INTEGRATION OF FLOW EXTENSION, WATER REALLOCATION AND DROUGHT MONITORING AND FORECASTING IN MULTI-PURPOSE RIVER/RESERVOIR SYSTEM MANAGEMENT

A Dissertation

by

GUNIL CHUN

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

DOCTOR OF PHILOSOPHY

Chair of Committee,	Ralph A. Wurbs
Committee Members,	Anthony Cahill
	Kelly Brumbelow
	Patricia Smith
Head of Department,	Robin Autenrieth

December 2018

Major Subject: Civil Engineering

ABSTRACT

Population and economic growth have contributed to increasing water uses while available water resources are limited. Recently, the occurrence and damage of drought are increasing worldwide due to the impact of climate change. The effective water management requires for assessment on the current and future water availability based on a water allocation strategy, scenarios, and updating hydrological condition.

The extension of hydrologic period-of-analysis for the Texas WAM/WRAP System increases the model capability. A new water allocation strategy based on Texas WRAP/WAM water priority system is established for water management in Korea. Groundwater drought monitoring and forecasting methodology in Korea was developed based on correlation between groundwater level observation data and precipitation data using Artificial Neural Network model. The research consist of following tasks:

- The original sequences of Brazos WAM input dataset has a 1940-1997 hydrologic period-of-analysis. The methodology developed in this research is to update and extend hydrologic sequences of input datasets to present using precipitation and evaporation maintained by TWDB. This approach is much easier to implement and is particularly advantageous in situations where accurate data required to adjust observed flows are unavailable or difficult to compile or stream gaging station have been discontinued.
- Korea has no water right system considering priority of each water right. The research included developing a water allocation strategy in Korea based on two alternative schemes. A priority-based long-term water allocation strategy was developed for national scale water management and planning. A water allocation strategy for relatively short-term water availability study for drought management

is established based on reallocating water supply to hydropower dam and reducing some portions of water supplies.

- The groundwater drought monitoring and forecasting methodology was developed to support the Drought Early Warning System in Korea. The methodology is based on Standardized Groundwater level Index (SGI). The SGIs for 256 monitoring sites were converted into the area SGI for 167 cities nationwide. The groundwater drought forecasting method was developed based on the correlation between SPI and SGI. The correlation model was employed NARX Neural Network Model. The groundwater drought forecasting was conducted with the correlation model and SPI forecasts.

DEDICATION

First, I will give thanks to you , Lord, with all my heart,

To my beloved wife Hyeunhee, lovely daughter Yewon, and thoughtful son Seungho

and

To my always encouraging, faithful parents, Changhak Chun and Youngnam Yeom

and

my mother-in-law Jongsuk Park

ACKNOWLEDGEMENTS

First of all, I would like to express my deepest appreciation to Dr. Wurbs who is my advisor, professor, and chair of my committee. Dr. Wurbs has continued to guide me to finish my Ph. D with encouragement and insightful comments even I returned to Korea. I could not have imagined having a better advisor for my Ph. D study.

My sincere thanks to my committee, Dr. Smith, Dr. Cahill, and Dr. Brumbelow for their encouragement and guidance. They have shown me good examples of scientist and professor during Ph. D study.

I am also grateful to my company K-water which gave a chance to study and develop myself in Texas A & M. A very special gratitude goes to all members at National Drought Analysis Information Center in Korea.

I am especially indebted to Dr. Jaeyoung Park, Dr. Sinwook Kang, Dr. Jungju Lee, Dr. Taejin Kim, Dr. Minkyu Ryu, Ms. Jihye Jung, Mr. Taeho Kim, and Mr. Sangsun Woo who have been supportive of my research

And finally, I am also grateful to my other family members and friends who have supported me along the way.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This research was supervised by a dissertation committee consisting of Dr. Ralph A. Wurbs (advisor), Dr. Anthony Cahill, and Dr. Kelly Brumbelow of the Department of Civil Engineering and Dr. Patricia Smith of Department of Biological & Agricultural Engineering.

The precipitation and evaporation dataset for Chapter III were provided by Texas Water Development Board (TWDB). The methodology developed in Chapter III was collaboration with Dr. Wurbs. In Chapter IV, naturalized flows and evaporation depths of the North Han River Basin in Korea were provided by Dr. Sinwook Kang of K-water. The groundwater level data analyzed in Chapter V and VI was provided by Dr. Jungju Lee of K-water.

All other work conducted for the dissertation was completed by Gunil Chun independently.

Funding Sources

Graduate study was sponsored by my employer which is Korea Water Resources Corporation (K-water). One of research topic "Extending TCEQ WAM System Hydrologic Period of Analysis" presented in Chapter III was supported by TCEQ.

NOMENCLATURE

ANN	Artificial Neural Networks
ASCE	American Society of Civil Engineers
BBEST	Basin and Bay Expert Science Team
CDF	Cumulative Distribution Function
HEC	Hydrology Engineering Center
KDE	Kernel Density Estimation
KMA	Korea Meteorological Administration
K-water	Korea Water Resources Corporation
MOLIT	Ministry of Land, Infrastructure and Transport
NARX	Nonlinear Autoregressive model process with eXogenous input
NDEW	National Drought Early Warning System
NDIAC	National Drought Information Analysis Center
NGMN	National Groundwater Monitoring Networks
PDSI	Palmer Drought Severe Index
ROC	Receiver Operating Characteristic
SGI	Standardized Groundwater level Index
SPI	Standardized Precipitation Index
TCEQ	Texas Commission on Water Quality
TPWD	Texas Parks and Wildlife Department

TWDB	Texas Water Development Board
USGS	U.S. Geological Survey
WAM	Water Availability Model
WRAP	Water Right Analysis Package

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER Ⅰ

INTRODUCTION

1.1 Motivation for the Research

The Water Availability Modeling (WAM) System maintained by the Texas Commission on Water Quality (TCEQ) consists of the Water Rights Analysis Package (WRAP) generalized river/reservoir system simulation modeling system developed at Texas A&M University over the past two decades and WRAP input datasets for the 23 river basins of Texas (Wurbs 2005b). The WRAP/WAM system developed based on the water right priorities has been extensively applied by the Texas water management community since 2002 in the water rights permitting process, regional and statewide planning studies, and other water management activities.

The original sequences of naturalized flows were developed by ten engineering consulting firms working under contract with the TCEQ during 1998-2001 at considerable expense. Several of the years since 2000 have been very dry, and severe drought conditions throughout Texas have occurred in 2011. There is a need to extend the hydrologic periods-of-analysis to reflect recent drought conditions and to be able to conveniently continue updates in the future.

Korea has been experiencing regional water scarcities due to continued water demand caused by economic development, rapid urbanization, and population growth. Moreover, the recent increase in frequency of the drought caused by the climate change is adding to the regional water shortages and conflicts between upstream and downstream water users. Therefore, the Korean government is seeking an effective solution for water security and adjustment of conflicts among water users like Texas WRAP/WAM system.

In 2015, Korean government decided to adopt the Drought Early Warning System (DEWS) for the effective drought management in Korea. To implement drought early warning system, National Drought Information Analysis Center (NDIAC) has been established a criteria for drought monitoring and forecasting based on each water source such as reservoirs, rivers, and groundwater. For groundwater drought monitoring and forecasting, Standardized Precipitation Index for 6 month of accumulation period (SPI-6) has been applied indirectly in the beginning stage, it is necessary to establish a direct methodology based on groundwater observation data.

The goals of the research are to further expand modeling and analysis capabilities provided by the WRAP/WAM System and to establish water allocation strategy in Korea based on WRAP/WAM priority system and to develop groundwater drought monitoring and forecasting methodology for water management community.

- The first concern addressed by the research is to develop a practical low-cost methodology for periodically (preferably annually) updating the period-of-analysis covered by the TCEQ WAM System hydrology datasets. The naturalized flows in the WAM datasets currently extend from about 1940 through the late 1990's, need to be extended now through 2016, and then continue to be updated each year in the future.
- The second concern is to establish a water allocation strategy to be applied to water right permit process and support the water management and planning practice in Korea. Two alternative approaches for the long-term and short-term water allocation strategy are evaluated based on North Han River WRAP/WAM dataset developed in this research.
- The final concern is to develop a groundwater drought monitoring and forecasting to support the National Drought Early Warning System. The groundwater drought monitoring and forecasting method are based on the groundwater observation data and correlation between groundwater level and precipitation. Several key issues associated with groundwater drought characteristics are investigated in the dissertation research.

1.1.1 Extension of WRAP/WAM Input Hydrology

The WRAP hydrology input files in the TCEQ WAM System consisting of naturalized monthly stream flows and reservoir surface evaporation less precipitation rates at pertinent locations covering the hydrologic periods-of-analysis. The original 1940-1997 sequences of naturalized flows were developed by ten engineering consulting firms working under contract with the TCEQ during 1998-2001 at considerable expense.

The original sequences of naturalized flows are based on adjusting gauged observed flows at about 500 gauging stations to remove the effects of reservoirs, water supply diversions, return flows from surface and groundwater sources, and other aspects of water resources development and use. The process of transforming actual measured flows to naturalized flows is complicated by channel losses and lag times between the stream sites of the flows and the locations of dam, diversion, and return flow sites which may be many miles upstream, difficulties in compiling the water management data upon which the flow adjustments are based, and the discontinuation of a signification number of stream gaging stations.

Several of the years since 2000 have been very dry, and severe drought conditions throughout Texas have occurred in 2011. There is a need to extend the hydrologic periods-of-analysis to reflect recent drought conditions and to be able to conveniently continue updates in the future. The alternative methodology investigated in this research relates naturalized flows to precipitation and evaporation datasets maintained by the Texas Water Development Board (TWDB). This approach should be much easier to implement and is applicable even at those sites at which stream gauging stations have been discontinued.

1.1.2 Establishment Water Allocation Strategy based on WRAP/WAM System

Over the past three decades, the water resources management policy of the Korean government has pursued a quantitative expansion of available water through the water resources development projects. However, the launch of new development projects including large dams is very difficult due to the spread of negative awareness on environmental impacts in local communities and environmental organizations. Therefore, the Korean government is seeking a solution to the water security through the effective management of existing water resources.

The Long-term Water Resources Management Master Plan covering entire Korea has been established every ten years by Korean government since 1980. According to the 2016 Long-term Water Resources Master Plan, all water rights were considered from upstream to downstream without priorities of water supply. Thus, the water balance study results in many disputes over water right holders and has made it difficult to make a consensus on the results of the Master Plan.

Several recent studies on the improvement of water right system in Korea show that most of disputes have been occurred recently between upstream and downstream water right holders (Ahn, Jung et al. 2011, Kim 2015). It is clear that these disputes were caused by the absence of water allocation strategy considering water right priority. During a severe drought from 2014 to 2017, serious disputes occurred between local governments of upstream and downstream are required for development of a water allocation strategy based on water right priority.

In this research, Texas WRAP/WAM System is applied for improvement of the water management policy in Korea. The water allocation strategy is developed in the two alternative schemes. A priority-based water allocation strategy for long-term water management and planning is developed and evaluated with WRAP/WAM system. A water allocation strategy for relatively short-term water availability study for drought management is established for increasing water supply from hydropower dam and reducing some portions of water demands.

1.1.3 Development Groundwater Drought Monitoring and Forecasting Methodology

Drought is a normal feature in nature and its recurrence is inevitable. The beginning and end of a drought and its geographical coverage are more difficult to delineate than for a flood (Wurbs 2002). The effects of drought often accumulate slowly over a considerable period of time and may linger for years after the termination of the event, the onset and end of drought is difficult to determine (Tannehill 1947).

In recent years, concern has grown worldwide that droughts may be increasing in frequency, severity, and duration given changing climatic conditions and documented increase in extreme events (Sivakumar, Stefanski et al. 2014). Although some droughts last a single season and affect only small area, the instrumental and paleoclimate records show that droughts have sometimes continued for decades and have impacted extensive areas in North America, West Africa, and Asia.

Unlike flood control, in which people have to make decisions and cope within a short time, drought can be managed efficiently because it spreads out slowly. Even though the drought is in progress, damages may be minimized if drought can be monitored its onset, end, and spatial characteristics. Drought Early Warning System (DEWS) aim to reduce vulnerability and improve capacities of people at risk. In United State, National Integrated Drought Information System program authorized by Congress in 2006 (Public Law 109-430) developed a National Drought Early Warning System. National Drought Mitigation Center (NDMC) established in 1995 conducts drought monitoring and management decision-making tool for drought mitigation as shown in Figure 1.1.

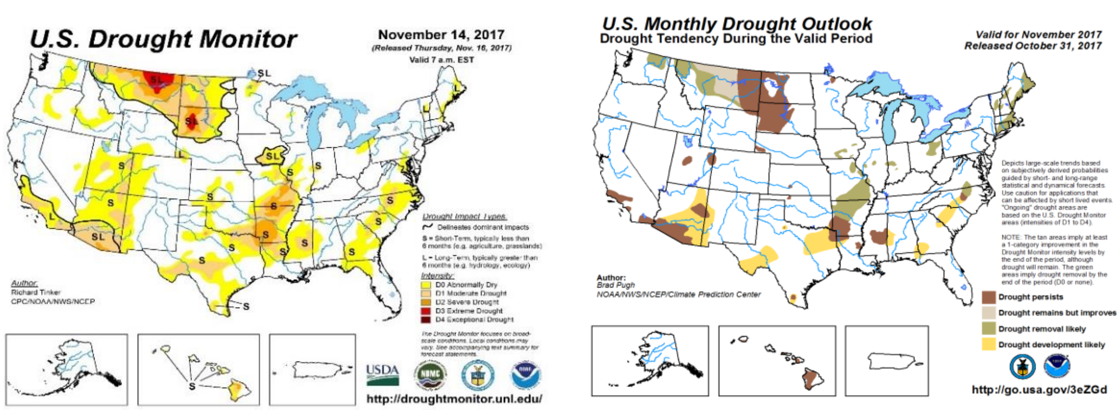


Figure 1.1 U.S Drought Monitor and Monthly Drought Outlook

(https://www.drought.gov/data-map-tool)

In 2015, Korean government decided to adopt the DEWS for the effective drought management and established National Drought Information Analysis Center (NDIAC) to support DEWS. NDIAC’ s mission are to improve the nation’s management capacity associated with hydrological drought, and to prepare for drought monitor, outlook, and drought risk map by integrating key information (water use, hydrological data, water source condition) and providing available drought information to people in Korea.

To implement the DEWS, NDIAC has been established a criteria for hydrological drought development, identification of drought characteristics, forecasting, and recovery based on hydrological data of current and future condition for each water sources (reservoirs, rivers, and groundwater wells). For reservoirs, NDIAC made an evaluation criteria associated with drought condition corresponding each drought level to the amount of available water in each reservoir. For rivers, drought is determined by the temporal reference flow rates based on flow duration analysis for each control point.

For groundwater, unfortunately, most of the area where groundwater is used as an only water source in Korea, the observations of groundwater levels are not performed. In the beginning of DEWS, the Standardized Precipitation Index for 6 month of accumulation period (SPI-6) which is known for the meteorological drought index to be suitable for hydrological drought assessment has been used for groundwater drought monitoring and forecasting. The advantage of SPI is that it can be estimated for various time-scales of drought by calculating using only precipitation data. Although there is a close relationship between precipitation and groundwater behavior, SPI differs from actual drought situation of the area because it explains a drought condition caused by lack of precipitation without information on the current and future condition of groundwater supply.

And also the responses of groundwater level to precipitation depend on the soil and geological characteristic of each groundwater well, which limits the application of SPI-6 as a tool nationwide. In 167 cities nationwide, there are over 13,000 water supply facilities using groundwater as an only drinking water source. In order to complete the drought monitoring and early warning system in Korea, it is necessary to establish drought criteria for the area using groundwater based on groundwater information.

1.2 Objectives of the Research

Components of the overall research address the following specific objectives.

1. Develop and test a methodology for extending the TCEQ WAM System historical period-of-analysis naturalized stream flows to the present using a database of precipitation and evaporation rates maintained by the TWDB.

2. Establish long-term water allocation strategy for water management and planning based on WRAP/WAM priority system and short-term water allocation strategy for drought management in Korea.

3. Develop a methodology of nationwide groundwater drought monitoring for Korea based on observation data of National Groundwater Monitoring Networks.

4. Develop a methodology of nationwide groundwater drought prediction for Korea based on correlation between Standardized Precipitation Index (SPI) and Standardized Groundwater level Index (SGI) using Artificial Neural Network (ANN)

The hydrology datasets in the TCEQ WAM System consist of naturalized monthly stream flows and reservoir surface evaporation less precipitation rates for hydrologic periods-of-analysis extending from about 1940 to between 1997 and 2000. These datasets need to be extended to the present to include the recent drought.

Research objective 1 in the preceding list consists of developing and testing a methodology for synthesizing monthly naturalized flows for recent years based on the TCEQ WAM System datasets of naturalized stream flows and TWDB datasets of precipitation and evaporation. The Brazos River Basin will serve as a case study for the research.

Research objective 2 is designed to improve water management policy, especially water availability study for water right permit system and drought management in Korea. Conventional water availability studies in Korea have been conducted that water rights are simply allocated from upstream to downstream along the stream without considering priorities. Water allocation strategy is developed in the two alternative schemes.

A priority-based water allocation strategy for the long-term water availability studies which are required for regional and national scale water resources development plan and evaluation of water right permit application. A short-term water allocation strategy for securing municipal water supply during severe drought.

In this research, North Han River basin WRAP/WAM dataset, as a case study, including naturalized flows, evaporations, control points, reservoirs, and water rights is developed. Newly established water allocation strategies were evaluated using the North Han River WAM dataset based on WRAP/WAM System.

Groundwater monitoring and forecasting methodologies are developed to support the National Drought Early Warning System (DEWS) maintained by Korean government. The methodology is to simply quantify current and future groundwater droughts and produce drought information for the NDEW every month. In this research, new approach based on SGI building on SPI was applied for identifying groundwater drought.

Research objective 3 focused on employing SGI for identifying current groundwater drought condition based on groundwater observation data. Monthly groundwater level data obtained from The National Groundwater Monitoring Networks (NGMN) is collected and analyzed for identifying regional groundwater characteristics.

Research objective 4 presents a new methodology to forecast monthly or seasonal groundwater drought outlook based on relationship between SGI and SPI. 1, 2, and 3-month precipitation forecasts resulting from Global Seasonal forecast system version 5 (GloSea5) produced by Korea Meteorological Agency are used for calculating SPI. To identify seasonal and regional correlation between SPI and SGI for 167 cities nationwide, ANN technique was applied.

1.3 Texas WAM System

The Water Availability Modeling (WAM) System maintained by the Texas Commission on Water Quality (TCEQ) consists of the Water Rights Analysis Package (WRAP) generalized river/reservoir system simulation modeling system developed at Texas A&M University over the past two decades and WRAP input datasets for the 23 river basins of Texas (Wurbs 2005a). The WRAP/WAM system has been extensively applied by the Texas water management community since 2002.

Implementation of the WAM system highlights the importance of the following institutional dimensions of water availability modeling: (1) modeling water rights, contractual agreements, treaties, interstates compacts, and other complex institutional aspects of water resources development, management, allocation, and use is important; and (2) effective implementation of the modeling system required a partnership effort of a water management community that includes the Legislature, water users, government agencies, consulting firms, and university researchers (Wurbs 2014).

The generalized WRAP modeling system has continued to be expanded and improved at Texas A&M University sponsored by the TCEQ and other agencies. The TCEQ continues to update WAM input datasets as new and revised water right permits are approved, hydrology data accumulates, and modeling capabilities are expanded (Wurbs 2015c).

The expansion of WAM and WRAP capabilities over the past several years has been motivated largely by environmental flow standards established pursuant to the 2007 Senate Bill 3 (Wurbs and Hoffpauir 2013). The environmental flow standards are incorporated in the WAM system with a priority based on the date the TCEQ receives the environmental flow regime recommendations from the applicable a Basin and Bay Expert Science Team (BBEST) (Wurbs and Hoffpauir 2017). Currently, research and development associated with expending WAM capabilities is focused on implementation the daily modeling system and incorporation of environmental flow standards.

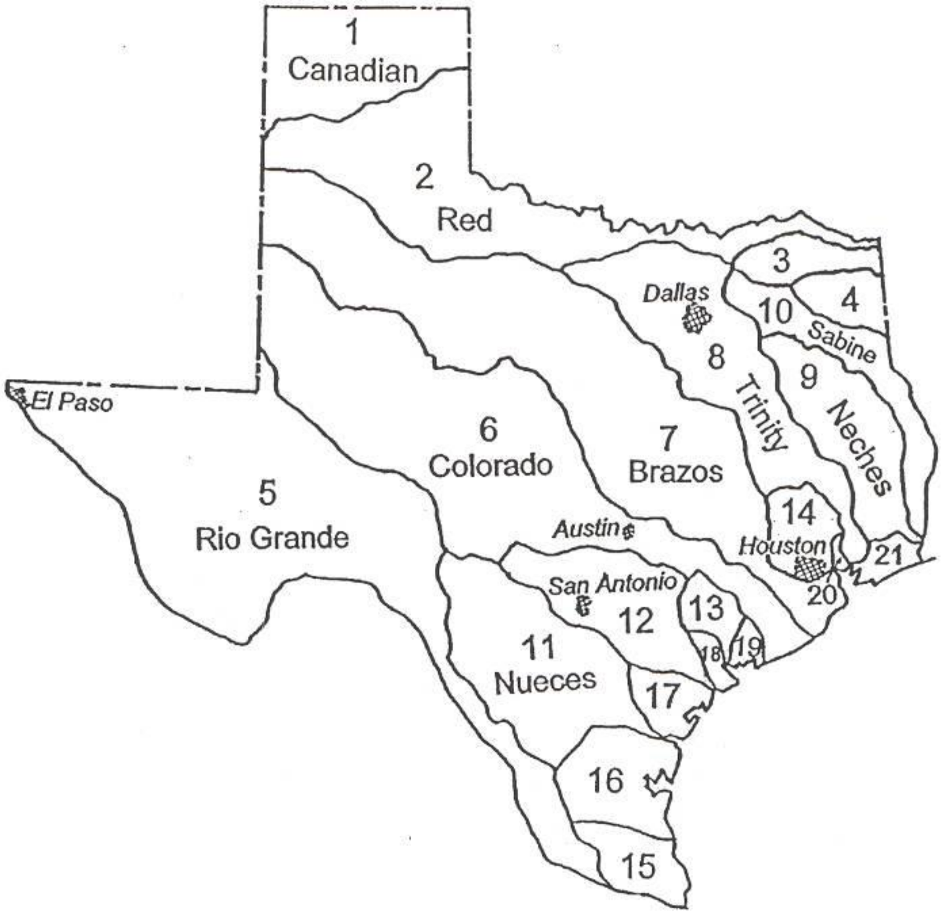


Figure 1.2 Major Rivers and Largest Cities in Texas (Wurbs, 2015a)

1.3.1 WAM System Datasets

Texas has 15 major river basins and eight coastal basins lying between the lower reaches of the major river basins as shown in Figure 1.2. The Texas WAM System includes the 20 WRAP input datasets listed in Table 1.1 covering the 23 river basins. Three of the 20 datasets each combine two basins. The datasets are available at the TCEQ website (https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/wam.html).

Several of the river systems are shared with neighboring states. The Rio Grande is shared with Mexico. For the interstate and international river basins, hydrology and water management in neighboring states and Mexico are considered to the extent necessary to assess water availability in Texas. The models reflect two international treaties and five interstate compacts as well as the two Texas water rights systems administered by the TCEQ. The water rights system allocating the Texas share of the waters of the lower Rio Grande is significantly different from the water rights system for the rest of Texas (Wurbs 2004).

The WRAP/WAM water rights input for two scenarios regarding different combinations of water use, return flows, and reservoir sedimentation are routinely adopted for both water right permit applications and planning studies. The TCEQ uses the authorized use scenario in evaluating new permanent water right permit applications or amendments to existing permanent water right permits and current use scenario for evaluation of term permit applications.

- The authorized use scenario (run 3) is based on the following premises.
  1. Water use targets are the full amounts authorized by the permits.
  2. Full reuse with no return flow is assumed.
  3. Reservoir storage capacities are those specified in the permits, which typically reflect no sediment accumulation.
  4. Reservoir storage capacities are those specified in the permits, which typically reflect no sediment accumulation
  5. Term permits are not included.
- The current use scenario (run 8) is based on the following premises.
  1. The water use target for each right is based on the maximum annual amount used in any year during a recent ten year period.
  2. Best estimates of actual return flows are adopted.
  3. Reservoir storage capacities and elevation-area-volume relations for major reservoirs reflect year 2000 conditions of sedimentation.
  4. Term permits are included.

The TCEQ WAM System datasets include naturalized flows at about 500 primary control points, most of which are stream gaging stations. These flows are distributed to over 10,000 other ungaged sites within the simulation model. The hydrological periods-of-analysis covered by the WAM datasets are typically from 1940s through late 1990s.

The hydrologic period of analysis, the number of control points for naturalized flow and reservoir net evaporation-precipitation rates, and the number of reservoirs in simulation model for each scenario are listed in Table 1.1 and 1.2.

Table 1.1 Texas WAM System the Authorized Use Scenario Datasets

Fig. 1.1 Map ID	Major River Basin or Coastal Basin	Period of Analysis	Number of Control Points				Number of Reservoirs
			Total	FLO	EVA	FAD	
1	Canadian River Basin	1948−1998	85	12	9	0	47
2	Red River Basin	1948−1998	448	47	40	5	247
3	Sulphur River Basin	1940−1996	84	8	4	0	57
4	Cypress Bayou Basin	1948−1998	147	10	11	0	91
5	Rio Grande Basin	1940−2000	957	55	25	1	113
6	Colorado River Basin and Brazos-Colorado Coastal Basin	1940−1998	2,422	45	48	20	518
7	Brazos River Basin and San Jacinto-Brazos Coastal Basin	1940−1997	3,842	77	67	0	678
8	Trinity River Basin	1940−1996	1,398	40	50	0	697
9	Neches River Basin	1940−1996	378	20	12	0	180
10	Sabine River Basin	1940−1998	387	27	20	0	212
11	Nueces River Basin	1934−1996	543	41	10	0	121
12	Guadalupe and San Antonio River Basins	1934−1989	1,338	46	11	5	238
13	Lavaca River Basin	1940−1996	185	8	7	0	22
14	San Jacinto River Basin	1940−1996	412	17	4	0	114
15	Nueces-Rio Grande Basin	1948−1998	200	29	5	0	64
16	San Antonio-Nueces Coastal	1948−1998	53	9	3	0	9
17	Lavaca-Guadalupe Coastal Basin	1940−1996	68	2	2	0	0
18	Colorado-Lavaca Coastal Basin	1940−1996	111	1	1	0	8
19	Trinity-San Jacinto Coastal Basin	1940−1996	94	2	3	0	13
20	Neches-Trinity Coastal Basin	1940−1996	249	4	4	0	31
	Totals		13,401	500	336	31	3,460

Table 1.2 Texas WAM System the Current Use Scenario Datasets

Fig. 1.1 Map ID	Major River Basin or Coastal Basin	Period of Analysis	Number of Control Points Total	FLO	EVA	FAD	Number of Reservoirs
1	Canadian River Basin	1948−1998	85	12	9	0	47
2	Red River Basin	1948−1998	451	47	40	12	248
3	Sulphur River Basin	1940−1996	89	8	4	0	57
4	Cypress Bayou Basin	1948−1998	147	10	11	0	91
5	Rio Grande Basin	1940−2000	957	55	25	1	113
6	Colorado River Basin and Brazos-Colorado Coastal Basin	1940−1998	2,396	45	47	20	510
7	Brazos River Basin and San Jacinto-Brazos Coastal Basin	1940−1997	3,852	77	67	0	719
8	Trinity River Basin	1940−1996	1,418	40	50	0	700
9	Neches River Basin	1940−1996	395	20	12	0	203
10	Sabine River Basin	1940−1998	387	27	20	0	213
11	Nueces River Basin	1934−1996	546	41	10	0	125
12	Guadalupe and San Antonio River Basins	1934−1989	1,340	46	13	5	241
13	Lavaca River Basin	1940−1996	184	8	7	0	21
14	San Jacinto River Basin	1940−1996	414	17	4	0	114
15	Nueces-Rio Grande Basin	1948−1998	200	29	5	0	65
16	San Antonio-Nueces Coastal	1948−1998	53	9	3	0	9
17	Lavaca-Guadalupe Coastal Basin	1940−1996	68	2	2	0	0
18	Colorado-Lavaca Coastal Basin	1940−1996	111	1	1	0	8
19	Trinity-San Jacinto Coastal Basin	1940−1996	94	2	3	0	13
20	Neches-Trinity Coastal Basin	1940−1996	249	4	4	0	31
	Totals		13,436	500	336	38	3,528

1.3.2 WRAP Modeling System

The WRAP modeling system developed at Texas A&M University simulates water resources management in a river basin or multiple-basin region under a priority-based water allocation system. WRAP is a generalized modeling system for simulating and analyzing water resources development, management, allocation, and use in river basins located anywhere in the world. WRAP is designed for assessing reliabilities in meeting water supply, hydroelectric power, and environmental flow needs. Reservoir operations for flood control can also be simulated (Wurbs 2015d).

The TCEQ, Texas Water Development Board (TWDB), Texas Parks and Wildlife Department (TPWD), and their contractors which consist of two universities and 10 consulting engineering firms developed the Texas WAM System during 1997-2003 pursuant to the 1997 Senate Bill 1 to support water rights regulatory and regional and statewide planning activities. The TCEQ has continued to improve and expand WRAP since implementation of the WAM System.

The original WRAP uses a monthly computational time step. The expanded daily modeling system allows capabilities for flow forecasting and routing, disaggregation of monthly naturalized flows and water demands to daily, simulation of flood control reservoir operations. Recently added daily modeling features expand capabilities for simulating Senate Bill 3 environmental flow standards and their impacts on water supply capabilities (Wurbs and Hoffpauir 2013)

Currently, the WRAP modeling System includes the following programs. WinWRAP is a user interface for applying the WRAP modeling system on personal computers with the Microsoft Windows operating system. SIM simulates a river/reservoir water allocation/management/use 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 develops or updates monthly naturalized stream flow and reservoir net evaporation less precipitation depth data for SIM hydrology input files. SIMD is an expanded version of SIM with additional features for daily time steps, flow forecasting and routing, pulse flows, and flood control operations. DAY assists in developing daily hydrology input for SIMD including monthly-to-daily flow disaggregation and determining routing parameters. SALT reads a SIM or SIMD output file and a salinity input file and tracks salt constituents through the river/reservoir/water use system (Wurbs 2015a).

1.4 Literature Review

Key topics are reviewed and pertinent references are cited in the following discussion prior to outlining the research methodology in chapter 2 of the dissertation.

1.4.1 River/Reservoir System Modeling and Analysis

Reservoir/river system management models are based on volume-balance accounting procedures for estimating water amounts of specific points throughout systems of reservoirs and river reaches. The inputs to the river/reservoir system include naturalized streamflow, reservoir surface evaporation rates, storage capacity data for reservoirs, and demand targets for municipal and industrial water supply, irrigation, and hydroelectric energy generation.

The reservoir system model has an operating plan or release plan for determining the quantities of water to be stored and to be released or withdrawn from the reservoirs under various conditions. The operating rules involve allocating storage capacity and streamflow between water users and types of use, minimizing the risk and consequence of shortage and flood, optimizing the beneficial use of water, energy, and land resources, and managing environmental resources (Wurbs 1996).

Several books on modeling and analysis of reservoir operations are available (Votruba and Broža 1989, Wurbs 1996, ReVelle 1999, Imve, Kofi et al. 2002). Labadie (2004) summarizes the extensive research literature on reservoir system optimization models. Wurbs (2011a) presents detailed reviews of the state-of-the-art of river/reservoir system modeling from a practical applications perspective. Wurbs (2011a) provides comparisons of WRAP and other similar generalized modeling systems including the ResSim Reservoir Simulation System developed by the USACE Hydrologic Engineering Center, the RiverWare River and Reservoir Operations Model developed at the University of Colorado, and the MODSIM River Basin Network Flow Model developed at Colorado State University.

1.4.2 Water Right System in Korea

In general, water right is defined as the exclusive right to use water for the purpose of irrigation, hydropower generation, municipal and industrial water use, and shipping, but there is no provision stipulated by law in the terms “water right” (Kwon 2009). However, there are analogous legal terms defined in several laws such as rights to use of water in the River Act article 50 (1961), rights to use water impounded of dam or reservoir in Act on Construction of Dams and Assistance, etc. to Their Environs article 24 (1999), and rights to use in a sharing river in Civil Act article 231 (1958). On the basis of these laws, the Korean government has assured adequate water supplies for existing water users and reviewed a water availability for a new application of water right.

According to the River Act article 49-53, the water right should be granted from government approval through permit system and the priority of water use types is provided in the order of domestic, industrial, agricultural, and other uses. River Water Adjustment Council which is comprised of 20 members including central government, local government, K-water, and water right holders is able to determine adjustment of water allocation in case of difficulty in securing instream flow requirements or severe drought.

The right to use impounded water in accordance with construction of a new dam or existing dam in Act on Construction of Dams and Assistance, etc. to Their Environs is granted a person who intends to use stored water in the dam through permitting system. The water users who have been using water from the river before the construction of dam will be granted their right to use with higher priority than new application rights. These rights are categorized to as the vested rights.

1.4.3 Water Availability Study in Korea

In general, water availability study is carried out to quantify the available water when establishing a water resources development plan or reviewing permits for a new water right application in the river/reservoir system. In particular, the Long-term Water Resources Master Plan published every ten years by Ministry of Land, Infrastructure, and

Transport (MOLIT) has established the water resources development plan such as dams and multi-region pipeline system based on the results of water availability studies.

Water availability study is conceptually simple to compare water demand and supply capacity at the target year with historical hydrology, but it has many uncertain components because it deals with the hydrological cycle. There are many uncertainties such as return flows, naturalized flows, water demand, and errors of the observation data which are also considerable (Lee, Kim et al. 2005). The uncertainty of the input contained in water budget studies made the water resources development projects which result from the studies cannot be implemented due to the lack of trust of stakeholders (K-water 2017).

With respect to a model for water resources planning and assessment, there has not been a formal decision at the government level, various models have been applied depending on the work scope and tasks. For decades, many studies have been carried out on the national scale model for planning and assessment of existing and new development of water resources. In 1999, K-water published a research report which compared the strengths and weaknesses of the water balance study models that have been applied globally for the study on water resources planning and assessment such as HEC-ResSim, CalSIM, WEAP, RAISON, MODSIM, and WRAP (K-water 1999).

Jung reviewed the applicability of the decision support system using K-ModSim, which is a customized model of ModSim developed by Colorado State University in the Kum River basin in 2007 (Jung, Kang et al. 2007). Moon and Choi conduct a water budget study reflecting real network of water demand and supply in the stream using K-WEAP which is a customized model of Water Evaluation and Planning System (WEAP) developed by Stockholm Environmental Institute (Choi, Lee et al. 2010). Jung proposed the development of a hydro-economic water allocation model that can more effectively deal with water allocation problems based on optimization algorithms in 2016. The K-WEAP model was also applied to several studies on water resources planning and assessment in Korea, but all of them did not consider the priorities of water rights and water use types. Kim introduce the Texas WRAP/WAM system which is developed by

Texas A&M University supported by TCEQ and conduct a reliability analysis for water rights and frequency analysis for streamflows at the watershed of Soyang Dam (Kim and Kim 2016).

1.4.4 Approaches for Drought Management

1.4.4.1 Definition of Drought

Drought is considered by many to be the most complex but least understood of all natural hazards, affecting more people than any other hazard (Hagman, Beer et al. 1984). Generally, drought is defined as a deficiency of precipitation relative to what is expected (i.e., “normal”) that, when extended over a season or a longer period of time, results in the inability to meet the demands of human activities and the environment (Hayes, Svoboda et al. 2011). However, the wide variety of sectors (i.e., natural habitats, ecosystems, and agriculture, water supply) affected by drought, and its diverse geographical and temporal distribution make it difficult to develop a single definition of drought. Wilhite and Glantz (1985) analyzed more than 150 definitions of drought and grouped by type as follows: meteorological, hydrological, agricultural, and socioeconomic. Figure1.3 explained the relationship between various types of drought and the duration of events.

Meteorological drought is expressed solely based on the degree of dryness (often with comparison to some normal or average amount) and the duration of the dry period. Thus, intensity and duration are the key characteristics of the meteorological drought. However, meteorological drought should be considered as specific atmospheric condition of the region because the deficiencies of precipitation is dependent on climate regime. Some definitions differentiated meteorological drought based on the number of days with precipitation less than some specified threshold rather than the magnitude of the deficiency over some period of time. Most definitions of meteorological drought relate to comparison actual precipitation with average amount on monthly, seasonal, or annual time scales (Wilhite 2000).

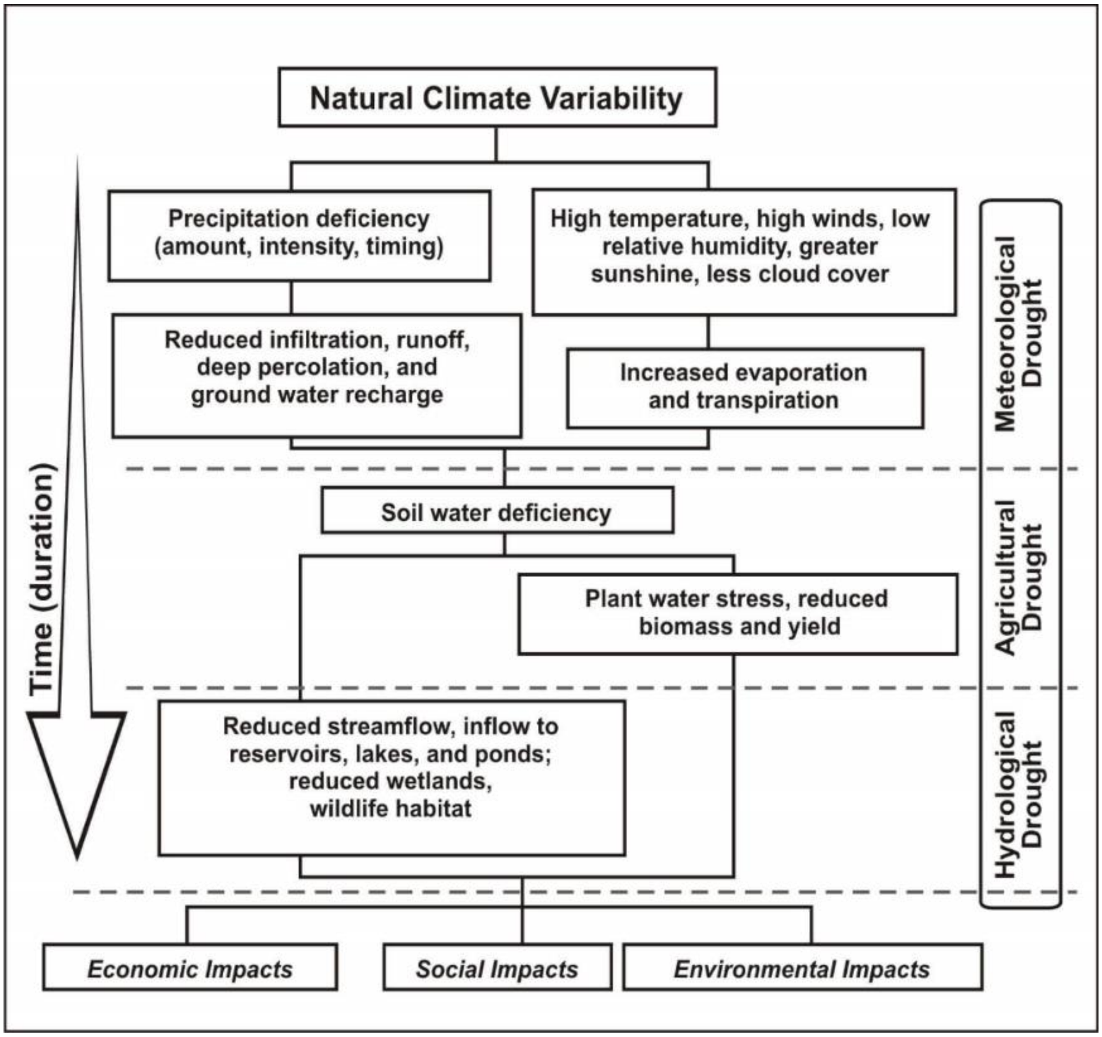


Figure 1.3 Drought types, casual factors and their usual sequence of occurrence (Wilhite, 2000)

Agricultural droughts focus on deficiencies of the amount of water necessary for crops. Agricultural drought links various characteristics of meteorological drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration (ET), soil water deficits, and so forth (Wilhite 2000). With respect to crop yields, soil moisture supply, temperature, timing of rainfall during the growing season is critical for determination on it. The impacts of agricultural drought depend on types of crop and region because planting dates and maturation period vary between crops and locations. It is common for agricultural drought to occur after a meteorological drought has officially ended.

Hydrological droughts refer to a lack of water in the hydrological system, manifesting itself in abnormally low streamflow in the river and abnormally low levels in lakes, reservoirs, and groundwater (Tallaksen and Van Lanen 2004). The primary cause of a drought is the lack of precipitation for an extensive period of time. Water in hydrological storage systems (e.g., reservoirs, rivers) is commonly used for multiple and competing purpose (e.g., power generation, flood control, irrigation, recreation), further complicating the sequence and quantification of impacts (Wilhite 2000). Water availability during drought season is important evaluation factor of hydrological drought impacts. Reduction of streamflow, reservoir, and groundwater level may cause serious problems such as restriction of water supply, decline of hydro-power generation, conflicts between water users and so forth. Hydrological droughts are usually out of phase or lag the occurrence of meteorological and agricultural droughts.

Socioeconomic drought is associated with the impacts of meteorological, agricultural, and hydrological drought, especially which focuses on human activities related to supply and demand of some economic good or service (water, hydropower, crops) with element of meteorological, agricultural, and hydrological drought. Some scientists suggested that the occurrence of drought could increase if the needs for drinking and industrial water in a growing city exceed the reserves. This is the serious concern where water is not enough and should be transported from other area.

1.4.5 Approaches for Drought Monitoring and Early Warning

Although all types of droughts (meteorological, agricultural, hydrological, socio-economic) are initiated by an extended precipitation deficiency, it is insufficient solely to monitor precipitation to assess severity and resultant impact (S. Pulwarty and Sivakumar 2014). Effective drought monitoring systems integrate precipitation frequency and intensity and other climatic parameters with water information such as streamflow, snow pack, groundwater levels, reservoir and lake levels, water demands at different stages of crop growth, and soil moisture into a comprehensive assessment of current and future drought and water supply conditions (Svoboda, LeComte et al. 2002)

Scientists and decision-makers have needed a straightforward method to produce clear results about current conditions, forecasts, and assessment of drought. The indicators and indices related to drought have been developed for these purposes. The handbook of drought indicators and indices (Svoboda and Fuchs 2016) defined that the indicators are variables or parameters used to describe drought conditions such as precipitation (for meteorological drought monitoring), streamflow, groundwater and reservoir levels (for hydrological drought monitoring), and soil moisture (for agricultural drought monitoring). The indices are typically used to provide quantitative assessment of the severity, location, timing and duration of the drought event using hydro-meteorological inputs including the indicators listed above. Standardized Precipitation Index (SPI) developed by McKee, Doesken et al. (1993) and Palmer Drought Severe Index (PDSI) developed by Palmer (1965) are indices which have been widely applied for drought monitoring and forecasting.

1.4.5.1 Drought Indices

In order to understand drought processes and impacts, drought characteristics of the concerned region such as the timing, duration, severity (or intensity), and spatial extent of a drought event need to be identified. This includes identification of historical and current droughts, and prediction of future droughts. Generally, drought indices (i.e., SPI, PDSI, SMI, etc.) have been applied for drought monitoring and forecasting works in worldwide. Every types of drought index, focusing on a specific part of the hydrological cycle or using a specific methodology, has its merit for a specific application and multiple indices should be used for quantify the diversity of drought impacts (Van Loon 2015). The drought indices frequently used in drought risk management and early warning system are followed.

Palmer Drought Severe Index (PDSI)

The Palmer Drought Severe Index (PDSI) developed by W. Palmer in 1965 has been applied for estimating agricultural drought damage based on soil moisture balance. PDSI is applied mainly in the United States, both for scientific and operational purposes. Palmer proposed a standardized index that can identify a drought condition from available temperature and precipitation data. It measures the departure of moisture balance from normal condition using a simple water balance model and can be regarded as a hydrological accounting system (Dai 2011, Van Loon 2015). PDSI has been reasonably successful at quantifying long-term drought. Despite it has been applied worldwide, PDSI has important limitations to use on the global scale: i) the calculation procedure of PDSI is complex and non-transparent (Sheffield and Wood 2011), ii) the time scale is fixed (Mishra and Singh 2010), iii) as it was developed for the United States, re-calibration is needed for application to other region (Dai 2011). Palmer also developed a soil moisture index (Z-index) and a hydrological drought index (PHDI).

Standardized Drought Indices (SPI)

Mckee et al. (1993) developed SPI as an alternative to Palmer drought Index. The SPI is a normalized index that are obtained by fitting a gamma distribution to historical observed precipitation records, where fitting is done for each month and season. The monthly fitted distributions are then transformed to a standard normal distribution and the estimated standardized values combine to produce the SPI time series. The strength of SPI is that: i) it uses only one variable parameter (precipitation), ii) it can be estimated for a variety of timescales by calculating using precipitation data for a range of accumulation period (i.e., past 2 months, 3months, 6 months, etc., up to 48 months), iii) it is spatially constant (no re-calibration is needed for to application to other region) (Bloomfield and Marchant 2013).

SPI has also some limitations that should be considered: i) the determination of suitable probability distribution for historical precipitation data (Guttman 1999), Guttman recommended that Pearson Type III distribution is the best universal model for computing the probability distribution, ii) the requirements for a long precipitation time series. Despite of these limitations, SPI is one of the most widely used indices of meteorological drought and has been recommended by the WMO as an index of choice to characterize meteorological droughts (Svoboda, Hayes et al. 2012).

Standardized Groundwater level Index (SGI)

Standardized Groundwater level Index (SGI) developed by Bloomfield and Marchant (2013) is a new index for standardizing groundwater level time series and characterizing groundwater drought or wet condition as deviation of normal groundwater level. The SGI builds on the standardized Precipitation Index (SPI) to account for differences in the form and characteristics of groundwater level and precipitation time series. Like SPI, SGI is a dimensionless index where negative values indicate drought; positive values, wet conditions.

The SGI is estimated using a non-parametric normal values transform of groundwater level data for each calendar month. Then, these monthly estimates are merged to a form a continuous index. SGI calculated at a concerned site compares with SPI for the same site. The relationship between SGI and SPI is site specific and the SPI accumulation period which leads to the strongest correlation between SGI and SPI varies between sites. Since SGI can be strongly influenced by location reflecting influences from local and site specific recharge processes and regional to site-specific saturated flow processes that are not simply spatially correlated. Consequently, interpretation or analysis of the resulting SGI needs to reflect an appreciation of hydrological context of the observation wells (Bloomfield and Marchant 2013).

1.4.6 Monitoring and Forecasting of the Groundwater Drought

In the past, groundwater drought was considered to result from groundwater over-exploitation rather than as a result of hydro-meteorological variability. Thus, it was treated as one of the variables that should be monitored in case of drought Hydrological drought edited by Lena M., 2004. Like other droughts, groundwater drought is originated from a lack of precipitation. It is associated with reduced groundwater recharges which leads to lower groundwater level and low well yield, or even drying-up of well.

Van Lanen and Peters (2000) define groundwater drought as a lack of groundwater recharge or a lack of groundwater expressed in terms of storages or groundwater head in a certain area and over a particular period of time. The lack is determined in comparison to some "normal" or average amount or level derived from historical data (Van Lanen and Peters 2000). It is very difficult to identify the total available groundwater amount expressed in terms of storage directly because the estimation of groundwater storage is required for some variables, such as aquifer thickness, storage coefficient, which are not generally observed. The recharge and water levels are spatially distributed and the discharge is also distributed along the longitudinal profile of the stream (Tallaksen and Van Lanen 2004). Relatively, groundwater levels or heads are readily measured and easy to obtain information of current condition of aquifers if there are long-term observation data.

Several studies have attempted to identify the effect of precipitation on groundwater level fluctuation. Viswanathan (1984) developed an analytical model to connect groundwater level to rainfall and then estimated the recharge of unconfined aquifers from groundwater level data. Butterworth, Schulze et al. (1999) evaluated the effect of rainfall intensity on groundwater level and concluded that long-term trend in groundwater level is an apparent indicator for reflecting the effect of cycles in rainfall. Ferdowsian, Pannell et al. (2001) proposed a statistical approach to estimate trends in groundwater level where the effect of a typical rainfall event from the underlying time trend was separated and the lag between rainfall and its impact on groundwater level can be distinguished. Jan, Chen et al. (2007) proposed a mathematical equation based on the empirical relationship between rainfall intensity and groundwater level variation and the variations of groundwater level were predicted by using this empirical equation and observed groundwater level and rainfall data.

USGS analyzes observed groundwater level data nationwide and provides a percentile of current groundwater level to the states considering groundwater level percentile classes by stations. In case of State Virginia, the monthly reference groundwater level is determined using groundwater monitoring data for at least 10 years. And then a percentile corresponding to a current water level is compared with the reference groundwater level of the month to determine the current drought condition. In Canada, the same way as in the U.S., the monthly reference groundwater level is compared with current groundwater level to determine the current drought condition.

1.4.7 Artificial Neural Network (ANN)

ANN are a type of machine learning that is a statistical learning algorithm inspired by biological neural networks (the central nervous system of animals, especially the brain). Machine learning can be simply defined as a technique for finding a model using data. In general, three datasets, training dataset, validation dataset, and test dataset, are used for conducting a machine learning. The performance of model is strongly influenced by the training dataset. The development of ANN was begun by McCulloch and Pitts (1943). The ability to identify a relationship from given patterns make it possible for ANNs to solve large-scale complex problems such as pattern recognition, nonlinear modeling, classification, association, and control (Hydrology 2000a).

The application of ANNs in hydrology such as precipitation forecasting, rainfall-runoff modeling, streamflow forecasting, reservoir operation, and groundwater modeling began in the 1990s. The analysis of hydrologic processes, specially prediction and estimation of hydrology, are often confronted with problems such as temporal and spatial variability, nonlinearity of physical processes, conflicting spatial and temporal scale, and uncertainty in parameter estimates. The advantage of ANNs is their ability to extract the relation between the inputs and outputs of a process, without physics being explicitly provided to them (Hydrology 2000b).

1.4.7.1 Applications in rainfall-runoff modeling

The relationship between rainfall and runoff for a watershed is an important component of water resource management for hydrologist and engineers. However, identifying this relationship is very complex because this process is highly nonlinear, time-varying and spatially distributed. Many studies have conducted to apply ANN in modeling watershed runoff based on rainfall input. Halff, Halff et al. (1993) designed a three-layer feedforward ANN using observed rainfall hyetographs as inputs and hydrographs produced by U.S. Geological Survey (USGS) as outputs. The authors used five nodes in the hidden layer. Of total five storm event, four storms were selected for training and remaining single storm was used for testing. This study opened up several possibilities for rainfall-runoff application for ANNs.

Carriere, Mohaghegh et al. (1996) developed a virtual runoff hydrograph system that used a recurrent back-propagation ANN to generate runoff hydrograph. A recurrent backpropagation was utilized, in which input layer feeds back to itself during training to capture time dependence in the series. The network was consisted of 7 nodes for input layer, 35 nodes for hidden layer, and a single node in the output layer. Of the total 45 watershed dataset which had different characteristics, 29 dataset were selected for training and remaining 16 dataset were used for testing. The author concluded that ANN could predict runoff hydrographs accurately.

1.4.7.2 Application ANNs in precipitation forecasting

Precipitation is the most important input in the hydrological process. It is very difficult to predict precipitation because it has a very large temporal and spatial variability. French, Krajewski et al. (1992) applied a three-layer feedforward ANN with back-propagation for prediction of rainfall intensity field at a lead time of 1 hour with the current rainfall intensity as input. The authors also compared the effect of changing the number of nodes in the hidden layer on using 15, 30, 45, 60, and 100 with forecasting models. According to their results, authors concluded that ANNs performance is slightly better than forecasting models and the ability of an ANN to generalized the underlying rule was strongly dependent on selecting a large enough hidden layer. Kuligowski and Barros (1998) present an ANN approach for short-term (0-6 hour) precipitation prediction. The model has a feedforward architecture with upper air wind direction and antecedent precipitation as input. Compared the results of precipitation prediction with persistence model, proposed ANN model showed improvement significantly.

1.4.7.3 Application ANNs in Groundwater

Aziz, Abd et al. (1992) applied ANNs for determining aquifer parameter values for normalized data obtained from pumping tests. The study was based on the pattern recognition ability of ANNs employing aquifer pumping test data. The ANN were trained to get output such as transmissivity T, storage coefficient S, and the ratio r/B, where r represents the distance to the observation well and B is the aquifer thickness. A three-layer network included total 28 nodes for the input layer was trained with data. Yang, Prasher et al. (1997) applied an ANNs to predict water table elevations in subsurface-drained farmlands. A three-layer feedforward ANN was used for predicting water table elevation. Daily rainfall, potential evapotranspiration, and previous water table locations were contained as input-layer. The output was current location of the water table.

1.5 Scope and Organization of the Research

The dissertation is divided into seven chapters and four appendices. The Chapter I begins with motivation of reseaarch and includes research objectives, general description of Texas WAM System, and literature reviews. The literature reviews in Chapter I describes the river/reservoir system modeling and analysis, the water right system and water availability study in Korea, and approaches for drought management such as drought early warning system.

The research methodologies are outlined in Chapter II. The extension of WAM hydrologic periods-of-analysis from 1940-1997 to 1940-2016 is covered Chapter III.

Establishment of the water allocation strategy in Korea based on Texas WRAP/WAM System is described in Chapter IV. Developing groundwater drought monitoring methodology based on groundwater level observation data is covered in Chapter V. A new approach for groundwater drought forecasting methodology based on correlation between SGI and SPI using ANN is described in Chapter VI. Chapter VII presents decribes the summary and conclusion of the research.

In Chapter II, a new approach of extending hydrologic period-of-analysis for the monthly naturalized flows and net evaporation-precipitation of the TCEQ WAM System datasets based on TWDB datasets of precipitation and evaporation are decribed and the calibration of flow extension equation and computational procedures incorporated in the WRAP program HYD for this research are ouliled. The calculation procedure of SGI for groundwater drought monitoring is presented in this chapter. The NARX Neural Networks for SGI forecasting based on SPI forecasts are also outlined in Chapter II.

Chapter III focuses on conducting a case study on the Brazos River Basin to validate the new methodology for extending hydrologic period-of-analysis of TCEQ WAM System input datasets. The extension results of net evaporation-precipitation rates and naturalized flows are presented in section 3.5 and section 3.6, respectively. The comparative analysis including water supply reliability, flows frequency relationship, and reservoir storages drawdown between original 1940-1997 and extended 1940-2016 period-of-analysis for the Brazos WAM are included in section 3.6 and Appendix A.1-A.3 and Appendix B.1-B.5.

Chapter IV presents the water allocation strategies for long-term and short-term water management in Korea based on Texas WRAP/WAM System. As a case study, North Han River basin WAM dataset including naturalized flows and reservoir evaporation-precipitation rates is developed and documented in Section 4.1 and Appendix C.1-C.2. The recommended water allocation strategies for water management and planning in Korea based on long-term and short-term simulation results of WRAP-SIM are presented in Section 4.2.

Chapter V discusses the methodology for groundwater drought monitoring based on SGI. The groundwater levels obtained from 256 National Groundwater Monitoring Network are included in Appendix D.1. The process of calculating SGI based on observation data is covered in Section 5.3-5.5. The evaluation results of groundwater drought based on the calculated SGI are presented in Section 5.7 and Appendix D.3

Chapter VI focuses on the new methodology for groundwater drought forecasting based on correlation between SGI and SPI. SPI calculation and correlation between SPI and SGI are presented in Section 6.3-6.4, Developing correlation model using ANN and evaluating ANN model performance are discussed in section 6.5-6.6 and Appendix D.2. The results of monthly and seasonal outlook based on forecasted SGI are presented in Section 6.7. The summary and conclusion of the dissertation research associated with integrates topics covered in the preceding chapters are presented in Chapter VII.

CHAPTER II

RESERCH METHODOLOGY

The chapter is organized as four sections:

1. The chapter begins with development and application of a new methodology for extending the hydrologic period-of-analysis of the WRAP/WAM Modeling System

2. The second section outlines the development of a water allocation strategy and evaluation of the strategy based on long-term and short-term simulation with WRAP/WAM dataset in Korea

3. The third section discusses a methodology for quantifying groundwater drought based on groundwater level data of National Groundwater Monitoring Networks.

4. The final section described a new approach for groundwater drought prediction methodology based on correlation between SPI and SGI using ANN

The Brazos River Basin of Texas serves as a case study for extending hydrologic period-of-analysis of WRAP/WAM Modeling System. The North Han River Basin in Korea serves as a case study for developing a dataset for establishing water allocation strategy based on WRAP/WAM priority system in Korea. The new methodology for the groundwater drought monitoring and forecasting is developed for whole South Korea and 26 cities in Chungcheong province which have been experienced severe drought recently are tested prior to extension nationwide.

2.1 Hydrologic Period-of-Analysis Extension Methodology

2.1.1 Organization of Extending Hydrologic Period-of-Analysis Methodology

The original sequences of naturalized flows developed during 1998-2001 are based on adjusting gauged observed flows at about 500 gauging stations to remove the effects of reservoirs, water supply diversions, return flows from surface and groundwater sources, and other aspects of water resources development and use. The process of transforming actual measured flows to naturalized flows is complicated by channel losses and lag times between the stream sites of the flows and the locations of dam, diversion, and return flow sites which may be many miles upstream, difficulties in compiling the water management data upon which the flow adjustments are based, and the discontinuation of a signification number of stream gaging stations.

The alternative methodology are considered relates naturalized flows developed in the past to concurrent precipitation and evaporation. The methodology is to update and extend hydrologic sequences of WAM/WRAP input dataset using precipitation and evaporation maintained by the Texas Water Development Board (TWDB). This approach is much easier to implement and is particularly advantageous in situations where accurate data required to adjust observed flows are unavailable or difficult to compile or stream gaging station have been discontinued.

The new approach outlined in this chapter are developed by Wurbs (2013) to periodically update the hydrologic period of analysis of WAM/WRAP input data files to near the present. However, the procedure can be applied to extend the hydrologic sequence to preceding years dating back to 1940. The program HYD of WRAP is improved for extending sequences of naturalized flows and reservoir surface net evaporation less precipitation rate based upon available naturalized flow of TCEQ WAM System dataset and precipitation and evaporation of TWDB dataset.

The WRAP/WAM system is designed for quantifying water supply reliabilities and flow and storage frequency metrics rather than focusing on predicting quantities in specific months of the simulation. Likewise, the extended stream flow and evaporation-precipitation sequences effectively reproduce relevant statistical characteristics.

The computational procedures are incorporated in the WRAP program HYD. The TWDB datasets of monthly precipitation depths and evaporation depths for all of the quadrangles encompassing the state of Texas are stored in two files which are read by HYD as input files with filenames Precipitation.PPP and Evaporation.EEE, respectively. These files currently contain statewide monthly data for 1940-2016 that can be easily updated each year in the future following the TWDB annual updates of the databases.

The case study in this research consists of extending the January 1940 through December 1997 hydrologic period-of-analysis of the Brazos WAM through December 2016. The final product is WRAP input FLO and EVA files with 1940-2016 sequences of monthly naturalized stream flows and reservoir evaporation-precipitation rates recorded on IN and EV records. The extended 1998-2016 series are combined with the original 1940-1997 sequences.

The comparative analyses of the Brazos WAM case study results demonstrate that the new extension methodologies yield valid results. Approximations are inherent in all aspects of the complex WRAP/WAM modeling system. The accuracy of the extended naturalized flows and evaporation-precipitation rates is consistent with the overall modeling system.

2.1.2 WRAP-HYD Routines for Extending a Hydrologic Period-of-Analysis

The purpose of the program HYD is to facilitate developing hydrology related input data for the program SIM. HYD provides a set of routines for creating or modifying sequences of naturalized or otherwise adjusted monthly stream flow volumes and reservoir surface evaporation-precipitation rates. Net evaporation-precipitation rates are developed by simply subtracting monthly precipitation depths from evaporation depths. Developing naturalized flows is more difficult. A methodology for extending sequences of naturalized flows based on adjusting gaged flows is outlined by Wurbs (2015a) and explored by Wurbs and Kim (2008).

The alternative strategy for synthesizing naturalized flows based on TWDB precipitation and evaporation datasets is added to HYD for this study. Companion features for extending sequences of evaporation-precipitation rates using the TWDB datasets are included in HYD along with the new naturalized flow extension capabilities.

The new evaporation-precipitation extension EE and flow extension FE records and auxiliary supporting records for updating hydrologic periods-of-analysis are added to WRAP-HYD Program. Net evaporation-precipitation rates are developed with EE records by subtracting monthly precipitation depths from evaporation depths from the TWDB datasets. The FE record methodology for extending sequences of monthly naturalized flows is also based on the TWDB precipitation and evaporation databases.

- The EE record extends a WRAP-SIM input EVA file of sequences of net evaporation-precipitation depths. The EE record also facilitates otherwise organizing and using the TWDB precipitation and evaporation datasets. QD and QA records designate quadrangles and areas used in the routines activated by EE as well as FE records.
- The new FE and FP records develop parameters for a flow equation based on naturalized flows from a WAM dataset and precipitation and evaporation depths from the TWDB dataset covering the original hydrologic period-of-analysis. The FE record then applies the flow equation based on precipitation and evaporation depths from the TWDB dataset covering the period of the extension. The new FZ, FR, UB, BM, B1, B2, B3, B4, XP, X1, X2, X3, X4, RC, and FX records provide parameter values for the FE record flow extension.

2.1.3 TWDB Precipitation and Evaporation Datasets

The basis of the hydrologic period-of-analysis extension strategy being developed and applied in this research is based on combining datasets of precipitation and evaporation compiled by the TWDB with TCEQ WAM datasets of naturalized flows to extend naturalized flows along with precipitation and net evaporation rates. The TWDB maintains statewide databases of historical observed monthly precipitation depths and reservoir surface evaporation depths and reproduces datasets along with one-degree quadrangles as shown Figure.2.1 are available at the following website.

http://midgewater.twdb.state.tx.us/Evaporation/evap.html

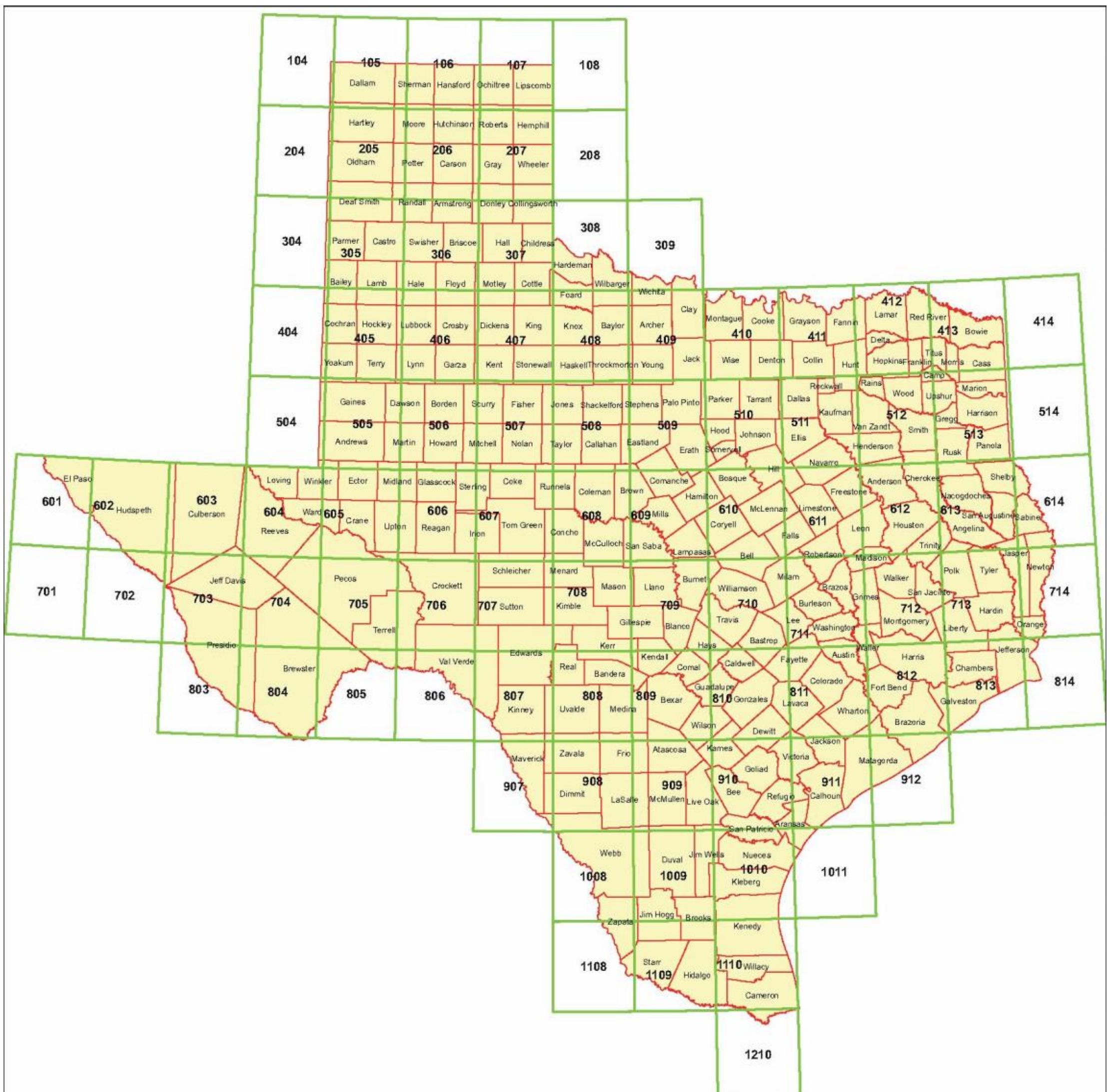


Figure 2.1 TWDB Quadrangle Map for Precipitation and Evaporation Data (Wurbs, 2013)

A total of 168 one-degree quadrangles covering an area which includes Texas and adjacent areas of surrounding states are provided by TWDB. Complete monthly precipitation and evaporation data from 1940 to present are available for the 92 one-degree quadrangles shown in Figure 2.1 that encompass the state.

In developing the new WRAP/WAM hydrologic period-of-analysis extension capabilities, the precipitation and evaporation datasets for 1940-2016 were obtained from the TWDB as text files. Microsoft Excel was used to convert the two files to a consistent format. These files can be easily updated each year in the future as the TWDB adds the most recent calendar year monthly precipitation and evaporation depths to the dataset. The filenames Precipitation.PPP and Evaporation.EEE are adopted for the two text files that are read by the WRAP program HYD as input files.

Watershed areas are required for HYD to convert monthly precipitation and evaporation depths in inches to monthly volumes in acre-feet. The watershed above stream sites for which flows are synthesized may range from a portion of a single quadrangle to all or portions of multiple quadrangles. For example, the 45,000 square mile Brazos River Basin encompasses all or parts of 26 of the one-degree quadrangles. The areas of the 168 quadrangles are tabulated in Table 2.1 and are also coded into the HYD computer program.

Those quadrangles located partially or completely within the watershed of a control point are used to extend naturalized flows at that control point. For large watersheds, the quadrangles covering upper portions of the watershed that contribute little to flow at the control point may be omitted. The parameter calibration procedure described in the section 2.2 may also result in exclusion of some of the quadrangles in the watershed. The quadrangles contained within the watershed of the control point of the extended flows are listed on a QD record. The watershed areas located in each quadrangle are entered on a QA record.

Table 2.1 Areas in Square Miles of 168 One-Degree Quadrangles

Quad ID	Area (sq. miles)	Quad ID	Area (sq. miles)	Quad ID	Area (sq. miles)	Quad ID	Area (sq. miles)
101	3,855.71	401	3,968.90	701	4,092.19	1001	4,226.81
102	3,855.71	402	3,968.78	702	4,092.19	1002	4,226.80
103	3,855.75	403	3,968.81	703	4,092.20	1003	4,226.81
104	3,855.77	404	3,968.79	704	4,092.17	1004	4,226.82
105	3,855.75	405	3,968.95	705	4,092.18	1005	4,226.83
106	3,855.68	406	3,968.89	706	4,092.14	1006	4,226.83
107	3,855.75	407	3,968.85	707	4,092.17	1007	4,226.83
108	3,855.74	408	3,968.84	708	4,092.14	1008	4,226.83
109	3,855.78	409	3,968.85	709	4,092.13	1009	4,226.81
110	3,855.70	410	3,968.84	710	4,092.16	1010	4,226.77
111	3,855.75	411	3,968.86	711	4,092.17	1011	4,226.82
112	3,855.70	412	3,968.87	712	4,092.16	1012	4,226.87
113	3,855.71	413	3,968.88	713	4,092.20	1013	4,226.87
114	3,855.71	414	3,968.77	714	4,092.22	1014	4,226.86
201	3,892.26	501	4,008.79	801	4,135.74	1101	4,274.40
202	3,892.31	502	4,008.76	802	4,135.72	1102	4,274.39
203	3,892.34	503	4,008.80	803	4,135.72	1103	4,274.40
204	3,892.34	504	4,008.80	804	4,135.74	1104	4,274.40
205	3,892.34	505	4,008.82	805	4,135.81	1105	4,274.40
206	3,892.38	506	4,008.75	806	4,135.74	1106	4,274.40
207	3,892.41	507	4,008.70	807	4,135.75	1107	4,274.39
208	3,892.37	508	4,008.73	808	4,135.77	1108	4,274.36
209	3,892.36	509	4,008.74	809	4,135.74	1109	4,274.39
210	3,892.31	510	4,008.76	810	4,135.70	1110	4,274.44
211	3,892.38	511	4,008.75	811	4,135.73	1111	4,274.46
212	3,892.46	512	4,008.70	812	4,135.77	1112	4,274.49
213	3,892.40	513	4,008.73	813	4,135.77	1113	4,274.48
214	3,892.36	514	4,008.75	814	4,135.71	1114	4,274.47
301	3,930.04	601	4,049.88	901	4,180.60	1201	4,323.42
302	3,929.98	602	4,049.88	902	4,180.60	1202	4,323.41
303	3,930.01	603	4,049.90	903	4,180.60	1203	4,323.41
304	3,930.01	604	4,049.91	904	4,180.62	1204	4,323.41
305	3,930.05	605	4,049.86	905	4,180.64	1205	4,323.41
306	3,930.06	606	4,049.82	906	4,180.62	1206	4,323.41
307	3,930.07	607	4,049.84	907	4,180.62	1207	4,323.41
308	3,930.02	608	4,049.90	908	4,180.60	1208	4,323.43
309	3,930.00	609	4,049.85	909	4,180.55	1209	4,323.46
310	3,930.00	610	4,049.88	910	4,180.53	1210	4,323.52
311	3,930.06	611	4,049.89	911	4,180.59	1211	4,323.55
312	3,930.13	612	4,049.87	912	4,180.64	1212	4,323.54
313	3,930.08	613	4,049.87	913	4,180.66	1213	4,323.53
314	3,930.06	614	4,049.87	914	4,180.65	1214	4,323.51

2.2 Extension of Net Evaporation-Precipitation Rates

The hydrology input data for the WRAP simulation program SIM includes monthly net reservoir surface evaporation less precipitation depths on EV records in an EVA file along with the naturalized flows on IN records in a FLO file. The evaporation-precipitation rates in the TCEQ WAM System datasets are in units of feet/month. The evaporation-precipitation rates are computed using the TWDB datasets by subtracting precipitation depths from evaporation depths.

Program HYD is applied with JC, CP, EE, QD, and QA records to extend a SIM input EVA file. The EE record provides specifications for HYD to manipulate the data read from the TWDB evaporation and precipitation databases and creates EV records with monthly net reservoir surface evaporation less precipitation depths.

The net evaporation less precipitation, evaporation or precipitation depths for each control point can be obtained from following computation procedure.

1. Identify quadrangles contributed to evaporation and precipitation depths of each control point on a QD record
2. Enter quadrangle areas or fractions in a QA record corresponding quadrangle identifiers listed on the QD record. Areas in square miles are computed by HYD using factors entered on the QA record that represent the fraction of each quadrangle encompassed by the watershed.
3. The fractions entered on the QA record are used in computing weighted averages of net evaporation less precipitation, evaporation, or precipitation depths for each control point in the TCEQ WAM System datasets

At the end of the HYD execution, the net evaporation-precipitation rates in the EP array will contain the original evaporation-precipitation rates for 1940-1997 and computed evaporation-precipitation rates for 1998-2016.

2.3 Extension of Naturalized Stream Flow

The extension of hydrologic period-of-analysis for the naturalized flows of the existing WAM dataset is also based on TWDB precipitation and evaporation datasets. The extension of naturalized flow can be continued in the future with annual update of the TWDB evaporation and precipitation dataset. Like the extension of evaporation-precipitation rates, the new approach for flow extension is implemented with the HYD contained in the WRAP modeling system.

The naturalized flow extension model combines base flow and precipitation-runoff components to convert input precipitation and evaporation sequences into output consisting of computed naturalized flows. The model includes base flow parameters and several precipitation-runoff parameters for each quadrangle in the watershed above the control point. Calibration consists of determining a set of parameter values that optimally reproduce the known 1940-1997 naturalized flows from the TCEQ WAM dataset. The model is then applied to synthesize flows for 1998-2016 based on 1998-2016 precipitation and evaporation. The flow extension procedures are performed in the following steps.

- Calibration of the flow extension model for each individual control point
  - Level 1 initial calibration process to obtain values for basic parameters
  - Level 2 final calibration process that incorporates additional parameters
- Extension of flows with the calibrated flow extension model for each control point

The level 1 calibration procedures are based on a complex set of optimization algorithms incorporated in HYD designed to replicate known flows. Level 2 calibration deals with additional parameters designed to improve model capabilities for reproducing relevant statistical characteristics. Although the calibration process is somewhat complicated, the resulting calibrated flow extension model is easy to apply to synthesize flows for the extension period.

2.3.1 Naturalized Stream Flow Equation

The flow model (Equations 2.1, 2.2, 2.3, 2.4, 2.5) upon which the flow extension methodology is based is calibrated using naturalized monthly flows from a WAM dataset covering the period-of-analysis and the corresponding monthly precipitation and evaporation sequences from the TWDB datasets for the same period-of-analysis. Upon completion of the calibration process, flows are synthesized for the period-of-extension by applying the calibrated flow model with precipitation and evaporation sequences from the TWDB datasets for the period-of-extension.

Although the evaporation extension *EE* record works directly with the observed monthly evaporation depths in inches, the flow extension *FE* record computations deal with precipitation and evaporation volumes P(i,t) and E(i,t) in units of acre-feet/month. Depths for each relevant month (t) and quadrangle (i) are read by *HYD* from the two files of precipitation and evaporation depths with filenames Precipitation.PPP and Evaporation.EEE. The depths (rates) in inches/month are transformed within *HYD* to volumes P(i,t) and E(i,t) in acre-feet/month.

P(i,t) = (precipitation depth)(area of quadrangle i within watershed)(units conversion factor)

E(i,t) = (evaporation depth)(area of quadrangle i within watershed)(units conversion factor)

Monthly naturalized flow volumes Q(t) at a control point location are synthesized with the combined Equations 2.1, 2.2, 2.3, 2.4, and 2.5. Q(t), RP(t), BF(t) and other variables are constrained to be non-negative. As discussed in the following section, flows may optionally be divided into zones (z) representing low, medium, high, and flood flows. A single flow model may be developed for all flows or separate models be developed for specified zones or some specified combination of zones. If flow zones are delineated, the flow Q(t) for month t is either assigned Q(t,z) for the appropriate flow zone or computed as a weighted average of Q(t,z) for overlapping zones.

$$Q(t) = U(1) \times RP(t)^{U(2)} + BF(t) \tag{2.1}$$

$$RP(t) = \sum_{i=1}^{N} \left[P(i,t) - X(i,1) \times P(i,t)^{X(i,2)} - X(i,3) \times E(i,t) + PP(i,t-1) - X(i,4) \times P(i,t-1)^{X(1,5)} \right] \tag{2.2}$$

$$PP(i,t) = X(i,1) \times P(i,t)^{X(1,2)} \tag{2.3}$$

$$BF(t) = B(m) \times DI(t) \times BX(z) \quad \text{where } DI(t) \text{ is the lesser of} \tag{2.4}$$

$$DI(t) = 1.0 \text{ or } DI(t) = DX\left[\left(\frac{\bar{E}(m\text{-}1) + \bar{E}(m)}{\bar{P}(m\text{-}1) + \bar{P}(m)}\right) \frac{\sum P(i,t\text{-}1) + P(i,t)}{\sum E(i,t\text{-}1) + E(i,t)}\right]^2 \tag{2.5}$$

Q(t) computed naturalized flow volume for month t which may consist of the weighted average of the Q(t,z) computed for two adjacent overlapping flow zones if flows are categorized by zones (acre-feet/month)

Q(t,z) naturalized flow computed for either low flow (z=1), medium flow (z=2), high flow (z=3), or flood flow (z=4) zones during month t (acre-feet/month)

RP(t) summation of runoff from individual quadrangles in current month t resulting from precipitation in the current month t and/or preceding month t-1 (acre-feet/month)

BF(m,z) base flow in each of the 12 months of the year that may reflect precipitation falling long before as well as during months t and t-1 (acre-feet/month)

U(k) dimensionless multiplier and exponent coefficients ($0.0 \leq U(1) \leq 1.0$ and $0.7 \geq U(2)$)

N number of quadrangles included in the watershed (i = 1, 2, 3, … , N)

P(i,t) precipitation during month t in quadrangle i (acre-feet/month)

PP(i,t) portion of precipitation in month t not contributing to Q(t) and becoming stream flow in the next month and/or hydrologic abstractions (acre-feet/month)

E(i,t) maximum potential evapotranspiration volume estimated based on reservoir surface evaporation rates during the month t in quadrangle i (acre-feet/month)

X(i,j,z) model parameters consisting of 5N dimensionless coefficients (j = 1, 2, 3, 4, 5) that may vary between zones (z = 1, 2, 3, 4) that have values ranging between 0.0 and 1.0

B(m,z) base flow parameters for the 12 months (m = 1, 2, 3, ..., 12) of the year (ac-ft/month)

DI(t) dimensionless drought index that varies from 1.0 to 0.0 each month depending on the ratio of precipitation to evaporation volume during the current and preceding months

BX(z) dimensionless multiplier factor in the base flow term entered on the *UB* record with a default of 1.0 (z = 1, 2, 3, 4 for low, medium, high, and flood flow zones)

DX dimensionless multiplier factor entered on the *FE* record with a default of 1.0

$\bar{P}(m)$ monthly means of precipitation volumes for each of the m = 1, 2, 3, ..., 12 months of the year for specified quadrangles (acre-feet/month)

$\bar{E}(m)$ monthly means of evaporation volumes for each of the m = 1, 2, 3, ..., 12 months of the year for specified quadrangles (acre-feet/month)

The flow model contains the following 4(13+5N)+3 parameters which are calibrated using naturalized flows from the TCEQ WAM System and precipitation and evaporation from the TWDB datasets. The index z refers to four flow zones (low, medium, high, and flood). Other parameters are provided as model input without being automatically calibrated.

B(m,z) base flow (ac-ft/month) for each month of the year (m = 1 to 12 and z = 1 to 4)

BX(z) dimensionless multiplier factor ranging between 0.0 and 1.0, with a default of 1.0, contained in the base flow term for low, medium, high, and flood flows

DX drought index multiplier factor with a default of 1.0

X(i,j,z) five dimensionless rainfall-runoff parameters (j=1,2,3,4,5) for each quadrangle (i = 1 to N) located in the watershed that range between 0.0 and 1.0

U(1) and U(2) two dimensionless parameters modeling nonlinear relationship between total rainfall and runoff which are constrained to $0.0 \leq U(1) \leq 1.0$ and $0.7 \geq U(2)$.

The flow equation (Eqs. 2.1, 2.2, 2.3, 2.4, 2.5) is essentially a form of regression equation with the time series of flows Q(t) regressed as a function of the N time series of monthly precipitation P(i,t) and evaporation E(i,t). The coefficients U(1), U(2), X(i,j,z), B(m,z), BX(z), and DX are determined based on known sequences of P(i,t), E(i,t), and Q(t). However, the flow equation is structured in a format that is representative of actual hydrologic processes. The terms are related to physical concepts.

B(m,z)×DX(z) represents base flows for each of the 12 months of the year in acre-feet/month that can be adjusted by a dimensionless drought index that reflects long-term hydrology. U(k) and X(i,j,z) are precipitation-runoff parameters. X(i,j,z) model runoff from each of the N individual quadrangles encompassed by the watershed above the control point location of the flows Q(t). U(1) and U(2) model the nonlinear response of total flow to rainfall.

The basic watershed volume budget is expressed as Eq. 2.6 below, where Q_T, B_T, P_T, P_{T-1}, L_T, L_{T-1}, and E_T represent volumes of stream flow, base flow, precipitation, total losses, and maximum potential evapotranspiration during the current month t and preceding month t-1, and a, b, and c are coefficients. Precipitation occurring in both the current and preceding months contributes to the volume flowing past the watershed outlet during the current month.

$$\text{stream flow} = \text{base flow} + \text{precipitation} - \text{losses}$$

$$Q_T = B_T + P_T - L_T + (P_{T-1} - L_{T-1}) \qquad \text{where} \qquad L = aP^b + cE \qquad (2.6)$$

Base flow B and precipitation P represent the sources of stream flow Q at the watershed outlet. A portion of the precipitation falling this month reaches the watershed outlet as stream flow this month, a portion contributes to flow next month, and the remainder is lost to hydrologic abstractions. The portions of P_T in month T that do not contribute to Q_T and Q_{T+1} include losses due to evapotranspiration, overland infiltration, stream seepage, and storage. These losses L are viewed as shown in Eq. 2.6 as a function of precipitation P and evaporation E. Hydrologic abstractions are viewed partially, but only partially, as a function of reservoir surface evaporation rates which represent a maximum potential evapotranspiration rate from a watershed.

The flow equation (Eq. 2.1) with its component Eqs. 2.2, 2.3, 2.4, and 2.5 visualize flows Q(t) conceptually as the summation of base flows BF(t), flows from rainfall P(i,t) occurring in the same month t as the resulting flow Q(t) at the watershed outlet, and contributions to flow from rainfall PP(i,t-1) in the preceding month less losses in the preceding and current months.

P(i,t) denotes volumes of precipitation falling on each portion of the watershed (quadrangle i) during the same current month as Q(t). Precipitation falling in the preceding month t-1 may also contribute to Q(t). $PP(t) = X(i,1)P(i,t)^{X(i,j)}$ represents the portion of P(i,t) that does not contribute to stream flow in month t but may contribute to flow in the next month. PP(i,t) contributes to Q(t+1) in the following month t+1 and/or is lost as hydrologic abstractions. The PP(t) computed in month t becomes a source of water available in the following month t+1.

Reservoir water surface evaporation rates approximate the potential evapotranspiration capacity rates for the hypothetical condition of a completely saturated ground surface throughout a watershed. Hydrologic abstractions (losses) are modeled in the flow equation partially as a function of E(i,t) which is the maximum evapotranspiration potential represented as reservoir evaporation rates applied over the total watershed land area. Losses are modeled as functions of P(i,t), PP(i,t), and E(i,t).

$$\text{Losses} = X(i,1) \times P(i,t)^{X(i,2)} + X(i,3) \times E(i,t) + X(i,4) \times PP(i,t)^{X(i,5)} \qquad (2.7)$$

Base flows BF(t) from subsurface hydrologic processes that respond slowly to precipitation may contribute to stream flow and maintain low flows during long periods of little or no precipitation. The BF(t) component of Q(t) may originate from precipitation occurring before and/or during the current and preceding months, including precipitation occurring many months or years before. *HYD* provides various options that are combined to model base flows.

The base flow calibration parameters B(m,z) and BX(z) may differ for different zones or may be the same for all zones. The B(m)×BX may vary seasonally over the 12 months of the year and may be zero in some or all months at some stream sites. The 12 B(m) for the 12 months of the year may be set at fixed values or included in the automated parameter calibration. Likewise, BX may be fixed at a specified value or treated as a calibration parameter in the automated calibration procedure. The default for BX is 1.0.

HYD includes a default routine that computes the values of the 12 B(m) as the mean of the smallest six naturalized flows in the WAM dataset for each month of the year. B(1) is the mean of the smallest six January flows, B(2) is the mean of the smallest six February flows, and so forth. These averages reflect the seasonality of low flows. These 12 B(m) can be fixed with BX treated as a calibration parameter. Alternatively, the 12 means can be treated as upper limits or initial estimates for B(m) subject to further adjustments in the automated optimization-based calibration procedure.

2.3.2 Drought Index

The base flow component BF(t,z) (Eq. 2.8) of the flow equation includes a drought index DI(t) term (Eq. 2.9). The DI(t) allows the base flow BF(t,z) to decrease below B(m,z)×BX(z) during dry periods. The DI(t) reduces the base flow BF(t,z) during months that are drier than normal but has no effect on the BF(t,z) during months that are wetter than normal. The dimensionless drought index DI(t) for any month t is constrained to range between 0.0 and 1.0.

$$BF(t,z) = B\times(m,z\times)\ DI \qquad (2.8)$$

$$DI(t) = \text{lesser of } 1.0 \text{ or } DX\left[\frac{\left(\dfrac{\sum P(i,t\text{-}1)+P(i,t)}{\sum E(i,t\text{-}1)+E(i,t)}\right)}{\left(\dfrac{\bar{P}(m\text{-}1)+\bar{P}(m)}{\bar{E}(m\text{-}1)+\bar{E}(m)}\right)}\right]^2 \qquad (2.9)$$

P(i,t)	precipitation volume in acre-feet/month during the month t in quadrangle i
E(i,t)	evaporation volume in acre-feet/month during the month t in quadrangle i
$\bar{P}(m)$	monthly averages of precipitation volumes in acre-feet/month for each of the 12 months of the year (m = 1, 2, 3, ..., 12 denoting January through December) covering the selected quadrangles specified on the *QD* record
$\bar{E}(m)$	monthly means of evaporation volumes in acre-feet/month for January, February, March, … , December covering the quadrangles specified on the *QD* record
DX	dimensionless non-negative multiplier factor with a default of 1.0

The drought index is based on the ratio of two-month precipitation volume to two-month evaporation volume occurring during the current and preceding months (t and t-1) summed over selected quadrangles expressed as a ratio of the corresponding long-term period-of-analysis means of the precipitation/evaporation ratio for these two months of the calendar year.

Approximately normal or average hydrologic conditions are represented by a DI(t) of 1.0. Thus, DI(t) at its upper limit of 1.0 indicates either average or wetter than average conditions than are normal for that season of the year. A DI(t) of significantly less than 1.0 indicates drier than average conditions than normal for that season. A DI(t) of 0.0 indicates that zero precipitation occurred during the current and preceding months. The DI(t) affects flows only during months that are drier than normal, with the effects being greater during very dry periods. The drought index DI(t) is constrained to vary only between 1.0 and 0.0, but the multiplier factor DX can significantly affect the variation of DI(t) between 1.0 and 0.0. The parameter DX defaults to 1.0, but any value for DX can be calibrated and applied. There is only one DX. DX does not vary with flow range or between months.

2.3.3 Combining Component Models for Alternative Flow Zones

Flow Zones (Low, Medium, High, and Flood)

As shown in Figure 2.2 and 2.3, Low, medium, high, and flood flow zones are defined by the parameters LU, ML, MU, HL, HU, and FL, in acre-feet/month, entered on the flow zone *FZ* record. These limits are designed to be set based on *TABLES* 2FRE frequency tables that relate naturalized stream flow quantities to specified exceedance frequencies. Figures 2.2 and 2.3 illustrate two variations of options for defining flow zones on the *FZ* record. The first option shown in Figure 2.2 has overlapping flood flow and high flow zones. The option shown in Figure 2.3 includes overlaps between each pair of adjacent zones. However, any of the overlaps can be removed by assigning the same value to two limits.

FL	lower limit of the flood flow zone
HU	upper limit of the high flow zone
HL	lower limit of the high flow zone
MU	upper limit of the medium flow zone
ML	lower limit of the medium flow zone
LU	upper limit of the low flow zone

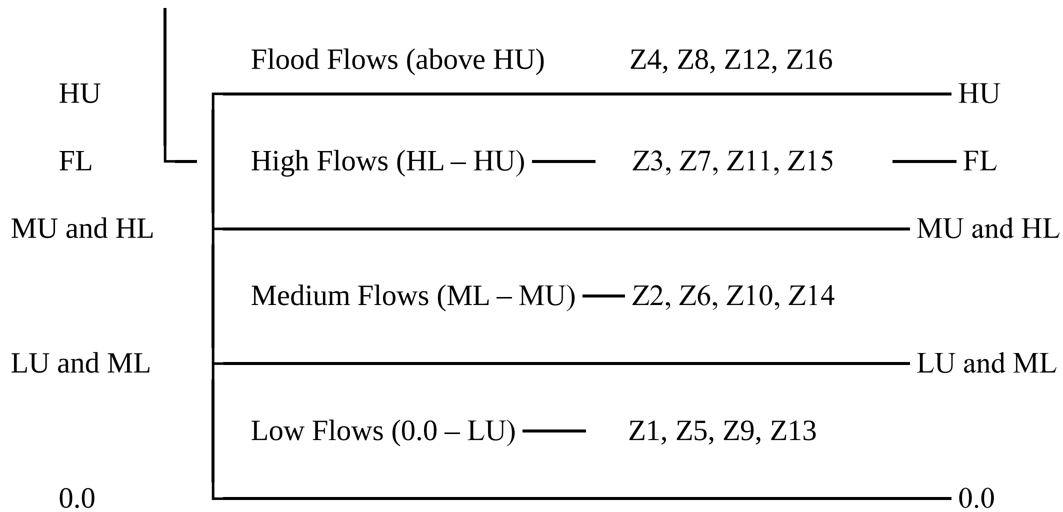


Figure 2.2 Flow Zones for the *FZ* Record FE(13) Default Option 1

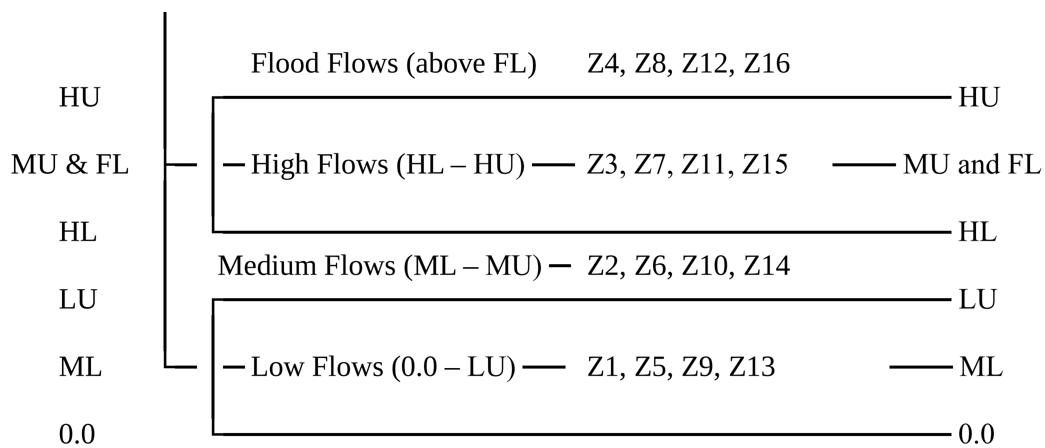


Figure 2.3 Flow Zones for *FZ* Record FE(13) Option 2

For example, LU/ML, MU/HL, FL, and HU in Figure 2.2 could be assigned the monthly naturalized flow volumes from a WAM dataset with exceedance frequencies of 80%, 60%, 40%, and 30%. With the overlapping flow zones shown in Figure 2.3, ML, LU, HL, MU/FL, and HU could be set as the known monthly naturalized flow volumes from a WAM dataset that have exceedance frequencies of 80%, 60%, 40%, 20%, and 10%.

Combining Component Models for Alternative Flow Zones

The user-specified quantities LU, ML, MU, HL, HU, and FL entered on the *FZ* record define the demarcation between low, medium, high, and flood flows for the purposes of both (1) establishing values the parameters B(m,z), BX(z), and X(i,j,z) through the parameter calibration process and (2) applying the resulting four different sets of values of the parameters to extend the flows.

Known flows are available for the period-of-analysis for use in the parameter calibration computations. The flow limits are referenced to known flows for computing the criterion metrics (defined in the section 2.3.4) in the parameter calibration process. Known flows are not available for the period-of-extension. After completion of parameter calibration, flows Q(t) are computed with Equation 2.1 for the period-of-extension based on defined rules which are described as follows. Since naturalized flows are not yet known for the extension period, the flow limits of necessity are referenced to the computed flows in applying the rules to synthesize flows.

A single set of parameter values reflecting a single model may be applied to all flows. In this case, low, medium, high, and flood flow zones may still be delineated for purposes of applying the optimization criteria metrics described in the next section even though the calibration results in a single set of parameter values. There is no need to overlap flow zones if the only purpose of the flow zones is the formulation of the criteria metrics used in calibration.

Flows may possibly be modeled more accurately by developing separate models for low, medium, high, and flood flows. However, the combining of the separate component models is a significant concern and a distinct disadvantage of this modeling option. The sole purpose of overlapping flow zones is to facilitate the adoption of separate models for low, medium, high, and flood flows. In general, *HYD* flow extension capabilities are designed for two alternative optional strategies for developing separate models for different levels of flow.

1. The alternative strategy illustrated by Figure 2.2 consists of adopting two models, one for flood flows and another for all other flows. The two models are combined following the rules outlined in Table 2.2.

2. The other alternative strategy illustrated by Figure 2.3 consists of adopting four separate models for low, medium, high, and flood flows. The four models are combined following the rules outlined in Table 2.3.

For the flow extension strategy with the flow zones shown in Figure 2.2 and rules outlined in Table 2.2, flows are synthesized for the period-of-extension using the flow equation (Eqs. 2.1, 2.2, 2.3, 2.4, 2.5) with the two sets of parameters B(m,z), BX(z), and X(i,j,z) provided as input on *BM*, *B4*, *XM*, *X4*, and *UB* records previously generated by the calibration process. For each month, *HYD* computes values of Q(t,z) with the two alternative sets of parameters yielding $Q(t)_X$ and $Q(t)_F$.

For the flow extension strategy with the flow zones shown in Figure 2.3 and rules outlined in Table 2.3, flows are synthesized with the four sets of parameters B(m,z), BX(z), and X(i,j,z) for low, medium, high, and flood flows provided as input on *B1*, *B2*, *B3*, *B4*, *X1*, *X2*, *X3*, *X4*, and *UB* records previously generated by the calibration process. For each month, *HYD* computes values of Q(t,z) with the four alternative sets of parameters yielding $Q(t)_L$, $Q(t)_M$, $Q(t)_H$ and $Q(t)_F$. The final Q(t) is adopted as outlined in Table 2.3 based on 14 possibilities for flow occurring in the ranges shown in Figure 2.3.

Table 2.2 Rules for Determining Q(t) based on $Q(t)_X$ and $Q(t)_F$ Illustrated by Figure 2.2

If $Q(t)_X \leq FL$	and	$Q(t)_F \leq FL$			then $Q(t) = Q(t)_X$
If $Q(t)_X \geq HU$	and	$Q(t)_F \geq HU$			then $Q(t) = Q(t)_F$
If $Q(t)_X \leq FL$	and	$Q(t)_F \geq FL$	and	$Q(t)_F \leq HU$	then

$$Q(t) = Q(t)_F[(Q(t)_F\text{-}FL)/(Q(t)_F\text{-}Q(t)_X)] + Q(t)_X[(FL\text{-}Q(t)_X)/(Q(t)_F\text{-}Q(t)_X)]$$

If $Q(t)_X < HU$ and $Q(t)_F > HU$ then

$$Q(t) = Q(t)_F[(Q(t)_F\text{-}HU)/(Q(t)_F\text{-}Q(t)_X)] + Q(t)_X[(HU\text{-}Q(t)_X)/(Q(t)_F\text{-}Q(t)_X)]$$

Else $Q(t) = (Q(t)_X + Q(t)_F)/2.0$

Table 2.3 Rules for Determining Q(t) based on $Q(t)_L$, $Q(t)_M$, $Q(t)_H$ and $Q(t)_F$ Illustrated by Figure 2.3

If $Q(t)_M \leq HL$ and

1. If	$Q(t)_L \leq ML$	and	$Q(t)_M < LU$	then	$Q(t) = Q(t)_L$
2. If	$ML < Q(t)_M < LU$	and	$ML < Q(t)_L < LU$	then	$Q(t) = (Q(t)_M + Q(t)_L)/2.0$
3. If	$ML < Q(t)_M < LU$	and	$Q(t)_L \geq LU$	then	$Q(t) = (Q(t)_M + LU)/2.0$
4. If	$ML < Q(t)_L < LU$	and	$Q(t)_M \leq ML$	then	$Q(t) = (Q(t)_L + ML)/2.0$
5. If	$Q(t)_L \leq ML$	and	$Q(t)_M \geq LU$	then	$Q(t) = (Q(t)_L + Q(t)_M)/2.0$
6. If	$LU \leq Q(t)_M \leq HL$	and	$Q(t)_L > ML$	then	$Q(t) = Q(t)_M$

If $Q(t)_M > HL$ and

7. If	$HL < Q(t)_M \leq MU$	and	$HL \leq Q(t)_H \leq MU$	then	$Q(t) = (Q(t)M + Q(t)H)/2.0$
8. If	$HL < Q(t)_M \leq MU$	and	$Q(t)_H < HL$	then	$Q(t) = (Q(t)_M + HL)/2.0$
9. If	$HL \leq Q(t)_H \leq MU$	and	$Q(t)_M > MU$	then	$Q(t) = (Q(t)_H + MU)/2.0$
10. If	$Q(t)_H < HL$	and	$Q(t)_M > MU$	then	$Q(t) = (HL + MU)/2.0$
11. If	$MU < Q(t)_H \leq HU$	and	$Q(t)_F < HU$	then	$Q(t) = (Q(t)_H + Q(t)_F)/2.0$
12. If	$MU < Q(t)_H \leq HU$	and	$Q(t)_F > HU$	then	

$$Q(t) = Q(t)_F[(Q(t)_F\text{-}HU)/(Q(t)_F\text{-}Q(t)_H)] + Q(t)_H[(HU\text{-}Q(t)_H)/(Q(t)_F\text{-}Q(t)_H)]$$

13. If	$Q(t)_F > HU$	and	$Q(t)_H \geq HU$	then	$Q(t) = Q(t)_F$
14. If	$Q(t)_F < HU$	and	$Q(t)_H > HU$	then	

$$Q(t) = Q(t)_F[(HU\text{-}Q(t)_F)/(Q(t)_H\text{-}Q(t)_F)] + Q(t)_H[(Q(t)_H\text{-}HU)/(Q(t)_H\text{-}Q(t)_F)]$$

2.3.4 Objective Function Criteria Metrics for the Optimization Algorithms

The automated calibration methodology requires metrics for comparing the optimality of alternative sets of values for the decision variables (model parameters). These metrics are called criterion or objective functions. The optimization problem consists of finding values for decision variables that minimize a specified objective function defined by Eq. 2.8. The 16 criteria functions defined by Eqs. 2.9, 2.10, 2.11, and 2.12 are computed. The objective function OF and all 16 criterion metrics Z are recorded in the *HYD* message HMS file for information. The automated parameter calibration optimization procedure incorporates Eq. 2.8 as its objective function OF. Eq. 2.8 is a weighted summation of the criterion functions Z defined by Eqs. 2.9, 2.10, 2.11, and 2.12 . Values for the 16 weighting factors W1−W16 are provided on the *FP* record.

$$\begin{aligned} & \qquad\quad \underline{\text{low flows}} \qquad \underline{\text{medium flow}} \qquad \underline{\text{high flow}} \qquad \underline{\text{flood flows}} \\ \text{OF} = {} & W1\times Z1 + W2\times Z2 + W3\times Z3 + W4\times Z4 + \\ & W5\times Z5 + W6\times Z6 + W7\times Z7 + W8\times Z8 + \\ & W9\times Z9 + W10\times Z10 + W11\times Z11 + W12\times Z12 + \\ & W13\times Z13 + W14\times Z14 + W15\times Z15 + W16\times Z16 \end{aligned} \qquad (2.8)$$

$$Z1 = Z2 = Z3 = Z4 = \left(\frac{1}{K}\right)\sum_{t=1}^{K}\left(\frac{100\times\left|Q(t)_{known} - Q(t)_{computed}\right|}{\overline{Q(t)}_{known}}\right)^{E1} \qquad (2.9)$$

$$Z5 = Z6 = Z7 = Z8 = \left(\frac{1}{K}\right)\sum_{t=1}^{K}\left(\frac{100\times\left|Q(t)_{known} - Q(t)_{computed}\right|}{ZZZ}\right)^{E1} \qquad (2.10)$$

where ZZZ is the greater of $Q(t)_{known}$ or $Q(t)_{computed}$

$$Z9 = Z10 = Z11 = Z12 = \left| N_K - N_C \right|^{E1} \tag{2.11}$$

$$Z13 = Z14 = Z15 = Z16 = \left(\frac{1}{K}\right) \frac{\left(100 \times \left| \sum_{t=1}^{K} Q(t)_{known} - \sum_{t=1}^{K} Q(t)_{computed} \right|\right)^{E2}}{\overline{Q}_{known}} \tag{2.12}$$

OF	objective function applied in the automated search optimization procedure
Z1−Z16	dimensionless criteria metrics that are recorded in the message HMS file and serve as components of the objective function OF of Eq. 2.8.
W1−W16	dimensionless weighting factors entered on the *FP* record that may serve as 1.0 or 0.0 on/off switches or priority weights having any value
$Q(t)_{known}$	known monthly naturalized stream flows from the TCEQ WAM System dataset at the location of interest in units of acre-feet/month.
$Q(t)_{computed}$	flows in ac-ft/month computed with the flow model (Eqs. 2.1-2.5) for each month t where the model parameters are optimization decision variables
N_K	number of months during which the known flows fall within the specified low, medium, high, or flood flow range
N_C	number of months during which the computed flows fall within the specified low, medium, high, or flood flow range
$\overline{Q(t)}_{known}$	mean of the known flows during the K months used in computing Z for either low, medium, high, flood, or all flows in acre-feet/month
K	number of months is either TL, TM, TH, TF, or T
E1, E2	exponents set on *FP* record with defaults of 2.0 that penalize large differences between computed and known flows more than small differences

T and NYRS are the total number of months and years in the period-of-analysis. The criterion metrics are based on specified flow ranges. The demarcations between low, medium, high, and flood flows are defined by the limits LU, ML, MU, HL, HU, and FL in acre-feet/month, from the *FZ* record, as illustrated by Figures 2.2 and 2.3. The T months are divided into the months of low (TL), medium (TM), high (TH), and flood flows [TF] where T≤TL+TM+TH+TF. The number of months K in Eqs. 2.9, 2.10, and 2.12 is either TL, TM, TH, TF, or T. The criterion metric equations are applied in only those months with flows falling within ranges defined by the limits LU, ML, MU, HL, HU, and FL.

Equations 2.9, 2.10, 2.11, and 2.12 provide four types of criteria metrics, measuring different flow characteristics, applied to flows falling within four ranges, generating a total of 16 metrics.

Z1, Z5, Z9, and Z13 apply to low flows (0.0 to LU).
Z2, Z6, Z10, and Z14 apply to medium flows (ML to MU).
Z3, Z7, Z11, and Z15 apply to high flows (HL to HU).
Z3, Z8, Z12, and Z16 apply to flood flows (above FL).

Z1, Z2, Z3, and Z4 computed with Eq. 2.9 are identical except for the TL, TM, TH, or TF months included in the summation of the absolute value of the differences between known and computed flows. Likewise, Z5, Z6, Z7, and Z8 computed with Eq. 2.10 are identical except for the selection of months to be included in the summation. Z9, Z10, Z11, and Z12 computed with Eq.2.11 and Z13, Z14, Z15, and Z16 computed with Eq.2.12 likewise include TL low (0.0 to LU), TM medium (ML to MU), TH high (HL to HU) or TF flood (above MU) flow months, respectively.

The objective function OF and criteria metrics Z of Eqs. 2.8, 2.9, 2.10, 2.11, and 2.12 are dimensionless. Differences between computed and known flow volumes in acre-feet/month are divided by a flow volume in acre-feet/month. Differences between computed and known flows as dimensionless fractions are multiplied by 100% and raised to a power (default=2.0) which penalizes large differences more than small differences. The primary purpose for formulating the metrics as similar dimensionless quantities is to facilitate combining the metrics in the objective function. Any or all of the criterion metrics may be selected for inclusion in the same objective function.

The objective function (OF) adopted for the optimization procedure is computed with Equation 2.8. The dimensionless OF is a weighted summation of Zs computed with Eqs. 2.9, 2.10, 2.11 and 2.12. The dimensionless weighting factors W1, W2, W3, W4, W5, W6, W7, W8, W9, W10, W11, W12, W13, W14, W15, and W16 are specified on the *FP* record. The weighting factors may be 0.0 or 1.0 switches or a mechanism for balancing the components of the OF. The optimization procedure consists of finding values for the parameters (decision variables) U(1), U(2), B(m), BX, DX, and X(i,j) that result in the objective function OF being as small (close to zero) as possible.

Either Z1, Z2, Z3, Z4, Z5, Z6, Z7, Z8, Z9, Z10, Z11, Z12, Z13, Z14, Z15, or Z16 or any linearly weighted summation of combinations thereof can be adopted as the objective function OF in the automated optimization procedure by selection of entries in the *FP* record for the factors W1, W2, W3, W4, W5, W6, W7, W8, W9, W10, W11, W12, W13, W14, W15, and W16 of Eq. 2.8. A Z1, Z2, Z3, and Z4 of exactly zero computed by *HYD* would indicate a perfect fit of computed flows to known flows with the other Z metrics being zero as well. However, since zero deviations in all months is essentially impossible with actual data, the alternative Z metrics provide a mechanism for weighting tradeoffs between the various flow characteristics that are best reproduced by the selected values of the parameters U(1), U(2), B(m), DX, and X(i,j).

Z1, Z2, Z3, and Z4 defined by Eq. 2.9 focus on deviations between known and computed flows in each of the individual months. These criterion metrics reflect the absolute values of the differences between known flows from a WAM dataset and the corresponding flows computed within *HYD* with Eq. 2.1 expressed as a dimensionless percentage of the average of the known flows for the same TL, TM, TH, TF, or T months.

The flow differences are divided by the period-of-analysis mean of the known flows for the low, medium, high, and flood flow ranges. Thus, the flow differences are expressed as percentages of the mean of the TL, TM, TH, or TF known flows. If flow limits are not specified, the mean is for the T known flows. The percent differences are raised to the exponent E1 (default = 2) which weights a large difference more than a smaller difference between computed and known flows for a given known flow.

Differences between known and computed flows for larger flows tend to be larger than differences between smaller flows. Thus, minimizing Z1, Z2, Z3, and Z4 tends to emphasize the larger flows within each of the four flow ranges. Z5, Z6, Z7, and Z8 are designed to increase the emphasis on lower flows in the calibration process.

Z5, Z6, Z7, and Z8 computed with Eq. 2.10 are based on the absolute values of deviations between known flows from a WAM dataset and the corresponding flows computed within *HYD* with Eq. 2.1, expressed as a percentage of the either the known or computed flow. The divisor ZZZ is set as the larger of the known or computed flow, which prevents dividing by zero or extremely small numbers. Differences are considered only for flows of at least 1.0 ac-ft/month.

Alternative criterion metrics Z9, Z10, Z11, and Z12 computed with Eq. 2.11 are based on counting the number of months of the period-of-analysis during which the known and computed flows fall within the specified flow range. The objective is to minimize the deviation between the number of months of computed and known flows in specified flow zones.

Z13, Z14, Z15, and Z16 defined by Eq. 2.12 are based on the differences between the mean of the known flows from the WAM System dataset and the mean of the flows computed with Eq. 2.1 divided by the mean of the known flows from the WAM System dataset. Values for Z13, Z14, Z15, and Z16 of exactly zero indicate that the flow equation (Eq. 2.1) with specified parameter values perfectly reproduces the long-term period-of-analysis mean and thus total volume of the known flows. Z13, Z14, Z15, and Z16 include either the TL months of low flows, TM months of medium flows, TH months of high flows, or TF months of flood flows, respectively.

Variations of the following objective functions may be adopted in calibrating parameters for low, medium, high, and flood flows.

Low flows	OF = 1.0×Z1 + 3.0×Z5 + 10.0×Z9 + 10.0×Z13
Medium flows	OF = 1.0×Z2 + 3.0×Z6 + 10.0×Z10 + 10.0×Z14
High flows	OF = 1.0×Z3 + 3.0×Z7 + 10.0×Z11 + 10.0×Z15
Flood flows	OF = 1.0×Z4 + 3.0×Z8 + 10.0×Z12 + 10.0×Z16

A W of 0.0 removes a Z from consideration. Numbers other than 1.0 may be assigned on the *FP* record for the W weighting factors to vary the influence of each of the Z criterion metrics on the parameter calibration. The alternative Z's allow different characteristics of the flows to be considered, realizing that the monthly volumes cannot be reproduced exactly in each and every month. For example, Z13, Z14, Z15, and Z16 focus on finding a set of parameter values that replicate the period-of-analysis means of the known low, medium, high, and flood flows.

2.3.5 Univariate Gradient Search Optimization Technique

The automated record parameter calibration procedure of the WRAP program *HYD* uses optimization algorithms that search for the set of values for decision variables that minimize a specified objective function. The gradient search algorithm is a key component of the overall parameter calibration strategy. The univariate gradient search technique is covered in the published literature (Wurbs 1996, Bartholomew-Biggs 2008) and is described below prior to outlining the overall parameter calibration methodology incorporated in *HYD.*

The univariate gradient search optimization procedure is a cyclic algorithm that optimizes one variable at a time while the other variables are temporarily held constant. The computations are repeated iteratively to adjust each individual variable in turn. A cycle consists of finding an improved value for each of the decision variables. The cyclic search begins with an initial estimate of decision variable values and continues until specified stop criteria are met.

1. Initial values are estimated for all of the decision variables.
2. One decision variable is improved using the Newton-Raphson method while all other decision variables are held constant at their current values.
3. Step 2 is repeated for the next decision variable in turn until the cycle is completed in which all decision variables are adjusted.
4. The stop criteria are checked. If the stop criteria are not satisfied, another cycle is performed by repeating steps 2 and 3 above.

For each univariate search iteration (step 2 above), the Newton-Raphson formula (Eq. 2.13) is applied to determine an improved value x* given the current value of x and the first and second derivatives $f'(x)$ and $f''(x)$ of the objective function f(x).

$$x^* = x - \frac{f'(x)}{f''(x)} \tag{2.13}$$

The first and second derivatives $f'(x)$ and $f''(x)$ are approximated with the following finite-difference formulas (Eqs. 2.14 and 2.15).

$$f'(x) = \frac{f(x+\Delta x) - f(x-\Delta x)}{2\Delta x} \tag{2.14}$$

$$f''(x) = \frac{f(x+\Delta x) - 2f(x) + f(x-\Delta x)}{\Delta x^2} \tag{2.15}$$

The objective function OF=f(x) is expressed by Eq. 2.8 in the *FE/FP* record automated parameter calibration procedure. Q(t) computed are computed with Eq. 2.1. B(m), BX, X(i,j), U(1), and U(2) are the decision variables (x) that are iteratively adjusted using Eq. 2.13. The objective function OF is computed three times [f(x), f(x+Δx), f(x-Δx)] for each decision variable adjustment in order to apply Eqs. 2.14 and 2.15 to estimate the first and second derivative terms of Eq. 2.13. A cycle consists of adjustments to all of the decision variables, excluding any that are fixed at set values by options on the *FE* and *FP* records.

The primary stop criteria are based on no further change occurring in each of the decision variables or in the objective function between cycles. A maximum limit is also set on the number of cycles. The cycles continue until occurrence of any one of the following conditions reflected in the stop criteria.

1. No decision variable changes by more than 0.01 percent and the objective function changes by no more than 0.01 percent between a cycle and its preceding cycle.
2. The objective function changes by no more than 0.01 percent between each two successive cycles over a total sequence of four cycles.
3. The maximum limit of FE(12) cycles is reached where the default limit is 500 cycles if the entry FE(12) is blank on the *FP* record.

The 13 decision variables B(m) and BX, 5×N decision variables X(i,j), and U(1) and U(2) may be included in the search. DX is optimized by another algorithm. Selected parameters can be fixed at either user-specified values or defaults. Thus, certain parameters can be removed by the user from the list of decision variables being optimized. The optimization based parameter calibration may be repeated for low, medium, high, and flood flows.

FE and *FP* records facilitate a calibration process in which flows may be categorized as low, medium, and high flows for two purposes. Different sets of model parameters may be adopted for low, medium, high, and flood flows. Multiple flow zones may also be employed in defining the objective function used to optimize a single set of parameter values.

The step size Δx in Eqs. 2.14 and 2.15 are required in the computation of the first and second derivatives f ′(x) and f ″(x) for the Newton formula. The step size Δx are may be set by *FP* record FEX(1) and FEX(2) as a dimensionless fraction of the latest value of B(m) or X(i,j) in the iterative computations. The default Δx are replaced with the optional FEX(1) and FEX(2) if so specified on the *FP* record. FEX(1) and FEX(2*)* are adopted for the entire search except for when Δx is increased to deal with a zero second derivative. Defaults for FEX(1) and FEX(2) are as follows.

Δx = greater of FEX(1)×B(m) or 1.0 acre-foot/month when B(m) are adjusted.

Δx = greater of FEX(2)×X(i,j) or 0.000001when X(i,j) are adjusted.

The Eqs. 2.14 and 2.15 step size Δx for the other optimization decision variables (model parameters) are fixed in *HYD* with no input options for changing Δx. Eq. 2.13 cannot be applied if f ″(x) is zero since dividing by zero is not allowed in mathematics. The Newton-Raphson formula (Eq. 2.13) is also not valid with a negative f ″(x). The second derivative f ″(x) represents a change in the slope of f(x). Occurrence of a flat segment of f(x) with non-zero slope f ′(x) and but zero change in slope f ″(x) is possible. The *HYD* optimization routine includes a feature to deal with this situation. If Eq. 2.15 results in a f ″(x) of zero, Δx is doubled and the computations are repeated. If the slope remains flat in the expanded range, Δx is doubled again as necessary up to five times to achieve a non-zero f ″(x). If f ″(x) still remains at zero, either x, x+Δ, or x-Δx is adopted based on which has the smallest f(x).

The search algorithm ensures that the decision variables are constrained within specified limits. Other auxiliary features deal with irregularities in the gradient search behavior due to complex non-smooth relationships between the decision variables and objective function.

2.3.6 Parameter Calibration

Calibration consists of determining an optimal set of values for model parameters fitted to the TWDB precipitation and evaporation datasets that allows the period-of-analysis naturalized flows from a TCEQ WAM System dataset to be reproduced as closely as possible with the model. The resulting calibrated model is then applied to extend the naturalized flows of the WRAP/WAM dataset. Considerable flexibility is provided by *WRAP-HYD* for experimentation.

Parameter calibration features of *HYD* are controlled by *FE*, *FP*, *FZ*, *FR*, *QD*, and *QA* records. The results of the parameter calibration is a subset of *UB*, *BM*, *B1*, *B2*, *B3*, *B4*, *XM*, *X1*, *X2*, *X3*, *X4*, *RC*, and *FX* records which are combined with *FE*, *FZ*, *ZR*, *QD*, and *QA* records to extend the naturalized flows. Two levels of calibration incorporating multiple stages are performed. The calibrated model created in level 1 consists of Eqs. 2.1-2.5 with values determined for all of their parameters. The basic model created in level 1 could be applied without further adjustments. The subsequent calibration level 2 methods consist of additional adjustments to improve model accuracy in reproducing statistical characteristics of the known naturalized flows.

2.3.6.1 Parameters of the Flow Model

Different parameters are optimized in the two levels of the calibration process. The results of the primary level 1 of the calibration process are recorded on *BM*, *B1*, *B2*, *B3*, *B4*, *XM*, *X1*, *X2*, *X3*, *X4*, and *UB* records along with the *FE* record. Additional parameters incorporated in subsequent optional level 2 of the calibration process are recorded on *RC*, *FX*, and *UB* records.

The level 1 calibration process consists of an automated optimization procedure that determines values for the parameters of Eqs. 2.1, 2.2, 2.3, 2.4, and 2.5.

- B(m,z) and BX(z) are base flow parameters in Eq. 2.4. B(m,z) for each of the 12 months of the year may be calibrated and BX(z) fixed at the default of 1.0. Alternatively, BX(z) may be calibrated and B(m,z) fixed. Without flow zones, values of B(m) are stored on *BM* records. B(m,z) for low, medium, high, and flood flows are stored on *B1*, *B2*, *B3*, and *B4* records, respectively. The 12 B(m) on a *BM* record or up to 4×12=48 B(m,z) recorded on *B1*, *B2*, *B3*, and *B4* records are flow volumes in units of acre-feet/month. The multiplier factors BX(z) are dimensionless.
- X(i,j,z) are dimensionless factors in Eq. 2.2 that range between 0.0 and 1.0. Without flow zones, the five calibrated X(i,j) for each of the N quadrangles are recorded on *XP* records. Calibrated X(i,j,z) for low, medium, high, and flood flows are recorded on *X1*, *X2*, *X3*, and *X4* records, respectively, for each of the N quadrangles.
- DX is a dimensionless multiplier factor in the drought index (Eq. 2.5). DX is calibrated at the end of the automated optimization procedure after B(m,z), BX(z), X(i,j,z), U(1), and U(2) have been set. *HYD* provides various options for calibrating DX.
- U(1) and U(2) in Eq. 2.1 are dimensionless parameters that model the nonlinear response of stream flows to precipitation from the perspective of the combined total runoff from the entire watershed combining all of the quadrangle components.

The second level of the calibration process results in values for the following optional parameters designed to further refine the flow model.

- Flow adjustment factors FX(r) for up to 12 flow ranges recorded on a *FX* record.
- Regression coefficients recorded on a *RC* record.

- Two optional parameters ZF(1) and ZF(2) on the *UB* record designed to improve the modeling of zero and close-to-zero flows.

The decision variables are constrained within the calibration procedure to the following ranges which realistically reflect the previously discussed physical concepts being modeled. Precipitation-runoff parameters may be calibrated separately for the four flow zones or subsets of the four zones. Base flow parameters are not referenced to flow zones. FX(r) factors on the *FX* record refer to 12 flow ranges rather than the four flow zones.

Base Flow	Rainfall-Runoff Parameters		*FX* Record
Parameters	Multiplier Factors	Exponents	Adjustment Factors
$0.0 \leq B(m,z)$	$0.0 \leq U(1) \leq 1.0$	$0.7 \leq U(2) \leq 1.4$	$0.0 \leq FX(r)$
$0.0 \leq BX(z) \leq 1.0$	$0.0 \leq X(i,1,z) \leq 1.0$	$0.0 \leq X(i,2,z) \leq 1.0$	
$0.0 \leq DX \leq 6.0$	$0.0 \leq X(i,3,z) \leq 1.0$	$0.0 \leq X(i,5,z) \leq 1.0$	
	$0.0 \leq X(i,4,z) \leq 1.0$		

2.3.6.2 Optimization-Based Automated Parameter Calibration Procedure

The automated optimization-based level 1 parameter calibration features of *HYD* consists of finding optimal values for the parameters of the flow model (Eqs. 2.1, 2.2, 2.3, 2.4, 2.5.) by assigning initial estimates and then adjusting these estimates in an iterative search for an optimal set of parameter values. Conceivably, calibration could involve numerous trial-and-error iterative executions of *HYD* while changing parameter values between executions. However, the automated optimization-based calibration capabilities of *HYD* are essential due to the complexities of fitting numerous interrelated parameters to large datasets. The *HYD* automated search procedure may be supplemented by experimentation with user-controlled trials.

FE(2) Calibration Options

The options outlined in Table 2.4 are activated by FE(2) in *FE* record field 8. FE(2) options 1 through 11 control the automated parameter (level 1) calibration process. A blank *FE* record field 8 (FE(2)=0) means parameter values are provided on input records for the flow extension computations applied in both the level 2 calibration and the final flow extension.

Table 2.4 FE(2) Calibration Options

FE(2) Option	Flow Zone	Initial Values	Combination
1	low	computed	none
2	medium	computed	none
3	high	computed	none
4	flood	computed	none
5	low	FE(2) option 1	Table 2.3
6	medium	FE(2) option 2	Table 2.3
7	high	FE(2) option 3	Table 2.3
8	flood	FE(2) option 4	Table 2.3
9	non-flood	computed	None
10	flood	computed	Table 2.2
11	none	computed	none

The options controlled by *FE* record switch FE(2) listed in Table 2.4 address two key issues in applying the automated search optimization algorithms to calibrate values for the parameters U(k), B(m), BX, and X(i,j).

- Search algorithms must begin with an initial estimate for each of the decision variables.

- Although the LU, ML, MU, HL, HU, and FL limits (Figures 2.2, 2.3) can be referenced to known naturalized flows in the calibration computations, there are no known flows during the period-of-extension. Flows are synthesized following the rules outlined in Tables 2.2 or 2.3 based on computing and combining low, medium, high, and flood flows. The LU, ML, MU, HL, HU, and FL limits optionally may refer to either known or computed flows during parameter calibration but must refer to computed flows during the final flow extension computations.

The FE(2) options differ in regard to dealing with these two issues. Options 1, 2, 3, 4, and 9 reference flow zones to known flows and apply the flow model to compute Q(t) without needing the combining rules of Tables 2.2 and 2.3. Options 5, 6, 7, 8 implement the combining rules of Table 2.3 and option 10 implements the combining rules of Table 2.2 while defining flow zones with reference to computed flows. FE(2) option 11 does not use the flow zone feature.

- Options 1, 2, 3, 4, 9, and 11 compute Q(t) directly without needing the rules of Tables 2.4 and 2.5. Flow zones for options 1, 2, 3, 4, and 9 are defined based on known flows.
- Options 5, 6, 7, and 8 compute flows $Q(t)_L$, $Q(t)_M$, $Q(t)_H$, and $Q(t)_F$ for each month t and apply the rules of Table 2.3 to determine the final Q(t). Flow zones are defined based on computed flows. Starting estimates are from preceding options 1, 2, 3, 4 optimizations.
- Option 10 is based on computing two flows $Q(t)_X$ and $Q(t)_F$ for each month t and applying the rules of Table 2.2 to determine the final Q(t). Flow zones are defined based on computed flows. Starting estimates of parameter values are computed.

The FE(2) options may be combined in various ways in a single execution of HYD. Options 5, 6, 7, 8 are designed to be applied in combination with options 1, 2, 3, 4.

Option 10 is applied in combination with option 9. Options 1, 2, 3, 4 and options 5, 6, 7, and 8 are based on defining low, medium, high, and flood flow zones as described in Figure 2.3 and Table 2.3. Options 9 and 10 are based on defining non-flood and flood flow zones as described in Figure 2.2 and Table 2.2. Option 11 performs calibration computations without reference to flow zones.

Stream flows vary dramatically from zero or near-zero to extremely high flood flows. Calibrating a single model to accurately represent the full range of flows is difficult. Up to four flow models can be created for different ranges of flow. However, combining the models based on defining flow zones referenced to computed flows introduces additional inaccuracies. Variations of the following three strategies for modeling flows by flow zone may be adopted.

1. Application of FE(2) option 1 to develop a single flow model without subdividing flows into zones.
2. Combination of FE(2) options 9 and 10 to subdivide flows into two zones. A model for each of two zones is calibrated one time.
3. Combination of FE(2) options 1, 2, 3, 4 and options 5, 6, 7, 8 to subdivide flows into four zones. Models for each of the four zones may be iteratively calibrated any number of times with latest results serving as starting values for the next iteration.

The second alternative based on FE(2) options 9 and 10 is the recommended default standard strategy. This recommended strategy consists of combining two *FE* records, the first with FE(2) option 9 and the second with option 10, along with auxiliary supporting records in a single execution of *HYD*.

The more complex third strategy should be investigated if the second strategy does not yield satisfactory results. This strategy combines at least eight *FE* records but perhaps many more *FE* records, along with supporting records. An initial four sets of parameter values are determined based on FE(2) options 1, 2, 3, and 4 for low, medium, high, and flood flows, respectively. Next, options 5, 6, 7, and 8 are applied starting with initial parameter values from the preceding application of options 1, 2, 3, and 4. This process is iteratively repeated with any number of additional options 5, 6, 7, and 8 calibrations starting with the latest parameter values.

2.3.6.3 General Level 1 Optimization Strategy

Mathematical optimization techniques are widely employed in the calibration of various types of computer simulation models. The *HYD* flow model calibration problem is similar to many other complex models in regard to the existence of an essentially infinite number of possible solutions, many of which are essentially indistinguishable in their level of optimality. Although many bad or clearly non-optimal solutions exist, there is not necessarily a single optimum solution. The *HYD* flow model has many parameters. Many different combinations of values for these parameters will result in similar values for the objective criteria. One of many different solutions that yield near-optimal results will be determined by the optimization procedure with a particular set of calibration options selected. Activating alternative calibration options may result in significantly different values for the individual parameters that in combination yield similar levels of optimality in reproducing flows.

Strategies for applying the automated optimization-based calibration capabilities are formulated by combining options associated with the following *HYD* features.

- Specification of flow zones as illustrated by Figures 2.2 and 2.3 and Tables 2.2 and 2.3 using the flow limits entered on the *FZ* record.
- Formulation of objective functions based on Eqs. 2.8, 2.9, 2.10, 2.11, and 2.12 using the weighting factors entered on the *FP* record.

- Combining of the calibration options listed in Table 2.4 which are selected by the entry for FE(2) on the *FE* record.
- Combining options for baseflow and drought index parameter calibration based on options controlled by entries on the *FE* record.

2.3.6.4 Optimization Computations Comprising Level 1 of the Calibration Process

The automated parameter calibration computations performed in a single execution of HYD are outlined as follows. The level 1 calibration computations performed by *HYD* proceed sequentially through the following four steps.

1. Initial estimates are developed for the parameter values using primarily enumeration algorithms or preset defaults. Conceivably these preliminary estimates could be adopted for the flow extension without proceeding to stage 2 and 3 listed next. However, both preciseness and accuracy would likely be very limited. The purpose of continuing to stages 2 and 3 is to improve model preciseness and accuracy. Values are assigned to all parameters in stage 1 though these values may be approximate.
2. A univariate gradient search algorithm using the Newton-Raphson method starts with the initial parameter estimates and cyclically searches for improved values. The gradient search optimization methodology efficiently searches for optimum values for five X(i,j) for N quadrangles, B(m) for each of the 12 months, BX, U(1), and U(2).
3. A final set of enumeration algorithms test the univariate gradient search results and may result in further refinements.
4. The drought index factor DX is calibrated as the final stage of the optimization.

The gradient search optimization methodology is very computationally efficient, requiring relatively minimal computer runtime. However, search algorithms are subject to resulting in local rather than global optima. The search algorithm may reach different sets of final optimal values of the decision values with searches that start with different initial starting values. Good initial estimates for the decision variables may be required for the gradient search algorithm to find a near-global optimum.

The overall approach outlined below includes methods for determining valid values for the parameters that are reasonably close to optimum prior to starting the gradient search procedure. Computed values of the parameters resulting from any stage of the computations remain in computer memory for use as starting values for the next stage. The univariate gradient search optimization procedure starts with initial estimates for all of the decision variables and adjusts the values for U(1), U(2), BX, B(m), and X(i,j).

Initial estimates for decision variables (model parameters) used to initiate the gradient search optimization may come from the following sources.

- Initial values can be specified on input records.
- Defaults for most of the parameters are automatically set if no other values are provided through the various options.
- FE(2) option 5, 6, 7, and 8 searches begin with initial values that are in computer memory from preceding FE(2) option 1, 2, 3, and 4 searches or preceding option 5, 6, 7, and 8 searches. Any number of option 5, 6, 7, and 8 searches can be performed in a single execution of *HYD* with each search starting with the most recent parameter values placed into memory.
- For FE(2) option 1, 2, 3, 5, 9, and 11 searches, an initial set of initial parameter values are computed as follows. The methodologies for developing initial estimates for parameter values to begin the gradient search are completely different for the different parameters.

Initial Estimates of Model Parameters Assigned as Defaults or with Input Records

The decision variables are listed below with the initial defaults that are automatically assigned by *HYD* subject to change by input options. The initial defaults may also be the final parameter values if no calibration options are activated to change them. Any of these model parameters may also be assigned fixed values on input records and thus excluded from the set of decision variables included in the optimization.

U(1), U(2)	Default = 1.0.	Set on *UB* record or optimized.
X(i,j)	Default = 1.0.	Set on *XP* records or optimized.
B(m)	Default = 0.0.	Set on *BM* record or optimized.
BX	Default = 1.0.	Set on *UB* record or optimized.
DX	Default = 1.0.	Set on *FE* record or optimized.

Base Flow Parameters B(m) and BX

Although *HYD* allows B(m) and BX to be optimized concurrently, normally either BX or the 12 B(m) or will be optimized with the other set at fixed values. Calibration of the drought index factor DX is the same regardless of the strategy adopted for combining B(m) and BX.

Eq. 2.5 models base flow as BF(t)=B(m)×BX×DI(t) where BF(t) represent seasonally varying long-term base flows that respond slowly to precipitation. During low flow conditions, base flows may represent most or all of Q(t). The twelve B(m)×BX in acre-feet/month are multiplied by a dimensionless drought index [$0.0 \leq DI(t) \leq 1.0$] that lowers the seasonal base flows during dry periods. BX is a dimensionless factor between 0.0 and 1.0 with a default of 1.0. The twelve B(m) may be optimized with BX set at 1.0, allowing the possibility of large variations between the twelve B(m) including the possibility of B(m) of zero in some months. Alternatively, the twelve B(m) may be treated as fixed maximum limits and BX optimized.

