586.	615.	8619.
1968	615.	575.	3436.	1130.	1168.	1130.	5557.	1969.	1905.	1969.	1487.	1537.	22479.
1969	1537.	1388.	1168.	1130.	4328.	1130.	1969.	1969.	3429.	1969.	2736.	2828.	25581.
1970	2828.	2554.	3905.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	18911.
1971	1537.	1388.	257.	178.	1198.	418.	152.	2016.	237.	245.	1487.	1537.	10651.
1972	1537.	1438.	1168.	1130.	3517.	3040.	3022.	799.	774.	799.	1487.	1537.	20249.
1973	1537.	1388.	4145.	2082.	2152.	2082.	1969.	1969.	4952.	1969.	2736.	2828.	29809.
1974	2828.	2554.	1168.	1130.	1168.	3565.	104.	842.	233.	245.	2736.	2828.	19401.
1975	2828.	2554.	2152.	2082.	4145.	2082.	3492.	1969.	1905.	1969.	2736.	2828.	30741.
1976	2828.	2645.	1168.	5163.	1168.	1130.	3923.	799.	774.	799.	1487.	1537.	23423.
1977	1537.	1388.	1168.	5096.	1168.	1130.	799.	2216.	926.	799.	197.	274.	16700.
1978	538.	504.	407.	150.	1992.	349.	109.	971.	237.	245.	595.	615.	6711.
1979	615.	555.	1168.	1130.	6102.	1130.	2383.	799.	774.	799.	1487.	1537.	18481.
1980	1537.	1438.	1168.	1130.	3836.	1130.	799.	799.	3152.	799.	1487.	1537.	18815.
1981	1537.	1388.	1168.	5293.	1168.	1130.	799.	2765.	774.	799.	1487.	1537.	19847.
1982	1537.	1388.	1168.	1130.	3315.	1130.	4750.	1969.	1905.	1969.	1487.	1537.	23286.
1983	1537.	1388.	1168.	1130.	3315.	1130.	799.	799.	774.	3103.	1487.	1537.	18169.
1984	1537.	1438.	1168.	1130.	1168.	1130.	115.	177.	1747.	245.	1487.	1537.	12880.
1985	1537.	1388.	2152.	4776.	2152.	2082.	4483.	1969.	1905.	1969.	2736.	2828.	29976.
1986	2828.	2554.	1168.	3273.	1624.	3277.	2246.	799.	774.	799.	2736.	2828.	24905.
1987	2828.	2554.	7344.	2082.	2152.	2082.	5650.	1969.	1905.	1969.	2736.	2828.	36098.
1988	2828.	2645.	1168.	1130.	1168.	1130.	2924.	799.	774.	799.	1487.	1537.	18391.
1989	1537.	1388.	1168.	1130.	3315.	1130.	799.	799.	2190.	799.	1487.	1537.	17282.
1990	1537.	1388.	5385.	1130.	1168.	1130.	2278.	1800.	774.	799.	1487.	1537.	20415.
1991	1537.	1388.	1168.	1130.	3315.	1130.	799.	2346.	774.	799.	2736.	2828.	19951.
1992	2828.	2645.	7578.	2082.	2152.	2082.	4941.	1969.	1905.	1969.	2736.	2828.	35715.
1993	2828.	2554.	6139.	2082.	2152.	2082.	1969.	1969.	1905.	1969.	2736.	2828.	31212.

1994	2828.	2554.	1168.	1130.	3315.	1130.	799.	1941.	1482.	799.	1487.	1537.	20171.
1995	1537.	1388.	1168.	1130.	5957.	1130.	2216.	1508.	774.	799.	2736.	2828.	23172.
1996	2828.	2645.	1168.	1130.	1168.	5058.	1638.	199.	237.	245.	1487.	1537.	19341.
1997	1537.	1388.	2152.	6044.	2152.	2082.	5710.	1969.	1905.	1969.	2736.	2828.	32471.
1998	2828.	2554.	6007.	2082.	2152.	2082.	799.	1983.	774.	1508.	327.	571.	23666.
1999	615.	186.	2513.	331.	431.	418.	799.	799.	3490.	799.	1487.	1537.	13406.
2000	1537.	1438.	431.	2795.	334.	418.	2036.	799.	774.	1806.	595.	615.	13576.
2001	615.	555.	5599.	2082.	2152.	2082.	799.	799.	774.	799.	1487.	1537.	19281.
2002	1537.	1388.	2349.	3346.	1168.	1130.	2216.	799.	774.	799.	1487.	1537.	18532.
2003	1537.	1388.	1168.	1130.	1168.	3877.	799.	799.	774.	799.	1487.	1537.	16465.
2004	1537.	1438.	6260.	1130.	1168.	1130.	2216.	799.	774.	799.	2736.	2828.	22816.
2005	2828.	2554.	2152.	2082.	5494.	2082.	1969.	3492.	1905.	1969.	1487.	1537.	29551.
2006	1537.	1388.	349.	373.	1335.	198.	195.	971.	196.	186.	369.	615.	7712.
2007	484.	454.	3688.	1130.	1168.	1130.	5857.	1969.	1905.	1969.	2736.	2828.	25320.
2008	2828.	2645.	1168.	1130.	2971.	2986.	2719.	1508.	774.	799.	1487.	1537.	22553.
2009	1537.	1388.	431.	418.	3049.	418.	950.	144.	234.	85.	1487.	1537.	11678.
2010	1537.	1388.	3064.	3277.	1168.	1130.	2756.	799.	774.	799.	1487.	1537.	19718.
2011	1537.	1388.	1168.	1130.	1168.	2359.	104.	61.	60.	157.	526.	615.	10274.
2012	615.	518.	389.	258.	317.	2612.	197.	102.	237.	245.	163.	298.	5951.
MEAN	1588.	1452.	1983.	1892.	2180.	1608.	2107.	1171.	1130.	989.	1519.	1591.	19212.

MONTHLY BASE FLOW TARGETS (AC-FT) – BRAZOS RIVER NEAR SEYMOUR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	61.	229.	61.	177.	291.	399.	799.	799.	774.	799.	1487.	1537.	7415.
1941	1537.	1388.	2152.	2082.	2152.	2082.	1969.	1969.	1905.	1969.	2736.	2828.	24768.
1942	2828.	2554.	2152.	2082.	2152.	2082.	1969.	1969.	1905.	1969.	2736.	2828.	27224.
1943	2828.	2554.	2152.	2082.	2152.	2082.	799.	799.	774.	799.	74.	468.	17564.
1944	578.	575.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	11947.
1945	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	13719.
1946	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	13719.
1947	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	440.	615.	11749.
1948	481.	464.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	11739.
1949	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	13719.
1950	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	13719.
1951	1537.	1388.	431.	374.	364.	418.	203.	165.	224.	61.	110.	99.	5375.
1952	156.	245.	174.	209.	344.	232.	186.	85.	65.	61.	167.	258.	2184.
1953	61.	323.	348.	173.	236.	84.	183.	245.	169.	233.	595.	615.	3266.
1954	615.	435.	177.	297.	431.	418.	175.	61.	60.	61.	183.	265.	3177.
1955	425.	371.	233.	329.	431.	418.	245.	245.	180.	245.	595.	615.	4332.
1956	615.	575.	431.	371.	431.	352.	69.	106.	60.	148.	135.	185.	3478.
1957	103.	493.	369.	315.	431.	418.	1969.	1969.	1905.	1969.	2736.	2828.	15505.
1958	2828.	2554.	2152.	2082.	2152.	2082.	1969.	1969.	1905.	1969.	1487.	1537.	24685.
1959	1537.	1388.	122.	304.	405.	418.	245.	245.	110.	233.	1487.	1537.	8032.
1960	1537.	1438.	2152.	2082.	2152.	2082.	799.	799.	774.	799.	1487.	1537.	17639.
1961	1537.	1388.	2152.	2082.	2152.	2082.	1969.	1969.	1905.	1969.	2736.	2828.	24768.
1962	2828.	2554.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	16175.
1963	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	595.	615.	11904.
1964	576.	575.	1168.	1130.	1168.	1130.	97.	91.	163.	208.	369.	422.	7099.
1965	415.	289.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	11497.
1966	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	13719.
1967	1537.	1388.	431.	418.	431.	418.	245.	245.	237.	245.	586.	615.	6796.
1968	615.	575.	1168.	1130.	1168.	1130.	1969.	1969.	1905.	1969.	1487.	1537.	16622.
1969	1537.	1388.	1168.	1130.	1168.	1130.	1969.	1969.	1905.	1969.	2736.	2828.	20898.
1970	2828.	2554.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	16175.
1971	1537.	1388.	257.	178.	101.	418.	152.	245.	237.	245.	1487.	1537.	7783.
1972	1537.	1438.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	13768.
1973	1537.	1388.	2152.	2082.	2152.	2082.	1969.	1969.	1905.	1969.	2736.	2828.	24768.
1974	2828.	2554.	1168.	1130.	1168.	1130.	104.	116.	221.	245.	2736.	2828.	16229.
1975	2828.	2554.	2152.	2082.	2152.	2082.	1969.	1969.	1905.	1969.	2736.	2828.	27224.
1976	2828.	2645.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	16266.

1977	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	197.	274.	11166.
1978	538.	504.	407.	150.	259.	349.	109.	245.	237.	245.	595.	615.	4252.
1979	615.	555.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	11963.
1980	1537.	1438.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	13768.
1981	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	13719.
1982	1537.	1388.	1168.	1130.	1168.	1130.	1969.	1969.	1905.	1969.	1487.	1537.	18358.
1983	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	13719.
1984	1537.	1438.	1168.	1130.	1168.	1130.	115.	177.	144.	245.	1487.	1537.	11277.
1985	1537.	1388.	2152.	2082.	2152.	2082.	1969.	1969.	1905.	1969.	2736.	2828.	24768.
1986	2828.	2554.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	2736.	2828.	18715.
1987	2828.	2554.	2152.	2082.	2152.	2082.	1969.	1969.	1905.	1969.	2736.	2828.	27224.
1988	2828.	2645.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	16266.
1989	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	13719.
1990	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	13719.
1991	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	2736.	2828.	16258.
1992	2828.	2645.	2152.	2082.	2152.	2082.	1969.	1969.	1905.	1969.	2736.	2828.	27316.
1993	2828.	2554.	2152.	2082.	2152.	2082.	1969.	1969.	1905.	1969.	2736.	2828.	27224.
1994	2828.	2554.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	16175.
1995	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	2736.	2828.	16258.
1996	2828.	2645.	1168.	1130.	1168.	1130.	196.	199.	237.	245.	1487.	1537.	13971.
1997	1537.	1388.	2152.	2082.	2152.	2082.	1969.	1969.	1905.	1969.	2736.	2828.	24768.
1998	2828.	2554.	2152.	2082.	2152.	2082.	799.	799.	774.	799.	327.	571.	17919.
1999	615.	186.	254.	331.	431.	418.	799.	799.	774.	799.	1487.	1537.	8430.
2000	1537.	1438.	431.	351.	334.	418.	799.	799.	774.	799.	595.	615.	8889.
2001	615.	555.	2152.	2082.	2152.	2082.	799.	799.	774.	799.	1487.	1537.	15834.
2002	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	13719.
2003	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	13719.
2004	1537.	1438.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	2736.	2828.	16308.
2005	2828.	2554.	2152.	2082.	2152.	2082.	1969.	1969.	1905.	1969.	1487.	1537.	24685.
2006	1537.	1388.	349.	373.	238.	198.	195.	245.	196.	186.	369.	615.	5889.
2007	484.	454.	1168.	1130.	1168.	1130.	1969.	1969.	1905.	1969.	2736.	2828.	18911.
2008	2828.	2645.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	16266.
2009	1537.	1388.	431.	418.	253.	418.	224.	144.	234.	85.	1487.	1537.	8157.
2010	1537.	1388.	1168.	1130.	1168.	1130.	799.	799.	774.	799.	1487.	1537.	13719.
2011	1537.	1388.	1168.	1130.	1168.	1130.	104.	61.	60.	157.	526.	615.	9045.
2012	615.	518.	389.	258.	317.	418.	197.	102.	237.	245.	163.	298.	3757.
MEAN	1588.	1452.	1184.	1145.	1190.	1161.	916.	916.	888.	921.	1519.	1591.	14473.

MONTHLY PULSE FLOW TARGETS (AC-FT) – BRAZOS RIVER NEAR SEYMOUR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0.	0.	0.	1111.	0.	0.	2360.	0.	0.	0.	0.	0.	3471.
1941	0.	0.	4412.	0.	0.	0.	3174.	0.	0.	0.	0.	0.	7586.
1942	0.	0.	0.	5135.	0.	0.	3483.	0.	0.	0.	0.	0.	8618.
1943	0.	0.	0.	4115.	0.	0.	2557.	0.	0.	0.	0.	0.	6672.
1944	0.	0.	0.	0.	4444.	0.	1468.	0.	0.	0.	0.	0.	5912.
1945	0.	0.	2397.	0.	0.	2709.	1964.	0.	0.	0.	0.	0.	7070.
1946	0.	0.	0.	0.	1111.	2338.	1468.	0.	0.	0.	0.	0.	4917.
1947	0.	0.	0.	0.	3578.	0.	0.	0.	0.	0.	0.	0.	3578.
1948	0.	0.	2597.	0.	2062.	251.	2202.	0.	0.	0.	0.	0.	7112.
1949	0.	0.	0.	0.	2222.	0.	0.	0.	1468.	0.	0.	0.	3690.
1950	0.	0.	0.	2222.	2222.	0.	1887.	0.	0.	0.	0.	0.	6331.
1951	0.	0.	0.	0.	2222.	0.	734.	0.	0.	0.	0.	0.	2956.
1952	0.	0.	0.	0.	1111.	0.	734.	0.	0.	0.	0.	0.	1845.
1953	0.	0.	0.	0.	1984.	0.	734.	0.	0.	0.	0.	0.	2718.
1954	0.	0.	0.	1111.	0.	0.	0.	0.	0.	0.	0.	0.	1111.
1955	0.	0.	2222.	0.	0.	0.	1537.	0.	0.	0.	0.	0.	3759.
1956	0.	0.	0.	0.	1111.	0.	0.	0.	0.	964.	0.	0.	2075.
1957	0.	0.	0.	2357.	0.	0.	3401.	0.	0.	0.	0.	0.	5758.
1958	0.	0.	0.	0.	4739.	0.	3034.	0.	0.	0.	0.	0.	7773.
1959	0.	0.	0.	0.	0.	2222.	1468.	0.	0.	0.	0.	0.	3690.

1960	0.	0.	0.	0.	0.	0.	2202.	0.	0.	0.	0.	0.	2202.
1961	0.	0.	0.	0.	2063.	0.	3174.	0.	0.	0.	0.	0.	5237.
1962	0.	0.	0.	1651.	542.	2829.	2072.	0.	0.	0.	0.	0.	7094.
1963	0.	0.	1111.	2746.	0.	0.	0.	0.	1468.	0.	0.	0.	5325.
1964	0.	0.	0.	0.	0.	4466.	0.	0.	1279.	0.	0.	0.	5745.
1965	0.	0.	0.	2222.	1111.	0.	0.	2087.	0.	0.	0.	0.	5420.
1966	0.	0.	0.	4093.	0.	0.	0.	1568.	0.	0.	0.	0.	5661.
1967	0.	0.	0.	1111.	0.	0.	734.	0.	0.	0.	0.	0.	1845.
1968	0.	0.	2407.	0.	0.	0.	3842.	0.	0.	0.	0.	0.	6249.
1969	0.	0.	0.	0.	3273.	0.	0.	0.	1587.	0.	0.	0.	4860.
1970	0.	0.	2887.	0.	0.	0.	0.	0.	0.	0.	0.	0.	2887.
1971	0.	0.	0.	0.	1111.	0.	0.	1803.	0.	0.	0.	0.	2914.
1972	0.	0.	0.	0.	2462.	1985.	2326.	0.	0.	0.	0.	0.	6772.
1973	0.	0.	2063.	0.	0.	0.	0.	0.	3174.	0.	0.	0.	5237.
1974	0.	0.	0.	0.	0.	2548.	0.	734.	19.	0.	0.	0.	3301.
1975	0.	0.	0.	0.	2063.	0.	1587.	0.	0.	0.	0.	0.	3650.
1976	0.	0.	0.	4184.	0.	0.	3252.	0.	0.	0.	0.	0.	7436.
1977	0.	0.	0.	4116.	0.	0.	0.	1468.	178.	0.	0.	0.	5763.
1978	0.	0.	0.	0.	1761.	0.	0.	734.	0.	0.	0.	0.	2495.
1979	0.	0.	0.	0.	5123.	0.	1661.	0.	0.	0.	0.	0.	6784.
1980	0.	0.	0.	0.	2781.	0.	0.	0.	2533.	0.	0.	0.	5314.
1981	0.	0.	0.	4388.	0.	0.	0.	2043.	0.	0.	0.	0.	6431.
1982	0.	0.	0.	0.	2222.	0.	2908.	0.	0.	0.	0.	0.	5130.
1983	0.	0.	0.	0.	2222.	0.	0.	0.	0.	2494.	0.	0.	4716.
1984	0.	0.	0.	0.	0.	0.	0.	0.	1626.	0.	0.	0.	1626.
1985	0.	0.	0.	2833.	0.	0.	2641.	0.	0.	0.	0.	0.	5474.
1986	0.	0.	0.	2293.	531.	2222.	1524.	0.	0.	0.	0.	0.	6569.
1987	0.	0.	5679.	0.	0.	0.	3871.	0.	0.	0.	0.	0.	9550.
1988	0.	0.	0.	0.	0.	0.	2205.	0.	0.	0.	0.	0.	2205.
1989	0.	0.	0.	0.	2222.	0.	0.	0.	1468.	0.	0.	0.	3690.
1990	0.	0.	4406.	0.	0.	0.	1556.	1052.	0.	0.	0.	0.	7013.
1991	0.	0.	0.	0.	2222.	0.	0.	1624.	0.	0.	0.	0.	3846.
1992	0.	0.	5704.	0.	0.	0.	3100.	0.	0.	0.	0.	0.	8804.
1993	0.	0.	4126.	0.	0.	0.	0.	0.	0.	0.	0.	0.	4126.
1994	0.	0.	0.	0.	2222.	0.	0.	1219.	734.	0.	0.	0.	4175.
1995	0.	0.	0.	0.	5053.	0.	1484.	734.	0.	0.	0.	0.	7270.
1996	0.	0.	0.	0.	0.	4267.	1474.	0.	0.	0.	0.	0.	5741.
1997	0.	0.	0.	4100.	0.	0.	3932.	0.	0.	0.	0.	0.	8032.
1998	0.	0.	3994.	0.	0.	0.	0.	1286.	0.	734.	0.	0.	6014.
1999	0.	0.	2301.	0.	0.	0.	0.	0.	2871.	0.	0.	0.	5172.
2000	0.	0.	0.	2500.	0.	0.	1288.	0.	0.	1058.	0.	0.	4846.
2001	0.	0.	3587.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3587.
2002	0.	0.	1257.	2329.	0.	0.	1468.	0.	0.	0.	0.	0.	5053.
2003	0.	0.	0.	0.	0.	2859.	0.	0.	0.	0.	0.	0.	2859.
2004	0.	0.	5318.	0.	0.	0.	1468.	0.	0.	0.	0.	0.	6786.
2005	0.	0.	0.	0.	3690.	0.	0.	1587.	0.	0.	0.	0.	5277.
2006	0.	0.	0.	0.	1111.	0.	0.	734.	0.	0.	0.	0.	1845.
2007	0.	0.	2640.	0.	0.	0.	4143.	0.	0.	0.	0.	0.	6783.
2008	0.	0.	0.	0.	1879.	1931.	2048.	734.	0.	0.	0.	0.	6592.
2009	0.	0.	0.	0.	2851.	0.	734.	0.	0.	0.	0.	0.	3585.
2010	0.	0.	1971.	2222.	0.	0.	2034.	0.	0.	0.	0.	0.	6227.
2011	0.	0.	0.	0.	0.	1304.	0.	0.	0.	0.	0.	0.	1304.
2012	0.	0.	0.	0.	0.	2222.	0.	0.	0.	0.	0.	0.	2222.
MEAN	0.	0.	837.	779.	1032.	468.	1246.	266.	252.	72.	0.	0.	4950.

Table 6.22
Little River near Cameron
BBASC Instream Flow *IF* Record Targets and Intermediate Base Flow and Pulse Flow Targets

MONTHLY INSTREAM FLOW TARGETS (AC-FT) – LITTLE RIVER NEAR CAMERON

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	2748.	7799.	5157.	19683.	6456.	6729.	12220.	9839.	9521.	9839.	21312.	11683.	122985.
1941	11683.	10552.	87806.	45223.	46731.	45223.	22909.	20290.	19635.	20290.	27373.	28285.	386000.
1942	28285.	25548.	46731.	82733.	46731.	45223.	22909.	20290.	19635.	20290.	43067.	28285.	429726.
1943	28285.	25548.	33533.	32189.	19060.	18446.	10811.	9839.	9521.	9839.	3881.	5040.	205991.
1944	10612.	6018.	41989.	18446.	19060.	18446.	12220.	9839.	9521.	9839.	18031.	11683.	185702.
1945	11683.	10552.	44402.	18446.	19060.	18446.	24415.	20290.	19635.	20290.	27373.	41945.	276538.
1946	28285.	25548.	94692.	45223.	46731.	45223.	20290.	20290.	23838.	20290.	16602.	11683.	398695.
1947	11683.	10552.	47946.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	2600.	3965.	171735.
1948	3366.	4705.	21062.	18446.	19060.	18446.	12874.	9839.	9521.	9839.	1927.	2181.	131266.
1949	6650.	2838.	19060.	49452.	19060.	18446.	11329.	9839.	9521.	9839.	11306.	11683.	179023.
1950	11683.	17613.	19060.	46145.	19060.	18446.	13759.	9839.	9521.	9839.	11306.	11683.	197954.
1951	11683.	10552.	3048.	2669.	5946.	15208.	1976.	1968.	3287.	1970.	1927.	1985.	62220.
1952	1968.	1891.	2010.	3405.	14491.	5562.	4228.	1968.	1905.	1968.	4138.	3069.	46604.
1953	3915.	3120.	3406.	9541.	18047.	5703.	3310.	2694.	5083.	3677.	14836.	15213.	88544.
1954	11683.	10552.	2790.	2125.	4657.	1909.	1968.	1968.	2160.	1980.	3054.	1968.	46816.
1955	2179.	6448.	3332.	5249.	26487.	7371.	4667.	3972.	3277.	2925.	1953.	2345.	70205.
1956	1968.	2589.	1968.	1974.	3653.	2988.	1968.	2388.	1905.	2028.	6906.	3573.	33910.
1957	2200.	2113.	4912.	25265.	7560.	8331.	22909.	20290.	19635.	20290.	47698.	28285.	209489.
1958	28285.	25548.	78705.	45223.	46731.	45223.	24962.	20290.	19635.	20290.	27373.	28285.	410549.
1959	28285.	30580.	19060.	33268.	27294.	18446.	12302.	9839.	9521.	9839.	16602.	11683.	226718.
1960	11683.	10929.	46731.	45223.	46731.	45223.	9839.	9839.	10315.	11426.	16602.	11683.	276222.
1961	11683.	10552.	85686.	45223.	46731.	45223.	12220.	9839.	9521.	9839.	16602.	15213.	318331.
1962	11683.	10552.	19060.	30185.	19690.	34548.	11607.	9839.	10315.	9839.	16602.	11683.	195602.
1963	11683.	10552.	19060.	18446.	19060.	18446.	5026.	1974.	2884.	2490.	4217.	2334.	116172.
1964	3740.	4899.	7520.	6994.	8463.	24785.	6123.	3928.	3743.	5964.	19442.	11683.	107284.
1965	13448.	10552.	19060.	58535.	21296.	18446.	12220.	9839.	9521.	9839.	18869.	11683.	213308.
1966	11683.	10552.	19060.	41374.	19060.	18446.	11448.	12220.	9521.	9839.	11306.	11683.	186193.
1967	11683.	10552.	7568.	6788.	20432.	2856.	5918.	3153.	4289.	3340.	16602.	11683.	104863.
1968	11683.	10929.	86698.	45223.	46731.	45223.	25528.	20290.	19635.	20290.	35132.	33182.	400545.
1969	28285.	25548.	68058.	69204.	46731.	45223.	20290.	22977.	19635.	21599.	12775.	16403.	396728.
1970	15213.	10552.	49056.	18446.	19060.	18446.	9839.	9839.	12921.	9839.	11306.	11683.	196199.
1971	11683.	10552.	7535.	7496.	16320.	3360.	5103.	5603.	3308.	4584.	13329.	17229.	106102.
1972	11683.	10929.	19060.	18446.	19060.	32982.	10823.	9839.	9521.	11426.	19653.	11683.	185105.
1973	11683.	10552.	37361.	38080.	19060.	18446.	24445.	20290.	19635.	20290.	39482.	28285.	287610.
1974	28285.	25548.	46731.	45223.	64902.	45223.	9839.	12220.	9521.	9839.	35440.	28285.	361054.
1975	28285.	25548.	46731.	70538.	69666.	45223.	22909.	20290.	19635.	20290.	11306.	11683.	392105.
1976	11683.	10929.	6741.	19958.	8608.	8331.	13013.	9839.	9521.	9839.	35731.	38564.	182757.
1977	28285.	25548.	46731.	79250.	46731.	45223.	9839.	9839.	9521.	9839.	4022.	4222.	319048.
1978	3994.	4430.	4805.	4516.	5426.	4770.	3089.	3623.	2595.	2308.	3857.	2190.	45604.
1979	10415.	5874.	50740.	18446.	19060.	18446.	24218.	20290.	19635.	20290.	27373.	28285.	263072.
1980	28285.	26460.	34462.	18446.	48157.	18446.	9839.	9839.	9521.	9839.	3324.	3941.	220558.
1981	4090.	5560.	8235.	7436.	24073.	8117.	12539.	9839.	9521.	9839.	27373.	28285.	154906.
1982	28285.	25548.	19060.	38634.	36257.	18446.	22416.	20290.	19635.	20290.	11306.	11683.	271851.
1983	11683.	18678.	37927.	18446.	48162.	18446.	9839.	13482.	9521.	9839.	11306.	11683.	219011.
1984	11683.	10929.	19060.	18446.	19060.	18446.	2887.	2203.	2418.	6592.	11306.	18744.	141774.
1985	11683.	10552.	62520.	45223.	46731.	45223.	11342.	9839.	9521.	11863.	19229.	11683.	295409.
1986	11683.	10552.	19060.	18446.	19060.	61226.	9839.	9839.	11902.	9839.	21433.	11683.	214562.
1987	11683.	10552.	75154.	45223.	70711.	45223.	22909.	20290.	19635.	20290.	15702.	18157.	375530.
1988	11683.	10929.	19060.	18446.	19060.	38178.	9839.	9839.	9521.	9839.	11306.	11683.	179383.
1989	11683.	10552.	19060.	18446.	45510.	37410.	13078.	9839.	9521.	9839.	11306.	11683.	207927.
1990	11683.	10552.	28870.	35642.	19060.	18446.	13807.	9839.	9521.	9839.	11306.	11683.	190248.
1991	18744.	10552.	19060.	58219.	19060.	18446.	11502.	11351.	11353.	9839.	27373.	44351.	259850.
1992	28285.	26460.	78705.	45223.	46731.	45223.	22909.	20290.	19635.	20290.	34999.	34950.	423701.
1993	28285.	25548.	94046.	45223.	46731.	45223.	21599.	20290.	19635.	22909.	11306.	11683.	392479.

1994	11683.	16066.	19060.	18446.	64704.	18446.	14686.	9839.	9521.	9839.	14948.	16978.	224216.
1995	11683.	10552.	51335.	18446.	19060.	18446.	21599.	22654.	19635.	20290.	11306.	11683.	236691.
1996	11683.	10929.	7816.	6260.	7397.	7596.	4225.	3622.	5121.	4763.	11306.	21979.	102698.
1997	11683.	10552.	80805.	45223.	46731.	45223.	22909.	20290.	19635.	20290.	27373.	38416.	389131.
1998	28285.	25548.	46731.	45223.	46731.	45223.	13807.	9839.	9521.	9839.	19065.	11683.	311494.
1999	11683.	10552.	19060.	18446.	19060.	18446.	11462.	9839.	9521.	9839.	11306.	11683.	160897.
2000	18744.	10929.	8394.	6203.	8608.	6548.	5835.	1968.	2059.	6937.	8470.	6764.	91460.
2001	6764.	6109.	72705.	45223.	46731.	45223.	10632.	11426.	9521.	9839.	18090.	11683.	293946.
2002	11683.	10552.	19060.	18446.	19060.	18446.	12220.	9839.	9521.	9839.	45481.	28285.	212432.
2003	28285.	25548.	46731.	45223.	46731.	45223.	9839.	9839.	11706.	10981.	18312.	11683.	310099.
2004	16567.	10929.	19060.	40738.	33349.	18446.	12220.	9839.	9521.	9839.	37370.	28285.	246164.
2005	28285.	25548.	46731.	45223.	46731.	45223.	9839.	13807.	9521.	9839.	1944.	1968.	284658.
2006	2771.	7095.	5893.	19920.	5795.	4342.	5998.	2402.	2828.	5835.	3538.	12456.	78873.
2007	6764.	2613.	52369.	18446.	19060.	18446.	22909.	20290.	19635.	20290.	36154.	28285.	265260.
2008	28285.	26460.	19060.	31612.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	204950.
2009	11683.	10552.	16143.	5491.	4482.	6625.	5449.	3250.	4241.	5449.	16602.	11683.	101649.
2010	11683.	10552.	67087.	59709.	46731.	45223.	12885.	9839.	9521.	9839.	11306.	11683.	306058.
2011	18818.	10552.	19060.	18446.	19060.	18446.	3737.	2226.	2203.	2610.	8470.	6609.	130236.
2012	6764.	6328.	14678.	5209.	5968.	8129.	6883.	5344.	5643.	3976.	3201.	3235.	75356.
MEAN	14368.	13125.	33435.	29509.	28098.	24791.	12555.	11014.	10689.	11081.	16754.	15239.	220658.

MONTHLY BASE FLOW TARGETS (AC-FT) – LITTLE RIVER NEAR CAMERON

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	2748.	3951.	5157.	7545.	6457.	6729.	9839.	9839.	9521.	9839.	11306.	11683.	94613.
1941	11683.	10552.	46731.	45223.	46731.	45223.	20290.	20290.	19635.	20290.	27373.	28285.	342306.
1942	28285.	25548.	46731.	45223.	46731.	45223.	20290.	20290.	19635.	20290.	27373.	28285.	373903.
1943	28285.	25548.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	3881.	5040.	176803.
1944	6764.	6018.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	149821.
1945	11683.	10552.	19060.	18446.	19060.	18446.	20290.	20290.	19635.	20290.	27373.	28285.	233411.
1946	28285.	25548.	46731.	45223.	46731.	45223.	20290.	20290.	19635.	20290.	11306.	11683.	341235.
1947	11683.	10552.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	2600.	3965.	142849.
1948	3366.	2782.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	1927.	2181.	124305.
1949	3253.	2838.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	143129.
1950	11683.	10552.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	159274.
1951	11683.	10552.	3048.	2669.	5946.	6998.	1976.	1968.	2369.	1970.	1927.	1985.	53091.
1952	1968.	1891.	2010.	3405.	6035.	5562.	2806.	1968.	1905.	1968.	2214.	3069.	34802.
1953	3915.	3120.	3406.	3471.	7874.	5703.	3310.	2694.	3246.	3677.	11306.	11683.	63405.
1954	11683.	10552.	2790.	2125.	4657.	1909.	1968.	1968.	2160.	1980.	3054.	1968.	46816.
1955	2179.	3574.	3332.	5249.	6478.	7371.	3224.	3972.	3277.	2925.	1953.	2345.	45878.
1956	1968.	2589.	1968.	1974.	3653.	2988.	1968.	2388.	1905.	2028.	2522.	3573.	29526.
1957	2200.	2113.	4912.	5973.	7560.	8331.	20290.	20290.	19635.	20290.	27373.	28285.	167252.
1958	28285.	25548.	46731.	45223.	46731.	45223.	20290.	20290.	19635.	20290.	27373.	28285.	373903.
1959	28285.	25548.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	190871.
1960	11683.	10929.	46731.	45223.	46731.	45223.	9839.	9839.	9521.	9839.	11306.	11683.	268546.
1961	11683.	10552.	46731.	45223.	46731.	45223.	9839.	9839.	9521.	9839.	11306.	11683.	268169.
1962	11683.	10552.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	159274.
1963	11683.	10552.	19060.	18446.	19060.	18446.	3396.	1974.	2884.	2490.	4217.	2334.	114542.
1964	3740.	4899.	7520.	6994.	8463.	6995.	4286.	3928.	3743.	5964.	11306.	11683.	79521.
1965	11683.	10552.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	159274.
1966	11683.	10552.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	159274.
1967	11683.	10552.	7568.	6788.	8293.	2856.	4081.	3153.	4289.	3340.	11306.	11683.	85592.
1968	11683.	10929.	46731.	45223.	46731.	45223.	20290.	20290.	19635.	20290.	27373.	28285.	342683.
1969	28285.	25548.	46731.	45223.	46731.	45223.	20290.	20290.	19635.	20290.	11306.	11683.	341235.
1970	11683.	10552.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	159274.
1971	11683.	10552.	7535.	7496.	8394.	3360.	3265.	5603.	3308.	4584.	11306.	11683.	88769.
1972	11683.	10929.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	159651.
1973	11683.	10552.	19060.	18446.	19060.	18446.	20290.	20290.	19635.	20290.	27373.	28285.	233411.
1974	28285.	25548.	46731.	45223.	46731.	45223.	9839.	9839.	9521.	9839.	27373.	28285.	332435.
1975	28285.	25548.	46731.	45223.	46731.	45223.	20290.	20290.	19635.	20290.	11306.	11683.	341235.
1976	11683.	10929.	6741.	7820.	8608.	8331.	9839.	9839.	9521.	9839.	27373.	28285.	148807.

1977	28285.	25548.	46731.	45223.	46731.	45223.	9839.	9839.	9521.	9839.	4022.	4222.	285021.
1978	3994.	4430.	4805.	4516.	5426.	4770.	3089.	3623.	2595.	2308.	3857.	2190.	45604.
1979	6764.	5874.	19060.	18446.	19060.	18446.	20290.	20290.	19635.	20290.	27373.	28285.	223813.
1980	28285.	26460.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	3324.	3941.	176060.
1981	4090.	5560.	8235.	7436.	6931.	8117.	9839.	9839.	9521.	9839.	27373.	28285.	135063.
1982	28285.	25548.	19060.	18446.	19060.	18446.	20290.	20290.	19635.	20290.	11306.	11683.	232340.
1983	11683.	10552.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	159274.
1984	11683.	10929.	19060.	18446.	19060.	18446.	2887.	2203.	2418.	4755.	11306.	11683.	132876.
1985	11683.	10552.	46731.	45223.	46731.	45223.	9839.	9839.	9521.	9839.	11306.	11683.	268169.
1986	11683.	10552.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	159274.
1987	11683.	10552.	46731.	45223.	46731.	45223.	20290.	20290.	19635.	20290.	11306.	11683.	309637.
1988	11683.	10929.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	159651.
1989	11683.	10552.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	159274.
1990	11683.	10552.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	159274.
1991	11683.	10552.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	27373.	28285.	191942.
1992	28285.	26460.	46731.	45223.	46731.	45223.	20290.	20290.	19635.	20290.	27373.	28285.	374816.
1993	28285.	25548.	46731.	45223.	46731.	45223.	20290.	20290.	19635.	20290.	11306.	11683.	341235.
1994	11683.	10552.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	159274.
1995	11683.	10552.	19060.	18446.	19060.	18446.	20290.	20290.	19635.	20290.	11306.	11683.	200742.
1996	11683.	10929.	7816.	6260.	7397.	7596.	2865.	3622.	5121.	4763.	11306.	11683.	91042.
1997	11683.	10552.	46731.	45223.	46731.	45223.	20290.	20290.	19635.	20290.	27373.	28285.	342306.
1998	28285.	25548.	46731.	45223.	46731.	45223.	9839.	9839.	9521.	9839.	11306.	11683.	299767.
1999	11683.	10552.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	159274.
2000	11683.	10929.	8394.	6203.	8608.	6548.	5835.	1968.	2059.	5166.	6546.	6764.	80705.
2001	6764.	6109.	46731.	45223.	46731.	45223.	9839.	9839.	9521.	9839.	11306.	11683.	258807.
2002	11683.	10552.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	27373.	28285.	191942.
2003	28285.	25548.	46731.	45223.	46731.	45223.	9839.	9839.	9521.	9839.	11306.	11683.	299767.
2004	11683.	10929.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	27373.	28285.	192319.
2005	28285.	25548.	46731.	45223.	46731.	45223.	9839.	9839.	9521.	9839.	1944.	1968.	280690.
2006	2771.	3247.	5893.	5521.	5795.	4342.	4013.	2402.	2828.	5835.	3538.	6764.	52949.
2007	6764.	2613.	19060.	18446.	19060.	18446.	20290.	20290.	19635.	20290.	27373.	28285.	220552.
2008	28285.	26460.	19060.	18446.	19060.	18446.	9839.	9839.	9521.	9839.	11306.	11683.	191784.
2009	11683.	10552.	4004.	5491.	4482.	6625.	5449.	3250.	3323.	5449.	11306.	11683.	83297.
2010	11683.	10552.	46731.	45223.	46731.	45223.	9839.	9839.	9521.	9839.	11306.	11683.	268169.
2011	11683.	10552.	19060.	18446.	19060.	18446.	3737.	2226.	2203.	2610.	6546.	6609.	121178.
2012	6764.	6328.	8608.	5209.	5968.	8129.	5964.	5344.	5643.	3976.	3201.	3235.	68368.
MEAN	13788.	12602.	23481.	22747.	23800.	22899.	10868.	10733.	10425.	10891.	13199.	13680.	189112.

