MODELING REALLOCATION OF RESERVOIR STORAGE CAPACITY BETWEEN FLOOD CONTROL AND CONSERVATION PURPOSES

A Dissertation

by

TAE JIN KIM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2009

Major Subject: Civil Engineering

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Approved by:

Chair of Committee,	Ralph Wurbs
Committee Members,	Anthony Cahill
	Francisco Olivera
	Hongbin Zhan
Head of Department,	David Rosowsky

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Major Subject: Civil Engineering

ABSTRACT

Modeling Reallocation of Reservoir Storage Capacity
between Flood Control and Conservation Purposes. (May 2009)
Tae Jin Kim, B.S., Korea University;
M.S., Korea University
Chair of Advisory Committee: Dr. Ralph Wurbs

Interest in converting portions of the large volumes of flood control storage capacity in federal multiple-purpose reservoirs in Texas and elsewhere to water supply and other conservation purposes has been growing for some time. Evaluation of storage reallocations involving tradeoffs between flood control and conservation purposes in multiple-purpose, multiple-reservoir systems represents a new area for applying the Water Rights Analysis Package (WRAP) and Texas Water Availability Modeling (WAM) System. A system of 12 multiple-purpose reservoirs operated by the U.S. Army Corps of Engineers (USACE) and Brazos River Authority (BRA) was adopted as a case study in this research to develop and test expanded WRAP/WAM-based methods for analyzing modifications in reservoir storage allocations and related system operations. The research consisted of the following tasks:

- The Brazos River Basin WRAP input dataset from the Texas WAM System (Brazos WAM) has a 1940-1997 hydrologic period-of-analysis. The research included developing and applying methods to extend the period-of-analysis to 1900-2007 providing a better representation of river basin hydrology. The methodology developed could potentially be used to update the other river basin datasets in the statewide WAM System.
- The Brazos WAM has 3,830 control points, 670 reservoirs, and hundreds of water rights. The research included developing and applying methods to create a much

easier-to-apply condensed dataset focused on the USACE/BRA reservoir system and associated water rights that have only 48 control points and 14 reservoirs.

- The WRAP/WAM System was developed based on a monthly computational time step. The research included applying developmental methodologies for converting a monthly model to a daily time step that includes disaggregation of monthly naturalized flows to daily flows, calibration of flow routing coefficients, and incorporation of forecasting in the simulation.
- The WRAP/WAM System is designed for assessing water supply reliabilities and stream flow and storage frequencies from the perspective of conservative purposes. The research added flood risk indices to the WRAP modeling system in order to address tradeoffs between flood control and conservation purposes.
- The WRAP/WAM-based simulation study performed with the modified WAM dataset developed in this research demonstrates the improvements in water supply capabilities and tradeoffs with flood control associated with various reservoir storage reallocation strategies and other modifications in reservoir system operations.

DEDICATION

To my beloved parents,

Juck Hwang Kim and Sun Bun An

To my beloved wife and son,

Hyun Hee Jung and Minwoo

ACKNOWLEDGEMENTS

I would like to express my immense appreciation and gratitude to Dr. Ralph A. Wurbs, my professor, advisor and chair of my Advisory Committee. Without his valuable guidance, motivation and constant encouragement, I could not have finished my dissertation. I want to express my sincere gratitude to the members of my Advisory Committee: Dr. Tony Cahill, Dr. Francisco Olivera, Dr. Hongbin Zhan, and Dr. Yuefeng Sun for reading the dissertation and for their contributions. I also owe gratitude to the Brazos River Authority, in particular Philip Price and Aaron Abel, for providing their expertise, ideas, data, and documents.

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CHAPTER I

INTRODUCTION

The research focuses on expanding the capabilities of the generalized Water Rights Analysis Package (WRAP) river/reservoir system model and the Texas Water Availability Modeling (WAM) System to evaluate plans for reallocating storage capacity between flood control and conservation purposes and other related modifications in multiple-purpose, multiple-reservoir system operations. The expanded modeling capabilities are applied to assess potentialities for modifying operations of the multiple-purpose 12-reservoir system operated by the U.S. Army Corps of Engineers and Brazos River Authority in response to intensifying demands on limited water resources.

1.1 BACKGROUND

The water supplies demanded for municipal, industrial, and agricultural needs, as well as environmental instream flow requirements, and hydropower generation and flood control have increased over the past decades as a result of population and economic growth. The Texas Water Development Board (TWDB) projects that the population in Texas is expected to more than double from about 21 million in 2000 to about 46 million in 2060. The demand for water in Texas is expected to increase by 27 percent, from almost 17 million acre-feet of water in 2000 to 21.6 million acre-feet in 2060. Existing water supplies are projected to decrease about 18 percent, from about 17.9 million acre-feet in 2010 to about 14.6 million acre-feet in 2060. Surface water supplies are projected to decrease about 6 percent, from about 9.0 million acre-feet in 2010 to about 8.4 million acre-feet in 2060. Groundwater supplies are projected to decrease 32 percent, from about 8.5 million acre-feet in 2010 to about 5.8 million acre-feet in 2060. Existing water supply from water reuse – the use of the same water for multiple purposes – is expected to be about 370,000 acre-feet per year by 2060. Eventually, Texas is going to need an additional 8.8 million acre-feet of water by 2060 if new water supplies are not developed (TWDB 2007).

This dissertation follows the style of the *Water Resources Planning and Management*.

Flood damage is also a serious problem in Texas. Economic and human life losses have resulted from various kinds of floods caused by thunderstorms and hurricanes. Flood damage has been increased by developing areas for industrial, commercial, or residential purposes. Structural measures, such as flood control reservoirs, levees, and increasing the capacity of the river channel, have been constructed and non-structural measures such as the National Flood Insurance Program (NFIP) has been established for protection from floods.

Surface water is usually defined as water available from reservoir storage, or other surface sources such as lakes and streams. Reservoirs are essential for utilizing the highly variable surface water resources. Reservoirs are also the most important structural measures for flood protection in Texas (Cabezas-Canelos 1985).

Numerous reservoir projects were constructed throughout the United States from the 1930's through the 1970's. The water management focus has transitioned since the 1970's from project construction and water resources development to the current focus on optimizing the use of limited available resources and facilities. Public needs, objectives, and numerous factors affecting reservoir operation change over time.

Reallocation of reservoir storage capacity between purposes represents a general strategy for optimizing the beneficial use of available resources in response to changing needs and conditions. Institutional considerations have constrained storage reallocation and other related major changes in reservoir operating policies in the past. However, storage reallocations will likely be proposed more frequently in the future as demands on limited resources intensify.

1.2 RESERVOIR STORAGE REALLOCATION

Reservoir operation is based on the conflicting objectives of maximizing the amount of water available for conservation purposes and maximizing the amount of empty space available for storing future flood waters to reduce downstream damages. Many reservoirs are operated either for flood control only or for only conservation purposes. The large federal reservoir projects are typically operated for both flood control and conservation purposes, with separate pools designated for each. The conservation and flood control pools are defined by a designated top of conservation pool elevation, which also serves as the bottom of the flood control pool. Conservation pools may be shared by various purposes, such as municipal and industrial water supply, agricultural irrigation, hydroelectric power, recreation, and environmental instream flow requirements. The different conservation purposes involve both complementary and conflicting interactions. A general reservoir pools is shown in Figure 1.1.

Institutional considerations are fundamental in establishing and modifying reservoir operating plans. The responsibilities of the various organizations involved in operating reservoir systems are based on project purposes. The Corps of Engineers is responsible for flood control operations. The majority of the large multiple-purpose reservoirs in Texas and throughout the United States that contains designated flood control storage capacity are owned and operated by the U.S. Army Corps of Engineers (USACE). Nonfederal water supply sponsors such as river authorities, water districts, and cities contract for conservation storage capacity in the federal reservoirs, reimburse all costs associated with water supply, and control releases or withdrawals from conservation storage. The Corps of Engineers are also responsible for flood control operations of multiple-purpose reservoir projects constructed by the U.S. Bureau of Reclamation in the 17 western states. Institutional arrangements governing reservoir operations also vary between municipal and industrial water supply, agricultural irrigation, hydroelectric energy generation, recreation, and protection of environmental instream flow needs.

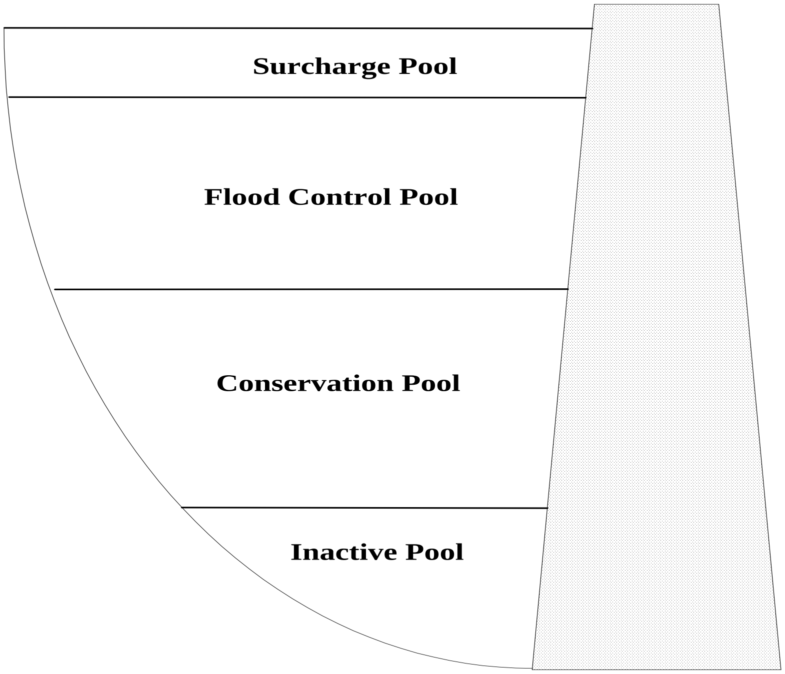

Figure 1.1 General Reservoir Pools

Interest in converting portions from the large volumes of flood control storage capacity contained in federal multiple-purpose reservoirs in Texas and elsewhere into water supply and other conservation purposes has been growing for some time. Such storage reallocations represent a potential strategy for meeting intensified demands for supplying water for human and environmental needs. Improved operation of water supply reservoirs during flood events is also a recognized concern. Multiple-reservoir systems operations also provide opportunities for improvements in multiple-purpose operations.

Reallocation of storage capacity in existing reservoir systems between flood control and conservation purposes may involve the following general strategies:

- Permanent reallocation of flood control capacity into conservation storage by permanently raising the designated top of conservation pool elevation.
- Seasonal rule curve operations of a multiple-purpose reservoir based on varying the designated top of conservation pool elevation as a function of season of the year or other conditions affecting flood and/or drought risk.
- Pre-releases based on flood forecasts or other strategies for operating non-federal water supply reservoirs with no officially designated flood control pool to reduce damages during flood events while minimizing adverse impacts on water supply reliability.
- Temporary storage reallocation of conservation storage into flood control capacity after considering the unused sediment storage in multiple-reservoir, multiple-purpose system operations.
- Storage reallocations between multiple reservoirs to optimize multiple-reservoir, multiple-purpose system operations.
- Integration of storage reallocations with other management strategies such as nonstructural flood damage reduction measures, emergency and long-term demand management strategies, and conjunctive use of surface and ground water.

These strategies involve tradeoffs between the purposes served by the reservoir system. The storage reallocations are typically to fulfill a particular purpose while minimizing adverse impacts on other purposes. Also, the storage reallocations result in improved capabilities for evaluating these interactions between reservoir purposes.

1.3 WATER AVAILABILITY MODEL (WAM)

The Texas Water Availability Modeling (WAM) System consists of the Water Rights Analysis Package (WRAP) simulation model, 21 WRAP input datasets covering the 23 river basins of Texas, and other supporting software and databases (Wurbs 2008a). The WAM System was implemented in Texas over the past several years to support water rights permitting policies and regional planning activities focused on water supply for municipal, industrial, agricultural and environmental needs. The WAM System is based on a monthly time step. Recent research at Texas A&M University is expanding the generalized WRAP modeling system to include a daily time step associated with forecasting and routing capabilities, which allows incorporation of flood control operations.

1.3.1 Texas Commission on Environmental Quality (TCEQ) WAM Dataset

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. The river basins covered by the 21 datasets are delineated in Figure 1.2 and listed in Tables 1.1 and 1.2. The map number in the first column of Tables 1.1 and 1.2 refers to the river basin shown in Figure 1.2.

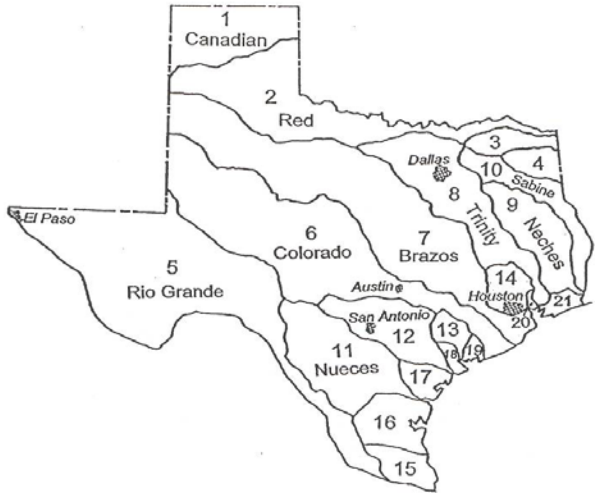

Figure 1.2 WAM System River Basin

Alternative versions of the water rights data files (with filename extension DAT) contained in the TCEQ WAM System datasets represent alternative scenarios reflecting combinations of premises regarding water use, return flows, reservoir sedimentation and term permits. The following two scenarios are routinely adopted for water right permit applications and planning studies:

The authorized use scenario (run 3) is based on the following premises.

1. Water use target 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.

Table 1.1 Texas WAM System Models (Authorized Use)

Map ID	River Basin	Period of Analysis	Primary Control Points	Total Control Points	Model Water Rights	Model Reservoirs
					WR/IF	
1	Canadian River Basin	1948-98	12	85	56/0	47
2	Red River Basin	1948-98	47	447	489/103	245
3	Sulphur River Basin	1940-96	8	83	85/5	53
4	Cypress Bayou Basin	1948-98	10	189	163/1	91
5	Rio Grande Basin	1940-00	55	957	2,584/4	113
6	Colorado River Basin and Brazos-Colorado Coastal	1940-98	45	2,395	1,922/86	511
7	Brazos River and San Jacinto-Brazos Coastal	1940-97	77	3,830	1,634/122	670
8	Trinity River Basin	1940-96	40	1,334	1,169/23	703
9	Neches River Basin	1940-96	20	318	333/17	176
10	Sabine River Basin	1940-98	27	376	310/21	207
11	Nueces River Basin	1934-96	41	542	373/30	121
12	Guadalupe and San Antonio River Basins	1934-89	46	1,349	860/184	237
13	Lavaca River Basin	1940-96	7	185	71/30	22
14	San Jacinto River Basin	1940-96	16	411	148/13	114
15	Lower Nueces-Rio Grande	1948-98	16	119	70/6	42
16	Upper Nueces-Rio Grande	1948-98	13	81	34/2	22
17	San Antonio-Nueces	1948-98	9	53	12/2	9
18	Lavaca-Guadalupe Coastal	1940-96	2	68	10/0	0
19	Colorado-Lavaca Coastal	1940-96	1	111	27/4	8
20	Trinity-San Jacinto	1940-96	2	94	24/0	13
21	Neches-Trinity Coastal	1940-96	4	245	138/9	31
Total			498	13,272	11,016/662	3,435

The current use scenario (run 8) is based on the following premises:

1. The target used for each water right is based on the maximum annual amount used in any year during a recent ten year period.
2. Best estimated of actual return flow are adopted.
3. Reservoir storage capacities and elevation-area-volume relations for major reflect year 2000 conditions of sedimentation.
4. Term permits are included.

Table 1.2 Texas WAM System Models (Current Use)

Map ID	River Basin	Period of Analysis	Primary Control Points	Total Control Points	Model Water Rights	Model Reservoirs
					WR/IF	
1	Canadian River Basin	1948-98	12	85	56/0	47
2	Red River Basin	1948-98	47	450	486/110	246
3	Sulphur River Basin	1940-96	8	83	85/5	53
4	Cypress Bayou Basin	1948-98	10	189	159/1	91
5	Rio Grande Basin	1940-00	55	957	2,594/4	113
6	Colorado River Basin and Brazos-Colorado Coastal	1940-98	45	2,396	1,928/93	510
7	Brazos River and San Jacinto-Brazos Coastal	1940-97	77	3,834	1,725/144	711
8	Trinity River Basin	1940-96	40	1,338	1,190/35	709
9	Neches River Basin	1940-96	20	318	317/21	198
10	Sabine River Basin	1940-98	27	375	314/21	206
11	Nueces River Basin	1934-96	41	545	392/32	125
12	Guadalupe and San Antonio River Basins	1934-89	46	1,352	879/202	243
13	Lavaca River Basin	1940-96	7	184	68/30	21
14	San Jacinto River Basin	1940-96	16	413	156/15	114
15	Lower Nueces-Rio Grande	1948-98	16	119	70/6	42
16	Upper Nueces-Rio Grande	1948-98	13	81	39/2	23
17	San Antonio-Nueces	1948-98	9	53	12/2	9
18	Lavaca-Guadalupe Coastal	1940-96	2	68	12/0	0
19	Colorado-Lavaca Coastal	1940-96	1	111	27/4	8
20	Trinity-San Jacinto	1940-96	2	94	26/1	13
21	Neches-Trinity Coastal	1940-96	4	245	138/9	31
Total			498	13,290	10,673/737	3,513

The data contained in the WAM System input datasets can be divided into the following three categories:

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

Information describing the authorized and current datasets as of August 2007 is tabulated in Tables 1.1 and 1.2. The 21 datasets for the authorized and current use contain 11,016 and 10,673 water rights WR records and 662 and 737 instream flow IF records (11,678 and 11,410 total model water rights) representing almost 80,000 water rights permits, respectively. Multiple water rights in the model may represent a single complex permit. The period-of-analysis is at least 50 years for all of the basins, with the longest being 1940 – 2000.

The datasets contain 13,272 and 13,290 control points. The number difference between the primary control points and the total control points is the number of secondary control points for which naturalized flows are computed within the WRAP-SIM simulation model based on flows input for the primary control points. The 498 primary control points are defined as locations at which naturalized flows are provided in the WAM datasets. Primary control points are usually stream gaging stations.

The datasets model approximately 3,435 and 3,513 reservoirs for which a water rights permit has been issued. Over 90 percent of the total capacity of the 3,414 reservoirs is contained in the approximately 210 reservoirs that have conservation capacities exceeding 5,000 acre-feet. Storage capacities for the reservoirs are cited in their water rights 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 ac-ft, were developed for both permitted and estimated year 2000 conditions of sedimentation. Generalized storage-area relationships were adopted in each river basin for the numerous small reservoirs (Wurbs 2008a).

1.3.2 Water Rights Analysis Package (WRAP) Modeling System

The WRAP modeling systems simulates management of the water resources of a river basin or multiple-basin region under a priority-based water allocation system. The generalized model is designed for assessing hydrologic and institutional water availability and reliability for water supply diversion, environmental instream flows, hydroelectric energy generation, and reservoir storage. Basinwide interactions among numerous water uses and diverse water management facilities and practices can be modeled using the WRAP modeling system (Wurbs 2005c).

The generalized WRAP consists of the following four programs: WINWRAP, WRAP-HYD, WRAP-SIM, and TABLES. The expanded version includes WRAP-SIMD, WRAP-DAY, and WRAP-SALT (Wurbs 2008a):

- WINWRAP facilitates execution of the WRAP programs within the Microsoft Windows environment. It also executes with Microsoft programs and HEC-DSSVue.
- SIM simulates the river/reservoir water allocation/management system for input sequences of monthly naturalized flows and net evaporation rates.
- TABLES develops frequency relationships, reliability indices, and various user specified tables for organizing, summarizing, and displaying simulation results.
- HYD assists in developing monthly naturalized stream flow and reservoir net evaporation-precipitation depth data for the SIM hydrology input files.
- SIMD (D for daily) is an expanded version of SIM that includes features for sub-monthly time steps, flow disaggregation, flow forecasting and routing, and flood control operations along with all of the capabilities of SIM.
- DAY assists in developing sub-monthly time step hydrology input for SIMD including disaggregating monthly flows to sub-monthly time intervals and determining routing parameters.

- WRAP-SALT reads a SIM or monthly SIMD output file and a salinity input file and tracks salt constituents through the river/reservoir/water use system.

The expanded version includes capabilities for converting the WAM datasets of monthly naturalized flows to daily flows, forecasting of future flows over a forecast period of up to 60 days, and routing flow adjustments using two alternative methods. Alternative methods for subdividing monthly naturalized flow volumes into daily flows range from a simple linear interpolation routine, that allows use of WAM system datasets without additional data, to options based on reproducing daily variations reflected in daily flow sequences provided as input. Future time steps extending over a user-defined forecast period are considered in the simulation model in determining both water availability under the priority system from a water supply perspective and remaining flood control channel capacity. An adaptation of the Muskingum routing method and an alternative lag and attenuation method are being added for use with daily computational time steps to route flow adjustments for reservoir storage and releases, diversions, and return flows.

Features for simulating reservoir operations for flood control are also incorporated into WRAP. The new modeling capabilities allow any number of flood control reservoirs to be operated in the simulation model either individually or as multiple-reservoir systems to reduce flooding at any number of downstream control points. Operating rules are based on emptying flood control pools expeditiously, while assuring that releases do not contribute to flows exceeding specified flood flow limits at downstream control points, during a specified future forecast period. Routines are also incorporated into the modeling system for frequency analyses of annual peak naturalized flow, regulated flow, and reservoir storage volume.

Each reservoir is composed of any combination of an inactive pool, conservation pool, and flood control pool (controlled and uncontrolled) shown in Figure 1.3. Reservoir operations for either flood control or conservation purposes consist of two separate operations: (1) storing flow and (2) making releases. Filling storage and making releases are two related aspects of reservoir operations that are handled differently in the model in defining operating rules and performing simulation computations. The algorithms for routing flood flows through uncontrolled reservoir pools with ungated outlet structures are performed in two steps. First, the inflow volume available for storage is determined and then the outflow is determined based on a storage-outflow relationship. Routing through flood control pools controlled by gated outlet structures is based on more complicated operating rules. Gates are closed if a flood is determined to be underway or imminent based on flows at control points in the current day or forecast period, and releases are based on emptying flood control pools as expeditiously as practical without contributing to river flows exceeding set flow limits.

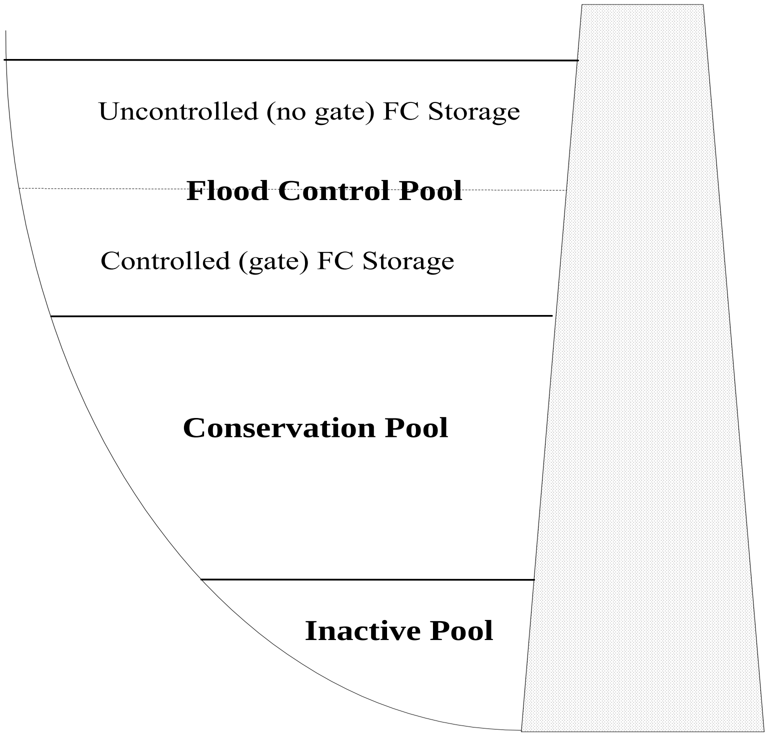

Figure 1.3 Reservoir Storage Pools within Program SIMD

1.4 LITERATURE REVIEW

The literature review related to this study includes various areas in the field of the water resources planning and management. In particular, this literature review focuses on two parts:

1) Technical and institutional aspects of reservoir operations and storage reallocations
2) Reservoir system modeling and analysis methods

1.4.1 Reservoir Operations and Storage Reallocation

Wurbs and Cabezas-Canelos (1987) applied economic analysis in an early evaluation of proposed reallocation of storage capacity between flood control, municipal, and industrial water supply. The economic analyses are based on estimating both average annual flood losses using the damage-frequency method and average annual water-supply losses developed by water shortage versus economic loss function curve. HEC-4 *Monthly Streamflow Simulation* is used for generating synthetic monthly streamflow data. HEC-5 *Simulation of Flood Control and Conservation System* is used for simulating both flood control and conservation operations. *Massachusetts Institute of Technology (MIT) simulation model* is used for computing reservoir reliability and average annual losses due to water shortage.

Johnson and Wurbs (1990) illustrate eight cases for reallocation of reservoir storage capacity for reservoirs in the Corps of Engineers and the state of Texas. The eight cases for reservoir storage capacity reallocation are the following: (1) use of water-supply storage not under contract; (2) temporary use of storage allocated for future conservation purposes and sediment; (3) storage made available by change in conservation demand or purpose; (5) reallocation of flood-control space; (6) modification of reservoir-water-control plan and method of regulation; (7) raising existing dams; and (8) system regulation of corps and non-corps reservoirs. Even though these general cases are developed to suggest possibilities, evaluation of alternatives is required for the specific reservoir system of concern based on hydrologic, economic, environmental, social, institutional, and legal considerations.

Craney (1996) evaluates the potential for operation of water supply reservoirs to mitigate flood damages and investigates the associated institutional considerations including agency responsibilities, practices, and legal liabilities. HEC-1 and HEC-5 are used for the case study to analyze the reservoir effects on flooding characteristics and evaluate operational strategies for minimizing downstream flooding.

Maddock et. al (2001) identifies and compares feasible operational changes utilizing the Physical Habitat Simulation System (PHABSIM). They examine the possibility of changing the diversion operation scheme and compensation flow release during dry periods. The intention of this study is to minimize the ecological impacts of regulation while protecting the amount of the public water supply.

Firoozi and Merrifield (2003) analyze the timing and adjustments related to the construction of new reservoirs and reallocation of existing supplies. A dynamic model in this study is used for generating the optimal construction timing of new projects and guidelines for reallocation of existing supplies. The net social benefits related to consumption and costs are considered to determine the optimal allocation, pricing, and construction timing.

Alejo (2004) develops the guidelines of simplifying Brazos Authorized Use WAM datasets and the display of WRAP results into ArcMap. Based on the simplified Brazos Authorize Use WAM datasets, short term diversion/storage reliabilities based on an initial storage level are evaluated using the Conditional Reliability Model (CRM) in WRAP model.

Huang and Yuan (2004) developed a color-coded early warning system of drought management for real-time reservoir operation. This system is composed of a) drought watch, b) water consumption measure, and c) policy making. The system has been applied to the two major reservoirs in northern Taiwan.

McMahon and Farmer (2004) demonstrate the feasibility of adapting the guiding principles of federal planning traditionally applied in formulation of new multipurpose reservoirs, to the reallocation of existing reservoirs. Construction of a new project or reallocation of an existing project are evaluated and compared by the accounts of National Economic Development (NED), Regional Economic Development (RED), Environmental Quality (EQ), Other Social Effects (OSE), and Natural Ecosystem Restoration (NER).

TWDB (2006) evaluates the potential for reallocation of federal storage in Texas to water supply. The TWDB completed this work with Espey Consultants Inc, the BRA and the USACE. This tasks are composed of four areas: (1) Develop a guidance document regarding the state permitting requirement and federal reallocation requirement, (2) Estimate additional water supply yield from federal reservoirs reallocation in Texas, (3) Investigate the advantages of federal reservoirs reallocation and system operation using the WRAP model, and (4) Develop a case study of the 5 reservoirs in the Brazos River Basin (BRB) using the WRAP model and WAM input files. Reallocation of USACE reservoirs can provide an effective use of water by converting storage to additional water supply.

1.4.2 Reservoir System Modeling and Analysis Methods

A detailed review of the literature of optimizing reservoir system operations is provided. There are many generalized models that have been applied by water management agencies to support reservoir system planning and/or operation decisions. Among these models, the USACE Southwestern Division Reservoir System Simulation Model (SUPER), USACE Hydrologic Engineering Center (HEC) Reservoir System Simulation (ResSIM), River and Reservoir Operations (RiverWare), Generalized River Basin Network Flow Model (MODSIM) modeling systems, and Water Rights Analysis Package (WRAP) are representative of state-of-the-art reservoir/river system modeling capabilities in general and are particularly pertinent to practical applications by water resources planning and management agencies in Texas and elsewhere (Wurbs 2005a).

SWD SUPER Modeling System

The SUPER model was developed by the Southwestern Division (SWD) of the U.S. Army Corps of Engineers (USACE) and has been applied by the SWD office in Dallas and the Forth Worth, Tulsa, and Little Rock District offices of the SWD. SUPER is a system of computer programs designed to simulate the daily sequential regulation of a multipurpose system of reservoirs and the corresponding hydrologic and economic impacts (Hula 1981). A simulation reflects a specified regulation plan, economic parameters, and long sequences of daily flows and net reservoir evaporation rates. Multiple simulations are performed to compare alternative variations in regulation plans. Simulation results include stage or discharge hydrographs for each reservoir and river control points, which may also be integrated with economic benefits functions. Hydrologic results may be expressed as monthly and annual frequency relationships for maximum and minimum reservoir storage and streamflow, storage and flow duration relationships, and diversion and instream flow shortages. Economic results may include flood damages, recreation benefits, power value, cost of purchased power, dredging costs, and navigation costs (Wurbs 2005a).

HEC-ResSim Modeling System

The ResSim modeling system (USACE, 2007) was developed by the USACE Hydrologic Engineering Center as the successor to the HEC-5 Simulation of Flood Control and Conservation Systems model. The object-oriented ResSim is composed of a Graphical User Interface (GUI), a computational program to simulate reservoir operation, data storage and management capabilities, and graphics and reporting facilities. ResSim has three sets of modules for providing access to specific types of data within a watershed. These models are Watershed Setup, Reservoir Network, and Simulation. Each module has specific purposes and an associated set of functions accessible through menus, toolbars, and schematic elements. The computational time interval is 15 minutes to a day. The routing methods of streamflow are coefficient routing, Muskingum, Muskingum-Cunge, modified Plus routing, and a routing methodology from the USACE streamflow Synthesis and Reservoir Regulation (SSARR) model. The simulation progresses from upstream to downstream. Single or multiple reservoirs are modeled, with each reservoir having multi-purposes pools and multiple outlet structures. Operations are controlled by specified goals and constrained governing releases.

The case study river/reservoir system was modeled with both HEC-ResSim and the expanded WRAP-SIM simulation model for comparison and testing of modeling capabilities.

RIVERWARE Modeling System

The objected-oriented RiverWare modeling system (Zagona et. al. 2001) was developed by the Center for Advanced Decision Support for Water and Environmental Systems at the University of Colorado, sponsored by the U.S. Bureau of Reclamation and the Tennessee Valley Authority. The computation time interval is an hour to a year. Options are provided for pure and rule-based simulation and optimization. The pure simulation solves a uniquely and completely specified problem. Each object should have enough information but not more information than is required. Each object has a number of dispatch methods that map the input/output configuration specified by the user to the correct solution algorithm. The rule-based simulation does not require information associated with the objects to obtain a solution. The additional information required is generated by prioritized policy statements (rules) that are specified by the user and interpreted by the rule processor. The optimization uses a linear programming (LP) solver, which is combined with preemptive goal programming. The optimization constraint editor and expression language in RiverWare are designed to allow the model-user to provide required input information without necessarily having to be proficient in linear programming.

MODSIM Modeling System

MODSIM was developed at Colorado State University (Labadie et al. 2000). The computational time interval is a month, week, or day. The objected-oriented simulation model is based on network flow programming and user-specified priorities. The objective function consists of the summation over all links in the network of the flow in each link multiplied by a priority or cost coefficient. The user assigns relative priorities for meeting diversion, instream flow, hydroelectric power, and storage targets, as well as lower and upper bounds on flows and storages. The program is divided into two functions; a graphical user interface allows the model user to build the river/reservoir system topology, and river/reservoir system as a network of nodes connected by links. The nodes represent river gages, diversion dams, tributary confluences, sites where return flows enter the river, consumptive diversion, instream flow requirement, reservoir, hydropower plants, and appurtenant structures. The links represent artificial, general flow, natural flow, storage ownership, and accrual. Tables 1.3 and 1.4 summarize 5 reservoir system models and analysis methods

Table 1.3 Structure of the Alternative Modeling Systems

Model	Organizing Computation Structure
SUPER	Ad hoc simulation computations progressing from upstream to downstream
ResSim	Object-oriented ad hoc simulation progressing from upstream to downstream
RiverWare	Object-oriented, options for pure and rule-based simulation and optimization
MODSIM	Objected-oriented based on network flow programming & user-specified priorities
WRAP	Ad hoc simulation progressing in order of user-defined priorities

Source: Wurbs (2005b)

Table 1.4 Characteristics of the Alternative Modeling Systems

Model	Language	Method	Time Step	GUI	Graphics	Cost
SUPER	Fortran	ad hoc	Day	No	No	Free
ResSim	Java	ad hoc	15 min to day	Yes	Yes	Free
RiverWare	C++	ad hoc/LP	Hour to year	Yes	Yes	Proprietary
MODSIM	C, C++	LP	Month, week, day	Yes	Yes	Free
WRAP	Fortran	ad hoc	Month, day, any sub-monthly	Yes	No	Free

Source: Wurbs (2005b)

1.5 OVERALL OBJECTIVES OF THE RESEARCH

The overall outline of the dissertation research is as follows:

I Updating and Extending Hydrology

a) Forward Extension of the Hydrologic Period-of-Analysis

The period-of-analysis for the WAM System hydrology datasets all begin in either 1934, 1940, or 1940 and end in either 1989, 1996, 1997, 1998, or 2000. The datasets were compiled during 1997-2001 in conjunction with implementation of the WAM System pursuant to the 1997 Senate Bill 1. Several years of additional hydrologic observations have accumulated since compilation of the original hydrology data sequences incorporated in the WAM System dataset.

This research investigates a procedure for extending the hydrologic simulation periods of the WAM datasets. The methodology is tested and refined by application to the WAM dataset for the Brazos River Basin and San Jacinto-Brazos Coastal Basin. This case study is designed to provide a basis for evaluating the feasibility of applying the procedure to extend the hydrologic sequences in the WAM System datasets for all of the river basins of the state. The Brazos WAM System hydrology dataset has an original period-of-analysis of 1940-1997. The case study consists of extending the sequences of naturalized flows and evaporation-precipitation depths to cover 1940-2007.

Development of the original hydrology datasets during implementation of the WAM System required considerable time and effort (HDR 2001a and b). The methodology presented in the research is designed to significantly reduce the effort required to update the hydrology datasets (FLO and EVA files) by utilizing the information now available in the WAM System water right datasets (DAT files). The information in the DAT file describes water resources development, allocation, management, and use. The flow extension procedure is based on creating a DAT file dataset representing actual water management/use during the extension period, which is 1998-2007 for the Brazos WAM, by modifying the current use scenario WAM System dataset. The results of SIM simulation with the actual use dataset are used to covert gaged 1998-2007 monthly stream flows to naturalized flows.

b) Backward Extension of the Hydrologic Period-of-Analysis

The hydrology period-of-analysis can also be extended backward in time. The period-of-analysis for the Brazos WAM was extended by the investigation documented by this research to cover 1900-1939 in addition to the original 1940-1997 and the forward extension of 1998-2007. The total extended Brazos WAM hydrologic period-of-analysis covers January 1900 through December 2007. The naturalized stream flows for 1900-1939 are significantly less accurate than later flows due to the small number of stream gaging station in operation during the earlier years. The process of converting gaged flows to naturalized flows is much simpler for 1900-1939 because water resources development and use were much less during this time period compared later years. Rapid population and economic growth in Texas began in the 1950s. Most of the reservoir projects in Texas were constructed during the 1950s through 1970s. For this reason, the approach adopted for the 1900-1939 extension is very different than for the 1998-2007 extension.

II Condensing and Simplifying a WAM Dataset to Focus on a Particular River/Reservoir Water Management System

The larger TCEQ WAM System datasets listed in Tables 1.1 and 1.2 contain hundreds of water rights, control points, and reservoirs. These large complex datasets are necessary for the regional and statewide planning and water right permitting applications for which the datasets were developed. However, simpler datasets are advantageous for certain other applications. A methodology is presented in this research for simplifying WAM System datasets to focus on management of a particular river/reservoir system. Selected water rights, control points, and reservoirs are removed with their effects retained in the adopted stream inflow input data for the simplified dataset. The objective is to develop a much simpler dataset for purpose of studying or providing decision support for the particular water management system. The motivation is simply that input datasets and corresponding simulation results with dramatically fewer control points, water rights, and reservoirs are much more manageable to use in modeling studies.

The methodology for developing a simplified dataset is based on developing flows at selected control points that represent stream inflow amounts available to the selected system that reflect the impacts of all of the water rights and accompanying reservoirs removed from the original complete dataset. These stream flows represent flows available to the selected system modeled in the simplified system-specific DAT input file considering the effects of all the other water rights in the river basin contained in the original complete DAT file that are not included in the simplified DAT file. The condensed model is designed for simulating alternative operating plans for the particular system of interest while considering the impacts of numerous other water users on stream flow availability. However, complexities associated with modeling the other water users and water management entities are greatly reduced.

A simplified authorized and current use datasets focused on operation of the Brazos River Authority (BRA) system are developed by condensing the TCEQ WAM System dataset for the Brazos River Basin and San Jacinto-Brazos Coastal Basin. The Brazos WAM authorized and current use datasets have 3,830 and 3,834 control points, 670 and 711 reservoirs, 1,634 and 1,725 water rights, 122 and 144 instream flow IF record, and 3,138 and 3,141 flow distribution FD records, respectively. The BRA System condensed authorized and current use dataset contains 48 control points, 15 and 14 reservoirs, 132 WR records, and no FD records, respectively. The impacts on stream flow available to the BRA system of the numerous water rights and reservoirs removed from the WAM datasets are reflected in the IN record inflows of the condensed dataset.

III Conversion of the Monthly Model to a Daily Time Step and Flood Control Operation Key Factors

SUPER model daily unregulated (naturalized) flows for 1 January 1939 through 31 December 1997 at 37 computation (control) points were developed by the USACE Forth Worth District. These daily naturalized flows were utilized as daily flow patterns for disaggregating monthly inflows of the Brazos River Authority Condensed datasets for 1900-2007 to daily inflows and source control points for transferring flow patterns from gaged to the other ungaged control points.

The flood damages versus discharge relationship curves, divided as crops, agriculture, and non-agriculture categories, at six control points, were developed by the USACE at Fort Worth District. These discharge versus flood damage data for three categories were aggregated as one category and used for computing the flood damage for regulated flows at six control points corresponding to two reallocation plans of reservoir storage capacity included the Brazos River Authority Condensed dataset.

The Muskingum routing parameters for normal flow and flood flow were calibrated using four optimization function alternatives in the program DAY and one conventional method, which use the distance of the reaches. The flood flow limits for calibrating flood flow K (travel time) and X (attenuation) were computed based on the regression equation developed by using daily naturalized flows. The results for K and X results under five alternatives were compared and the most reasonable K and X results were determined.

IV Evaluation of Storage Reallocation for BRA System

The BRAC8 datasets for 1900-2007 hydrologic period-of-analysis developed provide a case study for evaluating the potential for storage reallocations with program SIMD. The BRAC dataset were modified for flood control operations as follows: i) adding flood control pools, ii) replacing from BRAC8 FLO file to BRAC3 FLO file, and iii) adding RUF file. The permanent and seasonal reallocation (May through October raised) plans developed in a previous study by Wurbs and Cabezas-Canelos (1987) were utilized for Brazos River Authority system reservoir reallocation plans. The firm yield and flood frequency analysis for individual and two multiple-reservoir systems were performed for evaluating the reallocations between flood control and conservation purposes. The firm yield and flood frequency analysis for multiple-reservoir systems are simulated based on Type 2 Water right and Type 3 Water right. Eight simulation runs are each applied to firm yield and flood frequency analysis for individual and multiple-reservoir system.

1.6 SCOPE AND ORGANIZATION OF THE RESEARCH

These general methodologies for extending the hydrologic period-of analysis, developing a simplified dataset, evaluating of BRA system reservoir storage reallocation are described in the following Chapter II of this dissertation. The remainder of the dissertation then presents the application of the methodologies to the TCEQ WAM System dataset for the Brazos River Basin and San Jacinto-Brazos Coastal Basin, which is for brevity called the Brazos WAM dataset throughout the dissertation.

The research methodologies are outlined in Chapter II. The existing Brazos WAM dataset is described in Chapter III. Extending the Brazos WAM hydrologic period-of-Analysis from 1940-1997 to 1900-2007 is covered in Chapter IV. Developing a condensed dataset focused on the BRA system is covered in Chapter V. Converting the monthly model to a daily time step and flood control operation key factors are covered in Chapter VI. The BRAC System reservoir storage reallocations are covered in Chapter VII. Chapter VIII presents the summary and conclusion of the research.

The general computational procedures for modifying WRAP input datasets are outlined in Chapter II. Extending the Brazos WAM hydrologic simulation period forward by ten years from 1940-1997 to 1940-2007 is reported in section 4.1. Extension of the period-of-analysis backward to also cover 1900-1939 is described in section 4.2. Naturalized Flows for alternative periods-of-analysis are compared in section 4.3. Simulation results for alternative periods-of-analysis are compared in section 4.4. The impacts of the extended period-of-analysis on simulation results are investigated and compared for alternative simulation periods.

The development of a simplified dataset focusing on the Brazos River Authority system is covered in Chapter V. Section 5.1 documents the tasks involved in the development of the dataset, and section 5.2 present a comparative analysis of simulation results derived from the condensed versus original datasets.

Chapter VI documents the tasks involved in converting the monthly model to a daily time step for simulating reservoir system operations for flood control within program SIMD and computing the flood control operation key factors. Chapter VII documents the tasks involved in evaluating storage reallocation.

WRAP-SIM simulation results are presented in sections 4.1, 4.4, and 5.2. Section 4.1 deals with SIM simulation results from the Bwam8A actual use dataset which has a hydrologic period-of-analysis of 1998-2007. Simulation results for the Bwam3 authorized used and Bwam8 current use scenario datasets with alternative hydrologic period-of-analysis of 1940-1997, 1940-2007, and 1900-2007 are covered in section 4.4. Simulation results from a BRAC condensed dataset focusing on operation of the Brazos River Authority system are compared with Bwam3 and Bwam8 results in section 5.2.

The WRAP-SIMD simulation results focusing on the BRA System are presented in Chapter VII.

The summary and conclusions of the investigation are presented in Chapter VIII. The appendices contain plots of 1900-2007 naturalized flows at 77 control points (Appendix A), observed gaged flows and naturalized flows for 1998-2007 at 48 gaged control points (Appendix B), 1998-2007 observed, Bwam8A, Bwam8, and Bwam3 simulated storage volume of the 14 reservoirs (Appendix C), 1900-2007 Bwam3 and Bwam8 storage volumes for the 14 reservoir (Appendix D), and adjusted inflows for the 48 control points of the condensed simplified dataset (Appendix E).

CHAPTER II

RESEARCH METHODOLOGY

The chapter is organized as three sections:

1. The chapter begins with a description of WRAP stream flow definitions and Water Rights Analysis Package (WRAP) modeling system developed and tested in the study.
2. The second section outlines the procedure for extending the hydrologic period-of-analysis forward and backward in time and developing a simplified condensed dataset focusing on a particular river/reservoir water management system.
3. The third section discusses key factors for converting monthly model to a daily time step and flood control operations. Also, it outlines the evaluation of storage reallocation for the BRA System of reservoirs.

2.1 WRAP STREAM FLOW DEFINITIONS

A WRAP-SIM simulation consist essentially of modifying hydrologic period-of-analysis sequences of monthly naturalized (or otherwise defined) flows read from the FLO file for the effects of the water rights described in the DAT flow to obtain the resulting sequences of regulated flows and unappropriated flows recorded in the SIM output file. The stream flow terms used with the WRAP modeling system are defined as follows:

Naturalized (unregulated) flows: historical gaged stream flow data adjusted through removing the effects of water resources development, management, and use. Naturalized flows represent natural conditions without the effects of human activities and are provided as SIM input data on inflow IN records.

Regulated flows: physical stream flows computed by SIM by adjusting naturalized flows for the effects of human activities modeled by the information contained in a SIM input DAT file. Regulated flows are the actual flows at a site which would be measured by a stream flow gage if the information in the SIM input DAT file perfectly modeled actual water resources development, management, and use during each month of the simulation.

Unappropriated flows: naturalized flows still remaining after the streamflow depletions are made and return flows are returned for all the water rights. Unappropriated flows may be less than regulated flows because a portion of the regulated flows may be committed to meet instream flow requirements or downstream diversion or storage rights.

Streamflow depletion: volume appropriated by a water right to meet diversion requirements and/or refill reservoir storage while also accounting for evaporation.

Return flow: portion of stream flow depletion that is returned to the stream.

Reservoir releases: those releases from reservoir storage made specifically for a water right to meet a diversion, instream flow, or refilling target at a control point located further downstream.

Reservoir storage shortage (drawdown): volume obtained by subtracting reservoir storage volume from reservoir storage capacity.

Firm yield: the maximum water supply diversion or hydropower electric energy generation than can be achieved with 100% volume or period reliability.

Reliability: the probability of being in a non-failure state during any particular time period. Period reliability is the percentage of the total months or years (periods) in the overall simulation period-of-analysis that a specified percentage of a diversion target or hydroelectric energy target is met. Volume reliability is the total volume of actual diversion or total hydroelectric energy generated during the simulation period-of-analysis expressed as a percentage of the corresponding total permitted diversion or hydroelectric energy targets.

2.2 DEVELOPING AND TESTING OF WRAP SIMULATION CAPABILITIES

The original program HYD was developed during 1998-2000. However, most of the datasets for the WAM System were completed prior to completion of the program HYD. Microsoft Excel was used during the 1997-2001 WAM hydrology dataset compilation work for most the computing tasks that have since been incorporated into program HYD. The original WRAP-HYD has been significantly expanded during 2007-2008. New features of HYD are applied in the procedures of both extension of the hydrologic simulation period and development of condensed dataset models.

The expanded WRAP modeling system provides capabilities for simulation of flood control reservoir system operations along with flow forecasting and routing with a daily time step. Flood control reservoir system operations may include uncontrolled and/or controlled releases. Controlled releases are based on setting maximum non-damaging river flow levels at pertinent stream gauging stations. Any number of flood control reservoirs may be operated in the simulation model either individually or as multiple-reservoir systems to reduce flooding at any number of downstream control points. These new capabilities for simulation of flood control reservoir system operations are tested. A flood frequency analysis component is also added to the modeling system. Frequency analyses of annual peak regulated flow and reservoir storage volumes are preformed based on the log-Pearson type III probability distribution.

The primary modeling application addressed is evaluation of reallocation of reservoir storage capacity between flood control and conservation purposes. The following indices for evaluating flood control capabilities are adopted: 1) annual frequency of storage volume, 2) expected value of flow, and 3) average annual damages in dollars corresponding to each exceedance frequency.

2.3 DEVELOPING AND TESTING METHODOLOGIES FOR COMPILING INPUT DATASETS

2.3.1 Forward Extension of the Hydrologic Period-of-Analysis

River basin hydrology is represented in the WAM System datasets by both sequences of monthly naturalized stream flows and net reservoir surface evaporation minus precipitation depths. The methodologies outlined here focus primarily on naturalized flows. Compiling monthly evaporation-precipitation depths is a step in the procedure for developing naturalized flows. The procedure for compiling evaporation-precipitation depths is still basically the same now as during the original development of the WAM System dataset. The procedure outlined here for developing naturalized flows is new. Developing naturalized flows represents a significantly greater portion of the total effort compared to compiling the evaporation-precipitation data, although both tasks are important.

The naturalized stream flow datasets for the WAM System were originally developed by adjusting observed flows at gaging stations to remove the effects of historical reservoir storage and operations, water supply diversions, return flows from diversions from surface and ground water sources, and other factors. The same general approach is adopted for extending the period-of-analysis covered by the naturalized flows. However, much time and effort is required to compile and manipulate the voluminous data describing actual water management and use that is required for the flow adjustments. The objective of the procedure outline below is to greatly reduce the required effort by using the existing current use scenario datasets (DAT files) from the TCEQ WAM System. These water rights datasets (DAT files) did not exist when the original naturalized flow datasets (FLO files) were developed but are now readily available. A current use dataset is modified to model actual use during the period of the extension.

The methodology outlined here is based on converting gaged stream flows to naturalized flows using a current use SIM input dataset from the WAM System modified to represent actual use. The WAM System current use scenario is defined Chapter I. An actual use scenario dataset is developed by modifying the current use DAT file to better represent actual water resources development, allocation, management, and use during the flow extension period. Flow adjustments are determined from the results of a SIM simulation with the actual use input dataset. Capabilities are incorporated in HYD for performing the flow adjustment computations necessary to implement this strategy. Iterative repetitions of the procedure are necessary since naturalized flows are required as input to the SIM simulation.

Regulated flows are computed from a set of naturalized flow, however regulated flows are required for the flow adjustments used to determine the naturalized flows. Thus, an iterative procedure is required. An initial set of adjustments is developed based on an initial approximation of naturalized flows. These initial flow adjustments are used to convert gaged flows to naturalized flows, which are then used to develop a better estimate of flow adjustments. Estimates of naturalized flows are upgraded with each iterative repetition of the SIM/HYD computation procedure. Program HYD is used to perform the flow adjustment computations based on the results from a SIM simulation.

Overview of the Flow Extension Methodology

The general methodology described in this chapter is applicable to all of the WAM datasets. The period-of-analysis in Tables 1.1 and 1.2 varies between the different WAM System datasets. In this chapter, any reference to a period-of-analysis refers to 1940-1997. The task addressed here is developing naturalized flows at the primary control points for the period January 1998 through December 2007.

The proposed procedure for extending a naturalized flow dataset to cover the period 1998-2007 at pertinent primary control points consists of combining two datasets:

- 1998-2007 sequences of monthly flows at pertinent gaging stations compiled from available USGS gage records of observed daily flows
- SIM input DAT file representing 1998-2007 actual water management and use developed based on modifying the TCEQ WAM System current use input dataset.

The procedure consists of iteratively adjusting gaged flows at USGS gaging stations with the differences between naturalized (unregulated) flows and regulated flows from a SIM simulation with a modified current use dataset. An iterative procedure is required because naturalized flows are computed as a function of flow adjustments but the flow adjustments are computed as a function of naturalized flows. The repetitive procedure begins with a statistically based set of 1998-2007 naturalized flows determined from the 1940-1997 naturalized flows that serves the sole purpose of determining an initial estimate of flow adjustments which are later updated.

The SIM simulation with the modified current use DAT input file serves the sole purpose of computing regulated flows allowing the differences between naturalized and regulated flows to be computed for use as adjustments in converting gaged flows to naturalized flows. The accuracy of the procedure depends upon the accuracy of the flow differences rather than the accuracy of the naturalized and regulated flows themselves. The flows are defined in section 2.1 in Chapter II.

Outline of the Methodology

The procedure for extending a naturalized flow dataset to cover the period 1998-2007 at pertinent primary control points consists of converting monthly gaged flows to naturalized flows based on a set of adjustments. Program HYD computes naturalized flows by developing flow adjustments from the results of a SIM simulation and adding the adjustments to gaged flows as follows:

$$\text{Naturalized flow} = \text{gaged flow} + \text{flow adjustment} \qquad (2.1)$$

$$\begin{aligned}\text{Flow adjustment} &= \text{naturalized flow} - \text{regulated flow} \\ &\quad + \text{storage shortage} + \text{diversion shortage}\end{aligned} \qquad (2.2)$$

Program HYD reads gaged flows from its FLO input file and writes naturalized flows to its FLO output file. The flow adjustment and naturalized flow in Equation 2.1 are computed by HYD by activating options defined in the JC and AC records in the HYD input HIN file. The naturalized flows, regulated flows, storage shortages, and diversion shortages in Equation 2.2 are read by HYD from a SIM simulation results OUT output file. The SIM simulation with an actual use DAT file models actual water resources development, allocation, management, and use during the 1998-2007 period-of-analysis. The naturalized flows in Equation 2.2 are read by SIM from its FLO input file.

The naturalized flow and regulated flow components of Equation 2.2 fare required for computing the basin flow adjustments. The storage shortage and diversion shortage component of Equation 2.2 are optional. These adjustments for shortages may or may not be applied depending on the particular application. Flows may alternatively be adjusted based on Equation 2.3 which reflects a rearrangement of Equation 2.1 and 2.2 with the storage and diversion shortages components omitted.

$$\text{Naturalized flow} = \text{naturalized flow} + \text{gaged flow} - \text{regulated flow} \qquad (2.3)$$

The diversion shortages in Equation 2.2 represent failures to meet targets specified on SIM water rights WR and target series TS records and associated input records defining diversion right targets. The storage shortage component of the flow adjustment is the difference between the capacities defined by the SIM water right storage WS and observed storage OS records and the storage volumes computed by SIM. Actual observed end-of-month reservoir storage volumes occurring each month during the 1998-2007 period-of-analysis may be entered as SIM input as observed storage OS records. The OS record storage levels are capacities to which storage is refilled constrained by the availability of stream flow. If the initial estimates of naturalized flow entered in the original FLO input file are too small, the storage levels on the OS records will not be reached in the SIM simulation. This part of the storage draw-down is expressed as a shortage in Equation 2.2.

Outline of Steps in the Flow Extension Procedure

The proposed procedure includes the following tasks. A general strategy is outlined that may be modified in various ways for a particular river basin. The details of performing each task may vary with different situations reflected in the datasets for the different river basins. A general strategy is outlined that may be modified in various ways for particular river basins:

1. A set of 1998-2007 monthly net evaporation-precipitation depths are compiled for all pertinent control points that have reservoirs. Note that the term 1998-2007 is adopted here to refer to any period over which the hydrology data is being extended.

2. Available gaged daily flow data for 1998-2007 at gaging stations are compiled and aggregated to monthly flows. HEC-DSSVue may be used to assist with this task.

3. An actual use SIM input dataset is developed that has a 1998-2007 simulation period. The original current use water rights input dataset already approximates the 1998-2007 conditions of water management and use but is modified to further improve the representation of actual 1998-2007 water management/use. Although the current use DAT file may be used with minimal or no modification, the following adjustments will improve accuracy in representing actual 1998-2007 water management and use:

- The upstream-to-downstream natural priority option may be adopted to replace the permit priorities. This is a simple option switch in SIM.
- Beginning of 1998-2007 simulation reservoir storage volumes are compiled as follows. A SIM execution of the modified dataset with the 1940-1997 hydrology results in end-of-simulation December 1997 storage volumes for all of the typically numerous reservoirs. These amounts are used to set the beginning of January 1998 reservoir storage using the SIM beginning-ending storage (BES) option. For the larger reservoirs, available observation from gage records are used to replace the SIM simulated beginning of January 1998 storage volumes. These are the beginning-of-simulation reservoir storage volumes for the 1998-2007 SIM simulation DAT files.
- For the larger reservoir with readily available gaged sequences of 1998-2007 end-of-month storage volume observations, the actual storages for all 120 months of the 1998-2007 period-of-analysis can be incorporated into the SIM DAT file with observed storage OS records. Thus, the SIM simulation reproduces actual observed storage contents.
- Diversion target and return flows in the DAT file are not changed for many of the water rights due to lack of data, the effort required to update, and minimal impact on final results. However, considering data availability, any number of the larger diversion targets and return flow specifications may be revised with actual 1998-2007 observations. Time series of diversion may be entered on TS records or, alternatively, representative water use practices may be modeled with WR and UC records and other supporting records.
- Other modifications may also be made to the DAT file dataset to more closely model actual 1998-2007 water management and use.

4. A FLO file with 1998-2007 naturalized flows is required for the SIM input dataset. However, 1998-2007 naturalized flows are the unknown data the overall procedure is designed to compute. An initial set of 1998-2007 naturalized flows is developed solely for use in developing the initial estimate of flow adjustments. Mean flows, median flows, or any other exceedance frequency flows could be adopted. For example, the 75 percent exceedance frequency flows are reasonably likely flows on the conservatively low side of mean flows. Using the 1940-1997 naturalized flows at a particular control point, the flow volume that is equaled or exceeded in 75% of the

58 years is determined for each of the 12 months January through December. The resulting set of 12 naturalized flow volumes for January through December is repeated for each of the ten years during 1998-2007.

5. The SIM simulation model is executed with the 1998-2007 period-of-analysis input dataset consisting of the DAT file developed in the preceding Task 3, EVA file from Task 1, and FLO file from Task 4. The objective is to simulate regulated flows that can be used to develop an initial estimate of flow adjustments consisting of naturalized (unregulated) flows minus regulated flows at the pertinent control points. Storage and diversion shortages determined by HYD from the SIM simulation results can also be included in the adjustments.

6. HYD reads the SIM output OUT file developed at Task 5 and the gaged flows from Task 2. 1998-2007 sequences of monthly naturalized flows are computed as follows:
    - Flow adjustments are computed by HYD using Equation 2.2 based on the results of the SIM simulation.
    - Naturalized flows are computed based on Equation 2.1 by adding the Equation 2.2 adjustments to the gaged flows reads by HYD from another HYD input file.

7. The naturalized flows developed in Task 6 are approximated for the initial application of the procedure since the flow adjustments were determined from SIM simulation results based on an initial estimate of 1998-2007 naturalized flows developed in Task 4. Thus, the computations in tasks 5 and 6 are repeated. The naturalized flows developed in Task 6 above are stored as a FLO or DSS file which replaces the FLO or DSS file used in Task 5. SIM is executed again. The procedure is repeated until the changes in the 1998-2007 naturalized flows resulting from subsequent iterations are negligible.

The procedure results in either a FLO or DSS file containing the final set of 1998-2007 naturalized flows at the pertinent primary control points. Flow distribution methods using data from a DIS file may be applied within SIM and/or HYD to determine naturalized flows at numerous ungaged secondary control points based on the naturalized flows at the primary control points.

The objective is to find a set of naturalized stream flows that closely reproduce actual observed flows at gaging stations when combined with an actual use DAT file in a SIM simulation. The iterations are continued until simulated regulated flows closely match gaged observed flows, in which case the naturalized flows will no longer be changing with additional iterations.

In the Brazos WAM investigation covered by subsequent chapters of this dissertation, the 1940-1997 period-of-analysis is extended through 1998-2007. Thus, the actual use SIM input DAT file represents actual 1998-2007 water resources development, allocation, management, and use.

In the Brazos WAM study presented in this dissertation, larger reservoirs are modeled with observed storage OS records, but observed storage levels are not available for numerous smaller reservoirs. Since actual diversions are mainly unknown, TS records can not be used to force the SIM simulation to closely reproduce actual water use. However, HYD flow adjustments are included for both storage shortage and diversion shortage at the larger reservoirs. Starting the procedure with reasonable initial estimates of naturalized flows is more important for the Brazos WAM.

Known 1998-2007 naturalized flows are not available for the Brazos River Basin for comparison with the naturalized flows computed by the flow extension procedure. However, the procedure develops a set of naturalized flows that closely reproduce the gaged flows when combined within the SIM simulation with the actual use DAT file information. The match between simulated regulated flows and observed gage flows provide the criterion for stopping the iterations. With an exact match between simulated regulated flows and observed gaged flows, naturalized flows no longer change with further repetitions in the iterative naturalized flow adjustment procedure.

Summary of the Methodology for Updating the Period-of-Analysis

The purpose of the procedure addressed by this research is to update the following two WRAP-SIM hydrology input files by extending the period-of-analysis covered by the data:

- EVA file containing sequences of monthly reservoir surface evaporation less precipitation depths.
- FLO file containing sequences of monthly naturalized stream flows.

Updating the EVA file consists of compiling evaporation and precipitation rates and subtracting precipitation rates from evaporation rates. Updating of the FLO file consists of compiling observed monthly stream flow volumes derived from measurements at stream gaging stations and adjusting these data to remove the effects of human water resources development, management, and use. The conversion of gaged flows to naturalized flows requires significant information and effort. The updated EVA file is a part of the information used in developing the updated FLO file.

EVA files in the WAM System datasets can be extended in essentially the same manner as the files were originally developed. The proposed new methodology for updating FLO files is based on the concept of developing an actual use DAT file by modifying the current use (run 8) scenario water rights DAT file to develop flow adjustments for converting gaged flows to naturalized flows.

A current use DAT file can be modified in various ways to better represent actual water resources development, allocation, management, and use during each month of the period-of-analysis extension. The objective is to convert a current use scenario dataset to an actual use dataset applicable to the extended portion (for example 1998-2007) of the period-of-analysis. The effort required to update the WAM datasets depends largely upon the detail to which the current use DAT file is refined.

The actual use *SIM* simulation input dataset with a 1998-2007 simulation period requires 1998-2007 sequences of monthly naturalized flows. However, the 1998-2007 naturalized flows are not known. Computation of these unknown naturalized flows is the sole reason for the flow extension procedure. Therefore, an initial estimate of the 1998-2007 naturalized flows must be developed and then iteratively replaced as the computational methodology proceeds. Various approaches could be adopted for determining an initially estimated set of the 1998-2007 naturalized flows. The strategy proposed here is to develop the initial estimate of 1998-2007 naturalized flows based on frequency statistics of the 1940-1997 naturalized flows. For each of the 12 months of the year, the flow volume that is equaled or exceeded during 75 percent of the 58 years of the period-of-analysis was adopted as being reasonable, though essentially arbitrary.

The sole purpose of the *SIM* simulation with an actual use input dataset with the 1998-2007 simulation period is to develop sequences of regulated flows, storage draw-down, and diversion shortages for use by HYD in developing flow adjustments. The flow adjustments are computed as the difference between regulated flows and naturalized flows. Storage draw-down shortages and diversion shortages appropriately cascaded downstream while accounting for channel losses, may also be included in the adjustments. These computed flow adjustments are then added to the observed flows to determine naturalized flows. The initial estimate of naturalized flows in the FLO file is replaced with the improved estimate of naturalized flows, and the *SIM* simulation is repeated. The next cycle of flow adjustments results in a revised set of naturalized flows.

The concept is to iteratively search for a set of naturalized stream flows that, when input to a SIM simulation along with an actual used DAT file, result in computed regulated flows that closely reproduce actual observe gaged flows. The iterative procedure is repeated until regulated flow computed by SIM closely match as observed flows, in which case further changes in naturalized flows with additional repetitions of the computational procedures are negligible.

2.3.2 Backward Extension of the Hydrologic Period-of-Analysis

The Brazos WAM hydrologic period-of-analysis has also been extended backward to cover 1900-1939 as described in section 5.2 in Chapter V. The extended SIM input dataset includes naturalized monthly stream flows extending from January 1900 through December 2007 at 77 primary control points which are distributed to the numerous secondary control points within the simulation model. Mean reservoir surface net evaporation less precipitation rates for each of the 12 months of the year are adopted for the years from 1900 through 1939. Sequences of 1900 – 1939 naturalized stream flows were developed by transferring the flows at 20 gaging stations compiled in the previous study referenced below to the other Brazos WAM primary control points.

Wurbs et al. (1988) document a water availability study for the Brazos River Basin which included developing 1900-1984 sequences of naturalized monthly flows at 20 U.S. Geological Survey (USGS) stream gaging stations based on data recorded at 24 stations. Ten of the gages have records extending back to 1924 or before. The USGS gage on the Brazos River at Waco has a continuously record dating back to October 1898. Gages on the Brazos River at Richmond and Bryan have records beginning in 1899 and 1903, respectively, but also have periods of missing data. The gage on the Little River at Cameron has continuous recorded monthly flows dating back to November 1916. The observed monthly flows at the 24 selected gaging stations were converted to unregulated flows in the 1988 investigation by adjusting for the storage and evaporation effects of 21 major reservoirs and diversions associated with two canal systems. The reservoir with the earliest storage record dates back to January 1936. Regression analyses with the Monthly Streamflow Synthesis (MOSS-IV) computer model were applied to fill in missing data as necessary to develop complete 1940-1984 sequences of unregulated flows at 20 gaging stations. The 1900-1939 portions of these sequences were adopted for the present study.

From a basin-wide perspective, the naturalized stream flows for the earlier years of the 1900-1939 period of extension are significantly less accurate than later flows due to the small number of stream gaging stations in operation during the earlier years. The process of converting gaged flows to naturalized flows is much simpler for 1900-1939 because the impact on stream flows of water resources development and use were much less during this time period. Essentially all of the major reservoir projects in Texas were constructed after 1939. Significant population growth with its associated impacts on water resources development and use occurred after 1939. From 1900 to 1939, natural flows are essentially the same as regulated flows. The primary task in extending the Brazos WAM hydrologic period-of-analysis to include 1900-1939 is developing flows at ungaged sites.

2.3.3 Development of a Condensed Model for Managing of a Particular River/Reservoir System

The WAM System datasets for the larger river basins of the state contain numerous water rights, reservoir, and control points. These voluminous datasets are necessary to support administration of the water rights permit system by the TCEQ and the planning studies conducted by TWDB and regional planning groups. The datasets are necessarily large to serve the original purposes for which the WAM System was developed. However, the modeling system is being applied for a growing range of applications. Simpler datasets are advantageous for certain types of applications. For example, a model may be formulated that focuses on a particular reservoir system and associated water users located in a river basin containing numerous other reservoirs and water users.

Overview of the Dataset Simplification Methodology

A methodology is presented here for reducing the number of control points, water rights, and reservoirs in a WAM dataset and thus simplifying the modeling system for certain applications. Selected water rights, control points, and reservoirs are removed with their effects retained in the adopted stream inflow input data for the simplified dataset. A SIM water rights DAT file for the particular river/reservoir water management and use system of interest, called the primary system, is developed along with a FLO file containing stream inflows that have been adjusted to reflect all other water rights in the original full dataset which are referred to as secondary water rights.

The Brazos WAM authorized and current use dataset described in Chapter III contains 1,634 and 1,725 water right WR records, 122 and 144 instream flow IF records, 670 and 711 reservoirs, and 3,830 and 3,834 control points, respectively. Naturalized flows are input on inflow IN records in a FLO file for 77 primary control points and distributed within SIM to the other ungaged secondary control points as specified by 3,138 or 3,141 flow distribution FD records in a DIS file, respectively. The size of the dataset is dramatically reduced in developing the simplified authorized and current use datasets described in Chapter V. The simplified dataset designed to focus on operation of the Brazos River Authority (BRA) reservoir system includes the 15 largest reservoirs (Allens Creek reservoir only in the simplified authorized use dataset) in the river basin and associated water rights. The 15 reservoirs include one proposed and 12 existing BRA reservoirs and 2 other reservoirs. The simplified dataset has 48 control points as compared to 3,138 or 3,834 control points in the complete WAM dataset. The simplified dataset has no DIS file. The impacts of the 655 or 697 reservoirs and numerous water rights removed from the Brazos WAM datasets are reflected in the IN record river flows developed for the simplified SIM input dataset.

The objective is to develop a simplified SIM input dataset for purposes of studying or providing decision support for a particular system, which in this case is the Brazos River Authority system. The reason for developing the greatly condensed dataset for the BRA system is simply that input datasets and corresponding simulation results with dramatically fewer control points, water rights, and reservoirs are much more manageable to use in modeling studies. The simplified dataset described in Chapter V consists of the following SIM input files:

- DAT file with information for 15 or 14 reservoirs and associated water rights diversions and instream flow requirements.
- FLO or DSS file with 1940-2007 and alternative 1900-2007 sequences of monthly flows at 48 control points representing conditions of river system

development that includes all of the water rights and associated reservoirs in the original complete DAT file except the 15 or 14 reservoirs and associated diversions contained in the simplified dataset DAT file.

- EVA with 1940-2007 and alternative 1900-2007 sequences of monthly net evaporation-precipitation depths for the 15 or 14 control points at which the 15 or 14 reservoir are located.

The simplified dataset should adopt the same net evaporation-precipitation depths for the 15 or 14 reservoirs as used in the original complete dataset SIM simulation. SIM includes an option for adjusting net evaporation-precipitation depths for the precipitation runoff from the portion of the watershed covered by the reservoir. In this case, net evaporation-precipitation depths should be obtained from the OUT file for the complete simulation rather than using the original evaporation precipitation depth input dataset.

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

The SIM input data vary as follows between the original Brazos WAM and simplified BRA system datasets. Numbers for the current use scenario original and simplified datasets are noted below. The numbers are similar for the authorized use datasets:

- In the original complete input dataset, the stream flows at the 77 primary control points provided on inflow IN records in a FLO file are naturalized flows representing river basin hydrology under natural conditions with no reservoirs and no diversions. The DAT input file contains 3,834 control points, 1,725 WR record water rights, 144 IF record instream flow rights, and 711 reservoirs. The DIS file contains 3,141 flow distribution FD records and associated watershed parameter WP records used to distribute flows to the 3,757 control points.

- In the simplified input dataset, the stream flows at the 48 primary control points provided on the FLO file IN records represent conditions with the 697 reservoirs and numerous water rights that were removed from the DAT file. The DAT input file contains 48 control points, 132 WR rights, and 14 reservoirs. Channel loss factors are aggregated for the fewer but longer reaches between control points. Finally, there in no flow distribution DIS file.

The methodology for developing a simplified dataset is based on developing flows at the selected control points that represent stream inflow amounts available to the selected system that reflect the impacts of all of the water rights and accompanying reservoirs removed from the original complete dataset. Stream flows are provided on IN records in either a FLO input file or a DSS file for the simplified dataset. These stream flows represent flows available to the selected system modeled in the water rights DAT input file considering the effects of all the other water rights in the river basin contained in the original complete DAT file that are not included in the simplified DAT file.

The river system inflows input on IN records in a FLO file or DSS records in a DSS file for the simplified dataset include stream flow depletions made for the selected water rights less return flows plus unappropriated flows. Hydropower releases and reservoir releases made specifically to meet instream flow requirements are also appropriately incorporated in the flows. Summation and cascading operations are applied in developing the stream flow input data.

Outline of Methodology for Developing Hydrology Files for Condensed Dataset

The methodology for developing the sequences of monthly stream flow volumes and net evaporation-precipitation depths (FLO and EVA files or DSS file) for the simplified dataset is outlined as follows:

1. SIM is executed with the original complete dataset.
2. HYD is used to retrieve the adjusted net evaporation-precipitation depths from the SIM output OUT file and store them in an EVA or DSS input file for the simplified dataset.
3. HYD is applied to read pertinent stream flow depletions, return flows, unappropriated flows, and any other pertinent variables from the SIM output OUT

file and combine these variables as required to develop the stream flow FLO or DSS input file for the condensed dataset. Combining the time sequences of flow volumes include summations and cascading operations that may include channel losses. HYD reads the necessary control points information from an input file. Options are also provided in HYD for dealing with the issue of computed flows being negative numbers.

Referring again to the BRA system dataset, stream flows developed for the 48 control points consist of the following 1940-2007 or 1900-2007 sequences of monthly volumes of the following variables obtained from the OUT file created by SIM with the original complete input dataset. The computations can be performed with HYD:

- Stream flow depletions made by each of the water rights associated with the 15 or 14 reservoirs are included in the flows being developed. These flow volumes are placed at the control points of the stream flow depletion and at all downstream control points. Channel losses are considered in cascading the stream flow depletions downstream.
- Return flows for the diversion component of the stream flow depletions are subtracted from the flows. These flow volumes are placed at the control points at which the return flow is returned to the stream and at all downstream control points. Channel losses are considered in cascading the return flows downstream.
- Unappropriated flows at each of the control points are added to the flows. Since unappropriated flows are cumulative total flows, these flows are not cascaded downstream.
- Any releases from the 15 or 14 selected reservoirs made specifically from instream flow rights are subtracted at the control points of the reservoir and cascaded downstream in the normal manner which includes consideration of channel losses.
- Though not included in the Brazos WAM, any hydroelectric power releases from the selected reservoirs are likewise subtracted at the control points of the reservoir and cascaded downstream in the normal manner which includes consideration of channel losses.

As previously discussed, the accuracy of the procedure is confirmed by reproducing the sequences of monthly diversions, storage contents, unappropriated flows, and other pertinent variables contained in the SIM simulation results associated with the 15 or 14 reservoirs and associated diversions, and 48 control points. These SIM simulation results should be same with the simplified dataset versus the original complete dataset. The system of 15 or 14 reservoirs and associated diversions must be operated the same in both the simplified and complete datasets for the comparison simulations. After completing the comparison to confirm that the dataset is correct, the simplified dataset can be used to simulate alternative river/reservoir system operating rules and water management and use scenarios for the system of 15 or 14 reservoirs and associated diversion at the 48 control points.

Summary of the Methodology for Updating the Period-of-Analysis

The purpose of the WRAP-SIM/HYD-based methodology is to develop a simpler dataset focusing on a primary river/reservoir water management/use system by reducing the number of control points, water rights, and reservoirs in a WAM dataset. Secondary water rights, control points, and reservoirs are removed with their effects incorporated in the stream inflow input data for the simplified dataset. A SIM water rights DAT file for the particular river/reservoir water management and use system of interest, called the primary system, is developed along with a FLO file containing stream inflows that reflect all other water rights in the original dataset that are not included in the primary system.

If the primary system is operated in the same manner in both the condensed and the original datasets, the water supply diversions and shortages, streamflow depletions, and reservoir storage volumes computed by the SIM simulation model will be the same. The condensed dataset will reproduce the simulation results for the primary system that are obtained with the original dataset. Unappropriated flows are also reproduced. Thus, a comparison of simulation results provides a check on the accuracy and validity of the condensed dataset. With a validated operational condensed dataset, studies can be performed in which various alternative operating plans, management strategies, and water use scenarios are simulated for the primary system. The river inflows for the condensed dataset do not include flows appropriated by the secondary water rights and thus represent only flows that are actually available to the primary system.

Data Files Comprising the Original and Condensed Datasets

The original Bwam3 and Bwam8 datasets for the Brazos WAM application of the methodology presented in Chapter V consist of DAT, FLO, EVA, and DIS files. The condensed simplified datasets in both cases consist of DAT, FLO, and EVA files. The other types of optional SIM input files (DSS, FAD, BES) can be accommodated in the methodology for developing condensed datasets as well.

The original Brazos WAM Bwam8 DAT file has 3,834 control points, 711 reservoirs, and 1,725 water rights. The condensed version of Chapter V has 48 control points, 14 reservoirs, and just those water rights associated with the 14 reservoir. The objective is to develop a simplified dataset designed for more conveniently studying a particular primary river/reservoir water management system. The simplification is achieved largely by reducing the size of the DAT file.

The DAT file for a condensed dataset is developed basically by excerpting pertinent water rights and associated data records from the original DAT file and modifying the control point CP records to reflect removal of some of the control points. Channel loss factor on the CP records of the DAT file may require computations. With removal of control points, channel loss factors for the stream reaches removed are aggregated for the combined longer reaches between the remaining control points.

The Brazos WAM activates a SIM option that adjusts net evaporation-precipitation depths for reservoir site runoff included in the naturalized flows. The condensed EVA file contains net evaporation-precipitation depths read by program HYD from the SIM output OUT file from the original dataset that reflects these adjustments. The EVA file in the condensed dataset provides 14 sets of net evaporation-precipitation depths for 14 reservoirs. The original current Brazos WAM datasets include 67 sets of net evaporation-precipitation depths that are shared by 711 reservoirs.

The Brazos WAM dataset contains over 3,000 FD records and over 3,000 WP records. There is no DIS file in the condensed datasets of the Brazos WAM. The stream inflows in a condensed dataset are not naturalized flows, the flow distribution method should generally not be applied. Thus, DIS files will normally not be included in condensed datasets. The FLO file in the Brazos WAM dataset contains flows at 77 control points. The FLO file in the condensed dataset contains flows at 48 control points.

The hydrologic period-of-analysis sequences of stream inflows provided on the IN record in a FLO file in a WRAP-SIM input dataset represent the inflows to the river system. In the original WAM datasets, these are naturalized flows representing natural conditions without the water resources development, management, and use described by the information in the DAT file. For the condensed datasets, the IN record inflows in a FLO file are the stream flows available to the water rights of the primary system described by the condensed DAT file. The flows appropriated by the secondary water rights are not available to the primary water rights and thus are not included in the IN record inflows in the FLO file.

The term *naturalized flow* is a misnomer for the condensed dataset. The more accurate term would be stream flow inflows for specified conditions, which for the original dataset are naturalized flows but for the condensed dataset are flows available to the primary system considering the effects of the secondary system.

Component of Condensed Dataset Stream Inflows

The streamflow inflows entered on IN records in the FLO file (or DSS record in a DSS file) of a SIM input dataset represent the inflow to the river system. These flows may be naturalized flows representing natural conditions or may reflect other defined conditions of water resources development, allocation, management, and use. There may also be other inflows to the river system. Return flows contribute to the flow amounts available for appropriation. WRAP-SIM also has optional constant inflow and flow adjustment features activated by constant inflow CI and flow adjustment FA records that allow additional inflows to the river system. Thus, inflows include the summation of flows from IN, CI, and FA records plus return flows from water right diversions.

The basic concept of the methodology for developing a condensed dataset is that the stream inflows in the original dataset can be partitioned based on the SIM simulation results between the following quantities:

1. Flows that are appropriated by the secondary water rights that are omitted from the condensed dataset DAT file.
2. Flows that are appropriated by the primary system water rights that are included in the condensed dataset DAT file.
3. Unappropriated flows.

The inflows entered on IN records in the FLO file of the condensed dataset consist of flows that are appropriated by the primary system water rights plus unappropriated flows. Flows that are appropriated by secondary water rights are not included.

The methodology for developing a condensed dataset is based on computing streamflow inflows that represent the flows allocated to and/or accessible to the primary system. These flows are recorded in the FLO or DSS file of the condensed dataset. Program HYD reads the components of these flows from the SIM simulation results output file and creates the FLO or DSS input file for the condensed dataset. The inflow for the condensed dataset consist of streamflow depletions minus return flows associated with the water rights in the primary system, properly cascaded downstream, plus unappropriated flows at each of the control points included in the condensed dataset. Channel losses are considered in cascading streamflow depletions and return flow to downstream control points.

Return Flows and Reservoir Release

Same-month return flows can be a problem in developing a condensed dataset just like they are in performing conventional SIM simulations. The next-month return flow option is applied instead of the same-month option in most cases in the TCEQ WAM System datasets. Return flow options are controlled by the parameter RFMETH on the water right WR record.

The *WRAP Reference Manual* addresses in detail the return flow options and the water rights priority sequence complexity that the next-month return flow option is designed to address. The problem is that, with the same-month return flow option activated, senior water rights do not have access to return flows associated with junior water rights. The next month return flow option solves this problem by adding the return flows to the IN record inflows (naturalized or otherwise defined inflows) at the beginning of the water rights priority sequence in the next month.

The same-month return flow option complicates the procedure for condensing datasets in the same way that it complicates conventional routine SIM simulation applications. The order in which various primary or secondary water rights have access to return flows can affect whether the condensed dataset can correctly reproduce simulation results.

Reservoir releases for hydroelectric energy generation involve essentially the same issue. Hydropower releases are analogous to diversions with 100 percent return flows. The problem is likewise solved by the next-month hydropower option provided in SIM.

A similar problem occurs with releases from reservoir storage to meet instream flow requirements at downstream control points. This is a problem for most of the instream flow IF record rights in the Brazos WAM dataset because releases are not required from reservoir storage. The reservoirs are required to pass inflows to meet the instream flow requirements but are not required to release from storage. Instream flow options are selected by parameter IFMETH on the IF record. The problem discussed here is relevant for IFMETH options 3 and 4 but not for options 1 and 2.

The problem is that an IFMETH option 3 and 4 instream flow IF record right may be assigned a priority that places it between the various primary and secondary rights may not perfectly preserve the effects of the instream flow IF record rights. This is not a problem if the IF record is the most senior water right in the dataset. The impact on simulation results may be so small as to not be a concern. However, if warranted, a possible strategy for dealing with the problem involves reproducing reservoir releases from storage made to meet an instream flow requirement during the original simulation on target series TS records in the DAT file of the condensed dataset.

Negative Flows

The WRAP-HYD based computations of inflows for the FLO file of a condensed dataset may possibly result in negative flows which will be treated as zeros in SIM. Inflows are the summation of unappropriated flows plus streamflow depletions less return flows. Return flows from diversions from reservoir storage can occur in months with no streamflow depletions. Streamflow depletions may be negative due to negative net evaporation-precipitation. Though components are sometimes negative, the summation of unappropriated flows plus streamflow depletions minus return flows is never a negative number. The parameter AS(7) on the HYD adjustment specifications AS record provides options for dealing with negative flows if necessary. Negative values may be set to zero with a corresponding adjustment in the next month.

Regulated Flows

Regulated flows represent the actual physical flows of the river at a control points. Unappropriated stream flows are the quantities remaining after all water rights have appropriated their allocated quantities of water in the simulation. Unappropriated flow at a particular control point in a particular month can not exceed regulated flow in the SIM simulation results for a particular input dataset. However, unappropriated flows may be less than regulated flows. The difference between regulated and unappropriated flows at some control points CP-X represents:

- instream flow requirement at either CP-X or downstream control points
- releases associated with water right types 2 and 3 from upstream reservoir located at or above CP-X for diversion at control points located downstream of CP-X
- the portion of flows appropriated by diversion and/or storage rights at downstream control points that is provided by the flows flowing through control point CP-X

A feature activated by the parameter RUF on the JO record for determining regulated flows in a condensed model has been added to WRAP-SIM that uses RU records stored in a regulated-unappropriated flow RUF file. Without this feature, differences between regulated and unappropriated flows in the simulation results are caused only by the primary water rights included in the condensed DAT file. The effects of the secondary water rights are neglected. Thus, the regulated flows may be smaller in the condensed model than in the original model

2.4 EVALUATION OF STORAGE REALLOCATION FOR BRA SYSTEM OF RESERVOIR

The key factors for operating flood control reservoir system within program SIMD include daily flow patterns at 48 control points for disaggregating monthly Brazos River Authority Condensed (BRAC) inflows, determination of flood flow versus average annual damage curve, calibration of Muskingum routing parameters K (travel time) and X (attenuation), and extension of storage contents to flood control capacity.

The 1939-1997 SUPER model daily unregulated (naturalized) flows at 25 of 37 control points developed by Forth Worth District of the USACE were utilized as daily flow pattern for disaggregating 1939-1997 monthly inflows of the simplified dataset. The mean value of 1939-1997 daily naturalized flow at 25 control points were used as the flow pattern for 1900-1939 and 1998-2007 hydrologic-of-analysis period. These 1900-2007 daily flows pattern at 25 control points were used for transferring flow pattern from gaged to the other 23 ungaged control points.

The flood damage corresponding to exceedance frequencies for regulated flow derived from SIMD simulation OUT file were computed at six control points of the simplified dataset.

The SUPER model daily naturalized flow at 35 control points were used for calibrating the lag time between two control points. The lag times at 48 control points of the simplified dataset are computed based on the distance of the reaches considering the lag time computed using SUPER daily naturalized flow.

The Muskingum routing parameters at 35 control points were calibrated using four optimization function alternatives in program DAY and the distance of the reaches. The flood flow limit at 35 control points for calibrating flood flow K and X were computed based on regression equation developed by using 35 SUPER daily naturalized flows. The K and X results for normal and flood flow according to each method were compared and then the reasonable values for normal and flood flow were selected.

The storage volumes for flood control reservoir system operations were greater than conservation storage capacities. Reservoir storage capacities on storage volume versus storage area records at 9 reservoirs were extended as necessary to assure that the flood control storages never exceeded storage capacities in the model.

The reservoir projects were constructed many years ago. Water demand, water management objectives, water resources development projects, and various other conditions affecting reservoir operation have changed over time. The importance of viewing the reservoirs as an integrated system rather that individual projects is not being emphasized. The Brazos River Authority condensed with flood control pool (BRACF) for the current use for 1900-2007 were developed based on the BRAC dataset developed in Chapter V. The permanent reallocation and May through October seasonal reallocation plans developed in the previous study were applied to the BRACF datasets. Eight simulation runs applied to BRACF dataset. The firm yield and flood frequency analysis for individual and multiple-reservoir system were performed. In particular, multiple-reservoir systems are divided in two systems: i) five reservoirs in Little River Subbasin and ii) nine reservoirs in Brazos River Basin. These two systems are simulated based on Type 2 water right and Type 3 water right. The flood frequency analysis for permanent and seasonal reallocation plans were performed using the following indexes: i) Flood Pool Capacity Exceedance Frequency based on Log-Normal and Log Pearson Type III distribution, ii) Number of Exceedance to flood control pool, iii) Expected value of Flood Storage, and iv) Expected total flood Damage Index (1984$) at six control points.

CHAPTER III

BRAZOS WATER AVAILABILITY MODEL (WAM) DATASET

The TCEQ WAM System dataset for the Brazos River Basin and San Jacinto-Brazos Coastal Basin shown in Figure 3.1 is adopted as a case study to investigate, test, evaluate, and further develop the methodology outlined in the preceding Chapter II. This case study dataset is called the Brazos WAM throughout this research.

The Brazos River Basin has a total area of 44,620 square miles. The climate, hydrology, and geography of the basin vary greatly as it extends across Texas from New Mexico to the Gulf of Mexico. Average annual temperature varies from 60°F in the high plains to 69°F in the Gulf Marshes and Prairies. 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 extreme upper end of the basin in and near New Mexico is an arid flat area that rarely contributes to stream flow.

The San Jacinto-Brazos Coastal Basin lies south of the City of Houston between the lower Brazos River Basin and Galveston Bay. This adjoining coastal basin has a watershed drainage area of 1,145 square miles. Mean annual precipitation is 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 Brazos WAM model has 77 primary control points and a 696-month hydrologic period-of-analysis extending from January 1940 to December 1997. The authorized use and current use scenarios adopted for the WAM system are described in Chapter I. 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 Bwam8 datasets and Bwam3 used in this research were last updated by the TCEQ in August 2007. The simulation model WRAP-SIM prints a listing to its message file of the number of various system components. The data in Table 3.1 are taken from this listing for the authorized use and current use scenario models.

Figure 3.1 Brazos River Basin and San Jacinto-Brazos Coastal Basin

Table 3.1 Number of System Components in Brazos WAM Dataset

Water Use Scenario	Authorized	Current
Filename	Bwam3	Bwam8
Last simulation input data DAT file update	August 2007	August 2007
Total number of control points	3,830	3,834
Number of primary control points	77	77
Control points with evaporation-precipitation rates	67	67
Number of reservoirs	670	711
Number of WR record water rights	1,634	1,725
Number of instream flow IF record water rights	122	144
Number of FD records in flow distribution DIS file	3,138	3,141

3.1 CONTROL POINTS

Primary control points are locations at which naturalized flows are provided in a WAM input dataset. Naturalized flows at all other control points (called secondary control points) are computed within the WRAP-SIM simulations based on the naturalized flows provided at the primary control points and watershed parameters provided in a flow distribution DIS file.

The 77 primary control points for which naturalized flows are provided as IN records in the Bwam3.FLO and Bwam8.FLO files are listed in Table 3.2 with the six-character identifiers used in the data files. Their locations are shown in the map of Figure 3.2 and schematic of Figure 3.3. The first 73 control points listed in Table 3.2 are located in the Brazos River Basin, and the last four are in the San Jacinto-Brazos Coastal Basin.

All but three of the primary control points are U.S. Geological Survey (USGS) gaging stations located on the Brazos River and its tributaries. Control points BRGM73 represents the site at which the Brazos River flows into the Gulf of Mexico. Control points SJGBC3 and SJCMC4 represent locations at which coastal basin stream flow into Galveston Bay and the Gulf of Mexico. The other 74 control points are at USGS gaging stations. The USGS gage numbers and the period-of-record is included in Table 3.2 for these 74 control points. IN record naturalized flows at the gaged control points were computed by adjusting observed flows. In cases of periods of missing data during 1940-1997, gaps in the naturalized flows at gaged sites were filled in using regression.

The Bwam3.EVA and Bwam8.EVA files contain EV records with January 1940 through December 1997 sequences of monthly net reservoir surface evaporation less precipitation depths at 67 control points. The control points with EV record evaporation-precipitation depths are listed in Table 3.3. None of the EV record control points in Table 3.3 are primary control points listed in Table 3.2. The state of Texas is divided into quadrangles for purposed of compiling evaporation and precipitation data. The location of control points are indicated in Table 3.3 either by quadrangle number or by a major reservoir with its control point identifier assigned to the net evaporation data. The net evaporation-precipitation depths entered as EV records in the EVA files for these 67 control points are applied to reservoirs located at these control points and other nearby control points.

Table 3.2 Primary Control Points in the Brazos WAM Dataset

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

Table 3.2 (Continued)

WAM CP ID	Stream	Nearest City	USGS Gage No.	Watershed Area	1940-1997 Mean Nat Flow
				(sq miles)	(ac-ft/year)
HGCR39	Hog Creek	Crawford	08095400	181	25,735
BOWA40	Bosque River	Waco	08095600	1,660	356,832
BRWA41	Brazos River	Waco	08096500	20,065	1,942,324
BRHB42	Brazos River	Highbank	08098290	20,900	2,331,139
LEDL43	Leon River	De Leon	08099100	267	56,375
SADL44	Sabana River	De Leon	08099300	476	35,079
LEHS45	Leon River	Hasse	08099500	1,283	141,273
LEHM46	Leon River	Hamilton	08100000	1,928	166,469
LEGT47	Leon River	Gatesville	08100500	2,379	257,793
COPI48	Cowhouse Creek	Pidcoke	08101000	455	77,373
LEBE49	Leon River	Belton	08102500	3,579	505,257
LAKE50	Lampasas River	Kempner	08103800	817	119,776
LAYO51	Lampasas River	Youngsport	08104000	1,240	208,870
LABE52	Lampasas River	Belton	08104100	1,321	233,258
LRLR53	Little River	Little River	08104500	5,266	846,554
NGGE54	N. Fork San Gabriel	Georgetown	08104700	248	57,922
SGGE55	S. Fork San Gabriel	Georgetown	08104900	132	36,173
GAGE56	San Gabriel River	Georgetown	08105000	404	104,317
GALA57	San Gabriel River	Laneport	08105700	737	189,268
LRCA58	Little River	Cameron	08106500	7,100	1,318,302
BRBR59	Brazos River	Bryan	08109000	30,016	4,027,961
MYDB60	Middle Yegua Creek	Dime Box	08109700	235	39,362
EYDB61	East Yegua Creek	Dime Box	08109800	239	43,189
YCSO62	Yegua Creek	Somerville	08110000	1,011	223,399
DCLY63	Davidson Creek	Lyons	08110100	195	47,485
NAGR64	Navasota River	Groesbeck	08110325	240	83,472
BGFR65	Big Creek	Freestone	08110430	97	32,237
NAEA66	Navasota River	Easterly	08110500	936	322,578
NABR67	Navasota River	Bryan	08111000	1,427	421,304
BRHE68	Brazos River	Hempstead	08111500	34,374	5,358,943
MCBL69	Mill Creek	Bellville	08111700	377	149,586
BRRI70	Brazos River	Richmond	08114000	35,454	5,850,224
BGNE71	Big Creek	Needville	08115000	46	25,631
BRRO72	Brazos River	Rosharon	08116650	35,775	6,112,278
BRGM73	Brazos River	Gulf of Mexico	–	36,027	6,105,239
CLPEC1	Clear Creek	Pearland	08077000	38.8	28,734
CBALC2	Chocolate Bayou	Alvin	08078000	87.7	76,372
SJGBC3	Coastal Basin	Galveston Bay	–	415	345,148
SJGMC4	Coastal Basin	Gulf of Mexico	–	1,004	834,204

** The number of significant digits in the tables of this dissertation does not imply level of accuracy. In general, more digits are included in the numbers than is justified by the level of accuracy.

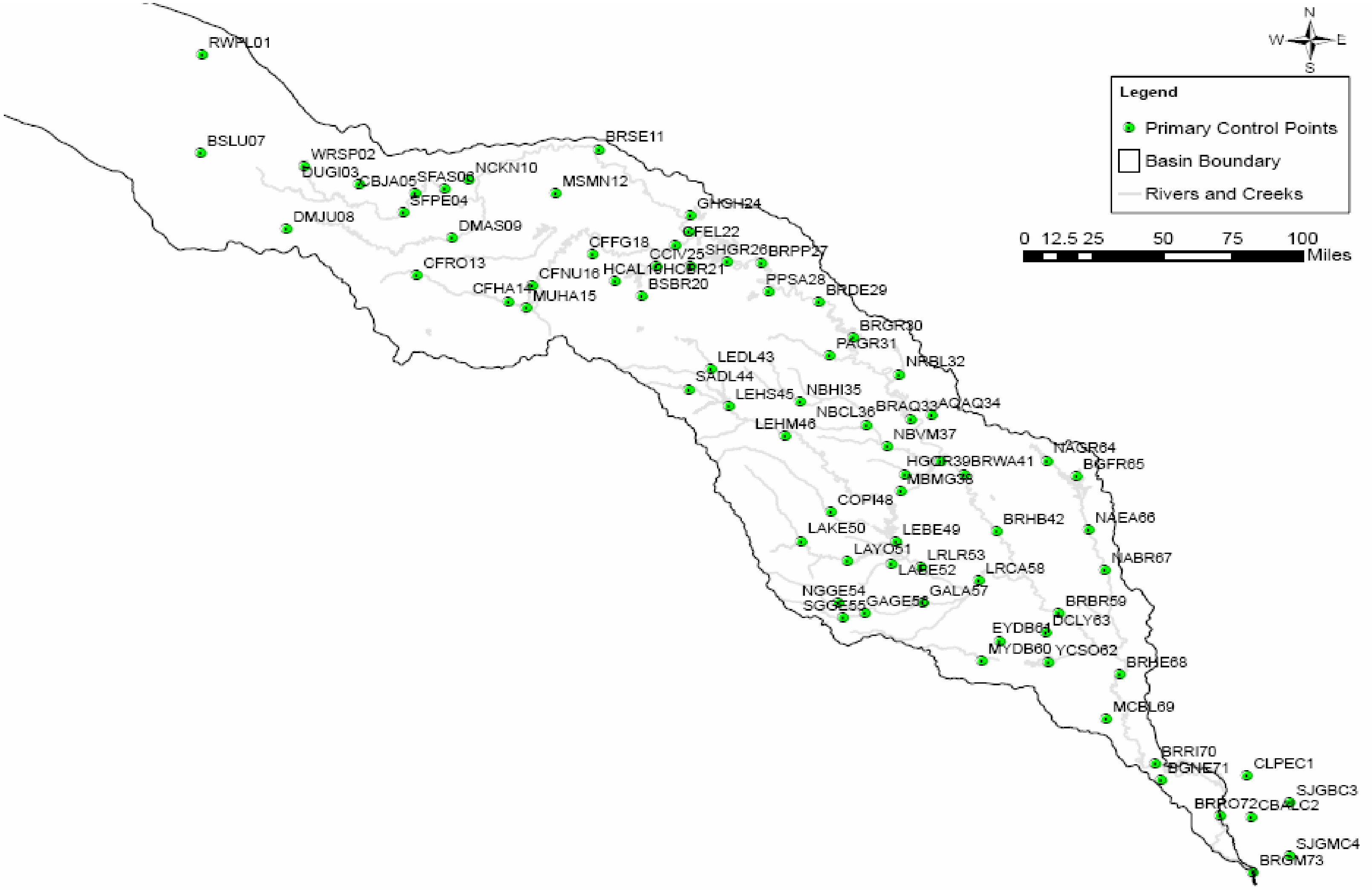

Figure 3.2 Primary Control Points in Brazos River Basin

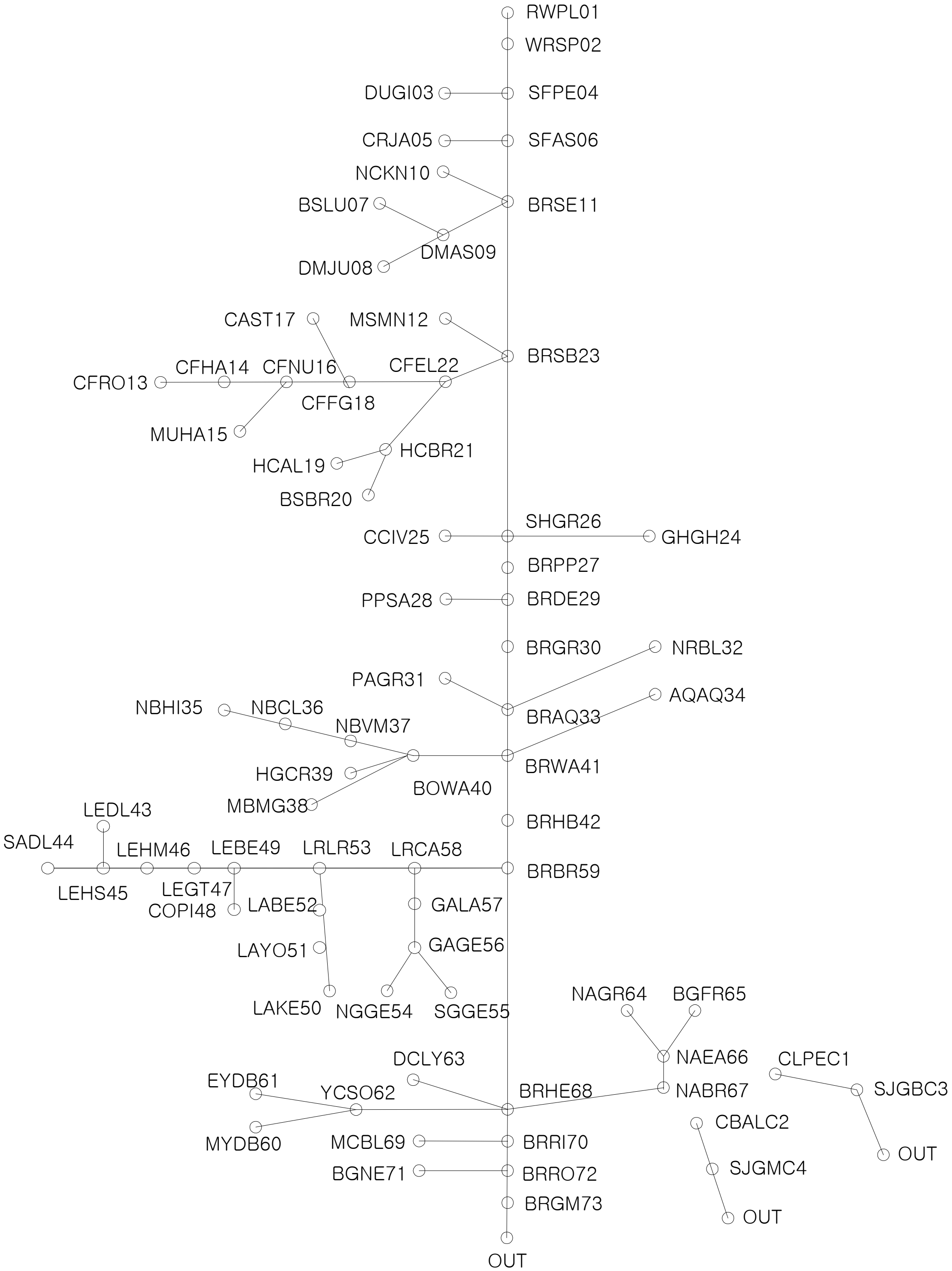

Figure 3.3 Schematic of Primary Control Points (Not to Scale)

Table 3.3 Control Points Assigned to Reservoir Net Evaporation-Precipitation Depth Input

Control Point	Quadrangle or Major Reservoirs	Mean Rage Feet/Month
366631	305	0.3216
368131	306	0.3120
370431	405	0.3216
368931	406	0.3053
341131	407	0.3184
341331	408	0.2815
344801	409	0.2262
371431	506	0.3411
372031	507	0.3022
413331	508	0.2785
220131	509	0.2364
227031	510	0.1912
225331	609	0.0308
228731	610	0.1818
406331	611	0.1422
299231	710	0.1519
375931	711	0.0888
531531	712	0.0131
401041	812	-0.0047
516841	813	-0.0144
414231	Abilene	0.2985
4146P1	Alan Henry	0.3109
527231	Alcoa	0.1354
292531	Allens Creek	0.0392
515831	Aquilla	0.1658
293631	Belton	0.1437
532842	Brazoria	0.0512
526831	Bryan Utilities	0.1011
370631	Buffalo Springs	0.3104
530131	Camp Creek	0.0848
421131	Cisco	0.1945
421431	Daniel	0.2523
344031	Davis	0.2913
549231	Eagle Nest	0.0320
416131	Fort Phantom Hill	0.2866
516231	Georgetown	0.1243
531131	Gibbons Creek	0.0673
345831	Graham	0.2473
515631	Granbury	0.1808
516331	Granger	0.1432
421331	Hubbard Creek	0.2557
415031	Kirby	0.2924
434531	Lake Creek	0.1611
347031	Leon	0.2235
516531	Limestone	0.1109
435533	Marlin City	0.1455
528731	Mexia	0.1480
344431	Millers Creek	0.2709
403931	Mineral Wells	0.2047
403131	Lake Palo Pinto	0.2183
410631	Pat Cleburne	0.1751
515531	Possum Kingdom	0.2324
371131	Post	0.4469
515931	Proctor	0.1734
554032	Sandow Surface Mine	0.1354
532531	Smithers	0.0043
516431	Somerville	0.0787
409731	Squaw Creek	0.1768
417931	Stamford	0.2911
516131	Stillhouse Hollow	0.1382
413031	Sweetwater	0.3014
434231	Tradinghouse Creek	0.1611
529831	Twin Oaks	0.1274
231531	Waco	0.1709
369331	White River	0.3106
515731	Whitney	0.1709
532841	William Harris	0.0294

The 670 reservoirs in the Bwam3 dataset and 711 reservoirs in the Bwam8 dataset are each assigned 1940-1997 sequences of monthly net evaporation-precipitation depths in feet/month read from EV records in the EVA file that are connected to one of the control points listed in Table 3.3. The first 20 control points listed in Table 3.3 serve as location identifiers for the one degree quadrangles that cover the Brazos River, which are shown on the figure on p.79. The other control points in Table 3.3 are locations of reservoirs. The 1940-1997 means of the monthly net evaporation-precipitation depth are shown in Table 3.3.

3.2 RESERVOIRS

The authorized use dataset contains 665 reservoirs with conservation storage capacities totaling 4,694,851 acre-feet (excluding flood control storage capacity). The current use dataset contains 706 reservoirs with conservation storage capacities totaling 4,023,350 acre-feet. The range in conservation storage capacity is shown in Table 3.4. The Bwam3 and Bwam8 datasets have 246 and 266 reservoirs, respectively, that have less than 50 acre-feet of storage capacity and 12 and 11 reservoirs, respectively, that each contain over 100,000 acre-feet of conservation storage capacity. Although there are numerous smaller reservoirs, most of the total reservoir storage capacity in the Brazos River Basin is contained in a relatively few large reservoirs.

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

Table 3.1 shows the total *WRAP-SIM* counts of 670 and 711 reservoirs in the Bwam3 and Bwam8 data files. Table 3.4 shows that the numbers of actual Bwam3 and Bwam8 reservoirs are 665 and 706. The difference of five reservoirs in these counts is due to subdividing Whitney and Waco Reservoirs into component reservoirs in the model to reflect multiple owners, as shown in Table 3.5. In the 670 and 711 reservoir count of Table 3.1, Whitney Reservoir is counted as three model reservoirs, and Waco Reservoir is counted as the four reservoirs shown in Table 3.5.

Table 3.4 Reservoirs in the Brazos WAM

Range of Conservation Storage Capacity (acre-feet)	Authorized Use (Bwam3) Number of Reservoirs	Authorized Use (Bwam3) Total Capacity (acre-feet)	Current Use (Bwam8) Number of Reservoirs	Current Use (Bwam8) Total Capacity (acre-feet)
less than 50	246	4,440	266	4,904
50 to 99	82	5,838	89	6,325
100 to 499	195	44,558	208	47,431
500 to 999	49	35,503	51	36,841
1,000 to 4,999	44	93,738	49	108,146
5,000 to 9,999	12	94,479	10	76,849
10,000 to 49,999	18	463,298	19	511,698
50,000 to 99,999	7	421,066	3	174,621
100,000 to 499,999	10	2,171,092	9	1,943,444
greater than 500,000	2	1,360,839	2	1,113,087
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Total	665	4,694,851	706	4,023,350

Table 3.5 Whitney and Waco Component Reservoirs

Reservoir ID	Storage Capacity (acre-feet) Bwam3	Storage Capacity (acre-feet) Bwam8
	Whitney Reservoir	
WHITNY	387,024	311,998
BRA	50,000	50,000
CORWHT	199,076	199,076
Total	636,100	561,074

Reservoir ID	Storage Capacity (acre-feet) Bwam3	Storage Capacity (acre-feet) Bwam8
	Waco Reservoir	
LKWACO	39,100	39,100
WACO2	65,000	65,000
WACO4	88,062	88,062
WACO5	14,400	14,400

Sixteen Largest Reservoirs in the Brazos River Basin

The 16 reservoirs listed in Table 3.6 are the only reservoirs in the Brazos River Basin that have a combined conservation and controlled (gated) flood control storage capacity of greater than 75,000 acre-feet. There are no reservoirs of this size in the San Jacinto-Brazos Coastal Basin. These 16 reservoirs contain about 80 percent of the conservation storage capacity and 100 percent of the flood control storage capacity in the basin. Figure 3.4 is a map showing their location. Several key gaging stations are also shown on the map.

A system of nine federal multiple-purpose reservoirs is operated by the Corps of Engineers Fort Worth District. The Brazos River Authority (BRA) has contracted for the conservation storage in the nine federal reservoirs and owns three other reservoirs. The BRA also holds a permit for Allens Creek Reservoir which has not yet been constructed. Two other municipal water supply reservoirs and a thermal-electric power plant cooling reservoir are included in Table 3.6.

The Brazos WAM dataset contains only conservation storage capacity, not flood control. Conservation capacity is used to store water for municipal, industrial, and agricultural water supply, hydroelectric power generation, and other beneficial uses. Flood control storage capacity is maintained empty except during and immediately following flood events. Flood control pools may be controlled by gated outlet structures operated by people or may consist of surcharge storage behind ungated structures. All of the controlled (gated) flood control storage capacity in the Brazos River Basin is contained in nine reservoirs operated by the Fort Worth District of the U.S. Army Corps of Engineers. These federal reservoirs contain flood control pools that are regulated by gated outlet structures and operating rules. There are numerous other smaller flood control dams constructed by the Natural Resource Conservation Service and other entities that have ungated outlet structures. These dams are not included in the storage capacity data presented here.

The storage capacity of the flood control pools of the nine Corps of Engineers reservoirs are tabulated in Table 3.6. The bottom of flood control pool is the top of the conservation pool. Flood control operations occur whenever lake levels rise above the top of conservation pool elevation. The flood control storage capacity shown in Table 3.6 is not included in the WAM dataset.

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

Table 3.6 Largest Reservoirs in the Brazos River Basin

Reservoir	WAM Identifier	Stream	Initial Impound-ment	Conservation Capacity		Flood Control (acre-feet)
				Bwam3 (acre-feet)	Bwam8 (acre-feet)	
Brazos River Authority and U.S. Army Corps of Engineers						
Possum Kingdom	POSDOM	Brazos River	1941	724,739	552,013	–
Granbury	GRNBRY	Brazos River	1969	155,000	132,821	–
Whitney	Table 3.5	Brazos River	1951	636,100	561,074	1,372,400
Aquilla	AQUILA	Aquilla Creek	1983	52,400	41,700	86,700
Waco	Table 3.5	Bosque River	1965	206,562	206,562	553,300
Proctor	PRCTOR	Leon River	1963	59,400	54,702	310,100
Belton	BELTON	Leon River	1954	457,600	432,978	640,000
Stillhouse Hollow	STLHSE	Lampasas R.	1968	235,700	224,279	390,660
Georgetown	GRGTWN	San Gabriel	1980	37,100	36,980	87,600
Granger	GRNGER	San Gabriel	1980	65,500	50,540	162,200
Limestone	LMSTNE	Navasota R.	1978	225,400	208,017	–
Somerville	SMRVLE	Yequa Creek	1967	160,110	154,254	337,700
Allens Creek	ALLENS	Allens Creek	–	145,533	–	–
City of Lubbock						
Alan Henry	ALANHN	Double Mountain	1993	115,937	115,773	–
West Central Texas Municipal Water District						
Hubbard Creek	HUBBRD	Hubbard Cr.	1962	317,750	317,750	–
Texas Utilities Services (cooling water for an electric power plant)						
Squaw Creek	SQWCRK	Squaw Creek	1977	151,500	151,015	–
Storage Capacity Totals						
Total for the 16 reservoirs listed above				3,746,331	3,240,458	3,940,660
Total of 16 reservoirs as a percentage of basin total				79.8%	80.5%	100.0%
Total for the entire river basin (665 and 706 reservoirs)				4,694,851	4,023,350	3,940,660

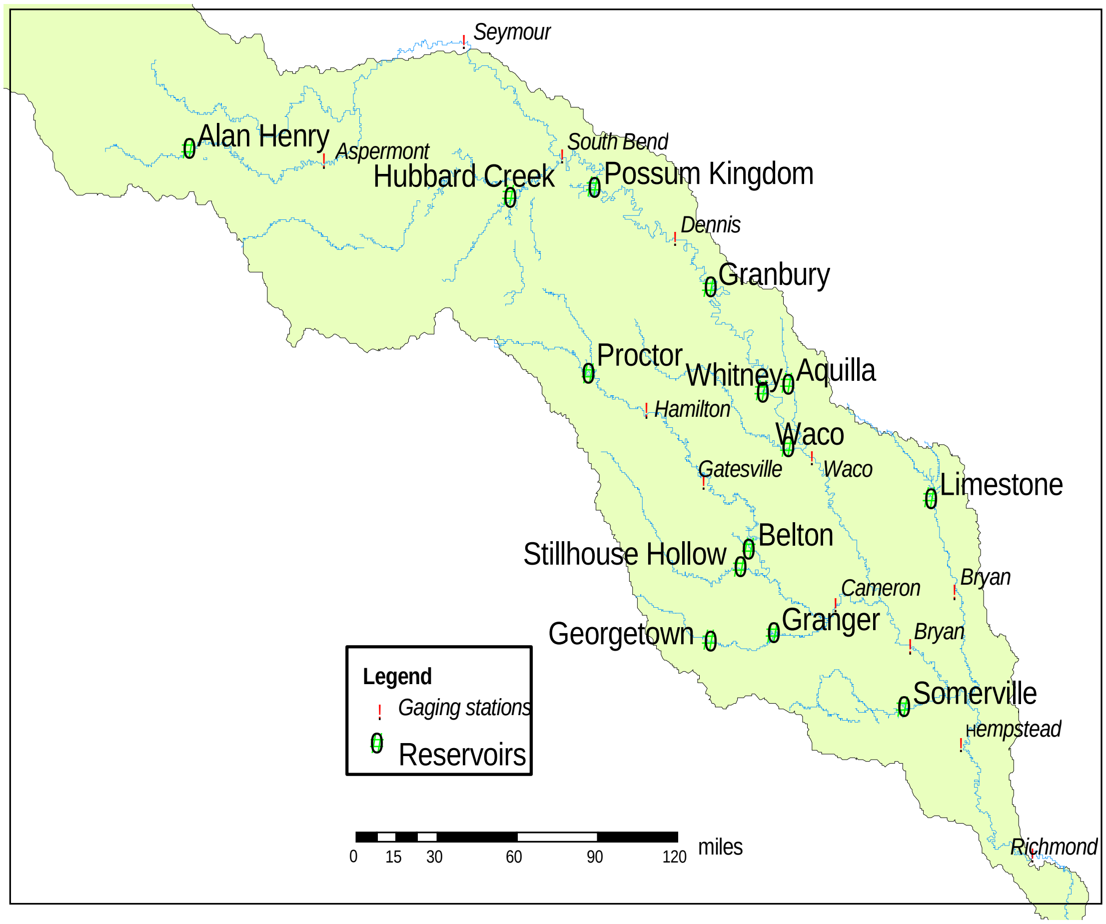

Figure 3.4 Largest Reservoirs and Selected Gaging Stations

The Fort Worth District of the U.S. Army Corps of Engineers operates a system of nine reservoirs in the Brazos River Basin that contain a little over 40 percent of the conservation storage capacity and all of the flood control storage capacity in the basin. The federal Whitney, Aquilla, Waco, Proctor, Belton, Stillhouse Hollow, Georgetown, Granger, and Somerville Reservoirs are the only reservoirs in Table 3.6 with flood control pools. The Corps of Engineers constructed, owns, and maintains the federal multiple-purpose reservoir system and is responsible for flood control operations. However, flood control operations are not modeled in the WAM datasets.

The Brazos River Authority (BRA) has contracted for most of the conservation storage capacity in the nine federal reservoirs, and owns three other reservoir projects: Lakes Possum Kingdom (Morris Sheppard Dam), Granbury (Decordova Bend Dam), and Limestone (Sterling C. Robertson Dam). The conservation storage in Lakes Waco and Proctor are dedicated to meeting local water supply needs in the vicinity of each individual reservoir. The City of Waco holds water right permits for use of water from Lake Waco. The BRA holds permits for use of most of the water supplied by the other reservoirs. The BRA operates the reservoirs as a system to meet water supply needs in the lower Brazos River Basin and adjoining coastal basins as well as in the vicinity of the reservoirs. However, the reservoirs are modeled essentially as individual projects in the August 2007 versions of the Bwam3 and Bwam 8 datasets, without detailed consideration of multiple-reservoir system operations. The water supply reservoirs are popular for recreation use.

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

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

Allens Creek Reservoir is a proposed BRA storage project that has not yet been constructed. The water rights associated with Allens Creek Reservoir consists of joint water right holders that include Brazos River Authority, City of Houston, and TWDB. 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 Allens Creek, a tributary of the lower Brazos River, in Austin County near the towns of Wallis and Simonton. Allens Creek Reservoir is included in the Bwam3 dataset but is not included in Bwam8.

Lake Alan Henry in the upper basin is the most recently constructed of the 16 largest reservoirs listed in Table 3.6. 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 the Texas Utilities Services Company provides cooling water for the Comanche Peak nuclear power plant. The reservoir 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 Possum Kingdom and Granbury Reservoirs as needed to meet demands of the Comanche Peak Nuclear Power Plant.

Reservoir with Authorized Storage Capacities Greater Than 10,000 Acre-feet

Table 3.7 and Figure 3.5 show the 37 reservoirs in the Brazos River Basin with water right permits that authorize storage capacities exceeding 10,000 acre-feet. The proposed Allens Creek Reservoir is included along with 36 actual existing reservoirs. These 37 reservoirs contain about 93.4 percent of the authorized storage capacity in the basin reflected in all of the water right permits. With the notable exception of Lake Whitney, the authorized storage capacities tabulated in Table 3.7 are the capacities included in the Bwam3 dataset. However, of the total Lake Whitney conservation storage capacity of 636,100 acre-feet shown in Table 3.5, only 50,000 acre-feet is authorized in a water right permit and thus tabulated in Table 3.7.

Table 3.7 Reservoirs with Authorized Storage Capacities Exceeding 10,000 Acre-feet

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

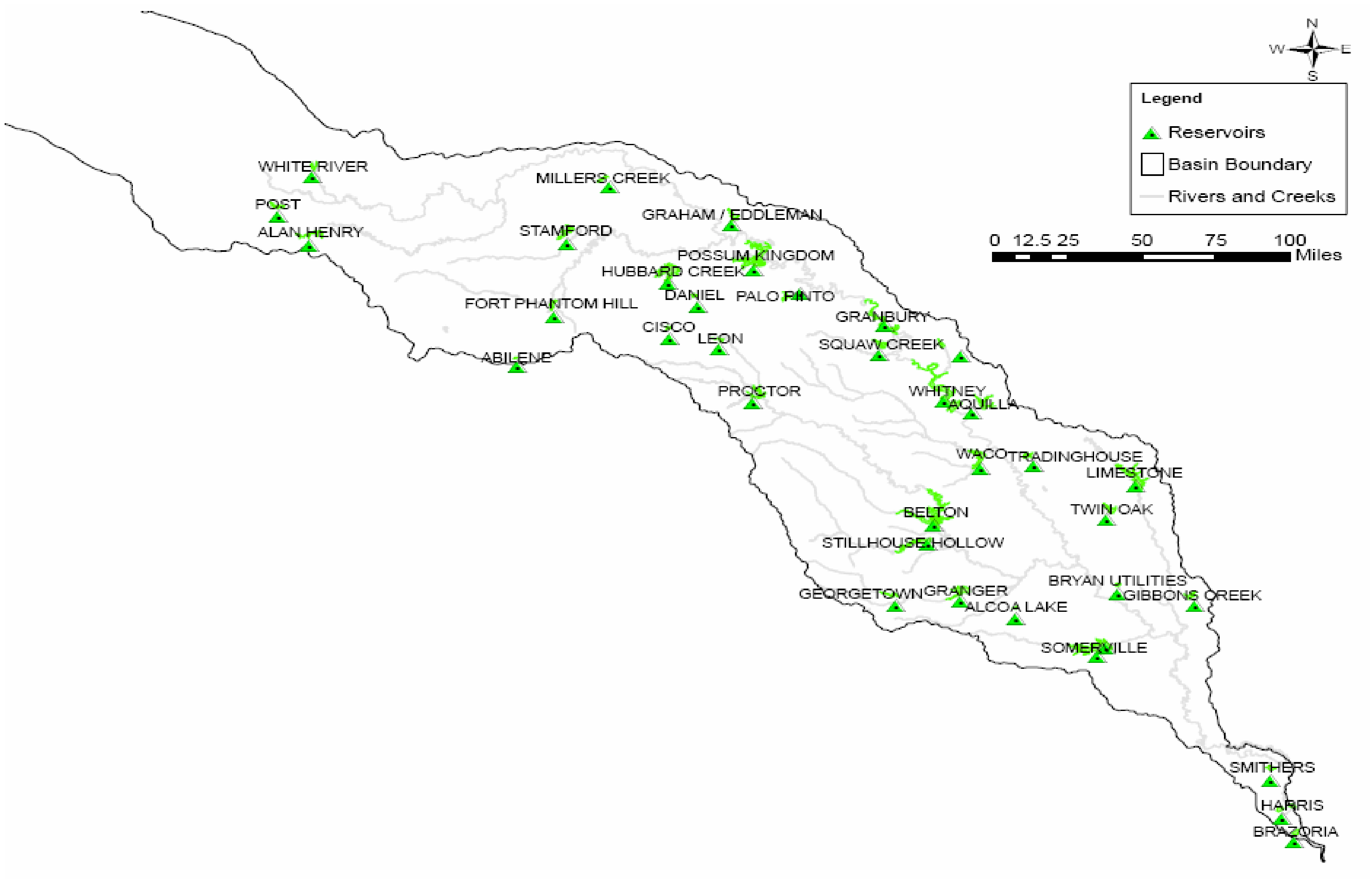

Figure 3.5 Major Reservoirs in Brazos River Basin and San Jacinto-Brazos Coastal

3.3 WATER RIGHTS

The Bwam3 authorized use scenario input data file with filename extension DAT contains 1,634 water right *WR* records and 122 instream flow *IF* records. The Bwam8 current use scenario DAT file contains 1,725 *WR* records and 144 *IF* records. In many cases, a single *WR* record represents a single actual water right permit. However, in some cases, multiple *WR* and *IF* records are used to model a particular water right permit. For example, separate *WR* records are included for municipal, industrial, and agricultural water use authorized by the same water right permit.

The Bwam3 and Bwam8 datasets model the authorized use and current use scenarios described in Chapter I. The differences between the Bwam3 authorized use scenario and Bwam8 current use scenario models are as follows:

- The Bwam3 water supply diversion targets are based on the authorized amounts specified in the water right permits. The Bwam8 dataset models the current use scenario. Diversion targets were adopted based on the maximum annual water use associated with each individual water right permit during any year during 1988 through 1997. The Bwam8 diversion targets are generally significantly smaller than the Bwam3 diversion targets.
- The Bwam3 authorized use dataset has no return flows associated with the authorized diversion. Bwam8 includes estimated return flows. The Bwam8 return flows significantly increase water availability.
- The Bwam3 reservoir storage capacities are authorized volumes from the water right permits which typically reflect conditions at the time of initial impoundment prior to accumulation of sediment deposits. The Bwam8 storage capacities are adjusted to reflect estimated year 2000 conditions of reservoir sedimentation. The total storage capacity in the Bwam8 dataset is smaller than the storage capacity in Bwam3.
- Bwam8 includes term permits which are issued for fixed relatively short-term periods of time as well as regular water right permits. Bwam3 does not. Thus, Bwam8 has more water rights. However, the term permits generally involve relatively small storage and diversion volumes.

Overview of All Water Rights in the Dataset

The authorized diversions associated with the 37 reservoirs with conservation storage capacities greater than 10,000 acre-feet are tabulated in Table 3.7. The storage volumes and annual diversion volumes in Table 3.7 are the amounts specified in the water right permits which are modeled by Bwam3. The authorized diversion amounts associated with these 37 reservoirs represent about 60.2 percent of the total of the authorized diversion targets in the Bwam3 dataset.

The diversion targets for the water rights in the Bwam3 and Bwam8 input data DAT files sum to 2,437,338 and 1,496,432 acre-feet/year, respectively. Diversion targets from the water right *WR* records of the Bwam3 and Bwam8 DAT files are summarized in Tables 3.8 and 3.9, respectively. The water use type identifier connecting the *WR* records to monthly water use distribution factor *UC* records are shown in the first column of Tables 3.8 and 3.9. The following four regions of the river basin cited in the first column are considered in specifying *UC* record sets of 12 monthly water use distribution factors as well as the type of use:

- Region 1 is the upper basin upstream of Possum Kingdom reservoir. Alan Henry and Hubbard Creek Reservoirs are located in Region 1.
- Region 2 is the upper middle basin between Regions 1 and 3. Possum Kingdom, Granbury, Aquilla, Waco, Proctor, and Belton Reservoirs are in Region 2.
- Region 3 is the lower middle basin below Whitney Dam that includes the Little River and Navasota River subbasins. Stillhouse Hollow, Georgetown, Granger, Limestone, Somerville Reservoirs are located in Region 3.
- Region 4 is the lower basin below the confluence of the Navasota River with the Brazos River. The proposed Allens Creek Reservoir will be located in Region 4.

The Bwam3 DAT file contains 122 *IF* records specifying instream flow requirements. The Bwam8 dataset has 144 *IF* records. All instream flow rights require junior rights to pass inflows through reservoirs if necessary to meet the minimum instream flow targets. However, most of the *IF* record rights do not require release of additional water from reservoir storage to meet the instream flow targets. The exceptions are the following three relatively small instream flow rights that do require releases from reservoir storage if necessary to satisfy instream flow targets:

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

Table 3.8 Water Rights Summary for Bwam3 Authorized Use Scenario

Water Use Type Identifier on *UC* and *WR* Records (Type of Use and Region)	Number of WR Records	Total of Diversion Targets	Total Storage Capacity	Priorities Range from	to
		(ac-ft/yr)	(acre-feet)		
MUN1 municipal, region 1	39	165,493	2,339,399	Jun 1914	Oct 1981
MUN2 municipal, region 2	85	329,774	15,974,008	Oct 1914	88888888
MUN3 municipal, region 3	31	159,377	1,850,580	Mar 1914	Feb 2000
MUN4 municipal, region 4	33	672,752	355,332	0	Jun 2001
IRR1 irrigation, region 1	156	25,875	490,764	Dec 1914	Jun 1996
IRR2 irrigation, region 2	570	81,869	3,373,950	Dec 1889	Apr 2002
IRR3 irrigation, region 3	225	53,248	883,133	Dec 1883	Apr 2002
IRR4 irrigation, region 4	71	101,554	39,884	Jun 1914	Jun 2000
IND1 industrial, region 1	20	19,691	707,547	Mar 1925	Oct 1981
IND2 industrial, region 2	24	251,692	4,176,287	Oct 1915	Mar 1986
IND3 industrial, region 3	43	148,368	1,647,647	Jun 1914	Nov 1993
IND4 industrial, region 4	21	269,902	74,232	Jun 1914	Jan 1997
MIN1 mining, region 1	24	23,133	523,695	Jul 1926	Jul 2000
MIN2 mining, region 2	13	21,040	2,900,952	Dec 1919	Oct 2000
MIN3 mining, region 3	17	547	717,644	Dec 1963	Oct 1976
MIN4 mining, region 4	3	54,300	0	Feb 1939	Jul 2000
HYD2 PK hydropower	1	3,600	724,739	Apr 1934	Apr 1934
WHIT1, Whitney municipal	3	18,336	299,076		
UNIFO uniform distribution	180	543	1,126,539	Jun 1914	99999999
other individual water rights	75	36,243	1,685,440	Jun 1914	99999999
Total	1,634	2,437,338			

Several water supply diversion rights held by the Brazos River Authority and other permit holders are authorized for multiple types of use but included in the WAM dataset as municipal use. Since reservoirs supply multiple types of use, the storage capacities in Tables 3.8 and 3.9 reflect counting the same reservoirs more than once.

Table 3.9 Water Rights for Bwam8 Current Use Scenario

Water Use Type Identifier on *UC* and *WR* Records (Type of Use and Region)	Number of WR Records	Total of Diversion Targets	Total Storage Capacity	Priorities Range from	to
		(ac-ft/yr)	(acre-feet)		
MUN1 municipal, region 1	39	50,502	2,284,300	Jun 1914	Oct 1981
MUN2 municipal, region 2	89	167,868	14,217,771	Oct 1914	88888888
MUN3 municipal, region 3	31	101,701	1,742,405	Mar 1914	Feb 2000
MUN4 municipal, region 4	32	484,515	64,301	0	Jun 2001
IRR1 irrigation, region 1	158	14,385	495,565	Dec 1914	Jun 1996
IRR2 irrigation, region 2	626	71,586	2,811,547	Dec 1889	Apr 2002
IRR3 irrigation, region 3	244	37,316	835,443	Dec 1883	Apr 2002
IRR4 irrigation, region 4	72	83,674	39,884	Jun 1914	Jun 2000
IND1 industrial, region 1	20	5,354	621,846	Mar 1925	Oct 1981
IND2 industrial, region 2	27	94,951	3,419,223	Oct 1915	Mar 1986
IND3 industrial, region 3	44	82,572	1,557,606	Jun 1914	Nov 1993
IND4 industrial, region 4	21	250,480	73,257	Jun 1914	Jan 1997
MIN1 mining, region 1	23	3,199	432,243	Jul 1926	Jul 2000
MIN2 mining, region 2	13	13,336	2,320,575	Dec 1919	Oct 2000
MIN3 mining, region 3	19	338	675,950	Dec 1963	Oct 1976
MIN4 mining, region 4	3	3,957	0	Feb 1939	Jul 2000
HYD2 PK hydropower	1	3,600	522,013	Apr 1934	Apr 1934
WHIT1 Whitney municipal					
UNIFO uniform distribution	184	426	184	Jun 1914	99999999
other individual water rights	79	26,470	1,769,002	Jun 1914	99999999
Total	1,725	1,496,432			

Water Rights Associated with the 16 Largest Reservoirs

The annual diversion targets for the Bwam3 authorized use scenario and Bwam8 current use scenario are tabulated in Table 3.10 for water rights associated with the 16 large reservoirs previously listed in Table 3.6. The totals for the entire dataset are shown at the bottom of Table 3.10. The diversion targets associated with these 16 reservoirs account for about 39.7 percent and 31.7 percent of the total authorized diversion amounts for the Bwam3 and Bwam8 datasets.

For most of the 1,634 water right *WR* records in the Bwam3 DAT file or 1,725 *WR* records in the Bwam8 DAT file, each individual *WR* record represents a particular water right permit. In most cases, a water right permit is modeled with a single *WR* record and associated reservoir storage WS record. However, the water right permits governing the water supplied by the larger reservoirs are more complex. Several *WR* records may be used to model a single water right permit.

Information from the 133 *WR* records in the Bwam3 DAT file connected to the 16 largest reservoirs is tabulated in Table 3.11. Each of the 133 model water rights listed in Table 3.11 corresponds to a *WR* record in the Bwam3 DAT file. The water right identifier and corresponding control point identifier for the right are tabulated in the first two columns of Table 3.11. The annual diversion target in acre-feet/year for the water right is shown in the third column. The use type in the fourth column connects the annual diversion target to a set of 12 monthly water use distribution factors entered on water use coefficient *UC* records.

Bwam3 has zero return flows for all water rights. However, the Bwam3 and Bwam8 data files are designed to contain essentially the same records with entries in certain fields being different as appropriate for the authorized and current use scenarios. Thus, the files are designed so that return flows are conveniently activated in Bwam8 and set at zero in Bwam3. Return flows may be specified on the *WR* record as a constant fraction of monthly diversion volumes, or alternatively, a set of 12 monthly varying fractions may be specified. Both of these alternative options are incorporated in the water rights listed in Table 3.11. The identifier of the control point at which Bwam8 diversion return flows return to the river system is tabulated in the sixth column of Table 3.11. The default is for return flows to enter the river at the control point located immediately downstream of the diversion. The sixth column is blank for the majority of the water rights in Table 3.11 indicating adoption of the default next downstream control point option.

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

The conservation pool of Lake Whitney serves largely to provide recreation and head for hydropower. Lake Whitney is an abnormality in the reservoir storage capacity inventory in that most of its conservation storage capacity, though included in both the Bwam3 and Bwam8 datasets, is not specified in any water right permit. The total conservation storage capacity of Lake Whitney is 636,100 and 561,074 acre-feet in the Bwam3 and Bwam8 datasets as shown in Table 3.5. The Lake Whitney storage capacity authorized by a water right permit is 50,000 acre-feet between elevation 520 feet above mean sea level (387,024 acre-feet storage level) and 523 feet (642,179 acre-feet).

Table 3.10 Brazos WAM Water Rights

	Reservoir	Control	Storage (acre-feet)		Diversion (ac-ft/year)	
Reservoir	Identifier	Point	Bwam3	Bwam8	Bwam3	Bwam8
Brazos River Authority System						
Possum Kingdom	POSDOM	515531	724,739	552,013	230,750	59,482
Granbury	GRNBRY	515631	155,000	132,821	64,712	36,025
Whitney	WHITNY	515731	387,024	311,998	0	0
	BRA	515731	50,000	50,000	18,336	18,336
	CORWHT	515731	199,076	199,076	0	0
Aquilla	AQUILA	515831	52,400	41,700	13,896	2,394
Waco	LKWACO	509431	39,100	39,100	39,100	37,448
	WACO2	509431	65,000	65,000	20,000	900
	WACO4	509431	88,062	88,062	20,777	0
	WACO5	509431	14,400	14,400	0	0
Proctor	PRCTOR	515931	59,400	54,702	19,658	14,068
Belton	BELTON	516031	457,600	432,978	112,257	107,738
Stillhouse Hollow	STLHSE	516131	235,700	224,279	67,768	67,768
Georgetown	GRGTWN	516231	37,100	36,980	13,610	11,943
Granger	GRNGER	516331	65,500	50,540	19,840	2,569
Limestone	LMSTNE	516531	225,400	208,017	65,074	39,337
Somerville	SMRVLE	516431	160,110	154,254	48,000	48,000
Allens Creek	ALLENS	292531	145,533	–	99,650	–
City of Lubbock						
Alan Henry	ALANHN	4146P1	115,937	115,773	35,000	288
West Central Texas Municipal Water District						
Hubbard Creek	HUBBRD	421331	317,750	317,750	56,000	9,924
Texas Utilities Services (cooling water for an electric power plant)						
Squaw Creek	SQWCRK	409702	151,500	151,015	23,180	17,536
Water Right Totals						
Total for the 16 reservoirs listed above			3,746,331	3,240,458	967,608	473,756
Percentage of basin total			(79.8%)	(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

Table 3.11 Bwam3 Water Right WR Records Connected to the 16 Largest Reservoirs

Water Right	Control Point	Diversion (ac-ft/yr)	Use Type	Priority	Return Flow CP	Permit Holder
Possum Kingdom Reservoir (POSDOM) on Brazos River with Storage Capacity of 724,739 acre-feet						
C5155_1	515531	1,000	MUN2	19380406	27891	Brazos River Authority
C5155_2	515531	237	MUN2	19380406		Brazos River Authority
C5155_3	515531	1,200	MUN2	19380406	101102	Brazos River Authority
C5155_4	515531	315	MUN2	19380406	106271	Brazos River Authority
C5155_5	515531	473	MUN2	19380406	104101	Brazos River Authority
C5155_6	515531	2051	MUN2	19380406	105685	Brazos River Authority
C5155_7	515531	3549	MUN2	19380406	103751	Brazos River Authority
C5155_8	515531	1499	MUN2	19380406	101731	Brazos River Authority
C5155_9	515531	40,753	MUN2	19380406		Brazos River Authority
C5155_10	515531	5240	MUN2	19380406		Brazos River Authority
C5155_11	515531	168	IND2	19380406		Brazos River Authority
C5155_12	515531	107,447	IND2	19380406		Brazos River Authority
C5155_13	515531	371	IND2	19380406		Brazos River Authority
C5155_14	515531	31,538	IND2	19380406		Brazos River Authority
C5155_15	515531	1273	IRR2	19380406		Brazos River Authority
C5155_16	515531	840	IRR2	19380406		Brazos River Authority
C5155_17	515531	10,099	IRR2	19380406		Brazos River Authority
C5155_18	515531	18,924	MIN2	19380406		Brazos River Authority
C5155_19	515531	158	MIN2	19380406		Brazos River Authority
C5155_20	515531	15	MIN2	19380406		Brazos River Authority
C5155_21	515531	3,600	HYD2	19380406	515551	Brazos River Authority
Granbury Reservoir (GRNBRY) on Brazos River with Storage Capacity of 155,000 acre-feet						
C5156_1	515631	1,557	MUN2	19640213		Brazos River Authority
C5156_2	515631	2,600	MUN2	19640213		Brazos River Authority
C5156_3	515631	6,705	MUN2	19640213	101782	Brazos River Authority
C5156_4	515631	1,475	MUN2	19640213		Brazos River Authority
C5156_5	515631	1,073	MUN2	19640213		Brazos River Authority
C5156_6	515631	2	IND2	19640213		Brazos River Authority
C5156_7	515631	3,748	IND2	19640213		Brazos River Authority
C5156_8	515631	40,000	IND2	19640213		Brazos River Authority
C5156_9	515631	4,544	IRR2	19640213		Brazos River Authority
C5156_10	515631	2,806	IRR2	19640213		Brazos River Authority
C5156_11	515631	200	IRR2	19640213		Brazos River Authority
C5156_12	515631	2	MIN2	19640213		Brazos River Authority
Whitney Reservoir (WHTNY) on Brazos River with Storage Capacity of 387,024 acre-feet						
USACE_WHIT	515731	0		88888888		Corps of Engineers
EVAP1	515731	0		99999999		Corps of Engineers
Whitney Reservoir (BRA) with Storage Capacity of 50,000 acre-feet						
C5157_2	515731	18,336	WHIT1	19820830		Brazos River Authority
C5157_3	515731	0	WHIT1	40000101		Brazos River Authority
EVAP2	515731	0		99999999		

Table 3.11 (Continued)

Water Right	Control Point	Diversion (ac-ft/yr)	Use Type	Priority	Return Flow CP	Permit Holder
Whitney Reservoir (BRA) with Storage Capacity of 50,000 acre-feet						
C5157_2	515731	18,336	WHIT1	19820830		Brazos River Authority
C5157_3	515731	0	WHIT1	40000101		Brazos River Authority
EVAP2	515731	0		99999999		
Whitney Reservoir (CORWHT) with Storage Capacity of 199,076 acre-feet						
FILLWHT	515731	0	WHIT1	99999999		Brazos River Authority
EVAP3	515731	0		99999999		Brazos River Authority
Aquilla Reservoir on Aquilla Creek with Storage Capacity of 52,400 acre-feet						
C5158_1	515831	12,246	MUN2	19761025		Brazos River Authority
C5158_2	515831	1,650	MUN2	19761025	106301	Brazos River Authority
C5158_3	515831	0	IND2	19761025		Brazos River Authority
C5158_4	515831	0	MIN2	19761025		Brazos River Authority
C5158_5	515831	0	UNIFO2	19761025		Brazos River Authority
Waco Reservoir (LKWACO)on Bosque River with Storage Capacity of 39,100 acre-feet						
C2315_1	509431	39,100	MUN2	19290110	110711	City of Waco
C2315_4	509431	0		99999999		City of Waco
Waco Reservoir (WACO2) with Storage Capacity of 65,000 acre-feet						
C2315_2	509431	19,100	MUN2	19580416	110711	City of Waco
C2315_3	509431	900	IRR21	19790221		City of Waco
C2315_5	509431	0		99999999		
Waco Reservoir (WACO4) with Storage Capacity of 88,062 acre-feet						
P5094_1	509431	20,089	MUN2	19860912	110711	City of Waco
P5094_2	509431	688	MUN2	19880121	110711	City of Waco
P5094_4	509431	0		99999999		
Waco Reservoir (WACO5) with Storage Capacity of 14,400 acre-feet						
P5094_3	509431	0		88888888		City of Waco
P5094_3	509431	0		99999999		City of Waco
Proctor Reservoir on Leon River with Storage Capacity of 59,400 acre-feet						
C5159_1	515931	2,685	MUN2	19631216		Brazos River Authority
C5159_2	515931	735	MUN2	19631216		Brazos River Authority
C5159_3	515931	1,147	MUN2	19631216		Brazos River Authority
C5159_4	515931	1,772	MUN2	19631216		Brazos River Authority
C5159_5	15931	1,671	MUN2	19631216		Brazos River Authority
C5159_6	515931	0	IND2	19631216		Brazos River Authority
C5159_7	515931	5,948	IRR2	19631216		Brazos River Authority
C5159_8	515931	5,700	IRR2	19631216		Brazos River Authority
C5159_9	515931	0	MIN2	19631216		Brazos River Authority
C5159_10	515931	0	INIFO2	19631216		Brazos River Authority
Belton Reservoir (BELTON) on Leon River with Storage Capacity of 10,000 acre-feet						
C2936_1	516031	10,000	MUN2	19530824		US Department of Army
Belton Reservoir (BELTON) with Storage Capacity of 12,000 acre-feet						
C2936_2	516031	2,000	MUN2	19540823		US Department of Army

Table 3.11 (Continued)

Water Right	Control Point	Diversion (ac-ft/yr)	Use Type	Priority	Return Flow CP	Permit Holder
Belton Reservoir (BELTON) with Storage Capacity of 457,600 acre-feet						
C5160_1	516031	7,056	MUN2	19631216	102191	Brazos River Authority
C5160_2	516031	1,245	MUN2	19631216		Brazos River Authority
C5160_3	516031	3,432	MUN2	19631216	101761	Brazos River Authority
C5160_4	516031	2,016	MUN2	19631216	101741	Brazos River Authority
C5160_5	516031	27,735	MUN2	19631216	103513	Brazos River Authority
C5160_6	516031	7,745	MUN2	19631216	103512	Brazos River Authority
C5160_7	516031	540	MUN2	19631216		Brazos River Authority
C5160_8	516031	1,758	MUN2	19631216	100451	Brazos River Authority
C5160_9	516031	4,549	MUN2	19631216	100455	Brazos River Authority
C5160_10	516031	1,758	MUN2	19631216	100451	Brazos River Authority
C5160_11	516031	5,424	MUN2	19631216	101551	Brazos River Authority
C5160_12	516031	17,484	MUN2	19631216	113181	Brazos River Authority
C5160_13	516031	10,469	MUN2	19631216	104702	Brazos River Authority
C5160_14	516031	5,411	MUN2	19631216		Brazos River Authority
C5160_15	516031	200	MUN2	19631216		Brazos River Authority
C5160_16	516031	2,365	IND2	19631216		Brazos River Authority
C5160_17	516031	1,070	IRR2	19631216		Brazos River Authority
C5160_18	516031	0	MIN2	19631216		Brazos River Authority
C5160_19	516031	0	UNIFO2	19631216		Brazos River Authority
Stillhouse Hollow Reservoir (STLHSE) on Lampases River with Storage Capacity of 235,700 acre-feet						
C5161_1	516131	6,973	MUN3	19631216	102051	Brazos River Authority
C5161_2	516131	2,092	MUN3	19631216		Brazos River Authority
C5161_3	516131	4,880	MUN3	19631216		Brazos River Authority
C5161_4	516131	53,823	MUN3	19631216		Brazos River Authority
C5161_5	516131	0	IND3	19631216		Brazos River Authority
C5161_6	516131	0	MIN3	19631216		Brazos River Authority
C5161_7	516131	0	IRR3	19631216		Brazos River Authority
Georgetown Reservoir (GRGTWN) on NF San Gabriel River with Storage Capacity of 37,100 acre-feet						
C5162_1	516231	4,764	MUN3	19680212	104893	Brazos River Authority
C5162_2	516231	2,041	MUN3	19680212	104892	Brazos River Authority
C5162_3	516231	3,198	MUN3	19680212	102641	Brazos River Authority
C5162_4	516231	3,607	MUN3	19680212	102642	Brazos River Authority
C5162_5	516231	0	IND3	19680212		Brazos River Authority
C5162_6	516231	0	MIN3	19680212		Brazos River Authority
C5162_7	516231	0	IRR3	19680212		Brazos River Authority
Granger Reservoir (GRNGER) on San Gabriel River with Storage Capacity of 65,500 acre-feet						
C5163_1	516331	6,566	MUN3	19680212		Brazos River Authority
C5163_2	516331	6,721	MUN3	19680212	102991	Brazos River Authority
C5163_3	516331	5,659	IND3	19680212		Brazos River Authority
C5163_4	516331	0	IND3	19680212		Brazos River Authority
C5163_5	516331	20	MIN3	19680212		Brazos River Authority
C5163_6	516331	874	IRR3	19680212		Brazos River Authority

Table 3.11 (Continued)

Water Right	Control Point	Diversion (ac-ft/yr)	Use Type	Priority	Return Flow CP	Permit Holder
Limestone Reservoir (LMSTNE) on Navasota River with Storage Capacity of 217,494 acre-feet						
C5165_1	516531	28,415	MUN3	19740506		Brazos River Authority
C5165_2	516531	200	MUN3	19740506		Brazos River Authority
C5165_3	516531	21,602	IND3	19740506		Brazos River Authority
C5165_4	516531	11,255	IND3	19740506		Brazos River Authority
C5165_5	516531	3,600	IND3	19740506		Brazos River Authority
C5165_6	516531	0	IRR3	19740506		Brazos River Authority
C5165_7	516531	2	MIN3	19740506		Brazos River Authority
C5165_8	516531	0	UNIFO	19790904		Brazos River Authority
Somerville Reservoir (SMRVLE) on Yequa Creek with Storage Capacity of 160,110 acre-feet						
C5164_1	516431	4,619	MUN3	19631216	103881	Brazos River Authority
C5164_2	516431	6,658	IND3	19631216		Brazos River Authority
C5164_3	516431	23,763	IND3	19631216		Brazos River Authority
C5164_4	516431	0	IRR3	19631216		Brazos River Authority
C5164_5	516431	12,928	IRR3	19631216		Brazos River Authority
C5164_6	516431	32	MIN3	19631216		Brazos River Authority
C5164_7	516431	0	UNIFO	19631216		Brazos River Authority
Proposed Allens Creek Reservoir (ALLENS) with Storage Capacity of 145,533 acre-feet						
ALLENS_1	292531	99,650	MUN4	19990901		Brazos River Authority
Alan Henry Reservoir (ALANHN) on Double Mountain Fork with Storage Capacity of 115,937 acre-feet						
P4146_1	4146P1	35,000	MUN1	19811005		City of Lubbock
P4146_2	4146P1	0	IRR1	19811005		City of Lubbock
P4146_3	4146P1	0	IND1	19811005		City of Lubbock
Hubbard Creek Reservoir (HUBBRD) on Hubbard Creek with Storage Capacity of 317,750 acre-feet						
C4213_1	421331	21,008	MUN1	19570528		West Central Texas MWD
C4213_2	421331	17,362	MUN1	19570528	103341	West Central Texas MWD
C4213_3	421331	1,882	MUN1	19570528		West Central Texas MWD
C4213_4	421331	2,061	MUN1	19570528		West Central Texas MWD
C4213_5	421331	2,487	MUN1	19570528	100401	West Central Texas MWD
C4213_6	421331	2,000	D&L1	19720814		West Central Texas MWD
C4213_7	421331	1,200	IND1	19570528		West Central Texas MWD
C4213_8	421331	6,000	MIN1	19570528		West Central Texas MWD
C4213_9	421331	2,000	IRR1	19720814		West Central Texas MWD
Squaw Creek Reservoir (SQWCRK) on Squaw Creek with Storage Capacity of 151,500 acre-feet						
C4097_1	409732	23,180	IND2	19730425		Texas Utilities Electric Co

CHAPTER IV

EXTENSION OF THE BRAZOS WAM SIMULATION PERIOD

4.1 FORWARD EXTENSION OF THE HYDROLOGIC PERIOD-OF-ANALYSIS

The procedures outlined in Chapter II are applied to the Brazos WAM dataset described in Chapter III to extend the period-of-analysis by ten years as described in the present section 4.1 in Chapter IV. The January 1940 to December 1997 simulation period is extend through January 1940 to December 2007. Sequences of monthly naturalized flows at 77 primary control points are developed for 1998-2007. Reservoir surface evaporation less precipitation depths for 1998-2007 are compiled for 67 control points.

Actual observed flows were compiled at 48 of the 77 primary control points. Naturalized monthly flows for 1998-2007 were developed at these 48 control points by adjusting gaged flows. 1998-2007 naturalized flows were developed at the 29 other primary control points by applying flows distribution method to the naturalized flows developed for the 48 control points.

4.1.1 Procedure for Extending the Hydrologic Period-of-Analysis

This chapter describes data compilation and computational methods for developing 1998-2007 sets of evaporation-precipitation depths at 67 control points and naturalized stream flows at 77 control points. Updating of the Brazos WAM hydrology dataset consisted of the following tasks:

1. Compilation of evaporation-precipitation depths for the 120 months of 1998-2007 for the 67 control points included in the EVA file.

2. Compilation and manipulation of available stream flow data at 48 USGS gaging stations (including reservoir releases representing flows at one site) to develop complete 1998-2007 sequences of actual monthly flows.

3. Development of a methodology and parameters for distributing naturalized flows to the original 29 primary control points that have no gaged flow data for 1998-2007.
4. Creation of an actual use Bwam8A DAT file by modifying the current use Bwam8 DAT file to better approximate actual water management and use during 1998-2007:

   - The upstream-to-downstream natural priority option was activated. With this option, flows are diverted for water supply and reservoir storage is refilled without regard to seniority specified in the water right permits.
   - Negative incremental flow option 4 was activated rather than option 5.
   - Beginning of January 1998 storage volumes were assigned based on observed storage contents for the 22 largest reservoirs and simulated volumes for the numerous small reservoirs.
   - End-of-month actual storage volumes for the 120 months of the 1998-2007 period-of-analysis were compiled for the largest 22 reservoirs. Water rights data and related data in the DAT file were modified to reproduce the observed storage volumes in the *SIM* simulation.
   - Brazos River Authority water supply diversions were adjusted to reflect system operations.

5. Computation of an initial set of 1998-2007 naturalized flows for the 48 control points based on an adopted 75 percent exceedance frequency using program *HYD*.

6. Iterative development of improved sets of 1998-2007 naturalized flows. Storage and diversion shortages were included in the flow adjustment (Equation 2.1 and 2.2) in early iterations and omitted in later iterations (equation 2.3). Improved sets of naturalized flows at 3,834 control points were repeatedly computed based on the preceding estimate of naturalized flows at 48 control points being recorded in the SIM FLO file. The procedure was iteratively repeated until computed regulated flow matched gaged flows:

   - *SIM* was executed with the 1998-2007 input dataset consisting of the EVA file from Task 1, FLO file from Task 5, and DAT file developed in Task 4, and DIS file with parameters for distributing flows to ungaged control points.

- Naturalized flows are distributed within SIM to control points that have no gaged data for 1998-2007 based on known flows at 48 control points.
- Flow adjustments were computed with program *HYD* as naturalized flows minus regulated flows combined with shortages in reaching observed reservoir storage levels and meeting diversion targets at the 22 largest reservoirs. Iterations were also performed without adjusting for shortages.
- Naturalized flows at 48 control points were computed with program *HYD* by adjusting observed flows. The resulting flows replaced the previously estimated naturalized flows in the SIM input FLO file.

4.1.2 Net Evaporation-Precipitation Depths

The Brazos WAM dataset includes sequences of monthly net evaporation less precipitation depths in feet/month recorded on *EV* records stored in a file with filename extension EVA for January 1940 through December 1997 at the 67 control points listed in Table 4.1. The net evaporation-precipitation rates represent reservoir water surface evaporation losses minus precipitation falling directly on the reservoir water surface. The task addressed in this section is to update the *WRAP-SIM* EVA input data file by extending the sequences by ten years to cover the period from January 1940 through December 2007.

Net evaporation-precipitation depths are provided in the EVA file for the 67 control points listed in Table 4.1. The first twenty control points identifiers listed in Table 4.1 represent the quadrangles delineated in Figure 4.1. Multiple smaller reservoirs are assigned the evaporation-precipitation rates recorded in the EVA file with these twenty control point identifiers. The 47 other control points listed in Table 4.1 represent individual major reservoirs.

Reservoirs are assigned a set of net evaporation-precipitation depths in one of two ways. All reservoirs in a WAM dataset are assigned a control point location. For the 47 reservoirs listed in Table 4.1, the control points assigned to identify the evaporation-precipitation sequences are the control points of the reservoirs. For the numerous other reservoirs in the dataset located at other control points, the *CP* record for each of their control points references one of the 67 control points in listed in Table 4.1 as the source for their evaporation-precipitation depths.

The Texas Water Development Board (TWDB) maintains a database of monthly reservoir surface gross evaporation depths and a database of precipitation depths for the entire state by quadrangles of one-degree latitude and longitude. Figure 4.1 is a map showing the quadrangles that cover the Brazos River Basin. The TWDB data are currently available only through December 2004. Monthly evaporation and precipitation rates were obtained from the TWDB databases for the period from January 1998 through December 2004. Net evaporation less precipitation rates were computed by subtracting precipitation from evaporation. 1940-2004 mean net evaporation less precipitation depths for each of the 12 months of the year were adopted for 2005, 2006, and 2007.

A weighted average for adjoining quadrangles was applied for reservoir sites extending into more than one quadrangle. The equations shown in Table 4.2 are used for 39 of the reservoirs that have water surfaces located in two or four adjacent quadrangles. These equations assign net evaporation-precipitation depths to these 39 reservoirs as a weighted-average of net evaporation-precipitation depths for the quadrangles. The other eight reservoirs listed in Table 4.1 are each assigned only one quadrangle for 1998-2007 net evaporation-precipitation depths as follows: Allen Creek (811), Brazoria (812), Bryan Utilities (711), Eagle Nest (812), Marlin (611), Post (406), Sandow (710), and William Harris (812).

The Brazos WAM dataset was developed during 1997-2001 by HDR Engineering, Inc. under contract with the TCEQ (HDR 2001a and 2001b). The equations in Table 4.2 are from the original HDR report. The original Brazos WAM 1940-1997 dataset is based largely upon the TWDB evaporation and precipitation databases that were used again for the 1998-2007 extension. The 1940-1997 dataset also contains some evaporation-precipitation data from weather stations located near several of the larger reservoirs obtained from the National Climatic Data Center (NCDC). The NCDC database was investigated but not actually used for the 1998-2007 extension.

Comparison of Mean Evaporation-Precipitation Depths

Net reservoir surface evaporation less precipitation rates were compiled for the 120 months of January 1998 through December 2007 for the 67 control point locations listed in Table 4.1. Monthly evaporation depths and precipitation depths were obtained from the Texas Water Development Board databases for 1998-2004. However, the TWDB has not yet updated the databases with data extending past 2004. Thus, 1940-2004 mean net evaporation less precipitation depths for each of the 12 months of the year were adopted for 2005, 2006, and 2007.

The 1998-2007 means are compared with the 1940-1997 means of the evaporation-precipitation rates from the original Brazos WAM dataset in Table 4.1. In most cases, the mean net depths are positive with mean evaporation exceeding mean precipitation. Quadrangles 812 and 813 covering the lower reach of the Brazos River Basin and the adjoining Brazos-San Jacinto Coastal Basin have negative net evaporation-precipitation depths indicating that mean precipitation exceeds mean reservoir surface evaporation.

The 1998-2007 means are expressed as a percentage of the 1940-1997 means in the last column of Table 4.1. Differences between 1998-2007 mean depths and 1940-1997 mean depths vary significantly between individual quadrangles or reservoirs. Precipitation varies more than evaporation. The mean net evaporation-precipitation depths for each of the 20 quadrangles covering the Brazos River Basin and Brazos-San Jacinto Coastal Basin (Figure 4.1) are tabulated in the first twenty lines of Table 4.1. The arithmetic average of the means for the 20 quadrangles is 29.0 inches/year for 1940-1997 and 30.2 inches/year for 1998-2007. Thus, the net evaporation-precipitation depths adopted for 1998-2007 are on average about 4.1 percent higher than the 1940-1997 means.

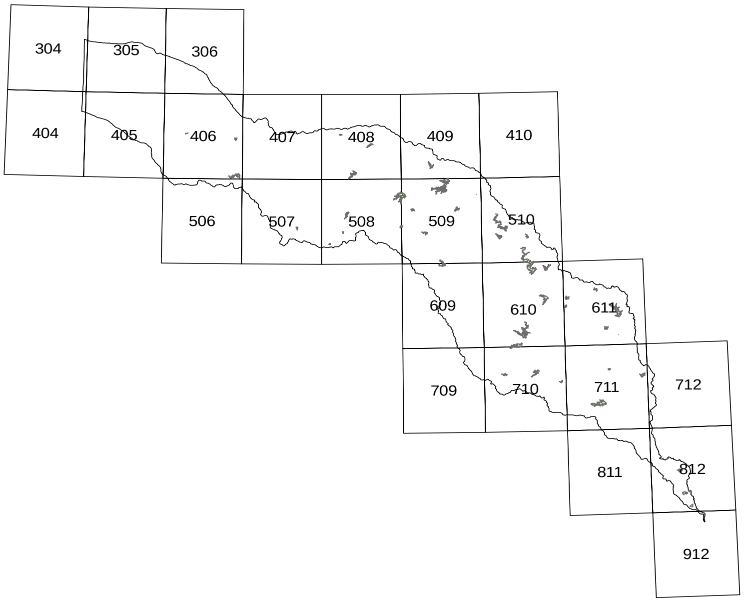

Figure 4.1 Quadrangles for TWDB Evaporation and Precipitation Data

Table 4.1 Means of Net Evaporation-Precipitation Depths

Control Point	Quadrangle or Major Reservoir	Mean Rate in feet/month		1998-2007 as Percent of 40-97
		1940-1997	1998-2007	
366631	305	0.3216	0.3513	109.3
368131	306	0.312	0.3625	116.2
370431	405	0.3216	0.362	112.6
368931	406	0.3053	0.3797	124.4
341131	407	0.3184	0.3626	113.9
341331	408	0.2815	0.28	99.5
344801	409	0.2262	0.2329	103
371431	506	0.3411	0.3703	108.6
372031	507	0.3022	0.3054	101.1
413331	508	0.2785	0.2629	94.4
220131	509	0.2364	0.2167	91.7
227031	510	0.1912	0.1573	82.3
225331	609	0.0308	0.143	463.8
228731	610	0.1818	0.1346	74
406331	611	0.1422	0.1165	82
299231	710	0.1519	0.1133	74.6
375931	711	0.0888	0.0804	90.5
531531	712	0.0131	0.0225	171.4
401041	812	-0.0047	-0.021	444.1
516841	813	-0.0144	-0.0429	297.9
414231	Abilene	0.2985	0.2892	96.9
4146P1	Alan Henry	0.3109	0.3302	106.2
527231	Alcoa	0.1354	0.1068	78.8
292531	Allen Creek	0.0392	0.0233	59.4
515831	Aquilla	0.1658	0.1317	79.4
293631	Belton	0.1437	0.1348	93.8
532842	Brazoria	0.0512	-0.006	-11.8
526831	Bryan Utilities	0.1011	0.0837	82.8
370631	Buffalo Springs	0.3104	0.372	119.8
530131	Camp Creek	0.0848	0.0764	90.1
421131	Cisco	0.1945	0.2148	110.4
421431	Daniel	0.2521	0.2402	95.3
344031	Davis	0.2913	0.302	103.7
549231	Eagle Nest	0.032	-0.0111	-34.8
416131	Fort Phantom Hill	0.2866	0.2822	98.5
516231	Georgetown	0.1243	0.1258	101.2
531131	Gibbons Creek	0.0673	0.0637	94.6
345831	Graham	0.2473	0.2427	98.1
515631	Granbury	0.1808	0.1644	90.9

Table 4.1 (continued)

Control Point	Quadrangle or Major Reservoir	Mean Rate in feet/month 1940-1997	 1998-2007	1998-2007 as Percent of 40-97
516331	Granger	0.1432	0.111	77.5
421331	Hubbard Creek	0.2557	0.246	96.2
415031	Kirby	0.2924	0.281	96.1
434531	Lake Creek	0.1611	0.1252	77.7
347031	Leon	0.2235	0.2267	101.4
516531	Limestone	0.1109	0.0948	85.5
435533	Marlin City	0.1455	0.1174	80.7
528731	Mexia	0.148	0.1202	81.2
344431	Millers Creek	0.2709	0.2677	98.8
403931	Mineral Wells	0.2047	0.192	93.8
403131	Lake Palo Pinto	0.2183	0.203	93
410631	Pat Cleburne	0.1751	0.1419	81
515531	Possum Kingdom	0.2324	0.223	95.9
371131	Post	0.4469	0.4177	93.4
515931	Proctor	0.1734	0.1907	110
554032	Sandow Surface Mine	0.1354	0.1089	80.4
532531	Smithers	0.0043	-0.0139	-321.2
516431	Somerville	0.0787	0.0731	92.9
409731	Squaw Creek	0.1768	0.1645	93
417931	Stamford	0.2911	0.2949	101.3
516131	Stillhouse Hollow	0.1382	0.1332	96.4
413031	Sweetwater	0.3014	0.2985	99
432431	Tradinghouse Creek	0.1611	0.1252	77.7
529831	Twin Oaks	0.1274	0.1066	83.6
231531	Waco	0.1709	0.1315	76.9
369331	White River	0.3106	0.3726	120
515731	Whitney	0.1709	0.1344	78.6
532841	William Harris	0.0294	0.0207	70.2

Table 4.2 Equation Developed by HDR for Averaging Net Evaporation-Precipitation Depths for Major Reservoirs in Multiple Quadrangles

	Reservoir	Quadrangle Interpolation Equation
1	White River	0.589*(406)+0.411*(407)
2	Buffalo Springs	0.097*(305)+0.115*(306)+0.170*(405)+0.618*(406)
3	Alan Henry	0.097*(406)+0.115*(407)+0.170*(506)+0.618*(507)
4	Davis	0.267*(407)+0.733*(408)
5	Sweetwater	0.633*(507)+0.158*(508)+0.114*(607)+0.094*(608)
6	Abilene	0.277*(507)+0.364*(508)+0.175*(607)+0.184*(608)
7	Kirby	0.193*(507)+0.550*(508)+0.116*(607)+0.141*(608)
8	Fort Phantom Hill	0.103*(407)+0.126*(408)+0.168*(507)+0.602*(508)
9	Stamford	0.188*(407)+0.339*(408)+0.176*(507)+0.297*(508)
10	Cisco	0.188*(407)+0.339*(408)+0.176*(507)+0.297*(508)
11	Hubbard	0.194*(408)+0.194*(409)+0.299*(508)+0.313*(509)
12	Daniel	0.142*(408)+0.158*(409)+0.255*(508)+0.446*(509)
13	Millers Creek	0.707*(408)+0.118*(409)+0.098*(508)+0.076*(509)
14	Graham	0.193*(408)+0.410*(409)+0.159*(508)+0.237*(509)
15	Possum Kingdom	0.386*(409)+0.614*(509)
16	Palo Pinto	0.137*(409)+0.108*(410)+0.586*(509)+0.170*(510)
17	Mineral Wells	0.206*(409)+0.195*(410)+0.312*(509)+0.287*(510)
18	Squaw Creek	0.218*(509)+0.468*(510)+0.142*(609)+0.173*(610)
19	Granbury	0.199*(509)+0.556*(510)+0.112*(609)+0.132*(610)
20	Pat Cleburne	0.577*(510)+0.154*(511)+0.157*(610)+0.112*(611)
21	Whitney	0.296*(510)+0.169*(511)+0.355*(610)+0.180*(611)
22	Aquilla	0.262*(510)+0.196*(511)+0.321*(610)+0.221*(611)
23	Waco	0.138*(510)+0.119*(511)+0.528*(610)+0.215*(611)
24	Tradinghouse	0.480*(610)+0.520*(611)
25	Lake Creek	0.480*(610)+0.520*(611)
26	Leon	0.266*(508)+0.42*(509)+0.15*(608)+0.165*(609)
27	Proctor	0.511*(509)+0.489*(609)
28	Belton	0.171*(609)+0.421*(610)+0.151*(709)+0.257*(710)
29	Stillhouse Hollow	0.175*(609)+0.329*(610)+0.168*(709)+0.329*(710)
30	Georgetown	0.128*(609)+0.158*(610)+0.200*(709)+0.514*(710)
31	Granger	0.157*(610)+0.117*(611)+0.557*(710)+0.169*(711)
32	Alcoa	0.153*(610)+0.146*(611)+0.391*(710)+0.309*(711)
33	Somerville	0.150*(710)+0.592*(711)+0.108*(811)+0.150*(811)
34	Mexia	0.064*(510)+0.086*(511)+0.094*(610)+0.755*(611)
35	Limestone	0.655*(611)+0.143*(612)+0.113*(711)+0.089*(712)
36	Twin Oaks	0.724*(611)+0.276*(711)
37	Camp Creek	0.338*(611)+0.197*(612)+0.284*(711)+0.182*(712)
38	Gibbons Creek	0.168*(611)+0.162*(612)+0.359*(711)+0.310*(712)
39	Smithers	0.144*(811)+0.856*(812)

4.1.3 Stream Flows at 77 Primary Control Points

The Brazos WAM dataset includes sequences of naturalized monthly stream flow volumes recorded on *IN* records stored in a file with filename extension FLO for January 1940 through December 1997 at 77 control points. The task addressed here is to extend these flow sequences ten years to cover the period from January 1940 through December 2007. The 77 primary control points are listed in Tables 3.2 and 4.3 and shown in the map of Figure 3.3 and schematic of Figure 4.2. The extended 1998-2007 sequences of naturalized flows were developed for each of the 77 control points in one of the following ways:

- Naturalized flows were computed by adjusting 1998-2007 observed gaged flows as outlined in the next section 4.1.4 if measured flow data are available. This approach was applied to the 48 control points shown in bold face type in Figure 4.2. The last column of Table 4.3 indicates that observed flows are adopted directly from the USGS database for 41 sites and certain adjustments are required for seven other sites.
- Naturalized flows for 1998-2007 for each of the remaining 29 control points listed in Table 4.3 for which gaged flows are not available are computed based on the naturalized flows at one or more of the 48 control points for which gaged flows are available. The distribution of flows to these 29 control points is based on ratios of 1940-1997 mean naturalized flows at pertinent control points.

Primary control points are the sites for which naturalized flows are included in a *SIM* simulation input file. The 77 primary control points listed in Table 4.3 were selected during development of the original Brazos WAM model by HDR Engineering, Inc. during 1997-2001 under contract with the TCEQ. Four of the primary control points are in the Jan Jacinto-Brazos Coastal Basin, and the other 73 control points are in the Brazos River Basin. The WRAP control point identifier in the first column of Table 4.3 consists of four letters referring to the stream and nearest town followed by the integers 1-73 for the Brazos Basin and 1-4 for the coastal basin.

All but the following five primary control points are at USGS stream gaging stations that were in operation during all or portions of 1940-1997:

- Control point BRGM73 represents the outlet of the Brazos River at the Gulf of Mexico.
- Control points SJGBC3 and SJGMC4 represent outlets of the San Jacinto-Brazos Coastal Basin into Galveston Bay and the Gulf of Mexico.
- Control points BSLU07 and GHGH24 are located at Buffalo Spring Lake and Lake Graham, respectively. The 1940-1997 flow data at these two sites are releases from the reservoirs. The release data were provided to HDR by the reservoir operators.

The other 72 primary control points are USGS gaging stations. However, a number of these gaging stations are no longer in operation. Only 20 of the 77 primary control points listed in Table 4.3 are stream gaging stations with periods-of-record that span the entire WAM 1940-1997 period-of-analysis. Flows for the months during 1940-1997 with missing observed data were synthesized by HDR based on regression with flows at other gaging stations. The period-of-record for 17 of the stream gaging stations end before 1997. Others with periods-of-record extending past 1997 could not be used in the present hydrology update investigation because of missing data in most of the months during 1998-2007.

4.1.4 Compilation of 1998-2007 Actual Flows at 48 Gaged Control Points

The U.S. Geological Survey (USGS) routinely measures stream stage in feet and converts the stage to flows in ft^3/s. Mean daily stage and flow are recorded in the USGS National Water Information System (NWIS) which is accessible through the internet. Monthly flow volumes computed by aggregating daily flows are also sometimes provided in the NWIS. Some USGS gaging stations have complete data records with few if any periods of missing data. Some stations have been discontinued with an official ending date for the period-of-record. Other stations are still listed as operational but have multiple-year periods with no data including most or all of 1998-2007.

Table 4.3 Availability of 1998-2007 Gaged Flows

Control Point	River or Stream	Nearest City	USGS Gage No.	USGS Period of Record	1998-2007 Availability
RWPL01	Running Water Draw	Plainview	08080700	1939–present	adjusted (1)
WRSP02	White River Reservoir	Spur	08080910	1964-1976	missing
DUGI03	Duck Creek	Girard	08080950	1964-1989	missing
SFPE04	Salt Fork Brazos River	Peacock	08081000	1950–1986	missing
CRJA05	Croton Creek	Jayton	08081200	1959–1986	missing
SFAS06	Salt Fork Brazos River	Aspermont	08082000	1924–present	observed (1)
BSLU07	Buffalo Spring Lake	Lubbock	reservoir releases		not a gage
DMJU08	Double Mountain Fork	Justiceburg	08079600	1961–present	observed (2)
DMAS09	Double Mountain Fork	Aspermont	08080500	1923–present	observed (3)
NCKN10	North Croton Creek	Knox City	08082180	1965–1986	missing
BRSE11	Brazos River	Seymour	08082500	1923–present	observed (4)
MSMN12	Millers Creek	Munday	08082700	1963–present	observed (5)
CFRO13	Clear Fork Brazos	Roby	08083100	1962–present	observed (6)
CFHA14	Clear Fork Brazos	Hawley	08083240	1967–1989	missing
MUHA15	Mulberry Creek	Hawley	08083245	1967–1989	missing
CFNU16	Clear Fork Brazos	Nugent	08084000	1924–present	observed (7)
CAST17	California Creek	Stamford	08084800	1962–present	observed (8)
CFFG18	Clear Fork Brazos	Fort Griffin	08085500	1924–present	observed (9)
HCAL19	Hubbard Creek	Albany	08086212	1966–present	observed (10)
BSBR20	Big Sandy Creek	Breckenridge	08086290	1962–present	observed (11)
HCBR21	Hubbard Creek	Breckenridge	08086500	1955–1986	missing
CFEL22	Clear Fork Brazos	Eliasville	08087300	1915–1982	missing
BRSB23	Brazos River	South Bend	08088000	1938–present	observed (12)
GHGH24	Lake Graham	Graham	reservoir releases		not a gage
CCIV25	Big Cedar Creek	Ivan	08088450	1964–1989	missing
SHGR26	Brazos River	Graford	08088600	1976–1994	missing
BRPP27	Brazos River	Palo Pinto	08089000	1924–present	observed (13)
PPSA28	Palo Pinto Creek	Santo	08090500	1924–1976	missing
BRDE29	Brazos River	Dennis	08090800	1968–present	observed (14)
BRGR30	Brazos River	Glen Rose	08091000	1923–present	observed (15)
PAGR31	Paluxy River	Glen Rose	08091500	1924–present	observed (16)
NRBL32	Nolan River	Blum	08092000	1947–present	missing
BRAQ33	Brazos River	Aquilla	08093100	1938–present	observed (17)
AQAQ34	Aquilla Creek	Aquilla	08093500	1939–2001	adjusted (2)
NBHI35	North Bosque River	Hico	08094800	1994–2003	missing
NBCL36	North Bosque River	Clifton	08095000	1923–2008	observed (18)
NBVM37	North Bosque River	Valley Mills	08095200	1959–present	observed (19)
MBMG38	Middle Bosque River	McGregor	08095300	1959–present	missing

Table 4.3 (continued)

Control Point	River or Stream	Nearest City	USGS Gage No.	Period-of Record	1998-2007 Availability
HGCR39	Hog Creek	Crawford	08095400	1959–present	missing
BOWA40	Bosque River	Waco	08095600	1959–1982	missing
BRWA41	Brazos River	Waco	08096500	1898–present	observed (20)
BRHB42	Brazos River	Highbank	08098290	1965–present	observed (21)
LEDL43	Leon River	De Leon	08099100	1960–present	missing
SADL44	Sabana River	De Leon	08099300	1960–present	adjusted (3)
LEHS45	Leon River	Hasse	08099500	1939–present	reservoir release
LEHM46	Leon River	Hamilton	08100000	1925–present	missing
LEGT47	Leon River	Gatesville	08100500	1950–present	observed (22)
COPI48	Cowhouse Creek	Pidcoke	08101000	1950–present	observed (23)
LEBE49	Leon River	Belton	08102500	1923–present	observed (24)
LAKE50	Lampasas River	Kempner	08103800	1962–present	observed (25)
LAYO51	Lampasas River	Youngsport	08104000	1924–1980	missing
LABE52	Lampasas River	Belton	08104100	1963–present	adjusted (4)
LRLR53	Little River	Little River	08104500	1923–present	observed (26)
NGGE54	North Fork San Gabriel	Georgetown	08104700	1968–present	observed (27)
SGGE55	South Fork San Gabriel	Georgetown	08104900	1967–present	observed (28)
GAGE56	San Gabriel River	Georgetown	08105000	1924–1987	missing
GALA57	San Gabriel River	Laneport	08105700	1965–present	observed (29)
LRCA58	Little River	Cameron	08106500	1916–present	observed (30)
BRBR59	Brazos River	Bryan	08109000	1899–1993	adjusted (5)
MYDB60	Middle Yegua Creek	Dime Box	08109700	1962–present	observed (31)
EYDB61	East Yegua Creek	Dime Box	08109800	1962–present	observed (32)
YCSO62	Yegua Creek	Somerville	08110000	1924–1991	missing
DCLY63	Davidson Creek	Lyons	08110100	1962–present	observed (33)
NAGR64	Navasota River	Groesbeck	08110325	1978–present	observed (34)
BGFR65	Big Creek	Freestone	08110430	1978–present	observed (35)
NAEA66	Navasota River	Easterly	08110500	1924–present	observed (36)
NABR67	Navasota River	Bryan	08111000	1951–1997	adjusted (6)
BRHE68	Brazos River	Hempstead	08111500	1938–present	observed (37)
MCBL69	Mill Creek	Bellville	08111700	1963–1993	missing
BRRI70	Brazos River	Richmond	08114000	1903–present	observed (38)
BGNE71	Big Creek	Needville	08115000	1947–present	observed (39)
BRRO72	Brazos River	Rosharon	08116650	1967–present	observed (40)
BRGM73	Brazos River	Gulf of Mexico	outlet cp	–	not a gage
CLPEC1	Clear Creek	Pearland	08077000	1944–1994	missing
CBALC2	Chocolate Bayou	Alvin	08078000	1959–present	observed (41)
SJGBC3	Coastal Basin	Galveston Bay	outlet cp	–	not a gage
SJGMC4	Coastal Basin	Gulf of Mexico	outlet cp	–	not a gage

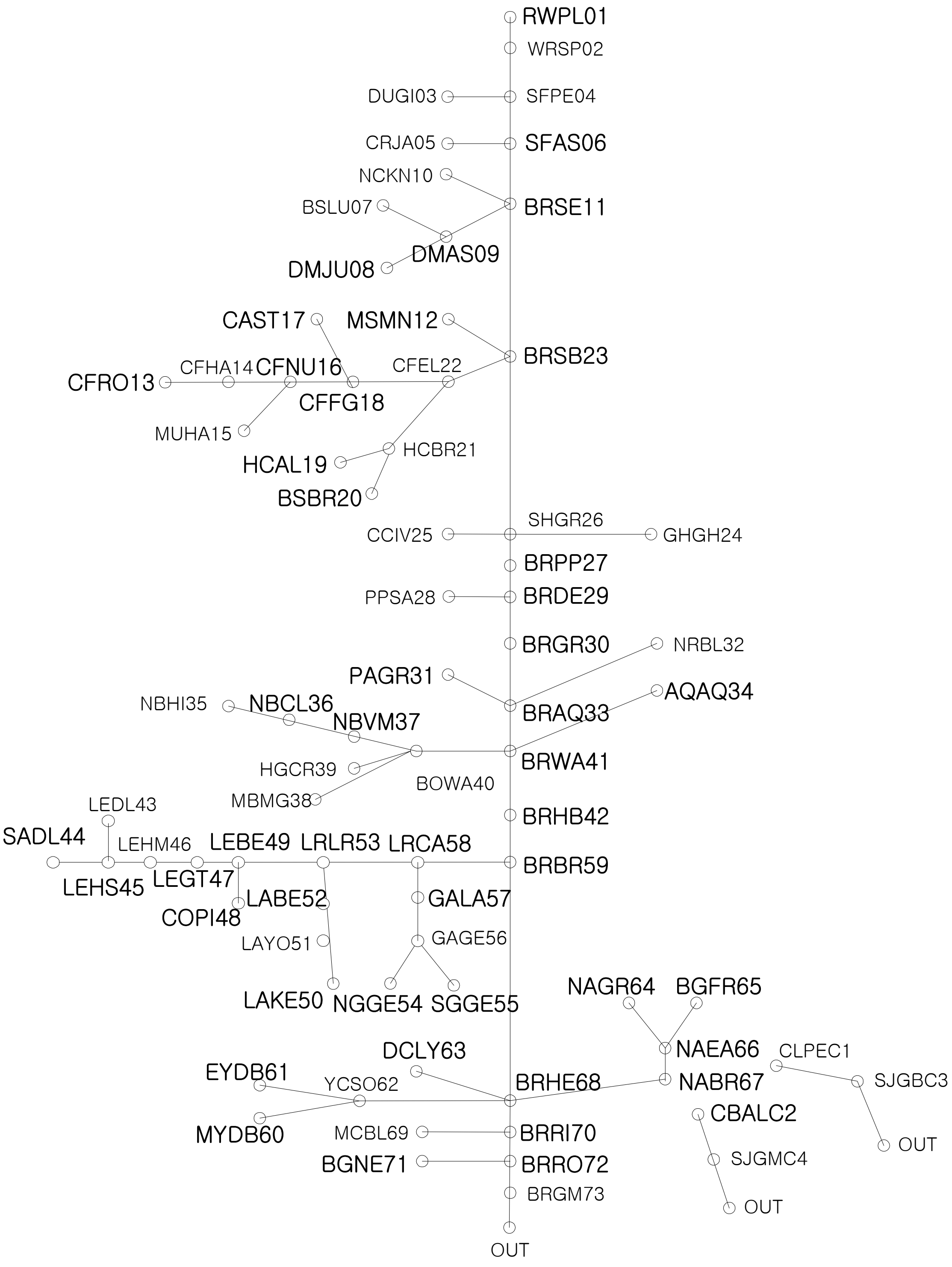

Figure 4.2 Schematic of Primary Control Points with 48 Control Points in Bold (Not to Scale)

The availability of actual observed flow data is indicated in the last column of Table 4.3. Seventy-two of the 77 control points are sites of USGS gaging stations, of which some are still operational today and others have been discontinued. The terms *observed*, *adjusted*, or *missing* is entered in the last column of Table 4.3 to categorize the availability of observed data from USGS gage measurements at each control point as follows:

observed − Mean daily measured flows in units of ft^3/s are available from the USGS NWIS for the 41 gaging stations categorized as *observed* in Table 4.3. The HEC-DSSVue computer program available from the USACE Hydrologic Engineering Center was used to retrieve these daily flows from the USGS database and aggregate them to monthly flow volumes in acre-feet/month for the period January 1998 through December 2007.

adjusted − The six control points listed as *adjusted* also have observed flow data covering all or most of 1998-2007. However, data adjustments were required to compile complete 1998-2007 sequences of monthly flow volumes. Methods adopted to compile flow data for each of these six control points are outlined below.

missing − Flow data are missing for all or most of 1998-2007 at 25 of the USGS gaging stations. Seventeen of the gaging stations have been terminated with their periods-of-record ending several years before 1997. The other eight gaging stations are still listed in the NWIS as operational but no data were collected during all or most of 1998-2007.

A set of actual 1998-2007 monthly flows were developed for 48 control points which include the 41 control points labeled *observed* in the last column of Table 4.3, the six control points labeled as being *adjusted*, and control point LEHS45 for which flows were determined as releases from Proctor Reservoir. Complete sets of 1998-2007 monthly flows were developed by summing daily flows downloaded with HEC-DSSVue from the USGS National Water Information System (NWIS) for the 41 control points labeled *observed*. Proctor Reservoir releases and adjustments of observed flows performed at the six other control points labeled *adjusted* are described below. Computation of naturalized flows at the 29 remaining control points labeled *missing* based on naturalized flows at one or more of the 48 control points are covered later.

Release from Proctor Reservoir

Control points LEHS45 located immediately downstream of Proctor Dam is the site of the former USGS streamflow gaging station on the Leon River near Hasse. Measured releases from Proctor Reservoir during 1998-2007 compiled by the Brazos River Authority were adopted at the gaged flows at control point LEHS45.

Control Points LEDL43, LEHS45 and LEHM46 are sites of discontinued USGS gaging stations on the Leon River above, immediately below, and further below Proctor Reservoir. These three former gaging stations have no measurements recorded during 1998-2007. Flows at LEHS45 were initially estimated based on flows at LEGT47 using the technique outlined later in this chapter. LEGT47 is an active USGS gage on the Leon River near Gatesville. As indicated in Table 3.2, the drainage areas of LEHS45 and LEGT47 are 1,283 and 2,379 square miles, respectively, reflecting a drainage area ratio of 0.539. WRAP-SIM simulated storage volumes for Proctor Reservoir for 1998-2007 were found to vary greatly from observed storage volume. Consequently, 1998-2007 release data for Proctor Reservoir were adopted as the gaged flows at LEHS45.

Observed Flow Data Adjustments at Six Control Points

Complete 1998-2007 records of observed daily flows are directly available without any adjustment other than aggregating daily mean flows to monthly volumes at 41 of the control points, as noted above. USGS gage measurements are also available for compiling flows at the following six other control points. However, extra manipulations were required in compiling the observed flows for these control points:

RWPL01	Running Water Draw near Plainview
SADL44	Sabana River near De Leon
AQAQ34	Aquilla Creek near Aquilla
LABE52	Lampasas River near Belton
BRBR59	Brazos River near Bryan
NABR67	Navasota River near Bryan

Control point RWPL01 on Running Water Draw near Plainview is at the extreme upper end of the Brazos River Basin. The watershed area is 1,291 square miles of which the USGS classifies only 382 square miles to be contributing drainage area. The region is flat and dry. Monthly flows at control point RWPL01 are typically small and are zero in many months. The USGS NWIS provides daily and aggregated monthly flows for most months from July 1939 through September 1978 and from October 2002 to the present. Observed gaged flows available for October 2002 through December 2007 were adopted for extending the Brazos WAM dataset. Period-of-record means for each of the 12 months of the year were adopted for January 1998 through September 2002. Adopting 12 monthly means for 1998-2002 for this particular control point is considered more accurate than transferring gaged or naturalized flows from other gaging stations.

Control point SADL44 on the Sabana River near De Leon has a drainage area of 264 square miles. The USGS NWIS provides daily and aggregated monthly flows for all months from September 1960 through September 1986 and from October 1999 to the present. Observed gaged flows available for October 1999 through December 2007 are adopted for the Brazos WAM dataset. January 1998 through September 1999 flows were synthesized based on flows at control point BSBR20 on Big Sandy Creek near Breckenridge which represents a nearby watershed with similar characteristics. The methodology for estimating 1998-1999 SADL44 actual flows consisted of multiplying BSBR20 gaged flows by 12 monthly ratios of 1940-1997 mean naturalized flows.

Control point AQAQ34 on Aquilla Creek near the town of Aquilla has a period-of-record of 1939 through May 2001. The January 1998 through May 2001 measured flows are adopted for extending the Brazos WAM dataset. Flows for June 2001 through December 2007 are synthesized as follows based on flows at the other two gaging stations listed below.

AQAQ34 on Aquilla Creek near Aquilla	08093500	DA = 308 square miles
Aquilla Creek just below Aquilla Dam	08093360	DA = 255 square miles
NAGR64 on Navasota River near Groesbeck	08110325	DA = 239 square miles

USGS gaging station 08093360 on Aquilla Creek is located just below Aquilla Reservoir and is not included in the 77 primary control points. Its period-of-record extends from 1982 to the present, but there are many months between 1982 and 2001 with missing data. The record is complete for June 2001 through December 2007. The June 2001 through December 2007 monthly actual flows at control point AQAQ34 were synthesized as the flows at gaging station 08093360 below Aquilla Dam plus the incremental flows from the 53 square mile (308 less 255 square miles) watershed between the dam and AQAQ34. The incremental flows were estimated based on applying the ratio of 1940-1997 naturalized flows to the June 2001 through December 2007 monthly actual gaged flows at control point NAGR64 on the Navasota River near Groesbeck.

Control point LABE52 on the Lampasas River near Belton has daily and monthly flows recorded in the USGS NWIS for October 1966 through September 1989 and May 1999 to the present. Observed gaged flows available for May 1999 through December 2007 are adopted for the Brazos WAM dataset. Actual observed flows for January 1998 through April 1999 were estimated as the difference in gaged flows at LRLR53 and LEBE49 less incremental flows determined by applying a drainage area ratio to gaged flows at LAKE50. The drainage area ratio is 0.448 computed by dividing 366 square miles by 817 square miles.

$$\text{LABE52} = \text{LRLR53} - \text{LEBE49} - (0.448)(\text{LAKE50})$$

LABE52	Lampasas River near Belton	DA = 1,321 square miles
LEBE49	Leon River at Belton	DA = 3,579 square miles
LRLR53	Little River at Little River	DA = 5,266 square miles
LAKE50	Lampasas River at Kempner	DA = 817 square miles

Control point BRBR59 is at USGS gaging station 08109000 on the Brazos River near Bryan which has a continuous record from October 1940 through September 1993 and a drainage area of 29,949 square miles. USGS gaging station 08108700 on the Brazos River at State Highway 21 near Bryan has a continuous record from August 1993 to the present and a drainage area of 29,483 square miles. The flows are identical at the two gaging stations for the two months of overlapping records (August and September 1993). The January 1997 through December 2007 flows at gaging station 08108700 were adopted for control point BRBR59.

Control point NABR67 is at USGS gaging station 08111000 on the Navasota River near Bryan which has a continuous record from October 1978 through March 1997 and a drainage area of 1,454 square miles. USGS gaging station 08110800 on the Navasota River at Old San Antonio Road near Bryan has a continuous record from April 1997 to the present and a drainage area of 1,287 square miles. Lake Limestone with a drainage area of 675 square miles is located upstream of these two gaging stations. The 1998-2007 monthly flows adopted for control point NABR67 consist of the flows at gaging station 08110800 multiplied by a drainage area ratio of 0.8851.

4.1.5 New Reservoir Storage Features Added to WRAP-SIM

A procedure for extending naturalized flow sequences is outlined generically in Chapter II and described again in the present section 4.1 from the perspective of application to the Brazos WAM. Conversion of gaged flows to naturalized flows by iterative execution of the simulation program *SIM* is a central thrust of the methodology. The features described below were added to *SIM* during June-July 2008 specifically to support this procedure. The basic idea is to reproduce actual observed reservoir storage levels in the *SIM* simulation. Two related new features were added to *SIM*:

1. Storage capacity limits varying in each month of the period-of-analysis can now be input on a set of observed storage *OS* records.
2. Storage capacities as governed by *WS*, *MS* and *OS* record limits are included in the *SIM* output file, allowing program *HYD* to tabulate shortages in reaching the storage limits.

OS records provide storage volumes for each individual month of the hydrologic period-of-analysis for a particular reservoir. In each month of the simulation, as each water right is considered in the priority sequence, the storage capacity of the reservoir is the lesser of the storage capacity specified for the water right on its *WS* record and the volume specified for the reservoir on its *OS* record. The reservoir is filled to the capacity defined by the *WR/WS* and *OS* records subject to being constrained to the amount of stream flow available for filling. The end-of-month storage volume contained in the reservoir is limited to not exceed its capacity. Excess storage is released as a spill which is cascaded downstream just as any other reservoir release. The *OS* record feature is explained in the last section of Chapter IV of the August 2008 *WRAP Reference Manual*.

Another related feature added to *SIM* consists of recording the storage capacity set by *WS*, *OS*, and *MS* records in the simulation results output file. The simulated storage volume has always been included in the *SIM* output file. Programs *HYD* and *TABLES* can now tabulate the shortage in reaching the storage capacity as the difference between the capacity and simulated storage volumes.

As discussed later in this section 4.1, in applying the methodology to the Brazos WAM, observed end-of-month storage contents for each of the 120 months of the 1998-2007 simulation are provided as *SIM* input on *OS* records in the DAT file for 22 large reservoirs. The objective is to reproduce observed storage contents in the *SIM* simulation. The *SIM* model attempts to reproduce the specified observed storage levels to the extent that available stream flow allows. Shortages in reaching the specified storage levels are incorporated in the *HYD* naturalized flow adjustments.

4.1.6 Creation of Actual Use Bwam8A Dataset from Bwam8 Dataset

The information contained in a *WRAP-SIM* water rights input file with filename extension DAT describes water resources development, allocation, management, and use. The filename root Bwam8A is adopted here for the Brazos dataset that models the actual water management and use that occurred during January 1998 through December 2007. This section outlines the development of a file with the filename Bwam8A.DAT by modifying the Brazos WAM current use scenario Bwam8.DAT file. The Bwam8A actual use DAT file is designed for application with FLO and EVA files with a hydrologic period-of-analysis of 1998-2007. This dataset is used as described later in this chapter to convert gaged flows to naturalized flows.

The Bwam8 current use scenario dataset already approximates recent conditions. Annual diversion targets for each individual water right are based on the greatest annual use reported for that right in any year during 1988-1997. Reservoir storage capacity is based upon estimated year 2000 sedimentation conditions. The modifications discussed here are designed to more closely represent actual water management and use during January 1998 through December 2007. Conversion of the Bwam8 current use DAT file to a Bwam8A actual use DAT file involved the following tasks:

- The beginning-of-simulation storage volume at the beginning of January 1998 was set for each of the 706 reservoirs. Observed storage contents were adopted for the 22 larger reservoirs containing 87.5 percent of the total storage capacity for which the data are available. Simulated storages were used for the 684 smaller reservoirs containing the remaining 12.5 percent of the total storage capacity for which measured storage data is not readily available.

- A dataset of observed end-of-month storage volumes for each of the 120 months of 1998-2007 were compiled for the 22 largest reservoirs for which recorded measurements are available. These data are input on the new reservoir storage.
- The observed actual storage volumes provided in the *SIM* input for the 22 larger reservoirs were greater than conservation storage capacities in some months reflecting encroachments into surcharge storage or flood control pools. Reservoir storage capacities on *WS* and *SV/SA* records were extended as necessary to assure that the observed storages never exceeded storage capacities in the model.
- Brazos River Authority (BRA) water supply diversions were adjusted to reflect system operations. In the Bwam8 dataset, the BRA diversions are all located at the reservoirs. In the Bwam8A dataset, a portion of the BRA diversions is located at the Richmond gage.
- The natural priority option switch in *JO* record field 9 was activated to replace the priority system. Storage refilling and water use targets are met in an upstream-to-downstream order, which was considered to better represent actual water management and use.
- Negative incremental inflow option 4 was activated on the JD record, replacint option 5.

Beginning of Simulation Storage Contents

A beginning reservoir storage (BES) file was created for the Bwam8A dataset. The beginning of January 1998 storage contents was assigned for each reservoir based on either simulated or observed storage volumes. The original Bwam8 dataset with the 1940-1997 hydrologic period-of-analysis was executed with the only modification being activation of the natural priority option. The simulation results provided end-of-simulation storage volumes for the 706 reservoirs. These end-of-month December 1997 (beginning of January 1998) storage volumes for the 22 reservoirs listed in Table 4.3 were replaced with actual observed storage volumes from the USGS National Water Information System supplemented by data from the TWDB website.

The observed end-of-month December 1997 (beginning of January 1998) storage contents obtained from the USGS NWIS and/or TWDB website for the 22 reservoirs are tabulated in Table 4.4 along with their Bwam8 storage capacities and end-of-month December 1997 simulated storage volume from the 1940-1997 Bwam8 simulation. The storage capacities for these 22 reservoirs represent 87.5 percent of the total storage capacity of the 706 reservoirs in the Bwam8 dataset.

Table 4.4 USGS Observed December 1997 End-of-Month Storage

Reservoir	WAM Reservoir Identifier	Storage Capacity (acre-feet)	End of December 1997 Simulated (acre-feet)	End of December 1997 Observed (acre-feet)
Alan Henry	ALANHN	115,773	112,592	38,910
Aquilla	AQUILA	41,700	41,700	57,800
Belton	BELTON	432,978	432,978	483,000
Fort Phantom Hill	FPHNHR	69,379	52,273	60,290
Georgetown	GRGTWN	36,980	36,980	43,760
Graham	EDLGRM	44,883	44,545	45,120
Granbury	GRNBRY	132,821	132,821	132,600
Granger	GRNGER	50,540	50,540	67,140
Hubbard Creek	HUBBRD	317,750	298,231	293,200
Limestone	LMSTNE	208,017	208,017	212,100
Millers Creek	MLRCRK	26,631	24,651	11,640
Lake Palo Pinto	PLPNTO	26,405	25,637	34,900
Pat Cleburne	CLEBRN	25,600	24,045	24,200
Possum Kingdom	POSDOM	552,013	537,716	454,800
Proctor	PRCTOR	54,702	54,702	48,800
Squaw Creek	SQWCRK	151,015	46,817	152,001
Somerville	SMRVLE	154,254	151,685	159,300
Stamford	STMFRD	47,557	41,901	29,200
Stillhouse Hollow	STLHSE	224,279	224,279	253,400
Waco	LKWACO	206,562	206,562	125,800
White River	WHTRVR	28,774	10,491	12,870
Whitney	WHITNY	561,074	561,074	531,300
Total		3,509,687	3,320,237	3,292,131

Sequences of 1998-2007 Storage Contents for 22 Reservoirs

Sequences of actual end-of-month storage contents for each of the 120 months from January 1998 through December 2007 were compiled from the USGS NWIS for the 22 reservoirs listed in Tables 4.4 and 4.5. Reservoir water surface elevation is actually measured, and the observed stage is converted to storage volume using an elevation versus volume table for the reservoir, which may be occasionally updated to reflect sedimentation. The USGS NWIS records daily reservoir surface elevations and storage volumes in acre-feet which represent storage amounts at midnight in some cases or the mean storage during the day in other cases. The volumes or elevations for the last day of each of the 120 months were compiled for 22 of the reservoirs.

The availability of 1998-2007 reservoir storage data in the USGS NWIS for the 22 reservoirs is outlined in Table 4.5. The midnight storage volume for the last day of each month was used if available. The second column of Table 4.5 shows the periods for which midnight storage volumes are recorded in the USGS NWIS. The mean storage volume for the last day of each month was used for the periods shown in the third column. For the periods listed in the fourth and fifth columns, water surface elevations are recorded in the USGS NWIS but storage volumes are not. Storage volumes were computed by linear interpolation and extrapolation of elevation-area tables available at the TWDB website. The last column of Table 4.5 shows periods for which no USGS data are available. Storage volumes were obtained from monthly TWDB Water Conditions Reports.

The 120 end-of-month storage volumes at each of 22 reservoirs were recorded on *OS* records for inclusion in the Bwam8A *SIM* input DAT file. The objective is to reproduce in the *SIM* simulation with the Bwam8A dataset the actual observed storage volumes of these 22 large reservoirs which account for 87.5 percent of the total Bwam8 storage capacity of the 706 reservoirs in the Bwam8 and Bwam8A datasets. Storage volumes are computed by *SIM* in the normal manner for the 684 other reservoirs. Compiling actual observed storage sequences for these 684 smaller reservoirs accounting for 12.5 percent of the total storage capacity is not feasible.

Table 4.5 Availability of Storage Content Data in USGS NWIS

	Storage Volume (acre-feet)		Water Surface Elevation (feet)		
Reservoir	Midnight	Mean Daily	Midnight	Mean Daily	Missing
Alan Henry	Jan 98 – Mar 03 May 2003 Jul 03 – Oct03	Apr 03, Jun 03	−	Nov 03 – Dec 07	−
Aquilla	Jan 98 – Oct 2000	−	−	Nov 02 – Dec 07	−
Belton	Jan 1998 – Jan 04	−	−	Feb 04 – Dec 07	−
Fort Phantom Hill	Apr 99 – Oct 00	Nov 00 – Oct 02	−	Nov 02 – Dec 07	Jan 98 – Mar 99
Georgetown	Jan 98 – Jan 04		−	Feb 04 – Dec 07	−
Graham	Jan 98 – Oct 00	Nov 00 – Oct 06	−	Nov 06 – Dec 07	−
Granbury	Jan 98 – Jul 01	Aug 01 – Dec 07	−		−
Granger	Jan 98 – Aug 03 Oct 03 – Jan 04	−	−	Feb 04 – Dec 07	Sep 2003
Hubbard Creek	Jan 98 – Oct 03	−	−	Nov 04 – Dec 07	−
Limestone	Jan 98 – Jan 01	Feb 01 – Oct 01	Nov 01 – Nov 04	Dec 04 – Dec 07	−
Millers Creek	Nov 98 – Feb 02	Mar 02 – Oct 07	−	Nov 07 – Dec 07	Jan 98 – Oct 98
Palo Pinto	Mar 99 – Oct 00	Nov 00 – Oct 02	−	Nov 02 – Dec 07	Jan 98 – Feb 99
Pat Cleburne	Jul 98 – Oct 00	Nov 00 – Oct 02	−	Nov 02 – Dec 07	Jan 98 – Jun 98
Possum Kingdom	Jan 98 – Oct 00	Nov 00 – Oct 07	−	Nov 07 – Dec 07	−
Proctor	Jan 98 – Oct 00	Nov 00 – Oct 02	−	Nov 04 – Dec 07	−
Somerville	Jan 98 – Jan 04	−	−	Feb 04 – Dec 07	−
Squaw Creek	−	−	−	Oct 00 – Dec 07	Jan 98 − Sep 00
Stamford	Mar 99 – Oct 00	Nov 00 – Oct 02	−	Nov 02 – Dec 07	Jan 98 – Feb 99 January 2005
Stillhouse Hollow	Jan 98 – Oct 02	Nov 02 – Oct 04	−	Nov 04 – Dec 07	−
White River	Feb 99 – Oct 00	Nov 00 – Oct 02	−	Nov 02 – Dec 07	Jan 1998 – Jan 99
Whitney	Jan 98 – Oct 00	Nov 00 – Oct 02	−	Nov 02 – Dec 07	−
Waco	Jan 98 – Jan 04	−	Feb 04 – May 04	Jun 04 – Dec 07	−

The program *SIM* input DAT file in the WAM System datasets includes reservoir storage capacities on *WS* records. Volume-area tables are provided on *SV* and *SA* records. These data have been adjusted in Bwam8A to facilitate the storage at the 22 reservoirs rising above the top of conservation pool into surcharge or flood control pools. Although elevation-volume relationships are sensitive to sediment survey updates, volume-area relationships remain relative constant. The Bwam8 surface area versus storage volume relationships are considered to still be valid with the actual observed volumes.

The observed storage contents entered on OS records for the 22 reservoirs are treated in SIM as storage capacities. In SIM, in each month, the storage capacity for a particular reservoir is the lesser of the storage volume read from an OS record and the largest WS record storage capacity associated with on or multiple water rights connected to the reservoir. In the Bwam8A DAT file, the WS record capacities at the 22 reservoirs are revised as necessary to not constrain the OS record capacities. Spills in SIM assure that the OS record capacities are never exceeded. SIM fills the reservoirs to the capacities specified by the OS records subject to stream flow availability. An option is activated within HYD that increases naturalized flows by the amount of the shortage in reaching the OS record storage level. Likewise, a similar flow adjustment option in HYD increases naturalized flows in the amount of water supply diversion shortages for diversions from the 22 reservoirs, with the exception of the Brazos River Authority system diversion at the Richmond gage control points discussed in the next section.

Brazos River Authority Reservoir System Operations

The 12 Brazos River Authority (BRA) reservoirs listed in Table 4.6 represent 66.0 percent of the total permitted conservation storage capacity of the 706 reservoirs in the Bwam8 and Bwam8A datasets. The diversion targets associated with these 12 reservoirs account for 29.8 percent of the total of all diversion targets in the Bwam8 and Bwam8A datasets. Reliabilities computed in the Bwam8 model for these diversions are 100 percent or close to 100 percent.

The U.S. Army Corps of Engineers Fort Worth owns and operates nine of the 12 reservoirs listed in Table 4.6. The BRA owns and operates the other three reservoirs. The BRA has contracted for the conservation storage capacity of the nine federal reservoirs. The Corps of Engineers is responsible for flood control operations. The large flood control pools contained in these nine reservoirs represent all of the flood control storage capacity controlled by gaged outlet structures in the Brazos River Basin. Flood control storage capacity and operations are not included in the Bwam3 and Bwam8 models but are reflected in Bwam8A to the extent noted below.

Hydropower operations at Whitney and Possum Kingdom Reservoirs actually rely primarily on excess flows and water supply releases for downstream diversions. There are no water rights for hydropower generation. Hydropower operations are included in the Bwam3 and Bwam8 models but are reflected in Bwam8A as discussed in the next paragraph.

Table 4.6 Brazos River Authority System Diversions

Reservoir	Control Point	Storage Capacity (acre-feet)	Bwam8 Diversion (ac-ft/year)	Bwam8A Diversion (ac-ft/year)
Possum Kingdom	515531	552,013	59,482	43,464
Granbury	515631	132,821	36,025	26,324
Whitney	515731	561,074	18,336	13,398
Aquilla	515831	41,700	2,394	1,749
Waco	509431	206,562	38,348	no change
Proctor	515931	54,702	14,068	no change
Belton	516031	432,978	107,738	78,725
Stillhouse Hollow	516131	224,279	67,768	49,518
Georgetown	516231	36,980	11,943	8,727
Granger	516331	50,540	2,569	1,877
Limestone	516531	208,017	39,337	28,744
Somerville	516431	154,254	48,000	35,074
System Diversion at the Richmond Gage			none	105,992
		---------------	---------------	---------------
Total		2,655,920	446,008	446,008
Total as Percent of Basin Total		66.0%	29.8%	29.8%

Multiple-reservoir, multiple-purpose operations of the 12 reservoir BRA/USACE system are modeled in the Bwam8A dataset with observed storage OS records as described in the preceding section. Flood control, hydroelectric power generation, and multiple-reservoir system operations are not modeled in the Bwam3 and Bwam8 datasets. However, the OS record observed storages in Bwam8A reflect all aspects of actual reservoir operations. WS record storage capacities and SV/SA record storage-area tables were modified to allow encroachment into flood control pools or into surcharge storage in reservoirs that have no flood control pool.

BRA multiple-purpose, multiple-reservoir system operations include diversions from the lower Brazos River supplied by releases from multiple reservoirs as well as lakeside diversions and diversions various distances below the dams on tributaries of the Brazos River. The City of Waco holds the water rights for diversions from Waco Reservoir. The BRA operates Proctor Reservoir to meet water supply needs in the vicinity of the reservoir. The other ten reservoirs are operated for downstream as well as lakeside diversions. About 26 percent of the BRA water right commitments occur in the lower Brazos River and can be supplied from releases from multiple reservoirs and/or unregulated stream flow under an excess flows permit.

In the BWAM8 dataset, all diversions associated with the BRA reservoirs occur at the individual reservoirs. The Bwam8A dataset includes modifications to more realistically approximate system operations. As discussed in the preceding section, observed end-of-month storage contents are reproduced in the Bwam8A model for these 12 BRA reservoirs and ten other reservoirs. The observed storage volumes input on *OS* records reflect actual system operations. The Bwam8 diversion targets are also adopted for the Bwam8A model with the following modification designed to better approximate system diversions from the lower Brazos River.

A diversion target of 105,992 acre-feet/year representing 26 percent of the total diversion amount associated with all the BRA water rights is assigned to the Richmond gage control point in the Bwam8A dataset. The BRA diversion rights are associated with the 11 reservoirs listed in Table 4.6 excluding Waco Reservoir. Proctor Reservoir is modeled in Bwam8A as well as Bwam8 as a local use reservoir. The diversion targets at the ten other BRA reservoirs are reduced by 26.93 percent for a total reduction of 105,992 acre-feet/year. The diversion targets in Bwam8 and Bwam8A are compared in the last two columns of Table 4.6.

The system diversion target 105,992 acre-feet/year is entered in the Bwam8A DAT file as a run-of-river diversion not connected to reservoir. However, 22 reservoirs are operated with observed storage OS records in Bwam8A including the ten reservoirs assumed to be include in the system that makes releases for the 105,992 acre-feet/year diversion at the Richmond gage. Reservoir spills mandated by OS records contribute the regulated flows at the Richmond gage and thus contribute the stream flows available to the system diversion. The HYD option to adjust naturalized flows for diversion shortages was not activated for this diversion.

Waco and Whitney Reservoirs are modeled in Bwam8 as multiple-owner reservoirs. The reservoirs are divided into component reservoirs and net evaporation is allocated using EA records. The dual simulation option is activated. These features in the Bwam8 dataset are designed for allocating storage between multiple water rights. Waco and Whitney Reservoirs are each modeled as individual reservoirs in the Bwam8A dataset. The component reservoirs are combined; the dual simulation feature is deactivated; and the evaporation allocation EA record feature is not used.

Water Supply Diversion and Return Flows

The Bwam8 diversion targets and return flow specifications are adopted for Bwam8A as well. As noted in Chapter I, the current use diversion targets were estimated during development of the original WAM dataset for each individual water right as the maximum annual diversion in any year of the ten year period from 1998 through 1997. As noted in section 4.4, diversion shortages occasionally occur in the Bwam8A simulation. Thus, the diversion targets impose maximum limits on diversion, but the computed diversions are sometimes less than the targets.

The diversions associated with the 22 larger reservoirs are handled differently in the HYD flow adjustments. The naturalized flows are increased in the HYD adjustments routines by the amount of the diversion shortages and storage shortages associated with the 22 reservoirs read by HYD from the SIM simulation results output file. These HYD flow adjustment options are applied to reproduce the actual observed reservoir storage levels and Bwam8 diversions. Storages and diversions are successfully reproduced for reservoirs located at primary control points for which naturalized flows are being computed by adjusting gaged flows. However, the 22 reservoirs are located at ungaged secondary control points for which naturalized flows are computed based on naturalized flows at primary gaged control points using flow distribution methods. Thus, the storage and diversion volumes are not always perfectly reproduced.

Reservoir storage volumes and diversions at the 684 other reservoirs and run-of-river diversions are computed in the conventional manner. Diversion shortages can and do occur in the Bwam8A as well as Bwam8 simulations.

4.1.7 Initial Estimate of 1998-2007 Naturalized Flows

A FLO file with 1998-2007 naturalized flows is required for the actual use Bwam8A *SIM* input dataset applied in the procedure described in section 4.1.8. However, 1998-2007 naturalized flows are the unknown data that the procedure is designed to compute. An initial set of 1998-2007 naturalized flows is developed for the 77 control points as follows solely for use in developing the initial estimate of flow adjustments. The new AN record features of program *HYD* was used to develop this initial set of naturalized flows.

Although mean flows, median flows, or any other exceedance frequency flows could be adopted, the 75 percent exceedance frequency flows was adopted as being reasonably likely flows on the conservatively low side of median flows. Using the 1940-1997 naturalized flows at a particular control point, the flow volume that is equaled or exceeded in 75 percent of the 58 years was determined for each of the 12 months January through December. For example, at each control point, the January naturalized flow volume that is equaled or exceeded during 75 percent of the 58 years in the 1940 to 1997 naturalized flow dataset was determined. The resulting set of twelve 75% exceedance frequency naturalized flow volumes for January through December are repeated for each of the ten years during 1998-2007.

4.1.8 Computation of 1998-2007 Naturalized Flows for 48 Control Points

The *SIM* simulation model was executed repeatedly with the Bwam8A dataset with a period-of-analysis of January 1998 through December 2007. The Bwam8A (modified Bwam8) water rights DAT file is designed to represent actual water management and use during 1998-2007. The EVA file contains the previously discussed 1998-2007 net evaporation-precipitation depths. Since naturalized flows are not known, the statistical (75% frequency) flows described in the preceding section were used as the initial-estimate FLO file. The methodology is based on iteratively replacing the FLO file 1998-2007 naturalized flows.

Naturalized flows for 1998-2007 at the 48 control points were computed using programs *SIM* and *HYD* by generating flow adjustments and adding the flow adjustments to actual 1998-2007 observed flows. Naturalized flows at the 29 other control points were determined by flow distribution computations based on flows at one or more of the 48 control points as discussed in section 4.1.9. Since the naturalized flows were originally computed based on an initial estimate of naturalized flows, the *SIM* simulation was repeated with the latest naturalized flows as the FLO file input data. The process was repeated until the resulting naturalized flows stabilized, essentially no longer changing with further iterations.

The naturalized flow volumes for each of the 120 months at each of the 48 control points were computed as follows.

Naturalized flow volume = actual observed flow volume + flow adjustment

The 75 percent frequency naturalized flows served only to obtain an initial set of flow adjustments. With the iterative procedure, the improved-estimate set of naturalized flows are input to *SIM* to obtain an improved-estimate set of flow adjustments which are added to observed flows to obtain an improved-estimate set of naturalized flows.

SIM simulations were performed with the Bwam8A dataset for the sole purpose of generating sequences of regulated and naturalized flows at the 48 control points and storage shortages at the 22 large reservoirs that were used only for computing flow adjustments. The flow adjustments at 48 control points involved *SIM* simulation results at 70 control points including the control points of the 22 reservoirs. Program *HYD* was used to read the *SIM* simulation results and compute the flow adjustments.

The flow adjustments for each of the 120 months at each of the 48 control points were computed by subtracting regulated flows from naturalized flows and adding storage shortages and diversion shortages associated with 22 large reservoirs. Additional iterations omitted the shortages. Storage shortages occur when the storage volumes computed by *SIM* fail to reach the observed storage levels input of *OS* records due to insufficient available stream flow for refilling.

Flow adjustment = naturalized flow − regulated flow + cascaded storage shortage
+ cascaded diversion shortage
Storage shortage = storage target from *OS* record − simulated storage volume

The naturalized flow less regulated flow adjustment pertains to 48 individual control points and does not require cascading to downstream control points. However, the storage shortages apply to the control point at which the reservoir is located and all downstream control points. Cascading computations are performed within *HYD* to adjust flows at each of the 48 control points which happen to be located downstream of the reservoir.

Channel loss factors are required in the cascading computations that translate the storage shortage adjustments to downstream control points. The channel loss factors on the *CP* records in the Bwam8 DAT file are for reaches defined by the over three thousand control points in the dataset. Any number of secondary control points with channel loss factors may be located between primary control points. Channel loss factors C_L were determined for the reaches defined by the 77 primary control points based on aggregating the delivery ratios ($1.0-C_L$) of the sub-reaches. Channel loss factors C_L for

N sub-reaches defined by secondary control points located between two primary control points are aggregated to a single reach based on the following relationship.

$$(1.0 - C_L)_{total} = (1.0 - C_L)_1 + (1.0 - C_L)_2 + \ldots + (1.0 - C_L)_N$$

Channel loss factors computed for the reaches between the primary control points are tabulated in Table 4.7.

4.1.9 Distribution of Naturalized Flows to the 29 Other Control Points

The 77 Brazos WAM primary control points are divided into two groups:

- Observed gaged flows from USGS gaging stations are available during 1998-2007 for 48 of the control points. Naturalized flows were determined at these 48 control points based on the methodology outlined in the preceding sections.
- Observed flow data are not available for the other 29 control points. Naturalized flows were determined at these 29 control points based on the methodology outlined in this section.

Naturalized monthly flow for 1998-2007 at each of the 29 control points are computed based on the naturalized flows at one or more of the 48 control points using program SIM. The resulting flows at 77 control points comprise the 1998-2007 extension to the FLO input file.

Program HYD and SIM both contain the same set of optional methods for distributing naturalized flows from gaged to ungaged control points. The option for generating naturalized flows is selected by parameter *INMETHOD(cp)* on the control points CP record. Information required to implement the flow distribution methods is provided in the DIS file. The August 2008 Fifth Edition of *Reference (Wurbs 2008a)* and *User Manuals (Wurbs 2008b)* describe the new *INMETHOD(cp)* option 10 which was added to support the flow extension applications This recently added flow distribution option is described as follows.

Table 4.7 Channel Loss Factors for Reaches between Primary Control Points

	Control Points		Loss
	Upstream	Downstream	Factor
1	RWPL01	WRSP02	0.9501
2	WRSP02	SFPE04	0.3814
3	DUGI03	SFPE04	0.1983
4	SFPE04	SFAS06	0.1520
5	CRJA05	SFAS06	0.1173
6	SFAS06	BRSE11	0.4687
7	NCKN10	BRSE11	0.3729
8	BSLU07	DMAS09	0.6335
9	DMJU08	DMAS09	0.4874
10	DMAS09	BRSE11	0.4918
11	BRSE11	BRSB23	0.4205
12	MSMN12	BRSB23	0.4616
13	CFRO13	CFHA14	0.3366
14	CFHA14	CFNU16	0.1217
15	MUHA15	CFNU16	0.1043
16	CFNU16	CFFG18	0.4346
17	CAST17	CFFG18	0.3271
18	CFFG18	CFEL22	0.3139
19	HCAL19	HCBR21	0.1357
20	BSBR20	HCBR21	0.0966
21	HCBR21	CFEL22	0.1554
22	CFEL22	BRSB23	0.0872
23	BRSB23	SHGR26	0.0179
24	GHGH24	SHGR26	0.0169
25	CCIV25	SHGR26	0.0080
26	SHGR26	BRPP27	0.0050
27	BRPP27	BRDE29	0.0198
28	PPSA28	BRDE29	0.0384
29	BRDE29	BRGR30	0.0179
30	BRGR30	BRAQ33	0.0208
31	PAGR31	BRAQ33	0.0218
32	NRBL32	BRAQ33	0.0119
33	BRAQ33	BRWA41	0.0090
34	AQAQ34	BRWA41	0.0080
35	NBHI35	NBCL36	0.2156
36	NBCL36	NBVM37	0.0637
37	NBVM37	BOWA40	0.1105
38	HGCR39	BOWA40	0.0534
39	MBMG38	BOWA40	0.0541
40	BOWA40	BRWA41	0.0139
41	BRWA41	BRHB42	0.0100
42	BRHB42	BRBR59	0.0139
43	SADL44	LEHS45	0.1747
44	LEDL43	LEHS45	0.1987
45	LEHS45	LEHM46	0.3624
46	LEHM46	LEGT47	0.0119
47	LEGT47	LEBE49	0.0267
48	COPI48	LEBE49	0.0070
49	LEBE49	LRLR53	0.0060
50	LAKE50	LAYO51	0.0070
51	LAYO51	LABE52	0.0080
52	LABE52	LRLR53	0.0040
53	LRLR53	LRCA58	0.0208
54	NGGE54	GAGE56	0.0010
55	SGGE55	GAGE56	0.0000
56	GAGE56	GALA57	0.0080
57	GALA57	LRCA58	0.0139
58	LRCA58	BRBR59	0.0364
59	BRBR59	BRHE68	0.0247
60	MYDB60	YCSO62	0.0228
61	EYDB61	YCSO62	0.0198
62	YCSO62	BRHE68	0.0228
63	DCLY63	BRHE68	0.0257
64	NAGR64	NAEA66	0.0139
65	BGFR65	NAEA66	0.0070
66	NAEA66	NABR67	0.0100
67	NABR67	BRHE68	0.0383
68	BRHE68	BRRI70	0.0236
69	MCBL69	BRRI70	0.0189
70	BRRI70	BRRO72	0.0100
71	BGNE71	BRRO72	0.0100
72	BRRO72	BRGM72	0.0169
73	BRGM73	OUT	0.0000
74	CBALC2	SJGMC4	0.0000
75	SJGMC4	OUT	0.0000
76	CLPEC1	SJGBC3	0.0000
77	SJGBC3	OUT	0.0000

Sequences of monthly naturalized flow volumes for January 1998 through December 2007 were computed at each of the 29 unknown-flow control points based on naturalized flows at one or more of the 48 known-flow control points and ratios between the means of 1940-1997 naturalized flows at the respective control points.

$$F_U = F_K \left(\frac{M_U}{M_K} \right)$$

F_U – naturalized flow at unknown flow control point
F_K – naturalized flow at known flow control point
M_U – 1940-1997 mean of naturalized flow at unknown flow control point
M_K – 1940-1997 mean of naturalized flow at known flow control point

Means of 1940-1997 naturalized flows at the 77 control points are tabulated in Table 3.2. The 29 unknown-flow control points are listed in Table 4.8 along with the relationships with known-flow control points from which their 1998-2007 naturalized flows were derived. The ratios of 1940-1997 mean naturalized flows were applied in the same manner that conventional drainage area ratios are applied routinely in many other studies. Mean flow ratios replace drainage area ratios.

The naturalized flows at each of the 29 unknown-flow (1998-2007) control points were related by ratios of 1940-1997 means to naturalized flows at one or more selected known-flow (1998-2007) control points as shown in Table 4.8. In most cases, the unknown-flow and known-flow control points are located on the same stream. In some cases, known-flow control points in adjacent watersheds were selected for synthesizing flows at a particular unknown-flow control point. For 21 of the unknown-flow control points, flows are transferred from a single known-flow control point. In four cases, incremental flows between known-flow control points are used to estimate flows at an unknown-flow control point. Flow at two or three upstream known-flow control points are used for synthesizing 1998-2007 monthly naturalized flows at four of the unknown-flow control points.

As an alternative to the approach outlined above, the flow distribution method based on combining the Natural Resource Conservation Service (NRCS) curve number (CN) equation with channel losses was also investigated. This is a technique that is activated as flow distribution option 8 on *CP* records in either program *HYD* or *SIM*. The watershed drainage area, curve number, and mean precipitation for each control point required for the NRCS CN method are available on the watershed parameter *WP* records in the flow distribution DIS file which is used by both *HYD* and *SIM*. The required channel loss factors are tabulated in Table 4.7. The NRCS CN method with channel losses was applied but not adopted for the final data set. The methodology outlined above based on ratios of 1940-1997 mean naturalized flows was concluded to yield more consistent and reasonable results.

Table 4.8 Relationship for Computing 1998-2007 Naturalized Flows for 30 Control Points

Control Point	River or Stream	Nearest City	Flow Synthesis Relationship with Source Control Points
WRSP02	White River Reservoir	Spur	6.7760RWPL01
DUGI03	Duck Creek	Girard	0.4534DMJU08
SFPE04	Salt Fork Brazos River	Peacock	0.6968SFAS06
CRJA05	Croton Creek	Jayton	0.5578DMJU08
BSLU07	Buffalo Spring Lake	Lubbock	6.8522RWPL01
NCKN10	North Croton Creek	Knox City	0.5821DMJU08
CFHA14	Clear Fork Brazos	Hawley	0.4721CFNU16
MUHA15	Mulberry Creek	Hawley	0.0813CFNU16
HCBR21	Hubbard Creek	Breckenridge	2.6780(HCAL19 + BSBR20)
CFEL22	Clear Fork Brazos	Eliasville	1.2071(CFFG18 + HCAL19 + BSBR20)
GHGH24	Lake Graham	Graham	0.2325(BRPP27 − BRSB23)
CCIV25	Big Cedar Creek	Ivan	0.5762BSBR20
SHGR26	Brazos River	Graford	0.9791BRPP27
PPSA28	Palo Pinto Creek	Santo	0.3316(BRDE29 − BRPP27)
NRBL32	Nolan River	Blum	0.3338(BRAQ33 − BRGR30 − PAGR31)
NBHI35	North Bosque River	Hico	0.2755NBCL36
MBMG38	Middle Bosque River	McGregor	0.2718NBVM37
HGCR39	Hog Creek	Crawford	0.1268NBVM37
BOWA40	Bosque River	Waco	1.7583NBVM37
LEDL43	Leon River	De Leon	1.6071SADL44
LEHS45	Leon River	Hasse	0.5480LEGT47
LEHM46	Leon River	Hamilton	0.6457LEGT47
LAYO51	Lampasas River	Youngsport	1.7438LAKE50
GAGE56	San Gabriel River	Georgetown	1.1086(NGGE54 + SGGE55)
YCSO62	Yegua Creek	Somerville	2.7062(MYDB60 + EYDB61)
MCBL69	Mill Creek	Bellville	0.3045(BRRI70 − BRHE68)
BRGM73	Brazos River	Gulf of Mexico	0.9988BRRO72
CLPEC1	Clear Creek	Pearland	0.3762CBALC2
SJGBC3	Coastal Basin	Galveston Bay	4.5193CBALC2
SJGMC4	Coastal Basin	Gulf of Mexico	10.9229CBALC2

4.1.10 Iterative Algorithm for Computing Naturalized Flows

The computational task addressed in this section is defined as follows:

> A repetitive search procedure using SIM and HYD is applied to find 1998-2007 sequences of naturalized flows at 48 gaged control points that satisfy the following requirement. When the naturalized flows are input to SIM as a FLO file along with the Bwam8A DAT file, the SIM simulation produces 1998-2007 sequences of regulated flows at the 48 control points that closely match the actual observed gaged flows at these sites.

The objective is to find a set of values for naturalized flows that will result in Bwam8A computed regulated flows that very closely reproduce the actual observed flows at the 48 gaged control points.

An iterative methodology is outlined in the preceding section 2.4.1 and beginning of the present section 4.1 for computing 1998-2007 monthly naturalized stream flows at 48 gaged control points based on observed gaged flows and the actual use scenario Bwam8A DAT file. *SIM* and *HYD* are applied in a repetitive search for a set of naturalized flows that will result in a set of regulated flows that closely reproduce gaged flows. *HYD* is used to adjust gaged flows based on *SIM* Bwam8A simulation results. Naturalized flows are distributed within SIM to 3,787 other control points based on the known flows at the 48 control points. This section focuses on the behavior of the simulation results as the iterations progress from the initial estimate of naturalized flows to the final adopted naturalized flows.

The adjustments to the naturalized flows performed in the repetitive *SIM/HYD* based computations are expressed in Equations 2.1, 2.2, and 2.3 introduced in section 2.4.1.

$$\text{Naturalized flow} = \text{Gaged flow} + \text{Flow adjustment} \qquad (2.1)$$

$$\begin{aligned}\text{Flow adjustment} = {} & \text{Naturalized flow} - \text{Regulated flow} \\ & + \text{Storage shortage} + \text{Diversion shortage} \qquad (2.2)\end{aligned}$$

$$\text{Naturalized flow} = \text{naturalized flow} + \text{gaged flow} - \text{regulated flow} \qquad (2.3)$$

The results of two sets of iterations are presented in Table 4.9 through 21. Iterations 1 through 12 are based on Equation 2.1 and 2.2. Iterations 13 through 20 are based on Equation 2.3. Storage shortages and diversion shortages associated with 22 reservoirs are included in the adjustments during the first twelve iterations but are omitted in the last eight iterations.

The storage shortage and diversion shortage adjustments in Equation 2.2 are associated with the 22 major reservoirs listed in Tables 4.2, 4.3, 4.9, and 4.10. Locations of the reservoirs are shown in the Figure 3.5 map. The storage and diversion shortage adjustments in Equation 2.2 work perfectly for the large reservoirs located at or near one of the 48 gaged control points at which flow adjustments are being applied. The procedure assures that observed storage contents are reproduced with the final computed set of naturalized flows. However, the majority of the 22 reservoirs are smaller reservoir projects located at ungaged control points significant distances from the nearest of the 48 gaged control points. Naturalized flows at ungaged control points are computed within *SIM* by flow distribution techniques. The Equation 2.2 flow adjustments tend to reduce storage shortages and diversion shortages at these ungaged control point reservoirs, but some shortages still occur. At some point in the iterations, no further reductions in storage and diversion shortages at the 22 reservoirs is possible and shifting from Equations 2.2 to Equation 2.3 is worthwhile.

The mean 1998-2007 end-of-month storage shortages (drawdowns) occurring in each the 22 reservoirs in each of 20 *SIM* simulations are tabulated in Table 4.9. The maximum shortages (drawdown) to occur in any of the 120 months of the 1998-2007 simulations are shown in Table 4.10. The shortage or drawdown volumes are the storage capacities recorded on observed storage *OS* records less the end-of-month storage volumes computed by *SIM*. The shortages are expressed in Tables 4.9 and 4.10 as a percentage of the volumes entered on the observed storage *OS* records.

Possum Kingdom, Granbury, Whitney, Belton, Stillhouse Hollow, Georgetown, Granger, and Somerville Reservoirs have no storage shortages, meaning their observed storage levels during 1998-2007 are reproduced in the *SIM* simulation. Of the 22 reservoirs, Millers Creek, Fort Phantom Hill, Stamford, Graham, Palo Pinto, and Waco are the only reservoirs with mean storage shortages greater than 1.0 percent of the *OS* record actual observed storage volumes.

Twenty iterations of the procedure outlined in sections 2.4.1 and 4.1 are summarized in Tables 4.9 through 4.21. Each iteration represents an execution of the *SIM* simulation model with the Bwam8A DAT file and 1998-2007 hydrologic period-of-analysis. The DAT, EVA, and DIS input files are the same for all 20 iterations. The naturalized flows in the FLO file change with each iteration. Program *HYD* uses data read from the *SIM* simulation results OUT file to adjust the naturalized flows based on Equations 2.1 and 2.2 for iterations 1 through 12 and Equation 2.3 for iterations 13 through 20. The iterations continue until the regulated flows at the 48 gaged control points very closely match the actual observed flows at the 48 gaging stations.

The interconnected executions of *SIM* and *HYD* are very efficient. With the *SIM* and *HYD* input files complete and the procedure understood, each additional iteration requires only a few minutes. *SIM* and *HYD* execute quickly, and the manual interchange of data files is also quick.

Table 4.9 Mean Reservoir Storage Shortage as Percentage of Observed Storage Volume

Reservoir	1998-2007 Mean Storage Shortage at Each Iteration as a Percentage of Observed Storage											
Name	1	2	3	4	5	6	7	8	9	10	11	12
Alan Henry	62.3%	0.1%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%
White River	78.6%	7.7%	3.4%	1.6%	0.9%	0.8%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%
Millers Creek	20.2%	0.4%	2.1%	2.2%	2.0%	2.2%	2.0%	2.1%	2.0%	2.1%	2.1%	2.1%
Fort Phantom	47.5%	0.2%	2.4%	0.8%	1.0%	1.0%	0.9%	1.0%	0.9%	1.0%	0.9%	1.0%
Stamford	64.1%	0.6%	5.7%	1.7%	2.9%	1.9%	2.2%	2.0%	2.2%	2.0%	2.2%	2.0%
Hubbard	31.1%	0.6%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Graham	16.7%	0.5%	2.1%	1.6%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%
Possum Kingd	4.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Palo Pinto	13.2%	3.1%	1.9%	2.1%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Proctor	71.2%	0.3%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Granbury	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Squaw Creek	7.5%	0.1%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%
Pat Cleburne	6.9%	0.2%	0.6%	0.5%	0.6%	0.6%	0.5%	0.6%	0.5%	0.6%	0.5%	0.6%
Whitney	9.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Aquilla	15.6%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Waco	10.6%	1.6%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
Belton	5.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stillhouse	3.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Georgetown	19.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Granger	5.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Somerville	12.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Limestone	7.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Reservoir	Reservoir	Mean Storage Shortage at Each Iteration as a Percentage of Observed Storage							
Name	WAM ID	13	14	15	16	17	18	19	20
Alan Henry	ALANHN	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%
White River	WHTRVR	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%
Millers Creek	MLRCRK	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%
Fort Phantom	FPHNHR	4.2%	7.3%	9.4%	10.7%	11.3%	11.6%	11.8%	11.9%
Stamford	STMFRD	7.1%	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%	7.4%
Hubbard	HUBBRD	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Graham	EDLGRM	2.6%	2.7%	2.7%	2.8%	2.8%	2.8%	2.8%	2.8%
Possum Kingdo	POSDOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Palo Pinto	PLPNTO	3.4%	3.7%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%
Proctor	PRCTOR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Granbury	GRNBRY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Squaw Creek	SQWCRK	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Pat Cleburne	CLEBRN	0.8%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%
Whitney	WHITNY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Aquilla	AQUILA	0.1%	0.2%	0.2%	0.3%	0.3%	0.3%	0.3%	0.4%
Waco	LKWACO	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
Belton	BELTON	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stillhouse	STLHSE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Georgetown	GRGTWN	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Granger	GRNGER	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Somerville	SMRVLE	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Limestone	LMSTNE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 4.10 Maximum Reservoir Storage Shortage as Percentage of Observed Storage Volume

Reservoir	Maximum Storage Shortage during 1998-2007 as a Percentage of Observed Storage Volume											
Name	1	2	3	4	5	6	7	8	9	10	11	12
Alan Henry	82.3%	5.0%	6.6%	6.5%	6.7%	6.7%	6.7%	6.8%	6.8%	6.8%	6.8%	6.8%
White River	97.9%	38.7%	28.6%	27.6%	26.7%	25.9%	25.1%	24.4%	23.8%	23.2%	22.7%	22.5%
Millers Creek	47.5%	13.1%	29.2%	27.7%	26.9%	27.6%	27.0%	27.6%	27.1%	27.5%	27.1%	27.5%
Fort Phantom	83.6%	11.8%	27.1%	17.7%	17.9%	17.8%	17.9%	17.8%	17.9%	17.8%	17.9%	17.8%
Stamford	96.2%	18.3%	36.4%	29.2%	31.6%	30.9%	31.4%	30.9%	31.4%	30.9%	31.4%	30.9%
Hubbard	86.3%	6.2%	5.7%	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
Graham	43.3%	32.3%	35.8%	32.8%	33.0%	33.0%	33.0%	33.0%	33.0%	33.0%	33.0%	33.0%
Possum Kingdom	19.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Palo Pinto	65.4%	24.2%	24.3%	24.3%	24.3%	24.3%	24.3%	24.3%	24.3%	24.3%	24.3%	24.3%
Proctor	100.0%	26.0%	6.2%	1.6%	0.6%	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Granbury	9.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Squaw Creek	12.0%	2.6%	4.4%	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%
Pat Cleburne	36.2%	12.9%	15.7%	14.7%	14.7%	14.7%	14.6%	14.7%	14.6%	14.7%	14.6%	14.7%
Whitney	56.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Aquilla	71.1%	4.4%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%	3.8%
Waco	63.5%	51.5%	50.9%	50.1%	49.9%	49.9%	49.9%	49.9%	49.9%	49.9%	49.9%	49.9%
Belton	60.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stillhouse	60.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Georgetown	78.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Granger	69.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Somerville	65.3%	13.0%	12.9%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%
Limestone	22.6%	0.5%	0.6%	0.6%	0.6%	0.6%	0.6%	0.5%	0.5%	0.5%	0.5%	0.5%

Reservoir	Maximum Storage Shortage as a Percentage of Observed Storage Volume							
Name	13	14	15	16	17	18	19	20
Alan Henry	8.1%	8.2%	8.2%	8.2%	8.2%	8.2%	8.2%	8.2%
White River	22.6%	22.7%	22.9%	23.1%	23.3%	23.5%	23.7%	23.9%
Millers Creek	34.6%	34.9%	34.8%	34.8%	34.8%	34.8%	34.7%	34.7%
Fort Phantom	32.5%	41.0%	45.3%	47.6%	48.8%	49.4%	49.7%	49.8%
Stamford	44.7%	46.6%	46.8%	46.8%	46.8%	46.8%	46.8%	46.8%
Hubbard	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
Graham	41.7%	42.9%	43.0%	43.1%	43.1%	43.1%	43.1%	43.1%
Possum Kingdom	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Palo Pinto	26.8%	28.2%	28.6%	28.7%	28.7%	28.7%	28.7%	28.7%
Proctor	0.3%	0.4%	0.6%	0.7%	0.8%	0.9%	1.1%	1.2%
Granbury	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Squaw Creek	5.4%	5.5%	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
Pat Cleburne	18.7%	19.3%	19.5%	19.5%	19.5%	19.5%	19.5%	19.5%
Whitney	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Aquilla	7.3%	10.2%	12.6%	14.5%	16.2%	17.5%	18.6%	19.5%
Waco	49.9%	49.9%	49.9%	49.9%	49.9%	49.9%	49.9%	49.9%
Belton	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stillhouse	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Georgetown	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Granger	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Somerville	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%	12.8%
Limestone	1.5%	2.2%	2.5%	2.7%	2.8%	2.9%	2.9%	2.9%

Basin summaries developed with program *TABLES* with a 2SBA record from the results of the 20 *SIM* simulations are tabulated in Table 4.11. The table consists of means of 1998-2007 annual volumes in acre-feet/year. Each line summaries one of the twenty *SIM* simulations. Most changes in flow volumes and other variables occur during the first three iterations, but gradual changes continue with further iterations. The results are stable by 20 iterations.