The means of the six lowest flows during the period-of-analysis are automatically computed by *HYD* for each of the 12 months. For example, for a period-of-analysis of 1940-1997, B(1) is computed as the average of the six smallest of the 58 January naturalized flow volumes from the WAM dataset. B(2) is the mean of the six lowest of the 58 known February flows and so forth. B(12) is the average of the six smallest December naturalized flows during the 58-year 1940-1997 period-of-analysis.

The initial estimate for the twelve B(m) may be set at the means of the six lowest flows or alternatively as the means of the six lowest flows constrained to not exceed a maximum limit specified on the *FE* record. The B(m) may be treated as 12 parameters to be calibrated in the optimization computations. Alternatively, the twelve B(m) may be treated as fixed maximum limits, and BX calibrated ($0.0 \leq BX \leq 1.0$). Baseflow = $B(m) \times BX \times DI(t)$

The default for BX is 1.0. If optimized, the initial estimate for BX is set in the enumeration process described next. If optimized, the initial estimates of for B(m) are adjusted in the enumeration process. The initial estimates are used in the same manner to start the gradient search procedure regardless of how they are determined.

<u>Default Enumeration Option for Initial Estimates for U(1), U(2), X(i,j), B(m), and BX</u>

The term enumeration is adopted here to refer to algorithms that compute and compare objective function values for numerous values of a decision variable or combinations of values for multiple decision variables. The numerous alterative values of the decision variables are enumerated simply by incrementing the variable by a set quantity over a specified range. For example, incrementing by 0.1 in the range of 0.0 to 1.0 results in the following eleven alternative values for the variable X(i,j): 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0. These eleven alternative values could be considered for each of twelve X(i,j) (three X(i,j) for each of four quadrangles) resulting in 9^{12} = 3,138,428,376,721 combinations.

Computer execution time limits the extent to which combinations can be enumerated. Complete detailed enumeration of all possible combinations of parameter values is not feasible because the combinations are too numerous for consideration even with high speed computers. The number of combinations of variables generated becomes extremely large as the number of variables becomes larger and the incremental step size is made smaller. The alternative *HYD* enumeration schemes are limited in detail and extent to preclude excessive computer execution time. Computer execution time can vary greatly with different enumeration options. The computer runtime for an execution of *HYD* in calibration mode may vary from several minutes to many hours depending on the enumeration options activated. The univariate gradient search is much more efficient. The enumeration algorithm provides starting values for the subsequent more precise and efficient gradient search algorithm.

The standard recommended default option for determining initial values for U(1), U(2), and X(i,j) is based on enumeration. The enumeration algorithm can also be used to develop initial values for B(m) and/or BX along with U(1), U(2), and X(i,j). Initial estimates are developed for X(i,1), X(i,3), and X(i,4) using an enumeration strategy. The same values may be assigned to all of the N quadrangles, with the subsequent univariate gradient search optimization allowing the X(i,j) to vary between the N quadrangles. Alternatively, the enumeration can be applied to X(i,j) for all the N quadrangles or to a subset consisting of ND of the N quadrangles.

The enumeration method consists of comparing objective function values computed for numerous combinations of U(1), U(2), X(i,1), X(i,3), X(i,4), and BX. The exponents X(i,2) and X(i,5) are set at 1.0 in the initial estimates. All or any subset of these variables can be included in the enumeration. Any variables not included in the enumeration are set at fixed values. The results of the enumeration algorithm are initial estimates that are adjusted in the subsequent gradient search algorithm and other auxiliary enumeration procedures.

Two enumerations are performed. In the first enumeration, the decision variables are incremented as follows.

U(1)	=	0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0
U(2)	=	0.9, 1.0, 1.1, 1.2, 1.3
X(i,1)	=	0.6, 0.7, 0.8, 0.9, 1.0
X(i,3)	=	0.0, 0.1, 0.2, 0.3, 0.4
X(i,4)	=	0.5, 0.6, 0.7, 0.8, 0.9, 1.0
BX	=	0.0, 0.2, 0.4, 0.6, 0.8, 1.0

This enumeration results in $36{,}000 \times N^3$ ($8 \times 5 \times 5N \times 5N \times 6N \times 6 = 36{,}000N^3$) combinations of values for the decision variables where N is the number of quadrangles. With only one quadrangle, there are 36,000 combinations. With seven quadrangles, there are 12,348,000 combinations. The objective function is computed for each of the combinations of values of the decision variables. The combination that results in the smallest value of the objective function (Eq. 2.8) is selected for use in the second enumeration. The decision variable values reflect only one significant figure in the first enumeration.

The second enumeration adds an additional digit of precision to the values of the decision variables. The entry for FE(10) on the *FP* record selects between alternative options 1, 2, 3, and 4 for the second enumeration. For the default option, the X(i,j) are incremented in steps of 0.01 for a distance of 0.06 on both sides of the values selected in the first enumeration. For example, if U(1) of 0.8 is selected in the first enumeration, the following values of U(1) are considered in the second enumeration:

0.74, 0.75, 0.76, 0.77, 0.78, 0.79, 0.80, 0.81, 0.82, 0.83, 0.84, 0.85, and 0.86.

FE(10) option 1 results in up to 13^{3+3N} combinations or sets of decision variable values. With only one quadrangle, this is 4,826,809 combinations. With seven quadrangles, there are up to 5.428×10^{26} combinations. However, most of the decision variables are each constrained to the range of 0.00 to 1.00. The number of combinations is reduced during the computations if and when reaching the limits 0.00 or 1.00.

The combination resulting in the smallest value of the Eq. 2.8 objective function is selected for use as the initial estimates of the decision variables. Other FE(10) options change the range and increments of the enumeration which may significantly affect computer runtime. The FE(10) and FE(11) options deal only with computing initial estimates for the decision variables (calibration parameters).

All of the decision variables, including separate X(i,j) for each individual quadrangle, are optimized in the subsequent gradient search. The key issue motivating consideration of the tradeoffs between accurate initial parameter estimates and computer runtime is the tendency for search algorithms to converge on local rather than global optima. Better initial parameter estimates improve the reliability of the gradient search algorithm in finding a near-global optimum set of parameter values. The five X(i,j) for each of the N individual quadrangles(i) are all optimized in the gradient search. In developing the initial estimates for X(i,j) to start the gradient search, the X(i,3), and X(i,4) are set at 1.0 for all i and are not optimized in the enumeration algorithm.

FE(11) on the *FP* record provides options for handling the N quadrangles in developing initial estimates for X(i,1), X(i,3), and X(i,4). The default FE(11) option 1 consists of optimizing a single set of X(i,1), X(i,3), and X(i,4) which are applied for all quadrangles. FE(11) option 2 consists of optimizing a different sets of X(i,1), X(i,3), and X(i,4) for each individual quad for ND quads that may include all N quads or a subset thereof. For a watershed encompassing several quadrangles, switching to FE(11) option 2 dramatically increases the number of combinations included in the enumeration and the corresponding computer runtime.

Computer runtime is reduced dramatically by grouping quadrangles together in the enumeration algorithm. N denotes the number of quadrangles listed on the *QD* record. The first ND quadrangles listed comprise a subset of the N quadrangles. ND and N are entered in *QD* record fields 2 and 3. If *QD* record field 2 is blank or zero, ND defaults to N. With FE(11) option 2, there are ND enumerations. The first ND less one quadrangles are each enumerated separately. The NDth enumeration combines all remaining quadrangles. Thus, FE(11) option 2 is relevant only for control points with more than one quadrangle. FE(12) option 2 with ND set at 1 is equivalent to FE(11) option 1. With ND of 5 and N of 11, the first 4 quadrangles listed on the *QD* record are each optimized individually in the enumeration algorithm. The fifth enumeration optimization applies to all of the remaining seven quadrangles.

The parameter ND entered in *QD* record field 2 is used for two different unrelated purposes: (1) enumeration options as discussed above and (2) drought index computations. ND affects the enumeration algorithm only if FE(11) option 2 is activated. However, with FE(11) option 2 activated, ND also affects the unrelated drought index computations. Only the first ND quadrangles are included in the drought index computations. Baseflow is defined by Eq. 2.5 as:

$$BF(t) = B(m) \times BX \times DI(t)$$

Typically either BX or the twelve B(m) will be optimized but not both. However, the multiplier factor BX is included in the enumeration for optimizing B(m) even if BX itself is not optimized. If the B(m) are optimized, a single multiplier factor X is included in the enumeration algorithm, with X=BX and B(m) treated as a maximum limit. At the completion of the enumeration, B(m)=X×B(m) and BX is set at either its default of 1.0, a value from the *BX* record, or an optimized value. Whereas the gradient search optimizes the B(m) as 12 separate decision variables, the enumeration adjusts the 12 B(m) in the same proportion by a multiplier factor.

<u>Alternative Option for Initial Estimates of U(k) and X(i,j)</u>

Option 5 activated by FE(10) on the *FE* record develops a single initial set of X(i,j) which are applied to all of the N quadrangles along with U(1) and U(2) of 1.0. Option 5 is much more approximate than the alternative enumeration schemes of FE(10) options 1, 2, 3, and 4 but requires less computer runtime. With FE(10) option 5, U(1) and U(2) and the exponents X(i,2) and X(i,5) are set at 1.0, converting the flow equation to linear. Q(t) less base flow BF(t) is assumed to come from solely precipitation in the same month (t). X(i,1) and X(i,3) for the N quadrangles are all set at the same fractions F_1 and F_2 defined by Eq. 2.17. The initial estimates for B(m) and X(i,j) result in the conversion of Eq. 2.1 to Eq. 2.16.

Current Month Precipitation			Preceding Month Precipitation		
X(i,1) = F1	for	i = 1 to N	X(i,4) = 1.0	for	i = 1 to N
X(i,2) = 1.0	for	i = 1 to N	X(i,5) = 1.0	for	i = 1 to N
X(i,3) = F2	for	i = 1 to N			

$$Q(t) = \left(\sum_{i=1}^{N} P(i,t) - F_1 \times P(i,t) - F_2 \times E(i,t) \right) + B(m) \qquad (2.16)$$

$$F_1 = \frac{\overline{P} - \overline{Q} - (F_2 \times \overline{E}) + \overline{C}(m)}{\overline{P}} \quad \text{and} \quad F_2 = 0.2 \times \left(\frac{\overline{P}}{\overline{E}} \right) \qquad (2.17)$$

$\overline{Q}$, $\overline{P}$, and $\overline{E}$ in Eq. 2.17 are the period-of-analysis means of the volumes of naturalized flow Q(t), precipitation P(i,t), and evaporation E(i,t) during the TL low flow, TM medium flow, or TH high flow months as specified by FE(2) on the *FE* record. F_1 and F_2 are the default initial estimates of X(i,1) and X(i,3). Equations 2.16 and 2.17 are based on a long-term volume balance combined with the arbitrary assumption that 20 percent of the precipitation is loss through the evaporation term of Eq. 2.16. The period-of-analysis mean of the computed flows closely approximates the mean of the known flows with these initial parameter values.

Univariate Gradient Search Optimization

The univariate gradient search methodology is described earlier. The 12 B(m), BX, 5N X(i,j), U(1), and U(2) are calibrated together in the search procedure. All of the decision variables except DX can be optimized in the search algorithm. The algorithm begins with initial values of the decision variables determined by the options outlined in the preceding discussion and applies Eq. 2.13 in an iterative search for improved values that minimize the specified objective function (Eq. 2.8). Details of the search are defined primarily by the specification of the W weighting factors for Eq. 2.8 on the *FP* record and selection of the FE(2) options listed in Table 2.4.

Final Testing and Refinements to Optimization Results

The univariate gradient search adjusts all of its decision variables in each cycle, thus capturing the interactions between the variables in the optimization process. After satisfying the stop criteria and thus completing the search, the B(m), BX, X(i,j), U(1), and U(2) are further tested and refined as follows. Each variable is tested by itself. Very small incremental increases and decreases [0.0001×B(m), 0.0001×X(i,j), 0.001×BX, 0.001×U(2)] to the value assigned to the decision variable are made to test whether the changes improve the objective function OF. The decision variable is incrementally increased as long as OF function improvements occur, with a limit of 1,000 incremental increases. Likewise, the decision variable is incrementally decreased as long as OF function improvements occur to a limit of 1,000 incremental decreases.

Calibration of Drought Index Multiplier Factor DX

Since the drought index DI(t) focuses specifically on modeling lower than normal flows, the parameter DX in Eq. 2.5 is calibrated at the end of the automated calibration process using a different objective function. The entry DX in *FE* record field 17 specifies the method for setting the parameter DX in the Eq. 2.5 drought index. DX may be set as the number entered in *FE* record field 17 or default to 1.0 with a blank field.

Alternatively, the drought index may be deactivated. Alternatively, DX may be incorporated in the automated parameter calibration procedure.

DX is optimized as the end of the level 1 automated parameter calibration procedure after values have been adopted for all other variables. DX is set at 1.0 for the objective function evaluations of the preceding optimization algorithms. Options for calibrating DX are based on an enumeration that extends from 0.000 to 6.000 in increments of 0.001 with the OF being computed for each of the 6,001 values of DX. The DX that minimizes the OF is adopted. The following DX calibration options are activated by *FE* record field 17.

1. Option 1 uses the same objective function OF as the other optimization procedures except only the Zs for low flows are included. Medium, high, and flood flows are excluded.

2. Option 2 uses exactly the same objective function as the other optimization procedures including all of the component Zs.

3. Option 3 is based on counting the number of months in which the known flows and computed flows are at or below ZU in FZ record field 3. The objective function consists of minimizing the difference between the counts for computed flows and known flows.

Whereas the optimization procedures for the other decision variables all use the same objective function, a different OF can be formulated specifically for calibrating DX. Option 1 uses only the low flow components of the OF. Option 2 uses the complete OF. The flow zone used in option 3 consists of flows at and below the limit ZU acre-feet/month entered in *FZ* record field 3. This flow zone is used only for calibrating DX. ZU will normally be the smallest flow limit on the *FZ* record and close zero. DX calibration option 1 uses the conventional low flow zone defined by LU on the *FZ* record.

2.3.6.5 Second Level of Analyses and Refinements

The flow model (Eqs. 2.1, 2.2, 2.3, 2.4, 2.5) with parameter values determined in the level 1 calibration process as outlined in the preceding section may be adopted for the flow extension without further modification. However, program *HYD* also includes level 2 options to analyze and further adjust the flows computed with the flow extension model. In the level 2 calibration, *HYD* is activated with *FE* record field 8 blank (FE(2)=0) and the parameters developed in the level 1 calibration provided on input records. The level 2 flow adjustment options result in adoption of additional parameters which are recorded on *FX*, *RC*, and/or *UB* records.

The accuracy of the flow extension model is evaluated by comparing the period-of-analysis flows computed with the calibrated model with the known naturalized flows from the WAM dataset. The computed and known naturalized flows are processed through *SIM* and *TABLES* to develop time series and frequency tables that facilitate comparisons. HEC-DSSVue is used to plot the flows. *HYD* also creates summary tables and metrics in the message HMS file for use in comparing computed and known flows. In addition to the comparative analyses of model results, these metrics may be used to modify the flow extension model.

The calibration process attempts to develop a model that reproduces the known naturalized flows as closely as possible. However, the flows computed for each individual month are necessarily approximate. The WRAP/WAM System is designed for developing frequency and reliability relationships rather than precisely synthesizing the exact flow in a particular month. Likewise, the flow model calibration process is designed to capture the statistical characteristics of the naturalized flows. The level 2 calibration focuses on developing flow sequences with the correct means, standard deviations, and flow-frequency relationships.

FX Record Factors

In the level 2 calibration process, FX(r) ratios are automated recorded in table format in the *HYD* message HMS file and *FX* input record format in the HOT file. The multiplier factors FX(r) correspond to flow ranges defined by QR(r) on the *FR* record. The FX(r) are automatically computed and recorded on a *FX* record when *HYD* is executed in calibration mode. The *FX* record is then manually inserted into the *HYD* input HIN file used for the final flow extension. Flows are grouped by flow range. FX(r) are computed as the mean of known flows $Q_K(t)$ divided by the mean of the corresponding computed flows $Q_C(t)$. In the flow extension, the flows computed with the flow equation (Eqs. 2.1, 2.2, 2.3, 2.4, 2.5) are multiplied by the FX(r) factors.

$$FX(r) = \frac{\overline{Q_K(t)}}{\overline{Q_C(t)}} \tag{2.18}$$

The standard recommended calibration procedure includes use of *FX* record FX(r) factors to improve the capability of the flow model to reproduce the mean, standard deviation, and flow frequency relationship of the known naturalized flows. Flows computed by the flow model (Eqs. 2.1, 2.2, 2.3, 2.4, 2.5) tend to be either high or low in general and particularly high or low in certain ranges of flow. The FX(r) provide adjustments to correct these tendencies.

The tables in the *HYD* message HMS file include the means of the known and computed flows. The ratio of the means of all the flows recorded as FX(13) can be used to adjust the computed flows to have exactly the same mean as the known flows. In extending the flows, as a last step, the computed flows are multiplied by the factor FX(13) entered in the second field of the *FX* record. FX(13) is applied to all flows after the 12 FX(r) for the 12 individual flow ranges.

A 2FRE record frequency table for known naturalized flows may be created with the WRAP program *TABLES* even before the flow model is created. Likewise, upon completion of the level 1 calibrated flow model, a 2FRE frequency table can be developed with *TABLES* for the computed flows. The flow frequency relationships for known and computed flows, respectively, are represented by two flow range *FR* records.

With the two *FR* records in its input HIN file, *HYD* automatically develops the *FX* record. The *FX* record is then added to the *HYD* input HIN file to adjust the computed flows to better reproduce the flow frequency relationship of the known flows in the final flow extension.

The flow limits QR(r) may be referenced to either known flows $Q_K(t)$ or computed flows $Q_C(t)$. Any flow quantities may be specified for the up to eleven QR(r) on a *FR* record. However, QR(r) with exceedance frequencies of 95%, 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, 10%, and 5% are recommended subject to combining ranges of low flows if necessary to deal with a large number of months with zero flow. With the ranges referenced to computed flows, the $Q_C(t)$ are in the lowest range $[Q_C(t) \le Q_C(95\%)]$ during 5 percent of the months, in the next lowest range $[Q_C(95\%) < Q_C(t) \le Q_C(90\%)]$ during 5 percent of the months, in each of the highest two ranges during 5 percent of the months, and in each of the eight other ranges during 10 percent of the months.

Two *FR* records may be provided with the first defining a flow-frequency relationship for known flows and the second defining a flow-frequency relationship for computed flows. With only one *FR* record, the known flow $Q_K(t)$ and corresponding computed flow $Q_C(t)$ in a particular month (t) are assigned to the same flow range. With two *FR* records, the flow ranges for specified exceedance frequencies are assigned for known flows and computed flows, respectively. Thus, the median (50%) known flow can be compared with the medium computed flow, the 90% known flow can be compared with the 90% computed flow, and so forth. The *FR* records are created based on frequency tables for naturalized flows developed with the program *TABLES* with a 2FRE record.

The up to twelve flow ranges defined by the up to eleven limits QR(r), in acre-feet/month, entered on the flow range *FR* record are similar to the four flow zones defined on the flow zone *FZ* record but are used for different purposes. The *FZ* and *FR* record parameters are associated with level 1 and level 2 calibration, respectively.

Parameters ZF(1) and ZF(2) for Adjusting Zero and Near-Zero Flows

The optional parameters ZF(1) and ZF(2) on the *UB* record are set as the very last step of the level 2 calibration process to assure that the model generates zero or near-zero flows in an appropriate number of months. ZF(1) and ZF(2) are flow volumes in acre-feet/month with defaults of zero. Any computed flows of magnitude ZF(1) or smaller are reduced by subtracting ZF(2). If subtraction of ZF(2) from a flow results in a negative number, the flow is set at zero.

Regression and Correlation Analyses

Regression and correlation analyses of flows $Q_C(t)$ computed with the flow model versus known flows $Q_K(t)$ from the WAM dataset are activated with *FE* record FE(1) option 3. The correlation and regression coefficients recorded in the HMS file provide metrics for comparing computed flows with known flows. A regression model can optionally be applied using a *RC* record to develop an adjusted set of predicted flows as a function of the flows computed with the calibrated flow model. The *RC* record feature is not recommended as a standard component of the calibration procedure but is available for experimentation and supplemental analyses.

A nonlinear power function is applied to flows below a specified regression boundary flow RBF. Linear regression is applied to flows above the specified RBF level. Optionally, the RBF may be set at zero, and either the linear or nonlinear regression equation applied. *HYD* creates a table in the HMS file that tabulates regression and correlation coefficients for the regression boundary flow RBF set alternatively at the flow levels specified on the flow range *FR* record. The regression coefficients are also provided on *RC* records.

Q_C are the flows in acre-feet/month computed with the flow model with previously calibrated parameters. In determining regression coefficients, Q are the known flows. In extending flows, Q are new improved estimates of the flows. The following power regression equation is applied to the Q_C that are less than 90% of the regression boundary flow RBF.

$$Q = A \times Q_C^B \tag{2.19}$$

The following linear regression equation is applied to the Q_C greater than 110% of RBF.

$$Q = A + B \times Q_C \tag{2.20}$$

For Q_C that fall between 90% and 110% of the RBF ($0.9RBF \leq Q_C \leq 1.1RBF$), Q is computed as the average of the two values determined with the linear and power regression equations. The coefficients A and B for both the power and linear equations are provided in both a HMS file table and on *RC* records.

The regression coefficients A and B are computed by applying linear regression to the logarithms of the flows based on the standard methods described in statistics and numerical methods textbooks. The correlation coefficient is also included in the FE(1) option 3 regression and correlation coefficient table in the HMS file. The correlation coefficient is the square root of the coefficient of determination as defined in statistics and numerical methods textbooks. The correlation coefficient ranges between -1.0 and 1.0, with 1.0 indicating a perfect fit.

2.4 Establishment of Water Allocation Strategy in Korea

Conventional water availability studies in Korea, especially national scale of water resources management and development plan, have been conducted that water rights are simply allocated from upstream to downstream along the stream without consideration of priorities of each water right because there is no water right permit system based on its priority. Texas WRAP/WAM system incorporates water allocation schemes based on water right priority. In this study, Texas WRAP/WAM System, which was developed by Texas A&M University with the support of TCEQ, was applied for water availability study and development of water allocation strategy in Korea.

Water allocation strategy is developed in the two alternative schemes. A priority-based water allocation strategy for the conventional long-term water availability studies which are required for regional and national scale water resources development plan and evaluation of water right permit application. A water allocation strategy for relatively short-term water availability study in case of minimizing shortages or restriction of municipal water supply during the drought period is established for adjustment priorities of various types of water use and reducing some portion of water use targets and increasing water supply from hydropower dam.

For long-term water availability study based on priority of all water rights, three alternatives with 5 scenarios are considered. One is modeled with the same priorities for all water rights from upstream to downstream, another is considered priorities of water rights based on their priority numbers, and the other is that four hydropower dams are considered for contributing to minimize water shortages in the river basin. A Firm yield target for 100% reliability of municipal water supply to Seoul and metropolitan area is also developed for the case study basin. The integer priority numbers are based on permit dates for each water right. They serve to set the order in which the rights are considered in the process of water right computational loop that allocates water. Smaller priority numbers are considered more senior rights in the computation process.

Short-term water allocation strategy are based on securing municipal water requirements during severe drought. According to the River Act, River Water Adjustment Council is able to determine adjustment of water allocation in case of difficulty in securing instream flow requirements or severe drought. The principles of water allocation established in this study are 1) the priority of water use types is in the order of municipal, industrial, agricultural, and hydropower use, 2) some portion of water supply for municipal, industrial, and irrigation can be restricted to overcome a severe drought, and 3) hydropower dams will contribute to meeting some portion of water supply if water shortages for municipal water supply will occur.

2.4.1 Evaporation-Precipitation Rates for Reservoirs

The most widely applied technique for estimating lake evaporation involves combining pan evaporation measurements and pan coefficient (Wurbs 2002). Unfortunately, there is no evaporation measurement in the 5 reservoirs and both stations does not produce evaporation measurement data any more. Many studies have been carried out on calculating evapotranspiration using mathematical model instead of directly measuring evapotranspiration.

The American Society of Civil Engineers (Walter, Allen et al. 2000) and the UN Food and Agricultural Organization (Allen, Pereira et al. 1998) outline detailed procedure for applying the Penman-Monteith equation shown in Eq. 2.21 to determine the daily or hourly potential evapotranspiration. Penman (H. L. Penman 1948) combined the mass and energy balance concept to derive an equation that was further expanded and refined by Monteith (Monteith 1965, Wurbs 2002). Rosenberry found that Penman-Monteith equation gave good estimates of lake evaporation, even monthly values, and performed well in comparative studies of lake (Rosenberry, Winter et al. 2007). The ASCE Standardized Penman-Monteith equation with daily calculation time step and short reference is listed in Eq. (2.21) The calculation process followed the ASCE standardized reference Evapotranspiration equation guideline.

$$ET_{os} = \frac{0.408\Delta(R_n - G) + \lambda\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (2.21)$$

Where, *ET* short reference evapotranspiration for daily time steps (mm/day)

R_n net radiation at reference crop surface (MJ·m^{-2} d^{-1})

G soil heat flux density at the soil surface (MJ·m^{-2} d^{-1})

T mean daily air temperature at 1.5 to 2.5 m height (℃)

u_2 mean daily wind speed at 2-m height (m/s)

e_s mean saturation vapor pressure at 1.5 to 2.5 m height above surface (kPa)

e_a mean actual vapor pressure at 1.5 to 2.5 m height above surface (kPa)

Δ slope of saturation vapor pressure-temperature curve (kPa℃-1)

γ psychrometic constant (kPa℃-1)

λ latent heat of vaporization (MJ/kg)

2.4.2 Water Availability and Reliability

Reliability is useful in analyzing and displaying results of the water availability study. Program *TABLES* allows to organize simulation results in a variety of ways. A reliability specified in *TABLES* with a 2REL record is provided either water supply diversion or hydropower generation targets for individual water rights, the aggregation of all rights associated with individual reservoirs or control points, groups of selected rights, or the aggregation of all rights in the model. Both period reliability and volume reliability are computed with the program *TABLES* (Wurbs 2015a).

Volume Reliabilities

Volume reliability is the percentage of the total target demand amount that is actually supplied. For water supply diversions, the target demand amounts are volume. For hydropower, the target demand amounts are kilowatt-hour of energy generated. Volume reliability (RV) is the ratio of the total diversion volume supplied or energy produced (v) to the total volume or energy target demanded (V) during a specified period of time.

$$R_V = \frac{v}{V} \ (100\%) \tag{2.22}$$

Equivalently, R_V may be viewed as the ratio of the mean actual water supply diversion rate to mean target diversion rate or the ratio of the mean energy production rate to mean target rate.

Period Reliabilities

Period reliability is based on counting the number of periods of the simulation during which the specified demand target is either fully supplied or a specified percentage of the target is equaled or exceeded. A reliability summary includes tabulations of period reliabilities expressed both as the percentage of months and the percentage of years during the simulation which either water supply diversions or hydroelectric energy produced equaled or exceeded specified magnitudes expressed as a percentage of the target demand. The various variations of period reliability (R_P) are computed by TABLES from the results of a SIM/SIMD simulation as:

$$R_P = \frac{n}{N} \ (100\%) \tag{2.23}$$

Where n denotes the number of periods during the simulation for which the specified percentage of the demand is met, and N is the total number of periods considered.

2.4.3 Firm Yield

The firm yield is defined that the maximum water supply diversion or hydropower electric energy generation that can be achieved with 100 percent of the volume and period reliability based on the premises reflected in the program SIM. The firm yield activated by the FY record may be determined by iteratively adjusting a target amount and rerunning SIM until the value meeting the definition of firm yield is found (Wurbs 2015a).

The reliabilities computed by the FY record yield-reliability routine in SIM are based on volume reliability with Eq.2.22 and period reliability with Eq. 2.23 just like the TABLES 2REL record reliability routine. The difference is that the FY record routine computes reliabilities for one single diversion right with the target incremented multiple times. The firm yield FY record activates a routine to develop a yield-reliability table for a diversion, which is written to the YRO file (filename extension YRO). The FY record for WR-41 (973,680 acre-feet) of the Soyang multi-purpose dam incorporated in NHAN.dat is followed.

```
CD     FYIN(2)  FYIN(3)  FYIN(4)FYIN(5)FYWRID                 MFY
FY    1000000. 100000. 10000.  1000.  WR-41                    1
```

The iterative simulations are organized as follows. The total annual target amount AMT equals FYIN(2) (=1,000,000 ac-ft/yr) from the FY record for the first simulation. The total annual target amount AMT is decreased by FYIN(3) for each subsequent level 1 iteration until either no shortages occur or the target is finally decreased to zero or less. Since FYIN(4) of 10,000 ac-ft has been entered on the FY record, the computations proceed to level 2. For level 2, the initial target amount AMT is set equal to the next-to-last target amount from the level 1 iterations (800,000 ac-ft). AMT is decreased by FYIN(4) (10,000 ac-ft) for each level 2 iteration until no shortages occur. In the same process, level 3 iterations are repeatedly performed with FYIN(5) (1,000 ac-ft) until no shortage occur.

2.5 The new approach for groundwater drought monitoring method

In general, a drought index should be applicable to any time of period and different region. It can be well explained the severity of drought and differences in the drought conditions according to the region. A new approach is applied for identifying groundwater drought based on groundwater level data. The groundwater level time series, which have different statistical characteristics by region, need to be standardized for evaluating drought conditions of whole country. SGI developed by Bloomfield and Marchant (2013) is an index for standardizing groundwater level time series and characterizing groundwater drought or wet condition as deviation of normal groundwater level.

2.5.1 SGI Calculation Method based on Groundwater Level Observation Data

Calculation of SGI requires three steps. First, the distribution of monthly observed groundwater levels is determined at each station for each calendar month. Kernel Density Estimation (KDE) which is a non-parametric way to estimate the probability density function is applied for estimating probability distribution of monthly observed groundwater levels at each stations. And a monthly Cumulative Distribution Function (CDF) for each station is determined to calculate a percentile corresponding to the observed groundwater level. Finally, a SGI value which is a normalized index with a standard normal distribution using the quantile function ($\boldsymbol{CDF^{-1}}$) is calculated based on a specific cumulative probability corresponding to an observed groundwater level.

Kernel Density Estimation

Like other hydrological time series, groundwater level is a continuous variable. The monthly groundwater levels show the various range and distribution by stations. In this study, probability distribution functions for each calendar month at 256 monitoring stations need to be determined. It is unreasonable to fit the monthly probability distribution at each of stations through a specific distribution such as gamma distribution, log-normal, etc. or estimating parametric density. Kernel Density Estimation (KDE) which is a non-parametric way to estimate the probability density function is applied for estimating probability distribution of monthly groundwater levels at 256 monitoring stations. The Kernel estimate of probability density function given by Scott (1981) is as follow equation 2.24.

$$\widehat{f_h}(x) = \frac{1}{n}\sum_{i=1}^{n} K_h(x - x_i) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x-x_i}{h}\right) \tag{2.24}$$

Where, K is the kernel function with non-negative value, x is sequence having length n, and h is a bandwidth parameter which controls to smoothness of the curve. In probability density estimation using KDE, it has advantage to estimate the probability density that faithfully reproduce the histogram of raw data. In this study, the probability density estimation of the monthly groundwater level data at all stations used the ksdensity function in MATLAB. The number of equally spaced point and bandwidth required for ksdensity function are adopted 100 and 0.8 (default values) provided by MATLAB.

Inverse Normal Cumulative Distribution Function

The most of hydrological studies with seasonal and spatial variation use a standardizing technique that the average of the time series is 0 and the variance is 1 in order to remove tendency of data and carry out relative comparison of the data. The average or variance of groundwater level time series also vary from seasonal and spatial characteristics. In order to conduct a national-scale drought monitoring, a quantile normalization technique is applied for standardization of groundwater level time series obtained from a number of stations. The inverse normal cumulative distribution function is used to standardize the groundwater level data with the non-parametric KDE for each calendar month at each of stations.

2.5.2 Receiver Operating Characteristic Model

In order to verify the adequacy of the categories of groundwater drought based on SGI, Receiver Operating Characteristic analysis is conducted. ROC analysis is a technique that is widely used for assessment of weather forecast based on probability. Kim and Lee (2011) applied ROC technique for quantitative evaluation of actual drought records and drought index. Yoo evaluated short-term drought using daily SPI based on ROC analysis (Yoo, Song et al. 2013). In this study, the ROC model is set up as shown in Table 2.5 to evaluate the ability to reproduce actual drought using SGI.

Table 2.5 ROC Model using Standardized Groundwater level Index (SGI)

Actual drought / Predicted drought	Drought	Normal
Drought	True Positive	False Positive
Normal	False Negative	True Negative

For ROC analysis, 29 sample sites are selected among the national groundwater monitoring network. The recorded droughts of the selected 29 stations are set as actual drought, droughts calculated by SGI values are classified as the predicted droughts and it is classified again into two classes by truth and false respectively as shown in Table 2.5.

If an actual drought is positive, it is indicated as 'TP (True Positive)' in case of positive for predicted drought and 'FN (False Negative)' in case of negative for predicted drought. If an actual drought is negative, it is indicated as 'FP (False Positive)' in case of positive for predicted drought and 'TN (True Negative)' in case of negative for predicted drought. In this case, TP and TN are judged to be true values consisting of positive and negative, FP and FN are taken as false values. The ROC space for the four elements classified as shown in Table 2.5 can be constructed by calculating the sensitivity and the specificity using equations 2.25 and 2.26 respectively.

Sensitivity = TP / (TP+FN) = True Positive rate (2.25)

Specificity = TN / (FP+TN) = True Negative rate (2.26)

2.6 Groundwater Drought Projection Method

The meteorological drought index, SPI, applied for drought monitoring at the beginning stage of Drought Early Warning System is able to use for future drought projection based on three-month precipitation forecasting data provided by the Korea Meteorological Agency. However, SPI has a limitation for describing groundwater drought appropriately because groundwater level response to precipitation varies temporally depending on the each watershed characteristics. As mentioned, alternative methodology using observed groundwater level data is able to identify current actual drought condition of groundwater sources. However, this approach has also a disadvantage that it is very difficult to forecast future groundwater level for each of monitoring wells (i.e., after 1 month, 3month, 6month).

In order to improve these limitations, new approach using SGI is applied for identifying future groundwater drought based on correlation with SPI. The relationship between meteorological drought (SPI) and groundwater drought (SGI) is investigated and quantified employing correlation analysis. SPI is calculated at 167 cities for accumulation periods from 1 month to 12 months to conduct correlation with SGI. Artificial Neural Network (ANN) technique is applied for SGI forecasting based on given input SPI values which are calculating for accumulation periods from 1 month to 12 month reflecting 3 month precipitation forecast.

2.6.1 NARX (Nonlinear Autoregressive model process with eXogenous input)

NARX Neural Networks, which are well suited for input-output modeling of nonlinear dynamic systems and specially time series such as hydrological data, are applied for SGI forecasting based on given input (SPI). The NARX model is based on the linear ARX model, which is commonly used in time series. The autoregressive in NARX means that the system output at current time t relates to output of past time t-1 as well as input of current time t. Equation 2.27 represents a mathematical formulation of the NARX model expressed as unknown function $\boldsymbol{f}$.

$$\begin{aligned}\hat{y}_i &= f(\{y\},\{u\}) \\ &= f(y_{i-1}, y_{i-2}, \cdots, y_{i-N}, u_{i-1}, u_{i-2}, \cdots, u_{i-N})\end{aligned} \tag{2.27}$$

Where $\hat{\boldsymbol{y}}_i$ represents the output of the estimated system at time $\boldsymbol{t_i}$, vector $\{\boldsymbol{y}\},\{\boldsymbol{u}\}$ are the lags of output and input of the system, $\boldsymbol{f}$ is a nonlinear function. A diagram of resulting NARX neural network is shown in Figure 2.4, where a two-layer feedforward network is used for the approximation of function. The input layer contains input values and output values from a specific past time to the present time of the system and play a role of passing them to the hidden layer (layer 1 in Figure 2.4). The input values passed to the hidden layer are multiplied by weighting parameters and converted into a weighted sum. The transformed input vectors are passed to the activation function introduced to account for nonlinear effects, and the activated vectors are weighted again in the output layer.

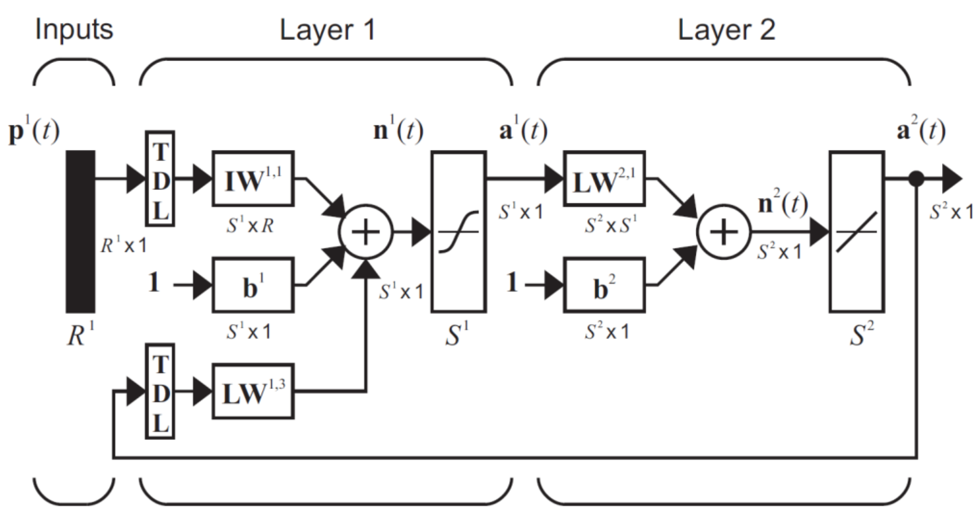


Figure 2.4 A diagram of NARX neural network (Demuth, Beale et al. 2014)

CHAPTER III

EXTENDING TCEQ WAM SYSTEM HYDROLOGIC PERIODS-OF-ANALYSIS BASED ON TWDB PRECIPITATION AND EVAPORATION DATASETS

3.1 TCEQ WAM System Hydrology Datasets

The original WRAP input datasets in the TCEQ WAM System were developed by the TCEQ and its contractors during 1997-2002. The sequences of naturalized flows and net evaporation-precipitation rates in the WAM System extend from either 1934, 1940, or 1948 through either 1989, 1996, 1997, 1998, or 2000. Although water rights and other aspects of the modeling system have been regularly updated, the hydrology datasets have not yet been updated.

The new capabilities explored in this chapter are motivated by the need to update the hydrologic periods-of-analysis of the WAM System WRAP input data files to near the present with continuing updates in the future. Several periods since 1998 have been very dry throughout much of Texas including the severe drought year 2011. The methodologies can also be applied to extend the hydrologic sequences to preceding years dating back to 1940. After initial creation of the HYD input datasets controlling the extension computations, the TCEQ WAM System hydrology datasets can be updated each year as the TWDB updates the precipitation and evaporation datasets.

The hydrologic periods-of-analysis covered by the datasets and the number of control points included in current versions are shown in Table 3.1. The watersheds covered by the datasets are delineated in Figure 3.1. The WAM hydrology input files, with filename extensions FLO (or INF) and EVA, consist of naturalized monthly stream flows recorded on IN records and reservoir surface evaporation less precipitation rates on EV records for pertinent locations covering the hydrologic period-of-analysis. Primary control points are sites for which naturalized flows are provided on IN records.

The TCEQ WAM System datasets include naturalized flows at about 500 primary control points, most of which are stream gaging stations. These flows are distributed to over 10,000 other ungaged sites within the simulation model. Table 3.1 also shows both the number of control points for which net evaporation-precipitation rates are provided as input on EV records in EVA files and the number of control points (called primary) for which naturalized flows are input on IN records in FLO or INF files.

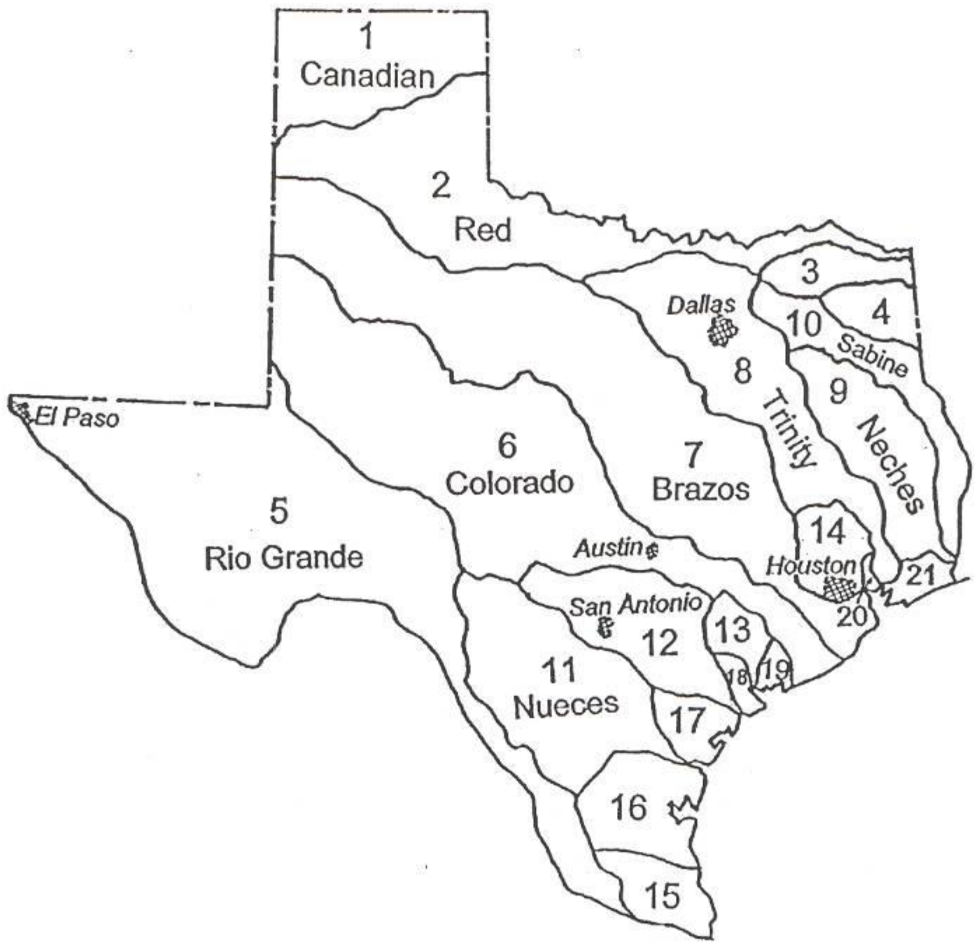


Figure 3.1 WAM System River Basins (Wurbs, 2015a)

Table 3.1 WAM System Datasets

Fig. 3.1 Map ID	Major River Basin or Coastal Basin	Period of Analysis	Number of Control Points: Total	with *IN* Records	with *EV* Records	Number of Reservoirs
1	Canadian River Basin	1948−1998	85	12	9	47
2	Red River Basin	1948−1998	447	47	40	245
3	Sulphur River Basin	1940−1996	83	8	4	53
4	Cypress Bayou Basin	1948−1998	189	10	11	91
5	Rio Grande Basin	1940−2000	957	55	25	113
6	Colorado River Basin and Brazos-Colorado Coastal Basin	1940−1998	2,395	45	25	511
7	Brazos River Basin and San Jacinto-Brazos Coastal Basin	1940−1997	3,830	77	67	670
8	Trinity River Basin	1940−1996	1,334	40	50	703
9	Neches River Basin	1940−1996	318	20	12	176
10	Sabine River Basin	1940−1998	376	27	20	207
11	Nueces River Basin	1934−1996	542	41	10	121
12	Guadalupe and San Antonio River Basins	1934−1989	1,349	46	11	237
13	Lavaca River Basin	1940−1996	185	7	7	22
14	San Jacinto River Basin	1940−1996	411	16	4	114
15	Lower Nueces-Rio Grande	1948−1998	119	16	3	42
16	Upper Nueces-Rio Grande	1948−1998	81	13	2	22
17	San Antonio-Nueces Coastal	1948−1998	53	9	3	9
18	Lavaca-Guadalupe Coastal Basin	1940−1996	68	2	2	0
19	Colorado-Lavaca Coastal Basin	1940−1996	111	1	1	8
20	Trinity-San Jacinto Coastal Basin	1940−1996	94	2	3	13
21	Neches-Trinity Coastal Basin	1940−1996	245	4	4	31
	Totals		13,272	498	313	3,435

3.2 TWDB Precipitation and Evaporation Datasets

Precipitation gages and evaporation pans have been maintained at many sites throughout Texas by many federal, state, and local agencies and individuals since the early 1900's. The periods-of-record of the observed data vary between sites. There are many more precipitation gages than evaporation pans. The Texas Water Development Board (TWDB) has compiled the available historical precipitation and pan evaporation data and developed monthly rates for the entire state by one-degree quadrangles of latitude and longitude for the period since 1940.

The TWDB also published 1940-1990 adjusted net evaporation rates that included effective precipitation adjusted for runoff at reservoir sites, but this dataset is no longer maintained. The TWDB maintains the statewide datasets of historical observed monthly precipitation depths and reservoir surface evaporation depths at the TWDB website (http://www.twdb.texas.gov/surfacewater/conditions/evaporation/index.asp).

The monthly precipitation and evaporation depths for the 92 one-degree quadrangles covering Texas as shown in Figure 3.2 date back to 1940 and are updated each year to add data for the preceding year. The TWDB datasets have been used in the past, along with other data in some cases, to develop the net evaporation less precipitation rates included in the TCEQ WAM System. The new methods applied in the Brazos WAM case study presented in this chapter use the TWDB evaporation and precipitation datasets to update the naturalized stream flow sequences as well as the net evaporation-precipitation rate sequences.

A total of 168 one-degree quadrangles covering an area extending 12 degrees longitude and 14 degrees latitude encompass adjacent surrounding land area along with Texas. Complete monthly precipitation and evaporation data for 1940 to near the present are available for the 92 one-degree quadrangles shown in Figure 3.2 that encompass the state. The datasets include an additional 76 quadrangles located outside of Texas, but there are periods of missing data for these quadrangles. The three or four digit quadrangle identifiers consist of the row and column numbers. The areas of each quadrangle are tabulated in Table 3.2. Although areas vary a little between quadrangles, each quadrangle encompasses about 4,000 square miles. The monthly precipitation and evaporation depths date back to 1940 and are updated each year about May to add data for January through December of the preceding year. The methodology for compiling evaporation data for 1940-1952 was somewhat different than the methodology that has been adopted for the evaporation data for 1953 to the present.

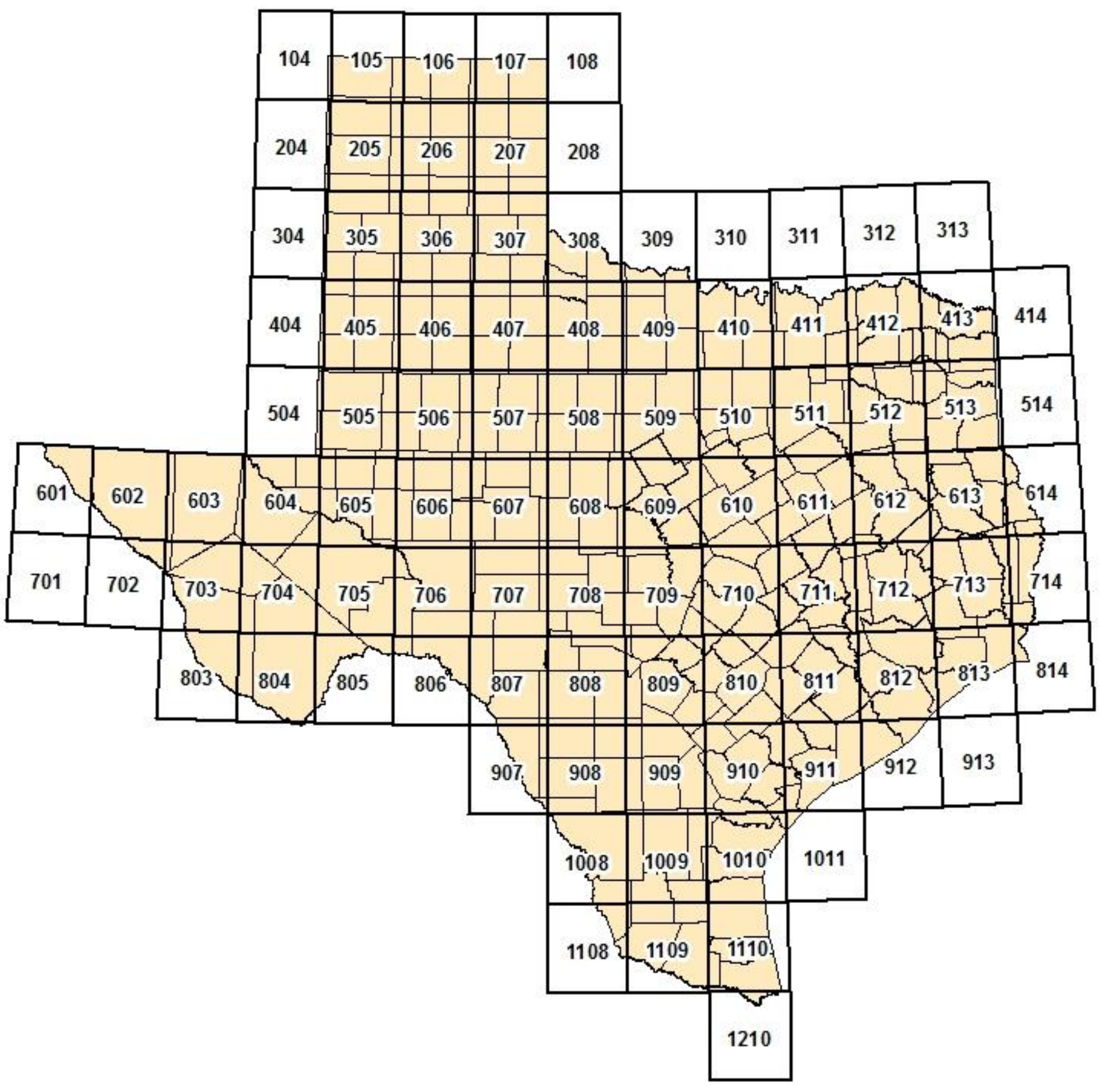


Figure 3.2 Quadrangle Map for TWDB Precipitation and Evaporation Datasets (Wurbs, 2013)

Table 3.2 Areas in Square Miles of 168 One-Degree Quadrangles

Quad ID	Area (sq miles)	Quad ID	Area (sq miles)	Quad ID	Area (sq miles)	Quad ID	Area (sq miles)
101	3,855.71	401	3,968.90	701	4,092.19	1001	4,226.81
102	3,855.71	402	3,968.78	702	4,092.19	1002	4,226.80
103	3,855.75	403	3,968.81	703	4,092.20	1003	4,226.81
104	3,855.77	404	3,968.79	704	4,092.17	1004	4,226.82
105	3,855.75	405	3,968.95	705	4,092.18	1005	4,226.83
106	3,855.68	406	3,968.89	706	4,092.14	1006	4,226.83
107	3,855.75	407	3,968.85	707	4,092.17	1007	4,226.83
108	3,855.74	408	3,968.84	708	4,092.14	1008	4,226.83
109	3,855.78	409	3,968.85	709	4,092.13	1009	4,226.81
110	3,855.70	410	3,968.84	710	4,092.16	1010	4,226.77
111	3,855.75	411	3,968.86	711	4,092.17	1011	4,226.82
112	3,855.70	412	3,968.87	712	4,092.16	1012	4,226.87
113	3,855.71	413	3,968.88	713	4,092.20	1013	4,226.87
114	3,855.71	414	3,968.77	714	4,092.22	1014	4,226.86
201	3,892.26	501	4,008.79	801	4,135.74	1101	4,274.40
202	3,892.31	502	4,008.76	802	4,135.72	1102	4,274.39
203	3,892.34	503	4,008.80	803	4,135.72	1103	4,274.40
204	3,892.34	504	4,008.80	804	4,135.74	1104	4,274.40
205	3,892.34	505	4,008.82	805	4,135.81	1105	4,274.40
206	3,892.38	506	4,008.75	806	4,135.74	1106	4,274.40
207	3,892.41	507	4,008.70	807	4,135.75	1107	4,274.39
208	3,892.37	508	4,008.73	808	4,135.77	1108	4,274.36
209	3,892.36	509	4,008.74	809	4,135.74	1109	4,274.39
210	3,892.31	510	4,008.76	810	4,135.70	1110	4,274.44
211	3,892.38	511	4,008.75	811	4,135.73	1111	4,274.46
212	3,892.46	512	4,008.70	812	4,135.77	1112	4,274.49
213	3,892.40	513	4,008.73	813	4,135.77	1113	4,274.48
214	3,892.36	514	4,008.75	814	4,135.71	1114	4,274.47
301	3,930.04	601	4,049.88	901	4,180.60	1201	4,323.42
302	3,929.98	602	4,049.88	902	4,180.60	1202	4,323.41
303	3,930.01	603	4,049.90	903	4,180.60	1203	4,323.41
304	3,930.01	604	4,049.91	904	4,180.62	1204	4,323.41
305	3,930.05	605	4,049.86	905	4,180.64	1205	4,323.41
306	3,930.06	606	4,049.82	906	4,180.62	1206	4,323.41
307	3,930.07	607	4,049.84	907	4,180.62	1207	4,323.41
308	3,930.02	608	4,049.90	908	4,180.60	1208	4,323.43
309	3,930.00	609	4,049.85	909	4,180.55	1209	4,323.46
310	3,930.00	610	4,049.88	910	4,180.53	1210	4,323.52
311	3,930.06	611	4,049.89	911	4,180.59	1211	4,323.55
312	3,930.13	612	4,049.87	912	4,180.64	1212	4,323.54
313	3,930.08	613	4,049.87	913	4,180.66	1213	4,323.53
314	3,930.06	614	4,049.87	914	4,180.65	1214	4,323.51

In developing the new WRAP/WAM hydrologic period-of-analysis extension capabilities, the precipitation and evaporation datasets for 1940-2016 were obtained from the TWDB as text files. Microsoft Excel was used to convert the two files to a consistent format. These files can be easily updated each year in the future as the TWDB adds the most recent calendar year monthly precipitation and evaporation depths to the dataset. The filenames Precipitation.PPP and Evaporation.EEE are adopted for the two text files that are read by the WRAP program HYD as input files.

Watershed areas are required for HYD to convert monthly precipitation and evaporation depths in inches to monthly volumes in acre-feet. The watershed above stream sites for which flows are synthesized may range from a portion of a single quadrangle to all or portions of multiple quadrangles. For example, the 45,000 square mile Brazos River Basin encompasses all or parts of 26 of the one-degree quadrangles. The areas of the 168 quadrangles are tabulated in Table 3.2 and are also coded into the HYD computer program.

Those quadrangles located partially or completely within the watershed of a control point are used to extend naturalized flows at that control point. For large watersheds, the quadrangles covering upper portions of the watershed that contribute little to flow at the control point may be omitted. The parameter calibration procedure described in the section 2.2 may also result in exclusion of some of the quadrangles in the watershed. The quadrangles contained within the watershed of the control point of the extended flows are listed on a QD record. The watershed areas located in each quadrangle are entered on a QA record.

3.3 Brazos WAM Dataset

The TCEQ WAM System combines the Brazos River Basin and adjoining San-Jacinto-Brazos Coastal Basin in the same dataset. The San Jacinto-Brazos Coastal Basin is much smaller than the Brazos River Basin. The San Jacinto-Brazos Coastal Basin lies south of Houston between the lower Brazos Basin and Galveston Bay as shown in Figures 3.1 and 3.3. The coastal basin has a watershed drainage area of 1,145 square miles and a mean annual precipitation of 46.3 inches. The small streams that drain into Galveston Bay and the Gulf of Mexico include Clear Creek, Oyster Creek, and Dickinson, Mustang, Chocolate, and Bastrop Bayous.

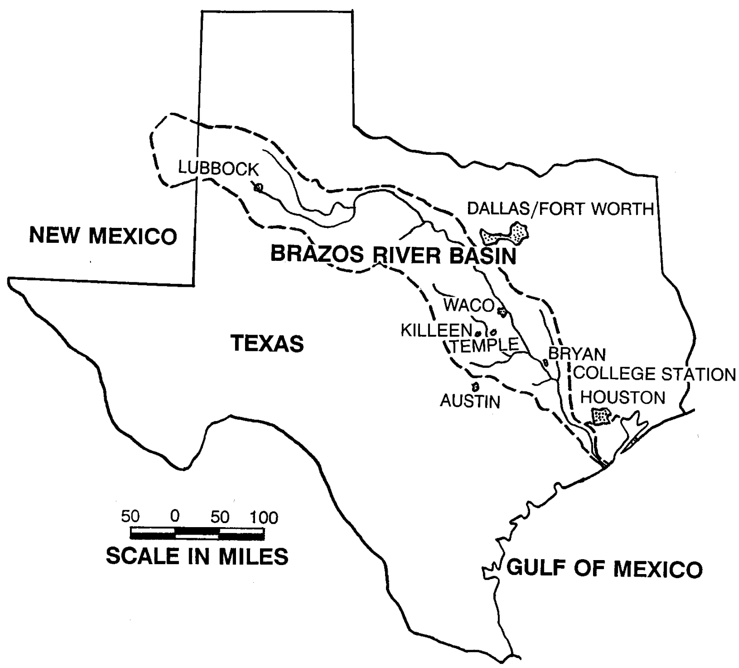


Figure 3.3 Brazos River Basin (Wurbs, 2015a)

The Brazos River Basin delineated in Figure 3.3 has a total area of 45,600 square miles, with about 43,000 square miles in Texas and the remainder in New Mexico. The extreme upper end of the basin in and near New Mexico is an arid flat area that rarely contributes to stream flow. The climate, hydrology, and geography of the basin vary greatly across Texas from New Mexico to the Gulf of Mexico. Mean annual precipitation varies from 19 inches in the upper basin which lies in the High Plains to 45 inches in the lower basin in the Gulf Coast region. The Brazos River flows in a meandering path about 920 miles from the confluence of the Salt Fork and Double Mountain Fork to the City of Freeport at the Gulf of Mexico. In its upper reaches, the Brazos River is a gypsum-salty intermittent stream. Toward the coast it is a rolling river flanked by levees, agricultural fields, and hardwood bottoms.

The 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 original Brazos WAM datasets is developed by several engineering firms under contract with Texas Natural Resource Conservation Commission (TNRCC) in 1998-2001.

Counts of system components for the August 2007 and September 2008 versions of the Brazos WAM are tabulated in Table 3.3. The flow extension deals only with the 77 primary control points with IN records and the 67 control points with EV records, which are the same in all versions of the Bwam datasets. All of the major reservoirs with greater than 5,000 acre-feet storage capacity are the same in the August 2007 and September 2008 versions, but the September 2008 updated datasets contain eight more small reservoirs than the datasets as last updated in August 2007.

Table 3.3 Number of System Components in Brazos WAM Datasets

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

Table 3.4 Brazos WAM Water Rights

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

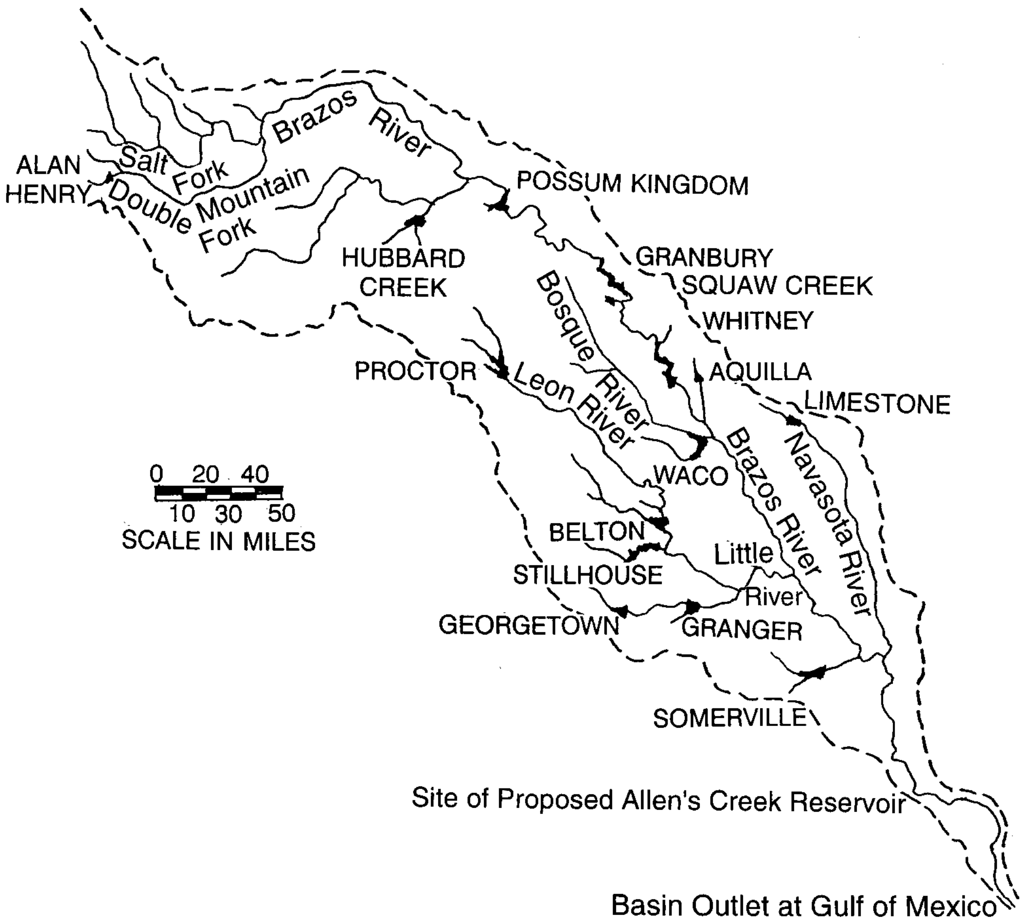


Figure 3.4 Major Tributaries and Largest Reservoirs in the Brazos River Basin (Wurbs, 2013)

The 16 largest reservoirs in the Brazos WAM are listed in the water rights summary of Table 3.4. Their locations are shown in Figure 3.4. The totals for the entire dataset are shown at the bottom of Table 3.4. The diversion targets associated with the 16 largest reservoirs account for about 39.7 percent and 31.7 percent of the total authorized diversion amounts for the Bwam3 and Bwam8 datasets. The storage capacity of the 16 largest reservoirs account for about 79.7 percent and 80.7 percent of the total storage capacity of the 678 and 719 reservoirs in the Bwam3 and Bwam8 datasets. Storage, releases, diversions, and return flows of the water right permit holders contribute to differences between gaged and naturalized stream flows.

3.3.1 Control Points for Naturalized Streamflows

Primary control points are locations at which naturalized stream flows are provided in a SIM input dataset. Naturalized flows at all other secondary control points are computed within the SIM simulation based on the naturalized flows provided at the primary control points and watershed parameters provided on DIS file flow distribution FD and watershed parameter WP records and/or DAT file control point CP records. The Brazos WAM has 77 primary control points for which January 1940 through December 1997 naturalized flows are provided on inflow IN records in the FLO file.

Naturalized flows are synthesized during execution of SIM for over 3,700 secondary control points based on information provided in a flow distribution DIS file. The combined drainage area ratio and channel loss factor method (CP record INMETHOD option 6) is used in the Brazos WAM for distributing flows to secondary control points. The drainage area method with or without channel losses is the standard option adopted in the TCEQ WAM System for the various river basins, though the DIS files contain the curve number and precipitation data required to switch to CP record INMETHOD options 4, 5, or 8.

The 77 primary control points for which naturalized flows are provided as IN records in the Brazos WAM input dataset are listed in Table 3.5 with the six-character identifiers used in the data files. The first 73 control points listed in Table 3.5 are located in the Brazos River Basin, and the last four are in the San Jacinto-Brazos Coastal Basin. The not-to-scale schematic of Figure 3.5 shows the upstream-to-downstream spatial configuration of the control points. The locations of the 77 control points and their watersheds are shown in Figure 3.6 along with the quadrangles that encompass the Brazos River Basin. The watershed drainage areas shown in Table 3.5 are from the DIS file WP records and do not include non-contributing areas of the upper basin.

Table 3.5 Primary Control Points in the Brazos WAM Datasets

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

Table 3.5 (continued)

WAM CP ID	Stream	Nearest City	USGS Gage No.	Watershed Area (sq miles)	USGS Period of Record
MBMG38	Middle Bosque River	McGregor	08095300	77	1959–present
HGCR39	Hog Creek	Crawford	08095400	181	1959–present
BOWA40	Bosque River	Waco	08095600	1,660	1959–1982
BRWA41	Brazos River	Waco	08096500	20,065	1898–present
BRHB42	Brazos River	Highbank	08098290	20,900	1965–present
LEDL43	Leon River	De Leon	08099100	267	1960–present
SADL44	Sabana River	De Leon	08099300	476	1960–present
LEHS45	Leon River	Hasse	08099500	1,283	1939–present
LEHM46	Leon River	Hamilton	08100000	1,928	1925–present
LEGT47	Leon River	Gatesville	08100500	2,379	1950–present
COPI48	Cowhouse Creek	Pidcoke	08101000	455	1950–present
LEBE49	Leon River	Belton	08102500	3,579	1923–present
LAKE50	Lampasas River	Kempner	08103800	817	1962–present
LAYO51	Lampasas River	Youngsport	08104000	1,240	1924–1980
LABE52	Lampasas River	Belton	08104100	1,321	1963–present
LRLR53	Little River	Little River	08104500	5,266	1923–present
NGGE54	North Fork San Gabriel	Georgetown	08104700	248	1968–present
SGGE55	South Fork San Gabriel	Georgetown	08104900	132	1967–present
GAGE56	San Gabriel River	Georgetown	08105000	404	1924–1987
GALA57	San Gabriel River	Laneport	08105700	737	1965–present
LRCA58	Little River	Cameron	08106500	7,100	1916–present
BRBR59	Brazos River	Bryan	08109000	30,016	1899–1993
MYDB60	Middle Yegua Creek	Dime Box	08109700	235	1962–present
EYDB61	East Yegua Creek	Dime Box	08109800	239	1962–present
YCSO62	Yegua Creek	Somerville	08110000	1,011	1924–1991
DCLY63	Davidson Creek	Lyons	08110100	195	1962–present
NAGR64	Navasota River	Groesbeck	08110325	240	1978–present
BGFR65	Big Creek	Freestone	08110430	97	1978–present
NAEA66	Navasota River	Easterly	08110500	936	1924–present
NABR67	Navasota River	Bryan	08111000	1,427	1951–1997
BRHE68	Brazos River	Hempstead	08111500	34,374	1938–present
MCBL69	Mill Creek	Bellville	08111700	377	1963–1993
BRRI70	Brazos River	Richmond	08114000	35,454	1903–present
BGNE71	Big Creek	Needville	08115000	46	1947–present
BRRO72	Brazos River	Rosharon	08116650	35,775	1967–present
BRGM73	Brazos River	Gulf of Mexico	–	36,027	–
CLPEC1	Clear Creek	Pearland	08077000	38.8	1944–1994
CBALC2	Chocolate Bayou	Alvin	08078000	87.7	1959–present
SJGBC3	Coastal Basin	Galveston Bay	–	415	–
SJGMC4	Coastal Basin	Gulf of Mexico	–	1,004	–

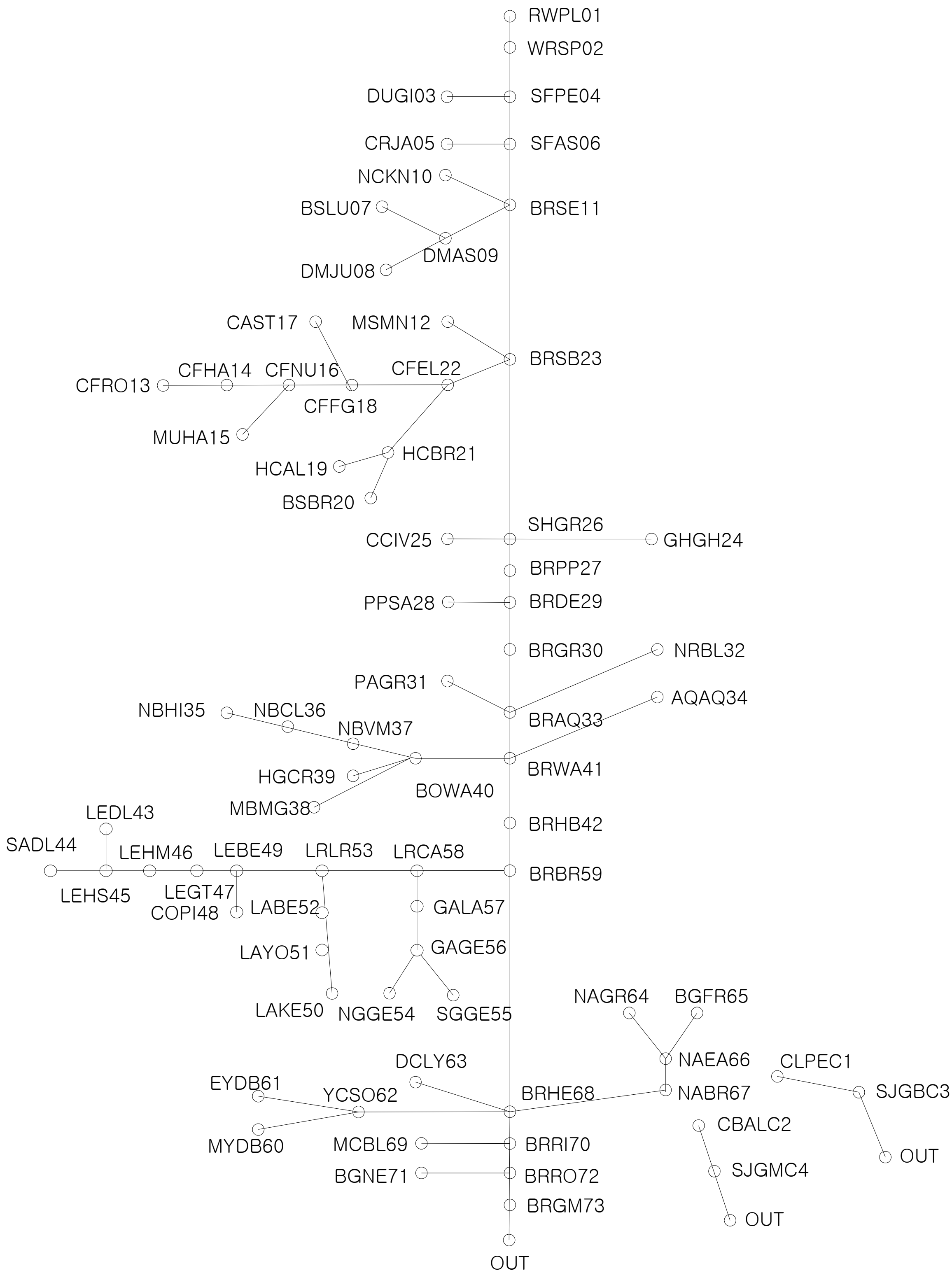


Figure 3.5 Schematic of Primary Control Points (Not to Scale)

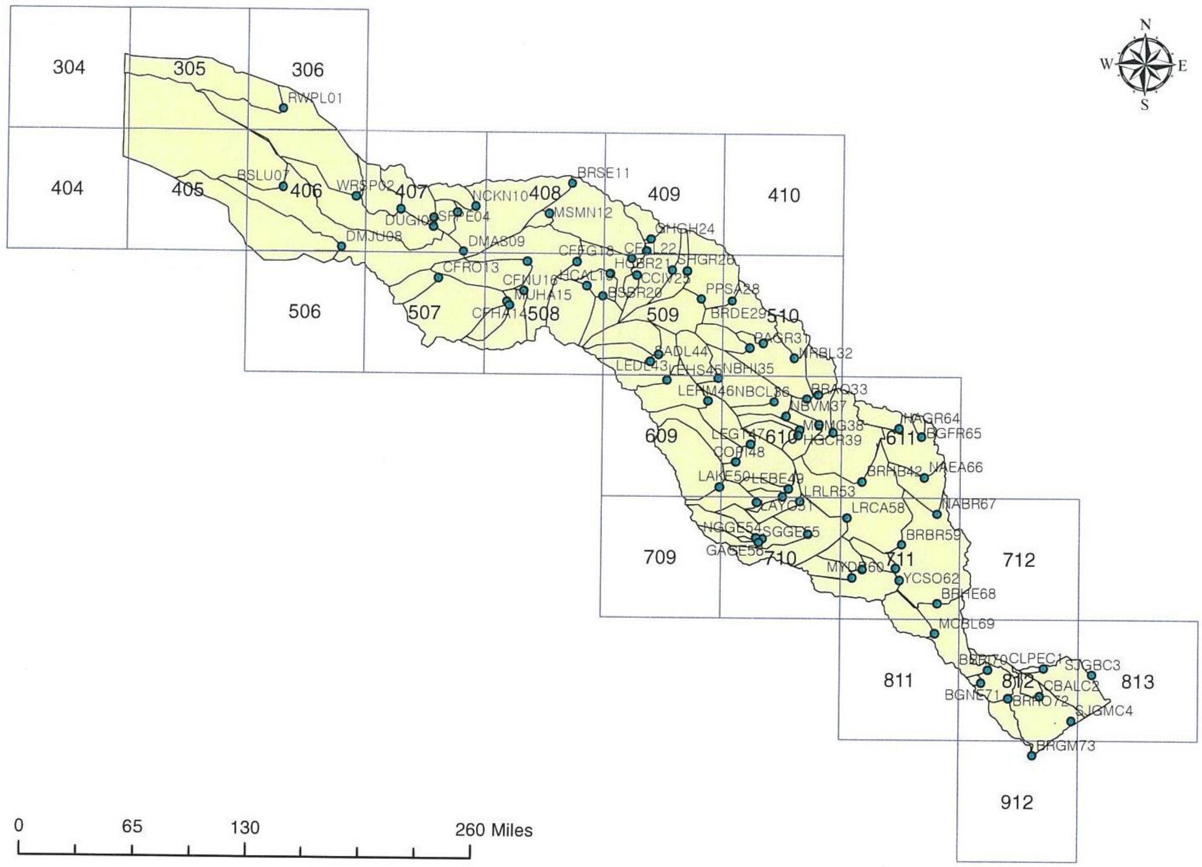


Figure 3.6 Quadrangles, Primary Control Points, and Watersheds

All but three of the 77 primary control points are U.S. Geological Survey (USGS) gaging stations located on the Brazos River and its tributaries. Control point BRGM73 represents the site at which the Brazos River flows into the Gulf of Mexico. Control points SJGBC3 and SJCMC4 represent locations at which coastal basin streams flow into Galveston Bay and the Gulf of Mexico. The other 74 control points are USGS gaging stations. For the original dataset developed during 1998-2001, IN record naturalized flows at the gaged control points were computed by adjusting observed flows. In cases of periods of missing data during 1940-1997, the missing naturalized flows at the gaged sites were filled in using regression.

The conventional approach of developing naturalized flows by adjusting gaged flows requires gaged flows. The discontinuation of stream gaging stations is a significant concern. The alternative proposed new method is particularly advantageous in situations where gages have been terminated. The new method is applied to all 77 primary control points in the same manner. The conventional flow adjustment approach is not applicable to control points without gaged flow records for the extension period 1998-2016, and thus flows at the sites of discontinued gages must be computed based on flows at the sites of observed flows.

The 77 primary control points in the Brazos WAM include the sites of 72 U.S. Geological Survey (USGS) stream gaging stations, two sites at which reservoir releases have been measured, and three ungaged basin outlets. The periods-of-analysis covered by the gaged data are listed in the last column of Table 3.4. Table 3.4 shows the beginning year and last year of data but does not show gaps or months of missing data during the period-of-record. The 72 USGS stream gaging stations can be categorized as follows.

21 of the stream gages have records that include 1940 to 1997.
19 of the stream gages have records that include 1940 to present.
49 of the stream gages have records that include 1998 to present.

A watershed area of the primary control point for which flow is synthesized may range from a portion of a single quadrangle to all or portions of multiple quadrangles. For large watersheds, the quadrangles covering upper portions of the watershed that contribute little to flow at the control point may be omitted. The parameter calibration procedure described in the section 2.3.6 may also result in exclusion of some of the quadrangles in the watershed. The quadrangles contained within the watershed of the control point of the extended flows are listed on a QD record. The watershed areas located in each quadrangle are entered on a QA record.

3.3.2 Control Points for Evaporation-Precipitation Rates

The TWDB compilation of evaporation and precipitation data is based on the one degree latitude and longitude quadrangles as shown in Figure 3.2. The quadrangles encompassing the Brazos River Basin are shown in Figure 3.6. The Brazos WAM EVA files contain EV records with January 1940 through December 1997 sequences of monthly net reservoir surface evaporation-precipitation depths at the 67 control points listed in Table 3.6, none of which are primary control points listed in Table 3.5. The location of control points are indicated in Table 3.6 either by the quadrangle identifier of the evaporation-precipitation data or by a major reservoir with its control point identifier assigned to the net evaporation data.

Table 3.6 Control Points Assigned to Reservoir Net Evaporation-Precipitation Depth Input

Control Point	Quadrangle
366631	305
368131	306
370431	405
368931	406
341131	407
341331	408
344801	409
371431	506
372031	507
413331	508
220131	509
227031	510
225331	609
228731	610
406331	611
299231	710
375931	711
531531	712
401041	812
516841	813

Control Point	Reservoir
414231	Abilene
4146P1	Alan Henry
527231	Alcoa
292531	Allen Creek
515831	Aquilla
293631	Belton
532842	Brazoria
526831	Bryan Utilities
370631	Buffalo Springs
530131	Camp Creek
421131	Cisco
421431	Daniel
344031	Davis
549231	Eagle Nest
416131	Fort Phantom Hill
516231	Georgetown
531131	Gibbons Creek
345831	Graham
515631	Granbury
516331	Granger
421331	Hubbard Creek
415031	Kirby
434531	Lake Creek
347031	Leon

Control Point	Reservoir
516531	Limestone
435533	Marlin City
528731	Mexia
344431	Millers Creek
403931	Mineral Wells
403131	Lake Palo Pinto
410631	Pat Cleburne
515531	Possum Kingdom
371131	Post
515931	Proctor
554032	Sandow Mine
532531	Smithers
516431	Somerville
409731	Squaw Creek
417931	Stamford
516131	Stillhouse Hollow
413031	Sweetwater
434231	Tradinghouse
529831	Twin oaks
231531	Waco
369331	White River
515731	Whitney
532841	William Harris

The 678 reservoirs in the Bwam3 dataset and 719 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 3.6. The first 20 control points listed in Table 3.5 serve as location identifiers for the one degree quadrangles that cover the Brazos River, which are shown on the Figure 3.6 map. The EVA file evaporation-precipitation depths are applied to multiple reservoirs located within each of these 20 quadrangles. The other control points in Table 3.6 are locations of large reservoirs.

The Brazos WAM dataset was developed during 1997-2001 by HDR Engineering, Inc. under contract with the TCEQ. HDR compiled 1940-1997 monthly net evaporation less precipitation depths as EV records stored in an EVA file. Observed data at precipitation gages and evaporation pans maintained near the ten reservoirs listed in Table 3.7 were obtained from the National Climatic Data Center and used in developing the WAM input for these reservoirs, supplemented with TWDB quadrangle data for periods of incomplete or missing records. TWDB quadrangle data were adopted for the numerous other reservoirs.

Table 3.7 Evaporation and Precipitation Stations Used by HDR for Ten Reservoirs

Reservoir	Evaporation Station	Beginning of Record	Precipitation Station	Beginning of record
Abilene	none		Lake Abilene	1960
Whitney	Whitney Dam	1952	Whitney Dam	1948
Waco	Waco Dam	1963	Waco Airport	1880
Proctor	Proctor Reservoir	1961	Proctor Reservoir	1961
Belton	Belton Dam	1962	Belton Dam	1962
Stillhouse	Stillhouse Dam	1962	Stillhouse Dam	1961
Georgetown	Georgetown Lake	1977	Georgetown Lake	1977
Granger	Granger Dam	1977	Granger Dam	1977
Somerville	Somerville Dam	1963	Somerville Dam	1963
Smithers	Thompsons 3	1956	Thompsons 3	1956

A weighted average for adjoining quadrangles was applied for reservoir sites extending into more than one quadrangle. The equations in Table 3.8 are from the 2001 HDR report. The equations shown in Table 3.8 were used for 39 of the reservoirs that have water surfaces located in either 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.

Eight other reservoirs are each assigned evaporation-precipitation rates for only one quadrangle as follows: Allen Creek (811), Brazoria (812), Bryan Utilities (711), Eagle Nest (812), Marlin (611), Post (406), Sandow Mine (710), and William Harris (812).

Table 3.8 Equations for Averaging Net Evaporation-Precipitation Depths for Major Reservoirs Lying in Multiple Quadrangles

	Reservoir	Quadrangle Weighting 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)

3.4 Extension of the 1940-1997 Hydrologic Period-of-Analysis to 1940-2016

The procedure outlined in the chapter 2 is applied to the Brazos WAM dataset described in the previous section. The case study in this chapter consists of extending the January 1940 through December 1997 hydrologic period-of-analysis of the Brazos WAM through December 2016. The final product is WRAP input FLO and EVA files with 1940-2016 sequences of monthly naturalized stream flows and reservoir evaporation-precipitation rates recorded on IN and EV records. The extended 1998-2016 series are combined with the original 1940-1997 sequences.

The comparative analyses of the Brazos WAM case study results demonstrate that the new extension methodologies yield valid results. Approximations are inherent in all aspects of the complex WRAP/WAM modeling system. The accuracy of the extended naturalized flows and evaporation-precipitation rates is consistent with the overall modeling system. The WRAP/WAM system is designed for quantifying water supply reliabilities and flow and storage frequency metrics rather than focusing on predicting quantities in specific months of the simulation. Likewise, the extended stream flow and evaporation-precipitation sequences effectively reproduce relevant statistical characteristics.

The methodology for updating SIM hydrology input data is described in the Chapter 2. The computational procedures are incorporated in the WRAP program HYD. The TWDB datasets of monthly precipitation depths and evaporation depths for all of the quadrangles encompassing the state of Texas are stored in two files which are read by HYD as input files with filenames Precipitation.PPP and Evaporation.EEE, respectively. These files currently contain statewide monthly data for 1940-2016 that can be easily updated each year in the future following the TWDB annual updates of the databases.

A FLO file with 1940-2016 naturalized flows is created by executing HYD with the following input files.

HIN file controlling the 1998-2016 naturalized flow extension
FLO file from Brazos WAM with 1940-1997 naturalized flows
Evaporation.EEE file with TWDB statewide 1940-2016 evaporation data
Precipitation.PPP file with TWDB statewide 1940-2016 precipitation data

An EVA file with 1940-2016 net evaporation-precipitation rates is created by executing HYD with the following input files.

HIN file controlling the 1998-2016 evaporation-precipitation update
EVA file from Brazos WAM with 1940-1997 evaporation-precipitation rates
Evaporation.EEE file with TWDB statewide 1940-2016 evaporation data
Precipitation.PPP file with TWDB statewide 1940-2016 precipitation data

The WRAP program HYD consists of an assortment of routines designed to facilitate developing and updating the naturalized flows (IN records in a FLO file) and net evaporation-precipitation rates (EV records in an EVA file) included in SIM input datasets. The results of applying new features of HYD in updating net evaporation-precipitation rates for the Brazos WAM are presented in the section 3.5. The section 3.6 explores the results of applying the new HYD capabilities for extending naturalized flows.

3.5 Extension of the Net Evaporation-Precipitation Rates

3.5.1 Summary and Procedure

For the Brazos WAM, the 67 control points to which reservoir surface net evaporation-precipitation rates are assigned are listed in Table 3.6. Twenty control points reference the 20 quadrangles encompassing the Brazos River Basin and San Jacinto-Brazos Coastal Basin. The other 47 control points refer to the locations of 49 large reservoirs. Eight of the specific reservoir control points are connected to single quadrangles. Thirty-nine of the control points for individual reservoirs are connected to combinations of two or four quadrangles as indicated in Table 3.8.

The new capabilities outlined in the previous chapter are to periodically update the monthly net reservoir surface evaporation less precipitation depths on EV records using the TWDB precipitation and evaporation dataset by subtracting precipitation depths from evaporation depths. The precipitation and evaporation dataset obtained from TWDB as text files are converted to a consistence format with filenames Precipitation.PPP and Evaporation.EEE using Microsoft Excel.

The new EE record extends a WRAP-SIM input EVA file of sequences of net evaporation-precipitation depths. The EE record also facilitates otherwise organizing and using the TWDB precipitation and evaporation datasets. QD and QA records designate quadrangles and areas used in the routines activated by EE records.

The original 1940-1997 net evaporation-precipitation rates are read by HYD from an input file. HYD creates an output file with filename extension EVA with 1998-2016 net evaporation-precipitation rates that is designed to be read by SIM as an input file. The 1998-2016 monthly net evaporation-precipitation rates are computed from HYD from the TWDB datasets without reference to the preceding 1940-1997 sequences. The final net evaporation-precipitation depths adopted for the updated EVA file consists of 1940-1997 monthly quantities from the original Brazos WAM dataset combined with the 1998-2016 monthly depths compiled with HYD from the TWDB datasets.

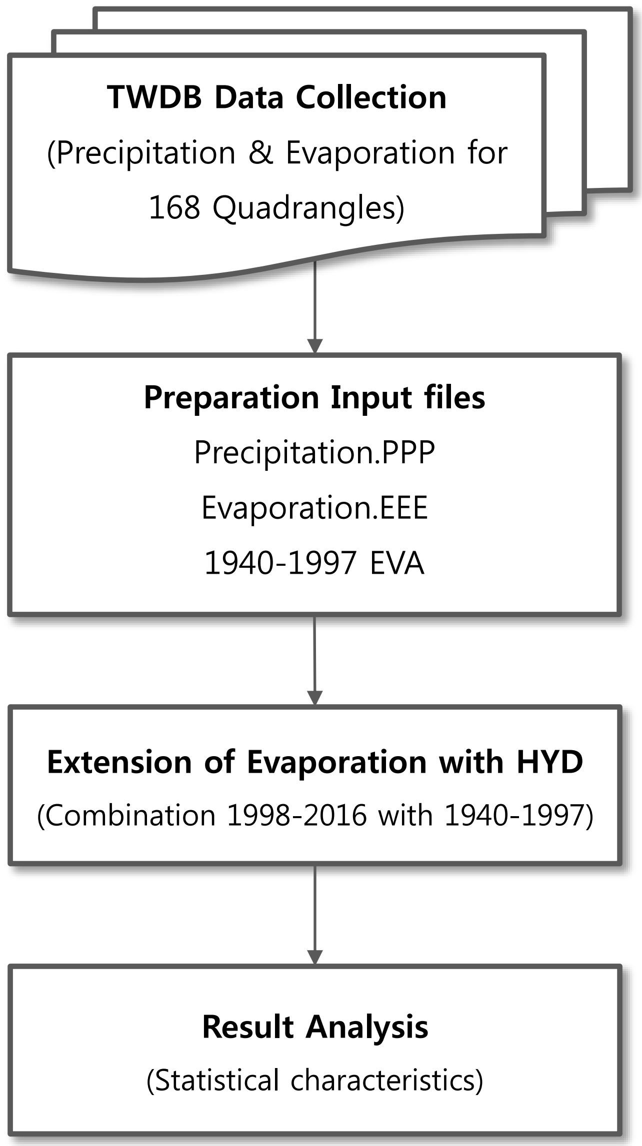


Figure 3.7 A procedure of Evaporation Extension

3.5.2 HYD Input HIN File for Extending Evaporation-Precipitation Rates

The HYD input HIN file for updating the SIM EVA input file is reproduced as Table 3.9. The job control JC and control point CP records control reading the 1940-1997 net evaporation-precipitation rates from the EVA file from the WAM dataset and creating either a new EVA file or a DSS file containing the extended evaporation-precipitation rates compiled by HYD.

An EE record is provided for each of the 67 control points to control the data manipulations. Evaporation and precipitation depths are read from the Evaporation.EEE and Precipitation.PPP files. Precipitation depths are subtracted from evaporation depths to obtain the quantities recorded on the EV records. One pair of QD and QA records is required for each control point. The weighted average equations shown in Table 3.8 were used for 37 reservoir sites extending into more than one quadrangles. The rates read from the Evaporation.EEE and Precipitation.PPP files are in units of inches/month. The rates recorded on the EV records are in feet/month.

The HIN file of Table 3.9 controls the combining of 1998-2016 net evaporation-precipitation rates compiled by HYD using quantities read from the Evaporation.EEE and Precipitation.PPP files with 1940-1997 net evaporation-precipitation rates read by HYD from the WAM EVA file for the 67 control points.

Table 3.9 HYD Input HIN File for Extending Evaporation-Precipitation Rates

```
**  WRAP-HYD Input File for Brazos WAM Evaporation-Precipitation Extension
**      1       2       3       4       5
**3456789012345678901234567890123456789012
**    !   !   !   !   !   !   !   !   !   !   !   !
JC  1940  58   1   0   1                       1
CP366631
CP368131
CP370431
CP368931
CP341131
CP341331
CP344801
CP371431
CP372031
CP413331
CP220131
CP227031
```

Table 3.9 (Continued)

CP225331						
CP228731						
CP406331						
CP299231						
CP375931						
CP531531						
CP401041						
CP516841						
CP414231						
CP4146P1						
CP527231						
CP292531						
CP515831						
CP293631						
CP532842						
CP526831						
CP370631						
CP530131						
CP421131						
CP421431						
CP344031						
CP549231						
CP416131						
CP516231						
CP531131						
CP345831						
CP515631						
CP516331						
CP421331						
CP415031						
CP434531						
CP347031						
CP516531						
CP435533						
CP528731						
CP344431						
CP403931						
CP403131						
CP410631						
CP515531						
CP371131						
CP515931						
CP554032						
CP532531						
CP516431						
CP409731						
CP417931						
CP516131						
CP413031						
CP434231						
CP529831						
CP231531						
CP369331						
CP515731						
CP532841						
EE366631	305	1997	2016	1	1.0833333	TWDB
EE368131	306					
EE370431	405					
EE368931	406					
EE341131	407					
EE341331	408					
EE344801	409					
EE371431	506					
EE372031	507					
EE413331	508					
EE220131	509					
EE227031	510					
EE225331	609					
EE228731	610					
EE406331	611					

Table 3.9 (Continued)

```
EE299231    710
EE375931    711
EE531531    712
EE401041    812
EE516841    813
EE292531    813                                             Allen Creek
EE532842    812                                             Brazoria
EE526831    711                                             Bryan Utilities
EE549231    812                                             Eagle Nest
EE435533    611                                             Marlin City
EE371131    406                                             Post
EE554032    710                                             Sandow Mine
EE532841    812                                             William Harris
EE414231                                                   Abilene
QD   4     507     508     607     608
QA   3   0.277   0.464   0.175   0.184
EE4146P1                                                   Alan Henry
QD   4     406     407     506     507
QA   3   0.097   0.115   0.170   0.618
EE527231                                                   Alcoa
QD   4     610     611     710     711
QA   3    .153    .146    .391    .309
EE515831                                                   Aquilla
QD   4     510     511     610     611
QA   3    .262    .196    .321    .221
EE293631                                                   Belton
QD   4     609     610     709     710
QA   3    .171    .421    .151    .257
EE370631                                                   Buffalo Springs
QD   4     305     306     405     507
QA   3   0.097   0.115   0.170   0.618
EE530131                                                   Camp Creek
QD   4     611     612     711     712
QA   3    .338    .197    .284    .182
EE421131                                                   Cisco
QD   4     407     408     507     508
QA   3    .188    .339    .176    .297
EE421431                                                   Daniel
QD   4     408     409     508     509
QA   3    .142    .158    .255    .446
EE344031                                                   Davis
QD   2     407     408
QA   3   0.267   0.733
EE416131                                                   Fort Phantom Hill
QD   4     407     408     507     508
QA   3   0.103   0.126   0.168   0.602
EE516231                                                   Georgetown
QD   4     609     610     709     710
QA   3    .128    .158    .200    .514
EE531131                                                   Gibbons Creek
QD   4     611     612     711     712
QA   3    .168    .162    .359    .310
EE345831                                                   Graham
QD   4     408     409     508     509
QA   3    .193    .410    .159    .237
EE515631                                                   Granbury
QD   4     509     510     609     610
QA   3    .199    .556    .112    .132
EE516331                                                   Granger
QD   4     610     611     710     711
QA   3    .157    .117    .557    .169
EE421331                                                   Hubbard Creek
QD   4     408     409     508     509
QA   3    .194    .194    .299    .313
EE415031                                                   Kirby
QA   4     507     508     607     608
QA   3   0.193   0.550   0.116   0.141
EE434531                                                   Lake Creek
QD   2     610     611
QA   3    .480    .520
```

Table 3.9 (Continued)

```
EE347031                                          Leon
QD  4    508    509    608    609
QA  3   .266   .42    .15    .165
EE516531                                          Limestone
QD  4    611    612    711    712
QA  3   .655   .143   .113   .089
EE528731                                          Mexia
QD  4    510    511    610    611
QA  3   .064   .086   .094   .755
EE344431                                          Millers Creek
QD  4    408    409    508    509
QA  3  0.708  0.118  0.098  0.076
EE403931                                          Mineral Wells
QD  4    409    410    509    510
QA  3   .206   .195   .312   .287
EE403131                                          Lake Palo Pinto
QD  4    409    410    509    510
QA  3   .137   .108   .586   .170
EE410631                                          Pat Cleburne
QD  4    510    511    610    611
QA  3   .577   .154   .157   .112
EE515531                                          Possum Kingdom
QD  2    409    509
QA  3   .386   .614
EE515931                                          Proctor
QD  2    509    609
QA  3   .511   .489
EE532531                                          Smithers
QD  2    811    812
QA  3   .144   .856
EE516431                                          Somerville
QD  4    710    711    811    811
QA  3   .150   .592   .108   .150
EE409731                                          Squaw Creek
QD  4    509    510    609    610
QA  3   .218   .468   .142   .173
EE417931                                          Stamford
QD  4    407    408    507    508
QA  3  0.188  0.339  0.176  0.297
EE516131                                          Stillhouse Hollow
QD  4    609    610    709    710
QA  3   .175   .329   .168   .329
EE413031                                          Sweetwater
QD  4    507    508    607    608
QA  3  0.633  0.158  0.114  0.094
EE434231                                          Tradinghouse Creek
QD  2    610    611
QA  3   .480   .520
EE529831                                          Twin oaks
QD  2    611    711
QA  3   .724   .276
EE231531                                          Waco
QD  4    510    511    610    611
QA  3   .138   .119   .528   .215
EE369331                                          White River
QD  2    406    407
QA  3  0.589  0.411
EE515731                                          Whitney
QD  4    510    511    610    611
QA  3   .296   .169   .355   .180
ED
```

3.5.3 The Results of Extending Evaporation-Precipitation Rates

The 1940-1997 monthly net evaporation-precipitation depths in the original Brazos WAM dataset are compared in Table 3.10 with the corresponding 1940-1997 and 1940-2016 depths computed with HYD based on TWDB dataset. HYD also includes options for recording the evaporation rates, precipitation rates, and/or net evaporation-precipitations rates in a DSS file to be read with HEC-DSSVue. The time series plots presented in this section were prepared with HEC-DSSVue. HYD also includes options for creating summary tables showing means and ranges.

Means, minimum values, and maximum values in feet/month of the monthly evaporation-precipitation rates are tabulated. The 1940-1997 evaporation-precipitation rates computed with HYD from the TWDB datasets are identical to the original Brazos WAM quantities at 41 of the 67 control points and are almost identical at two other control points. Differences in many months occur at 24 of the control points. As previously noted, observed data collected near the reservoirs were used in the original WAM dataset for the ten reservoirs listed in Table 3.7. Other differences may be due to either TWDB refinements to the statewide evaporation and precipitation datasets or HDR refinements during creation of the Brazos WAM dataset.

Figures 3.8-3.21 are HEC-DSSVue plots for 14 of the largest reservoirs. The 1940-1997 monthly and aggregated annual net evaporation-precipitation depths in the original Brazos WAM dataset are plotted as dashed red lines in Figures 3.8-3.21 along with the 1940-2016 depths computed with HYD from the TWDB datasets shown as solid blue lines.

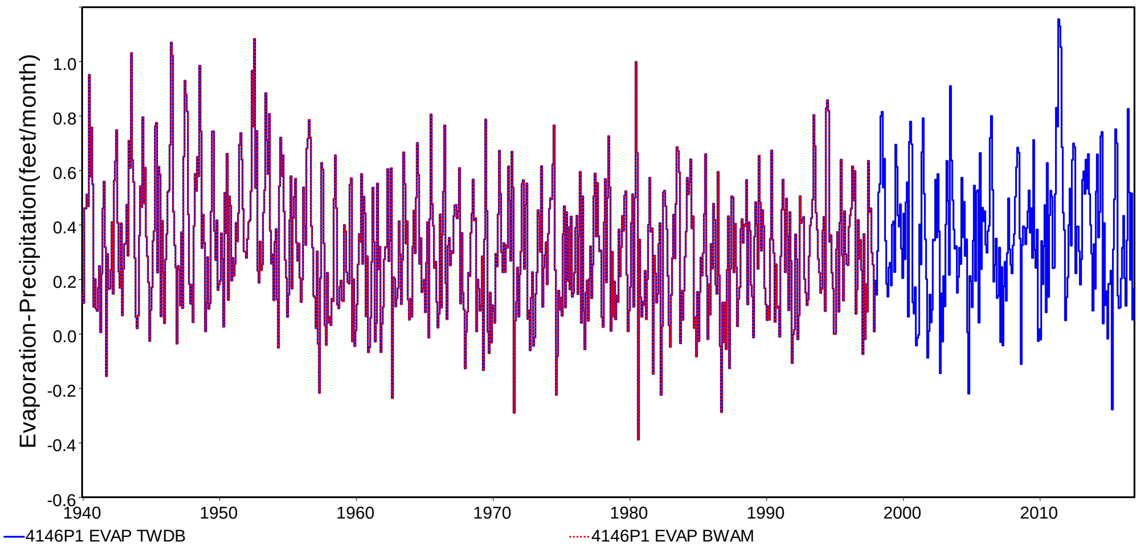
Figures 3.8 through 3.21 all include plots of both the 1940-2016 net evaporation less precipitation rates compiled with *HYD* and the *EV* record 1940-1997 monthly quantities from the EVA file of the original Brazos WAM dataset. However, in some cases the two datasets are identical for 1940-1997 making the two plots look like only one plot. The 1940-2016 evaporation-precipitation rates compiled with *HYD* are plotted as solid blue lines. The original WAM 1940-1997 evaporation-precipitation rates are plotted as dashed red lines.

Table 3.10 Means and Ranges of 1940-1997 and 1940-2016 Evaporation-Precipitation Rates

		1940-1997 Net Evaporation-Precipitation rate						1940-2016 Net EV		
Control Point	Quadrangle or Reservoir	WAM Mean (ft/mon)	WAM Min (ft/mon)	WAM Max (ft/mon)	TWDB Mean (ft/mon)	TWDB Min (ft/mon)	TWDB Max (ft/mon)	TWDB Mean (ft/mon)	TWDB Min (ft/mon)	TWDB Max (ft/mon)
366631	305	0.3216	-0.2400	0.9830	0.3215	-0.2400	0.9833	0.3313	-0.2933	1.0825
368131	306	0.3120	-0.2130	1.0340	0.3120	-0.2125	1.0342	0.3250	-0.6267	1.0342
370431	405	0.3216	-0.2400	0.9830	0.3386	-0.6933	1.0758	0.3452	-0.6933	1.1550
368931	406	0.3053	-0.4440	1.1330	0.3052	-0.4442	1.1333	0.3249	-0.6058	1.1333
341131	407	0.3184	-0.3920	1.1090	0.3183	-0.3917	1.1092	0.3339	-0.3942	1.2958
341331	408	0.2815	-0.5000	1.1980	0.2815	-0.5000	1.1975	0.2871	-0.6917	1.1975
344801	409	0.2262	-0.6580	1.3580	0.2262	-0.6575	1.3583	0.2329	-1.1308	1.3583
371431	506	0.3411	-0.3090	1.0960	0.3410	-0.3092	1.0958	0.3538	-0.3092	1.1933
372031	507	0.3022	-0.5520	1.1130	0.3021	-0.5517	1.1125	0.3117	-0.5517	1.2017
413331	508	0.2785	-0.5800	1.2770	0.2784	-0.5800	1.2767	0.2780	-0.5800	1.2767
220131	509	0.2364	-0.8340	1.2380	0.2364	-0.8342	1.2375	0.2284	-0.8508	1.2375
227031	510	0.1912	-0.7240	1.1170	0.1912	-0.7242	1.1167	0.1838	-0.9150	1.1167
225331	609	0.0308	-0.4190	0.3480	0.2256	-0.5092	1.0675	0.2181	-0.5983	1.0675
228731	610	0.1818	-0.7130	1.0180	0.1818	-0.7125	1.0175	0.1790	-0.7125	1.0175
406331	611	0.1421	-0.7440	1.1460	0.1421	-0.7442	1.1458	0.1458	-0.7442	1.1458
299231	710	0.1519	-0.8020	1.3300	0.1519	-0.8017	1.3300	0.1476	-0.8083	1.3300
375931	711	0.0888	-0.7940	0.7980	0.0888	-0.7942	0.7983	0.0941	-0.7942	0.7983
531531	712	0.0131	-0.9920	0.5980	0.0132	-0.9917	0.5983	0.0236	-0.9917	0.6942
401041	812	-0.0047	-0.9390	0.5830	-0.0048	-0.9392	0.5825	-0.0031	-0.9908	0.5825
516841	813	-0.0144	-0.9860	0.5700	-0.0144	-0.9858	0.5700	-0.0220	-0.9950	0.5700
414231	Abilene	0.2985	-0.3850	1.1770	0.2967	-0.4027	1.1860	0.2989	-0.4027	1.1860
4146P1	Alan Henry	0.3109	-0.3880	1.0830	0.3109	-0.3884	1.0826	0.3227	-0.3884	1.1553
527231	Alcoa	0.1354	-0.6580	0.8710	0.1355	-0.6587	0.8718	0.1356	-0.7337	0.8718
292531	Allen Creek	0.0392	-0.7160	0.6290	-0.0144	-0.9858	0.5700	-0.0220	-0.9950	0.5700
515831	Aquilla	0.1658	-0.7510	0.9540	0.1658	-0.7515	0.9542	0.1640	-0.7515	0.9542
293631	Belton	0.1437	-0.9520	0.8570	0.1820	-0.6559	0.9914	0.1780	-0.6597	0.9914
532842	Brazoria	0.0512	-0.7840	0.5890	-0.0048	-0.9392	0.5825	-0.0031	-0.9908	0.5825
526831	Bryan Utilities	0.1011	-0.7200	0.7950	0.0888	-0.7942	0.7983	0.0941	-0.7942	0.7983
370631	Buffalo Springs	0.3104	-0.3460	1.0790	0.3113	-0.2751	1.0812	0.3208	-0.2751	1.0812
530131	Camp Creek	0.0848	-0.7880	0.7710	0.0847	-0.7869	0.7702	0.0915	-0.7869	0.7776
421131	Cisco	0.1945	-0.3980	0.8650	0.2911	-0.3446	1.1628	0.2975	-0.4827	1.1628
421431	Daniel	0.2521	-0.6390	1.2620	0.2519	-0.6379	1.2609	0.2501	-0.7648	1.2609
344031	Davis	0.2913	-0.4340	1.1360	0.2913	-0.4344	1.1361	0.2996	-0.6122	1.1645
549231	Eagle Nest	0.0320	-0.8370	0.5600	-0.0048	-0.9392	0.5825	-0.0031	-0.9908	0.5825
416131	Fort Phantom Hill	0.2866	-0.4430	1.2060	0.2869	-0.4436	1.2072	0.2906	-0.4436	1.2072

Table 3.10 (Continued)

Control Point	Quadrangle or Reservoir	1940-1997 Net Evaporation-Precipitation rate WAM Mean (ft/mon)	WAM Min (ft/mon)	WAM Max (ft/mon)	TWDB Mean (ft/mon)	TWDB Min (ft/mon)	TWDB Max (ft/mon)	1940-2016 Net EV TWDB Mean (ft/mon)	TWDB Min (ft/mon)	TWDB Max (ft/mon)
516231	Georgetown	0.1243	-0.7710	1.0310	0.1726	-0.7088	0.9789	0.1685	-0.7344	0.9789
531131	Gibbons Creek	0.0673	-0.8290	0.7060	0.0674	-0.8296	0.7068	0.0750	-0.8296	0.7400
345831	Graham	0.2473	-0.5840	1.2840	0.2476	-0.5849	1.2856	0.2495	-0.8678	1.2856
515631	Granbury	0.1808	-0.5800	0.9960	0.2028	-0.6393	1.1139	0.1959	-0.8188	1.1139
516331	Granger	0.1432	-1.0850	0.9970	0.1448	-0.6964	0.9966	0.1433	-0.7417	0.9966
421331	Hubbard Creek	0.2557	-0.5980	1.2650	0.2557	-0.5983	1.2649	0.2555	-0.7480	1.2649
415031	Kirby	0.2924	-0.4430	1.2060	0.2557	-0.5983	1.2649	0.2555	-0.7480	1.2649
434531	Lake Creek	0.1611	-0.7290	1.0840	0.1611	-0.7290	1.0842	0.1617	-0.7290	1.0842
347031	Leon	0.2235	-0.5140	1.0330	0.2554	-0.6119	1.2039	0.2508	-0.6119	1.2039
516531	Limestone	0.1109	-0.7240	0.9540	0.1109	-0.7239	0.9535	0.1165	-0.7239	0.9535
435533	Marlin City	0.1455	-0.7040	0.9810	0.1421	-0.7442	1.1458	0.1458	-0.7442	1.1458
528731	Mexia	0.1480	-0.7490	1.0800	0.1481	-0.7499	1.0816	0.1503	-0.7499	1.0816
344431	Millers Creek	0.2709	-0.4580	1.2260	0.2712	-0.4590	1.2273	0.2753	-0.7298	1.2273
403931	Mineral Wells	0.2047	-0.7260	1.1480	0.2047	-0.7258	1.1476	0.2032	-0.9648	1.1476
403131	Lake Palo Pinto	0.2183	-0.7660	1.1900	0.2181	-0.7654	1.1892	0.2141	-0.9210	1.1892
410631	Pat Cleburne	0.1751	-0.7450	1.0250	0.1751	-0.7455	1.0250	0.1710	-0.7964	1.0250
515531	Possum Kingdom	0.2324	-0.7660	1.2840	0.2324	-0.7660	1.2841	0.2301	-0.9589	1.2841
371131	Post	0.4469	-0.3710	1.5360	0.3052	-0.4442	1.1333	0.3249	-0.6058	1.1333
515931	Proctor	0.1734	-0.8200	0.8880	0.2311	-0.6395	1.1544	0.2234	-0.7274	1.1544
554032	Sandow Mine	0.1354	-0.6580	0.8710	0.1519	-0.8017	1.3300	0.1476	-0.8083	1.3300
532531	Smithers	0.0043	-0.8740	0.5930	0.0043	-0.8740	0.5932	0.0059	-0.9984	0.5932
516431	Somerville	0.0787	-1.3180	0.7550	0.0904	-0.6845	0.7519	0.0932	-0.6978	0.7519
409731	Squaw Creek	0.1768	-0.5510	0.9610	0.2043	-0.6244	1.1081	0.1975	-0.7935	1.1081
417931	Stamford	0.2911	-0.3450	1.1630	0.2911	-0.3446	1.1628	0.2975	-0.4827	1.1628
516131	Stillhouse Hollow	0.1382	-0.8130	0.7860	0.1801	-0.6687	0.9831	0.1760	-0.6819	0.9831
413031	Sweetwater	0.3014	-0.4630	1.1400	0.3017	-0.4637	1.1410	0.3076	-0.4637	1.1410
434231	Tradinghouse Creek	0.1611	-0.7290	1.0840	0.1611	-0.7290	1.0842	0.1617	-0.7290	1.0842
529831	Twin oaks	0.1274	-0.7350	0.9850	0.1274	-0.7354	0.9853	0.1316	-0.7354	0.9853
231531	Waco	0.1709	-0.8700	0.9880	0.1686	-0.7385	0.9881	0.1671	-0.7385	0.9881
369331	White River	0.3106	-0.3350	1.0940	0.3106	-0.3347	1.0939	0.3286	-0.3991	1.1563
515731	Whitney	0.1709	-0.7240	1.0030	0.1690	-0.7466	0.9674	0.1668	-0.7466	0.9674
532841	William Harris	0.0294	-0.8440	0.5560	-0.0048	-0.9392	0.5825	-0.0031	-0.9908	0.5825



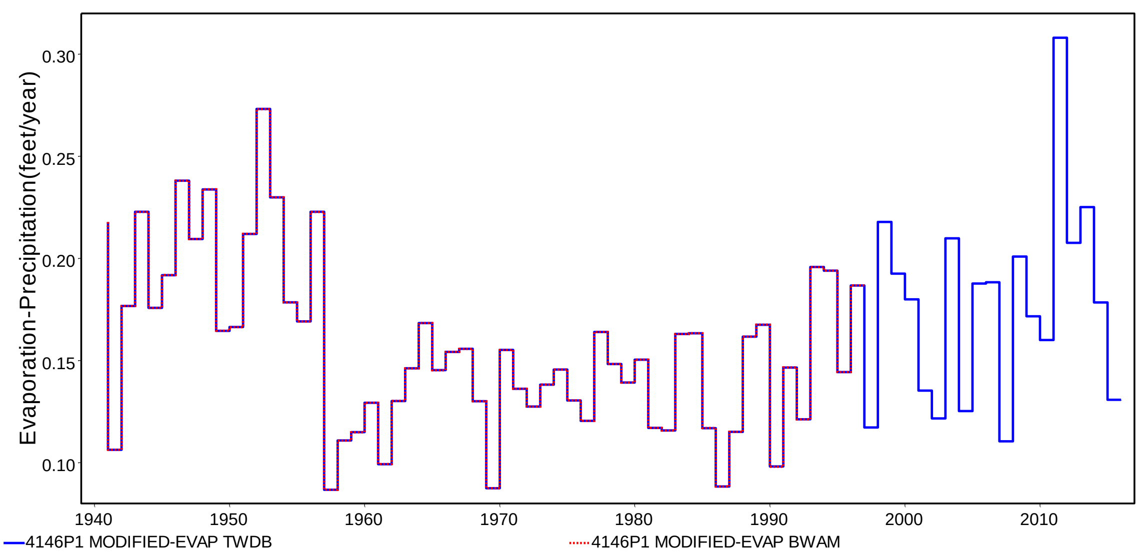
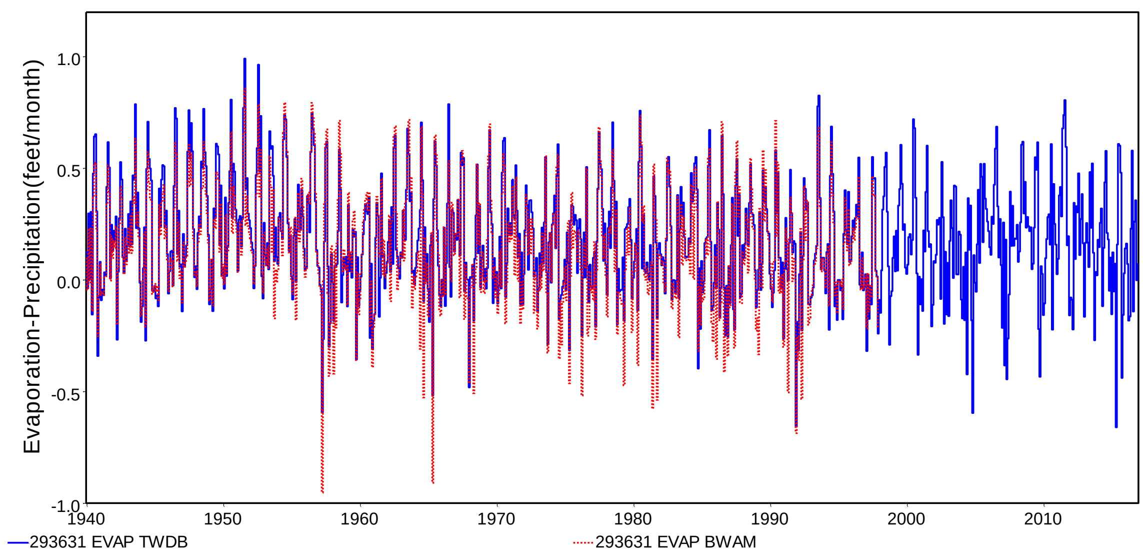


Figure 3.8 Monthly and Annual Net Evaporation-Precipitation Depths at Alan Henry Reservoir at Control Point 4146P1



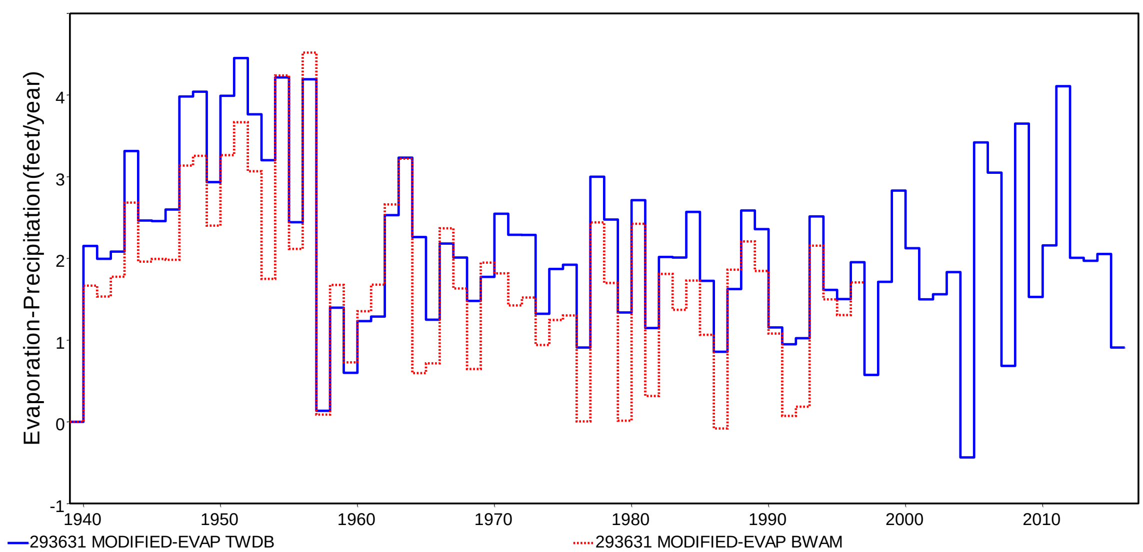
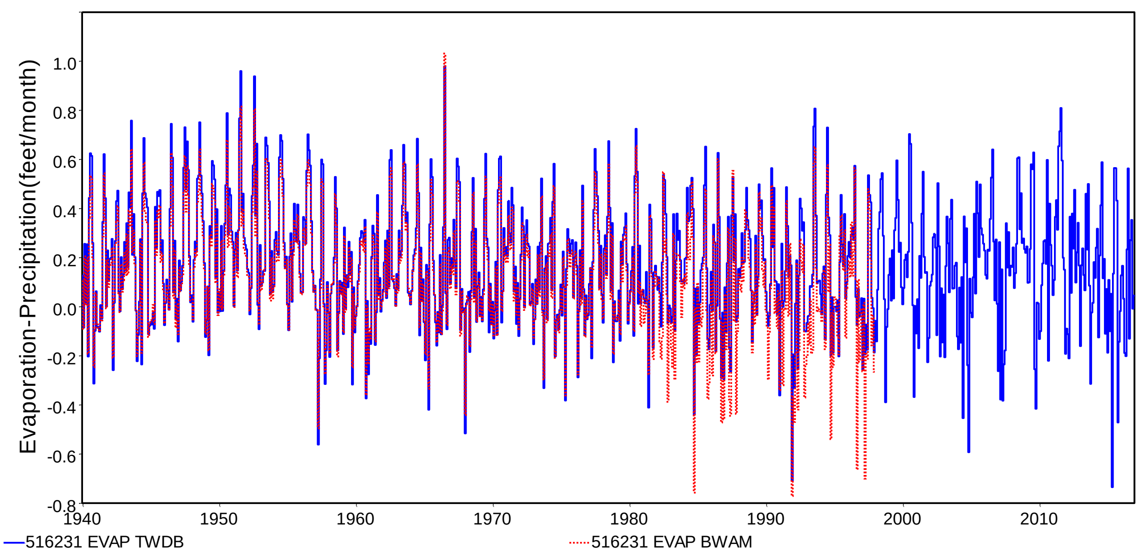


Figure 3.9 Monthly and Annual Net Evaporation-Precipitation Depths at Belton Reservoir at Control Point 293631



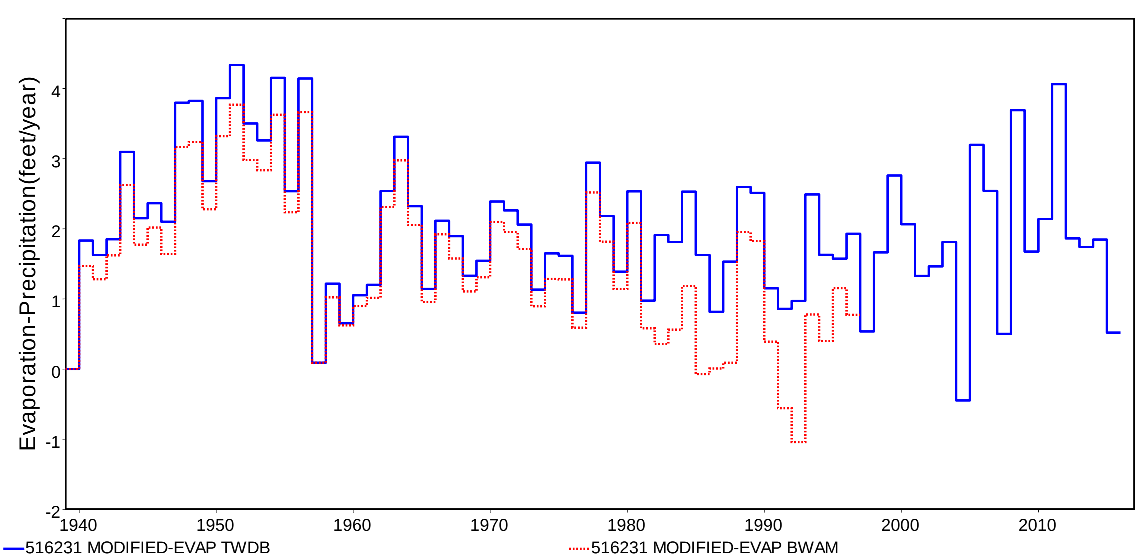
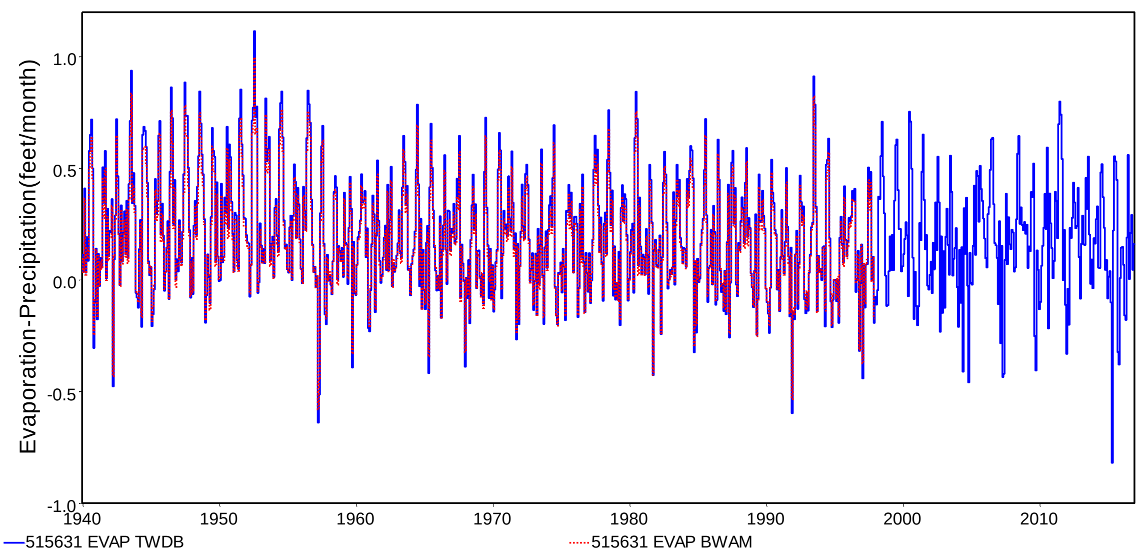


Figure 3.10 Monthly and Annual Net Evaporation-Precipitation Depths at Georgetown Reservoir at Control Point 516231



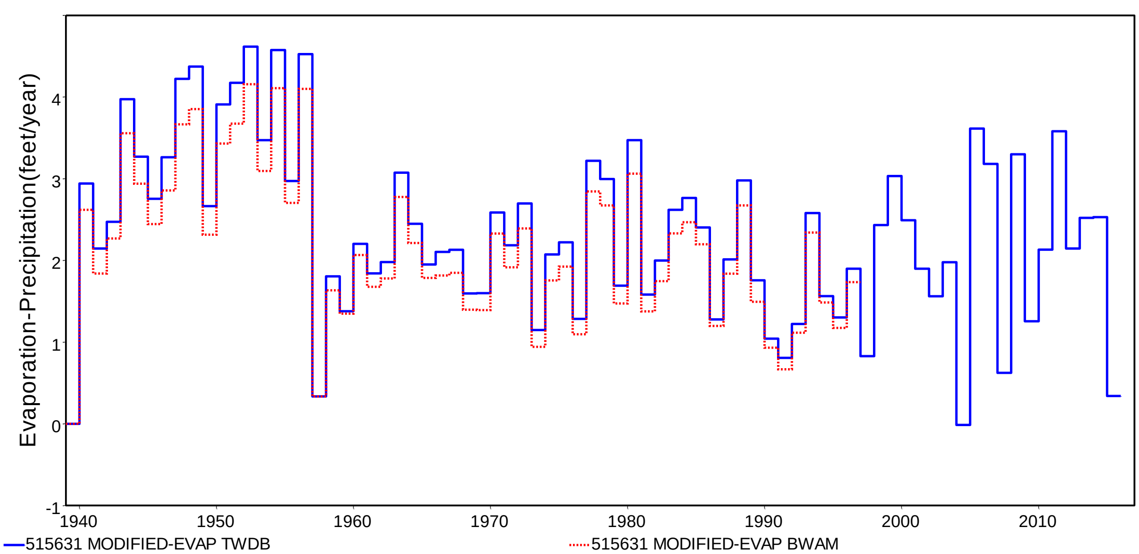
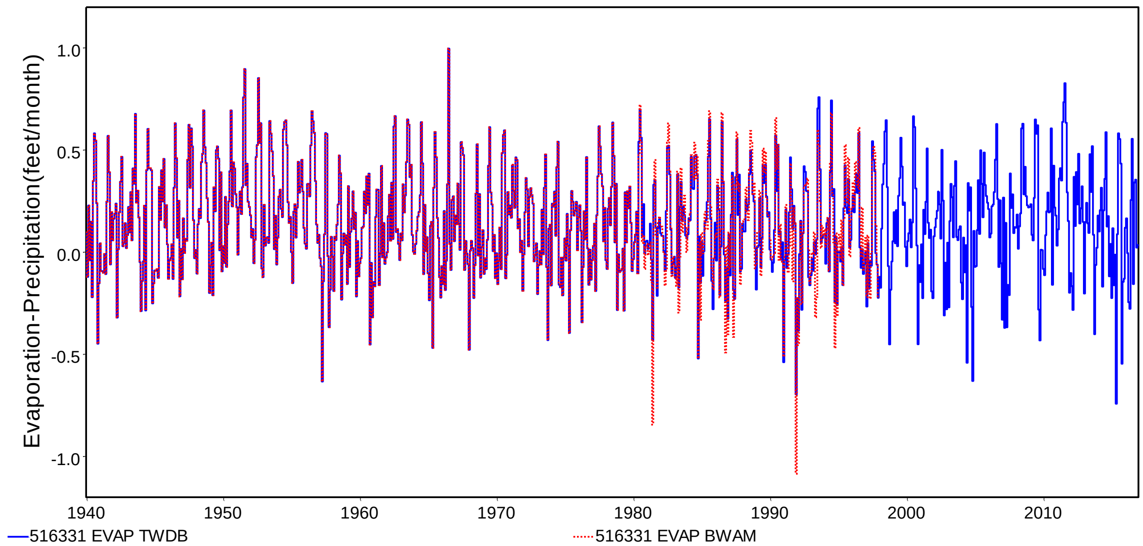


Figure 3.11 Monthly and Annual Net Evaporation-Precipitation Depths at Granbury Reservoir at Control Point 515631



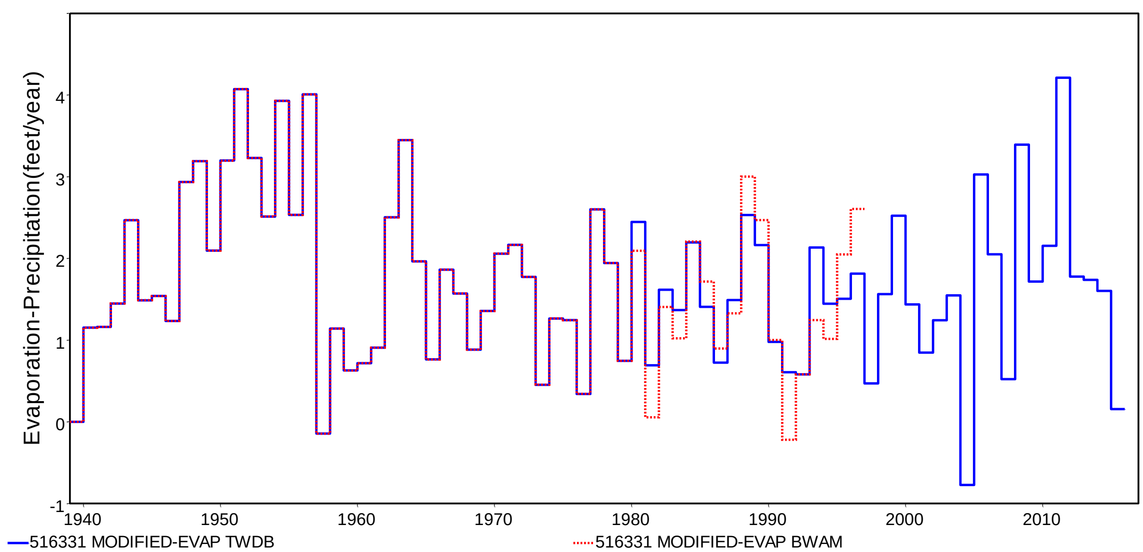


Figure 3.12 Monthly and Annual Net Evaporation-Precipitation Depths at Granger Reservoir at Control Point 516331

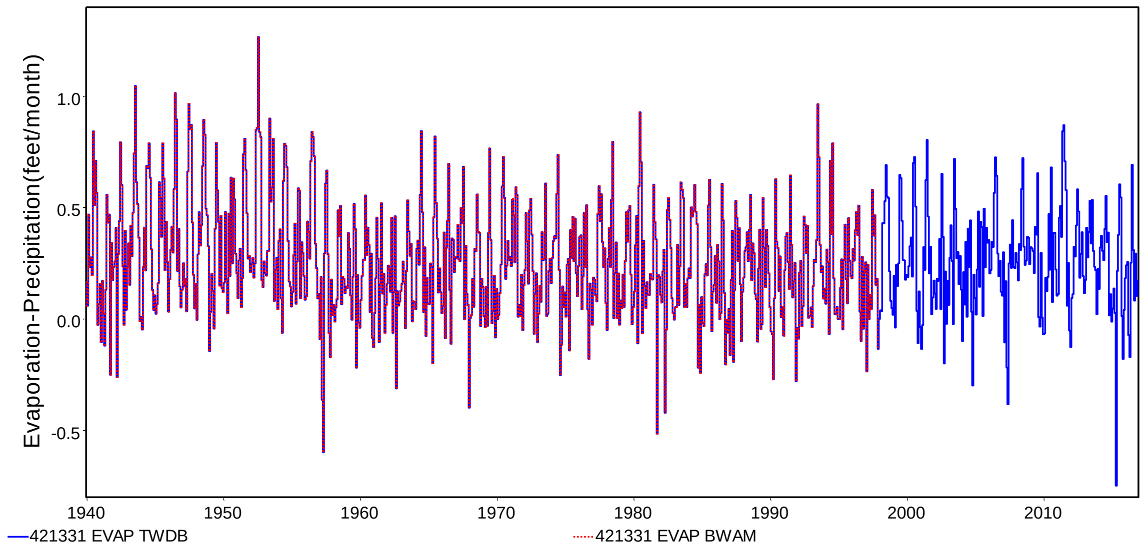
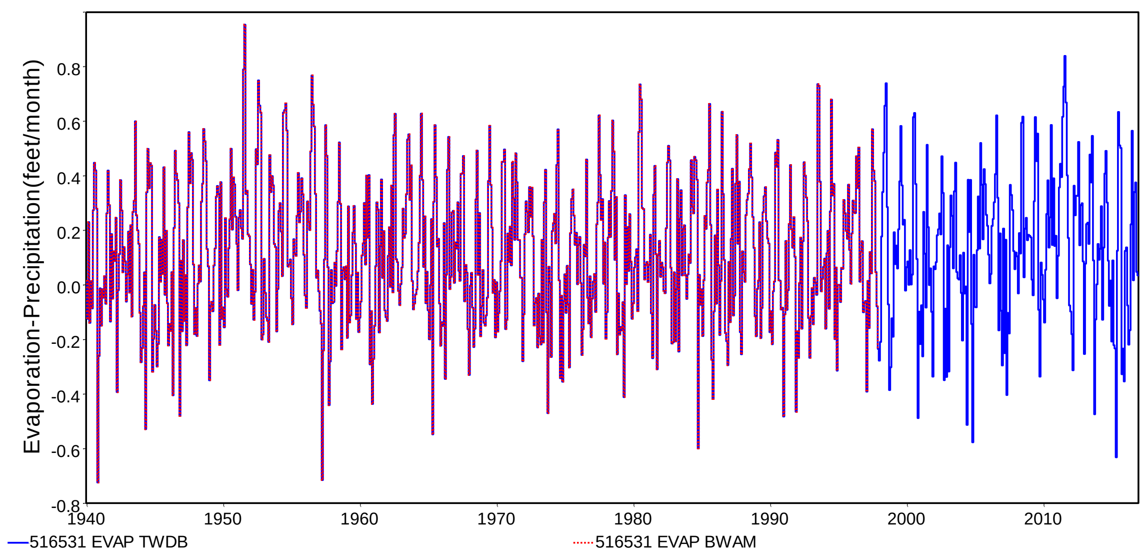