MONTHLY PULSE FLOW TARGETS (AC-FT) – LITTLE RIVER NEAR CAMERON

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0.	4284.	0.	12694.	0.	0.	3333.	0.	0.	0.	12511.	0.	32822.
1941	0.	0.	50356.	0.	0.	0.	3928.	0.	0.	0.	0.	0.	54284.
1942	0.	0.	0.	45047.	0.	0.	3928.	0.	0.	0.	20256.	0.	69231.
1943	0.	0.	16317.	15588.	0.	0.	1607.	0.	0.	0.	0.	0.	33512.
1944	4492.	0.	25388.	0.	0.	0.	3333.	0.	0.	0.	8986.	0.	42199.
1945	0.	0.	28416.	0.	0.	0.	8052.	0.	0.	0.	0.	21917.	58385.
1946	0.	0.	57624.	0.	0.	0.	0.	0.	7793.	0.	6426.	0.	71843.
1947	0.	0.	32669.	0.	0.	0.	0.	0.	0.	0.	0.	0.	32669.
1948	0.	2142.	3231.	0.	0.	0.	4345.	0.	0.	0.	0.	0.	9718.
1949	4052.	0.	0.	35310.	0.	0.	2443.	0.	0.	0.	0.	0.	41805.
1950	0.	8568.	0.	33848.	0.	0.	6112.	0.	0.	0.	0.	0.	48528.
1951	0.	0.	0.	0.	0.	9043.	0.	0.	1111.	0.	0.	0.	10154.
1952	0.	0.	0.	0.	9289.	0.	1807.	0.	0.	0.	2142.	0.	13238.
1953	0.	0.	0.	6347.	12394.	0.	0.	0.	2222.	0.	4284.	4284.	29531.
1954	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1955	0.	3310.	0.	0.	21953.	0.	1828.	0.	0.	0.	0.	0.	27091.
1956	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	5039.	0.	5039.
1957	0.	0.	0.	20403.	0.	0.	3928.	0.	0.	0.	26712.	0.	51043.
1958	0.	0.	38004.	0.	0.	0.	8882.	0.	0.	0.	0.	0.	46886.
1959	0.	10853.	0.	19517.	12951.	0.	3993.	0.	0.	0.	6426.	0.	53741.

1960	0.	0.	0.	0.	0.	0.	0.	0.	1111.	2222.	6515.	0.	9848.
1961	0.	0.	46493.	0.	0.	0.	3333.	0.	0.	0.	6692.	4284.	60802.
1962	0.	0.	0.	13584.	3316.	19791.	2998.	0.	1111.	0.	6426.	0.	47225.
1963	0.	0.	0.	0.	0.	0.	2014.	0.	0.	0.	0.	0.	2014.
1964	0.	0.	0.	0.	0.	18901.	2222.	0.	0.	0.	10397.	0.	31520.
1965	2142.	0.	0.	47468.	5310.	0.	3333.	0.	0.	0.	9447.	0.	67700.
1966	0.	0.	0.	25388.	0.	0.	2791.	3333.	0.	0.	0.	0.	31512.
1967	0.	0.	0.	0.	12694.	0.	2222.	0.	0.	0.	6426.	0.	21342.
1968	0.	0.	47505.	0.	0.	0.	8256.	0.	0.	0.	10497.	7133.	73391.
1969	0.	0.	34894.	28503.	0.	0.	0.	4650.	0.	1964.	2223.	6227.	78462.
1970	4284.	0.	33684.	0.	0.	0.	0.	0.	5092.	0.	0.	0.	43060.
1971	0.	0.	0.	0.	9036.	0.	2222.	0.	0.	0.	2777.	7054.	21089.
1972	0.	0.	0.	0.	0.	19341.	1619.	0.	0.	2222.	12869.	0.	36051.
1973	0.	0.	23834.	22094.	0.	0.	7308.	0.	0.	0.	19409.	0.	72645.
1974	0.	0.	0.	0.	22694.	0.	0.	3333.	0.	0.	11717.	0.	37743.
1975	0.	0.	0.	32852.	28966.	0.	3928.	0.	0.	0.	0.	0.	65746.
1976	0.	0.	0.	12694.	0.	0.	4444.	0.	0.	0.	12587.	14841.	44565.
1977	0.	0.	0.	41564.	0.	0.	0.	0.	0.	0.	0.	0.	41564.
1978	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1979	4087.	0.	35984.	0.	0.	0.	6888.	0.	0.	0.	0.	0.	46959.
1980	0.	0.	17861.	0.	32785.	0.	0.	0.	0.	0.	0.	0.	50647.
1981	0.	0.	0.	0.	18809.	0.	3970.	0.	0.	0.	0.	0.	22779.
1982	0.	0.	0.	22648.	19041.	0.	3435.	0.	0.	0.	0.	0.	45124.
1983	0.	10185.	21941.	0.	32791.	0.	0.	5548.	0.	0.	0.	0.	70465.
1984	0.	0.	0.	0.	0.	0.	0.	0.	0.	2222.	0.	8568.	10790.
1985	0.	0.	23326.	0.	0.	0.	2456.	0.	0.	3001.	9807.	0.	38590.
1986	0.	0.	0.	0.	0.	48929.	0.	0.	3338.	0.	12668.	0.	64935.
1987	0.	0.	35459.	0.	28503.	0.	3928.	0.	0.	0.	5903.	8358.	82151.
1988	0.	0.	0.	0.	0.	22807.	0.	0.	0.	0.	0.	0.	22807.
1989	0.	0.	0.	0.	30139.	23409.	5215.	0.	0.	0.	0.	0.	58762.
1990	0.	0.	11654.	19041.	0.	0.	5555.	0.	0.	0.	0.	0.	36250.
1991	8568.	0.	0.	45922.	0.	0.	2615.	2147.	2784.	0.	0.	23036.	85073.
1992	0.	0.	38004.	0.	0.	0.	3928.	0.	0.	0.	11276.	8490.	61698.
1993	0.	0.	59375.	0.	0.	0.	2191.	0.	0.	4411.	0.	0.	65977.
1994	0.	7775.	0.	0.	51792.	0.	8220.	0.	0.	0.	5149.	6426.	79362.
1995	0.	0.	36579.	0.	0.	0.	2617.	3673.	0.	0.	0.	0.	42870.
1996	0.	0.	0.	0.	0.	0.	1744.	0.	0.	0.	0.	12582.	14326.
1997	0.	0.	43120.	0.	0.	0.	3928.	0.	0.	0.	0.	13781.	60828.
1998	0.	0.	0.	0.	0.	0.	5764.	0.	0.	0.	9643.	0.	15407.
1999	0.	0.	0.	0.	0.	0.	2576.	0.	0.	0.	0.	0.	2576.
2000	8568.	0.	0.	0.	0.	0.	0.	0.	0.	2156.	2142.	0.	12866.
2001	0.	0.	32004.	0.	0.	0.	1111.	2222.	0.	0.	8292.	0.	43628.
2002	0.	0.	0.	0.	0.	0.	3437.	0.	0.	0.	24496.	0.	27933.
2003	0.	0.	0.	0.	0.	0.	0.	0.	3137.	1777.	8890.	0.	13804.
2004	6077.	0.	0.	25367.	16133.	0.	3333.	0.	0.	0.	12735.	0.	63645.
2005	0.	0.	0.	0.	0.	0.	0.	5555.	0.	0.	0.	0.	5555.
2006	0.	4284.	0.	15510.	0.	0.	2754.	0.	0.	0.	0.	6347.	28895.
2007	0.	0.	37612.	0.	0.	0.	3928.	0.	0.	0.	11561.	0.	53101.
2008	0.	0.	0.	15011.	0.	0.	0.	0.	0.	0.	0.	0.	15011.
2009	0.	0.	12694.	0.	0.	0.	0.	0.	1111.	0.	6426.	0.	20231.
2010	0.	0.	24879.	21681.	0.	0.	4315.	0.	0.	0.	0.	0.	50876.
2011	9019.	0.	0.	0.	0.	0.	0.	0.	0.	0.	2280.	0.	11299.
2012	0.	0.	6347.	0.	0.	0.	1111.	0.	0.	0.	0.	0.	7458.
MEAN	703.	704.	11990.	7919.	5049.	2222.	2592.	417.	395.	274.	4685.	2100.	39050.

Table 6.23
Brazos River near Waco
BBASC Instream Flow *IF* Record Targets and Intermediate Base Flow and Pulse Flow Targets

MONTHLY INSTREAM FLOW TARGETS (AC-FT) – BRAZOS RIVER NEAR WACO

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	7378.	6902.	9223.	38640.	9223.	8925.	25666.	15373.	14877.	15373.	38985.	12912.	203478.
1941	12912.	11662.	125383.	113824.	42427.	41058.	63784.	36276.	35106.	36276.	51707.	29515.	599929.
1942	29515.	26659.	42427.	190140.	42427.	41058.	36276.	36276.	49268.	36276.	28563.	29515.	588399.
1943	29515.	26659.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	3551.	4233.	190286.
1944	5757.	13616.	16601.	26102.	55017.	16065.	15373.	15373.	23200.	15373.	12495.	12912.	227883.
1945	22834.	15848.	76067.	16065.	16601.	16065.	60618.	36276.	35106.	36276.	28563.	39116.	399436.
1946	29515.	44458.	121526.	41058.	42427.	41058.	36276.	36276.	35106.	36276.	25052.	12912.	501940.
1947	12912.	11662.	16601.	16065.	71777.	16065.	15373.	15373.	14877.	15373.	6506.	17621.	230206.
1948	6999.	5750.	16601.	16065.	16601.	26102.	32431.	15373.	22392.	15373.	7140.	7378.	188205.
1949	7378.	16176.	16601.	16065.	60703.	16065.	23435.	15373.	14877.	18804.	12495.	12912.	230885.
1950	12912.	11662.	16601.	16065.	16601.	16065.	38947.	15373.	14877.	15373.	12495.	12912.	199883.
1951	12912.	11662.	9223.	8925.	9223.	39560.	8609.	8609.	8331.	8609.	7140.	7314.	140117.
1952	7378.	6902.	9223.	8925.	36600.	8498.	7978.	8523.	8331.	6608.	17253.	5790.	132009.
1953	5112.	3508.	7101.	6886.	23192.	5965.	15302.	8609.	7977.	8609.	18633.	12912.	123806.
1954	12912.	11662.	9223.	8925.	38361.	8925.	8609.	8609.	8331.	14860.	7140.	7173.	144731.
1955	7378.	5454.	6247.	8268.	31390.	8925.	8609.	8609.	14588.	8609.	7140.	7378.	122596.
1956	7378.	6902.	9223.	8925.	23785.	8925.	8609.	8609.	8331.	8609.	7140.	18198.	124635.
1957	7378.	6664.	9223.	19055.	9223.	8925.	50438.	36276.	35106.	36276.	64730.	29515.	312810.
1958	29515.	26659.	42427.	66664.	182338.	41058.	57519.	36276.	35106.	36276.	28563.	29515.	611916.
1959	29515.	26659.	16601.	16065.	16601.	16065.	31070.	15373.	14877.	22235.	12495.	31700.	249257.
1960	17097.	12079.	42427.	41058.	42427.	41058.	34449.	15373.	14877.	15373.	22027.	25207.	323452.
1961	12912.	11662.	42427.	41058.	42427.	125656.	36797.	15373.	14877.	15373.	25519.	12912.	396992.
1962	12912.	11662.	16601.	16065.	16601.	61828.	25666.	15373.	14877.	15373.	16681.	17097.	240737.
1963	12912.	11662.	16601.	33971.	38780.	45184.	8609.	8609.	8331.	8609.	7140.	6472.	206880.
1964	7378.	6902.	8597.	38368.	9223.	8925.	8609.	8609.	15366.	8517.	33525.	12912.	166932.
1965	12912.	11662.	30682.	24459.	54666.	16065.	15373.	15373.	14877.	23776.	22763.	12912.	255522.
1966	12912.	11662.	16601.	74879.	19052.	16065.	15373.	34933.	14877.	15373.	12495.	12912.	257134.
1967	12912.	11662.	9223.	8925.	9223.	20219.	15908.	8609.	8331.	8609.	20627.	12912.	147159.
1968	29199.	12079.	199553.	41058.	42427.	41058.	71680.	36276.	35106.	36276.	28563.	29515.	602790.
1969	29515.	26659.	42427.	41058.	139773.	41058.	36276.	36276.	35106.	36276.	12495.	25468.	502388.
1970	17678.	11662.	84389.	16065.	16601.	16065.	15373.	15373.	14877.	22235.	12495.	12912.	255726.
1971	12912.	11662.	7139.	8925.	28840.	8925.	12258.	8609.	8331.	8609.	12495.	32878.	161584.
1972	12912.	12079.	16601.	16065.	16601.	16065.	23910.	21395.	25222.	15373.	21008.	12912.	210143.
1973	21467.	11662.	40841.	54272.	16601.	16065.	59914.	47226.	35106.	36276.	28563.	29515.	397509.
1974	29515.	26659.	42427.	41058.	42427.	41058.	15373.	29098.	23615.	15373.	43241.	29515.	379358.
1975	29515.	26659.	42427.	113372.	136563.	41058.	36276.	36276.	35106.	36276.	12495.	12912.	558936.
1976	12912.	12079.	5664.	7842.	26315.	8925.	29098.	15373.	14877.	15373.	28563.	47310.	224330.
1977	29515.	33998.	136746.	95825.	42427.	41058.	15373.	15373.	14877.	15373.	7140.	4253.	451959.
1978	3830.	4318.	7471.	7459.	8276.	7137.	6938.	15412.	8331.	8609.	7140.	7378.	92300.
1979	7378.	6664.	26637.	25926.	46697.	16065.	36276.	36276.	35106.	36276.	28563.	29515.	331380.
1980	40796.	27611.	16601.	16065.	37776.	16065.	15373.	15373.	30203.	15373.	7140.	7378.	245755.
1981	7378.	6664.	9223.	8925.	9223.	29474.	23052.	15373.	14877.	22235.	50177.	29515.	226117.
1982	29515.	26659.	16601.	16065.	69941.	16065.	50438.	36276.	35106.	36276.	12495.	12912.	358349.
1983	12912.	39836.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	35139.	12495.	12912.	224249.
1984	12912.	12079.	16601.	16065.	16601.	16065.	8609.	8609.	8331.	13201.	12495.	34152.	175720.
1985	12912.	11662.	42427.	41058.	42427.	41058.	15373.	15373.	20950.	22235.	12495.	18279.	296249.
1986	12912.	20033.	16601.	16065.	16601.	83712.	39008.	15373.	14877.	15373.	27259.	25822.	303636.
1987	12912.	11662.	42427.	41058.	119246.	83974.	36276.	36276.	35106.	36276.	12495.	21283.	488991.
1988	12912.	12079.	16601.	16065.	16601.	35793.	15373.	15373.	22612.	15373.	12495.	12912.	204189.
1989	12912.	20033.	30971.	16065.	46710.	16065.	15373.	23148.	31850.	15373.	12495.	12912.	253908.
1990	12912.	28223.	66160.	36138.	16601.	16065.	15373.	15373.	32033.	19042.	12495.	12912.	283327.
1991	22736.	11662.	16601.	16065.	40534.	46175.	31362.	18804.	14877.	15373.	43241.	29515.	306945.
1992	29515.	27611.	180228.	41058.	42427.	41058.	55695.	36276.	35106.	36276.	28563.	41355.	595168.
1993	29515.	37530.	42427.	41058.	42427.	41058.	36276.	36276.	35106.	36276.	12495.	12912.	403356.

1994	12912.	16925.	16601.	16065.	77579.	16065.	15373.	15373.	14877.	38866.	26751.	17097.	284485.
1995	12912.	11662.	56747.	36138.	16601.	16065.	36276.	51019.	35106.	36276.	12495.	12912.	334209.
1996	12912.	12079.	9223.	8925.	9223.	8925.	8609.	15802.	8331.	8609.	25052.	26699.	154389.
1997	12912.	11662.	132371.	41058.	42427.	41058.	51810.	36276.	35106.	36276.	28563.	58871.	528389.
1998	29515.	26659.	99566.	41058.	42427.	41058.	15373.	15373.	14877.	28385.	18472.	12912.	385674.
1999	26635.	11662.	43441.	16065.	16601.	75093.	24200.	15373.	14877.	15373.	12495.	12912.	284727.
2000	12912.	12079.	5637.	5187.	6040.	48427.	8609.	8609.	8331.	15445.	14183.	7251.	152711.
2001	7378.	6664.	131060.	41058.	42427.	41058.	15373.	15373.	29014.	15373.	38236.	12912.	395926.
2002	12912.	11662.	60137.	37725.	16601.	16065.	31515.	15373.	14877.	15373.	28563.	49823.	310627.
2003	29515.	26659.	42427.	41058.	42427.	169090.	22235.	15373.	30090.	15373.	12495.	12912.	459653.
2004	12912.	41044.	36674.	64303.	16601.	16065.	31306.	15373.	14877.	15373.	57919.	29515.	351962.
2005	29515.	26659.	42427.	41058.	42427.	41058.	35233.	15373.	14877.	15373.	7140.	7378.	318518.
2006	7378.	15392.	9124.	8925.	36943.	8925.	8609.	8609.	12990.	5817.	6711.	4692.	134116.
2007	17559.	5796.	100616.	16065.	16601.	16065.	50438.	36276.	35106.	36276.	28563.	29515.	388876.
2008	29515.	27611.	16601.	43553.	16601.	16065.	15373.	27692.	14877.	15373.	12495.	12912.	248669.
2009	12912.	11662.	8472.	18970.	19066.	8925.	15823.	8609.	7877.	8609.	20866.	12912.	154703.
2010	30890.	11662.	42427.	106993.	120410.	41330.	29098.	15373.	14877.	15373.	12495.	20961.	461889.
2011	12912.	11662.	16601.	16065.	16601.	16065.	8609.	8609.	8331.	15908.	16018.	7378.	154759.
2012	7378.	6663.	19124.	8739.	9223.	8925.	8395.	8032.	11981.	7224.	3830.	3522.	103037.
MEAN	16844.	16184.	39007.	32237.	36953.	29808.	25822.	20255.	20477.	20475.	19911.	18722.	296697.

MONTHLY BASE FLOW TARGETS (AC-FT) – BRAZOS RIVER NEAR WACO

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	7378.	6902.	9223.	8925.	9223.	8925.	15373.	15373.	14877.	15373.	12495.	12912.	136980.
1941	12912.	11662.	42427.	41058.	42427.	41058.	36276.	36276.	35106.	36276.	28563.	29515.	393556.
1942	29515.	26659.	42427.	41058.	42427.	41058.	36276.	36276.	35106.	36276.	28563.	29515.	425156.
1943	29515.	26659.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	3551.	4233.	190286.
1944	5757.	6825.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	164317.
1945	12912.	11662.	16601.	16065.	16601.	16065.	36276.	36276.	35106.	36276.	28563.	29515.	291919.
1946	29515.	26659.	42427.	41058.	42427.	41058.	36276.	36276.	35106.	36276.	12495.	12912.	392485.
1947	12912.	11662.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	6506.	6770.	164178.
1948	6999.	5750.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	7140.	7378.	153597.
1949	7378.	6664.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	165778.
1950	12912.	11662.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	176310.
1951	12912.	11662.	9223.	8925.	9223.	8925.	8609.	8609.	8331.	8609.	7140.	7314.	109482.
1952	7378.	6902.	9223.	8925.	9223.	8498.	7978.	8523.	8331.	6608.	6186.	5790.	93564.
1953	5112.	3508.	7101.	6886.	8501.	5965.	8004.	8609.	7977.	8609.	12495.	12912.	95679.
1954	12912.	11662.	9223.	8925.	9223.	8925.	8609.	8609.	8331.	8609.	7140.	7173.	109341.
1955	7378.	5454.	6247.	8268.	9016.	8925.	8609.	8609.	8331.	8609.	7140.	7378.	93965.
1956	7378.	6902.	9223.	8925.	9223.	8925.	8609.	8609.	8331.	8609.	7140.	7378.	99253.
1957	7378.	6664.	9223.	8780.	9223.	8925.	36276.	36276.	35106.	36276.	28563.	29515.	252206.
1958	29515.	26659.	42427.	41058.	42427.	41058.	36276.	36276.	35106.	36276.	28563.	29515.	425156.
1959	29515.	26659.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	207910.
1960	12912.	12079.	42427.	41058.	42427.	41058.	15373.	15373.	14877.	15373.	12495.	12912.	278363.
1961	12912.	11662.	42427.	41058.	42427.	41058.	15373.	15373.	14877.	15373.	12495.	12912.	277947.
1962	12912.	11662.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	176310.
1963	12912.	11662.	16601.	16065.	16601.	16065.	8609.	8609.	8331.	8609.	7140.	6472.	137676.
1964	7378.	6902.	8597.	7779.	9223.	8925.	8609.	8609.	8331.	8517.	12495.	12912.	108278.
1965	12912.	11662.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	176310.
1966	12912.	11662.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	176310.
1967	12912.	11662.	9223.	8925.	9223.	8925.	8609.	8609.	8331.	8609.	12495.	12912.	120435.
1968	12912.	12079.	42427.	41058.	42427.	41058.	36276.	36276.	35106.	36276.	28563.	29515.	393972.
1969	29515.	26659.	42427.	41058.	42427.	41058.	36276.	36276.	35106.	36276.	12495.	12912.	392485.
1970	12912.	11662.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	176310.
1971	12912.	11662.	7139.	8925.	8291.	8925.	8609.	8609.	8331.	8609.	12495.	12912.	117420.
1972	12912.	12079.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	176726.
1973	12912.	11662.	16601.	16065.	16601.	16065.	36276.	36276.	35106.	36276.	28563.	29515.	291919.
1974	29515.	26659.	42427.	41058.	42427.	41058.	15373.	15373.	14877.	15373.	28563.	29515.	342218.
1975	29515.	26659.	42427.	41058.	42427.	41058.	36276.	36276.	35106.	36276.	12495.	12912.	392485.
1976	12912.	12079.	5664.	7842.	9223.	8925.	15373.	15373.	14877.	15373.	28563.	29515.	175719.

1977	29515.	26659.	42427.	41058.	42427.	41058.	15373.	15373.	14877.	15373.	7140.	4253.	295533.
1978	3830.	4318.	7471.	7459.	8276.	7137.	6938.	8609.	8331.	8609.	7140.	7378.	85497.
1979	7378.	6664.	16601.	16065.	16601.	16065.	36276.	36276.	35106.	36276.	28563.	29515.	281387.
1980	29515.	27611.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	7140.	7378.	197973.
1981	7378.	6664.	9223.	8925.	9223.	8925.	15373.	15373.	14877.	15373.	28563.	29515.	169413.
1982	29515.	26659.	16601.	16065.	16601.	16065.	36276.	36276.	35106.	36276.	12495.	12912.	290848.
1983	12912.	11662.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	176310.
1984	12912.	12079.	16601.	16065.	16601.	16065.	8609.	8609.	8331.	8499.	12495.	12912.	149777.
1985	12912.	11662.	42427.	41058.	42427.	41058.	15373.	15373.	14877.	15373.	12495.	12912.	277947.
1986	12912.	11662.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	176310.
1987	12912.	11662.	42427.	41058.	42427.	41058.	36276.	36276.	35106.	36276.	12495.	12912.	360885.
1988	12912.	12079.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	176726.
1989	12912.	11662.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	176310.
1990	12912.	11662.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	176310.
1991	12912.	11662.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	28563.	29515.	208981.
1992	29515.	27611.	42427.	41058.	42427.	41058.	36276.	36276.	35106.	36276.	28563.	29515.	426108.
1993	29515.	26659.	42427.	41058.	42427.	41058.	36276.	36276.	35106.	36276.	12495.	12912.	392485.
1994	12912.	11662.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	176310.
1995	12912.	11662.	16601.	16065.	16601.	16065.	36276.	36276.	35106.	36276.	12495.	12912.	259248.
1996	12912.	12079.	9223.	8925.	9223.	8925.	8609.	8504.	8331.	8609.	12495.	12912.	120747.
1997	12912.	11662.	42427.	41058.	42427.	41058.	36276.	36276.	35106.	36276.	28563.	29515.	393556.
1998	29515.	26659.	42427.	41058.	42427.	41058.	15373.	15373.	14877.	15373.	12495.	12912.	309547.
1999	12912.	11662.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	176310.
2000	12912.	12079.	5637.	5187.	6040.	8739.	8609.	8609.	8331.	8609.	7140.	7251.	99143.
2001	7378.	6664.	42427.	41058.	42427.	41058.	15373.	15373.	14877.	15373.	12495.	12912.	267415.
2002	12912.	11662.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	28563.	29515.	208981.
2003	29515.	26659.	42427.	41058.	42427.	41058.	15373.	15373.	14877.	15373.	12495.	12912.	309547.
2004	12912.	12079.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	28563.	29515.	209397.
2005	29515.	26659.	42427.	41058.	42427.	41058.	15373.	15373.	14877.	15373.	7140.	7378.	298658.
2006	7378.	6664.	9124.	8925.	8981.	8925.	8609.	8609.	8114.	5817.	6711.	4693.	92550.
2007	5220.	5796.	16601.	16065.	16601.	16065.	36276.	36276.	35106.	36276.	28563.	29515.	278361.
2008	29515.	27611.	16601.	16065.	16601.	16065.	15373.	15373.	14877.	15373.	12495.	12912.	208862.
2009	12912.	11662.	8472.	8695.	9223.	8925.	8609.	8609.	7877.	8609.	12495.	12912.	119000.
2010	12912.	11662.	42427.	41058.	42427.	41058.	15373.	15373.	14877.	15373.	12495.	12912.	277947.
2011	12912.	11662.	16601.	16065.	16601.	16065.	8609.	8609.	8331.	8609.	6737.	7378.	138179.
2012	7378.	6663.	8850.	8739.	9223.	8925.	8395.	8032.	8331.	7224.	3830.	3522.	89113.
MEAN	15353.	13980.	21864.	21250.	22024.	21323.	18817.	18849.	18237.	18772.	14862.	15266.	220598.

MONTHLY PULSE FLOW TARGETS (AC-FT) – BRAZOS RIVER NEAR WACO

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0.	0.	0.	30904.	0.	0.	11781.	0.	0.	0.	29822.	0.	72508.
1941	0.	0.	91167.	76872.	0.	0.	33358.	0.	0.	0.	26953.	0.	228350.
1942	0.	0.	0.	159211.	0.	0.	0.	0.	16502.	0.	0.	0.	175713.
1943	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1944	0.	7505.	0.	10572.	40558.	0.	0.	0.	9810.	0.	0.	0.	68446.
1945	11172.	4602.	64286.	0.	0.	0.	29023.	0.	0.	0.	0.	12457.	121540.
1946	0.	20656.	89690.	0.	0.	0.	0.	0.	0.	0.	13806.	0.	124152.
1947	0.	0.	0.	0.	58389.	0.	0.	0.	0.	0.	0.	11620.	70010.
1948	0.	0.	0.	0.	0.	10572.	20529.	0.	10065.	0.	0.	0.	41166.
1949	0.	10226.	0.	0.	47315.	0.	10045.	0.	0.	3927.	0.	0.	71513.
1950	0.	0.	0.	0.	0.	0.	28603.	0.	0.	0.	0.	0.	28603.
1951	0.	0.	0.	0.	0.	32420.	0.	0.	0.	0.	0.	0.	32420.
1952	0.	0.	0.	0.	28270.	0.	0.	0.	0.	0.	11781.	0.	40051.
1953	0.	0.	0.	0.	15286.	0.	7854.	0.	0.	0.	6971.	0.	30111.
1954	0.	0.	0.	0.	30626.	0.	0.	0.	0.	7085.	0.	0.	37710.
1955	0.	0.	0.	0.	23267.	0.	0.	0.	6812.	0.	0.	0.	30079.
1956	0.	0.	0.	0.	15157.	0.	0.	0.	0.	0.	0.	11772.	26928.
1957	0.	0.	0.	10572.	0.	0.	16502.	0.	0.	0.	40928.	0.	68002.
1958	0.	0.	0.	26975.	148123.	0.	24753.	0.	0.	0.	0.	0.	199851.
1959	0.	0.	0.	0.	0.	0.	18672.	0.	0.	7854.	0.	20871.	47398.

1960	4602.	0.	0.	0.	0.	0.	22547.	0.	0.	0.	12031.	13545.	52726.
1961	0.	0.	0.	0.	0.	90073.	24895.	0.	0.	0.	14689.	0.	129657.
1962	0.	0.	0.	0.	0.	48976.	11781.	0.	0.	0.	4602.	4919.	70278.
1963	0.	0.	0.	18977.	23786.	30725.	0.	0.	0.	0.	0.	0.	73488.
1964	0.	0.	0.	32672.	0.	0.	0.	0.	7590.	0.	24362.	0.	64624.
1965	0.	0.	15152.	12678.	40743.	0.	0.	0.	0.	9891.	11518.	0.	89982.
1966	0.	0.	0.	62562.	2986.	0.	0.	23527.	0.	0.	0.	0.	89076.
1967	0.	0.	0.	0.	0.	11889.	7854.	0.	0.	0.	9798.	0.	29541.
1968	17954.	0.	170812.	0.	0.	0.	42103.	0.	0.	0.	0.	0.	230868.
1969	0.	0.	0.	0.	102821.	0.	0.	0.	0.	0.	0.	13806.	116627.
1970	5599.	0.	72072.	0.	0.	0.	0.	0.	0.	7854.	0.	0.	85525.
1971	0.	0.	0.	0.	21144.	0.	3927.	0.	0.	0.	0.	22466.	47537.
1972	0.	0.	0.	0.	0.	0.	10024.	7014.	13320.	0.	9763.	0.	40121.
1973	9805.	0.	28520.	40349.	0.	0.	28319.	16067.	0.	0.	0.	0.	123059.
1974	0.	0.	0.	0.	0.	0.	0.	16134.	10469.	0.	16582.	0.	43185.
1975	0.	0.	0.	76420.	102348.	0.	0.	0.	0.	0.	0.	0.	178768.
1976	0.	0.	0.	0.	17687.	0.	15708.	0.	0.	0.	0.	20651.	54046.
1977	0.	8291.	99794.	67085.	0.	0.	0.	0.	0.	0.	0.	0.	175170.
1978	0.	0.	0.	0.	0.	0.	0.	7636.	0.	0.	0.	0.	7636.
1979	0.	0.	10572.	14680.	32238.	0.	0.	0.	0.	0.	0.	0.	57490.
1980	16041.	0.	0.	0.	22782.	0.	0.	0.	17805.	0.	0.	0.	56628.
1981	0.	0.	0.	0.	0.	21144.	9166.	0.	0.	7854.	24471.	0.	62635.
1982	0.	0.	0.	0.	56553.	0.	16502.	0.	0.	0.	0.	0.	73055.
1983	0.	33959.	0.	0.	0.	0.	0.	0.	0.	22742.	0.	0.	56701.
1984	0.	0.	0.	0.	0.	0.	0.	0.	0.	5258.	0.	24358.	29616.
1985	0.	0.	0.	0.	0.	0.	0.	0.	7065.	7854.	0.	6200.	21119.
1986	0.	9204.	0.	0.	0.	71931.	28967.	0.	0.	0.	16846.	14993.	141941.
1987	0.	0.	0.	0.	80925.	45653.	0.	0.	0.	0.	0.	9204.	135782.
1988	0.	0.	0.	0.	0.	20799.	0.	0.	9223.	0.	0.	0.	30021.
1989	0.	9204.	15441.	0.	31716.	0.	0.	9263.	20444.	0.	0.	0.	86068.
1990	0.	20309.	53308.	21144.	0.	0.	0.	0.	19635.	4661.	0.	0.	119057.
1991	12080.	0.	0.	0.	26611.	31716.	19460.	3927.	0.	0.	16582.	0.	110376.
1992	0.	0.	146013.	0.	0.	0.	22929.	0.	0.	0.	0.	15649.	184591.
1993	0.	12775.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	12775.
1994	0.	6096.	0.	0.	64727.	0.	0.	0.	0.	26964.	17172.	4602.	119560.
1995	0.	0.	42288.	21144.	0.	0.	0.	18253.	0.	0.	0.	0.	81685.
1996	0.	0.	0.	0.	0.	0.	0.	7854.	0.	0.	13806.	15870.	37530.
1997	0.	0.	95418.	0.	0.	0.	22555.	0.	0.	0.	0.	33164.	151138.
1998	0.	0.	61245.	0.	0.	0.	0.	0.	0.	14995.	6810.	0.	83050.
1999	15389.	0.	30489.	0.	0.	62776.	10315.	0.	0.	0.	0.	0.	118969.
2000	0.	0.	0.	0.	0.	42664.	0.	0.	0.	7392.	7757.	0.	57813.
2001	0.	0.	94108.	643.	0.	0.	0.	0.	16616.	0.	29120.	0.	140487.
2002	0.	0.	46214.	26479.	0.	0.	18621.	0.	0.	0.	0.	23165.	114479.
2003	0.	0.	0.	0.	0.	134875.	7898.	0.	19676.	0.	0.	0.	162449.
2004	0.	32714.	21144.	54128.	0.	0.	18615.	0.	0.	0.	33164.	0.	159765.
2005	0.	0.	0.	0.	0.	0.	23331.	0.	0.	0.	0.	0.	23331.
2006	0.	9204.	0.	0.	30640.	0.	0.	0.	5431.	0.	0.	0.	45275.
2007	13052.	0.	88835.	0.	0.	0.	16502.	0.	0.	0.	0.	0.	118389.
2008	0.	0.	0.	29095.	0.	0.	0.	15295.	0.	0.	0.	0.	44389.
2009	0.	0.	0.	10572.	11331.	0.	7770.	0.	0.	0.	9204.	0.	38876.
2010	20060.	0.	0.	70041.	87400.	1938.	15708.	0.	0.	0.	0.	9489.	204636.
2011	0.	0.	0.	0.	0.	0.	0.	0.	0.	7854.	9995.	0.	17849.
2012	0.	0.	10572.	0.	0.	0.	0.	0.	3927.	0.	0.	0.	14499.
MEAN	1723.	2531.	18454.	11970.	15937.	9016.	8310.	1712.	2663.	1948.	5733.	3956.	83952.