Table 4.11 Summary Table of 1998-2007 Mean Annual Volumes for the Twenty Iterative Simulations

	Naturalized Flow (ac-ft/yr)	Return Flow (ac-ft/yr)	Flow Depletion (ac-ft/yr)	Unappropriated Flow (ac-ft/yr)	Storage (acre-feet)	Net Evap-Pre (ac-ft/yr)	Diversion Target (ac-ft/yr)	Actual Diversion (ac-ft/yr)	Shortage (ac-ft/yr)
1	2,040,574	223,516	1,376,162	905,145	2,844,063	281,611	1,613,065	1,007,602	605,463
2	26,241,132	294,661	2,727,068	9,130,894	3,404,096	550,253	1,526,470	1,425,663	100,807
3	13,471,006	285,897	2,635,423	6,531,769	3,389,539	462,655	1,564,328	1,387,270	177,059
4	13,476,056	289,859	2,641,184	6,512,200	3,395,097	461,795	1,539,065	1,392,586	146,479
5	13,438,992	286,804	2,635,597	6,492,053	3,393,569	460,493	1,559,088	1,388,325	170,764
6	13,444,754	289,226	2,639,080	6,497,911	3,394,479	460,902	1,541,795	1,391,255	150,541
7	13,441,368	287,324	2,636,491	6,492,452	3,394,257	460,584	1,555,943	1,389,032	166,911
8	13,443,494	288,846	2,638,424	6,495,959	3,394,296	460,815	1,543,366	1,390,669	152,697
9	13,441,648	287,609	2,637,001	6,492,650	3,394,446	460,623	1,554,081	1,389,467	164,615
10	13,443,283	288,648	2,638,474	6,495,319	3,394,211	460,791	1,544,370	1,390,766	153,604
11	13,441,894	287,810	2,637,460	6,492,958	3,394,563	460,648	1,552,748	1,389,893	162,855
12	13,443,096	288,511	2,638,435	6,495,045	3,394,134	460,768	1,544,914	1,390,795	154,119
13	13,053,365	283,070	2,616,205	6,379,536	3,385,230	457,185	1,572,119	1,375,407	196,712
14	13,042,354	281,602	2,607,133	6,370,500	3,380,228	456,226	1,574,600	1,369,061	205,539
15	13,041,504	281,034	2,603,246	6,367,670	3,377,655	455,790	1,574,843	1,366,359	208,485
16	13,041,218	280,910	2,601,347	6,367,029	3,376,403	455,555	1,574,935	1,365,293	209,643
17	13,041,117	280,874	2,600,273	6,366,750	3,375,785	455,430	1,574,964	1,364,683	210,280
18	13,041,059	280,852	2,599,579	6,366,614	3,375,491	455,360	1,574,979	1,364,244	210,736
19	13,041,053	280,831	2,599,095	6,366,526	3,375,348	455,318	1,575,040	1,363,901	211,139
20	13,041,063	280,820	2,598,888	6,366,312	3,375,284	455,293	1,575,069	1,363,788	211,281

The first column of Table 4.11 numbers the 20 consecutive iterative repetitions of the *SIM* simulation with naturalized flows being adjusted in each iteration. The mean of the basin total naturalized flows as defined by the *TABLES* 2SBA record are tabulated in the second column. The naturalized flows for the first iteration were arbitrarily set as 75 percent exceedance flows for each of the 12 months of the year which were repeated of each of the ten years of the 1998-2007 hydrologic simulation periods. The naturalized flows for each of the 12 months January through December are the amounts equaled or exceeded during 75 percent of the 58 years of the original 1940-1997 hydrologic period-of-analysis.

The mean basin total shown in Table 4.11 is 2,040,574 acre-feet/year. With the *HYD* adjustments reflected in Equations 2.1 and 2.2, the mean basin total naturalized flows shown in Table 4.11 increased to 26,241,132 acre-feet/year for the second iteration and then to 13,471,006 acre-feet/year for the third iteration. Between iterations 3 and 20, the mean naturalized flows gradually changed from 13,471,006 acre-feet/year to 13,041,063 acre-feet/year. The mean naturalized flows stayed essentially constant, varying between 13,041,053 and 13,041,504 acre-feet/year, during the last six iterations.

To the extent that the Bwam8A DAT file and all other aspects of the *SIM* simulation represents actual water resources development, allocation, management, and use during each month of the 1998-2007 period-of-analysis, the regulated flows computed by *SIM* at the 48 gaged control points represent actual physical monthly flow volumes at these locations. Thus, the iterations are continued until the computed regulated flows closely reproduce actual observed flows at the 48 gaging stations. Frequency tables are presented as Tables 4.12 through 4.21 as measures of how closely regulated flows match gaged flows in each of the consecutive 20 iterations of the *SIM/HYD* computational procedure. Frequency tables were created from the *SIM* simulation results using the *TABLES* 2FRE record feature. Observed gaged flows are shown in Tables 4.12−4.21 in units of acre-feet/month. *SIM* computed monthly regulated flow volumes at the 48 gaged control points are expressed in the tables as a percentage of the corresponding actual observed flow volumes at the 48 gaging stations. The objective is to iterate to a set of naturalized flows resulting in regulated flows that are 100.0 percent of the corresponding gaged flows.

Frequency statistics for gaged observed flows and *SIM* computed regulated flows at the Richmond, Waco, and Cameron gages (control points BRRI70, BRWA41, LRCA58) for each of the 20 iterations are presented as Tables 4.12, 4.13, and 4.14. Regulated flows are expressed as a percentage of gaged flows. The locations of the control points are shown in Figure 3.5 as well as in several other figures in Chapter III and section 4.1. The Richmond gage on the Brazos River about 60 miles above its confluence at the Gulf of Mexico represents the outlet for most of the Brazos River Basin. If rounded to the nearest one percent, all regulated flow statistics for the Richmond gage shown in Table 4.12 are 100 percent of the corresponding gaged flow volume in iterations 15 through 20. The regulated flow statistics for the Waco gage on the Brazos River and Cameron gage on the Little River similarly reach 100 percent of the corresponding gaged flow volumes as the iterations proceed.

Means and flow-frequency relationships for all 48 gaged control points are presented as Tables 4.15 through 4.21. The 1998-1997 mean gaged flow in acre-feet/month at the 48 gaging stations and corresponding mean regulated flows as a percentage of gaged flows are tabulated in Table 4.15 for each of the 20 repeats of the *SIM* Bwam8A simulation. By the 20th iteration, the mean regulated flow is 100.0% of the mean gaged flow at 47 of the 48 control points and 100.3% at the remaining control point. Thus, mean gaged flows at the 48 gaged control points are closely reproduced. Flows equaled or exceeded during 98%, 90%, 75%, 50%, 25%, and 10% of the 120 months of the 1998-2007 simulations are tabulated in Tables 4.16-4.21. Though not perfect, the flow-frequency relationships are reproduced reasonably closely.

Table 4.12 Frequency Statistics for Observed and Regulated Flow Richmond Gage on the Brazos River (Control Point BRRI70)

	Gaged	Iterations																			
	Flow	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	(acre-feet/month)	Regulated Flow at Each Iteration as a Percentage of Gaged Flow																			
Mean	515,766	18.7	145.3	102.7	102.3	102.0	102.1	102.0	102.0	102.0	102.0	102.0	102.0	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0
Std Dev	609,133	9.0	125.9	100.8	100.4	100.2	100.2	100.2	100.2	100.2	100.2	100.2	100.2	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Minimum	25,763	126.9	249.5	152.7	142.7	142.8	141.5	143.4	141.0	143.7	140.7	143.9	140.4	103.8	101.0	100.4	100.2	100.1	100.0	100.1	100.0
99.50%	28,715	113.9	224.5	141.3	137.0	137.2	135.8	137.6	135.4	137.8	135.1	138.0	135.0	103.6	101.0	100.4	100.2	100.1	100.0	100.0	100.0
99%	30,941	106.0	211.5	136.0	132.8	133.0	131.6	133.4	131.3	133.6	131.0	133.7	130.9	103.5	101.0	100.4	100.2	100.1	100.0	99.9	100.0
98%	32,170	103.4	214.7	144.2	131.5	131.7	130.5	132.0	130.1	132.1	129.9	132.2	129.8	102.8	100.9	100.4	100.2	100.1	100.1	100.1	100.0
95%	39,537	87.0	229.1	136.1	131.5	131.5	131.5	131.5	130.9	125.4	125.5	125.4	125.5	104.1	101.9	101.0	100.5	100.3	100.2	100.1	100.1
90%	50,666	109.9	328.8	136.7	121.1	120.8	120.6	121.0	120.4	121.1	120.3	121.2	120.3	103.3	101.1	101.1	101.1	101.1	101.1	100.9	100.2
85%	69,911	79.6	302.6	117.7	120.5	118.4	118.1	118.3	117.5	118.3	117.4	118.4	117.3	103.2	102.2	100.4	100.3	100.2	100.2	100.2	100.2
80%	79,503	73.8	308.1	114.8	111.1	108.3	108.9	108.4	108.9	108.4	108.9	108.4	108.9	100.7	100.2	100.1	100.1	100.0	100.0	100.0	100.0
75%	89,465	69.6	309.0	114.4	116.8	116.3	116.0	116.3	116.0	116.3	116.0	116.3	116.0	101.6	100.6	100.3	100.2	100.2	100.2	100.2	100.2
70%	117,687	55.0	244.6	104.5	106.4	104.9	105.1	104.9	104.7	105.0	104.6	105.1	104.6	100.7	100.3	100.1	100.1	100.0	100.0	100.0	100.0
60%	184,770	36.5	195.0	105.8	102.3	101.3	101.5	101.3	101.4	101.3	101.4	101.3	101.4	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0
50%	259,662	27.2	184.6	102.5	102.4	102.4	102.3	102.4	102.3	102.4	102.3	102.4	102.3	100.3	100.1	100.1	100.1	100.1	100.0	100.0	100.0
40%	382,268	26.4	162.7	102.8	101.7	101.5	101.6	101.5	101.6	101.5	101.6	101.5	101.6	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0
30%	595,999	17.9	144.4	101.2	101.4	101.4	101.4	101.4	101.3	101.4	101.3	101.4	101.3	100.1	100.1	100.0	100.0	100.0	100.0	100.0	100.0
25%	741,909	15.0	141.8	101.6	101.5	100.7	100.8	100.7	100.8	100.7	100.8	100.7	100.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
20%	1,021,248	11.1	123.4	101.5	101.2	101.2	101.2	101.2	101.2	101.2	101.2	101.2	101.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
15%	1,220,529	15.1	114.2	100.4	101.2	100.5	100.6	100.6	100.5	100.6	100.5	100.6	100.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
10%	1,357,154	15.0	128.9	102.9	103.7	102.7	102.9	102.8	102.9	102.9	102.9	102.9	102.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
5%	1,632,496	13.2	138.7	100.3	100.5	100.3	100.4	100.3	100.4	100.3	100.4	100.3	100.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2%	2,365,662	10.1	142.6	101.7	100.4	100.2	100.2	100.2	100.2	100.2	100.2	100.2	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1%	3,530,287	7.3	138.1	101.8	100.4	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Max	3,751,359	7.0	137.2	101.7	100.4	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.13 Frequency Statistics for Observed and Regulated Flow Waco Gage on the Brazos River (Control Point BRWA41)

	Gaged	Iterations																			
	Flow	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	(acre-feet/month)	Regulated Flow at Each Iteration as a Percentage of Gaged Flow																			
Mean	116,466	9.4	246.3	108.7	109.8	108.3	108.9	108.4	108.7	108.5	108.7	108.5	108.7	100.5	100.1	100.1	100.0	100.0	100.0	100.0	100.0
Std Dev	217,543	6.8	143.4	100.8	100.5	100.3	100.3	100.4	100.4	100.4	100.4	100.4	100.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Minimum	2,029	0.0	1,446.8	572.9	678.2	683.4	660.1	689.2	655.1	692.6	651.0	695.0	648.8	134.1	108.1	108.1	103.7	101.8	102.1	100.9	100.8
99.50%	2,140	0.0	1,434.8	552.8	657.6	655.8	640.0	659.9	634.5	661.5	630.3	662.4	627.6	139.3	104.4	104.4	102.0	101.1	101.3	100.9	100.8
99%	2,250	0.0	1,408.3	537.2	635.5	629.2	618.6	633.3	612.7	634.5	608.6	634.9	605.9	142.8	102.5	102.5	101.2	100.7	100.8	100.8	100.7
98%	2,496	0.0	1,316.8	507.9	577.5	570.9	565.2	578.6	560.6	582.2	557.7	584.5	556.1	144.2	104.4	104.4	102.0	100.9	100.0	100.1	100.1
95%	7,256	0.0	939.1	228.7	236.9	212.7	226.1	213.9	225.7	214.2	225.7	214.2	225.7	119.3	105.4	105.4	102.4	101.0	99.9	99.9	99.8
90%	10,699	9.0	779.8	174.3	199.4	190.0	193.5	190.0	193.3	190.2	193.1	190.4	193.0	110.1	101.1	101.1	100.5	100.2	100.1	100.1	100.0
85%	15,310	8.6	645.5	153.5	155.2	145.5	151.8	145.9	151.8	145.9	151.8	145.9	151.8	102.4	100.7	100.7	100.3	100.2	100.1	100.0	100.0
80%	19,615	10.8	617.8	145.3	154.2	151.6	154.2	151.4	154.3	151.3	154.4	151.2	154.5	106.0	100.7	100.7	100.4	100.2	100.1	100.1	100.0
75%	25,456	10.2	523.8	132.9	134.8	132.1	134.5	132.4	132.5	132.0	132.0	132.0	131.7	101.3	100.1	100.1	100.0	100.0	100.0	100.0	100.0
70%	27,301	13.1	517.6	129.6	133.4	128.2	132.5	128.1	132.3	128.1	132.1	128.1	132.0	101.8	100.9	100.9	100.5	100.2	100.1	100.1	100.0
60%	35,970	10.7	472.7	127.1	127.3	125.6	127.1	125.6	127.2	125.6	127.2	125.6	127.2	103.4	103.0	103.0	102.5	102.0	101.6	101.3	101.1
50%	53,248	11.7	381.6	116.4	122.7	116.5	121.9	117.7	119.2	118.4	118.7	118.8	118.3	104.0	100.9	100.9	100.4	100.2	100.1	100.0	100.0
40%	70,157	10.2	318.2	110.2	111.5	108.7	111.0	108.9	109.6	109.1	109.3	109.2	109.1	100.7	100.6	100.6	100.5	100.5	100.4	100.3	100.2
30%	96,781	8.3	289.0	97.6	105.1	101.6	103.1	101.6	102.5	101.5	102.5	101.5	102.5	100.0	99.9	99.9	100.0	100.0	100.0	100.0	100.0
25%	113,875	14.3	266.8	104.0	102.1	102.2	102.0	102.3	102.0	102.3	102.0	102.3	102.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
20%	135,027	12.1	283.5	108.0	107.9	105.3	106.3	105.4	105.8	105.6	105.8	105.6	105.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
15%	176,838	14.1	258.7	109.5	104.8	104.2	104.5	104.1	104.5	104.1	104.6	104.1	104.6	99.7	99.7	99.7	99.7	99.7	99.8	99.8	99.9
10%	262,860	11.7	225.2	105.7	106.1	104.2	104.5	104.2	104.5	104.2	104.4	104.2	104.4	99.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0
5%	451,872	9.0	180.0	113.0	112.3	111.7	111.8	111.6	111.8	111.6	111.7	111.7	111.7	100.4	100.1	100.1	100.0	100.0	100.0	100.0	100.0
2%	1,076,980	5.9	152.0	101.5	100.5	100.4	100.4	100.4	100.4	100.4	100.4	100.4	100.4	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1%	1,541,777	5.3	141.0	100.4	100.3	100.2	100.2	100.2	100.2	100.2	100.2	100.2	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Max	1,629,606	5.3	138.2	100.1	100.3	100.2	100.2	100.2	100.2	100.2	100.2	100.2	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.14 Frequency Statistics for Observed and Regulated Flow Cameron Gage on the Little River (Control Point LRCA58)

	Gaged	Iteration																			
	Flow	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	(acre-feet/month)	Regulated Flow at Each Iteration as a Percentage of Gaged Flow																			
Mean	133,094	9.7	143.4	101.1	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Std Dev	167,904	6.0	159.8	102.2	100.3	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Minimum	3,382	125.9	190.0	128.9	114.1	112.6	112.0	111.6	111.1	111.0	110.9	110.9	110.9	109.9	108.9	108.0	107.2	106.4	105.8	105.2	104.7
99.50%	3,751	113.6	203.1	139.6	114.6	108.1	106.4	105.5	104.2	104.0	104.0	104.0	104.0	103.6	103.2	102.9	102.6	102.4	102.1	101.9	101.7
99%	4,366	97.7	193.0	133.6	110.9	104.0	102.4	101.5	100.3	100.1	100.1	100.1	100.0	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0
98%	5,891	72.9	149.8	100.9	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
95%	6,887	63.2	145.0	106.8	101.0	100.9	100.8	100.6	100.3	100.2	100.1	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
90%	8,547	54.4	200.1	103.3	102.0	101.6	101.3	100.8	100.5	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
85%	9,715	50.7	257.8	108.6	101.8	100.6	100.2	100.1	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
80%	12,789	42.3	252.1	102.1	102.1	102.0	102.0	102.0	101.9	101.9	101.9	101.9	101.9	101.9	101.7	101.5	101.4	101.2	101.1	101.0	100.9
75%	15,310	38.0	240.0	102.5	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
70%	21,029	29.3	207.4	104.9	101.5	101.2	100.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
60%	33,818	23.2	190.3	101.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
50%	54,417	15.6	185.2	101.7	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
40%	92,416	12.4	147.3	100.3	100.0	100.0	100.1	100.1	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
30%	181,450	7.5	121.5	100.8	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
25%	218,834	8.4	117.1	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
20%	240,663	8.8	117.5	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
15%	293,911	8.1	115.0	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
10%	377,472	7.0	116.5	100.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
5%	504,690	7.3	122.0	100.4	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2%	709,567	6.2	199.2	103.7	100.6	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1%	779,294	5.8	209.3	108.1	101.3	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Max	795,096	5.7	208.0	108.6	101.4	100.3	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.15 Mean Regulated Flow at the 48 Control Points as a Percentage of Mean Gaged Flow

Control Point	Gaged Flow (ac-ft/month)	Regulated Flow as Percentage of Gaged Flow : Mean 1	2	3	4	5	6	7	8	9	10	11	12
RWPL01	100.0	0.3	30.7	64.9	81.8	92.2	97.0	98.5	99.2	99.6	99.8	99.9	99.9
SFAS06	2653.9	20.5	220.4	114.5	107.1	104.6	103.5	103.2	103.1	103.1	103.0	103.0	103.0
DMJU08	2242.3	4.5	98.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMAS09	5379.9	15.0	626.8	102.5	105.0	105.0	105.1	105.1	105.2	105.2	105.2	105.2	105.2
BRSE11	13484.6	21.8	218.5	102.0	101.8	101.5	101.4	101.4	101.4	101.4	101.4	101.4	101.4
MSMN12	537.3	0.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFRO13	220.1	27.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFNU16	1725.4	2.9	1372.3	185.2	321.1	224.5	270.8	233.6	263.8	237.9	259.9	241.3	257.0
CAST17	2037.6	5.7	96.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFFG18	7366.8	4.3	494.6	111.0	151.2	120.2	134.5	122.9	130.7	124.1	129.7	124.8	129.1
HCAL19	2301.4	4.8	93.6	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BSBR20	1409.8	3.0	90.2	99.0	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRSB23	30399.9	22.5	336.8	106.9	112.8	108.0	110.1	108.3	109.5	108.5	109.3	108.6	109.3
BRPP27	31076.1	5.2	406.0	109.3	115.4	110.2	112.2	110.6	111.7	110.7	111.5	110.8	111.4
BRDE29	38118.2	11.2	352.6	110.2	114.7	110.5	112.2	110.8	111.7	111.0	111.6	111.0	111.5
BRGR30	43592.7	8.6	319.4	108.9	112.6	109.0	110.4	109.3	110.1	109.4	110.0	109.5	109.9
PAGR31	4576.3	17.1	97.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRAQ33	66702.3	3.9	322.3	109.2	111.3	108.8	109.7	109.0	109.5	109.1	109.4	109.1	109.4
AQAQ34	11988.9	1.3	149.6	100.6	100.3	100.3	100.3	100.3	100.3	100.3	100.3	100.3	100.3
NBCL36	15189.3	6.7	99.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBVM37	27723.7	5.5	99.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRWA41	116466.2	9.4	246.3	108.7	109.8	108.3	108.9	108.4	108.7	108.5	108.7	108.5	108.7
BRHB42	155638.4	12.7	209.0	106.4	107.2	106.2	106.6	106.3	106.5	106.3	106.4	106.3	106.4
SADL44	1975.0	8.0	97.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEGT47	5700.6	0.5	636.0	109.6	101.9	100.5	100.2	100.1	100.0	100.0	100.0	100.0	100.0
COPI48	21397.2	7.6	189.6	101.3	100.3	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEBE49	7595.6	5.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LAKE50	39383.9	1.1	206.4	101.7	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LABE52	13135.1	11.7	100.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRLR53	25229.4	0.4	128.6	103.1	100.6	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0
NGGE54	78574.7	5.5	162.6	101.8	100.3	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SGGE55	4397.3	1.0	261.8	100.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
GALA57	3433.9	11.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRCA58	18227.7	6.0	153.6	100.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRBR59	133094.0	9.7	143.4	101.1	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
MYDB60	334336.8	14.3	166.8	103.4	103.4	102.9	103.0	102.9	103.0	102.9	103.0	102.9	102.9
EYDB61	5381.8	4.8	98.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DCLY63	5326.7	8.0	98.0	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAGR64	5333.2	5.3	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BGFR65	8073.7	5.5	99.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAEA66	3841.2	5.7	99.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NABR67	30221.5	3.0	141.6	101.5	100.8	100.8	100.8	100.8	100.8	100.8	100.8	100.8	100.8
BRHE68	33730.7	6.7	136.4	101.3	100.7	100.7	100.7	100.7	100.7	100.7	100.7	100.7	100.7
BRRI70	486485.3	17.6	150.5	102.5	102.5	102.1	102.2	102.1	102.2	102.1	102.2	102.2	102.2
BGNE71	515766.2	18.7	145.3	102.7	102.3	102.0	102.1	102.0	102.0	102.0	102.0	102.0	102.0
BRRO72	2477.5	8.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CBALC2	525369.6	14.4	144.3	102.3	102.3	101.9	102.0	101.9	102.0	101.9	102.0	101.9	102.0

Table 4.15 (Continued)

Control Point	Gaged Flow	Regulated Flow as Percentage of Gaged Flow : Mean							
		13	14	15	16	17	18	19	20
	(ac-ft/month)								
RWPL01	100.0	99.9	99.9	99.9	99.9	100.0	100.0	100.0	100.0
SFAS06	2653.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMJU08	2242.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMAS09	5379.9	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRSE11	13484.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
MSMN12	537.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFRO13	220.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFNU16	1725.4	156.1	125.1	111.7	105.5	102.6	101.2	100.6	100.3
CAST17	2037.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFFG18	7366.8	105.6	103.1	101.5	100.7	100.3	100.2	100.1	100.0
HCAL19	2301.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BSBR20	1409.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRSB23	30399.9	100.9	100.5	100.2	100.1	100.1	100.0	100.0	100.0
BRPP27	31076.1	101.0	100.5	100.2	100.1	100.0	100.0	100.0	100.0
BRDE29	38118.2	101.1	100.4	100.2	100.1	100.0	100.0	100.0	100.0
BRGR30	43592.7	100.9	100.4	100.2	100.1	100.0	100.0	100.0	100.0
PAGR31	4576.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRAQ33	66702.3	100.8	100.2	100.1	100.0	100.0	100.0	100.0	100.0
AQAQ34	11988.9	100.1	100.1	100.1	100.1	100.1	100.0	100.0	100.0
NBCL36	15189.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBVM37	27723.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRWA41	116466.2	100.5	100.2	100.1	100.0	100.0	100.0	100.0	100.0
BRHB42	155638.4	100.3	100.1	100.1	100.0	100.0	100.0	100.0	100.0
SADL44	1975.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEHS45	5700.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEGT47	21397.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
COPI48	7595.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEBE49	39383.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LAKE50	13135.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LABE52	25229.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRLR53	78574.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NGGE54	4397.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SGGE55	3433.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
GALA57	18227.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRCA58	133094.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRBR59	334336.8	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0
MYDB60	5381.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EYDB61	5326.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DCLY63	5333.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAGR64	8073.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BGFR65	3841.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAEA66	30221.5	100.4	100.2	100.1	100.1	100.0	100.0	100.0	100.0
NABR67	33730.7	100.3	100.2	100.1	100.1	100.0	100.0	100.0	100.0
BRHE68	486485.3	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRRI70	515766.2	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0
BGNE71	2477.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRRO72	525369.6	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0
CBALC2	7168.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.16 98% Regulated Flow at the 48 Control Points as a Percentage of 98% Gaged Flow

Control Point	Gaged Flow (ac-ft/month)	98% Regulated Flow as Percentage of 98% Gaged Flow at Each Iteration											
		1	2	3	4	5	6	7	8	9	10	11	12
RWPL01	0.0	-	-	-	-	-	-	-	-	-	-	-	-
SFAS06	0.6	38083.3	84388.3	4455.0	1.7	0.0	0.0	0.0	0.0	3.3	38.3	100.0	100.0
DMJU08	0.0	-	-	-	-	-	-	-	-	-	-	-	-
DMAS09	0.0	-	-	-	-	-	-	-	-	-	-	-	-
BRSE11	87.3	1387.7	1455.6	244.3	241.5	244.9	245.3	245.5	245.5	245.6	245.6	245.5	245.5
MSMN12	0.0	-	-	-	-	-	-	-	-	-	-	-	-
CFRO13	0.0	-	-	-	-	-	-	-	-	-	-	-	-
CFNU16	0.0	-	-	-	-	-	-	-	-	-	-	-	-
CAST17	1.8	1236.1	442.2	159.4	108.9	102.8	102.8	102.8	102.8	102.8	102.8	102.8	102.8
CFFG18	0.0	-	-	-	-	-	-	-	-	-	-	-	-
HCAL19	0.0	-	-	-	-	-	-	-	-	-	-	-	-
BSBR20	0.0	-	-	-	-	-	-	-	-	-	-	-	-
BRSB23	18.4	13554.5	54513.8	8952.6	9036.3	8608.8	8245.0	8724.8	7041.3	9049.2	6413.1	9322.6	6056.5
BRPP27	2468.1	12.0	596.1	147.5	166.9	165.9	161.4	168.2	157.8	169.7	155.1	170.5	152.8
BRDE29	1881.5	22.0	786.4	193.1	201.2	218.8	195.3	225.1	192.0	228.9	189.3	231.4	187.3
BRGR30	1033.0	0.0	1276.0	297.8	307.3	290.9	286.8	299.5	275.1	307.5	265.8	313.9	260.6
PAGR31	0.0	-	-	-	-	-	-	-	-	-	-	-	-
BRAQ33	1598.7	4.2	1581.3	387.9	588.4	479.5	541.8	483.7	539.9	483.5	539.9	482.9	540.2
AQAQ34	2.4	0.0	2597.1	2360.0	2385.0	2385.0	2385.0	2385.0	2385.0	2385.0	2385.0	2385.0	2385.0
NBCL36	24.6	5.1	7.9	10.0	92.5	87.4	86.3	99.1	115.7	118.5	119.0	119.0	118.7
NBVM37	209.1	127.9	34.5	35.8	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRWA41	2496.4	0.0	1316.8	507.9	577.5	570.9	565.2	578.6	560.6	582.2	557.7	584.5	556.1
BRHB42	7476.9	57.2	516.3	246.3	261.2	251.8	255.7	252.8	254.4	253.0	253.8	253.0	253.2
SADL44	0.0	-	-	-	-	-	-	-	-	-	-	-	-
LEHS45	0.0	-	-	-	-	-	-	-	-	-	-	-	-
LEGT47	146.3	197.1	1034.0	265.3	130.7	115.0	111.5	103.7	101.8	100.8	100.4	100.2	100.2
COPI48	0.0	-	-	-	-	-	-	-	-	-	-	-	-
LEBE49	498.1	0.0	387.1	166.9	117.4	111.0	105.1	102.6	101.1	100.5	100.3	100.1	100.0
LAKE50	708.4	122.7	105.7	102.9	100.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LABE52	136.7	0.0	200.9	258.1	246.6	246.5	246.5	246.5	246.5	246.5	246.5	246.5	246.5
LRLR53	3358.5	37.8	199.4	114.0	108.0	105.8	105.4	105.2	105.0	105.0	105.0	105.0	105.0
NGGE54	26.3	2.2	124.4	124.3	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SGGE55	9.5	863.6	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7
GALA57	291.5	2.8	129.1	100.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRCA58	5890.5	72.9	149.8	100.9	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRBR59	15581.7	88.5	360.6	164.7	172.4	171.6	169.5	172.1	168.8	172.5	168.4	172.7	168.1
MYDB60	181.6	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EYDB61	626.3	20.9	92.9	99.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DCLY63	0.0	-	-	-	-	-	-	-	-	-	-	-	-
NAGR64	0.0	-	-	-	-	-	-	-	-	-	-	-	-
BGFR65	0.0	-	-	-	-	-	-	-	-	-	-	-	-
NAEA66	660.9	3.2	149.8	130.0	130.0	130.0	130.0	130.0	130.0	129.9	129.9	129.9	129.9
NABR67	793.3	11.0	231.2	174.5	158.5	157.5	157.4	157.4	157.4	157.4	157.4	157.4	157.4
BRHE68	27694.0	90.1	240.7	129.6	138.9	137.7	137.3	138.0	137.0	138.2	136.9	138.3	136.8
BRRI70	32170.4	103.4	214.7	144.2	131.5	131.7	130.5	132.0	130.1	132.1	129.9	132.2	129.8
BGNE71	72.5	151.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRRO72	25234.5	39.5	247.0	150.5	144.5	144.2	143.2	144.6	142.8	144.9	142.6	145.1	142.4
CBALC2	89.5	259.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.16 (Continued)

Control Point	Gaged Flow (ac-ft/month)	98% Regulated Flow as Percentage of 98% Gaged Flow at Each Iteration							
		13	14	15	16	17	18	19	20
RWPL01	0.0	-	-	-	-	-	-	-	-
SFAS06	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DMJU08	0.0	-	-	-	-	-	-	-	-
DMAS09	0.0	-	-	-	-	-	-	-	-
BRSE11	87.3	124.2	102.6	100.2	100.0	100.0	100.0	100.0	100.0
MSMN12	0.0	-	-	-	-	-	-	-	-
CFRO13	0.0	-	-	-	-	-	-	-	-
CFNU16	0.0	-	-	-	-	-	-	-	-
CAST17	1.8	102.8	102.8	102.8	102.8	102.8	102.8	102.8	102.8
CFFG18	0.0	-	-	-	-	-	-	-	-
HCAL19	0.0	-	-	-	-	-	-	-	-
BSBR20	0.0	-	-	-	-	-	-	-	-
BRSB23	18.4	2441.3	1636.3	1049.3	598.8	354.6	386.8	267.9	225.2
BRPP27	2468.1	111.3	104.7	102.1	101.2	100.7	100.2	99.8	99.7
BRDE29	1881.5	113.3	104.2	100.8	100.3	100.4	100.5	100.4	100.5
BRGR30	1033.0	144.2	123.2	109.8	104.8	102.5	103.0	101.8	101.2
PAGR31	0.0	-	-	-	-	-	-	-	-
BRAQ33	1598.7	147.6	111.6	104.0	101.7	101.3	101.1	101.2	101.0
AQAQ34	2.4	2014.6	1707.9	1455.4	1135.0	632.1	279.2	250.0	250.0
NBCL36	24.6	118.8	118.7	118.6	118.3	118.2	123.8	113.2	96.6
NBVM37	209.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRWA41	2496.4	144.2	112.2	104.4	102.0	100.9	100.0	100.1	100.1
BRHB42	7476.9	114.6	104.6	101.8	100.8	100.4	100.4	100.2	100.2
SADL44	0.0	-	-	-	-	-	-	-	-
LEHS45	0.0	-	-	-	-	-	-	-	-
LEGT47	146.3	100.1	100.1	100.1	100.2	100.1	100.1	100.1	100.1
COPI48	0.0	-	-	-	-	-	-	-	-
LEBE49	498.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LAKE50	708.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LABE52	136.7	246.6	242.0	235.4	229.5	219.4	209.9	196.9	186.8
LRLR53	3358.5	104.5	104.1	103.8	103.4	103.1	102.9	102.6	102.4
NGGE54	26.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SGGE55	9.5	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7
GALA57	291.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRCA58	5890.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRBR59	15581.7	106.8	102.2	100.9	100.4	100.2	100.2	100.1	100.0
MYDB60	181.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EYDB61	626.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DCLY63	0.0	-	-	-	-	-	-	-	-
NAGR64	0.0	-	-	-	-	-	-	-	-
BGFR65	0.0	-	-	-	-	-	-	-	-
NAEA66	660.9	122.4	117.0	110.0	104.7	103.9	103.4	102.2	101.3
NABR67	793.3	140.5	125.2	120.1	114.9	108.8	105.0	102.8	101.6
BRHE68	27694.0	103.3	101.0	100.5	100.3	100.2	100.1	100.1	100.1
BRRI70	32170.4	102.8	100.9	100.4	100.2	100.1	100.1	100.1	100.0
BGNE71	72.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRRO72	25234.5	108.4	104.8	104.4	104.3	104.2	104.1	104.0	100.1
CBALC2	89.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.17 90% Regulated Flow at the 48 Control Points as a Percentage of 90% Gaged Flow

Control Point	Gaged Flow (ac-ft/month)	90% Regulated Flow as Percentage of 90% Gaged Flow at Each Iteration											
		1	2	3	4	5	6	7	8	9	10	11	12
RWPL01	0.0	-	-	-	-	-	-	-	-	-	-	-	-
SFAS06	13.5	1710.8	11167.6	1254.7	424.9	500.1	432.7	417.5	417.8	418.5	418.9	418.7	419.3
DMJU08	0.0	-	-	-	-	-	-	-	-	-	-	-	-
DMAS09	61.5	153.3	1959.3	394.0	559.7	599.8	599.8	599.8	599.8	599.8	599.8	599.8	599.8
BRSE11	252.1	491.2	2320.6	246.4	246.8	238.2	220.0	218.0	215.8	214.4	213.3	212.1	211.0
MSMN12	0.0	-	-	-	-	-	-	-	-	-	-	-	-
CFRO13	0.0	-	-	-	-	-	-	-	-	-	-	-	-
CFNU16	12.3	57.9	20065.7	4735.1	14186.7	5298.2	10603.3	5058.5	7749.4	5086.2	5760.7	4799.7	4382.4
CAST17	8.0	482.8	193.1	119.6	110.3	100.8	99.8	99.8	99.8	99.8	99.8	99.8	99.8
CFFG18	36.9	0.0	9399.5	1968.2	4631.2	2646.4	3690.1	2722.4	2353.2	2860.0	1901.9	2836.4	1581.5
HCAL19	0.0	-	-	-	-	-	-	-	-	-	-	-	-
BSBR20	0.0	-	-	-	-	-	-	-	-	-	-	-	-
BRSB23	362.8	742.5	4826.7	708.5	1027.8	631.2	670.6	651.5	627.3	663.6	598.8	675.5	582.2
BRPP27	3873.7	7.8	578.9	150.2	157.0	148.2	152.4	149.4	150.0	151.1	148.3	152.3	148.4
BRDE29	4673.1	26.7	497.6	140.7	145.0	133.1	139.4	134.6	139.1	136.3	139.0	137.5	139.0
BRGR30	1783.1	0.0	1268.5	224.1	219.0	203.9	209.4	206.4	207.1	209.9	204.4	212.3	202.2
PAGR31	110.7	212.5	117.5	99.8	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRAQ33	6210.0	1.6	949.7	171.8	185.9	187.6	182.2	188.8	181.0	189.5	180.1	189.9	179.5
AQAQ34	59.5	0.0	278.2	125.5	134.2	134.2	134.2	134.2	134.2	134.2	134.2	134.2	134.2
NBCL36	116.8	2.1	142.8	125.1	91.7	102.6	100.6	100.1	100.0	100.0	100.0	100.0	100.0
NBVM37	553.4	51.0	99.7	103.5	101.4	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0
BRWA41	10698.8	9.0	779.8	174.3	199.4	190.0	193.5	190.0	193.3	190.2	193.1	190.4	193.0
BRHB42	18692.2	32.3	521.5	131.4	139.1	138.6	138.4	139.3	138.0	139.7	137.8	140.0	137.7
SADL44	0.0	-	-	-	-	-	-	-	-	-	-	-	-
LEHS45	0.0	-	-	-	-	-	-	-	-	-	-	-	-
LEGT47	504.2	84.8	441.7	150.1	113.0	109.9	104.0	100.8	100.1	100.0	100.0	100.0	100.0
COPI48	6.1	655.6	141.5	103.1	100.2	100.2	100.2	100.2	100.2	100.2	100.2	100.2	100.2
LEBE49	1186.7	0.0	292.6	130.3	105.4	101.4	100.4	100.2	100.1	100.0	100.0	100.0	100.0
LAKE50	1174.4	81.8	100.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LABE52	449.3	0.0	96.2	107.8	104.1	104.3	104.1	104.3	104.2	104.2	104.2	104.2	104.2
LRLR53	5792.1	28.2	189.6	109.2	103.6	100.4	100.1	100.0	100.0	100.0	100.0	100.0	100.0
NGGE54	89.2	0.7	100.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SGGE55	43.0	224.6	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
GALA57	387.4	6.3	128.3	102.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRCA58	8546.8	54.4	200.1	103.3	102.0	101.6	101.3	100.8	100.5	100.2	100.1	100.0	100.0
BRBR59	38054.7	55.2	370.8	118.5	123.2	121.9	122.2	122.2	122.0	122.4	121.8	122.5	121.8
MYDB60	440.9	1.4	98.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EYDB61	935.2	14.5	96.2	100.2	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DCLY63	8.0	462.5	101.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAGR64	0.0	-	-	-	-	-	-	-	-	-	-	-	-
BGFR65	0.0	-	-	-	-	-	-	-	-	-	-	-	-
NAEA66	905.7	2.8	214.9	158.0	146.3	146.3	146.3	146.3	146.5	146.6	146.6	146.3	146.3
NABR67	1465.2	8.8	202.1	135.6	132.5	132.4	132.4	132.4	132.4	132.4	132.4	132.4	132.4
BRHE68	50235.4	93.9	362.3	127.4	125.6	122.6	125.2	122.6	125.1	122.6	125.1	122.7	125.0
BRRI70	50665.8	109.9	328.8	136.7	121.1	120.8	120.6	121.0	120.4	121.1	120.3	121.2	120.3
BGNE71	97.8	134.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRRO72	50419.8	66.8	306.6	126.1	124.5	123.8	123.5	123.7	123.2	123.5	123.1	123.6	123.0
CBALC2	386.1	88.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.17 (Continued)

Control Point	Gaged Flow (ac-ft/month)	90% Regulated Flow as Percentage of 90% Gaged Flow at Each Iteration							
		13	14	15	16	17	18	19	20
RWPL01	0.0	-	-	-	-	-	-	-	-
SFAS06	13.5	99.6	99.6	99.6	99.6	99.6	99.6	99.6	99.6
DMJU08	0.0	-	-	-	-	-	-	-	-
DMAS09	61.5	127.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRSE11	252.1	103.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0
MSMN12	0.0	-	-	-	-	-	-	-	-
CFRO13	0.0	-	-	-	-	-	-	-	-
CFNU16	12.3	3754.6	2083.4	1910.7	1340.0	809.2	517.6	321.1	211.1
CAST17	8.0	99.8	99.8	99.8	99.8	99.8	99.8	99.8	99.8
CFFG18	36.9	1782.0	1142.6	648.5	340.2	238.5	186.6	138.0	121.5
HCAL19	0.0	-	-	-	-	-	-	-	-
BSBR20	0.0	-	-	-	-	-	-	-	-
BRSB23	362.8	250.2	142.3	112.7	104.0	106.3	107.0	106.1	106.8
BRPP27	3873.7	108.0	106.3	100.8	100.3	100.2	100.0	100.0	100.0
BRDE29	4673.1	106.5	99.0	99.9	99.8	99.8	99.9	100.0	100.0
BRGR30	1783.1	118.5	107.8	102.6	101.1	100.3	100.1	100.0	100.0
PAGR31	110.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRAQ33	6210.0	122.1	104.6	100.0	99.9	99.9	99.9	100.0	100.0
AQAQ34	59.5	126.5	124.0	124.0	108.5	108.3	108.1	108.0	107.9
NBCL36	116.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBVM37	553.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRWA41	10698.8	110.1	103.2	101.1	100.5	100.2	100.1	100.1	100.0
BRHB42	18692.2	104.2	100.8	100.2	100.1	100.0	100.0	100.0	100.0
SADL44	0.0	-	-	-	-	-	-	-	-
LEHS45	0.0	-	-	-	-	-	-	-	-
LEGT47	504.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
COPI48	6.1	100.2	100.2	100.2	100.2	100.2	100.2	100.2	100.2
LEBE49	1186.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LAKE50	1174.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LABE52	449.3	104.2	104.2	104.2	104.2	104.2	103.7	102.2	100.7
LRLR53	5792.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NGGE54	89.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SGGE55	43.0	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
GALA57	387.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRCA58	8546.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRBR59	38054.7	101.4	100.3	100.1	100.0	100.1	100.1	100.0	100.1
MYDB60	440.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EYDB61	935.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DCLY63	8.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAGR64	0.0	-	-	-	-	-	-	-	-
BGFR65	0.0	-	-	-	-	-	-	-	-
NAEA66	905.7	145.8	120.3	110.6	102.7	102.7	102.7	102.7	102.7
NABR67	1465.2	102.8	101.8	101.8	101.8	100.3	100.2	100.1	100.1
BRHE68	50235.4	103.6	101.8	100.9	100.6	100.4	100.3	100.3	100.2
BRRI70	50665.8	103.3	101.1	101.1	101.1	101.1	101.1	100.9	100.2
BGNE71	97.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRRO72	50419.8	104.1	103.0	100.8	100.4	100.2	100.1	100.1	100.1
CBALC2	386.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.18 75% Regulated Flow at the 48 Control Points as a Percentage of 75% Gaged Flow

Control	Gaged	75% Regulated Flow as Percentage of 75% Gaged Flow at Each Iteration											
Point	Flow (ac-ft/month)	1	2	3	4	5	6	7	8	9	10	11	12
RWPL01	2.5	0.0	11.6	18.8	26.8	34.0	38.4	43.2	47.6	51.6	55.2	58.8	62.0
SFAS06	159.9	178.2	1863.6	277.3	246.4	197.1	162.1	160.4	155.0	151.9	152.0	157.6	160.4
DMJU08	5.5	36.9	143.5	99.3	86.2	92.7	96.0	97.6	98.4	99.3	99.3	99.3	99.3
DMAS09	547.2	28.2	4752.2	111.6	119.5	121.6	121.8	122.0	122.4	122.7	121.4	121.4	121.5
BRSE11	2016.8	65.9	829.5	107.2	106.8	106.7	106.7	106.7	106.7	106.7	106.7	106.7	106.7
MSMN12	0.0	-	-	-	-	-	-	-	-	-	-	-	-
CFRO13	0.0	-	-	-	-	-	-	-	-	-	-	-	-
CFNU16	104.5	10.3	7809.7	1056.6	2133.7	1147.1	1859.3	1090.3	1712.7	1087.1	1553.7	1087.4	1410.5
CAST17	48.6	101.0	107.3	100.7	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFFG18	633.3	0.0	1849.2	176.4	416.7	226.4	367.6	247.3	326.4	276.2	315.7	293.1	312.9
HCAL19	0.0	-	-	-	-	-	-	-	-	-	-	-	-
BSBR20	0.0	-	-	-	-	-	-	-	-	-	-	-	-
BRSB23	3750.7	89.6	769.9	141.0	190.2	149.5	171.5	153.8	165.5	154.3	162.1	155.8	159.8
BRPP27	6739.0	5.7	734.7	137.9	153.6	139.7	146.5	141.8	145.5	143.1	144.3	143.9	143.4
BRDE29	7378.5	29.4	733.4	143.0	160.3	144.1	152.6	147.7	152.7	147.8	152.5	147.9	152.1
BRGR30	3258.8	9.1	1610.0	181.6	206.5	178.8	193.8	182.5	191.3	184.9	189.9	186.7	189.7
PAGR31	498.0	81.1	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRAQ33	13957.7	1.6	580.5	138.2	140.3	134.1	134.2	134.9	133.7	135.5	133.5	135.9	133.3
AQAQ34	141.4	0.0	1230.4	139.2	139.2	139.2	139.2	139.2	139.2	139.2	139.2	139.2	139.2
NBCL36	547.2	57.9	96.1	97.9	99.5	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBVM37	1106.8	49.9	104.0	101.0	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRWA41	25456.0	10.2	523.8	132.9	134.8	132.1	134.5	132.4	132.5	132.0	132.0	132.0	131.7
BRHB42	35847.0	24.0	434.0	115.2	120.7	117.5	120.2	117.3	119.9	117.2	119.7	117.1	119.6
SADL44	22.1	176.2	142.9	102.0	100.4	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
LEHS45	0.0	-	-	-	-	-	-	-	-	-	-	-	-
LEGT47	1617.1	33.2	938.7	122.6	104.0	101.6	100.7	100.3	100.2	100.1	100.1	100.0	100.0
COPI48	221.4	43.4	100.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEBE49	1764.7	0.4	1089.1	120.8	105.2	102.6	100.7	100.0	100.0	100.0	100.0	100.0	100.0
LAKE50	1666.3	60.9	99.9	99.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LABE52	806.5	0.0	105.7	100.5	100.5	100.5	100.1	99.9	100.1	99.9	100.1	99.9	100.1
LRLR53	8208.6	31.0	346.4	100.7	100.2	100.1	99.9	99.8	100.0	100.0	100.0	100.0	100.0
NGGE54	156.8	0.8	161.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SGGE55	172.8	90.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
GALA57	1076.0	3.9	148.4	100.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRCA58	15310.4	38.0	240.0	102.5	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRBR59	61862.7	41.0	352.9	118.2	121.6	117.6	119.7	118.8	118.9	119.1	118.8	119.2	118.6
MYDB60	661.0	2.9	98.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EYDB61	1268.5	20.6	93.5	98.6	101.1	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DCLY63	140.2	28.8	104.8	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAGR64	0.6	8053.3	8025.0	8020.0	7333.3	6166.7	4250.0	2050.0	2050.0	1233.3	200.0	200.0	200.0
BGFR65	91.0	20.0	88.0	98.2	99.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAEA66	1719.8	2.8	334.4	115.0	112.2	112.2	112.2	112.2	112.2	112.2	112.2	112.2	112.2
NABR67	2763.3	13.3	323.0	110.0	108.3	108.4	108.4	108.4	108.4	108.4	108.4	108.4	108.4
BRHE68	92662.0	53.7	287.7	112.0	117.0	115.5	116.5	115.5	116.5	115.5	116.5	115.5	116.4
BRRI70	89464.5	69.6	309.0	114.4	116.8	116.3	116.0	116.3	116.0	116.3	116.0	116.3	116.0
BGNE71	175.2	93.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRRO72	95429.0	46.1	275.9	116.9	113.8	112.1	113.1	112.2	113.1	112.1	113.0	112.1	113.1
CBALC2	1090.8	60.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.18 (Continued)

Control Point	Gaged Flow (ac-ft/month)	75% Regulated Flow as Percentage of 75% Gaged Flow at Each Iteration							
		13	14	15	16	17	18	19	20
RWPL01	2.5	64.8	67.6	70.4	72.4	74.4	76.8	85.2	92.0
SFAS06	159.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMJU08	5.5	99.3	99.3	99.3	99.3	99.3	99.3	99.3	99.3
DMAS09	547.2	92.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRSE11	2016.8	100.4	100.1	100.0	100.0	100.0	100.0	100.0	100.0
MSMN12	0.0	-	-	-	-	-	-	-	-
CFRO13	0.0	-	-	-	-	-	-	-	-
CFNU16	104.5	722.4	531.8	296.4	216.3	149.4	118.8	107.4	109.6
CAST17	48.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFFG18	633.3	142.8	122.7	124.1	110.1	103.4	100.2	100.0	100.0
HCAL19	0.0	-	-	-	-	-	-	-	-
BSBR20	0.0	-	-	-	-	-	-	-	-
BRSB23	3750.7	92.5	95.9	98.5	99.5	99.8	99.9	100.0	100.0
BRPP27	6739.0	107.2	103.5	101.7	100.8	100.4	100.2	100.3	100.2
BRDE29	7378.5	110.3	105.7	102.4	101.0	100.4	100.2	100.1	100.0
BRGR30	3258.8	121.2	112.2	102.9	102.7	101.4	101.5	100.9	100.5
PAGR31	498.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRAQ33	13957.7	106.0	101.4	100.8	100.4	100.2	100.1	100.1	100.0
AQAQ34	141.4	126.9	126.9	126.9	126.9	126.9	122.7	113.1	113.1
NBCL36	547.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBVM37	1106.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRWA41	25456.0	101.3	100.3	100.1	100.0	100.0	100.0	100.0	100.0
BRHB42	35847.0	100.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SADL44	22.1	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9
LEHS45	0.0	-	-	-	-	-	-	-	-
LEGT47	1617.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
COPI48	221.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEBE49	1764.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LAKE50	1666.3	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LABE52	806.5	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRLR53	8208.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NGGE54	156.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SGGE55	172.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
GALA57	1076.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRCA58	15310.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRBR59	61862.7	101.3	100.7	100.2	100.1	100.0	100.0	100.0	100.0
MYDB60	661.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EYDB61	1268.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DCLY63	140.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAGR64	0.6	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0
BGFR65	91.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAEA66	1719.8	109.0	104.5	103.5	101.1	100.5	100.5	100.5	100.4
NABR67	2763.3	105.9	105.9	105.9	105.5	102.9	101.4	100.6	100.1
BRHE68	92662.0	100.2	100.0	100.1	100.1	100.1	100.0	100.0	100.0
BRRI70	89464.5	101.6	100.6	100.3	100.2	100.2	100.2	100.2	100.2
BGNE71	175.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRRO72	95429.0	100.7	100.6	100.3	100.2	100.1	100.1	100.0	100.0
CBALC2	1090.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.19 50% Regulated Flow at the 48 Control Points as a Percentage of 50% Gaged Flow

Control	Gaged	50% Regulated Flow as Percentage of 50% Gaged Flow at Each Iteration											
Point	Flow	1	2	3	4	5	6	7	8	9	10	11	12
	(ac-ft/month)												
RWPL01	19.7	0.0	8.6	15.4	22.3	29.4	52.2	59.9	67.3	78.2	83.0	87.8	96.8
SFAS06	720.0	43.6	639.0	159.0	123.8	114.9	114.9	114.9	114.9	114.9	114.9	114.9	114.9
DMJU08	443.9	2.1	96.7	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMAS09	1746.2	18.4	1931.5	109.1	124.1	124.9	125.2	125.3	125.3	125.4	125.4	125.4	125.4
BRSE11	5220.3	36.3	474.7	105.0	102.0	101.0	101.0	101.0	101.0	101.0	101.0	101.0	101.0
MSMN12	0.6	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFRO13	0.6	6743.3	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0
CFNU16	325.9	8.6	6790.5	553.3	950.1	592.4	888.9	655.9	880.5	695.3	884.6	742.6	894.1
CAST17	154.3	39.4	105.6	98.1	99.7	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFFG18	1561.8	0.7	2327.9	136.1	323.1	161.9	249.4	174.9	222.1	174.3	219.5	175.1	215.5
HCAL19	61.5	73.4	117.1	102.5	100.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BSBR20	17.9	0.0	67.9	90.8	96.3	98.9	99.6	100.0	100.0	100.0	100.0	100.0	100.0
BRSB23	10176.2	37.1	752.1	110.8	121.7	110.4	118.8	110.3	117.0	112.3	116.4	113.7	115.9
BRPP27	12494.3	3.6	729.8	118.8	134.5	118.5	127.9	118.5	123.6	120.1	123.9	120.3	123.8
BRDE29	13281.3	22.4	723.3	129.9	136.0	126.6	135.5	127.3	135.0	127.8	134.9	128.0	134.2
BRGR30	8731.2	12.4	1130.1	142.4	148.9	140.1	139.6	140.4	138.3	140.9	137.5	141.1	137.4
PAGR31	1192.9	49.9	95.3	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRAQ33	25763.3	2.1	615.7	118.8	126.2	120.2	125.8	120.5	124.4	120.6	124.6	120.7	124.6
AQAQ34	1549.5	1.4	570.8	104.6	104.6	104.6	104.6	104.6	104.6	104.6	104.6	104.6	104.6
NBCL36	2822.3	24.6	98.4	99.3	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBVM37	4119.7	29.4	93.2	99.8	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRWA41	53248.3	11.7	381.6	116.4	122.7	116.5	121.9	117.7	119.2	118.4	118.7	118.8	118.3
BRHB42	67083.0	16.5	327.3	114.9	115.4	113.4	114.7	113.6	114.6	113.6	114.5	113.6	114.5
SADL44	283.5	26.8	95.8	99.8	100.0	100.0	99.5	99.6	100.0	100.0	100.0	100.0	100.0
LEHS45	60.0	1.4	58447.1	1253.8	301.4	157.1	111.5	101.9	101.7	101.6	101.7	101.7	101.7
LEGT47	5398.6	16.1	531.0	110.2	102.6	100.3	100.1	100.0	100.0	100.0	100.0	100.0	100.0
COPI48	1801.6	9.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEBE49	5029.7	0.4	794.4	106.1	101.0	100.3	100.1	100.0	100.0	100.0	100.0	100.0	100.0
LAKE50	4765.3	26.6	104.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LABE52	9244.7	0.2	96.9	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRLR53	30153.5	10.5	205.9	103.2	100.3	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NGGE54	357.2	0.8	1951.2	105.2	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SGGE55	1247.6	17.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
GALA57	6849.7	9.3	260.1	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRCA58	54416.5	15.6	185.2	101.7	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRBR59	139263.3	20.8	254.2	105.5	106.0	104.0	104.4	103.9	104.4	103.9	104.4	103.9	104.4
MYDB60	1307.8	21.0	98.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EYDB61	2021.1	18.2	93.8	99.2	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DCLY63	941.4	24.6	100.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAGR64	386.1	14.8	134.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BGFR65	726.2	18.3	95.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAEA66	3804.2	13.2	613.9	114.3	112.4	112.4	112.4	112.4	112.4	112.4	112.4	112.4	112.1
NABR67	7010.2	20.0	350.3	106.2	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRHE68	235313.0	24.7	196.3	104.1	104.8	104.3	104.6	104.3	104.6	104.2	104.6	104.2	104.7
BRRI70	259662.0	27.2	184.6	102.5	102.4	102.4	102.3	102.4	102.3	102.4	102.3	102.4	102.3
BGNE71	768.0	22.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRRO72	295325.0	19.8	167.2	102.1	102.6	101.8	102.1	101.8	102.0	101.8	102.0	101.8	102.0
CBALC2	3054.7	41.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.19 (Continued)

Control Point	Gaged Flow (ac-ft/month)	50% Regulated Flow as Percentage of 50% Gaged Flow at Each Iteration							
		13	14	15	16	17	18	19	20
RWPL01	19.7	97.1	99.7	99.9	99.9	99.9	99.9	99.9	99.9
SFAS06	720.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMJU08	443.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMAS09	1746.2	101.6	100.3	100.1	100.1	100.1	100.1	100.1	100.0
BRSE11	5220.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
MSMN12	0.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFRO13	0.6	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0
CFNU16	325.9	397.0	257.9	171.1	128.4	114.0	105.8	101.8	99.9
CAST17	154.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFFG18	1561.8	126.1	113.2	104.3	99.8	99.9	100.0	100.0	100.0
HCAL19	61.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BSBR20	17.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRSB23	10176.2	99.9	99.8	99.9	100.0	100.0	100.0	100.0	100.0
BRPP27	12494.3	100.9	100.7	100.4	100.4	100.2	100.1	100.0	100.0
BRDE29	13281.3	103.4	99.0	99.4	99.8	100.0	100.0	100.0	100.0
BRGR30	8731.2	110.0	103.9	101.7	100.8	100.3	100.2	100.1	100.0
PAGR31	1192.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRAQ33	25763.3	101.6	101.2	100.3	99.9	100.0	100.0	100.0	100.0
AQAQ34	1549.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBCL36	2822.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBVM37	4119.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRWA41	53248.3	104.0	102.0	100.9	100.4	100.2	100.1	100.0	100.0
BRHB42	67083.0	101.1	100.4	100.2	100.1	100.0	100.0	100.0	100.0
SADL44	283.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEHS45	60.0	101.6	101.7	101.6	101.7	101.7	101.7	101.6	101.6
LEGT47	5398.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
COPI48	1801.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEBE49	5029.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LAKE50	4765.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LABE52	9244.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRLR53	30153.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NGGE54	357.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SGGE55	1247.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
GALA57	6849.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRCA58	54416.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRBR59	139263.3	100.2	100.2	100.1	100.0	100.0	100.0	100.0	100.0
MYDB60	1307.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EYDB61	2021.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DCLY63	941.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAGR64	386.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BGFR65	726.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAEA66	3804.2	102.7	100.4	100.0	100.0	100.0	100.0	100.0	100.0
NABR67	7010.2	99.9	99.9	100.0	100.0	100.0	100.0	100.0	100.0
BRHE68	235313.0	101.5	100.4	100.1	100.1	100.0	100.0	100.0	100.0
BRRI70	259662.0	100.3	100.1	100.1	100.1	100.1	100.0	100.0	100.0
BGNE71	768.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRRO72	295325.0	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CBALC2	3054.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.20 25% Regulated Flow at the 48 Control Points as a Percentage of 25% Gaged Flow

Control Point	Gaged Flow (ac-ft/month)	25% Regulated Flow as Percentage of 25% Gaged Flow at Each Iteration											
		1	2	3	4	5	6	7	8	9	10	11	12
RWPL01	62.7	0.5	9.1	20.8	40.8	64.8	93.5	97.2	98.8	105.5	110.0	112.0	111.9
SFAS06	3077.5	15.7	216.8	101.5	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMJU08	2211.7	7.3	96.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMAS09	5620.0	14.2	780.2	99.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRSE11	14302.0	20.4	232.5	101.2	100.8	100.8	100.8	100.8	100.8	100.8	100.8	100.8	100.8
MSMN12	71.9	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFRO13	15.4	371.6	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7
CFNU16	1383.5	3.4	2321.2	195.2	407.8	213.3	305.8	233.8	273.3	250.2	271.9	272.1	272.2
CAST17	962.9	10.5	86.0	99.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFFG18	5693.8	1.3	871.4	110.3	202.0	125.4	161.0	134.8	161.5	136.9	161.9	136.7	162.3
HCAL19	657.9	20.8	92.8	99.4	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BSBR20	297.5	4.7	91.7	99.2	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRSB23	23912.5	23.5	605.1	115.6	132.9	113.3	119.2	113.4	119.1	116.7	119.0	116.8	118.9
BRPP27	25566.5	4.5	710.3	111.1	115.5	112.2	113.9	112.1	114.1	112.1	114.2	112.1	114.2
BRDE29	28899.2	15.6	634.2	119.9	123.6	111.7	117.5	111.5	116.2	111.4	116.2	111.5	116.3
BRGR30	36954.1	9.3	490.2	122.3	124.5	121.2	124.3	121.2	124.1	121.3	124.0	121.3	124.0
PAGR31	4494.7	28.9	93.1	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRAQ33	54785.5	2.6	472.9	105.1	110.3	105.5	107.0	105.5	107.1	105.5	107.1	105.6	107.0
AQAQ34	12758.1	1.2	170.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBCL36	11787.2	13.7	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBVM37	16540.2	12.8	99.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRWA41	113875.0	14.3	266.8	104.0	102.1	102.2	102.0	102.3	102.0	102.3	102.0	102.3	102.0
BRHB42	157592.7	17.5	246.8	102.4	104.0	102.7	103.7	102.8	103.4	102.8	103.4	102.8	103.4
SADL44	863.0	27.2	93.4	98.9	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEHS45	246.0	1.4	20416.0	722.4	364.0	216.6	103.3	101.2	100.4	100.2	100.1	100.0	100.0
LEGT47	24877.9	8.7	180.6	100.9	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
COPI48	7563.0	9.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEBE49	55769.3	0.1	164.2	102.4	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LAKE50	10791.1	15.5	102.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LABE52	27979.3	0.3	109.4	101.0	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRLR53	98909.0	5.3	142.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NGGE54	4024.4	0.2	387.6	101.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SGGE55	4558.1	12.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
GALA57	28868.4	5.8	127.5	100.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRCA58	218834.4	8.4	117.1	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRBR59	480796.2	15.4	134.6	101.2	101.6	101.1	101.3	101.1	101.1	101.1	101.1	101.1	101.0
MYDB60	4734.5	9.9	98.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EYDB61	5409.1	10.9	103.8	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DCLY63	6210.2	7.3	100.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAGR64	9759.9	8.8	99.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BGFR65	3546.6	12.9	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAEA66	35192.4	4.8	126.3	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NABR67	53123.4	7.2	111.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRHE68	719097.5	13.9	149.5	100.6	100.7	100.5	100.7	100.5	100.6	100.6	100.6	100.6	100.6
BRRI70	741909.0	15.0	141.8	101.6	101.5	100.7	100.8	100.7	100.8	100.7	100.8	100.7	100.8
BGNE71	2824.7	9.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRRO72	775973.6	11.6	138.9	100.4	100.6	100.5	100.6	100.5	100.6	100.5	100.6	100.5	100.5
CBALC2	9430.4	17.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.20 (Continued)

Control Point	Gaged Flow (ac-ft/month)	25% Regulated Flow as Percentage of 25% Gaged Flow at Each Iteration							
		13	14	15	16	17	18	19	20
RWPL01	62.7	111.8	111.8	110.9	109.9	108.8	107.9	107.0	103.0
SFAS06	3077.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMJU08	2211.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMAS09	5620.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRSE11	14302.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
MSMN12	71.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFRO13	15.4	99.7	99.7	99.7	99.7	99.7	99.7	99.7	99.7
CFNU16	1383.5	151.0	126.2	110.7	104.5	103.3	100.8	100.4	100.2
CAST17	962.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFFG18	5693.8	107.2	108.7	107.2	101.8	99.7	99.8	99.9	99.9
HCAL19	657.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BSBR20	297.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRSB23	23912.5	101.7	101.7	101.0	100.3	100.0	100.0	100.0	100.0
BRPP27	25566.5	98.3	100.9	100.6	100.2	100.1	100.0	100.0	100.0
BRDE29	28899.2	100.9	100.2	100.2	100.1	100.0	100.0	100.0	100.0
BRGR30	36954.1	101.4	101.0	100.2	100.1	100.0	100.0	100.0	100.0
PAGR31	4494.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRAQ33	54785.5	100.6	100.3	100.2	100.1	100.0	100.0	100.0	100.0
AQAQ34	12758.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBCL36	11787.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBVM37	16540.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRWA41	113875.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRHB42	157592.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SADL44	863.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEHS45	246.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEGT47	24877.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
COPI48	7563.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEBE49	55769.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LAKE50	10791.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LABE52	27979.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRLR53	98909.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NGGE54	4024.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SGGE55	4558.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
GALA57	28868.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRCA58	218834.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRBR59	480796.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
MYDB60	4734.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EYDB61	5409.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DCLY63	6210.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAGR64	9759.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BGFR65	3546.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAEA66	35192.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NABR67	53123.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRHE68	719097.5	99.8	100.1	100.0	100.0	100.0	100.0	100.0	100.0
BRRI70	741909.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BGNE71	2824.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRRO72	775973.6	99.9	100.1	100.0	100.0	100.0	100.0	100.0	100.0
CBALC2	9430.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.21 10% Regulated Flow at the 48 Control Points as a Percentage of 10% Gaged Flow

Control	Gaged	10% Regulated Flow as Percentage of 10% Gaged Flow at Each Iteration											
Point	Flow (ac-ft/month)	1	2	3	4	5	6	7	8	9	10	11	12
RWPL01	216.4	0.6	10.6	84.2	94.5	97.6	98.9	99.5	99.8	99.9	100.0	100.0	100.0
SFAS06	7223.6	17.9	154.8	106.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMJU08	6376.9	5.3	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMAS09	11381.4	25.0	455.1	106.2	109.0	108.3	108.3	108.4	108.5	108.5	108.6	108.6	108.6
BRSE11	38128.5	17.0	153.0	100.6	100.6	100.5	100.5	100.6	100.6	100.6	100.6	100.6	100.6
MSMN12	1215.0	1.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFRO13	144.5	112.1	99.9	100.0	100.0	99.9	99.9	99.9	100.0	100.0	100.0	100.0	100.0
CFNU16	3713.9	2.3	1351.0	210.5	312.3	261.8	238.5	262.3	238.2	264.3	237.8	265.8	237.5
CAST17	4668.8	6.7	95.5	102.2	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFFG18	14246.7	11.5	507.2	110.6	124.3	105.8	118.0	107.9	118.1	107.9	118.1	107.9	118.2
HCAL19	3787.6	10.7	91.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BSBR20	3379.8	4.1	90.4	99.1	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRSB23	81440.3	23.3	249.6	101.8	107.8	103.2	105.8	103.2	105.1	103.4	105.1	103.4	105.1
BRPP27	61014.1	4.2	424.9	106.5	107.0	106.5	107.0	106.4	107.0	106.4	107.0	106.4	107.0
BRDE29	58413.2	13.6	456.4	116.3	121.2	120.0	119.1	119.9	119.2	119.8	119.2	119.8	119.2
BRGR30	103914.0	15.0	270.0	107.7	104.9	104.1	104.7	104.0	104.8	104.0	104.8	103.9	104.8
PAGR31	9887.2	15.7	99.0	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRAQ33	141728.9	3.2	296.4	105.9	108.1	104.5	104.0	104.6	104.0	104.6	104.0	104.6	104.0
AQAQ34	38380.6	1.3	117.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBCL36	42500.2	5.9	98.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBVM37	57859.8	6.4	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRWA41	262859.5	11.7	225.2	105.7	106.1	104.2	104.5	104.2	104.5	104.2	104.4	104.2	104.4
BRHB42	348142.8	14.6	194.1	101.5	104.6	100.5	101.5	101.0	101.3	101.1	101.1	101.4	101.0
SADL44	5289.5	8.9	94.9	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEHS45	14400.0	0.1	422.6	101.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEGT47	55345.0	6.6	148.1	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
COPI48	20690.6	6.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEBE49	138439.3	0.8	131.1	100.3	100.1	100.1	100.1	100.0	100.0	100.0	100.0	100.0	100.0
LAKE50	26427.4	10.3	100.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LABE52	79380.5	0.2	94.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRLR53	244702.2	3.9	109.0	100.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NGGE54	14232.5	0.2	207.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SGGE55	8077.0	9.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
GALA57	55252.8	5.1	120.3	100.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRCA58	377472.4	7.0	116.5	100.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRBR59	919609.0	11.9	135.3	102.8	102.5	102.4	102.4	102.4	102.4	102.4	102.4	102.4	102.4
MYDB60	17148.3	3.1	98.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EYDB61	13852.5	4.9	100.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DCLY63	17829.6	3.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAGR64	31772.5	4.8	101.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BGFR65	14404.1	3.6	100.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAEA66	119579.2	1.9	116.4	100.0	99.9	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NABR67	133049.3	4.4	107.5	100.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRHE68	1286075.0	14.3	125.3	100.3	100.6	100.1	100.2	100.2	100.2	100.2	100.2	100.2	100.2
BRRI70	1357154.0	15.0	128.9	102.9	103.7	102.7	102.9	102.8	102.9	102.9	102.9	102.9	102.8
BGNE71	8511.7	3.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRRO72	1464450.0	12.0	118.7	100.7	101.0	100.8	100.9	100.8	100.9	100.8	100.9	100.8	100.9
CBALC2	19910.3	9.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4.21 (Continued)

Control Point	Gaged Flow (ac-ft/month)	10% Regulated Flow as Percentage of 10% Gaged Flow at Each Iteration							
		13	14	15	16	17	18	19	20
RWPL01	216.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SFAS06	7223.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMJU08	6376.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DMAS09	11381.4	100.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRSE11	38128.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
MSMN12	1215.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFRO13	144.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFNU16	3713.9	178.6	137.9	113.6	104.9	100.4	98.7	98.3	98.2
CAST17	4668.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CFFG18	14246.7	103.8	103.1	100.7	99.5	99.7	99.8	99.9	100.0
HCAL19	3787.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BSBR20	3379.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRSB23	81440.3	100.2	100.4	100.1	100.0	100.0	100.0	100.0	100.0
BRPP27	61014.1	100.9	100.7	100.5	100.2	100.1	100.0	100.0	100.0
BRDE29	58413.2	103.8	101.1	100.4	100.3	100.1	100.1	100.0	100.0
BRGR30	103914.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
PAGR31	9887.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRAQ33	141728.9	99.8	99.5	99.8	100.0	100.0	100.0	100.0	100.0
AQAQ34	38380.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBCL36	42500.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NBVM37	57859.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRWA41	262859.5	99.3	99.8	100.0	100.0	100.0	100.0	100.0	100.0
BRHB42	348142.8	99.5	99.8	100.0	100.0	100.0	100.0	100.0	100.0
SADL44	5289.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEHS45	14400.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEGT47	55345.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
COPI48	20690.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LEBE49	138439.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LAKE50	26427.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LABE52	79380.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRLR53	244702.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NGGE54	14232.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SGGE55	8077.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
GALA57	55252.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
LRCA58	377472.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRBR59	919609.0	100.1	100.1	100.0	100.0	100.0	100.0	100.0	100.0
MYDB60	17148.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EYDB61	13852.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DCLY63	17829.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAGR64	31772.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BGFR65	14404.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NAEA66	119579.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NABR67	133049.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRHE68	1286075.0	99.6	99.8	99.9	99.9	100.0	100.0	100.0	100.0
BRRI70	1357154.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BGNE71	8511.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BRRO72	1464450.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CBALC2	19910.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Bwam8A Simulation Results

The basin summary table presented below as Table 4.22 was developed with the program *TABLES* with a 2SBA record for the *SIM* simulation with the Bwam8A DAT, EVA, and DIS files and the FLO file with the adopted naturalized flows. The mean annual volumes in the last line of Table 4.22 correspond to the final iteration 20 in Table 4.11.

Table 4.22 Annual Summary for Bwam8A Simulation with Final Adopted Naturalized Flows

	Naturalized Flow (ac-ft/yr)	Return Flow (ac-ft/yr)	Flow Depletion (ac-ft/yr)	Unappropriated		Net Evap-Prec (ac-ft/yr)	Diversion Target (ac-ft/yr)	Actual Diversion (ac-ft/yr)	Shortage (ac-ft/yr)
				Flow (ac-ft/yr)	Storage (acre-feet)				
1998	15,290,265	270,721	2,551,686	9,411,566	3,602,484	578,638	1,568,510	1,382,592	185,918
1999	3,393,795	278,642	1,812,217	2,134,353	3,009,098	541,245	1,589,966	1,310,630	279,336
2000	8,601,709	267,119	2,367,799	1,854,199	3,344,236	431,163	1,597,250	1,252,477	344,774
2001	13,684,570	278,694	2,300,169	7,608,931	3,340,252	366,373	1,567,788	1,412,753	155,035
2002	10,751,553	289,615	2,286,167	5,221,468	3,472,843	327,932	1,570,752	1,401,516	169,236
2003	6,853,309	284,468	1,950,031	4,368,417	3,089,225	451,190	1,576,217	1,355,158	221,059
2004	24,123,398	292,161	3,757,403	10,982,540	3,835,481	201,307	1,579,557	1,445,808	133,750
2005	9,545,607	286,733	2,018,485	4,929,907	3,300,310	454,348	1,569,217	1,360,846	208,371
2006	5,234,924	271,105	1,823,148	1,789,598	3,088,017	386,470	1,578,015	1,256,945	321,070
2007	32,931,514	288,946	5,121,776	15,362,143	3,670,893	814,263	1,553,413	1,459,153	94,260
Mean	13,041,063	280,820	2,598,888	6,366,312	3,375,284	455,293	1,575,069	1,363,788	211,281

The Bwam8 diversion targets in Bwam8A were developed for the original Brazos WAM current use scenario with the annual target for each individual water right set at the maximum annual in any year in the ten year period 1988-1997. The total mean diversion target, diversion, and shortage shown in Table 4.22 are 1,575,069 acre-feet/yr, 1,363,788 acre-feet/yr, and 211,281 acre-feet/yr, resulting in a volume reliability of 86.6 percent. Diversion shortages vary greatly between water rights and between months and years. The annual net evaporation-precipitation volume shown in Table 4.22 averages 445,293 acre-feet/year with significant variations between years and seasons.

The January 1998 through December 2007 sequences of monthly naturalized flows at the completion (20th iteration) of the iterative procedure discussed in the preceding section were adopted for the 77 primary control points. The 77 primary control points in the original Brazos WAM dataset include the 48 control points in the Bwam8A dataset for which gaged flow data were compiled for 1998-2007 and the 29 other control points for which gaged flow data are not available for 1998-2007. Naturalized flows at the 29 control points were computed within *SIM* as a function of flows at the 48 control points using the methodology and parameters described earlier in this chapter. The 1998-2007 naturalized flows developed in this investigation are combined with the 1940-1997 naturalized flows from the original Brazos WAM dataset to obtain a FLO file with 1940-2007 naturalized flows at 77 control points. The period-of-analysis is further lengthened in the following section 4.2 to also include 1900-1939. The 1900-2007 naturalized flow sequences at the 77 control points are plotted in Appendix A. The 1998-2007 gaged and naturalized flows at 48 control points are plotted for comparison in Appendix B. Naturalized flows for the sub-periods 1900-1939, 1940-1997, and 1998-2007 are compared in section 4.3. WRAP-SIM simulation results for the alternative hydrologic period-of-analysis are compared in section 4.4.

Program SIM and HYD Data Files

This chapter is summarized with an inventory of the *SIM* and *HYD* input files created and/or used. The Brazos WAM dataset consists of the following program *SIM* input files for the authorized use scenario (run 3) and current use scenario (run 8).

Bwam3.DAT	Bwam8.DAT
Bwam3.FLO	Bwam8.FLO
Bwam3.EVA	Bwam8.EVA
Bwam3.DIS	Bwam8.DIS

The FLO and EVA files are the same for run 3 and run 8. The FLO file contains 1940-1997 monthly naturalized flows in acre-feet/month for 77 control points. The EVA file contains 67 sequences of 1940-1997 monthly net evaporation-precipitation depths in units of feet.

The purpose of the methodology outlined in this chapter is to update the FLO and EVA files by ten years to cover the entire 816 month period from January 1940 through December 2007. The hydrologic period-of-analysis is further lengthened in section 4.2 to cover January 1900 through December 2007. The final product of the hydrology dataset update consists of the following four new files. Bwam3 and Bwam8 simulation results with the 1940-1997, 1940-2007, and 1900-2007 hydrology are present in section 4.3.

BwamExtended.FLO – 1940-2007 naturalized flows at 77 control points
BwamExtended.EVA – 1940-2007 evaporation-precipitation rates at 67 control points
BwamExtended.FLO – 1900-2007 naturalized flows at 77 control points
BwamExtended.EVA – 1900-2007 evaporation-precipitation rates at 67 control points

The following *SIM* actual use dataset with filename root Bwam8A (A for actual) was created by modifying the Bwam8 input dataset as described in section 4.1 to model actual water resources development, allocation, management, and use occurring during January 1940 through December 2007.

Bwam8A.DAT –	Bwam8.DAT file was modified to develop Bwam8A.DAT file.
Bwam8A.BES	January 1998 beginning reservoir storage contents are assigned.
Bwam8A.EVA –	1998-2007 evaporation-precipitation rates at 67 control points.
Bwam8A.DIS –	The flow distribution parameters for 3,141 control points are identical in the Bwam8.DIS and Bwam8A.DIS files. Flow distribution parameter for an additional 30 control points are included in the Bwam8A.DIS file. Naturalized flows for these 30 control points for 1940-1997 are included in the original bwam8.FLO, which includes 77 primary control points. However, 1998-2007 flows are not included in Bwam8A.FLO for these 30 control points.
Bwam8A.FLO –	Naturalized flows fro 1998-2007 at 47 control points. An initial FLO file contains 75% exceedance frequency naturalized points. However, 1998-2007 flows are not included in Bwam8A.FLO for these 30 control points.

The following HYD input files were created in the process of converting 1998-2007 gaged flows to naturalized flows at the 48 control points.

Bwam8H.HIN –	This HYD input HIN file controls the reading of SIM simulation results from the Bwam8A.OUT file, performing flows adjustments, and writing the resulting naturalized flows to the Bwam8H.FLO file.
Bwam8H.FLO –	This HYD input file contains 1998-2007 gaged flows at 47 control points. This input file is applied at each repetition but does not itself change during the iterative computational procedure
Bwam8HOUT.FLO –	This HYD output file contains 1998-2007 naturalized flows at 47 control points. This output file changes with each iteration of the computational procedure. This HYD output file is converted to the SIM input file with filename Bwam8A.FLO simply by removing the header and changing the filename.

4.2 BACKWARD EXTENSION OF THE HYDROLOGIC PERIOD-OF-ANALYSIS

The Brazos WAM hydrologic period-of-analysis has also been extended backward to cover the period from January 1900 through December 1939. Thus, the period-of-analysis now spans 1900-2007. The naturalized flows at most control points are significantly less accurate for the 1900-1940 periods than for later years due to the limited number of stream gaging station in operation prior to 1940, particular prior to 1924. Since water resources development and use were relatively minimal during these early years, naturalized flows at gaging station in operation during 1900-1940 are essentially the same as the actual observed gaged flows.

Monthly flows during 1900-1939 at 20 control points located at sites that were gaged during at least portions of 1900-1939 were taken from an investigation conducted at Texas A&M University during 1986-1988 (Wurbs et al. 1988). Naturalized flows at the other 57 Brazos WAM primary control points were developed in the current study based on distributing the 1900-1939 sequences of flows at the 20 control points. Thus, 1900-1939 monthly naturalized flow sequences are developed for the 77 primary control points in the Brazos WAM dataset. The extend SIM input dataset includes naturalized monthly stream flows extending from January 1900 through December 2007 at 77 primary control points which are distributed to the numerous other secondary control points within the SIM simulation model. The 1900-2007 naturalized flows at the 77 primary control points are plotted in Appendix A.

The Brazos WAM dataset contains reservoir surface net evaporation less precipitation rates for 67 control points. Evaporation-precipitation depths at each of the 67 control points for each of the 12 months of the year for the 40 years from 1900 through 1939 were assigned as the 1940-1997 means. The same set of twelve 1940-1997 mean evaporation-precipitation depths for the 12 months of the year were repeated for each year of 1900-1939.

4.2.1 Historical Water Resources Development

Converting gaged flows to naturalized flows was the key central concern in the 1998-1997 flow extension computations described in the preceding section 4.1. However, gaged flows are essentially natural flows during 1900-1939. Water resources development during 1900-1939 was minimal as compared to 1940-2007. Statewide population growth in Texas is shown in Table 4.23.

Table 4.23 Texas Population Growth

Year	Population	Year	Population
1930	5,820,000	1970	11,200,000
1940	6,410,000	1980	14,230,000
1950	7,710,000	1990	16,990,000
1960	9,580,000	2000	20,850,000

Wurbs et al. (1988) compiled the information in Table 4.24 regarding reservoirs in the Brazos River Basin as an index of water resources development during 1900-1986. Table 4.24 reflects data for the 1,178 reservoirs located in the Brazos River Basin included in the dam inventory maintained by the Texas Water Commission as of 1986. Reservoirs are categorized as small or major depending on whether total controlled storage capacity is greater than 5,000 acre-feet. The 40 major reservoirs account for most of the total storage of the 1,178 reservoirs. Few dams were constructed in the Brazos River Basin prior to 1940 compared to subsequent decades. Of the 3,908,000 acre-feet of conservation storage capacity in 40 major reservoirs as of the end of 1986, only 3.0 percent (117,000 acre-feet) of the total was contained in reservoirs with initial impoundment before 1940.

As indicated by Table 3.4, the Bwam3 and Bwam8 datasets include 665 and 706 reservoirs, respectively, with total conservation storage capacities of 4,694,851 and 4,023,350 acre-feet. The counts in Table 4.24 include many small flood control dams and very small water supply reservoirs that are not included in the Brazos WAM dataset, but Table 4.24 excludes several large reservoirs with construction completed after 1986. As indicated by Table 3.6, Possum Kingdom with impoundment beginning in 1941 is the oldest of the 16 largest reservoirs in the Brazos River Basin.

Table 4.24 Growth in Reservoir Storage Capacity in the Brazos River Basin

Initial Impoundment Date	Number of Reservoirs		Controlled Storage Capacity of Major Reservoirs in acre-feet	
	Small	Major	Conservation	Flood Control
Before 1910	11	0	0	0
1910-1919	12	0	0	0
1920-1929	50	4	31,000	0
1930-1939	20	2	86,000	0
1940-1949	34	4	600,000	0
1950-1959	161	10	1,271,000	2,012,000
1960-1969	524	11	1,261,000	1,592,000
1970-1979	285	4	417,000	0
1980-1986	41	5	242,000	337,000
Total	1,138	40	3,908,000	3,941,000

Adjusting 1900-1939 gaged flows to remove the effects of water resources development, management, and use is a relatively minor concern compared to developing naturalized flows for 1940-1997 and 1998-2007. The primary concern in extending the hydrologic period-of-analysis to include 1900-1939 is the stream flow synthesis necessitated by the small number of gaging stations in operation before 1940, particularly the very small number of gages before 1924.

4.2.2 Naturalized Flows from Past Studies at 20 Control Points

Wurbs et al. (1988) document a water availability study for the Brazos River Basin which included developing 1900-1984 sequences of naturalized monthly flows at 20 U.S. Geological Survey (USGS) stream gaging stations. Flows at the 24 gaging stations listed in Table 4.25 were compiles. Only one of the 24 gages had a continuous record during 1900-1939 with no gaps. The flows at the 24 gaging stations were used to develop complete 1900-1984 sequences of flows, will all missing flows synthesized, at 20 of 24 gaging stations which were adopted for the water availability study described by the 1988 report.

The observed monthly flows at the 24 gaging stations were converted to unregulated (naturalized) flows in the 1986-1988 investigation by adjusting for the storage and evaporation effects of 21 major reservoir and diversions associated with two canal systems. The reservoir with the earliest storage record dates back to January 1939. Thus, for the period 1900-1939, the adjustments affect flow only during 1936-1939. Naturalized flows equal gaged flows for 1900-1935.

Table 4.25 Availability of 1900-1939 Gaged Flow and Naturalized Flow

	River or Stream	Nearest City	USGS Gage	Record Begin	Drainage Area	Control Point ID
					(square miles)	
1	Hubbard Creek	Breckenridge	08086500	May 1955	1,089	HCBR21
2	Brazos River	South Bend	08088000	Oct 1938	22,670	BRSB23
3	Brazos River	Palo Pinto	08089000	Jan 1924	23,810	BRPP27
4	Brazos River	Glen Rose	08091000	Oct 1923	25,820	BRGR30
5	Brazos River	Aquilla	08093100	Oct 1938	27,240	BRAQ33
6	Aquilla Creek	Aquilla	08093500	Jan 1939	308	AQAQ34
7	Bosque River	Waco	08095600	Sep 1959	1,656	BOWA40
8	Brazos River	Waco	08096500	Oct 1898	29,570	BRWA41
9	Leon River	Hasse	08099500	Jan 1939	1,260	LEHS45
10	Leon River	Belton	08102500	Oct 1923	3,540	LEBE49
11	Lampasas River	Belton	08104100	Oct 1923	1,320	LABE52
12	Little River	Little River	08104500	Oct 1923	5,270	LRLR53
13	N. Fork San Gabriel	Georgetown	08104700	Jul 1968	248	NGGE54
14	San Gabriel River	Laneport	08105700	Aug 1965	738	GALA57
15	Little River	Cameron	08106500	Nov 1916	7,065	LRCA58
16	Brazos River	Bryan	08109000	Aug 1899	39,515	BRBR59
17	Yegua Creek	Somerville	08110000	Jun 1924	1,010	YCSO62
18	Navasota River	Easterly	08110500	Oct 1938	968	NAEA66
19	Brazos River	Hempstead	08111500	Jan 1903	43,880	BRHE68
20	Brazos River	Richmond	08114000		45,010	BRRI70
	Additional Gaging Stations Not Included in 20 for Which Flows Were Developed					
	Brazos River	Dennis	08090800	May 1968	25,240	BRDE29
	North Bosque River	Clifton	08095000	Oct 1923	968	NBCL36
	Lampasas River	Youngsport	08104000	Nov 1924	1,240	LAYO51
	Navasota River	Bryan	08111000	Jan 1951	1,450	NABR67

Records of flow measurements at each of the 24 stream gages began at the dates shown in Table 4.25. Twelve of the 24 gaged have records dating back to 1924 or before. The USGS gaging station on the Brazos River at Waco has a continuous record from October 1898 to the present. The gage on the Little River at Cameron has continuous recorded monthly flows dating back to November 1916. Gaged on the Brazos River at Richmond and Bryan have records beginning in 1899 and 1903, respectively, but also have periods of missing data. Flow measurements are missing during January 1903 through February 1918 at gage 08109000 on the Brazos River near Bryan and during July 1906 through September 1922 at gage 08114000 on the Brazos River near Richmond.

Wurbs et al. (1988) synthesized monthly flows for the periods of missing records. Flows were reconstituted at all of the gaged to cover January 1900 through December 1984 using the following computer models:

HEC-4 Monthly Streamflow Synthesis developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers

MOSS-IS Monthly Streamflow Synthesis developing by the Texas Water Development Board by modifying HEC-4

Both HEC-4 and MOSS-IV were applied for comparison. Flows synthesized with MOSS-IV were adopted. Wurbs et al. (1988) adopted the resulting unregulated flows at the first 20 gaging stations listed in Table 4.25. The 1900-1939 flows at these 20 control points are adopted for the present extended Brazos WAM dataset. The 77 Brazos WAM primary control points in the Brazos WAM are shown in Figure 4.3 with these 20 control points highlighted in bold print.

4.2.3 Transfer of Naturalized Flows to the Other Primary Control Points

Mean flow relationships used to distribute 1900-1939 flows from 20 to 48 control points are presented in Table 4.26. The 1940-1997 mean flows from which these relationships are derived are tabulated in Table 3.2. The same flow distribution methodology is applied in both sections 4.1 and 4.2 but to different subsets of control points and for different time periods.

Distribution of 1998-2007 naturalized flows from 48 control points with gaged flows during 1998-2007 to the other 29 Brazos WAM primary control points is described in section 4.1. The mean flow relationships used to distribute 1998-2007 flows from 48 to 29 other control points are presented in Table 4.8 based on the mean flow volumes of Table 3.2. Similar mean flow relationships used to distribute 1900-1939 flows from 20 to 31 other control points are presented in Table 4.26. Sequences of monthly naturalized flow volumes for unknown-flow control points are computed based on naturalized flows at one or more known-flow control points and ratios between the means of 1940-1997 naturalized flows at the respective control points. The ratios of 1940-1997 mean naturalized flows were applied in a manner similar to the conventional application of drainage area ratios, with mean flow ratios replacing drainage area ratios.

$$F_U = F_K \left(\frac{M_U}{M_K} \right)$$

F_U – naturalized flow at unknown flow control point
F_K – naturalized flow at known flow control point
M_U – 1940-1997 mean of naturalized flow at unknown flow control point or the summation or difference in means at multiple control points
M_K – 1940-1997 mean of naturalized flow at known flow control point or the summation or difference in means at multiple control points

The 1900-1939 monthly flows at the 20 control points listed in Table 4.25 are combined with the relationships shown in Table 4.26 to compute flows at the 31 other control points listed in Table 4.26. The 1900-1939 monthly flows at these 51 control points are combined with the relationships shown in Table 4.8 of section 4.1 to obtain flows at the remainder of the 77 original Brazos WAM primary control points. The flow distribution computations are performed with *WRAP-HYD*. The results of these computations are January 1900 through December 1939 sequences of naturalized flows at the 77 Brazos WAM primary control points.

The distribution of flows from 20 to 77 control points involves major uncertainties and approximations in addition to the inaccuracies reflected in the flows at the 20 control points. The level of accuracy of the 1900-1939 naturalized flows that may logically be expected varies greatly between the different control points depending largely upon their distance from USGS gaging stations with periods-of-record covering major portions of 1900-1939.

The accuracy of the 1900-1939 monthly naturalized flows varies temporally as well as spatially. Several of the 20 gaging stations have records beginning in 1923 or 1924. Thus, inaccuracies and uncertainties prior to 1924 are greater than 1924-1939.

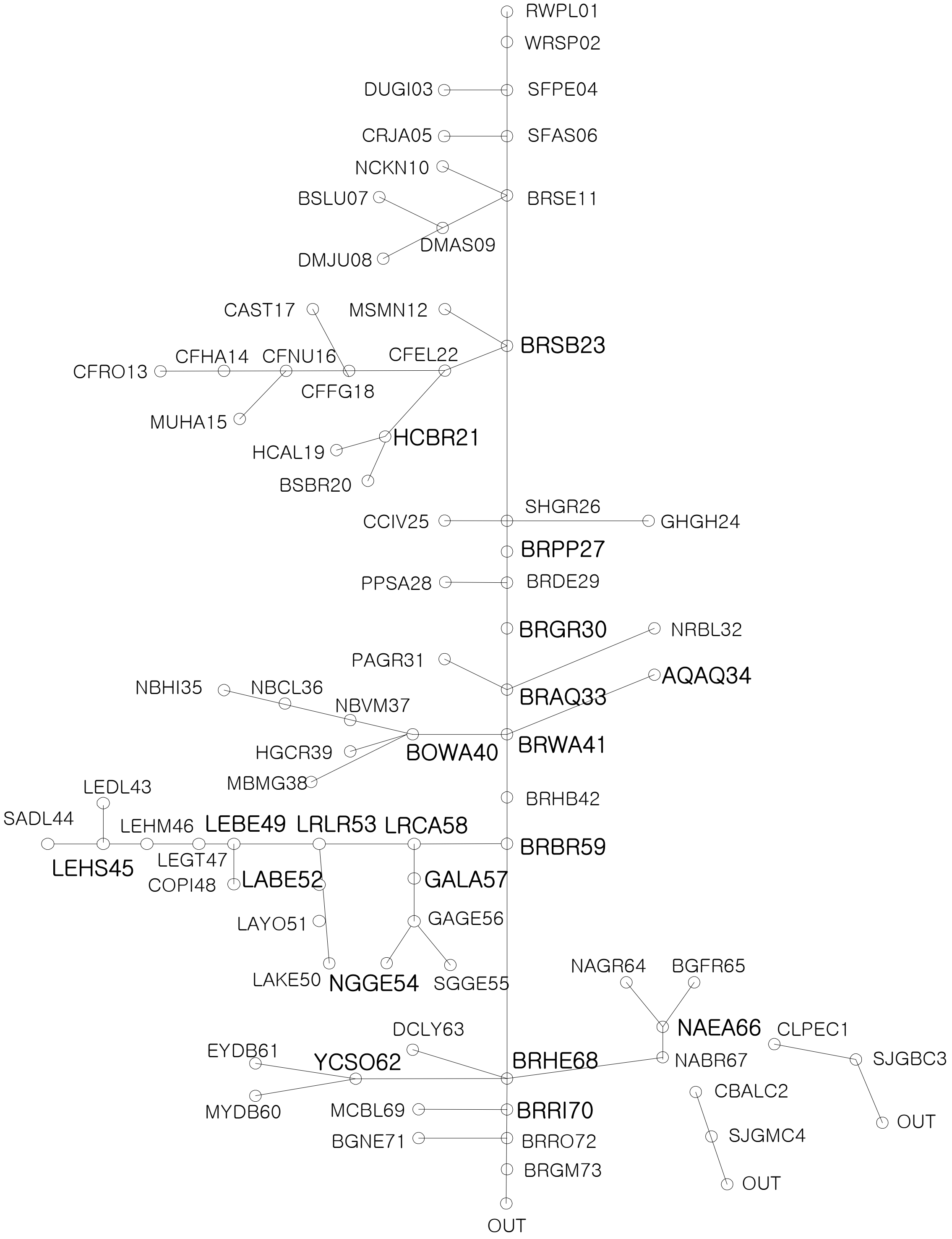

Figure 4.3 Schematic of Primary Control Points with 20 Control Points in Bold (Not to Scale)

Table 4.26 Relationships for Computing 1900-1939 Naturalized Flow for 57 Control Points

Control Point	River or Stream	Nearest City	Flow Synthesis Relationship with Source Control Points
RWPL01	Running Water Draw	Plainview	0.0038 (BRSB23)
SFAS06	Salt Fork Brazos River	Aspermont	0.1174 (BRSB23)
DMJU08	Double Mountain Fork	Justiceburg	0.0339 (BRSB23)
DMAS09	Double Mountain Fork	Aspermont	0.1651 (BRSB23)
BRSE11	Brazos River	Seymour	0.3811 (BRSB23)
MSMN12	Millers Creek	Munday	0.0088 (BRSB23)
CFRO13	Clear Fork Brazos	Roby	0.0743 (HCBR21)
CFNU16	Clear Fork Brazos	Nugent	0.9844 (HCBR21)
CAST17	California Creek	Stamford	0.2838 (HCBR21)
CFFG18	Clear Fork Brazos	Fort Griffin	1.8006 (HCBR21)
HCAL19	Hubbard Creek	Albany	0.5912 (HCBR21)
BSBR20	Big Sandy Creek	Breckenridge	0.2403 (HCBR21)
BRDE29	Brazos River	Dennis	BRPP27 + 0.6266 (BRGR30-BRPP23)
PAGR31	Paluxy River	Glen Rose	0.0523 (BRGR30)
NBCL36	North Bosque River	Clifton	0.4566 (BOWA40)
NBVM37	North Bosque River	Valley Mills	0.5687 (BOWA40)
BRHB42	Brazos River	Highbank	BRWA41 + 0.1864 (BRBR59 – BRWA41)
SADL44	Sabana River	De Leon	0.2483 (LEHS45)
LEGT47	Leon River	Gatesville	LEHS45 +0.3201 (LEBE49-LEHS45)
COPI48	Cowhouse Creek	Pidcoke	0.2126 (LEBE49-LEHS45)
LAKE50	Lampasas River	Kempner	0.5135 (LABE52)
SGGE55	South Fork San Gabriel	Georgetown	0.2754 (GALA57-NGGE54)
MYDB60	Middle Yegua Creek	Dime Box	0.1762 (YCSO62)
EYDB61	East Yegua Creek	Dime Box	0.1933 (YCSO62)
DCLY63	Davidson Creek	Lyons	0.2126 (YCSO62)
NAGR64	Navasota River	Groesbeck	0.2588 (NAEA66)
BGFR65	Big Creek	Freestone	0.0999 (NAEA66)
NABR67	Navasota River	Bryan	1.3060 (NAEA66)
BGNE71	Big Creek	Needville	0.0044 (BRRI70)
BRRO72	Brazos River	Rosharon	1.0012 (BRRI70)
CBALC2	Chocolate Bayou	Alvin	0.0131 (BRRI70)

Flows are most subject to uncertainties in the upper basin above Possum Kingdom Reservoir. As indicated in Figure 4.3, control point BRSB23 at the South Bend gage on the Brazos River is the most upstream control point on the main-stem Brazos River included in the 20 control points for which flows were obtained from the study by Wurbs et al. (1988). Records at the South Bend gage date back to October 1938. Distribution of flows from control point BRSB23 to the other control points located further upstream in the upper basin involves large distances between gaged and ungaged control points and is necessarily highly approximate.

Control point BRWA41 is at the Waco Gage on the Brazos River which has a continuous record from October 1898 to the present. This is the only gage with a continuous record covering the complete 1900-1939 period. As indicated in Table 4.25, the gaging stations on the Brazos River at Bryan and Richmond and the Little River at Cameron have the next longest records. The record at the Bryan gage extends from August 1899 through December 1902 and from March 1918 through the remainder of the 1900-1939 period-of-analysis. The record at the Richmond gage extends from January 1903 through June 1905 and from October 1923 to the present. The gage on the Little River at Cameron has a continuous record of monthly flows dating back to November 1916. The 1900-1939 flows should be most accurate at these sites.

4.2.4 Resulting Naturalized Flows

The 1900-1939 naturalized flows are combined with the 1940-2007 naturalized flows to obtain the 1900-2007 sequences of naturalized flows at 77 primary control points which are plotted in Appendix A. The January 1900 through December 1939 flows at three selected control points (Richmond, Waco, and Cameron gages) are tabulated in Tables 4.27, 4.28, and 4.29. These naturalized flows are essentially gaged flows since the differences are negligible. Naturalized flows for the sub-periods 1900-1939, 1940-1997, and 1998-2007 are compared in section 4.3.

Table 4.27 Naturalized Flows at the Richmond Gage on the Brazos River

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1900	563104.	293242.	526759.	2493000.	4250000.	850751.	278379.	260077.	997696.	645893.	301272.	222493.	11682666.
1901	154940.	86087.	105469.	194555.	365099.	537395.	38577.	72725.	124230.	28031.	46201.	38639.	1791948.
1902	40535.	34444.	182346.	116407.	826999.	278613.	1193000.	848246.	169242.	148713.	673457.	403116.	4915118.
1903	451521.	994702.	2194000.	415000.	268400.	228099.	296088.	718200.	77834.	397536.	82711.	88540.	6212631.
1904	62537.	110100.	62967.	142800.	924804.	300901.	249083.	162600.	112492.	118792.	144201.	69790.	2461067.
1905	159506.	374400.	822759.	1052000.	3424000.	1016000.	148994.	325302.	188584.	163898.	148600.	274502.	8098545.
1906	231989.	229000.	120010.	134000.	296000.	649000.	181816.	182094.	409334.	107436.	211167.	876227.	3628073.
1907	302595.	179971.	263659.	89980.	534924.	391254.	437457.	274646.	73375.	854220.	437173.	559635.	4398889.
1908	486531.	381635.	595986.	3594000.	2892000.	1101000.	183103.	95862.	195678.	374831.	116457.	192072.	10209155.
1909	45137.	19370.	43491.	60789.	177845.	267037.	108448.	63829.	19417.	86768.	71697.	189641.	1153469.
1910	84308.	163813.	14403.	278443.	418457.	68823.	16737.	0.	51321.	66550.	26993.	54768.	1244616.
1911	42804.	281703.	139067.	257339.	194704.	212449.	214758.	232263.	168502.	39552.	61212.	118436.	1962789.
1912	167914.	303873.	349263.	586694.	178999.	272091.	61777.	124169.	44958.	306012.	40550.	33177.	2469477.
1913	23929.	102122.	151891.	191575.	924321.	514784.	259640.	49996.	344048.	582821.	983894.	2508000.	6637021.
1914	239598.	299825.	303234.	820334.	5291000.	2842000.	474478.	196136.	254455.	311151.	433732.	556373.	12022316.
1915	364565.	329877.	455656.	2066000.	3335000.	1836000.	1274000.	297568.	152664.	730442.	186635.	263874.	11292281.

Table 4.27 (Continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1916	529132.	911642.	512171.	969370.	1161000.	577509.	156082.	53198.	140818.	300651.	116155.	59780.	5487508.
1917	59362.	20139.	77768.	64042.	223268.	232751.	60513.	25332.	156860.	24872.	25513.	26845.	997265.
1918	44852.	60047.	24130.	638718.	309505.	293781.	54150.	65234.	171070.	425882.	869449.	1066000.	4022818.
1919	842635.	960761.	739365.	630317.	1469000.	970336.	1016000.	339230.	745913.	1417000.	1294000.	1190000.	11614557.
1920	1498000.	804309.	381188.	134134.	1925000.	525964.	265914.	755479.	704325.	332805.	340019.	373431.	8040568.
1921	277810.	277343.	540520.	843805.	351962.	1103000.	378890.	44363.	861015.	174876.	117951.	103592.	5075127.
1922	82959.	146592.	387834.	2573000.	7354000.	903061.	190258.	236121.	45977.	54601.	113999.	63500.	12151902.
1923	79608.	221001.	435079.	1400000.	615998.	405999.	99099.	45500.	189999.	296002.	631988.	1870000.	6290273.
1924	727024.	893998.	1380000.	765000.	632002.	909001.	88794.	46100.	108012.	83798.	41000.	45101.	5719830.
1925	44094.	34400.	30894.	27000.	514001.	52700.	31903.	42400.	289993.	990923.	1120000.	95801.	3274109.
1926	539003.	186000.	955161.	2190000.	1240000.	462001.	372041.	272000.	340027.	382974.	203006.	701009.	7843222.
1927	292003.	544001.	678773.	961001.	421001.	838002.	378040.	103999.	58589.	598964.	81499.	82400.	5038272.
1928	85505.	318000.	298026.	214000.	295000.	814999.	160988.	264000.	104978.	37601.	40800.	230997.	2864894.
1929	327997.	96100.	296001.	708001.	1130000.	2360000.	321963.	57500.	393010.	86100.	555002.	97799.	6429473.
1930	213977.	408000.	238020.	134000.	2600000.	582001.	128003.	58000.	117980.	916048.	212005.	935027.	6543061.
1931	713016.	782995.	867016.	378000.	416000.	218000.	96495.	59500.	44995.	175453.	152001.	179998.	4083469.
1932	1750000.	1470000.	971892.	165000.	938027.	447200.	575062.	139451.	1153000.	162996.	68400.	106001.	7947029.
1933	282002.	270000.	434088.	220000.	390680.	346541.	51695.	165610.	115752.	57197.	48400.	34100.	2416065.
1934	329998.	513998.	787098.	1330000.	189400.	47500.	26130.	19650.	33220.	37481.	155002.	229900.	3699377.
1935	207578.	443501.	197279.	210250.	3310000.	1420000.	425448.	163750.	563707.	328996.	285100.	1213000.	8768609.
1936	201487.	144447.	118424.	81216.	1199000.	839344.	1091000.	96394.	458420.	1443000.	466254.	784662.	6923648.
1937	850138.	380693.	583095.	237926.	118970.	278637.	131333.	65289.	125478.	169899.	177502.	430605.	3549565.
1938	1140000.	1047000.	510080.	1191000.	1170000.	327504.	368193.	374854.	79643.	47868.	38356.	39772.	6334270.
1939	165143.	155105.	169399.	83678.	561454.	471581.	216692.	56261.	51533.	32584.	34721.	57839.	2055990.
MEAN	367621.	381856.	448606.	716059.	1320946.	669840.	302526.	186323.	260954.	338530.	278852.	411661.	5683774.

Table 4.28 Naturalized Flows at the Waco Gage on the Brazos River

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1900	143003.	49197.	67006.	653964.	449023.	296997.	185900.	131997.	908007.	268708.	115496.	38968.	3308266.
1901	21631.	22680.	15721.	37560.	184001.	161295.	7798.	30130.	44740.	15808.	15400.	6770.	563534.
1902	2970.	2590.	62238.	61329.	266188.	127998.	946036.	144503.	98840.	74633.	275196.	100803.	2163324.
1903	66625.	343584.	406427.	67850.	43561.	96368.	86374.	45810.	33160.	231610.	26811.	9150.	1457330.
1904	6880.	14920.	22699.	28770.	132397.	202902.	108458.	104999.	65470.	115400.	27460.	12010.	842365.
1905	21480.	30280.	98805.	435384.	1122000.	229597.	351156.	137599.	110499.	95898.	42697.	57200.	2732595.
1906	33700.	40700.	21600.	32500.	244000.	511994.	189934.	246993.	180001.	86103.	38099.	78104.	1703728.
1907	50796.	32200.	34198.	20900.	195997.	220001.	208963.	52799.	22400.	156991.	153992.	212014.	1361251.
1908	74995.	86300.	80586.	1140000.	1350000.	186000.	65196.	47800.	55100.	27303.	13000.	22601.	3148881.
1909	1970.	1220.	1960.	1600.	21799.	274004.	22104.	86701.	6720.	14100.	26000.	169010.	627188.
1910	7010.	10699.	2559.	89198.	201999.	36899.	10507.	1140.	36700.	16600.	4680.	3450.	421441.
1911	756.	62195.	14800.	26400.	11500.	1982.	190955.	106000.	303999.	10901.	4710.	141996.	876194.
1912	16200.	21101.	55299.	43600.	47201.	58901.	16101.	215997.	25700.	61798.	8170.	2480.	572548.
1913	655.	5020.	14300.	31900.	245004.	79900.	64694.	21600.	159999.	316994.	333960.	1520000.	2794026.
1914	53398.	18199.	43797.	433982.	1190000.	441996.	88026.	669990.	204999.	69428.	72609.	115100.	3401524.
1915	77964.	51342.	84360.	838398.	485325.	679604.	184763.	141697.	129499.	198007.	30300.	25499.	2926758.
1916	91597.	86300.	29297.	821014.	397982.	148000.	32199.	10600.	22800.	101001.	16701.	8360.	1765851.
1917	7190.	4770.	5860.	15900.	51999.	70203.	29501.	23999.	77999.	10799.	2480.	3220.	303920.
1918	2720.	1470.	1290.	198000.	167998.	179003.	13997.	167.	159000.	282009.	672047.	382987.	2060688.
1919	358974.	221998.	215036.	261008.	580989.	564000.	324014.	271999.	319002.	762006.	701984.	181004.	4762014.
1920	380028.	152008.	124999.	59500.	909977.	329998.	87304.	480013.	607003.	144012.	170008.	89805.	3534655.
1921	139990.	128008.	124018.	88101.	32599.	361999.	49693.	9530.	36100.	10698.	3990.	5560.	990286.
1922	4860.	4850.	17901.	1130000.	1460000.	229996.	47705.	7250.	8520.	6981.	13499.	8490.	2940052.
1923	9000.	42900.	11300.	413998.	182997.	342000.	14800.	1040.	52600.	267013.	245986.	348024.	1931658.
1924	61004.	51497.	352013.	170992.	219999.	129998.	5608.	4590.	115000.	18599.	10400.	9070.	1148770.
1925	8980.	3500.	2080.	79303.	499000.	18499.	4658.	43200.	359998.	165996.	74203.	9390.	1268807.
1926	94807.	19600.	110986.	407004.	184001.	345996.	219888.	166001.	286005.	332008.	38699.	102015.	2307010.
1928	11200.	57498.	25001.	101998.	303989.	317997.	143993.	209004.	61300.	5139.	9940.	46097.	1293156.
1929	45697.	24700.	52208.	131002.	316997.	174006.	41601.	10100.	319002.	50504.	24500.	16001.	1206318.

Table 4.28 (Continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1930	7620.	28800.	16500.	26400.	922016.	358995.	41095.	14400.	63100.	632994.	70199.	277991.	2460110.
1931	118002.	253989.	158978.	105999.	114002.	83301.	29198.	12400.	8930.	275012.	90393.	84900.	1335104.
1932	340986.	471991.	215993.	53300.	415991.	255007.	503895.	42500.	619007.	56400.	21200.	101000.	3097270.
1933	94703.	22501.	131980.	55401.	429007.	91004.	65196.	82400.	101001.	25502.	18500.	23900.	1141095.
1934	70103.	35000.	175017.	286001.	39901.	6660.	1022.	959.	14000.	7292.	87193.	24160.	747308.
1935	49949.	74744.	40018.	113195.	1359000.	662015.	268092.	61789.	314598.	108503.	90393.	99223.	3241519.
1936	31766.	16197.	9570.	11696.	287938.	104422.	64360.	5454.	1166000.	434273.	104448.	218681.	2454805.
1937	132584.	79783.	141667.	42189.	31661.	149986.	24747.	77988.	50037.	75580.	12374.	167004.	985600.
1938	413360.	453019.	272830.	358737.	306932.	284614.	230301.	87513.	14142.	4229.	4116.	4762.	2434555.
1939	54745.	45072.	21859.	28198.	274819.	355948.	58396.	34402.	11002.	1633.	15061.	4979.	906114.
MEAN	78600.	78521.	84869.	229332.	395145.	239952.	128331.	97054.	179792.	141687.	92370.	118612.	1864264.

Table 4.29 Naturalized Flows at the Cameron Gage on the Brazos River

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1900	44761.	26135.	84947.	371334.	1009000.	179298.	129199.	97148.	88021.	489064.	115882.	115410.	2750199.
1901	6709.	64009.	35808.	26156.	236076.	35519.	5907.	11261.	13573.	237.	12601.	6192.	454048.
1902	8454.	3043.	69009.	14688.	932527.	59363.	165111.	29239.	30718.	24453.	41866.	36887.	1415358.
1903	176223.	375920.	503529.	134286.	39650.	45523.	35566.	17305.	3737.	99146.	105157.	20946.	1556988.
1904	23638.	22515.	34025.	53361.	100788.	135863.	84615.	33562.	28210.	26035.	36013.	40579.	619204.
1905	26010.	40418.	47742.	566403.	1443000.	120869.	77125.	29769.	10989.	16097.	78591.	165265.	2622278.
1906	64457.	73669.	53693.	13628.	313500.	109630.	11896.	6422.	195471.	6471.	58136.	189730.	1096703.
1907	42043.	43783.	69712.	13484.	108559.	117398.	74813.	59139.	14785.	337198.	39846.	54632.	975392.
1908	44934.	77181.	132848.	873944.	706608.	71629.	43705.	9139.	64062.	74642.	49117.	33471.	2181280.
1909	2816.	2158.	11903.	8158.	35211.	45988.	20195.	14525.	487.	15371.	19971.	56171.	232954.
1910	9729.	29382.	726.	77509.	28906.	29839.	0.	0.	6524.	21775.	5234.	2935.	212559.
1911	6324.	15831.	23359.	35508.	35527.	20545.	9675.	17265.	26296.	2549.	20732.	19471.	233082.
1912	10280.	32560.	41671.	92270.	58030.	0.	3488.	7534.	1905.	57588.	6777.	574.	312677.
1913	2730.	12135.	18496.	47566.	345200.	178851.	29981.	3583.	71090.	196963.	167468.	770067.	1844130.
1914	13059.	36121.	58046.	369294.	1672000.	372485.	105880.	37674.	27216.	129989.	105057.	94696.	3021517.
1915	89886.	37523.	120116.	862941.	728985.	589506.	302793.	43755.	8035.	288804.	62907.	82345.	3217596.
1916	147447.	219405.	104663.	163718.	123994.	110451.	64746.	15416.	28591.	64641.	7200.	5790.	1056062.
1917	5850.	5030.	5110.	13787.	26600.	13200.	4830.	867.	35196.	1210.	3480.	1880.	117040.
1918	2340.	4651.	2290.	163972.	29000.	47999.	2550.	512.	5140.	46199.	178000.	186018.	668671.
1919	219997.	189028.	141002.	124064.	257005.	317005.	246996.	101996.	134996.	433997.	335992.	234023.	2736101.
1920	499994.	203963.	122001.	75023.	228003.	120001.	68899.	194989.	167981.	60200.	101999.	84192.	1927245.
1921	69500.	53499.	87300.	183993.	105998.	146001.	79902.	10699.	1565000.	36099.	20200.	23299.	2381490.
1922	20200.	29802.	108000.	825975.	1000000.	126001.	31201.	10600.	9520.	7780.	12100.	9200.	2190379.
1923	7760.	19998.	39901.	244971.	98595.	53001.	17800.	2670.	62795.	29601.	72801.	316994.	966887.
1924	98398.	178992.	217002.	179879.	172004.	130999.	22301.	10899.	27500.	8460.	6310.	7790.	1060534.
1925	8350.	6280.	5330.	3656.	53702.	4870.	1810.	2510.	20100.	141994.	182997.	16701.	448300.
1926	123000.	38297.	218999.	571392.	273999.	96103.	105000.	21500.	13100.	30300.	15400.	28301.	1535391.
1927	33700.	173027.	164000.	182956.	91298.	222003.	39398.	10899.	5860.	180004.	26600.	21799.	1151544.
1928	18200.	85719.	41100.	27611.	42099.	98203.	12900.	21500.	8390.	3060.	2430.	11901.	373113.
1929	17600.	12099.	33799.	141901.	535006.	140003.	26300.	8241.	53897.	8480.	29300.	7810.	1014436.
1930	15500.	25401.	25601.	10087.	559013.	37400.	11600.	10899.	17000.	207004.	30300.	134988.	1084793.
1931	152000.	222006.	198998.	97660.	121003.	73801.	35701.	9590.	10199.	23600.	6370.	13301.	964229.
1932	140001.	197958.	161997.	61290.	303003.	134005.	35198.	28999.	179021.	13200.	8330.	14401.	1277403.
1933	67601.	34304.	68202.	49681.	114002.	48401.	14700.	27199.	12099.	4480.	6250.	3820.	450739.
1934	71300.	78288.	121000.	293237.	39701.	10500.	3060.	1490.	6840.	968.	68330.	9601.	704315.
1935	11380.	73862.	15420.	27978.	656502.	470104.	63002.	21340.	290722.	100402.	65989.	246790.	2043491.
1936	64560.	37261.	36400.	46184.	682917.	203488.	184110.	19630.	352692.	359407.	176906.	352868.	2516423.
1937	292102.	157507.	216699.	85543.	37601.	114000.	86805.	12740.	17999.	29480.	47500.	186309.	1284285.
1938	459591.	323908.	144702.	334890.	268699.	134505.	278700.	106003.	22439.	12400.	10030.	11250.	2107117.
1939	28010.	19930.	27171.	25106.	118105.	63620.	18640.	14449.	3720.	11990.	3020.	4100.	337861.
MEAN	78661.	82065.	90308.	187377.	343285.	125699.	63902.	27074.	91048.	90033.	58580.	90562.	1328595.

4.3 NATURALIZED FLOW COMPARISON

The hydrologic period-of-analysis for the original Brazos WAM dataset is 1940-1997. The procedures outlined in sections 4.1 and 4.2 resulted in lengthening the hydrologic period-of-analysis to 1900-2007. Section 4.1 documents the hydrology update to cover 1998-2007. Section 4.2 describes the extension of the hydrologic period-of-analysis backward in time to include 1900-1939. Monthly net evaporation-precipitation depths for 1900-2007 have been compiled for 67 control point locations. Naturalized monthly flow volumes for 1900-2007 have been developed for the 77 Brazos WAM primary control points. This chapter provides a comparison of the naturalized flows spanning the 1900-1939, 1940-1997, and 1998-2007 sub-periods of the overall 1900-2007 hydrologic period-of-analysis. Naturalized flows are also compared with observed gaged flows.

4.3.1 Comparison of 1900-1939, 1940-1997, and 1998-2007 Naturalized Flows

The 1900-2007 sequences of naturalized stream flows at the 77 control points are plotted in Appendix A, allowing a visual comparison of the 1900-1939, 1940-1997 and 1998-2007 segments. Statistics for eight selected control points are compared in Tables 4.30 and 4.31. Table 4.30 compares 1900-1939, 1940-1997 and 1998-2007 mean naturalized flow volumes and also includes 1998-2007 mean observed flows. Table 4.31 compares naturalized flow frequency relationships for the eight selected control points. The eight control points selected for inclusion in Tables 4.30 and 4.31 are gaging stations with records covering the complete 1940-2007 period. The Waco gage on the Brazos River (control BRWA41) has gaged flow records covering the complete 1900-2007 period. Control points LEBE49, LRCA58, and BRRI70 have gaged flows covering much of 1900-1939 as well as all of 1940-2007. Tables 4.32, 4.33, 4.34, and 4.35 provide statistics for all the 77 control points.

Mean 1900-1939, 1940-1997 and 1998-2007 naturalized flows are compared in Table 4.29. Control points locations are shown in the maps of Figures 3.2 and 3.4 and schematic of Figure 3.3. The relative comparison of mean flows varies spatially. The Seymour and South Bend gaging stations are upstream of Possum Kingdom Reservoir and are the most upstream of the six gages on the Brazos River. The period 1900-1939 has the highest mean flows, and 1998-2007 has the lowest mean flows at the Seymour and South Bend gaging stations. Conversely, the smallest mean flow occurs during 1900-1939 and the largest during 1998-2007 at the Belton gage on the Leon River and the Waco, Hempstead, and Richmond gages on the Brazos River. The period 1940-1997 has the smallest mean flow at the Aquilla gage on the Brazos River and Cameron gage on the Little River.

Table 4.30 Comparison of Mean Flows at Selected Gaging Stations

Control Point ID	Stream	Nearest Town	Drainage Area (sq. miles)	Mean Naturalized Flow			Gaged Flow
				1900-1939 (ac-ft/year)	1940-1997 (ac-ft/year)	1998-2007 (ac-ft/year)	1998-2007 (ac-ft/year)
BRSE11	Brazos River	Seymour	6,000	285,440	250,096	172,359	161,815
BRSB23	Brazos River	South Bend	13,170	748,990	656,260	440,512	364,799
BRAQ33	Brazos River	Aquilla	17,750	1,625,743	1,379,050	1,392,972	800,427
BRWA41	Brazos River	Waco	20,070	1,854,264	1,942,324	2,129,842	1,397,595
LEBE49	Leon River	Belton	3,580	465,934	505,257	755,088	472,607
LRCA58	Little River	Cameron	7,100	1,328,595	1,318,302	2,070,813	1,597,128
BRHE68	Brazos River	Hempstead	34,370	5,279,984	5,358,943	7,208,408	5,837,823
BRRI70	Brazos River	Richmond	35,450	5,683,774	5,850,224	7,637,494	6,189,194

The 1998-2007 means in Table 4.30 range from 67.1 percent (South Bend gage) to 157.1 percent (Cameron gage) of the 1940-1997 means. For the Belton and Cameron gages in the Little River subbasin, the 1998-2007 mean naturalized flows are 149.4 and 157.1 percent, respectively, of the corresponding 1940-1997 means. For the Hempstead and Richmond gages on the lower Brazos River below the other six gages, the mean of the 1998-2007 naturalized flows are 134.5 and 130.6 percent, respectively, of the corresponding means of the 1940-1997 naturalized flows.

Naturalized flow exceedance frequency relationships at the eight control points included in Table 4.30 are tabulated in Table 4.31. Monthly naturalized flow volumes that occur during specified percentages of the 480 months of 1900-1939, the 696 months of 1940-1997 or the 120 months of 1998-2007 are shown in Table 4.31.

Means of the naturalized flows for 1900-1939, 1940-1997 and 1998-2007 at the 77 primary control points are compared in Table 4.32. Frequency tables developed with *TABLES* are presented as Tables 4.33, 4.34, and 4.35 for naturalized flows at the 77 control points for 1900-1939, 1940-1997, and 1998-2007.

Table 4.31 Comparison of Exceedance Frequency Relationship for Naturalized Flows

	Percentage of Months in which Flows (acre-feet/month) Equaled or Exceeded Values							
	100%	95%	90%	75%	50%	25%	10%	maximum
	Monthly Naturalized Flow Volume (acre-feet/month)							
	Seymour Gage on Brazos River (BRSE11)							
1900-1939	0	0	305	1,424	5,789	24,483	70,839	453,509
1940-1997	0	266	621	1,711	5,042	18,500	57,693	414,811
1998-2007	134	312	488	2,215	5,454	15,080	40,328	149,614
	South Bend Gage on Brazos River (BRSB23)							
1900-1939	0	0	801	3,737	15,190	64,242	185,879	1,190,000
1940-1997	0	785	2,083	4,889	13,817	52,133	145,077	1,395,822
1998-2007	200	439	1,150	5,171	11,793	33,713	104,323	464,133
	Aquilla Gage on Brazos River (BRAQ33)							
1900-1939	0	3,891	6,688	18,670	62,971	169,895	351,497	1,770,000
1940-1997	0	3,425	6,929	16,626	46,163	131,747	280,970	2,981,239
1998-2007	6,756	18,517	23,526	35,410	55,651	109,472	286,403	1,260,169
	Waco Gage on Brazos River (BRWA41)							
1900-1939	167	3,500	7,010	21,600	70,103	198,000	382,987	1,520,000
1940-1997	0	6,300	10,364	24,749	68,642	183,578	422,755	3,376,485
1998-2007	9,308	23,728	34,641	51,358	85,511	193,678	371,886	1,723,996
	Belton Gage on Leon River (LEBE49)							
1900-1939	0	365	956	3,398	13,916	40,493	106,409	718,653
1940-1997	0	0	479	3,360	12,757	47,585	113,249	629,618
1998-2007	5,116	6,594	7,913	11,125	22,819	69,258	178,412	470,319
	Cameron Gage on Little River (LRCA58)							
1900-1939	0	2,816	5,850	13,787	41,100	124,064	273,999	1,672,000
1940-1997	0	2,706	5,440	15,032	44,799	130,473	290,433	1,403,136
1998-2007	13,800	16,930	19,187	33,797	84,776	250,225	435,180	1,165,964
	Hempstead Gage on Brazos River (BRHE68)							
1900-1939	0	27,522	36,415	86,285	223,744	521,818	1,032,000	6,113,000
1940-1998	1,634	30,122	44,643	89,698	229,331	581,968	1,153,505	5,723,482
1998-2007	39,826	72,281	88,276	156,830	319,808	961,557	1,442,134	4,013,333
	Richmond Gage on Brazos River (BRRI70)							
1900-1939	0	34,444	45,977	104,978	263,874	563,707	1,066,000	7,354,000
1940-1997	0	39,522	53,888	111,204	257,456	653,272	1,230,723	6,135,975
1998-2007	46,995	73,997	93,596	165,769	352,399	975,173	1,549,853	4,193,992

Table 4.32 Means of Flows at the Primary Control Points

WAM CP ID	Stream	Nearest City	1900-1939 Naturalized (ac-ft/year)	1940-1997 Naturalized (ac-ft/year)	1998-2007 Naturalized (ac-ft/year)
RWPL01	Running Water Draw	Plainview	2,846	2,469	2,882
WRSP02	White River Reservoir	Spur	19,285	16,730	19,527
DUGI03	Duck Creek	Girard	11,512	10,078	12,396
SFPE04	Salt Fork Brazos River	Peacock	61,271	53,686	25,031
CRJA05	Croton Creek	Jayton	14,163	12,399	15,250
SFAS06	Salt Fork Brazos River	Aspermont	87,931	77,052	35,922
BSLU07	Buffalo Spring Lake	Lubbock	19,502	16,918	19,747
DMJU08	Double Mountain Fork	Justicebury	25,391	22,230	27,340
DMAS09	Double Mountain Fork	Aspermont	123,658	108,367	76,392
NCKN10	North Croton Creek	Knox City	14,780	12,941	15,914
BRSE11	Brazos River	Seymour	285,440	250,096	172,359
MSMN12	Millers Creek	Munday	6,591	5,806	6,447
CFRO13	Clear Fork Brazos	Roby	6,689	7,221	2,658
CFHA14	Clear Fork Brazos	Hawley	41,838	45,162	25,506
MUHA15	Mulberry Creek	Hawley	7,205	7,780	4,392
CFNU16	Clear Fork Brazos	Nugent	88,621	95,668	54,028
CAST17	California Creek	Stamford	25,549	27,572	25,671
CFFG18	Clear Fork Brazos	Fort Griffin	162,090	174,974	122,120
HCAL19	Hubbard Creek	Albany	53,223	57,538	29,753
BSBR20	Big Sandy Creek	Breckenridge	21,633	23,348	18,959
HCBR21	Hubbard Creek	Breckenridge	90,025	97,181	58,527
CFEL22	Clear Fork Brazos	Eliasville	286,018	308,856	206,210
BRSB23	Brazos River	South Bend	748,990	656,260	440,512
GHGH24	Lake Graham	Graham	50,535	35,827	44,817
CCIV25	Big Cedar Creek	Ivan	12,465	13,452	10,924
SHGR26	Brazos River	Graford	881,580	793,483	600,404
BRPP27	Brazos River	Palo Pinto	900,399	810,380	613,221
PPSA28	Palo Pinto Creek	Santo	63,122	64,126	39,624
BRDE29	Brazos River	Dennis	1,059,323	1,003,749	707,975
BRGR30	Brazos River	Glen Rose	1,154,028	1,118,978	823,607
PAGR31	Paluxy River	Glen Rose	60,356	58,474	56,897
NRBL32	Nolan River	Blum	157,661	67,304	172,267
BRAQ33	Brazos River	Aquilla	1,625,743	1,379,053	1,392,972
AQAQ34	Aquilla Creek	Aquilla	96,925	89,186	170,893
NBHI35	North Bosque River	Hico	42,291	44,879	51,710
NBCL36	North Bosque River	Clifton	153,506	162,919	187,695
NBVM37	North Bosque River	Valley Mills	191,193	202,937	337,745

Table 4.32 (continued)

WAM CP ID	Stream	Nearest City	1900-1939 Naturalized (ac-ft/year)	1940-1997 Naturalized (ac-ft/year)	1998-2007 Naturalized (ac-ft/year)
MBMG38	Middle Bosque River	McGregor	51,966	55,164	91,799
HGCR39	Hog Creek	Crawford	24,243	25,735	42,826
BOWA40	Bosque River	Waco	336,193	356,832	593,857
BRWA41	Brazos River	Waco	1,864,264	1,942,324	2,129,842
BRHB42	Brazos River	Highbank	2,248,474	2,331,139	2,591,359
LEDL43	Leon River	De Leon	51,444	56,375	39,434
SADL44	Sabana River	De Leon	32,011	35,079	24,537
LEHS45	Leon River	Hasse	128,920	141,273	132,198
LEHM46	Leon River	Hamilton	152,900	166,469	195,042
LEGT47	Leon River	Gatesville	236,798	257,793	302,062
COPI48	Cowhouse Creek	Pidcoke	73,130	77,373	91,262
LEBE49	Leon River	Belton	465,934	505,257	755,088
LAKE50	Lampasas River	Kempner	108,367	119,776	155,574
LAYO51	Lampasas River	Youngsport	188,970	208,870	271,290
LABE52	Lampasas River	Belton	211,036	233,258	437,327
LRLR53	Little River	Little River	983,126	846,554	1,351,407
NGGE54	N. Fork San Gabriel	Georgetown	66,056	57,922	83,750
SGGE55	S. Fork San Gabriel	Georgetown	32,543	36,173	41,209
GAGE56	San Gabriel River	Georgetown	109,306	104,317	138,530
GALA57	San Gabriel River	Laneport	184,221	189,268	295,650
LRCA58	Little River	Cameron	1,328,595	1,318,302	2,070,813
BRBR59	Brazos River	Bryan	3,925,480	4,027,961	5,192,002
MYDB60	Middle Yegua Creek	Dime Box	44,755	39,362	65,487
EYDB61	East Yegua Creek	Dime Box	49,098	43,189	65,453
YCSO62	Yegua Creek	Somerville	253,999	223,399	354,350
DCLY63	Davidson Creek	Lyons	54,000	47,485	63,814
NAGR64	Navasota River	Groesbeck	86,637	83,472	99,685
BGFR65	Big Creek	Freestone	33,443	32,237	46,733
NAEA66	Navasota River	Easterly	334,764	322,578	430,544
NABR67	Navasota River	Bryan	437,201	421,304	476,575
BRHE68	Brazos River	Hempstead	5,279,984	5,358,943	7,208,408
MCBL69	Mill Creek	Bellville	179,813	149,586	144,158
BRRI70	Brazos River	Richmond	5,683,774	5,850,225	7,637,494
BGNE71	Big Creek	Needville	25,009	25,631	28,652
BRRO72	Brazos River	Rosharon	5,938,407	6,112,278	8,089,455
BRGM73	Brazos River	Gulf of Mexico	5,931,281	6,105,238	8,079,747
CLPEC1	Clear Creek	Pearland	28,011	28,734	32,770
CBALC2	Chocolate Bayou	Alvin	74,457	76,372	87,106
SJGBC3	Coastal Basin	Galveston Bay	336,495	345,148	393,660
SJGMC4	Coastal Basin	Gulf of Mexico	813,298	834,204	951,464

Table 4.33 Frequency Analysis of 1900-1939 Naturalized Flows (acre-feet/month)

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
			100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
RWPL01	237.2	448.	0.0	0.0	0.0	0.0	3.0	14.2	35.	58.	104.	244.	706.	4522.
WRSP02	1607.1	3036.	0.0	0.0	0.0	0.0	20.3	96.2	239.	391.	706.	1654.	4786.	30641.
DUGI03	959.3	1812.	0.0	0.0	0.0	0.0	12.3	57.4	143.	234.	421.	987.	2857.	18291.
SFPE04	5105.9	9646.	0.0	0.0	0.0	0.0	65.5	305.7	759.	1243.	2243.	5255.	15206.	97347.
CRJA05	1180.2	2230.	0.0	0.0	0.0	0.0	15.2	70.7	175.	287.	518.	1215.	3515.	22502.
SFAS06	7327.6	13843.	0.0	0.0	0.0	0.0	94.0	438.7	1089.	1783.	3219.	7542.	21822.	139706.
BSLU07	1625.2	3070.	0.0	0.0	0.0	0.0	20.6	97.3	242.	395.	714.	1673.	4840.	30986.
DMJU08	2115.9	3997.	0.0	0.0	0.0	0.0	27.2	126.7	315.	515.	929.	2178.	6301.	40341.
DMAS09	10304.8	19468.	0.0	0.0	0.0	0.0	132.2	617.0	1532.	2508.	4526.	10606.	30689.	196469.
NCKN10	1231.7	2327.	0.0	0.0	0.0	0.0	15.8	73.8	183.	300.	541.	1268.	3668.	23482.
BRSE11	23786.7	44937.	0.0	0.0	0.0	0.0	305.3	1424.2	3537.	5789.	10449.	24483.	70838.	453509.
MSMN12	549.3	1038.	0.0	0.0	0.0	0.0	7.0	32.9	82.	134.	241.	565.	1636.	10472.
CFRO13	557.4	1348.	0.0	0.0	0.0	0.0	0.0	0.0	36.	92.	183.	480.	1610.	14114.
CFHA14	3486.5	8433.	0.0	0.0	0.0	0.0	0.0	0.0	224.	579.	1144.	3002.	10069.	88282.
MUHA15	600.4	1452.	0.0	0.0	0.0	0.0	0.0	0.0	39.	100.	197.	517.	1734.	15203.
CFNU16	7385.1	17863.	0.0	0.0	0.0	0.0	0.0	0.0	474.	1226.	2424.	6358.	21329.	186999.
CAST17	2129.1	5150.	0.0	0.0	0.0	0.0	0.0	0.0	137.	353.	699.	1833.	6149.	53911.
CFFG18	13507.5	32671.	0.0	0.0	0.0	0.0	0.0	0.0	868.	2242.	4433.	11629.	39011.	342027.
HCAL19	4435.2	10728.	0.0	0.0	0.0	0.0	0.0	0.0	285.	736.	1456.	3819.	12810.	112306.
BSBR20	1802.8	4360.	0.0	0.0	0.0	0.0	0.0	0.0	116.	299.	592.	1552.	5207.	45648.
HCBR21	7502.1	18146.	0.0	0.0	0.0	0.0	0.0	0.0	482.	1245.	2462.	6459.	21667.	189962.
CFEL22	23834.8	57650.	0.0	0.0	0.0	0.0	0.0	0.0	1531.	3955.	7822.	20521.	68838.	603526.
BRSB23	62415.8	117915.	0.0	0.0	0.0	0.0	801.0	3737.0	9280.	15190.	27417.	64242.	185879.	1190000.
GHGH24	4211.2	8699.	0.0	0.0	0.0	0.0	0.0	0.0	113.	437.	1100.	4285.	14100.	81349.
CCIV25	1038.7	2512.	0.0	0.0	0.0	0.0	0.0	0.0	67.	172.	341.	894.	3000.	26302.
SHGR26	73465.0	132466.	0.0	0.0	0.0	0.0	681.5	4358.0	12204.	19484.	34232.	79581.	214424.	1412841.
BRPP27	75033.2	135293.	0.0	0.0	0.0	0.0	696.0	4451.0	12465.	19900.	34963.	81280.	219001.	1443000.
PPSA28	5260.2	9072.	0.0	0.0	0.0	0.0	0.0	264.5	947.	1739.	2783.	5977.	14778.	70392.
BRDE29	88276.9	143124.	0.0	0.0	232.4	879.5	1935.0	7668.6	19681.	29962.	47378.	117488.	233589.	1340238.
BRGR30	96169.0	150707.	0.0	0.0	352.0	1110.0	2340.0	8649.0	22030.	34209.	58698.	129249.	248469.	1279000.
PAGR31	5029.6	7882.	0.0	0.0	18.4	58.1	122.4	452.3	1152.	1789.	3070.	6760.	12995.	66892.
NRBL32	13138.4	25132.	0.0	0.0	0.0	0.0	0.0	962.6	2733.	4688.	7286.	13117.	39916.	305041.
BRAQ33	135478.5	201772.	0.0	1976.0	2549.8	3891.0	6688.0	18670.0	39822.	62971.	88519.	169895.	351497.	1770000.
AQAQ34	8077.1	20204.	0.0	0.0	0.0	0.0	0.0	168.0	741.	1280.	2514.	5682.	21490.	182916.
NBHI35	3524.2	6984.	15.5	75.8	106.8	147.1	190.0	360.1	704.	1018.	1564.	3453.	10508.	74027.
NBCL36	12792.2	25349.	56.2	275.0	387.6	533.8	689.5	1307.2	2557.	3694.	5676.	12535.	38141.	268701.
NBVM37	15932.8	31572.	70.0	342.5	482.7	664.8	858.7	1628.2	3185.	4601.	7070.	15612.	47505.	334670.
MBMG38	4330.5	8581.	19.0	93.1	131.2	180.7	233.4	442.5	866.	1251.	1922.	4244.	12912.	90963.
HGCR39	2020.3	4003.	8.9	43.4	61.2	84.3	108.9	206.5	404.	584.	896.	1980.	6024.	42436.
BOWA40	28016.1	55517.	123.0	602.2	848.8	1169.0	1510.0	2863.0	5600.	8091.	12431.	27453.	83532.	588483.
BRWA41	155355.3	229021.	167.0	1036.4	1548.0	3500.0	7010.0	21600.0	45697.	70103.	101998.	198000.	382987.	1520000.
BRHB42	187372.9	269152.	927.5	2431.1	2976.4	6897.3	11191.2	28476.4	59456.	92560.	127558.	235646.	465093.	1862624.
LEDL43	4287.0	11649.	0.0	0.0	0.0	0.0	29.1	231.1	608.	1037.	1597.	3382.	9352.	141974.
SADL44	2667.6	7248.	0.0	0.0	0.0	0.0	18.1	143.8	378.	645.	994.	2105.	5819.	88342.
LEHS45	10743.3	29191.	0.0	0.0	0.0	0.0	73.0	579.0	1524.	2598.	4002.	8476.	23437.	355787.
LEHM46	12741.7	25929.	0.0	0.0	47.2	129.5	336.5	1196.1	2745.	4331.	6514.	12503.	32227.	244046.
LEGT47	19733.2	40157.	0.0	0.0	73.1	200.6	521.2	1852.4	4251.	6707.	10088.	19363.	49910.	377956.
COPI48	6094.2	11218.	0.0	0.0	0.0	0.0	0.0	383.7	1201.	1954.	3215.	6722.	19024.	109557.
LEBE49	38827.8	71801.	0.0	0.0	0.0	365.0	956.0	3398.0	9014.	13916.	20189.	40493.	106409.	718653.
LAKE50	9030.6	15392.	0.0	0.0	39.6	211.0	415.4	1228.3	2281.	3567.	5512.	10433.	21862.	149890.
LAYO51	15747.5	26841.	0.0	0.0	69.1	367.9	724.4	2141.9	3978.	6220.	9612.	18193.	38122.	261378.
LABE52	17586.3	29975.	0.0	0.0	77.2	411.0	809.0	2392.0	4442.	6946.	10734.	20317.	42574.	291899.
LRLR53	81927.1	142488.	0.0	374.4	823.4	2083.0	4328.0	10202.0	21460.	30414.	50024.	91807.	202759.	1237000.
NGGE54	5504.6	8773.	0.0	0.0	0.0	0.0	119.0	584.0	1469.	2168.	3432.	6662.	15036.	69958.
SGGE55	2711.9	4528.	0.0	0.0	0.0	0.0	57.0	246.5	649.	981.	1607.	3048.	7399.	37940.
GAGE56	9108.9	14713.	0.0	0.0	0.0	0.0	207.3	920.4	2385.	3462.	5674.	10688.	25246.	119616.

Table 4.33 (continued)

CONTROL		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
GALA57	15351.8	25158.	0.0	0.0	0.0	0.0	321.0	1474.0	3867.	5458.	9305.	17682.	42241.	207723.
LRCA58	110716.3	192576.	0.0	507.0	1113.2	2816.0	5850.0	13787.0	29000.	41100.	67601.	124064.	273999.	1672000.
BRBR59	327123.3	491282.	0.0	6487.6	9474.6	14510.0	23549.0	57000.0	117370.	157614.	234001.	402283.	765525.	4463000.
MYDB60	3729.6	7914.	0.0	0.0	0.0	0.0	0.0	44.2	339.	693.	1250.	3157.	11383.	63606.
EYDB61	4091.5	8682.	0.0	0.0	0.0	0.0	0.0	48.5	372.	760.	1372.	3464.	12487.	69778.
YCSO62	21166.6	44912.	0.0	0.0	0.0	0.0	0.0	251.0	1927.	3934.	7097.	17918.	64601.	360985.
DCLY63	4500.0	9548.	0.0	0.0	0.0	0.0	0.0	53.4	410.	836.	1509.	3809.	13734.	76745.
NAGR64	7219.7	14262.	0.0	0.0	0.0	4.9	35.2	200.6	887.	1584.	3204.	7453.	18862.	107072.
BGFR65	2786.9	5505.	0.0	0.0	0.0	1.9	13.6	77.4	343.	612.	1237.	2877.	7281.	41331.
NAEA66	27897.0	55109.	0.0	0.0	0.0	19.0	136.0	775.0	3429.	6121.	12379.	28800.	72882.	413723.
NABR67	36433.5	71972.	0.0	0.0	0.0	24.8	177.6	1012.2	4478.	7994.	16167.	37613.	95184.	540322.
BRHE68	439998.7	642280.	0.0	14333.8	17724.4	27522.0	36415.0	86285.0	171425.	223744.	308642.	521818.	1032000.	6113000.
MCBL69	14984.4	40314.	0.0	0.0	0.0	0.0	0.0	0.0	3133.	4899.	7002.	14078.	39552.	680253.
BRRI70	473647.8	689697.	0.0	19603.4	25148.0	34444.0	45977.0	104978.0	183103.	263874.	332805.	563707.	1066000.	7354000.
BGNE71	2084.1	3035.	0.0	86.3	110.7	151.6	202.3	461.9	806.	1161.	1464.	2480.	4690.	32358.
BRRO72	494867.3	720595.	0.0	20481.4	26274.7	35987.0	48037.0	109681.0	191306.	275696.	347715.	588961.	1113757.	7683460.
BRGM73	494273.4	719731.	0.0	20456.5	26243.1	35944.0	47979.0	109549.4	191076.	275365.	347298.	588254.	1112420.	7674240.
CLPEC1	2334.2	3399.	0.0	96.6	123.9	169.7	226.6	517.4	902.	1300.	1640.	2778.	5254.	36242.
CBALC2	6204.8	9035.	0.0	256.8	329.4	451.2	602.3	1375.2	2399.	3457.	4360.	7385.	13965.	96337.
SJGBC3	28041.3	40832.	0.0	1160.6	1488.7	2039.1	2722.0	6214.9	10840.	15622.	19703.	33373.	63110.	435378.
SJGMC4	67774.9	98690.	0.0	2805.0	3598.1	4928.5	6579.0	15021.3	26200.	37758.	47621.	80662.	152535.	1052293.

Table 4.34 Frequency Analysis of 1940-1997 Naturalized Flows (acre-feet/month)

CONTROL		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
RWPL01	205.7	993.	0.0	0.0	0.0	0.0	0.0	0.0	4.	12.	26.	71.	304.	21017.
WRSP02	1394.1	3644.	0.0	0.0	0.0	0.0	0.0	17.0	109.	214.	357.	897.	3286.	38538.
DUGI03	839.8	2247.	0.0	1.0	1.0	3.0	9.0	57.0	89.	127.	190.	415.	1952.	18749.
SFPE04	4473.9	10838.	0.0	3.0	6.0	15.8	36.6	224.0	448.	693.	1219.	3100.	10907.	95241.
CRJA05	1033.2	2527.	0.0	0.0	0.0	0.0	2.0	33.0	80.	141.	260.	700.	2640.	20787.
SFAS06	6421.0	15348.	0.0	4.0	8.9	24.8	67.2	362.0	723.	1111.	1886.	4700.	15583.	135865.
BSLU07	1409.8	3084.	0.0	0.0	0.0	0.0	0.0	17.0	161.	314.	574.	1189.	3428.	23740.
DMJU08	1852.5	4374.	0.0	0.0	0.0	0.0	0.6	12.0	82.	224.	466.	1363.	5331.	34415.
DMAS09	9030.6	20143.	0.0	0.0	0.0	8.0	81.2	344.0	938.	1636.	2762.	7870.	25049.	175553.
NCKN10	1078.4	3218.	0.0	0.0	1.0	3.0	7.0	48.0	89.	156.	253.	627.	2379.	50743.
BRSE11	20841.3	42817.	0.0	0.0	52.0	266.2	621.2	1711.0	3082.	5042.	8026.	18500.	57693.	414811.
MSMN12	483.8	1887.	0.0	0.0	0.0	0.0	0.0	0.0	0.	7.	29.	158.	983.	24988.
CFRO13	601.7	1569.	0.0	0.0	0.0	0.8	8.6	43.0	91.	130.	195.	398.	1355.	15773.
CFHA14	3763.5	8370.	0.0	0.0	0.0	18.6	184.6	484.0	922.	1262.	1791.	3546.	8977.	137859.
MUHA15	648.4	1475.	0.0	0.0	0.0	0.0	0.0	38.0	89.	162.	269.	610.	1671.	24066.
CFNU16	7972.3	17242.	0.0	0.0	0.0	0.0	255.0	892.0	1759.	2568.	3737.	7960.	19821.	297109.
CAST17	2297.7	6263.	0.0	0.0	0.0	0.0	9.6	76.0	180.	286.	511.	1592.	5914.	73502.
CFFG18	14581.1	37167.	0.0	0.0	0.0	0.0	0.0	492.0	1584.	2837.	4686.	11953.	35198.	471164.
HCAL19	4794.8	14739.	0.0	0.0	0.0	0.0	13.0	69.0	229.	473.	999.	2726.	11977.	206975.
BSBR20	1945.7	5352.	0.0	0.0	0.0	0.0	0.0	0.0	59.	167.	423.	1383.	5708.	77964.
HCBR21	8098.4	23079.	0.0	0.0	0.0	0.0	0.0	17.0	631.	1251.	2171.	5118.	22114.	265359.
CFEL22	25738.0	60025.	0.0	0.0	0.0	150.8	469.4	1770.0	3520.	5945.	9807.	23129.	65587.	759321.
BRSB23	54688.3	116203.	0.0	64.8	119.4	785.0	2082.8	4889.0	9258.	13817.	23707.	52133.	145077.	1395822.
GHGH24	2985.6	13628.	0.0	0.0	0.0	0.0	0.0	0.0	99.	287.	597.	1514.	5474.	263724.
CCIV25	1121.0	3117.	0.0	0.0	0.0	0.0	0.0	2.0	66.	186.	378.	890.	2900.	47074.
SHGR26	66123.6	137151.	0.0	0.0	0.0	284.0	2186.8	6883.0	12816.	18404.	30992.	64391.	166331.	1794495.

Table 4.34 (continued)

CONTROL		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
BRPP27	67531.7	137771.	0.0	0.0	0.0	340.0	2097.6	6759.0	13251.	19022.	31092.	65601.	170549.	1810792.
PPSA28	5343.8	12081.	0.0	0.0	0.0	0.0	0.0	148.0	673.	1125.	2075.	4779.	14879.	159551.
BRDE29	83645.7	165799.	0.0	0.0	529.0	1992.8	3713.4	9442.0	17481.	27265.	44882.	87622.	211034.	2450046.
BRGR30	93248.2	182476.	0.0	0.0	527.5	1861.6	4597.8	10445.0	20145.	30585.	50324.	96926.	242476.	2710228.
PAGR31	4872.8	9601.	0.0	0.0	29.4	124.0	252.8	607.0	1047.	1520.	2138.	4522.	12192.	84978.
NRBL32	5608.7	11447.	0.0	0.0	0.0	0.0	0.0	136.0	633.	1348.	2170.	5793.	14986.	107634.
BRAQ33	114921.1	204744.	0.0	0.0	1717.0	3425.4	6929.0	16626.0	28719.	46163.	65837.	131747.	280970.	2981239.
AQAQ34	7432.2	14492.	0.0	0.0	0.0	0.0	0.0	45.0	570.	1194.	2438.	7957.	23510.	123995.
NBHI35	3739.9	8289.	0.0	0.0	0.0	0.0	9.6	145.0	333.	623.	1337.	3270.	10319.	78927.
NBCL36	13576.6	31085.	0.0	0.0	0.0	1.6	166.2	771.0	1619.	2594.	4889.	11722.	40586.	450470.
NBVM37	16911.4	37025.	0.0	0.0	0.0	60.4	270.6	1241.0	2366.	3710.	6320.	14679.	48135.	459004.
MBMG38	4597.0	8416.	0.0	0.0	0.0	0.0	13.0	224.0	718.	1257.	2187.	5339.	12819.	76944.
HGCR39	2144.6	4084.	0.0	0.0	0.0	1.0	12.0	111.0	309.	565.	1025.	2341.	6093.	38904.
BOWA40	29736.0	53194.	0.0	0.0	0.0	0.0	469.0	2712.0	5984.	9936.	15246.	34506.	80009.	526505.
BRWA41	161860.3	266253.	0.0	1576.8	3433.8	6300.4	10363.6	24749.0	45705.	68642.	102411.	183578.	422755.	3376485.
BRHB42	194261.6	300104.	1251.0	3561.2	6377.8	8762.8	14725.6	31658.0	60614.	89483.	125100.	232892.	488252.	3599269.
LEDL43	4697.9	11403.	0.0	0.0	0.0	0.0	4.2	159.0	454.	876.	1451.	3796.	12326.	135961.
SADL44	2923.3	7129.	0.0	0.0	0.0	4.0	15.0	84.0	222.	503.	856.	2322.	7600.	85534.
LEHS45	11772.8	27843.	0.0	0.0	0.0	0.0	55.0	483.0	1276.	2390.	3709.	10572.	32405.	319157.
LEHM46	13872.5	29227.	0.0	0.0	0.9	60.6	192.0	829.0	2198.	3408.	5291.	12774.	37199.	269330.
LEGT47	21482.8	41916.	0.0	0.0	0.0	31.6	383.0	1361.0	3722.	5793.	9792.	21255.	56294.	383340.
COPI48	6447.8	14071.	0.0	0.0	0.0	1.0	15.6	201.0	668.	1286.	2217.	5935.	18477.	130144.
LEBE49	42104.7	75480.	0.0	0.0	0.0	0.0	478.6	3360.0	7761.	12757.	22410.	47585.	113249.	629618.
LAKE50	9981.3	20700.	15.0	89.5	229.3	362.0	665.8	1229.0	2006.	2702.	3963.	9847.	25207.	202765.
LAYO51	17405.8	34980.	26.0	158.1	342.3	605.2	999.0	1878.0	3190.	4593.	6991.	17488.	45780.	334157.
LABE52	19438.1	34333.	0.0	0.0	116.9	435.6	695.6	2091.0	3927.	6061.	9827.	21523.	54148.	310885.
LRLR53	70546.2	120022.	30.0	297.1	562.4	1577.4	3418.4	8225.0	16213.	25741.	37521.	80406.	190524.	950933.
NGGE54	4826.8	8471.	0.0	0.0	0.0	19.8	85.8	346.0	885.	1425.	2348.	5545.	14575.	75382.
SGGE55	3014.4	5397.	0.0	4.0	10.8	26.0	60.0	241.0	571.	946.	1536.	3497.	8301.	50622.
GAGE56	8693.1	15106.	0.0	16.7	26.9	97.8	203.8	751.0	1691.	2754.	4354.	10232.	25510.	140494.
GALA57	15772.4	25225.	0.0	0.0	0.0	175.4	481.4	1805.0	3652.	5489.	8552.	19998.	45534.	212283.
LRCA58	109858.4	170466.	0.0	494.4	1249.0	2706.4	5440.0	15032.0	28988.	44799.	65294.	130473.	290433.	1403136.
BRBR59	335663.5	483897.	0.0	6558.6	11161.7	17707.0	28172.8	60717.0	107622.	158629.	232671.	402271.	810073.	4704312.
MYDB60	3280.1	6625.	0.0	0.0	0.0	0.0	0.0	59.0	295.	552.	1104.	3021.	10826.	62553.
EYDB61	3599.0	6547.	0.0	0.0	0.0	11.8	78.6	344.0	557.	814.	1320.	3411.	11912.	52708.
YCSO62	18616.6	33266.	0.0	0.0	0.0	0.0	3.6	766.0	2332.	3904.	7387.	18933.	60819.	251523.
DCLY63	3957.1	7512.	0.0	0.0	0.0	0.0	0.0	71.0	290.	649.	1311.	3709.	13339.	54457.
NAGR64	6956.0	13055.	0.0	0.0	0.0	0.0	32.6	184.0	483.	1066.	2598.	7384.	23055.	85878.
BGFR65	2686.4	4704.	0.0	0.0	0.0	1.0	13.0	73.0	223.	528.	1149.	2993.	8669.	37449.
NAEA66	26881.5	46900.	0.0	0.0	0.0	0.0	125.4	848.0	2577.	5743.	11060.	28826.	87562.	332958.
NABR67	35108.6	57655.	0.0	0.0	0.0	76.0	295.4	1759.0	4736.	8530.	16202.	40035.	109997.	384272.
BRHE68	446578.6	588542.	1634.0	13817.1	17422.0	30122.4	44643.0	89698.0	157333.	229331.	306815.	581968.	1153505.	5723482.
MCBL69	12465.5	21465.	0.0	0.0	0.0	47.0	175.8	681.0	1829.	3110.	5192.	12318.	40523.	128658.
BRRI70	487518.7	613002.	0.0	18382.7	25401.7	39521.8	53887.8	111204.0	184723.	257456.	358553.	653272.	1230723.	6135975.
BGNE71	2135.9	3490.	0.0	0.0	0.0	0.0	9.6	91.0	280.	591.	1024.	2602.	6679.	27782.
BRRO72	509356.5	639652.	0.0	19044.5	26315.8	40684.8	59060.2	118878.0	198276.	269256.	375960.	671495.	1274444.	6356870.
BRGM73	508769.8	634290.	4.0	18771.8	25991.5	42893.2	59767.2	121025.0	199329.	269220.	376386.	676536.	1272971.	6254466.
CLPEC1	2394.5	3196.	0.0	10.8	26.0	63.4	134.4	397.0	688.	1000.	1566.	3369.	6670.	29816.
CBALC2	6364.4	8768.	0.0	0.0	39.4	116.4	332.4	1100.0	2085.	2957.	4313.	8180.	17827.	99985.
SJGBC3	28762.3	38137.	0.0	149.0	296.4	866.6	1956.0	5169.0	10039.	13799.	19653.	38605.	78692.	385928.
SJGMC4	69517.0	92174.	0.0	360.6	716.4	2095.2	4728.0	12492.0	24264.	33350.	47498.	93306.	190193.	932768.

Table 4.35 Frequency Analysis of 1998-2007 Naturalized Flows (acre-feet/month)

CONTROL		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
RWPL01	240.2	425.	0.0	0.0	0.0	0.0	0.0	25.2	69.	101.	165.	208.	481.	2165.
WRSP02	1627.3	2882.	0.0	0.0	0.0	0.0	0.0	170.8	467.	686.	1115.	1411.	3261.	14669.
DUGI03	1033.0	2026.	0.1	0.1	0.1	0.1	0.1	5.5	73.	216.	505.	1037.	2905.	11355.
SFPE04	2085.9	3670.	4.3	24.3	53.1	80.9	97.1	201.6	450.	644.	1037.	2438.	5298.	23019.
CRJA05	1270.8	2492.	0.1	0.1	0.1	0.1	0.1	6.8	90.	266.	621.	1275.	3574.	13970.
SFAS06	2993.5	5267.	6.2	34.9	76.2	116.1	139.3	289.4	647.	924.	1489.	3499.	7603.	33036.
BSLU07	1645.6	2914.	0.0	0.0	0.0	0.0	0.0	172.7	473.	694.	1128.	1427.	3298.	14834.
DMJU08	2278.3	4468.	0.1	0.1	0.1	0.1	0.1	12.1	161.	476.	1113.	2286.	6408.	25045.
DMAS09	6366.0	12644.	48.6	78.7	94.5	123.2	174.2	649.0	1519.	2393.	3540.	6163.	14794.	95389.
NCKN10	1326.2	2601.	0.1	0.1	0.1	0.1	0.1	7.0	93.	277.	648.	1331.	3730.	14579.
BRSE11	14363.2	24435.	133.7	190.1	248.5	312.0	487.5	2215.0	3836.	5454.	8806.	15080.	40328.	149614.
MSMN12	537.3	2588.	0.0	0.0	0.0	0.0	0.0	0.0	0.	1.	11.	72.	1215.	26677.
CFRO13	221.5	1169.	0.0	0.4	0.5	0.6	0.9	1.4	2.	3.	4.	15.	146.	11083.
CFHA14	2125.5	5875.	32.0	42.7	52.1	71.0	102.2	438.4	1087.	1216.	1517.	1976.	4288.	63402.
MUHA15	366.0	1012.	5.5	7.4	9.0	12.2	17.6	75.5	187.	209.	261.	340.	738.	10918.
CFNU16	4502.3	12445.	67.7	90.4	110.3	150.4	216.4	928.6	2303.	2576.	3212.	4186.	9084.	134299.
CAST17	2139.2	6373.	1.4	1.6	2.2	3.7	9.5	57.9	122.	184.	325.	1127.	4775.	41886.
CFFG18	10176.6	24678.	83.1	122.2	124.9	188.0	211.9	1764.3	2660.	3087.	4248.	8224.	18572.	195161.
HCAL19	2479.4	8526.	0.0	0.0	0.0	0.0	0.0	0.0	21.	84.	192.	767.	4136.	66437.
BSBR20	1579.9	6214.	0.0	0.0	0.0	0.0	0.0	0.0	9.	26.	130.	390.	3811.	60518.
HCBR21	4877.3	17194.	0.0	0.0	0.0	0.0	0.0	0.0	60.	234.	542.	1505.	13039.	152537.
CFEL22	17184.2	40487.	100.3	147.4	150.8	226.9	255.8	2135.5	3338.	4570.	5992.	11620.	38843.	255859.
BRSB23	36709.4	72270.	199.8	261.4	336.8	439.0	1150.1	5171.3	9106.	11793.	18064.	33713.	104323.	464133.
GHGH24	3734.8	6003.	0.0	0.0	0.0	0.0	0.0	828.1	1700.	2339.	2885.	4667.	6400.	42315.
CCIV25	910.3	3580.	0.0	0.0	0.0	0.0	0.0	0.0	5.	15.	75.	225.	2196.	34871.
SHGR26	50033.7	81727.	5131.9	5406.3	6107.5	7777.6	8686.4	13930.9	19745.	23582.	31814.	46137.	105425.	602990.
BRPP27	51101.7	83472.	5241.4	5521.6	6237.9	7943.6	8871.8	14228.3	20167.	24086.	32493.	47122.	107675.	615861.
PPSA28	3302.0	9623.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	535.	1747.	9014.	62817.
BRDE29	58997.9	104759.	4891.1	5248.0	6168.4	8780.1	9729.2	14722.1	20769.	25229.	30935.	53206.	132181.	805297.
BRGR30	68633.9	123267.	5911.1	6436.3	7374.5	8575.5	9412.7	15235.9	19252.	26640.	37286.	65652.	158128.	923880.
PAGR31	4741.4	10479.	0.2	0.2	0.2	32.3	126.8	549.3	897.	1280.	2009.	4853.	10110.	84005.
NRBL32	14355.5	22135.	0.0	0.0	0.0	380.0	1727.9	4648.7	6504.	7800.	10057.	16468.	29985.	182355.
BRAQ33	116081.0	183990.	6755.5	7420.4	10461.3	18517.3	23526.0	35410.0	49455.	55651.	69683.	109472.	286402.	1260169.
AQAQ34	14241.1	29374.	0.0	0.0	0.0	120.5	228.9	342.2	789.	1987.	4492.	16629.	38484.	226284.
NBHI35	4309.2	9694.	23.2	30.0	50.0	58.0	83.5	238.2	454.	914.	1407.	3264.	11949.	69382.
NBCL36	15641.2	35189.	84.3	108.9	181.4	210.6	303.2	864.5	1649.	3317.	5107.	11846.	43372.	251841.
NBVM37	28145.4	103253.	207.1	311.1	362.3	499.6	758.2	1329.6	2394.	4452.	6304.	17127.	57972.	930907.
MBMG38	7649.9	28064.	56.3	84.6	98.5	135.8	206.1	361.4	651.	1210.	1713.	4655.	15757.	253021.
HGCR39	3568.8	13092.	26.3	39.5	46.0	63.3	96.1	168.6	304.	564.	799.	2172.	7351.	118039.
BOWA40	49488.1	181549.	364.1	547.0	637.1	878.5	1333.1	2337.8	4210.	7828.	11084.	30115.	101932.	1636814.
BRWA41	177486.8	270057.	9307.9	10517.7	13322.9	23727.5	34641.4	51357.8	70659.	85511.	109447.	193678.	371886.	1723996.
BRHB42	215946.6	311299.	13102.5	16339.4	19148.0	27117.4	38967.3	57194.9	87376.	110752.	148848.	233288.	504804.	1891643.
LEDL43	3286.2	10106.	0.6	2.9	3.1	4.5	7.1	56.9	254.	518.	719.	1485.	9028.	95570.
SADL44	2044.8	6288.	0.4	1.8	1.9	2.8	4.4	35.4	158.	322.	448.	924.	5617.	59467.
LEHS45	11016.5	30366.	0.9	6.6	8.7	15.1	50.8	187.5	406.	905.	2698.	7176.	26858.	223374.
LEHM46	16253.5	32914.	195.0	213.4	234.6	387.2	504.7	1369.6	3091.	4981.	7856.	17419.	40154.	210357.
LEGT47	25171.9	50975.	302.0	330.4	363.4	599.7	781.6	2121.1	4787.	7715.	12166.	26977.	62186.	325782.
COPI48	7605.1	15417.	0.5	0.6	0.9	4.7	19.5	231.5	1336.	1808.	4038.	7565.	20704.	114880.
LEBE49	62924.0	93203.	5115.7	5636.1	6040.5	6594.0	7913.0	11125.2	16758.	22818.	32867.	69258.	178412.	470319.
LAKE50	12964.5	28122.	385.6	514.9	552.9	723.6	973.4	1503.0	2853.	4594.	6351.	10584.	26261.	183688.
LAYO51	22607.5	49040.	672.4	897.9	964.1	1261.8	1697.4	2620.9	4975.	8011.	11074.	18457.	45794.	320314.
LABE52	36443.9	53434.	3354.4	3504.4	3609.6	3778.6	4358.5	6498.6	10859.	15575.	19899.	39434.	98398.	290823.
LRLR53	112617.2	157631.	11282.7	12016.8	12413.0	13115.3	16135.9	23264.9	34850.	51052.	69928.	136617.	276113.	856802.
NGGE54	6979.2	11854.	640.3	669.7	687.6	733.4	843.0	1032.2	1206.	1508.	2944.	8410.	19217.	72264.
SGGE55	3434.1	6553.	6.5	7.7	9.8	17.2	43.1	173.1	664.	1248.	1732.	4558.	8077.	52320.
GAGE56	11544.1	19724.	748.6	805.5	844.4	948.4	1057.6	1401.5	2071.	3302.	5754.	12884.	31917.	138114.
GALA57	24637.5	34289.	670.4	736.6	854.1	1013.7	1507.0	2815.4	5556.	8172.	15820.	37626.	62285.	171880.
LRCA58	172567.8	223802.	13800.2	14067.2	14938.8	16929.6	19186.8	33796.9	57537.	84776.	117677.	250225.	435180.	1165964.
BRBR59	432666.8	556638.	25363.3	28615.9	35721.0	54829.7	67176.7	99897.7	161197.	206599.	328883.	569912.	1016283.	3260673.
MYDB60	5457.3	9502.	34.1	146.2	182.8	369.4	449.7	668.0	1076.	1334.	2268.	4823.	17484.	46561.

Table 4.35 (continued)

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CONTROL           STANDARD      PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE
 POINT      MEAN DEVIATION    100%     99%     98%     95%     90%     75%     60%     50%     40%     25%      10%  MAXIMUM
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MYDB60    5457.3    9502.    34.1   146.2   182.8   369.4   449.7   668.0   1076.   1334.   2268.   4823.   17484.   46561.
EYDB61    5454.4    8087.   497.8   550.3   668.8   791.5   904.4  1352.9   1822.   2157.   2917.   5185.   13789.   43891.
YCSO62   29529.1   46787.  1727.6  2075.4  2505.0  3220.1  3603.9  5906.0   7951.   9177.  13903.  30876.   89324.  244781.
DCLY63    5317.8    9581.     0.0     0.0     0.0     0.0     0.0   126.3    476.    934.   1859.   6177.   17784.   57069.
NAGR64    8307.1   14877.     0.0     0.0     0.0     0.0     0.0     0.0    218.    746.   2366.  10060.   31572.   59660.
BGFR65    3894.4    7093.     0.0     0.0     0.0     0.0     0.0   102.3    377.    775.   1152.   3614.   14410.   45865.
NAEA66   35878.6   54183.  1188.5  1387.8  1503.8  1633.6  2429.1  3953.1   6471.   8793.  14730.  43637.  137279.  260707.
NABR67   39714.6   53318.  1251.4  1548.0  1681.9  2269.0  3267.6  5661.8   8099.  13055.  20046.  60852.  140647.  258290.
BRHE68  600700.6  685783. 39826.3 40788.4 47439.5 72281.0 88276.0156830.0 224432. 319808. 480254. 961557. 1442134. 4013333.
MCBL69   12013.2   16926.     0.0     0.0     0.0     0.0     0.0   559.7   2779.   5437.   9398.  16692.   36858.   79233.
BRRI70  636457.9  715803. 46995.4 47231.1 52862.4 73997.4 93596.0165769.0 265988. 352399. 493394. 975173. 1549853. 4193992.
BGNE71    2387.7    3964.     0.0     0.0     0.0     0.0    13.4    87.7    352.    680.   1248.   2729.    8425.   21429.
BRRO72  674121.2  709461. 63968.4 66178.0 70851.3 91663.4122857.0206814.0 315967. 423120. 541748. 931660. 1651272. 4165656.
BRGM73  673312.3  708609. 63891.6 66098.5 70766.3 91553.4122710.0206566.0 315588. 422612. 541098. 930542. 1649290. 4160657.
CLPEC1    2730.8    3678.    20.2    24.1    36.8    96.9   154.0   457.4    746.   1234.   1998.   3551.    7493.   22706.
CBALC2    7258.9    9776.    53.6    63.9    98.0   257.5   409.4  1215.8   1984.   3280.   5312.   9438.   19917.   60357.
SJGBC3   32805.0   44182.   242.2   288.9   442.7  1163.7  1850.2  5494.6   8966.  14825.  24006.  42653.   90010.  272773.
SJGMC4   79288.6  106786.   585.5   698.2  1070.0  2812.7  4471.9 13280.2  21670.  35832.  58021. 103091.  217551.  659284.
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4.3.2 Comparison of Observed Flows and Naturalized Flows

The 1998-2007 observed gaged flows and computed naturalized flows at the 48 control points for which 1998-2007 gaged flows are available are plotted in Appendix B. Differences between gaged and naturalized flows vary greatly between gaging stations. At some of the gages, the naturalized flows are the same or almost the same as the observed flows. At a number of the gages, the differences between gaged and naturalized flows are large. In most but not all cases, monthly naturalized flow volumes are equal to or greater than gaged flows. Differences are generally more pronounced for lower flows than for higher flows.

Mean naturalized versus gaged flows during 1900-1939, 1940-1997, and 1998-2007 for the Richmond and Waco gages on the Brazos River (control points BRRI70 and BRWA41) and Cameron gage on the Little River (control point LRCA58) are compared in Table 4.36. Annual observed versus naturalized flows at the Richmond and Waco gages for each year from 1940 through 2007 are compared in Table 4.37. Annual observed versus naturalized flows at the Cameron gage are compared in Table 4.38. The means of the 1998-2007 observed and naturalized monthly flows at the 48 gaging stations are compared in Table 4.39.

Mean flows for the Richmond and Waco gages on the Brazos River (control points BRRI70 and BRWA41) and Cameron gage on the Little River (control point LRCA58) are compared in Table 4.36. The locations of these gaging stations are shown in Figure 3.4. The 1900-1939, 1940-1997, and 1998-2007 means of the naturalized flows are tabulated in Table 4.36 along with the means of the observed gaged flows. The means of naturalized flows are expressed both in units of acre-feet/year and as a percentage of the corresponding means of the gaged flows.

As discussed in the preceding section 4.2, the naturalized flows for 1900-1939 are essentially the same as the gaged flows at the three control points in Table 4.25. The gage on the Brazos River near the City of Waco has a complete record from before 1900 to the present. Thus the monthly gaged flows at the Waco gage for all months of 1900-2007 are based directly on actual daily or periodic measurements. However, the Richmond gage on the Brazos River has a gap of January 1906 through September 1922 in the gaged flow record. Flows have been measured at the Cameron gage from November 1916 to the present. Thus, the gaged/naturalized flows for 1906-1922 at the Richmond gage and 1900-1916 at the Cameron gage are synthesized based on regression analyses with flows at the Waco and Bryan gages on the Brazos River.

Table 4.36 Comparison of Mean Gaged and Naturalized Flows

Period	Gaged Flow (acre-feet/yr)	Naturalized (acre-feet/yr)	Naturalized (percent)
Richmond Gage on Brazos River (BRRI70)			
1900-1930	5,683,774	5,683,774	100.0%
1940-1997	5,501,256	5,850,225	106.3%
1998-2007	6,189,194	7,637,494	123.4%
Waco Gage on Brazos River (BRWA41)			
1900-1930	1,864,264	1,864,264	100.0%
1940-1997	1,683,861	1,942,324	115.3%
1998-2007	1,397,595	2,129,842	152.4%
Cameron Gage on Little River (LRCA58)			
1900-1930	1,328,595	1,328,595	100.0%
1940-1997	1,257,447	1,318,301	104.8%
1998-2007	1,597,128	2,070,813	127.9%

Naturalized flows in a particular month at a particular control month are generally related to gaged flows as follows.

naturalized flow = gaged flow + diversions − return flows
+ net reservoir evaporation + reservoir storage change

Water supply diversions at the particular control point and all upstream control points (adjusted for channel losses) are added to gaged flows to obtain naturalized flows. Return flows from diversions from surface and ground water sources are subtracted after adjustments for channel losses. Net reservoir evaporation less precipitation is added to gaged flows to obtain naturalized flows. Differences in the long term means of Table 4.36 are due to water supply diversions, return flows from diversions from surface and groundwater sources, and net reservoir surface evaporation-precipitation. Increases and decreases in reservoir storage contents can greatly affect the difference between gaged and naturalized flows at downstream sites in individual months or years. Reservoir operations tend to result in naturalized flows at downstream locations being greater than observed flows during periods of high flows and less than observed flows during low flow periods.

At the USGS gage on the Brazos River near Richmond (control point BRRI70), the mean of the 1940-1997 naturalized flows is 106.3 percent of the mean actual observed flow. The 1998-2007 mean naturalized flow is 123.4 percent of the mean observed flow.

Naturalized versus gaged annual flows for each year of 1940-2007 at the Richmond and Waco gages on the Brazos River are compared in Table 4.37 and at the Cameron gage on the Little River in Table 4.38. Annual naturalized flows are expressed as a percentage of the corresponding annual observed flow. Means for 1940-1997, 1998-2007, and 1940-2007 are also shown.

The differences between naturalized and gaged flows are larger during 1998-2007 than during 1940-1997. The 1998-2007 means of the observed and naturalized flows at the 48 control points at which flow measurements are available are tabulated in Table 4.39. Mean 1998-2007 naturalized flows are expressed as a percentage of the corresponding mean gaged flow in the last column of Table 4.39.

Table 4.37 Comparison of Annual Gaged and Naturalized Flows at the Richmond and Waco Gages

	Richmond Gage on Brazos River			Waco Gage on Brazos River		
Year	Gaged Flow (acre-feet)	Naturalized Flow (acre-feet)	Naturalized Flow (percent)	Gaged Flow (acre-feet)	Naturalized Flow (acre-feet)	Naturalized Flow (percent)
1940	7,785,910	7,841,679	100.7	2,003,570	2,034,539	101.5
1941	13,910,500	13,684,804	98.4	4,965,660	5,647,660	113.7
1942	8,296,710	8,469,720	102.1	3,831,550	3,952,184	103.1
1943	2,108,960	2,011,176	95.4	738,920	530,337	71.8
1944	8,600,480	8,834,957	102.7	1,472,020	1,643,253	111.6
1945	9,695,400	9,991,619	103.1	2,835,030	3,054,936	107.8
1946	8,227,090	8,366,898	101.7	1,808,160	1,890,929	104.6
1947	4,781,200	4,863,706	101.7	1,361,740	1,349,834	99.1
1948	1,697,900	1,859,931	109.5	737,470	803,997	109.0
1949	4,023,710	4,243,070	105.5	1,540,300	1,663,146	108.0
1950	3,670,770	3,908,155	106.5	197,430	1,343,758	680.6
1951	891,910	986,470	110.6	610,680	604,241	98.9
1952	1,466,990	1,628,778	111.0	412,650	474,625	115.0
1953	3,668,980	4,456,996	121.5	432,510	1,177,981	272.4
1954	1,127,660	1,281,563	113.6	761,420	786,410	103.3
1955	2,236,590	2,755,168	123.2	1,424,510	1,732,494	121.6
1956	960,020	883,332	92.0	649,280	465,716	71.7
1957	14,209,420	14,772,683	104.0	6,151,850	6,613,671	107.5
1958	5,756,700	5,827,879	101.2	1,864,540	1,861,937	99.9
1959	5,447,250	5,721,406	105.0	1,572,870	1,784,617	113.5
1960	6,857,140	7,041,315	102.7	1,459,370	1,563,712	107.1
1961	9,693,800	9,854,994	101.7	2,639,660	2,713,791	102.8
1962	2,941,700	3,235,419	110.0	1,627,110	1,802,003	110.7
1963	1,353,000	1,504,835	111.2	370,760	668,431	180.3
1964	1,659,280	2,032,605	122.5	582,220	832,905	143.1
1965	7,861,000	8,379,350	106.6	1,680,290	2,106,619	125.4
1966	5,822,080	6,148,246	105.6	2,139,400	2,370,887	110.8
1967	1,381,440	1,701,876	123.2	626,760	805,654	128.5
1968	10,009,900	10,657,393	106.5	3,006,640	3,195,781	106.3
1969	5,524,730	6,103,360	110.5	1,936,150	2,369,829	122.4
1970	4,711,890	4,936,341	104.8	1,311,110	1,399,606	106.7
1971	2,073,450	2,879,221	138.9	1,042,860	1,625,753	155.9
1972	2,370,460	2,786,808	117.6	802,910	1,044,318	130.1
1973	8,566,400	8,969,173	104.7	1,911,350	2,093,291	109.5
1974	6,601,540	7,362,952	111.5	1,339,000	1,780,668	133.0
1975	7,084,590	7,078,169	99.9	1,721,810	1,777,613	103.2
1976	5,707,000	6,143,273	107.6	1,057,090	1,344,485	127.2

Table 4.37 (continued)

Year	Richmond Gage on Brazos River Gaged Flow (acre-feet)	Naturalized Flow (acre-feet)	Naturalized Flow (percent)	Waco Gage on Brazos River Gaged Flow (acre-feet)	Naturalized Flow (acre-feet)	Naturalized Flow (percent)
1977	6,167,470	6,280,123	101.8	1,861,470	1,894,519	101.8
1978	1,519,940	2,087,555	137.3	340,850	884,057	259.4
1979	8,385,830	9,061,564	108.1	1,479,820	1,669,579	112.8
1980	2,911,890	3,552,621	122.0	563,450	1,054,753	187.2
1981	5,405,430	6,053,657	112.0	1,974,480	2,257,379	114.3
1982	4,135,140	4,348,172	105.2	1,269,840	2,410,785	189.8
1983	3,770,640	4,084,160	108.3	406,130	583,860	143.8
1984	2,412,720	2,990,547	123.9	303,070	723,947	238.9
1985	5,046,526	5,758,660	114.1	1,160,136	1,540,374	132.8
1986	6,484,186	7,138,266	110.1	1,677,766	2,044,984	121.9
1987	7,902,950	7,814,200	98.9	2,131,167	2,040,554	95.7
1988	1,273,984	1,442,051	113.2	343,750	445,383	129.6
1989	4,002,619	4,873,756	121.8	1,983,359	2,538,832	128.0
1990	5,704,184	6,334,269	111.0	3,502,795	3,863,113	110.3
1991	7,852,162	10,498,568	133.7	2,788,821	4,356,073	156.2
1992	17,622,924	15,849,417	89.9	5,553,514	4,455,003	80.2
1993	6,765,668	7,076,105	104.6	1,162,456	1,329,271	114.4
1994	4,767,698	5,605,638	117.6	1,259,074	1,746,770	138.7
1995	6,355,345	6,481,162	102.0	2,718,023	2,811,341	103.4
1996	1,834,257	2,403,022	131.0	780,173	1,218,348	156.2
1997	9,967,741	10,374,193	104.1	3,777,127	3,874,236	102.6
1998	8,640,175	10,034,555	116.1	1,672,586	2,237,137	133.8
1999	2,297,177	3,065,042	133.4	309,652	770,376	248.8
2000	2,003,451	3,284,465	163.9	405,080	1,110,914	274.2
2001	7,618,926	8,805,778	115.6	2,110,316	2,752,590	130.4
2002	5,104,455	6,255,982	122.6	888,127	1,532,733	172.6
2003	4,183,309	5,070,984	121.2	486,244	882,526	181.5
2004	10,309,136	12,723,546	123.4	2,139,338	3,411,089	159.4
2005	5,047,579	5,977,538	118.4	1,134,139	1,672,477	147.5
2006	1,239,406	2,027,884	163.6	228,488	651,774	285.3
2007	15,448,332	18,866,508	122.1	4,601,978	6,276,804	136.4
Means for						
1940-1997	5,501,256	5,850,225	106.3	1,683,861	1,942,324	115.3
1998-2007	6,189,195	7,637,495	123.4	1,397,595	2,129,841	152.4
1940-2007	5,602,424	6,113,058	109.1	1,641,763	1,969,900	120.0

Table 4.38 Comparison of Annual Gaged and Naturalized Flows at the Cameron Gage on the Little River

Year	Gaged Flow (acre-feet)	Naturalized Flow (acre-feet)	Naturalized Flow (percent)	Year	Gaged Flow (acre-feet)	Naturalized Flow (acre-feet)	Naturalized Flow (percent)
1940	2,051,350	2,053,698	100.1	1976	1,195,070	1,266,407	106.0
1941	3,280,800	3,280,172	100.0	1977	1,507,640	1,541,864	102.3
1942	2,150,180	2,149,685	100.0	1978	192,960	130,169	67.5
1943	389,420	389,762	100.1	1979	1,594,690	1,786,547	112.0
1944	2,584,280	2,585,087	100.0	1980	505,490	584,289	115.6
1945	2,443,240	2,444,495	100.1	1981	1,171,790	1,365,655	116.5
1946	1,689,000	1,690,748	100.1	1982	506,720	549,584	108.5
1947	998,350	999,834	100.1	1983	579,470	632,909	109.2
1948	261,030	263,134	100.8	1984	309,450	365,878	118.2
1949	712,810	714,337	100.2	1985	870,767	1,121,864	128.8
1950	363,350	362,915	99.9	1986	1,656,118	1,792,262	108.2
1951	133,230	132,148	99.2	1987	2,056,822	2,009,869	97.7
1952	327,952	327,475	99.9	1988	302,066	275,047	91.1
1953	835,610	851,217	101.9	1989	434,169	625,018	144.0
1954	73,087	95,386	130.5	1990	987,650	1,120,348	113.4
1955	274,780	454,168	165.3	1991	1,438,878	2,337,733	162.5
1956	216,220	211,606	97.9	1992	5,099,168	4,345,021	85.2
1957	3,244,730	3,360,434	103.6	1993	1,458,836	1,500,613	102.9
1958	1,614,040	1,627,243	100.8	1994	711,682	818,168	115.0
1959	1,450,690	1,477,691	101.9	1995	1,298,057	1,351,564	104.1
1960	1,740,640	1,761,436	101.2	1996	460,564	566,776	123.1
1961	2,385,510	2,403,600	100.8	1997	3,440,561	3,623,957	105.3
1962	547,420	584,044	106.7	1998	2,208,635	2,582,203	116.9
1963	201,030	242,974	120.9	1999	508,626	674,791	132.7
1964	647,770	703,134	108.5	2000	491,470	841,336	171.2
1965	2,905,700	2,938,979	101.1	2001	1,970,555	2,264,688	114.9
1966	1,331,540	1,372,707	103.1	2002	1,001,818	1,239,200	123.7
1967	379,370	395,024	104.1	2003	838,629	1,047,791	124.9
1968	2,284,140	2,573,868	112.7	2004	2,490,186	3,369,483	135.3
1969	1,012,770	1,097,181	108.3	2005	1,630,344	1,866,049	114.5
1970	1,424,410	1,479,782	103.9	2006	253,144	433,151	171.1
1971	427,860	596,915	139.5	2007	4,577,874	6,103,181	133.3
1972	378,960	455,853	120.3				
1973	1,142,550	1,329,373	116.4	Means for			
1974	1,188,100	1,440,097	121.2	1940-1997	1,257,447	1,318,301	104.8
1975	2,061,360	1,903,733	92.4	1998-2007	1,597,128	2,070,813	129.7
				1940-2007	1,307,400	1,428,965	109.3

Table 4.39 Means of Observed and Naturalized Flows

WAM CP ID	Stream	Nearest City	1998-2007 Observed (ac-ft/year)	1998-2007 Naturalized (ac-ft/year)	1998-2007 Naturalized (percent)
RWPL01	Running Water Draw	Plainview	1,200	2,882	240.2
SFAS06	Salt Fork Brazos River	Aspermont	31,846	35,922	112.8
DMJU08	Double Mountain Fork	Justicebury	26,907	27,340	101.6
DMAS09	Double Mountain Fork	Aspermont	64,558	76,392	118.3
BRSE11	Brazos River	Seymour	161,815	172,359	106.5
MSMN12	Millers Creek	Munday	6,447	6,447	100.0
CFRO13	Clear Fork Brazos	Roby	2,642	2,658	100.6
CFNU16	Clear Fork Brazos	Nugent	20,705	54,028	260.9
CAST17	California Creek	Stamford	24,452	25,671	105.0
CFFG18	Clear Fork Brazos	Fort Griffin	88,401	122,120	138.1
HCAL19	Hubbard Creek	Albany	27,617	29,753	107.7
BSBR20	Big Sandy Creek	Breckenridge	16,917	18,959	112.1
BRSB23	Brazos River	South Bend	364,799	440,512	120.8
BRPP27	Brazos River	Palo Pinto	372,913	613,221	164.4
BRDE29	Brazos River	Dennis	457,419	707,975	154.8
BRGR30	Brazos River	Glen Rose	523,112	823,607	157.4
PAGR31	Paluxy River	Glen Rose	54,915	56,897	103.6
BRAQ33	Brazos River	Aquilla	800,427	1,392,972	174.0
AQAQ34	Aquilla Creek	Aquilla	143,867	170,893	118.8
NBCL36	North Bosque River	Clifton	182,272	187,695	103.0
NBVM37	North Bosque River	Valley Mills	332,685	337,745	101.5
BRWA41	Brazos River	Waco	1,397,595	2,129,841	152.4
BRHB42	Brazos River	Highbank	1,867,661	2,591,359	138.7
SADL44	Sabana River	De Leon	23,701	24,537	103.5
LEHS45	Leon River	Hasse	68,407	132,198	193.3
LEGT47	Leon River	Gatesville	256,766	302,062	117.6
COPI48	Cowhouse Creek	Pidcoke	91,147	91,262	100.1
LEBE49	Leon River	Belton	472,607	755,088	159.8
LAKE50	Lampasas River	Kempner	157,622	155,574	98.7
LABE52	Lampasas River	Belton	302,753	437,327	144.5
LRLR53	Little River	Little River	942,896	1,351,407	143.3
NGGE54	North Fork San Gabriel	Georgetown	52,767	83,751	158.7
SGGE55	South Fork San Gabriel	Georgetown	41,207	41,209	100.0
GALA57	San Gabriel River	Laneport	218,733	295,650	135.2
LRCA58	Little River	Cameron	1,597,128	2,070,813	129.7

Table 4.39 (continued)

WAM CP ID	Stream	Nearest City	1998-2007 Observed (ac-ft/year)	1998-2007 Naturalized (ac-ft/year)	1998-2007 Naturalized (percent)
BRBR59	Brazos River	Bryan	4,012,042	5,192,002	129.4
MYDB60	Middle Yegua Creek	Dime Box	64,581	65,487	101.4
EYDB61	East Yegua Creek	Dime Box	63,921	65,453	102.4
DCLY63	Davidson Creek	Lyons	63,998	63,814	99.7
NAGR64	Navasota River	Groesbeck	96,885	99,685	102.9
BGFR65	Big Creek	Freestone	46,094	46,732	101.4
NAEA66	Navasota River	Easterly	362,658	430,544	118.7
NABR67	Navasota River	Bryan	404,769	476,575	117.7
BRHE68	Brazos River	Hempstead	5,837,824	7,208,408	123.5
BRRI70	Brazos River	Richmond	6,189,195	7,637,495	123.4
BGNE71	Big Creek	Needville	29,730	28,652	96.4
BRRO72	Brazos River	Rosharon	6,304,435	8,089,455	128.3
CBALC2	Chocolate Bayou	Alvin	86,027	87,107	101.3

4.3.3 Naturalized Flows at Control Point LEHS45

As discussed in section 4.1, control point LEHS45 located immediately downstream of Proctor Dam is the only control point for which reservoir releases were adopted for 1998-2007 observed flows. Control point LEHS45 is the site of the discontinued USGS stream gaging station on the Leon River near Hasse for which gage measurements were not made during 1998-2007. Two other USGS gaging stations (control points LEDL43 and LEHM46) on the Leon River upstream and downstream of Proctor Reservoir also had no gage measurements recorded during 1998-2007. The gaging station at Gatesville (control point LEGT47) is the most upstream gage on the Leon River with measurements recorded during 1998-2007.

The 1998-2007 monthly naturalized flows at control point LEHS45 were initially computed as follows.

$$\text{Flow at LEHS45} = 0.5480 \text{ (Flow at LEGT47)}$$

The 1940-1997 mean naturalized flows at control points LEHS45 and LEGT47 from Table 3.2 are 141,270 and 257,790 acre-feet/year, with their ratio being 0.5480. The drainage areas of LEHS45 and LEGT47 are 1,283 and 2,379 square miles. The drainage area ratio of 0.539 is close to the mean flow ratio of 0.5480. However, as discussed in section 4.4, the 1998-2007 storage volumes for Proctor Reservoir from Bwam8 and Bwam8A *SIM* simulations with these synthesized naturalized flows deviated dramatically from observed storage volumes. Consequently, 1998-2007 reservoir release data for Lake Proctor compiled by the Brazos River Authority were adopted as the actual measured flows at control point LEHS45. With gaged flows at LEHS45 converted to naturalized flows as outlined in section 4.1, 1998-2007 *SIM* simulated Proctor Reservoir storages closely match observed storages.

The measured flows at control point LEHS45 shown in Table 4.40 are gaged releases from Proctor Reservoir. Two sets of naturalized flows are compared in Table 4.40. The initial set, which was not adopted in the final results presented in this research, is based on computing the naturalized monthly flows at LEHS45 as 54.8 percent of the naturalized flows at control point LEGT47. The adopted flows summarized in the last column of Table 4.40 were computed based on including LEHS45 with the 48 control points with measured flows as outlined in section 4.1, with the measured flows being releases and spills from Proctor Reservoir. The differences between naturalized flows developed by the two alternative approaches are dramatic. The 1998-2007 annual naturalized mean of 132,198 acre-feet/year is 77.8 percent of the corresponding mean of the naturalized flows initially estimated based on the flow ratio technique.

Table 4.40 Flows at Control Point LEHS45

Year	Measured Flow (ac-ft/year)	Naturalized Flow Initial (ac-ft/year)	Naturalized Flow Adopted (ac-ft/year)
1998	81,505	167,283	138,330
1999	1,222	27,057	22,544
2000	738	57,185	27,117
2001	16,562	139,993	74,637
2002	31,784	98,162	90,909
2003	3,003	69,777	24,166
2004	69,566	286,597	179,889
2005	72,673	206,268	96,092
2006	390	14,246	21,410
2007	406,631	631,628	646,886
Average	68,407	169,820	132,198

4.4 BRAZOS WAM SIMULATION RESULTS

This chapter explores the impacts of extending the hydrologic period-of-analysis on the Brazos WAM simulation results. *WRAP-SIM* simulation results for the authorized use scenario and current use scenario datasets with the 1940-1997 versus 1940-2007 and 1900-2007 simulation periods are compared. The program *SIM* was executed with the four alternative input datasets listed in Table 4.41. A 1940-1997 simulation is embedded within the 1940-2007 and 1900-2007 simulations. The simulation results summarized in this chapter demonstrate the effects of lengthening the hydrologic period-of-analysis from 1940-1997 (58 years) to either 1940-2007 (68 years) or 1900-2007 (108 years).

Table 4.41 Brazos WAM Simulation Compared in Section 4.4

Simulation	Water Use Scenario	Filename	Hydrologic Period-of-Analysis
1	authorized use (run 3)	Bwam3	January 1940 through December 2007
2	authorized use (run 3)	Bwam3	January 1900 through December 2007
3	current use (run 8)	Bwam8	January 1940 through December 2007
4	current use (run 8)	Bwam8	January 1900 through December 2007

The four simulations presented in this chapter incorporate the premise that the beginning-of-simulation storage volume in each reservoir is equal to its storage capacity. The simulations begin with all reservoirs full to capacity. The Bwam3 and Bwam8 simulations with the 1940-2007 and 1900-2007 simulation periods begin with all storage volumes at the beginning of January 1940 or January 1900 set at capacity. The end-of-month December 1939 (beginning of January 1940) storage volumes computed in the 1900-2007 simulation is not necessarily equal to the storage capacity in each of the numerous reservoirs. Thus, simulation results for January 1940 and subsequent months vary between a 1940-2007 simulation and 1900-2007 simulation.

Results are presented by sub-periods of the hydrologic period-of-analysis. The 1940-1997 hydrologic simulation period is a sub-period incorporated in all four simulations. Likewise, the periods 1998-2007 and 1940-2007 are also included in all four of the simulations. The hydrologic simulation period 1900-1939 is included in only simulations 2 and 4 listed in Table 4.41.

4.4.1 River Basin Summary

Summaries of annual means developed with program *TABLES* with a 2SBA record from the results of the *SIM* simulations are tabulated in Tables 4.42 through 4.47 for simulations that begin with full reservoirs at the beginning of January 1900 and January 1940, respectively. The period 1940-1997 is a sub-period of all four simulations. Complete Bwam3 and Bwam8 annual summaries for the 1940-2007 and 1900-2007 simulations are reproduced as Tables 4.44, 4.45, 4.46, and 4.47. These four annual summary tables are further summarized in Tables 4.42 and 4.43. The tables are basin summaries of *SIM* simulation results for the entire Brazos River Basin and San Jacinto-Brazos Coastal Basin with Bwam3 and Bwam8 input datasets consisting of flow volumes in acre-feet/year and reservoir storage volumes in acre-feet. The last line of Tables 4.42 and 4.43 shows volume reliabilities with mean diversions expressed as a percentage of the mean diversion targets.

The naturalized and unappropriated flows shown in Tables 4.42 through 4.47 represent the maximum flow at any control point in a given month, based on *TABLES* comparing all control points. All other quantities shown are the sum of the amounts for all of the control points. The volume reliabilities in Tables 4.42 and 4.43 are the total volume diverted in the simulations expressed as a percentage of the summation of the diversion targets of all water rights in the dataset.

The 1900-1939 mean naturalized flow of 11,777,327 acre-feet is larger than the 1940-1997 mean and smaller than the 1998-2007 mean naturalized flow. The three smallest annual naturalized flows during 1900-1939 are 2,884,847 ac-ft, 2,552,019 ac-ft, and 3,157,185 ac-ft in 1939, 1917, and 1910, respectively. These flow volumes are all greater than the 1900-2007 minimum annual flow of 1,779,414 acre-feet occurring in 1954.

Table 4.42 Brazos WAM Simulation Results Summaries for Simulations 1 and 3 That Begin with January 1940

	Bwam3 Authorized Use			Bwam8 Current Use		
	1940-1997	1998-2007	1940-2007	1940-1997	1998-2007	1940-2007
	mean flow volumes in acre-feet/year and storage volumes in acre-feet					
naturalized flow	7,735,889	13,041,066	8,516,062	7,735,889	13,041,066	8,516,062
return flow	99,889	115,727	102,218	309,285	313,780	309,946
streamflow depletion	2,598,568	2,663,523	2,608,120	1,861,770	1,923,270	1,870,814
unappropriated flow	5,588,001	8,289,901	5,985,340	6,306,919	9,354,053	6,755,028
reservoir storage	3,439,055	3,446,550	3,440,158	3,419,647	3,531,101	3,436,037
evaporation-precip	396,684	399,441	397,089	432,426	455,454	435,813
diversion target	2,463,873	2,503,687	2,469,728	1,522,967	1,535,392	1,524,794
diversion amount	2,216,748	2,248,042	2,221,350	1,434,398	1,454,490	1,437,353
diversion shortage	247,125	255,645	248,378	88,569	80,901	87,442
volume reliability	89.97%	89.79%	89.94%	94.18%	94.73%	94.27%

Table 4.43 Brazos WAM Simulation Results Summaries for Simulations 2 and 4 That Begin with January 1900

	Bwam3 Authorized Use			Bwam8 Current Use		
	1900-1939	1940-1997	1900-2007	1900-1939	1940-1997	1900-2007
	mean flow volumes in acre-feet/year and storage volumes in acre-feet					
naturalized flow	11,777,329	7,735,889	9,723,938	11,777,329	7,735,889	9,723,938
return flow	98,490	99,937	100,863	307,699	309,545	309,253
streamflow depletion	2,620,138	2,618,390	2,623,217	1,885,993	1,870,215	1,880,971
unappropriated flow	6,030,213	5,573,745	5,994,304	7,351,694	6,301,068	6,972,873
reservoir storage	3,584,999	3,411,349	3,478,922	3,634,382	3,409,515	3,504,055
evaporation-precip	430,194	391,817	406,736	464,856	430,900	445,750
diversion target	2,473,032	2,464,366	2,471,217	1,522,126	1,523,116	1,523,886
diversion amount	2,229,743	2,213,797	2,222,874	1,436,381	1,433,719	1,436,628
diversion shortage	243,290	250,568	248,343	85,744	89,397	87,258
volume reliability	90.16%	89.83%	89.95%	94.37%	94.13%	94.27%

Table 4.44 Annual Summary for Bwam3 Authorized Use Scenarios for 1940-2007 Simulation

YEAR	NATURALIZED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	UNAPPROPRIATED FLOW (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1940	8370545.5	95084.2	2677444.5	6477945.0	4549303.0	575009.2	2444632.8	2247522.0	197110.7
1941	14544272.0	116848.9	2831736.5	12950069.0	4513898.0	458632.2	2454964.5	2408408.2	46556.3
1942	9232316.0	120574.6	2871871.0	7387587.0	4477174.0	560100.4	2464162.2	2348459.2	115702.9
1943	2388090.2	97975.4	1800948.9	1140338.9	3348253.8	678012.8	2460730.8	2251652.8	209078.1
1944	9223878.0	117277.5	2969924.2	6984807.5	3559961.5	470739.2	2459416.8	2287378.8	172037.9
1945	12917494.0	124383.7	3011946.5	11255917.0	3745396.5	484590.3	2466244.8	2342023.0	124221.8
1946	8863349.0	113838.2	2647603.8	7299583.5	3694094.2	419084.5	2464091.2	2279743.5	184347.9
1947	5245481.0	105734.3	2365084.2	3743309.5	3229799.2	574131.4	2454908.8	2254991.5	199917.3
1948	2514889.8	86779.4	1979463.6	709825.9	2622397.5	557916.6	2472266.5	2028617.2	443649.3
1949	5013065.5	106840.1	3218548.8	3449821.0	3268181.0	336811.2	2503255.5	2235647.0	267608.5
1950	4923034.5	98462.2	2553761.2	2490827.2	3030832.2	520479.0	2471446.5	2270422.8	201023.6
1951	2002667.8	54896.1	1360055.8	246898.0	2058979.9	509917.9	2453212.5	1821756.8	631455.8
1952	2495267.8	66434.3	1786501.9	718095.8	1653170.9	383170.3	2572577.0	1808989.0	763588.0
1953	4774741.5	95439.7	3617196.5	2604531.5	2822490.8	333037.5	2512636.2	2114797.5	397838.6
1954	1779414.1	60812.2	1587336.1	494609.2	2051048.5	515909.3	2473997.0	1842632.2	631364.8
1955	3203789.5	80096.0	2987390.5	1167288.5	2565614.8	345664.3	2496536.5	2126995.0	369541.6
1956	2125384.8	43835.5	1123748.8	139854.7	1623477.4	471628.7	2484974.2	1594030.9	890943.4
1957	21224914.0	101564.5	5218321.0	16532849.0	4287877.5	299945.8	2462667.5	2253883.2	208784.3
1958	6977795.5	102445.6	2259105.2	5624533.5	3880702.2	371695.8	2447012.8	2294201.5	152811.2
1959	7165160.5	107783.0	2821713.5	5035284.5	4100848.8	270473.5	2449744.5	2330959.5	118785.1
1960	9940976.0	106223.7	2571764.0	7015193.0	4013977.2	361408.2	2455848.5	2297056.8	158791.7
1961	12710218.0	115445.5	2767116.8	10491396.0	4100573.2	316605.7	2443621.0	2363902.8	79718.3
1962	3917897.5	101944.6	2601388.8	1779667.8	3968188.0	399451.8	2458239.5	2334263.8	123975.8
1963	1944356.6	85819.3	1624138.0	713807.4	2998040.8	514302.6	2455551.2	2079756.5	375794.8
1964	2961722.2	91084.4	2321345.5	572970.6	2875173.0	340947.6	2511213.5	2103077.0	408136.5
1965	9283932.0	110612.7	3372167.2	6250665.5	3597841.8	360715.6	2448756.0	2288693.0	160063.0
1966	7376064.0	113161.2	2762089.0	5628382.0	3635569.5	412953.9	2450223.0	2311206.5	139016.6
1967	2139661.2	82551.3	2164631.5	568053.0	3210132.8	432998.2	2439226.8	2156959.0	282267.6
1968	13836409.0	114274.0	2975111.5	11864195.0	3548911.5	273201.1	2452272.5	2363104.0	89168.6
1969	7232474.5	101339.5	2923010.2	4578038.0	3786250.8	379184.7	2466369.5	2306370.2	159999.3
1970	6979219.5	107416.2	2205797.2	4951430.5	3246448.2	460936.1	2468494.0	2284602.2	183891.7
1971	8958747.0	87429.6	2857330.5	4105093.0	3564710.2	381594.8	2443474.0	2157462.0	286012.1
1972	5750679.0	93805.1	2364943.0	3826187.0	3340851.5	398345.1	2455826.2	2190271.5	265554.7
1973	11014019.0	114585.7	2856249.5	9067088.0	3651367.5	224902.1	2448043.8	2320831.0	127212.7
1974	8317648.0	102552.9	2748269.8	5796975.0	3894460.8	336644.9	2446899.2	2168421.0	278478.3
1975	8856902.0	110919.4	2363186.2	7474202.0	3525611.0	392969.2	2453742.2	2338872.5	114869.7
1976	7339916.0	113405.1	2634927.0	4899571.0	3655089.0	247280.1	2445317.2	2258167.2	187150.0
1977	9376888.0	94823.4	1907480.0	8466600.0	2886946.0	488233.9	2450625.0	2187083.5	263541.6
1978	3394920.5	71490.9	2492097.0	1071550.4	2973570.0	348661.1	2463991.0	2056590.5	407400.4
1979	10518358.0	115978.6	3088890.0	8463230.0	3470829.5	272111.8	2460654.8	2319456.0	141198.7
1980	3992167.2	83255.3	2359793.0	2125313.2	3259858.8	473751.2	2505795.2	2096948.5	408846.7
1981	7976748.0	107177.9	3229496.0	5940489.5	3947997.0	250382.7	2464769.5	2290916.5	173852.9
1982	5818414.0	89873.1	2337060.8	3492629.0	3636172.2	407448.6	2443434.5	2241302.8	202131.9
1983	4470741.5	96163.7	2247009.8	3259094.2	3293543.5	346210.3	2471345.5	2243401.2	227944.2
1984	3368378.5	84607.2	2172223.5	1837923.9	3082849.0	355173.9	2498895.8	2027596.5	471299.3
1985	7730600.5	101256.8	3018351.8	4525745.5	3547084.8	349929.0	2452090.5	2204122.8	247967.7
1986	8187564.0	116877.5	2986001.8	5439041.0	3959067.0	256889.5	2469361.2	2317011.0	152350.3
1987	10085820.0	110722.1	2389537.0	8474686.0	3608620.2	384182.2	2452459.5	2355747.5	96711.9
1988	1950015.5	78401.9	1571423.2	419269.2	2653959.8	464866.5	2463017.5	2061089.5	401928.1
1989	9760159.0	103735.1	3053368.0	4703507.0	3103008.8	344617.1	2470549.8	2259482.8	211067.1
1990	12102569.0	111043.5	3039748.2	9779651.0	3551451.8	332015.1	2447252.5	2258796.8	188455.8
1991	15821836.0	115711.8	3193204.5	13315830.0	4099623.8	288565.0	2457198.0	2356336.0	100862.1
1992	20150672.0	126239.2	2882411.2	18141320.0	4162364.2	407648.9	2464328.5	2411541.5	52787.0
1993	9483550.0	115903.2	2340650.5	7535488.5	3665048.0	507638.3	2455581.5	2330155.8	125425.8
1994	9155517.0	109375.2	2862084.5	4589815.0	3837656.0	379007.4	2459312.0	2310444.0	148867.9
1995	17313834.0	112816.6	2509412.0	15476137.0	3648593.2	356351.2	2442512.0	2341885.0	100627.1

Table 4.44 (continued)

YEAR	NATURALIZED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	UNAPPROPRIATED FLOW (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1996	3013868.2	82502.5	2344319.5	1134823.0	3557033.2	357230.3	2448287.0	2078138.2	370148.8
1997	11462574.0	115947.3	2889221.2	9875049.0	3823235.8	265343.3	2450579.0	2357191.2	93387.7
1998	15290264.0	115774.6	2660634.5	10643707.0	3635182.2	556532.5	2456620.8	2291981.2	164639.5
1999	3393794.8	106493.6	2131150.0	1917304.9	3062180.0	510482.2	2476242.5	2193659.0	282583.4
2000	8601712.0	101902.6	2701070.2	1390593.8	3277615.0	359911.9	2519633.8	2125687.8	393946.1
2001	13684570.0	117858.9	2713651.5	10028019.0	3416524.0	314464.9	2531450.5	2260175.0	271275.6
2002	10751560.0	117992.3	2660354.0	6107816.5	3527275.5	280580.9	2519450.0	2268994.0	250456.1
2003	6853310.0	118995.9	2260947.0	3985050.2	3195426.2	378015.8	2536985.8	2214780.5	322205.2
2004	24123402.0	125065.9	3010511.2	19826378.0	3789226.2	145012.7	2520867.5	2271700.8	249166.8
2005	9545604.0	116963.3	2421168.8	5379465.0	3493837.0	416347.7	2508477.8	2300186.2	208291.5
2006	5234925.5	110335.2	2111170.0	1573682.6	3085066.2	333847.9	2500624.5	2186005.0	314619.6
2007	32931516.0	125884.1	3964571.2	22046994.0	3983172.0	699209.4	2466515.5	2367254.2	99261.3
MEAN	8516062.0	102218.3	2608120.2	5985339.5	3440158.0	397089.0	2469727.8	2221350.0	248378.2

Table 4.45 Annual Summary for Bwam8 Current Use Scenarios for 1940-2007 Simulation

YEAR	NATURALIZED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	UNAPPROPRIATED FLOW (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1940	8370545.5	289079.5	1896166.5	7070435.5	3964690.8	537329.2	1513487.5	1417116.9	96370.7
1941	14544272.0	315944.7	1879891.4	13451233.0	3934535.8	418679.9	1513887.0	1491180.4	22706.6
1942	9232316.0	320157.1	1972179.5	8044901.0	3914925.5	526515.9	1530211.6	1465196.2	65015.4
1943	2388090.2	311422.8	1414866.8	1455324.2	3237079.0	663008.8	1530742.4	1429477.8	101264.6
1944	9223878.0	318577.5	2340202.5	7569803.0	3620695.2	502647.7	1526708.4	1453797.0	72911.3
1945	12917494.0	323516.5	2084901.4	11973507.0	3688965.0	540838.8	1520453.0	1475792.2	44660.7
1946	8863349.0	316214.7	1976607.9	7803201.0	3679513.8	511686.7	1521539.5	1474276.0	47263.5
1947	5245481.0	317683.2	1713783.4	4312791.0	3303058.8	628657.4	1520541.8	1461361.1	59180.7
1948	2514889.8	301270.0	1590439.8	1175078.1	2845638.8	652681.8	1543669.1	1395045.9	148623.2
1949	5013065.5	317079.8	2349193.0	3828765.0	3348117.0	394983.5	1522744.2	1451126.6	71617.7
1950	4923034.5	314320.8	1833234.4	3023610.8	3135470.8	577601.9	1513844.4	1467974.0	45870.4
1951	2002667.8	280065.8	1286724.0	422549.8	2537673.8	617243.9	1516264.0	1267211.1	249052.9
1952	2495267.8	277821.7	1514243.0	950747.1	2247811.8	541949.1	1568837.6	1262034.1	306803.5
1953	4774741.5	302919.5	2695005.2	3201225.2	3053507.0	464911.0	1543400.0	1424394.9	119005.1
1954	1779414.1	289186.6	1285728.5	707343.4	2480901.2	608676.9	1522102.1	1249600.5	272501.6
1955	3203789.5	294843.2	2157512.5	1779528.6	2801263.8	426133.8	1544443.0	1410982.0	133461.0
1956	2125384.8	266583.5	1149695.9	283340.9	2213593.8	599135.6	1552637.9	1138187.9	414450.0
1957	21224914.0	304768.6	3266915.5	17532042.0	3778304.0	275989.2	1509228.2	1426195.6	83032.6
1958	6977795.5	317866.2	1596062.1	6049156.0	3567634.2	356907.3	1517039.1	1449485.5	67553.7
1959	7165160.0	315218.8	1942616.8	5605235.5	3758939.2	276779.9	1515995.6	1474435.9	41559.7
1960	9940976.0	313870.3	1741750.5	7434134.0	3670365.0	369542.3	1516786.0	1460657.1	56128.8
1961	12710218.0	318039.3	1889984.4	11447192.0	3771126.8	304251.8	1514346.4	1484969.0	29377.3
1962	3917897.5	304931.1	1824012.4	2818412.5	3737472.5	393777.2	1512500.1	1463503.2	48996.9
1963	1944356.6	298531.2	1301005.8	961456.5	3156777.2	527251.1	1523627.5	1354308.8	169318.7
1964	2961722.2	304388.2	1901498.6	995389.4	3273651.2	401753.5	1529950.5	1382829.8	147120.7
1965	9283932.0	309401.2	2159886.0	7977208.5	3584637.2	395111.7	1512466.6	1453654.6	58812.0
1966	7376064.0	314669.9	1921093.6	6190580.5	3597861.0	436120.8	1513442.9	1471638.5	41804.4
1967	2139661.2	296156.0	1611864.5	1160358.0	3327427.2	480599.8	1509084.2	1401669.5	107414.8
1968	13836409.0	321820.3	1986565.0	12632114.0	3543580.5	286425.7	1519750.2	1483965.6	35784.7

Table 4.45 (continued)

YEAR	NATURALIZED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	UNAPPROPRIATED FLOW (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1969	7232474.5	309800.6	1998292.8	5384186.5	3675093.2	385998.8	1526755.5	1480668.2	46087.2
1970	6979219.5	316942.8	1638137.9	5617201.5	3370048.2	487543.3	1522973.4	1455630.4	67343.0
1971	8958747.0	301133.9	2045752.1	6870027.5	3552828.2	445733.0	1512148.8	1417193.4	94955.4
1972	5750679.0	304462.4	1669186.5	4310577.5	3318624.8	451552.5	1520945.6	1451474.9	69470.8
1973	11014019.0	320215.3	1972820.2	9597924.0	3550190.0	252482.6	1516020.5	1488774.0	27246.5
1974	8317648.0	309985.5	2042199.5	6416070.0	3760761.0	382299.9	1516043.6	1449241.8	66801.9
1975	8856902.0	321659.6	1669998.1	7996713.0	3533485.8	410734.5	1517152.4	1486163.9	30988.6
1976	7339916.0	316662.9	1884993.2	5436993.5	3667516.0	292104.6	1515566.5	1458773.0	56793.5
1977	9376888.0	309941.2	1445172.5	8650271.0	3106628.8	553231.1	1518352.1	1452586.5	65765.6
1978	3394920.5	299355.3	1775207.9	1390915.9	3050487.5	425882.1	1532496.2	1405424.6	127071.7
1979	10518358.0	324905.6	2195236.2	8994097.0	3455277.0	295536.3	1529161.6	1494898.4	34263.2
1980	3992167.2	302588.2	1734431.8	2692309.0	3265747.8	525266.6	1517991.0	1398685.4	119305.6
1981	7976748.0	320380.9	2172406.5	6326888.5	3688221.2	286302.2	1531060.0	1463535.8	67524.3
1982	5818414.0	307172.0	1602496.5	3988762.5	3443673.8	399131.6	1516889.6	1447894.1	68995.5
1983	4470741.5	316404.7	1699678.9	3651692.8	3334037.5	367295.1	1542635.9	1442009.4	100626.5
1984	3368378.5	303010.8	1689251.8	2371658.0	3235523.8	426642.8	1547813.0	1361093.0	186720.0
1985	7730600.5	312865.9	2126743.2	5233767.0	3556567.2	377993.0	1523111.5	1427695.4	95416.1
1986	8187564.0	316405.3	1912869.1	7151695.5	3724177.2	282010.0	1515425.8	1463061.4	52364.4
1987	10085820.0	314418.7	1729391.8	8942787.0	3599754.0	377945.2	1519089.8	1475839.6	43250.2
1988	1950015.5	294500.6	1365328.1	713567.9	3057667.2	518671.7	1524772.2	1388720.2	136052.0
1989	9760159.0	314113.4	2050693.4	7908290.0	3255521.5	394349.1	1519058.0	1458373.5	60684.5
1990	12102569.0	319631.2	2070861.2	11002817.0	3525401.2	340104.5	1520338.9	1460534.2	59804.6
1991	15821836.0	317631.2	2090911.5	14762970.0	3816594.0	315550.8	1516162.8	1483982.1	32180.6
1992	20150672.0	323878.4	1890339.6	18807504.0	3817034.2	389421.7	1518301.0	1500102.6	18198.4
1993	9483550.0	318850.2	1735355.0	7930398.5	3566941.8	501572.3	1523918.2	1483759.2	40159.0
1994	9155517.0	313181.0	2000054.1	7142004.5	3686651.0	397257.3	1528953.6	1483086.8	45866.9
1995	17313834.0	318711.8	1821151.9	16873542.0	3639876.8	377556.1	1512576.0	1490177.4	22398.6
1996	3013868.2	291988.1	1766289.9	1622711.9	3587958.5	419958.2	1507921.6	1397779.0	110142.7
1997	11462574.0	321387.5	1903771.0	10156282.0	3721993.8	283403.9	1518735.6	1485862.6	32873.0
1998	15290264.0	316110.9	1962704.0	11256589.0	3622689.0	590812.3	1521943.5	1471093.2	50850.3
1999	3393794.8	308540.1	1596706.0	2358625.2	3247325.2	558277.4	1519051.2	1413651.5	105399.7
2000	8601712.0	308884.2	2065085.1	5012547.0	3456264.8	448924.4	1525065.9	1407221.8	117844.1
2001	13684570.0	314305.2	1859461.5	10602506.0	3469575.0	373956.5	1537114.2	1472108.1	65006.1
2002	10751560.0	316529.3	1954556.4	7647719.0	3605430.8	334001.3	1540526.1	1484696.2	55829.9
2003	6853310.0	312019.6	1724633.1	4477041.5	3408574.5	472932.6	1557258.5	1448560.5	108697.9
2004	24123402.0	317536.6	1978448.2	20485200.0	3700172.0	202363.0	1550721.2	1484293.8	66427.5
2005	9545604.0	315202.6	1759045.0	6786871.0	3549027.2	458342.8	1537011.6	1451841.4	85170.3
2006	5234925.5	306978.8	1661888.2	1868764.2	3397321.2	400501.4	1535679.8	1413005.9	122673.9
2007	32931516.0	321694.0	2670170.5	23044670.0	3854629.2	714432.1	1529544.4	1498431.0	31113.4
MEAN	8516062.0	309946.1	1870814.0	6755027.5	3436037.2	435812.8	1524794.2	1437353.0	87441.6

Table 4.46 Annual Summary for Bwam3 Authorized Use Scenarios for 1900-2007 Simulation

YEAR	NATURALIZED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	UNAPPROPRIATED FLOW (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1900	20518162.0	115782.7	2923646.0	14060025.0	4615140.0	595411.1	2457415.2	2407711.0	49704.3
1901	3379020.0	87259.8	1622517.1	1780524.1	3635787.0	446002.4	2476631.5	2155456.5	321175.1

Table 4.46 (continued)

YEAR	NATURALIZED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	UNAPPROPRIATED FLOW (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1902	13035603.0	96789.2	3313589.0	5370549.5	4176011.5	457708.2	2457121.0	2315526.5	141594.4
1903	13264413.0	109472.8	2436378.5	4756698.5	3782193.0	472239.2	2456636.0	2357748.8	98887.3
1904	6586585.5	100893.4	2383809.8	865902.8	3497742.2	376182.2	2468929.5	2291746.5	177183.1
1905	15143339.0	104631.5	3189198.2	6504685.5	3868260.2	482404.1	2462581.0	2335933.5	126647.6
1906	7665399.0	107161.4	2792644.5	2220590.0	3873828.8	429533.8	2474755.0	2357128.8	117626.3
1907	9928151.0	103410.4	2982251.2	4111780.2	4067438.2	440596.3	2454626.2	2347622.5	107003.7
1908	25028760.0	112888.2	2666181.2	14252279.0	3817191.8	563940.9	2453035.8	2352232.2	100803.5
1909	6029185.5	70058.1	1474140.8	148171.7	2948069.8	343536.2	2471545.2	1999570.5	471974.7
1910	3157185.0	61546.4	1473233.8	361235.4	2339298.0	279014.1	2464146.0	1802441.2	661704.8
1911	6005543.0	98407.9	2043062.2	514648.0	2101582.5	226628.4	2583206.5	2053919.5	529287.0
1912	4342691.5	86167.8	1824352.8	1244339.8	1817620.4	210084.6	2595040.0	1897765.6	697274.4
1913	13644529.0	105227.3	4152382.5	9319216.0	3612665.5	270897.1	2567641.5	2085974.2	481667.2
1914	18150640.0	120367.1	3171906.0	10845221.0	3919364.0	492423.9	2472241.5	2372674.0	99567.5
1915	13140758.0	116017.5	3260127.2	10980914.0	4218068.0	554493.8	2449819.5	2406446.0	43373.6
1916	10330962.0	103398.8	2247043.0	8968288.0	3709767.8	465519.0	2454182.0	2289379.5	164802.6
1917	2552019.0	65560.0	1164692.1	173190.2	2629120.0	322208.7	2484025.5	1922891.5	561133.9
1918	11526029.0	85189.7	3098926.8	1842709.8	3311432.8	317671.2	2537568.2	2098447.0	439121.4
1919	26814616.0	119528.2	4031175.2	12127385.0	4361430.0	572949.3	2446937.2	2408190.0	38747.3
1920	18201364.0	110131.6	2914818.2	12969379.0	4317948.0	551511.1	2451905.5	2406486.5	45418.9
1921	9428539.0	109704.9	2198931.2	5650838.0	3728287.0	463319.5	2469071.2	2325194.5	143876.7
1922	21163070.0	90872.0	2582788.2	18629510.0	3474184.5	550259.6	2452589.8	2286588.8	166001.0
1923	13257192.0	105724.8	3191331.2	7325662.0	3942681.0	444884.0	2477447.0	2277763.5	199683.6
1924	11488936.0	85600.6	1904882.8	4621720.5	3272280.0	439100.7	2449270.0	2136103.0	313167.1
1925	4674278.5	71563.2	2495387.8	1722100.6	3480027.5	340352.3	2484945.2	1946872.5	538072.8
1926	11351932.0	109212.2	3149039.5	7248236.0	3820294.5	442556.9	2457578.2	2365848.0	91730.2
1927	9763355.0	109460.4	2520155.0	7006577.0	3600245.2	424598.1	2459894.8	2315350.0	144544.8
1928	7173268.5	95888.5	2729793.8	1572152.2	3647016.2	399014.0	2461100.5	2283514.8	177585.8
1929	9462536.0	100423.2	2758375.5	4819936.0	3652752.5	447431.4	2459900.5	2304828.0	155072.6
1930	8656993.0	97561.1	3111631.2	5667074.5	4045936.0	446841.3	2466402.5	2271336.2	195066.2
1931	10104903.0	100512.7	2141321.8	4298818.5	3530742.5	436753.8	2470726.5	2219547.5	251179.0
1932	18228772.0	107868.4	3294584.8	12598689.0	3958635.8	499480.6	2452943.0	2366824.8	86118.4
1933	6533672.5	80931.1	1961755.0	1160001.8	3324870.5	409144.2	2466289.8	2186309.0	279980.8
1934	6331331.0	82572.4	2087623.9	3459317.8	3113163.2	373783.8	2464956.2	1925325.0	539631.2
1935	30036858.0	120158.5	3760486.2	7813480.0	3986083.5	516759.4	2455065.5	2370772.8	84292.6
1936	13102664.0	106217.2	2843277.0	8443198.0	4024331.2	469859.3	2448176.5	2335124.0	113052.6
1937	11812503.0	99581.7	2236143.8	4163335.5	3626550.0	408418.5	2464856.5	2225403.5	239452.9
1938	17192544.0	100964.6	2618011.5	10940952.0	3460000.8	474490.3	2460632.0	2309758.5	150873.6
1939	2884847.0	84901.4	2053927.5	649184.2	3091912.2	349742.3	2459458.2	2071946.1	387512.1
1940	8370545.5	98510.4	3380087.8	6033346.5	3876865.5	420696.7	2463782.5	2173929.8	289852.7
1941	14544272.0	116816.9	3246432.5	12616606.0	4286944.0	429608.0	2463421.5	2406554.0	56867.6
1942	9232316.0	120574.6	2902487.2	7352362.0	4307901.0	541929.1	2464328.2	2339417.8	124910.5
1943	2388090.2	97701.6	1801055.8	1127513.5	3218676.5	658556.1	2461321.8	2231654.2	229667.5
1944	9223878.0	117260.4	2970596.5	6984222.0	3456828.5	458527.6	2459425.8	2273755.5	185670.3
1945	12917494.0	124383.7	3012043.0	11255894.0	3656429.0	475213.9	2466244.8	2337229.2	129015.5
1946	8863349.0	113838.2	2647755.8	7299560.5	3620671.8	410162.4	2464100.2	2273187.2	190913.1
1947	5245481.0	105552.8	2365028.2	3743228.5	3180366.2	564439.1	2454933.8	2240769.8	214164.1
1948	2514889.8	86676.8	1979868.1	709620.4	2601294.5	551081.6	2472274.5	2007656.5	464618.0
1949	5013065.5	106759.5	3218747.5	3449900.5	3250054.8	335003.2	2503389.0	2234759.8	268629.2
1950	4923034.5	98462.2	2553815.8	2490823.2	3015891.5	517521.0	2471448.2	2270239.2	201209.0
1951	2002667.8	54896.1	1360055.8	246898.0	2047844.1	507279.1	2453212.5	1820590.2	632622.2
1952	2495267.8	66434.3	1786501.9	718095.8	1645943.9	381153.9	2572577.0	1807096.4	765480.6
1953	4774741.5	95439.7	3617198.5	2604529.2	2817549.0	331864.4	2512636.2	2113691.5	398944.8
1954	1779414.1	60812.2	1587336.1	494609.2	2047193.5	514822.8	2473997.0	1842632.2	631364.8
1955	3203789.5	80096.0	2987390.5	1167288.5	2562487.5	344943.5	2496537.0	2126990.8	369546.2
1956	2125384.8	43835.5	1123748.9	139854.7	1622214.5	470849.2	2484997.0	1592946.0	892050.9
1957	21224914.0	101564.5	5218345.5	16532829.0	4286808.5	299894.6	2462667.5	2253749.8	208917.6

Table 4.46 (continued)

YEAR	NATURALIZED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	UNAPPROPRIATED FLOW (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1958	6977795.5	102445.6	2259106.2	5624532.0	3879764.0	371566.3	2447012.8	2294201.5	152811.2
1959	7165160.5	107783.0	2821714.0	5035284.0	4099991.8	270392.9	2449744.5	2330959.5	118785.1
1960	9940976.0	106223.7	2571764.8	7015192.5	4013196.2	361332.6	2455848.5	2297056.8	158791.7
1961	12710218.0	115445.5	2767117.2	10491396.0	4099895.0	316506.7	2443621.0	2363902.8	79718.3
1962	3917897.5	101944.6	2601389.0	1779667.5	3967617.0	399345.7	2458239.5	2334263.8	123975.8
1963	1944356.6	85819.3	1624138.0	713807.4	2997607.8	514164.3	2455551.2	2079756.5	375794.8
1964	2961722.2	91084.4	2321345.5	572970.6	2874809.8	340879.3	2511213.5	2103076.2	408137.3
1965	9283932.0	110612.7	3372167.5	6250665.5	3597512.2	360681.7	2448756.0	2288693.0	160063.0
1966	7376064.0	113161.2	2762089.2	5628381.5	3635287.2	412907.6	2450223.0	2311206.5	139016.6
1967	2139661.2	82551.3	2164631.5	568053.0	3209893.2	432955.5	2439226.8	2156959.0	282267.6
1968	13836409.0	114274.0	2975114.5	11864195.0	3548698.0	273178.3	2452272.5	2363104.0	89168.6
1969	7232474.5	101339.5	2923010.5	4578038.0	3786062.5	379159.3	2466369.5	2306370.2	159999.3
1970	6979219.5	107416.2	2205797.2	4951430.5	3246291.0	460910.1	2468494.0	2284602.2	183891.7
1971	8958747.0	87429.6	2857332.0	4105091.5	3564583.5	381565.7	2443474.0	2157462.0	286012.1
1972	5750679.0	93805.1	2364943.0	3826187.0	3340743.8	398326.1	2455826.2	2190271.5	265554.7
1973	11014019.0	114585.7	2856251.0	9067086.0	3651265.2	224894.2	2448043.8	2320831.0	127212.7
1974	8317648.0	102552.9	2748269.2	5796975.5	3894384.8	336631.6	2446899.2	2168407.0	278492.2
1975	8856902.0	110919.4	2363186.2	7474202.0	3525548.2	392958.8	2453742.2	2338872.5	114869.7
1976	7339916.0	113405.1	2634927.0	4899571.0	3655031.2	247276.7	2445317.2	2258167.2	187150.0
1977	9376888.0	94823.4	1907480.1	8466600.0	2886901.2	488220.7	2450625.0	2187083.5	263541.6
1978	3394920.5	71490.9	2492097.0	1071550.4	2973532.5	348654.1	2463991.0	2056590.5	407400.4
1979	10518358.0	115978.6	3088890.0	8463230.0	3470795.2	272108.4	2460654.8	2319456.0	141198.7
1980	3992167.2	83255.3	2359793.0	2125313.2	3259831.8	473743.8	2505795.2	2096948.5	408846.7
1981	7976748.0	107177.9	3229496.2	5940489.5	3947973.5	250379.8	2464769.5	2290916.5	173852.9
1982	5818414.0	89873.1	2337060.8	3492629.0	3636152.2	407444.9	2443434.5	2241302.8	202131.9
1983	4470741.5	96163.7	2247009.8	3259094.2	3293525.5	346207.8	2471345.5	2243401.2	227944.2
1984	3368378.5	84607.2	2172236.5	1837951.5	3082791.5	355167.6	2498895.8	2027596.5	471299.3
1985	7730600.5	101256.8	3018352.8	4525820.5	3547033.0	349924.0	2452090.5	2204122.8	247967.7
1986	8187564.0	116877.5	2986003.0	5439040.0	3959019.8	256886.1	2469361.5	2317011.0	152350.6
1987	10085820.0	110722.1	2389571.8	8474685.0	3608610.2	384180.0	2452459.5	2355747.5	96711.9
1988	1950015.5	78401.9	1571423.2	419269.2	2653951.5	464864.2	2463017.5	2061089.5	401928.1
1989	9760159.0	103735.1	3053368.0	4703507.0	3103001.8	344615.9	2470549.8	2259482.8	211067.1
1990	12102569.0	111043.5	3039748.2	9779651.0	3551445.8	332014.4	2447252.5	2258796.8	188455.8
1991	15821836.0	115711.8	3193204.5	13315830.0	4099618.2	288564.6	2457198.0	2356336.0	100862.1
1992	20150672.0	126239.2	2882411.2	18141320.0	4162359.2	407648.3	2464328.5	2411541.5	52787.0
1993	9483550.0	115903.2	2340650.8	7535488.5	3665043.8	507637.6	2455581.5	2330155.8	125425.8
1994	9155517.0	109375.2	2862084.5	4589815.0	3837652.5	379006.7	2459312.0	2310444.0	148867.9
1995	17313834.0	112816.6	2509412.0	15476137.0	3648590.0	356350.9	2442512.0	2341885.0	100627.1
1996	3013868.2	82502.5	2344319.2	1134823.2	3557029.5	357229.9	2448287.0	2078138.2	370148.8
1997	11462574.0	115947.3	2889223.0	9875047.0	3823234.5	265343.2	2450579.0	2357191.2	93387.7
1998	15290264.0	115774.6	2660634.5	10643707.0	3635181.2	556532.2	2456620.8	2291981.2	164639.5
1999	3393794.8	106493.6	2131150.0	1917304.9	3062179.0	510482.0	2476242.5	2193659.0	282583.4
2000	8601712.0	101902.6	2701070.5	1390593.9	3277614.2	359911.8	2519634.0	2125688.0	393946.1
2001	13684570.0	117858.9	2713651.2	10028019.0	3416519.8	314464.7	2531450.5	2260175.0	271275.6
2002	10751560.0	117992.3	2660357.8	6107816.5	3527275.0	280580.8	2519450.0	2268994.0	250456.1
2003	6853310.0	118995.9	2260947.0	3985050.2	3195425.8	378015.7	2536985.8	2214780.5	322205.2
2004	24123402.0	125065.9	3010511.2	19826378.0	3789225.8	145012.7	2520867.5	2271700.8	249166.8
2005	9545604.0	116963.3	2421168.8	5379465.0	3493836.8	416347.6	2508477.8	2300186.2	208291.5
2006	5234925.5	110335.2	2111170.0	1573682.6	3085065.8	333847.8	2500624.5	2186005.0	314619.6
2007	32931516.0	125884.1	3964571.2	22046994.0	3983171.8	699209.4	2466515.5	2367254.2	99261.3
MEAN	9723938.0	100862.9	2623216.5	5994304.0	3478921.8	406736.2	2471216.8	2222873.8	248342.6

Table 4.47 Annual Summary for Bwam8 Current Use Scenarios for 1900-2007 Simulation

YEAR	NATURALIZED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	UNAPPROPRIATED FLOW (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1900	20518162.0	299317.0	2021455.5	14688779.0	3991231.5	554882.6	1511151.0	1498513.5	12637.5
1901	3379020.0	305447.8	1345656.4	2068188.8	3512315.2	430926.2	1523375.8	1393346.5	130029.3
1902	13035603.0	302530.3	2275128.0	6351650.0	3860924.5	463452.9	1516810.5	1462959.6	53850.9
1903	13264413.0	316865.1	1838441.0	9443452.0	3731151.2	477264.7	1522014.9	1490675.1	31339.8
1904	6586585.5	303991.6	1867044.6	1373201.2	3699696.2	426061.2	1521007.8	1472166.9	48840.9
1905	15143339.0	310045.0	2126663.0	7320221.5	3833294.0	513577.0	1518789.8	1479200.4	39589.3
1906	7665399.0	316112.5	1909229.0	5965567.5	3808905.2	450574.5	1520570.6	1482762.9	37807.8
1907	9928151.0	312719.8	2012860.4	5236187.5	3884803.8	459797.4	1513004.9	1476791.2	36213.6
1908	25028760.0	315982.1	1923898.5	14768228.0	3768090.2	558378.1	1515893.6	1482040.8	33852.8
1909	6029185.5	289258.5	1335675.6	381476.0	3385344.0	392904.0	1531897.5	1325404.1	206493.4
1910	3157185.0	271675.2	1268644.9	674177.2	3056730.5	377260.8	1527038.4	1219567.1	307471.3
1911	6005543.0	311937.0	1749927.6	862289.8	2992019.2	362538.8	1524315.9	1451971.1	72344.8
1912	4342691.5	302860.4	1543757.6	1784507.4	2788698.8	348571.1	1564724.1	1398346.5	166377.7
1913	13644529.0	302274.4	2645808.0	9937974.0	3613642.0	410017.9	1565786.0	1410474.2	155311.8
1914	18150640.0	320105.2	2158203.8	12060635.0	3737689.2	539891.3	1515608.8	1494177.8	21431.0
1915	13140758.0	318745.8	2118063.5	11688886.0	3826796.5	532112.1	1512455.1	1496472.5	15982.6
1916	10330962.0	314050.5	1680370.6	9379830.0	3596702.2	459100.7	1519616.1	1451065.6	68550.5
1917	2552019.0	284616.9	1132158.4	374069.7	3077710.5	372103.4	1520698.6	1278914.0	241784.6
1918	11526029.0	304840.0	2212698.0	5267410.0	3487823.0	412044.0	1522374.9	1390378.5	131996.4
1919	26814616.0	317735.5	2558746.5	16216007.0	3936469.2	611919.8	1513421.5	1498174.9	15246.7
1920	18201364.0	309479.8	1977209.1	13858836.0	3901297.2	525390.1	1507737.9	1486718.5	21019.4
1921	9428539.0	316122.8	1670416.1	7810154.0	3640381.0	463515.9	1533823.5	1467808.5	66015.0
1922	21163070.0	313269.2	1834526.0	19189772.0	3475858.8	529788.8	1522648.2	1469254.0	53394.3
1923	13257192.0	311727.0	2244278.2	8068172.0	3815258.2	472205.2	1525873.5	1432569.0	93304.4
1924	11488936.0	306868.8	1523436.0	7044814.0	3454652.0	467937.1	1518289.1	1416099.1	102190.0
1925	4674278.5	291677.6	1885472.1	2288305.8	3657110.8	405327.1	1518938.9	1277313.6	241625.2
1926	11351932.0	316889.2	2099666.5	7930687.5	3791405.5	473818.8	1512737.6	1491191.1	21546.5
1927	9763355.0	316192.4	1869959.2	7544032.0	3731284.5	457046.5	1518804.4	1472839.4	45965.0
1928	7173268.5	304626.2	1827686.0	2497423.0	3661619.2	426991.5	1513662.5	1469898.1	43764.4
1929	9462536.0	314138.3	1958790.9	5510797.0	3696435.0	463472.6	1517276.1	1460204.0	57072.1
1930	8656993.0	310990.1	2093109.4	6926529.5	3876077.2	468072.6	1519733.6	1445174.8	74558.9
1931	10104903.0	310010.2	1694097.2	4725092.5	3663431.8	469065.7	1522840.4	1437488.4	85352.0
1932	18228772.0	309722.8	2191214.2	15934165.0	3843967.0	526045.2	1515444.1	1484303.1	31141.0
1933	6533672.5	301419.2	1500786.8	2184241.8	3484733.5	433527.8	1521237.0	1426480.2	94756.8
1934	6331331.0	300681.9	1602793.8	4400483.5	3392951.2	423684.3	1529026.0	1270780.4	258245.6
1935	30036858.0	322841.8	2581625.2	10750938.0	3915351.0	559883.4	1518743.2	1499251.5	19491.7
1936	13102664.0	309963.7	1965422.4	9250356.0	3913767.0	496010.8	1516760.1	1470993.0	45767.2
1937	11812503.0	309254.8	1796451.1	7565081.0	3814315.8	452331.7	1536430.0	1443494.8	92935.2
1938	17192544.0	304780.5	1825797.6	13561555.0	3649919.8	515769.6	1511171.4	1474172.2	36999.2
1939	2884847.0	306187.6	1572566.2	1183570.0	3405440.2	410991.7	1523298.4	1405819.0	117479.3
1940	8370545.5	305831.0	2345083.5	6748149.0	3854399.8	499442.8	1522028.2	1396312.5	125715.8
1941	14544272.0	314456.3	1909364.2	13440013.0	3863478.2	412335.5	1513894.2	1487766.0	26128.3
1942	9232316.0	320157.1	1979333.5	8039178.5	3857209.0	520643.5	1530211.6	1464881.5	65330.1
1943	2388090.2	311389.0	1414180.2	1455320.8	3185827.5	656845.4	1530807.6	1428489.1	102318.5
1944	9223878.0	318527.0	2340260.0	7569758.0	3573123.8	499183.8	1526708.6	1453639.2	73069.4
1945	12917494.0	323516.5	2085072.5	11973493.0	3645064.5	537338.9	1520453.0	1475792.2	44660.7
1946	8863349.0	316214.7	1978028.5	7803201.0	3639900.5	508820.0	1521539.5	1474276.0	47263.5
1947	5245481.0	317683.2	1715110.5	4312791.0	3267104.2	625014.8	1520541.8	1462672.2	57869.5
1948	2514889.8	301270.0	1590956.8	1175078.1	2813810.0	648572.8	1543669.1	1395546.2	148122.9
1949	5013065.5	317079.8	2349088.8	3828732.5	3318120.5	393192.8	1522744.2	1450981.1	71763.1
1950	4923034.5	314231.5	1834330.8	3023610.8	3115468.0	573678.6	1513844.4	1463089.1	50755.2
1951	2002667.8	280044.9	1287587.6	422549.8	2529873.8	614680.8	1516264.0	1258456.2	257807.8
1952	2495267.8	277821.7	1514003.0	950747.1	2241262.2	540698.5	1568837.6	1261794.2	307043.3
1953	4774741.5	302919.5	2694299.2	3201225.2	3048353.2	463998.8	1543400.0	1423205.5	120194.5
1954	1779414.1	289186.6	1285728.5	707343.4	2476827.2	607597.4	1522102.1	1249600.5	272501.6
1955	3203789.5	294843.2	2158063.2	1779528.6	2797771.8	425551.9	1544443.2	1411532.1	132911.2

Table 4.47 (continued)

YEAR	NATURALIZED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	UNAPPROPRIATED FLOW (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1956	2125384.8	266583.5	1149695.9	283340.9	2211610.8	598491.4	1552660.8	1137323.2	415337.4
1957	21224914.0	304768.6	3266915.5	17532042.0	3776406.5	275903.7	1509228.2	1426195.6	83032.6
1958	6977795.5	317866.2	1596062.1	6049156.0	3565909.2	356735.0	1517039.1	1449485.5	67553.7
1959	7165160.0	315218.8	1942616.8	5605235.5	3757352.5	276641.5	1515995.6	1474435.9	41559.7
1960	9940976.0	313870.3	1741750.5	7434134.0	3668913.0	369407.4	1516786.0	1460657.1	56128.8
1961	12710218.0	318039.3	1889984.4	11447192.0	3769800.8	304126.2	1514346.4	1484969.0	29377.3
1962	3917897.5	304931.1	1824012.4	2818412.5	3736291.0	393632.6	1512500.1	1463503.2	48996.9
1963	1944356.6	298531.2	1301005.8	961456.5	3155779.2	527066.8	1523627.5	1354308.8	169318.7
1964	2961722.2	304388.2	1901498.6	995389.4	3272772.5	401634.7	1529950.5	1382829.8	147120.7
1965	9283932.0	309401.2	2159886.0	7977208.5	3583833.2	395036.8	1512466.6	1453654.6	58812.0
1966	7376064.0	314669.9	1921093.6	6190580.5	3597141.0	436037.0	1513442.9	1471638.5	41804.4
1967	2139661.2	296156.0	1611864.5	1160358.0	3326789.2	480517.5	1509084.2	1401669.5	107414.8
1968	13836409.0	321820.3	1986565.0	12632114.0	3542989.5	286378.4	1519750.2	1483965.6	35784.7
1969	7232474.5	309800.6	1998292.8	5384186.5	3674547.5	385954.2	1526755.5	1480668.2	46087.2
1970	6979219.5	316942.8	1638137.9	5617201.5	3369560.2	487485.5	1522973.4	1455630.4	67343.0
1971	8958747.0	301133.9	2045752.1	6870027.5	3552394.8	445678.4	1512148.8	1417193.4	94955.4
1972	5750679.0	304462.4	1669186.5	4310577.5	3318236.8	451506.8	1520945.6	1451474.9	69470.8
1973	11014019.0	320215.3	1972820.2	9597924.0	3549826.5	252458.4	1516020.5	1488774.0	27246.5
1974	8317648.0	309985.5	2042199.5	6416070.0	3760427.8	382269.4	1516043.6	1449241.8	66801.9
1975	8856902.0	321659.6	1669998.1	7996713.0	3533183.0	410703.9	1517152.4	1486163.9	30988.6
1976	7339916.0	316662.9	1884993.2	5436993.5	3667233.2	292084.8	1515566.5	1458773.0	56793.5
1977	9376888.0	309941.2	1445172.5	8650271.0	3106379.8	553197.0	1518352.1	1452586.5	65765.6
1978	3394920.5	299355.3	1775207.9	1390915.9	3050264.5	425856.4	1532496.2	1405424.6	127071.7
1979	10518358.0	324905.6	2195236.2	8994097.0	3455071.2	295519.2	1529161.6	1494898.4	34263.2
1980	3992167.2	302588.2	1734431.8	2692309.0	3265566.0	525242.3	1517991.0	1398685.4	119305.6
1981	7976748.0	320380.9	2172406.5	6326888.5	3688056.8	286284.9	1531060.0	1463535.8	67524.3
1982	5818414.0	307172.0	1602496.5	3988762.5	3443521.8	399119.1	1516889.6	1447894.1	68995.5
1983	4470741.5	316404.7	1699678.9	3651692.8	3333898.0	367282.6	1542635.9	1442009.4	100626.5
1984	3368378.5	303010.8	1689251.8	2371658.0	3235398.2	426628.9	1547813.0	1361093.0	186720.0
1985	7730600.5	312865.9	2126743.2	5233767.0	3556452.5	377982.3	1523111.5	1427695.4	95416.1
1986	8187564.0	316405.3	1912869.1	7151695.5	3724069.0	282003.1	1515425.8	1463061.4	52364.4
1987	10085820.0	314418.7	1729391.8	8942787.0	3599653.2	377938.0	1519089.8	1475839.6	43250.2
1988	1950015.5	294500.6	1365328.1	713567.9	3057577.0	518661.1	1524772.2	1388720.2	136052.0
1989	9760159.0	314113.4	2050693.4	7908290.5	3255438.0	394342.2	1519058.0	1458373.5	60684.5
1990	12102569.0	319631.2	2070861.2	11002817.0	3525322.2	340100.2	1520338.9	1460534.2	59804.6
1991	15821836.0	317631.2	2090911.5	14762970.0	3816519.8	315546.1	1516162.8	1483982.1	32180.6
1992	20150672.0	323878.4	1890339.6	18807504.0	3816964.8	389416.9	1518301.0	1500102.6	18198.4
1993	9483550.0	318850.2	1735355.0	7930398.5	3566878.8	501566.2	1523918.2	1483759.2	40159.0
1994	9155517.0	313181.0	2000054.1	7142004.5	3686592.5	397252.5	1528953.6	1483086.8	45866.9
1995	17313834.0	318711.8	1821151.9	16873542.0	3639822.0	377552.4	1512576.0	1490177.4	22398.6
1996	3013868.2	291988.1	1766289.9	1622711.9	3587908.2	419953.8	1507921.6	1397779.0	110142.7
1997	11462574.0	321387.5	1903771.0	10156282.0	3721947.0	283400.5	1518735.6	1485862.6	32873.0
1998	15290264.0	316110.9	1962704.0	11256589.0	3622646.8	590807.7	1521943.5	1471093.2	50850.3
1999	3393794.8	308540.1	1596706.0	2358625.2	3247288.0	558272.5	1519051.2	1413651.5	105399.7
2000	8601712.0	308884.2	2065085.1	5012547.0	3456231.5	448920.2	1525065.9	1407221.8	117844.1
2001	13684570.0	314305.2	1859461.5	10602506.0	3469545.0	373953.4	1537114.2	1472108.1	65006.1
2002	10751560.0	316529.3	1954556.4	7647719.0	3605403.2	333998.8	1540526.1	1484696.2	55829.9
2003	6853310.0	312019.6	1724633.1	4477041.5	3408550.0	472929.7	1557258.5	1448560.5	108697.9
2004	24123402.0	317536.6	1978448.2	20485200.0	3700149.0	202361.6	1550721.2	1484293.8	66427.5
2005	9545604.0	315202.6	1759045.0	6786871.0	3549006.0	458340.8	1537011.6	1451841.4	85170.3
2006	5234925.5	306978.8	1661888.2	1868764.2	3397302.0	400499.5	1535679.8	1413005.9	122673.9
2007	32931516.0	321694.0	2670170.5	23044670.0	3854612.0	714429.9	1529544.4	1498431.0	31113.4
MEAN	9723938.0	309253.3	1880971.0	6972873.0	3504054.8	445749.6	1523886.2	1436628.2	87257.7

The 1998-2007 mean of the unappropriated flows for Bwam3 in Table 4.42 is 148.0 percent of the 1940-1997 mean unappropriated flow. The Bwam3 1940-2007 mean unappropriated flow is 107.1 percent of the 1940-1997 mean unappropriated flow. The 1900-1939 mean of the unappropriated flows for Bwam3 in Table 4.43 is 107.1 percent of the 1940-1997 mean unappropriated flow. The Bwam3 1900-2007 mean unappropriated flow is 107.5 percent of the 1940-1997 mean unappropriated flow. Frequency statistics for naturalized and regulated flows at selected gaging stations are compared later in this chapter.