Figure 3.13 Monthly and Annual Net Evaporation-Precipitation Depths at Hubbard Creek Reservoir at Control Point 421331



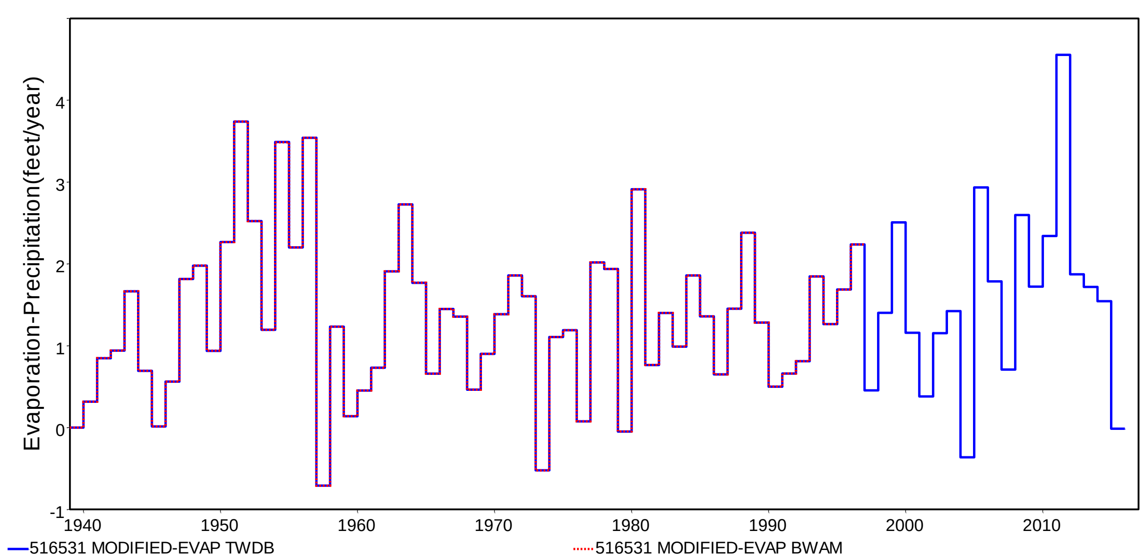
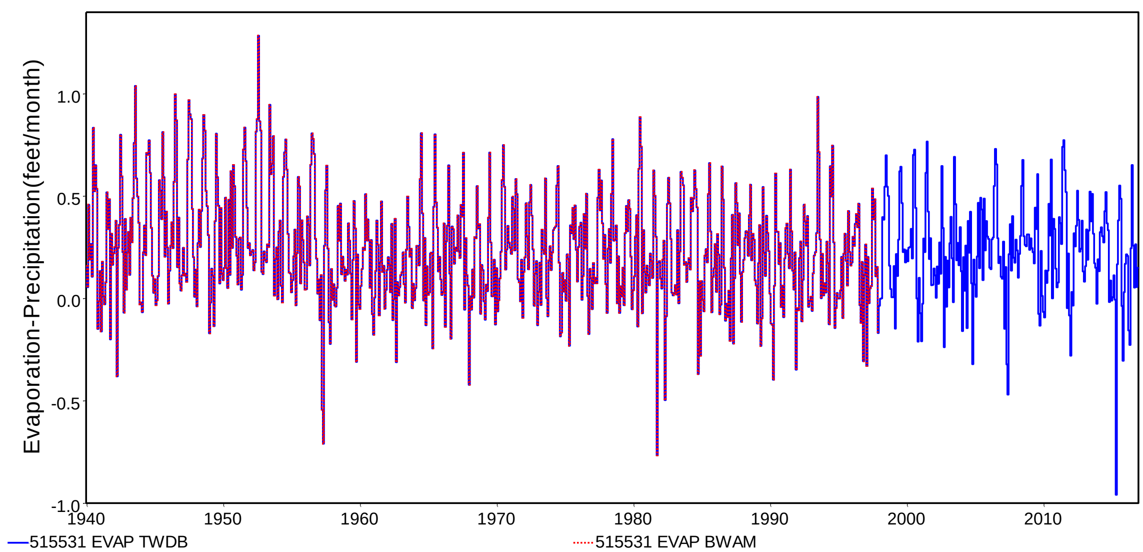


Figure 3.14 Monthly and Annual Net Evaporation-Precipitation Depths at Limestone Reservoir at Control Point 516531



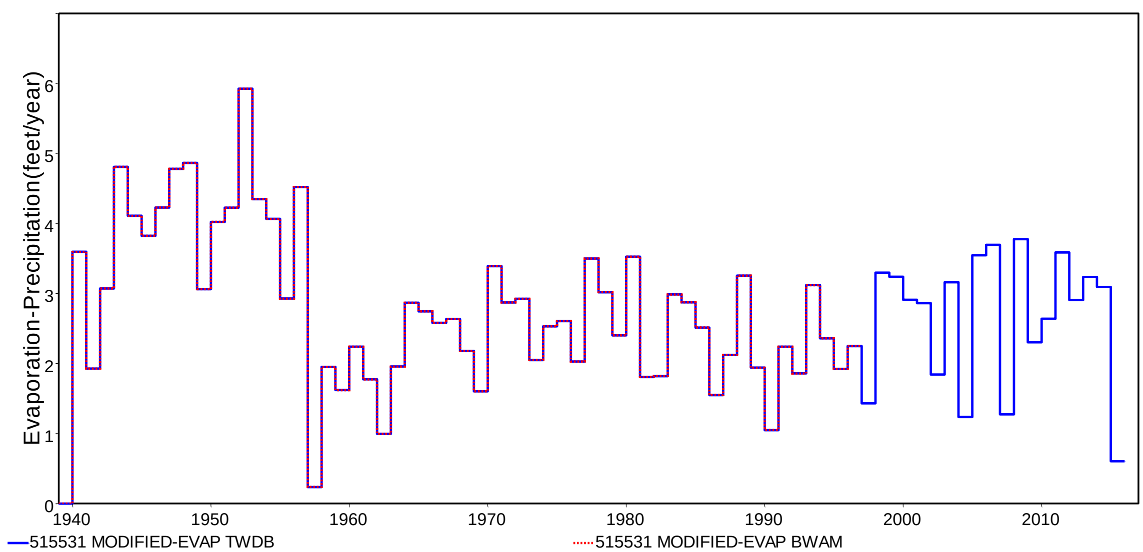
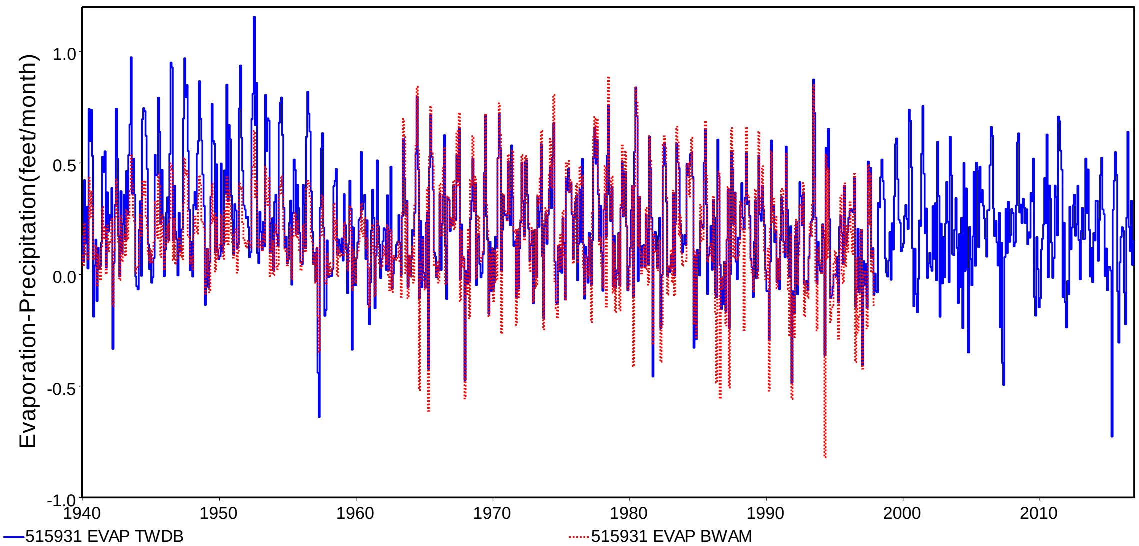


Figure 3.15 Monthly and Annual Net Evaporation-Precipitation Depths at Possum Kingdom Reservoir at Control Point 515531



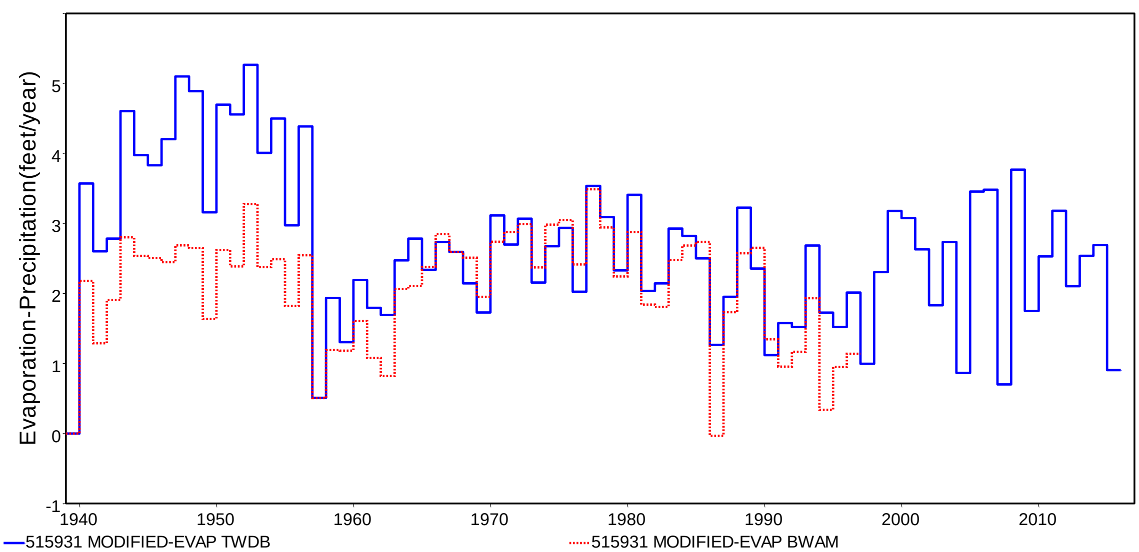
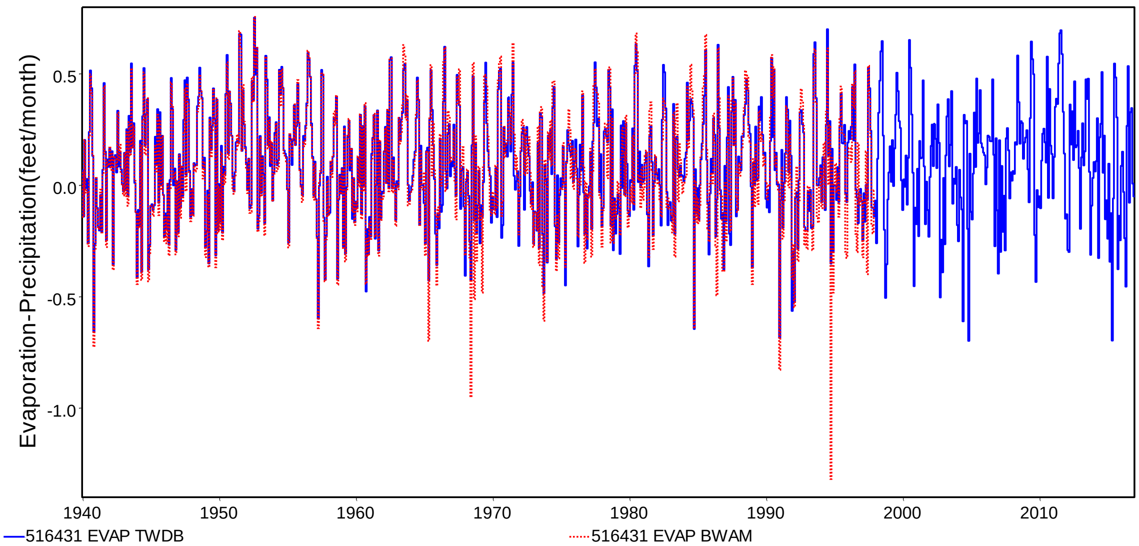


Figure 3.16 Monthly and Annual Net Evaporation-Precipitation Depths at Proctor Reservoir at Control Point 515931



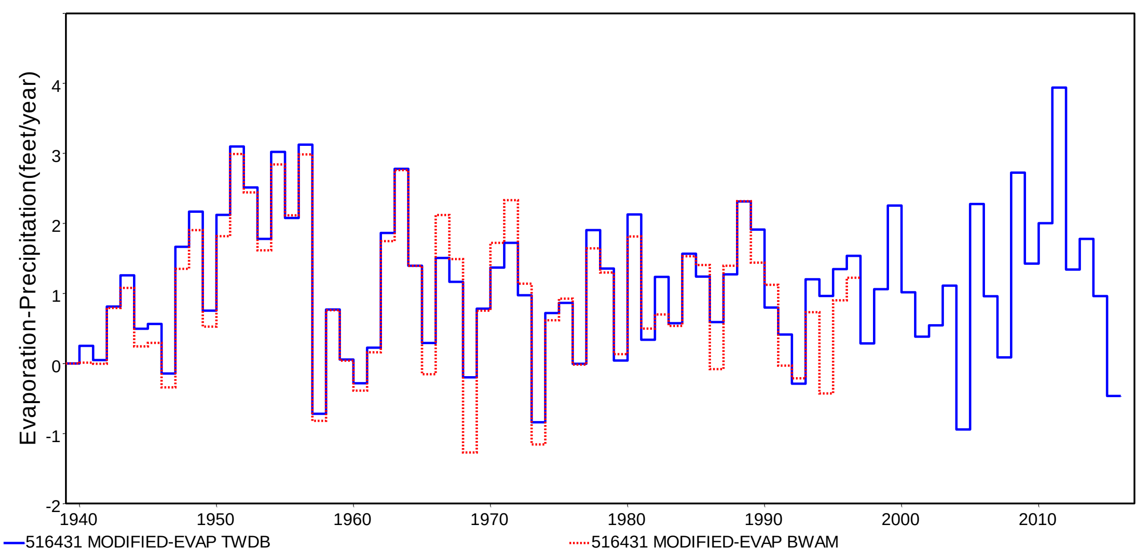
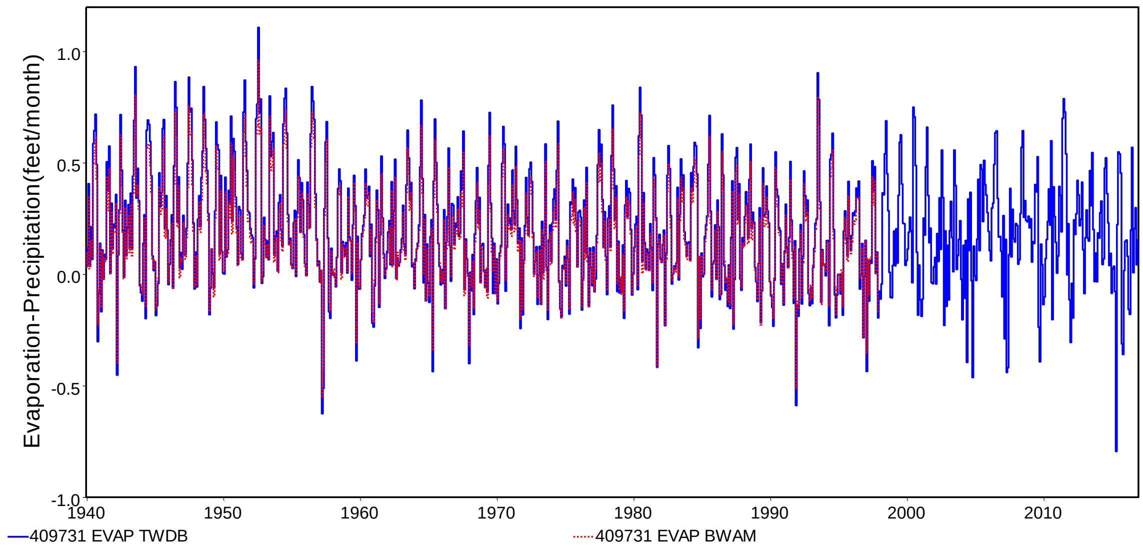


Figure 3.17 Monthly and Annual Net Evaporation-Precipitation Depths at Somerville Reservoir at Control Point 516431



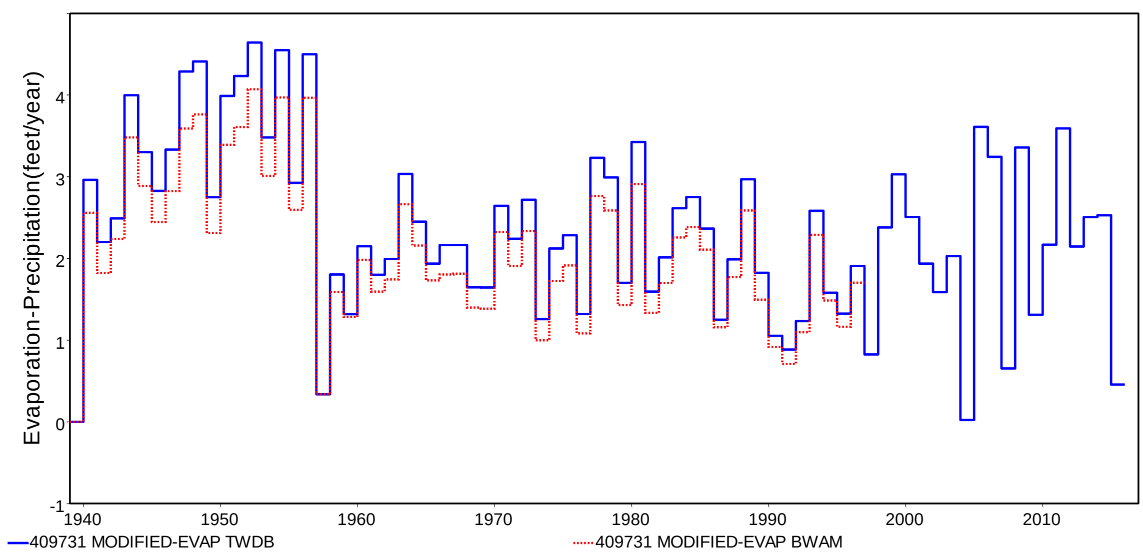
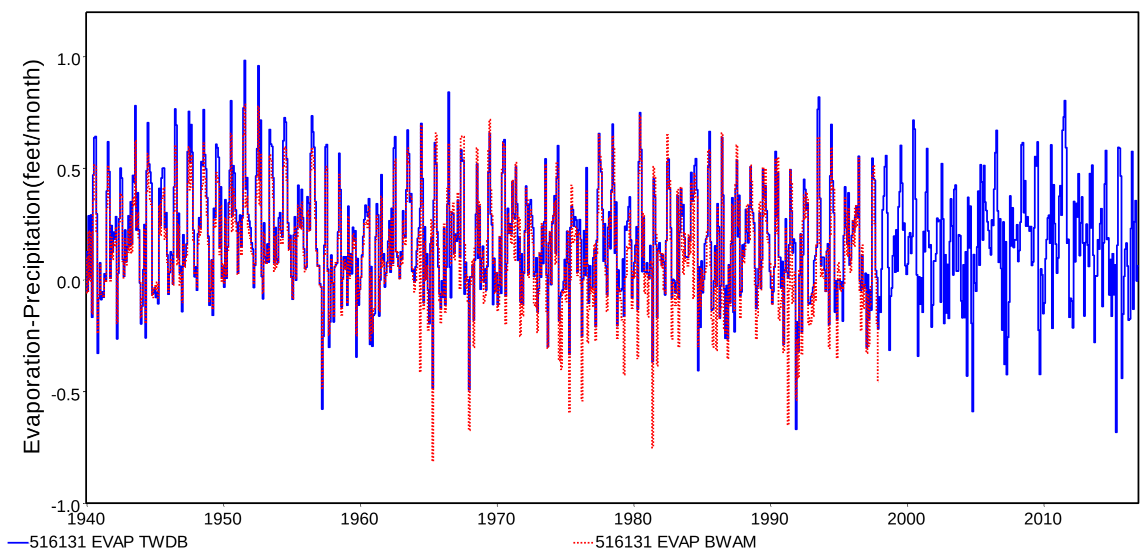


Figure 3.18 Monthly and Annual Net Evaporation-Precipitation Depths at Squaw Creek Reservoir at Control Point 409731



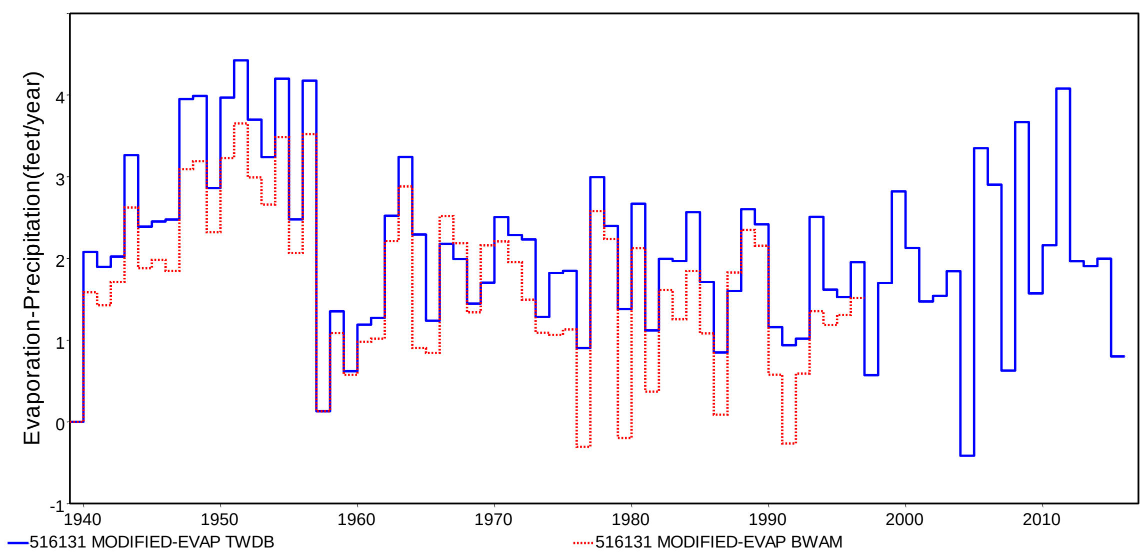


Figure 3.19 Monthly and Annual Net Evaporation-Precipitation Depths at Stillhouse Hollow Reservoir at Control Point 516131

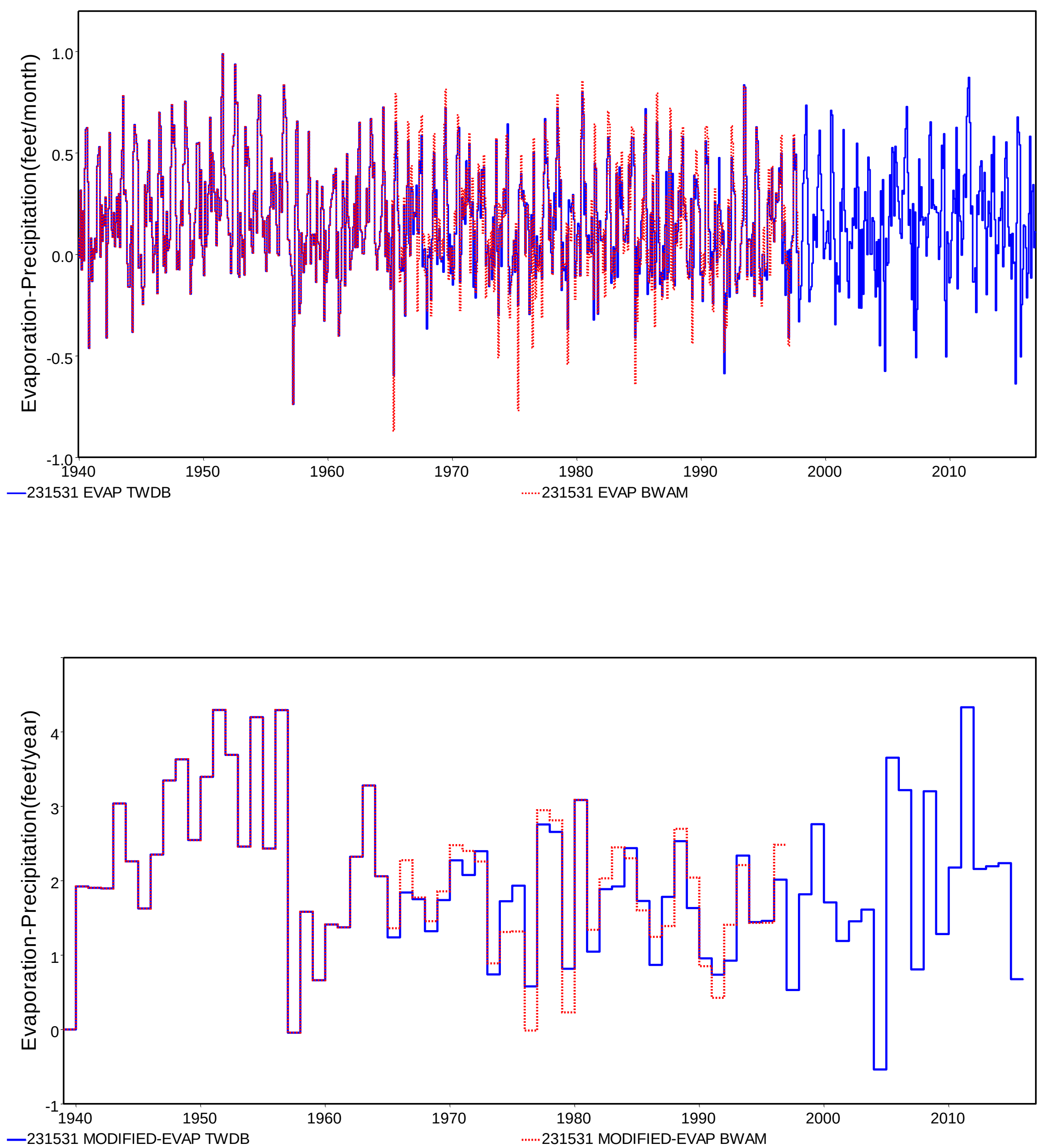
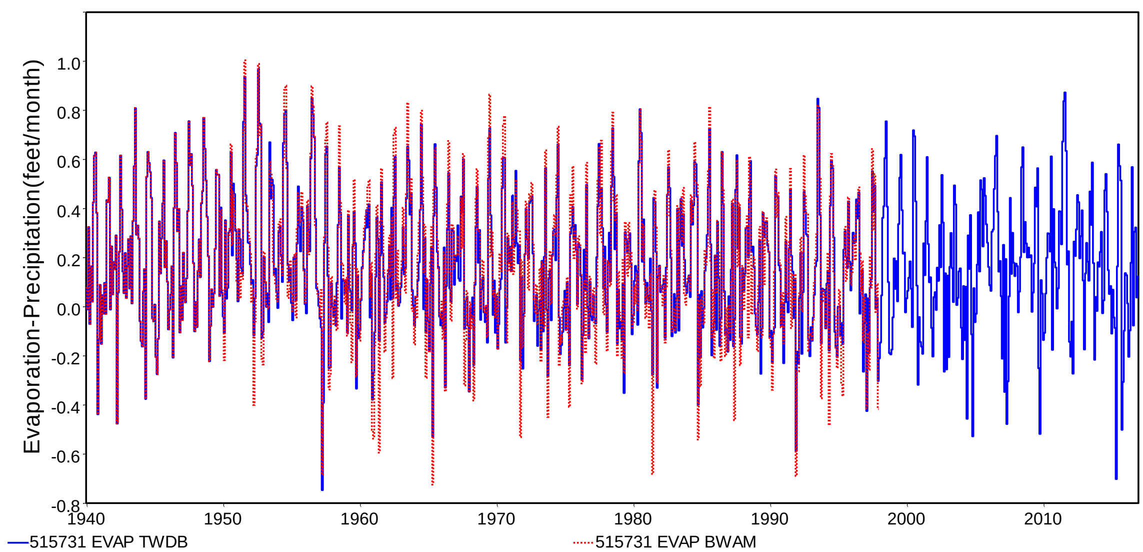


Figure 3.20 Monthly and Annual Net Evaporation-Precipitation Depths at Waco Reservoir at Control Point 231531



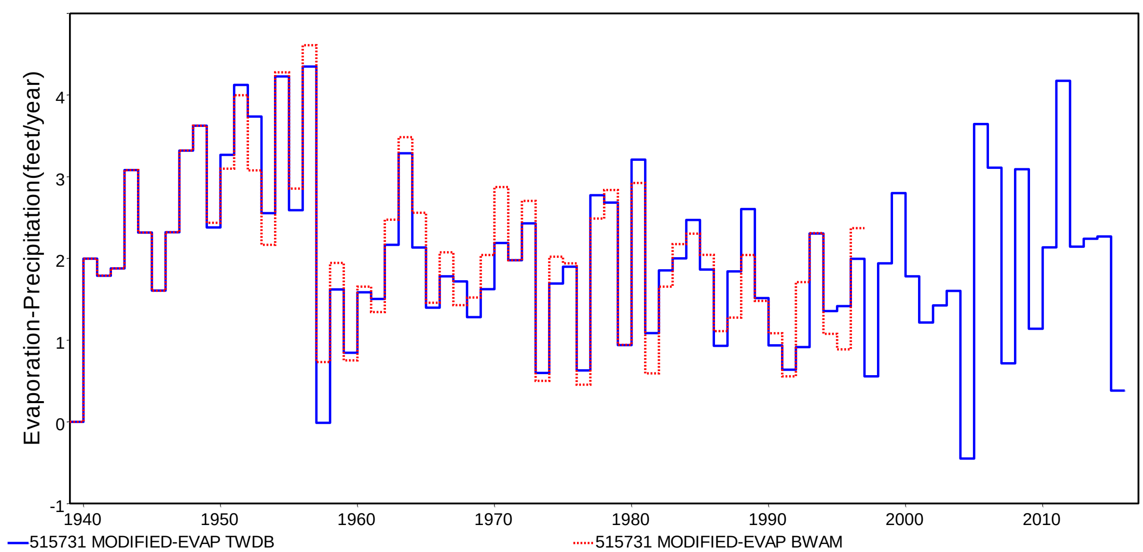


Figure 3.21 Monthly and Annual Net Evaporation-Precipitation Depths at Whitney Reservoir at Control Point 515731

3.6 Extension of Naturalized Streamflows

3.6.1 Summary and Procedure

The original sequences of naturalized flows in the TCEQ WAM datasets extending from about 1940 through the late 1990's were developed by ten engineering consulting firms during 1998-2001. The new approach outlined in this chapter are to periodically update the hydrologic period of analysis of WAM /WRAP input data files to near the present. The methodologies of naturalized flows extension are described in Section 2.3.

The flow extension model expressed by Eq. 2.1, 2.2, 2.3, 2.4, and 2.5 is applied for extending sequences of naturalized flows based upon available naturalized flow of TCEQ WAM System dataset and precipitation and evaporation of TWDB dataset. The flow extension model combines base flow and precipitation-runoff components to convert input precipitation and evaporation sequences into output consisting of computed naturalized flows.

The model includes base flow parameters and several precipitation-runoff parameters for each quadrangle in the watershed above the control point. Calibration consists of determining a set of parameter values that optimally reproduce the known 1940-1997 naturalized flows from the TCEQ WAM dataset. The model is then applied to synthesize flows for 1998-2016 based on 1998-2016 precipitation and evaporation. The flow extension procedures are performed in the following steps and shown in Figure 3.22.

- Calibration of the flow extension model for each individual control point
    - Level 1 initial calibration process to obtain values for basic parameters
    - Level 2 final calibration process that incorporates additional parameters
- Extension of flows with the calibrated flow extension model for each control point

The level 1 calibration procedures are based on a complex set of optimization algorithms incorporated in HYD designed to replicate known flows. Level 2 calibration deals with additional parameters designed to improve model capabilities for reproducing relevant statistical characteristics. Although the calibration process is somewhat complicated, the resulting calibrated flow extension model is easy to apply to synthesize flows for the extension period. In order to validate the flows extension methodology and the model calibration, several tasks were performed.

1. The statistical characteristics such as maximum, minimum, mean, standard deviation, and 12-month moving average of 1940-1997 flows computed with flow extension model were compared with 1940-1997 original known flows.
2. Flow frequency of 1940-1997 original naturalized flow of the Brazos WAM dataset were compared with 1998-2016 extended flows and 1940-2016 combined flows at 77 primary control points.
3. 1998-2016 Observed flows at 31 selected control points which are included most of the mainstream of Brazos River and representing its tributaries sites are compared with 1998-2016 extended flows.
4. Water supply capabilities such as flow depletions, diversion targets, and shortages with WRAP/WAM modeling system were assessed with 1940-2016 extended naturalized flows of the Brazos River.

The program HYD facilitates to extend sequences of monthly naturalized flows of WRAP input datasets. The new FE and FP records of program HYD develop parameters for the flow equation. The new FZ, FR, UB, BM, B1, B2, B3, B4, XP, X1, X2, X3, X4, RC, and FX records provide parameter values for the FE record. All the results tabulated in this chapter were developed with the program TABLES and the time series plots presented in this chapter and appendix were prepared with HEC-DSSVue.

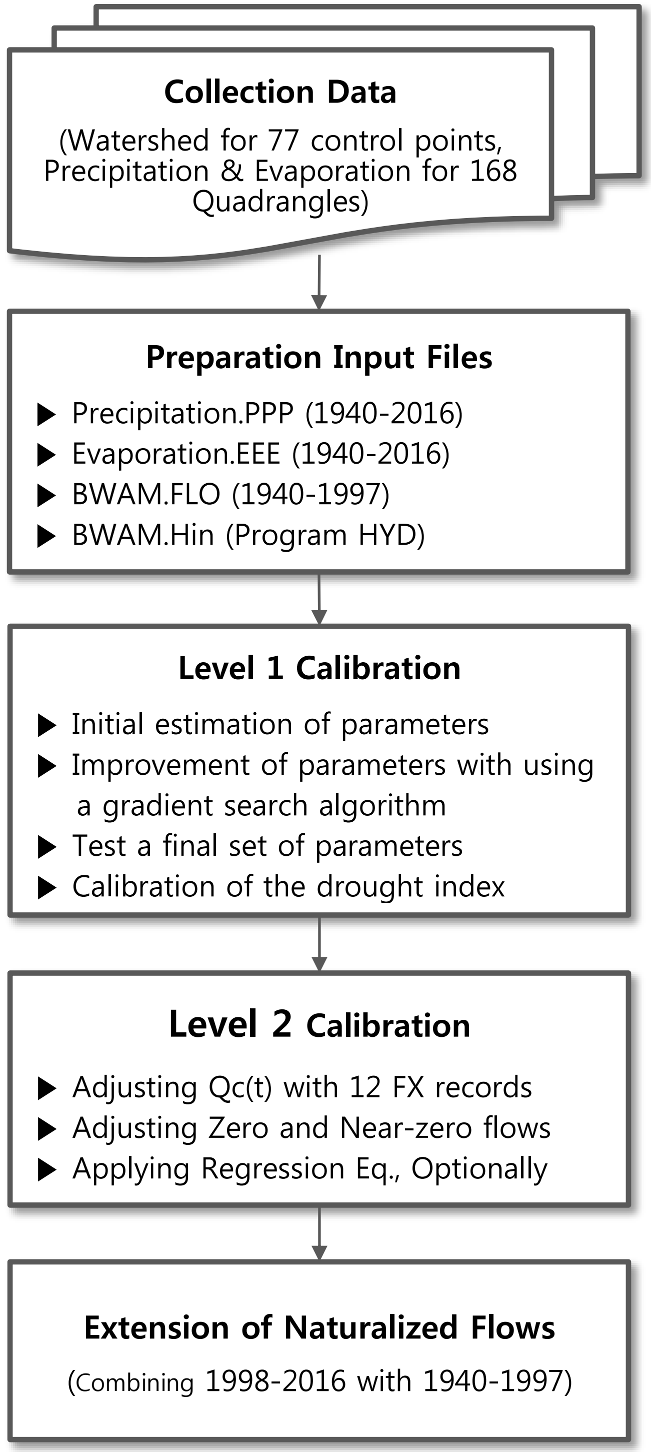


Figure 3.22 A procedure of Naturalized Flow Extension

3.6.2 Naturalized Flows and Watershed at 77 Primary Control Points

The TCEQ WAM System dataset for the Brazos River basin and San Jacinto-Brazos Costal basin includes sequences of monthly naturalized stream flows at 77 primary control points for January 1940 through December 1997 recorded on IN records in the FLO file. The original 1940-1997 naturalized flows were developed by Engineering consulting firms during 1997-2001 under contract with TCEQ. The 77 primary control points are listed in Table 3.5.

The extended 1998-2016 sequences of naturalized flows were developed for each of the 77 primary control points in the Brazos WAM dataset. The location of the primary control points and their watershed along with the quadrangles encompassing the Brazos River Basin are shown in Figure 3.6.

The quadrangles contained within the watershed of the 77 primary control points for naturalized flow extension are listed on a QD record. The watershed located in each quadrangle are entered on a QA record. The QA record follows a QD record and refers to the quadrangles on the QD record in a input file of HYD

The areas of quadrangles including the watersheds of the 77 primary control points were calculated by using Arc-GIS and listed in Table 3.11. For large watersheds such as main stream of Brazos River, some of quadrangles covering upper portions of the watershed that contribute little to flow at the control point may be excluded during the parameter calibration procedure.

The 1940-1997 naturalized flows at control points BRSE11 (Brazos river at Seymour), BRWA41 (Brazos river at Waco), LRCA58 (Little River at Cameron), and BRGM73 (Outlet of the Brazos River at the Gulf of Mexico) from the Brazos WAM dataset are plotted in Figure 3.23, 3.24, 3.25, and 3.26 and tabulated in Table 3.12, 3.13, 3.14, and 3.15. In this chapter, control points BRSE11, BRWA41, LRCA58, and BRGM73 are mainly selected to describe the procedures and methodologies for the naturalized flows extension of the Brazos WAM dataset.

Table 3.11 Watershed Quadrangles of the Control Points in the Brazos WAM

WAM CP ID	The Area of Each Quadrangle Encompassed by the Watershed of Each Control Point (sq miles)
RWPL01	830(305) + 255(306)
WRSP02	1,060(305) + 839(306) + 914(406)
DUGI03	111(406) + 265(407)
SFPE04	1,060(305) + 839(306) +1,570(406) + 854(407)
CRJA05	286(407)
SFAS06	1,060(305) + 839(306) +1,570(406) + 1362(407)
BSLU07	1,149(305) + 1,441(405) + 478(406)
DMJU08	455(405) + 872(406) + 94(506)
DMAS09	1,149(305) +1,896(405) + 2,072(406) + 323(407) + 159(506) + 539(507)
NCKN10	248(407)
BRSE11	1,149(305) +2,209(306) + 1,896(405) + 3,642(406) +2,437(407) + 818(408) + 159(506) + 558(507)
MSMN12	104(408)
CFRO13	223(507)
CFHA14	1,284(507) + 114(508)
MUHA15	99(507) + 103(508)
CFNU16	1,436(507) + 731(508)
CAST17	223(507) + 258(508)
CFFG18	599(408) + 1,668(507) + 1,691(508)
HCAL19	609(508)
BSBR20	204(508) + 78(509)
HCBR21	938(508) + 150(509)
CFEL22	660(408) + 26(409) + 1,668(507) +2,847(508) + 460(509)
BRSB23	2,209(305) +839(306) + 1,896(405) + 3,842(406) + 2,438(407) + 2,147(408) + 478(409) + 159(506) + 2,226(507) + 2,847(508) +494(509)
GHGH24	211(409)
CCIV25	97(509)
SHGR26	3,842(406) + 2,438(407) + 2,417(408) + 924(409) + 159(506) + 2,226(507) + 2,847(508) + 958(509)
BRPP27	3,842(406) + 2,438(407) + 2,417(408) + 924(409) + 159(506) + 2,226(507) + 2,847(508) + 1149(509)
PPSA28	574(509)
BRDE29	3842(406) + 2,438(407) + 2,417(408) +1,112(409) + 2,226(507) + 2,847(508) + 2,252(509) +148(510)
BRGR30	3842(406) + 2,438(407) + 2,417(408)+ 1,112(409) + 2,226(507) + 2,847(508) + 2,304(509)+ 653(510)
PAGR31	172(510) + 238(509)
NRBL32	276(510)
BRAQ33	3,842(406)+2,438(407)+2,417(408)+1,112(409)+2,226(507)+2,847(508)+2,542(509)+1,631(510)+227(610)
AQAQ34	189(510) + 112(610)
NBHI35	319(509) + 40(609)
NBCL36	371(509) + 140(510) + 96(609) + 368(610)
NBVM37	371(509) + 140(510) + 96(609) + 551(610)
MBMG38	181(610)
HGCR39	78(610)
BOWA40	371(509) + 140(510) + 96(609) + 1,053(610)

Table 3.11 (Continued)

WAM CP ID	The Area of Each Quadrangle Encompassed by the Watershed of Each Control Point (sq miles)
BRWA41	2,417(408) + 1,112(409) + 2,226(507) + 2,847(508)+ 2,914(509) + 1,960(510) + 96(609) + 1,743(610)
BRHB42	2,417(408)+1,112(409)+2,226(507)+2,847(508)+2,914(509)+1,960(510)+ 96(609)+2,261(610)+ 666(611)
LEDL43	64(508) + 412(509)
SADL44	51(508) + 216(509)
LEHS45	115(508) + 1,021(509) + 141(609)
LEHM46	115(508) + 1,063(509) + 742(609)
LEGT47	115(508) + 1,063(509) + 916(609) + 276(610)
COPI48	355(609) + 99(610)
LEBE49	115(508) + 1,063(509) + 1,285(609) + 1,106(610)
LAKE50	800(609)+13(709)
LAYO51	844(609) + 108(610) + 135(709) + 150(710)
LABE52	844(609) + 166(610) + 135(709) + 173(710)
LRLR53	115(508) + 1,063(509) + 2,129(609) +1,445(610)+135(709) + 367(710)
NGGE54	127(709) + 120(710)
SGGE55	61(709) + 68(710)
GAGE56	189(709) + 211(710)
GALA57	189(709) + 545(710)
LRCA58	115(508) + 1,063(509) + 2,129(609) +1,470(610) + 324(709) +1,896(710) + 77(711)
BRBR59	2,417(408) + 1,112(409) + 2,226(507) + 2,847(508) + 3,976(509) + 1,960(510) + 2,225(609) + 4,028(610) + 1,138(611) + 324(709) + 2,020(710) + 850(711)
MYDB60	197(710) + 37(711)
EYDB61	71(710) + 174(711)
YCSO62	378(710) + 620(711)
DCLY63	195(711)
NAGR64	234(611)
BGFR65	92(611)
NAEA66	925(611)
NABR67	1,317(611) + 88(711)
BRHE68	2,417(408) + 1,112(409) + 2,226(507) + 2,962(508) + 3,976(509) + 1,960(510) + 2,225(609) +4,028(610) +2,462(611)+ 324(709) + 2,398(710) + 3,338(711) + 128(712)
MCBL69	206(711) + 162(811)
BRRI70	2,417(408) + 1,112(409) + 2,226(507) + 2,962(508) + 3,976(509) + 1,960(510) + 2,225(609) +4,028(610) +2,462(611)+ 324(709) + 2,398(710) + 3,733(711) + 148(712) + 473(811) + 203(812)
BGNE71	47(812)
BRRO72	2,417(408) + 1,112(409) + 2,226(507) + 2,962(508) + 3,976(509) + 1,960(510) + 2,225(609) +4,028(610) +2,462(611)+ 324(709) + 2,398(710) + 3,733(711) + 148(712) + 473(811) + 572(812)
BRGM73	2,417(408) + 1,112(409) + 2,226(507) + 2,962(508) + 3,976(509) + 1,960(510) + 2,225(609) +4,028(610) +2,462(611)+324(709) + 2,398(710) + 3,733(711) + 148(712) + 473(811) + 890(812)
CLPEC1	33(812)
CBALC2	114(812)
SJGBC3	456(812) + 275(813)
SJGMC4	983(812)+12(813)+47(912)

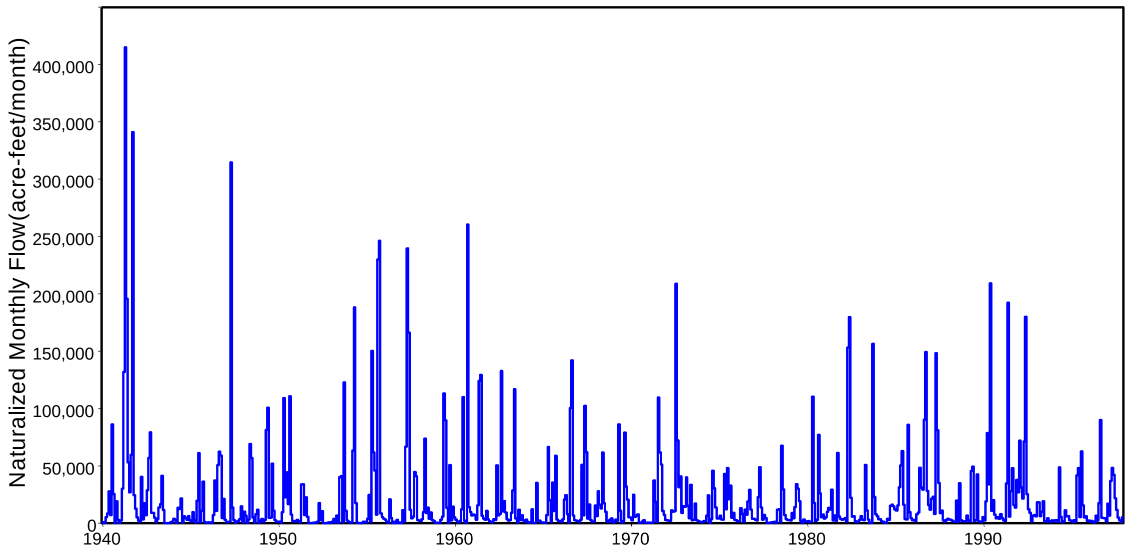


Figure 3.23 1940-1997 Naturalized Flows at Seymour on the Brazos River (BRSE11)

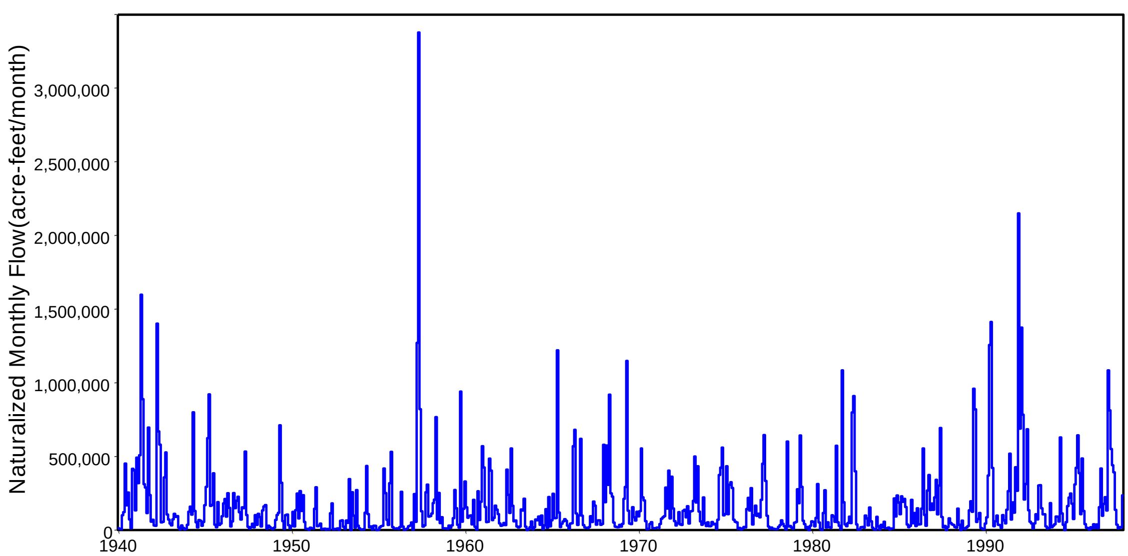


Figure 3.24 1940-1997 Naturalized Flows at Waco on the Brazos River (BRWA41)

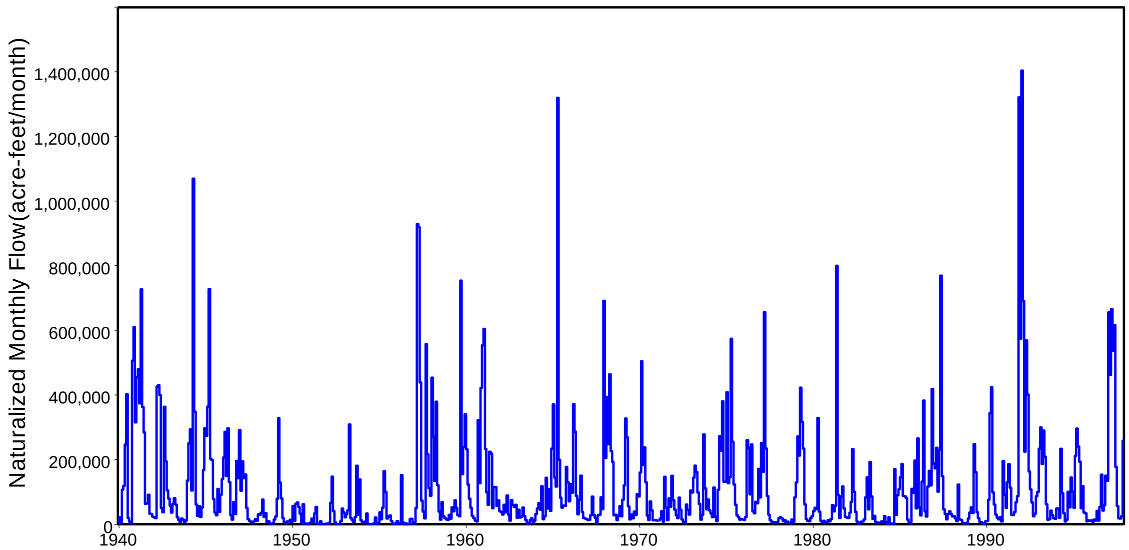


Figure 3.25 1940-1997 Naturalized Flows at Cameron on the Little River (LRCA58)

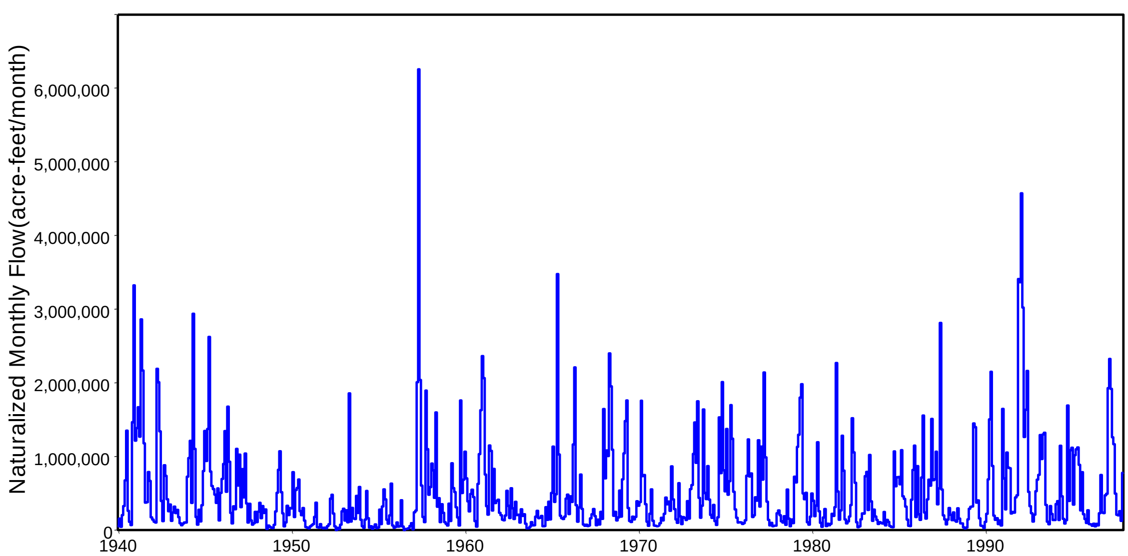


Figure 3.26 1940-1997 Naturalized Flows at Cameron on the Little River (BRGM73)

Table 3.12 1940-1997 Naturalized Flows at Seymour on the Brazos River (BRSE11)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0.	871.	1.	5303.	8506.	27760.	7092.	86156.	25468.	4.	19173.	3002.	183336.
1941	323.	2459.	30114.	131878.	414811.	195658.	52999.	26939.	59657.	340923.	24494.	12651.	1292906.
1942	5076.	2313.	1352.	40474.	3240.	17449.	6990.	28711.	56903.	79222.	9033.	9064.	259827.
1943	4868.	997.	3690.	13733.	16624.	41364.	11521.	0.	0.	54.	60.	978.	93889.
1944	1409.	3879.	2870.	366.	13446.	12377.	21577.	560.	6061.	4569.	3052.	6191.	76357.
1945	2469.	1394.	9718.	2760.	455.	19603.	61219.	954.	10749.	36235.	1060.	560.	147176.
1946	685.	776.	191.	624.	7023.	37285.	10721.	50644.	62426.	59016.	4508.	21191.	255090.
1947	2888.	904.	1025.	1412.	314512.	13732.	2740.	306.	1428.	2131.	3611.	14705.	359394.
1948	845.	10013.	6568.	276.	3247.	69094.	56846.	4943.	800.	7966.	11823.	199.	172620.
1949	2229.	3752.	1178.	2842.	81345.	100652.	4658.	4828.	51955.	10933.	2616.	1259.	268247.
1950	1386.	1371.	324.	9625.	109057.	22560.	44413.	16640.	110677.	7584.	1721.	1969.	327327.
1951	1522.	2851.	1732.	780.	33876.	33946.	7154.	22554.	5638.	0.	130.	134.	110317.
1952	252.	625.	446.	1416.	17569.	2658.	10488.	110.	29.	0.	615.	821.	35029.
1953	0.	1418.	3720.	693.	6693.	395.	40117.	41032.	859.	122758.	10912.	2445.	231042.
1954	1465.	692.	259.	63367.	188184.	17493.	473.	0.	2.	0.	1355.	1235.	274525.
1955	681.	3868.	24679.	1000.	150226.	61774.	45910.	7474.	229964.	246199.	8552.	5368.	785695.
1956	3971.	3185.	1329.	542.	20889.	4542.	20.	1232.	0.	2900.	178.	617.	39405.
1957	104.	11392.	1637.	66762.	239563.	166184.	11594.	4215.	5726.	44714.	40954.	2790.	595635.
1958	2333.	1646.	3465.	9650.	73778.	8962.	13669.	3920.	9366.	2735.	2211.	500.	132235.
1959	374.	322.	135.	3202.	5713.	113139.	89801.	13357.	219.	50708.	2533.	14423.	293926.
1960	5156.	3149.	1554.	628.	2089.	12098.	109896.	2177.	478.	260415.	13899.	9802.	421341.
1961	6683.	7585.	7128.	3054.	15597.	124137.	129277.	6421.	4143.	3050.	10786.	3279.	321140.
1962	1835.	957.	831.	3519.	2844.	50440.	6812.	8032.	132703.	10334.	19288.	9469.	247064.
1963	3417.	2247.	2726.	9094.	28647.	116893.	4105.	640.	11812.	2798.	6961.	2513.	191853.
1964	1210.	3166.	1024.	427.	946.	12143.	221.	226.	35221.	2247.	2236.	608.	59675.
1965	712.	528.	259.	7023.	66447.	20152.	1166.	35475.	10637.	58877.	3173.	1711.	206160.
1966	1993.	1355.	3493.	20667.	24484.	7926.	650.	100471.	142019.	6654.	2692.	2253.	314657.
1967	1865.	1167.	2924.	50970.	6864.	102268.	62062.	4030.	16311.	2648.	1181.	1411.	253701.
1968	15484.	6181.	27862.	16193.	12859.	61597.	17465.	9979.	1711.	993.	3153.	4255.	177732.
1969	666.	913.	3291.	2140.	86206.	10868.	532.	1954.	79052.	31909.	20681.	5162.	243374.
1970	4971.	2542.	24793.	5464.	6592.	7676.	372.	268.	1578.	2610.	510.	465.	57841.
1971	534.	418.	475.	506.	37265.	18500.	1191.	109518.	61703.	51224.	10614.	7219.	299167.
1972	2740.	2492.	2329.	2124.	11332.	10023.	10431.	208723.	72235.	31320.	40786.	8976.	403511.
1973	14885.	14291.	39994.	15122.	4381.	33497.	2525.	2998.	17205.	2606.	1882.	1324.	150710.
1974	994.	939.	1876.	1799.	6769.	24292.	418.	3335.	45777.	30506.	13745.	4160.	134610.
1975	4173.	6565.	3206.	3105.	42971.	12124.	48137.	20905.	32884.	4769.	9057.	2924.	190820.
1976	2589.	1676.	1684.	13099.	8016.	1305.	11841.	7307.	19091.	29146.	11908.	3837.	111499.
1977	3881.	3010.	2405.	22868.	48808.	13726.	2963.	7158.	4498.	234.	321.	455.	110327.
1978	795.	941.	1251.	192.	11735.	12122.	861.	67573.	29478.	7157.	3642.	2796.	138543.
1979	2748.	2393.	8918.	4278.	14067.	34030.	30179.	19268.	1924.	93.	3326.	1677.	122901.
1980	1400.	1852.	900.	1256.	110262.	17720.	1871.	3040.	77092.	26018.	5255.	7613.	254279.
1981	4043.	5225.	9933.	13360.	11889.	29244.	2442.	6860.	2142.	61248.	5839.	3748.	155973.
1982	2969.	3478.	4550.	1457.	153145.	179680.	22051.	5708.	6089.	1760.	834.	1538.	383259.
1983	3066.	6188.	3003.	2650.	50807.	11163.	3126.	109.	454.	156379.	22943.	7778.	267666.
1984	6056.	3377.	3473.	1618.	1263.	699.	193.	3866.	2940.	15162.	16247.	14698.	69592.
1985	12062.	11063.	15540.	31408.	50453.	62944.	16052.	3651.	3237.	85770.	9676.	4406.	306262.
1986	2474.	2884.	1845.	7879.	9281.	48365.	31144.	29246.	90264.	149202.	28175.	15867.	416626.
1987	11799.	21425.	23083.	8038.	148204.	81067.	34999.	8803.	11080.	2555.	1391.	2731.	355175.
1988	3940.	3223.	2998.	2339.	1359.	1435.	19817.	1206.	34934.	2708.	1945.	1494.	77398.
1989	1393.	6659.	2580.	1565.	45677.	49352.	2000.	2689.	42618.	1831.	1223.	1392.	158979.
1990	5380.	2432.	18975.	78672.	33823.	209170.	10781.	20091.	7462.	4276.	5383.	3932.	400377.
1991	7962.	4451.	2568.	1855.	34669.	192272.	5761.	27942.	48029.	15772.	13614.	37795.	392690.
1992	26922.	72064.	31115.	21460.	71282.	179925.	25266.	12173.	9049.	1594.	6578.	7038.	464466.
1993	5919.	18342.	18191.	6103.	9944.	19148.	1669.	1292.	4381.	1679.	1020.	2563.	90251.
1994	1567.	2543.	2609.	1270.	48710.	5480.	694.	1670.	11315.	5954.	6273.	2471.	90556.
1995	2251.	1222.	2619.	1449.	41737.	48130.	5414.	62634.	15584.	5042.	6145.	2054.	194281.
1996	2437.	1319.	1980.	1339.	493.	6547.	2273.	17513.	89964.	4764.	4538.	4411.	137578.
1997	1399.	17062.	6620.	36918.	48167.	42167.	21775.	11603.	4973.	2525.	1161.	5197.	199567.
MEAN	3677.	5208.	6639.	13097.	52049.	48913.	19801.	19847.	31379.	36250.	8046.	5192.	250096.

Table 3.13 1940-1997 Naturalized Flows at Waco on the Brazos River (BRWA41)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	13511.	8751.	6311.	101058.	122519.	451522.	168538.	255025.	72277.	13015.	416155.	405857.	2034539.
1941	133251.	492000.	318981.	508670.	1597861.	889095.	311899.	289184.	115304.	696350.	238298.	56767.	5647660.
1942	70132.	31336.	29147.	1401100.	670494.	579811.	51907.	55723.	358139.	527354.	105937.	71104.	3952184.
1943	44340.	31851.	73147.	110754.	89262.	95298.	17695.	5540.	32245.	15965.	5048.	9192.	530337.
1944	35857.	124744.	159193.	105126.	799391.	129965.	53302.	18829.	68051.	63554.	29701.	55540.	1643253.
1945	169336.	293601.	623968.	921067.	164507.	169682.	385705.	37233.	19884.	190258.	34980.	44715.	3054936.
1946	94816.	181795.	211690.	91267.	250528.	150689.	24717.	58841.	251697.	149131.	199340.	226418.	1890929.
1947	121070.	71206.	154912.	148784.	533060.	102259.	22351.	11410.	20402.	43651.	18216.	102513.	1349834.
1948	36297.	110596.	88161.	24339.	133683.	160620.	169895.	10027.	30427.	20527.	12101.	7324.	803997.
1949	16811.	69629.	103325.	116907.	711815.	321502.	61082.	9058.	101714.	105862.	33496.	11945.	1663146.
1950	27468.	124134.	24277.	135709.	248739.	79302.	264857.	129938.	237233.	54828.	9336.	7937.	1343758.
1951	2807.	16680.	11695.	10058.	145072.	290951.	26291.	31130.	44937.	6144.	8128.	10348.	604241.
1952	2679.	7888.	4138.	114264.	181202.	4674.	8307.	7541.	11621.	2868.	63290.	66153.	474625.
1953	22309.	8344.	65384.	49725.	346687.	658.	257207.	98607.	15421.	271823.	29943.	11873.	1177981.
1954	4012.	4515.	6528.	117990.	435691.	108754.	19080.	25155.	4504.	30170.	29672.	339.	786410.
1955	1612.	19071.	26282.	29644.	418528.	251878.	69588.	34920.	318764.	530893.	20788.	10526.	1732494.
1956	11472.	11813.	8006.	20571.	260403.	24749.	1858.	6619.	9965.	26692.	31205.	52363.	465716.
1957	3483.	245003.	56524.	1270684.	3376485.	820741.	128189.	23015.	31869.	257701.	308852.	91125.	6613671.
1958	95673.	112397.	183794.	207233.	766687.	72614.	252763.	47863.	87224.	12453.	10802.	12434.	1861937.
1959	9281.	31288.	15685.	32092.	80840.	272887.	149083.	35498.	16332.	940385.	57196.	144050.	1784617.
1960	330275.	154751.	83972.	97134.	99926.	39077.	205696.	22776.	4688.	264411.	68642.	192364.	1563712.
1961	569683.	424506.	156875.	54263.	56062.	485169.	403672.	67637.	82401.	165966.	139137.	108420.	2713791.
1962	45581.	29229.	33000.	48551.	33921.	410648.	239547.	115982.	554450.	165200.	59877.	66017.	1802003.
1963	24652.	17881.	23959.	140145.	133079.	213550.	23618.	0.	6964.	19390.	59273.	5920.	668431.
1964	19843.	72007.	66433.	92482.	35696.	99403.	6707.	31985.	142709.	15875.	224565.	25200.	832905.
1965	66295.	246828.	81367.	81729.	1220316.	118840.	20771.	43436.	59297.	73862.	63809.	30069.	2106619.
1966	10374.	44689.	46120.	569538.	680919.	113837.	35109.	100582.	619618.	98012.	34137.	17952.	2370887.
1967	15551.	13758.	20187.	94040.	55008.	194189.	166585.	37344.	66041.	66191.	35471.	41289.	805654.
1968	578887.	189354.	574446.	306677.	919100.	249612.	227613.	51312.	23272.	20152.	19894.	35462.	3195781.
1969	23923.	43026.	212274.	293027.	1148063.	131668.	44874.	41169.	155342.	87233.	64356.	124874.	2369829.
1970	93143.	129342.	553969.	222928.	202014.	60775.	6199.	9244.	41546.	53912.	13753.	12781.	1399606.
1971	13573.	18053.	13645.	41723.	77352.	86968.	94432.	288674.	146109.	404187.	78671.	362366.	1625753.
1972	147430.	61154.	31200.	46158.	122561.	38502.	34945.	130904.	138500.	86679.	162195.	44090.	1044318.
1973	126836.	129346.	198391.	499647.	187195.	433977.	125866.	59295.	35877.	221935.	47265.	27661.	2093291.
1974	52972.	26028.	27132.	55440.	38405.	42590.	8813.	70810.	374528.	423863.	559597.	100490.	1780668.
1975	108418.	433919.	108148.	308048.	325572.	286249.	70107.	57066.	52545.	9001.	14406.	4134.	1777613.
1976	11436.	21516.	18152.	142907.	219231.	132632.	285252.	37920.	101104.	166410.	96377.	111548.	1344485.
1977	86797.	205150.	450576.	645516.	333823.	97432.	24617.	8897.	17760.	9325.	8368.	6258.	1894519.
1978	7479.	22674.	33817.	66443.	42195.	26714.	3940.	601580.	24760.	28105.	17598.	8752.	884057.
1979	50578.	55002.	277256.	182194.	641949.	293719.	64127.	40800.	13017.	21506.	0.	29431.	1669579.
1980	59915.	56220.	25129.	82858.	312875.	52285.	7002.	1770.	116130.	270537.	17054.	52978.	1054753.
1981	19262.	16236.	100688.	92179.	55974.	572020.	53624.	29058.	5815.	1084073.	189644.	38806.	2257379.
1982	26170.	48280.	91801.	47773.	798827.	909409.	399441.	38612.	4688.	4578.	20062.	21144.	2410785.
1983	16155.	98914.	79337.	31696.	153482.	59490.	16447.	6653.	2272.	90284.	25296.	3834.	583860.
1984	36045.	18372.	57088.	13022.	12071.	17494.	5094.	11300.	10639.	215466.	92306.	235050.	723947.
1985	187713.	107914.	229495.	192150.	211973.	156915.	38047.	19983.	27913.	205158.	46862.	116251.	1540374.
1986	27195.	148119.	37447.	39350.	146315.	554207.	103128.	28863.	268976.	374276.	136909.	180199.	2044984.
1987	137076.	222062.	342034.	106827.	302223.	692822.	89092.	19057.	28631.	0.	20793.	79937.	2040554.
1988	48540.	38539.	34550.	20310.	16721.	146444.	35656.	733.	65076.	12339.	8221.	18254.	445383.
1989	27278.	134660.	196265.	124012.	959549.	819937.	55020.	75519.	116305.	15328.	8189.	6770.	2538832.
1990	44449.	86468.	370518.	1256164.	1413028.	422384.	26589.	60116.	98748.	35689.	33843.	15117.	3863113.
1991	101793.	65719.	45123.	138624.	265234.	518743.	70969.	187815.	118244.	427178.	267234.	2149397.	4356073.
1992	688885.	1374527.	782802.	207501.	312731.	684912.	135066.	57084.	45690.	11869.	45727.	108209.	4455003.
1993	72204.	303711.	305636.	147662.	106685.	108164.	25035.	11003.	15278.	183578.	19803.	30512.	1329271.
1994	40182.	92230.	91292.	58439.	628787.	113259.	35650.	0.	53915.	163384.	220838.	248794.	1746770.
1995	179571.	75637.	309638.	423311.	643423.	386179.	107773.	486342.	129703.	40271.	15609.	13884.	2811341.
1996	4694.	19703.	12795.	39749.	16030.	39054.	13167.	155998.	418270.	96992.	177896.	224000.	1218348.
1997	132951.	1084526.	813019.	550390.	440237.	391916.	137380.	37188.	12231.	21032.	16987.	236379.	3874236.
MEAN	88793.	143564.	157012.	225477.	425897.	261704.	101569.	73029.	104260.	165739.	82640.	112640.	1942324.

Table 3.14 1940-1997 Naturalized Flows at the Cameron on the Little River (LRCA59)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	20668.	40863.	18746.	232186.	269190.	646623.	691218.	261673.	94493.	31194.	1301729.	1338018.	4946601.
1941	710547.	1136414.	949374.	879686.	2428023.	1515114.	736924.	388540.	227319.	790700.	346374.	99034.	10208049.
1942	86065.	63247.	57321.	1837072.	1499241.	1018999.	114300.	106386.	819979.	708839.	311067.	232995.	6855511.
1943	137313.	93056.	195609.	277770.	219434.	168291.	43756.	24076.	54065.	67328.	18608.	26616.	1325922.
1944	331524.	600771.	731463.	262076.	2432620.	666071.	130087.	50875.	183724.	94057.	135088.	335714.	5954070.
1945	643403.	693734.	1174414.	2061579.	458369.	453957.	501845.	103625.	69389.	401886.	82677.	307965.	6952843.
1946	343076.	500678.	720575.	326420.	1019157.	426611.	82391.	80020.	303125.	215606.	562145.	444505.	5024309.
1947	577925.	186644.	471549.	322965.	784759.	211096.	50204.	73898.	39808.	46734.	37497.	135331.	2938410.
1948	63473.	154787.	158409.	88709.	265752.	179801.	228033.	12546.	47060.	28242.	16194.	13332.	1256338.
1949	49103.	99176.	252885.	499544.	833944.	402271.	120344.	16338.	104622.	138821.	54999.	54827.	2626874.
1950	70681.	372554.	49927.	260313.	354736.	188170.	256778.	173689.	285075.	72119.	14156.	6454.	2104652.
1951	8154.	32457.	43441.	17205.	184440.	355573.	24966.	34059.	68700.	11166.	12091.	14454.	806706.
1952	8450.	17399.	22390.	224521.	370047.	63548.	19041.	4904.	23481.	5777.	80381.	144168.	984107.
1953	130628.	41891.	168690.	102145.	1030533.	31157.	279846.	109045.	56701.	478235.	76056.	303244.	2808171.
1954	35073.	19810.	13704.	122697.	505466.	104827.	16290.	31227.	5876.	32506.	62050.	6984.	956510.
1955	10935.	84768.	55278.	204561.	598436.	388871.	101842.	76287.	268192.	583972.	33283.	15789.	2422214.
1956	25010.	43550.	15754.	23532.	438298.	36784.	0.	5855.	9871.	22982.	53982.	75640.	751258.
1957	1883.	238085.	122823.	2575770.	4704312.	1428314.	305708.	94533.	64379.	1171344.	627748.	269783.	11604682.
1958	227387.	746379.	522873.	386687.	1385864.	243002.	319525.	96150.	234711.	69381.	43714.	41737.	4317410.
1959	29438.	103051.	43023.	184050.	181537.	404838.	213850.	88275.	38543.	1815182.	302927.	482214.	3886928.
1960	841752.	446710.	249074.	191568.	211473.	107604.	259405.	59668.	18138.	644793.	397761.	1044906.	4472852.
1961	1568862.	1234340.	415351.	190522.	148911.	778990.	669785.	150363.	266838.	305735.	199992.	220598.	6150287.
1962	110853.	83602.	73799.	131405.	96537.	533392.	251466.	148374.	625066.	227694.	124091.	139644.	2545923.
1963	45390.	91175.	54180.	182572.	192516.	219579.	46651.	6563.	11112.	37216.	86357.	19623.	992934.
1964	32690.	98509.	122636.	135074.	101209.	200949.	20893.	53216.	319138.	68985.	327413.	67386.	1548098.
1965	391181.	715945.	271277.	334569.	3000872.	481830.	137428.	118211.	134786.	155448.	315403.	229532.	6286482.
1966	113934.	251106.	208576.	1237884.	1198005.	227672.	52837.	247046.	784402.	173674.	50470.	39499.	4585105.
1967	46404.	38335.	45863.	135090.	177145.	237986.	183891.	44326.	115766.	73244.	246832.	148446.	1493328.
1968	1456047.	499351.	1023672.	661448.	1630044.	738836.	525281.	91423.	56740.	46094.	64073.	150477.	6943486.
1969	67139.	188301.	486894.	821188.	1370058.	189881.	84930.	88684.	179242.	134767.	133769.	300468.	4045321.
1970	226770.	334741.	1314819.	461875.	493554.	222459.	41362.	35919.	120143.	157540.	35542.	31185.	3475909.
1971	31733.	37100.	29824.	64915.	133948.	101408.	243694.	362640.	158860.	479717.	206127.	667264.	2517230.
1972	282938.	137065.	70220.	62409.	239490.	90488.	59117.	152047.	151333.	187220.	258263.	120976.	1811566.
1973	387381.	273673.	551852.	790557.	531459.	759130.	235485.	101959.	73258.	735800.	278158.	124905.	4843617.
1974	230549.	95450.	95595.	107648.	223017.	75510.	33128.	174376.	929972.	599620.	1419990.	324889.	4309744.
1975	317743.	1029292.	284850.	415787.	1148909.	697819.	286069.	172329.	103478.	57768.	50750.	31664.	4596458.
1976	43514.	55532.	69354.	638177.	783592.	318658.	696011.	100920.	159915.	335644.	222986.	528660.	3952963.
1977	197206.	714687.	626263.	1623026.	742476.	256305.	65097.	29075.	40506.	23522.	27873.	20942.	4366978.
1978	24244.	66038.	133612.	97909.	57925.	70884.	16539.	590426.	37295.	30065.	42841.	20180.	1187958.
1979	204317.	284602.	746604.	667920.	1544669.	1037689.	461235.	154551.	48134.	49124.	19702.	87363.	5305910.
1980	144797.	156432.	116637.	163071.	870273.	129138.	41584.	19635.	133167.	268692.	70583.	74069.	2188078.
1981	29035.	47918.	176533.	155016.	141509.	1686724.	239821.	66728.	111621.	1269107.	309487.	84569.	4318068.
1982	60717.	77192.	154648.	159158.	1114046.	991608.	506453.	58639.	17784.	20682.	27297.	58388.	3246612.
1983	44400.	287728.	295842.	101672.	477801.	171481.	41447.	68193.	23027.	103195.	34210.	15631.	1664627.
1984	48189.	28983.	106616.	24779.	12659.	49373.	13113.	13490.	19652.	502419.	159079.	485231.	1463583.
1985	359162.	377037.	494009.	296332.	334995.	257228.	79603.	24541.	27010.	361258.	353325.	508298.	3472798.
1986	93270.	663642.	124137.	90513.	453801.	1063516.	151292.	68313.	380713.	605711.	361675.	905421.	4962004.
1987	386738.	467130.	687962.	246082.	554823.	1925770.	333193.	99913.	81133.	29584.	63610.	168556.	5044494.
1988	110619.	84809.	95577.	63081.	44710.	278428.	67731.	28069.	68913.	21596.	12100.	28659.	904292.
1989	55393.	195076.	237878.	181464.	1366744.	1206576.	164281.	198010.	134151.	37834.	20563.	15711.	3813681.
1990	63679.	112238.	612734.	1578256.	2063005.	680096.	116895.	110832.	138567.	72464.	100667.	37777.	5687210.
1991	647776.	309362.	118790.	380206.	609368.	688054.	116911.	228305.	183482.	455039.	469377.	3911671.	8118341.
1992	1814637.	3506035.	1901729.	652463.	1129677.	1389551.	402612.	193329.	118134.	56491.	100849.	281377.	11546884.
1993	241136.	596137.	938832.	488331.	645052.	484741.	130651.	43218.	46892.	267753.	74857.	65862.	4023462.
1994	60683.	201915.	154683.	62718.	1055930.	237677.	78113.	27619.	74995.	275205.	280381.	457109.	2967028.
1995	313401.	134437.	610845.	803469.	1042254.	665492.	158629.	750065.	179379.	80944.	28909.	35832.	4803656.
1996	31915.	49764.	37673.	73305.	38478.	97057.	28400.	240100.	657038.	166013.	274760.	465320.	2159823.
1997	323624.	2003794.	1538703.	1537338.	1186964.	1196446.	384127.	107716.	39410.	48934.	54443.	651944.	9073443.
MEAN	257941.	366284.	363214.	463764.	812622.	508275.	201071.	121738.	168419.	275046.	197885.	291704.	4027961.

Table 3.15 1940-1997 Naturalized Flows at Gulf of Mexico on the Brazos River (BRGM73)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	52435.	156451.	44398.	204339.	326625.	676111.	1350846.	262307.	112440.	68628.	1465291.	3321573.	8041444.
1941	1213863.	1384529.	1667737.	1267354.	2860813.	2165749.	1177738.	372470.	378506.	788423.	667985.	173201.	14118368.
1942	143269.	113252.	101820.	2190079.	2008013.	1340817.	395971.	121025.	880186.	736070.	419404.	255371.	8705277.
1943	347222.	124888.	237811.	319335.	231461.	275056.	175695.	93456.	65195.	89941.	103862.	102379.	2166301.
1944	725440.	978853.	1211688.	369011.	2937554.	1103160.	177438.	74335.	275961.	117285.	338780.	802254.	9111759.
1945	1346704.	937205.	1373933.	2622893.	793496.	598370.	556766.	482610.	368609.	565338.	132006.	504049.	10281979.
1946	693957.	898516.	1343657.	520988.	1675540.	928245.	231983.	90189.	322021.	282624.	1102939.	605124.	8695783.
1947	1023792.	311372.	829291.	443094.	1040245.	362035.	102854.	357928.	132049.	72914.	93769.	247682.	5017025.
1948	107660.	250417.	370430.	161725.	325807.	233304.	280532.	17231.	61687.	45472.	33561.	28150.	1915976.
1949	72285.	254674.	506625.	819337.	1070739.	515230.	226470.	50464.	105160.	329938.	203270.	299725.	4453917.
1950	294046.	786124.	176791.	543838.	571183.	686426.	257491.	202924.	300240.	128877.	40806.	33754.	4022500.
1951	23269.	50928.	66154.	80917.	179643.	373206.	38729.	33029.	81000.	33545.	24824.	33468.	1018712.
1952	23801.	55136.	79696.	428009.	480499.	225293.	51019.	239.	30925.	12658.	74648.	256380.	1718303.
1953	290977.	128504.	268911.	105527.	1856532.	115218.	301068.	159031.	151070.	464428.	232906.	584988.	4659160.
1954	140605.	52934.	29634.	142189.	532042.	162258.	32965.	53198.	18836.	43560.	76706.	26341.	1311268.
1955	36315.	278373.	80949.	320851.	552886.	417247.	140317.	86929.	200675.	631014.	61398.	31537.	2838491.
1956	42298.	105330.	46074.	52053.	405720.	48133.	4.	16926.	16691.	24928.	55989.	95261.	909407.
1957	11064.	242488.	264754.	2006816.	6254466.	2037745.	604047.	176404.	108553.	1894546.	1099521.	479587.	15179991.
1958	582649.	903325.	811844.	437695.	1597873.	317387.	433947.	108938.	351100.	235025.	108586.	84638.	5973007.
1959	63015.	360220.	123044.	907099.	570257.	516407.	309809.	171483.	62095.	1759738.	503461.	685539.	6032167.
1960	1064752.	702724.	389391.	254019.	491676.	548272.	448267.	120962.	46533.	628042.	1031807.	1627100.	7353545.
1961	2361173.	2061868.	754485.	324306.	209867.	1148282.	1076586.	265224.	831287.	367885.	397567.	413531.	10212061.
1962	234482.	201861.	139985.	132358.	199198.	534343.	328793.	163052.	567617.	296402.	150223.	383418.	3331732.
1963	204560.	209645.	102307.	282194.	191930.	215268.	88039.	24779.	26084.	46585.	108002.	63602.	1562995.
1964	65506.	183425.	262263.	161882.	167661.	192764.	53147.	53718.	310524.	138783.	386997.	144853.	2121523.
1965	505612.	1133382.	382911.	485888.	3475435.	1026580.	194335.	161466.	150155.	183320.	429214.	482810.	8611108.
1966	217511.	458906.	381472.	1161434.	2208674.	337461.	114310.	307940.	754881.	288849.	75162.	59026.	6365626.
1967	73633.	53715.	61643.	160343.	215947.	286855.	189937.	66820.	142272.	75251.	248567.	152997.	1727980.
1968	1642866.	701563.	1081404.	1004687.	2398932.	1950904.	1090371.	195103.	247755.	131225.	170866.	537186.	11152862.
1969	182767.	689513.	1040970.	1480394.	1759743.	300530.	124254.	110461.	183104.	144964.	178520.	392717.	6587937.
1970	329663.	380065.	1755677.	732103.	747509.	351935.	114860.	59172.	223010.	552955.	126929.	61521.	5435399.
1971	58020.	53583.	61405.	92012.	168228.	132173.	220978.	441788.	349402.	388951.	262157.	864966.	3093663.
1972	417680.	284630.	145546.	98141.	636864.	185903.	82009.	177429.	164969.	137031.	392911.	155706.	2878819.
1973	556870.	611453.	1032912.	1460838.	913882.	1747980.	438552.	167974.	330926.	1637228.	503272.	419687.	9821574.
1974	868545.	415812.	206588.	165639.	342197.	122573.	69253.	172493.	1530253.	772717.	2010011.	811725.	7487806.
1975	525613.	1372487.	479255.	664656.	1695891.	1240122.	520190.	280441.	167132.	103381.	106283.	104703.	7260154.
1976	84261.	95168.	132504.	739233.	1231200.	727081.	768628.	176535.	200967.	445628.	399290.	1218961.	6219456.
1977	319591.	1133554.	684932.	2139368.	987627.	385381.	138459.	65024.	99474.	52173.	60164.	61046.	6126793.
1978	228282.	266945.	201655.	119222.	103332.	188201.	71675.	551010.	155786.	53258.	144117.	95750.	2179233.
1979	725812.	647432.	1128935.	1294908.	1797729.	1979672.	497069.	417999.	507534.	106914.	74541.	183911.	9362456.
1980	496899.	398778.	189276.	331667.	1192366.	255535.	97833.	45352.	172116.	286862.	54673.	86784.	3608141.
1981	65854.	86187.	220627.	192354.	310737.	2268585.	523414.	141109.	267009.	1281396.	808352.	144624.	6310248.
1982	90833.	118084.	184054.	340865.	1519157.	1055288.	642628.	106083.	39202.	50072.	147349.	227149.	4520764.
1983	223144.	733494.	789861.	272957.	1020368.	390799.	126072.	278989.	185303.	139839.	83470.	107986.	4352282.
1984	96504.	88341.	246632.	65073.	138930.	112714.	57472.	43042.	40035.	1067366.	594298.	717587.	3267994.
1985	721881.	621504.	1085025.	458355.	425225.	319718.	141879.	57793.	54492.	413056.	817961.	1145958.	6262847.
1986	178176.	869467.	213565.	139297.	713608.	1555926.	239408.	155568.	417014.	685812.	602612.	1509321.	7279774.
1987	676536.	688097.	1065289.	349145.	566933.	2812974.	550120.	199526.	144596.	77325.	143161.	300723.	7574425.
1988	207872.	134780.	239886.	131416.	114365.	296117.	156107.	90681.	91907.	36457.	22690.	35997.	1558275.
1989	146572.	290960.	316284.	320259.	1447535.	1398426.	372480.	403988.	159881.	60745.	53831.	26888.	4997849.
1990	111952.	222172.	689498.	1502335.	2148268.	870742.	197061.	138898.	161708.	81002.	131218.	62987.	6317841.
1991	1645100.	699581.	281005.	1053047.	847780.	840772.	224833.	246573.	236178.	444138.	471429.	3408208.	10398644.
1992	3363756.	4570580.	3021573.	1263782.	1633746.	2161286.	517412.	323985.	229426.	115252.	209535.	527901.	17938232.
1993	685963.	750635.	1290274.	964015.	1298427.	1320627.	343005.	114407.	79248.	326164.	219804.	136090.	7528659.
1994	136136.	353848.	394740.	137375.	1145550.	459406.	152748.	89594.	135635.	1691352.	396258.	1085111.	6177753.
1995	1118352.	345992.	1017452.	1097650.	1121847.	885777.	267204.	786444.	214666.	149969.	96510.	269220.	7371083.
1996	82354.	77959.	58190.	87952.	51559.	85910.	63462.	228168.	748503.	238267.	231269.	473003.	2426596.
1997	492959.	1926255.	2323784.	1917878.	1260005.	1165403.	495210.	208212.	199834.	258239.	124661.	776392.	11148832.
MEAN	490392.	569103.	580836.	646934.	1089161.	775098.	321444.	182223.	251542.	384135.	332852.	481520.	6105239.

3.6.3 Parameter Calibration

The purpose of the flow extension model is to develop sequences of monthly naturalized flows of WAM dataset based on the TWDB precipitation and evaporation datasets. Parameter calibration is to determine an optimal set of values for the flow extension model fitted to the TWDB precipitation and evaporation datasets that allows the period-of-analysis naturalized flows from a TCEQ WAM System dataset to be reproduced as closely as possible with the model. The resulting calibrated model is then applied to extend the naturalized flows of the WRAP/WAM dataset.

The parameter calibration process consists of two levels and each level of calibration is performed with multiple stages. An initial level-1 calibration focus on replicating flows in each of the 696 months of the original 1940-1997 period-of-analysis. Following level-2 calibration consists of additional adjustments to improve model accuracy in reproducing statistical characteristics of original known naturalized flows. The flow extension model, model parameters, and detailed calibration methodologies are described in Chapter 2.

3.6.3.1 Level-1 Parameter Calibration

The initial level-1 calibration is an automated optimization procedure that determines a set of parameter values of Eqs. 2.1, 2.2, 2.3, 2.4, and 2.5 that minimize a specified objective function defined by Eq. 2.8. The objective function was composed of 16 weighting factors and 16 criteria functions defined by Eqs. 2.9, 2.10, 2.11, and 2.12 measuring differences between 1940-1997 computed flows and 1940-1997 known flows in each month.

Figure 3.27-3.34 are expressed the comparison results of flow extension with parameter values of the Level-1 calibration with original sequences naturalized flows at control points BRSE11, BRWA41, LRCA58, and BRGM73. The original 1940-1997 naturalized flows are plotted as dashed red line and computed flows with TWDB datasets are shown as solid blue lines in Figure 3.27-3.34.

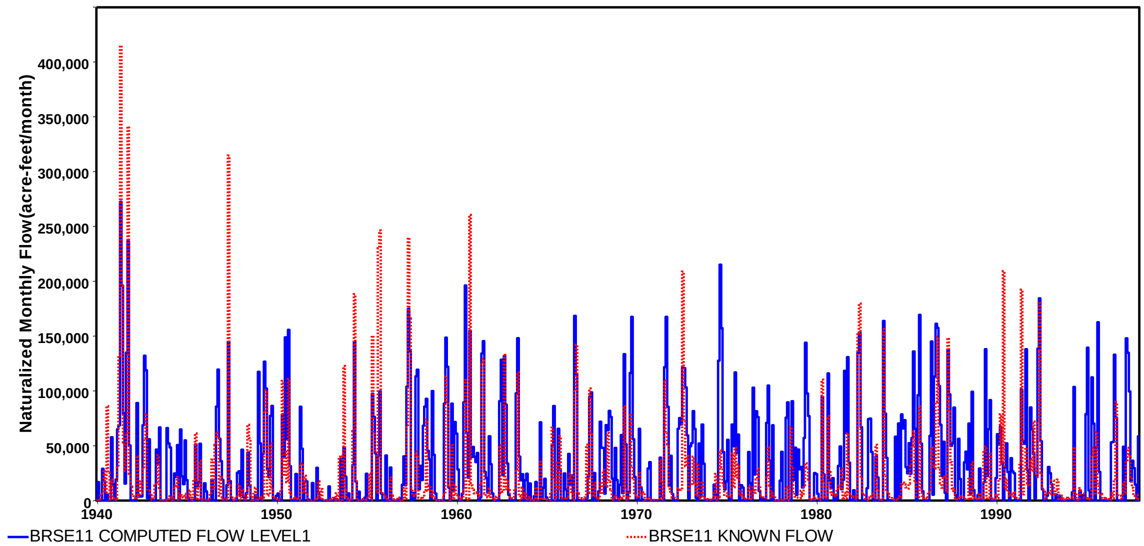


Figure 3.27 Comparison 1940-1997 Known and Level-1 Computed Flows at BRSE11

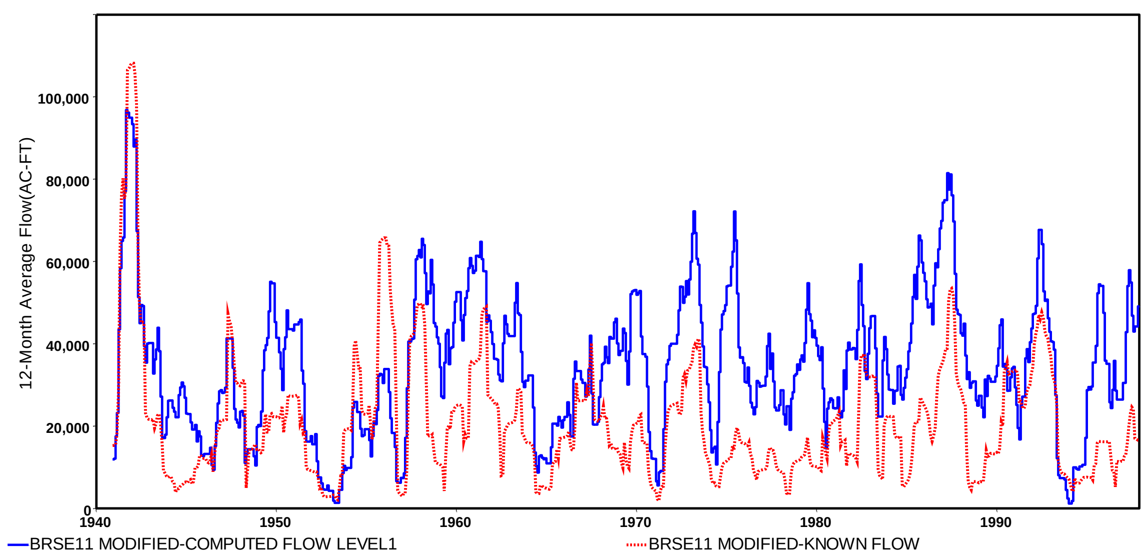


Figure 3.28 Comparison 1940-1997 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at Seymour (BRSE11)

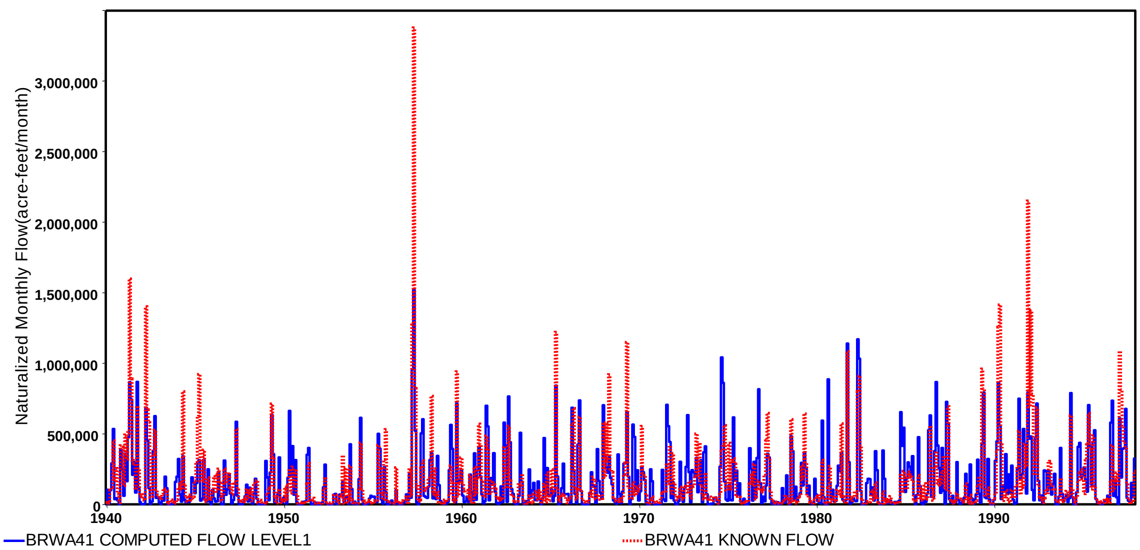


Figure 3.29 Comparison 1940-1997 Known and Level-1 Computed Flows at BRWA41

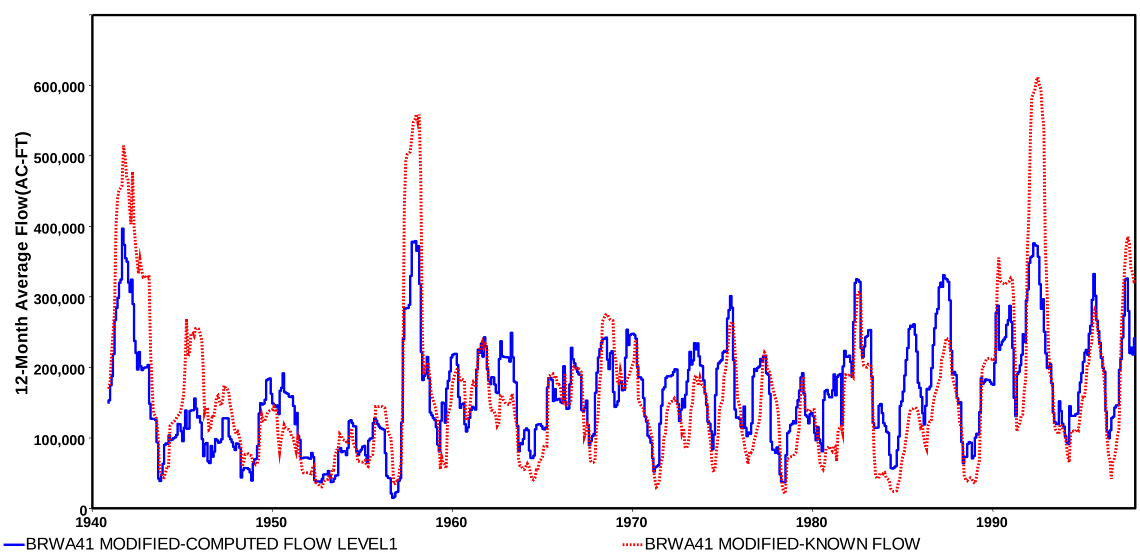


Figure 3.30 Comparison 1940-1997 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at Waco (BRWA41)

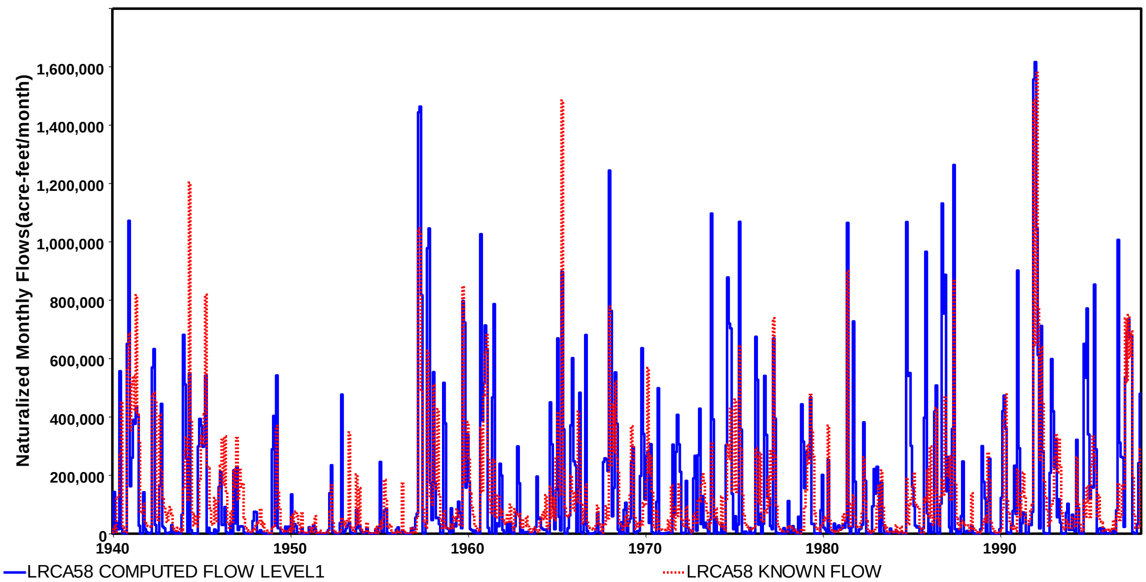


Figure 3.31 Comparison 1940-1997 Known and Level-1 Computed Flows at LRCA58

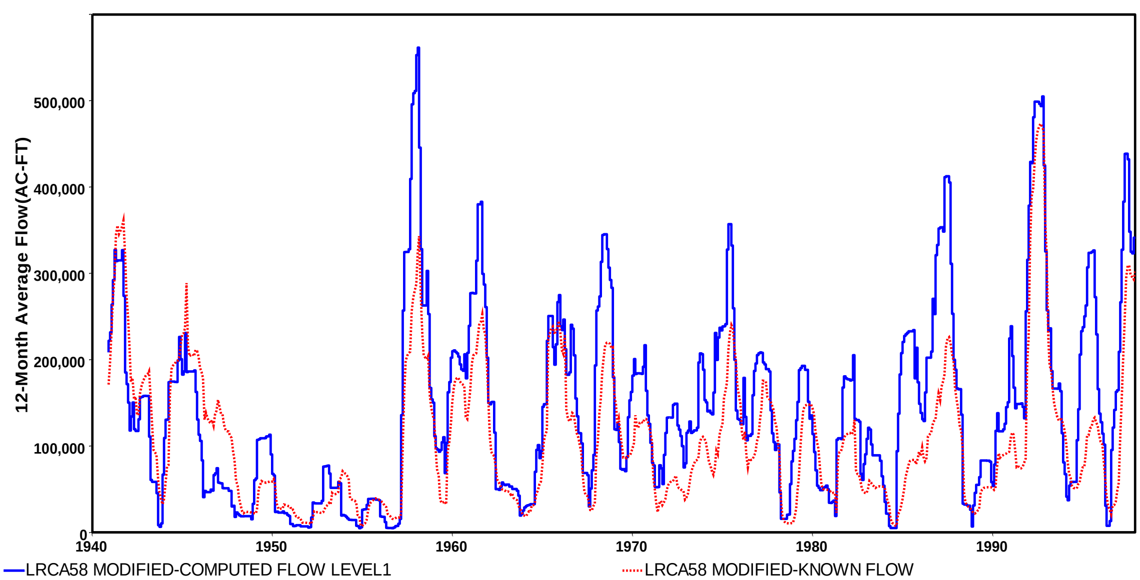


Figure 3.32 Comparison 1940-1997 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Little River at Cameron (LRCA58)

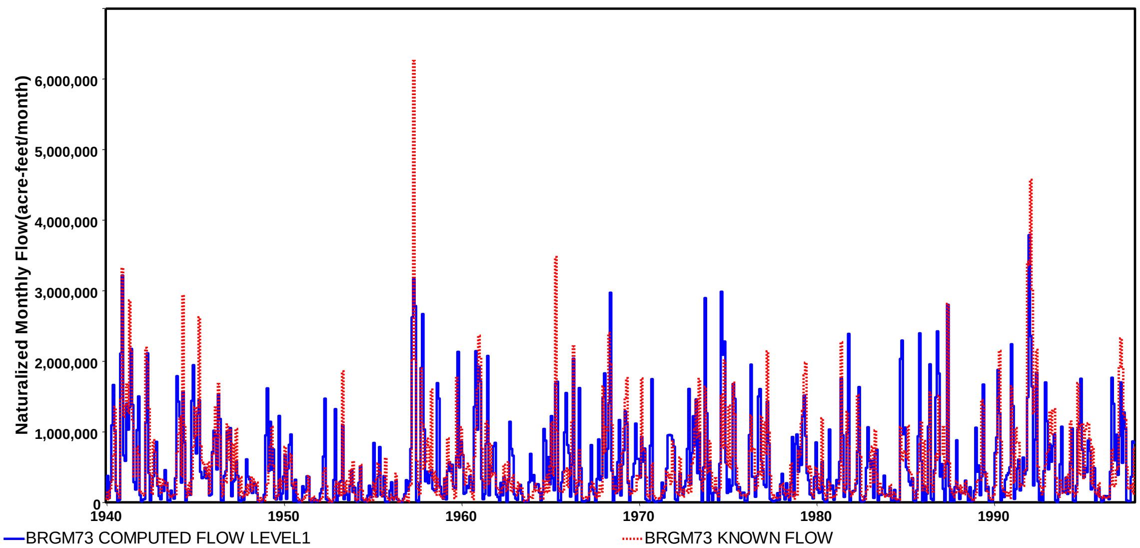


Figure 3.33 1940-1997 Naturalized Flows at Gulf of Mexico on the Brazos River BRGM73

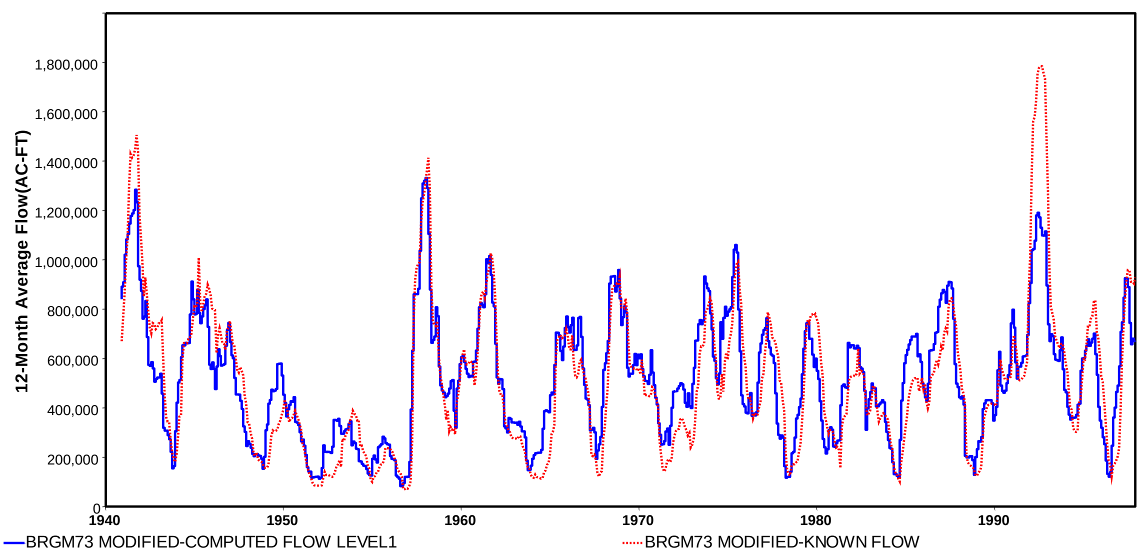


Figure 3.34 Comparison 1940-1997 Known and Level-1 Computed 12-Month Forward Moving Average Flows at Gulf of Mexico on the Brazos River (BRGM73)

3.6.3.2 Level-2 Parameter Calibration

The flow extension model developed with Level 1 calibration could be applied without further adjustment. However, the flows computed with the Level 1 calibration for each individual month are necessarily approximate. WRAP/WAM System is designed for developing frequency and reliability relationships rather than precisely synthesizing the exact flow in a particular month. Likewise, the flow model calibration process is designed to capture the statistical characteristics of the naturalized flows.

The level 2 calibration focuses on improving model accuracy in reproducing statistical characteristics of the original 1940-1997 naturalized flows such as means, standard deviations, and flow-frequency relationships. Upon completion of Level-1 calibration, computed and known flows are grouped by 12 flow ranges based on flow frequency analysis. The computed flows grouped into 12 flow ranges are multiplied by 12 FX(r) factors which are the ratios of mean between known and computed flows corresponding to 12 flow ranges.

Optionally, ZF(1) and ZF(2) parameters on the UB record are set to generate zero or near zero flows in an appropriated number of months. Regression and correlation analysis of computed flows versus known flows are available with RC record optionally. However, it is not recommended as a standard process of calibration.

Figure 3.35-3.42 are presented the results for 1940-1997 period-of-analysis with the Level 2 calibration at Brazos River at Seymour (BRSE11), Brazos River at Waco (BRWA41), Little River at Cameron (LRCA58) and the outlet of Brazos River at Gulf of Mexico (BRGM73). The result of flow-frequency relationship for four control points naturalized flows with Level 2 calibration are tabulated in Table 3.19, 3.21, 3.23, and 3.25.

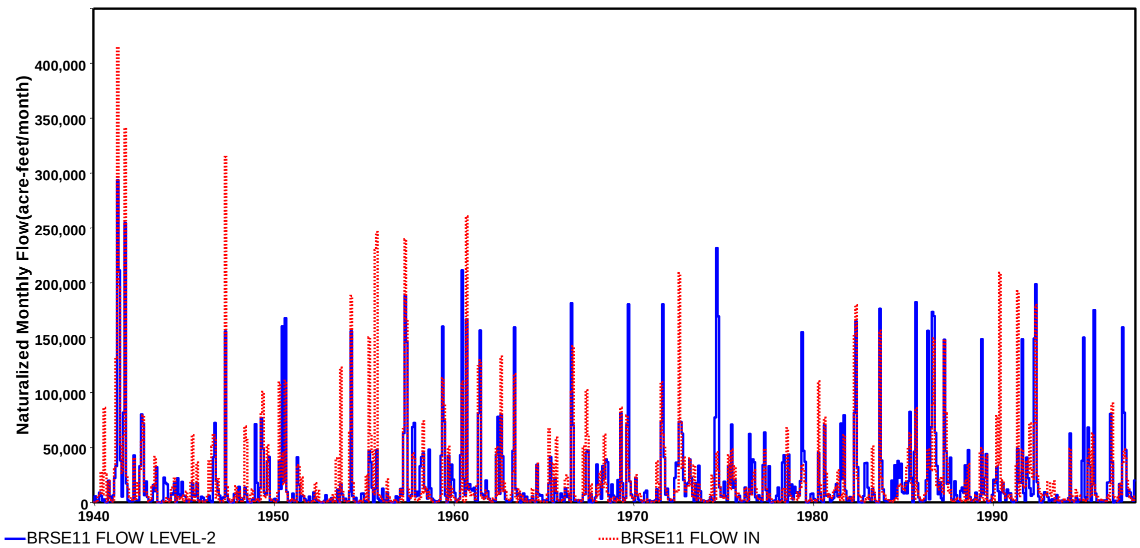


Figure 3.35 Comparison 1940-1997 Known and Level-2 Computed Flows at BRSE11

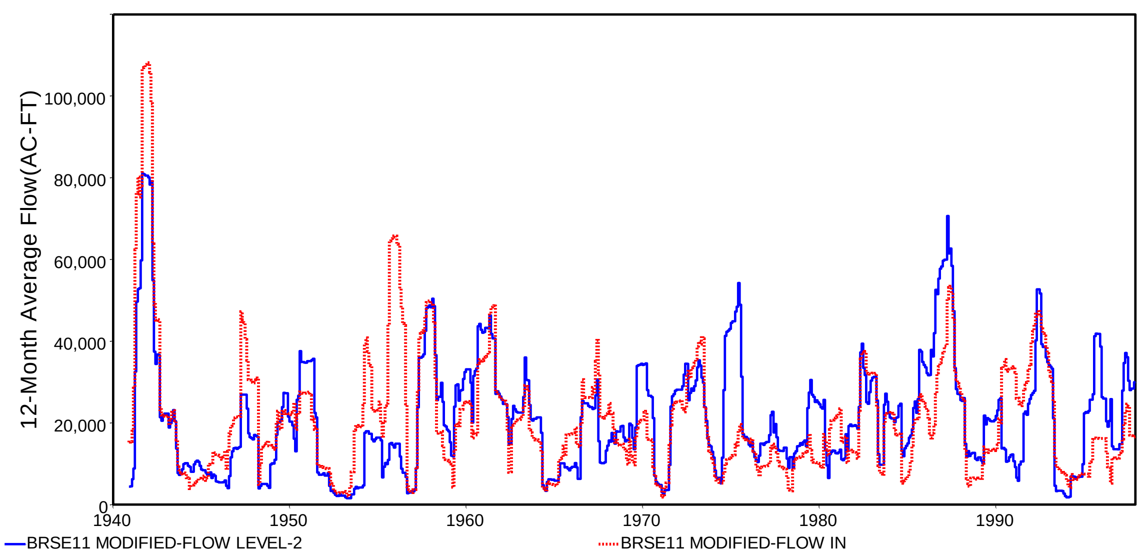


Figure 3.36 Comparison 1940-1997 Known and Level-2 Computed 12-Month Forward Moving Average Flows for Brazos River at Seymour (BRSE11)

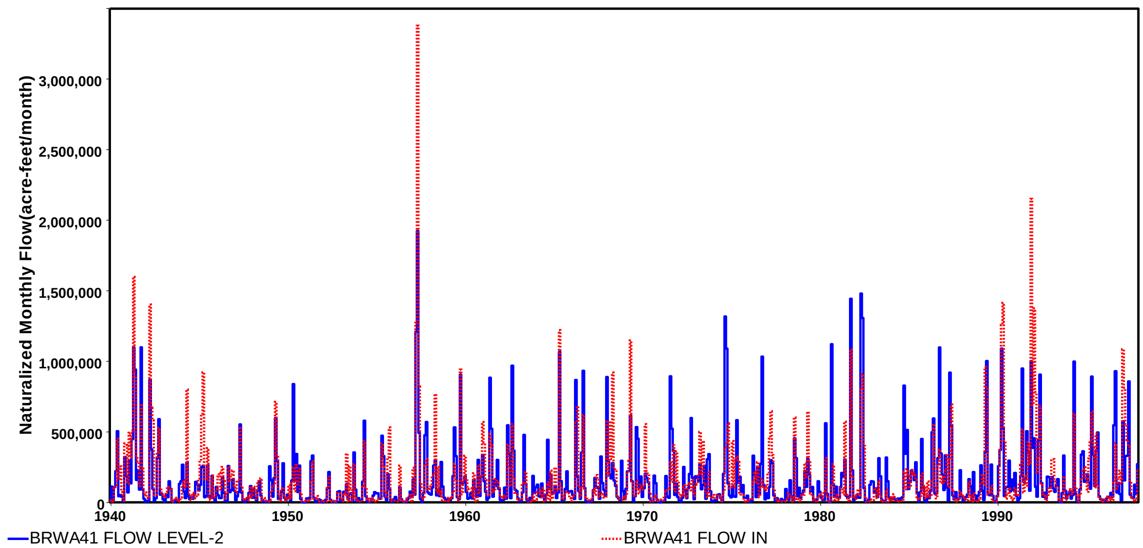


Figure 3.37 Comparison 1940-1997 Known and Level-2 Computed Flows at BRWA41

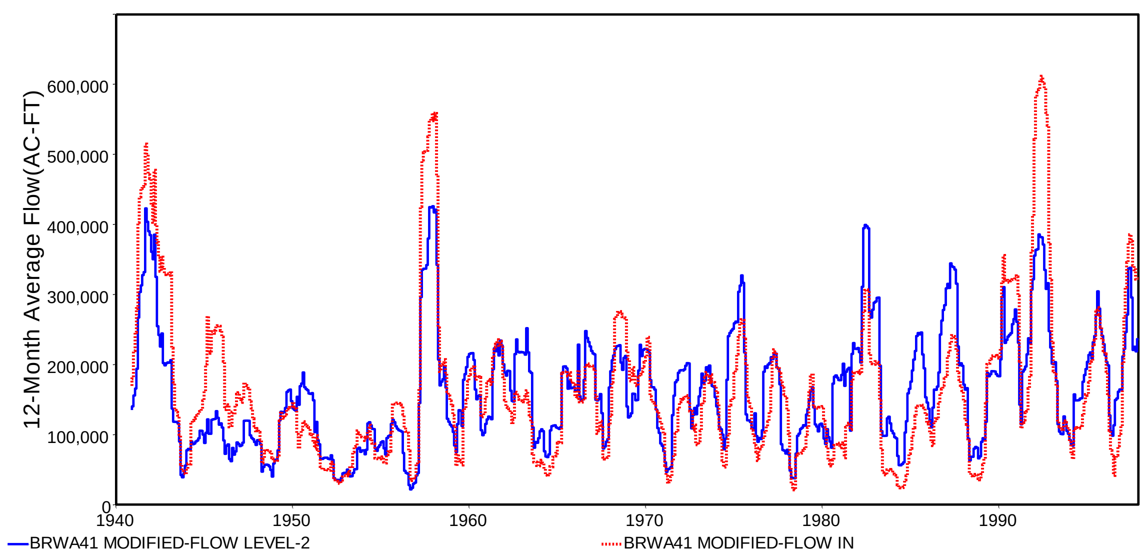


Figure 3.38 Comparison 1940-1997 Known and Level-2 Computed 12-Month Forward Moving Average Flows for Brazos River at Waco (BRWA41)

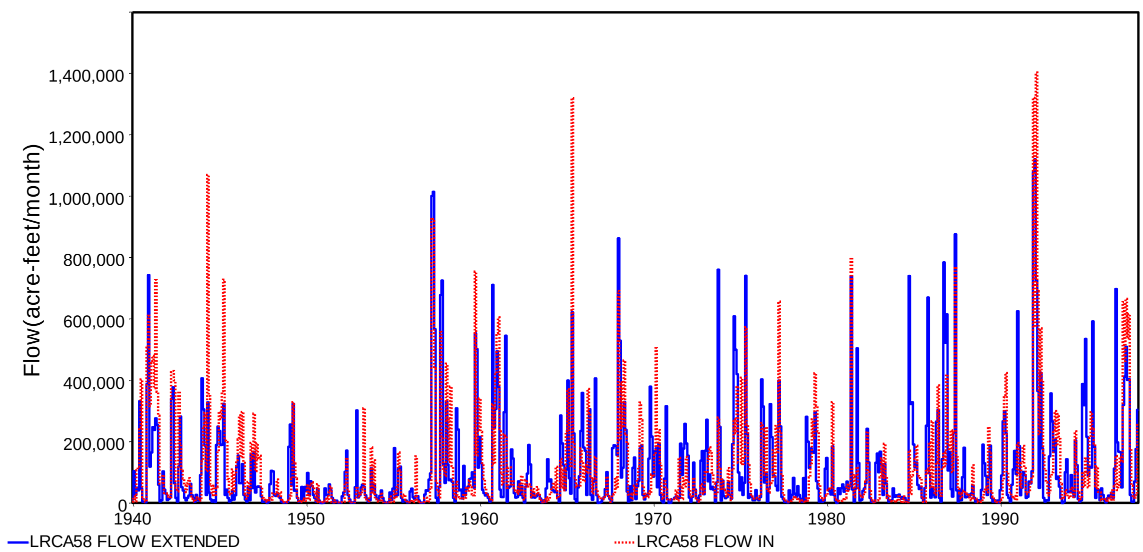


Figure 3.39 Comparison 1940-1997 Known and Level-2 Computed Flows at LRCA58

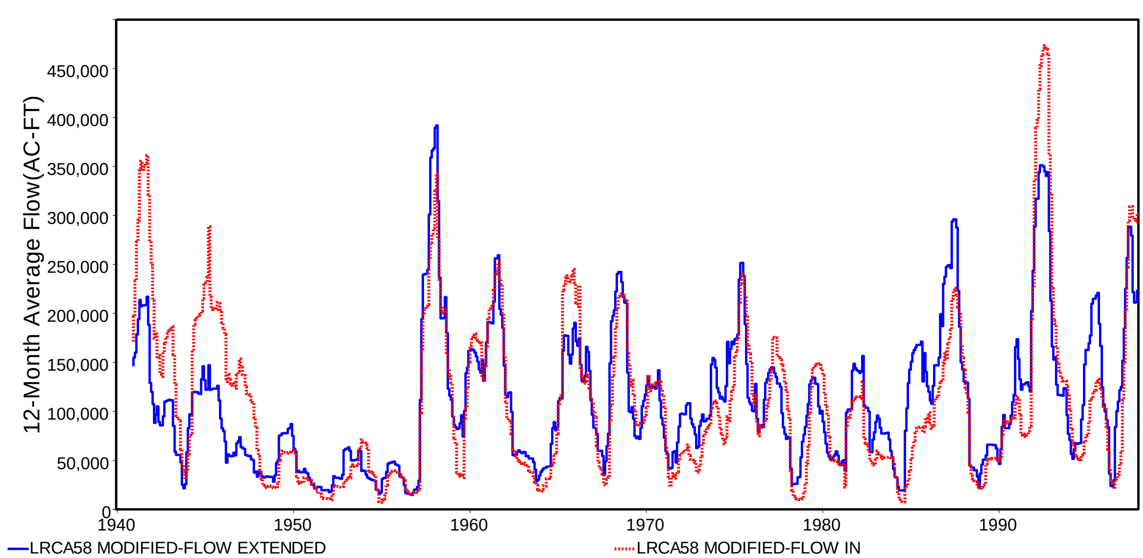


Figure 3.40 Comparison 1940-1997 Known and Level-2 Computed 12-Month Forward Moving Average Flows for Little River at Cameron (LRCA58)

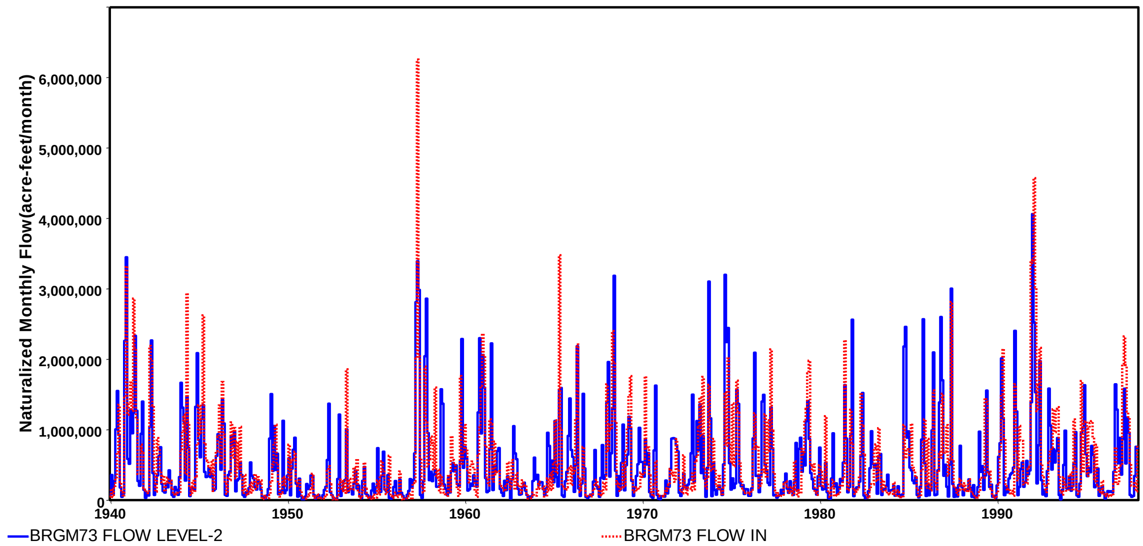


Figure 3.41 Comparison 1940-1997 Known and Level-2 Computed Flows at BRGM73

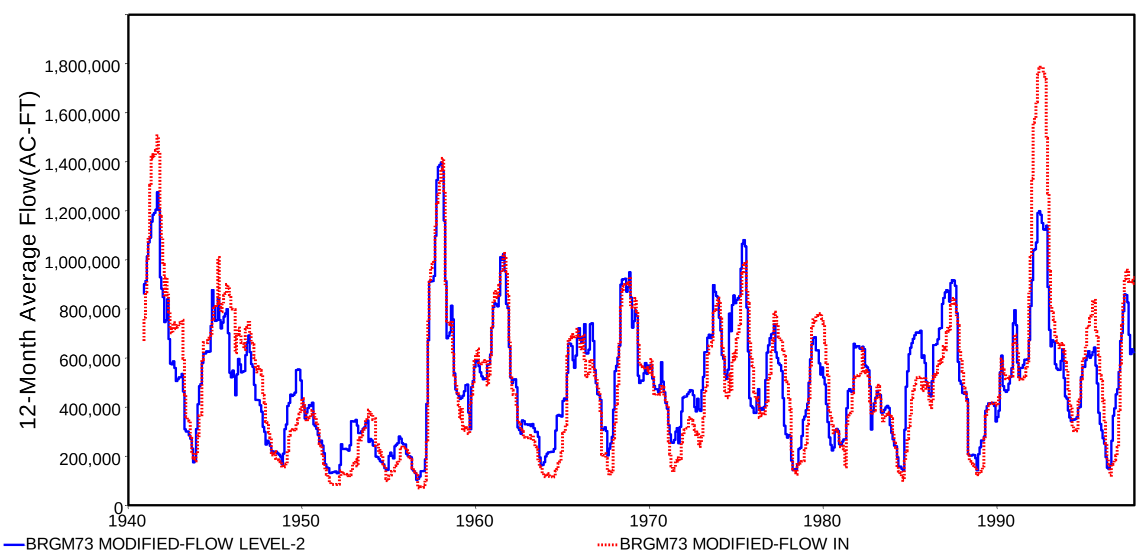


Figure 3.42 Comparison 1940-1997 Known and Level-2 Computed 12-Month Forward Moving Average Flows for Brazos River at Gulf of Mexico (BRGM73)

3.6.4 Final Flow Extension Model for Brazos WAM

As previously mentioned, the flow extension model and calibration methodologies are incorporated in the WRAP program HYD. The final flow extension model consists of a HIN input file of the program HYD shown in Table 3.16 and precipitation and evaporation input from PPP and EEE files combined with original 1940-1997 sequence of naturalized flows provided in a FLO file of Brazos WAM dataset.

The calibration process requires significant time and expertise. However, future updates of the naturalized flows do not require additional calibration studies. The TWDB updates the precipitation and evaporation database each year. A Microsoft Excel spreadsheet facilitates convenient updating of the Precipitation.PPP and Evaporation.EEE files used with HYD whenever the TWDB updates their original database. The HIN file can be easily updated by simply changing the extension period years on the FE records.

The HIN input file presented in Table 3.16 controls flow extension process. The job control JC and control point CP records in the HIN file control reading the 1940-1997 naturalized flows from the FLO file and creating either a new FLO file or a DSS file containing the 1940-2016 flows. The level-1 calibration begins with FE, FP, FZ, QD, and QA records in a HIN file and produces the a set of parameter values for each quadrangle recorded on the BM, B4, XP, and X4 records. The level-2 calibration results in adding parameters controlled by the UB, FR, and FX records inserted into the HIN file.

Each of the 77 control points has a FE record followed by a set of FZ, FR, FX, UB, UM, BM, XP, B4, and X4 records containing the final calibrated values for the model parameters. The quadrangles encompassing the watersheds at 77 control points listed in Table 3.11 entered on QD records and the corresponding drainage areas in square miles are entered on QA records. Table 3.16 shows an example of the input HIN file including only two control points (RWPL01, BRGM73). All 77 primary control points in the Brazos River basin are included in the final HIN file shown in Appendix A.3.

Table 3.16 *HYD* Input HIN File for Synthesizing 1998-2016 Naturalized Flows

```
**   WRAP-HYD Input File Bwam.HIN for Extending Naturalized Flows for the Brazos WAM
** Flow Extension for Control Point RWPL01
FERWPL01   1998   2016   1940   1997    1    0                                          0.626996
FN                         Ext1998-2016
QD      2       306       305
QA             255.      830.
FZ                  26.0             49.2            303.8      99.0
FR      2      4.0      12.0      26.0      49.2      71.0      99.0    303.8   1008.2   3616.8
FR             0.0       0.9       2.9       6.1      42.5     160.3   1156.2   2552.0   4908.7
FX         1.0000013.89098 8.90507 9.06144 2.75042 1.09445 0.27705 0.32147 0.58103 1.24454
UB                 0.12096 0.72399 1.00000 0.35812 0.91998 1.00000
BM             0.00      0.00      0.00      7.85      4.30      8.30      0.91      0.00      6.95      0.00      0.00      0.00
XP    306   0.86171991   0.98137707   0.37111071   0.95913601   0.99400699
XP    305   0.95638746   0.99871624   0.00020500   0.96800011   0.99900001
B4            0.00      0.00      0.00    160.00    125.00    115.00    125.00      0.00      0.00      0.00      0.00      0.00
X4    306   0.67157602   0.99935585   0.39999875   0.97990203   1.00000000
X4    305   1.00000000   1.00000000   0.00000000   0.82428634   1.00000000
**
**
** Flow Extension for Control Point BRGM73
FEBRGM73   1998   2016   1940   1997    1    0                                          1.709024
FN                         Ext1998-2016
QD   4 15       812       811       711       712       611       710       610       709       609       510       509       409
QD              508       408       507
QA             890.      473.     3733.      148.     2462.     2398.     4028.      324.     2225.     1960.     3976.     1112.
QA            2962.     2417.     2226.
FZ                 101917.            199329.            526071. 376386.
FR   2     42893.2 59767.2 101917. 142127. 199329. 269220. 376386. 526071. 792769.1272971.1759739.
FR         16683.8 22591.8 45423.0 117235. 183169. 281879. 387097. 575789. 927893.1444129.1827851.
FX         2.35462 2.74728 2.47362 1.42524 1.11885 0.99304 0.95014 0.92687 0.87735 0.91990 0.93145 1.07228
UB                 0.43000 1.00000 0.76000 0.65000 1.10000 1.00000
BM         31530.3357375.8350224.0059767.0059767.0059767.0038889.3322541.0028628.8332770.0038397.5030023.00
XP    812   1.00000000   1.00000000   0.36108109   0.98000002   1.00000000
XP    811   1.00000000   1.00000000   0.40120122   0.98000002   1.00000000
XP    711   1.00000000   1.00000000   0.42000002   0.70000005   1.00000000
XP    712   0.84589267   1.00000000   0.00000100   0.96047485   1.00000000
XP    611   0.80000007   1.00000000   0.00007167   1.00000012   1.00000000
XP    710   0.83286285   1.00000000   0.00003292   0.98000002   1.00000000
XP    610   0.84000009   1.00000000   0.00007747   1.00000012   1.00000000
XP    709   0.84336007   0.94999999   0.00001300   0.98000002   1.00000000
XP    609   0.80000007   1.00000000   0.00003180   0.98000002   1.00000000
XP    510   0.80080009   0.99936968   0.00006106   1.00000000   0.98000002
XP    509   0.76000005   1.00000000   0.00004617   1.00000012   1.00000000
XP    409   0.77390617   0.99900001   0.00002167   0.98000002   1.00000000
XP    508   0.80000007   1.00000000   0.00004250   1.00000012   1.00000000
XP    408   0.80080009   0.99900001   0.00005446   0.98000002   1.00000000
XP    507   0.80080009   1.00000000   0.00004110   0.98000002   1.00000000
B4          32264.   57894.   51392.   81203. 125886. 104235.   39794.   23065.   29295.   33532.   20791.   30721.
X4    812   0.95000011   1.00000000   0.39999995   0.96000010   1.00000000
X4    811   1.00000000   1.00000000   0.40000001   1.00000012   1.00000000
X4    711   0.60000002   1.00000000   0.40000001   1.00000012   1.00000000
X4    712   0.94999999   1.00000000   0.00000000   0.97990203   1.00000000
X4    611   1.00000000   1.00000000   0.00000000   0.90000010   1.00000000
X4    710   1.00000000   1.00000000   0.00000000   0.90090007   1.00000000
X4    610   1.00000000   1.00000000   0.00000000   0.90000010   1.00000000
X4    709   1.00000000   1.00000000   0.00000000   0.85500008   1.00000000
X4    609   1.00000000   1.00000000   0.00000000   0.90000010   1.00000000
X4    510   1.00000000   1.00000000   0.00000000   0.90000010   1.00000000
X4    509   1.00000000   1.00000000   0.00000000   0.90000010   1.00000000
X4    409   1.00000000   1.00000000   0.00000000   0.90000010   1.00000000
X4    508   1.00000000   1.00000000   0.00000000   0.90000010   1.00000000
X4    408   1.00000000   1.00000000   0.00000000   0.90000010   1.00000000
X4    507   1.00000000   1.00000000   0.00000000   0.90000010   1.00000000
ED
```

3.6.5 The Results of Flow Extension for the 77 Control Points of the Brazos WAM

The HIN file of Table 3.16 contains flow extension parameters for the 77 primary control points in the Brazos WAM dataset. The 77 control points are listed in Table 3.4 with descriptive information, and their locations are shown in Figures 3.5 and 3.6. The 77 primary control points reflect a diverse range of watershed drainage area size, topography, climate, land use, and other characteristics. FLO and DSS files containing 1940-2016 naturalized flows for the 77 control points were created with HYD.

Table 3.17 provides a comparison of the mean, standard deviation, and median for three sets of monthly naturalized flows at the 77 primary control points.

1940-1997 flows from the original TCEQ WAM System dataset

1940-1997 flows computed with HYD using the flow extension methodology

1998-2016 flows computed with HYD using the flow extension methodology

This comparison in Table 3.17 provides an indication of the validity of the flow extension methodology and the model calibration. The statistics for the 1940-1997 flows computed with HYD should be as close to the statistics for the 1940-1997 flows as possible. Differences between the statistics for 1998-2016 flows versus 1940-1997 flows are an indication of the differences in actual hydrologic conditions between the periods 1998-2016 and 1940-1997.

Synthesized naturalized flows during the 1998-2016 extension period exhibit extreme variability, ranging from the extremely dry year 2011 to several major floods (2004, 2007, and 2015). Several very wet years during 1998-2016 result in 1998-2016 mean flows being higher than 1940-1997 means at some of locations. However, 2011 extreme drought results in average flows during 1998-2016 being lower than 1940-1997 means at most of control points located in the upper watershed above the Glen Rose gage (BRGR30). The 1950-1957 drought is still the hydrologically most severe drought occurring during the extended 1940-2016 simulation period.