Table 6.24
Brazos River near Richmond
BBASC Instream Flow *IF* Record Targets and Intermediate Base Flow and Pulse Flow Targets

MONTHLY INSTREAM FLOW TARGETS (AC-FT) – BRAZOS RIVER NEAR RICHMOND

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	39760.	51398.	41960.	104502.	69497.	70042.	88502.	81779.	79141.	81779.	154746.	101454.	964558.
1941	101454.	91636.	440214.	236826.	244720.	236826.	160363.	134658.	130314.	134658.	323167.	203524.	2438361.
1942	203524.	183828.	244720.	407883.	244720.	236826.	171596.	134658.	130314.	134658.	196959.	203524.	2493211.
1943	203524.	183828.	185453.	182909.	131584.	127339.	88502.	84020.	79141.	81779.	42757.	53296.	1444131.
1944	102286.	56946.	225855.	127339.	131584.	127339.	88502.	81779.	79141.	81779.	140806.	120337.	1363691.
1945	101454.	91636.	239322.	127339.	131584.	127339.	169916.	134658.	130314.	134658.	196959.	387073.	1972253.
1946	203524.	183828.	400957.	236826.	244720.	236826.	164567.	134658.	130314.	134658.	162158.	101454.	2334491.
1947	101454.	91636.	249171.	127339.	131584.	127339.	81779.	90743.	79141.	81779.	47143.	59375.	1268482.
1948	55788.	67696.	175118.	127339.	186125.	127339.	92984.	81779.	79141.	81779.	32770.	33818.	1141675.
1949	38152.	71123.	244718.	154274.	131584.	127339.	88502.	81779.	79141.	81779.	134249.	174940.	1407579.
1950	101454.	91636.	131584.	269337.	131584.	127339.	98945.	81779.	79141.	81779.	98182.	101454.	1394214.
1951	101454.	91636.	39131.	42906.	53747.	56837.	40533.	48217.	43798.	37002.	32742.	34276.	622278.
1952	33818.	35937.	41796.	109869.	63213.	55114.	39528.	33818.	33263.	33818.	34337.	49939.	564450.
1953	92377.	46676.	62741.	41891.	148680.	53731.	55288.	40405.	44515.	50338.	98182.	164992.	899815.
1954	101454.	91636.	34304.	43206.	130843.	45085.	44337.	48991.	37090.	36243.	36868.	34183.	684240.
1955	34318.	55759.	42101.	122073.	55827.	68825.	60791.	49606.	42384.	46311.	44856.	35939.	658789.
1956	34931.	39155.	37610.	42445.	52095.	36006.	35358.	42196.	36304.	35359.	36519.	39051.	467030.
1957	33818.	38457.	53620.	106696.	73171.	70810.	147510.	134658.	130314.	134658.	378359.	203524.	1505596.
1958	203524.	183828.	424607.	236826.	244720.	236826.	161929.	134658.	130314.	134658.	196959.	203524.	2492374.
1959	203524.	183828.	131584.	236950.	131584.	127339.	94015.	81779.	79141.	81779.	172605.	101454.	1625580.
1960	101454.	94909.	244720.	261263.	364538.	315155.	88502.	81779.	79141.	81779.	154829.	101454.	1969523.
1961	101454.	91636.	498678.	236826.	244720.	236826.	88502.	81779.	79141.	81779.	173712.	111769.	2026822.
1962	101454.	91636.	131584.	127339.	131584.	252466.	88502.	81779.	79141.	81779.	107623.	169285.	1444170.
1963	101454.	91636.	131584.	181208.	131584.	127339.	63673.	52217.	36253.	37769.	42622.	40873.	1038213.
1964	40154.	46198.	69375.	49903.	51773.	40278.	41906.	38748.	46224.	41184.	121972.	101454.	689170.
1965	141007.	91636.	185030.	235078.	131584.	127339.	88502.	81779.	79141.	81779.	184138.	101454.	1528466.
1966	101454.	91636.	238199.	154274.	131584.	127339.	87678.	88502.	79141.	81779.	98182.	101454.	1381221.
1967	101454.	91636.	40792.	52314.	108380.	63071.	50009.	48419.	50071.	42498.	162803.	101454.	912903.
1968	136910.	94909.	494756.	236826.	244720.	236826.	147510.	134658.	130314.	134658.	214989.	361236.	2568312.
1969	203524.	183828.	541233.	236826.	244720.	236826.	134658.	134658.	136740.	134658.	98182.	171131.	2456984.
1970	110896.	91636.	270594.	127339.	131584.	127339.	95087.	81779.	83623.	81779.	98182.	101454.	1401290.
1971	101454.	91636.	38579.	40039.	62289.	39855.	48430.	56753.	42486.	49497.	107623.	157280.	835924.
1972	101454.	94909.	151593.	127339.	222097.	127339.	81779.	87696.	79141.	90743.	154829.	101454.	1420374.
1973	133240.	91636.	261890.	127339.	131584.	127339.	153936.	134658.	130314.	134658.	352207.	246480.	2025281.
1974	203524.	183828.	244720.	236826.	244720.	236826.	81779.	94433.	79141.	81779.	310259.	203524.	2201360.
1975	203524.	183828.	244720.	480001.	244720.	236826.	160363.	134658.	130314.	134658.	98182.	101454.	2353248.
1976	101454.	94909.	65618.	98798.	73171.	70810.	92984.	81779.	79141.	81779.	196959.	364570.	1401972.
1977	203524.	183828.	269157.	423938.	244720.	236826.	93490.	81779.	79141.	81779.	45561.	45846.	1989589.
1978	94428.	54458.	69106.	47899.	40185.	47773.	37746.	47899.	55339.	36326.	73475.	52768.	657402.
1979	60873.	54982.	262863.	127339.	131584.	127339.	179212.	134658.	130314.	134658.	196959.	203524.	1744304.
1980	294563.	190394.	158518.	206043.	171986.	127339.	81779.	81779.	81382.	86683.	38562.	41013.	1560040.
1981	40117.	40975.	59501.	52765.	70297.	132217.	88502.	81779.	79141.	81779.	305137.	203524.	1235732.
1982	203524.	183828.	131584.	194676.	181415.	127339.	160363.	134658.	130314.	134658.	98182.	132538.	1813078.
1983	138937.	119960.	258553.	127339.	131584.	127339.	86261.	93085.	79141.	81779.	98182.	101454.	1443612.
1984	101454.	94909.	131584.	127339.	131584.	127339.	44223.	38346.	40009.	58064.	154829.	101454.	1151134.
1985	101454.	91636.	439576.	236826.	244720.	236826.	81779.	81779.	79141.	89668.	163148.	101454.	1948007.
1986	101454.	91636.	131584.	127339.	296649.	127339.	97133.	81779.	79141.	81779.	174497.	101454.	1491783.
1987	101454.	91636.	457966.	236826.	244720.	236826.	152489.	134658.	130314.	134658.	128068.	152620.	2202236.
1988	101454.	94909.	131584.	127339.	131584.	127339.	81779.	81779.	81382.	81779.	98182.	101454.	1240562.
1989	110896.	105563.	158518.	135513.	198920.	127339.	92486.	81779.	79141.	81779.	98182.	101454.	1371569.
1990	101454.	127855.	281536.	140806.	131584.	127339.	90743.	81779.	85864.	81779.	98182.	101454.	1450375.
1991	154428.	91636.	131584.	261111.	131584.	127339.	100866.	81779.	79141.	81779.	268421.	270610.	1780276.
1992	203524.	190394.	353158.	236826.	244720.	236826.	159911.	134658.	130314.	134658.	196959.	361514.	2583461.
1993	203524.	183828.	453908.	236826.	244720.	236826.	147510.	134658.	130314.	134658.	98182.	101454.	2306409.

1994	101454.	138906.	186547.	127339.	196521.	127339.	88051.	81779.	84336.	86261.	98182.	164693.	1481408.
1995	101454.	91636.	225855.	127339.	131584.	127339.	150551.	147510.	130314.	134658.	98182.	136758.	1603181.
1996	101454.	94909.	43356.	47781.	41358.	41568.	56355.	63252.	53861.	57184.	98182.	166391.	865652.
1997	136265.	91636.	348189.	236826.	244720.	236826.	160363.	134658.	130314.	134658.	196959.	311702.	2363117.
1998	203524.	183828.	367006.	236826.	244720.	236826.	81779.	81779.	85864.	86261.	167770.	101454.	2077637.
1999	101454.	91636.	131584.	160021.	191522.	127339.	81779.	84020.	79141.	81779.	98182.	101454.	1329911.
2000	101454.	94909.	73171.	60655.	64604.	101514.	47604.	33818.	39969.	48076.	69660.	60873.	796307.
2001	60873.	54982.	351964.	236826.	244720.	236826.	84973.	86261.	79141.	81779.	145388.	101454.	1765187.
2002	101454.	91636.	131584.	127339.	186708.	127339.	88502.	81779.	79141.	81779.	323167.	203524.	1623951.
2003	203524.	183828.	244720.	236826.	244720.	388386.	89535.	86261.	79141.	81779.	135022.	101454.	2075196.
2004	167769.	94909.	248268.	154274.	131584.	127339.	88502.	81779.	79141.	81779.	303455.	203524.	1762321.
2005	203524.	183828.	244720.	236826.	244720.	236826.	86760.	88502.	79141.	81779.	40697.	39107.	1766430.
2006	47642.	52354.	116460.	66770.	61861.	59126.	52505.	40277.	57380.	55792.	101539.	60873.	772580.
2007	60873.	52419.	204146.	127339.	131584.	127339.	147510.	134658.	130314.	134658.	196959.	203524.	1651322.
2008	203524.	190394.	268669.	127339.	131584.	127339.	81779.	90743.	79141.	81779.	98182.	101454.	1581926.
2009	101454.	91636.	120177.	60438.	68113.	32764.	52386.	37183.	55339.	56430.	150043.	101454.	927418.
2010	101454.	91636.	244720.	282110.	244720.	236826.	94704.	81779.	79141.	81779.	98182.	101454.	1738505.
2011	137910.	101078.	131584.	127339.	131584.	127339.	40059.	33818.	32936.	49195.	35471.	103594.	1051905.
2012	60873.	56946.	88522.	60077.	67046.	44729.	61433.	40463.	55339.	34686.	36143.	34943.	641200.
MEAN	120445.	106297.	204819.	164128.	158973.	146037.	95598.	86735.	83705.	86112.	137872.	133153.	1523873.

MONTHLY BASE FLOW TARGETS (AC-FT) – BRAZOS RIVER NEAR RICHMOND

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	39760.	51398.	41960.	48856.	69497.	70042.	81779.	81779.	79141.	81779.	98182.	101454.	845625.
1941	101454.	91636.	244720.	236826.	244720.	236826.	134658.	134658.	130314.	134658.	196959.	203524.	2090954.
1942	203524.	183828.	244720.	236826.	244720.	236826.	134658.	134658.	130314.	134658.	196959.	203524.	2285216.
1943	203524.	183828.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	42757.	53296.	1325727.
1944	60873.	56946.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1159776.
1945	101454.	91636.	131584.	127339.	131584.	127339.	134658.	134658.	130314.	134658.	196959.	203524.	1645706.
1946	203524.	183828.	244720.	236826.	244720.	236826.	134658.	134658.	130314.	134658.	98182.	101454.	2084369.
1947	101454.	91636.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	47143.	59375.	1141931.
1948	55788.	56946.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	32770.	33818.	1021644.
1949	38152.	49622.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1129732.
1950	101454.	91636.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1235049.
1951	101454.	91636.	39131.	42906.	53747.	56837.	40533.	48217.	43798.	37002.	32742.	34276.	622278.
1952	33818.	35937.	41796.	54405.	61519.	55114.	39528.	33818.	33263.	33818.	34337.	49939.	507291.
1953	53952.	46676.	62741.	41891.	73171.	53731.	49219.	40405.	44515.	50338.	98182.	101454.	716275.
1954	101454.	91636.	34304.	43206.	65416.	45085.	44337.	48991.	37090.	36243.	36868.	34183.	618812.
1955	34318.	45009.	42101.	60667.	55827.	68825.	55383.	49606.	42384.	46311.	44856.	35939.	581224.
1956	34931.	39155.	37610.	42445.	52095.	36006.	35358.	42196.	36304.	35359.	36519.	39051.	467030.
1957	33818.	38457.	53620.	65094.	73171.	70810.	134658.	134658.	130314.	134658.	196959.	203524.	1269741.
1958	203524.	183828.	244720.	236826.	244720.	236826.	134658.	134658.	130314.	134658.	196959.	203524.	2285216.
1959	203524.	183828.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1429311.
1960	101454.	94909.	244720.	236826.	244720.	236826.	81779.	81779.	79141.	81779.	98182.	101454.	1683569.
1961	101454.	91636.	244720.	236826.	244720.	236826.	81779.	81779.	79141.	81779.	98182.	101454.	1680296.
1962	101454.	91636.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1235049.
1963	101454.	91636.	131584.	127339.	131584.	127339.	55556.	52217.	36253.	37769.	42622.	40873.	976226.
1964	40154.	46198.	69375.	49903.	51773.	40278.	41906.	38748.	41981.	41184.	98182.	101454.	661138.
1965	101454.	91636.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1235049.
1966	101454.	91636.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1235049.
1967	101454.	91636.	40792.	52314.	62481.	63071.	46975.	43085.	50071.	42498.	98182.	101454.	794015.
1968	101454.	94909.	244720.	236826.	244720.	236826.	134658.	134658.	130314.	134658.	196959.	203524.	2094227.
1969	203524.	183828.	244720.	236826.	244720.	236826.	134658.	134658.	130314.	134658.	98182.	101454.	2084369.
1970	101454.	91636.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1235049.
1971	101454.	91636.	38579.	40039.	62289.	39855.	43325.	56753.	42486.	49497.	98182.	101454.	765552.
1972	101454.	94909.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1238322.
1973	101454.	91636.	131584.	127339.	131584.	127339.	134658.	134658.	130314.	134658.	196959.	203524.	1645706.
1974	203524.	183828.	244720.	236826.	244720.	236826.	81779.	81779.	79141.	81779.	196959.	203524.	2075405.
1975	203524.	183828.	244720.	236826.	244720.	236826.	134658.	134658.	130314.	134658.	98182.	101454.	2084369.
1976	101454.	94909.	65618.	68095.	73171.	70810.	81779.	81779.	79141.	81779.	196959.	203524.	1199017.

1977	203524.	183828.	244720.	236826.	244720.	236826.	81779.	81779.	79141.	81779.	45561.	45846.	1766328.
1978	52379.	54458.	69106.	47899.	40185.	47773.	37746.	44864.	55339.	36326.	41224.	52768.	580067.
1979	60873.	54982.	131584.	127339.	131584.	127339.	134658.	134658.	130314.	134658.	196959.	203524.	1568470.
1980	203524.	190394.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	38562.	41013.	1315814.
1981	40117.	40975.	59501.	52765.	70297.	70810.	81779.	81779.	79141.	81779.	196959.	203524.	1059425.
1982	203524.	183828.	131584.	127339.	131584.	127339.	134658.	134658.	130314.	134658.	98182.	101454.	1639121.
1983	101454.	91636.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1235049.
1984	101454.	94909.	131584.	127339.	131584.	127339.	44223.	38346.	40009.	50203.	98182.	101454.	1086626.
1985	101454.	91636.	244720.	236826.	244720.	236826.	81779.	81779.	79141.	81779.	98182.	101454.	1680296.
1986	101454.	91636.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1235049.
1987	101454.	91636.	244720.	236826.	244720.	236826.	134658.	134658.	130314.	134658.	98182.	101454.	1890107.
1988	101454.	94909.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1238322.
1989	101454.	91636.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1235049.
1990	101454.	91636.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1235049.
1991	101454.	91636.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	196959.	203524.	1435896.
1992	203524.	190394.	244720.	236826.	244720.	236826.	134658.	134658.	130314.	134658.	196959.	203524.	2291781.
1993	203524.	183828.	244720.	236826.	244720.	236826.	134658.	134658.	130314.	134658.	98182.	101454.	2084369.
1994	101454.	91636.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1235049.
1995	101454.	91636.	131584.	127339.	131584.	127339.	134658.	134658.	130314.	134658.	98182.	101454.	1444860.
1996	101454.	94909.	43356.	47781.	41358.	41568.	56355.	57184.	53861.	57184.	98182.	101454.	794647.
1997	101454.	91636.	244720.	236826.	244720.	236826.	134658.	134658.	130314.	134658.	196959.	203524.	2090954.
1998	203524.	183828.	244720.	236826.	244720.	236826.	81779.	81779.	79141.	81779.	98182.	101454.	1874558.
1999	101454.	91636.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1235049.
2000	101454.	94909.	73171.	60655.	64604.	70810.	39365.	33818.	39969.	48076.	58909.	60873.	746614.
2001	60873.	54982.	244720.	236826.	244720.	236826.	81779.	81779.	79141.	81779.	98182.	101454.	1603060.
2002	101454.	91636.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	196959.	203524.	1435896.
2003	203524.	183828.	244720.	236826.	244720.	236826.	81779.	81779.	79141.	81779.	98182.	101454.	1874558.
2004	101454.	94909.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	196959.	203524.	1439168.
2005	203524.	183828.	244720.	236826.	244720.	236826.	81779.	81779.	79141.	81779.	40697.	39107.	1754726.
2006	47642.	52354.	73171.	66770.	61861.	59126.	52505.	40277.	51312.	55792.	58909.	60873.	680592.
2007	60873.	52419.	131584.	127339.	131584.	127339.	134658.	134658.	130314.	134658.	196959.	203524.	1565907.
2008	203524.	190394.	131584.	127339.	131584.	127339.	81779.	81779.	79141.	81779.	98182.	101454.	1435876.
2009	101454.	91636.	67834.	49351.	68113.	32764.	45359.	37183.	55339.	56430.	98182.	101454.	805100.
2010	101454.	91636.	244720.	236826.	244720.	236826.	81779.	81779.	79141.	81779.	98182.	101454.	1680296.
2011	101454.	91636.	131584.	127339.	131584.	127339.	40059.	33818.	32936.	46161.	35471.	60873.	960253.
2012	60873.	56946.	73171.	60077.	67046.	44729.	52762.	40463.	55339.	34686.	36143.	34943.	617178.
MEAN	112683.	103856.	143950.	139324.	145877.	139912.	85892.	85338.	83097.	85541.	107993.	112242.	1345705.

MONTHLY PULSE FLOW TARGETS (AC-FT) – BRAZOS RIVER NEAR RICHMOND

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0.	0.	0.	76889.	0.	0.	14637.	0.	0.	0.	79473.	0.	170999.
1941	0.	0.	264461.	0.	0.	0.	43080.	0.	0.	0.	172165.	0.	479706.
1942	0.	0.	0.	226317.	0.	0.	63001.	0.	0.	0.	0.	0.	289318.
1943	0.	0.	70848.	89527.	0.	0.	14637.	5585.	0.	0.	0.	0.	180597.
1944	49268.	0.	123984.	0.	0.	0.	14637.	0.	0.	0.	58988.	25428.	272305.
1945	0.	0.	146836.	0.	0.	0.	61321.	0.	0.	0.	0.	264722.	472879.
1946	0.	0.	219391.	0.	0.	0.	64660.	0.	0.	0.	86885.	0.	370936.
1947	0.	0.	160034.	0.	0.	0.	0.	19516.	0.	0.	0.	0.	179550.
1948	0.	12714.	64757.	0.	84254.	0.	28040.	0.	0.	0.	0.	0.	189765.
1949	0.	25428.	159311.	35866.	0.	0.	14637.	0.	0.	0.	52431.	102940.	390613.
1950	0.	0.	0.	188689.	0.	0.	40868.	0.	0.	0.	0.	0.	229557.
1951	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1952	0.	0.	0.	69626.	4055.	0.	0.	0.	0.	0.	0.	0.	73681.
1953	46279.	0.	0.	0.	89696.	0.	9758.	0.	0.	0.	0.	86447.	232180.
1954	0.	0.	0.	0.	81950.	0.	0.	0.	0.	0.	0.	0.	81950.
1955	0.	12714.	0.	70848.	0.	0.	10942.	0.	0.	0.	0.	0.	94504.
1956	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1957	0.	0.	0.	48683.	0.	0.	21540.	0.	0.	0.	260183.	0.	330407.
1958	0.	0.	243041.	0.	0.	0.	48990.	0.	0.	0.	0.	0.	292031.
1959	0.	0.	0.	147812.	0.	0.	28427.	0.	0.	0.	100854.	0.	277093.
1960	0.	0.	0.	32331.	165050.	109906.	14637.	0.	0.	0.	76284.	0.	398207.

1961	0.	0.	348688.	0.	0.	0.	14637.	0.	0.	0.	102433.	16860.	482618.
1962	0.	0.	0.	0.	0.	187000.	17120.	0.	0.	0.	12714.	97285.	314119.
1963	0.	0.	0.	73019.	0.	0.	15496.	0.	0.	0.	0.	0.	88515.
1964	0.	0.	0.	0.	0.	0.	0.	0.	7932.	0.	49819.	0.	57751.
1965	55916.	0.	70425.	141696.	0.	0.	14637.	0.	0.	0.	118684.	0.	401358.
1966	0.	0.	149062.	35424.	0.	0.	13814.	14637.	0.	0.	0.	0.	212936.
1967	0.	0.	0.	0.	57701.	0.	4879.	10868.	0.	0.	94076.	0.	167523.
1968	48546.	0.	338677.	0.	0.	0.	21540.	0.	0.	0.	24595.	236495.	669853.
1969	0.	0.	399137.	0.	0.	0.	0.	0.	10770.	3009.	0.	95858.	508774.
1970	12714.	0.	185701.	0.	0.	0.	29907.	0.	12239.	0.	0.	0.	240561.
1971	0.	0.	0.	0.	0.	0.	8794.	0.	0.	0.	12714.	75462.	96970.
1972	0.	0.	39266.	0.	120226.	0.	0.	16303.	0.	22045.	76284.	0.	274124.
1973	44877.	0.	176997.	0.	0.	0.	32310.	0.	0.	0.	214336.	65788.	534307.
1974	0.	0.	0.	0.	0.	0.	0.	30897.	0.	0.	159257.	0.	190154.
1975	0.	0.	0.	374221.	0.	0.	43507.	0.	0.	0.	0.	0.	417728.
1976	0.	0.	0.	36381.	0.	0.	26970.	0.	0.	0.	0.	226699.	290050.
1977	0.	0.	32331.	258160.	0.	0.	31655.	671.	0.	0.	0.	0.	322817.
1978	51067.	0.	0.	0.	0.	0.	0.	4879.	0.	0.	38142.	0.	94088.
1979	0.	0.	182215.	0.	0.	0.	74961.	0.	0.	0.	0.	0.	257176.
1980	130431.	0.	35424.	120360.	53136.	0.	0.	0.	4879.	13230.	0.	0.	357460.
1981	0.	0.	0.	0.	0.	70848.	14637.	0.	0.	0.	149601.	0.	235086.
1982	0.	0.	0.	90566.	71055.	0.	43080.	0.	0.	0.	0.	44174.	248876.
1983	60392.	38142.	169416.	0.	0.	0.	9758.	29772.	0.	0.	0.	0.	307479.
1984	0.	0.	0.	0.	0.	0.	0.	0.	0.	13394.	77025.	0.	90419.
1985	0.	0.	289586.	0.	0.	0.	0.	0.	0.	18442.	91148.	0.	399175.
1986	0.	0.	0.	0.	220245.	0.	34021.	0.	0.	0.	105770.	0.	360036.
1987	0.	0.	292188.	0.	0.	0.	34397.	0.	0.	0.	42977.	77003.	446565.
1988	0.	0.	0.	0.	0.	0.	0.	0.	4879.	0.	0.	0.	4879.
1989	12714.	23745.	35424.	14514.	88560.	0.	23897.	0.	0.	0.	0.	0.	198854.
1990	0.	55855.	213622.	18413.	0.	0.	21840.	0.	15282.	0.	0.	0.	325012.
1991	72610.	0.	0.	180463.	0.	0.	46144.	0.	0.	0.	123303.	93347.	515867.
1992	0.	0.	147909.	0.	0.	0.	42628.	0.	0.	0.	0.	223642.	414179.
1993	0.	0.	280236.	0.	0.	0.	21540.	0.	0.	0.	0.	0.	301776.
1994	0.	66906.	76187.	0.	89328.	0.	16252.	0.	16354.	9758.	0.	86147.	360933.
1995	0.	0.	123984.	0.	0.	0.	46300.	21540.	0.	0.	0.	50848.	242672.
1996	0.	0.	0.	0.	0.	0.	0.	9925.	0.	0.	0.	95398.	105324.
1997	47902.	0.	144925.	0.	0.	0.	43080.	0.	0.	0.	0.	147570.	383477.
1998	0.	0.	169651.	0.	0.	0.	0.	0.	14637.	9758.	105589.	0.	299634.
1999	0.	0.	0.	45416.	92286.	0.	0.	4879.	0.	0.	0.	0.	142581.
2000	0.	0.	0.	0.	0.	35424.	14834.	0.	0.	0.	12714.	0.	62972.
2001	0.	0.	146715.	0.	0.	0.	8470.	9758.	0.	0.	63570.	0.	228513.
2002	0.	0.	0.	0.	76348.	0.	14637.	0.	0.	0.	172165.	0.	263150.
2003	0.	0.	0.	0.	0.	209228.	20864.	9758.	0.	0.	56477.	0.	296327.
2004	92496.	0.	154886.	35424.	0.	0.	14637.	0.	0.	0.	145888.	0.	443331.
2005	0.	0.	0.	0.	0.	0.	12895.	14637.	0.	0.	0.	0.	27532.
2006	0.	0.	50370.	0.	0.	0.	0.	0.	11105.	0.	50485.	0.	111959.
2007	0.	0.	98030.	0.	0.	0.	21540.	0.	0.	0.	0.	0.	119570.
2008	0.	0.	188022.	0.	0.	0.	0.	19516.	0.	0.	0.	0.	207538.
2009	0.	0.	61785.	13447.	0.	0.	14405.	0.	0.	0.	71761.	0.	161398.
2010	0.	0.	0.	61072.	0.	0.	34319.	0.	0.	0.	0.	0.	95391.
2011	52819.	12714.	0.	0.	0.	0.	0.	0.	0.	4879.	0.	50576.	120988.
2012	0.	0.	17712.	0.	0.	0.	15773.	0.	0.	0.	0.	0.	33485.
MEAN	10658.	3400.	83168.	34043.	17725.	8389.	19370.	3057.	1344.	1295.	41901.	29626.	253975.

If daily pulse flow targets were always larger than the daily base flow limit, the second and third time series in the tables below could be added together to replicate the final monthly instream flow target in the first time series. However, pulse flow targets may be less than the base flow target when the regulated flow falls below the base flow limit but does not exceed the minimum pulse flow criterion in column 7 of Table 5.9. When the pulse flow target is less than the base flow target, the base flow target is adopted as the final daily instream flow requirement.

As seen in Tables 6.21 through 6.24 for the Seymour, Cameron, Waco, and Richmond locations, the annual mean pulse flow target is a relatively small volume compared to the annual mean base flow target. This is primarily a result of limiting pulse flow targets to not exceed the flow rate trigger criterion in *PF* record field 5. It is very common for regulated flow to greatly exceed the flow rate trigger and satisfy a pulse flow event volume in one or two days. During such events, the recorded daily pulse flow target will only equal the trigger flow criterion while the total event volume was counted in the regulated flow.

For example, the BBASC wet spring pulse at Richmond in Table 6.16 has a trigger criterion of 32,331 acre-feet per day, a total event volume criterion of 215,000 acre-feet, and required frequency of two pulses per season. If regulated flow greatly exceeds the trigger flow rate and the total event volume for both spring pulses is met in four days, the pulse flow target volume recorded for the entire four month spring season is only equal to 129,324 acre-feet. The wet spring base flow limit is 3,980 cfs or approximately 7,894 acre-feet per day. The base flow target for the entire spring season is 963,092 acre-feet.

Another contributing factor to the annual mean pulse flow target being much lower than the mean annual subsistence and base flow target is the number and magnitude of pulses. The BBASC recommendation has fewer and smaller pulses than recommended by the BBEST. The monthly total pulse flow targets from the ED model for the BBEST recommendation at Richmond are given in Table 6.25. The mean annual pulse flow target is equal to 1,326,194 acre-feet. For comparison, the mean annual pulse flow target for the BBASC recommendation at Richmond in the third time series of Table 6.24 is 261,084 acre-feet. The BBASC mean annual pulse target is only 19.7% of the magnitude of the BBEST mean annual pulse target.

The total number of days in the 73 year period of analysis when the BBEST pulse flow targets exceed the base flow target is given in Table 6.26 as 3,395 days. For comparison, the total number of days when the BBASC pulse flow targets exceed the base flow target is 1,304 days in Table 6.20.

Inclusion of larger and more frequent pulse flow events in the environmental flow regime requirement will increase the mean annual pulse flow target and total number of days of pulse flow target setting. However, large flow events can and will occur regardless of the pulse flow requirement set during any particular day or season. Even with unprotected high flow pulses, significant diversion capability is required to meaningfully reduce regulated flows. A comparison of the daily regulated flow from alternative configurations of the ED model in Chapter 7 will be made at all 19 locations in the BBASC and BBEST recommendations.

Table 6.25
Brazos River near Richmond BBEST Pulse Flow Targets

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0.	0.	0.	80478.	0.	120813.	129324.	64168.	0.	0.	637132.	964434.	1996348.
1941	0.	1072328.	151407.	632139.	0.	0.	81419.	35911.	50686.	0.	368335.	0.	2392226.
1942	0.	0.	0.	802584.	1020168.	57208.	84126.	9758.	28797.	26419.	0.	50442.	2079503.
1943	12714.	0.	70848.	93716.	0.	0.	56053.	74445.	0.	0.	0.	0.	307776.
1944	137741.	191679.	406332.	0.	1130649.	53136.	0.	0.	67714.	0.	111094.	432882.	2531228.
1945	11497.	0.	368135.	1204090.	92382.	53136.	140482.	12512.	0.	4879.	0.	139532.	2026643.
1946	172425.	286518.	854376.	86101.	1010197.	52878.	117918.	0.	14637.	18151.	447679.	94891.	3155771.
1947	12714.	0.	241020.	86139.	617918.	125287.	0.	81640.	0.	0.	0.	0.	1164718.
1948	0.	24595.	121801.	0.	79937.	0.	44609.	0.	0.	0.	0.	0.	270942.
1949	0.	49190.	167625.	164654.	139659.	0.	0.	0.	0.	113059.	30920.	48100.	713207.
1950	59345.	144748.	0.	239853.	93659.	160328.	9758.	44107.	14036.	0.	0.	0.	765833.
1951	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1952	0.	0.	0.	67064.	149316.	34824.	0.	0.	0.	0.	0.	0.	251205.
1953	48629.	0.	0.	0.	688827.	0.	10871.	0.	17344.	87531.	57607.	191837.	1102646.
1954	0.	0.	0.	0.	92318.	0.	0.	0.	0.	0.	0.	0.	92318.
1955	0.	45141.	0.	81278.	59566.	14290.	15864.	0.	62776.	26419.	0.	0.	305335.
1956	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1957	0.	0.	0.	659364.	1000265.	0.	41570.	0.	9762.	63264.	500415.	46877.	2321518.
1958	69478.	127775.	809390.	17712.	590864.	53413.	148576.	4879.	32310.	0.	0.	0.	1854397.
1959	0.	41708.	0.	205360.	287838.	0.	31867.	16015.	0.	41124.	136537.	136522.	896972.
1960	377880.	0.	0.	32331.	254536.	284382.	173702.	14170.	0.	148672.	382524.	960381.	2628579.
1961	1172238.	0.	199691.	0.	0.	597137.	284625.	0.	21540.	56019.	141739.	98138.	2571128.
1962	0.	0.	0.	0.	0.	64402.	155713.	13556.	9758.	0.	12714.	54451.	310595.
1963	25428.	38142.	0.	70848.	0.	0.	15185.	0.	0.	0.	0.	0.	149603.
1964	0.	0.	0.	0.	0.	0.	0.	0.	31454.	0.	50091.	0.	81545.
1965	291493.	242568.	0.	79641.	1169896.	0.	137652.	31175.	38904.	0.	193220.	101813.	2286363.
1966	0.	149222.	70848.	404826.	1028817.	0.	15716.	45870.	123495.	0.	0.	0.	1838793.
1967	0.	0.	0.	0.	56849.	0.	4879.	0.	0.	0.	49749.	0.	111476.
1968	678505.	345133.	375548.	55686.	451950.	0.	102348.	14637.	69242.	0.	95379.	163259.	2351688.
1969	0.	339832.	307585.	691584.	1045054.	0.	4879.	14408.	13005.	0.	0.	98676.	2515024.
1970	59756.	24595.	988680.	142726.	175959.	0.	4879.	0.	28572.	109685.	0.	0.	1534852.
1971	0.	0.	0.	0.	0.	0.	31795.	49712.	0.	0.	12714.	191759.	285981.
1972	50335.	0.	39396.	0.	190277.	0.	0.	13181.	0.	9758.	69423.	0.	372371.
1973	149236.	16165.	292745.	388225.	630639.	0.	93544.	14637.	16051.	76761.	228552.	105907.	2012462.
1974	334623.	19649.	0.	0.	85046.	0.	0.	41236.	138516.	0.	1113448.	146449.	1878968.
1975	42806.	1039969.	104092.	197079.	439339.	138842.	168671.	38601.	14152.	9758.	0.	0.	2193310.
1976	0.	0.	0.	133084.	85467.	211431.	178473.	30175.	0.	32310.	12714.	505378.	1189032.
1977	12714.	98380.	50043.	1092766.	230758.	89335.	4879.	0.	0.	0.	0.	0.	1578875.
1978	53343.	96523.	0.	0.	0.	0.	0.	42901.	35229.	0.	55021.	65351.	348368.
1979	187845.	25428.	195970.	209033.	369128.	1119174.	119070.	49575.	32188.	0.	0.	0.	2307410.
1980	145040.	50534.	35424.	35424.	688541.	0.	0.	0.	9758.	11598.	0.	0.	976319.
1981	0.	0.	0.	0.	0.	722004.	137796.	20528.	81791.	0.	347482.	0.	1309602.
1982	0.	0.	0.	75551.	768441.	164748.	22809.	0.	0.	0.	0.	32072.	1063620.
1983	59536.	300329.	255806.	0.	601563.	198564.	0.	62931.	46300.	0.	0.	0.	1525029.
1984	0.	0.	0.	0.	0.	0.	0.	0.	0.	131475.	0.	161117.	292592.
1985	207171.	146379.	276127.	0.	0.	46965.	0.	0.	0.	115065.	410720.	127577.	1330005.
1986	0.	37530.	0.	0.	157257.	164748.	24298.	16400.	43080.	123978.	136254.	443983.	1147528.
1987	0.	0.	213807.	0.	209860.	1497579.	136680.	4879.	0.	0.	43187.	102423.	2208415.
1988	10676.	0.	0.	0.	0.	0.	0.	0.	4879.	0.	0.	0.	15555.
1989	12714.	17367.	50043.	91228.	192665.	757876.	47798.	4879.	16079.	0.	0.	0.	1190650.
1990	0.	54332.	70848.	764370.	0.	0.	11675.	0.	29179.	0.	0.	0.	930404.
1991	344844.	121129.	0.	226184.	246599.	0.	44184.	0.	0.	79097.	118641.	878235.	2058914.
1992	425707.	937907.	0.	0.	907116.	0.	127638.	62346.	21237.	0.	12714.	114225.	2608890.
1993	180456.	0.	310213.	204602.	681378.	0.	0.	0.	0.	49961.	0.	0.	1426610.
1994	0.	136423.	27390.	0.	151478.	88850.	16260.	0.	16049.	1084904.	89667.	422284.	2033305.
1995	139087.	0.	165267.	269250.	688642.	0.	24395.	113118.	0.	0.	0.	51776.	1451536.
1996	0.	0.	0.	0.	0.	0.	0.	20899.	163370.	31965.	0.	38142.	254376.

1997	157489.	499254.	1398300.	256151.	39482.	56469.	0.	38863.	0.	32310.	12714.	371789.	2862821.
1998	37242.	114524.	987608.	0.	0.	0.	0.	12854.	15180.	1335430.	257860.	25428.	2786126.
1999	0.	0.	0.	79225.	102198.	0.	0.	4879.	0.	0.	0.	0.	186303.
2000	0.	0.	0.	0.	0.	1445962.	14910.	0.	0.	155142.	246944.	98380.	1961338.
2001	0.	25428.	216457.	155709.	0.	0.	20408.	137506.	46947.	11727.	363956.	78692.	1056831.
2002	0.	0.	0.	0.	153632.	0.	126490.	0.	9758.	21540.	405387.	689399.	1406206.
2003	47435.	0.	0.	0.	0.	131357.	14940.	26419.	89782.	46139.	57087.	0.	413159.
2004	48018.	447701.	155929.	216922.	0.	1633179.	10770.	56944.	0.	102348.	202351.	0.	2874161.
2005	52214.	0.	75367.	0.	0.	0.	8060.	373215.	21540.	0.	0.	0.	530396.
2006	0.	0.	182845.	89942.	87980.	0.	0.	0.	21984.	191127.	86538.	17357.	677774.
2007	393205.	24595.	717888.	193514.	1468197.	35424.	72714.	0.	0.	11027.	49315.	0.	2965878.
2008	0.	0.	180331.	204726.	16865.	0.	0.	35754.	0.	42632.	0.	0.	480307.
2009	0.	0.	60299.	108418.	98508.	0.	8122.	0.	134641.	1159295.	370075.	56393.	1995750.
2010	187932.	0.	184337.	156078.	6221.	0.	140695.	0.	7688.	0.	0.	0.	682950.
2011	54141.	25428.	0.	0.	0.	0.	0.	0.	0.	61944.	0.	226268.	367780.
2012	258889.	0.	640791.	0.	0.	0.	21279.	12736.	32310.	0.	0.	0.	966005.
MEAN	92090.	100797.	164666.	151310.	281286.	139366.	47128.	24143.	23037.	77021.	108464.	116885.	1326194.