The average volume of water stored in the 665 Bwam3 reservoirs at the end of December during 1998-2007 is 100.06 percent of the corresponding 1940-1997 mean storage volume. The Bwam3 1940-2007 mean end-of-year storage volume is 100.03 percent of the 1940-1997 mean storage. The simulation begins in January 1940 with all reservoirs filled to capacity, but the period 1998-1997 begins with end of December 1997 storage contents, which reflects significant draw-downs. Storage volumes are explored later in this chapter.

4.4.2 Water Supply Diversion Reliabilities

Diversion targets increase a little during 1998-2007 because some targets are computed within *SIM* as a function of stream flow. Lengthening the hydrologic period-of-analysis has only minimal impacts on volume reliabilities for the aggregate summation of all diversion targets in the dataset. Volume reliabilities for the summation of all diversions in the dataset are shown in the last line of the Tables 4.42 and 4.43 summaries. Total volume reliabilities are 89.97% and 89.94%, respectively, for 1940-1997 and 1940-2007 periods-of-analysis, for the Bwam3 dataset of Table 4.42. The volume reliabilities for the total of all diversions in the Bwam8 dataset are 94.18% and 94.27%, respectively, for 1940-1997 and 1940-2007 periods-of-analysis. Volume reliabilities are 90.16% and 89.95%, respectively, for 1900-1939 and 1900-2007 periods-of-analysis, for the Bwam3 dataset of Table 4.43. The volume reliabilities for the total of all diversions in the Bwam8 dataset are 94.37% and 94.27%, respectively, for 1900-1939 and 1900-2007 periods-of-analysis.

Reliabilities computed with the *TABLES* 2REL record feature for water supply diversions from 14 of the larger reservoirs are tabulated in Tables 4.48, 4.49, and 4.50 for Bwam3 and Tables 4.51, 4.52, and 4.53 for Bwam8. The locations of these 14 reservoirs are shown in Figure 3.4. Storage capacities, diversion targets, and other information are tabulated in Tables 3.6 and 3.10. The statistics shown in the reliability tables represent the aggregated totals of all diversions at the specified control points. The control points corresponding to each of the 14 reservoirs are listed below Tables 4.51 and 4.53.

Lengthening the hydrologic period-of-analysis has little impact on the reliabilities of the diversions from these 14 reservoirs. Bwam3 volume reliabilities for the total of all diversions from the 14 reservoirs are 96.76% and 96.53%, respectively, for 1940-1997 and 1940-2007 periods-of-analysis. The Bwam8 reliabilities are 100.0% for all 14 reservoirs except Somerville Reservoir which has 1940-1997 and 1940-2007 reliabilities of 99.80% and 99.98%. Bwam3 and Bwam8 volume reliabilities for the aggregate of all diversions associated with the 14 reservoirs for a 1900-1939 simulation are 97.76% and 100.00%, respectively.

Table 4.48 1900-1939 Reliabilities for Bwam3 Authorized Use Diversions

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          TARGET       MEAN    *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|---------- PERCENTAGE OF YEARS ----------
NAME     DIVERSION   SHORTAGE  PERIOD VOLUME|   WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT
        (AC-FT/YR) (AC-FT/YR)   (%)     (%) | 100%   95%   90%   75%   50%   25%    1% | 100%   98%   95%   90%   75%   50%    1%
------------------------------------------------------------------------------------------------------------------------
515531    230750.0       0.02  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515631     64712.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515731     19084.6       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515831     13896.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
509431     95612.2    2518.90   92.50  97.37| 92.5  92.5  92.7  92.7  99.6 100.0 100.0| 87.5  87.5  90.0  92.5  95.0 100.0 100.0
515931     19658.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516031    112257.0       0.01  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516131     67768.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516231     13610.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516331     19840.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516531     65074.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516431     48000.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
4146P1     35000.0    9507.24   68.96  72.84| 69.0  69.6  70.0  70.6  71.7  74.2  75.4| 32.5  35.0  37.5  40.0  67.5  75.0  97.5
421331     56000.0    7247.76   84.58  87.06| 84.6  84.6  84.8  85.2  86.2  87.3  87.7| 70.0  70.0  70.0  70.0  90.0  90.0  97.5
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Total     861261.8   19273.93          97.76
--------------------------------------------
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Table 4.49 1940-1997 Reliabilities for Bwam3 Authorized Use Diversions for Simulation Beginning in 1940

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            TARGET      MEAN    *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|---------- PERCENTAGE OF YEARS ----------
NAME     DIVERSION   SHORTAGE  PERIOD VOLUME|    WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT
        (AC-FT/YR) (AC-FT/YR)   (%)     (%) | 100%  95%   90%   75%   50%   25%    1% | 100%  98%   95%   90%   75%   50%    1%
--------------------------------------------------------------------------------------------------------------------------------
515531    230750.0       0.02  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515631     64712.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515731     18907.4       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515831     13896.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
509431     91518.6    2280.27   94.68  97.51| 94.7  94.7  94.8  95.1  99.6  99.7 100.0| 89.7  89.7  93.1  94.8  96.6 100.0 100.0
515931     19658.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516031    112257.0       0.01  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516131     67768.0     367.19   98.85  99.46| 98.9  99.0  99.0  99.3  99.4  99.6  99.6| 94.8  94.8  96.6  96.6 100.0 100.0 100.0
516231     13610.0     229.43   98.13  98.31| 98.1  98.1  98.1  98.1  98.3  98.4  98.6| 93.1  94.8  94.8  94.8  98.3  98.3 100.0
516331     19840.0      53.35   99.57  99.73| 99.6  99.6  99.6  99.6  99.6  99.7  99.9| 96.6  96.6  98.3  98.3 100.0 100.0 100.0
516531     65074.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516431     48000.0     189.42   99.14  99.61| 99.1  99.1  99.1  99.1  99.3  99.4  99.6| 96.6  96.6  96.6  98.3 100.0 100.0 100.0
4146P1     35000.0   15852.58   49.28  54.71| 49.3  49.6  50.4  51.1  52.9  56.0  58.6| 24.1  24.1  27.6  29.3  34.5  46.6  89.7
421331     56000.0    8804.43   82.76  84.28| 82.8  83.0  83.0  83.5  84.2  84.5  85.1| 69.0  69.0  70.7  70.7  77.6  84.5  98.3
--------------------------------------------------------------------------------------------------------------------------------
Total     856990.9   27776.70          96.76
--------------------------------------------
```

Table 4.50 1940-2007 Reliabilities for Bwam3 Authorized Use Diversions for Simulation Beginning in 1940

```
--------------------------------------------------------------------------------------------------------------------------------
            TARGET      MEAN    *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|---------- PERCENTAGE OF YEARS ----------
NAME     DIVERSION   SHORTAGE  PERIOD VOLUME|    WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT
        (AC-FT/YR) (AC-FT/YR)   (%)     (%) | 100%  95%   90%   75%   50%   25%    1% | 100%  98%   95%   90%   75%   50%    1%
--------------------------------------------------------------------------------------------------------------------------------
515531    230750.0       0.02  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515631     64712.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515731     18894.9       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515831     13896.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
509431     90900.9    1944.94   95.47  97.86| 95.5  95.5  95.6  95.8  99.6  99.8 100.0| 91.2  91.2  94.1  95.6  97.1 100.0 100.0
515931     19658.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516031    112257.0       0.01  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516131     67768.0     313.19   99.02  99.54| 99.0  99.1  99.1  99.4  99.5  99.6  99.6| 95.6  95.6  97.1  97.1 100.0 100.0 100.0
516231     13610.0     195.69   98.41  98.56| 98.4  98.4  98.4  98.4  98.5  98.7  98.8| 94.1  95.6  95.6  95.6  98.5  98.5 100.0
516331     19840.0      45.51   99.63  99.77| 99.6  99.6  99.6  99.6  99.6  99.8  99.9| 97.1  97.1  98.5  98.5 100.0 100.0 100.0
516531     65074.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516431     48000.0     161.56   99.26  99.66| 99.3  99.3  99.3  99.3  99.4  99.5  99.6| 97.1  97.1  97.1  98.5 100.0 100.0 100.0
4146P1     35000.0   16944.20   46.32  51.59| 46.3  46.6  47.3  48.2  49.9  53.1  55.5| 22.1  22.1  25.0  26.5  30.9  44.1  89.7
421331     56000.0   10124.41   80.15  81.92| 80.1  80.4  80.4  80.9  82.0  82.4  83.0| 63.2  63.2  64.7  66.2  73.5  82.4  98.5
--------------------------------------------------------------------------------------------------------------------------------
Total     856360.8   29729.53          96.53
--------------------------------------------
```

Table 4.51 1900-1939 Reliabilities for Bwam8 Current Use Diversions

```
-------------------------------------------------------------------------------------------------------------------------------
           TARGET       MEAN   *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|---------- PERCENTAGE OF YEARS ----------
NAME     DIVERSION   SHORTAGE  PERIOD VOLUME|    WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT
         (AC-FT/YR) (AC-FT/YR)   (%)    (%) | 100%   95%   90%   75%   50%   25%    1% | 100%   98%   95%   90%   75%   50%    1%
-------------------------------------------------------------------------------------------------------------------------------
515531     59482.2       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515631     36025.3       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515731     18773.2       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515831      2394.3       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
509431     43558.4       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515931     14068.1       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516031    107737.4       0.01  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516131     67768.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516231     11943.4       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516331      2569.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516531     39337.1       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516431     48000.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
4146P1       288.4       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
421331      9923.5       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
-------------------------------------------------------------------------------------------------------------------------------
Total     461868.3       0.01         100.00
-------------------------------------------
```

Table 4.52 1940-1997 Reliabilities for Bwam8 Current Use Diversions for Simulation Beginning in 1940

```
-------------------------------------------------------------------------------------------------------------------------------
CONTROL    TARGET       MEAN   *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|---------- PERCENTAGE OF YEARS ----------
 POINT   DIVERSION   SHORTAGE  PERIOD VOLUME|    WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT
         (AC-FT/YR) (AC-FT/YR)   (%)    (%) | 100%   95%   90%   75%   50%   25%    1% | 100%   98%   95%   90%   75%   50%    1%
-------------------------------------------------------------------------------------------------------------------------------
515531     59482.2       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515631     36025.3       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515731     18789.1       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515831      2394.3       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
509431     43244.2       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515931     14068.1       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516031    107737.5       0.01  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516131     67768.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516231     11943.4       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516331      2569.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516531     39337.1       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516431     48000.0      95.78   99.43  99.80| 99.4  99.6  99.6  99.6  99.6  99.7  99.9| 96.6  96.6  98.3 100.0 100.0 100.0 100.0
4146P1       288.4       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
421331      9923.5       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
-------------------------------------------------------------------------------------------------------------------------------
Total     461570.0      95.79          99.98
-------------------------------------------
```

Table 4.53 1940-2007 Reliabilities for Bwam8 Current Use Diversions for Simulation Beginning in 1940

```
---------------------------------------------------------------------------------------------------------------------------------
            TARGET       MEAN   *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|---------- PERCENTAGE OF YEARS ----------
NAME      DIVERSION   SHORTAGE  PERIOD VOLUME|    WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT
         (AC-FT/YR) (AC-FT/YR)     (%)    (%) | 100%   95%   90%   75%   50%   25%    1% | 100%   98%   95%   90%   75%   50%    1%
---------------------------------------------------------------------------------------------------------------------------------
515531      59482.2       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515631      36025.3       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515731      18762.2       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515831       2394.3       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
509431      42935.6       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515931      14068.1       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516031     107737.5       0.01  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516131      67768.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516231      11943.4       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516331       2569.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516531      39337.1       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516431      48000.0      81.69   99.51  99.83| 99.5  99.6  99.6  99.6  99.6  99.8  99.9| 97.1  97.1  98.5 100.0 100.0 100.0 100.0
4146P1        288.4       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
421331       9923.5       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
---------------------------------------------------------------------------------------------------------------------------------
Total      461234.6      81.70          99.98
---------------------------------------------
```

4.4.3 Naturalized and Regulated Flow Frequency Statistics

Naturalized monthly flows for 1900-2007 at the 77 primary control points are plotted in Appendix A. Naturalized flows are the same for both the Bwam3 and Bwam8 input datasets. Regulated flows are computed in the *SIM* simulation. Frequency statistics for regulated and naturalized flows for the periods 1940-1997 and 1940-2007 at the Richmond and Waco gaging stations on the Brazos River and Cameron gaging station on the Little River are compared in Tables 4.54, 4.55, and 4.56. The locations of these gaging stations are shown in Figure 3.4.

The Richmond gaging station (control point BRRI70) on the lower Brazos River is near the outlet of the Brazos River Basin. The Bwam3 1940-2007 mean regulated flow at the Richmond gage is 105.2 percent of the 1940-1997 mean regulated flow. The Bwam8 1940-2007 mean regulated flow at the Richmond gage is 104.8 percent of the 1940-1997 mean regulated flow. The monthly regulated flows for all the exceedance frequencies listed in Table 4.54 are higher for the 1940-2007 hydrologic period-of-analysis than for the 1940-1997 period-of-analysis. The minimum and maximum monthly flow volumes occur during 1940-1997 and thus are the same for 1940-1997 and 1940-2007.

The differences between 1940-2007 and 1940-1997 regulated flows are smaller at the Waco gage and larger at the Cameron gage. The Bwam3 and Bwam8 1940-2007 mean regulated flows at the Waco gage are 100.88 and 101.07 percent of the 1940-1997 mean regulated flow. The Bwam3 and Bwam8 1940-2007 mean regulated flows at the Cameron gage are 110.6 and 109.7 percent of the 1940-1997 mean regulated flow.

Table 4.54 Stream Flow Frequency Statistics
Richmond Gage on Brazos River (Control Point BRRI70)

	Naturalized Flow		Bwam3 Regulated Flow		Bwam8 Regulated Flow	
	1940-1997	1940-2007	1940-1997	1940-2007	1940-1997	1940-2007
	Monthly Flow Volumes in acre-feet/month					
Mean	487,519	509,422	386,857	407,019	431,605	452,266
Std Dev	613,002	630,905	563,876	582,501	591,821	609,670
Minimum	0.0	0.0	307	307	8,291	8,291
99.50%	14,215	16,279	10,582	11,833	16,088	16,643
99%	18,383	22,129	13,297	14,657	19,519	20,403
98%	25,402	28,095	17,714	18,909	24,983	25,642
95%	39,522	44,498	27,684	27,919	32,928	33,228
90%	53,888	57,081	36,444	37,496	43,425	46,235
85%	72,717	79,495	43,725	46,337	56,039	57,557
80%	89,258	98,228	53,567	55,253	66,842	69,919
75%	111,204	117,514	64,431	66,244	82,597	84,368
70%	133,510	138,601	71,386	72,188	95,838	98,628
60%	184,723	193,899	95,550	101,294	133,416	141,432
50%	257,456	275,325	148,801	162,456	191,962	209,882
40%	358,553	375,995	236,229	254,218	283,122	306,974
30%	512,053	537,955	382,698	405,691	435,104	461,306
25%	653,272	665,039	474,586	527,407	571,341	595,695
20%	779,791	808,886	633,476	675,605	687,082	752,153
15%	981,968	1,025,466	823,337	853,112	904,138	937,893
10%	1,230,723	1,313,844	1,064,539	1,122,514	1,147,463	1,236,303
5%	1,674,399	1,730,180	1,484,334	1,527,559	1,559,551	1,586,916
2%	2,220,046	2,339,623	2,060,751	2,222,482	2,102,152	2,285,604
1%	2,859,000	2,895,033	2,667,753	2,738,197	2,776,821	2,818,921
0.50%	3,570,109	3,709,790	3,360,573	3,515,712	3,498,644	3,656,486
Maximum	6,135,975	6,135,975	5,489,781	5,489,781	5,994,799	5,994,799

Table 4.55 Stream Flow Frequency Statistics
Waco Gage on Brazos River (Control Point BRWA41)

	Naturalized Flow		Bwam3 Regulated Flow		Bwam8 Regulated Flow	
	1940-1997	1940-2007	1940-1997	1940-2007	1940-1997	1940-2007
	Monthly Flow Volumes in acre-feet/month					
Mean	161,860	164,158	116,077	117,104	134,062	135,498
Std Dev	266,253	266,706	239,206	238,274	257,189	256,204
Minimum	0.0	0.0	0.00	0.00	0.00	0.00
99.50%	163	365	0.00	1.43	4.78	5.23
99%	1,577	1,784	30.1	47.0	49.5	55.1
98%	3,434	3,963	342	693	446	960
95%	6,300	6,925	1,704	1,835	1,783	2,028
90%	10,364	11,561	3,166	3,542	3,430	3,824
85%	15,181	16,696	5,041	5,499	5,693	5,951
80%	19,453	21,508	6,327	7,071	6,365	7,459
75%	24,749	28,105	7,794	8,380	8,510	10,006
70%	31,006	35,469	9,398	10,988	12,160	14,943
60%	45,705	52,398	16,568	18,728	22,147	25,689
50%	68,642	72,277	27,046	29,727	39,225	42,490
40%	102,411	103,161	48,735	50,483	66,374	67,832
30%	146,341	146,641	84,108	85,280	109,302	110,672
25%	183,578	183,794	118,686	121,435	136,962	141,624
20%	233,939	229,119	152,683	154,544	188,975	190,705
15%	298,821	294,282	230,865	221,762	253,320	253,166
10%	422,755	418,373	343,890	326,824	383,896	364,820
5%	642,244	642,244	576,939	576,939	606,972	606,972
2%	941,918	953,417	817,529	828,847	884,561	897,974
1%	1,274,838	1,357,912	1,151,579	1,240,458	1,197,035	1,309,408
0.50%	1,509,141	1,692,190	1,393,884	1,485,719	1,466,739	1,554,218
Maximum	3,376,485	3,376,485	3,131,747	3,131,747	3,319,012	3,319,012

Table 4.56 Stream Flow Frequency Statistics
Cameron Gage on Little River (Control Point LRCA58)

	Naturalized Flow		Bwam3 Regulated Flow		Bwam8 Regulated Flow	
	1940-1997	1940-2007	1940-1997	1940-2007	1940-1997	1940-2007
	Monthly Flow Volumes in acre-feet/month					
Mean	109,858	119,080	83,223	92,032	91,173	100,049
Std Dev	170,466	180,519	157,642	168,636	161,881	172,663
Minimum	0.00	0.00	0.00	0.00	1,112	1,112
99.50%	200	219	2.37	4.99	1,230	1,230
99%	494	660	85.5	209	1,230	1,423
98%	1,249	1,322	579	875	2,576	2,607
95%	2,706	3,067	1,190	1,230	3,475	3,714
90%	5,440	6,508	1,261	1,774	5,045	5,385
85%	8,667	10,274	2,597	3,244	6,184	6,745
80%	11,904	13,974	3,809	4,969	7,725	8,226
75%	15,032	17,905	5,832	6,872	9,493	10,057
70%	19,041	21,484	7,550	8,472	11,601	12,209
60%	28,988	32,137	12,459	13,819	16,299	17,959
50%	44,799	49,457	18,935	21,426	23,839	27,067
40%	65,294	74,405	31,839	36,107	40,617	45,225
30%	104,549	113,804	63,957	73,404	74,615	82,334
25%	130,473	143,003	87,682	102,047	98,849	112,672
20%	165,070	187,538	122,211	140,475	135,248	159,670
15%	226,731	239,431	176,409	199,822	192,577	213,333
10%	290,433	315,687	235,472	264,861	248,450	278,106
5%	426,869	458,577	389,504	412,225	409,628	436,402
2%	667,571	710,418	592,517	638,865	605,900	649,114
1%	804,195	957,932	696,354	913,298	712,484	945,745
0.50%	1,198,902	1,161,034	1,173,751	1,120,576	1,185,201	1,131,497
Maximum	1,403,136	1,403,136	1,399,450	1,399,450	1,406,391	1,406,391

4.4.4 Reservoir Storage

The Bwam3 and Bwam8 datasets contain 665 and 706 reservoirs, respectively, with total conservation storage capacities of 4,694,850 acre-feet and 4,023,350 acre-feet. Frequency statistics for end-of-month storage volumes in these reservoirs are compared in Table 4.57 for the 1900-1939, 1940-1997, and 1940-2007 hydrologic periods-of-analysis. The 1900-1939 simulations begin with the reservoirs full to capacity at the beginning of January 1900. Likewise, the 1940-1997 and 1940-2007 simulations start with the reservoirs full at the beginning of January 1940. The mean end-of-month storage volume in the 665 Bwam3 reservoirs during the 1900-1939 (480 months) simulation is 103.9% of the corresponding mean storage of the 1940-1997 (696 months) simulation. The Bwam3 mean storage volume for the 1940-2007 simulation is 99.4% of the corresponding mean storage of the 1940-1997 simulation.

Table 4.57 Storage-Frequency for Alternative Simulation Periods

	Bwam3 Authorized Use			Bwam8 Current Use		
	1900-1939	1940-1997	1940-2007	1900-1939	1940-1997	1940-2007
End-of-Month Storage Volume (acre-feet) of 665 Bwam3 or 706 Bwam8 Reservoirs						
mean	3,644,940	3,506,458	3,504,212	3,666,620	3,460,329	3,472,296
standard deviation	588,348	607,338	570,852	275,907	363,554	342,144
100%	1,733,141	1,518,825	1,518,825	2,740,942	2,093,678	2,093,678
99%	1,842,157	1,675,468	1,707,477	2,787,847	2,235,064	2,249,634
98%	2,047,281	1,811,885	1,888,234	2,937,744	2,358,366	2,441,818
95%	2,298,465	2,266,194	2,365,693	3,050,321	2,670,920	2,751,328
90%	2,780,294	2,691,605	2,763,078	3,216,304	2,980,643	3,052,299
75%	3,465,788	3,236,247	3,262,166	3,561,048	3,303,272	3,334,038
60%	3,653,495	3,497,950	3,486,026	3,687,980	3,477,918	3,483,882
50%	3,799,856	3,597,546	3,575,640	3,745,262	3,552,828	3,553,784
40%	3,878,855	3,724,485	3,675,425	3,811,594	3,612,524	3,605,531
25%	3,993,207	3,898,245	3,868,355	3,867,448	3,713,852	3,705,539
10%	4,250,634	4,172,872	4,103,305	3,923,675	3,795,034	3,792,939
maximum	4,688,516	4,647,887	4,647,887	4,019,208	3,996,971	3,996,971

Bwam3 and Bwam8 Simulated Storage Volume in 14 Reservoirs

Bwam3 and Bwam8 end-of-month storage volumes for 14 reservoirs are plotted in Figures 4.4 through 4.31 for simulations 1 and 3 listed in Table 4.41. Figures 4.32 and 4.33 are plots of the summation of the total storage volume in all 14 reservoirs. The plots of Figures 4.4 through 4.33 span the 1940-2007 hydrologic period-of-analysis. The corresponding plots of the Bwam3 and Bwam8 1900-2007 monthly storage volumes from simulations 2 and 4 listed in Table 4.41 are provided as Appendix D.

The locations of Possum Kingdom, Granbury, Whitney, Aquilla, Waco, Proctor, Belton, Stillhouse Hollow, Georgetown, Granger, Limestone, Somerville, Alan Henry, and Hubbard Creek Reservoirs are shown in Figure 3.4. Storage capacities and other information regarding the reservoirs are tabulated in Tables 3.6 and 3.10. These 14 reservoirs contain 73.5 percent and 76.8 percent of the total conservation storage capacity of the 665 and 706 reservoirs, respectively, in the Bwam3 and Bwam8 datasets. Water supply reliabilities associated with these 14 reservoirs are presented in Tables 4.48 through 4.53.

Reservoir storage volumes or drawdowns provide an index of dry periods or critical drought periods. Severe storage drawdowns representing major drought periods can be readily identified. Individual reservoirs represent different regions of the Brazos River Basin. Figures 4.32 and 4.33 in this chapter and Figures D.29 and D.30 in Appendix D represent general basin-wide conditions. The plots of Figures 4.4−4.33 and D.1−D.30 show that, with a few exceptions, the reservoir storage depletions during 1900-1939 and 1998-2007 are generally not nearly as large as the 1951-1957 drought and other drought periods during the original 1940-1997 hydrologic period-of-analysis.

Bwam3 storage drawdowns are greater than Bwam8 drawdowns as expected since Bwam3 diversion targets are larger. The patterns and timing of major storage depletion periods, though generally similar, also vary between Bwam3 and Bwam8 at some of the reservoirs.

Alan Henry and Hubbard Creek Reservoirs are the extreme cases of dramatic differences between Bwam3 and Bwam8 simulated storage sequences. Bwam3 storage depletions in Lakes Alan Henry and Hubbard Creek are unusually severe, much different than the 12 other reservoirs. Lake Alan Henry (Figures 4.4 and 4.5) is empty much of the time in the Bwam3 simulation but never empties or even comes close to emptying in the Bwam8 simulation, which is very unusual. Lake Hubbard Creek (Figures 4.6 and 4.7) also empties a number of times in the Bwam3 simulation but never empties in the Bwam8 simulation.

The critical drought period for most of the Brazos River Basin began gradually during 1951 and ended abruptly with the flood of April-May 1957. The severity of the 1950's drought relative to the overall 1940-2007 period-of-analysis at the majority of the reservoirs is clearly illustrated by the reservoir storage plots of Figures 4.4-4.33. However, there are exceptions in which more severe or almost as severe drawdowns occur during the 1998-2007 hydrologic period-of-analysis extension.

Likewise, the severity of the 1950's drought relative to the overall 1900-2007 period-of-analysis at the majority of the reservoirs is illustrated by the reservoir storage plots of Figures D.1-D.30 of Appendix D. The Bwam3 reservoir storage plots indicate that severe droughts occurred during the periods from about January 1909 through August 1913 and from about December 1916 through August 1918 that are comparable to the 1950's drought at over half of the 14 reservoirs. The 1909-1913 and 1916-1918 droughts are significantly less severe relative to the 1950's drought in the Bwam8 simulation.

At most of the reservoirs, drawdowns during 1998-2007 are much less severe than the droughts of 1909-1913, 1916-1918, and 1950-1957. However, relatively severe draw-downs do occur at several reservoirs after 1997 in the Bwam3 and Bwam8 simulations. Although the 1950's represent a more severe drought period for Waco Reservoir, severe Bwam3 storage drawdowns also occur during the 1960's, 1970's, and early 2000's. Major drawdowns during 1999-2003 occur at Lake Granbury in the Bwam3, though even lower storage levels occur in the 1950's and 1980's. Severe Bwam3 and Bwam8 drawdowns occur at Alan Henry and Hubbard Creek Reservoirs periodically throughout the 1900-2007 hydrologic period-of-analysis including 1998-2007.

Proctor Reservoir is somewhat unique in that it has multiple periods of "critical" Bwam3 and Bwam8 simulated draw-downs of fairly comparable magnitude. In addition to the droughts of 1909-1913, 1916-1918, and 1950-1957, severe Bwam3 and Bwam8 drawdowns for Lake Proctor extend from the late 1970's through early 1980's and during 1999-2001.

Proctor Reservoir

As discussed in sections 4.1 and 4.3, control point LEHS45 located immediately downstream of Proctor Dam is the only control point for which reservoir releases were adopted for 1998-2007 observed flows. Naturalized flows synthesized earlier using the standard flow distribution method resulted in 1998-2007 Bwam8 storage volumes at Proctor that did not match observed volumes. Consequently, naturalized flows were recomputed based on releases from Proctor Reservoir.

Observed flows measured at USGS stream gaging stations were adopted for 47 other control points. Control point LEHS45 is the site of one of three discontinued USGS gaging stations on the Leon River upstream and downstream of Proctor Reservoir for which gage measurements were not made during 1998-2007. Earlier in the study, naturalized flows at control point LEHS45 were synthesized by applying the 1940-1997 mean flow ratio of 0.548 to naturalized flows at control point LEGT47 which is the still active gaging station on the Leon River near Gatesville. For comparison, the drainage area ratio is 0.539, just slightly less than the 0.548 flow ratio.

Bwam8 storage volumes for 1998-2007 for Proctor Reservoir are very different than observed volumes with the initially estimated naturalized flows. The flows at the site were relatively high, and the reservoir drawdowns were relatively minimal. However, as shown in Figure C.8 in Appendix C, large drawdowns had actually occurred in Proctor Reservoir from 1999 to early 2001 with the storage contents reaching a minimum level of about 11.5 percent of capacity n October 2000. Consequently, the originally computed 1998-2007 naturalized flows at control point LEHS45 were replaced with naturalized flows developed based on adopting measured releases from Proctor Reservoir as gaged flows at LEHS45. The mean of the revised 1998-2007 flows is 77.8% of the mean of the original 1998-2007 naturalized flows. The revised LEHS45 naturalized flows resulted in Bwam8 storage volumes that closely reproduce the observed volumes as shown in Figure C.8.

Proctor Reservoir storage volumes are plotted in Figures 4.18, 4.19, D.15, D.16, and C.8. Severe drawdowns occur in 1999-2001 as well as 1909-1913, 1916-1918, 1950-1957, and 1978-1986. The relative severity of these different drought periods vary between Bwam3 and Bwam8.

Observed Versus Simulated 1998-2007 Simulated Storage Volumes

Appendix C provides plots comparing 1998-2007 observed and Bwam3, Bwam8, and Bwam8A simulated storage volumes of the 14 reservoirs. The observed storage volumes available from the U.S. Geological Survey (USGS) National Water Information System (NWIS) online database are determined by reservoir operators and/or USGS personnel based on combining measured water surface elevations with the latest updated relationships between reservoir water surface elevation and storage volume. Bwam3 reservoir storage capacities are based on the information recorded in the water right permits which typically cite pre-construction storage capacities without adjustments for sedimentation. Bwam8 reservoir storage capacities are based on designated top of conservation elevations and estimated year 2000 conditions of sedimentation.

Nine of the 14 reservoirs have flood control pools. The bottom of a flood control pool is the top of the conservation pool. All of the reservoirs allow uncontrolled surcharge storage above the top of conservation pool. The Bwam3 and Bwam8 datasets allow no storage above the designated top of conservation pool. This is evident in the Bwam3 and Bwam8 storage plots in which the storage volume never exceeds the conservation storage capacity. The actual use Bwam8A dataset discussed in earlier chapters does allow storage volumes to exceed conservation storage capacities. The Bwam8A dataset is designed to actually reproduce observed storage volumes.

Plots of 1940-1997 current use scenario simulated storage levels combined with 1998-2007 observed storage levels provide a convenient way to predict whether updating the period-of-analysis will likely change critical reservoir drawdown periods and associated results of firm yield analyses and related types of water availability analyses.

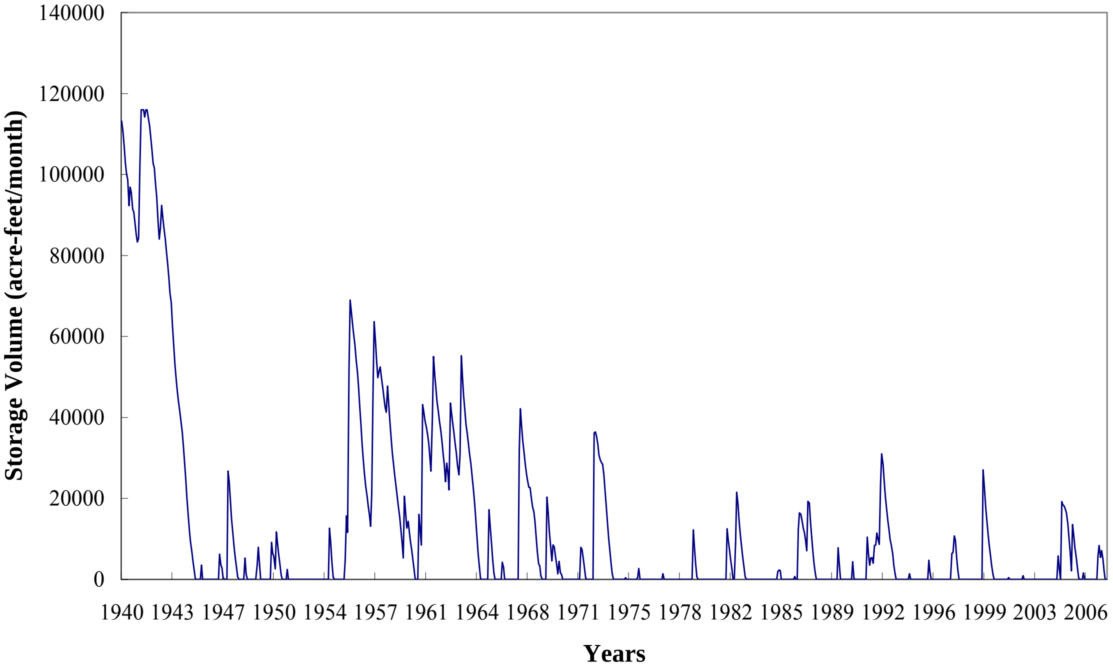

Figure 4.4 Bwam3 Storage Volume of Alan Henry Reservoir

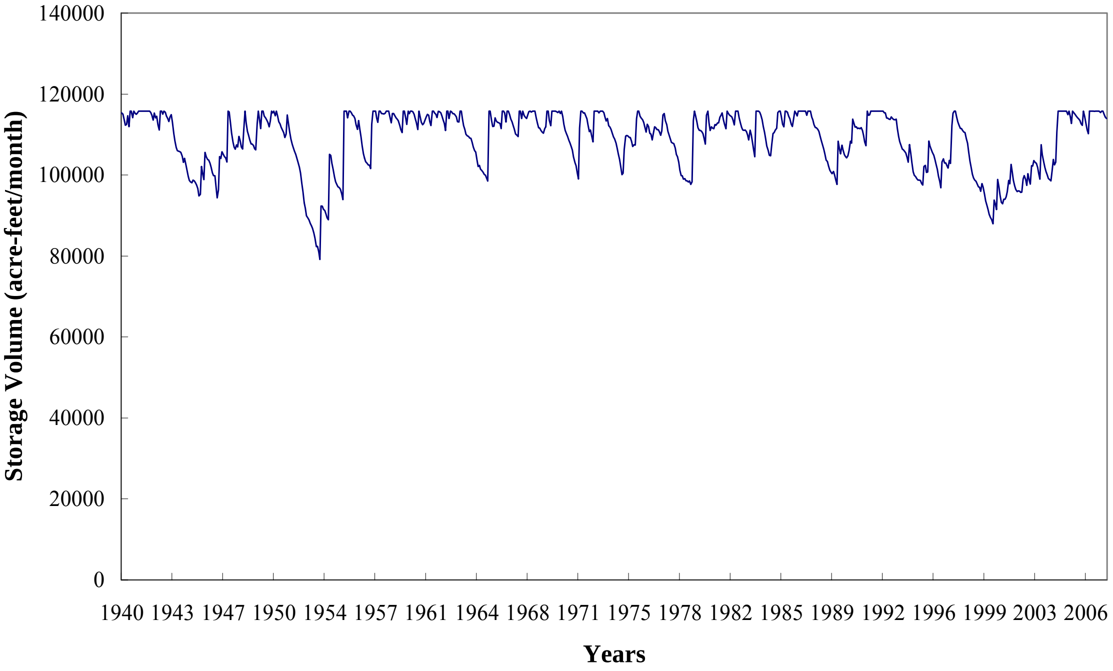

Figure 4.5 Bwam8 Storage Volume of Alan Henry Reservoir

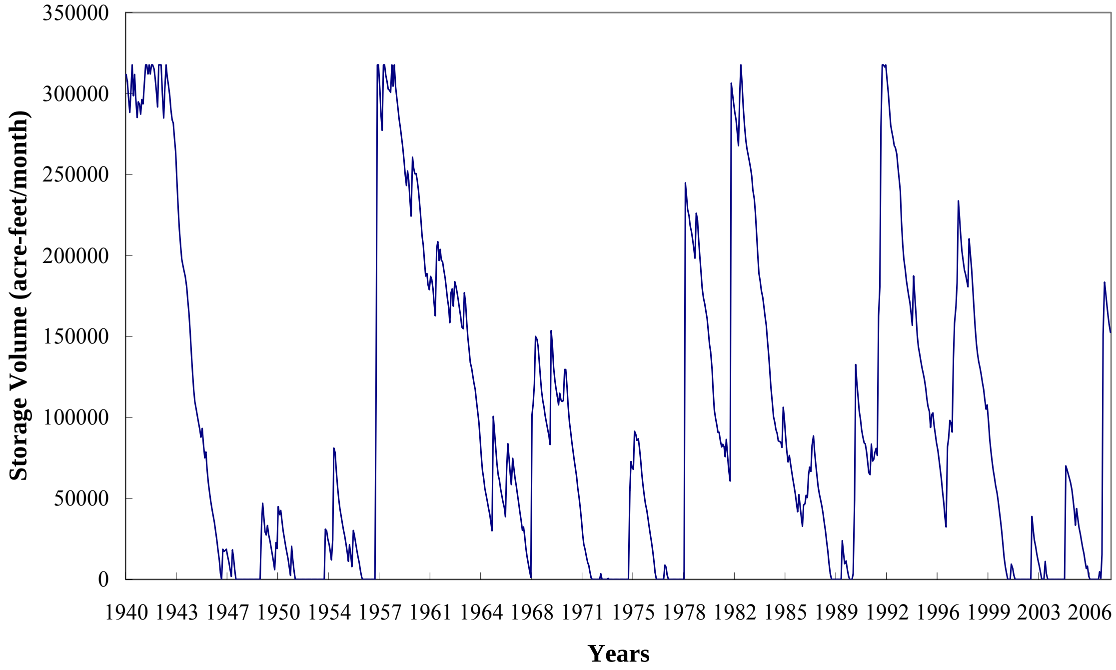

Figure 4.6 Bwam3 Storage Volume of Hubbard Creek Reservoir

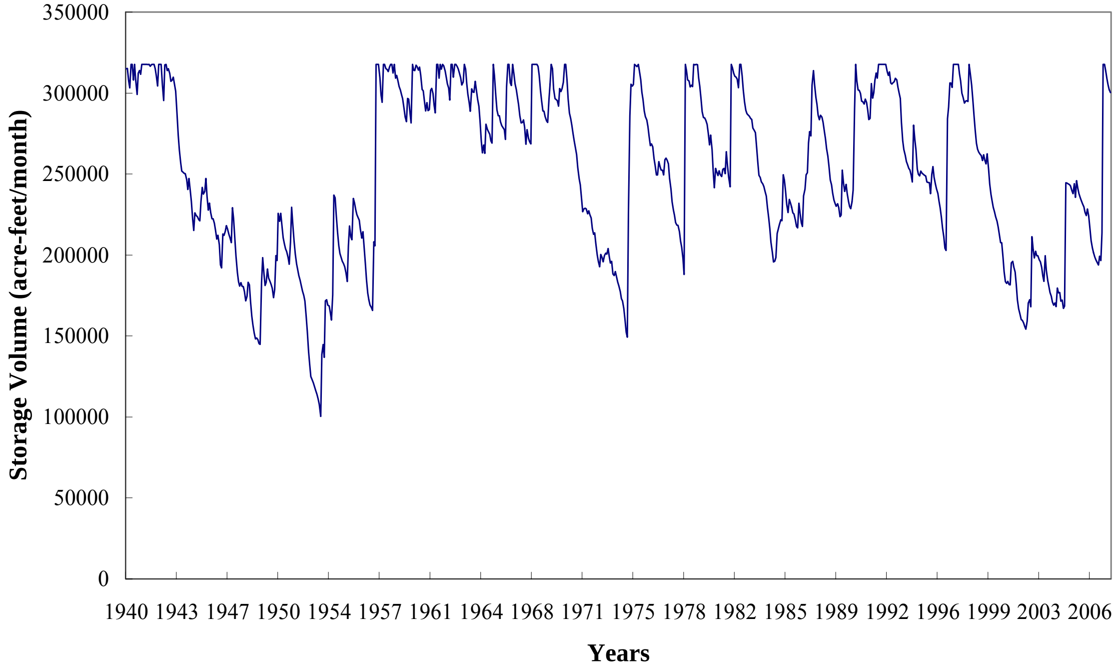

Figure 4.7 Bwam8 Storage Volume of Hubbard Creek Reservoir

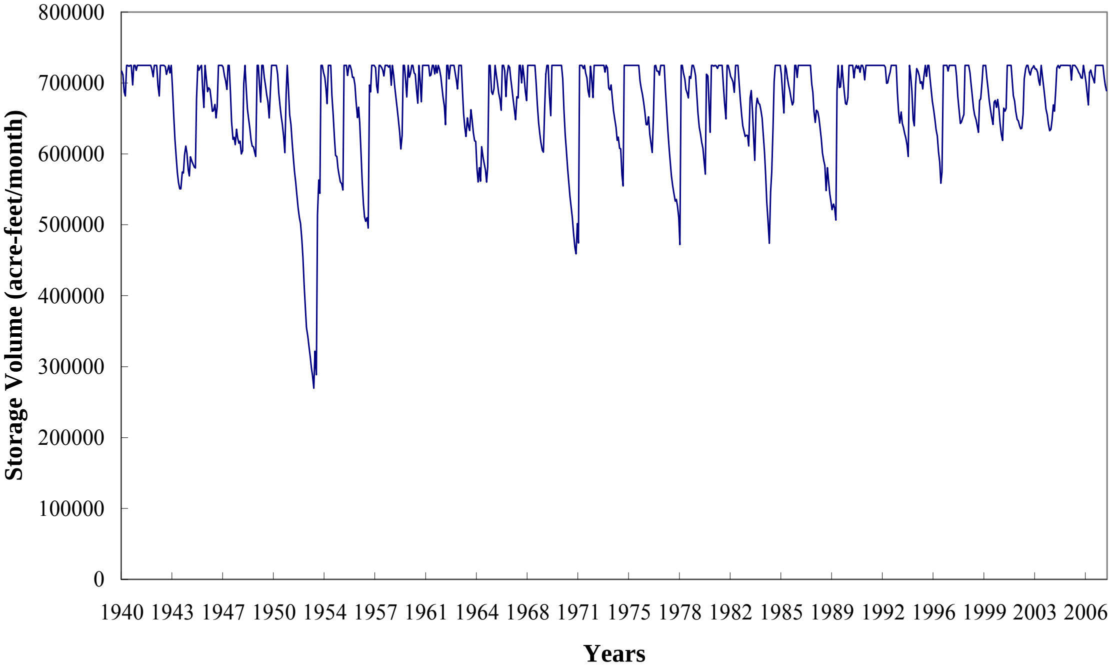

Figure 4.8 Bwam3 Storage Volume of Possum Kingdom Reservoir

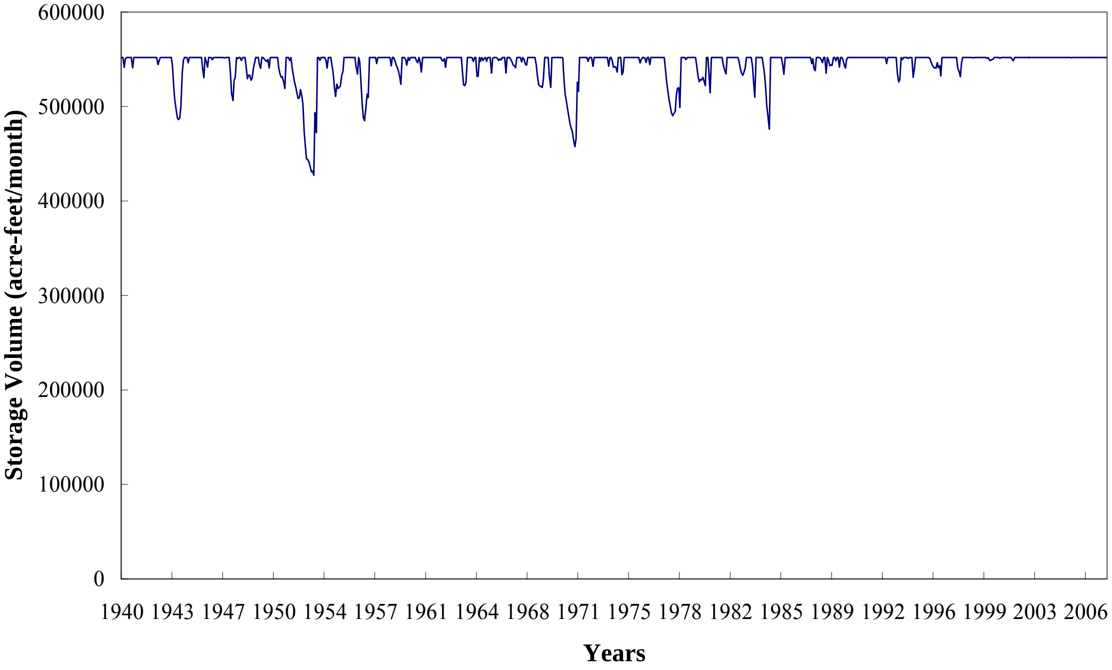

Figure 4.9 Bwam8 Storage Volume of Possum Kingdom Reservoir

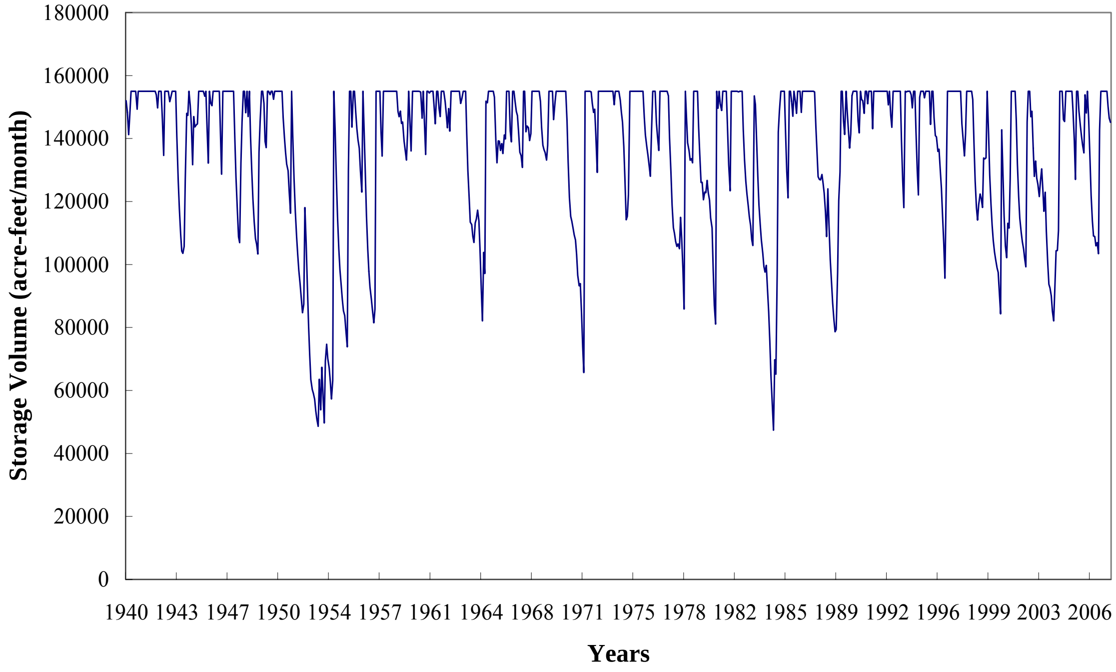

Figure 4.10 Bwam3 Storage Volume of Granbury Reservoir

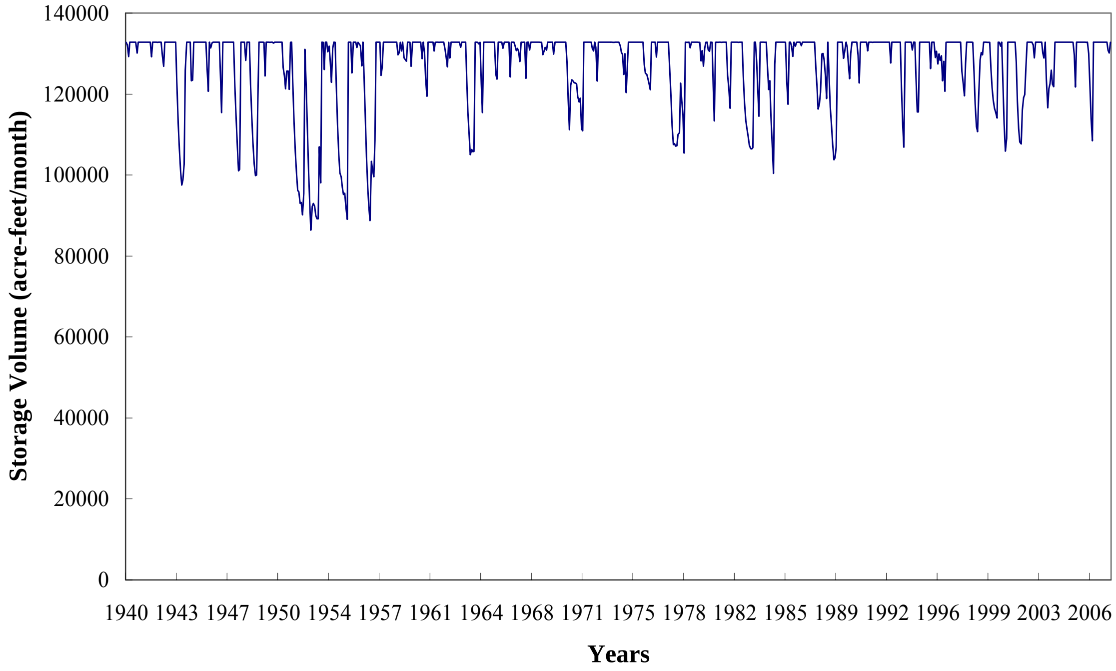

Figure 4.11 Bwam8 Storage Volume of Granbury Reservoir

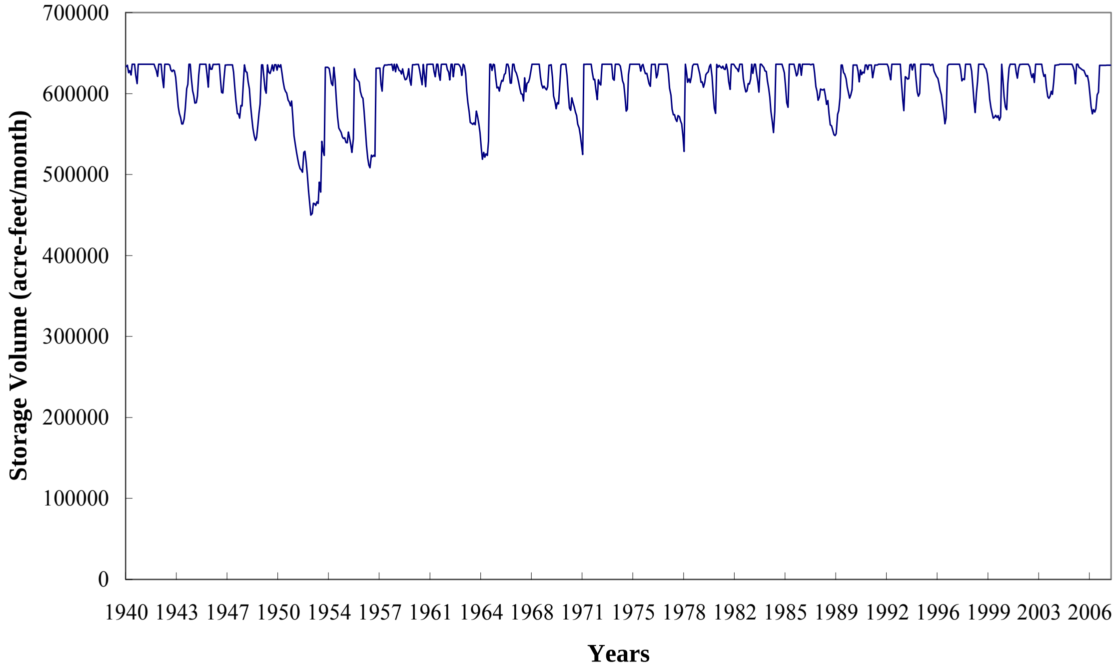

Figure 4.12 Bwam3 Storage Volume of Whitney Reservoir

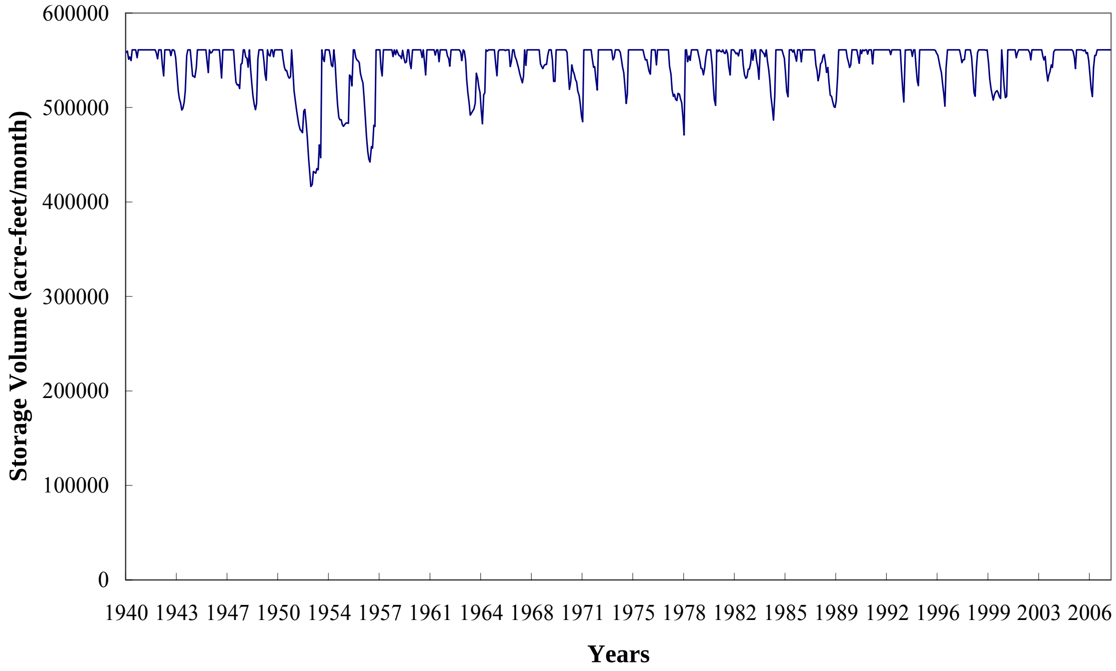

Figure 4.13 Bwam8 Storage Volume of Whitney Reservoir

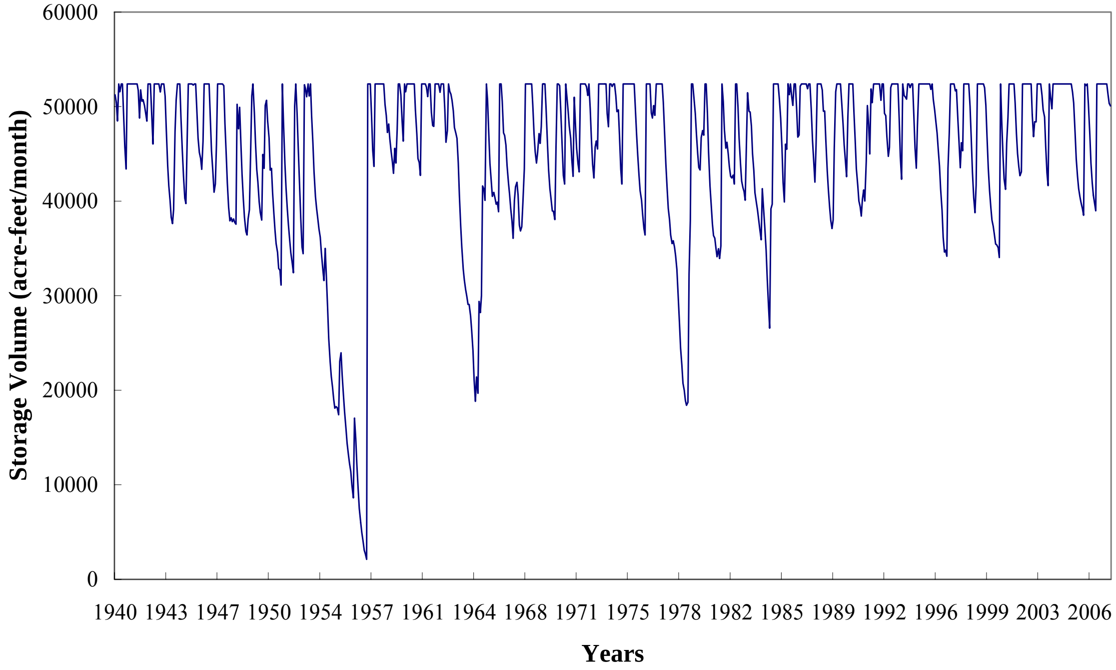

Figure 4.14 Bwam3 Storage Volume of Aquilla Reservoir

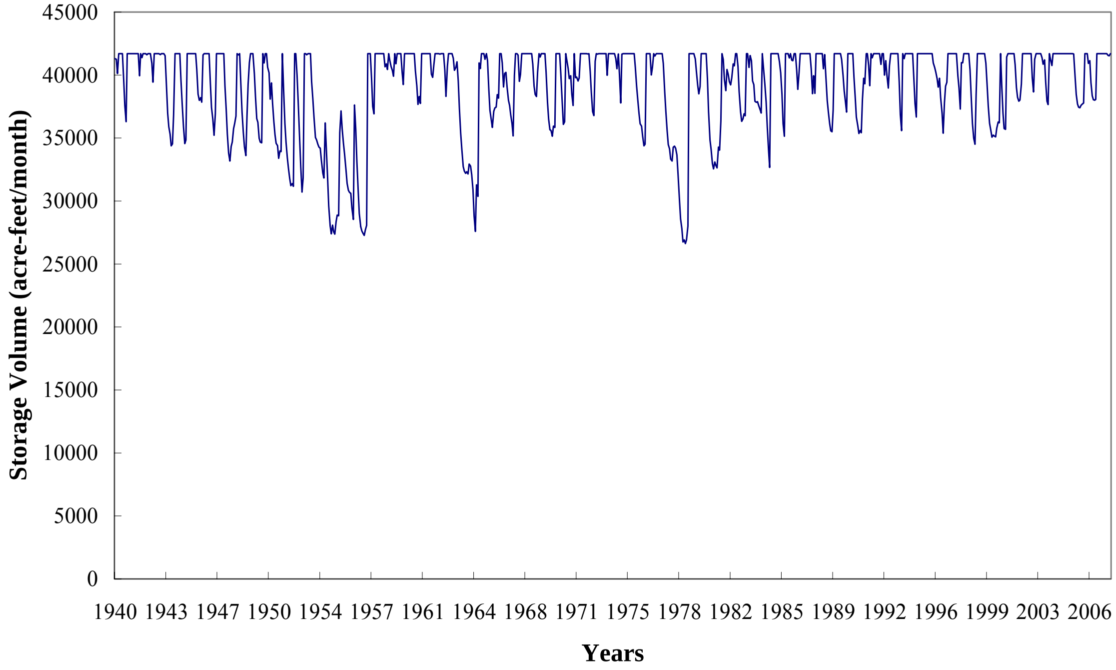

Figure 4.15 Bwam8 Storage Volume of Aquilla Reservoir

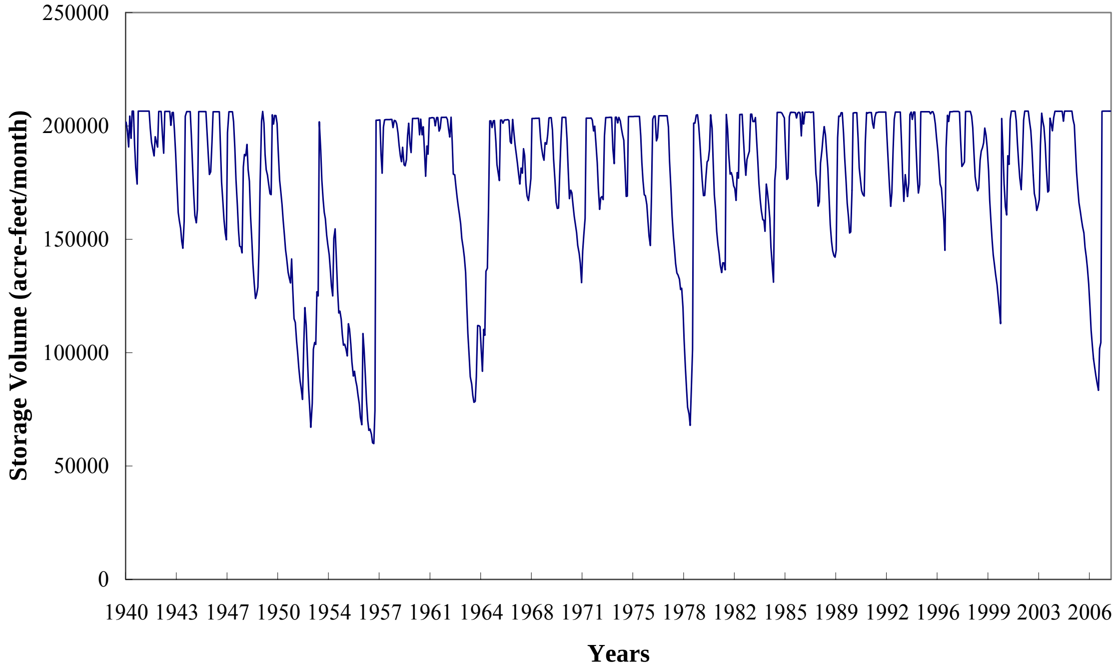

Figure 4.16 Bwam3 Storage Volume of Waco Reservoir

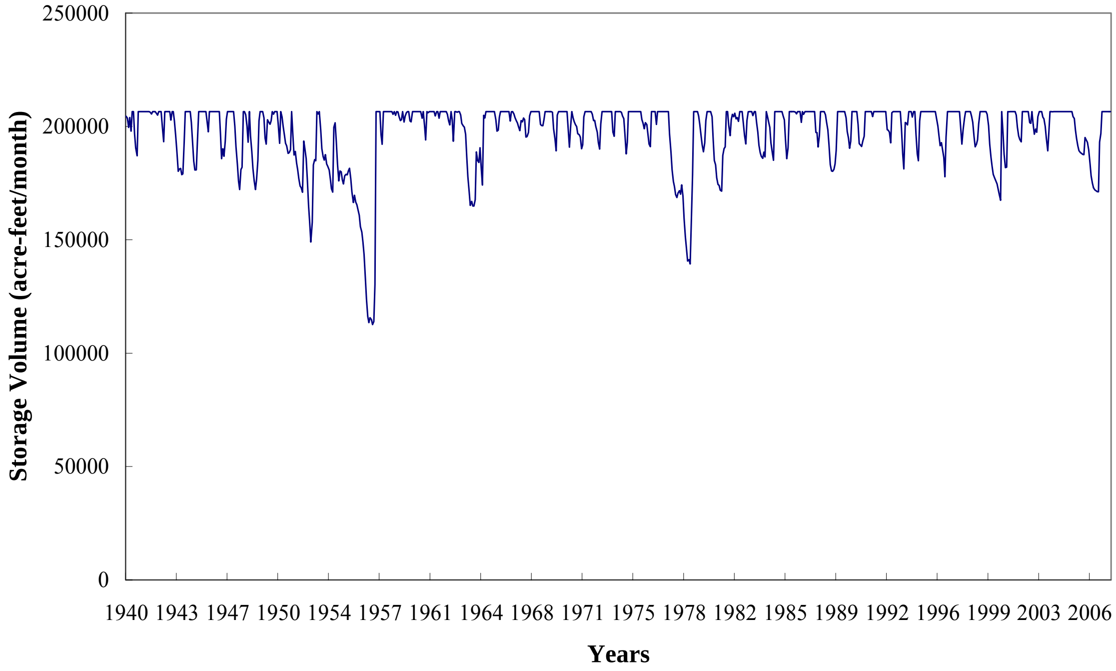

Figure 4.17 Bwam8 Storage Volume of Waco Reservoir

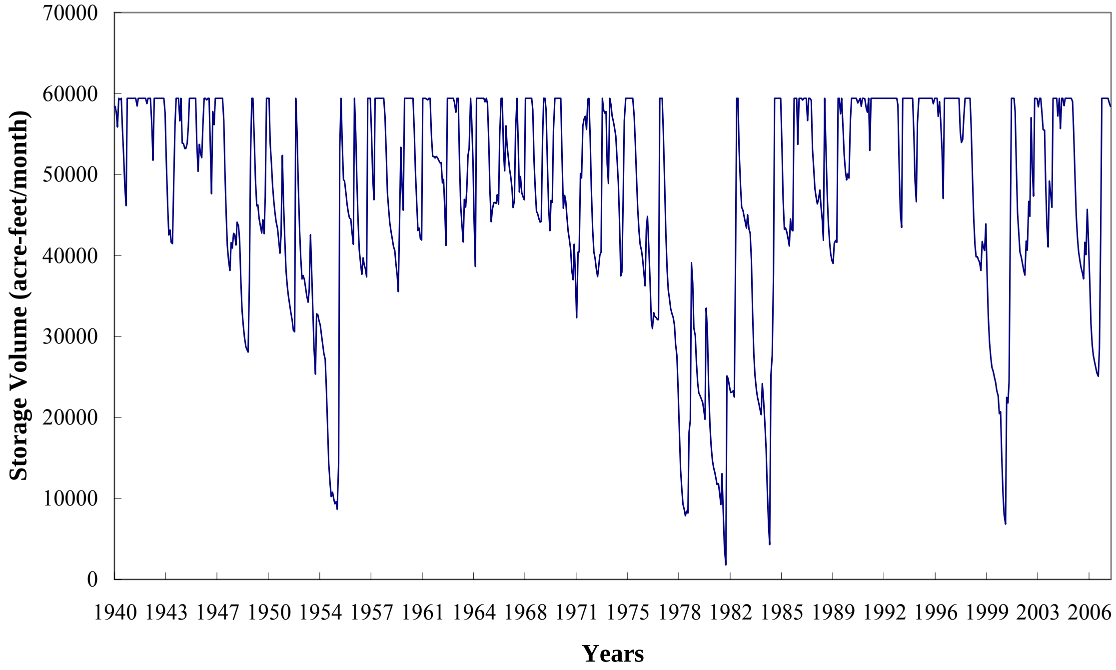

Figure 4.18 Bwam3 Storage Volume of Proctor Reservoir

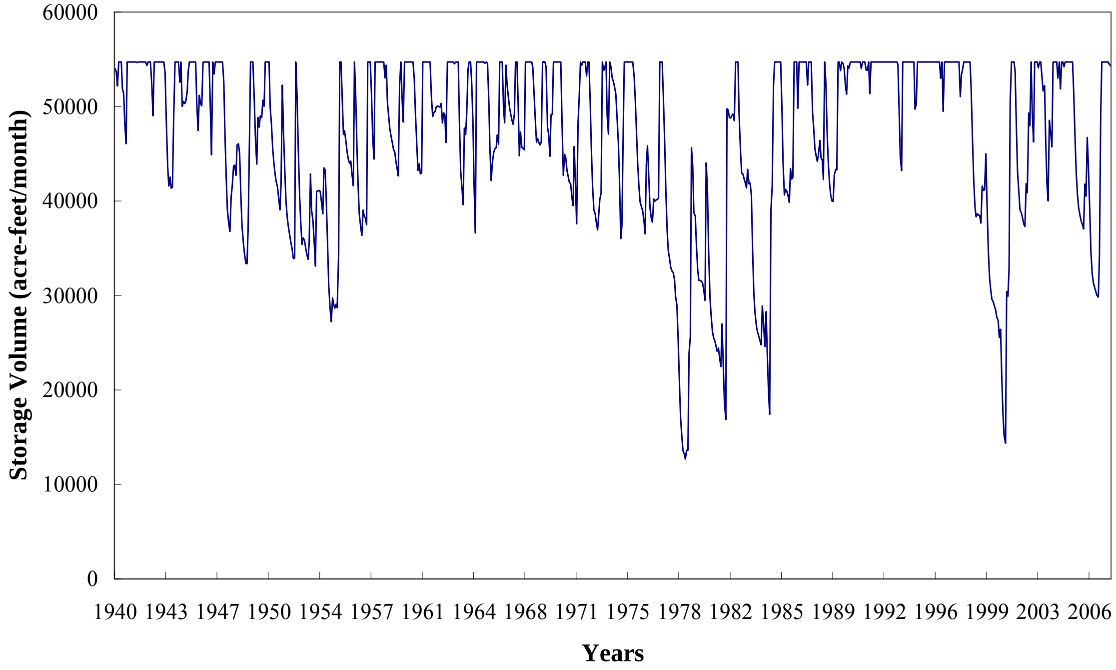

Figure 4.19 Bwam8 Storage Volume of Proctor Reservoir

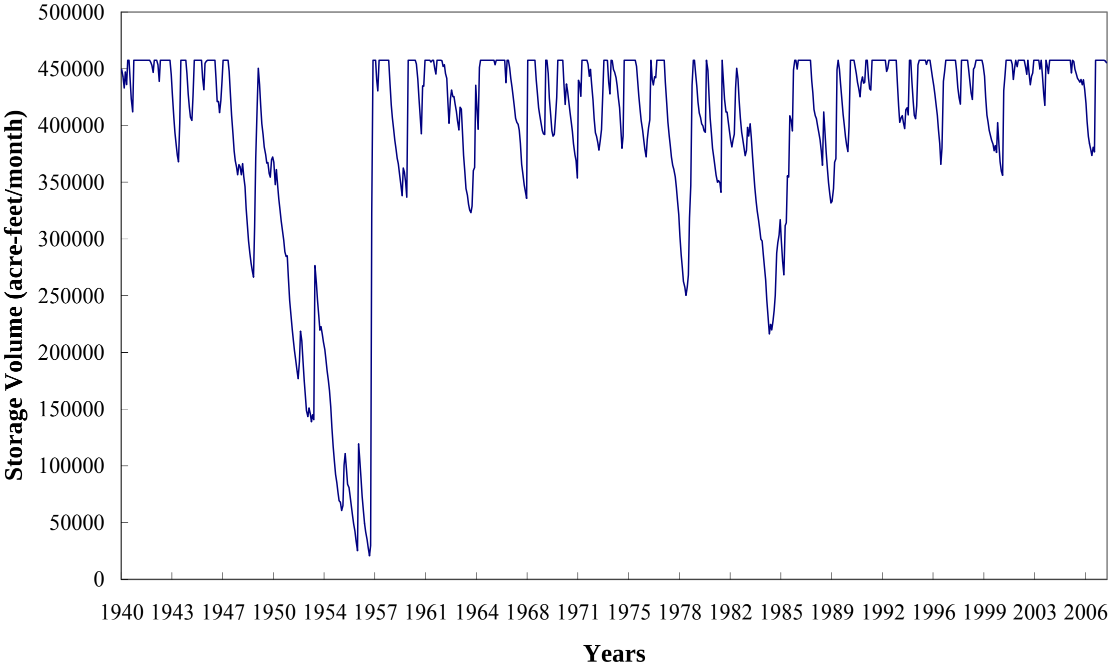

Figure 4.20 Bwam3 Storage Volume of Belton Reservoir

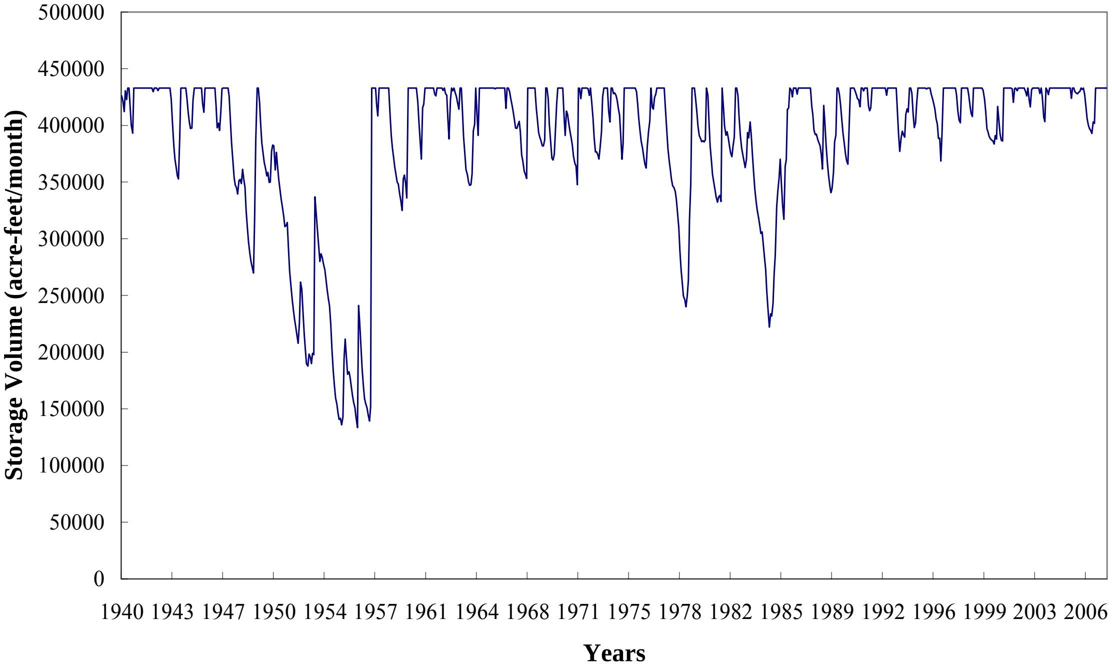

Figure 4.21 Bwam8 Storage Volume of Belton Reservoir

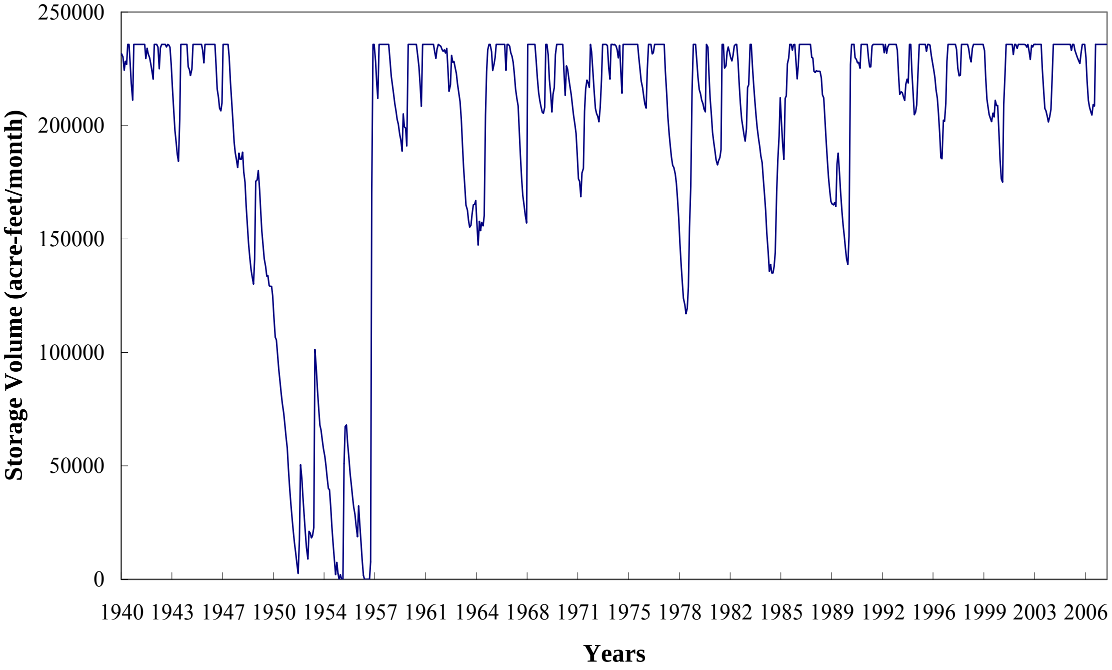

Figure 4.22 Bwam3 Storage Volume of Stillhouse Hollow Reservoir

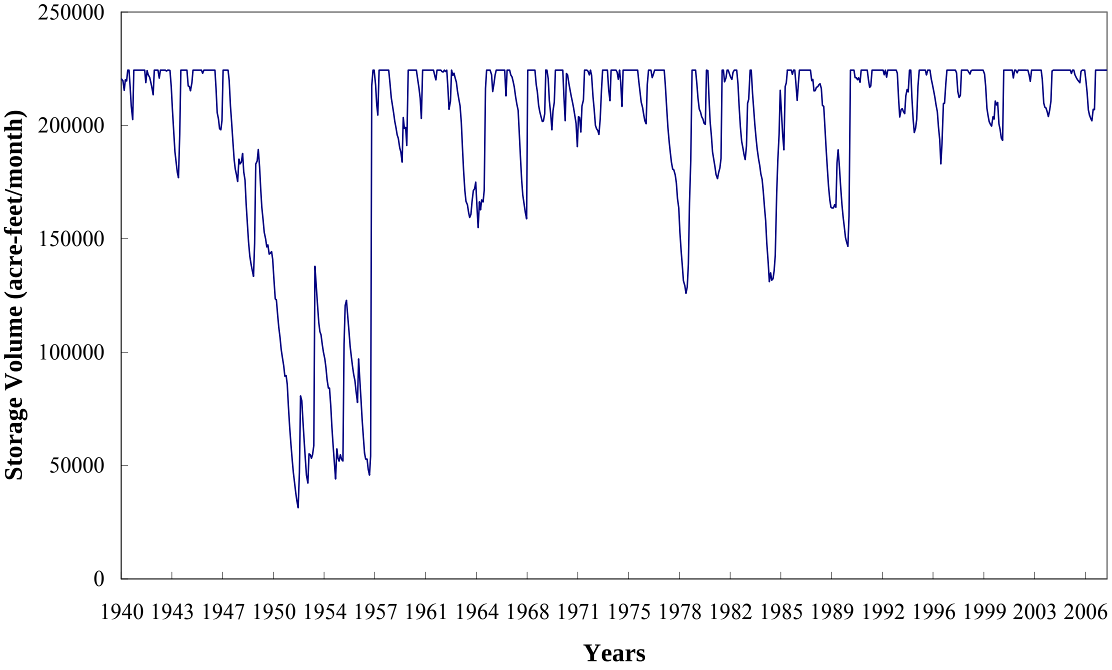

Figure 4.23 Bwam8 Storage Volume of Stillhouse Hollow Reservoir

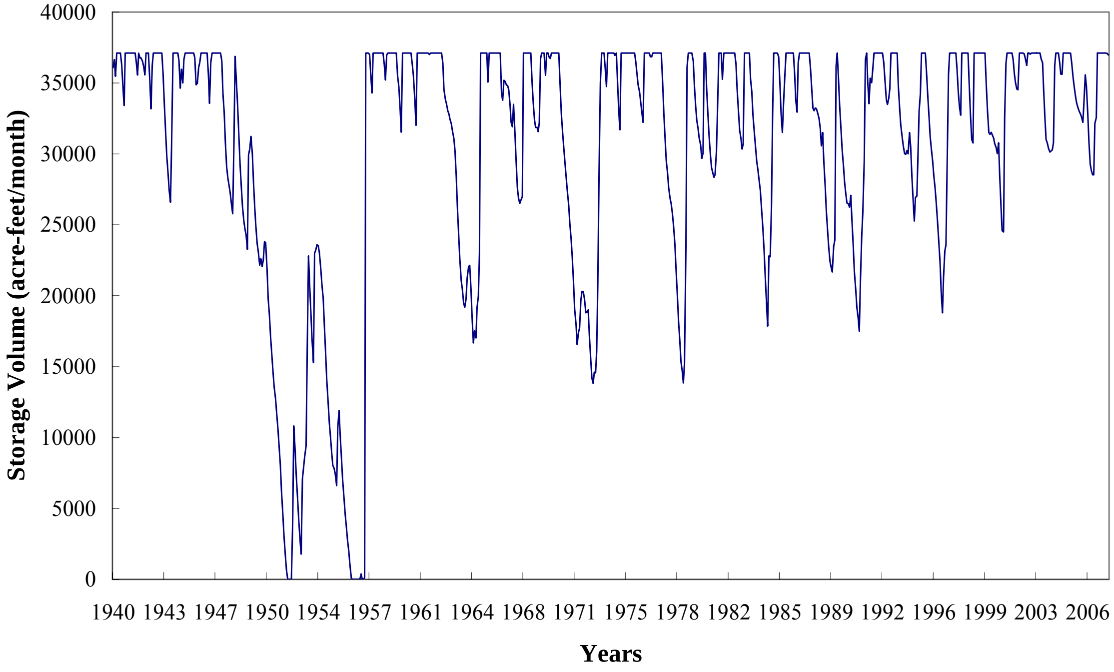

Figure 4.24 Bwam3 Storage Volume of Georgetown Reservoir

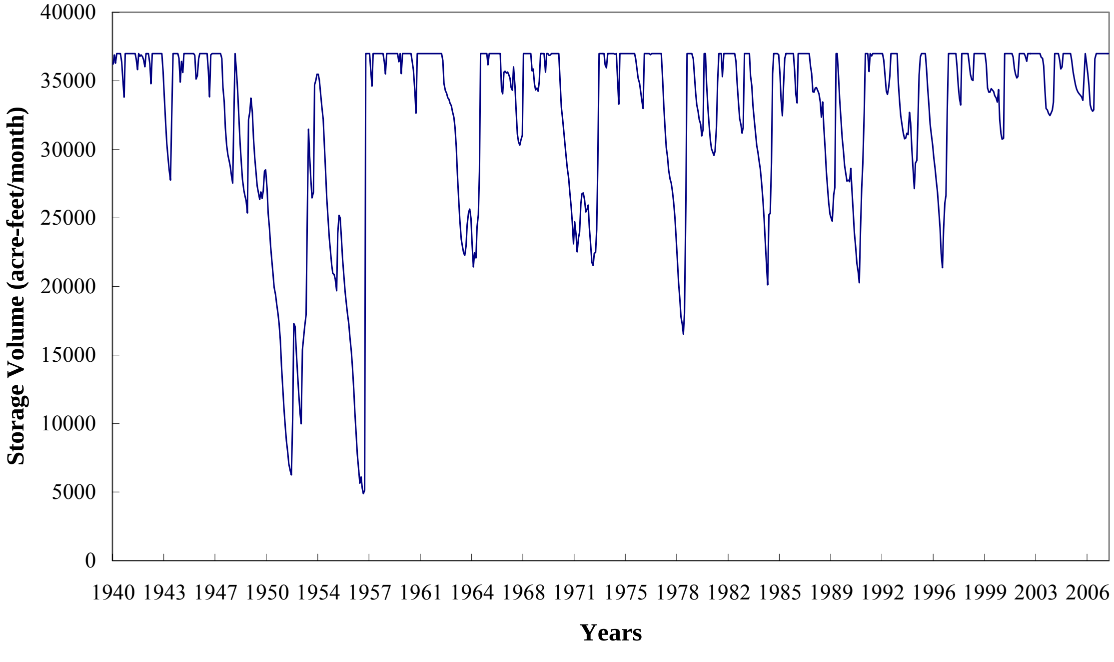

Figure 4.25 Bwam8 Storage Volume of Georgetown Reservoir

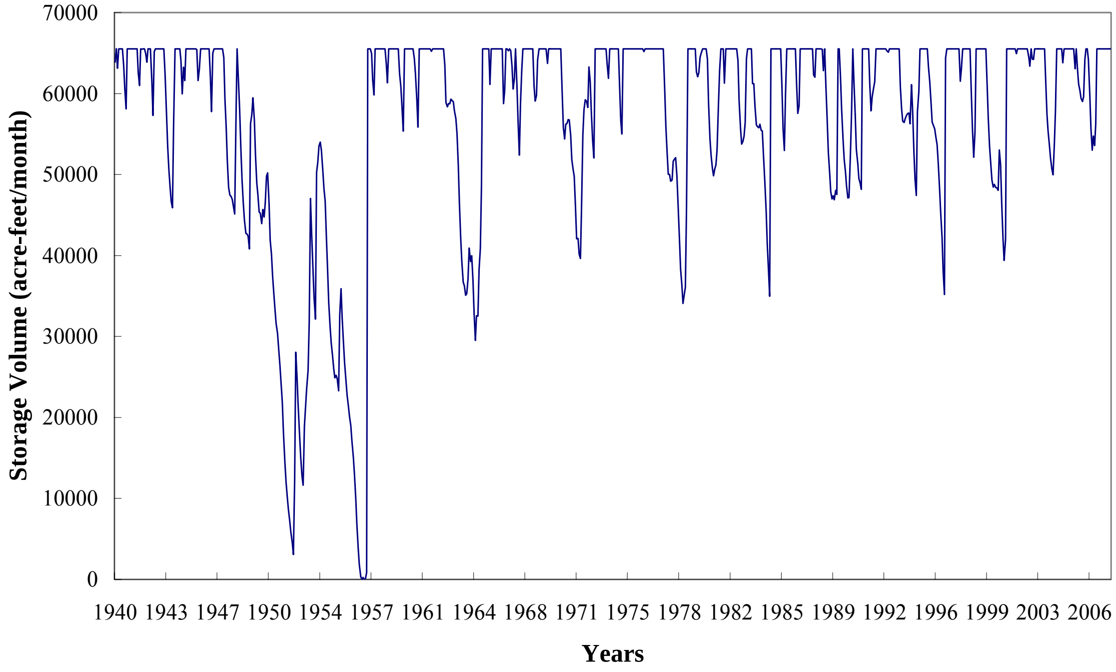

Figure 4.26 Bwam3 Storage Volume of Granger Reservoir

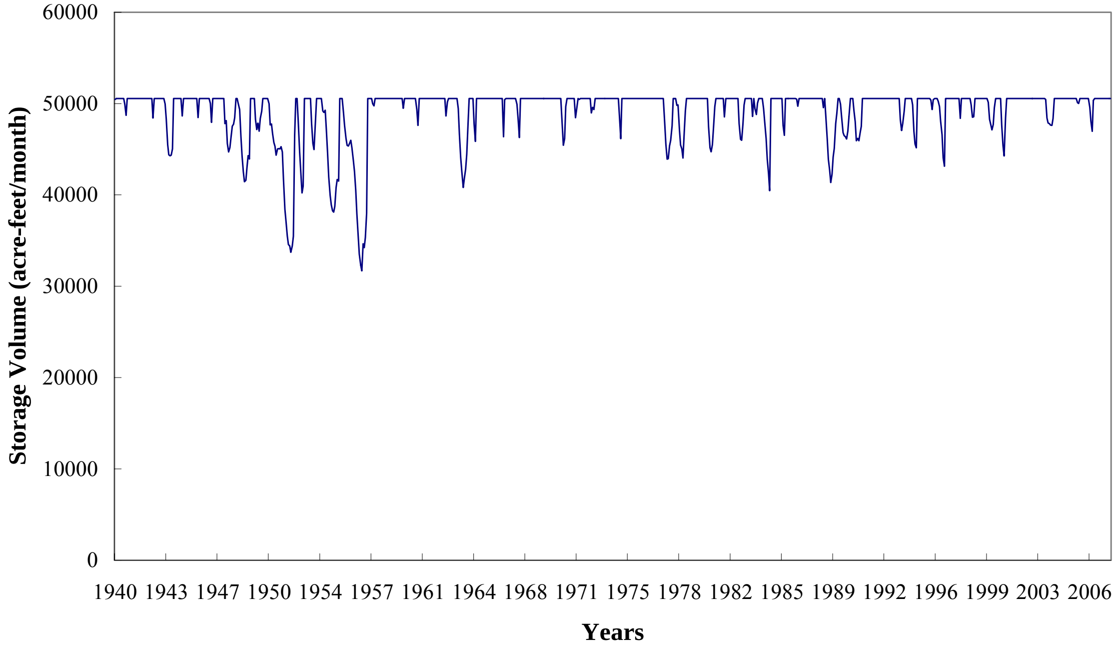

Figure 4.27 Bwam8 Storage Volume of Granger Reservoir

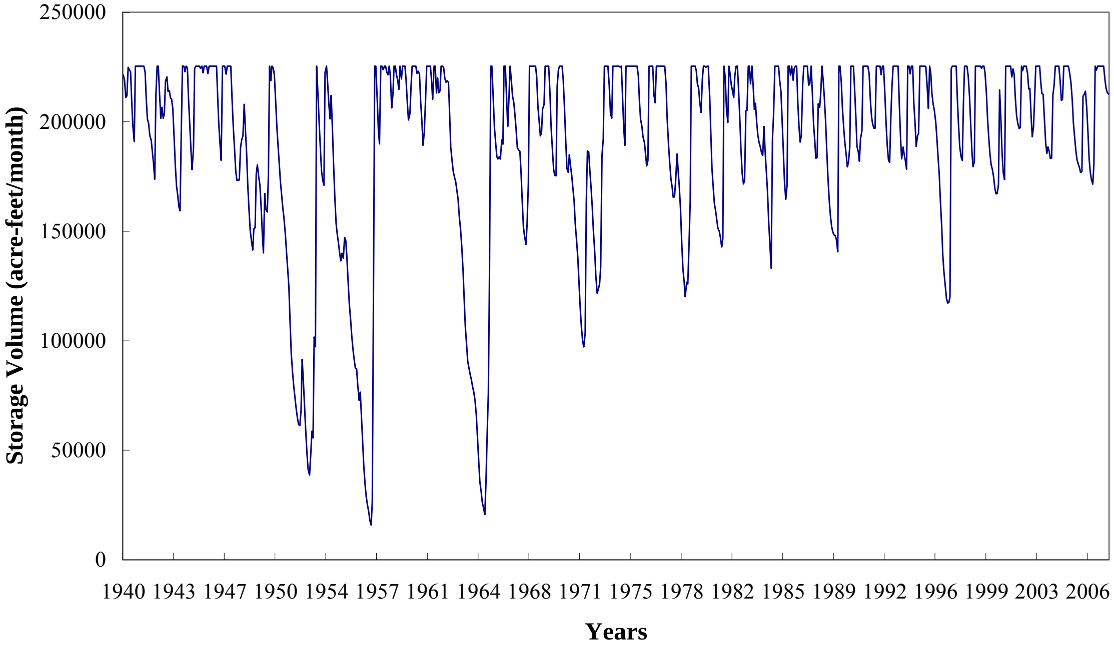

Figure 4.28 Bwam3 Storage Volume of Limestone Reservoir

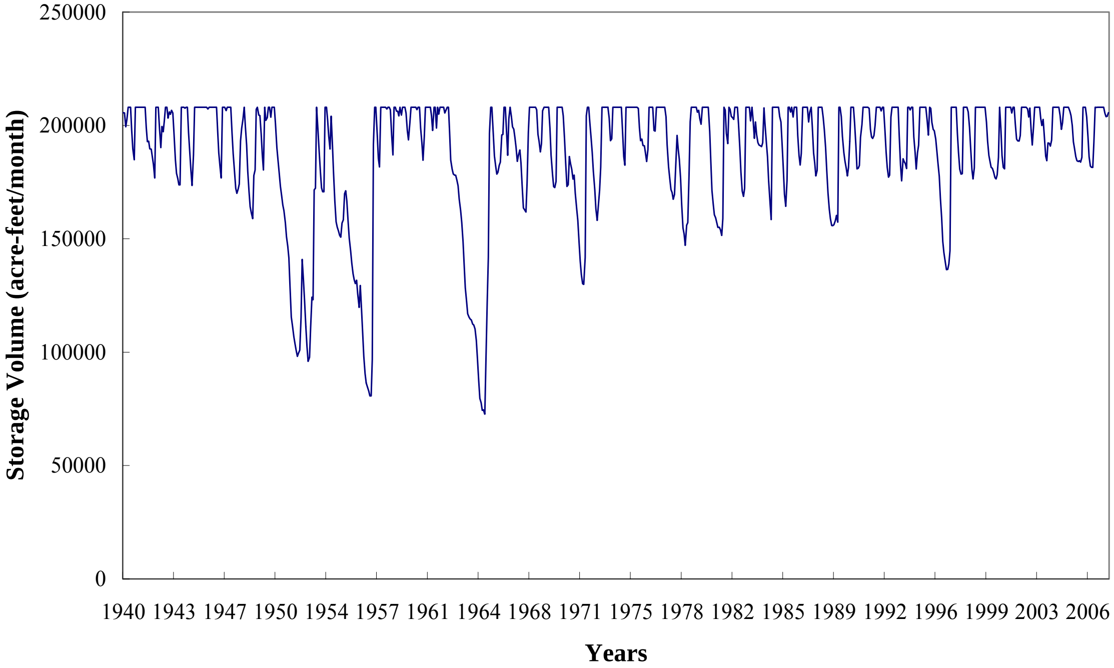

Figure 4.29 Bwam8 Storage Volume of Limestone Reservoir

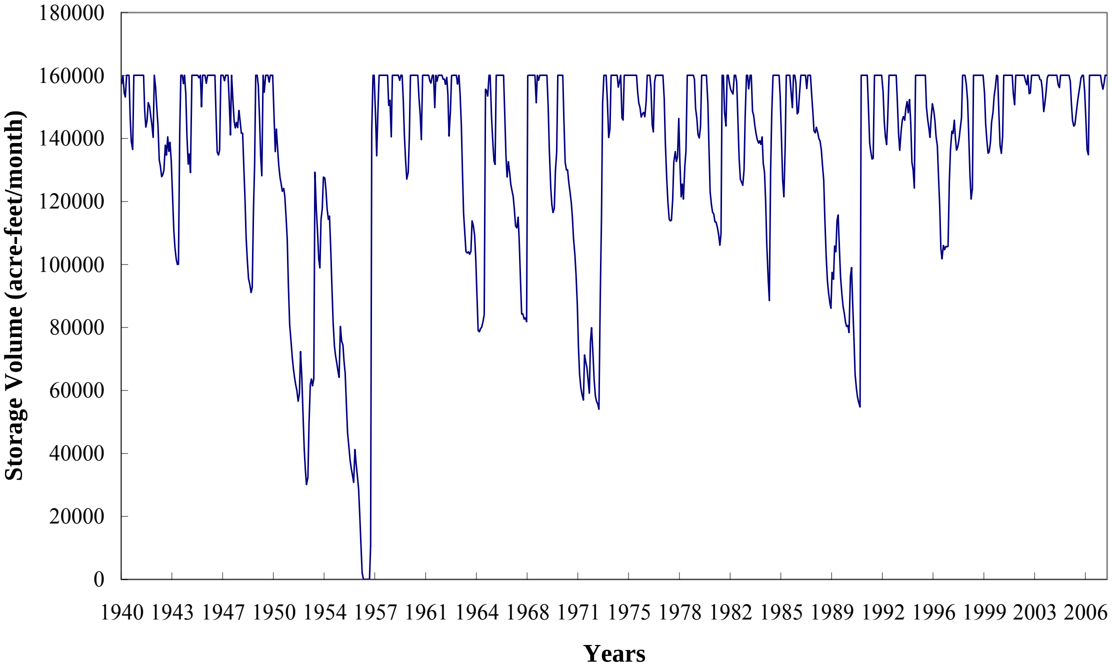

Figure 4.30 Bwam3 Storage Volume of Somerville Reservoir

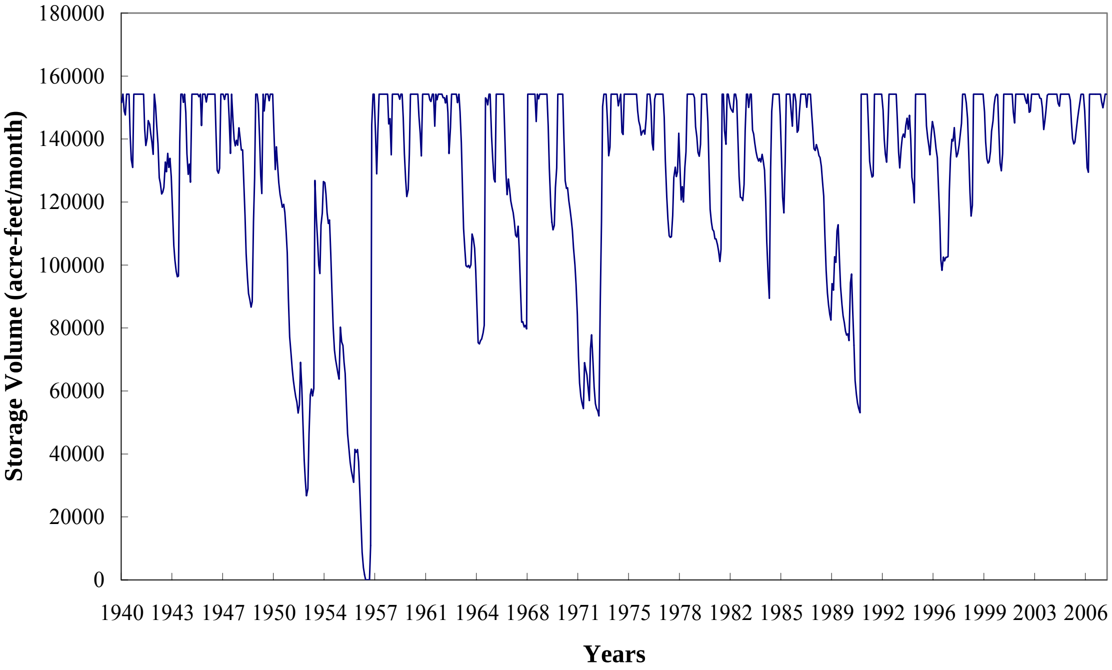

Figure 4.31 Bwam8 Storage Volume of Somerville Reservoir

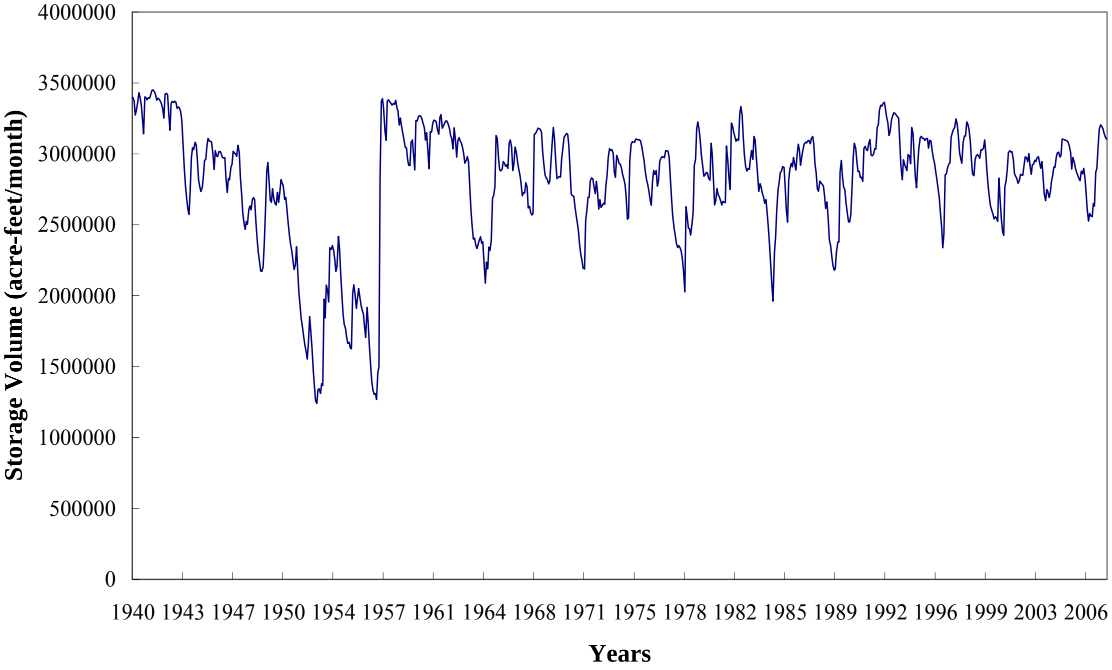

Figure 4.32 Bwam3 Storage Volume of 14 Reservoirs

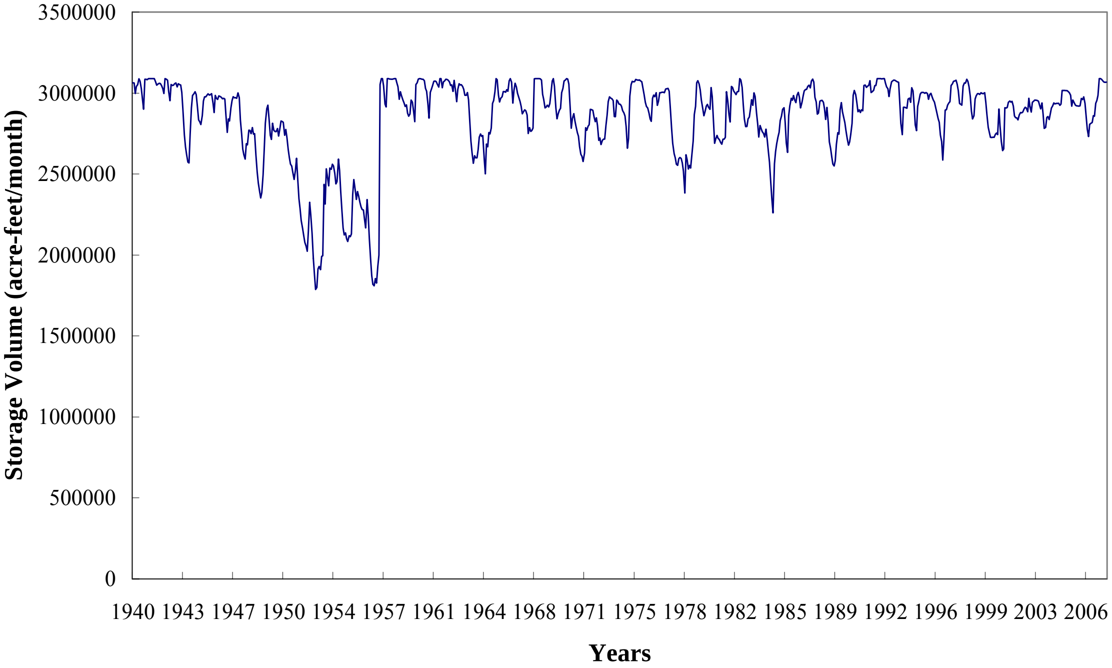

Figure 4.33 Bwam8 Storage Volume of 14 Reservoirs

CHAPTER V

CONDENSING THE BRAZOS WAM DATASET FOCUSING ON THE BRAZOS RIVER AUTHORITY SYSTEM

The procedure outlined in Chapter II for condensing WAM datasets is applied to the Brazos WAM described in Chapter III to develop a much simpler model designed for studies of operations of the Brazos River Authority (BRA) system. The development of condensed datasets from the TCEQ Water Availability Modeling (WAM) System authorized use and current use datasets for the Brazos River Basin and Brazos-San Jacinto Coastal Basin is described in the present section 5.1. Simulation results with the Brazos River Authority Condensed (BRAC) dataset versus original complete Brazos WAM dataset are compared in section 5.2.

5.1 DEVELOPMENT OF CONDENSED BRAZOS WAM DATASETS

Section 5.1 describes the authorized use scenario and current use scenario condensed datasets focused on the BRA system developed from the Brazos WAM datasets. These datasets are listed in Table 5.1. The filename root BRAC is adopted to refer to the condensed Brazos WAM dataset. BRAC3 and BRAC8 refer to the authorized and current use BRAC datasets corresponding to the Bwam3 and Bwam8 datasets described in Chapter III. Versions of the simplified model are developed with hydrologic periods-of-analysis of 1940-2007 and 1900-2007, which includes the 1998-2007 and 1900-1939 extensions covered in sections 4.1 and 4.2. The 1940-1997 hydrologic period-of-analysis is readily adopted as a subset of the 1940-2007 BRAC3 and BRAC8 datasets.

The reduced-size condensed BRAC dataset designed for modeling BRA river/reservoir water management system operations consists of DAT, FLO, and EVA files. Alternative versions of the files with filename roots BRAC3 and BRAC8, corresponding to the original full Brazos WAM Bwam3 and Bwam8 files, model the authorized use (run 3) and current use (run 8) scenarios defined in Chapter I. The FLO and EVA input files storing monthly stream flow volumes and net evaporation-precipitation depths can also be easily converted to DSS files with the data stored in the binary format of the Hydrologic Engineering Center (HEC) Data Storage System (DSS).

Table 5.1 WRAP-SIM Input Datasets Discussed in Section 5.1

Filename	Water Use Scenario	Hydrologic Period-of-Analysis
	Original Brazos WAM Datasets	
Bwam3	authorized use (run 3)	January 1940 through December 2007
Bwam3	authorized use (run 3)	January 1900 through December 2007
Bwam8	current use (run 8)	January 1940 through December 2007
Bwam8	current use (run 8)	January 1900 through December 2007
	Brazos River Authority Condensed (BRAC) Datasets	
BRAC3	authorized use (run 3)	January 1940 through December 2007
BRAC3	authorized use (run 3)	January 1900 through December 2007
BRAC8	current use (run 8)	January 1940 through December 2007
BRAC8	current use (run 8)	January 1900 through December 2007

5.1.1 Component of the BRA Condensed Datasets

The purpose for developing the condensed BRAC dataset is to have a much simpler model that facilitates operational planning studies and other decision support activities for the Brazos River Authority system. An input dataset and corresponding simulation results with dramatically fewer control points, water rights, and reservoirs are much more manageable to use in modeling studies. The Brazos WAM authorized use dataset described in Chapter III contains 1,634 water right *WR* records, 122 instream flow *IF* records, 670 reservoirs, and 3,830 control points. The Brazos WAM current use dataset is slightly larger. Naturalized flows are input on inflow *IN* records in a FLO file for 77 primary control points and distributed within *SIM* to the other ungaged secondary control points as specified by 3,138 flow distribution *FD* records in a DIS file. The size of the Bwam dataset is dramatically reduced in developing the simplified BRAC dataset.

The Brazos River Authority Condensed (BRAC) dataset (DAT, FLO, and EVA files) created by condensing the Brazos WAM dataset has 48 control points. The BRAC3 authorized use and BRAC8 current use versions of the condensed dataset have 15 and 14 reservoirs, respectively. The permitted but not yet constructed Allens Creek Reservoir is included in the Bwam3 and BRAC3 datasets but is not included in the Bwam8 and BRAC8 datasets. Net evaporation-precipitation depths are provided in the EVA file for the reservoir control points. River flows are included in the BRAC3 and

BRAC8 versions of the FLO file for all of the 48 control points. Thus, there is no flow distribution DIS file. Only water rights associated with the 15 or 14 reservoirs are included in the two versions of the BRAC DAT file. The impacts of the over 650 reservoirs and numerous water rights removed from the Brazos WAM dataset are reflected in the *IN* record river flows developed for the condensed dataset.

As discussed in Chapter II, the control points, reservoirs, and water rights included in the simplified condensed dataset are called the *primary* system. The control points, reservoirs, and water rights that are not included in the primary system comprise the secondary system. The effects of the secondary water rights on stream flows available to the primary water rights are reflected in the FLO file inflow *IN* record stream flows.

BRAC Reservoir

Figure 5.1 is a map showing the locations of the 15 BRAC reservoirs and 11 of the USGS stream gaging stations included in the BRAC control points. Information describing the reservoirs is provided in Tables 3.6 and 3.10 of Chapter III as well as Table 5.2.

Nine of the 15 BRAC reservoirs are federal Corps of Engineers multiple-purpose projects for which the BRA has contracted for most of the conservation storage capacity. Lakes Possum Kingdom, Granbury, and Limestone are owned and operated by the BRA for water supply and other purposes. The BRA holds a water right permit for the proposed Allens Creek Reservoir, but the project has not yet been constructed. Allens Creek Reservoir is included in the authorized use Bwam3 and BRAC3 datasets but is not included in the current use Bwam8 and BRAC8 datasets.

Squaw Creek Reservoir owned by the Texas Utilities Services Company provides cooling water for the Comache Peak nuclear power plant. Hubbard Creek Reservoir is owned and operated by the West Central Texas Municipal Water District to supply water to several cities.

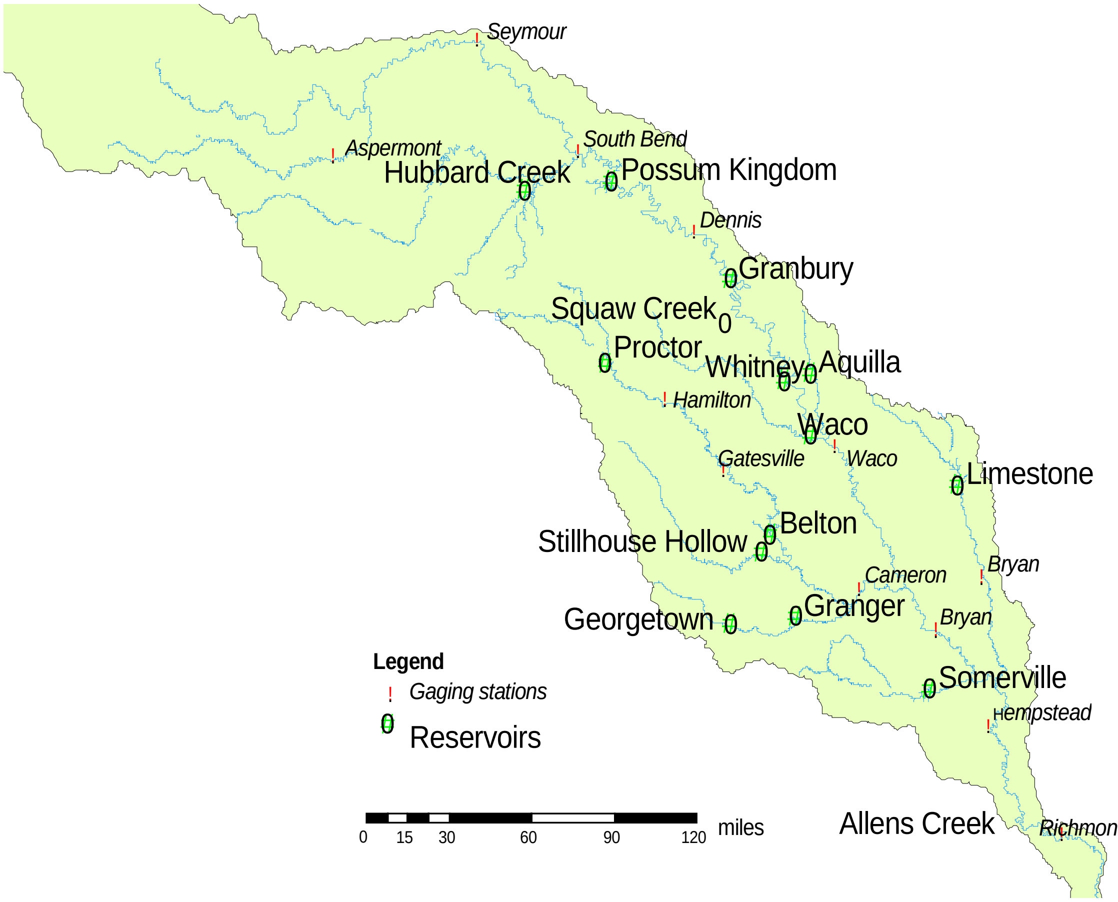

Figure 5.1 BRAC Reservoirs

The objective of the BRAC dataset is to model operations of the Brazos River Authority system composed of the nine federal reservoirs for which BRA partners with the Corps of Engineers and the three BRA owned reservoirs. The proposed Allens Creek Reservoir planned for construction in the future is also an integral consideration in BRA operational planning. Squaw Creek Reservoir at the Comanche Peak nuclear power plant is owned by Texas Utilities Services which purchases water from the BRA to maintain constant levels in the large cooling reservoir. Hubbard Creek Reservoir is owned and operated by the West Central Texas Municipal Water District. The BRA is not directly involved in its operation. However, the conservation storage capacity of Hubbard Creek Reservoir is the fourth largest in the Brazos River Basin. Since it is a very large reservoir located upstream of the three main-stem BRA reservoirs, inclusion of Hubbard Creek Reservoir in the BRAC model was judged to be worthwhile.

BRAC Control Points

Figure 5.2 is a BRAC control point map. Figure 5.3 is a schematic of the spatial configuration of the system as defined by the 48 control points. The 48 control points included in the BRAC dataset are listed in Tables 5.2, 5.3, and 5.4. The 15 control points in Table 5.2 are locations of reservoir projects. The 11 control points in Table 5.3 represent stream confluences and the basin outlet. The 22 control points in Table 5.4 are locations of stream gaging stations.

The control points are referenced by the six-character identifiers originally assigned in the Brazos WAM data files and continued in the BRAC dataset. The six-character WAM reservoir identifiers are shown in parenthesis under the control point identifiers in the Figure 5.3 schematic.

The WRAP term *primary control point* refers to locations at which stream flows are provided as input on *IN* records stored in a FLO file. The Brazos WAM dataset has 77 primary control points which are listed in Table 3.2 of Chapter III. The locations of the 77 Brazos WAM primary control points are shown on the map of Figure 3.2.

The 22 BRAC gaging station control points listed in Table 5.4 are included in the 77 primary control points in the Brazos WAM. All 48 control points listed in Tables 5.2, 5.3, and 5.4 are primary control points in the BRAC dataset even though only 22 are located at gaging stations. Stream flows for all 48 control points computed as outlined in this chapter are stored as *IN* records in the FLO files of the BRAC3 and BRAC8 datasets.

The BRAC3 and BRAC8 DAT files include *CP* records for each of the 48 control points. The EVA file contains evaporation-precipitation depths for the 15 reservoir control points.

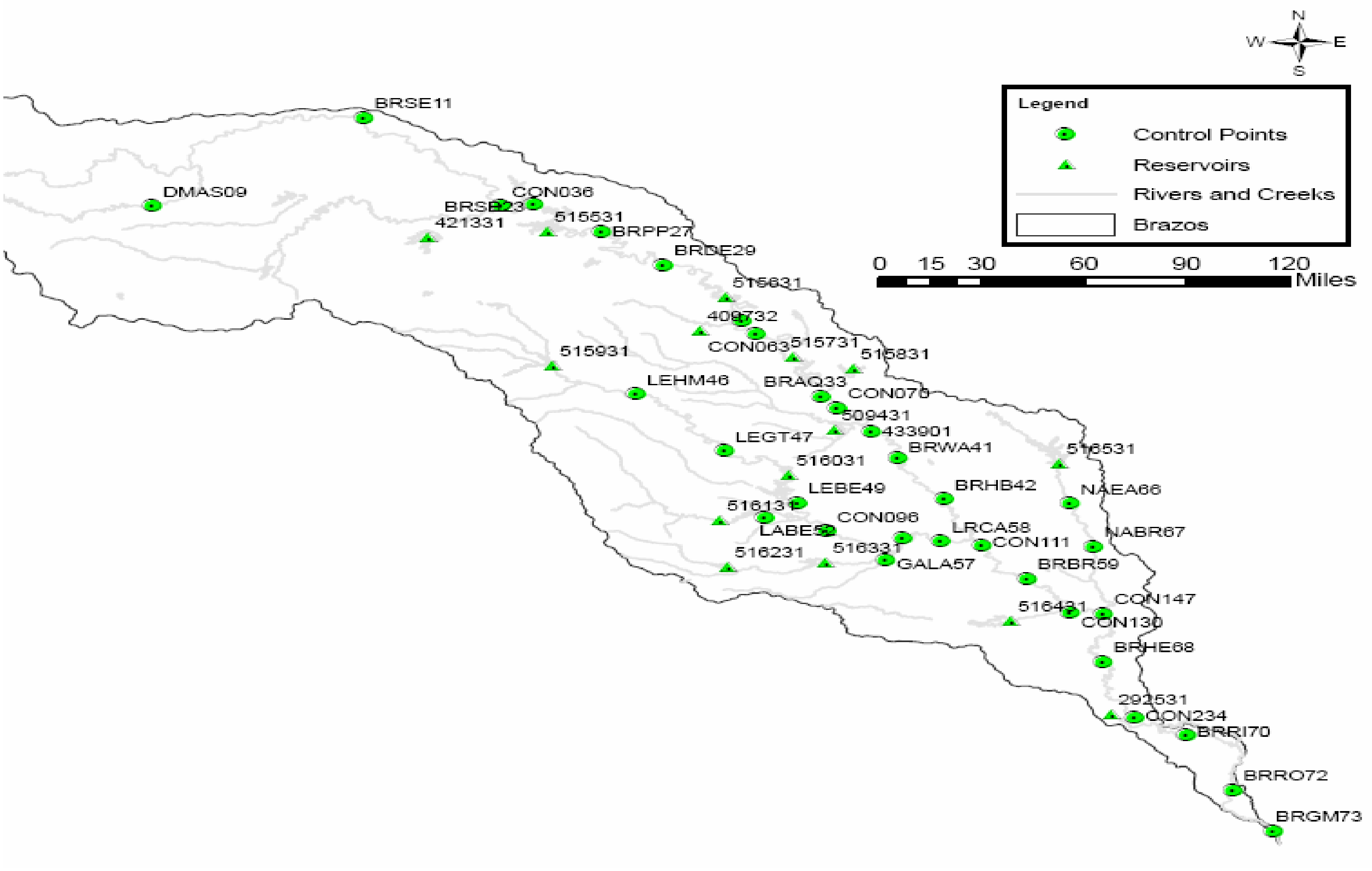

Figure 5.2 BRAC Control Points

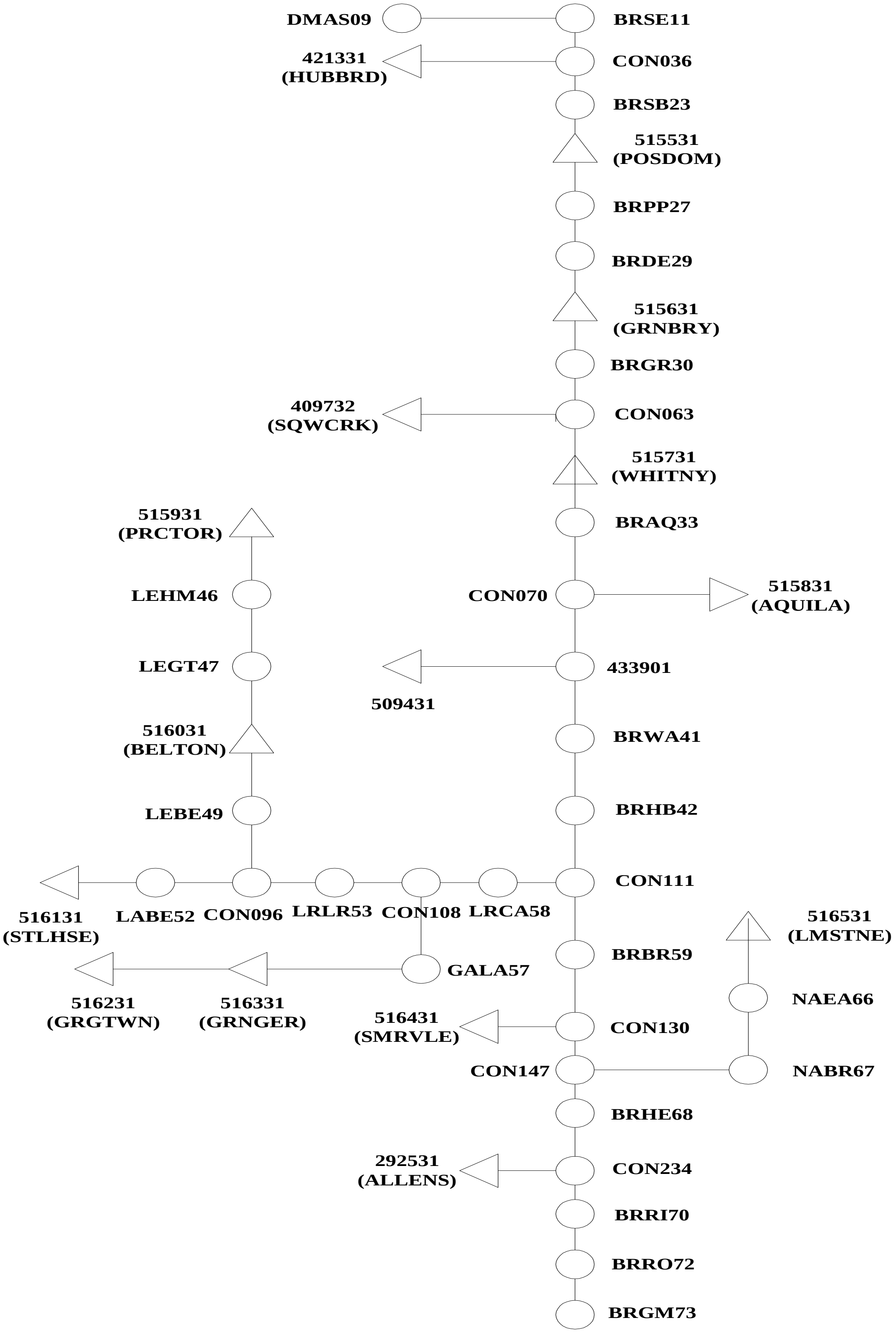

Figure 5.3 Schematic of BRAC Control Points (Not to Scale)

Table 5.2 BRAC Control Points for Reservoirs

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

Table 5.3 BRAC Control Points for Stream Confluences and the Basin Outlet

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

Table 5.4 BRAC Control Points for USGS Gaging Stations

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

BRAC Water Rights

The BRAC3 and BRAC8 DAT files include only those water rights from the Brazos WAM dataset that are associated with the 15 and 14 reservoirs, respectively. Water rights associated with Allens Creek Reservoir are included in the authorized use scenario BRAC3 but are not included in the current use scenario BRAC8 version of the dataset. *WR* record water rights in the BRAC3 and BRAC8 DAT files refill storage in the 15 or 14 reservoirs and supply water supply diversion requirements with withdrawals and releases from the reservoirs. The BRAC water rights are listed in Table 5.5 with their storage capacities and annual diversion targets for the BRAC3 and BRAC8 versions of the condensed dataset.

Whitney and Waco reservoirs are modeled in the Brazos WAM and BRAC datasets as sets of component reservoirs with the evaporation allocation *EA* record option activated. The storage capacity and diversion target of the water rights associated with each component reservoir are shown in parenthesis in Table 5.5.

The locations of the 14 BRAC3/BRAC8 reservoirs shown in Figure 5.4 are also the locations of the water rights associated with the reservoirs. The main portion of the water right identifiers is tabulated in Table 5.5 and used as labels in Figure 5.4. Multiple *WR* records are assigned at these locations with extensions to the main water right identifiers shown in Figure 5.4. A complete listing of water rights with their full identifiers is provided in Table 3.11 of Chapter III.

BRAC dataset totals are compared with Brazos WAM dataset totals at the bottom of Table 5.5. The 15 reservoirs in the authorized use scenario BRAC3 dataset account for 77.3 percent of the total reservoir storage capacity in the 665 reservoirs included the Bwam3 dataset. The 14 reservoirs in the current use scenario BRAC8 dataset account for 77.7 percent of the total reservoir storage capacity in the 706 reservoirs included the Bwam8 dataset. The diversion targets for the water rights in the BRAC3 and BRAC8 datasets are 38.3 and 31.6 percent of the of the total diversion targets in the Bwam 3 and Bwam8 datasets.

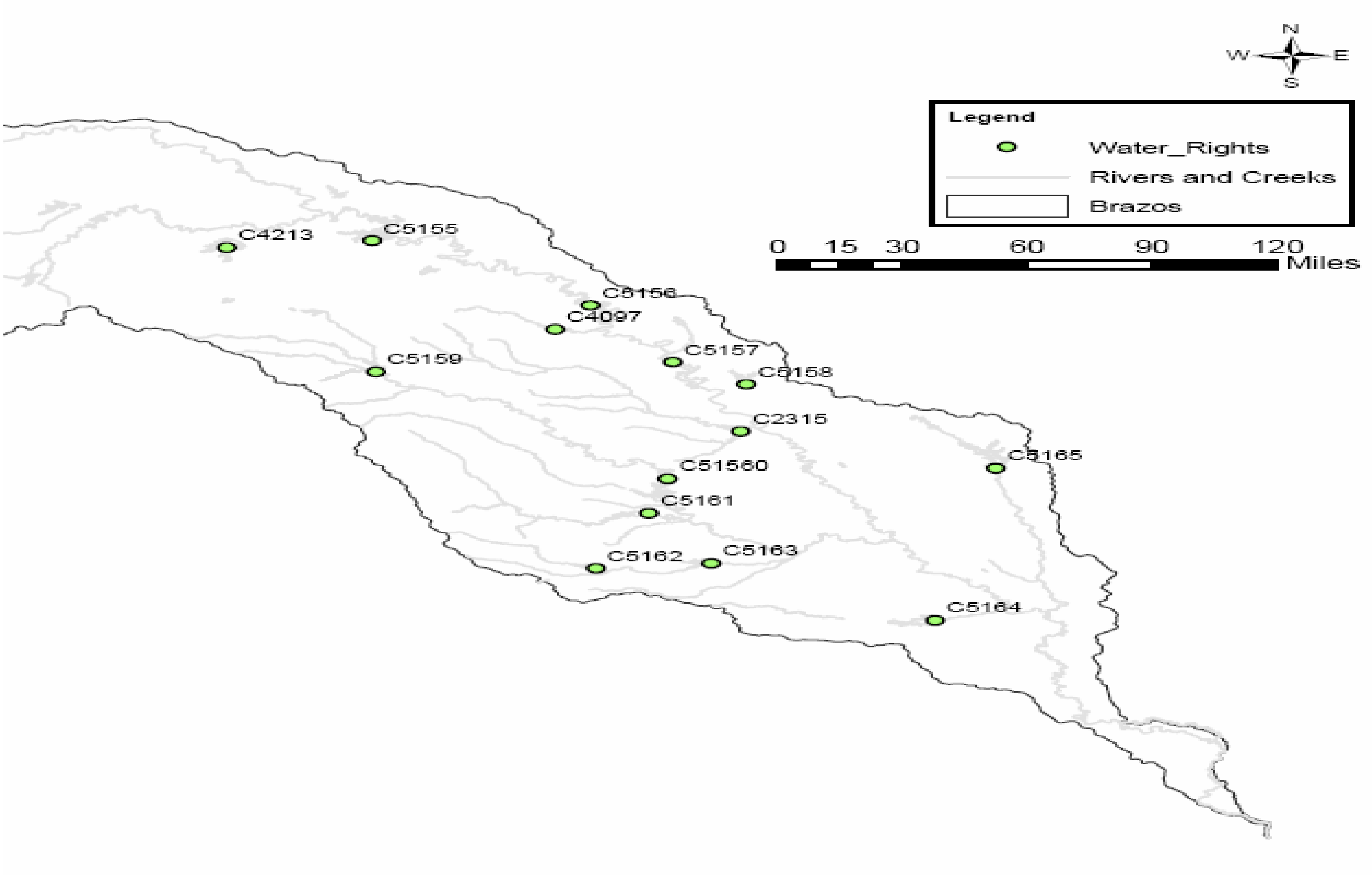

Figure 5.4 BRAC Water Rights

Table 5.5 BRAC Water Rights Summary

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

5.1.2 Procedure for Developing the Condensed Dataset

The objective is to develop a much simpler dataset designed specifically for modeling the management and operation of the BRA system by reducing the number of control points, water rights, and reservoirs in the Brazos WAM dataset. Secondary water rights, control points, and reservoirs are removed with their effects incorporated in the river system inflow input data for the simplified dataset. A *WRAP-SIM* water rights input DAT file for the BRA river/reservoir water management and use system and other closely associated reservoirs and water users, called the primary system, is developed along with a FLO file containing stream flow inflows that exclude the flows appropriated by all of the other water rights in the original Brazos WAM dataset that are not included in the primary system.

The procedure is repeated four times to develop the following four alternative *WRAP-SIM* input datasets. Each of these four BRAC datasets is comprised of a DAT, FLO, and EVA file.

BRAC3	authorized use (run 3)	January 1940 through December 2007
BRAC3	authorized use (run 3)	January 1900 through December 2007
BRAC8	current use (run 8)	January 1940 through December 2007
BRAC8	current use (run 8)	January 1900 through December 2007

BRAC3 and BRAC8 datasets were developed for alternative hydrologic periods-of-analysis of 1940-2007 and 1900-2007. Datasets for the 1940-1997 period-of-analysis are automatically contained within the datasets with a 1940-2007 period-of-analysis. Likewise, models for 1900-1939 are automatically contained within the datasets with a 1900-2007 simulation period.

The *WRAP-SIM/HYD*-based methodology is described in section 2.4. Application of the programs *SIM* and *HYD* to develop the 1940-2007 BRAC3, 1900-2007 BRAC3, 1940-2007 BRAC8, and 1900-2007 BRAC8 datasets consists of applying the methodology described in section 2.4 four times to create four sets of DAT, FLO, and EVA files:

- The BRAC3 and BRAC8 DAT files contain water rights and related information for 15 and 14 reservoirs, respectively, and associated water supply diversions. This information is excerpted from the Bwam3 and Bwam8 DAT files. All but 48 of the original over 3,800 control point *CP* records are omitted. Thus, the next downstream control point identifiers and channel loss factors on the *CP* records are modified for the adopted 48 control points.
- FLO files with 1940-2007 and alternative 1900-2007 sets of monthly flows at 48 control points represent conditions of river system development that includes all of the water rights and associated reservoirs in the original complete DAT file except the 15 reservoirs and associated diversions contained in the simplified dataset DAT file.
- EVA files contain 1940-2007 and alternative 1900-2007 sets of monthly net evaporation-precipitation depths for the 15 control points at which the 15 reservoirs are located. *SIM* includes an option for adjusting net evaporation-precipitation depths for the precipitation runoff from the portion of the watershed covered by the reservoir. Thus, net evaporation-precipitation depths are obtained from the OUT file for the complete simulation rather than using the original evaporation-precipitation depth input dataset.

The DAT file for a condensed dataset is developed by excerpting pertinent water rights and associated data records from the original DAT file, excerpting pertinent records providing reservoir data, and modifying remaining control point *CP* records to reflect removal of many of the control points. With removal of control points, channel loss factors for the stream reaches removed are aggregated for the combined longer reaches between the remaining control points.

Channel loss factors C_L for N reaches that are combined into one single reach with the removal of intermediate control points are aggregated as follows.

$$(1.0 - C_L)_{total} = (1.0 - C_L)_1 + (1.0 - C_L)_2 + \ldots + (1.0 - C_L)_N$$

Channel loss factors for the stream reaches between the 77 primary control points in the Brazos WAM are tabulated in Table 4.7 of section 4.1. Channel loss factors for the stream reaches defined by the 48 control points in the BRAC dataset are tabulated in Table 5.6

Table 5.6 Channel Loss Factors for Reaches between 48 Control Points

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

A number of the water rights included in the BRAC dataset have water supply diversion return flows that are returned back to the river in the Brazos WAM dataset at control points that have been removed in the BRAC dataset. The return flows are returned in the BRAC dataset at the next downstream control point that was not removed. The return flow locations that were modified are listed in Table 5.7. Return flows returning to the river system in Bwam at the control point locations listed in the first column of Table 5.7 are returned at the control points listed in the 4th column. The Bwam return flow locations removed in the BRAC datasets are shown in Figure 5.5.

Table 5.7 Return Flow Control Points

Bwam Return Flow CP	Water Rights	Reservoir ID	BRAC Return Flow CP	Control Point Description
103341	C4213_2	HUBBARD	CON036	confluence
100401	C4213_5	HUBBARD	CON036	confluence
027891	C5155_1	POSDOM	BRPP27	Palo Pinto gage
101102	C5155_3	POSDOM	BRHB42	Highbank gage
106271	C5155_4	POSDOM	OUT	Gulf of Mexico
104101	C5155_5	POSDOM	OUT	Gulf of Mexico
105685	C5155_6	POSDOM	OUT	Gulf of Mexico
103751	C5155_7	POSDOM	OUT	Gulf of Mexico
101731	C5155_8	POSDOM	OUT	Gulf of Mexico
BRA_AB	C5155_A	POSDOM	OUT	City of Abilene
SHGR26	C5155_20	POSDOM	BRPP27	Palo Pinto gage
515551	C5155_21	POSDOM	BRPP27	Palo Pinto gage
101782	C5156_3	GRNBRY	515631	Granbury Reservoir
106301	C5158_2	AQUILA	515831	Aquilla Reservoir
110711	C2315_1	LKWACO	BRHB42	Highbank gage
110711	C2315_3	LKWACO	BRHB42	Highbank gage
110711	P5094_1	LKWACO	BRHB42	Highbank gage
110711	P5094_2	LKWACO	BRHB42	Highbank gage
110711	P5094_3	LKWACO	BRHB42	Highbank gage
102191	C5160_1	BELTON	509431	Lake Waco
101761	C5160_3	BELTON	516031	Lake Belton
101741	C5160_4	BELTON	OUT	Gulf of Mexico
103513	C5160_5	BELTON	CON096	confluence
103512	C5160_6	BELTON	CON096	confluence
100451	C5160_8	BELTON	516131	Stillhouse Reservoir
100455	C5160_9	BELTON	516031	Belton Reservoir
100451	C5160_10	BELTON	516131	Stillhouse Reservoir
101551	C5160_11	BELTON	CON096	confluence
113181	C5160_12	BELTON	CON096	confluence
104702	C5160_13	BELTON	CON111	confluence
102051	C5161_1	STLHSE	516131	Stillhouse Reservoir
104893	C5162_1	STLHSE	516331	Granger Reservoir
104892	C5162_2	STLHSE	516331	Granger Reservoir
102641	C5162_3	STLHSE	CON108	confluence
102642	C5162_4	STLHSE	CON108	confluence
102991	C5163_2	GRNGER	CON108	confluence
103881	C5164_1	LMSTNE	BRHE68	Hempstead gage

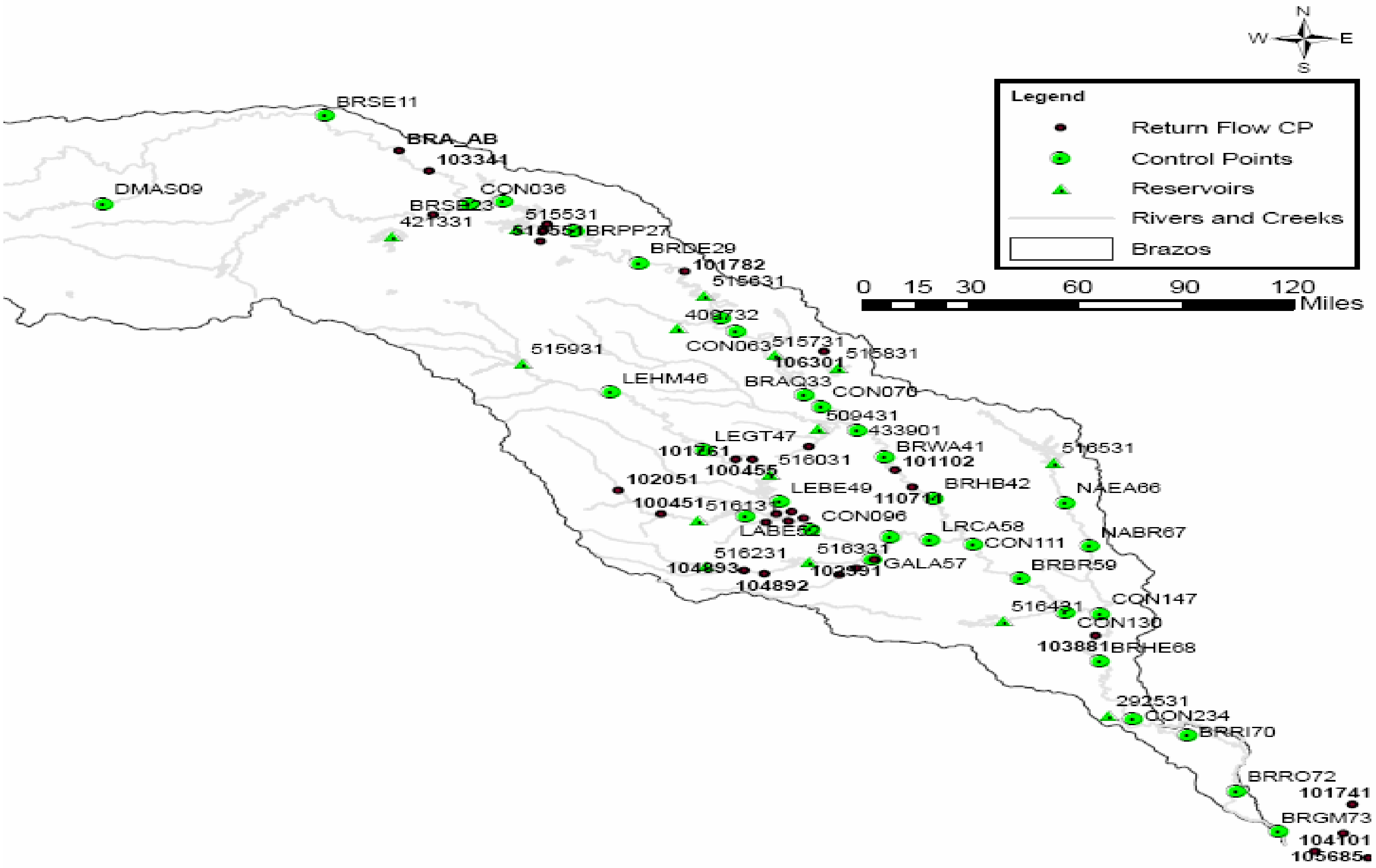

Figure 5.5 BRAC Control Points and the Bwam Return Flow Control Points Removed

The EVA file in the condensed dataset provides 15 sets of net evaporation-precipitation depths for 15 reservoirs. The simplified dataset adopts the same net evaporation-precipitation depths for the 15 reservoirs as used in the original complete dataset *SIM* simulation. The Bwam activates a *SIM* option that adjusts net evaporation-precipitation depths for reservoir site runoff included in the naturalized flows. The condensed EVA file contains net evaporation-precipitation depths read by program *HYD* from the *SIM* output OUT file from the original dataset that reflects these adjustments.

The hydrologic period-of-analysis sequences of stream flows provided on *IN* records in a FLO file in a *WRAP-SIM* input dataset represent the inflows to the river system. In the original WAM datasets, these are naturalized flows representing natural conditions without the water resources development, management, and use described by the information in the DAT file. For the condensed datasets, the *IN* record inflows in a FLO file are the stream flows available to the water rights of the primary system described by the condensed DAT file. The flows appropriated by the secondary water rights are not available to the primary water rights and thus are not included in the *IN* record inflows.

5.1.3 Methodology for Developing Hydrology Files for the Condensed Datasets

The methodology for developing the sequences of monthly stream flow volumes and net evaporation-precipitation depths (FLO and EVA files) for the BRAC condensed dataset is outlined as follows:

1. *SIM* is executed with the original complete Brazos WAM dataset.

2. *HYD* is used to retrieve the adjusted net evaporation-precipitation depths from the *SIM* output OUT file and store them in an EVA input file for the condensed dataset.

3. *HYD* reads stream flow depletions, return flows, unappropriated flows, and reservoir releases from storage to meet instream flow requirements from the *SIM* output OUT file and combines these variables as required to develop the stream flow FLO for the condensed dataset. Combining the time sequences of flow volumes includes summations and cascading operations that may include channel losses. *HYD* reads the necessary control point information from an input file.

River flows developed for the 48 control points and stored in a FLO file consist of 1940-2007 or 1900-2007 sequences of monthly volumes of the following variables obtained from the OUT file created by *SIM* with the original complete Brazos WAM input dataset. The computations are performed with *HYD*:

- Stream flow depletions made by each of the water rights associated with the 15 reservoirs are included in the flows being developed. These flow volumes are placed at the control point of the stream flow depletion and at all downstream control points. Channel losses are considered in cascading the stream flow depletions downstream.
- Return flows from the diversion component of the stream flow depletions are subtracted from the flows. These flow volumes are placed at the control point at which the return flow is returned to the stream and at all downstream control points. Channel losses are considered in cascading the return flows downstream.
- Unappropriated flows at each of the control points are added to the flows. Since unappropriated flows are cumulative total flows, these flows are not cascaded downstream.
- Any releases from storage in Aquilla and Squaw Creek Reservoirs made specifically for instream flow rights are subtracted at the control point of the reservoir and cascaded downstream in the normal manner which includes consideration of channel losses.
- Water Supplied from Waco and Whitney Reservoirs by backup rights are subtracted from the flows and cascaded downstream accounting for channel losses.

Of the 15 BRAC reservoirs, Aquilla and Squaw Creek are the only reservoirs that release from storage to meet instream flow requirements in the Brazos WAM. The Bwam3 and Bwam8 DAT files contain 122 and 144 instream flow *IF* records, respectively. Reservoirs must pass inflows as necessary to meet senior instream flow requirements at downstream control points. However, though required to pass inflows, reservoirs are not required to release from storage to meet instream flow requirements unless specifically required in a water right permit as is the case with Aquilla and Squaw Creek Reservoirs. The BRAC datasets contain no *IF* records.

5.1.4 Results of Condensing the Brazos WAM Datasets

The validity and accuracy of the condensed dataset is confirmed by reproducing the sequences of monthly diversions and diversion shortages, reservoir storage contents, and unappropriated flows contained in the Brazos WAM simulation results associated with the 15 reservoirs and associated diversion targets and 48 control points. As discussed in the following section 5.2, simulation results from the original Brazos WAM datasets are properly reproduced by the condensed BRAC datasets.

After completing the comparison of simulation results discussed in section 5.2 that confirms that the datasets are correct, the simplified BRAC datasets are available thereafter to simulate alternative river/reservoir system operating rules and water management and use scenarios for the system of 15 reservoirs and associated diversions at the 48 control points. The primary system is modeled by the DAT file with secondary water rights reflected in the FLO file. The primary system may be modified in any manner without altering the FLO file. However, changes to the secondary water rights would require repeating the procedure for developing the condensed BRAC dataset.

The 1900-2007 monthly inflows at 48 control points on the *IN* records in the BRAC3 and BRAC8 FLO files are plotted in Appendix E. Table 5.8 shows the 1940-1997 means from Table 5.10 for three control points. Table 5.9 shows tables of inflow frequency statistics created with the WRAP program *TABLES* from the *SIM* simulation results. These tables are reproduced as Tables 5.11 through 5.16. Mean annual inflows for the 48 control points are tabulated in Table 5.10 for BRAC3 and BRAC8 1940-1997, 1940-2007, and 1900-2007 simulations along with the 1940-1997 means for the original Brazos WAM (Bwam) naturalized flows. The Bwam flows are naturalized flows. The BRAC inflows are the portion of the naturalized flows still available to the primary system water rights after the secondary water rights have appropriated their appropriate quantities of the stream flow. Naturalized flows are the same in the Bwam3 and Bwam8 datasets. Inflows are different in the BRAC3 versus BRAC8 datasets.

Table 5.8 Mean Annual Inflow Comparison for Three Control Points

USGS Gaging Station	CP ID	Bwam	BRAC3	BRAC8
Cameron gage on Little River	LRCA58	1,318,302	81.5%	83.9%
Waco gage on Brazos River	BRWA41	1,942,324	85.6%	87.5%
Richmond gage on Brazos River	BRRI70	5,850,224	77.8%	78.2%

The 1940-1997 means of the Bwam naturalized flows at the three control points are tabulated above in acre-feet/year. The corresponding 1940-1997 means of the BRAC3 and BRAC8 inflows are shown as a percentage of the Bwam naturalized flows. The BRAC8 inflows reflect smaller Bwam streamflow depletions but larger Bwam unappropriated flows than the BRAC3 inflows. At the Richmond gage, the mean BRAC3 and BRAC8 inflows are 77.8% and 78.2% of naturalized flows.

Table 5.9 Summary of Tables of Inflow Frequency Statistics

	1940-2007	1900-2007
Bwam3/Bwam8	Table 5.11	Table 5.12
BRAC3	Table 5.13	Table 5.14
BRAC8	Table 5.15	Table 5.16

Table 5.10 Mean Annual Inflow Comparison

Control Point	Naturalized Flow (ac-ft/yr)	Mean BRAC3 Inflow (acre-feet/year)			Mean BRAC8 Inflow (acre-feet/year)		
		1940-1997	1940-2007	1900-2007	1940-1997	1940-2007	1900-2007
DMAS09	108,367	44,460	41,448	49,049	74,326	68,686	79,680
BRSE11	250,096	132,042	122,291	141,209	178,075	166,901	191,777
BRSB23	656,260	325,207	300,005	316,578	436,956	411,960	445,290
BRPP27	810,380	645,899	618,482	634,690	624,593	598,655	630,120
BRDE29	1,003,749	792,955	752,366	754,205	798,957	762,134	784,013
BRGR30	1,118,978	932,062	892,724	886,411	925,180	890,746	905,653
BRAQ33	1,379,053	1,218,568	1,190,261	1,166,993	1,243,201	1,221,912	1,220,264
BRWA41	1,942,324	1,663,149	1,686,928	1,611,058	1,699,166	1,718,060	1,636,552
BRHB42	2,331,139	1,918,534	1,954,640	1,870,079	1,986,461	2,016,201	1,925,838
LEHM46	166,469	113,636	119,420	115,191	122,293	127,543	122,418
LEGT47	257,793	184,085	191,969	179,490	189,827	196,724	184,256
LEBE49	505,257	446,925	478,982	441,827	470,944	503,780	467,118
LABE52	233,258	218,704	247,266	226,513	225,028	253,675	233,181
LRLR53	846,554	710,551	777,686	779,200	725,859	793,653	801,211
GALA57	189,268	175,267	191,153	180,737	177,635	193,089	182,689
LRCA58	1,318,302	1,074,595	1,176,515	1,110,913	1,105,941	1,208,634	1,147,454
BRBR59	4,027,961	3,145,590	3,310,844	3,165,701	3,287,679	3,449,920	3,297,971
NAEA66	322,578	287,078	303,273	299,980	297,182	312,708	307,907
NABR67	421,304	361,504	371,745	367,369	381,092	390,136	383,551
BRHE68	5,358,943	3,757,219	4,005,896	3,843,813	4,172,630	4,431,278	4,248,752
BRRI70	5,850,224	4,551,922	4,801,128	4,640,343	4,576,835	4,829,480	4,666,459
BRRO72	6,112,278	5,339,820	5,608,814	5,436,508	5,521,223	5,798,844	5,628,089
515531	793,475	637,768	611,695	629,478	614,423	589,726	622,464
515631	1,093,872	915,523	875,199	871,423	906,356	871,328	887,824
515731	1,366,866	1,209,580	1,181,014	1,159,213	1,233,376	1,211,803	1,211,986
515831	73,769	69,596	79,049	74,773	70,125	80,386	76,996
509431	357,464	353,635	387,177	353,043	352,265	386,751	357,087
515931	144,846	107,035	103,695	100,307	113,572	109,565	105,029
516031	502,986	447,362	479,435	442,248	471,037	503,749	467,130
516131	230,861	217,295	243,982	224,282	223,474	250,244	230,835
516231	57,558	54,078	57,935	58,486	55,307	59,222	60,091
516331	186,622	173,350	188,883	178,833	175,398	190,528	180,403
516531	232,793	214,648	226,470	224,267	221,471	232,922	229,746
516431	222,869	214,876	233,113	235,218	220,247	238,246	240,575
516031	502,986	447,362	479,435	442,248	471,037	503,749	467,130
421331	97,210	74,124	70,032	66,820	86,166	81,529	79,944
409732	14,098	13,221	15,210	18,821	13,533	15,694	19,485
CON036	662,147	328,374	302,930	319,652	441,183	415,942	449,570
CON063	1,199,051	991,691	954,808	946,986	988,825	957,204	973,168
CON070	1,561,064	1,368,216	1,356,717	1,316,078	1,404,556	1,393,136	1,360,283
433901	1,931,926	1,665,658	1,689,099	1,612,865	1,701,747	1,720,293	1,638,257
CON096	845,754	711,975	779,245	780,747	727,315	795,244	802,803
CON108	1,317,498	1,075,127	1,177,054	1,111,452	1,106,360	1,209,058	1,147,878
CON111	3,912,185	3,141,016	3,301,748	3,153,338	3,300,309	3,458,168	3,300,920
CON130	4,431,340	3,490,079	3,698,147	3,542,856	3,826,467	4,027,983	3,860,363
CON147	5,208,345	3,781,114	4,028,176	3,867,402	4,201,584	4,457,335	4,275,463
CON234	5,840,577	4,579,370	4,830,076	4,668,324	4,604,430	4,858,597	4,694,593
BRGM73	6,105,239	5,265,884	5,529,828	5,358,612	5,467,242	5,740,995	5,570,803

Table 5.11 Frequency Analysis of 1940-2007 Bwam3 and Bwam8 Naturalized Flows (acre-feet/month)

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CONTROL          STANDARD    PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE
 POINT     MEAN DEVIATION  100%     99%     98%     95%     90%     75%     60%     50%     40%     25%      10%  MAXIMUM
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DMAS09   8638.7  19241.     0.0     0.0     0.0    15.4    98.0   408.0   1017.   1767.   2904.   7570.   23284.  175553.
BRSE11  19888.7  40692.     0.0     0.2    96.5   274.4   608.8  1760.0   3204.   5076.   8319.  17493.   50872.  414811.
421331   7627.1  22331.     0.0     0.0     0.0     0.0     0.8    18.8    432.   1008.   1846.   4738.   18768.  264176.
CON036  52532.7 112023.     0.0    87.7   155.2   712.3  1908.3  4934.5   9298.  13531.  22024.  47557.  137224. 1408762.
BRSB23  52044.4 110987.     0.0    86.9   152.7   705.0  1889.5  4889.0   9211.  13404.  21821.  47106.  135962. 1395822.
515531  63756.7 130569.     0.0     0.0     0.1   568.6  2755.3  7862.5  14038.  19434.  31477.  60972.  159486. 1794484.
BRPP27  65115.5 131291.     0.0     0.0     0.0   763.4  2807.6  8130.0  14381.  20365.  31391.  63786.  161781. 1810792.
BRDE29  80021.1 158495.     0.0     0.0   640.3  2692.2  4501.0 10357.0  17917.  26875.  41030.  81692.  208141. 2450046.
515631  87528.8 171460.     0.0   126.1   881.8  2754.5  5183.5 10883.1  19707.  29263.  45641.  92473.  229614. 2653863.
BRGR30  89628.4 175185.     0.0     0.0   729.0  2333.4  5335.4 11197.0  19899.  29923.  47105.  94546.  236741. 2710228.
409732   1359.8   2459.     0.0     0.0     0.0     0.0     0.0   146.7    385.    576.    863.   1486.    3176.   30604.
CON063  96637.8 183347.    86.7   777.5  1292.6  3294.6  6291.2 13088.8  23397.  34255.  53425. 103451.  252195. 2804884.
515731 113888.0 200287.     7.5   777.2  1970.7  3751.1  8094.7 19030.7  33162.  48393.  65813. 122066.  277133. 2962997.
BRAQ33 115091.6 201719.     0.0     0.0  1830.0  3799.4  8324.0 19278.0  33513.  49170.  67669. 123659.  280970. 2981239.
515831   6975.7  14584.     0.0     0.0     0.0     0.0     0.0    99.7    482.   1069.   2154.   6999.   21039.  187168.
CON070 129977.2 213882.     0.0  1815.5  2684.5  5117.0  9361.7 22584.8  40119.  60066.  83655. 143918.  346730. 3096309.
509431  32698.5  85476.     0.0     2.3    13.4    63.6   619.6  2662.4   5671.   9463.  14947.  33162.   80856. 1639712.
515931  11955.4  28919.     0.0     0.0     0.0     0.9    52.4   383.8   1163.   2226.   3694.  10569.   32460.  327284.
LEHM46  14222.6  29789.     0.0     0.0     7.3    74.4   224.6   865.0   2348.   3590.   5709.  13080.   37199.  269330.
LEGT47  22025.3  43352.     0.0     0.0     0.0    89.2   446.7  1451.0   3817.   5895.  10268.  21255.   56490.  383340.
516031  44943.3  78296.     0.0     0.0     0.2     7.3   802.1  4554.4   9117.  14907.  23731.  48793.  117463.  627569.
LEBE49  45166.4  78621.     0.0     0.0     0.0     0.0   800.2  4569.0   9169.  14959.  23869.  49052.  117978.  629618.
516131  21565.9  37850.    27.8   137.0   150.9   523.1   846.9  2504.7   4762.   7160.  10853.  24145.   60046.  309090.
LABE52  21939.0  38189.     0.0     0.0   140.0   510.0   823.8  2490.0   4833.   7533.  11070.  24775.   60886.  310885.
CON096  76664.2 126984.    30.0   301.9   604.8  1922.7  3701.2 10054.5  18744.  28467.  43054.  86716.  204999.  950215.
LRLR53  76733.1 127022.    30.0   301.8   604.5  1923.2  3749.8 10072.0  18766.  28506.  43231.  86704.  205310.  950933.
516231   5111.1   9015.     0.0     0.0     0.0    39.7   116.1   436.2   1016.   1418.   2392.   5901.   14849.   74909.
516331  16827.5  26548.     0.0     1.8     8.3   227.0   535.8  1921.2   3899.   5737.   8919.  21197.   48208.  210085.
GALA57  17076.1  26910.     0.0     0.0     1.3   231.0   541.2  1946.0   3966.   5845.   9069.  21498.   48945.  212283.
CON108 119008.5 180423.     0.1   659.7  1320.9  3072.9  6504.3 17904.1  32113.  49411.  74413. 142871.  315478. 1402268.
LRCA58 119080.4 180519.     0.0   660.1  1321.8  3067.0  6508.2 17905.0  32137.  49457.  74405. 143003.  315687. 1403136.
433901 163479.0 267106.   200.9  2268.1  3844.9  7262.7 11600.5 28518.7  52015.  71785. 102600. 182272.  416331. 3370212.
BRWA41 164158.3 266706.     0.0  1784.1  3963.0  6925.2 11561.4 28105.0  52398.  72277. 103161. 183794.  418373. 3376485.
BRHB42 197450.5 301679.  1251.0  3762.4  6853.4  9600.6 16185.2 36387.0  63924.  92690. 129238. 232892.  489825. 3599269.
CON111 339663.1 485237.   499.4  7419.8 11718.6 17898.6 29289.3 64077.9 112144. 160906. 238121. 433617.  838762. 4659786.
BRBR59 349928.7 496087.     0.0  7171.2 12242.7 19632.6 29968.6 67176.7 116114. 166979. 242256. 444505.  846307. 4704312.
516431  20173.4  35669.     0.0     0.0     0.0     1.7    82.6  1070.1   3240.   5460.   8300.  20488.   63443.  250982.
516531  20311.8  34957.     0.0     0.0     3.6    52.3   131.7   841.8   2306.   4296.   8295.  22329.   64525.  240424.
NAEA66  28204.6  48110.     0.0     0.0     0.0     0.0   154.2  1188.5   3502.   6471.  11678.  30642.   90733.  332958.
NABR67  35786.0  57030.     0.0     0.0     0.0   119.8   352.4  2178.0   5590.   9361.  17303.  42839.  116126.  384272.
CON130 386687.5 527842.   876.8  8981.0 13246.1 23708.8 35594.0 76544.7 133030. 188137. 266314. 480081.  991065. 4931350.
CON147 455240.0 595796.  1424.1 13458.1 17286.4 30280.3 44812.2 92772.8 159987. 232849. 311701. 579669. 1185598. 5562412.
BRHE68 469243.6 605833.  1634.0 14606.9 18902.8 33083.4 46601.8 97408.0 167049. 241867. 320295. 603980. 1247625. 5723482.
292531   3833.6   5328.     0.0     0.0     0.0     0.0     0.0   620.3   1361.   1987.   2890.   5158.    9723.   59403.
CON234 508765.2 631899.   185.0 21564.0 27555.7 43536.4 56287.6115854.1 192580. 274735. 373212. 665466. 1314572. 6125002.
BRRI70 509421.5 630905.     0.0 22128.5 28095.2 44498.2 57081.2117514.0 193899. 275325. 375995. 665039. 1313844. 6135975.
BRRO72 533586.6 652544.     0.0 22803.2 27751.5 46727.6 62696.0130248.0 212511. 286867. 397569. 688980. 1360593. 6356870.
BRGM73 532967.2 647922.     4.0 22782.6 27291.8 46441.2 63546.0132173.0 213375. 286855. 397043. 689498. 1344876. 6254466.
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The mean and standard deviation of the monthly naturalized flows in acre-feet/month at the 48 control points are tabulated in the second and third columns of the tables. The naturalized flow volumes (acre-feet/month) that are equaled or exceeded in specified percentages of the 816 months of 1940-2007 (Table 5.9) or 1,296 months of 1900-2007 (Table 5.10) are also tabulated. For example, the flow at control point BRRI70 (Richmond gage), is equal to or greater than 57,081 acre-feet during 90 percent of the months of 1940-2007.

Table 5.12 Frequency Analysis of 1900-2007 Bwam3 and Bwam8 Naturalized Flows (acre-feet/month)

CONTROL		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
DMAS09	9255.8	19335.	0.0	0.0	0.0	8.0	108.2	464.8	1162.	1970.	3473.	8511.	25930.	196469.
BRSE11	21332.4	42338.	0.0	0.0	0.0	180.7	474.1	1678.0	3238.	5383.	9029.	20152.	61576.	453509.
421331	7581.6	20874.	0.0	0.0	0.0	0.0	0.0	9.0	442.	1073.	2012.	5152.	20605.	264176.
CON036	56406.1	114722.	0.0	0.0	0.0	383.8	1371.0	4627.9	9298.	14233.	23908.	54846.	156395.	1408762.
BRSB23	55885.6	113667.	0.0	0.0	0.0	380.6	1359.0	4587.0	9211.	14092.	23692.	54349.	154951.	1395822.
515531	67352.2	131307.	0.0	0.0	0.1	198.6	1526.2	6662.0	13374.	19480.	32705.	67263.	190079.	1794484.
BRPP27	68788.7	132822.	0.0	0.0	0.0	191.0	1558.8	6714.0	13737.	20111.	33088.	69049.	196500.	1810792.
BRDE29	83078.8	152978.	0.0	0.0	416.0	1444.2	3142.2	9601.0	18241.	27314.	42907.	89330.	218696.	2450046.
515631	90104.7	163483.	0.0	39.5	621.8	1705.6	3653.1	10266.1	20267.	30441.	47942.	99877.	235096.	2653863.
BRGR30	92050.9	166509.	0.0	0.0	403.3	1677.6	3731.4	10484.0	20268.	31280.	49647.	101401.	239023.	2710228.
409732	1689.0	3243.	0.0	0.0	0.0	0.0	0.0	153.6	426.	663.	984.	1775.	4155.	50627.
CON063	99527.7	175573.	0.0	671.5	1124.8	2260.0	4810.6	12741.6	23758.	36707.	55877.	115126.	256948.	2804884.
515731	121222.7	199896.	0.0	1286.0	2151.2	3751.1	7522.7	18856.7	35013.	52745.	74263.	140961.	313472.	2962997.
BRAQ33	122642.4	201902.	0.0	1283.8	2097.8	3850.8	7703.2	19021.0	35664.	53399.	75411.	141059.	317574.	2981239.
515831	6866.5	15401.	0.0	0.0	0.0	0.0	0.0	113.3	516.	1059.	2120.	6249.	19701.	187168.
CON070	130795.6	206744.	0.0	761.0	1716.1	3929.5	7064.9	20598.3	39142.	59498.	84157.	150653.	329390.	3096309.
509431	30982.7	75810.	0.0	6.7	28.4	395.4	1138.6	2772.9	5631.	8788.	14018.	30824.	82506.	1639712.
515931	11607.1	29289.	0.0	0.0	0.0	0.1	57.4	456.1	1244.	2392.	3806.	9650.	28030.	364784.
LEHM46	13674.1	28419.	0.0	0.0	14.4	87.6	256.6	968.3	2495.	3768.	6082.	12696.	35299.	269330.
LEGT47	21176.3	42195.	0.0	0.0	0.0	125.3	466.3	1618.0	4046.	6174.	10154.	20732.	54451.	383340.
516031	42614.1	75881.	0.0	0.0	0.3	19.6	850.0	4126.8	9006.	14207.	22394.	47127.	115439.	715440.
LEBE49	42818.8	76200.	0.0	0.0	0.0	8.0	855.6	4149.0	9052.	14267.	22532.	47388.	116204.	718653.
516131	20025.1	35088.	0.0	83.0	141.8	504.7	803.1	2447.8	4645.	7005.	10696.	22442.	52410.	309090.
LABE52	20326.9	35420.	0.0	0.0	112.0	471.6	807.0	2463.0	4691.	7084.	10864.	22681.	53407.	310885.
CON096	78461.1	132488.	0.0	305.7	618.0	1989.2	3849.0	10098.5	19931.	28967.	45779.	88772.	203232.	1232362.
LRLR53	78656.8	132929.	0.0	305.8	617.7	2003.8	3877.8	10084.0	20095.	28926.	45788.	88886.	203518.	1237000.
516231	5244.0	8904.	0.0	0.0	0.0	14.7	117.9	479.0	1088.	1668.	2698.	6259.	14894.	74909.
516331	16209.3	25929.	0.0	0.0	0.0	133.5	489.8	1824.7	3820.	5600.	9016.	19728.	46321.	210085.
GALA57	16437.4	26278.	0.0	0.0	0.0	135.4	496.8	1858.0	3882.	5664.	9192.	19991.	47087.	212283.
CON108	115922.2	184952.	0.0	512.2	1259.3	2934.0	6265.3	16213.4	30324.	46165.	69471.	134457.	298298.	1670985.
LRCA58	115982.6	185046.	0.0	511.5	1260.8	2934.8	6268.0	16227.0	30332.	46184.	69514.	134505.	298422.	1672000.
433901	161154.5	253994.	200.9	1627.2	2475.8	5218.4	9653.9	25211.9	49999.	72162.	102600.	187963.	406610.	3370212.
BRWA41	160898.0	253348.	0.0	1136.0	2256.6	5042.4	9331.6	25200.0	49706.	71206.	102563.	187713.	406658.	3376485.
BRHB42	193718.1	289993.	927.5	2955.6	4493.7	8477.2	13990.4	33140.9	62898.	92565.	128826.	233093.	475728.	3599269.
CON111	331738.2	479817.	311.5	6191.5	9722.8	17063.5	25890.5	61444.5	111343.	156128.	232562.	407631.	802176.	4659786.
BRBR59	341482.3	494246.	0.0	6932.6	11161.7	17747.0	27683.4	64259.0	116195.	162593.	239988.	415787.	820463.	4704312.
516431	20522.6	39287.	0.0	0.0	0.0	0.0	2.0	777.2	2730.	4922.	8089.	20021.	63443.	360128.
516531	20245.3	36798.	0.0	0.0	0.0	28.7	111.6	723.8	2336.	4388.	8525.	21556.	62675.	298569.
NAEA66	28090.7	50794.	0.0	0.0	0.0	11.6	141.0	1024.0	3485.	6366.	11996.	29608.	87042.	413723.
NABR67	36025.8	62952.	0.0	0.0	0.0	55.5	244.1	1862.0	5058.	8907.	16543.	40035.	108614.	540322.
CON130	378020.6	531480.	0.0	8884.6	13123.1	21218.7	32759.0	73776.6	133030.	183411.	265307.	462088.	946012.	4969734.
CON147	445171.7	606750.	0.0	13386.8	16245.1	27044.2	41973.4	89460.8	158928.	225676.	306386.	558092.	1138511.	5900311.
BRHE68	458412.1	619496.	0.0	14555.2	17788.1	29512.4	43971.0	95023.0	167539.	235452.	313516.	577625.	1153505.	6113000.
292531	3762.5	6907.	0.0	0.0	0.0	0.0	0.0	499.3	1159.	1688.	2506.	4775.	9646.	148840.
CON234	495780.4	653584.	0.0	19853.9	24924.9	38273.7	52782.6	111618.6	189102.	265929.	359086.	627990.	1195949.	7237370.
BRRI70	496172.0	653262.	0.0	19640.7	25510.6	38637.8	52998.8	113055.0	189402.	267037.	362043.	630317.	1194136.	7354000.
BRRO72	519246.1	678527.	0.0	20520.3	26640.9	40611.6	57984.2	123258.0	204316.	280424.	383575.	658555.	1245282.	7683460.
BRGM73	518636.2	675392.	0.0	20495.3	26427.6	41180.6	58122.0	123118.0	203218.	280532.	383903.	657765.	1242238.	7674240.

Table 5.13 Frequency Analysis of 1940-2007 BRAC3 Inflows (acre-feet/month)

CONTROL		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
DMAS09	3454.0	13005.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	7296.	158444.
BRSE11	10190.9	34306.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	248.	26596.	408040.
421331	5836.0	21353.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1202.	16523.	254365.
CON036	25244.8	91412.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	3574.	67182.	1381721.
BRSB23	25001.1	90538.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	3538.	66540.	1369052.
515531	50975.2	109563.	0.0	0.0	0.0	220.4	2078.1	7071.4	13086.	18182.	26687.	46107.	124379.	1763180.
BRPP27	51540.8	110704.	0.0	0.0	0.0	0.0	1764.7	6767.2	12878.	17857.	26505.	48484.	130020.	1779641.
BRDE29	62697.7	141036.	0.0	0.0	0.0	0.0	1729.7	6802.6	13354.	20217.	29737.	57025.	177967.	2414256.
515631	72933.8	153525.	0.0	0.0	0.0	571.6	3216.0	9249.8	16285.	25873.	39238.	72099.	195115.	2617464.
BRGR30	74394.2	156648.	0.0	0.0	0.0	568.1	3226.2	9202.3	16363.	25951.	39888.	72569.	199819.	2673790.
409732	1267.5	2488.	0.0	0.0	0.0	0.0	0.0	0.0	179.	445.	750.	1370.	3176.	30604.
CON063	79568.0	164409.	0.0	0.0	0.0	655.1	3408.8	9848.2	17566.	27585.	41805.	78583.	212533.	2768396.
515731	98418.4	190217.	0.0	0.0	0.0	875.6	3768.5	12190.5	22728.	36935.	53105.	98094.	260895.	2921541.
BRAQ33	99189.0	191443.	0.0	0.0	0.0	875.6	3768.5	12190.5	22871.	37148.	53873.	98546.	261165.	2939689.
515831	6587.4	14410.	0.0	0.0	0.0	0.0	0.0	0.0	255.	810.	1840.	6570.	20388.	187126.
CON070	113060.3	208932.	0.0	0.0	0.0	840.8	4029.9	12658.2	25248.	42485.	63716.	118763.	307892.	3054515.
509431	32265.8	83703.	0.0	0.0	0.0	0.0	378.7	2113.6	4571.	6682.	11497.	30476.	87095.	1504543.
515931	9057.6	26530.	0.0	0.0	0.0	0.0	0.0	0.0	359.	1022.	2072.	5231.	20615.	278004.
LEHM46	10136.1	27601.	0.0	0.0	0.0	0.0	0.0	0.0	280.	824.	1907.	6338.	25666.	261235.
LEGT47	16282.7	41705.	0.0	0.0	0.0	0.0	0.0	0.0	289.	840.	2122.	11622.	48163.	374981.
516031	40271.0	77247.	0.0	0.0	0.0	0.0	0.0	1079.3	4938.	9309.	17748.	42809.	113051.	618545.
LEBE49	40232.9	77179.	0.0	0.0	0.0	0.0	0.0	1078.2	4933.	9300.	17730.	42766.	112938.	617926.
516131	20332.2	37679.	0.0	0.0	0.0	0.0	0.0	1208.6	3793.	6311.	9173.	20883.	59399.	308044.
LABE52	20605.8	38223.	0.0	0.0	0.0	0.0	0.0	1207.4	3789.	6305.	9164.	21926.	60102.	309463.
CON096	65254.2	122896.	0.0	0.0	0.0	0.0	0.0	2435.1	9909.	17592.	28541.	71328.	186266.	912758.
LRLR53	65123.7	122650.	0.0	0.0	0.0	0.0	0.0	2430.3	9889.	17557.	28484.	71185.	185894.	910932.
516231	4828.3	9025.	0.0	0.0	0.0	0.0	0.0	42.7	786.	1176.	1863.	5509.	14623.	74899.
516331	15740.8	26812.	0.0	0.0	0.0	0.0	0.0	405.3	2814.	4545.	7349.	19703.	48066.	209947.
GALA57	15930.0	27174.	0.0	0.0	0.0	0.0	0.0	402.9	2797.	4547.	7486.	19879.	48668.	212137.
CON108	98399.0	174345.	0.0	0.0	0.0	0.0	0.0	5141.1	15108.	26072.	45528.	117088.	288959.	1393346.
LRCA58	98354.0	174318.	0.0	0.0	0.0	0.0	0.0	5130.8	15085.	26020.	45452.	117051.	288813.	1393344.
433901	140759.8	256133.	0.0	0.0	166.9	2853.6	6421.7	16173.0	32999.	50937.	76137.	148478.	365172.	3310588.
BRWA41	140578.9	255980.	0.0	0.0	166.6	2847.9	6408.8	16140.0	32933.	50835.	75985.	148181.	364663.	3303970.
BRHB42	162888.7	286864.	0.0	0.0	164.9	2819.4	6577.8	16297.8	35864.	56516.	86806.	191437.	427072.	3503276.
CON111	275450.0	462153.	0.0	0.0	338.6	3194.0	8620.4	25341.7	56397.	94523.	139907.	318368.	742728.	4585996.
BRBR59	276205.0	464295.	0.0	0.0	335.2	3162.1	8534.2	25088.3	55833.	93577.	138510.	323908.	755014.	4572952.
516431	19426.1	35147.	0.0	0.0	0.0	0.0	0.9	854.0	3001.	5041.	7925.	19051.	62133.	248962.
516531	18872.5	33938.	0.0	0.0	0.0	0.0	0.0	379.9	1538.	3461.	6916.	20079.	62754.	239515.
NAEA66	25272.8	45250.	0.0	0.0	0.0	0.0	0.0	437.7	1847.	4199.	8445.	26057.	86955.	309336.
NABR67	30978.8	53138.	0.0	0.0	0.0	0.0	0.0	501.3	2415.	5581.	11231.	35233.	105096.	373377.
CON130	308473.3	500133.	0.0	0.0	535.4	4077.3	9357.3	31025.0	65841.	103266.	154552.	377729.	895887.	4854951.
CON147	335974.6	544131.	0.0	13.5	533.2	4276.4	9555.5	32692.0	68979.	106256.	170234.	411150.	965516.	5390970.
BRHE68	334115.3	541884.	0.0	13.4	528.4	4237.9	9469.8	32397.0	68358.	105300.	168703.	407450.	970358.	5342528.
292531	3664.6	5426.	0.0	0.0	0.0	0.0	0.0	0.0	959.	1915.	2874.	5158.	9723.	59403.
CON234	402792.2	592300.	0.0	13.1	674.0	4253.7	11048.9	42967.0	95337.	157132.	251514.	544564.	1144791.	5731446.
BRRI70	400378.0	588751.	0.0	13.1	669.8	4228.6	10982.2	42709.0	94765.	156190.	250005.	541300.	1137931.	5697100.
BRRO72	467696.1	644595.	0.0	12.9	663.2	4207.6	11733.6	63921.0	133043.	218196.	329273.	630852.	1278923.	6171675.
BRGM73	461110.3	635249.	0.0	12.8	654.2	4139.8	11537.9	62843.0	130796.	214513.	323733.	624086.	1257840.	6067532.

Table 5.14 Frequency Analysis of 1900-2007 BRAC3 Inflows (acre-feet/month)

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
			100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
DMAS09	4087.4	13428.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	369.	10919.	159572.
BRSE11	11767.4	36233.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	2044.	37132.	431046.
421331	5568.3	19870.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	1249.	15532.	254365.
CON036	26638.1	88617.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	5635.	74696.	1381721.
BRSB23	26381.9	87772.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	5578.	73964.	1369052.
515531	52456.9	105356.	0.0	0.0	0.0	139.3	1069.4	5989.2	12490.	18028.	27427.	52796.	132556.	1763180.
BRPP27	52891.2	106345.	0.0	0.0	0.0	0.0	778.1	5652.2	12310.	17784.	27103.	54082.	133395.	1779641.
BRDE29	62850.8	129577.	0.0	0.0	0.0	0.0	762.6	5765.7	13041.	20283.	31110.	64255.	171647.	2414256.
515631	72619.0	140363.	0.0	0.0	0.0	89.8	1915.1	8246.3	16110.	25960.	39783.	79322.	190388.	2617464.
BRGR30	73868.0	142961.	0.0	0.0	0.0	89.3	1903.7	8328.4	16151.	26412.	40433.	81484.	195346.	2673790.
409732	1568.4	3276.	0.0	0.0	0.0	0.0	0.0	0.0	143.	453.	828.	1692.	4093.	50627.
CON063	78915.9	150544.	0.0	0.0	0.0	142.9	2009.4	8904.4	17566.	28732.	42981.	89302.	204308.	2768396.
515731	96601.4	175472.	0.0	0.0	0.0	140.0	2184.9	11004.2	22864.	37044.	54437.	103094.	255068.	2921541.
BRAQ33	97249.7	176566.	0.0	0.0	0.0	140.0	2184.9	11004.2	23035.	37302.	54587.	104674.	255068.	2939689.
515831	6231.1	14882.	0.0	0.0	0.0	0.0	0.0	0.0	232.	738.	1617.	5354.	17910.	187126.
CON070	109673.5	196054.	0.0	0.0	0.0	129.6	2212.1	11634.6	25158.	41065.	62377.	119207.	286189.	3054515.
509431	29420.9	74388.	0.0	0.0	0.0	24.2	594.0	2023.8	3947.	6149.	9867.	28312.	79409.	1504543.
515931	8621.1	26713.	0.0	0.0	0.0	0.0	0.0	0.0	416.	1109.	2171.	5100.	18228.	356617.
LEHM46	9715.4	26568.	0.0	0.0	0.0	0.0	0.0	0.0	306.	860.	1912.	6914.	25617.	261235.
LEGT47	15137.2	40442.	0.0	0.0	0.0	0.0	0.0	0.0	305.	871.	2021.	10513.	44202.	374981.
516031	37054.3	72864.	0.0	0.0	0.0	0.0	0.0	993.4	4506.	9029.	16435.	37604.	106827.	624850.
LEBE49	37019.0	72798.	0.0	0.0	0.0	0.0	0.0	992.4	4502.	9020.	16419.	37567.	106720.	624308.
516131	18690.4	34902.	0.0	0.0	0.0	0.0	0.0	1137.0	3647.	5906.	9173.	19839.	51732.	308044.
LABE52	18876.3	35339.	0.0	0.0	0.0	0.0	0.0	1135.9	3643.	5946.	9164.	19840.	52087.	309463.
CON096	65262.0	125750.	0.0	0.0	0.0	0.0	0.0	2369.2	9909.	17340.	28373.	70138.	180693.	1207736.
LRLR53	65132.6	125501.	0.0	0.0	0.0	0.0	0.0	2364.5	9889.	17305.	28316.	69998.	180332.	1205321.
516231	4874.1	8898.	0.0	0.0	0.0	0.0	0.0	0.1	859.	1274.	2112.	5758.	14580.	74899.
516331	14903.1	25914.	0.0	0.0	0.0	0.0	0.0	219.1	2645.	4487.	7167.	17522.	44754.	209947.
GALA57	15061.8	26241.	0.0	0.0	0.0	0.0	0.0	217.8	2629.	4514.	7195.	17750.	45166.	212137.
CON108	92816.9	172137.	0.0	0.0	0.0	0.0	0.0	4083.8	13869.	24338.	40122.	101897.	263532.	1602019.
LRCA58	92771.9	172110.	0.0	0.0	0.0	0.0	0.0	4075.6	13850.	24289.	40054.	101859.	263391.	1601961.
433901	134406.4	237921.	0.0	0.0	357.2	1705.7	4691.2	14715.1	32239.	49546.	74288.	144517.	349855.	3310588.
BRWA41	134255.8	237842.	0.0	0.0	356.5	1701.9	4682.1	14685.7	32175.	49447.	74140.	144228.	349156.	3303970.
BRHB42	155841.2	271733.	0.0	0.0	353.0	1684.9	4667.6	15342.0	35382.	55209.	86697.	175362.	411311.	3503276.
CON111	262969.8	454423.	0.0	0.0	483.3	1963.1	6347.4	24858.0	53448.	86558.	134811.	300862.	685487.	4585996.
BRBR59	263998.1	459522.	0.0	0.0	478.4	1943.4	6283.6	24610.0	52914.	85693.	133466.	304014.	688445.	4572952.
516431	19601.5	38044.	0.0	0.0	0.0	0.0	0.0	564.6	2437.	4557.	7567.	18132.	61603.	354347.
516531	18688.9	35855.	0.0	0.0	0.0	0.0	0.0	301.1	1469.	3298.	6736.	19614.	58833.	296656.
NAEA66	24998.4	48157.	0.0	0.0	0.0	0.0	0.0	337.9	1739.	4013.	8219.	25474.	82086.	411558.
NABR67	30614.1	58151.	0.0	0.0	0.0	0.0	0.0	383.2	2078.	4813.	9756.	32120.	95746.	525438.
CON130	295423.4	501292.	0.0	0.0	654.9	2163.4	7348.4	28512.0	60610.	98701.	149142.	355587.	816933.	4856550.
CON147	322468.1	549224.	0.0	0.0	652.2	2296.7	7667.7	30031.0	66415.	102494.	158676.	379486.	903766.	5390970.
BRHE68	320500.8	546454.	0.0	0.0	646.4	2276.0	7598.7	29761.0	65817.	101572.	157249.	376071.	895644.	5342528.
292531	3597.9	6981.	0.0	0.0	0.0	0.0	0.0	0.0	568.	1614.	2501.	4775.	9646.	148840.
CON234	389207.0	611251.	0.0	0.0	651.8	2418.9	8487.1	39997.5	91710.	152067.	242423.	496668.	1049179.	6959821.
BRRI70	386874.2	607588.	0.0	0.0	647.8	2404.1	8436.1	39757.5	91159.	151155.	240969.	493690.	1042892.	6918116.
BRRO72	453228.1	669541.	0.0	0.0	641.3	2614.6	9147.6	57655.8	126281.	200055.	306419.	579087.	1175748.	7531104.
BRGM73	446734.4	661024.	0.0	0.0	632.6	2572.5	8999.5	56690.1	124149.	196678.	301296.	574498.	1160847.	7491199.

Table 5.15 Frequency Analysis of 1940-2007 BRAC8 Inflows (acre-feet/month)

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CONTROL           STANDARD     PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE
 POINT        MEAN DEVIATION    100%      99%      98%      95%      90%      75%      60%      50%      40%      25%      10%  MAXIMUM
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DMAS09      5723.9   16624.      0.0      0.0      0.0      0.0      0.0      0.0       0.       0.     154.    2820.   15058.  170160.
BRSE11     13908.4   35542.      0.0      0.0      0.0      0.0      0.0      0.0       0.       0.    2161.    9891.   42186.  414568.
421331      6794.1   21654.      0.0      0.0      0.0      0.0      0.0      0.0       0.      42.     802.    3824.   17263.  254612.
CON036     34661.8   96793.      0.0      0.0      0.0      0.0      0.0      0.0       0.     693.    5326.   27437.   98782. 1399552.
BRSB23     34330.0   95869.      0.0      0.0      0.0      0.0      0.0      0.0       0.     686.    5273.   27163.   97846. 1386704.
515531     49143.9  112266.      0.0    229.1    334.5    677.4   2527.0   6221.5   10601.   15080.   20465.   41170.  131932. 1781832.
BRPP27     49887.9  113708.      0.0      0.0      0.0    340.4   2169.6   5858.6   10314.   14998.   20528.   43935.  134723. 1798194.
BRDE29     63511.2  145542.      0.0      0.0      0.0    376.4   2273.9   6423.2   12397.   16695.   25818.   57017.  171792. 2435600.
515631     72613.3  156846.      0.0      0.0    154.5   1741.5   4216.1   9203.6   15498.   23240.   34007.   67018.  192033. 2639156.
BRGR30     74231.5  160070.      0.0      0.0    153.6   1731.0   4189.4   9330.5   15640.   23439.   34619.   68743.  202610. 2695414.
409732      1307.8    2478.      0.0      0.0      0.0      0.0      0.0      0.0     291.     497.     812.    1418.    3176.   30604.
CON063     79769.7  168048.      0.0      0.0    178.1   1741.5   4470.6  10486.5   16951.   24984.   37957.   76009.  216697. 2789586.
515731    100986.3  194008.      0.0      0.0    287.8   2166.3   5883.0  13149.8   22271.   33332.   52477.   99777.  272562. 2942644.
BRAQ33    101828.7  195300.      0.0      0.0    287.8   2166.3   5883.0  13192.2   22300.   33548.   52825.  100455.  278973. 2960819.
515831      6698.9   14576.      0.0      0.0      0.0      0.0      0.0      0.0     321.     818.    1833.    6559.   20695.  187135.
CON070    116097.4  212439.      0.0      0.0    267.6   2349.8   5989.2  14063.0   25120.   39613.   64704.  125054.  324412. 3075976.
509431     32229.3   84588.      0.0      0.0      0.0     80.1    546.7   2389.4    4497.    7027.   13456.   33379.   81911. 1581689.
515931      9555.6   27422.      0.0      0.0      0.0      0.0      0.0     73.3     706.    1323.    2356.    5383.   22548.  320171.
LEHM46     10822.3   28343.      0.0      0.0      0.0      0.0      0.0     63.7     559.    1132.    2240.    6903.   27929.  266621.
LEGT47     16693.3   41662.      0.0      0.0      0.0      0.0      0.0     63.0     568.    1241.    2649.   12214.   47372.  375084.
516031     42302.0   77578.      0.0      0.0      0.0      0.0      0.0   2602.7    7246.   12333.   20408.   44321.  115210.  624695.
LEBE49     42304.2   77666.      0.0      0.0      0.0      0.0      0.0   2600.1    7239.   12321.   20388.   44276.  115095.  625804.
516131     20853.7   37643.      0.0      0.0      0.0      0.0    130.2   2030.3    4415.    6575.    9765.   22441.   59708.  308679.
LABE52     21140.0   38196.      0.0      0.0      0.0      0.0    130.0   2028.3    4411.    6568.    9755.   22419.   60416.  310105.
CON096     66591.5  123314.      0.0      0.0      0.0      0.0      0.0   3498.9   11862.   19284.   31388.   73539.  187495.  915725.
LRLR53     66458.3  123068.      0.0      0.0      0.0      0.0      0.0   3491.9   11838.   19245.   31326.   73392.  187120.  913893.
516231      4935.1    9026.      0.0      0.0      0.0      0.0      0.0    316.0     910.    1222.    2001.    5504.   14624.   74909.
516331     15877.3   26866.      0.0      0.0      0.0      0.0      0.0   1212.2    2429.    3906.    7546.   19834.   48208.  210097.
GALA57     16090.7   27236.      0.0      0.0      0.0      0.0      0.0   1205.7    2441.    3933.    7645.   20039.   48880.  212298.
CON108    101068.7  174991.      0.0      0.0      0.0      0.0      0.0   5701.2   17435.   28580.   50644.  121436.  295730. 1394836.
LRCA58    101033.3  174973.      0.0      0.0      0.0      0.0      0.0   5697.7   17414.   28546.   50609.  121418.  295537. 1394844.
433901    143360.5  260527.      0.0    418.8   1150.9   4478.6   8230.0  16450.3   30218.   46697.   76973.  150155.  374318. 3332584.
BRWA41    143174.4  260358.      0.0    417.9   1148.6   4469.6   8213.5  16417.4   30158.   46604.   76819.  151156.  373790. 3325921.
BRHB42    168019.4  294159.      0.0      0.0      0.0   2409.7   6248.7  15101.6   29995.   57926.   93780.  197207.  439492. 3538790.
CON111    288494.7  471058.      0.0      0.0      0.0   1027.9   6413.9  26163.3   56611.   93340.  172711.  362432.  758667. 4579194.
BRBR59    287804.2  470812.      0.0      0.0      0.0   1017.6   6349.8  25901.7   56046.   92407.  170990.  361587.  771239. 4533595.
516431     19856.5   35420.      0.0      0.0      0.0      0.1     43.7   1057.6    3167.    5283.    8015.   20120.   62672.  249646.
516531     19410.2   34231.      0.0      0.0      0.0      0.0     23.6    513.8    1730.    3816.    7335.   21060.   63415.  239896.
NAEA66     26061.6   45606.      0.0      0.0      0.0      0.0     23.5    664.5    2372.    4737.    9068.   27919.   87591.  309796.
NABR67     32517.5   54234.      0.0      0.0      0.0      0.0     59.3    826.9    3149.    6343.   11927.   37675.  108276.  381282.
CON130    335973.2  517531.      0.0      0.0      0.0   1519.3   8074.2  31470.0   69170.  120664.  204261.  428522.  940725. 4900865.
CON147    371751.2  567575.      0.0      0.0      0.0   1788.6   8497.5  35135.7   75013.  130701.  222695.  504307. 1094823. 5452128.
BRHE68    369577.2  565317.      0.0      0.0      0.0   1495.4   8139.2  34567.0   74042.  129288.  220452.  499543. 1096556. 5402860.
292531      3572.3    5461.      0.0      0.0      0.0      0.0      0.0      0.0     611.    1665.    2771.    5147.    9723.   59403.
CON234    405181.7  599581.      0.0      0.0      0.0   2120.1   8556.9  39206.6   92048.  157650.  255166.  555800. 1161514. 5791300.
BRRI70    402753.4  595988.      0.0      0.0      0.0   2107.3   8505.7  38971.4   91497.  156705.  253637.  552470. 1154554. 5756598.
BRRO72    483539.1  649383.      0.0      0.0      0.0   4839.0  17796.0  80590.5  156368.  233103.  349981.  647024. 1313377. 6247460.
BRGM73    478715.3  641370.      0.0      0.0      0.0   5168.6  17816.4  80098.4  153880.  232470.  344768.  646667. 1292227. 6143430.
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Table 5.16 Frequency Analysis of 1900-2007 BRAC8 Inflows (acre-feet/month)

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CONTROL           STANDARD     PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE
 POINT      MEAN DEVIATION   100%     99%     98%     95%     90%     75%     60%     50%     40%     25%      10%  MAXIMUM
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DMAS09    6640.0    17560.    0.0     0.0     0.0     0.0     0.0     0.0      0.      0.    524.   4684.   19230.  195071.
BRSE11   15981.4    39022.    0.0     0.0     0.0     0.0     0.0     0.0      0.      0.   2576.  12858.   46728.  452211.
421331    6662.0    20149.    0.0     0.0     0.0     0.0     0.0     0.0      0.     70.    936.   3991.   17880.  254612.
CON036   37464.1    96599.    0.0     0.0     0.0     0.0     0.0     0.0      0.    862.   6520.  30125.  109698. 1399552.
BRSB23   37107.5    95684.    0.0     0.0     0.0     0.0     0.0     0.0      0.    853.   6457.  29843.  108657. 1386704.
515531   51872.0   110138.    0.0   177.6   267.1   493.5  1564.4  5617.6  10316.  14870.  21146.  45704.  143929. 1781832.
BRPP27   52510.0   111595.    0.0     0.0     0.0   176.0  1278.2  5293.8  10071.  14756.  21123.  48151.  148407. 1798194.
BRDE29   65334.4   137180.    0.0     0.0     0.0   197.6  1316.8  5886.0  12201.  17677.  26808.  64948.  184215. 2435600.
515631   73987.1   146952.    0.0     0.0     0.0   936.4  2691.3  8597.6  15516.  23767.  35906.  76054.  203814. 2639156.
BRGR30   75472.8   149727.    0.0     0.0     0.0   930.8  2675.1  8556.8  15640.  23922.  36579.  78375.  205983. 2695414.
409732    1623.7     3262.    0.0     0.0     0.0     0.0     0.0     0.0    308.    554.    915.   1747.    4140.   50627.
CON063   81099.0   158066.    0.0     0.0     0.0   957.9  2826.4  9374.7  17096.  26139.  38538.  84421.  219044. 2789586.
515731  101000.5   185040.    0.0     0.0     0.0  1296.1  4155.3 12119.8  22283.  34785.  54527. 108049.  271291. 2942644.
BRAQ33  101690.3   186128.    0.0     0.0     0.0  1296.1  4155.3 12119.8  22348.  35678.  54845. 108736.  275675. 2960819.
515831    6416.4    15157.    0.0     0.0     0.0     0.0     0.0     0.0    338.    794.   1644.   5434.   18963.  187135.
CON070  113358.6   201512.    0.0     0.0     0.0  1267.7  4281.7 12588.5  24284.  39613.  60905. 125600.  303994. 3075976.
509431   29757.3    74950.    0.0     0.0    32.2   125.5   888.5  2264.6   3991.   6558.  11738.  30036.   79260. 1581689.
515931    9020.1    27322.    0.0     0.0     0.0     0.0     0.0    71.3    731.   1385.   2350.   5354.   19340.  356254.
LEHM46   10323.5    27115.    0.0     0.0     0.0     0.0     0.0    58.5    547.   1075.   2240.   7332.   27083.  266621.
LEGT47   15543.4    40321.    0.0     0.0     0.0     0.0     0.0    57.8    557.   1129.   2512.  11577.   44281.  375084.
516031   39130.8    73378.    0.0     0.0     0.0     0.0     0.0  2060.7   7150.  11419.  18673.  40591.  112176.  625377.
LEBE49   39129.6    73450.    0.0     0.0     0.0     0.0     0.0  2058.6   7143.  11408.  18655.  40551.  112063.  627166.
516131   19236.2    34909.    0.0     0.0     0.0     0.0     0.0  1837.9   4267.   6470.   9806.  20680.   52027.  308679.
LABE52   19432.0    35356.    0.0     0.0     0.0     0.0     0.0  1836.1   4263.   6463.   9796.  21198.   52322.  310105.
CON096   67102.5   126434.    0.0     0.0     0.0     0.0     0.0  3235.5  12068.  19284.  31730.  72196.  185214. 1209164.
LRLR53   66969.4   126184.    0.0     0.0     0.0     0.0     0.0  3229.1  12044.  19245.  31667.  72052.  184844. 1206746.
516231    5007.6     8883.    0.0     0.0     0.0     0.0     0.0   338.8    954.   1404.   2340.   5900.   14672.   74909.
516331   15033.6    25929.    0.0     0.0     0.0     0.0     0.0  1053.2   2268.   3806.   7433.  18038.   45333.  210097.
GALA57   15224.1    26280.    0.0     0.0     0.0     0.0     0.0  1046.9   2254.   3886.   7551.  18191.   45819.  212298.
CON108   95854.1   173400.    0.0     0.0     0.0     0.0     0.0  4719.7  16114.  24962.  46780. 109582.  267498. 1604282.
LRCA58   95818.8   173382.    0.0     0.0     0.0     0.0     0.0  4710.2  16082.  24953.  46707. 109554.  267403. 1604234.
433901  136523.1   242247.    0.0   534.0  1127.3  2821.2  6144.8 15391.6  28672.  46697.  73788. 146332.  356967. 3332584.
BRWA41  136381.0   242192.    0.0   532.9  1125.0  2815.6  6132.5 15360.8  28615.  46604.  73640. 146040.  356253. 3325921.
BRHB42  160488.2   278902.    0.0     0.0     0.0   671.9  4270.7 13814.5  30088.  54318.  92088. 186661.  419261. 3538790.
CON111  275274.4   463236.    0.0     0.0     0.0     0.0  4268.6 24017.5  56611.  89131. 166030. 333005.  705118. 4579194.
BRBR59  275026.7   465218.    0.0     0.0     0.0     0.0  4225.9 23778.0  56046.  88243. 164374. 330259.  700413. 4533595.
516431   20049.6    38477.    0.0     0.0     0.0     0.0    40.4   731.7   2639.   4751.   7820.  18998.   62227.  356198.
516531   19145.5    36175.    0.0     0.0     0.0     0.0    19.0   427.7   1710.   3729.   6990.  20307.   60487.  297209.
NAEA66   25660.5    48495.    0.0     0.0     0.0     0.0    20.0   538.4   2331.   4678.   8564.  26169.   83324.  412107.
NABR67   31966.4    59392.    0.0     0.0     0.0     0.0    32.1   706.5   2798.   5896.  10833.  35074.  100622.  537211.
CON130  321890.8   518577.    0.0     0.0     0.0     0.0  5868.7 29348.1  67966. 113328. 193060. 409676.  856202. 4917121.
CON147  356481.7   572438.    0.0     0.0     0.0    26.2  6997.7 31222.6  72586. 120318. 210999. 451369.  990890. 5452128.
BRHE68  354254.0   569921.    0.0     0.0     0.0     0.0  6666.8 30701.0  71667. 118946. 208822. 447059.  986372. 5402860.
292531    3500.6     7008.    0.0     0.0     0.0     0.0     0.0     0.0      0.   1372.   2341.   4728.    9646.  148840.
CON234  391404.1   618912.    0.0     0.0     0.0   200.2  6908.0 35055.0  86728. 149511. 247067. 494207. 1062469. 7006333.
BRRI70  389058.5   615203.    0.0     0.0     0.0   199.0  6866.3 34845.0  86208. 148615. 245586. 491245. 1056103. 6964348.
BRRO72  469197.6   674516.    0.0     0.0     0.0  1092.8 13409.1 74971.0 147616. 224086. 330110. 600101. 1190878. 7581990.
BRGM73  464421.8   667509.    0.0     0.0     0.0  1210.3 13587.8 73943.0 146205. 221799. 325033. 592815. 1178557. 7550727.
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5.2 COMPARATIVE EVALUATION OF SIMULATION RESULTS FROM THE BRAC AND BRAZOS WAM DATASETS

The procedure outlined in Chapter II for condensing TCEQ WAM System datasets was applied to the Brazos WAM as described in section 5.1 to develop a much simpler BRAC dataset designed for studies of operations of the Brazos River Authority river/reservoir water management system. Simulation results obtained with the Brazos WAM and BRAC datasets are compared in the present section 5.2. Simulation results with the alternative versions of the Bwam and BRAC datasets reflecting authorized versus current use scenarios and different hydrologic periods-of-analysis are also compared. Section 5.2 is a comparative evaluation of the alternative models listed in Table 5.17.

Table 5.17 WRAP-SIM Input Datasets Discussed in Section 5.2

Filename	Water Use Scenario	Hydrologic Period-of-Analysis
	Original Brazos WAM Datasets	
Bwam3	authorized use (run 3)	January 1940 through December 2007
Bwam3	authorized use (run 3)	January 1900 through December 2007
Bwam8	current use (run 8)	January 1940 through December 2007
Bwam8	current use (run 8)	January 1900 through December 2007
	Brazos River Authority Condensed (BRAC) Datasets	
BRAC3	authorized use (run 3)	January 1940 through December 2007
BRAC3	authorized use (run 3)	January 1900 through December 2007
BRAC8	current use (run 8)	January 1940 through December 2007
BRAC8	current use (run 8)	January 1900 through December 2007

The Brazos WAM hydrologic period-of-analysis has been lengthened from 1940-1997 to 1900-2007 as described in sections 4.1 and 4.2. Versions of the simplified BRAC model are developed with hydrologic periods-of-analysis of 1940-2007 and 1900-2007. The 1940-1997 hydrologic period-of-analysis in the original Brazos WAM dataset is a subset of the 1940-2007 period-of-analysis. Simulation results for 1940-1997 are also addressed in the comparative evaluation discussions of section 5.2.

5.2.1 River System Inflows at the 48 BRAC Control Points

The 48 control points included in the Brazos River Authority Condensed (BRAC3 and BRAC8) datasets are listed in Table 5.18. Information describing these control points is provided in Tables 5.2, 5.3, and 5.4 and Figures 5.1 and 5.2 of section 5.1. Twenty-two of the control points are USGS stream gaging stations, 15 control points are reservoirs, 10 control points are stream confluences and the remaining control point is the basin outlet. The six-character control point identifiers listed in Table 5.18 are the same in the Bwam and BRAC datasets.

Sequences of monthly river system inflows are stored as *IN* records in the FLO input files for the BRAC3 and BRAC8 datasets. The inflows are plotted in Appendix D. Mean annual inflows for the 48 control points are tabulated in Table 5.10 of the preceding section 5.1 for BRAC3 and BRAC8 1940-1997, 1940-2007, and 1900-2007 simulations. The 1940-1997 means for the original Brazos WAM (Bwam) naturalized flows are also included in Table 5.10. Program *TABLES* flow-frequency tables are provided as Tables 5.11 through 5.16 for the alternative inflow datasets.

5.2.2 Confirmation of the Validity and Accuracy of the BRAC Datasets

As discussed in section 2.4, if the primary system is operated in the same manner in both the condensed and original datasets, the water supply diversions and shortages, streamflow depletions, and storage volumes computed by the *SIM* simulation model should be the same. The condensed dataset should reproduce the simulation results for the primary system that are obtained with the original dataset. Unappropriated flows should also be reproduced. Thus, a comparison of simulation results provides a check on the accuracy and validity of the condensed datasets.

A key objective of the computational methodology is to reproduce the quantities connected directly to the water rights and reservoirs included in the condensed DAT file. Diversions and diversion shortages, return flows, streamflow depletions, and reservoir evaporation and storage volumes for primary system water rights and reservoirs should be the same in the *SIM* simulation results obtained from condensed versus original *SIM* input datasets.

Table 5.18 BRAC Control Points

Control Points at Gaging Stations

DMAS09	Double Mountain at Aspermont
BRSE11	Brazos River at Seymour
BRSB23	Brazos River at South Bend
BRPP27	Brazos River at Palo Pinto
BRDE29	Brazos River at Dennis
BRGR30	Brazos River at Glen Rose
BRAQ33	Brazos River at Aquilla
BRWA41	Brazos River at Waco
BRHB42	Brazos River at Highbank
LEHM46	Leon River at Hamilton
LEGT47	Leon River at Gatesville
LEBE49	Leon River at Belton
LABE52	Lampasas River at Belton
LRLR53	Little River at Little River
GALA57	San Gabriel River Laneport
LRCA58	Little River at Cameron
BRBR59	Brazos River at Bryan
NAEA66	Navasota River at Easterly
NABR67	Navasota River at Bryan
BRHE68	Brazos River at Hempstead
BRRI70	Brazos River at Richmond
BRRO72	Brazos River at Rosharon

Control Points at Reservoirs

515531	Possum Kingdom (POSDOM)
515631	Granbury (GRNBRY)
515731	Whitney (WHIT)
515831	Aquilla (AQUILA)
509431	Waco (WACO)
515931	Proctor (PRCTOR)
516031	Belton (BELTON)
516131	Stillhouse Hollow (STLHSE)
516231	Georgetown (GRGTWN)
516331	Granger (GRNGER)
516531	Limestone (LMSTNE)
516431	Somerville (SMRVLE)
516031	Allens Creek (ALLENS)
421331	Hubbard Creek (HUBBRD)
409732	Squaw Creek (SQWCRK)

Control Points at Confluences and Basin Outlet

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

Unappropriated flows should also match since they are included along with streamflow depletions less return flows in the FLO file inflows of the condensed *SIM* input dataset. Regulated flows are not reproduced. Regulated flows represent the actual physical flows at a control point. Unappropriated flows are the quantities remaining after all water rights have appropriated their allocated quantities of water in the simulation. Unappropriated flow at a particular control point in a particular month can not exceed regulated flow. However, unappropriated flows may be less than regulated flows. The regulated flows in the condensed model may be smaller than the correct regulated flows in the full original model.

5.2.3 Comparison of Simulation Results from the Alternative Datasets

The remainder of this chapter focuses on comparison of tables and plots that summarize the results of WRAP-SIM simulations with the input datasets listed in Table 5.17. The following comparisons show that the Brazos River Authority Condensed (BRAC) datasets do appropriately reproduce the simulation results of the original Brazos WAM (Bwam) datasets.

Water Supply Reliabilities Resulting from BRAC and Bwam Datasets

The reliability tables reproduced as Tables 5.19 through 5.26 were created with program *TABLES* from the results of *WRAP-SIM* simulations with the input datasets listed in Table 5.17. The reliabilities are for the aggregation of all diversion rights associated with each of the 15 BRAC3 reservoirs or 14 BRAC8 reservoirs. The reliabilities are listed by the control point identifiers of the reservoirs. The Bwam3 versus BRAC3 reliabilities are compared by Tables 5.19 and 5.20 for the 1940-2007 simulations and Tables 5.21 and 5.22 for the 1900-2007 simulations. The Bwam8 versus BRAC8 reliabilities are compared by Tables 5.23 and 5.24 for the 1940-2007 simulations and Tables 5.25 and 5.26 for the 1900-2007 simulations.

In the Bwam8 and BRAC8 simulations reflected in Tables 5.23-5.26, the diversions from 12 of the 14 reservoirs have reliabilities of 100.00 percent. Diversions at Squaw Creek Reservoir (control point 409732) and Somerville Reservoir (control point 516431) are the only current use scenario diversions with reliabilities less than 100.00 percent. The diversion shortages and reliabilities associated with diversions from Squaw Creek and Somerville Reservoirs are essentially identical in the Bwam8 and BRAC8 simulations as they should. For example, for the 1940-2007 simulations reported in Tables 5.23 and 5.24, the volume reliabilities are 73.53 percent for Squaw Creek and 99.51 percent for Somerville for both the Bwam8 and BRAC8 simulations.

Diversion shortages occur at seven of the 15 reservoirs in the Bwam3 and BRAC3 simulations reflected in Tables 5.19 through 5.22. For the 1940-2007 simulations of Tables 5.19 and 5.20, the total volume reliabilities for the Bwam3 and BRAC8 simulations are 97.77 and 97.93 percent, respectively. The Bwam3 and BRAC3 diversion shortages and associated reliabilities are not absolutely identical but are very close.

Unappropriated Flows of BRAC and Bwam Datasets

Frequency tables for unappropriated flows were created with program *TABLES* from the results of *WRAP-SIM* simulations with the input datasets listed in Table 5.17. The frequency tables were then converted to the format of Tables 5.27 through 5.30. Exceedance frequencies are tabulated in the first column in Tables 5.27 through 5.30. Means and standard deviations of the monthly naturalized flows and the minimum and maximum naturalized flow are also included in the tables. BRAC simulated monthly unappropriated flow volumes are recorded in the tables as a percentage of the corresponding Bwam simulated unappropriated flows. The exceedance frequency versus BRAC flows as a percentage of Bwam flow relationships are tabulated for each of the control points at which a reservoir is located.

The objective is to have a value of 100.0% entered in Tables 5.27 through 5.30 for the mean, standard deviation, and volumes associated with each exceedance frequency. For most of the control points, most of the entries in the tables are 100.0% or very close to 100.0%. The unappropriated flows are reproduced essentially perfectly at some of the control points and at least reasonably closely at all of the control points. The Bwam and BRAC unappropriated flows at the control points of the reservoirs are plotted in Figures 5.6 through 5.35.

End-of-Month Reservoir Storage Contents

Reservoir storage contents are also closely reproduced in the *SIM* simulation results for the simplified condensed input datasets. BRAC3 and Bwam3 storage volumes are compared in Tables 5.31 and 5.32 for 1940-2007 and 1900-2007 hydrologic simulation periods. BRAC8 and Bwam8 storage volumes are compared in Tables 5.33 and 5.34. Exceedance frequencies are tabulated in the first column of the tables. End-of-month storage from the BRAC simulations expressed as a percentage of the corresponding Bwam volumes are shown for each exceedance frequency. Means and standard deviations are also shown. The statistics are provided for each of the reservoirs.

A perfect BRAC reproduction of Bwam storage levels would be indicated by all entries in Tables 5.31-5.34 being 100.0%, meaning the BRAC storage is 100% of the corresponding Bwam storage. The entries are almost all 100.0% or very close thereto. Storage contents are very closely reproduced.

BRAC3 versus Bwam3 and BRAC8 versus Bwam8 storage sequences are compared in Figure 5.34 through 5.65. The summation of storage in all the reservoirs is plotted in Figure 5.66 and 5.67. The plots represent Bwam storage as a regular line and BRAC storage as a dashed line. The two lines look one line since the Bwam and BRAC storages are essentially the same.

Table 5.19 Bwam3 Reliabilities for 1940-2007 at 15 Control Points

```
-----------------------------------------------------------------------------------------------------------------------
          TARGET       MEAN    *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|---------- PERCENTAGE OF YEARS ----------
NAME     DIVERSION   SHORTAGE  PERIOD VOLUME|    WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT
        (AC-FT/YR)  (AC-FT/YR)   (%)    (%) | 100%   95%   90%   75%   50%   25%    1% | 100%   98%   95%   90%   75%   50%    1%
-----------------------------------------------------------------------------------------------------------------------
421331     56000.0   10124.41   80.15  81.92| 80.1  80.4  80.4  80.9  82.0  82.4  83.0| 63.2  63.2  64.7  66.2  73.5  82.4  98.5
515531    230750.0       0.02  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515631     64712.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
409732     23180.0    8231.25   54.90  64.49| 54.9  56.1  56.5  58.7  63.2  70.6  78.2| 30.9  33.8  38.2  41.2  50.0  64.7  98.5
515731     18894.9       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515831     13896.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
509431     90900.9    1944.94   95.47  97.86| 95.5  95.5  95.6  95.8  99.6  99.8 100.0| 91.2  91.2  94.1  95.6  97.1 100.0 100.0
515931     19658.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516031    112257.0       0.01  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516131     67768.0     313.19   99.02  99.54| 99.0  99.1  99.1  99.4  99.5  99.6  99.6| 95.6  95.6  97.1  97.1 100.0 100.0 100.0
516231     13610.0     195.69   98.41  98.56| 98.4  98.4  98.4  98.4  98.5  98.7  98.8| 94.1  95.6  95.6  95.6  98.5  98.5 100.0
516331     19840.0      45.51   99.63  99.77| 99.6  99.6  99.6  99.6  99.6  99.8  99.9| 97.1  97.1  98.5  98.5 100.0 100.0 100.0
516431     48000.0     161.56   99.26  99.66| 99.3  99.3  99.3  99.3  99.4  99.5  99.6| 97.1  97.1  97.1  98.5 100.0 100.0 100.0
516531     65074.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
292531     99650.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
-----------------------------------------------------------------------------------------------------------------------
Total     944190.8   21016.57          97.77
--------------------------------------------
```

Table 5.20 BRAC3 Reliabilities for 1940-2007 at 15 Control Points

```
-----------------------------------------------------------------------------------------------------------------------
          TARGET       MEAN    *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|---------- PERCENTAGE OF YEARS ----------
NAME     DIVERSION   SHORTAGE  PERIOD VOLUME|    WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT
        (AC-FT/YR)  (AC-FT/YR)   (%)    (%) | 100%   95%   90%   75%   50%   25%    1% | 100%   98%   95%   90%   75%   50%    1%
-----------------------------------------------------------------------------------------------------------------------
421331     56000.0   10159.68   80.02  81.86| 80.0  80.4  80.4  80.9  81.9  82.4  82.8| 63.2  63.2  64.7  66.2  72.1  82.4  98.5
515531    230750.0       0.02  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515631     64712.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
409732     23180.0    8224.53   54.90  64.52| 54.9  56.1  56.5  58.7  63.4  70.6  78.2| 30.9  33.8  38.2  41.2  50.0  64.7  98.5
515731     18336.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515831     13896.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
509431     79877.0     224.02   98.90  99.72| 98.9  98.9  98.9  99.0 100.0 100.0 100.0| 97.1  97.1  97.1  98.5 100.0 100.0 100.0
515931     19658.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516031    112257.0       0.01  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516131     67768.0     313.14   99.02  99.54| 99.0  99.1  99.1  99.4  99.5  99.6  99.6| 95.6  95.6  97.1  97.1 100.0 100.0 100.0
516231     13610.0     195.66   98.41  98.56| 98.4  98.4  98.4  98.4  98.5  98.7  98.8| 94.1  95.6  95.6  95.6  98.5  98.5 100.0
516331     19840.0      45.41   99.63  99.77| 99.6  99.6  99.6  99.6  99.6  99.8  99.9| 97.1  97.1  98.5  98.5 100.0 100.0 100.0
516431     48000.0     161.43   99.26  99.66| 99.3  99.3  99.3  99.3  99.4  99.5  99.6| 97.1  97.1  97.1  98.5 100.0 100.0 100.0
516531     65074.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
292531     99650.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
-----------------------------------------------------------------------------------------------------------------------
Total     932608.0   19323.89          97.93
--------------------------------------------
```

Table 5.21 Bwam3 Reliabilities for 1900-2007 at 15 Control Points

```
-------------------------------------------------------------------------------------------------------------------------------------
          TARGET        MEAN     *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|---------- PERCENTAGE OF YEARS ----------
NAME      DIVERSION    SHORTAGE  PERIOD VOLUME|     WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT
         (AC-FT/YR)  (AC-FT/YR)     (%)    (%) |  100%   95%   90%   75%   50%   25%    1% |  100%   98%   95%   90%   75%   50%    1%
-------------------------------------------------------------------------------------------------------------------------------------
421331      56000.0     9251.21   81.40  83.48|  81.4  81.6  81.6  82.1  83.2  83.8  84.3|  64.8  64.8  65.7  66.7  78.7  85.2  98.1
515531     230750.0        0.02  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
515631      64712.0        0.00  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
409732      23180.0     5955.96   67.13  74.31|  67.1  67.9  68.4  70.3  73.5  78.7  84.6|  47.2  50.0  53.7  56.5  63.0  75.0  99.1
515731      18972.7        0.00  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
515831      13896.0        0.00  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
509431      92810.8     2157.63   94.37  97.68|  94.4  94.4  94.5  94.7  99.6  99.8 100.0|  89.8  89.8  92.6  94.4  96.3 100.0 100.0
515931      19658.0        0.00  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
516031     112257.0        0.01  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
516131      67768.0      197.19   99.38  99.71|  99.4  99.5  99.5  99.6  99.7  99.8  99.8|  97.2  97.2  98.1  98.1 100.0 100.0 100.0
516231      13610.0      123.21   99.00  99.09|  99.0  99.0  99.0  99.0  99.1  99.2  99.2|  96.3  97.2  97.2  97.2  99.1  99.1 100.0
516331      19840.0       28.65   99.77  99.86|  99.8  99.8  99.8  99.8  99.8  99.8  99.9|  98.1  98.1  99.1  99.1 100.0 100.0 100.0
516431      48000.0      101.73   99.54  99.79|  99.5  99.5  99.5  99.5  99.6  99.7  99.8|  98.1  98.1  98.1  99.1 100.0 100.0 100.0
516531      65074.0        0.00  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
292531      99650.0        0.00  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
-------------------------------------------------------------------------------------------------------------------------------------
Total      946178.5    17815.62           98.12
----------------------------------------------
```

Table 5.22 BRAC3 Reliabilities for 1900-2007 at 15 Control Points

```
-------------------------------------------------------------------------------------------------------------------------------------
          TARGET        MEAN     *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|---------- PERCENTAGE OF YEARS ----------
NAME      DIVERSION    SHORTAGE  PERIOD VOLUME|     WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT
         (AC-FT/YR)  (AC-FT/YR)     (%)    (%) |  100%   95%   90%   75%   50%   25%    1% |  100%   98%   95%   90%   75%   50%    1%
-------------------------------------------------------------------------------------------------------------------------------------
421331      56000.0     9363.98   81.33  83.28|  81.3  81.6  81.6  81.9  83.0  83.5  84.0|  64.8  64.8  65.7  66.7  75.9  85.2  97.2
515531     230750.0        0.02  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
515631      64712.0        0.00  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
409732      23180.0     5949.35   67.21  74.33|  67.2  68.1  68.5  70.3  73.5  78.7  84.6|  47.2  50.0  53.7  56.5  63.0  75.0  99.1
515731      18336.0        0.00  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
515831      13896.0        0.00  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
509431      79877.0      427.70   97.84  99.46|  97.8  97.8  97.9  98.0  99.9 100.0 100.0|  95.4  95.4  95.4  98.1  99.1 100.0 100.0
515931      19658.0        0.00  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
516031     112257.0        0.01  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
516131      67768.0      197.16   99.38  99.71|  99.4  99.5  99.5  99.6  99.7  99.8  99.8|  97.2  97.2  98.1  98.1 100.0 100.0 100.0
516231      13610.0      123.19   99.00  99.09|  99.0  99.0  99.0  99.0  99.1  99.2  99.2|  96.3  97.2  97.2  97.2  99.1  99.1 100.0
516331      19840.0       28.59   99.77  99.86|  99.8  99.8  99.8  99.8  99.8  99.8  99.9|  98.1  98.1  99.1  99.1 100.0 100.0 100.0
516431      48000.0      101.64   99.54  99.79|  99.5  99.5  99.5  99.5  99.6  99.7  99.8|  98.1  98.1  98.1  99.1 100.0 100.0 100.0
516531      65074.0        0.00  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
292531      99650.0        0.00  100.00 100.00| 100.0 100.0 100.0 100.0 100.0 100.0 100.0| 100.0 100.0 100.0 100.0 100.0 100.0 100.0
-------------------------------------------------------------------------------------------------------------------------------------
Total      932608.0    16191.65           98.26
----------------------------------------------
```

Table 5.23 Bwam8 Reliabilities for 1940-2007 at 14 Control Points

```
------------------------------------------------------------------------------------------------------------------------------
            TARGET      MEAN *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|---------- PERCENTAGE OF YEARS ----------
NAME     DIVERSION  SHORTAGE PERIOD VOLUME|    WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT
        (AC-FT/YR)(AC-FT/YR)    (%)    (%)| 100%   95%   90%   75%   50%   25%    1%| 100%   98%   95%   90%   75%   50%    1%
------------------------------------------------------------------------------------------------------------------------------
421331      9923.5      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515531     59482.2      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515631     36025.3      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
409732     17536.0   3624.78  73.53  79.33| 73.5  74.0  74.5  75.6  77.9  83.5  88.0| 57.4  57.4  60.3  61.8  72.1  79.4 100.0
515731     18762.2      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515831      2394.3      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
509431     42935.6      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515931     14068.1      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516031    107737.5      0.01 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516131     67768.0      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516231     11943.4      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516331      2569.0      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516431     48000.0     81.69  99.51  99.83| 99.5  99.6  99.6  99.6  99.6  99.8  99.9| 97.1  97.1  98.5 100.0 100.0 100.0 100.0
516531     39337.1      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
------------------------------------------------------------------------------------------------------------------------------
Total     478482.2   3706.48         99.23
------------------------------------------
```

Table 5.24 BRAC8 Reliabilities for 1940-2007 at 14 Control Points

```
------------------------------------------------------------------------------------------------------------------------------
            TARGET      MEAN *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|---------- PERCENTAGE OF YEARS ----------
NAME     DIVERSION  SHORTAGE PERIOD VOLUME|    WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT
        (AC-FT/YR)(AC-FT/YR)    (%)    (%)| 100%   95%   90%   75%   50%   25%    1%| 100%   98%   95%   90%   75%   50%    1%
------------------------------------------------------------------------------------------------------------------------------
421331      9923.5      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515531     59482.2      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515631     36025.3      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
409732     17536.0   3621.49  73.53  79.35| 73.5  74.0  74.5  75.7  77.9  83.5  88.0| 57.4  57.4  60.3  61.8  72.1  79.4 100.0
515731     18336.0      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515831      2394.3      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
509431     38348.0      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515931     14068.1      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516031    107737.5      0.01 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516131     67768.0      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516231     11943.4      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516331      2569.0      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516431     48000.0     81.57  99.51  99.83| 99.5  99.6  99.6  99.6  99.6  99.8  99.9| 97.1  97.1  98.5 100.0 100.0 100.0 100.0
516531     39337.1      0.00 100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
------------------------------------------------------------------------------------------------------------------------------
Total     473468.4   3703.07         99.22
------------------------------------------
```

Table 5.25 Bwam8 Reliabilities for 1900-2007 at 14 Control Points

```
-------------------------------------------------------------------------------------------------------------------------------
           TARGET       MEAN  *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|---------- PERCENTAGE OF YEARS ----------
NAME    DIVERSION   SHORTAGE  PERIOD VOLUME|    WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT
       (AC-FT/YR) (AC-FT/YR)    (%)    (%) | 100%   95%   90%   75%   50%   25%    1% | 100%   98%   95%   90%   75%   50%    1%
-------------------------------------------------------------------------------------------------------------------------------
421331     9923.5       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515531    59482.2       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515631    36025.3       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
409732    17536.0    2418.55   82.41  86.21| 82.4  82.7  83.0  83.8  85.2  88.9  92.2| 72.2  72.2  74.1  75.0  80.6  86.1 100.0
515731    18778.3       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515831     2394.3       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
509431    43163.6       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515931    14068.1       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516031   107737.3       0.01  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516131    67768.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516231    11943.4       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516331     2569.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516431    48000.0      51.44   99.69  99.89| 99.7  99.8  99.8  99.8  99.8  99.8  99.9| 98.1  98.1  99.1 100.0 100.0 100.0 100.0
516531    39337.1       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
-------------------------------------------------------------------------------------------------------------------------------
Total    478726.0    2469.99          99.48
-------------------------------------------
```

Table 5.26 BRAC8 Reliabilities for 1900-2007 at 14 Control Points