Stream flow estimates for sites in the arid flat extreme upper watershed above the

Seymour gage (control point (BRSE11) for both 1940-1997 and 1998-2016 are probably less accurate than for other locations in the Brazos River Basin. Otherwise, the flow extension methodology appears to work about equally well for all of the control points in synthesizing flows for 1998-2016.

As an example, the results of 1998-2016 flow extension and statistical characteristics of 4 control points on the Brazos River basin (BESE11, BRWA41, LRCA58, and BRGM73) were tabulated in Table 3.18-3.25 and extended monthly naturalized flows combined with original 1940-1997 flows are plotted in Figure 3.43-3.46. The 1998-2016 observed gaged flows and extended naturalized flows at 4 control points (BESE11, BRWA41, LRCA58, and BRRO72) are plotted in Figure 3.47-3.50. The results of flow extension for the all 77 primary controls are tabulated and plotted in Appendix A and B.

Table 3.17 Comparison of Naturalized Flow Statistics

Control Point	Mean (acre-feet/month)			Standard Deviation (ac-ft/mo)			Median (acre-feet/month		
	Original 1940-1997	HYD 1940-1997	HYD 1998-2016	Original 1940-1997	HYD 1940-1997	HYD 1998-2016	Original 1940-1997	HYD 1940-1997	HYD 1998-2016
RWPL01	206	205	291	993	821	1,234	12	10	5
WRSP02	1,394	1,382	1,201	3,644	3,557	4,363	214	124	32
DUGI03	840	839	667	2,247	2,097	1,973	127	125	101
SFPE04	4,474	4,471	3,821	10,838	10,263	10,578	693	689	545
CRJA05	1,033	1,030	897	2,527	2,469	2,566	141	139	129
SFAS06	6,421	6,420	5,634	15,348	15,137	17,777	1,111	1,162	842
BSLU07	1,410	1,411	1,344	3,084	3,056	3,061	314	290	250
DMJU08	1,853	1,852	1,528	4,374	4,281	4,592	224	145	73
DMAS09	9,031	8,996	7,728	20,143	19,549	17,965	1,636	1,764	1,431
NCKN10	1,078	1,077	913	3,218	2,666	2,598	156	128	113
BRSE11	20,841	20,846	17,792	42,817	40,244	38,343	5,042	5,808	5,354
MSMN12	484	474	396	1,887	1,534	1,666	7	0	0
CFRO13	602	599	472	1,569	1,497	1,118	130	123	105
CFHA14	3,764	3,754	3,146	8,370	7,191	5,505	1,262	1,239	1,304
MUHA15	648	636	522	1,475	1,311	1,144	162	147	147
CFNU16	7,972	7,947	6,373	17,242	14,828	11,449	2,568	2,441	2,282
CAST17	2,298	2,291	1,909	6,263	5,643	5,236	286	304	254
CFFG18	14,581	14,239	13,164	37,167	36,098	37,835	2,837	2,138	2,234
HCAL19	4,795	4,764	4,178	14,739	12,577	12,128	473	325	289
BSBR20	1,946	1,932	1,937	5,352	4,775	4,766	167	0	0
HCBR21	8,098	7,985	7,652	23,079	22,669	23,716	1,251	842	1,134
CFEL22	25,738	25,661	21,584	60,025	54,675	50,667	5,945	5,829	5,273
BRSB23	54,688	54,676	49,227	116,203	104,417	99,688	13,817	13,843	13,206
GHGH24	2,986	2,968	3,585	13,628	12,110	19,440	287	222	0
CCIV25	1,121	1,107	1,315	3,117	3,016	4,211	186	96	198
SHGR26	66,124	65,970	57,138	137,151	123,939	119,919	18,404	18,248	18,299
BRPP27	67,532	67,413	57,931	137,771	125,101	118,807	19,022	18,684	18,208

Table 3.17 (Continued)

	Mean (acre-feet/month)			Standard Deviation (ac-ft/mo)			Median (acre-feet/month		
Control Point	Original 1940-1997	HYD 1940-1997	HYD 1998-2016	Original 1940-1997	HYD 1940-1997	HYD 1998-2016	Original 1940-1997	HYD 1940-1997	HYD 1998-2016
PPSA28	5,344	5,227	5,538	12,081	11,874	14,384	1,125	241	585
BRDE29	83,646	83,621	76,309	165,799	145,812	140,843	27,265	28,441	24,900
BRGR30	93,248	93,210	86,900	182,476	162,341	164,686	30,585	30,902	32,593
PAGR31	4,873	4,873	5,774	9,601	9,195	12,311	1,520	1,351	1,366
NRBL32	5,609	5,553	7,017	11,447	11,311	16,360	1,348	1,329	1,574
BRAQ33	114,921	114,880	112,947	204,744	182,589	189,517	46,163	46,453	47,299
AQAQ34	7,432	7,362	8,739	14,492	14,494	19,545	1,194	304	82
NBHI35	3,740	3,713	3,822	8,289	8,221	10,241	623	573	556
NBCL36	13,577	13,515	17,550	31,085	28,745	39,819	2,594	2,791	2,670
NBVM37	16,911	16,846	25,789	37,025	34,390	53,020	3,710	3,746	4,364
MBMG38	4,597	4,575	6,368	8,416	8,244	12,149	1,257	1,241	1,383
HGCR39	2,145	2,142	2,956	4,084	3,946	5,691	565	648	639
BOWA40	29,736	29,495	41,863	53,194	51,477	78,841	9,936	9,314	10,831
BRWA41	161,860	161,802	154,278	266,253	244,711	251,691	68,642	70,631	75,666
BRHB42	194,262	194,398	180,861	300,104	283,328	292,822	89,483	90,262	86,709
LEDL43	4,698	4,680	4,850	11,403	10,929	13,152	876	679	550
SADL44	2,923	2,885	2,940	7,129	7,076	8,410	503	467	350
LEHS45	11,773	11,745	12,513	27,843	27,947	36,063	2,390	1,995	1,879
LEHM46	13,873	13,845	13,860	29,227	28,074	33,200	3,408	3,191	2,880
LEGT47	21,483	21,196	23,994	41,916	41,979	56,827	5,793	5,680	5,957
COPI48	6,448	6,433	7,769	14,071	13,843	18,675	1,286	1,277	936
LEBE49	42,105	41,795	48,936	75,480	73,267	97,541	12,757	13,674	15,589
LAKE50	9,981	9,977	11,696	20,700	18,913	23,777	2,702	2,504	2,572
LAYO51	17,406	17,395	20,337	34,980	32,492	40,227	4,593	4,543	4,786
LABE52	19,438	19,443	22,052	34,333	32,696	40,831	6,061	6,116	5,991
LRLR53	70,546	70,531	73,458	120,022	115,611	138,860	25,741	23,265	23,914
NGGE54	4,827	4,799	5,744	8,471	8,251	10,852	1,425	1,254	1,147
SGGE55	3,014	3,015	4,090	5,397	5,101	7,511	946	870	767
GAGE56	8,693	8,705	11,342	15,106	14,433	20,617	2,754	2,813	2,211
GALA57	15,772	15,700	20,763	25,225	24,266	35,645	5,489	5,446	5,362
LRCA58	109,858	109,682	135,643	170,466	166,120	232,332	44,799	43,369	44,278
BRBR59	335,664	335,656	342,652	483,897	463,786	569,702	158,629	156,212	151,813
MYDB60	3,280	3,269	4,896	6,625	6,572	10,491	552	428	428
EYDB61	3,599	3,595	4,348	6,547	6,448	8,352	814	860	770
YCSO62	18,617	18,583	22,710	33,266	33,423	42,849	3,904	3,392	3,218
DCLY63	3,957	3,937	4,516	7,512	7,466	9,338	649	289	247
NAGR64	6,956	6,928	8,086	13,055	13,027	16,293	1,066	852	763
BGFR65	2,686	2,677	3,103	4,704	4,670	5,918	528	425	333
NAEA66	26,882	26,812	31,224	46,900	46,966	60,090	5,743	4,524	3,885
NABR67	35,109	35,120	40,822	57,655	58,158	72,524	8,530	7,931	8,472
BRHE68	446,579	446,299	459,727	588,542	569,446	696,257	229,331	224,696	200,590
MCBL69	12,466	12,448	13,956	21,465	21,390	27,489	3,110	2,793	2,715
BRRI70	487,519	487,360	528,708	613,002	593,770	734,977	257,456	256,396	256,498
BGNE71	2,136	2,136	2,379	3,490	3,465	3,994	591	581	683
BRRO72	509,357	508,931	553,017	639,653	621,529	770,601	269,256	266,547	250,498
BRGM73	508,770	508,521	545,663	634,290	612,606	835,854	269,220	271,838	246,414
CLPEC1	2,395	2,394	2,605	3,196	3,115	3,584	1,000	1,052	930
CBALC2	6,364	6,362	6,876	8,768	8,200	9,336	2,957	2,962	3,252
SJGBC3	28,762	28,765	32,596	38,137	36,063	41,904	13,799	14,265	15,812
SJGMC4	69,517	69,500	75,463	92,174	87,203	100,318	33,350	34,172	35,755

Table 3.18 1940-2016 Naturalized Flows for Brazos River at Seymour (BRSE11)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0.	871.	1.	5303.	8506.	27760.	7092.	86156.	25468.	4.	19173.	3002.	183336.
1941	323.	2459.	30114.	131878.	414811.	195658.	52999.	26939.	59657.	340923.	24494.	12651.	1292906.
1942	5076.	2313.	1352.	40474.	3240.	17449.	6990.	28711.	56903.	79222.	9033.	9064.	259827.
1943	4868.	997.	3690.	13733.	16624.	41364.	11521.	0.	0.	54.	60.	978.	93889.
1944	1409.	3879.	2870.	366.	13446.	12377.	21577.	560.	6061.	4569.	3052.	6191.	76357.
1945	2469.	1394.	9718.	2760.	455.	19603.	61219.	954.	10749.	36235.	1060.	560.	147176.
1946	685.	776.	191.	624.	7023.	37285.	10721.	50644.	62426.	59016.	4508.	21191.	255090.
1947	2888.	904.	1025.	1412.	314512.	13732.	2740.	306.	1428.	2131.	3611.	14705.	359394.
1948	845.	10013.	6568.	276.	3247.	69094.	56846.	4943.	800.	7966.	11823.	199.	172620.
1949	2229.	3752.	1178.	2842.	81345.	100652.	4658.	4828.	51955.	10933.	2616.	1259.	268247.
1950	1386.	1371.	324.	9625.	109057.	22560.	44413.	16640.	110677.	7584.	1721.	1969.	327327.
1951	1522.	2851.	1732.	780.	33876.	33946.	7154.	22554.	5638.	0.	130.	134.	110317.
1952	252.	625.	446.	1416.	17569.	2658.	10488.	110.	29.	0.	615.	821.	35029.
1953	0.	1418.	3720.	693.	6693.	395.	40117.	41032.	859.	122758.	10912.	2445.	231042.
1954	1465.	692.	259.	63367.	188184.	17493.	473.	0.	2.	0.	1355.	1235.	274525.
1955	681.	3868.	24679.	1000.	150226.	61774.	45910.	7474.	229964.	246199.	8552.	5368.	785695.
1956	3971.	3185.	1329.	542.	20889.	4542.	20.	1232.	0.	2900.	178.	617.	39405.
1957	104.	11392.	1637.	66762.	239563.	166184.	11594.	4215.	5726.	44714.	40954.	2790.	595635.
1958	2333.	1646.	3465.	9650.	73778.	8962.	13669.	3920.	9366.	2735.	2211.	500.	132235.
1959	374.	322.	135.	3202.	5713.	113139.	89801.	13357.	219.	50708.	2533.	14423.	293926.
1960	5156.	3149.	1554.	628.	2089.	12098.	109896.	2177.	478.	260415.	13899.	9802.	421341.
1961	6683.	7585.	7128.	3054.	15597.	124137.	129277.	6421.	4143.	3050.	10786.	3279.	321140.
1962	1835.	957.	831.	3519.	2844.	50440.	6812.	8032.	132703.	10334.	19288.	9469.	247064.
1963	3417.	2247.	2726.	9094.	28647.	116893.	4105.	640.	11812.	2798.	6961.	2513.	191853.
1964	1210.	3166.	1024.	427.	946.	12143.	221.	226.	35221.	2247.	2236.	608.	59675.
1965	712.	528.	259.	7023.	66447.	20152.	1166.	35475.	10637.	58877.	3173.	1711.	206160.
1966	1993.	1355.	3493.	20667.	24484.	7926.	650.	100471.	142019.	6654.	2692.	2253.	314657.
1967	1865.	1167.	2924.	50970.	6864.	102268.	62062.	4030.	16311.	2648.	1181.	1411.	253701.
1968	15484.	6181.	27862.	16193.	12859.	61597.	17465.	9979.	1711.	993.	3153.	4255.	177732.
1969	666.	913.	3291.	2140.	86206.	10868.	532.	1954.	79052.	31909.	20681.	5162.	243374.
1970	4971.	2542.	24793.	5464.	6592.	7676.	372.	268.	1578.	2610.	510.	465.	57841.
1971	534.	418.	475.	506.	37265.	18500.	1191.	109518.	61703.	51224.	10614.	7219.	299167.
1972	2740.	2492.	2329.	2124.	11332.	10023.	10431.	208723.	72235.	31320.	40786.	8976.	403511.
1973	14885.	14291.	39994.	15122.	4381.	33497.	2525.	2998.	17205.	2606.	1882.	1324.	150710.
1974	994.	939.	1876.	1799.	6769.	24292.	418.	3335.	45777.	30506.	13745.	4160.	134610.
1975	4173.	6565.	3206.	3105.	42971.	12124.	48137.	20905.	32884.	4769.	9057.	2924.	190820.
1976	2589.	1676.	1684.	13099.	8016.	1305.	11841.	7307.	19091.	29146.	11908.	3837.	111499.
1977	3881.	3010.	2405.	22868.	48808.	13726.	2963.	7158.	4498.	234.	321.	455.	110327.
1978	795.	941.	1251.	192.	11735.	12122.	861.	67573.	29478.	7157.	3642.	2796.	138543.
1979	2748.	2393.	8918.	4278.	14067.	34030.	30179.	19268.	1924.	93.	3326.	1677.	122901.
1980	1400.	1852.	900.	1256.	110262.	17720.	1871.	3040.	77092.	26018.	5255.	7613.	254279.
1981	4043.	5225.	9933.	13360.	11889.	29244.	2442.	6860.	2142.	61248.	5839.	3748.	155973.
1982	2969.	3478.	4550.	1457.	153145.	179680.	22051.	5708.	6089.	1760.	834.	1538.	383259.
1983	3066.	6188.	3003.	2650.	50807.	11163.	3126.	109.	454.	156379.	22943.	7778.	267666.
1984	6056.	3377.	3473.	1618.	1263.	699.	193.	3866.	2940.	15162.	16247.	14698.	69592.
1985	12062.	11063.	15540.	31408.	50453.	62944.	16052.	3651.	3237.	85770.	9676.	4406.	306262.
1986	2474.	2884.	1845.	7879.	9281.	48365.	31144.	29246.	90264.	149202.	28175.	15867.	416626.
1987	11799.	21425.	23083.	8038.	148204.	81067.	34999.	8803.	11080.	2555.	1391.	2731.	355175.
1988	3940.	3223.	2998.	2339.	1359.	1435.	19817.	1206.	34934.	2708.	1945.	1494.	77398.
1989	1393.	6659.	2580.	1565.	45677.	49352.	2000.	2689.	42618.	1831.	1223.	1392.	158979.
1990	5380.	2432.	18975.	78672.	33823.	209170.	10781.	20091.	7462.	4276.	5383.	3932.	400377.
1991	7962.	4451.	2568.	1855.	34669.	192272.	5761.	27942.	48029.	15772.	13614.	37795.	392690.
1992	26922.	72064.	31115.	21460.	71282.	179925.	25266.	12173.	9049.	1594.	6578.	7038.	464466.
1993	5919.	18342.	18191.	6103.	9944.	19148.	1669.	1292.	4381.	1679.	1020.	2563.	90251.
1994	1567.	2543.	2609.	1270.	48710.	5480.	694.	1670.	11315.	5954.	6273.	2471.	90556.
1995	2251.	1222.	2619.	1449.	41737.	48130.	5414.	62634.	15584.	5042.	6145.	2054.	194281.
1996	2437.	1319.	1980.	1339.	493.	6547.	2273.	17513.	89964.	4764.	4538.	4411.	137578.
1997	1399.	17062.	6620.	36918.	48167.	42167.	21775.	11603.	4973.	2525.	1161.	5197.	199567.

Table 3.18 (Continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	820.	5354.	6395.	1874.	1167.	1167.	1321.	2372.	20.	17441.	13528.	1877.	53336.
1999	5791.	1052.	5046.	5771.	71777.	80093.	1321.	142.	10180.	0.	1472.	1381.	184026.
2000	820.	1052.	7892.	8427.	1167.	79605.	3845.	142.	0.	7969.	36665.	6065.	153649.
2001	11152.	8528.	36683.	1874.	10894.	1167.	1321.	142.	6150.	0.	19565.	10497.	107973.
2002	1838.	5039.	9310.	8043.	1167.	1167.	9690.	142.	20.	72655.	10158.	16297.	135526.
2003	6151.	1052.	910.	1874.	1167.	79648.	1321.	142.	20.	0.	1472.	1877.	95635.
2004	7448.	18992.	18415.	35954.	1167.	67104.	64468.	40194.	64565.	74502.	213545.	19858.	626212.
2005	7688.	10484.	2179.	1874.	12084.	4047.	5641.	72075.	4682.	7774.	1472.	0.	130000.
2006	0.	1334.	2173.	1874.	6377.	1167.	1321.	16028.	81979.	64588.	3302.	11902.	192044.
2007	11768.	1052.	73956.	22584.	74031.	147378.	14212.	9539.	19939.	0.	449.	1877.	376787.
2008	820.	864.	910.	1874.	10951.	8721.	5350.	38658.	171467.	47497.	6562.	0.	293674.
2009	0.	1052.	910.	1874.	5866.	14026.	39909.	4821.	12833.	12127.	1472.	12212.	107104.
2010	17530.	32213.	11654.	71982.	22030.	6081.	215238.	18211.	8060.	5460.	1472.	919.	410849.
2011	0.	1052.	910.	0.	1403.	1980.	418.	0.	0.	2200.	1472.	9806.	19242.
2012	820.	1052.	910.	1874.	2902.	12894.	1321.	142.	15886.	2276.	472.	1692.	42242.
2013	7057.	8038.	910.	1546.	1167.	7237.	33854.	7022.	20.	0.	1472.	5859.	74183.
2014	820.	1052.	910.	1874.	17793.	47289.	9486.	142.	177317.	8920.	7302.	4932.	277837.
2015	11369.	5515.	910.	13232.	303414.	155222.	20468.	1039.	20.	48503.	37809.	12930.	610430.
2016	6706.	1052.	910.	3639.	40372.	13209.	1321.	32531.	47725.	6615.	6439.	5388.	165907.
MEAN	4050.	5297.	7363.	12307.	46828.	46314.	20523.	18112.	31700.	32221.	10815.	5539.	241068.

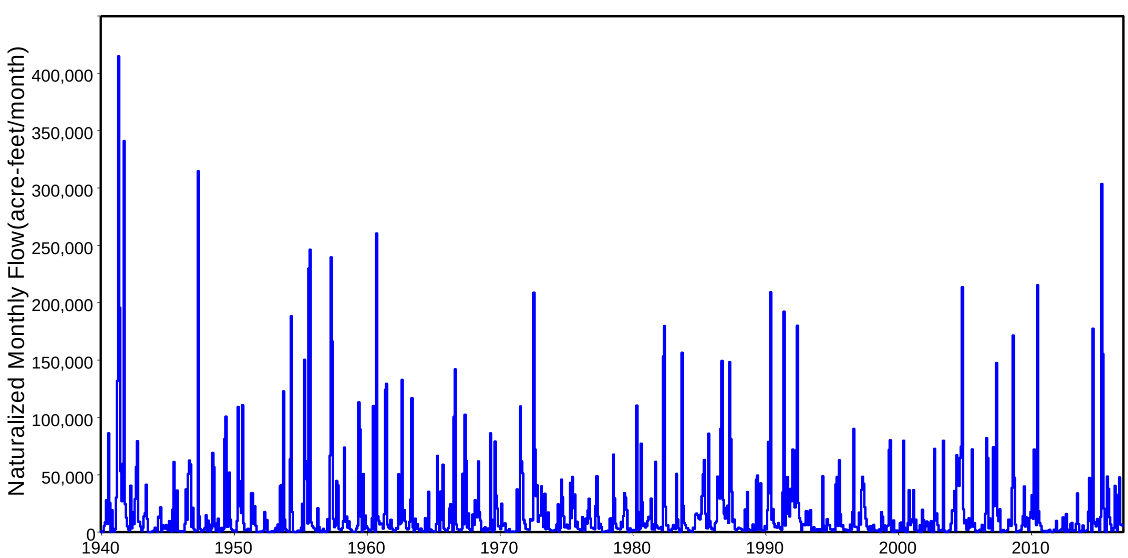


Figure 3.43 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Seymour (BRSE11)

Table 3.19 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Seymour (BRSE11)

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	20,841.4	34,243.2	20,846.1	20,089.0	17,792.4
Std Dev	42,816.9	45,749.9	40,243.6	41,758.1	38,343.4
Minimum	0.0	15.4	0.0	0.0	0.0
99.5%	0.0	16.4	0.0	0.0	0.0
99.0%	0.0	16.4	0.0	0.0	0.0
98.0%	52.0	16.4	0.0	0.0	0.0
95.0%	266.2	77.5	142.2	142.2	0.0
90.0%	621.2	114.4	819.6	537.2	142.2
85.0%	995.2	127.0	909.8	909.8	873.5
80.0%	1,387.0	197.1	1,166.8	1,222.8	1,047.1
75.0%	1,711.0	250.9	1,472.2	1,472.2	1,166.8
70.0%	2,269.0	293.6	1,874.0	1,874.0	1,320.8
60.0%	3,081.6	2,801.0	3,154.9	2,933.6	1,874.0
50.0%	5,042.0	14,104.2	5,808.3	5,076.0	5,353.7
40.0%	8,025.6	25,113.3	8,144.2	7,905.7	7,418.5
30.0%	13,727.2	46,548.8	14,557.8	12,596.2	11,071.7
25.0%	18,500.0	54,087.7	18,448.8	17,440.7	13,208.9
20.0%	26,935.6	66,650.5	30,206.1	24,330.4	18,292.4
15.0%	39,114.4	80,681.9	38,804.0	37,056.8	35,533.9
10.0%	57,692.6	102,492.6	54,472.3	56,880.2	51,695.7
5.0%	100,975.2	135,994.3	95,315.4	89,082.0	77,564.2
2.0%	179,699.6	161,314.8	173,771.5	174,508.8	174,040.7
1.0%	230,348.0	175,083.3	188,603.3	214,831.8	214,764.0
0.5%	288,545.4	205,995.8	221,902.8	276,754.5	291,069.0
Maximum	414,811.0	272,444.4	293,482.6	414,811.0	303,413.6

Table 3.20 1940-2016 Naturalized Flows for Brazos River at Waco (BRWA41)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	13511.	8751.	6311.	101058.	122519.	451522.	168538.	255025.	72277.	13015.	416155.	405857.	2034539.
1941	133251.	492000.	318981.	508670.	1597861.	889095.	311899.	289184.	115304.	696350.	238298.	56767.	5647660.
1942	70132.	31336.	29147.	1401100.	670494.	579811.	51907.	55723.	358139.	527354.	105937.	71104.	3952184.
1943	44340.	31851.	73147.	110754.	89262.	95298.	17695.	5540.	32245.	15965.	5048.	9192.	530337.
1944	35857.	124744.	159193.	105126.	799391.	129965.	53302.	18829.	68051.	63554.	29701.	55540.	1643253.
1945	169336.	293601.	623968.	921067.	164507.	169682.	385705.	37233.	19884.	190258.	34980.	44715.	3054936.
1946	94816.	181795.	211690.	91267.	250528.	150689.	24717.	58841.	251697.	149131.	199340.	226418.	1890929.
1947	121070.	71206.	154912.	148784.	533060.	102259.	22351.	11410.	20402.	43651.	18216.	102513.	1349834.
1948	36297.	110596.	88161.	24339.	133683.	160620.	169895.	10027.	30427.	20527.	12101.	7324.	803997.
1949	16811.	69629.	103325.	116907.	711815.	321502.	61082.	9058.	101714.	105862.	33496.	11945.	1663146.
1950	27468.	124134.	24277.	135709.	248739.	79302.	264857.	129938.	237233.	54828.	9336.	7937.	1343758.
1951	2807.	16680.	11695.	10058.	145072.	290951.	26291.	31130.	44937.	6144.	8128.	10348.	604241.
1952	2679.	7888.	4138.	114264.	181202.	4674.	8307.	7541.	11621.	2868.	63290.	66153.	474625.
1953	22309.	8344.	65384.	49725.	346687.	658.	257207.	98607.	15421.	271823.	29943.	11873.	1177981.
1954	4012.	4515.	6528.	117990.	435691.	108754.	19080.	25155.	4504.	30170.	29672.	339.	786410.
1955	1612.	19071.	26282.	29644.	418528.	251878.	69588.	34920.	318764.	530893.	20788.	10526.	1732494.
1956	11472.	11813.	8006.	20571.	260403.	24749.	1858.	6619.	9965.	26692.	31205.	52363.	465716.
1957	3483.	245003.	56524.	1270684.	3376485.	820741.	128189.	23015.	31869.	257701.	308852.	91125.	6613671.
1958	95673.	112397.	183794.	207233.	766687.	72614.	252763.	47863.	87224.	12453.	10802.	12434.	1861937.
1959	9281.	31288.	15685.	32092.	80840.	272887.	149083.	35498.	16332.	940385.	57196.	144050.	1784617.
1960	330275.	154751.	83972.	97134.	99926.	39077.	205696.	22776.	4688.	264411.	68642.	192364.	1563712.
1961	569683.	424506.	156875.	54263.	56062.	485169.	403672.	67637.	82401.	165966.	139137.	108420.	2713791.
1962	45581.	29229.	33000.	48551.	33921.	410648.	239547.	115982.	554450.	165200.	59877.	66017.	1802003.
1963	24652.	17881.	23959.	140145.	133079.	213550.	23618.	0.	6964.	19390.	59273.	5920.	668431.
1964	19843.	72007.	66433.	92482.	35696.	99403.	6707.	31985.	142709.	15875.	224565.	25200.	832905.
1965	66295.	246828.	81367.	81729.	1220316.	118840.	20771.	43436.	59297.	73862.	63809.	30069.	2106619.
1966	10374.	44689.	46120.	569538.	680919.	113837.	35109.	100582.	619618.	98012.	34137.	17952.	2370887.
1967	15551.	13758.	20187.	94040.	55008.	194189.	166585.	37344.	66041.	66191.	35471.	41289.	805654.
1968	578887.	189354.	574446.	306677.	919100.	249612.	227613.	51312.	23272.	20152.	19894.	35462.	3195781.
1969	23923.	43026.	212274.	293027.	1148063.	131668.	44874.	41169.	155342.	87233.	64356.	124874.	2369829.
1970	93143.	129342.	553969.	222928.	202014.	60775.	6199.	9244.	41546.	53912.	13753.	12781.	1399606.
1971	13573.	18053.	13645.	41723.	77352.	86968.	94432.	288674.	146109.	404187.	78671.	362366.	1625753.
1972	147430.	61154.	31200.	46158.	122561.	38502.	34945.	130904.	138500.	86679.	162195.	44090.	1044318.
1973	126836.	129346.	198391.	499647.	187195.	433977.	125866.	59295.	35877.	221935.	47265.	27661.	2093291.
1974	52972.	26028.	27132.	55440.	38405.	42590.	8813.	70810.	374528.	423863.	559597.	100490.	1780668.
1975	108418.	433919.	108148.	308048.	325572.	286249.	70107.	57066.	52545.	9001.	14406.	4134.	1777613.
1976	11436.	21516.	18152.	142907.	219231.	132632.	285252.	37920.	101104.	166410.	96377.	111548.	1344485.
1977	86797.	205150.	450576.	645516.	333823.	97432.	24617.	8897.	17760.	9325.	8368.	6258.	1894519.
1978	7479.	22674.	33817.	66443.	42195.	26714.	3940.	601580.	24760.	28105.	17598.	8752.	884057.
1979	50578.	55002.	277256.	182194.	641949.	293719.	64127.	40800.	13017.	21506.	0.	29431.	1669579.
1980	59915.	56220.	25129.	82858.	312875.	52285.	7002.	1770.	116130.	270537.	17054.	52978.	1054753.
1981	19262.	16236.	100688.	92179.	55974.	572020.	53624.	29058.	5815.	1084073.	189644.	38806.	2257379.
1982	26170.	48280.	91801.	47773.	798827.	909409.	399441.	38612.	4688.	4578.	20062.	21144.	2410785.
1983	16155.	98914.	79337.	31696.	153482.	59490.	16447.	6653.	2272.	90284.	25296.	3834.	583860.
1984	36045.	18372.	57088.	13022.	12071.	17494.	5094.	11300.	10639.	215466.	92306.	235050.	723947.
1985	187713.	107914.	229495.	192150.	211973.	156915.	38047.	19983.	27913.	205158.	46862.	116251.	1540374.
1986	27195.	148119.	37447.	39350.	146315.	554207.	103128.	28863.	268976.	374276.	136909.	180199.	2044984.
1987	137076.	222062.	342034.	106827.	302223.	692822.	89092.	19057.	28631.	0.	20793.	79937.	2040554.
1988	48540.	38539.	34550.	20310.	16721.	146444.	35656.	733.	65076.	12339.	8221.	18254.	445383.
1989	27278.	134660.	196265.	124012.	959549.	819937.	55020.	75519.	116305.	15328.	8189.	6770.	2538832.
1990	44449.	86468.	370518.	1256164.	1413028.	422384.	26589.	60116.	98748.	35689.	33843.	15117.	3863113.
1991	101793.	65719.	45123.	138624.	265234.	518743.	70969.	187815.	118244.	427178.	267234.	2149397.	4356073.
1992	688885.	1374527.	782802.	207501.	312731.	684912.	135066.	57084.	45690.	11869.	45727.	108209.	4455003.
1993	72204.	303711.	305636.	147662.	106685.	108164.	25035.	11003.	15278.	183578.	19803.	30512.	1329271.
1994	40182.	92230.	91292.	58439.	628787.	113259.	35650.	0.	53915.	163384.	220838.	248794.	1746770.
1995	179571.	75637.	309638.	423311.	643423.	386179.	107773.	486342.	129703.	40271.	15609.	13884.	2811341.
1996	4694.	19703.	12795.	39749.	16030.	39054.	13167.	155998.	418270.	96992.	177896.	224000.	1218348.
1997	132951.	1084526.	813019.	550390.	440237.	391916.	137380.	37188.	12231.	21032.	16987.	236379.	3874236.

Table 3.20 (Continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	62291.	105417.	273381.	36774.	9951.	18228.	8396.	6725.	8460.	77636.	129669.	65279.	802208.
1999	106922.	24461.	173695.	157900.	227180.	297932.	26424.	3634.	7309.	31800.	20831.	7970.	1086060.
2000	25219.	28310.	76116.	42575.	41397.	339284.	30689.	0.	2743.	194085.	494956.	96833.	1372206.
2001	127933.	314778.	278288.	43754.	106261.	25370.	9650.	9271.	143873.	41405.	208136.	84967.	1393685.
2002	29975.	38698.	221715.	149709.	207928.	61198.	509255.	44315.	20156.	599904.	96136.	130924.	2109914.
2003	34464.	49228.	29376.	18852.	112052.	893140.	44856.	22409.	95876.	71991.	39887.	11390.	1423522.
2004	34899.	358238.	146634.	304290.	100614.	568310.	283732.	319451.	43855.	332564.	1220458.	162407.	3875452.
2005	31519.	114490.	85653.	16167.	135740.	51091.	82916.	860237.	61026.	32867.	7255.	2152.	1481112.
2006	4201.	28878.	99916.	75666.	125059.	41720.	9007.	6713.	92813.	165363.	41605.	32175.	723116.
2007	87730.	23515.	460874.	280775.	927507.	1572139.	376799.	206065.	103056.	23237.	17917.	24044.	4103658.
2008	4736.	8816.	154381.	178355.	167044.	92171.	11133.	98030.	89216.	88686.	26880.	7283.	926731.
2009	2701.	8660.	27576.	102543.	148846.	91950.	267424.	39368.	338621.	557557.	45877.	58072.	1689194.
2010	193667.	262084.	112156.	296110.	224780.	69315.	333245.	42710.	347227.	71591.	9447.	27335.	1989668.
2011	17058.	23034.	7797.	11434.	31883.	13508.	2491.	3493.	7587.	208937.	46047.	102738.	476007.
2012	310552.	146748.	121290.	42015.	92371.	92751.	23540.	27143.	384332.	57245.	2622.	3880.	1304487.
2013	38034.	42879.	14361.	50625.	48829.	68727.	267671.	48801.	96544.	98329.	34928.	85950.	895677.
2014	24632.	7892.	8586.	14440.	147347.	216594.	91394.	31790.	77877.	46124.	215725.	86829.	969232.
2015	111300.	81879.	81227.	306534.	1977584.	968414.	195473.	31994.	10587.	481201.	974100.	269953.	5490246.
2016	31918.	12269.	35700.	544650.	1170718.	291539.	24418.	168457.	477449.	90322.	161975.	53785.	3063200.
MEAN	83504.	129961.	149551.	204556.	398767.	272107.	110253.	80601.	109814.	167321.	111527.	101910.	1919872.

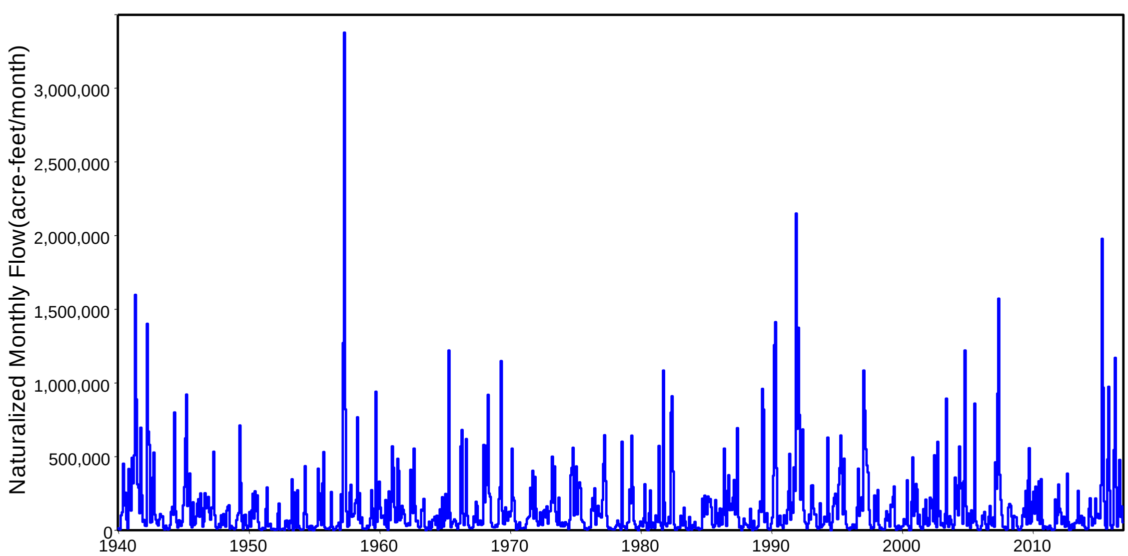


Figure 3.44 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Waco (BRWA41)

Table 3.21 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Waco BRWA41

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	161,860.3	162,544.9	161,801.6	159,989.	154,278.0
Std Dev	266,252.6	218,075.1	244,711.4	262,620.3	251,690.9
Minimum	0.0	196.5	0.0	0.0	0.0
99.5%	162.7	528.2	39.3	210.2	2,199.3
99.0%	1,576.8	682.5	2,240.6	1,791.1	2,527.8
98.0%	3,433.8	1,010.8	3,421.5	2,836.3	2,724.576
95.0%	6,300.4	1,469.4	6,184.8	6,354.4	6,717.8
90.0%	10,363.6	2,584.5	8,920.0	9,380.5	8,645.5
85.0%	15,181.4	4,875.8	13,717.9	14,170.1	12,516.9
80.0%	19,452.6	10,084.2	19,728.9	19,835.0	22,783.9
75.0%	24,749.0	16,128.0	26,087.0	25,129.0	26,879.6
70.0%	31,006.4	20,647.1	31,167.3	31,221.6	31,833.6
60.0%	45,704.8	35,132.3	44,291.5	44,911.8	43,774.2
50.0%	68,642.0	62,646.4	70,631.0	69,629.0	75,666.3
40.0%	102,411.4	106,253.3	101,710.2	100,643.6	96,462.4
30.0%	146,340.8	190,882.6	150,610.8	146,273.8	145,529.6
25.0%	183,578.0	241,634.8	183,748.8	181,202.0	168,457.0
20.0%	233,939.0	300,693.8	245,594.2	226,570.4	218,642.7
15.0%	298,821.4	369,061.5	306,623.7	293,648.2	289,977.6
10.0%	422,754.8	466,275.4	408,479.7	408,731.6	340,872.7
5.0%	642,243.8	652,040.6	657,283.3	623,098.0	564,008.6
2.0%	941,918.1	818,597.1	1,035,558.3	964,158.8	1,060,611.9
1.0%	1,274,837.8	888,701.1	1,124,242.3	1,267,199.3	1,473,668.4
0.5%	1,509,141.1	1,092,723.6	1,382,338.8	1,581,913.4	1,920,821.6
Maximum	3,376,485.0	1,519,428.0	1,922,137.0	3,376,485.0	1,977,584.0

Table 3.22 1940-2016 Naturalized Flows for Little River at Cameron (LRCA58)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	4226.	21590.	5258.	106875.	118827.	246700.	402103.	19420.	8136.	4495.	506043.	610025.	2053698.
1941	315015.	455249.	479749.	373647.	726451.	362613.	284318.	63419.	64427.	91154.	32427.	31703.	3280172.
1942	23611.	21123.	19061.	425969.	430471.	399415.	50025.	37408.	363203.	194891.	104993.	79515.	2149685.
1943	57420.	35888.	63316.	80835.	60426.	21544.	13364.	5496.	17900.	14417.	7410.	11746.	389762.
1944	135108.	250462.	293583.	104171.	1068994.	348162.	61100.	25487.	56027.	22390.	51862.	167741.	2585087.
1945	297407.	273083.	363821.	727424.	202570.	198540.	78128.	36705.	27622.	108972.	38913.	91310.	2444495.
1946	139675.	206939.	285995.	149245.	296669.	130473.	28745.	14295.	68529.	31980.	195864.	142339.	1690748.
1947	291011.	104021.	194624.	143003.	153937.	50414.	16068.	10291.	7176.	4705.	8829.	15755.	999834.
1948	10867.	30930.	28825.	35462.	76134.	22574.	34972.	6921.	9553.	2397.	1731.	2768.	263134.
1949	14724.	24366.	78939.	328272.	128540.	79661.	19280.	6422.	3333.	8832.	8073.	13895.	714337.
1950	6727.	56793.	10489.	63097.	67404.	53390.	32616.	3481.	61698.	3378.	1664.	2178.	362915.
1951	2612.	5157.	17554.	5356.	33662.	53473.	1469.	357.	9342.	1084.	813.	1269.	132148.
1952	1434.	2197.	4451.	66336.	147443.	40467.	6170.	631.	194.	42.	9515.	48595.	327475.
1953	36748.	21496.	31670.	43639.	308665.	18478.	11832.	6446.	22462.	180731.	30011.	139039.	851217.
1954	12248.	7277.	5001.	8669.	33502.	885.	383.	499.	1261.	3035.	21181.	1445.	95386.
1955	3872.	36918.	15379.	51025.	99776.	17921.	23814.	27151.	10262.	1651.	2016.	454168.	
1956	2934.	9845.	1134.	2816.	152079.	5674.	0.	2835.	0.	965.	16402.	16922.	211606.
1957	2608.	4490.	50463.	929072.	918874.	438716.	73019.	39289.	18151.	557391.	216694.	111667.	3360434.
1958	88002.	453666.	271342.	134038.	378932.	120411.	39544.	14005.	68454.	24501.	19316.	15032.	1627243.
1959	13153.	29231.	17095.	52065.	40144.	73992.	51048.	28166.	24919.	753704.	155207.	238967.	1477691.
1960	340219.	231706.	122548.	79105.	51140.	26225.	19517.	11294.	8639.	322054.	127079.	421910.	1761436.
1961	553706.	604542.	232899.	98858.	60088.	224407.	218538.	49457.	115461.	115421.	56456.	73767.	2403600.
1962	40457.	37607.	29942.	60340.	37024.	88833.	30018.	11344.	74927.	59877.	53625.	60050.	584044.
1963	19814.	44799.	20596.	23763.	51968.	25929.	13560.	1460.	4582.	13295.	18464.	4744.	242974.
1964	11307.	31646.	48923.	65542.	44837.	117572.	15580.	24676.	143601.	48880.	109312.	41258.	703134.
1965	233735.	370929.	143957.	116742.	1318816.	199502.	82164.	51249.	57907.	57116.	177225.	129637.	2938979.
1966	70898.	124114.	97968.	371795.	286922.	87782.	31012.	76562.	150089.	37779.	20018.	17768.	1372707.
1967	15648.	12770.	13966.	27670.	85515.	28518.	19777.	3479.	27728.	29354.	83485.	47114.	395024.
1968	691195.	205119.	393816.	247919.	463806.	225958.	192749.	27593.	29522.	13098.	26881.	56212.	2573868.
1969	24533.	75747.	120277.	327202.	268971.	55233.	15243.	30381.	18782.	39111.	28597.	93104.	1097181.
1970	85925.	160015.	504530.	182973.	237648.	129579.	26751.	13200.	70584.	43533.	12277.	12767.	1479782.
1971	11879.	11593.	12004.	17895.	40452.	7665.	146759.	51247.	12873.	80498.	54209.	149841.	596915.
1972	74681.	45317.	27688.	18960.	82310.	44853.	14989.	7141.	4276.	61086.	44521.	30031.	455853.
1973	104438.	98034.	143990.	181291.	161860.	98294.	62933.	14159.	29256.	278181.	110709.	46228.	1329373.
1974	76926.	43133.	33649.	22309.	113400.	22808.	9571.	106606.	272382.	227246.	380376.	131691.	1440097.
1975	131636.	408286.	126988.	145374.	573701.	255471.	123061.	60054.	27287.	21599.	14049.	16227.	1903733.
1976	14865.	13265.	22672.	260733.	235938.	92373.	247140.	39966.	34043.	69352.	64923.	171137.	1266407.
1977	82730.	251201.	161950.	656109.	234136.	87293.	29728.	13090.	7981.	4645.	6539.	6462.	1541864.
1978	7337.	19546.	21682.	18293.	9536.	13266.	4802.	8269.	3698.	1519.	14720.	7501.	130169.
1979	83145.	129735.	272084.	212412.	422369.	316696.	233681.	61632.	15847.	10211.	9322.	19413.	1786547.
1980	25594.	40885.	50864.	46476.	328986.	38696.	10670.	6084.	10707.	5963.	6568.	12796.	584289.
1981	8964.	16086.	59378.	39855.	57057.	799417.	90423.	19309.	85928.	117109.	48980.	23149.	1365655.
1982	20992.	19687.	35745.	69523.	232452.	100366.	38295.	8665.	2009.	5190.	7951.	8709.	549584.
1983	15134.	83314.	145185.	46042.	192718.	86093.	16414.	26040.	6341.	5588.	4951.	5089.	632909.
1984	9168.	6405.	25218.	6843.	207.	21514.	3465.	1259.	2302.	170360.	29158.	89979.	365878.
1985	108080.	145987.	186568.	87601.	86664.	81531.	14701.	3966.	3075.	109496.	96981.	197214.	1121864.
1986	49014.	265813.	52271.	27167.	131271.	382704.	40139.	23807.	116569.	165242.	119916.	418349.	1792262.
1987	187741.	172902.	236611.	100795.	229780.	769125.	148625.	46189.	31538.	15023.	31699.	39841.	2009869.
1988	31269.	24431.	25216.	18001.	9350.	122843.	15192.	13400.	4700.	2730.	3617.	4298.	275047.
1989	17931.	36193.	52408.	34837.	247694.	161443.	37365.	19098.	7286.	6161.	2531.	2071.	625018.
1990	9514.	10753.	76108.	344155.	423858.	98865.	61149.	30140.	19711.	15035.	22719.	8341.	1120348.
1991	195638.	91220.	50450.	130030.	186205.	112987.	28856.	28875.	37788.	68174.	87033.	1320477.	2337733.
1992	574007.	1403136.	690408.	224458.	568694.	401559.	163609.	107953.	67406.	24855.	32663.	86273.	4345021.
1993	100136.	233876.	299945.	186726.	290048.	208711.	62120.	13708.	16249.	42243.	28287.	18564.	1500613.
1994	16754.	48847.	49040.	19774.	233470.	96358.	34327.	8664.	13725.	100557.	52099.	144553.	818168.
1995	100503.	51057.	211495.	295836.	240525.	193678.	49472.	118107.	36377.	33867.	8819.	11828.	1351564.
1996	10371.	12165.	7739.	14624.	11049.	41477.	11180.	53649.	153452.	42102.	58669.	150299.	566776.
1997	134515.	655338.	461944.	665585.	536956.	616065.	177556.	56231.	17994.	17905.	25341.	258527.	3623957.

Table 3.22 (Continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	55930.	247290.	177650.	25983.	15275.	16235.	16369.	4245.	91633.	720851.	418397.	204125.	1993983.
1999	34271.	15921.	64311.	27918.	83129.	40260.	16369.	4245.	37.	1882.	7859.	27078.	323280.
2000	121666.	48329.	32204.	30611.	49760.	52427.	16369.	0.	1777.	53701.	821680.	407339.	1635863.
2001	183182.	120255.	372157.	43247.	69992.	25983.	14751.	58675.	53086.	44895.	265641.	373987.	1625851.
2002	41514.	41274.	38036.	25983.	19862.	51534.	206377.	4245.	8881.	406056.	301599.	245427.	1390788.
2003	108953.	260947.	49149.	19830.	15617.	60337.	25308.	4245.	63273.	146038.	56262.	3797.	813757.
2004	94890.	307564.	92182.	225915.	218669.	725590.	200243.	57126.	52113.	297248.	1219481.	369121.	3860142.
2005	90233.	126300.	70066.	21789.	65750.	25983.	16369.	67828.	8881.	1173.	1776.	1026.	497176.
2006	7912.	30579.	50711.	47054.	40385.	25983.	16369.	1906.	8358.	84442.	12066.	55061.	380827.
2007	326044.	25983.	495444.	310981.	677182.	1092662.	1201130.	28449.	42337.	8777.	32547.	10896.	4252432.
2008	9332.	12829.	60763.	64571.	44278.	18868.	9808.	4245.	8881.	7597.	9351.	1070.	251594.
2009	1824.	13689.	64360.	60584.	42974.	20771.	16369.	4245.	398350.	986766.	381379.	85742.	2077053.
2010	170948.	394397.	105886.	43773.	21636.	23426.	51052.	4245.	237310.	8777.	1216.	3869.	1066534.
2011	56946.	32461.	12925.	7615.	17658.	16738.	1464.	0.	1026.	30697.	122620.	273852.	574001.
2012	306144.	390727.	527299.	25983.	53958.	25983.	41625.	4245.	64910.	8777.	299.	166.	1450117.
2013	159378.	47643.	20156.	39340.	54784.	25983.	47086.	4245.	70145.	696820.	348329.	49231.	1563140.
2014	15448.	10889.	18412.	20401.	146322.	165907.	16369.	4245.	43600.	31581.	231741.	131512.	836426.
2015	237956.	60853.	138554.	99496.	1404414.	729218.	16369.	1333.	1422.	683773.	920947.	312040.	4606375.
2016	20143.	18731.	70134.	384420.	730472.	129031.	16369.	181927.	41034.	3616.	57710.	73642.	1727228.
MEAN	101201.	136293.	129440.	140911.	234645.	162597.	74148.	26404.	49340.	113302.	113250.	113119.	1394650.

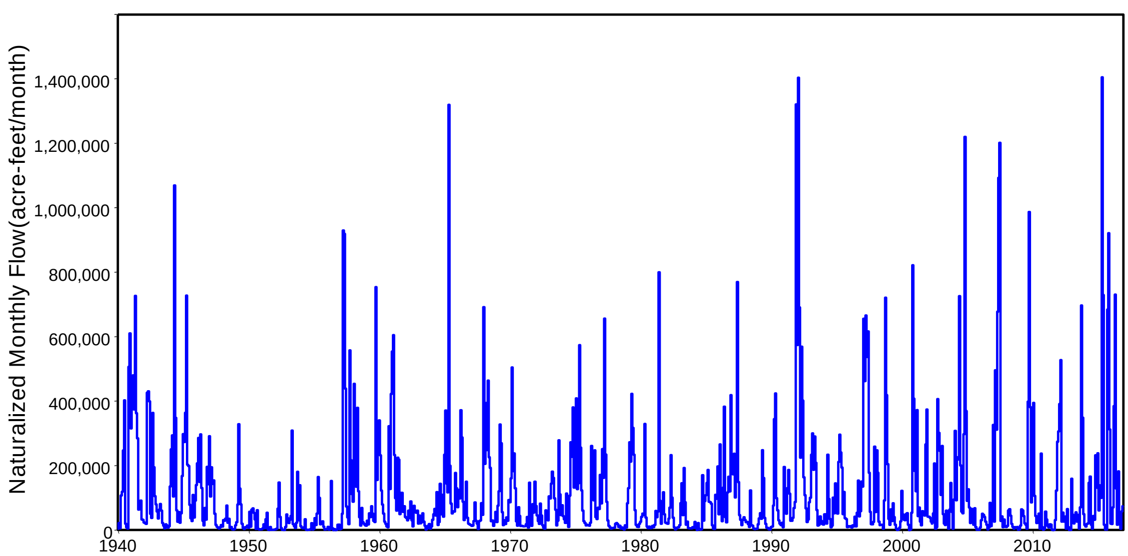


Figure 3.45 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Little River at Cameron (LRCA58)

Table. 3.23 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Little River at Cameron LRCA58

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	109,858.5	143,277.5	109,682.5	116,220.8	135,642.8
Std Dev	170,465.5	257,423.2	166,119.7	187,828.0	232,331.9
Minimum	0.0	132.8	0.0	0.0	0.0
99.5%	200.2	373.6	163.2	40.3	5.2
99.0%	494.4	481.2	1,021.4	312.7	73.5
98.0%	1,249.0	569.8	1,240.3	1,047.3	706.1
95.0%	2,706.4	900.2	3,107.5	2,181.8	1,438.6
90.0%	5,440.0	1,126.6	4,245.3	4,767.2	4,245.3
85.0%	8,666.6	1,312.0	8,237.0	8,654.0	8,001.4
80.0%	11,904.0	1,690.0	10,611.3	11,831.2	10,893.1
75.0%	15,032.0	2,606.0	16,369.4	15,275.2	16,369.0
70.0%	19,040.8	3,308.2	18,311.6	18,799.3	18,539.4
60.0%	28,988.2	6,417.3	25,983.2	28,843.6	28,023.9
50.0%	44,799.0	18,830.3	43,369.2	44,521.0	44,277.7
40.0%	65,294.4	33,487.3	60,508.6	62,445.2	57,592.9
30.0%	104,549.0	106,995.6	103,752.0	100,747.4	91,962.2
25.0%	130,473.0	174,771.6	131,816.0	131,271.0	138,554.0
20.0%	165,070.2	258,952.1	177,549.0	177,291.2	211,294.0
15.0%	226,730.8	341,261.7	216,100.5	233,791.4	300,728.9
10.0%	290,433.2	502,319.2	305,357.8	311,616.4	385,681.0
5.0%	426,869.4	712,169.9	438,513.4	460,605.0	711,239.0
2.0%	667,570.9	1,045,815.4	724,801.8	728,356.9	1,033,360.2
1.0%	804,195.3	1,135,659.4	787,069.1	972,919.4	1,214,342.6
0.5%	1,198,901.5	1,453,802.8	1,007,558.1	1,257,228.3	1,378,523.4
Maximum	1,403,136.0	1,615,861.0	1,119,872.0	1,404,414.0	1,404,414.0

Table 3.24 1940-2016 Naturalized Flows for Brazos River at Gulf of Mexico (BRGM73)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	52435.	156451.	44398.	204339.	326625.	676111.	1350846.	262307.	112440.	68628.	1465291.	3321573.	8041444.
1941	1213863.	1384529.	1667737.	1267354.	2860813.	2165749.	1177738.	372470.	378506.	788423.	667985.	173201.	14118368.
1942	143269.	113252.	101820.	2190079.	2008013.	1340817.	395971.	121025.	880186.	736070.	419404.	255371.	8705277.
1943	347222.	124888.	237811.	319335.	231461.	275056.	175695.	93456.	65195.	89941.	103862.	102379.	2166301.
1944	725440.	978853.	1211688.	369011.	2937554.	1103160.	177438.	74335.	275961.	117285.	338780.	802254.	9111759.
1945	1346704.	937205.	1373933.	2622893.	793496.	598370.	556766.	482610.	368609.	565338.	132006.	504049.	10281979.
1946	693957.	898516.	1343657.	520988.	1675540.	928245.	231983.	90189.	322021.	282624.	1102939.	605124.	8695783.
1947	1023792.	311372.	829291.	443094.	1040245.	362035.	102854.	357928.	132049.	72914.	93769.	247682.	5017025.
1948	107660.	250417.	370430.	161725.	325807.	233304.	280532.	17231.	61687.	45472.	33561.	28150.	1915976.
1949	72285.	254674.	506625.	819337.	1070739.	515230.	226470.	50464.	105160.	329938.	203270.	299725.	4453917.
1950	294046.	786124.	176791.	543838.	571183.	686426.	257491.	202924.	300240.	128877.	40806.	33754.	4022500.
1951	23269.	50928.	66154.	80917.	179643.	373206.	38729.	33029.	81000.	33545.	24824.	33468.	1018712.
1952	23801.	55136.	79696.	428009.	480499.	225293.	51019.	239.	30925.	12658.	74648.	256380.	1718303.
1953	290977.	128504.	268911.	105527.	1856532.	115218.	301068.	159031.	151070.	464428.	232906.	584988.	4659160.
1954	140605.	52934.	29634.	142189.	532042.	162258.	32965.	53198.	18836.	43560.	76706.	26341.	1311268.
1955	36315.	278373.	80949.	320851.	552886.	417247.	140317.	86929.	200675.	631014.	61398.	31537.	2838491.
1956	42298.	105330.	46074.	52053.	405720.	48133.	4.	16926.	16691.	24928.	55989.	95261.	909407.
1957	11064.	242488.	264754.	2006816.	6254466.	2037745.	604047.	176404.	108553.	1894546.	1099521.	479587.	15179991.
1958	582649.	903325.	811844.	437695.	1597873.	317387.	433947.	108938.	351100.	235025.	108586.	84638.	5973007.
1959	63015.	360220.	123044.	907099.	570257.	516407.	309809.	171483.	62095.	1759738.	503461.	685539.	6032167.
1960	1064752.	702724.	389391.	254019.	491676.	548272.	448267.	120962.	46533.	628042.	1031807.	1627100.	7353545.
1961	2361173.	2061868.	754485.	324306.	209867.	1148282.	1076586.	265224.	831287.	367885.	397567.	413531.	10212061.
1962	234482.	201861.	139985.	132358.	199198.	534343.	328793.	163052.	567617.	296402.	150223.	383418.	3331732.
1963	204560.	209645.	102307.	282194.	191930.	215268.	88039.	24779.	26084.	46585.	108002.	63602.	1562995.
1964	65506.	183425.	262263.	161882.	167661.	192764.	53147.	53718.	310524.	138783.	386997.	144853.	2121523.
1965	505612.	1133382.	382911.	485888.	3475435.	1026580.	194335.	161466.	150155.	183320.	429214.	482810.	8611108.
1966	217511.	458906.	381472.	1161434.	2208674.	337461.	114310.	307940.	754881.	288849.	75162.	59026.	6365626.
1967	73633.	53715.	61643.	160343.	215947.	286855.	189937.	66820.	142272.	75251.	248567.	152997.	1727980.
1968	1642866.	701563.	1081404.	1004687.	2398932.	1950904.	1090371.	195103.	247755.	131225.	170866.	537186.	11152862.
1969	182767.	689513.	1040970.	1480394.	1759743.	300530.	124254.	110461.	183104.	144964.	178520.	392717.	6587937.
1970	329663.	380065.	1755677.	732103.	747509.	351935.	114860.	59172.	223010.	552955.	126929.	61521.	5435399.
1971	58020.	53583.	61405.	92012.	168228.	132173.	220978.	441788.	349402.	388951.	262157.	864966.	3093663.
1972	417680.	284630.	145546.	98141.	636864.	185903.	82009.	177429.	164969.	137031.	392911.	155706.	2878819.
1973	556870.	611453.	1032912.	1460838.	913882.	1747980.	438552.	167974.	330926.	1637228.	503272.	419687.	9821574.
1974	868545.	415812.	206588.	165639.	342197.	122573.	69253.	172493.	1530253.	772717.	2010011.	811725.	7487806.
1975	525613.	1372487.	479255.	664656.	1695891.	1240122.	520190.	280441.	167132.	103381.	106283.	104703.	7260154.
1976	84261.	95168.	132504.	739233.	1231200.	727081.	768628.	176535.	200967.	445628.	399290.	1218961.	6219456.
1977	319591.	1133554.	684932.	2139368.	987627.	385381.	138459.	65024.	99474.	52173.	60164.	61046.	6126793.
1978	228282.	266945.	201655.	119222.	103332.	188201.	71675.	551010.	155786.	53258.	144117.	95750.	2179233.
1979	725812.	647432.	1128935.	1294908.	1797729.	1979672.	497069.	417999.	507534.	106914.	74541.	183911.	9362456.
1980	496899.	398778.	189276.	331667.	1192366.	255535.	97833.	45352.	172116.	286862.	54673.	86784.	3608141.
1981	65854.	86187.	220627.	192354.	310737.	2268585.	523414.	141109.	267009.	1281396.	808352.	144624.	6310248.
1982	90833.	118084.	184054.	340865.	1519157.	1055288.	642628.	106083.	39202.	50072.	147349.	227149.	4520764.
1983	223144.	733494.	789861.	272957.	1020368.	390799.	126072.	278989.	185303.	139839.	83470.	107986.	4352282.
1984	96504.	88341.	246632.	65073.	138930.	112714.	57472.	43042.	40035.	1067366.	594298.	717587.	3267994.
1985	721881.	621504.	1085025.	458355.	425225.	319718.	141879.	57793.	54492.	413056.	817961.	1145958.	6262847.
1986	178176.	869467.	213565.	139297.	713608.	1555926.	239408.	155568.	417014.	685812.	602612.	1509321.	7279774.
1987	676536.	688097.	1065289.	349145.	566933.	2812974.	550120.	199526.	144596.	77325.	143161.	300723.	7574425.
1988	207872.	134780.	239886.	131416.	114365.	296117.	156107.	90681.	91907.	36457.	22690.	35997.	1558275.
1989	146572.	290960.	316284.	320259.	1447535.	1398426.	372480.	403988.	159881.	60745.	53831.	26888.	4997849.
1990	111952.	222172.	689498.	1502335.	2148268.	870742.	197061.	138898.	161708.	81002.	131218.	62987.	6317841.
1991	1645100.	699581.	281005.	1053047.	847780.	840772.	224833.	246573.	236178.	444138.	471429.	3408208.	10398644.
1992	3363756.	4570580.	3021573.	1263782.	1633746.	2161286.	517412.	323985.	229426.	115252.	209535.	527901.	17938232.
1993	685963.	750635.	1290274.	964015.	1298427.	1320627.	343005.	114407.	79248.	326164.	219804.	136090.	7528659.
1994	136136.	353848.	394740.	137375.	1145550.	459406.	152748.	89594.	135635.	1691352.	396258.	1085111.	6177753.
1995	1118352.	345992.	1017452.	1097650.	1121847.	885777.	267204.	786444.	214666.	149969.	96510.	269220.	7371083.
1996	82354.	77959.	58190.	87952.	51559.	85910.	63462.	228168.	748503.	238267.	231269.	473003.	2426596.
1997	492959.	1926255.	2323784.	1917878.	1260005.	1165403.	495210.	208212.	199834.	258239.	124661.	776392.	11148832.

Table 3.24 (Continued)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	245188.	1128518.	489564.	84231.	24595.	19538.	25027.	47064.	227927.	1489136.	2748298.	904082.	7433168.
1999	318227.	70084.	278645.	269869.	412725.	324034.	73110.	47064.	17524.	94768.	28375.	133685.	2068110.
2000	183769.	220140.	260646.	211027.	279418.	428017.	65165.	13742.	48813.	352035.	2444065.	2359006.	6865843.
2001	770332.	502218.	1289224.	305694.	215465.	179589.	73110.	150981.	980258.	415065.	535598.	1534230.	6951764.
2002	307680.	122413.	248432.	233163.	299753.	140022.	289811.	110672.	129984.	1623953.	2808514.	1388942.	7703339.
2003	593353.	573002.	187215.	72678.	91385.	356633.	342233.	47064.	324129.	432524.	319491.	107042.	3446747.
2004	273193.	1145658.	687381.	426077.	1245108.	2312169.	1611656.	319626.	83380.	445310.	3157781.	2305435.	14012774.
2005	245251.	636314.	361285.	110496.	270588.	99235.	119459.	271742.	59775.	47941.	64516.	38132.	2324733.
2006	110222.	209156.	344340.	261887.	257566.	141288.	73110.	47064.	193620.	1214010.	331966.	285411.	3469640.
2007	1251871.	247204.	507771.	2090614.	993723.	3061270.	3840541.	296201.	225497.	108287.	159423.	170815.	12953217.
2008	99688.	109001.	224545.	402552.	369211.	80112.	50482.	232415.	184152.	204487.	67785.	37343.	2061771.
2009	17691.	27769.	246414.	557415.	283552.	26439.	152578.	46070.	534741.	3472227.	2405658.	190525.	7961079.
2010	405202.	925700.	319237.	314680.	142882.	196935.	250812.	47064.	285106.	190970.	27006.	87532.	3193126.
2011	203171.	168706.	29307.	17202.	47889.	67298.	34532.	9507.	14750.	251890.	129878.	434350.	1408478.
2012	911077.	2325737.	1589000.	150694.	187290.	150226.	109787.	104726.	203809.	272506.	49108.	34487.	6088447.
2013	374893.	307026.	62288.	200966.	211252.	135189.	268066.	47064.	220882.	1511916.	1405913.	366786.	5112241.
2014	48049.	76001.	94419.	101842.	802990.	782985.	212030.	47064.	143626.	216144.	608378.	754865.	3888392.
2015	673837.	421802.	772072.	1025422.	3813288.	4518736.	161579.	34491.	59775.	709292.	3970435.	2966976.	19127704.
2016	239242.	89051.	276940.	1086300.	4110515.	1001532.	73110.	350589.	337188.	33062.	277078.	466089.	8340696.
MEAN	463826.	549525.	544899.	590195.	1002994.	765934.	343766.	166742.	244992.	459290.	530450.	551868.	6214482.

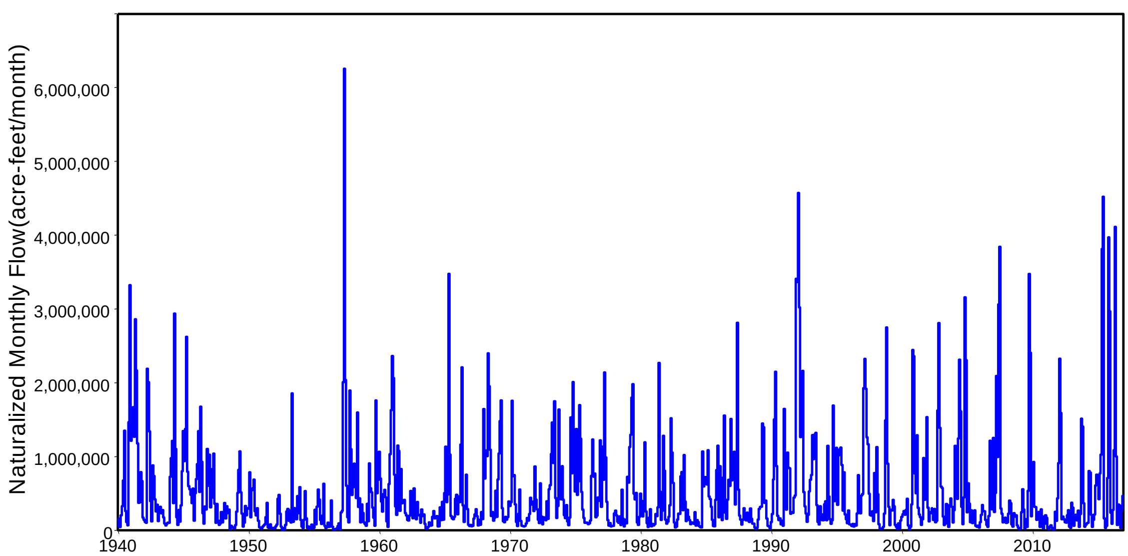


Figure 3.46 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Gulf of Mexico (BRGM73)

Table 3.25 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Gulf of Mexico BRGM73

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	508,769.8	516,636.3	508,520.9	517,873.5	545,663.4
Std Dev	634,290.5	614,025.7	612,605.9	689,216.8	835,854.2
Minimum	4.0	4,513.0	10,625.0	4.0	9,506.7
99.5%	14,593.8	6,529.5	15,374.3	13,330.1	13,883.1
99.0%	18,771.8	8,743.6	20,587.7	17,209.1	15,436.3
98.0%	25,991.5	10,955.6	25,796.3	24,683.3	17,617.4
95.0%	42,893.2	16,683.8	44,535.9	36,343.4	28,011.3
90.0%	59,767.2	22,591.8	59,248.6	53,763.2	47,064.0
85.0%	79,427.2	29,556.0	73,110.0	73,110.0	59,775.0
80.0%	101,917.4	45,423.0	89,548.0	94,288.8	73,110.0
75.0%	121,025.0	89,615.5	127,723.5	114,310.0	99,687.8
70.0%	142,127.0	117,235.3	148,323.0	139,992.4	125,398.9
60.0%	199,329.2	183,168.7	192,322.7	196,202.3	191,499.9
50.0%	269,220.0	281,878.8	271,838.0	262,263.0	246,414.0
40.0%	376,386.0	387,097.2	362,749.3	347,991.2	299,042.6
30.0%	526,070.6	575,788.8	524,350.4	503,061.2	404,141.9
25.0%	676,536.0	757,851.0	664,900.0	628,042.0	502,218.0
20.0%	792,769.0	927,893.3	845,683.4	783,612.5	727,521.1
15.0%	1,048,216.1	1,063,238.3	978,072.8	1,040,535.0	1,020,644.0
10.0%	1,272,970.8	1,444,129.0	1,335,151.0	1,297,019.4	1,516,378.8
5.0%	1,759,739.0	1,827,850.6	1,754,082.9	1,945,974.1	2,626,604.5
2.0%	2,326,775.3	2,357,515.5	2,527,917.0	2,837,850.3	3,825,279.3
1.0%	3,033,573.0	2,804,653.5	3,007,374.3	3,456,862.5	4,071,292.5
0.5%	3,443,166.0	3,077,025.3	3,299,432.3	4,023,665.5	4,461,585.0
Maximum	6,254,466.0	3,787,551.0	4,061,315.0	6,254,466.0	4,518,736.0

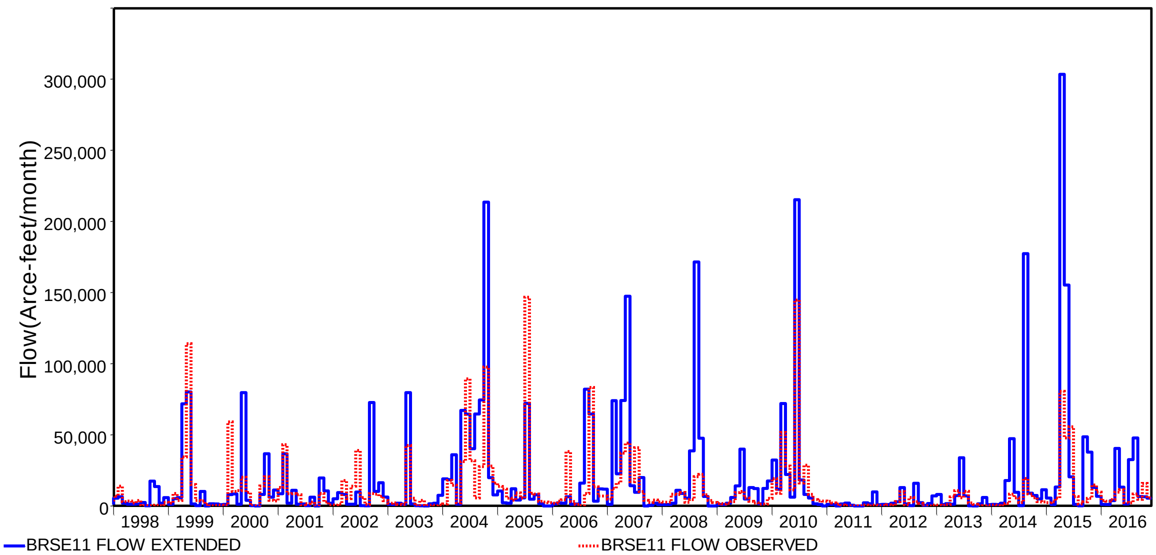


Figure 3.47 Gaged and Extended 1998-2016 Naturalized Flows for Brazos River at Seymour (BRSE11)

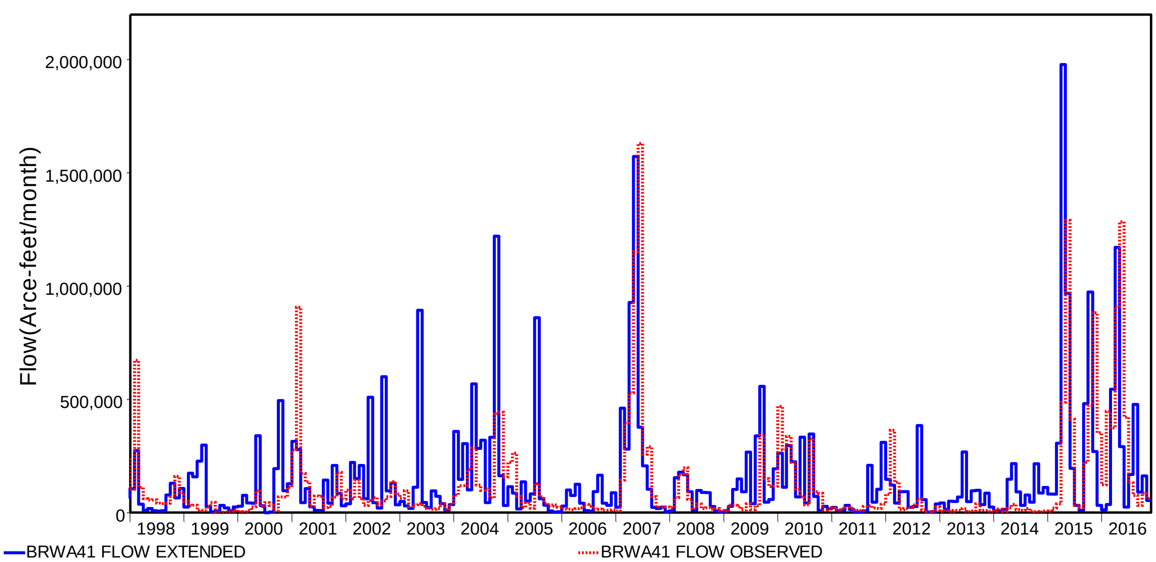


Figure 3.48 Gaged and Extended 1998-2016 Naturalized Flows for Brazos River at Waco (BRWA41)

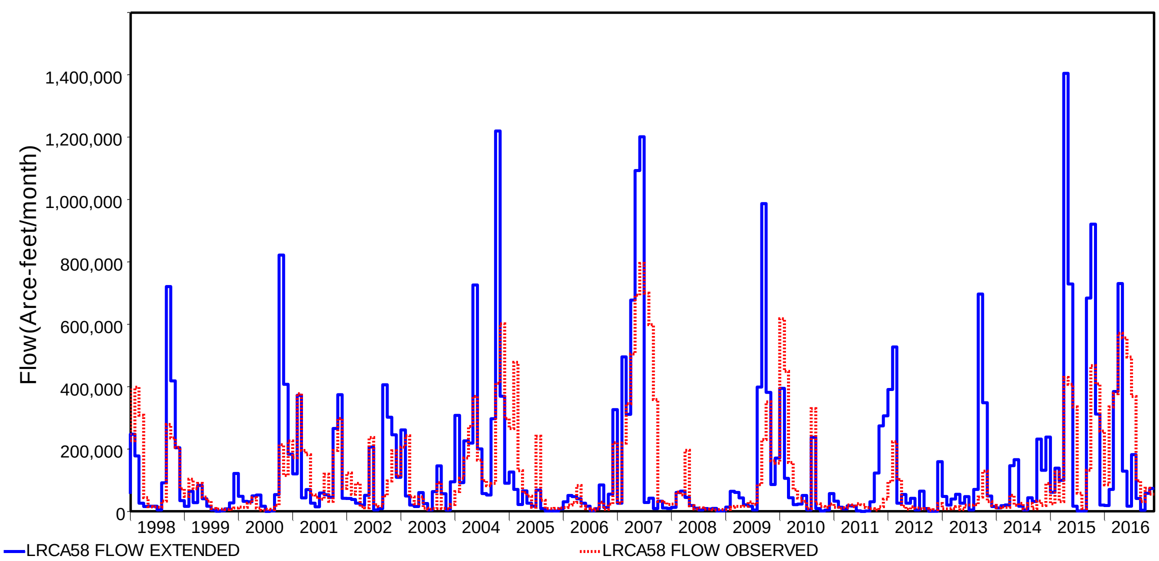


Figure 3.49 Gaged and Extended 1998-2016 Naturalized Flows for Little River at Cameron (LRCA58)

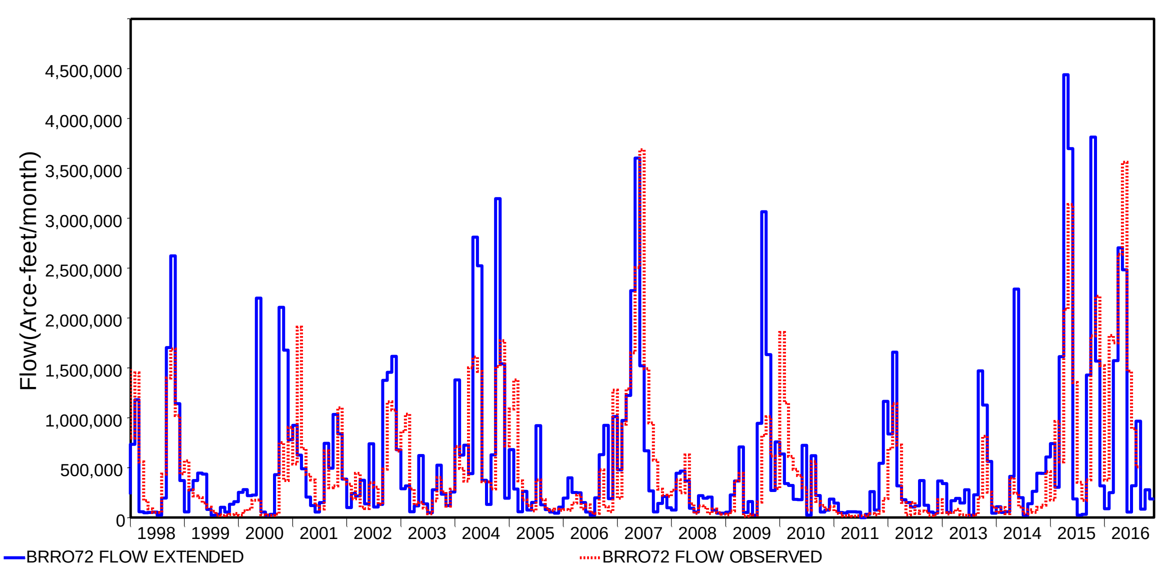


Figure 3.50 Gaged and Extended 1998-2016 Naturalized Flows for Brazos River at Rosharon (BRRO72)

3.6.6 Comparative Analysis of Flows at 31 Control Points

The 1998-2016 extension period continues to replicate the great flow variability that is also exhibited by 1940-1997 hydrology. The validity of the extended flows is further investigated through comparative analyses. Statistics for the naturalized flows at all 77 primary control points are presented in Table 3.17. The comparative analysis is conducted for the 31 primary control points listed in Table 3.26.

The model calibration process attempts to replicate flows in each of the 696 months of the original 1940-1997 period-of-analysis. However, perfect replication is not possible. Another concurrent objective is to replicate the mean, standard deviation, and frequency metrics. The overall WRAP/WAM modeling strategy is to assess water supply capabilities in terms of supply reliability metrics and flow and storage frequency metrics, rather than focus on quantities in particular months. Thus, a flow extension process that accurately reproduces the statistical characteristics of naturalized flows is consistent with the overall modeling system.

The comparative analysis focuses on assessing model validity by comparing computed 1940-1997 naturalized flows with the 1940-1997 flows from the original WAM dataset and comparing 1998-2016 extended flows with the 1940-1997 flows. The computed 1940-1997 flows should closely replicate the original WAM 1940-1997 flows. The 1998-2016 flows reflect different hydrologic conditions than experienced during 1940-1997 and thus are expected to be different. However, the 1998-2016 naturalized but should exhibit some similarities to the 1940-1997 flows. The 1998-2016 naturalized flows are also compared with observed gaged flows. Differences between naturalized and gaged flows vary greatly with location.

The 31 control points for the comparative analysis listed in Table 3.26 include most of the main-stem Brazos River primary control points and a selection of tributary sites that are representative of locations throughout the Brazos River Basin. The watershed drainage areas for these 31 sites range from 46 to 36,027 square miles. Most are gaging stations that have records covering all or most of the years since 1940. The comparative analysis information presented for these 31 control points are considered to be representative of the entire set of 77 control points. The tables and plots demonstrate that the flow extension model is valid. The development and application of flow extension models for the 31 control points listed in Table 3.26 are presented in the Appendix A.1, A.2 and B.1-B.5.

Table 3.26 Thirty-One Selected Control Points in the Brazos River Basin

WAM CP ID	Stream	Nearest City	USGS Gage No.	Watershed Area (sq miles)	USGS Period of Record
RWPL01	Running Water Draw	Plainview	08080700	295	1939–present
SFAS06	Salt Fork Brazos River	Aspermont	08082000	2,504	1924–present
DMAS09	Double Mountain Fork	Aspermont	08080500	1,891	1923–present
BRSE11	Brazos River	Seymour	08082500	5,996	1923–present
CFNU16	Clear Fork Brazos	Nugent	08084000	2,236	1924–present
CFFG18	Clear Fork Brazos	Fort Griffin	08085500	4,031	1924–present
BRSB23	Brazos River	South Bend	08088000	13,171	1938–present
SHGR26	Brazos River	Graford	08088600	14,093	1976–1994
BRPP27	Brazos River	Palo Pinto	08089000	14,309	1924–present
BRDE29	Brazos River	Dennis	08090800	15,733	1968–present
BRGR30	Brazos River	Glen Rose	08091000	16,320	1923–present
PAGR31	Paluxy River	Glen Rose	08091500	411	1924–present
BRAQ33	Brazos River	Aquilla	08093100	17,746	1938–present
NBCL36	North Bosque River	Clifton	08095000	977	1923–2008
NBVM37	North Bosque River	Valley Mills	08095200	1,158	1959–present
BRWA41	Brazos River	Waco	08096500	20,065	1898–present
BRHB42	Brazos River	Highbank	08098290	20,900	1965–present
COPI48	Cowhouse Creek	Pidcoke	08101000	455	1950–present
LEBE49	Leon River	Belton	08102500	3,579	1923–present
LRLR53	Little River	Little River	08104500	5,266	1923–present
LRCA58	Little River	Cameron	08106500	7,100	1916–present
BRBR59	Brazos River	Bryan	08109000	30,016	1899–1993
MYDB60	Middle Yegua Creek	Dime Box	08109700	235	1962–present
EYDB61	East Yegua Creek	Dime Box	08109800	239	1962–present
DCLY63	Davidson Creek	Lyons	08110100	195	1962–present
NAEA66	Navasota River	Easterly	08110500	936	1924–present
BRHE68	Brazos River	Hempstead	08111500	34,374	1938–present
BRRI70	Brazos River	Richmond	08114000	35,454	1903–present
BGNE71	Big Creek	Needville	08115000	46	1947–present
BRRO72	Brazos River	Rosharon	08116650	35,775	1967–present
BRGM73	Brazos River	Gulf of Mexico	–	36,027	–

3.6.6.1 Tables of Flow Frequency of Metrics (Appendix A.1 pages 336-366)

Flow frequency metrics for each of the 31 control points are tabulated in Appendix A.1 on pages 336 through 366 for the following sets of monthly naturalized flows.

- 1940-1997 flows from the original Brazos WAM dataset
- 1940-1997 flows computed with the HYD model with level 1 calibration
- 1940-1997 flows computed with the HYD model after final level 2 calibration
- 1940-2016 final flows combining the 1998-2016 flows computed with the HYD flow extension model with the original WAM 1940-1997 flows
- 1998-2016 final extended flows

The mean, standard deviation, and volumes associated with specified exceedance frequencies for the original Brazos WAM 1940-1997 monthly naturalized flows are shown in column 2 of the tables of frequency metrics. Model calibration is performed in two stages called level 1 (intermediate) and level 2 (final). Summary statistics for the flows computed with the level 1 and final calibrated models are tabulated in columns 3 and 4. The metrics for the final flow sequences consisting of the original 1940-1997 flows and synthesized 1998-2016 flows are presented in column 5. Metrics for just the 1998-2016 flows are compared in column 6.

The success of the calibration process is measured by how closely the frequency metrics in column 4 for the 696 monthly flows for 1940-1997 computed with the final calibrated HYD model replicate the metrics in column 2 for the original known flows. A comparison of columns 6 and 2 shows the difference in hydrologic conditions between 1998-2016 and 1940-1997.

3.6.6.2 Naturalized Streamflow Tables (Appendix A.2 pages 367-428)

The tables on pages 367 through 428 contain the 1940-2016 naturalized flows from the final updated *SIM* input FLO file which consist of the original 1940-1997 flows and extended 1998-2016 flows. The final product of the flow extension process consists of a FLO file with 1940-2016 sequences of naturalized flows recorded on *IN* records for all primary control points.

The flows consist of 1940-1997 flows from the original WAM dataset combined with 1998-2016 flows computed with *HYD* based on the TWDB precipitation and evaporation datasets. Flows for the 31 selected control points are tabulated in Appendix A.2 in tables created with program *TABLES* from a *SIM* output OUT file derived from a *SIM* input dataset that includes the FLO file created with *HYD*. These final naturalized flows are plotted in Appendix B.1 on pages 459-490.

3.6.6.3 Naturalized Streamflow Plots (Appendix B.1 pages 457-487)

The 1940-2016 naturalized flows in the final updated *SIM* input FLO file consist of the original 1940-1997 flows and extended 1998-2016 flows. The tremendous variability of the naturalized flows is evident in the plots. The 1998-2016 naturalized flows appear to be reasonable extensions of the 1940-1997 flows.

3.6.6.4 Plots of Known and Computed Flows (Appendix B.2 pages 488-518)

These plots compare the 1940-1997 sequences of monthly flows computed with *HYD* to the known flows from the original WAM dataset. The flows computed with *HYD* are plotted as solid blue lines. The known flows are plotted as dashed red lines. Frequency metrics for these two sets of flows are presented in columns 2 and 4 of the frequency metric tables in Appendix A.1.

The objective of the calibration process is to develop a set of model parameters that result in computed 1940-1997 naturalized flows that reproduce the original naturalized flows as closely as possible. The 1940-1997 flows computed with the final model (computed flows) are compared with the original Brazos WAM flows (known flows). The plots show that the original naturalized flows are replicated reasonably closely by the flows computed with *HYD*.

3.6.6.5 Plots of 12-Month Moving Averages for Known and Level-1 Computed Flows (Appendix B.3 pages 519-549)

The 1940-1997 flows computed with the intermediate model with only the level 1 calibrated parameters are compared with the known flows from the original WAM dataset. The plots on pages 519-549 are 12-month forward moving averages. For each month, the mean of the flow in that month and subsequent 11 months is plotted. All of the time series plots in this study were developed with HEC-DSSVue from DSS files created with *HYD*. The HEC-DSSVue moving average option was employed.

3.6.6.6 Plots of 12-Month Moving Averages for Known and Final Computed Flows (Appendix B.4 pages 550-580)

The 12-month moving averages of the 1940-1997 monthly flows computed with the final calibrated *HYD* model are compared with the known flows from the original WAM dataset. The 12-month moving averages computed by HEC-DSSVue consist of the mean of the flow volume in each month and the 11 months that follow. The flows computed with *HYD* are plotted as solid blue lines. The known flows are plotted as dashed red lines.

3.6.6.7 Gaged and Extended Flows Plots (Appendix B.5 pages 581-608)

The 28 plots in Appendix B.5 on pages 581-608 compare the 1998-2016 extended flows with observed gaged flows consisting of the monthly totals of daily flow volumes at the gaging stations compiled by the USGS. Gaged flows are not available and thus plots are not provided for control points SHGR26, BRBR60, which are discontinued gaging stations, and BRGM73, which is the basin outlet. Gaged flows are not available at control point RWPL01 for January 1998 through September 2002. Many of the 77 primary control points listed in Table 3.4 but excluded from the 31 selected control points listed in Table 3.26 are former USGS gaging stations that have been discontinued.

Table 3.27

Tables and Plots for Comparing Flows Analysis

	1	2	3	4	5	6	7
Control Point	Tables of Flow Frequency Metrics	Tables of 1940-1997 Known & 1998-2016 Extended 1940-2016	Plots of 1940-1997 Known & 1998-2016 Extended 1940-2016	Plots of 1940-1997 Known & Computed Flows 1940-1997	Plots of Level 1 12-Month Moving Average 1940-1997	Plots of Level 2 12-Month Moving Average 1940-1997	Plots of Gaged & Extended Flows 1998-2016
RWPL01	336	367	457	488	519	550	581
SFAS06	337	369	458	489	520	551	582
DMAS09	338	371	459	490	521	552	583
BRSE11	339	373	460	491	522	553	584
CFNU16	340	375	461	492	523	554	585
CFFG18	341	377	462	493	524	555	586
BRSB23	342	379	463	494	525	556	587
SHGR26	343	381	464	495	526	557	-
BRPP27	344	383	465	496	527	558	588
BRDE29	345	385	466	497	528	559	589
BRGR30	346	387	467	498	529	560	590
PAGR31	347	389	468	499	530	561	591
BRAQ33	348	391	469	500	531	562	592
NBCL36	349	393	470	501	532	563	593
NBVM37	350	395	471	502	533	564	594
BRWA41	351	397	472	503	534	565	595
BRHB42	352	399	473	504	535	566	596
COPI48	353	401	474	505	536	567	597
LEBE49	354	403	475	506	537	568	598
LRLR53	355	405	476	507	538	569	599
LRCA58	356	407	477	508	539	570	600
BRBR59	357	409	478	509	540	571	-
MYDB60	358	411	479	510	541	572	601
EYDB61	359	413	480	511	542	573	602
DCLY63	360	415	481	512	543	574	603
NAEA66	361	417	482	513	544	575	604
BRHE68	362	419	483	514	545	576	605
BRRI70	363	421	484	515	546	577	606
BGNE71	364	423	485	516	547	578	607
BRRO72	365	425	486	517	548	579	608
BRGM73	366	427	487	518	549	580	-

3.6.7 The Brazos WRAP/WAM Simulation Results with 1998-2016 Extended Flows

3.6.7.1 Summary of the Results

The WRAP simulation model SIM is executed with the Brazos WAM authorized use Bwam3 input dataset with the extended 1940-2016 hydrologic period-of-analysis. Summaries of the annual means developed with program TABLE with a 2SBA record from the results of the SIM simulation are expressed in Table 3.28. The summary table aggregates the results of simulating all water rights in the Brazos WAM.

A fundamental concept of probability and statistics is that frequency and reliability estimates are improved with an increase in the length of the period-of-analysis. Water supply reliability and flow and storage frequency estimates based on 1940-2016 period-of-analysis are more credible than those based on 1940-1997 period-of-analysis. Both 1940-1997 and 1940-2016 annual means are shown at the end of Table 3.28.

Dramatic temporal and spatial variations in climate, hydrology, and geography occur over the very large Brazos River Basin and adjoining coastal basin. The effects on simulation results of extending the hydrologic period-of-analysis vary with location. General overall aggregated simulation results are presented in this section, realizing that impacts on individual water rights vary. The simulation results with the extended 1940-2016 hydrologic period-of-analysis are reasonable. The 1998-2016 simulation results are comparable to 1940-1997.

The WRAP SIM simulation results are summarized and compared in preceding section in terms of mean annual flows, water supply reliabilities, and reservoir storage volumes for five alternative periods:

- the 77 years of the entire 1940-2016 period-of-analysis
- the 58 years of the original 1940-1997 period-of-analysis
- the 19 years of the 1998-2016 extension period
- the year 2011 which is the driest single year of the 1998-2016 extension period
- the year 2015 which is the wettest single year of the 1998-2016 extension period

Simulation results are presented in Tables 3.29-3.34 and Figures 3.52-56. The 14 large reservoirs and several control points (BRSE11, BRWA41, LRCA58, BRRI70, and BRGM73) in the Brazos WAM are selected to demonstrate the simulation results. The locations of pertinent control points and reservoirs are shown in Figure 3.51.

3.6.7.2 River Basin Summary

A basin summary table created with the TABLES 2SBA record is reproduced as Table 3.28. The summary table aggregates the results of simulating all water rights in the Brazos WAM. In 2SBA Tables, naturalized and unappropriated flows are computed as the summation of the maximum flow occurring at any control point in each month of the simulation. Due to negative incremental flows in individual months, these flows may be much larger than the flows at the basin outlet, reflecting possible double counting of flows in adjoining months.

Table 3.28 illustrates the great variability in annual flows during the 1998-2016 extension period. The 1998-2016 mean naturalized flow of 13,010,966 acre-feet is larger than the 1940-1997 mean of 7,735,887 acre-feet. The naturalized annual flows for sixteen of the 19 years of 1998-2016 exceed the 1940-1997 mean annual flows. The flows are less than the 1940-1997 means in the other three years. The years 1999, 2006, and 2011 are very dry during 1998-2016 period of analysis. Especially, the year 2011 is the driest year of the 1998-2016 extension period.

For the 77 years of the 1940-2016 simulation, The 1940-2016 mean naturalized flow of 9,037,529 acre-feet is 116.8 percent of the 1940-1997 mean of 7,735,887 acre-feet. The years 2004, 2007, and 2015 have the third, second, and first highest annual naturalized flows during 1940-2016 in the Brazos River. The three lowest annual naturalized flows during 1940-2016 are 1,779,414 acre-feet, 1,944,357 acre-feet, and 1,950,015 acre-feet in 1954, 1963, and 1988, respectively.

Table 3.28 *TABLES* 2SBA Record 1940-2016 Simulation Results Summary

Year	Naturalized Streamflow (acre-feet)	Return Flow (acre-feet)	Streamflow Depletion (acre-feet)	Unapprop Flow (acre-feet)	EOY Storage (acre-feet)	Net Evaporation (acre-feet)	Target Diverion (acre-feet)	Actual Diversion (acre-feet)	Diversion Shortage (acre-feet)
1940	8,370,546	95,083	2,699,956	6,466,415	4,550,991	597,744	2,442,909	2,245,508	197,401
1941	14,544,272	116,849	2,839,711	12,756,189	4,516,989	475,522	2,443,802	2,397,199	46,602
1942	9,232,315	120,574	2,868,622	7,380,761	4,477,564	574,500	2,448,509	2,332,776	115,733
1943	2,388,090	97,975	1,798,625	1,080,173	3,334,748	704,667	2,447,102	2,238,010	209,092
1944	9,223,876	117,278	2,985,432	6,900,048	3,542,664	495,242	2,452,367	2,279,243	173,124
1945	12,917,492	124,382	3,041,691	11,247,094	3,752,930	506,954	2,448,548	2,323,943	124,605
1946	8,863,349	113,838	2,654,813	7,300,480	3,690,307	450,689	2,447,577	2,266,033	181,544
1947	5,245,479	105,734	2,361,372	3,629,232	3,199,473	602,499	2,451,769	2,251,377	200,392
1948	2,514,890	86,779	1,950,275	669,975	2,574,811	570,454	2,449,213	2,004,369	444,844
1949	5,013,066	106,829	3,190,327	3,361,514	3,222,226	350,012	2,459,949	2,192,052	267,897
1950	4,923,034	98,450	2,540,395	2,482,940	2,974,823	533,823	2,453,518	2,252,445	201,073
1951	2,002,667	54,891	1,360,432	246,899	2,000,081	519,304	2,449,696	1,816,459	633,236
1952	2,495,268	66,434	1,791,255	637,981	1,615,805	400,138	2,532,293	1,775,244	757,049
1953	4,774,742	95,437	3,591,555	2,622,004	2,739,276	347,872	2,510,923	2,116,465	394,459
1954	1,779,414	60,812	1,589,286	496,149	1,987,549	505,254	2,472,772	1,837,924	634,847
1955	3,203,790	80,081	2,976,107	1,131,303	2,516,090	331,151	2,474,254	2,114,482	359,772
1956	2,125,384	43,835	1,127,969	74,995	1,611,264	458,059	2,450,557	1,575,550	875,007
1957	21,224,904	101,564	5,198,265	16,533,434	4,294,341	278,717	2,448,200	2,232,634	215,566
1958	6,977,796	102,440	2,240,436	4,559,190	3,881,330	358,898	2,446,266	2,293,456	152,810
1959	7,165,160	107,780	2,817,278	5,011,209	4,108,345	265,900	2,443,072	2,323,927	119,146
1960	9,940,976	106,224	2,556,586	6,986,673	4,014,187	359,756	2,448,139	2,290,158	157,981
1961	12,710,216	115,446	2,764,949	10,328,095	4,101,744	315,579	2,441,030	2,361,223	79,807
1962	3,917,898	101,945	2,587,255	1,787,115	3,987,719	391,403	2,436,428	2,312,229	124,199
1963	1,944,357	85,819	1,617,231	719,290	3,031,456	504,431	2,444,818	2,069,030	375,788
1964	2,961,722	91,069	2,386,119	463,486	2,969,578	358,297	2,452,770	2,089,313	363,457
1965	9,283,932	110,613	3,296,537	6,192,677	3,599,094	377,414	2,445,824	2,285,696	160,128
1966	7,376,064	113,160	2,740,141	5,646,623	3,651,113	385,249	2,441,756	2,302,669	139,086
1967	2,139,662	82,549	2,140,449	570,854	3,193,844	442,756	2,437,388	2,154,486	282,902
1968	13,836,407	114,266	3,010,863	11,840,731	3,569,534	287,672	2,444,748	2,346,727	98,021
1969	7,232,475	101,340	2,902,406	4,588,321	3,828,060	361,707	2,442,119	2,281,108	161,010
1970	6,979,219	107,407	2,157,835	4,975,602	3,273,861	448,381	2,448,308	2,264,298	184,010
1971	8,958,746	87,420	2,823,224	4,745,218	3,563,398	387,307	2,439,823	2,144,778	295,045
1972	5,750,680	93,805	2,362,533	3,812,527	3,345,876	402,986	2,444,125	2,176,021	268,104
1973	11,014,018	114,585	2,850,761	9,037,942	3,653,381	227,405	2,446,467	2,315,431	131,036
1974	8,317,648	102,553	2,749,803	5,790,261	3,896,846	336,513	2,446,506	2,169,147	277,359
1975	8,856,901	110,919	2,366,175	7,474,865	3,536,496	395,738	2,446,624	2,330,029	116,596
1976	7,339,916	113,402	2,654,219	4,856,731	3,662,271	269,733	2,444,269	2,258,142	186,128
1977	9,376,887	94,824	1,925,629	8,454,524	2,902,292	504,136	2,447,331	2,183,531	263,800
1978	3,394,921	71,486	2,486,380	1,069,523	2,965,195	360,995	2,463,991	2,062,218	401,773
1979	10,518,358	115,983	3,097,608	8,284,784	3,458,269	286,300	2,456,278	2,314,914	141,364
1980	3,992,167	83,257	2,376,056	2,100,505	3,250,731	488,234	2,505,294	2,096,881	408,413
1981	7,976,747	107,173	3,255,611	5,929,713	3,943,522	278,492	2,456,248	2,280,878	175,370
1982	5,818,413	89,869	2,338,467	2,968,355	3,622,421	421,485	2,441,956	2,239,661	202,294
1983	4,470,742	96,164	2,244,342	3,250,808	3,267,898	354,795	2,471,747	2,243,940	227,807
1984	3,368,379	84,607	2,179,513	1,808,549	3,046,145	368,558	2,499,761	2,029,609	470,151
1985	7,730,598	101,252	3,012,483	4,518,825	3,505,981	348,157	2,450,177	2,203,839	246,338

Table 3.28 (Continued)

Year	Naturalized Streamflow (acre-feet)	Return Flow (acre-feet)	Streamflow Depletion (acre-feet)	Unapprop Flow (acre-feet)	EOY Storage (acre-feet)	Net Evaporation (acre-feet)	Target Diversion (acre-feet)	Actual Diversion (acre-feet)	Diversion Shortage (acre-feet)
1986	8,187,563	116,877	3,041,498	5,420,519	3,958,801	280,490	2,459,519	2,307,492	152,028
1987	10,085,818	110,722	2,397,616	8,456,043	3,612,325	394,344	2,445,810	2,349,192	96,618
1988	1,950,015	78,396	1,569,748	407,435	2,659,478	477,446	2,450,377	2,047,403	402,974
1989	9,760,157	103,519	3,039,341	4,658,217	3,110,797	354,870	2,441,769	2,230,401	211,368
1990	12,102,565	111,023	3,023,246	9,781,334	3,554,280	323,195	2,444,014	2,255,177	188,836
1991	15,821,834	115,709	3,206,524	13,319,830	4,104,897	313,733	2,442,131	2,340,511	101,619
1992	20,150,670	126,239	2,878,292	18,135,798	4,177,693	408,047	2,448,794	2,396,003	52,791
1993	9,483,548	115,905	2,336,559	7,536,377	3,654,879	538,503	2,446,470	2,320,804	125,666
1994	9,155,516	109,372	2,890,084	4,560,462	3,835,250	414,387	2,443,012	2,293,588	149,424
1995	17,313,834	112,773	2,521,705	15,474,770	3,650,102	367,147	2,439,733	2,339,215	100,518
1996	3,013,868	82,477	2,325,465	1,041,263	3,544,304	357,218	2,439,416	2,072,356	367,060
1997	11,462,574	115,943	2,903,836	9,349,486	3,810,191	286,390	2,443,125	2,350,463	92,661
1998	9,516,113	87,509	1,916,542	7,319,274	3,382,538	409,270	2,457,019	1,934,269	522,749
1999	6,254,824	87,868	1,952,040	1,440,741	2,858,511	448,728	2,488,433	2,028,536	459,897
2000	11,590,690	93,078	3,140,201	4,957,352	3,663,641	349,343	2,555,300	1,982,756	572,545
2001	9,765,391	112,079	2,422,089	5,894,235	3,602,068	262,428	2,451,826	2,220,777	231,048
2002	14,091,656	103,198	2,695,166	6,525,390	3,799,511	284,245	2,505,031	2,213,438	291,593
2003	8,641,920	97,529	2,166,891	2,164,938	3,387,950	387,896	2,462,437	2,189,298	273,139
2004	22,474,004	105,439	3,175,023	18,725,530	4,088,769	145,762	2,475,374	2,327,572	147,802
2005	18,261,030	87,219	1,963,235	1,259,277	3,274,473	579,418	2,446,063	2,200,177	245,886
2006	6,844,460	93,301	2,252,743	2,173,712	2,884,134	478,880	2,456,211	2,160,716	295,495
2007	24,628,604	108,768	3,651,458	18,110,924	3,915,895	250,316	2,447,137	2,367,073	80,064
2008	8,551,118	82,618	1,881,541	908,621	3,081,202	575,531	2,447,118	2,141,640	305,477
2009	15,317,852	90,861	2,981,303	5,941,551	3,675,723	373,006	2,462,620	2,010,575	452,045
2010	13,729,078	98,329	2,404,163	2,076,415	3,423,730	421,585	2,442,332	2,233,317	209,015
2011	2,742,302	65,671	1,501,040	329,190	2,624,906	593,654	2,520,744	1,708,030	812,713
2012	12,008,428	81,714	2,465,041	4,687,272	2,664,280	344,973	2,524,869	2,078,912	445,958
2013	11,178,393	108,545	2,659,952	3,146,804	2,980,401	300,739	2,575,230	2,040,257	534,973
2014	9,681,183	94,003	2,407,261	2,284,476	3,005,411	329,372	2,529,272	2,053,515	475,757
2015	25,209,736	100,694	3,709,300	17,726,676	4,228,085	281,383	2,461,448	2,202,273	259,175
2016	16,721,585	97,342	2,500,682	7,172,603	4,029,182	430,169	2,440,558	2,271,648	168,909
Mean									
1940-2016	9,037,529	98,557	2,577,748	5,633,468	3,424,363	399,394	2,459,875	2,186,265	273,610
1998-2016	13,010,966	94,629	2,510,652	5,943,641	3,511,430	400,466	2,478,444	2,144,168	334,276
1940-1997	7,735,887	99,882	2,597,257	5,533,312	3,432,853	405,287	2,452,782	2,206,511	246,271

3.6.7.3 Naturalized, Regulated, and Unappropriated Flows

1940-2016 naturalized flows synthesized with WRAP program HYD at selected 31 control points are in Appendix A.2 The computational methodologies and calibration procedures are described in Chapter II and summarized in previous section. Regulated flows and unappropriated flows are resulted from WRAP-SIM simulation.

The annual variation of synthesized naturalized flows during the 1998-2016 extension period varied with location. The naturalized flows, regulated flows, and unappropriated flows for the period-of-analysis 1940-1997, 1940-2016, and 1998-2016 at the Seymour, Waco, and Richmond gages on the Brazos River and Gulf of Mexico (outlet of the Brazos River) and Cameron gage on the Little River are compared in Table 3.29. The last two columns of Table 3.29 are tabulated the means of naturalized, regulated, and unappropriated flows for 2011(the driest year during extension period) and 2015 (the wettest year during extension period). Location of the 5 gages are shown in Figure 3.51.

The 1940-2016 mean regulated flow at the Seymour gage on the upper Brazos River is 96.3 percent of 1940-1997 mean regulated flow while 1940-2016 mean regulated flow at Richmond gage on the lower Brazos River (BRRI70) is 102.9 percent of 1940-1997 mean regulated flow. For the same period, the regulated flow at Waco gage on the middle of Brazos River is 98.8 percent of 1940-1997 mean regulated flow. The unappropriated flow at Cameron gage on the Little River (LRCA58) for the 12months of 2011 and 2015, respectively, are 5.7 percent and 468.8 percent of 1940-1997 mean unappropriated flow.

Table 3.29 Mean Annual naturalized, Regulated, and Unappropriated Flows
at Control Points BRSE11, BRWA41, LRCA58, BRRI70, and BRGM73

	1940-1997	1940-2016	1998-2016	2011	2015
Annual Flows (acre-feet/year) at the Seymour Gage on the Brazos River (BRSE11)					
naturalized flow	250,096	241,068	213,508	19,242	610,430
regulated flow	233,555	224,991	198,615	18,795	553,066
unappropriated flow	131,323	123,170	99,618	1,008	458,774
Percent of 1940-1997		96.4	85.4	7.7	244.1
means		96.3	85.0	8.0	236.8
		93.8	75.9	0.8	349.3
Annual Flows (acre-feet/year) at the Waco Gage on the Brazos River (BRWA41)					
naturalized flow	1,942,324	1,919,872	1,851,335	476,007	5,490,246
regulated flow	1,352,115	1,335,697	1,292,538	249,168	4,900,532
unappropriated flow	1,040,835	994,758	859,684	-0-	4,431,850
Percent of 1940-1997		98.8	95.3	24.5	282.7
means		98.8	95.6	18.4	362.4
		95.6	82.6	0.0	425.8
Annual Flows (acre-feet/year) at the Cameron Gage on the Little River (LRCA58)					
naturalized flow	1,318,301	1,394,650	1,627,714	574,001	4,606,375
regulated flow	990,118	1,071,891	1,322,830	348,834	4,304,120
unappropriated flow	801,066	855,427	1,022,557	45,724	3,755,282
Percent of 1940-1997		105.8	123.5	43.5	349.4
means		108.3	133.6	35.2	434.7
		106.8	127.6	5.7	468.8
Annual Flows (acre-feet/year) at the Richmond Gage on the Brazos River (BRRI70)					
naturalized flow	5,850,225	5,972,188	6,344,498	1,609,115	17,705,884
regulated flow	4,599,190	4,733,249	5,152,608	862,138	16,416,144
unappropriated flow	3,473,476	3,413,595	3,240,636	169,800	12,581,436
Percent of 1940-1997		102.1	108.4	27.5	302.7
means		102.9	112.0	18.7	356.9
		98.3	93.3	4.9	362.2
Annual Flows (acre-feet/year) at the Gulf of Mexico on the Brazos River (BRGM73)					
naturalized flow	6,105,239	6,214,482	6,547,962	1,408,478	19,127,704
regulated flow	4,210,381	4,347,296	4,774,826	297,412	17,202,532
unappropriated flow	4,210,381	4,347,296	4,774,826	297,412	17,202,532
Percent of 1940-1997		101.8	107.3	23.1	313.3
means		103.3	113.4	7.1	408.6
		103.3	113.4	7.1	408.6

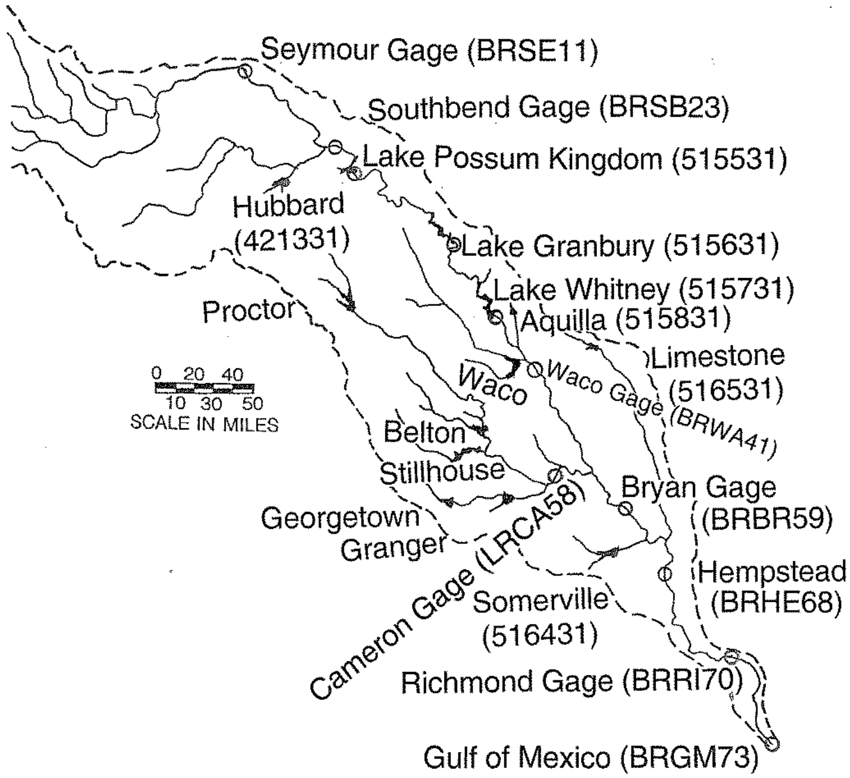


Figure 3.51 Selected Control Points and Major Reservoirs in the Brazos River Basin

3.6.7.4 Water Supply Diversion Reliabilities

Table 3.28 shows the means of total storage contents in acre-feet of the 3,842 reservoirs, annual means in acre-feet/year of the net evaporation-precipitation volumes for the 3,842 reservoirs, and annual means in acre-feet/year for the total streamflow depletions, diversion targets, and shortages for all water rights during each period-of-analysis. Table 3.30 summarizes the results of WRAP-SIM simulation with three datasets of 1940-1997, 1940-2016, and 1998-2016 period-of-analysis.

As shown in Table 3.30, diversion shortages increase a little during 1940-2016 comparing with 1940-1997 means due to several drought years including 2011 extreme drought. The volume reliabilities for the total of all diversion rights are 89.97 and 88.88 percent for simulation period of 1940-1997 and 1940-2016, respectively. Volume reliabilities for the 228 months of 1998-2016, the 12 months of 2011 and 2015, respectively, are 86.51, 67.76, and 89.47 percent.

Reliabilities of water supply diversion computed with the TABLE 2REL from the 14 large reservoirs for 1940-1997 and 1940-2016 period-of-analysis are tabulated in Table 3.31 and 3.32. The volume reliabilities for the total of all diversions from the 14 reservoirs are 96.82 and 96.56 percent, respectively. The means of shortage were slightly increased or decreased depending on reservoirs but overall reliabilities did not show any significant changes. The location of 14 reservoirs in the Brazos WAM are shown in Figure 3.51.

Table 3.30 Brazos WAM Simulation Results Summaries

	1940-1997	1940-2016	1998-2016	2011	2015
	Mean flow volumes in acre-feet/year and storage volumes in acre-feet				
Naturalized Flow	7,735,887	9,037,529	13,010,966	2,742,302	25,209,736
Return Flow	99,882	98,557	94,629	65,671	100,694
Streamflow Depletion	2,597,257	2,577,748	2,510,653	1,501,040	3,709,300
Unappropriated Flow	5,533,312	5,633,468	5,943,641	329,190	17,726,676
Reservoir Storage	3,432,853	3,424,363	3,511,430	2,624,906	4,228,085
Evaporation-precipitation	405,287	399,394	400,466	593,654	281,383
Diversion Target	2,452,782	2,459,875	2,478,444	2,520,744	2,461,448
Diversion Amount	2,206,511	2,186,265	2,144,168	1,708,030	2,202,273
Diversion Shortage	246,271	273,610	334,276	812,713	259,175
Volume Reliability	89.97	88.88	86.51	67.76	89.47

Table 3.31 1940-1997 Reliabilities for 14 large Reservoirs of Brazos WAM

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS 100%	98%	95%	90%	75%	50%	1%
421331	56000.0	8804.26	82.76	84.28	82.8	83.0	83.0	83.5	84.2	84.5	85.1	69.0	69.0	70.7	70.7	77.6	84.5	98.3
515531	230750.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
4146P1	35000.0	16234.38	47.99	53.62	48.0	48.3	49.1	50.1	51.9	54.7	57.5	22.4	22.4	25.9	27.6	32.8	46.6	89.7
515731	18946.7	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	80401.7	303.60	98.56	99.62	98.6	98.6	98.6	98.6	100.0	100.0	100.0	96.6	96.6	96.6	98.3	100.0	100.0	100.0
515931	19658.0	11.57	99.71	99.94	99.7	99.7	99.7	99.7	99.9	100.0	100.0	98.3	98.3	100.0	100.0	100.0	100.0	100.0
516031	112257.0	358.13	99.57	99.68	99.6	99.6	99.6	99.6	99.6	99.6	99.9	96.6	96.6	96.6	98.3	100.0	100.0	100.0
516131	67768.0	614.01	98.42	99.09	98.4	98.6	98.6	98.9	99.0	99.0	99.4	91.4	91.4	93.1	94.8	100.0	100.0	100.0
516231	13610.0	272.66	97.84	98.00	97.8	97.8	97.8	97.8	97.8	98.0	98.3	93.1	93.1	93.1	93.1	98.3	98.3	100.0
516331	19840.0	53.35	99.57	99.73	99.6	99.6	99.6	99.6	99.6	99.7	99.9	96.6	96.6	98.3	98.3	100.0	100.0	100.0
516431	48000.0	208.13	99.14	99.57	99.1	99.1	99.1	99.1	99.1	99.4	99.6	96.6	96.6	96.6	98.3	100.0	100.0	100.0
516531	65074.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total	845913.3	26860.09		96.82														

Table 3.32 1940-2016 Reliabilities for 14 large Reservoirs of Brazos WAM

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT							PERCENTAGE OF YEARS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT						
					100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%
421331	56000.0	10115.21	80.41	81.94	80.4	80.6	80.6	81.1	81.7	82.0	82.8	63.6	63.6	64.9	66.2	72.7	84.4	94.8
515531	230750.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
515631	64712.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
4146P1	35000.0	17498.21	45.24	50.01	45.2	45.5	46.2	47.3	48.7	51.1	54.2	20.8	20.8	23.4	24.7	29.9	42.9	88.3
515731	18988.9	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	80400.6	228.63	98.92	99.72	98.9	98.9	98.9	98.9	100.0	100.0	100.0	97.4	97.4	97.4	98.7	100.0	100.0	100.0
515931	19658.0	10.28	99.78	99.95	99.8	99.8	99.8	99.8	99.8	100.0	100.0	98.7	98.7	100.0	100.0	100.0	100.0	100.0
516031	112257.0	352.08	99.57	99.69	99.6	99.6	99.6	99.6	99.6	99.7	99.8	97.4	97.4	97.4	98.7	100.0	100.0	100.0
516131	67768.0	461.82	98.81	99.32	98.8	98.9	98.9	99.1	99.2	99.2	99.6	93.5	93.5	94.8	96.1	100.0	100.0	100.0
516231	13610.0	205.39	98.38	98.49	98.4	98.4	98.4	98.4	98.4	98.5	98.7	94.8	94.8	94.8	94.8	98.7	98.7	100.0
516331	19840.0	40.16	99.68	99.80	99.7	99.7	99.7	99.7	99.7	99.8	99.9	97.4	97.4	98.7	98.7	100.0	100.0	100.0
516431	48000.0	176.75	99.24	99.63	99.2	99.2	99.4	99.4	99.4	99.5	99.6	97.4	97.4	97.4	98.7	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
Total	845954.4	29088.52		96.56														

3.6.7.5 Reservoir Storage

Reservoir storage volumes or drawdowns provides a general index of basin-wide hydrologic conditions that include stream inflows and net evaporation-precipitation rates over extended periods of time. Severe storage drawdowns representing major drought periods can be readily identified. The total end-of-month storage volume of the 3,842 reservoirs during each of the 924 months of the 1940-2016 Brazos WAM simulation plotted in Figure 3.52 provides a metric of drought conditions.

The critical drought period of the Brazos River basin began in 1951 and lasted until 1957. The lowest total storage volume is 1,485,374 acre-feet, or 31.6 percent of capacity, which occurs in November 1952. The 36 months with the lowest end-of-month total storage contents of the 3,842 reservoirs are all within the years 1951-1957. Excluding the period 1951-1957, the minimum storage consists of 2,217,031 acre-feet, or 47.2 percent of capacity, that occurs in October 2011. One of major droughts occurred in 1984, when the total storages is 2,226,205 acre-feet.

Frequency statistics for end-of-month storage volumes of the 3,482 reservoirs are compared in Table 3.33 for the 1940-1997 (696 months) and 1940-2016 (924months) hydrologic period-of-analysis. The mean storage volume of end-of-month for 1940-2016 simulation is 99.2 percent of the corresponding mean storage volume of the 1940-1997 simulation.

End-of-month storage contents of each of 14 of the largest reservoirs in the river basin for the 924 months of the Bwam3 1940-2016 simulation are plotted in Figures 3.53-3.56. Information about these reservoirs is provided in Table 3.4 These 14 reservoirs account for 73.5 percent of the total conservation storage capacity of the 3,842 reservoirs in the dataset and are located throughout the river basin. The plots demonstrate that the 1950-1957 drought is the most severe drought of the 1940-2016 hydrologic period-of-analysis. Extending the hydrologic period-of-analysis through 2016 enhances the validity of the reliability and frequency analyses, but the critical drought period is not changed for most of the Brazos River Basin.

Table 3.33 Storage Frequency for 1940-1997 and 1940-2016 Simulation Period

		STANDARD	PERCENTAGE OF MONTHS WITH VOLUME EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
PERIOD	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
1940-1997	3500438.	620035.	1480260.	1645738.	1782771.	2223339.	2657078.	3216222.	3483443.	3599586.	3721431.	3902868.	4180701.	4650210.
1940-2016	3473267.	587543.	1485374.	1689118.	1906076.	2365793.	2712098.	3158819.	3442793.	3571518.	3688841.	3864546.	4113178.	4649022.

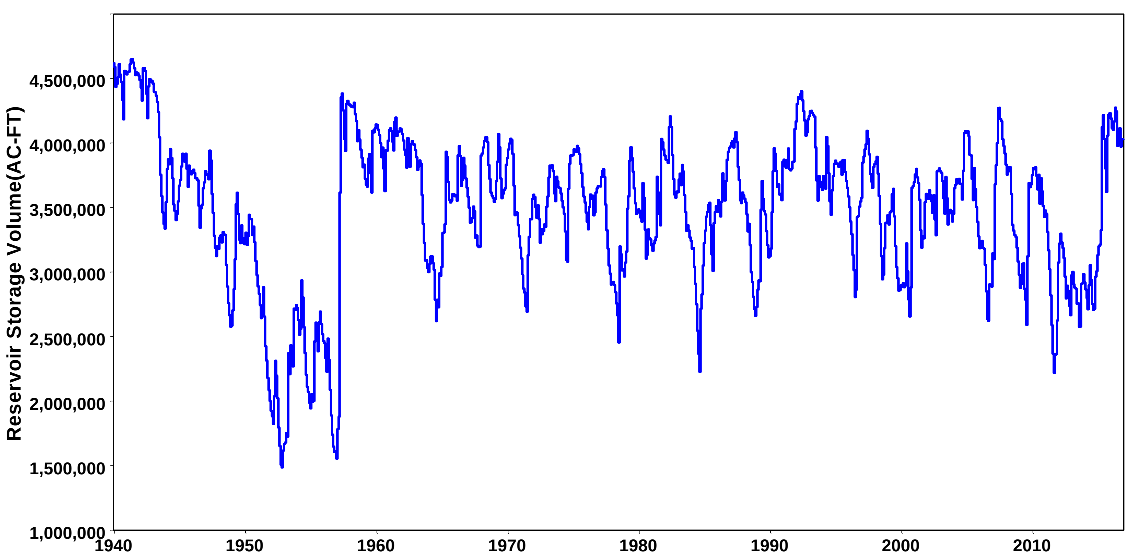


Figure 3.52 The total end-of-month storage volume of the 3,842 reservoirs in Brazos WAM dataset during 1940-2016

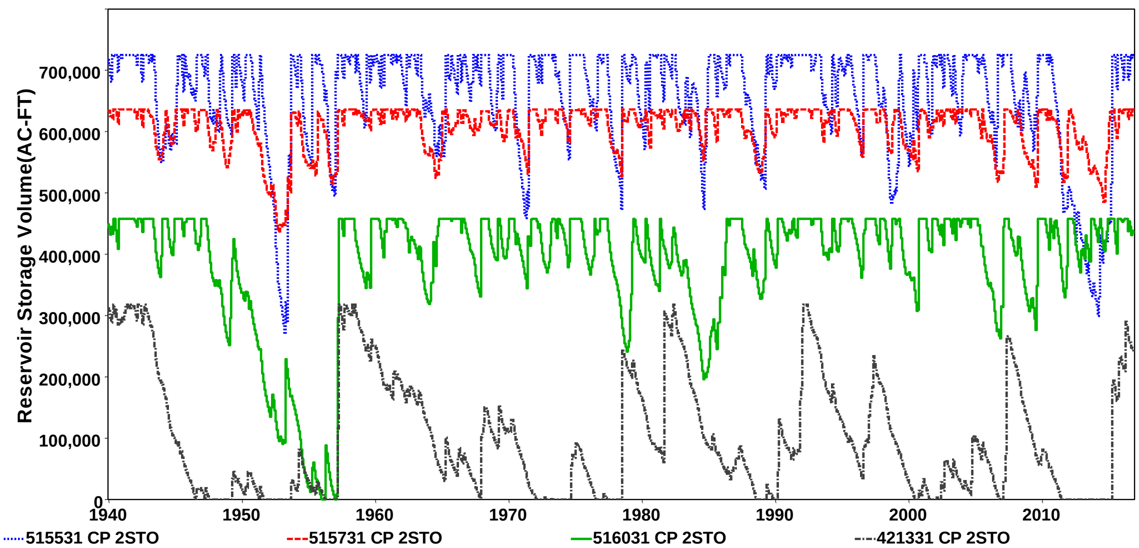


Figure 3.53 Storage Contents for Possum Kingdom, Whitney, Hubbard Creek, and Waco Reservoirs

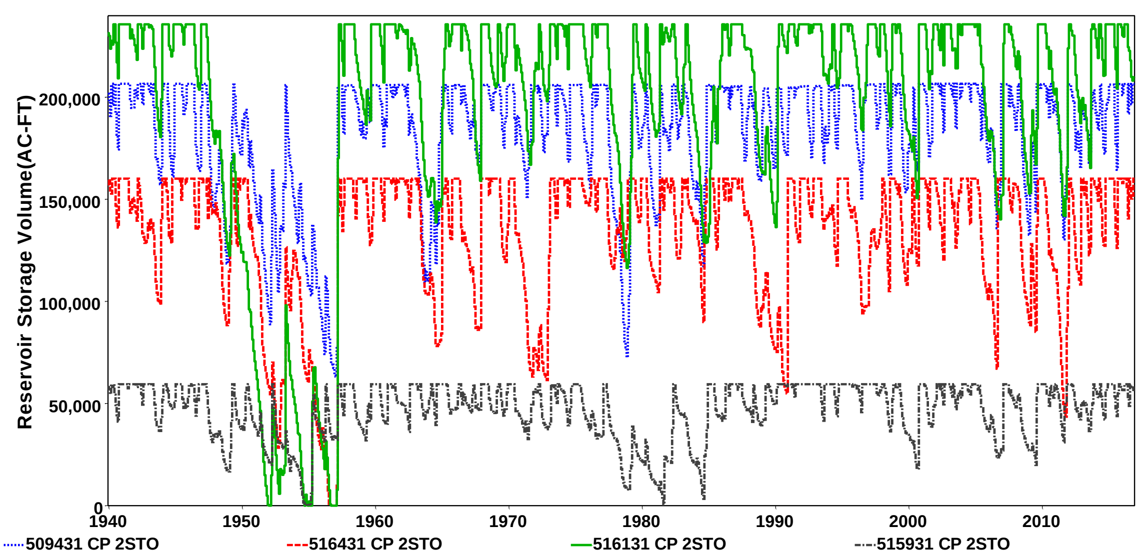


Figure 3.54 Storage Contents for Belton, Georgetown, Granger, and Stillhouse Hollow Reservoirs

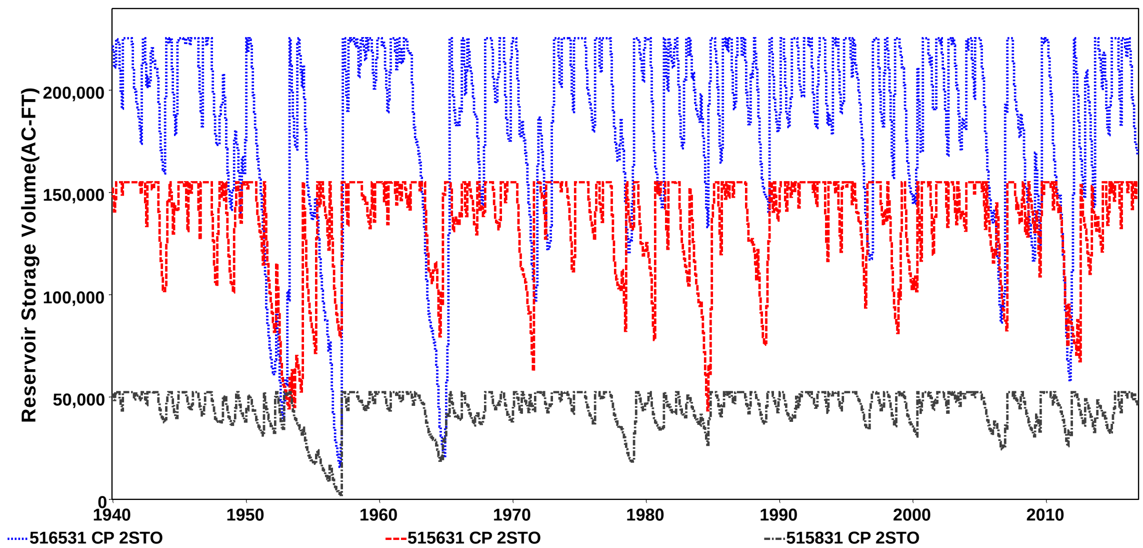


Figure 3.55 Storage Contents for Limestone, Somerville, and Granbury Reservoirs

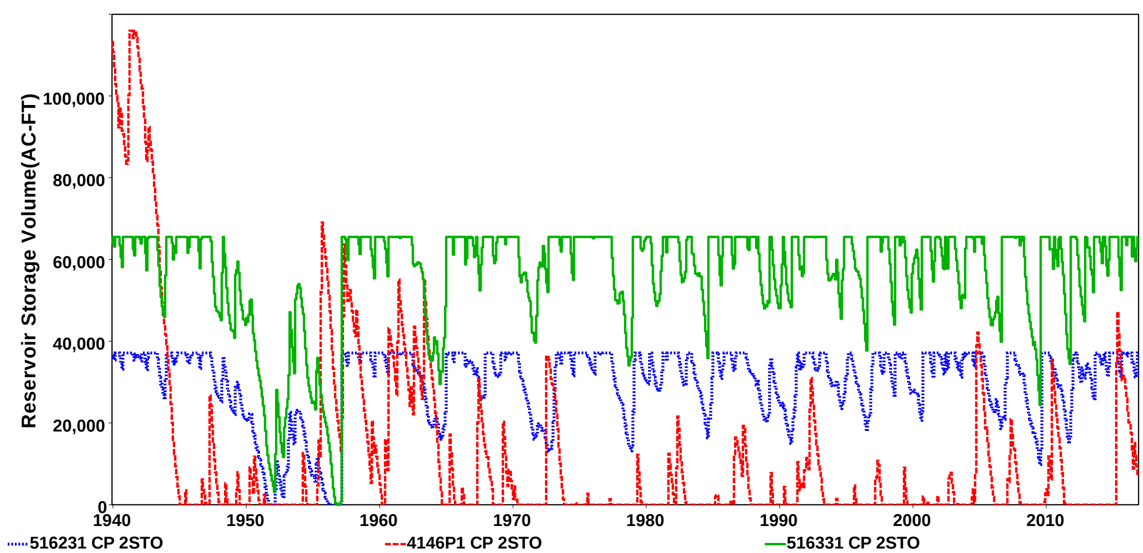


Figure 3.56 Storage Contents for Proctor, Alan Henry, and Aquilla Reservoirs

CHAPTER IV

ESTABLISHMENT WATER ALLOCATION STRATEGY IN KOREA BASED ON WRAP/WAM SYSTEM

4.1 Development of North Han River WRAP/WAM Dataset

WRAP/WAM simulation studies combine a specified scenario of river/reservoir system management and water use with river basin hydrology represented by sequences of naturalized stream flows and reservoir evaporation-precipitation rates at pertinent locations for each monthly or sub-monthly interval of a hydrologic period-of-analysis. Model application consists of compiling water management and hydrology input data for the river system and simulating alternative water resources development, management, and use scenarios (Wurbs 2015a).

The North Han River Basin, a tributary of Han River, shown in Figure 4.1 is adopted as a case study to 1) develop WRAP/WAM dataset, 2) establish the water allocation strategy, and 3) evaluate simulation results for water availability study. The study area is located in the northeast of South Korea and occupy most of Gangwon Province.

The North Han River Basin has a total area of 4,148 square miles, with about 67% (2,276 square miles) of total watershed in South Korea and the remainder 33% (1,372 square miles) in North Korea. Mean annual precipitation is 47.8 inches (1,213mm). The basin has an overall length of approximately 181 miles. The river basin includes the Soyang Multi-purpose dam (SYCC08) which is the largest dam with 2,350,081 acre-feet of total storage in Korea and a main water source of 25 million people living in the Seoul Metropolitan area.

Especially, the North Han River basin is very important for the military aspects because it includes the borderline with North Korea. The Gumgangsan dam constructed by North Korea occupy the most upstream of the watershed, the Peace dam, which was constructed to protect downstream area including Seoul from discharge of Gumgangsan dam, is located in the downstream. The Peace dam is still under construction for the 3rd dam enhancement project.

There are four hydropower dams which are Hwacheon (NHHW03), Chuncheon (NHSA05), Uiam (NHUI11), and Cheongpyeong (NHCH14) managed by Korea Hydro and Nuclear Power (KHNP) in the River Basin. The Paldang (NWGW15) is the outlet of river basin. The Cheongpyeong and Uiam hydropower dam are located in series at the upstream of Paldang. Hongcheon river joins to North Han River at upstream of Cheongpyeong and downstream of Uiam hydropower dam. The Hwacheon and Chuncheon hydropower are located in series at downstream of the Pease dam. Soyang river joins at Seomyeon (NHSE10) upstream of the Chuncheon hydropower dam. The streams that drain into Soyang river include Inbuk Creek and Nelin creek (SYIN07).