Table 6.26
Number of Days per Month that BBEST Pulse Targets Are Set at Richmond

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0	0	0	9	0	6	4	8	0	0	9	9	45
1941	0	25	5	12	0	0	4	5	7	0	9	0	67
1942	0	0	0	17	15	3	4	2	3	3	0	4	51
1943	1	0	4	8	0	0	3	10	0	0	0	0	26
1944	9	9	16	0	13	3	0	0	7	0	5	17	79
1945	1	0	12	20	6	3	9	1	0	1	0	6	59
1946	12	7	20	5	17	2	13	0	3	4	14	4	101
1947	1	0	9	5	14	4	0	4	0	0	0	0	37
1948	0	1	12	0	6	0	9	0	0	0	0	0	28
1949	0	2	10	5	6	0	0	0	0	7	3	4	37
1950	6	8	0	9	7	5	2	5	2	0	0	0	44
1951	0	0	0	0	0	0	0	0	0	0	0	0	0
1952	0	0	0	6	5	3	0	0	0	0	0	0	14
1953	4	0	0	0	16	0	2	0	4	4	6	10	46
1954	0	0	0	0	8	0	0	0	0	0	0	0	8
1955	0	6	0	5	7	3	3	0	5	3	0	0	32
1956	0	0	0	0	0	0	0	0	0	0	0	0	0
1957	0	0	0	8	14	0	4	0	2	3	14	3	48
1958	5	3	24	1	12	3	8	1	3	0	0	0	60
1959	0	4	0	8	13	0	3	3	0	2	7	7	47
1960	10	0	0	1	13	5	12	3	0	8	20	21	93
1961	19	0	7	0	0	12	11	0	2	8	8	11	78
1962	0	0	0	0	0	5	9	3	2	0	1	5	25
1963	2	3	0	4	0	0	4	0	0	0	0	0	13
1964	0	0	0	0	0	0	0	0	3	0	6	0	9
1965	7	14	0	5	17	0	6	6	5	0	16	9	85
1966	0	8	4	4	11	0	3	5	8	0	0	0	43
1967	0	0	0	0	5	0	1	0	0	0	4	0	10
1968	15	16	13	3	8	0	4	3	7	0	7	10	86
1969	0	10	13	16	21	0	1	3	3	0	0	9	76
1970	6	1	27	7	14	0	1	0	7	10	0	0	73
1971	0	0	0	0	0	0	4	7	0	0	1	10	22
1972	4	0	3	0	9	0	0	2	0	2	6	0	26
1973	8	1	14	8	19	0	10	3	2	3	10	6	84
1974	10	1	0	0	5	0	0	3	8	0	21	7	55
1975	3	21	6	7	9	2	10	4	3	2	0	0	67
1976	0	0	0	4	4	8	12	7	0	3	1	19	58
1977	1	4	2	18	4	7	1	0	0	0	0	0	37

1978	5	8	0	0	0	0	0	5	4	0	3	12	37
1979	10	2	7	8	8	12	8	5	5	0	0	0	65
1980	7	4	2	2	15	0	0	0	2	2	0	0	34
1981	0	0	0	0	0	15	7	3	11	0	8	0	44
1982	0	0	0	5	16	6	1	0	0	0	0	3	31
1983	7	14	11	0	16	12	0	10	7	0	0	0	77
1984	0	0	0	0	0	0	0	0	0	9	0	8	17
1985	12	3	9	0	0	4	0	0	0	9	17	3	57
1986	0	3	0	0	9	6	5	3	4	5	8	13	56
1987	0	0	8	0	13	21	6	1	0	0	4	8	61
1988	2	0	0	0	0	0	0	0	1	0	0	0	3
1989	1	2	2	9	6	16	6	1	4	0	0	0	47
1990	0	6	4	24	0	0	2	0	6	0	0	0	42
1991	9	5	0	9	9	0	9	0	0	5	7	14	67
1992	4	10	0	0	21	0	5	6	3	0	1	5	55
1993	9	0	13	7	14	0	0	0	0	6	0	0	49
1994	0	7	2	0	6	6	3	0	4	17	10	13	68
1995	8	0	6	11	15	0	5	5	0	0	0	5	55
1996	0	0	0	0	0	0	0	3	15	4	0	3	25
1997	10	9	18	8	1	3	0	7	0	3	1	11	71
1998	1	5	31	0	0	0	0	3	2	26	11	2	81
1999	0	0	0	6	7	0	0	1	0	0	0	0	14
2000	0	0	0	0	0	26	4	0	0	8	5	4	47
2001	0	2	6	10	0	0	2	10	6	2	13	6	57
2002	0	0	0	0	10	0	5	0	2	2	7	10	36
2003	4	0	0	0	0	4	3	3	4	6	6	0	30
2004	4	14	9	7	0	17	1	8	0	4	6	0	70
2005	4	0	4	0	0	0	2	6	2	0	0	0	18
2006	0	0	8	8	8	0	0	0	4	12	7	3	50
2007	11	1	17	14	29	2	4	0	0	2	4	0	84
2008	0	0	6	10	2	0	0	4	0	5	0	0	27
2009	0	0	4	5	5	0	2	0	7	14	10	5	52
2010	10	0	12	6	1	0	14	0	1	0	0	0	44
2011	5	2	0	0	0	0	0	0	0	3	0	14	24
2012	6	0	14	0	0	0	5	3	3	0	0	0	31
TOTAL	253	241	394	344	509	224	256	175	183	207	296	313	3395

Summary of Results from the Daily ED Model with BBASC Environmental Flows

The remainder of Chapter 6 consists of summarizing results from the version of the daily ED simulation that contains the environmental flow requirements recommended by the BBASC. Simulation results are summarized by presenting (1) frequency tables for environmental flow targets and shortages in meeting the targets and (2) time series plots of naturalized, regulated, and unappropriated flows, and environmental flow targets and shortages.

The 19 control points with BBASC environmental flow recommendations are listed in Table 5.8 with their locations shown in Figure 5.17. The map showing the locations of the 19 control points is reproduced on the next page as Figure 6.7. The notation shown in Table 6.12 is used to assign a separate adjacent control point at the same location for the BBASC environmental flow regimes. The following presentation focuses largely on control points BRSE11 (BRSE1E), LRCA58 (LRCA5E), BRWA41 (BRWA4E), and BRRI70 (BRRI7E) at the USGS gages near the towns of Seymour, Cameron, Waco, and Richmond.

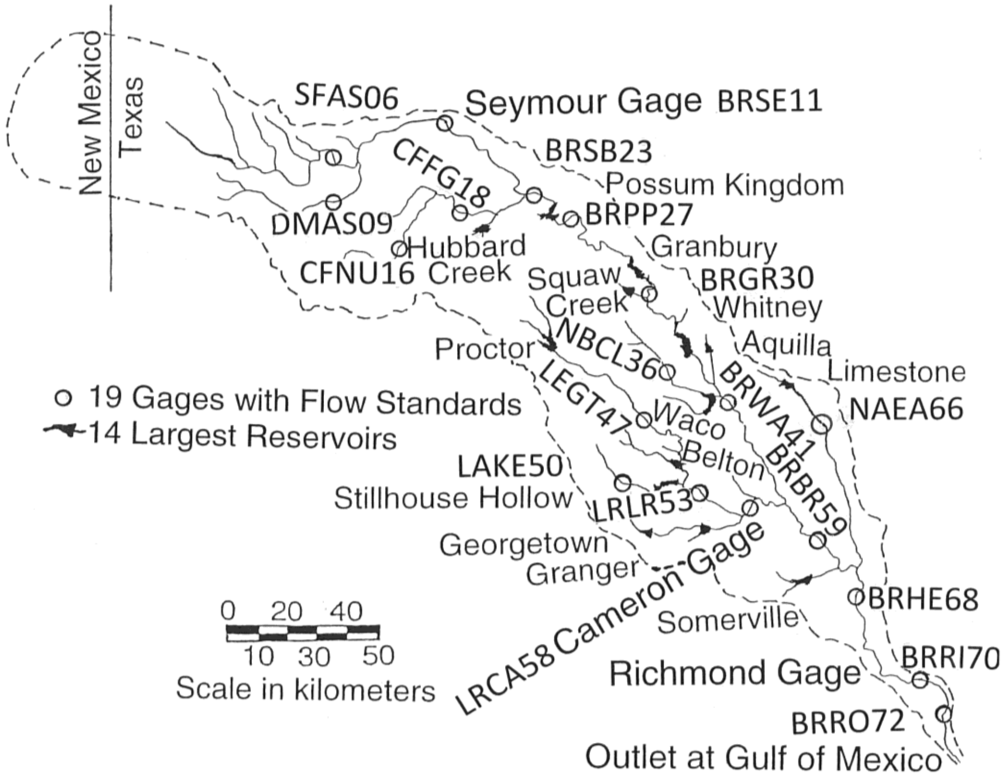

Figure 6.7 Locations for Environmental Flow Requirements

Frequency Metrics for Environmental Flow Targets and Shortages at Four Sites

Base flow targets are set independently of daily regulated flow. Instream flow shortages are incurred when regulated flow falls below the base flow limit, either by natural daily flow variability or by stream flow depletions of upstream senior water rights. However, pulse flow targets are set only when the daily regulated flow initiates a pulse event. Pulse targets are set not to exceed either the trigger flow criterion or the magnitude of the regulated flow at the priority of the *WR* or *IF* record associated with the *PF* record. Therefore, no instream flow shortages for targets set by *PF* records will occur unless an upstream junior water right violates the instream flow requirement set by the *IF* record. As discussed previously and illustrated in Figure 6.4, junior flood control reservoir *FR* records can cause pulse flow shortages.

Daily BBASC instream flow target frequency metrics are presented in Tables 6.27 and 6.28 for the Seymour, Cameron, Waco, and Richmond locations. The lowest base flow targets set at Seymour, Cameron, Waco, and Richmond are 7.9, 192.4, 238.0, and 1844.6 ac-ft per day, respectively. The highest base flow targets set at the same locations are 91.2, 1507.4, 1368.6 and 7894.3 acre-feet per day, respectively. As seen in the target frequency table, base flow targets dominate. Base flow targets occupy the 90% through 2% exceedance frequencies at Seymour. Base flow targets occupy the 85% through 5% exceedance frequencies at Cameron. Base flow targets occupy the 95% through 5% exceedance frequencies at Waco. Base flow targets occupy the 85% through 5% exceedance frequencies at Richmond.

Table 6.27
BBASC Daily Instream Flow Target Frequency, acre-feet per day

	BRSE1E	LRCA5E	BRWA4E	BRRI7E
Mean	52.72	606.31	812.30	4179.33
Std Dev	120.69	791.01	1661.82	3512.51
Minimum	2.00	63.50	111.10	1090.90
99.5%	2.00	63.50	111.10	1090.90
99%	2.00	63.50	111.10	1090.90
98%	2.00	63.50	145.56	1090.90
95%	2.10	63.50	238.00	1090.90
90%	7.90	75.80	277.70	1319.64
85%	13.90	192.40	277.70	1844.60
80%	19.80	277.70	297.50	1963.60
75%	25.80	317.40	416.50	2638.00
70%	25.80	317.40	416.50	2638.00
60%	25.80	317.40	416.50	2638.00
50%	37.70	376.90	495.90	3272.70
40%	49.60	614.90	535.50	4244.60
30%	49.60	614.90	535.50	4244.60
25%	49.60	654.50	952.10	4343.80
20%	63.50	654.50	1170.20	6529.16
15%	69.40	912.40	1170.20	6565.30
10%	69.40	1507.40	1368.60	7894.20
5%	91.20	1507.40	1368.60	7894.20
2%	91.20	1964.00	3927.00	15011.22
1%	734.00	4245.00	8291.00	17712.00
0.5%	1111.00	6347.00	10572.00	24595.00
Maximum	2063.00	9501.00	26975.00	32331.00

Table 6.28 replaces the numerical data of Table 6.27 with the applicable environmental flow component label. In both target frequency tables, subsistence flow targets, the 50% rule targets, and pulse flow targets occur during a small percentage of the total days of the simulation. However, replicating and assessing flow variability at the low and high flow ends of the flow regime are important in analyzing the reliability of meeting environmental flow requirements.

Instream flow shortage frequency metrics are tabulated in Table 6.29 for the control points at the USGS gaging stations near Seymour, Cameron, Waco, and Richmond. With the exception of the maximum shortages listed at Cameron and Waco, all shortages are attributable to shortages for meeting subsistence or base flow targets. Targets set for pulse flow or the 50% rule low flows are based on regulated flow measured at the priority date of the water right *WR* record. Only junior water rights that ignore the downstream instream flow requirements are capable of further reducing stream flow and causing an instream flow shortage. In the case of the maximum shortage at Cameron and Waco in Table 6.29, upstream flood control operations in the ED model deplete stream flow and reduce regulated flow that was used earlier in the day to set a pulse flow target. This occurrence is discussed in an earlier section of this chapter and illustrated in Figure 6.4 at Cameron.

BBASC instream flow requirements at the Brazos River near Waco benefit from EM and ED modeled hydropower releases to Lake Whitney. Hydropower is assigned a junior priority. However, the next-day return flow option allows hydropower releases to benefit senior rights.

Table 6.28
BBASC Daily Instream Flow Target Frequency by Component

	BRSE1E	LRCA5E	BRWA4E	BRRI7E
Minimum	Subsistence	Subsistence	Subsistence	Subsistence
99.5%	Subsistence	Subsistence	Subsistence	Subsistence
99%	Subsistence	Subsistence	Subsistence	Subsistence
98%	Subsistence	Subsistence	50% Rule	Subsistence
95%	50% Rule	Subsistence	Base	Subsistence
90%	Base	50% Rule	Base	50% Rule
85%	Base	Base	Base	Base
80%	Base	Base	Base	Base
75%	Base	Base	Base	Base
70%	Base	Base	Base	Base
60%	Base	Base	Base	Base
50%	Base	Base	Base	Base
40%	Base	Base	Base	Base
30%	Base	Base	Base	Base
25%	Base	Base	Base	Base
20%	Base	Base	Base	Base
15%	Base	Base	Base	Base
10%	Base	Base	Base	Base
5%	Base	Base	Base	Base
2%	Base	Pulse	Pulse	Pulse
1%	Pulse	Pulse	Pulse	Pulse
0.5%	Pulse	Pulse	Pulse	Pulse
Maximum	Pulse	Pulse	Pulse	Pulse

Table 6.29
BBASC Daily Instream Flow Shortage Frequency, acre-feet per day

	BRSE1E	LRCA5E	BRWA4E	BRRI7E
Mean	8.09	113.10	44.95	655.39
Std Dev	16.04	225.25	352.44	1261.45
Minimum	0.00	0.00	0.00	0.00
99.5%	0.00	0.00	0.00	0.00
99%	0.00	0.00	0.00	0.00
98%	0.00	0.00	0.00	0.00
95%	0.00	0.00	0.00	0.00
90%	0.00	0.00	0.00	0.00
85%	0.00	0.00	0.00	0.00
80%	0.00	0.00	0.00	0.00
75%	0.00	0.00	0.00	0.00
70%	0.00	0.00	0.00	0.00
60%	0.00	0.00	0.00	0.00
50%	0.00	0.00	0.00	0.00
40%	0.00	6.67	0.00	0.00
30%	2.00	56.89	0.00	496.22
25%	6.38	157.74	0.00	818.57
20%	17.66	236.81	0.00	1339.92
15%	25.80	288.54	6.88	1726.34
10%	31.48	362.56	114.06	2226.65
5%	47.29	563.65	297.46	3261.16
2%	62.45	834.88	465.57	5064.22
1%	66.71	1115.50	550.34	6064.14
0.5%	69.40	1274.35	727.16	6866.13
Maximum	91.20	6329.74	26969.93	7810.35

Further graduation of the exceedance frequencies or choosing an alternative method for developing exceedance frequencies may change the assessment. Frequencies presented in this report were developed using the default relative frequency method in *TABLES*.

At least 50% of the daily instream flow targets are met without shortage at Seymour, Cameron, Waco, and Richmond. However, modeling assumptions such as water right demands, flood control, system operations, hydropower releases, and simulation time step can affect shortage frequency. Each modeling assumption will affect regulated flow and consequently affect shortage frequency. Comparison of environmental flow requirements under different modeling assumptions is the subject of Chapter 7.

Frequency Metrics for Environmental Flow Targets and Shortages at the 19 Sites

Daily BBASC instream flow target and instream flow shortage frequencies are given in Tables 6.30 and 6.31 for all of the 19 locations shown in Figure 6.7. These tables do not contain the same number of exceedance frequencies as examined in Tables 6.27 and 6.29. However, the same conclusions can be drawn. Base flow targets tend to dominate the number of days of target setting at all locations. Flood control operations cause at least one pulse flow shortage at Waco and Cameron in the period of analysis as evident by the maximum shortage values in Table 6.30.

Since pulse flow targets are set according to the value of daily regulated flow, it is not possible to accurately assess if pulse flows are being satisfied during the simulation using an instream flow shortage analysis. Except when junior water rights, such as flood control reservoirs, ignore the downstream instream flow requirements, pulse flow targets will not result in an instream flow shortage. Totaling the number of pulse flow initiations during the simulation is an alternative method for examining whether pulse flows are being satisfied. The total number of pulse flows initiated during the simulation can be compared against the theoretical maximum number of pulse flows possible. The theoretical maximum number of pulse flows is obtained by multiplying the recommended pulse flow frequency by the number of years or seasons in the period of analysis.

Table 6.32 provides a summation of all BBASC pulse flows initiated during the period of analysis at all 19 locations. This information was compiled from output tables in the *SIMD* daily message SMM file. The second column from the right gives the maximum number of pulses expected if the pulse frequency is met in every season of every year. The far right column gives the percentage of the total number of pulses initiated in the simulation as compared to the maximum.

The total number of days that pulse targets are larger than the base flow targets are given in Table 6.33. Pulse flow targets set the final instream flow requirement when they create a target larger than the base flow target. This information is compiled from the monthly OUT file with the use of type 8 target setting water rights that track the relative size of the pulse flow and base flow target setting water rights. The far right column of Table 6.33 is created by dividing the total number of pulses in Table 6.32 by the total number of pulse days in Table 6.33.

A more detailed pulse flow analysis can be made for individual pulse flow requirements. Tables 6.32 and 6.33 summarize all pulse flow events into a single table for illustration purposes.

Inspection of the number of pulses and the number of days per pulse for individual pulse requirements is more appropriate when multiple pulses of varying sizes can be engaged simultaneously by a single flow event. This is the case for the BBEST recommendations.

Table 6.30
BBASC Daily Instream Flow Target Frequency, 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
SFAS0E	8.76	32.4	2.00	2.00	2.00	2.00	2.00	2.00	2.0	4.0	6.0	7.9	9.9	595.0
DMAS0E	14.35	61.2	2.00	2.00	2.00	2.00	2.00	4.00	4.0	6.0	7.9	7.9	15.9	1131.0
BRSE1E	52.72	120.7	2.00	2.00	2.00	2.10	7.90	25.80	25.8	37.7	49.6	49.6	69.4	2063.0
CFNU1E	16.20	41.9	2.00	2.00	2.00	2.00	2.00	7.90	9.9	11.9	15.9	15.9	23.8	1170.0
CFFG1E	33.93	95.3	2.00	2.00	2.00	2.00	2.00	9.90	15.9	25.8	33.7	33.7	53.6	2440.0
BRSB2E	145.30	253.2	2.00	2.00	2.00	6.10	31.70	91.20	91.2	119.0	144.8	144.8	198.3	4919.0
BRPP2E	251.67	657.7	33.70	33.70	33.70	33.70	77.40	79.30	121.0	142.8	148.8	198.3	238.0	6684.0
BRGR3E	382.05	1170.8	31.70	31.70	31.70	73.40	73.40	93.20	138.8	152.7	182.5	317.4	337.2	12853.0
NBCL3E	37.51	116.6	2.00	2.00	2.00	2.00	3.30	15.90	15.9	23.8	31.7	33.7	65.5	1408.0
BRWA4E	812.30	1661.8	111.10	111.10	145.56	238.00	277.70	416.50	416.5	495.9	535.5	952.1	1368.6	26975.0
LEGT4E	51.15	84.4	2.00	2.00	2.00	2.00	3.80	23.80	23.8	39.7	47.6	53.6	107.1	1250.0
LAKE5E	64.31	135.8	19.80	19.80	19.80	19.80	19.80	45.60	45.6	53.6	57.5	63.5	85.3	2598.0
LRLR5E	349.90	528.7	109.10	109.10	109.10	109.10	109.10	218.20	218.2	238.0	297.5	376.9	674.4	6526.0
LRCA5E	606.31	791.0	63.50	63.50	63.50	63.50	75.80	317.40	317.4	376.9	614.9	654.5	1507.4	9501.0
BRBR5E	2435.86	1884.4	595.00	595.00	595.00	654.82	890.64	1705.80	1705.8	1824.8	2499.2	2915.7	4879.3	20628.0
NAFA6E	47.96	173.3	2.00	4.60	5.70	6.00	6.00	15.90	19.8	27.8	31.7	37.7	57.5	2658.0
BRHE6E	3870.46	3367.9	1011.60	1011.60	1011.60	1043.36	1378.74	2638.00	2638.0	2856.2	3768.6	4066.1	6823.1	33322.0
BRRI7E	4179.33	3512.5	1090.90	1090.90	1090.90	1090.90	1319.64	2638.00	2638.0	3272.7	4244.6	4343.8	7894.2	32331.0
BRRO7E	4785.51	3767.7	852.90	852.90	852.90	852.90	852.90	2816.50	2816.5	4145.5	5097.5	5216.5	9401.7	28165.0

Table 6.31
BBASC Daily Instream Flow Shortage Frequency, 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
SFAS0E	1.28	2.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	1.6	4.6	17.3
DMAS0E	3.03	5.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	2.0	4.0	7.9	29.8
BRSE1E	8.09	16.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	6.4	31.5	91.2
CFNU1E	2.42	4.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	2.0	8.8	25.8
CFFG1E	9.36	15.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	2.0	9.9	33.7	67.4
BRSB2E	22.77	44.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	19.5	91.2	238.0
BRPP2E	34.90	60.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	52.0	130.6	227.9
BRGR3E	35.61	75.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	15.6	145.4	337.2
NBCL3E	4.44	9.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	2.0	16.0	65.5
BRWA4E	44.95	352.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	114.1	26969.9
LEGT4E	9.17	19.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	3.6	36.1	107.1
LAKE5E	13.11	18.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	8.9	22.3	43.0	84.7
LRLR5E	83.02	248.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	46.9	109.1	220.7	6526.0
LRCA5E	113.10	225.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	6.7	157.7	362.6	6329.7
BRBR5E	323.44	659.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	318.1	1221.3	4656.4
NAFA6E	3.02	7.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	13.1	57.5
BRHE6E	478.76	978.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	497.1	1772.8	6554.4
BRRI7E	655.39	1261.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	818.6	2226.7	7810.4
BRRO7E	1289.84	2025.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	616.9	2150.5	4016.5	9392.0

Table 6.32
Number of BBASC Pulses Initiated During the 73 Year Period-of-Analysis

CP ID	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MAX	% MAX
SFAS0E	0	0	18	26	40	20	60	24	12	3	0	0	203	219	92.7%
DMAS0E	0	0	20	26	40	23	55	29	13	3	0	0	209	219	95.4%
BRSE1E	0	0	24	25	43	15	59	20	15	5	0	0	206	219	94.1%
CFNU1E	1	0	23	28	30	17	75	14	5	7	13	2	215	237	90.7%
CFFG1E	0	0	22	19	32	24	52	17	15	8	13	2	204	237	86.1%
BRSB2E	0	0	38	21	33	10	67	21	10	8	0	0	208	219	95.0%
BRPP2E	21	21	78	61	95	52	123	35	64	47	105	25	727	1149	63.3%
BRGR3E	16	33	76	51	84	52	112	35	61	59	127	23	729	1149	63.4%
NBCL3E	3	2	57	34	25	17	31	2	3	0	17	4	195	255	76.5%
BRWA4E	13	19	33	24	38	19	64	14	26	20	44	27	341	492	69.3%
LEGT4E	2	2	77	28	30	12	128	11	11	9	21	3	334	365	91.5%
LAKE5E	9	11	28	18	27	23	78	33	27	14	87	27	382	492	77.6%
LRLR5E	10	16	57	25	26	15	93	21	15	11	56	33	378	492	76.8%
LRCA5E	14	13	54	35	20	8	95	17	14	10	70	29	379	492	77.0%
BRBR5E	9	16	75	29	24	10	99	21	18	14	79	26	420	492	85.4%
NAEA6E	14	22	69	19	27	2	20	4	4	2	65	28	276	365	75.6%
BRHE6E	19	15	74	39	28	9	102	34	19	19	66	39	463	492	94.1%
BRRI7E	16	9	75	32	18	7	106	26	10	10	68	33	410	492	83.3%
BRRO7E	19	16	84	30	20	6	97	24	11	13	53	29	402	492	81.7%

Table 6.33
Number of Days BBASC Pulses Initiated During the 73 Year Period-of-Analysis

CP ID	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL DAYS	TOTAL PULSES /TOTALS DAYS
SFAS0E	0	0	36	54	72	37	93	39	24	5	0	0	360	1.77
DMAS0E	0	0	35	45	68	41	97	59	28	6	0	0	379	1.81
BRSE1E	0	0	59	62	89	37	115	33	29	11	0	0	435	2.11
CFNU1E	1	2	50	65	71	35	158	28	7	12	22	6	457	2.13
CFFG1E	0	0	59	35	102	88	106	36	34	12	20	6	498	2.44
BRSB2E	0	0	90	53	69	23	134	39	18	11	0	0	437	2.10
BRPP2E	32	32	142	113	156	80	187	57	93	66	129	44	1131	1.56
BRGR3E	33	66	171	131	195	149	165	70	128	115	200	52	1475	2.02
NBCL3E	11	3	116	71	72	42	42	2	5	0	32	10	406	2.08
BRWA4E	35	52	107	97	111	62	143	36	62	40	98	67	910	2.67
LEGT4E	5	4	150	59	65	26	135	13	15	12	22	6	512	1.53
LAKE5E	13	15	69	46	70	66	103	43	28	19	144	42	658	1.72
LRLR5E	19	25	184	96	80	70	130	26	23	17	95	66	831	2.20
LRCA5E	22	27	167	115	72	48	150	28	23	12	137	58	859	2.27
BRBR5E	24	37	223	79	90	35	185	42	48	26	156	58	1003	2.39
NAEA6E	32	63	215	52	81	2	29	4	8	2	120	45	653	2.37
BRHE6E	53	45	289	174	120	30	189	67	39	39	183	130	1358	2.93
BRRI7E	58	29	299	147	93	33	200	43	20	18	211	153	1304	3.18
BRRO7E	78	56	282	106	72	18	166	38	17	23	173	139	1168	2.91

Final daily target frequency, daily shortage frequency, number of pulses in the period of analysis, and number of days that pulse requirements set the final daily target are given in Tables 6.34 through 6.37. The BBEST recommendations contain larger and more frequent pulse flows as seen in a comparison of BBASC and BBEST target frequencies in Tables 6.30 and 6.34.

Table 6.34
BBEST Daily Instream Flow Target Frequency, 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											
SFAS0E	59.45	471.1	2.00	2.00	2.00	2.00	2.00	2.00	4.0	4.0	6.0	7.9	17.9	11980.0
DMAS0E	101.22	850.0	2.00	2.00	2.00	2.00	2.00	4.00	6.0	6.0	7.9	13.9	29.8	32331.0
BRSE1E	254.68	1510.1	2.00	2.00	2.00	2.00	6.60	25.80	37.7	37.7	49.6	63.5	91.2	33322.0
CFNU1E	60.17	432.0	2.00	2.00	2.00	2.00	2.00	7.90	11.9	11.9	15.9	17.9	25.8	15570.0
CFFG1E	114.57	756.3	2.00	2.00	2.00	2.00	2.00	9.90	25.8	25.8	33.7	39.7	67.4	17117.0
BRSB2E	568.03	2646.4	2.00	2.00	2.00	3.20	18.50	91.20	119.0	119.0	144.8	188.4	341.2	50380.0
BRPP2E	544.35	2763.2	33.70	33.70	33.70	33.70	77.40	121.00	121.0	142.8	148.8	198.3	238.0	51174.0
BRGR3E	693.33	3530.4	31.70	31.70	31.70	73.40	73.40	138.80	152.7	152.7	182.5	317.4	337.2	66645.0
NBCL3E	134.61	1157.1	2.00	2.00	2.00	2.00	2.60	13.90	15.9	23.8	31.7	33.7	65.5	39273.0
BRWA4E	1513.57	5352.5	111.10	111.10	127.93	238.00	277.70	416.50	416.5	495.9	535.5	952.1	1368.6	84496.0
LEGT4E	154.62	767.1	2.00	2.00	2.00	2.00	2.00	23.80	39.7	39.7	47.6	53.6	107.1	15035.0
LAKE5E	115.70	670.6	19.80	19.80	19.80	19.80	19.80	45.60	45.6	53.6	57.5	57.5	85.3	25785.0
LRLR5E	639.80	1721.7	109.10	109.10	109.10	109.10	109.10	218.20	218.2	238.0	297.5	376.9	674.4	23207.0
LRCA5E	1163.57	3439.6	63.50	63.50	63.50	63.50	82.80	317.40	376.9	376.9	614.9	654.5	1507.4	59306.0
BRBR5E	4233.86	9113.8	595.00	595.00	595.00	624.04	809.84	1705.80	1824.8	1824.8	2499.2	2915.7	5931.0	132694.0
NAFA6E	258.10	1635.1	2.00	4.60	5.70	6.00	6.00	15.90	19.8	27.8	31.7	37.7	57.5	33124.0
BRHE6E	5931.61	11504.5	1011.60	1011.60	1011.60	1011.60	1248.36	2638.00	2856.2	2856.2	3768.6	4066.1	7273.0	126744.0
BRRI7E	6615.69	12625.7	1090.90	1090.90	1090.90	1090.90	1214.76	2638.00	3272.7	3272.7	4244.6	4343.8	10770.0	135074.0
BRRO7E	7272.40	13003.7	852.90	852.90	852.90	852.90	852.90	2816.50	4145.5	4145.5	5097.5	5216.5	9878.0	120793.0

Table 6.35
BBEST Daily Instream Flow Shortage Frequency, 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											
SFAS0E	1.13	2.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	1.5	3.8	17.3
DMAS0E	2.68	4.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1.8	3.5	7.9	29.8
BRSE1E	6.61	14.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	2.0	25.9	91.2
CFNU1E	2.18	4.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	2.0	8.7	25.8
CFFG1E	8.10	14.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	2.0	9.9	33.5	67.4
BRSB2E	17.59	39.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	1.9	81.8	238.0
BRPP2E	33.55	59.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	37.9	130.2	225.3
BRGR3E	33.35	70.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	14.4	142.5	337.2
NBCL3E	3.14	7.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	2.0	13.2	65.5
BRWA4E	186.05	2420.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	68.0	84492.0
LEGT4E	6.60	15.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	2.0	23.8	107.1
LAKE5E	11.62	16.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	7.2	19.8	40.2	84.7
LRLR5E	162.51	945.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	37.0	102.3	217.3	23207.0
LRCA5E	95.82	327.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	73.5	304.4	14606.9
BRBR5E	221.05	497.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	144.9	892.9	4810.0
NAFA6E	2.51	6.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	9.9	57.5
BRHE6E	335.68	755.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	231.6	1333.9	14376.7
BRRI7E	480.06	955.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	569.3	1800.5	7885.2
BRRO7E	1024.68	1636.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	434.9	1782.6	3453.2	9392.9

Mean instream flow shortage frequency is lower for the BBEST requirements than for the BBASC requirements at all locations except for Waco and Little River. Instream flow targets set by pulse flow events do not result in a shortage because the instream flow target is set up to the regulated flow observed at the priority date of the *WR/PF* or *IF/PF* record pair. Flood control rights are the only junior rights in the simulations that ignore downstream water availability computations including instream flow requirements. Mean shortages at Waco and Little River are influenced by upstream flood control storage operations that occur after pulse flow targets are set. Maximum values of shortage at several gages are reflective of pulse flow requirement shortages.

Table 6.36
Number of BBEST Pulses Initiated During the 73 Year Period-of-Analysis

CP ID	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MAX	% MAX
SFAS0E	21	19	40	85	180	168	170	134	137	65	70	41	1130	1788	63.2%
DMAS0E	15	19	40	80	194	194	138	152	134	68	75	38	1147	1803	63.6%
BRSE1E	20	23	41	79	194	152	125	139	133	74	70	34	1084	1788	60.6%
CFNU1E	28	31	39	69	153	106	142	102	110	61	72	24	937	1365	68.6%
CFFG1E	31	20	30	53	119	94	91	76	99	72	52	24	761	1387	54.9%
BRSB2E	18	20	71	112	189	114	154	130	146	94	62	36	1146	1788	64.1%
BRPP2E	29	46	47	74	98	74	80	47	83	70	64	37	749	1642	45.6%
BRGR3E	29	52	49	59	93	64	71	44	73	83	72	44	733	1642	44.6%
NBCL3E	54	59	55	81	95	39	65	37	66	77	62	47	737	1511	48.8%
BRWA4E	41	68	49	64	87	51	95	49	58	71	49	61	743	1642	45.2%
LEGT4E	47	46	112	135	150	98	150	128	101	114	78	60	1219	1861	65.5%
LAKE5E	32	35	58	52	75	51	91	94	92	71	122	80	853	1438	59.3%
LRLR5E	53	60	81	86	97	58	81	69	101	80	72	79	917	1657	55.3%
LRCA5E	89	88	85	112	128	48	107	88	145	114	118	114	1236	2299	53.8%
BRBR5E	87	93	116	115	132	63	125	115	122	126	107	121	1322	2299	57.5%
NAEA6E	100	96	131	82	133	42	47	40	60	86	97	135	1049	2007	52.3%
BRHE6E	60	64	61	83	77	38	72	61	73	86	64	70	809	1423	56.9%
BRRI7E	59	51	72	85	84	46	85	74	73	80	85	69	863	1423	60.6%
BRRO7E	61	48	75	87	86	42	72	63	78	75	75	50	812	1423	57.1%

Table 6.37
Number of Days BBEST Pulses Initiated During the 73 Year Period-of-Analysis

CP ID	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL DAYS	TOTAL PULSES /TOTALS DAYS
SFAS0E	60	51	86	130	334	309	269	211	220	169	146	106	2091	1.85
DMAS0E	38	38	63	138	362	427	292	260	279	142	142	93	2274	1.98
BRSE1E	44	44	82	163	432	474	281	284	343	145	129	71	2492	2.30
CFNU1E	68	77	119	170	387	399	346	249	292	162	152	54	2475	2.64
CFFG1E	72	41	80	127	356	328	259	217	240	134	133	58	2045	2.69
BRSB2E	43	60	173	256	514	403	346	261	293	225	176	75	2825	2.47
BRPP2E	52	85	118	183	309	197	200	101	195	189	122	54	1805	2.41
BRGR3E	62	112	148	160	302	226	159	145	207	186	179	103	1989	2.71
NBCL3E	100	130	131	144	215	120	78	56	70	148	125	82	1399	1.90
BRWA4E	121	175	169	209	348	194	228	122	146	155	149	149	2165	2.91
LEGT4E	121	99	274	285	404	297	236	179	163	159	197	108	2522	2.07
LAKE5E	57	78	136	114	221	148	114	124	97	92	204	110	1495	1.75
LRLR5E	164	215	287	279	376	240	177	118	168	143	168	196	2531	2.76
LRCA5E	229	280	224	293	417	209	218	167	262	175	319	297	3090	2.50
BRBR5E	231	252	419	357	529	294	289	246	250	271	297	337	3772	2.85
NAEA6E	258	233	343	219	312	120	67	43	74	120	219	234	2242	2.14
BRHE6E	240	266	337	357	432	222	212	155	182	276	192	271	3142	3.88
BRRI7E	253	241	394	344	509	224	256	175	183	207	296	313	3395	3.93
BRRO7E	294	274	379	399	489	256	218	134	143	160	224	233	3203	3.94

BBASC recommendations include setting the hydrologic condition for all 19 gages using 3 weighted average PHDI series. Additionally, the BBASC recommendations retain the same hydrologic condition throughout the entire season as set on the first day of each season. BBEST recommendations set the hydrologic condition based on a separate weighted average PHDI series at each of the 19 gages. The hydrologic condition is recomputed and updated each month.

Table 6.38 shows the number of months that the three hydrologic conditions are engaged at each gage per the BBASC and BBEST recommendations. There are 876 months in the 73-year period of analysis. Less frequent wet and more frequent dry hydrologic conditions are set using the BBEST methodology at all gages in the lower basin below Whitney. The BBEST methodology for setting the hydrologic condition will result in lower base flow requirements, on average, during the period of analysis. Lower mean instream flow shortages in the lower basin are expected in the BBEST recommendation. Only base flow and subsistence flow requirements result in instream flow shortages unless flood control operations cause a pulse flow shortage.

Table 6.38
Number of Months Per Hydrologic Condition
During the 73 Year Period-of-Analysis

	BBASC			BBEST		
CP ID	Dry	Avg	Wet	Dry	Avg	Wet
SFAS0E	212	460	204	232	418	226
DMAS0E	212	460	204	234	420	222
BRSE1E	212	460	204	234	421	221
CFNU1E	212	460	204	233	422	221
CFFG1E	212	460	204	227	432	217
BRSB2E	212	460	204	227	434	215
BRPP2E	236	444	196	225	436	215
BRGR3E	236	444	196	225	438	213
NBCL3E	216	436	224	231	432	213
BRWA4E	216	436	224	224	438	214
LEGT4E	216	436	224	231	432	213
LAKE5E	216	436	224	223	470	183
LRLR5E	216	436	224	225	451	200
LRCA5E	216	436	224	225	451	200
BRBR5E	216	436	224	225	448	203
NAEA6E	216	436	224	219	433	224
BRHE6E	216	436	224	225	445	206
BRRI7E	216	436	224	224	446	206
BRRO7E	216	436	224	223	446	207

The increased magnitude and frequency of BBEST pulse flow requirements reduces the amount of excess stream flow that can be depleted by the downstream system demands at the control points listed in Table 6.6. Reduced excess stream flow depletions result in additional reservoir releases to meet downstream needs. Regulated flow at Palo Pinto and Glen Rose benefit from increased releases from lakes Possum Kingdom and Granbury under the BBEST recommendation.

Increased reservoir releases to meet downstream system demands under the BBEST recommendation tend to cause lower reservoir storage levels as compared to the BBASC recommendation. Refilling of storage in Lake Possum Kingdom occurs with a relatively senior priority date. Increased refilling in Possum Kingdom and other downstream system reservoirs results in greater regulated flows upstream as junior water rights must forgo stream flow depletions for the downstream senior need.

<u>Time Series Plots for Seymour, Cameron, Waco, and Richmond Gage Control Points</u>

The quantities plotted in Figures 6.8 through 6.23 are all derived from the single *SIMD* daily ED simulation that contains the BBASC recommended flow regimes at the 19 locations. Figures 6.8 through 6.23 are plots of the following quantities.

Quantity	BRSE11 BRSE1E Brazos River at Seymour	LRCA58 LRCA5E Little River at Cameron	BRWA41 BRWA4E Brazos River at Waco	BRRI70 BRRI7E Brazos River at Richmond
daily environmental flow targets (ac-ft/day)	Figure 6.8	Figure 6.12	Figure 6.16	Figure 6.20
monthly total of flow targets (ac-ft/month)	Figure 6.9	Figure 6.13	Figure 6.17	Figure 6.21
daily regulated stream flows (ac-ft/day)	Figure 6.10	Figure 6.14	Figure 6.18	Figure 6.22
annual totals of flows and targets (ac-ft/year)	Figure 6.11	Figure 6.15	Figure 6.19	Figure 6.23

Figures 6.8, 6.12, 6.16, and 6.20 are plots of BBASC daily environmental flow targets computed in the *SIMD* simulation at the Seymour, Cameron, Waco, and Richmond control points, respectively. Figures 6.9, 6.13, 6.17, and 6.21 are the aggregated monthly totals of the daily targets summed within *SIMD* and provided input to a monthly *SIM* model on *TS* records in a TSF file.