```
-------------------------------------------------------------------------------------------------------------------------------
           TARGET       MEAN  *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|---------- PERCENTAGE OF YEARS ----------
NAME    DIVERSION   SHORTAGE  PERIOD VOLUME|    WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT
       (AC-FT/YR) (AC-FT/YR)    (%)    (%) | 100%   95%   90%   75%   50%   25%    1% | 100%   98%   95%   90%   75%   50%    1%
-------------------------------------------------------------------------------------------------------------------------------
421331     9923.5       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515531    59482.2       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515631    36025.3       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
409732    17536.0    2415.99   82.41  86.22| 82.4  82.7  83.0  83.8  85.2  89.0  92.2| 72.2  72.2  74.1  75.0  80.6  86.1 100.0
515731    18336.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515831     2394.3       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
509431    38348.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
515931    14068.1       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516031   107737.3       0.01  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516131    67768.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516231    11943.4       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516331     2569.0       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
516431    48000.0      51.36   99.69  99.89| 99.7  99.8  99.8  99.8  99.8  99.8  99.9| 98.1  98.1  99.1 100.0 100.0 100.0 100.0
516531    39337.1       0.00  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0 100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
-------------------------------------------------------------------------------------------------------------------------------
Total    473468.1    2467.35          99.48
-------------------------------------------
```

Table 5.27 BRAC3 UNA Flows as Percentages of Bwam3 UNA Flows for 1940-2007

Control	421331	515531	515631	409732	515731	515831	509431	515931	516031	516131	516231	516331	516431	516531	292531
Points				1940-2007 BRAC3 Unappropriated Flows as a Percentage of Bwam3 Unappropriated Flows											
Mean	100.0%	94.8%	95.4%	-	100.2%	100.1%	99.8%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	128.5%
Std Dev	100.0%	99.4%	99.4%	-	100.2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	122.6%
Minimum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
99.50%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
99%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
98%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
95%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
90%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
85%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
80%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
75%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
70%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40%	-	-	-	-	6.7%	-	-	-	-	-	-	-	-	-	-
30%	-	-	53.3%	-	100.9%	#DIV/0!	99.9%	-	-	-	15.4%	100.0%	100.1%	-	-
25%	-	-	80.5%	-	104.2%	109.3%	99.0%	-	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	-
20%	-	27.3%	79.1%	-	100.0%	100.2%	99.3%	55.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.1%	-
15%	-	88.5%	87.5%	-	101.2%	100.4%	99.4%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	-
10%	-	90.4%	93.1%	-	100.0%	100.0%	100.2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	217.0%
5%	-	93.8%	99.5%	-	101.8%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	132.8%
2%	99.8%	100.0%	100.0%	-	100.0%	100.5%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	125.4%
1%	100.0%	100.0%	91.6%	-	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	118.5%
0.50%	100.0%	100.0%	100.0%	-	100.1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	122.6%
Maximum	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%	118.3%

Table 5.28 BRAC3 UNA Flows as Percentages of Bwam3 UNA Flows for 1900-2007

Control	421331	515531	515631	409732	515731	515831	509431	515931	516031	516131	516231	516331	516431	516531	292531
Points				1900-2007 BRAC3 Unappropriated Flows as a Percentage of Bwam3 Unappropriated Flows											
Mean	100.0%	94.3%	94.9%	100.0%	100.2%	100.0%	99.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	136.7%
Std Dev	100.0%	98.9%	99.2%	99.9%	100.2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	124.8%
Minimum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
99.50%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
99%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
98%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
95%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
90%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
85%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
80%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
75%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
70%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40%	-	-	-	-	10.4%	-	-	-	-	-	-	-	-	-	-
30%	-	-	63.0%	-	100.0%	-	0.0%	-	-	-	100.0%	100.0%	100.1%	-	-
25%	-	-	78.8%	-	100.3%	93.7%	94.5%	-	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	-
20%	-	50.6%	82.8%	-	100.7%	99.9%	100.6%	99.9%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	-
15%	-	84.0%	94.4%	-	100.7%	100.0%	99.1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	-
10%	-	90.0%	94.1%	-	100.0%	100.0%	101.2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	758.9%
5%	-	90.6%	94.8%	-	100.5%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	147.6%
2%	-	100.0%	100.0%	-	100.1%	100.2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	132.7%
1%	100.0%	100.0%	100.0%	-	100.1%	100.0%	100.1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	116.8%
0.50%	100.0%	98.3%	100.0%	-	100.1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	130.3%
Maximum	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	123.1%

Table 5.29 BRAC8 UNA Flows as Percentages of Bwam8 UNAFlows for 1940-2007

Control	421331	515531	515631	409732	515731	515831	509431	515931	516031	516131	516231	516331	516431	516531
Points	1940-2007 BRAC8 Unappropriated Flows as a Percentage of Bwam8 Unappropriated Flows													
Mean	100.0%	96.0%	96.0%	#DIV/0!	100.1%	100.1%	100.0%	99.9%	100.1%	100.2%	100.0%	100.2%	100.0%	100.0%
Std Dev	100.0%	99.2%	99.4%	#DIV/0!	100.0%	100.0%	100.0%	100.0%	100.0%	100.1%	100.0%	100.1%	100.0%	100.0%
Minimum	-	-	-	-	-	-	-	-	-	-	-	-	-	-
99.50%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
99%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
98%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
95%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
90%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
85%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
80%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
75%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
70%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50%	-	-	-	-	108.2%	-	-	-	-	-	-	99.1%	-	-
40%	-	76.4%	79.4%	-	100.4%	-	103.4%	-	-	-	-	101.0%	-	-
30%	-	85.3%	90.1%	-	100.0%	100.0%	101.3%	-	100.1%	110.1%	100.0%	100.3%	100.1%	99.9%
25%	-	95.3%	92.5%	-	100.0%	100.0%	97.8%	0.9%	102.6%	100.2%	101.9%	99.8%	100.0%	100.0%
20%	-	97.6%	95.6%	-	100.2%	100.0%	100.1%	97.4%	101.2%	99.8%	100.0%	100.6%	100.0%	100.0%
15%	-	90.8%	92.6%	-	100.0%	100.0%	100.1%	100.0%	100.8%	100.1%	100.0%	100.0%	100.0%	100.0%
10%	-	93.6%	94.6%	-	100.0%	100.0%	100.2%	100.0%	100.0%	100.0%	100.0%	100.1%	100.0%	100.0%
5%	99.9%	97.9%	93.9%	-	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2%	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%
1%	100.0%	100.0%	100.0%	-	100.0%	100.0%	100.0%	100.0%	100.0%	103.0%	100.0%	100.0%	100.0%	100.0%
0.50%	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%
Maximum	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%

Table 5.30 BRAC8 UNA Flows as Percentages of Bwam8 UNA Flows for 1900-2007

Control	421331	515531	515631	409732	515731	515831	509431	515931	516031	516131	516231	516331	516431	516531
Points	1900-2007 BRAC8 Unappropriated Flows as a Percentage of Bwam8 Unappropriated Flows													
Mean	97.2%	95.1%	95.2%	100.8%	100.1%	100.1%	100.1%	99.9%	100.1%	100.3%	100.0%	100.3%	100.0%	100.0%
Std Dev	98.6%	98.4%	98.9%	100.2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.1%	100.0%	100.0%	100.0%	100.0%
Minimum	98.6%	98.4%	98.9%	100.2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.1%	100.0%	100.0%	100.0%	100.0%
99.50%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
99%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
98%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
95%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
90%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
85%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
80%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
75%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
70%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50%	-	-	0.0%	-	112.4%	-	-	-	-	-	-	107.5%	-	-
40%	-	63.3%	77.8%	-	101.4%	-	102.3%	-	-	-	-	101.1%	-	-
30%	-	88.1%	87.3%	-	100.0%	99.9%	101.0%	-	100.4%	101.6%	100.2%	102.0%	100.2%	100.2%
25%	-	91.6%	89.8%	-	100.2%	99.9%	100.6%	1.7%	100.5%	104.4%	100.5%	100.0%	100.1%	99.9%
20%	-	94.2%	93.9%	-	100.0%	100.0%	100.0%	100.1%	100.3%	101.0%	100.0%	100.4%	100.0%	100.0%
15%	-	89.3%	89.1%	-	100.0%	100.0%	100.1%	100.0%	100.0%	100.1%	100.2%	100.2%	100.0%	100.0%
10%	-	93.9%	93.3%	-	100.0%	100.1%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
5%	98.5%	96.4%	95.0%	-	100.0%	100.0%	100.2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2%	98.6%	100.0%	99.5%	-	100.0%	100.0%	100.0%	100.0%	100.4%	100.0%	100.0%	100.0%	100.0%	100.0%
1%	94.5%	100.0%	98.0%	135.5%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.1%	100.0%	100.0%
0.50%	100.0%	91.8%	100.0%	102.5%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Maximum	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 5.31 BRAC3 STO Vol. as Percentages of Bwam3 STO Vol. for 1940-2007

Control Points	421331	515531	515631	409732	515731	515831	509431	515931	516031	516131	516231	516331	516431	516531	292531
				1940-2007 BRAC3 Unappropriated Flows as a Percentage of Bwam3 Unappropriated Flows											
Mean	99.8%	100.0%	100.8%	100.1%	100.2%	100.1%	100.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	101.8%
Std Dev	100.0%	100.0%	95.0%	100.0%	98.4%	99.2%	103.1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	79.3%
Minimum	-	100.0%	110.9%	-	100.4%	121.7%	74.6%	100.2%	100.1%	-	-	-	-	100.1%	431.9%
99.50%	-	100.0%	109.1%	-	100.4%	108.6%	77.4%	100.0%	100.0%	-	-	101.6%	-	100.1%	193.5%
99%	-	100.0%	110.4%	-	100.4%	104.5%	86.2%	100.0%	100.0%	100.0%	-	100.2%	100.0%	100.1%	152.9%
98%	-	100.0%	107.4%	-	100.7%	101.9%	96.3%	100.0%	100.0%	100.0%	100.2%	100.0%	100.0%	100.0%	140.8%
95%	-	100.0%	103.1%	-	101.0%	101.1%	100.2%	99.8%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	113.3%
90%	-	100.0%	103.7%	-	100.2%	100.5%	100.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	107.3%
85%	-	100.0%	102.0%	-	100.4%	100.2%	101.9%	99.8%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	105.4%
80%	64.2%	100.0%	102.0%	-	100.2%	100.3%	101.4%	99.8%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	102.6%
75%	92.8%	100.0%	102.3%	-	100.1%	100.2%	101.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.1%	100.0%	101.7%
70%	99.7%	100.0%	101.7%	-	100.1%	100.2%	101.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	102.2%
60%	99.5%	100.0%	100.4%	-	100.4%	100.0%	101.2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
50%	99.1%	100.0%	100.7%	100.0%	100.2%	100.1%	100.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
40%	99.3%	100.0%	100.0%	100.0%	100.5%	100.0%	101.1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
30%	99.8%	100.0%	100.0%	100.0%	100.0%	100.0%	101.6%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
25%	99.9%	100.0%	100.0%	100.0%	100.0%	100.0%	101.4%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
20%	100.0%	100.0%	100.0%	100.2%	100.0%	100.0%	100.9%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
15%	100.0%	100.0%	100.0%	100.2%	100.0%	100.0%	100.3%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
10%	100.0%	100.0%	100.0%	100.3%	100.0%	100.0%	100.2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
5%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
0.50%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Maximum	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 5.32 BRAC3 STO Vol. as Percentages of Bwam3 STO Vol. for 1900-2007

Control Points	421331	515531	515631	409732	515731	515831	509431	515931	516031	516131	516231	516331	516431	516531	292531
				1940-2007 BRAC3 Unappropriated Flows as a Percentage of Bwam3 Unappropriated Flows											
Mean	99.7%	100.0%	100.9%	100.2%	100.3%	100.1%	100.5%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	101.4%
Std Dev	100.0%	99.8%	93.3%	100.1%	99.2%	99.1%	106.3%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	83.1%
Minimum	-	100.0%	249.1%	-	100.0%	121.7%	72.8%	100.2%	100.1%	-	-	-	-	100.1%	431.9%
99.50%	-	100.0%	136.9%	-	100.0%	105.9%	74.2%	99.8%	100.0%	-	-	100.1%	100.2%	100.1%	175.7%
99%	-	100.5%	114.7%	-	100.0%	104.1%	75.9%	100.0%	100.0%	100.0%	100.8%	100.0%	100.0%	100.0%	148.5%
98%	-	100.2%	110.8%	-	100.0%	102.5%	81.6%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	116.1%
95%	-	100.2%	106.3%	-	100.4%	101.2%	95.9%	99.9%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	108.5%
90%	-	100.1%	103.6%	-	100.2%	100.8%	102.4%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	105.2%
85%	-	100.2%	102.1%	-	100.5%	100.5%	101.6%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	104.1%
80%	91.8%	100.0%	101.4%	-	100.4%	100.2%	101.1%	99.9%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	102.2%
75%	99.5%	100.0%	102.2%	-	100.4%	100.1%	100.8%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	101.7%
70%	100.0%	100.0%	100.9%	-	100.4%	100.2%	100.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	102.6%
60%	99.2%	100.0%	100.6%	100.7%	100.3%	100.2%	101.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
50%	99.5%	100.0%	100.4%	100.0%	100.2%	100.1%	101.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
40%	99.2%	100.0%	100.0%	100.1%	100.6%	100.0%	100.9%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
30%	99.3%	100.0%	100.0%	100.1%	100.2%	100.0%	101.8%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
25%	100.0%	100.0%	100.0%	100.4%	100.1%	100.0%	101.4%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
20%	99.9%	100.0%	100.0%	100.1%	100.0%	100.0%	100.8%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
15%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
10%	99.7%	100.0%	100.0%	100.3%	100.0%	100.0%	100.4%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
5%	100.0%	100.0%	100.0%	100.2%	100.0%	100.0%	100.2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2%	100.0%	100.0%	100.0%	100.1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
0.50%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Maximum	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 5.33 BRAC8 STO Vol. as Percentages of Bwam8 STO Vol. for 1940-2007

Control	421331	515531	515631	409732	515731	515831	509431	515931	516031	516131	516231	516331	516431	516531
Points	1940-2007 Unappropriated Flows as a Percentage of Bwam3 Unappropriated Flows													
Mean	100.0%	100.0%	100.2%	100.0%	100.0%	100.1%	100.0%	100.1%	100.2%	100.5%	100.1%	100.4%	100.0%	100.0%
Std Dev	100.0%	99.9%	95.0%	100.0%	99.7%	98.5%	99.3%	99.8%	97.8%	96.2%	100.1%	87.8%	100.0%	100.0%
Minimum	100.0%	100.0%	103.4%	-	100.1%	100.9%	100.7%	100.0%	105.1%	115.2%	100.0%	108.1%	-	100.0%
99.50%	100.0%	100.0%	104.5%	-	100.1%	101.1%	100.7%	100.0%	104.5%	113.2%	100.0%	105.1%	100.5%	100.0%
99%	100.0%	100.0%	102.3%	-	100.1%	100.8%	100.5%	100.0%	104.2%	111.7%	100.0%	106.8%	100.0%	100.0%
98%	100.0%	100.0%	101.5%	-	100.1%	101.1%	100.1%	100.0%	104.1%	113.3%	100.0%	104.2%	100.0%	100.0%
95%	100.0%	100.0%	101.0%	-	99.9%	100.3%	100.0%	100.2%	102.0%	108.2%	100.0%	102.6%	100.0%	100.0%
90%	100.0%	100.0%	100.8%	-	99.9%	100.2%	100.1%	100.0%	101.5%	102.2%	100.0%	101.2%	100.0%	100.0%
85%	100.0%	100.0%	100.7%	-	100.0%	100.1%	100.1%	100.0%	100.5%	101.1%	100.0%	100.9%	100.0%	100.0%
80%	100.0%	100.0%	100.5%	-	100.1%	100.1%	100.0%	100.2%	100.3%	100.4%	100.3%	101.3%	100.0%	100.0%
75%	100.0%	100.0%	100.1%	66.7%	100.0%	100.2%	100.1%	100.1%	100.3%	100.2%	100.3%	101.1%	100.0%	100.0%
70%	100.0%	100.0%	100.3%	100.0%	100.0%	100.1%	100.1%	100.2%	100.1%	100.3%	100.5%	100.1%	100.0%	100.0%
60%	100.0%	100.0%	100.0%	100.2%	100.0%	100.0%	100.0%	100.0%	100.2%	100.3%	100.6%	100.0%	100.0%	100.0%
50%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.1%	100.2%	100.1%	100.0%	100.0%	100.0%
40%	100.0%	100.0%	100.0%	100.2%	100.0%	100.0%	100.0%	100.1%	100.0%	100.0%	100.2%	100.0%	100.0%	100.0%
30%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
25%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
20%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
15%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
10%	100.0%	100.0%	100.0%	100.1%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
5%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
0.50%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
Maximum	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%

Table 5.34 BRAC8 STO Vol. as Percentages of Bwam8 STO Vol. for 1900-2007

Control	421331	515531	515631	409732	515731	515831	509431	515931	516031	516131	516231	516331	516431	516531
Points	1900-2007 BRAC8 Unappropriated Flows as a Percentage of Bwam8 Unappropriated Flows													
Mean	100.0%	100.0%	100.2%	100.0%	100.0%	100.1%	100.0%	100.0%	100.2%	100.4%	100.1%	100.4%	100.0%	100.0%
Std Dev	100.2%	99.9%	94.8%	100.0%	99.4%	98.4%	99.2%	99.8%	98.1%	96.1%	100.0%	87.2%	100.0%	100.0%
Minimum	100.0%	100.0%	103.4%	-	100.1%	100.9%	100.7%	100.0%	103.6%	115.2%	100.0%	108.1%	-	100.0%
99.50%	100.0%	100.0%	103.1%	-	100.1%	101.0%	100.6%	100.0%	103.9%	113.1%	100.0%	105.8%	100.0%	100.0%
99%	100.0%	100.0%	103.0%	-	100.1%	100.7%	100.0%	102.3%	104.0%	112.9%	100.0%	103.1%	100.0%	100.0%
98%	99.2%	100.0%	101.5%	-	100.0%	100.6%	100.0%	100.7%	103.7%	114.8%	100.0%	102.9%	100.0%	100.0%
95%	99.7%	100.0%	101.2%	-	100.2%	100.4%	100.2%	100.0%	101.7%	105.9%	100.0%	101.9%	100.0%	100.0%
90%	99.8%	100.0%	100.6%	-	100.1%	100.2%	100.1%	100.0%	101.0%	101.8%	100.0%	101.2%	100.0%	100.0%
85%	100.0%	100.0%	101.3%	-	100.0%	100.2%	100.1%	100.0%	100.6%	101.2%	100.1%	100.9%	100.0%	100.0%
80%	100.0%	100.0%	100.5%	100.0%	100.1%	100.2%	100.1%	100.0%	100.2%	100.6%	100.2%	100.9%	100.0%	100.0%
75%	99.9%	100.0%	100.3%	100.8%	100.1%	100.2%	100.1%	100.1%	100.2%	100.4%	100.3%	100.9%	100.0%	100.0%
70%	100.0%	100.0%	100.2%	100.0%	100.1%	100.1%	100.1%	100.1%	100.1%	100.4%	100.4%	100.1%	100.0%	100.0%
60%	100.0%	100.0%	100.0%	100.0%	100.0%	100.1%	100.0%	100.0%	100.2%	100.3%	100.1%	100.0%	100.0%	100.0%
50%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.2%	100.1%	100.2%	100.2%	100.0%	100.0%	100.0%
40%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
30%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
25%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
20%	100.0%	100.0%	100.0%	100.1%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
15%	100.0%	100.0%	100.0%	100.1%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
10%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
5%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
2%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
0.50%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
Maximum	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%

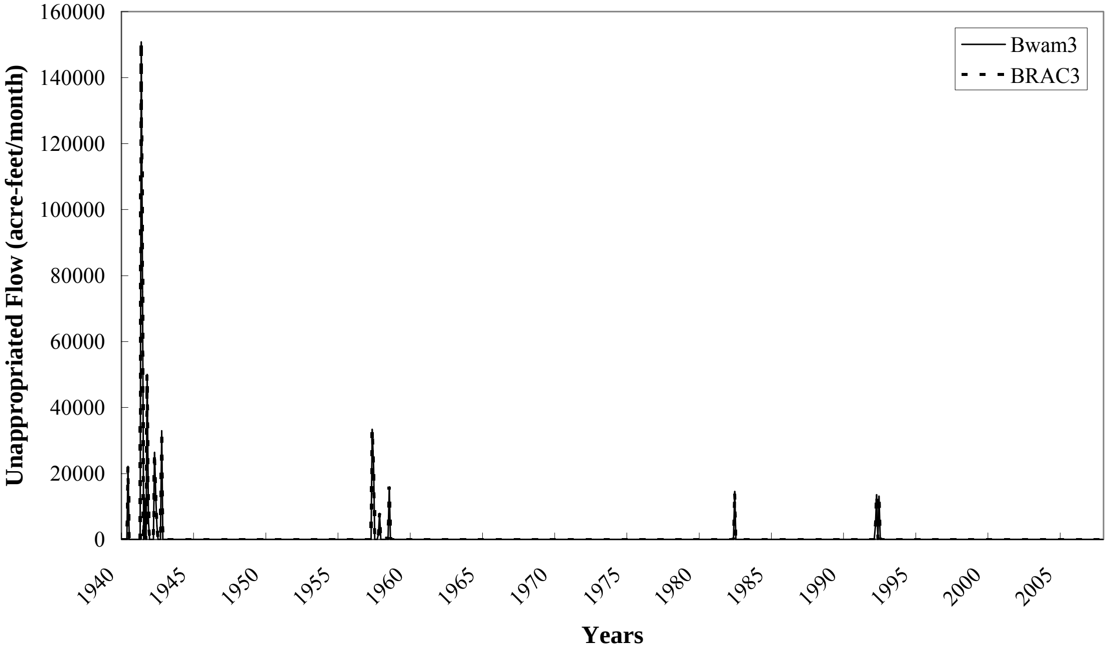

Figure 5.6 1940-2007 Bwam3 and BRAC3 UNA Flows at Hubbard Creek

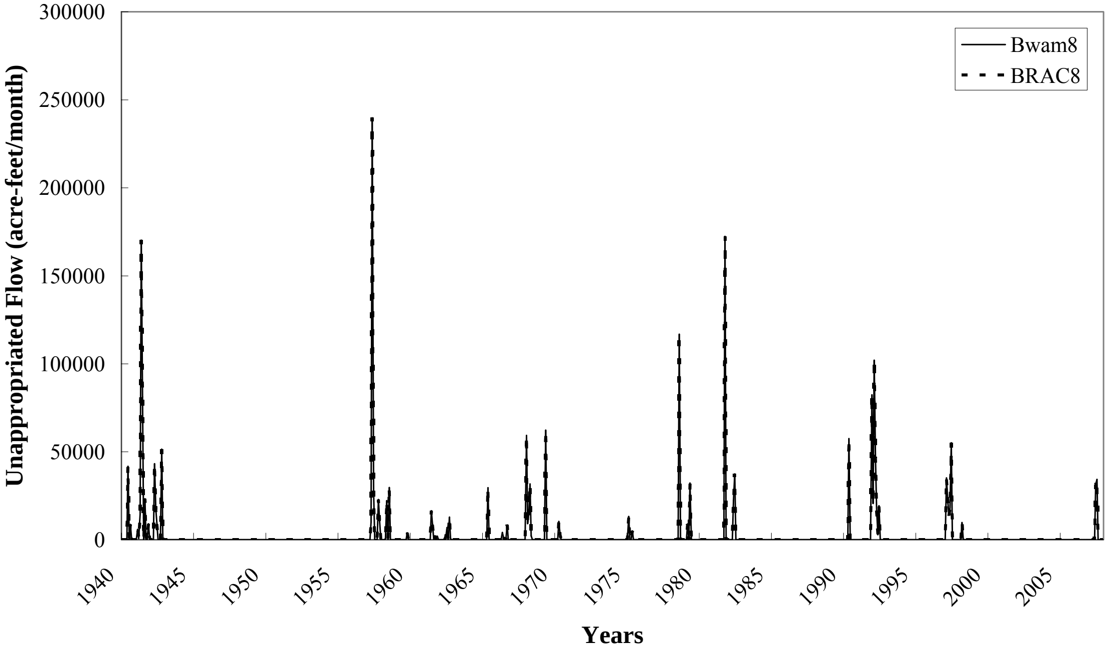

Figure 5.7 1940-2007 Bwam8 and BRAC8 UNA Flows at Hubbard Creek

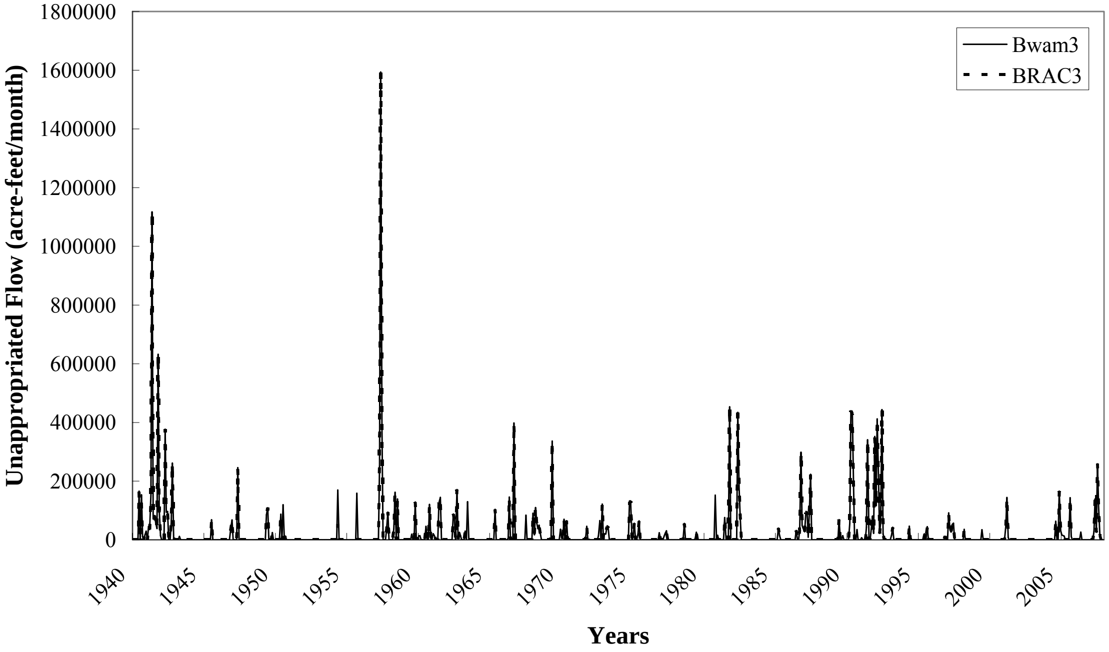

Figure 5.8 1940-2007 Bwam3 and BRAC3 UNA Flows at Possum Kingdom

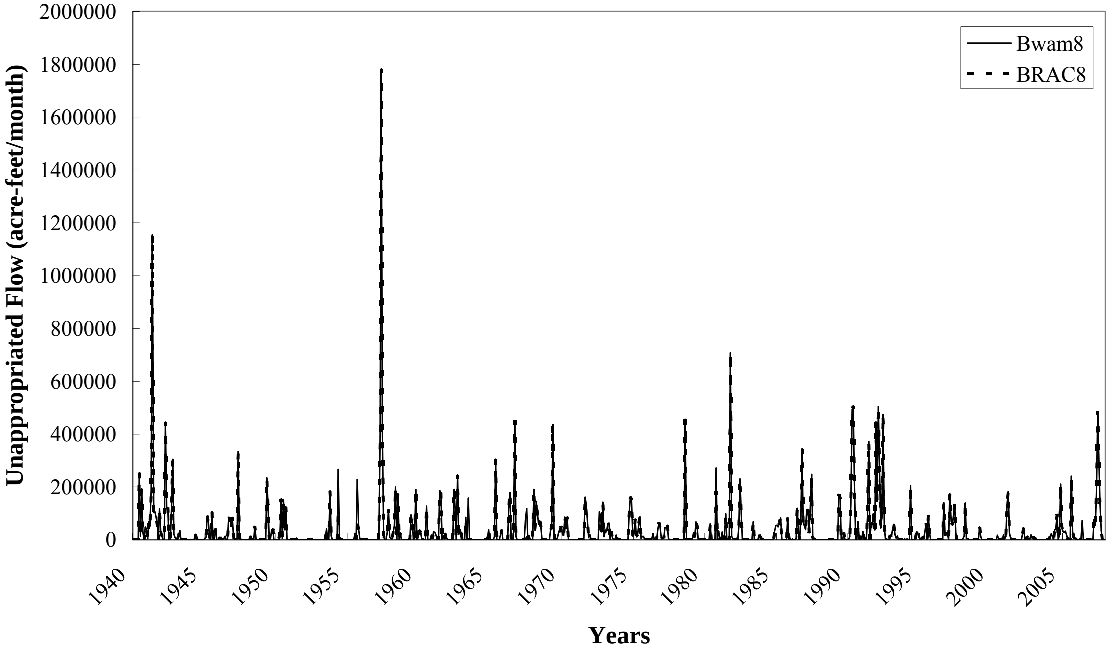

Figure 5.9 1940-2007 Bwam8 and BRAC8 UNA Flows at Possum Kingdom

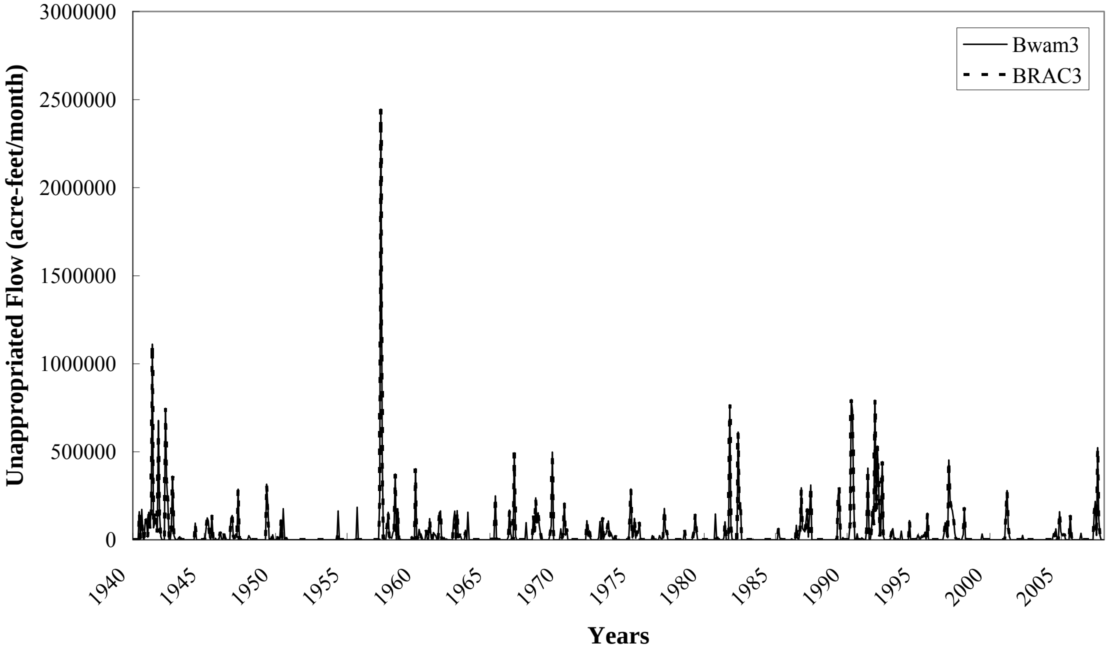

Figure 5.10 1940-2007 Bwam3 and BRAC3 UNA Flows at Granbury Reservoir

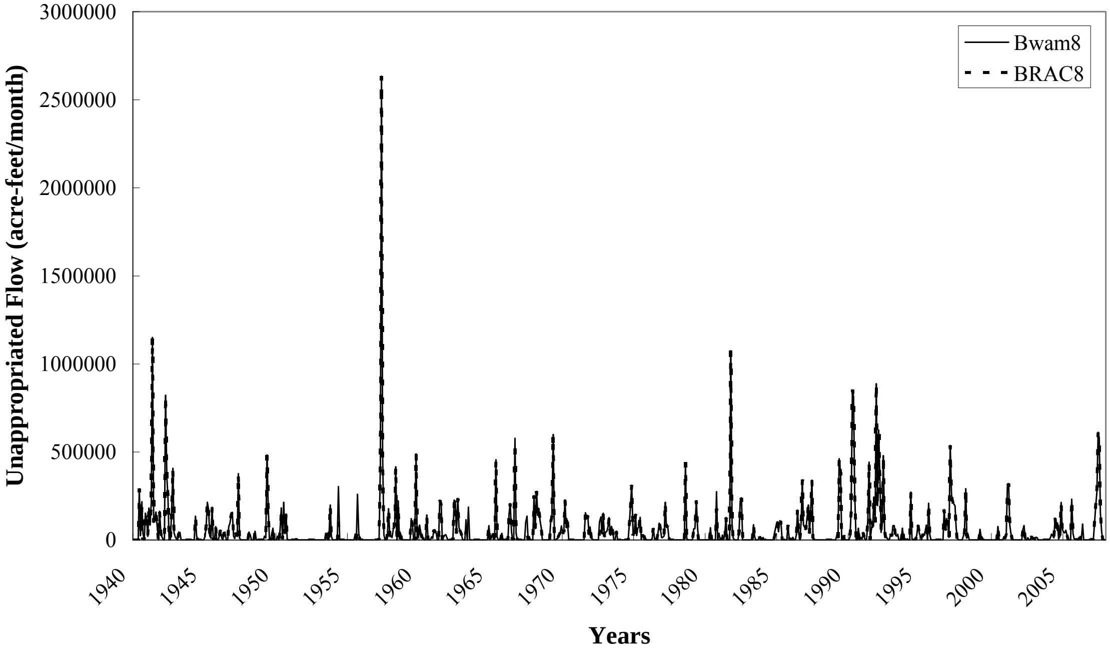

Figure 5.11 1940-2007 Bwam8 and BRAC8 UNA Flows at Granbury Reservoir

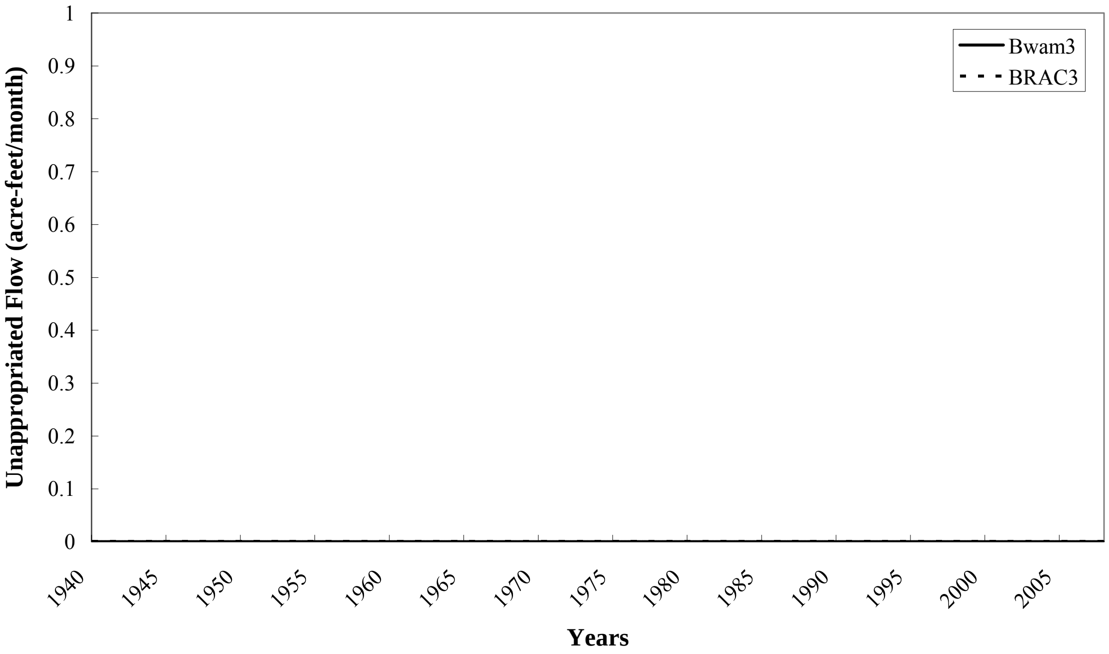

Figure 5.12 1940-2007 Bwam3 and BRAC3 UNA Flows at Squaw Creek Reservoir

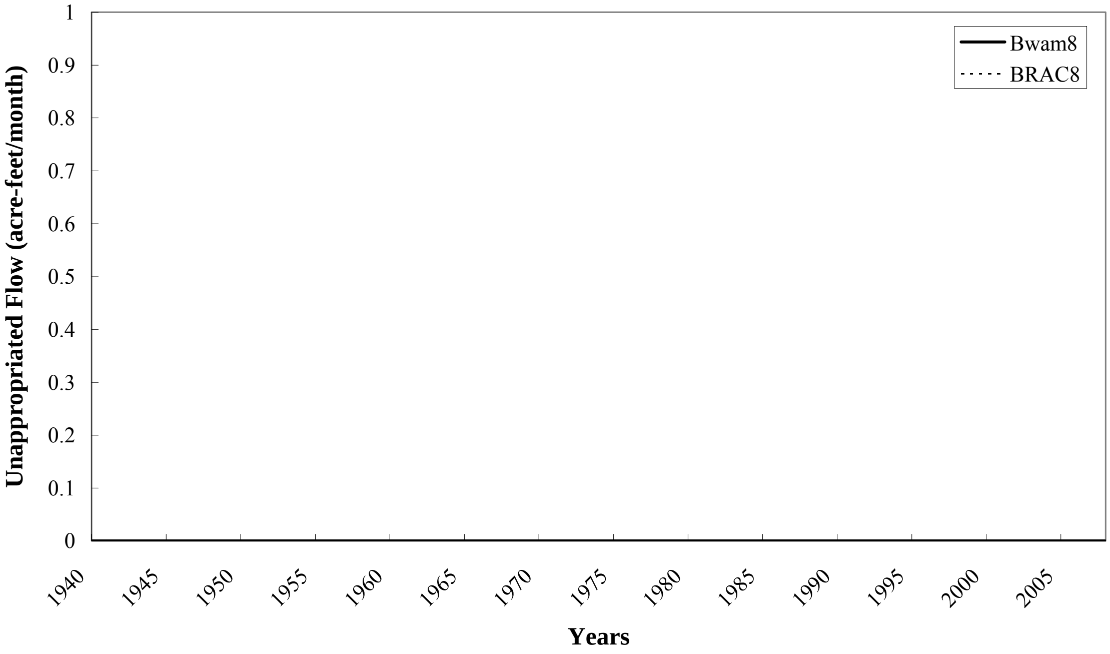

Figure 5.13 1940-2007 Bwam8 and BRAC8 UNA Flows at Squaw Creek Reservoir

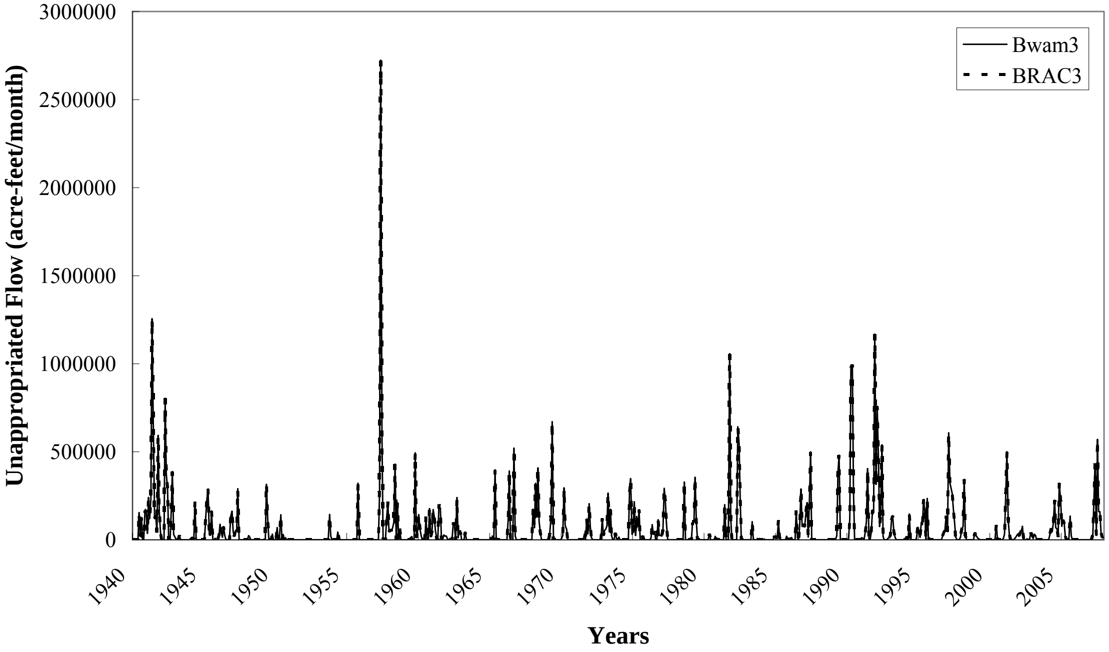

Figure 5.14 1940-2007 Bwam3 and BRAC3 UNA Flows at Whitney Reservoir

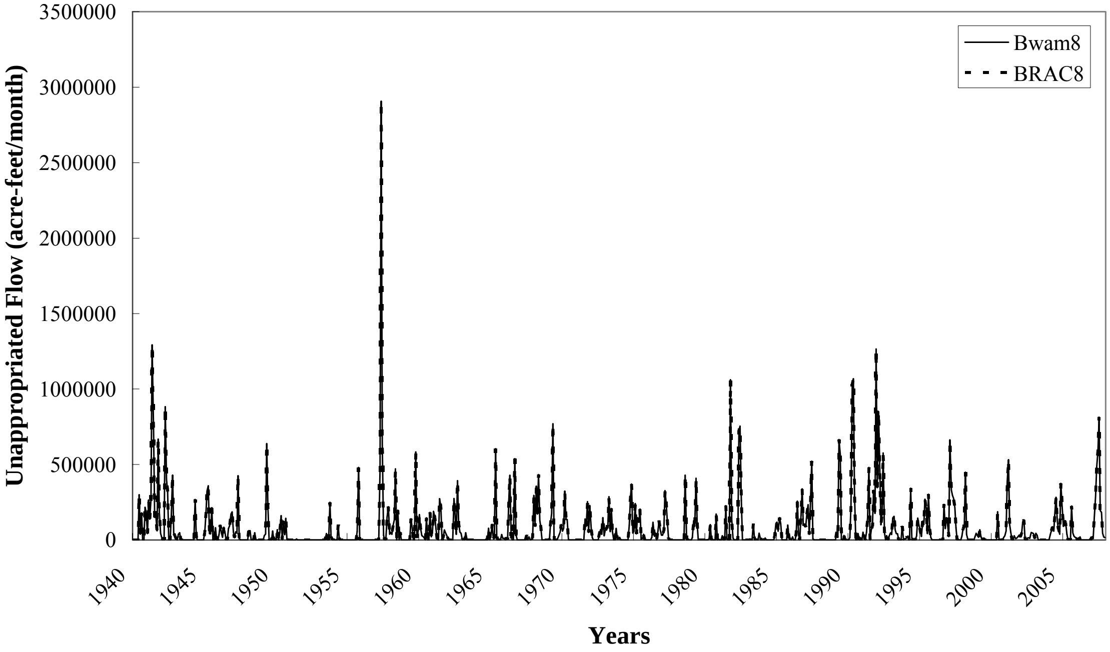

Figure 5.15 1940-2007 Bwam8 and BRAC8 UNA Flows at Whitney Reservoir

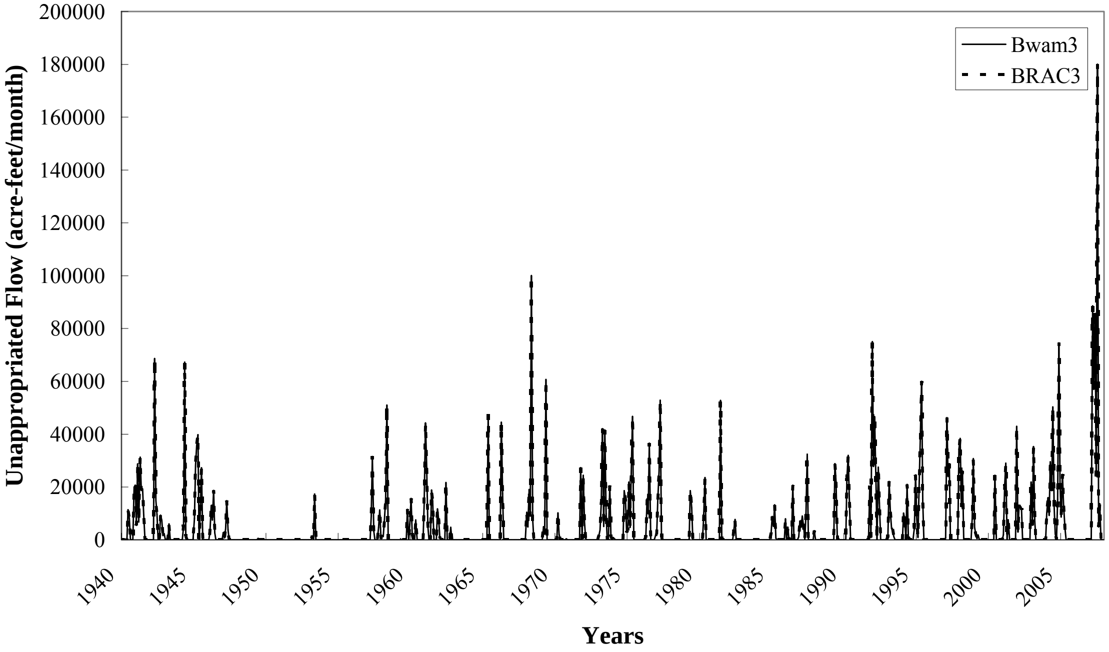

Figure 5.16 1940-2007 Bwam8 and BRAC8 UNA Flows at Aquilla Reservoir

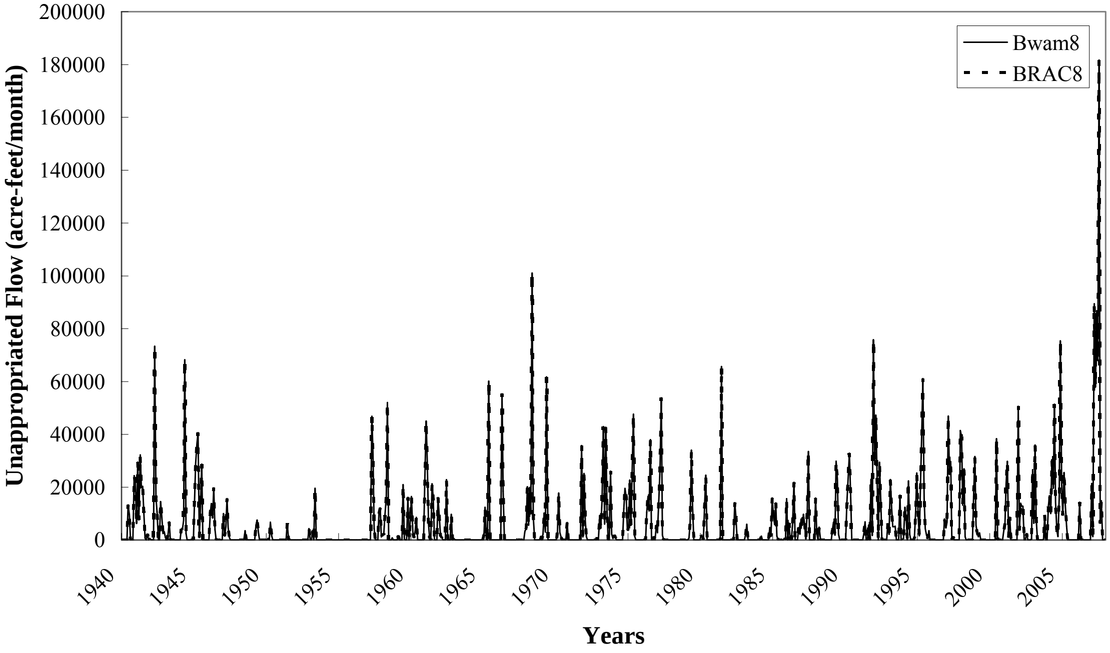

Figure 5.17 1940-2007 Bwam8 and BRAC8 UNA Flows at Aquilla Reservoir

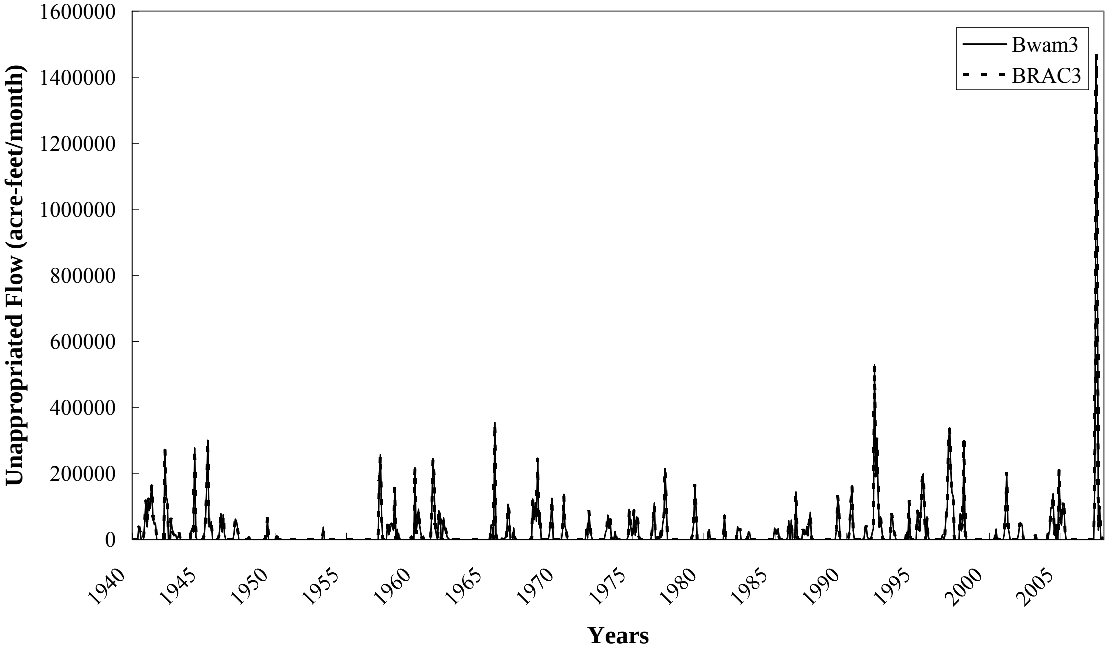

Figure 5.18 1940-2007 Bwam8 and BRAC8 UNA Flows at Waco Reservoir

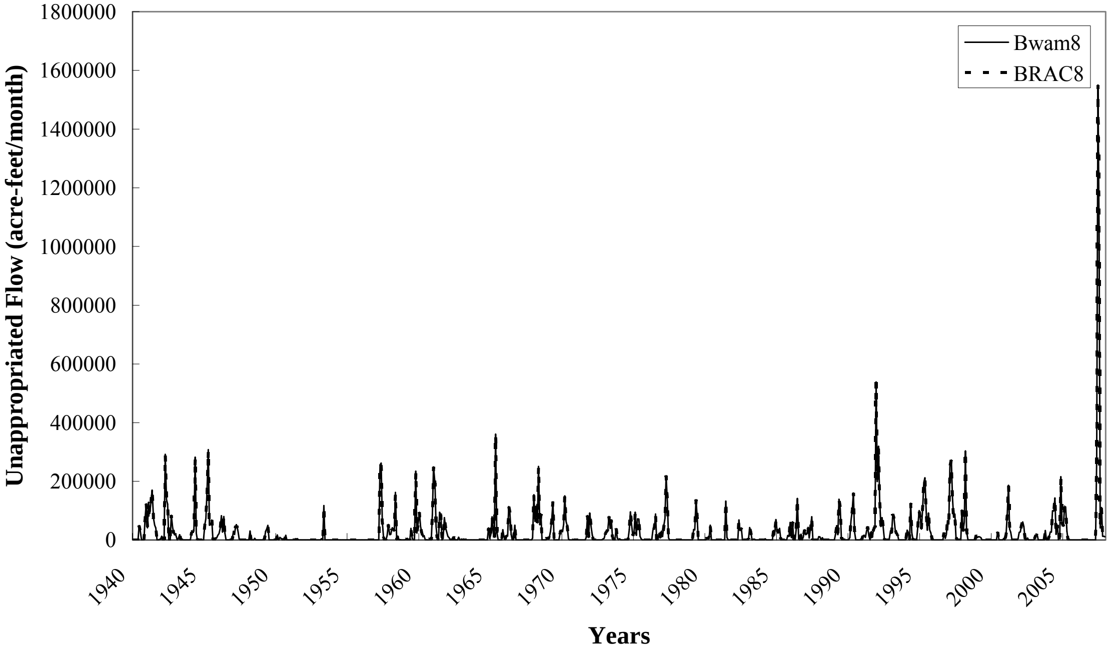

Figure 5.19 1940-2007 Bwam8 and BRAC8 UNA Flows at Waco Reservoir

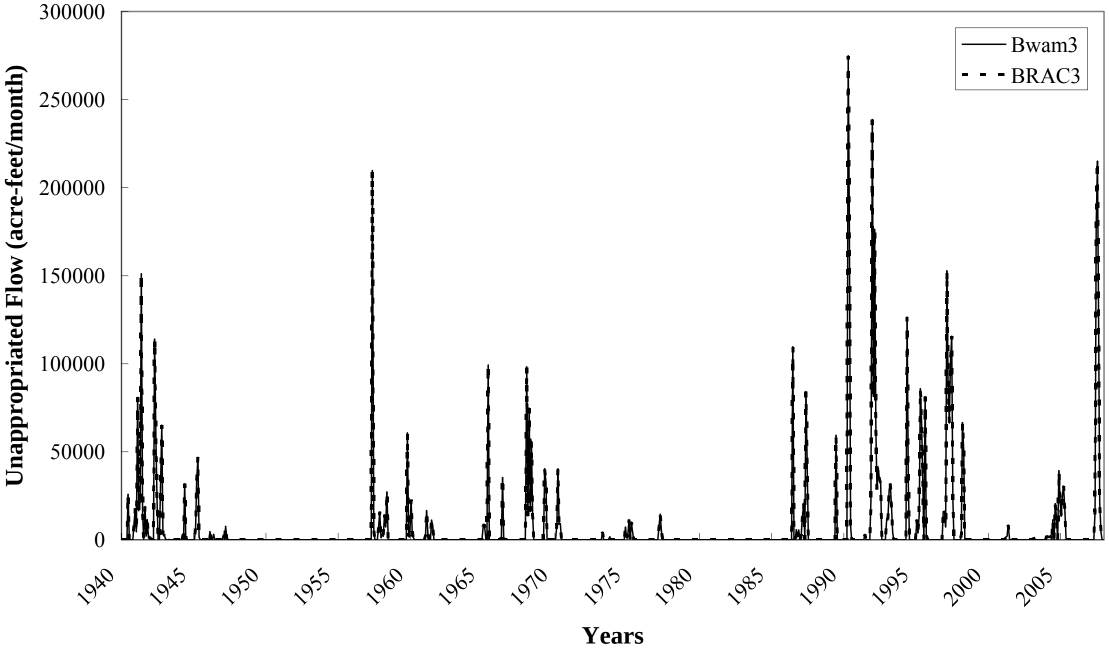

Figure 5.20 1940-2007 Bwam3 and BRAC3 UNA Flows at Proctor Reservoir

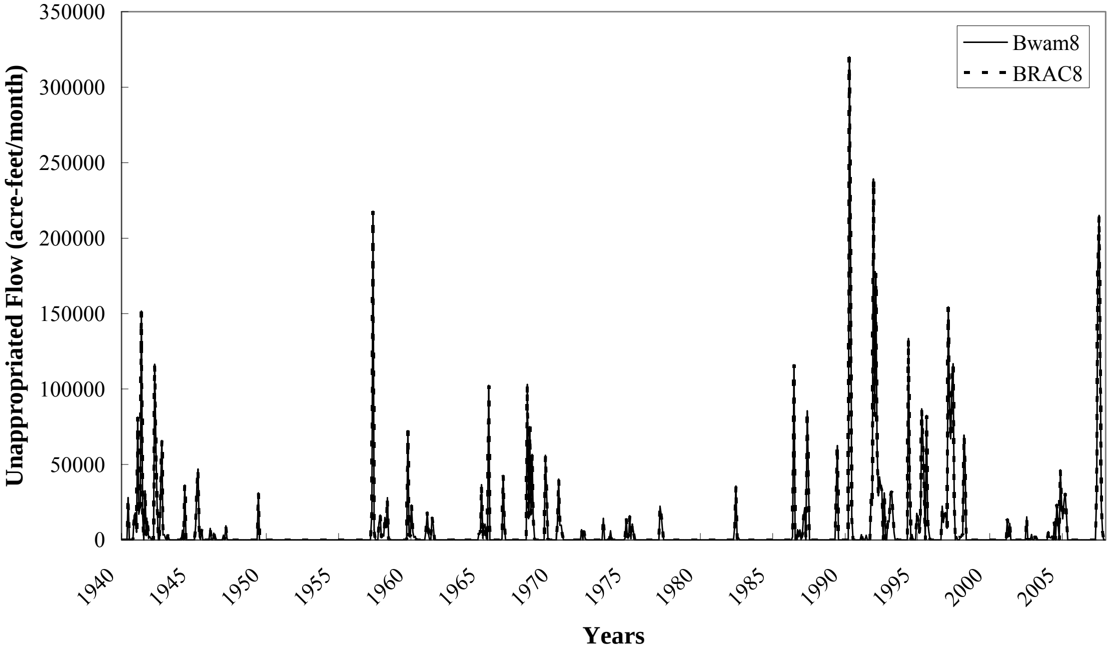

Figure 5.21 1940-2007 Bwam8 and BRAC8 UNA Flows at Proctor Reservoir

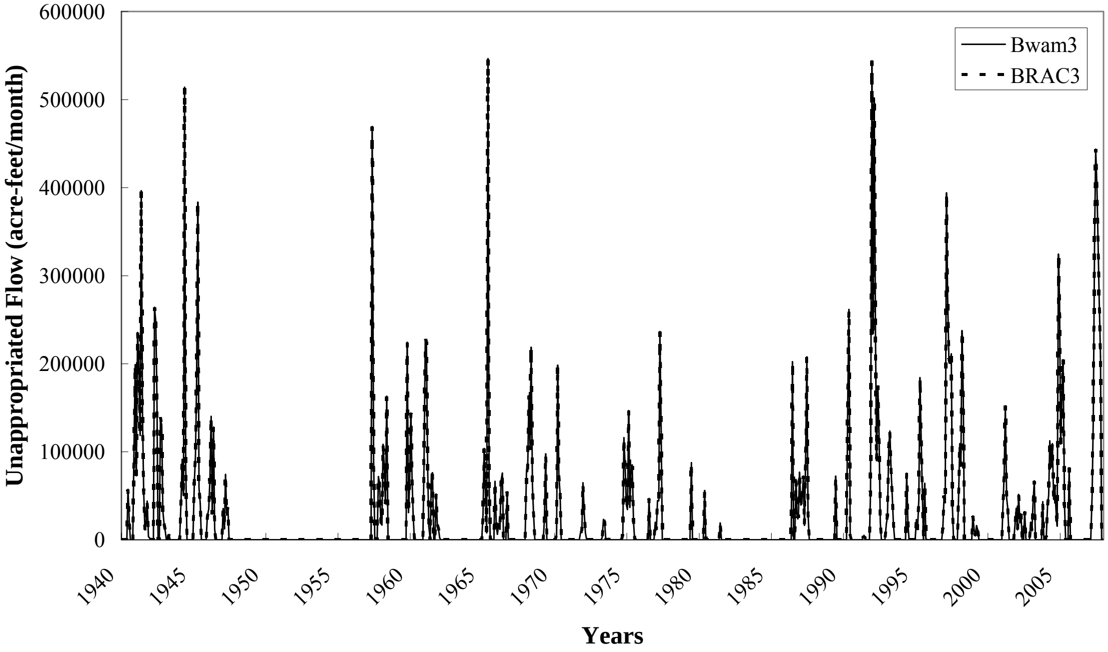

Figure 5.22 1940-2007 Bwam3 and BRAC3 UNA Flows at Belton Reservoir

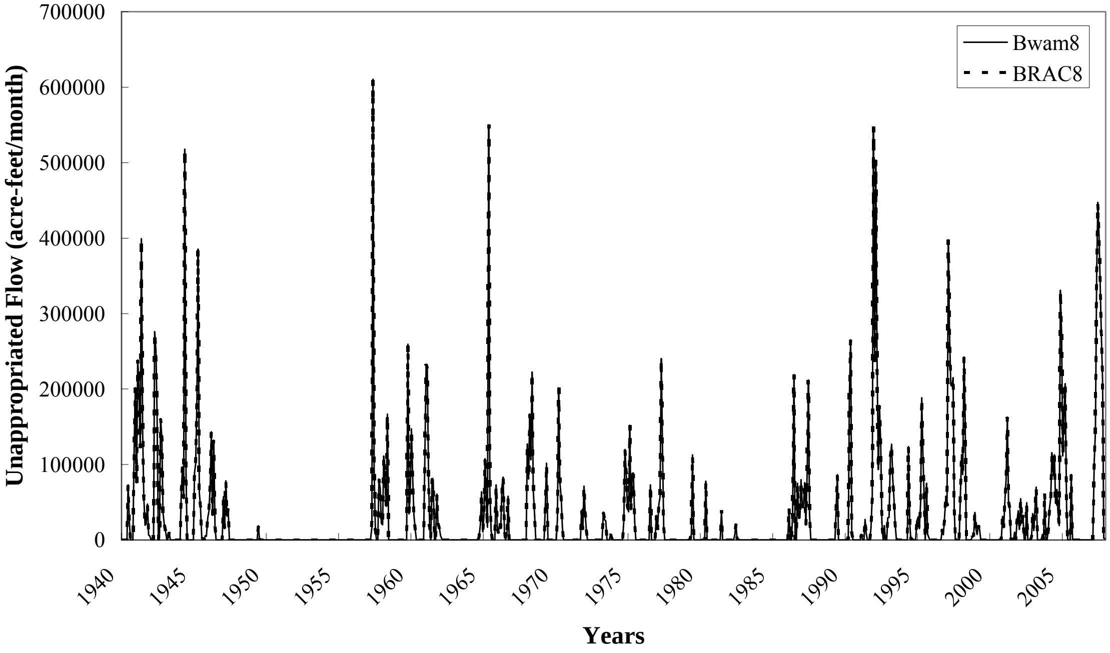

Figure 5.23 1940-2007 Bwam8 and BRAC8 UNA Flows at Belton Reservoir

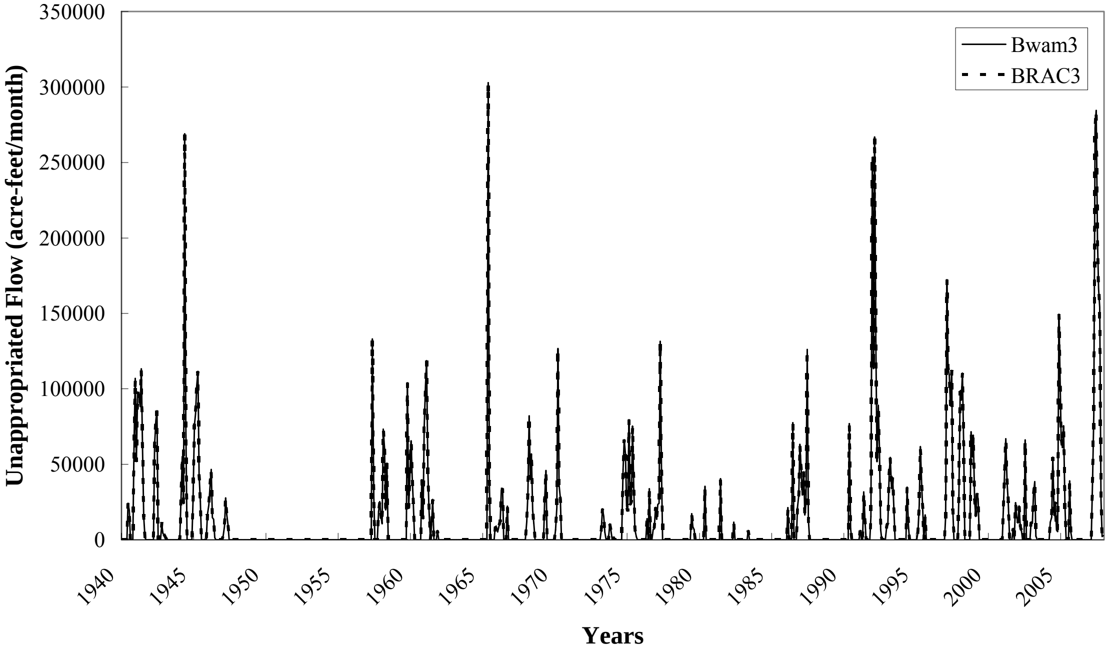

Figure 5.24 1940-2007 Bwam3 and BRAC3 UNA Flows at Stillhouse Hollow

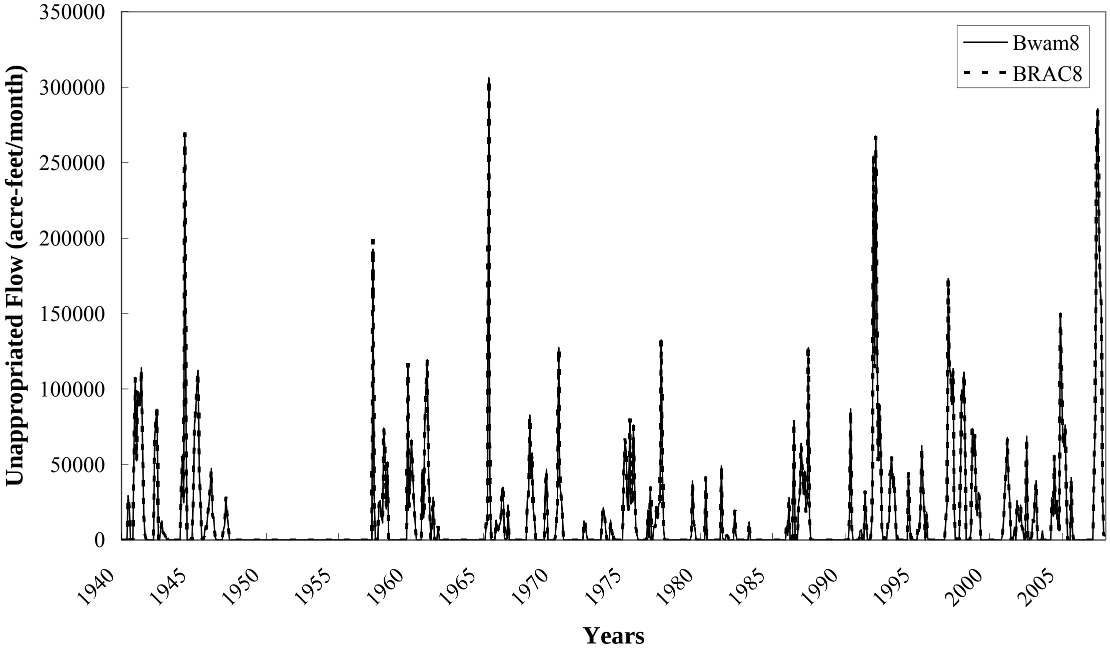

Figure 5.25 1940-2007 Bwam8 and BRAC8 UNA Flows at Stillhouse Hollow

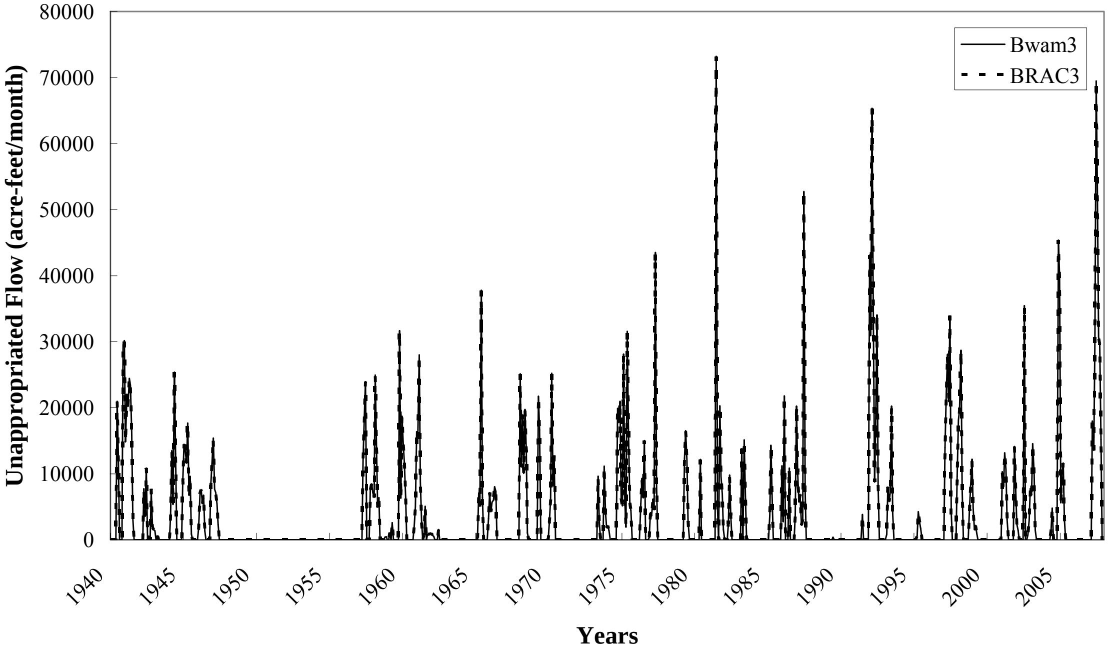

Figure 5.26 1940-2007 Bwam3 and BRAC3 UNA Flows at Georgetown Reservoir

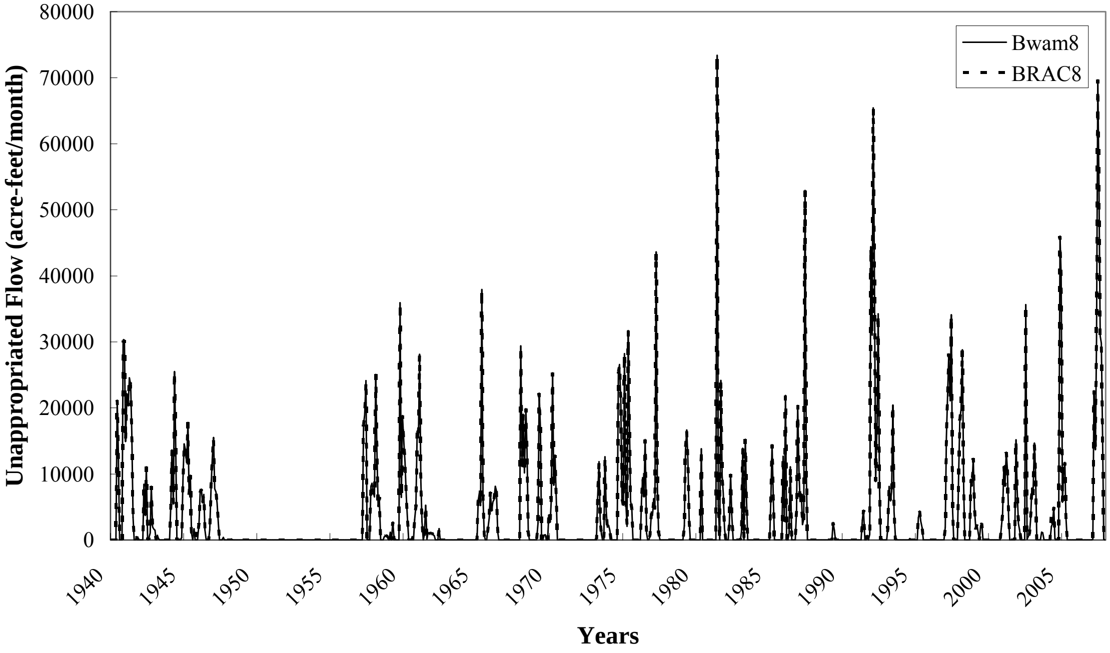

Figure 5.27 1940-2007 Bwam8 and BRAC8 UNA Flows at Georgetown Reservoir

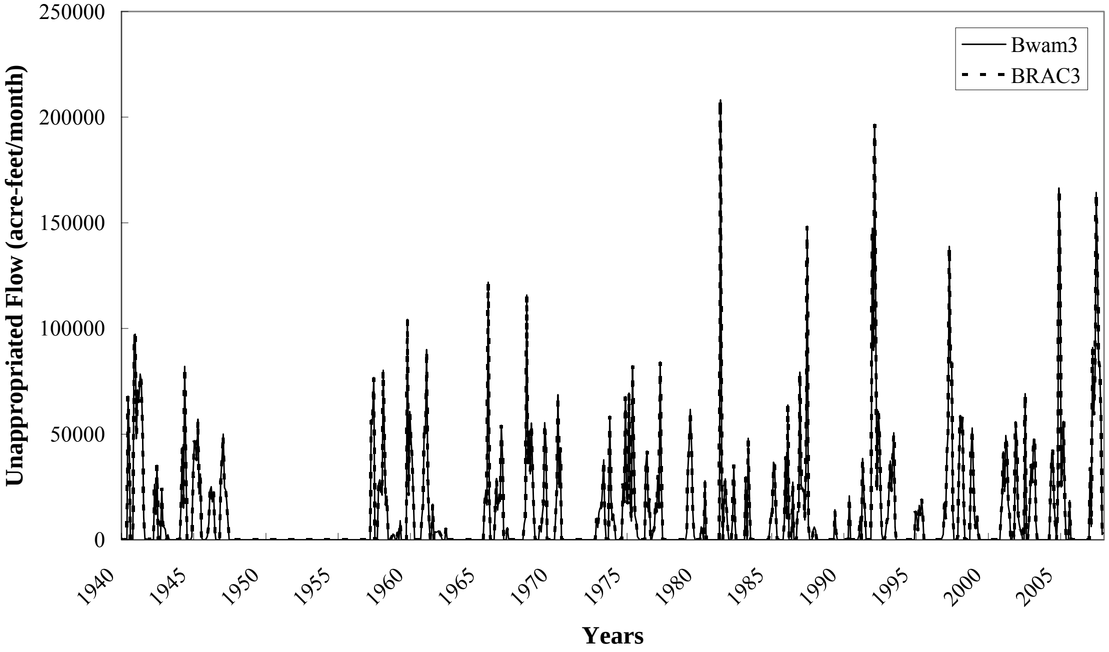

Figure 5.28 1940-2007 Bwam3 and BRAC3 UNA Flows at Granger Reservoir

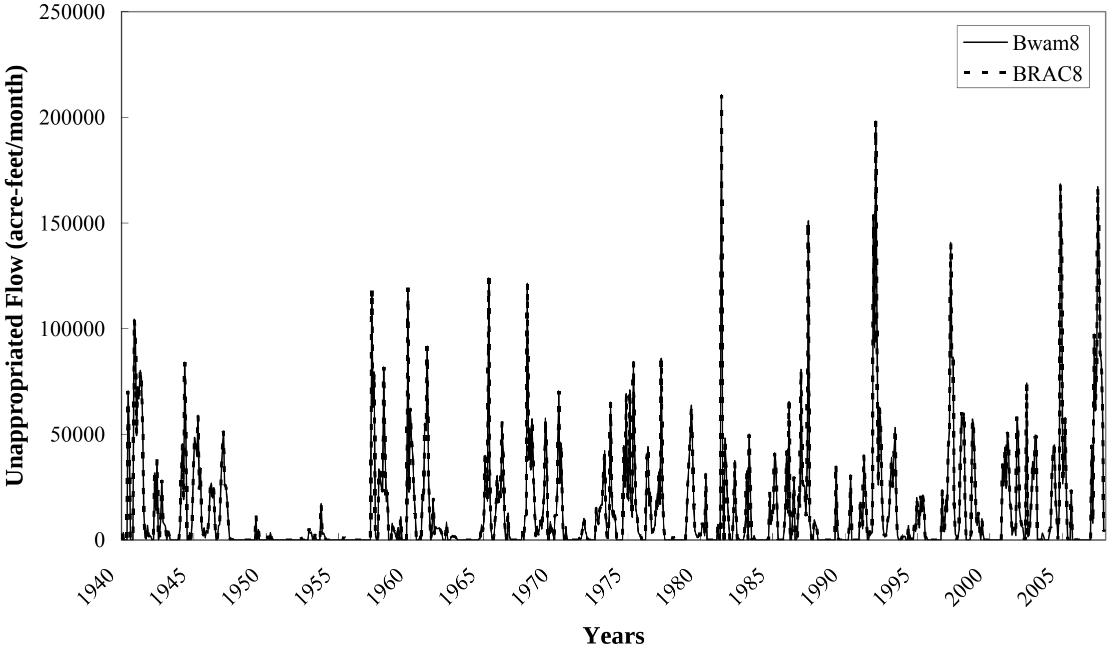

Figure 5.29 1940-2007 Bwam8 and BRAC8 UNA Flows at Granger Reservoir

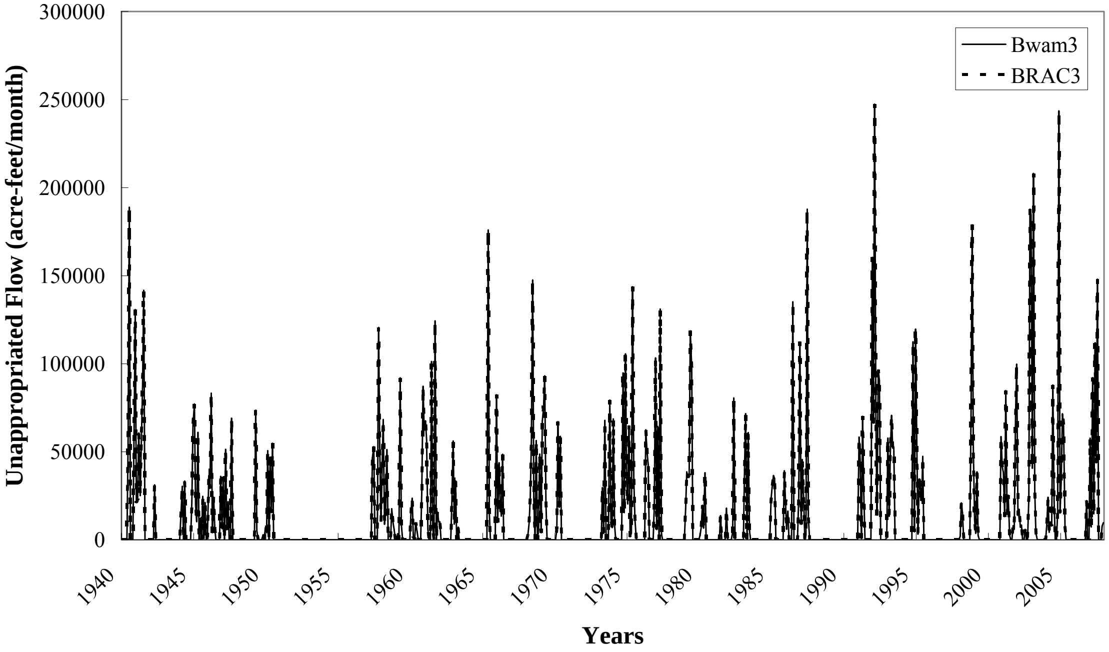

Figure 5.30 1940-2007 Bwam3 and BRAC3 UNA Flows at Somerville Reservoir

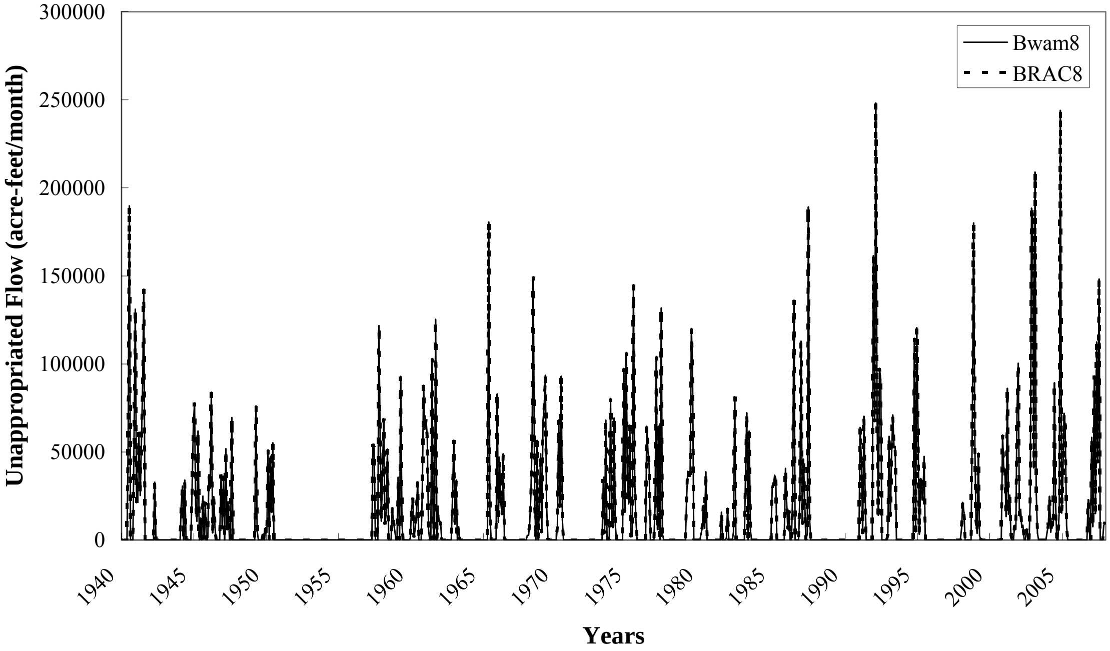

Figure 5.31 1940-2007 Bwam8 and BRAC8 UNA Flows at Somerville Reservoir

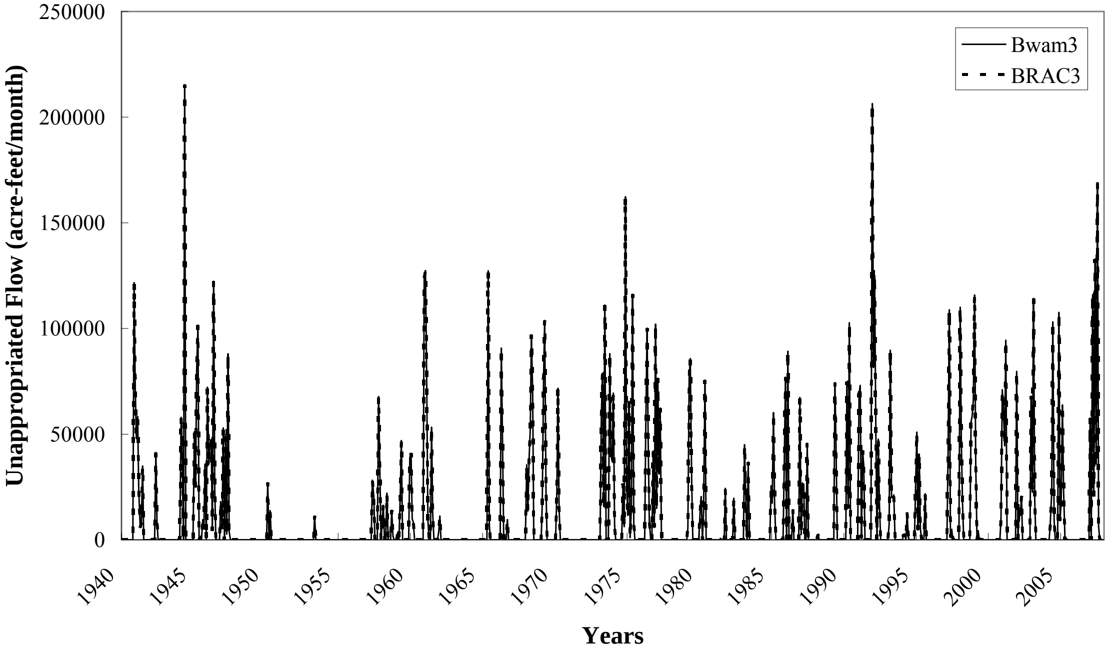

Figure 5.32 1940-2007 Bwam3 and BRAC3 UNA Flows at Limestone Reservoir

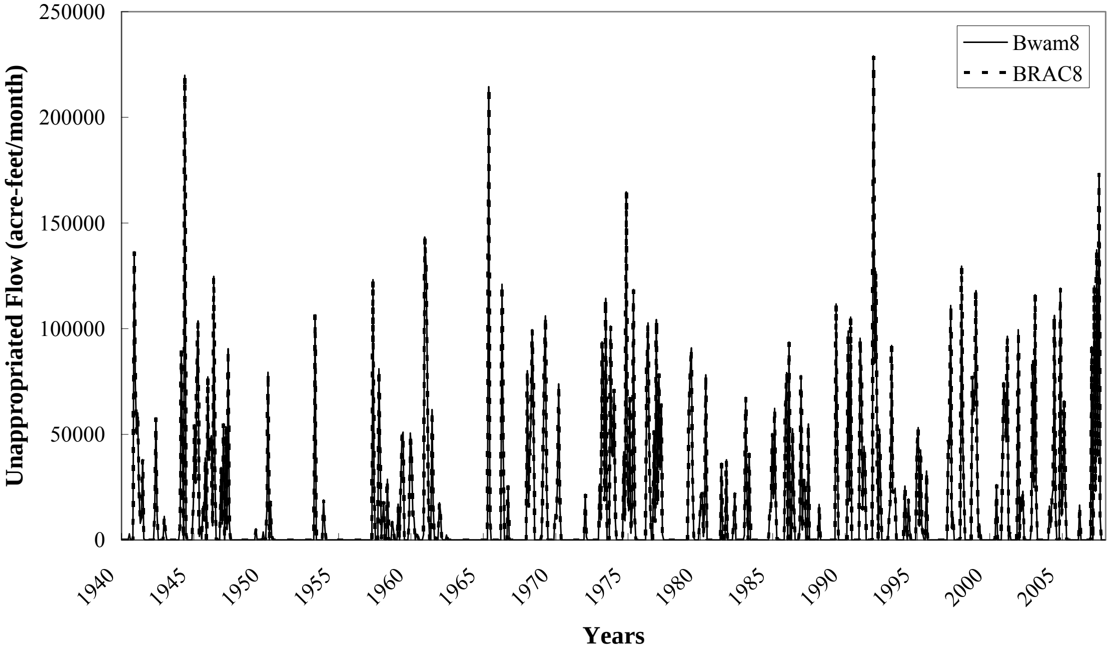

Figure 5.33 1940-2007 Bwam8 and BRAC8 UNA Flows at Limestone Reservoir

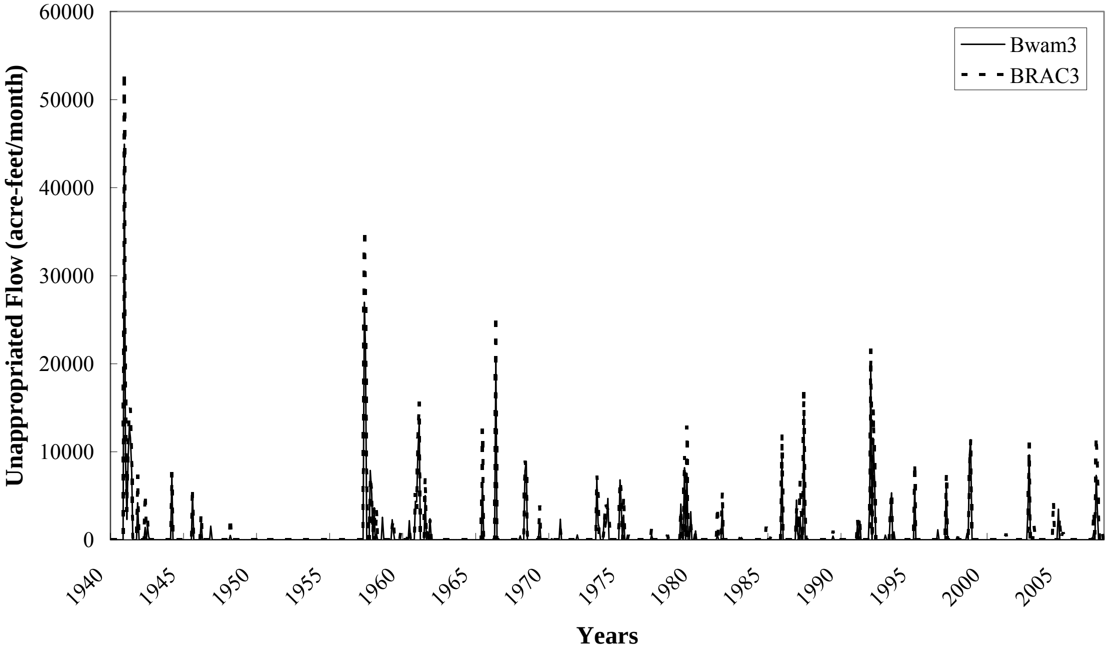

Figure 5.34 1940-2007 Bwam3 and BRAC3 UNA Flows at Allens Creek Reservoir

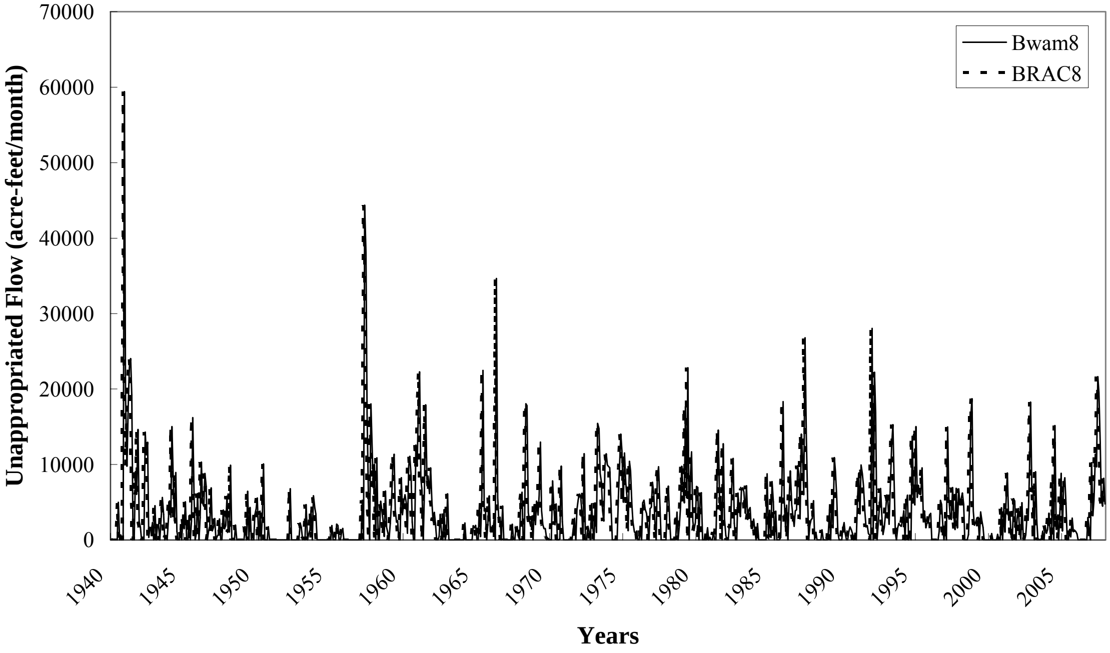

Figure 5.35 1940-2007 Bwam8 and BRAC8 UNA Flows at Allens Creek Reservoir

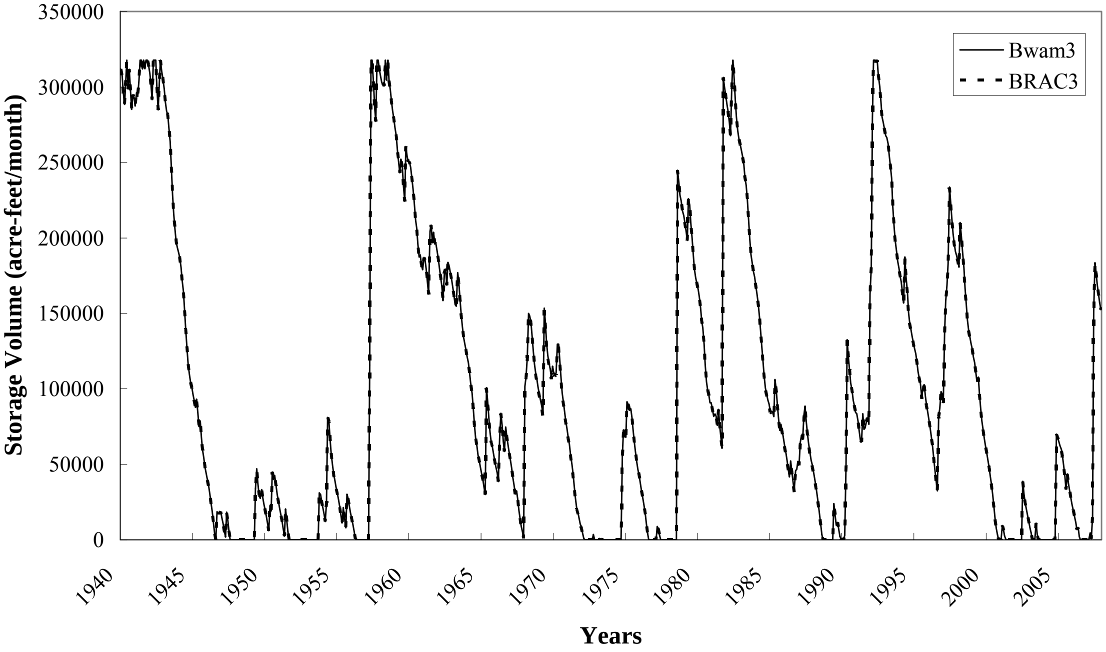

Figure 5.36 1940-2007 Bwam3 and BRAC3 Storage Volume of Hubbard Creek

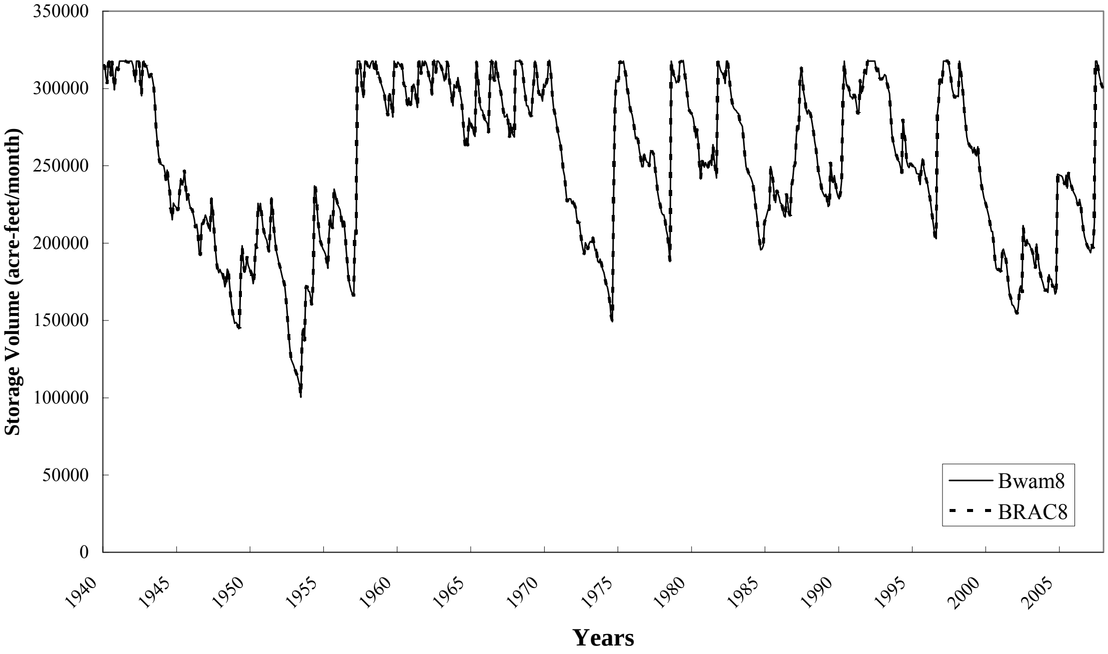

Figure 5.37 1940-2007 Bwam8 and BRAC8 Storage Volume of Hubbard Creek

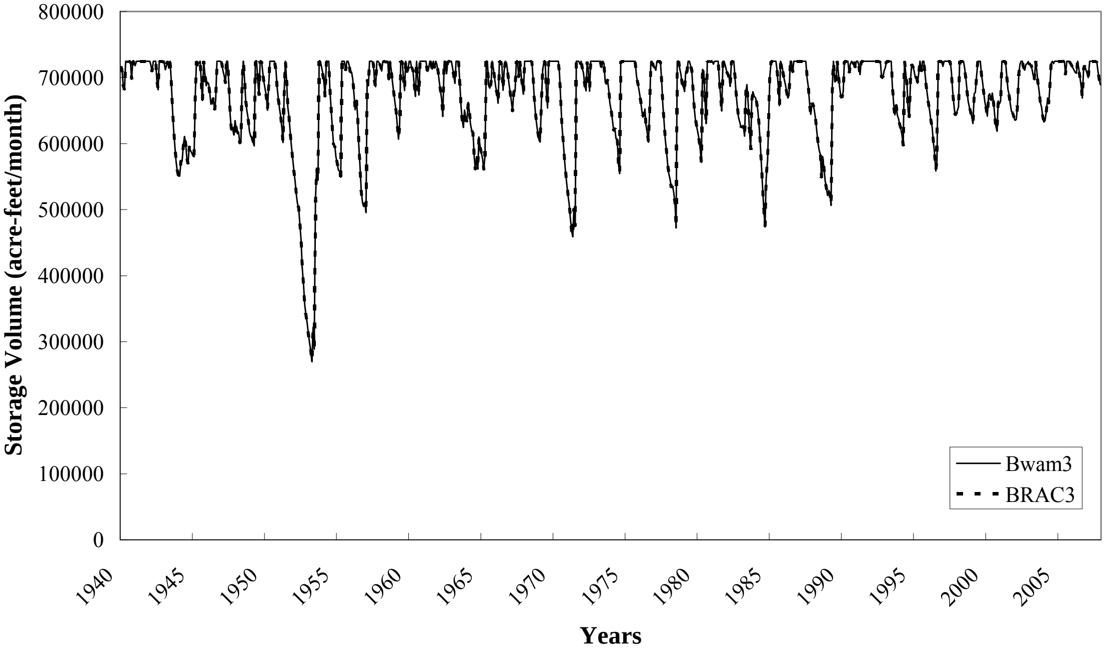

Figure 5.38 1940-2007 Bwam3 and BRAC3 Storage Volume of Possum Kingdom

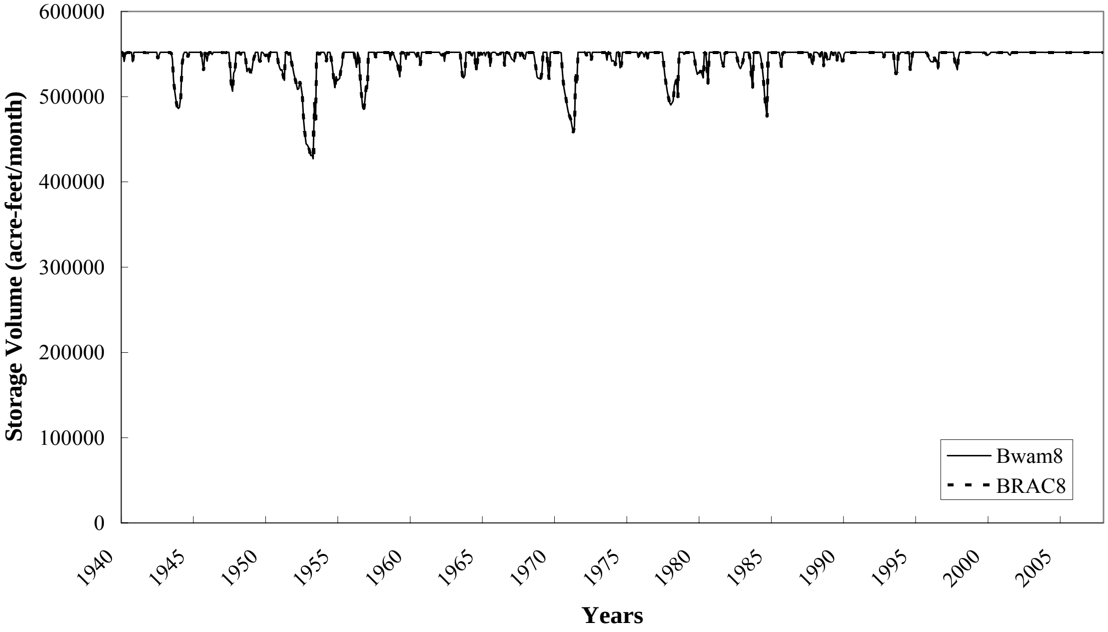

Figure 5.39 1940-2007 Bwam8 and BRAC8 Storage Volume of Possum Kingdom

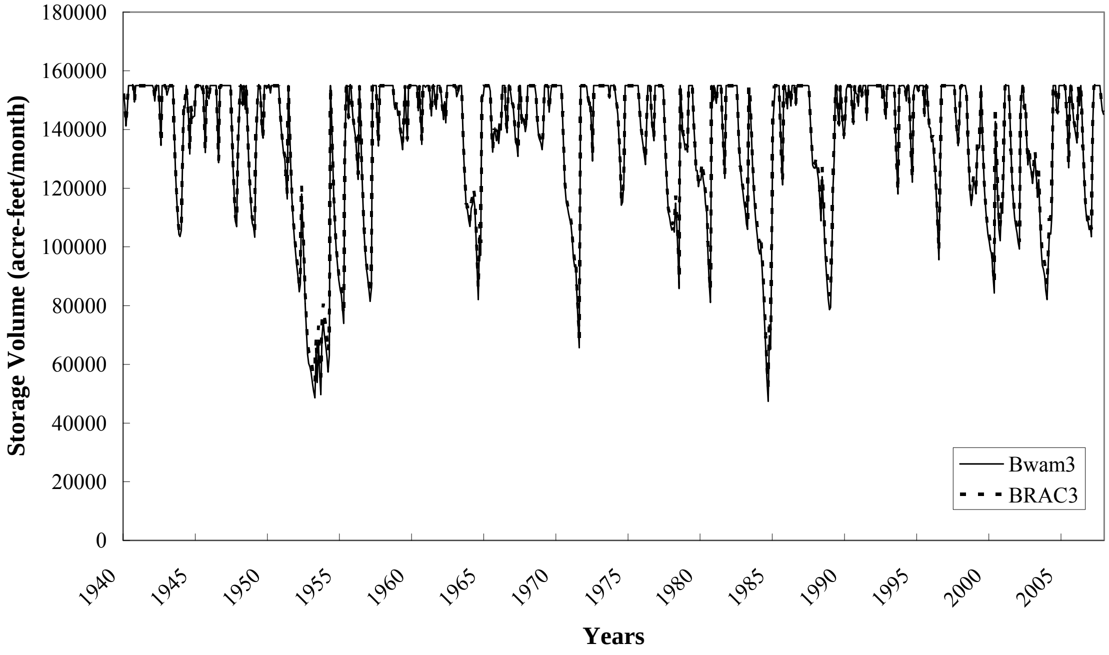

Figure 5.40 1940-2007 Bwam3 and BRAC3 Storage Volume of Granbury Reservoir

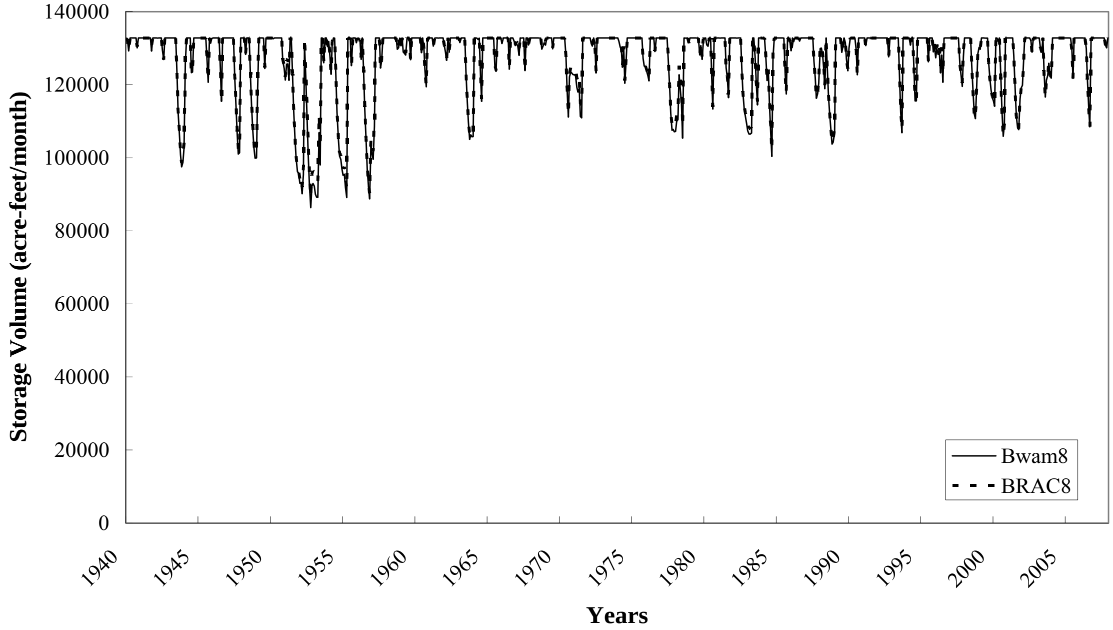

Figure 5.41 1940-2007 Bwam8 and BRAC8 Storage Volume of Granbury Reservoir

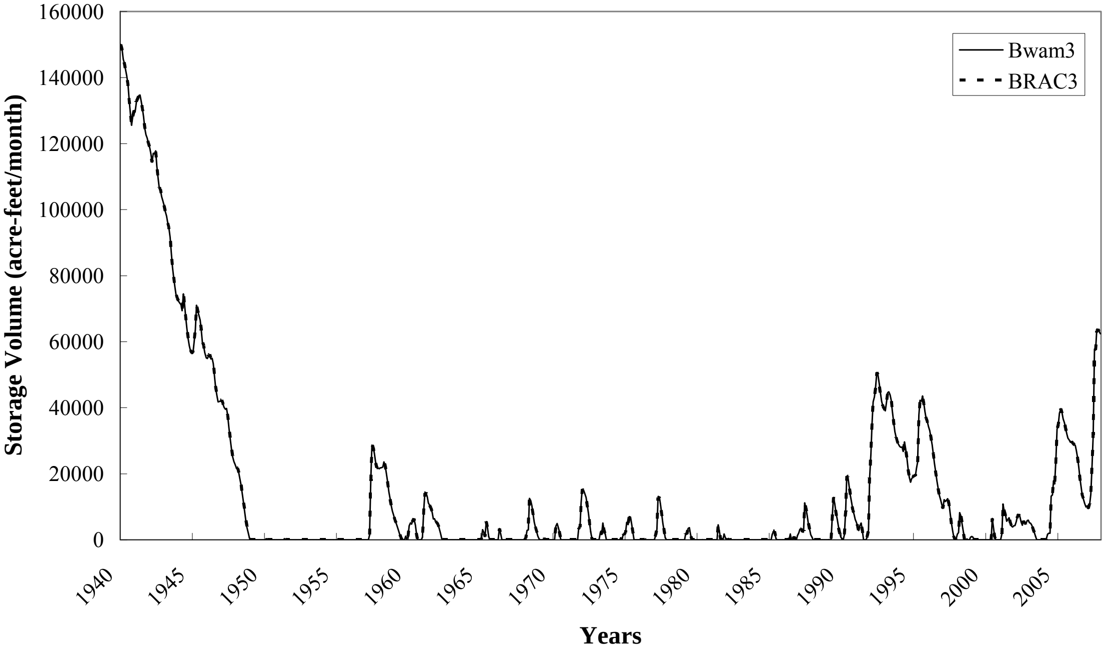

Figure 5.42 1940-2007 Bwam3 and BRAC3 Storage Volume of Squaw Creek

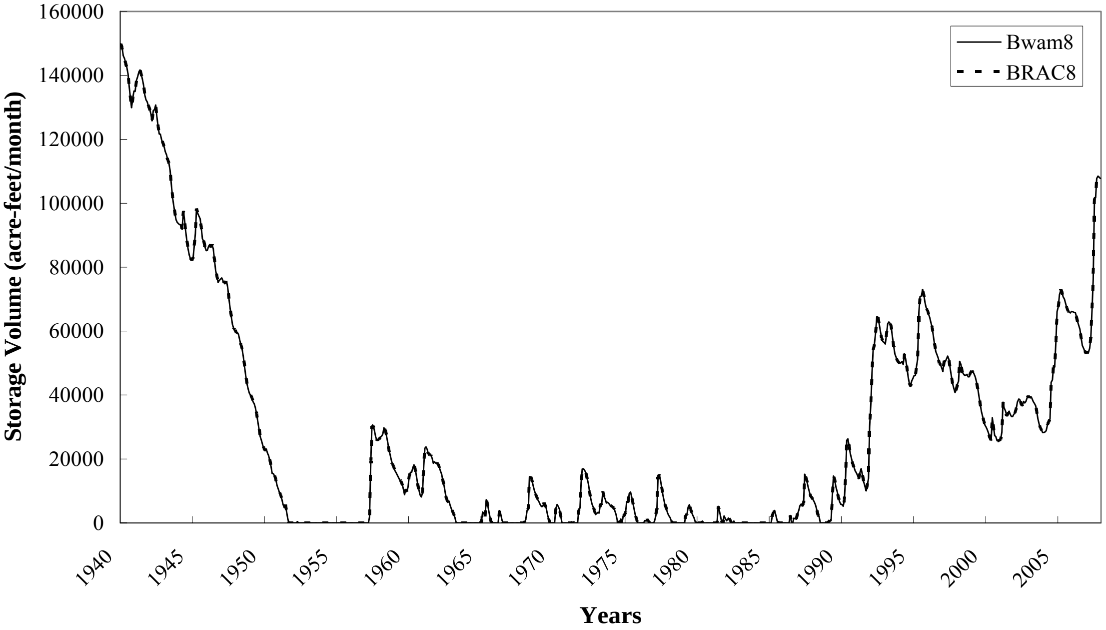

Figure 5.43 1940-2007 Bwam8 and BRAC8 Storage Volume of Squaw Creek

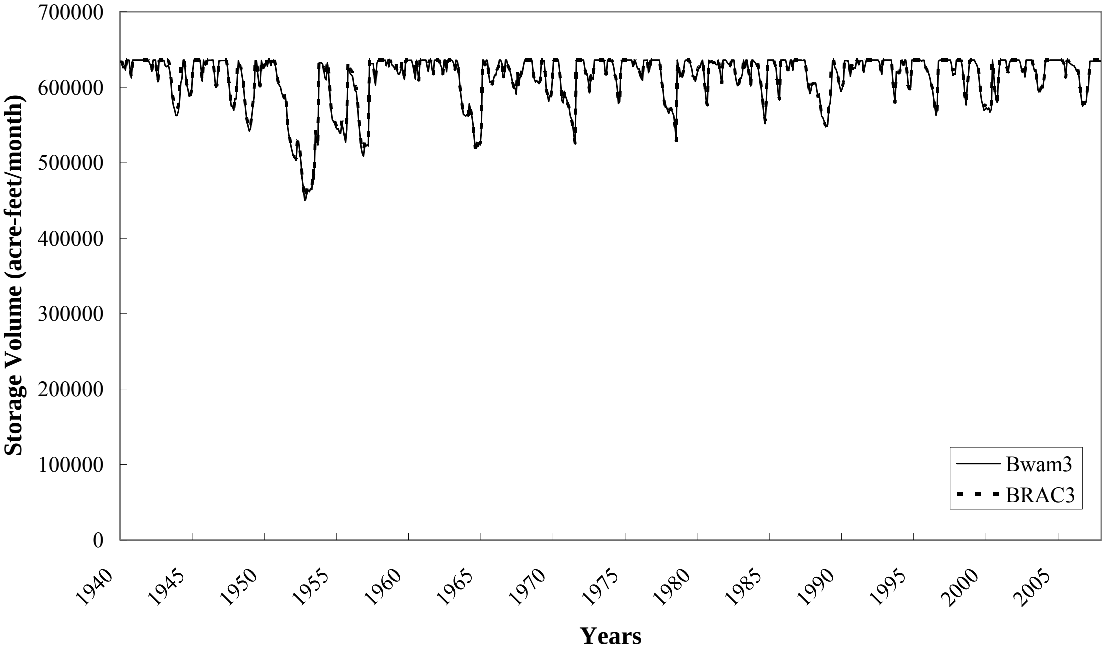

Figure 5.44 1940-2007 Bwam3 and BRAC3 Storage Volume of Whitney Reservoir

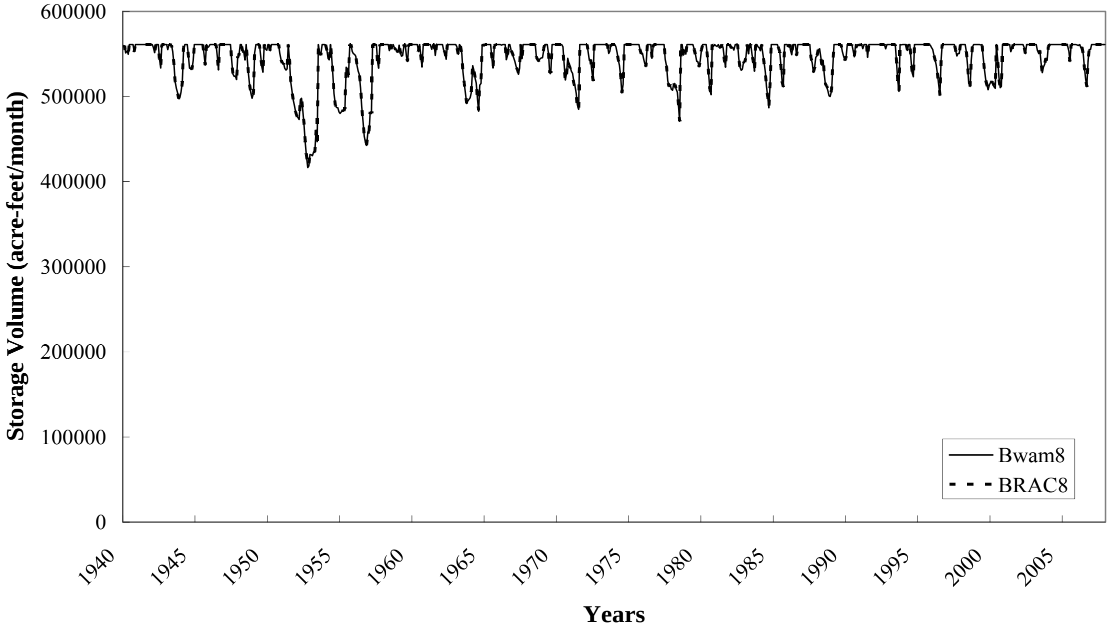

Figure 5.45 1940-2007 Bwam8 and BRAC8 Storage Volume of Whitney Reservoir

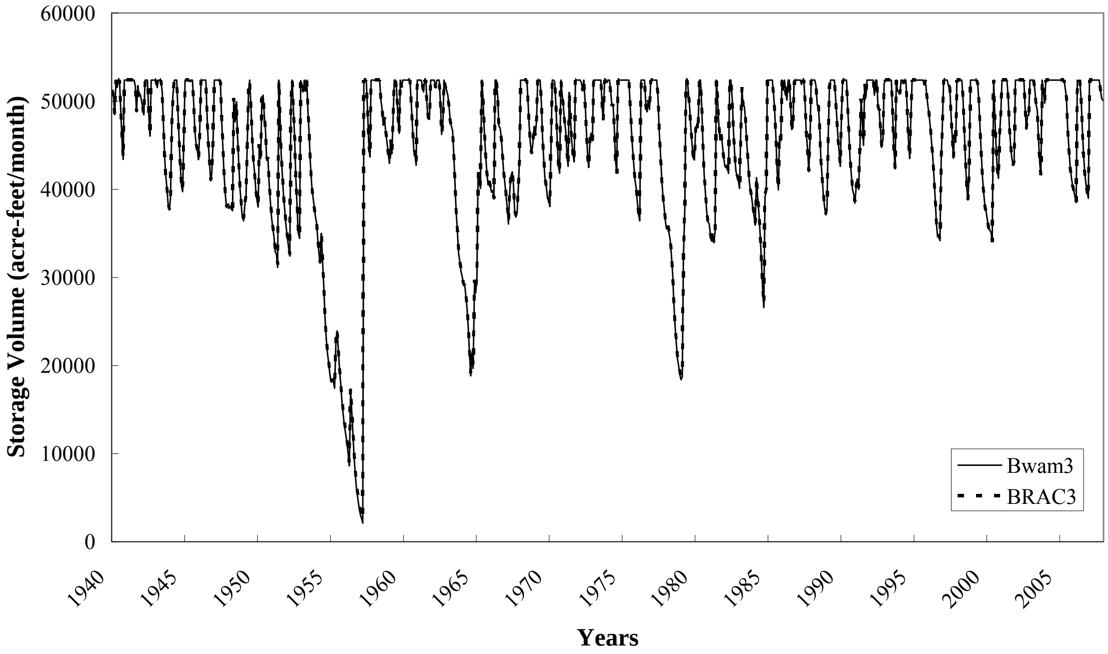

Figure 5.46 1940-2007 Bwam3 and BRAC3 Storage Volume of Aquilla Reservoir

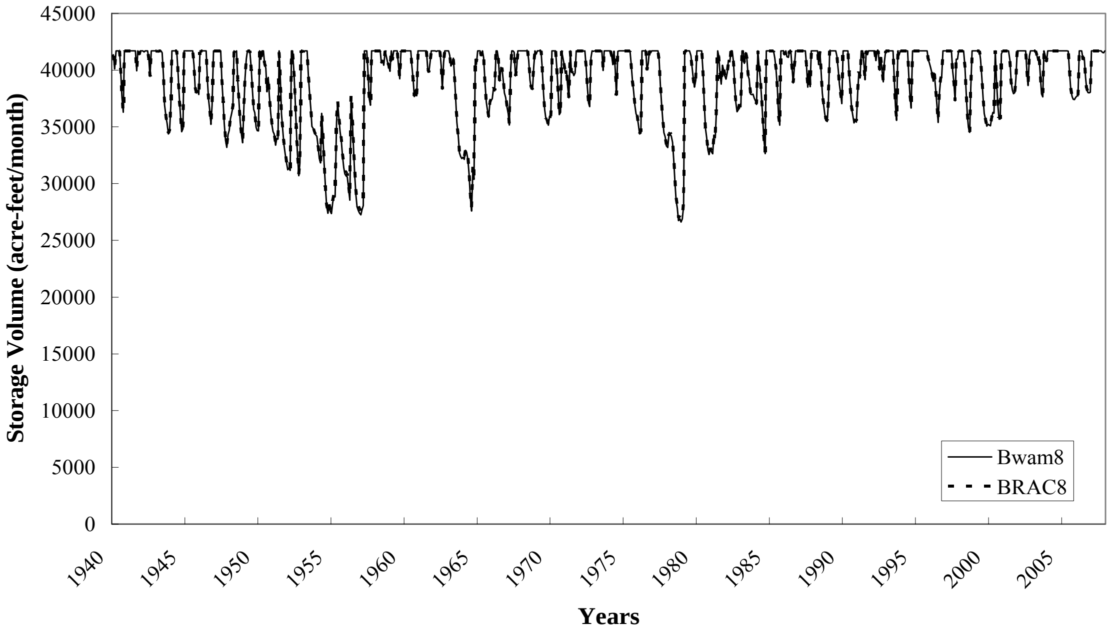

Figure 5.47 1940-2007 Bwam8 and BRAC8 Storage Volume of Aquilla Reservoir

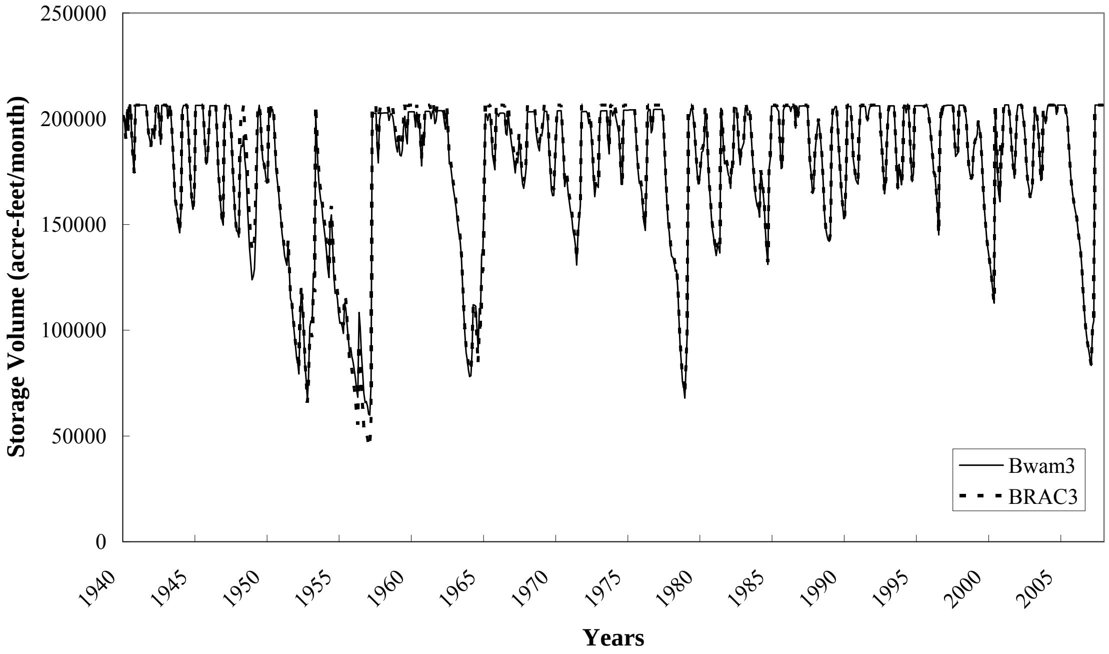

Figure 5.48 1940-2007 Bwam3 and BRAC3 Storage Volume of Waco Reservoir

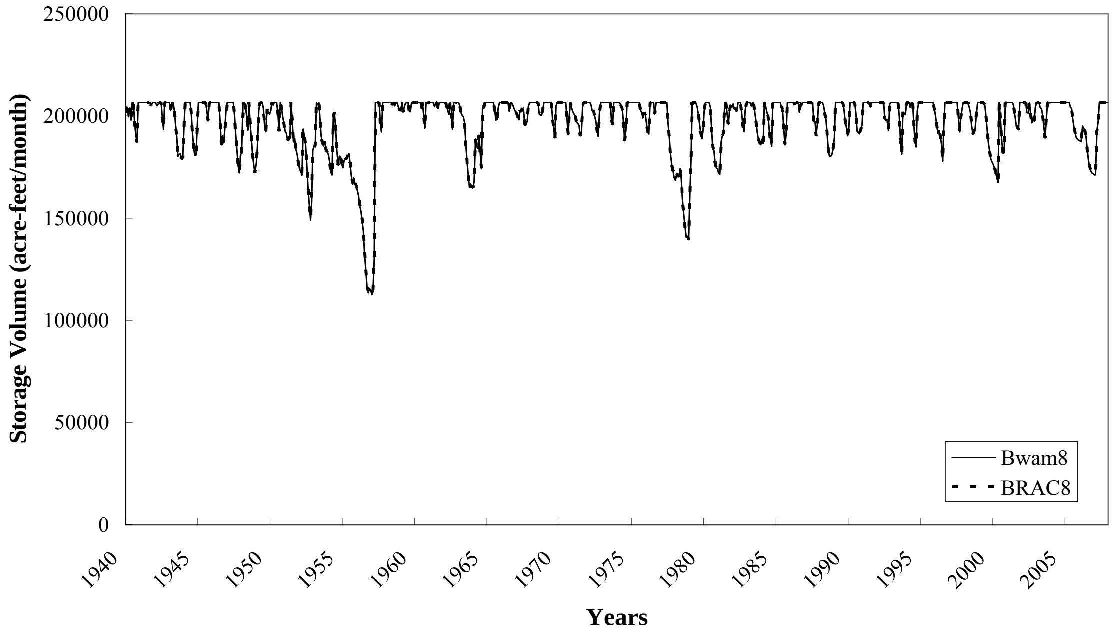

Figure 5.49 1940-2007 Bwam8 and BRAC8 Storage Volume of Waco Reservoir

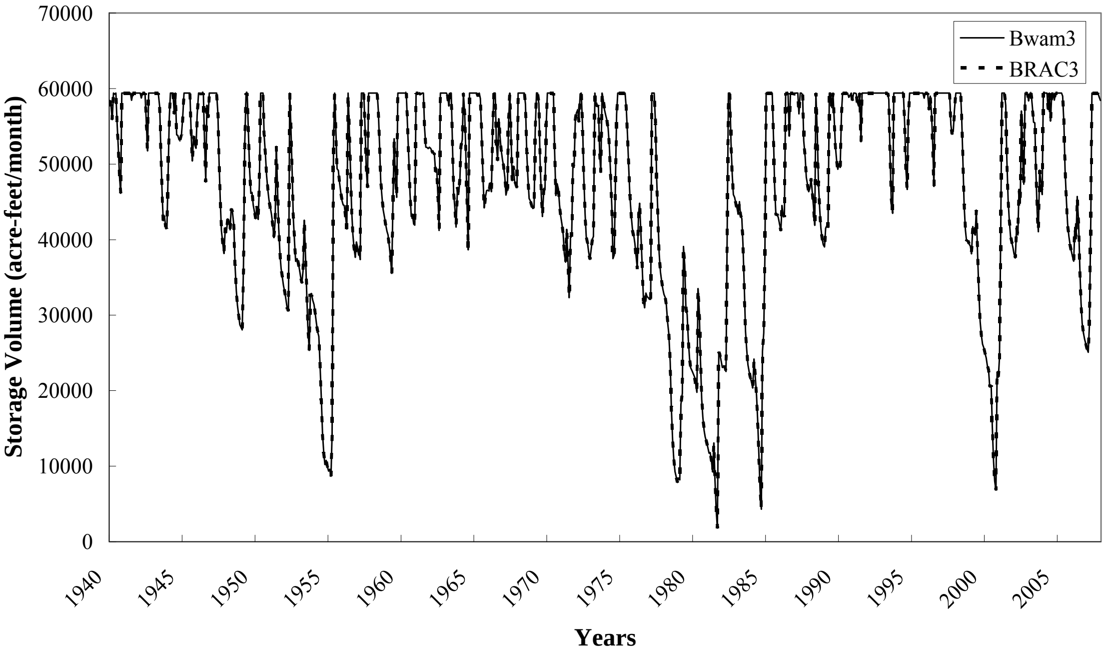

Figure 5.50 1940-2007 Bwam3 and BRAC3 Storage Volume of Proctor Reservoir

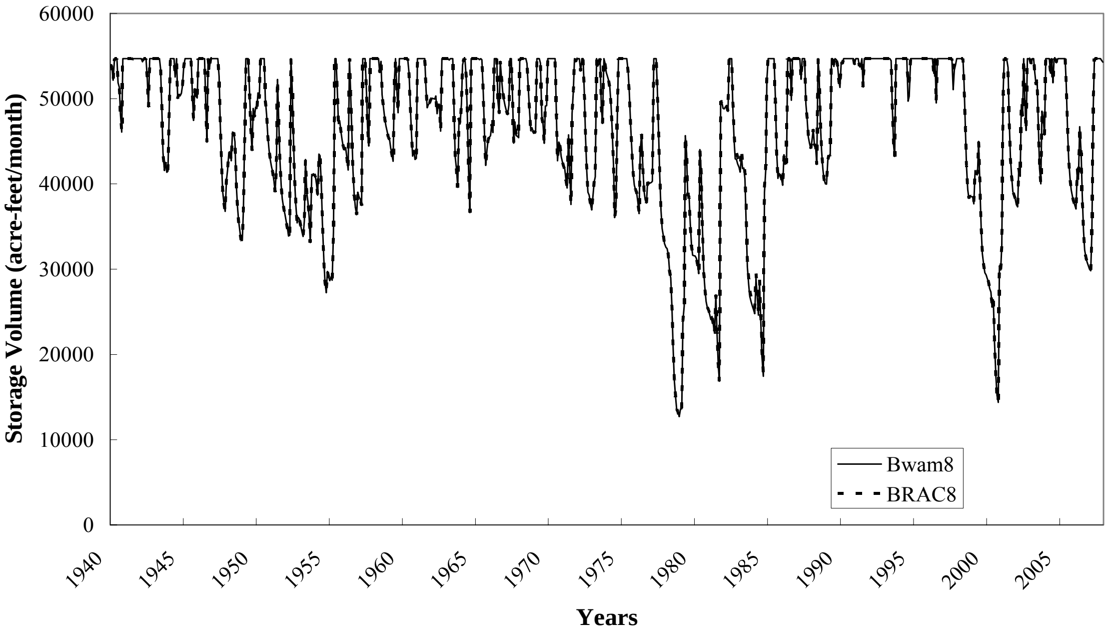

Figure 5.51 1940-2007 Bwam8 and BRAC8 Storage Volume of Proctor Reservoir

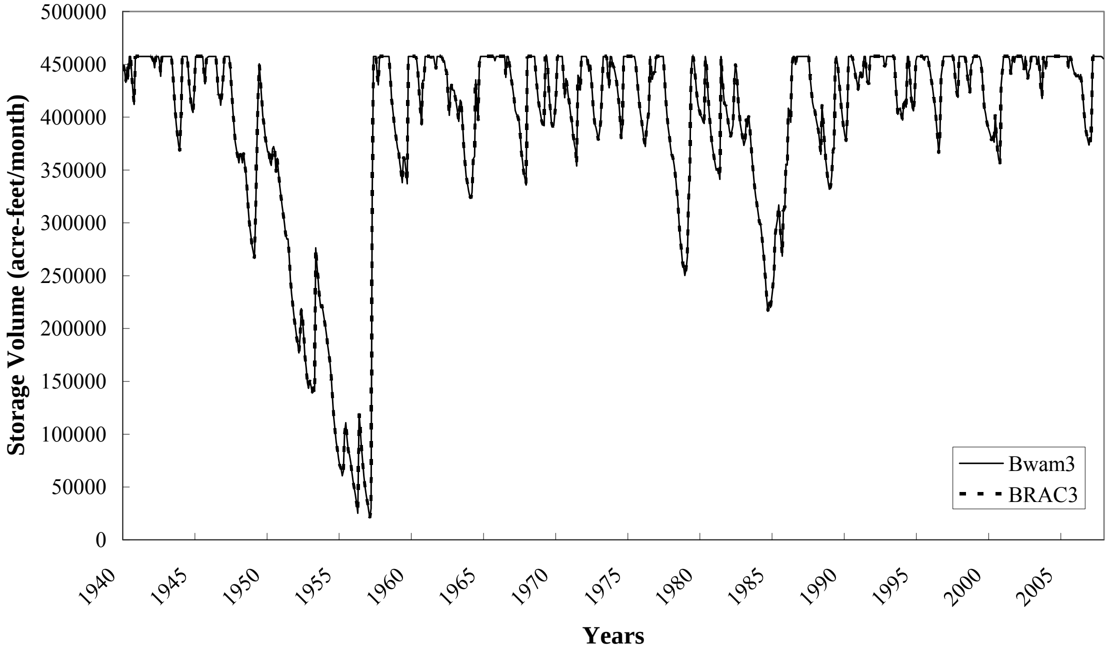

Figure 5.52 1940-2007 Bwam3 and BRAC3 Storage Volume of Belton Reservoir

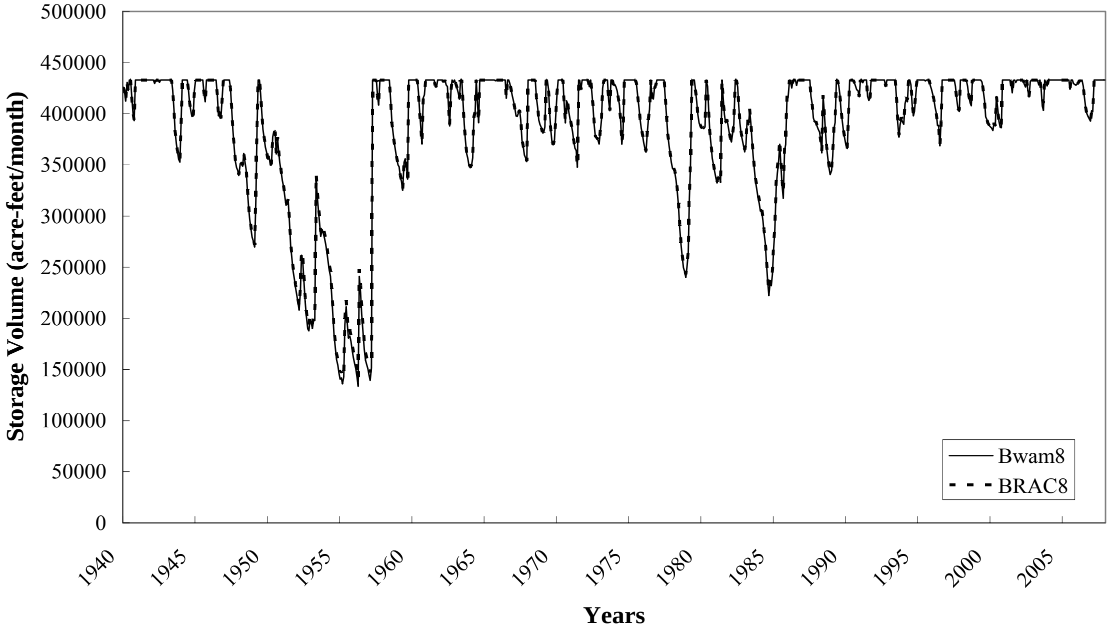

Figure 5.53 1940-2007 Bwam8 and BRAC8 Storage Volume of Belton Reservoir

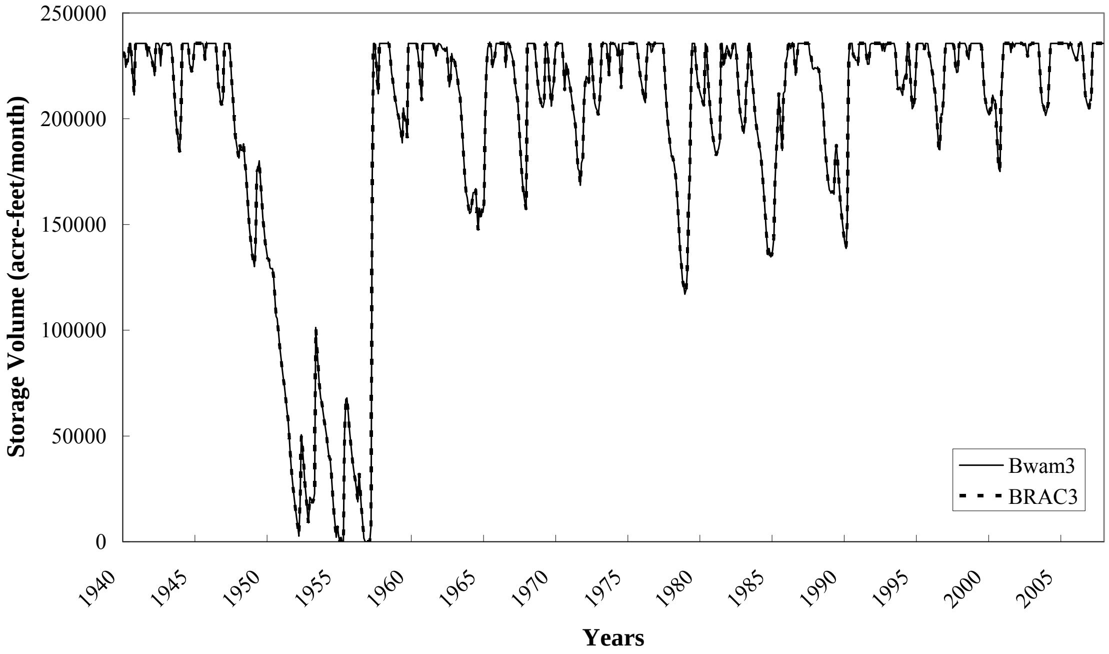

Figure 5.54 1940-2007 Bwam3 and BRAC3 Storage Volume of Stillhouse Hollow

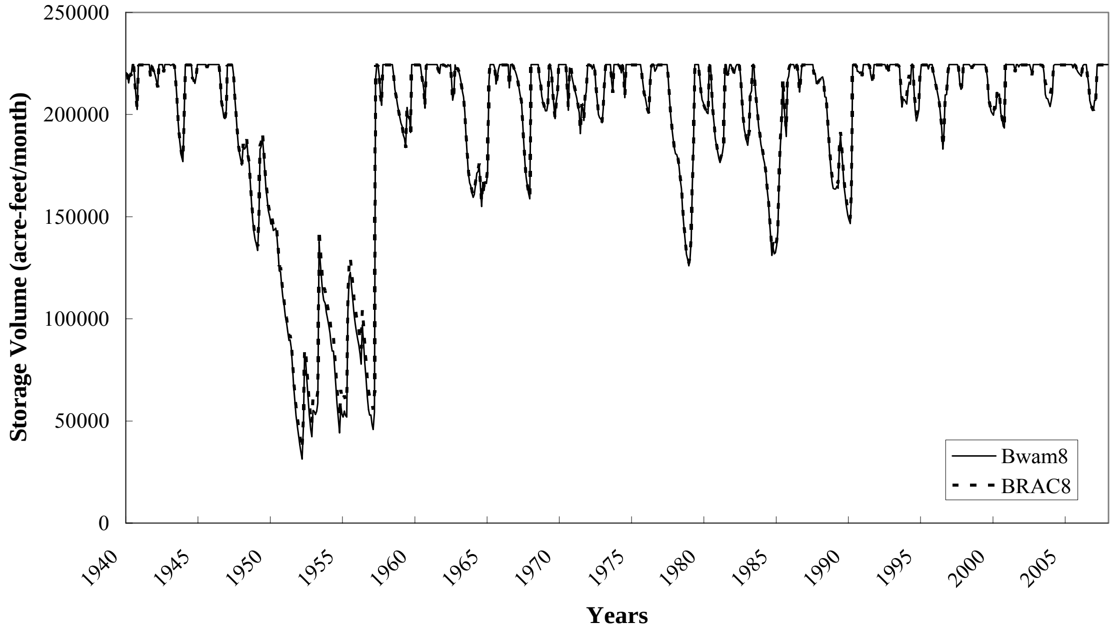

Figure 5.55 1940-2007 Bwam8 and BRAC8 Storage Volume of Stillhouse Hollow

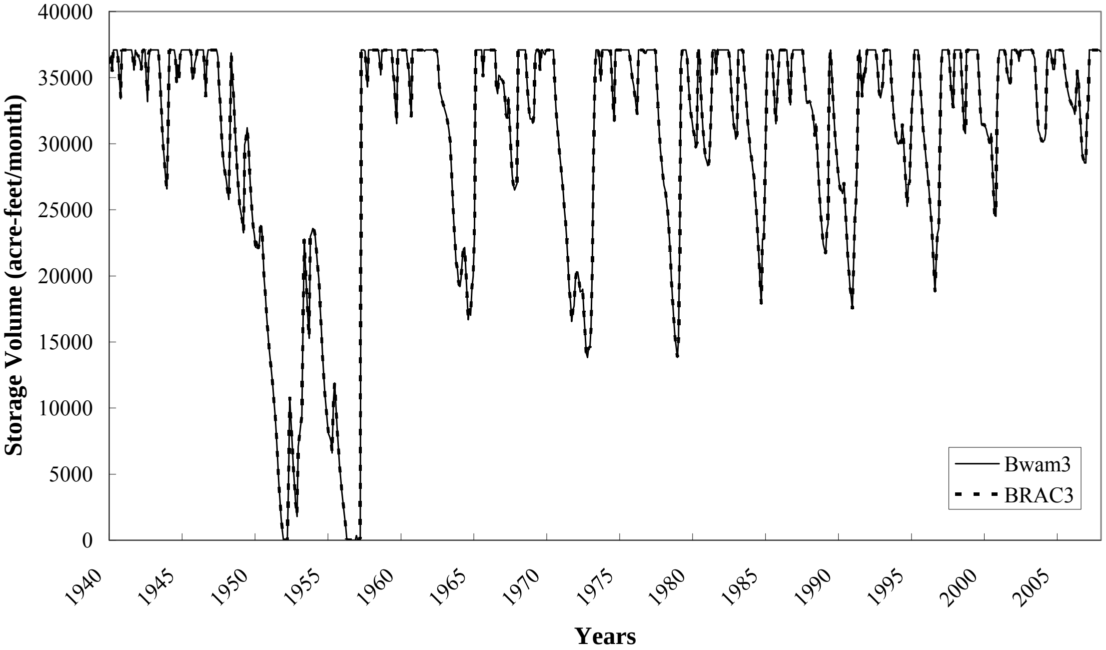

Figure 5.56 1940-2007 Bwam3 and BRAC3 Storage Volume of Georgetown

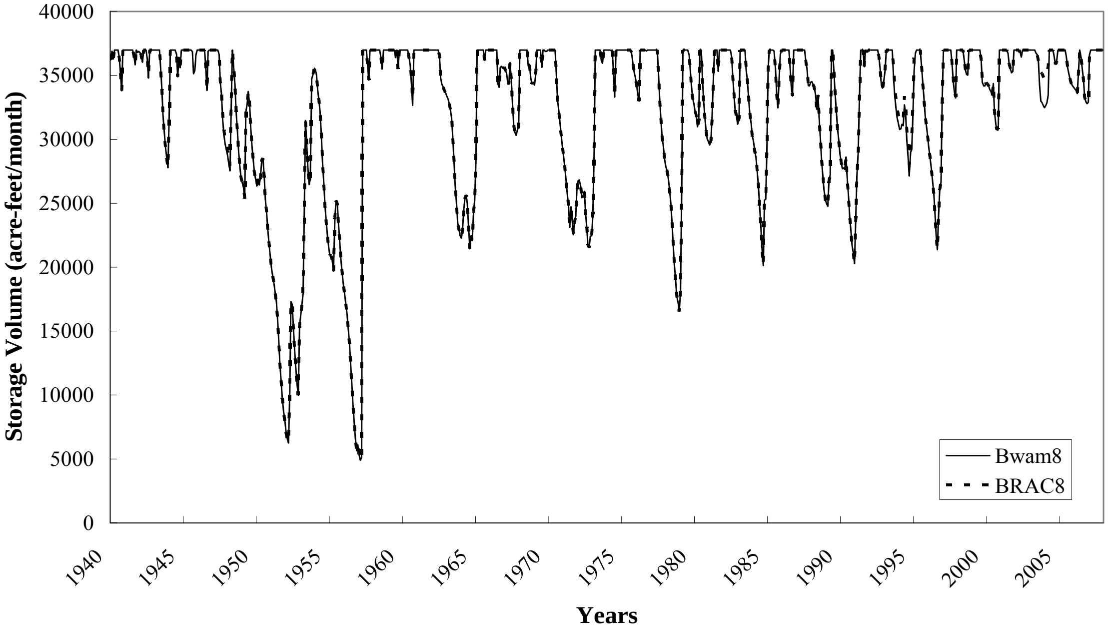

Figure 5.57 1940-2007 Bwam8 and BRAC8 Storage Volume of Georgetown

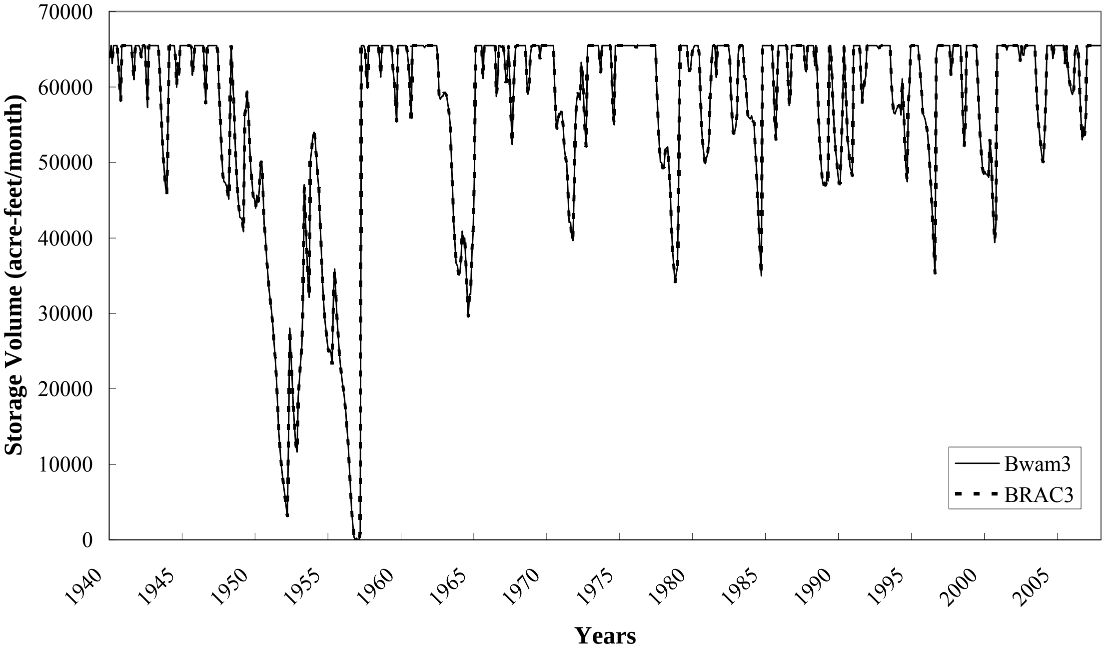

Figure 5.58 1940-2007 Bwam3 and BRAC3 Storage Volume of Granger Reservoir

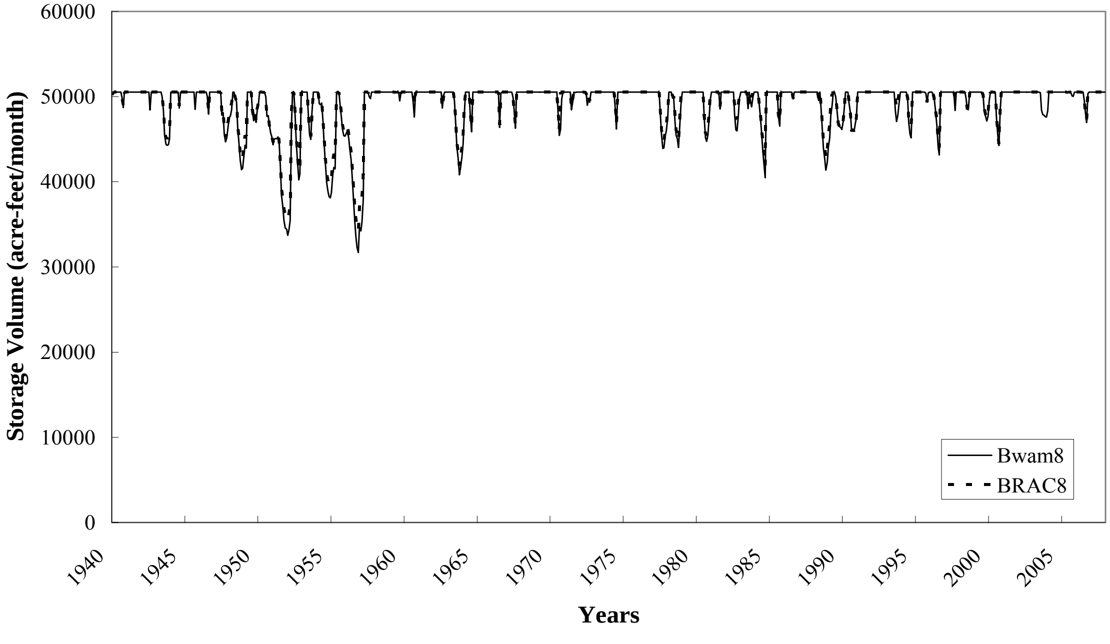

Figure 5.59 1940-2007 Bwam8 and BRAC8 Storage Volume of Granger Reservoir

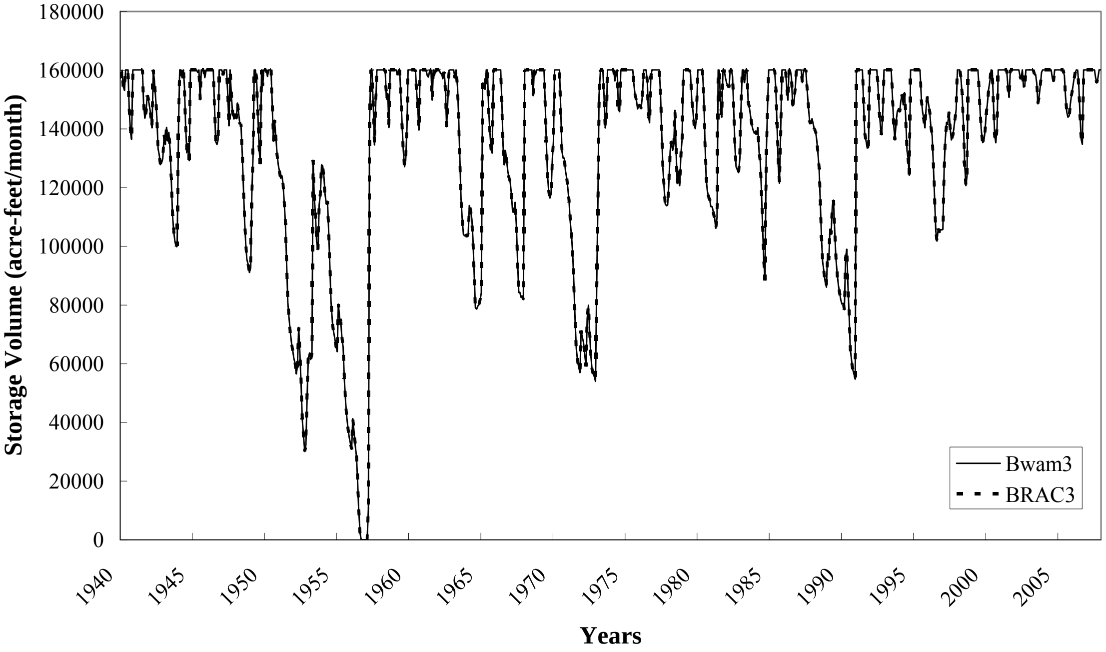

Figure 5.60 1940-2007 Bwam3 and BRAC3 Storage Volume of Somerville

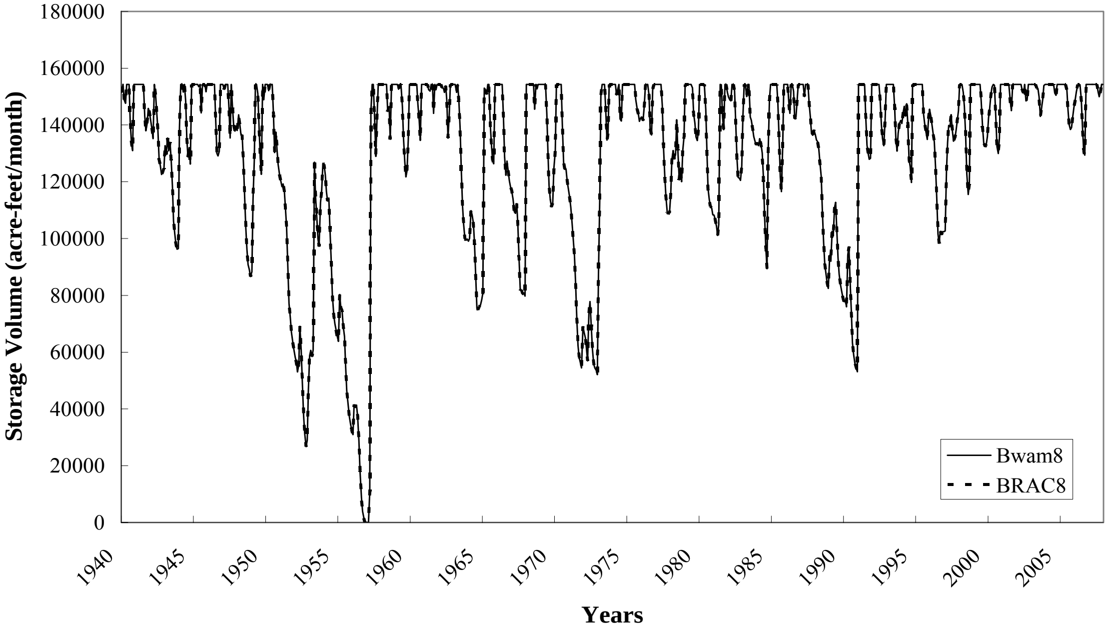

Figure 5.61 1940-2007 Bwam8 and BRAC8 Storage Volume of Somerville

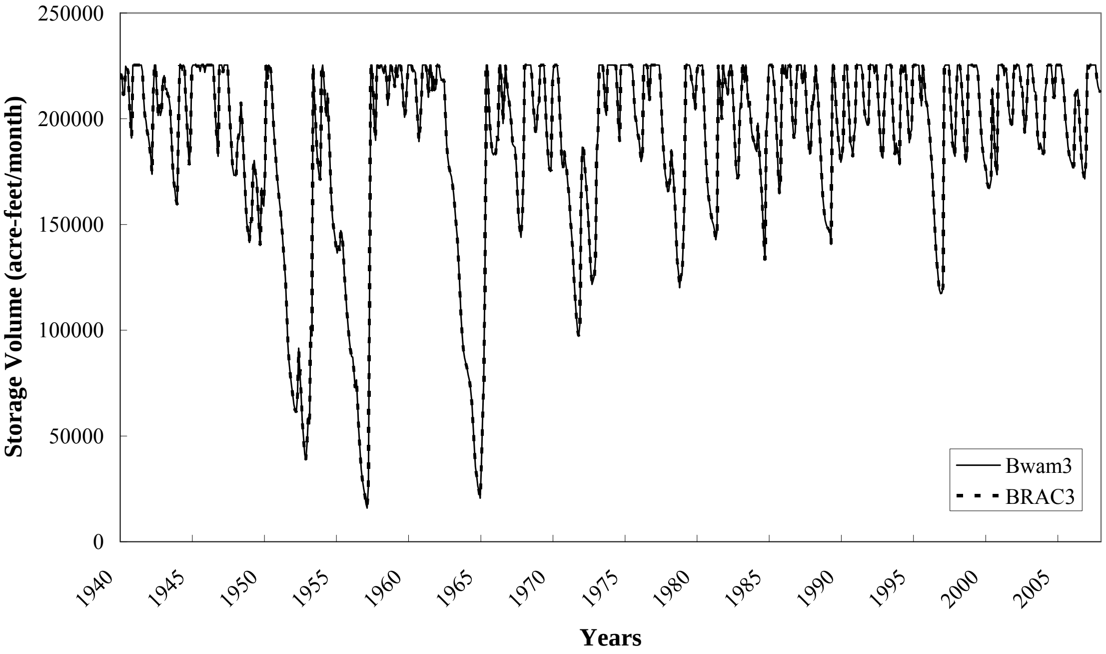

Figure 5.62 1940-2007 Bwam3 and BRAC3 Storage Volume of Limestone

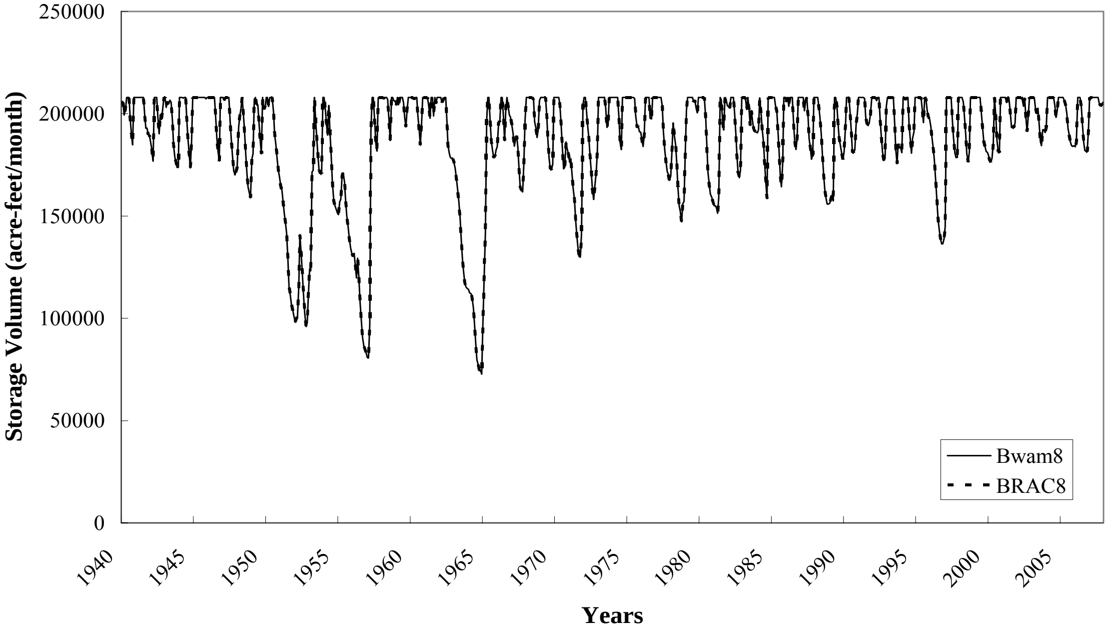

Figure 5.63 1940-2007 Bwam8 and BRAC8 Storage Volume of Limestone

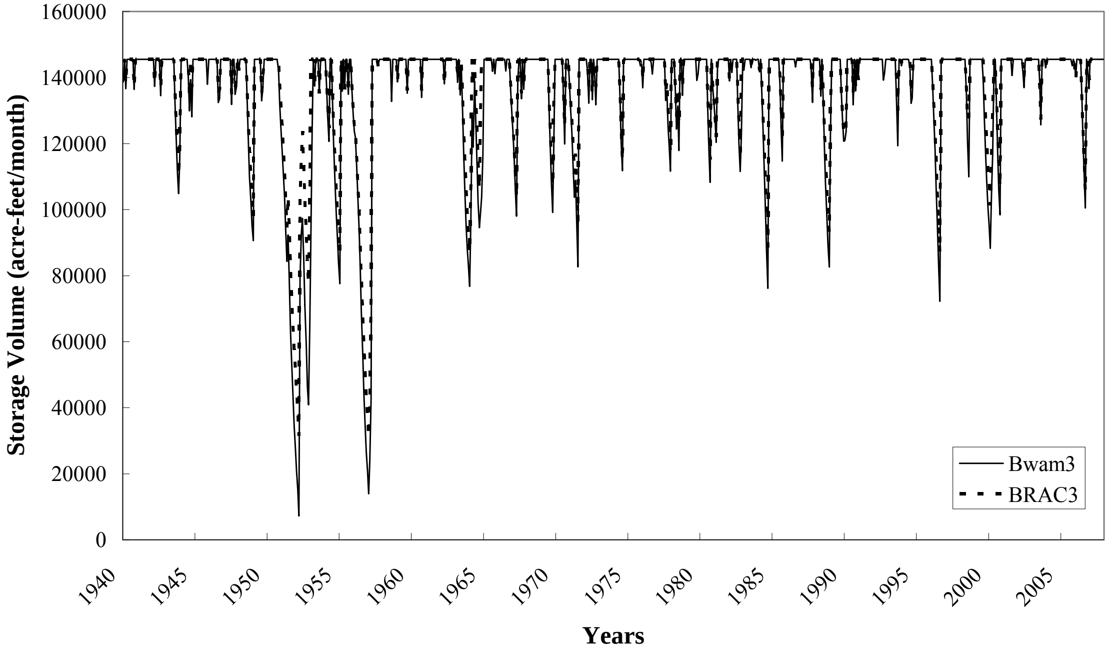

Figure 6.64 1940-2007 Bwam3 and BRAC3 Storage Volume of Allens Creek

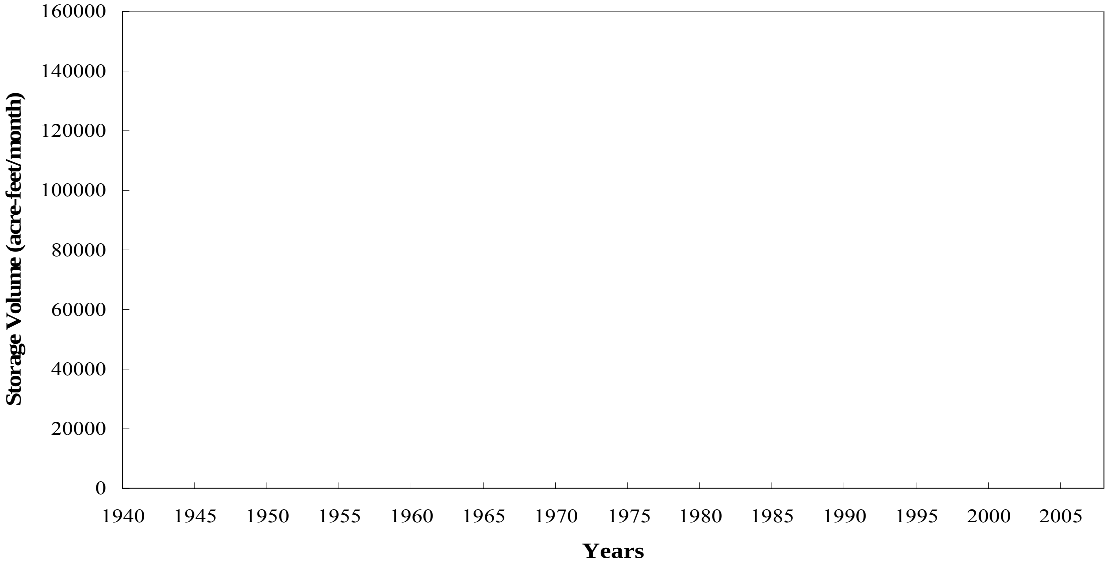

Figure 5.65 1940-2007 Bwam8 and BRAC8 Storage Volume of Allens Creek

(Allens Creek Reservoir is not included in the current use scenario Bwam8 and BRAC8 Dataset)

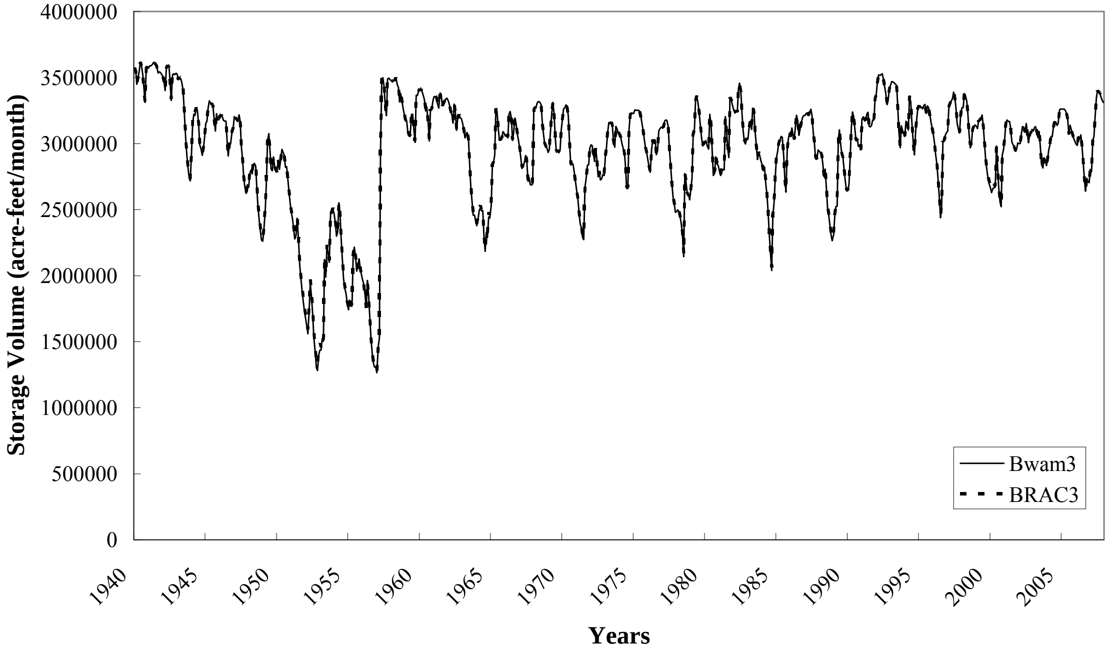

Figure 5.66 1940-2007 Bwam3 and BRAC3 Storage Volume of 15 Reservoirs

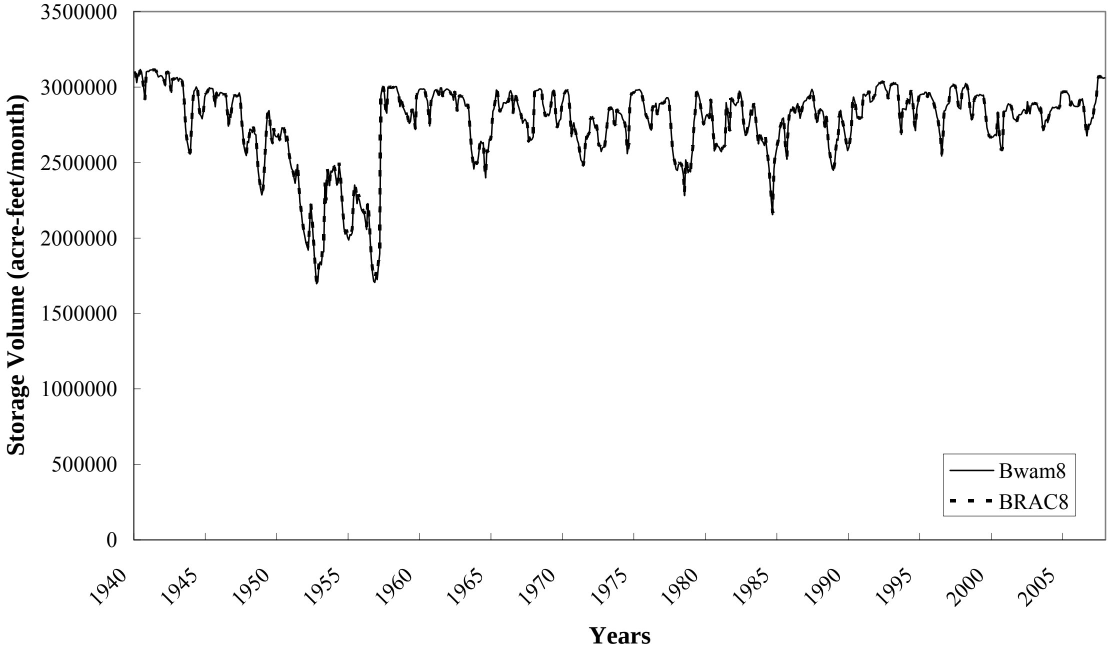

Figure 5.67 1940-2007 Bwam8 and BRAC8 Storage Volume of 14 Reservoirs

CHAPTER VI

CONVERSION OF THE MONTHLY MODEL TO A DAILY TIME STEP AND FLOOD CONTROL OPERATION KEY FACTORS

The monthly flows from January 1900 to December 2007 developed in Chapter IV were disaggregated to daily flows from January 1, 1900 to December 31, 2007. The lag time and Muskingum routing parameters were calibrated based upon daily naturalized flows generated by the SUPER model and the distances between two control points, respectively. The storage volume versus area tables were extended to the flood control capacity. Flood flow and average annual damage at six control points were determined:

1. Disaggregation of stream flows at 48 primary control points:
   - Determination of available SUPER model daily naturalized flow
   - Extension of flow pattern period
   - Transfer using program DAY for daily flow patterns at 25 primary control points to the 23 primary control points that have no daily naturalized flow data considering lag time.

2. Determination of flood flow and average annual damage curve at six control points.

3. Calibration of Muskingum routing parameters.

4. Extension of storage contents to flood control capacity.

6.1 DISAGGREGATION OF MONTHLY VALUES OF INPUT VARIABLES

The disaggregation refers to the process of subdividing monthly time intervals into daily or sub-monthly time intervals. Table 6.1 outlines the alternative methods for dividing monthly naturalized flow volumes between time steps within each month. The monthly values of input variables disaggregated within SIMD to sub-monthly amounts are as follows:

Naturalized flows: are provided directly as input data or disaggregated monthly naturalized flows.

Diversion and hydropower targets: are uniformly distributed over the sub-monthly time intervals. Alternatively, options later limit targets to a specified number of days or allow targets to vary across a month depending upon daily water availability.

Instream flow target: are uniformly distributed over the sub-monthly time intervals. Alternatively, an option limits targets to a specified number of days.

Net evaporation depths or constant inflows: are uniformly distributed over the sub-monthly time intervals. The monthly quantities are simply divided by the number of days in the month to obtain the daily amounts.

6.1.1 Determination of Available SUPER Model Daily Naturalized Flows

The availability of SUPER model daily naturalized flows in Bwam8 is listed in Tables 6.2. The 33 SUPER model gage identifiers are identical to control points of Bwam8 datasets. SUPER model gages not matched in the Bwam8 datasets are at the following locations: South Fork Outflow is located upstream of South Fork San Gabriel near Georgetown (SGGE55). Navasota outflow and Millican Outflow are located between downstream of Limestone outflow (516531) and upstream of Navasota near Easterly (NAEA66). Aquilla mouth is similar to SUPER model gage 4. Table 6.3 shows the availability of SUPER daily flow in BRAC datasets. 25 SUPER model gages ID are matched to BRAC control points. The 25 control points are shown in bold face type in Figure 6.1.

Table 6.1 Alternative Flow Disaggregation Methods

Daily Flows Input Without Monthly Flows

No Disaggregation – Daily flows are provided on daily flow records for use directly without disaggregating monthly flows. Monthly flows are not required.

Monthly Flows Disaggregated without Input of Daily Flows

1. Uniform Distribution Options – Monthly flow volumes are distributed evenly over the month with the same amount assigned to each daily time step.
2. Linear Interpolation Option – A linear spline interpolation routine is applied to the sequence of monthly flow volumes to assign a non-uniform daily flow distribution.

Monthly Flows Disaggregated Using Input Daily Flows or Flow Patterns

3. Variability Adjustment Option – The daily flow volumes computed with the linear interpolation routine (option 2 above) are adjusted to reflect the variability determined from daily flow sequences provided as input on daily flow records.
4. Flow Pattern Option – Daily flow amount on Daily Flow (DF) records define a daily flow distribution pattern. Location adjustments are available with options 5 or 6 below.

Transferring Flow Patterns to Other Control Point Locations

5. Drainage Area Ratio Transfer Option – The daily flow pattern defined by the DF record flows are adjusted for location upstream or downstream with a nonlinear equation that is based a drainage area ratio.
6. Regression Equation Transfer Option – The daily flow pattern defined by the DF record flows are adjusted for location upstream or downstream with a nonlinear equation that is based regression coefficients.

Source: Wurbs et al. (2005b)

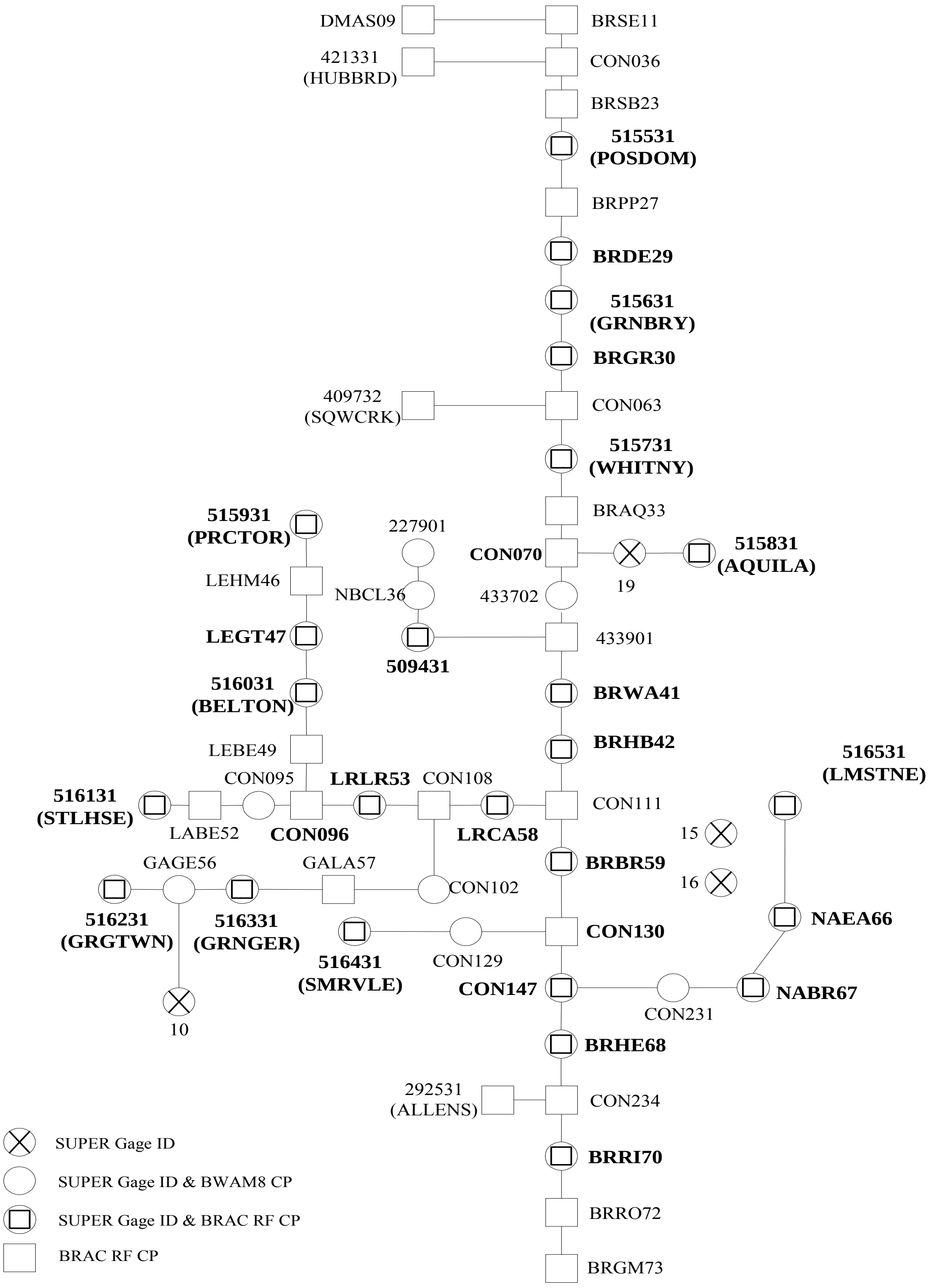

Figure 6.1 Schematic of Available SUPER Model Daily Naturalized Flows in Bwam8 or BRAC Datasets (Not to Scale)

Table 6.2 Availability of SUPER Model Daily Naturalized Flows in Bwam Dataset

SUPER Model Gage No	 Gage ID	BWAM8 CP	WAM Area	WAM Length	 Availability
			(miles^2)	(miles)	
1	Possum Kingdom Outflow	515531	14,093	706	Yes (1)
2	Granbury Outflow	515631	16,181	559	Yes (2)
3	Whitney Outflow	515731	17,690	462	Yes (3)
4	Aquilla Outflow	515831	254	458	Yes (4)
5	Bosque Outflow	227901	710	490	Yes (5)
6	Waco Outflow	509431	1,655	428	Yes (6)
7	Proctor Outflow	515931	1,280	639	Yes (7)
8	Belton Outflow	516031	3,568	442	Yes (8)
9	Stillhouse Outflow	516131	1,313	441	Yes (9)
10	South Fork Outflow	-	-	-	-
11	Georgetown Outflow	516231	247	432	Yes (10)
12	Granger Outflow	516331	726	399	Yes (11)
13	Somerville Outflow	516431	1,008	271	Yes (12)
14	Limestone Outflow	516531	675	351	Yes (13)
15	Navasota Outflow	-	-	-	-
16	Millican Outflow	-	-	-	-
17	Dennis	BRDE29	15,733	605	Yes (14)
18	Glen Rose	BRGR30	16,320	527	Yes (15)
19	Aquilla Mouth	-	-	-	-
20	Elm Mott	433702	23	427	Yes (16)
21	Clifton	NBCL36	977	468	Yes (17)
22	Waco (Brazos)	BRWA41	20,065	418	Yes (18)
23	Highbank	BRHB42	20,900	358	Yes (19)
24	Gatesville	LEGT47	2,379	519	Yes (20)
25	Lampasas Mouth	CON095	1,511	426	Yes (21)
26	Little River	LRLR53	5,266	419	Yes (22)
27	Georgetown	GAGE56	404	427	Yes (23)
28	Rockdale	CON102	1,357	373	Yes (24)
29	Cameron	LRCA58	7,100	357	Yes (25)
30	Bryan (Brazos)	BRBR59	30,016	290	Yes (26)
31	Yegua Mouth	CON129	1,302	257	Yes (27)
32	Washington	CON147	33,930	234	Yes (28)
33	Easterly	NAEA66	936	334	Yes (29)
34	Bryan (Navasota)	NABR67	1,427	300	Yes (30)
35	Navasota Mouth	CON231	2,241	240	Yes (31)
36	Hempstead	BRHE68	34,374	202	Yes (32)
37	Richmond	BRRI70	35,454	97	Yes (33)

** The number of significant digits in the tables of this dissertation does not imply level of accuracy. In general, more digits are included in the numbers than is justified by the level of accuracy.

Table 6.3 Availability of SUPER Model Daily Naturalized Flows in BRAC Dataset

BRAC CP ID	SUPER Model Gage No.	SUPER Model Gage ID	WAM Area (miles^2)	WAM Length (miles)	Availability
DMAS09	-	-	1,891	981	
BRSE11	-	-	5,996	866	
421331	-	-	1,087	816	
CON036	-	-	13,168	773	
BRSB23	-	-	13,171	772	
515531	1	Possum Kingdom Outflow	14,093	706	Yes (1)
BRPP27	-	-	14,309	686	
BRDE29	17	Dennis	15,733	605	Yes (2)
515631	2	Granbury Outflow	16,181	559	Yes (3)
BRGR30	18	Glen Rose	16,320	527	Yes (4)
409732	-	-	59	528	
CON063	-	-	16,835	523	
515731	3	Whitney Outflow	17,690	462	Yes (5)
BRAQ33	-	-	17,746	453	
515831	4	Aquilla Outflow	254	458	Yes (6)
CON070	-	-	18,313	434	
509431	6	Waco Outflow	1,655	428	Yes (7)
433901	-	-	20,028	424	
BRWA41	22	Waco (Brazos)	20,065	418	Yes (8)
BRHB42	23	Highbank	20,900	358	Yes (9)
515931	7	Proctor Outflow	1,280	639	Yes (10)
LEHM46	-	-	1,928	592	
LEGT47	27	Gatesville	2,379	519	Yes (11)
516031	8	Belton Outflow	3,568	442	Yes (12)
LEBE49	-	-	3,579	438	
516131	9	Stillhouse Hollow Outflow	1,313	441	Yes (13)
LABE52	-	-	1,321	438	
CON096	-	-	5,258	425	
LRLR53	26	Little River	5,266	419	Yes (14)
516231	11	Georgetown Outflow	247	432	Yes (15)
516331	12	Granger Out	726	399	Yes (16)
GALA57	-	-	737	394	
CON108	-	-	7,097	357	
LRCA58	29	Cameron	7,100	357	Yes (17)
CON111	-	-	29,341	322	
BRBR59	30	Bryan (Brazos)	30,016	290	Yes (18)
516431	13	Somerville Outflow	1,008	271	Yes (19)
CON130	-	-	31,636	251	
516531	14	Limestone Outflow	675	351	Yes (20)
NAEA66	33	Easterly	936	334	Yes (21)
NABR67	34	Bryan (Navasota)	1,427	300	Yes (22)
CON147	32	Washington	33,930	234	Yes (23)
BRHE68	36	Hempstead	34,374	202	Yes (24)

Table 6.3 (continued)

BRAC RF CP ID	SUPER Model Gage No.	 Gage ID	WAM Area (miles^2)	WAM Length (miles)	Availability
292531	-	-	62	136	
CON234	-	-	35,388	119	
BRRI70	37	Richmond	35,454	97	Yes (25)
BRRO72	-	-	35,775	59	
BRGM73	-	-	36,028	0	

6.1.2 Extension of Flow Pattern for 1900-1938 and 1998-2007 Hydrologic Simulation Periods