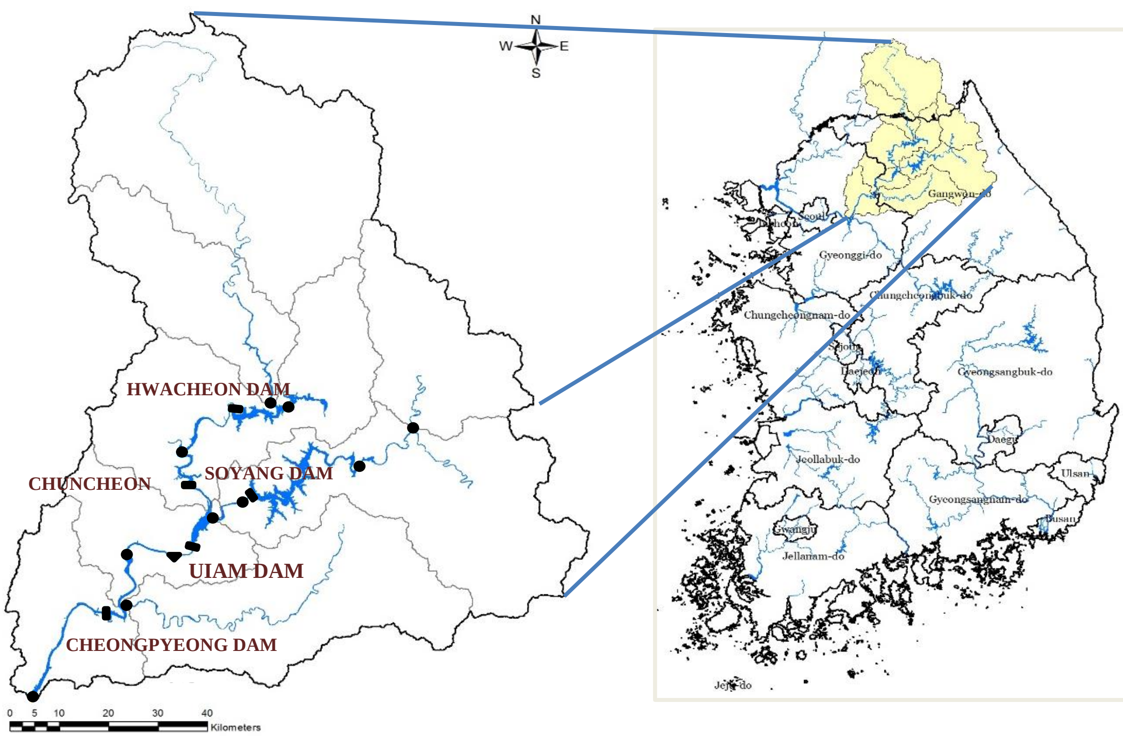


Figure 4.1 North Han River Basin

Table 4.1 Number of System Components in North Han River WAM Dataset

total number of control points	15
number of primary control points	15
control points with evaporation-precipitation rates	5
number of reservoirs as counted by SIM	5
number of WR record water rights	42
number of instream flow IF record rights	8

4.1.1 Control Points

Primary control points are locations at which naturalized stream flows are provided in a SIM input dataset. The North Han River WAM has 15 primary control points for which January 1966 through December 2017 naturalized flows are provided on inflow IN records in the FLO file.

The 15 primary control points contained in the North Han River WAM input dataset are listed in Table 4.2 with the six-character identifiers used in the data files. The 9 control points are located in the North Han River, 4 control points are in the Soyang River, and 2 control points in Yanggusecheon creek and Hongcheon River, respectively.

The locations of the 15 control points are shown in Figure 4.2 and their watersheds are listed in Table 4.2. The not-to-scale schematic of Figure 4.3 shows the upstream-to-downstream spatial configuration of the control points.

4.1.2 Naturalized Flows

The stream flows in the WRAP/WAM input dataset are naturalized flows representing natural hydrology unaffected by water resources development and management such as the reservoirs, diversions, return flows, and water uses. The conventional approach of developing naturalized flows is to adjust historical observed flows. In this case, long-term observation data are required at the gaging stations.

There are 25 gaging stations managed by Ministry of Land, Infrastructure, and Transport (MOLIT) and Korea Water Resources Corporation (K-water) in the North Han

River Basin. However, most of gages, except for three dam-sites and Gangchon gage, have been installed recently and only a few gages have the stage-discharge relation curves. The reliability of the rating curves is a significant concern because most of them have not been updated periodically. It is very difficult to obtain low flows under natural stream condition because stream flows are controlled by dam operation.

Thus, in this research, naturalized flows for 15 primary control points in the North Han River Basin are applied to naturalized flows announced by MOLIT in 2016 Long-term Water Resources Development and Management Master Plan. The Tank Model, which is a typical conceptual rainfall-runoff model, is used for calculating naturalized flows at 113 major control points nationwide. Naturalized flow for all control points are tabulated in Appendix C.1 and naturalized flows at control point NHGA 12 (North Han River at Gangchon) presented in Table 4.3

Table 4.2 Primary Control Points in the North Han River WAM Dataset

WAM CP ID	Stream	Nearest City	Watershed Area (mi^2)	Period of Record
NHYA01	North Han River	Yanggu	1,284	-
YGSE02	Yangguseocheon Creek	Yanggu-Seocheon	235	-
NHHW03	North Han River	Hwacheon-Hwacheon	1,577	2000-present
NHHA04	North Han River	Hwacheon-Hanam	1,823	-
NHSA05	North Han River	Chuncheon-Sabuk	1,876	2000-present
SYBU06	Bucheon Creek	Inje-Bukcheon	778	-
SYIN07	Soyang River	Inje-inje	886	-
SYCC08	Soyang River	Chuncheon-Chuncheon	1,040	1994-present
SYCJ09	Soyang River	Chuncheon-Cheonjeon	1,075	-
NHSE10	North Han River	Chuncheon-Seomyeon	1,897	-
NHUI11	North Han River	Chuncheon-Uiam	3,025	-
NHGA12	North Han River	Chuncheon-Gangchon	3,098	1996- present
HOSO13	Hongcheon River	Hongcheon-Songsan	604	-
NHCH14	North Han River	Gapyeong	3,901	-
NHGW15	North Han River	Gwangju	4,148	-

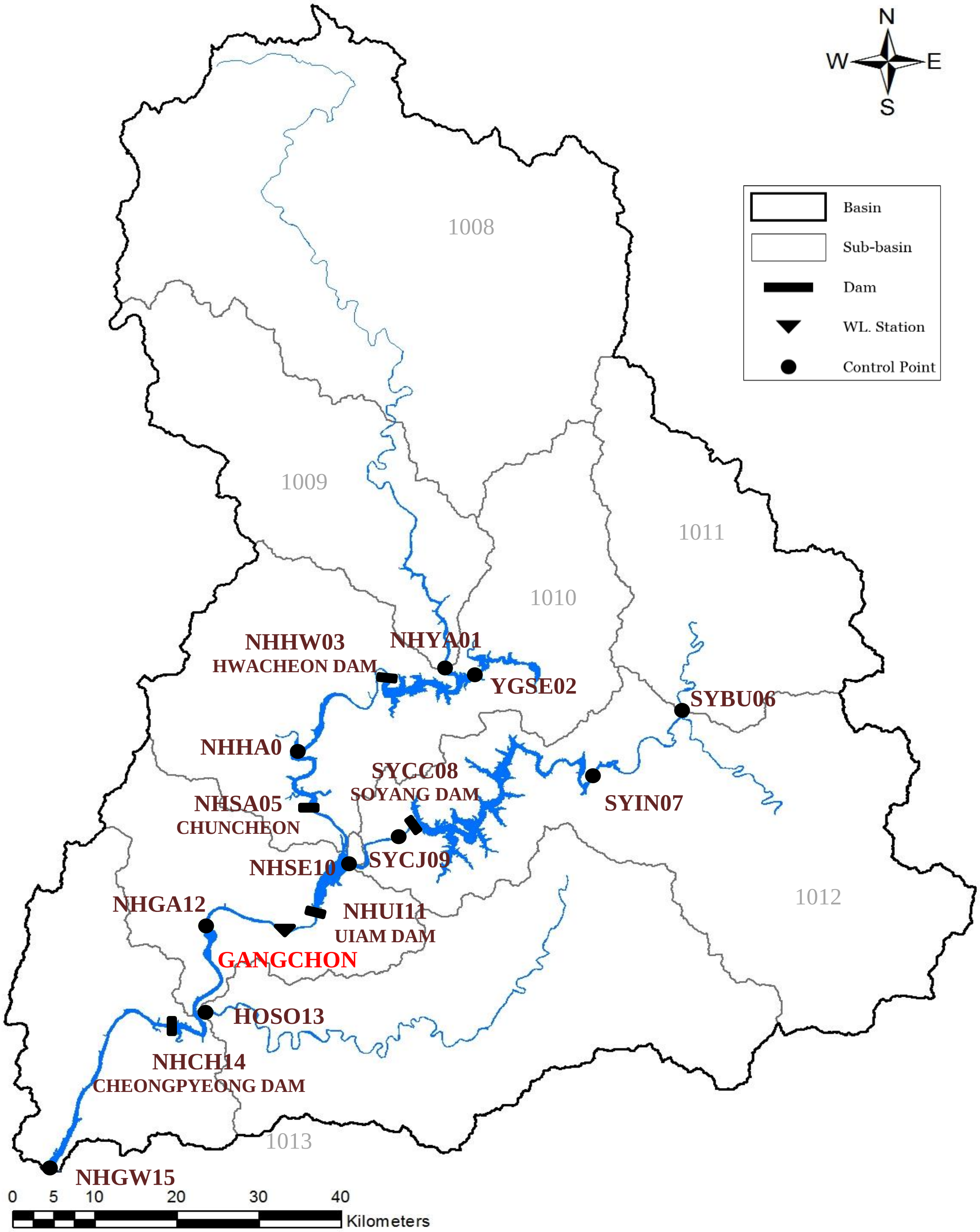


Figure 4.2 Major Tributaries and Largest Reservoirs in the North Han River Basin

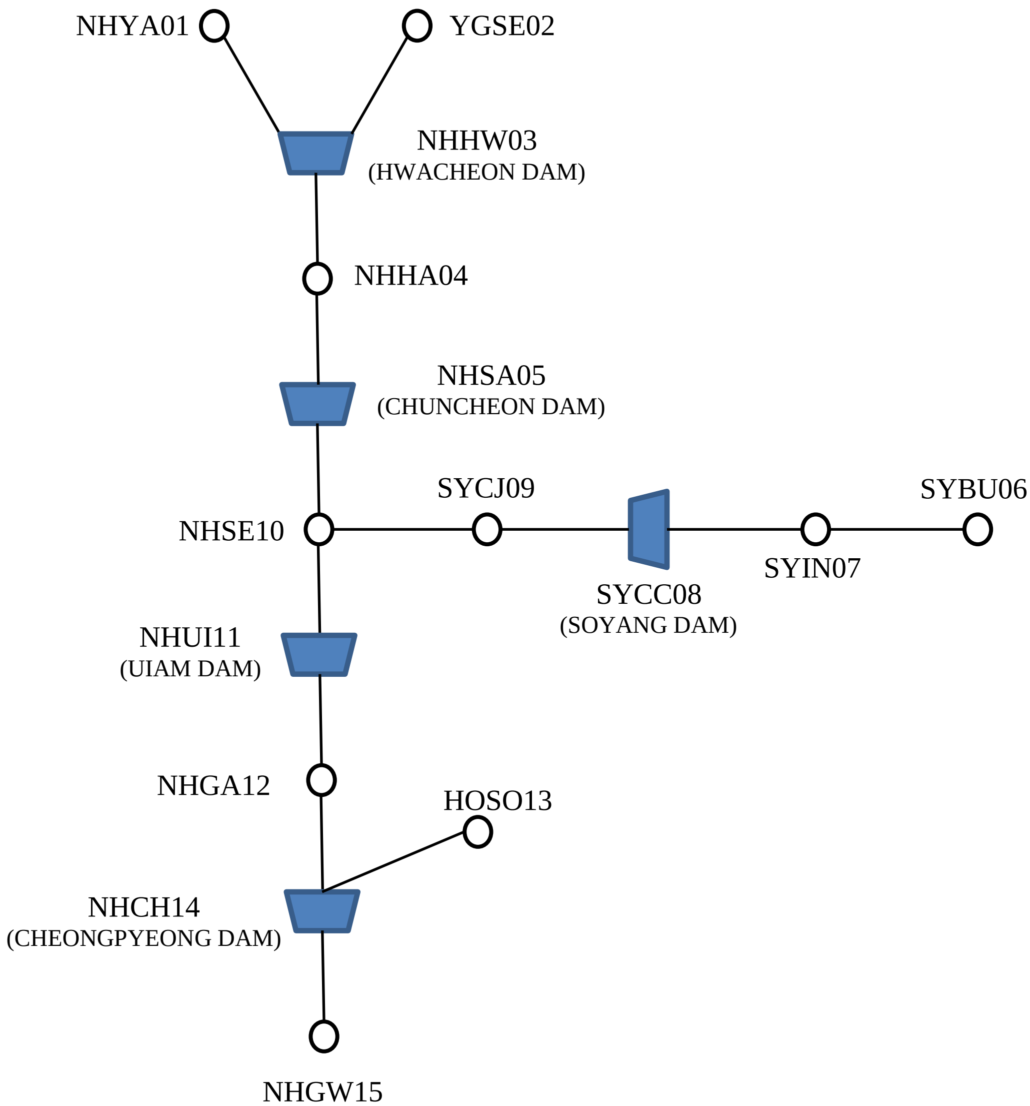


Figure 4.3 Schematic of Primary Control Points (Not to Scale)

Table 4.3 Naturalized Flows at Gangchon on North Han River (NHGA12)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	37159.	33504.	175268.	211309.	134289.	861745.	3695671.	1152124.	1525289.	314376.	144429.	82284.	8367447.
1967	47708.	71380.	284314.	348429.	159879.	112733.	1411934.	1215503.	673563.	105834.	57952.	53503.	4542732.
1968	42455.	37848.	70954.	116598.	58604.	94648.	1248495.	1595862.	557175.	566827.	274975.	143666.	4808107.
1969	59667.	88201.	400610.	881322.	837705.	354814.	1586789.	2347594.	448454.	114472.	57931.	43627.	7221186.
1970	41435.	57167.	122981.	87464.	50312.	92568.	1230306.	1218911.	2114644.	335581.	208662.	91465.	5651496.
1971	75403.	89122.	293864.	87905.	120441.	117816.	1104894.	996912.	438161.	128993.	46883.	44018.	3544412.
1972	95480.	120305.	388064.	220929.	84281.	54277.	472149.	2999982.	728995.	270748.	240485.	157644.	5833339.
1973	109458.	116529.	155972.	257100.	502363.	86603.	267406.	1072467.	918501.	168605.	124202.	53677.	3832883.
1974	36291.	41816.	118987.	478491.	877773.	333368.	575096.	1397022.	363132.	180890.	67678.	44604.	4515148.
1975	37528.	37523.	114516.	267833.	205395.	283902.	2308525.	796987.	907872.	208477.	129810.	76879.	5375247.
1976	43019.	84224.	313225.	170749.	100407.	77949.	229769.	2741019.	502667.	128884.	139997.	135982.	4667891.
1977	68653.	82614.	98302.	644429.	259961.	165686.	680018.	622630.	185956.	51636.	154155.	108265.	3122305.
1978	71062.	47953.	577983.	335028.	64789.	1315472.	1499448.	1689714.	454860.	163222.	175790.	89294.	6484615.
1979	89012.	120313.	275133.	827907.	418343.	1422365.	765384.	1786931.	237208.	93939.	46001.	43779.	6126315.
1980	41500.	37015.	52504.	680263.	183321.	96832.	1215785.	704936.	450932.	101276.	57910.	46384.	3668658.
1981	38374.	51874.	223952.	254054.	337665.	507141.	2816835.	806038.	1757183.	154930.	126386.	59211.	7133643.
1982	53633.	50403.	164372.	136910.	281861.	107272.	326878.	1692319.	280373.	93397.	233259.	284227.	3704904.
1983	94482.	58892.	379664.	494223.	337687.	57763.	1341414.	629533.	684843.	284575.	67951.	43605.	4474632.
1984	37485.	34599.	43909.	189653.	175529.	140439.	916408.	1129030.	2786862.	161637.	85238.	113908.	5814697.
1985	49791.	50599.	176831.	343808.	472996.	94270.	154062.	706672.	992774.	737472.	176021.	94504.	4049800.
1986	54718.	37190.	244702.	236158.	125412.	115233.	741530.	1213419.	606074.	367379.	157410.	91053.	3990278.
1987	57236.	104080.	185860.	193854.	194889.	356495.	1206930.	2322394.	751344.	102556.	88514.	47751.	5611903.
1988	39481.	35980.	40371.	68392.	49748.	76500.	1775341.	206805.	167430.	59124.	36002.	35227.	2590401.
1989	42455.	45130.	306627.	188876.	86039.	173458.	1217478.	702092.	660393.	252929.	688938.	92941.	4457356.
1990	48424.	160071.	445105.	353470.	397788.	1464543.	2416789.	841829.	3097482.	188638.	120463.	75533.	9610135.
1991	43584.	42463.	186446.	151214.	163851.	114960.	1497278.	533835.	537178.	157513.	59171.	72994.	3560487.
1992	74926.	55879.	271660.	215405.	291911.	202970.	363299.	1083884.	581520.	228684.	140249.	138066.	3648453.
1993	82327.	108648.	264107.	297597.	674201.	720530.	913022.	851163.	217358.	77226.	108574.	50377.	4365130.
1994	39004.	39836.	88578.	211750.	309557.	150899.	751189.	665368.	300622.	677479.	177302.	89056.	3500640.
1995	43649.	32249.	70346.	93304.	54805.	54004.	1245651.	3649179.	546357.	116947.	79398.	46297.	6032186.
1996	36378.	36264.	128863.	237733.	124565.	360695.	2044765.	476382.	143253.	85952.	91434.	74340.	3840624.
1997	53850.	101689.	612733.	365380.	1059466.	711939.	1017575.	461275.	696437.	160053.	130608.	261632.	5632637.
1998	113213.	131605.	360434.	488951.	532403.	472630.	1290559.	2747509.	328306.	353336.	199063.	120919.	7138928.
1999	54827.	37445.	92767.	282809.	159054.	141615.	787328.	3938811.	1332401.	388824.	282809.	81133.	7579823.
2000	55283.	40528.	89316.	95299.	154366.	170496.	355593.	2257040.	1231956.	164958.	87569.	76054.	4778458.
2001	47881.	68439.	254839.	202256.	366055.	221307.	1701652.	1309225.	119224.	285117.	60767.	40849.	4677611.
2002	87840.	56873.	110500.	206772.	353119.	146047.	843457.	2152943.	805936.	149005.	75302.	65050.	5052844.
2003	52852.	95219.	310404.	451163.	477511.	216245.	1214157.	3257533.	1660749.	234827.	274870.	122481.	8368011.
2004	51615.	103392.	184406.	139388.	256836.	427260.	2413013.	1137994.	772517.	151154.	68182.	63487.	5769244.
2005	42672.	37915.	120593.	292661.	165609.	453117.	1096907.	1518505.	785435.	300072.	134746.	55869.	5004101.
2006	42216.	42797.	56194.	277222.	317349.	519513.	4003101.	453613.	164132.	286094.	167955.	75099.	6405285.
2007	47534.	41993.	161355.	249790.	322558.	124958.	593046.	2511358.	1387791.	282122.	90111.	47534.	5860150.
2008	40697.	36772.	84302.	167577.	155386.	250021.	2075456.	1789579.	502436.	90423.	52029.	43041.	5287719.
2009	39503.	83515.	161811.	205196.	226991.	767896.	2770733.	1661650.	260901.	88839.	228806.	73558.	6569399.
2010	48120.	62480.	211667.	221307.	354834.	245400.	662915.	2022539.	2230926.	336450.	85427.	50616.	6532681.
2011	42455.	38739.	92094.	238111.	567217.	1091014.	3929130.	1230545.	201206.	122633.	109624.	189702.	7852470.
2012	56498.	40427.	123241.	498361.	152282.	85742.	1042557.	1342195.	790161.	291607.	292052.	119356.	4834479.
2013	66548.	147799.	441632.	297597.	236237.	142812.	3899416.	1184964.	585616.	243400.	103533.	108959.	7458513.
2014	65202.	74732.	171904.	94039.	100776.	65766.	199513.	598994.	578978.	152760.	72572.	58473.	2233709.
2015	40567.	53854.	133486.	297807.	105443.	53331.	1111536.	537264.	118488.	84888.	391006.	204331.	3132001.
2016	70672.	125564.	388281.	307805.	306996.	92127.	2052644.	294754.	246933.	372393.	72341.	121223.	4451733.
2017	108113.	46384.	104271.	269030.	65571.	49719.	2191643.	1805815.	311922.	135439.	68455.	38418.	5194780.
MEAN	56922.	66881.	210198.	287128.	280239.	319556.	1409086.	1424281.	764056.	218358.	142519.	89268.	5268493.

4.1.3 Reservoirs

There are 92 reservoirs, not included in the WAM dataset, in the North Han River Basin. The 87 small reservoirs which have less than 1,500 acer-feet are used for irrigation purpose and remainder 5 largest reservoirs are used for water supply and hydropower generation. The Soyang multi-purpose dam operated by K-water is the only reservoir in the basin that have a combined conservation and flood control storage capacity. The four hydropower reservoirs operated by Korea Hydro and Nuclear Power (KHNP) have been used for only power generation purpose.

The one multi-purpose dam and four hydropower dams in the North Han River WAM are listed in the water rights summary of Table 4.4. Their locations are also shown in Figure 4.2. The totals for the entire dataset are shown at the bottom of Table 4.4. The diversion targets associated with the Soyang reservoirs account for about 86.0 percent of the total diversion amounts for the North Han River WAM dataset. The 5 largest reservoirs contain about 99.6 percent of the conservation storage capacity and 100% of flood control storage capacity and hydropower generation.

Table 4.4 Reservoirs in the North Han River Basin

Reservoir	Reservoir Identifier	Control Point	Conservation Capacity (Ac-ft)	Diversion Target (Ac-ft/year)	Energy Target (kWh/year)
Korea Hydropower and Nuclear Co.					
Hwacheon	HWACHN	NHHW03	825,284	-	227,100
Chuncheon	CHNCHN	NHSA05	112,734	-	129,700
Uiam	UIAMDM	NHUI11	65,493	-	145,400
Cheongpyeong	CHEPYE	NHCH14	125,484	-	264,400
Korea Water Resources Corporation					
Soyang	SOYANG	SYCC08	2,029,036	1,022,830	28,500
Storage Capacity Totals					
Total for 5 reservoirs			3,369,486	1,022,830	795,100
Percentage 5 Reservoir vs. Basin			99.6	86.0	100.0
Total for the entire river basin			3,382,476	1,189,001	795,100

4.1.4 Evaporation-Precipitation Rates for Reservoirs

In Korea, evaporation has been measured at 16 stations nationwide by the Korea Meteorological Administration since 1964. There are two measurement stations which are Chuncheon station with station code 1010101 and Inje station with station code 1010211 in the study area. Chuncheon and Inje stations have measured monthly evaporation rates from Jan. 1966 to Mar. 2017 and from Jan. 1973 to Dec. 1990, respectively. Monthly average evaporation rates of two stations in mm during period of measurement are presented in Table 4.5.

Table 4.5 Monthly Average Evaporation Rates of Chuncheon and Inje Station

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Chuncheon	31.7	40.5	72.3	116.5	140.1	140.2	121.6	122	95.1	68.9	41.2	32.1
Inje	33.5	37.8	72.2	130.3	155	142.8	116.2	126	95.4	76.7	46.7	37.6

The most widely applied technique for estimating lake evaporation involves combining pan evaporation measurements and pan coefficient (Wurbs 2002). Unfortunately, there is no evaporation measurement in the five reservoirs and both stations does not produce evaporation measurement data any more. Thus, Penman-Monteith equation described in Chapter II Eq. 2.21 was applied for calculating of daily reservoir evapotranspiration

As shown in Eq. 2.21, the Penman-Monteith equation are required for weather data based on meteorological measurements such as maximum and minimum temperature, dew point, wind speed, and solar radiation. Based on Eq. 2.21 and meteorological data obtaining from KMA, reservoir evaporation rates for five largest reservoirs are calculated. The calculation process followed the ASCE standardized reference Evapotranspiration equation guideline. The KMA meteorological measuring stations in the study area are shown in Figure 4.4.

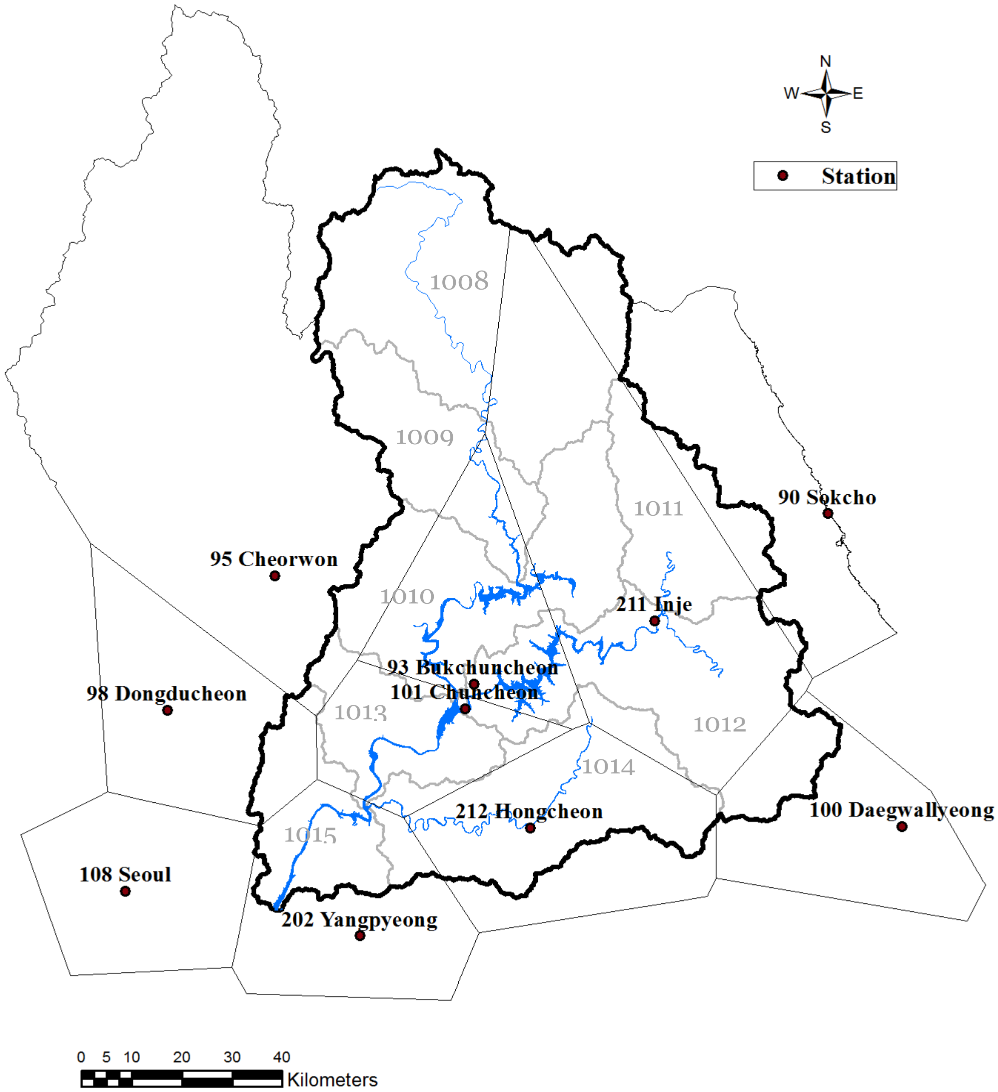


Figure 4.4 Measuring Station Thiessen Network in the North Han River Basin

The WRAP/WAM Input dataset contain EV records with sequence of monthly net reservoir surface evaporation-precipitation depths. The monthly net reservoir surface evaporation-precipitation depths in inches from January 1966 to December 2017 for the 5 reservoirs in North Han River EVA files tabulated in Appendix C.2 and net reservoir evaporation-precipitation for Soyang reservoir (SYCC08) presented in Table 4.6

Table 4.6 Reservoir Net Evaporation-Precipitation for Soyang Reservoir (SYCC08)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	0.0350	−0.0050	−0.0810	0.1640	0.2340	−0.5850	−2.2540	−0.1710	−0.3670	−0.1130	−0.0690	0.0320	−3.1800
1967	−0.0260	−0.0380	−0.0040	0.1030	0.2280	0.0530	−0.7760	−0.4610	−0.0950	0.1130	−0.0260	0.0410	−0.8880
1968	0.0440	0.0770	0.0310	0.2740	0.2800	0.1310	−0.4850	−0.8150	−0.0360	−0.5460	−0.0190	0.0540	−1.0100
1969	−0.1320	0.0190	0.1250	−0.2900	−0.0600	0.2220	−0.9440	−1.0230	−0.2270	0.1830	0.0560	0.0390	−2.0320
1970	0.0440	0.0160	0.1410	0.3280	0.2360	−0.1000	−0.9590	−0.5580	−1.1030	−0.0550	−0.0430	0.0110	−2.0420
1971	0.0060	−0.0280	0.0330	0.1530	0.0990	−0.1270	−0.5760	−0.5020	−0.0940	0.1460	0.0570	−0.0140	−0.8470
1972	−0.2080	0.0570	0.0570	0.1620	0.2270	0.3970	0.1230	−1.8800	−0.1200	0.0130	−0.1540	0.0160	−1.3100
1973	−0.0420	0.1090	0.1610	0.0510	0.0990	0.0810	0.0560	−0.3570	−0.1580	0.0950	0.0260	0.0460	0.1670
1974	0.0380	0.0370	0.0700	−0.0700	−0.2690	0.2200	−0.3030	−0.4060	0.0150	0.0250	0.0570	0.0310	−0.5550
1975	0.0470	0.0650	0.0700	0.0730	0.1420	0.0800	−1.4120	−0.0090	−0.4060	0.1030	0.0320	0.0170	−1.1980
1976	0.0510	−0.1590	0.1750	0.1720	0.2620	0.2160	−0.0950	−1.2920	0.0890	0.0270	0.0180	−0.0150	−0.5510
1977	0.0520	0.1080	0.1370	−0.3170	0.2170	0.2870	−0.3640	−0.1030	0.1210	0.1010	−0.1620	−0.0670	0.0100
1978	0.0210	−0.0500	−0.0060	0.2310	0.3420	−1.0410	−0.2930	−0.8570	0.0650	0.0190	0.0660	−0.0430	−1.5460
1979	0.0220	0.0260	0.0060	−0.1790	0.0460	−0.8300	−0.1670	−0.6090	0.1030	0.1160	0.0640	−0.0410	−1.4430
1980	0.0220	0.1020	0.1500	−0.3110	0.2040	0.1850	−0.6530	−0.2390	0.0160	0.0830	0.0340	−0.0430	−0.4500
1981	−0.0140	0.0540	0.0730	0.1100	−0.0660	−0.2640	−1.4290	−0.5110	−0.5360	0.0560	−0.0200	0.0370	−2.5100
1982	−0.0170	0.0880	0.0670	0.2890	−0.2730	0.3020	−0.0140	−0.7100	0.2970	0.0850	−0.2870	−0.0650	−0.2380
1983	0.0300	0.0340	0.0150	−0.0440	0.2810	0.3300	−0.9770	−0.0680	−0.2440	−0.0350	0.0360	0.0280	−0.6140
1984	0.0150	0.0500	0.0980	0.0780	0.1940	0.0070	−0.6730	−0.6510	−1.2170	0.1490	0.0010	−0.0160	−1.9650
1985	0.0030	0.0520	0.0690	0.1180	−0.0090	0.3090	0.0080	−0.2910	−0.4820	−0.1920	−0.0230	−0.0020	−0.4400
1986	0.0410	0.0790	0.1390	0.1960	0.2510	0.0590	−0.2060	−0.4940	−0.0810	−0.0770	0.0190	0.0090	−0.0650
1987	0.0100	0.0290	0.1310	0.2030	0.1510	0.0510	−0.7090	−1.1680	0.2130	0.1550	−0.0590	0.0680	−0.9250
1988	0.0740	0.1010	0.1500	0.1730	0.2720	0.1570	−1.1380	0.2090	0.0800	0.1660	0.0420	0.0520	0.3380
1989	−0.0170	0.0560	0.0310	0.3040	0.2740	0.1240	−0.7090	−0.1740	−0.1270	0.0300	−0.2350	0.0560	−0.3870
1990	0.0020	−0.0130	0.0850	0.0520	−0.0970	−0.8350	−1.1730	−0.4680	−1.5380	0.1480	−0.0410	0.0280	−3.8500
1991	0.0330	0.0510	0.1410	0.1280	0.1110	0.2460	−1.2480	0.1710	−0.2190	0.1310	0.0490	−0.0070	−0.4130
1992	0.0370	0.0260	0.1780	0.1540	−0.0220	0.1830	−0.0060	−0.6840	−0.1630	0.0460	−0.0200	−0.0720	−0.3430
1993	0.0250	−0.0460	0.1020	0.0270	−0.2230	−0.1910	−0.5680	−0.3090	0.1590	0.1340	−0.0630	0.0000	−0.9530
1994	0.0040	0.0820	0.1280	0.1960	−0.0180	0.0450	0.0380	−0.2730	0.1260	−0.2700	−0.0420	0.0290	0.0450
1995	0.0510	0.0720	0.0690	0.2050	0.2740	0.2350	−0.8590	−2.3130	0.0620	0.0710	0.0250	0.0480	−2.0600
1996	0.0050	0.0750	−0.0290	0.0920	0.3130	−0.2850	−0.9410	0.1330	0.2210	−0.0060	−0.0370	−0.0260	−0.4850
1997	−0.0050	−0.0170	0.1180	0.1870	−0.6390	−0.1650	−0.3720	0.0350	−0.2380	0.1170	−0.2060	−0.0520	−1.2370
1998	0.0440	0.0000	0.1230	−0.0830	0.0850	−0.1620	−0.6680	−1.4380	−0.0220	0.0760	−0.0580	0.0330	−2.0700
1999	0.0560	0.0990	0.0220	0.0370	0.0850	0.1260	−0.5820	−1.3120	−0.7960	−0.1960	0.0490	0.0310	−2.3810
2000	−0.0180	0.0830	0.1100	0.1690	0.0000	0.0400	−0.2370	−1.0690	−0.1810	0.1130	−0.0120	−0.0010	−1.0030
2001	−0.0050	0.0120	0.1640	0.2910	0.4040	−0.2390	−1.0460	0.1350	0.2550	−0.0730	0.0600	0.0340	−0.0080
2002	−0.0740	0.1030	0.1540	−0.0950	0.1970	0.1620	−0.3060	−1.3030	0.0910	−0.0130	0.0770	−0.0300	−1.0370
2003	−0.0110	−0.0260	0.0950	−0.1610	0.0450	0.0190	−0.5600	−1.4230	−0.7150	0.0700	−0.0920	0.0440	−2.7150
2004	0.0580	−0.0210	0.1940	0.1570	−0.0500	−0.0710	−1.2810	−0.3630	−0.4180	0.2020	−0.0240	0.0110	−1.6060
2005	0.0750	0.0450	0.1400	0.0840	0.1670	−0.0910	−0.4540	−0.6110	−0.3740	0.0770	0.0050	0.0680	−0.8690
2006	−0.0070	0.0780	0.1710	0.0560	0.0200	−0.1920	−2.3380	0.1100	0.2370	−0.0490	−0.0480	0.0350	−1.9270
2007	0.0720	0.0930	−0.0730	0.1640	−0.0170	0.2450	−0.2750	−1.0650	−0.6980	0.1150	0.0450	0.0500	−1.3440
2008	0.0470	0.0900	0.0530	0.1970	0.0670	−0.0140	−1.2090	−0.4790	0.0310	0.1100	0.0700	0.0030	−1.0340
2009	0.0720	0.0540	0.0240	0.0930	0.0850	−0.1640	−1.4090	−0.6830	0.2240	0.0640	−0.0590	0.0360	−1.6630
2010	−0.0010	0.0210	0.0170	0.0460	0.0290	0.2810	−0.3010	−0.9900	−1.0680	0.0740	0.0560	0.0220	−1.8140
2011	0.0560	−0.0080	0.1290	−0.1610	−0.0580	−0.9710	−2.3790	−0.1450	0.0580	0.1020	−0.1150	0.0120	−3.4800
2012	0.0580	0.1040	0.0660	−0.1130	0.3120	0.0970	−0.4330	−0.6440	−0.1760	−0.0090	−0.0870	−0.0430	−0.8680
2013	−0.0090	−0.0680	0.0810	0.0660	0.1350	0.1630	−2.0060	−0.1430	−0.2260	0.1670	−0.0590	−0.0140	−1.9130
2014	0.0510	0.0460	0.1880	0.2070	0.2950	0.1510	0.0470	−0.2540	−0.0690	0.0020	0.0340	0.0400	0.7380
2015	0.0270	0.0300	0.2000	0.0000	0.3510	0.2220	−0.4700	0.1120	0.2290	0.0010	−0.3410	0.0040	0.3650
2016	0.0810	−0.0650	0.0610	0.0310	0.0520	0.2510	−1.3770	0.2030	0.0890	−0.1040	0.0620	−0.1840	−0.9000
2017	0.0470	0.0640	0.1120	0.1590	0.3700	0.2670	−1.0010	−0.8970	0.2010	0.0370	0.0480	0.0010	−0.5920
MEAN	0.0167	0.0354	0.0896	0.0799	0.1084	−0.0074	−0.7377	−0.5598	−0.1772	0.0343	−0.0252	0.0064	−1.1365

4.1.5 Water Rights

With respect to water right in Korea, there is no accurate data on water users and permit amounts, except for large-scale withdrawals from large multi-purpose dam managed by K-water or major rivers managed by MOLIT. One of the most important components in the input dataset of WRAP/WAM system is the water right and its allocation based on the priority. In this study, two types of water rights are considered based on data managed by Flood Control Office of MOLIT. One is the legal water rights authorized through permit process under the River Act enacted in1961 and the Act on Construction of Dams and Assistance, etc. to Their Environs enacted in 1999. The other is the exiting riparian rights that have been appropriated some amount of streamflow prior to River Act and dam construction.

The North Han River WRAP/WAM input dataset contains 42 water rights on WR records and 8 instream flow rights on IF records listed in Table 4.8. Of the 42 water rights, 9 rights were recognized as existing rights, and the remaining 33 rights were granted by Flood Control Office of MOLIT. Total annual diversion target for water rights in the North Han River WAM input DAT file is 1,189,001 acre-feet/year. Diversion target for control points are listed in Table 4.7.

The North Han River water rights consist of 5 hydropower, 12 municipal, 7 industrial, 13 irrigation water uses, and 5 reservoir refill rights. In terms of water use types, 94.0 percent (1,118,540 acre-feet/year) of the total diversion targets is the municipal water use. Industrial and irrigation water uses refer to 1.0 percent (13,853 acre-feet/year) and 5 percent (56,658 acre-feet/year) of the total target amounts, respectively. Total energy generation targets for five hydropower dam such as Hwacheon (WR-4), Chuncheon (WR-10), Soyang (WR-14), Uiam (WR-20), and Cheongpyeong (WR-34) are 795.1GWh/year.

The water rights in the North Han River WAM dataset contain 8 IF rights representing environmental streamflow requirements. Two instream flow rights (IF-2, IF-5) was set a minimum requirement, if necessary, upstream reservoirs will release to meet instream flow targets. In case of the remaining six instream flow rights, the upstream reservoirs pass inflow but does not make a releases from the storages to meet the instream flow targets.

The priority of each water right is based on date of permit issue. The water users who have been using water from the river before the dam construction will be granted their right to use with higher priority than recently granted water rights. These rights are categorized as the vested rights. In case of the vested right, the priority is set to Dec.29, 1961 which is a day before the effective day of the River Act. The priority numbers for four hydropower dams have their completion date of construction.

The most senior right is the hydropower right granted to Cheongpyeong dam (Jul. 1, 1943) while most junior rights are instream flow rights issued at Soyang river, Hongcheon river, and downstream of Cheonhpyeong dam (Sep. 30, 2015). The largest amount of a single right is 978,630 acre-feet/year at control point (NHGW15) which is a location of intake facility suppling water to Seoul. The smallest one is 56 acre-feet/year for municipal water use at downstream of the Peace dam.

Table 4.7 Water Rights Input Data Summary by Control Points

CONTROL POINT	NUMBER OF RIGHTS	PERMITTED DIVERSIONS (AC-FT/YR)	NUMBER OF RESERVOIRS	RESERVOIR STORAGE (AC-FT)	PRIORITIES RANGE FROM	PRIORITIES RANGE TO
NHYA01	1	56.	0	0.	20110524	20110524
YGSE02	2	1552.	0	0.	20060523	20080324
NHHW03	2	0.	1	825284.	19440501	99999999
NHHA04	4	4335.	0	0.	19860526	20091027
NHSA05	2	0.	1	112734.	19650101	99999999
SYBU06	1	2907.	0	0.	19611229	19611229
SYIN07	1	2373.	0	0.	19611229	19611229
SYCC08	3	15418.	1	2240491.	19740101	99999999
NHSE10	3	16909.	0	0.	19611229	19980506
NHUI11	2	0.	1	65493.	19670801	99999999
NHGA12	5	18708.	0	0.	19611229	20080912
HOSO13	7	22142.	0	0.	19960918	20100701
NHCH14	2	0.	1	125484.	19430701	99999999
NHGW15	7	1104601.	0	0.	19820702	20040128
SUM	42	1189001.	5	3369486.	19430701	99999999

Table 4.8 Water Rights contained in the North Han River WAM Input Dataset

Water Right No.	Control Points	Annual Target (ac-feet/year)	Water Use Type	UC Record	WR Type	Priority
WR-1	NHYA01	56	Municipal	MUN1	Permitted	2011-05-24
WR-2	YGSE02	1,080	Industrial	IND1	Permitted	2008-03-24
WR-3	YGSE02	472	Irrigation	IRR1	Permitted	2006-05-23
WR-4	NHHW03	227,100	Hydropower	POW2	Existing	1944-05-01
WR-5	NHHW03		Refill			
WR-6	NHHA04	2,000	Municipal	MUN1	Permitted	2001-04-23
WR-7	NHHA04	887	Municipal	MUN1	Permitted	2008-12-17
WR-8	NHHA04	213	Industrial	IND1	Permitted	2009-10-27
WR-9	NHHA04	1,235	Irrigation	IRR1	Permitted	1986-05-26
WR-10	NHSA05	129,700	Hydropower	POW3	Existing	1965-01-01
WR-11	NHSA05		Refill			
WR-12	SYBU06	2,907	Irrigation	IRR1	Existing	1961-12-29
WR-13	SYIN07	2,373	Irrigation	IRR1	Existing	1961-12-29
WR-14	SYCC08	28,500	Hydropower	POW1	Existing	1974-01-01
WR-15	SYCC08		Refill			
WR-16	SYCJ09	15,418	Irrigation	IRR1	Permitted	1996-07-11
WR-17	NHSE10	185	Irrigation	IRR1	Permitted	1998-05-06
WR-18	NHSE10	2,721	Irrigation	IRR1	Permitted	1996-07-11
WR-19	NHSE10	14,003	Irrigation	IRR1	Existing	1961-12-29
WR-20	NHUI11	145,400	Hydropower	POW4	Existing	1967-08-01
WR-21	NHUI11		Refill			
WR-22	NHGA12	887	Municipal	MUN1	Permitted	2001-10-23
WR-23	NHGA12	611	Industrial	IND1	Permitted	1992-10-19
WR-24	NHGA12	2,751	Industrial	IND1	Permitted	2008-09-12
WR-25	NHGA12	242	Irrigation	IRR1	Permitted	1981-11-12
WR-26	NHGA12	14,226	Irrigation	IRR1	Existing	1961-12-29
WR-27	HOSO13	9,761	Municipal	MUN1	Permitted	2000-01-01
WR-28	HOSO13	2,927	Municipal	MUN1	Permitted	2004-08-27
WR-29	HOSO13	5,187	Industrial	IND1	Permitted	1996-09-18
WR-30	HOSO13	1,389	Industrial	IND1	Permitted	2010-07-01
WR-31	HOSO13	812	Irrigation	IRR1	Permitted	2004-03-06
WR-32	HOSO13	717	Irrigation	IRR1	Permitted	2006-03-08
WR-33	HOSO13	1,349	Irrigation	IRR1	Permitted	2000-01-01
WR-34	NHCH14	264,400	Hydropower	POW5	Existing	1943-07-01
WR-35	NHCH14		Refill			
WR-36	NHGW15	4,437	Municipal	MUN1	Permitted	1982-07-02
WR-37	NHGW15	7,809	Municipal	MUN1	Permitted	1989-06-07
WR-38	NHGW15	97,609	Municipal	MUN1	Permitted	1996-10-15
WR-39	NHGW15	1,479	Municipal	MUN1	Permitted	1997-09-22
WR-40	NHGW15	17,008	Municipal	MUN1	Permitted	1998-04-06
WR-41	SYCJ09	973,680	Municipal	MUN1	Permitted	1998-05-06
WR-42	NHGW15	2,579	Industrial	IND1	Permitted	2004-01-28
IF-1	NHHA04	118579	Instream Flow	INF1	Permitted	2015-09-30
IF-2	SYCJ09	66701	Instream Flow	INF1	Permitted	2007-04-30
IF-3	SYCJ09	269104	Instream Flow	INF1	Permitted	2015-09-30
IF-4	NHSAE10	132891	Instream Flow	INF1	Permitted	2015-09-30
IF-5	NHGA12	431384	Instream Flow	INF1	Permitted	2007-04-30
IF-6	NHGA12	488885	Instream Flow	INF1	Permitted	2015-09-30
IF-7	HOSO13	38334	Instream Flow	INF1	Permitted	2015-09-30
IF-8	NHGW15	244826	Instream Flow	INF1	Permitted	2015-09-30

4.2 Establishment of Water Right Allocation Strategy

4.2.1 Organization of Scenarios for Simulation

For the WRAP/WAM simulation studies, the input dataset which are the sequences of naturalized flows and reservoir evaporation-precipitation rates for 1966-2017 monthly hydrologic period-of-analysis and water rights were developed in the previous section 4.1.1-4.1.5. Along with compiling the WRAP input dataset, alternative scenarios for the simulation study are consisted of reflecting combinations of premises regarding water right priority, water management policy, and reservoir operation as shown in Table 4.9.

In this study, the simulations are performed based on two alternative perspectives. The long-term simulations of two alternative approaches with 4 scenarios are carried out for evaluating the possibility of introducing the Texas WRAP/WAM priority system to water right permit system and water management and planning in Korea. The results of the long-term simulation for 1966-2017 hydrologic period-of-analysis in the North Han River Basin are compared an existing natural upstream-to-downstream priority with 1) a newly assigned prior appropriation system based on the priority of each water right. 2) In order to diminish water shortage in the river basin, 5 large reservoirs including four run of river type hydropower dams are considered employing multiple reservoir operation rule.

The short-term simulation is focused on securing municipal water requirements during severe drought. The principles of short-term water allocation strategy established in this study are considered 1) hydropower dams contribute to meeting some portion of water supply if water shortages for municipal water supply will occur and 2) water demand management based on reduction of water use for municipal, industrial, and irrigation is needed for drought management.

In all scenarios of simulation, term permits are included and the return flow are assumed full reuses with no return and reservoir storage capacities are reflected no sedimentation accumulation.

Table 4.9 Scenarios for Long-term and short-term simulation

Simulation	Alternative	Concept	Scenario No.	Description
Long-term	Original	No priority	SC-1	Upstream-to-downstream
	Alt. 1	Priority system	SC-2	Priority based on date of permit issue
			SC-3	Municipal-Industrial-Irrigation-Instream flow-Hydropower priority
	Alt. 2	Reallocation to hydropower	SC-4	Multiple Reservoirs System Operation
Short-term	Original	No priority	SC-5	Upstream-to-downstream
	Alt.3	Reallocation to hydropower	Sc-6	Soyang FY+ 4 hydropower based on forced distribution (Three Cases)
	Alt. 4	Water demand management (reduction)	SC-7	Reduction water use (10 to 20%)
			SC-8	Reduction refer to reservoir storage with Drought Index (Three cases)

4.2.2 Long-term Simulations

<u>Comparison Natural Priority vs. WRAP Priority System</u>

The most severe drought in the North Han River Basin during 1966-2017 period-of analysis occurred in 2014. The drought was lasting to 2017. The 1973-1977 and 1991-1994 are second and third severe drought during the period of analysis in the North Han River basin. The most severe drought for two consecutive years occurred in 2014-2015.

The main concern of long-term simulation is to propose an effective way to resolve the conflicts between upstream and downstream users associated with water use and distribution based on Texas WRAP/WAM priority system. The long-term simulation with the North Han River WRAP/WAM dataset for 1966-2017 hydrologic period-of-analysis including several severe droughts were conducted to evaluate water availability and reliability of water supply based on two alternative approaches with four scenarios as shown in Table 4.9. The simulations based on each scenario begin with all reservoir storages set to full capacities.

Alternative 1 with scenario 2 is based on Texas WRAP/WAM priority system. In the Texas WAM System, priorities are based on seniority dates specified in the water right permits. The scenario 2 gives priority to each water right based on date authorized from MOLIT. The WRAP is an accounting system for tracking stream flow sequences, subject to reservoir storage capacities and operating rules and water supply diversion, hydroelectric power, and instream flow requirements.

The simulation results are compared scenario 1 conventional upstream-to-downstream priority system in Korea with Texas WRAP/WAM priority system defined in scenario 2. Water diversion shortages, reliability for water right, control point, and hydropower, and frequency of flows and reservoir storages are examined with both scenarios. The annual summary for the North Han River Basin with scenarios 1 and scenario 2 were compared in Table 4.10.

Table 4.10 Comparison of Results for Annual Basin Summary of Scenario 1 and 2

Year	Naturalized Flows (AC-FT)	Annual Diversion Targets (AC-FT)	Scenario 1 (Natural Priority) Streamflows Depletion (AC-FT)	Scenario 1 (Natural Priority) Unappropriated Flows (AC-FT)	Scenario 1 (Natural Priority) Diversion Shortages (AC-FT)	Scenario 2 (WRAP Priority) Streamflows Depletion (AC-FT)	Scenario 2 (WRAP Priority) Unappropriated Flows (AC-FT)	Scenario 2 (WRAP Priority) Diversion Shortages (AC-FT)
1966	9,263,235	1,189,001	1,632,099	8,537,645	-	1,083,900	8,426,155	-
1967	5,043,054	1,189,001	2,149,982	3,773,964	-	1,286,390	3,775,297	-
1968	4,939,045	1,189,001	2,882,676	3,292,255	-	1,799,835	3,240,098	-
1969	7,275,722	1,189,001	2,084,523	6,183,788	-	1,399,316	6,238,325	-
1970	6,713,932	1,189,001	2,553,880	5,205,839	-	1,558,770	5,209,413	-
1971	4,284,883	1,189,001	2,678,970	3,062,696	-	1,527,315	3,050,145	-
1972	6,748,702	1,189,001	2,564,041	5,194,716	-	1,808,934	5,203,496	-
1973	3,321,637	1,189,001	2,327,811	2,300,914	-	1,416,718	2,268,984	-
1974	4,296,018	1,189,001	2,819,130	2,867,290	-	1,859,714	2,834,541	-
1975	5,206,699	1,189,001	2,884,103	3,493,138	-	1,689,864	3,563,680	-
1976	4,433,538	1,189,001	2,815,833	3,009,554	-	1,818,168	2,976,477	-
1977	3,267,893	1,189,001	2,735,902	2,162,427	-	1,626,877	2,127,804	-
1978	6,703,679	1,189,001	2,580,377	4,992,680	-	1,630,867	5,026,321	-
1979	5,847,090	1,189,001	2,211,875	4,726,880	-	1,473,619	4,733,269	-
1980	3,792,592	1,189,001	2,890,721	2,490,924	-	1,844,802	2,453,616	-
1981	7,506,623	1,189,001	2,722,226	5,807,494	-	1,647,394	5,874,177	-
1982	3,680,093	1,189,001	2,800,932	2,326,873	-	1,812,335	2,290,830	-
1983	4,506,880	1,189,001	2,570,872	3,067,291	-	1,582,804	3,108,064	-
1984	6,097,250	1,189,001	2,712,096	4,712,607	-	1,654,403	4,706,589	-
1985	4,555,431	1,189,001	2,957,551	3,068,029	-	2,139,404	3,043,535	-
1986	3,962,446	1,189,001	2,590,136	2,649,317	-	1,619,449	2,610,338	-
1987	6,368,054	1,189,001	2,180,403	5,018,926	-	1,206,103	5,089,217	-
1988	2,781,251	1,189,001	2,297,970	2,502,496	-	1,457,436	2,391,260	-
1989	4,854,288	1,189,001	2,997,664	3,158,649	333,140	2,105,449	3,386,530	451,643
1990	10,305,500	1,189,001	2,686,299	8,366,918	-	1,761,853	8,372,295	-
1991	4,127,761	1,189,001	2,749,886	2,799,381	-	1,663,491	2,798,137	-
1992	3,980,198	1,189,001	2,860,586	2,491,674	-	1,955,592	2,465,774	-
1993	4,858,965	1,189,001	2,448,578	3,669,719	-	1,641,212	3,664,844	-
1994	3,507,437	1,189,001	2,755,760	2,236,487	-	1,671,785	2,204,172	-
1995	6,772,346	1,189,001	3,199,829	5,151,095	87,183	1,853,038	5,132,316	-
1996	4,073,886	1,189,001	2,669,717	2,949,761	-	1,661,566	2,943,073	-
1997	5,596,211	1,189,001	2,892,394	3,745,208	-	2,106,303	3,746,155	-
1998	7,948,319	1,189,001	1,964,587	6,619,562	-	1,445,330	6,602,381	-
1999	7,542,246	1,189,001	2,428,860	6,113,080	-	1,450,176	6,140,527	-
2000	4,814,133	1,189,001	2,493,541	3,593,763	-	1,490,017	3,593,844	-
2001	4,733,913	1,189,001	2,324,548	3,506,345	-	1,394,559	3,474,284	-
2002	5,186,941	1,189,001	2,597,776	3,626,672	-	1,558,630	3,659,326	-
2003	9,104,249	1,189,001	2,086,434	7,579,831	-	1,467,883	7,580,517	-
2004	6,238,589	1,189,001	2,075,339	5,042,010	-	1,215,893	5,043,143	-
2005	5,744,188	1,189,001	2,473,162	4,239,023	-	1,541,852	4,240,319	-
2006	6,939,178	1,189,001	2,554,833	5,736,348	-	1,666,718	5,706,610	-
2007	6,026,024	1,189,001	2,614,380	4,556,443	-	1,669,842	4,589,908	-
2008	5,516,463	1,189,001	2,420,730	4,231,779	-	1,393,173	4,227,676	-
2009	6,648,918	1,189,001	2,408,172	5,249,040	-	1,495,811	5,218,805	-
2010	6,825,929	1,189,001	2,502,079	5,363,691	-	1,578,146	5,402,069	-
2011	9,069,229	1,189,001	2,187,672	7,820,540	-	1,359,683	7,783,188	-
2012	5,513,455	1,189,001	2,506,398	3,956,483	-	1,571,046	3,992,780	-
2013	7,774,704	1,189,001	2,224,839	6,494,934	-	1,175,727	6,493,763	-
2014	2,314,801	1,189,001	2,641,586	1,542,151	-	1,576,349	1,492,256	-
2015	2,844,092	1,189,001	2,782,850	1,949,117	157,982	1,869,600	1,649,843	-
2016	4,424,819	1,189,001	2,935,310	2,931,675	220,597	2,104,825	3,084,343	192,629
2017	5,079,669	1,189,001	3,105,645	3,375,214	86,595	1,946,252	3,218,464	-
MEAN	5,556,967	1,189,001	2,562,184	4,202,776	17,029	1,621,850	4,195,172	12,390

Table 4.11 Comparison of Reliability of Control Points for Scenario 1 and 2

Name	Target Div. (Ac-Ft/Yr)	Original (Natural Priority) *Scenario 1* Mean Shor. (Ac-Ft/Yr)	Reliability Period (%)	Reliability Volume (%)	Alternative 1(WRAP Priority) *Scenario 2* Mean Shor. (Ac-Ft/Yr)	Reliability Period (%)	Reliability Volume (%)
NHYA01	56		100	100		100	100
YGSE02	1,552		100	100		100	100
NHHW03	0						
NHHA04	4,335		100	100		100	100
NHSA05	0						
SYBU06	2,907		100	100		100	100
SYIN07	2,373		100	100		100	100
SYCC08	15,418		100	100		100	100
SYCJ09	0						
NHSE10	16,909		100	100		100	100
NHUI11	0						
NHGA12	18,708	4.0	99.98	99.8		100	100
HOSO13	22,142		100	100		100	100
NHCH14	0						
NHGW15	1,104,600	17,025	98.46	97.8	12,390	98.88	98.88
Total	1,189,000	17,029		98.57	12,390		98.96

Table 4.12 Comparison of Reliability of Hydropower for Scenario 1 and 2

Name	Energy Target (KWh/YR)	Original (Natural Priority) *Scenario 1* Mean Shortage (KWh/YR)	Reliability Period (%)	Reliability Volume (%)	Alternative 1(WRAP Priority) *Scenario 2* Mean Shortage (KWh/YR)	Reliability Period (%)	Reliability Volume (%)
HWACHN	227,100	-	100.0	100.0	-	100.0	100.0
CHUCHN	129,700	16,295	85.9	87.4	5,930	90.4	95.4
SOYANG	28,500	956	96.3	96.6	212	98.9	99.3
UIAMDM	145,400	49,578	14.9	65.9	20,340	42.6	86.0
CHEPYE	264,400	48,192	34.6	81.8	37,541	53.2	85.8
Total	795,100	115,022		85.53	64,024		91.95

As the results of simulation with scenario 1 and 2, diversion shortages occurred 5 years and 2 years during 1966-2017 period-of-simulation, respectively. The scenario 1 and scenario 2 could not meet annual diversion target during year 1989 and 2016. The mean annual diversion shortage of both scenarios are 17,029 acre-feet/year and 12,290 acre-feet/year, respectively. As shown in Table 4.11, most of diversion shortages of both scenarios 1 and 2 occurred at control point NHGW15 which is outlet of river basin with WR-38, WR-40, and WR-41. The reliability of control points for scenarios 1 and scenario 2 are 98.57 percent and 98.96 percent, respectively.

The reliability of energy generation for scenario 1 and scenario 2 are 85.53 percent and 91.95 percent, respectively. The scenario 2 was evaluated higher than reliability of conventional upstream-to-downstream priority as shown in Table 4.12. Even though four hydropower dams have not meet their annual energy targets in both scenario 1 and scenario 2, there were no drawdowns that water levels of reservoir were below the low water level of each hydropower dam.

With respect to reservoir storage reliability, scenario 2 is a more effective way to operate reservoirs during severe drought. As shown in Figure 4.5, Soyang reservoir, which is the only water supply reservoir in the North Han River Basin, have secured storage volumes during 1966-2017 period-of-simulation compared to the scenario 1. For the scenario 2, the periods of falling below the volume of low water level are also a little shorter than those of scenario 1. Reservoir storage volume of four hydropower dams during 1966-2017 period-of-simulation are plotted in Figure 4.6-4.9.

There are 8 instream flow rights in the North Han River WRAP/WAM dataset. Two IF rights, which are the downstream control point of Soyang reservoir (SYCJ09, IF-2) and Gangchon station (NHGA12, IF-5) were set to target amounts daily basis in April 2007. The rest of them were additionally announced by MOLIT in Sep. 2015. According to the simulation results, all scenarios met the instream flow requirements announced in 2007 during 1966-2017 period-of-simulation. However, some of six IF rights expanded in 2015 failed to meet their targets in both scenario 1 and scenario 2.

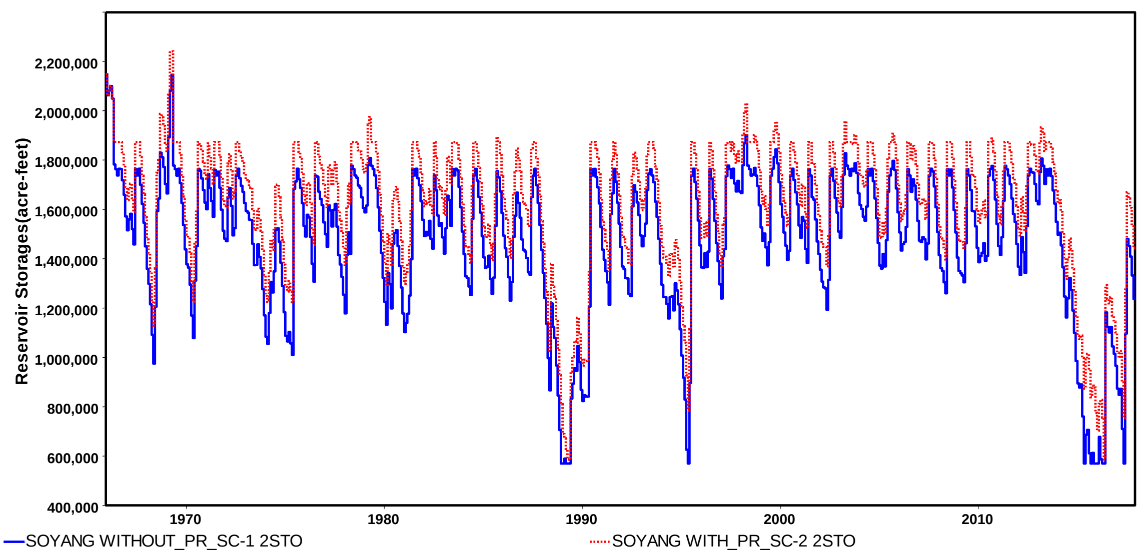


Figure 4.5 Scenario 1 and 2 Reservoir Storage Volumes at Soyang Reservoir

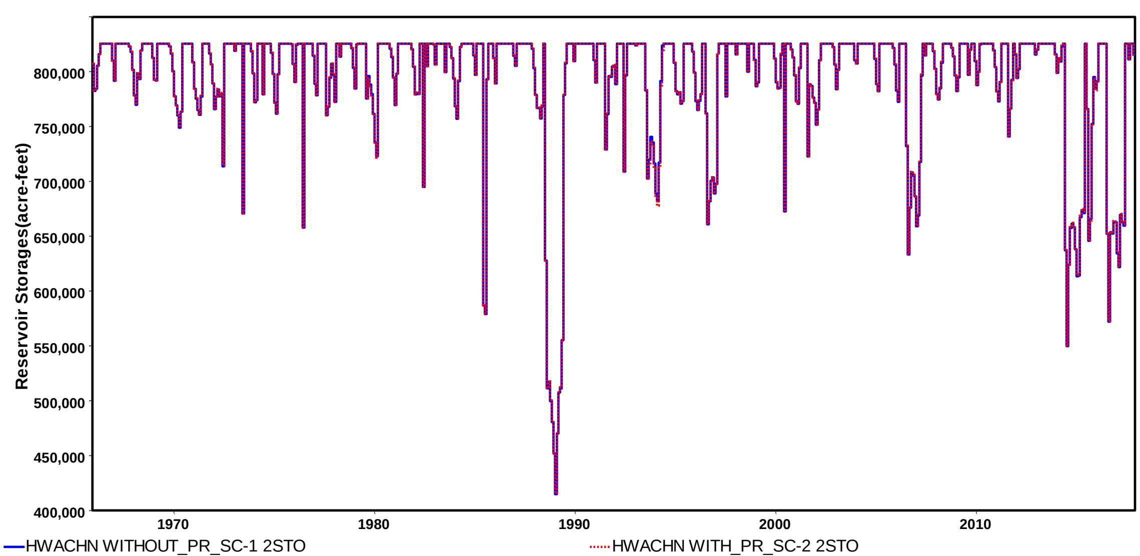


Figure 4.6 Scenario 1 and 2 Reservoir Storage Volumes at Hwacheon Reservoir

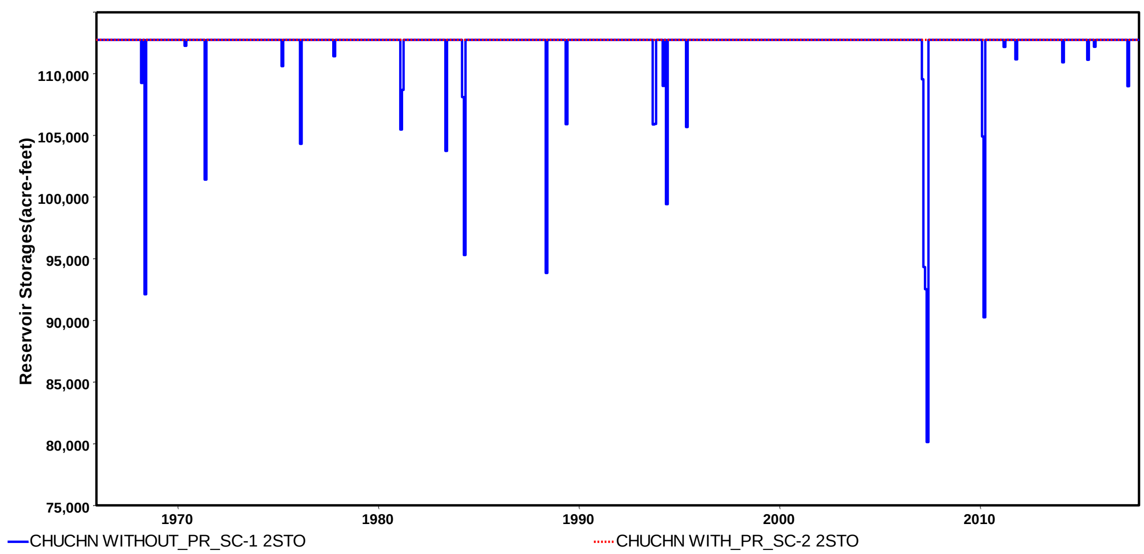


Figure 4.7 Scenario 1 and 2 Reservoir Storage Volumes at Chuncheon Reservoir

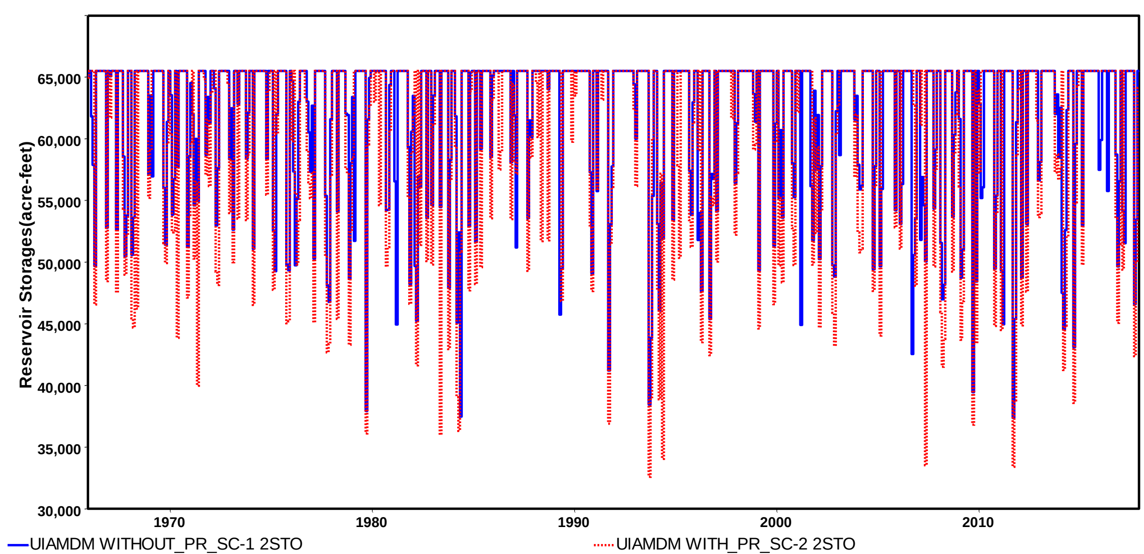


Figure 4.8 Scenario 1 and 2 Reservoir Storage Volumes at Uiam Reservoir

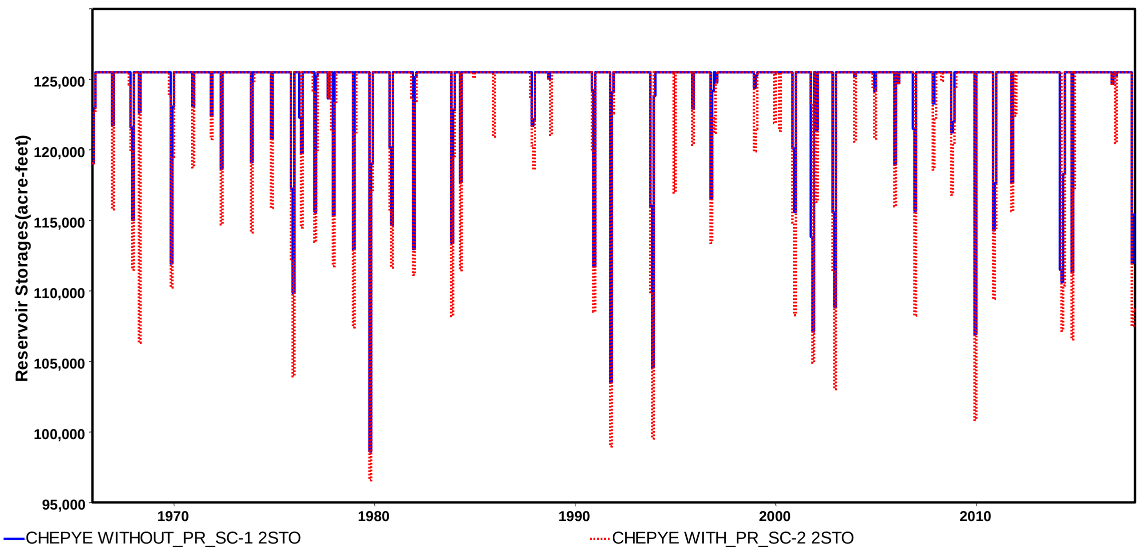


Figure 4.9 Scenario 1 and 2 Reservoir Storage Volumes at Cheongpyeong Reservoir

Alternative 1: Water Use Priority based on the River Act. in Korea

Alternative 1 with scenario 3 is also based on priority system. The difference is that scenario 2 introduces the priority system of Texas WRAP/WAM, whereas scenario 3 takes priority system in considering current situation in Korea. The scenario 2 gives priorities based on dates specified in the water right permits. Scenario 3 takes priorities considering types of water use in order of municipal, industrial, irrigation, instream flow, and hydropower provided in the River Act of Korea.

The simulation results of scenario 3 are also compared with the conventional upstream-to-downstream priority system in Korea. Water diversion shortages, reliability for water right, control point, and hydropower, and reservoir storages are examined with scenario 3. With respect to developing input data related priority of each water right, the program SIM allows to modify priority at once using UP record field 2 and 3 (Wurbs 2015b). A new priority entered on UP record field 2 and 3 supersede priority of WR record field 4 and 5. The priority number for the types of water use applied for scenario 3 are followed.

```
UP  MUN110000000
UP  IND115000000
UP  IRR122222222
UP  INF133333333
UP  POW188888888
UP  POW288888888
UP  POW388888888
UP  POW488888888
UP  POW588888888
```

The annual summary for the North Han River Basin with scenarios 3 are tabulated in Table 4.13. As the result of simulation with scenario 3, no diversion shortage occurred in scenario 3. The reliability for control points is presented in Table 4.14. As shown in Table 4.15, the reliability of energy generation for scenario 3 is 98.45 percent. The energy generation of Scenario 3 was increased than those of Scenario 1 and 2 because municipal, industrial, and irrigation water use are senior rights than hydropower rights due to new priority numbers defined in UP record. All diversions for senior water right are allowed to pass through the turbines to generate power for junior hydropower rights in program SIM of WRAP.

The reliabilities of reservoir storage for Soyang dam and four hydropower dams compared to scenario 2 were not different with four hydropower dams, but Soyang dam was operated with slightly higher reservoir storages during drought period. The reservoir storages of Soyang dam with scenario 3 for 1966-2017 period-of-simulation comparing with scenario 2 are illustrated in Figure 4.10. The reservoir storage volume results for four hydropower dams are almost the same as in scenario 2, and the figures are omitted in this chapter. For the instream flow targets with eight IF rights in the river basin, all instream flow requirements were satisfied except for IF-7 at control point HOSO13 in the Hongcheon River.

Table 4.13 Comparison of Results for Annual Basin Summary of Scenario 1 and 3

Year	Naturalized Flows (AC-FT)	Annual Diversion Targets (AC-FT)	Scenario 1 (Natural Priority)			Scenario 3 (Water Use Priority)		
			Streamflows Depletion (AC-FT)	Unappropriated Flows (AC-FT)	Diversion Shortages (AC-FT)	Streamflows Depletion (AC-FT)	Unappropriated Flows (AC-FT)	Diversion Shortages (AC-FT)
1966	9,263,235	1,189,001	1,632,099	8,537,645	-	1,083,900	8,409,122	-
1967	5,043,054	1,189,001	2,149,982	3,773,964	-	1,286,390	3,770,268	-
1968	4,939,045	1,189,001	2,882,676	3,292,255	-	1,799,835	3,189,374	-
1969	7,275,722	1,189,001	2,084,523	6,183,788	-	1,399,316	6,288,007	-
1970	6,713,932	1,189,001	2,553,880	5,205,839	-	1,558,770	5,215,158	-
1971	4,284,883	1,189,001	2,678,970	3,062,696	-	1,527,315	3,052,029	-
1972	6,748,702	1,189,001	2,564,041	5,194,716	-	1,808,934	5,219,606	-
1973	3,321,637	1,189,001	2,327,811	2,300,914	-	1,416,718	2,251,075	-
1974	4,296,018	1,189,001	2,819,130	2,867,290	-	1,859,714	2,777,509	-
1975	5,206,699	1,189,001	2,884,103	3,493,138	-	1,689,864	3,605,439	-
1976	4,433,538	1,189,001	2,815,833	3,009,554	-	1,818,168	3,001,898	-
1977	3,267,893	1,189,001	2,735,902	2,162,427	-	1,626,877	2,085,146	-
1978	6,703,679	1,189,001	2,580,377	4,992,680	-	1,630,867	5,055,895	-
1979	5,847,090	1,189,001	2,211,875	4,726,880	-	1,473,619	4,728,263	-
1980	3,792,592	1,189,001	2,890,721	2,490,924	-	1,844,802	2,363,294	-
1981	7,506,623	1,189,001	2,722,226	5,807,494	-	1,647,394	5,968,130	-
1982	3,680,093	1,189,001	2,800,932	2,326,873	-	1,812,335	2,299,841	-
1983	4,506,880	1,189,001	2,570,872	3,067,291	-	1,582,804	3,105,879	-
1984	6,097,250	1,189,001	2,712,096	4,712,607	-	1,654,403	4,718,372	-
1985	4,555,431	1,189,001	2,957,551	3,068,029	-	2,139,404	3,001,382	-
1986	3,962,446	1,189,001	2,590,136	2,649,317	-	1,619,449	2,579,192	-
1987	6,368,054	1,189,001	2,180,403	5,018,926	-	1,206,103	5,157,957	-
1988	2,781,251	1,189,001	2,297,970	2,502,496	-	1,457,436	2,170,481	-
1989	4,854,288	1,189,001	2,997,664	3,158,649	333,140	2,105,449	2,954,446	-
1990	10,305,500	1,189,001	2,686,299	8,366,918	-	1,761,853	8,557,624	-
1991	4,127,761	1,189,001	2,749,886	2,799,381	-	1,663,491	2,804,115	-
1992	3,980,198	1,189,001	2,860,586	2,491,674	-	1,955,592	2,443,576	-
1993	4,858,965	1,189,001	2,448,578	3,669,719	-	1,641,212	3,680,334	-
1994	3,507,437	1,189,001	2,755,760	2,236,487	-	1,671,785	2,161,629	-
1995	6,772,346	1,189,001	3,199,829	5,151,095	87,183	1,853,038	5,198,225	-
1996	4,073,886	1,189,001	2,669,717	2,949,761	-	1,661,566	2,922,872	-
1997	5,596,211	1,189,001	2,892,394	3,745,208	-	2,106,303	3,772,955	-
1998	7,948,319	1,189,001	1,964,587	6,619,562	-	1,445,330	6,595,994	-
1999	7,542,246	1,189,001	2,428,860	6,113,080	-	1,450,176	6,128,017	-
2000	4,814,133	1,189,001	2,493,541	3,593,763	-	1,490,017	3,586,484	-
2001	4,733,913	1,189,001	2,324,548	3,506,345	-	1,394,559	3,472,164	-
2002	5,186,941	1,189,001	2,597,776	3,626,672	-	1,558,630	3,650,147	-
2003	9,104,249	1,189,001	2,086,434	7,579,831	-	1,467,883	7,609,476	-
2004	6,238,589	1,189,001	2,075,339	5,042,010	-	1,215,893	5,036,600	-
2005	5,744,188	1,189,001	2,473,162	4,239,023	-	1,541,852	4,241,775	-
2006	6,939,178	1,189,001	2,554,833	5,736,348	-	1,666,718	5,703,701	-
2007	6,026,024	1,189,001	2,614,380	4,556,443	-	1,669,842	4,599,782	-
2008	5,516,463	1,189,001	2,420,730	4,231,779	-	1,393,173	4,215,720	-
2009	6,648,918	1,189,001	2,408,172	5,249,040	-	1,495,811	5,208,452	-
2010	6,825,929	1,189,001	2,502,079	5,363,691	-	1,578,146	5,410,660	-
2011	9,069,229	1,189,001	2,187,672	7,820,540	-	1,359,683	7,797,141	-
2012	5,513,455	1,189,001	2,506,398	3,956,483	-	1,571,046	3,995,679	-
2013	7,774,704	1,189,001	2,224,839	6,494,934	-	1,175,727	6,491,058	-
2014	2,314,801	1,189,001	2,641,586	1,542,151	-	1,576,349	1,442,705	-
2015	2,844,092	1,189,001	2,782,850	1,949,117	157,982	1,869,600	1,509,378	-
2016	4,424,819	1,189,001	2,935,310	2,931,675	220,597	2,104,825	2,739,731	-
2017	5,079,669	1,189,001	3,105,645	3,375,214	86,595	1,946,252	3,343,690	-
MEAN	5,556,967	1,189,001	2,562,184	4,202,776	17,029	1,621,850	4,178,604	-

Table 4.14 Comparison of Reliability of Control Points for Scenario 1 and 3

Name	Target Diversion (Ac-Ft/Yr)	Original (Natural Priority) Scenario 1			Alt.2 (Water Use Priority) Scenario 3		
		Mean Shor. (Ac-Ft/Yr)	Reliability Period (%)	Reliability Volume (%)	Mean Shortage (Ac-Ft/Yr)	Reliability Period (%)	Reliability Volume (%)
NHYA01	56		100	100		100	100
YGSE02	1,552		100	100		100	100
NHHW03	-						
NHHA04	4,335		100	100		100	100
NHSA05	-						
SYBU06	2,907		100	100		100	100
SYIN07	2,373		100	100		100	100
SYCC08	15,418		100	100		100	100
SYCJ09	-						
NHSE10	16,909		100	100		100	100
NHUI11	-						
NHGA12	18,708	4.0	99.98	99.8		100	100
HOSO13	22,142		100	100		100	100
NHCH14	-						
NHGW15	1,104,600	17,025	98.46	97.8		100	100
Total	1,189,000	17,029		98.57	-		100

Table 4.15 Comparison of Reliability of Hydropower for Scenario 1 and 3

Name	Energy Target (KWh/YR)	Original (Natural Priority) Scenario 1			Alt.2 (Water Use Priority) Scenario 3		
		Mean Shortage (KWh/YR)	Reliability Period (%)	Reliability Volume (%)	Mean Shortage (KWh/YR)	Reliability Period (%)	Reliability Volume (%)
HWACHN	227,100	-	100.0	100.0	-	100.0	100.0
CHUCHN	129,700	16,295	85.9	87.4	5,979	90.2	95.4
SOYANG	28,500	956	96.3	96.6	-	100.0	100.0
UIAMDM	145,400	49,578	14.9	65.9	2,487	83.8	98.3
CHEPYE	264,400	48,192	34.6	81.8	3,897	97.4	98.5
Total	795,100	115,022		85.53	12,363		98.45

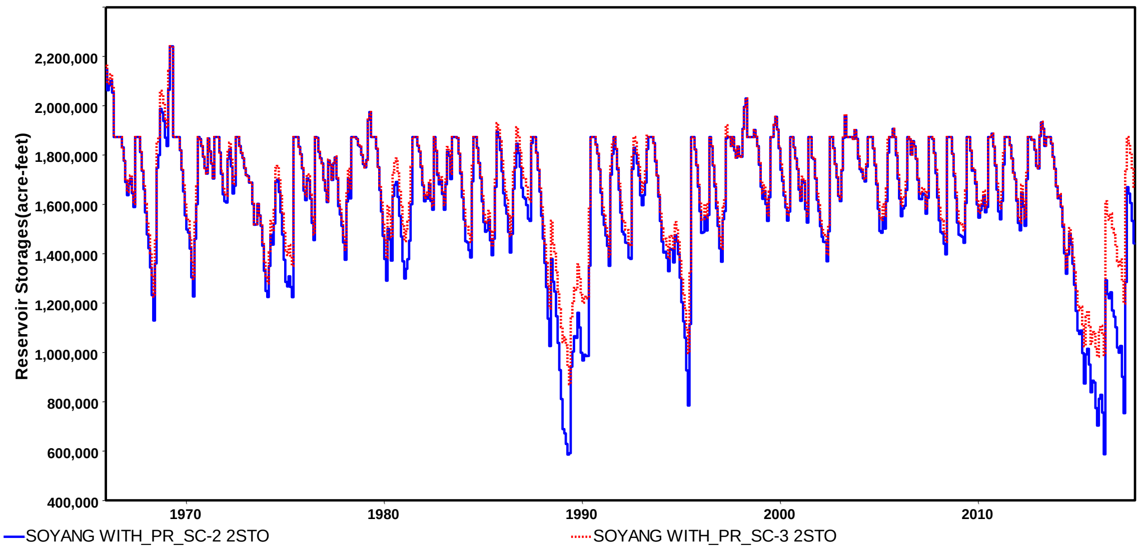


Figure 4.10 Scenario 2 and 3 Reservoir Storage Volumes at Soyang Reservoir

<u>Alternative 2: Reallocation Municipal Water Rights to Hydropower Dams</u>

In the current water supply system in the North Han River Basin, most water supplies have been provided by Soyang multi-purpose dam while four hydropower dams have only produced hydro-electric energy and meet instream flow requirements of downstream. There is no question that everyone who is interested in water security in Seoul and Metro area has no doubt that diversification of water sources except for Soyang multi-purpose dam is essential.

The Alternative 2 with Scenario 4 considered reallocating some portion of the municipal water supply to four hydropower dams in the river basin. The scenario 4 examined to supply municipal water demands (WR-38, WR-40, and WR-41) at control points NHGW15, where most municipal water demands are concentrated, by multiple reservoir operation rule employing Soyang dam and four hydropower dams in the river basin.

For the multiple reservoir operation, four hydropower dams are divided into Zone1 and Zone2 so that storage content of each reservoir maintains the balance. OR record in the program SIM was applied for multiple reservoirs system operation. The storage at top of Zone 2 for each reservoir was set to 50 percent of total conservation storage capacity.

The long-term simulations of the Alternative 2 with scenario 4 were performed for 1966-2017 period-of-simulation. Basically, scenario 4 has the same priority system, which is natural upstream-to-downstream priority, as scenario 1. According to the simulation results, no water shortage occurred during 52 years period-of-simulation in scenario 4. The annual summary and reliability of control points for the river basin with the scenario 4 compared to original scenario 1 in Table 4.16 and 4.17, respectively.

A major concern of scenario 4 is to make sure whether the reliability of power generation for four hydropower dams is decreased or not due to water reallocation. As shown in Table 4.18, reliabilities of power generation in Scenario 4 are decreased slightly than original Scenario 1. The reliability of hydropower for Scenario 4 is 81.46 percent.

Regarding reservoir storage reliability, Scenario 4 is different from Scenario 2 and scenario 3. As shown in Figure 4.11, water rights of Soyang dam are reallocated to the four hydropower dams by the multiple reservoir system operation, so that it maintains storages of the Soyang dam high compared to other Scenarios during the period-of-simulation. However, as shown in Figure 4.12-16, the fluctuation of reservoir storages for four hydropower dams such as Hwacheon, Chuncheon, Uiam, and Cheongpyeong shows that the risk of operator for four hydropower dams is increased.

With respect to instream flow targets, Scenario 4 was not met the instream targets at the control points NHHA04, SYCJ09, and HOSO13 while all cases in Scenario 3 satisfied all instream flow targets except for IF-7 at control point HOSO13.

Table 4.16 Comparison of Results for Annual Basin Summary Scenario 1 and 4

Year	Naturalized Flows (AC-FT)	Annual Diversion Targets (AC-FT)	Scenario 1 (Natural Priority)			Scenario 4 (System Operation)		
			Streamflows Depletion (AC-FT)	Unappropriated Flows (AC-FT)	Diversion Shortages (AC-FT)	Streamflows Depletion (AC-FT)	Unappropriated Flows (AC-FT)	Diversion Shortages (AC-FT)
1966	9,263,235	1,189,001	1,632,099	8,537,645	-	1,960,087	8,128,772	-
1967	5,043,054	1,189,001	2,149,982	3,773,964	-	1,964,130	3,857,982	-
1968	4,939,045	1,189,001	2,882,676	3,292,255	-	2,476,496	3,213,677	-
1969	7,275,722	1,189,001	2,084,523	6,183,788	-	1,534,645	6,351,668	-
1970	6,713,932	1,189,001	2,553,880	5,205,839	-	2,561,427	4,978,920	-
1971	4,284,883	1,189,001	2,678,970	3,062,696	-	2,219,014	3,227,311	-
1972	6,748,702	1,189,001	2,564,041	5,194,716	-	2,712,910	5,005,939	-
1973	3,321,637	1,189,001	2,327,811	2,300,914	-	2,308,340	2,125,802	-
1974	4,296,018	1,189,001	2,819,130	2,867,290	-	2,324,744	2,999,355	-
1975	5,206,699	1,189,001	2,884,103	3,493,138	-	2,419,241	3,683,319	-
1976	4,433,538	1,189,001	2,815,833	3,009,554	-	2,686,496	2,984,072	-
1977	3,267,893	1,189,001	2,735,902	2,162,427	-	2,547,298	2,125,403	-
1978	6,703,679	1,189,001	2,580,377	4,992,680	-	2,361,167	5,041,196	-
1979	5,847,090	1,189,001	2,211,875	4,726,880	-	2,021,857	4,781,312	-
1980	3,792,592	1,189,001	2,890,721	2,490,924	-	2,739,229	2,215,006	-
1981	7,506,623	1,189,001	2,722,226	5,807,494	-	2,342,587	6,002,345	-
1982	3,680,093	1,189,001	2,800,932	2,326,873	-	2,665,683	2,245,668	-
1983	4,506,880	1,189,001	2,570,872	3,067,291	-	2,346,380	3,119,625	-
1984	6,097,250	1,189,001	2,712,096	4,712,607	-	2,444,815	4,734,738	-
1985	4,555,431	1,189,001	2,957,551	3,068,029	-	2,868,106	2,953,380	-
1986	3,962,446	1,189,001	2,590,136	2,649,317	-	2,459,266	2,522,152	-
1987	6,368,054	1,189,001	2,180,403	5,018,926	-	1,890,520	5,306,856	-
1988	2,781,251	1,189,001	2,297,970	2,502,496	-	2,357,326	1,863,772	-
1989	4,854,288	1,189,001	2,997,664	3,158,649	333,140	3,246,141	2,599,552	-
1990	10,305,500	1,189,001	2,686,299	8,366,918	-	1,844,233	9,161,866	-
1991	4,127,761	1,189,001	2,749,886	2,799,381	-	2,356,644	2,921,199	-
1992	3,980,198	1,189,001	2,860,586	2,491,674	-	2,837,420	2,354,395	-
1993	4,858,965	1,189,001	2,448,578	3,669,719	-	2,332,531	3,786,022	-
1994	3,507,437	1,189,001	2,755,760	2,236,487	-	3,091,509	1,565,204	-
1995	6,772,346	1,189,001	3,199,829	5,151,095	87,183	2,183,241	5,671,342	-
1996	4,073,886	1,189,001	2,669,717	2,949,761	-	2,277,387	2,984,399	-
1997	5,596,211	1,189,001	2,892,394	3,745,208	-	2,919,225	3,677,379	-
1998	7,948,319	1,189,001	1,964,587	6,619,562	-	2,032,980	6,607,719	-
1999	7,542,246	1,189,001	2,428,860	6,113,080	-	2,205,757	6,110,639	-
2000	4,814,133	1,189,001	2,493,541	3,593,763	-	2,246,398	3,625,122	-
2001	4,733,913	1,189,001	2,324,548	3,506,345	-	2,210,362	3,494,961	-
2002	5,186,941	1,189,001	2,597,776	3,626,672	-	2,389,561	3,639,080	-
2003	9,104,249	1,189,001	2,086,434	7,579,831	-	2,060,654	7,522,545	-
2004	6,238,589	1,189,001	2,075,339	5,042,010	-	1,954,394	5,090,489	-
2005	5,744,188	1,189,001	2,473,162	4,239,023	-	2,251,250	4,179,032	-
2006	6,939,178	1,189,001	2,554,833	5,736,348	-	2,252,899	5,817,545	-
2007	6,026,024	1,189,001	2,614,380	4,556,443	-	2,541,069	4,481,496	-
2008	5,516,463	1,189,001	2,420,730	4,231,779	-	2,056,580	4,340,608	-
2009	6,648,918	1,189,001	2,408,172	5,249,040	-	2,292,048	5,210,200	-
2010	6,825,929	1,189,001	2,502,079	5,363,691	-	2,491,310	5,276,444	-
2011	9,069,229	1,189,001	2,187,672	7,820,540	-	2,054,757	7,941,464	-
2012	5,513,455	1,189,001	2,506,398	3,956,483	-	2,537,590	3,752,735	-
2013	7,774,704	1,189,001	2,224,839	6,494,934	-	1,911,743	6,561,824	-
2014	2,314,801	1,189,001	2,641,586	1,542,151	-	2,480,459	1,343,780	-
2015	2,844,092	1,189,001	2,782,850	1,949,117	157,982	3,025,819	1,103,056	-
2016	4,424,819	1,189,001	2,935,310	2,931,675	220,597	2,625,701	3,082,363	-
2017	5,079,669	1,189,001	3,105,645	3,375,214	86,595	2,295,898	3,682,644	-
MEAN	5,556,967	1,189,001	2,562,184	4,202,776	17,029	2,369,564	4,174,103	-

Table 4.17 Comparison of Reliability of Control Points for Scenario 1 and 4

Name	Target Diversion (Ac-Ft/Yr)	Original (Natural Priority) *Scenario 1* Mean Shor. (Ac-Ft/Yr)	Reliability Period (%)	Reliability Volume (%)	Alt.2 (System Operation) *Scenario 4* Mean Shortage (Ac-Ft/Yr)	Reliability Period (%)	Reliability Volume (%)
NHYA01	56		100	100		100	100
YGSE02	1,552		100	100		100	100
NHHW03	-						
NHHA04	4,335		100	100		100	100
NHSA05	-						
SYBU06	2,907		100	100		100	100
SYIN07	2,373		100	100		100	100
SYCC08	15,418		100	100		100	100
SYCJ09	-						
NHSE10	16,909		100	100		100	100
NHUI11	-						
NHGA12	18,708	4.0	99.98	99.8		100	100
HOSO13	22,142		100	100		100	100
NHCH14	-						
NHGW15	1,104,600	17,025	98.46	97.8		100	100
Total	1,189,000	17,029		98.57	-		100

Table 4.18 Comparison of Reliability of Hydropower for Scenario 1 and 4

Name	Energy Target (KWh/YR)	Original (Natural Priority) *Scenario 1* Mean Shortage (KWh/YR)	Reliability Period (%)	Reliability Volume (%)	Alt.2 (System Operation) *Scenario 4* Mean Shortage (KWh/YR)	Reliability Period (%)	Reliability Volume (%)
HWACHN	227,100	-	100.0	100.0	120	99.8	100.0
CHUCHN	129,700	16,295	85.9	87.4	22,772	80.0	82.4
SOYANG	28,500	956	96.3	96.6	-	100.0	100.0
UIAMDM	145,400	49,578	14.9	65.9	57,610	16.5	60.4
CHEPYE	264,400	48,192	34.6	81.8	66,938	26.0	74.7
Total	795,100	115,022		85.53	147,440		81.46

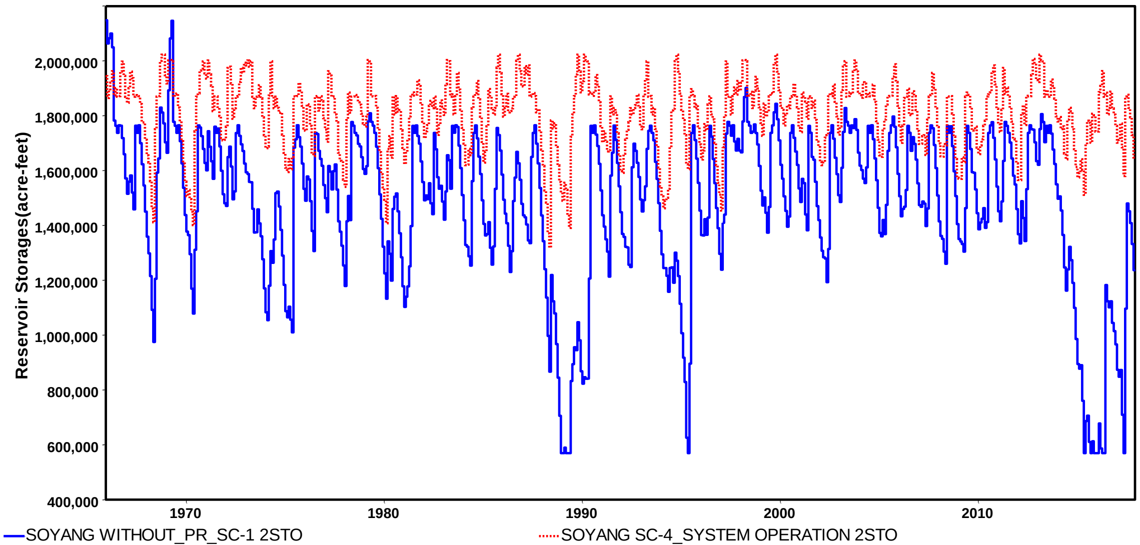


Figure 4.11 Scenario 1 and 4 Reservoir Storage Volumes at Soyang Reservoir

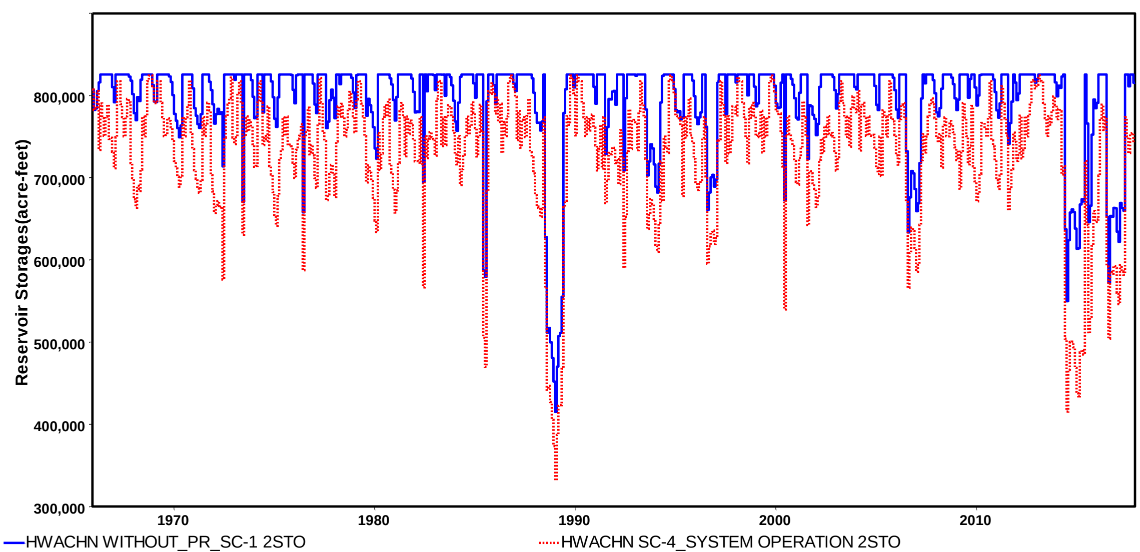


Figure 4.12 Scenario 1 and 4 Reservoir Storage Volumes at Hwacheon Reservoir

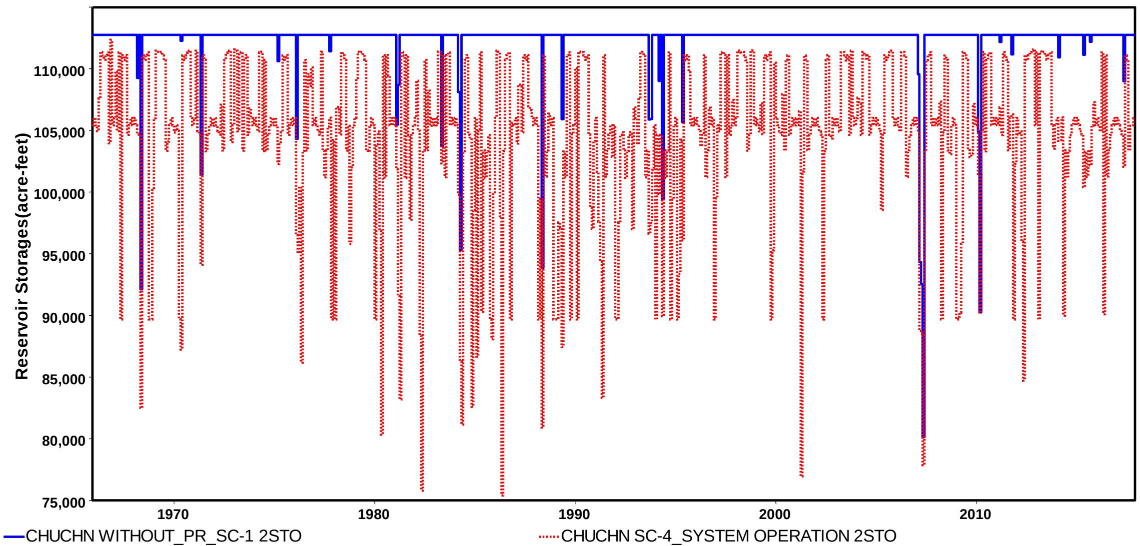


Figure 4.13 Scenario 1 and 4 Reservoir Storage Volumes at Chuncheon Reservoir

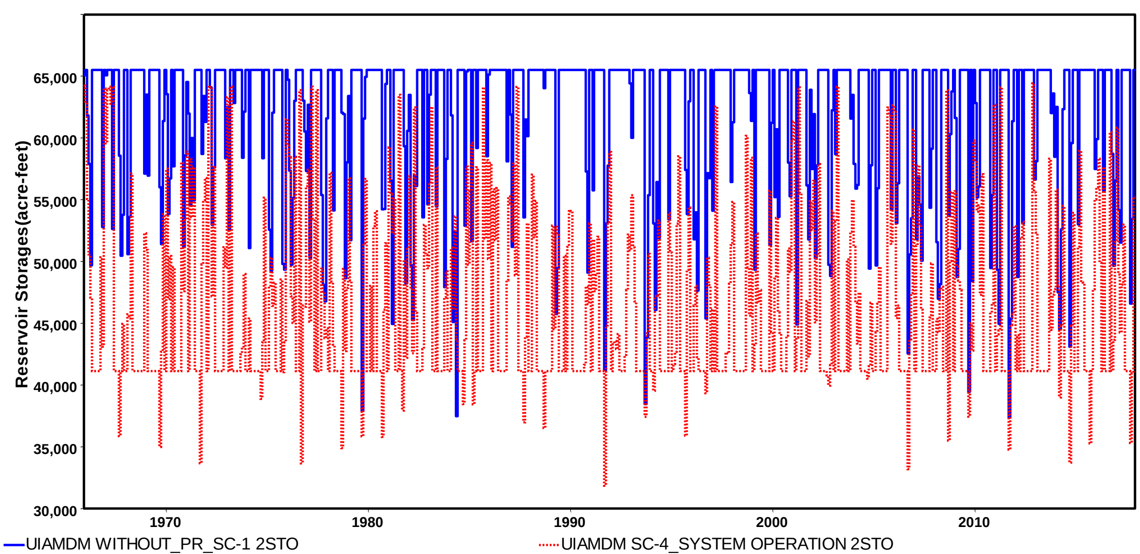


Figure 4.14 Scenario 1 and 4 Reservoir Storage Volumes at Uiam Reservoir

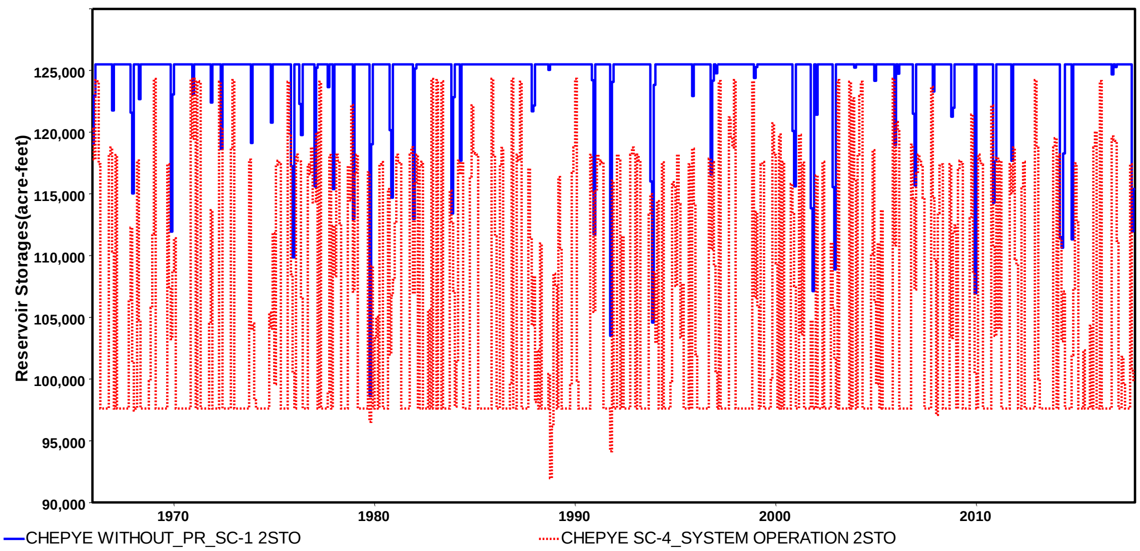


Figure 4.15 Scenario 1 and 4 Reservoir Storage Volumes at Cheongpyeong Reservoir

4.2.3 Short-term Simulations

The short-term simulations are focused on securing municipal water supply during severe drought. The period-of simulation is set to 2014-2017 when the drought was the most severe during 1966-2017 period-of-analysis. As previously mentioned, the water demands of the North Han River Basin are mostly municipal water use and most of total water supply depends on reservoir storage of Soyang dam. It is difficult to secure reliability of water supply during severe drought without improving the current water allocation system in the river basin.

Therefore, based on the water supply capacities of reservoirs in the river basin including Soyang multipurpose dam, short-term water allocation strategy is examined to minimize the water supply restriction during 2014-2017 severe drought. The short-term simulation with the North Han River WRAP/WAM dataset for 2014-2017 hydrologic period-of-analysis are conducted to evaluate reliability of water supply based on two alternative approaches with four scenarios as shown in Table 4.9.

The principles of short-term water allocation strategy established in this study are considered that 1) hydropower dams contribute to meeting some portion of water supply if water shortages for municipal water supply are expected, 2) water demand management based on reduction of water use for municipal, industrial, and irrigation is needed for drought management.

Prior to the simulation of alternatives, the short-term simulation with natural upstream-to-downstream priority system defined scenario 5 for 2014-2017 period-of-simulation was conducted. The observed reservoir storage in the end of Dec. 2013 was applied for the initial storages for each reservoir in all simulations.

As shown in Table 4.19, the mean annual shortage during 2014-2017 is 136,520 acre-feet and maximum annual shortage is 242,788 acre-feet in 2015 due to minimum inflow in 2014. The annual summary and reliability of control points for the river basin with the original scenario 5 presented in Table 4.20 and 4.21, respectively. The mean annual shortage of power generation for scenario 5 is 185,610 (kWh/Yr) with 76.66

percent of reliability. The instream flow targets were not met at the control points NHHA04, SYCJ09, and HOSO13.

Table 4.19 Annual Basin Summary with Scenario 5

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)
2014	2314801.0	2125386.2	2681731.8	1513629.6	1723348.2	25897.0	1189000.9	1189000.9	0.0
2015	2844092.0	2076742.0	2841745.5	1834262.6	1532938.1	9200.3	1189000.9	946213.0	242787.8
2016	4424819.0	1788814.4	3183834.0	2784973.2	1974010.4	-17458.5	1189000.9	971406.2	217594.7
2017	5079669.0	1602592.2	3062789.5	3374646.2	2353306.5	-22400.9	1189000.9	1103302.0	85698.8
MEAN	3665845.0	1898383.6	2942524.8	2376877.8	1895900.8	-1190.5	1189000.8	1052480.4	136520.3

Table 4.20 Reliability for Control Points of Scenario 5

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	+++++++ PERCENTAGE OF MONTHS +++++++ WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS --------- 100%	98%	95%	90%	75%	50%	1%
NHYA01	56.0	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
YGSE02	1552.0	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
NHHW03	0.0	0.00	There are no diversions at this control point.															
NHHA04	4335.0	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
NHSA05	0.0	0.00	There are no diversions at this control point.															
SYBU06	2907.0	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
SYIN07	2373.0	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
SYCC08	15418.0	3989.41	78.57	74.12	78.6	78.6	78.6	78.6	78.6	78.6	78.6	25.0	25.0	25.0	25.0	50.0	100.0	100.0
SYCJ09	0.0	0.00	There are no diversions at this control point.															
NHSE10	16909.0	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
NHUI11	0.0	0.00	There are no diversions at this control point.															
NHGA12	18708.0	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
HOSO13	22142.0	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
NHCH14	0.0	0.00	There are no diversions at this control point.															
NHGW15	1104601.0	132530.94	79.17	88.00	79.2	79.2	81.2	83.3	87.5	91.7	100.0	25.0	25.0	25.0	50.0	100.0	100.0	100.0
Total	1189001.0	136520.34		88.52														

Table 4.21 Reliability Summary for Hydropower Dams of Scenario 5

NAME	ENERGY TARGET	MEAN SHORTAGE	*RELIABILITY* PERIOD (%)	*RELIABILITY* AMOUNT (%)	+++++++ PERCENTAGE OF MONTHS +++++++ WITH ENERGY GENERATION EQUALING OR EXCEEDING PERCENTAGE OF TARGET 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS --------- 100%	98%	95%	90%	75%	50%	1%
HWACHN	227100.0	8357.03	97.92	96.32	97.9	97.9	97.9	97.9	97.9	100.0	100.0	75.0	75.0	75.0	75.0	100.0	100.0	100.0
CHUCHN	129700.0	25679.64	81.25	80.20	81.2	81.2	81.2	87.5	97.9	100.0	100.0	0.0	0.0	25.0	25.0	50.0	100.0	100.0
SOYANG	28500.0	9538.05	64.58	66.53	64.6	64.6	64.6	64.6	68.8	70.8	79.2	25.0	25.0	25.0	25.0	50.0	50.0	100.0
UIAMDM	145400.0	60454.65	12.50	58.42	12.5	14.6	14.6	16.7	56.2	100.0	100.0	0.0	0.0	0.0	0.0	0.0	75.0	100.0
CHEPYE	264400.0	81580.91	22.92	69.14	22.9	25.0	27.1	50.0	85.4	100.0	100.0	0.0	0.0	0.0	0.0	25.0	100.0	100.0
Total	795100.0	185610.28		76.66														

Alternative 3: Reallocation Municipal Water Rights to Hydropower Dams

As previously mentioned, the current water supply system in the North Han River Basin totally depends on Soyang multi-purpose dam while four hydropower dams have only produced hydro-electric energy. If the duration of drought is prolonged, the risk associated with water security of Seoul and Metro area will be increased. From the water security perspective in Seoul and Metro area, it is necessary to prepare an alternative to the current water supply system, which depends entirely on the Soyang multi-purpose dam.

The Alternative 3 with Scenario 6 considered reallocating a portion of the municipal water supply to four hydropower dams in the river basin. Scenario 6 is a scheme in which Soyang dam supplies firm yield of the WR-41, which accounts for 81.9 percent of total diversion targets in the river basin, and four hydropower dams are compulsorily assigned the remaining amount from WR-41. The scenario 6 consisted of three cases based upon the allocation methods shown in Table 4.23. The allocation methods described case 1, 2, and 3 are 1) allocation equally to four hydropower dams, 2) proportional allocation of conservation capacities to four hydropower dams, and 3) Allocation to Hwacheon Dam only which largest hydropower dam except for Soyang dam in the river basin.

The firm yield associated with a particular water diversion is defined as the maximum annual demand target that can be met with a reliability of 100.0 percent (Wurbs 2015c). Determining the firm yield of Soyang dam related to WR-41, a simulation with the following FY and ZZ records in the program SIM was applied by iteratively adjusting a target amount and rerunning SIM until a value meeting with a reliability of 100.0 percent as shown in Table 4.22. The firm yield of Soyang dam meeting with volume and period reliability of 100.0 percent is 789,300 acre-feet /year. Therefore, 184,380 acre-feet subtracting Soyang dam firm yield from 973,680 acre-feet of WR-41 was allocated to the four hydropower dams.

```
FY    1000000. 100000. 10000.  1000.  WR-41                  1
ZZ   2   0.01          NHGA12 NHGW15
```

Table 4.22 Yield vs. Reliability Table for WR-41

Iteration	Level	Annual Target	Mean Shortage	Mean Actual	Volume Reliability (%)	Periods Without Shortage	Period Reliability (%)
1	0	1000000.0	134084.1	865915.9	86.59	38	79.17
2	1	900000.0	80488.1	819511.9	91.06	41	85.42
3	1	800000.0	24602.1	775397.9	96.92	45	93.75
4	1	700000.0	0.00	700000.0	100.00	48	100.00

5	2	790000.0	14924.2	775075.8	98.11	47	97.92
6	2	780000.0	0.01	780000.0	100.00	48	100.00

7	3	789000.0	0.01	789000.0	100.00	48	100.00

8	4	789900.0	14922.2	774977.8	98.11	47	97.92
9	4	789800.0	14920.2	774879.8	98.11	47	97.92
10	4	789700.0	7039.7	782660.2	99.11	47	97.92
11	4	789600.0	4510.4	785089.6	99.43	47	97.92
12	4	789500.0	2374.3	787125.8	99.70	47	97.92
13	4	789400.0	843.2	788556.8	99.89	47	97.92
14	4	789300.0	0.00	789300.0	100.00	48	100.00

Table 4.23 Reallocation methods for Alternative 3 with Scenario 6

Reservoir	Reservoir ID	Conservation Storage (AC-FT, %)	*Scenario 6*		
			Case 1	Case 2	Case 3
HWACHEON	HWACHN	529,015 (77.8)	46,095	143,522	184,380
CHUNCHEON	CHUCHN	46,111 (6.8)	46,095	12,510	
UIAM	UIAMDM	48,737 (7.2)	46,095	13,222	
CHEONGPYEONG	CHEPYE	55,752 (8.2)	46,095	15,126	
Total (AC-FT)		679,615	184,380	184,380	184,380

The short-term simulation of the scenario 6 were performed for 2014-2017 period-of-simulation with three cases. Table 4.24 shows the reliability of the control points for Case-1, 2 and Case-3 in Scenario 6. No water shortage occurred in any case of scenario 6 during 4 years period-of-simulation. However, as shown in Table 4.25, reliabilities of hydropower for case-1, 2, and 3 in Scenario 6 are decreased slightly than scenario 5 which has 76.66 percent of hydropower reliability. The reliabilities of hydropower for case-1, 2, and 3 in Scenario 6 are 75.34 %, 74.69 %, and 74.15 %, respectively.

Table 4.24 Reliability of Control Points for Case-1, 2, and 3 in Scenario 6

Name	Target Div. (Ac-Ft/Yr)	Scenario 6 (Reallocation WR-41 to Hydropower Dams) Case 1 Mean Shor. (Ac-Ft/Yr)	Case 1 Reliability Period (%)	Case 1 Reliability Vol. (%)	Case 2 Mean Shor. (Ac-Ft/Yr)	Case 2 Reliability Period (%)	Case 2 Reliability Vol. (%)	Case 3 Mean Shor. (Ac-Ft/Yr)	Case 3 Reliability Period (%)	Case 3 Reliability Vol. (%)
NHYA01	56		100	100		100	100		100	100
YGSE02	1,552		100	100		100	100		100	100
NHHW03	0									
NHHA04	4,335		100	100		100	100		100	100
NHSA05	0									
SYBU06	2,907		100	100		100	100		100	100
SYIN07	2,373		100	100		100	100		100	100
SYCC08	15,418		100	100		100	100		100	100
SYCJ09	0									
NHSE10	16,909		100	100		100	100		100	100
NHUI11	0									
NHGA12	18,708		100	100		100	100		100	100
HOSO13	22,142		100	100		100	100		100	100
NHCH14	0									
NHGW15	1,104,600	0.03	100	100	0.04	100	100	0.02	100	100
Total	1,189,000	0.03		100	0.04		100	0.02		100

Table 4.25 Comparison of Hydropower generation for Case 1, 2 and 3 in Scenario 6

Name	Energy Target (KWh/YR)	Generate Energy(kWh/year) Scenario5	Scenario 6 Case-1	Scenario 6 Case-2	Scenario 6 Case-3	Mean Shortage(kWh/year) Scenario5	Scenario 6 Case-1	Scenario 6 Case-2	Scenario 6 Case-3
HWACHN	227,100	260,301	255,400	241,810	236,203	8,357	9,786	17,386	21,078
CHUCHN	129,700	116,326	109,960	103,875	101,512	25,680	26,521	30,032	32,383
SOYANG	28,500	38,765	61,954	61,963	61,973	9,538	515	515	515
UIAMDM	145,400	87,689	77,678	78,122	77,973	60,455	68,424	68,006	68,152
CHEPYE	264,400	203,868	189,198	190,174	190,713	81,581	90,845	85,271	83,422
Total	795,100	706,949	694,190	675,944	668,374	185,610	196,091	201,210	205,550
Reliability (%)						76.66	75.34	74.69	74.15

Regarding reservoir storage volume, as shown in Figure 4.16, the storage volume of Soyang dam was higher than that of scenario 5 due to decrease of water supply from the Soyang dam during the period-of-simulation. Three cases in scenario 6, there was no period when the reservoir volume of any month was below the storage of the low water level of the reservoir while in scenario 5, the low water level storage occurred for 10 months during 48 months period of simulation. In case of four hydropower dams, the changes in reservoir storage were closely related to the water allocation amount of each dam. For instance, Hwacheon dam had been operated with the lowest reservoir storage during 48 months in case-3, which allocated the largest municipal water demand among the three cases while Chuncheon dam has the lowest reservoir storage in case-1 which water supply is the largest among three cases.

With respect to instream flow targets, Scenario 5 was not met the instream targets at the control points NHHA04, SYCJ09, and HOSO13 while all cases in Scenario 6 satisfied all instream flow targets except for IF-7 at control point HOSO13.

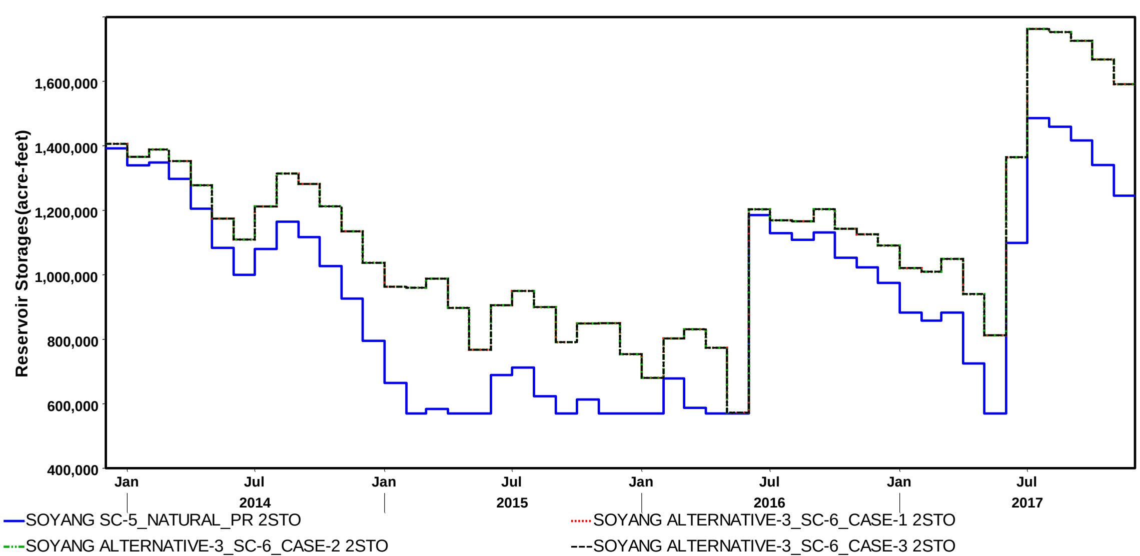


Figure 4.16 Scenario 5 and 3 Cases in Scenario 6 Reservoir Storage at Soyang Dam

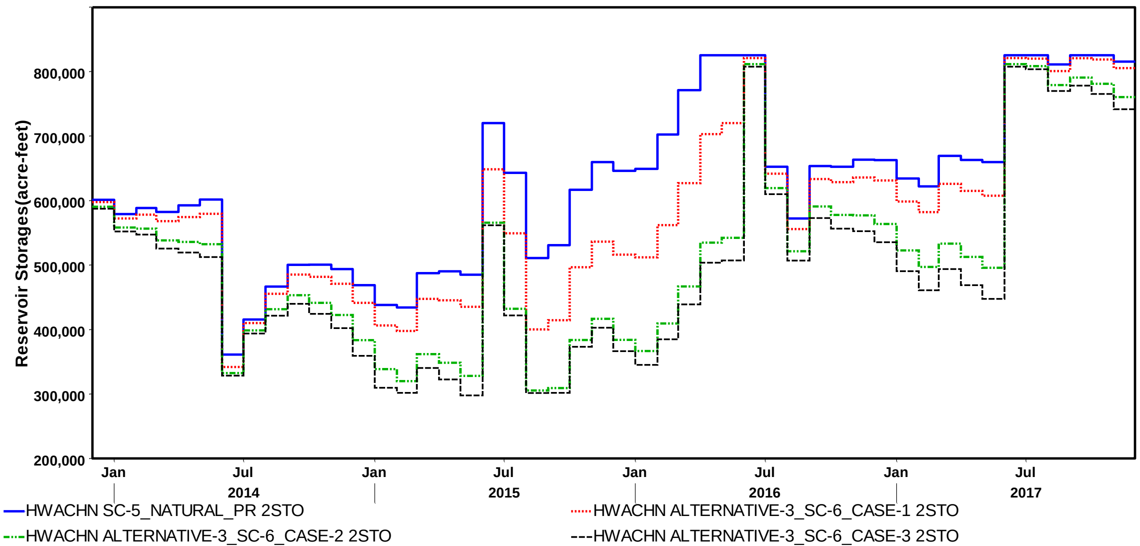


Figure 4.17 Scenario 5 and 3 Cases in Scenario 6 Reservoir Storage at Hwacheon Dam

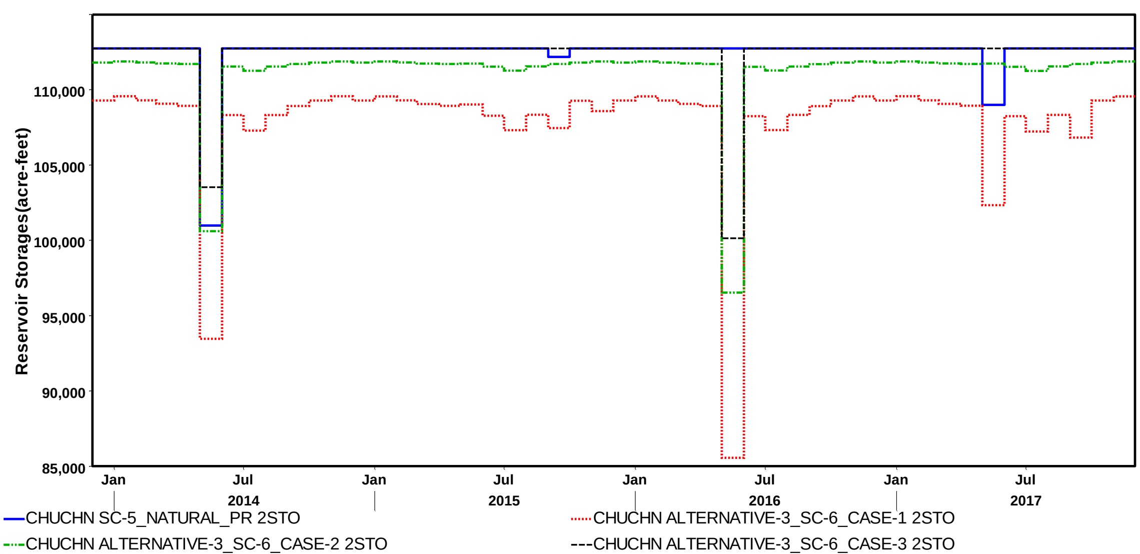


Figure 4.18 Scenario 5 and 3 Cases in Scenario 6 Reservoir Storage at Chuncheon Dam

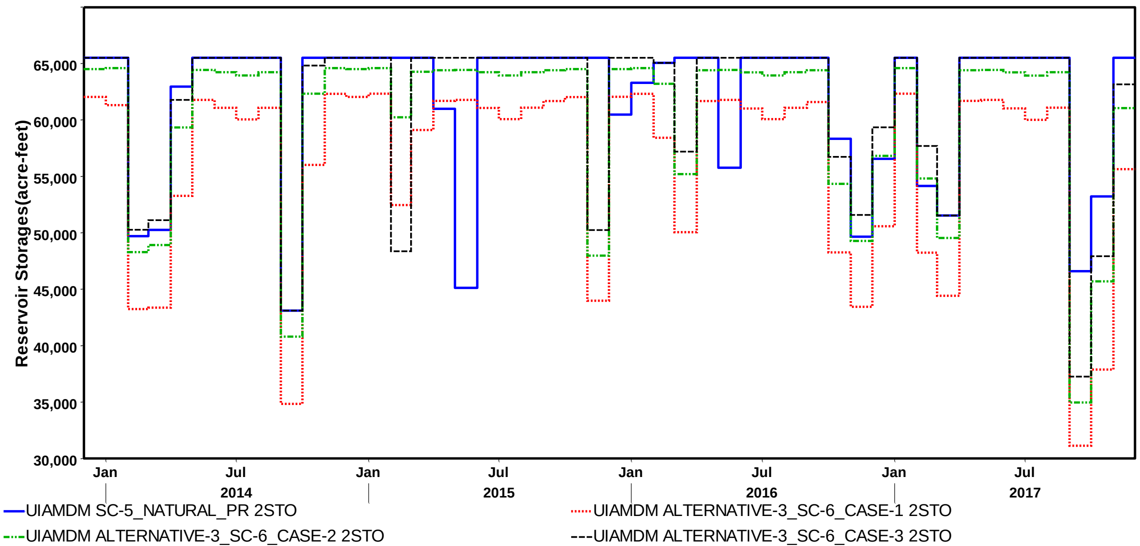


Figure 4.19 Scenario 5 and 3 Cases in Scenario 6 Reservoir Storage at Uiam Dam

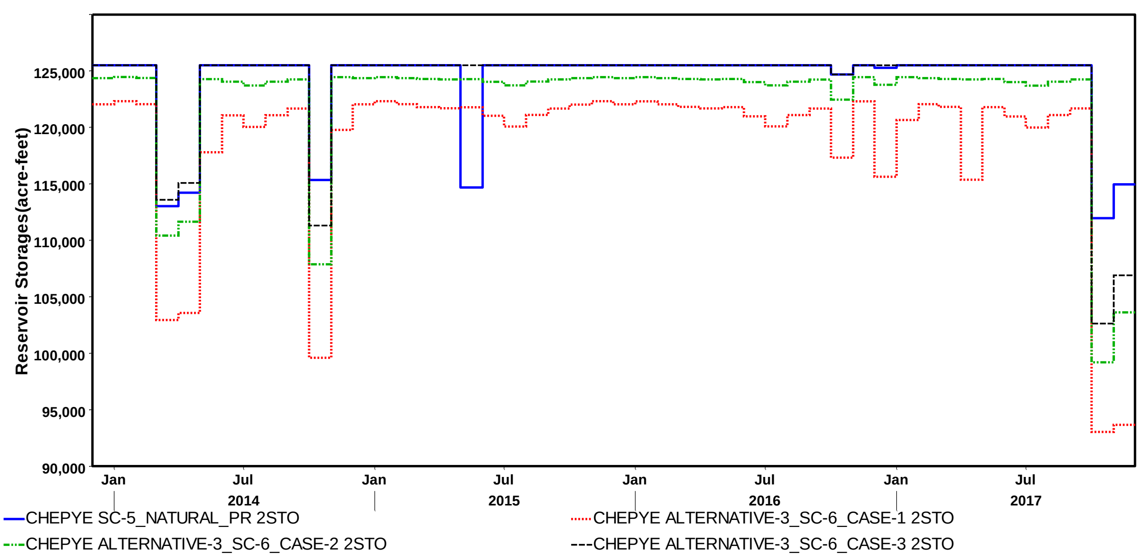


Figure 4.20 Scenario 5 and 3 Cases in Scenario 6 Reservoir Storage at Cheongpyeong Dam

<u>Alternative 4: Water Demand Management: Water Supply Reduction</u>

In general, water supply system employing multi-purpose dam or reservoir for a certain area or a river basin establishes an annual operation plan based on expected inflows and diversion targets of reservoirs. Several multi-purpose dams are designated to be prepared for drought more than one year from the planning stage, but most of dams commonly set up an operation and management plan on a yearly basis. Therefore, preemptive action is necessary to prevent the worst situation in which water supply interrupts when drought prolongs.

In this regard, Alternative 4 with scenario 7 and scenario 8 proposed to reduce the diversion targets as a water demand management and drought management policy in case of prolonged drought. The scenario 7 with two cases is a scheme of reducing consistently at a fixed rate of 10 % and 20 % for all diversion targets associated with municipal, industrial, and irrigation water demand in the river basin.

The scenario 8 is modeled to reduce all diversion targets for municipal, industrial, irrigation water rights supplied by the Soyang dam as the drought condition progressed. Drought conditions for the Soyang dam are defined as the storage contents of the reservoirs based on the storage-frequency. In order to determine the reduction ratio which does not occur diversion shortage based on reservoir contents of the Soyang dam, simulations conducted with three cases described in Table 4.26.

As results of simulation, case-3 is adopted for final drought index for Soyang dam. Based on the case-3, 1,606,414 acre-feet on DI record, which is 60 % of exceedance frequency for Soyang reservoir storage, represents is a trigger to start a reduction of diversion targets. The diversion targets for Soyang dam are reduced by 30 % in total until the storage of reservoir reaches 569,733 acre-feet of the low water level of the Soyang dam. For instance, the annual diversion target of 973,680 acre-feet for WR-41 is converted to 12 month target and multiplied by a factor based on the storage contents on IS record and IP record.

The following final drought index, which is case-3, referencing the storage contents of the Soyang dam is incorporated in input data file of NHAN.dat.

```
DI   1    1 SOYANG
IS   9    0 569733 846927 1088893 1342989 1530722 1606414 2029036 2261605
IP       70      70     75      80      85      90      100      100      100
```

Table 4.26 Reduction Rate of Water Supply based on Soyang Reservoir Storage

Reservoir Storage (AC-FT)	Storage-Frequency								
		L.W.L	95%	90%	75%	50%	40%	N.H.W.L	F.W.L
	0	569,733	846,927	1,088,893	1,342,989	1,530,722	1,606,414	2,029036	2,261,605
Case-1 (%)	70	70	80	85	90	95	100	100	100
Case-2 (%)	60	60	70	75	80	85	90	100	100
Case-3 (%)	70	70	75	80	85	90	100	100	100

The short-term simulation for the North Han River Basin with scenarios 7 and 8 in Alternative 4 are compared with original condition of scenario 5. The basin summary for two cases of scenario 7 and three cases of scenario 8 are presented in Table 4.27 and 4.28.

Table 4.27 Comparison of Annual Basin Summary for Scenario 7

Year	Natural Flows (Ac-Ft)	Original Div. Target (Ac-Ft)	*Case-1 (10%)*				*Case-2 (20%)*			
			Stream. Depletion (Ac-Ft)	Target Div. (Ac-Ft)	Actual Div. (Ac-Ft)	Div. Short. (Ac-Ft)	Stream. Depletion (Ac-Ft)	Target Div. (Ac-Ft)	Actual Div. (Ac-Ft)	Div. Short. (Ac-Ft)
2014	2,314,801	1,189,001	2,670,697	1,070,100	1,070,100	-	2,660,827	951,202	951,202	-
2015	2,844,092	1,189,001	2,872,292	1,070,100	939,779	130,321	3,001,154	951,202	951,202	-
2016	4,424,819	1,189,001	3,150,240	1,070,100	887,614	182,486	3,242,189	951,202	951,202	-
2017	5,079,669	1,189,001	3,105,909	1,070,100	1,070,100	-	2,561,969	951,202	951,202	-
MEAN	3,665,845	1,189,001	2,949,784	1,070,100	991,898	78,202	2,866,534	951,202	951,202	-

Table 4.28 Comparison of Annual Basin Summary for Scenario 8

Year	*Case-1*			*Case-2*			*Case-3*		
	Target Div. (Ac-Ft)	Actual Div. (Ac-Ft)	Div. Short. (Ac-Ft)	Target Div. (Ac-Ft)	Actual Div. (Ac-Ft)	Div. Short. (Ac-Ft)	Target Div. (Ac-Ft)	Actual Div. (Ac-Ft)	Div. Short. (Ac-Ft)
2014	1,064,986	1,064,986	-	962,677	962,677	-	1,013,719	1,013,719	-
2015	938,484	898,678	39,806	899,886	899,886	-	934,041	934,041	-
2016	966,371	855,402	110,969	1,008,644	1,008,644	-	997,439	997,439	-
2017	1,086,727	1,086,727	-	1,068,428	1,068,428	-	1,100,522	1,100,522	-
MEAN	1,014,142	976,448	37,694	984,909	984,909	-	1,011,430	1,011,430	-

The scenario 7 is consisted of two cases based on reduction rates of all diversion targets in the basin. As the result of simulation with scenario 7, diversion shortages occurred in 2015 and 2016 at WR-14, WR-40, and WR-41 for the case-1 which is 10 % of reduction for all diversion targets in the river basin. In case of 20% reduction for all diversion targets, no diversion shortage occurred during 2014-2017 severe drought.