Figures 6.10, 6.14, 6.18, and 6.22 are the daily regulated flows computed in the simulation at control points BRSE11 (BRSE1E), LRCA58 (LRCA5E), BRWA41 (BRWA4E), and BRRI70 (BRRI7E), respectively.

Figures 6.11, 6.15, 6.19, and 6.23 compare annual volumes of naturalized, regulated, and unappropriated flows, and environmental flow targets and shortages from the daily simulation results. Daily volumes in acre-feet/day are summed to annual totals in acre-feet/year. Naturalized flows have the largest magnitude of the five variables and are plotted as solid blue lines. Regulated flows are shown as dashed red lines. Unappropriated flow are plotted as dotted blue lines. BBASC environmental flow targets are shown as thick solid black lines, and the corresponding shortages are plotted as thick dashed black lines in Figures 6.11, 6.15, 6.19, and 6.23. These are the total targets including subsistence, base, and pulse flows. The environmental flow shortages are relatively small compared to the corresponding targets. The shortages at Seymour in Figure 6.11 are so small as to be difficult to see in the graph.

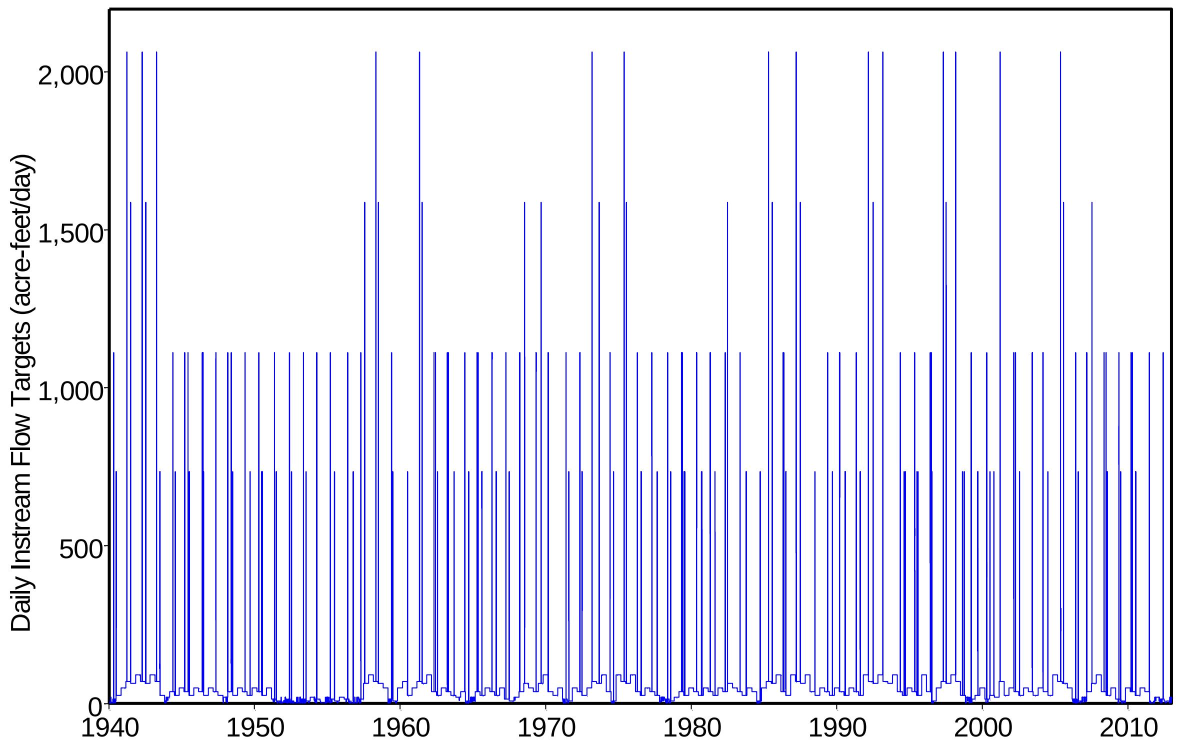

Figure 6.8 Daily Instream Flow Targets for the Brazos River at Seymour (BRSE11)

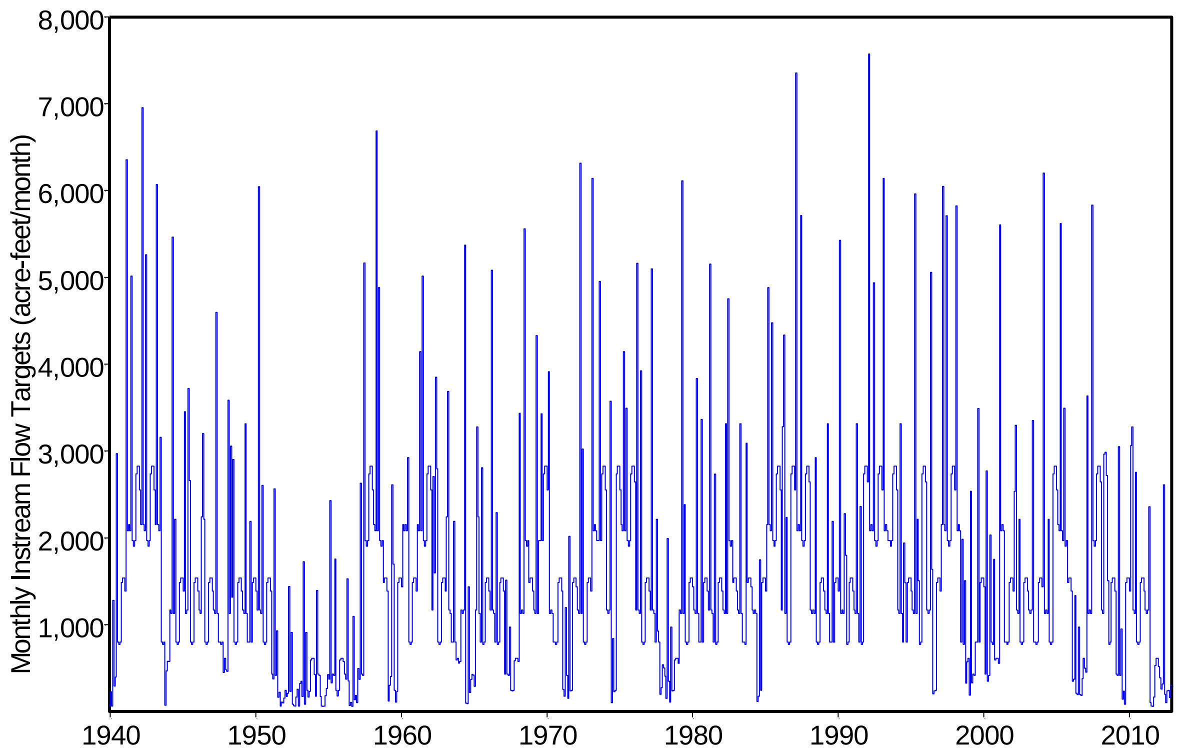

Figure 6.9 Monthly Totals of Instream Flow Targets for Brazos River at Seymour (BRSE11)

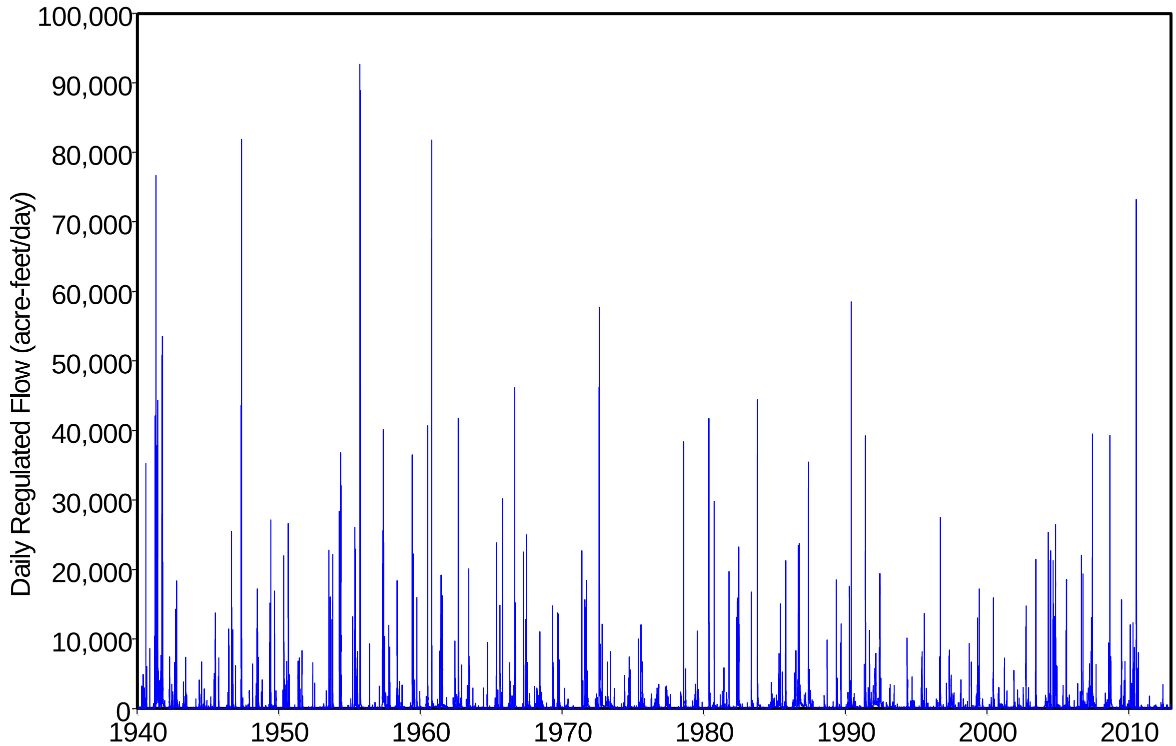

Figure 6.10 Daily Regulated Flows for the Brazos River at Seymour (BRSE11)

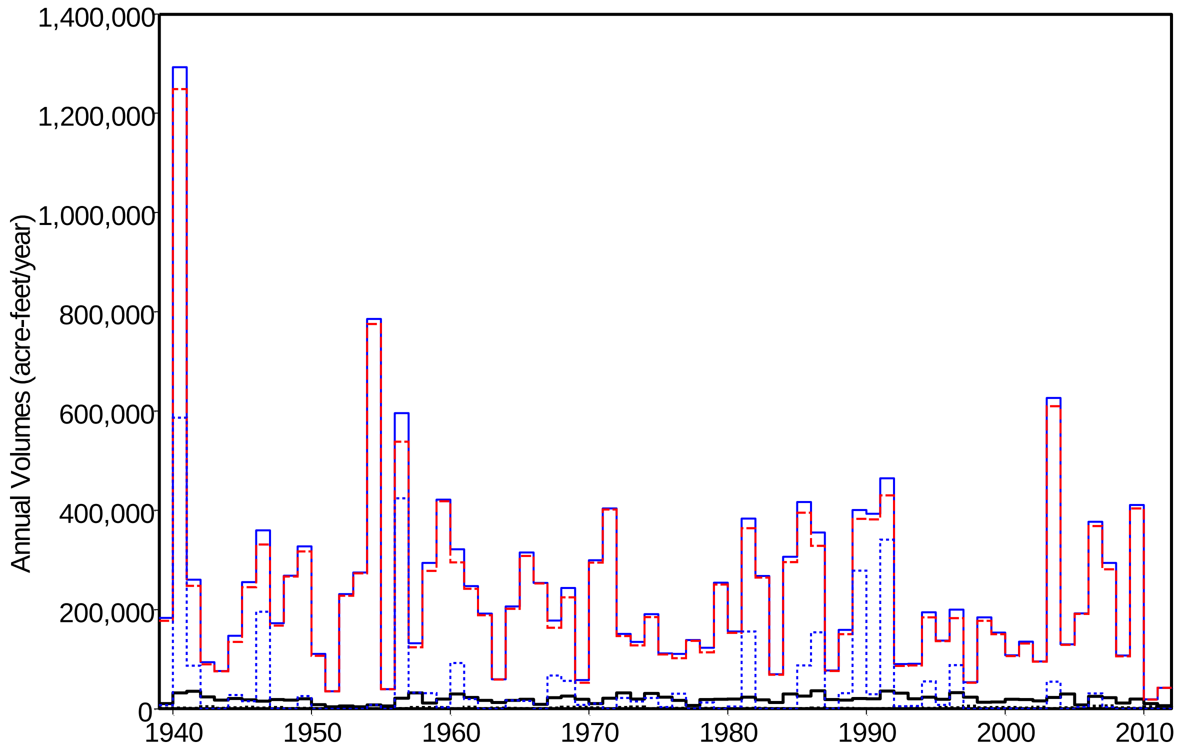

Figure 6.11 Annual Totals of Naturalized Flow (solid blue line), Regulated Flow (dashed red line), Unappropriated Flow (dotted blue line), Flow Targets (solid black line), and Shortages (dotted black line) for the Brazos River at Seymour (BRSE11)

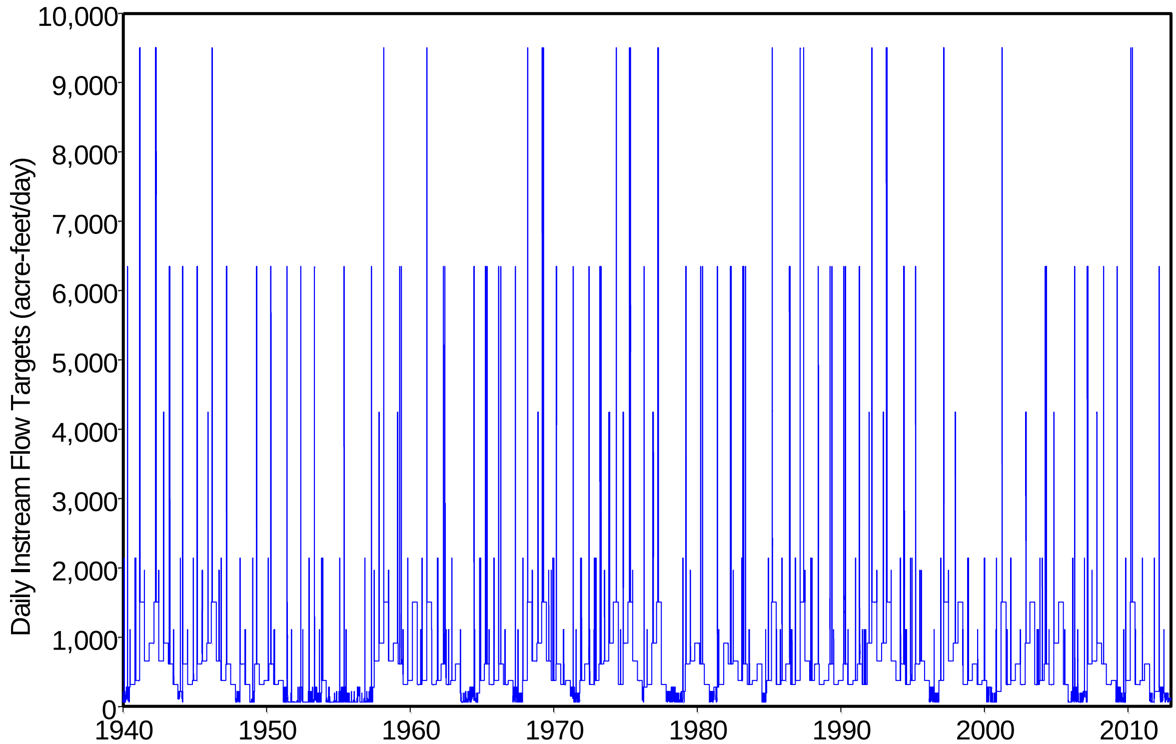

Figure 6.12 Daily Instream Flow Targets for the Little River at Cameron (LRCA58)

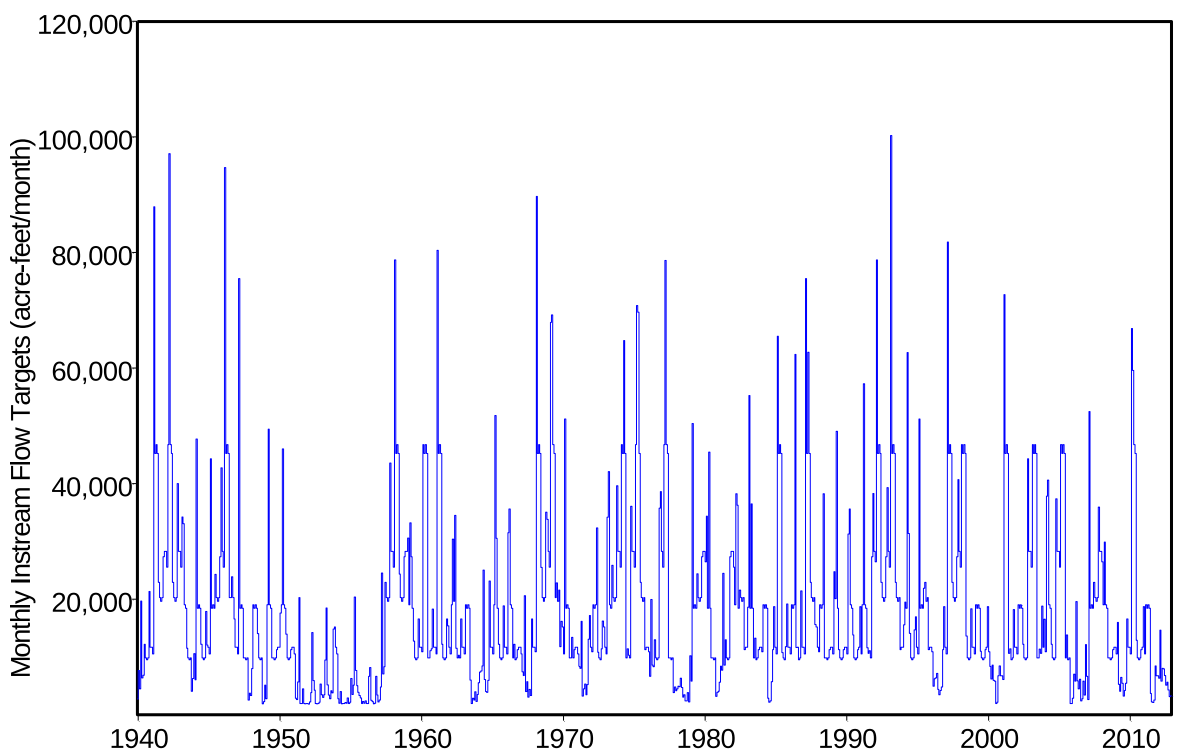

Figure 6.13 Monthly Totals of Instream Flow Targets for the Little River at Cameron (LRCA58)

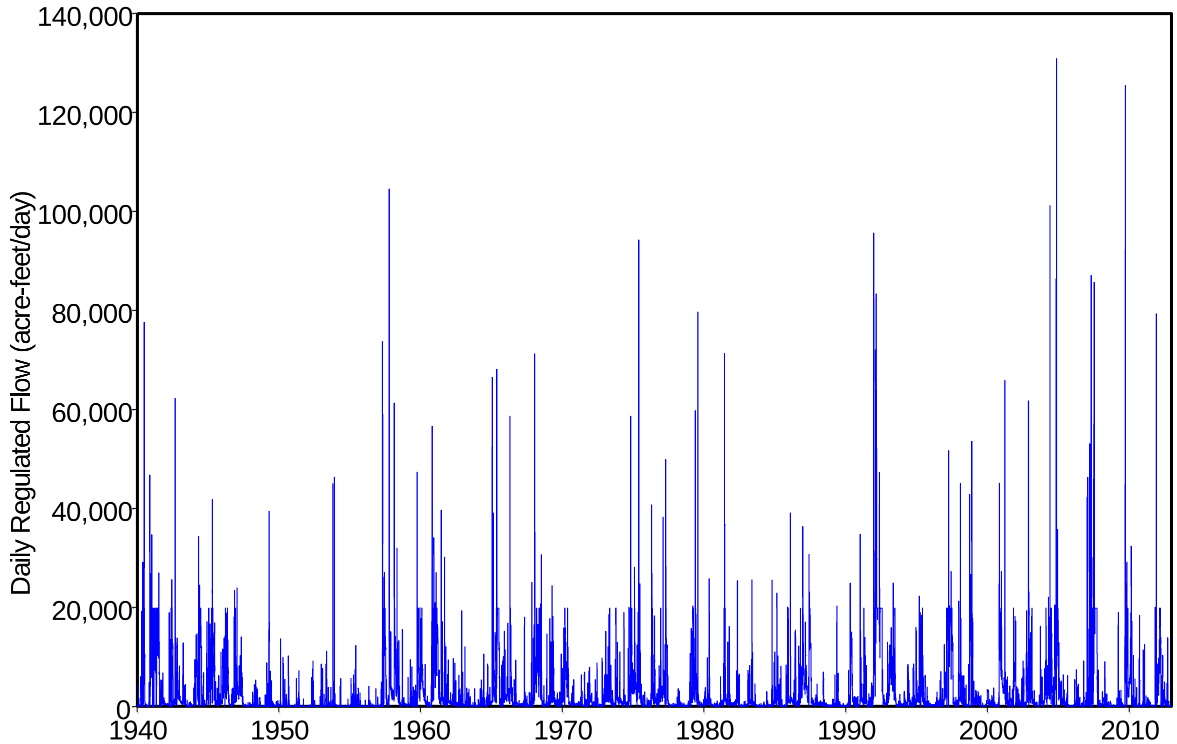

Figure 6.14 Daily Regulated Flow for Little River at Cameron (LRCA58)

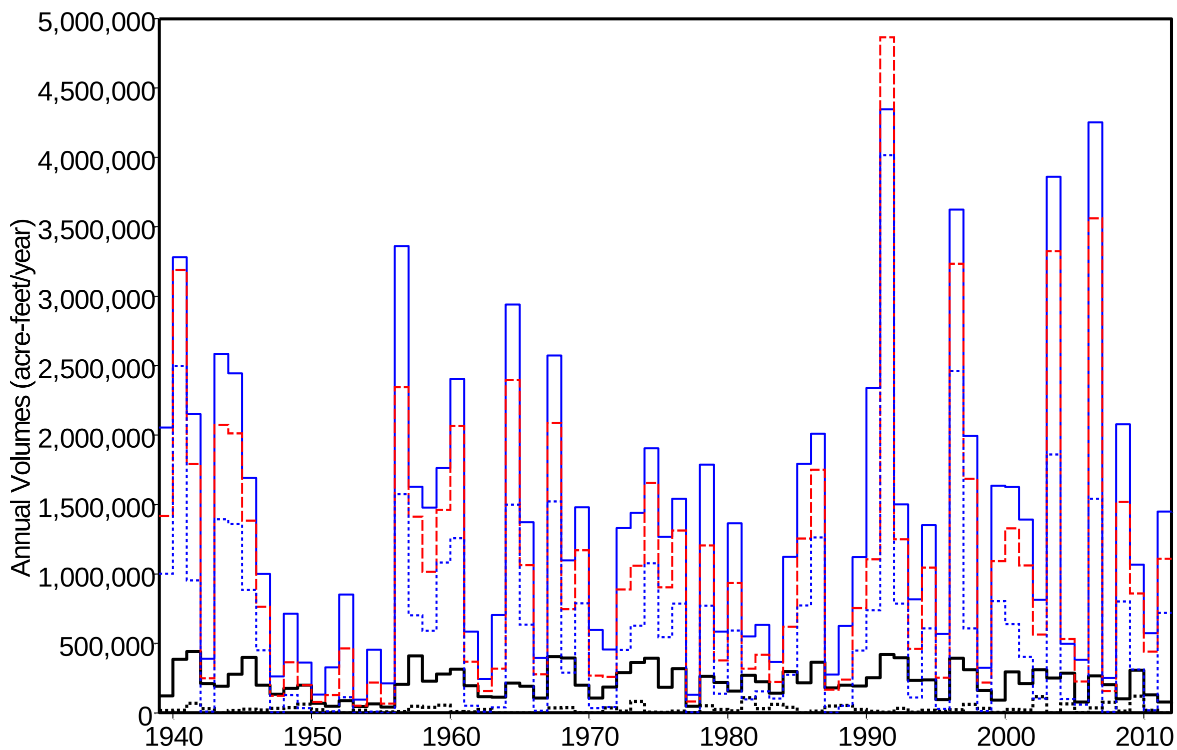

Figure 6.15 Annual Totals of Naturalized Flow (solid blue line), Regulated Flow (dashed red line), Unappropriated Flow (dotted blue line), Flow Targets (solid black line), and Shortages (dotted black line) for the Little River at Cameron (LRCA58)

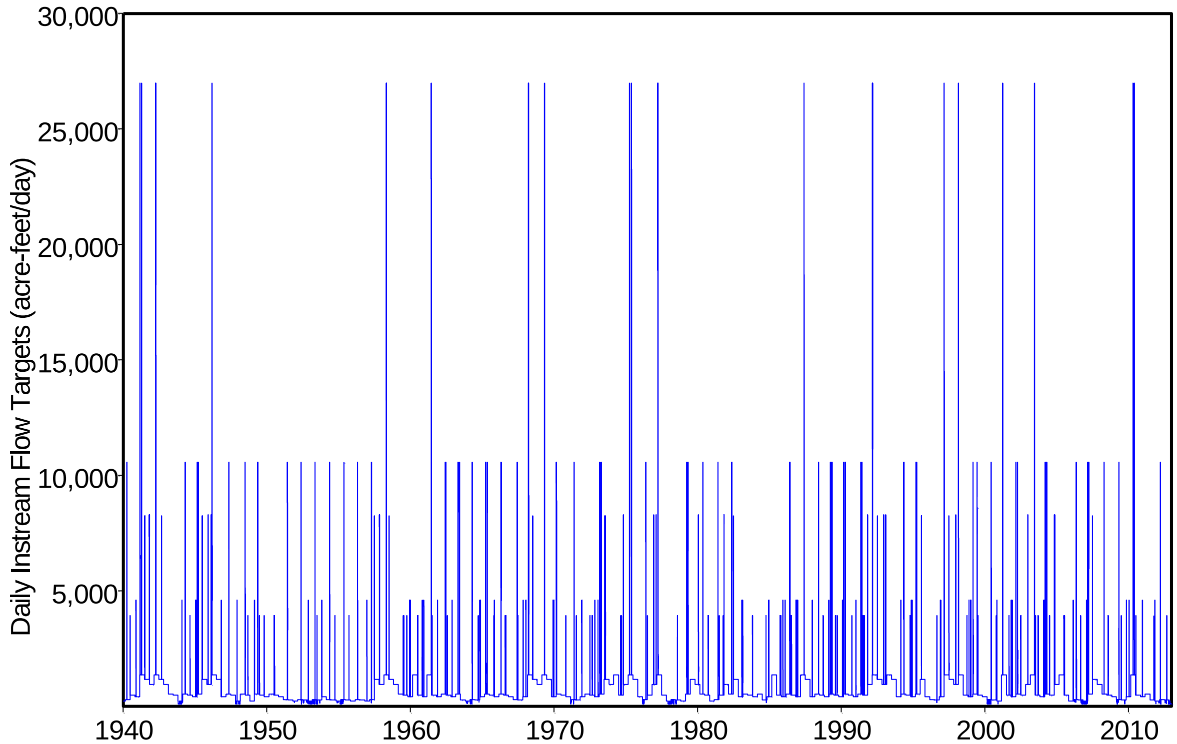

Figure 6.16 Daily Instream Flow Targets for the Brazos River at Waco (BRWA41)

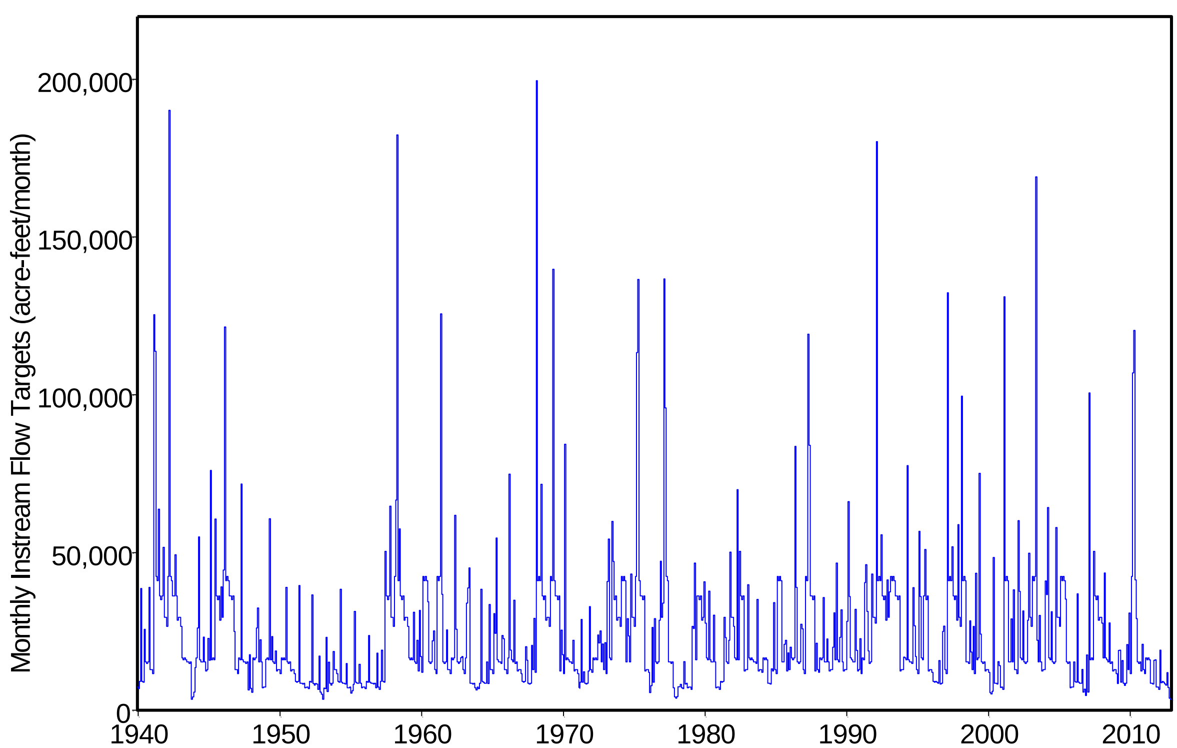

Figure 6.17 Monthly Totals of Instream Flow Targets for Brazos River at Waco (BRWA41)

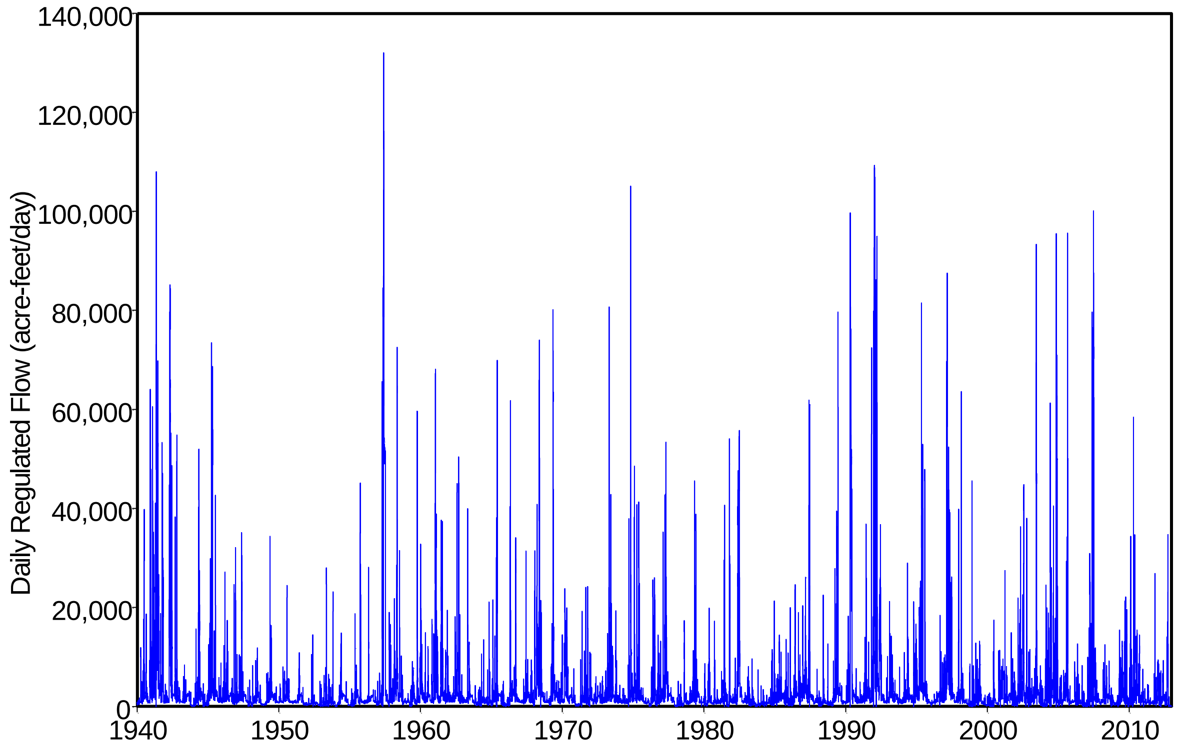

Figure 6.18 Daily Regulated Flow for the Brazos River at Waco (BRWA41)

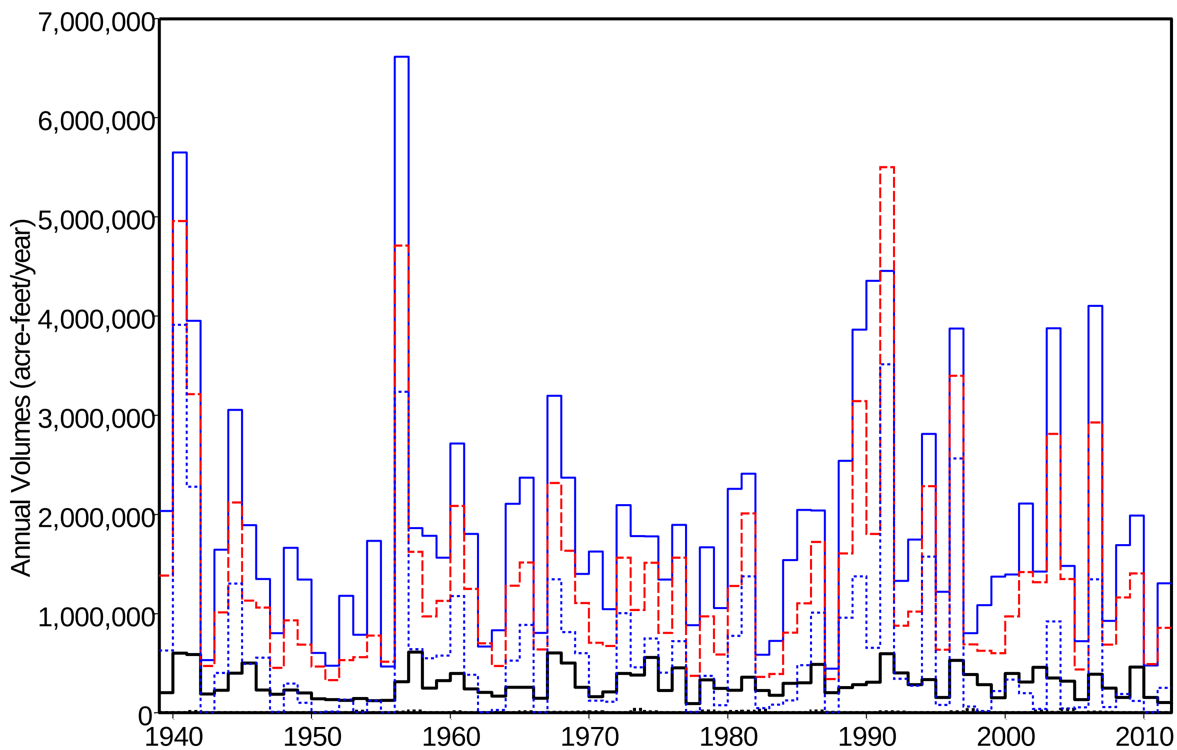

Figure 6.19 Annual Totals of Naturalized Flow (solid blue line), Regulated Flow (dashed red line), Unappropriated Flow (dotted blue line), Flow Targets (solid black line), and Shortages (dotted black line) for the Brazos River at Waco (BRWA41)

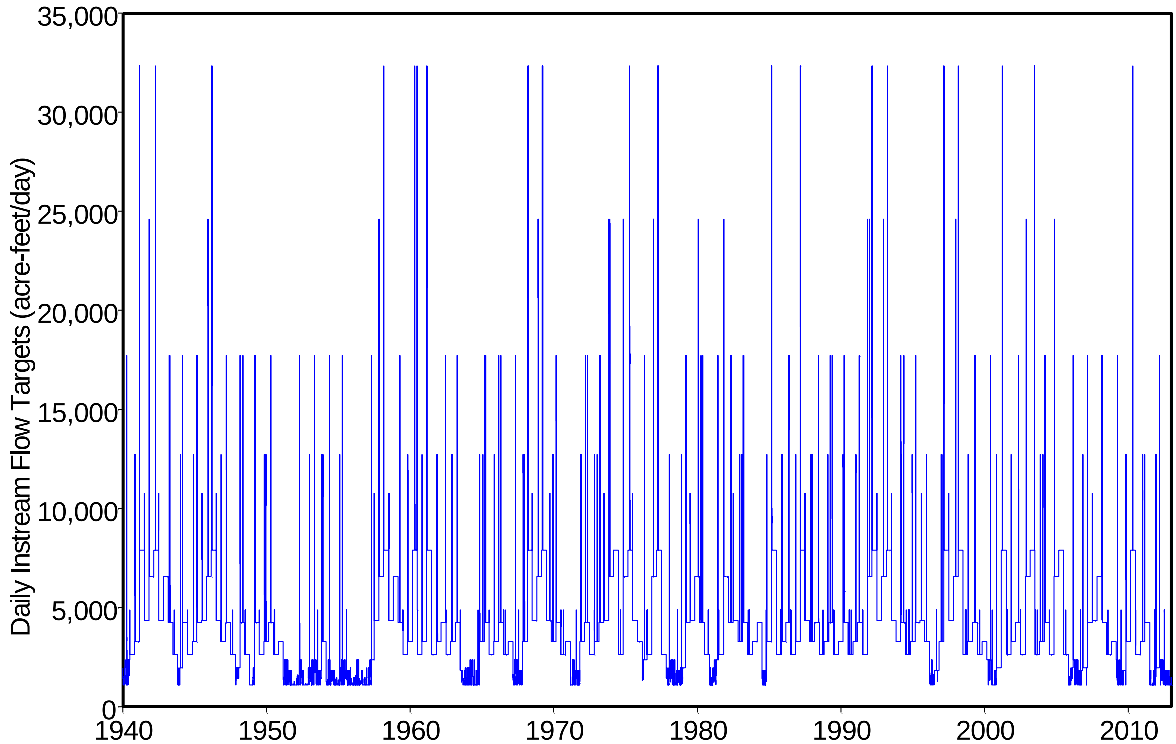

Figure 6.20 Daily Instream Flow Targets for the Brazos River at Richmond (BRRI70)