The hydrologic simulation periods of BRAC flow are covered by 1900 through 2007 while those of daily naturalized flow are covered by 1939 through 1997. The Flow patterns for 1900-1938 and 1998-2007 at 25 control points that have SUPER model daily naturalized flow for 1939-1997 are developed using the procedure described below. Although mean flows, median flows, or any other exceedance frequency flows could be adopted, the mean daily flows in each day are proposed as being reasonably likely flows. The flow volume in the 59 years is determined using 1939-1997 SUPER model flows at a particular control point.

For example, at each control point, the January 1 flow volume that is averaged for 59 years in the 1939-1997 SUPER model flow dataset is determined. Average flows are determined for each of the 365 days. The resulting set of 365 flow volumes for January 1 through December 31 are repeated for each of 39 years during 1900-1938 and 10 years during 1998-2007. Figures 6.2 through 6.28 show the average daily flow pattern at 25 BRAC control points. The plotted average daily flows sustain their patterns even though each day during the 59 years is averaged. These computed data can be used for utilizing the daily flow pattern for the two periods (1900-1938 and 1998-2007) of BRAC flow. The unknown daily flow pattern at 23 control points illustrated in Table 6.3 can be acquired by transferring known flow patterns at 25 control points based upon the drainage area ratio method illustrated in Table 6.1. Table 6.3 lists the drainage areas at 48 control points.

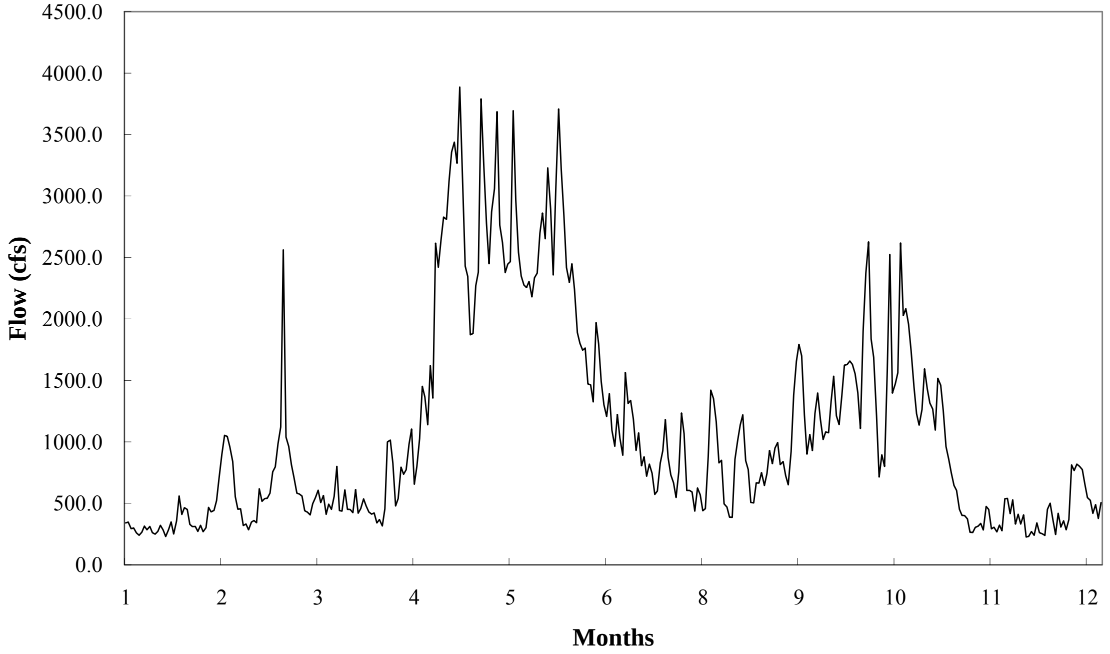

Figure 6.2 Average Daily Flow Pattern at 515531 (Possum Kingdom Reservoir)

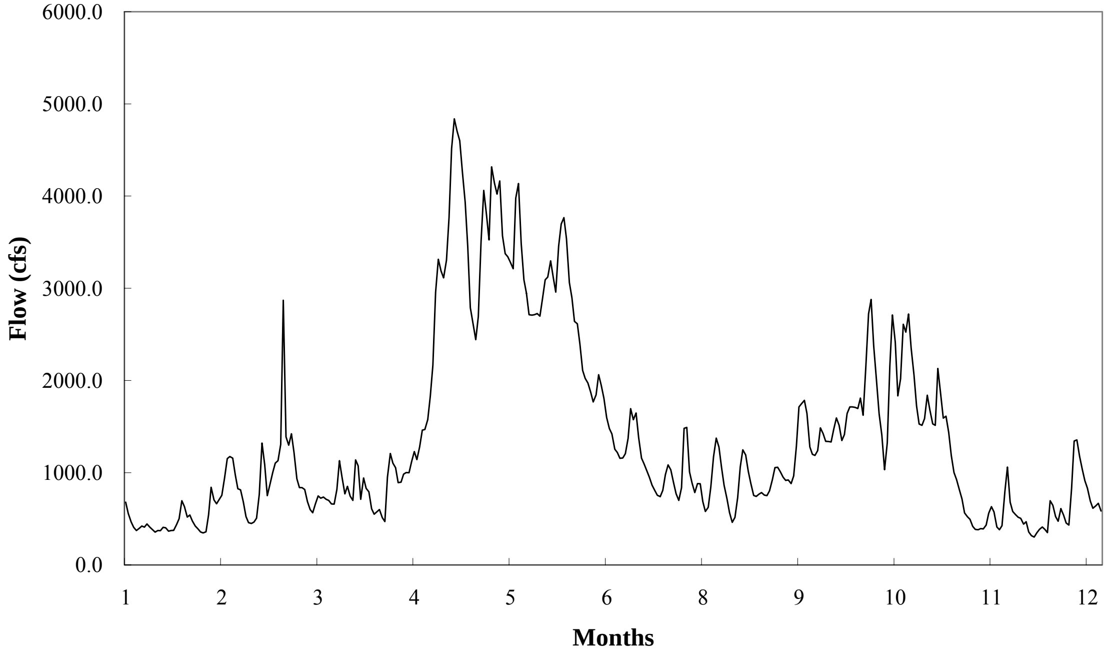

Figure 6.3 Averaged Daily Flow Pattern at BRDE29 (Dennis)

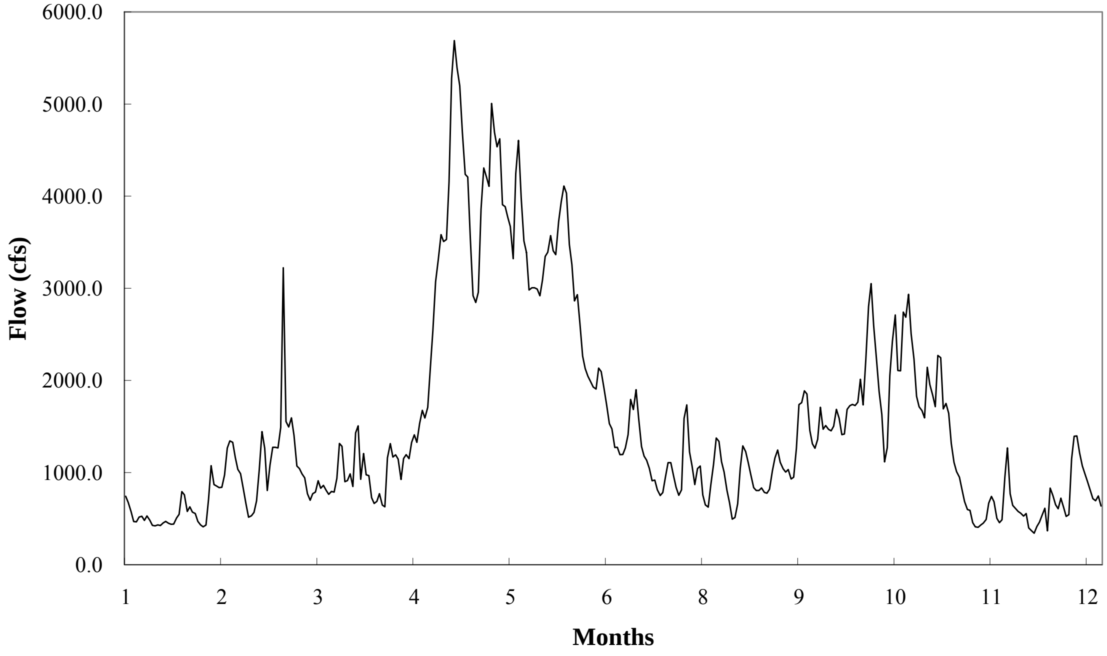

Figure 6.4 Averaged Daily Flow Pattern at 515631 (Granbury Reservoir)

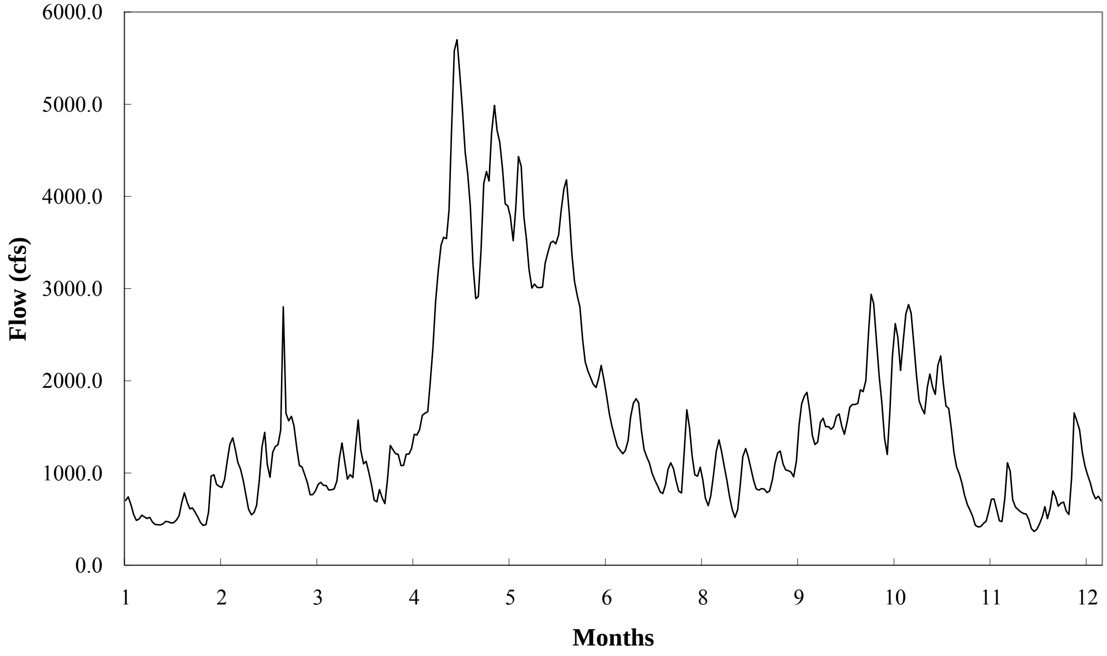

Figure 6.5 Averaged Daily Flow Pattern at BRGR30 (Glen Rose)

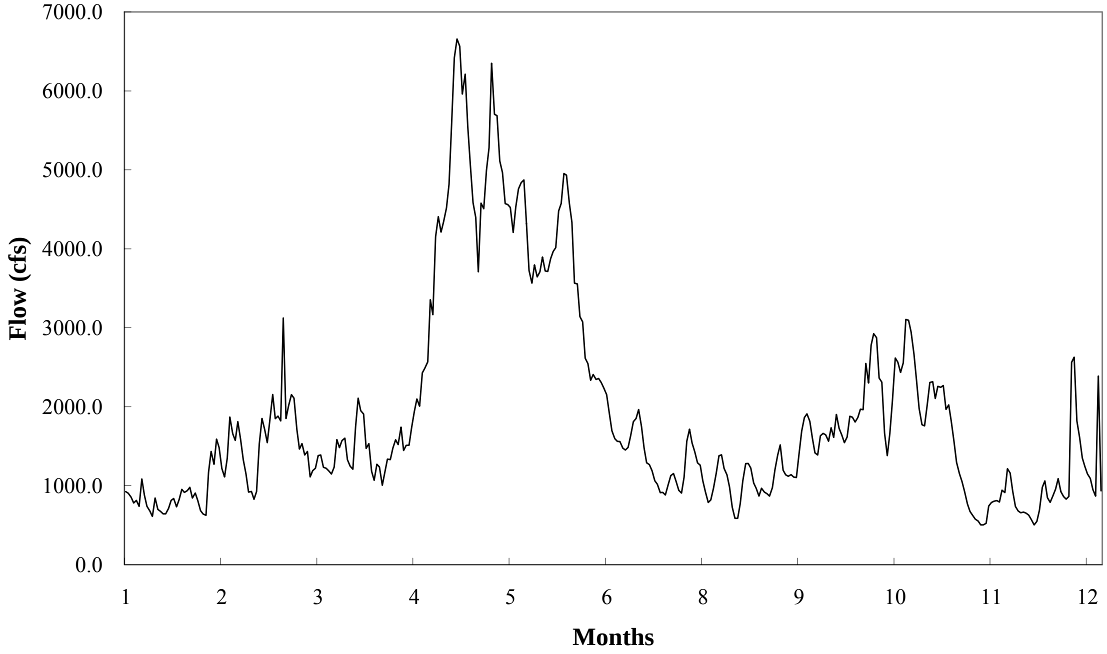

Figure 6.6 Average Daily Flow Pattern at 515731 (Whitney Reservoir)

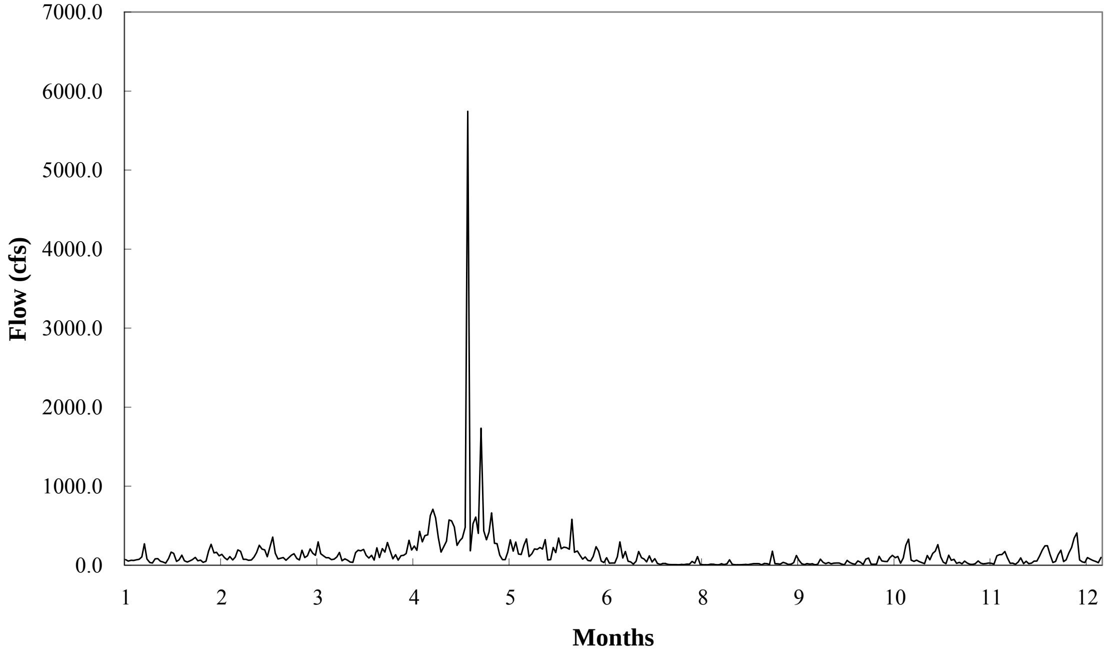

Figure 6.7 Averaged Daily Flow Pattern at 515831 (Aquilla Reservoir)

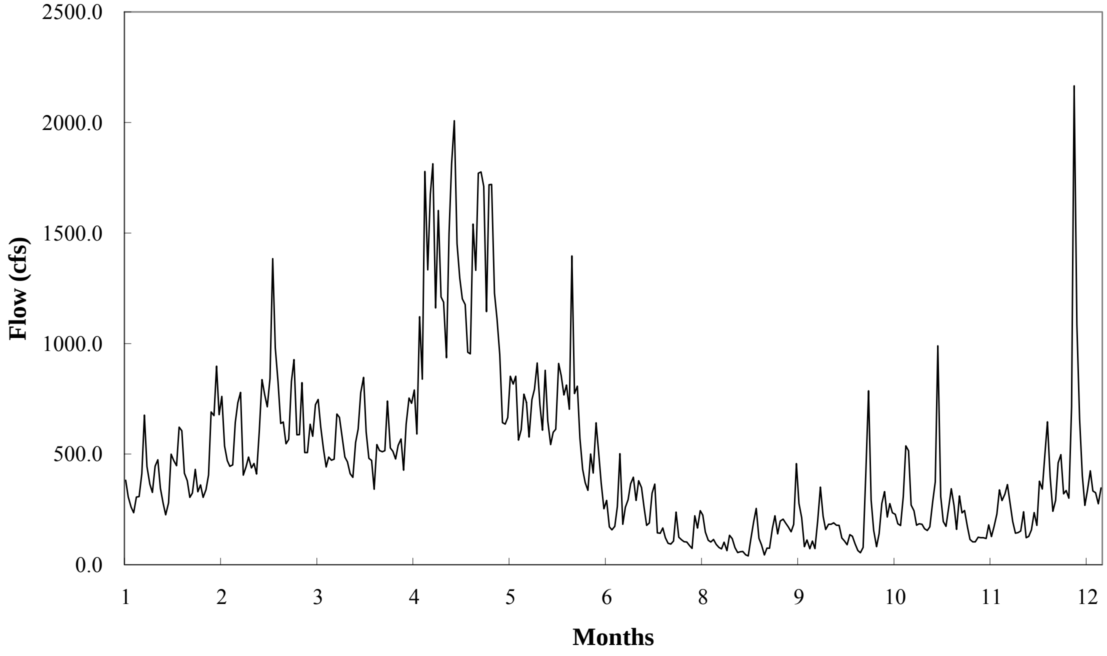

Figure 6.8 Averaged Daily Flow Pattern at 509431 (Waco Reservoir)

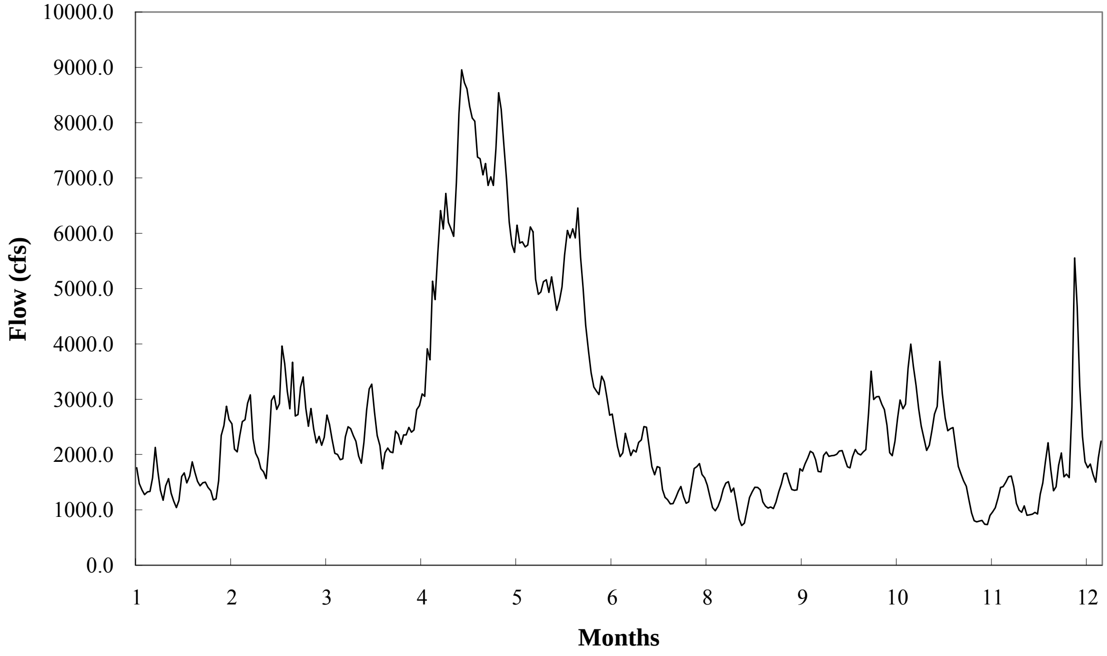

Figure 6.9 Averaged Daily Flow Pattern at BRWA41 (Waco near Brazos River)

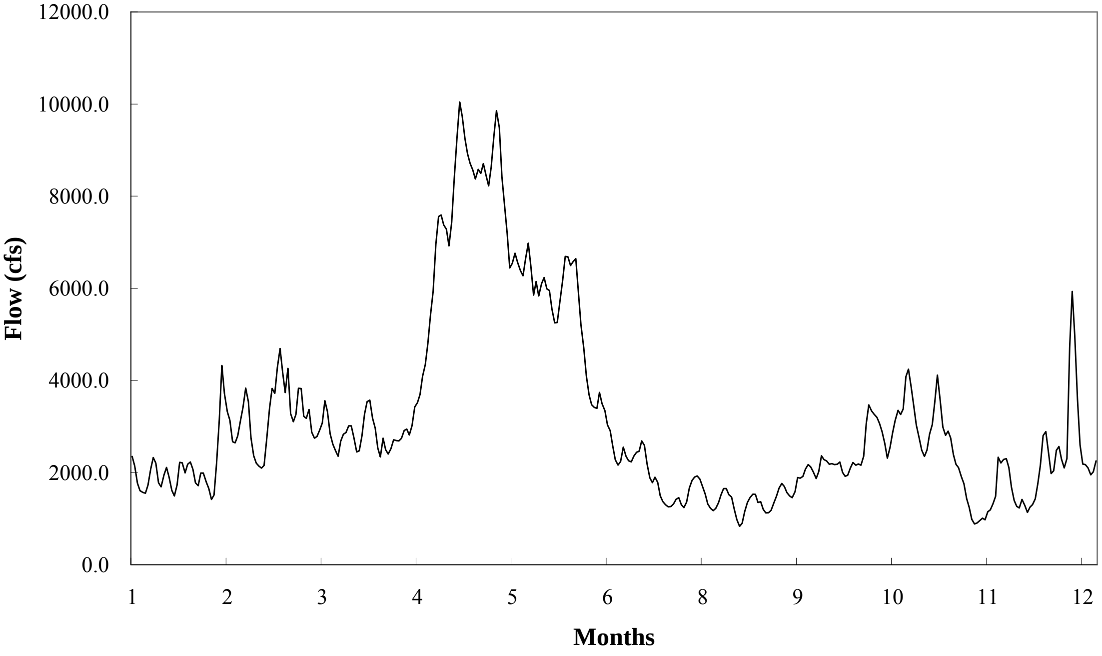

Figure 6.10 Averaged Daily Flow Pattern at BRHB42 (High Bank)

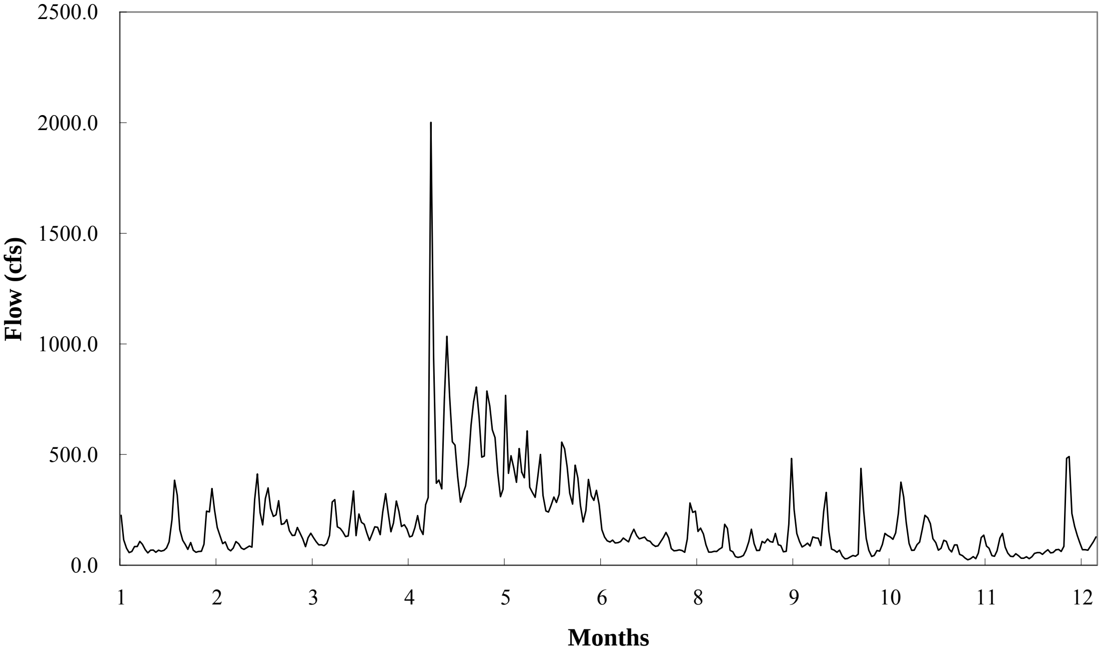

Figure 6.11 Averaged Daily Flow Pattern at 515931 (Proctor Reservoir)

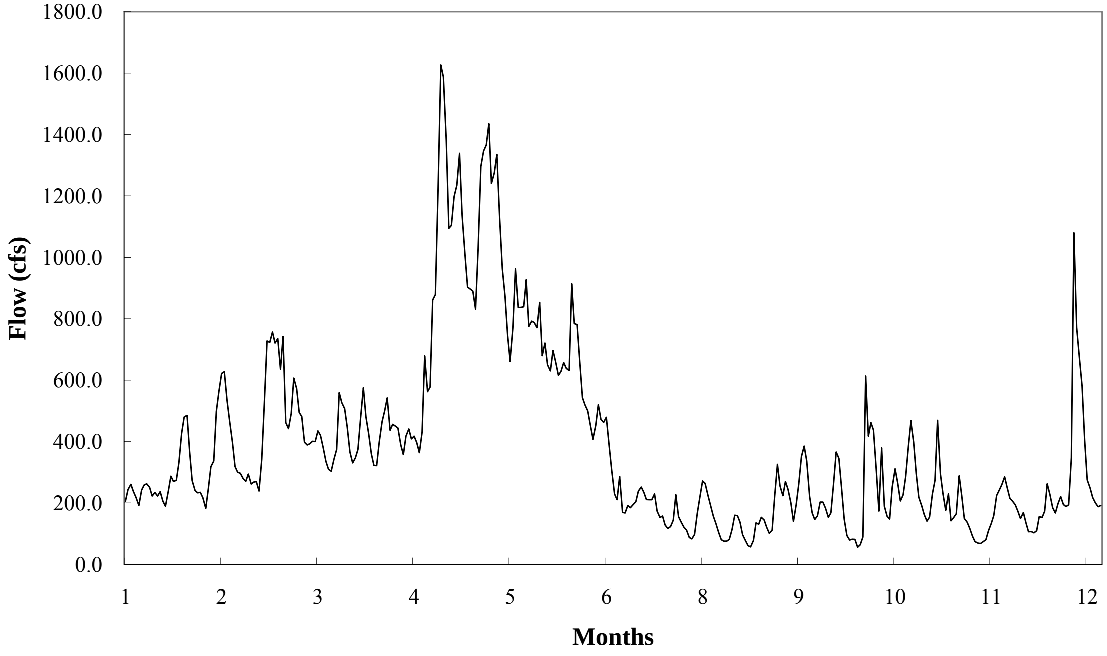

Figure 6.12 Averaged Daily Flow Pattern at LEGT47 (Gatesville)

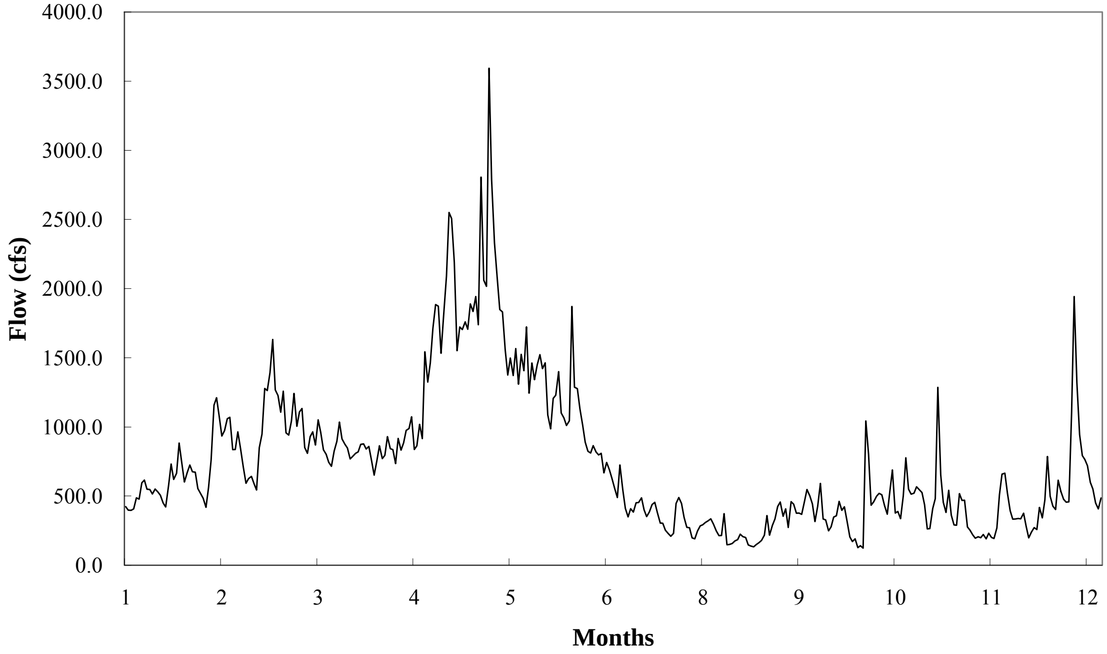

Figure 6.13 Averaged Daily Flow Pattern at 516031 (Belton Reservoir)

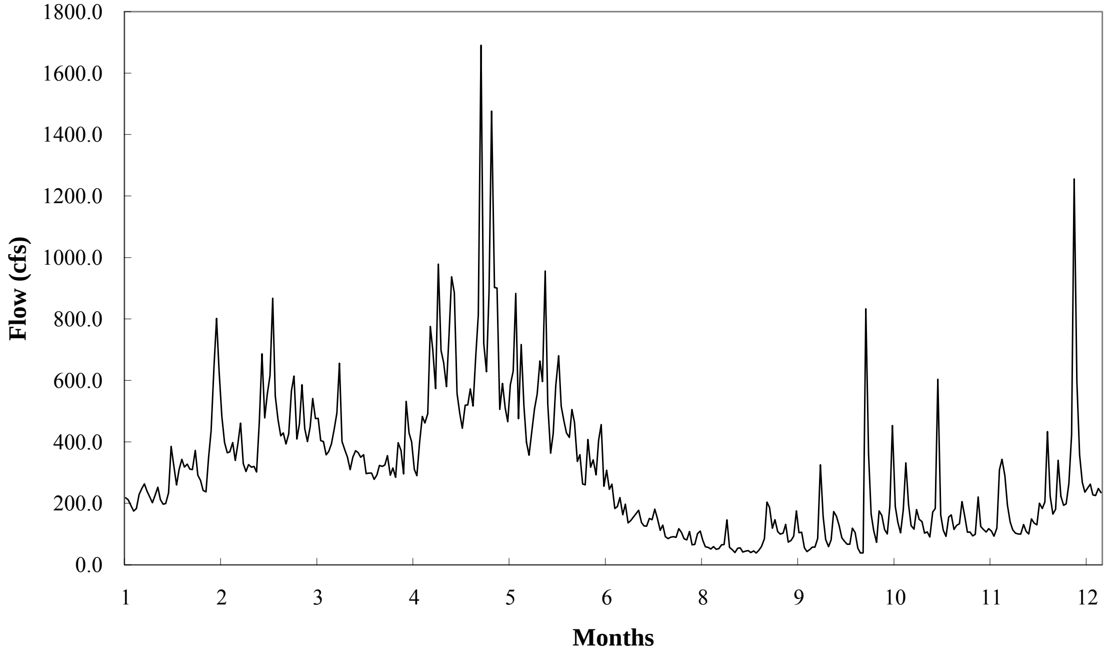

Figure 6.14 Averaged Daily Flow Pattern at 516131 (Stillhouse Hollow Reservoir)

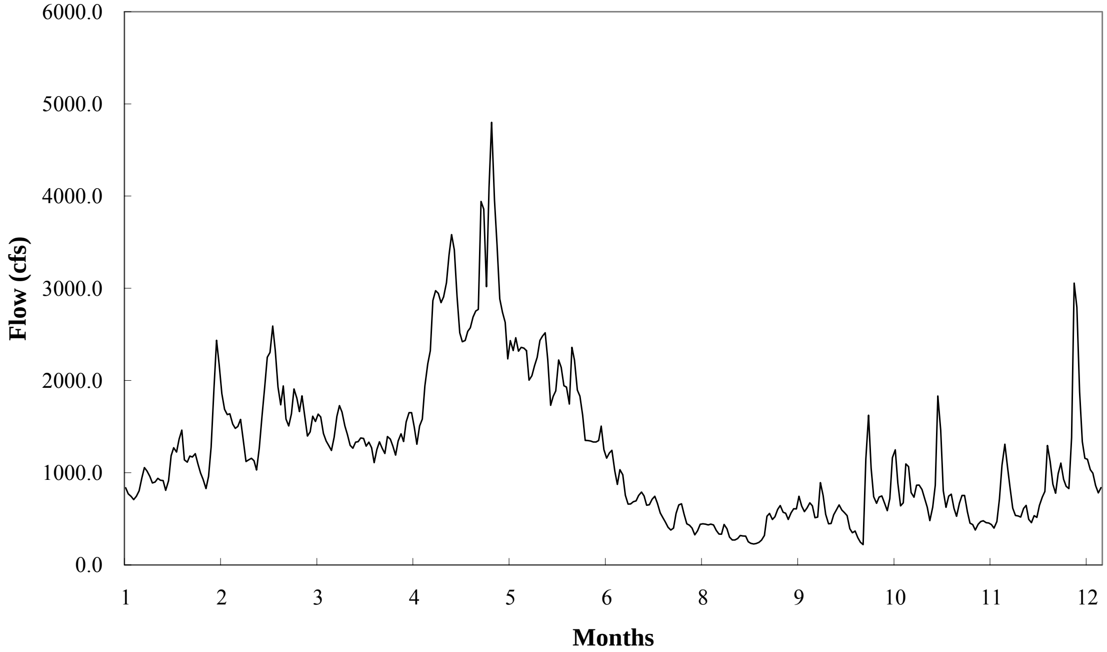

Figure 6.15 Averaged Daily Flow Pattern at LRLR53 (Little River)

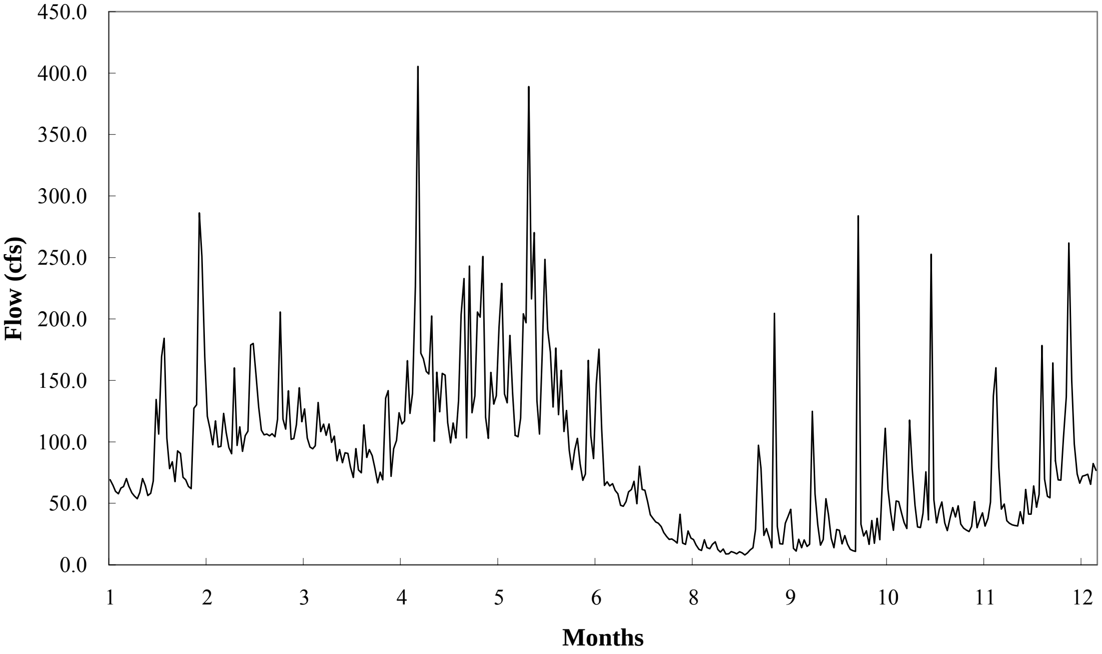

Figure 6.16 Averaged Daily Flow Pattern at 516231 (Georgetown Reservoir)

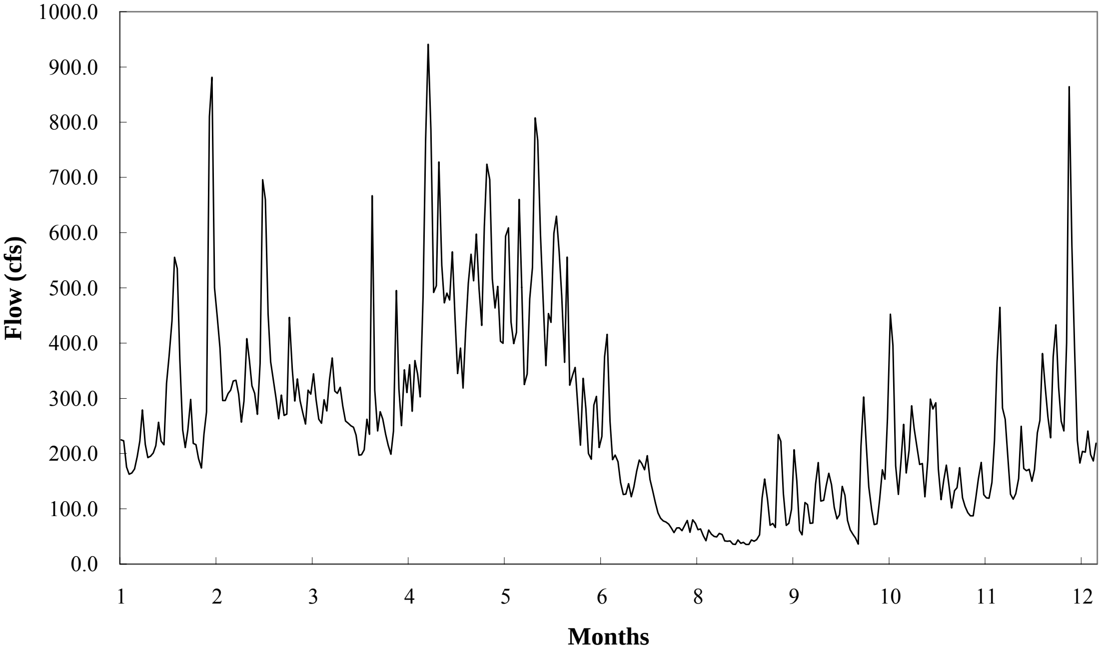

Figure 6.17 Averaged Daily Flow Pattern at 516331 (Granger Reservoir)

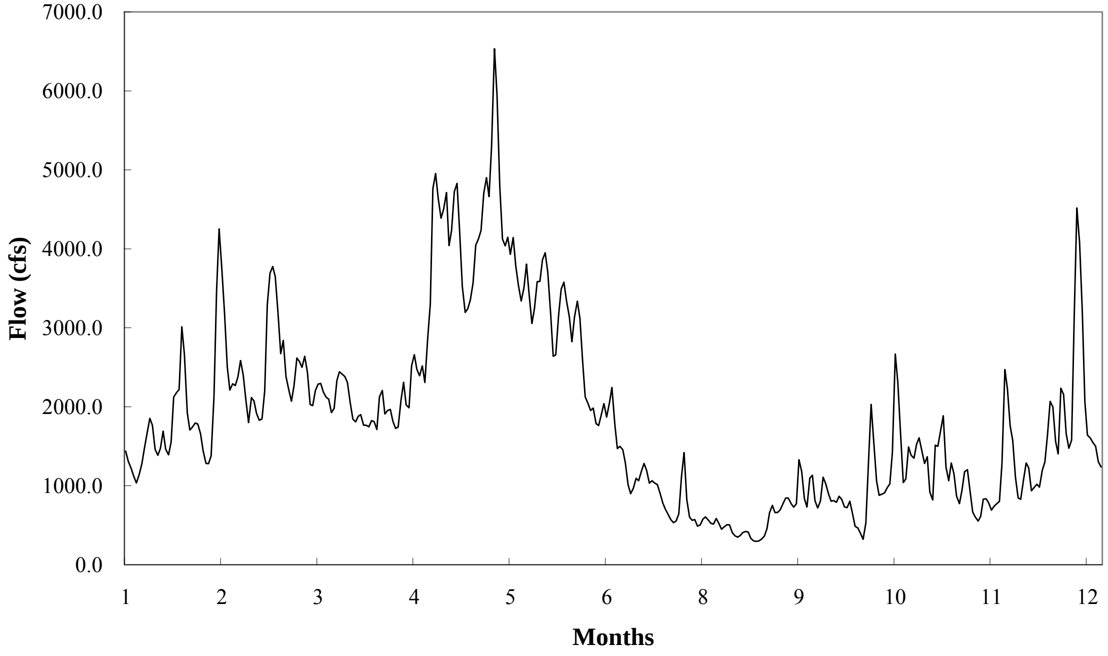

Figure 6.18 Averaged Daily Flow Pattern at LRCA58 (Cameron)

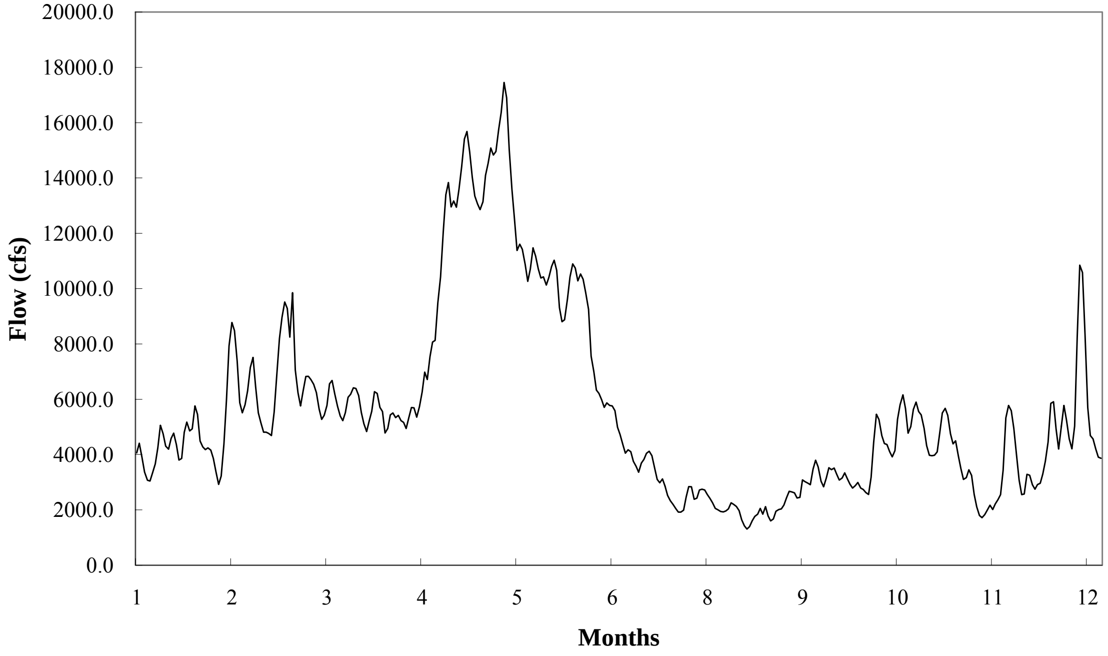

Figure 6.19 Averaged Daily Flow Pattern at BRBR59 (Bryan in Brazos River)

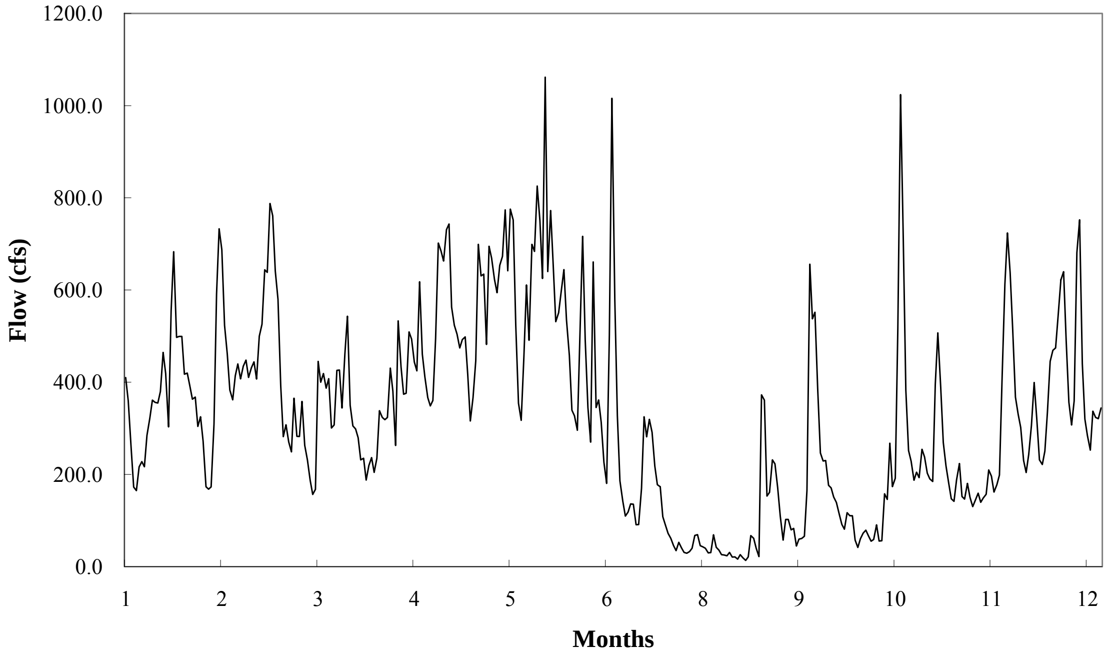

Figure 6.20 Averaged Daily Flow Pattern at 516431 (Somerville Reservoir)

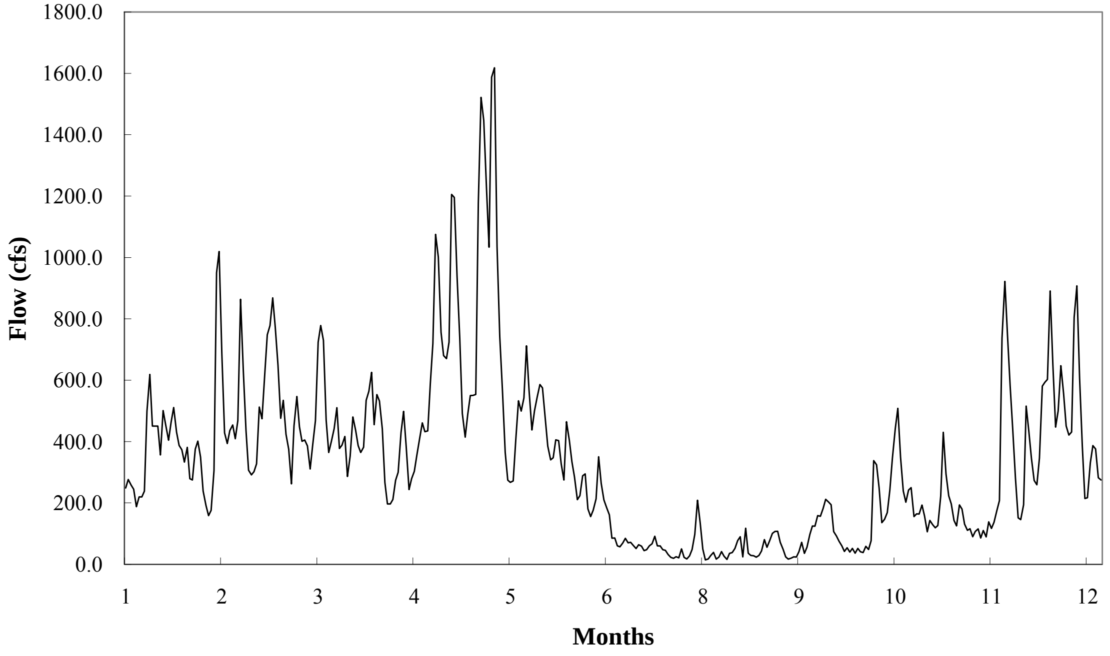

Figure 6.21 Averaged Daily Flow Pattern at 516531 (Limestone Reservoir)

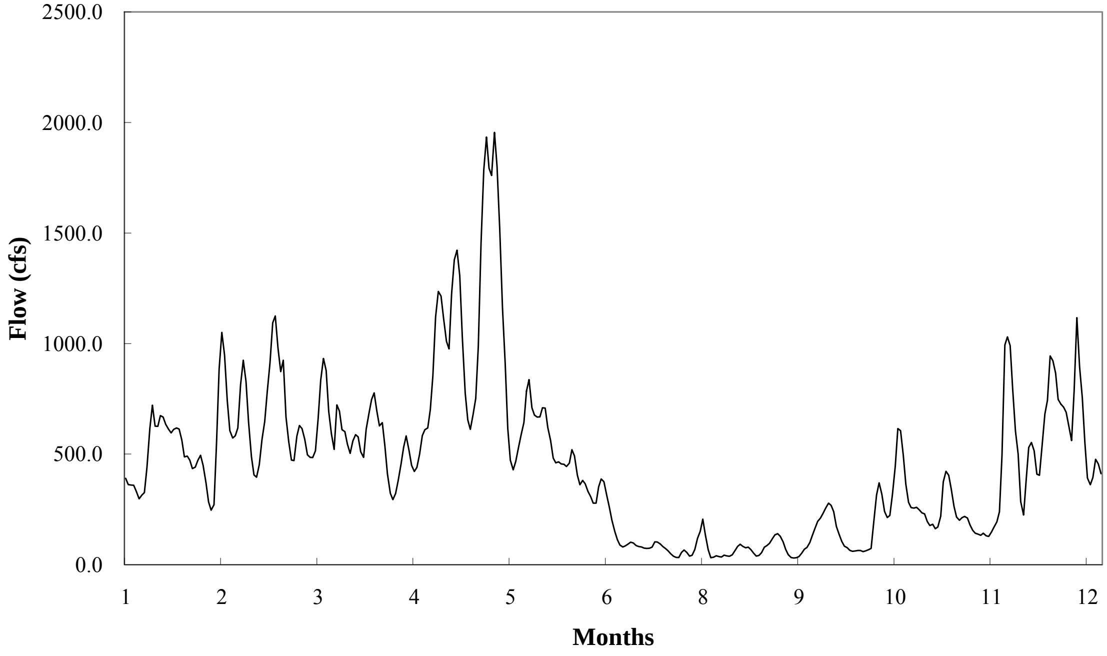

Figure 6.22 Averaged Daily Flow Pattern at NAEA66 (Easterly)

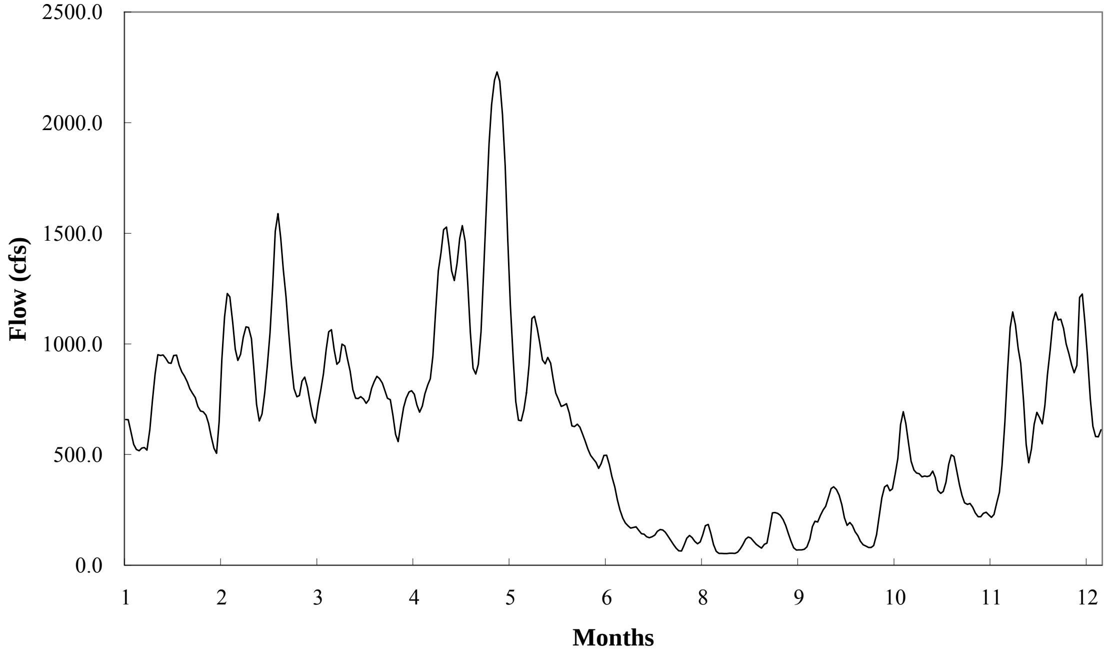

Figure 6.23 Averaged Daily Flow Pattern at NABR67 (Bryan in Navasota)

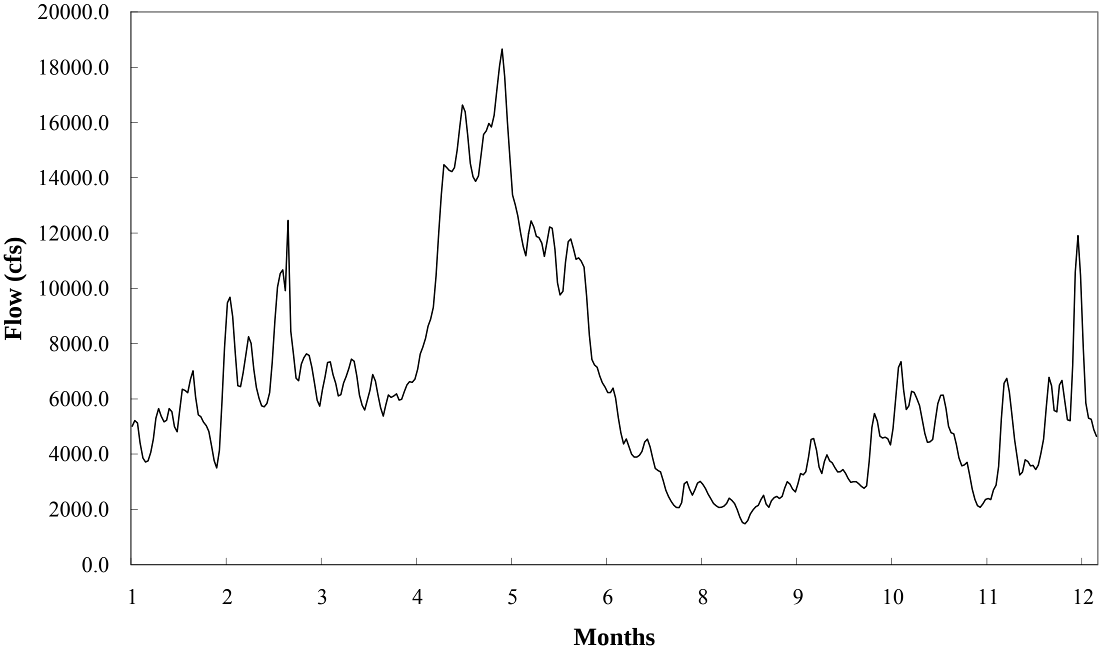

Figure 6.24 Averaged Daily Flow Pattern at CON147 (Washington)

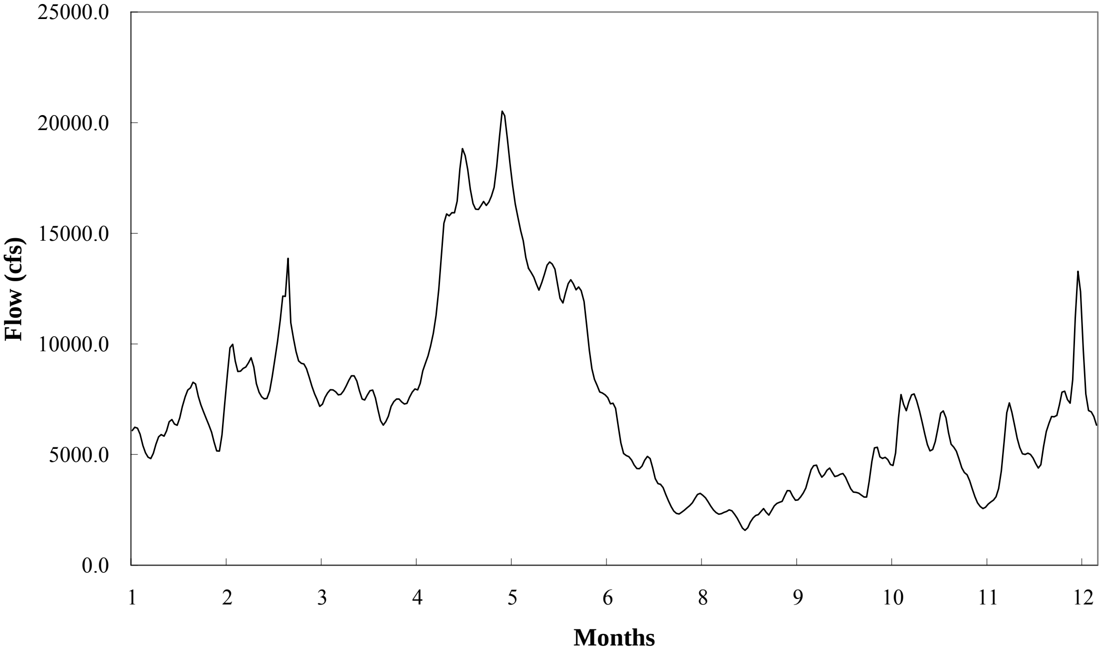

Figure 6.25 Averaged Daily Flow Pattern at BRHE68 (Hempstead)

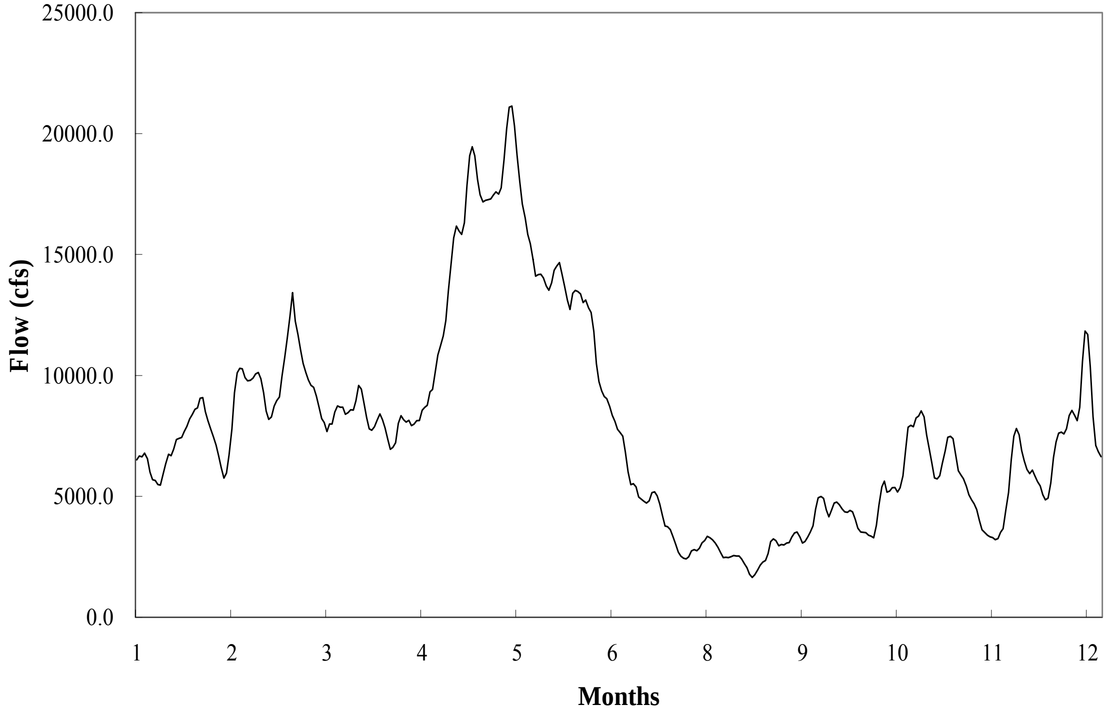

Figure 6.26 Averaged Daily Flow Pattern at BRRI70 (Richmond)

6.1.3 Transferring Daily Naturalized Flows Patterns at 25 Control Points to 23 Other Control Points

The 48 control points of the condensed datasets are divided into two groups:

- Daily flow patterns from SUPER model daily naturalized flows are available during 1990-2007 for 25 of the control points. Daily flow pattern were determined at these 25 control points based on the methodology outlined in this section.
- Daily flow patterns are not available for the other 23 control points.

Daily flow pattern for 1900-2007 at each of the 23 control points are transferred based on the SUPER daily naturalized flow at one of the 25 control points within the program DAY considering lag time. The resulting daily flows at 48 control points comprise the 1900-2007 disaggregation to the DCF input file.

Lag times are computed using linear cross-correlation method in program DAY between gaged inflow and gaged outflow. The results of calibration of the lag time are listed in Table 6.4. The values for lag time may be transferred to other reaches based on reach lengths. In this study, the lag time of intermediate control points are assumed to be zero if the computed lag time is zero or one between two control points in the SUPER model dataset and one or more intermediated control points in the BRAC datasets are located on the reach. Also, if the computed lag time is more than 2 between two control points included in the SUPER model dataset and one or more intermediate control points in the BRAC datasets, the value of the lag time is estimated based on reach lengths. The results of calibration of 48 control points in the BRAC dataset are shown in Table 6.5.

Table 6.4 Calibration Results of Lag Time Using SUPER Daily Naturalized Flows

Upstream CP	Downstream CP	Lag Time	R Square	Upstream CP	Downstream CP	Lag Time	R Square
515531	BRDE29	1	0.93	10	GAGE56	0	0.95
BRDE29	515631	0	0.99	GAGE56	516331	0	0.79
515631	BRGR30	0	0.98	516331	CON102	0	0.86
BRGR30	515731	0	0.95	CON102	LRCA58	0	0.87
515731	433702	0	0.98	LRLR53	LRCA58	1	0.93
515831	19	0	0.37	BRHB42	BRBR59	1	0.93
19	433702	0	0.56	LRCA58	BRBR59	1	0.89
227901	NBCL36	0	0.97	516431	CON129	0	0.95
NBCL36	509431	0	0.75	CON129	CON147	1	0.58
509431	BRWA41	0	0.75	BRBR59	CON147	1	0.98
433702	BRWA41	0	0.97	516531	NAEA66	1	0.94
BRWA41	BRHB42	1	0.97	NAEA66	NABR67	2	0.95
516131	CON095	0	0.94	NABR67	CON231	5	0.90
515931	LEGT47	2	0.72	CON231	CON147	0	0.44
LEGT47	516031	0	0.80	CON147	BRHE68	1	0.97
516031	LRLR53	0	0.92	BRHE68	BRRI70	1	0.99
CON095	LRLR53	0	0.91	BRRI70	OUT	-	-
516231	GAGE56	0	0.98				

Table 6.5 Calibration Results of Lag Time of Control Points in BRAC Dataset

Upstream CP	Downstream CP	Lag Time	Upstream CP	Downstream CP	Lag Time
DMAS09	BRSE11	0	LEBE49	CON096	0
BRSE11	CON036	0	516131	LABE52	0
421331	CON036	0	LABE52	CON096	0
CON036	BRSB23	0	CON096	LRLR53	0
BRSB23	515531	0	LRLR53	CON108	0
515531	BRPP27	0	516231	516331	0
BRPP27	BRDE29	0	516331	GALA57	0
BRDE29	515631	0	GALA57	CON108	0
515631	BRGR30	0	CON108	LRCA58	0
BRGR30	CON063	0	LRCA58	CON111	0
409732	CON063	0	CON111	BRBR59	0
CON063	515731	0	BRBR59	CON130	0
515731	BRAQ33	0	516431	CON130	0
BRAQ33	CON070	0	CON130	CON147	0
515831	CON070	0	516531	NAEA66	0
CON070	433901	0	NAEA66	NABR67	0
509431	433901	0	NABR67	CON147	0
433901	BRWA41	0	CON147	BRHE68	0
BRWA41	BRHB42	0	BRHE68	CON234	0
BRHB42	CON111	0	292531	CON234	0
515931	LEHM46	1	CON234	BRRI70	0
LEHM46	LEGT47	1	BRRI70	BRRO72	0
LEGT47	516031	0	BRRO72	BRGM73	0
516031	LEBE49	0	BRGM73	OUT	0

The program DAY and SIMD both contain the same optional methods for transferring flow pattern of daily naturalized flows from gaged to ungaged control points. The option for disaggregating naturalized flows is selected by parameter *DFMETHOD (CP)* on the control point DC record. Information required to implement the monthly volume disaggregation is provided in the DCF file.

The flow pattern of daily naturalized flow for January 1, 1900 through December 31, 2007 were computed at each of the 23 unknown-flow control points based on daily naturalized flows at one of the 25 known-flow control points and ratios between the drainage area at the respective control points.

Drainage areas for the 48 control points are tabulated in Table 6.3. The 23 unknown-flow control points are listed in Table 6.6 along with the relationship with known-flow control points.

The flow pattern of the daily naturalized flow at each of the 23 unknown flow control points were related by ratios of drainage area at one selected known-flow control points as shown in Table 6.3. In most cases, the unknown-flow and known-flow control points are located on the same stream. In some cases, known-flow control points in adjacent watershed were selected for transferring at a particular unknown-flow control point. For 8 of the unknown-flow control points, flow patterns are transferred from the same control points that are used for distributing primary control point flows to secondary control points in DIS file. In 15 cases, different control points in the DIS file are used to transfer daily naturalized flow at an unknown-flow control points.

Table 6.6 Relationships for Transferring 1900-2007 Flow Patterns for 23 Control Points

Control Points	Flow transferring relationship With Source Control Points	Control Points	Flow transferring relationship With Source Control Points
DMAS09	0.1342 (515531)	LEBE49	1.0031 (516031)
BRSE11	0.4255 (515531)	LABE52	1.0061 (516131)
421331	0.0771 (515531)	CON096	0.9985 (LRLR53)
CON036	0.9344 (515531)	GALA57	1.0152 (516331)
BRSB23	0.9346 (515531)	CON108	0.9996 (LRCA58)
BRPP27	1.0153 (515531)	CON111	0.9775 (BRBR59)
409732	0.0036 (BRGR30)	CON130	0.9203 (BRHE68)
CON063	1.0316 (BRGR30)	292531	0.0017 (BRRI70)
BRAQ33	1.0031 (515731)	CON234	0.9981 (BRRI70)
CON070	0.9127 (BRWA41)	BRRO72	1.0091 (BRRI70)
433901	0.9982 (BRWA41)	BRGM72	1.0162 (BRRI70)
LEHM46	1.5062 (515931)		

6.2 DETERMINATION OF FLOOD FLOW AND AVERAGE ANNUAL DAMAGE CURVE

A set of July 1972 discharge (cfs) versus flood damage ($) curves at the Waco, High Bank, Valley Junction, Washington, Hempstead, and Richmond gage stations were developed by USACE Army Corps at Fort Worth and was utilized for computing average annual damage in this research. A set of July 1972 discharge versus flood damage curve is converted to a set of September 1984 data by multiplying the index shown in Table 6.7. Table 6.8 illustrates flood flow limits for these control points. Figures 6.27 to 32 show the September 1984 discharge versus flood damage curve for these six control points.

Table 6.7 1972 and 1984 Discharge versus Flood Damage Curve Index

Lists	July 1972 Index	September 1984 Index	Multiplier Factor
Crops	356	635	1.7837
Other Agriculture	433	1,134	2.6189
Non Agriculture	1,726	4,176	2.4195

Table 6.8 Flood Flow Limit at Six Control Points

Gage Identifiers	River Miles (miles)	Flood Flow Limit (acre-feet/year)	BRAC Control Points
Waco Gage	401.8 to 408.0	47,146,320	BRWA41
Highbank Gage	317.9 to 401.8	48,596,976	BRHB42
Valley Junction Gage	249.9 to 317.9	72,532,800	CON111
Washington Gage	236.0 to 249.9	65,279,520	CON147
Hempstead Gage	157.8 to 236.0	60,927,552	BRHE68
Richmond Gage	0.0 to 157.8	43,519,680	BRRI70

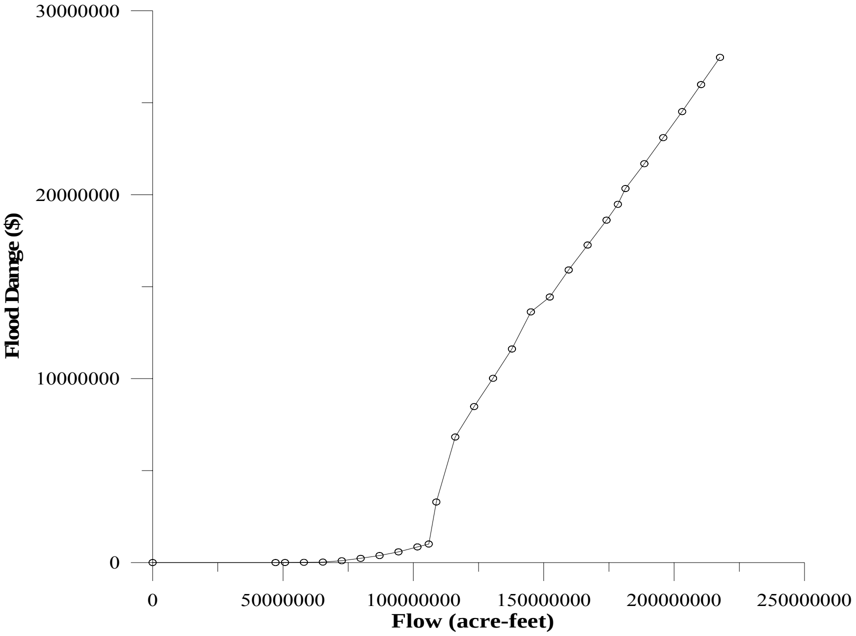

Figure 6.27 Flood Flow versus Damage at Waco Gage (BRWA41)

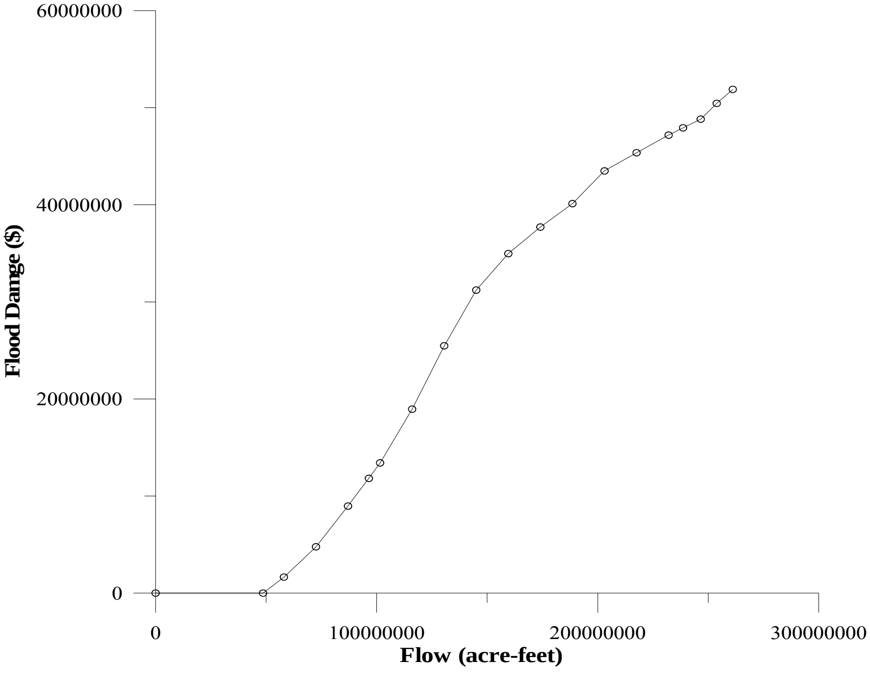

Figure 6.28 Flood Flow versus Damage at Highbank Gage (BRHB42)

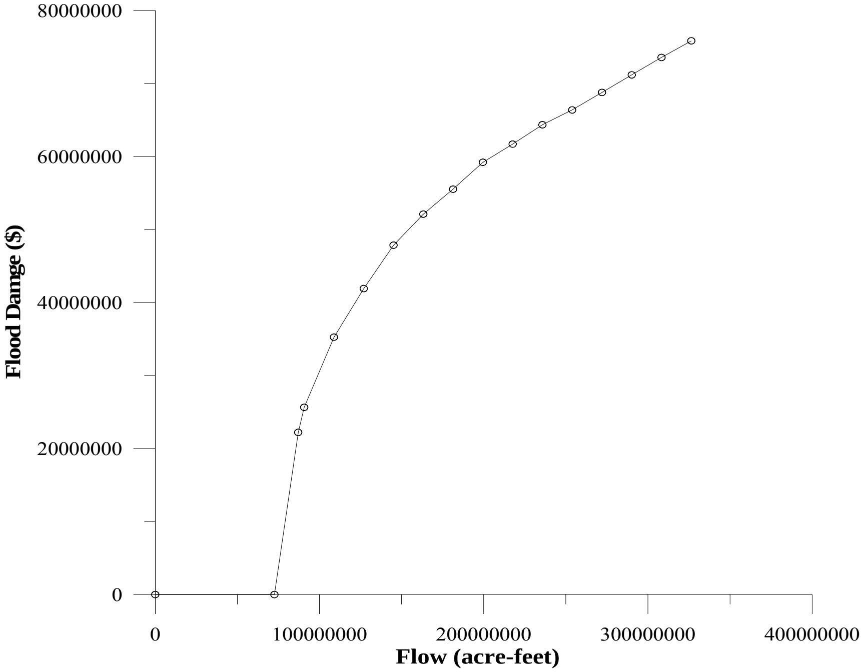

Figure 6.29 Flood Flow versus Damage at Valley Junction Gage (CON111)

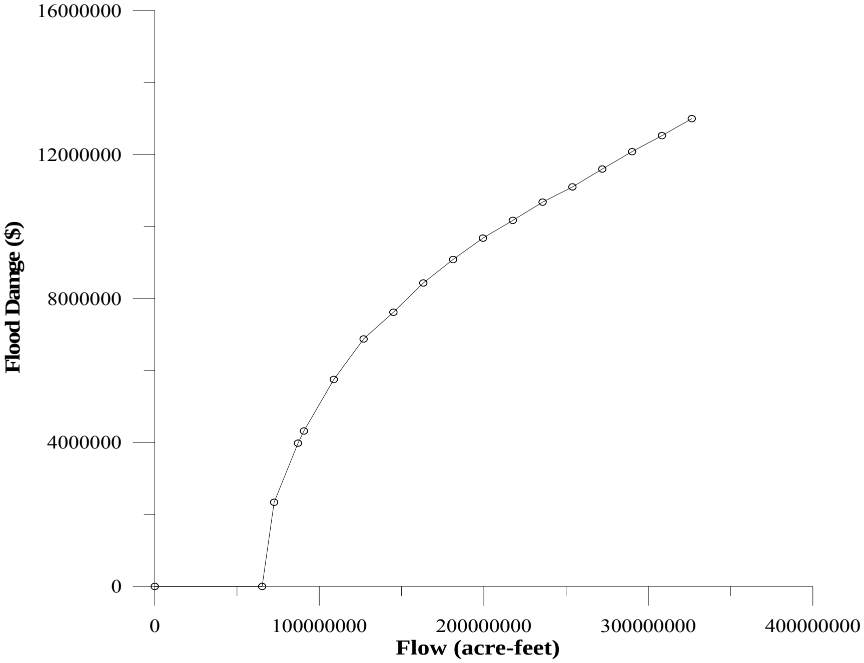

Figure 6.30 Flood Flow versus Damage at Washington Gage (CON147)

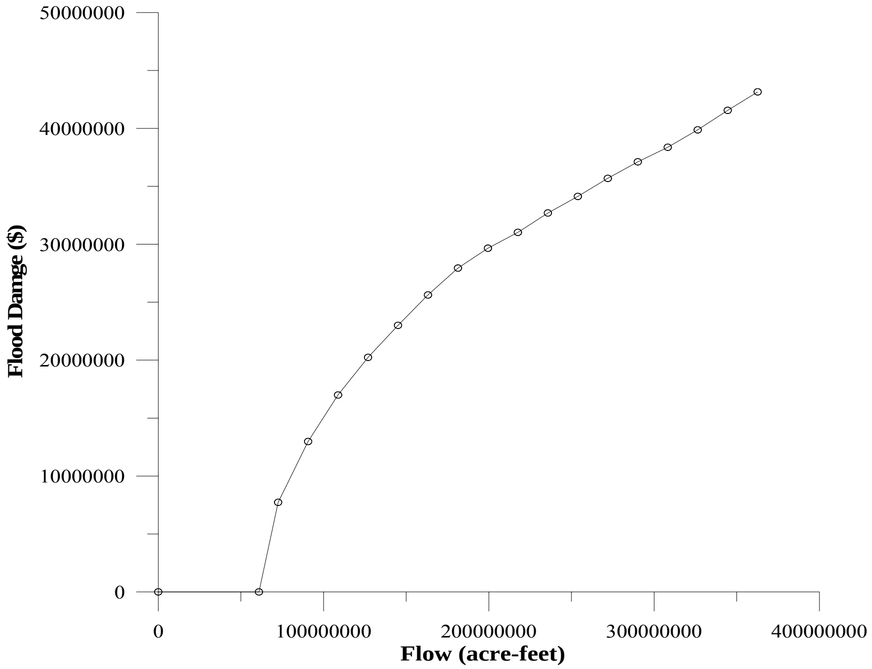

Figure 6.31 Flood Flow versus Damage at Hempstead Gage (BRHE68)

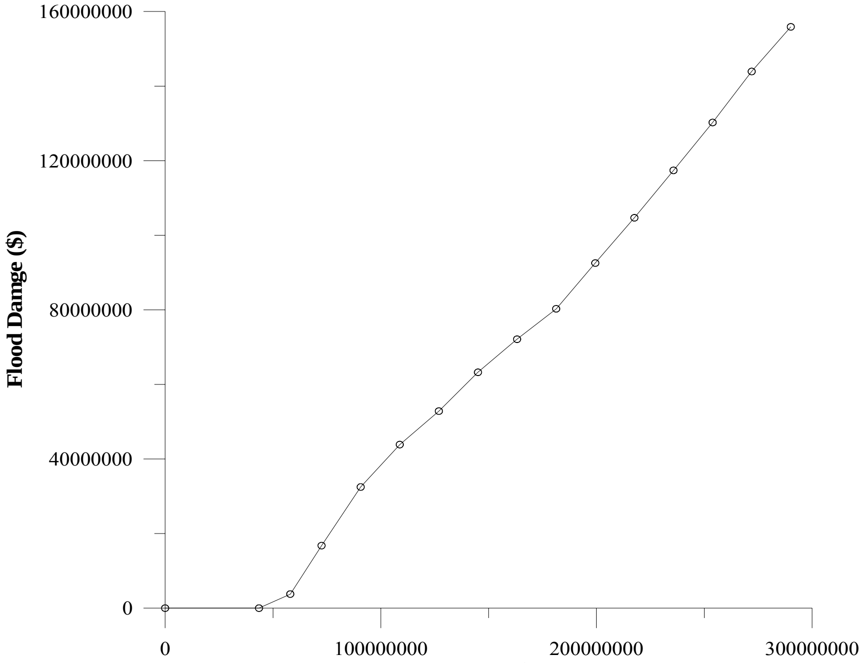

Figure 6.32 Flood Flow versus Damage at Richmond Gage (BRRI70)

6.3 CALIBRATION OF MUSKINGUM ROUTING PARAMETERS

Calibration of routing parameters is another key data development task. The Muskingum routing parameter K represents flow travel time through a river reach. The parameter X tends to be similar in different reaches. X may be assumed to be the same for multiple reaches, and K may be estimated based on proportioning travel time. Distance can serve as a surrogate for travel time in proportioning K to reaches of varying length. The values of K for the selected reaches determined by calibration computations may be transferred to other reaches based on reach lengths. Flow velocities are greater and travel times shorter for flood flows compared to normal flows. The Muskingum Routing method is well documented by the following reference book.

Conditional Reliability, Sub-Monthly Time Step, Flood Control, and Salinity Features of WRAP, TWRI TR-284, September 2006

The procedure for calibrating Muskingum parameters K and X is as follows:

1. The 30 regression equations are fitted between two control points having SUPER daily naturalized flows, considering the lag times shown in Table 6.4.

2. Based on the flood flow limits shown in Table 6.8, the flood flow limits at 30 control points are computed using the regression equation shown in Table 6.9.

3. Calibration of Muskingum K and X based on flood flow limits using optimization function alternatives in program DAY and distance between two control points shown in Table 6.2.

4. Investigation and selection of Muskingum Parameter K and X results based upon two calibration methodologies shown in Table 6.10.

5. The Muskingum parameters at 48 control points in the BRAC datasets are computed based on the distance shown in Table 6.11.

As shown in Table 6.10, three kinds of K and X for normal flow and flood flow are calibrated. The hydrologic period of simulation is January 1939 through December 1997. Flood flow limits shown in Table 6.9 are set to lower limit of the flood flow for calibrating K and X for flood flow. Options 2 and 5 on JOBMSK record in the program DAY are used for calibrating K and X of normal flow. Option 1 and 4 on JOBMSK record are used for calibrating K and X of flood flow. When the K and X are calibrated based on the distance, normal stream velocity and flood stream velocity are assumed to be 15 miles/day (0.92 ft/s) and 40 miles/day (2.44 ft/s), respectively. The value of X is assumed to zero at every control points.

As shown in Table 6.10, the travel time from 515531 control point to BRRI70 control point located on the Brazos River is 8.839 days (option 2), 8,868 day (option 5) , 41.138 days (distance), 7.491 days (option 1), 6.049 days (option 4), and 15.225 days (distance), respectively. Travel times are shorter for flood flows than normal flows for all methods. The values of K and X at each reach based on distance are reasonable. Accordingly, The Muskingum K and X results based on distance are used in this research and the Muskingum calibration methodology in the program DAY was not actually used for the K and X calibration.

Table 6.9 Regression Equations Developed Using SUPER Model Daily Naturalized Flows

Upstream CP	Downstream CP	Routing Para.	R^2	Regression Equation	Flood Flow Limit At Upstream (CFS)
515531	BRDE29	1	0.93	515531 = 0.728 *BRDE29+ 88.470	25,649
BRDE29	515631	0	0.99	BRDE29 = 0.913 * 515631 - 19.824	35,111
515631	BRGR30	0	0.98	515631 = 0.986 * BRGR30 - 3.975	38,479
BRGR30	515731	0	0.95	BRGR30 = 0.834 * 515731 - 35.897	39,030
515731	433702	0	0.98	515731 = 0.905 * 433702 - 63.802	46,842
515831	19	0	0.37	515831 = 1.143 * 19 - 59.679	4,339
19	433702	0	0.56	19 = 0.074 * 433702 + 11.011	3,846
227901	NBCL36	0	0.97	227931 = 0.566 * NBCL36 + 62.747	3,952
NBCL36	509431	0	0.75	NBCL36 = 0.542 * 509431 - 33.215	6,872
509431	BRWA41	0	0.75	509431 = 0.197 * BRWA41 - 63.053	12,741
433702	BRWA41	0	0.97	433702 = 0.797 * BRWA41 + 25.454	51,830
BRWA41	BRHB42	1	0.97	-	65,000
516131	CON095	0	0.94	516131 = 0.890 * CON095 - 47.140	10,201
515931	LEGT47	2	0.72	515931 = 0.376 * LEGE47 + 43.192	3,254
LEGT47	516031	0	0.80	LEGT47 = 0.506 * 516031 + 10.122	8,542
516031	LRLR53	0	0.92	516031 = 0.631 * LRLR53 -27.717	17,212
CON095	LRLR53	0	0.91	CON096 = 0.331* LRLR53 - 13.132	11,515
516231	GAGE56	0	0.98	516231 = 0.0878 * GAGE56 + 51.968	289
10	GAGE56	0	0.95	10 = 0.0524 * GAGE56 + 28.217	169
GAGE56	516331	0	0.79	GAGE56 = 0.697 * 516331 + 203.805	2,700
516331	CON102	0	0.86	516331 = 0.458 * CON102 + 40.725	3,582
CON102	LRCA58	0	0.87	CON102 = 0.283 * LRCA58 - 39.971	7,732
LRLR53	LRCA58	1	0.93	LRLR53 = 1.263 * LRCA58 + 323.776	34,831
BRHB42	BRBR59	1	0.93	-	67,000
LRCA58	BRBR59	1	0.89	LRCA58 = 0.332 * BRBR59 + 6.198	27,322
516431	CON129	0	0.95	516431 = 0.783 * CON129 – 70.019	4,422
CON129	CON147	1	0.58	CON129 = 0.0615 * CON147 + 122.418	5,657
BRBR59	CON147	1	0.98	BRBR59 = 0.916 * CON147 - 160.594	82,279
516531	NAEA66	1	0.94	516531 = 0.707 * NAEA66 + 13.563	175.
NAEA66	NABR67	2	0.95	NAEA66 = 0.686 * NABR67 + 20.954	229.
NABR67	CON231	5	0.90	NABR67 = 0.423 * CON231 + 208.02	3,035
CON231	CON147	0	0.44	CON231 = 0.068 * CON147 + 565.013	6,685
CON147	BRHE68	1	0.97	-	90,000
BRHE68	BRRI70	1	0.99	-	84,000
BRRI70	OUT	-	-	-	60,000

Table 6.10 Calibration of Muskingum Routing Parameters Using Alternative Methods

Up stream CP	Down stream CP	Normal Flow						Flood Flow					
		Option 2		Option 5		Distance		Option 1		Option 4		Distance	
		K	X	K	X	K	X	K	X	K	X	K	X
		(Day)		(Day)		(Day)		(Day)		(Day)		(Day)	
515531	BRDE29	1.462	0.158	1.462	0.158	6.733	0.0	0.953	0.173	0.564	0.111	2.525	0.0
BRDE29	515631	0.564	0.111	0.506	0.013	3.607	0.0	0.500	0.001	0.532	0.059	1.150	0.0
515631	BRGR30	0.501	0.000	0.564	0.111	2.133	0.0	0.564	0.111	0.532	0.059	0.800	0.0
BRGR30	515731	0.564	0.111	0.501	0.000	4.333	0.0	0.509	0.015	0.504	0.009	1.625	0.0
515731	433702	0.512	0.024	0.501	0.000	2.333	0.0	0.501	0.000	0.564	0.111	0.875	0.0
515831	19	0.501	0.000	0.525	0.001	-	-	0.501	0.000	0.500	0.001	-	-
19	433702	0.564	0.111	0.564	0.111	-	-	0.532	0.059	0.564	0.111	-	-
227901	NBCL36	0.519	0.000	0.533	0.001	1.467	0.0	0.501	0.000	0.501	0.000	0.550	0.0
NBCL36	509431	1.035	0.083	1.035	0.083	2.667	0.0	0.564	0.111	0.501	0.003	1.000	0.0
509431	BRWA41	0.604	0.001	0.533	0.001	0.667	0.0	0.508	0.016	0.501	0.000	0.250	0.0
433702	BRWA41	0.564	0.111	0.501	0.000	0.600	0.0	0.532	0.059	0.533	0.061	0.225	0.0
BRWA41	BRHB42	0.788	0.154	0.789	0.151	4.000	0.0	0.658	0.238	0.564	0.111	1.500	0.0
516131	CON095	0.501	0.000	0.519	0.000	1.067	0.0	0.501	0.000	0.501	0.000	0.400	0.0
515931	LEGT47	2.495	0.200	2.490	0.201	8.000	0.0	1.969	0.169	0.564	0.111	3.000	0.0
LEGT47	516031	1.694	0.280	1.689	0.268	5.133	0.0	0.501	0.000	0.502	0.005	1.925	0.0
516031	LRLR53	0.501	0.000	0.501	0.000	1.533	0.0	0.500	0.001	0.501	0.000	0.575	0.0
CON095	LRLR53	0.501	0.000	0.504	0.007	0.400	0.0	0.564	0.111	0.564	0.111	0.150	0.0
516231	GAGE56	0.647	0.000	0.500	0.001	0.333	0.0	0.501	0.000	0.501	0.000	0.125	0.0
10	GAGE56	0.533	0.001	0.517	0.000	-	-	0.501	0.000	0.501	0.000	-	-
GAGE56	516331	0.501	0.000	0.526	0.013	1.867	0.0	0.501	0.000	0.501	0.001	0.700	0.0
516331	CON102	0.504	0.009	0.564	0.111	1.733	0.0	0.564	0.111	0.501	0.000	0.650	0.0
CON102	LRCA58	0.501	0.000	0.501	0.000	1.067	0.0	0.501	0.001	0.564	0.111	0.400	0.0
LRLR53	LRCA58	1.176	0.283	1.152	0.250	4.133	0.0	0.705	0.289	0.500	0.001	1.550	0.0
BRHB42	BRBR59	1.138	0.386	1.138	0.386	4.533	0.0	0.905	0.448	0.564	0.111	1.700	0.0
LRCA58	BRBR59	1.180	0.334	1.080	0.362	4.467	0.0	0.705	0.289	0.532	0.059	1.675	0.0
516431	CON129	0.501	0.000	0.506	0.003	0.933	0.0	0.501	0.000	0.564	0.111	0.350	0.0
CON129	CON147	0.523	0.006	0.503	0.000	1.533	0.0	0.564	0.111	0.500	0.001	0.575	0.0
BRBR59	CON147	0.697	0.228	0.698	0.227	3.733	0.0	0.564	0.111	0.564	0.111	1.400	0.0
516531	NAEA66	1.344	0.158	1.348	0.159	1.133	0.0	0.974	0.169	0.754	0.143	0.425	0.0
NAEA66	NABR67	2.167	0.231	2.268	0.218	2.267	0.0	2.002	0.250	1.601	0.312	0.850	0.0
NABR67	CON231	4.942	0.101	4.942	0.101	4.000	0.0	3.996	0.125	0.564	0.111	1.500	0.0
CON231	CON147	9.980	0.045	9.980	0.045	0.400	0.0	0.509	0.015	0.564	0.111	0.150	0.0
CON147	BRHE68	0.837	0.002	0.834	0.001	2.133	0.0	0.564	0.111	0.564	0.111	0.800	0.0
BRHE68	BRRI70	1.212	0.388	1.204	0.330	7.000	0.0	1.241	0.275	0.564	0.111	2.625	0.0
BRRI70	OUT	-	-	-	-	-	-	-	-	-	-	-	-

Table 6.11 Muskingum K and X for Normal and Flood Flow for BRAC Dataset

Upstream	Downstream	Normal Flow		Flood Flow		Distance	
Control Points	Control Points	K	X	K	X	Length	Difference
		(Day)		(Day)			
DMAS09	BRSE11	7.667	0.000	2.875	0.000	981	115
BRSE11	CON036	6.200	0.000	2.325	0.000	866	93
421331	CON036	2.867	0.000	1.075	0.000	816	43
CON036	BRSB23	0.067	0.000	0.025	0.000	773	1
BRSB23	515531	4.400	0.000	1.650	0.000	772	66
515531	BRPP27	1.333	0.000	0.500	0.000	706	20
BRPP27	BRDE29	5.400	0.000	2.025	0.000	686	81
BRDE29	515631	3.067	0.000	1.150	0.000	605	46
515631	BRGR30	2.133	0.000	0.800	0.000	559	32
BRGR30	CON063	0.267	0.000	0.100	0.000	527	4
409732	CON063	0.333	0.000	0.125	0.000	528	5
CON063	515731	4.067	0.000	1.525	0.000	523	61
515731	BRAQ33	0.600	0.000	0.225	0.000	462	9
BRAQ33	CON070	1.267	0.000	0.475	0.000	453	19
515831	CON070	1.600	0.000	0.600	0.000	458	24
CON070	433901	0.667	0.000	0.250	0.000	434	10
509431	433901	0.267	0.000	0.100	0.000	428	4
433901	BRWA41	0.400	0.000	0.150	0.000	424	6
BRWA41	BRHB42	4.000	0.000	1.500	0.000	418	60
BRHB42	CON111	2.400	0.000	0.900	0.000	358	36
515931	LEHM46	3.133	0.000	1.175	0.000	639	47
LEHM46	LEGT47	4.867	0.000	1.825	0.000	592	73
LEGT47	516031	5.133	0.000	1.925	0.000	519	77
516031	LEBE49	0.267	0.000	0.100	0.000	442	4
LEBE49	CON096	0.867	0.000	0.325	0.000	438	13
516131	LABE52	0.200	0.000	0.075	0.000	441	3
LABE52	CON096	0.867	0.000	0.325	0.000	438	13
CON096	LRLR53	4.533	0.000	1.700	0.000	425	68
LRLR53	CON108	4.133	0.000	1.550	0.000	419	62
516231	516331	2.200	0.000	0.825	0.000	432	33
516331	GALA57	0.333	0.000	0.125	0.000	399	5
GALA57	CON108	2.467	0.000	0.925	0.000	394	37
CON108	LRCA58	0.000	0.000	0.000	0.000	357	0
LRCA58	CON111	2.333	0.000	0.875	0.000	357	35
CON111	BRBR59	2.133	0.000	0.800	0.000	322	32
BRBR59	CON130	2.600	0.000	0.975	0.000	290	39
516431	CON130	1.333	0.000	0.500	0.000	271	20
CON130	CON147	1.133	0.000	0.425	0.000	251	17
516531	NAEA66	1.133	0.000	0.425	0.000	351	17
NAEA66	NABR67	2.267	0.000	0.850	0.000	334	34
NABR67	CON147	4.400	0.000	1.650	0.000	300	66
CON147	BRHE68	2.133	0.000	0.800	0.000	234	32
BRHE68	CON234	5.533	0.000	2.075	0.000	202	83
292531	CON234	1.133	0.000	0.425	0.000	136	17
CON234	BRRI70	1.467	0.000	0.550	0.000	119	22
BRRI70	BRRO72	2.533	0.000	0.950	0.000	97	38
BRRO72	BRGM73	3.933	0.000	1.475	0.000	59	59
BRGM73	OUT	-	-	-	-	-	-

6.4 EXTENSION OF STORAGE VOLUME AND STORAGE AREA TABLE

A reservoir consists of any or all of the four pools shown in Figure 1.1 of Chapter I. SIM includes only the bottom two pools (inactive pool and conservation pool). 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 Flood Control Reservoir Operations (FC) records as shown in Figure 1.3 of Chapter I. A reservoir may contain any combination of one or more pools defined as follows (Wurbs 2005b):

Flood Control Pools – A flood control pool defined by FC record may include zones with outflows through either controlled (gated) or uncontrolled (ungated) outlet structures. The zones are separated by the storage level entered in FC record.

Uncontrolled Flood Control Storage – Uncontrolled means that releases are controlled by the hydraulic design of outlet structures that have no gates operated by people. Outflow from an individual reservoir is specified as a function of storage level based on interpolation of storage versus outflow table provided on Reservoir Storage Volume (FV) and Reservoir Outflow (FQ) records.

Controlled Flood Control Storage – Controlled means that releases are through gated outlet structures with release decisions based on maximum allowable flows at downstream control points specified on Flood Flow Limits (FF) records. Any number of reservoirs may be operated as a system to control river flows at any number of downstream control points. Flows during the current and forecast periods are considered.

Conservation Pool – Releases or withdrawals from the conservation pool defined by a WA record are for water supply diversion, hydropower, and instream flow requirements.

Inactive Pool – The only way that water can be removed from the inactive pool defined by a WS record is through evaporation occurring while the conservation pool is empty.

Storage Volume (SV) and Storage Area (SA) record of TCEQ WAM system dataset was extended to the conservation pool. For operating the flood control pool in SIMD, reservoir storage capacities on the WS and SV/SA records were extended as necessary to assure that the simulated storages never exceed storage capacities in the model.

In a previous study, based on 2010 sediment calculation data, the SV/SA records to flood control points of thirteen reservoirs were developed in 2010HEC5 datasets. Figures 6.33 to 6.45 show each SV and SA records of WAM and 2010HEC5 in thirteen reservoirs.

The two SV and SA relationship curves show a similar tendency. That means that modification of the SV and SA relationship for matching the 2010HEC5 data and WAM are not required. The SV and SA relationship curve of WAM is utilized for the conservation storage capacity. From the top of the conservation storage capacity to flood control capacity, the SV and SA relationship curve of 2010HEC5 is utilized. Figures 6.46 to 58 show extended SV and SA relationship curves in each reservoir. In other words, nine reservoirs, which are owned and operated by USACE, are extended to the flood control capacities based on 2010HEC5 data. If conservation storage capacities of the remaining four reservoirs in 2010HEC5 are extended more than conservation storage capacities of WAM data, these conservation storage capacities are also extended.

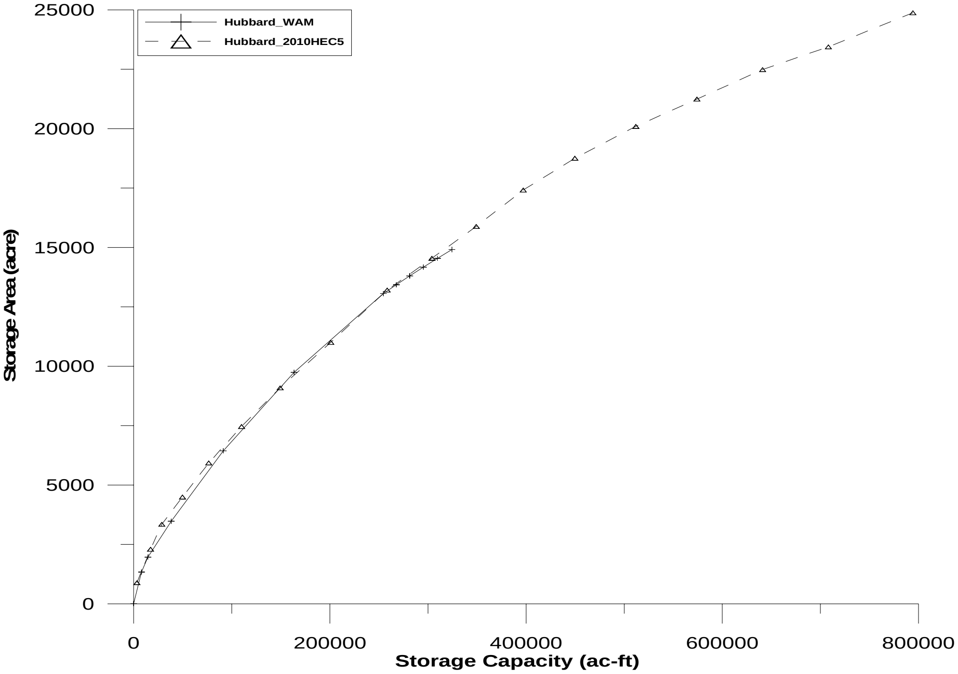

Figure 6.33 SV and SA Record at Hubbard Creek Reservoir

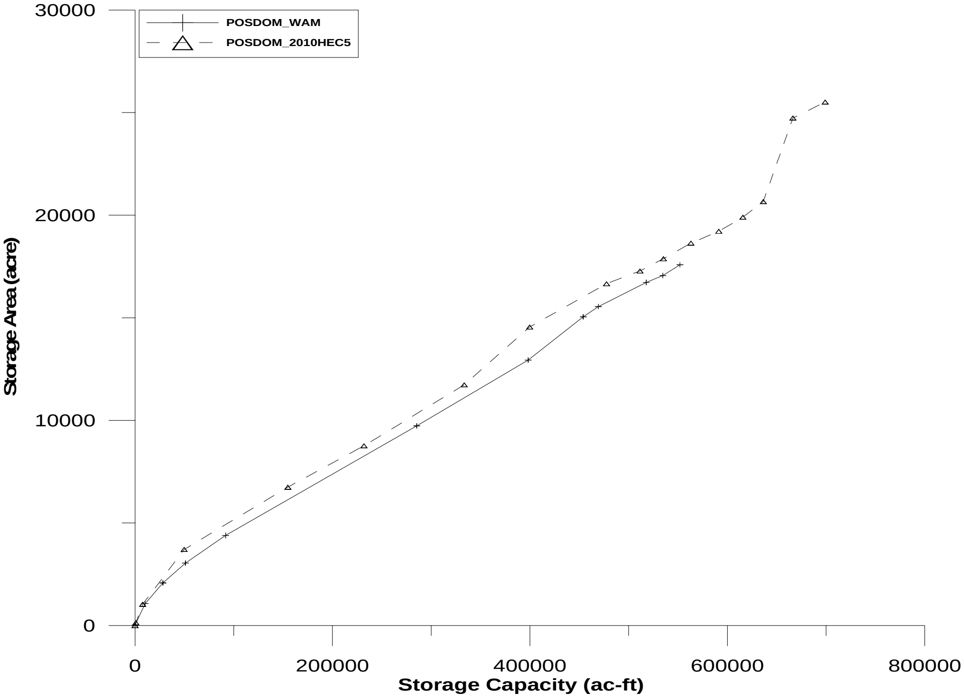

Figure 6.34 SV and SA Record at Possum Kingdom Reservoir

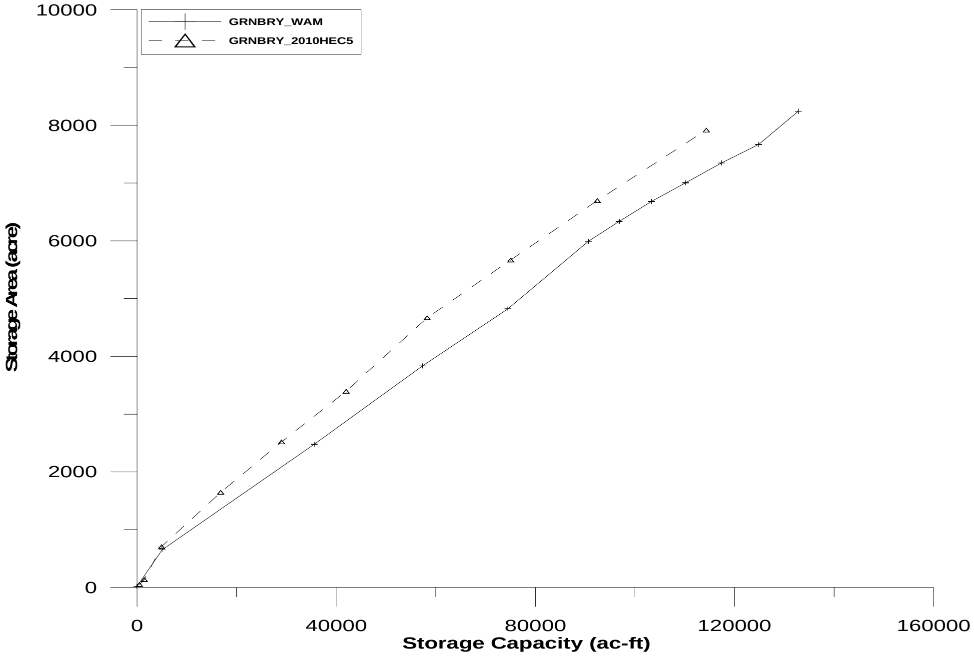

Figure 6.35 SV and SA Record at Granbury Reservoir

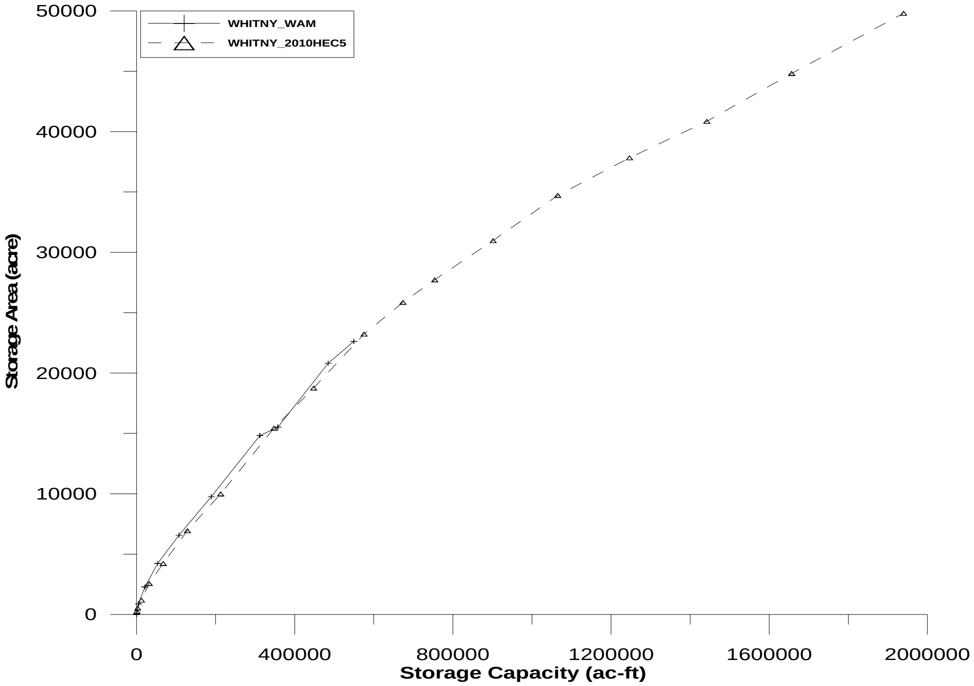

Figure 6.36 SV and SA Record at Whitney Reservoir

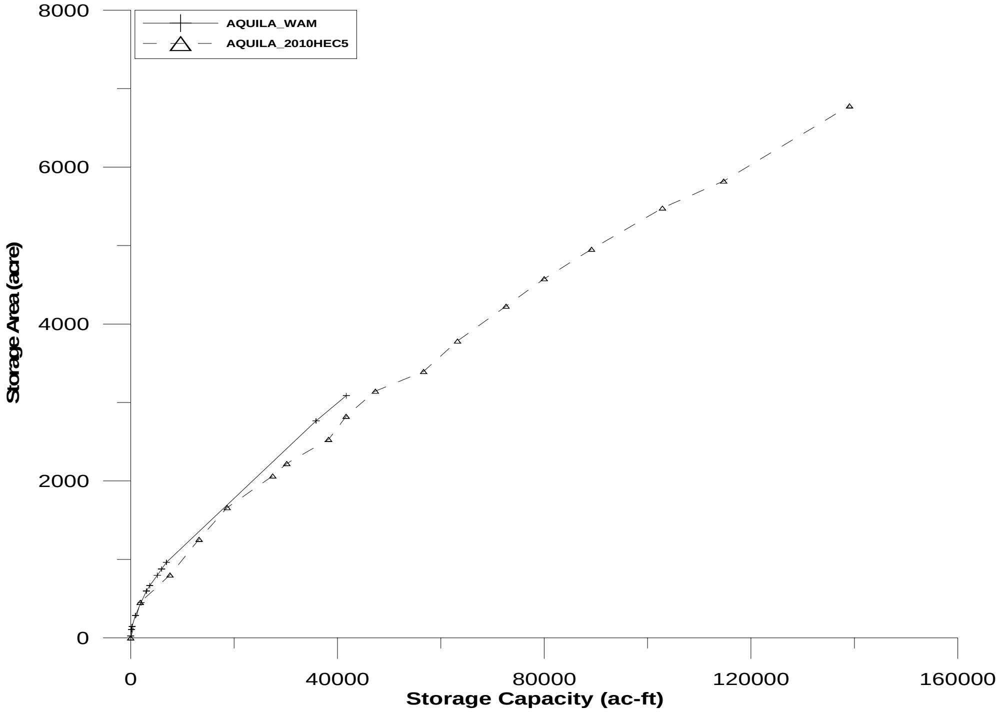

Figure 6.37 SV and SA Record at Aquilla Reservoir

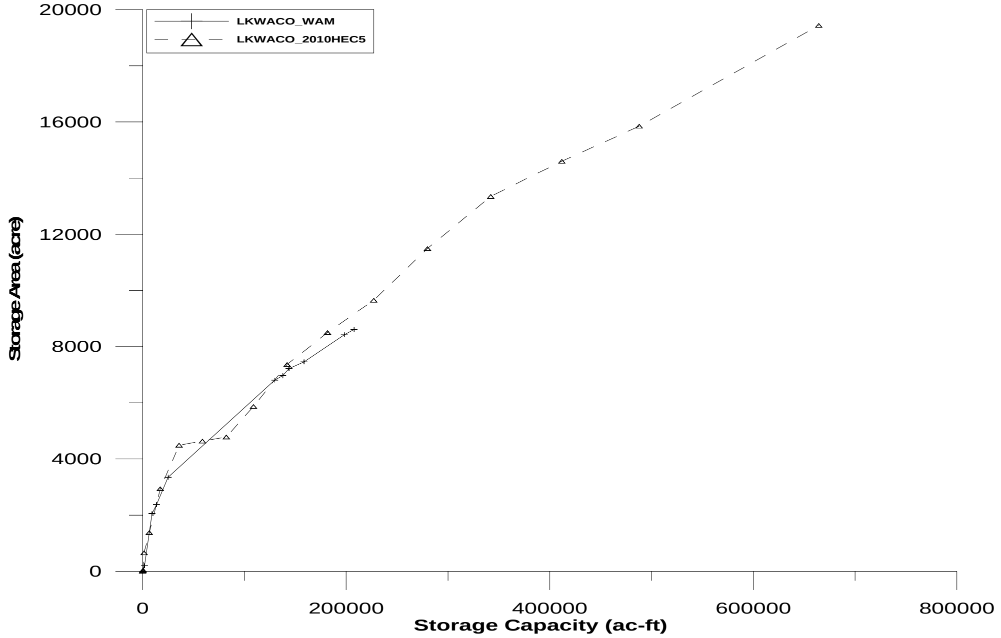

Figure 6.38 SV and SA Record at Waco Reservoir

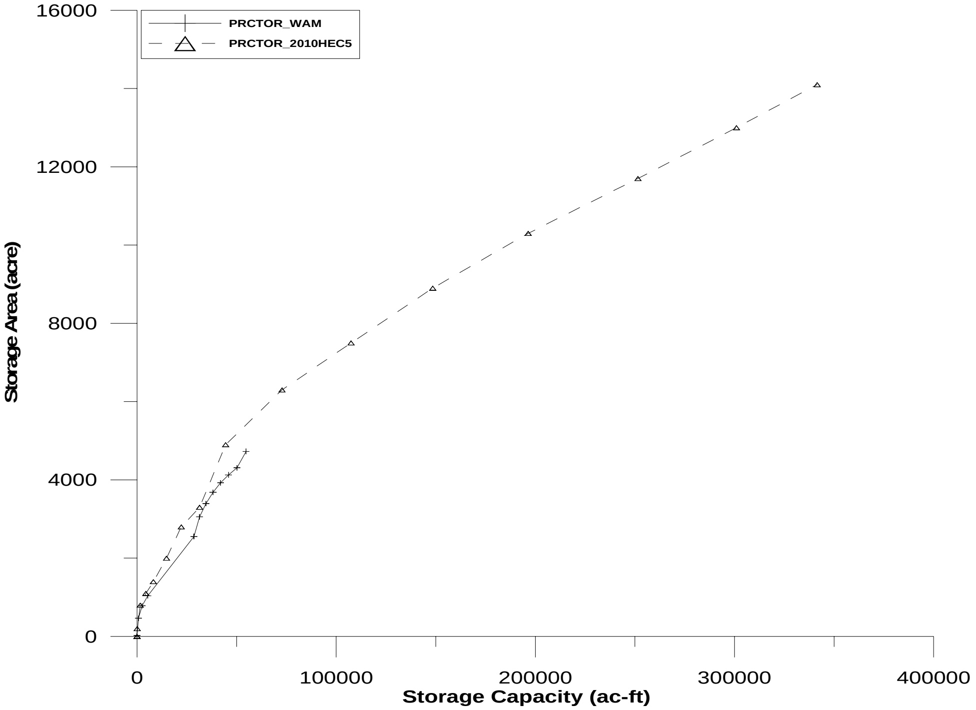

Figure 6.39 SV and SA Record at Proctor Reservoir

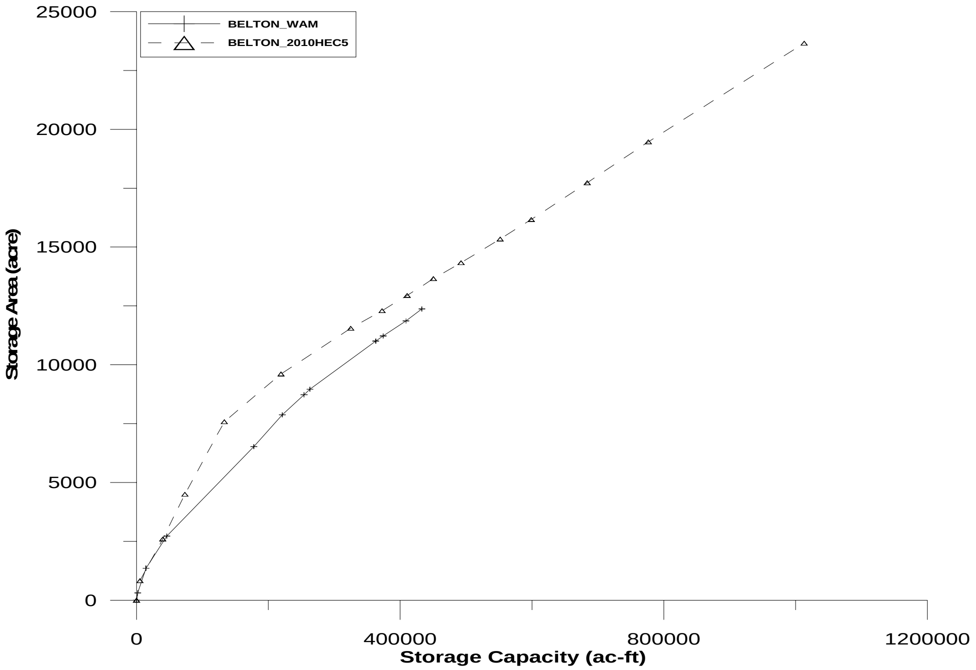

Figure 6.40 SV and SA Record at Belton Reservoir

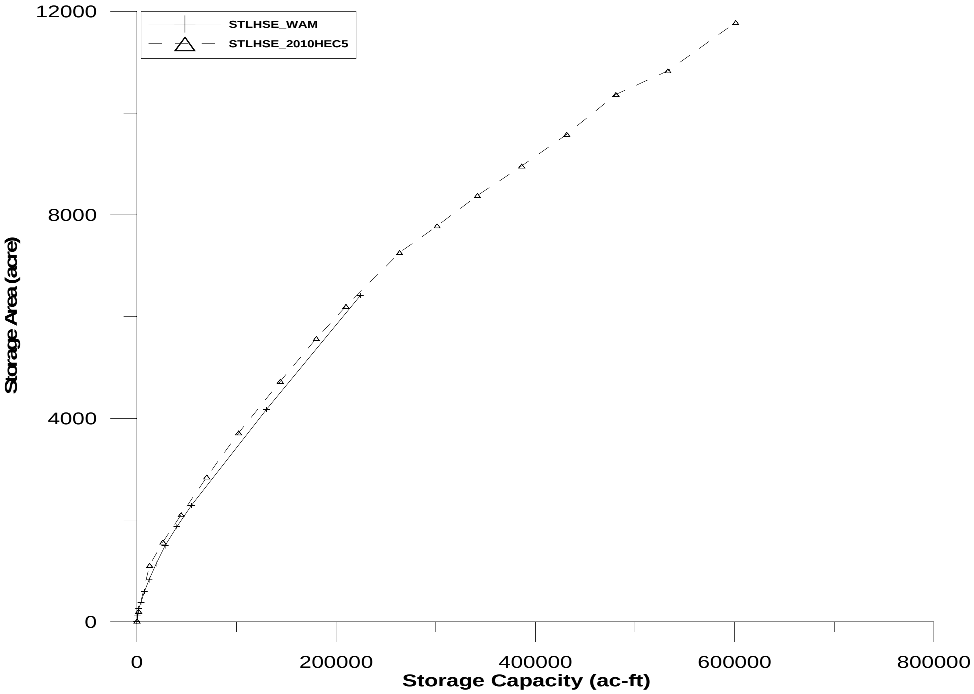

Figure 6.41 SV and SA Record at Stillhouse Hollow Reservoir

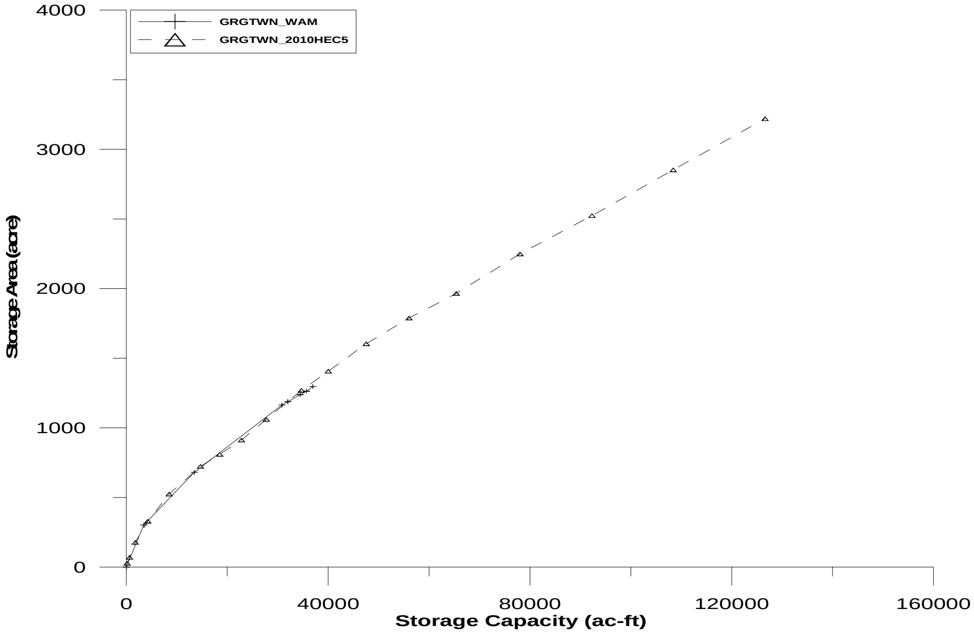

Figure 6.42 SV and SA Record at Georgetown Reservoir

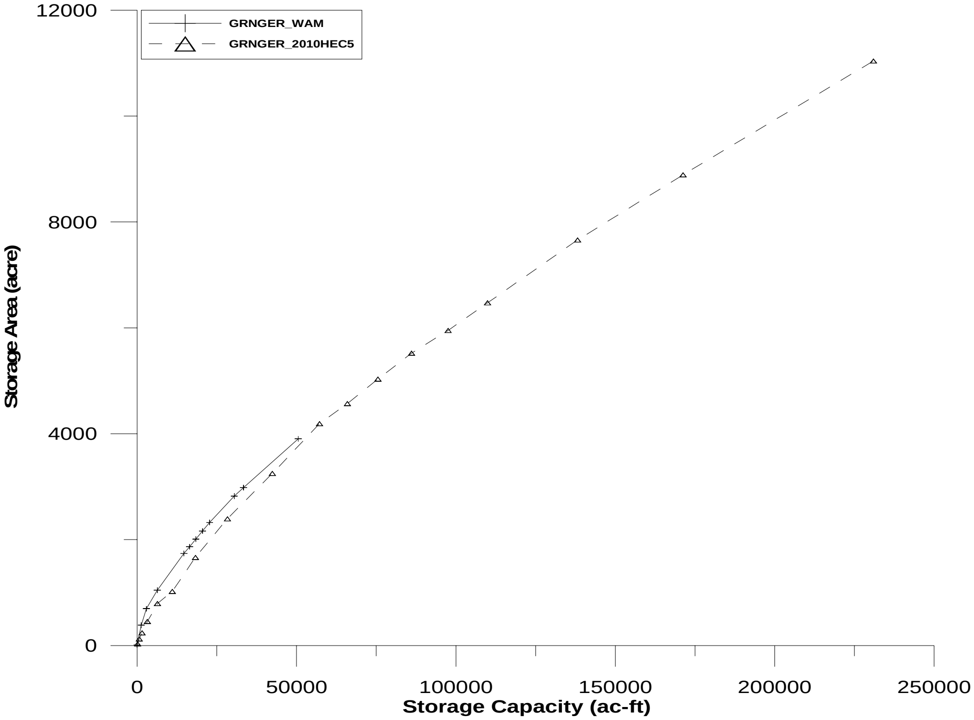

Figure 6.43 SV and SA Record at Granger Reservoir

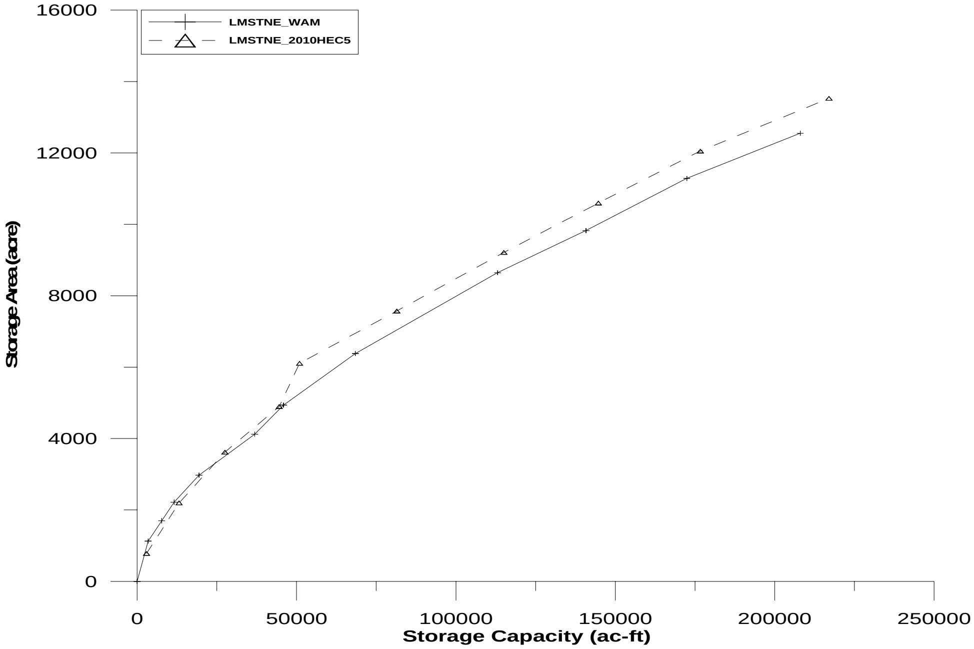

Figure 6.44 SV and SA Record at Limestone Reservoir

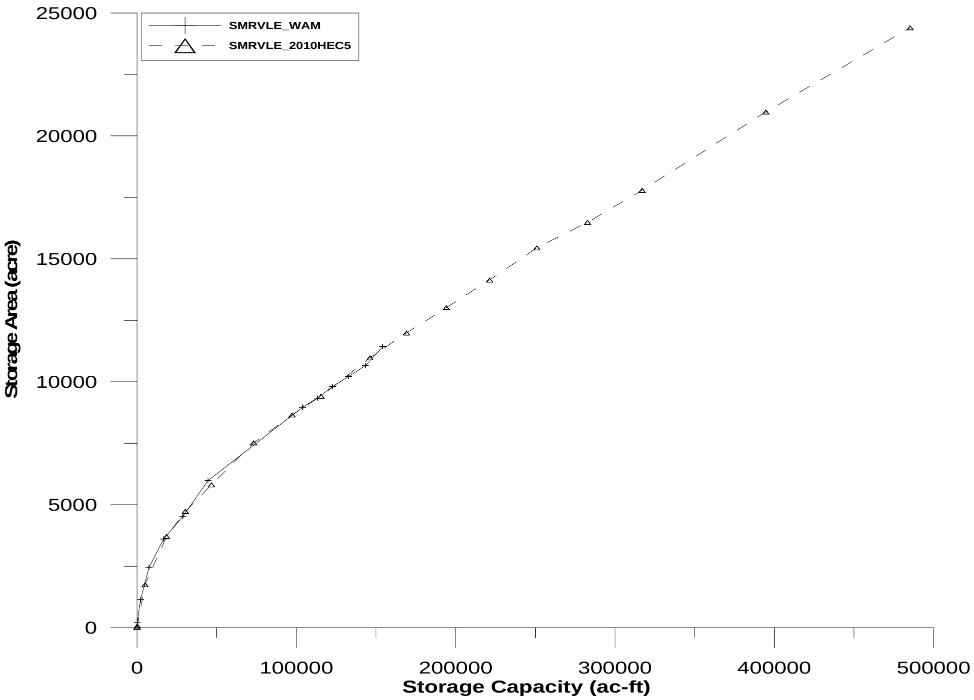

Figure 6.45 SV and SA Record at Somerville Reservoir

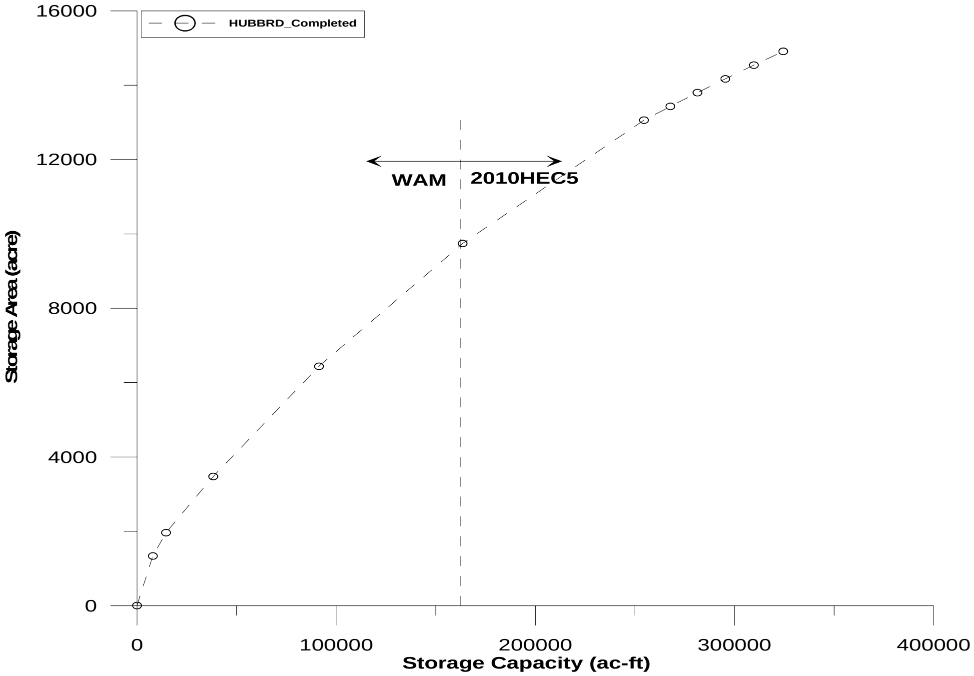

Figure 6.46 Extended SV and SA Record at Hubbard Reservoir

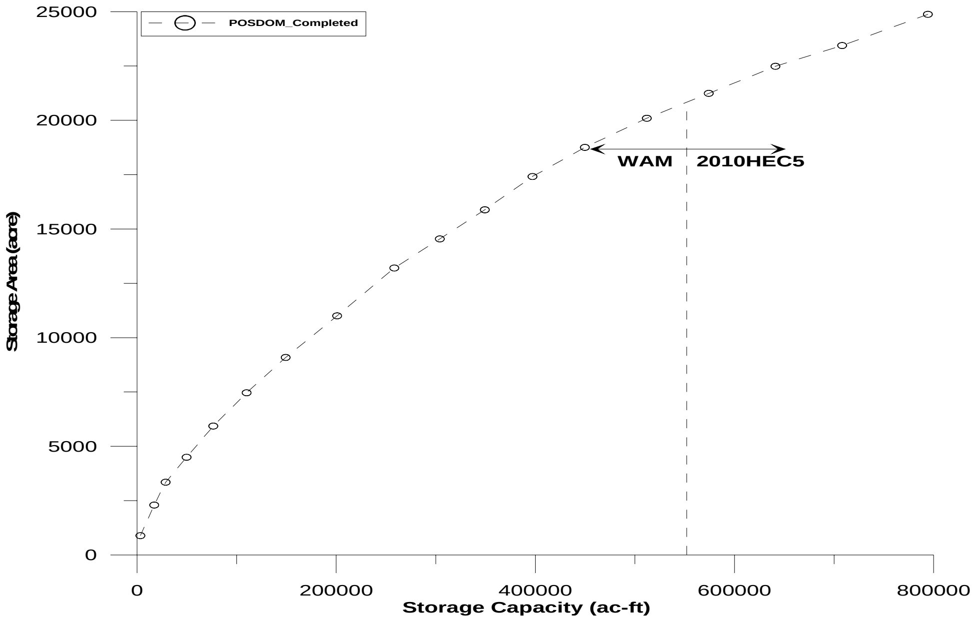

Figure 6.47 Extended SV and SA Record at Possum Kingdom Reservoir

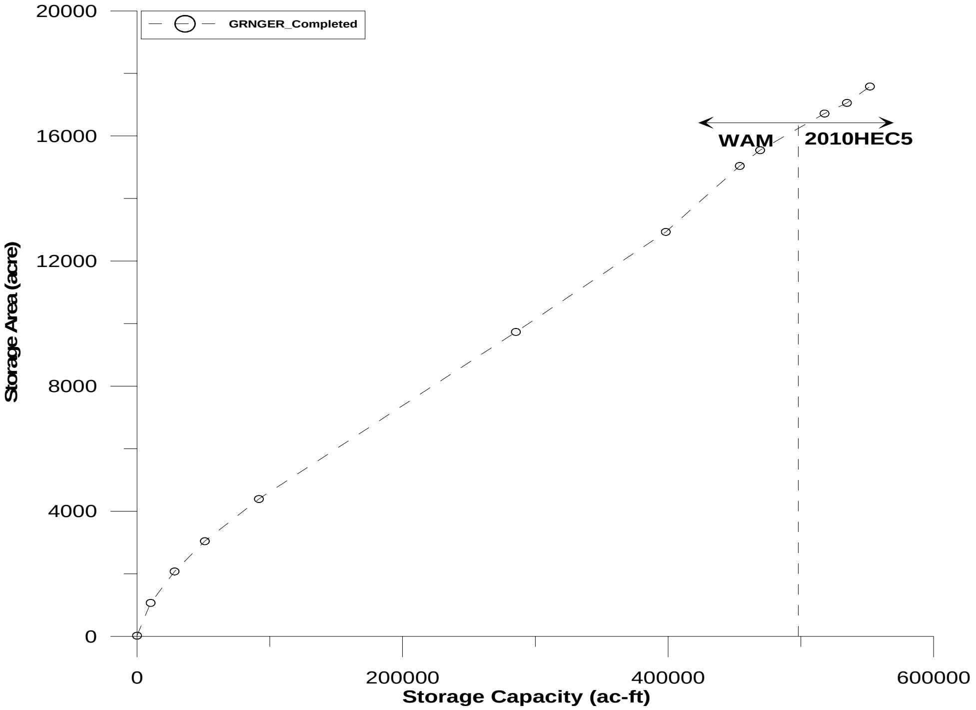

Figure 6.48 Extended SV and SA Record at Granbury Reservoir

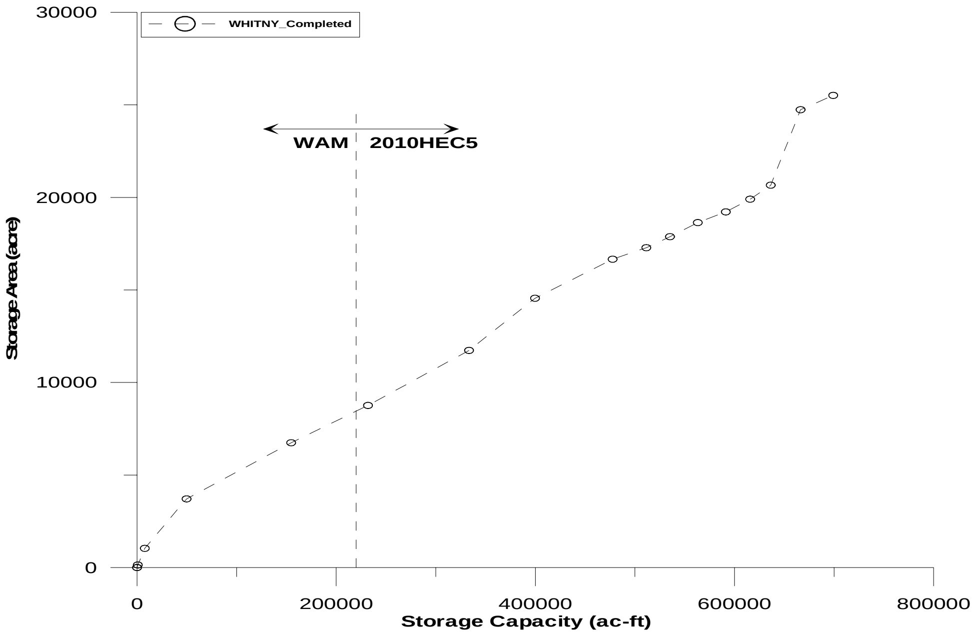

Figure 6.49 Extended SV and SA Record at Whitney Reservoir

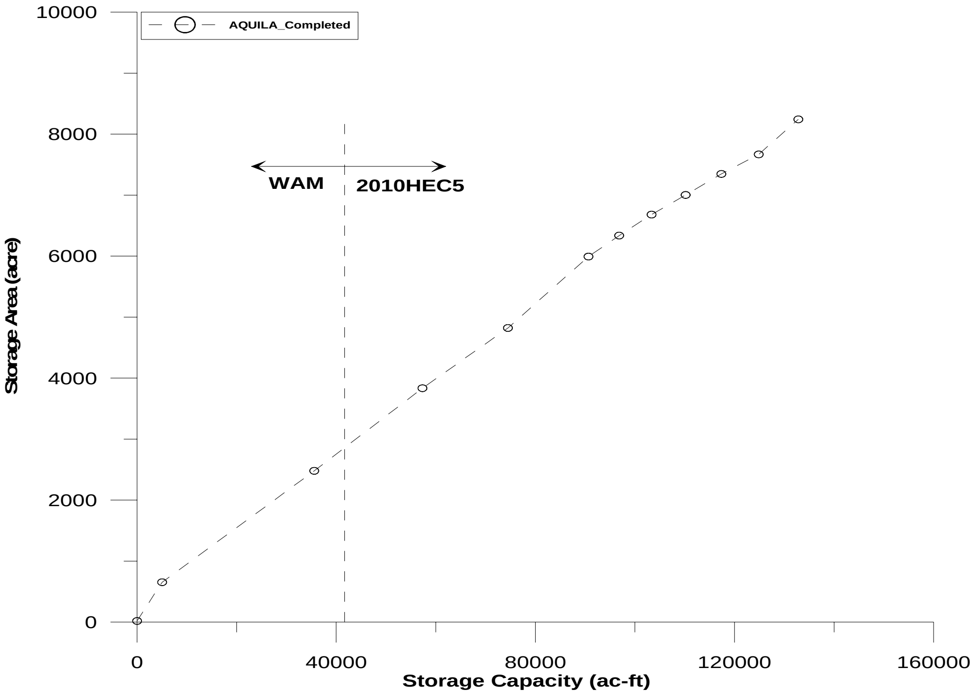

Figure 6.50 Extended SV and SA Record at Aquilla Reservoir

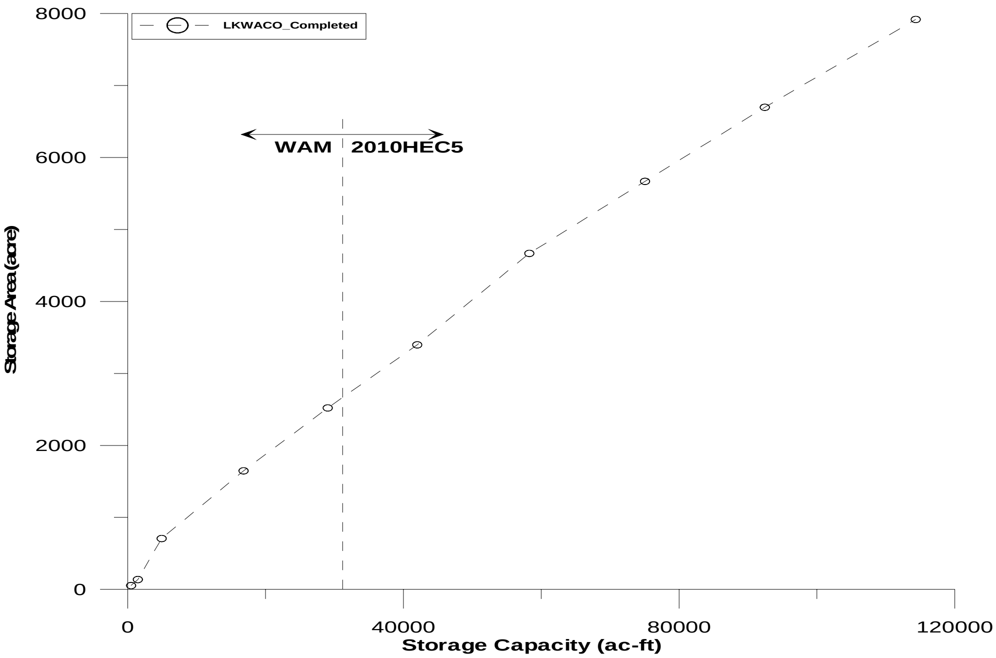

Figure 6.51 Extended SV and SA Record at Waco Reservoir

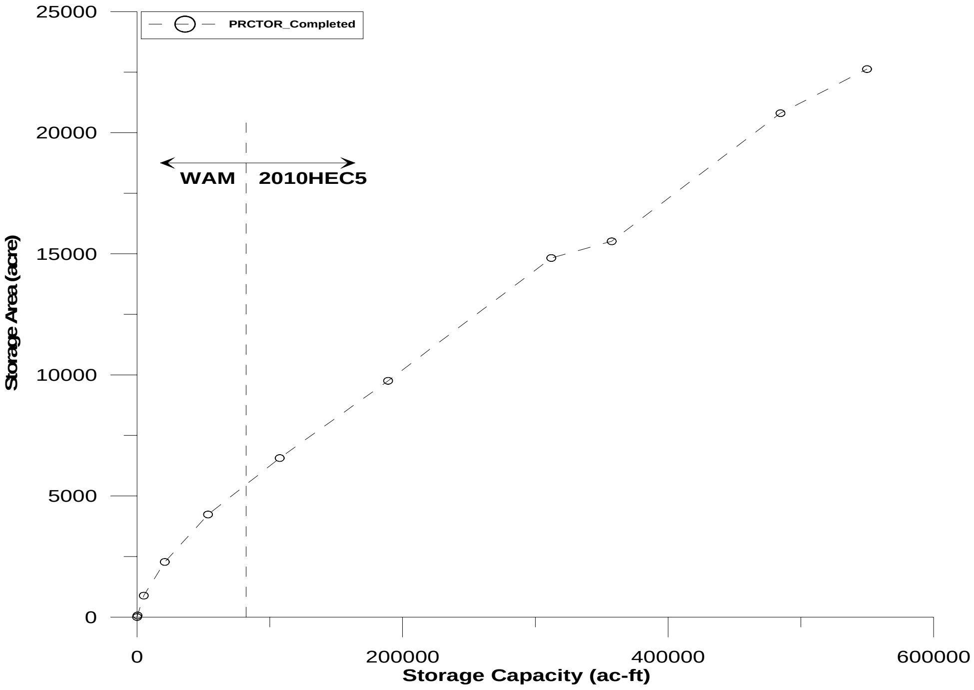

Figure 6.52 Extended SV and SA Record at Proctor Reservoir

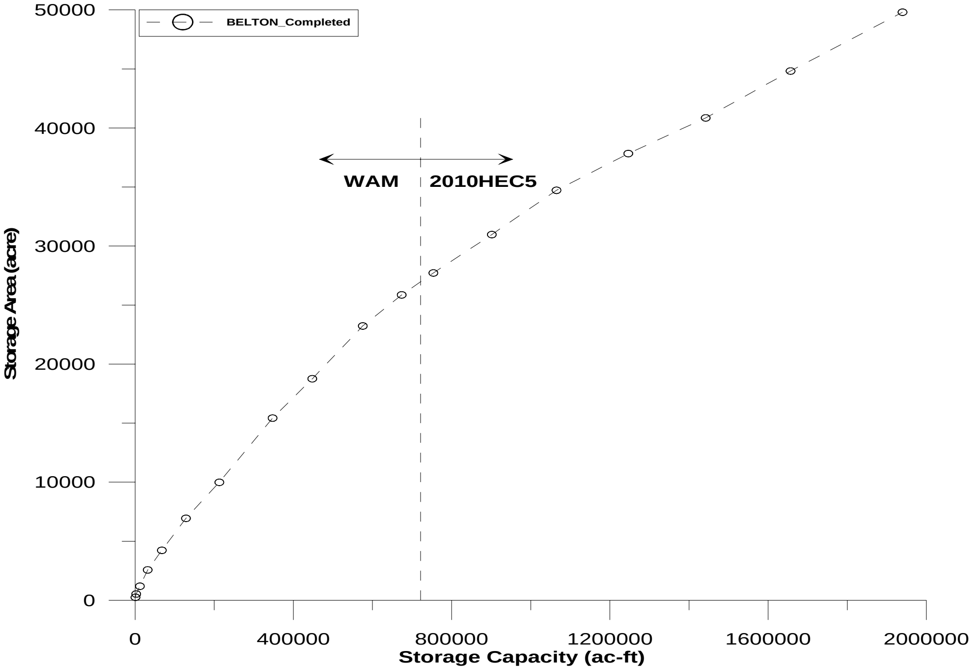

Figure 6.53 Extended SV and SA Record at Belton Reservoir

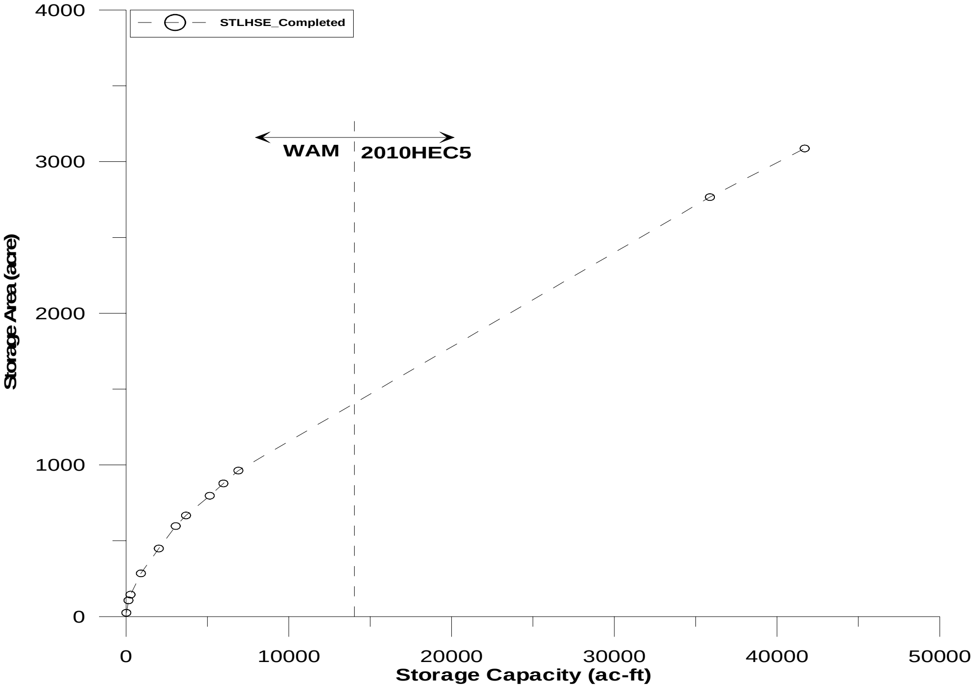

Figure 6.54 Extended SV and SA Record at Stillhouse Hollow Reservoir

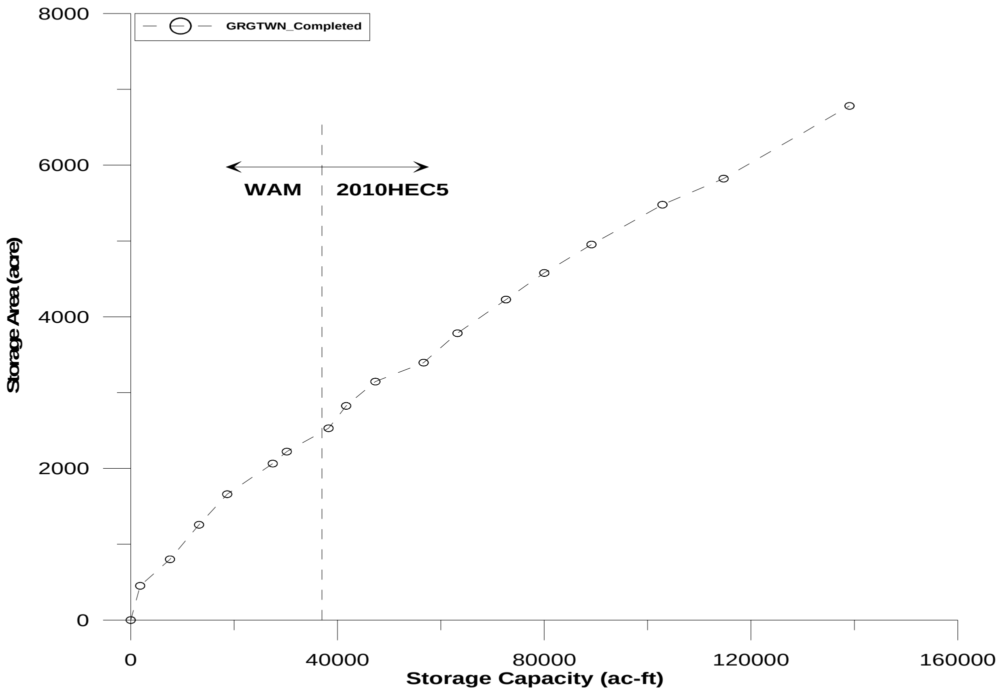

Figure 6.55 Extended SV and SA Record at Georgetown Reservoir

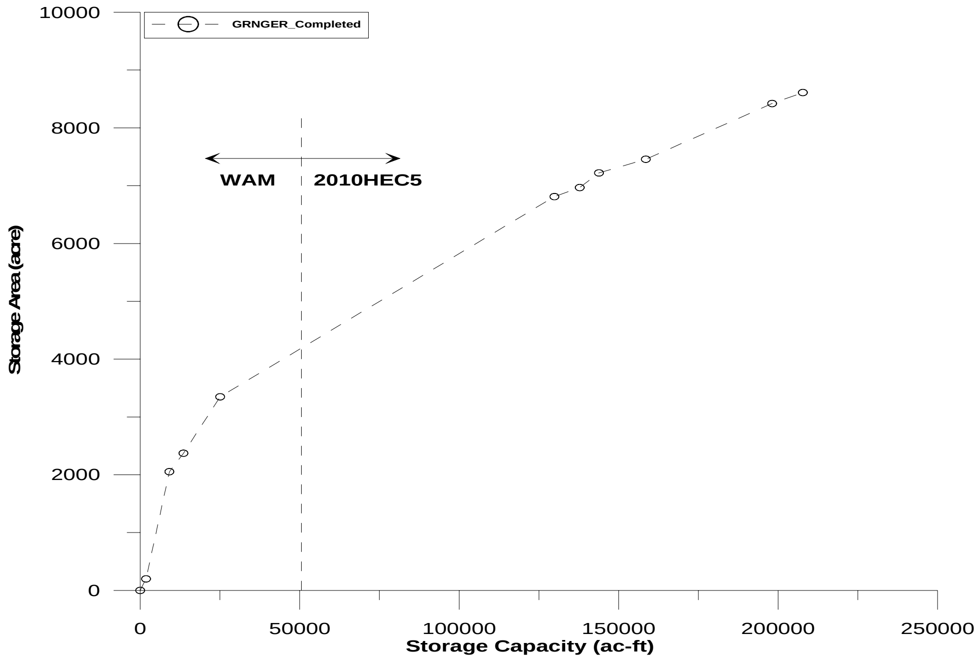

Figure 6.56 Extended SV and SA Record at Granger Reservoir

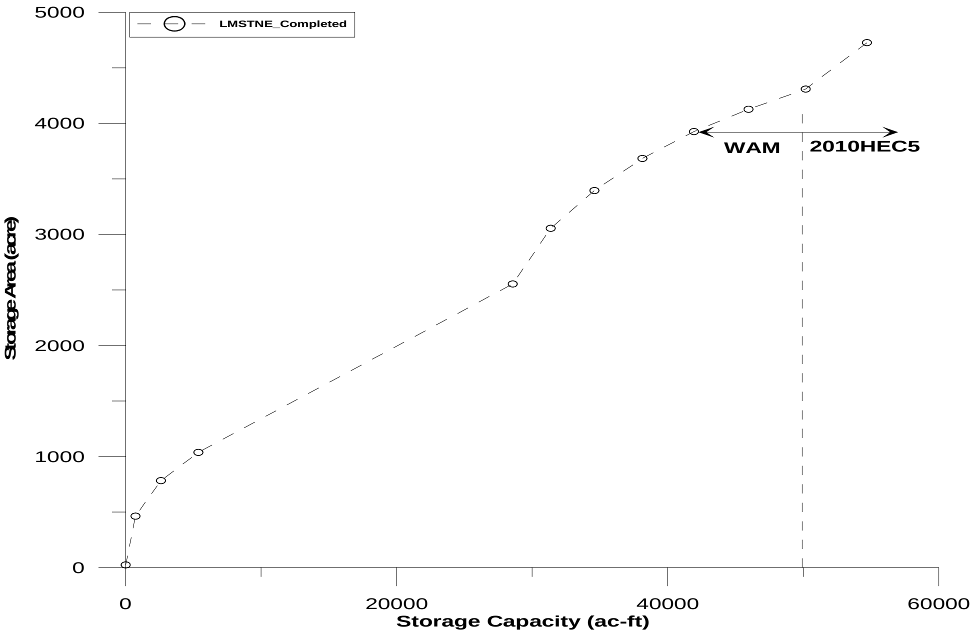

Figure 6.57 Extended SV and SA Record at Limestone Reservoir

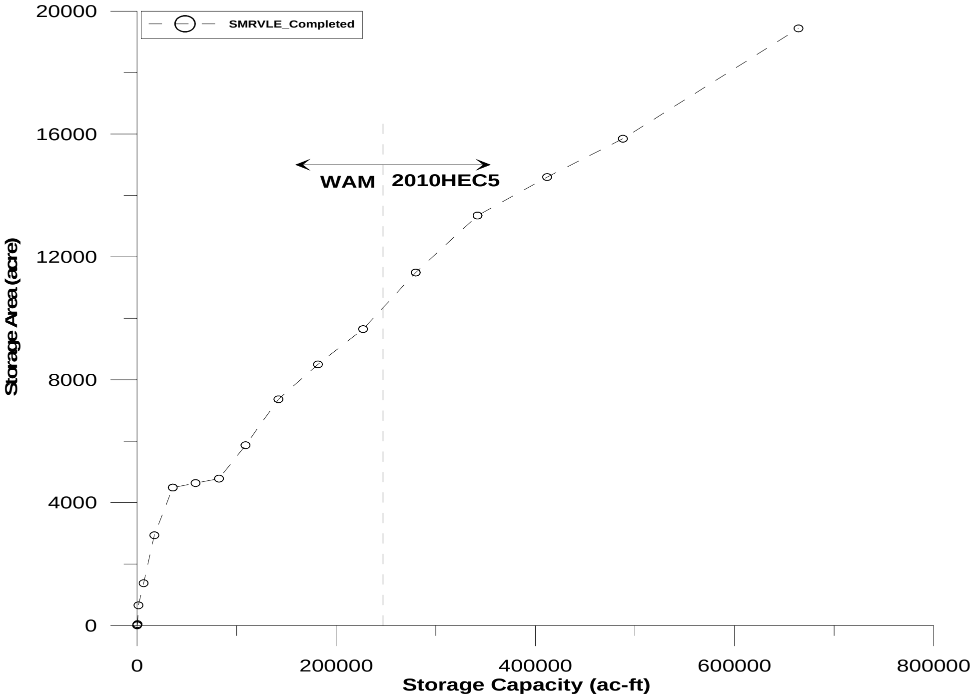

Figure 6.58 Extended SV and SA Record at Somerville Reservoir

CHAPTER VII

EVALUATION OF STORAGE REALLOCATION FOR BRA RESERVOIR SYSTEM

The objective of this chapter is to investigate alternative plans for reallocating storage capacity between flood control and conservation pools by applying the recently developed daily time step and flood control modeling features of the program SIMD using the dataset developed as described in the preceding chapters.

The development of the four Brazos River Authority Condensed (BRAC) datasets is described in Table 5.1 of Chapter V. The 1900-2007 BRAC8 dataset with the year 2000 storage capacities was applied to the proposed Brazos River Authority (BRA) System with the following modifications: i) adding flood control pools, ii) replacing the BRAC3 FLO file with the BRAC8 FLO file, and iii) adding a RUF file. The dataset is listed in Table 7.1. The BRAC8F (F for flood control) dataset developed in this Chapter is based on the current use BRAC dataset for the Brazos River Basin. The BRAC8F dataset consists of 14 reservoirs and 48 control points, shown in Figures 5.1 and 5.2. Tables 5.2, 5.3 and 5.4 list the reservoirs and control points included in the BRA system.

The daily time step BRACF inflows at 48 control points, Muskingum K and X coefficients for normal flow and flood flow, flood flow versus September 1984 damage index curve at six control points, and extended SV and SA curves developed in Chapter VI are utilized for evaluating storage reallocation of the BRA System.

Table 7.1 WRAP-SIMD Input Dataset Discussed in Chapter VII

Filename	Water Use Scenario	Hydrologic Period-of-Analysis
	Brazos River Authority Condensed (BRAC) Datasets	
BRAC8	current use (run 8)	January 1900 through December 2007
	Brazos River Authority Condensed with Flood Control (BRACF) Datasets	
BRAC8F	current use (run 8)	January 1900 through December 2007

7.1 ALTERNATIVE STORAGE CAPACITY REALLOCATION PLANS AND SIMULATION PLANS

Wurbs and Carriere (1988) investigated the seasonal characteristics of factors affecting reservoir operation in the Brazos River Basin. Three seasonal storage allocation plans and one permanent storage allocation plan were investigated in the previous study as follows. In this study, the seasonal (plan 2) and permanent (plan 4) reallocation plans were adopted:

Reallocation Plan 1: Seasonal reallocation with April-October raised,
Reallocation Plan 2: Seasonal reallocation with May-October raised, and
Reallocation Plan 3: Seasonal reallocation with May-October raised and April lowered,
Reallocation Plan 4: Permanent reallocation with January-December raised.

Evaluations of storage reallocation between flood control and conservation pool were preformed for eight SIMD simulation runs for each permanent and seasonal reallocation plans. Year 2000 conditions of water use and reservoir sedimentation were simulated assuming the present allocation of storage capacity (run 1). The reallocation by each 10, 20, 30, and 50 percent from the flood control pool to the conservation pool were simulated (runs 2 through 5). The USACE is authorized to reallocate storage capacity in its reservoirs without obtaining congressional approval as long as the reallocation does not exceed either 50,000 acre-feet or 15 percent of the flood control capacity. The reallocation based on USACE criteria was simulated (run 6). The Whitney reservoir active conservation pool is used for both water supply (50,000 acre-feet) and hydroelectric power (remaining conservation pool) generation. The 50,000 acre-feet reallocation from the flood control pool to the conservation pool at Whitney reservoir were simulated assuming that Whitney reservoir does not have conservation pool for water supply (run 7). The final reallocation plan (run 8) assumes that all of conservation pool at Whitney reservoir is used for water supply. The eight alternative simulation runs are described below:

Simulation Run 1: Existing allocation of storage capacity.
Simulation Run 2: 10 percent reallocation of storage capacity.
Simulation Run 3: 20 percent reallocation of storage capacity.

Simulation Run 4: 30 percent reallocation of storage capacity.
Simulation Run 5: 50 percent reallocation of storage capacity.
Simulation Run 6: 15% or 50,000 ac-ft reallocation of storage capacity.
Simulation Run 7: Run 6 including Whitney with none of conservation pool.
Simulation Run 8: Run 1 plus all of Whitney conservation pool.

Run 1 through Run 6 and Run8 are applied to individual reservoirs for defining firm yield. Run 1 through Run 6 are applied to two multiple-reservoir systems for defining firm yield. Run 1 through Run 5 are applied to individual reservoirs for defining flood frequency. Run 6 through Run 8 are applied to two multiple-reservoir system for defining flood frequency.

Analysis	Selected Simulation Runs
Individual Firm Yield	Run 1 through Run6 and Run 8
Multiple-Reservoir System Firm Yield	Run 1 through Run 6
Individual Flood Frequency	Run 1 through Run 5
Multiple-Reservoir System Flood Frequency	Run 1 and Run 6 through Run 8

The multiple-reservoir system reallocation plans for firm yield analysis and flood frequency analysis were each performed based on Type 2 and Type 3 water rights. Water right types are specified on WR records as describe in the WRAP *References (Wurbs 2008a) and User Manuals (Wurbs 2008b)*:

- A type 2 water right diverts stream flow without making reservoir releases if stream flow is available. Reservoir releases are made as necessary to supplement available stream flow.
- A type 3 water right supplies the diversion only from releases from the system reservoir. Unregulated stream flow is not diverted.

The individual reallocation plans were simulated for nine reservoirs (Whitney, Aquilla, Waco, Proctor, Belton, Stillhouse Hollow, Georgetown, Granger, and Somerville). The multiple-reservoir systems reallocation plans were simulated for the five BRA reservoirs in Little River Sub-basin (Proctor, Belton, Stillhouse Hollow, Georgetown, and Granger) and also the nine BRA reservoirs in Brazos River basin. The matrix of simulation runs for two reallocation plans, individual reservoirs, and two multiple-reservoir systems are shown in Figure 7.1.

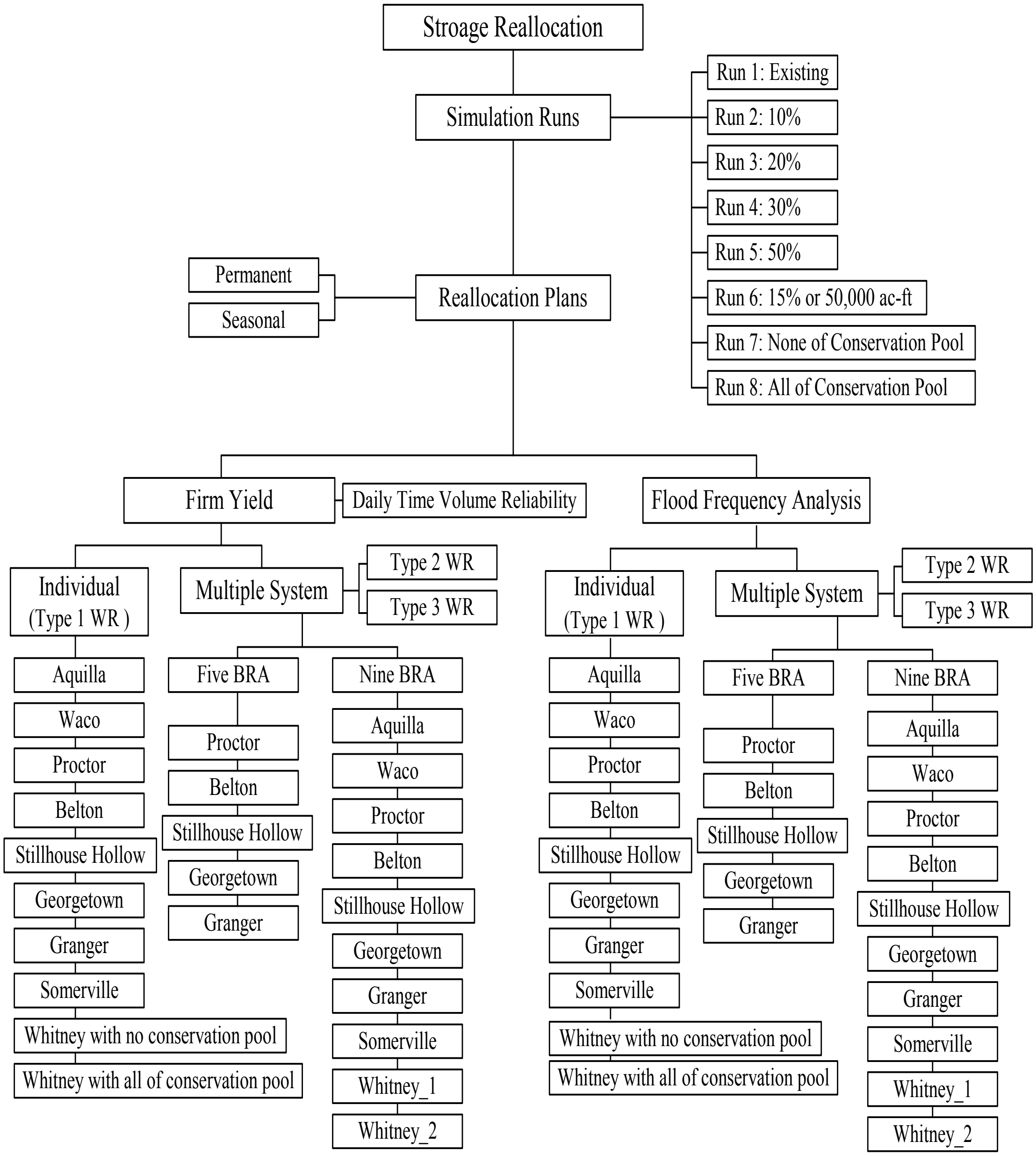

Figure 7.1 Storage Reallocation Flowchart

7.2 INDIVIDUAL AND MULTIPLE RESERVOIR SYSTEM FIRM YIELD ANALYSIS

Computation of firm yield represents one type of evaluation of reservoir storage reallocation. Firm yield analyses with condensed BRACF datasets for alternative reallocation plans are presented for comparison in this section of Chapter VII.

Individual firm yield analysis at nine reservoirs with conservation pool or with conservation pool and flood control pool and firm yield analyses for two multiple-reservoir systems with four and nine reservoirs were computed for alternative reallocation plans. Also, daily time step volume reliabilities were performed for monthly time step firm yields for alternative reallocation plans. Firm yield is expressed in terms of a constant average annual discharge rate. The firm yield terms in this study are used in the following context:

Individual reservoir firm yield: is computed considering the impacts of any of 15 reservoirs located upstream of the reservoir for which the firm yield is computed. The individual reservoir firm yield of the upstream reservoirs is diverted at the upstream reservoirs.

System firm yield: is the maximum diversion rate which can be maintained continuously during the 108-year hydrologic record with two or more reservoir making releases as required to satisfy a diversion at a common downstream control point.

7.2.1 Individual Reservoir Firm Yield

The BRACF individual reservoir firm yields for the existing allocation plan are presented in Table 7.2. The FLO file in the BRAC3 and EVA file in the BRAC8 are used without modification. The DAT files are modified as follows. Each reservoir is modeled individually with a single diversion and storage refilling water right at that reservoir. The municipal monthly water use distribution factors and 2000 year reservoir storage capacities from the BRAC8 DAT file are adopted. The reservoir storage content at the beginning of the simulation period is assumed to be at full capacity. For reservoirs located in series, upstream reservoirs are computed in the model with a diversion set at their firm yield in order to reflect their impacts on inflows to downstream reservoirs.

Table 7.2 Firm Yields for 14 Reservoirs

Reservoirs	Storage Capacity Conservation Pool	 Flood Pool	Total Pool	Monthly Time Step Firm Yield
	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft/year)
Hubbard Creek	317,750	–	317,750	22,400
Squaw Creek	151,015	–	151,015	8,800
Possum Kingdom	552,013	–	552,013	292,600
Granbury	132,821	–	132,821	61,100
Aquilla	41,700	86,700	128,400	12,600
Waco	206,562	553,300	759,862	85,800
Proctor	54,702	310,100	364,802	20,400
Belton	432,978	640,000	1,072,978	113,400
Stillhouse Hollow	224,279	390,660	614,939	63,300
Georgetown	36,980	87,600	124,580	11,400
Granger	50,540	162,200	212,740	16,100
Somerville	154,254	337,700	491,954	42,800
Limestone	208,017	–	208,017	66,900
Whitney	50,000 (561,074)	1,372,400 (1,372,400)	1,422,400 (1,933,474)	39,500 (130,800)
Total	3,270,218	3,940,660	6,554,271 (7,065,345)	857,100 (948,400)

** The number of significant digits in the tables of this dissertation does not imply level of accuracy. In general, more digits are included in the numbers than is justified by the level of accuracy.

Hubbard Creek reservoir is located upstream of Possum Kingdom reservoir. Thus, the firm yield for Hubbard Creek reservoir is computed first and set as a diversion in the model for computing firm yield for Possum Kingdom reservoir. Firm yields for Granbury, Whitney, Belton, Georgetown reservoirs are computed based on this methodology. The Whitney reservoir active conservation pool is used for both water supply and hydroelectric power. The individual reservoir firm yields are estimated considering two kinds of conservation capacities: 50,000 ac-ft water supply pool and the entire conservation capacity of Whitney reservoir. The individual reservoir firm yield for 50,000 ac-ft water supply pool is utilized in the system firm yield simulation. Individual firm yields for the five conservation reservoirs and nine multipurpose reservoirs are presented in Table 7.2. Two total firm yields at fourteen reservoirs using two kinds of 50,000 ac-ft and 561,074 ac-ft conservation storage capacities at Whitney reservoir are

857,100 and 948,400 ac-ft/year, respectively. The 231.1 percent for Whitney reservoir firm yield and 10.65 percent for total firm yield are increased by using all of conservation pool at Whitney reservoir.

Channel loss factors are required for the computation of firm yield for individual reservoirs, which have other reservoirs located upstream. Channel loss factors C_L for N reaches that are combined into one single reach with the removal of intermediate control points are aggregated as follows. Channel loss factors for stream reaches defined for the six reservoirs are tabulated in Table 7.3.

$$(1.0- C_L)_{total}=(1.0- C_L)_1 * (1.0- C_L)_2 * \cdots * (1.0- C_L)_N$$

Table 7.3 Channel Loss Factors for Reaches between 14 Reservoirs

	Reservoirs (Control Points) Upstream	Downstream	Loss Factor
1	Hubbard Creek (421331)	Possum Kingdom (515531)	0.2489
2	Possum Kingdom (515531)	Granbury (515631)	0.0363
3	Squaw Creek (409732)	Whitney (515731)	0.0198
4	Granbury (515631)	Whitney (515731)	0.0795
5	Proctor (515931)	Belton (516031)	0.4023
6	Georgetown (516231)	Granger (516331)	0.0080

Individual reservoir storage for permanent and seasonal reallocation plans between flood control and water supply are evaluated based on monthly time step firm yield and daily time step volume reliability. If a monthly time interval is adopted, the stream flow volume exceeds water right diversion or instream flow requirements, with no failures to meet the target. However, results can be changed significantly if a daily time step is adopted. Failure to meet water rights diversions or instream flow requirements can occur during certain simulation periods. In this research, the computed monthly firm yields at the nine reservoirs in Table 7.2 for existing allocation and reallocation (permanent and seasonal) plans are used as the diversion for daily time step volume reliability computation. The monthly and daily time step computation results are compared.

The individual firm yield versus storage capacity relationships for the nine multi-purpose reservoirs with existing allocation, permanent and seasonal storage reallocation are tabulated in Table 7.4 through Table 7.13. The storage reallocations are expressed in terms of the volume amount of the flood control capacity that has been converted to conservation. As discussed in the preceding chapter, the Whitney reservoir active pool is used for water supply and hydroelectric power. The individual firm yields for water supply conservation pool and entire conservation pool at Whitney reservoir are compared in Tables 7.12 and 7.13.

1900-2007 BRAC3 FLO file, 1900-2007 BRAC8 EVA file, and 1900-2007 BRAC8 DAT file with year 2000 storage capacities are used for computing the individual firm yield. For a given reservoir, the individual firm yield was computed for alternative storage capacities, representing changes in the conservation pool volume, with all other factors held constant. The daily time step volume reliability for a specified reservoir is computed assuming the firm yield for alternative storage capacities as a diversion.

In most cases, percent increase in individual firm yield for permanent reallocation was decreased by increasing the conversion volume amount from flood control pool to conservation pool. For example, referring to Waco reservoir in Table 7.11, increasing the conservation storage capacity of Belton reservoir by 10, 15, 20, 30 or 50 percent would increase the individual firm yield by 10.37, 13.29, 16.32, 22.84, and 35.20 percent, respectively. The percent increased for eight multi-purpose reservoirs with permanent reallocation are shown in Figure 7.2. The percent increased for Whitney reservoir for two conservation pools are shown in Figure 7.3. The individual firm yield for seasonal reallocation increased compared to the individual firm yield for existing allocation but was not affected by the conversion of flood control pool except in the case of Aquilla reservoir and Whitney reservoir with entire conservation pool. The daily time step volume reliabilities of nine multi-purpose reservoirs for existing allocation and permanent and seasonal reallocation are 100% or nearly 100%, which means daily time step firm yield for a given reservoir is almost same as the monthly time step firm yield. As shown in Tables 7.12 and 7.13, the individual firm yields for the entire conservation pool at Whitney reservoir are increased by 166.33, 131.56, 114.57, 101.98, 83.83, and 62.94 percent for 10, 15, 20, 30, 50 percent increased of conservation pool, respectively.

Table 7.4 Aquilla Reservoir Storage Reallocations

Plan	Storage Capacity Conservation Pool (acre-feet)	Storage Capacity Flood Pool (acre-feet)	Monthly Time Step Firm Yield (ac-ft/year)	Daily Time Step Volume Reliability (%)
Existing	41,700	86,700	12,600	100.00
		Permanent Storage Reallocation		
50,000	91,700	36,700	19,000	100.00
10%	50,370	78,030	14,100	99.99
15%	54,705	73,695	14,800	100.00
20%	59,040	69,360	15,600	100.00
30%	67,710	60,690	16,900	100.00
50%	85,050	43,350	18,400	100.00
		Seasonal Storage Reallocation		
50,000	91,700	36,700	15,300	99.97
10%	50,370	78,030	14,100	99.99
15%	54,705	73,695	14,800	100.00
20%	59,040	69,360	15,300	99.97
30%	67,710	60,690	15,300	99.97
50%	85,050	43,350	15,300	99.97

Table 7.5 Proctor Reservoir Storage Reallocations

Plan	Storage Capacity Conservation Pool (acre-feet)	Storage Capacity Flood Pool (acre-feet)	Monthly Time Step Firm Yield (ac-ft/year)	Daily Time Step Volume Reliability (%)
Existing	54,702	310,100	20,400	99.98
		Permanent Storage Reallocation		
50,000	104,702	260,100	24,300	99.98
10%	85,712	279,090	22,800	99.99
15%	101,217	263,585	24,000	99.98
20%	116,722	248,080	25,500	99.98
30%	147,732	217,070	28,200	99.94
50%	209,752	155,050	32,200	99.95
		Seasonal Storage Reallocation		
50,000	104,702	260,100	20,700	99.99
10%	85,712	279,090	20,700	99.99
15%	101,217	263,585	20,700	99.99
20%	116,722	248,080	20,700	99.99
30%	147,732	217,070	20,700	99.99
50%	209,752	155,050	20,700	99.99

Table 7.6 Belton Reservoir Storage Reallocations

	Storage Capacity		Monthly Time Step	Daily Time Step
Plan	Conservation Pool (acre-feet)	Flood Pool (acre-feet)	Firm Yield (ac-ft/year)	Volume Reliability (%)
Existing	432,978	640,000	113,400	100.00
		Permanent Storage Reallocation		
50,000	482,978	590,000	116,900	100.00
10%	496,978	576,000	117,900	100.00
15%	528,978	544,000	120,300	100.00
20%	560,978	512,000	122,800	100.00
30%	624,978	448,000	128,100	100.00
50%	752,978	320,000	139,300	100.00
		Seasonal Storage Reallocation		
50,000	482,978	590,000	115,900	100.00
10%	496,978	576,000	115,900	100.00
15%	528,978	544,000	115,900	100.00
20%	560,978	512,000	115,900	100.00
30%	624,978	448,000	115,900	100.00
50%	752,978	320,000	115,900	100.00

Table 7.7 Stillhouse Hollow Reservoir Storage Reallocations

	Storage Capacity		Monthly Time Step	Daily Time Step
Plan	Conservation Pool (acre-feet)	Flood Pool (acre-feet)	Firm Yield (ac-ft/year)	Volume Reliability (%)
Existing	224,279	390,660	63,300	99.99
		Permanent Storage Reallocation		
50,000	274,279	340,660	66,800	99.98
10%	263,345	351,594	66,000	99.99
15%	282,878	332,061	67,400	99.99
20%	302,411	312,528	68,900	100.00
30%	341,477	273,462	72,000	99.99
50%	419,609	195,330	78,500	99.99
		Seasonal Storage Reallocation		
50,000	274,279	340,660	64,000	99.99
10%	263,345	351,594	64,000	99.99
15%	282,878	332,061	64,000	99.99
20%	302,411	312,528	64,000	99.99
30%	341,477	273,462	64,000	99.99
50%	419,609	195,330	64,000	99.99

Table 7.8 Georgetown Reservoir Storage Reallocations

Plan	Storage Capacity Conservation Pool (acre-feet)	 Flood Pool (acre-feet)	Monthly Time Step Firm Yield (ac-ft/year)	Daily Time Step Volume Reliability (%)
Existing	36,980	87,600	11,400	100.00
		Permanent Storage Reallocation		
50,000	86,980	37,600	15,000	100.00
10%	45,740	78,840	12,100	100.00
15%	50,120	74,460	12,400	100.00
20%	54,500	70,080	12,700	99.99
30%	63,260	61,320	13,300	99.99
50%	80,780	43,800	14,500	100.00
		Seasonal Storage Reallocation		
50,000	86,980	37,600	11,700	100.00
10%	45,740	78,840	11,700	100.00
15%	50,120	74,460	11,700	100.00
20%	54,500	70,080	11,700	100.00
30%	63,260	61,320	11,700	100.00
50%	80,780	43,800	11,700	100.00

Table 7.9 Granger Reservoir Storage Reallocations

Plan	Storage Capacity Conservation Pool (acre-feet)	 Flood Pool (acre-feet)	Monthly Time Step Firm Yield (ac-ft/year)	Daily Time Step Volume Reliability (%)
Existing	50,540	162,200	16,100	100.00
		Permanent Storage Reallocation		
50,000	100,540	112,200	20,100	100.00
10%	66,760	145,980	17,700	100.00
15%	74,870	137,870	18,200	100.00
20%	82,980	129,760	18,700	100.00
30%	99,200	113,540	20,000	100.00
50%	131,640	81,100	22,800	100.00
		Seasonal Storage Reallocation		
50,000	100,540	112,200	16,100	100.00
10%	66,760	145,980	16,100	100.00
15%	74,870	137,870	16,100	100.00
20%	82,980	129,760	16,100	100.00
30%	99,200	113,540	16,100	100.00
50%	131,640	81,100	16,100	100.00

Table 7.10 Somerville Reservoir Storage Reallocations

Plan	Storage Capacity Conservation Pool (acre-feet)	Storage Capacity Flood Pool (acre-feet)	Monthly Time Step Firm Yield (ac-ft/year)	Daily Time Step Volume Reliability (%)
Existing	154,254	337,700	42,800	99.95
		Permanent Storage Reallocation		
50,000	204,254	287,700	47,700	99.95
10%	188,024	303,930	46,100	99.94
15%	204,909	287,045	47,800	99.95
20%	221,794	270,160	49,600	99.94
30%	255,564	236,390	53,500	99.94
50%	323,104	168,850	62,300	99.93
		Seasonal Storage Reallocation		
50,000	204,254	287,700	45,600	99.90
10%	188,024	303,930	45,600	99.90
15%	204,909	287,045	45,600	99.90
20%	221,794	270,160	45,600	99.90
30%	255,564	236,390	45,600	99.90
50%	323,104	168,850	45,600	99.90

Table 7.11 Waco Reservoir Storage Reallocations

Plan	Storage Capacity Conservation Pool (acre-feet)	Storage Capacity Flood Pool (acre-feet)	Monthly Time Step Firm Yield (ac-ft/year)	Daily Time Step Volume Reliability (%)
Existing	206,562	553,300	85,800	100.00
		Permanent Storage Reallocation		
50,000	256,562	503,300	94,300	99.97
10%	261,892	497,970	94,700	99.98
15%	289,557	470,305	97,200	99.98
20%	317,222	442,640	99,800	99.98
30%	372,552	387,310	105,400	99.98
50%	483,212	276,650	116,000	99.98
		Seasonal Storage Reallocation		
50,000	256,562	503,300	89,900	99.98
10%	261,892	497,970	89,900	99.98
15%	289,557	470,305	89,900	99.98
20%	317,222	442,640	89,900	99.98
30%	372,552	387,310	89,900	99.98
50%	483,212	276,650	89,900	99.98

Table 7.12 Whitney Reservoir Storage Reallocations (50,000 acre-feet)

Plan	Storage Capacity Conservation Pool (acre-feet)	Storage Capacity Flood Pool (acre-feet)	Monthly Time Step Firm Yield (ac-ft/year)	Daily Time Step Volume Reliability (%)
Existing	50,000	1,372,400	39,500	100.00
		Permanent Storage Reallocation		
50,000	100,000	1,322,400	49,900	100.00
10%	187,240	1,235,160	64,000	100.00
15%	255,860	1,166,540	74,800	100.00
20%	324,480	1,097,920	85,700	100.00
30%	461,720	960,680	108,200	100.00
50%	736,200	686,200	154,900	100.00
		Seasonal Storage Reallocation		
50,000	100,000	1,322,400	37,000	100.00
10%	187,240	1,235,160	37,000	100.00
15%	255,860	1,166,540	37,000	100.00
20%	324,480	1,097,920	37,000	100.00
30%	461,720	960,680	37,000	100.00
50%	736,200	686,200	37,000	100.00

Table 7.13 Whitney Reservoir Storage Reallocations (561,074 acre-feet)

Plan	Storage Capacity Conservation Pool (acre-feet)	Storage Capacity Flood Pool (acre-feet)	Monthly Time Step Firm Yield (ac-ft/year)	Daily Time Step Volume Reliability (%)
Existing	561,074	1,372,400	130,800	100.00
		Permanent Storage Reallocation		
50,000	611,074	1,322,400	132,900	100.00
10%	698,314	1,235,160	148,200	100.00
15%	766,934	1,166,540	160,500	100.00
20%	835,554	1,097,920	173,100	100.00
30%	972,794	960,680	198,900	100.00
50%	1,247,274	686,200	252,400	100.00
		Seasonal Storage Reallocation		
50,000	611,074	1,322,400	132,900	100.00
10%	698,314	1,235,160	137,300	100.00
15%	766,934	1,166,540	137,300	100.00
20%	835,554	1,097,920	137,300	100.00
30%	972,794	960,680	137,300	100.00
50%	1,247,274	686,200	137,300	100.00

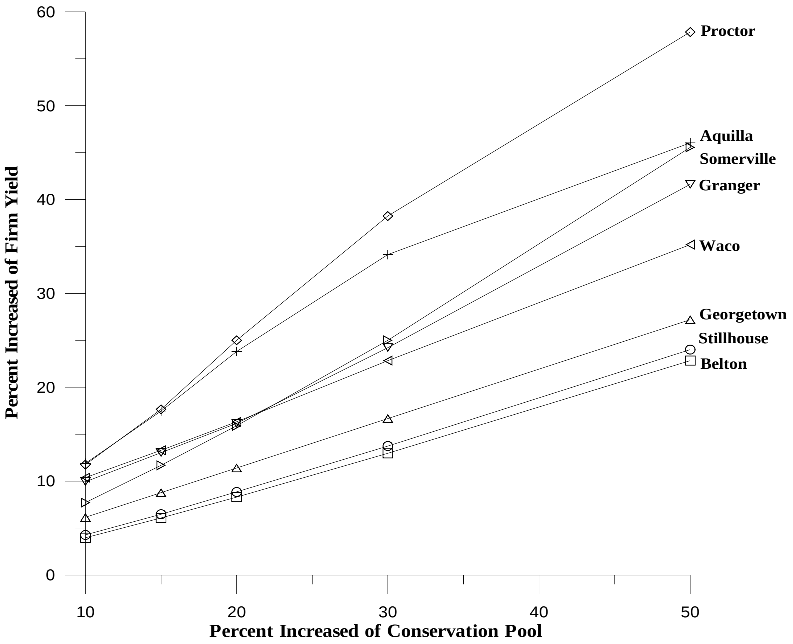

Figure 7.2 Percent Increased of Firm Yield for a Given Conservation Pool at Eight Reservoirs for Permanent Reallocation Plan

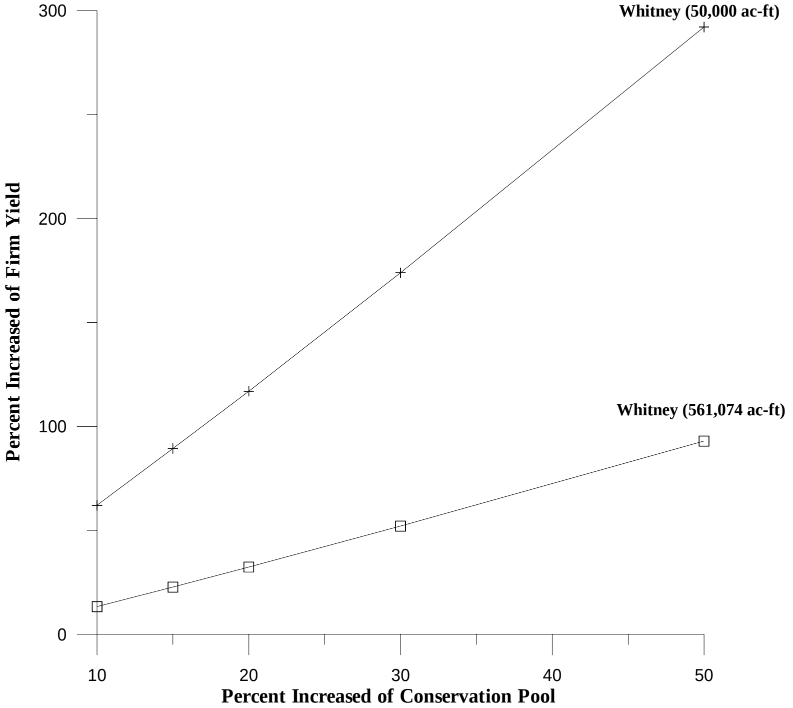

Figure 7.3 Percent Increased of Firm Yield for a Given Conservation Pool at Whitney Reservoir for Permanent Reallocation Plan

7.2.2 Multiple-Reservoir System Firm Yields

System firm yield represents the maximum diversion rate which can be supplied continuously during 108 year hydrologic simulation periods by five BRA reservoirs in the Little River subbasin or 12 BRA reservoirs in the Brazos River basin. The multiple-reservoir system firm yield is modeled as either a diversion at control point LRCA58 on which the Cameron gage on the Little River is located or a diversion at control point BRRI70 on which the Richmond gage on the Brazos River is located. Multiple reservoir operating releases are made by balancing the percentage storage depletion in the reservoirs. Inflows and evaporation-precipitation depths are the same as the previous individual reservoir firm yield simulation. The firm yield simulation is performed with negative incremental flow option 4. System firm yield were repeated based on excluding and including inflows at a given control point. The inflows are originated from the watershed and which in not upstream of and regulated by any one of reservoirs.

As shown in Figure 7.1 and illustrated in section 7.1, the diversion at control point LRCA58 located at the Cameron gage on the Little River is supplied by releases from Belton, Stillhouse Hollow, Georgetown, and Granger reservoirs. These four reservoirs are operated only for the firm yield diversion at control point LRCA58. There are no other diversions at these four reservoirs. Proctor reservoir has an impact on the inflows to Belton reservoir and the flows at the Cameron gage. Proctor is included in the DAT file with a diversion equal to its individual reservoir firm yield for existing, permanent, and season allocation plan shown in Tables 7.4 through 7.13. Its priority is set as the most senior. The upstream-to-downstream sequencing in the river system is used. The eight reservoirs, which are not included in Little River subbasin, have no effect on the firm yield and no relevance.

Also, as shown in Figure 7.1 and illustrated in section 7.1, the diversion at control point BRRI70 on the Brazos River (Richmond gage) is supplied by releases from Possum Kingdom, Granbury, Aquilla, Limestone, Somerville, Belton, Stillhouse Hollow, Georgetown, and Granger reservoirs. These nine reservoirs are operated only for the firm yield diversion at control point BRRI70. The three other reservoirs – Whitney, Waco and Proctor reservoir – are operated as individual reservoirs with 9 lakeside diversion at each reservoir set at its firm yield. The upstream-to-downstream sequencing in the river system is used.

In computing firm yields for diversions located alternatively at the Cameron and Richmond gages, the diversion is modeled in SIM alternatively as either a type 2 or type 3 water right for alternative permanent and seasonal reallocation plans. The daily time step volume reliabilities for multiple reservoirs system with alternative permanent and seasonal reallocation plans are computed assuming the firm yield for alternative storage capacities as a diversion. The firm yield for five BRA reservoirs for existing allocation, permanent and seasonal reallocation plans are shown in Tables 7.14 and 7.15, respectively. The firm yield for 12 BRA reservoirs for existing allocation, permanent and seasonal reallocation plans are shown in Tables 7.16 and 7.17, respectively.

Daily time step volume reliabilities for two multiple-reservoir system excluding and including inflows are shown in Tables 7.14 through 7.16. The volume reliability at control points LRCA58 and BRRI70 for type 2 WR and type 3 WR considering three allocation plans are near 100 % and 99%, respectively. The daily time step volume reliabilities for the permanent reallocation plan are increased as the percent reallocated to conservation pool increases.

System Firm Yield for Permanent Reallocation Plans

The reallocations consist of conversion of a portion of the flood control storage capacity in each of five reservoirs in Little River subbasin and nine reservoirs in Brazos River basin to conservation. Alternative plans include the following storage reallocation amounts: 10%, 20%, 30%, 50%, and USACE criteria of the flood control pool. The existing operating plan is performed except for the reallocated storage capacity. Whitney reservoir is operated only for the water supply conservation pool (50,000 acre-feet).

Tables 7.14 and 7.16 show the percent increase in the active conservation capacity of five BRA reservoirs and 12 BRA reservoirs and the corresponding increase in firm yield. For five BRA reservoirs including inflows, increase of 10, 20, 30, and 50 percent in conservation storage capacity result in corresponding increases of 27.47, 27.02, 27.39, and 27.68 percent in firm yield. Increase of 10, 20, 30, and 50 percent in conservation storage capacity for 12 BRA reservoirs including inflows result in corresponding increases of 41.50, 37.67, 34.98, 32.61, and 29.12 percent in firm yield. The increase percent in firm yield is decreased corresponding with the increase of conservation storage capacity. The firm yield for multiple reservoir systems including inflows has the highest than any other firm yield.

System Firm Yield for Seasonal Reallocation Plans

System firm yield for the five reservoir system in Little River subbasin and the nine reservoir system in Brazos River basin are presented in Tables 7.15 and 7.17, respectively. The alternative seasonal rule curve is a May through October raise. The existing operating plan for five reservoir systems excluding and including inflows have 286,300 ac-ft/yr and 251,840 ac-ft/yr, which is a 27.47 and 12.13 percent increase, respectively. For five BRA reservoirs excluding inflows, increase of 10, 20, 30, and 50% percent in conservation storage capacity result in corresponding increases of 19.96, 20.51, 20.53 and 20.19 percent in firm yield. Increase of 10, 20, 30, and 50% percent in conservation storage capacity for 12 BRA reservoirs excluding inflows result in corresponding increases of 1.04 and decrease of 4.55, 3.74, and 6.50 percent in firm yield. The results in Tables 7.14 through 7.17 show the seasonal rule curve plans including inflows increase the system firm yields almost as much as a permanent reallocation.

System Firm Yield for Permanent and Seasonal Reallocation Plans based on USACE Criteria

Simulation results for permanent and seasonal reallocation plans are based on the 50,000 acre-feet or 15 percent criterion, which is reallocated without obtaining Congressional approval. Firm yield results for these reallocation plans are shown in the last column in Tables 7.14 through 7.17. The alternative plans involve reallocating 50,000 acre-feet or 15 percent of the flood control capacity in five reservoirs in Little River subbasin and 9 reservoirs in Brazos River basin. The total individual five BRA reservoirs firm yield for permanent and seasonal reallocation plans is 238,300 acre-feet/yr and 228,400 acre-feet/yr, respectively. With permanent and seasonal reallocation plans, the firm yield for total 12 BRA reservoirs is 865,600 acre-feet/yr and 836,800 acre-feet/yr, respectively. The percent increase in the five BRA reservoir systems firm yield for permanent reallocation plan is 26.56 and 19.14 percent, respectively, for type 2 water right and type 3 water right. For season reallocation plan, the percent increase in 12 BRA reservoir system firm yield for type 2 water right and type 3 water right is 40.67 and 9.81 percent, respectively.

Table 7.14 Firm Yield for Five BRA Reservoirs in Little River Subbasin for Permanent Reallocation Plans

Reallocation Plans	Existing	10%	20%	30%	50%	USACE
	Firm Yield					
	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)
<u>Individual Reservoirs</u>						
Proctor	20,400	22,800	25,500	28,200	32,200	24,000
Belton	113,400	117,900	122,800	128,100	139,300	116,900
Stillhouse Hollow	63,300	66,000	68,900	72,000	78,500	66,800
Georgetown	11,400	12,100	12,700	13,300	14,500	12,400
Granger	16,100	17,700	18,700	20,000	22,800	18,200
Total	224,600	236,500	248,600	261,600	287,300	238,300
<u>Multiple-Reservoir System</u>						
Type 2 diversion at LRAC58 (4 reservoirs)	265,900	277,600	291,200	305,800	332,700	277,600
Proctor Reservoir	20,400	22,800	25,500	28,200	32,200	24,000
Total	286,300	300,400	316,700	334,000	364,900	301,600
Firm yield as Percentage of individual firm yield(%)	127.47	127.02	127.39	127.68	127.01	126.56
Daily Time Step Volume Reliability (%)	99.21	99.26	99.32	99.34	99.44	99.29
Type 3 diversion at LRCA58 (4 reservoir)	249,800	260,900	274,100	287,100	313,100	259,900
Proctor Reservoir	20,400	22,800	25,500	28,200	32,200	24,000
Total	251,840	283,700	299,600	315,300	345,300	283,900
Firm yield as Percentage of individual firm yield (%)	112.13	119.96	120.51	120.53	120.19	119.14
Daily Time Step Volume Reliability (%)	98.05	98.24	98.32	98.40	98.53	98.31

Table 7.15 Firm Yield for Five BRA Reservoirs in Little River Subbasin for Seasonal Reallocation Plans

Reallocation Plans	Existing	10%	20%	30%	50%	USACE
	Firm Yield					
	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)
<u>Individual Reservoirs</u>						
Proctor	20,400	20,700	20,700	20,700	20,700	20,700
Belton	113,400	115,900	115,900	115,900	115,900	115,900
Stillhouse Hollow	63,300	64,000	64,000	64,000	64,000	64,000
Georgetown	11,400	11,700	11,700	11,700	11,700	11,700
Granger	16,100	16,100	16,100	16,100	16,100	16,100
Total	224,600	228,400	228,400	228,400	228,400	228,400
<u>Multiple-Reservoir System</u>						
Type 2 diversion at LRAC58 (4 reservoirs)	265,900	272,100	272,100	271,600	271,600	270,900
Proctor Reservoir	20,400	20,700	20,700	20,700	20,700	20,700
Total	286,300	292,800	292,800	292,300	292,300	291,600
Firm yield as Percentage of individual firm yield(%)	127.47	128.20	128.20	127.98	127.98	127.67
Daily Time Step Volume Reliability (%)	99.21	99.10	99.06	99.06	98.55	99.08
Type 3 diversion at LRCA58 (4 reservoir)	249,800	253,900	253,200	249,700	249,700	252,700
Proctor Reservoir	20,400	20,700	20,700	20,700	20,700	20,700
Total	251,840	274,600	273,900	270,400	270,400	273,400
Firm yield as Percentage of individual firm yield (%)	112.13	120.23	119.92	118.39	118.39	119.70
Daily Time Step Volume Reliability (%)	98.05	97.99	97.17	98.13	97.28	98.01

Table 7.16 Firm Yield for 12 Brazos River Authority Reservoirs for Permanent Reallocation Plans

Reallocation Plans	Existing	10%	20%	30%	50%	USACE
			Firm Yield			
	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)
<u>Individual Reservoirs</u>						
Five reservoirs in Little River Subbasin	224,600	236,500	248,600	261,600	287,300	238,300
Possum Kingdom	292,600	292,600	292,600	292,600	292,600	292,600
Granbury	61,100	61,100	61,100	61,100	61,100	61,100
Whitney (50,000 acre-feet)	39,500	64,000	85,700	108,200	154,900	49,900
Aquilla	12,600	14,100	15,600	16,900	18,400	14,800
Waco	85,000	94,700	99,800	105,400	116,000	94,300
Limestone	66,900	66,900	66,900	66,900	66,900	66,900
Somerville	42,800	46,100	49,600	53,500	62,300	47,700
Total	825,100	876,000	919,900	966,200	1,059,500	865,600
<u>Multiple-Reservoir System</u>						
Type 2 diversion at BRRI70 (9 reservoirs)	1,022,600	1,024,500	1,030,700	1,039,500	1,064,900	1,052,900
Proctor Reservoir	20,400	22,800	25,500	28,200	32,200	24,000
Waco Reservoir	85,000	94,700	99,800	105,400	116,000	94,300
Whitney Reservoir	39,500	64,000	85,700	108,200	154,900	49,900
Total	1,167,500	1,206,000	1,241,700	1,281,300	1,368,000	1,221,100
Firm yield as Percentage of individual firm yield (%)	141.50	137.67	134.98	132.61	129.12	141.06
Daily Time Step Volume Reliability (%)	99.95	99.96	99.97	99.96	99.95	99.92
Type 3 diversion at BRRI70 (9 reservoir)	794,100	798,800	805,400	810,400	826,300	820,300
Proctor Reservoir	20,400	22,800	25,500	28,200	32,200	24,000
Waco Reservoir	85,000	94,700	99,800	105,400	116,000	94,300
Whitney Reservoir	39,500	64,000	85,700	108,200	154,900	49,900
Total	939,000	980,300	1,016,400	1,052,200	1,129,400	988,500
Firm yield as Percentage of individual firm yield (%)	124.87	121.52	119.99	118.29	115.80	114.20
Daily Time Step Volume Reliability (%)	99.55	99.62	99.66	99.68	99.87	99.55

Table 7.17 Firm Yield for 12 Brazos River Authority Reservoirs for Seasonal Reallocation Plans

Reallocation Plans	Existing	10%	20%	30%	50%	USACE
	Firm Yield					
	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)	(ac-ft/yr)
Individual Reservoirs						
Five reservoirs in Little River Subbasin	224,600	228,400	228,400	228,400	228,400	228,400
Possum Kingdom	292,600	292,600	292,600	292,600	292,600	292,600
Granbury	61,100	61,100	61,100	61,100	61,100	61,100
Whitney (50,000 acre-feet)	39,500	37,000	37,000	37,000	37,000	37,000
Aquilla	12,600	14,100	15,300	15,300	15,300	14,800
Waco	85,000	89,900	89,900	89,900	89,900	89,900
Limestone	66,900	66,900	66,900	66,900	66,900	66,900
Somerville	42,800	45,600	45,600	45,600	45,600	45,600
Total	825,100	835,600	836,800	836,800	836,800	836,800
Multiple-Reservoir System						
Type 2 diversion at BRRI70 (9 reservoirs)	1,022,600	977,700	927,000	926,000	920,800	1,029,500
Proctor Reservoir	20,400	20,700	20,700	20,700	20,700	20,700
Waco Reservoir	85,000	89,900	89,900	89,900	89,900	89,900
Whitney Reservoir	39,500	37,000	37,000	37,000	37,000	37,000
Total	1,167,500	1,125,300	1,074,600	1,073,600	1,068,400	1,177,100
Firm yield as Percentage of individual firm yield (%)	141.93	134.67	128.42	128.30	127.68	140.67
Daily Time Step Volume Reliability (%)	99.95	100.00	99.56	100.00	100.00	99.98
Type 3 diversion at BRRI70 (9 reservoir)	794,100	696,700	651,100	657,900	634,800	771,300
Proctor Reservoir	20,400	20,700	20,700	20,700	20,700	20,700
Waco Reservoir	85,000	89,900	89,900	89,900	89,900	89,900
Whitney Reservoir	39,500	37,000	37,000	37,000	37,000	37,000
Total	939,000	844,300	798,700	805,500	782,400	918,900
Firm yield as Percentage of individual firm yield (%)	124.87	101.04	95.45	96.26	93.50	109.81
Daily Time Step Volume Reliability (%)	99.55	99.79	98.68	99.98	99.99	99.58

7.3 INDIVIDUAL AND MULTIPLE RESERVOIR SYSTEMS FLOOD FREQUENCY ANALYSIS

The flood control releases in the program SIMD are computed based on input values of maximum allowable discharge at reservoirs and downstream control points. The maximum allowable discharges at 13 control points investigated in the previous study were utilized in this study and are shown in Table 7.18.

Table 7.18 Maximum Allowable Discharges for Flood Control Operations

Control Point	Allowable Discharge (cfs)	Allowable Discharge (ac-ft/year)	Forecast Periods (days)	Location
515731	25,000	18,099,174	10	Brazos River below Whitney Dam
515831	3,000	2,171,901	10	Aquilla Creek below Aquilla Dam
509431	10,000	7,239,669	10	Bosque River below Waco Dam
515931	2,000	1,447,934	5	Leon River Proctor Dam
516031	6,000	4,343,802	5	Little River near Little River
516131	3,000	2,171,901	5	Little River near Litter River
516231	3,000	2,171,901	5	San Gabriel below Georgetown Dam
516331	6,000	4,343,802	5	San Gabriel below Granger Dam
516431	2,500	1,809,917	10	Yegua & Davidson Creeks
LRCA58	10,000	7,239,669	10	Little River at Cameron
BRWA41	60,000	43,438,017	10	Brazos River at Waco
BRBR59	60,000	43,438,017	10	Brazos River at Bryan
BRRI70	60,000	43,438,017	10	Brazos River at Richmond

Flow forecasting in the program SIMD is the process of considering future flows over a forecast period in determining water availability for WR record water rights and available flood flow channel capacity for FC record flood control rights. The forecast period in days for each WR record water right and FF record control point in the input parameter controlling forecasting (Wurbs 2005b). The number of exceedance to flood control pool corresponding the different forecast periods is shown in Table 7.19. The number of exceedance was found not to be affected by the forecast period.

Table 7.20 shows the times of the 100 percent empty conservation pool depending on the different forecast period. There is no empty conservation storage for nine reservoirs for up to eight forecast days. An empty conservation pool for two reservoirs on which Little River subbasins are located occurred first at nine forecast days. Number of drawdowns resulting in depletion of at least 50 percent of the active conservation capacity at each of nine reservoirs is shown in Table 7.21. The number of drawdowns is increased. The results of Tables 7.19 through 7.21 are based on the premise of a 108 year simulation period, using 2000 water use and reservoir sedimentation and existing top of conservation pool capacity and infinite flood control capacity.

In this study, the forecast periods for nine reservoirs and four control points are assumed as follows. The forecast periods for reservoirs or control points, which are located on or connected to the Brazos River, are 10 days. The remaining reservoirs or control points are 5 days, as shown in Table 7.18.

Table 7.19 Number of Exceedance to Flood Control Pool

Forecast Period (days)	Nine Reservoirs									
	Whitney	Aquilla	Proctor	Belton	Stillhouse Hollow	George-town	Granger	Somer-ville	Waco	Total
0	2	3	0	2	2	2	2	4	3	20
1	1	3	0	2	2	2	1	4	3	18
2	1	3	0	2	1	2	1	5	3	18
3	1	3	0	2	1	2	1	4	3	17
4	1	3	0	2	1	2	1	4	3	17
5	1	3	0	2	1	2	1	4	3	17
6	1	3	0	2	1	1	1	4	3	16
7	1	3	0	2	1	1	1	4	3	16
8	1	3	0	2	1	1	1	4	3	16
9	1	3	0	2	1	1	1	4	3	16
10	1	3	0	1	1	1	1	4	3	15
15	1	3	0	1	1	1	1	4	3	15
20	1	3	0	1	1	1	1	4	3	15
25	1	3	0	1	1	1	1	4	3	15
30	1	3	0	1	1	1	1	4	3	15
35	1	3	0	1	1	1	1	4	3	15
40	1	3	0	1	1	1	1	4	2	14
45	1	3	0	1	1	1	1	4	2	14
50	1	3	0	1	1	1	1	4	2	14
60	1	3	0	1	1	1	1	4	2	14

Table 7.20 Number of Empty Conservation Pool

Forecast Period (days)	Nine Reservoirs									
	Whitney	Aquilla	Proctor	Belton	Stillhouse Hollow	George-town	Granger	Somer-ville	Waco	Total
0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	1	0	0	0	1
10	0	0	0	0	0	1	0	0	0	1
15	0	0	0	0	1	2	0	0	0	3
20	0	0	0	0	1	2	0	0	0	3
25	0	0	0	0	1	2	0	0	0	3
30	0	0	0	0	3	2	0	0	0	5
35	0	0	0	0	4	2	0	0	0	6
40	0	0	0	0	4	2	0	0	0	6
45	0	0	0	0	4	2	0	0	0	6
50	0	0	0	0	4	2	0	0	0	6
60	0	0	0	0	4	2	0	0	0	6

Table 7.21 Number of Below 50 Percent Conservation Pool

Forecast Period (days)	Nine Reservoirs									
	Whitney	Aquilla	Proctor	Belton	Stillhouse Hollow	George-town	Granger	Somer-ville	Waco	Total
0	0	0	0	2	7	2	0	2	0	13
1	0	0	1	6	9	2	0	2	0	20
2	0	0	5	8	11	4	0	2	0	30
3	0	0	9	8	17	7	0	2	0	43
4	0	0	13	9	17	7	0	2	0	48
5	0	0	16	10	17	8	2	2	0	55
6	0	0	17	11	19	7	2	2	2	60
7	0	0	18	10	20	8	2	2	0	60
8	0	0	17	13	23	8	2	2	0	65
9	0	0	21	13	25	8	2	3	0	72
10	0	0	24	14	29	9	2	3	0	81
15	0	0	29	18	40	10	4	3	0	104
20	0	2	28	26	46	11	4	6	0	123
25	0	3	30	30	54	14	5	7	0	143
30	0	3	31	35	58	15	6	7	0	155
35	0	3	30	37	59	25	6	8	0	168
40	0	3	30	37	59	12	6	8	0	155
45	0	4	30	39	59	23	7	8	0	170
50	0	4	32	39	59	16	7	8	0	165
60	0	5	32	39	59	17	7	8	0	167

7.3.1 Individual Reservoir Flood Frequency Analysis

The flood pool capacity exceedance frequency, the number of exceedance of flood control pool, the expected value of flood storage, and the 1984 flood damage index were estimated by applying the BRACF dataset. The individual reservoir was simulated for alternative allocation plans using the program SIMD. The nine reservoirs are reallocated by 10, 20, 30, and 50 percent simultaneously. The annual maximum storage volume for nine reservoir and regulated flows at six control points for 108 hydrologic simulation periods are stored in the AFF file. The individual reservoir flood frequency is simulated based on a Type 1 water right. The flood pool capacity exceedance frequencies are estimated based on Log Normal and Log Pearson Type III distribution:

- Log Normal Distribution has two parameters: the mean and standard deviation. Its probability density function is bell-shaped and symmetrical about the mean.
- Log Pearson Type III Distribution has three parameters: the mean, standard deviation, and the skew coefficient. If the skew coefficient has a value of zero, the Log Pearson type III distribution reduces to the normal distribution.