According to results of simulation with three cases in scenario 8, there were no water shortage in case-2 and case-3. In case-1, the reliability was improved by 96.26 percent, but water shortage occurred in irrigation water requirement (WR-14) supplied by Soyang dam directly and in municipal use at control point NHGW15 (WR-41). The reliability for all control points are tabulated in table 4.29. In both case-2 and case-3, there were no water shortages, but case-3 was adopted as the reduction rate referencing storage contents of Soyang dam in accordance with the principle to minimize water supply restriction.

Table 4.29 Comparison of Reliability of Control Points for Scenario 5, 7 and 8

Name	Original Scenario 5 Target Diversion (Ac-Ft)	Original Scenario 5 Diversion Shortage (Ac-Ft)	Alternative 4 Scenario 7 Case-2 Target Diversion (Ac-Ft)	Alternative 4 Scenario 7 Case-2 Diversion Shortage (Ac-Ft)	Alternative 4 Scenario 8 Case-3 Target Diversion (Ac-Ft)	Alternative 4 Scenario 8 Case-3 Diversion Shortage (Ac-Ft)
NHYA01	56	-	45	-	56	-
YGSE02	1,552	-	1,242	-	1,552	-
NHHW03	0	-	-	-	-	-
NHHA04	4,335	-	3,468	-	4,335	-
NHSA05	0	-	-	-	-	-
SYBU06	2,907	-	2,326	-	2,907	-
SYIN07	2,373	-	1,898	-	2,373	-
SYCC08	15,418	3,989	12,334	-	12,662	-
SYCJ09	0	-	-	-	-	-
NHSE10	16,909	-	13,527	-	14,342	-
NHUI11	0	-	-	-	-	-
NHGA12	18,708	-	14,967	-	16,090	-
HOSO13	22,142	-	17,715	-	22,142	-
NHCH14	0	-	-	-	-	-
NHGW15	1,104,600	132,531	883,680	0.01	934,972	0.02
Total	1,189,000	136,520	951,202	0.01	1,011,431	0.02
Reliability (%)		88.52		100.00		100.00

Table 4.30 Comparison of Reliability of Hydropower for Scenario 5, 7 and 8

Name	Energy Target (KWh/YR)	Original Scenario 5 Mean Shortage (KWh/YR)	Original Scenario 5 Reliability Period (%)	Original Scenario 5 Reliability Vol. (%)	Alternative 4 Scenario 7 Case-2 Mean Shortage (KWh/YR)	Scenario 7 Case-2 Reliability Period (%)	Scenario 7 Case-2 Reliability Vol. (%)	Alternative 4 Scenario 8 Case-3 Mean Shortage (KWh/YR)	Scenario 8 Case-3 Reliability Period (%)	Scenario 8 Case-3 Reliability Vol. (%)
HWACHN	227,100	8,357	97.9	96.3	8,333	97.9	96.3	8,357	97.9	96.3
CHUCHN	129,700	25,680	81.3	80.2	25,664	81.3	80.2	25,680	81.3	80.2
SOYANG	28,500	9,538	64.6	66.5	-	100.0	100.0	-	100.0	100.0
UIAMDM	145,400	60,455	12.5	58.4	65,582	6.3	54.9	64,270	6.3	55.8
CHEPYE	264,400	81,581	22.9	69.1	86,037	14.6	67.5	84,395	14.6	68.1
Total	795,100	185,610		76.66	185,615		76.66	182,702		77.02

Table 4.30 shows the reliability of hydropower in case-2 of scenario 7 and case-3 of scenario 8. As shown in Table 4.30, although diversion target was reduced, there was little change in the reliabilities of hydropower in both scenarios. Regarding reservoir storage reliability, With respect to reservoir storage reliability, the reservoir storage of Soyang dam did not reach the low water level of reservoir storage due to the effect of preemptive reduction of water supply. On the other hand, the change of reservoir storage for Hwacheon dam shows was almost identical to original scenario 5 as shown in Figure 4.21 and 4.22. The three hydropower dams located downstream of Soyang dam and Hwacheon dam showed slightly different features from those of original scenario 5 due to the change in flow regime, but there was no significant change in reliabilities as shown in Figure 4.23-4.25.

With respect to instream flow targets, both scenario 7 and scenario 8 did not meet the instream targets at the control points NHHA04 and HOSO13. The original scenario 5 did not meet the instream flow target at the control points NHHA04, SYCC09, and HOSO13.

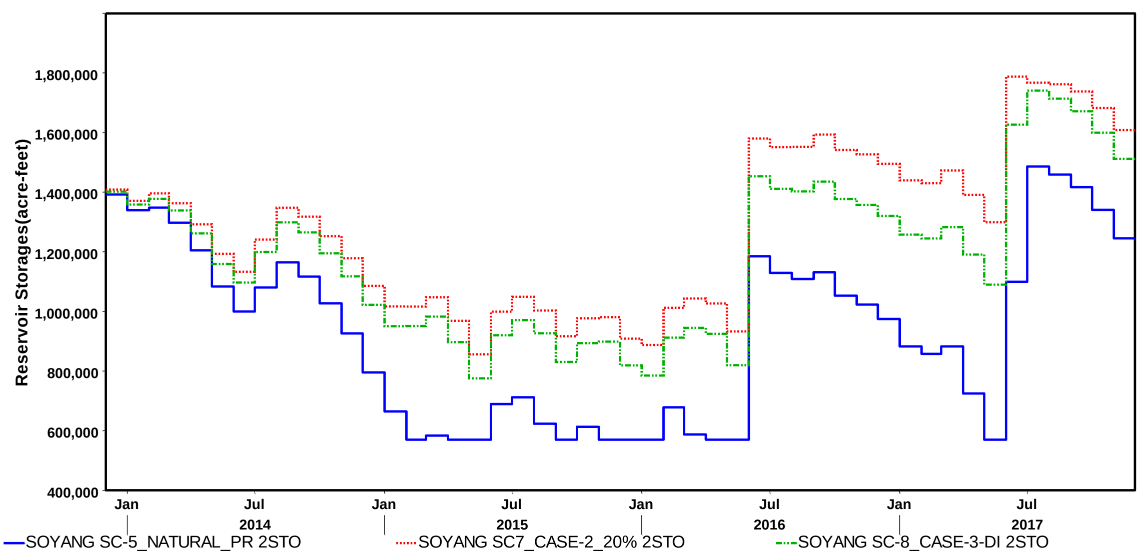


Figure 4. 21 Comparison of Storage of Soyang Reservoir Original vs. Scenario 7 vs. Scenario 8

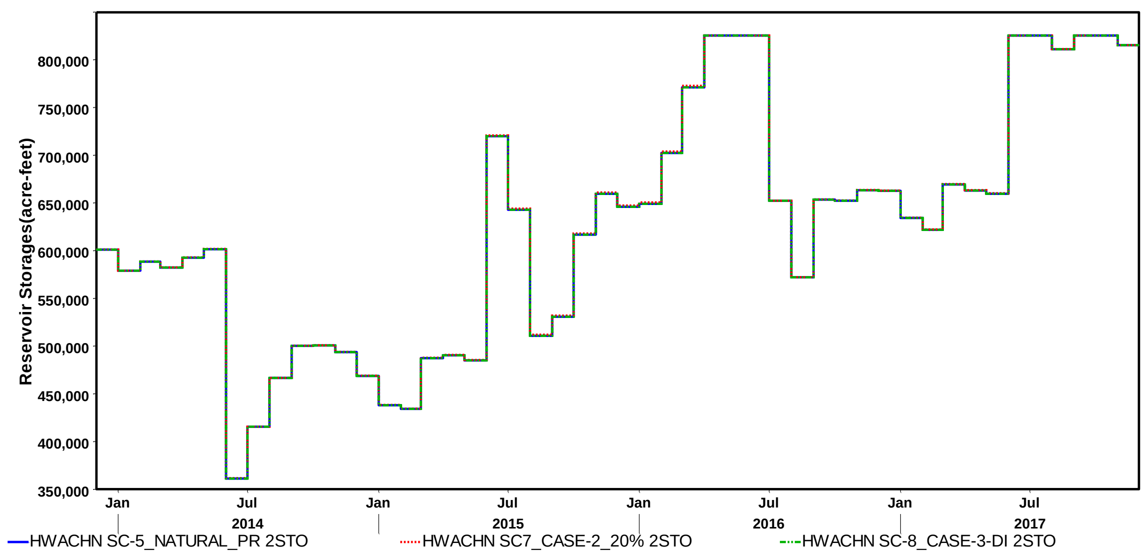


Figure 4.22 Comparison of Storage of Hwacheon Reservoir Original vs. Scenario 7 vs. Scenario 8

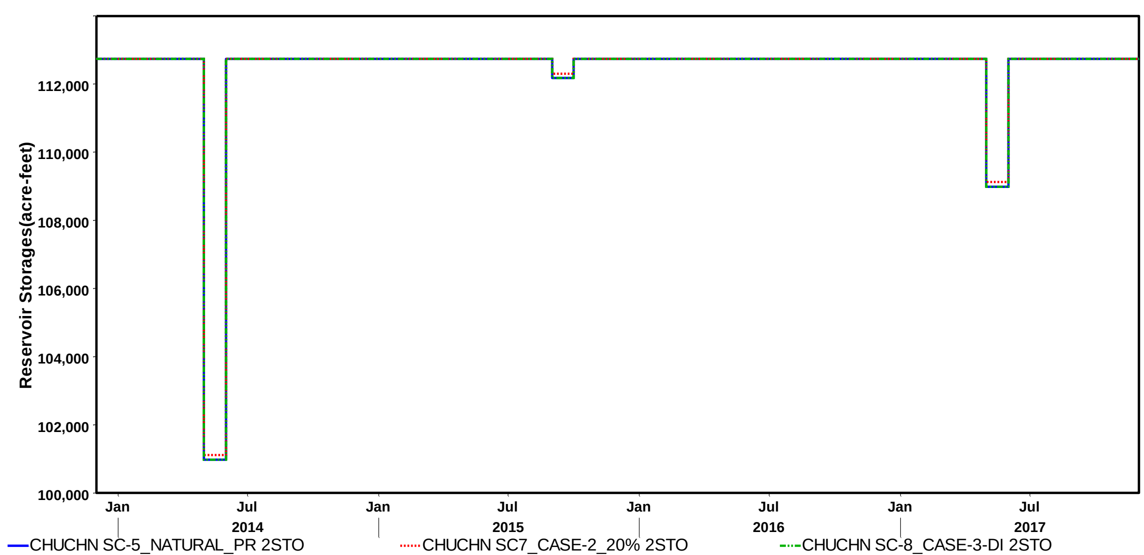


Figure 4.23 Comparison of Storage of Chuncheon Reservoir Original vs. Scenario 7 vs. Scenario 8

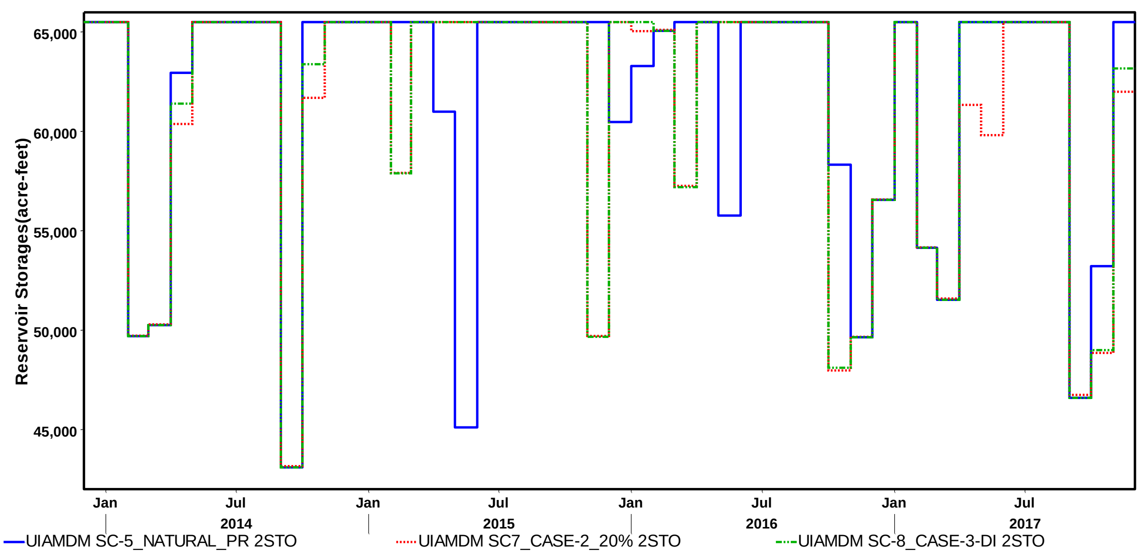


Figure 4.24 Comparison of Storage of Uiam Reservoir Original vs. Scenario 7 vs. Scenario 8

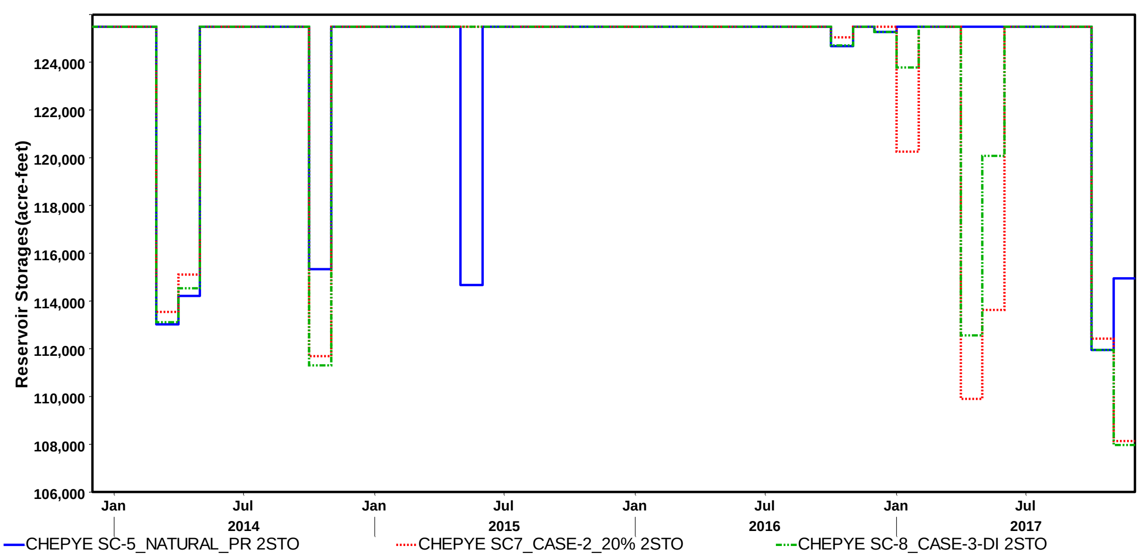


Figure 4.25 Comparison of Storage of Cheongpyeong Reservoir Original vs. Scenario 7 vs. Scenario 8

4.2.4 Water Allocation Strategy

The 1966-2017 North Han River WRAP/WAM model for reservoir/river system management was developed including naturalized flows, net evaporation-precipitation, water rights, and reservoirs, etc. The water allocation strategy was developed in the two alternative schemes. A priority-based long-term water allocation strategy for water management and planning was developed and evaluated with WRAP/WAM system. A water allocation strategy for relatively short-term water availability study for drought management is established for increasing water supply from hydropower dam and reducing some portions of water demands.

Two Alternatives with four Scenarios were established to conduct for long-term simulation in the river basin. Water shortages, reliability of control points, reservoir storages, hydropower generation, and instream flow requirements satisfaction were examined based on each scenario for 1966-2017 period-of-simulation.

As results of long-term simulation, Texas WRAP/WAM system is strongly recommended for water management and planning, especially new water right permit process and water reallocation considering water right priority in Korea. Based on simulation results, Scenario 4 in Alternative 2, which has a scheme to supply municipal water requirement to Seoul and Metro area employing multiple reservoir operation rule, is recommended for long-term water resources management and planning.

However, in order to implement the scenario 4, the consensus of stakeholders such as dam operator Korea Hydro & Nuclear Power and Ministry of Trade, Industry, and Energy (MOTIE), and Seoul City should be preceded because the risk of the four hydropower dams was increased as shown in Figure 4.12-4.15.

The scenario 3, which takes priorities considering types of water use in the order of municipal, industrial, irrigation, instream flow, and hydropower, can also be recommended since the River Act of Korea already defined a priority on the types of water use in a critical situation such as a drought. However, in natural condition of river/reservoir system, it is difficult to implement as the water allocation strategy.

The short-term simulations are focused on securing municipal water supply during severe drought. The period-of-simulation was set to 2014-2017 when the drought was the most severe during 1966-2017 period-of-analysis. To establish a short-term water allocation strategy, two Alternatives with four scenarios were tested and simulated. One approach is to reallocate some portion of water rights supplied by Soyang dam to four hydropower dams and the other is to adopt a drought management policy based on water supply reduction for all water rights in the North Han River Basin.

Based on the simulation results, the case-2 in scenario 6, which is the proportional allocation of conservation capacities to four hydropower dams, is recommended for the short-term drought management. No diversion shortage occurred in any cases of scenario 6, but it is reasonable to allocate in proportion to the conservation capacity of each reservoir as case-2.

The case-3 in scenario 8 may be implemented during severe drought. However, in practice, it is recommended to combine case-2 in scenario 6 and case-3 in scenario 8 according to the situation of drought. For instance, if some index of the meteorological drought is getting worse and reservoir storage of the Soyang dam is expected to decrease more and more, some of the water rights supplied from the Soyang dam according to scenario 6 can be reallocated to four hydroelectric dams. If the drought condition becomes more serious, some portions of water supply reduction for all water rights based on case-3 in scenario 8 maybe an effective drought management to Korean government.

With respect to instream flow requirement, target at control points HOSO13 recommended by MOLIT in 2015 was not met in all scenarios. It is recommended that the instream flow target has to be reviewed and modified, if necessary.

CHAPTER V

DEVELOPMENT OF GROUNDWATER DROUGHT MONITORING METHOD

5.1 Summary and Procedure

Groundwater drought monitoring method has a concept to compare a monthly groundwater level hydrograph based on observation data with current groundwater level. The long-term observation data is needed for securing a statistical reliability. 288 sites with more than 10 years of observation data among 386 sites of national groundwater monitoring network were selected. The station which has a trend variation or an irregular variation is excluded. Finally, 256 monitoring stations are selected for development of groundwater drought monitoring methodology in this research.

Monthly probability distribution for each station is determined based on groundwater level observed data. Kernel Density Estimation (KDE) which is a non-parametric way to estimate the probability density function is applied for estimating probability distribution of monthly groundwater level data at 256 monitoring stations. A percentile of the groundwater level data from Cumulative Distribution Function (CDF) of the monthly Kernel Density Estimation for each station are calculated and A Standardized Groundwater level Index (SGI) corresponding current groundwater level is calculated using the quantile function ($\boldsymbol{CDF^{-1}}$).

The SGI of each monitoring well is converted into the area SGI for 167 cities nationwide considering the areal weights of each monitoring well for its nearby city. The thiessen polygons are established for converting estimated SGI of groundwater observation wells to 167 cities based on their spatial locations using Arc-GIS Tool. Based on the SGI for each city and groundwater drought evaluation criteria described in section 5.6, current groundwater drought conditions for each city is determined. Regarding starting point of groundwater drought, 25 percentile was selected in this study. The national drought monitor map is produced reflecting drought condition of 167 cities.

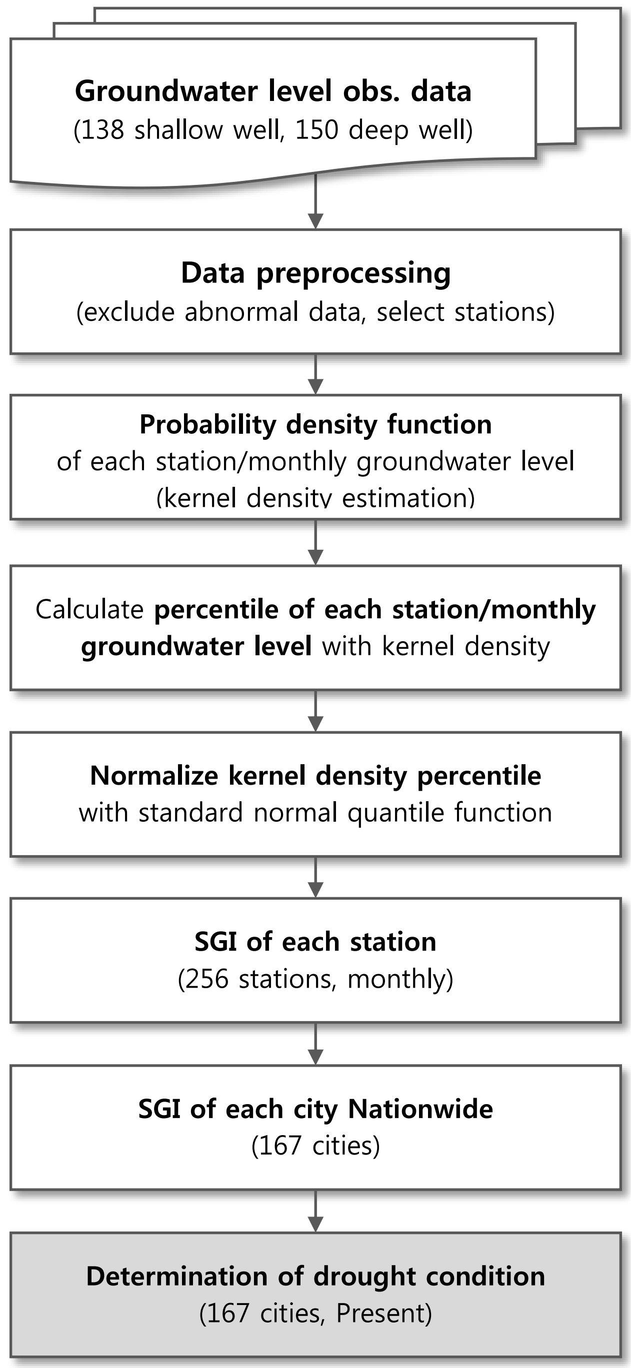


Figure 5.1 A Procedure of Groundwater Drought Monitoring Based on SGI

5.2 Study Area

5.2.1 Korea

In this research, the study area is covered the entire Korea because the spatial extent of national drought early warning system is 167 cities nationwide. As of 2017, as shown in Figure 5.2 South Korea is composed of 1 capital cities, 5 metropolitan cities (Busan, Daegu, Gwangju, Daejeon, Ulsan), 8 provinces, 167 cities, and 3482 dongs. According to the type of main water sources in use, 81% of 3,482 dongs are receiving water from reservoirs, about 17% of them use streamflow, and about 2% of them depend on groundwater use. There are 13,000 groundwater supply facilities in Korea. Each of these facilities is responsible for supplying 30-100 households of water. The research focus on the establishment of drought monitoring and forecasting methodology for the area using groundwater throughout the country. Therefore, the methodology of groundwater drought monitoring and forecasting was developed for 167 cities nationwide in this study.

5.2.2 Chungcheong Province

Korea has been suffering from a severe drought which was started in 2014 and lasted through 2017. Specially, Chungcheong province located in the middle-western part of Korea was damaged to restrict municipal, industrial, and irrigation water use to 8 cities (600 thousand people) of province during 2014-2015. The Chungcheong province serves as the primary case study for developing the groundwater drought projection methodology with ANN in Chapter 6. Figure 5.3 shows the groundwater monitoring networks in Chungcheong province.

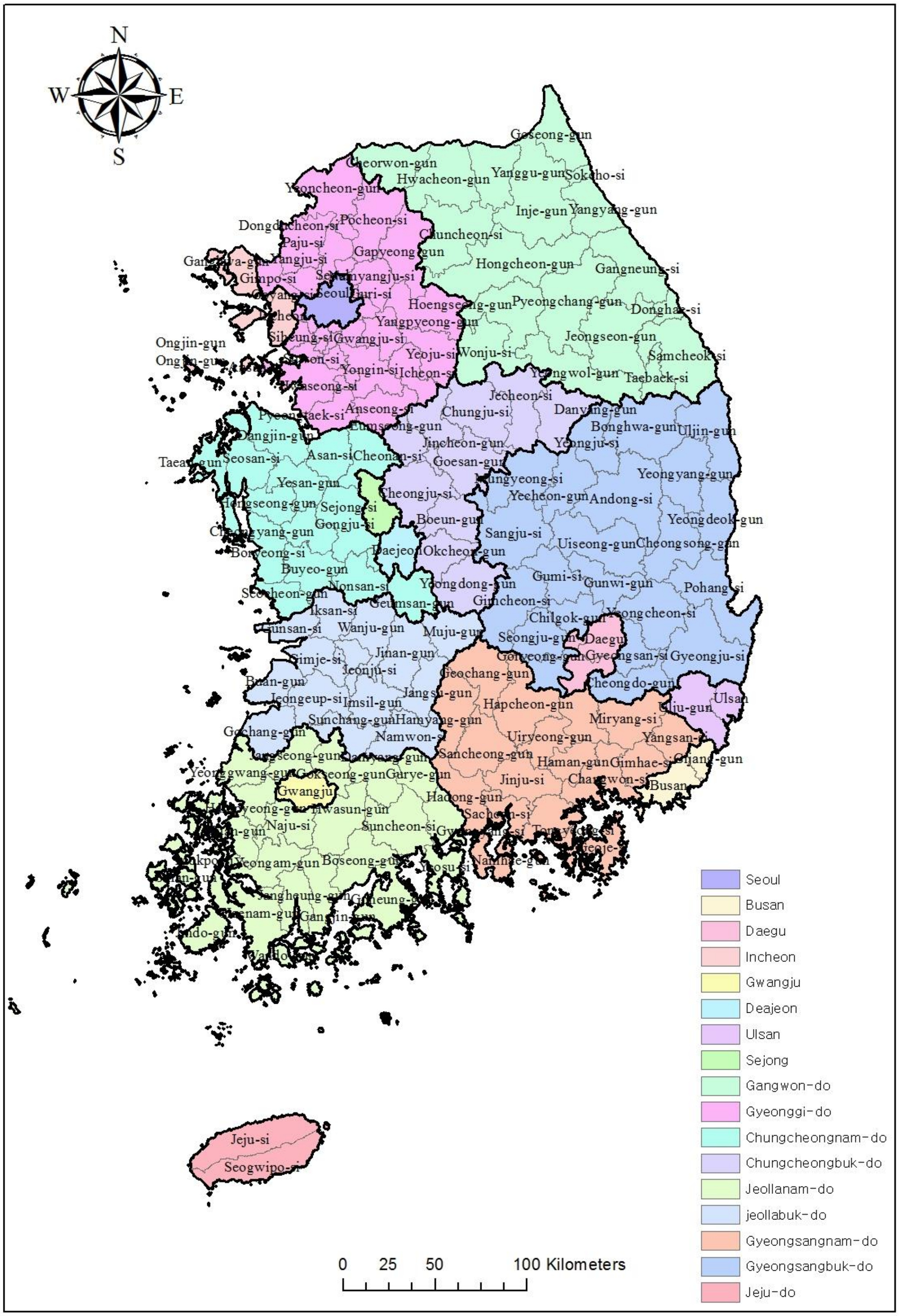


Figure 5.2 Administrative District Map in Korea

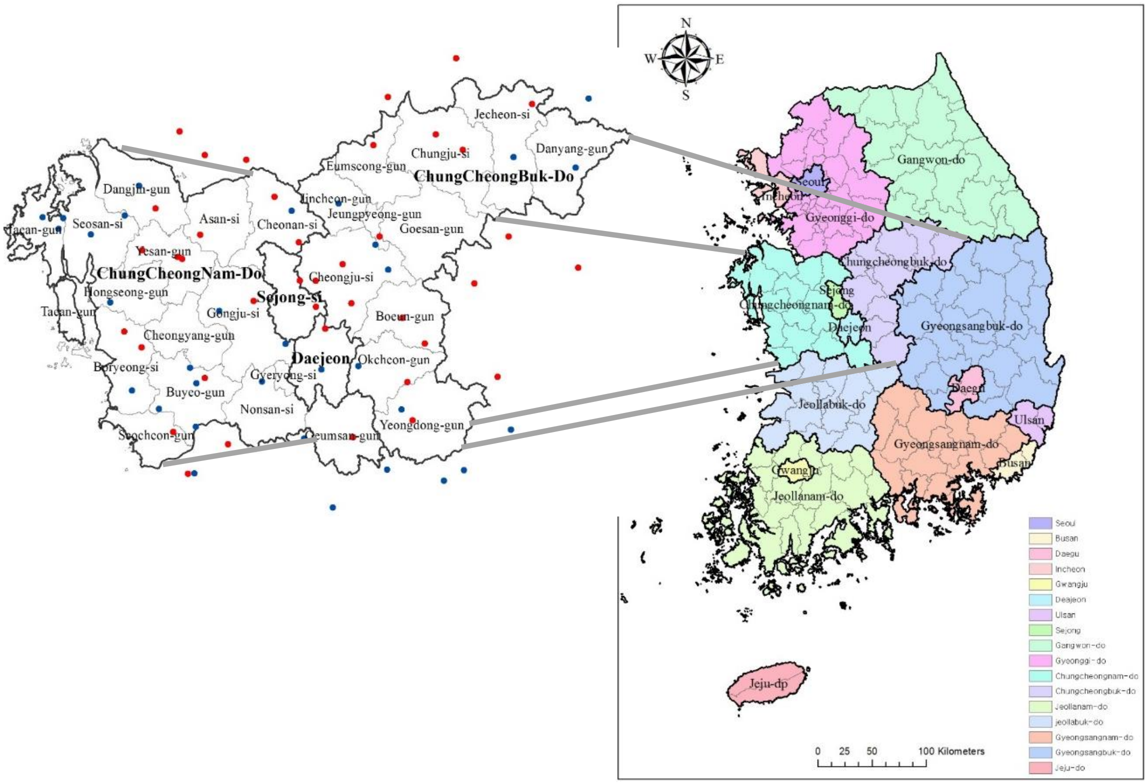


Figure 5.3 Groundwater Monitoring Networks of Chungcheong Province

5.3 National Groundwater Monitoring Networks in Korea

In case of the local water supply system using groundwater as a source of drinking water, it is not possible for groundwater drought monitoring by directly using the groundwater observation data because there is no groundwater monitoring system. Fortunately, the Korean government has been operating the National Groundwater Monitoring Networks (NGMN) to collect groundwater information across the country.

NGMN has been operated and maintained by the Ministry of Land, Infrastructure, and Transport (MOLIT) to continuously monitor groundwater level and groundwater quality. Some of ministry and local governments listed in Table 5.1 have engaged in the domestic groundwater monitoring network including the national groundwater monitoring network operated by MOLIT, the auxiliary groundwater monitoring networks operated by the local governments, agricultural groundwater monitoring networks maintained by Ministry of Agriculture, Food and Rural Affairs (MAFRA), and the water quality monitoring networks managed by Ministry of Environment (ME).

However, it is the only national groundwater monitoring network that has long-term observation data and has secured reliability through the data quality control. Groundwater level data obtained from 402 stations on a real-time basis are available at the website (http://www.gims.go.kr/natnObsvStts.do).

Table 5.1 Groundwater Monitoring Wells in Korea_

Management agency	National groundwater monitoring wells (MOLIT)	Assistant monitoring wells (Local gov.)	Agricultural monitoring wells (MAFRA)	Water quality monitoring wells (ME)
No. of wells	402	2,500(1,545)	176	193

The observed data obtained from NGMW include groundwater level, water temperature, electric conductivity which is measured automatically at 1 hour interval, and water quality which is gaged at twice a year. The groundwater annual report have been regularly published by MOLIT based on observation data produced by the end of previous year in the following year. The most recently published “Groundwater observation annual report 2016” is based on observation from 386 stations nationwide as of Dec. 31, 2015. Figure 5.4 shows the location of national groundwater monitoring network in Korea and the number of monitoring wells in major river basin is given in Table 5.2.

Table 5.2 Status of National Groundwater Monitoring Stations

Basin	Total	Han River	Nakdong River	Geum River	Sumjin River	Youngsan River	Jeju Island
No. of Installed	402	125	112	89	38	34	4
No. of operating	386	121	106	88	35	32	4

※ Source: Annual report of national groundwater monitoring networks (MOLIT, 2016)

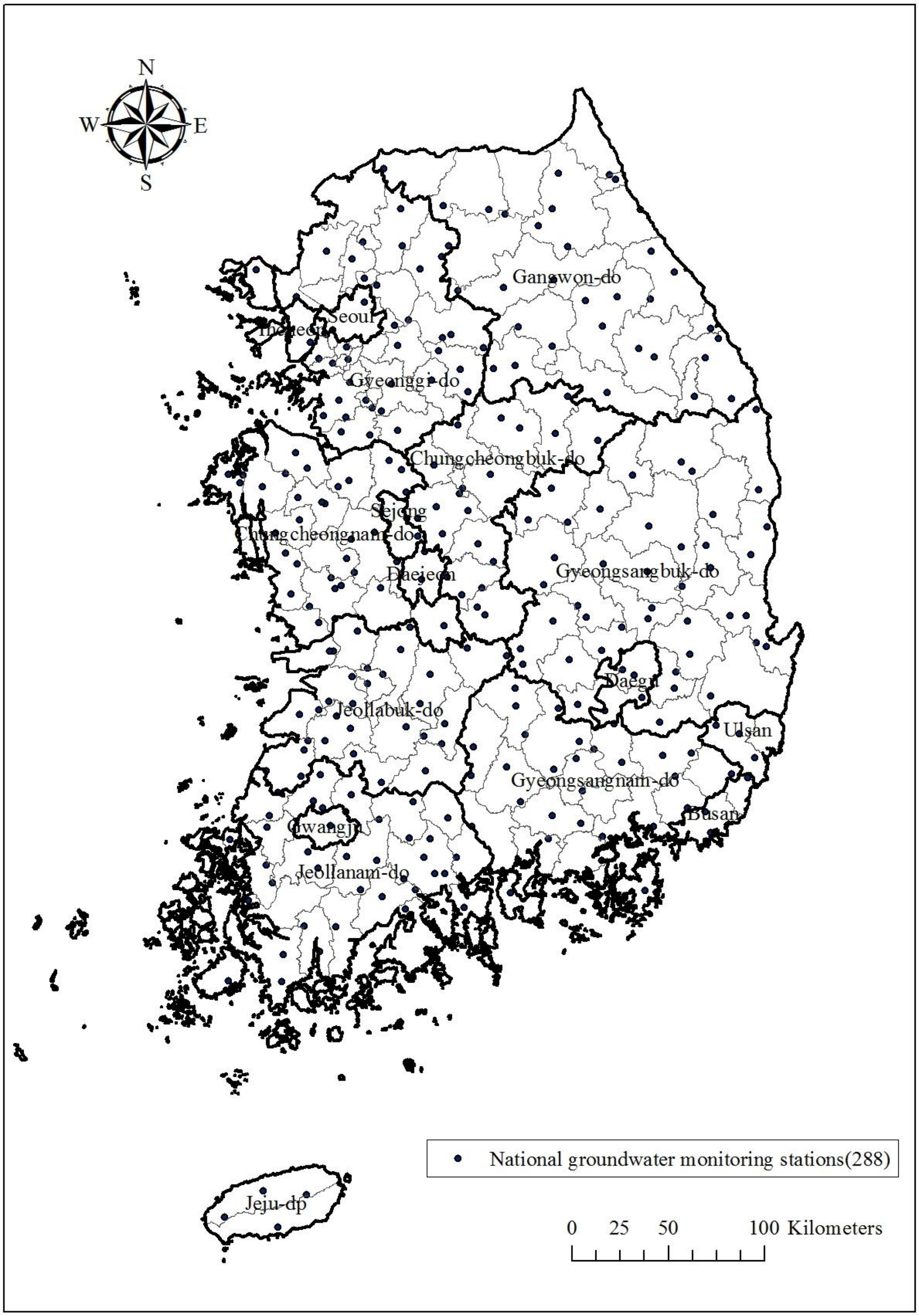


Figure 5.4 National Groundwater Monitoring Wells with Long-Term Observation Data

5.3.1 Collecting of Groundwater Observation Data

Groundwater drought monitoring method is a concept to compare groundwater level hydrograph based on observation data with current groundwater level. The long-term observation data is needed for securing a statistical reliability. 288 sites with more than 10 years of observation data among 386 sites of national groundwater monitoring network were selected for this research. The national groundwater monitoring wells are classified into alluvial aquifer (shallow well) and rock aquifer (deep well). 138 sites have been measured groundwater level from both alluvial aquifer (most of unconfined, shallow well) and rock aquifer (most of confined, deep well) at the same time.

The propagation of meteorological drought to agriculture or hydrological drought might be generally described that combined with the lack of precipitation and high evaporation rates reduce soil moisture, streamflow, and groundwater recharge. With regard to groundwater, it is common that a shallow well in the soil zone responds quickly to rainfall at the site while a deep well in the rock zone shows slower response but longer duration. For 138 sites which have both shallow well and deep well, shallow well observation data were used in this study.

The 288 selected groundwater monitoring wells listed in Table 5.3. The meaning of the term “excluded” in the last column of the Table 5.3 is that some observation wells were excluded due to its irregular variation or trend. In order to verify whether any type of variation exist in the observed data at each station, time series plot based on monthly average groundwater level data was examined. The components of groundwater level time series are generally concerned with seasonal variation, irregular variation (abrupt increase or decrease like a step), trend, and disturbance due to pumping. In some case, two or more type of variation may appear in combination.

For instance, time series plot, as shown in Figure 5.5, Station 9895 (Seongju-Byeokjin) shows a variation type which is a combination of seasonal variation and decrease trend. Groundwater levels have been declining since beginning of observation (May 1998), and it is now 3.8m lower than the initial stage of groundwater level.

In Figure 5.6, Station 82042 (Cheongsong-Hyeonseo) shows irregular variation in which the groundwater level dropped suddenly to 45.22m in 2004, then rose sharply again in 2010, and is now stable. The below these cases are excluded from the target station of this study because the deviation is too large to be seen as the natural fluctuation on groundwater level. The 32 stations which have trend variation or irregular variation were excluded from the study and finally selected 256 stations of which 132 stations were shallow wells and 124 stations were deep wells.

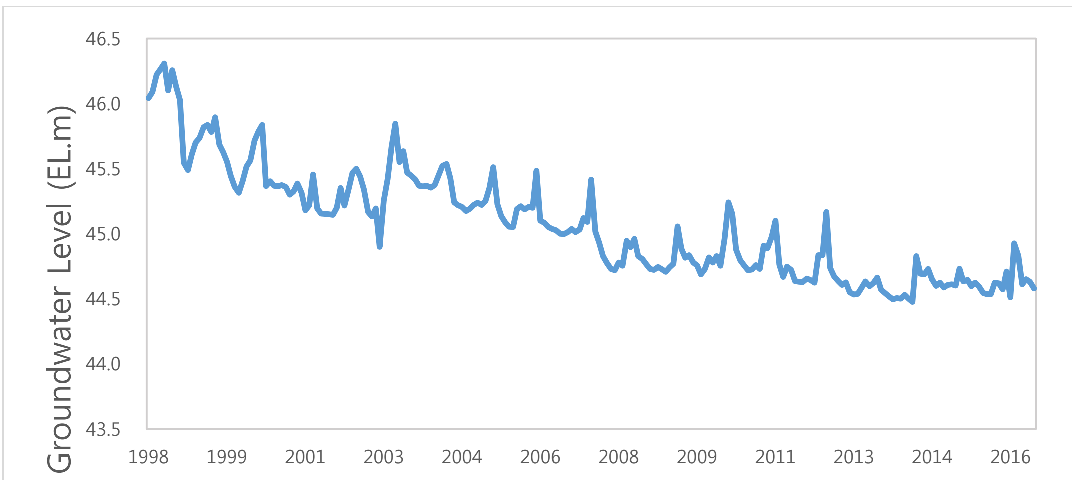


Figure 5.5 Excluded Station (Seongju-Byeokjin) due to Decreasing Trend

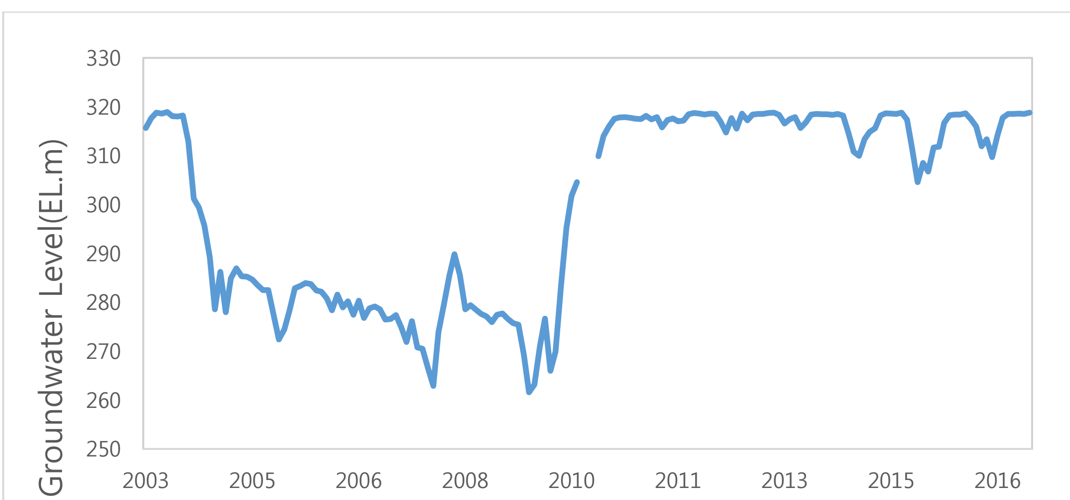


Figure 5.6 Excluded Station (Cheongsong-Hyeonseo) due to Irregular Variation

Table 5.3 Selected National Groundwater Monitoring Stations

Classify	Well ID	Station Name	Well Type	Period of Record	Note
1	241	Daegu bisan	shallow	1995-present	
2	442	Gwangju yudeok	shallow	1995-present	
3	2224	Gapyeong gapyeong	shallow	1995-present	
4	3985	Chungju gageum	shallow	1995-present	
5	4084	Cheongwon gadeok	shallow	1995-present	
6	4854	Buyeo buyeo	shallow	1995-present	
7	5723	Namwon dotong	shallow	1995-present	
8	6752	Suncheon pungdeok	shallow	1995-present	
9	7850	Pohang yeonil	shallow	1995-present	
10	8936	Yecheon yecheon	shallow	1995-present	
11	9250	Jinju chojeon	shallow	1995-present	
12	9858	Daejeon munpyeong	shallow	1997-present	
13	9860	Ulsan beomseo	shallow	1997-present	
14	9862	Ulsan sangbuk	shallow	1997-present	
15	9864	Ulsan onyang	shallow	1997-present	
16	9866	Gangneung hongje	shallow	1997-present	
17	9874	Siheung gunja	shallow	1997-present	
18	9879	Geochang geochang	shallow	1997-present	
19	9881	Uiryeong bongsu	shallow	1997-present	
20	9883	Changnyeong seongsan	shallow	1997-present	
21	9885	Mungyeong nongam	shallow	1997-present	
22	9887	Andong taehwa	shallow	1997-present	
23	9891	Goryeong goryeong	shallow	1997-present	
24	9893	Gunwi uiheung	shallow	1997-present	
25	9895	Seongju byeokjin	shallow	1997-present	excluded
26	9897	Suncheon oeseo	shallow	1997-present	
27	9900	Hampyeong singwang	shallow	1997-present	
28	9903	Hwasun neungju	shallow	1997-present	
29	9908	Jangsu sanseo	shallow	1997-present	
30	9911	Asan dogo	shallow	1997-present	
31	9917	Yesan deoksan	shallow	1997-present	
32	9920	Cheongju naedeok	shallow	1997-present	
33	9922	Chungju dongnyang	shallow	1997-present	
34	11741	Yongin mapyeong	shallow	1996-present	
35	11743	Pyeongtaek tongbok	shallow	1996-present	
36	11745	Icheon yulhyeon	shallow	1996-present	
37	11747	Wonju munmak	shallow	1996-present	
38	11749	Donghae gwiun	shallow	1996-present	
39	11753	Jecheon goam	shallow	1996-present	
40	11755	Okcheon cheongseong	shallow	1996-present	
41	11757	Boeun boeun	shallow	1996-present	

Table 5.3 (continued)

Classify	Well ID	Station Name	Well Type	Period of Record	Note
41	11757	Boeun boeun	shallow	1996-present	
42	11761	Cheonan seonggeo	shallow	1996-present	
43	11763	Yesan yesan	shallow	1996-present	
44	11767	Jeonju manseong	shallow	1996-present	
45	11769	Gochang gosu	shallow	1996-present	
46	11774	Naju sam-do	shallow	1996-present	
47	11779	Jangseong hwangnyong	shallow	1996-present	
48	11784	Geoje sinhyeon	shallow	1996-present	
49	11786	Miryang gagok	shallow	1996-present	
50	11790	Jinhae jaeun	shallow	1996-present	
51	11794	Gyeongju sannae	shallow	1996-present	
52	11796	Gumi wonpyeong	shallow	1996-present	
53	11798	Sangju gongseong	shallow	1996-present	
54	11800	Cheongsong pacheon	shallow	1996-present	
55	11802	Bonghwa myeongho	shallow	1996-present	
56	11804	Gyeongsan namsan	shallow	1996-present	
57	65002	Gangjin seongjeon	shallow	1998-present	
58	65004	Gangjin chillyang	shallow	1998-present	
59	65009	Gwangmyeong cheolsan	shallow	1998-present	
60	65013	Jeungpyeong jeungpyeong	shallow	1998-present	
61	65018	Mungyeong mungyeong	shallow	1998-present	
62	65025	Yangyang sonyang	shallow	1998-present	
63	65028	Yeongdong yanggang	shallow	1998-present	
64	65031	Wanju yongjin	shallow	1998-present	
65	65034	Eumseong saenggeuk	shallow	1998-present	
66	65038	Jangheung jangheung	shallow	1998-present	
67	65049	Hapcheon jeokjung	shallow	1998-present	
68	65051	Naju bonghwang	shallow	1999-present	excluded
69	65053	Bucheon ok-gil	shallow	1999-present	
70	65056	Sunchang sunchang	shallow	1999-present	
71	65060	Suncheon hwangjeon	shallow	1999-present	excluded
72	65062	Asan deuksan	shallow	1999-present	excluded
73	65064	Yangpyeong gae-gun	shallow	1999-present	
74	65066	Yangpyeong yang-dong	shallow	1999-present	
75	65069	Yeongju munjeong	shallow	1999-present	
76	65074	Jangsu jangsu	shallow	1999-present	
77	65076	Jeongeup sintaein	shallow	1999-present	
78	65079	Cheongwon gangnae	shallow	1999-present	
79	65589	Hongcheon hongcheon	shallow	2000-present	
80	65591	Boeun ma-ro	shallow	2000-present	
81	65594	Sejong jochiwon	shallow	2000-present	
82	65602	Cheongdo cheong-do	shallow	2000-present	

Table 5.3 (continued)

Classify	Well ID	Station Name	Well Type	Period of Record	Note
83	65606	Hamyang macheon	shallow	2000-present	
84	65608	Jeongeub ong-dong	shallow	1996-present	
85	65610	Uijeongbu singok	shallow	1995-present	
86	73504	Sokcho nohak	shallow	2001-present	
87	73508	Jeongseon jeongseon	shallow	2001-present	excluded
88	73510	Hwacheon gan-dong	shallow	2001-present	
89	73516	Geumsan geumsan	shallow	2001-present	
90	73519	Yesan oga	shallow	2001-present	
91	73521	Cheonan susin	shallow	2001-present	
92	73526	Gokseong godal	shallow	2001-present	
93	73529	Jangseong nam-myeon	shallow	2001-present	
94	73531	Hwasun iyang	shallow	2001-present	
95	73538	Andong giran	shallow	2001-present	
96	73540	Chilgok gasan	shallow	2001-present	
97	73543	Pohang gibuk	shallow	2001-present	
98	73547	Uiryeong uiryeong	shallow	2001-present	
99	73550	Hadong hwagae	shallow	2001-present	
100	82001	Yangju gwangjeok	shallow	2002-present	
101	82003	Hwaseong yanggam	shallow	2002-present	
102	82006	Samcheok gagok	shallow	2002-present	excluded
103	82012	Pyeongchang bongpyeong	shallow	2002-present	
104	82017	Sejong bugang	shallow	2002-present	
105	82021	Boryeong cheongso	shallow	2002-present	
106	82024	Gochang sangha	shallow	2002-present	
107	82027	Buan baeksan	shallow	2002-present	
108	82029	Buan sangseo	shallow	2002-present	
109	82031	Sunchang ssangchi	shallow	2002-present	
110	82038	Jangseong bugi	shallow	2002-present	
111	82045	Chilgog waegwan	shallow	2002-present	
112	82049	Hamyang byeonggok	shallow	2002-present	
113	84005	Daegu gachang	shallow	2003-present	
114	84011	Inje inje	shallow	2003-present	
115	84014	Namyangju byeollae	shallow	2003-present	
116	84020	Hwaseong paltan	shallow	2003-present	
117	84022	Gongju jeongan	shallow	2003-present	
118	84024	Dangjin sunseong	shallow	2003-present	
119	84027	Gochang seongnae	shallow	2003-present	
120	84038	Sancheong danseong	shallow	2003-present	
121	87234	Wonju myeongnyun	shallow	2004-present	
122	87240	Yeoju jeom-dong	shallow	2004-present	
123	87243	Yongin namsa	shallow	2004-present	

Table 5.3 (continued)

Classify	Well ID	Station Name	Well Type	Period of Record	Note
124	87248	Hwaseong ujeong	shallow	2004-present	
125	87250	Boryeong cheongna	shallow	2004-present	
126	87256	Wanju samnye	shallow	2004-present	
127	87260	Yeongdeok dalsan	shallow	2004-present	
128	87262	Uljin buk-myeon	shallow	2004-present	
129	87265	Yangsan ungsang	shallow	2004-present	
130	87267	Uiryeong nakseo	shallow	2004-present	
131	95508	Yangpyeong yangseo	shallow	2005-present	
132	95510	Pyeongtaeg anjung	shallow	2005-present	
133	95512	Pocheon yeongbuk	shallow	2005-present	
134	95515	Inje nam-myeon	shallow	2005-present	
135	95521	Seocheon masan	shallow	2005-present	
136	95523	Gunsan impi	shallow	2005-present	
137	95526	Iksan nangsan	shallow	2005-present	
138	95533	Gimcheon daedeok	shallow	2005-present	
139	6721	Mokpo yongdang	deep	1995-present	
140	9345	Gimhae samjeong	deep	1995-present	excluded
141	9855	Busan dongdaesin	deep	1997-present	
142	9856	Daegu hyeonpung	deep	1997-present	
143	9867	Taebaek wangji	deep	1997-present	
144	9869	Pyeongchang daehwa	deep	1997-present	
145	9870	Hoengseong anheung	deep	1997-present	
146	9871	Dongducheon sangpae	deep	1997-present	
147	9872	Suwon omokcheon	deep	1997-present	
148	9875	Gapyeong buk-myeon	deep	1997-present	
149	9876	Yangpyeong yongmun	deep	1997-present	
150	9877	Yeoju yeoju	deep	1997-present	
151	9888	Pohang jangheung	deep	1997-present	excluded
152	9889	Pohang singwang	deep	1997-present	excluded
153	9898	Damyang damyang	deep	1997-present	excluded
154	9901	Haenam haenam	deep	1997-present	
155	9904	Gimje bongnam	deep	1997-present	
156	9906	Imsil imsil	deep	1997-present	excluded
157	9909	Seosan seongnam	deep	1997-present	
158	9914	Buyeo yanghwa	deep	1997-present	
159	9915	Buyeo oksan	deep	1997-present	
160	9918	Hongseong hongseong	deep	1997-present	excluded
161	11758	Cheongwon miwon	deep	1996-present	
162	11759	Cheongwon bugil	deep	1996-present	
163	11764	Gongju banpo	deep	1996-present	
164	11765	Nonsan sangwol	deep	1996-present	

Table 5.3 (continued)

Classify	Well ID	Station Name	Well Type	Period of Record	Note
165	11772	Gunsan seosu	deep	1996-present	
166	11775	Muan muan	deep	1996-present	excluded
167	11782	Masan jinjeon	deep	1996-present	
168	65005	Goseong georyu	deep	1998-present	
169	65006	Goheung daeseo	deep	1998-present	
170	65007	Gongju sinpung	deep	1998-present	
171	65010	Gwangju gwangju	deep	1998-present	
172	65011	Goesan goesan	deep	1998-present	excluded
173	65014	Danyang danyang	deep	1998-present	
174	65015	Daegu daebong	deep	1998-present	excluded
175	65016	Daejeon taepyeong	deep	1998-present	
176	65019	Boseong gyeombaek	deep	1998-present	
177	65020	Buyeo gyuam	deep	1998-present	
178	65026	Yeongdeog yeonghae	deep	1998-present	
179	65029	Yeongyang ibam	deep	1998-present	
180	65032	Uljin onjeong	deep	1998-present	
181	65035	Uiseong uiseong	deep	1998-present	excluded
182	65036	Incheon hajeom	deep	1998-present	excluded
183	65039	Jinan maryeong	deep	1998-present	
184	65040	Jincheon jincheon	deep	1998-present	
185	65041	Changnyeong yeongsan	deep	1998-present	
186	65042	Cheongyang jeongsan	deep	1998-present	excluded
187	65043	Taean wonbuk	deep	1998-present	
188	65044	Taean taean	deep	1998-present	
189	65045	Tongyeong yongnam	deep	1998-present	
190	65047	Pocheon hwahyeon	deep	1998-present	
191	65054	Sangju seomun	deep	1999-present	
192	65057	Suncheon sangsa	deep	1999-present	
193	65058	Suncheon seungju	deep	1999-present	
194	65067	Yeongdong simcheon	deep	1999-present	
195	65070	Okcheon gunbuk	deep	1999-present	
196	65071	Okcheon iwon	deep	1999-present	excluded
197	65077	Jecheon cheongpung	deep	1999-present	
198	65080	Hwasun buk-myeon	deep	1999-present	
199	65586	Gunpo dangjeong	deep	2000-present	
200	65587	Pyeongchang jinbu	deep	2000-present	
201	65592	Dangjin dangjin	deep	2000-present	
202	65595	Cheonan buk-myeon	deep	2000-present	
203	65596	Wanju gosan	deep	2000-present	
204	65597	Wanju unju	deep	2000-present	
205	65598	Jinan jeongcheon	deep	2000-present	

Table 5.3 (continued)

Classify	Well ID	Station Name	Well Type	Period of Record	Note
206	65599	Haenam hyeonsan	deep	2000-present	
207	65600	Mungyeong yeongsun	deep	2000-present	
208	73502	Goseong toseong	deep	2001-present	
209	73505	Yeongwol yeongwol	deep	2001-present	
210	73511	Hwacheon sanae	deep	2001-present	
211	73514	Hoengseong hoengseong	deep	2001-present	
212	73517	Seosan unsan	deep	2001-present	
213	73524	Jangsu beonam	deep	2001-present	
214	73527	Muan mongtan	deep	2001-present	excepted
215	73532	Gyeongsan jillyang	deep	2001-present	
216	73535	Gimcheon jijwa	deep	2001-present	
217	73536	Bonghwa jaesan	deep	2001-present	
218	73541	Pohang guryongpo	deep	2001-present	
219	73544	Miryang danjang	deep	2001-present	
220	73545	Sancheong sancheong	deep	2001-present	
221	73548	Jinju ilbanseong	deep	2001-present	
222	82004	Gangneung wangsan	deep	2002-present	
223	82007	Jeongseon dong-myeon	deep	2002-present	
224	82008	Chuncheon buksan	deep	2002-present	excluded
225	82015	Hongcheon seoseok	deep	2002-present	
226	82018	Gongju tancheon	deep	2002-present	excluded
227	82019	Boryeong ungcheon	deep	2002-present	
228	82022	Gochang daesan	deep	2002-present	excluded
229	82025	Gochang heungdeok	deep	2002-present	
230	82032	Jeongeup sangpyeong	deep	2002-present	
231	82033	Gokseong moksa-dong	deep	2002-present	
232	82034	Boseong beolgyo	deep	2002-present	
233	82035	Yeosu sora	deep	2002-present	
234	82036	Yeonggwang bulgap	deep	2002-present	
235	82039	Gumi goa	deep	2002-present	excluded
236	82040	Yeongcheon hwabuk	deep	2002-present	
237	82041	Uiseong angye	deep	2002-present	excluded
238	82042	Cheongsong hyeonseo	deep	2002-present	excluded
239	82046	Geochang sinwon	deep	2002-present	
240	84003	Busan jangan	deep	2003-present	
241	84006	Gwangju unjeong	deep	2003-present	
242	84007	Gangneung yeongok	deep	2003-present	
243	84008	Samcheong mapyeong	deep	2003-present	
244	84009	Samcheok singi	deep	2003-present	
245	84015	Ansan bugok	deep	2003-present	
246	84016	Anseong sinmosan	deep	2003-present	excluded

Table 5.3 (continued)

Classify	Well ID	Station Name	Well Type	Period of Record	Note
247	84025	Hongseong gyeolseong	deep	2003-present	
248	84028	Gimje yongji	deep	2003-present	
249	84029	Muan haeje	deep	2003-present	
250	84030	Gimcheon buhang	deep	2003-present	
251	84031	Cheongsong bunam	deep	2003-present	
252	84032	Yeongcheon geumno	deep	2003-present	
253	84036	Sacheon sacheon	deep	2003-present	
254	84039	Namhae namhae	deep	2003-present	
255	84040	Geochang ungyang	deep	2003-present	
256	84041	Hapcheon ya-ro	deep	2003-present	
257	87232	Busan deokcheon	deep	2004-present	excluded
258	87236	Gimpo yangchon	deep	2004-present	
259	87237	Anyang bisan	deep	2004-present	
260	87238	Yeoju geumsa	deep	2004-present	excluded
261	87241	Osan gwol-dong	deep	2004-present	
262	87244	Paju munsan	deep	2004-present	
263	87245	Pyeongtaek jinwi	deep	2004-present	
264	87246	Hanam hasangok	deep	2004-present	
265	87251	Buyeo eunsan	deep	2004-present	
266	87252	Seosan palbong	deep	2004-present	
267	87253	Gimje buryang	deep	2004-present	
268	87254	Muju mupung	deep	2004-present	
269	87257	Gurye toji	deep	2004-present	
270	87258	Hwasun nam-myeon	deep	2004-present	
271	87263	Gimhae saengnim	deep	2004-present	
272	87268	Hapcheon sam-ga	deep	2004-present	
273	95501	Seoul hang-dong	deep	2005-present	
274	95502	Seoul jangwi	deep	2005-present	
275	95503	Incheon mansu	deep	2005-present	excluded
276	95506	Gapyeong sang-myeon	deep	2005-present	
277	95516	Inje sangnam	deep	2005-present	excluded
278	95517	Inje seohwa	deep	2005-present	
279	95518	Cheorwon cheorwon	deep	2005-present	
280	95519	Hongcheon seo-myeon	deep	2005-present	
281	95524	Muju muju	deep	2005-present	
282	95527	Gwangyang bonggang	deep	2005-present	
283	95528	Jindo uisin	deep	2005-present	
284	95531	Gunwi sanseong	deep	2005-present	
285	95534	Jeju nohyeong	deep	2005-present	
286	95535	Jeju dongheung	deep	2005-present	excluded
287	95536	Jeju hangyeong	deep	2005-present	
288	95537	Jeju jocheon	deep	2005-present	

5.4 The SGI Calculation based on Groundwater Level Data

The most widely used index for meteorological drought monitoring is SPI, which was proposed by McKee, Doesken et al. (1993). The most of hydrological studies use a standardizing technique that the average of the time series is 0 and the variance is 1 in order to remove tendency of data and carry out relative comparison of the data. If the raw data follows a normal distribution, the normalization using mean value can be easily calculated by the following equation 5.1, 5.2, and 5.3.

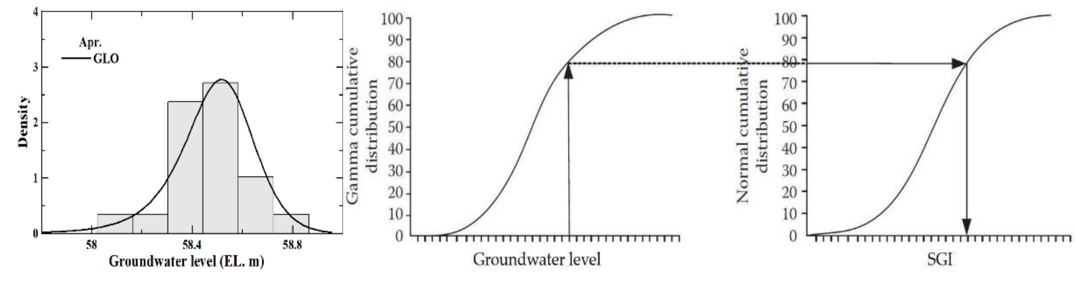
$$\tilde{d} = \frac{d_i - E(d)}{\sigma_d} \tag{5.1}$$

$$E_d = \frac{1}{N}\sum_{i-1}^{N} d_i \tag{5.2}$$

$$\sigma_d = \sqrt{\left(\frac{1}{N}\sum_{i-1}^{N}(d_i - E(d))^2\right)} \tag{5.3}$$

Where, $\tilde{d}$ is a normalized value, E_d is mean of d, σ_d is refer to standard deviation of d. However, the average or variance of hydrological data such as precipitation and groundwater level vary depending on seasonal and spatial characteristics. In order to normalize data, quantile normalization technique can be widely applied for normalizing hydrological time series obtained from a number of stations. The following procedure is used to normalize the groundwater level data with different probability distribution by month or by sites using standard normal distribution.

The probability distribution considering monthly data characteristics at each station is determined. And then, it is converted into a cumulative distribution function which can be obtained the cumulative probability of 0 to 1 corresponding to the range of the data. Thus, when a specific cumulative probability corresponding to an observed groundwater level is substituted into the quantile function (CDF^{-1}) , a normalized index can be obtained with a standard normal distribution as shown in Figure. 5.7



(a) PDF of G.W.L. (b) CDF of G.W.L. (c) Normalization

Figure 5.7. SGI Calculation Process through the Normalization of Groundwater Level Data

Monthly groundwater level data shows the various range and distribution by stations. Thus, it is unreasonable to fit the monthly probability distribution at each of stations through generalizing a specific distribution or estimating parametric density. In this research, Kernel Density Estimation (KDE) which is a non-parametric way to estimate the probability density function was applied for estimating probability distribution of monthly groundwater level data at 256 monitoring stations. Histogram is the simplest way of non-parametric density estimation. The drawbacks of histogram are that the resulting estimate is not smooth and discontinuity appears at boundary of neighboring bins. KDE is a method to improve these histogram problems using Kernel Function. The Kernel estimate of probability density function is shown at the eq. 2.24.

The Figure 5.8 shows the results of estimating the monthly groundwater level distribution with KDE in MATLAB based on groundwater level observation data from 1997 to 2016. The red line in Figure 5.8 shows probability density estimates of the monthly groundwater level and the blue bar on the background of the graph represents the histogram of the monthly groundwater level. The Figure 5.9 is plots of the monthly groundwater levels of several groundwater monitoring stations.

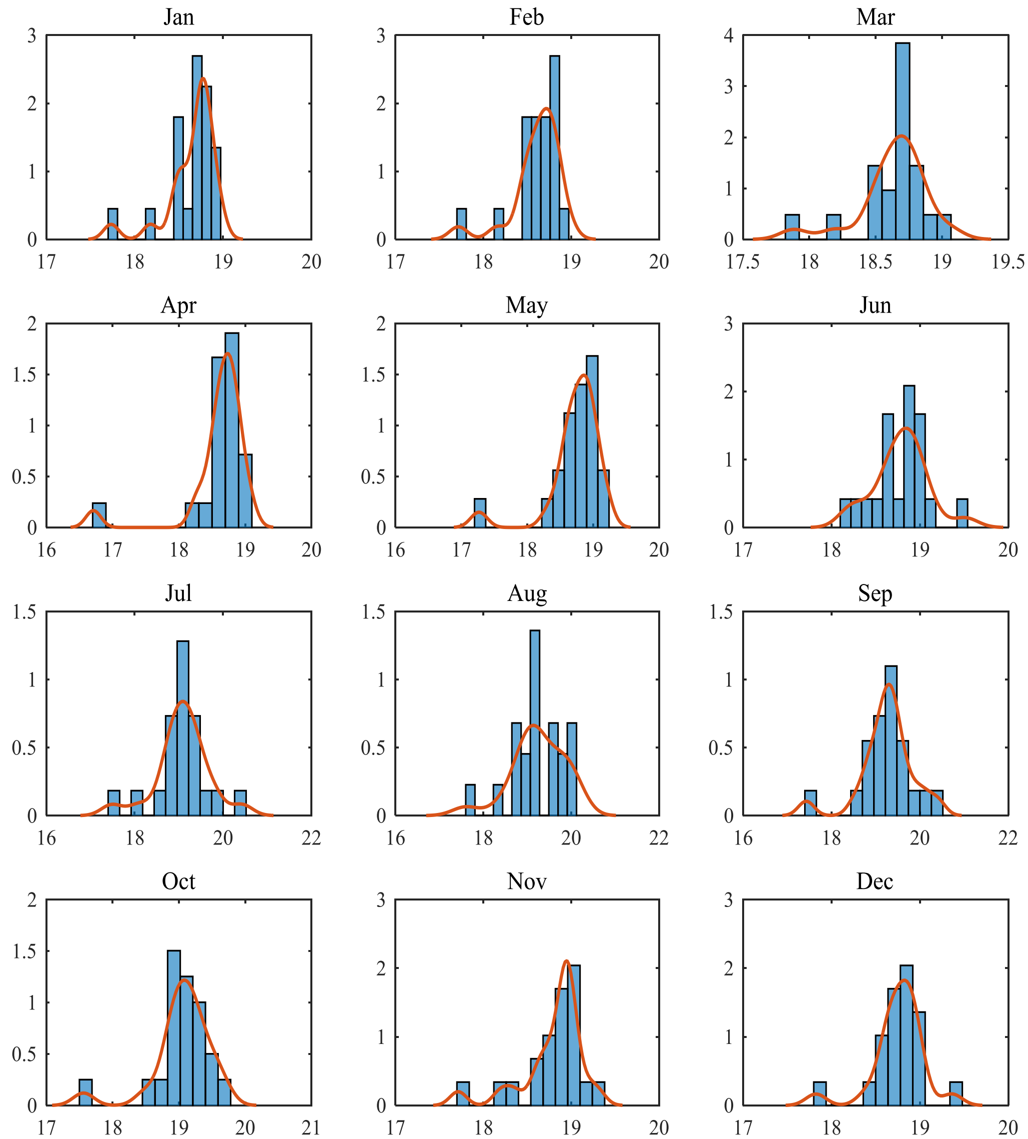


Figure 5.8 Example of Monthly Kernel Density Function at Daegu-Bysan Station

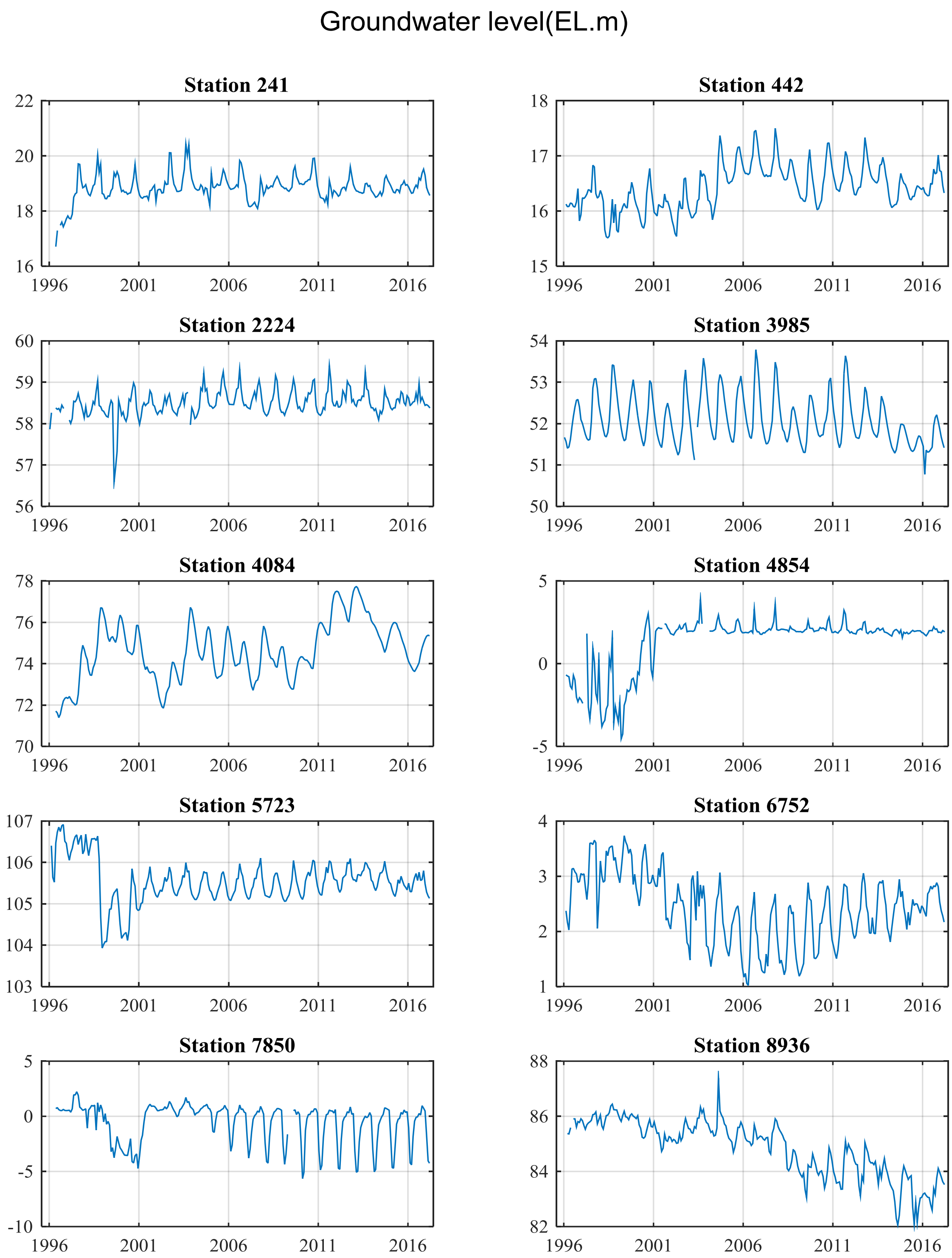


Figure 5.9 Plots of Groundwater Levels for Station No. 241 – 8936

5.5 The Results of SGI Calculation

5.5.1 SGI Calculation for Each of Monitoring Station

According to the process described in previous section, monthly groundwater levels, pertinent groundwater level percentiles, and corresponding SGI values for 256 national groundwater monitoring stations were calculated. The results shown in Table 5.4 are the results of SGI calculation for monthly average groundwater levels of Daegu-Bysan station from 1997 to 2016.

Table 5.4 Calculated Percentile and SGI at Daegu-Bysan Station

Date	GWL (EL.m)	Percentile	SGI	Date	GWL (EL.m)	Percentile	SGI
1997-01	17.7342	0.0238	-1.9808	1999-07	19.3874	0.7201	0.5830
1997-02	17.7171	0.0238	-1.9807	1999-08	19.2535	0.4924	-0.0191
1997-03	17.8839	0.0251	-1.9587	1999-09	19.4267	0.6317	0.3363
1997-04	18.5047	0.2317	-0.7333	1999-10	19.2823	0.7077	0.5467
1997-05	18.6233	0.2677	-0.6198	1999-11	18.9333	0.5967	0.2448
1997-06	18.6680	0.3247	-0.4547	1999-12	18.7081	0.3638	-0.3483
1997-07	19.7123	0.8747	1.1491	2000-01	18.7546	0.5806	0.2035
1997-08	19.6939	0.7399	0.6430	2000-02	18.6834	0.5446	0.1121
1997-09	19.1167	0.3457	-0.3969	2000-03	18.6887	0.5398	0.1001
1997-10	18.8455	0.2234	-0.7606	2000-04	18.6113	0.3637	-0.3485
1997-11	18.8793	0.4895	-0.0262	2000-05	18.6465	0.2944	-0.5406
1997-12	18.9577	0.7933	0.8178	2000-06	18.6633	0.3193	-0.4696
1998-01	18.7352	0.5359	0.0901	2000-07	18.8845	0.3243	-0.4557
1998-02	18.6079	0.4079	-0.2330	2000-08	19.1961	0.4549	-0.1133
1998-03	18.5581	0.2987	-0.5281	2000-09	19.6950	0.8079	0.8703
1998-04	18.7180	0.5353	0.0887	2000-10	19.1229	0.5300	0.0753
1998-05	18.9165	0.6730	0.4481	2000-11	18.7987	0.3680	-0.3373
1998-06	18.9730	0.7405	0.6450	2000-12	18.5839	0.1923	-0.8696
1998-07	19.3519	0.6962	0.5135	2001-01	18.4900	0.1941	-0.8628
1998-08	20.0216	0.8841	1.1958	2001-02	18.4664	0.2071	-0.8164
1998-09	19.3940	0.6023	0.2593	2001-03	18.5213	0.2458	-0.6877
1998-10	19.6945	0.9599	1.7494	2001-04	18.5227	0.2504	-0.6733
1998-11	18.6397	0.2222	-0.7648	2001-05	18.5435	0.1886	-0.8832
1998-12	18.6084	0.2201	-0.7717	2001-06	18.4107	0.1297	-1.1278
1999-01	18.4545	0.1616	-0.9878	2001-07	18.7371	0.2274	-0.7473
1999-02	18.4475	0.1875	-0.8872	2001-08	18.7597	0.1941	-0.8627
1999-03	18.5487	0.2844	-0.5698	2001-09	18.8627	0.1815	-0.9097
1999-04	18.5403	0.2702	-0.6122	2001-10	18.9384	0.3125	-0.4889
1999-05	18.7435	0.4201	-0.2015	2001-11	18.3507	0.1170	-1.1903
1999-06	18.8230	0.5317	0.0794	2001-12	18.7555	0.4441	-0.1405

Table 5.4 (continued)

Date	GWL (EL.m)	Percentile	SGI	Date	GWL (EL.m)	Percentile	SGI
2002-01	18.7891	0.6620	0.4180	2005-11	18.9914	0.7170	0.5740
2002-02	18.7831	0.7332	0.6225	2005-12	18.8610	0.6346	0.3440
2002-03	18.6542	0.4707	-0.0736	2006-01	18.7880	0.6594	0.4108
2002-04	18.6684	0.4524	-0.1196	2006-02	18.8028	0.7677	0.7312
2002-05	19.0610	0.8526	1.0475	2006-03	18.8200	0.7838	0.7851
2002-06	18.9641	0.7295	0.6112	2006-04	18.8675	0.7750	0.7556
2002-07	18.9810	0.3995	-0.2547	2006-05	18.9537	0.7255	0.5992
2002-08	20.1165	0.9167	1.3835	2006-06	18.8827	0.6185	0.3016
2002-09	20.1118	0.9237	1.4303	2006-07	19.8323	0.9069	1.3216
2002-10	19.3073	0.7317	0.6181	2006-08	19.7460	0.7651	0.7226
2002-11	18.9755	0.6851	0.4820	2006-09	19.4964	0.6895	0.4943
2002-12	18.8566	0.6268	0.3234	2006-10	19.1476	0.5597	0.1502
2003-01	18.7130	0.4880	-0.0302	2006-11	18.9454	0.6222	0.3112
2003-02	18.7111	0.5976	0.2471	2006-12	18.3954	0.0773	-1.4234
2003-03	18.7260	0.6151	0.2926	2007-01	18.1784	0.0715	-1.4649
2003-04	18.7590	0.6051	0.2667	2007-02	18.1596	0.0717	-1.4632
2003-05	19.1848	0.9439	1.5886	2007-03	18.1908	0.0753	-1.4374
2003-06	19.5145	0.9748	1.9558	2007-04	18.2514	0.0843	-1.3765
2003-07	20.4277	0.9758	1.9746	2007-05	18.3207	0.0770	-1.4253
2003-08	20.0134	0.8810	1.1801	2007-06	18.1923	0.0451	-1.6947
2003-09	20.4047	0.9736	1.9359	2007-07	18.0952	0.0722	-1.4599
2003-10	19.5408	0.8978	1.2692	2007-08	18.3867	0.0854	-1.3698
2003-11	19.1654	0.9217	1.4168	2007-09	19.1877	0.4070	-0.2352
2003-12	18.9843	0.8282	0.9471	2007-10	18.9412	0.3155	-0.4803
2004-01	18.8363	0.7670	0.7289	2007-11	18.5833	0.1872	-0.8884
2004-02	18.7849	0.7364	0.6323	2007-12	18.7020	0.3538	-0.3752
2004-03	18.7556	0.6729	0.4478	2008-01	18.9157	0.8976	1.2677
2004-04	18.7784	0.6378	0.3525	2008-02	18.8137	0.7860	0.7927
2004-05	18.9511	0.7219	0.5886	2008-03	18.8526	0.8295	0.9523
2004-06	18.8801	0.6148	0.2919	2008-04	18.9161	0.8360	0.9784
2004-07	18.6384	0.1782	-0.9221	2008-05	18.8804	0.6200	0.3054
2004-08	18.8453	0.2360	-0.7192	2008-06	19.0435	0.8178	0.9071
2004-09	18.8086	0.1567	-1.0081	2008-07	19.1581	0.5469	0.1177
2004-10	18.4871	0.0747	-1.4413	2008-08	19.2606	0.4969	-0.0078
2004-11	18.1965	0.0739	-1.4473	2008-09	19.1521	0.3755	-0.3174
2004-12	19.3634	0.9761	1.9796	2008-10	19.0001	0.3818	-0.3008
2005-01	18.8746	0.8383	0.9874	2008-11	18.9002	0.5291	0.0731
2005-02	18.8440	0.8331	0.9664	2008-12	18.8673	0.6459	0.3743
2005-03	18.8961	0.8783	1.1663	2009-01	18.8135	0.7181	0.5771
2005-04	18.9805	0.8988	1.2748	2009-02	18.8299	0.8118	0.8847
2005-05	18.9337	0.6977	0.5179	2009-03	18.7531	0.6681	0.4346
2005-06	18.9442	0.7038	0.5354	2009-04	18.7171	0.5337	0.0847
2005-07	19.2168	0.5948	0.2398	2009-05	18.7928	0.4901	-0.0247
2005-08	19.5066	0.6434	0.3675	2009-06	18.8650	0.5929	0.2350
2005-09	19.3706	0.5806	0.2034	2009-07	19.4663	0.7682	0.7328
2005-10	19.1465	0.5583	0.1466	2009-08	19.6238	0.7050	0.5387

Table 5.4 (continued)

Date	GWL (EL.m)	Percentile	SGI	Date	GWL (EL.m)	Percentile	SGI
2009-09	19.2544	0.4692	-0.0773	2013-05	18.6452	0.2929	-0.5450
2009-10	19.1210	0.5277	0.0694	2013-06	18.6697	0.3266	-0.4494
2009-11	18.9849	0.7041	0.5361	2013-07	18.9894	0.4062	-0.2372
2009-12	18.9985	0.8449	1.0149	2013-08	19.0074	0.3311	-0.4370
2010-01	18.9642	0.9459	1.6060	2013-09	18.8943	0.1975	-0.8505
2010-02	18.9689	0.9563	1.7094	2013-10	18.9274	0.3009	-0.5219
2010-03	19.0613	0.9704	1.8862	2013-11	18.7510	0.3158	-0.4795
2010-04	19.0790	0.9590	1.7396	2013-12	18.6727	0.3079	-0.5017
2010-05	19.1390	0.9167	1.3835	2014-01	18.5868	0.2967	-0.5340
2010-06	19.1397	0.8901	1.2270	2014-02	18.5018	0.2490	-0.6777
2010-07	19.3890	0.7211	0.5862	2014-03	18.5287	0.2558	-0.6563
2010-08	19.9061	0.8377	0.9852	2014-04	18.5980	0.3446	-0.4000
2010-09	19.9183	0.8800	1.1752	2014-05	18.6987	0.3597	-0.3592
2010-10	19.3939	0.8050	0.8596	2014-06	18.5640	0.2226	-0.7633
2010-11	18.9207	0.5703	0.1771	2014-07	18.7039	0.2094	-0.8085
2010-12	18.6861	0.3286	-0.4438	2014-08	19.1723	0.4391	-0.1532
2011-01	18.4948	0.1989	-0.8455	2014-09	19.2857	0.4992	-0.0019
2011-02	18.4704	0.2115	-0.8014	2014-10	19.1294	0.5378	0.0949
2011-03	18.4510	0.1692	-0.9573	2014-11	19.0317	0.7895	0.8046
2011-04	18.3323	0.1158	-1.1963	2014-12	18.9223	0.7398	0.6427
2011-05	18.5219	0.1710	-0.9501	2015-01	18.7916	0.6679	0.4342
2011-06	18.2540	0.0663	-1.5041	2015-02	18.6818	0.5415	0.1041
2011-07	19.1100	0.5068	0.0169	2015-03	18.6613	0.4847	-0.0385
2011-08	18.8552	0.2413	-0.7023	2015-04	18.7797	0.6399	0.3583
2011-09	18.5390	0.0776	-1.4214	2015-05	18.7703	0.4578	-0.1060
2011-10	18.7481	0.1561	-1.0106	2015-06	18.6750	0.3328	-0.4323
2011-11	18.6997	0.2689	-0.6162	2015-07	18.9394	0.3662	-0.3420
2011-12	18.6265	0.2428	-0.6974	2015-08	18.9768	0.3118	-0.4907
2012-01	18.5387	0.2444	-0.6922	2015-09	19.0943	0.3278	-0.4461
2012-02	18.5834	0.3674	-0.3387	2015-10	18.9381	0.3121	-0.4899
2012-03	18.7794	0.7166	0.5728	2015-11	18.9600	0.6529	0.3932
2012-04	18.8513	0.7523	0.6817	2015-12	18.8742	0.6582	0.4076
2012-05	18.8648	0.5968	0.2449	2016-01	18.7497	0.5691	0.1741
2012-06	18.7620	0.4447	-0.1392	2016-02	18.6466	0.4760	-0.0602
2012-07	18.9842	0.4020	-0.2481	2016-03	18.6645	0.4911	-0.0223
2012-08	19.1313	0.4120	-0.2225	2016-04	18.8370	0.7312	0.6165
2012-09	19.6017	0.7608	0.7090	2016-05	18.9416	0.7088	0.5499
2012-10	19.2716	0.6971	0.5162	2016-06	18.8520	0.5740	0.1865
2012-11	18.9697	0.6731	0.4484	2016-07	19.1974	0.5791	0.1997
2012-12	18.8239	0.5672	0.1692	2016-08	19.1255	0.4081	-0.2324
2013-01	18.7303	0.5251	0.0630	2016-09	19.3790	0.5884	0.2235
2013-02	18.7189	0.6125	0.2860	2016-10	19.5194	0.8864	1.2078
2013-03	18.6813	0.5248	0.0623	2016-11	19.2983	0.9721	1.9133
2013-04	18.6723	0.4588	-0.1036	2016-12	18.8587	0.6305	0.3332

5.5.2 SGI Calculation for 167 Cities Nationwide

In order to conduct a groundwater drought monitoring for 167 cities nationwide, the SGI values calculated based on groundwater levels of 256 monitoring stations were reproduced to SGI values of 167 cities. The Thiessen polygon of national groundwater monitoring networks was constructed as shown in Figure 5.10 to calculate area average SGI for each city. Table 5.5 and 5.6 show the area weight factors by station for calculating area average SGI of Cheongju city in Chungcheong province and the results of area average SGI calculation during the period of observation.

Table 5.5 Area Weight Factors by Station for Calculating Area Average SGI of Cheongju

City	City Code	Station Name	Station Code	Area (km^2)	Weight Factor
Cheongju	43110	Okchun-Gunbuk	65070	1.470	0.002
		Jincheon-Jincheon	65040	7.202	0.008
		Cheongwon-Miwon	11758	161.305	0.172
		Cheongwon-Bukil	11759	96.449	0.103
		Daejeon-Munpyung	9858	35.735	0.038
		Sejong-Bugang	82017	26.045	0.028
		Sejong-Jochiwon	65594	31.570	0.034
		JeungpyeungJeungpyeung	65013	12.606	0.013
		Cheonan-Susin	73521	67.342	0.072
		Cheongwon-Gaduck	4084	188.717	0.201
		Cheongwon-Gangne	65079	102.198	0.109
		Cheongju-Neduck	9920	208.728	0.222

Table 5.6 Results of Calculating Area Average SGI at Cheongju

Date	SGI	Date	SGI	Date	SGI	Date	SGI
2005-01	-0.3996	2005-07	-0.0069	2006-01	-0.1464	2006-07	0.5691
2005-02	-0.4771	2005-08	-0.1924	2006-02	-0.0706	2006-08	0.2103
2005-03	-0.4304	2005-09	-0.0529	2006-03	-0.2121	2006-09	-0.0295
2005-04	-0.2697	2005-10	0.2056	2006-04	-0.1458	2006-10	-0.1973
2005-05	-0.3545	2005-11	0.0874	2006-05	0.0892	2006-11	-0.1086
2005-06	0.0584	2005-12	-0.1483	2006-06	0.2552	2006-12	-0.0455

Table 5.6 (continued)

Date	SGI	Date	SGI	Date	SGI	Date	SGI
2007-01	-0.0549	2009-07	-0.5947	2012-01	0.4130	2014-07	-0.5582
2007-02	0.0301	2009-08	-0.5210	2012-02	0.3531	2014-08	-0.4488
2007-03	0.0944	2009-09	-0.6582	2012-03	0.2825	2014-09	-0.4254
2007-04	0.1191	2009-10	-0.6242	2012-04	0.6056	2014-10	-0.2465
2007-05	-0.0272	2009-11	-0.3483	2012-05	0.2413	2014-11	-0.0144
2007-06	-0.3518	2009-12	-0.1911	2012-06	-0.0238	2014-12	-0.0925
2007-07	-0.2855	2010-01	-0.1571	2012-07	0.1507	2015-01	-0.0100
2007-08	0.0059	2010-02	-0.0676	2012-08	0.4024	2015-02	0.1065
2007-09	0.5945	2010-03	0.2633	2012-09	0.6571	2015-03	0.0888
2007-10	0.6257	2010-04	0.3208	2012-10	0.3691	2015-04	0.2231
2007-11	0.4952	2010-05	0.1650	2012-11	0.5317	2015-05	-0.2106
2007-12	0.2931	2010-06	0.0000	2012-12	0.6005	2015-06	-0.3677
2008-01	0.4594	2010-07	-0.3539	2013-01	0.6948	2015-07	-0.4219
2008-02	0.4872	2010-08	-0.0372	2013-02	0.8657	2015-08	-0.7069
2008-03	0.3629	2010-09	0.3417	2013-03	0.6858	2015-09	-0.9340
2008-04	0.0438	2010-10	0.0640	2013-04	0.5575	2015-10	-0.9742
2008-05	-0.1283	2010-11	-0.0323	2013-05	0.4907	2015-11	-0.7184
2008-06	0.2780	2010-12	0.0356	2013-06	0.7213	2015-12	-0.5050
2008-07	-0.0643	2011-01	0.0146	2013-07	0.4667	2016-01	-0.5904
2008-08	0.0647	2011-02	0.0763	2013-08	0.3277	2016-02	-0.5533
2008-09	-0.0630	2011-03	0.1473	2013-09	0.2007	2016-03	-0.4467
2008-10	-0.0111	2011-04	0.0634	2013-10	0.1048	2016-04	-0.1675
2008-11	-0.3626	2011-05	0.5901	2013-11	0.0563	2016-05	-0.0428
2008-12	-0.3297	2011-06	0.6516	2013-12	0.2452	2016-06	-0.3103
2009-01	-0.5183	2011-07	1.0841	2014-01	0.2150	2016-07	0.0173
2009-02	-0.4916	2011-08	1.0498	2014-02	0.2409	2016-08	-0.6048
2009-03	-0.5904	2011-09	0.5598	2014-03	0.1321	2016-09	-0.7677
2009-04	-0.6720	2011-10	0.5344	2014-04	-0.0120	2016-10	-0.6553
2009-05	-0.6268	2011-11	0.5473	2014-05	-0.1756	2016-11	-0.6927
2009-06	-0.5554	2011-12	0.5401	2014-06	-0.0975	2016-12	-0.4559

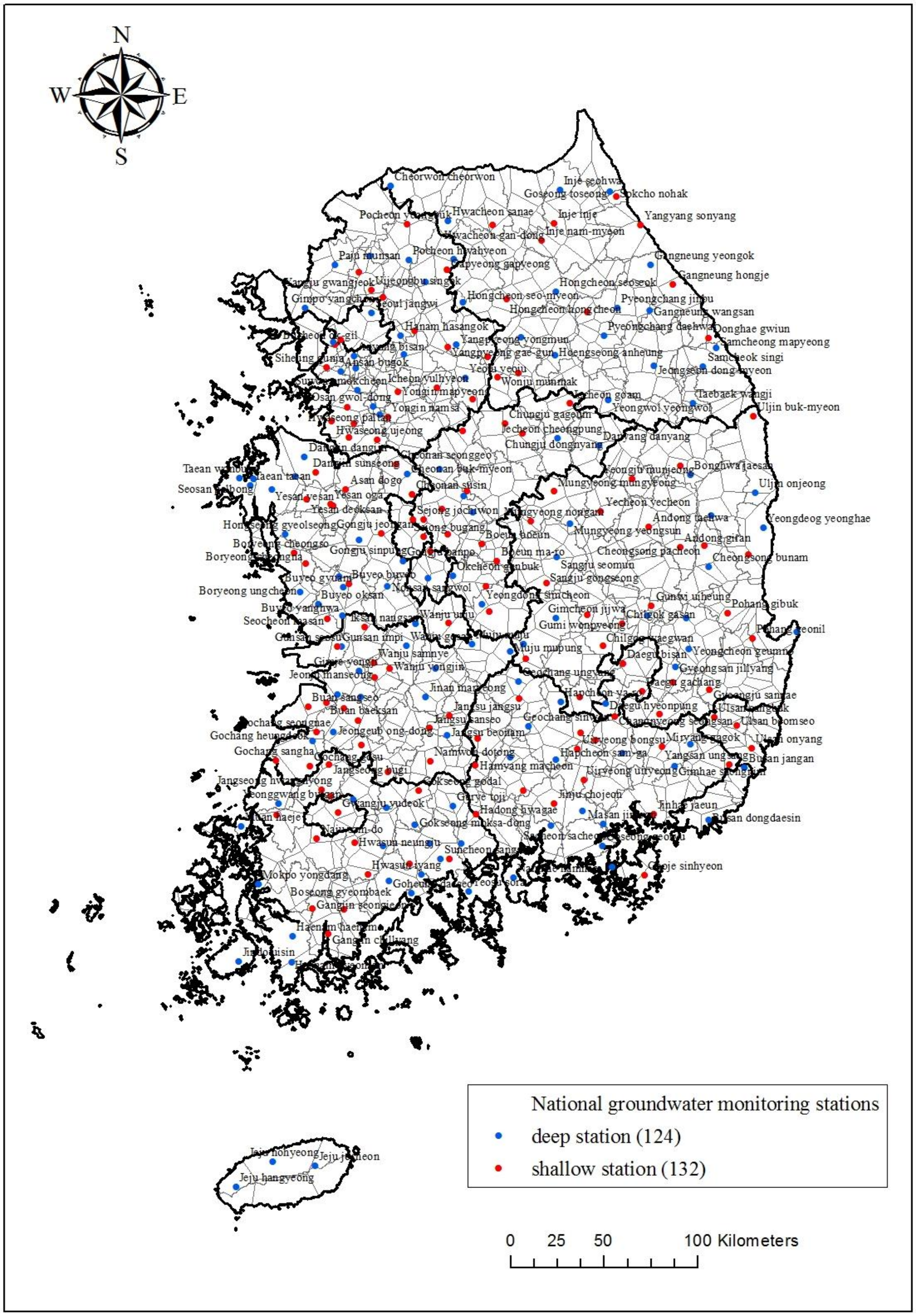


Figure 5.10 Groundwater Monitoring Station Location Map and Thiessen Networks

5.6 Evaluation Criteria of Groundwater Drought based on SGI

Determination of the beginning and end of a drought is difficult because drought is slowly developing and affects it extensively. It is also difficult to define the severity or magnitude of groundwater drought because the impacts of drought are very complex depending on the region to region.

For the monitoring and forecasting of groundwater drought, it is necessary to determine the severity categories of groundwater droughts based on the SGI calculated in the previous section 5.5. The drought severity categories based on SGI was established by referring to drought indices and indicators which have been applied worldwide and the applicability of these categories was confirmed by the Receiver Operating Characteristics (ROC) analysis on the historical drought records.

5.6.1 The criteria of drought severity or magnitude

Standardized Precipitation Index (SPI)

In case of the meteorological drought, McKee, Doesken et al. (1993) proposed an indicator to define the drought intensity based on SPI. Drought intensity arbitrarily defined based on values of the SPI is shown in Table 5.7.

Table 5.7 Classification Scale for SPI Values

SPI Values	0 to –0.99	−1 to –1.49	−1.5 to –1.99	SPI≤−2.0
Drought Category	Mild drought	Moderate drought	Severe drought	Extreme drought

Palmer Drought Severity Index (PDSI)

PDSI developed by W. Palmer in 1965 has been applied for identifying a drought condition based on precipitation, temperature, and local available water content of soil. Despite PDSI has a limitation to use on the global scale, Palmer proposed the drought categories of PDSI as shown in Table 5.8.

Table 5.8 Classification Scale for PDSI Values

PDSI Values	-1.0 to –1.99	−2.0 to –2.99	−3.0 to –3.99	PDSI≤−4.0
Drought Category	Mild drought	Moderate drought	Severe drought	Extreme drought

<u>Groundwater drought monitoring of United States Geological Survey (USGS)</u>

With respect to groundwater drought monitoring, USGS analyzes observed groundwater level data nationwide and provides a percentile information of current groundwater level to the states considering groundwater level percentile classes by stations. The percentile classes produced by USGS is presented in Table 5.9. The States monitor current groundwater drought condition based on percentile values provided by USGS.

Table 5.9 Groundwater Level Classes of USGS

Explanation – Percentile classes							
Low	<10	10-24	25-75	76-90	>90	High	Not Ranked
	Much Below Normal	Below Normal	Normal	Above Normal	Much Above Normal		

Source; USGS Groundwater Watch

<u>Groundwater monitoring indicator of Ontario Ministry of Natural Resources</u>

In Canada, the same way as in the U.S., the monthly threshold (percentile) groundwater level is compared with current groundwater level to determine a current drought condition. Ontario Ministry of Natural Resources proposed the percentile method as a groundwater drought indicator and calculate it on a monthly basis, using the available historical groundwater level data for a particular well. Totally twelve sets of triggers, one set of triggers corresponding to each month of the year, are prepared for each well to reduce the socio-economical and environmental effects of low water. The three levels are defined: LevelⅠ-conservation; LevelⅡ–conservation and restriction; and LevelⅢ-conservation, restriction, and regulation as shown in Table 5.10.

Table 5.10 Criteria for Drought Stage in Canada

Drought stage	Criteria
Level I	10～25 percentile of monthly average groundwater level
Level II	5～10 percentile of monthly average groundwater level
Level III	Less than 5 percentile of monthly average groundwater level

Source; Ontario Ministry of Natural Resources

Drought magnitude categories for Drought Monitor by NDMC

National Drought Mitigation Center (NDMC) uses a percentile approach for identifying drought magnitude. NDMC classified magnitude of drought severity into four levels listed in table 5.11 through comprehensive drought information analysis using six key objective indicators such as PDSI, SPI, Daily Streamflow Percentiles (http://droughtmonitor.unl.edu/AboutUSDM/DroughtClassification.aspx) and so forth and several additional indicators such as reservoir and lake level. Each category is associated with its percentile chance of happening in any given year out of 100 year.

Table 5.11 The Categories of Drought Magnitude Used in Drought Monitor (NDMC)

Category and description	D0 Abnormally dry	D1 Moderate drought	D2 Severe drought	D3 Extreme drought	D4 Exceptional drought
Percentile chance	20 to ≤30	10 to ≤20	5 to ≤10	2 to ≤5	≤2

5.6.2 Determination of the Categories for Groundwater Drought Magnitude

A percentile approach was applied to determine the thresholds for each drought severity level based on historical frequency of occurrence for each station. The advantages of the percentile class can be applied to any parameter and used for any length of data record and put drought in historical perspective how many occurrence in a given period of time.

Based on drought indices and criteria of relevant agency, the categories for identifying the groundwater drought classified into four levels as shown in Table 5.12. 25 percentile was selected as threshold level for drought onset and end. For example, groundwater drought at certain monitoring well is issued when observed groundwater level is less than 25 percentile. The severe level and very severe level were determined to be below 10 percentile chance and 5 percentile chance, respectively, with reference to the USGS, NDMC, and Ontario Ministry of Natural Resources criteria. In this study, drought magnitude criteria tabulated below was applied and not only a groundwater drought monitoring but also a groundwater drought forecasting described in chapter 6.

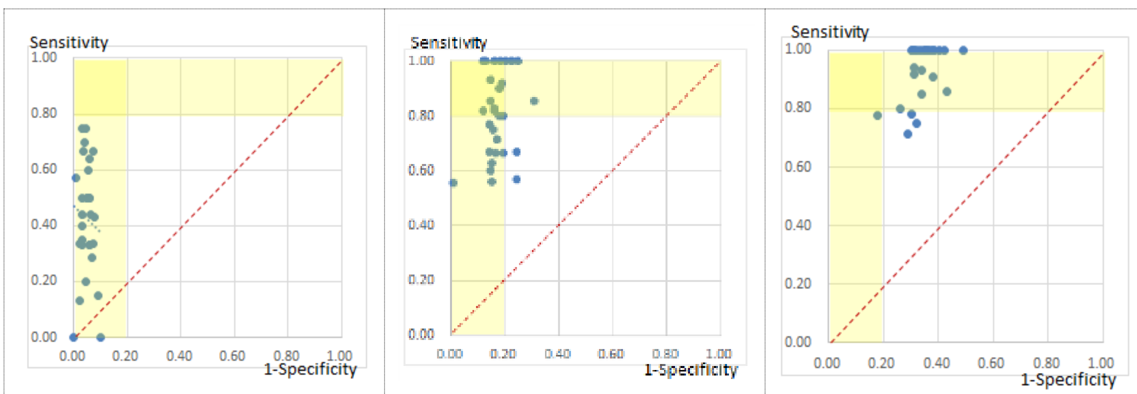
Table 5.12 The Criteria of Groundwater Drought Magnitude Based on SGI

Drought categories	Normal	Caution	Severe	Very severe
Percentile chance	>25	10 to ≤25	5 to ≤10	≤5

The applicability of the groundwater drought categories in Table 5.12 was confirmed by the Receiver Operating Characteristics analysis on the historical drought records. As mentioned in Chapter 2, ROC analysis is a technique that is mainly used for qualitative verification of weather forecast based on probability. Yoo, Song et al. (2013) applied ROC technique for quantitative evaluation of actual drought records and drought index. ROC model applied for this study is shown in Table 2.5, eq.2.25 and 2.26.

For ROC analysis, 29 sample sites were selected among 256 the national groundwater monitoring network. Historical drought records were compared with predicted droughts which were estimated by criteria listed above in Table 5.12. Historical drought records were collected from the drought investigation reports documented by (MOLIT 2015) and press releases. Unfortunately, there are no records for quantifying the severity of historical droughts, the historical drought records only refer to the determination of whether a drought has occurred or not for ROC analysis.

With respect to ROC analysis, the percentile classes were compared for the 40, 30, 25, 20, 10, and 5 percentiles as shown in Table 5.13 and sensitivity and specificity of each groundwater level percentile classes were analyzed based on equation 2.25 and 2.26. As result shown in Figure 5.11 and Table 5.13, when the groundwater level reached to 25 percentile, it was analyzed that the sensitivity and specificity were both higher than 80%. In general, the results of ROC analysis are accepted as appropriate criteria when both sensitivity and specificity are over 80% simultaneously.



10%tile | 25%tile | 40%tile

Figure 5.11 Plot of ROC Analysis at 29 Sample Sites

Table 5.13 ROC Analysis Results at 29 Sample Sites

Station	5%tile		10% tile		20% tile		25% tile		30% tile		40% tile	
	Sens.	Spec.	Sens.	Spec.	Sens.	Spec.	Sens.	Spec.	Sens.	Spec.	Sens.	Spec.
Kangrung	0.00	0.98	0.15	0.91	0.38	0.89	0.77	0.86	0.85	0.80	0.85	0.66
Geoje	0.00	0.95	0.00	0.90	0.57	0.82	0.57	0.76	0.71	0.71	0.86	0.57
Gumi	0.13	0.99	0.50	0.97	0.88	0.92	1.00	0.88	1.00	0.81	1.00	0.64
Gumsa	0.29	0.97	0.29	0.93	0.43	0.85	0.71	0.83	0.71	0.80	0.71	0.71
Mokpo	0.00	0.96	0.33	0.94	0.67	0.82	0.67	0.76	0.67	0.66	1.00	0.51
Milyang	0.17	0.99	0.67	0.97	1.00	0.86	1.00	0.80	1.00	0.75	1.00	0.61
Boryung	0.00	0.94	0.75	0.92	1.00	0.77	1.00	0.69	1.00	0.64	1.00	0.58
Boeun	0.00	0.99	0.43	0.97	0.71	0.93	0.86	0.87	1.00	0.84	1.00	0.69
Buyeo	0.00	1.00	0.00	1.00	0.33	1.00	0.56	0.99	0.67	0.94	0.78	0.82
Sanchung	0.00	0.97	0.50	0.94	0.83	0.87	0.83	0.84	0.83	0.80	1.00	0.65
Seosan	0.19	0.95	0.44	0.94	0.75	0.85	1.00	0.77	1.00	0.71	1.00	0.60
Suwon	0.00	0.97	0.33	0.94	0.67	0.87	1.00	0.84	1.00	0.79	1.00	0.70
Suncheon	0.00	1.00	0.50	0.95	1.00	0.80	1.00	0.76	1.00	0.72	1.00	0.64
Yangpyung	0.10	0.99	0.50	0.95	0.80	0.86	0.80	0.81	0.90	0.79	1.00	0.69
Yongduk	0.08	0.94	0.67	0.93	0.75	0.86	0.92	0.82	1.00	0.74	1.00	0.62
Yongcheon	0.14	1.00	0.57	0.99	0.71	0.91	0.86	0.85	1.00	0.78	1.00	0.69
Wonju	0.11	0.99	0.44	0.97	0.67	0.89	0.67	0.86	1.00	0.81	1.00	0.68
Eusung	0.36	0.98	0.64	0.94	0.82	0.90	0.82	0.84	0.91	0.77	0.91	0.62
Icheon	0.06	0.98	0.35	0.97	0.71	0.92	0.82	0.88	0.82	0.83	0.94	0.69
Inje	0.20	0.99	0.40	0.97	0.60	0.90	0.60	0.85	0.60	0.81	0.80	0.74
Imsil	0.22	1.00	0.33	0.97	0.56	0.89	0.56	0.85	0.67	0.79	0.78	0.70
Janghung	0.50	0.97	0.70	0.96	0.80	0.88	0.90	0.82	1.00	0.76	1.00	0.66
Jungeup	0.00	1.00	0.33	0.98	0.50	0.91	0.67	0.83	0.83	0.77	1.00	0.69
Jecheon	0.33	0.99	0.75	0.96	0.75	0.87	0.75	0.84	0.92	0.78	0.92	0.69
CheongJu	0.27	0.97	0.60	0.95	0.80	0.86	0.80	0.82	0.80	0.74	0.93	0.66
Taebak	0.07	0.99	0.20	0.96	0.73	0.89	0.93	0.85	1.00	0.80	1.00	0.65
Pocheon	0.00	1.00	0.33	0.93	0.33	0.85	0.67	0.81	1.00	0.77	1.00	0.65
Haenam	0.00	0.96	0.50	0.94	0.83	0.86	1.00	0.82	1.00	0.76	1.00	0.63
Hongcheon	0.00	1.00	0.13	0.98	0.63	0.90	0.63	0.85	0.63	0.77	0.75	0.68
Average	11%	98%	42%	95%	70%	88%	81%	83%	88%	77%	94%	66%

The estimated SGI is a value obtained by converting the groundwater level percentile into the Z-score corresponding to the same probability of the standard normal distribution. Drought classes based on SGI were determined using the Z-score of the standard normal distribution corresponding to the probability of occurrence for each drought class in Table 5.14. The groundwater drought criteria reflecting each drought level of SGI values for drought monitoring and forecasting class are shown below in Table 5.14.

Table 5.14 SGI Range Associated with Groundwater Drought Magnitude Categories

Drought categories	Normal	Caution	Severe	Very severe
Percentile chance	>25	10 to ≤25	5 to ≤10	≤5
SGI	>-0.674	-0.674 to ≤ -1.282	-1.282 to ≤-1.645	≤-1.645

5.7 Results of Groundwater Drought Monitoring Based on SGI

Based on the SGI estimation process developed in the previous section, National Groundwater Drought Monitor in Dec. 2017 was produced as shown in Figure 5.12. Table 5.15 shows the groundwater levels measured from 256 National Groundwater Monitoring Networks (NGMN), percentile values obtained from Kernel Density Estimation for each station, and SGI values. The SGI of 167 cities considering the area weights of each monitoring station are shown in Table 5.16. The results of applying the SGI for each city to the groundwater drought criteria described in Table 5.12 are included the last colume of the Table 5.16. In total 167 cities, 83 cities are experiencing groundwater drought conditions in Dec. 2017. Figure 5.13 represents the Monthly Groundwater Drought Monitor in 2017.

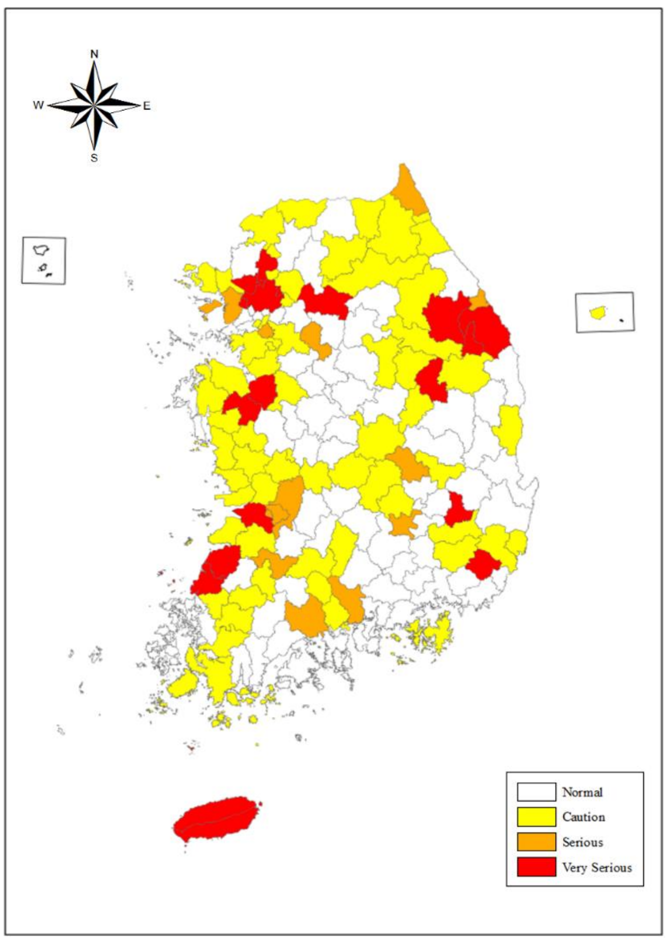


Figure 5.12 Groundwater Drought map of Korea Based on SGI (Dec. 2017)

Table 5.15 Groundwater Drought Monitor at 256 NGMN in Dec. 2017

	Well ID	Station Name	Groundwater Level	Percentile	SGI	Drought Categories
1	241	Daegu bisan	18.69	0.335	-0.427	
2	442	Gwangju yudeok	15.78	0.086	-1.364	Severe
3	2224	Gapyeong gapyeong	58.29	0.402	-0.248	
4	3985	Chungju gageum	51.81	0.202	-0.835	Caution
5	4084	Cheongwon gadeok	76.50	0.818	0.909	
6	4854	Buyeo buyeo	1.86	0.522	0.054	
7	5723	Namwon dotong	105.09	0.239	-0.711	Caution
8	6752	Suncheon pungdeok	2.09	0.515	0.037	
9	7850	Pohang yeonil	-2.45	0.318	-0.475	
10	8936	Yecheon yecheon	84.14	0.235	-0.722	Caution
11	9250	Jinju chojeon	15.53	0.300	-0.525	
12	9858	Daejeon munpyeong	21.41	0.468	-0.081	
13	9860	Ulsan beomseo	15.76	0.335	-0.427	
14	9862	Ulsan sangbuk	192.37	0.026	-1.940	Very Severe
15	9864	Ulsan onyang	9.91	0.066	-1.509	Severe
16	9866	Gangneung hongje	15.04	0.298	-0.531	
17	9874	Siheung gunja	4.69	0.491	-0.024	
18	9879	Geochang geochang	201.62	0.102	-1.268	Severe
19	9881	Uiryeong bongsu	69.72	0.827	0.944	
20	9883	Changnyeong seongsan	64.38	0.201	-0.838	Caution
21	9885	Mungyeong nongam	170.58	0.535	0.087	
22	9887	Andong taehwa	87.53	0.819	0.910	
23	9891	Goryeong goryeong	22.54	0.034	-1.820	Very Severe
24	9893	Gunwi uiheung	118.63	0.720	0.583	
25	9897	Suncheon oeseo	196.36	0.019	-2.074	Very Severe
26	9900	Hampyeong singwang	37.69	0.229	-0.741	Caution
27	9903	Hwasun neungju	39.76	0.167	-0.966	Caution
28	9908	Jangsu sanseo	145.33	0.739	0.641	
29	9911	Asan dogo	11.05	0.000	-12.053	Very Severe
30	9917	Yesan deoksan	48.15	0.286	-0.565	
31	9920	Cheongju naedeok	33.97	0.320	-0.468	
32	9922	Chungju dongnyang	74.09	0.497	-0.008	
33	11741	Yongin mapyeong	79.87	0.112	-1.216	Severe
34	11743	Pyeongtaek tongbok	2.01	0.350	-0.386	
35	11745	Icheon yulhyeon	45.97	0.030	-1.887	Very Severe
36	11747	Wonju munmak	53.90	0.334	-0.428	
37	11749	Donghae gwiun	3.86	0.061	-1.548	Severe

Table 5.15 (continued)

	Well ID	Station Name	Groundwater Level	Percentile	SGI	Drought Categories
38	11753	Jecheon goam	265.53	0.525	0.062	
39	11755	Okcheon cheongseong	136.34	0.048	-1.668	Very Severe
40	11757	Boeun boeun	150.21	0.316	-0.480	
41	11761	Cheonan seonggeo	46.28	0.695	0.509	
42	11763	Yesan yesan	6.84	0.095	-1.313	Severe
43	11767	Jeonju manseong	30.04	0.468	-0.080	
44	11769	Gochang gosu	53.40	0.138	-1.088	Caution
45	11774	Naju sam-do	2.72	0.098	-1.291	Severe
46	11779	Jangseong hwangnyong	32.25	0.712	0.559	
47	11784	Geoje sinhyeon	136.67	0.083	-1.382	Severe
48	11786	Miryang gagok	6.76	0.824	0.932	
49	11790	Jinhae jaeun	14.87	0.901	1.289	
50	11794	Gyeongju sannae	198.70	0.885	1.201	
51	11796	Gumi wonpyeong	33.97	0.068	-1.494	Severe
52	11798	Sangju gongseong	77.61	0.235	-0.722	Caution
53	11800	Cheongsong pacheon	167.38	0.065	-1.515	Severe
54	11802	Bonghwa myeongho	196.62	0.144	-1.061	Caution
55	11804	Gyeongsan namsan	63.26	0.000	-4.108	Very Severe
56	65002	Gangjin seongjeon	52.18	0.122	-1.163	Caution
57	65004	Gangjin chillyang	5.42	0.558	0.147	
58	65009	Gwangmyeong cheolsan	5.05	0.405	-0.239	
59	65013	Jeungpyeong jeungpyeong	93.36	0.937	1.530	
60	65018	Mungyeong mungyeong	184.36	0.088	-1.350	Severe
61	65025	Yangyang sonyang	0.71	0.193	-0.867	Caution
62	65028	Yeongdong yanggang	147.21	0.080	-1.408	Severe
63	65031	Wanju yongjin	23.36	0.000	-3.528	Very Severe
64	65034	Eumseong saenggeuk	74.46	0.460	-0.099	
65	65038	Jangheung jangheung	20.29	0.493	-0.016	
66	65049	Hapcheon jeokjung	8.50	0.412	-0.223	
67	65053	Bucheon ok-gil	9.50	0.880	1.173	
68	65056	Sunchang sunchang	80.43	0.000	-3.325	Very Severe
69	65064	Yangpyeong gae-gun	34.03	0.399	-0.255	
70	65066	Yangpyeong yang-dong	101.77	0.120	-1.174	Caution
71	65069	Yeongju munjeong	129.30	0.021	-2.038	Very Severe
72	65074	Jangsu jangsu	412.05	0.581	0.203	
73	65076	Jeongeup sintaein	0.85	0.024	-1.983	Very Severe
74	65079	Cheongwon gangnae	37.85	0.736	0.630	

Table 5.15 (continued)

	Well ID	Station Name	Groundwater Level	Percentile	SGI	Drought Categories
75	65589	Hongcheon hongcheon	119.18	0.128	-1.137	Caution
76	65591	Boeun ma-ro	125.24	0.442	-0.146	
77	65594	Sejong jochiwon	22.91	0.902	1.292	
78	65602	Cheongdo cheong-do	57.46	0.072	-1.464	Severe
79	65606	Hamyang macheon	286.14	0.172	-0.948	Caution
80	65608	Jeongeub ong-dong	16.72	0.110	-1.227	Caution
81	65610	Uijeongbu singok	33.47	0.235	-0.722	Caution
82	73504	Sokcho nohak	11.16	0.368	-0.336	
83	73510	Hwacheon gan-dong	182.24	0.308	-0.502	
87	73526	Gokseong godal	46.66	0.373	-0.325	
88	73529	Jangseong nam-myeon	33.31	0.174	-0.940	Caution
89	73531	Hwasun iyang	92.30	0.628	0.327	
90	73538	Andong giran	124.78	0.578	0.197	
91	73540	Chilgok gasan	107.76	0.203	-0.829	Caution
92	73543	Pohang gibuk	116.68	0.166	-0.968	Caution
93	73547	Uiryeong uiryeong	8.22	0.488	-0.031	
94	73550	Hadong hwagae	11.10	0.006	-2.516	Very Severe
95	82001	Yangju gwangjeok	88.86	0.000	-5.485	Very Severe
96	82003	Hwaseong yanggam	22.74	0.083	-1.387	Severe
97	82012	Pyeongchang bongpyeong	560.64	0.211	-0.804	Caution
98	82017	Sejong bugang	16.63	0.114	-1.206	Caution
99	82021	Boryeong cheongso	14.31	0.132	-1.116	Caution
100	82024	Gochang sangha	4.98	0.000	-7.577	Very Severe
101	82027	Buan baeksan	5.72	0.192	-0.870	Caution
102	82029	Buan sangseo	5.92	0.271	-0.611	
103	82031	Sunchang ssangchi	224.16	0.746	0.663	
104	82038	Jangseong bugi	81.47	0.612	0.286	
105	82045	Chilgog waegwan	27.98	0.372	-0.326	
106	82049	Hamyang byeonggok	213.97	0.078	-1.421	Severe
107	84005	Daegu gachang	161.91	0.707	0.543	
108	84011	Inje inje	191.21	0.562	0.155	
109	84014	Namyangju byeollae	58.67	0.071	-1.467	Severe
110	84020	Hwaseong paltan	27.53	0.492	-0.019	
111	84022	Gongju jeongan	30.24	0.296	-0.537	

Table 5.15 (continued)

	Well ID	Station Name	Groundwater Level	Percentile	SGI	Drought Categories
112	84024	Dangjin sunseong	12.98	0.127	-1.139	Caution
113	84027	Gochang seongnae	3.90	0.003	-2.702	Very Severe
114	84038	Sancheong danseong	51.57	0.461	-0.099	
115	87234	Wonju myeongnyun	160.32	0.292	-0.547	
116	87240	Yeoju jeom-dong	56.88	0.280	-0.584	
117	87243	Yongin namsa	15.36	0.389	-0.281	
118	87248	Hwaseong ujeong	17.15	0.171	-0.948	Caution
119	87250	Boryeong cheongna	50.03	0.274	-0.600	
120	87256	Wanju samnye	9.13	0.350	-0.385	
121	87260	Yeongdeok dalsan	40.84	0.176	-0.930	Caution
122	87262	Uljin buk-myeon	12.18	0.104	-1.259	Caution
123	87265	Yangsan ungsang	109.46	0.198	-0.848	Caution
124	87267	Uiryeong nakseo	3.31	0.121	-1.171	Caution
125	95508	Yangpyeong yangseo	23.56	0.297	-0.533	
126	95510	Pyeongtaeg anjung	13.17	0.056	-1.593	Severe
127	95512	Pocheon yeongbuk	132.12	0.352	-0.379	
128	95515	Inje nam-myeon	190.67	0.048	-1.663	Very Severe
129	95521	Seocheon masan	18.06	0.173	-0.941	Caution
130	95523	Gunsan impi	11.01	0.152	-1.029	Caution
131	95526	Iksan nangsan	10.10	0.113	-1.210	Caution
132	95533	Gimcheon daedeok	223.38	0.696	0.513	
133	6721	Mokpo yongdang	17.31	0.574	0.186	
134	9855	Busan dongdaesin	104.07	0.292	-0.548	
135	9856	Daegu hyeonpung	13.09	0.267	-0.623	
136	9867	Taebaek wangji	682.86	0.023	-1.999	Very Severe
137	9869	Pyeongchang daehwa	411.77	0.072	-1.463	Severe
138	9870	Hoengseong anheung	422.68	0.118	-1.184	Caution
139	9871	Dongducheon sangpae	55.11	0.235	-0.721	Caution
140	9872	Suwon omokcheon	21.82	0.041	-1.738	Very Severe
141	9875	Gapyeong buk-myeon	109.66	0.285	-0.569	
142	9876	Yangpyeong yongmun	41.82	0.000	-4.177	Very Severe
143	9877	Yeoju yeoju	30.51	0.397	-0.262	
144	9901	Haenam haenam	35.27	0.060	-1.552	Severe
145	9904	Gimje bongnam	12.87	0.014	-2.208	Very Severe
146	9909	Seosan seongnam	14.63	0.106	-1.246	Caution
147	9914	Buyeo yanghwa	1.87	0.260	-0.643	
148	9915	Buyeo oksan	21.11	0.550	0.125	

Table 5.15 (continued)

	Well ID	Station Name	Groundwater Level	Percentile	SGI	Drought Categories
149	11758	Cheongwon miwon	228.08	0.535	0.089	
150	11759	Cheongwon bugil	101.38	0.626	0.322	
151	11764	Gongju banpo	72.01	0.381	-0.302	
152	11765	Nonsan sangwol	18.87	0.126	-1.145	Caution
153	11772	Gunsan seosu	0.36	0.300	-0.523	
154	11782	Masan jinjeon	18.47	0.592	0.232	
155	65005	Goseong georyu	4.25	0.365	-0.344	
156	65006	Goheung daeseo	8.58	0.446	-0.136	
157	65007	Gongju sinpung	37.90	0.439	-0.154	
158	65010	Gwangju gwangju	44.71	0.496	-0.009	
159	65014	Danyang danyang	316.31	0.053	-1.614	Severe
160	65016	Daejeon taepyeong	44.48	0.697	0.515	
161	65019	Boseong gyeombaek	114.90	0.514	0.034	
162	65020	Buyeo gyuam	15.01	0.170	-0.955	Caution
163	65026	Yeongdeog yeonghae	7.85	0.016	-2.145	Very Severe
164	65029	Yeongyang ibam	187.72	0.144	-1.062	Caution
165	65032	Uljin onjeong	105.60	0.509	0.024	
166	65039	Jinan maryeong	275.98	0.006	-2.539	Very Severe
167	65040	Jincheon jincheon	57.25	0.333	-0.432	
168	65041	Changnyeong yeongsan	35.64	0.800	0.840	
169	65043	Taean wonbuk	25.23	0.659	0.409	
170	65044	Taean taean	18.52	0.055	-1.599	Severe
171	65045	Tongyeong yongnam	-0.86	0.147	-1.050	Caution
172	65047	Pocheon hwahyeon	145.54	0.292	-0.549	
173	65054	Sangju seomun	53.32	0.022	-2.012	Very Severe
174	65057	Suncheon sangsa	7.49	0.134	-1.109	Caution
175	65058	Suncheon seungju	121.32	0.004	-2.648	Very Severe
176	65067	Yeongdong simcheon	104.85	0.743	0.652	
177	65070	Okcheon gunbuk	90.91	0.525	0.062	
178	65077	Jecheon cheongpung	187.92	0.090	-1.341	Severe
179	65080	Hwasun buk-myeon	253.22	0.789	0.804	
180	65586	Gunpo dangjeong	41.22	0.114	-1.205	Caution
181	65587	Pyeongchang jinbu	537.32	0.308	-0.502	
182	65592	Dangjin dangjin	9.92	0.243	-0.696	Caution
183	65595	Cheonan buk-myeon	103.38	0.141	-1.076	Caution
184	65596	Wanju gosan	68.11	0.096	-1.307	Severe
185	65597	Wanju unju	118.75	0.142	-1.071	Caution

Table 5.15 (continued)

	Well ID	Station Name	Groundwater Level	Percentile	SGI	Drought Categories
186	65598	Jinan jeongcheon	267.64	0.791	0.811	
187	65599	Haenam hyeonsan	11.07	0.078	-1.419	Severe
188	65600	Mungyeong yeongsun	103.01	0.524	0.059	
189	73502	Goseong toseong	75.43	0.074	-1.444	Severe
190	73505	Yeongwol yeongwol	195.18	0.337	-0.422	
191	73511	Hwacheon sanae	267.44	0.732	0.620	
192	73514	Hoengseong hoengseong	133.16	0.549	0.124	
193	73517	Seosan unsan	28.24	0.866	1.109	
194	73524	Jangsu beonam	306.85	0.364	-0.346	
195	73532	Gyeongsan jillyang	71.82	0.076	-1.431	Severe
196	73535	Gimcheon jijwa	85.50	0.036	-1.798	Very Severe
197	73536	Bonghwa jaesan	310.08	0.862	1.088	
198	73541	Pohang guryongpo	28.74	0.772	0.745	
199	73544	Miryang danjang	119.86	0.000	-3.946	Very Severe
200	73545	Sancheong sancheong	108.00	0.378	-0.310	
201	73548	Jinju ilbanseong	27.03	0.730	0.613	
202	82004	Gangneung wangsan	970.71	0.713	0.561	
203	82007	Jeongseon dong-myeon	393.99	0.000	-15.321	Very Severe
204	82015	Hongcheon seoseok	292.44	0.304	-0.512	
205	82019	Boryeong ungcheon	14.50	0.064	-1.523	Severe
206	82025	Gochang heungdeok	26.03	0.069	-1.482	Severe
207	82032	Jeongeup sangpyeong	22.91	0.570	0.176	
208	82033	Gokseong moksa-dong	93.68	0.082	-1.389	Severe
209	82034	Boseong beolgyo	7.11	0.250	-0.674	Caution
210	82035	Yeosu sora	31.78	0.697	0.514	
211	82036	Yeonggwang bulgap	22.04	0.034	-1.823	Very Severe
212	82040	Yeongcheon hwabuk	151.94	0.920	1.402	
213	82046	Geochang sinwon	195.82	0.269	-0.617	
214	84003	Busan jangan	52.77	0.536	0.089	
215	84006	Gwangju unjeong	57.41	0.135	-1.105	Caution
216	84007	Gangneung yeongok	39.46	0.166	-0.970	Caution
217	84008	Samcheok mapyeong	6.44	0.071	-1.471	Severe
218	84009	Samcheok singi	135.43	0.002	-2.846	Very Severe
219	84015	Ansan bugok	44.36	0.152	-1.028	Caution
220	84025	Hongseong gyeolseong	42.40	0.207	-0.819	Caution
221	84028	Gimje yongji	13.82	0.404	-0.242	
222	84029	Muan haeje	3.57	0.240	-0.708	Caution

Table 5.15 (continued)

	Well ID	Station Name	Groundwater Level	Percentile	SGI	Drought Categories
223	84030	Gimcheon buhang	235.90	0.196	-0.856	Caution
224	84031	Cheongsong bunam	240.18	0.637	0.352	
225	84032	Yeongcheon geumno	70.60	0.360	-0.358	
226	84036	Sacheon sacheon	26.52	0.378	-0.311	
227	84039	Namhae namhae	80.70	0.377	-0.313	
228	84040	Geochang ungyang	296.21	0.741	0.646	
229	84041	Hapcheon ya-ro	102.98	0.143	-1.066	Caution
230	87236	Gimpo yangchon	50.66	0.217	-0.783	Caution
231	87237	Anyang bisan	42.56	0.285	-0.569	
232	87241	Osan gwol-dong	45.13	0.123	-1.161	Caution
233	87244	Paju munsan	25.00	0.467	-0.084	
234	87245	Pyeongtaek jinwi	43.72	0.217	-0.783	Caution
235	87246	Hanam hasangok	73.37	0.131	-1.121	Caution
236	87251	Buyeo eunsan	6.58	0.035	-1.813	Very Severe
237	87252	Seosan palbong	1.92	0.008	-2.427	Very Severe
238	87253	Gimje buryang	1.40	0.000	-3.801	Very Severe
239	87254	Muju mupung	450.02	0.084	-1.382	Severe
240	87257	Gurye toji	28.32	0.083	-1.388	Severe
241	87258	Hwasun nam-myeon	110.41	0.213	-0.797	Caution
242	87263	Gimhae saengnim	2.39	0.285	-0.569	
243	87268	Hapcheon sam-ga	94.52	0.341	-0.410	
244	95501	Seoul hang-dong	13.36	0.000	-3.656	Very Severe
245	95502	Seoul jangwi	16.08	0.000	-7.186	Very Severe
246	95506	Gapyeong sang-myeon	135.69	0.226	-0.752	Caution
247	95517	Inje seohwa	284.57	0.110	-1.227	Caution
248	95518	Cheorwon cheorwon	141.43	0.053	-1.615	Severe
249	95519	Hongcheon seo-myeon	56.02	0.063	-1.531	Severe
250	95524	Muju muju	208.88	0.493	-0.017	
251	95527	Gwangyang bonggang	50.05	0.179	-0.918	Caution
252	95528	Jindo uisin	5.43	0.249	-0.679	Caution
253	95531	Gunwi sanseong	131.00	0.000	-3.553	Very Severe
254	95534	Jeju nohyeong	88.19	0.021	-2.043	Very Severe
255	95536	Jeju hangyeong	36.89	0.123	-1.161	Caution
256	95537	Jeju jocheon	84.65	0.022	-2.019	Very Severe

Table 5.16 Groundwater Drought Monitor for 167 cities in Dec. 2017

No.	City name	SGI	Drought condition	No.	City name	SGI	Drought condition
1	Seoul	-3.466	Very Severe	43	Gapyeong	-0.640	
2	Busan	-0.371		44	Yangpyeong	-1.740	Very Severe
3	Gijang	-0.212		45	Chuncheon	-0.760	Caution
4	Daegu	-0.611		46	Wonju	-0.487	
5	Dalseong	-0.279		47	Gangneung	-0.485	
6	Incheon	-1.346	Severe	48	Donghae	-1.547	Severe
7	Ganghwa	-0.783	Caution	49	Taeback	-2.120	Very Severe
8	Ongjin	-0.291		50	Sokcho	-0.721	Caution
9	Gwangju	-1.099	Caution	51	Samcheok	-2.688	Very Severe
10	Daejeon	0.203		52	Hongcheon	-0.934	Caution
11	Ulsan	-0.978	Caution	53	Hoengseong	-0.581	
12	Ulju	-1.019	Caution	54	Yeongwol	-1.106	Caution
13	Sejong	-0.100		55	Pyeongchang	-0.844	Caution
14	Suwon	-1.606	Severe	56	Jeongseon	-9.587	Very Severe
15	Seongnam	-0.477		57	Cheorwon	-0.700	Caution
16	Uijeongbu	-0.851	Caution	58	Hwacheon	-0.022	
17	Anyang	-0.658		59	Yanggu	-0.833	Caution
18	Bucheon	-3.450	Very Severe	60	Inje	-0.773	Caution
19	Gwangmyeong	0.542		61	Goseong	-1.352	Severe
20	Pyeongtaek	-1.053	Caution	62	Yangyang	-0.773	Caution
21	Dongducheon	-0.721	Caution	63	Cheongju	0.158	
22	Ansan	-0.494		64	Chungju	-0.462	
23	Goyang	-2.165	Very Severe	65	Jecheon	-0.729	Caution
24	Gwacheon	-0.569		66	Boeun	-0.199	
25	Guri	-6.541	Very Severe	67	Okcheon	-0.448	
26	Namyangju	-1.149	Caution	68	Yeongdong	-0.971	Caution
27	Osan	-1.117	Caution	69	Jeungpyeong	1.312	
28	Siheung	0.032		70	Jincheon	-0.457	
29	Gunpo	-1.140	Caution	71	Goesan	0.409	
30	Uiwang	-1.054	Caution	72	Eumseong	-0.015	
31	Hanam	-1.112	Caution	73	Danyang	-1.269	Caution
32	Yongin	-1.101	Caution	74	Cheonan	-0.776	Caution
33	Paju	-0.644		75	Gongju	-0.512	
34	Icheon	-1.384	Severe	76	Boryeong	-1.084	Caution
35	Anseong	-0.179		77	Asan	-8.623	Very Severe
36	Gimpo	-0.803	Caution	78	Seosan	-1.151	Caution
37	Hwaseong	-0.812	Caution	79	Nonsan	-1.117	Caution
38	Gwangju	-0.421		80	Gyeryong	-0.949	Caution
39	Yangju	-2.975	Very Severe	81	Dangjin	-0.874	Caution
40	Pocheon	-0.485		82	Geumsan	-0.779	Caution
41	Yeoju	-0.605		83	Buyeo	-0.682	
42	Yeoncheon	-1.032	Caution	84	Seocheon	-0.748	Caution

Table 5.16 (continued)

No.	City name	SGI	Drought condition	No.	City name	SGI	Drought condition
85	Cheongyang	-0.742	Caution	127	Gimcheon	-1.050	Caution
86	Hongseong	-0.868	Caution	128	Andong	0.257	
87	Yesan	-1.888	Very Severe	129	Gumi	-1.328	Severe
88	Taean	-0.522		130	Yeongju	-1.874	Very Severe
89	Jeonju	-1.431	Severe	131	Yeongcheon	-0.209	
90	Gunsan	-0.966	Caution	132	Sangju	-0.888	Caution
91	Iksan	-0.802	Caution	133	Mungyeong	-0.654	
92	Jeongeup	-0.929	Caution	134	Gyeongsan	-2.356	Very Severe
93	Namwon	-0.829	Caution	135	Gunwi	-0.969	Caution
94	Gimje	-2.135	Very Severe	136	Uiseong	0.062	
95	Wanju	-1.615	Severe	137	Cheongsong	-0.156	
96	Jinan	-0.469		138	Yeongyang	-0.335	
97	Muju	-0.453		139	Yeongdeok	-1.280	Caution
98	Jangsu	0.159		140	Cheongdo	-1.139	Caution
99	Imsil	-0.503		141	Goryeong	-1.366	Severe
100	Sunchang	-1.538	Severe	142	Seongju	-0.754	Caution
101	Gochang	-3.632	Very Severe	143	Chilgok	-0.618	
102	Buan	-1.098	Caution	144	Yecheon	-0.786	Caution
103	Mokpo	0.186		145	Bonghwa	-0.886	Caution
104	Yeosu	0.442		146	Uljin	-0.576	
105	Suncheon	-1.440	Severe	147	Ulleung	-1.259	Caution
106	Naju	-1.167	Caution	148	Changwon	0.784	
107	Gwangyang	-1.220	Caution	149	Jinju	-0.135	
108	Damyang	-0.745	Caution	150	Tongyeong	-0.946	Caution
109	Gokseong	-0.644		151	Sacheon	-0.301	
110	Gurye	-1.195	Caution	152	Gimhae	-0.024	
111	Goheung	-0.070		153	Miryang	-0.874	Caution
112	Boseong	-0.301		154	Geoje	-1.201	Caution
113	Hwasun	-0.329		155	Yangsan	-1.748	Very Severe
114	Jangheung	0.078		156	Uiryeong	0.050	
115	Gangjin	-0.385		157	Haman	0.335	
116	Haenam	-1.155		158	Changnyeong	-0.082	
117	Yeongam	-0.816	Caution	159	Goseong	-0.132	
118	Muan	-0.211		160	Namhae	-0.313	
119	Hampyeong	-0.926		161	Hadong	-1.586	Severe
120	Yeonggwang	-3.036	Very Severe	162	Sancheong	-0.389	
121	Jangseong	0.032		163	Hamyang	-1.084	Caution
122	Wando	-0.872	Caution	164	Geochang	-0.376	
123	Jindo	-0.679	Caution	165	Hapcheon	-0.539	
124	Sinan	-0.328		166	Jeju	-1.823	Very Severe
125	Pohang	-0.503		167	Seogwipo	-1.769	Very Severe
126	Gyeongju	0.126					

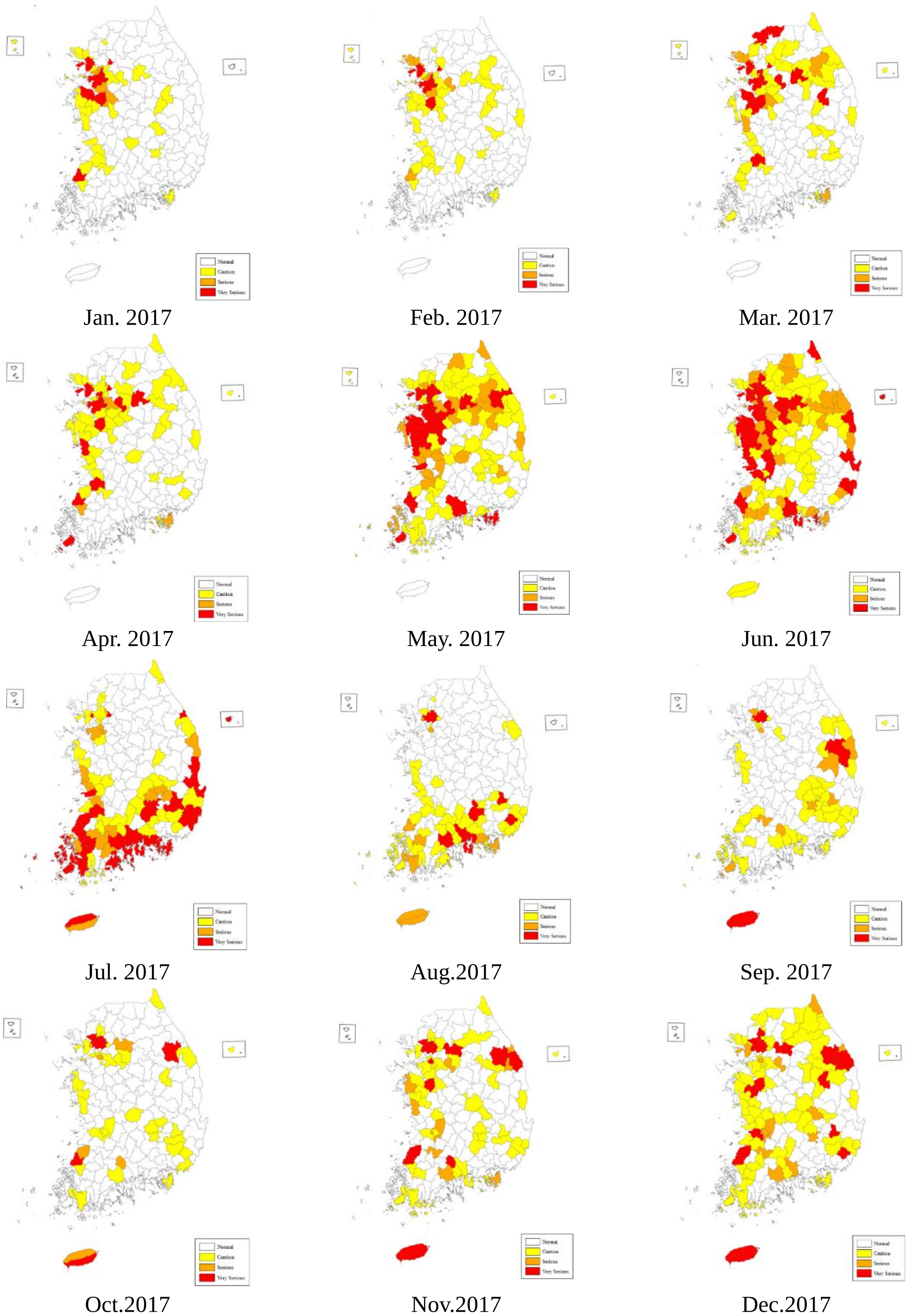


Figure 5.13 Monthly Groundwater Drought Monitor of Korea in 2017

CHAPTER VI

DEVELOPMENT OF GROUNDWATER DROUGHT FORECASTING METHOD

6.1 Summary and Procedure

The National Drought Information Analysis Center (NDIAC) established by K-water has implemented the National Drought Early Warning System (DEWS) with a focus on municipal and industrial water use since Mar. 2016. The main water sources of municipal and industrial water in Korea are reservoirs, rivers, and groundwater. In the beginning, the groundwater drought monitoring and early warning has been carried out with SPI-6. However, unlike rivers and reservoirs drought forecasting methodologies that are based on observed hydrological data reflecting weather forecasts, groundwater drought forecast methodologies based on observed groundwater data considering weather forecasts have not been developed.