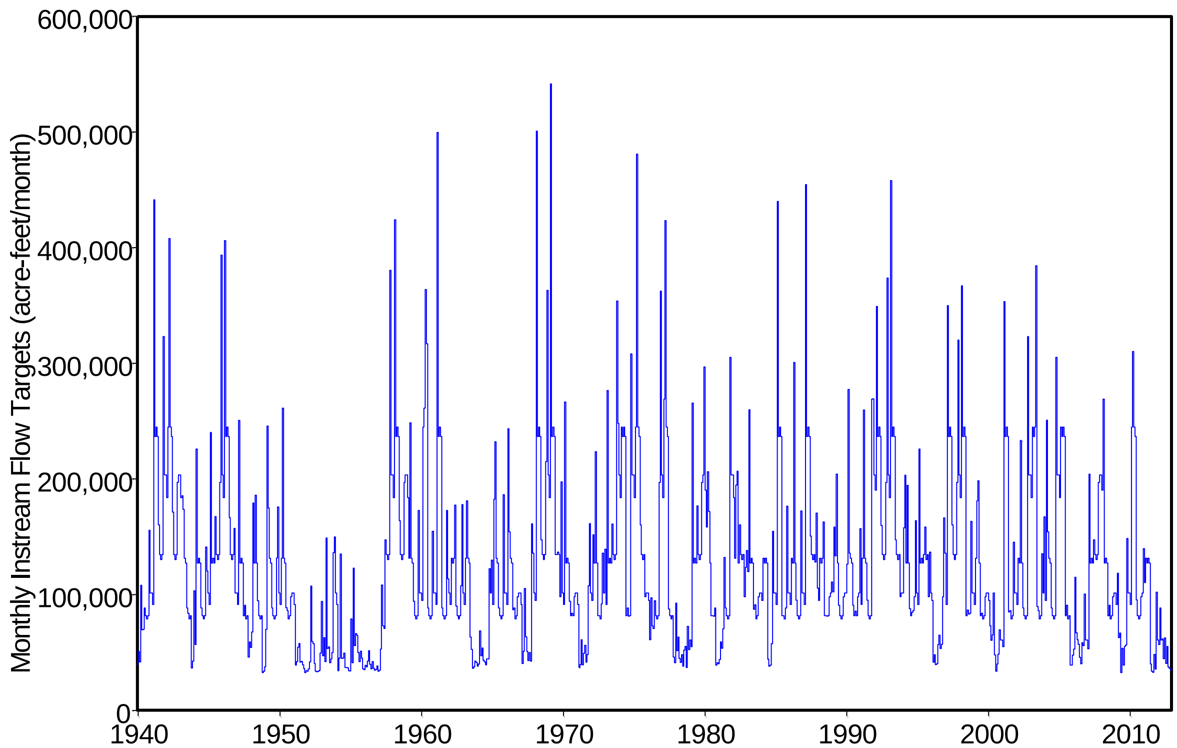

Figure 6.21 Monthly Totals of Instream Flow Targets for Brazos River at Richmond (BRRI70)

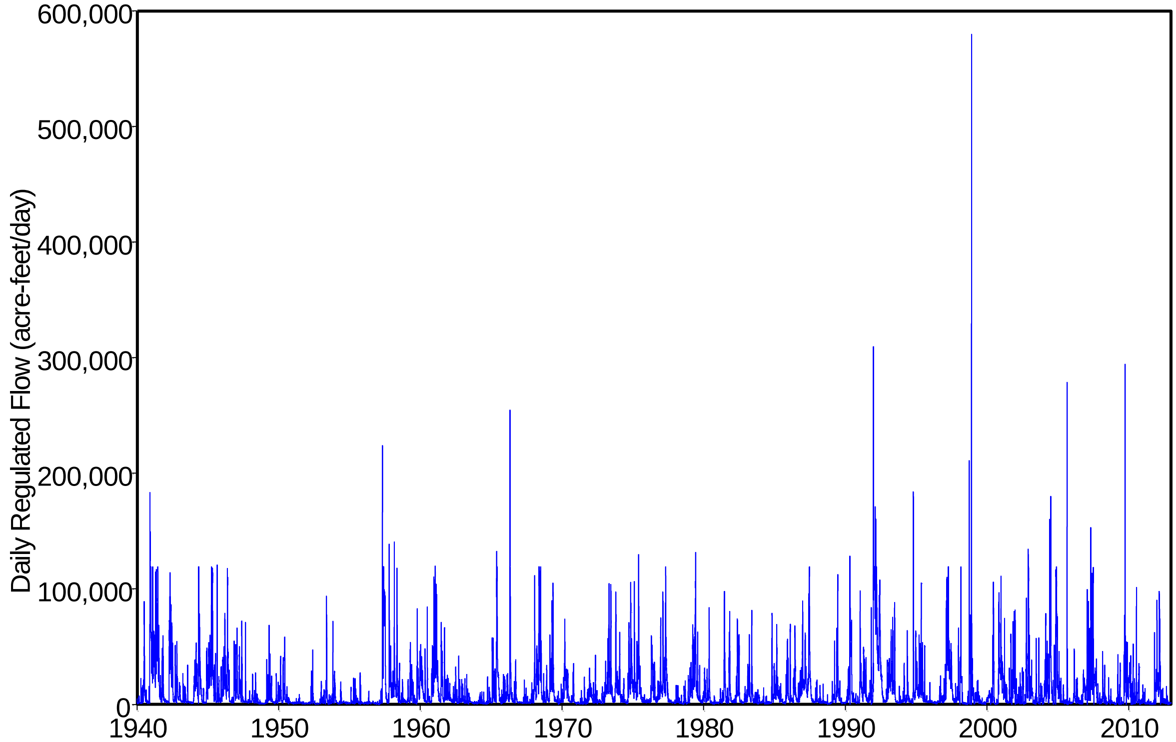

Figure 6.22 Daily Regulated Flow for the Brazos River at Richmond (BRRI70)

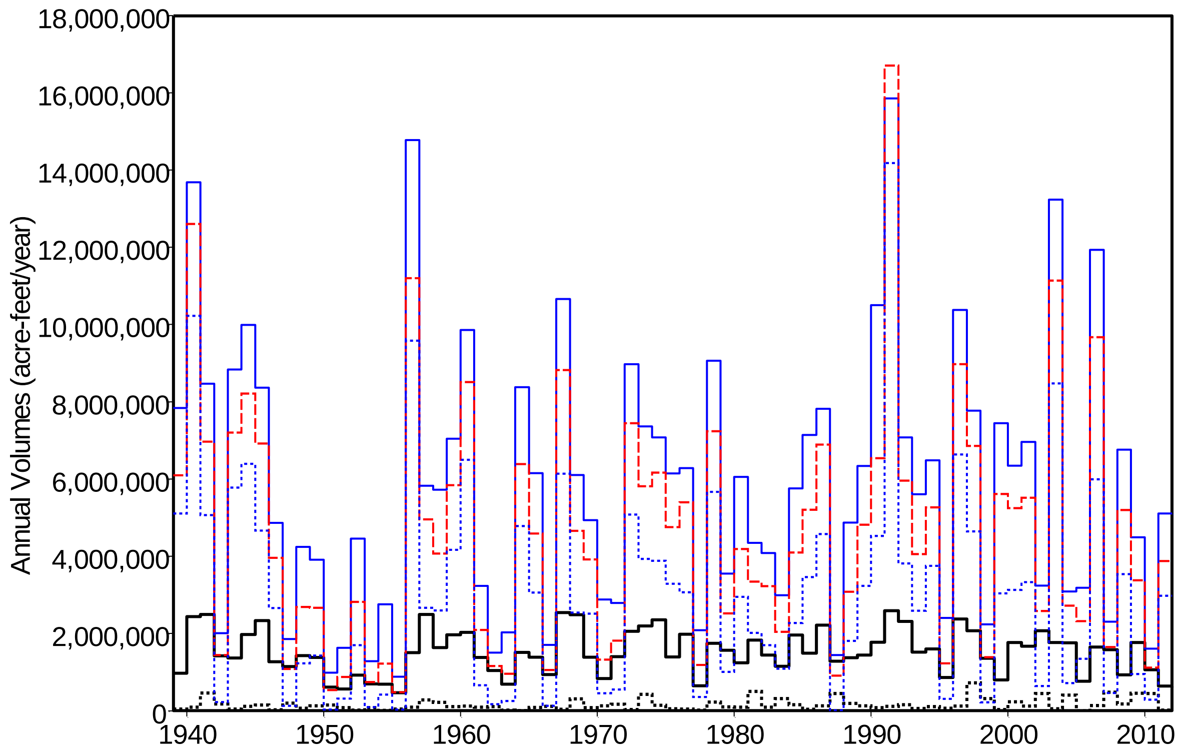

Figure 6.23 Annual Totals of Naturalized Flow (solid blue line), Regulated Flow (dashed red line), Unappropriated Flow (dotted blue line), Flow Targets (solid black line), and Shortages (dotted black line) for the Brazos River at Richard (BRRI70)

CHAPTER 7
COMPARATIVE ANALYSIS OF SIMULATION RESULTS WITH HYPOTHETICAL NEW WATER RIGHTS FOR ALTERNATIVE MODELING SCENARIOS

The purpose of the Brazos WAM case study presented in Chapters 5, 6, and 7 is to support development and application of WRAP/WAM capabilities for modeling and analyzing environmental flow requirements. Case study objectives include both

- testing and improving WRAP/WAM modeling capabilities and
- developing guidance for model users in applying WRAP/WAM expanded modeling capabilities to address environmental flow considerations.

Chapter 5 provides background information regarding the Brazos River Basin, Brazos WAM, and BBEST and BBASC recommended environmental instream flow requirements. Chapter 6 explains concepts and mechanics of incorporating instream flow requirements and multiple-purpose system operations into the WRAP input dataset for the Brazos WAM and presents simulation results showing environmental flow targets and the extent to which the targets are satisfied. The daily and monthly models developed in Chapter 6 are applied in Chapter 7 to investigate the effects on hypothetical new projects and the interactions between environmental flow requirements and integrated multiple-purpose water management.

Hypothetical Projects

The BBEST and BBASC environmental flow requirements are placed in the model in Chapter 6 at a priority that is junior to all of the existing water rights. Thus, existing water rights are not affected by the new environmental flow requirements. Table 6.13 details the priority date selection for the WAM, EM, and ED datasets. Hypothetical future storage and diversion projects are modeled in Chapter 7 with a priority junior to the new environmental flow requirements. The impacts of the environmental flow requirements on the projects are evaluated.

Hypothetical projects are added to the monthly and daily models so that the case study can include an evaluation of the impacts of the environmental flow requirements on new projects. The following two hypothetical reservoir storage reallocation projects are adopted.

- The Proctor project consists of reallocation of 31,480 acre-feet (10 percent) of the flood control storage capacity of Proctor Reservoir to conservation capacity and adding a constant water supply diversion target of 10,000 acre-feet/year.
- The Whitney project consists of reallocation of 136,340 acre-feet (10 percent) of the flood control storage capacity of Whitney Reservoir to conservation storage capacity and adding a constant water supply diversion of 30,000 acre-feet/year.

The hypothetical Proctor and Whitney projects consist of storage reallocations in USACE multiple-purpose reservoirs. Ten percent of the flood control storage capacity is reallocated to conservation storage by raising the designated top of conservation pool elevation. The two projects are added to the model together and simulated simultaneously in the same executions of the model. The water rights added to the DAT file to model these hypothetical projects are junior to all other water rights in the model relevant to water supply and instream flow requirements including the BBEST and BBASC environmental flow requirements added in the preceding Chapter 6. Flood control in the ED model is junior to all water supply and instream flow rights as shown in Table 6.13.

Hypothetical Proctor Project

The conservation storage capacity of Proctor Reservoir is increased by 31,480 acre-feet from 59,400 to 90,880 acre-feet by raising the designated top of conservation pool elevation, encroaching into the flood control pool. A new lakeside constant diversion target of 10,000 acre-feet/year (27.4 acre-feet/day or 13.8 cfs) is added at Proctor Lake (control point 515931). A dual simulation is already performed in the original Brazos WAM. DUAL(wr) option 2 is activated on the *PX* record for the hypothetical new water right and DUAL(wr) option 3 is activated on *PX* records for the existing water rights at Proctor Lake to prevent refilling of storage drawn-down by the 10,000 acre-feet/year diversion at the priority of the existing rights. The hypothetical new right is modeled with the following new additional records inserted in the DAT file.

```
WR515931  10000.   NDAYS99999999   1   2  0.0000                NewProctor
WSPRCTOR  90880.
PX     2
```

The hypothetical new water right at Proctor Lake is junior to all other water supply and instream flow rights in the Brazos WAM except the new hypothetical Whitney project. With this junior priority, any non-zero target diversion from Proctor Reservoir has a firm yield of zero. The priority dates used for modeling the new Proctor and new Whitney projects in the EM and ED models are shown in Table 6.13. The existing TCEQ WAM contains water right *WR* records with priority dates of 88888888 and 99999999. These existing water right records were reassigned priority dates senior to the new environmental flow requirements and the new system and project water rights.

Hypothetical Whitney Project

The conservation storage capacity of Whitney Reservoir is increased by 136,340 acre-feet from 636,100 to 772,440 acre-feet with a corresponding decrease in the capacity of the flood control pool. A new constant diversion target of 30,000 acre-feet/year (82.2 acre-feet/day or 41.4 cfs) is added at control point W12422 which is located immediately downstream of Whitney Dam. The water supply diversion has access to releases through the hydropower turbines. This hypothetical new water right is junior to all other water supply and instream flow rights in the Brazos WAM. The pool capacities of Whitney Lake before and after the storage reallocation are shown in Table 7.1. The component reservoir capacities are shown in Table 7.2. Tables 7.1 and 7.2 can be compared with Tables 6.4 and 6.5.

The hypothetical Whitney water supply project shares reservoir storage capacity with hydropower. The hypothetical new diversion right of 30,000 acre-feet/year is supplied from the USACE controlled portion of the Lake Whitney conservation pool, modeled as component reservoir CORWHT, which also provides storage and releases for hydroelectric energy generation.

Table 7.1
Whitney Reservoir Storage Capacity

Pool Level	Whitney Storage Capacity (acre-feet) Without Reallocation Incremental	Cumulative	With Reallocation Incremental	Cumulative
Top of Flood Control Pool		1,999,500		1,999,500
	1,363,400		1,227,060	
Top of Conservation Pool		636,100		772,440
	249,076		385,416	
Bottom of Conservation Pool		387,024		387,024

Table 7.2
Whitney Component Reservoirs in the Brazos WAM

Component Reservoir Identifiers	Storage Capacity (acre-feet) Without Reallocation	With Reallocation
WHITNY	387,024	387,024
BRA	50,000	50,000
CORWHIT	199,076	335,416
Total	636,100	772,440

Hydroelectric power operations and their incorporation in the *SIM/SIMD* model are described in Chapter 6. The hypothetical new water right diverts water from the Brazos River just downstream of Whitney Dam. The diversion is supplied in the model by hydropower releases from component reservoir CORWHT plus additional releases from component reservoir CORWHT as necessary to supply the diversion target. The input records for the hydropower and diversion rights are reproduced below.

```
WR515731  36000.   POWER99999999   6   2     1.0  W12422         WhitneyHP
WSCORWHT 335416.                                                1      -1
HP 0.87     440.
**
WR515731           WHIT199999999   1                             FILLWHIT
WSCORWHT 335416.                                                1      -1
**
WRW12422  30000.   NDAYS99999999   2                             NewWhitney
WSCORWHT 335416.                                                1      -1
**
WR515731           WHIT199999999   1                             NewFill
WSCORWHT 335416.                                                1      -1
```

Hydroelectric energy reliabilities are less than 100 percent, with CORWHT storage capacities of either 335,416 or 199,076 acre-feet, meaning that component reservoir CORWHT is sometimes empty during the simulation. Therefore, the firm yield associated with a water supply diversion from CORWHT, which is shared with hydropower, is zero.

The hypothetical Whitney project is one of a variety of alternative storage reallocation strategies for Whitney Reservoir that could be formulated. Various amounts of flood control storage capacity could be converted to conservation storage either permanently or seasonally. A portion of the 387,224 acre-feet inactive conservation pool could be converted to active conservation storage for hydropower release and/or water supply). Interactions between hydropower and water supply could be investigated. Whitney storage reallocations could be coordinated with multiple-reservoir system operations and trade-offs between firm and interruptible yields. However, the study presented here is limited to the one hypothetical Whitney reallocation plan.

Alternative Simulations

The TCEQ WAM System monthly dataset for the Brazos River Basin and San Jacinto-Brazos Coastal Basin, called the Brazos WAM, and its daily version are described in Chapter 5. Chapter 6 describes the development of the additional *SIM* and *SIMD* input required to model the BBEST and BBASC environmental flow recommendations, Whitney hydroelectric power operations, BRA system operations, flood control operations, and other refinements. The preceding section of Chapter 7 describes two hypothetical projects added to the model, which are included in all 14 of the simulations listed in Table 7.3. Chapter 7 presents a simulation study focused on comparing the results of a series of six monthly *SIM* and eight daily *SIMD* simulations, which are listed in Table 7.3. *SIM* and *SIMD* provide identical results for the monthly simulations.

The simulations presented in Chapter 6 do not include the hypothetical new Proctor and Whitney projects added in Chapter 7. The M6 simulation of Chapter 7 is the expanded monthly EM model of Chapter 6 with the hypothetical new Proctor and Whitney projects added. The D1 and D2 simulations of Chapter 7 are the BBASC and BBEST versions of the expanded daily ED model of Chapter 6 with the hypothetical Proctor and Whitney projects added.

Monthly simulations M4, M5, and M6 (Table 7.3) include BBASC instream flow targets provided as input on target series *TS* records in a TSF file. These monthly targets were developed with the daily ED model of Chapter 6, which does not include the hypothetical Proctor and Whitney projects. The same TSF file was used for the three simulations M4, M5, and M6.

As noted in Chapters 5 and 6, the datasets developed and applied in the Brazos case study are designed for exploring modeling capabilities and the effects on simulation results of various premises regarding water management issues. Various aspects of the datasets that are not reflected in the actual water right permits preclude adoption of the datasets, without significant modification, for use by the TCEQ in the actual water right permitting process.

Boldface type is used in Table 7.3 for the monthly simulations to highlight the difference between each of the other monthly simulations and simulation M2. For the daily simulations, the boldface type highlights the difference between each of the other simulations and simulation D1. All of the 14 simulations include water rights for the two hypothetical projects, consisting of reservoir storage reallocations and water supply diversions at Proctor and Whitney Reservoirs.

Table 7.3
Simulations Presented in Chapter 7

Label	Time Step	Simulation Period	BBASC BBEST	Existing IF Rights	Flood Control	System Operations	Whitney Hydropower
M1	month	**1940-1997**	neither	yes	no	no	no
M2	month	1940-2012	neither	yes	no	no	no
M3	month	1940-2012	neither	**no**	no	no	no
M4	month	1940-2012	**BBASC**	**no**	no	no	no
M5	month	1940-2012	**BBASC**	yes	no	no	no
M6	month	1940-2012	**BBASC**	yes	no	**yes**	**yes**
D1	day	1940-2012	BBASC	yes	yes	yes	yes
D2	day	1940-2012	**BBEST**	yes	yes	yes	yes
D3	day	1940-2012	**neither**	yes	yes	yes	yes
D4	day	1940-2012	BBASC	**no**	yes	yes	yes
D5	day	1940-2012	BBASC	yes	**no**	yes	yes
D6	day	1940-2012	BBASC	yes	yes	**no**	yes
D7	day	1940-2012	BBASC	yes	yes	yes	**no**
D8	day	**1940-1997**	BBASC	yes	yes	yes	yes

The 14 simulations listed in Table 7.3 are designed for investigating the effects of key water management and modeling issues on simulation results. The following considerations are discussed in Chapters 5 and 6 and further explored in the Chapter 7 simulations.

- daily versus monthly computational time step
- original 1940-1997 versus updated 1940-2012 hydrologic simulation period
- different sets of environmental instream flow requirements discussed in Chapters 5 and 6 including the 122 instream flow *IF* records already contained in the TCEQ WAM dataset, BBEST recommended regime, and BBASC recommended regime
- flood control operations of the nine Corps of Engineers multiple-purpose reservoirs which are described by Tables 6.1, 6.2, and 6.3 and the accompanying discussion in Chapter 6.
- Brazos River Authority (BRA) multiple-reservoir system operations including the modeling scenario adopted for this case study which is described by Tables 6.6 and 6.7 and the accompanying discussion in Chapter 6
- Lake Whitney hydroelectric power operations discussed in Chapter 6.

Addition of BRA system operations also includes activation of an option controlled by parameter IFFLAG2 on the *IF* record for the existing Hale clause instream flow rights that excludes BRA reservoir releases when applying the *IF* record limits. As discussed in Chapter 5, Hale clause provisions in the instream flow requirements found in many of the existing water rights permits preclude crediting BRA reservoir releases in satisfying instream flow requirements mandated by these particular water right permits.

The six monthly simulations are labeled M1, M2, M3, M4, M5, and M6. Simulation M1 is an execution of the official TCEQ WAM authorized use scenario Brazos WAM dataset, with filename extension Bwam3, as last updated in September 2008, which is described in Chapter 5, with the hypothetical Proctor and Whitney projects added. Simulation M2 is identical to M1 except the hydrologic period-of-analysis is updated from 1940-1997 to 1940-2012.

Simulation results for the monthly model without the two hypothetical projects added are presented in Tables 5.5 and 5.6 and Figures 5.5 through 5.10 of Chapter 5. The only difference between the *SIM* datasets producing the simulation results presented in Chapter 5 and the M1 and M2 models of Chapter 7 is the hypothetical Proctor and Whitney projects.

Simulation M3 is identical to simulation M2 except the 122 existing *IF* record water rights are removed. Simulation M3 has no instream flow requirements.

Simulations M4, M5, and M6 incorporate BBASC instream flow requirements as targets provided as input on target series *TS* records in a TSF file created with the daily ED model of Chapter 6, which does not include the hypothetical Proctor and Whitney projects. The daily model aggregates the computed daily targets to monthly totals as discussed in Chapter 6. The same TSF file was used for the three simulations M4, M5, and M6.

Simulation M4 is identical to simulation M3 except the BBASC instream flow requirements are added. The BBASC recommendations are the only instream flow requirements in simulation M4. Simulation M5 is identical to simulation M2 except the BBASC instream flow requirements are added. M5 contains both existing and BBASC *IF* record water rights.

M6 is identical to M5 except BRA multiple reservoir system operations and Lake Whitney hydropower operations are added. Flood control operations cannot be simulated with *SIM* and are not included in the monthly model. M6 is the monthly equivalent of the daily D1.

Simulation D1 is the base daily *SIMD* simulation. The monthly M6 and daily D1 simulations differ only in the restrictions imposed by the monthly model. Unlike simulation D1, simulation M6 does not include flood control operations.

Simulation D1 employs a daily time step and 1940-2012 hydrologic simulation period, incorporates the BBASC recommended instream flow requirements as well as the 122 existing *IF* record rights, and includes flood control, BRA multiple-reservoir system operations, and Whitney hydropower operations. Each of the other daily simulations is almost the same as D1 with just one specified factor changed. The differing factor is highlighted in bold type in Table 7.1. A comparison of simulation results shows the effects of each of the factors.

Simulation D2 is identical to D1 except the BBEST recommended environmental flow requirements replace the BBASC requirements. Simulation D3 is the same as D1 and D2 except neither the BBASC nor BBEST instream flow requirements are included in the input dataset.

The 122 original Brazos WAM *IF* record rights are removed from the DAT file used in simulation D1 to obtain simulation D4. Simulation D5 is the same as D1 except the flood control pools in the nine USACE reservoirs are removed. Simulation D6 is the same as D1 except the BRA system operations are removed. Simulation D7 is the same as D1 except the Whitney hydroelectric power operations are removed. Simulation D8 is the same as simulation D1 with the one exception of shortening the 1940-2012 period-of-analysis to 1940-1997.

Simulation Results

Fourteen alternative simulations were performed with the 14 alternative configurations outlined in Table 7.3. The alternative monthly and daily simulations in Chapter 7 are used to investigate the effects on hypothetical new projects and the interactions between environmental flow requirements and integrated multiple-purpose water management.

Table 7.4
Brazos WAM Control Point Locations for BBEST and BBASC
Environmental Instream Flow Recommendations

WAM CP ID	Downstream Env. Flow CP ID	Stream	Nearest City	USGS Gage No.	Watershed Area (sq miles)
SFAS06	SFAS0E	Salt Fork Brazos River	Aspermont	08082000	2,504
DMAS09	DMAS0E	Double Mountain Fork	Aspermont	08080500	1,891
BRSE11	BRSE1E	Brazos River	Seymour	08082500	5,996
CFNU16	CFNU1E	Clear Fork Brazos	Nugent	08084000	2,236
CFFG18	CFFG1E	Clear Fork Brazos	Fort Griffin	08085500	4,031
BRSB23	BRSB2E	Brazos River	South Bend	08088000	13,171
BRPP27	BRPP2E	Brazos River	Palo Pinto	08089000	14,309
BRGR30	BRGR3E	Brazos River	Glen Rose	08091000	16,320
NBCL36	NBCL3E	North Bosque River	Clifton	08095000	977
BRWA41	BRWA4E	Brazos River	Waco	08096500	20,065
LEGT47	LEGT4E	Leon River	Gatesville	08100500	2,379
LAKE50	LAKE5E	Lampasas River	Kempner	08103800	817
LRLR53	LRLR5E	Little River	Little River	08104500	5,266
LRCA58	LRCA5E	Little River	Cameron	08106500	7,100
BRBR59	BRBR5E	Brazos River	Bryan	08109000	30,016
NAEA66	NAEA6E	Navasota River	Easterly	08110500	936
BRHE68	BRHE6E	Brazos River	Hempstead	08111500	34,374
BRRI70	BRRI7E	Brazos River	Richmond	08114000	35,454
BRRO72	BRRO7E	Brazos River	Rosharon	08116650	35,775

All 19 control points where BBEST and BBASC environmental flow recommendations are provided are included in Table 7.4 above and the Figure 6.7 map. However, in order to simplify the presentation of results, only four control points are selected for stream flow results reporting. The following four control points were selected to represent a range of flow regimes from the upper to lower portion of the basin, major tributary flow from the Little River, and flows immediately downstream of major reservoirs and releases including hydropower.

- Brazos River near Seymour, BRSE11
- Brazos River near Waco, BRWA41
- Little River near Cameron, LCRA58
- Brazos River near Richmond, BRRI70

Monthly flow frequency metrics are adopted for all 14 alternative simulations to serve as a basis for comparison in the tables presented in this chapter. Daily frequency analysis can also be performed for the eight daily simulations. However, aggregated total monthly flows from the monthly OUT output file created by the eight daily simulations are used for consistent comparisons with the six monthly simulations.

Naturalized Flows

Monthly naturalized stream flow frequencies are given in Table 7.5 for the 58 year WAM period of analysis and the 73 year extended period of analysis. The naturalized flows show great variability from zero flow to extreme high flows. Within the daily time step simulation, the naturalized flows during high flow events are often well in excess of the maximum flood flow limits managed by flood control reservoirs. The extended period of analysis creates slightly reduced mean naturalized flow along the main stem Brazos River, but slightly greater naturalized flow at the Cameron gage on the Little River.

Table 7.5
Naturalized Flow Frequency, acre-feet per month

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
January 1940 through December 1997														
BRSE11	20841.3	42817.	0.0	0.0	52.0	266.2	621.2	1711.0	3082.	5042.	8026.	18500.	57693.	414811.
BRWA41	161860.3	266253.	0.0	1576.9	3433.8	6300.4	10363.6	24749.0	45705.	68642.	102411.	183578.	422755.	3376485.
LRCA58	109858.4	170466.	0.0	494.4	1249.0	2706.4	5440.0	15032.0	28988.	44799.	65294.	130473.	290433.	1403136.
BRRI70	487518.8	613002.	0.0	18382.8	25401.7	39521.8	53887.8	111204.0	184723.	257456.	358553.	653272.	1230723.	6135975.
January 1940 through December 2012														
BRSE11	19901.7	41038.	0.0	0.0	0.0	142.2	533.2	1472.2	2911.	4971.	7912.	17441.	58933.	414811.
BRWA41	156862.8	255655.	0.0	1732.1	2776.5	6188.0	9276.9	24717.0	44545.	68642.	100910.	179571.	403878.	3376485.
LRCA58	112619.7	180174.	0.0	276.7	1026.3	2156.6	4778.8	15023.0	28550.	43533.	61439.	129579.	303417.	1403136.
BRRI70	485191.7	619448.	0.0	16507.4	23028.8	34215.8	51415.0	103518.0	180297.	255020.	352753.	658380.	1232602.	6135975.

Regulated Flows

Monthly regulated flow frequency metrics are given in Table 7.6 for the four representative control points. Only slight variations in mean regulated flow are apparent. This is due to the simulations being based on existing water right demands at fully authorized levels and new project demands being small relative to overall downstream average flows.

The absence of flood control increases the maximum regulated flow in D5 at Cameron, Waco, and Richmond. These three locations are downstream of flood control reservoirs. The maximum regulated monthly flow in D5 is greater than all other daily alternative simulations. In addition to reducing flood flows at downstream gages, flood control tends to help the refill of conservation storage during periods of high flow. Higher reservoir storages can lead to greater consumption by evaporation.

Table 7.6
Regulated Flow Frequency, acre-feet per month

Brazos River near Seymour (BRSE11)

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LABEL	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
M1	19438.1	40217.	0.0	0.0	28.2	224.7	587.5	1680.4	2998.	4812.	7904.	17278.	51071.	408040.
M2	18550.1	38418.	0.0	0.0	0.0	133.7	487.9	1444.6	2836.	4758.	7618.	16125.	51478.	408040.
M3	18537.0	38407.	0.0	0.0	0.0	133.7	487.9	1444.6	2836.	4758.	7618.	16125.	51478.	408040.
M4	18537.0	38407.	0.0	0.0	0.0	133.7	487.9	1444.6	2836.	4758.	7618.	16125.	51478.	408040.
M5	18550.1	38418.	0.0	0.0	0.0	133.7	487.9	1444.6	2836.	4758.	7618.	16125.	51478.	408040.
M6	18384.9	38401.	0.0	0.0	0.0	126.5	473.3	1409.9	2745.	4578.	7302.	16125.	51152.	408145.
D1	19189.8	39515.	0.0	0.0	0.0	142.2	531.0	1466.6	2859.	4836.	7695.	16607.	54176.	393889.
D2	19201.9	39540.	0.0	0.0	0.0	142.2	531.0	1466.6	2875.	4834.	7695.	16580.	55750.	394373.
D3	19170.3	39506.	0.0	0.0	0.0	142.2	531.0	1466.6	2876.	4837.	7704.	16584.	54972.	394247.
D4	19175.3	39495.	0.0	0.0	0.0	142.2	531.0	1466.5	2873.	4815.	7678.	16583.	54148.	394441.
D5	19204.1	39525.	0.0	0.0	0.0	142.2	529.9	1466.6	2877.	4836.	7696.	16584.	55857.	394026.
D6	19286.3	39587.	0.0	0.0	0.0	142.2	528.5	1467.3	2886.	4940.	7731.	16975.	55800.	392781.
D7	19156.4	39508.	0.0	0.0	0.0	142.2	529.3	1464.2	2853.	4824.	7714.	16563.	55515.	394519.
D8	20035.7	41157.	0.0	0.0	50.4	265.9	616.3	1704.8	3013.	4959.	7938.	17463.	53516.	393858.

Little River near Cameron (LCRA58)

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LABEL	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
M1	82788.7	156614.	0.0	85.5	579.4	1204.4	1466.7	5910.6	12543.	18939.	31881.	87962.	235241.	1399006.
M2	85871.5	165157.	0.0	9.5	552.7	1190.1	1260.8	5892.5	12543.	18687.	31183.	88346.	247646.	1399006.
M3	85712.2	166021.	0.0	0.0	0.0	44.3	1010.3	4825.7	11060.	17774.	31395.	88521.	249035.	1399006.
M4	85728.1	165815.	0.0	0.0	0.0	59.2	1010.3	5085.3	11421.	18163.	31585.	88521.	249035.	1399006.
M5	85878.6	165105.	0.0	9.5	552.7	1190.1	1260.8	5892.5	12651.	18768.	31114.	88521.	247928.	1399006.
M6	85873.0	162078.	211.0	651.0	1065.8	1434.8	1849.8	7225.4	13844.	20493.	34361.	88752.	243493.	1397863.
D1	86371.8	138688.	216.3	741.2	944.9	1598.4	3081.2	8950.1	16641.	23851.	38555.	97375.	268310.	869669.
D2	86371.9	138511.	216.3	744.0	945.0	1580.5	3172.7	8852.8	16653.	24267.	38703.	95427.	268984.	856642.
D3	86322.6	139112.	216.3	661.3	944.8	1492.6	3093.1	8488.3	16070.	22910.	38019.	96414.	269317.	868671.
D4	86230.4	139023.	190.5	365.6	532.1	1271.9	2792.6	8620.0	16289.	23495.	38405.	95749.	273406.	866481.
D5	86748.1	159186.	216.3	698.0	901.9	1496.3	3139.8	9429.7	16446.	23339.	38212.	87386.	236821.	1396860.
D6	86144.8	141677.	0.0	109.4	516.0	1181.7	2421.7	6611.2	13663.	21320.	35811.	95210.	271200.	871474.
D7	86519.6	138384.	216.3	794.9	1010.7	1602.0	3243.0	9772.2	16978.	24784.	39016.	95830.	265807.	876694.
D8	83442.5	133334.	216.3	765.8	1018.2	1614.9	3176.2	8819.4	16042.	22971.	38011.	94046.	257598.	848832.

Table 7.6 Continued
Regulated Flow Frequency, acre-feet per month

Brazos River near Waco (BRWA41)

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LABEL	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
M1	109583.6	234869.	0.0	30.1	342.4	1666.0	3121.1	7447.0	15067.	24272.	39700.	97518.	309968.	3122472.
M2	105050.9	224848.	0.0	17.8	282.1	1639.1	3029.0	7423.1	15947.	25474.	41137.	96443.	288732.	3122472.
M3	104729.3	227883.	0.0	0.0	0.0	439.5	1171.1	4775.0	11607.	21352.	40287.	96877.	289952.	3126970.
M4	104820.1	225500.	0.0	0.0	0.0	753.2	2055.4	6614.9	15135.	24672.	42419.	93561.	288225.	3124305.
M5	105084.7	224016.	0.0	17.8	282.1	1639.1	3029.0	8043.5	17122.	26683.	43103.	96443.	279043.	3122151.
M6	114044.4	214823.	162.6	5151.8	8148.9	11561.0	17184.0	28434.5	37516.	48804.	61251.	99477.	263381.	3114786.
D1	109630.0	187148.	1339.7	6255.0	9452.3	14397.4	20680.1	30570.1	42576.	55506.	66414.	93731.	248333.	1887878.
D2	109785.6	187207.	1349.4	5391.9	9212.0	13901.5	19471.9	29565.6	42045.	53785.	66075.	95810.	243613.	1832477.
D3	109255.2	188103.	1132.2	5111.8	9804.2	14452.2	21138.9	29420.9	40959.	54082.	65937.	92160.	249869.	1888458.
D4	109056.0	187393.	1208.6	5275.3	9798.5	15794.8	21625.8	30725.8	41777.	54638.	65306.	89906.	251308.	1884988.
D5	109747.1	196148.	1343.2	6310.9	10689.5	15275.0	21846.8	30597.2	42780.	57033.	66663.	93525.	247985.	2724514.
D6	101637.5	183756.	246.6	1474.6	2065.9	5134.8	10409.1	26601.7	37631.	48708.	64480.	88589.	233603.	1904197.
D7	108056.5	202726.	833.0	3053.1	4322.3	7626.6	10836.2	18360.8	27590.	38143.	52462.	98799.	268206.	1898827.
D8	112735.8	197589.	1342.8	8470.1	11405.5	15556.8	22083.0	30963.1	42635.	55945.	66390.	94850.	261184.	1887950.