The exceedance frequencies are estimates of the average exceedance frequencies between successive occurrences of a flood control pool capacity being filled to 100 percent capacity or overtopped. Increases in water use resulted in increasing the flood control exceedance frequencies. The flood frequency analysis results for existing storage allocation for nine reservoirs are tabulated in Table 7.22. The flood frequency analysis result for permanent and seasonal reallocation plans are tabulated in Tables 7.23 through 7.30. The permanent reallocation resulted in a significant increase in the exceedance frequencies as the percent reallocated is increased. Seasonal reallocation for raising it during May through October has little impact on the exceedance frequencies except Belton reservoir. In particular, the exceedance frequency for Whitney reservoir with existing storage allocation was affected little by seasonal reallocation. Exceedance frequency based on Log Pearson Type III distribution for nine reservoirs with one existing and two reallocation plans have bigger percent than exceedance frequency based on Log Normal distribution. Only exceedance frequency based on Log Normal distribution for Aquilla reservoir with permanent 50% storage reallocation plan has bigger percent than exceedance frequency based on Log Pearson Type III distribution.

The number of exceedance of the flood control pool for seasonal reallocation plan does not change much for each reallocated percent, while the number of exceedance for permanent reallocation plan shows a dramatic increase for each reallocated percent. In particular, for 50% permanent reallocation plan, five reservoirs have above ten exceedance of flood control pool during the 108 hydrologic simulation periods.

Expected value of flood storage and 1984 flood damage is a probability-weighted average of the full range of possible flood magnitudes and can be viewed as what might be expected to occur, on average, in any future year. The expected value of flood storage and flood damage is determined by integrating the exceedance frequency versus storage or damage function, respectively. Expected value of flood storage for reallocation plans is increased as the percent is increased. Expected value for nine each reservoir is smaller than the total of each flood capacity. Expected total flood damage index (1984$) with reallocation plans for six control points shows similar results for expected total flood damage index of existing allocation plan.

Table 7.22 Existing Storage Allocation for Nine Reservoirs

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	1.95	4.31	4	63,081	
Waco	0.33	2.34	3	291,508	
Proctor	-	0.68	0	78,015	
Belton	0.83	1.30	3	520,797	
Stillhouse Hollow	2.07	-	2	237,310	23,442,561
Georgetown	0.92	2.13	3	50,246	
Granger	1.12	3.43	4	85,779	
Somerville	1.32	1.84	4	208,300	
Whitney	-	0.95	1	701,197	

Table 7.23 Permanent 10% Storage Reallocation for Nine Reservoirs

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	3.04	5.83	5	68,775	
Waco	0.46	2.81	5	327,657	
Proctor	-	0.72	0	103,056	
Belton	1.36	3.33	4	566,050	
Stillhouse Hollow	3.08	-	2	287,597	23,449,851
Georgetown	1.44	2.91	4	57,158	
Granger	1.67	3.98	5	96,963	
Somerville	1.85	2.64	5	237,669	
Whitney	-	1.25	1	804,142	

Table 7.24 Permanent 20% Storage Reallocation for Nine Reservoirs

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	4.71	7.45	8	80,265	
Waco	0.79	3.36	5	398,466	
Proctor	0.12	0.88	0	135,168	
Belton	2.23	4.40	4	645,202	
Stillhouse Hollow	3.87	-	2	305,164	23,461,719
Georgetown	2.32	3.78	4	66,724	
Granger	2.71	5.69	6	118,142	
Somerville	2.92	3.72	5	272,474	
Whitney	-	1.64	2	976,047	

Table 7.25 Permanent 30% Storage Reallocation for Nine Reservoirs

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	7.71	9.10	11	88,918	
Waco	1.46	4.01	8	452,344	
Proctor	0.26	1.41	3	166,191	
Belton	3.73	6.45	5	708,761	
Stillhouse Hollow	5.23	-	3	341,757	23,468,867
Georgetown	3.86	5.76	6	74,957	
Granger	4.54	7.46	8	134,371	
Somerville	4.52	5.97	5	305,715	
Whitney	0.02	2.05	2	1,112,778	

Table 7.26 Permanent 50% Storage Reallocation for Nine Reservoirs

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	18.03	16.29	19	106,303	
Waco	5.33	7.82	9	558,674	
Proctor	1.22	3.47	6	228,510	
Belton	10.27	11.14	11	837,812	
Stillhouse Hollow	9.54	1.15	6	415,483	23,487,573
Georgetown	11.00	11.73	11	91,715	
Granger	13.35	12.73	15	166,753	
Somerville	11.69	12.35	10	373,509	
Whitney	1.43	4.40	6	1,386,813	

Table 7.27 Seasonal 10% Storage Reallocation for Nine Reservoirs

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal (%)	Flood Pool Capacity Exceedance Frequency Log-Pearson III (%)	Number of Exceedance	Expected Value of Flood Storage (acre-feet)	Expected Total Flood Damage Index (1984 $)
Aquilla	2.68	5.20	5	67,818	
Waco	0.32	2.23	3	317,942	
Proctor	-	0.69	0	85,473	
Belton	0.95	3.24	5	561,033	
Stillhouse Hollow	2.90	-	2	249,443	24,018,673
Georgetown	1.21	2.59	3	53,579	
Granger	0.84	3.10	4	89,539	
Somerville	1.89	2.63	5	226,471	
Whitney	-	0.99	1	801,806	

Table 7.28 Seasonal 20% Storage Reallocation for Nine Reservoirs

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal (%)	Flood Pool Capacity Exceedance Frequency Log-Pearson III (%)	Number of Exceedance	Expected Value of Flood Storage (acre-feet)	Expected Total Flood Damage Index (1984 $)
Aquilla	3.27	5.69	5	69,831	
Waco	0.45	2.20	3	331,217	
Proctor	0.19	0.81	0	87,657	
Belton	1.21	3.30	4	571,030	
Stillhouse Hollow	3.32	-	2	254,024	24,102,285
Georgetown	1.51	2.50	3	54,679	
Granger	1.03	3.10	5	93,028	
Somerville	2.68	3.02	5	233,775	
Whitney	-	0.93	1	883,751	

Table 7.29 Seasonal 30% Storage Reallocation for Nine Reservoirs

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	4.07	6.35	7	71,929	
Waco	0.65	2.24	3	338,520	
Proctor	0.33	0.99	0	89,273	
Belton	1.62	3.48	4	580,483	
Stillhouse Hollow	3.75	-	2	259,625	24,227,462
Georgetown	1.97	2.91	3	56,259	
Granger	1.64	3.45	5	96,577	
Somerville	3.28	3.49	6	238,703	
Whitney	-	0.84	1	935,450	

Table 7.30 Seasonal 50% Storage Reallocation for Nine Reservoirs

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	6.07	7.36	7	74,415	
Waco	1.61	3.12	3	356,795	
Proctor	0.41	1.45	0	91,124	
Belton	2.98	4.45	4	603,625	
Stillhouse Hollow	4.72	-	2	267,946	24,325,262
Georgetown	3.04	3.59	4	58,327	
Granger	2.70	4.23	5	100,777	
Somerville	4.30	4.62	6	246,577	
Whitney	0.60	1.39	2	999,938	

7.3.2 Multiple-Reservoir Systems Flood Frequency Analysis

The flood frequency for multiple-reservoir systems are performed based on the exceedance frequency using Log Normal and Log Pearson Type III distributions, Number of exceedance, expected value of flood storage, and Expected 1984 total flood damage index. The reallocation strategies for multiple-reservoir systems are divided to two different systems: 1) four reservoirs reallocation in Little River Basin and 2) nine reservoirs reallocation in Brazos River Basin. These simulations are performed with negative incremental option 4. System flood frequency analysis was repeated excluding (Type 3 Water Right) and including (Type 2 Water Right) inflows at control points, which are connected to four or nine reservoirs.

As illustrated in section 7.1, the flood frequency for multiple-reservoir systems is simulated based on Simulation Run 1 and Simulation Run 6 and Run8. Plan A is equal to simulation Run 1. Simulation plan 6 is divided into Plan B and C. Plans C and D are equal to Simulation runs 7 and 8, respectively. Plan D is simulated based on the Whitney reservoir with no conservation pool for water supply. The purpose of Plan E simulation is to investigate the impact of eight reservoir operations when the conservation pool at Whitney reservoirs is changed. These simulation runs are listed detail as follows:

Run A - Existing
Run B - Permanent reallocation of 50,000 acre-feet or 15% in system reservoirs
Run C - Seasonal reallocation of 50,000 acre-feet or 15% in system reservoirs
Run D - Plan B including Whitney with none of conservation pool
Run E - Plan A plus all of Whitney conservation pool

The flood frequency analysis results for Four BRA reservoirs in Littler River Subbasin using Type 2 water right and Type 3 water right for reallocation plans A through E are shown in Tables 7.31 through 7.35 and Tables 7.36 through 7.40. For reallocation plans A through E, the flood frequency analysis result for nine BRA reservoirs based on Type 2 and Type 3 water rights are shown in Table 7.41 through 7.45 and Tables 7.46 through 7.50, respectively.

In some cases exceedance frequency based on type 2 Water Right is larger than exceedance frequency based on type 3 Water Right, and in other cases the exceedance frequency based on type 3 Water Rights are larger. Exceedance frequency based on Log

Normal distribution is smaller than exceedance frequency based on Log Pearson Type III distribution. The Number of exceedance to flood control capacity was found to be affected a little by these reallocation plans. The conversion from flood control pool to conservation pool at Whitney reservoir (Plan D) shows same reservoir for Plan B in most cases. Compared between Plan A and Plan E, the change of Whitney reservoir conservation capacity does not affect a lot for the four reservoir operations in Little River Subbasin and nine reservoir operations in Brazos River Basin. Expected total 1984 flood damage index based on Type 2 and Type 3 water rights for four reservoirs reallocations in Little River Subbasin are increased 0.89 percent and 0.93 percent by permanent reallocation plan, respectively. Type 2 expected total 1984 flood damage index is smaller than Type 3 expected total 1984 flood damage index.

Table 7.31 Multiple-Reservoir System Storage Reallocation Run A for Four BRA Reservoirs in Little River Subbasin Using Type 2 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	1.96	4.31	4	63,135	
Waco	0.33	2.35	3	291,539	
Proctor	-	0.87	0	82,517	
Belton	1.33	1.97	3	506,077	
Stillhouse Hollow	1.65	-	2	239,505	23,434,465
Georgetown	0.85	2.28	3	50,540	
Granger	1.12	3.42	4	85,698	
Somerville	1.29	1.86	4	208,526	
Whitney	-	0.95	2	701,106	
	1.96	4.31		63,135	

Table 7.32 Multiple-Reservoir System Storage Reallocation Run B for Four BRA Reservoirs in Little River Subbasin Using Type 2 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	1.93	4.24	4	63,039	23,643,651
Waco	0.32	2.33	3	291,358	
Proctor	-	0.82	0	80,001	
Belton	1.19	1.80	3	503,040	
Stillhouse Hollow	1.75	-	2	241,330	
Georgetown	0.39	1.79	3	47,736	
Granger	1.53	3.64	5	89,017	
Somerville	1.30	1.86	4	208,550	
Whitney	-	0.94	1	700,895	

Table 7.33 Multiple-Reservoir System Storage Reallocation Run C for Four BRA Reservoirs in Little River Subbasin Using Type 2 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	1.98	4.36	4	63,190	23,434,465
Waco	0.33	2.35	3	291,490	
Proctor	-	0.97	0	84,050	
Belton	1.78	2.91	4	517,236	
Stillhouse Hollow	1.80	-	2	242,296	
Georgetown	0.93	2.68	4	50,622	
Granger	1.13	3.35	4	86,251	
Somerville	1.30	1.86	4	208,579	
Whitney	-	0.95	1	701,392	

Table 7.34 Multiple-Reservoir System Storage Reallocation Run D for Four BRA Reservoirs in Little River Subbasin Using Type 2 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	1.91	4.17	5	62,969	
Waco	0.32	2.33	3	291,359	
Proctor	-	0.82	0	80,008	
Belton	1.19	1.79	3	502,987	
Stillhouse Hollow	1.75	-	2	241,328	23,643,651
Georgetown	0.39	1.79	3	47,736	
Granger	1.53	3.64	5	89,017	
Somerville	1.30	1.86	4	208,550	
Whitney	-	0.99	1	750,793	

Table 7.35 Multiple-Reservoir System Storage Reallocation Run E for Four BRA Reservoirs in Little River Subbasin Using Type 2 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	1.96	4.31	4	63,135	
Waco	0.33	2.35	3	291,539	
Proctor	-	0.87	1	82,517	
Belton	1.33	1.97	3	506,077	
Stillhouse Hollow	1.65	-	2	239,505	23,434,616
Georgetown	0.85	2.28	3	50,540	
Granger	1.12	3.42	4	85,698	
Somerville	1.29	1.86	4	208,526	
Whitney	-	0.95	1	701,106	

Table 7.36 Multiple-Reservoir System Storage Reallocation Run A for Four BRA Reservoirs in Little River Subbasin Using Type 3 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	1.88	4.29	4	63,045	23,434,465
Waco	0.33	2.34	3	291,509	
Proctor	-	0.85	0	81,928	
Belton	2.30	0.54	3	487,018	
Stillhouse Hollow	2.68	-	2	231,823	
Georgetown	1.06	1.93	3	49,731	
Granger	1.11	3.41	4	85,659	
Somerville	1.29	1.87	4	208,630	
Whitney	-	0.95	1	701,238	

Table 7.37 Multiple-Reservoir System Storage Reallocation Run B for Four BRA Reservoirs in Little River Subbasin Using Type 3 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	1.92	4.23	4	62,968	23,653,182
Waco	0.32	2.33	3	291,330	
Proctor	-	0.79	0	79,557	
Belton	2.13	0.32	3	483,451	
Stillhouse Hollow	2.83	-	2	233,310	
Georgetown	0.50	1.51	3	46,869	
Granger	1.49	3.61	5	88,754	
Somerville	1.29	1.87	4	208,627	
Whitney	-	0.94	1	700,675	

Table 7.38 Multiple-Reservoir System Storage Reallocation Run C for Four BRA Reservoirs in Little River Subbasin Using Type 3 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	1.96	4.34	4	63,105	
Waco	0.33	2.35	3	291,498	
Proctor	-	0.94	0	83,406	
Belton	2.94	1.40	4	497,750	
Stillhouse Hollow	2.91	-	2	234,337	23,582,179
Georgetown	1.20	2.38	4	49,850	
Granger	1.12	3.35	4	86,188	
Somerville	1.29	1.86	4	208,634	
Whitney	-	0.95	1	701,144	

Table 7.39 Multiple-Reservoir System Storage Reallocation Run D for Four BRA Reservoirs in Little River Subbasin Using Type 3 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	1.90	4.16	4	62,899	
Waco	0.32	2.33	3	291,330	
Proctor	-	0.79	0	79,574	
Belton	2.13	0.32	3	483,384	
Stillhouse Hollow	2.83	-	2	233,305	23,654,162
Georgetown	0.50	1.51	3	46,867	
Granger	1.49	3.61	5	88,754	
Somerville	1.29	1.87	4	208,627	
Whitney	-	0.99	1	750,707	

Table 7.40 Multiple-Reservoir System Storage Reallocation Run E for Four BRA Reservoirs in Little River Subbasin Using Type 3 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal (%)	Flood Pool Capacity Exceedance Frequency Log-Pearson III (%)	Number of Exceedance	Expected Value of Flood Storage (acre-feet)	Expected Total Flood Damage Index (1984 $)
Aquilla	1.94	4.29	4	63,045	
Waco	0.33	2.34	3	291,509	
Proctor	-	0.85	0	81,928	
Belton	2.30	0.54	3	487,018	
Stillhouse Hollow	2.68	-	2	231,823	23,460,581
Georgetown	1.06	1.93	3	49,731	
Granger	1.11	3.41	4	85,659	
Somerville	1.29	1.87	4	208,630	
Whitney	-	0.95	1	701,238	

Table 7.41 Multiple-Reservoir System Storage Reallocation Run A for Nine Brazos River Authority Reservoirs Using Type 2 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal (%)	Flood Pool Capacity Exceedance Frequency Log-Pearson III (%)	Number of Exceedance	Expected Value of Flood Storage (acre-feet)	Expected Total Flood Damage Index (1984 $)
Aquilla	1.96	4.31	4	63,135	
Waco	0.33	2.35	3	291,539	
Proctor	-	0.87	3	82,517	
Belton	1.33	1.97	2	506,077	
Stillhouse Hollow	1.65	-	2	239,505	23,431,390
Georgetown	0.85	2.28	3	50,540	
Granger	1.12	3.42	4	85,698	
Somerville	1.29	1.86	4	208,526	
Whitney	-	0.95	1	701,106	

Table 7.42 Multiple-Reservoir System Storage Reallocation Run B for Nine Brazos River Authority Reservoirs Using Type 2 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	3.64	6.60	6	75,932	
Waco	0.32	2.33	3	291,358	
Proctor	-	0.83	0	80,061	
Belton	1.19	1.80	3	503,019	
Stillhouse Hollow	1.75	-	2	241,335	23,635,590
Georgetown	0.39	1.79	3	47,754	
Granger	1.53	3.64	5	89,019	
Somerville	2.27	1.57	5	255,365	
Whitney	-	0.94	1	700,917	

Table 7.43 Multiple-Reservoir System Storage Reallocation Run C for Nine Brazos River Authority Reservoirs Using Type 2 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	2.98	5.43	5	68,946	
Waco	0.32	2.34	3	291,421	
Proctor	-	0.95	0	83,444	
Belton	1.81	2.97	4	518,087	
Stillhouse Hollow	1.80	-	2	242,416	23,616,777
Georgetown	0.93	2.72	4	50,696	
Granger	1.14	3.36	4	86,282	
Somerville	2.21	2.80	5	230,089	
Whitney	-	0.96	1	701,497	

Table 7.44 Multiple-Reservoir System Storage Reallocation Run D for Nine Brazos River Authority Reservoirs Using Type 2 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	3.62	6.57	6	75,894	
Waco	0.32	2.33	3	291,358	
Proctor	-	0.83	0	80,049	
Belton	1.19	1.79	3	502,950	
Stillhouse Hollow	1.75	-	2	241,333	23,636,517
Georgetown	0.39	1.79	3	47,754	
Granger	1.53	3.64	5	89,019	
Somerville	2.27	3.14	5	255,365	
Whitney	-	1.00	1	750,800	

Table 7.45 Multiple-Reservoir System Storage Reallocation Run E for Nine Brazos River Authority Reservoirs Using Type 2 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	1.96	4.31	4	63,128	
Waco	0.33	2.35	3	291,538	
Proctor	-	0.87	0	82,517	
Belton	1.33	1.97	3	506,099	
Stillhouse Hollow	1.65	-	2	239,509	23,431,565
Georgetown	0.84	2.28	3	50,558	
Granger	1.12	3.42	4	85,699	
Somerville	1.31	1.84	4	208,201	
Whitney	-	0.95	1	701,116	

Table 7.46 Multiple-Reservoir System Storage Reallocation Run A for Nine Brazos River Authority Reservoirs Using Type 3 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	1.94	4.29	4	63,036	
Waco	0.33	2.34	3	291,508	
Proctor	-	0.85	0	81,930	
Belton	2.29	0.56	3	487,154	
Stillhouse Hollow	2.68	-	2	231,893	23,458,276
Georgetown	1.05	1.94	3	49,756	
Granger	1.11	3.42	4	85,665	
Somerville	1.38	1.78	4	207,695	
Whitney	-	0.95	1	701,243	
				63,036	

Table 7.47 Multiple-Reservoir System Storage Reallocation Run B for Nine Brazos River Authority Reservoirs Using Type 3 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	3.62	6.59	6	75,858	
Waco	0.32	2.33	3	291,329	
Proctor	-	0.80	0	79,633	
Belton	2.11	0.33	3	483,534	
Stillhouse Hollow	2.82	-	2	233,383	23,645,551
Georgetown	0.50	1.52	3	46,899	
Granger	1.49	3.61	5	88,758	
Somerville	1.18	3.07	5	254,616	
Whitney	-	0.94	1	700,804	

Table 7.48 Multiple-Reservoir System Storage Reallocation Run C for Nine Brazos River Authority Reservoirs Using Type 3 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	2.97	5.43	5	68,927	23,648,397
Waco	0.32	2.33	3	291,340	
Proctor	-	0.92	0	82,930	
Belton	2.95	1.43	4	498,176	
Stillhouse Hollow	2.88	-	2	234,352	
Georgetown	1.19	2.46	4	49,981	
Granger	1.09	3.32	4	86,009	
Somerville	2.27	2.75	5	229,637	
Whitney	-	0.96	1	701,250	

Table 7.49 Multiple-Reservoir System Storage Reallocation Run D for Nine Brazos River Authority Reservoirs Using Type 3 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	3.60	6.56	6	75,820	23,646,517
Waco	0.32	2.33	3	291,329	
Proctor	-	0.80	0	79,620	
Belton	2.11	0.33	3	483,457	
Stillhouse Hollow	2.82	-	2	233,378	
Georgetown	0.50	1.52	3	46,898	
Granger	1.49	3.61	4	88,758	
Somerville	2.37	3.07	5	254,614	
Whitney	-	0.99	1	750,709	

Table 7.50 Multiple-Reservoir System Storage Reallocation Run E for Nine Brazos River Authority Reservoirs Using Type 3 Water Right

Reservoirs	Flood Pool Capacity Exceedance Frequency Log-Normal	Flood Pool Capacity Exceedance Frequency Log-Pearson III	Number of Exceedance	Expected Value of Flood Storage	Expected Total Flood Damage Index
	(%)	(%)		(acre-feet)	(1984 $)
Aquilla	1.94	4.29	4	63,036	
Waco	0.33	2.34	3	291,508	
Proctor	-	0.85	0	81,930	
Belton	2.29	0.56	3	487,154	
Stillhouse Hollow	2.68	-	2	231,893	23,458,441
Georgetown	1.05	1.94	3	49,756	
Granger	1.11	3.42	4	85,665	
Somerville	1.38	1.78	4	207,695	
Whitney	-	0.95	1	701,243	

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Reallocation of reservoir storage capacity between flood control and conservation purposes in multiple-purpose, multiple-reservoir systems represents a general strategy for optimizing the beneficial use of available resources in response to changing needs and conditions. Evaluation of storage reallocations and other related modifications in reservoir system operations also represents a new expanded type of application of the Texas Water Availability Modeling (WAM) and Water Rights Analysis Package (WRAP) modeling system. This research addresses key issues in expanding the WAM/WRAP modeling system for applicability to analyses of these types of modifications to reservoir system operating plans. A system of 12 reservoirs operated by the U.S. Army Corps of Engineers and Brazos River Authority provided a case study for formulating and testing reservoir system operating strategies and associated WAM/WRAP-based simulation modeling methodologies.

The following modeling issues representing the primary focus of this research are relevant to a broad range of WAM/WRAP applications but are particularly important in studying reservoir storage reallocations and related modifications to operating plans:

- The original Brazos WAM hydrologic period-of-analysis of 1940-1997 was extended to cover 1900-2007. The reservoir flood control pools are sized to contain infrequent flood control events without releases that contribute to downstream flooding. Increasing the simulation period from 58 years to 108 years is particularly useful in providing a better basis for assessing flood control capabilities and also improves assessments of water supply capabilities.

- The original Brazos WAM authorized use and current use scenario datasets have 3,830 and 3,834 control points and 670 and 711 reservoirs, respectively, and hundreds of water rights. The condensed datasets developed in this research have 48 control points and 15 reservoirs. The effects of all of the other water rights are incorporated in the river inflows in the FLO input files. The condensed datasets are designed for operational planning studies for a particular reservoir system.

- Applications of the WAM/WRAP System by the Texas water management community to date have been limited to a monthly computational time step. Recently developed daily time step features were adopted in this research to model flood control operations. These features include disaggregation of monthly flows to daily flows, forecasting, and routing.

- Applications of the WAM/WRAP System by the Texas water management community to date have been limited to reservoir conservation pools, while ignoring flood control pools. This research included application of WRAP simulation features for modeling flood control operations to the system of nine multiple-purpose Corps of Engineers reservoirs that contain flood control pools. Indices were developed for quantifying flood control capacities provided by the 9-reservoir system with existing storage allocations and alternative storage reallocations.

8.1 FORWARD EXTENSION OF HYDROLOGIC PERIOD-OF-ANALYSIS

Updating the WAM System datasets by lengthening the hydrologic period-of-analysis consist of extending both the evaporation-precipitation data in the EVA file and naturalized flow data in the FLO file. However, the procedure in this research focuses on the extension of the sequences of monthly naturalized flow volumes. The extension of the monthly evaporation-precipitation depths is treated as a component task within the procedure of extending the naturalized flows.

The actual DAT file is developed by modifying a WAM System current use scenario (run 8) DAT file. A DAT file represents actual water resources development, allocation, management, and use during the period-of-analysis and is utilized for converting observed gaged stream flows to naturalized flows.

The objective is to develop a FLO file of naturalized flows that when input to SIM along with the actual use DAT file, and updated EVA and revised DIS files produce simulated regulated flows that closely reproduce actual observed flows.

Consideration of the strengths and weaknesses of the proposed methodology for extension of naturalized flow sequences focuses on the following tasks:

1. The iterative computational methodology in finding a set of naturalized flows that result in simulated regulated flows that very closely match observed flows.

2. The development of the actual use DAT file and the accuracy of the actual use DAT file in representing actual water resources development, allocation, management, and use during the time period of concern.

3. Other key considerations:
    - Compilation of observed gaged stream flow data.
    - Synthesis of naturalized flows at ungaged control points.
    - Compilation of net evaporation-precipitation rates.

Applications of the procedure for extending hydrologic simulation periods may vary significantly in level of detail and accuracy depending largely on the extent to which a current use scenario WAM dataset is modified to develop an actual use dataset for the period of extension. Other aspects of the procedure are also characterized by judgments regarding appropriated levels of detail and accuracy. Many of the issues related to extending the hydrologic period-of-analysis were also relevant during the development of the original WAM System datasets.

A fundamental concept of the procedure is to both improve accuracy and reduce the effort required to update the WAM System FLO files by utilizing the information available in the current use scenario DAT files. An approximated dataset for preliminary screening investigations may be created based on an actual use DAT file created with minimal or no revisions to the current use DAT file. Improvements in accuracy are achieved by devoting greater effort and resources to modifying the current use dataset to create an extension-period actual use dataset. The flow extension methodology may be implemented at levels of detail that provide extended sequences of naturalized flow at comparable or higher levels of accuracy as the naturalized flow for the original period-of-analysis.

8.2 BACKWARD EXTENSION OF HYDROLOGIC PERIOD-OF-ANALYSIS

Wurbs et al. (1988) document a water availability modeling study for the Brazos River Basin conducted at Texas A&M University during 1986-1988 that included developing January 1900 through December 1984 sequences of naturalized stream flows at 20 USGS gaging stations which all happen to be included in the 77 Brazos WAM primary control points. The 1900-1939 portions of these flow sequences were adopted for the present research. Although compilation of naturalized flows during the 1986-1988 study included adjustments to 1900-1984 gaged streamflows to remove the impacts of 21 reservoirs and selected diversions, only one small reservoir with records dating back to 1936 was included in the flow adjustments prior to 1940. Thus, 1900-1939 naturalized flows are essentially the same as the gaged flows. The compilation of 1900-1939 flows focused on distributing flows from gaged to ungaged sites in both the 1986-1988 and current studies.

Records of flow measurements at 24 stream gage stations were used in the 1986-1988 investigation to fill in missing data and develop complete 1900-1984 naturalized flow sequences at 20 gaging stations. Wurbs et al. (1988) synthesized monthly flows for the periods of missing records using the *MOSS-IV Monthly Streamflow Synthesis* computer model. MOSS-IV fills in gaps in monthly streamflow data based on measured streamflow at multiple nearby gaging stations. The program uses a multiple linear regression algorithm based on the transformed incremental logarithm of the monthly flow volumes, with a random component included to reproduce the distribution of random departures from the regression model observed in the basic data.

Eleven of the 20 gages have records dating back to 1924 or before. The USGS gaging station on the Brazos River at Waco has a continuous record from October 1898 to the present. This is the only gage with a continuous record during 1900-1939. Gages on the Brazos River at Richmond and Bryan have records beginning in 1899 and 1903, respectively, but also have periods of missing data. Flow measurements are missing during July 1906 through September 1922 at the Richmond gage and during January 1903 through February 1918 at the Bryan gage. The gage on the Little River at Cameron has continuous recorded monthly flows dating back to November 1916.

The same flow distribution methodology based on 1940-1997 mean flows was used in the current investigation for both the 1998-2007 and 1900-1939 flow extensions. The 1900-1939 monthly flows at 20 control points was distributed to 57 other control points. The 1900-2007 flows at the 77 Brazos WAM primary control points are plotted in Appendix A. These naturalized flows are distributed to over 3,700 other secondary control points in the *WRAP-SIM* simulation. The 1940-1997 averages of the net evaporation-precipitation depths for each of the 12 months of the year were adopted for each of the years 1900 through 1939.

The 1900-1939 flows synthesized at the numerous remote control points are not accurate enough for various conventional WRAP modeling applications. Flows before

1924 are based on even fewer active gaging stations than the flows during 1924-1939. However, the 1900-2007 hydrologic period-of-analysis is useful for some applications of WRAP, such as conditional reliability modeling studies. The 108-year hydrologic period-of-analysis provides meaningful insights into the river basin hydrology of 1900-1939 and the impacts on water availability analyses of incorporating this early hydrology into the model simulations.

8.3 BRAZOS RIVER AUTHORITY CONDENSED (BRAC) DATASET

The purpose of developing the Brazos River Authority Condensed (BRAC) datasets is to provide a much simpler model that evaluates the storage reallocation, and facilitates operational planning studies and other decision support activities for the Brazos River Authority (BRA). Condensed datasets also provide a mechanism for allocating water between a primary system of concern and all of the other water rights in the river basin that can be useful in certain types of modeling applications.

The BRAC dataset is composed of DAT, FLO, EVA, and RUF files. Alternative versions of the datasets, have hydrologic periods-of-analysis of 1900-2007 and 1940-2007, were developed for BRAC3 (authorized use condensed) and BRAC8 (current use condensed) by reducing the size of the original full Brazos WAM authorized use scenario Bwam3 and current use scenario Bwam8 files.

The BRAC3 and BRAC8 input datasets appropriately reproduce the relevant SIM simulation results of the original full Brazos WAM Bwam3 and Bwam8 datasets. The simulation results for the primary system between Brazos WAM and BRAC datasets do not match perfectly but are very close. These small differences are caused by the complexities of two instream flow rights requiring releases from storage, a few rights with same-month return flows, backup rights requiring releases from storage, and certain channel losses of return flows. Some of the diversion return flows in the full WAM dataset are returned at the control points not included in the BRAC dataset. Changes in the control points at which return flows are returned affects channel losses in some cases. Return flows were not revised to mitigate the channel loss change even though return flow factors could be revised.

The Brazos WAM authorized use scenario (Bwam3) and current use scenario (Bwam8) dataset contain 1,634 and 1,725 water rights, 122 and 144 instream flow IF records, 670 and 711 reservoirs, and 3,830 and 3,834 control points, respectively, as shown in Tables 1.1 and 1.2. 77 primary control points have naturalized flows, which are input on inflow IN records in a FLO file. The naturalized flows at 77 primary control points are distributed within SIM to the other ungaged secondary control points as specified by 3,138 and 3,141 flow distribution FD records in a DIS file.

The BRAC3 and BRAC8 datasets includes 48 control points, 12 BRA reservoirs, Hubbard Creek Reservoir, Squaw Creek Reservoir, Allens Creek Reservoir (only in BRAC3 and the permitted but not yet constructed), and associated water rights. Accordingly, the BRAC3 and BRAC8 have 15 or 14 reservoirs, respectively.

Net reservoir surface evaporation less precipitation depths are provided in the EVA file for the reservoir control points. These are adjusted evaporation-precipitation depths read by program HYD from the SIM simulation output OUT file for the original Brazos WAM. The EVA files have hydrologic periods-of-analysis of 1900-2007 and 1940-2007 for BRAC3 and BRAC8 datasets.

River flows are included in the BRAC3 and BRAC8 versions of the FLO file for all of the 48 control points. There is no flow distribution DIS file. Only water rights associated with the 15 or 14 reservoirs are included in the BRAC3 and BRAC8 DAT input files. The impacts of the over 650 reservoirs and numerous water rights not included in the BRAC dataset are reflected in the IN record river flows in the FLO files developed for the BRAC3 and BRAC8 datasets.

Reliabilities for diversion from 15 or 14 reservoirs of Bwam3, BRAC3, Bwam8, and BRAC8 simulation results for 1940-1997, 1940-2007 and 1900-2007 hydrologic period-of-analysis are tabulated. The reliabilities between Bwam and BRAC dataset do not match exactly but are nearly the same. Most of the reliability differences for Bwam3 and BRAC3 are associated with Waco Reservoir.

With the primary operated in the same manner in both the condensed and original datasets, the water supply diversions and shortages, streamflow depletions, and reservoir storage volumes computed by the SIM simulation model will be the same. The condensed dataset will reproduce the simulation results for the primary system that are obtained with the original dataset. Unappropriated flows are also reproduced. Thus, a comparison of simulation results provides a check on the accuracy and validity of the condensed dataset. With a validated operational condensed dataset, studies can be performed in which various alternative operating plans, management strategies, and water use scenarios are simulated for the primary system. The river inflows for the condensed dataset do not include flows appropriated by the secondary water rights and thus represent only flows that are actually available to the primary system.

The methodology for developing and applying condensed datasets focuses upon properly modeling unappropriated rather than regulated flows. An optional regulated minus unappropriated flow (RUF) file is required if but only if conventionally-defined regulated flows are of concern. A RUF file created with program HYD contains differences between unappropriated flows and regulated flows from the SIM simulations results for a complete WAM datasets. Options recently added to SIM allow the data from a RUF file of a condensed dataset to the applied to adjust unappropriated flow to obtain regulated flows. The RUF file is also utilized for computing indices developed for evaluating storage reallocations of 9-reservoir system.

8.4 CONVERSION OF THE MONTHLY MODEL TO A DAILY TIME STEP AND FLOOD CONTROL OPERATION KEY FACTORS

The tasks 1 and 3 are preformed for converting the monthly model to a daily time step model. Key factors for flood control operation are performed in tasks 2 and 4. The program SIMD inputs developed in this research is to provide a sufficient level of accuracy for adopting as a flood control operations for 9-reservoir system in Brazos River Basin. However, further refinements are always possible by expending more time and effort to compile more detailed data:

1. The daily flow pattern for disaggregating BRAC monthly inflow at 48 control points for 1900-2007 hydrologic period-of-analysis were developed based on SUPER daily naturalized (unregulated) flows and Drainage Area Ratio Transfer Option in program SIMD. The SUPER daily naturalized flows were developed by Forth Worth District of the USACE.

2. The flood flow and average annual damage curves divided by each three categories as crops, other agriculture, and non-agriculture were aggregated and developed as one flood flow and average annual damage curve at each of the six control points included in BRACF DAT file.

3. The Muskingum parameter K (travel time) for normal flow and flood flow were developed by distances of certain reaches at control points included in BRACF DAT file. The normal stream velocity and flood stream velocity are assumed to the 15 miles/day (0.92feet/second) and 40 miles/day (2.44feet/second), respectively. The value of X (attenuation) is assumed to zero at all reaches.