There is an obvious correlation between groundwater level fluctuations and precipitation in a specific region. But it is difficult to quantify groundwater response to precipitation variation. Generally, a physical model is mainly used for forecasting groundwater levels. However, such a modeling technique requires a lot of time and efforts to build the model and optimize parameters. There are also difficulties in updating periodically and applying practically. However, if long-term observation data of precipitation and groundwater levels at a certain region can be obtained, the correlation between them can be identified and a numerical forecast model based on observed data can be developed.

The main objective of this chapter is to develop a practical method for groundwater drought forecasting on a regular basis (weekly, monthly). The process of forecasting groundwater drought using the correlation between precipitation and groundwater response is roughly divided into two main processes. The one is to develop a correlation model between SPIs and SGI for a specific region based on historical observation data of precipitation and groundwater levels, and the other is to estimate SGI values during drought projection period using the correlation model and SPI forecasts.

This research focused on developing the correlation model considering the lag time between precipitation and groundwater response and autocorrelation of groundwater level time series converted to SGI simultaneously. A groundwater drought forecasting model based on correlation between precipitation data (SPI) and groundwater level (SGI) as input and output respectively was developed employing ANN which is one of Machine Learning technique.

The process of collecting groundwater level data from the national groundwater monitoring networks and calculating SGI for each monitoring well and estimating the calculated SGI based on the area weights of 167 cities nationwide is the same as the process for groundwater drought monitoring described in previous chapter 5.

SPI values for the correlation analysis with SGI were calculated based on historical precipitation data obtained from KMA, MOLIT, and Korea Water Resources Corporation (K-water) stations by 1966-2016. SPI forecasts (1, 2, and 3 month) were used by obtaining from Global Seasonal Forecast System version 5 (GloSea5) maintained by KMA.

The MATLAB program was used for the development of correlation model through ANN, data processing, and visualization of results. The correlation models for each cities were tested to 26 cities in Chungcheong region and then applied to the groundwater drought forecasting in 167 cities nationwide. The groundwater drought projection process based on SGI forecasting is presented in Figure 6.1.

Procedure of development of groundwater drought projection

SPIs considering accumulated precipitation from 1-month to 12-month are calculated based on observation records of 660 precipitation gauging stations. The spatial extent of SPIs calculation should be consistent with 167 cities for correlation analysis between SPIs and SGI.

A correlation analysis between SPIs and SGI is implemented to confirm the validity of SPI as a factor of groundwater drought forecasting. Since the characteristics of groundwater response to precipitation vary from region to region, the correlation between SPIs and SGI is performed for each SPI from 1-month to 12-month.

A correlation model between SPIs and SGI is developed through Artificial Neuron Networks (ANN). Nonlinear Autoregressive model process with eXogenous input (NARX) neural networks is applied to develop a correlation model between target SGI and given input SPIs. The network consisted of 12 nodes for input layer, 12 nodes structured in a hidden layer, and an output layer containing one neuron. The inputs are the SPI 1-12 values and the output corresponding to the target value is the monthly SGI value. A total of 167 correlation models for 167 cities nationwide were developed to reflect the regional characteristics of groundwater response to precipitation.

Model performance evaluation should be carried out to verify a generalization of the developed correlation models. During the training process of network, 85% of dataset were selected as training sets while the remaining 15% of dataset were used for verification of the performance of the ANN model developed during the training stage. The network model should be adjusted until the performances are high in both the training dataset and testing dataset.

The SGI forecasts are estimated by applying to SPIs forecasts with correlation models. Precipitation forecasts are essential for SGI prediction. SPI 1-month to 12-month can be updated using precipitation forecasts which are provided by Korea Meteorological Agency on the 23rd of each month including forecasts of 1, 2, 3 month precipitation. And then it is possible to estimate SGI using SPI 1-12 values and network model developed above for each 167 cities.

Groundwater drought outlook (1 month, 2 month, 3 month) for each city is determined based on the SGI for each city and groundwater drought criteria

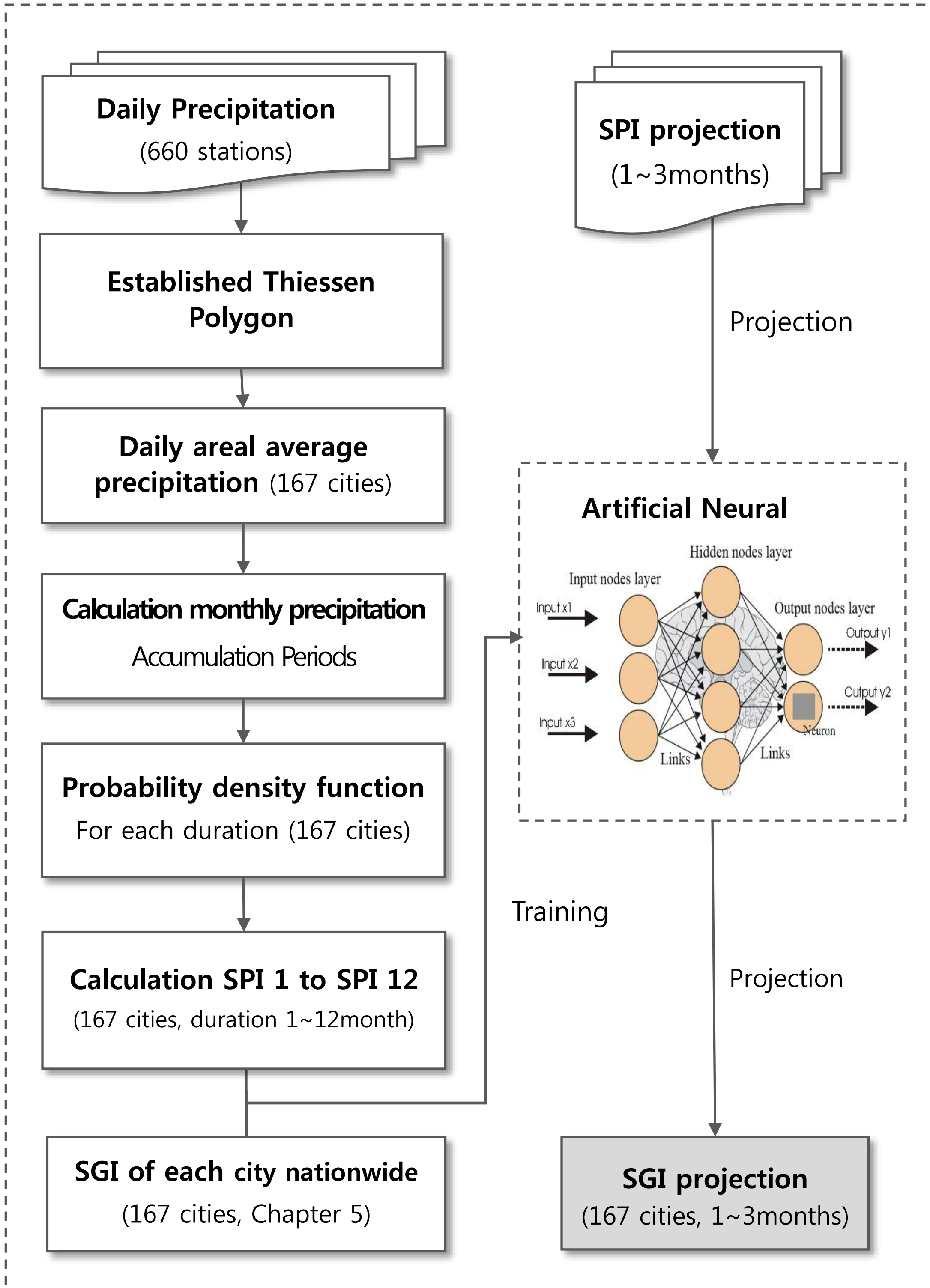
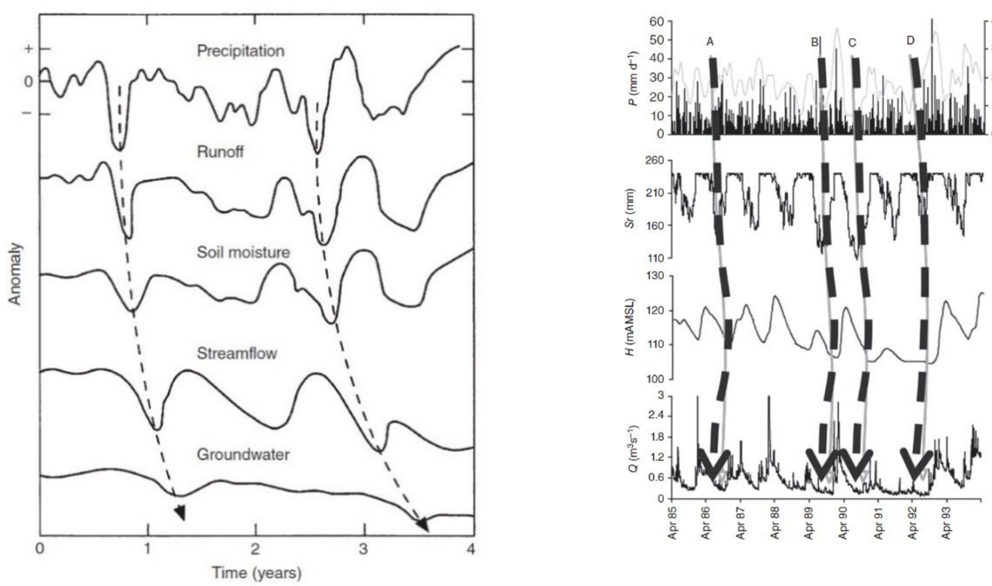


Figure 6.1 A Procedure Diagram of Groundwater Drought Projection

6.2 Groundwater Level Response to Precipitation

The relationship between precipitation, soil moisture, runoff, recharge, groundwater, and discharge is an old concept in hydrology, but the application of this knowledge to drought is relatively recent (Van Loon 2015). Changnon (1987) addressed an approach how precipitation deficiencies are translated in the drought signal through the other components in the hydrological cycle. McKee, Doesken et al. (1993) developed a SPI to quantify severity of droughts based on severity of only precipitation deficiency.

Peters, Torfs et al. (2003) published a study on the propagation of drought through groundwater system. Figure 6.2 (a) describes the propagation of drought due to precipitation deficiency in the hydrological cycle by Changnon (1987) and Figure 6.2 (b) shows an example of drought propagation in groundwater by the Pang catchment (UK) by Peters, Torfs et al. (2003). In both figure 6.2 (a) and (b), the order of the variables are different, but the correlation between precipitation and groundwater response is well represented. As shown in the Figure 6.2, the factors affecting groundwater level are not only precipitation, but the precipitation deficiency is a significant factor affecting behavior on groundwater levels.



(a) (b)

Figure 6.2 Propagation of Drought due to Precipitation Anomaly through the Hydrological Cycles.

6.3 Calculation of Standardized Precipitation Index (SPI)

In order to calculate the SPI of 167 cities nationwide, daily precipitation observation data were collected from 660 gauging stations shown and monthly area average precipitation data were reproduced for each city based on the Thiessen polygon.

Area average precipitation calculation

From 1966 to 2016 daily observation data of 660 rainfall gauging stations were collected to estimate area average precipitation by 167 cities nationwide. The 660 gauging stations consist of 412 stations managed by MOLIT, 168 stations managed by K-water, and 80 stations controlled by KMA. The collected daily precipitation data was used the approval data in which missing data was supplemented by each agencies. The areal weight ratio of each station for 167 cities was calculated by using Arc-GIS Thiessen polygon shown in Figure 6.3.

SPI calculation

SPI developed by McKee, Doesken et al. (1993) is one of the most widely used indices of meteorological drought. It was developed to quantify the deficiency of precipitation over various time scales. The deficiency of precipitation affects the availability of various water sources and ultimately causes hydrological droughts. The SPI for a particular region or point is calculated based on long-term precipitation records for a specific period of time. A monthly precipitation dataset was prepared from 1966 to 2016. To calculate the SPI, monthly accumulated dataset with 1 to 12 months duration were reproduced. Each of the dataset were fitted to the Gamma distribution to define the relationship of probability to precipitation. After cumulative probability was obtained using the parameters of gamma distribution function, the SPI was estimated by applying it to the standard normal distribution. The SPI for each 167 cities nationwide was calculated by this process. Figure 6.4 shows the estimated SPI with 1 to 12 month duration at Cheoingju city in Chungcheong province.

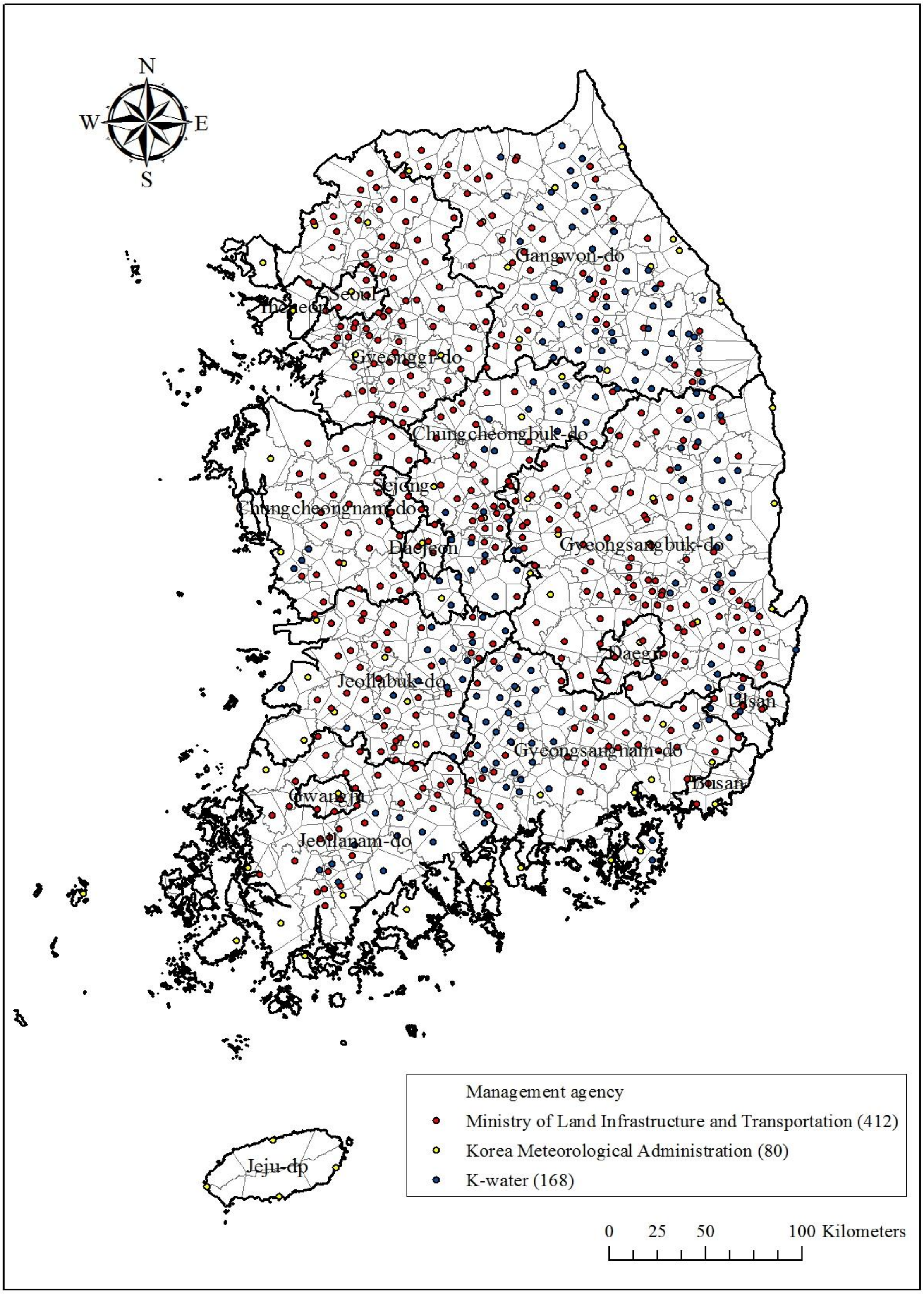


Figure 6.3 Precipitation Monitoring Station Location Map and Thiessen Networks in Korea

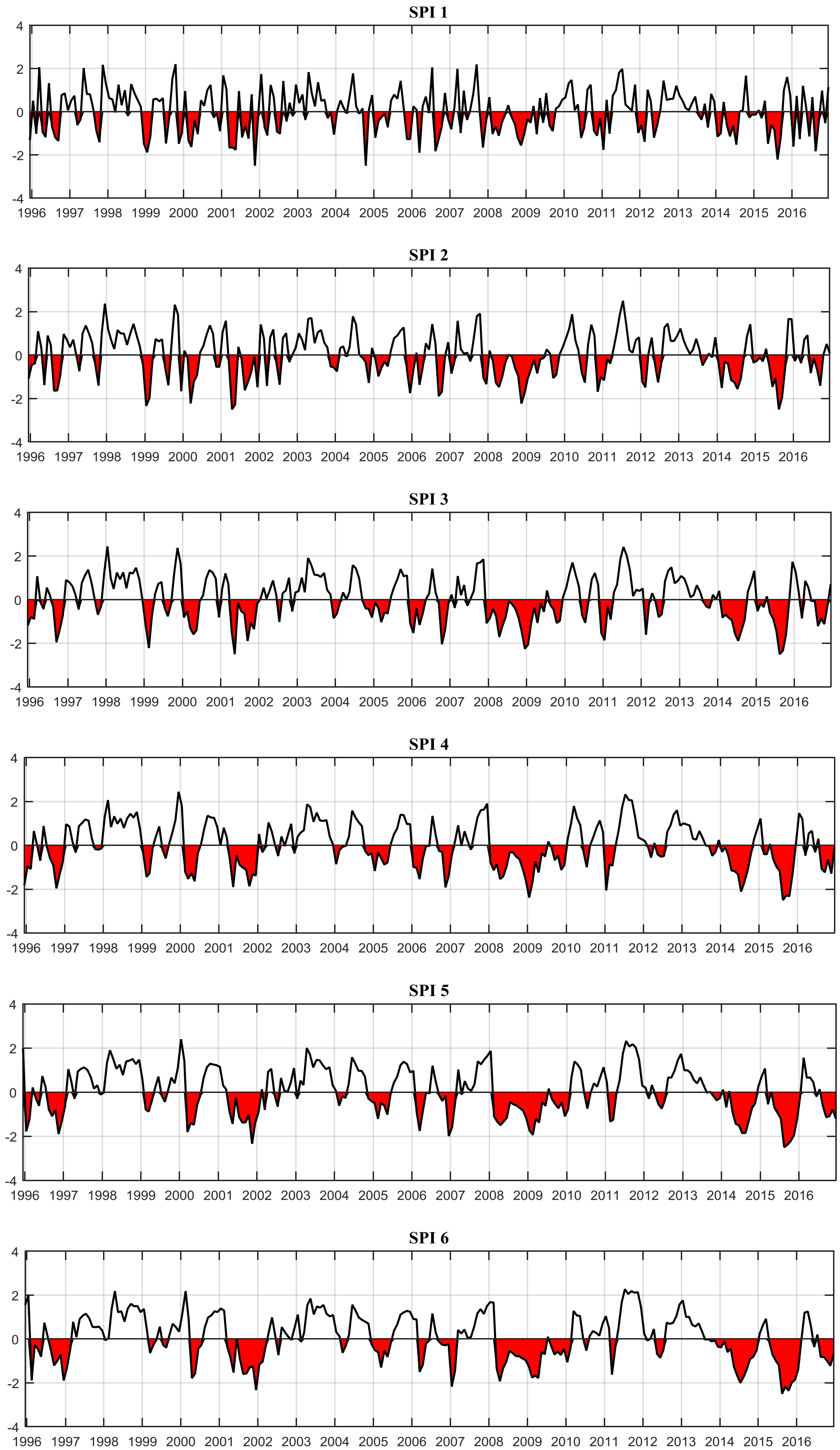


Figure 6.4 SPI at Cheongju City in Chungcheong Province

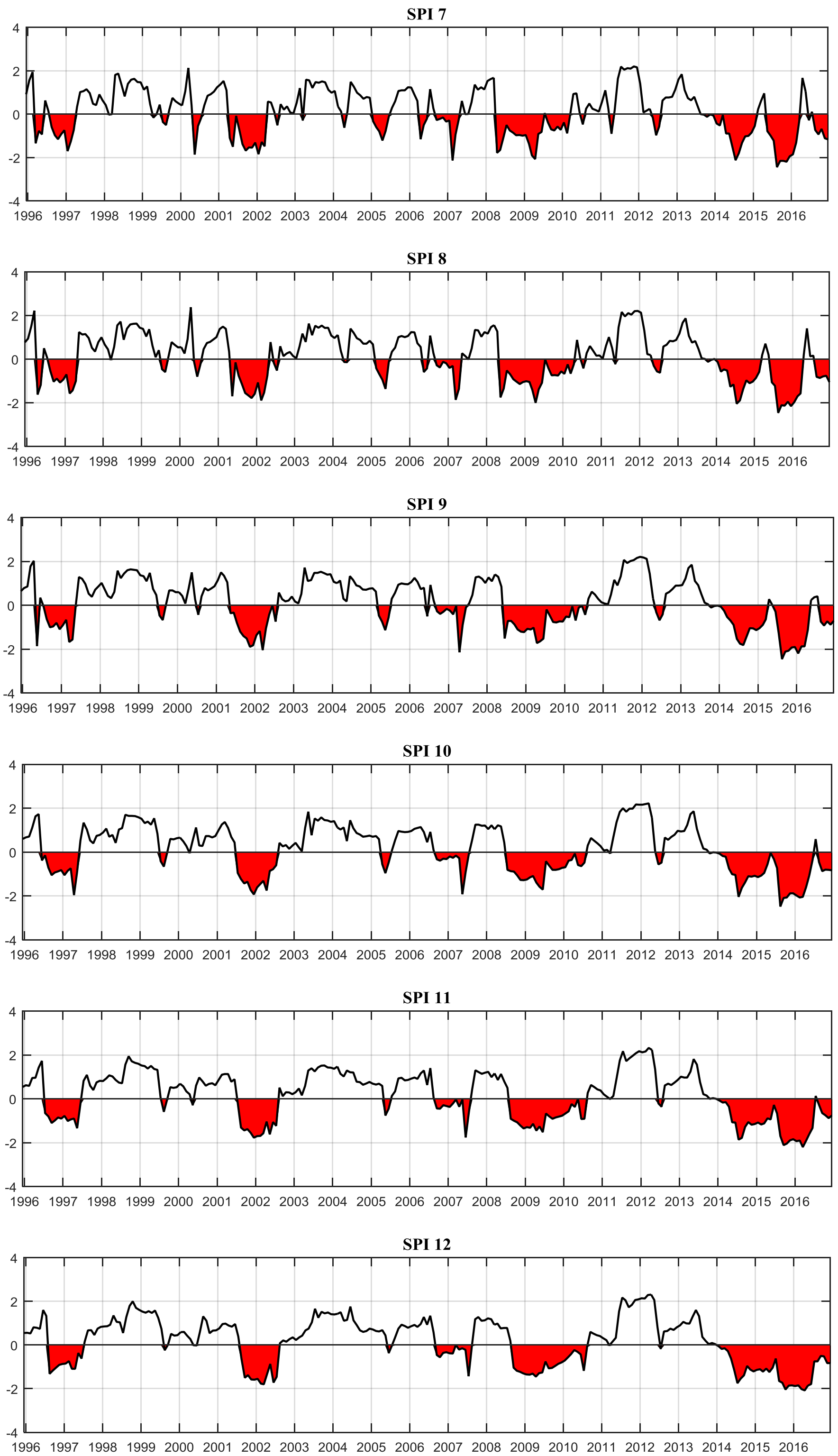


Figure 6.4 (continued)

6.4 Correlation between SPI and SGI

Figure 6.5 include plots of both the monthly SGI and SPI (1-month up to 12-month) for 2003-2016 periods of time at Cheongju in Chungcheong province. A bold black line on the graph correspond to SGI and other 12 colored lines is used for SPI 1-SPI12. As shown in Figure 6.5, it can be seen that the behavior of both SGI and SPI (1-month to 12-month) time series represent a similar tendency with lag time.

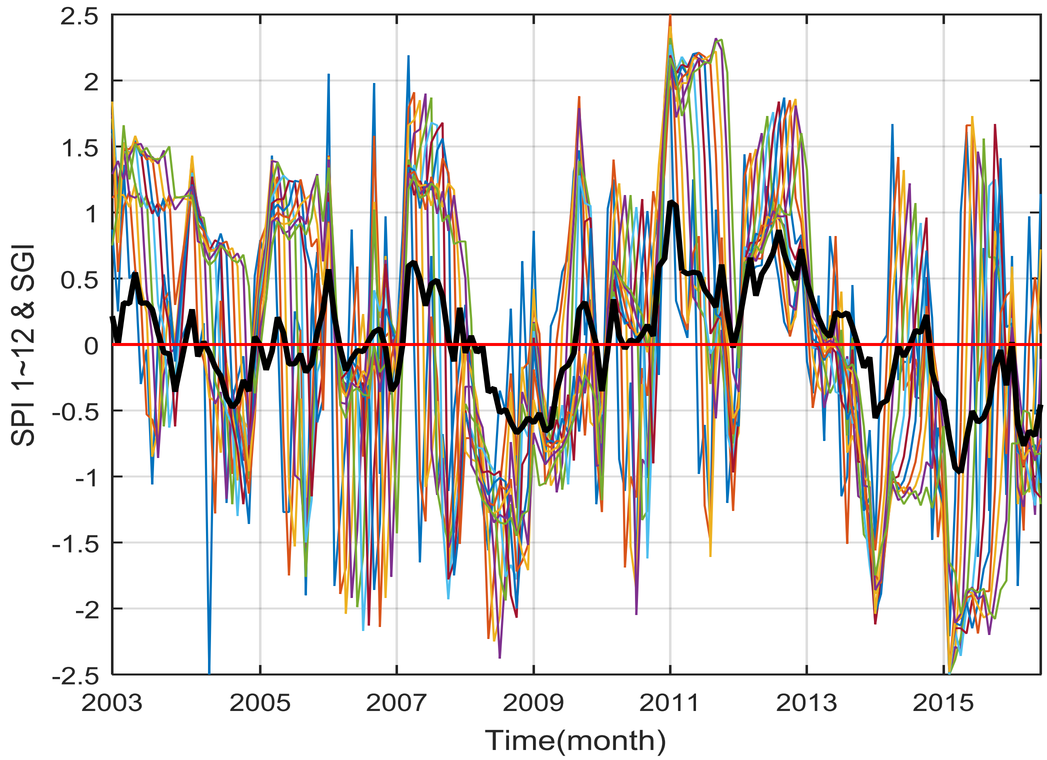


Figure 6.5. Time Series of SGI and 1 Month to 12 Month SPI of Cheongju City

The correlation analysis between SGI and SPI was performed to conform the validity of SPI as a factor for groundwater level forecasting. Total 12 SPI values corresponding to SGI of a specific city were analyzed for correlation from 1-month to 12-month relatively in order to identify how the lag time of the groundwater level fluctuation due to precipitation has a high correlation with the period of time. Figure 6.6 shows the correlation analysis results between SGI and SPI for 1-month to 12-month for 26 cities in

Chungcheong province. In Figure 6.6, the rows correspond to cities in Chungcheong province, and 12 columns are the results of correlation analysis from 1-month to 12-month of SPI calculated for each city relatively. The color of each block is expressed in red as the correlation is higher. The correlation coefficient for each city in a span is expressed on SPI that has the highest correlation with SGI among the 12 SPIs. For instance, at the top of the Figure 6.6, the correlation coefficient of 0.769 for the 7th column in Cheongju shows the highest correlation of SGI of Cheongju is 7-month SPI of Cheongju. Table 6.1 shows the correlation coefficients analyzed with SGI and SPIs of 26 cities in Chungcheong province by tabulating the correlation in Figure 6.6.

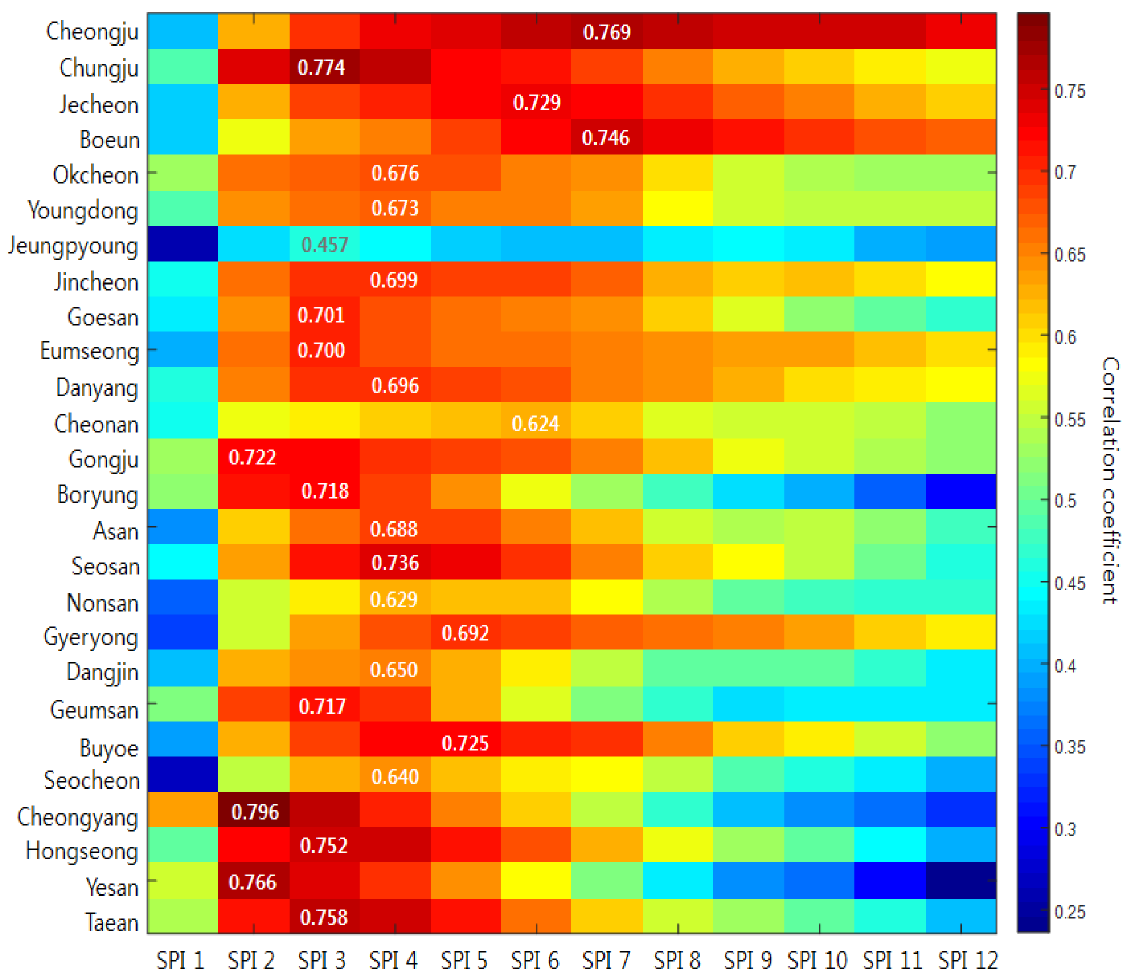


Figure 6.6 Correlation between SGI and SPI on 26 Cities in Chungcheong Province

Table 6.1 Correlation Coefficient between SGI and SPIs for Chungcheong Province

City	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Cheongju	0.408	0.625	0.695	0.730	0.737	0.755	0.769	0.757	0.745	0.752	0.747	0.730
Chungju	0.483	0.735	0.774	0.752	0.726	0.711	0.687	0.652	0.625	0.608	0.587	0.577
Jecheon	0.412	0.625	0.685	0.706	0.717	0.729	0.722	0.695	0.673	0.648	0.623	0.610
Boeun	0.415	0.574	0.631	0.655	0.686	0.719	0.746	0.732	0.716	0.693	0.682	0.671
Okcheon	0.533	0.657	0.672	0.676	0.674	0.656	0.643	0.602	0.559	0.539	0.530	0.529
Youngdong	0.483	0.640	0.665	0.673	0.651	0.649	0.633	0.585	0.551	0.550	0.544	0.547
Jeungpyoung	0.260	0.422	0.457	0.438	0.413	0.410	0.410	0.436	0.444	0.435	0.398	0.387
Jincheon	0.447	0.658	0.696	0.699	0.686	0.688	0.665	0.630	0.607	0.617	0.602	0.582
Goesan	0.431	0.647	0.701	0.677	0.659	0.651	0.642	0.608	0.563	0.519	0.491	0.467
Eumseong	0.396	0.658	0.700	0.682	0.663	0.658	0.656	0.640	0.631	0.632	0.619	0.603
Danyang	0.458	0.649	0.693	0.696	0.686	0.674	0.653	0.640	0.625	0.602	0.588	0.577
Cheonan	0.449	0.571	0.589	0.610	0.619	0.624	0.604	0.562	0.553	0.556	0.547	0.518
Gongju	0.531	0.722	0.720	0.699	0.684	0.675	0.654	0.614	0.571	0.554	0.542	0.517
Boryung	0.521	0.716	0.718	0.691	0.640	0.575	0.533	0.475	0.427	0.398	0.355	0.305
Asan	0.385	0.611	0.658	0.688	0.686	0.656	0.613	0.558	0.540	0.547	0.517	0.479
Seosan	0.440	0.636	0.714	0.736	0.732	0.693	0.650	0.608	0.581	0.546	0.507	0.459
Nonsan	0.350	0.555	0.589	0.629	0.616	0.616	0.582	0.539	0.492	0.475	0.469	0.469
Gyeryong	0.335	0.556	0.630	0.677	0.692	0.687	0.672	0.663	0.648	0.635	0.606	0.587
Dangjin	0.403	0.622	0.642	0.650	0.628	0.586	0.543	0.499	0.496	0.498	0.470	0.430
Geumsan	0.510	0.684	0.717	0.694	0.623	0.564	0.515	0.466	0.421	0.432	0.433	0.437
Buyoe	0.388	0.626	0.687	0.721	0.725	0.708	0.697	0.654	0.611	0.589	0.556	0.524
Seocheon	0.268	0.545	0.622	0.640	0.621	0.594	0.584	0.544	0.489	0.461	0.430	0.394
Cheongyang	0.632	0.796	0.760	0.708	0.654	0.605	0.544	0.465	0.403	0.382	0.366	0.328
Hongseong	0.492	0.726	0.752	0.750	0.716	0.679	0.627	0.570	0.533	0.490	0.443	0.399
Yesan	0.558	0.766	0.743	0.695	0.639	0.582	0.508	0.429	0.384	0.360	0.305	0.236
Taean	0.541	0.709	0.758	0.746	0.711	0.658	0.607	0.552	0.525	0.492	0.457	0.405

Figure 6.7 and 6.8 show the time series comparison of SPI 7 and SPI 3, which showed the highest correlation with SGI for Cheongju and Chungju respectively. In both time series, negative values corresponding to below normal were colored to facilitate comparison of both indices during the drought period.

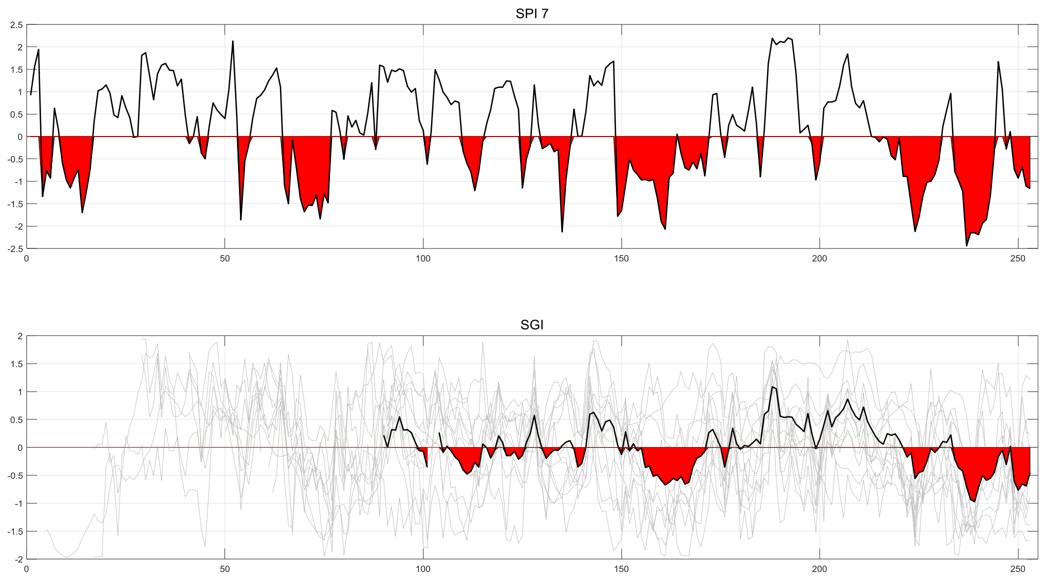


Figure 6.7 Comparison between SPI 7 and SGI of Cheongju City

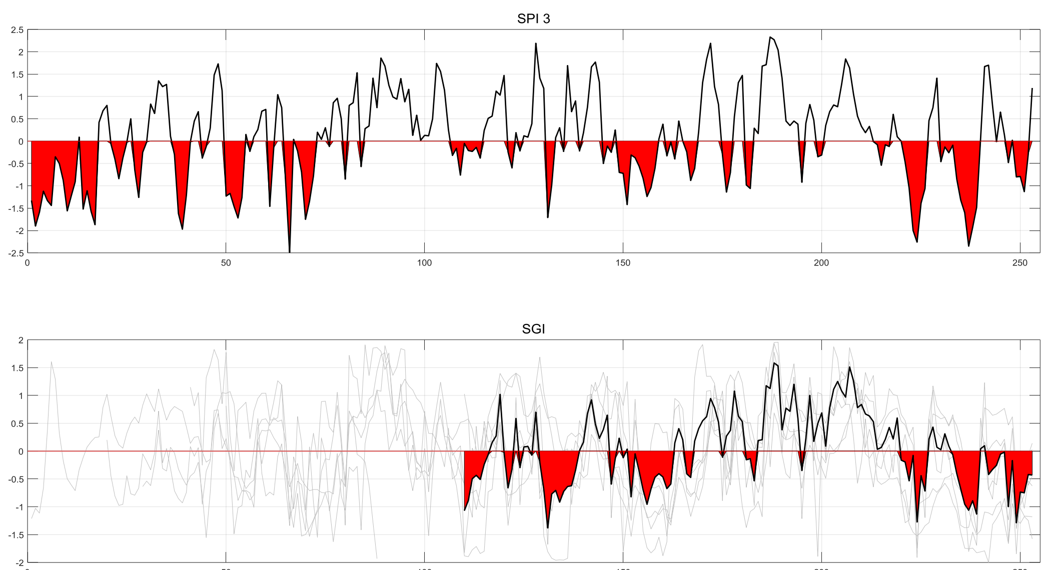


Figure 6.8 Comparison between SPI 3 and SGI of Chungju City

6.5 SGI Forecasting Model using ANN

Most of hydrologic processes exhibit a high degree of temporal and spatial variability and are further plagued by issues of nonlinearity of physical processes, conflicting spatial and temporal scales, and uncertainty in parameter estimates. The advantage of ANN models is their ability to extract the relation between the inputs and outputs of a process, without physics being explicitly provided to them (Hydrology 2000b).

As mentioned in chapter 2, NARX Neural Networks were applied for SGI forecasting based on given input (SPI). As shown in Figure 2.4, a two-layer feedforward network was used for the approximation of function. The input layer contains input values and target values from a specific past time to the present time of the system and play a role of passing them to the hidden layer (layer 1 in Figure 2.4).

In this study, the network consisted of 12 nodes for input layer, 12 nodes structured in a hidden layer, and an output layer containing one neuron. A tangent sigmoid function was used for the activation function provided in MATLAB Neural Network Toolbox in the hidden layer. The SPIs dataset from 167 cities nationwide were used as the input layer. Based on correlation analysis results, only the SPI with the highest correlation might be considered as the input data. However, since the SPIs having the different duration showed an irreducible correlation with the SGI, the SPI 1 to SPI 12 are all contained as input data. In the NARX neural network training process, the weight of each data was determined by itself.

The spatially interpolated SGI values from 256 national groundwater monitoring networks to 167 cities nationwide were used in the output layer. During the training of the network, the output is fed back to the feedforward neural network as an input. The number of delay time step for the past output which influences the current output was set up to take into consideration up to three month. The network system updates the weight and bias of each neuron so that the error between the target SGI and the estimated SGI is minimized during training stage. The Bayesian Regularization Backpropagation was selected for the network training function to update the weight and bias values. Table 6.2 shows examples of input and target at Cheongju city of Chungcheong province, among the 167 cities nationwide for ANN training. The inputs are the SPI 1-12 values from 2004 to 2016, and the output corresponding to the target value is the monthly SGI value.

Table 6.2 Example of Dataset for ANN Training at Cheongju City

Year	Month	SPI (Input)												SGI (Target)
		1	2	3	4	5	6	7	8	9	10	11	12	
2004	1	0.05	-0.75	-0.65	-0.86	0.06	0.31	1.07	0.97	1.07	1.41	1.37	1.4	0.087
2004	2	0.53	0.33	-0.12	-0.23	-0.62	0.12	0.35	1.11	1.01	1.12	1.47	1.43	-0.062
2004	3	0.19	0.4	0.33	-0.07	-0.19	-0.63	0.13	0.38	1.13	1.03	1.14	1.5	-0.070
2004	4	-0.08	-0.07	0.01	-0.03	-0.26	-0.3	-0.62	-0.13	0.3	1.12	1.02	1.11	-0.358
2004	7	0.25	1.42	1.43	1.28	1.3	1.3	1.27	1.21	1.16	1.09	1.2	1.13	0.266
2004	8	-0.09	0.02	0.98	1.05	0.97	0.98	0.99	0.96	0.91	0.87	0.78	0.91	-0.092
2004	9	0.16	-0.12	-0.03	0.88	0.96	0.87	0.87	0.88	0.86	0.8	0.76	0.67	0.021
2004	10	-2.5	-0.32	-0.4	-0.26	0.7	0.79	0.71	0.71	0.72	0.7	0.64	0.6	-0.062
2004	11	0.11	-1.28	-0.43	-0.45	-0.28	0.7	0.79	0.71	0.71	0.72	0.7	0.64	-0.171
2004	12	0.77	0.33	-0.82	-0.36	-0.41	-0.25	0.76	0.84	0.76	0.75	0.77	0.75	-0.239
2005	1	-1.2	-0.15	-0.14	-1.17	-0.5	-0.51	-0.32	0.68	0.78	0.7	0.69	0.71	-0.400
2005	2	-0.42	-0.98	-0.39	-0.34	-1.21	-0.61	-0.6	-0.41	0.63	0.73	0.65	0.64	-0.477
2005	3	-0.26	-0.6	-1.03	-0.58	-0.48	-1.3	-0.79	-0.67	-0.46	0.59	0.69	0.62	-0.430
2005	4	-0.09	-0.3	-0.58	-0.88	-0.61	-0.54	-1.21	-0.94	-0.75	-0.55	0.59	0.68	-0.270
2005	5	-0.72	-0.52	-0.64	-0.79	-1.02	-0.82	-0.78	-1.36	-1.13	-0.96	-0.76	0.44	-0.355
2005	6	0.52	0.23	0.13	0.06	-0.05	-0.19	-0.11	-0.14	-0.56	-0.48	-0.45	-0.37	0.058
2005	7	0.79	0.78	0.58	0.5	0.43	0.37	0.29	0.34	0.3	0.06	0.13	-0.03	-0.007
2005	8	0.6	0.9	0.93	0.77	0.7	0.66	0.6	0.53	0.57	0.54	0.34	0.35	-0.192
2005	9	1.43	1.13	1.4	1.39	1.22	1.11	1.07	1.01	0.94	0.96	0.93	0.75	-0.053
2005	10	0.15	1.27	1.07	1.38	1.38	1.21	1.1	1.06	1.0	0.93	0.96	0.93	0.206
2005	11	-1.27	-0.7	1.11	0.97	1.28	1.28	1.1	1.01	0.97	0.91	0.84	0.87	0.087
2005	12	-1.27	-1.75	-1.08	0.97	0.9	1.24	1.24	1.06	0.96	0.92	0.86	0.79	-0.148
2006	1	0.25	-0.7	-1.53	-0.99	0.96	0.91	1.23	1.24	1.06	0.96	0.92	0.86	-0.146
2006	2	0.09	0.11	-0.41	-1.03	-0.9	0.89	0.9	1.23	1.25	1.06	0.97	0.92	-0.071
2006	3	-1.9	-1.37	-1.16	-1.54	-1.76	-1.5	0.61	0.73	1.07	1.1	0.91	0.83	-0.212
2006	4	0.26	-0.57	-0.63	-0.6	-0.84	-1.18	-1.15	0.56	0.74	1.14	1.16	0.96	-0.146
2006	5	0.7	0.54	0.02	-0.04	-0.01	-0.21	-0.5	-0.59	0.8	0.91	1.29	1.28	0.089
2006	6	-0.05	0.25	0.28	-0.03	-0.06	-0.07	-0.2	-0.42	-0.5	0.45	0.63	0.93	0.255
2006	7	2.05	1.43	1.42	1.34	1.2	1.16	1.15	1.08	0.93	0.92	1.4	1.34	0.569
2006	8	-1.83	0.52	0.34	0.45	0.46	0.3	0.27	0.27	0.21	0.08	0.05	0.59	0.210
2006	9	-1.28	-1.89	-0.16	-0.26	-0.14	-0.12	-0.27	-0.28	-0.27	-0.33	-0.44	-0.46	-0.029
2006	10	-0.7	-1.69	-2.04	-0.3	-0.4	-0.26	-0.22	-0.38	-0.39	-0.39	-0.45	-0.56	-0.197
2006	11	0.87	-0.04	-1.37	-1.92	-0.18	-0.29	-0.15	-0.12	-0.29	-0.3	-0.29	-0.36	-0.109
2006	12	-0.35	0.59	-0.18	-1.41	-1.99	-0.23	-0.34	-0.19	-0.16	-0.32	-0.33	-0.33	-0.045

Table 6.2 (continued)

Year	Month	SPI (Input)												SGI (Target)
		1	2	3	4	5	6	7	8	9	10	11	12	
2007	1	-0.81	-0.85	0.23	-0.43	-1.6	-2.17	-0.29	-0.4	-0.24	-0.2	-0.37	-0.38	-0.055
2007	2	0.25	-0.24	-0.38	0.22	-0.41	-1.45	-2.13	-0.31	-0.41	-0.26	-0.21	-0.39	0.030
2007	3	1.98	1.58	1.08	0.91	1.02	0.41	-0.94	-1.86	-0.03	-0.16	-0.03	0	0.094
2007	4	-0.98	0.27	0.2	-0.02	-0.11	0.25	-0.24	-1.36	-2.14	-0.28	-0.36	-0.21	0.119
2007	5	0.97	0.06	0.67	0.64	0.5	0.43	0.61	0.27	-0.9	-1.92	-0.04	-0.15	-0.027
2007	6	-0.38	0.11	-0.28	0.17	0.16	0.04	0	0.14	-0.1	-0.9	-1.76	-0.22	-0.352
2007	7	0.07	-0.29	0.03	-0.2	0.06	0.08	0.01	-0.01	0.08	-0.09	-0.63	-1.43	-0.285
2007	8	0.86	0.72	0.4	0.56	0.36	0.56	0.55	0.5	0.47	0.55	0.42	-0.04	0.006
2007	9	2.19	1.79	1.66	1.29	1.4	1.17	1.36	1.34	1.28	1.25	1.3	1.18	0.594
2007	10	-0.03	1.91	1.7	1.6	1.26	1.36	1.13	1.32	1.31	1.25	1.22	1.28	0.626
2007	11	-1.65	-1.02	1.85	1.63	1.48	1.14	1.24	1.03	1.21	1.2	1.14	1.11	0.495
2007	12	-0.43	-1.34	-1.08	1.9	1.65	1.5	1.14	1.24	1.02	1.21	1.19	1.13	0.293
2008	1	0.67	0.21	-0.86	-0.79	1.87	1.68	1.53	1.17	1.27	1.05	1.23	1.22	0.459
2008	2	-1.03	-0.26	-0.43	-1.14	-1.1	1.66	1.62	1.47	1.1	1.22	0.99	1.18	0.487
2008	3	-0.68	-1.28	-0.75	-0.86	-1.33	-1.34	1.68	1.56	1.41	1.04	1.16	0.93	0.363
2008	4	-1.11	-1.47	-1.71	-1.54	-1.5	-1.93	-1.78	1.27	1.3	1.22	0.86	0.98	0.044
2008	5	-0.5	-1	-1.2	-1.42	-1.34	-1.35	-1.65	-1.75	0.85	1.17	1.13	0.76	-0.128
2008	6	-0.13	-0.33	-0.8	-0.98	-1.17	-1.04	-1.08	-1.35	-1.51	0.43	0.79	0.78	0.278
2008	7	0.3	0.02	-0.07	-0.32	-0.45	-0.55	-0.5	-0.52	-0.71	-0.81	0.5	0.78	-0.064
2008	8	-0.24	-0.06	-0.21	-0.32	-0.55	-0.65	-0.75	-0.69	-0.71	-0.87	-0.91	0.19	0.065
2008	9	-0.55	-0.6	-0.42	-0.52	-0.61	-0.78	-0.85	-0.92	-0.87	-0.89	-1	-1.04	-0.063
2008	10	-1.22	-0.97	-0.82	-0.63	-0.72	-0.79	-0.97	-1.03	-1.1	-1.06	-1.07	-1.18	-0.011
2008	11	-1.56	-2.23	-1.47	-1.07	-0.84	-0.89	-0.96	-1.14	-1.2	-1.27	-1.22	-1.23	-0.363
2008	12	-1.04	-1.75	-2.25	-1.6	-1.18	-0.96	-0.99	-1.05	-1.22	-1.28	-1.35	-1.3	-0.330
2009	1	-0.35	-1.07	-2.06	-2.38	-1.74	-1.26	-0.96	-1.01	-1.07	-1.25	-1.29	-1.35	-0.518
2009	2	-0.51	-0.65	-1.02	-1.71	-1.94	-1.76	-1.37	-1.04	-1.1	-1.15	-1.32	-1.36	-0.492
2009	3	0.27	-0.22	-0.36	-0.74	-1.21	-1.67	-1.9	-1.41	-1.02	-1.09	-1.14	-1.31	-0.590
2009	4	-1.04	-0.84	-1.07	-1.24	-1.38	-1.78	-2.07	-2	-1.72	-1.39	-1.45	-1.45	-0.672
2009	5	0.63	-0.19	-0.17	-0.36	-0.45	-0.6	-0.91	-1.38	-1.64	-1.58	-1.26	-1.29	-0.627
2009	6	-0.51	-0.14	-0.56	-0.51	-0.62	-0.7	-0.82	-1.08	-1.52	-1.71	-1.52	-1.26	-0.555
2009	7	0.86	0.26	0.42	0.17	0.16	0.1	0.05	-0.01	-0.19	-0.42	-0.67	-0.76	-0.595
2009	8	-0.63	0.08	-0.25	-0.1	-0.32	-0.32	-0.38	-0.41	-0.47	-0.62	-0.8	-1.07	-0.521
2009	9	-0.9	-1.06	-0.44	-0.68	-0.55	-0.71	-0.7	-0.74	-0.76	-0.81	-0.91	-1.05	-0.658
2009	10	0.14	-0.9	-1.07	-0.47	-0.73	-0.58	-0.75	-0.73	-0.78	-0.81	-0.85	-0.96	-0.624
2009	11	0.26	0.03	-0.97	-1.12	-0.47	-0.73	-0.57	-0.75	-0.73	-0.78	-0.81	-0.86	-0.348
2009	12	0.55	0.36	0.13	-0.9	-1.1	-0.46	-0.72	-0.56	-0.74	-0.72	-0.77	-0.8	-0.191
2010	1	0.66	0.77	0.55	0.29	-0.77	-1.06	-0.38	-0.67	-0.51	-0.69	-0.67	-0.71	-0.157
2010	2	1.31	1.21	1.22	0.97	0.68	-0.4	-0.88	-0.24	-0.54	-0.39	-0.57	-0.56	-0.068
2010	3	1.47	1.88	1.7	1.79	1.39	1.28	-0.05	-0.66	-0.05	-0.36	-0.24	-0.42	0.263
2010	4	0.07	0.69	1.13	1.23	1.25	1.07	0.93	-0.23	-0.69	-0.07	-0.37	-0.23	0.321
2010	5	0.34	0.21	0.61	0.92	1.01	1.05	0.96	0.88	-0.1	-0.59	0.0	-0.31	0.165
2010	6	-1.21	-0.8	-0.71	-0.32	-0.05	0.0	0.05	0.04	-0.03	-0.64	-0.92	-0.43	0.000

Table 6.2 (continued)

Year	Month	SPI (Input)												SGI (Target)
		1	2	3	4	5	6	7	8	9	10	11	12	
2010	7	-0.74	-1.27	-1.06	-1	-0.75	-0.53	-0.47	-0.42	-0.43	-0.48	-0.91	-1.18	-0.354
2010	8	1.03	0.49	-0.08	-0.01	-0.02	0.13	0.25	0.28	0.31	0.3	0.27	-0.08	-0.037
2010	9	1.25	1.4	0.93	0.38	0.4	0.36	0.49	0.6	0.62	0.64	0.63	0.6	0.342
2010	10	-0.87	0.9	1.22	0.8	0.25	0.28	0.25	0.39	0.49	0.52	0.54	0.52	0.064
2010	11	-1.11	-1.69	0.68	1.13	0.7	0.15	0.19	0.16	0.29	0.4	0.43	0.45	-0.032
2010	12	-0.29	-1.0	-1.53	0.61	1.13	0.68	0.12	0.17	0.14	0.27	0.38	0.41	0.036
2011	1	-1.76	-1.16	-1.86	-2.05	0.44	1.04	0.58	0.03	0.08	0.07	0.2	0.31	0.015
2011	2	0.55	-0.18	-0.3	-0.87	-1.33	0.49	1.1	0.61	0.05	0.1	0.09	0.22	0.076
2011	3	-1.01	-0.39	-0.91	-0.93	-1.26	-1.62	0.29	1.01	0.49	-0.06	-0.01	-0.02	0.147
2011	4	0.74	0.27	0.34	0.01	-0.06	-0.41	-0.9	0.5	1.16	0.68	0.13	0.16	0.063
2011	5	1.0	1.0	0.69	0.75	0.54	0.47	0.16	-0.23	0.91	1.36	0.92	0.33	0.590
2011	6	1.81	1.87	1.85	1.75	1.75	1.66	1.63	1.46	1.32	1.83	1.75	1.54	0.652
2011	7	1.98	2.5	2.41	2.32	2.32	2.27	2.19	2.16	2.07	2.0	2.17	2.17	1.084
2011	8	0.33	1.42	2.02	2.07	2.07	2.05	2.05	1.96	1.93	1.84	1.72	2.05	1.050
2011	9	0.19	0.23	1.34	2.05	2.17	2.18	2.12	2.11	2.02	1.98	1.85	1.73	0.560
2011	10	0.05	0.11	0.16	1.3	2.02	2.11	2.1	2.04	2.06	1.98	1.96	1.84	0.534
2011	11	1.25	0.69	0.45	0.36	1.47	2.13	2.2	2.2	2.16	2.17	2.08	2.06	0.547
2011	12	-0.98	0.82	0.4	0.28	0.29	1.46	2.16	2.21	2.21	2.16	2.17	2.09	0.540
2012	1	-0.61	-1.22	0.51	0.2	0.2	0.23	1.4	2.13	2.18	2.16	2.12	2.14	0.413
2012	2	-1.39	-1.49	-1.61	-0.08	-0.3	-0.07	0.08	1.32	2.12	2.19	2.16	2.13	0.353
2012	3	1.02	0.06	-0.19	-0.56	0.32	0.01	0.16	0.23	1.44	2.22	2.32	2.29	0.282
2012	4	0.46	0.81	0.3	0.11	-0.11	0.46	0.25	0.19	0.31	1.56	2.23	2.31	0.606
2012	5	-1.2	-0.37	-0.07	-0.41	-0.54	-0.68	-0.17	-0.3	-0.31	0.05	1.35	2.06	0.241
2012	6	-0.63	-1.26	-0.8	-0.52	-0.75	-0.86	-0.97	-0.56	-0.68	-0.56	-0.21	0.8	-0.024
2012	7	0.07	-0.42	-0.67	-0.49	-0.37	-0.5	-0.56	-0.62	-0.41	-0.48	-0.36	-0.18	0.151
2012	8	1.44	1.27	0.85	0.62	0.66	0.74	0.63	0.58	0.53	0.66	0.61	0.62	0.402
2012	9	0.54	1.45	1.33	0.91	0.66	0.69	0.77	0.66	0.61	0.56	0.69	0.64	0.657
2012	10	0.59	0.65	1.48	1.4	0.98	0.74	0.77	0.84	0.74	0.69	0.63	0.75	0.369
2012	11	0.6	0.65	0.75	1.6	1.46	1.04	0.8	0.82	0.9	0.79	0.74	0.69	0.532
2012	12	1.2	0.89	0.86	0.9	1.73	1.57	1.13	0.88	0.9	0.97	0.86	0.81	0.601
2013	1	0.75	1.22	1.08	1.0	0.99	1.76	1.6	1.17	0.92	0.94	1.01	0.9	0.695
2013	2	0.49	0.68	0.97	0.95	0.99	1	1.84	1.67	1.22	0.96	0.97	1.06	0.866
2013	3	0.17	0.35	0.61	0.9	0.87	1.01	1.11	1.87	1.7	1.23	0.97	0.99	0.686
2013	4	0.07	0.06	0.11	0.3	0.55	0.64	0.74	1.07	1.85	1.73	1.24	0.98	0.558
2013	5	0.39	0.24	0.21	0.26	0.4	0.57	0.64	0.76	1.11	1.86	1.81	1.3	0.491
2013	6	0.7	0.75	0.66	0.65	0.67	0.71	0.8	0.83	0.92	1.06	1.56	1.6	0.721
2013	7	-0.13	0.27	0.37	0.34	0.32	0.36	0.4	0.48	0.51	0.58	0.76	1.32	0.467
2013	8	-0.37	-0.48	-0.09	-0.01	-0.02	-0.03	0.0	0.04	0.12	0.16	0.21	0.37	0.328
2013	9	0.37	-0.2	-0.32	-0.04	0.01	-0.01	-0.02	0.01	0.05	0.11	0.15	0.19	0.201
2013	10	-0.73	0.07	-0.38	-0.48	-0.17	-0.11	-0.12	-0.12	-0.1	-0.06	0.0	0.04	0.105
2013	11	0.82	-0.1	0.22	-0.3	-0.37	-0.07	-0.01	-0.03	-0.03	-0.01	0.03	0.09	0.056
2013	12	0.47	0.82	0	0.24	-0.28	-0.36	-0.06	0.01	-0.01	-0.02	0.0	0.04	0.245

Table 6.2 (continued)

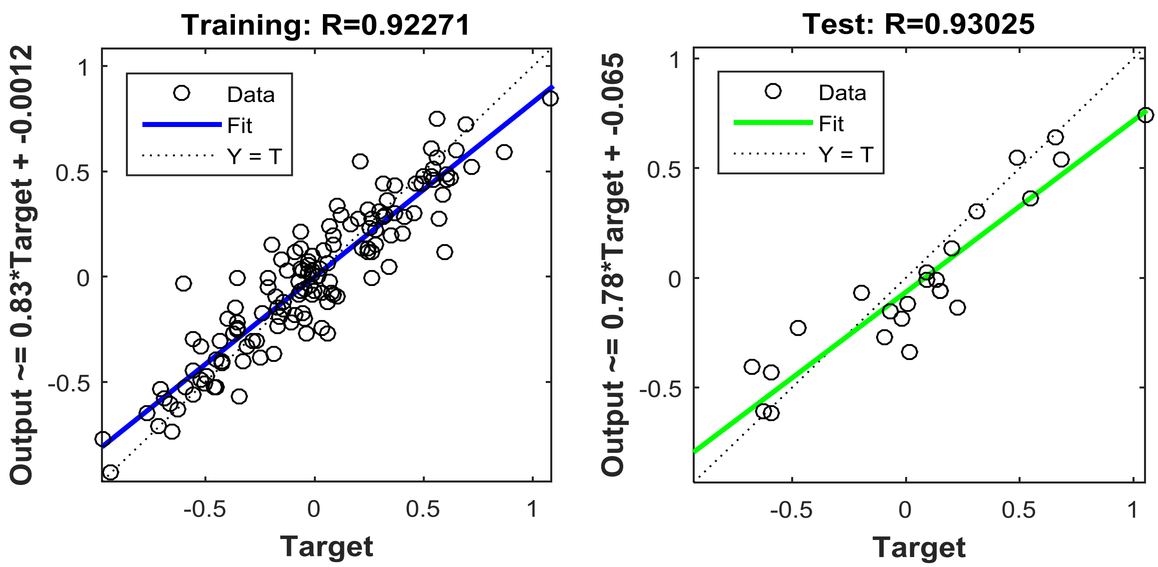
Year	Month	SPI (Input)												SGI (Target)
		1	2	3	4	5	6	7	8	9	10	11	12	
2014	1	-1.15	-0.36	0.4	-0.3	0.11	-0.38	-0.43	-0.13	-0.06	-0.07	-0.08	-0.05	0.215
2014	2	-1	-1.51	-0.82	-0.09	-0.69	-0.11	-0.52	-0.57	-0.25	-0.18	-0.17	-0.18	0.241
2014	3	0.45	-0.3	-0.69	-0.46	0.05	-0.6	-0.04	-0.47	-0.53	-0.21	-0.15	-0.15	0.132
2014	4	-0.62	-0.4	-0.83	-1.15	-0.92	-0.44	-0.89	-0.52	-0.69	-0.75	-0.36	-0.28	-0.012
2014	5	-1.14	-1.15	-0.94	-1.18	-1.44	-1.27	-0.89	-1.26	-0.89	-1.01	-1.07	-0.62	-0.176
2014	6	-0.65	-1.25	-1.57	-1.32	-1.51	-1.67	-1.51	-1.16	-1.53	-1.04	-1.08	-1.16	-0.097
2014	7	-1.52	-1.56	-1.89	-2.11	-1.86	-2.0	-2.12	-2.04	-1.75	-2.04	-1.86	-1.75	-0.558
2014	8	0	-1.11	-1.42	-1.68	-1.85	-1.73	-1.8	-1.89	-1.81	-1.63	-1.78	-1.54	-0.449
2014	9	0.07	-0.11	-0.92	-1.15	-1.3	-1.37	-1.32	-1.37	-1.42	-1.38	-1.28	-1.39	-0.425
2014	10	1.67	0.88	0.36	-0.41	-0.73	-0.92	-1.02	-0.97	-1.04	-1.1	-1.06	-0.96	-0.246
2014	11	-0.27	1.42	0.79	0.29	-0.5	-0.81	-1.0	-1.1	-1.05	-1.12	-1.18	-1.13	-0.014
2014	12	-0.13	-0.35	1.32	0.75	0.27	-0.54	-0.85	-1.03	-1.13	-1.08	-1.15	-1.21	-0.093
2015	1	-0.14	-0.27	-0.53	1.22	0.71	0.25	-0.54	-0.86	-1.04	-1.14	-1.08	-1.14	-0.010
2015	2	0.07	-0.11	-0.18	-0.4	1.07	0.64	0.22	-0.58	-0.89	-1.07	-1.17	-1.11	0.107
2015	3	-0.3	-0.29	-0.34	-0.41	-0.55	0.92	0.6	0.19	-0.64	-0.95	-1.12	-1.22	0.089
2015	4	0.51	0.29	0.15	0.06	0.02	-0.13	0.96	0.71	0.28	-0.56	-0.89	-1.08	0.223
2015	5	-1.48	-0.48	-0.61	-0.64	-0.71	-0.7	-0.78	0.2	0.02	-0.04	-0.94	-1.24	-0.211
2015	6	-0.63	-1.46	-0.89	-0.98	-0.95	-0.99	-0.99	-1.06	-0.29	-0.32	-0.28	-1.04	-0.368
2015	7	-0.83	-1.07	-1.44	-1.17	-1.21	-1.19	-1.22	-1.22	-1.27	-0.73	-0.67	-0.62	-0.422
2015	8	-2.21	-2.5	-2.5	-2.5	-2.5	-2.5	-2.44	-2.46	-2.45	-2.48	-1.7	-1.65	-0.707
2015	9	-1.18	-1.96	-2.34	-2.29	-2.39	-2.17	-2.15	-2.11	-2.11	-2.09	-2.11	-1.73	-0.934
2015	10	1.0	-0.59	-1.6	-2.32	-2.22	-2.36	-2.15	-2.13	-2.07	-2.07	-2.04	-2.04	-0.974
2015	11	1.61	1.66	-0.03	-1.27	-1.96	-1.99	-2.19	-1.95	-1.92	-1.88	-1.89	-1.86	-0.718
2015	12	0.74	1.66	1.73	0.03	-1.23	-1.87	-1.94	-2.15	-1.9	-1.88	-1.84	-1.85	-0.505
2016	1	-1.61	-0.28	1.27	1.46	-0.12	-1.39	-1.85	-1.97	-2.19	-1.98	-1.93	-1.88	-0.590
2016	2	0.73	0.02	0.27	1.2	1.56	0.0	-1.31	-1.7	-1.87	-2.07	-1.9	-1.85	-0.553
2016	3	-1.26	-0.37	-0.86	-0.47	0.66	1.2	-0.32	-1.57	-1.87	-2.04	-2.2	-2.02	-0.447
2016	4	1.2	0.71	0.86	0.54	0.66	1.25	1.67	0.21	-1.11	-1.6	-1.91	-2.08	-0.168
2016	5	0.22	0.92	0.56	0.67	0.47	0.57	1.05	1.41	0.24	-1.07	-1.61	-1.86	-0.043
2016	6	-1.14	-0.83	-0.07	-0.32	-0.2	-0.37	-0.28	0.13	0.37	-0.37	-1.33	-1.79	-0.310
2016	7	0.67	-0.15	-0.05	0.3	0.13	0.2	0.11	0.16	0.41	0.59	0.13	-0.75	0.017
2016	8	-1.83	-0.66	-1.21	-1.08	-0.65	-0.82	-0.73	-0.81	-0.74	-0.45	-0.27	-0.75	-0.605
2016	9	-0.43	-1.41	-0.86	-1.23	-1.14	-0.82	-0.93	-0.86	-0.92	-0.87	-0.65	-0.5	-0.768
2016	10	0.97	0.02	-1.12	-0.66	-1.09	-1.0	-0.68	-0.79	-0.73	-0.8	-0.75	-0.52	-0.655
2016	11	-0.53	0.51	-0.24	-1.29	-0.79	-1.22	-1.11	-0.76	-0.88	-0.81	-0.88	-0.83	-0.693
2016	12	1.14	0.08	0.72	-0.11	-1.21	-0.72	-1.16	-1.05	-0.71	-0.83	-0.76	-0.83	-0.456

In general, the dataset is divided into a training dataset, and a testing dataset. The purpose of the testing was to evaluate with how well trained network could generalize and predict using unused test data. During the training process of network, 85% of dataset were randomly selected as training sets while the remaining 15% of dataset were used for verification of the performance of the ANN model developed during the training stage.

The results of performance evaluation were plotted by the linear regression analysis between the target SGI values and the estimated SGI outputs. When the performance of training data are only high, the network model should be adjusted until the performances are high in both the training data and testing data because of concern over overfitting.

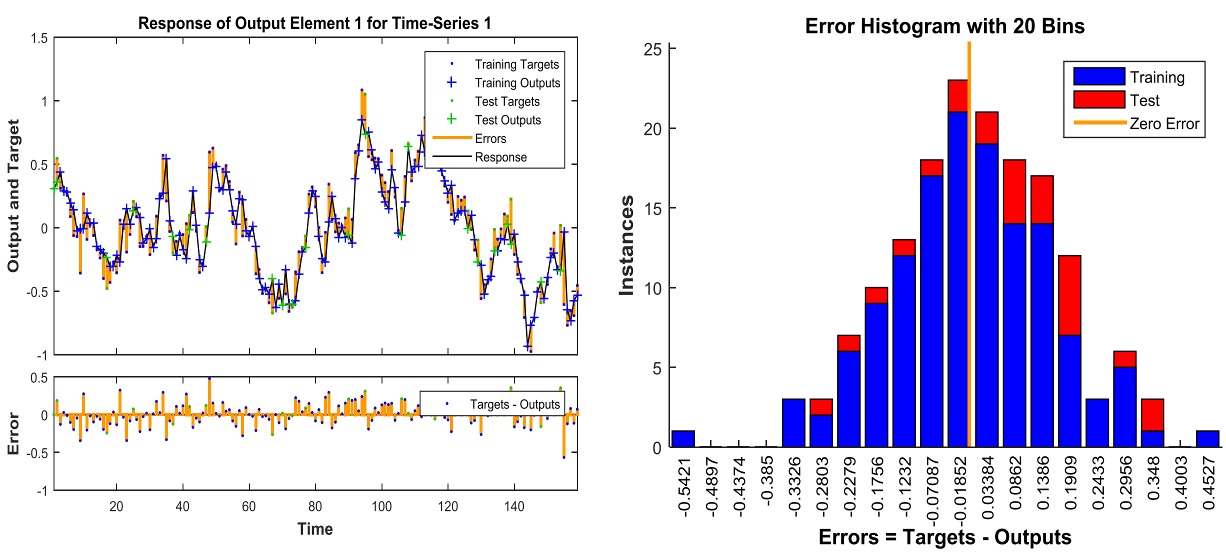
Based on the correlation between precipitation and groundwater level response, correlation models between SPIs and SGI for 167 cities nationwide were developed using ANN. In this study, a total of 167 models were developed to reflect the regional characteristic of groundwater response to precipitation. Figure 6.9 shows the performance of the final developed model through ANN with 85% of the training dataset and the result of performance test using 15% the of test dataset for Cheongju city in Chungcheong province.

As shown in Figure 6.9 (a) and (b), in case of Cheongju city, the correlation coefficient for both train dataset and test dataset were more than 0.9, so the network system was adopted. Figure 6.10 show the time series and the histogram of the error between the target and the output resulting from the training and testing process. In Figure 6.10 (b), if the histograms were concentrated around zero, the accuracy of the prediction can be interpreted as high. Correlation between target SGI and estimated SGI on training and testing for 26 cities in Chungcheong province were included in the Appendix D.2



(a) (b)

Figure 6.9 The Results of Regression Analysis for Training and Testing between the Targets and the Estimated Outputs at Cheongju City in Chungcheong Province.



(a) (b)

Figure 6.10 The Time Series and the Histogram of the Error between the Target Values and the Outputs Resulting from the Training and Testing Process.

6.6 Evaluation of ANN Model Performance

The performance of SPI-SGI correlation model was evaluated through correlation analysis between the SGI target and SGI output estimated by ANN model developed in this study. Figure 6.11 shows the correlation analysis results for 167 cities nationwide.

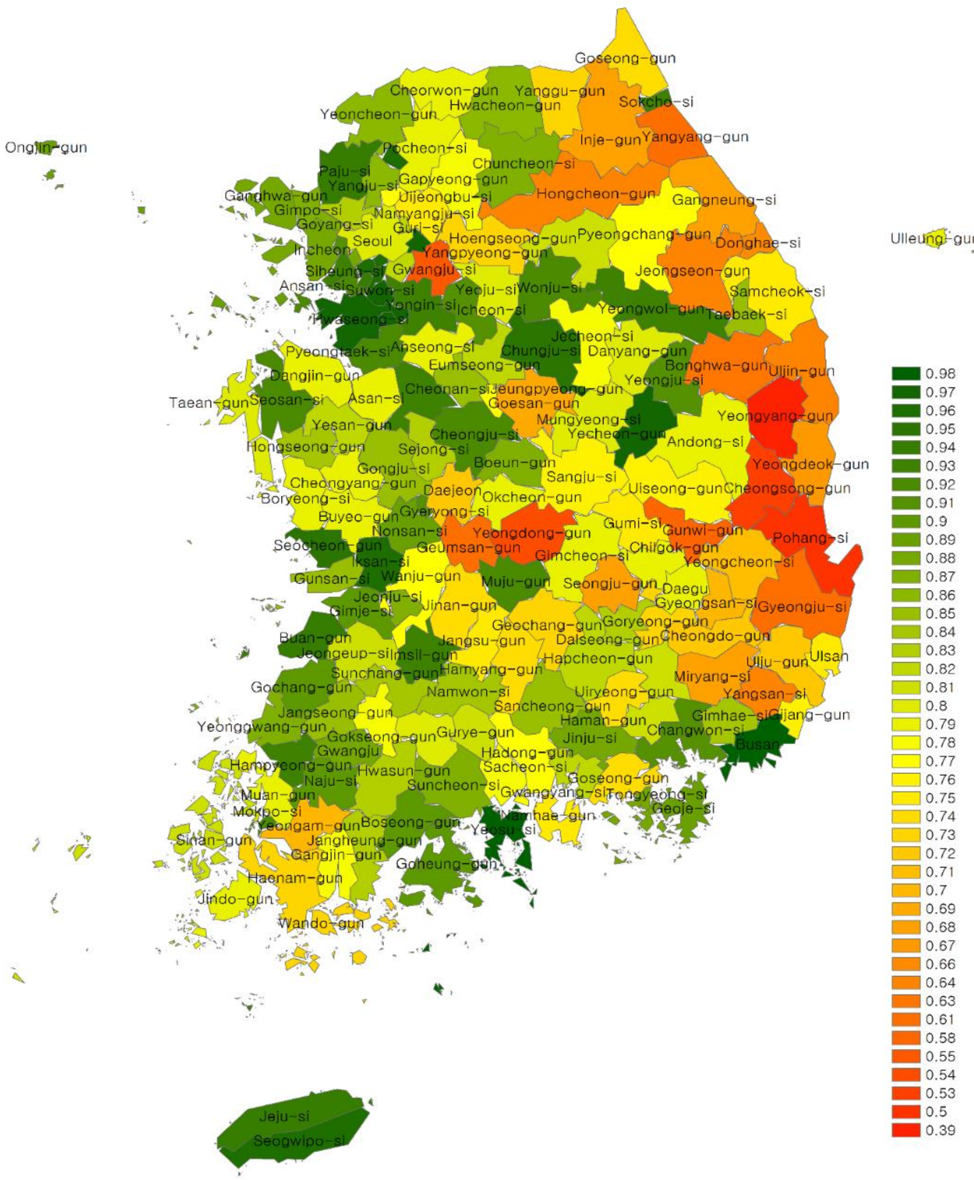


Figure 6.11 Correlation Coefficient between ANN Target and Estimated Output

As the result of the performance evaluation between the target SGI values and the estimated SGI outputs based on SPI 1-12 values, 146 cities (87%) out of 167 cities nationwide with a correlation coefficient of 0.7 or more were practically acceptable. As shown in Figure 6.11, 8 cities with a correlation coefficient of less than 0.5 were considered to be in regions where the groundwater response to precipitation based on historical observation data were not clearly defined. The performance evaluation results of ANN for 167 cities nationwide were tabulated in Table 6.3.

Table 6.3 Correlation Coefficient between ANN Target and Estimated Output

No.	City name	Corr. coeff.	No.	City name	Corr. coeff.
1	Seoul	0.80	21	Dongducheon	0.96
2	Busan	0.98	22	Ansan	0.92
3	Gijang	0.76	23	Goyang	0.83
4	Daegu	0.79	24	Gwacheon	0.96
5	Dalseong	0.73	25	Guri	0.82
6	Incheon	0.88	26	Namyangju	0.75
7	Ganghwa	0.88	27	Osan	0.97
8	Ongjin	0.89	28	Siheung	0.93
9	Gwangju	0.88	29	Gunpo	0.94
10	Daejeon	0.72	30	Uiwang	0.96
11	Ulsan	0.75	31	Hanam	0.97
12	Ulju	0.72	32	Yongin	0.93
13	Sejong	0.83	33	Paju	0.94
14	Suwon	0.97	34	Icheon	0.91
15	Seongnam	0.82	35	Anseong	0.79
16	Uijeongbu	0.77	36	Gimpo	0.87
17	Anyang	0.96	37	Hwaseong	0.97
18	Bucheon	0.91	38	Gwangju	0.55
19	Gwangmyeong	0.88	39	Yangju	0.86
20	Pyeongtack	0.92	40	Pocheon	0.79

Table 6.3 (continued)

No.	City name	Corr. coeff.	No.	City name	Corr. coeff.
41	Yeoju	0.80	71	Goesan	0.69
42	Yeoncheon	0.86	72	Eumseong	0.82
43	Gapyeong	0.78	73	Danyang	0.80
44	Yangpyeong	0.73	74	Cheonan	0.93
45	Chuncheon	0.87	75	Gongju	0.85
46	Wonju	0.92	76	Boryeong	0.79
47	Gangneung	0.68	77	Asan	0.79
48	Donghae	0.66	78	Seosan	0.92
49	Taeback	0.85	79	Nonsan	0.89
50	Sokcho	0.93	80	Gyeryong	0.91
51	Samcheok	0.75	81	Dangjin	0.79
52	Hongcheon	0.64	82	Geumsan	0.61
53	Hoengseong	0.81	83	Buyeo	0.79
54	Yeongwol	0.93	84	Seocheon	0.95
55	Pyeongchang	0.77	85	Cheongyang	0.79
56	Jeongseon	0.64	86	Hongseong	0.84
57	Cheorwon	0.79	87	Yesan	0.82
58	Hwacheon	0.86	88	Taean	0.80
59	Yanggu	0.73	89	Jeonju	0.87
60	Inje	0.68	90	Gunsan	0.85
61	Goseong	0.74	91	Iksan	0.96
62	Yangyang	0.61	92	Jeongeup	0.81
63	Cheongju	0.92	93	Namwon	0.84
64	Chungju	0.95	94	Gimje	0.90
65	Jecheon	0.78	95	Wanju	0.77
66	Boeun	0.87	96	Jinan	0.74
67	Okcheon	0.79	97	Muju	0.92
68	Yeongdong	0.54	98	Jangsu	0.75
69	Jeungpyeong	0.77	99	Imsil	0.93
70	Jincheon	0.85	100	Sunchang	0.84

Table 6.3 (continued)

No.	City name	Corr. coeff.	No.	City name	Corr. coeff.
101	Gochang	0.90	135	Gunwi	0.58
102	Buan	0.94	136	Uiseong	0.76
103	Mokpo	0.92	137	Cheongsong	0.53
104	Yeosu	0.98	138	Yeongyang	0.39
105	Suncheon	0.87	139	Yeongdeok	0.67
106	Naju	0.90	140	Cheongdo	0.72
107	Gwangyang	0.78	141	Goryeong	0.83
108	Damyang	0.78	142	Seongju	0.68
109	Gokseong	0.80	143	Chilgok	0.79
110	Gurye	0.81	144	Yecheon	0.97
111	Goheung	0.90	145	Bonghwa	0.63
112	Boseong	0.90	146	Uljin	0.64
113	Hwasun	0.83	147	Ulleung	0.79
114	Jangheung	0.83	148	Changwon	0.91
115	Gangjin	0.78	149	Jinju	0.88
116	Haenam	0.73	150	Tongyeong	0.88
117	Yeongam	0.70	151	Sacheon	0.82
118	Muan	0.79	152	Gimhae	0.84
119	Hampyeong	0.93	153	Miryang	0.68
120	Yeonggwang	0.87	154	Geoje	0.89
121	Jangseong	0.85	155	Yangsan	0.64
122	Wando	0.73	156	Uiryeong	0.74
123	Jindo	0.79	157	Haman	0.81
124	Sinan	0.81	158	Changnyeong	0.81
125	Pohang	0.50	159	Goseong	0.74
126	Gyeongju	0.61	160	Namhae	0.75
127	Gimcheon	0.79	161	Hadong	0.77
128	Andong	0.79	162	Sancheong	0.85
129	Gumi	0.75	163	Hamyang	0.74
130	Yeongju	0.91	164	Geochang	0.73
131	Yeongcheon	0.71	165	Hapcheon	0.82
132	Sangju	0.76	166	Jeju	0.94
133	Mungyeong	0.80	167	Seogwipo	0.96
134	Gyeongsan	0.70			

6.7 Groundwater Drought Projection Based on SGI Forecasting

6.7.1 SGI Forecasting based on Precipitation (SPI) Forecasts

In the previous section, the SPI-SGI correlation models for 167 cities nationwide based on precipitation and groundwater level observation data were developed using ANN. A total of 167 models were developed to reflect the regional characteristic of groundwater response to precipitation. The performance of SPI-SGI correlation models were evaluated through correlation analysis between the SGI target and the estimated SGI output.

Based on these SPI-SGI correlation models, it is possible to forecast for next 1 month, 2 month, and 3 month of groundwater drought if the precipitation was predicted for 1 month, 2month, and 3 month later. Therefore, precipitation forecasts are essential for groundwater drought prediction. Korea Meteorological Agency has produced the weather forecast information on the 23^{rd} of each month including forecasts of 1, 2, 3 month precipitation. Upon completion of gathering precipitation forecasts data through DB, from 1 month to 12 month SPI reflecting 1, 2, 3 month precipitation forecasts for 167 cities nationwide are estimated. And then it is possible to estimate SGI using SPI 1-12 values and network model developed in section 6.5 for each 167 cities. The overall process of the SGI projection combining the SPI derived from precipitation and ANN is shown in Figure 6.1.

At the current time t, the input dataset required by ANN correlation model for the SGI forecast at time t+1 (one month later) and the estimated output were expressed as shown in Figure 6.12. To forecast SGI after 1 month, the input which were shown in bold and shaded in the middle of Figure 6.13 were required for the known SPI 1-12 and SGI values from 3 months (t-3) to current month (t) based on precipitation and groundwater level observation records and SPI 1-12 values reflecting 1 month precipitation forecast.

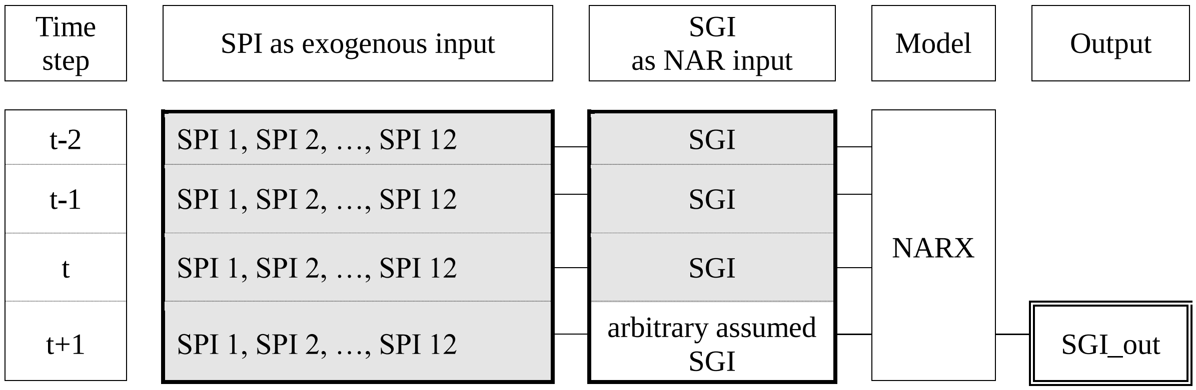


Figure 6.12 NARX ANN Input Datasets for 1 Month SGI Forecasting

Note that the SPIs and target SGI for input dataset should be the same length of the data to run the correlation model. Thus, SGI target for 1 month later should be filled with arbitrary number which does not affect the calculation result of the output. The output of SGI at t+1 month estimated were again taken into account for projection of the next month (t+2). The inputs and outputs for the 2-month and 3-month forecasting are in Figure 6.13.

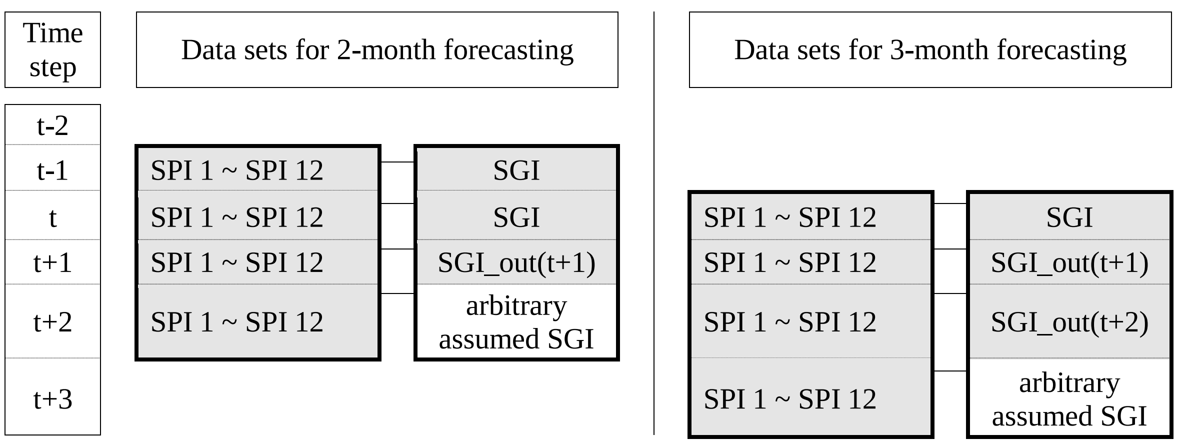


Figure 6.13 NARX ANN Input Datasets for 2 and 3 Month SGI Forecasting

Table 6.4 Forecasted SGI with SPI-SGI Correlation Model

No.	City name	Forecasted SGI			No.	City name	Forecasted SGI		
		1month	2month	3month			1month	2month	3month
1	Seoul	-2.940	-1.478	-1.035	31	Hanam	-1.376	-1.480	-1.304
2	Busan	-0.127	-0.297	-0.548	32	Yongin	-1.041	-1.151	-1.197
3	Gijang	-0.285	0.654	0.693	33	Paju	-2.011	-2.024	-1.370
4	Daegu	-0.855	-0.073	0.197	34	Icheon	-1.660	-1.472	-1.278
5	Dalseong	0.020	0.154	0.420	35	Anseong	-0.349	-0.175	-0.259
6	Incheon	-3.056	-1.931	-1.592	36	Gimpo	-1.055	-1.205	-1.340
7	Ganghwa	-0.992	-1.075	-1.159	37	Hwaseong	-0.867	-0.883	-0.834
8	Ongjin	-0.399	-0.634	-0.741	38	Gwangju	-0.524	-0.356	-0.297
9	Gwangju	-0.634	-0.609	-0.395	39	Yangju	-9.048	-2.588	-2.183
10	Daejeon	0.486	-0.044	-0.190	40	Pocheon	-0.071	-0.601	-0.364
11	Ulsan	-0.883	-0.454	-0.256	41	Yeoju	-0.476	-0.383	-0.027
12	Ulju	-0.926	-0.293	-0.167	42	Yeoncheon	-0.757	-1.320	-0.657
13	Sejong	-0.206	0.034	-0.081	43	Gapyeong	-0.189	-0.348	-0.178
14	Suwon	-1.922	-0.901	-0.576	44	Yangpyeong	-0.773	-0.719	-0.452
15	Seongnam	-0.657	-0.575	-0.520	45	Chuncheon	-0.651	-0.846	-0.425
16	Uijeongbu	-0.517	-0.541	-0.572	46	Wonju	-0.638	-0.631	-0.643
17	Anyang	-0.936	-0.980	-0.667	47	Gangneung	-0.380	-0.627	-0.439
18	Bucheon	-9.448	-5.347	-3.721	48	Donghae	-1.334	-0.931	-0.415
19	Gwangmyeong	0.803	0.339	0.225	49	Taeback	-3.209	-2.395	-1.487
20	Pyeongtack	-1.454	-1.069	-0.977	50	Sokcho	-0.715	-0.948	-0.491
21	Dongducheon	-0.632	-0.588	-0.167	51	Samcheok	-5.227	-2.922	-2.103
22	Ansan	-0.395	-0.376	0.054	52	Hongcheon	-0.862	-0.486	-0.375
23	Goyang	-2.691	-1.433	-1.046	53	Hoengseong	-0.406	-0.387	-0.356
24	Gwacheon	-0.880	-1.071	-0.938	54	Yeongwol	-1.161	-1.184	-0.898
25	Guri	-5.026	-1.697	-0.840	55	Pyeongchang	-0.779	-0.841	-0.415
26	Namyangju	-0.600	-0.613	-0.539	56	Jeongseon	-8.376	-3.176	-1.522
27	Osan	-1.852	-2.068	-1.586	57	Cheorwon	0.152	-0.446	-0.233
28	Siheung	0.053	-0.038	0.137	58	Hwacheon	0.548	-0.172	0.267
29	Gunpo	-1.275	-1.063	-0.856	59	Yanggu	-0.720	-0.490	0.172
30	Uiwang	-1.288	-1.065	-0.778	60	Inje	-0.694	-0.535	0.016

Table 6.4 (continued)

No.	City name	Forecasted SGI			No.	City name	Forecasted SGI		
		1month	2month	3month			1month	2month	3month
61	Goseong	-1.149	-0.404	0.085	91	Iksan	-0.720	-0.687	-0.728
62	Yangyang	-0.693	-0.388	-0.130	92	Jeongeup	-0.962	-0.721	-0.546
63	Cheongju	0.294	-0.027	0.060	93	Namwon	-0.852	-0.574	-0.218
64	Chungju	-0.517	-0.866	-0.561	94	Gimje	-1.159	-0.694	-0.698
65	Jecheon	-0.498	-0.514	-0.248	95	Wanju	-0.922	-0.694	-0.303
66	Boeun	0.136	-0.016	-0.007	96	Jinan	0.322	0.065	0.068
67	Okcheon	-0.197	-0.289	-0.396	97	Muju	-0.575	-0.780	-0.932
68	Yeongdong	-0.763	-0.474	-0.431	98	Jangsu	0.643	0.639	0.706
69	Jeungpyeong	1.793	1.142	1.281	99	Imsil	0.170	0.129	0.171
70	Jincheon	-0.581	-0.599	-0.283	100	Sunchang	-0.676	-0.823	-0.836
71	Goesan	0.848	0.425	0.548	101	Gochang	-3.045	-1.368	-1.300
72	Eumseong	-0.410	-0.535	-0.284	102	Buan	-5.157	-2.172	-1.510
73	Danyang	-0.891	-0.864	-0.754	103	Mokpo	0.134	0.144	0.059
74	Cheonan	-0.981	-1.378	-1.040	104	Yeosu	0.555	-2.393	1.351
75	Gongju	-0.482	-0.563	-0.426	105	Suncheon	-1.402	-0.915	-0.335
76	Boryeong	-1.258	-0.769	-0.485	106	Naju	-1.015	-0.297	0.345
77	Asan	-18.198	-4.153	0.147	107	Gwangyang	-1.885	-1.082	-0.625
78	Seosan	-0.771	-0.916	-0.795	108	Damyang	-0.372	-0.357	-0.127
79	Nonsan	-0.877	-0.899	-0.924	109	Gokseong	-0.839	-0.562	0.119
80	Gyeryong	-0.681	-0.903	-0.750	110	Gurye	-1.018	-0.840	-0.176
81	Dangjin	-2.616	-1.155	-0.647	111	Goheung	0.081	-0.269	0.642
82	Geumsan	-0.094	-0.369	-0.198	112	Boseong	0.252	-0.386	0.383
83	Buyeo	-0.522	-0.452	-0.226	113	Hwasun	0.077	-0.080	0.373
84	Seocheon	-1.024	-1.010	-0.935	114	Jangheung	0.493	0.538	1.063
85	Cheongyang	-0.270	-0.465	-0.134	115	Gangjin	0.408	0.465	0.602
86	Hongseong	-0.524	-0.762	-0.559	116	Haenam	-0.813	-0.130	-0.037
87	Yesan	-2.880	-1.299	-1.013	117	Yeongam	-0.085	0.083	0.193
88	Taean	-0.412	-0.291	-0.093	118	Muan	0.007	0.074	0.099
89	Jeonju	-0.783	-0.793	-0.600	119	Hampyeong	0.610	0.483	0.808
90	Gunsan	-1.533	-1.056	-0.823	120	Yeonggwang	-2.557	-1.666	-1.377

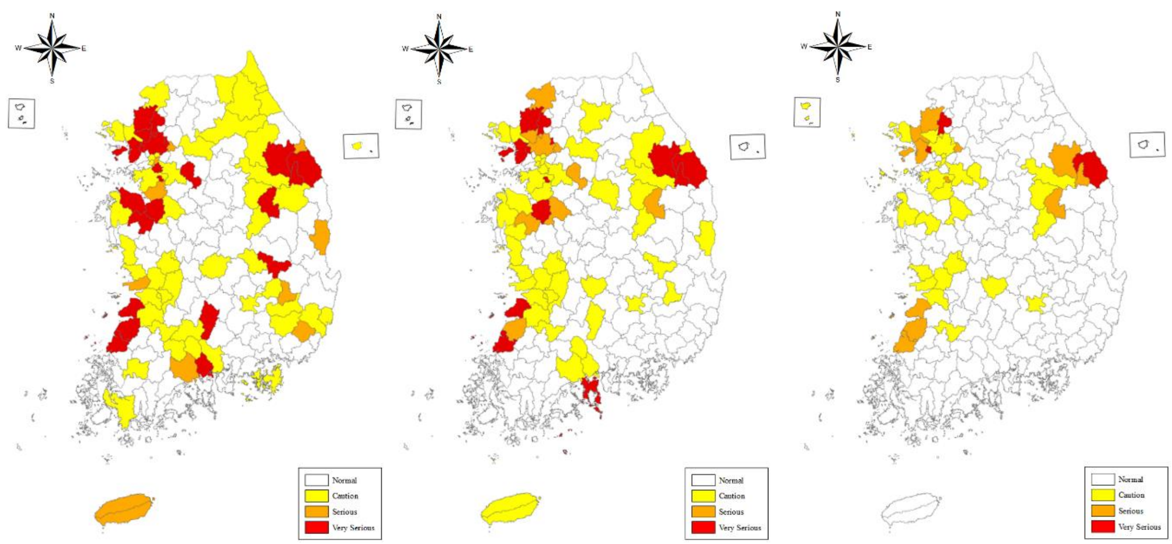
Table 6.4 (continued)

No.	City name	Forecasted SGI			No.	City name	Forecasted SGI		
		1month	2month	3month			1month	2month	3month
121	Jangseong	0.153	0.022	0.361	145	Bonghwa	-0.802	-0.565	-0.080
122	Wando	-0.330	-0.229	-0.025	146	Uljin	-0.603	-0.394	-0.103
123	Jindo	-0.491	-0.078	-0.063	147	Ulleung	-0.964	-0.389	-0.418
124	Sinan	-0.253	-0.080	-0.129	148	Changwon	1.246	1.092	1.357
125	Pohang	-0.378	-0.231	-0.079	149	Jinju	-0.001	0.140	0.516
126	Gyeongju	0.278	0.385	0.348	150	Tongyeong	-0.835	-0.447	-0.251
127	Gimcheon	-0.631	-0.584	-0.321	151	Sacheon	0.072	-0.218	0.453
128	Andong	0.377	0.244	0.148	152	Gimhae	0.520	0.698	1.075
129	Gumi	-0.867	-0.592	-0.546	153	Miryang	-0.879	-0.371	-0.171
130	Yeongju	-1.820	-1.575	-1.346	154	Geoje	-0.968	-0.651	-0.539
131	Yeongcheon	-0.208	0.050	0.172	155	Yangsan	-1.472	-0.559	-0.405
132	Sangju	-0.576	-0.408	-0.352	156	Uiryeong	0.128	0.318	0.547
133	Mungyeong	-0.298	-0.192	-0.397	157	Haman	0.312	0.584	0.706
134	Gyeongsan	-1.446	-0.700	-0.310	158	Changnyeong	0.045	0.068	0.386
135	Gunwi	-1.912	-0.764	-0.482	159	Goseong	0.242	-0.152	0.366
136	Uiseong	0.137	0.155	0.114	160	Namhae	0.002	-0.316	0.094
137	Cheongsong	0.023	-0.082	0.048	161	Hadong	-0.886	-0.538	0.052
138	Yeongyang	-0.210	-0.199	-0.133	162	Sancheong	-0.191	-0.173	0.168
139	Yeongdeok	-1.525	-0.707	-0.492	163	Hamyang	-1.764	-0.971	-0.587
140	Cheongdo	-0.817	-0.035	0.477	164	Geochang	-0.215	-0.117	0.146
141	Goryeong	-1.111	-0.773	-0.773	165	Hapcheon	-0.142	-0.115	0.052
142	Seongju	-0.358	-0.255	0.026	166	Jeju	-1.307	-0.792	-0.233
143	Chilgok	-0.186	-0.549	-0.405	167	Seogwipo	-1.366	-0.837	-0.477
144	Yecheon	-0.869	-0.937	-0.896					

6.7.2 Monthly groundwater drought outlook

Monthly groundwater drought outlook for January 2018 through March 2108 were delineated based on SGI values for 167 cities nationwide listed in Table 6.4. The purpose of this map are to conduct the National Drought Early Warning System and to provide drought information to local government and people in the drought region.

As shown in Figure 5.13 of the previous chapter 5, Korea has been in a severe drought situation. Groundwater droughts were occurred throughout the country and coastal regions were more severe than inland area. This drought that started in 2014 is currently underway. Especially, in 2017, the average annual precipitation in Korea was about 70% of the average year. With respect to groundwater drought projection, it is expected that the drought will gradually weaken from January to March, as shown in Figure 6.14.



Jan. 2018 Feb. 2018 Mar. 2018

Figure 6.14 Monthly Groundwater Drought Outlook (Jan. 2018 to Mar. 2018)

CHAPTER VII

CONCLUSION

7.1 Extending TCEQ WAM System Hydrologic Period-of-analysis

The WRAP hydrology input files in the TCEQ WAM System consist of naturalized monthly stream flows and reservoir surface evaporation less precipitation rates at pertinent locations covering the hydrologic periods-of-analysis. The original sequences of input hydrology in the TCEQ WAM datasets extending from about 1940 through the late 1990's were developed by ten engineering consulting firms under contract with the TCEQ during 1998-2001 at considerable expense based on adjusting observed flows at about 500 gauging stations to remove the effects of water resources development and use.

The methodology developed in this research is to update and extend hydrologic sequences of WRAP/WAM input dataset using precipitation and evaporation maintained by TWDB. This approach is much easier to implement and is particularly advantageous in situations where accurate data required to adjust observed flows are unavailable or difficult to compile or stream gaging station have been discontinued.

The program HYD facilitates to extend monthly surface evaporation less precipitation depths and monthly naturalized flows of WRAP input datasets. With respect to net evaporation less precipitation, the new EE record in the HYD extends a WRAP-SIM input EVA file of sequences of net evaporation-precipitation depths. QD and QA records designate quadrangles and areas used in the routines activated by EE records.

The original 1940-1997 net evaporation-precipitation rates are read by HYD from an input file. HYD creates an output file with filename extension EVA with 1998-2016 net evaporation-precipitation rates that is designed to be read by SIM as an input file. The 1998-2016 monthly net evaporation-precipitation rates are computed from HYD from the TWDB datasets without reference to the preceding 1940-1997 sequences. The final net evaporation-precipitation depths adopted for the updated EVA file consists of 1940-1997 monthly quantities from the original Brazos WAM dataset combined with the 1998-2016 monthly depths compiled with HYD from the TWDB datasets.

For naturalized flows extension of the TCEQ WAM datasets, the flow extension model expressed by Eq. 2.1, 2.2, 2.3, 2.4, and 2.5 is applied for extending sequences of naturalized flows based upon available naturalized flows of TCEQ WAM System dataset and precipitation and evaporation of TWDB dataset. The flow extension model includes base flow parameters and several precipitation-runoff parameters for each quadrangle in the watershed above the control point.

The parameter calibration of flow model consists of determining a set of parameter values that optimally reproduce the known 1940-1997 naturalized flows from the TCEQ WAM dataset. The calibrated flow model is then applied to synthesize flows for 1998-2016 based on 1998-2016 precipitation and evaporation. The new FE and FP records of program HYD develop parameters for the flow equation. The new FZ, FR, UB, BM, B1, B2, B3, B4, XP, X1, X2, X3, X4, RC, and FX records provide parameter values for the FE record.

The parameter calibration process consists of two levels and each level of calibration is performed with multiple stages. The level 1 calibration procedures are based on a complex set of optimization algorithms incorporated in HYD designed to replicate flows in each of the 696 months for original 1940-1997 period-of-analysis. The Level 2 calibration deals with additional parameters designed to improve model accuracy in reproducing relevant statistical characteristics. In order to validate the flows extension methodology and the model calibration, several tasks below were performed.

1. The statistical characteristics such as maximum, minimum, mean, standard deviation, and 12-month moving average of 1940-1997 flows computed with flow extension model were compared with 1940-1997 original known flows.

2. Flow frequency of 1940-1997 original naturalized flow of the Brazos WAM dataset were compared with 1998-2016 extended flows and 1940-2016 combined flows at 77 primary control points.

3. 1998-2016 Observed flows at 28 selected control points which are included most of the mainstream of Brazos River and representing its tributaries sites are compared with 1998-2016 extended flows.

4. Water supply capabilities such as flow depletions, diversion targets, and shortages with WRAP/WAM modeling system were assessed with 1940-2016 extended naturalized flows of the Brazos River.

The WRAP/WAM system is designed to evaluate water supply reliability and available stream flows rather than predicting quantities in specific month through the simulation. In this respect, the statistical characteristics and flow frequency of the synthesized naturalized flows for period-of-analysis should be compared with original naturalized flows. TABLES can facilitate to develop a flow frequency table and compare to results of extension.

The comparison results of the mean, standard deviation, and median for three sets of naturalized flows at 77 primary control points are presented in Table 3.17. The 1940-1997 synthesized flows with flow extension model and TWDB dataset were well reproduced the statistical characteristics and flow frequency relationship of original 1940-1997 known flows.

The 1998-2016 naturalized flows synthesized with the flow extension model were varied by regions and years because 1998-2016 synthesized flows reflect hydrologic conditions of 1998-2016 period-of-extension including 2011 extreme dry year and 2004, 2007, and 2015 flood years. However, the flow extension methodology appears to work about equally well for all of the control points in synthesizing flows for 1998-2016.

The comparison results of flow frequency metrics of 1940-1997 original flows, 1998-2016 extended flows, and 1940-2016 combined naturalized flows for 31 selected control points are presented in Appendix A.1. The comparison results of 1998-2016 synthesized flows and observed flows for 28 gaging stations are presented in Appendix B.5.

A fundamental concept of probability and statistics is that frequency and reliability estimates are improved with an increase in the length of the period-of-analysis. Water supply reliability and flow and storage frequency estimates based on 1940-2016 period-of-analysis are more credible than those based on 1940-1997 period-of-analysis. The simulation results with 1940-2016 hydrologic period-of-analysis are shown in Table 3.28.

Dramatic temporal and spatial variations in climate, hydrology, and geography occur over the very large Brazos River Basin and adjoining coastal basin. The effects on simulation results of extending the hydrologic period-of-analysis vary with location. Due to several drought years including 2011 extreme drought, the volume reliability was decreased a little while mean diversion shortage was increased during 1940-2016 comparing with 1940-1997 means. The mean storage volume of the 3,482 reservoirs for 1940-2016 period-of-simulation is 99.2 percent of the mean storage volume of 1940-1997 simulation.

Overall simulation results with the extended 1940-2016 hydrologic period-of-analysis are reasonable. Extending the hydrologic period-of-analysis through 2016 enhances the validity of the reliability and frequency analyses, but the critical drought period is not changed for most of the Brazos River Basin.

7.2 Establishment Water Allocation Strategy in Korea

The 1966-2017 North Han River WRAP/WAM model for reservoir/river system management was developed including naturalized flows, net evaporation-precipitation, water rights, and reservoirs, etc. The water allocation strategy was developed in the two alternative schemes. A priority-based long-term water allocation strategy for water management and planning were developed and evaluated with WRAP/WAM system. A water allocation strategy for relatively short-term water availability study for drought management is established for increasing water supply from hydropower dam and reducing some portions of water demands.

Two Alternatives with four Scenarios were established to conduct for long-term simulation in the river basin. As results of long-term simulation, Texas WRAP/WAM system is strongly recommended for water management and planning, especially new water right permit process and water reallocation considering water right priority in Korea. Based on simulation results, Scenario 4 in Alternative 2, which has a scheme to supply municipal water requirement to Seoul and Metro area employing multiple reservoir operation rule, is recommended for long-term water resources management and planning.

The short-term simulations are focused on securing municipal water supply during severe drought. The period-of-simulation was set to 2014-2017 when the drought was the most severe during 1966-2017 period-of-analysis. To establish a short-term water allocation strategy, two Alternatives with four scenarios were tested and simulated. One approach is to reallocate some portion of water rights supplied by Soyang dam to four hydropower dams and the other is to adopt a drought management policy based on water supply reduction for all water rights in the North Han River Basin.

Based on the simulation results, the case-2 in scenario 6, which is the proportional allocation of conservation capacities to four hydropower dams, is recommended for the short-term drought management. The case-3 in scenario 8 may be implemented during severe drought.

However, in practice, it is recommended to combine case-2 in scenario 6 and case-3 in scenario 8 according to the situation of drought. For instance, if some index of the meteorological drought is getting worse and reservoir storage of the Soyang dam is expected to decrease more and more, some of the water rights supplied from the Soyang dam according to scenario 6 can be reallocated to four hydroelectric dams. If the drought condition becomes more serious, some portions of water supply reduction for all water rights based on case-3 in scenario 8 maybe an effective drought management to Korean government.

With respect to instream flow requirement, target at control points HOSO13 recommended by MOLIT in 2015 was not met in all scenarios. It is recommended that the instream flow target has to be reviewed and modified, if necessary.

In addition, for the effective national scale water management and planning, it is necessary to improve the current tariff system associated with agricultural water usage. In Korea, there is no data associated with water use and supply of agricultural water since 1997. The former president Daejung Kim abolished the charge of agricultural water use, and since then, there are permits, but no monitoring, even though illegal water usages are actually taking place in the rivers. Therefore, for accurate water available study, it is necessary to charge for agricultural water use, to manage information for agricultural water use and supply.

7.3 Development of Groundwater Drought Monitoring Method

The methodology for groundwater drought monitoring based on groundwater level observation data obtained from national groundwater monitoring network (NGMN) was developed to support the National Drought Early Warning System in Korea. Standardized Groundwater level Index (SGI) based on groundwater observation data was developed to replace to SPI-6 which has been applied for monitoring of groundwater drought in the beginning stage of drought early warning system.

The 256 gaging stations in NGMN which have observation data more than 10 years were used for calculating SGI values for each station. Kernel Density Estimation (KDE) was applied for estimating probability distribution of monthly groundwater level observation data at 256 monitoring stations. A percentile corresponding to the observed current groundwater level was obtained from the monthly KDE for 256 stations. SGI which is a normalized index with standard normal distribution can be obtained from a percentile corresponding to observed groundwater level.

The SGI of each monitoring well is converted into the area SGI for 167 cities nationwide considering the areal weights of each monitoring well for its nearby city. The thiessen polygons are established for converting estimated SGI of groundwater observation wells to 167 cities based on their spatial locations using Arc-GIS Tool. Based on the SGI for each city and groundwater drought evaluation criteria, current groundwater drought conditions for each city are determined. The national drought monitor map is produced reflecting drought condition of 167 cities.

7.4 Development of Groundwater Drought Forecasting Method

The objective of this research is to develop a practical method for groundwater drought forecasting on a regular basis (weekly, monthly) to support National Drought Early Warning System. The methodology was developed based on the correlation between groundwater level fluctuations and precipitation in a specific region. The process of forecasting groundwater drought using the correlation between precipitation and groundwater response is roughly divided into two main processes. The one is to develop a correlation model between SGI and SPI, which has 12 values with 1 month to 12 months of the accumulation period of time, for a specific region based on historical observation data of precipitation and groundwater levels, and the other is to estimate SGI values during drought projection period using the correlation model and SPI forecasts.

The correlation model considering the lag time between precipitation and groundwater response and autocorrelation of groundwater level time series converted to SGI simultaneously. A groundwater drought forecasting model based on correlation between precipitation data (SPI) and groundwater level (SGI) as input and output relatively was developed employing NARX Neural Networks Model.

Based on forecasted SPI and NARX model for 167 cities, SGI for 167 cities were predicted. The precipitation forecasts were obtained from Korea Meteorological Administration. The monthly and seasonal outlook of groundwater drought were also illustrated in Figure 6.12. The methodology is simply applicable in practice. However, the groundwater drought forecasting methodology should be improved with National Drought Early Warning System comparing with actual drought condition for 167cities

REFERENCES

Ahn, J.-S., K.-S. Jung and G.-M. Lee (2011). "Problems of Water Use and Estimation of Water Right in North Han River Shared by North and South Korea (I)-Analysis of Diversion Impacts on Downstream Area by Imnam Dam." Journal of Korea Water Resources Association 44(4): 305-314.

Allen, R. G., L. S. Pereira, D. Raes and M. Smith (1998). "Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56." Fao, Rome 300(9): D05109.

Aziz, A., R. Abd and K. F. V. Wong (1992). "A neural-network approach to the determination of aquifer parameters." Groundwater 30(2): 164-166.

Bloomfield, J. P. and B. P. Marchant (2013). "Analysis of groundwater drought building on the standardised precipitation index approach." Hydrology and Earth System Sciences 17(12): 4769-4787.

Butterworth, J., R. Schulze, L. Simmonds, P. Moriarty and F. Mugabe (1999). "Hydrological processes and water resources management in a dryland environment IV: Long-term groundwater level fluctuations due to variation in rainfall." Hydrology and Earth System Sciences Discussions 3(3): 353-361.

Carriere, P., S. Mohaghegh and R. Gaskari (1996). "Performance of a virtual runoff hydrograph system." Journal of Water Resources Planning and Management 122(6): 421-427.

Changnon, S. A. (1987). "Detecting drought conditions in Illinois." Circular no. 169.

Choi, S., D. Lee, J. Moon and S. Kang (2010). "Application of K-WEAP (Korea-Integrated Water Resources Evaluation and Planning Model)." Journal of Korea Water Resources Association 43(7): 625-633.

Dai, A. (2011). "Characteristics and trends in various forms of the Palmer Drought Severity Index during 1900–2008." Journal of Geophysical Research: Atmospheres 116(D12): n/a-n/a.

Demuth, H. B., M. H. Beale, O. De Jess and M. T. Hagan (2014). Neural network design, Martin Hagan.

Ferdowsian, R., D. J. Pannell, C. McCarron, A. Ryder and L. Crossing (2001). "Explaining groundwater hydrographs: Separating atypical rainfall events from time trends." Australian Journal of Soil Research 39(4): 861-861.

French, M. N., W. F. Krajewski and R. R. Cuykendall (1992). "Rainfall forecasting in space and time using a neural network." Journal of Hydrology 137(1): 1-31.

Guttman, N. B. (1999). "ACCEPTING THE STANDARDIZED PRECIPITATION INDEX: A CALCULATION ALGORITHM1." JAWRA Journal of the American Water Resources Association 35(2): 311-322.

H. L. Penman, a. (1948). "Natural Evaporation from Open Water, Bare Soil and Grass." Proceedings of the Royal Society of London. Series A, Mathematical and physical sciences 193(1032): 120-145.

Hagman, G., H. Beer, M. Bendz and A. Wijkman (1984). "Prevention better than cure. Report on human and environmental disasters in the Third World. 2."

Halff, A. H., H. M. Halff and M. Azmoodeh (1993). Predicting runoff from rainfall using neural networks. Engineering hydrology, ASCE.

Hayes, M., M. Svoboda, N. Wall and M. Widhalm (2011). "The Lincoln Declaration on Drought Indices: Universal Meteorological Drought Index Recommended." Bulletin of the American Meteorological Society 92(4): 485-488.

Hydrology, T. A. T. C. o. A. o. A. N. N. i. (2000a). "Artificial Neural Networks in Hydrology. I: Preliminary Concepts." Journal of Hydrologic Engineering 5(2): 115.

Hydrology, T. A. T. C. o. A. o. A. N. N. i. (2000b). "Artificial Neural Networks in Hydrology. II: Hydrologic Applications." Journal of Hydrologic Engineering 5(2): 124.

Imve, V., A. Kofi and Z. Istvan (2002). Hydrological dimensioning and operation of reservoir: Practical design concept and principles, Kluwer Academic Publisher.

Jan, C.-D., T.-H. Chen and W.-C. Lo (2007). "Effect of rainfall intensity and distribution on groundwater level fluctuations." Journal of Hydrology 332(3-4): 348-360.

Jung, T., S. Kang, I. Ko and M. Hwang (2007). "Development and Validation of KModSim for the Decision Support System in Geum River Basin." Korean Society o fCivil Engineers 27(3B): 319-329.

K-water (1999). "The Study on Water Resources Planning based on Optimization Algorism."

K-water (2017). "Development Advanced Technologies for River Flow Mangement."

Kim, G.-S. and J.-W. Lee (2011). "Evaluation of drought indices using the drought records." Journal of Korea Water Resources Association 44(8): 639-652.

Kim, H. (2015). "Water Right and financial allocation to water users in Korea." Korea Public Land Law Association 71: 389-416.

Kim, T. and J. Kim (2016). "Evaluation of Impact on Water Right for Single Reservoir Operation." Journal of Korean Society of Hazard Mitigation 16(1): 221-226.

Kuligowski, R. J. and A. P. Barros (1998). "Experiments in short-term precipitation forecasting using artificial neural networks." Monthly weather review 126(2): 470-482.

Kwon (2009). "The study on the Principle of Water Right." Journal of Korea Environmental Policy 7-14.

Labadie, J. W. (2004). "Optimal operation of multireservoir systems: state-of-the-art review." Journal of water resources planning and management 130(2): 93-111.

Lee, S. U., Y. O. Kim and D. Lee (2005). "Quantifying Uncertainty for the water balance analysis."

McCulloch, W. S. and W. Pitts (1943). "A logical calculus of the ideas immanent in nervous activity." The bulletin of mathematical biophysics 5(4): 115-133.

McKee, T. B., N. J. Doesken and J. Kleist (1993). The relationship of drought frequency and duration to time scales. Proceedings of the 8th Conference on Applied Climatology, American Meteorological Society Boston, MA.

Mishra, A. K. and V. P. Singh (2010). "A review of drought concepts." Journal of Hydrology 391(1): 202-216.

MOLIT (2015). "Drought Damage Investigation." 256.

Monteith, J. L. (1965). Evaporation and environment. Symp. Soc. Exp. Biol.

Palmer, W. C. (1965). Meteorological drought, Citeseer.

Peters, E., P. Torfs, H. Van Lanen and G. Bier (2003). "Propagation of drought through groundwater—a new approach using linear reservoir theory." Hydrological processes 17(15): 3023-3040.

ReVelle, C. (1999). Optimizing reservoir resources: including a new model for reservoir reliability, John Wiley & Sons.

Rosenberry, D. O., T. C. Winter, D. C. Buso and G. E. Likens (2007). "Comparison of 15 evaporation methods applied to a small mountain lake in the northeastern USA." Journal of Hydrology 340(3-4): 149-166.

S. Pulwarty, R. and M. V. K. Sivakumar (2014). "Information systems in a changing climate: Early warnings and drought risk management." Weather and Climate Extremes 3: 14-21.

Scott, D. W. (1981). Using computer-binned data for density estimation. Computer Science and Statistics: Proceedings of the 13th Symposium on the Interface, Springer.

Sheffield, J. and E. F. Wood (2011). Drought, Earth scan.

Sivakumar, M. V., R. Stefanski, M. Bazza, S. Zelaya, D. Wilhite and A. R. Magalhaes (2014). "High level meeting on national drought policy: summary and major outcomes." Weather and climate Extremes 3: 126-132.

Svoboda, M. and B. Fuchs (2016). "Handbook of Drought Indicators and Indices."

Svoboda, M., M. Hayes and D. Wood (2012). "Standardized precipitation index user guide." World Meteorological Organization Geneva, Switzerland.

Svoboda, M., D. LeComte, M. Hayes, R. Heim, K. Gleason, J. Angel, B. Rippey, R. Tinker, M. Palecki and D. Stooksbury (2002). "The drought monitor." Bulletin of the American Meteorological Society 83(8): 1181-1190.

Tallaksen, L. M. and H. A. Van Lanen (2004). Hydrological drought: processes and estimation methods for streamflow and groundwater, Elsevier.

Tannehill, I. R. (1947). Drought its causes and effects, Princeton University Press; New Jersey.

Van Lanen, H. and E. Peters (2000). Definition, effects and assessment of groundwater droughts. Drought and drought mitigation in Europe, Springer: 49-61.

Van Loon, A. F. (2015). "Hydrological drought explained." Wiley Interdisciplinary Reviews: Water 2(4): 359-392.

Viswanathan, M. N. (1984). "Recharge characteristics of an unconfined aquifer from the rainfall-water table relationship." Journal of Hydrology 70(1): 233-250.

Votruba, L. and V. Broža (1989). Water management in reservoirs, Elsevier.

Walter, I. A., R. G. Allen, R. Elliott, M. Jensen, D. Itenfisu, B. Mecham, T. Howell, R. Snyder, P. Brown and S. Echings (2000). ASCE's standardized reference evapotranspiration equation. Watershed management and operations management 2000: 1-11.

Wilhite, D. A. (2000). "Drought as a natural hazard: concepts and definitions."

Wilhite, D. A. and M. H. Glantz (1985). "Understanding: the drought phenomenon: the role of definitions." Water international 10(3): 111-120.

Wurbs, R. and R. Hoffpauir (2013). Environmental flows in water availability modeling, Texas Water Resources Institute.

Wurbs, R. A. (1996). Modeling and analysis of reservoir system operations.

Wurbs, R. A. (2002). "Wesley P. James (2002).“." Water Resources Engineering.” Prentice Hall, Inc.

Wurbs, R. A. (2004). "Water allocation systems in Texas." International Journal of Water Resources Development 20(2): 229-242.

Wurbs, R. A. (2005a). "Modeling river/reservoir system management, water allocation, and supply reliability." Journal of Hydrology 300(1-4): 100-113.

Wurbs, R. A. (2005b). "Texas water availability modeling system." Journal of Water Resources Planning and Management 131(4): 270-279.

Wurbs, R. A. (2011a). Generalized models of river system development and management. Current issues of water management, InTech.

Wurbs, R. A.(2013). "Water Right Analysis Package (WRAP) River System Hydrology" "Texas Water Resources Institute (TWRI) 189 pages.

Wurbs, R. A. (2014). "Sustainable statewide water resources management in Texas." Journal of Water Resources Planning and Management 141(12): A4014002.

Wurbs, R. A. (2015a). "Water Right Analysis Package Modeling System reference Manual." Texas Water Resources Institute (TWRI) 11th Ed: 384.

Wurbs, R. A. (2015b). " Water Rights Analysis Package Modeling System Users Manual,." 11th Edition.

Wurbs, R. A. (2015c). "Institutional and hydrologic water availability in Texas." Water resources management 29(2): 217-231.

Wurbs, R. A. (2015d). Simulation modeling of river/reservoir system water allocation and management. World Water Congress XV. Edinburgh: International Water Resources Association.

Wurbs, R. A. and R. J. Hoffpauir (2017). "Environmental flow requirements in a water availability modeling system." Sustainability of Water Quality and Ecology 9-10: 9-21.

Wurbs, R. A. and T. J. Kim (2008). "Extending and Condensing the Brazos River Basin Water Availability Model." TWRI TR-340 491 pages.

Yang, C.-C., S. O. Prasher, R. Lacroix, S. Sreekanth, N. K. Patni and L. Masse (1997). "Artificial neural network model for subsurface-drained farmlands." Journal of Irrigation and Drainage Engineering 123(4): 285-292.

Yoo, J. Y., H. Song, T.-W. Kim and J.-H. Ahn (2013). "Evaluation of short-term drought using daily standardized precipitation index and ROC analysis." Journal of the Korean Society of Civil Engineers 33(5): 1851-1860.