Brazos River near Richmond (BRRI70)

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LABEL	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
M1	380384.3	559015.	306.6	13296.9	17713.9	27683.5	35376.0	61420.5	93482.	145445.	229100.	462922.	1038953.	5449262.
M2	379176.9	564883.	273.1	11272.2	14637.0	23181.9	32756.9	57542.8	92962.	144823.	219176.	462862.	1020437.	5449262.
M3	378449.7	569194.	265.3	9664.7	13298.2	22177.7	31151.9	50998.9	86224.	137487.	217849.	474231.	1036426.	5460220.
M4	378547.0	566817.	265.3	11186.2	13989.0	22177.7	31291.8	52878.7	89997.	142831.	222396.	472530.	1017622.	5457744.
M5	379214.9	563881.	273.1	11272.2	14637.0	23181.9	32756.9	57542.8	94775.	145437.	221983.	462862.	1012750.	5448962.
M6	381166.4	554603.	6263.8	20675.2	27942.2	34371.8	44535.2	72246.2	109606.	154049.	216140.	473730.	1004904.	5504892.
D1	377963.2	496407.	5650.0	16917.5	23044.1	31590.9	42083.8	71071.8	117983.	162579.	246764.	499748.	1037181.	3588010.
D2	378135.3	496323.	5671.3	16869.6	22305.0	31307.5	41159.0	70870.9	118312.	163141.	245565.	501402.	1037442.	3552946.
D3	377501.1	497770.	5654.8	16814.7	23350.2	32238.2	42637.5	69722.8	114904.	161902.	245088.	503993.	1045398.	3588595.
D4	377017.8	497560.	5676.0	17256.1	21253.9	30789.1	39043.7	68884.5	118578.	161998.	245847.	501954.	1036411.	3586922.
D5	378379.2	531430.	4421.6	17734.0	22370.7	32110.0	42305.4	70498.6	116060.	162104.	230855.	477282.	1024181.	4397462.
D6	376444.2	495048.	284.7	12114.7	15164.7	27167.9	37430.3	71559.1	118308.	163475.	244694.	494927.	1046412.	3591813.
D7	377101.3	508151.	5664.8	13936.1	17824.4	25591.0	35846.1	59561.4	106502.	157088.	241693.	502544.	1048350.	3586638.
D8	377977.7	494838.	5657.9	22792.7	26144.5	36258.2	44783.6	73663.4	116229.	162538.	246504.	501547.	1037213.	3588054.

Regulated flows at Waco are particularly sensitive to the addition of hydropower at Lake Whitney. The absence of hydropower operations at Whitney Lake in M1, M2, M3, M4, M5 and D7 greatly reduces regulated flow at BRWA41 for exceedance frequencies greater than 25%. Regulated flow is greater in the 10% exceedance frequency without the presence of hydropower suggesting greater reservoir spilling during high flow events as a result of carrying more storage contents during the period of analysis.

The mean regulated flows are very similar but slightly lower in the middle and lower portions of the basin in the daily simulation as represented with the Waco and Richmond gages. For example, simulations M6 and D5 have the same model configurations except for time step size. The mean monthly regulated flow is 0.7% lower at Richmond in D5. As noted in Wurbs et al. (2012), computation of reservoir net evaporation-precipitation is slightly higher with more frequent time steps in the daily simulation. Slightly higher net evaporation-precipitation volume results in slightly greater reservoir refill and slightly lower mean regulated flows in the daily simulation. Individual exceedance frequency values of regulated flow differ between daily and monthly simulations as a result of different reservoir refill sequences and the action of flood control storage and release in the daily simulation.

The variability of daily flows creates different sequences of stream flow depletion and shortages for run-of-river rights within the basin. Regulated flows are greater at upstream gages in the daily simulation as represented by Seymour. Greater upstream regulated flow is due to greater passage of inflows to downstream senior run-of-river water rights under low flow conditions, greater downstream senior reservoir refill, and reduced efficiency of upstream rights in diverting stream flows during sub-monthly high flow events.

Multiple-purpose multiple-reservoir system operation has a significant effect on the minimum regulated flow at the Cameron, Waco, and Richmond gages. Mean regulated flows are also lowest without system operations when compared against other alternatives with the same time step size. Alternatives M1, M2, M3, M4, M5, and D6 do not include system operations. All BRA system demands are modeled as lakeside diversions. With the addition of system operations, BRA system demands are modeled at locations downstream. Stream flow shortages result in releases from multiple upstream reservoirs. Reservoir releases increase regulated flows especially in periods with low or zero natural stream flow.

Unappropriated Flows

Unappropriated flow frequency relationships are tabulated in Table 7.7. In general, unappropriated flows at all control points in the Brazos River Basin are concentrated almost exclusively within high flow events. This is due to the simulations being based on the WAM model of existing water right demands at fully authorized levels.

The presence of BBASC, BBEST, or existing instream flow requirements greatly affects the remaining daily unappropriated flows. In particular, the larger and more frequent high flow pulse requirements of the BBEST greatly diminish D2 mean unappropriated flow. M1, M2, and M3 have no BBASC instream flow requirements and consequently have the greatest unappropriated flow in the monthly alternatives. D3 has the highest unappropriated flow in the daily alternatives due to the absence of BBASC and BBEST instream flow requirements.

D5 contains BBASC but not existing *IF* record rights. Compared to the other daily simulations, D5 has the second highest mean unappropriated flow behind D3. Some of the existing *IF* record rights, especially those pertaining to the Hale clause, set instream flow requirements that are often greater than the base flow requirements in the BBASC or BBEST recommendations. D5 and M4 eliminate the existing *IF* record rights while retaining the BBASC instream flow requirements.

The extended period of analysis also contributes to a lower mean unappropriated flow when compared against the 58 year WAM period of analysis in alternatives M1 and D8. This is consistent with the lower mean naturalized flow in Table 7.5 along the main steam Brazos River.

Simulations M6 and D5 reflect the same input and assumptions except for time step. The mean unappropriated flow at the Richmond gage is higher in D5 than in M6 as a result of daily stream flow variability. Run of river rights generally have lower reliability in a daily simulation, as discussed in Wurbs et a. 2012, as a result of mismatches between short term high flow events and total monthly water right demand. Upstream run-of-river diversion shortages result in additional downstream flow. However, increased need for reservoir storage backup in the daily simulation results in greater reservoir refill during high flow events. The maximum unappropriated flow in M6 is therefore greater than D5.

Table 7.7
Unappropriated Flow Frequency, acre-feet per month

Brazos River near Seymour (BRSE11)

LABEL	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
M1	10859.3	36345.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	253.	29447.	408040.
M2	10043.6	34319.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	67.	26395.	408040.
M3	10802.6	34855.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	935.	30888.	408040.
M4	9057.7	33534.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	21229.	405888.
M5	8911.5	33451.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	20069.	405888.
M6	9093.3	33365.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	21100.	405993.
D1	3411.2	20899.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	1909.	376672.
D2	1188.6	13025.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	339229.
D3	4492.0	22823.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	6111.	379734.
D4	3508.1	21232.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	2336.	377590.
D5	3294.5	20585.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	1397.	377466.
D6	2851.5	19728.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	354.	368551.
D7	3832.0	21759.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	2957.	375494.
D8	4155.9	23097.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	3539.	365231.

Little River near Cameron (LCRA58)

LABEL	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
M1	66445.9	151259.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	5401.	65196.	205420.	1391674.
M2	67946.8	157876.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	2373.	61908.	219312.	1391674.
M3	81694.6	166070.	0.0	0.0	0.0	0.0	0.0	0.0	5187.	13065.	26641.	84509.	247297.	1399006.
M4	65100.9	156770.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	47206.	204230.	1372546.
M5	62117.0	154130.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	44155.	200326.	1372546.
M6	60452.5	151142.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	41082.	197904.	1371403.
D1	48590.3	106790.	0.0	0.0	0.0	0.0	0.0	0.0	0.	213.	2674.	34537.	178802.	718620.
D2	23673.9	71386.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	520.	7581.	55726.	634567.
D3	58051.9	115457.	0.0	0.0	0.0	0.0	0.0	0.0	293.	2989.	9192.	55698.	200484.	768133.
D4	50474.2	108852.	0.0	0.0	0.0	0.0	0.0	0.0	4.	648.	4170.	36810.	185040.	718749.
D5	52288.2	134843.	0.0	0.0	0.0	0.0	0.0	0.0	0.	234.	2819.	33429.	155618.	1313133.
D6	50584.2	109909.	0.0	0.0	0.0	0.0	0.0	0.0	0.	287.	3038.	39044.	188769.	742938.
D7	47858.8	105848.	0.0	0.0	0.0	0.0	0.0	0.0	0.	86.	2169.	31672.	174583.	718749.
D8	50013.5	108507.	0.0	0.0	0.0	0.0	0.0	0.0	0.	295.	3125.	37869.	182055.	718634.

Table 7.7 Continued
Unappropriated Flow Frequency, acre-feet per month

Brazos River near Waco (BRWA41)

LABEL	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											
M1	83569.6	227406.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	514.	53088.	264691.	3092342.
M2	77006.9	216914.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	49417.	244711.	3092342.
M3	93497.3	227368.	0.0	0.0	0.0	0.0	0.0	0.0	122.	6089.	22695.	81123.	277896.	3126970.
M4	73366.9	214707.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	38805.	215748.	3115082.
M5	68088.2	209989.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	32176.	202192.	3092020.
M6	63744.6	205752.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	24061.	168549.	3084656.
D1	46107.1	137069.	0.0	0.0	0.0	0.0	0.0	0.0	0.	983.	3604.	20670.	116555.	1359078.
D2	18904.8	85817.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	1008.	5873.	26864.	1168842.
D3	57741.4	145303.	0.0	0.0	0.0	0.0	0.0	0.0	2800.	7203.	15857.	38538.	154625.	1353787.
D4	48243.6	140030.	0.0	0.0	0.0	0.0	0.0	0.0	393.	1917.	5055.	23118.	128557.	1380432.
D5	54747.7	184234.	0.0	0.0	0.0	0.0	0.0	0.0	0.	946.	3917.	22982.	135561.	2694384.
D6	43728.6	132130.	0.0	0.0	0.0	0.0	0.0	0.0	0.	1274.	4156.	21096.	111939.	1411669.
D7	53206.0	149717.	0.0	0.0	0.0	0.0	0.0	0.0	0.	131.	2364.	19931.	155926.	1607083.
D8	53029.6	149627.	0.0	0.0	0.0	0.0	0.0	0.0	0.	1283.	4728.	25767.	144707.	1358748.

Brazos River near Richmond (BRRI70)

LABEL	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											
M1	286565.9	524623.	0.0	0.0	0.0	0.0	0.0	0.0	8178.	48926.	120637.	365016.	906583.	5120828.
M2	274096.2	520029.	0.0	0.0	0.0	0.0	0.0	0.0	0.	40298.	99863.	324225.	869670.	5120828.
M3	323509.5	559947.	0.0	0.0	0.0	0.0	0.0	0.0	34501.	83275.	154842.	400337.	975090.	5460220.
M4	238766.4	512165.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	36230.	243338.	779673.	5384572.
M5	229364.3	499284.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	30386.	224641.	764006.	5120530.
M6	223376.8	494254.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	25846.	199529.	738487.	5176460.
D1	234215.7	441466.	0.0	0.0	0.0	0.0	0.0	0.0	8415.	29898.	69803.	259171.	797249.	3384487.
D2	142653.6	312299.	0.0	0.0	0.0	0.0	0.0	0.0	5833.	17418.	46265.	135925.	432081.	3089205.
D3	277161.6	459954.	0.0	0.0	0.0	0.0	0.0	3436.4	31431.	69948.	131313.	352935.	874427.	3525319.
D4	244964.5	453356.	0.0	0.0	0.0	0.0	0.0	278.2	10433.	34910.	78770.	277764.	838624.	3383398.
D5	236248.9	479470.	0.0	0.0	0.0	0.0	0.0	0.0	7574.	27165.	67137.	241342.	768138.	4069030.
D6	234804.1	439166.	0.0	0.0	0.0	0.0	0.0	31.8	10940.	32864.	74188.	251654.	806142.	3388290.
D7	238828.2	450422.	0.0	0.0	0.0	0.0	0.0	0.0	6472.	29235.	69308.	258781.	796234.	3383115.
D8	239475.0	444287.	0.0	0.0	0.0	0.0	0.0	60.7	8438.	30897.	78334.	288594.	798110.	3384530.

Reservoir Storage Contents

The 14 largest reservoirs in the Brazos River Basin are listed in Table 7.8 with their conservation, flood control, and total combined conservation and flood control storage capacities. The following frequency tables reflect the total storage contents of all 14 reservoirs at the end of each month of the simulation.

The daily alternative simulations, except for D5, contain flood control pools. A total capacity of 7,430,689 acre-feet is available in the 14 largest reservoirs with flood control pools included in the simulation. All monthly alternative simulations and daily alternative D5 contain reservoirs with only conservation storage. However, total conservation storage is increased from

3,484,859 acre-feet to 3,652,679 acre-feet by reallocation of flood control storage in Lakes Proctor and Whitney. The hypothetical new projects reallocate 31,480 acre-feet of flood control storage in Proctor and 136,340 acre-feet of flood control storage in Lake Whitney.

Table 7.8
14 Largest Reservoirs in the Brazos River Basin

Reservoir	Stream	Storage Capacity Conservation (acre-feet)	Storage Capacity Flood Control (acre-feet)	Storage Capacity Total (acre-feet)
Brazos River Authority and U.S. Army Corps of Engineers				
Possum Kingdom	Brazos River	724,739	−	724,739
Granbury	Brazos River	155,000	−	155,000
Whitney	Brazos River	636,100	1,363,400	1,999,500
Aquilla	Aquilla Creek	52,400	93,600	146,000
Waco	Bosque River	206,560	519,840	726,400
Proctor	Leon River	59,400	314,800	374,200
Belton	Leon River	457,600	640,000	1,097,600
Stillhouse Hollow	Lampasas River	235,700	394,700	630,400
Georgetown	San Gabriel	37,100	93,700	130,800
Granger	San Gabriel	65,500	178,500	244,000
Somerville	Yequa Creek	160,110	347,290	507,400
Limestone	Navasota River	225,400	−	225,400
West Central Texas Municipal Water District				
Hubbard Creek	Hubbard Creek	317,750	−	317,750
Texas Utilities Services (cooling water for Comanche Peak Power Plant)				
Squaw Creek	Squaw Creek	151,500	−	151,500
Total Storage Capacity		3,484,859	3,945,830	7,430,689

Total reservoir storage frequency for all alternative simulations is given in Table 7.9. The addition of hydropower demand at Lake Whitney results in consistently the lowest mean total reservoir storage content. Alternatives M1, M2, M3, M4, M5, and D7 do not include Lake Whitney hydropower. These alternatives have the highest mean total reservoir storage content when compared to alternatives of the same time step size.

Other than sensitivity to the presence of hydropower demands, the alternatives have similar mean reservoirs storage contents. Daily simulations have consistently lower mean contents than the monthly alternatives. Daily alternative D5 lacks flood control capacity which reduces the maximum simulated storage contents. However, D5 has similar mean storage contents compared to the other daily alternatives.

Table 7.9
Total End-of-Month Storage Frequency for the 14 Largest Reservoirs, acre-feet

LABEL	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
M1	2922246.	480780.	1293720.	1386454.	1534879.	1867359.	2278366.	2727908.	2938879.	3036283.	3120892.	3247798.	3424752.	3640088
M2	2915694.	453230.	1293720.	1396959.	1638704.	1976016.	2313530.	2705474.	2924265.	3019612.	3106476.	3225921.	3382406.	3640050
M3	2941630.	434273.	1326961.	1507133.	1681844.	2040704.	2378319.	2746948.	2945135.	3038818.	3126454.	3235682.	3382238.	3639189
M4	2924032.	440246.	1328283.	1472367.	1653692.	2024010.	2334267.	2729008.	2921505.	3020909.	3108050.	3228205.	3381034.	3640031
M5	2907564.	454984.	1285335.	1389396.	1629000.	1973121.	2302059.	2692940.	2914264.	3009946.	3096797.	3219602.	3381402.	3640050
M6	2814858.	479996.	1299862.	1424646.	1576946.	1927005.	2148854.	2536890.	2775118.	2897484.	3003308.	3180217.	3360030.	3635936
D1	2659104.	642751.	1014548.	1107772.	1209707.	1558516.	1842020.	2277709.	2537160.	2694886.	2836829.	3072950.	3381169.	6125498
D2	2632012.	632297.	973212.	1085211.	1192195.	1544326.	1847674.	2267189.	2519209.	2675626.	2799509.	3032293.	3333953.	6055742
D3	2687580.	639876.	1031302.	1109007.	1217944.	1577894.	1882965.	2305334.	2572480.	2722938.	2868868.	3096720.	3393354.	6137984
D4	2680173.	633671.	1037993.	1132861.	1258151.	1610117.	1893419.	2298039.	2558355.	2711262.	2848810.	3083370.	3388647.	6132003
D5	2580082.	574245.	940640.	1029756.	1146476.	1482741.	1796166.	2223905.	2497402.	2652760.	2795109.	3016286.	3266434.	3630706
D6	2564251.	678966.	850684.	912984.	991649.	1304552.	1729596.	2177060.	2449806.	2603808.	2734266.	3006303.	3337990.	6048278
D7	2812881.	587726.	1190786.	1305115.	1430821.	1749574.	2072430.	2498835.	2773915.	2902987.	2986997.	3151486.	3431996.	6103810
D8	2702618.	669470.	1015364.	1096119.	1172003.	1494689.	1775047.	2333336.	2606732.	2770519.	2891468.	3138218.	3414358.	6124026

All reservoirs begin the simulation with full conservation storage as an initial condition assumption. All of the 14 reservoirs, except for Squaw Creek, fluctuate between full and empty conservation storage contents throughout the period of analysis. Squaw Creek Reservoir has zero or near zero storage contents throughout most of the period of analysis after the full condition at the beginning of the simulation is depleted during the first decade of the simulation. This behavior is consistent in both monthly and daily time step alternatives.

Environmental Instream Targets

Instream flow target frequency for either the BBASC or BBEST requirements are given in Table 7.10. Alternatives M1, M2, M3, and D3 do not contain either BBASC or BBEST environmental instream flow requirements. Alternatives M4, M5, and M6 contain identically the same monthly instream flow targets. The monthly targets were developed on a daily basis with the ED model for all 19 gages in the BBASC recommendations report. Development of the monthly BBASC instream flow targets is presented in Chapter 6.

The monthly instream flow targets for alternatives M4, M5, and M6 are provided as simulation inputs using target series *TS* records in the target series TSF file. The *TS* records with the BBASC instream flow targets are fixed and are not modified according to the regulated flow within the simulation. Seven daily alternative simulations use either the BBASC or BBEST instream flow requirements. Within the daily alternative simulations, regulated flow is measured and directly used in setting the daily value of the subsistence, 50% rule, and high pulse flow targets.

The new hypothetical projects have the ability to affect setting of regulated flow dependent elements of the environmental instream flow regime. For example, regulated flow may be slightly greater than the pulse flow trigger flow rate. A pulse flow event would be engaged and daily instream flow targets would be set up to the trigger flow rate until the pulse flow event is terminated. However, if one of the hypothetical new projects reduces the regulated flow, then the trigger flow rate might not be reached and a pulse flow event is not engaged. Similar effects related to application of the subsistence and 50% rule targets might be found in comparing simulations with and without new project demands.

The mean BBASC instream flow targets vary between the daily alternative simulations as a result of the changes to regulated flow produced by the simulation configuration. The greatest difference in instream flow target frequency is seen in comparison of the BBEST versus BBASC simulations. The BBEST recommendations result in significantly larger and more frequent pulse flow targets. Regulated flow frequencies do not exhibit as large of a difference as seen in unappropriated or instream flow target frequencies. This suggests that the pulse flow targets set by the BBEST requirements are protecting flow events that are greatly above the diversion capability of the demands that are junior to the BBASC and BBEST priority dates. Additionally, run-of-river shortages at the downstream junior system operation control points listed in Table 6.6 and shortages by the new hypothetical projects as a result of larger and more frequent BBEST pulse flow requirements are backed up by senior reservoir storage. Refilling senior reservoir storage may offset the stream flow depletions forgone by junior rights.

Table 7.10
Environmental Instream Flow Target Frequency, acre-feet per month

Brazos River near Seymour (BRSE11)

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LABEL	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
M1,M2,M3	–	–	–	–	–	–	–	–	–	–	–	–	–	–
M4,M5,M6	1604.5	1250.	59.5	61.5	94.2	177.6	270.3	799.5	1130.	1388.	1537.	2082.	2828.	7572.
D1	1602.2	1243.	59.5	61.5	94.2	177.6	270.4	799.4	1130.	1388.	1537.	2082.	2828.	7572.
D2	7736.7	17420.	59.5	61.5	63.9	155.6	322.0	1130.5	1537.	1969.	2736.	5016.	20476.	144681.
D3	–	–	–	–	–	–	–	–	–	–	–	–	–	–
D4	1602.3	1242.	59.5	61.5	94.2	177.6	270.3	799.4	1130.	1388.	1537.	2082.	2828.	7578.
D5	1602.3	1243.	59.5	61.5	94.2	177.6	270.4	799.4	1130.	1388.	1537.	2082.	2828.	7572.
D6	1601.3	1243.	59.5	61.5	94.2	177.6	270.4	799.4	1130.	1388.	1537.	2082.	2828.	7568.
D7	1600.4	1238.	59.5	61.5	94.2	177.6	263.8	799.4	1130.	1388.	1537.	2082.	2828.	7577.
D8	1643.2	1266.	59.5	61.5	90.7	176.7	270.4	799.4	1168.	1438.	1537.	2152.	2858.	7572.

Little River near Cameron (LCRA58)

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LABEL	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
M1,M2,M3	–	–	–	–	–	–	–	–	–	–	–	–	–	–
M4,M5,M6	18455.2	15689.	1874.0	1969.0	1971.0	2420.6	3817.2	9521.0	10957.	11683.	18446.	20602.	45223.	100209.
D1	18387.5	15674.	1868.3	1968.5	1969.6	2417.7	3731.1	9521.3	10929.	11683.	18446.	20290.	45223.	100148.
D2	35169.0	50998.	1871.3	1967.8	1969.1	2417.0	3695.9	9838.7	11734.	18446.	20418.	38036.	81478.	446585.
D3	–	–	–	–	–	–	–	–	–	–	–	–	–	–
D4	18374.0	15735.	1876.3	1952.7	1968.5	2383.3	3699.0	9521.3	10938.	11683.	18446.	20290.	45223.	100148.
D5	18454.6	15525.	1868.4	1968.5	1968.5	2446.0	3778.2	9521.3	10972.	11683.	18446.	21128.	45223.	100666.
D6	18343.3	15912.	1845.4	1937.5	1968.5	2215.6	3427.2	9521.3	11001.	11683.	18446.	20290.	45223.	101300.
D7	18427.3	15609.	1875.1	1968.5	1971.7	2455.7	3769.5	9521.3	11110.	11683.	18446.	20290.	45223.	100195.
D8	18727.7	16013.	1867.9	1967.6	1968.5	2368.2	3665.9	9838.7	11306.	12220.	18446.	21600.	45223.	100148.

Table 7.10 Continued
Environmental Instream Flow Target Frequency, acre-feet per month

Brazos River near Waco (BRWA41)

LABEL	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											
M1,M2,M3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M4,M5,M6	24724.8	22839.	3508.0	5011.4	5806.9	7140.0	8331.0	12495.0	15373.	16065.	20916.	35106.	42427.	199553.
D1	25028.6	23700.	3519.3	5644.6	6634.8	7144.6	8331.3	12495.2	15373.	16065.	20735.	35106.	42427.	226876.
D2	47142.7	85854.	3484.2	4910.9	5854.4	7140.2	8331.3	12495.2	15373.	16601.	28668.	41058.	102080.	827214.
D3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D4	24933.4	23672.	3396.0	5616.5	6550.7	7229.1	8331.3	12495.2	15373.	16065.	20033.	35106.	42427.	232004.
D5	24785.7	22651.	3518.9	5719.4	6645.8	7140.2	8331.3	12495.2	15373.	16065.	21393.	35106.	42427.	217219.
D6	24769.6	24427.	3343.0	3543.8	3816.4	5336.9	7140.2	12495.2	15373.	16065.	20033.	35102.	42427.	233305.
D7	24924.5	23450.	3332.2	4285.4	5337.0	6901.6	8041.3	12495.2	15373.	16065.	20055.	35106.	42427.	207442.
D8	25394.8	23846.	3519.2	6490.4	6864.4	7378.2	8516.6	12495.2	15373.	16065.	22235.	35106.	42427.	220457.

Brazos River near Richmond (BRRI70)

LABEL	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											
M1,M2,M3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M4,M5,M6	127208.9	79765.	32727.0	33818.0	34784.4	38881.2	42942.4	79141.0	91636.	101455.	127339.	158518.	236826.	541419.
D1	127398.4	80039.	32727.2	33818.2	34913.5	38757.9	44113.5	79140.6	91636.	101454.	127339.	158518.	236826.	539936.
D2	201635.9	240478.	31486.3	33818.2	34363.6	36900.0	42074.6	81778.6	101454.	128981.	140665.	219630.	414409.	1689069.
D3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D4	127258.9	79946.	32925.9	33818.2	34235.6	37331.3	43272.7	79140.6	91636.	101454.	127339.	158518.	236826.	540089.
D5	126850.9	78521.	32727.2	33818.2	34777.0	38891.9	43901.7	79140.6	91636.	101454.	127339.	157725.	236826.	520362.
D6	127142.7	80065.	32727.2	33818.2	34003.7	37334.0	42318.5	79140.6	91636.	101454.	127339.	158518.	236826.	537437.
D7	126700.1	80123.	32727.2	33818.2	33912.8	37262.2	41171.9	79140.6	91636.	101454.	127339.	157176.	236826.	542758.
D8	129226.7	81522.	32727.2	33818.2	35071.4	38668.9	43002.6	81778.6	94589.	101454.	130314.	160017.	236826.	539933.

The two lowest mean BBASC instream flow targets in the daily alternative simulations occur in D5 and D7. Flood control reservoirs are not simulated in D5. Flood events are impounded and released over a longer period of time by flood control reservoirs. This tends to increase the chance of a flood event that occurs in one season to trigger small pulse flow events in a following season as flood storage is released. Hydropower at Lake Whitney is not simulated in D7. Regulated flows below Whitney benefit from the presence of hydropower releases. The benefit to regulated flow is seen by comparison of D1 and D7 regulated flow for exceedances greater than 50% at Richmond in Table 7.6. Lower regulated flows during low flow periods in D7 increases the probability for setting subsistence and 50% rule targets. Similar effects in D7 are seen for instream flow targets set at Waco for exceedances greater than 50 percent.

Alternative D6 does not use the multiple-reservoir multiple-purpose system operation to transfer demands from lakeside diversion to downstream locations in Table 6.6. Reservoir releases are not made without the system operation assumption. Without reservoir releases, there are increased subsistence and 50% rule targets rather than dry base flow targets. Targets at Waco for frequencies greater than 75% reflect the lack of reservoir releases in D6.

Environmental Instream Shortages

Monthly environmental instream flow shortage frequency relationships are given in Table 7.11. Alternatives M1, M2, and M3 do not contain monthly BBASC target series *TS* records and therefore have zero shortage frequency. Daily alternative D3 does not set *IF* record targets for either the BBASC or BBEST requirements as do the seven other daily alternatives. The same monthly targets are input to M4, M5, and M6 as *TS* records compiled from the aggregated daily results of the daily ED model presented in Chapter 6. The ED model in Chapter 6 does not contain the two new hypothetical projects that are modeled in the 14 alternative simulations of Chapter 7.

Table 7.11
Monthly Environmental Instream Flow Shortage Frequency, acre-feet per month

Brazos River near Seymour (BRSE11)

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LABEL	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
M1,M2,M3	–	–	–	–	–	–	–	–	–	–	–	–	–	–
M4	122.1	344.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	505.	2362.
M5	122.1	344.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	505.	2362.
M6	126.8	350.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	557.	2362.
D1	115.2	331.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	429.	2296.
D2	82.9	276.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	229.	2297.
D3	–	–	–	–	–	–	–	–	–	–	–	–	–	–
D4	115.3	332.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	429.	2297.
D5	115.1	331.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	429.	2295.
D6	115.7	332.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	431.	2295.
D7	116.1	332.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	435.	2292.
D8	92.5	285.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	278.	1849.

Little River near Cameron (LCRA58)

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LABEL	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
M1,M2,M3	–	–	–	–	–	–	–	–	–	–	–	–	–	–
M4	3628.8	6597.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	733.	5429.	11675.	41110.
M5	3321.1	6418.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	354.	4192.	10551.	41113.
M6	2823.9	5730.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	2933.	9465.	38264.
D1	2291.9	5173.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1328.	8418.	36462.
D2	1459.7	3476.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	556.	6633.	27673.
D3	–	–	–	–	–	–	–	–	–	–	–	–	–	–
D4	2402.8	5296.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1523.	8619.	36413.
D5	2392.9	5291.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1503.	8440.	36492.
D6	2920.2	6096.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	3220.	9732.	43054.
D7	2150.8	5008.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	987.	8282.	36007.
D8	2037.0	4416.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1202.	7889.	36412.

Table 7.11 Continued
Monthly Environmental Instream Flow Shortage Frequency, acre-feet per month

Brazos River near Waco (BRWA41)

LABEL	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											
M1,M2,M3	0.0	0.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	0.
M4	4717.5	8400.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	401.	6495.	15349.	41058.
M5	4251.3	7892.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	5474.	14948.	39752.
M6	1004.8	3902.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	1161.	31465.
D1	402.6	1974.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	17563.
D2	658.9	5715.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	95570.
D3	0.0	0.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	0.
D4	438.4	2094.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	18494.
D5	388.6	1978.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	17395.
D6	760.3	2645.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	1442.	18396.
D7	2019.8	5705.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	7487.	33571.
D8	355.2	1833.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	16916.

Brazos River near Richmond (BRRI70)

LABEL	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											
M1,M2,M3	0.0	0.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	0.
M4	19131.8	36650.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	163.	24933.	67232.	233058.
M5	17852.1	35713.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	21729.	63649.	233030.
M6	13425.9	31643.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	6791.	51789.	227183.
D1	13109.4	31202.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7218.	48476.	221884.
D2	8580.0	21094.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	3564.	34334.	180522.
D3	0.0	0.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	0.
D4	13765.4	31984.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	8588.	52609.	222576.
D5	13399.0	31450.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7534.	49993.	221801.
D6	13758.7	31522.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	10212.	48870.	214124.
D7	15945.8	34164.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	14122.	59402.	224570.
D8	10734.5	25115.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	5646.	43277.	180506.

Instream flow shortages are computed in the WRAP program *TABLES* using the regulated flow and instream flow targets at each control point. The shortages shown in Tables 6.31 and 6.35 of the preceding Chapter 6 are computed on a daily basis. The maximum daily shortage shown at Waco for the BBASC and BBEST requirements are 26,970 and 84,492 acre-feet per day, respectively. These maximum daily shortages are a result of upstream flood control operations reducing regulated flow below a pulse flow requirement that was set earlier in the time step. However, high flow conditions persist for many days after the relatively few days in which the pulse flow targets are set. The daily shortages in Tables 6.31 and 6.35 are not expected to be reflective of the monthly shortages shown in Table 7.11. Monthly regulated flow may exceed the monthly instream flow targets when regulated flow and instream flow targets are aggregated to a monthly basis.

The lowest mean instream flow shortages for the monthly time step alternatives at locations below the system reservoirs occur in simulation M6 when hydropower and multi-reservoir system operations are modeled. Additional reservoir releases contribute to increased regulated flow and consequently reduced instream flow shortage.

Table 6.38 of Chapter 6 and the accompanying discussion show that the BBEST methodology for setting the hydrologic condition in the lower basin causes less frequent wet base flow requirements and more frequent months of dry base flow requirements. Even though the overall targets for the BBEST environmental instream flow requirements are larger than the BBASC as a result of the difference in pulse flow requirements, the mean shortages are lower for the lower basin. Pulse flow targets do not result in shortages unless flood control operations reduce regulated flows below the pulse flow target set earlier in the time step. The mean monthly shortage at Richmond is the lowest in the daily alternatives in simulation D2.

Mean environmental instream flow shortage and shortage frequencies are different between the daily and monthly simulation alternatives. Pulse flow, subsistence, and 50% rule instream flow targets in the daily simulations are set within the simulation according to the observed regulated flow. Environmental instream flow targets within the alternative monthly simulation are fixed and independent of regulated flow. However, the magnitudes of the shortages in both the daily and monthly simulation alternatives are low relative to the instream flow targets.

Reliability of Hypothetical New Proctor and Whitney Projects

As described earlier in this chapter, the two hypothetical storage and diversion projects are modeled with a priority junior to the new environmental flow requirements and junior to the depletion of excess flows at the system operation control points listed in Table 6.6. Priority dates of the hypothetical projects relative to all other rights are listed in Table 6.13.

The changes in water availability created by the environmental instream flow requirements are relevant to the potential for new surface water appropriation. The impacts of the environmental instream flow requirements on the hypothetical new Proctor and Whitney projects are evaluated using the reliability metrics given in Table 7.12.

The project at Lake Proctor consists of reallocation of 10% of the flood control pool for junior conservation storage. A uniformly distributed 10,000 acre-feet per year demand is adopted as a junior lakeside diversion. Dual simulation options are used to prevent refilling of storage drawn-down by the 10,000 acre-feet/year diversion at the priority of the existing rights.

Volume and period reliabilities for the entire period of analysis for the Lake Proctor project are generally above 95%. Reliability for the Lake Proctor project is less than 100% because the reservoir reaches zero storage content during the droughts of the 1950's and 1980's. The lowest reliability for the daily alternative simulations occurs in D6 which does not contain the multiple-purpose multiple-system reservoir operation configuration. Lake Proctor is not utilized in multiple-reservoir system operations. However, refilling conservation storage in Lake Proctor may benefit from the effects of system operations such as the presence of reservoir releases to meet instream flow requirements.

Table 7.12
Reliability of Hypothetical Projects

New Lake Proctor Storage Reallocation and Water Supply Diversion

LABEL	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%
M1	10000.0	410.25	95.69	95.90	95.7	95.7	95.7	95.8	95.8	96.0	96.1	89.7	89.7	89.7	89.7	94.8	96.6
M2	10000.0	325.95	96.58	96.74	96.6	96.6	96.6	96.7	96.7	96.8	96.9	91.8	91.8	91.8	91.8	95.9	97.3
M3	10000.0	271.05	97.03	97.29	97.0	97.0	97.0	97.3	97.3	97.4	97.5	93.2	93.2	93.2	94.5	95.9	97.3
M4	10000.0	303.06	96.80	96.97	96.8	96.8	96.8	96.9	96.9	97.0	97.1	91.8	91.8	91.8	94.5	95.9	97.3
M5	10000.0	325.95	96.58	96.74	96.6	96.6	96.6	96.7	96.7	96.8	96.9	91.8	91.8	91.8	91.8	95.9	97.3
M6	10000.0	152.13	98.29	98.48	98.3	98.3	98.3	98.4	98.5	98.6	98.6	94.5	94.5	95.9	95.9	97.3	98.6
D1	10000.0	163.70	97.95	98.36	97.9	98.1	98.1	98.2	98.2	98.6	99.0	95.9	95.9	95.9	95.9	97.3	98.6
D2	10000.0	260.27	96.46	97.40	96.5	96.5	96.5	97.1	97.3	97.7	98.4	91.8	91.8	91.8	93.2	94.5	98.6
D3	10000.0	160.07	98.06	98.40	98.1	98.1	98.1	98.2	98.3	98.6	98.9	95.9	95.9	95.9	95.9	98.6	98.6
D4	10000.0	245.59	97.03	97.54	97.0	97.0	97.0	97.1	97.4	97.7	98.5	93.2	93.2	93.2	93.2	94.5	98.6
D5	10000.0	451.10	94.52	95.49	94.5	94.5	94.5	94.7	95.3	96.0	97.1	90.4	90.4	90.4	90.4	91.8	95.9
D6	10000.0	512.21	93.15	94.88	93.2	93.2	93.4	94.1	94.7	95.7	97.0	86.3	87.7	87.7	87.7	91.8	95.9
D7	10000.0	160.94	97.95	98.39	97.9	97.9	97.9	98.2	98.3	98.5	99.2	94.5	95.9	95.9	95.9	97.3	98.6
D8	10000.0	208.22	97.27	97.92	97.3	97.4	97.4	97.7	97.7	98.3	98.7	93.1	94.8	94.8	94.8	96.6	98.3

New Lake Whitney Storage Reallocation and Water Supply Diversion

LABEL	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%
M1	30000.0	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
M2	30000.0	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
M3	30000.0	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
M4	30000.0	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
M5	30000.0	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
M6	30000.0	2899.13	90.18	90.34	90.2	90.2	90.2	90.3	90.4	90.4	90.5	72.6	74.0	74.0	79.5	82.2	91.8
D1	30000.0	5650.01	74.32	81.17	74.3	75.1	76.0	77.6	81.1	84.6	87.9	46.6	49.3	50.7	54.8	64.4	89.0
D2	30000.0	6245.28	72.72	79.18	72.7	73.4	74.2	75.9	78.7	82.5	86.6	43.8	47.9	49.3	50.7	64.4	82.2
D3	30000.0	5142.99	76.48	82.86	76.5	77.1	77.9	79.8	82.4	86.0	89.5	49.3	50.7	50.7	56.2	69.9	90.4
D4	30000.0	4449.50	78.77	85.17	78.8	79.2	79.7	82.0	84.7	88.7	92.0	47.9	49.3	53.4	60.3	72.6	91.8
D5	30000.0	4949.46	77.28	83.50	77.3	77.9	78.4	80.6	83.4	86.6	89.7	49.3	50.7	52.1	57.5	69.9	89.0
D6	30000.0	8030.95	65.07	73.23	65.1	66.0	67.2	69.5	72.7	77.2	82.1	31.5	34.2	35.6	42.5	56.2	74.0
D7	30000.0	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
D8	30000.0	4761.68	78.16	84.13	78.2	78.4	79.2	80.9	83.9	87.5	90.2	53.4	55.2	55.2	60.3	69.0	91.4

Reliability of the new project at Lake Whitney is sensitive to the presence of hydropower. Component reservoir CORWHT is relatively frequently drawn down to zero storage contents by hydropower releases. Component reservoir CORWHT serves as the backup reservoir to meet shortages of the new downstream project diversion. Simulations M1, M2, M3, M4, M5, and D7 do not contain hydropower demands.