4. For flood control reservoir system operations, the conservation storage capacities for the 9 flood control reservoirs of the BRAC datasets were extended as necessary to assure that flood control storage never exceeded storage capacities in the model.

8.5 EVALUATION OF STORAGE REALLOCATION FOR BRA SYSTEM

The purpose of the Brazos River Authority Condensed with flood control pool (BRACF) datasets is to evaluate storage reallocation for the BRA System. The BRACF datasets consist of DAT, FLO, and EVA files. The BRACF DAT file has 14 reservoirs, 48 control points, and water rights associated with reservoirs. The inflows in FLO file and evaporation less precipitation volume in the EVA file have a hydrologic period of simulation of 1900-2007. The BRAC8 FLO file is substituted for the BRAC3 FLO file and then the RUF file is added. The key factors for conversion of the monthly time step to daily time step and flood control operation in the program SIMD investigated in Chapter VI were utilized for the evaluation of storage reallocation between flood control and conservation purposes. The permanent (January-December raised) and seasonal (May-October raised) reallocation plans investigated by Wurbs, et al. (1988) in a previous study were adopted for storage reallocation plans in this research. Some of eight simulation runs were each applied to four kinds of analysis: i) individual firm yield, ii) multiple-reservoir system firm yield, iii) individual flood frequency, and iv) multiple reservoir system flood frequency. The eight alternative simulation runs are described below:

Simulation Run 1: Existing allocation of storage capacity.
Simulation Run 2: 10 percent reallocation of storage capacity.
Simulation Run 3: 20 percent reallocation of storage capacity.
Simulation Run 4: 30 percent reallocation of storage capacity.
Simulation Run 5: 50 percent reallocation of storage capacity.

Simulation Run 6: 15% or 50,000 ac-ft reallocation of storage capacity.
Simulation Run 7: Run 6 including Whitney with none of conservation pool.
Simulation Run 8: Run 1 plus all of Whitney conservation pool.

The firm yield for reallocation plans are greater than the firm yield for the existing allocation plan except the firm yield for seasonal reallocation plan at Whitney reservoir (50,000 acre-feet). System firm yield in this research represents releases from two or more reservoirs to meet a diversion at a common downstream location. The firm yield for two multiple-reservoir system is greater than the sum of individual reservoir firm yields. Two multiple-reservoir systems are as follows: the five reservoir system in Little River Subbasin and nine-reservoir system in Brazos River Basin. The firm yield including inflows at a given control point (Type 2 water right) is greater than firm yield excluding inflows (Type 3 water right). Reallocation between conservation purposes for Whitney reservoir focused on using the hydroelectric power generation inactive pool for water supply. After reallocating from inactive pool to conservation pool, the individual firm yield is increased by 331 percent. By permanent reallocation of top of conservation pool, the firm yield is increased significantly. However, the incremental increase in firm yield is decreased with further increases in storage capacity. After reallocating the conservation capacity by more than 15 percent, the percent increased of system firm yield as percentage for total individual firm yield are very little.

The significant losses in flood control pool by reallocation results in the significant increases in flood pool capacity exceedance frequency, number of exceedance to flood control pool, and flood damage at downstream control points. Small storage reallocation plan by below 10 percent and multiple-reservoir system with existing allocation plan are reliable strategies for obtaining additional water supply yield.

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APPENDIX A

1900-2007 MONTHLY NATURALIZED FLOWS

AT THE 77 PRIMARY CONTROL POINTS

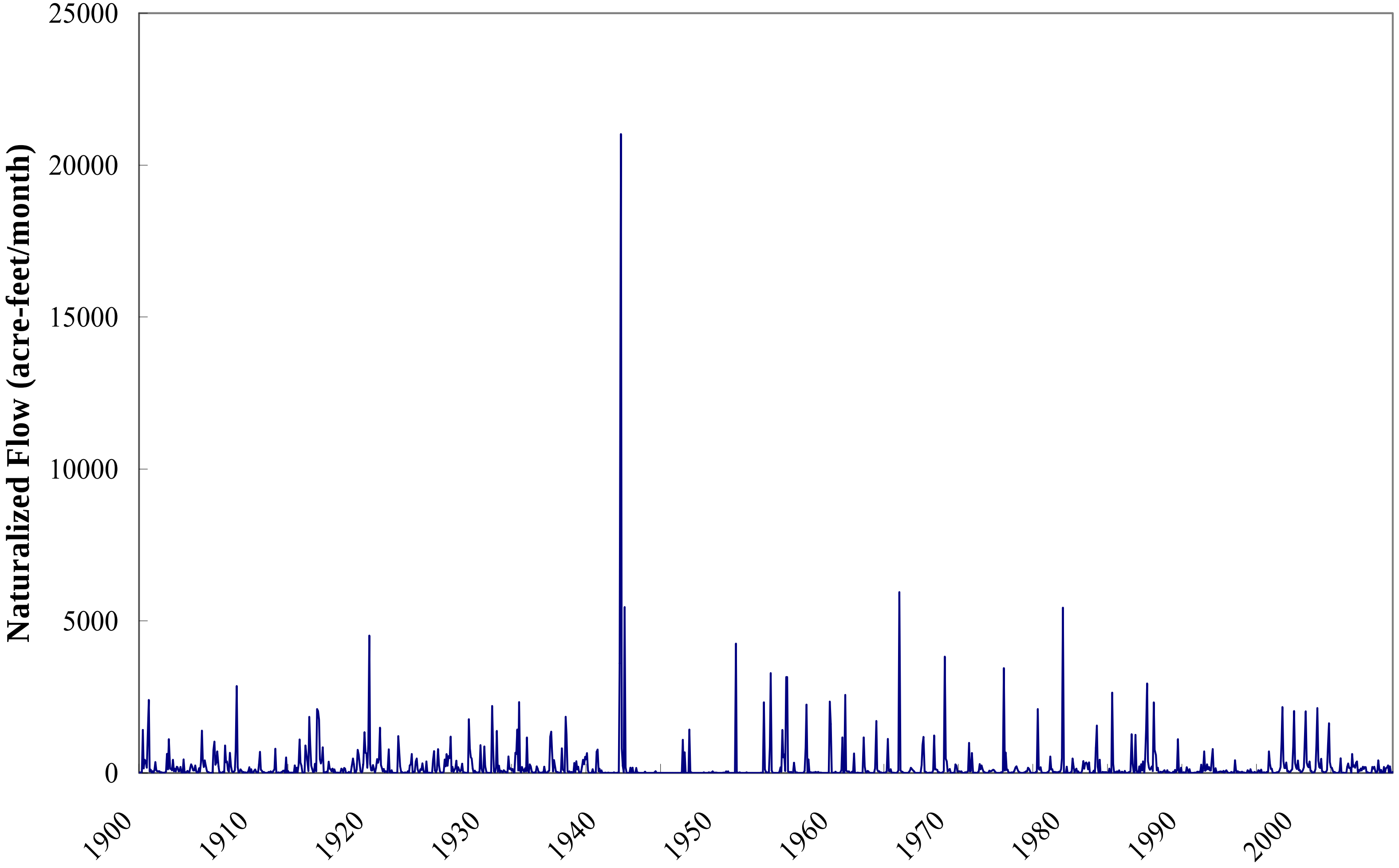

Figure A.1 Monthly Naturalized Flow at RWPL01 – Running Water Draw at Plainview

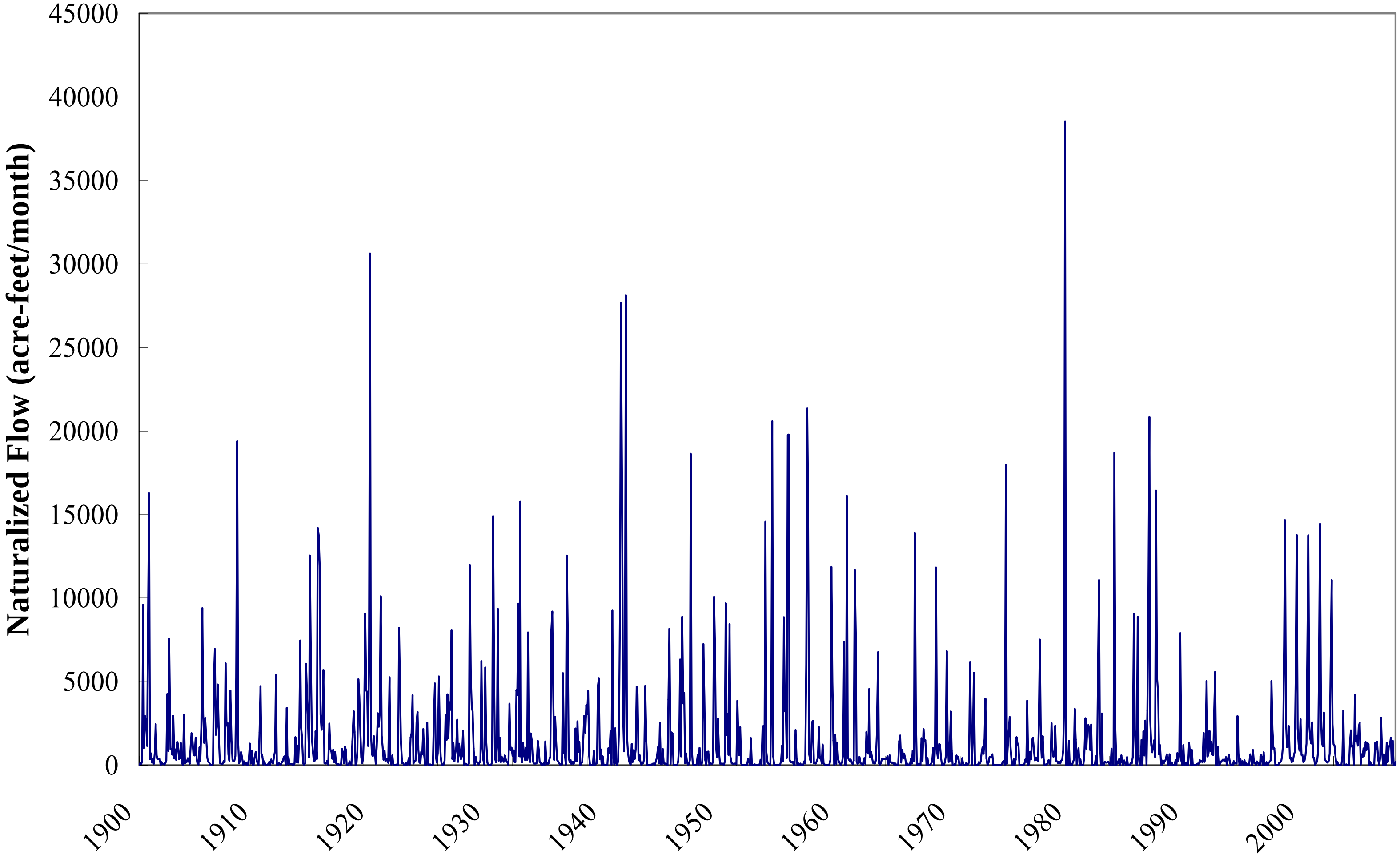

Figure A.2 Monthly Naturalized Flow at WRSP02 – White River Reservoir near Spur

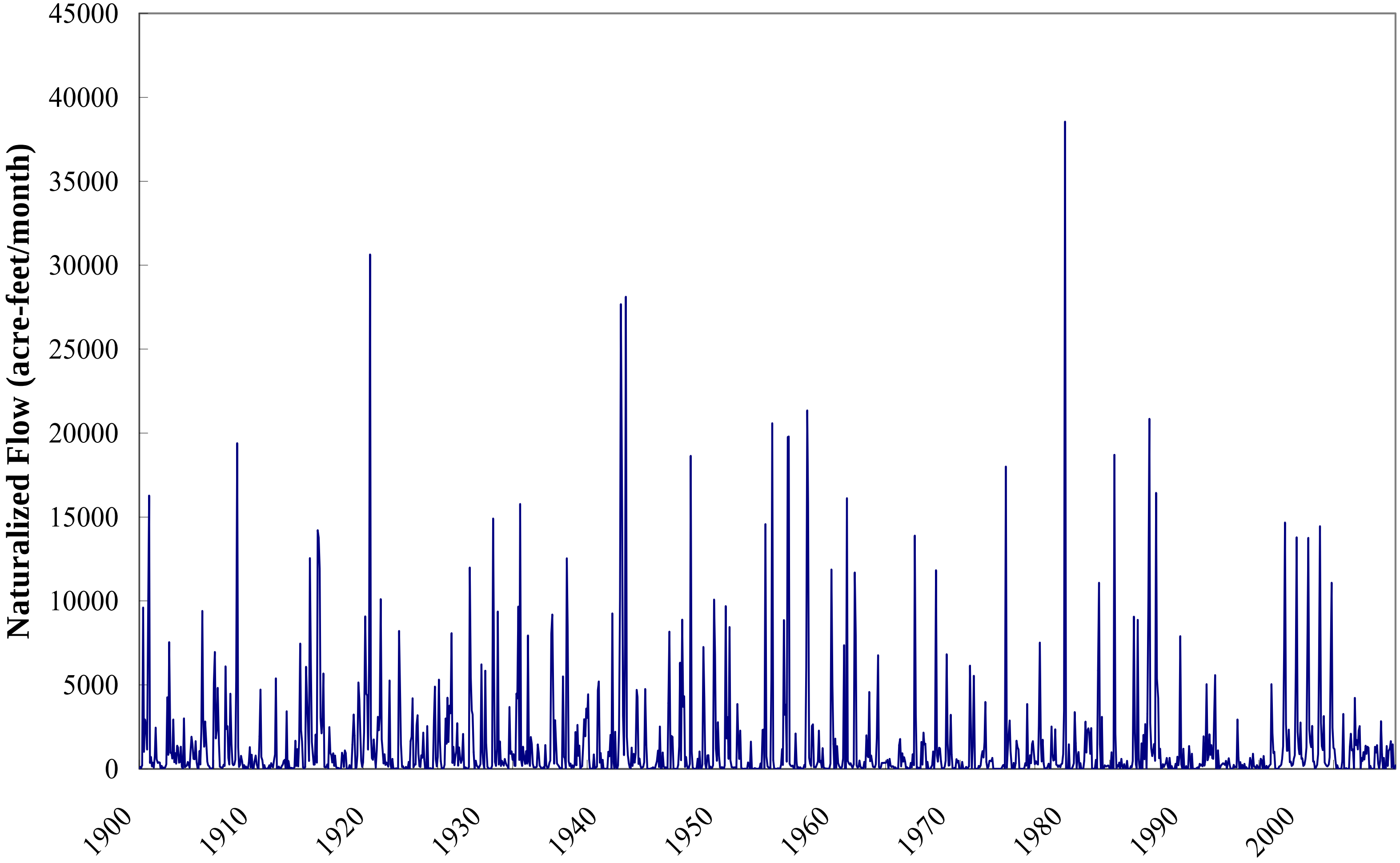

Figure A.3 Monthly Naturalized Flow at DUGI03 – Duck Creek near Girard

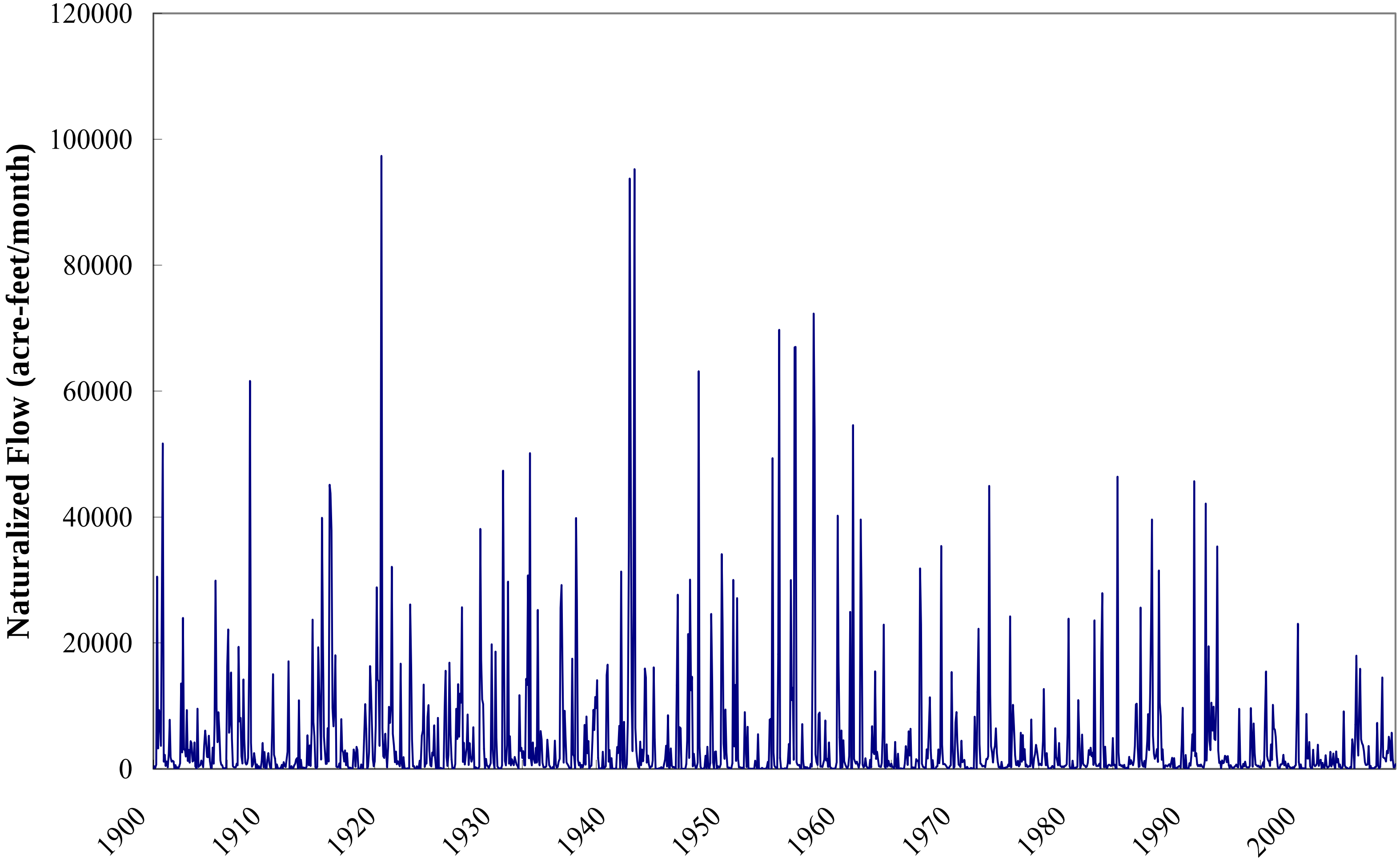

Figure A.4 Monthly Naturalized Flow at SFPE04 – Salt Fork Brazos River Near Peacock

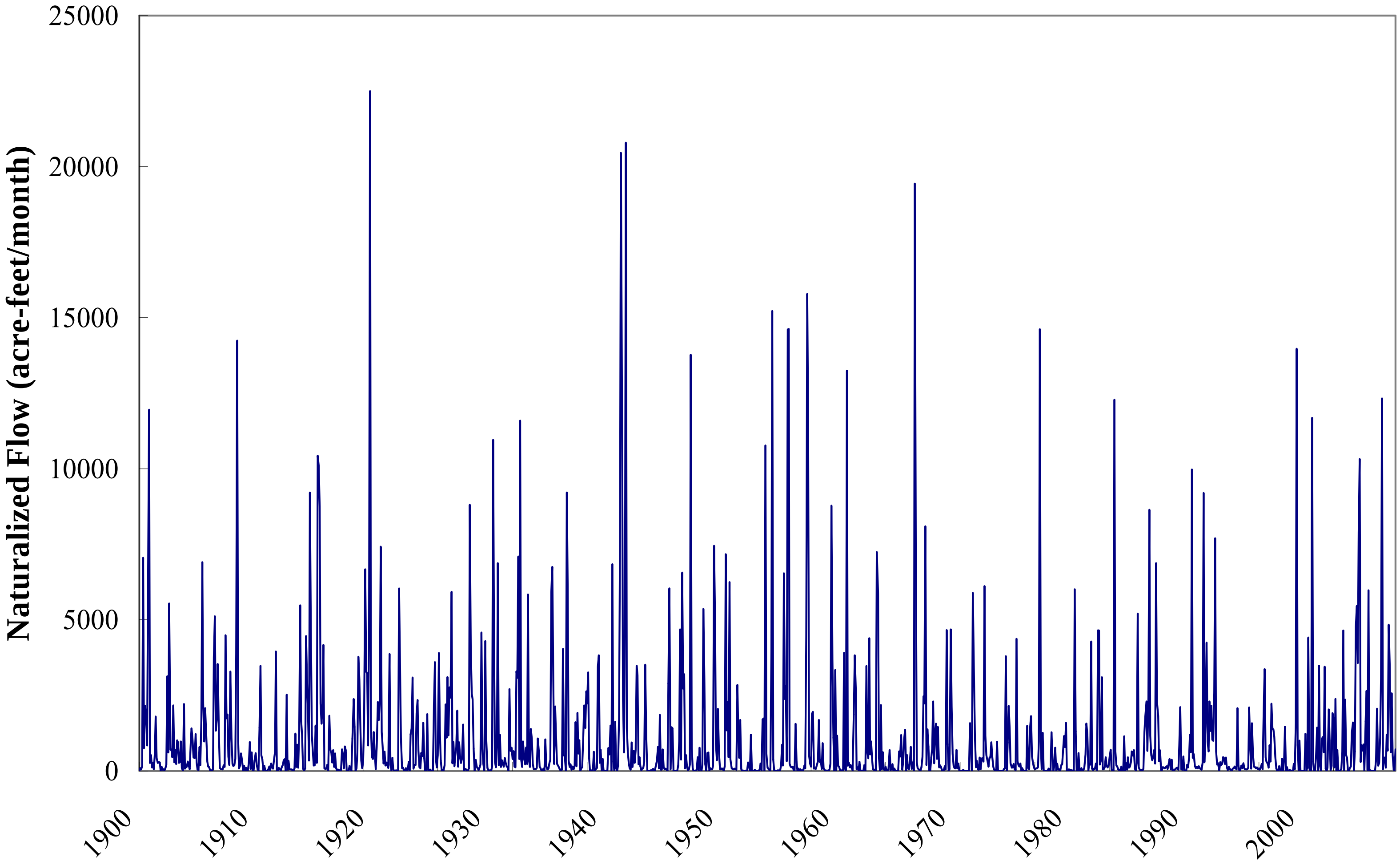

Figure A.5 Monthly Naturalized Flow at CRJA05 – Croton Creek near Jayton

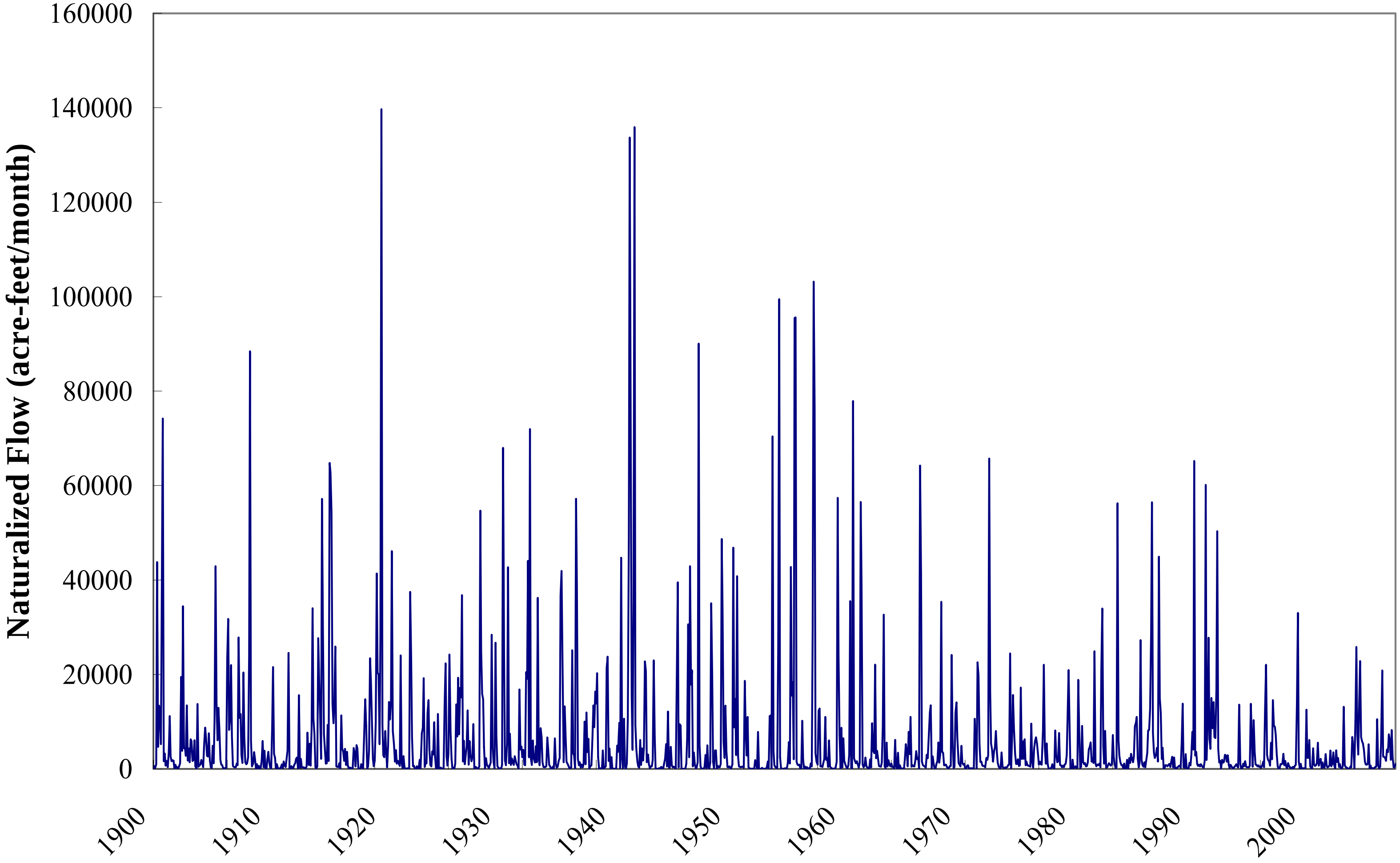

Figure A.6 Monthly Naturalized Flow at SFAS06 – Salt Fork Brazos River near Lubbock

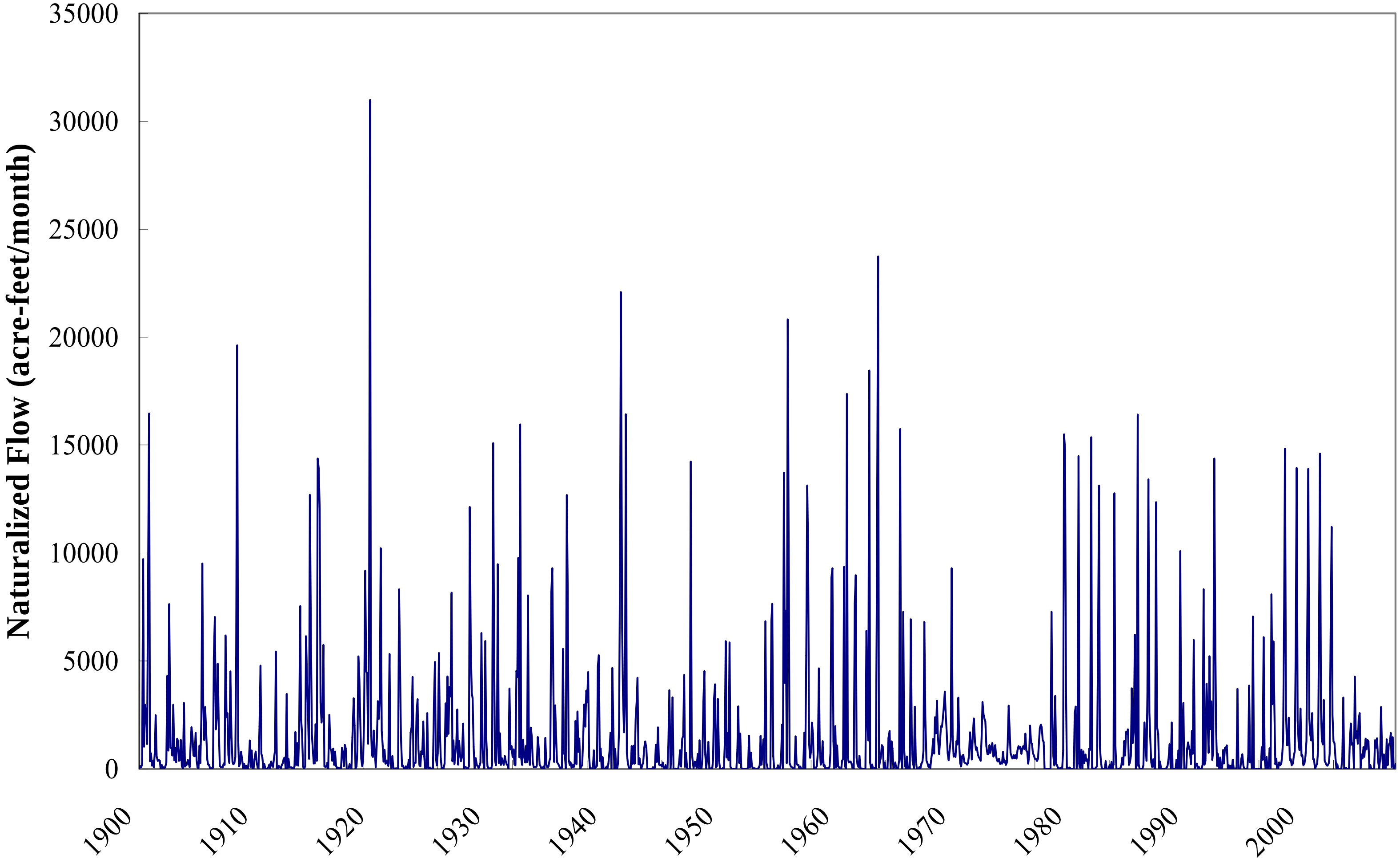

Figure A.7 Monthly Naturalized Flow at BSLU07 – Buffalo Springs Lake near Lubbock

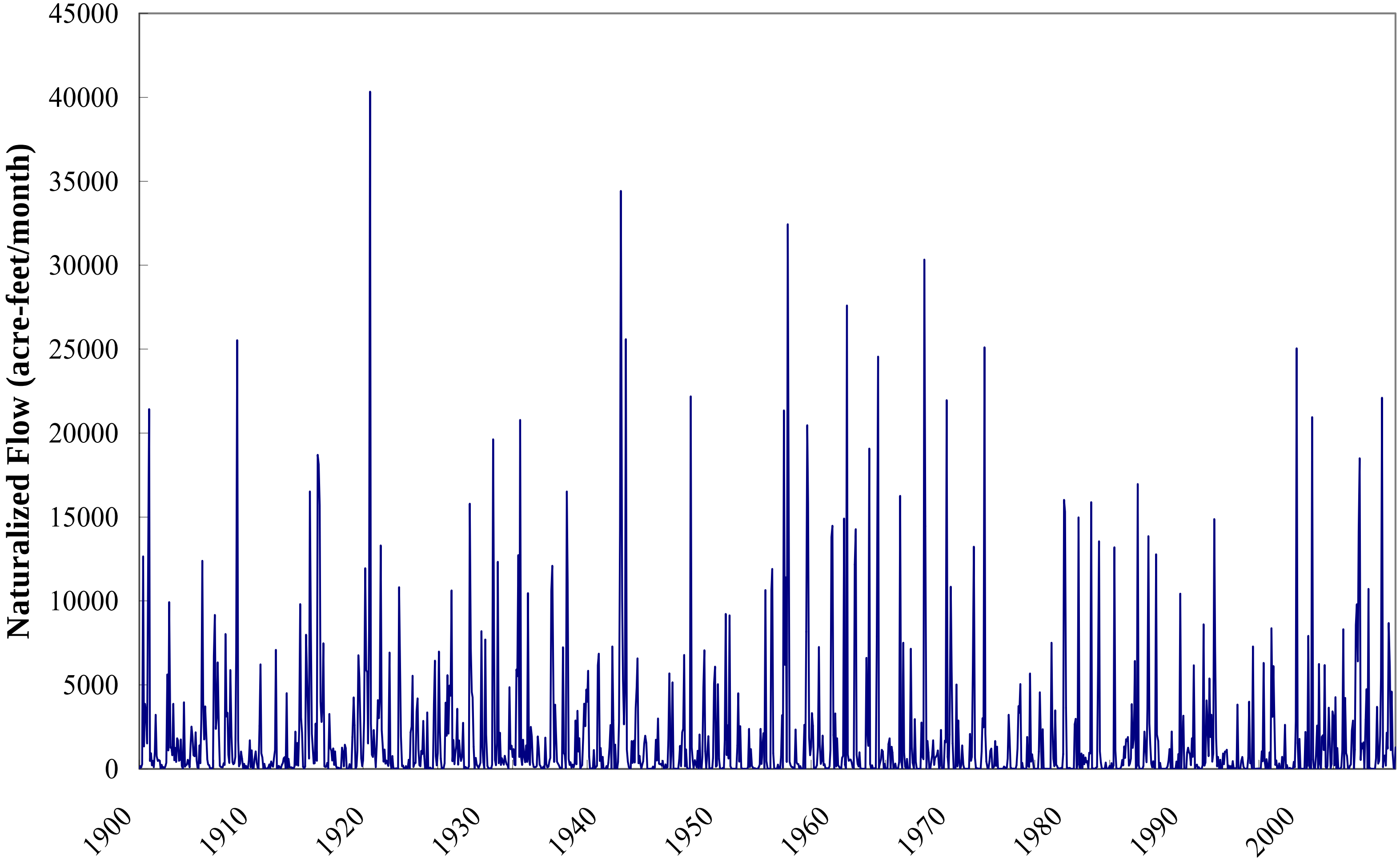

Figure A.8 Monthly Naturalized Flow at DMJU08 – Double Mountain Fork Brazos River near Justiceburg

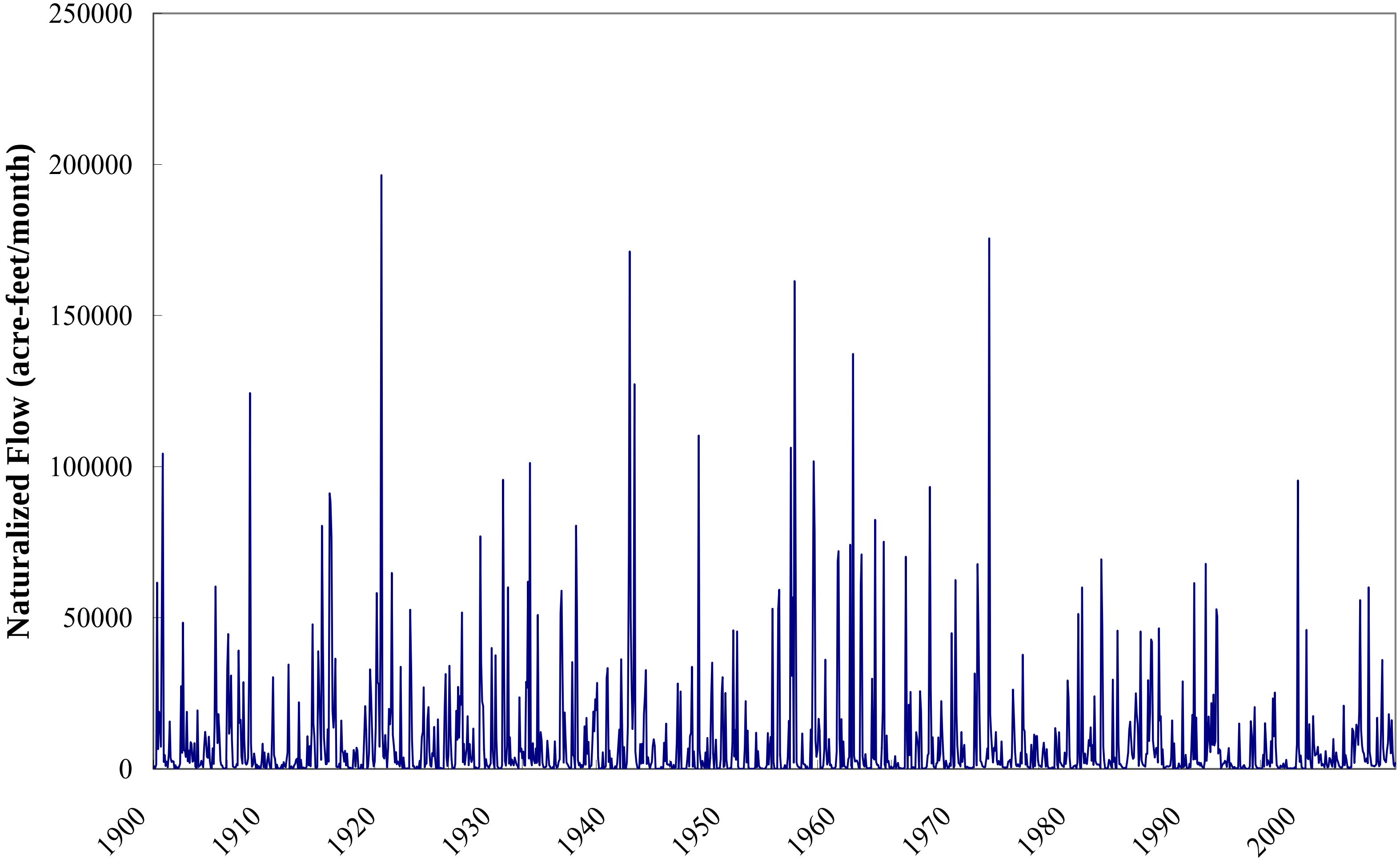

Figure A.9 Monthly Naturalized Flow at DMAS09 – Double Mountain Fork Brazos River near Aspermont

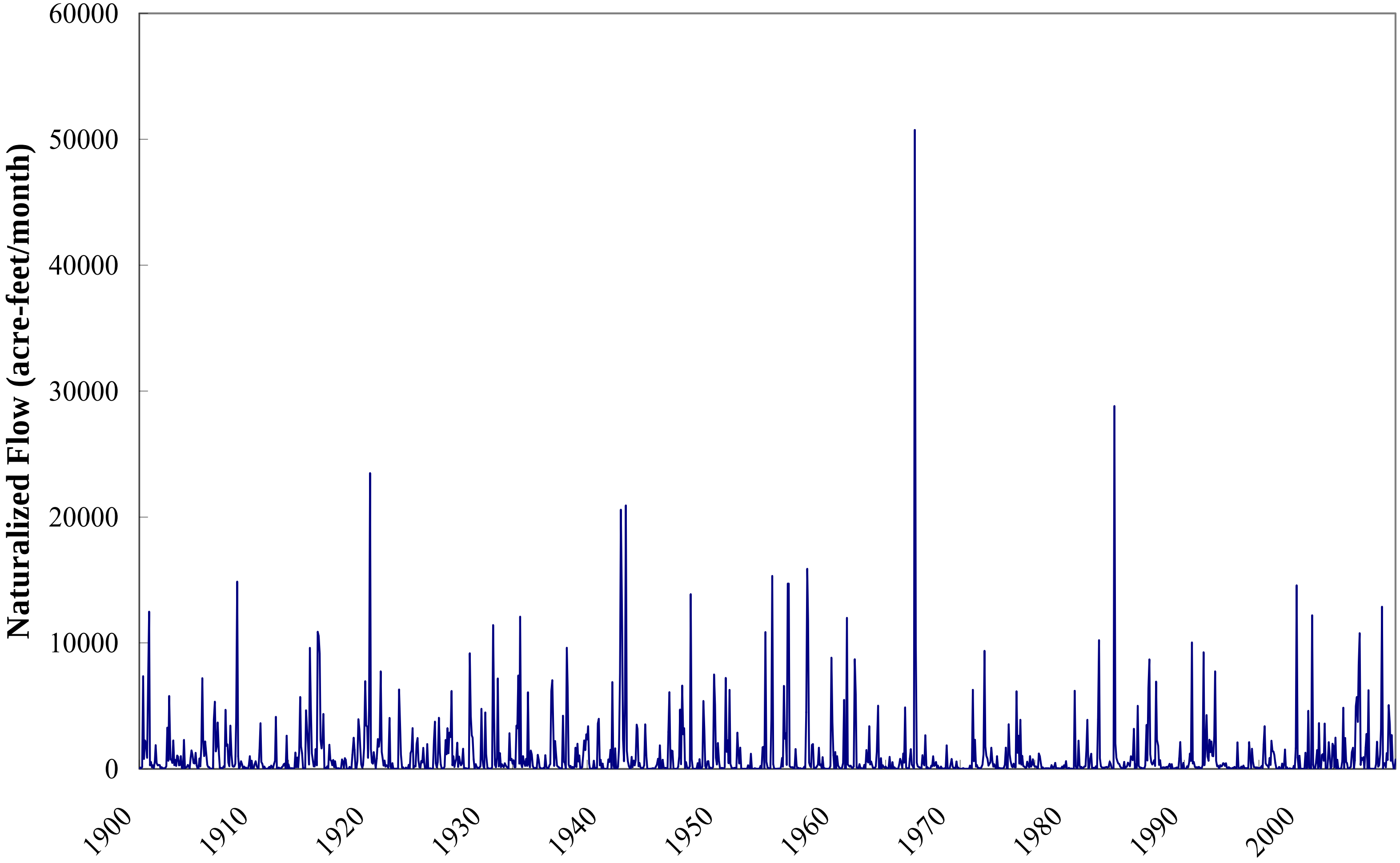

Figure A.10 Monthly Naturalized Flow at NCKN10 – North Croton Creek Near Knox

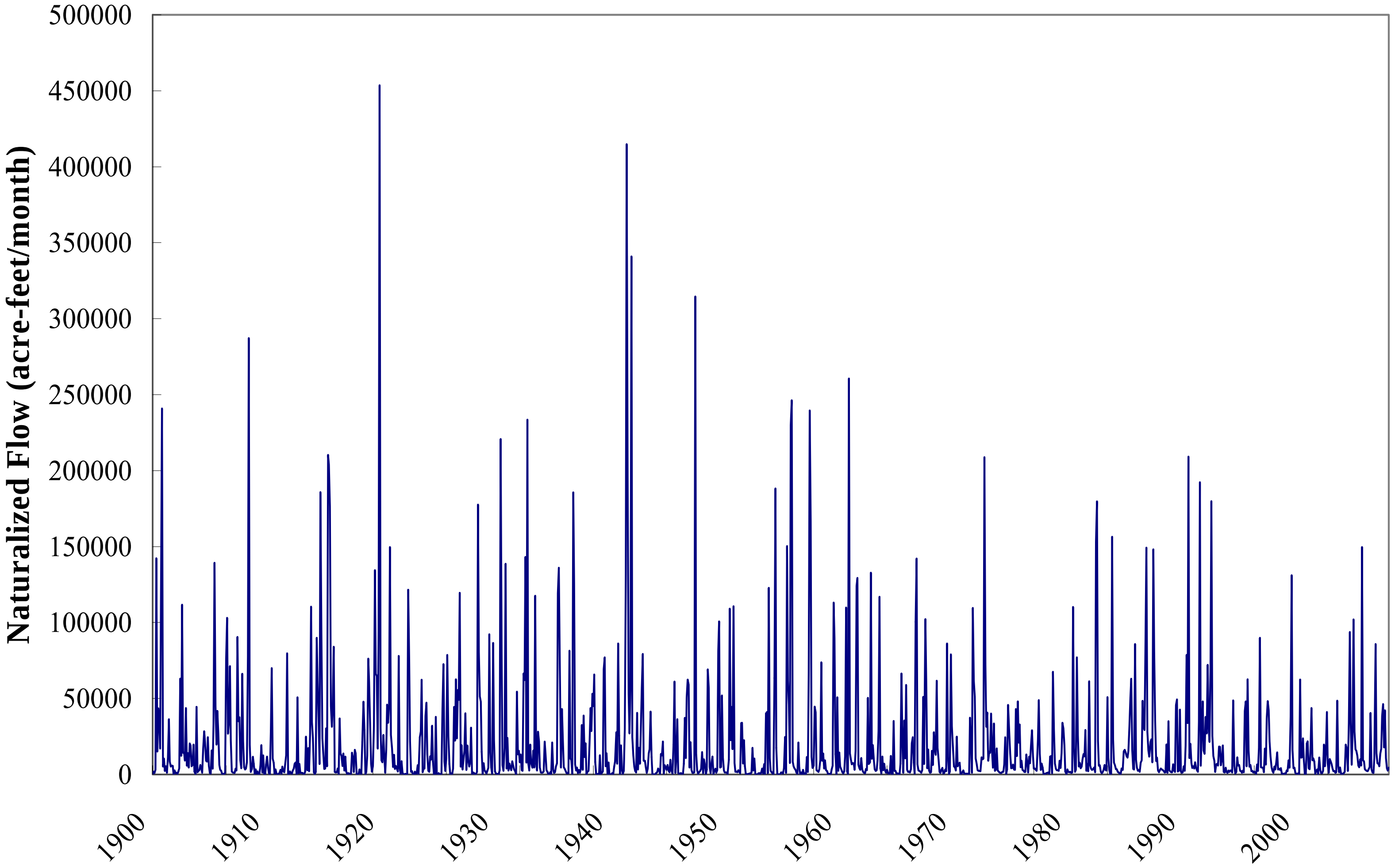

Figure A.11 Monthly Naturalized Flow at BRSE11 – Brazos River at Seymour

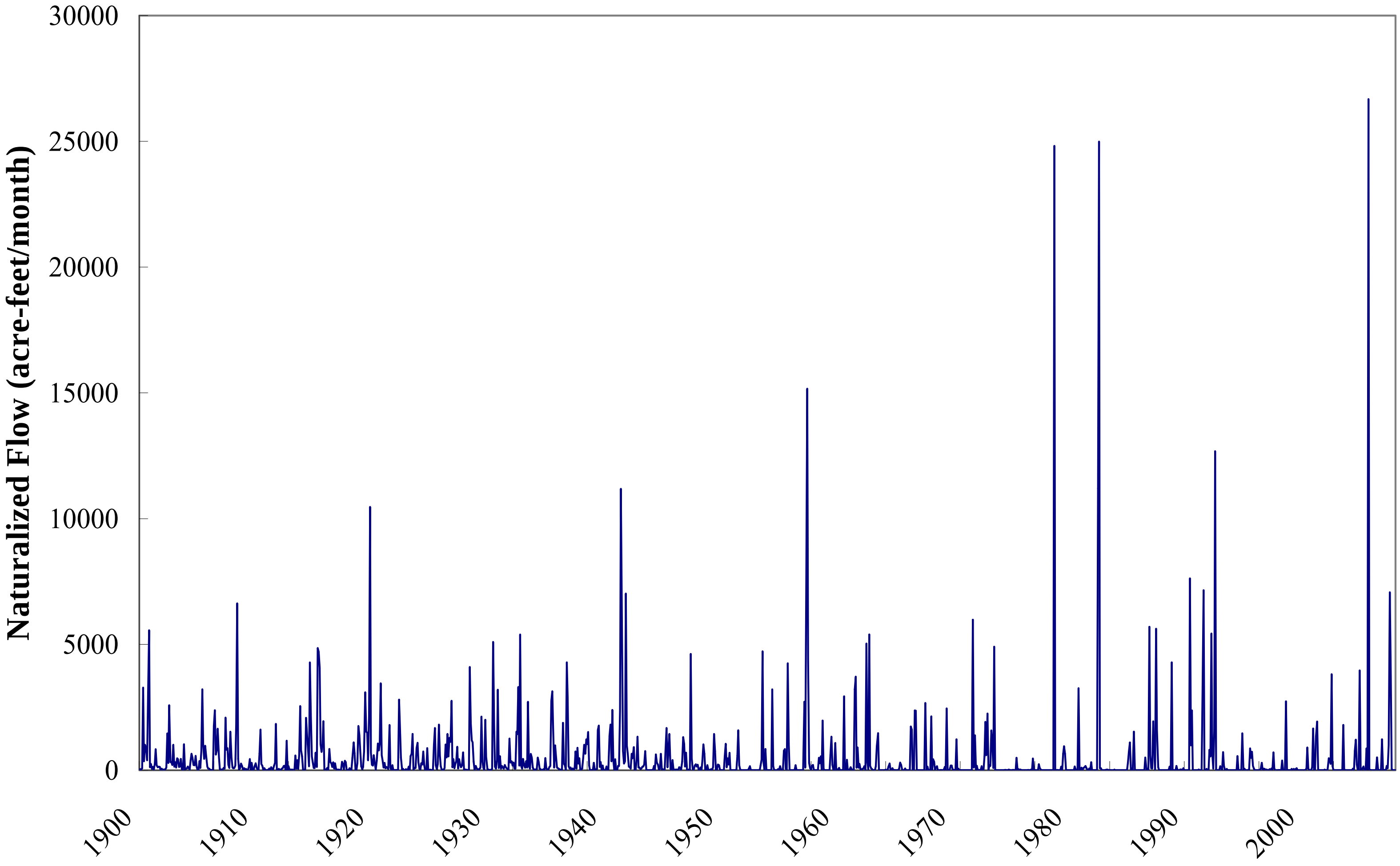

Figure A.12 Monthly Naturalized Flow at MSMN12 – Millers Creek near Munday

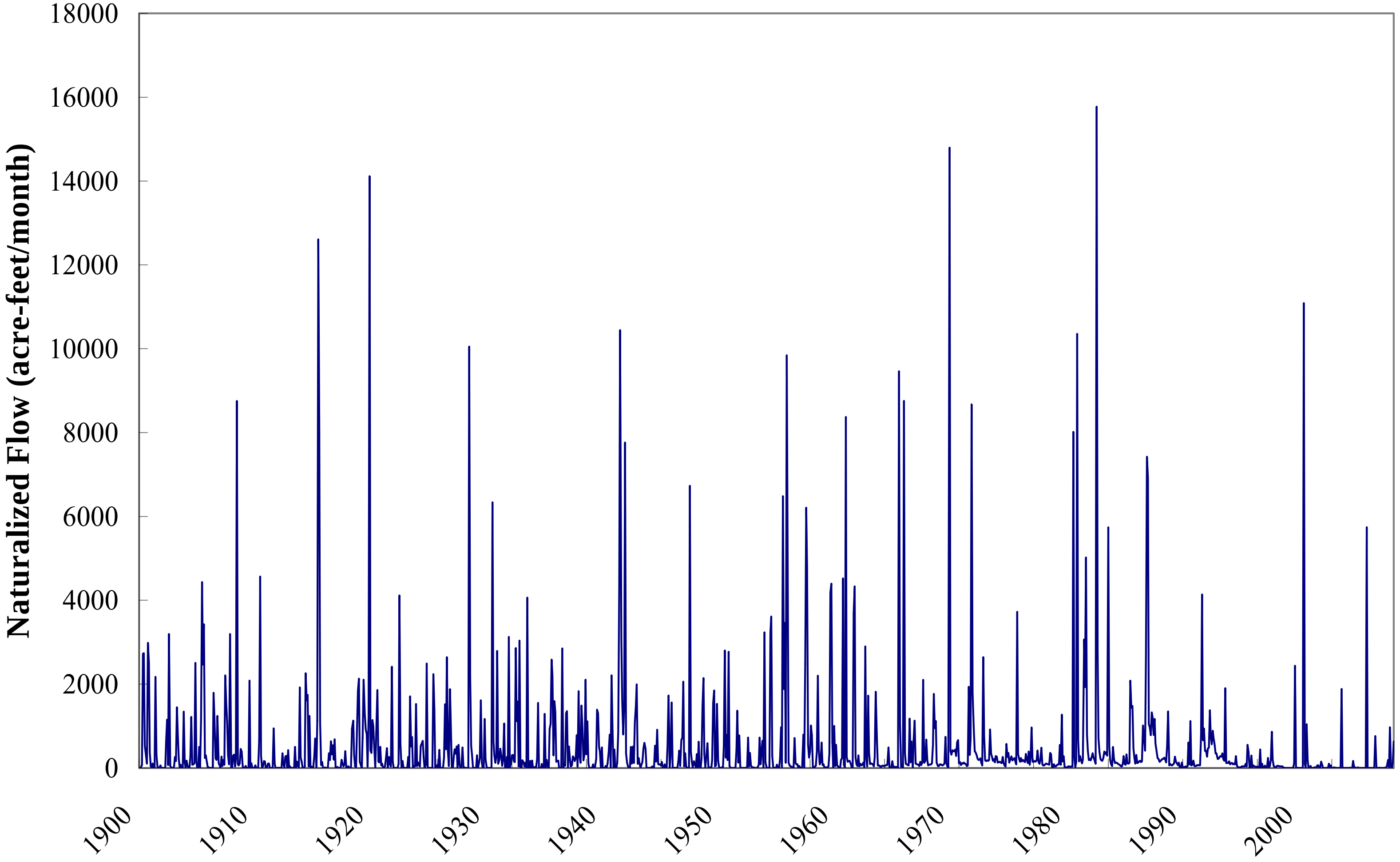

Figure A.13 Monthly Naturalized Flow at CFRO13 – Clear Fork Brazos River near Roby

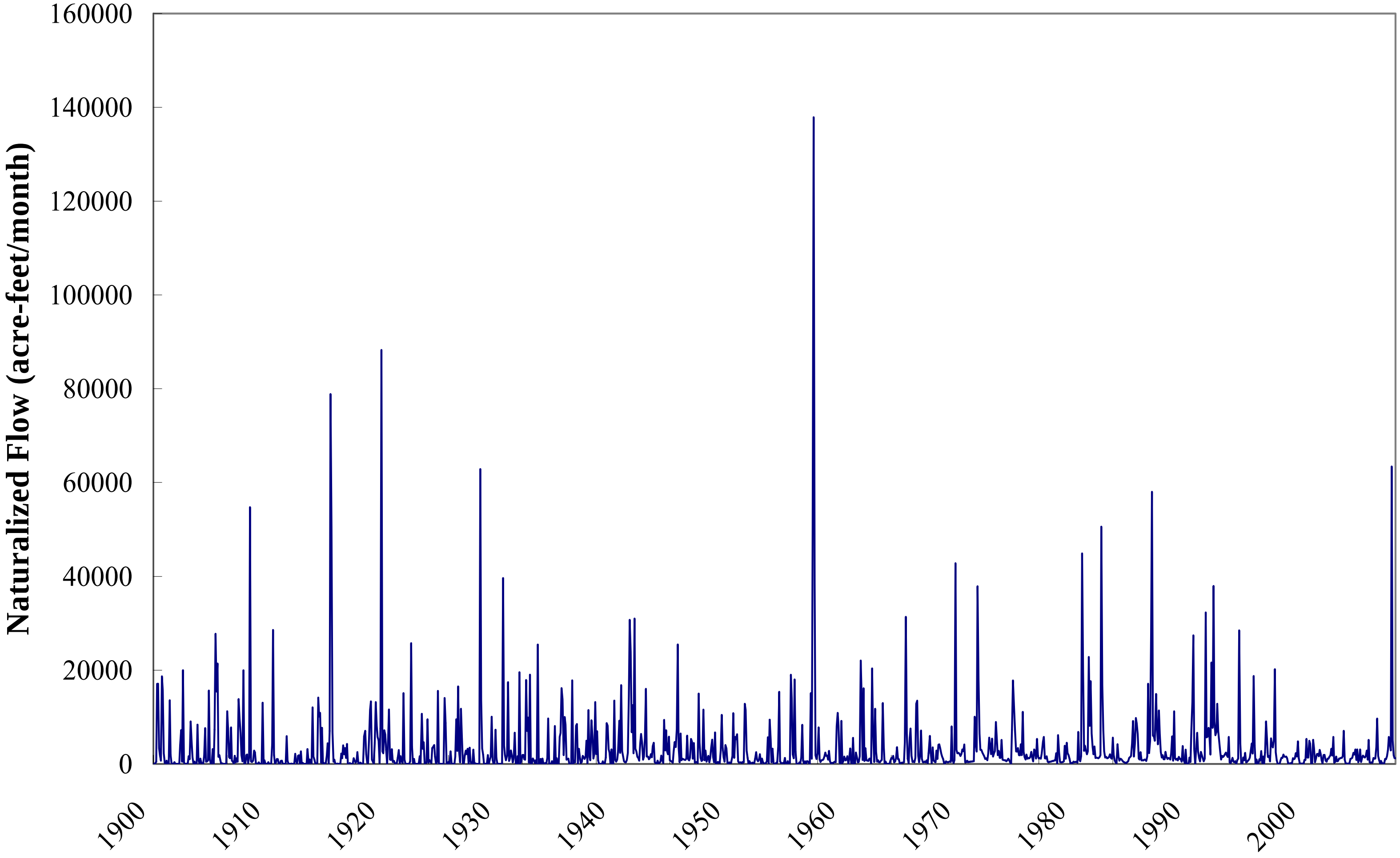

Figure A.14 Monthly Naturalized Flow at CFHA14 – Clear Fork Brazos River at Hawley

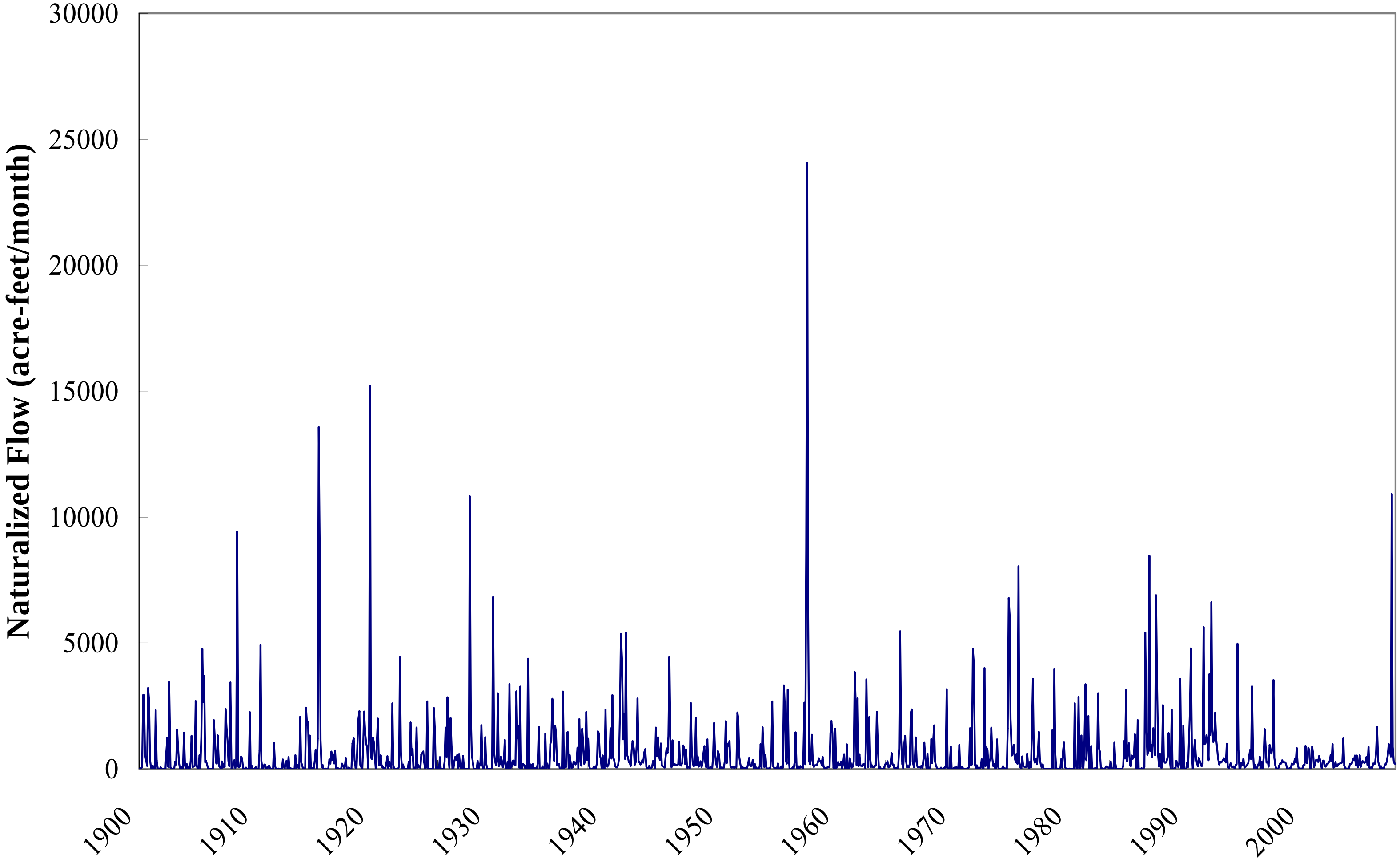

Figure A.15 Monthly Naturalized Flow at MUHA15 – Mulberry Creek near Hawley

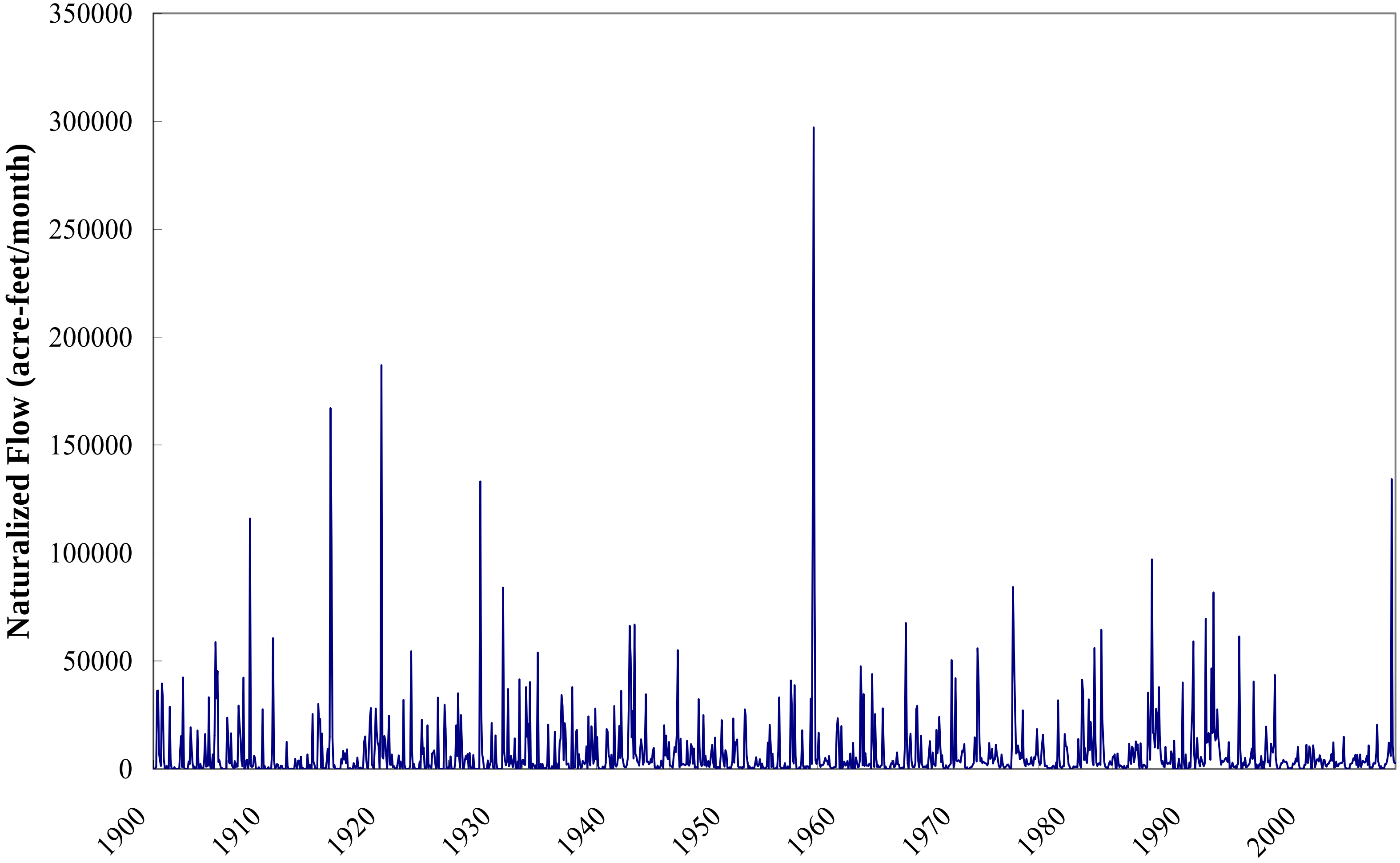

Figure A.16 Monthly Naturalized Flow at CFNU16 – Clear Fork Brazos River at Nugent

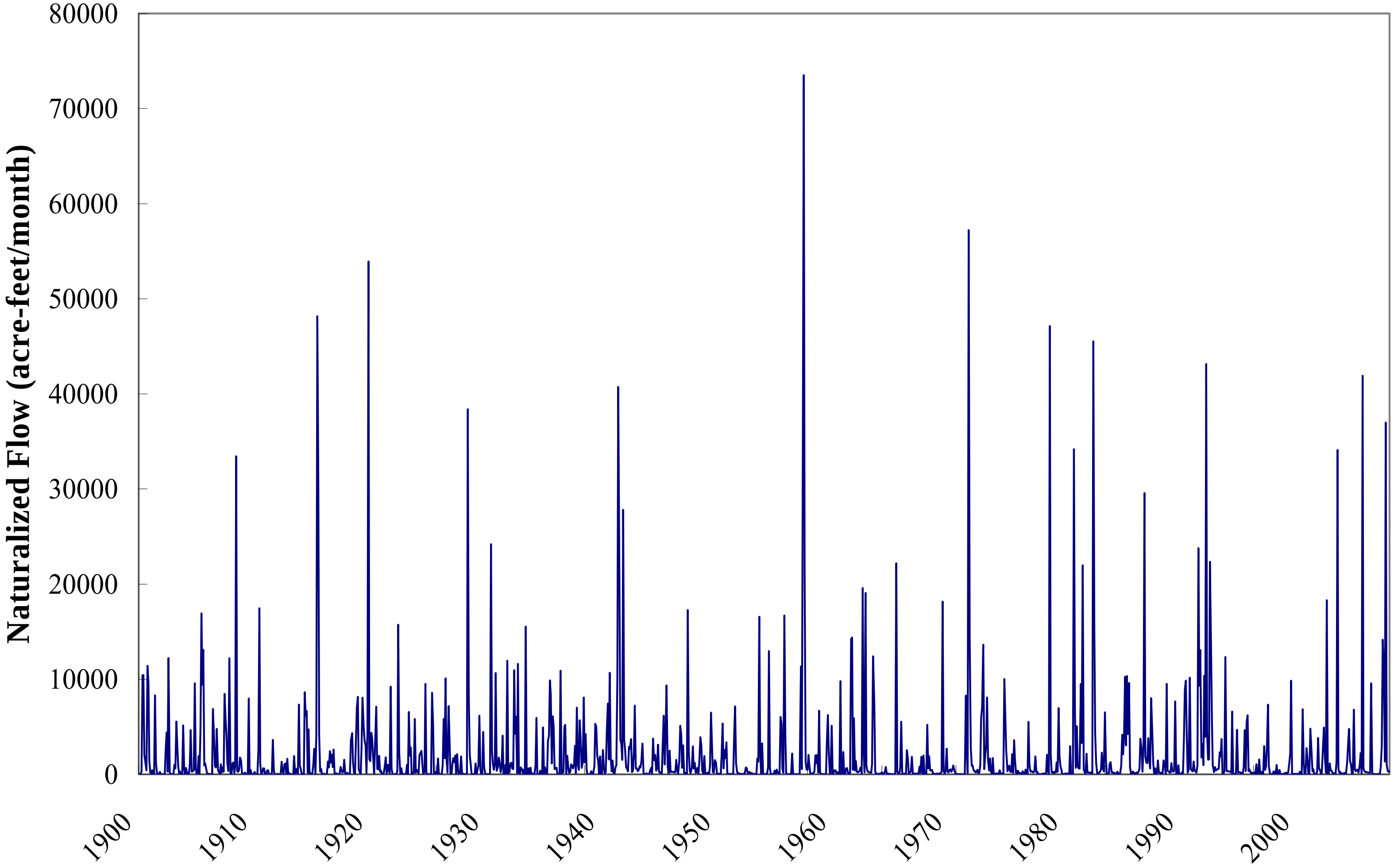

Figure A.17 Monthly Naturalized Flow at CAST17 – California Creek near Stamford

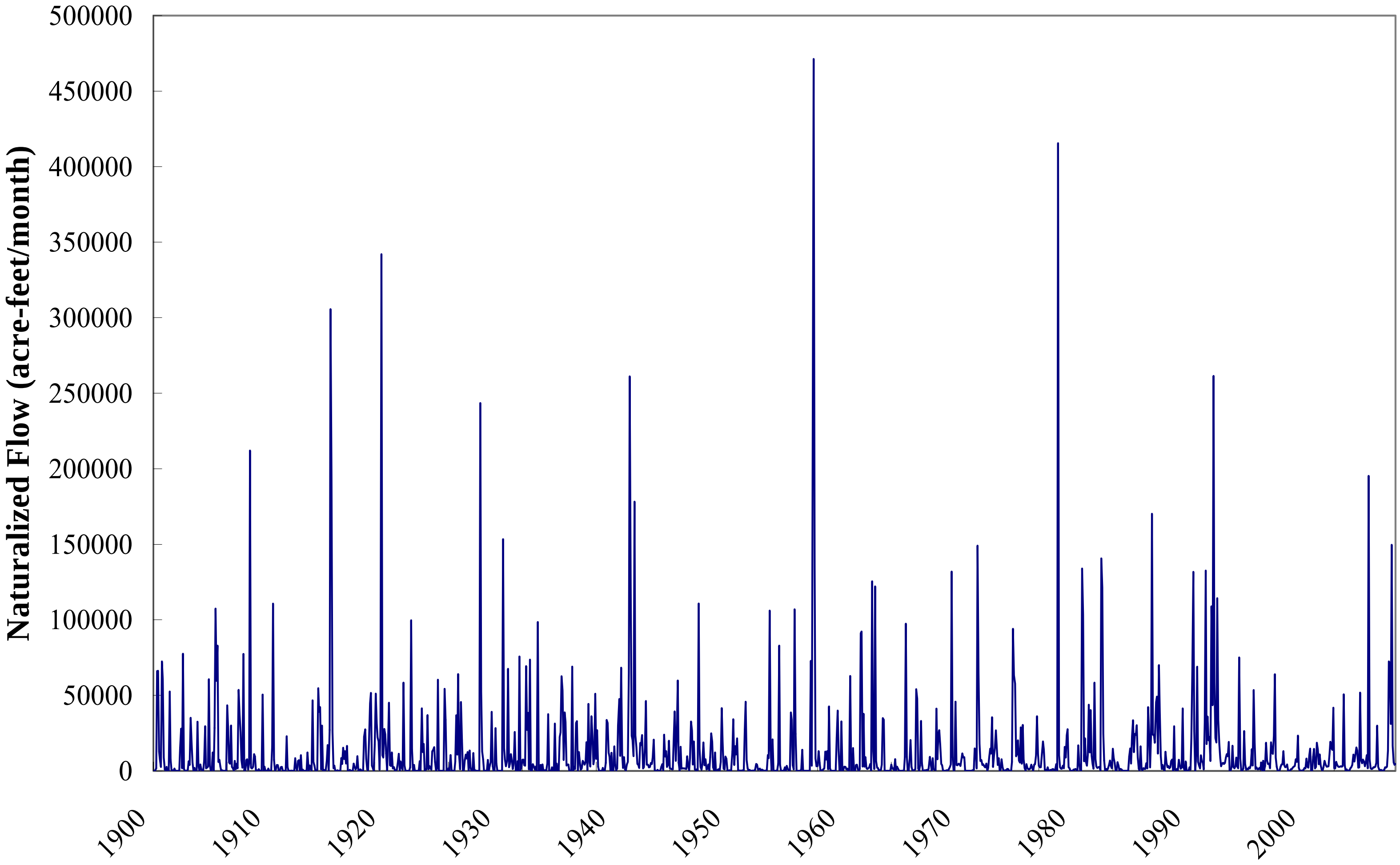

Figure A.18 Monthly Naturalized Flow at CFFG18 – Clear Fork Brazos River at Fort Griffin

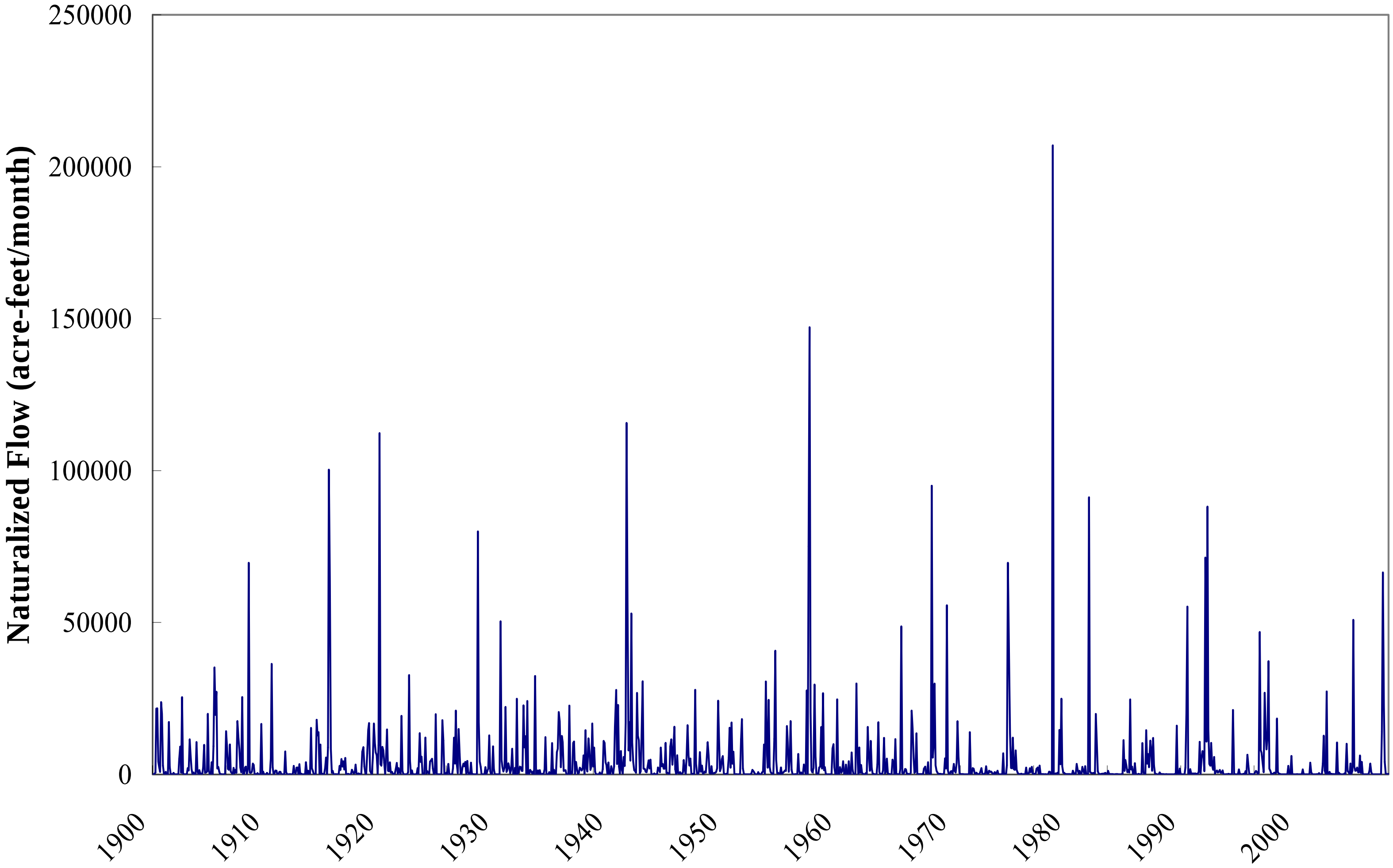

Figure A.19 Monthly Naturalized Flow at HCAL19 – Hubbard Creek below Albany

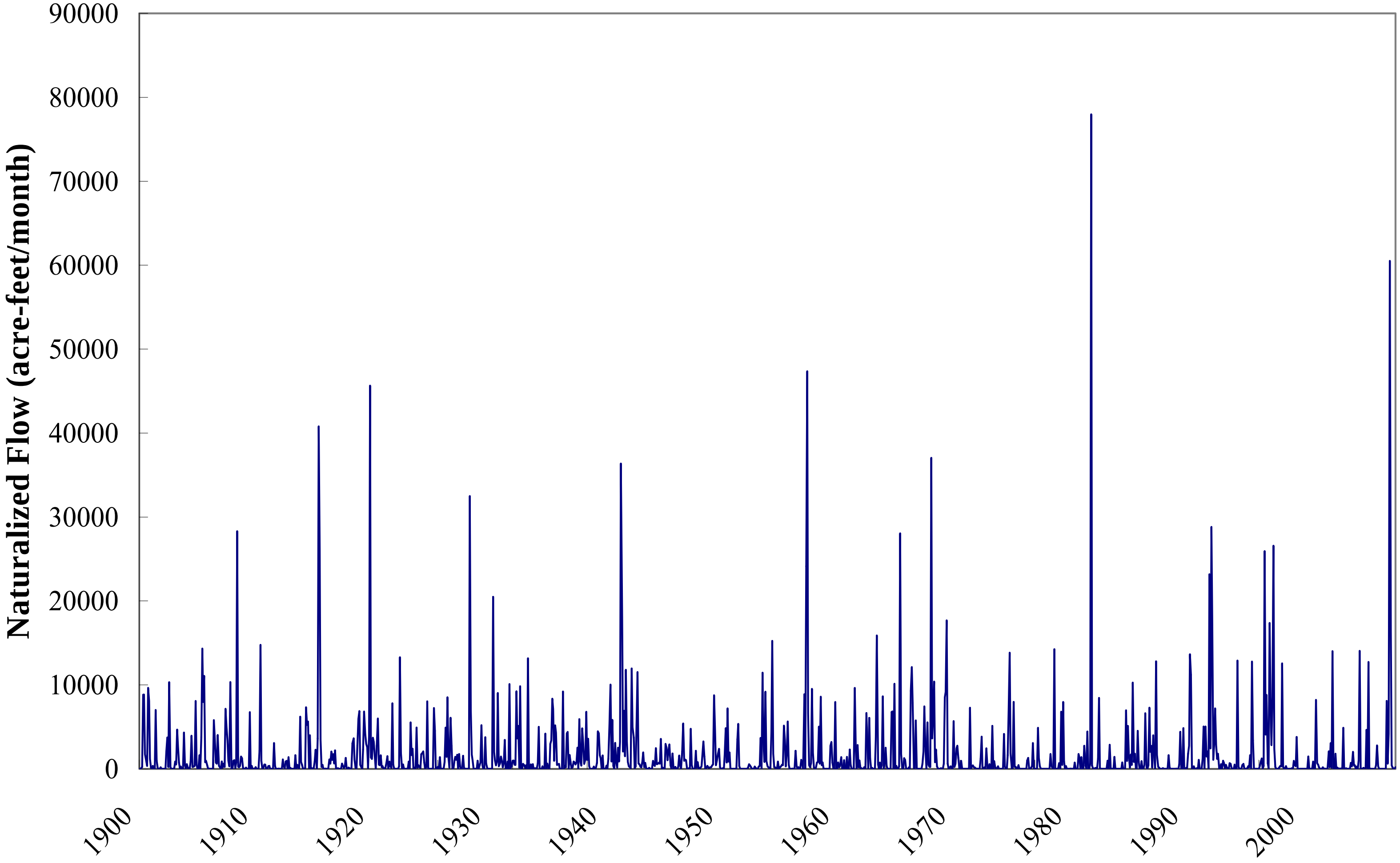

Figure A.20 Monthly Naturalized Flow at BSBR20 – Big Sandy Creek above Breckenridge

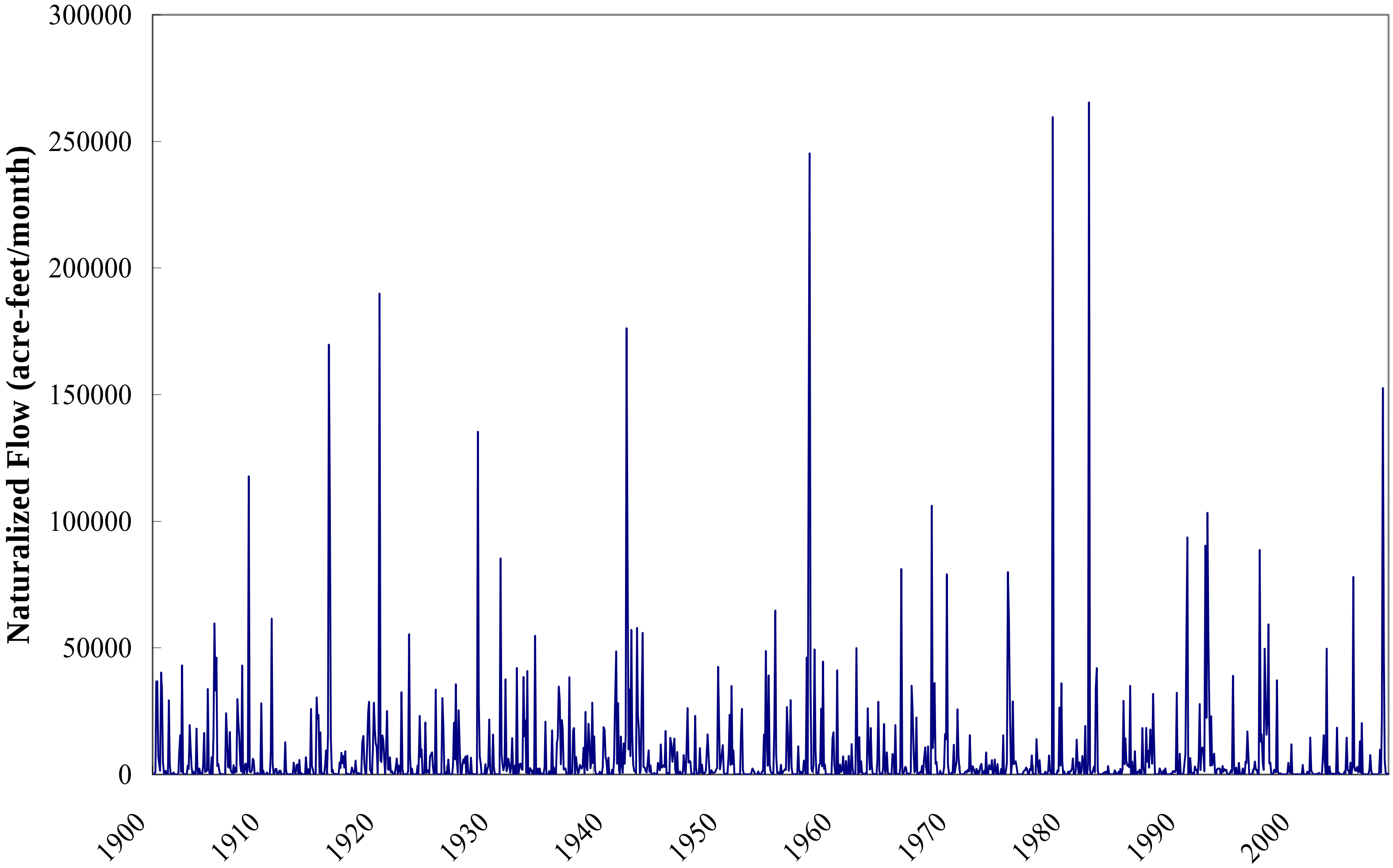

Figure A.21 Monthly Naturalized Flow at HCBR21 – Hubbard Creek near Breckenridge

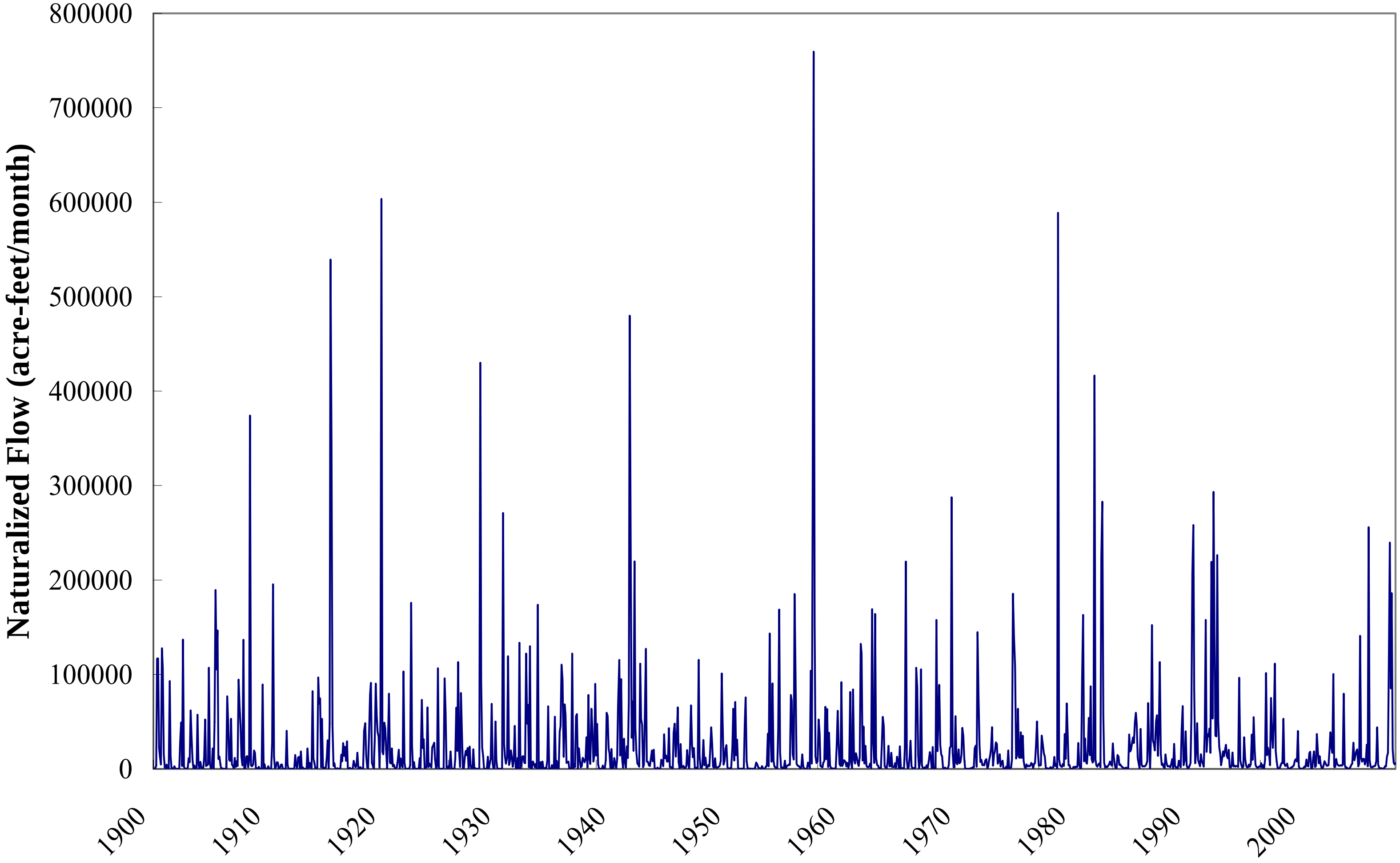

Figure A.22 Monthly Naturalized Flow at CFEL22 – Clear Fork Brazos River at Eliasville

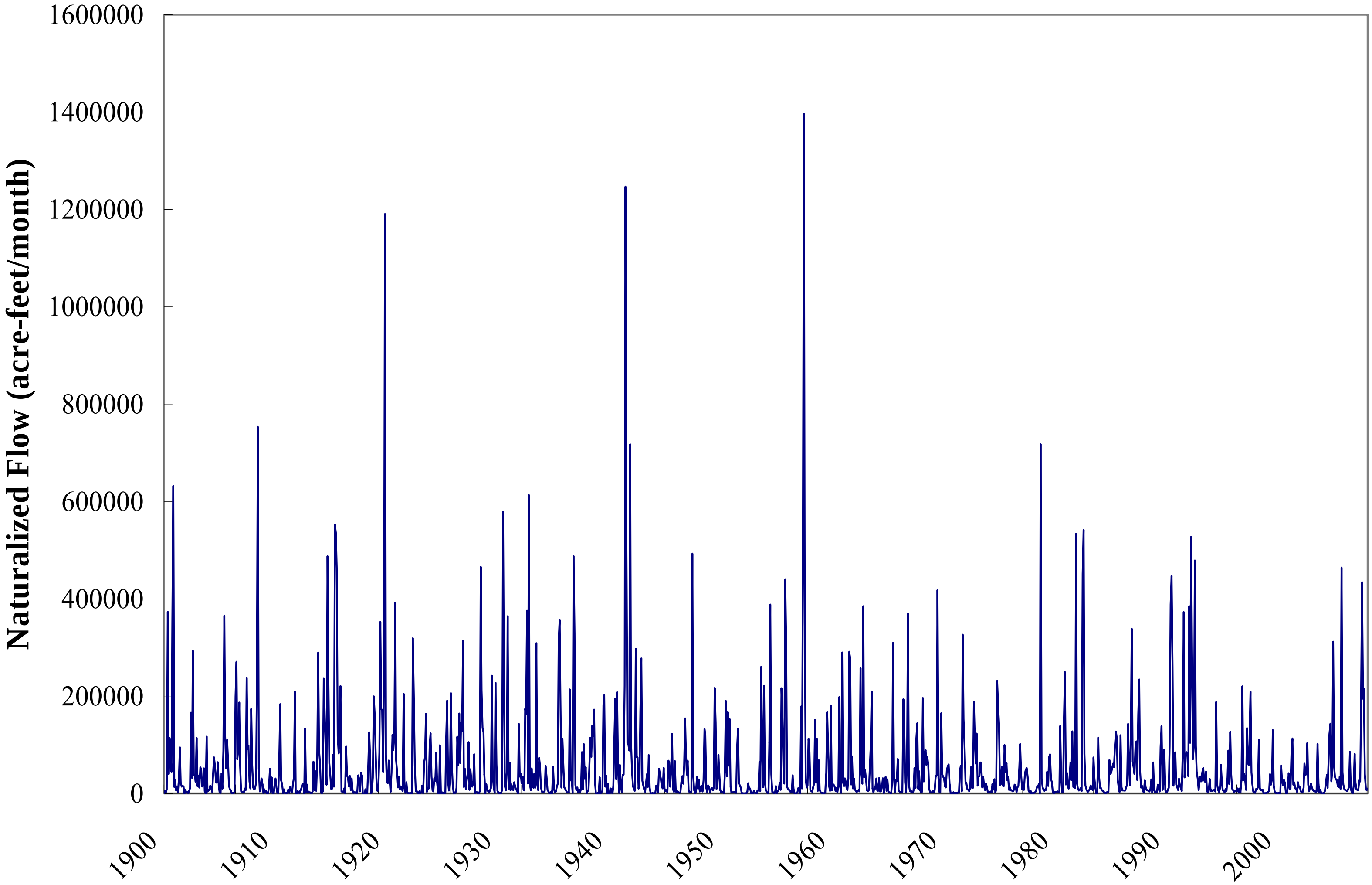

Figure A.23 Monthly Naturalized Flow at BRSB23 – Brazos River near South Bend

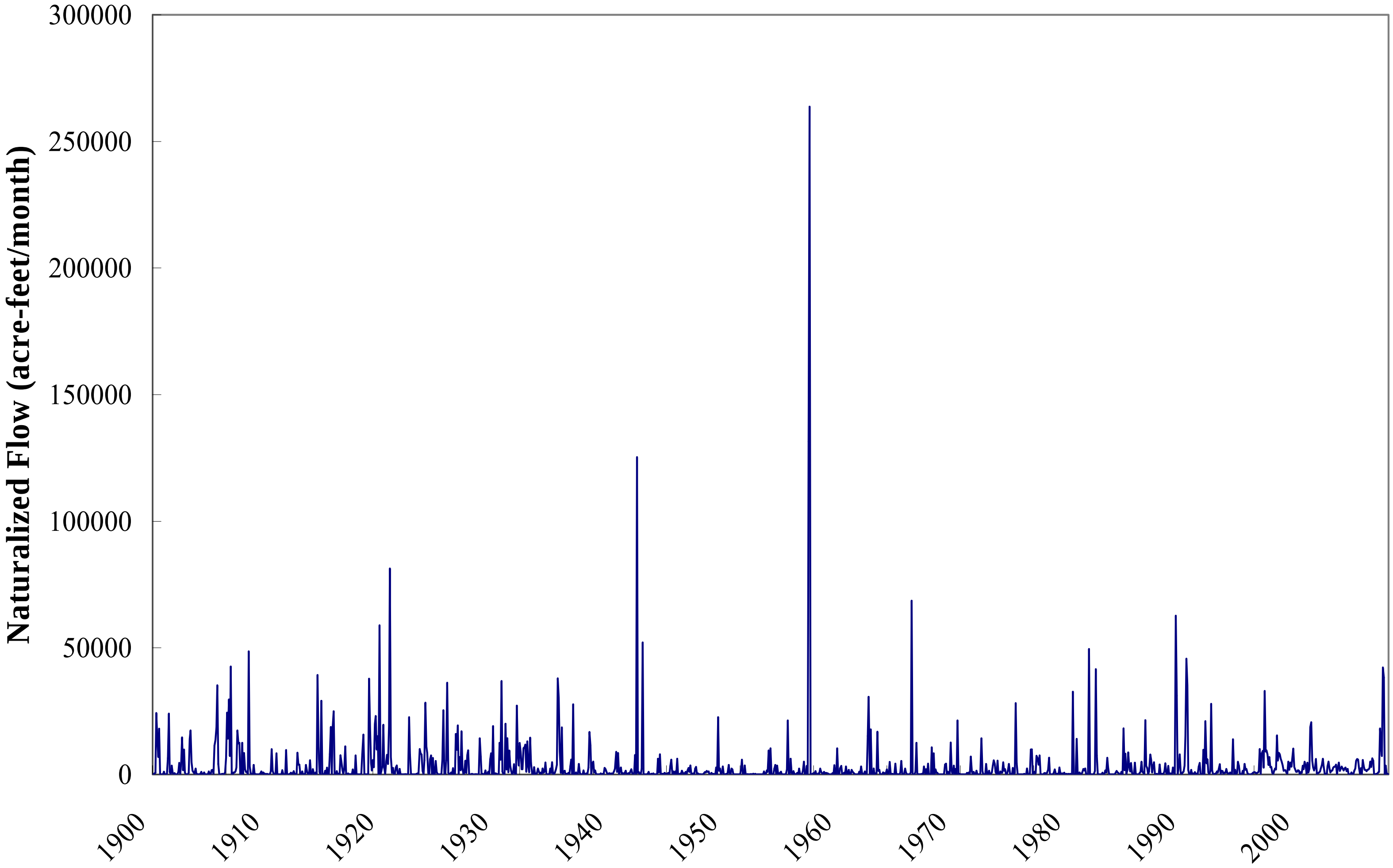

Figure A.24 Monthly Naturalized Flow at GHGH24 – Lake Graham near Graham

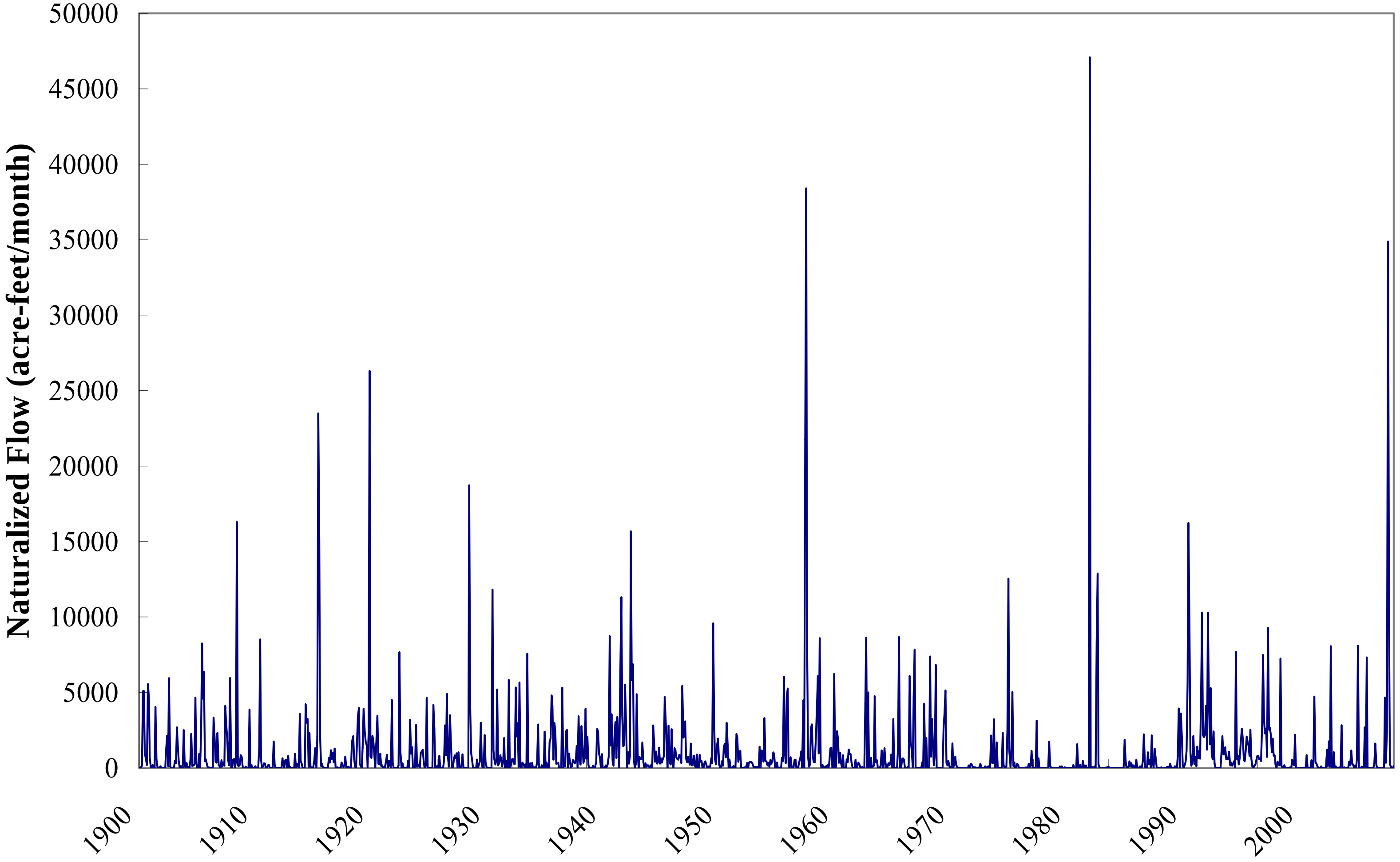

Figure A.25 Monthly Naturalized Flow at CCIV25 – Big Cedar Creek near Ivan

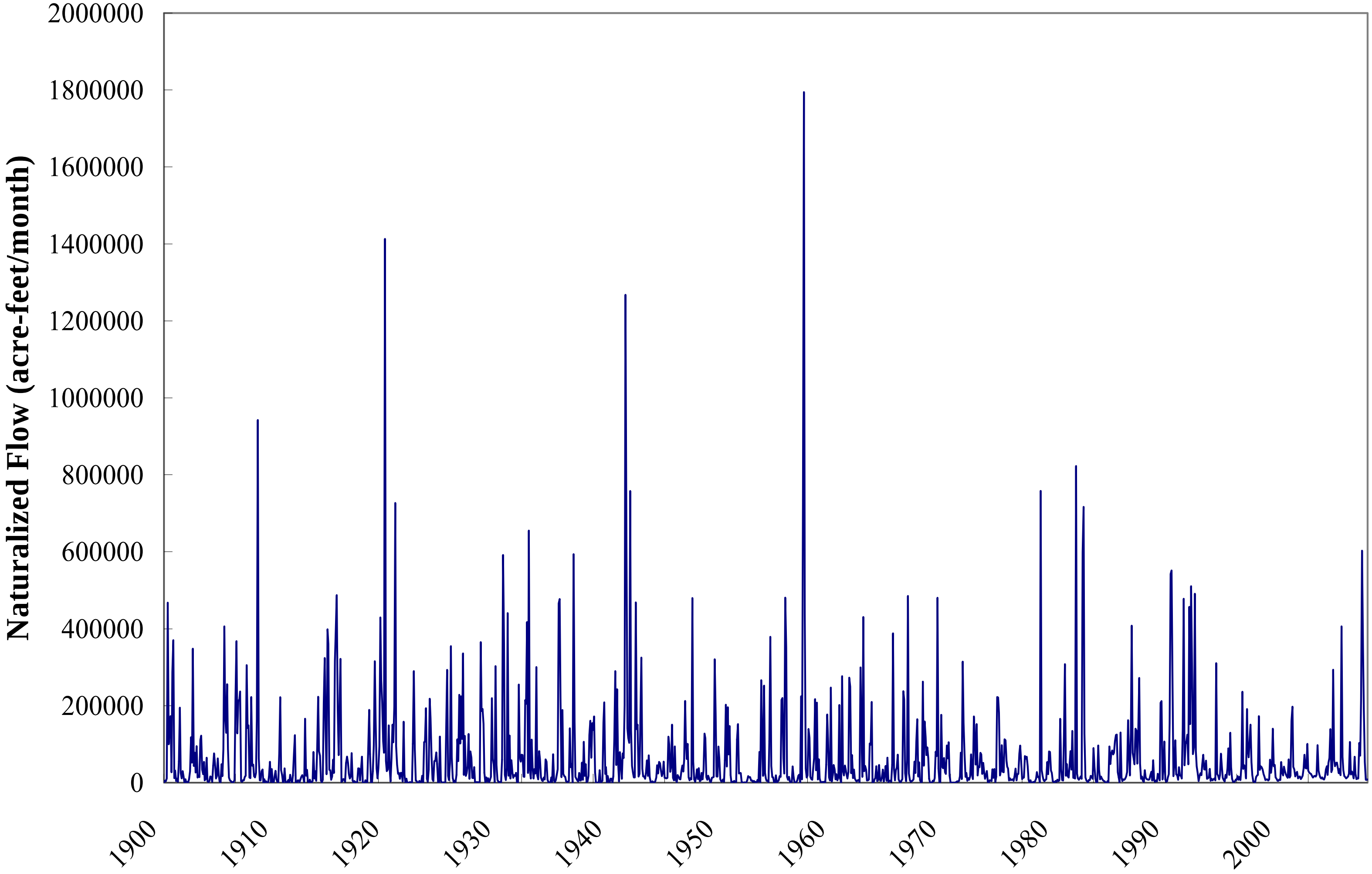

Figure A.26 Monthly Naturalized Flow at SHGR26 – Brazos River at Morris Sheppard Dam near Graford

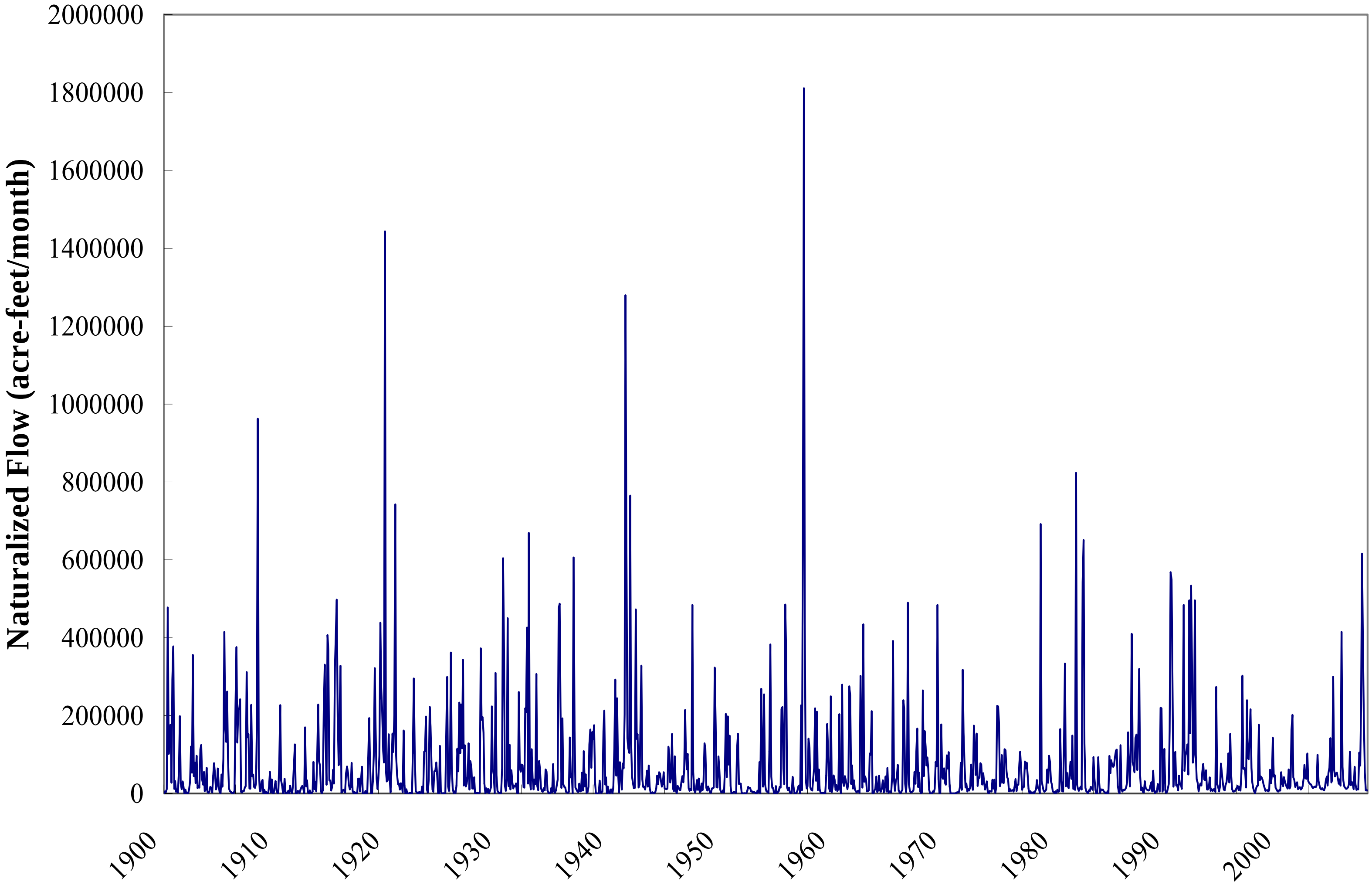

Figure A.27 Monthly Naturalized Flow at BRPP27 – Brazos River near Palo Pinto

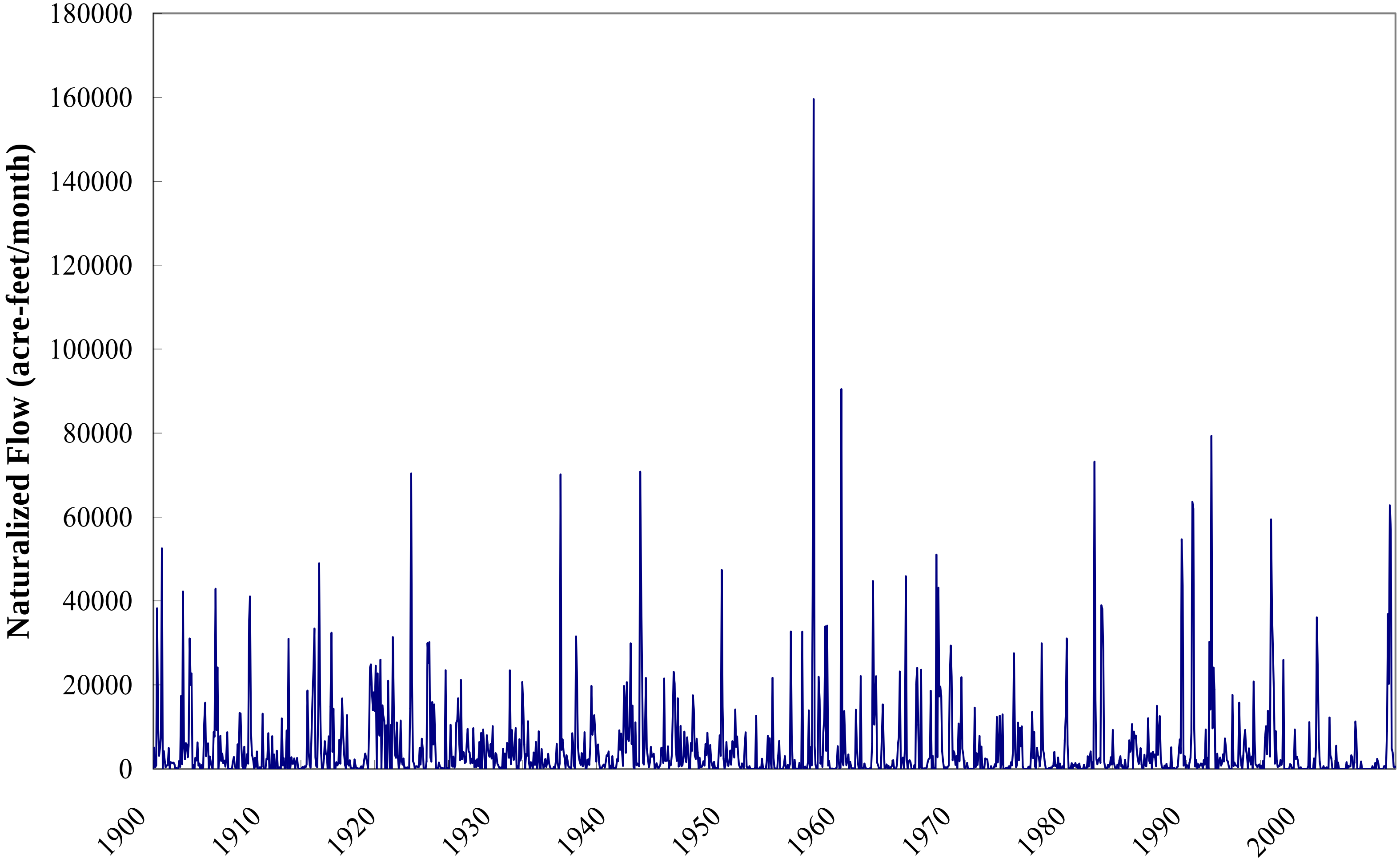

Figure A.28 Monthly Naturalized Flow at PPSA28 – Palo Pinto Creek near Santo

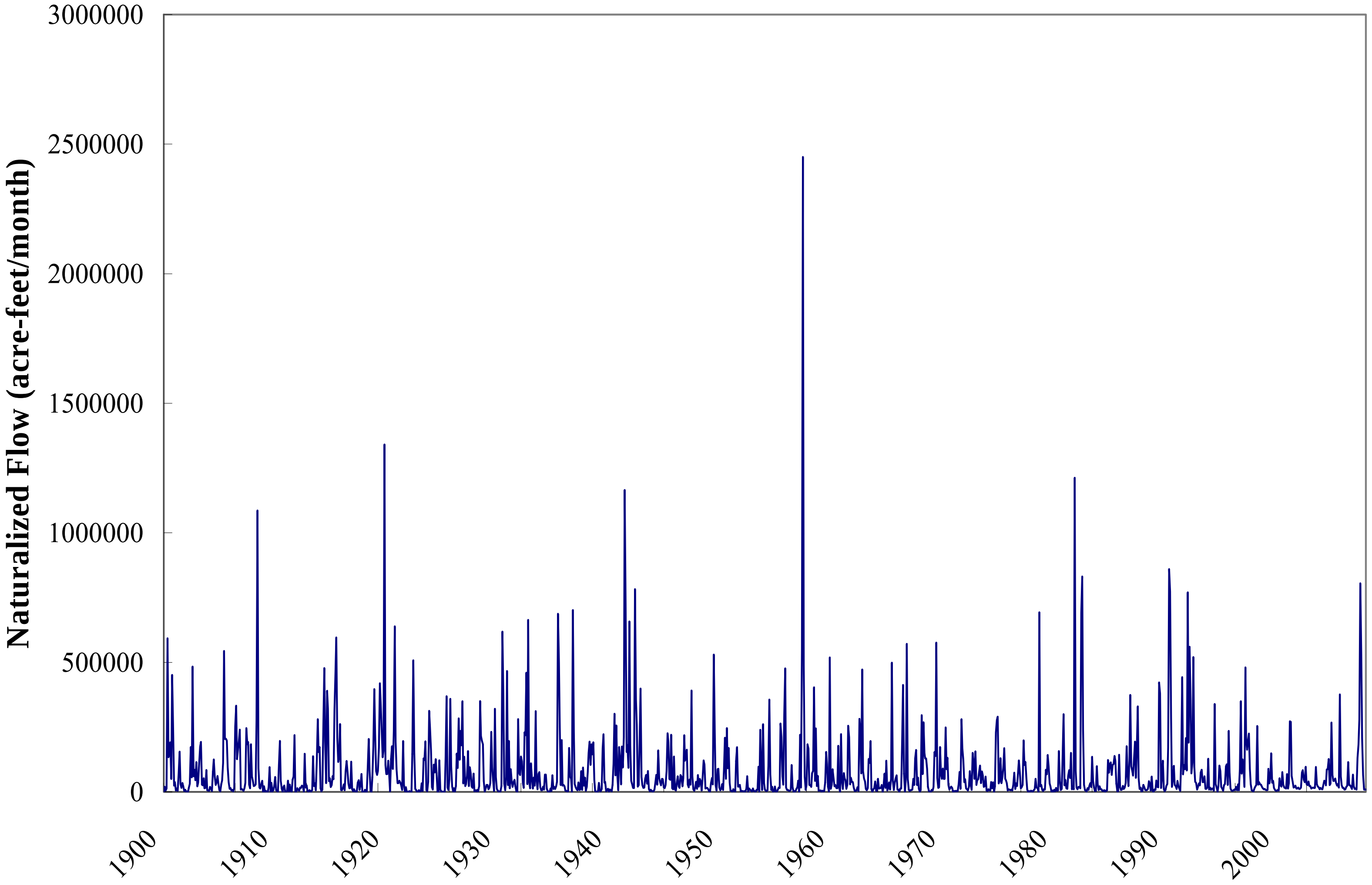

Figure A.29 Monthly Naturalized Flow at BRDE29 – Brazos River near Dennis

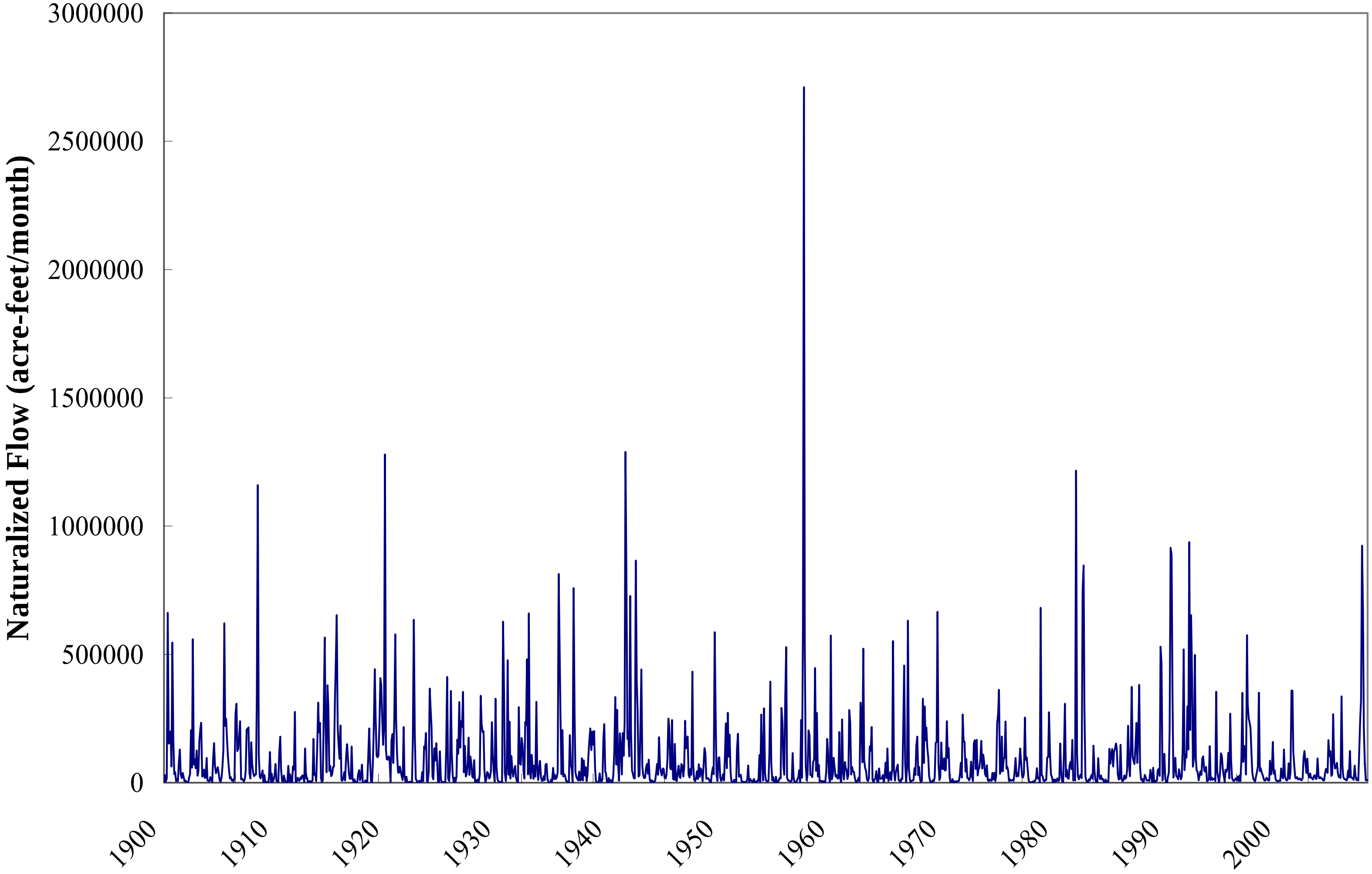

Figure A.30 Monthly Naturalized Flow at BRGR30 – Brazos River near Glen Rose

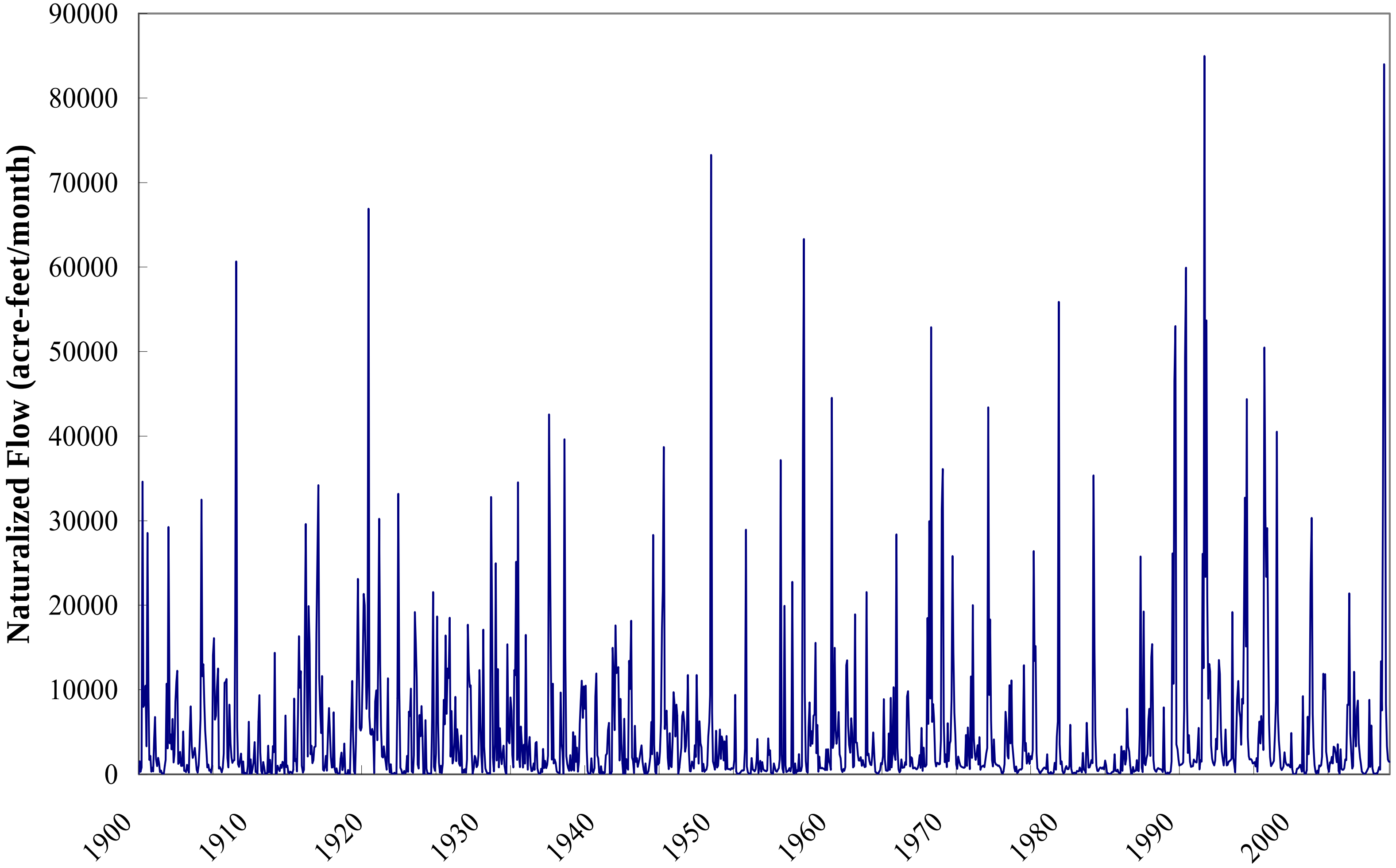

Figure A.31 Monthly Naturalized Flow at PAGR31 – Paluxy River at Glen Rose

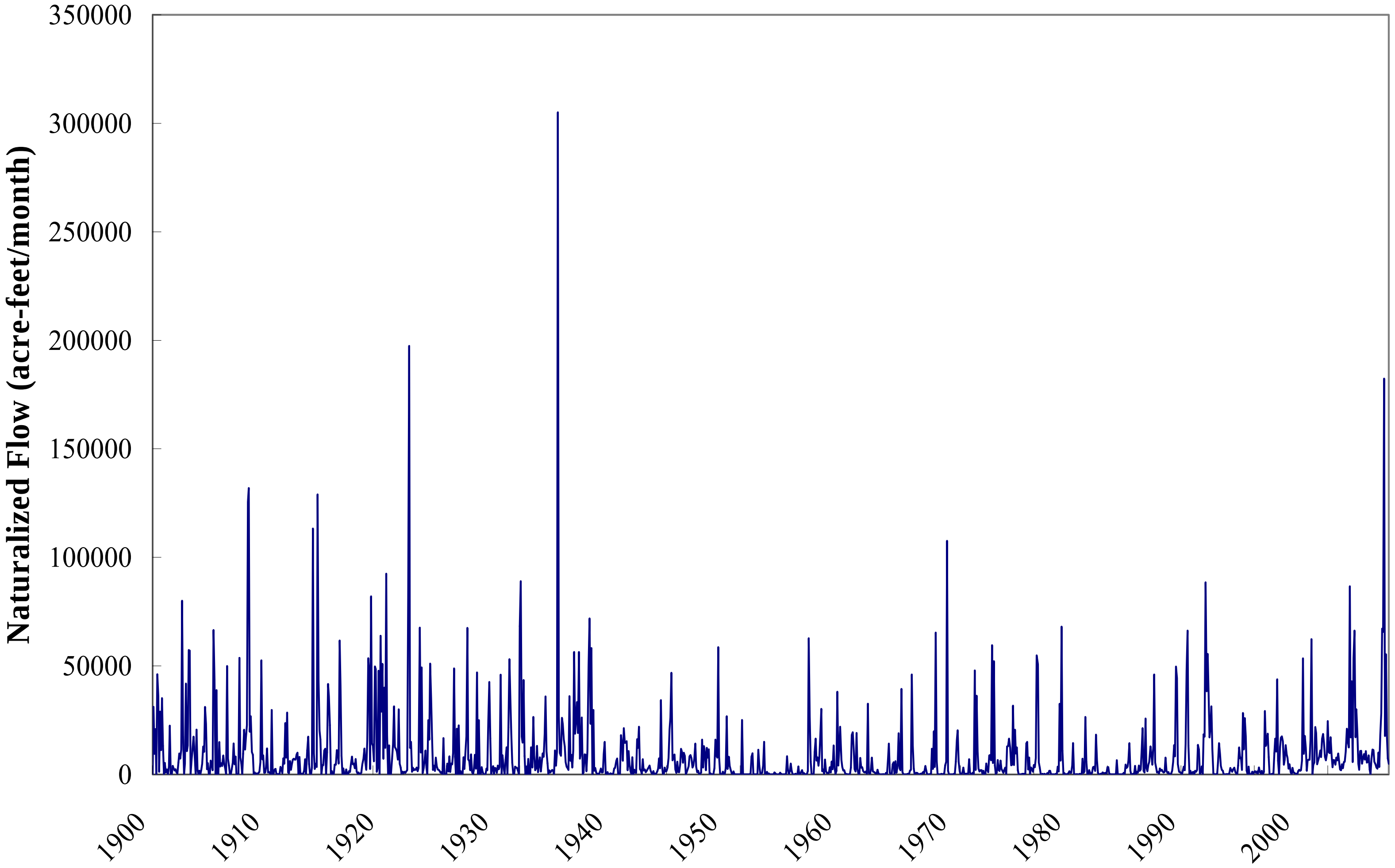

Figure A.32 Monthly Naturalized Flow at NRBL32 – Nolan River at Blum

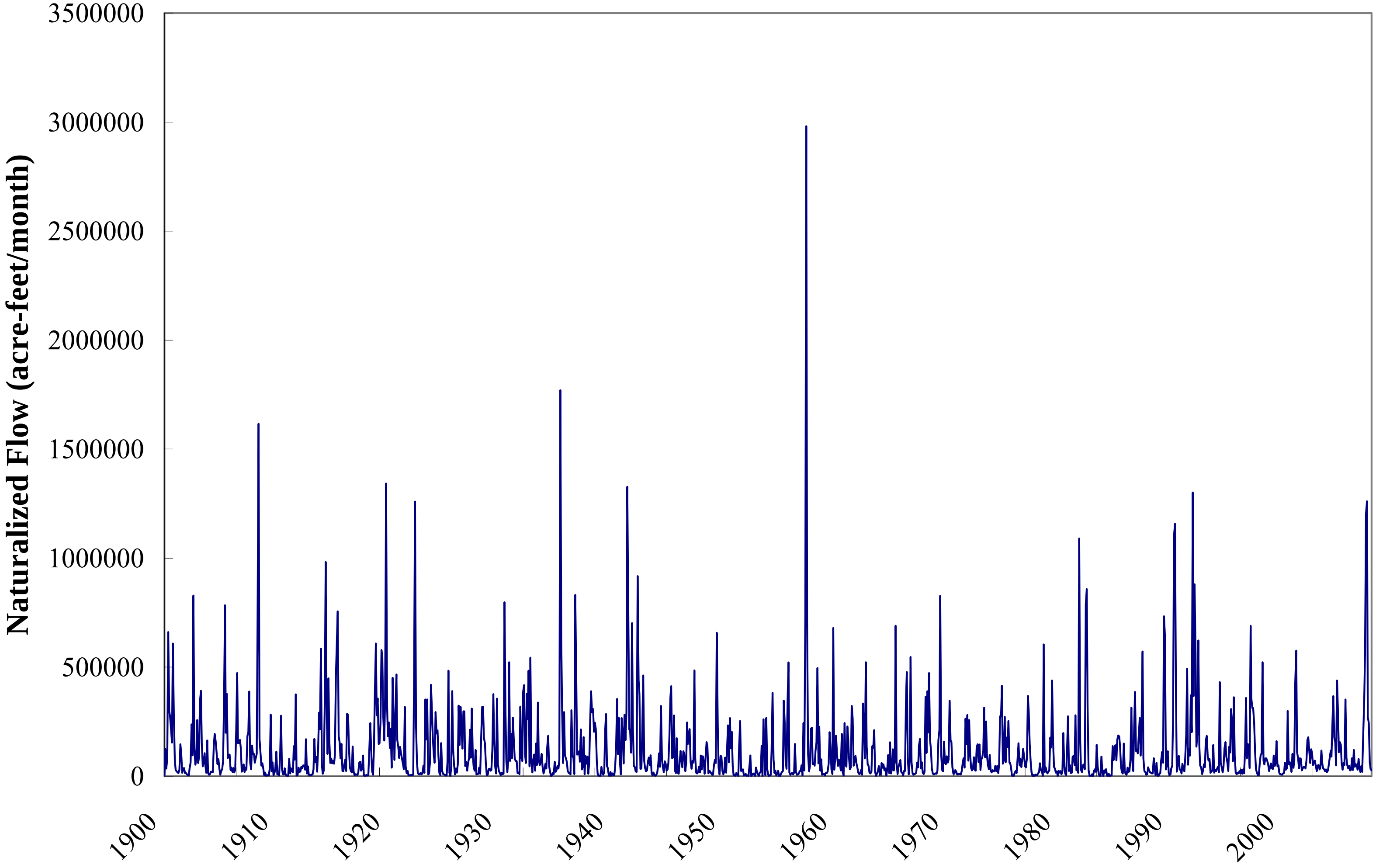

Figure A.33 Monthly Naturalized Flow at BRAQ33 – Brazos River near Aquilla

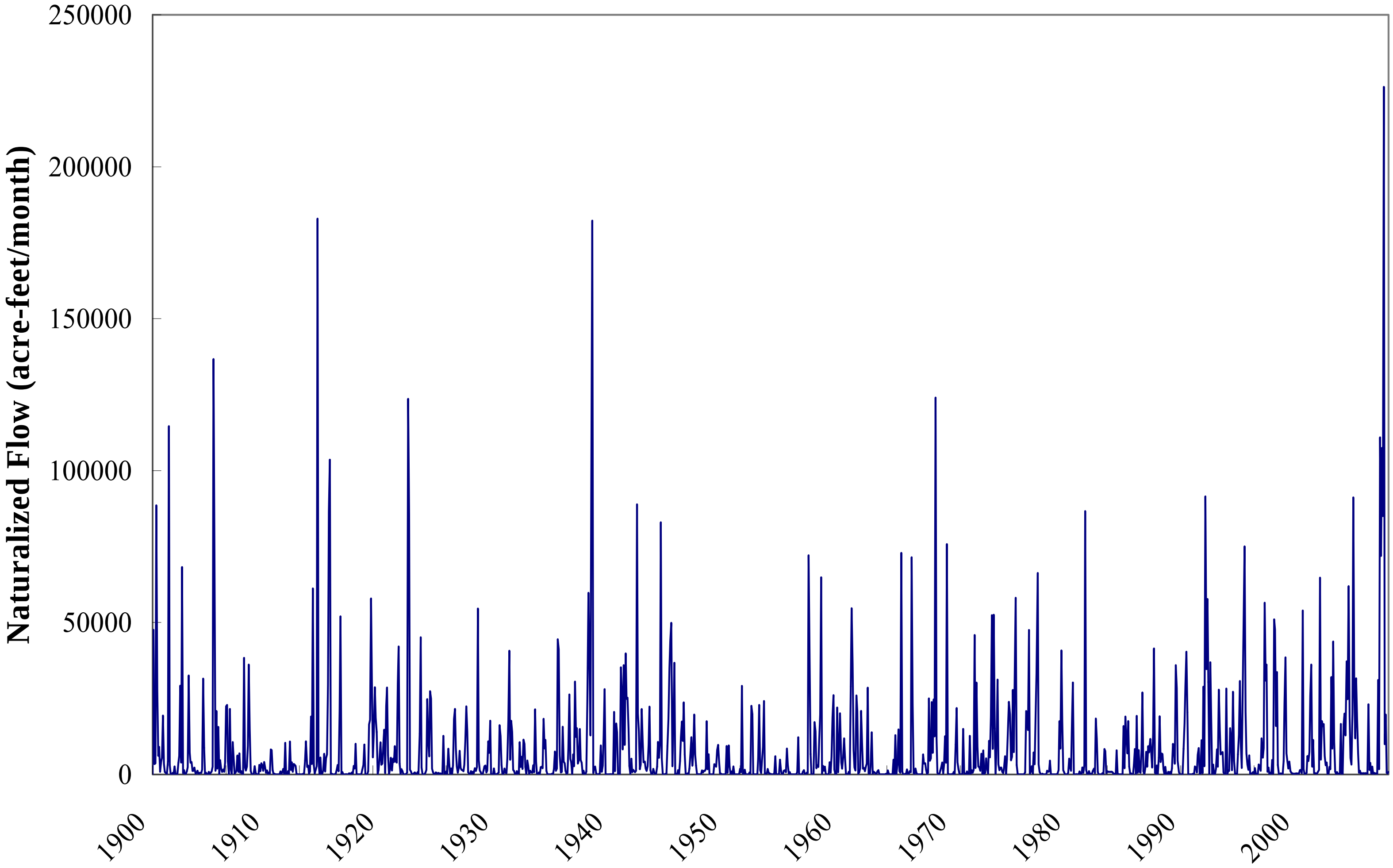

Figure A.34 Monthly Naturalized Flow at AQAQ34 – Aquilla Creek near Aquilla

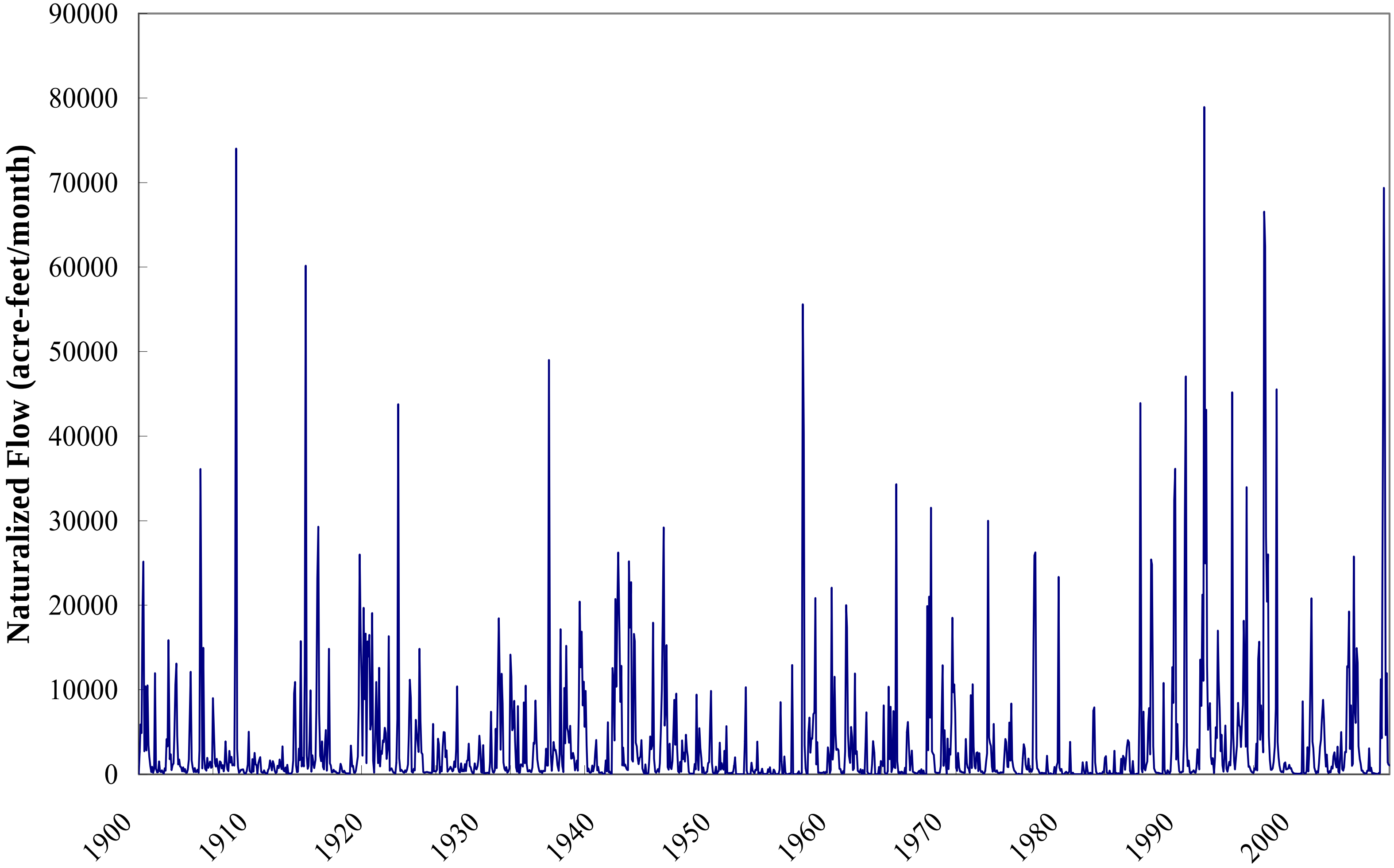

Figure A.35 Monthly Naturalized Flow at NBHI35 – North Bosque River at Hico

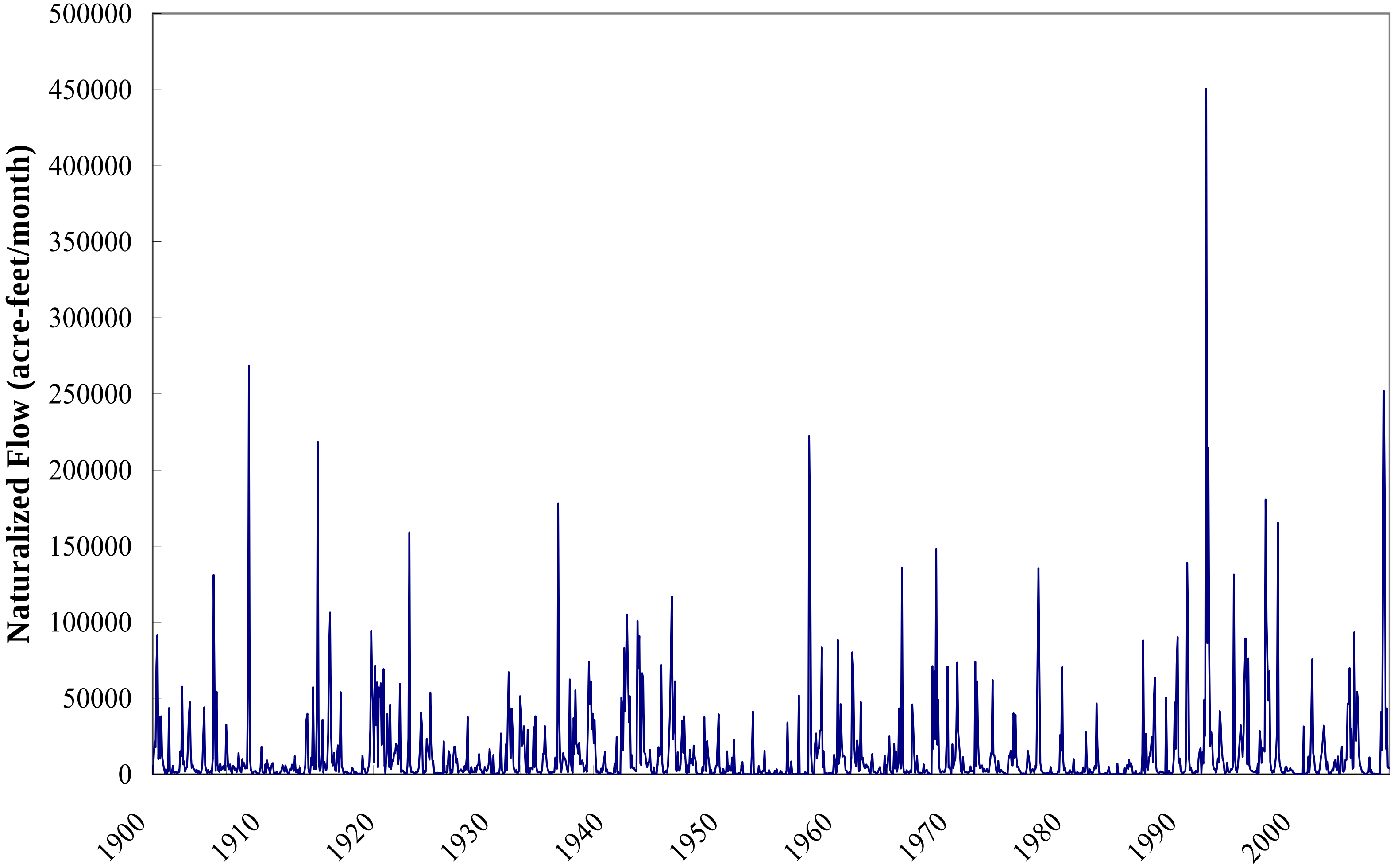

Figure A.36 Monthly Naturalized Flow at NBCL36 – North Bosque River near Clifton

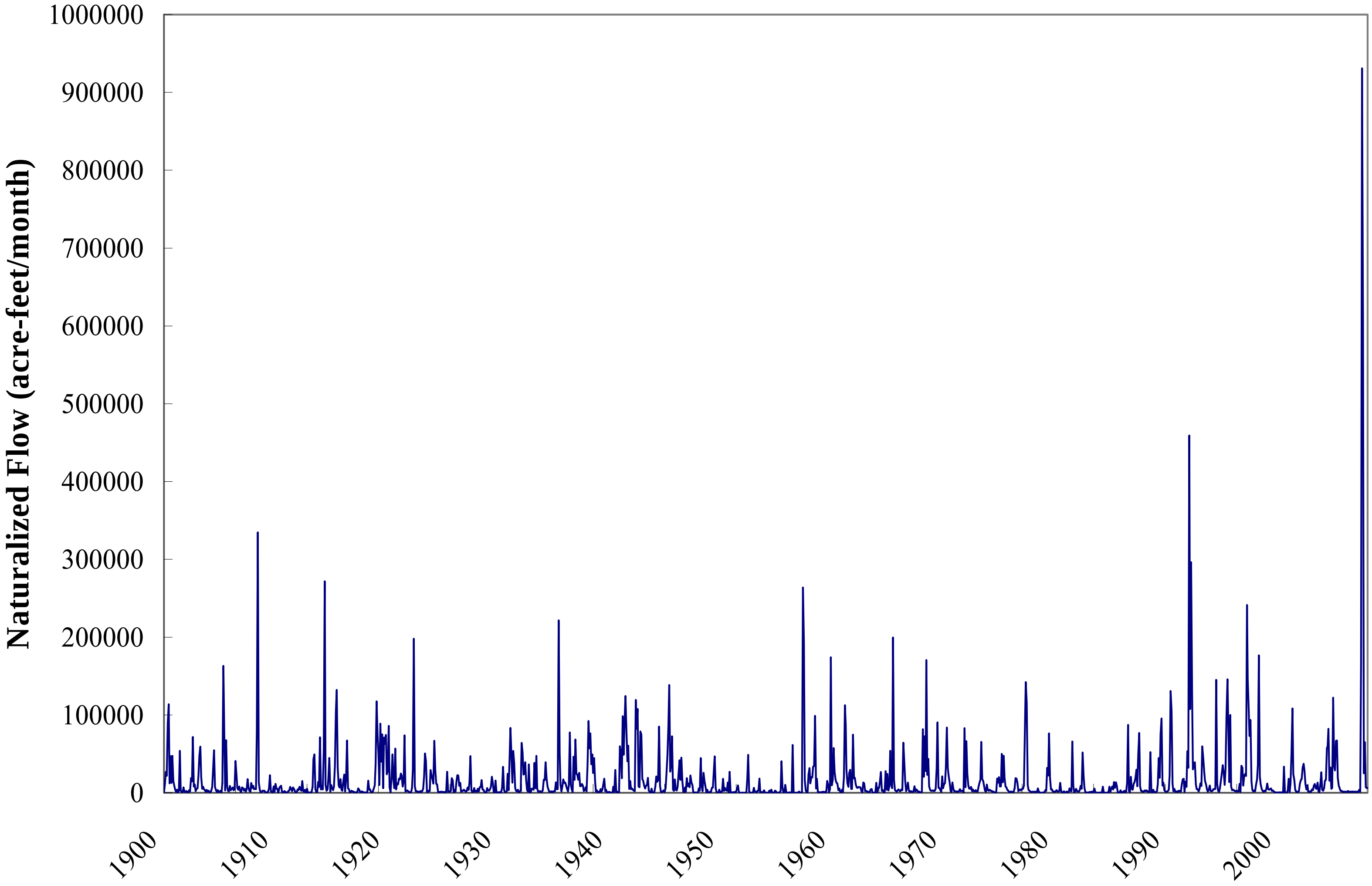

Figure A.37 Monthly Naturalized Flow at NBVM37 – North Bosque River at Valley Mills

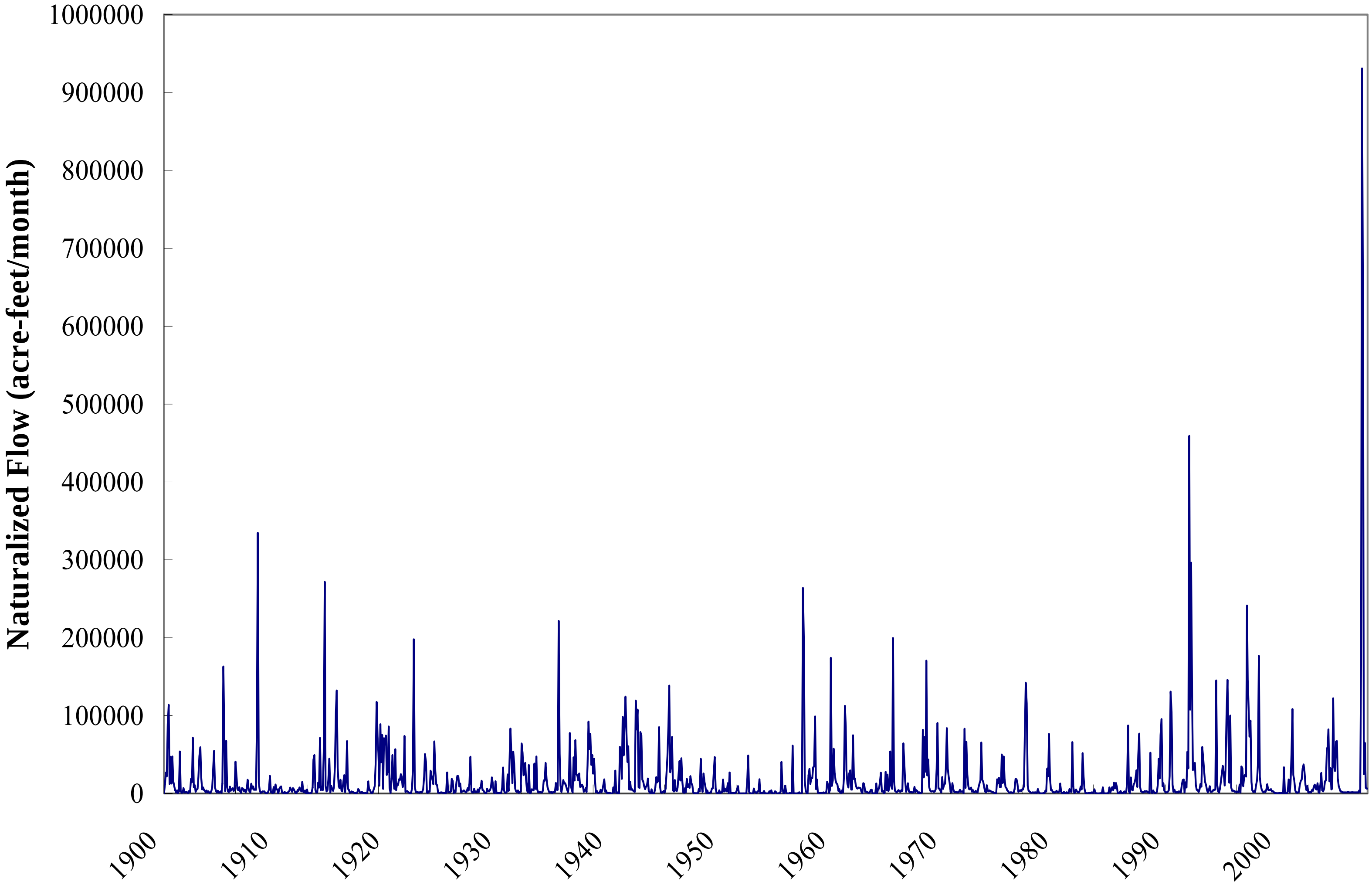

Figure A.38 Monthly Naturalized Flow at MBMG38 – Middle Bosque River near McGregor

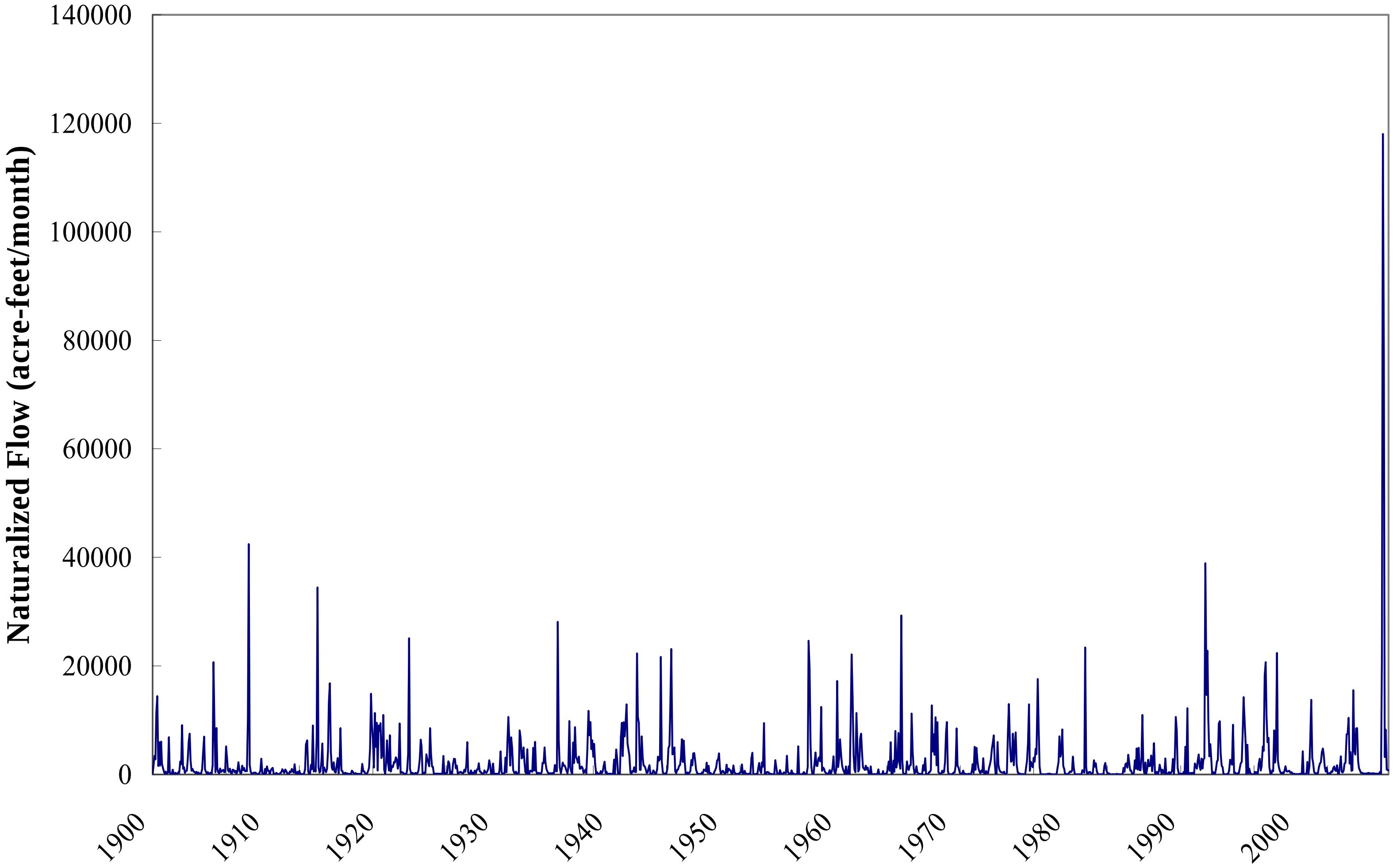

Figure A.39 Monthly Naturalized Flow at HGCR39 – Hog Creek near Crawford

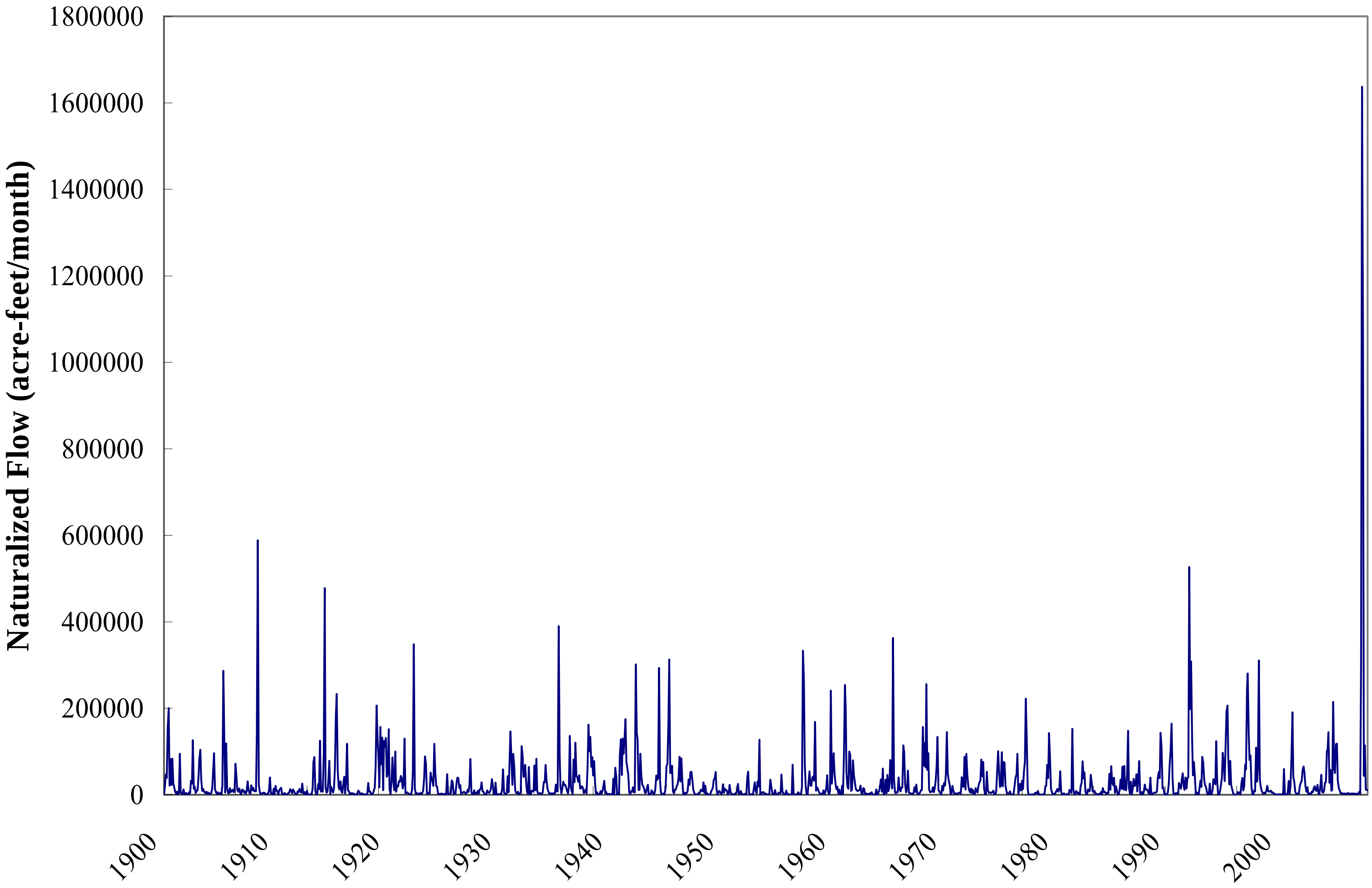

Figure A.40 Monthly Naturalized Flow at BOWO40 – Bosque River near Waco

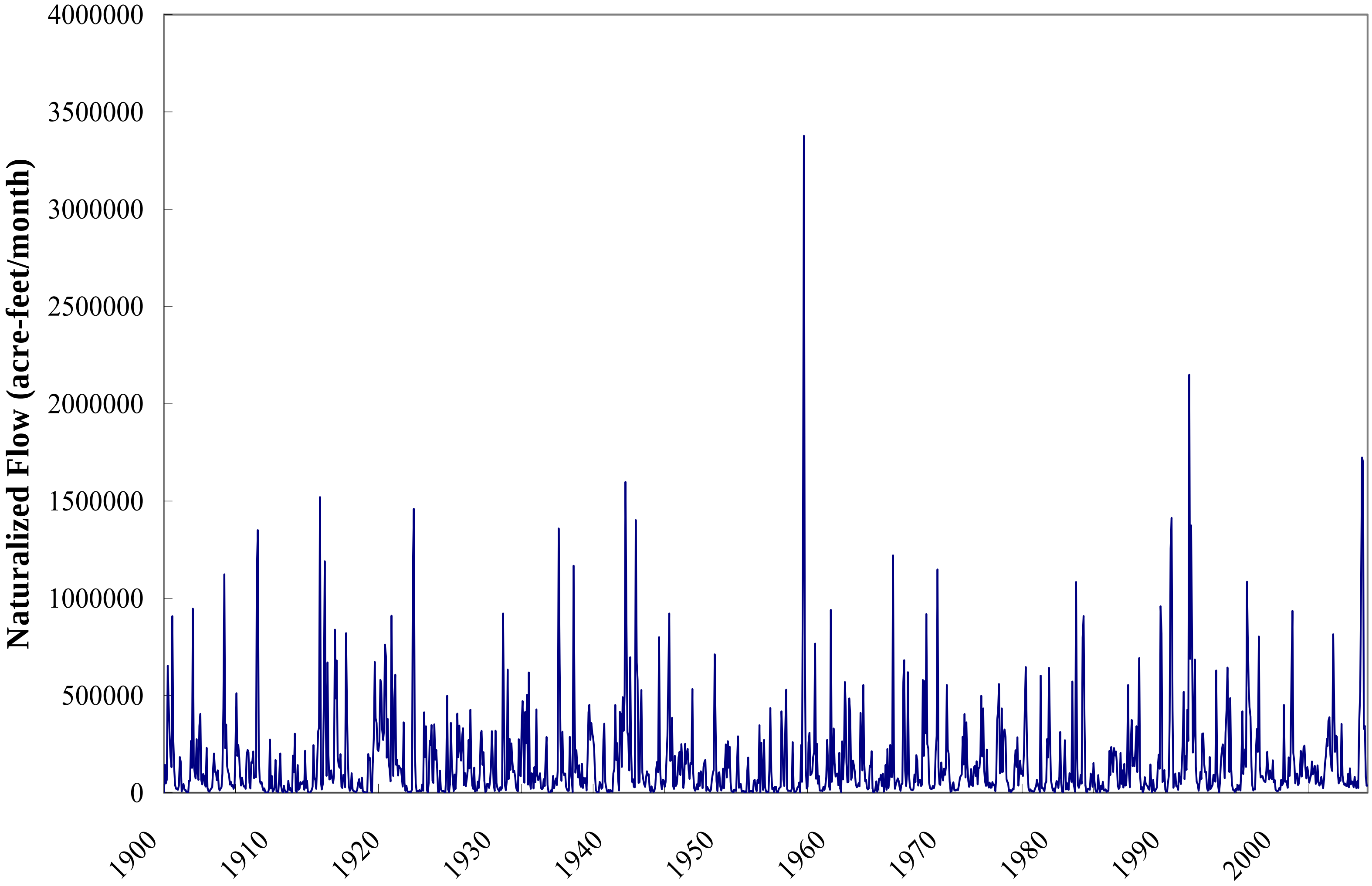

Figure A.41 Monthly Naturalized Flow at BRWA41 – Brazos River at Waco

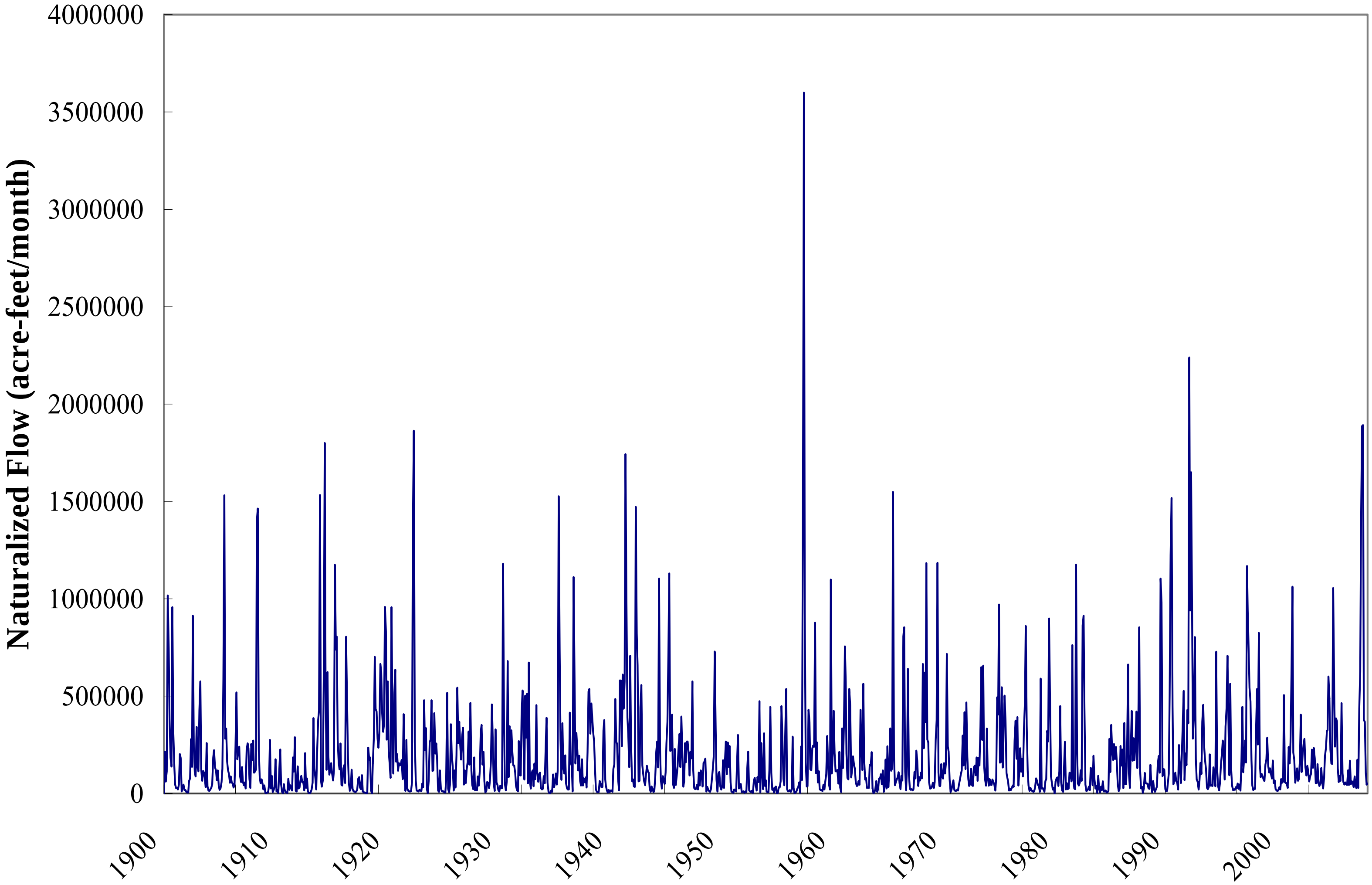

Figure A.42 Monthly Naturalized Flow at BRHB42 – Brazos River near Highbank

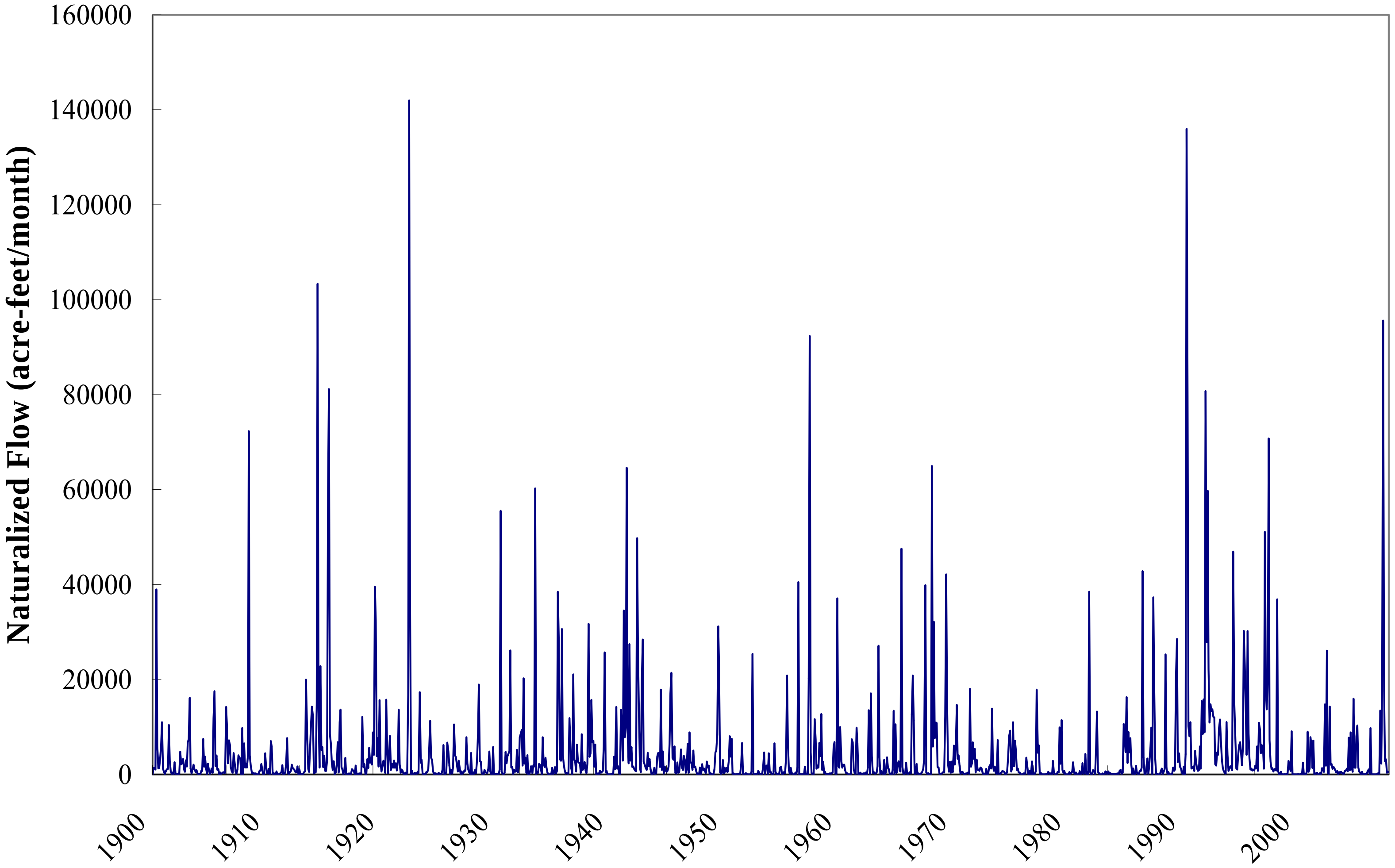

Figure A.43 Monthly Naturalized Flow at LEDL43 – Leon River near De Leon

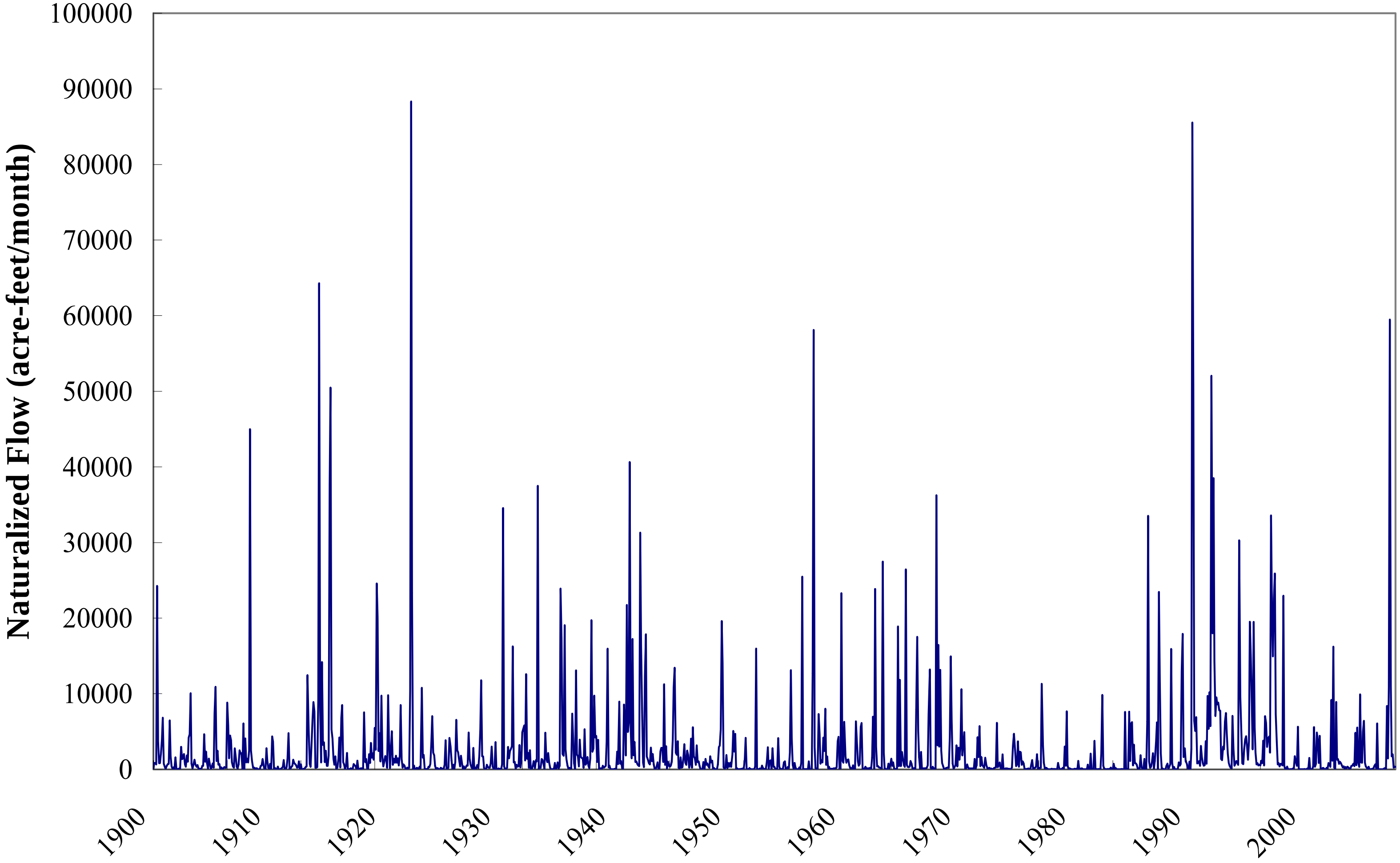

Figure A.44 Monthly Naturalized Flow at SADL44 – Sabana River near De Leon

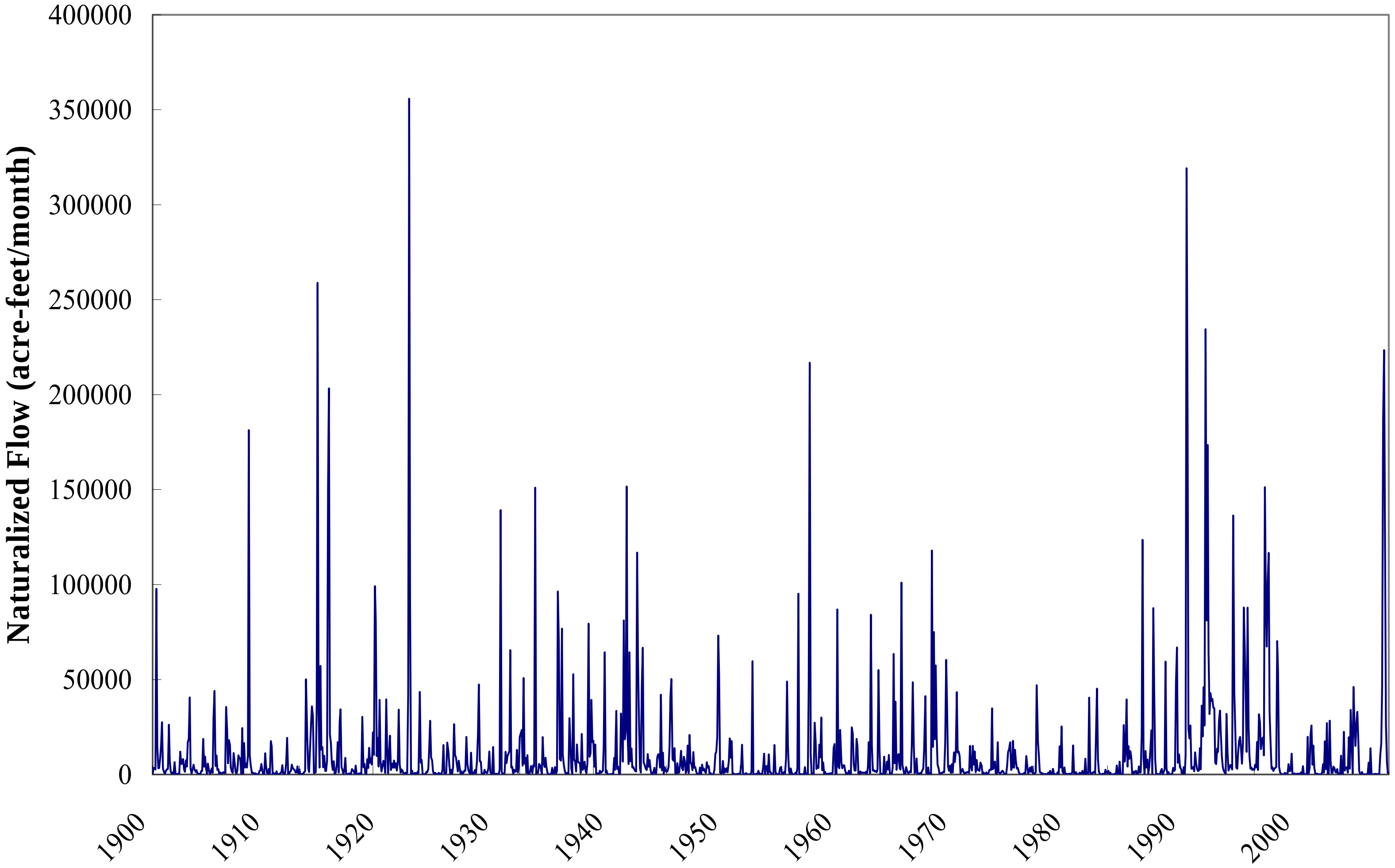

Figure A.45 Monthly Naturalized Flow at LEHS45 – Leon River near Hasse

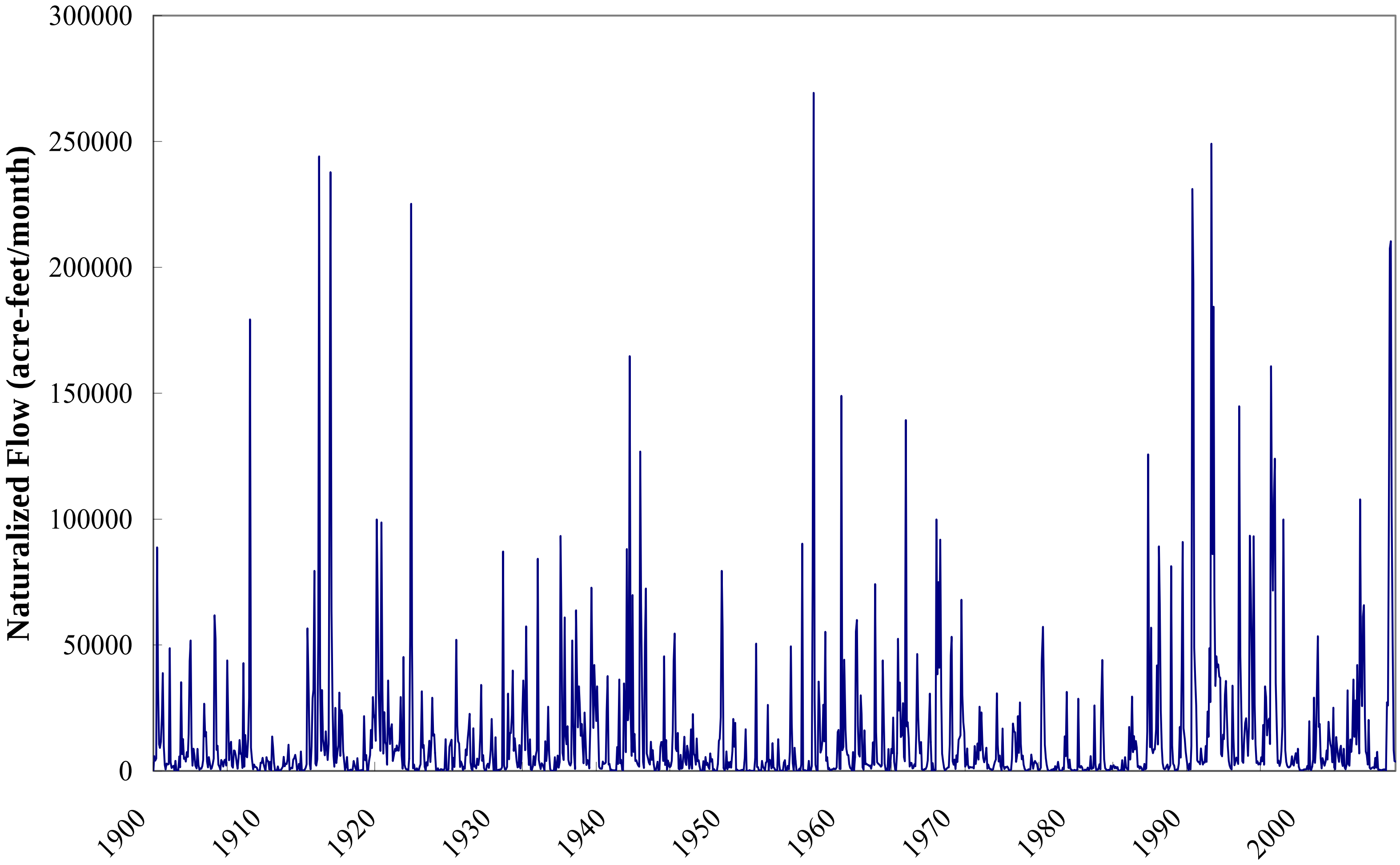

Figure A.46 Monthly Naturalized Flow at LEHM46 – Leon River Hamilton

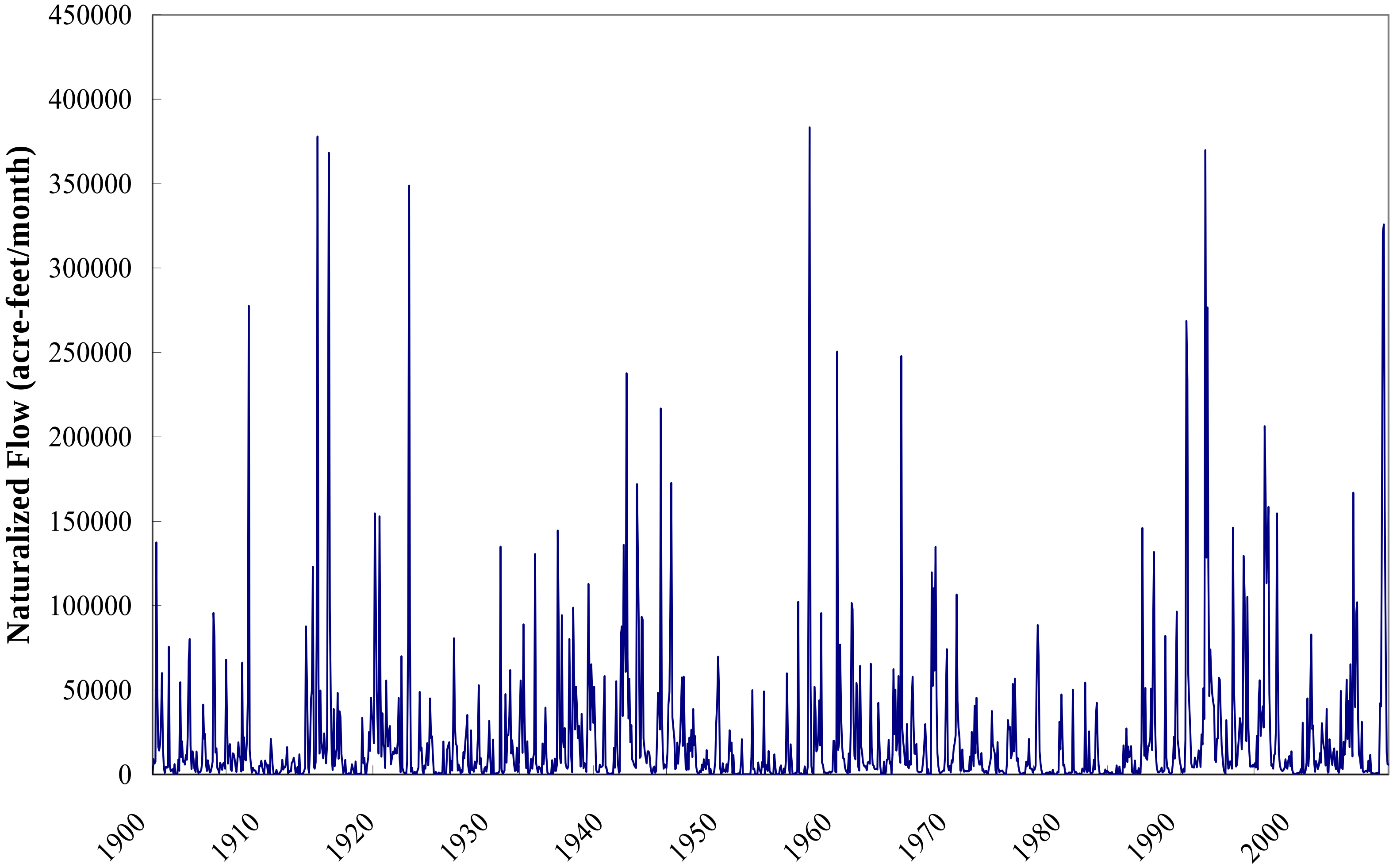

Figure A.47 Monthly Naturalized Flow at LEGT47 – Leon River at Gatesville

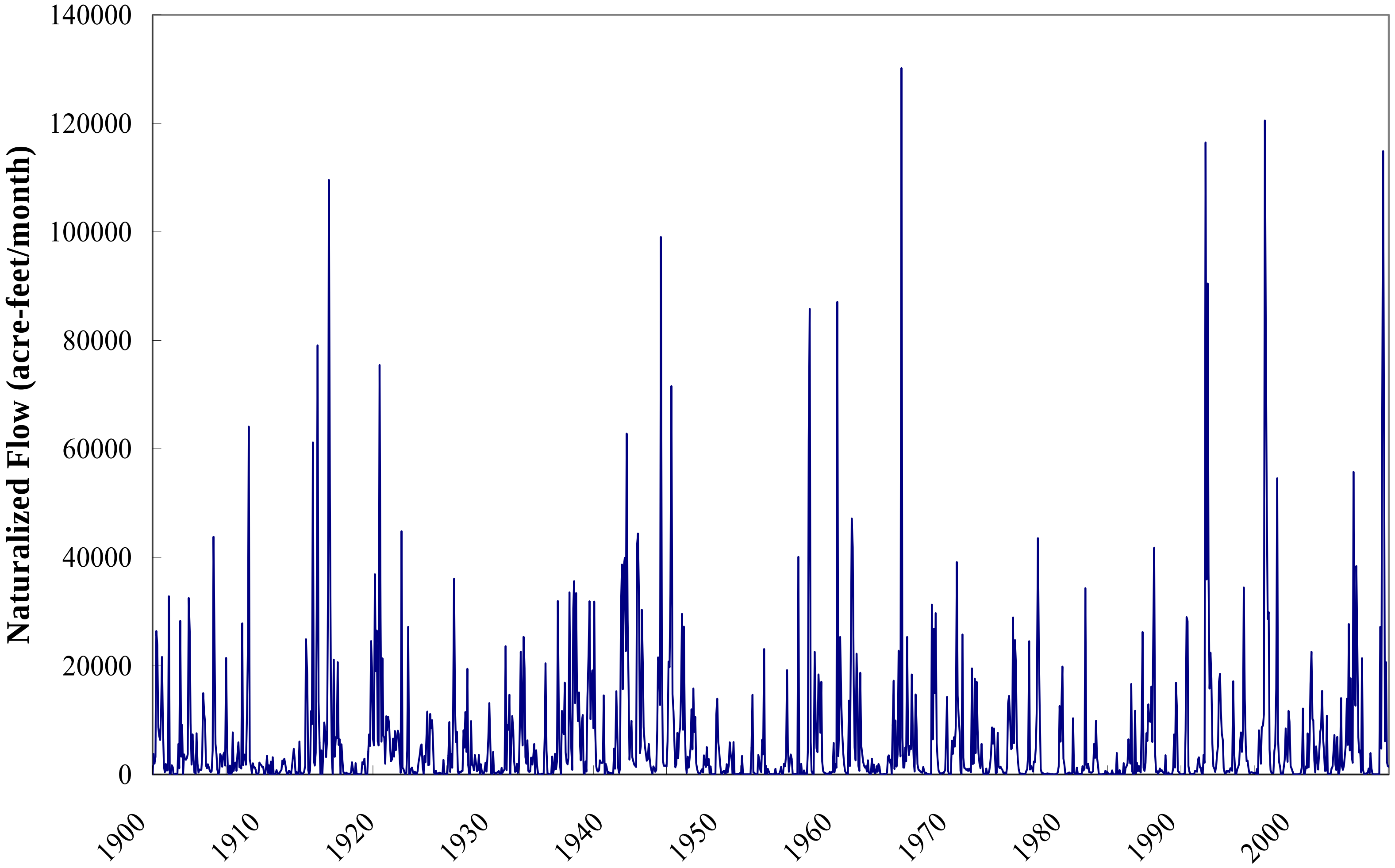

Figure A.48 Monthly Naturalized Flow at COPI48 – Cowhouse Creek at Pidcoke

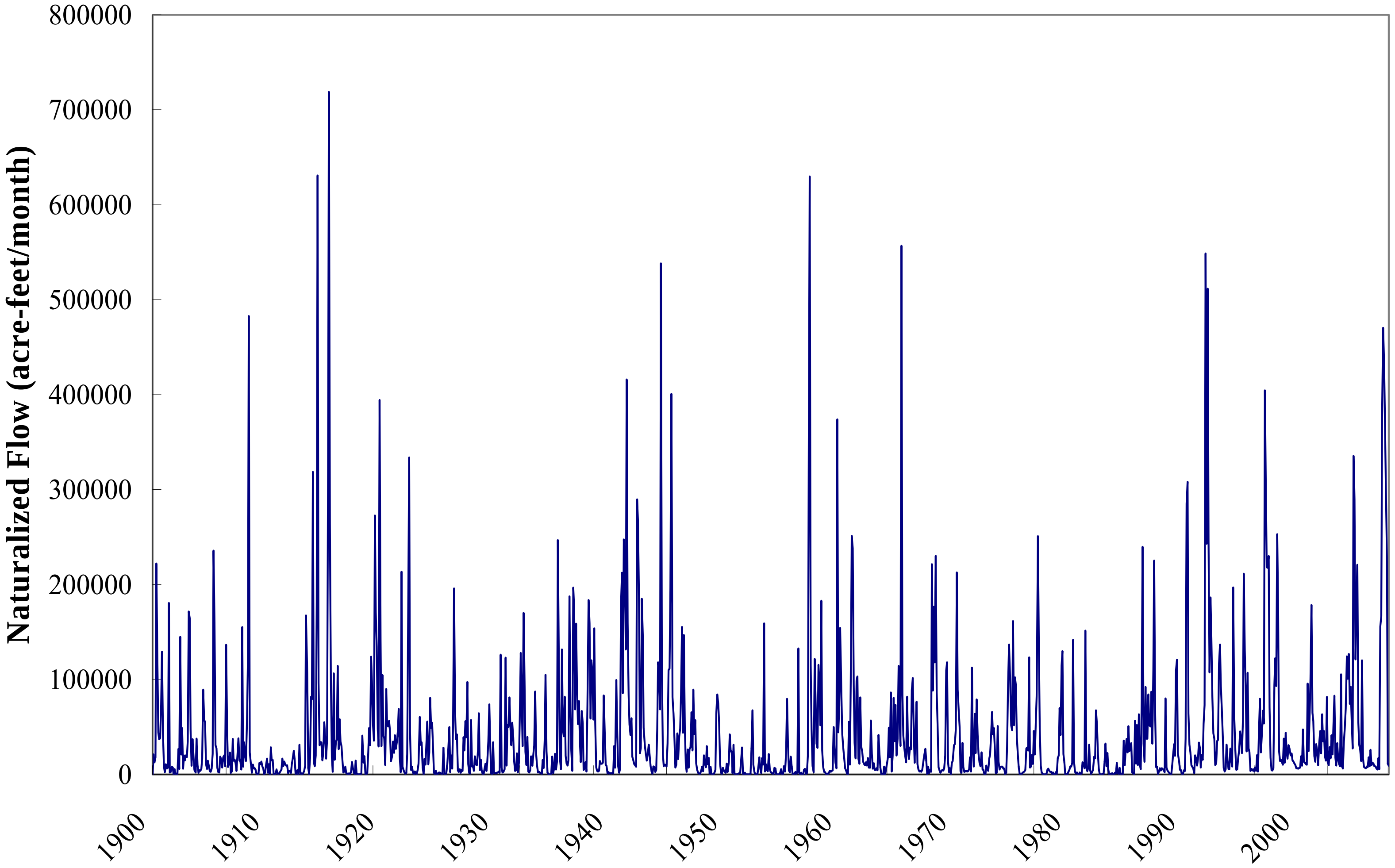

Figure A.49 Monthly Naturalized Flow at LEBE49 – Leon River near Belton

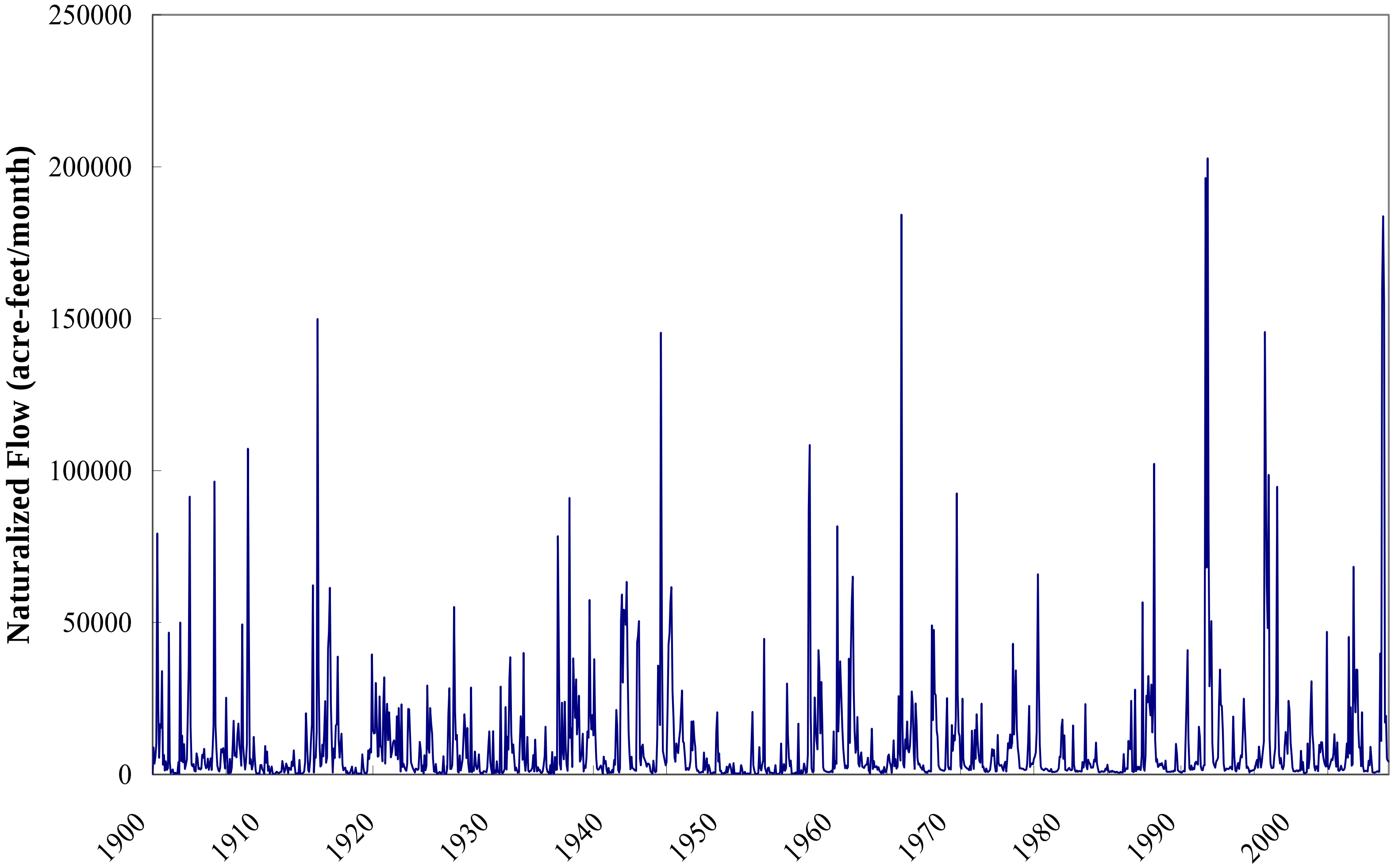

Figure A.50 Monthly Naturalized Flow at LAKE50 – Lampasas River near Kempner

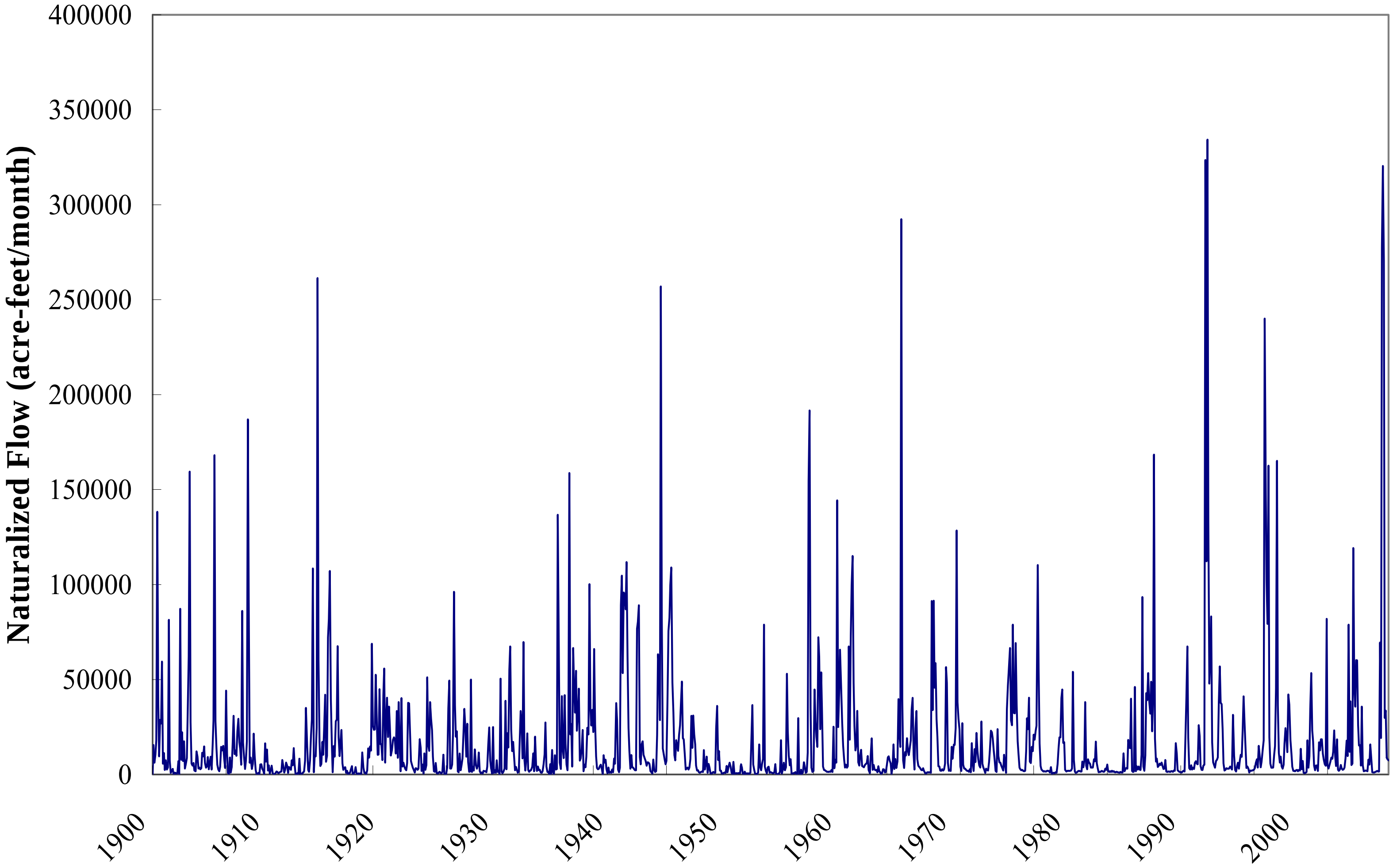

Figure A.51 Monthly Naturalized Flow at LAYO51 – Lampasas River at Youngsport

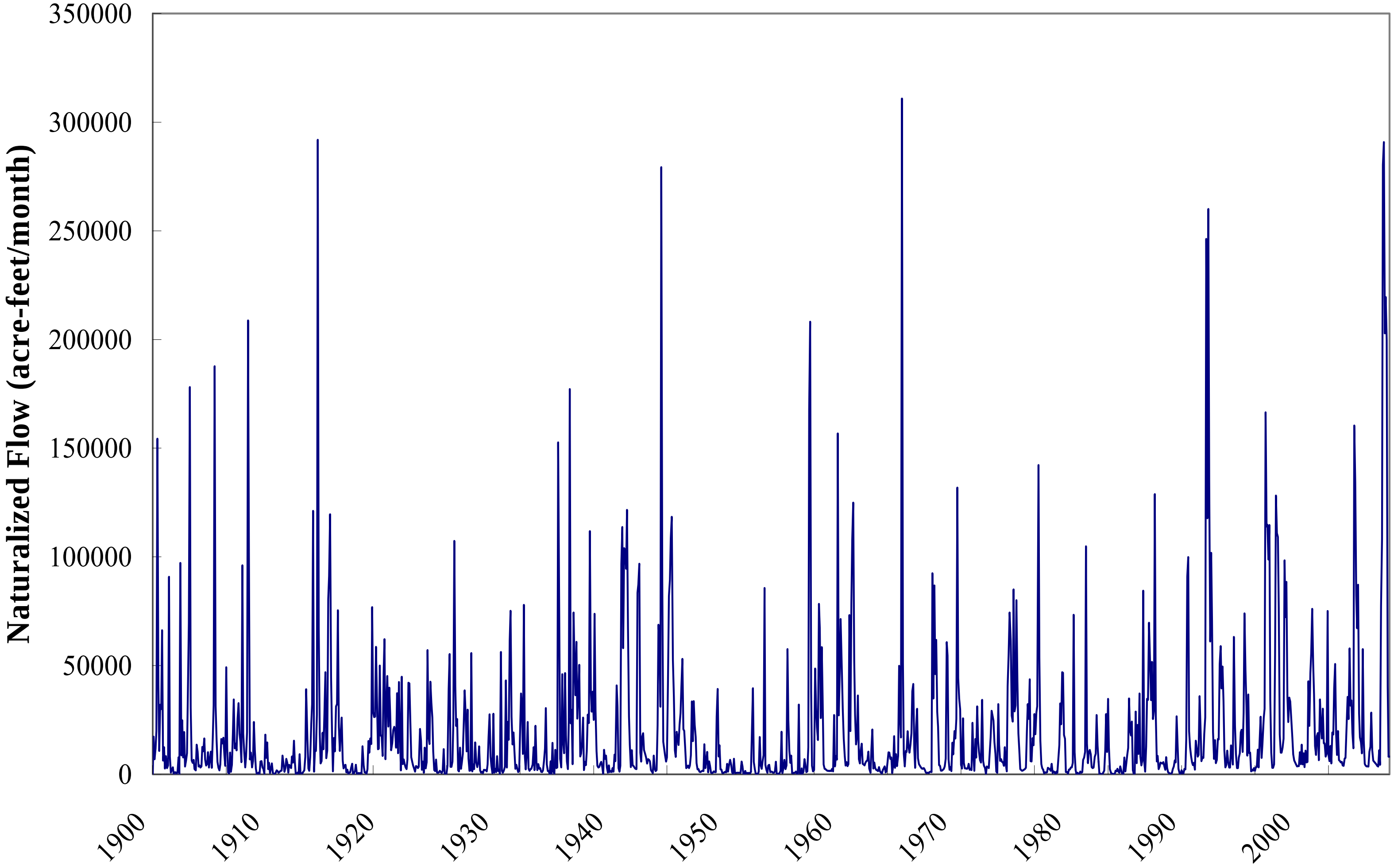

Figure A.52 Monthly Naturalized Flow at LABE52 – Lampasas River near Belton

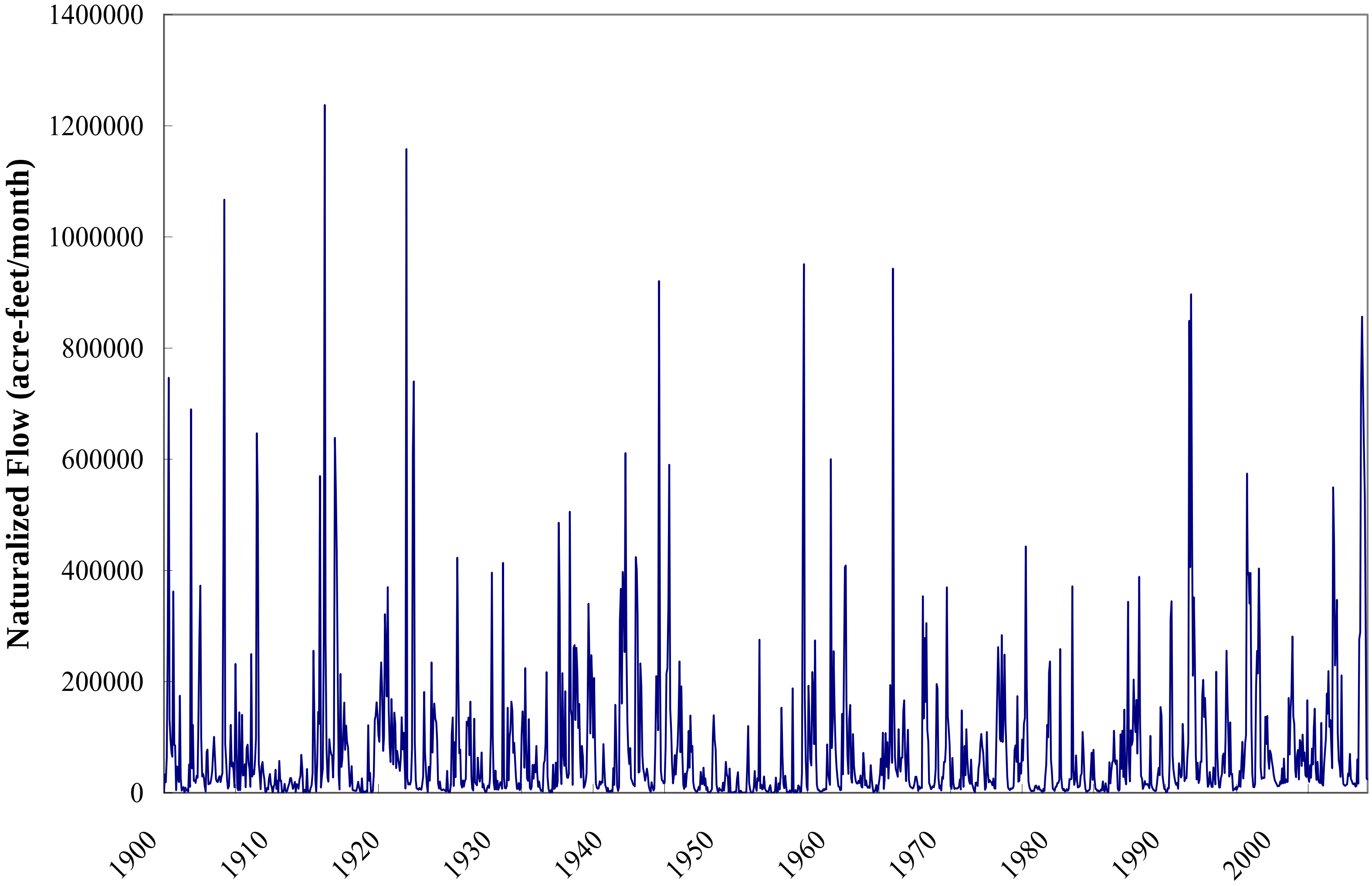

Figure A.53 Monthly Naturalized Flow at LRLR53 – Little River near Little River

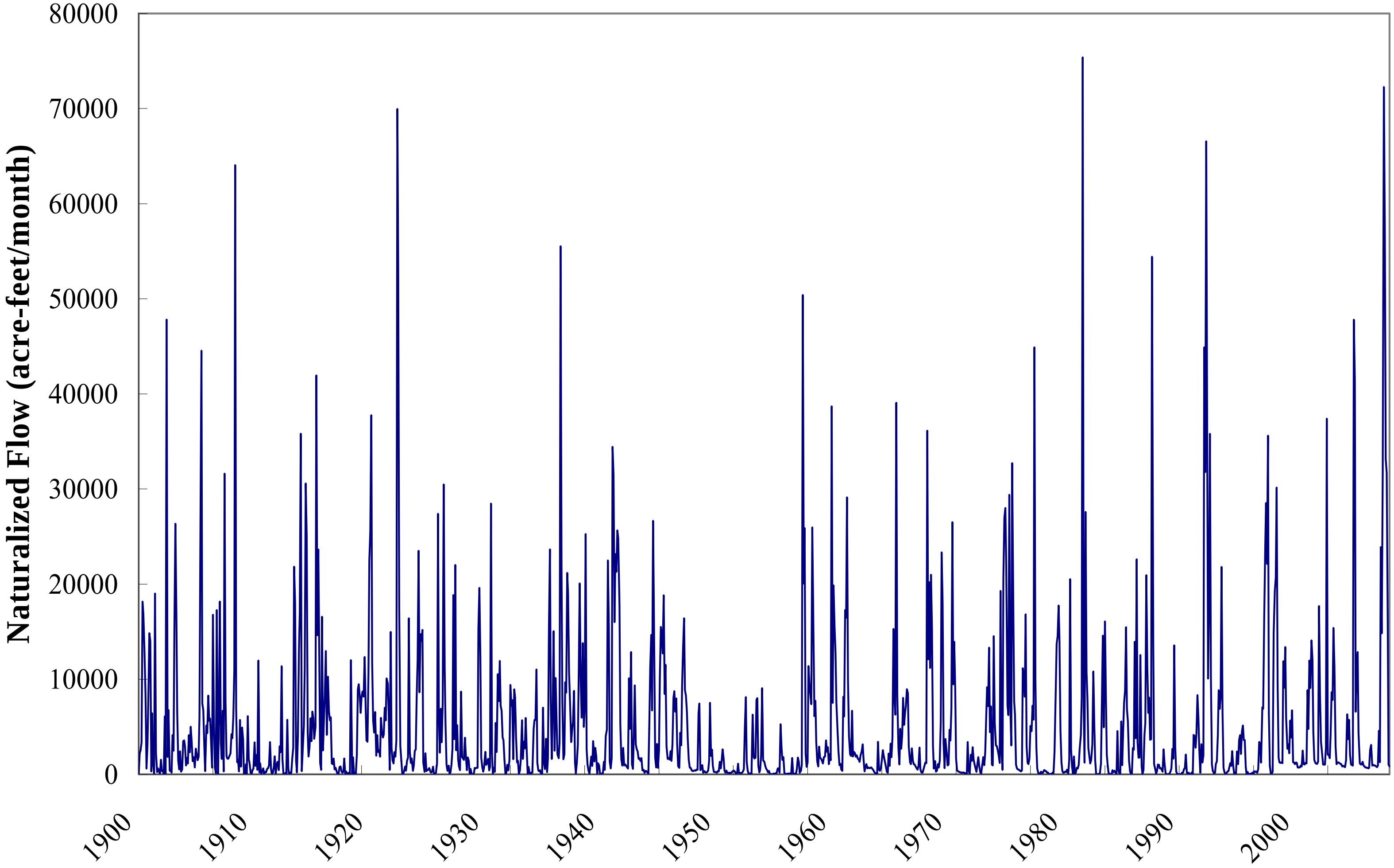

Figure A.54 Monthly Naturalized Flow at NGGE54 – North Fork San Gabriel River at Georgetown

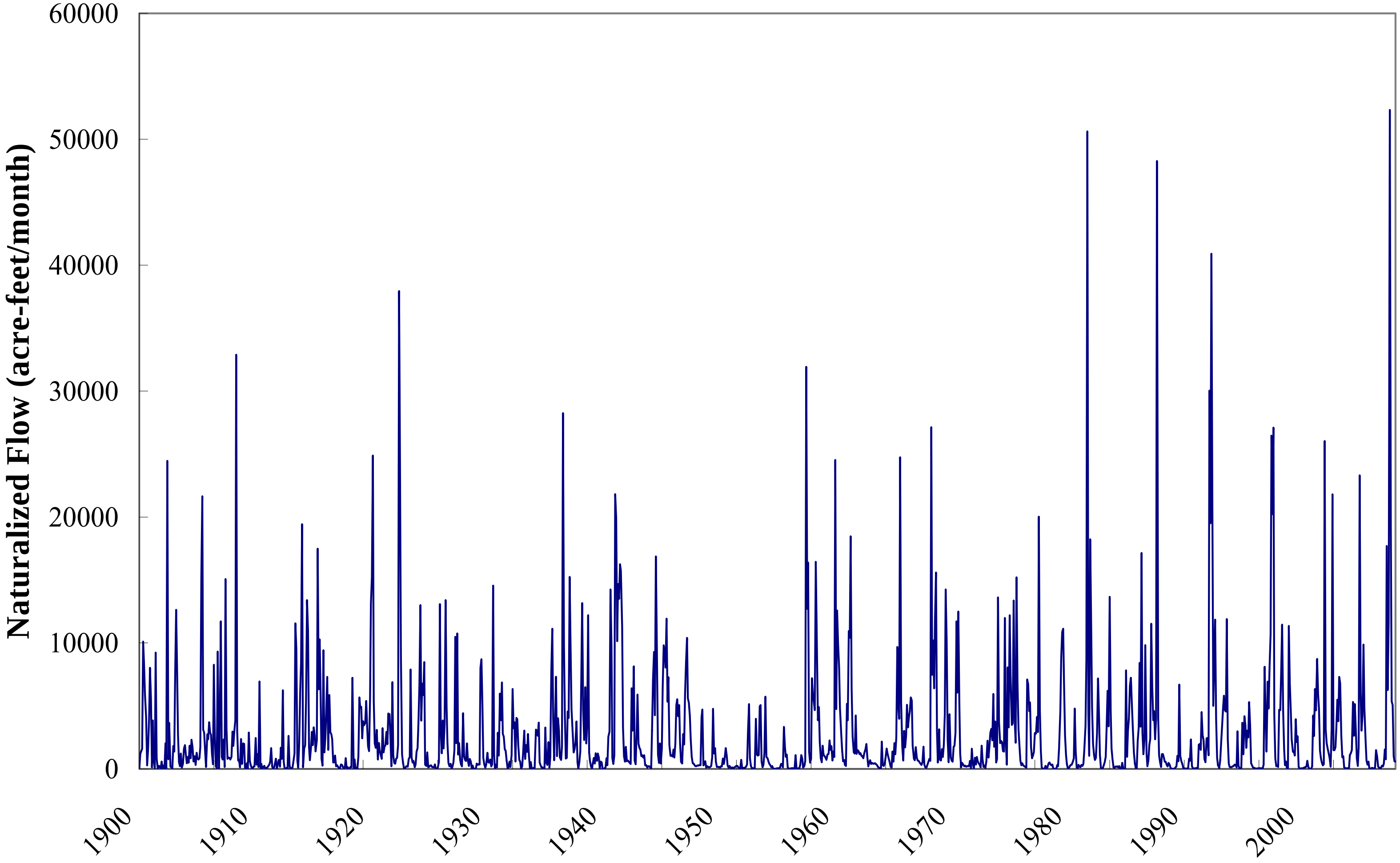

Figure A.55 Monthly Naturalized Flow at SGGE55 – South Fork San Gabriel River at Georgetown

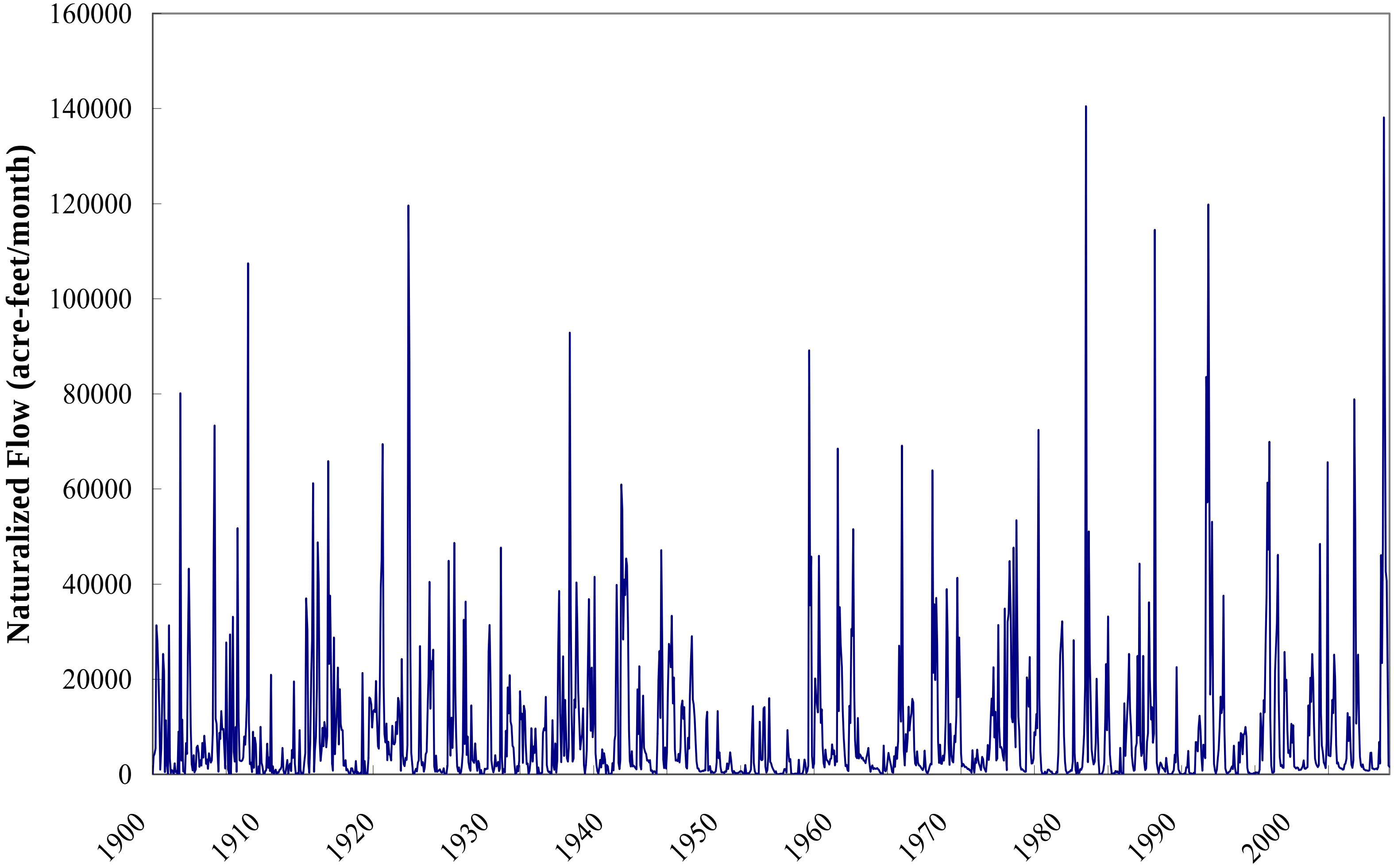

Figure A.56 Monthly Naturalized Flow at GAGE56 – San Gabriel River at Georgetown

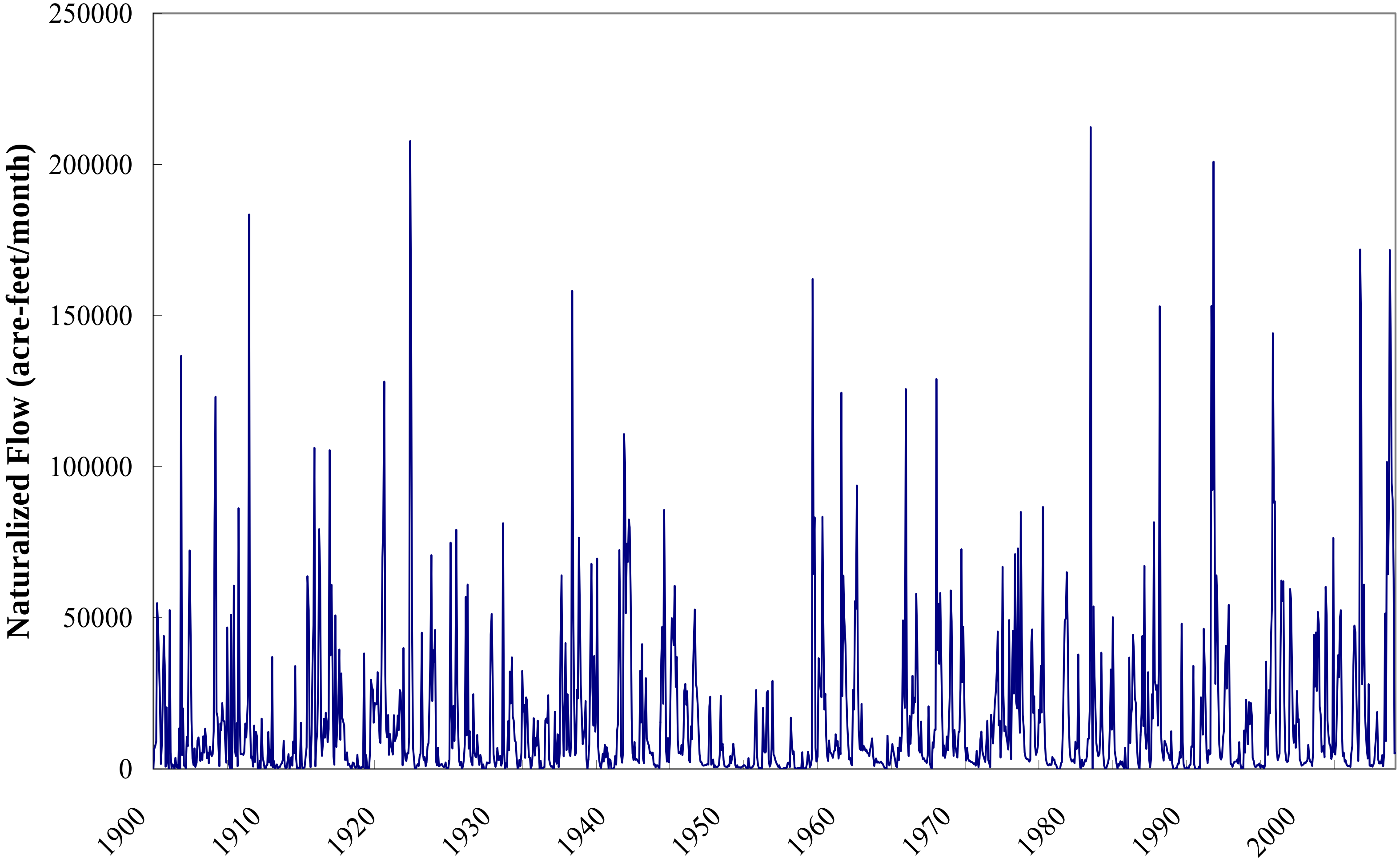

Figure A.57 Monthly Naturalized Flow at GALA57 – San Gabriel River at Laneport

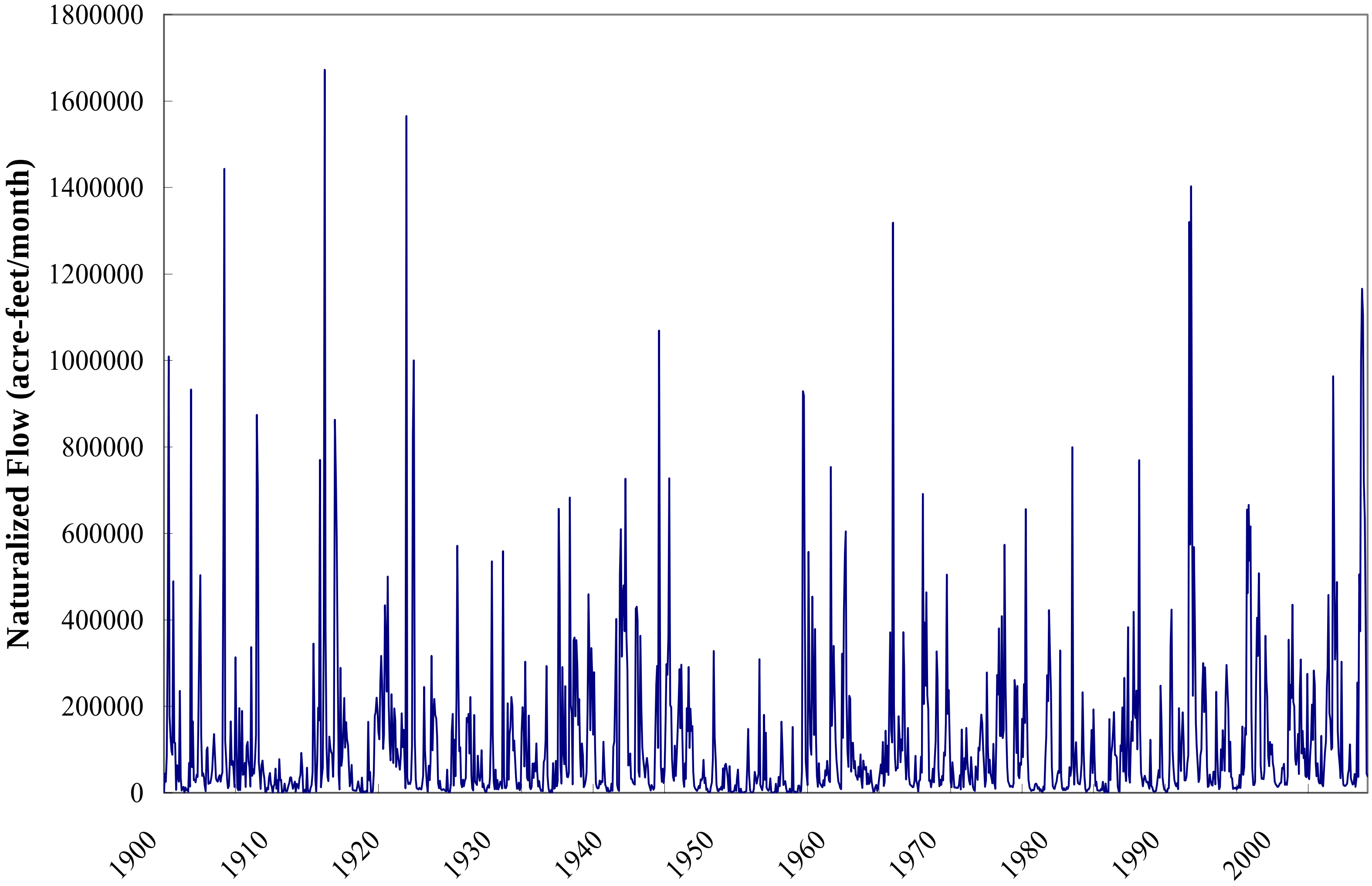

Figure A.58 Monthly Naturalized Flow at LRCA58 – Little River at Cameron

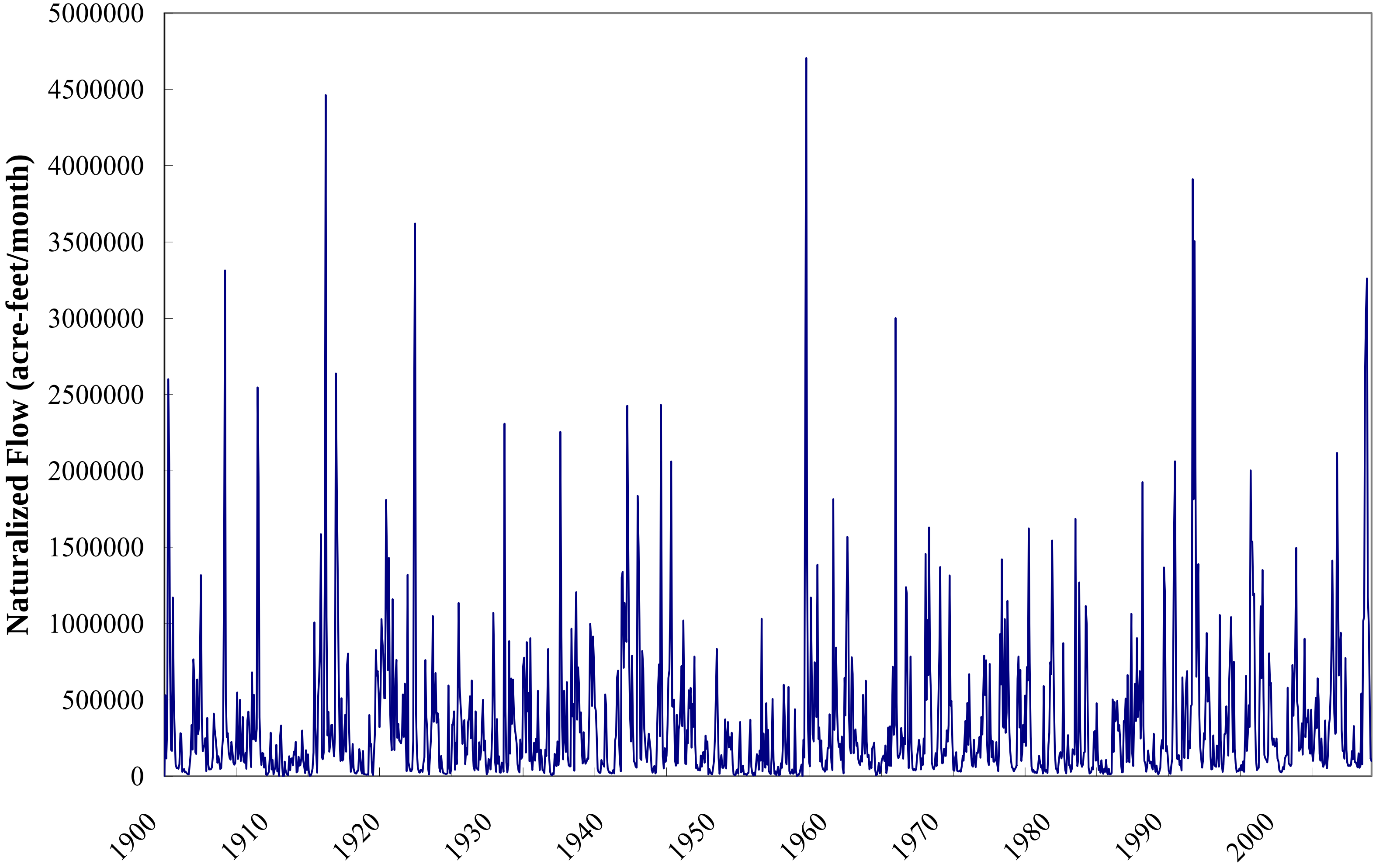

Figure A.59 Monthly Naturalized Flow at BRBR59 – Brazos River near Bryan

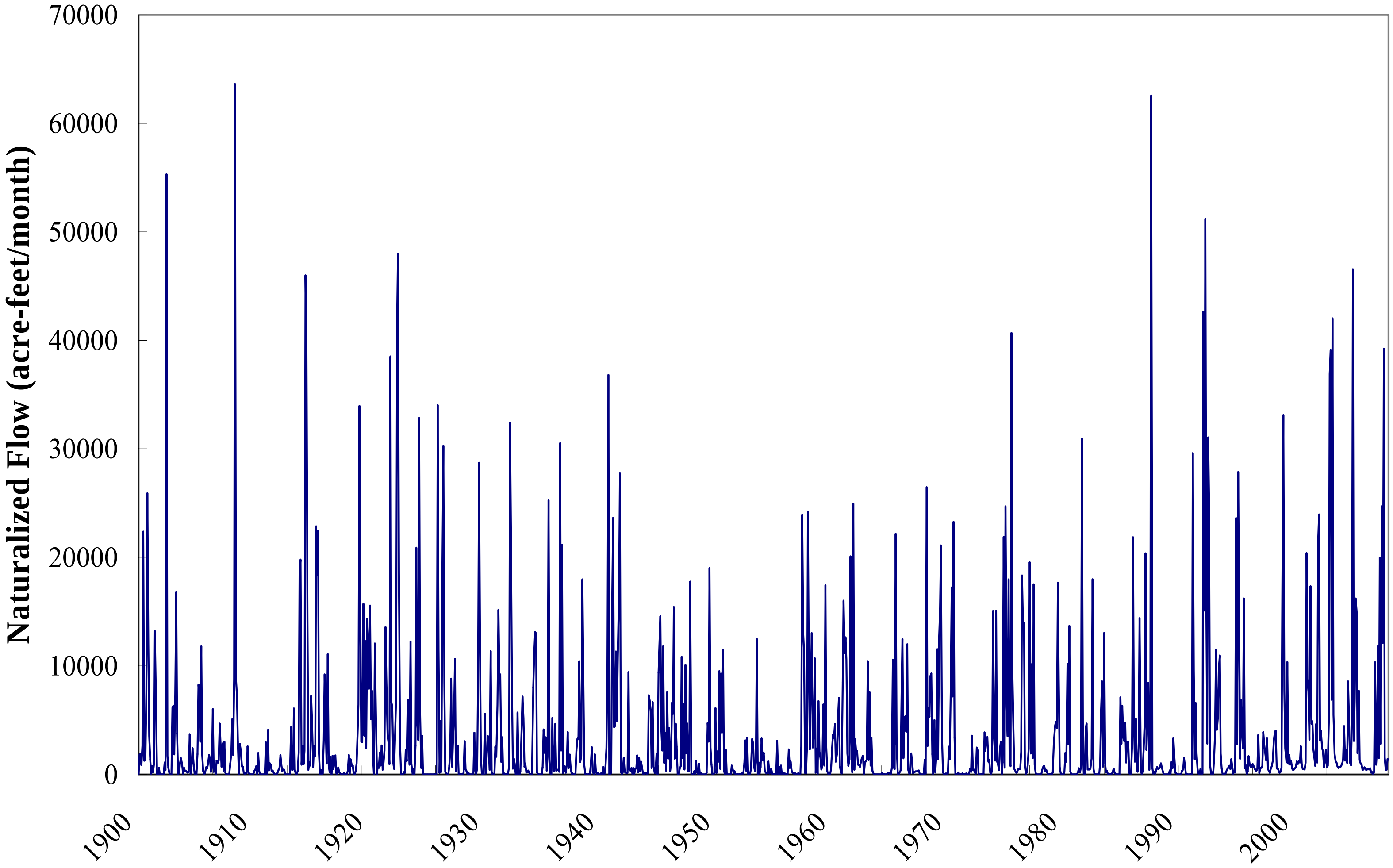

Figure A.60 Monthly Naturalized Flow at MYDB60 – Middle Yegua Creek near Dime Box

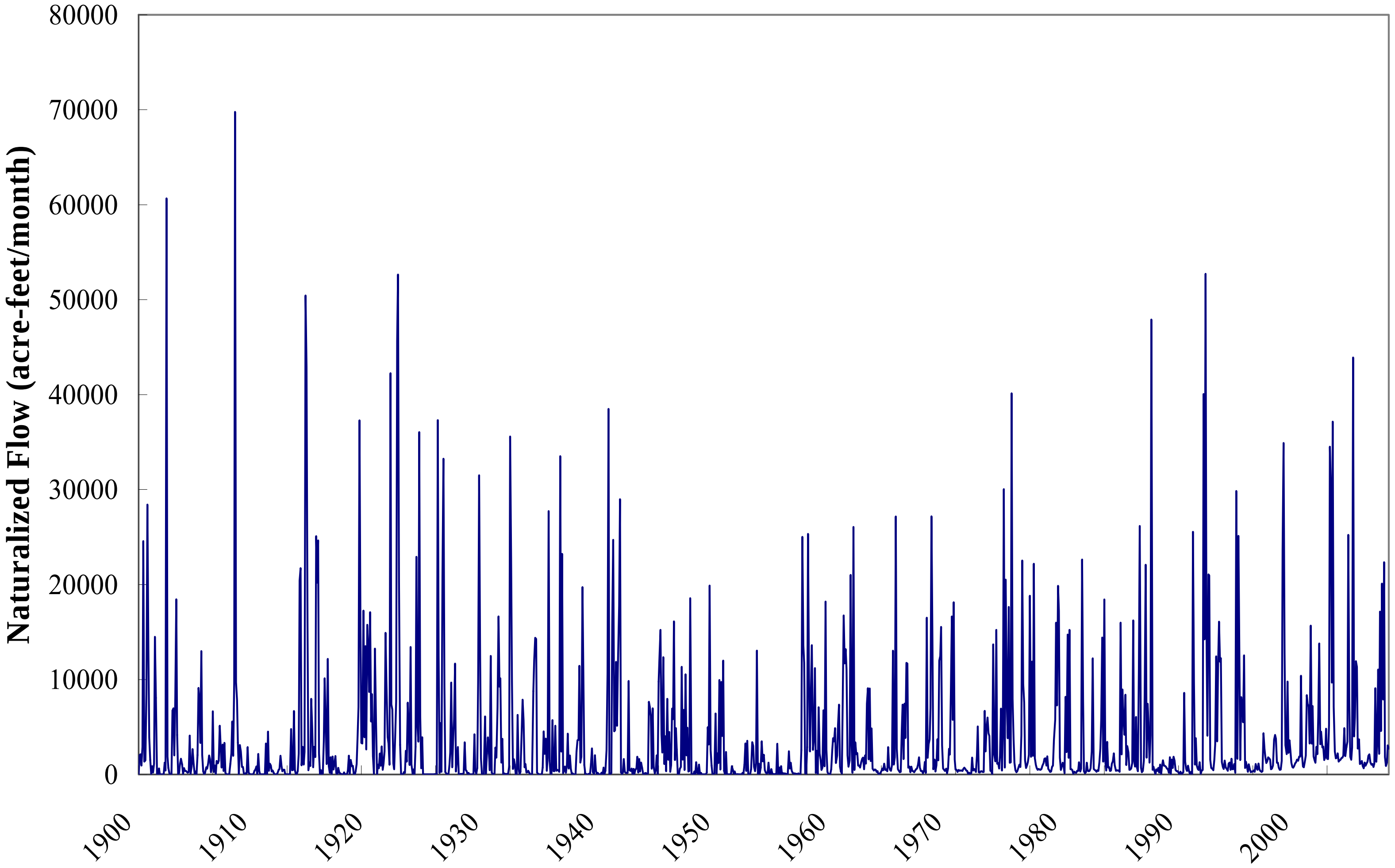

Figure A.61 Monthly Naturalized Flow at EYDB61 – East Yegua Creek near Dime Box

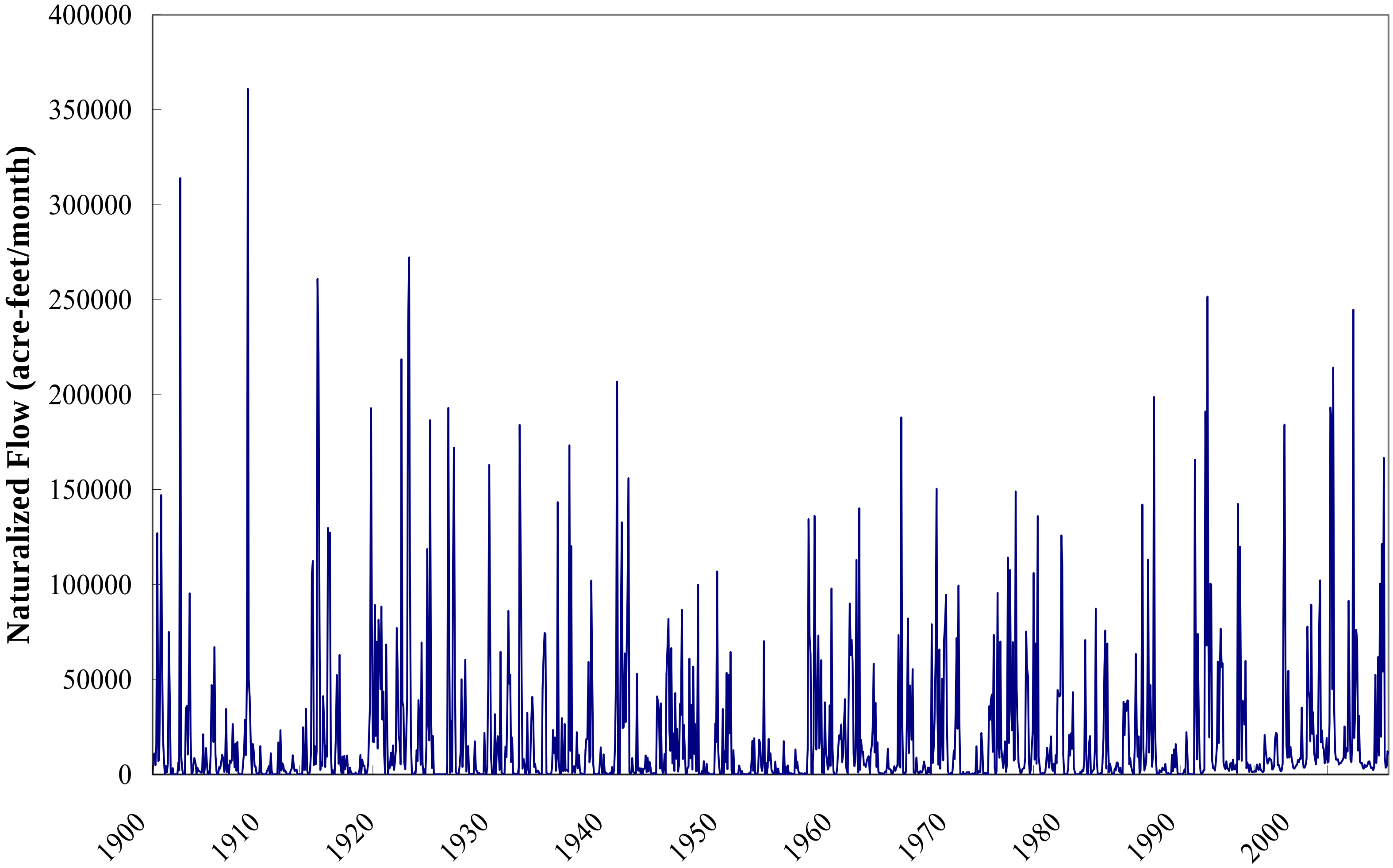

Figure A.62 Monthly Naturalized Flow at YCSO62 – Yegua Creek near Somerville

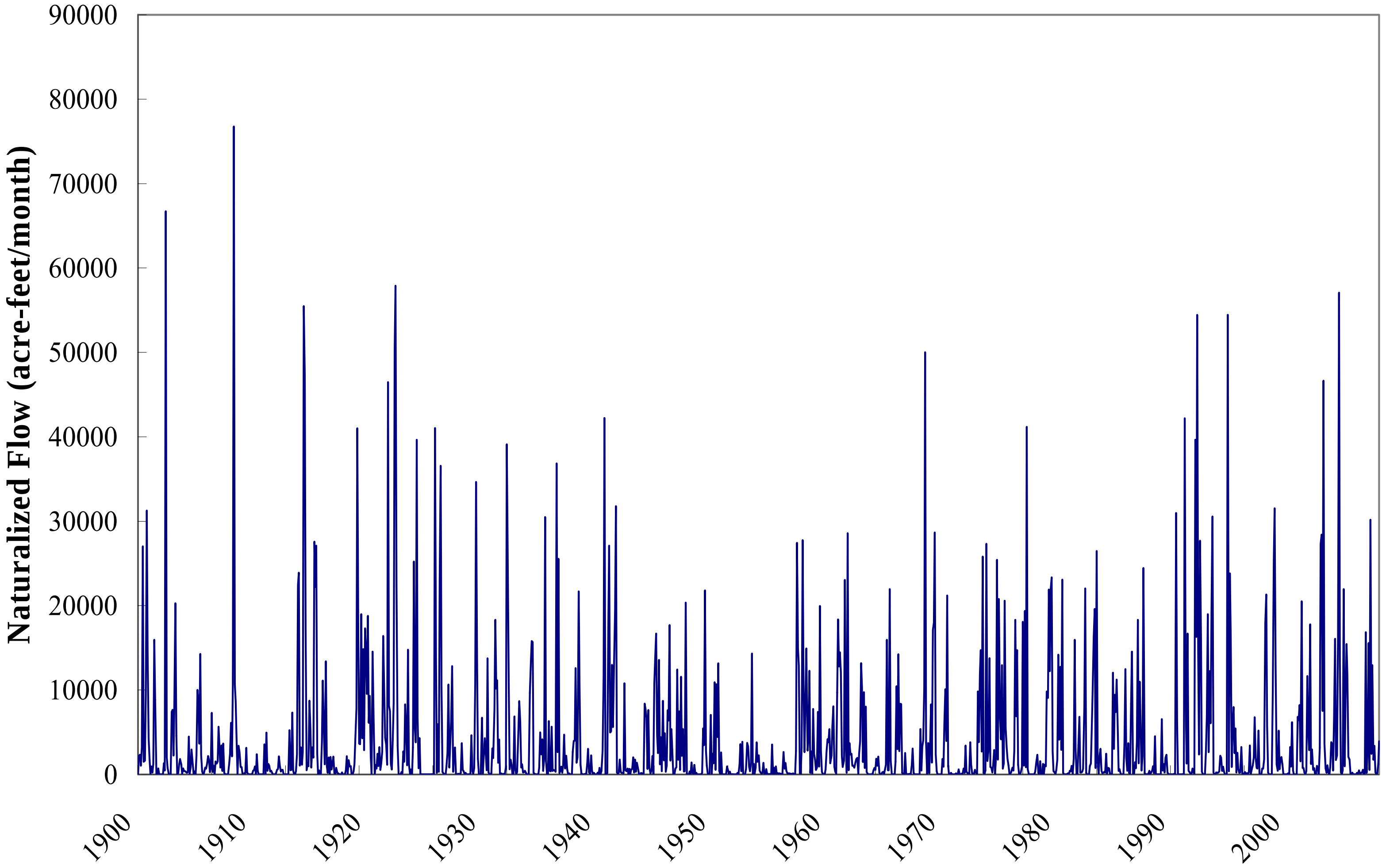

Figure A.63 Monthly Naturalized Flow at DCLY63 – Davison Creek near Lyons

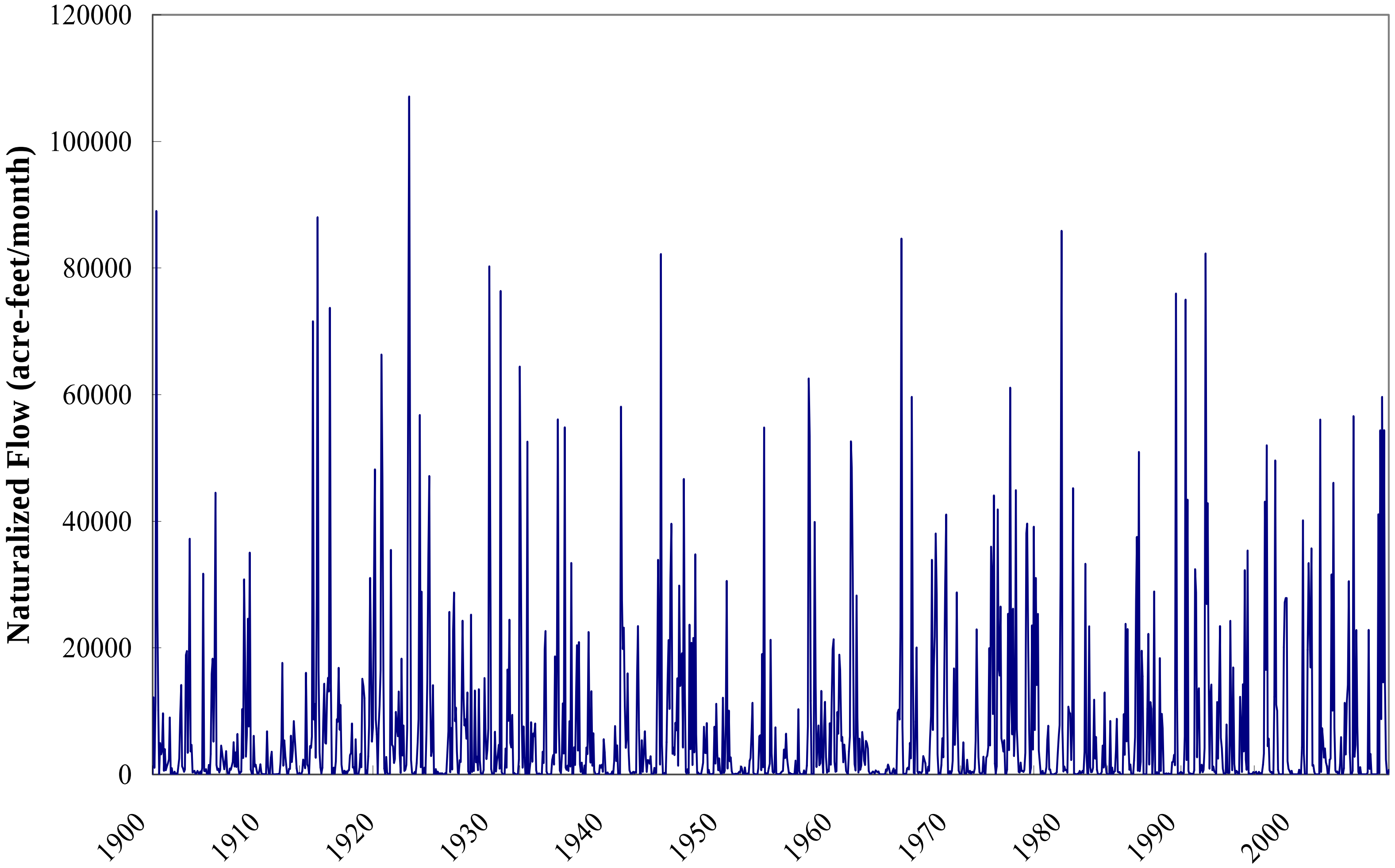

Figure A.64 Monthly Naturalized Flow at NAGR64 – Navasota River above Groesbeck

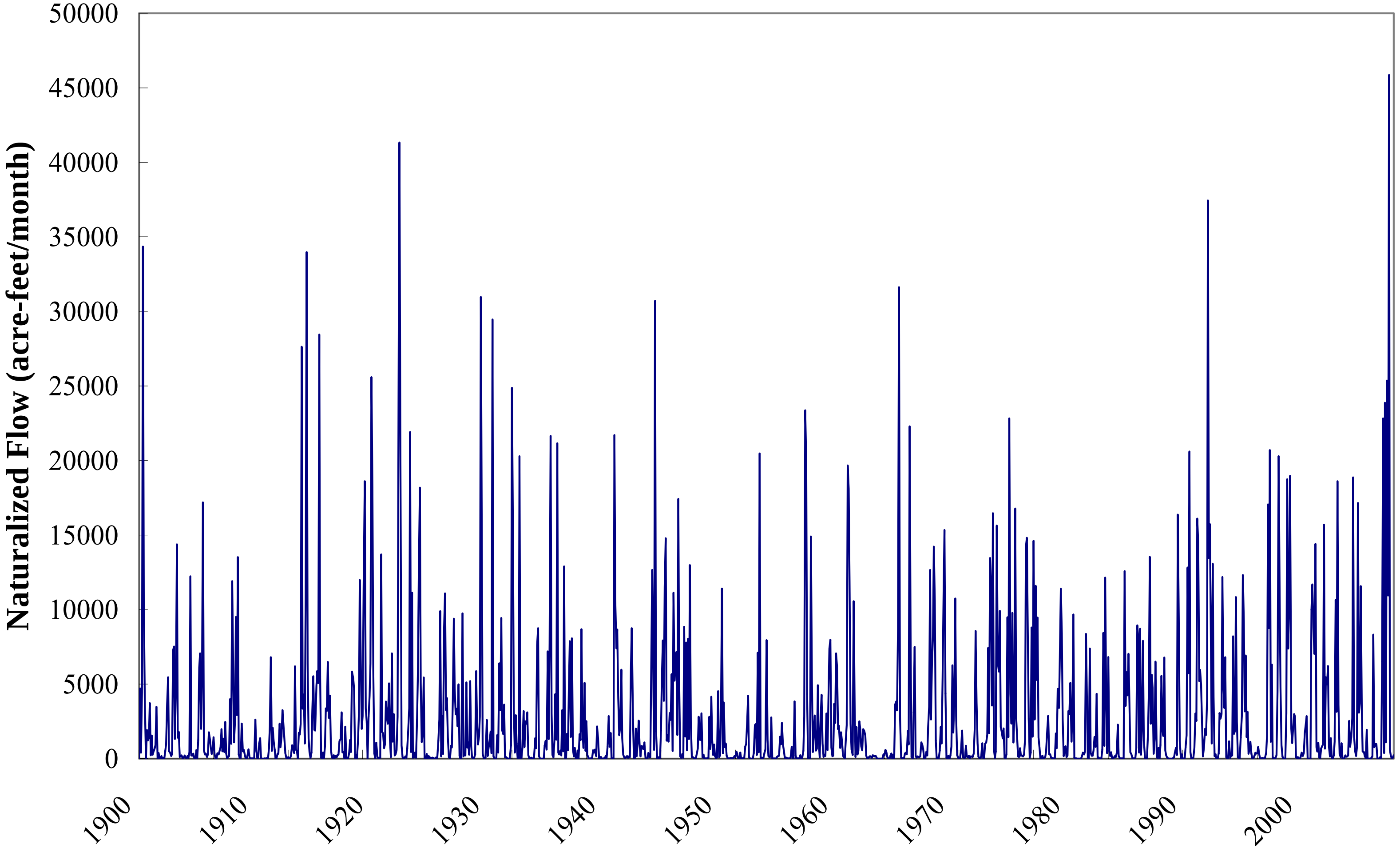

Figure A.65 Monthly Naturalized Flow at BGFR65 – Big Creek near Freestone

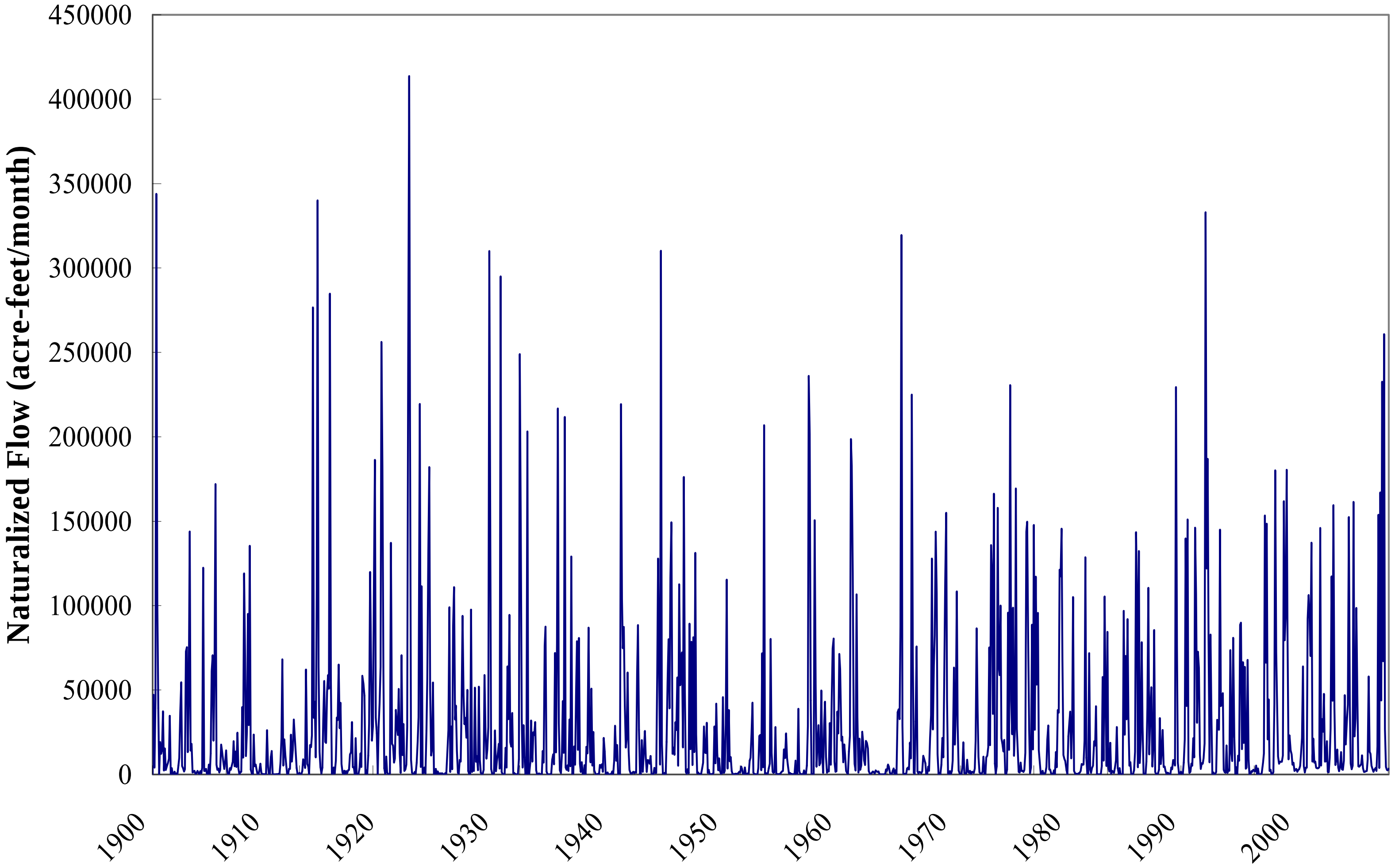

Figure A.66 Monthly Naturalized Flow at NAEA66 – Navasota River near Easterly

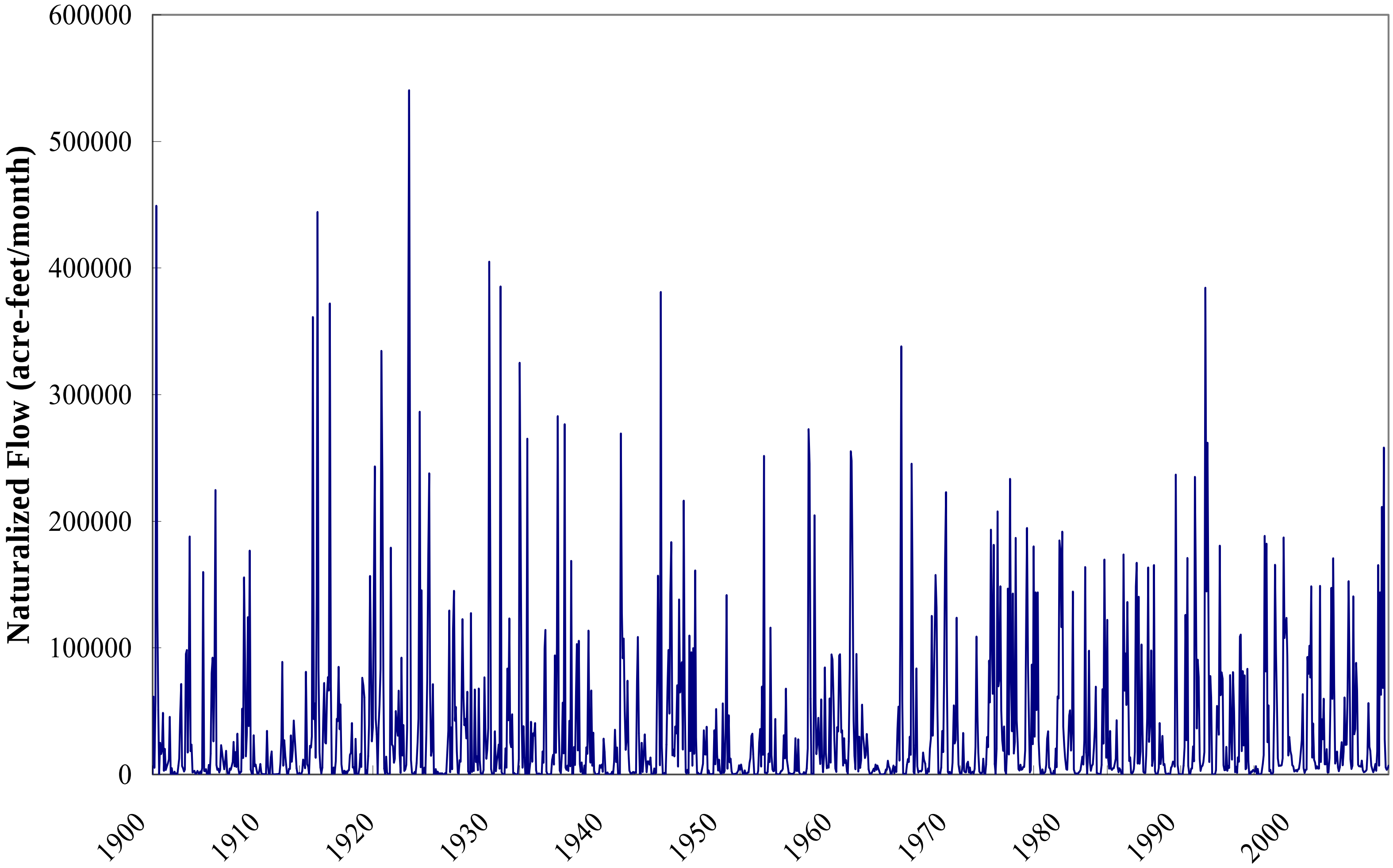

Figure A.67 Monthly Naturalized Flow at NABR67 – Navasota River near Bryan

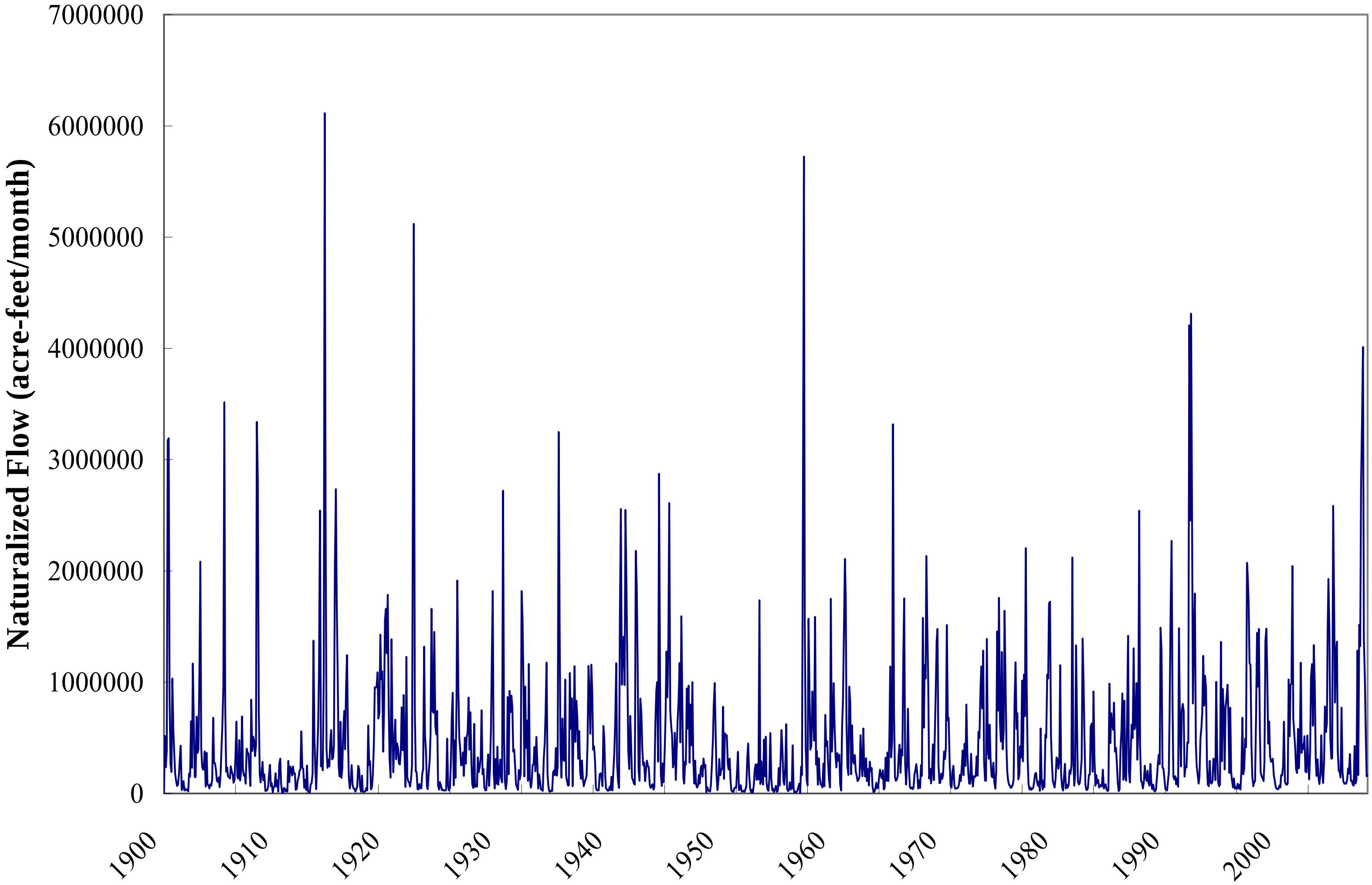

Figure A.68 Monthly Naturalized Flow at BRHE68 – Brazos River near Hempstead

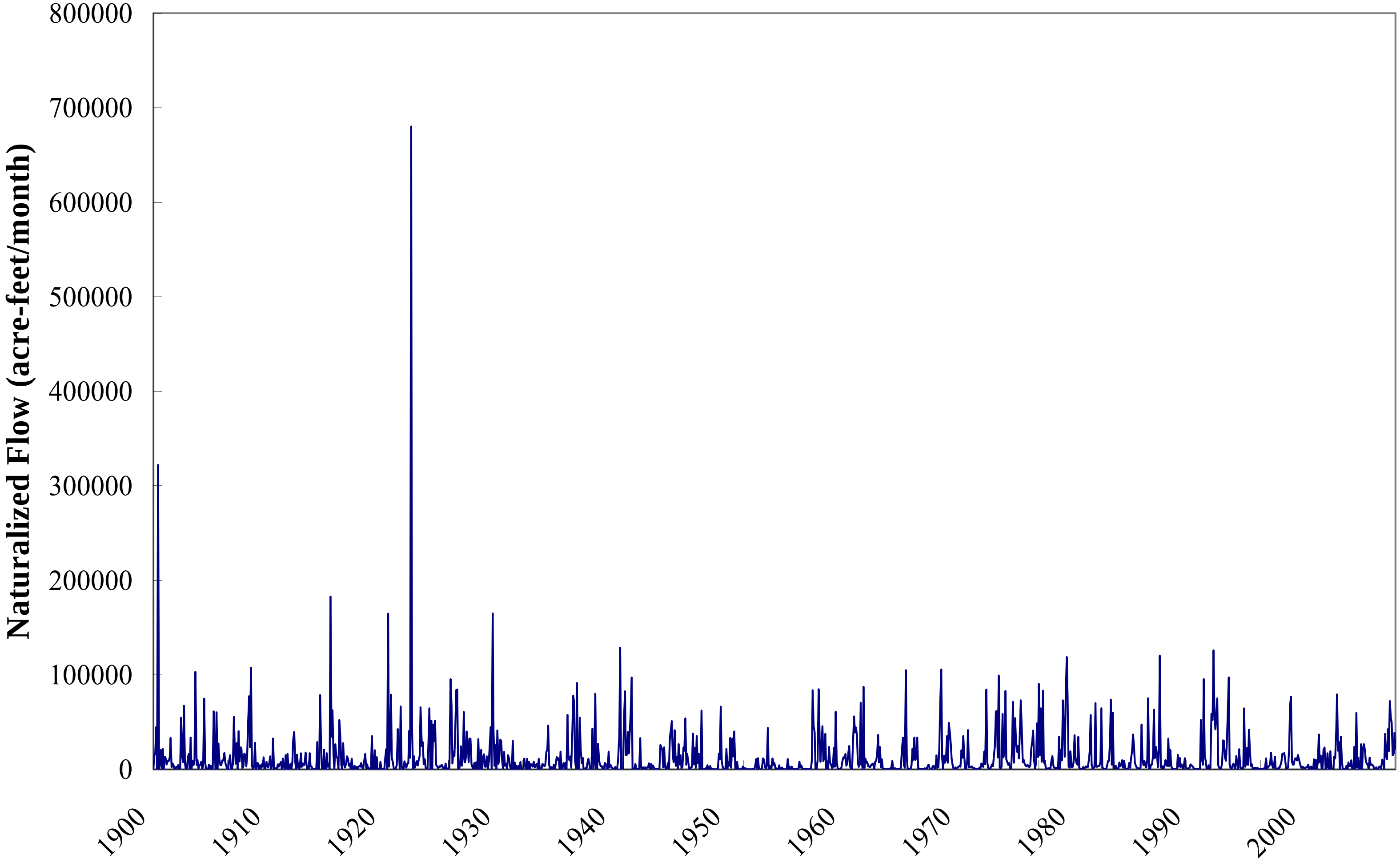

Figure A.69 Monthly Naturalized Flow at MCBL69 – Mill Creek near Bellville

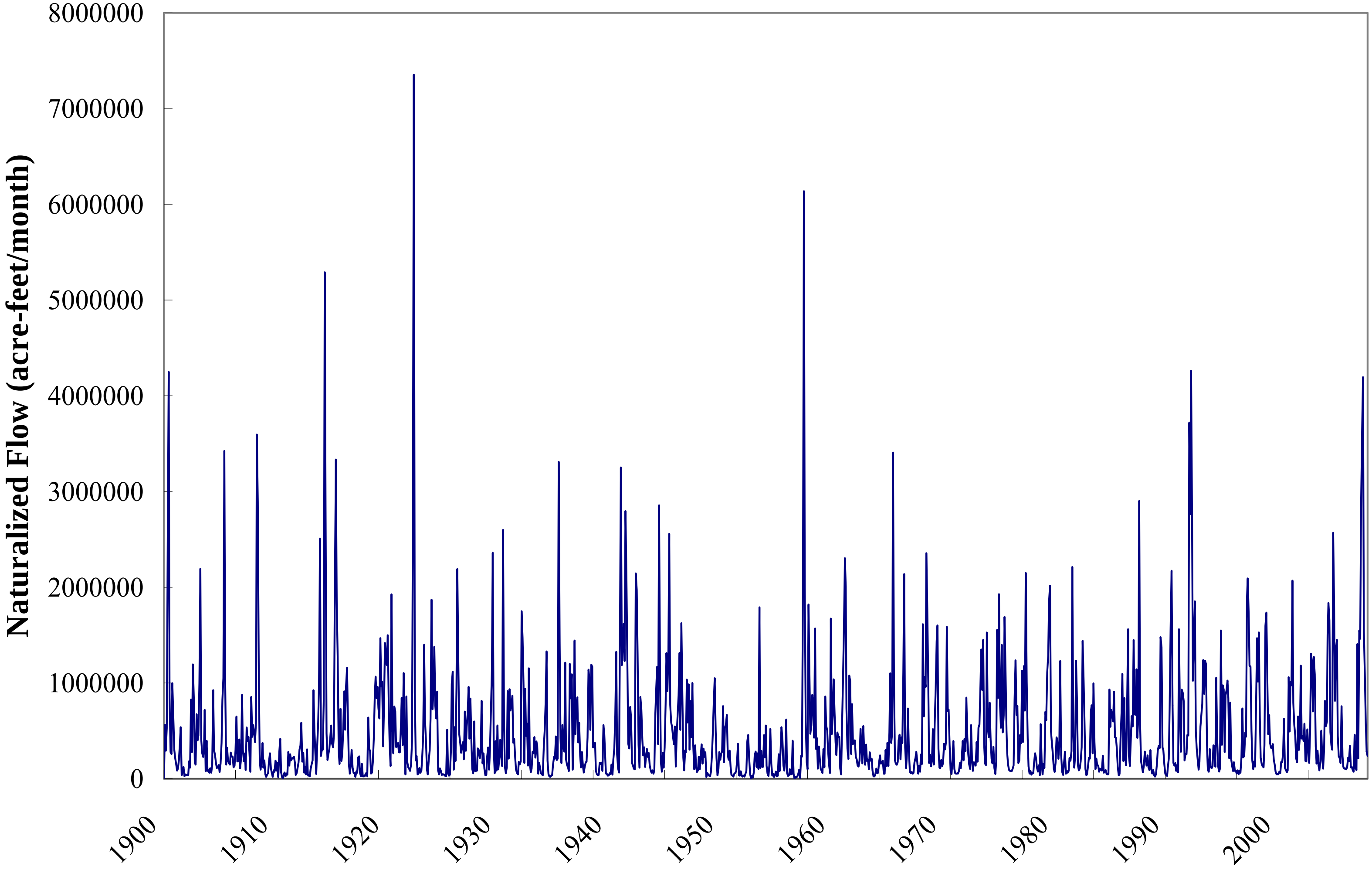

Figure A.70 Monthly Naturalized Flow at BRRI70 – Brazos River at Richmond

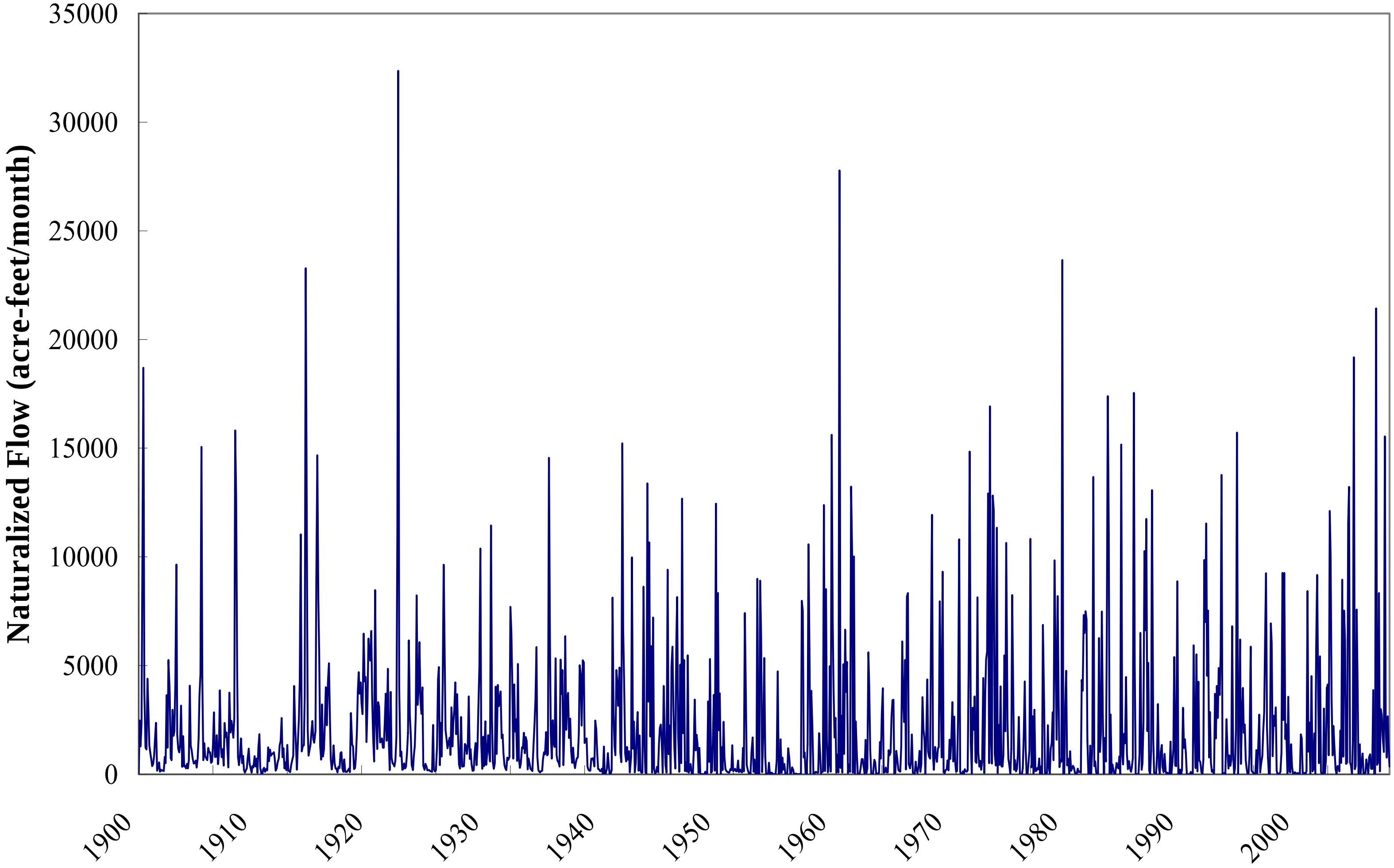

Figure A.71 Monthly Naturalized Flow at BGNE71 – Big Creek near Needville

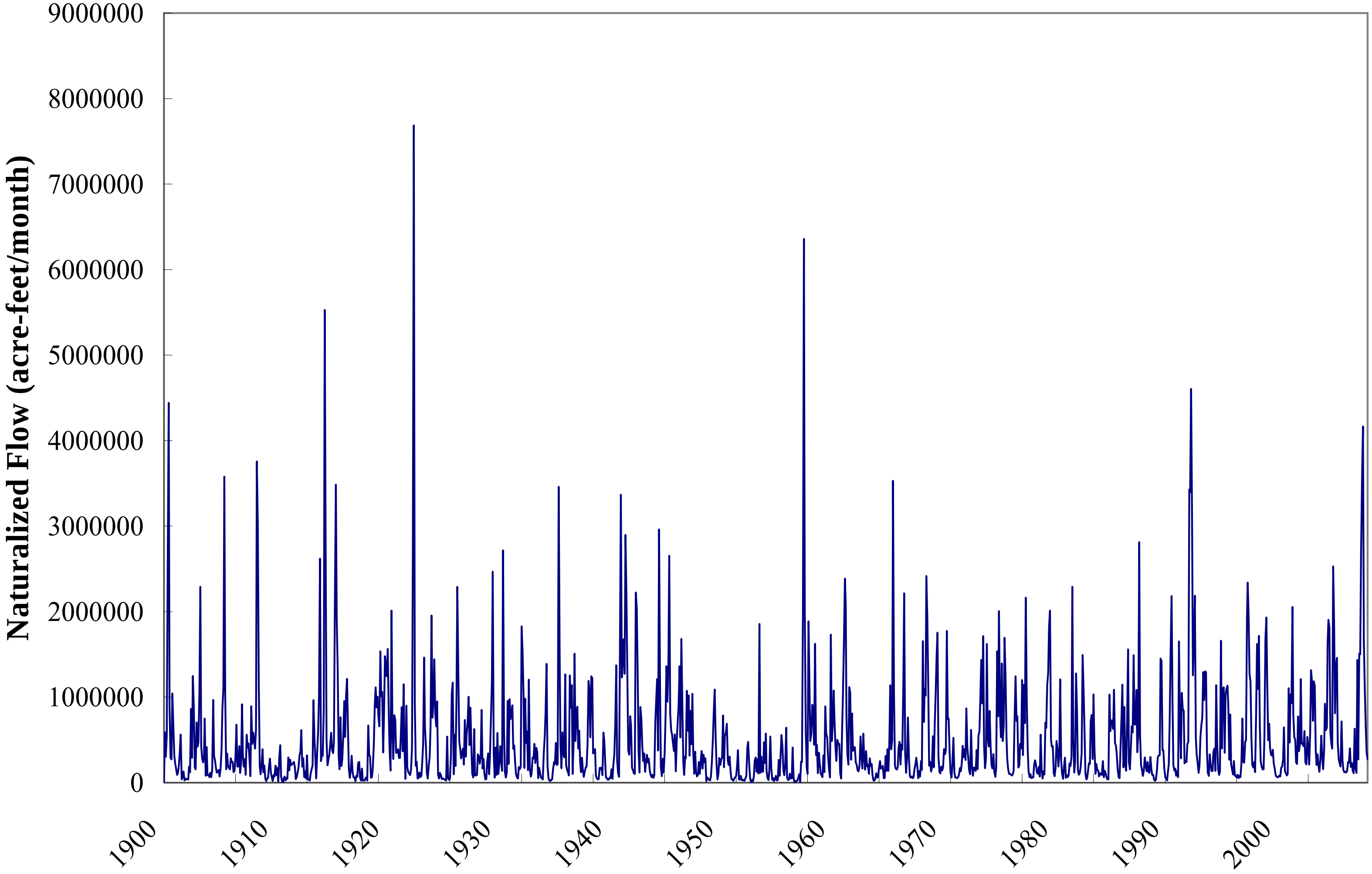

Figure A.72 Monthly Naturalized Flow at BRRO72 – Brazos River at Rosharon

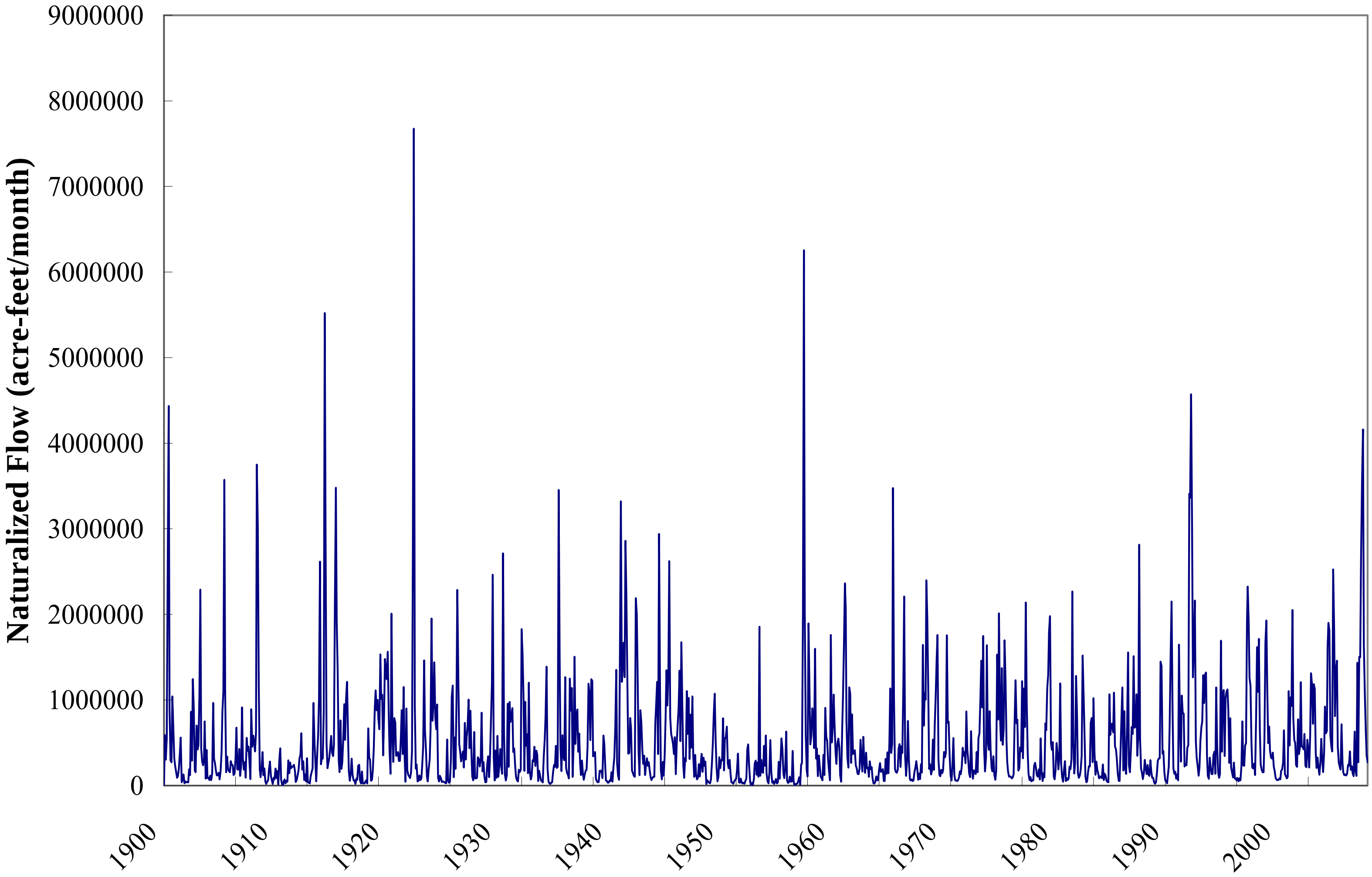

Figure A.73 Monthly Naturalized Flow at BRGM73 – Brazos River at Gulf of Mexico

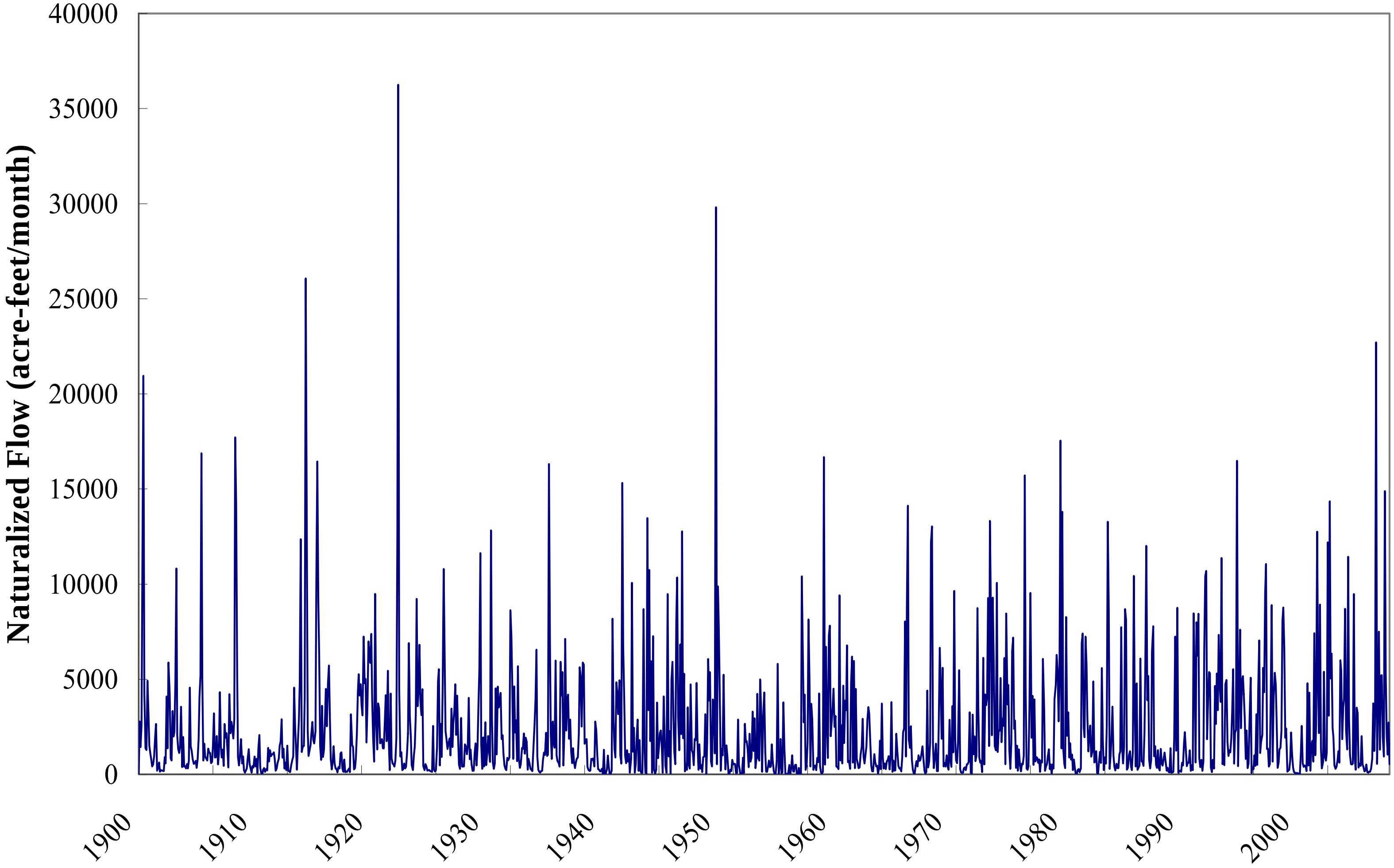

Figure A.74 Monthly Naturalized Flow at CLPEC1 – Clear Creek near Pearland

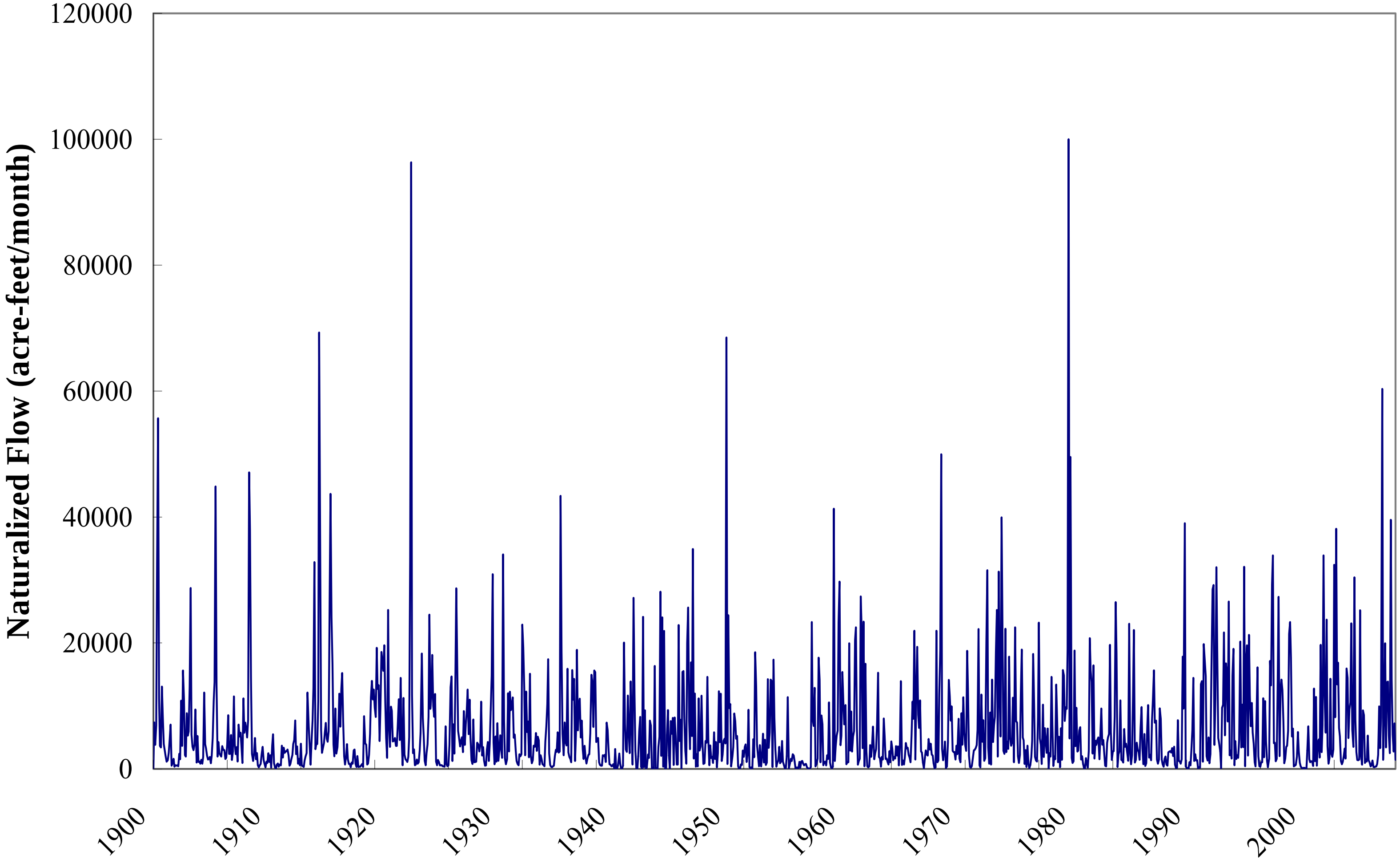

Figure A.75 Monthly Naturalized Flow at CBALC2 – Chocolate Bayou near Alvin

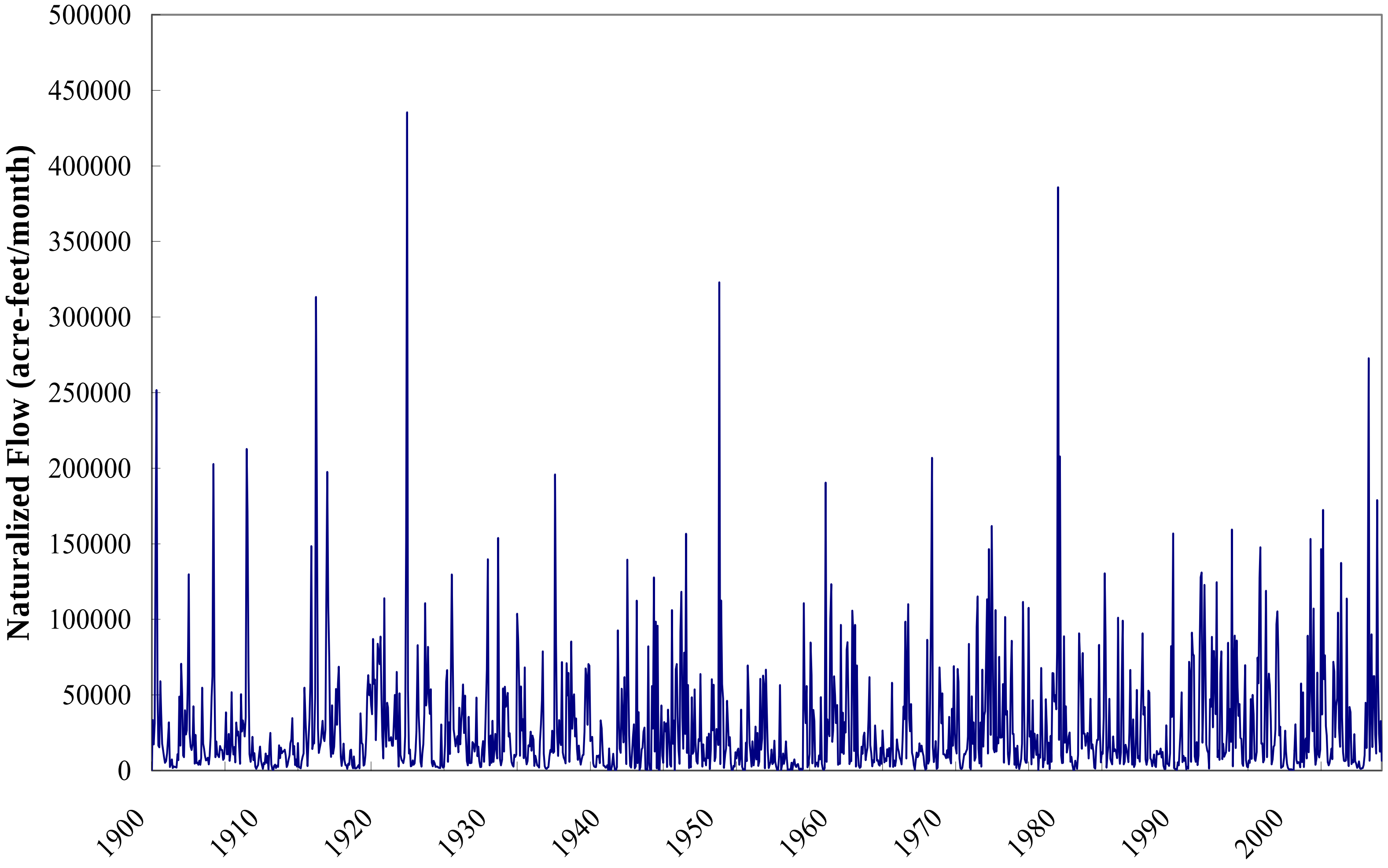

Figure A.76 Monthly Naturalized Flow at SJGBC3 – San Jacinto-Brazos Coastal Basin at Galveston Bay

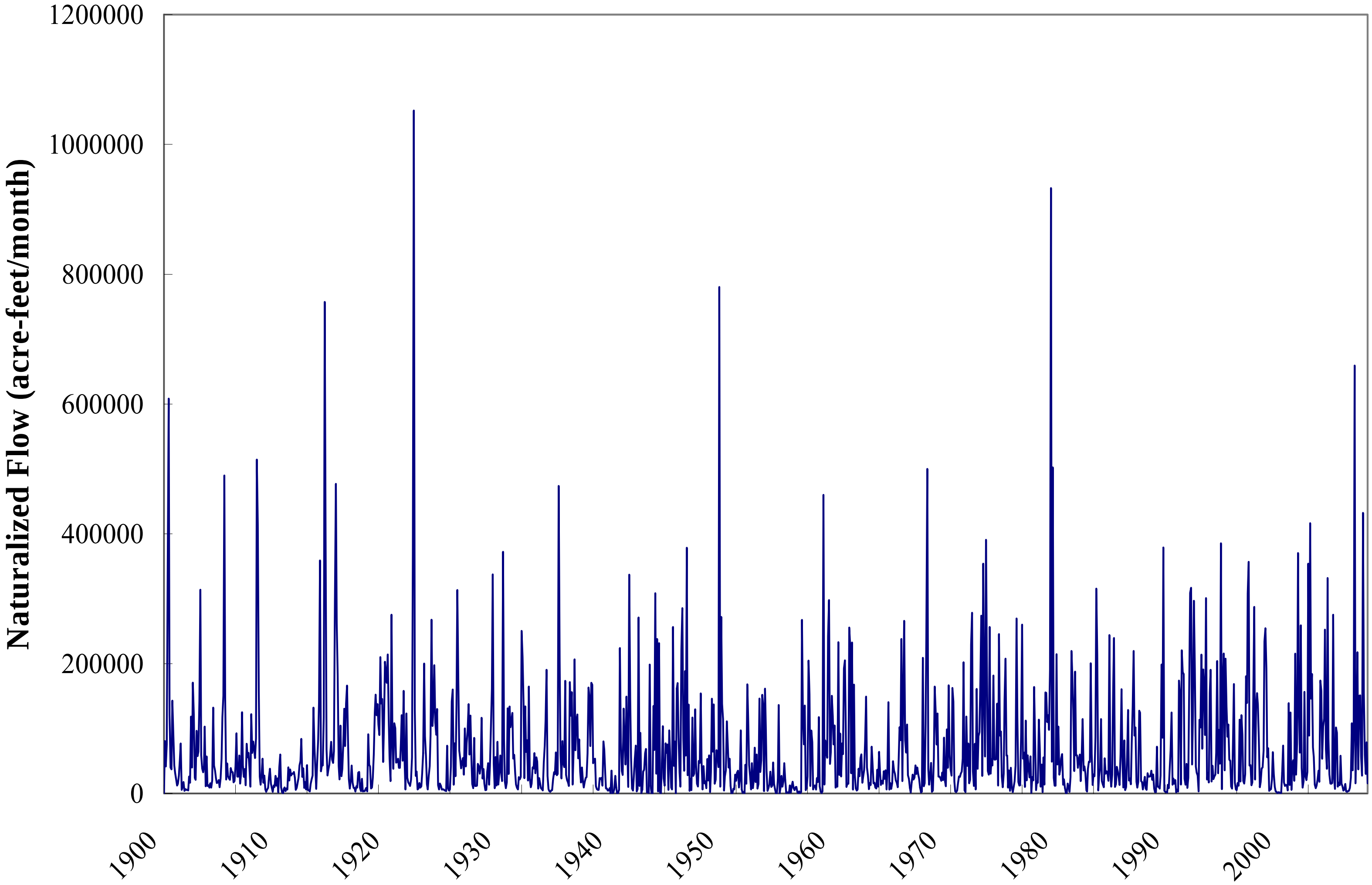

Figure A.77 Monthly Naturalized Flow at SJGMC4 – San Jacinto-Brazos Coastal Basin at the Gulf of Mexico

APPENDIX B

PLOTS OF 1998-2007 GAGED AND NATURALIZED FLOWS AT 48 CONTROL POINTS

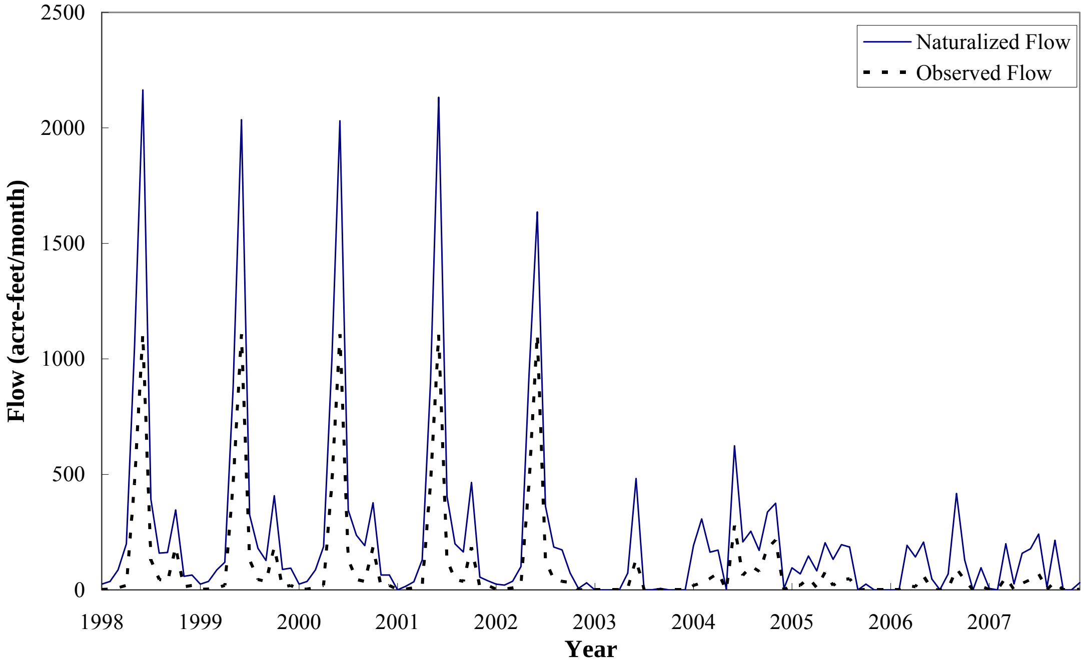

Figure B.1 Monthly Naturalized and Observed Flows at RWPL01

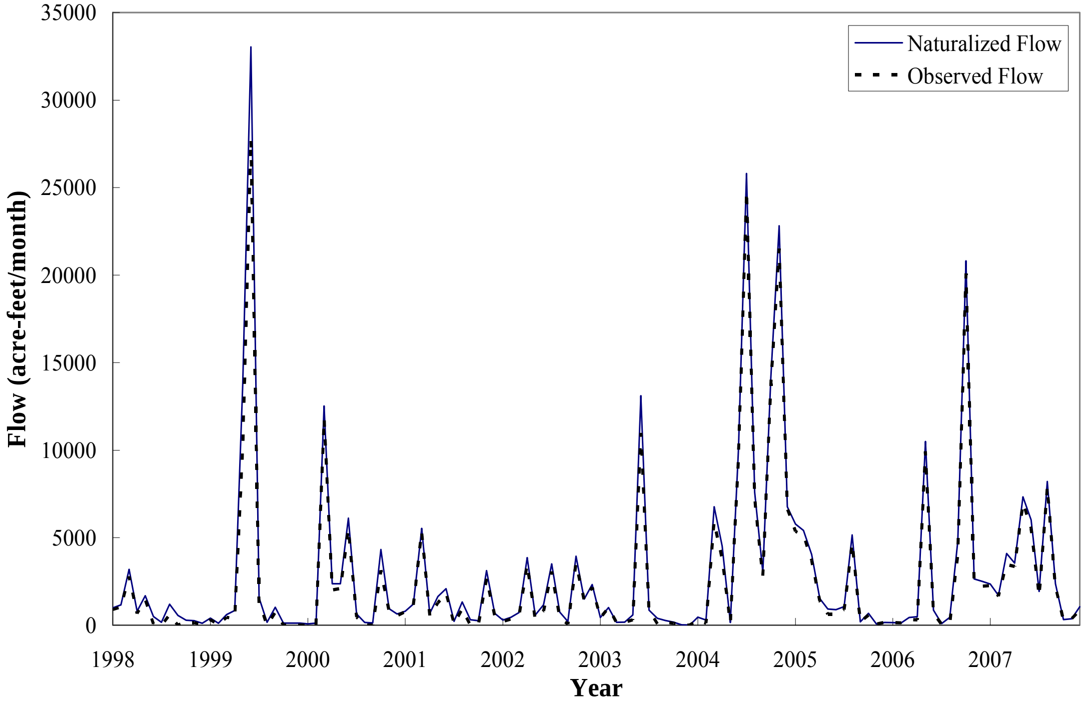

Figure B.2 Monthly Naturalized and Observed Flows at SFAS06

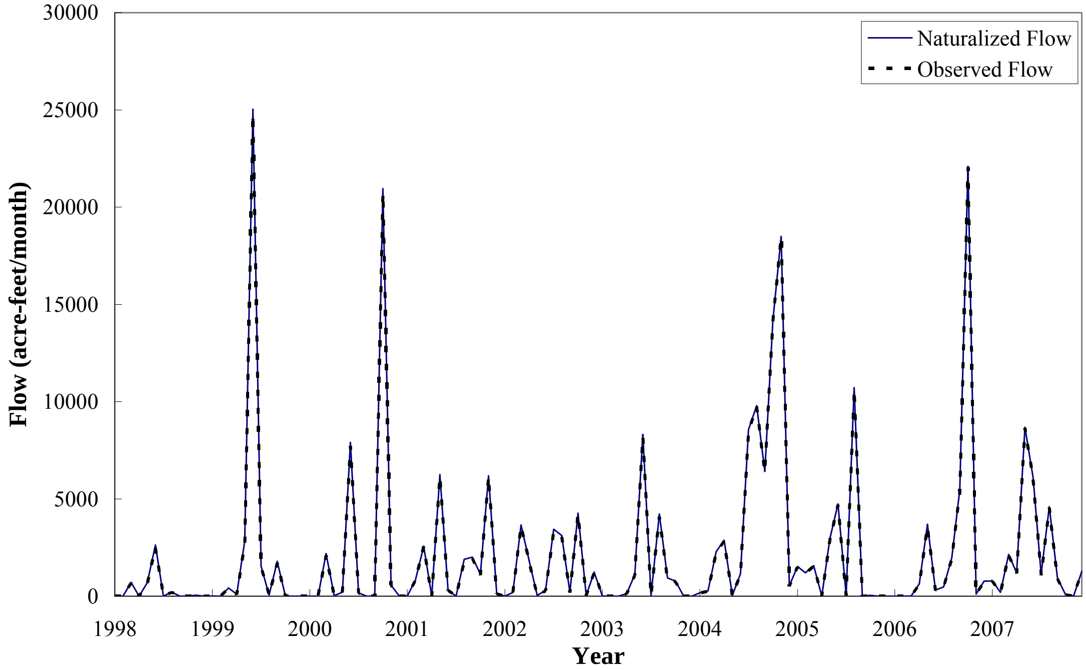

Figure B.3 Monthly Naturalized and Observed Flows at DMJU08

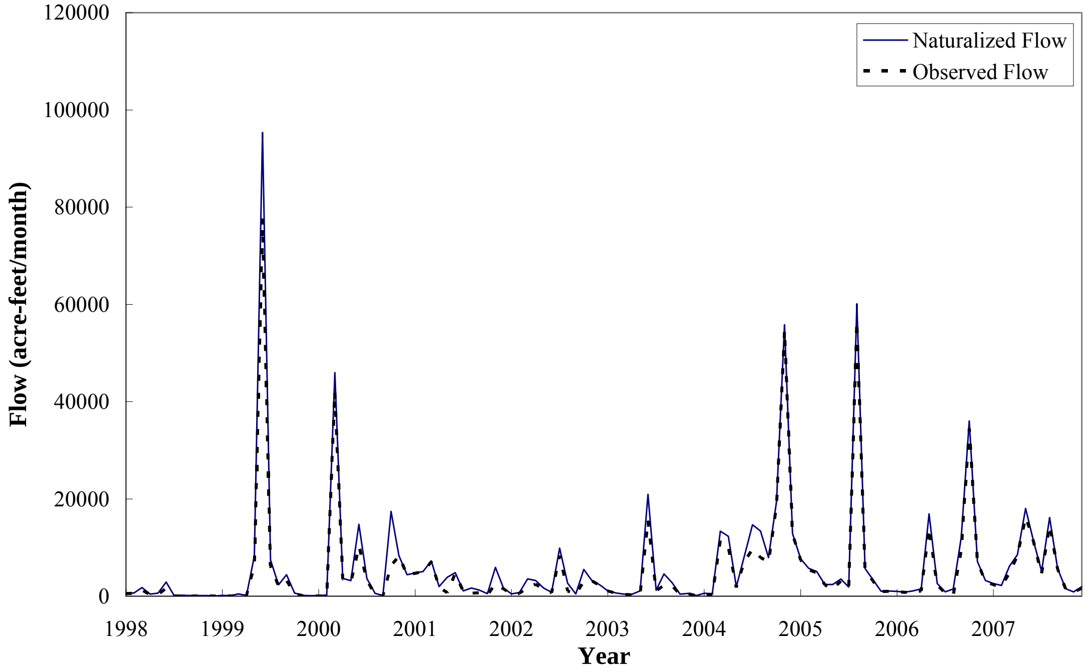

Figure B.4 Monthly Naturalized and Observed Flows at DMAS09

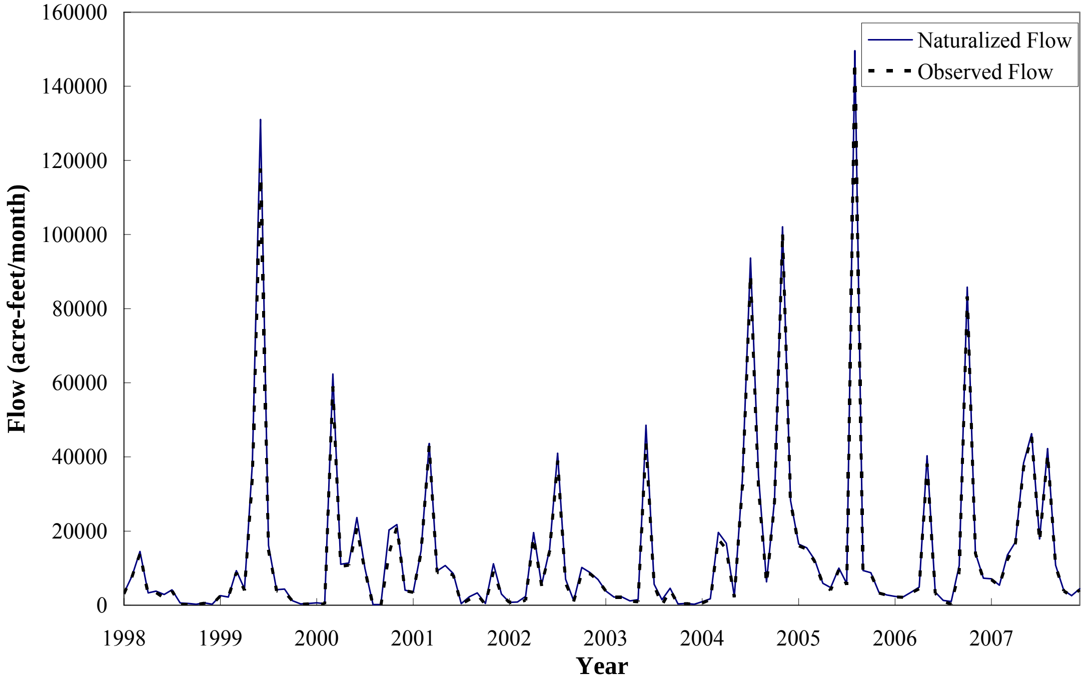

Figure B.5 Monthly Naturalized and Observed Flows at BRSE11

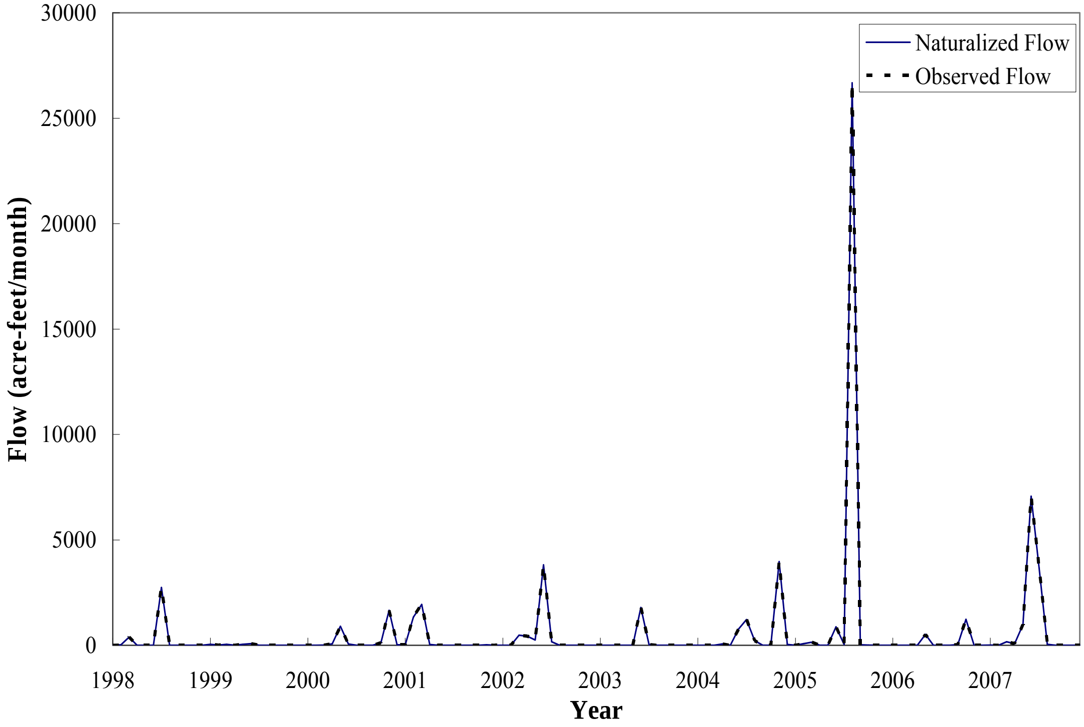

Figure B.6 Monthly Naturalized and Observed Flows at MSMN12

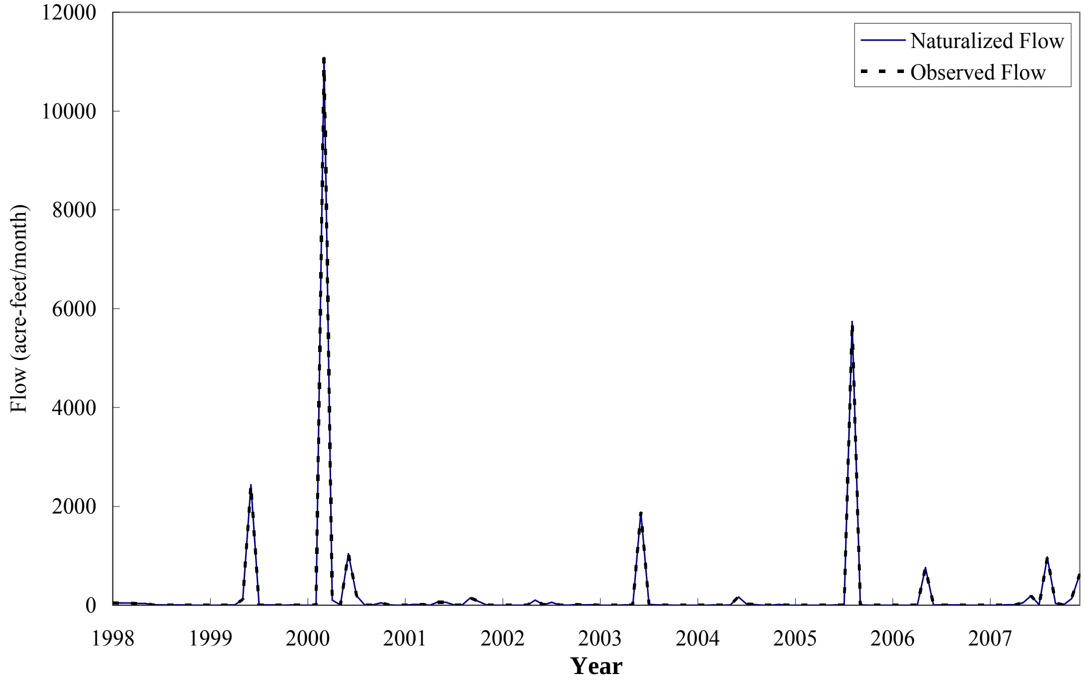

Figure B.7 Monthly Naturalized and Observed Flows at CFRO13

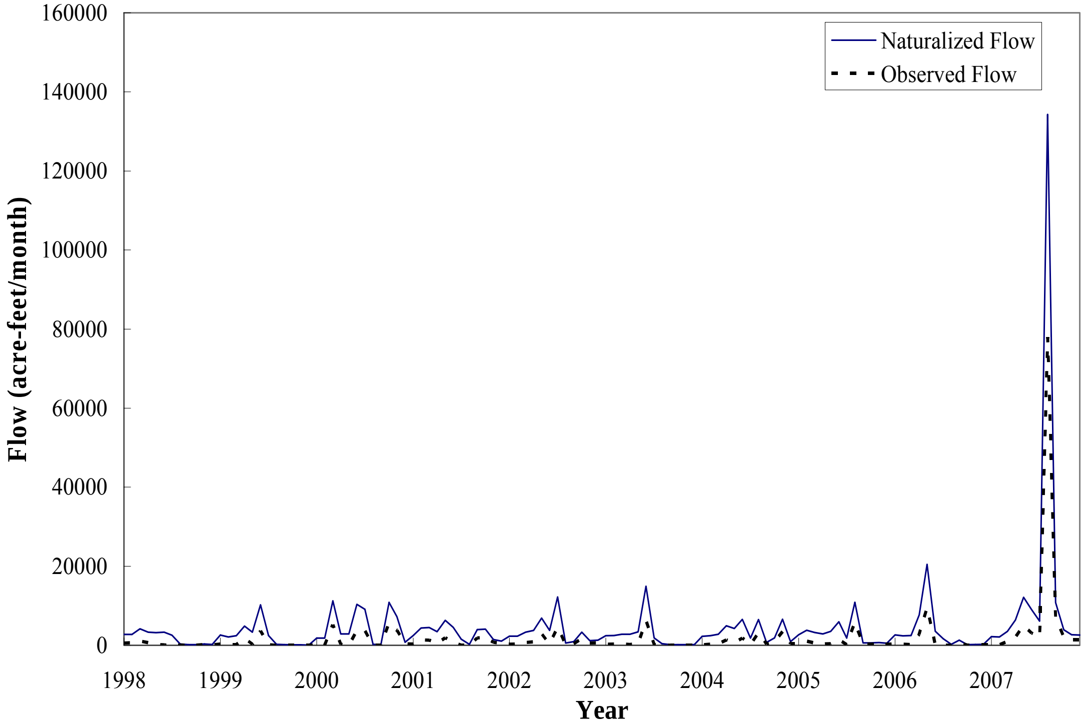

Figure B.8 Monthly Naturalized and Observed Flows at CFNU16

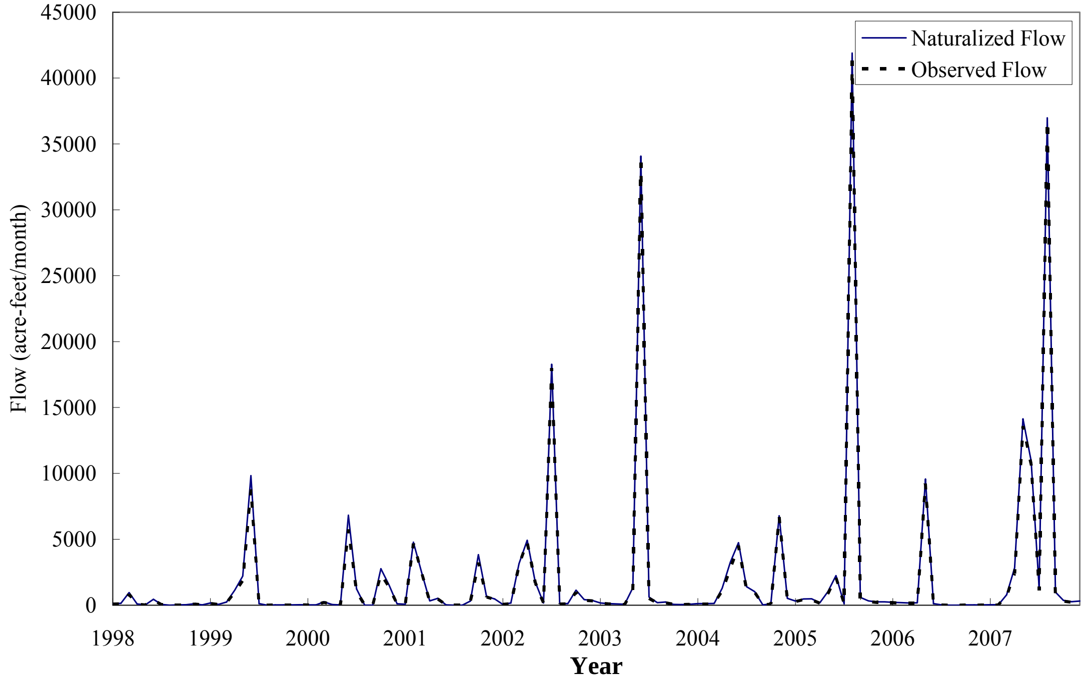

Figure B.9 Monthly Naturalized and Observed Flows at CAST17

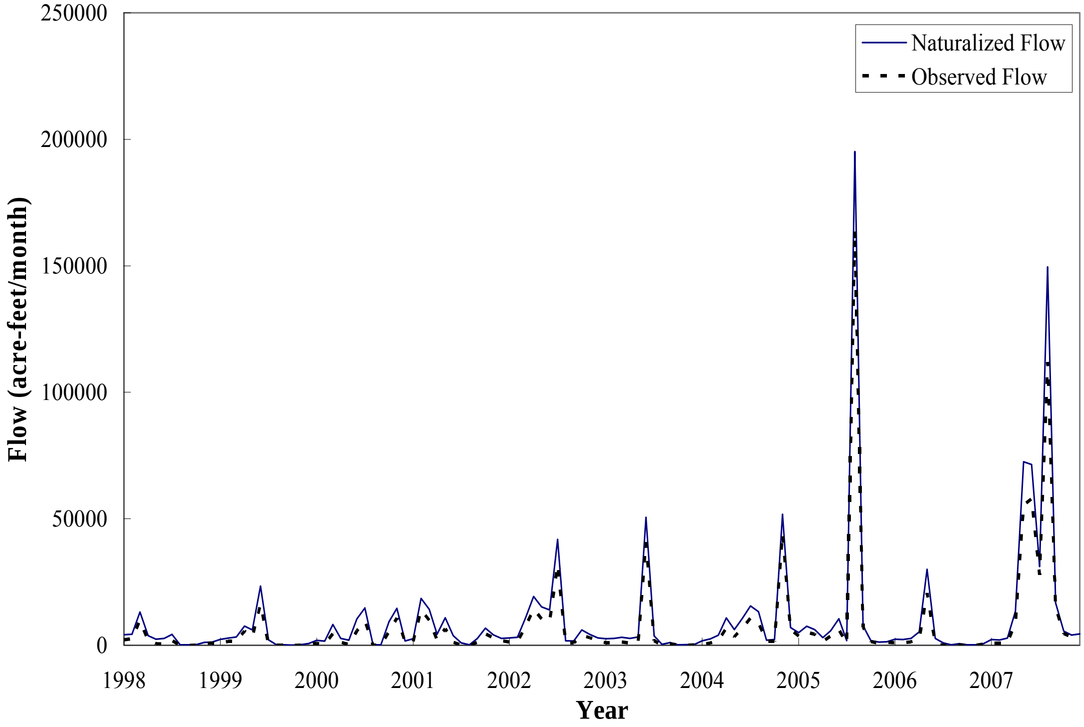

Figure B.10 Monthly Naturalized and Observed Flows at CFFG18

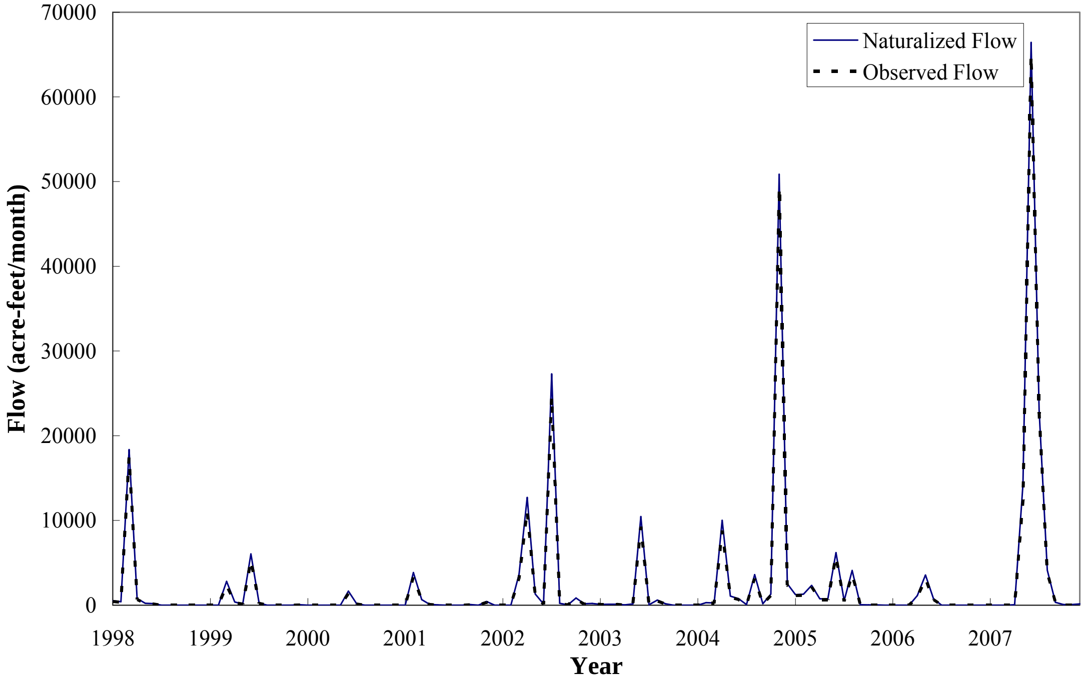

Figure B.11 Monthly Naturalized and Observed Flows at HCAL19

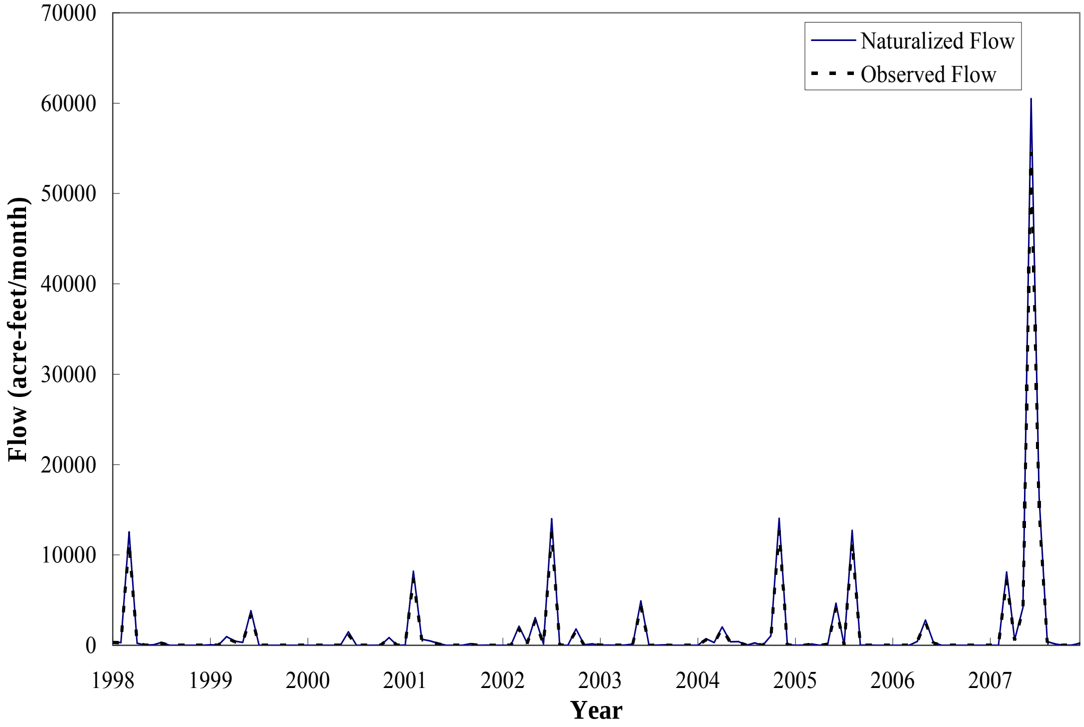

Figure B.12 Monthly Naturalized and Observed Flows at BSBR20

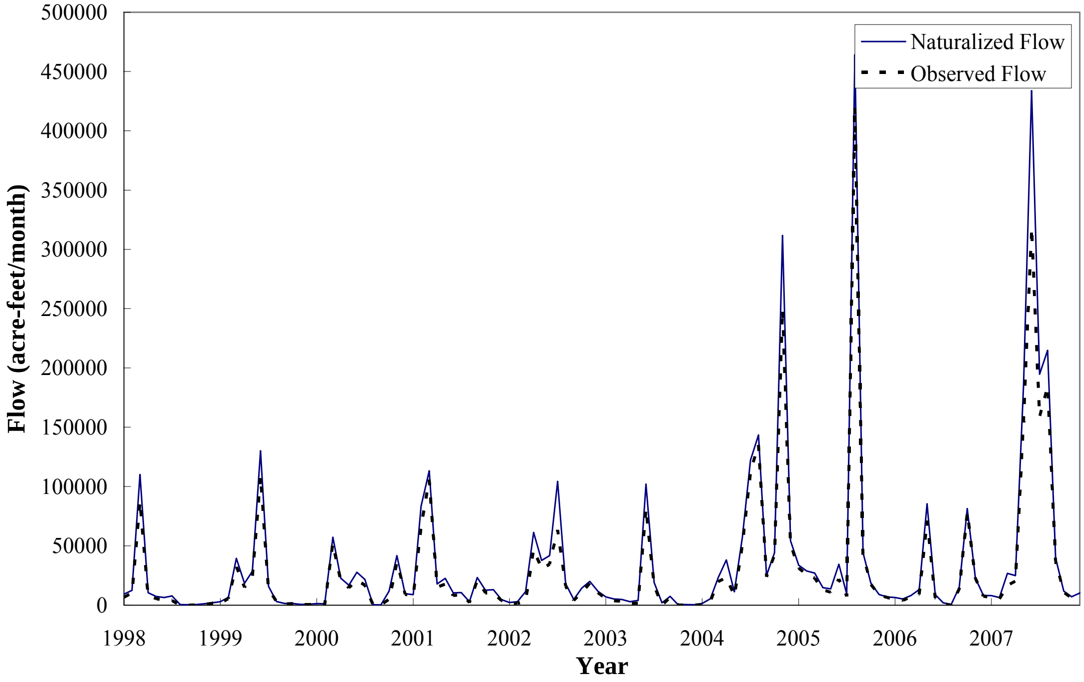

Figure B.13 Monthly Naturalized and Observed Flows at BRSB23

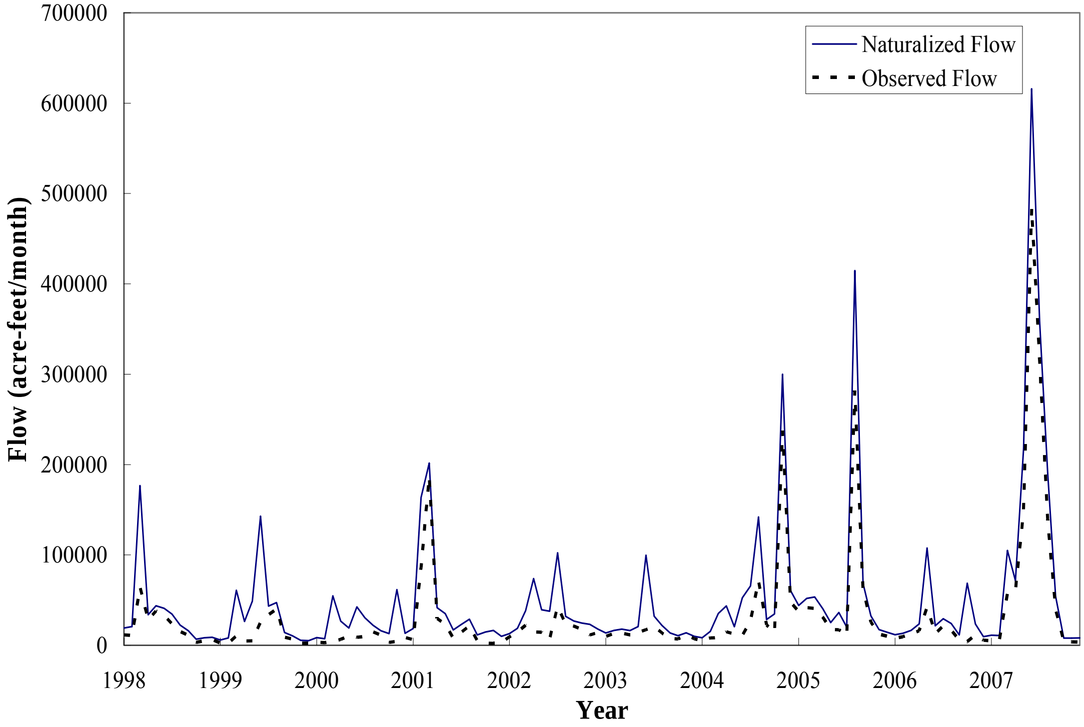

Figure B.14 Monthly Naturalized and Observed Flows at BRPP27

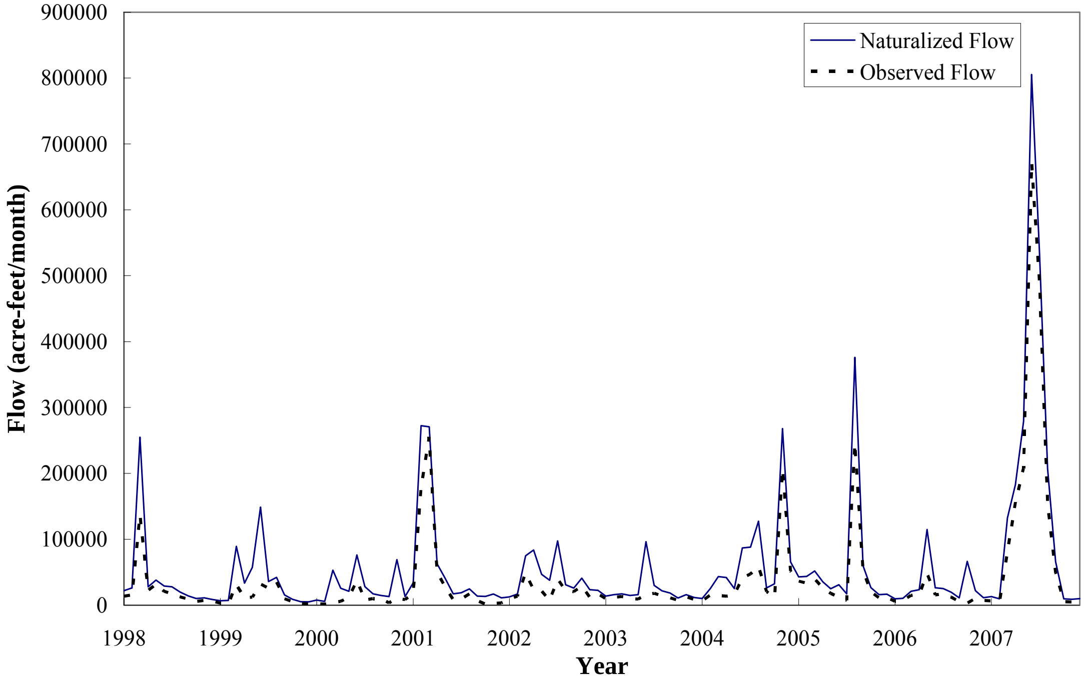

Figure B.15 Monthly Naturalized and Observed Flows at BRDE29

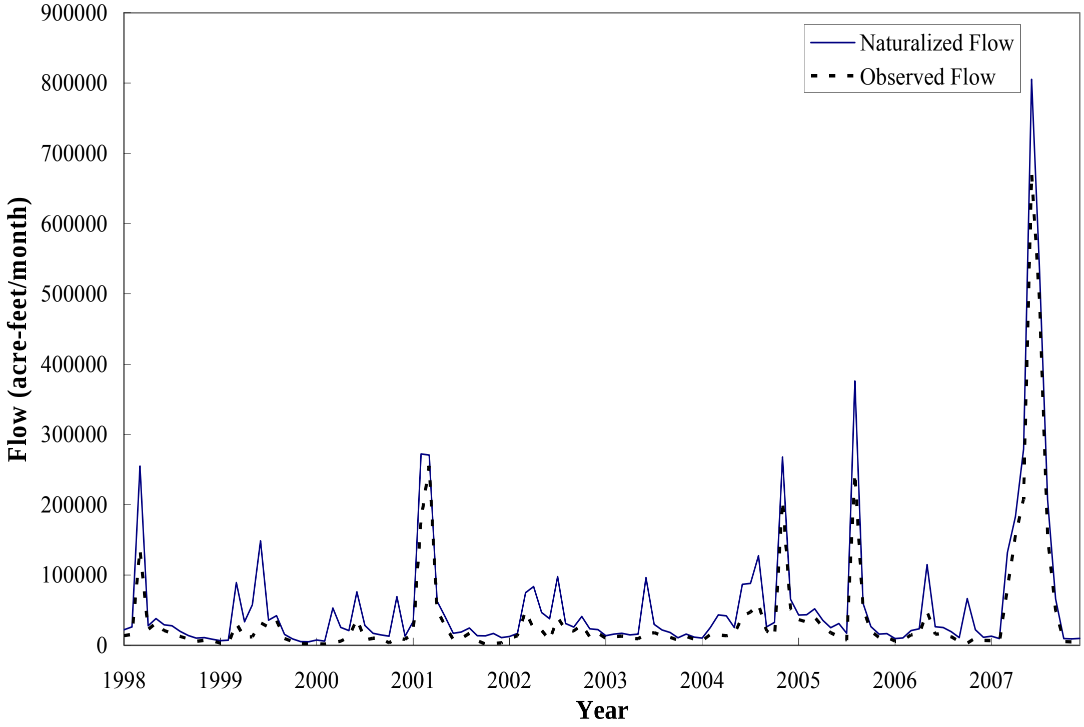

Figure B.16 Monthly Naturalized and Observed Flows at BRGR30

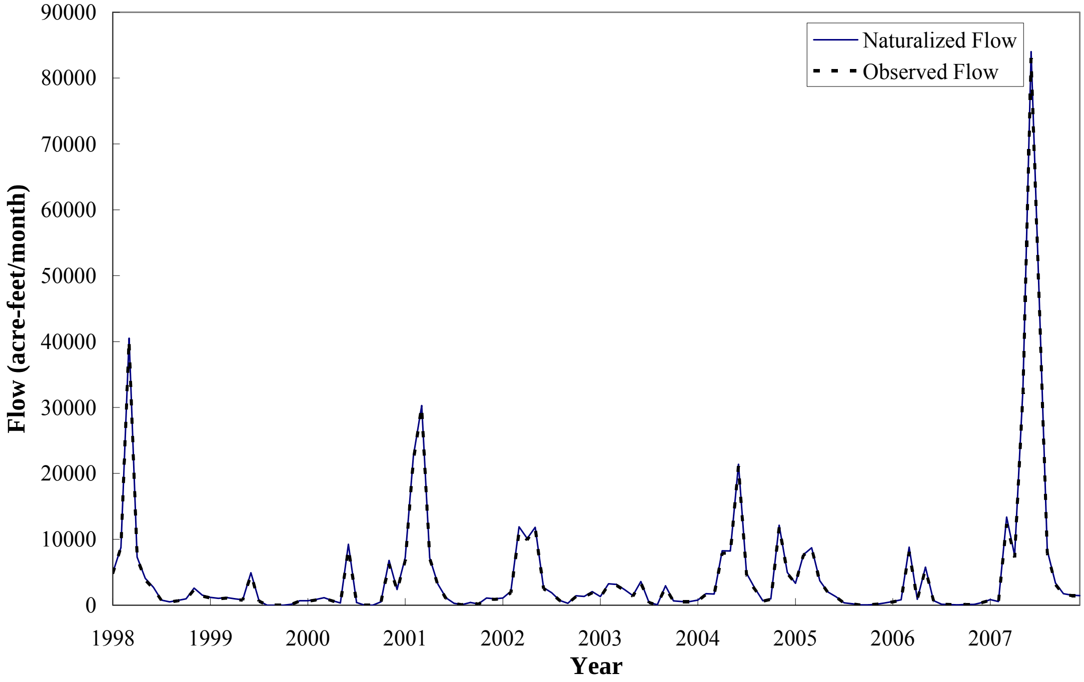

Figure B.17 Monthly Naturalized and Observed Flows at PAGR31

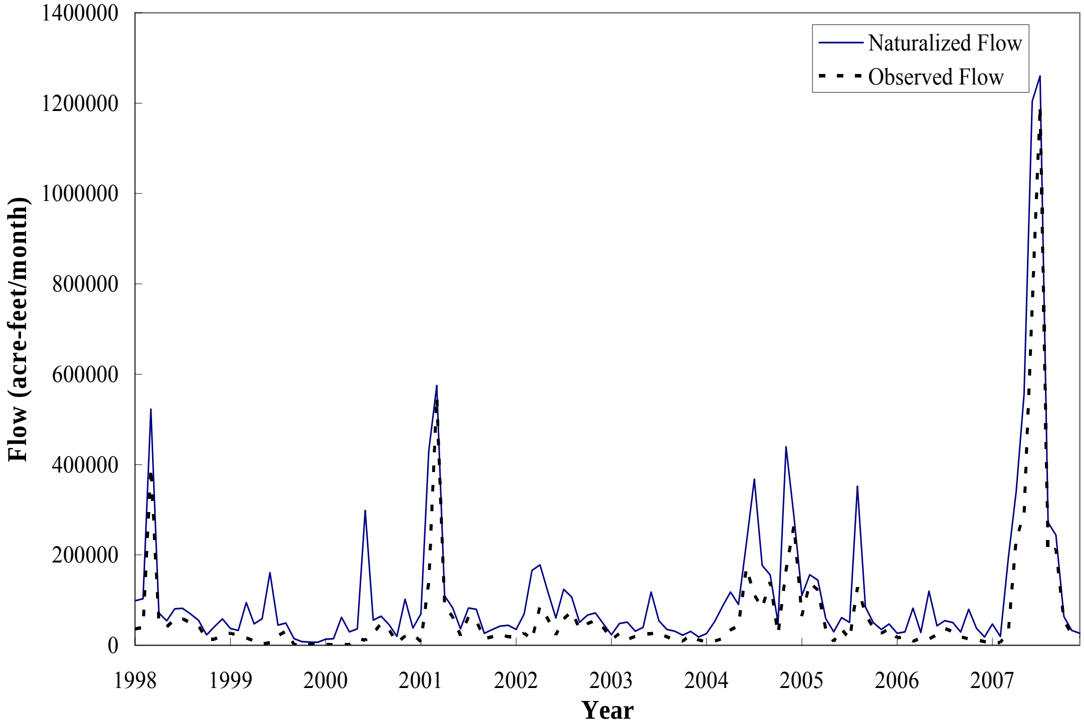

Figure B.18 Monthly Naturalized and Observed Flows at BRAQ33

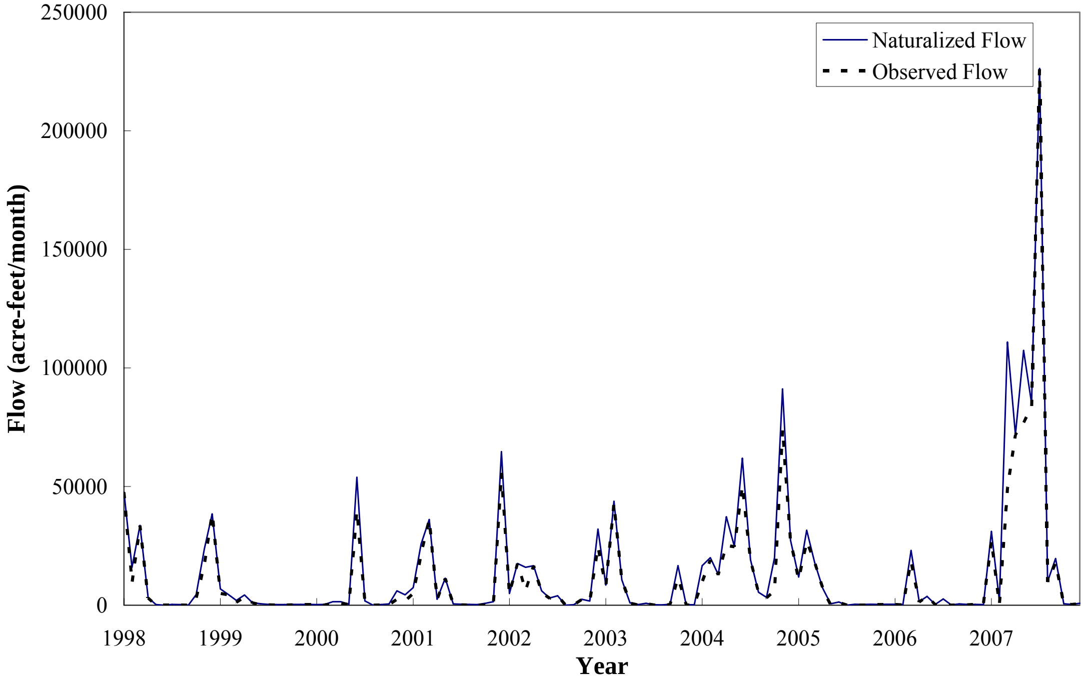

Figure B.19 Monthly Naturalized and Observed Flows at AQAQ34

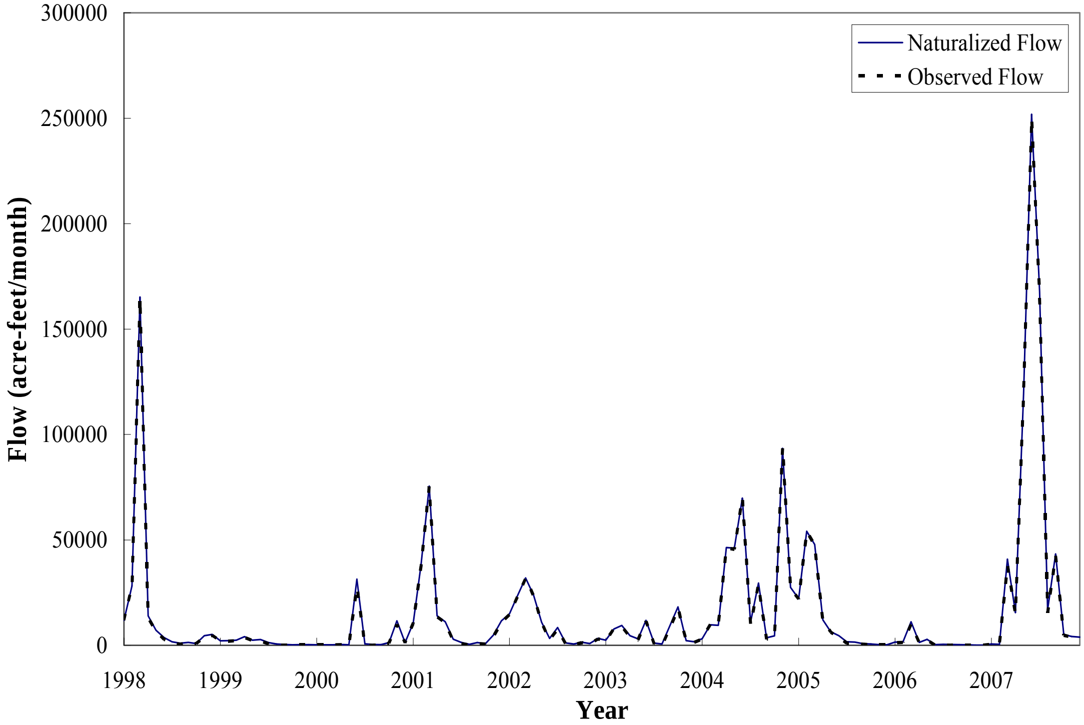

Figure B.20 Monthly Naturalized and Observed Flows at NBCL36

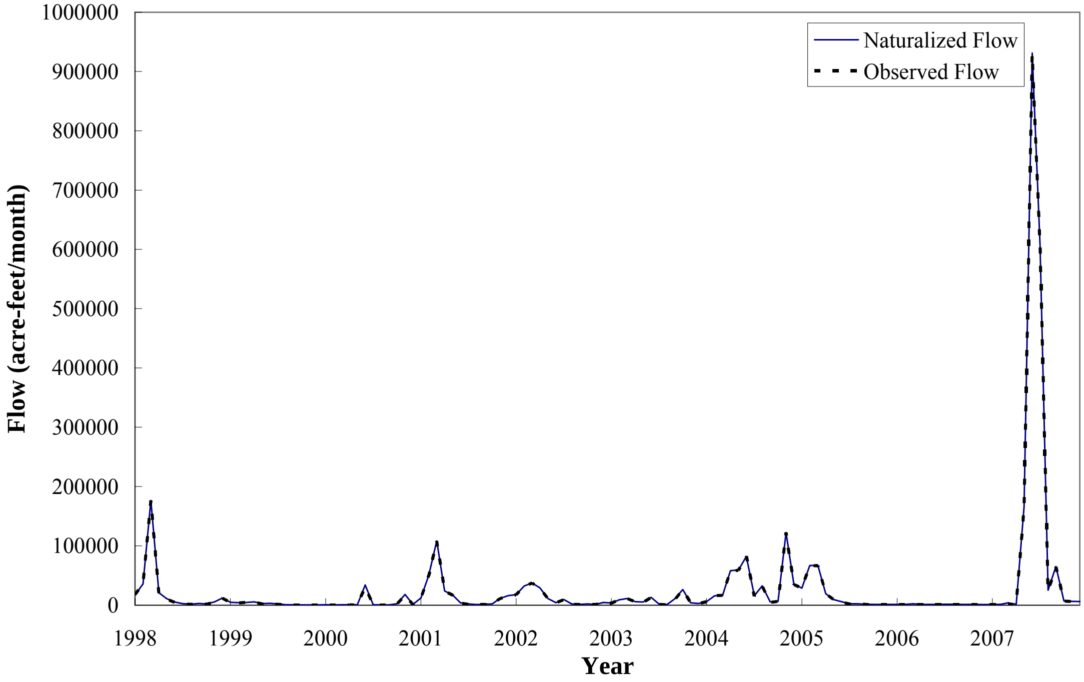

Figure B.21 Monthly Naturalized and Observed Flows at NBVM37

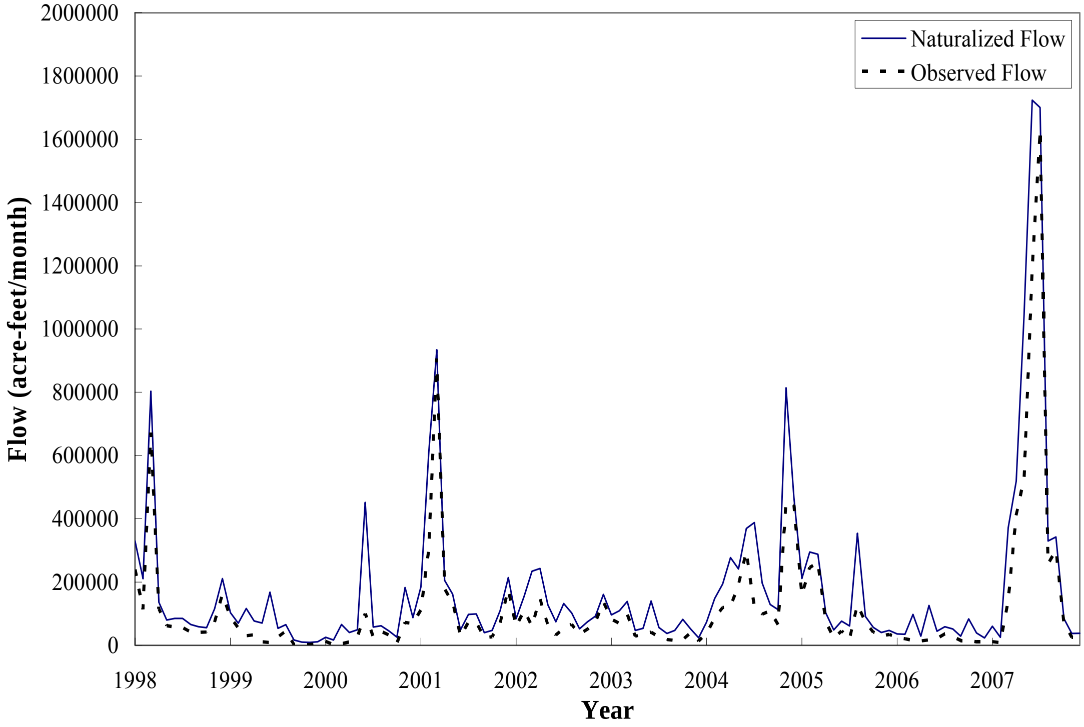

Figure B.22 Monthly Naturalized and Observed Flows at BRWA41

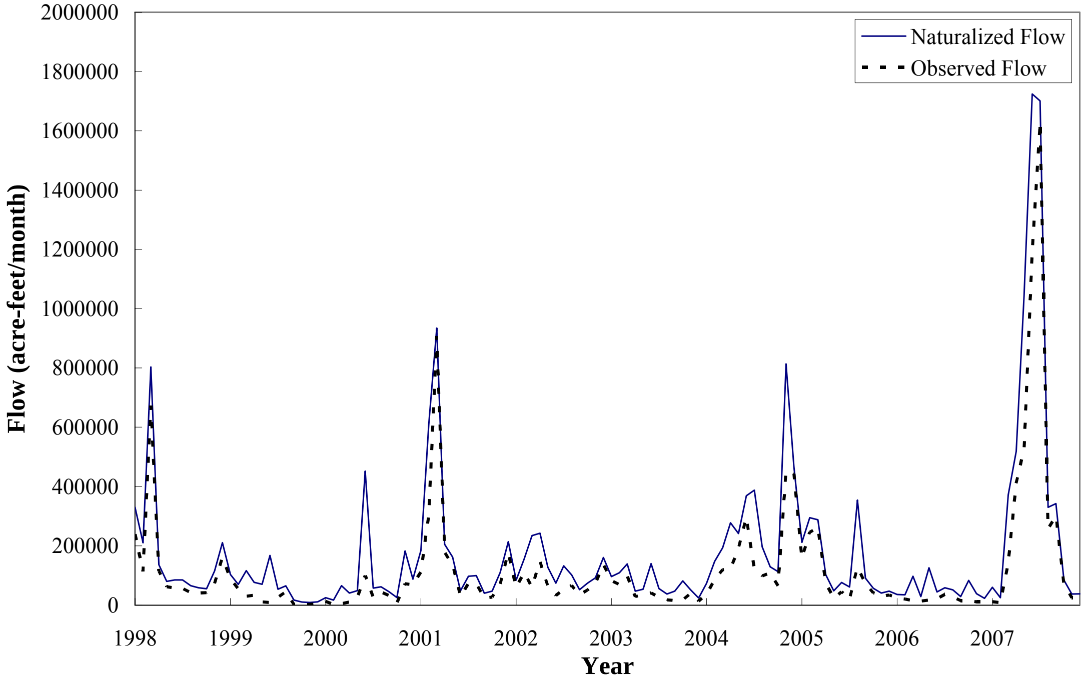

Figure B.23 Monthly Naturalized and Observed Flows at BRHB42

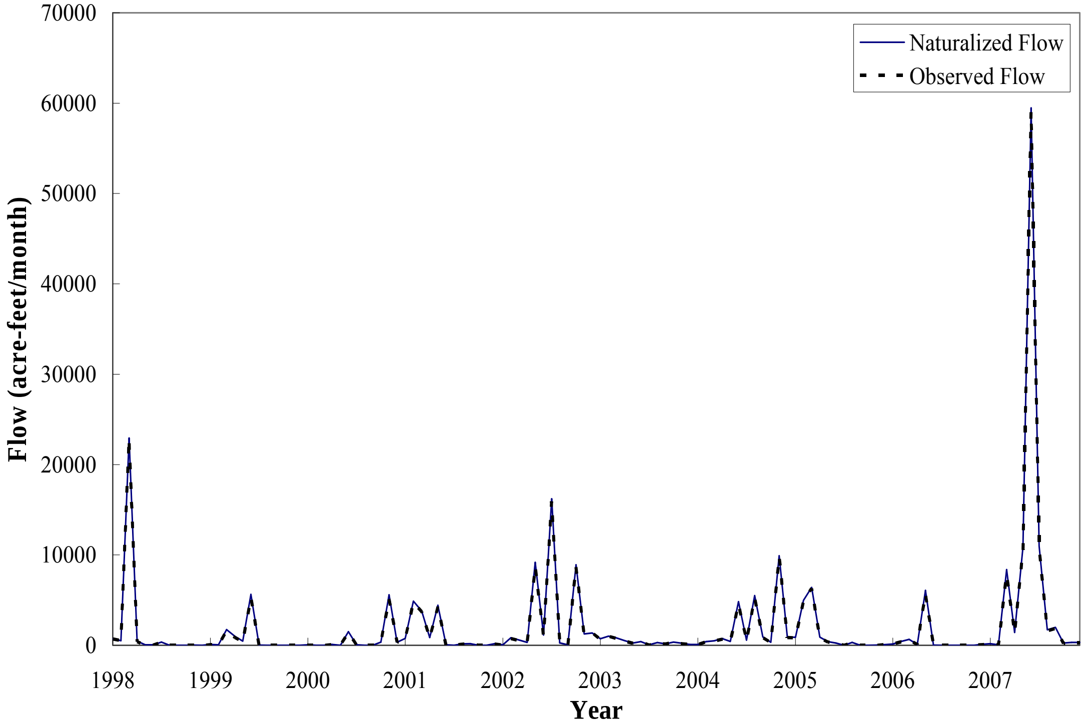

Figure B.24 Monthly Naturalized and Observed Flows at SADL44

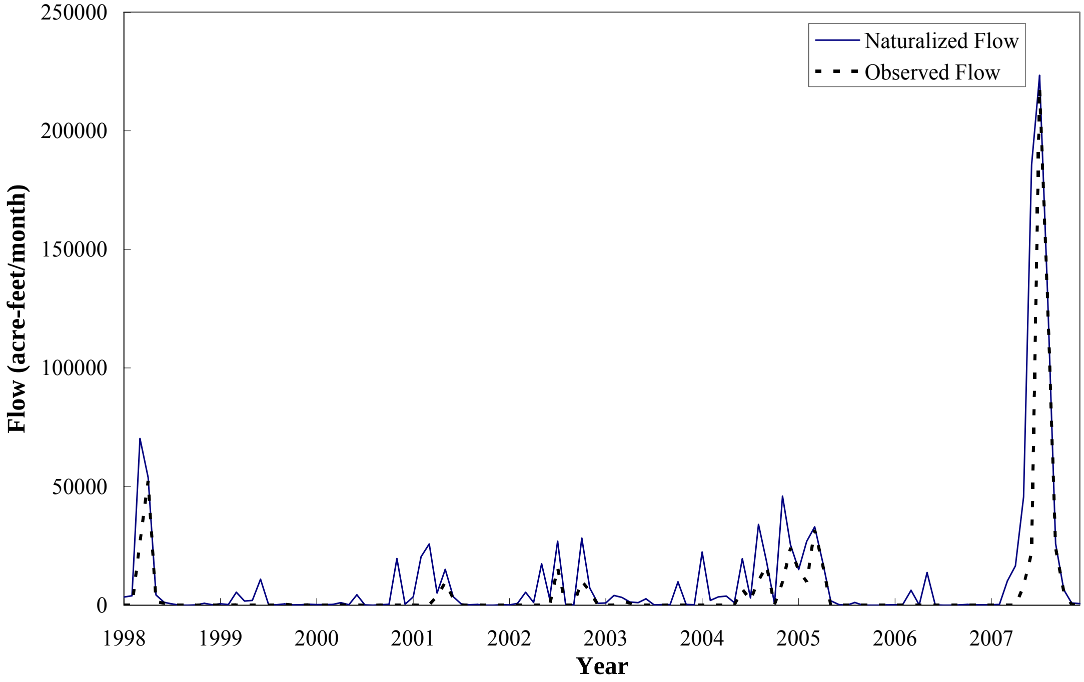

Figure B.25 Monthly Naturalized and Observed Flows at LEHS45

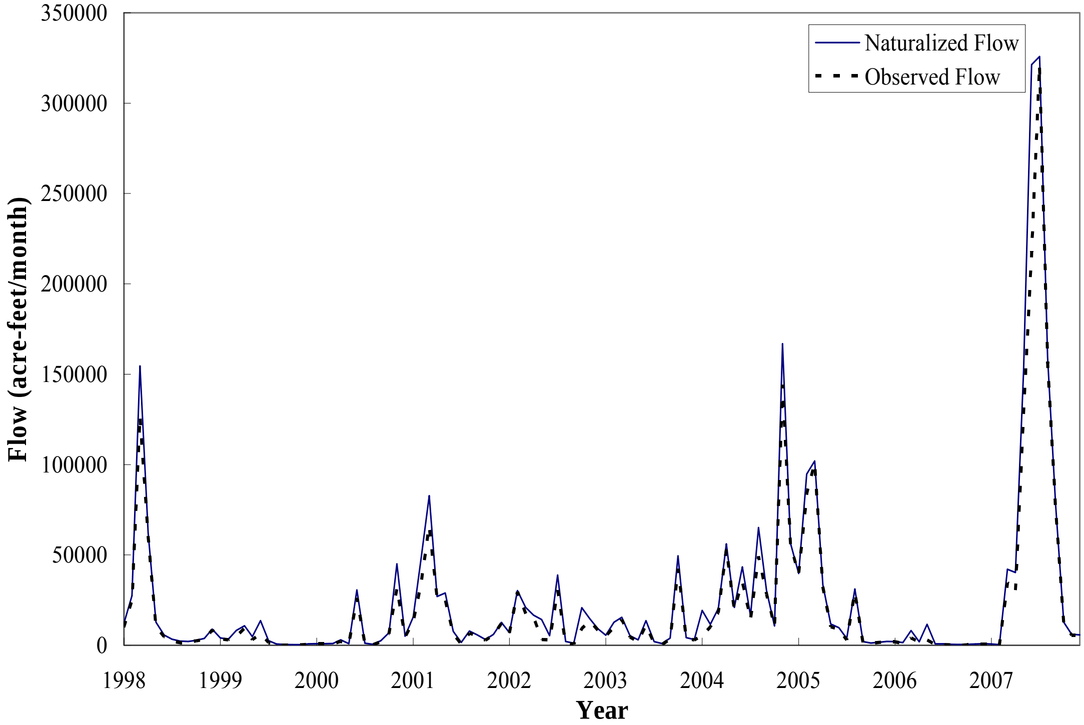

Figure B.26 Monthly Naturalized and Observed Flows at LEGT47

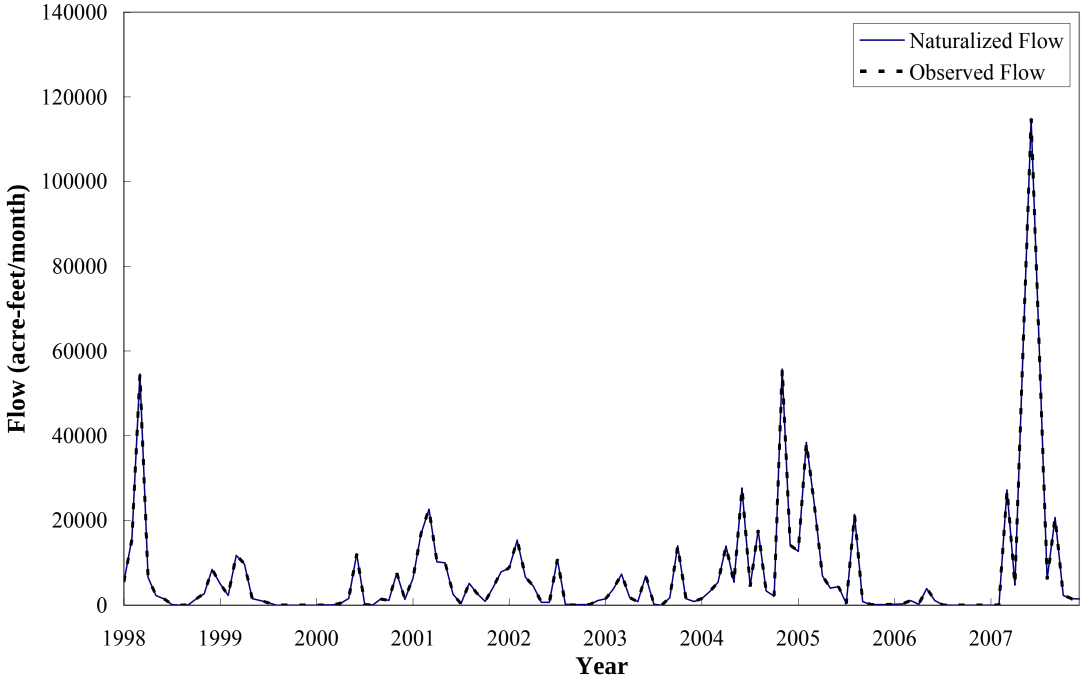

Figure B.27 Monthly Naturalized and Observed Flows at COPI48

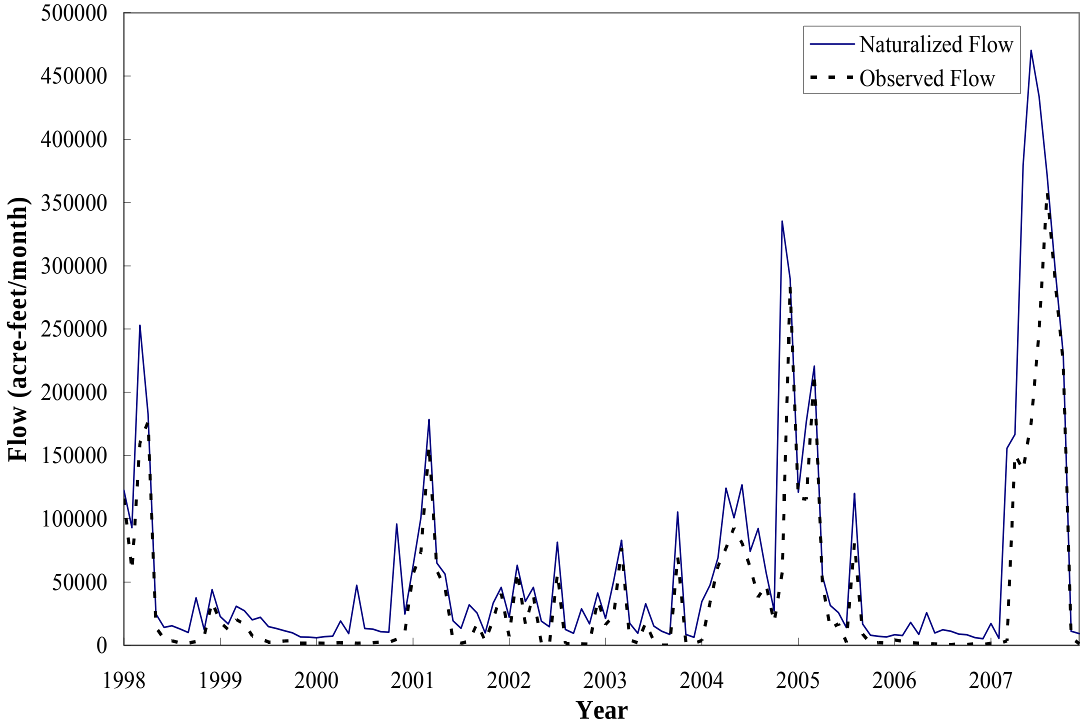

Figure B.28 Monthly Naturalized and Observed Flows at LEBE49

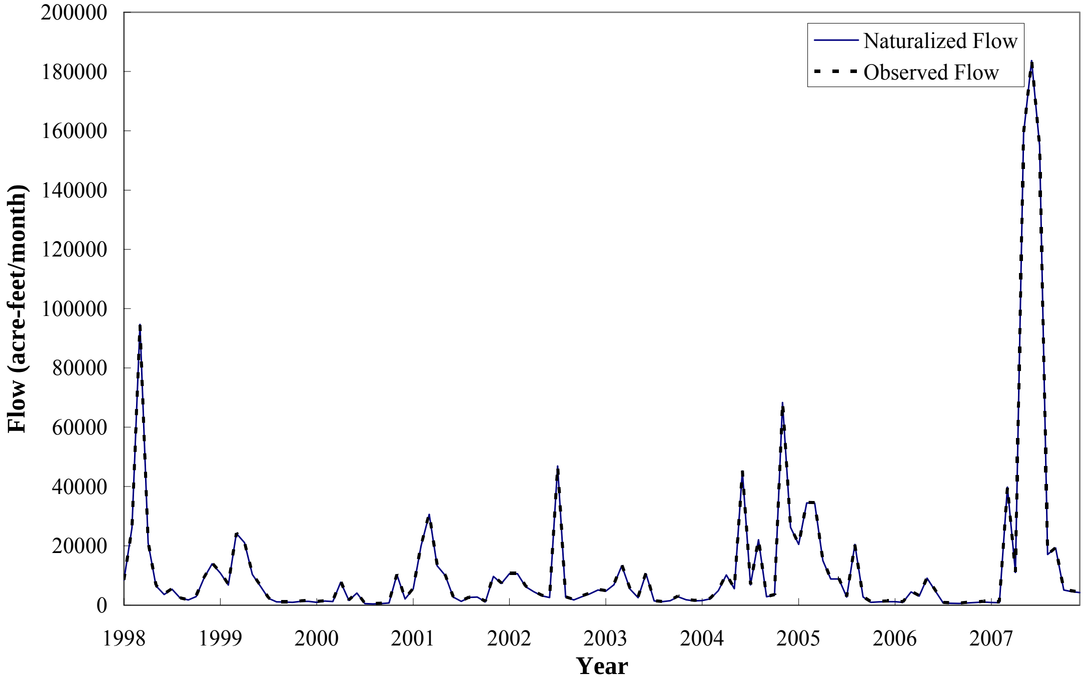

Figure B.29 Monthly Naturalized and Observed Flows at LAKE50

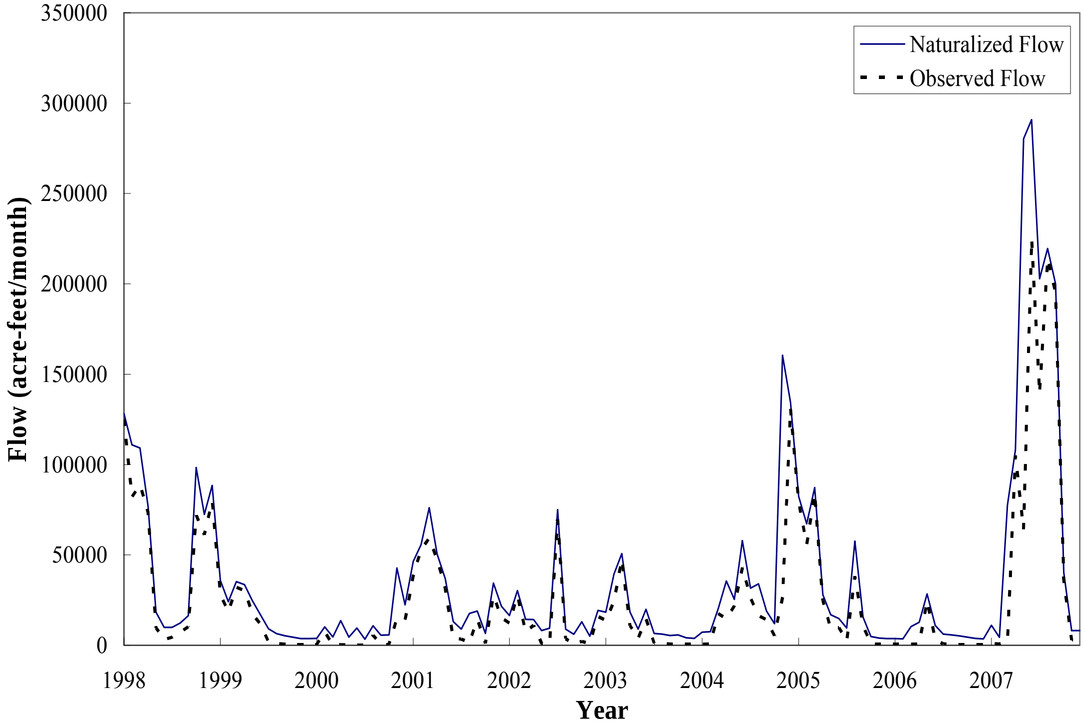

Figure B.30 Monthly Naturalized and Observed Flows at LABE52

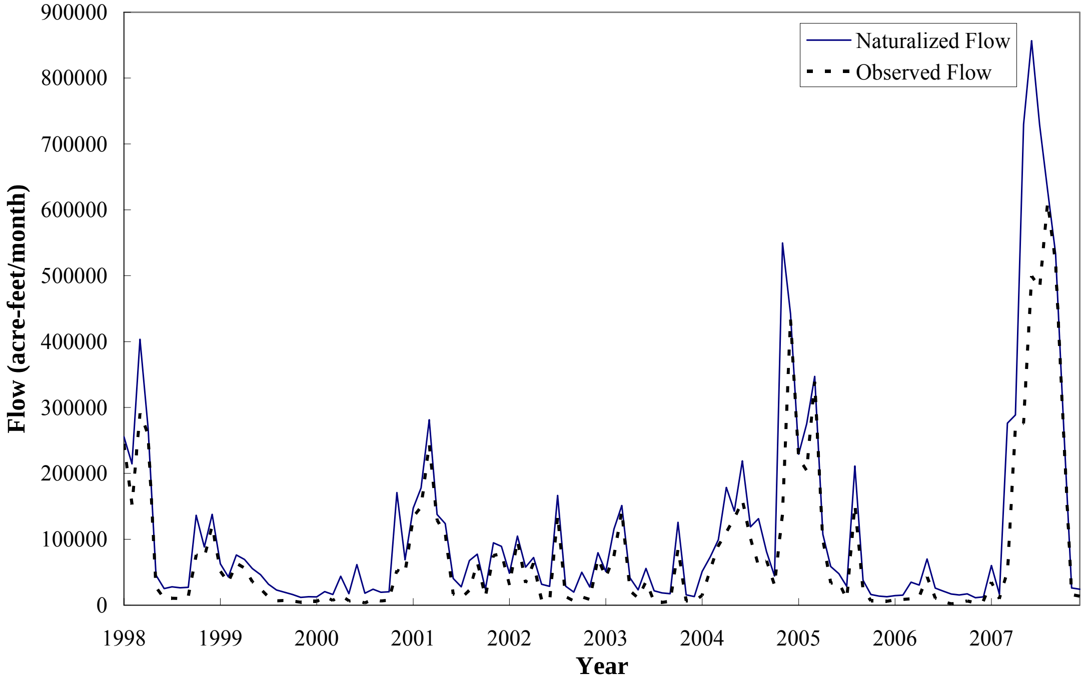

Figure B.31 Monthly Naturalized and Observed Flows at LRLR53

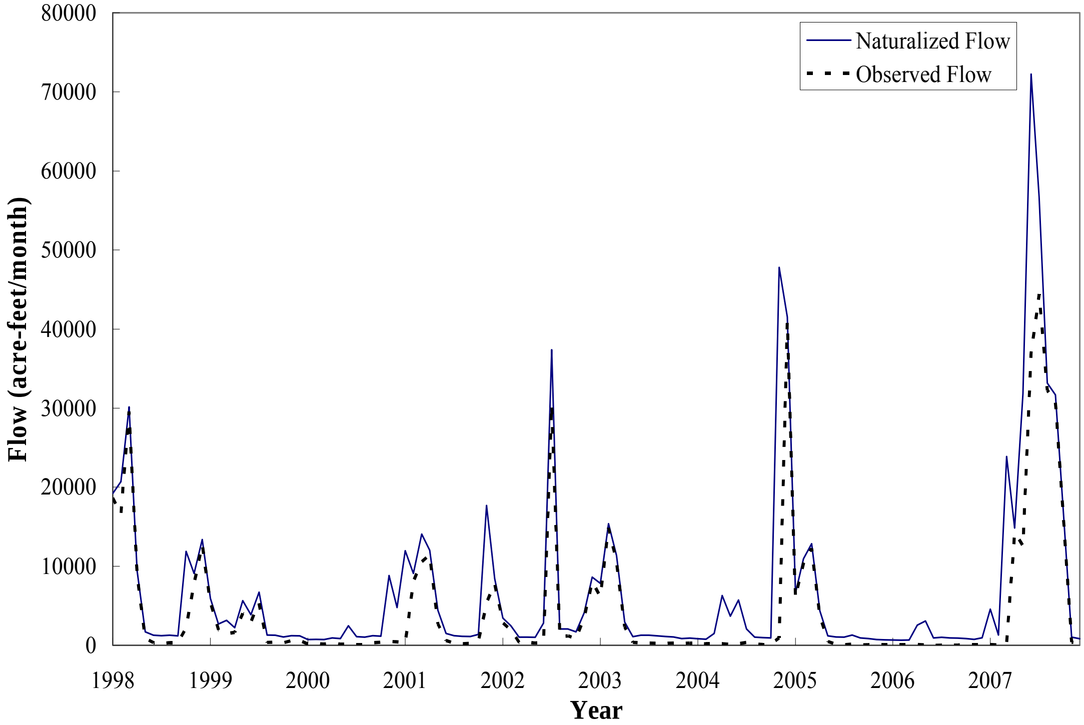

Figure B.32 Monthly Naturalized and Observed Flows at NGGE54

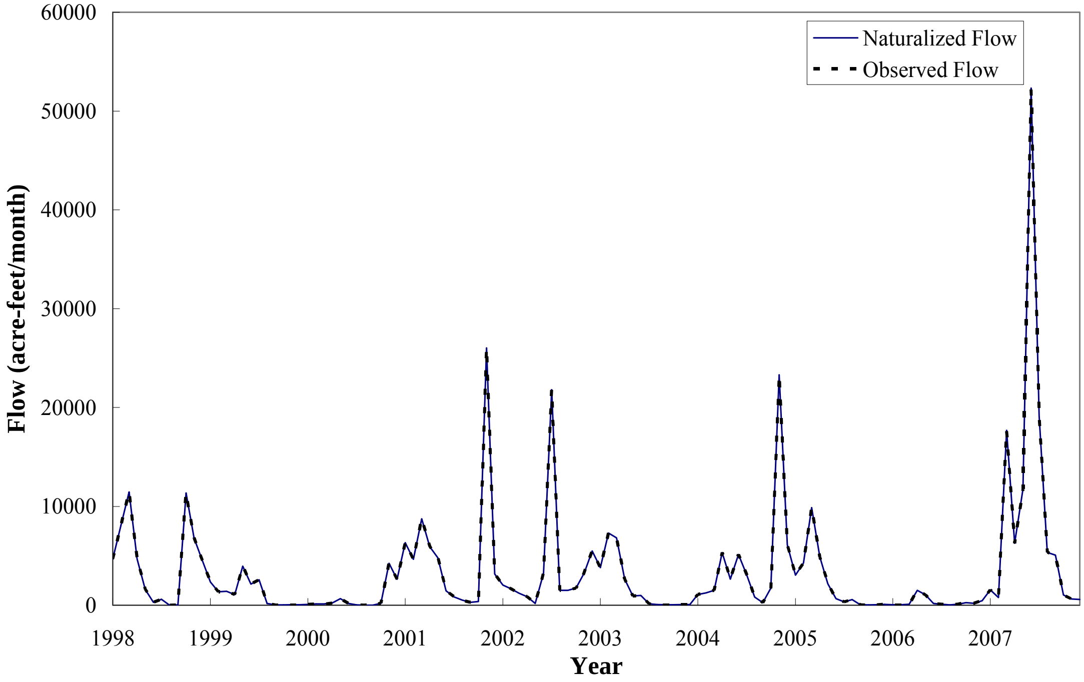

Figure B.33 Monthly Naturalized and Observed Flows at SGGE55

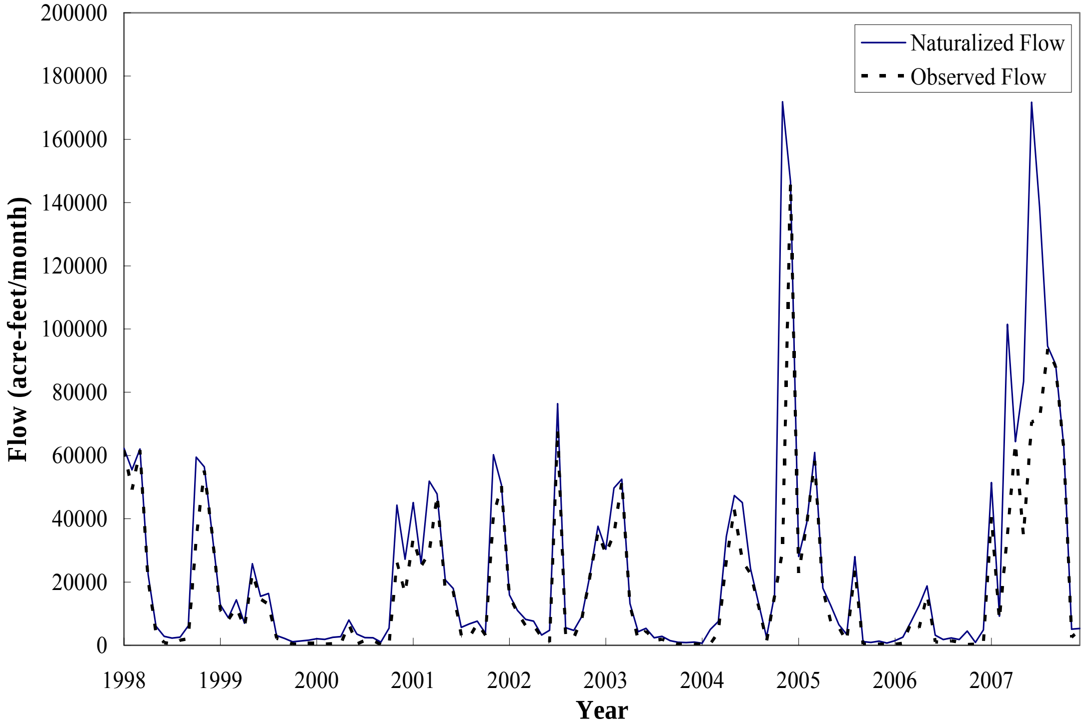

Figure B.34 Monthly Naturalized and Observed Flows at GALA57

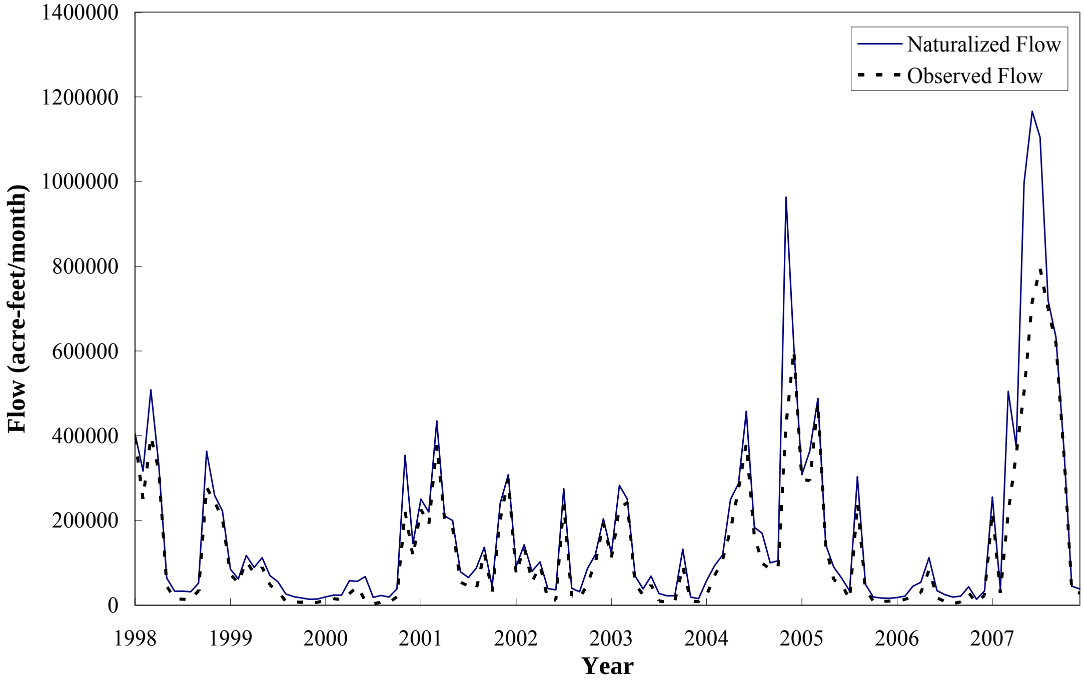

Figure B.35 Monthly Naturalized and Observed Flows at LRCA58

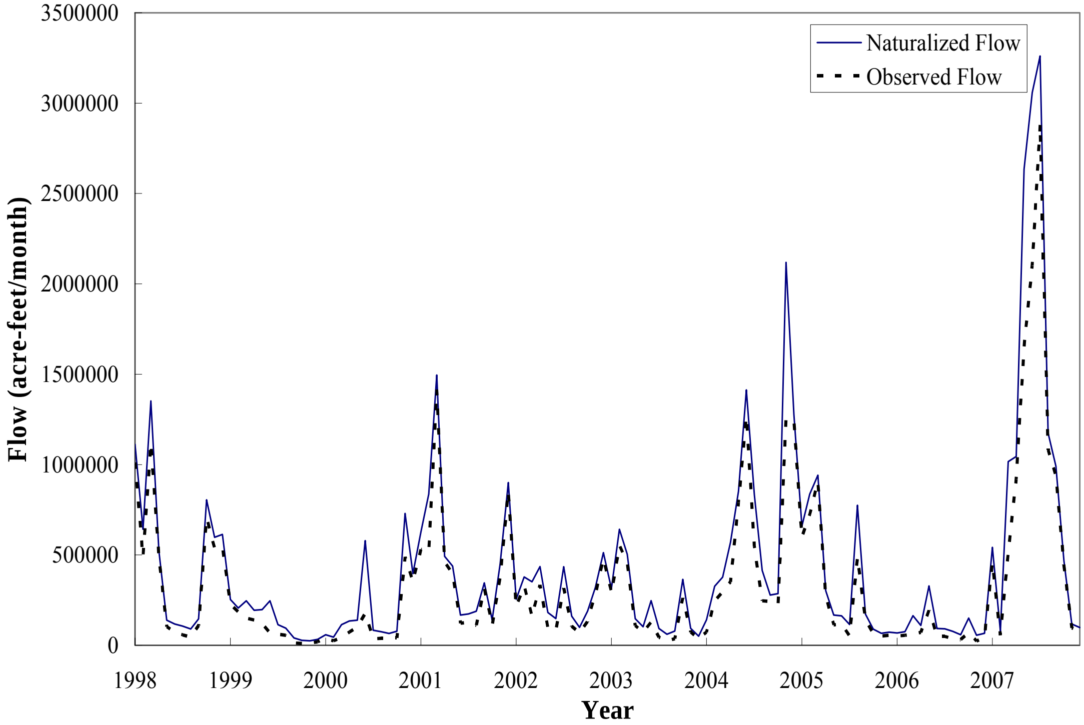

Figure B.36 Monthly Naturalized and Observed Flows at BRBR59

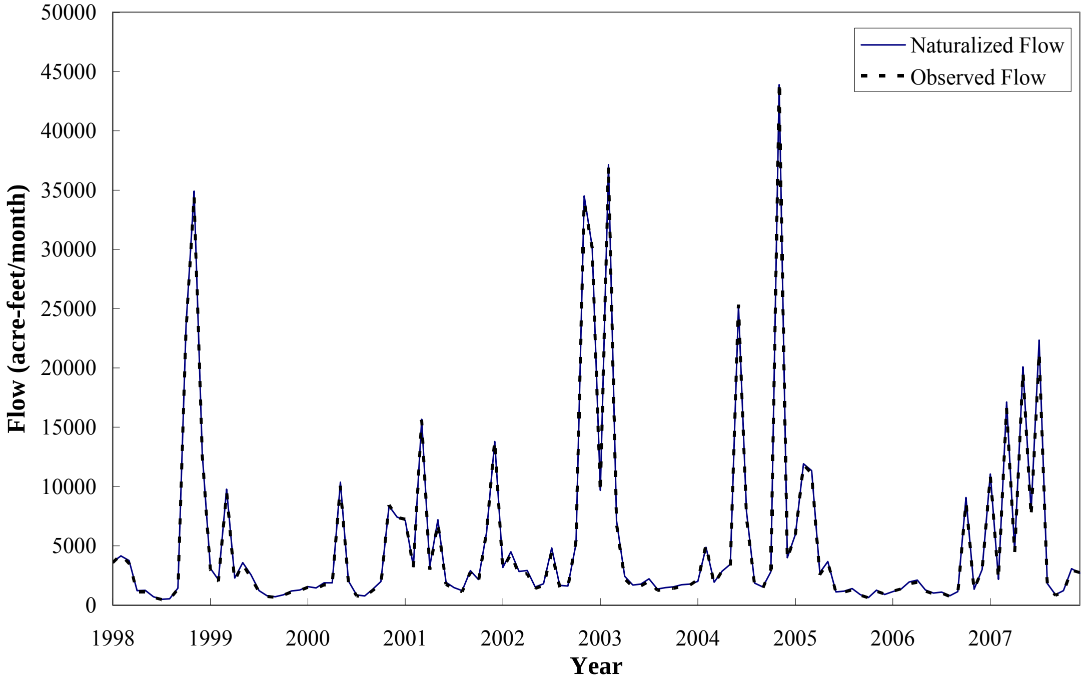

Figure B.37 Monthly Naturalized and Observed Flows at MYDB60

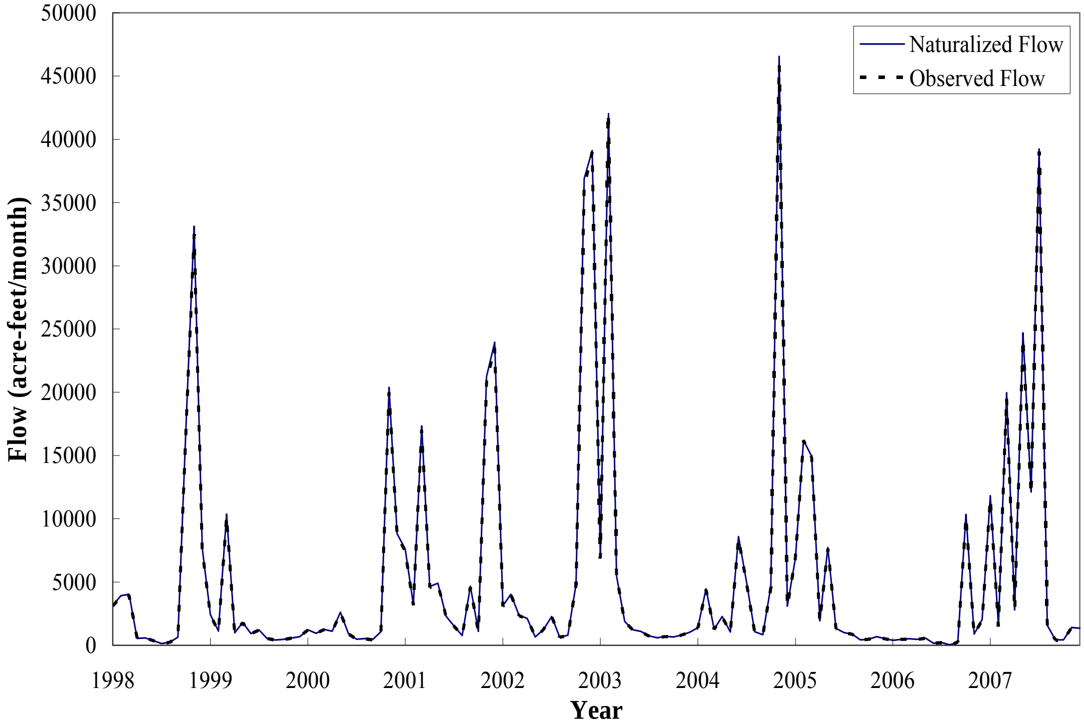

Figure B.38 Monthly Naturalized and Observed Flows at EYDB61

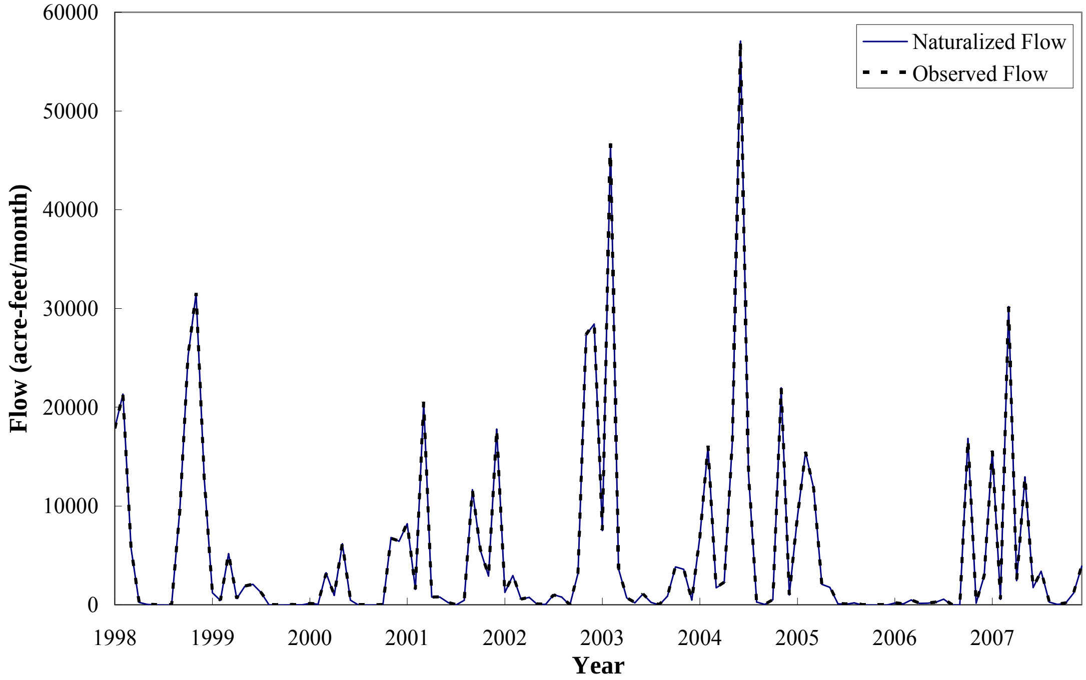

Figure B.39 Monthly Naturalized and Observed Flows at DCLY63

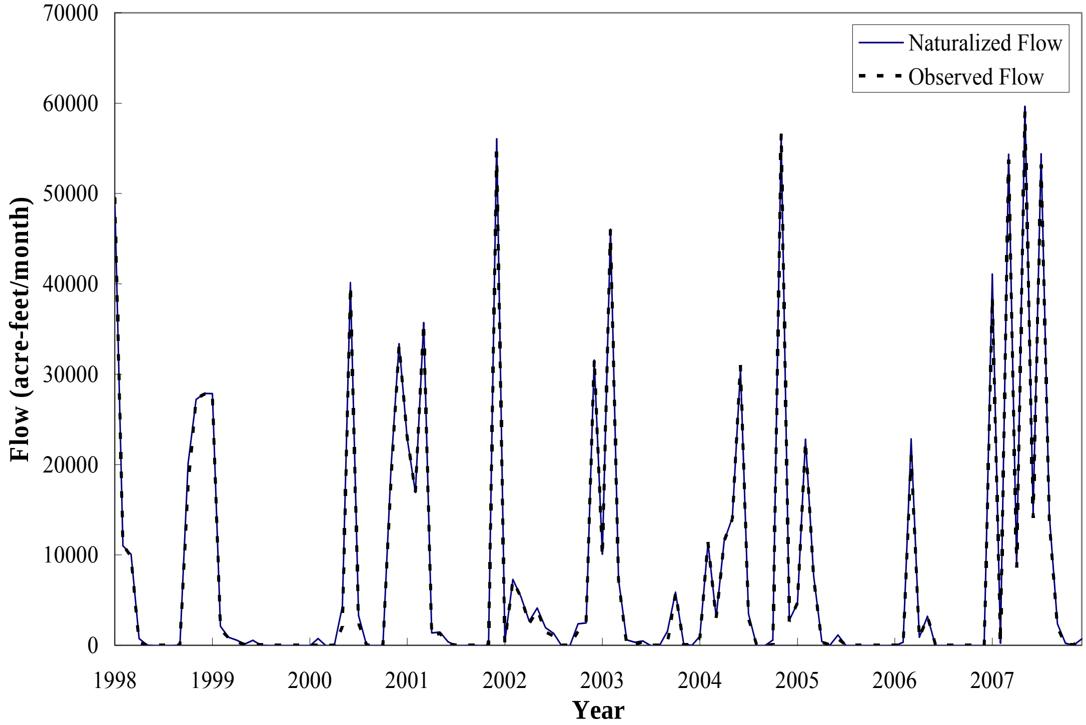

Figure B.40 Monthly Naturalized and Observed Flows at NAGR64

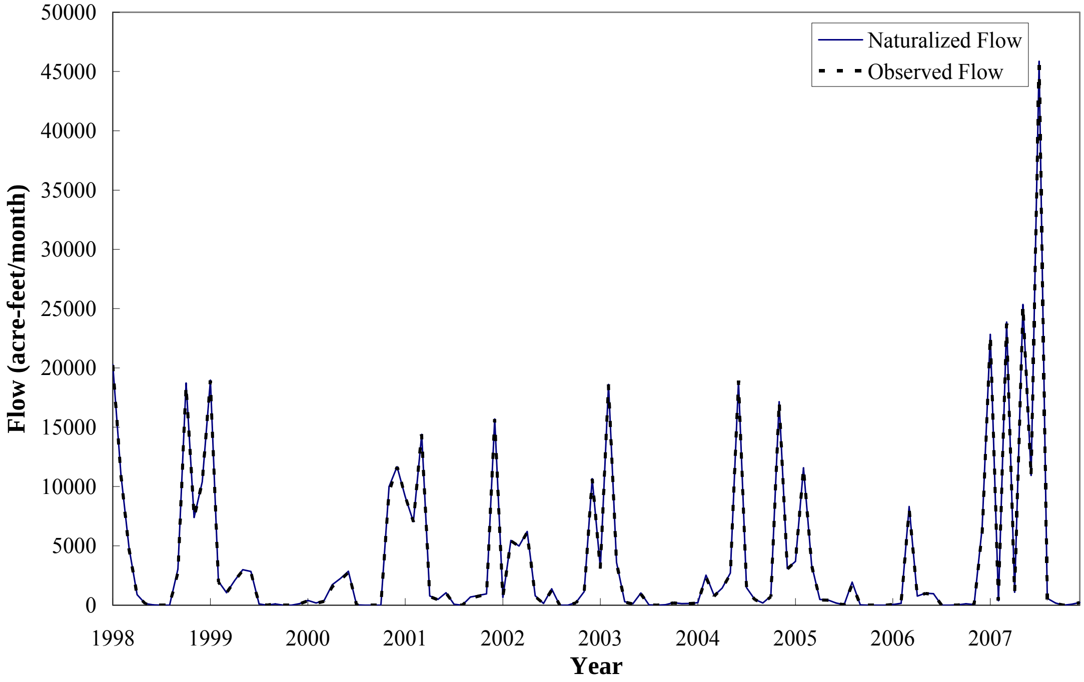

Figure B.41 Monthly Naturalized and Observed Flows at BGFR65

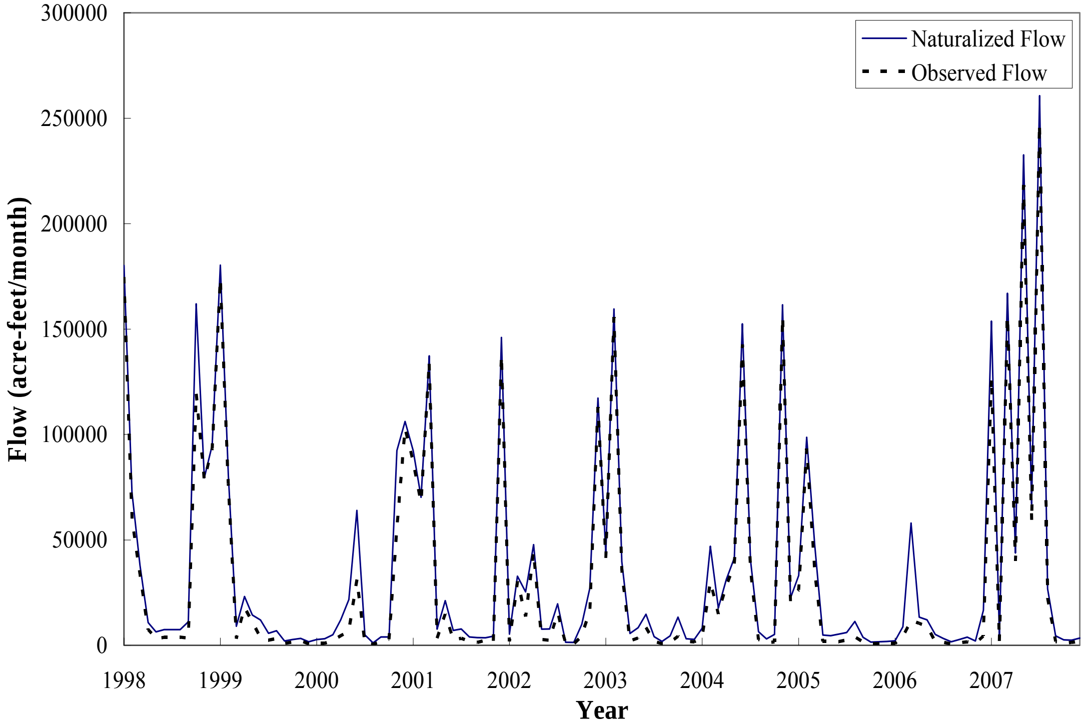

Figure B.42 Monthly Naturalized and Observed Flows at NAEA66

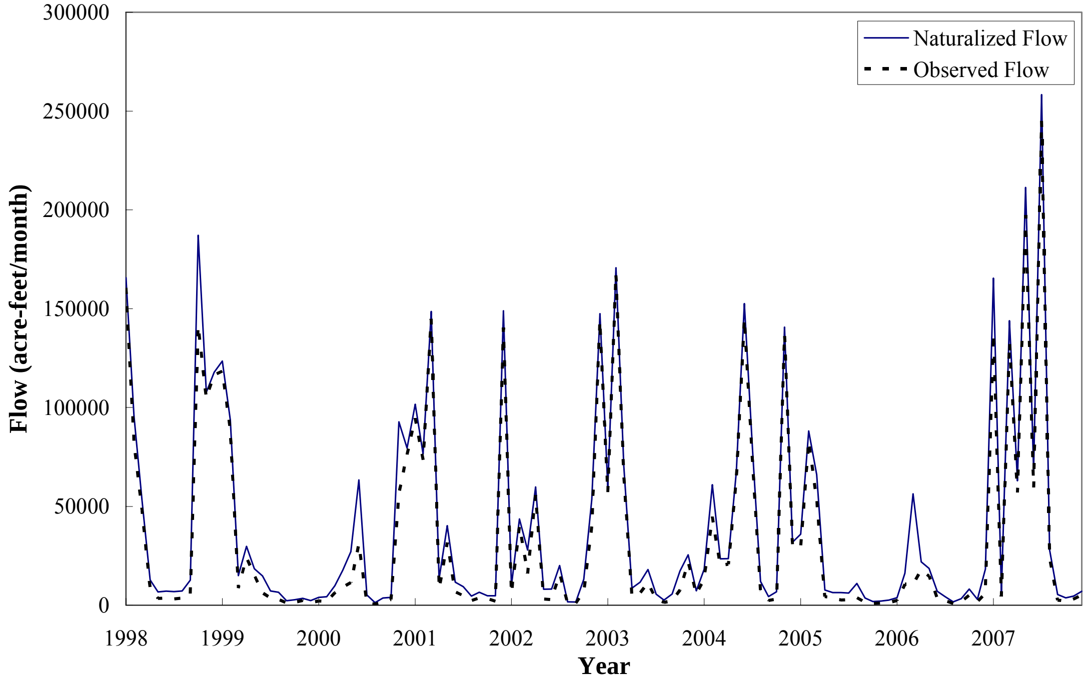

Figure B.43 Monthly Naturalized and Observed Flows at NABR67

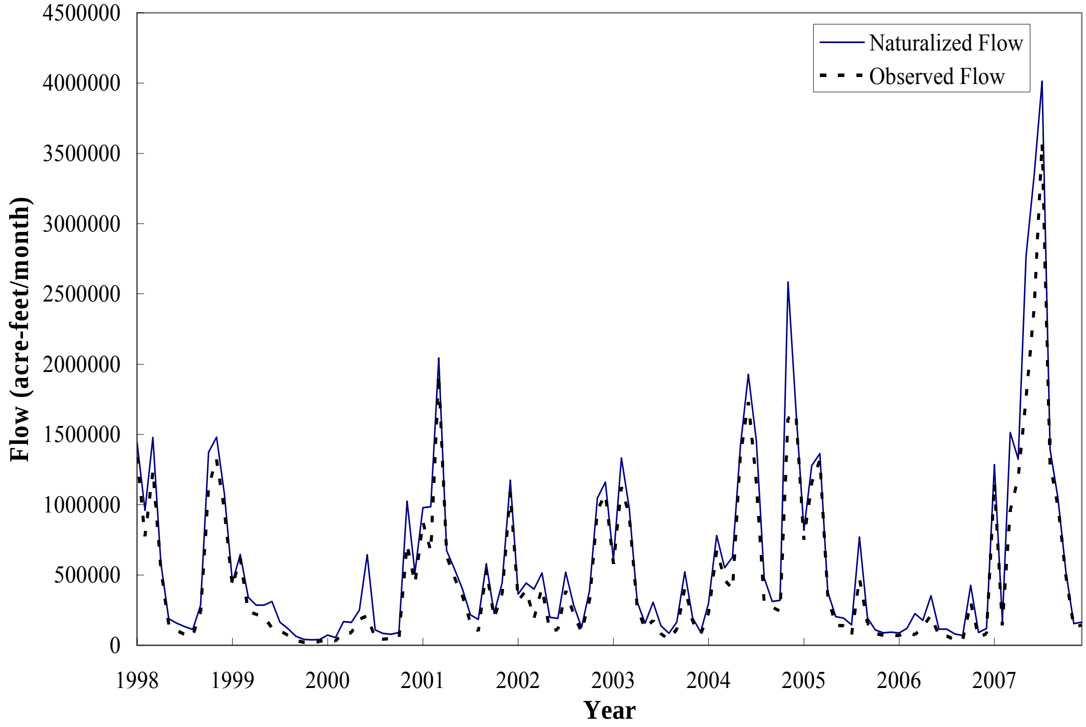

Figure B.44 Monthly Naturalized and Observed Flows at BRHE68

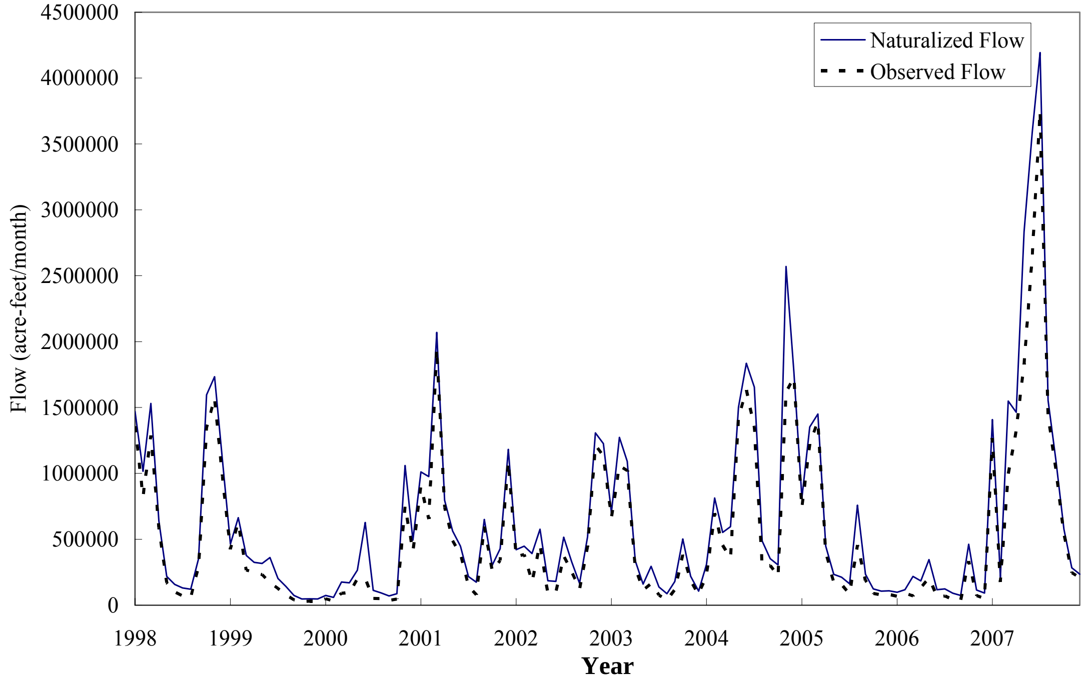

Figure B.45 Monthly Naturalized and Observed Flows at BRRI70

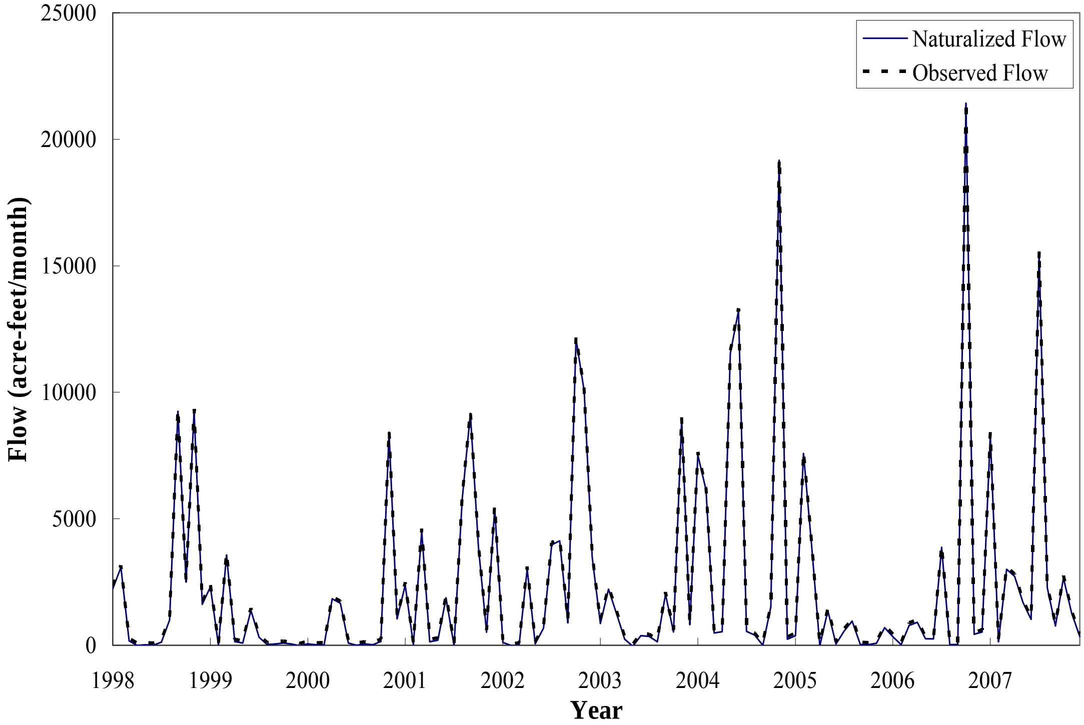

Figure B.46 Monthly Naturalized and Observed Flows at BGNE71

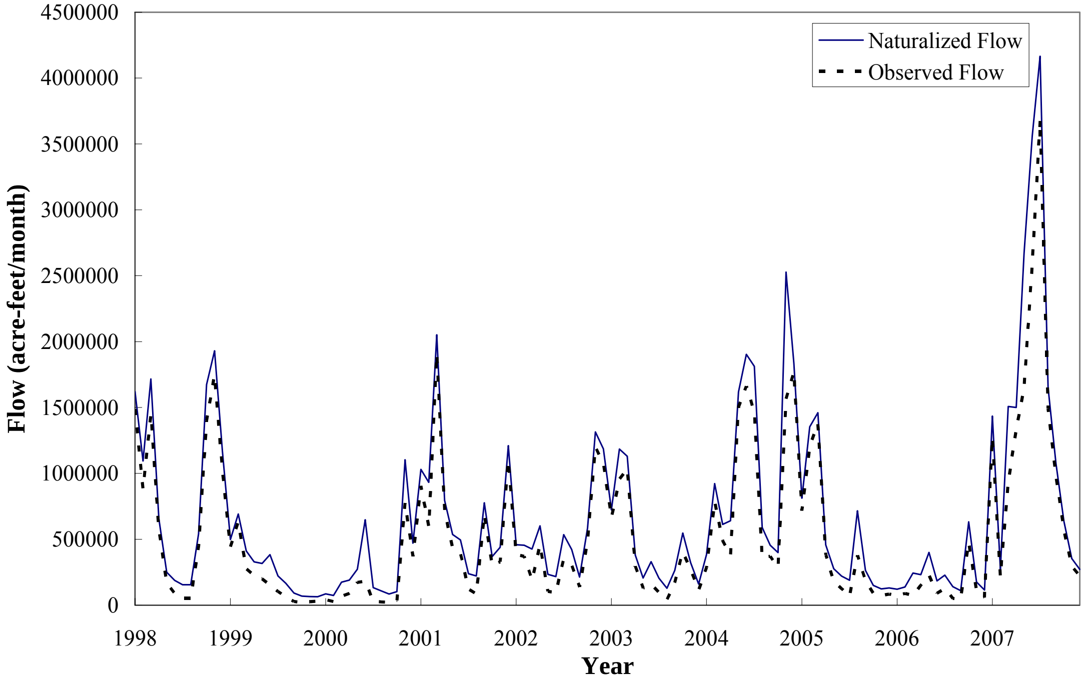

Figure B.47 Monthly Naturalized and Observed Flows at BRRO72

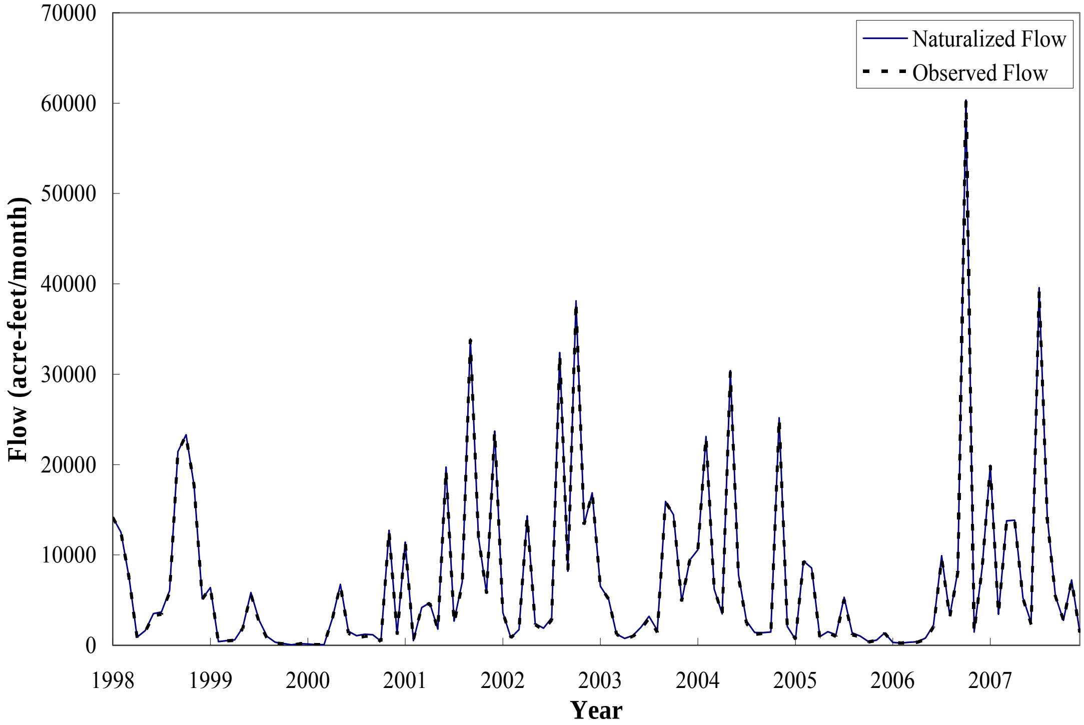

Figure B.48 Monthly Naturalized and Observed Flows at CBALC2

APPENDIX C

PLOTS OF 1998-2007 STORAGE VOLUME AT 14 RESERVOIRS

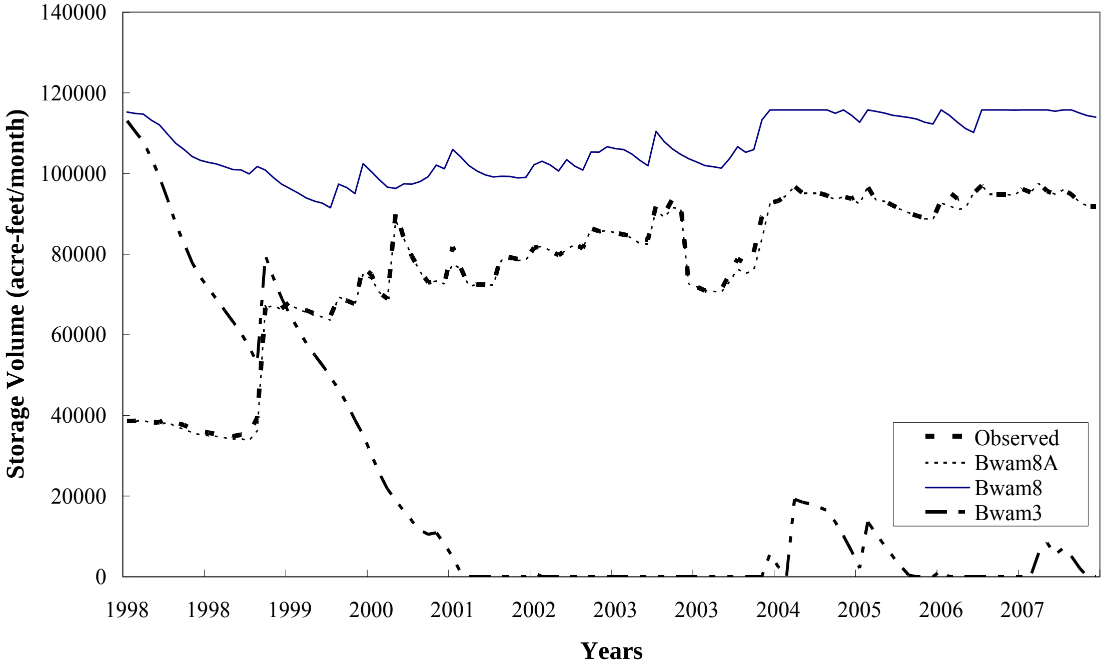

Figure C.1 Storage Volume at Alan Henry Reservoir
(Bwam3 and Bwam8 Capacities = 115,937 and 115,773 acre-feet)

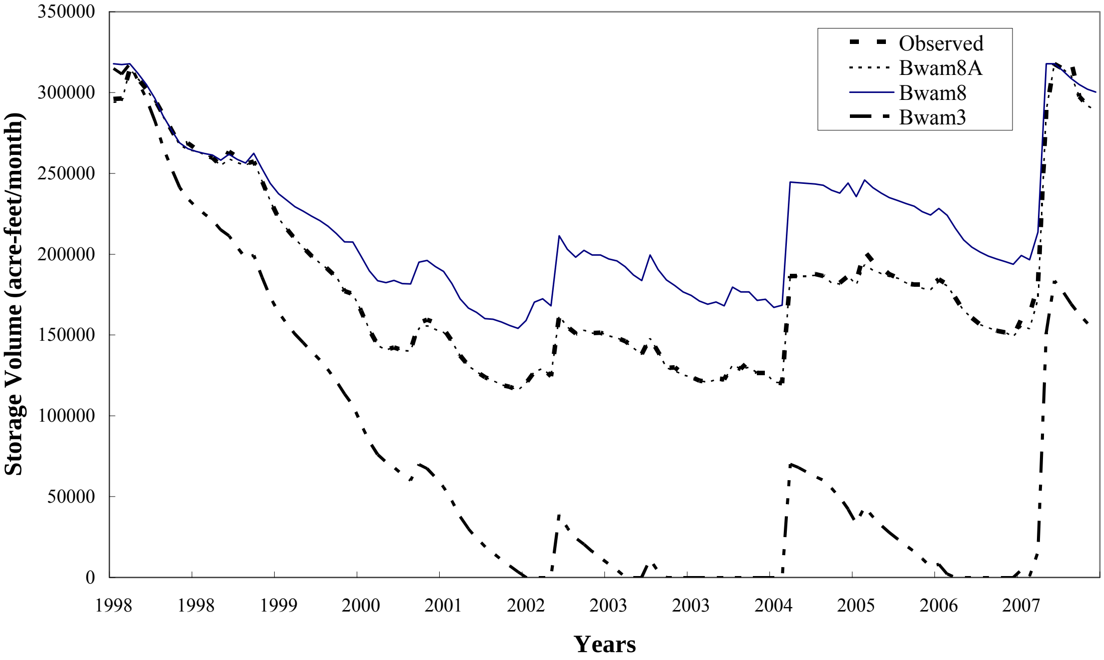

Figure C.2 Storage Volume at Hubbard Creek Reservoir
(Bwam3 and Bwam8 Capacities = 317,750 and 317,750 acre-feet)

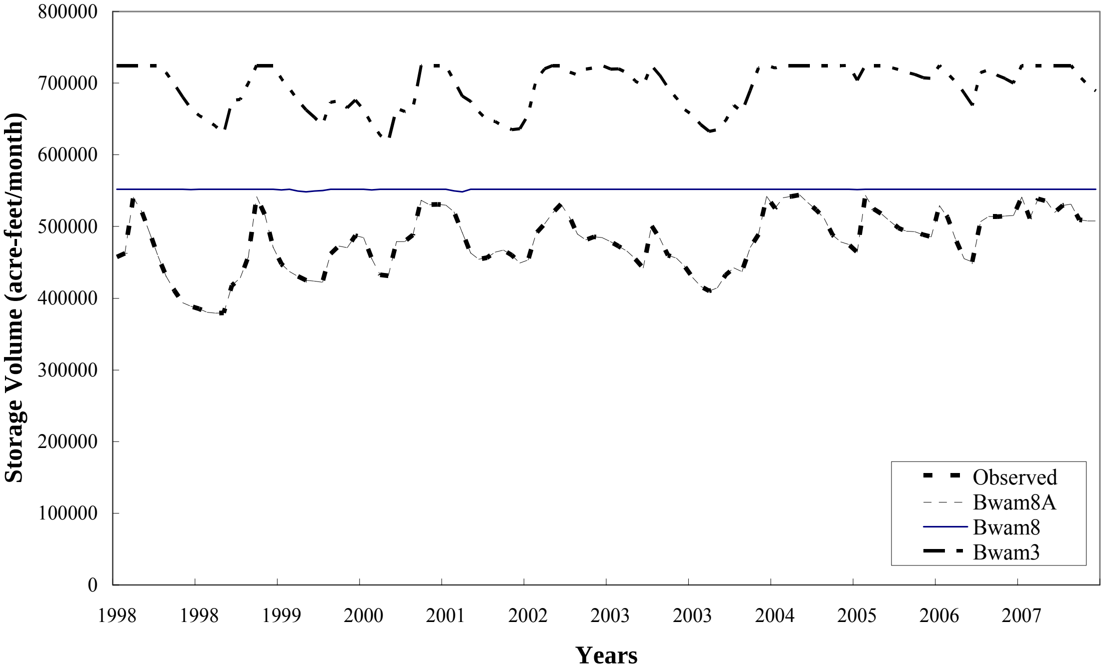

Figure C.3 Storage Volume at Possum Kingdom Reservoir
(Bwam3 and Bwam8 Capacities = 724,739 and 552,013 acre-feet)

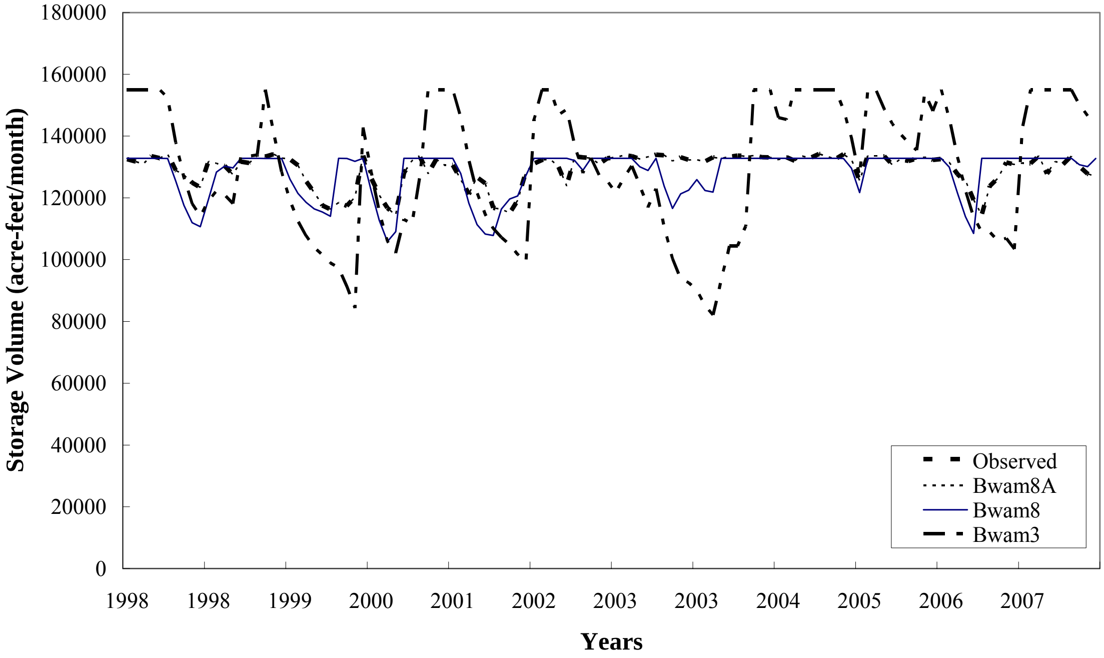

Figure C.4 Storage Volume at Granbury Reservoir
(Bwam3 and Bwam8 Capacities = 155,000 and 132,821 acre-feet)

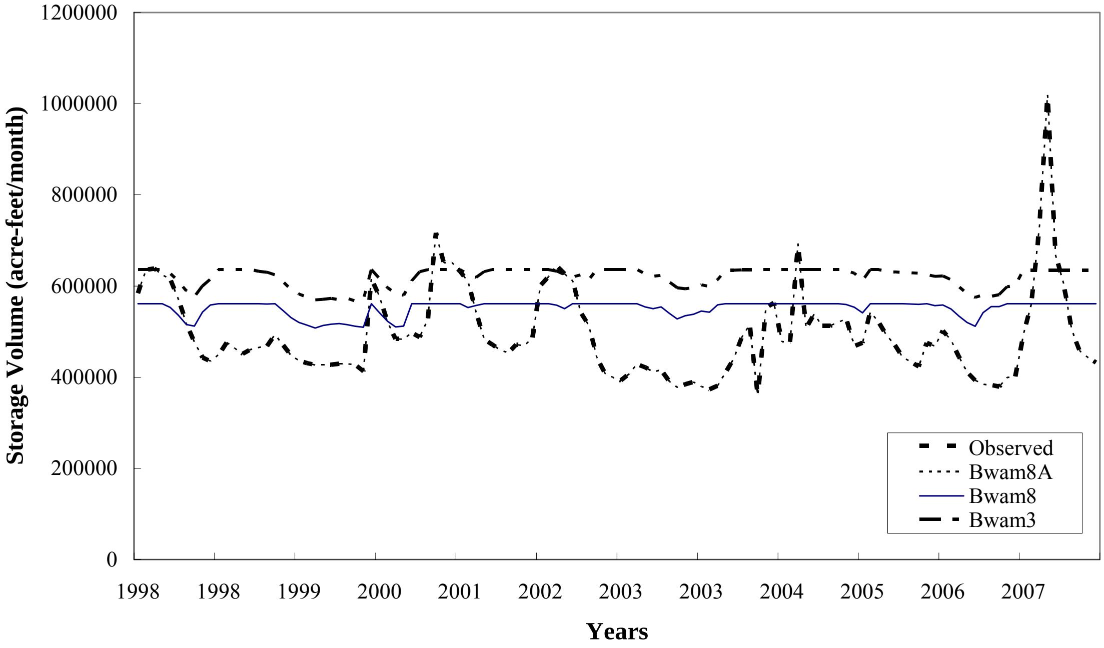

Figure C.5 Storage Volume at Whitney Reservoir
(Bwam3 and Bwam8 Capacities = 636,100 and 561,074 acre-feet)

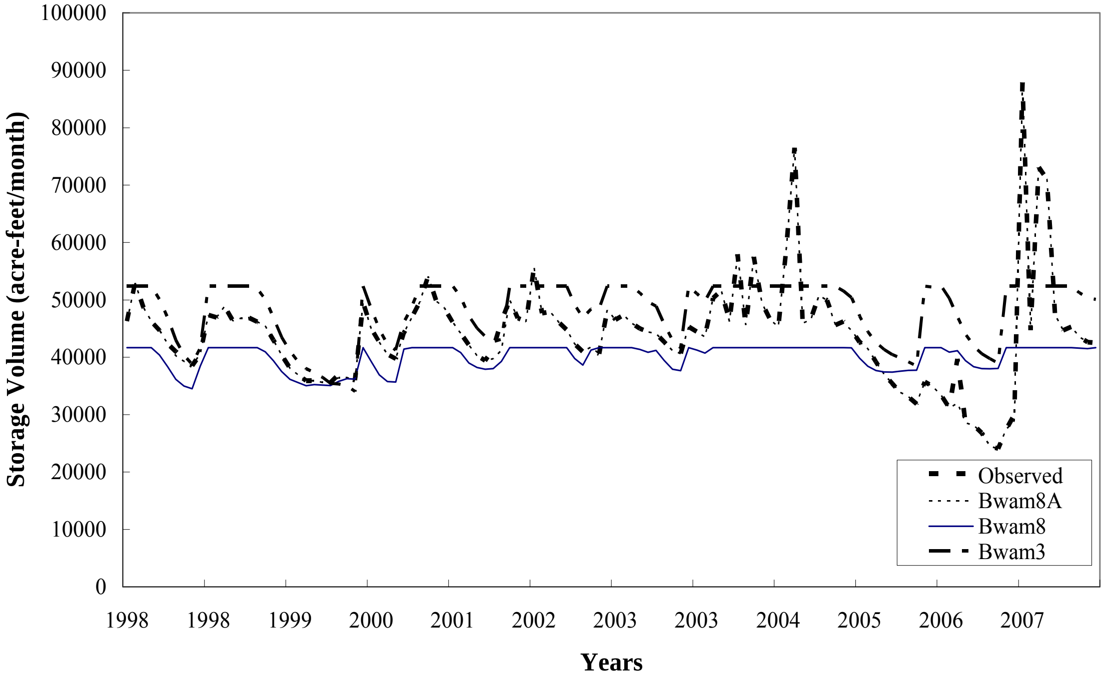

Figure C.6 Storage Volume at Aquilla Reservoir
(Bwam3 and Bwam8 Capacities = 52,400 and 41,700 acre-feet)

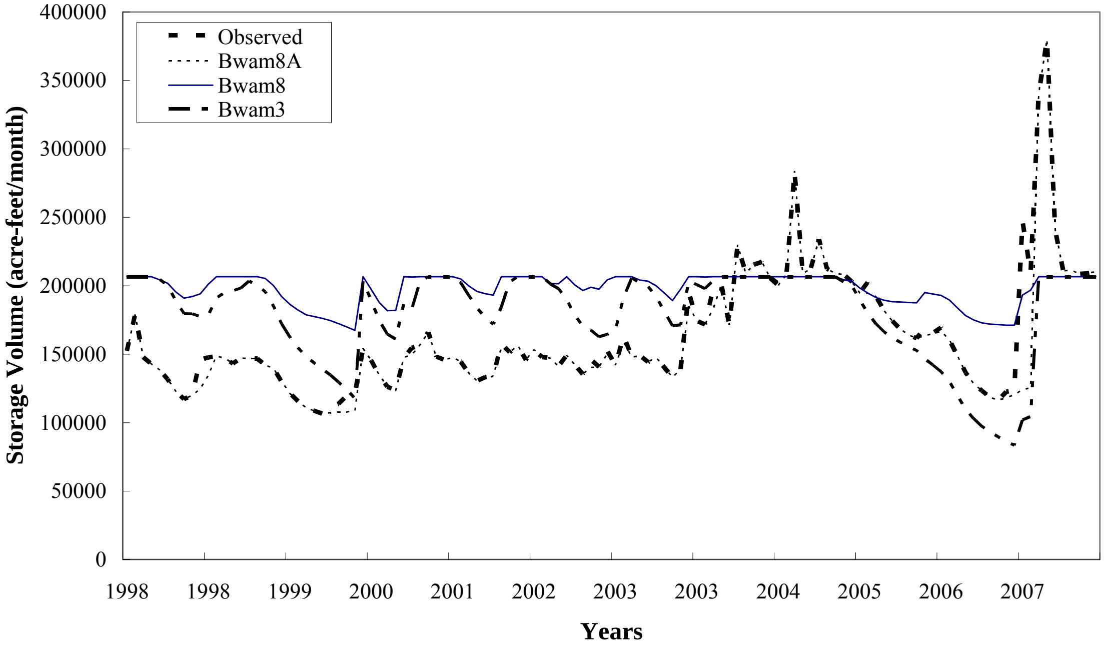

Figure C.7 Storage Volume at Waco Reservoir (Bwam3 and Bwam8 Capacities = 206,562 ac-ft)

The designated top of conservation pool elevation of Lake Waco was raised in September 2003 reallocating flood control storage capacity to conservation capacity.

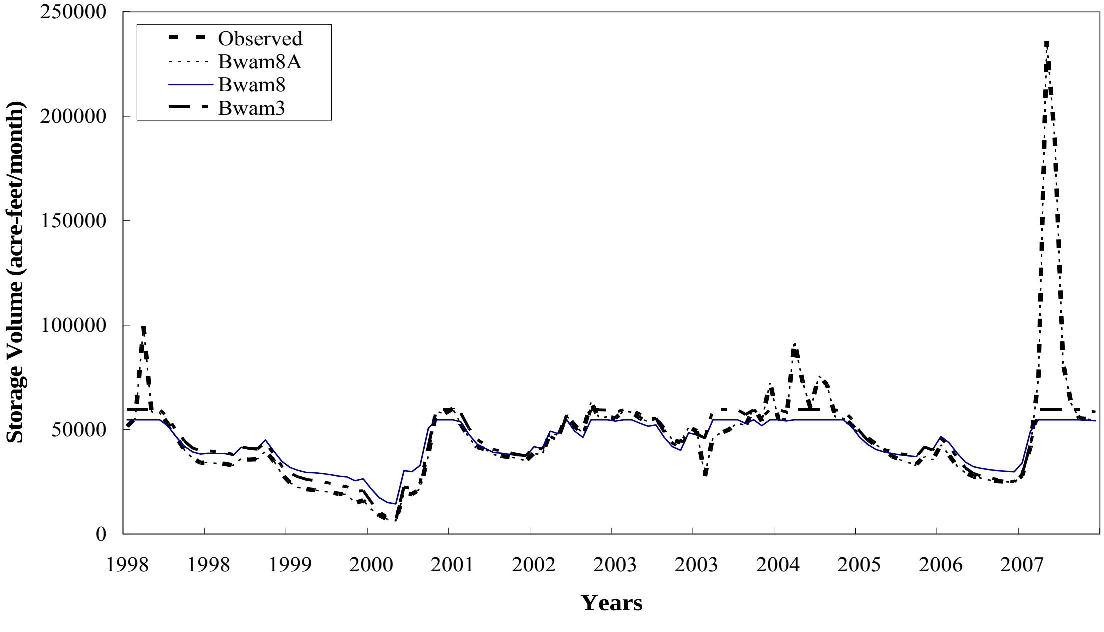

Figure C.8 Storage Volume at Proctor Reservoir
(Bwam3 and Bwam8 Capacities = 59,400 and 54,702 acre-feet)

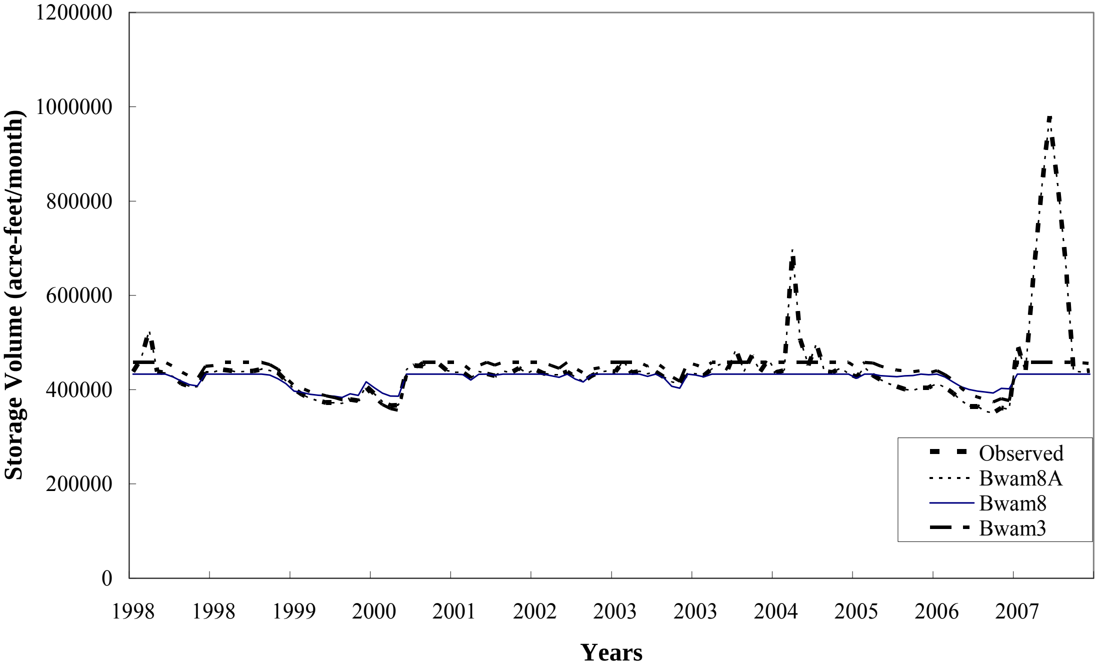

Figure C.9 Storage Volume at Belton Reservoir
(Bwam3 and Bwam8 Capacities = 457,600 and 432,978 acre-feet)

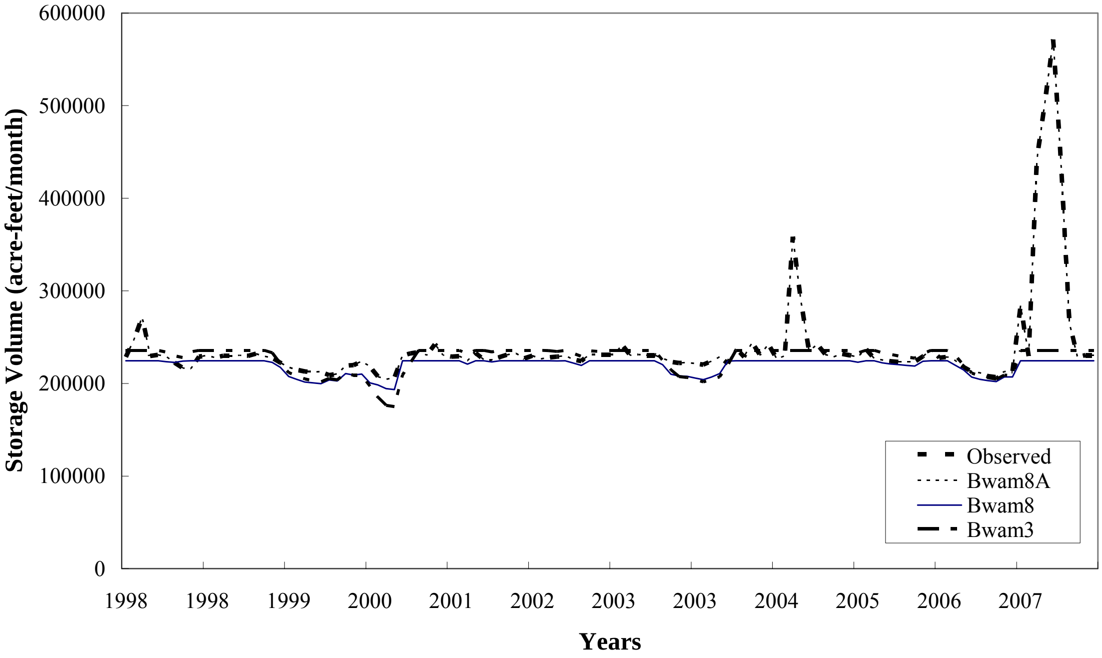

Figure C.10 Storage Volume at Stillhouse Hollow Reservoir
(Bwam3 and Bwam8 Capacities = 235,700 and 224,279 acre-feet)

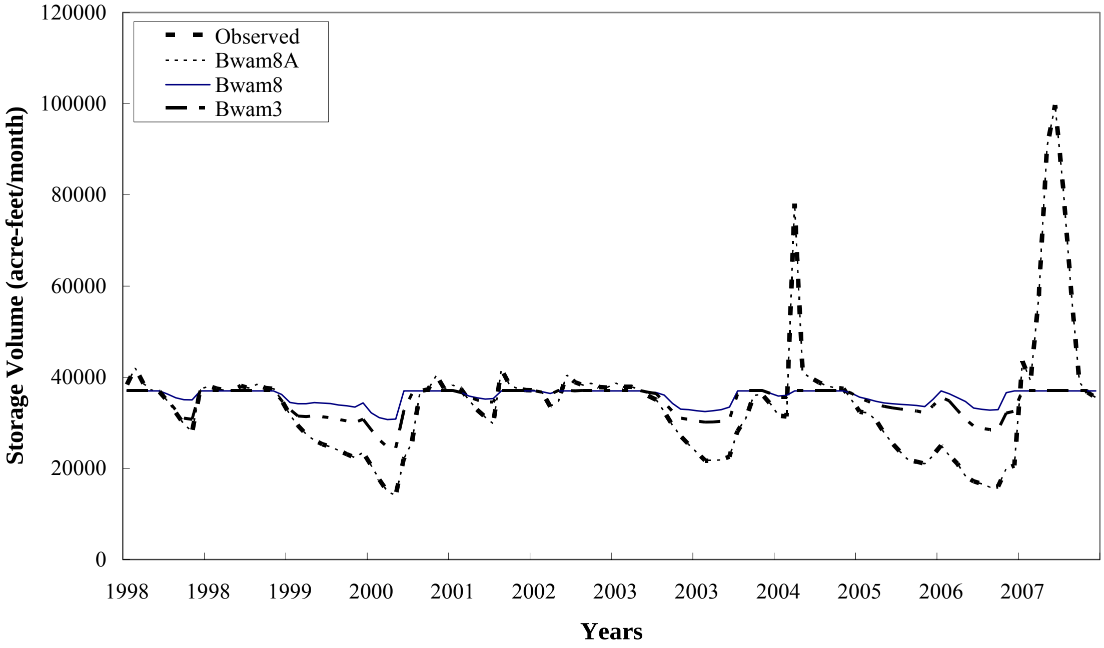

Figure C.11 Storage Volume at Georgetown Reservoir
(Bwam3 and Bwam8 Capacities = 37,100 and 36,980 acre-feet)

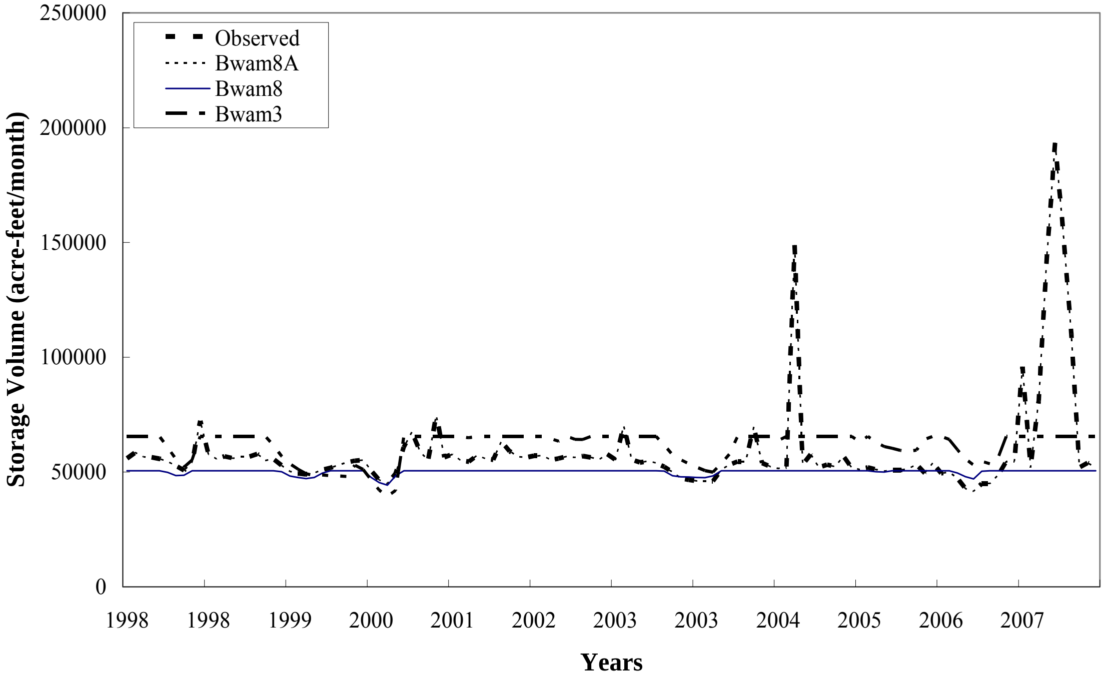

Figure C.12 Storage Volume at Granger Reservoir
(Bwam3 and Bwam8 Capacities = 65,500 and 50,540 acre-feet)

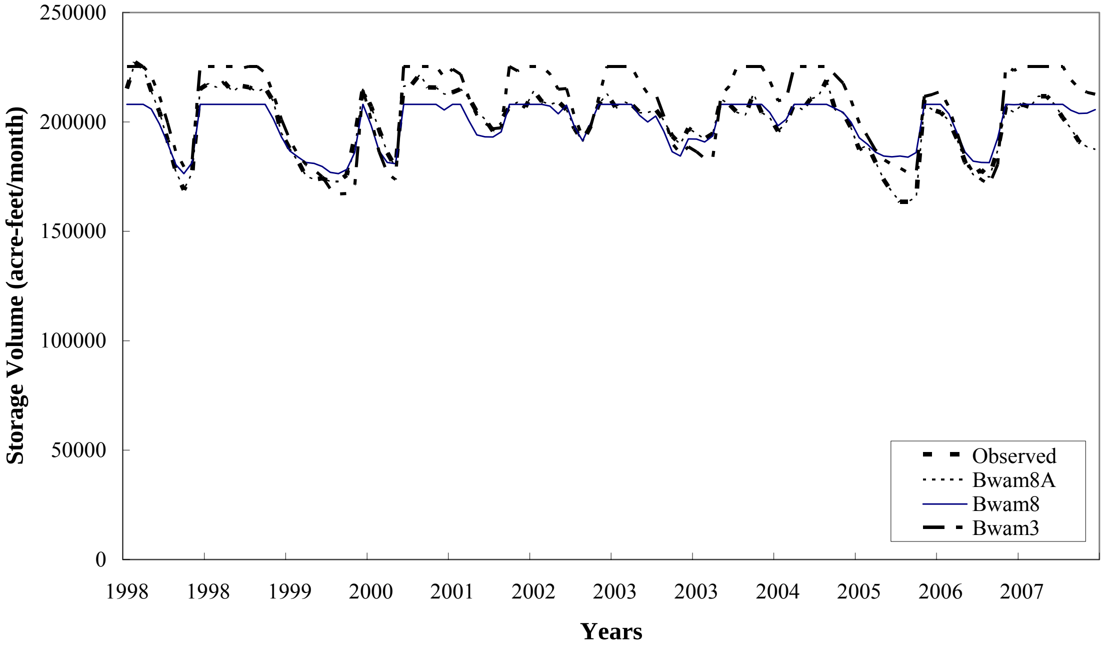

Figure C.13 Storage Volume at Limestone Reservoir
(Bwam3 and Bwam8 Capacities = 225,400 and 208,017 acre-feet)

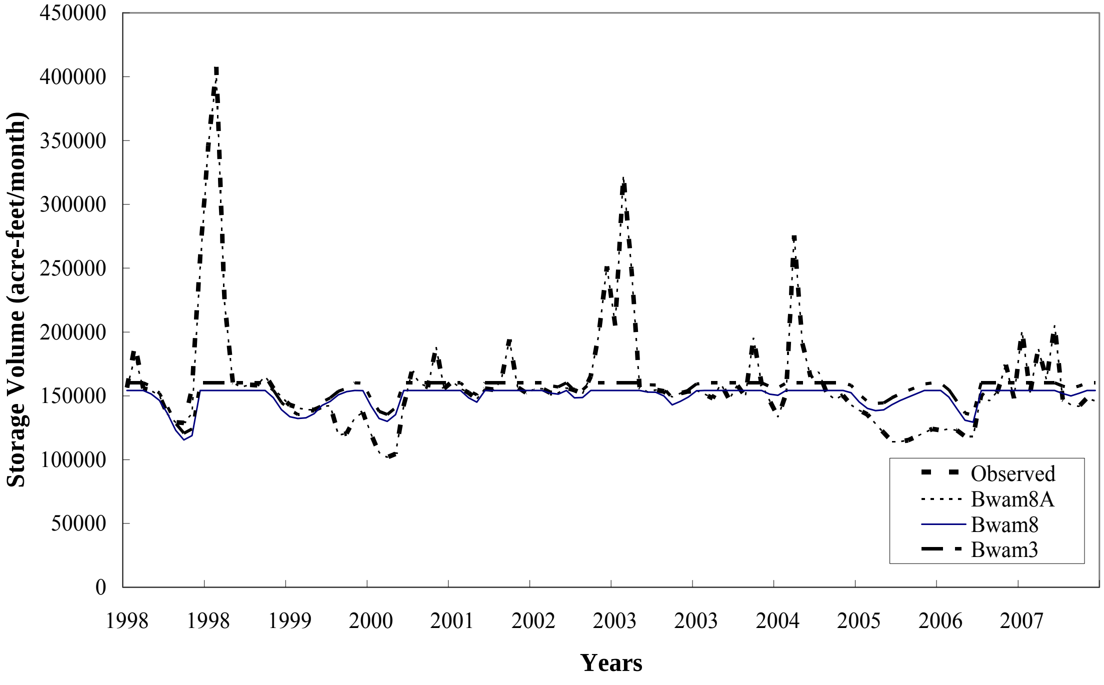

Figure C.14 Storage Volume at Somerville Reservoir
(Bwam3 and Bwam8 Capacities = 160,110 and 154,254 acre-feet)

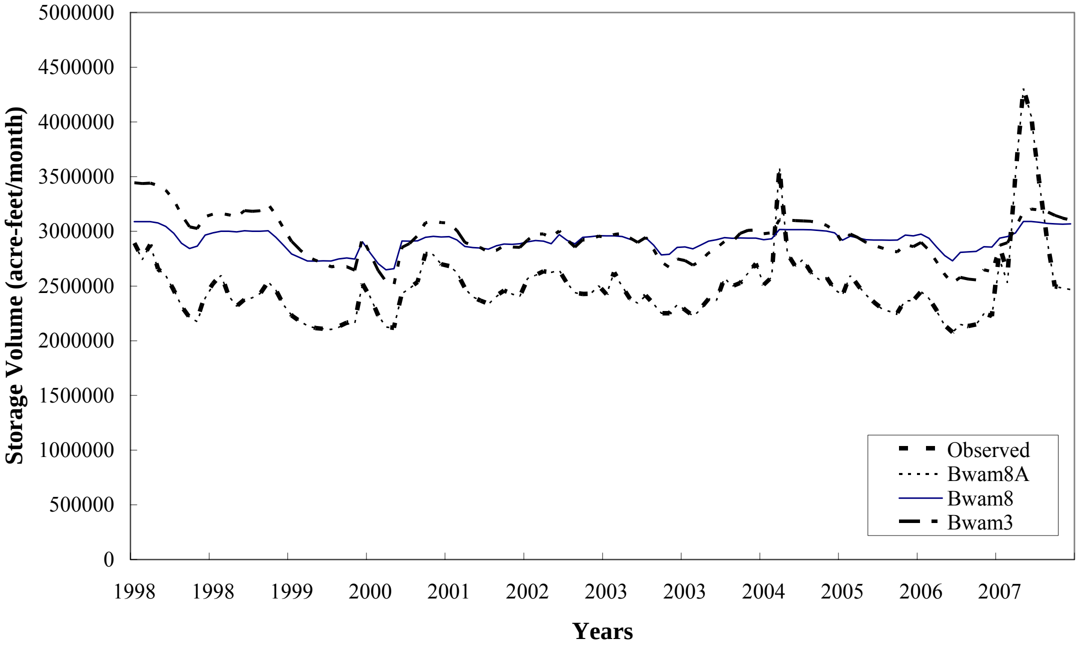

Figure C.15 Storage Volume at 14 Reservoirs
(Bwam3 and Bwam8 Capacities = 3,594,831 and 3,089,443 acre-feet)

APPENDIX D

PLOTS OF 1900-2007 END-OF-MONTH STORAGE VOLUME AT 14 RESERVOIRS

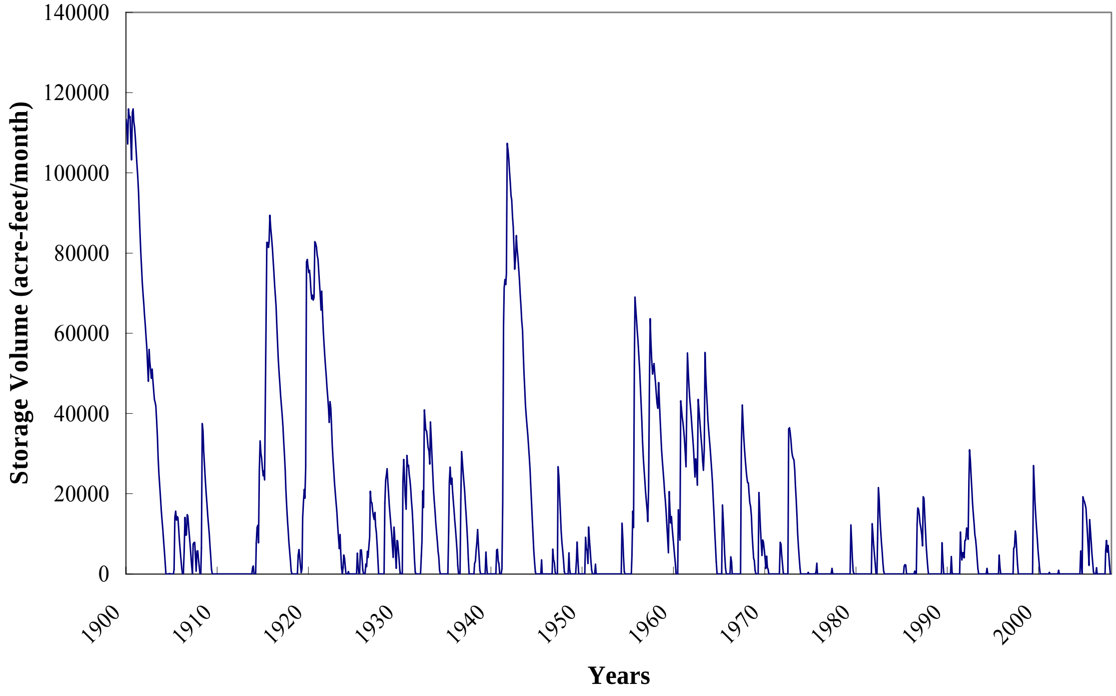

Figure D.1 Bwam3 Storage Volume of Alan Henry Reservoir

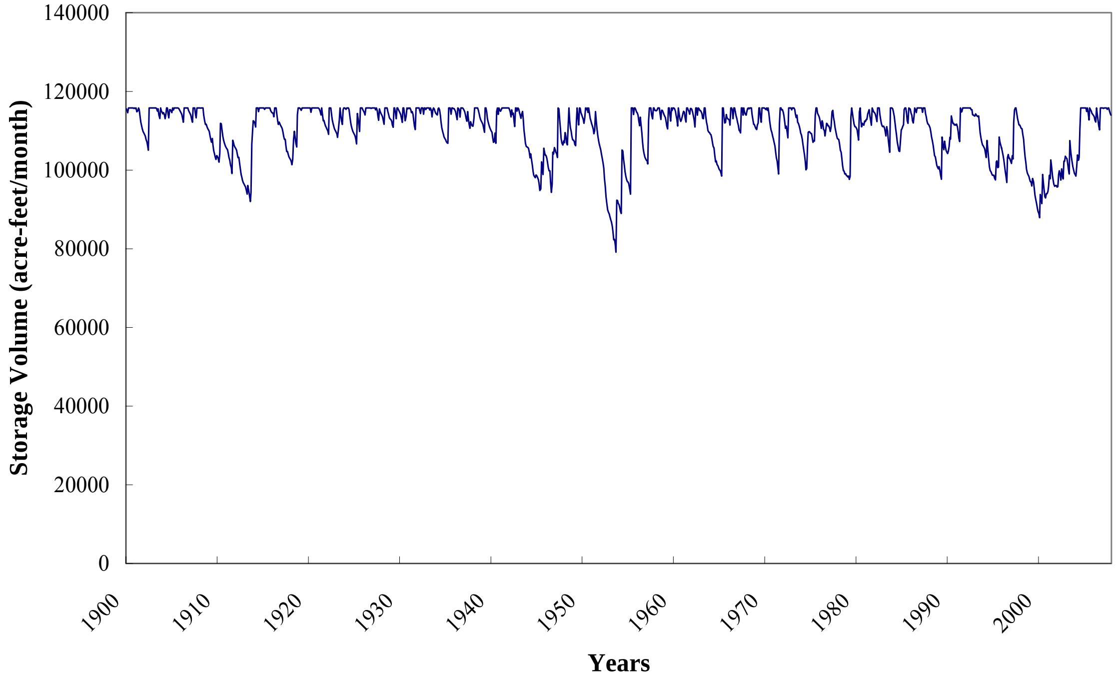

Figure D.2 Bwam8 Storage Volume of Alan Henry Reservoir

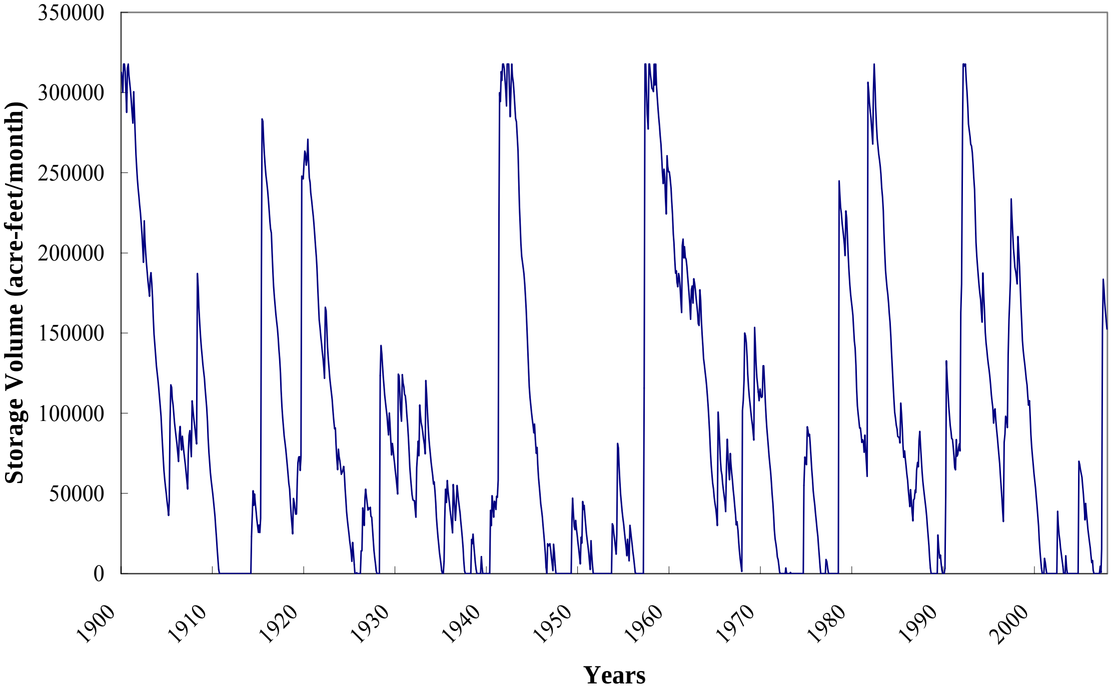

Figure D.3 Bwam3 Storage Volume of Hubbard Creek Reservoir

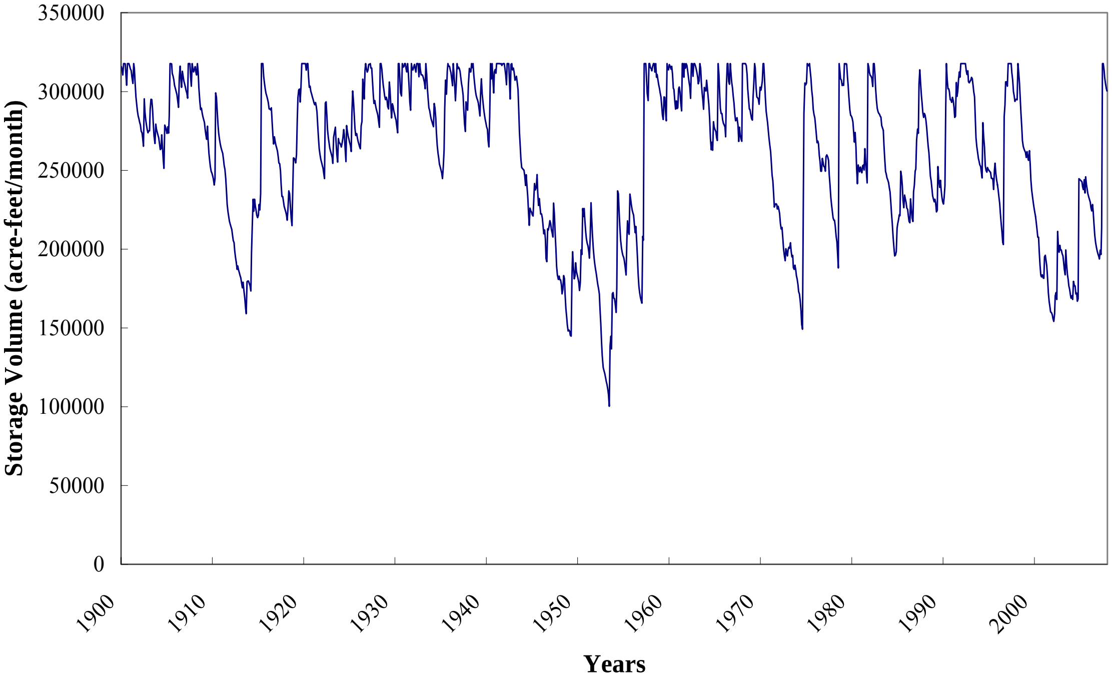

Figure D.4 Bwam8 Storage Volume of Hubbard Creek Reservoir

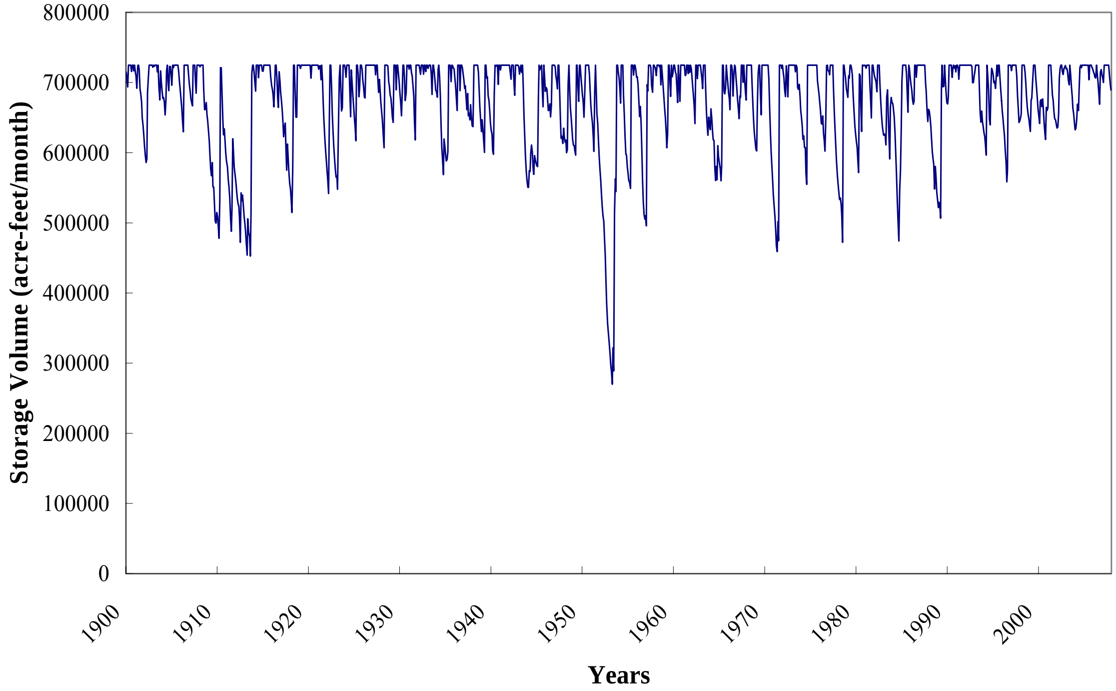

Figure D.5 Bwam3 Storage Volume of Possum Kingdom Reservoir

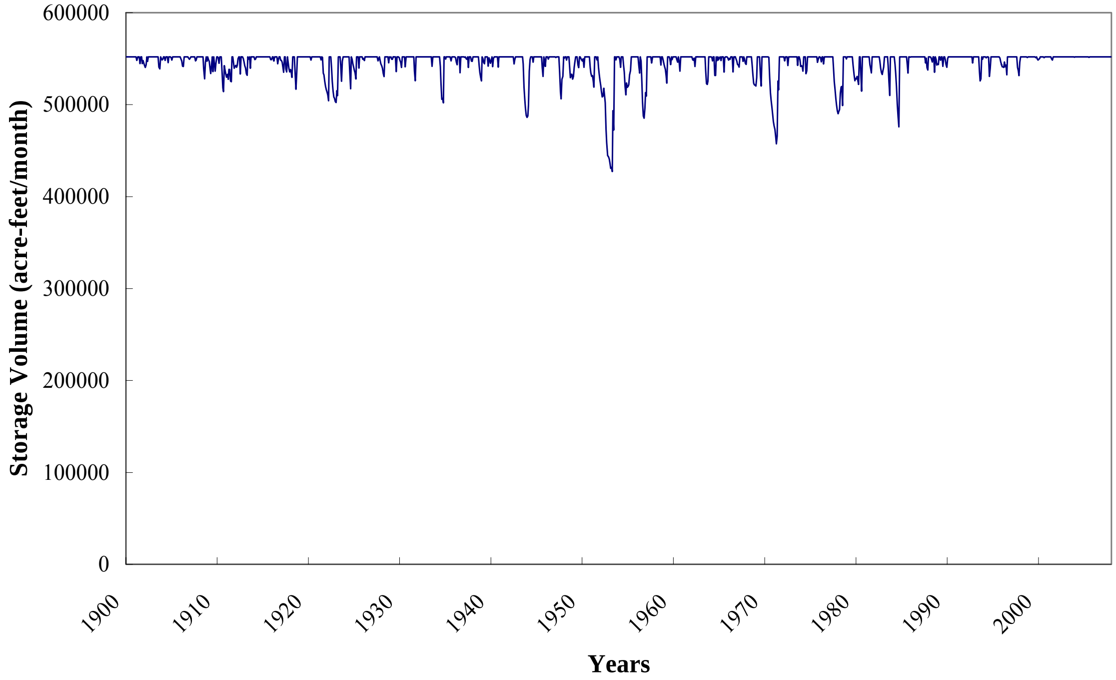

Figure D.6 Bwam8 Storage Volume of Possum Kingdom Reservoir

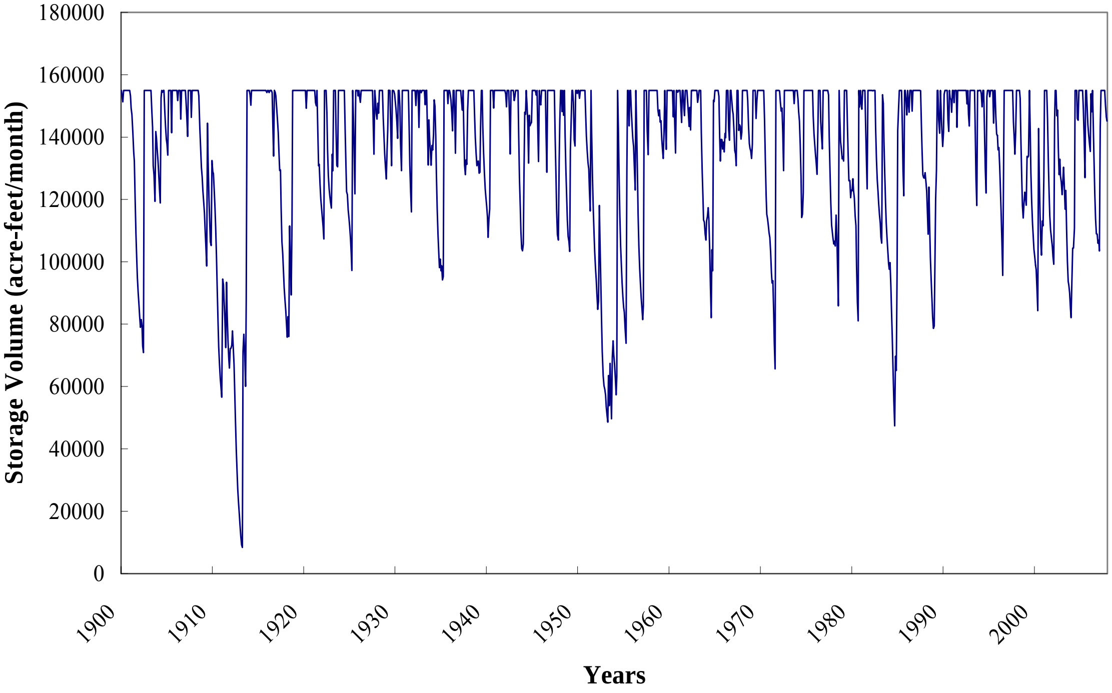

Figure D.7 Bwam3 Storage Volume of Granbury Reservoir

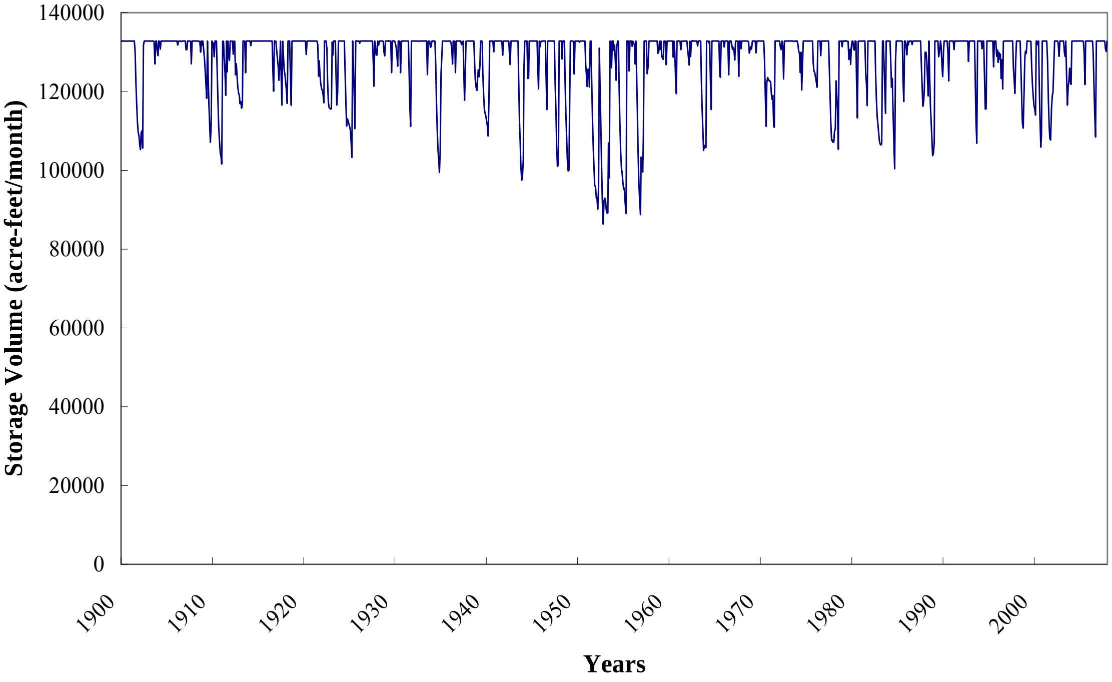

Figure D.8 Bwam8 Storage Volume of Granbury Reservoir

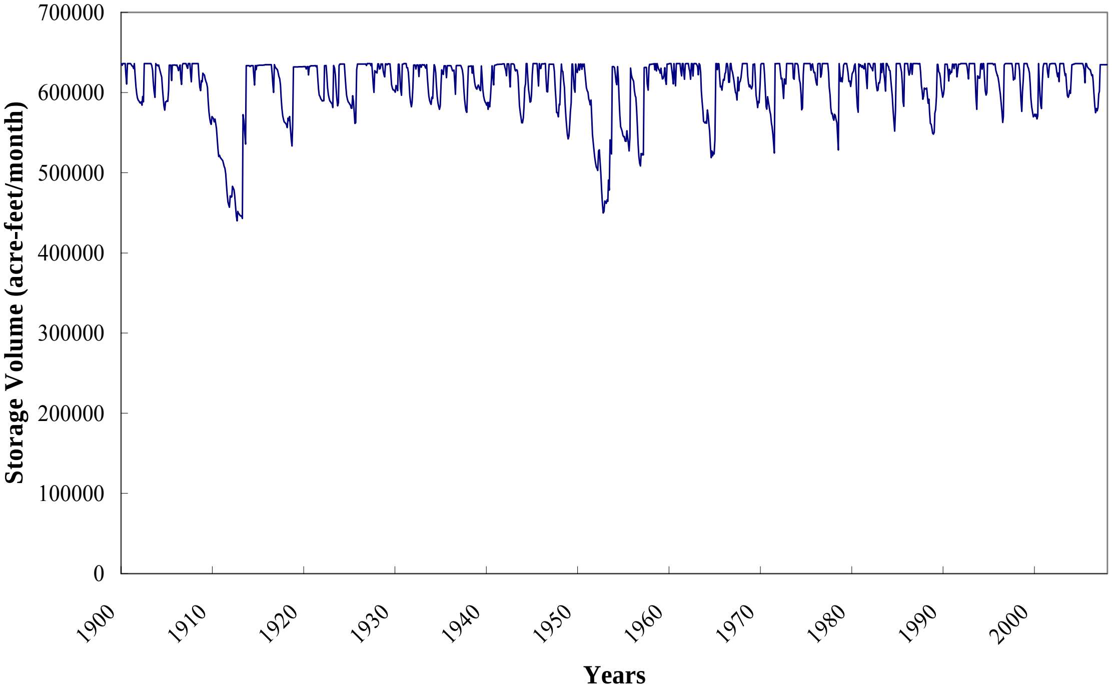

Figure D.9 Bwam3 Storage Volume of Whitney Reservoir

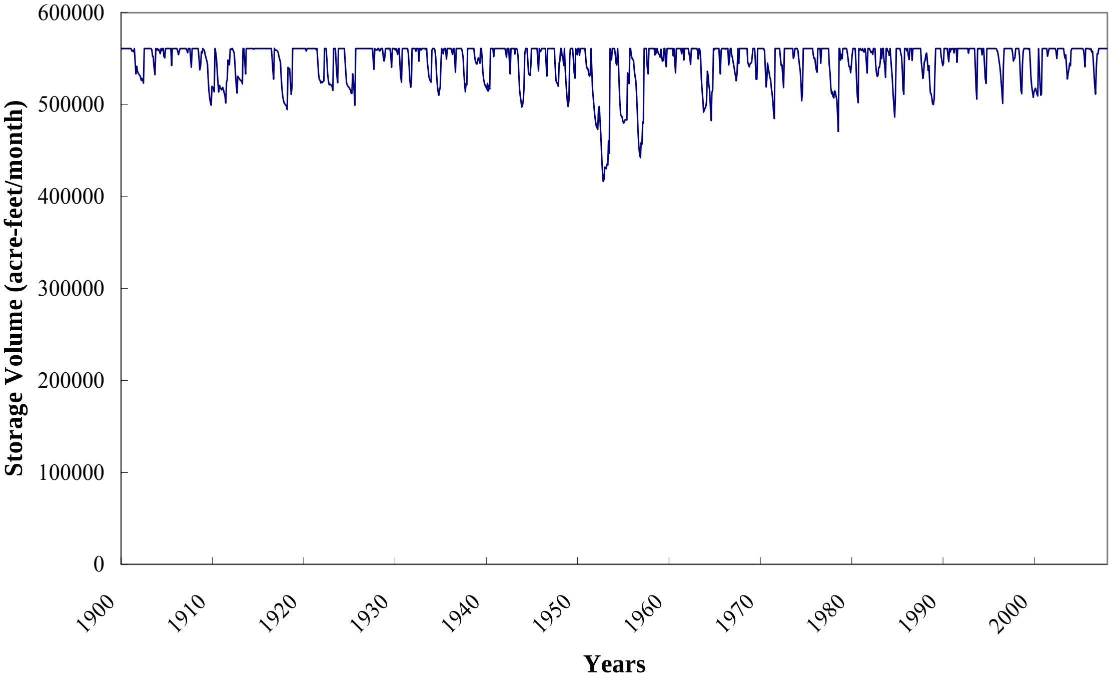

Figure D.10 Bwam8 Storage Volume of Whitney Reservoir

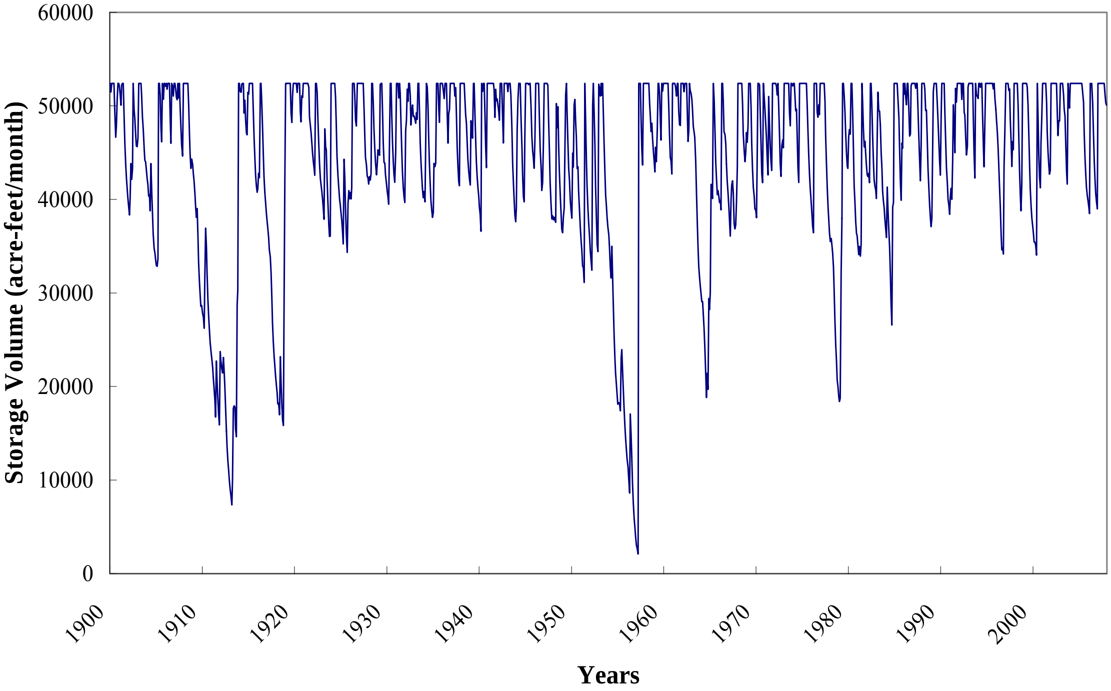

Figure D.11 Bwam3 Storage Volume of Aquilla Reservoir

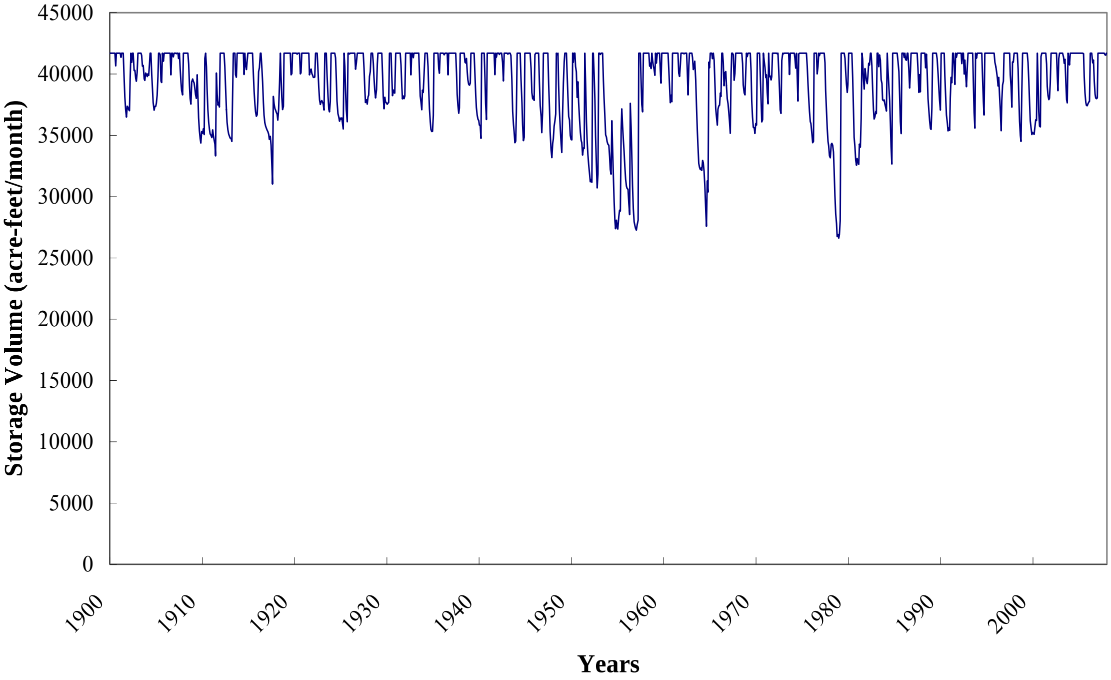

Figure D.12 Bwam8 Storage Volume of Aquilla Reservoir

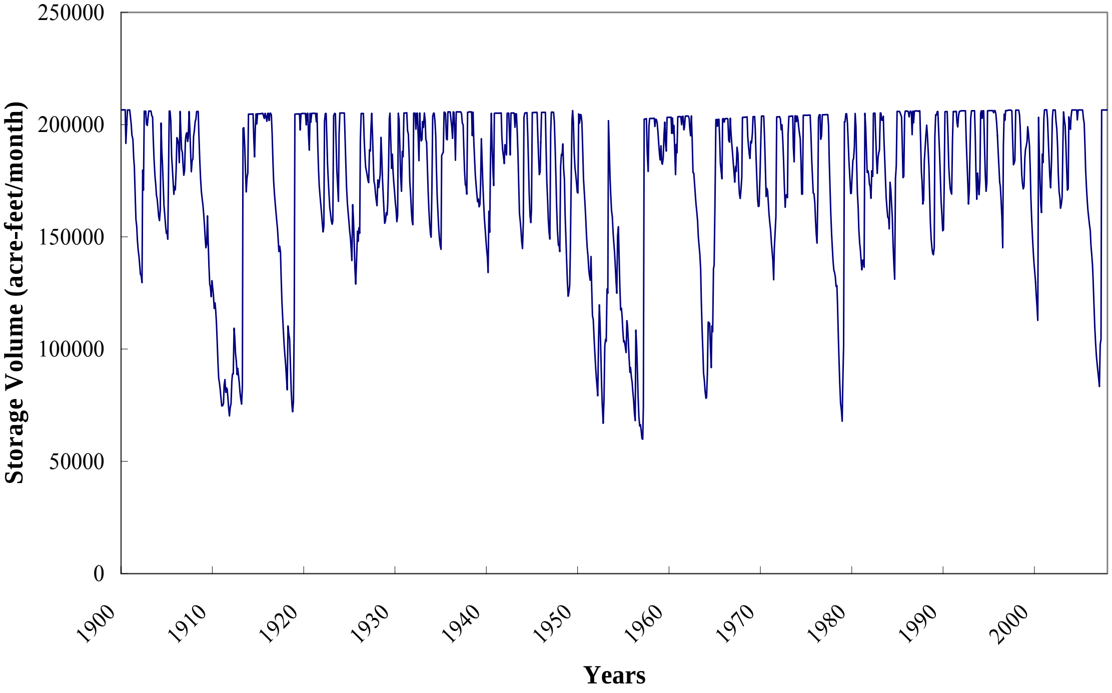

Figure D.13 Bwam3 Storage Volume of Waco Reservoir

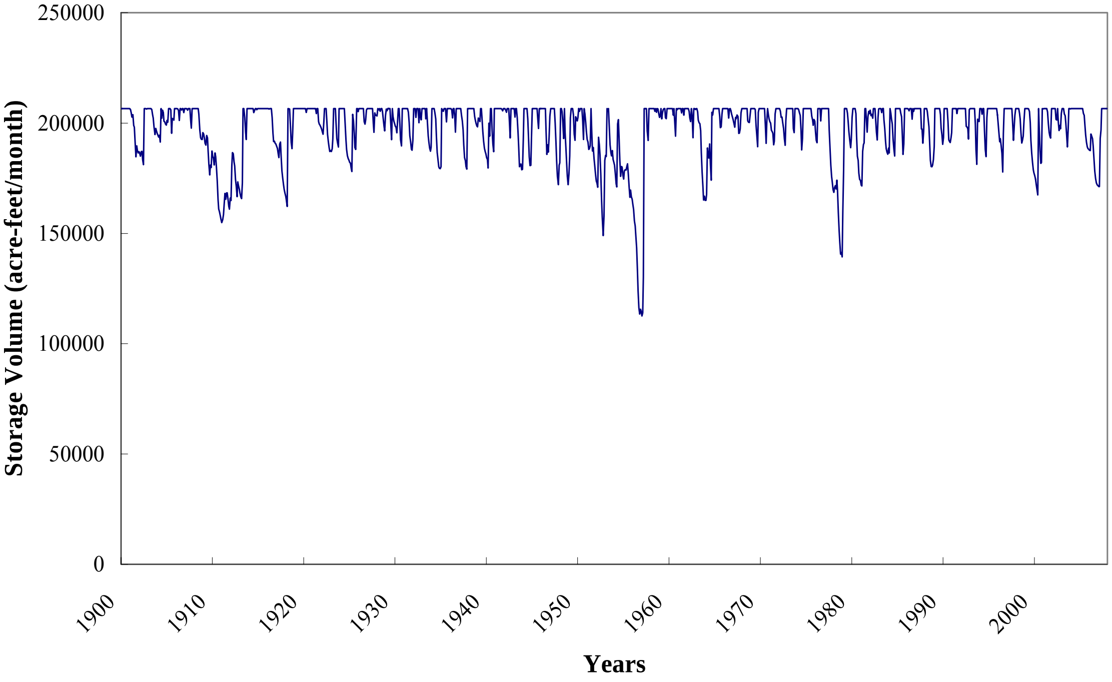

Figure D.14 Bwam8 Storage Volume of Waco Reservoir

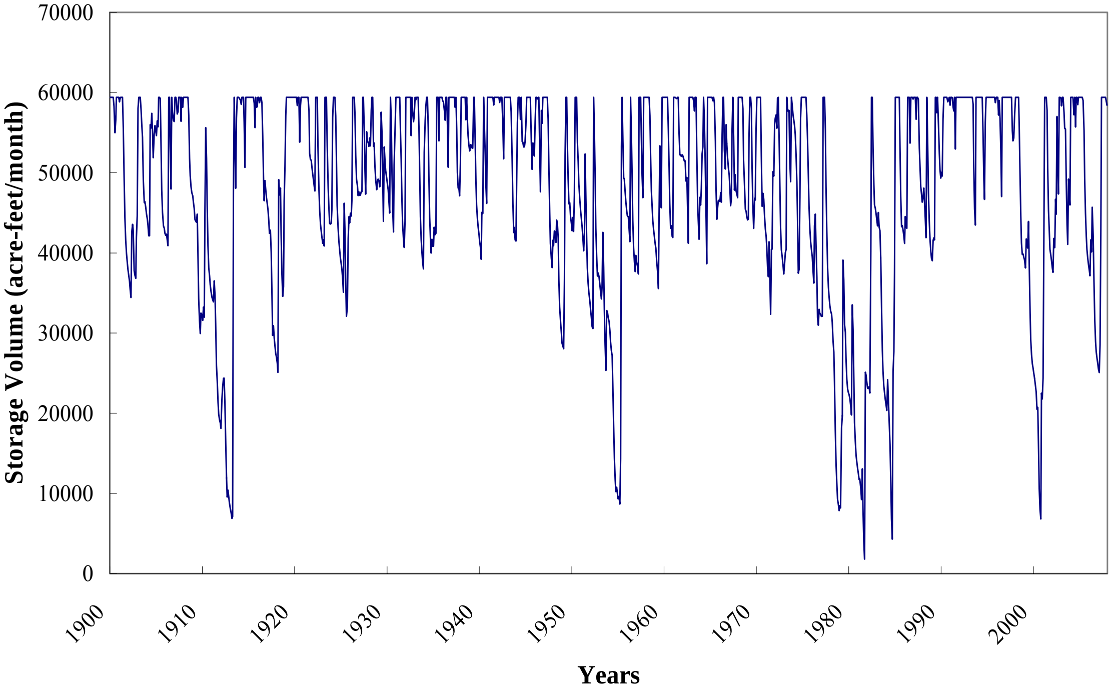

Figure D.15 Bwam3 Storage Volume of Proctor Reservoir

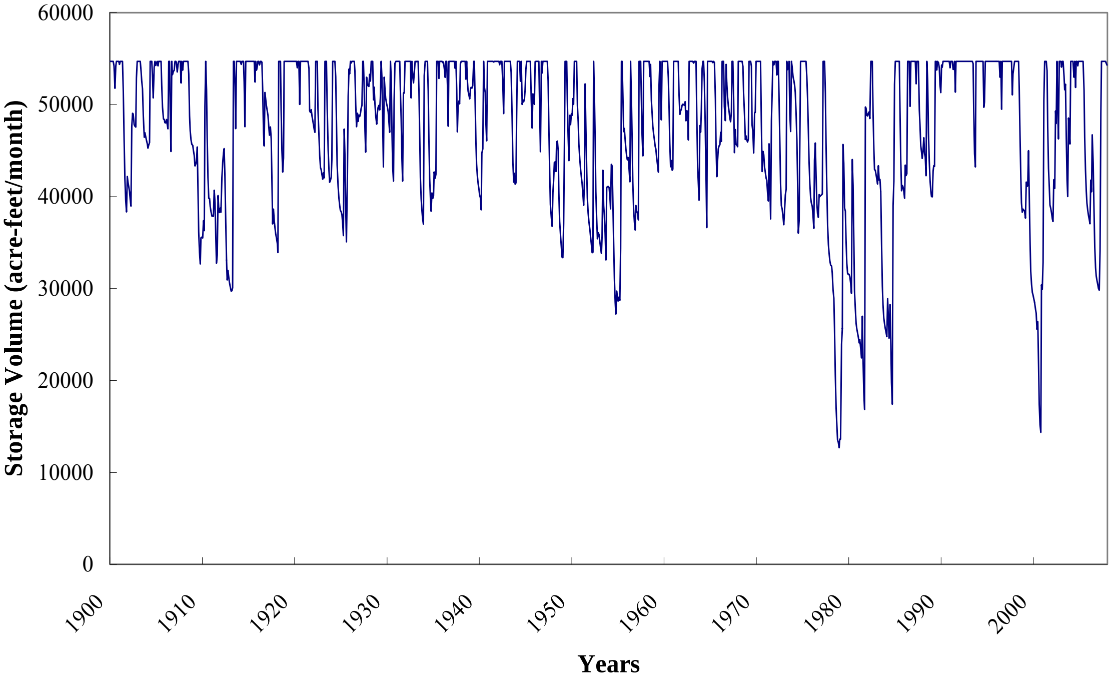

Figure D.16 Bwam8 Storage Volume of Proctor Reservoir

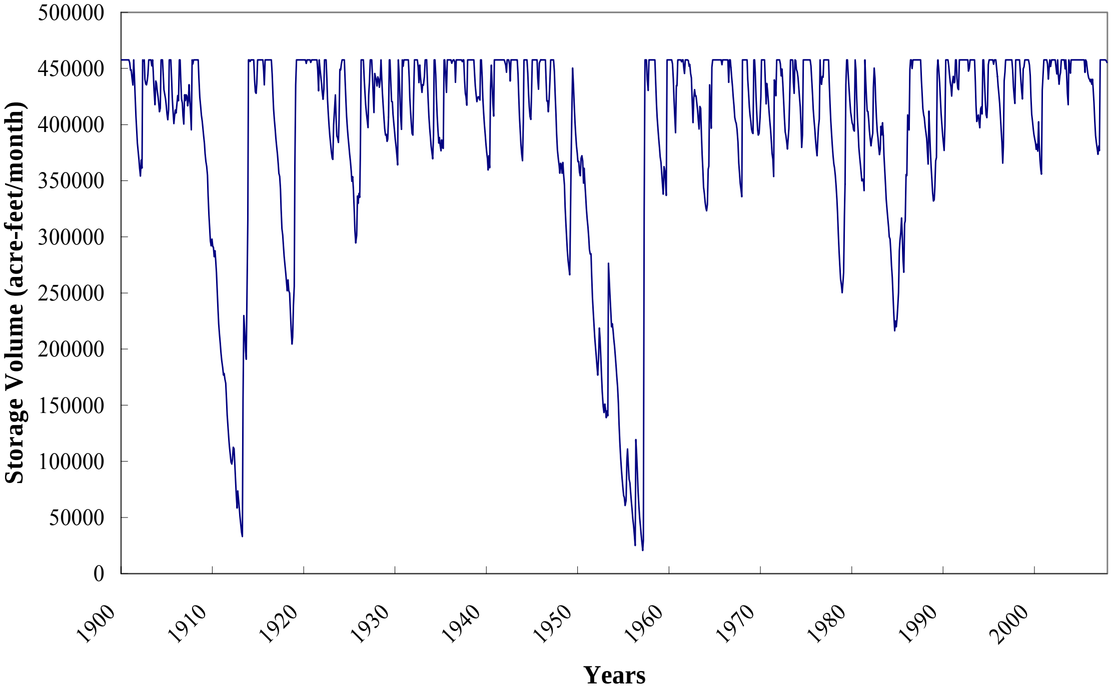

Figure D.17 Bwam3 Storage Volume of Belton Reservoir

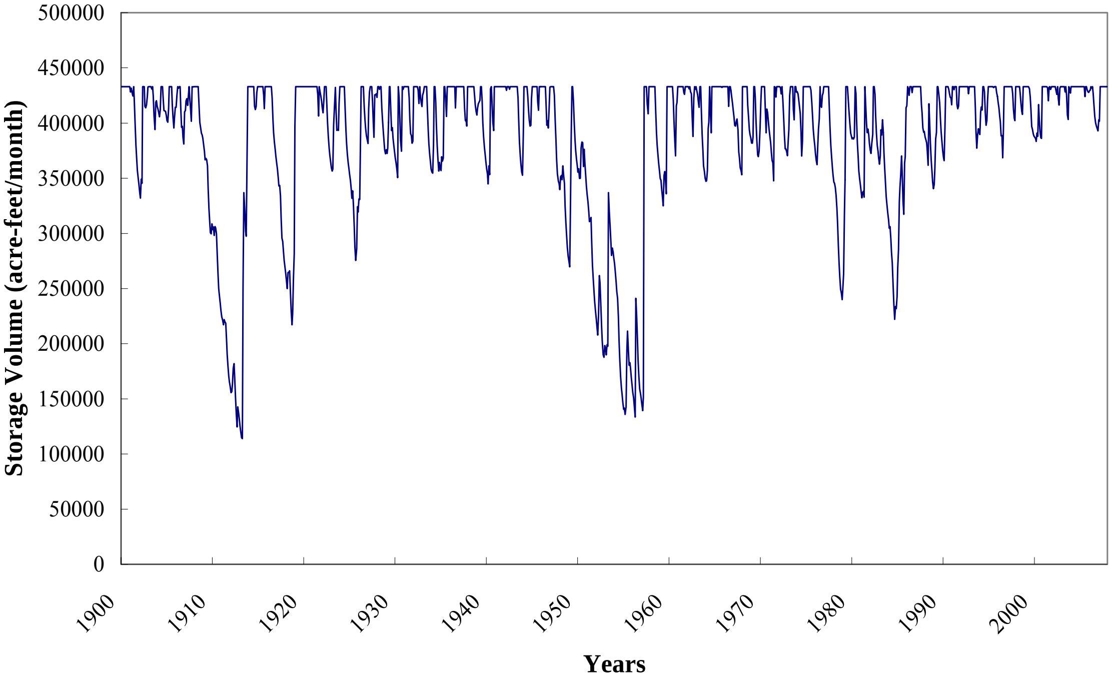

Figure D.18 Bwam8 Storage Volume of Belton Reservoir

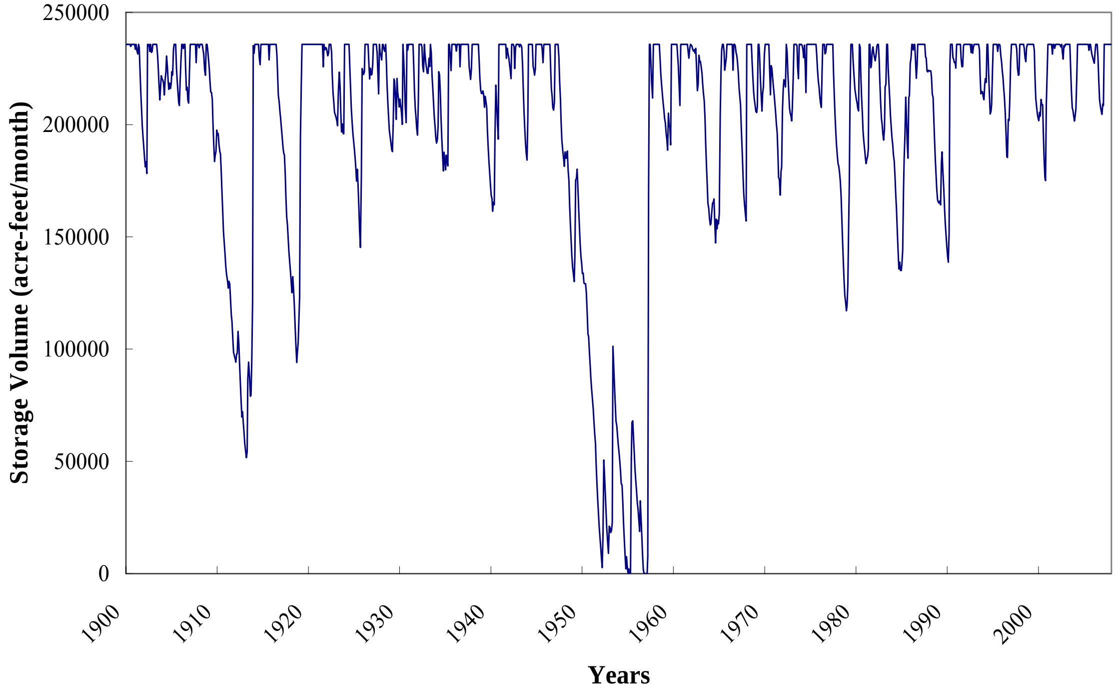

Figure D.19 Bwam3 Storage Volume of Stillhouse Hollow Reservoir

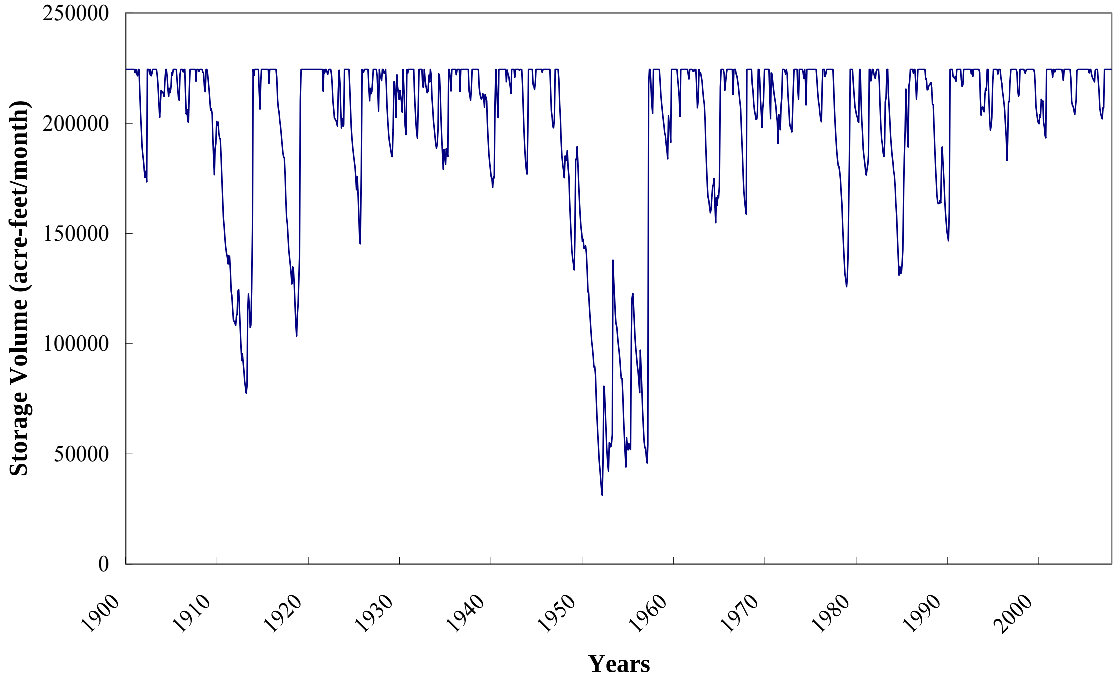

Figure D.20 Bwam8 Storage Volume of Stillhouse Hollow Reservoir

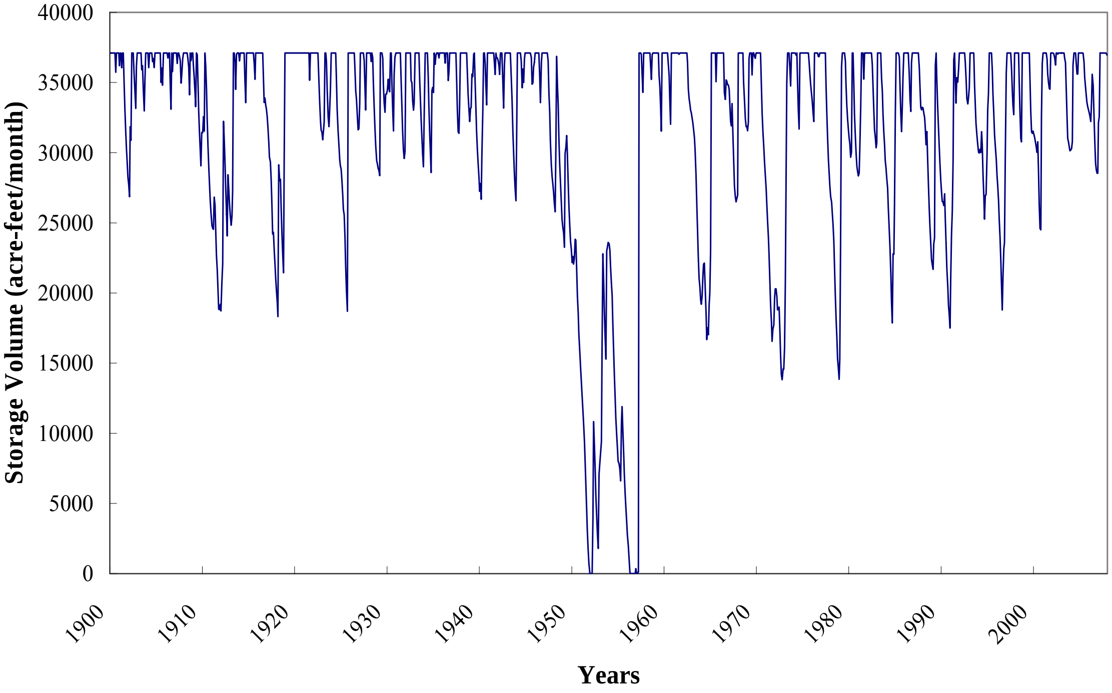

Figure D.21 Bwam3 Storage Volume of Georgetown Reservoir

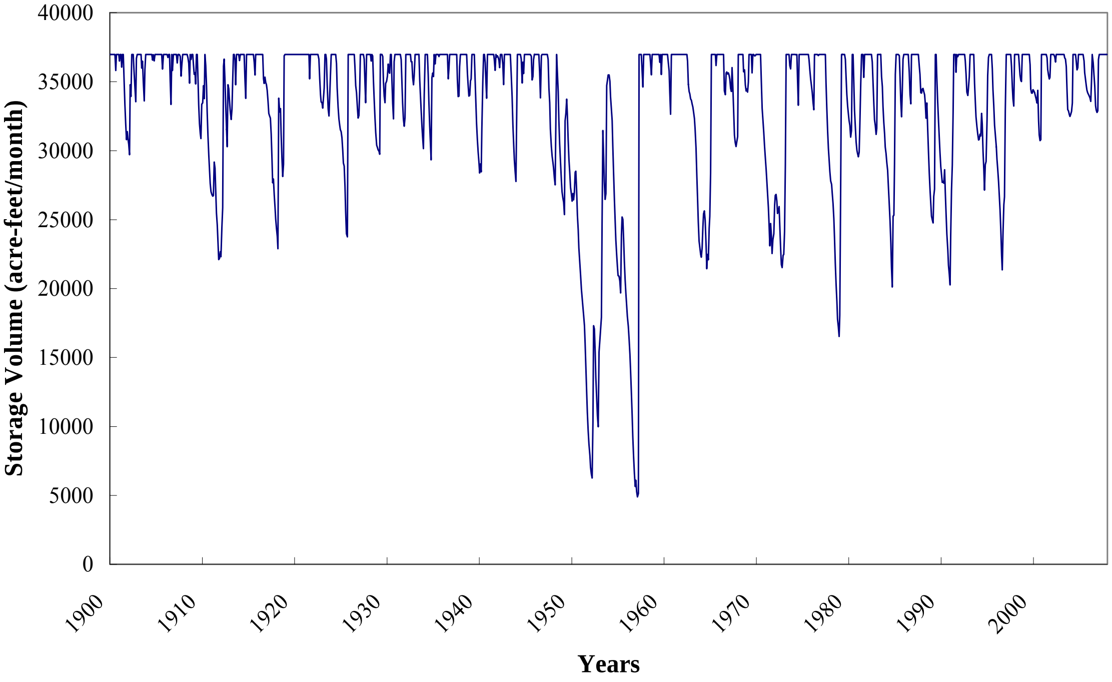

Figure D.22 Bwam8 Storage Volume of Georgetown Reservoir

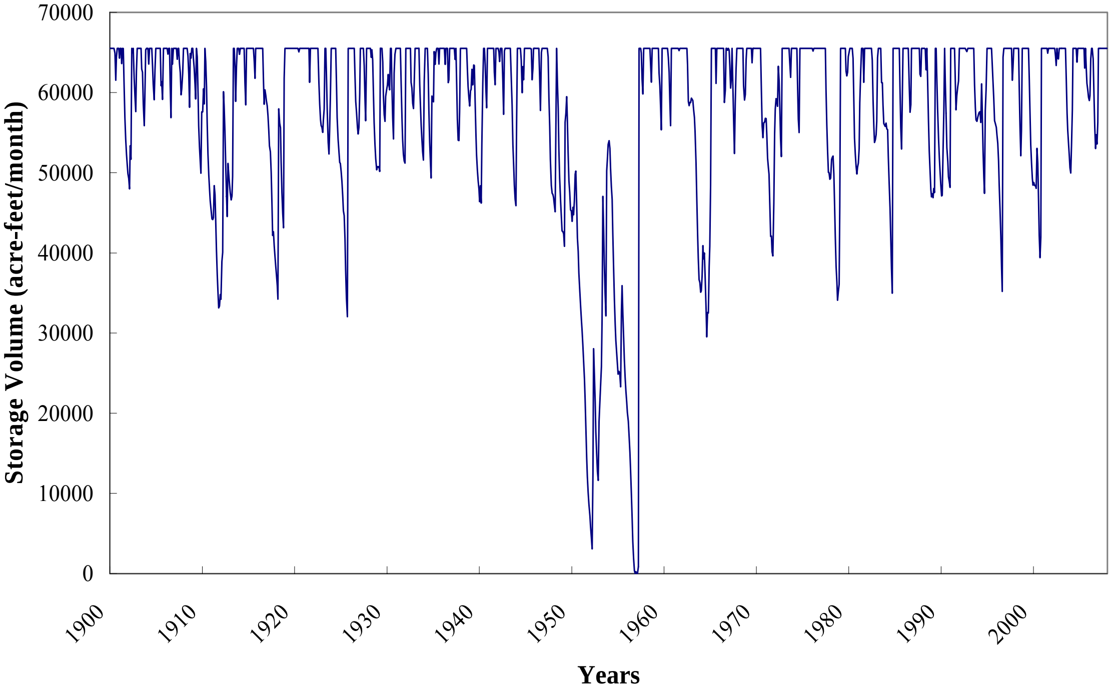

Figure D.23 Bwam3 Storage Volume of Granger Reservoir

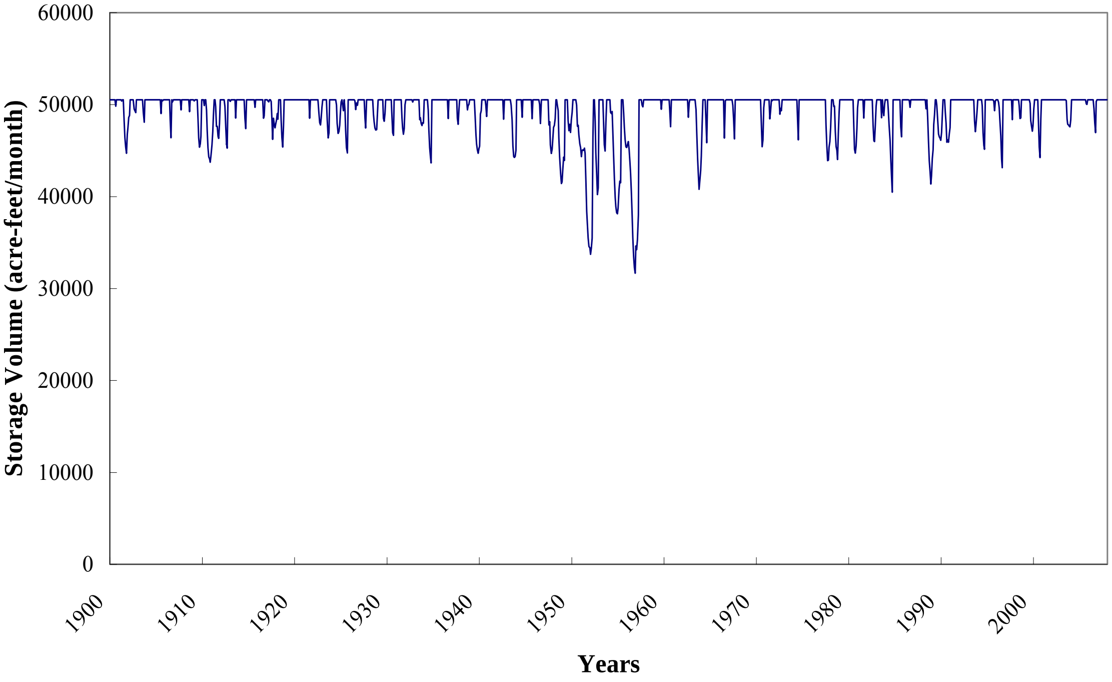

Figure D.24 Bwam8 Storage Volume of Granger Reservoir

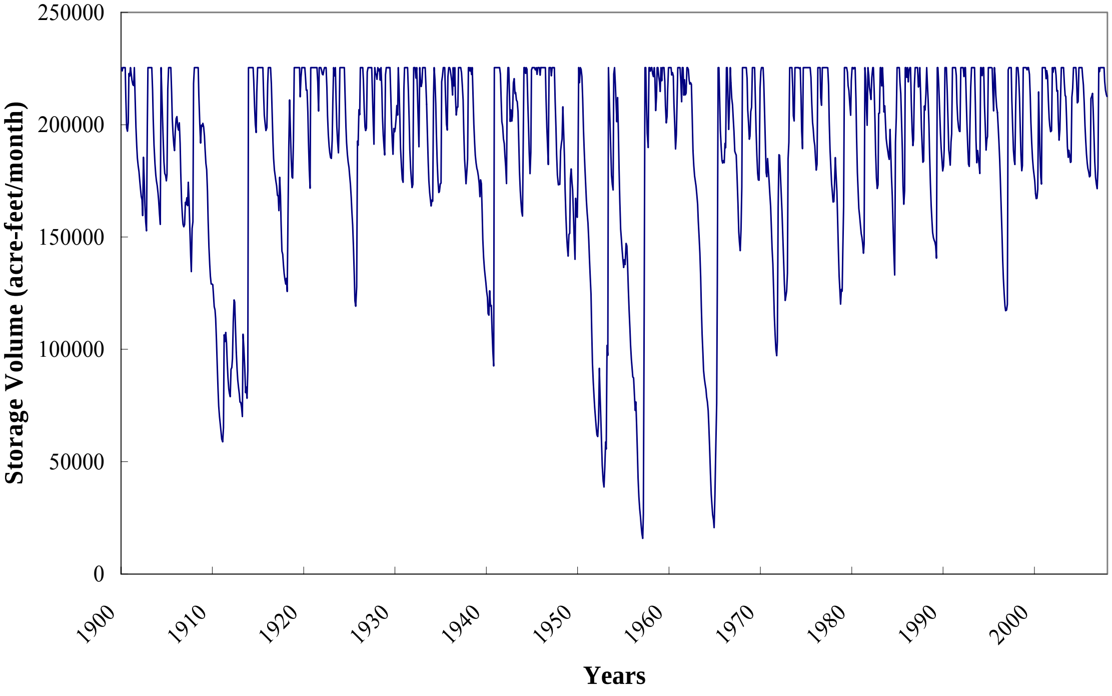

Figure D.25 Bwam3 Storage Volume of Limestone Reservoir

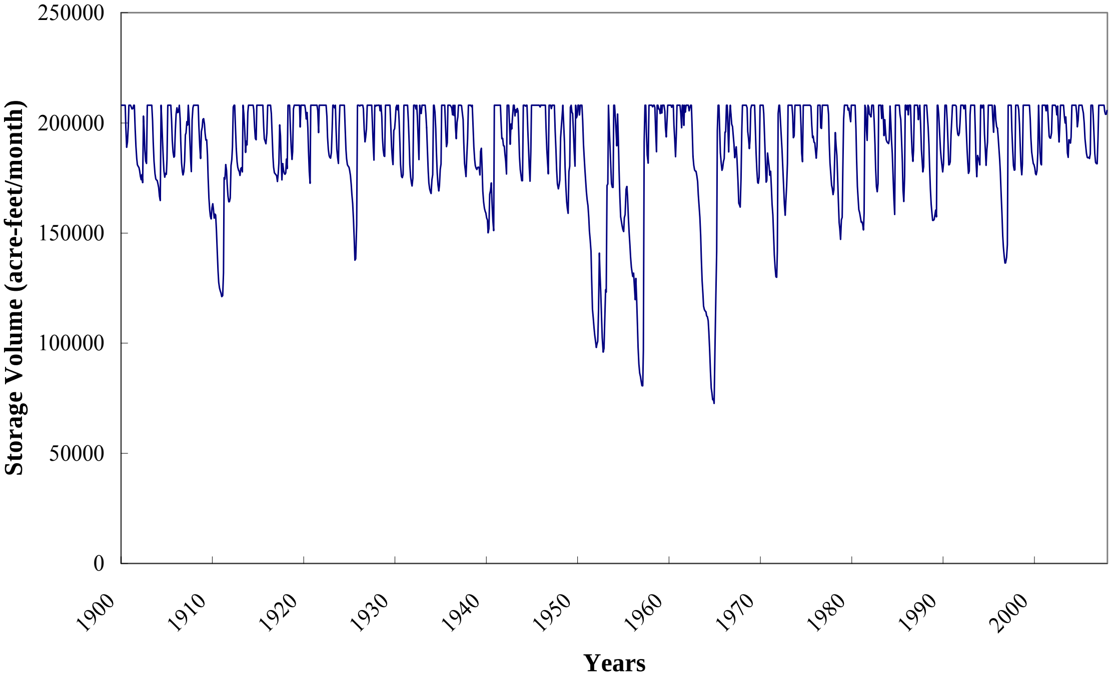

Figure D.26 Bwam8 Storage Volume of Limestone Reservoir

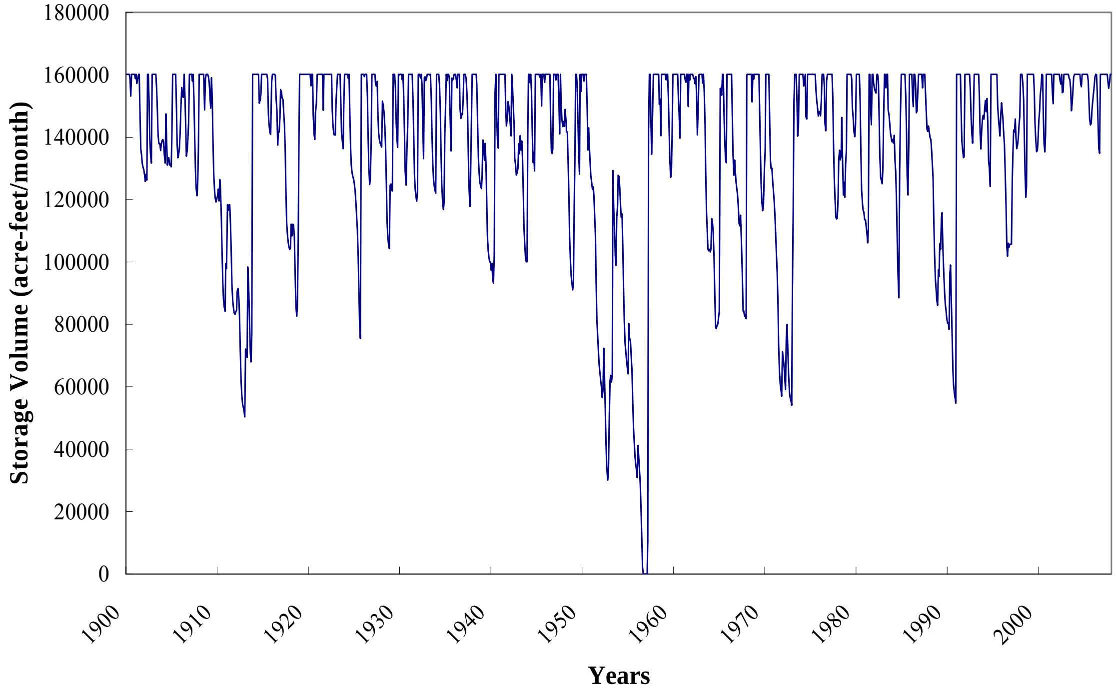

Figure D.27 Bwam3 Storage Volume of Somerville Reservoir

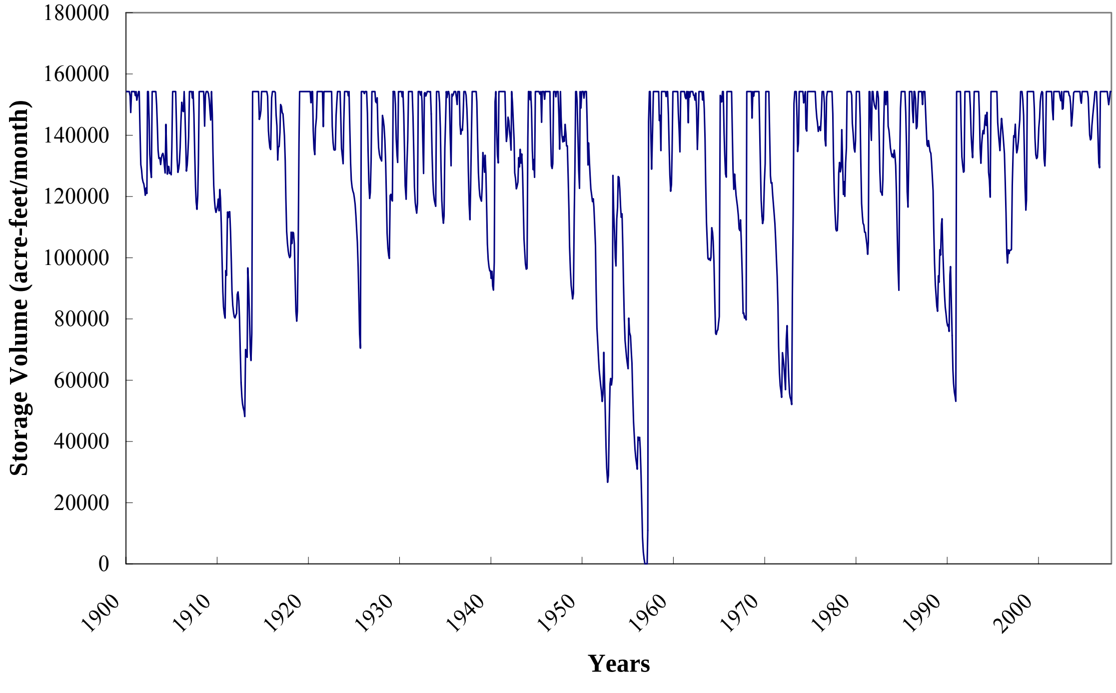

Figure D.28 Bwam8 Storage Volume of Somerville Reservoir

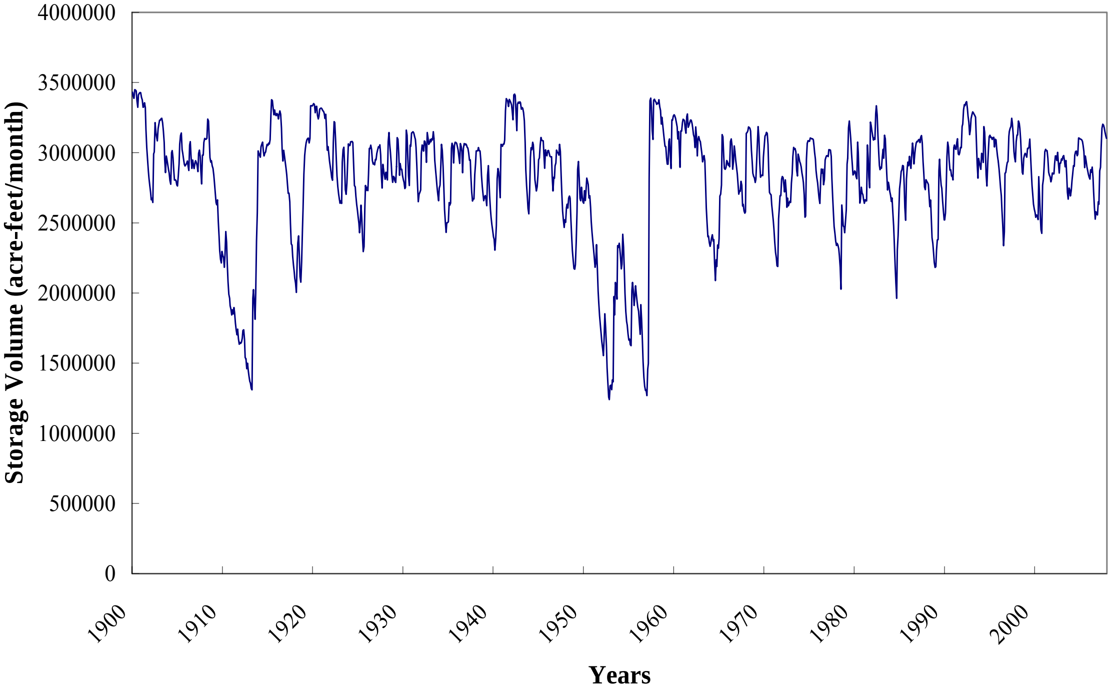

Figure D.29 Bwam3 Total Storage Volume of 14 Reservoirs

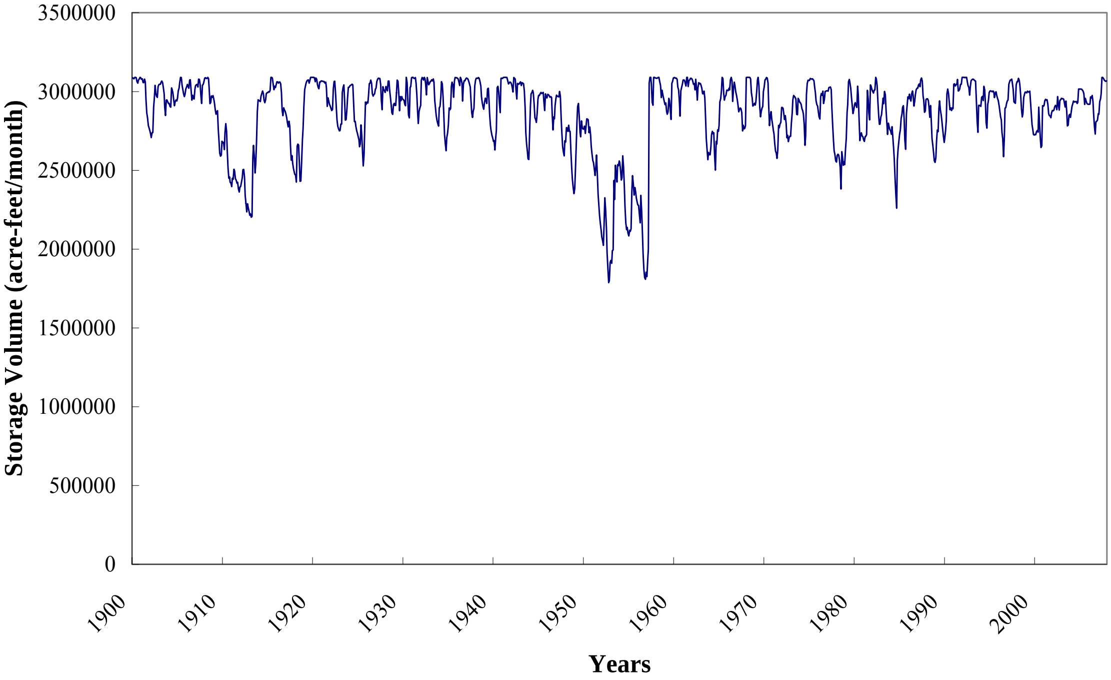

Figure D.30 Bwam8 Total Storage Volume of 14 Reservoirs

APPENDIX E

PLOTS OF 1900-2007 BRAC INFLOWS AT 48 CONTROL POINTS

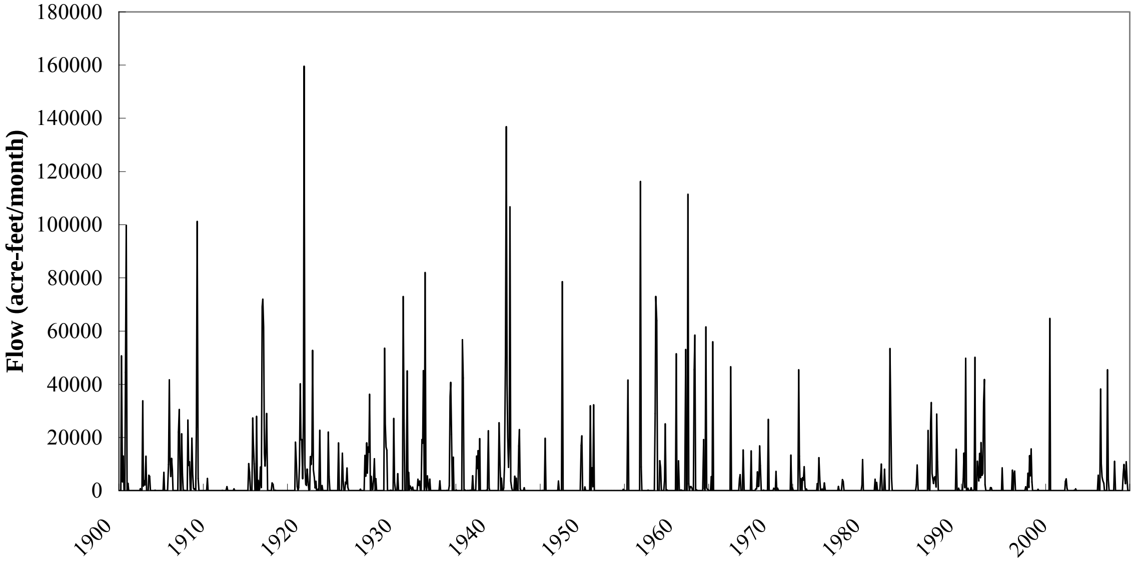

Figure E.1 Monthly BRAC3 Inflows at DMAS09 − Double Mountain Fork at Aspermont Gage

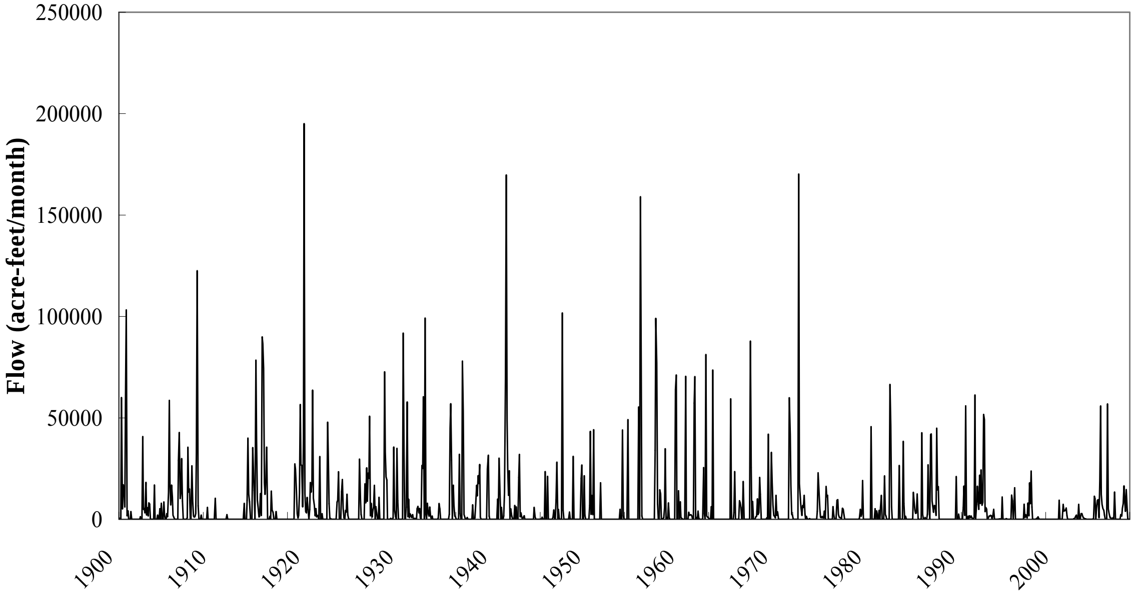

Figure E.2 Monthly BRAC8 Inflows at DMAS09 − Double Mountain Fork at Aspermont Gage

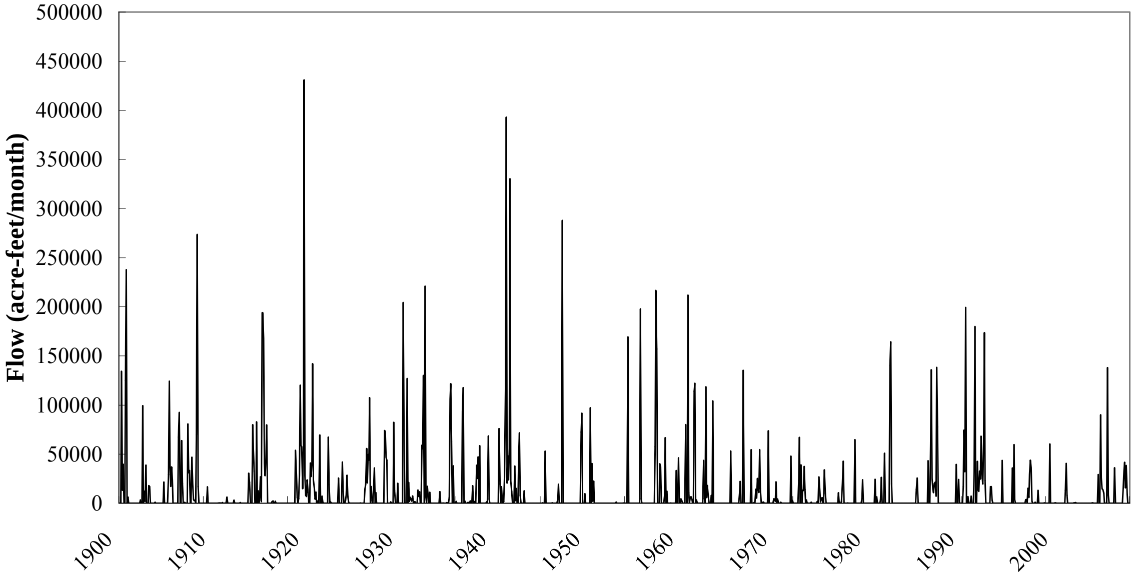

Figure E.3 Monthly BRAC3 Inflows at BRSE11 − Brazos River at Seymour Gage

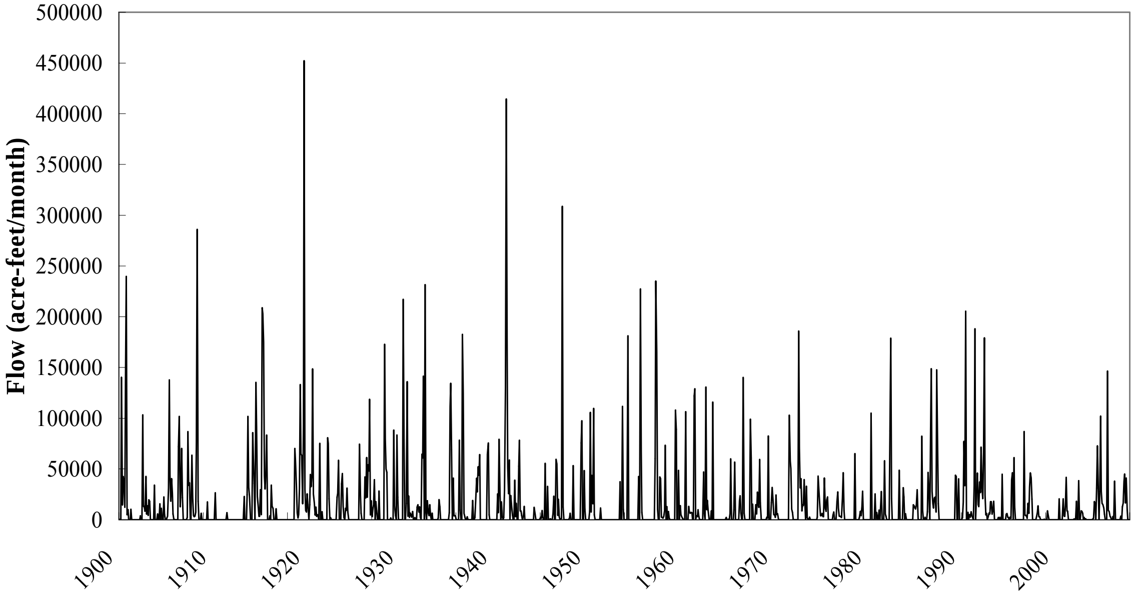

Figure E.4 Monthly BRAC8 Inflows at BRSE11 − Brazos River at Seymour Gage

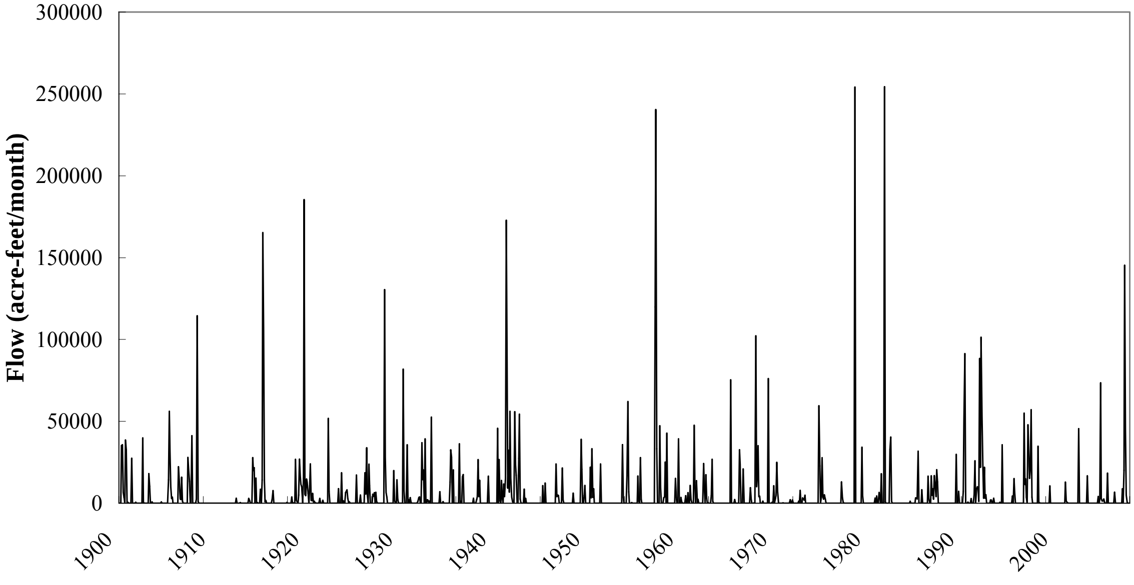

Figure E.5 Monthly BRAC3 Inflows at 421331 − Hubbard Creek Reservoir

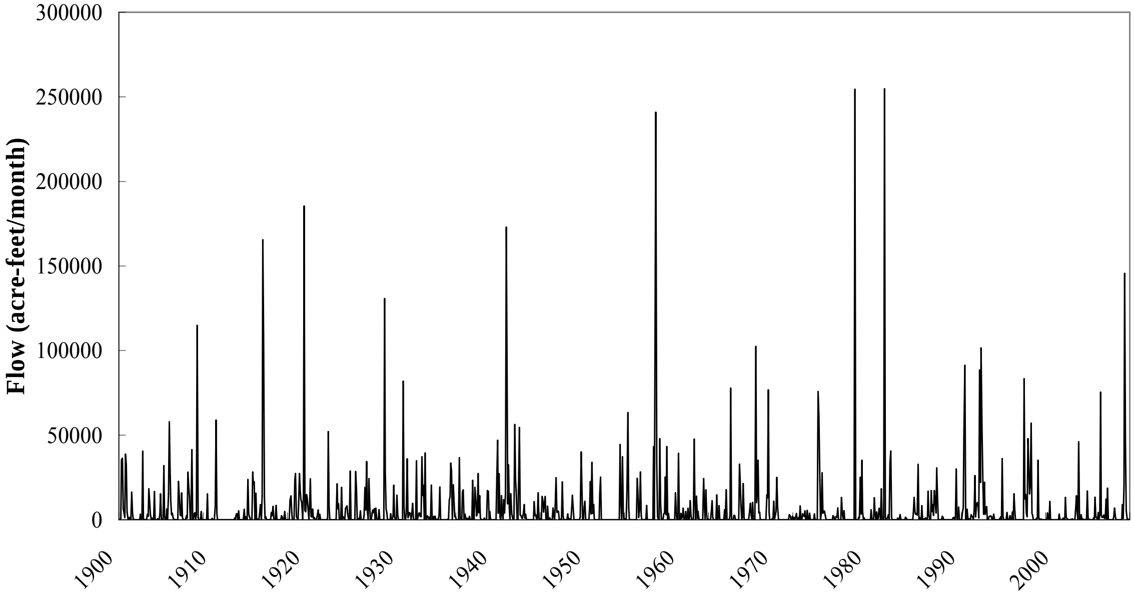

Figure E.6 Monthly BRAC8 Inflows at 421331 − Hubbard Creek Reservoir

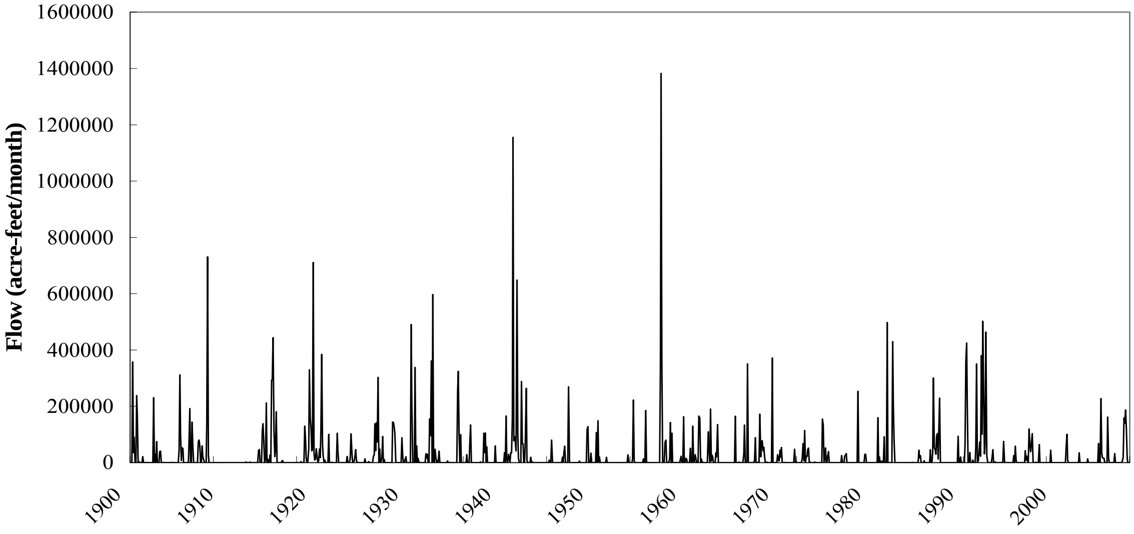

Figure E.7 Monthly BRAC3 Inflows and Bwam3 Naturalized Flows at CON036

Confluence of Hubbard Creek and Brazos River

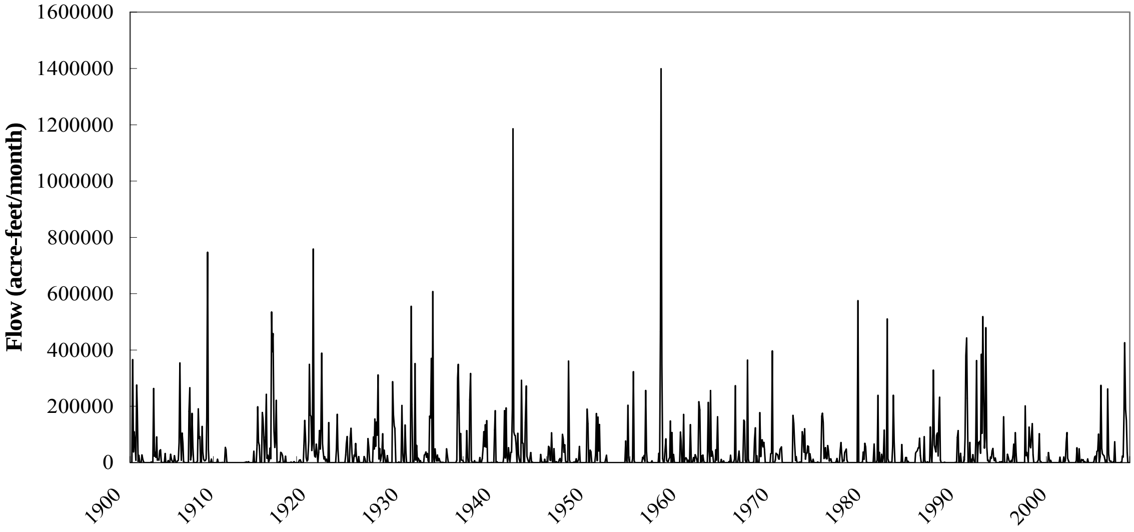

Figure B.8 Monthly BRAC8 Inflows at CON036

Confluence of Hubbard Creek and Brazos River

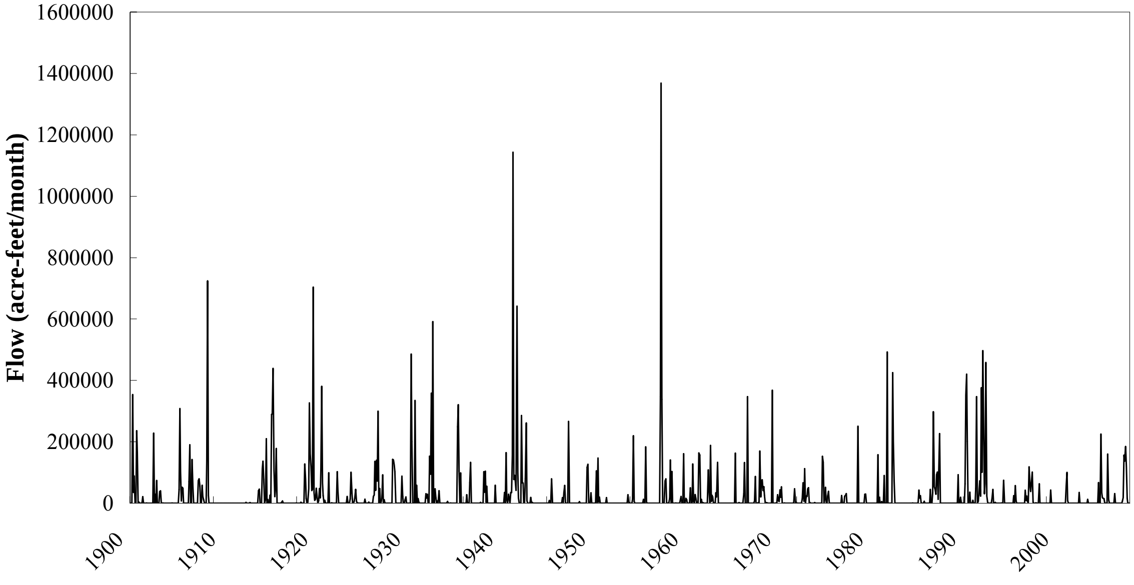

Figure E.9 Monthly BRAC3 Inflows at BRSB23 − Brazos River at South Bend Gage

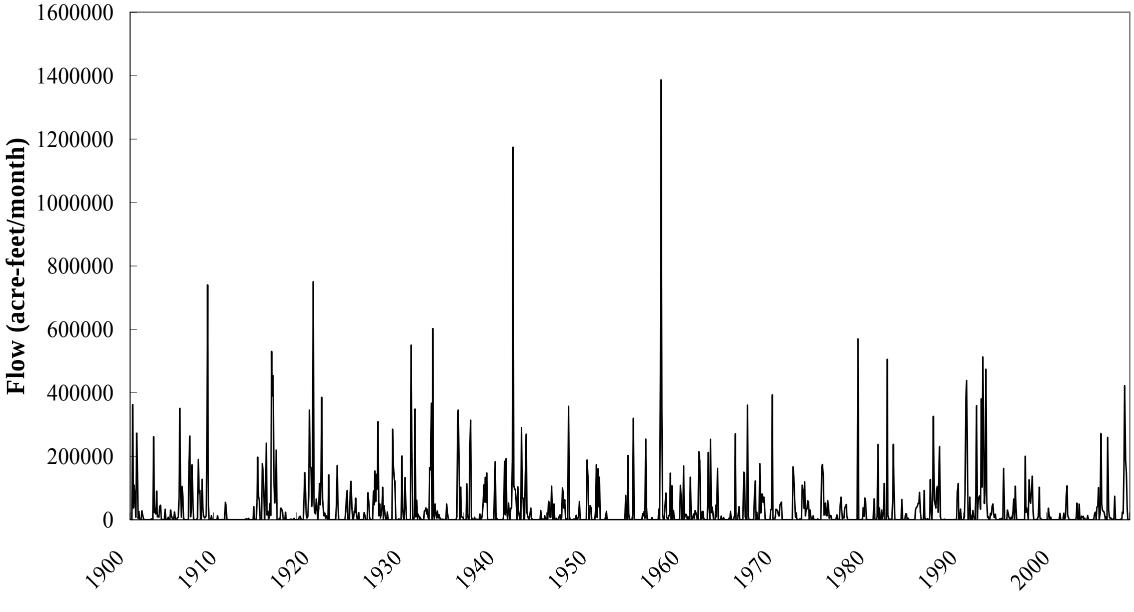

Figure E.10 Monthly BRAC8 Inflows at BRSB23 − Brazos River at South Bend Gage

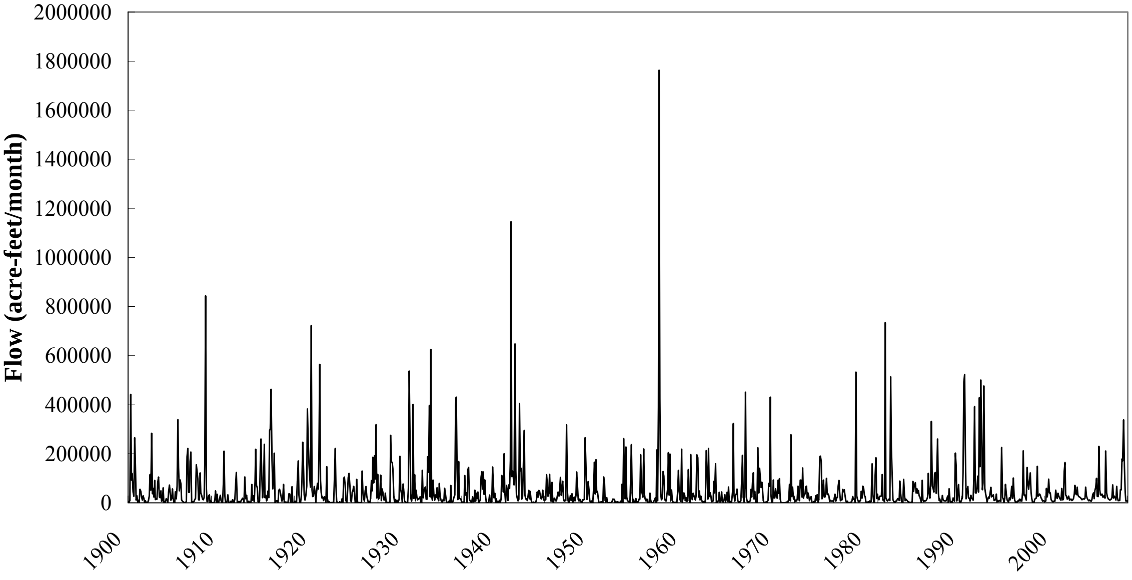

Figure E.11 Monthly BRAC3 Inflows at 515531 − Possum Kingdom Reservoir

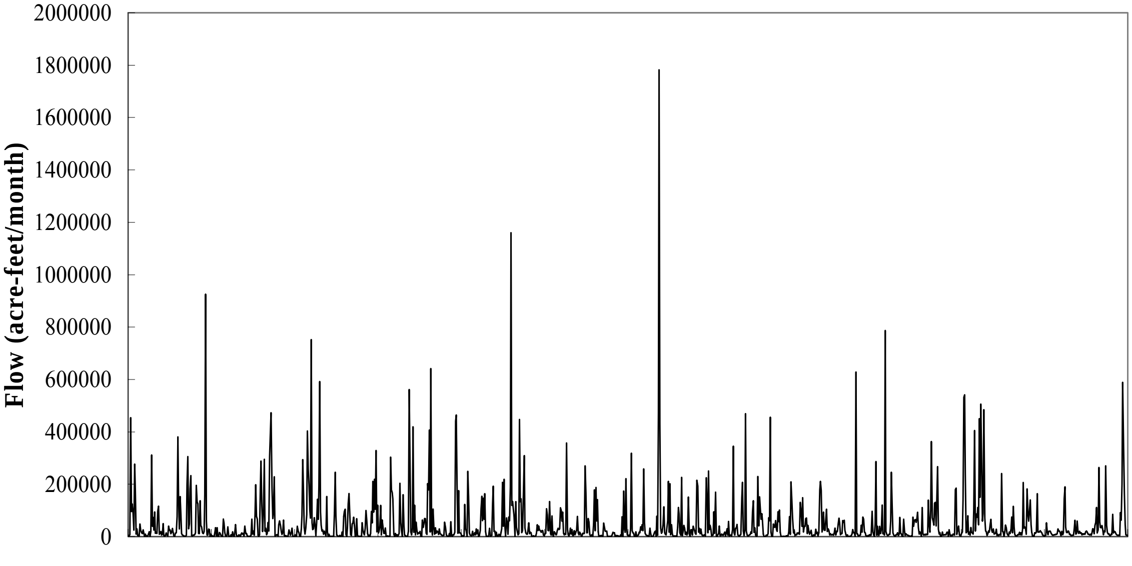

Figure E.12 Monthly BRAC8 Inflows at 515531 − Possum Kingdom Reservoir

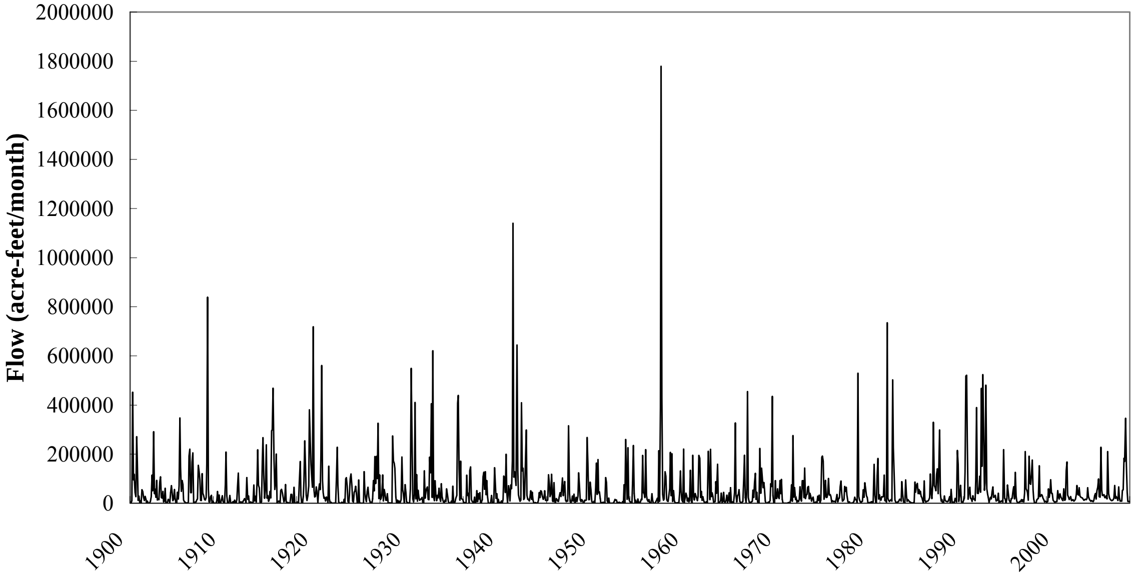

Figure E.13 Monthly BRAC3 Inflows at BRPP27 − Brazos River at Palo Pinto Gage

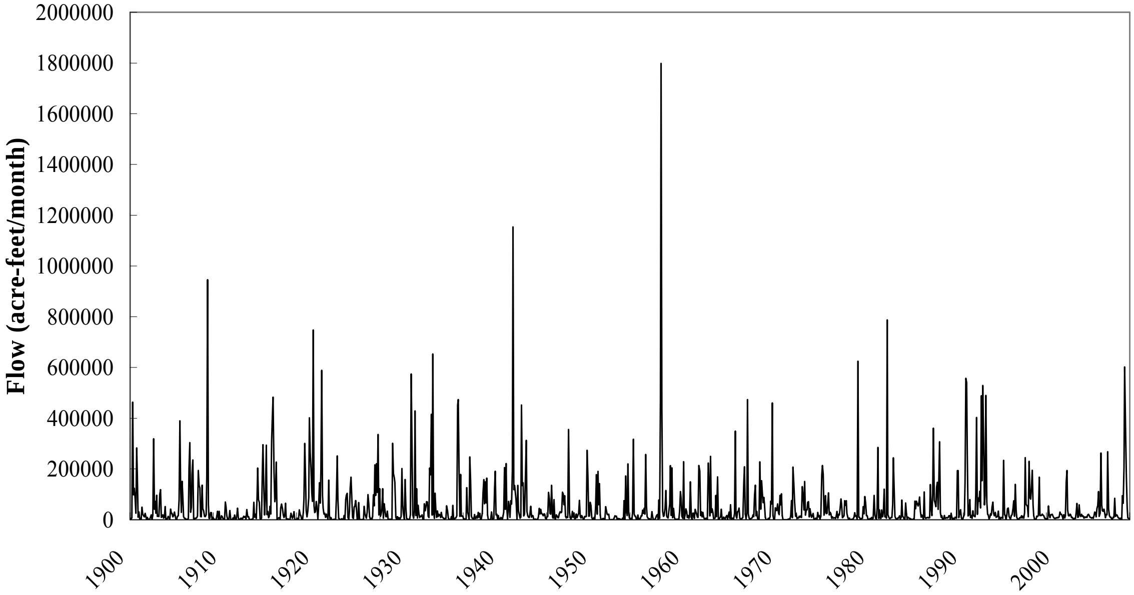

Figure E.14 Monthly BRAC8 Inflows at BRPP27 − Brazos River at Palo Pinto Gage

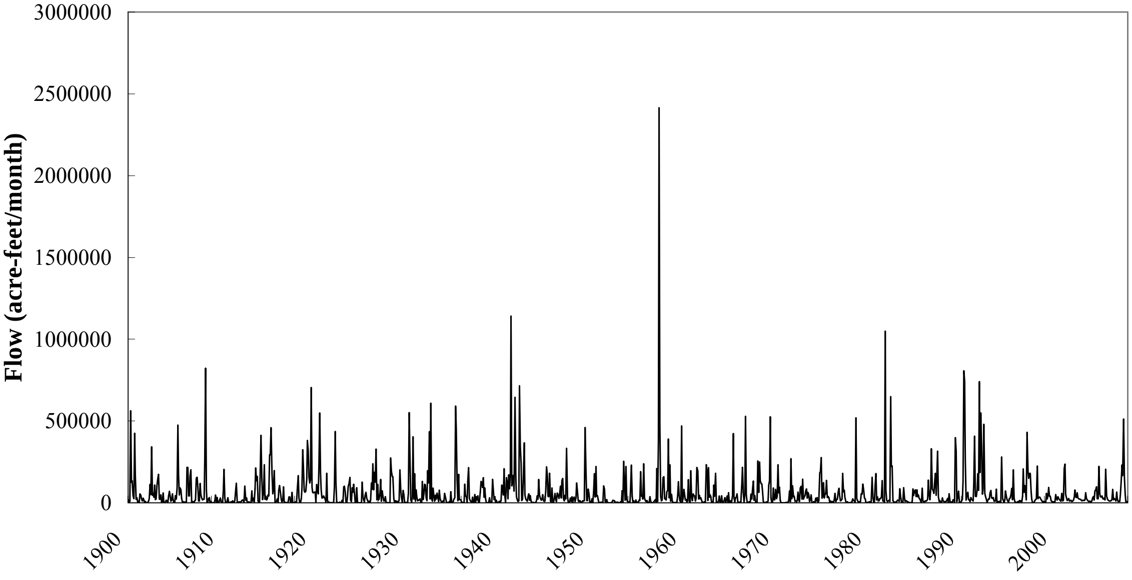

Figure E.15 Monthly BRAC3 Inflows at BRDE29 − Brazos River at Dennis Gage

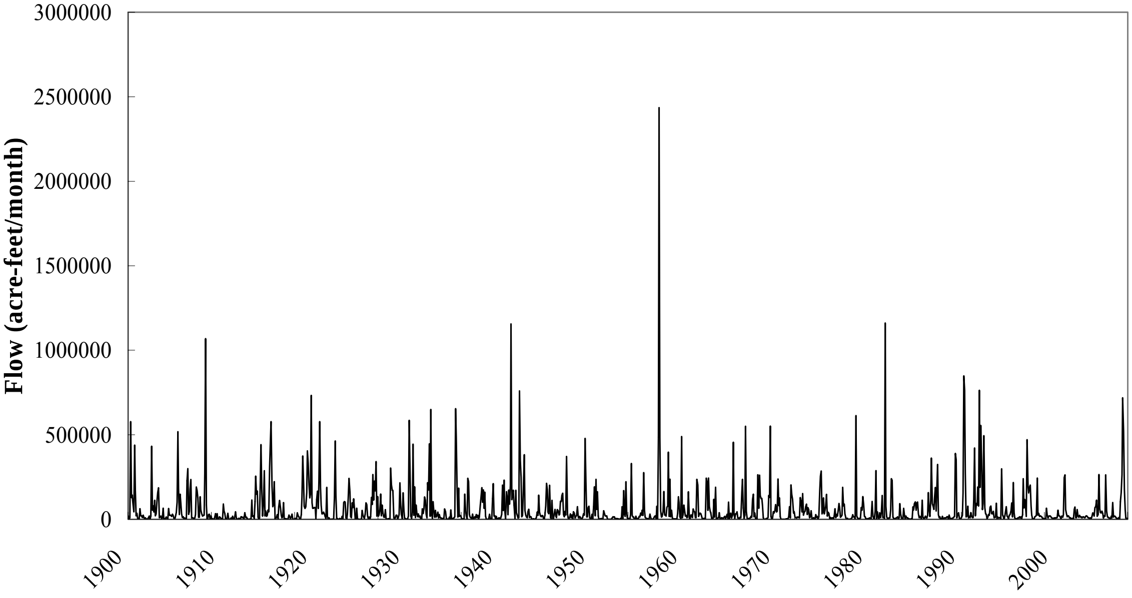

Figure E.16 Monthly BRAC8 Inflows at BRDE29 − Brazos River at Dennis Gage

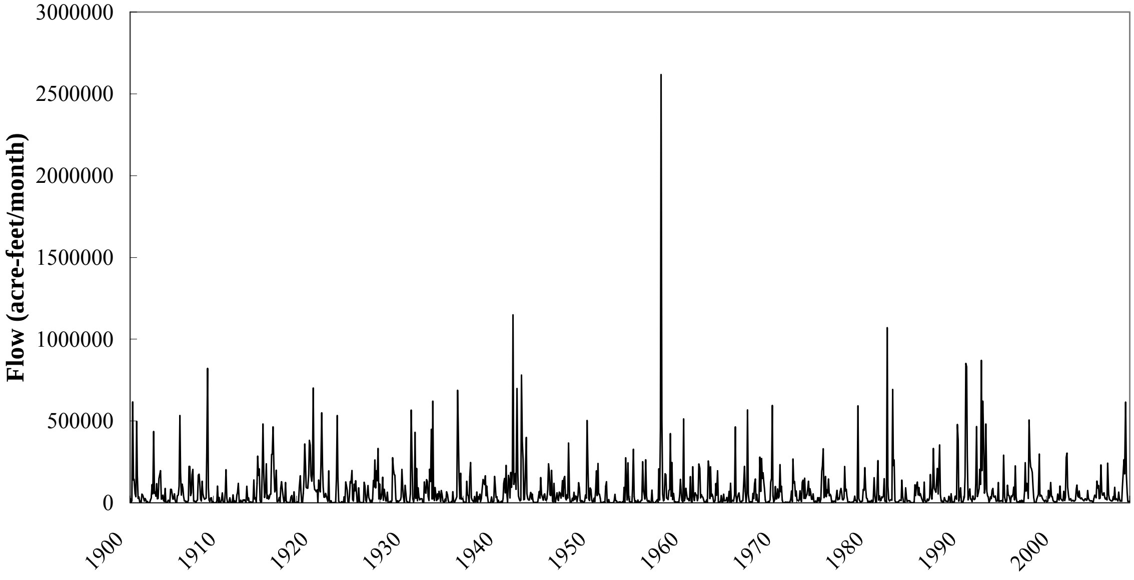

Figure E.17 Monthly BRAC3 Inflows at 515631 − Granbury Reservoir

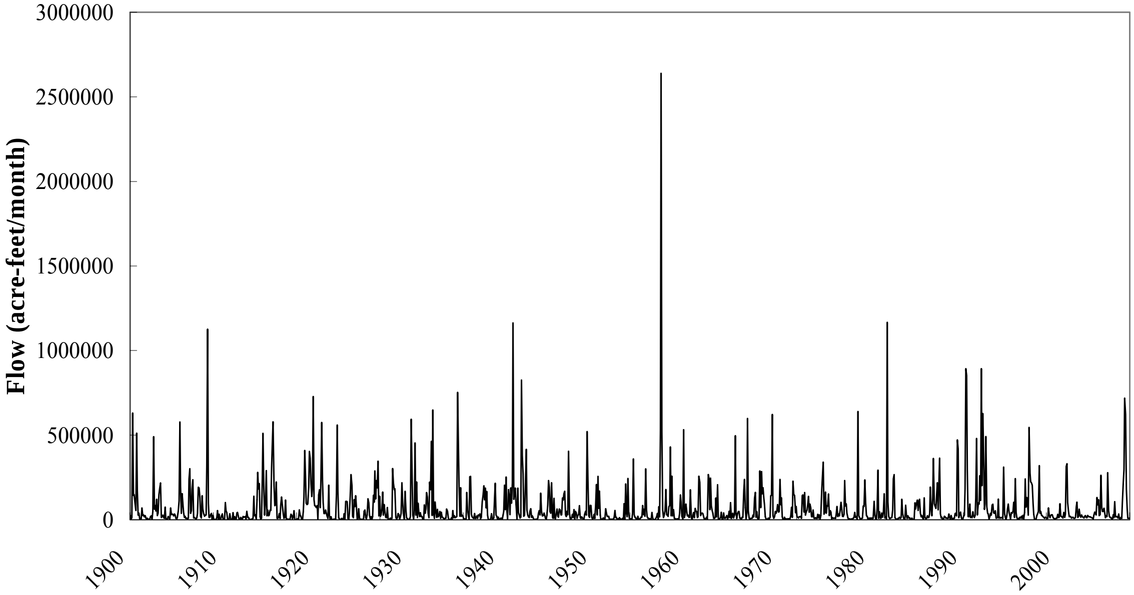

Figure E.18 Monthly BRAC8 Inflows at 515631 − Granbury Reservoir

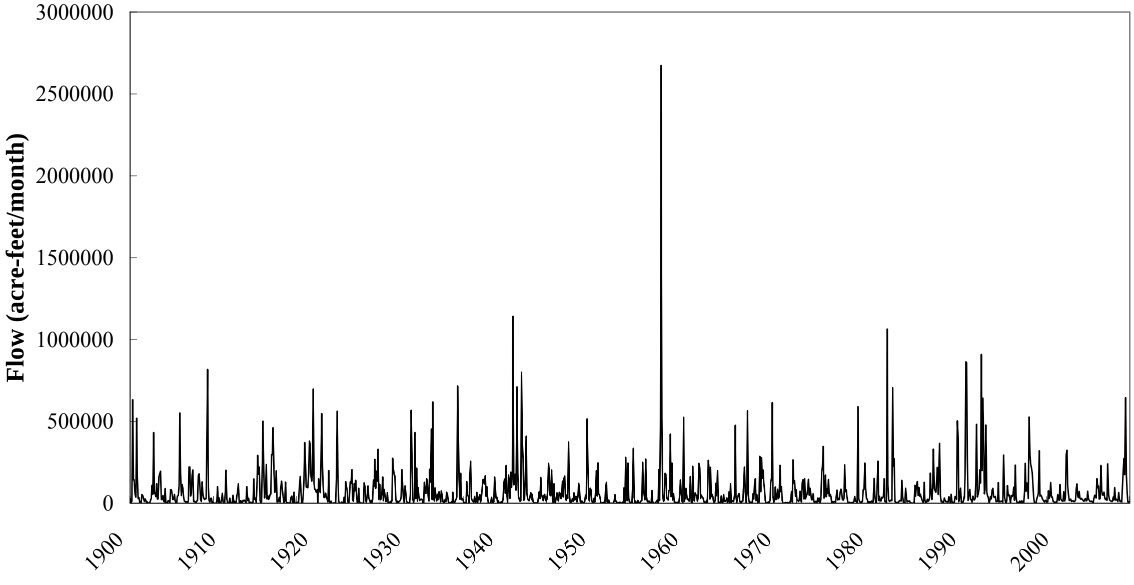

Figure E.19 Monthly BRAC3 Inflows at BRGR30 − Brazos River at Glen Rose

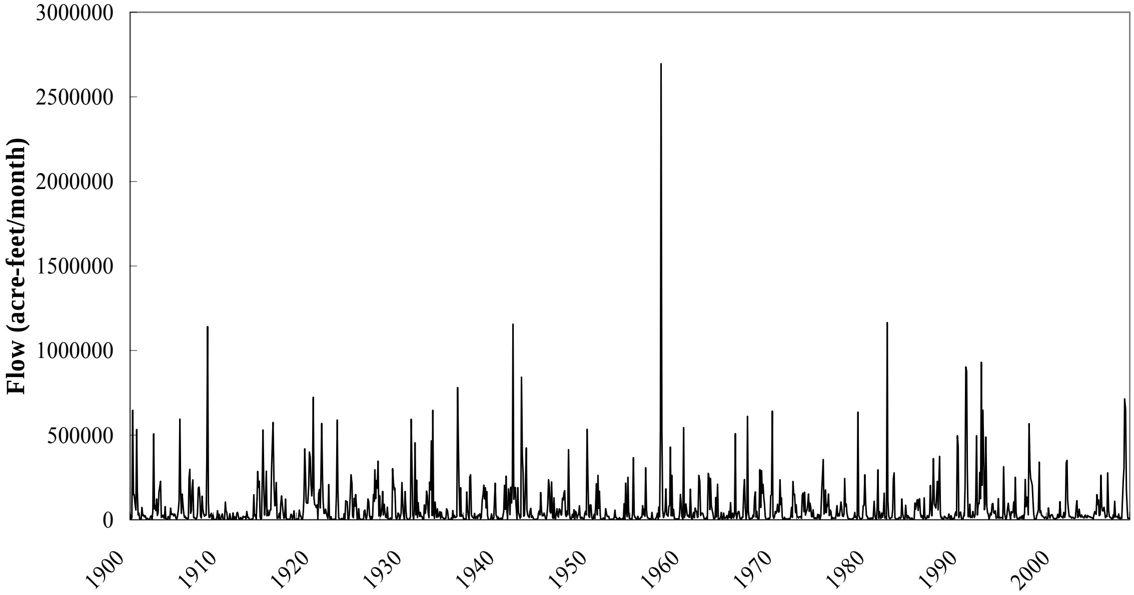

Figure E.20 Monthly BRAC8 Inflows at BRGR30 − Brazos River at Glen Rose

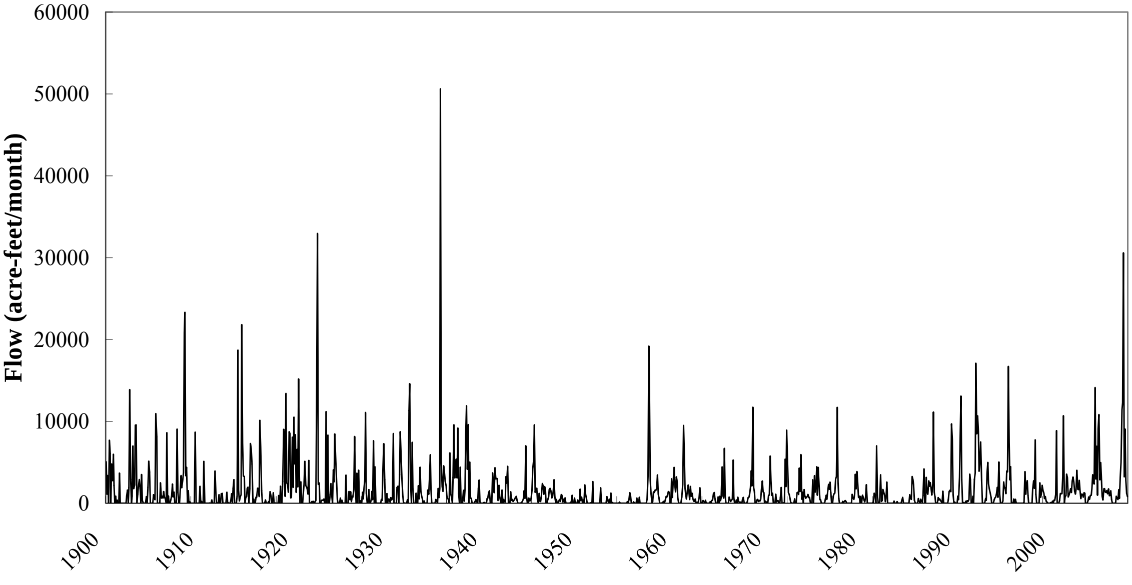

Figure E.21 Monthly BRAC3 Inflows at 409732 − Squaw Creek Reservoir

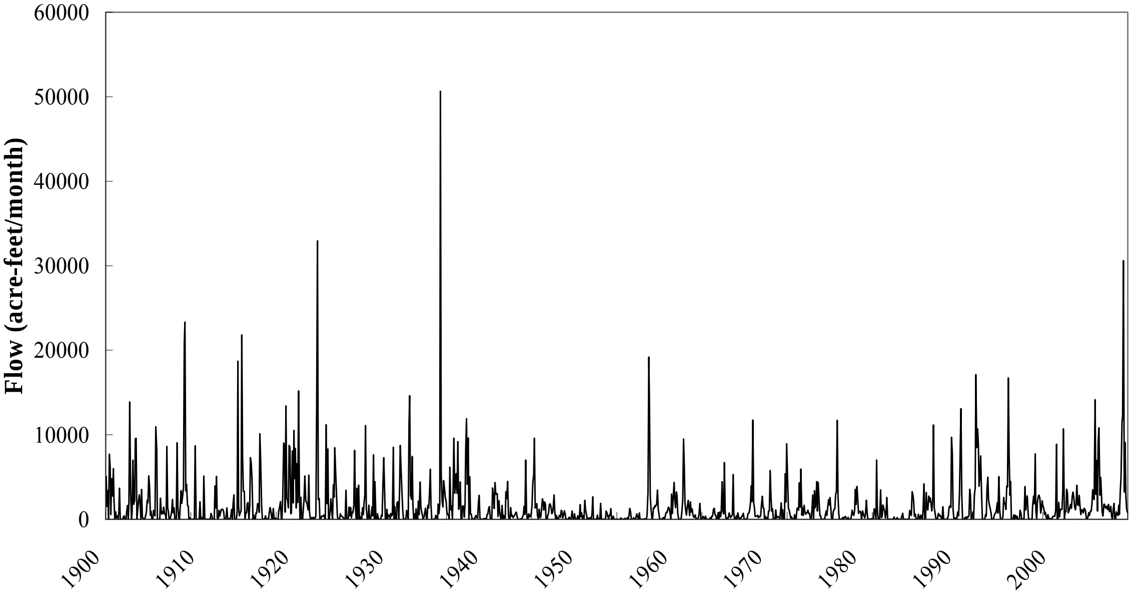

Figure E.22 Monthly BRAC8 Inflows at 409732 − Squaw Creek Reservoir

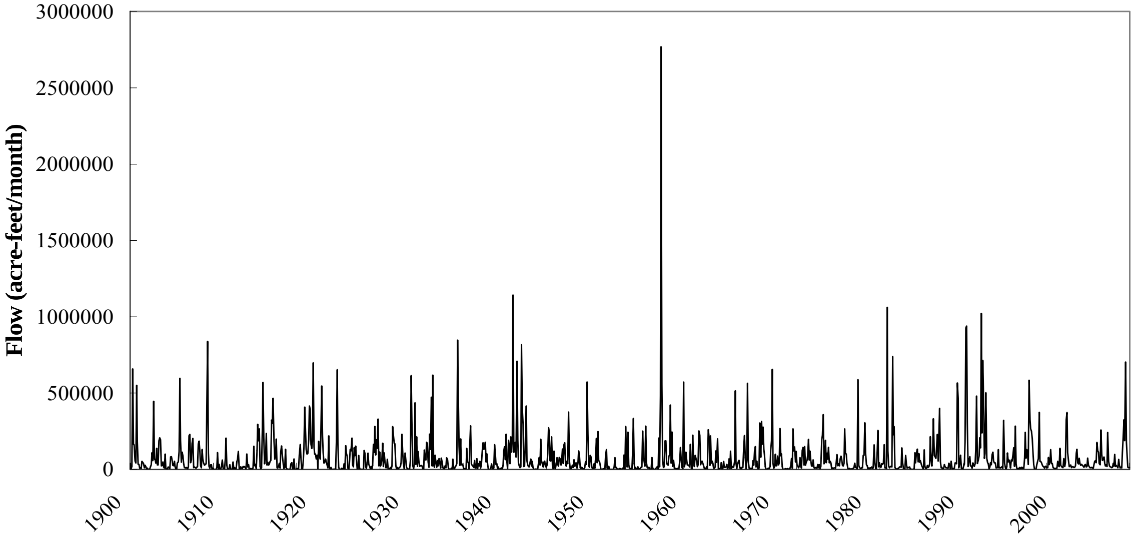

Figure E.23 Monthly BRAC3 Inflows at CON063 − Confluence of Squaw Creek and Brazos River

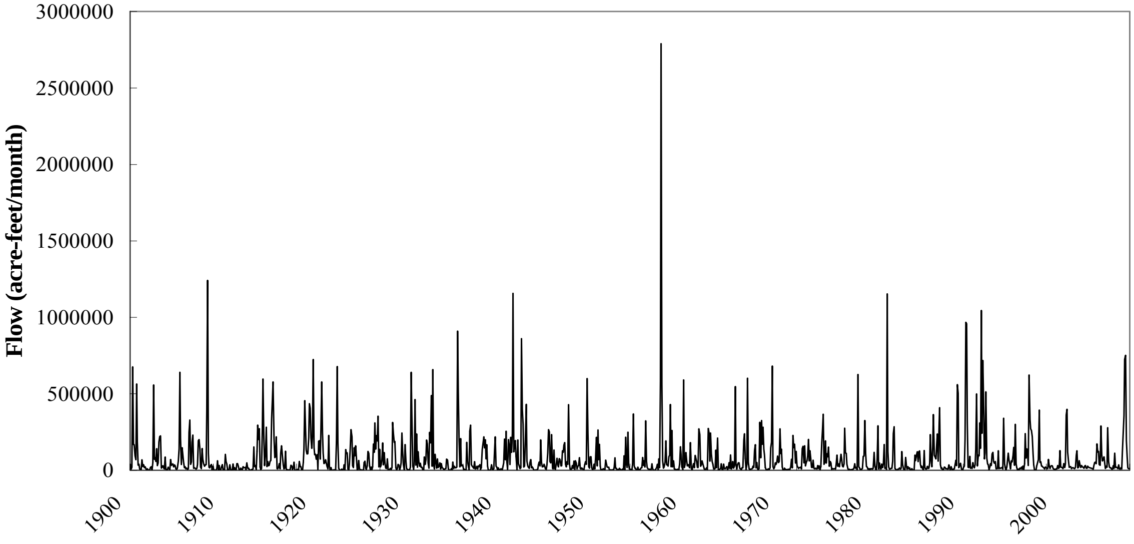

Figure E.24 Monthly BRAC8 Inflows at CON063 − Confluence of Squaw Creek and Brazos River

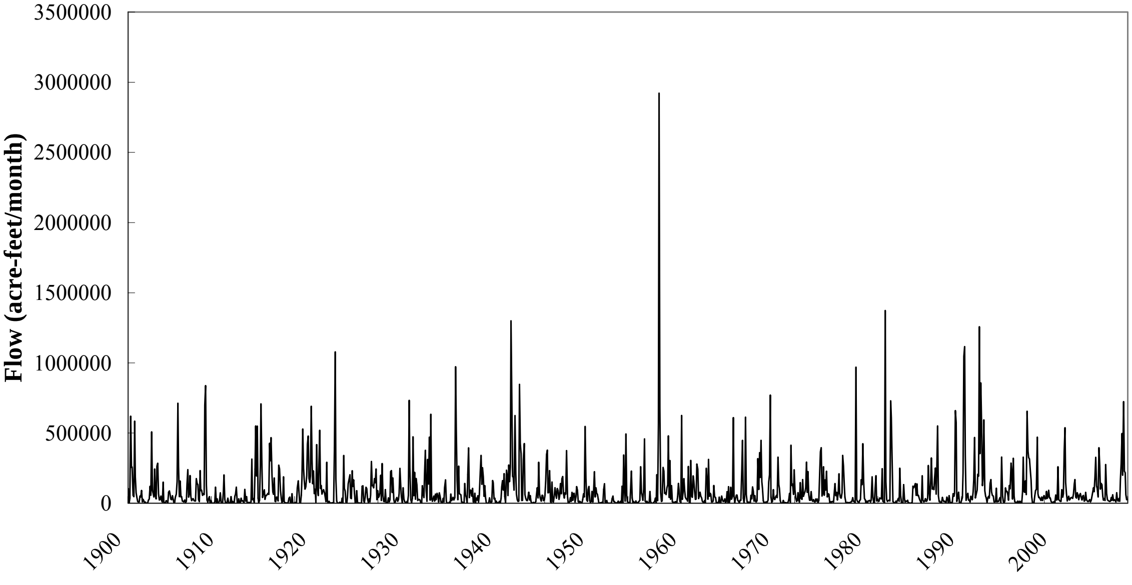

Figure E.25 Monthly BRAC3 Inflows at 515731 − Whitney Reservoir

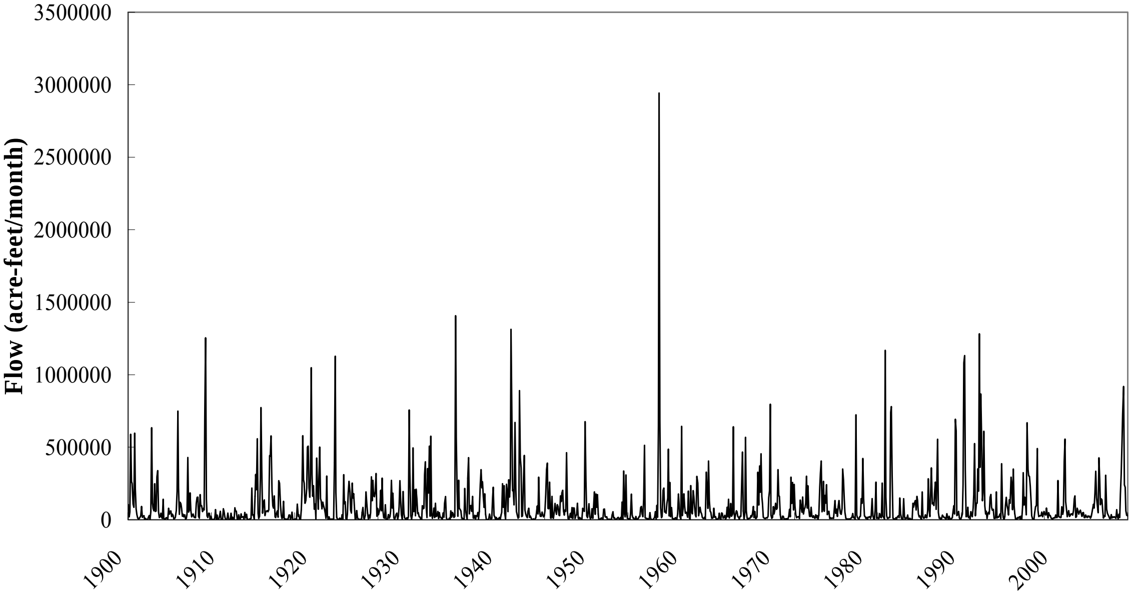

Figure E.26 Monthly BRAC8 Inflows at 515731 − Whitney Reservoir

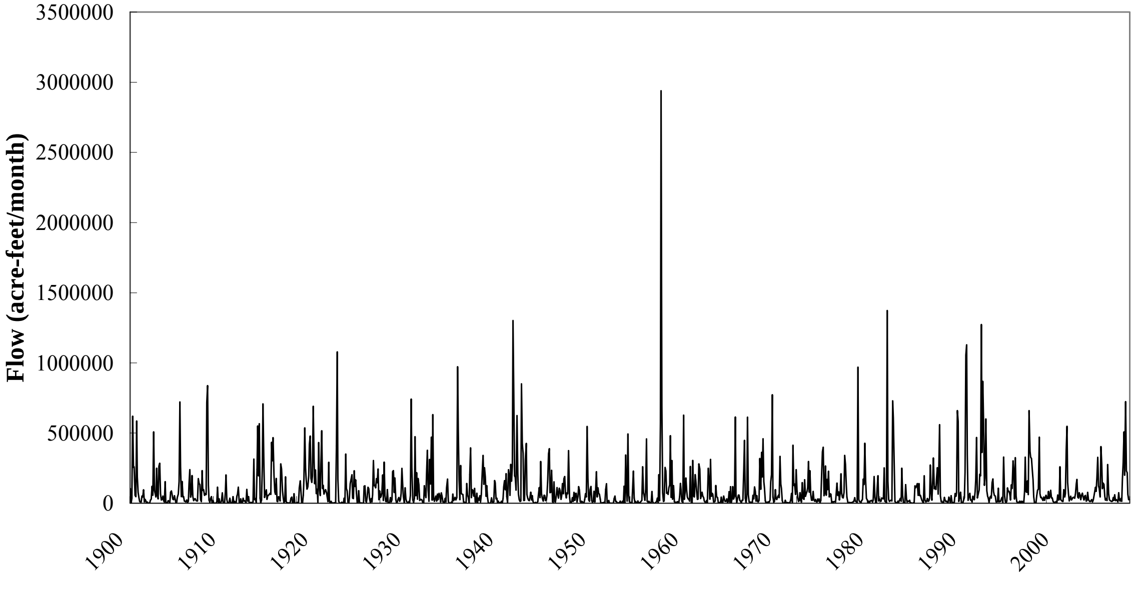

Figure E.27 Monthly BRAC3 Inflows at BRAQ33 − Brazos River at Aquilla Gage

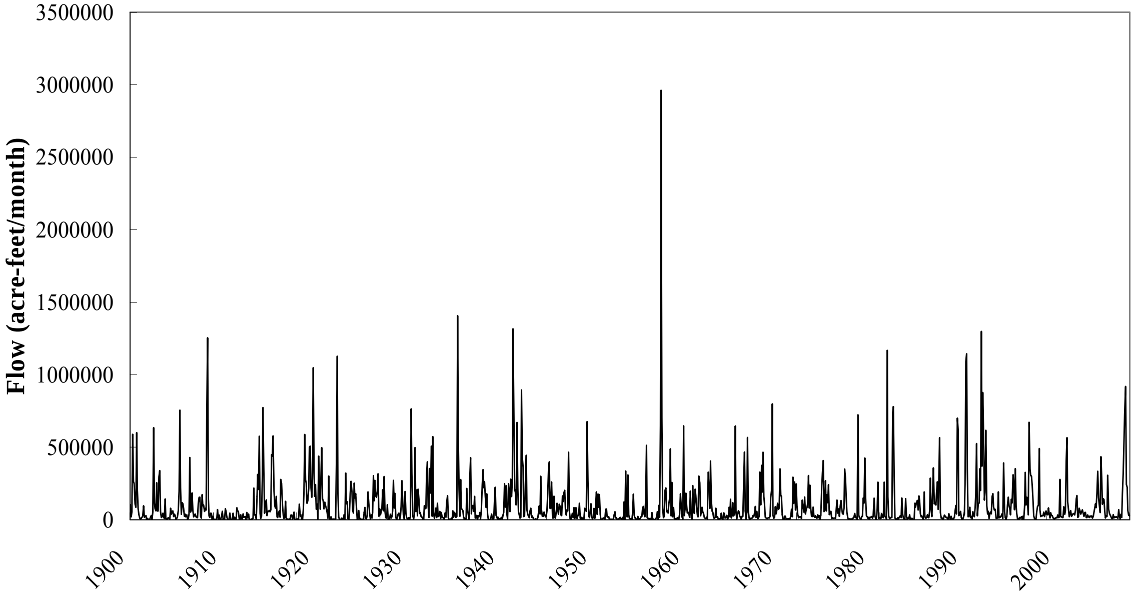

Figure E.28 Monthly BRAC8 Inflows at BRAQ33 − Brazos River at Aquilla Gage

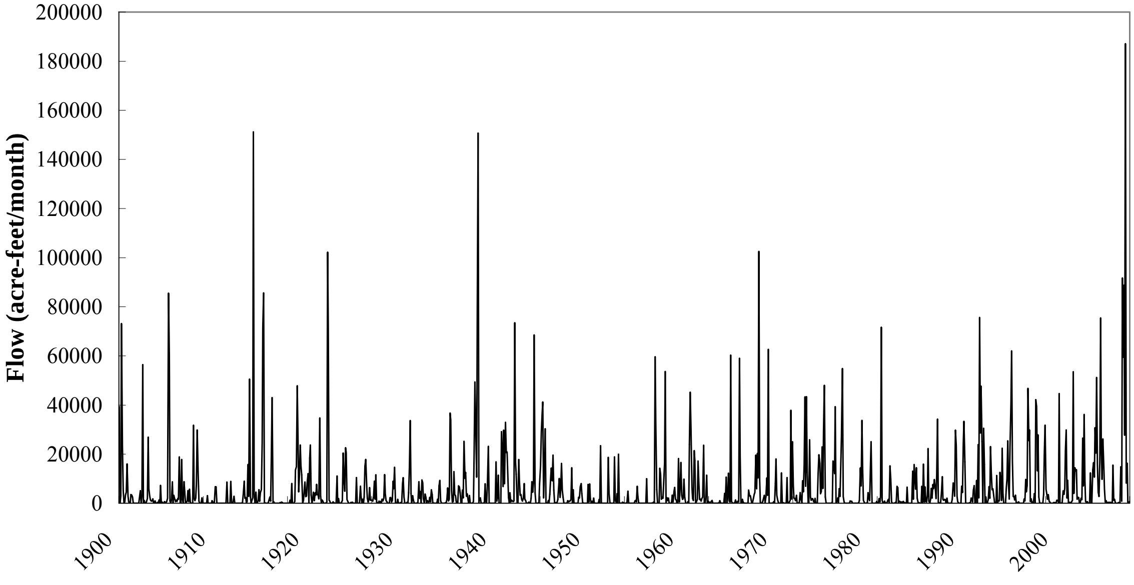

Figure E.29 Monthly BRAC3 Inflows at 515831 − Aquilla Reservoir

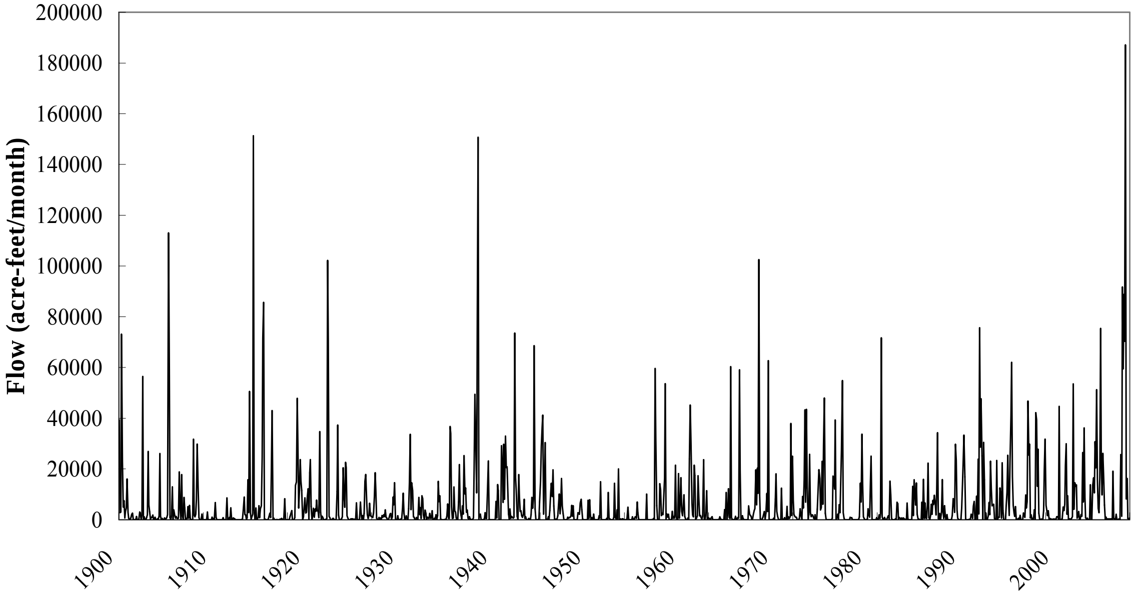

Figure E.30 Monthly BRAC8 Inflows at 515831 − Aquilla Reservoir

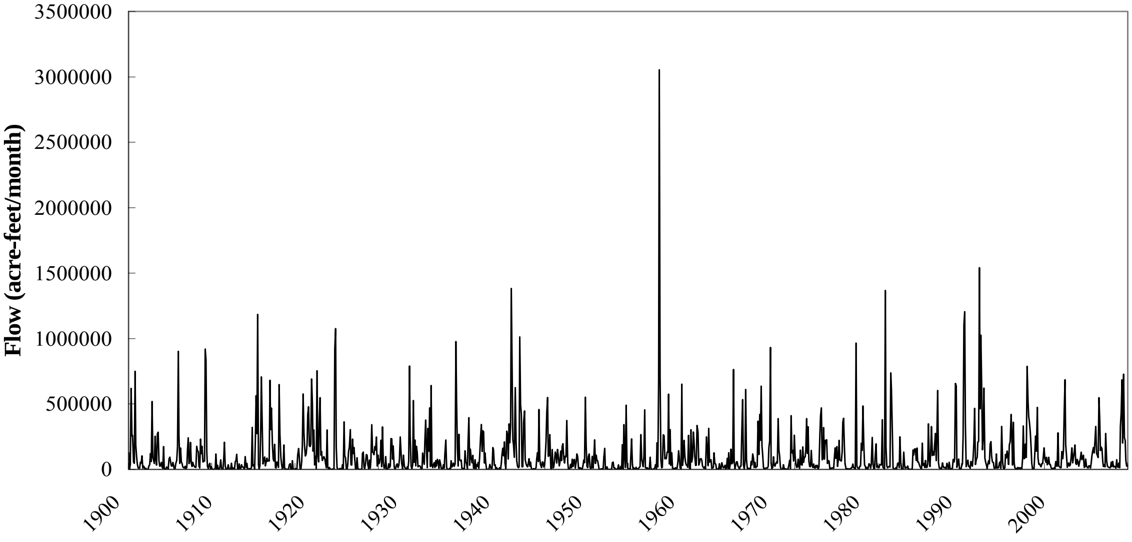

Figure E.31 Monthly BRAC3 Inflows at CON070 − Confluence of Aquilla Creek and Brazos River

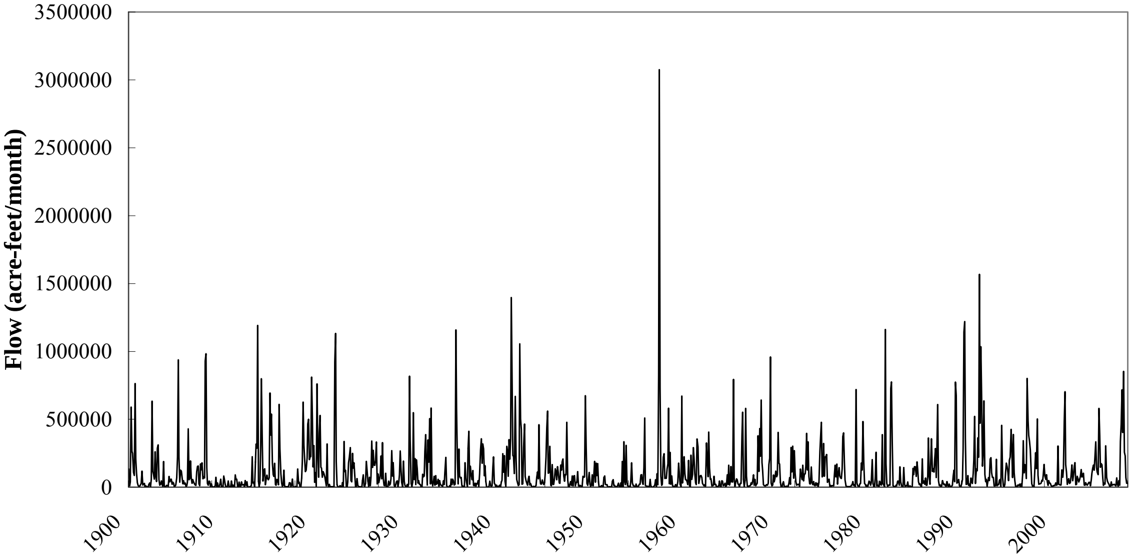

Figure E.32 Monthly BRAC8 Inflows at CON070 − Confluence of Aquilla Creek and Brazos River

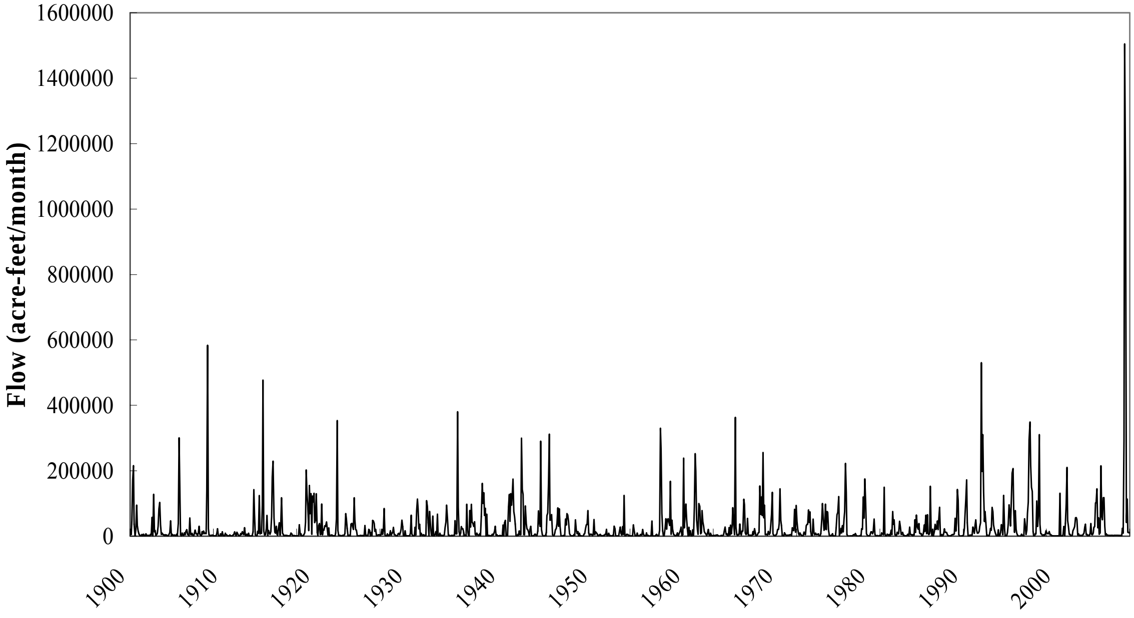

Figure E.33 Monthly BRAC3 Inflows at 509431 − Waco Reservoir

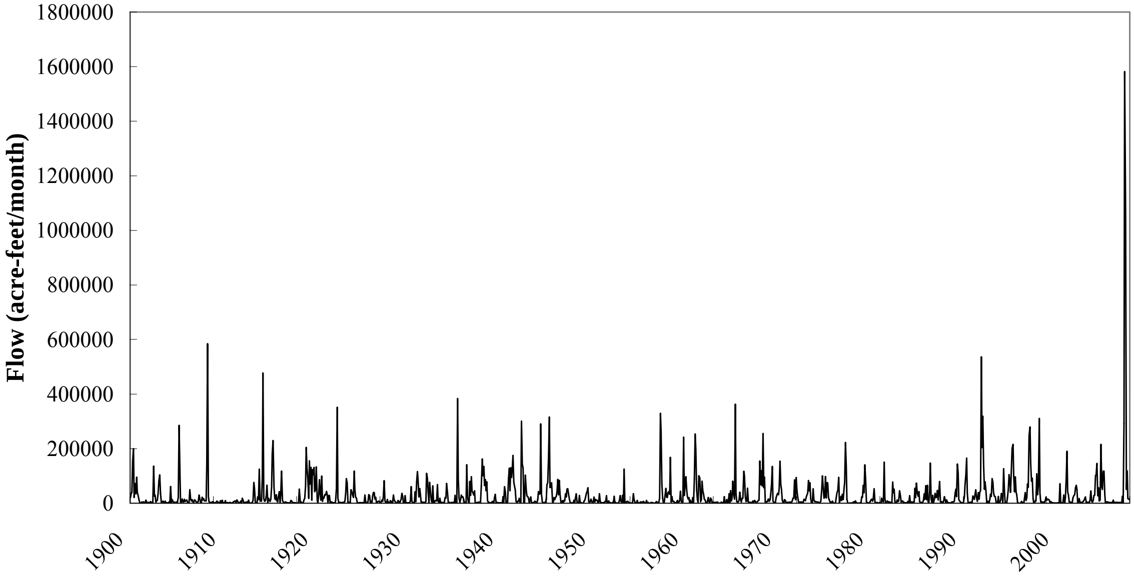

Figure E.34 Monthly BRAC8 Inflows at 509431 − Waco Reservoir

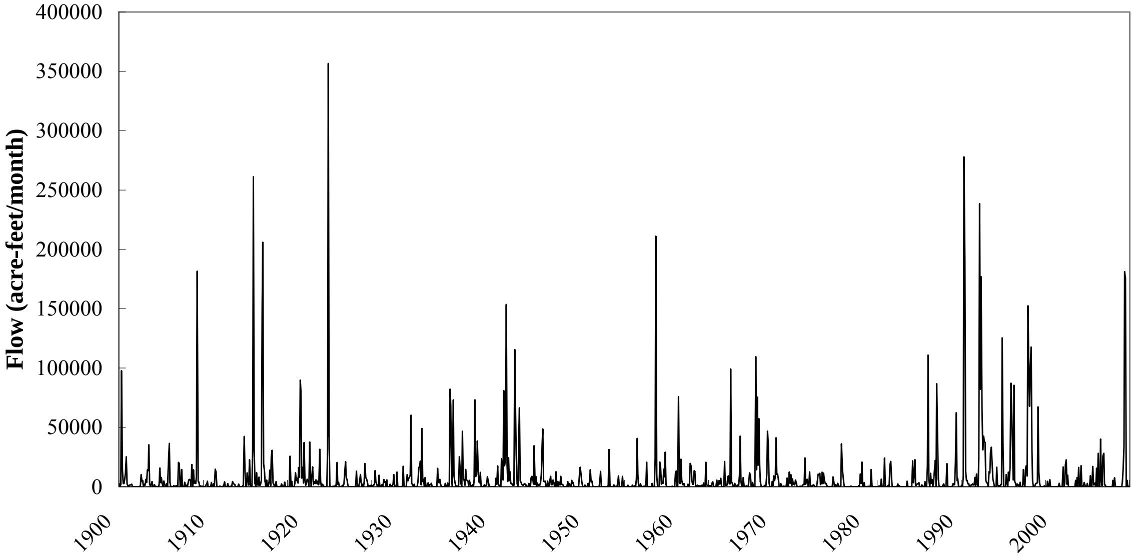

Figure E.35 Monthly BRAC3 Inflows at 515931 − Proctor Reservoir

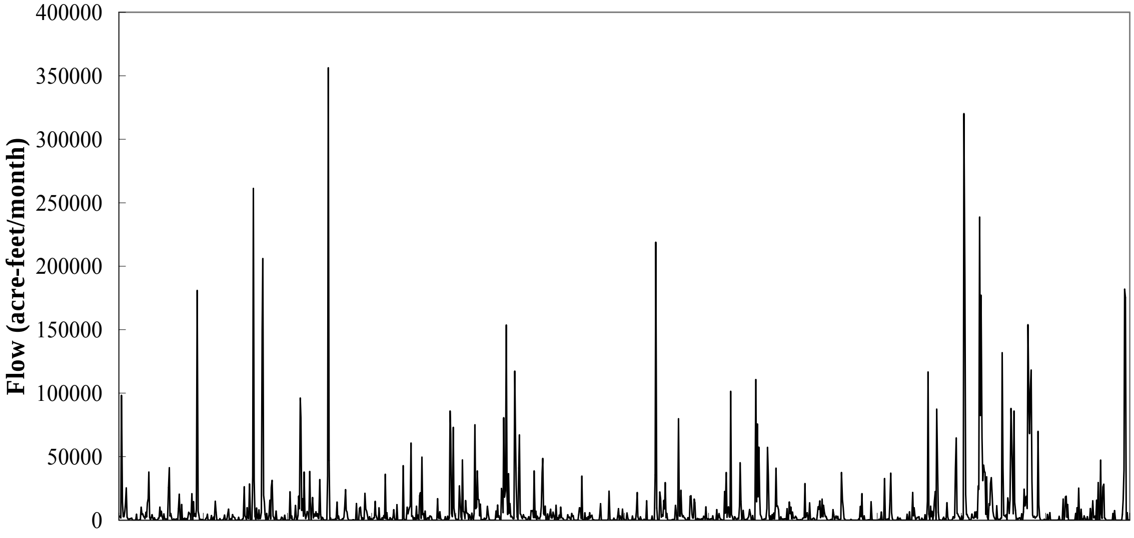

Figure E.36 Monthly BRAC8 Inflows at 515931 − Proctor Reservoir

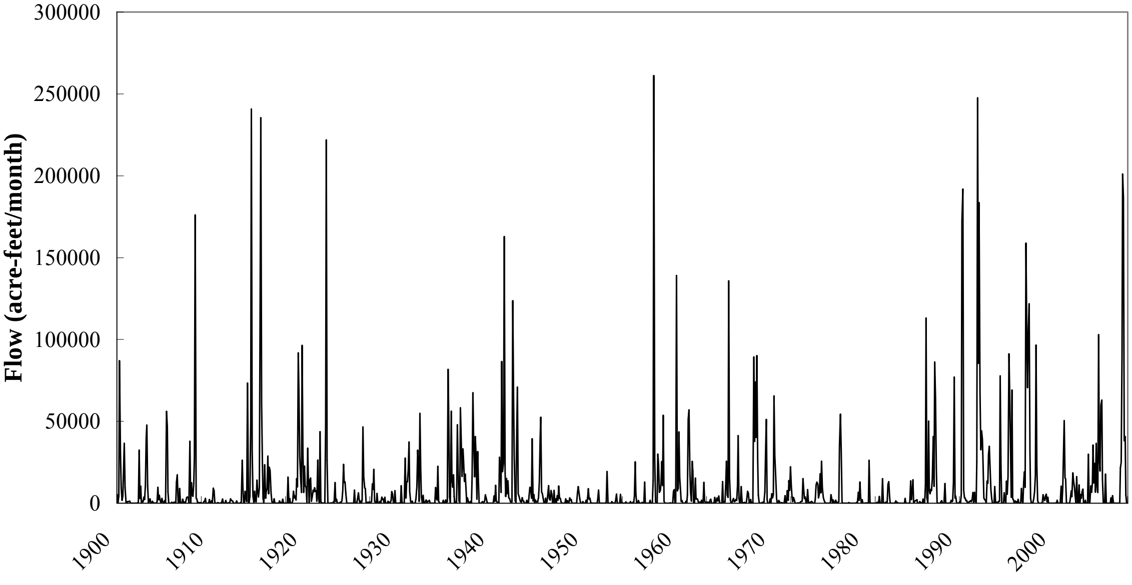

Figure E.37 Monthly BRAC3 Inflows at LEHM46 − Leon River at Hamilton Gage

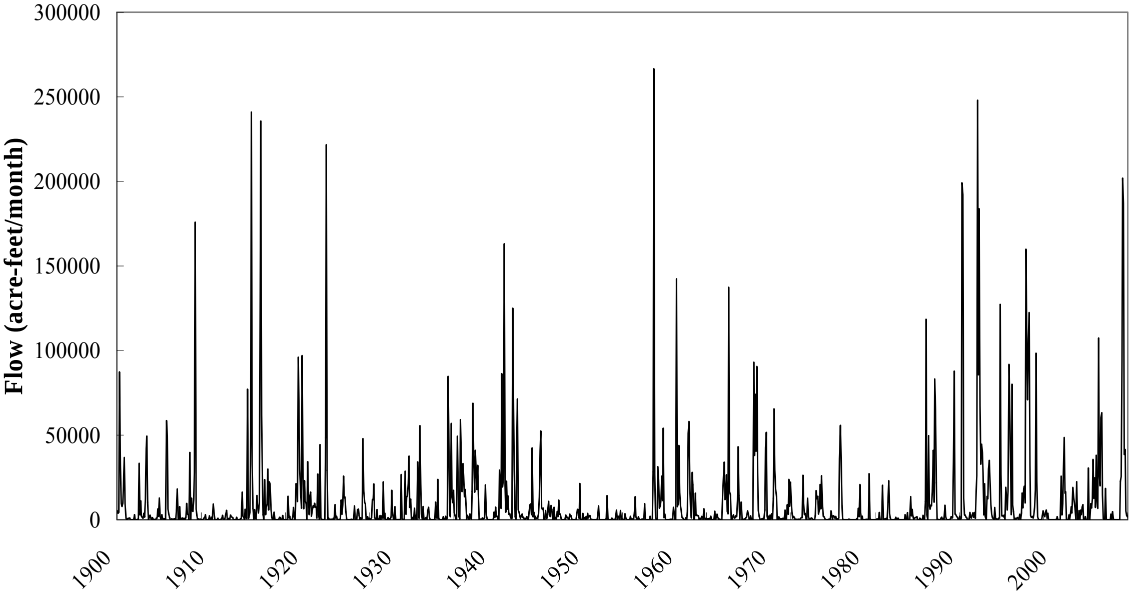

Figure B.38 Monthly BRAC8 Inflows at LEHM46 − Leon River at Hamilton Gage

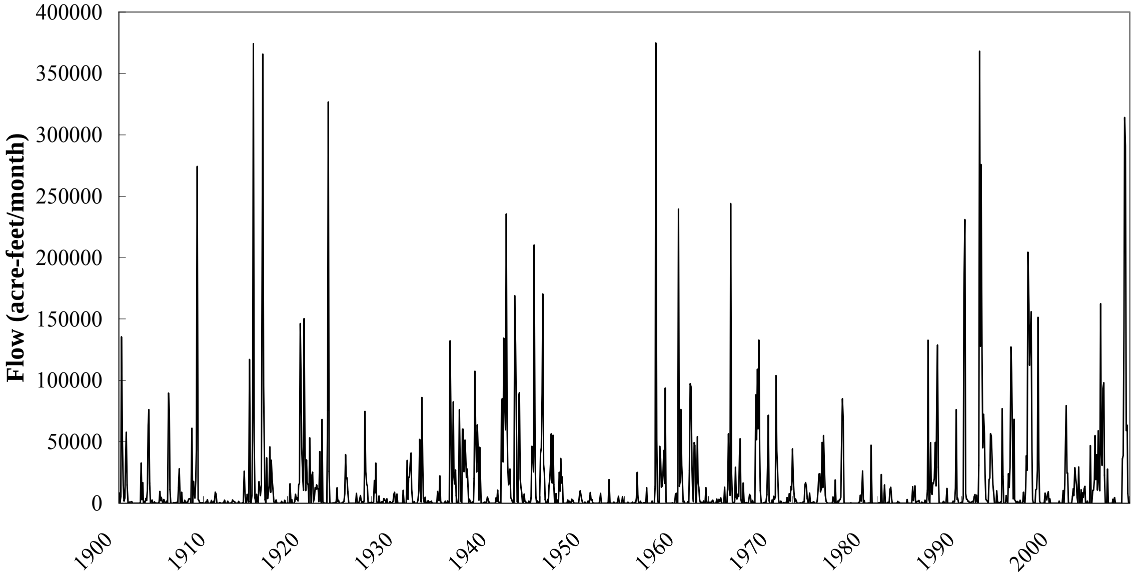

Figure E.39 Monthly BRAC3 Inflows at LEGT47 − Leon River at Gatesville Gage

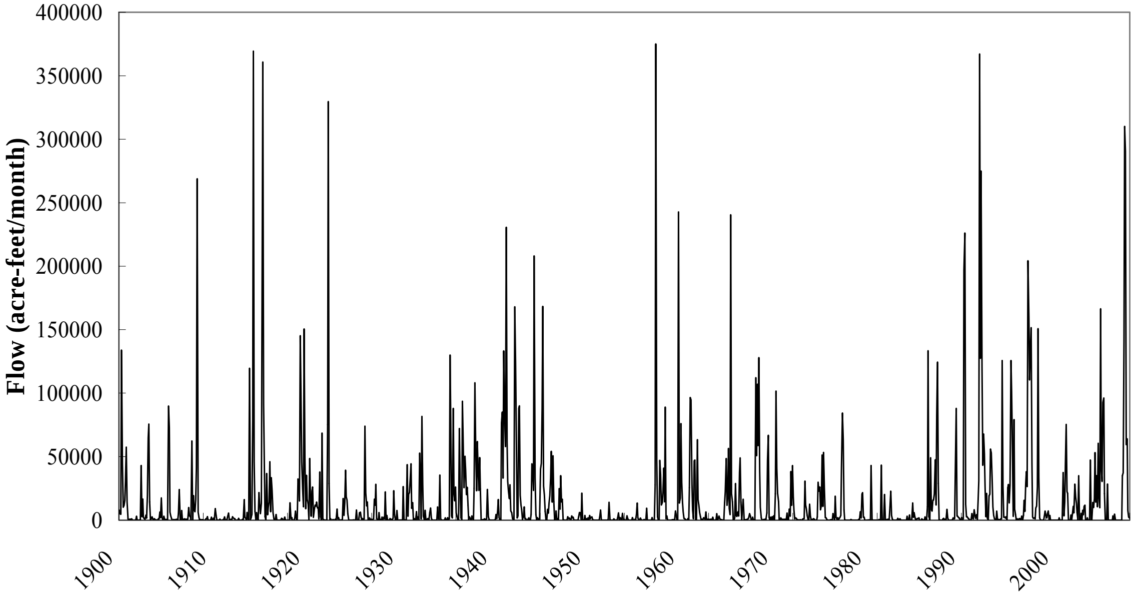

Figure E.40 Monthly BRAC8 Inflows at LEGT47 − Leon River at Gatesville Gage

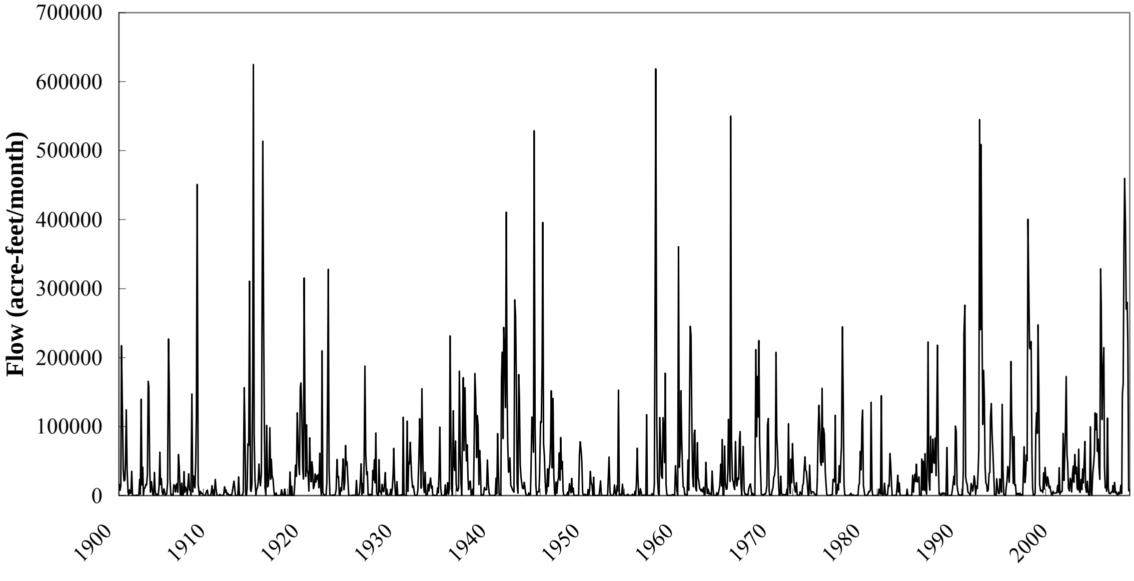

Figure E.41 Monthly BRAC3 Inflows at 516031 − Belton Reservoir

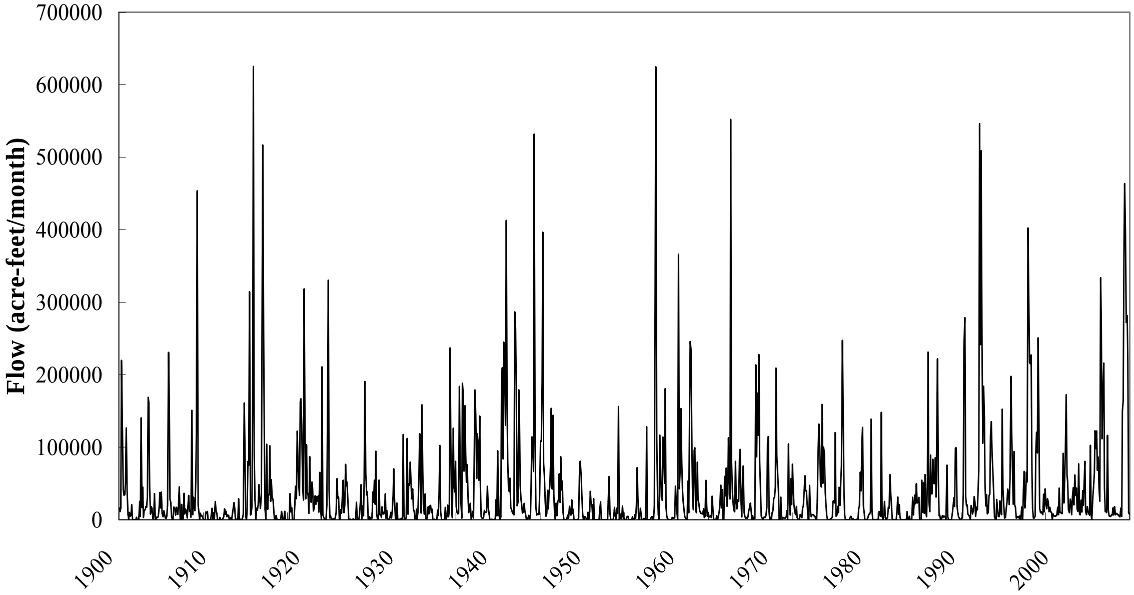

Figure E.42 Monthly BRAC8 Inflows at 516031 − Belton Reservoir

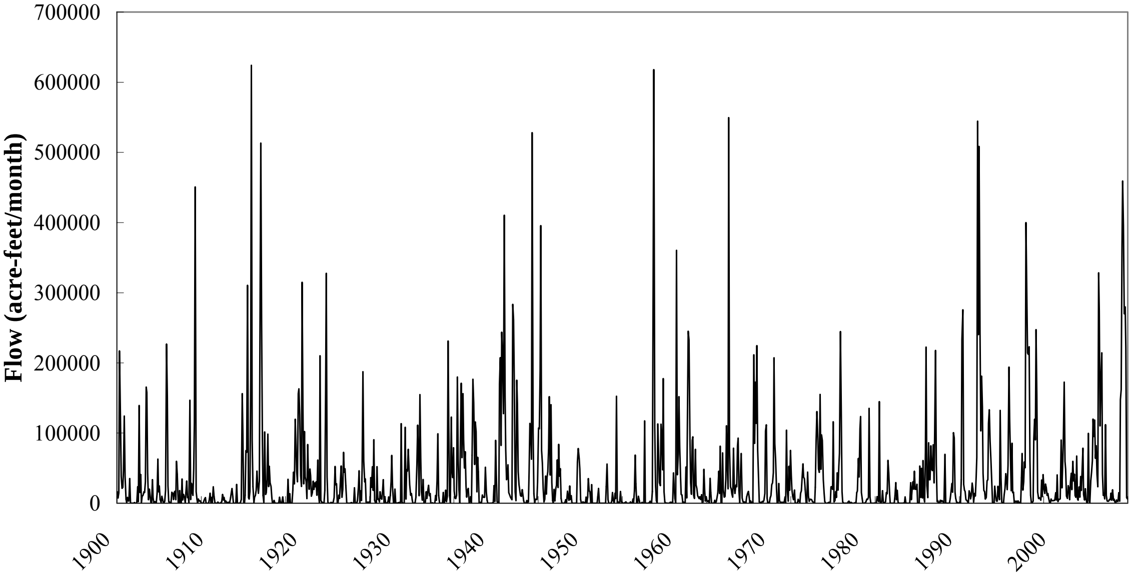

Figure E.43 Monthly BRAC3 Inflows at LEBE49 − Leon River at Belton

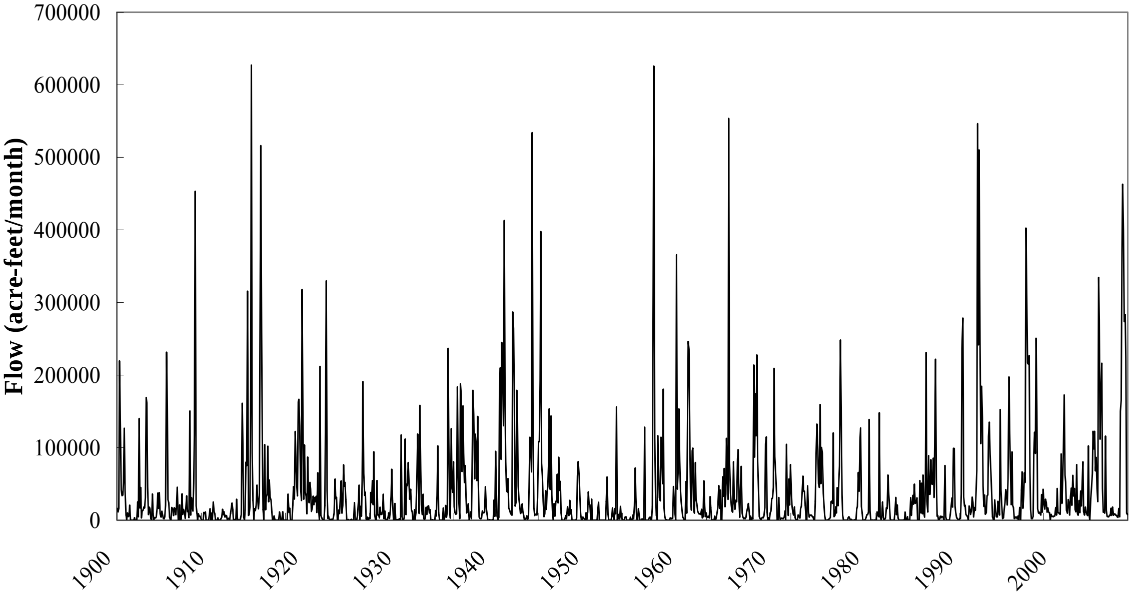

Figure E.44 Monthly BRAC8 Inflows at LEBE49 − Leon River at Belton

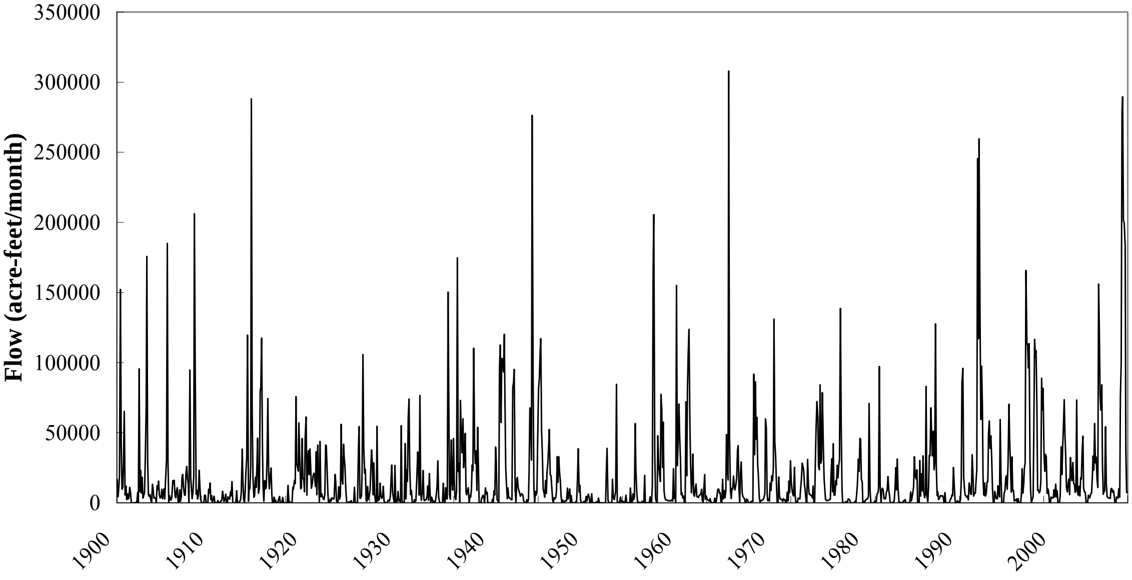

Figure E.45 Monthly BRAC3 Inflows at 516131 − Stillhouse Hollow Reservoir

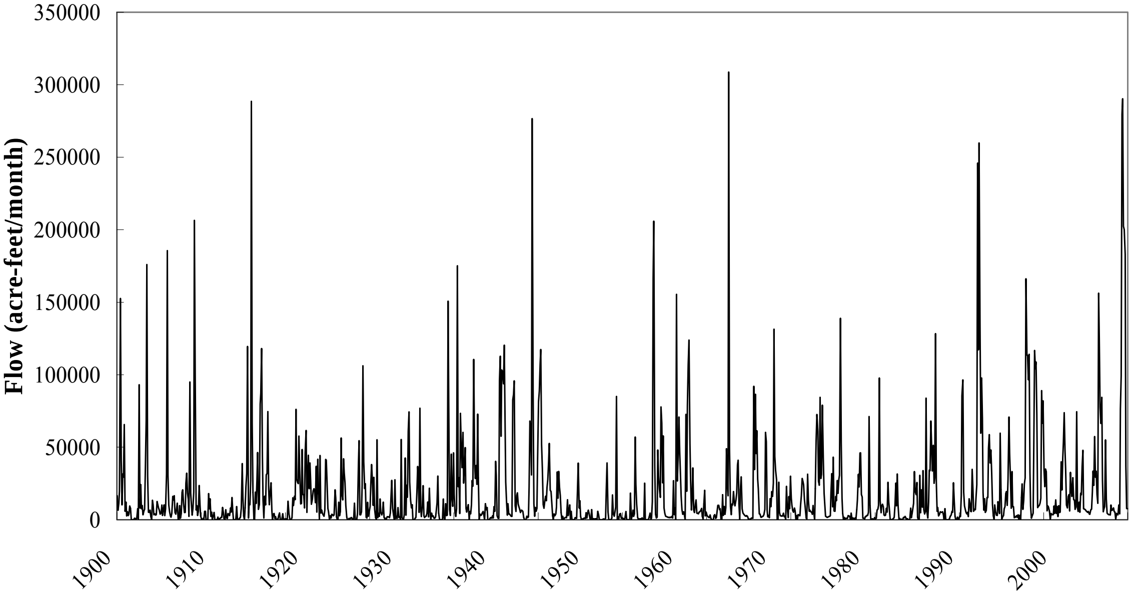

Figure E.46 Monthly BRAC8 Inflows at 516131 − Stillhouse Hollow Reservoir

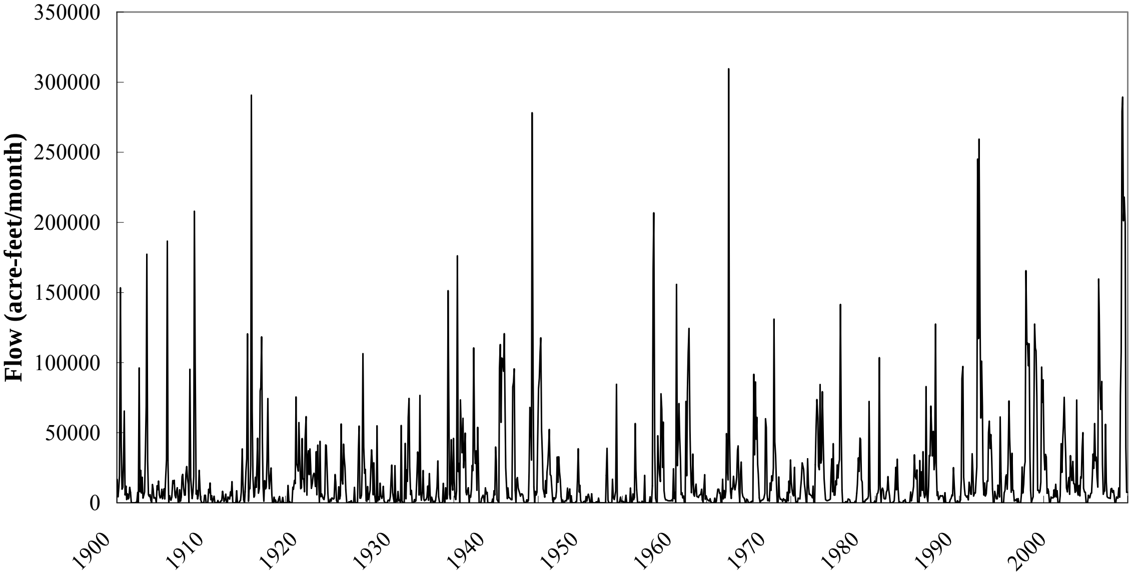

Figure E.47 Monthly BRAC3 Inflows at LABE52 − Lampasas River at Belton Gage

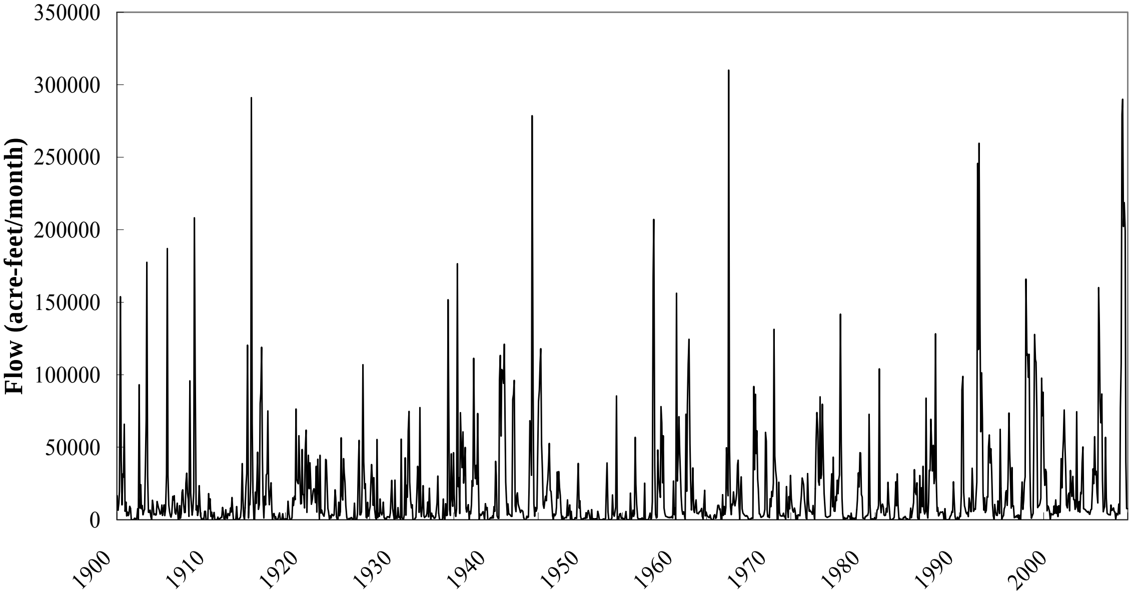

Figure E.48 Monthly BRAC8 Inflows at LABE52 − Lampasas River at Belton Gage

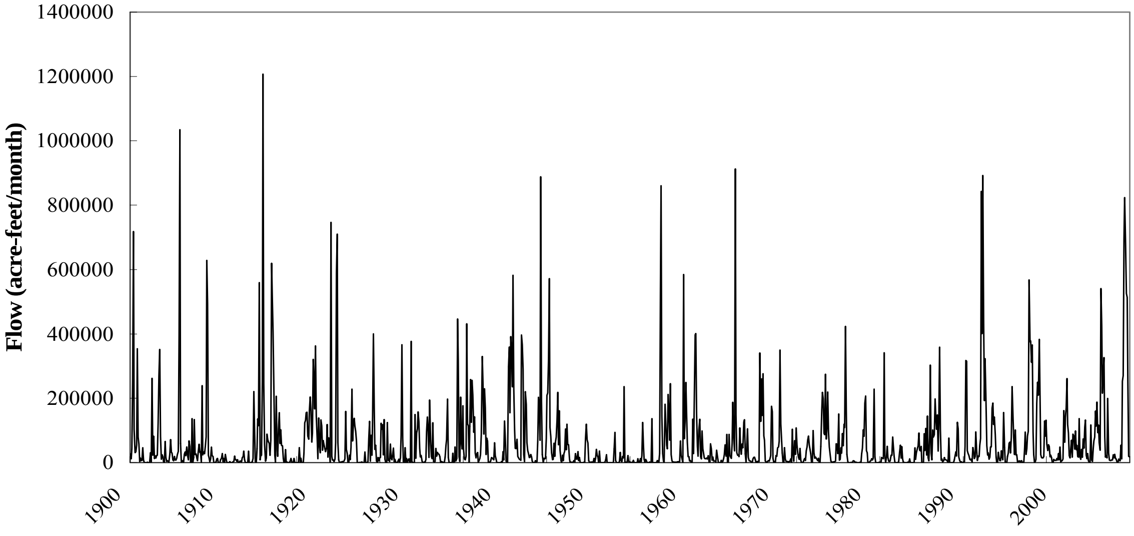

Figure E.49 Monthly BRAC3 Inflows at CON096 − Confluence of Lampasas and Little Rivers

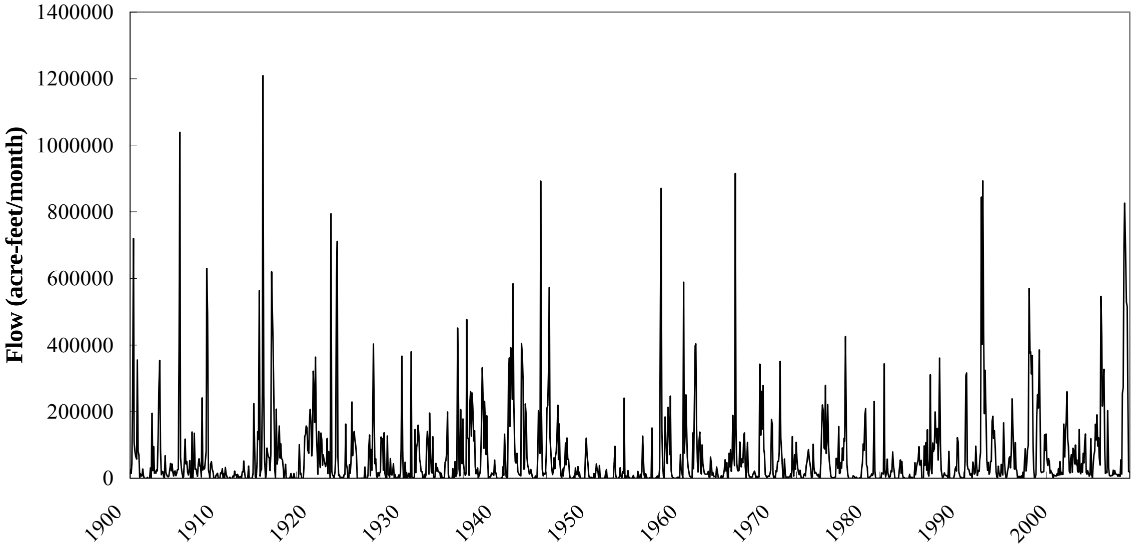

Figure E.50 Monthly BRAC8 Inflows at CON096 − Confluence of Lampasas and Little Rivers

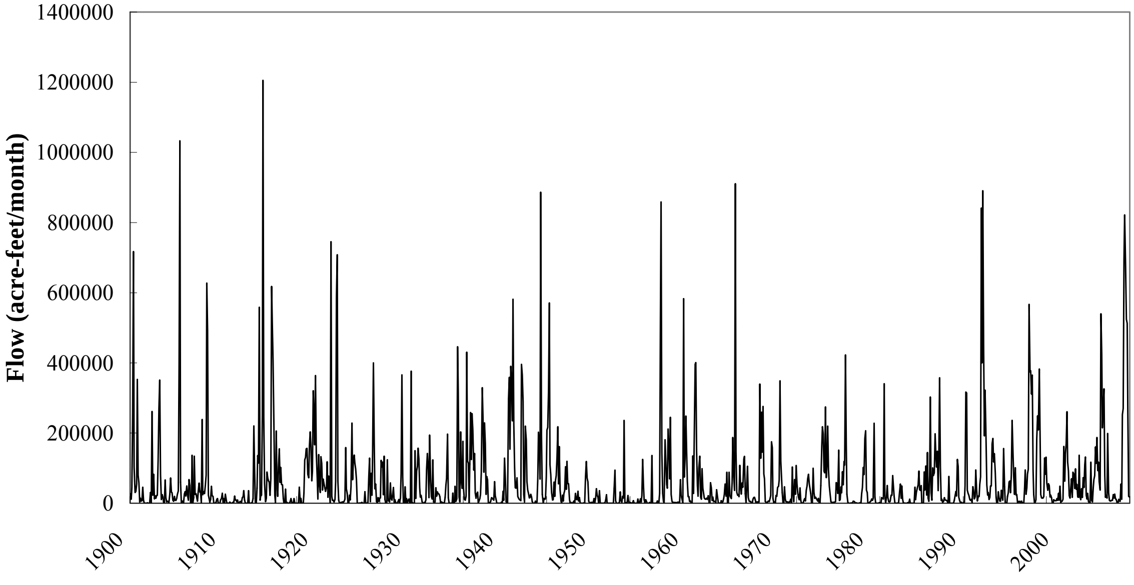

Figure E.51 Monthly BRAC3 Inflows at LRLR53 − Little River at Little River Gage

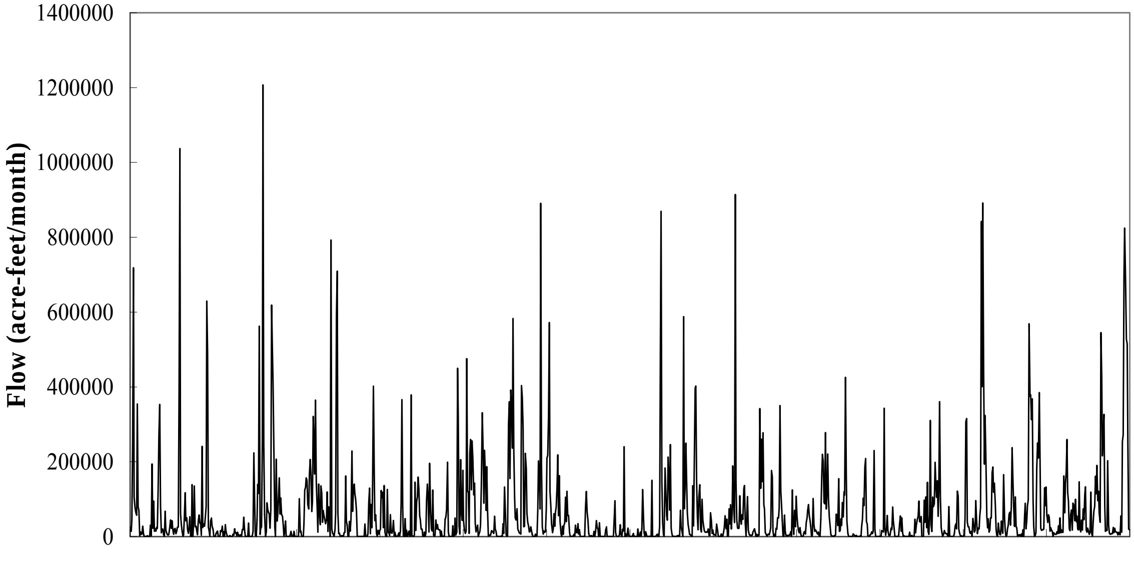

Figure E.52 Monthly BRAC8 Inflows at LRLR53 − Little River at Little River Gage

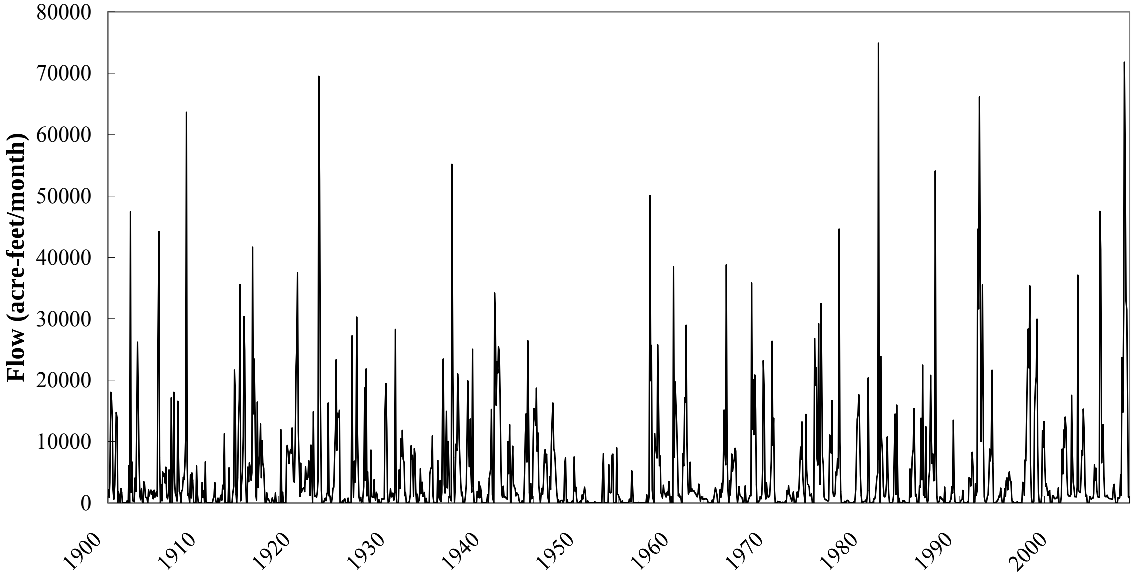

Figure E.53 Monthly BRAC3 Inflows at 516231 − Georgetown Reservoir

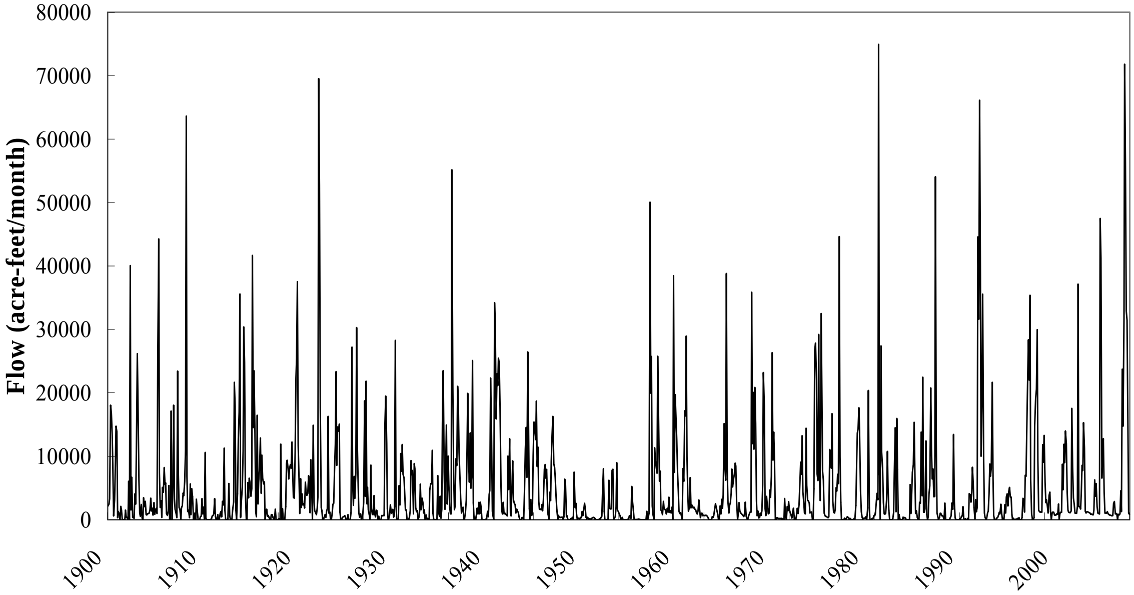

Figure E.54 Monthly BRAC8 Inflows at 516231 − Georgetown Reservoir

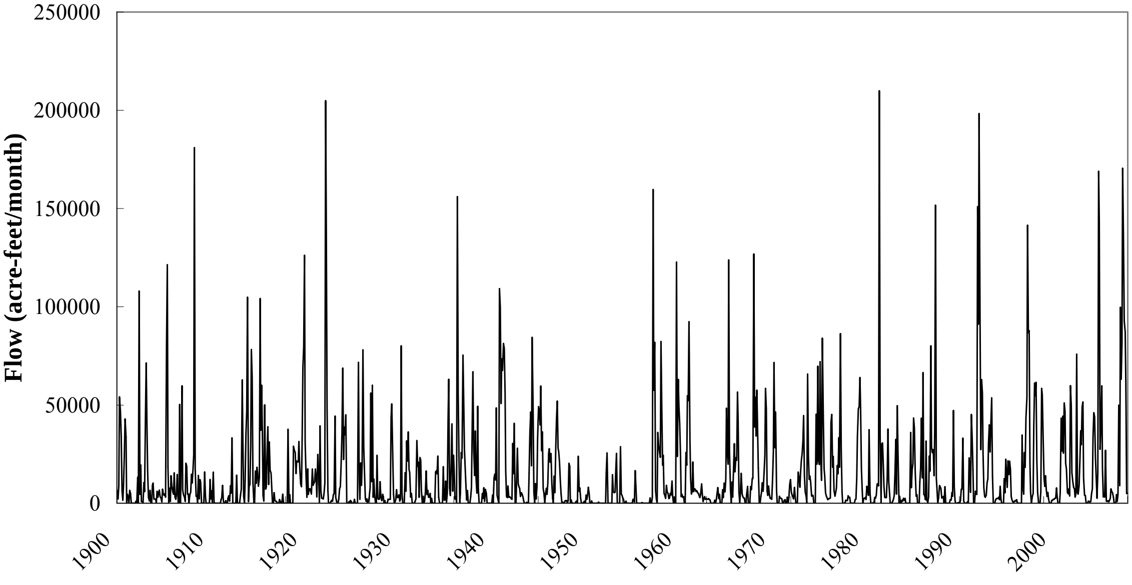

Figure E.55 Monthly BRAC3 Inflows at 516331 − Granger Reservoir

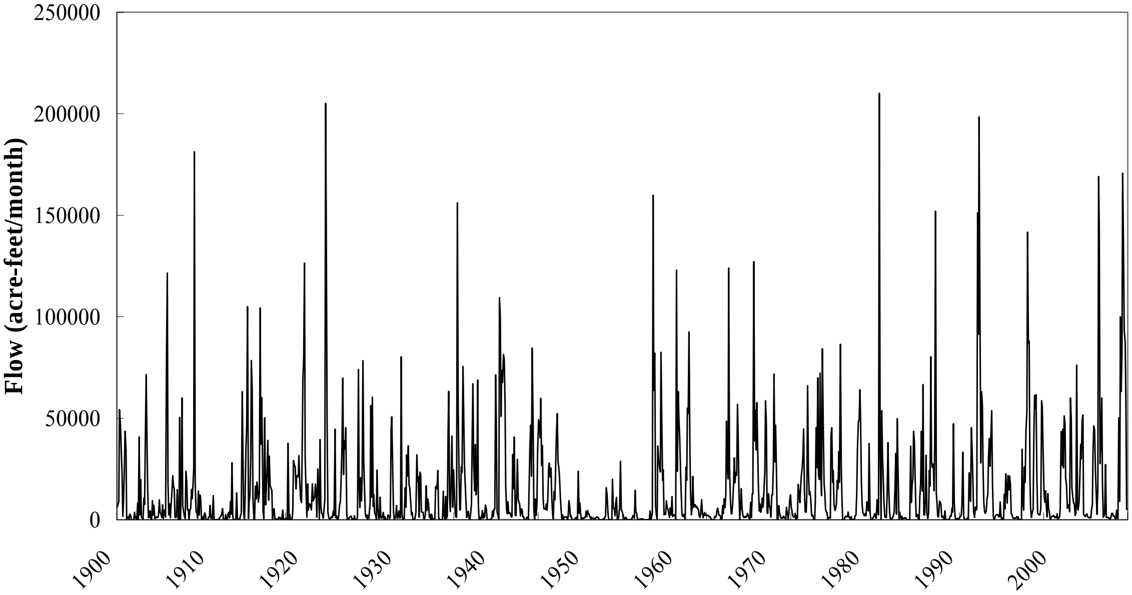

Figure E.56 Monthly BRAC8 Inflows at 516331 − Granger Reservoir

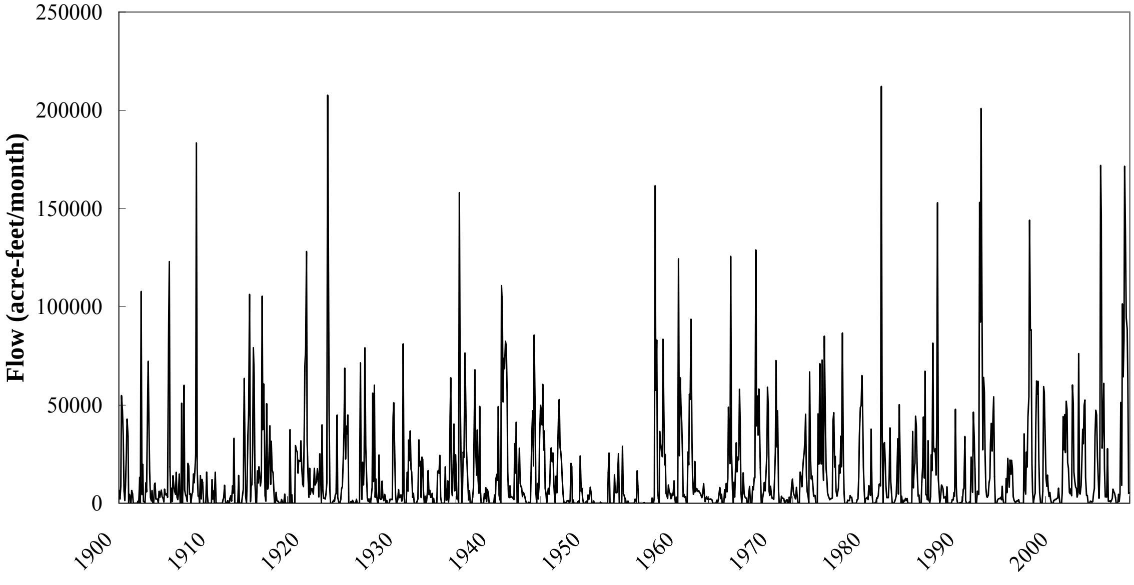

Figure E.57 Monthly BRAC3 Inflows at GALA57 − San Gabriel River at Laneport Gage

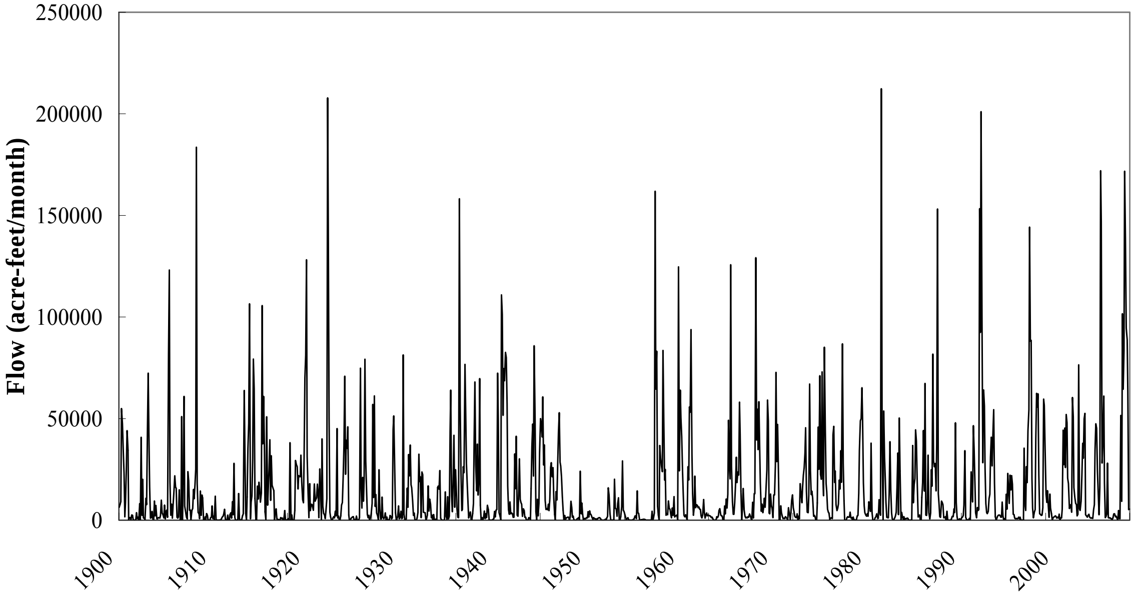

Figure E.58 Monthly BRAC8 Inflows at GALA57 − San Gabriel River at Laneport Gage

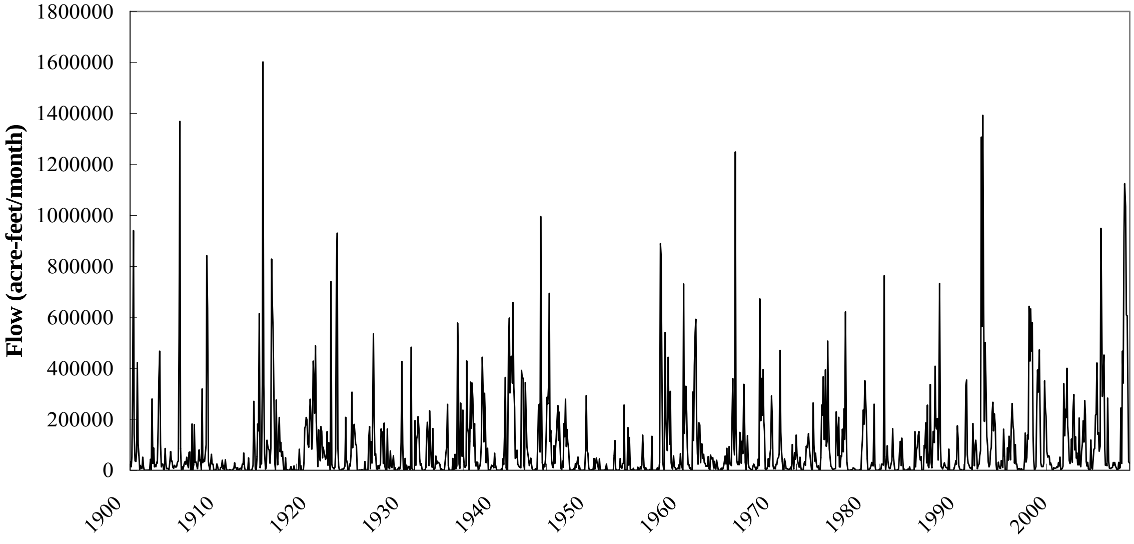

Figure E.59 Monthly BRAC3 Inflows at CON108 − Confluence of Little River and San Gabriel River

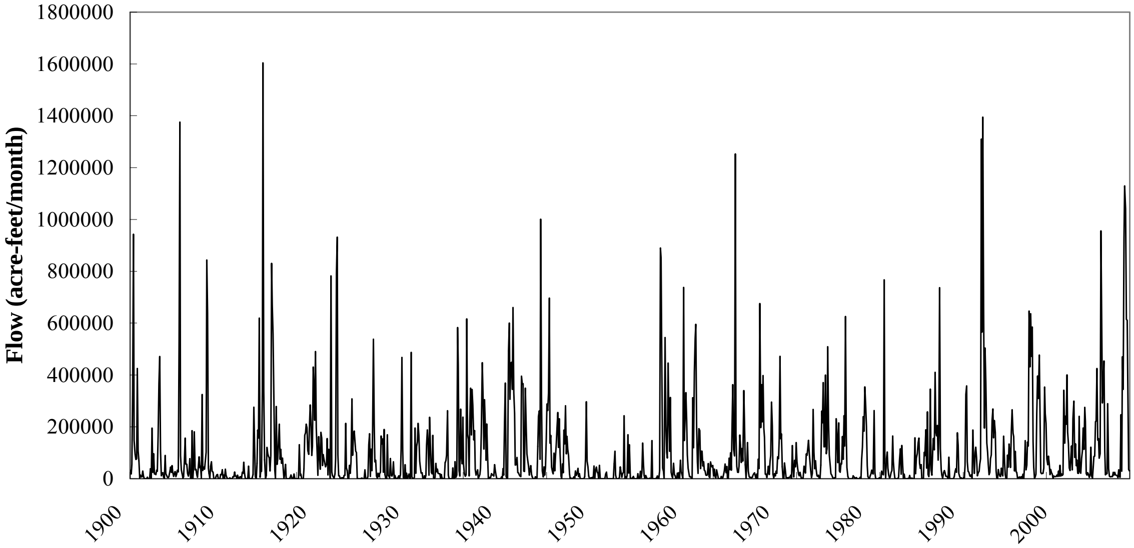

Figure E.60 Monthly BRAC8 Inflows at CON108 − Confluence of Little River and San Gabriel River

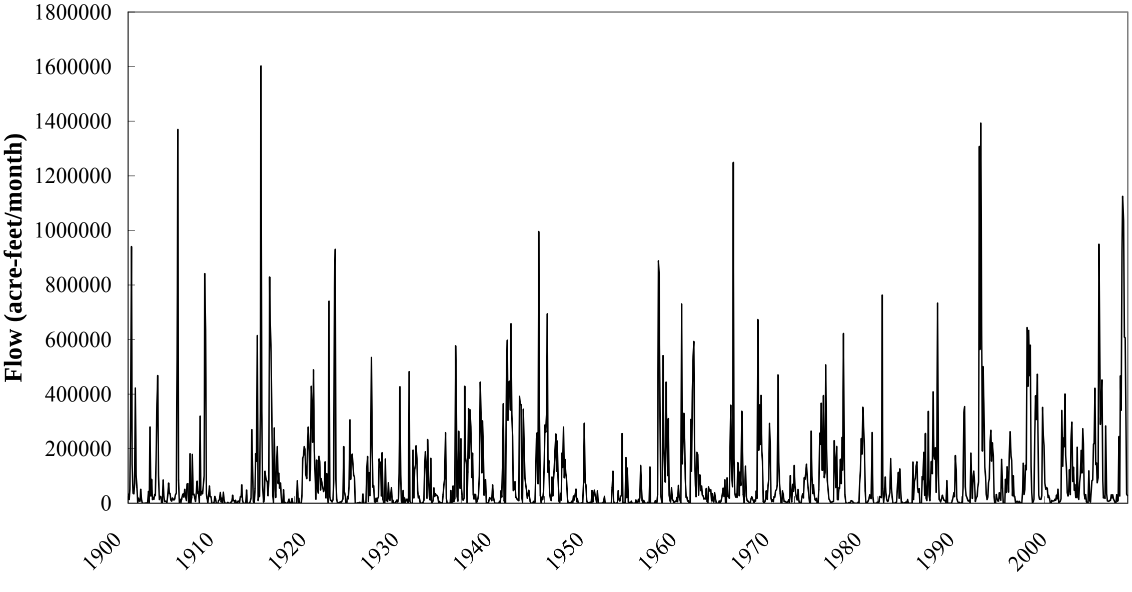

Figure E.61 Monthly BRAC3 Inflows at LRCA58 − Little River at Cameron Gage

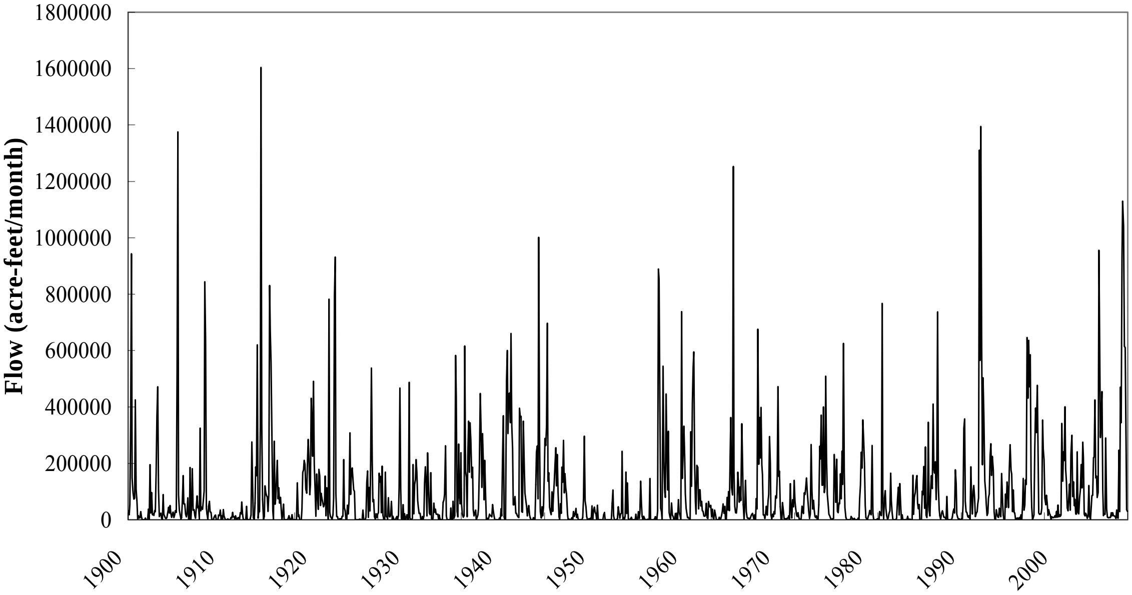

Figure E.62 Monthly BRAC8 Inflows at LRCA58 − Little River at Cameron Gage

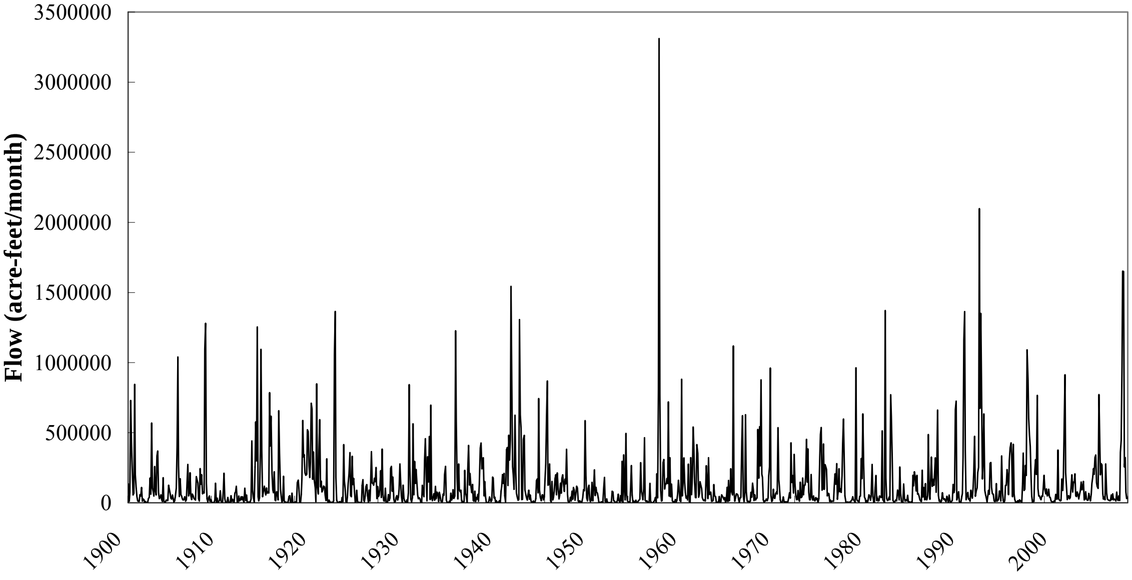

Figure E.63 Monthly BRAC3 Inflows at 433901 − Confluence of Bosque and Brazos River

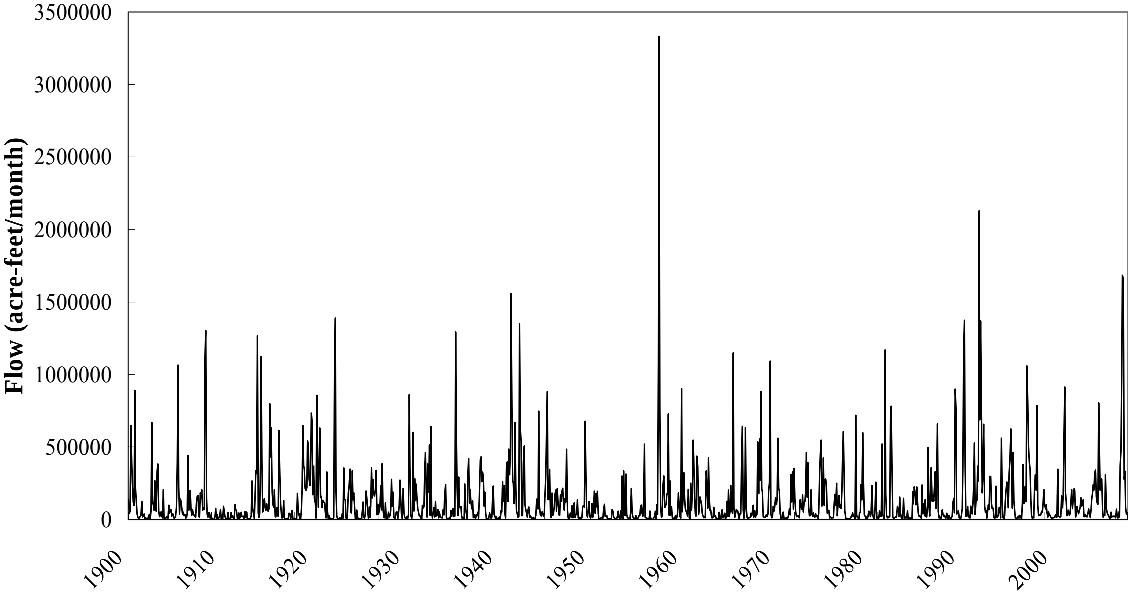

Figure E.64 Monthly BRAC8 Inflows at 433901 − Confluence of Bosque and Brazos River

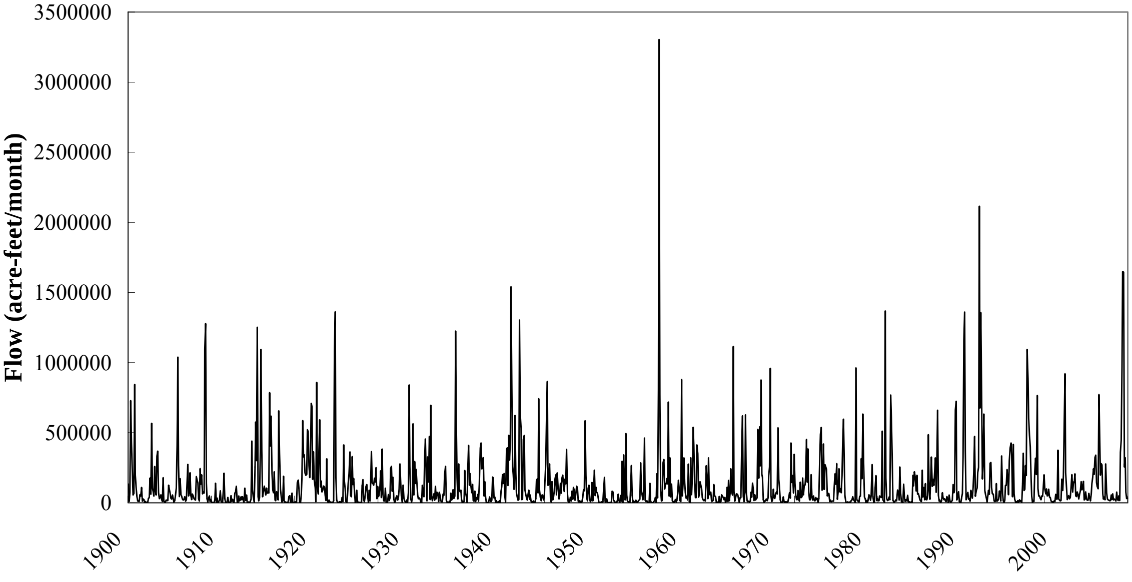

Figure E.65 Monthly BRAC3 Inflows at BRWA41 − Brazos River at Waco Gage

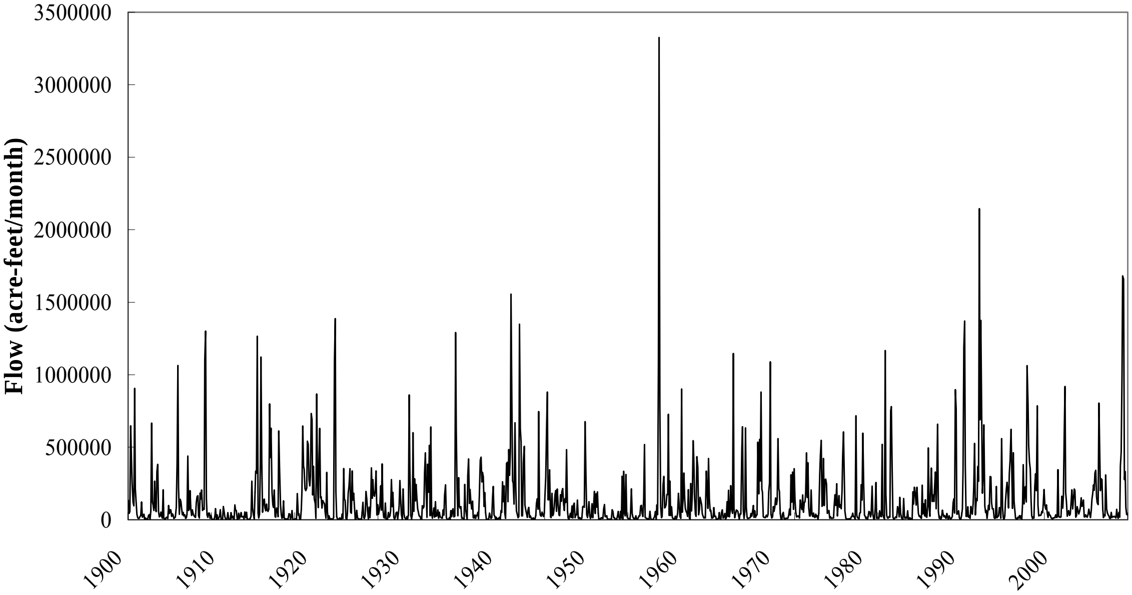

Figure E.66 Monthly BRAC8 Inflows at BRWA41 − Brazos River at Waco Gage

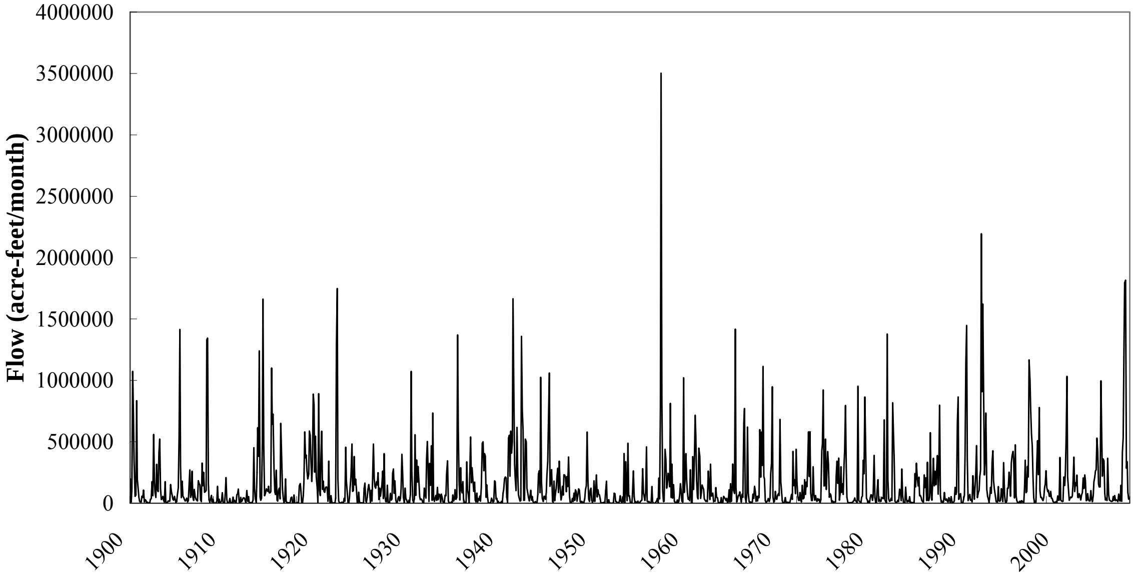

Figure E.67 Monthly BRAC3 Inflows at BRHB42 − Brazos River at Highbank Gage

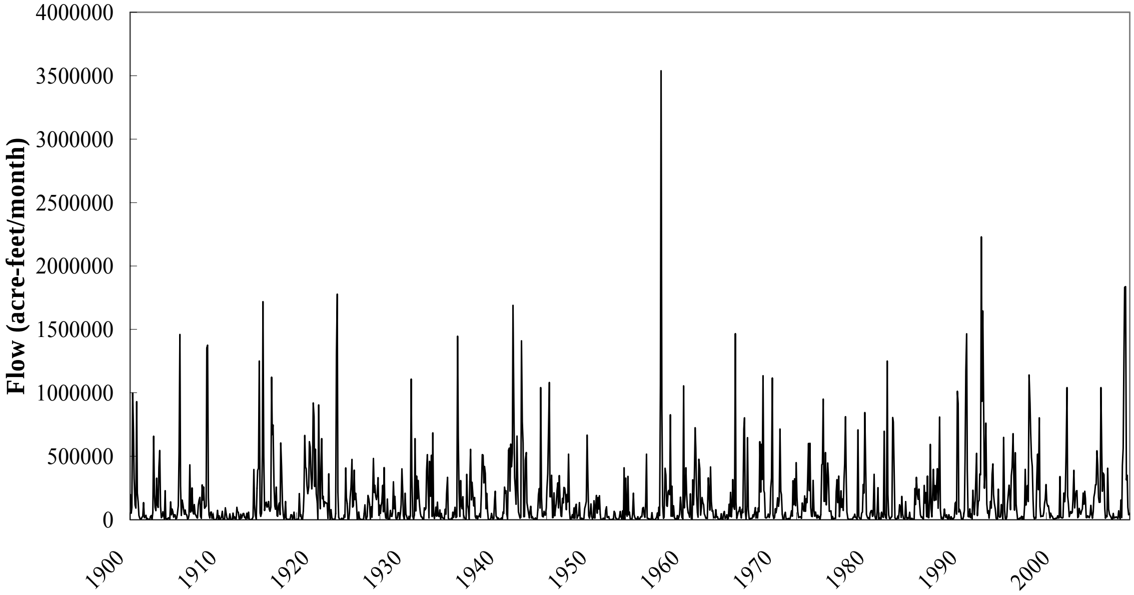

Figure E.68 Monthly BRAC8 Inflows at BRHB42 − Brazos River at Highbank Gage

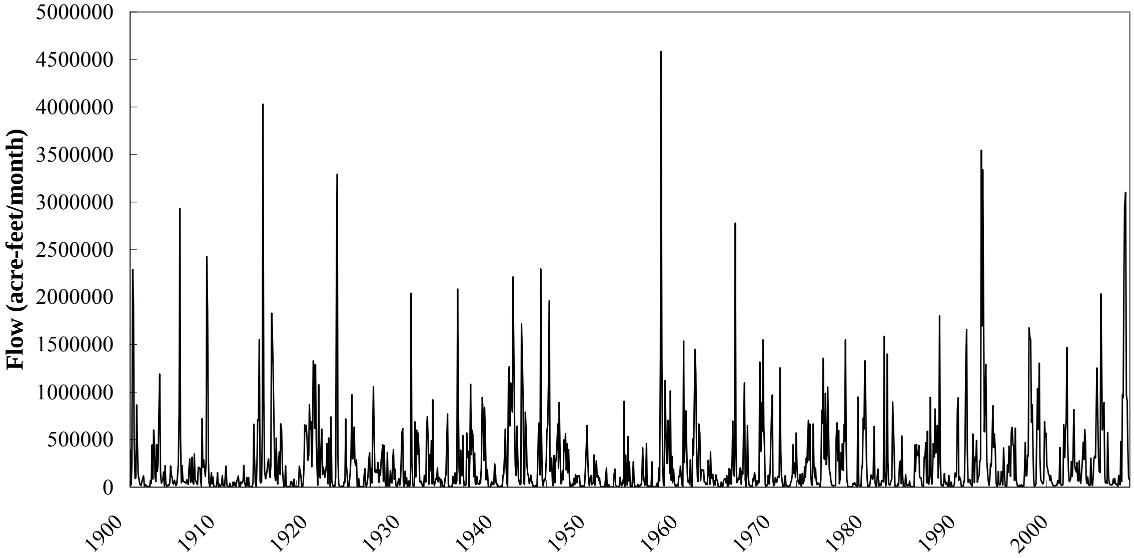

Figure E.69 Monthly BRAC3 Inflows at CON111 − Confluence of Little River and Brazos River

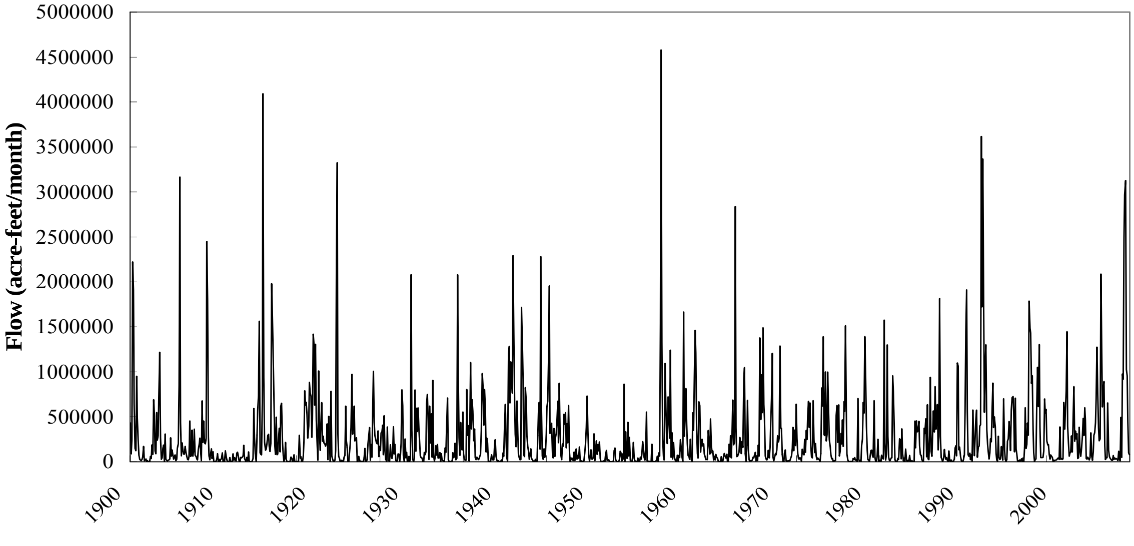

Figure E.70 Monthly BRAC8 Inflows at CON111 − Confluence of Little River and Brazos River

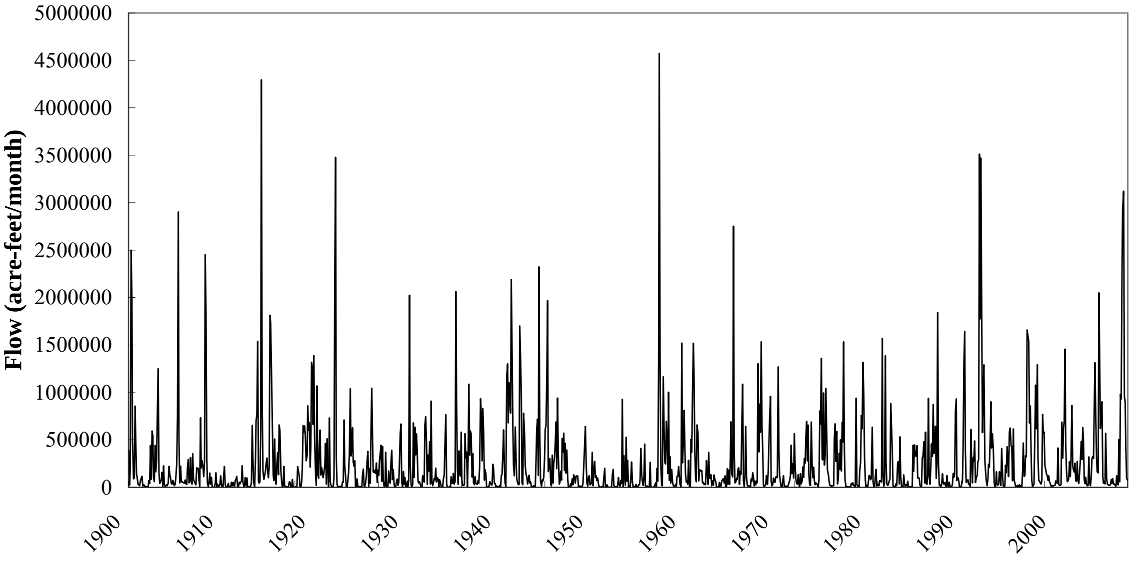

Figure E.71 Monthly BRAC3 Inflows at BRBR59 − Brazos River at Bryan Gage

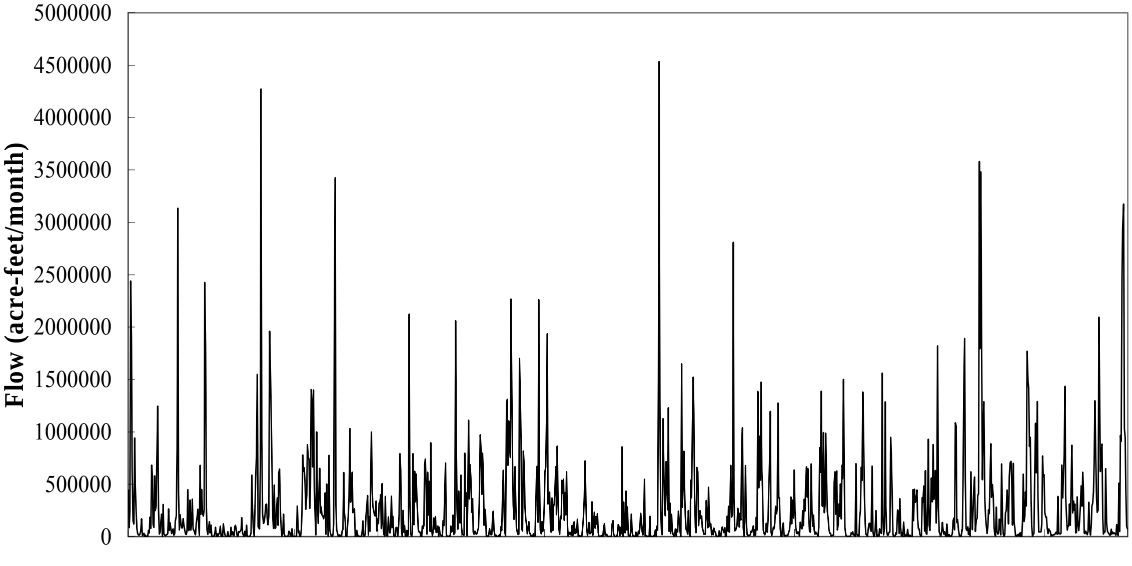

Figure E.72 Monthly BRAC8 Inflows at BRBR59 − Brazos River at Bryan Gage

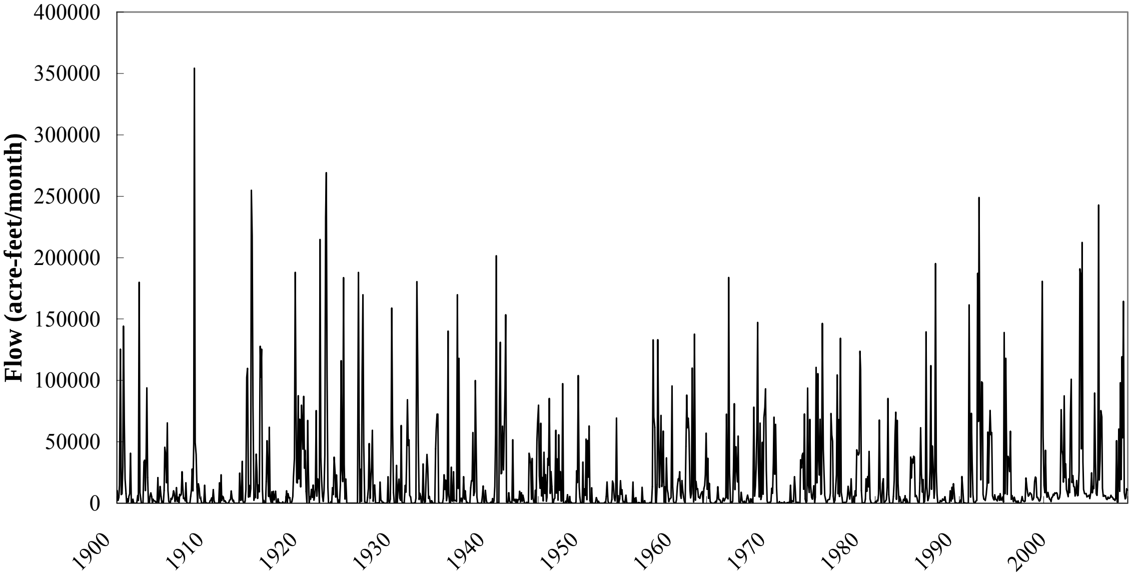

Figure E.73 Monthly BRAC3 Inflows at 516431 − Somerville Reservoir

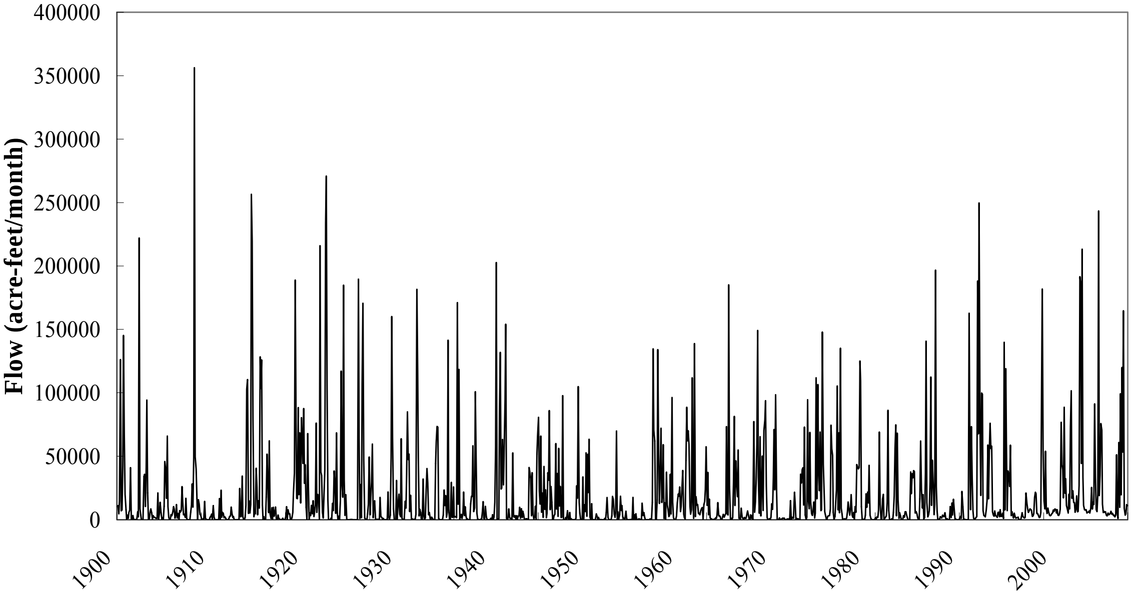

Figure E.74 Monthly BRAC8 Inflows at 516431 − Somerville Reservoir

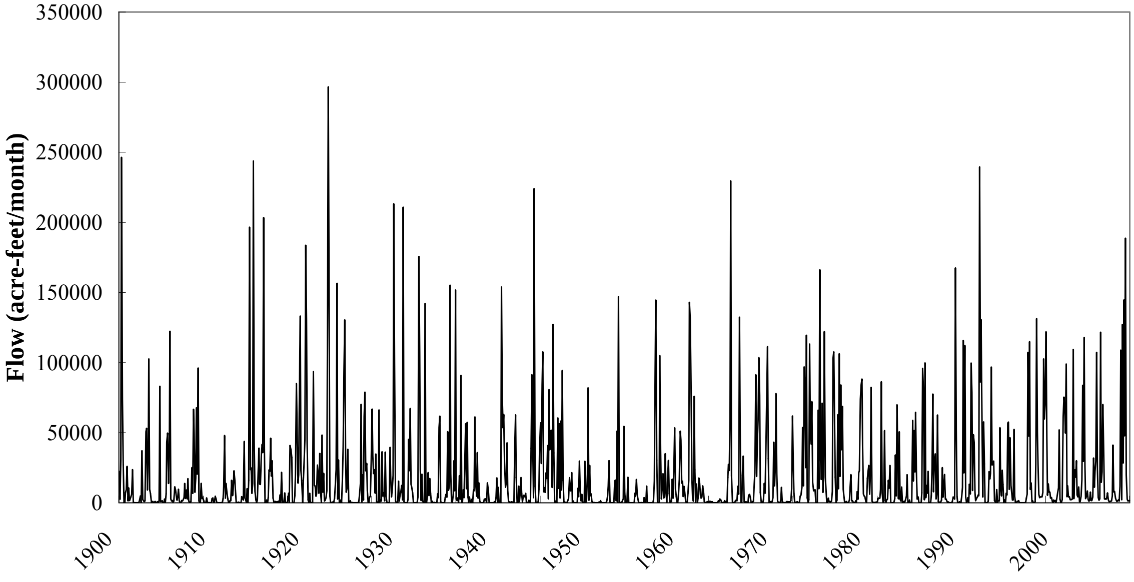

Figure E.75 Monthly BRAC3 Inflows at 516531 − Limestone Reservoir

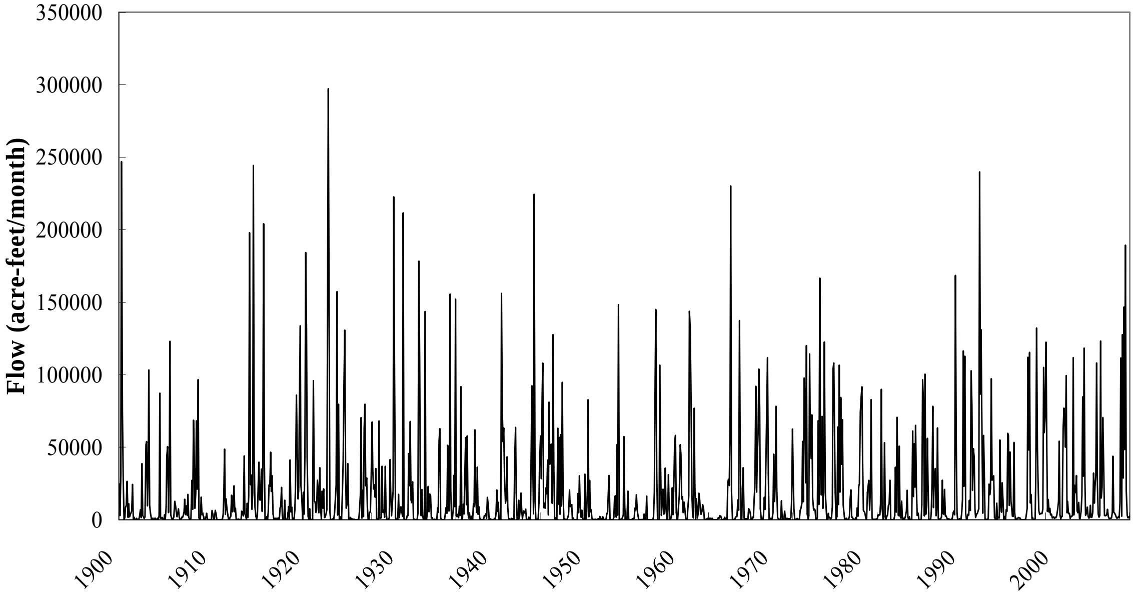

Figure E.76 Monthly BRAC8 Inflows at 516531 − Limestone Reservoir

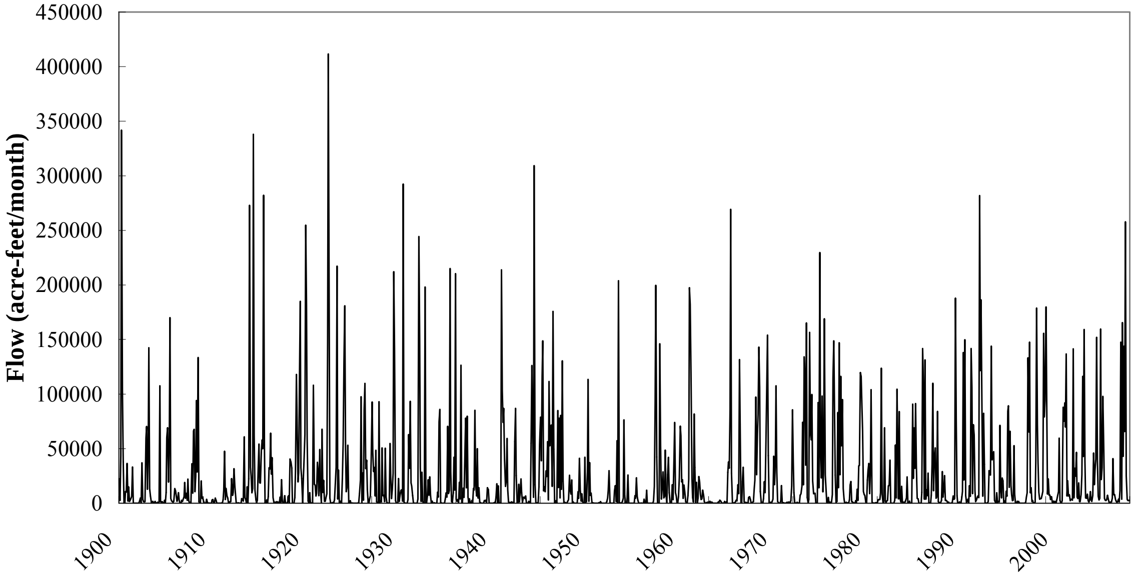

Figure E.77 Monthly BRAC3 Inflows at NAEA66 − Navasota River at Easterly Gage

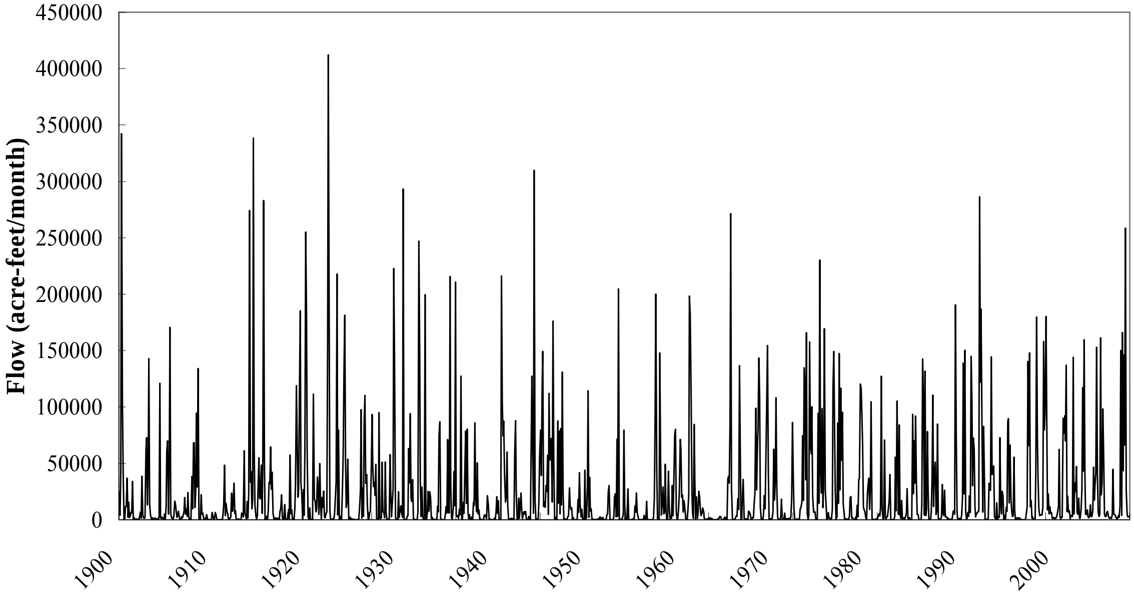

Figure E.78 Monthly BRAC8 Inflows at NAEA66 − Navasota River at Easterly Gage

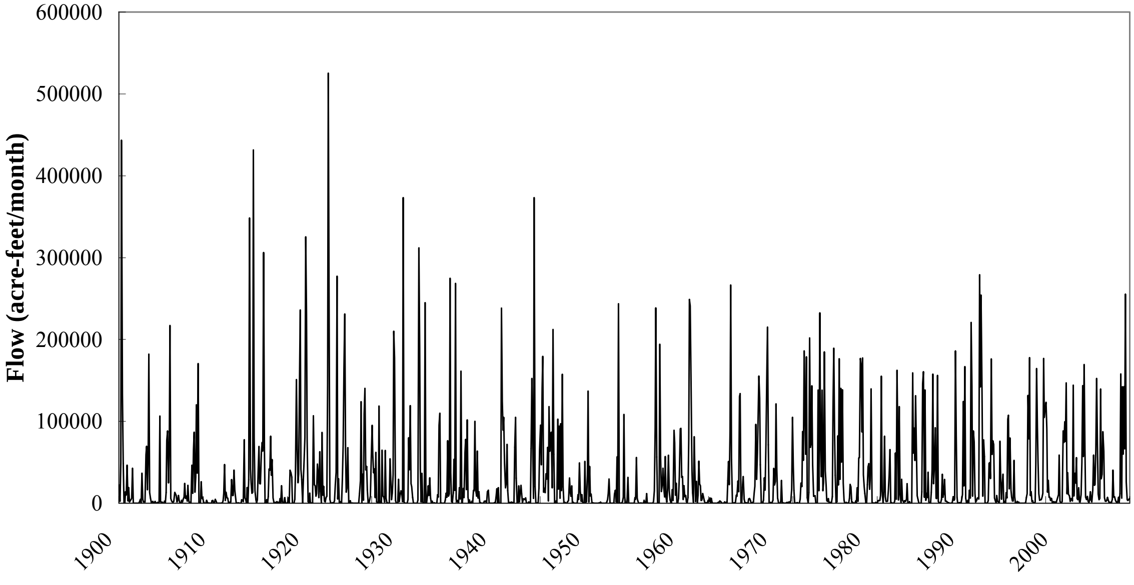

Figure E.79 Monthly BRAC3 Inflows at NABR67 − Navasota River at Bryan Gage

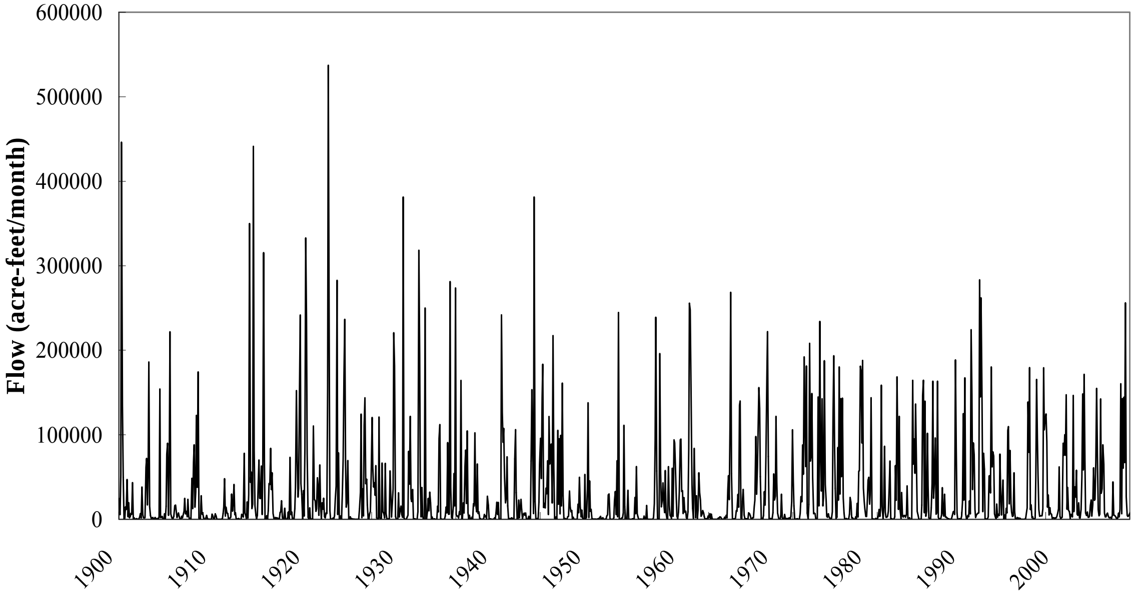

Figure E.80 Monthly BRAC8 Inflows at NABR67 − Navasota River at Bryan Gage

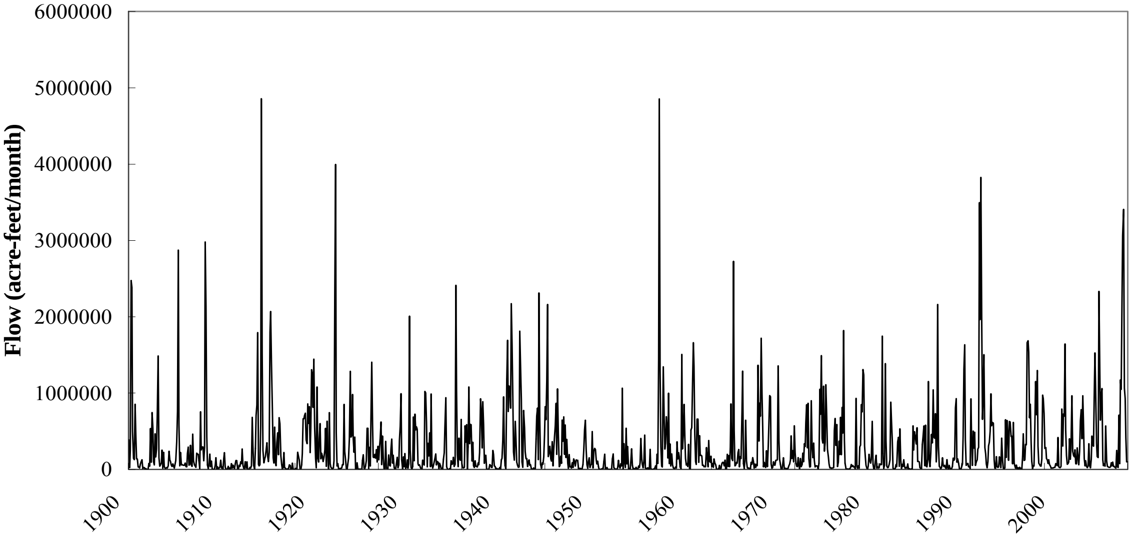

Figure E.81 Monthly BRAC3 Inflows at CON130 − Confluence of Yequa Creek and Brazos River

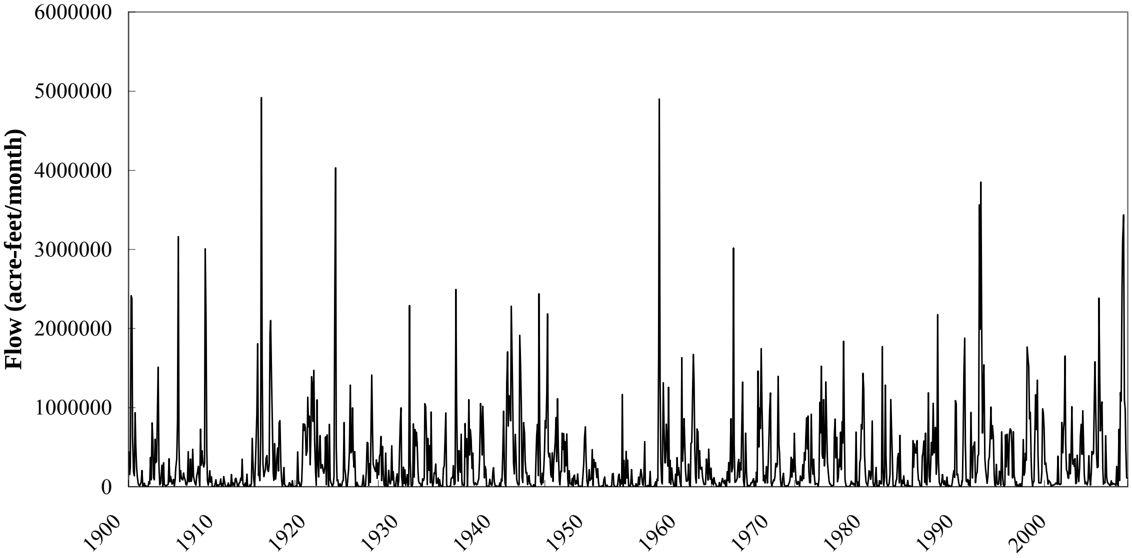

Figure E.82 Monthly BRAC8 Inflows at CON130 − Confluence of Yequa Creek and Brazos River

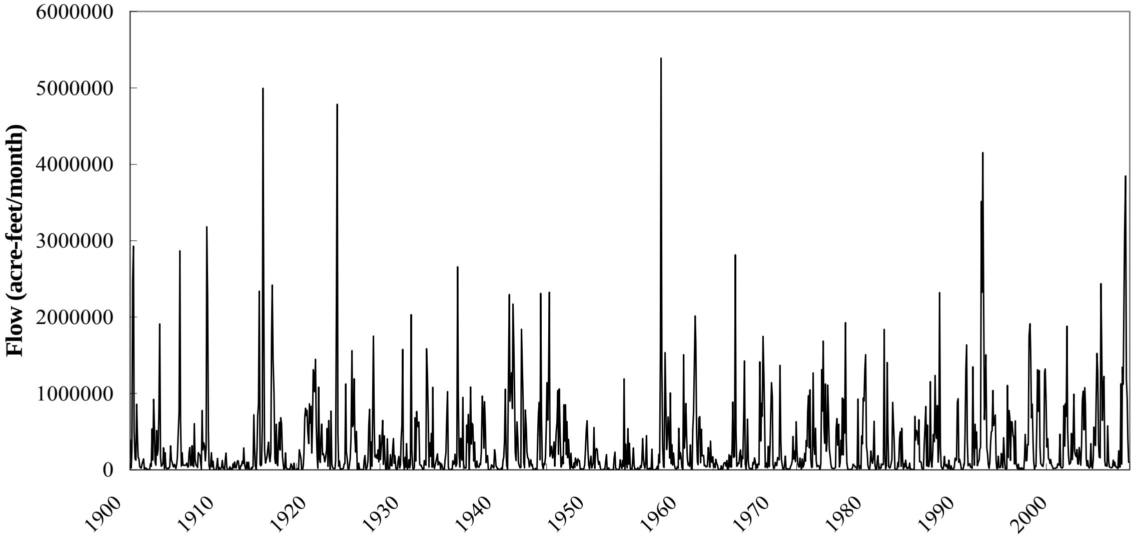

Figure E.83 Monthly BRAC3 Inflows at CON147 − Confluence of Navasota River and Brazos River

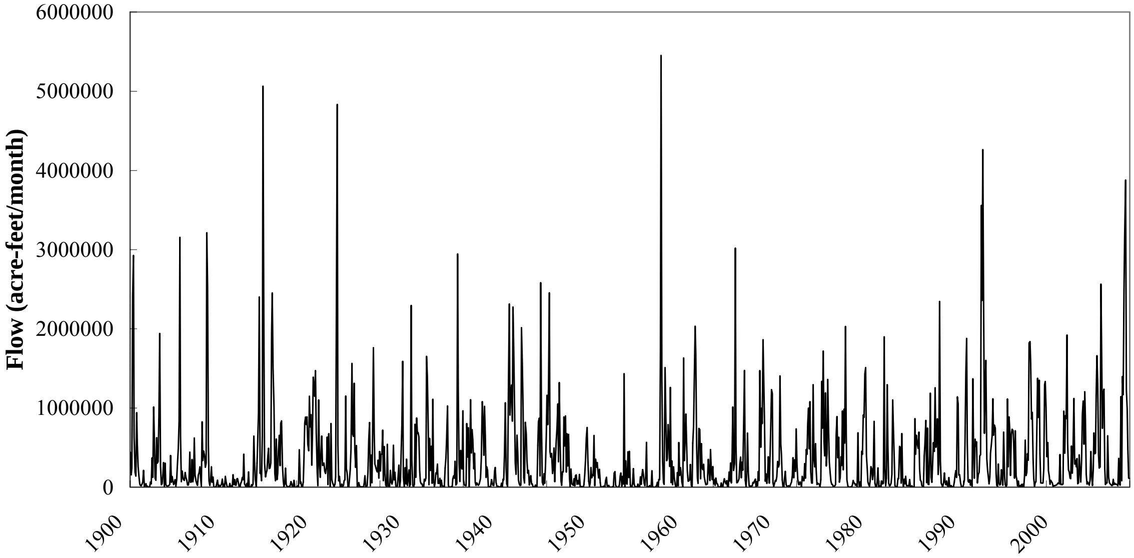

Figure E.84 Monthly BRAC8 Inflows at CON147 − Confluence of Navasota River and Brazos River

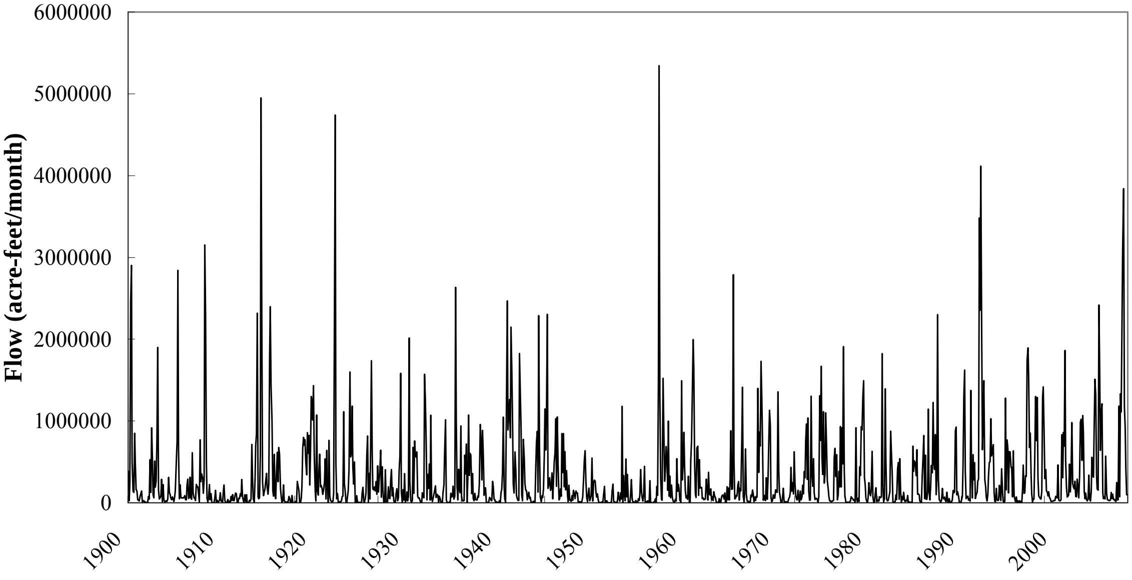

Figure E.85 Monthly BRAC3 Inflows at BRHE68 − Brazos River at Hempstead Gage

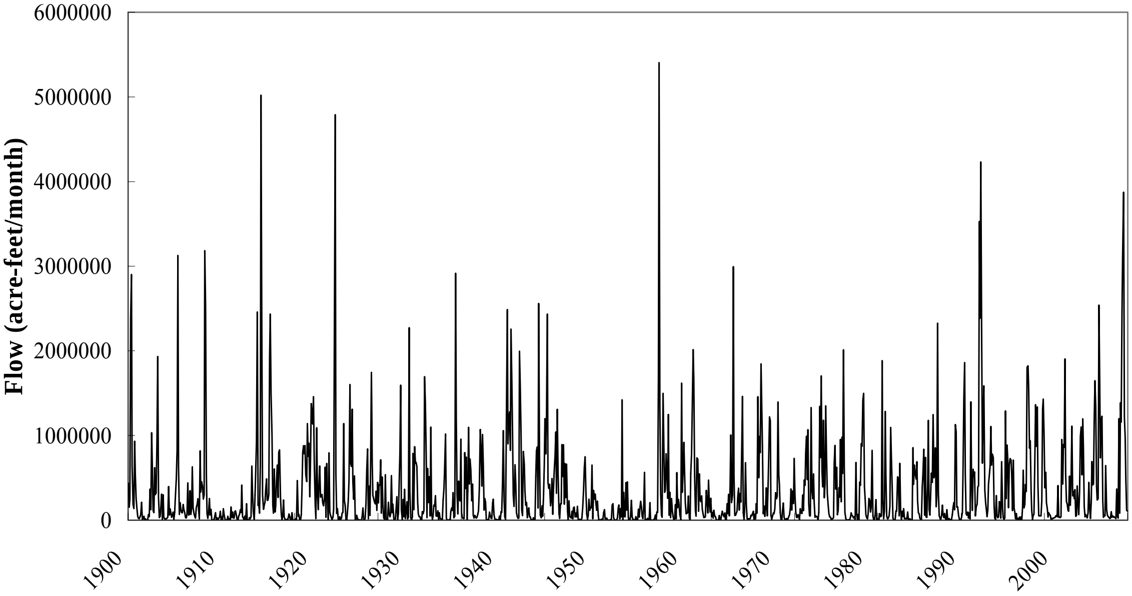

Figure E.86 Monthly BRAC8 Inflows at BRHE68 − Brazos River at Hempstead Gage

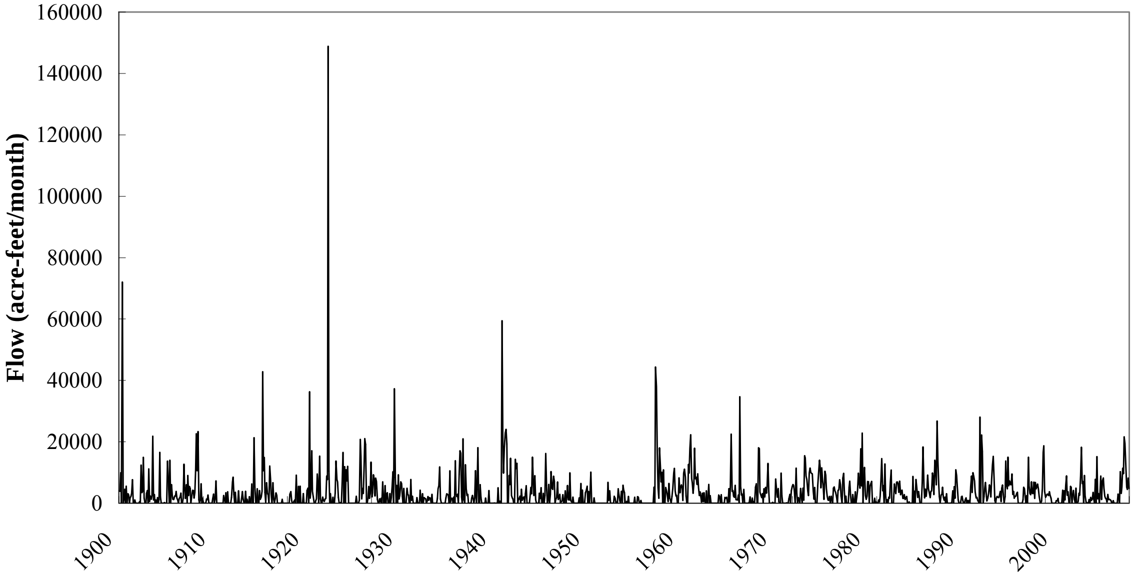

Figure E.87 Monthly BRAC3 Inflows at 292531 − Allens Creek Reservoir

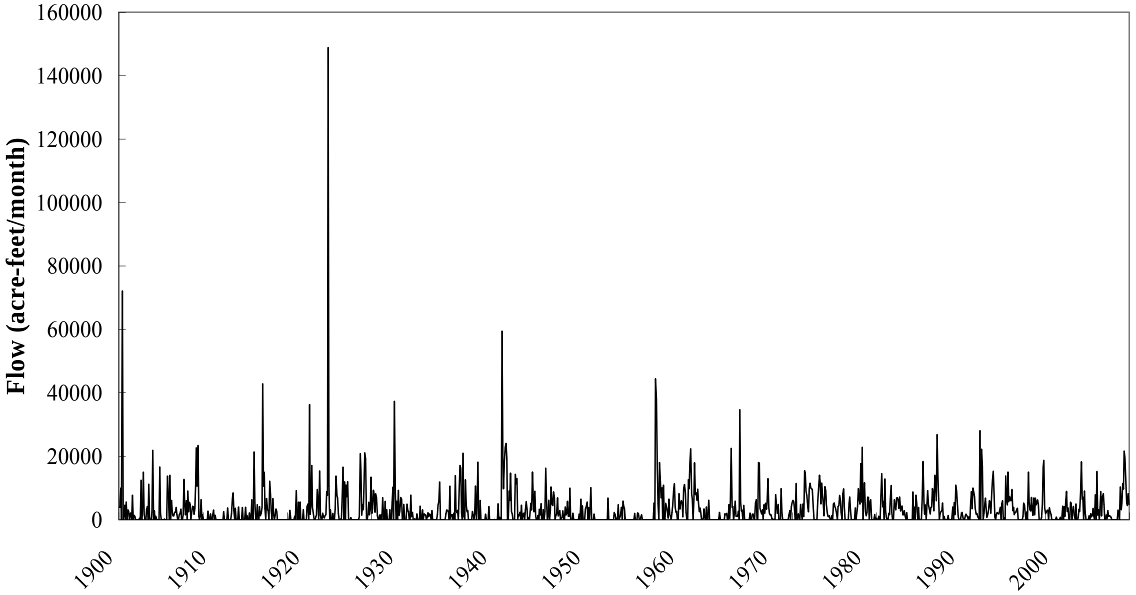

Figure E.88 Monthly BRAC8 Inflows at 292531 − Allens Creek Reservoir

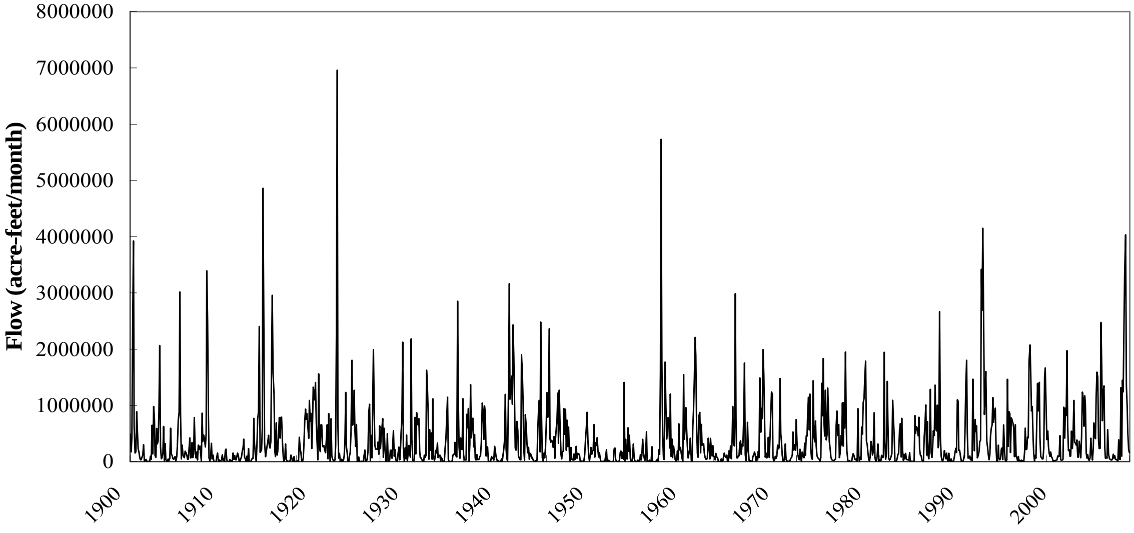

Figure E.89 Monthly BRAC3 Inflows at CON234 − Confluence of Allens Creek and Brazos River

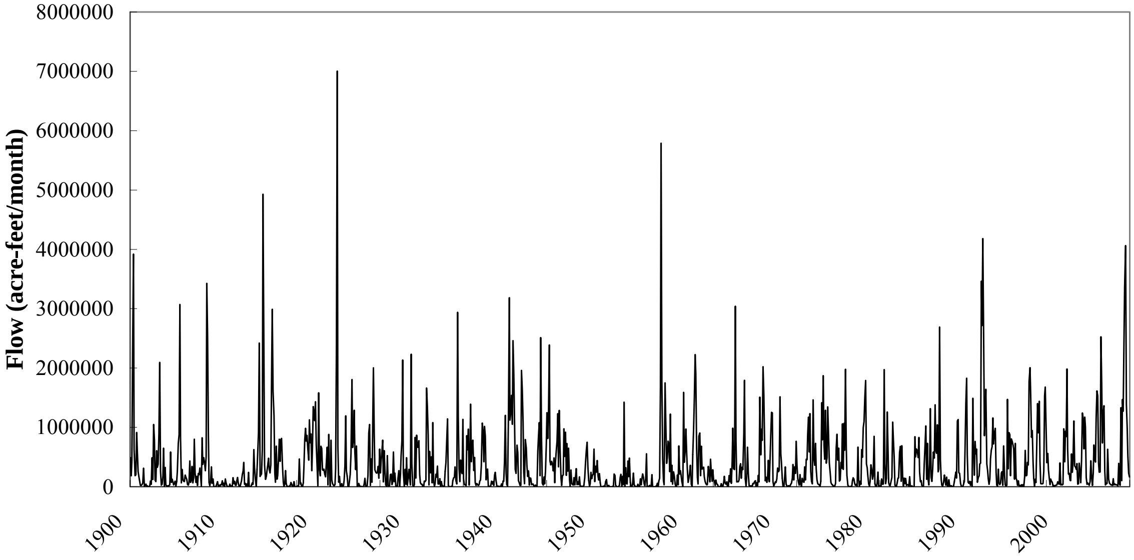

Figure E.90 Monthly BRAC8 Inflows at CON234 − Confluence of Allens Creek and Brazos River

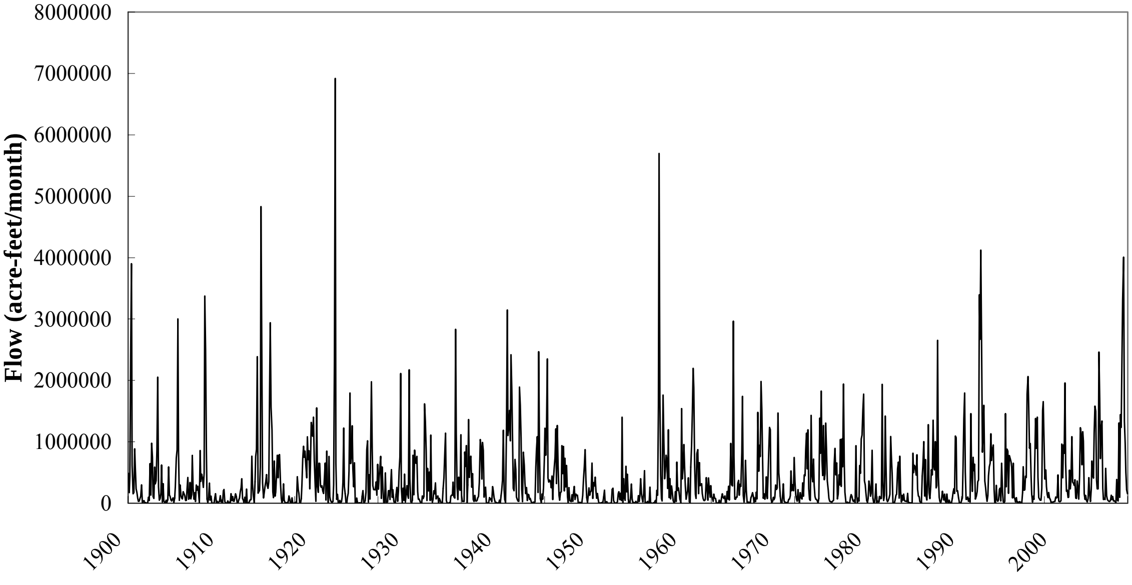

Figure E.91 Monthly BRAC3 Inflows at BRRI70 − Brazos River at Richmond Gage

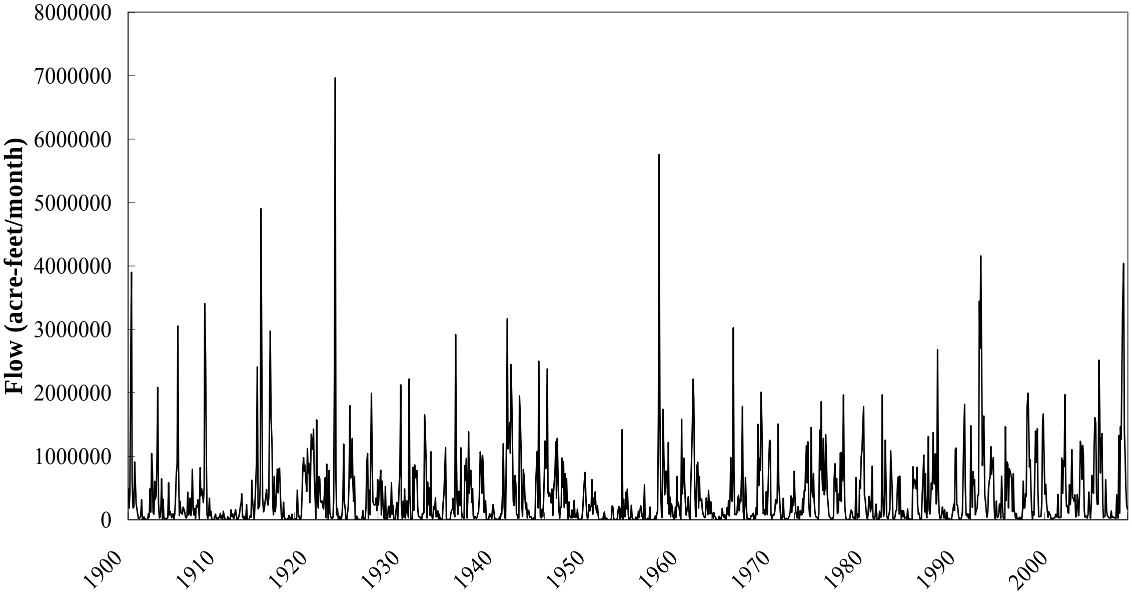

Figure E.92 Monthly BRAC8 Inflows at BRRI70 − Brazos River at Richmond Gage

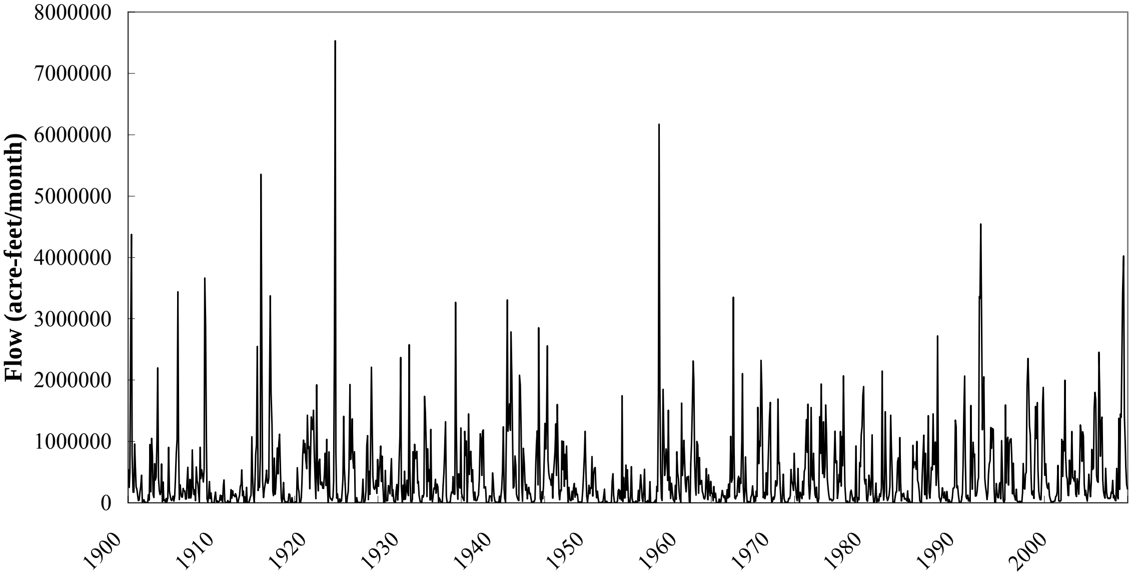

Figure E.93 Monthly BRAC3 Inflows at BRRO72 − Brazos River at Rosharon Gage

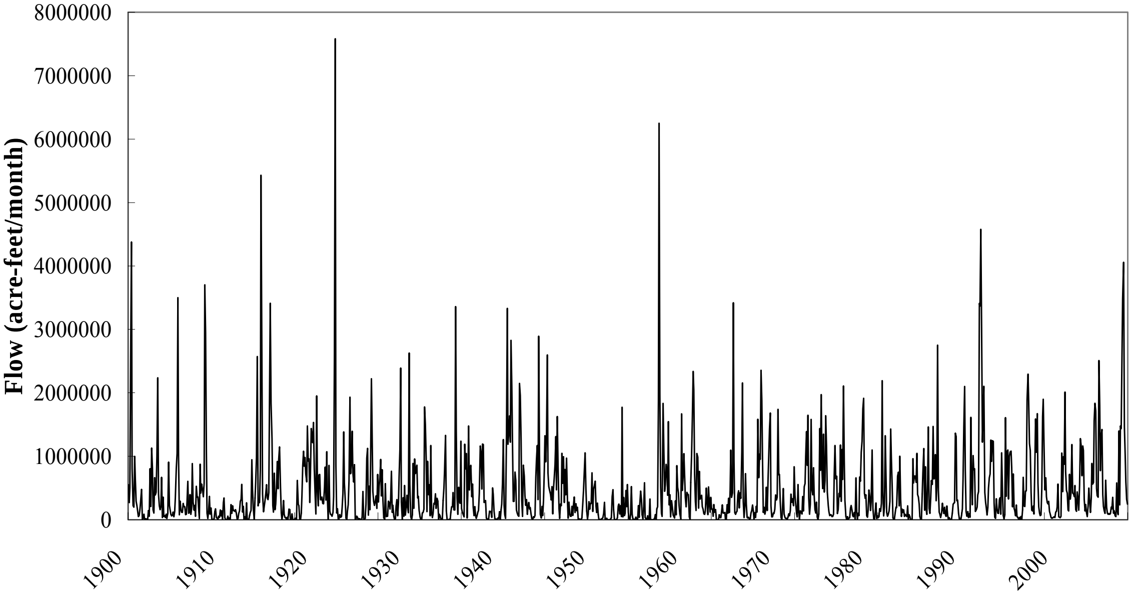

Figure E.94 Monthly BRAC8 Inflows at BRRO72 − Brazos River at Rosharon Gage

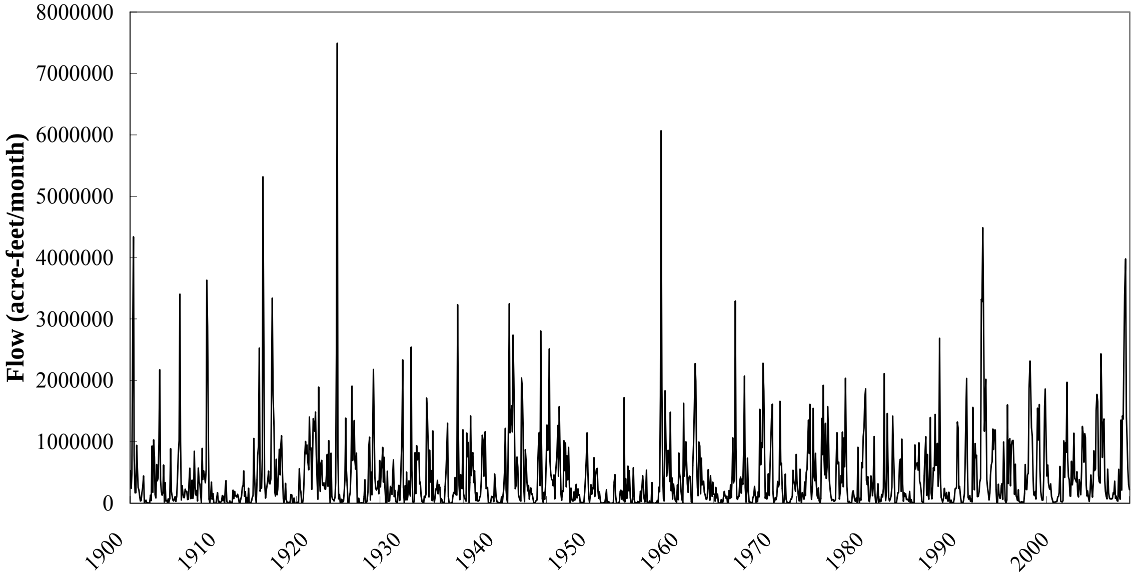

Figure E.95 Monthly BRAC3 Inflows at BRGM73 − Brazos River Outlet at Gulf of Mexico

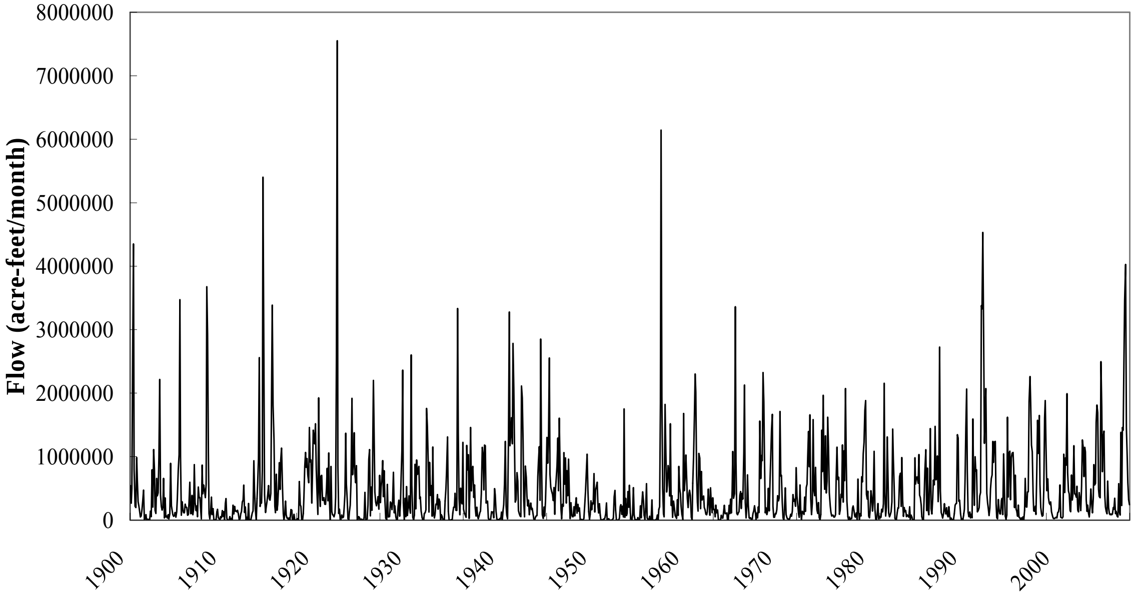

Figure E.96 Monthly BRAC8 Inflows at BRGM73 − Brazos River Outlet at Gulf of Mexico

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