Daily alternative D6 has the lowest reliability for the Lake Whitney project of the 73-year 1940-2012 period-of-analysis simulations. The highest reliability of the daily simulations occurs in simulation D4 in which existing senior instream flow requirements are deactivated. This suggests the project at Lake Whitney is sensitive to the presence of reservoir releases from system operations in meeting existing instream flow requirements.

Monthly alternative simulations M2 and M5 have the same modeling assumptions except for the addition of BBASC environmental instream flow requirements. The reliabilities for the new project at Lake Whitney are 100% for both M2 and M5. The reliabilities for the new project at Lake Proctor are less than 100% for M2 and M5. However, the reliabilities are identical. The new project at Lake Proctor appears to be insensitive to the presence of the BBASC instream flow requirements in the monthly time step simulations.

Daily alternatives D1 and D3 have the same modeling assumptions except for the addition of BBASC environmental instream flow requirements. Both the Lake Proctor and Lake Whitney projects show a slight increase in reliability when the BBASC instream flow requirements are not included in the simulation. Greater differences are apparent at lower diversion exceedances for the Lake Whitney project. The monthly period reliability for the 75% diversion exceedance of the Lake Whitney project is 77.6% and 82.0% for alternatives D1 and D6, respectively. The annual period reliability for the 75% diversion exceedance of the Lake Whitney project is 64.4% and 72.6% for alternatives D1 and D6, respectively.

Daily alternative D1 applies the BBASC environmental instream requirements and alternative D2 applies the BBEST environmental instream requirements. The BBEST requirements result in much larger mean instream flow targets due to the larger and more frequent pulse flow requirements. However, the BBEST requirements set lower base flow requirements for the lower portion of the basin as a result of the selected methodology for setting base flow requirements. The effect on reliability of the higher pulse flow requirements may be mostly offset by the lower base flow requirements. The reliability of the Lake Proctor and Lake Whitney projects are slightly lower in D2 as compared to D1. However, the difference in reliability is not proportional to the increase in daily targets as seen in Tables 6.30 and 6.34 and the monthly aggregate targets shown in Table 7.10.

Daily alternatives D1 and D5 have the same modeling assumptions except for flood control reservoirs which are excluded from D5. Flood control reservoirs are modeled at the junior-most priority in the simulation with option to ignore downstream water availability considerations when determining the amount of water available for depletion at the reservoir.

Lake Proctor flood control is modeled as a junior component of the conservation reservoir. Flood control depletions are able to refill conservation storage in Lake Proctor as it is drawn down by the project diversion demand. As a result, the reliability of the Lake Proctor project is increased by the presence of flood control in D1 as compared to D5.

Lake Whitney is modeled as three separate owner component reservoirs for the purposes of computing separate evaporation quantities. Flood control is modeled as a fourth separate component reservoir. The flood control component reservoir at Whitney is not simulated as refilling conservation storage in the three other component conservation reservoirs. The reliability of the Lake Whitney project is decreased by the presence of flood control in D1 as compared to D5. Lack of a flood control pool at Whitney and also at nearby Lakes Waco and Aquilla may increase downstream regulated flow during high flow events. Junior conservation storage at Lake Whitney may be able to refill to a greater extent in D5 while downstream regulated flows are elevated.

The volume reliability and monthly and annual period reliabilities shown in Table 7.12 for the two new hypothetical projects reflect the reliabilities expected from a combination of stream flow depletions and reservoir storage backup. Reliabilities in Table 7.12 do not exhibit a high degree of sensitivity to the presence of the BBASC instream flow requirements. Reservoir storage tends to mitigate sensitivity to the new environmental instream flow requirements. The new projects reallocate flood control storage to provide additional junior storage for the projects. However, the original conservation storage capacity in lakes Proctor and Whitney are refilled senior to the new environmental flow requirements. Run-of-river shortage in one day or month for the new projects is backed up with reservoir storage that can be refilled at a senior priority.

Stream flow depletion frequency for the two new projects is developed using the *TABLES* DATA record. Monthly and annual stream flow depletion arrays are developed. The *TABLES* 2FRE input record creates frequency tables from the arrays created by the DATA time series.

The new Proctor project is modeled as a water right with the ability to make stream flow depletions for both satisfying the target demand and refilling conservation storage. Therefore, it has stream flow depletions in excess of the 10,000 acre-feet per year target demand. Depletions for the new Proctor project are also sensitive to the presence of flood control at Proctor which will help refill conservation storage. The new Whitney project is modeled as a downstream demand that receives reservoir releases to backup shortages. The new water right *WR* record for the 30,000 acre-feet per year project demand does not have the ability to refill storage.

Sensitivity to the BBASC instream flow requirements is seen in comparison of the stream flow depletion frequency for M2 and D3 versus M5 and D1. M2 and D3 do not contain the BBASC instream flow requirements. M5 and D1 are equivalent simulations except for the addition of the BBASC instream flow requirements. The increase in stream flow depletion capability without the BBASC instream flow requirements is most evident in the results for the new Whitney project water right.

Table 7.13
Monthly and Annual Stream Flow Depletion Frequency, acre-feet

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
LABEL	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
New Proctor Monthly Depletion Frequency														
M1	1247.9	4834.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	80.1	1626.9	57280.4
M2	1352.7	4961.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	235.9	2437.5	57280.4
M3	1510.0	4650.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	920.4	4165.9	59496.4
M4	1363.9	4985.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2634.7	59496.4
M5	1330.9	5043.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1830.0	57280.4
M6	1251.1	5068.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1769.1	70105.1
D1	644.6	2705.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	79.5	1027.6	35775.5
D2	177.8	1174.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	344.0	25808.5
D3	769.2	2999.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	307.9	1302.0	35855.8
D4	675.1	2764.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	170.2	1152.7	35838.6
D5	1128.9	4269.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.6	1679.9	57567.7
D6	561.6	2558.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.1	1006.7	44537.7
D7	651.4	2859.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	69.1	989.8	42175.0
D8	602.2	2607.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	108.4	1002.7	35775.5

Table 7.13 Continued
Monthly and Annual Stream Flow Depletion Frequency, acre-feet

LABEL	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											
New Proctor Annual Depletion Frequency														
M1	14974.7	17917.9	0.0	0.0	0.0	0.0	0.0	0.0	2367.7	8429.3	13336.4	28081.8	39741.4	76750.7
M2	16231.8	17746.9	0.0	0.0	0.0	0.0	0.0	0.0	4914.8	9213.9	17241.6	29589.0	39321.9	76750.7
M3	18120.2	16826.0	0.0	0.0	0.0	0.0	0.0	3194.4	9281.3	16087.8	20564.7	29307.3	38341.6	78966.7
M4	16366.8	17700.4	0.0	0.0	0.0	0.0	0.0	0.0	5522.8	9112.9	18663.4	29186.4	39262.1	78966.7
M5	15971.1	18009.2	0.0	0.0	0.0	0.0	0.0	0.0	4370.2	8647.4	15481.4	31495.4	38835.6	76750.7
M6	15013.7	17790.8	0.0	0.0	0.0	0.0	0.0	0.0	3968.0	8465.1	16789.5	29724.4	36764.0	86016.9
D1	7735.1	9695.9	0.0	0.0	0.0	0.0	0.0	755.6	3267.7	5160.0	6227.9	9448.4	22894.9	42770.3
D2	2134.0	4264.5	0.0	0.0	0.0	0.0	0.0	0.0	308.3	706.7	1189.8	2571.6	5853.5	28204.8
D3	9230.5	10243.6	0.0	0.0	0.0	0.0	24.8	1856.6	4432.0	6368.2	7699.5	13273.2	26023.7	45175.3
D4	8100.8	10095.4	0.0	0.0	0.0	0.0	18.9	1231.0	3224.2	4681.9	6247.6	10632.8	25969.7	43125.7
D5	13546.5	16304.9	0.0	0.0	0.0	0.0	0.0	225.3	2012.9	6271.9	15332.0	23712.1	36558.4	79516.7
D6	6739.2	9804.2	0.0	0.0	0.0	0.0	0.0	36.7	1332.6	2901.2	5265.3	10080.6	17655.9	50629.9
D7	7816.7	10334.5	0.0	0.0	0.0	0.0	0.0	628.1	3204.2	4803.9	6085.6	10933.6	22641.8	49137.2
D8	7226.1	9145.4	0.0	0.0	0.0	0.0	0.0	603.5	3423.2	5104.0	6071.2	9292.6	22793.2	42770.4
New Whitney Monthly Depletion Frequency														
M1	850.2	1175.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	2465.8	2547.9	2547.9
M2	784.0	1151.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2465.8	2547.9	2547.9
M3	1110.9	1230.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	2301.4	2465.8	2547.9	2547.9
M4	736.5	1137.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2465.8	2547.9	2547.9
M5	661.4	1098.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2301.4	2547.9	2547.9
M6	751.3	1141.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2465.8	2547.9	2547.9
D1	489.8	719.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.2	246.6	739.7	1808.2	2547.9
D2	269.8	479.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.2	328.8	986.3	2547.9
D3	830.1	902.2	0.0	0.0	0.0	0.0	0.0	0.0	164.4	443.3	865.3	1643.8	2301.4	2547.9
D4	550.9	752.2	0.0	0.0	0.0	0.0	0.0	0.0	2.0	164.4	328.8	904.4	1890.4	2547.9
D5	494.2	732.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.2	246.6	765.2	1808.2	2547.9
D6	468.8	691.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.2	246.6	728.0	1672.6	2547.9
D7	412.0	696.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.2	493.1	1686.4	2547.9
D8	548.9	748.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	109.9	328.8	922.3	1890.4	2547.9
New Whitney Annual Depletion Frequency														
M1	10201.9	7344.3	0.0	0.0	0.0	0.0	7.0	4511.0	7561.9	10027.4	12411.0	17383.6	19906.9	30000.0
M2	9408.4	7383.2	0.0	0.0	0.0	0.0	0.0	2547.9	7439.0	9116.5	10109.1	15073.1	19890.4	30000.0
M3	13330.8	7991.8	0.0	0.0	0.0	7.9	778.7	7567.5	11629.6	12793.1	15056.7	19890.4	24159.1	30000.0
M4	8838.5	6572.5	0.0	0.0	0.0	0.0	0.0	3851.2	7046.5	7900.5	10095.1	14883.8	17424.7	24986.3
M5	7936.8	6656.0	0.0	0.0	0.0	0.0	0.0	649.3	5025.4	7561.7	9774.1	14262.6	17424.7	22438.4
M6	9015.2	6729.0	0.0	0.0	0.0	0.0	0.0	2547.9	7413.7	9863.0	10114.4	14958.9	17424.7	22438.4
D1	5878.1	4585.6	0.0	0.0	17.3	189.0	330.4	1737.6	3888.7	5215.4	6668.3	9627.2	12410.2	18411.0
D2	3237.5	2895.7	0.0	0.0	0.0	34.1	328.8	773.0	1854.6	2593.2	3838.3	5074.2	7245.6	12365.9
D3	9961.6	7077.3	82.2	82.2	146.4	558.0	1590.9	3704.6	7519.5	9725.1	11037.0	14948.8	19560.4	27165.5
D4	6610.4	4560.6	0.0	183.3	362.4	508.3	988.2	2621.8	4442.8	6332.5	7612.6	10382.6	13408.8	18416.8
D5	5930.2	4571.1	0.0	0.0	0.0	192.6	542.5	1737.4	3878.3	5586.7	6851.5	9450.0	12513.8	18215.2
D6	5625.6	4443.0	0.0	0.0	37.8	271.2	542.5	1583.5	3748.7	5304.7	6586.2	8655.7	11712.0	18575.3
D7	4943.5	4301.4	0.0	0.0	37.8	135.6	267.6	794.2	3137.6	4023.9	5461.8	8274.5	11400.5	18184.9
D8	6586.5	4709.4	0.0	0.0	6.0	77.7	316.9	2530.6	5005.8	6410.7	7626.0	10554.5	12519.4	18493.2

CHAPTER 8
GUIDUANCE SUMMARY

Stream flow in Texas is characterized by extreme temporal and spatial variability, controlled by extensive constructed infrastructure and diverse water management practices, and allocated among numerous waters users for various types of use by complex institutional mechanisms. Consequently, the Texas Water Availability Modeling (WAM) System is necessarily complex. Establishment of instream flow standards pursuant to the 2001 Senate Bill 2 and 2007 Senate Bill 3 and integration of environmental flow needs in comprehensive water management adds to the complexities of water allocation and modeling thereof.

The Water Rights Analysis Package (WRAP) has been continually expanded and improved since its incorporation in the Texas WAM System in 1997. New WRAP features added during the last several years have been motivated primarily by needs for improved capabilities for modeling environmental flow requirements and their impacts on water rights. Recently developed modeling capabilities include the following features.

- Target building features of the monthly *SIM* simulation are activated by the new flow switch *FS*, cumulative volume *CV*, hydrologic index *HI*, seasonal drought index *IM*, and water rights group *RG* input records along with new options on the instream flow *IF*, water right *WR*, target options *TO*, target series *TS*, and operating rules *OR* records. These features are applicable for daily as well as monthly simulations.

- The WRAP daily modeling system is implemented within *SIMD*, *DAY*, and *TABLES*. The *SIMD* daily simulation model includes disaggregation of monthly naturalized flows to daily quantities, daily variations in instream flow and diversion targets, flow forecasting and routing, simulation of environmental pulse flow requirements, and reservoir flood control operations. These recently developed daily simulation features are combined with the complete conventional monthly *SIM* simulation model.

- Program *TABLES* pre- and post-simulation frequency analysis and time series display capabilities are expanded with features activated by the new DATA record and new options on the 2FRE, 2FRQ, 6FRE, 6FRQ, and time series records.

- A new strategy for updating the hydrologic period-of-analysis of monthly naturalized flows and net monthly evaporation-precipitation rates is implemented in the WRAP program *HYD*. Naturalized flows are extended with a hydrologic model within *HYD* based on a dataset of observed monthly precipitation and evaporation.

Environmental flow requirements have been included in Texas water rights permitting processes for many years and are incorporated in the original TCEQ WAM System datasets and WRAP simulation model. However, the establishment of environmental flow standards and modeling thereof are currently being greatly expanded as outlined in this report.

Environmental flow standards are an integral part of the WRAP/WAM modeling system. WRAP is documented by *Reference*, *Users*, *Daily*, *Hydrology*, *Salinity*, *Fundamentals*, and *Programming Manuals*. Detailed guidance on modeling environmental flow standards and their impacts on other water rights is provided by the *Reference*, *Users*, and *Daily Manuals*.

Environmental Flows

The term *environmental flow* refers to water flowing in rivers, streams, lakes, and reservoirs, and includes freshwater inflows to bays and estuaries as well as flow in inland stream systems. Environmental flow needs are defined in terms of flow rates, flow volumes, frequency, timing, duration, spatial distribution, and water quality of the stream flows required to sustain freshwater and estuarine ecosystems. Environmental flow needs can be categorized from the perspectives of (1) flows of rivers and streams at inland locations, (2) inflows into bays and estuaries, and (3) reservoir inflows and associated storage level fluctuations. River flows, reservoir storage fluctuations, and freshwater inflows to bays and estuaries are interconnected.

For water right permits issued or revised since 1985, the TCEQ has used special permit conditions to implement Texas Water Code provisions that require consideration of instream uses, freshwater inflows, water quality, and fish and wildlife habitat. However, few of the several thousand permits issued before 1985 address environmental flows. The Texas Instream Flow Program authorized by the 2001 Senate Bill 2 and the process for establishing environmental flow standards created by the 2007 Senate Bill 3 are resulting in additional new environmental instream flow standards that are being incorporated in the WAM System datasets.

Under the Senate Bill 3 process, environmental flow requirements are defined in terms of a flow regime that contains subsistence, base, pulse, and overbank flows. High flow pulse requirements, including either within bank or overbank flow pulses, are particularly complicated to define and model. In the past in Texas, environmental flow requirements have been defined in terms of minimum flow limits that may vary seasonally, which are comparable to base flows in flow standards established through the Senate Bill 3 process.

The WAM System supports assessments of hydrologic and institutional water availability for existing water right permit holders and applicants for new and amended permits. The impacts of proposed new water rights on existing water rights are evaluated. Instream flow standards are being incorporated into the WAM datasets to simulate their effects on stream flow availability and supply reliability for future more junior permit applications for water supply diversions and reservoir storage.

Application of the WAM System in the Senate Bill 3 process during the initial development of environmental flow recommendations has been limited to date. However, the WAM System could be used in the design of environmental flow standards as follows.

- WAM System naturalized flows or sequences of regulated flows for a specified water use scenario may be used as input for the methods described in Chapter 2 used to develop instream flow requirements. Standard-setting methods have commonly been based on historical gaged flows. The WAM naturalized or regulated flows can solve the non-homogeneity problems associated with historical observed flows.

- Flow standards can be designed based on simulations of alternative trial designs. Capabilities of a river system in meeting alternative variations of proposed instream flow standards can be evaluated based on WAM simulation results and associated flow frequency analyses. Impacts of the instream flow standards on other water rights can likewise be evaluated through WRAP/WAM simulations.

Monthly Versus Daily Modeling

WRAP and the WAM System employ a monthly step time and will continue to employ a monthly time step. However, August 2012 and later versions of WRAP also include optional features for daily simulations. The primary motivation for the daily modeling system is to improve capabilities for simulating environmental flow requirements and their impacts on stream flow availability and supply reliability for other water rights.

The WRAP daily modeling system was developed by expanding *SIM* (to *SIMD*) and *TABLES* to incorporate additional features and creating the new auxiliary program *DAY*. *SIMD* includes all of the capabilities of *SIM* plus additional features either required for or made feasible by a daily computational time step. The *Daily Manual* supplements the *Reference* and *Users Manuals*. S*IMD* incorporates the following features applicable to daily simulations.

- options for disaggregating monthly naturalized flows to daily volumes and features for reading daily flows as input for use as pattern hydrographs for monthly flow disaggregation or for adoption as the actual daily naturalized flows
- flow forecasting needed to curtail streamflow depletions by junior water rights that would adversely affect downstream senior rights one or more days in the future
- lag and attenuation routing methodology for downstream propagation of stream flow changes resulting from diversions, return flows, and reservoir refilling or releases
- pulse flow environmental instream flow requirements
- reservoir operations for flood control and/or surcharge reservoir storage

The advantages of a daily model in modeling environmental flows and the work and data required to convert from a monthly to daily simulation are discussed in Chapter 3. A daily time step is essentially required for modeling high flow pulses, though monthly targets from a daily simulation may be incorporated in a monthly input dataset. A daily model is also more accurate than monthly in modeling subsistence and base flows. Reservoir operations for flood control can be incorporated in a daily model but not in a monthly model. Fundamental differences between daily and monthly simulation models are as follows.

- The smaller computational time interval improves the accuracy of the simulation. The increased level of accuracy is particularly relevant in simulating instream flow requirements and flood control operations. The effects of changing the size of the computational time step are diminished by reservoir storage and thus tend to be least pronounced for water supply rights with large reservoir storage capacities.
- In a monthly model, the effects of reservoir releases and water management/use actions on stream flows at downstream locations are assumed to propagate through the river system within the same month, without needing flow forecasting and routing computations. However, flow forecasting and routing are important in typical modeling applications based on a daily time step.
- Significant additional input data is required for a daily simulation along with the original input dataset from the WAM System.

A monthly WAM is complex, and monthly modeling results vary depending upon the approximations and premises adopted in developing input datasets. A daily WAM includes all of the input data of a monthly WAM plus additional input to convert from a monthly to daily simulation. Simulation results will vary with different choices of flow disaggregation, routing parameter calibration, forecasting, and target disaggregation methods and data. The variations in simulation results with differing though still reasonable input choices are often negligibly small but is some cases may be significant. Thus, daily modeling is applied with meticulous caution.

Monthly Simulation with Environmental Flow Targets from Daily Simulation

The TCEQ WAM System is constructed based on a monthly computational time step. In general, the month is the optimum time interval for the WAM System. However, environmental flows can be modeled much more accurately using a daily interval. In general, all components of environmental flow regimes can be modeled more accurately with a daily than with a monthly model. However, with a monthly time step, the subsistence and base flow components can be modeled much more accurately than the high pulse flow components. Approximating high pulse flow requirements in a monthly model directly using *IF* and supporting target-building records is perhaps possible but necessarily very approximate.

A strategy is proposed in this report in which instream flow targets are computed with the daily *SIMD* simulation model and provided as input to the monthly *SIM* simulation model. The daily targets computed in the daily *SIMD* simulation are summed to monthly target volumes within *SIMD*. The resulting sequences of monthly target volumes from the *SIMD* simulation results are inserted in the monthly *SIM* input dataset as target series *TS* records in a TSF file. Since subsistence, base, and pulse flow targets are interdependent, the final daily targets considering all components will normally be reflected in the adopted monthly totals.

Instream flow targets can be included in the aggregated monthly OUT file simulation results of a *SIMD* simulation and input TSF file for a *SIM* monthly simulation as targets for either individual water rights or as the final targets at control points that may reflect multiple intermediate targets created at the same control point. The WRAP program *HYD* has a feature activated by the output-input *OI* record that reads targets from a *SIMD* output OUT file and creates target series *TS* records for a *SIM* input file.

Instream flow requirements are reflected in two aspects of a simulation.

1. The instream flow targets at each pertinent control point in each time period are computed and adopted as minimum limits on regulated flows which represent quantities of appropriated stream flows.
2. The effects of the minimum instream flow limits are reflected in the computation of streamflow availability for other more junior water rights.

The strategy of computing monthly instream flow targets with a daily *SIMD* simulation for inclusion in the input dataset for a monthly *SIM* simulation provides the correct quantities for the monthly target volumes. However, since the monthly regulated flows limits are being applied in a monthly simulation, the effects on other more junior water rights are still subject to the impreciseness of a monthly computational time step. Combining the monthly and daily simulations greatly improves accuracy but does not completely resolve preciseness issues.

Constructing and Applying Instream Flow Targets

Instream flow targets are constructed in the same manner as water supply diversion targets, using a flexible array of target building options that range from simple to complex. An instream flow requirement is defined as an instream flow *IF* record water right. An instream flow target is set as the minimum limit on the regulated flow rate at a control point location, in units of acre-feet/month in a monthly simulation or acre-feet/day in a daily simulation. Instream flow *IF* record water rights add constraints limiting water availability for junior rights based on regulated flow targets. The objective is to maintain regulated flows equal to or greater than the instream flow targets. Two types of actions may occur in the *SIM* or *SIMD* simulation in order to prevent or minimize shortfalls in meeting the instream flow requirements.

1. Constraints placed on the streamflow available to diversion and storage rights that are junior to an instream flow requirement may result in these rights being curtailed to minimize shortages in meeting the instream flow target. Only releases not exceeding inflows are passed through reservoirs with no additional releases from storage.
2. Releases from any number of reservoirs identified by storage *WS* records associated with the *IF* record may be made specifically to meet instream flow requirements.

Any number of *IF* records may be input for a particular control point, with the next more junior instream flow target replacing the latest more senior target or optionally the largest or smallest controlling at different priorities. Thus, the magnitude of flow limits may be increased in the priority sequence. Junior diversion and storage rights are curtailed as necessary to prevent or minimize violation of senior instream flow rights.

Instream flow targets are specified in a *SIM* or *SIMD* DAT file using an instream flow *IF* record and optional supporting *UC*, *DI/IS/IP/IM*, *TO*, *SO*, *CV*, *FS*, *HI*, *TS*, and/or *WR* records. *SIMD* also has *DW* and *DO* records that are not applicable in *SIM*. An *IF* record is required for each instream flow right. The auxiliary records activate various options. Most but not all of the instream flow requirements in the existing WAM datasets are simply monthly minimum flow limits that vary over the 12 months of the year. However, the optional auxiliary records allow instream flow targets to be specified as functions of flexible combinations of the following.

- month of the year (water use coefficient *UC* record)
- beginning-of-each-month or beginning-of-multiple-month-season storage contents of any number of specified reservoirs (drought index *DI*, *IS*, *IP*, and *IM* records)
- arithmetic combinations of naturalized flow, regulated flow, unappropriated flow, reservoir storage, reservoir drawdown, streamflow depletions, withdrawal from storage, diversions, other instream flow targets, or instream flow shortages at selected control points or for selected water rights (target options *TO* records)
- monthly, seasonal, or annual limits (supplemental options *SO* records)
- arithmetic functions of the total cumulative volume over a specified number of preceding months of naturalized, regulated, and unappropriated flows at a specified control point, or diversions, targets, or shortages for specified *IF* or *WR* record rights (cumulative volume *CV* records)

- switches that completely or partially turn targets on or off depending on the total volume of a selected switch variable (same variable options as *CV* record) that has accumulated during a specified number of preceding months (flow switch *FS* records)
- a hydrologic index such as the Palmer hydrologic drought index used in arithmetic operations controlled by *TO*, *CV*, and/or *FS* records (hydrologic index *HI* records)
- flow sequences entered on input records (target series *TS* records)
- target components may be created as type 8 water rights and combined (*WR* records)

The options listed above can be adopted in either a monthly *SIM* or daily *SIMD* simulation. The following additional daily options are available only in *SIMD*.

- alternative options for distributing monthly targets over the days of a month or computing daily targets (daily water right *DW* and daily target options *DO* records)
- pulse flow requirements (pulse flow *PF* and pulse options *PO* records)
- daily disaggregation of monthly hydrologic index (daily hydrologic index DH record)

Each input record type noted above provides options that can be applied in various combinations. The resulting target is a minimum limit for regulated flows at specified control point locations for that time step. For a given monthly or daily time step of the simulation, each water right is considered in priority order of seniority. The target for each *IF* record water right is set at its specified priority and then applied throughout the remainder of the priority sequence for that time step. The details of both setting and applying the target depend upon options activated on the instream flow *IF* record and auxiliary target-building records and in some cases options activated on the job *JD* and *JO* records. Options controlling the details of applying instream flow targets are summarized as follows.

- By default, each *IF* record instream flow right is applied at a single control point. However, an option activated on the *IF* record allows the same computed target to be applied at all control points located within a defined stream reach.
- By default, each *IF* record instream flow target is applied as a minimum limit on total regulated flow. An option activated on the *IF* record allows the limit to be applied to regulated flows excluding reservoir releases made for use at downstream locations.
- Multiple *IF* records with different priorities may set any number of targets at the same control point. The default is for each junior *IF* record target to replace the preceding senior target in the priority sequence. An *IF* record option allows either the largest or smallest target to be adopted.

All water rights with junior priorities curtail diversions if and as required to protect the minimum flow limits. Junior rights with reservoirs likewise curtail refilling of depleted storage capacity. Optionally, releases from any number of reservoirs specified on water right storage *WS* records may be made to achieve the instream flow target. The full array of reservoir operation options provided by *WS* and operating rules *OR* records may be employed. A parameter on the *IF* record controls whether releases from reservoir storage, in excess of inflows, are made specifically to satisfy instream flow targets.

Environmental Pulse Flow Requirements

High flow pulses from rainfall-runoff events are characterized as hydrographs that peak rapidly with rising limbs ranging from less than a day to several days and total durations measured in days. Peaks may be either within banks or overflow the banks inundating the floodplain. The rising limb of a typical high flow pulse hydrograph typically climbs quickly to a peak, after which flows recede more slowly back to base flow levels.

Capabilities for modeling pulse flow requirements are explained in Chapter 8 of the *Daily Manual* along with illustrative examples. The pulse flow *PF* and pulse flow options *PO* records are described in Appendix A of the *Daily Manual*. These options are designed for modeling the high flow pulse and overbank flow components of the flow regime described in Table 2.4 of Chapter 2 of the present report. The *PF/PO* record feature requires a daily time step and is included only in *SIMD*, not *SIM*.

The *SIMD* pulse flow feature activated with the *PF* and *PO* records is designed for a daily simulation. However, instream flow targets for high flow pulses can be computed in a daily *SIMD* simulation and provided as input to the monthly *SIM*. The computed daily targets are summed to monthly target volumes within *SIMD*. The resulting sequences of monthly target volumes are provided as input to *SIM* as target series *TS* records.

The daily pulse flow targets computed by the *PF* and *PO* record target-building routine in *SIMD* are minimum regulated flow limits that are observed to the extent possible by curtailing junior diversion and storage refilling rights in the same way as for instream flow targets determined using any other records. *PF/PO* records can be combined with other target-setting records to compute minimum flow limits at a control point. Like most aspects of WRAP, *PF* and *PO* records are generalized for a variety of applications that depend upon the creative ingenuity of the modeler in combining various options activated by various input records. *PF* and *PO* records are inserted with the other target-building records following an *IF* or *WR* record. *SIMD* input parameters define each pulse flow target as follows.

A pulse event is considered to be engaged when it has been initiated and is being tracked. An engaged pulse may set daily pulse targets. A pulse event is engaged based on regulated flow exceeding the trigger criterion and satisfaction of optional initiation criteria. The decision to declare that a pulse event is no longer engaged is based on satisfaction of either the total event volume or maximum duration parameter or satisfaction of other optional termination criteria. Pulse tracking can be either seasonal or continuous.

Targets are developed each day during a pulse flow event. Daily pulse targets are less than or equal to the daily regulated flow measured at the priority assigned to the instream flow requirement. The minimum flow limit for each day of the pulse flow event may be either the complete final target or a component of the target-building process for an instream flow requirement. Daily pulse targets are not used to set a final target if the frequency criterion has already been met. A frequency parameter limits the number of pulse events meeting the specified criteria during the tracking period that are adopted as target setting events. When the number of pulse events exceeds the frequency parameter, events may optionally be tracked for information purposes but are not used to set targets.

Reservoir Operations for Flood Control

Reservoir storage contents never exceed conservation storage capacity in *SIM*. The monthly model is based on the premise that monthly outflows equal inflows for reservoir surcharge and flood control pools that may exist above the top of conservation pool. However in actuality, when conservation storage capacity is full and inflows exceed outlet structure discharge capacities, flows are attenuated by temporary ponding in surcharge and/or flood control pools above the top of conservation pool.

Although *SIMD* may be applied in studies focused specifically on flood control, *SIMD* simulation of reservoir flood control operations will most likely be applied to address integrated river system management dealing with interactions between multiple operating objectives. Flood control and surcharge pools affect downstream flows that meet environmental pulse flow needs and can also affect base flows.

Flood control reservoir operations are treated in *SIMD* as a type of water right. Flood control rights activated by pairs of *FR* and *WS* records are simulated along with all the other water rights activated by *WR* and *IF* records. Any number of *FR*, *WR*, or *IF* record rights may be associated with the same reservoir with the use of *WS* records. The auxiliary records that may be attached to the *WR* and *IF* records to activate target setting options are also applicable to setting the *FF* record maximum non-damaging flow limit used in flood control operations.

Reservoirs with designated flood control pools controlled by gated outlet structures are modeled in *SIMD* as *FR* and *FF* record water rights. Operation of multiple-reservoir systems with any number of reservoirs may be based on flood flow limits at any number of downstream control points. Releases from flood control and surcharge pools are also limited by the flow capacity of the spillway and other outlet structures at the dam, as modeled by *FV* and *FQ* records. *FV* and *FQ* records defining a storage-outflow relationship are provided along with a *FR* record to model (1) surcharge storage in a reservoir with no intentional flood control, (2) surcharge above a flood control pool, and/or (3) limits on releases from a flood control pool.

Multiple-reservoir system operations require allocation of storage and/or releases between reservoirs during each day of the flood event. *SIMD* includes flexible capabilities for modeling multiple-reservoir release decisions. Simulation results can vary, perhaps significantly, with different though still reasonable operating rules. Flood control operations are complex and incorporate significant operator judgment that may be difficult to model. Thus, flood control operations should be modeled cautiously, carefully combining an understanding of actual operating practices with the modeling options provided by *SIMD*.

Manuals and Examples

This report provides a focused summary of WRAP/WAM capabilities for modeling and analysis of environmental flow requirements and their impacts on integrated water management. The general framework for establishing and modeling environmental flow standards is outlined. Guidance in applying relevant WRAP features is provided along with examples from a general overview perspective. The *Reference*, *Users*, *Hydrology*, and *Daily Manuals* noted below provide in depth guidance for applying the modeling system and are necessary for its application.

The *Reference* and *Users Manuals* cover instream flow requirements in detail from a monthly modeling perspective. Five of the nine simplified examples in Appendix B of the *Reference Manual* include instream flow *IF* record rights. The *Daily Manual* explains in detail the additional features for modeling instream flow requirements using a daily time interval. The *Hydrology Manual*, which was added to the set of manuals in November 2013, covers the recently developed procedures for extending the hydrologic period-of-analysis.

The daily manual provides guidance for employing all additional features of the daily modeling system that are not covered in the *Reference* and *Users Manuals*. Chapter 8 of the *Daily Manual* focuses specifically on modeling pulse flow requirements. Chapter 5 explains flood control operations. Chapter 6 covers frequency analyses including techniques that are useful in flow frequency analyses dealing with environmental flows. Examples 7.4, 7.5, 8.1, and 8.2 in the *Daily Manual* focus specifically on modeling instream flow requirements. Additional examples are provided in Chapter 4 of the present report.

Brazos WAM Case Study

The TCEQ WAM System dataset for the Brazos River Basin and San Jacinto-Brazos Coastal Basin, called the Brazos WAM, was adopted for the environmental flow modeling case study presented in Chapters 5, 6, and 7 of this report. The purpose of the Brazos case study is to support TCEQ-sponsored research and development in improving capabilities for integrating environmental flow standards in the WAM System. The datasets developed in the case study are not designed for direct use by the TCEQ in the water rights permitting process. Rather the purpose of the investigation is to develop, test, and demonstrate modeling capabilities that may be useful to the TCEQ and water management community. The actual application of modeling features explored in the case study will depend on the policies and practices of the TCEQ and other agencies that will apply the new modeling capabilities in the future.

Wurbs et al. (2012) document the conversion of the monthly Brazos WAM to a daily time step and application of the new capabilities covered in the August 2012 *Daily Manual*. The original Brazos WAM has a hydrologic period-of-analysis of 1940-1997. Wurbs and Chun (2012) demonstrate the new hydrology extension capabilities documented in the November 2012 *Hydrology Manual* by updating the Brazos WAM period-of-analysis to cover 1940-2011. The hydrology was further extended in 2013 to include 2012.

The Brazos WAM datasets used in the case study presented in Chapters 5, 6, and 7 include the original and expanded monthly Brazos WAM datasets and an expanded daily *SIMD* input dataset. The investigation focuses on adding environmental flow requirements and system operations that affect environmental flows. The Brazos WAM is large and complex, providing opportunities to explore a number of issues involved in integrating environmental flow and other related water management practices and associated modeling methods. A diverse array of environmental flow requirements are considered in the case study.

Chapter 5 provides background information regarding the Brazos River Basin, Brazos WAM, and BBEST and BBASC recommended environmental instream flow requirements. Chapter 6 explains concepts and procedures for incorporating environmental flow requirements and multiple-purpose system operations into the WRAP input dataset for the Brazos WAM and presents simulation results showing environmental flow targets and the extent to which the targets are satisfied. Chapter 6 provides a case study example of incorporating environmental flow requirements into a WAM along with exploring other pertinent WRAP modeling features. The modeling strategies and methods adopted for the Brazos WAM are applicable to other river basin WAMs as well.

The daily and monthly models developed in Chapter 6 are applied in Chapter 7 to investigate the effects on hypothetical new projects and the interactions between environmental flow requirements and integrated multiple-purpose water management. Since the proposed new environmental flow requirements are junior to all existing water rights, two hypothetical new junior water rights are added in Chapter 7 to explore the potential impacts on new permit applicants. A series of frequency tables are presented in Chapter 7 comparing naturalized flows, regulated flows, unappropriated flows, reservoir storage contents, instream flow targets, and instream flow shortages at selected control points for 14 alternative simulations (six monthly and eight daily). Reliability tables and streamflow depletion frequency tables are presented for the two hypothetical new water rights for the 14 alternative simulations. This information is designed for comparing the effects on simulation results of the following modeling premises.

- Whether a daily or monthly computational time step is adopted.
- Whether the original 1940-1997 versus updated 1940-2012 hydrologic simulation period is adopted.
- Effects of different sets of environmental instream flow requirements including the instream flow *IF* records already contained in the TCEQ WAM dataset, the BBEST recommended requirements, and the BBASC recommended requirements.
- Whether or not flood control operations of the nine Corps of Engineers multiple-purpose reservoirs are included in the model.
- Whether Brazos River Authority diversions are placed in the model at approximately the actual diversion locations, which in some cases are significant distances downstream of the dams, or all of the diversions are assumed to be lakeside.
- Whether or not hydroelectric power operations at Whitney Reservoir are included in the model.

This report does not include evaluations or conclusions regarding which of these modeling premises should be adopted for various types of applications. However, the frequency and reliability tables in Chapter 7 provide insight on the effects of the alternative premises on simulation results.

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