APPENDIX A

TABLES FOR NATURALIZED FLOW EXTENSION

A.1 Flow Frequency Metrics of Calibration and Extension

Table A.1.1 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Running Water Draw at Plainview RWPL01

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	205.7	347.3	205.0	226.8	291.2
Std Dev	993.0	962.8	821.2	1,057.4	1,233.6
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	0.0	0.0	0.0	0.0	0.0
90.0%	0.0	0.0	0.0	0.0	0.0
85.0%	0.0	0.0	0.0	0.0	0.0
80.0%	0.0	0.0	0.0	0.0	0.0
75.0%	0.0	0.0	0.0	0.0	0.0
70.0%	1.0	0.0	0.0	0.0	0.0
60.0%	4.0	0.0	0.0	2.4	0.0
50.0%	12.0	0.9	9.5	9.0	5.1
40.0%	26.0	2.9	24.6	23.7	19.5
30.0%	49.2	6.1	42.2	46.2	35.5
25.0%	71.0	42.5	64.7	67.0	46.9
20.0%	99.0	160.3	95.9	94.3	77.8
15.0%	156.6	603.2	168.8	143.0	139.1
10.0%	303.8	1,156.2	341.5	301.8	277.5
5.0%	1,008.2	2,552.0	954.1	974.0	1,142.9
2.0%	2,574.4	3,837.7	2,229.8	2,884.1	6,918.1
1.0%	3,616.8	4,908.7	2,986.8	5,445.4	8,104.7
0.5%	5,441.8	5,873.2	7,309.4	7,487.9	8,386.3
Maximum	21,017.0	8,859.1	11,025.5	21,017.0	8,411.0

Table A.1.2 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Salt Fork Brazos River at Aspermont SFAS06

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	6,421.0	8,409.9	6,420.3	6,226.8	5,633.7
Std Dev	15,348.3	15,860.2	15,137.0	15,975.6	17,777.4
Minimum	0.0	0.3	0.0	0.0	0.0
99.5%	3.0	0.4	13.4	0.0	0.0
99.0%	4.0	0.4	26.7	3.0	0.0
98.0%	8.9	0.4	26.7	8.0	0.0
95.0%	24.8	0.4	30.0	26.7	26.7
90.0%	67.2	0.6	111.7	74.0	111.7
85.0%	166.8	1.3	184.3	149.4	117.5
80.0%	265.4	1.6	265.1	243.6	184.3
75.0%	362.0	2.2	354.6	323.0	259.1
70.0%	478.6	2.7	433.3	421.6	266.2
60.0%	722.8	281.3	710.2	645.2	433.3
50.0%	1,111.0	643.1	1,161.5	1,051.0	841.8
40.0%	1,885.6	1,263.2	1,582.1	1,563.4	1,213.6
30.0%	3,396.6	5,772.7	3,683.6	2,999.6	1,794.1
25.0%	4,700.0	10,167.9	4,991.3	4,251.3	2,795.1
20.0%	6,675.8	15,962.7	7,556.7	6,117.7	4,294.8
15.0%	9,710.2	21,607.6	10,290.2	9,148.4	6,136.1
10.0%	15,583.4	28,049.3	15,505.8	14,930.2	11,681.5
5.0%	35,140.8	45,883.7	33,455.0	28,993.6	25,726.6
2.0%	64,297.8	59,779.0	58,538.0	64,715.0	87,449.5
1.0%	90,273.1	69,337.2	68,580.3	94,199.3	114,497.7
0.5%	101,401.0	87,286.9	106,214.1	111,042.4	156,165.9
Maximum	135,865.0	114,837.8	139,739.2	162,485.9	162,485.9

Table A.1.3 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Double Mountain Fork at Aspermont DMAS09

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	9,030.6	10,994.8	8,995.7	8,709.3	7,728.4
Std Dev	20,142.5	23,500.7	19,548.8	19,626.3	17,965.1
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	8.0	0.0	0.0	0.0	0.0
90.0%	81.2	0.0	0.0	10.8	0.0
85.0%	146.8	0.0	0.0	91.4	0.0
80.0%	238.4	0.0	0.0	175.4	0.0
75.0%	344.0	12.2	89.1	297.0	89.1
70.0%	501.0	21.5	319.2	452.8	222.5
60.0%	938.4	378.2	1,065.8	935.6	940.3
50.0%	1,636.0	834.0	1,764.1	1,524.3	1,431.3
40.0%	2,761.6	1,319.6	2,808.0	2,565.7	2,151.3
30.0%	5,856.6	3,257.3	5,086.4	5,046.0	3,402.6
25.0%	7,870.0	9,168.5	7,959.4	7,014.0	4,397.6
20.0%	10,549.6	16,071.2	10,992.7	10,195.9	7,994.6
15.0%	15,080.4	25,807.4	15,442.7	14,786.6	13,833.4
10.0%	25,049.4	39,726.1	25,034.8	24,695.6	21,904.6
5.0%	47,990.8	65,743.0	47,437.5	45,852.6	42,970.7
2.0%	74,061.5	89,021.6	79,783.0	74,163.6	81,762.0
1.0%	106,427.6	108,764.8	97,477.2	106,178.6	107,085.6
0.5%	149,790.3	135,380.5	121,330.7	131,094.0	109,261.5
Maximum	175,553.0	198,375.8	177,788.3	175,553.0	109,540.8

Table A.1.4 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Seymour BRSE11

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	20,841.4	34,243.2	20,846.1	20,089.0	17,792.4
Std Dev	42,816.9	45,749.9	40,243.6	41,758.1	38,343.4
Minimum	0.0	15.4	0.0	0.0	0.0
99.5%	0.0	16.4	0.0	0.0	0.0
99.0%	0.0	16.4	0.0	0.0	0.0
98.0%	52.0	16.4	0.0	0.0	0.0
95.0%	266.2	77.5	142.2	142.2	0.0
90.0%	621.2	114.4	819.6	537.2	142.2
85.0%	995.2	127.0	909.8	909.8	873.5
80.0%	1,387.0	197.1	1,166.8	1,222.8	1,047.1
75.0%	1,711.0	250.9	1,472.2	1,472.2	1,166.8
70.0%	2,269.0	293.6	1,874.0	1,874.0	1,320.8
60.0%	3,081.6	2,801.0	3,154.9	2,933.6	1,874.0
50.0%	5,042.0	14,104.2	5,808.3	5,076.0	5,353.7
40.0%	8,025.6	25,113.3	8,144.2	7,905.7	7,418.5
30.0%	13,727.2	46,548.8	14,557.8	12,596.2	11,071.7
25.0%	18,500.0	54,087.7	18,448.8	17,440.7	13,208.9
20.0%	26,935.6	66,650.5	30,206.1	24,330.4	18,292.4
15.0%	39,114.4	80,681.9	38,804.0	37,056.8	35,533.9
10.0%	57,692.6	102,492.6	54,472.3	56,880.2	51,695.7
5.0%	100,975.2	135,994.3	95,315.4	89,082.0	77,564.2
2.0%	179,699.6	161,314.8	173,771.5	174,508.8	174,040.7
1.0%	230,348.0	175,083.3	188,603.3	214,831.8	214,764.0
0.5%	288,545.4	205,995.8	221,902.8	276,754.5	291,069.0
Maximum	414,811.0	272,444.4	293,482.6	414,811.0	303,413.6

Table A.1.5 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Clear Fork Brazos at Nugent CFNU16

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	7,972.3	8,754.0	7,946.8	7,577.6	6,372.6
Std Dev	17,241.8	15,778.8	14,828.3	16,017.5	11,449.4
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	0.0	0.0	0.0	0.0	0.0
90.0%	255.0	0.0	0.0	143.8	0.0
85.0%	460.8	5.3	194.3	388.3	60.5
80.0%	667.0	23.2	414.5	618.0	376.9
75.0%	892.0	74.2	710.0	811.0	634.0
0.0%	1,114.6	275.1	1,047.7	1,079.4	838.9
60.0%	1,758.6	1,003.5	1,953.3	1,776.8	1,858.4
50.0%	2,568.0	1,686.5	2,440.9	2,491.0	2,282.1
40.0%	3,736.8	3,877.4	4,055.3	3,731.0	3,714.2
30.0%	6,088.2	6,364.3	5,672.9	5,845.4	5,636.0
25.0%	7,960.0	10,185.1	8,374.0	7,720.0	6,873.5
20.0%	10,750.2	13,995.7	10,699.1	10,128.4	9,459.9
15.0%	13,474.4	19,353.9	13,623.0	12,815.4	11,185.0
10.0%	19,821.4	28,135.7	20,861.0	18,248.6	15,660.7
5.0%	34,788.2	43,386.9	36,444.4	32,266.8	26,161.2
2.0%	56,219.0	57,526.7	57,958.2	55,927.7	54,053.7
1.0%	70,045.8	89,616.0	90,288.1	68,709.4	68,214.4
0.5%	90,914.2	94,366.4	95,074.1	83,547.2	79,105.9
Maximum	297,109.0	106,132.9	106,928.9	297,109.0	80,736.4

Table A.1.6 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Clear Fork Brazos at Fort Griffin CFFG18

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	14,581.1	17,371.3	14,239.3	14,231.4	13,163.8
Std Dev	37,167.4	35,839.8	36,097.7	37,317.5	37,834.5
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	0.0	0.0	0.0	0.0	0.0
90.0%	0.0	0.0	0.0	0.0	0.0
85.0%	48.6	0.0	0.0	0.0	0.0
80.0%	272.0	0.0	0.0	0.0	0.0
75.0%	492.0	0.0	0.0	165.0	0.0
70.0%	869.6	0.0	0.0	457.8	0.0
60.0%	1,584.2	0.0	0.0	1,388.6	0.0
50.0%	2,837.0	278.1	2,137.8	2,687.0	2,234.4
40.0%	4,686.4	1,365.8	4,283.5	4,613.0	4,542.1
30.0%	9,078.6	8,744.8	9,169.6	8,909.0	7,860.3
25.0%	11,953.0	16,324.9	13,032.7	11,437.5	11,235.2
20.0%	17,092.8	28,519.3	17,280.5	16,856.0	15,976.9
15.0%	23,632.6	44,665.7	25,016.8	22,604.2	19,271.0
10.0%	35,198.2	59,680.7	34,788.4	33,993.6	28,923.3
5.0%	68,065.2	99,754.6	66,626.7	64,543.2	48,111.6
2.0%	131,777.5	141,114.0	122,728.3	124,423.5	109,139.6
1.0%	170,502.9	173,780.9	155,212.0	176,278.7	293,157.2
0.5%	261,277.4	191,542.4	278,554.3	279,777.2	321,447.8
Maximum	471,164.0	290,772.5	422,861.7	471,164.0	324,259.5

Table A.1.7 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at South Bend BRSB23

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	54,688.3	60,003.4	54,675.6	53,340.7	49,226.9
Std Dev	116,202.6	91,130.0	104,417.3	112,326.1	99,688.4
Minimum	0.0	16.2	0.0	0.0	0.0
99.5%	0.0	26.6	0.0	0.0	0.0
99.0%	64.8	35.6	50.0	15.9	0.0
98.0%	119.4	42.6	241.3	109.4	23.9
95.0%	785.0	76.5	433.5	712.0	359.2
90.0%	2,082.8	123.6	1,324.3	1,695.9	1,161.8
85.0%	2,609.0	300.0	2,146.3	2,401.4	1,600.2
80.0%	3,409.2	1,077.7	3,665.7	3,202.8	2,066.5
75.0%	4,889.0	2,644.8	5,317.3	4,555.2	3,800.0
70.0%	6,185.6	3,807.2	6,353.9	5,926.4	5,419.2
60.0%	9,258.4	7,459.1	9,033.0	9,065.4	8,949.7
50.0%	13,817.0	14,094.6	13,842.8	13,587.0	13,206.1
40.0%	23,707.2	26,857.3	21,368.9	23,401.3	19,878.1
30.0%	39,091.8	62,901.8	40,498.2	39,450.6	40,736.2
25.0%	52,133.0	87,774.6	52,738.5	51,517.6	49,891.0
20.0%	68,303.6	111,173.7	73,752.6	67,594.4	70,904.8
15.0%	98,713.6	142,322.6	96,627.1	97,263.2	94,682.2
10.0%	145,077.2	199,251.7	145,644.6	134,223.2	110,834.6
5.0%	256,094.6	278,319.1	255,191.6	224,089.2	215,852.8
2.0%	440,343.0	333,597.2	449,512.2	435,549.3	437,871.2
1.0%	527,384.8	350,682.3	472,533.8	523,716.8	532,124.4
0.5%	717,127.5	469,773.8	633,006.1	717,099.4	838,248.6
Maximum	1,395,822.0	579,199.8	780,454.4	1,395,822.0	883,767.8

Table A.1.8 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Graford SHGR26

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	66,123.6	68,343.0	65,970.3	63,906.4	57,138.2
Std Dev	137,150.9	116,780.5	123,939.1	133,099.8	119,918.9
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	284.0	0.0	0.0	0.0	0.0
90.0%	2,186.8	0.0	0.0	1,070.2	0.0
85.0%	3,376.0	102.0	1,070.2	2,923.4	0.0
80.0%	5,228.4	919.8	4,906.3	4,941.0	2,938.4
75.0%	6,883.0	2,141.2	7,197.1	6,698.0	5,678.9
70.0%	8,574.4	4,853.7	9,475.3	8,588.0	8,990.1
60.0%	12,816.0	8,556.7	12,615.7	12,575.0	12,235.4
50.0%	18,404.0	14,513.1	18,247.5	18,299.0	18,299.0
40.0%	30,992.4	28,315.1	30,673.3	30,142.2	26,944.5
30.0%	47,795.6	50,579.3	48,102.5	46,738.9	42,233.3
25.0%	64,391.0	70,912.6	62,293.2	63,025.0	51,098.4
20.0%	89,032.8	110,857.7	90,097.9	81,820.4	73,605.4
15.0%	116,238.4	158,120.3	116,729.1	112,837.6	97,589.7
10.0%	166,331.4	229,576.1	173,303.4	160,881.2	149,168.3
5.0%	279,295.4	344,767.2	297,061.8	260,855.2	237,168.0
2.0%	485,885.8	450,107.8	534,818.2	483,194.8	494,515.4
1.0%	716,794.5	539,637.3	641,197.1	695,014.6	706,052.0
0.5%	791,922.7	646,685.6	768,391.8	782,856.4	1,051,706.8
Maximum	1,794,495.0	732,482.4	870,335.6	1,794,495.0	1,099,972.0

Table A.1.9 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Palo Pinto BRPP27

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	67,531.7	73,832.6	67,412.8	65,162.6	57,930.5
Std Dev	137,770.8	123,517.3	125,100.9	133,344.4	118,806.8
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	340.0	0.0	0.0	0.0	0.0
90.0%	2,097.6	0.0	0.0	1,280.0	0.0
85.0%	3,944.2	134.8	1,035.6	3,155.2	842.7
80.0%	5,275.6	1,256.7	4,417.8	5,085.6	3,113.4
75.0%	6,759.0	2,924.4	8,362.8	6,722.0	5,904.3
70.0%	8,828.2	5,720.8	9,827.0	8,804.8	8,845.2
60.0%	13,250.6	9,811.5	12,950.6	12,797.8	12,443.2
50.0%	19,022.0	16,065.2	18,684.3	18,757.0	18,208.0
40.0%	31,091.8	31,780.4	31,853.7	29,989.1	26,952.8
30.0%	53,560.8	56,094.7	48,965.9	48,435.2	41,261.3
25.0%	65,601.0	87,033.2	68,386.3	64,965.0	50,449.3
20.0%	92,936.4	124,701.5	91,824.2	89,347.6	82,751.8
15.0%	116,903.0	161,472.9	113,781.9	113,343.0	104,769.5
10.0%	170,549.2	245,606.0	178,499.7	165,527.	165,025.9
5.0%	294,283.8	352,849.8	294,464.8	265,916.2	241,079.5
2.0%	495,689.1	470,170.5	532,576.2	492,880.4	506,336.9
1.0%	652,355.4	603,433.4	683,527.2	646,418.2	688,212.0
0.5%	795,350.6	707,212.8	801,081.2	787,201.7	1,031,206.1
Maximum	1,810,792.0	741,689.7	840,134.2	1,810,792.0	1,081,810.0

Table A.1.10 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Dennis BRDE29

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	83,645.7	84,737.6	83,620.7	818,35.3	76,308.7
Std Dev	165,799.4	116,058.9	145,811.8	159,961.2	140,842.8
Minimum	0.0	32.3	0.0	0.0	0.0
99.5%	0.0	122.3	0.0	0.0	0.0
99.0%	0.0	131.3	0.0	0.0	0.0
98.0%	529.0	202.7	696.9	113.1	0.0
95.0%	1,992.8	391.8	2,107.1	1,749.2	1,018.0
90.0%	3,713.4	739.6	3,296.3	3,612.2	3,156.7
85.0%	5,569.4	1,449.0	4,867.5	5,258.1	4,388.8
80.0%	7,273.6	2,729.3	7,067.9	6,704.2	5,555.0
75.0%	9,442.0	5,702.9	9,642.4	9,190.0	7,473.2
70.0%	11,534.6	8,238.4	12,239.4	11,106.8	10,022.3
60.0%	17,481.4	17,243.3	18,556.0	16,934.7	15,141.7
50.0%	27,265.0	32,692.2	28,440.8	27,186.0	24,900.3
40.0%	44,882.0	54,102.3	43,471.3	43,212.6	42,198.8
30.0%	69,265.2	98,933.7	73,133.6	69,813.2	71,941.4
25.0%	87,622.0	121,333.9	89,292.0	87,622.0	89,172.2
20.0%	116,080.8	153,177.9	117,282.7	118,935.0	127,363.5
15.0%	154,341.4	201,050.1	155,415.8	152,156.0	143,212.2
10.0%	211,033.6	261,486.1	213,038.4	208,436.2	184,891.2
5.0%	355,314.8	341,982.5	341,328.8	301,675.8	277,772.3
2.0%	571,324.2	424,097.7	627,715.5	571,430.8	612,382.1
1.0%	773,111.1	489,771.2	724,920.1	772,106.3	779,381.4
0.5%	1,018,901.4	596,153.0	882,378.0	976,167.1	1,139,994.6
Maximum	2,450,046.0	685,913.9	1,015,235.0	2,450,046.0	1,197,890.0

Table A.1.11 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Glen Rose BRGR30

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	93,248.2	99,384.7	93,210.3	91,681.9	86,900.5
Std Dev	182,476.4	148,874.1	62,340.6	178,185.6	164,686.1
Minimum	0.0	61.5	0.0	0.0	0.0
99.5%	0.0	187.4	0.0	0.0	0.0
99.0%	0.0	215.9	0.0	0.0	0.0
98.0%	527.5	306.9	676.0	26.4	0.0
95.0%	1,861.6	433.8	1,021.6	1,732.8	1,021.6
90.0%	4,597.8	823.7	3,659.6	4,069.9	3,672.8
85.0%	6,393.6	1,344.5	5,933.4	6,394.4	6,508.4
80.0%	8,275.8	2,692.0	8,697.0	8,429.8	8,696.9
75.0%	10,445.0	4,032.0	10,746.0	10,419.3	10,419.3
70.0%	13,311.4	6,083.7	13,469.6	13,183.6	12,829.4
60.0%	20,144.8	12,511.2	20,079.1	19,587.0	18,984.5
50.0%	30,585.0	25,505.8	30,901.8	30,725.0	32,592.6
40.0%	50,324.2	53,662.0	48,082.7	48,651.0	45,305.4
30.0%	77,054.8	107,725.4	80,050.2	76,231.0	74,524.0
25.0%	96,926.0	133,993.7	95,908.7	96,346.0	92,678.9
20.0%	131,327.8	181,177.0	131,750.7	129,813.4	123,903.8
15.0%	169,178.8	242,648.3	177,143.0	168,440.2	175,527.4
10.0%	242,476.0	326,165.3	243,467.1	233,490.6	203,439.1
5.0%	383,294.6	436,752.9	380,989.4	353,341.8	313,392.9
2.0%	653,682.3	534,111.8	681,921.8	659,249.6	693,277.6
1.0%	866,703.6	628,712.8	802,702.8	882,843.2	958,234.3
0.5%	1,082,487.8	755,366.0	964,406.0	1,069,901.6	1,357,956.3
Maximum	2,710,228.0	1,028,444.0	1,313,055.0	2,710,228.0	1,419,473.0

Table A.1.12 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Paluxy River at Glen Rose PAGR31

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	4,872.9	5,553.9	4,873.1	5,095.2	5,774.0
Std Dev	9,600.9	8,521.4	9,195.2	10,336.0	12,311.0
Minimum	0.0	4.6	0.0	0.0	0.0
99.5%	0.0	6.1	0.0	0.0	0.5
99.0%	0.0	7.0	0.0	0.8	16.0
98.0%	29.4	10.3	52.4	36.4	65.4
95.0%	124.0	16.2	134.7	135.8	177.3
90.0%	252.8	34.9	198.7	254.0	300.2
85.0%	359.0	69.3	318.0	381.2	455.2
80.0%	484.4	144.2	468.6	500.1	567.3
75.0%	607.0	220.7	618.6	629.0	667.5
70.0%	732.8	370.9	730.3	757.0	838.0
60.0%	1,047.4	663.5	1,080.9	1,067.9	1,092.6
50.0%	1,520.0	942.2	1,351.0	1,467.5	1,366.2
40.0%	2,138.4	2,214.8	2,052.1	2,065.2	1,920.6
30.0%	3,493.0	6,166.7	3,746.6	3,455.6	3,293.0
25.0%	4,522.0	8,410.3	4,599.2	4,522.7	4,597.4
20.0%	6,087.4	10,645.2	6,363.3	6,082.6	6,042.1
15.0%	8,103.8	13,526.9	8,257.5	8,256.6	9,313.7
10.0%	12,191.6	17,223.3	11,734.9	12,977.0	15,094.4
5.0%	22,869.8	24,905.0	21,915.4	23,376.2	37,883.8
2.0%	43,499.0	32,938.7	41,504.5	44,701.7	56,470.0
1.0%	53,022.0	36,053.2	45,428.8	55,353.6	65,850.0
0.5%	61,686.2	41,841.8	52,722.8	65,714.2	81,980.6
Maximum	84,978.0	58,795.3	74,085.0	84,978.0	84,588.3

Table A.1.13 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Aquilla BRAQ33

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	114,921.1	116,536.6	114,880.3	114,433.9	112,946.8
Std Dev	204,743.8	160,173.1	182,588.6	200,994.6	189,516.6
Minimum	0.0	18.3	0.0	0.0	0.0
99.5%	0.0	74.6	0.0	0.0	0.0
99.0%	0.0	85.9	0.0	0.0	0.0
98.0%	1,717.0	114.7	1,519.9	1,551.5	880.1
95.0%	3,425.4	174.6	2,816.1	3,321.2	2,574.9
90.0%	6,929.0	309.7	5,088.3	6,120.0	5,169.5
85.0%	10,324.4	536.1	7,318.6	9,352.7	6,444.2
80.0%	13,619.8	894.4	11,053.2	12,544.0	9,236.0
75.0%	16,626.0	5,537.6	16,656.6	15,926.0	12,207.5
70.0%	21,604.4	10,458.3	22,083.4	20,646.6	17,263.9
60.0%	28,719.4	23,213.9	31,740.2	29,755.2	31,015.9
50.0%	46,163.0	44,046.6	46,452.6	46,371.1	47,298.5
40.0%	65,837.2	73,422.6	65,547.9	65,395.6	64,958.0
30.0%	97,383.8	132,318.9	102,703.4	98,755.6	103,750.2
25.0%	131,747.0	165,431.9	125,445.4	130,531.0	127,200.7
20.0%	160,917.0	224,213.4	175,626.9	163,637.8	186,971.1
15.0%	220,406.8	268,096.0	211,648.4	215,925.2	208,866.6
10.0%	280,970.0	342,706.8	277,615.3	279,014.0	256,794.0
5.0%	444,565.4	487,530.9	459,568.6	436,922.4	400,511.9
2.0%	733,178.9	571,899.1	771,446.1	733,590.6	748,670.7
1.0%	924,275.8	661,311.8	892,056.6	974,638.3	1,007,577.6
0.5%	1,232,033.9	766,407.1	1,033,821.8	1,211,818.5	1,457,345.4
Maximum	2,981,239.0	985,532.2	1,329,404.0	2,981,239.0	1,529,623.0

Table A.1.14 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for North Bosque River at Clifton NBCL36

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	13,576.6	15,813.7	13,514.9	14,557.0	17,549.9
Std Dev	31,085.5	32,144.1	28,744.8	33,473.8	39,819.1
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	1.6	0.0	0.0	0.0	0.0
90.0%	166.2	0.0	0.0	79.2	0.0
85.0%	334.8	0.0	0.0	274.8	0.0
80.0%	590.2	0.0	0.0	507.4	375.0
75.0%	771.0	19.5	507.4	754.0	507.4
70.0%	1,046.6	115.8	944.4	1,043.4	979.8
60.0%	1,619.4	627.8	1,864.0	1,655.0	1,760.3
50.0%	2,594.0	1,425.3	2,790.9	2,640.6	2,670.3
40.0%	4,889.4	2,557.5	4,117.6	4,696.6	4,239.6
30.0%	8,412.6	9,549.8	9,347.1	8,507.0	9,263.2
25.0%	11,722.0	16,158.8	11,261.3	12,006.0	14,256.7
20.0%	15,376.0	26,304.8	17,027.8	16,021.0	17,534.4
15.0%	22,602.4	36,501.6	22,858.4	23,174.0	27,580.3
10.0%	40,586.0	54,214.4	38,719.0	46,061.8	62,014.9
5.0%	71,183.8	86,542.0	74,799.8	73,676.8	95,092.2
2.0%	100,519.1	115,493.0	108,372.8	118,989.8	15,7078.1
1.0%	139,412.2	162,935.1	152,890.1	158,661.4	244,751.7
0.5%	198,313.4	176,111.6	165,254.4	217,623.6	284,837.1
Maximum	450,470.0	344,718.8	323,466.8	450,470.0	288,914.9

Table A.1.15 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for North Bosque River at Valley Mills NBVM37

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	16,911.4	20,839.5	16,845.8	19,102.1	25,789.3
Std Dev	37,025.3	39,887.2	34,390.0	41,692.6	53,020.4
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	60.4	0.0	0.0	0.0	0.0
90.0%	270.6	0.0	0.0	134.8	0.0
85.0%	630.2	0.0	0.0	537.2	0.0
80.0%	975.6	28.1	553.8	966.6	888.7
75.0%	1,241.0	60.5	1,046.9	1,229.0	1,128.7
70.0%	1,560.8	235.4	1,440.9	1,587.2	1,958.9
60.0%	2,365.6	1,101.8	2,519.9	2,469.8	2,867.7
50.0%	3,710.0	2,300.0	3,746.5	3,983.0	4,364.3
40.0%	6,320.4	4,348.5	5,669.4	6,319.6	6,326.8
30.0%	10,938.6	13,848.0	11,074.9	11,435.6	12,854.0
25.0%	14,679.0	24,307.2	15,044.1	15,087.0	21,795.4
20.0%	19,246.6	33,956.3	20,651.0	21,411.8	32,941.0
15.0%	27,349.2	47,183.7	28,344.6	31,912.4	60,303.1
10.0%	48,134.8	73,359.1	48,154.6	59,672.4	76,513.6
5.0%	85,228.8	108,289.1	84,281.7	95,274.8	150,248.7
2.0%	131,236.3	157,661.5	146,776.5	154,704.8	259,201.8
1.0%	174,880.9	180,928.5	168,437.2	241,517.4	270,211.6
0.5%	253,031.8	233,408.9	217,294.3	267,262.2	299,696.9
Maximum	459,004.0	301,532.5	280,714.7	459,004.0	304,051.6

Table A.1.16 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Waco BRWA41

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	161,860.3	162,544.9	161,801.6	159,989.	154,278.0
Std Dev	266,252.6	218,075.1	244,711.4	262,620.3	251,690.9
Minimum	0.0	196.5	0.0	0.0	0.0
99.5%	162.7	528.2	39.3	210.2	2,199.3
99.0%	1,576.8	682.5	2,240.6	1,791.1	2,527.8
98.0%	3,433.8	1,010.8	3,421.5	2,836.3	2,724.576
95.0%	6,300.4	1,469.4	6,184.8	6,354.4	6,717.8
90.0%	10,363.6	2,584.5	8,920.0	9,380.5	8,645.5
85.0%	15,181.4	4,875.8	13,717.9	14,170.1	12,516.9
80.0%	19,452.6	10,084.2	19,728.9	19,835.0	22,783.9
75.0%	24,749.0	16,128.0	26,087.0	25,129.0	26,879.6
70.0%	31,006.4	20,647.1	31,167.3	31,221.6	31,833.6
60.0%	45,704.8	35,132.3	44,291.5	44,911.8	43,774.2
50.0%	68,642.0	62,646.4	70,631.0	69,629.0	75,666.3
40.0%	102,411.4	106,253.3	101,710.2	100,643.6	96,462.4
30.0%	146,340.8	190,882.6	150,610.8	146,273.8	145,529.6
25.0%	183,578.0	241,634.8	183,748.8	181,202.0	168,457.0
20.0%	233,939.0	300,693.8	245,594.2	226,570.4	218,642.7
15.0%	298,821.4	369,061.5	306,623.7	293,648.2	289,977.6
10.0%	422,754.8	466,275.4	408,479.7	408,731.6	340,872.7
5.0%	642,243.8	652,040.6	657,283.3	623,098.0	564,008.6
2.0%	941,918.1	818,597.1	1,035,558.3	964,158.8	1,060,611.9
1.0%	1,274,837.8	888,701.1	1,124,242.3	1,267,199.3	1,473,668.4
0.5%	1,509,141.1	1,092,723.6	1,382,338.8	1,581,913.4	1,920,821.6
Maximum	3,376,485.0	1,519,428.0	1,922,137.0	3,376,485.0	1,977,584.0

Table A.1.17 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Highbank BRHB42

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	194,261.6	195,013.5	194,397.6	190,954.9	180,861.0
Std Dev	300,104.3	257,356.1	283,327.8	298,222.3	292,822.3
Minimum	1,251.0	765.7	1,476.1	1,165.1	1,165.1
99.5%	2,455.4	1,910.8	3,683.4	2,534.5	2,997.2
99.0%	3,561.2	2,367.3	4,563.8	3,438.0	3,428.1
98.0%	6,377.8	3,117.9	6,010.2	5,170.2	4,680.4
95.0%	8,762.8	4,273.4	9,199.8	8,696.2	8,872.4
90.0%	14,725.6	6,252.8	16,682.0	14,711.4	16,094.3
85.0%	20,716.8	7,470.4	19,930.3	20,043.8	18,583.0
80.0%	25,155.0	10,852.5	25,059.8	24,539.7	22,646.6
75.0%	31,658.0	14,578.7	30,207.0	31,572.0	30,004.8
70.0%	39,693.6	22,585.3	40,287.4	39,793.4	40,105.9
60.0%	60,613.6	39,771.6	56,432.6	60,589.0	60,772.4
50.0%	89,483.0	76,360.5	90,262.1	87,735.6	86,709.0
40.0%	125,100.2	136,639.9	124,042.1	123,732.8	120,721.4
30.0%	182,646.8	237,873.7	187,982.1	178,725.9	165,477.6
25.0%	232,892.0	307,350.9	234,607.0	228,763.0	209,763.3
20.0%	272,759.0	355,352.3	294,667.5	266,729.6	239,013.2
15.0%	367,070.0	414,986.2	350,921.0	357,577.9	344,014.0
10.0%	488,252.2	570,814.6	501,230.2	454,933.6	406,981.5
5.0%	770,657.4	767,692.3	761,835.9	726,525.4	652,295.3
2.0%	1,133,165.8	931,147.0	1,166,466.1	1,171,914.0	1,432,274.8
1.0%	1,508,354.3	1,048,367.9	1,313,311.1	1,499,721.6	1,766,747.9
0.5%	1,697,646.8	1,263,537.6	1,582,859.0	1,794,571.4	2,172,482.0
Maximum	3,599,269.0	1,892,692.0	2,371,013.0	3,599,269.0	2,219,970.0

Table A.1.18 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Cowhouse Creek at Pidcoke COPI48

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	6,447.8	7,186.6	6,432.6	6,773.7	7,768.6
Std Dev	14,071.2	13,635.1	13,842.5	15,335.7	18,674.8
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	1.0	0.0	0.0	0.0	0.0
90.0%	15.6	0.0	0.0	0.4	0.0
85.0%	51.8	0.0	0.0	13.0	0.0
80.0%	121.4	0.0	0.0	69.4	0.0
75.0%	201.0	0.0	0.0	153.0	0.1
70.0%	312.8	0.0	0.8	271.0	2.2
60.0%	667.6	16.5	628.3	632.5	466.4
50.0%	1,286.0	108.7	1,276.6	1,180.0	936.2
40.0%	2,216.8	2,705.8	2,811.1	2,235.6	2,486.2
30.0%	4,556.0	4,738.8	4,001.9	4,527.0	4,589.1
25.0%	5,935.0	8,457.2	6,005.6	5,984.0	7,030.5
20.0%	8,277.2	12,526.6	9,022.4	8,411.9	8,497.0
15.0%	12,718.2	16,985.8	12,276.3	12,641.0	12,661.1
10.0%	18,477.0	23,417.1	17,869.6	19,649.2	22,154.2
5.0%	29,613.0	35,929.1	30,416.9	32,533.6	39,779.2
2.0%	44,645.1	51,459.8	48,253.9	51,633.9	75,505.2
1.0%	85,843.6	65,271.0	62,107.1	89,659.0	121,778.6
0.5%	108,101.5	82,002.5	104,946.8	118,005.7	144,773.8
Maximum	130,144.0	108,758.1	139,188.6	147,351.9	147,351.9

Table A.1.19 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Leon River at Belton LEBE49

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	42,104.7	40,164.6	41,795.3	43,790.3	48,935.6
Std Dev	75,480.1	68,404.8	73,266.9	81,477.1	97,541.3
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	0.0	0.0	0.0	0.0	0.0
90.0%	478.6	0.0	0.0	0.0	0.0
85.0%	1,387.6	0.0	0.0	781.6	0.0
80.0%	2,370.6	0.0	0.0	1,932.8	0.0
75.0%	3,360.0	0.0	0.0	3,202.0	543.8
70.0%	4,687.6	304.3	3,888.9	4,661.2	4,557.8
60.0%	7,760.8	2,528.3	8,380.7	8,034.2	9,308.7
50.0%	12,757.0	6,537.3	13,674.1	13,198.0	15,588.6
40.0%	22,409.6	10,753.7	18,492.6	20,906.0	18,676.2
30.0%	35,576.6	44,790.9	41,271.8	35,347.6	32,253.3
25.0%	47,585.0	59,400.1	51,323.9	47,248.9	47,241.3
20.0%	63,118.0	76,625.6	65,418.5	63,604.6	68,354.3
15.0%	83,725.6	100,606.2	86,145.1	84,518.7	94,766.0
10.0%	113,249.2	129,032.9	111,652.0	114,405.4	118,382.2
5.0%	189,269.0	197,193.1	185,593.3	208,500.2	249,369.6
2.0%	285,574.1	243,595.4	289,544.9	322,109.5	451,440.6
1.0%	404,785.2	291,109.5	346,021.6	465,079.9	537,472.1
0.5%	543,596.1	366,523.0	435,660.3	547,226.2	570,985.4
Maximum	629,618.0	523,634.6	622,407.8	629,618.0	574,996.5

Table A.1.20 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Little River at Little River LRLR53

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	70,546.2	76,289.6	70,530.8	71,264.7	73,458.2
Std Dev	120,021.7	116,902.8	115,610.8	124,862.1	138,859.6
Minimum	30.0	69.7	157.9	30.0	185.5
99.5%	156.9	166.4	377.2	174.5	240.6
99.0%	297.1	207.9	471.2	293.9	318.4
98.0%	562.4	312.7	708.7	494.5	462.7
95.0%	1,577.4	446.9	1,634.5	1,405.6	906.7
90.0%	3,418.4	784.0	2,829.6	3,014.1	2,770.2
85.0%	4,915.4	1,490.5	4,700.7	4,919.6	5,202.6
80.0%	6,581.2	2,501.4	6,400.7	6,394.6	5,908.2
75.0%	8,225.0	4,511.2	8,685.5	8,228.0	8,373.9
70.0%	10,498.2	6,353.8	10,933.7	10,544.0	11,351.3
60.0%	16,213.2	9,832.4	15,629.8	16,087.0	15,889.5
50.0%	25,741.0	17,172.6	23,265.2	24,802.0	23,913.5
40.0%	37,521.4	39,507.2	39,856.1	37,493.6	37,597.5
30.0%	63,522.2	82,833.2	65,480.2	63,579.6	63,634.2
25.0%	80,406.0	105,062.4	79,503.8	79,067.1	78,833.0
20.0%	105,606.2	135,304.3	103,271.1	102,123.2	94,826.7
15.0%	137,144.0	178,694.2	136,677.8	135,311.0	132,868.0
10.0%	190,523.6	237,053.1	186,816.5	189,295.0	172,220.3
5.0%	310,851.8	344,111.2	302,111.1	301,146.4	262,548.4
2.0%	409,998.7	427,128.4	469,486.7	494,451.9	568,644.5
1.0%	600,470.3	506,623.2	556,865.1	608,576.1	880,914.5
0.5%	909,076.8	575,848.1	632,955.1	929,014.8	1,018,828.6
Maximum	950,933.0	969,855.1	1,066,036.0	1,026,545.0	1,026,545.0

Table A.1.21 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Little River at Cameron LRCA58

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	109,858.5	143,277.5	109,682.5	116,220.8	135,642.8
Std Dev	170,465.5	257,423.2	166,119.7	187,828.0	232,331.9
Minimum	0.0	132.8	0.0	0.0	0.0
99.5%	200.2	373.6	163.2	40.3	5.2
99.0%	494.4	481.2	1,021.4	312.7	73.5
98.0%	1,249.0	569.8	1,240.3	1,047.3	706.1
95.0%	2,706.4	900.2	3,107.5	2,181.8	1,438.6
90.0%	5,440.0	1,126.6	4,245.3	4,767.2	4,245.3
85.0%	8,666.6	1,312.0	8,237.0	8,654.0	8,001.4
80.0%	11,904.0	1,690.0	10,611.3	11,831.2	10,893.1
75.0%	15,032.0	2,606.0	16,369.4	15,275.2	16,369.0
70.0%	19,040.8	3,308.2	18,311.6	18,799.3	18,539.4
60.0%	28,988.2	6,417.3	25,983.2	28,843.6	28,023.9
50.0%	44,799.0	18,830.3	43,369.2	44,521.0	44,277.7
40.0%	65,294.4	33,487.3	60,508.6	62,445.2	57,592.9
30.0%	104,549.0	106,995.6	103,752.0	100,747.4	91,962.2
25.0%	130,473.0	174,771.6	131,816.0	131,271.0	138,554.0
20.0%	165,070.2	258,952.1	177,549.0	177,291.2	211,294.0
15.0%	226,730.8	341,261.7	216,100.5	233,791.4	300,728.9
10.0%	290,433.2	502,319.2	305,357.8	311,616.4	385,681.0
5.0%	426,869.4	712,169.9	438,513.4	460,605.0	711,239.0
2.0%	667,570.9	1,045,815.4	724,801.8	728,356.9	1,033,360.2
1.0%	804,195.3	1,135,659.4	787,069.1	972,919.4	1,214,342.6
0.5%	1,198,901.5	1,453,802.8	1,007,558.1	1,257,228.3	1,378,523.4
Maximum	1,403,136.0	1,615,861.0	1,119,872.0	1,404,414.0	1,404,414.0

Table A.1.22 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Bryan BRBR59

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	335,663.5	351,972.9	335,656.4	337,388.0	342,652.0
Std Dev	483,896.8	465,401.1	463,785.5	506,108.0	569,701.9
Minimum	0.0	985.6	0.0	0.0	848.0
99.5%	5,814.4	4,046.9	7,153.4	5,445.3	3,064.8
99.0%	6,558.6	4,888.5	8,641.1	6,664.0	7,625.6
98.0%	11,161.7	6,171.4	10,908.7	10,009.7	9,089.7
95.0%	17,707.0	8,995.2	18,539.4	16,299.6	13,839.0
90.0%	28,172.8	12,460.9	27,419.5	25,169.7	21,228.5
85.0%	37,714.6	15,510.3	34,814.0	35,354.4	30,691.2
80.0%	47,961.2	23,321.6	45,676.6	46,047.8	42,742.5
75.0%	60,717.0	34,839.0	56,484.5	59,668.0	51,658.5
70.0%	73,088.0	53,895.3	77,987.2	73,916.6	75,958.9
60.0%	107,621.6	91,837.1	112,634.3	109,275.0	114,541.9
50.0%	158,629.0	141,347.0	156,212.5	156,013.3	151,812.9
40.0%	232,671.4	233,786.4	229,739.7	225,681.5	209,703.6
30.0%	323,096.8	382,206.9	328,910.6	315,280.0	265,091.7
25.0%	402,271.0	491,158.0	407,101.0	388,871.0	348,395.9
20.0%	502,304.2	641,076.6	518,465.9	503,028.4	513,870.3
15.0%	659,684.0	781,911.4	623,738.9	652,151.6	645,741.2
10.0%	810,073.0	1,049,241.3	871,673.7	784,616.2	739,616.3
5.0%	1,304,347.0	1,423,526.3	1,319,316.9	1,295,204.6	1,469,178.8
2.0%	1,816,933.3	1,699,211.6	1,889,778.5	1,966,342.5	2,810,406.3
1.0%	2,428,207.0	1,917,785.0	2,132,864.8	2,734,509.8	3,429,347.0
0.5%	3,263,556.8	2,161,300.0	2,403,689.3	3,536,292.3	3,595,907.5
Maximum	4,704,312.0	3,744,534.0	4,164,483.0	4,704,312.0	3,597,576.0

Table A.1.23 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Middle Yegua Creek at Dime Box MYDB60

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	3,280.1	3,590.1	3,269.4	4,895.9	3,678.8
Std Dev	6,625.2	6,736.3	6,572.0	10,491.0	7,784.9
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	0.0	0.0	0.0	0.0	0.0
90.0%	0.0	0.0	0.0	0.0	0.0
85.0%	7.8	0.0	0.0	0.0	0.0
80.0%	31.2	0.0	0.0	0.0	9.0
75.0%	59.0	0.0	0.0	0.0	44.0
70.0%	111.0	0.0	0.0	0.0	99.2
60.0%	294.6	41.7	330.5	210.0	292.6
50.0%	552.0	95.5	428.1	428.1	482.0
40.0%	1,104.4	752.8	1,046.2	805.4	994.0
30.0%	2,229.2	2,792.0	2,249.7	2,163.9	2,198.3
25.0%	3,021.0	4,523.9	2,985.2	3,728.2	3,083.0
20.0%	4,282.0	6,697.0	5,071.0	6,802.9	4,451.4
15.0%	6,717.0	9,024.2	7,051.7	11,872.8	7,567.4
10.0%	10,826.0	12,353.5	10,304.3	17,943.1	11,970.8
5.0%	17,271.4	17,592.3	16,191.9	25,569.1	18,895.9
2.0%	24,707.3	26,053.0	24,736.3	45,094.5	28,148.4
1.0%	30,943.2	33,832.6	32,408.1	54,983.6	42,589.5
0.5%	41,709.2	36,699.6	42,370.4	62,923.6	49,207.6
Maximum	62,553.0	46,204.1	53,343.6	63,773.0	63,773.0

Table A.1.24 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for East Yegua Creek at Dime Box EYDB61

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	3,599.0	4,015.0	3,595.1	3,784.0	4,348.4
Std Dev	6,546.7	7,457.8	6,448.1	7,038.0	8,352.1
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	11.8	0.0	0.0	0.0	0.0
90.0%	78.6	0.0	0.1	47.0	0.0
85.0%	146.0	17.5	148.5	130.5	31.0
80.0%	249.6	30.1	237.5	220.2	139.8
75.0%	344.0	71.5	299.3	311.0	221.7
70.0%	388.6	169.1	412.5	381.0	312.3
60.0%	557.4	325.7	567.0	555.2	545.0
50.0%	814.0	559.0	859.7	808.0	770.4
40.0%	1,320.0	965.7	1,253.9	1,262.8	1,097.5
30.0%	2,221.6	2,591.1	2,218.3	2,106.5	1,956.9
25.0%	3,411.0	4,653.9	3,403.5	3,272.0	2,720.9
20.0%	4,963.2	6,532.1	5,406.9	5,429.6	7,187.8
15.0%	7,898.4	9,918.1	8,448.8	8,562.8	10,507.2
10.0%	11,912.2	13,207.2	11,428.2	12,405.6	14,382.3
5.0%	17,273.6	19,715.3	17,377.9	18,527.6	23,958.4
2.0%	25,335.2	29,543.3	25,864.0	27,171.7	34,040.2
1.0%	29,869.0	35,339.4	30,938.2	35,344.3	42,792.9
0.5%	40,095.3	43,498.3	38,081.1	41,753.6	48,016.7
Maximum	52,708.0	49,701.4	43,511.6	52,708.0	48,607.4

Table A.1.25 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Davidson Creek at Lyons DCLY63

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	3,957.1	4,195.0	3,937.1	4,094.9	4,515.7
Std Dev	7,511.6	7,895.9	7,466.1	7,999.5	9,338.4
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	0.0	0.0	0.0	0.0	0.0
90.0%	0.0	0.0	0.0	0.0	0.0
85.0%	1.0	0.0	0.0	0.0	0.0
80.0%	37.0	0.0	0.0	0.0	0.0
75.0%	71.0	0.0	0.0	40.0	0.0
70.0%	122.6	0.0	0.0	94.2	0.0
60.0%	289.6	28.2	190.1	241.0	190.1
50.0%	649.0	112.5	289.1	496.0	246.7
40.0%	1,310.6	1,335.3	1,694.9	1,163.6	562.3
30.0%	2,720.2	2,937.3	2,531.6	2,558.5	2,036.8
25.0%	3,709.0	4,814.9	3,804.4	3,709.0	3,728.8
20.0%	5,889.4	7,625.7	6,731.9	5,950.8	7,573.7
15.0%	9,294.2	9,708.7	8,791.1	9,787.4	10,966.1
10.0%	13,338.6	15,151.7	13,769.0	14,220.4	16,146.4
5.0%	20,034.6	21,653.8	20,021.7	21,871.8	26,403.2
2.0%	27,700.8	28,799.5	27,880.3	30,760.0	36,070.6
1.0%	39,702.9	35,741.1	34,600.2	40,799.5	48,326.4
0.5%	46,254.6	49,614.6	48,030.9	49,966.2	55,578.1
Maximum	54,457.0	52,530.1	50,853.3	56,495.0	56,495.0

Table A.1.26 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Navasota River at Easterly NAEA66

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	26,881.5	27,617.2	26,812.2	27,953.0	31,223.8
Std Dev	46,900.3	51,032.3	46,965.6	50,476.1	60,090.4
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	0.0	0.0	0.0	0.0	0.0
90.0%	125.4	0.0	0.0	0.0	0.0
85.0%	269.0	0.0	0.0	154.2	0.0
80.0%	594.8	0.0	0.0	453.4	0.0
75.0%	848.0	53.8	570.1	771.0	498.3
70.0%	1,342.6	233.1	911.6	1,164.6	911.6
60.0%	2,576.8	1,313.1	2,859.2	2,503.2	2,237.5
50.0%	5,743.0	2,475.3	4,524.0	4,882.5	3,884.9
40.0%	11,059.6	11,347.5	13,158.5	10,159.4	6,286.7
30.0%	21,528.2	22,554.3	20,708.5	20,493.5	14,920.5
25.0%	28,826.0	34,038.4	30,699.6	28,447.1	24,326.2
20.0%	40,601.6	45,373.3	45,338.3	41,463.8	51,561.2
15.0%	64,383.2	58,640.6	60,008.1	66,366.2	80,002.9
10.0%	87,562.4	87,932.2	88,569.3	89,928.1	116,310.7
5.0%	131,424.6	136,478.6	128,890.9	143,656.8	173,068.0
2.0%	176,648.4	190,347.9	172,091.6	195,748.4	244,335.6
1.0%	225,212.6	261,185.8	236,135.4	230,253.4	284,973.6
0.5%	274,632.0	298,603.8	269,964.8	295,279.2	329,844.5
Maximum	332,958.0	387,377.1	350,223.7	336,962.4	336,962.4

Table A.1.27 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Hempstead BRHE68

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	446,578.6	477,358.5	446,299.2	449,823.0	459,727.2
Std Dev	588,542.4	609,475.9	569,446.3	616,502.0	696,257.0
Minimum	1,634.0	2,083.7	4,526.6	1,634.0	4,105.3
99.5%	11,082.0	5,776.6	12,549.3	10,088.9	8,205.5
99.0%	13,817.1	6,251.7	13,581.7	12,973.3	11,525.7
98.0%	17,422.0	8,801.3	19,119.6	16,792.0	16,174.3
95.0%	30,122.4	12,855.4	30,207.2	26,222.0	21,420.3
90.0%	44,643.0	19,112.9	45,749.7	39,791.1	33,927.2
85.0%	56,054.2	23,703.0	55,371.1	55,153.8	40,990.6
80.0%	77,417.0	34,136.0	63,642.9	69,508.8	58,165.4
75.0%	89,698.0	55,630.0	89,368.0	84,251.0	68,259.0
70.0%	111,822.2	83,581.4	116,670.8	109,191.2	94,128.5
60.0%	157,333.4	133,209.1	159,135.0	156,580.0	155,698.1
50.0%	229,331.0	205,709.0	224,696.0	220,827.0	200,590.0
40.0%	306,814.6	332,019.0	305,799.5	304,835.8	302,422.8
30.0%	468,793.0	546,071.6	470,075.9	454,580.6	425,988.3
25.0%	581,968.0	683,192.0	586,472.4	577,767.0	560,470.8
20.0%	724,072.0	853,519.6	710,943.6	721,947.2	711,814.1
15.0%	911,674.9	1,065,589.8	868,999.0	899,464.9	893,131.2
10.0%	1,153,504.8	1,416,864.3	1,179,256.4	1,143,206.8	1,057,076.1
5.0%	1,587,840.0	1,803,522.6	1,608,316.6	1,637,404.0	1,993,831.1
2.0%	2,208,881.5	2,169,848.3	2,232,123.0	2,404,275.8	2,798,721.8
1.0%	2,569,895.8	2,559,369.8	2,632,824.3	2,833,272.8	3,917,055.3
0.5%	3,780,357.3	2,826,479.8	2,907,600.3	4,154,599.3	5,067,131.0
Maximum	5,723,482.0	4,352,882.0	4,477,810.0	5,723,482.0	5,220,954.0

Table A.1.28 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Richmond BRRI70

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	487,518.7	500,872.3	487,360.0	497,682.3	528,708.2
Std Dev	613,001.8	599,498.7	593,769.9	645,071.0	734,976.6
Minimum	0.0	2,878.0	0.0	0.0	0.0
99.5%	14,214.6	5,323.2	16,035.8	11,773.5	2,229.7
99.0%	18,382.7	6,576.8	19,811.3	16,658.1	15,986.3
98.0%	25,401.7	8,320.6	25,063.5	23,301.9	17,625.6
95.0%	39,521.8	12,672.5	38,293.3	34,414.8	28,597.6
90.0%	53,887.8	19,986.4	54,734.4	51,120.4	44,320.2
85.0%	72,716.6	24,566.3	65,014.0	63,730.0	53,611.6
80.0%	89,258.2	38,811.9	84,761.7	83,333.4	62,079.2
75.0%	111,204.0	77,299.1	115,916.2	103,518.0	71,945.0
70.0%	133,509.6	109,843.6	142,533.4	130,967.6	98,761.2
60.0%	184,722.8	167,091.9	183,592.2	182,531.9	179,430.8
50.0%	257,456.0	250,201.0	256,395.5	256,498.0	256,498.0
40.0%	358,553.2	379,650.0	354,872.5	355,083.6	350,835.7
30.0%	512,052.7	600,396.8	526,502.8	507,547.6	473,106.8
25.0%	653,272.0	761,391.0	646,954.0	660,079.0	679,436.8
20.0%	779,791.0	903,200.4	775,956.6	785,604.6	849,328.4
15.0%	981,967.8	1,133,907.0	976,826.9	979,986.1	987,582.4
10.0%	1,230,722.8	1,346,884.0	1,202,092.1	1,296,201.4	1,449,939.6
5.0%	1,674,398.6	1,757,201.8	1,701,121.5	1,842,461.0	2,203,139.3
2.0%	2,220,046.0	2,235,978.5	2,424,583.3	2,548,975.6	3,126,711.3
1.0%	2,858,999.8	2,420,742.5	2,624,932.5	3,182,248.0	3,461,229.0
0.5%	3,570,108.8	2,729,370.3	2,959,592.3	3,561,313.5	4,574,880.0
Maximum	6,135,975.0	4,369,937.0	4,738,541.0	6,135,975.0	4,755,752.0

Table A.1.29 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Big Creek at Needville BGNE71

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	2,135.9	2,260.5	2,135.8	2,195.9	2,379.1
Std Dev	3,490.3	3,855.9	3,464.9	3,620.3	3,993.6
Minimum	0.0	0.0	0.0	0.0	0.0
99.5%	0.0	0.0	0.0	0.0	0.0
99.0%	0.0	0.0	0.0	0.0	0.0
98.0%	0.0	0.0	0.0	0.0	0.0
95.0%	0.0	0.0	0.0	0.0	0.0
90.0%	9.6	0.0	0.0	8.6	2.6
85.0%	33.0	0.0	11.4	32.9	32.5
80.0%	56.0	0.3	41.9	55.0	51.1
75.0%	91.0	0.8	69.4	85.0	64.4
70.0%	125.4	2.3	104.4	120.4	114.9
60.0%	279.8	65.7	313.1	291.8	313.3
50.0%	591.0	247.8	580.6	609.0	683.1
40.0%	1,024.0	1,125.6	1,130.2	1,074.7	1,198.2
30.0%	1,874.2	1,886.1	1,694.4	1,880.8	2,121.3
25.0%	2,602.0	2,655.2	2,471.5	2,692.0	3,170.1
20.0%	3,640.8	3,919.7	3,565.9	3,670.1	3,765.3
15.0%	5,055.6	5,530.0	4,949.7	5,051.4	5,026.1
10.0%	6,678.6	7,747.9	7,010.1	6,835.8	7,311.8
5.0%	9,990.6	10,694.8	9,808.1	10,004.4	11,560.3
2.0%	13,247.1	14,591.2	13,252.9	13,893.8	16,853.3
1.0%	15,610.2	17,423.4	15,825.1	16,895.7	20,193.1
0.5%	17,473.4	20,814.9	18,905.5	18,956.5	22,683.0
Maximum	27,782.0	24,978.1	22,686.8	27,782.0	22,922.6

Table A.1.30 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Rosharon BRRO72

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	509,356.5	478,724.9	508,931.1	520,129.9	553,017.4
Std Dev	639,652.5	541,938.4	621,529.0	674,154.4	770,601.1
Minimum	0.0	6,303.0	0.0	0.0	0.0
99.5%	14,726.3	7,339.9	24,396.7	15,294.6	24,396.7
99.0%	19,044.5	7,339.9	24,396.7	22,828.8	24,396.7
98.0%	26,315.8	7,340.0	24,397.0	24,397.0	24,397.0
95.0%	40,684.8	10,267.0	41,444.8	39,062.0	32,587.1
90.0%	59,060.2	13,195.0	55,562.2	55,278.6	50,718.6
85.0%	78,738.6	19,947.0	58,828.0	69,058.6	55,903.7
80.0%	97,964.6	48,081.6	96,415.5	91,709.8	58,828.0
75.0%	118,878.0	80,751.9	129,320.0	115,156.0	98,555.2
70.0%	139,926.8	112,082.2	148,933.6	137,499.2	124,313.5
60.0%	198,275.8	171,812.0	192,685.4	194,243.9	187,744.1
50.0%	269,256.0	276,513.0	266,547.1	260,100.0	250,498.0
40.0%	375,960.2	395,900.4	374,009.3	369,489.6	341,118.9
30.0%	528,254.6	573,514.8	527,439.4	525,385.9	513,288.5
25.0%	671,495.0	720,912.3	663,715.1	671,390.0	668,455.0
20.0%	797,573.4	860,694.6	820,442.4	794,304.6	803,590.9
15.0%	1,045,463.6	1,067,168.8	1,025,933.6	1,047,470.4	1,138,866.4
10.0%	1,274,444.4	1,281,727.6	1,278,126.3	1,361,307.3	1,569,120.8
5.0%	1,758,208.3	1,621,308.4	1,777,017.6	1,880,387.0	2,405,411.0
2.0%	2,342,685.5	1,879,193.3	2,397,906.3	2,678,184.5	3,374,808.5
1.0%	3,067,954.8	2,367,063.3	3,020,444.0	3,387,642.3	3,780,291.5
0.5%	3,481,395.3	2,608,834.8	3,328,950.5	3,740,911.8	4,350,285.0
Maximum	6,356,870.0	4,028,285.0	5,140,212.0	6,356,870.0	4,437,795.0

Table A.1.31 Flow Frequency Metrics in acre-feet/month for Calibration and Extension for Brazos River at Gulf of Mexico BRGM73

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2016	Extension 1998-2016
Mean	508,769.8	516,636.3	508,520.9	517,873.5	545,663.4
Std Dev	634,290.5	614,025.7	612,605.9	689,216.8	835,854.2
Minimum	4.0	4,513.0	10,625.0	4.0	9,506.7
99.5%	14,593.8	6,529.5	15,374.3	13,330.1	13,883.1
99.0%	18,771.8	8,743.6	20,587.7	17,209.1	15,436.3
98.0%	25,991.5	10,955.6	25,796.3	24,683.3	17,617.4
95.0%	42,893.2	16,683.8	44,535.9	36,343.4	28,011.3
90.0%	59,767.2	22,591.8	59,248.6	53,763.2	47,064.0
85.0%	79,427.2	29,556.0	73,110.0	73,110.0	59,775.0
80.0%	101,917.4	45,423.0	89,548.0	94,288.8	73,110.0
75.0%	121,025.0	89,615.5	127,723.5	114,310.0	99,687.8
70.0%	142,127.0	117,235.3	148,323.0	139,992.4	125,398.9
60.0%	199,329.2	183,168.7	192,322.7	196,202.3	191,499.9
50.0%	269,220.0	281,878.8	271,838.0	262,263.0	246,414.0
40.0%	376,386.0	387,097.2	362,749.3	347,991.2	299,042.6
30.0%	526,070.6	575,788.8	524,350.4	503,061.2	404,141.9
25.0%	676,536.0	757,851.0	664,900.0	628,042.0	502,218.0
20.0%	792,769.0	927,893.3	845,683.4	783,612.5	727,521.1
15.0%	1,048,216.1	1,063,238.3	978,072.8	1,040,535.0	1,020,644.0
10.0%	1,272,970.8	1,444,129.0	1,335,151.0	1,297,019.4	1,516,378.8
5.0%	1,759,739.0	1,827,850.6	1,754,082.9	1,945,974.1	2,626,604.5
2.0%	2,326,775.3	2,357,515.5	2,527,917.0	2,837,850.3	3,825,279.3
1.0%	3,033,573.0	2,804,653.5	3,007,374.3	3,456,862.5	4,071,292.5
0.5%	3,443,166.0	3,077,025.3	3,299,432.3	4,023,665.5	4,461,585.0
Maximum	6,254,466.0	3,787,551.0	4,061,315.0	6,254,466.0	4,518,736.0

A.2 Original 1940-1997 and Extended 1998-2016 Naturalized Flow

Table A.2.1 1940-2016 Naturalized Flows at Control Points RWPL01

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT RWPL01

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	1.	9.	0.	3.	5.	0.	0.	0.	0.	3.	20.	1.	42.
1941	1.	1.	8.	6.	3608.	21017.	813.	240.	23.	5449.	184.	2.	31352.
1942	0.	0.	0.	175.	0.	169.	0.	2.	9.	161.	0.	6.	522.
1943	0.	0.	0.	0.	3.	0.	44.	0.	0.	0.	0.	1.	48.
1944	3.	0.	0.	0.	14.	59.	0.	0.	0.	0.	0.	2.	78.
1945	0.	0.	0.	0.	0.	0.	0.	1.	0.	1.	0.	0.	2.
1946	0.	0.	0.	0.	0.	0.	0.	2.	18.	1085.	0.	682.	1787.
1947	0.	0.	0.	0.	1426.	17.	15.	0.	0.	0.	0.	0.	1458.
1948	0.	1.	0.	2.	3.	3.	0.	18.	3.	1.	0.	0.	31.
1949	16.	6.	1.	13.	49.	11.	9.	6.	7.	2.	0.	1.	121.
1950	0.	0.	0.	7.	7.	5.	50.	20.	48.	4.	1.	2.	144.
1951	1.	3.	1.	1.	4253.	4.	5.	0.	19.	0.	0.	0.	4287.
1952	1.	0.	0.	20.	0.	0.	3.	0.	0.	0.	0.	0.	24.
1953	0.	0.	0.	0.	0.	0.	7.	2.	0.	2323.	122.	24.	2478.
1954	13.	7.	1.	857.	3283.	82.	1.	1.	0.	1.	4.	2.	4252.
1955	2.	39.	186.	39.	1411.	513.	606.	68.	3152.	3155.	50.	31.	9252.
1956	26.	30.	4.	1.	335.	64.	1.	15.	0.	0.	0.	0.	476.
1957	0.	1.	12.	73.	837.	2247.	2.	438.	0.	24.	19.	3.	3656.
1958	19.	8.	33.	21.	8.	34.	7.	5.	5.	1.	1.	0.	142.
1959	0.	0.	0.	0.	13.	2344.	1607.	0.	0.	6.	0.	40.	4010.
1960	6.	4.	2.	1.	26.	99.	1173.	8.	0.	2569.	75.	54.	4017.
1961	40.	53.	11.	4.	40.	17.	639.	3.	3.	0.	7.	0.	817.
1962	0.	0.	0.	6.	1170.	220.	49.	5.	68.	46.	9.	1.	1574.
1963	0.	2.	1.	10.	157.	1711.	115.	52.	60.	6.	15.	1.	2130.
1964	2.	9.	1.	14.	58.	1121.	65.	55.	126.	9.	1.	7.	1468.
1965	0.	2.	1.	13.	79.	5955.	93.	41.	41.	12.	0.	0.	6237.
1966	1.	0.	4.	29.	85.	170.	125.	90.	55.	8.	0.	0.	567.
1967	0.	1.	3.	20.	263.	914.	1187.	42.	42.	6.	0.	2.	2480.
1968	7.	8.	5.	16.	86.	1231.	114.	125.	98.	16.	24.	4.	1734.
1969	0.	5.	22.	62.	3827.	465.	384.	50.	87.	130.	11.	1.	5044.
1970	0.	12.	19.	282.	241.	38.	61.	57.	44.	49.	0.	0.	803.
1971	0.	22.	0.	30.	65.	989.	56.	62.	658.	18.	2.	8.	1910.
1972	0.	0.	14.	46.	298.	121.	244.	134.	49.	27.	7.	0.	940.
1973	2.	6.	72.	51.	68.	79.	107.	92.	41.	5.	0.	0.	523.
1974	0.	0.	19.	22.	47.	3454.	78.	670.	98.	110.	6.	5.	4509.
1975	3.	18.	12.	31.	79.	178.	220.	129.	57.	23.	12.	1.	763.
1976	0.	0.	19.	26.	58.	59.	174.	143.	67.	2.	0.	0.	548.
1977	0.	0.	36.	44.	2103.	127.	109.	185.	7.	7.	0.	0.	2618.
1978	0.	0.	26.	36.	104.	542.	116.	120.	22.	36.	31.	16.	1049.
1979	28.	15.	40.	44.	125.	488.	5434.	0.	0.	0.	205.	0.	6379.
1980	0.	0.	20.	47.	477.	215.	6.	99.	142.	0.	47.	0.	1053.
1981	0.	5.	71.	396.	138.	321.	340.	303.	126.	343.	4.	0.	2047.
1982	0.	5.	75.	0.	825.	1563.	207.	3.	436.	0.	0.	29.	3143.
1983	22.	22.	26.	27.	2.	0.	140.	0.	0.	2637.	299.	0.	3175.
1984	31.	19.	51.	1.	82.	21.	0.	40.	15.	0.	66.	0.	326.
1985	0.	0.	22.	15.	67.	1279.	305.	40.	0.	1251.	81.	0.	3060.
1986	0.	213.	0.	285.	81.	375.	3.	464.	1446.	2940.	386.	170.	6363.
1987	107.	159.	211.	68.	2318.	760.	591.	90.	169.	4.	0.	39.	4516.
1988	16.	34.	47.	91.	29.	0.	92.	0.	22.	0.	0.	0.	331.
1989	42.	0.	102.	31.	94.	1115.	40.	0.	169.	5.	6.	22.	1626.
1990	0.	0.	190.	108.	0.	126.	0.	0.	0.	0.	9.	12.	445.
1991	5.	42.	27.	37.	22.	273.	27.	77.	711.	73.	104.	290.	1688.
1992	119.	200.	89.	85.	480.	786.	5.	0.	156.	0.	15.	31.	1966.
1993	40.	47.	42.	33.	67.	0.	45.	90.	37.	0.	0.	0.	401.
1994	33.	12.	18.	12.	416.	93.	0.	56.	0.	32.	0.	42.	714.
1995	0.	15.	0.	0.	4.	92.	51.	0.	126.	18.	18.	0.	324.
1996	32.	18.	0.	0.	86.	71.	0.	109.	0.	0.	25.	0.	341.
1997	19.	29.	40.	711.	300.	132.	143.	0.	0.	0.	0.	18.	1392.
MEAN	11.	19.	27.	68.	512.	893.	271.	73.	146.	390.	32.	27.	2469.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT RWPL01

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	0.	0.	0.	79.	10.	7.	1.	0.	24.	86.	6542.	0.	6751.
1999	0.	0.	0.	75.	157.	187.	74.	0.	77.	0.	0.	0.	570.
2000	0.	0.	0.	47.	9.	47.	70.	0.	3.	0.	0.	0.	175.
2001	468.	449.	181.	40.	22.	40.	1.	0.	20.	0.	34.	1491.	2745.
2002	0.	240.	0.	75.	8.	15.	4.	0.	27.	470.	1724.	260.	2823.
2003	0.	0.	0.	20.	8.	100.	9.	0.	32.	0.	0.	0.	169.
2004	0.	0.	0.	75.	26.	20.	215.	0.	133.	8411.	7771.	620.	17273.
2005	0.	130.	0.	100.	23.	36.	6.	165.	307.	0.	0.	0.	766.
2006	0.	0.	0.	36.	9.	24.	5.	0.	2417.	270.	0.	0.	2761.
2007	137.	0.	89.	584.	159.	446.	18.	0.	30.	0.	0.	0.	1464.
2008	0.	0.	0.	13.	16.	46.	8.	0.	6607.	0.	0.	0.	6690.
2009	0.	0.	0.	18.	18.	42.	28.	0.	32.	0.	0.	0.	138.
2010	58.	134.	0.	75.	48.	37.	140.	0.	30.	0.	0.	0.	522.
2011	0.	0.	0.	8.	1.	5.	1.	0.	13.	0.	0.	115.	143.
2012	0.	0.	0.	24.	15.	41.	5.	0.	30.	0.	0.	0.	115.
2013	0.	0.	0.	10.	6.	30.	53.	143.	31.	0.	0.	0.	273.
2014	0.	0.	0.	10.	22.	602.	96.	0.	45.	1790.	0.	0.	2564.
2015	0.	0.	0.	53.	8234.	7314.	244.	615.	35.	462.	2824.	0.	19782.
2016	0.	0.	0.	34.	25.	43.	5.	0.	566.	0.	0.	0.	672.
MEAN	35.	50.	14.	72.	464.	478.	52.	49.	551.	605.	994.	131.	3494.

Table A.2.2 1940-2016 Naturalized Flows at Control Points SEAS06

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT SFAS06

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	10.	44.	4.	4903.	3596.	9751.	168.	44689.	2032.	146.	10639.	515.	76497.
1941	15.	1101.	11038.	49242.	133707.	73526.	15382.	4008.	35606.	135865.	9268.	4008.	472766.
1942	1564.	521.	245.	6136.	849.	4349.	1758.	4472.	22753.	20685.	1421.	3010.	67763.
1943	991.	171.	528.	553.	1908.	22981.	6733.	10.	9.	8.	36.	141.	34069.
1944	181.	417.	187.	84.	1141.	2206.	5243.	541.	12125.	270.	299.	4672.	27366.
1945	724.	312.	456.	323.	10.	18941.	39490.	296.	9460.	9167.	37.	9.	79225.
1946	9.	3.	0.	1111.	6439.	30592.	2462.	42907.	17820.	20881.	546.	3432.	126202.
1947	874.	159.	369.	1399.	90055.	5067.	517.	8.	3.	5.	345.	2948.	101749.
1948	52.	4956.	430.	62.	1289.	35079.	19725.	1514.	35.	3865.	3935.	63.	71005.
1949	615.	362.	348.	1049.	48666.	33002.	5752.	2312.	13417.	3698.	394.	297.	109912.
1950	533.	330.	33.	1008.	46842.	8766.	14833.	2945.	40823.	2518.	523.	402.	119556.
1951	343.	455.	446.	267.	18624.	8836.	2843.	11009.	413.	33.	31.	9.	43309.
1952	45.	24.	12.	1822.	890.	21.	7815.	5.	18.	2.	217.	66.	10937.
1953	7.	0.	25.	369.	1592.	4.	11126.	11314.	108.	70393.	3682.	715.	99335.
1954	405.	214.	40.	25958.	99489.	2483.	24.	36.	4.	22.	126.	66.	128867.
1955	56.	1167.	5651.	1170.	42768.	15545.	18377.	2062.	95508.	95601.	1520.	929.	280354.
1956	790.	912.	126.	26.	10140.	1930.	24.	468.	9.	389.	50.	84.	14948.
1957	18.	1129.	530.	29118.	103166.	76333.	3290.	1549.	886.	12360.	12776.	501.	241656.
1958	579.	434.	1259.	2102.	10996.	1928.	2319.	435.	5992.	508.	226.	43.	26821.
1959	43.	37.	23.	370.	1534.	57391.	24049.	7159.	64.	8701.	329.	6506.	106206.
1960	1715.	863.	425.	44.	787.	2998.	35549.	241.	11.	77862.	2264.	1639.	124398.
1961	1197.	1613.	883.	268.	1334.	56510.	38417.	951.	349.	626.	2427.	540.	105115.
1962	338.	188.	166.	1990.	326.	9676.	3936.	3356.	22103.	2234.	3841.	2076.	50230.
1963	613.	514.	475.	1349.	8870.	32670.	581.	171.	5528.	500.	1836.	854.	53961.
1964	583.	1176.	472.	326.	38.	6115.	493.	105.	3400.	131.	717.	149.	13705.
1965	74.	52.	38.	2003.	5258.	3570.	560.	7865.	3156.	10980.	454.	772.	34782.
1966	580.	546.	1810.	3742.	2055.	2330.	151.	64222.	41259.	1563.	768.	648.	119674.
1967	485.	245.	3005.	2224.	6143.	11997.	13446.	205.	2615.	1199.	50.	93.	41707.
1968	1030.	1681.	5609.	1283.	3154.	35388.	3623.	3399.	716.	797.	883.	424.	57987.
1969	168.	163.	559.	641.	24141.	5810.	141.	494.	11867.	14066.	6643.	1237.	65930.
1970	883.	533.	4884.	1315.	875.	1051.	87.	68.	659.	739.	71.	56.	11221.
1971	170.	74.	93.	123.	10576.	6471.	146.	22527.	19696.	5260.	1452.	1522.	68110.
1972	680.	649.	637.	321.	2302.	1927.	2956.	65711.	16223.	5402.	4074.	1496.	102378.
1973	3740.	4480.	8021.	3470.	1271.	477.	226.	178.	3474.	394.	242.	175.	26148.
1974	328.	247.	421.	849.	899.	24439.	186.	5861.	15641.	8595.	3236.	1054.	61756.
1975	1027.	2023.	610.	810.	17237.	2106.	5797.	2135.	6255.	784.	1507.	713.	41004.
1976	688.	620.	479.	9585.	1496.	271.	4353.	5873.	6684.	5374.	3075.	939.	39437.
1977	1496.	1007.	887.	8232.	22051.	4624.	1082.	5371.	1021.	17.	63.	66.	45917.
1978	366.	1007.	251.	117.	8127.	2901.	1413.	1568.	7612.	852.	734.	385.	25333.
1979	673.	355.	928.	1094.	2863.	11037.	20940.	9032.	123.	4.	1926.	228.	49203.
1980	310.	522.	196.	265.	18810.	7483.	221.	490.	9127.	1415.	1002.	1237.	41078.
1981	522.	607.	1381.	4158.	4700.	5581.	1514.	2322.	1247.	24887.	1159.	599.	48677.
1982	950.	792.	1175.	290.	20748.	33934.	4672.	1095.	8047.	273.	375.	722.	73073.
1983	1217.	889.	655.	1013.	7188.	2689.	955.	98.	418.	56268.	6049.	2779.	80218.
1984	1423.	829.	773.	217.	1124.	163.	32.	1909.	90.	2253.	1269.	3178.	13260.
1985	2083.	1404.	2579.	9006.	9733.	10969.	2240.	337.	1254.	27234.	1867.	812.	69518.
1986	493.	1417.	331.	1831.	3342.	8135.	8283.	12639.	28496.	56457.	7570.	3396.	132390.
1987	2310.	3119.	4464.	1585.	44942.	15016.	11854.	2080.	4422.	205.	207.	798.	91002.
1988	721.	558.	819.	1035.	421.	1444.	2540.	293.	2422.	106.	103.	263.	10725.
1989	378.	632.	681.	284.	5434.	13800.	362.	250.	3108.	38.	43.	92.	25102.
1990	1274.	731.	3000.	7835.	4069.	65170.	2828.	3609.	1012.	609.	895.	537.	91569.
1991	1005.	631.	374.	285.	1755.	60126.	1888.	9600.	27759.	6361.	4244.	14995.	129023.
1992	8657.	14126.	6751.	6528.	16874.	50359.	4185.	1370.	1650.	91.	1882.	1302.	113775.
1993	1479.	2990.	2822.	1517.	2886.	816.	198.	858.	473.	204.	120.	493.	14856.
1994	616.	989.	514.	308.	13596.	1046.	21.	227.	1095.	566.	1641.	484.	21103.
1995	352.	346.	356.	671.	13756.	6355.	490.	10313.	3638.	930.	858.	541.	38606.
1996	741.	398.	537.	244.	758.	1492.	387.	12496.	22042.	2963.	2003.	1570.	45631.
1997	691.	5548.	2016.	14522.	9136.	8912.	7295.	3068.	533.	52.	107.	1012.	52892.
MEAN	861.	1161.	1411.	3766.	15910.	15941.	6310.	6899.	9350.	12128.	1966.	1350.	77052.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT SFAS06

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	118.	1082.	630.	433.	433.	427.	355.	929.	27.	1300.	1318.	265.	7317.
1999	118.	184.	1038.	1241.	12962.	27430.	1853.	259.	1304.	29.	266.	265.	46949.
2000	118.	122.	1195.	1232.	433.	24532.	1199.	259.	0.	1822.	9212.	1110.	41234.
2001	6128.	4290.	9962.	433.	1483.	433.	355.	259.	27.	29.	9028.	6914.	39340.
2002	701.	5307.	2900.	1188.	433.	433.	355.	1194.	27.	24392.	2783.	10782.	50494.
2003	695.	150.	112.	433.	433.	21400.	1141.	259.	27.	29.	266.	265.	25209.
2004	4329.	2795.	3858.	5685.	210.	21003.	45380.	5716.	4280.	11443.	107180.	3703.	215582.
2005	2347.	3310.	842.	433.	1150.	433.	760.	12682.	1216.	1752.	266.	0.	25192.
2006	0.	34.	112.	433.	640.	433.	355.	1694.	28180.	22716.	1455.	1194.	57246.
2007	3389.	184.	26523.	2915.	23126.	27355.	1380.	3545.	4249.	29.	121.	265.	93080.
2008	118.	165.	112.	433.	1410.	1204.	592.	4251.	85812.	10784.	1077.	0.	105958.
2009	0.	184.	112.	433.	392.	1226.	2064.	1103.	1052.	1747.	266.	7686.	16266.
2010	4619.	9025.	2746.	28291.	2689.	1448.	117343.	1720.	616.	596.	266.	245.	169605.
2011	0.	184.	112.	123.	166.	256.	269.	180.	27.	162.	266.	6138.	7882.
2012	118.	184.	112.	433.	433.	1270.	355.	259.	1460.	29.	199.	265.	5117.
2013	799.	1041.	112.	300.	433.	1294.	4915.	1946.	27.	29.	266.	1041.	12202.
2014	118.	184.	112.	393.	1188.	4302.	1465.	259.	89533.	1316.	1410.	790.	101069.
2015	4904.	1071.	112.	1478.	162486.	20341.	1998.	1145.	27.	11322.	8871.	5548.	219301.
2016	946.	184.	112.	932.	19233.	1850.	355.	4912.	12636.	666.	819.	2788.	45432.
MEAN	1556.	1562.	2674.	2487.	12091.	8267.	9605.	2240.	12133.	4747.	7649.	2593.	67604.

Table A.2.3 1940-2016 Naturalized Flows at Control Points DMAS09

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT DMAS09

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	35.	783.	0.	1763.	6268.	12978.	238.	36206.	14416.	1.	7172.	287.	80147.
1941	10.	2049.	13944.	70834.	171221.	50398.	26317.	13150.	24768.	127313.	5714.	2138.	507856.
1942	570.	84.	18.	8202.	1739.	8356.	1904.	17952.	24147.	32709.	1665.	3848.	101194.
1943	1601.	84.	1410.	2281.	7434.	9814.	7593.	4.	3.	1.	4.	64.	30293.
1944	12.	627.	26.	411.	8640.	2509.	14930.	1555.	1370.	1458.	987.	2327.	34852.
1945	210.	52.	1315.	398.	529.	8924.	28243.	201.	5167.	25605.	128.	7.	70779.
1946	43.	0.	8.	25.	2620.	6781.	815.	10865.	11833.	33737.	723.	5794.	73244.
1947	548.	1.	16.	89.	110305.	6460.	2567.	235.	2577.	1241.	408.	5367.	129814.
1948	20.	10187.	661.	8.	3574.	24056.	35143.	5260.	259.	4794.	9636.	13.	93611.
1949	95.	173.	16.	3230.	25283.	30300.	633.	964.	25104.	2903.	307.	5.	89013.
1950	0.	291.	0.	8401.	45894.	4076.	12917.	3065.	45450.	807.	19.	8.	120928.
1951	0.	0.	0.	40.	6926.	22400.	2101.	12698.	457.	0.	0.	0.	44622.
1952	0.	0.	0.	520.	11897.	570.	5871.	884.	480.	0.	183.	18.	20423.
1953	0.	0.	414.	1223.	11846.	1499.	6585.	10578.	123.	52950.	2309.	151.	87678.
1954	20.	0.	0.	53029.	59242.	4623.	0.	65.	0.	113.	1266.	0.	118358.
1955	0.	3676.	15889.	344.	106266.	30848.	56724.	2066.	161354.	74054.	2131.	1041.	454393.
1956	617.	478.	31.	19.	11668.	1906.	1445.	1406.	0.	813.	69.	26.	18478.
1957	0.	13037.	219.	40652.	101800.	78471.	9304.	4022.	6456.	16571.	12708.	319.	283559.
1958	394.	301.	1105.	6477.	36119.	7392.	1487.	2513.	9910.	1107.	1357.	227.	68389.
1959	173.	148.	164.	782.	5622.	68647.	72057.	10004.	139.	16412.	750.	9068.	183966.
1960	1015.	672.	280.	138.	3221.	3886.	74148.	1207.	171.	137263.	4303.	2447.	228751.
1961	2697.	2814.	1945.	501.	196.	60537.	70986.	4193.	1465.	739.	4895.	647.	151615.
1962	279.	137.	167.	304.	346.	29871.	3783.	3129.	82381.	2384.	1311.	1269.	125361.
1963	341.	222.	156.	6845.	19685.	75134.	1445.	286.	11046.	2211.	2617.	529.	120517.
1964	279.	759.	130.	120.	874.	4197.	338.	1220.	1933.	115.	303.	123.	10391.
1965	104.	80.	131.	619.	70249.	12608.	146.	21214.	4459.	25389.	268.	498.	135765.
1966	572.	353.	285.	12126.	9802.	7300.	128.	25696.	19103.	386.	114.	113.	75978.
1967	130.	132.	815.	4566.	4992.	93258.	26702.	1767.	10436.	841.	370.	241.	144250.
1968	1774.	2020.	10397.	2761.	4799.	22380.	13497.	5853.	436.	250.	2660.	1031.	67858.
1969	233.	235.	1769.	965.	44896.	5694.	443.	983.	62433.	18201.	7599.	1919.	145370.
1970	1691.	792.	12152.	2283.	5331.	7939.	563.	397.	710.	519.	325.	297.	32999.
1971	257.	240.	477.	601.	31524.	9652.	1128.	67768.	44554.	17357.	2714.	2176.	178448.
1972	1018.	713.	514.	645.	3428.	6813.	3384.	175553.	18036.	12020.	6283.	2099.	230506.
1973	7014.	5985.	12179.	2810.	1437.	2623.	1417.	1308.	9098.	671.	576.	438.	45556.
1974	466.	435.	460.	2404.	2563.	2984.	501.	5047.	26281.	16911.	5565.	1214.	64831.
1975	895.	1520.	857.	772.	5394.	1835.	37764.	13221.	12452.	1382.	4893.	695.	81680.
1976	648.	364.	324.	7964.	3409.	407.	11369.	911.	10801.	10912.	2762.	1162.	51033.
1977	1072.	707.	633.	6420.	8640.	4143.	758.	6534.	987.	142.	153.	170.	30359.
1978	268.	456.	357.	73.	13528.	10373.	1306.	328.	12135.	2263.	1768.	1151.	44006.
1979	930.	669.	5377.	1629.	4754.	29230.	23283.	3934.	530.	66.	227.	813.	71442.
1980	951.	1176.	222.	2034.	51242.	5240.	206.	443.	60015.	5971.	1893.	5042.	134435.
1981	1859.	1663.	4892.	9582.	7570.	13707.	2727.	7870.	1305.	24052.	2737.	1806.	79770.
1982	1374.	1444.	1365.	289.	69363.	47389.	7269.	2789.	176.	160.	108.	459.	132185.
1983	3016.	2532.	1053.	441.	29477.	2271.	3753.	204.	84.	45687.	8391.	1558.	98467.
1984	1636.	1017.	615.	222.	234.	303.	144.	2261.	5432.	12802.	15575.	10114.	50355.
1985	4829.	3337.	3791.	15284.	25013.	18196.	14691.	1018.	4288.	45458.	2935.	1779.	140619.
1986	1162.	994.	761.	4956.	4959.	29326.	9240.	18605.	42803.	42017.	9446.	6037.	170306.
1987	3780.	6873.	6961.	2138.	46478.	15995.	17386.	1432.	6427.	295.	95.	498.	108358.
1988	799.	906.	703.	919.	1097.	3602.	16013.	82.	8459.	389.	30.	124.	33123.
1989	169.	1787.	615.	914.	361.	28905.	535.	1193.	4665.	392.	93.	22.	39651.
1990	1660.	574.	6804.	17927.	3132.	61496.	3216.	16990.	1858.	1503.	2127.	1051.	118338.
1991	1966.	852.	452.	254.	2330.	67851.	2727.	8312.	17350.	10072.	5550.	21782.	139498.
1992	7937.	24587.	7732.	9047.	52791.	50443.	5085.	6581.	6060.	133.	1087.	1829.	173312.
1993	1784.	2688.	2180.	687.	3623.	6889.	293.	1851.	1196.	656.	8.	673.	22528.
1994	151.	278.	142.	272.	14961.	1020.	57.	31.	1007.	1205.	335.	68.	19527.
1995	32.	0.	101.	906.	15796.	10906.	201.	8540.	20401.	1418.	624.	176.	59101.
1996	212.	232.	100.	84.	243.	4644.	720.	15160.	8433.	1250.	2876.	1714.	35668.
1997	746.	9159.	1970.	23285.	10780.	25274.	7490.	1180.	730.	0.	42.	1076.	81732.
MEAN	1036.	1920.	2157.	5905.	22645.	20092.	11236.	9807.	14727.	14415.	2607.	1820.	108367.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT DMAS09

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	0.	934.	1431.	89.	733.	996.	0.	851.	0.	1893.	3506.	1049.	11483.
1999	0.	0.	1657.	1467.	12020.	62539.	2259.	472.	2700.	956.	187.	0.	84258.
2000	0.	0.	1319.	89.	1567.	20144.	1845.	307.	0.	3108.	18747.	1513.	48638.
2001	12890.	11910.	16722.	89.	2565.	1965.	0.	472.	2170.	0.	5578.	22405.	76765.
2002	1524.	3294.	10232.	1650.	1567.	1965.	1474.	472.	0.	29939.	16165.	10816.	79097.
2003	443.	0.	0.	89.	1567.	14426.	0.	416.	0.	0.	334.	0.	17274.
2004	1264.	3670.	2823.	15372.	1370.	5951.	4970.	31330.	76589.	43877.	107546.	31055.	325816.
2005	1674.	5396.	0.	89.	4258.	2272.	1024.	29513.	2231.	1704.	334.	0.	48495.
2006	0.	0.	889.	1021.	1404.	1965.	0.	2864.	35579.	20899.	829.	1866.	67317.
2007	6150.	0.	32459.	13339.	43249.	42553.	4398.	3740.	16409.	0.	129.	397.	162823.
2008	0.	0.	0.	89.	2077.	3544.	2218.	12253.	105902.	59189.	1075.	0.	186347.
2009	0.	0.	0.	89.	1567.	4721.	2942.	1352.	1809.	4484.	334.	7341.	24640.
2010	21780.	15016.	2419.	8975.	13957.	3460.	69371.	31949.	3316.	1019.	324.	0.	171586.
2011	0.	0.	0.	86.	261.	936.	0.	155.	0.	0.	334.	4686.	6457.
2012	991.	0.	0.	89.	2196.	4013.	0.	1037.	3109.	0.	93.	0.	11528.
2013	1003.	868.	0.	137.	1170.	3114.	4347.	2507.	0.	0.	334.	1320.	14801.
2014	0.	0.	0.	197.	3789.	5644.	2417.	472.	74178.	16619.	2332.	1124.	106771.
2015	9289.	1850.	456.	2319.	109541.	88346.	3637.	1116.	0.	29652.	12412.	9668.	268288.
2016	1533.	0.	0.	1171.	2840.	6328.	0.	4146.	28746.	961.	2544.	1428.	49697.
MEAN	3081.	2260.	3706.	2444.	10931.	14468.	5311.	6601.	18565.	11279.	9112.	4983.	92741.

Table A.2.4 1940-2016 Naturalized Flows at Control Points BRSE11

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRSE11

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0.	871.	1.	5303.	8506.	27760.	7092.	86156.	25468.	4.	19173.	3002.	183336.
1941	323.	2459.	30114.	131878.	414811.	195658.	52999.	26939.	59657.	340923.	24494.	12651.	1292906.
1942	5076.	2313.	1352.	40474.	3240.	17449.	6990.	28711.	56903.	79222.	9033.	9064.	259827.
1943	4868.	997.	3690.	13733.	16624.	41364.	11521.	0.	0.	54.	60.	978.	93889.
1944	1409.	3879.	2870.	366.	13446.	12377.	21577.	560.	6061.	4569.	3052.	6191.	76357.
1945	2469.	1394.	9718.	2760.	455.	19603.	61219.	954.	10749.	36235.	1060.	560.	147176.
1946	685.	776.	191.	624.	7023.	37285.	10721.	50644.	62426.	59016.	4508.	21191.	255090.
1947	2888.	904.	1025.	1412.	314512.	13732.	2740.	306.	1428.	2131.	3611.	14705.	359394.
1948	845.	10013.	6568.	276.	3247.	69094.	56846.	4943.	800.	7966.	11823.	199.	172620.
1949	2229.	3752.	1178.	2842.	81345.	100652.	4658.	4828.	51955.	10933.	2616.	1259.	268247.
1950	1386.	1371.	324.	9625.	109057.	22560.	44413.	16640.	110677.	7584.	1721.	1969.	327327.
1951	1522.	2851.	1732.	780.	33876.	33946.	7154.	22554.	5638.	0.	130.	134.	110317.
1952	252.	625.	446.	1416.	17569.	2658.	10488.	110.	29.	0.	615.	821.	35029.
1953	0.	1418.	3720.	693.	6693.	395.	40117.	41032.	859.	122758.	10912.	2445.	231042.
1954	1465.	692.	259.	63367.	188184.	17493.	473.	0.	2.	0.	1355.	1235.	274525.
1955	681.	3868.	24679.	1000.	150226.	61774.	45910.	7474.	229964.	246199.	8552.	5368.	785695.
1956	3971.	3185.	1329.	542.	20889.	4542.	20.	1232.	0.	2900.	178.	617.	39405.
1957	104.	11392.	1637.	66762.	239563.	166184.	11594.	4215.	5726.	44714.	40954.	2790.	595635.
1958	2333.	1646.	3465.	9650.	73778.	8962.	13669.	3920.	9366.	2735.	2211.	500.	132235.
1959	374.	322.	135.	3202.	5713.	113139.	89801.	13357.	219.	50708.	2533.	14423.	293926.
1960	5156.	3149.	1554.	628.	2089.	12098.	109896.	2177.	478.	260415.	13899.	9802.	421341.
1961	6683.	7585.	7128.	3054.	15597.	124137.	129277.	6421.	4143.	3050.	10786.	3279.	321140.
1962	1835.	957.	831.	3519.	2844.	50440.	6812.	8032.	132703.	10334.	19288.	9469.	247064.
1963	3417.	2247.	2726.	9094.	28647.	116893.	4105.	640.	11812.	2798.	6961.	2513.	191853.
1964	1210.	3166.	1024.	427.	946.	12143.	221.	226.	35221.	2247.	2236.	608.	59675.
1965	712.	528.	259.	7023.	66447.	20152.	1166.	35475.	10637.	58877.	3173.	1711.	206160.
1966	1993.	1355.	3493.	20667.	24484.	7926.	650.	100471.	142019.	6654.	2692.	2253.	314657.
1967	1865.	1167.	2924.	50970.	6864.	102268.	62062.	4030.	16311.	2648.	1181.	1411.	253701.
1968	15484.	6181.	27862.	16193.	12859.	61597.	17465.	9979.	1711.	993.	3153.	4255.	177732.
1969	666.	913.	3291.	2140.	86206.	10868.	532.	1954.	79052.	31909.	20681.	5162.	243374.
1970	4971.	2542.	24793.	5464.	6592.	7676.	372.	268.	1578.	2610.	510.	465.	57841.
1971	534.	418.	475.	506.	37265.	18500.	1191.	109518.	61703.	51224.	10614.	7219.	299167.
1972	2740.	2492.	2329.	2124.	11332.	10023.	10431.	208723.	72235.	31320.	40786.	8976.	403511.
1973	14885.	14291.	39994.	15122.	4381.	33497.	2525.	2998.	17205.	2606.	1882.	1324.	150710.
1974	994.	939.	1876.	1799.	6769.	24292.	418.	3335.	45777.	30506.	13745.	4160.	134610.
1975	4173.	6565.	3206.	3105.	42971.	12124.	48137.	20905.	32884.	4769.	9057.	2924.	190820.
1976	2589.	1676.	1684.	13099.	8016.	1305.	11841.	7307.	19091.	29146.	11908.	3837.	111499.
1977	3881.	3010.	2405.	22868.	48808.	13726.	2963.	7158.	4498.	234.	321.	455.	110327.
1978	795.	941.	1251.	192.	11735.	12122.	861.	67573.	29478.	7157.	3642.	2796.	138543.
1979	2748.	2393.	8918.	4278.	14067.	34030.	30179.	19268.	1924.	93.	3326.	1677.	122901.
1980	1400.	1852.	900.	1256.	110262.	17720.	1871.	3040.	77092.	26018.	5255.	7613.	254279.
1981	4043.	5225.	9933.	13360.	11889.	29244.	2442.	6860.	2142.	61248.	5839.	3748.	155973.
1982	2969.	3478.	4550.	1457.	153145.	179680.	22051.	5708.	6089.	1760.	834.	1538.	383259.
1983	3066.	6188.	3003.	2650.	50807.	11163.	3126.	109.	454.	156379.	22943.	7778.	267666.
1984	6056.	3377.	3473.	1618.	1263.	699.	193.	3866.	2940.	15162.	16247.	14698.	69592.
1985	12062.	11063.	15540.	31408.	50453.	62944.	16052.	3651.	3237.	85770.	9676.	4406.	306262.
1986	2474.	2884.	1845.	7879.	9281.	48365.	31144.	29246.	90264.	149202.	28175.	15867.	416626.
1987	11799.	21425.	23083.	8038.	148204.	81067.	34999.	8803.	11080.	2555.	1391.	2731.	355175.
1988	3940.	3223.	2998.	2339.	1359.	1435.	19817.	1206.	34934.	2708.	1945.	1494.	77398.
1989	1393.	6659.	2580.	1565.	45677.	49352.	2000.	2689.	42618.	1831.	1223.	1392.	158979.
1990	5380.	2432.	18975.	78672.	33823.	209170.	10781.	20091.	7462.	4276.	5383.	3932.	400377.
1991	7962.	4451.	2568.	1855.	34669.	192272.	5761.	27942.	48029.	15772.	13614.	37795.	392690.
1992	26922.	72064.	31115.	21460.	71282.	179925.	25266.	12173.	9049.	1594.	6578.	7038.	464466.
1993	5919.	18342.	18191.	6103.	9944.	19148.	1669.	1292.	4381.	1679.	1020.	2563.	90251.
1994	1567.	2543.	2609.	1270.	48710.	5480.	694.	1670.	11315.	5954.	6273.	2471.	90556.
1995	2251.	1222.	2619.	1449.	41737.	48130.	5414.	62634.	15584.	5042.	6145.	2054.	194281.
1996	2437.	1319.	1980.	1339.	493.	6547.	2273.	17513.	89964.	4764.	4538.	4411.	137578.
1997	1399.	17062.	6620.	36918.	48167.	42167.	21775.	11603.	4973.	2525.	1161.	5197.	199567.
MEAN	3677.	5208.	6639.	13097.	52049.	48913.	19801.	19847.	31379.	36250.	8046.	5192.	250096.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRSE11

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	820.	5354.	6395.	1874.	1167.	1167.	1321.	2372.	20.	17441.	13528.	1877.	53336.
1999	5791.	1052.	5046.	5771.	71777.	80093.	1321.	142.	10180.	0.	1472.	1381.	184026.
2000	820.	1052.	7892.	8427.	1167.	79605.	3845.	142.	0.	7969.	36665.	6065.	153649.
2001	11152.	8528.	36683.	1874.	10894.	1167.	1321.	142.	6150.	0.	19565.	10497.	107973.
2002	1838.	5039.	9310.	8043.	1167.	1167.	9690.	142.	20.	72655.	10158.	16297.	135526.
2003	6151.	1052.	910.	1874.	1167.	79648.	1321.	142.	20.	0.	1472.	1877.	95635.
2004	7448.	18992.	18415.	35954.	1167.	67104.	64468.	40194.	64565.	74502.	213545.	19858.	626212.
2005	7688.	10484.	2179.	1874.	12084.	4047.	5641.	72075.	4682.	7774.	1472.	0.	130000.
2006	0.	1334.	2173.	1874.	6377.	1167.	1321.	16028.	81979.	64588.	3302.	11902.	192044.
2007	11768.	1052.	73956.	22584.	74031.	147378.	14212.	9539.	19939.	0.	449.	1877.	376787.
2008	820.	864.	910.	1874.	10951.	8721.	5350.	38658.	171467.	47497.	6562.	0.	293674.
2009	0.	1052.	910.	1874.	5866.	14026.	39909.	4821.	12833.	12127.	1472.	12212.	107104.
2010	17530.	32213.	11654.	71982.	22030.	6081.	215238.	18211.	8060.	5460.	1472.	919.	410849.
2011	0.	1052.	910.	0.	1403.	1980.	418.	0.	0.	2200.	1472.	9806.	19242.
2012	820.	1052.	910.	1874.	2902.	12894.	1321.	142.	15886.	2276.	472.	1692.	42242.
2013	7057.	8038.	910.	1546.	1167.	7237.	33854.	7022.	20.	0.	1472.	5859.	74183.
2014	820.	1052.	910.	1874.	17793.	47289.	9486.	142.	177317.	8920.	7302.	4932.	277837.
2015	11369.	5515.	910.	13232.	303414.	155222.	20468.	1039.	20.	48503.	37809.	12930.	610430.
2016	6706.	1052.	910.	3639.	40372.	13209.	1321.	32531.	47725.	6615.	6439.	5388.	165907.
MEAN	5189.	5570.	9573.	9897.	30889.	38379.	22728.	12815.	32678.	19922.	19269.	6598.	213508.

Table A.2.5 1940-2016 Naturalized Flows at Control Points CFNU16

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT CFNU16

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	29043.	1972.	1043.	1923.	5469.	19873.	5074.	36202.	5853.	3726.	1188.	748.	112114.
1941	667.	1783.	5045.	30826.	66235.	51406.	14510.	26921.	4826.	66794.	7026.	5802.	281841.
1942	3309.	2872.	1495.	9319.	13702.	9754.	1914.	3318.	11757.	34529.	3343.	3368.	98680.
1943	2148.	2753.	4535.	3013.	8173.	9698.	947.	378.	18.	1456.	449.	398.	33966.
1944	1003.	3862.	1805.	420.	20192.	6161.	15479.	6012.	4419.	12513.	1601.	1369.	74836.
1945	1062.	577.	5701.	10088.	7835.	16017.	54939.	7606.	738.	13994.	1717.	2326.	122600.
1946	2118.	1920.	1753.	2318.	13019.	2117.	1531.	2934.	11499.	10122.	2414.	9548.	61293.
1947	591.	650.	852.	465.	32283.	9767.	2862.	1365.	1640.	24972.	1701.	6063.	83211.
1948	1051.	2420.	3713.	834.	2576.	7642.	11143.	3224.	762.	14420.	325.	304.	48414.
1949	899.	618.	292.	6097.	22497.	7959.	3090.	1022.	8691.	7071.	518.	18.	58772.
1950	683.	503.	599.	3601.	23342.	2843.	12387.	11380.	13654.	1188.	578.	680.	71438.
1951	667.	336.	950.	824.	27617.	24826.	6064.	2699.	165.	1211.	312.	120.	65791.
1952	536.	467.	210.	2481.	5385.	2007.	1295.	2083.	4453.	0.	2371.	633.	21921.
1953	207.	0.	404.	1094.	12160.	135.	20349.	11296.	818.	6996.	454.	76.	53989.
1954	2.	525.	565.	7996.	33109.	1188.	426.	188.	291.	476.	2670.	0.	47436.
1955	0.	1190.	263.	558.	40935.	30107.	4408.	2572.	38823.	5510.	0.	0.	124366.
1956	0.	715.	219.	3010.	17900.	1467.	0.	1160.	1.	1290.	1088.	618.	27468.
1957	0.	32495.	2333.	107620.	297109.	83130.	3999.	2241.	4877.	16747.	2141.	947.	553639.
1958	1679.	1769.	1980.	3322.	5162.	3748.	3785.	1957.	5950.	1129.	213.	397.	31091.
1959	316.	707.	961.	755.	17361.	23494.	17441.	763.	0.	19787.	421.	1317.	83323.
1960	3353.	1530.	1940.	3535.	157.	2448.	7114.	531.	0.	11976.	0.	377.	32961.
1961	5230.	3168.	638.	918.	3468.	47448.	31668.	1767.	34684.	1343.	7202.	1531.	139065.
1962	1589.	1353.	2344.	2390.	381.	43817.	15828.	881.	25381.	5520.	967.	1705.	102156.
1963	786.	762.	1491.	1752.	28011.	7896.	0.	1022.	0.	27.	0.	0.	41747.
1964	1392.	2683.	2340.	3744.	732.	1104.	2586.	7720.	2198.	2091.	9.	297.	26896.
1965	529.	592.	627.	9975.	67504.	13984.	2392.	285.	11771.	16288.	3759.	892.	128598.
1966	1293.	786.	2673.	27603.	29144.	3675.	811.	3855.	15333.	2303.	811.	845.	89132.
1967	1137.	631.	1593.	295.	4991.	12862.	5109.	453.	7527.	2548.	1569.	1341.	40056.
1968	18047.	7210.	11170.	24045.	10679.	3085.	6319.	977.	0.	0.	1582.	661.	83775.
1969	205.	1262.	1828.	2545.	50381.	10768.	599.	2325.	42040.	3930.	3592.	4030.	123505.
1970	3762.	2935.	6086.	8472.	7960.	11501.	733.	0.	653.	0.	0.	624.	42726.
1971	807.	946.	1911.	2793.	14631.	9636.	3448.	55884.	42098.	12373.	3589.	5126.	153242.
1972	2662.	3279.	3021.	2576.	2372.	1658.	2852.	12057.	4740.	5289.	9322.	2568.	52396.
1973	4540.	4310.	11225.	6708.	4888.	1461.	559.	957.	6625.	2770.	1113.	330.	45486.
1974	876.	1199.	1928.	2115.	1075.	374.	458.	11164.	84228.	54824.	27544.	7050.	192835.
1975	7827.	10899.	7918.	4461.	7596.	5065.	27104.	4834.	2313.	1196.	4641.	2360.	86214.
1976	1907.	2127.	2491.	5385.	2428.	1506.	5424.	4500.	7280.	18383.	7231.	3383.	62045.
1977	1815.	2648.	9497.	15803.	8360.	1231.	1385.	1462.	214.	487.	0.	342.	43244.
1978	243.	1029.	1460.	798.	0.	2999.	450.	31733.	6385.	975.	753.	359.	47184.
1979	1263.	1209.	16105.	10673.	10266.	6945.	2111.	1200.	0.	160.	0.	1170.	51102.
1980	834.	1085.	977.	712.	13901.	3408.	1474.	580.	41310.	35205.	4153.	9614.	113253.
1981	4597.	2734.	8206.	32202.	8652.	21785.	13789.	3216.	1730.	55968.	12533.	2856.	168268.
1982	1406.	2246.	2733.	1873.	64466.	23267.	13049.	3558.	1078.	522.	698.	437.	115333.
1983	2451.	3594.	2306.	1862.	5648.	5457.	6619.	187.	292.	7065.	2757.	920.	39158.
1984	1596.	1276.	946.	0.	1370.	51.	454.	1325.	802.	11699.	4301.	2305.	26125.
1985	10247.	9442.	3118.	5348.	12707.	8561.	11305.	2625.	0.	11828.	997.	510.	76688.
1986	1932.	1782.	1426.	323.	1033.	35369.	14323.	4247.	30875.	97086.	16850.	16059.	221305.
1987	9987.	27859.	24859.	9458.	37923.	15187.	5782.	2365.	3646.	1099.	799.	10154.	149118.
1988	3175.	2236.	2537.	2844.	2250.	8117.	6576.	0.	13062.	0.	0.	0.	40797.
1989	0.	4737.	1692.	25.	0.	39934.	4237.	0.	6644.	0.	0.	0.	57269.
1990	2909.	945.	15840.	28278.	59105.	6837.	0.	7062.	14282.	5767.	2836.	1166.	145027.
1991	5500.	3924.	2498.	1219.	2388.	69557.	12137.	12489.	16620.	12646.	4283.	46566.	189827.
1992	16605.	81777.	19456.	13205.	14608.	27581.	14913.	10203.	5435.	1997.	3676.	3149.	212605.
1993	3604.	4476.	5154.	3923.	3181.	12411.	734.	310.	1479.	2835.	966.	793.	39866.
1994	1271.	0.	1797.	2319.	61376.	9200.	0.	28.	2892.	1702.	5128.	660.	86373.
1995	929.	1475.	2020.	2889.	6288.	9339.	4725.	40399.	8471.	15.	2070.	336.	78956.
1996	0.	2182.	1652.	5815.	473.	3332.	0.	5308.	19530.	11035.	3109.	3580.	56016.
1997	1115.	11698.	8564.	7504.	11069.	43541.	5421.	1647.	0.	0.	0.	1619.	92178.
MEAN	2990.	4692.	3945.	7809.	21268.	14582.	7140.	6284.	10015.	11084.	2920.	2939.	95668.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT CFNU16

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	1203.	1824.	5626.	741.	0.	1784.	388.	0.	0.	1864.	2414.	2038.	17883.
1999	2452.	264.	2223.	3999.	4858.	11262.	661.	0.	0.	1689.	0.	0.	27408.
2000	0.	677.	4630.	830.	0.	9946.	841.	0.	0.	9453.	23667.	2699.	52742.
2001	3562.	5399.	7375.	1196.	2668.	905.	171.	697.	8204.	4788.	11343.	9470.	55778.
2002	680.	2186.	6600.	2970.	2836.	2170.	5156.	0.	1318.	23637.	10034.	3817.	61404.
2003	1065.	1731.	1110.	388.	1755.	24944.	841.	1514.	1978.	2465.	2282.	0.	40074.
2004	1883.	10920.	3617.	4754.	2115.	5267.	7902.	19216.	5643.	24546.	69090.	15676.	170629.
2005	1966.	4250.	2587.	418.	5336.	6496.	5669.	65963.	10719.	2025.	0.	0.	105429.
2006	0.	634.	2254.	2696.	5731.	2246.	306.	0.	8047.	10099.	1756.	2196.	35964.
2007	5911.	287.	16055.	24919.	31947.	31285.	14558.	33333.	25615.	0.	642.	2272.	186824.
2008	0.	360.	2519.	2794.	5913.	3198.	562.	6257.	10588.	2254.	0.	0.	34444.
2009	0.	308.	553.	1277.	2126.	3316.	26900.	1710.	2541.	11571.	981.	4796.	56080.
2010	12784.	14426.	4808.	7452.	5862.	3052.	13476.	1296.	14075.	4034.	0.	0.	81266.
2011	1714.	666.	294.	566.	0.	675.	33.	0.	0.	2444.	1032.	2613.	10037.
2012	9809.	5738.	1289.	1984.	7160.	2754.	490.	0.	16370.	12888.	0.	0.	58481.
2013	1935.	294.	266.	262.	2198.	2626.	8592.	3783.	4414.	6874.	1857.	2173.	35274.
2014	0.	450.	352.	838.	4944.	19686.	2221.	0.	10469.	3994.	3753.	5138.	51844.
2015	5371.	5778.	2531.	11251.	80736.	59071.	7462.	0.	0.	9638.	50054.	15657.	247549.
2016	808.	400.	605.	10324.	50112.	26526.	626.	2168.	13655.	3738.	7094.	7774.	123831.
MEAN	2692.	2979.	3436.	4193.	11384.	11432.	5098.	7155.	7033.	7263.	9790.	4017.	76471.

Table A.2.6 1940-2016 Naturalized Flows at Control Points CFFG18

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT CFFG18

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	16265.	4082.	480.	1610.	30141.	47554.	9979.	68394.	11151.	1999.	9234.	925.	201814.
1941	344.	4289.	6127.	64943.	261137.	123305.	23264.	20500.	9804.	178204.	23572.	15900.	731389.
1942	4631.	4077.	2034.	18449.	17147.	23673.	1557.	2407.	15134.	46213.	4061.	4089.	143472.
1943	2243.	2640.	5294.	4561.	9133.	20671.	602.	0.	0.	617.	47.	0.	45808.
1944	343.	2660.	4422.	213.	23911.	9523.	13128.	2579.	3928.	19968.	1725.	1527.	83927.
1945	1067.	908.	19539.	39346.	6683.	24258.	59840.	5555.	158.	15915.	1445.	1764.	176478.
1946	1621.	1592.	1480.	1351.	9657.	3100.	492.	8535.	32748.	26571.	4303.	19419.	110869.
1947	1004.	554.	940.	465.	110727.	14849.	2542.	767.	4654.	18836.	3818.	7668.	166824.
1948	923.	1385.	4304.	540.	9203.	24906.	19349.	2528.	655.	12159.	385.	105.	76442.
1949	857.	1163.	334.	5918.	41508.	19623.	1504.	936.	9491.	8011.	461.	0.	89806.
1950	270.	203.	300.	12767.	34175.	3965.	16409.	10886.	21447.	649.	150.	214.	101435.
1951	202.	84.	253.	334.	27436.	45806.	7272.	1846.	178.	589.	147.	0.	84147.
1952	217.	203.	69.	1059.	4539.	4219.	774.	1207.	1479.	5.	792.	255.	14818.
1953	117.	1.	165.	632.	10511.	8533.	106153.	13305.	684.	20839.	446.	0.	161386.
1954	0.	204.	322.	4934.	82927.	3881.	0.	0.	0.	336.	2317.	0.	94921.
1955	3194.	1309.	333.	572.	38581.	33879.	3788.	962.	106936.	24550.	0.	14.	214118.
1956	0.	0.	0.	917.	13976.	0.	0.	0.	0.	0.	54.	0.	14947.
1957	0.	72687.	3457.	207129.	471164.	134742.	8210.	3123.	3235.	13021.	5338.	170.	922276.
1958	332.	381.	1087.	1634.	12817.	7520.	13151.	1103.	42752.	1580.	0.	0.	82357.
1959	0.	0.	0.	0.	21985.	39951.	14150.	0.	0.	32757.	0.	754.	109597.
1960	2714.	2687.	917.	1391.	0.	758.	62779.	0.	0.	14967.	0.	0.	86213.
1961	3797.	4165.	1160.	0.	1227.	91114.	92208.	2950.	37712.	2751.	9109.	1895.	248088.
1962	1292.	1759.	2414.	4466.	365.	125456.	15964.	1324.	122188.	6571.	2190.	1763.	285752.
1963	8.	446.	739.	4136.	35021.	33818.	0.	0.	0.	0.	0.	0.	74168.
1964	334.	4082.	1462.	1634.	427.	7714.	352.	2837.	1490.	384.	0.	0.	20716.
1965	0.	186.	0.	9071.	97397.	9344.	722.	0.	8122.	20476.	2617.	231.	148166.
1966	286.	418.	1308.	54078.	47791.	1760.	0.	3370.	33093.	5165.	51.	9.	147329.
1967	478.	113.	674.	0.	1482.	9240.	4846.	0.	8348.	1164.	824.	673.	27842.
1968	41128.	7721.	24868.	27034.	16851.	4579.	3707.	0.	0.	0.	83.	468.	126439.
1969	0.	1088.	2514.	4256.	131921.	8961.	0.	692.	45748.	3936.	3774.	4779.	207669.
1970	4383.	3318.	7646.	11652.	8885.	8915.	0.	0.	0.	0.	0.	0.	44799.
1971	0.	174.	484.	877.	14876.	14115.	1586.	149057.	64695.	17914.	6556.	7121.	277455.
1972	3853.	4383.	3102.	2230.	4802.	0.	2109.	8996.	14689.	11423.	35464.	2665.	93716.
1973	10455.	15203.	26786.	14323.	3936.	8380.	0.	859.	7705.	2477.	280.	0.	90404.
1974	418.	289.	1359.	1155.	0.	0.	0.	5848.	93992.	63233.	57677.	9575.	233546.
1975	11204.	20212.	6860.	5593.	28722.	4708.	30455.	7669.	2011.	223.	4455.	1875.	123987.
1976	1208.	1168.	1655.	4119.	2281.	0.	4012.	4425.	10157.	36178.	11217.	3200.	79620.
1977	2524.	2463.	9618.	19485.	14242.	874.	678.	0.	2319.	0.	119.	635.	52957.
1978	567.	1204.	1076.	0.	762.	4467.	0.	415460.	10451.	2332.	1492.	1476.	439287.
1979	3515.	1740.	15782.	8794.	23516.	27565.	2421.	1615.	0.	0.	0.	868.	85816.
1980	788.	1372.	799.	90.	16876.	4449.	172.	0.	133990.	103366.	6405.	21546.	289853.
1981	5909.	3481.	10440.	43859.	12246.	40257.	9905.	4414.	1459.	58371.	7851.	2958.	201150.
1982	1971.	2381.	2692.	560.	140590.	121430.	24623.	6855.	0.	1364.	671.	1600.	304737.
1983	3882.	6793.	3286.	1758.	14792.	8658.	5293.	0.	0.	5653.	3480.	569.	54164.
1984	1374.	1047.	368.	0.	0.	0.	0.	0.	0.	9486.	14955.	4881.	32111.
1985	22978.	33555.	12386.	24478.	23937.	30239.	9171.	1561.	0.	16125.	1307.	420.	176157.
1986	1720.	1249.	1336.	5081.	1604.	42111.	25810.	2350.	25091.	170182.	23799.	23942.	324275.
1987	18658.	45672.	49283.	11411.	69985.	39154.	10164.	1283.	3898.	955.	350.	12635.	263448.
1988	5627.	2412.	3208.	1873.	2456.	6549.	7525.	0.	29424.	983.	384.	1376.	61817.
1989	457.	7368.	3512.	1546.	2173.	41379.	2270.	0.	6137.	0.	0.	86.	64928.
1990	2261.	826.	21738.	67983.	131765.	26683.	0.	9946.	69065.	6127.	3664.	1583.	341641.
1991	10301.	6509.	5259.	995.	32050.	132608.	17800.	35946.	20251.	22355.	6585.	108881.	399540.
1992	43439.	261407.	58307.	21701.	18884.	114296.	34070.	18588.	8451.	3080.	4942.	5459.	592624.
1993	4565.	5247.	8925.	11130.	9723.	19118.	0.	230.	2886.	16729.	2489.	1718.	82760.
1994	2957.	8810.	2740.	1730.	74987.	8201.	0.	0.	1579.	26382.	4528.	870.	132784.
1995	1539.	959.	2292.	1658.	3886.	14404.	3540.	53452.	18712.	1315.	2338.	1085.	105180.
1996	1175.	1908.	1058.	5612.	78.	6643.	0.	3287.	18667.	7034.	4589.	4930.	54981.
1997	1819.	18925.	11953.	11257.	23213.	63936.	8794.	2855.	0.	0.	104.	2667.	145523.
MEAN	4366.	10020.	6223.	13007.	38812.	28894.	11778.	15353.	18392.	18302.	4873.	4952.	174974.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT CFFG18

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	3646.	3940.	12546.	0.	0.	0.	0.	0.	0.	0.	8739.	8045.	36916.
1999	7388.	0.	13376.	6518.	2943.	23167.	0.	0.	0.	0.	0.	0.	53392.
2000	0.	0.	3511.	0.	0.	37966.	0.	0.	0.	17010.	87464.	11049.	157000.
2001	17023.	43233.	29958.	0.	5708.	0.	0.	0.	9005.	4016.	40382.	20859.	170184.
2002	0.	3412.	23740.	7421.	9335.	0.	54242.	0.	0.	102089.	19892.	18164.	238294.
2003	0.	2533.	0.	0.	0.	43394.	0.	0.	0.	0.	4137.	0.	50065.
2004	2858.	14823.	6720.	18370.	0.	7082.	7072.	19329.	0.	41346.	264823.	19041.	401464.
2005	1681.	9887.	2009.	0.	13258.	6692.	3950.	88173.	2502.	2234.	0.	0.	130385.
2006	0.	0.	0.	0.	4431.	0.	0.	0.	7101.	11438.	0.	1603.	24573.
2007	6712.	0.	41508.	27165.	94754.	304176.	20662.	18015.	16950.	0.	0.	0.	529943.
2008	0.	0.	4244.	0.	6511.	0.	0.	5887.	47097.	6083.	0.	0.	69823.
2009	0.	0.	0.	0.	3498.	4132.	3131.	0.	5101.	20106.	0.	10826.	46794.
2010	36875.	27942.	6912.	10290.	7583.	0.	28665.	0.	14860.	4116.	0.	0.	137242.
2011	0.	0.	0.	0.	0.	0.	0.	0.	0.	2385.	0.	8651.	11036.
2012	15476.	12147.	0.	0.	4242.	0.	0.	0.	26217.	7097.	0.	0.	65179.
2013	0.	0.	0.	0.	0.	0.	9993.	0.	6618.	2076.	0.	11235.	29922.
2014	0.	0.	0.	0.	4772.	4122.	3638.	0.	4601.	0.	17311.	2616.	37060.
2015	14752.	11990.	4570.	16728.	324260.	48788.	12966.	0.	0.	40553.	102268.	31360.	608234.
2016	0.	0.	0.	27744.	117886.	18009.	0.	0.	18319.	6613.	6965.	8294.	203831.
MEAN	5601.	6837.	7847.	6012.	31536.	26186.	7596.	6916.	8335.	14061.	29052.	7986.	157965.

Table A.2.7 1940-2016 Naturalized Flows at Control Points BRSB23

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRSB23

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	10237.	8532.	0.	14856.	109142.	195281.	29415.	207978.	50301.	1632.	58147.	14864.	700385.
1941	2362.	38110.	39327.	221308.	1246324.	512940.	103139.	102802.	88632.	717023.	107636.	45614.	3225217.
1942	14445.	10495.	5673.	296982.	74380.	74183.	9971.	28293.	168798.	277367.	26137.	17708.	1004432.
1943	8501.	3551.	19738.	39539.	13817.	78762.	11221.	97.	0.	1048.	35.	112.	176421.
1944	1705.	16300.	13490.	3114.	50868.	39033.	30313.	12935.	10526.	52674.	5160.	8082.	244200.
1945	4748.	3702.	67190.	64832.	14094.	51379.	122832.	8374.	3709.	67024.	3960.	2357.	414201.
1946	4529.	1766.	1545.	2084.	23582.	35601.	19865.	56834.	154276.	91488.	38491.	67358.	497419.
1947	6801.	2106.	3740.	3622.	492576.	37396.	7065.	631.	3797.	33825.	10013.	28645.	630217.
1948	3928.	11253.	15843.	3975.	27594.	132529.	119635.	11021.	2218.	16778.	12413.	1907.	359094.
1949	8534.	11353.	6452.	11548.	216900.	145679.	9707.	13069.	79063.	42527.	7005.	2131.	553968.
1950	2335.	2903.	1021.	43054.	190123.	35081.	166758.	57089.	152688.	13586.	2217.	2541.	669396.
1951	2290.	2884.	1763.	1569.	89017.	132591.	20082.	17320.	12032.	524.	347.	0.	280419.
1952	107.	319.	120.	3482.	21297.	10411.	10069.	965.	963.	15.	4987.	1775.	54510.
1953	196.	0.	6083.	6000.	65446.	4965.	260437.	79091.	13127.	221055.	20626.	6276.	683302.
1954	3343.	1382.	756.	105127.	388238.	39551.	2769.	2651.	0.	1921.	15198.	769.	561705.
1955	5385.	7745.	21894.	7385.	216436.	155303.	51978.	20762.	439744.	300587.	13944.	9179.	1250342.
1956	7351.	5575.	2243.	1846.	37100.	8472.	99.	145.	66.	2081.	10921.	8244.	84143.
1957	352.	178536.	10518.	489321.	1395822.	350627.	28463.	12764.	16535.	112472.	85683.	6994.	2688087.
1958	5201.	3601.	13037.	19653.	151352.	21918.	112677.	5674.	68540.	8054.	2445.	1341.	413493.
1959	822.	526.	330.	2378.	42978.	167119.	98894.	15933.	5387.	181167.	6703.	19059.	541296.
1960	18220.	13943.	5152.	10954.	2609.	14355.	198282.	13391.	1321.	289876.	24147.	15238.	607488.
1961	31228.	24220.	13040.	7004.	30884.	291224.	276993.	18632.	76447.	10691.	30554.	8881.	819798.
1962	5045.	3174.	5390.	6866.	4678.	257641.	43871.	20163.	384721.	33863.	48005.	27236.	840653.
1963	6344.	5104.	6843.	48494.	97268.	209756.	9928.	1792.	13789.	10069.	30528.	6498.	446413.
1964	5460.	31681.	4339.	4314.	12581.	31080.	769.	12733.	34307.	5361.	28477.	1945.	173047.
1965	2361.	1398.	581.	24685.	309135.	31633.	2769.	26979.	25394.	71094.	7445.	3340.	506814.
1966	2934.	2958.	3253.	193453.	154717.	23706.	2417.	71395.	370118.	19039.	5229.	4081.	853300.
1967	4407.	2587.	5348.	52522.	11235.	112170.	144486.	9689.	46007.	6797.	2835.	2963.	401046.
1968	195945.	24547.	84067.	88916.	58583.	75328.	57811.	9891.	2513.	2023.	1852.	5850.	607326.
1969	2581.	7174.	35069.	36816.	417988.	32099.	3252.	2434.	165097.	39954.	34852.	30606.	807922.
1970	14358.	12704.	48904.	56198.	59688.	18287.	866.	185.	1028.	2321.	650.	789.	215978.
1971	1430.	1191.	2081.	1278.	47369.	56802.	4433.	326184.	153042.	98936.	23708.	21862.	738316.
1972	9222.	7756.	5073.	10995.	54511.	11391.	11802.	188519.	111975.	61676.	123138.	16285.	612343.
1973	34663.	35610.	63614.	58470.	12541.	34236.	16302.	7145.	20705.	13404.	3055.	2598.	302343.
1974	2483.	3834.	2501.	19577.	8107.	29276.	2179.	8500.	231483.	180176.	144676.	17676.	650468.
1975	19750.	54589.	16253.	15011.	99671.	44232.	62142.	27771.	35164.	7421.	12743.	6564.	401311.
1976	6304.	4619.	5922.	18088.	16676.	2609.	12704.	15092.	54261.	101767.	38626.	8963.	285631.
1977	8672.	7584.	40590.	48897.	52133.	33648.	6052.	2350.	6096.	428.	228.	1648.	208326.
1978	1397.	2688.	5466.	13147.	14767.	19110.	701.	717224.	30734.	13227.	8014.	5731.	832206.
1979	9062.	7355.	44883.	15687.	74452.	80477.	30012.	23704.	1841.	85.	2329.	3391.	293278.
1980	3096.	4734.	3028.	2702.	138765.	29992.	2652.	2122.	148172.	249254.	18407.	42505.	645429.
1981	15001.	10136.	33730.	63586.	27808.	127706.	13728.	13970.	11332.	533740.	20779.	9821.	881337.
1982	6239.	7447.	10857.	5262.	451010.	541510.	81221.	15853.	9271.	5520.	3659.	5944.	1143793.
1983	9505.	16584.	10095.	6969.	73832.	29624.	10575.	129.	97.	114671.	34762.	11472.	318315.
1984	11287.	6782.	5680.	2721.	2085.	169.	2087.	2772.	3090.	68778.	40255.	42503.	188209.
1985	52598.	61449.	54420.	99472.	127454.	114233.	27893.	11251.	2936.	119478.	13239.	6711.	691134.
1986	6383.	5986.	6208.	12573.	18814.	143013.	59684.	17561.	118071.	338475.	65977.	52624.	845369.
1987	39478.	96110.	107311.	27432.	162457.	234112.	47106.	11822.	15351.	4886.	2594.	26835.	775494.
1988	12902.	6807.	6647.	6259.	3930.	8853.	28467.	2185.	63907.	6702.	3205.	3816.	153680.
1989	2653.	18075.	8298.	3863.	95690.	138559.	7727.	17883.	90568.	6886.	3194.	2281.	395677.
1990	8204.	11582.	97260.	388039.	447232.	260120.	16158.	43763.	84252.	18357.	12987.	6854.	1394808.
1991	30033.	16106.	10581.	4941.	84551.	372419.	33392.	76720.	84862.	79543.	35910.	384864.	1213922.
1992	103835.	527120.	255708.	70632.	98443.	478767.	97843.	45340.	31163.	7212.	21759.	35008.	1772830.
1993	25306.	43005.	52533.	26440.	24346.	44623.	4361.	2938.	8132.	29688.	4903.	6921.	273196.
1994	4826.	6790.	6826.	4169.	188235.	17921.	7150.	3108.	10558.	59049.	21628.	7051.	337311.
1995	4372.	3149.	9250.	4838.	32792.	87987.	19234.	126940.	42638.	10037.	7238.	3324.	351799.
1996	4315.	4889.	4937.	10618.	2434.	10159.	2215.	26032.	220137.	26922.	39906.	26544.	379108.
1997	7413.	134230.	64979.	58336.	111437.	209048.	43799.	19477.	3596.	2821.	1459.	8810.	665405.
MEAN	14181.	26661.	23750.	49516.	146517.	111840.	44973.	44794.	68700.	82639.	23362.	19327.	656260.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRSB23

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	2874.	19566.	40575.	8464.	1873.	3332.	2802.	1764.	310.	61040.	19580.	7115.	169295.
1999	31291.	5687.	40844.	40088.	167850.	207913.	11760.	351.	12054.	6127.	2813.	1397.	528174.
2000	1106.	1189.	51530.	9065.	3617.	214764.	13647.	0.	0.	117588.	78181.	11508.	502194.
2001	25486.	29909.	96330.	8258.	62621.	6054.	1320.	8169.	22382.	7424.	107202.	13451.	388607.
2002	2763.	5457.	51518.	19460.	15133.	17136.	78629.	13822.	4555.	223393.	14607.	41518.	487990.
2003	7830.	2016.	1454.	4095.	6620.	431005.	14362.	1501.	5904.	3961.	6636.	1825.	487209.
2004	25367.	60845.	49717.	105756.	11770.	216579.	105019.	107404.	78318.	166596.	558630.	19351.	1505352.
2005	19931.	26495.	18691.	3742.	59129.	10867.	29342.	405253.	14813.	35880.	6861.	0.	631005.
2006	302.	1129.	8172.	9281.	25166.	7220.	1894.	11596.	128750.	88968.	9335.	38560.	330374.
2007	23598.	5394.	387868.	43841.	222731.	446610.	45275.	96732.	26744.	1195.	1061.	3463.	1304512.
2008	1511.	1694.	1875.	8954.	59774.	23281.	5828.	103689.	116693.	77996.	9625.	0.	410919.
2009	28.	1158.	1698.	5641.	15224.	49891.	103930.	9717.	38679.	66178.	8949.	45383.	346474.
2010	49883.	83503.	38541.	134213.	38447.	31462.	463966.	15206.	52666.	12321.	916.	1004.	922128.
2011	1324.	1582.	404.	1487.	2542.	1753.	19.	317.	364.	18964.	9790.	36556.	75101.
2012	13136.	9475.	5464.	2100.	13587.	19667.	4315.	1163.	87898.	13139.	407.	279.	170630.
2013	5318.	15307.	1751.	4111.	4092.	29196.	100381.	13206.	7005.	9066.	4091.	15981.	209506.
2014	4703.	1674.	894.	3751.	91766.	95060.	39341.	7854.	224263.	10823.	42035.	11017.	533180.
2015	47369.	19189.	5232.	80450.	883768.	109388.	93173.	9796.	356.	207229.	98783.	49809.	1604541.
2016	8753.	1064.	1318.	61037.	190277.	63704.	3800.	90035.	116623.	12807.	49368.	17750.	616536.
MEAN	14346.	15386.	42309.	29147.	98736.	104467.	58884.	47241.	49388.	60037.	54151.	16630.	590722.

Table A.2.8 1940-2016 Naturalized Flows at Control Points SHGR26

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT SHGR26

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	10094.	10172.	836.	16772.	114403.	289797.	45691.	242432.	54126.	3317.	79433.	49363.	916436.
1941	9910.	75951.	64391.	201160.	1267722.	627107.	140733.	116128.	103454.	758197.	137798.	43317.	3545868.
1942	26025.	13531.	14131.	468326.	139111.	151003.	15609.	23207.	166710.	325061.	35589.	16542.	1394845.
1943	16615.	10142.	26089.	57649.	17708.	70893.	14538.	1024.	1980.	2856.	802.	166.	220462.
1944	3922.	13485.	45426.	23584.	54063.	50477.	32829.	17198.	25757.	54397.	12288.	11908.	345334.
1945	11431.	12504.	119261.	98987.	28038.	42120.	151123.	12303.	6233.	94508.	6698.	1150.	584356.
1946	19379.	15155.	9356.	8718.	29334.	44444.	28702.	58775.	212225.	111731.	61578.	100854.	700251.
1947	13623.	6554.	12028.	8687.	479473.	54788.	8891.	2760.	13188.	34369.	9626.	37997.	681984.
1948	3748.	5871.	25281.	8583.	32120.	127828.	115435.	14256.	7234.	18154.	10575.	2927.	372012.
1949	2099.	12673.	13813.	15030.	320457.	176336.	16034.	15527.	93914.	63534.	9174.	2868.	741459.
1950	3037.	7982.	2631.	57812.	202611.	42025.	196046.	73270.	146770.	19577.	804.	1782.	754347.
1951	2761.	4274.	1833.	2048.	112117.	152042.	24098.	25353.	24699.	0.	348.	0.	349573.
1952	484.	55.	820.	7073.	16673.	13986.	14388.	5388.	5349.	2645.	4576.	2382.	73819.
1953	986.	576.	6662.	3116.	79575.	0.	265689.	89225.	17631.	252122.	25691.	10753.	752026.
1954	5182.	5221.	1602.	107969.	379232.	43287.	14581.	13551.	492.	539.	18851.	0.	590507.
1955	3906.	5662.	16837.	14931.	214934.	220077.	63325.	23962.	480744.	351752.	15346.	7815.	1419291.
1956	15225.	4032.	23.	2811.	42134.	14472.	0.	0.	1468.	6654.	17993.	20585.	125397.
1957	0.	224472.	8925.	724847.	1794495.	436949.	36297.	13320.	18908.	139484.	116312.	15332.	3529341.
1958	9566.	7775.	35228.	64389.	216647.	32253.	208256.	8415.	60971.	10037.	2757.	0.	656294.
1959	1940.	1386.	2360.	293.	46332.	176976.	111079.	14016.	5523.	247161.	3430.	19495.	629991.
1960	45796.	35331.	9037.	22013.	6439.	13086.	201748.	9875.	0.	276670.	30007.	19004.	669006.
1961	44320.	34142.	23417.	10919.	28155.	272921.	249576.	24226.	71484.	12239.	33666.	11388.	816453.
1962	5357.	2918.	6050.	6906.	1965.	298988.	142004.	14825.	430354.	29743.	43409.	34142.	1016661.
1963	5451.	6225.	8225.	101737.	98556.	209029.	1862.	0.	7862.	11866.	43033.	3851.	497697.
1964	7867.	45741.	7915.	4575.	12812.	33748.	3084.	16691.	43424.	5058.	64870.	2110.	247895.
1965	5258.	4967.	2753.	46413.	387943.	35922.	6551.	32331.	39812.	72654.	8707.	3327.	646638.
1966	244.	4735.	9563.	237550.	216184.	24612.	3806.	59066.	485457.	23755.	7052.	2802.	1074826.
1967	3807.	5802.	8540.	54846.	25142.	105293.	164976.	15885.	53029.	7088.	200.	2797.	447405.
1968	261954.	43953.	159011.	118990.	71618.	91659.	63212.	9995.	0.	0.	0.	4969.	825361.
1969	3913.	11786.	80277.	68897.	479926.	36886.	1347.	949.	175947.	41054.	37679.	64380.	1003041.
1970	26851.	22662.	97074.	63512.	105175.	18404.	0.	0.	0.	0.	0.	0.	333678.
1971	1139.	3007.	3146.	3892.	16938.	78061.	9211.	314526.	155232.	74358.	15352.	25431.	700293.
1972	5175.	11671.	7401.	15629.	73325.	19891.	9225.	172471.	113146.	47078.	152376.	19114.	646502.
1973	41253.	40138.	77266.	73590.	22940.	51406.	29617.	10070.	20393.	30462.	2692.	0.	399827.
1974	6198.	5824.	4714.	34603.	12562.	35083.	1810.	15255.	222780.	221348.	181421.	18757.	760355.
1975	30513.	97638.	28268.	27030.	112632.	110014.	57507.	41354.	37246.	5830.	11343.	6712.	566087.
1976	7548.	8493.	5107.	18254.	36498.	6133.	21751.	22568.	75235.	96050.	56332.	9625.	363594.
1977	12822.	13139.	69064.	62246.	67365.	42633.	8361.	0.	6149.	0.	0.	1634.	283413.
1978	217.	3801.	10109.	27861.	14393.	15249.	926.	758248.	33598.	17672.	7256.	3868.	893198.
1979	7244.	8608.	53583.	21763.	80955.	79809.	31312.	24895.	4048.	1933.	0.	4548.	318698.
1980	2709.	7432.	4084.	6158.	166079.	34913.	6775.	5405.	122743.	308062.	18514.	48318.	731192.
1981	16754.	13051.	43450.	81707.	34055.	134281.	12772.	12582.	10867.	823007.	23184.	11220.	1216930.
1982	7437.	11680.	16168.	9818.	598989.	716459.	127253.	14071.	5822.	3824.	1133.	7055.	1519709.
1983	7059.	17701.	16621.	10202.	89776.	40709.	10794.	248.	0.	96101.	33579.	8647.	331437.
1984	15485.	10450.	7204.	4653.	3202.	0.	0.	3839.	1228.	93904.	48426.	74734.	263125.
1985	83643.	73563.	78249.	108177.	124038.	124847.	27090.	12993.	427.	130355.	13138.	4705.	781225.
1986	8722.	7251.	10302.	15700.	27714.	162128.	76310.	18963.	127328.	408117.	77209.	63025.	1002769.
1987	47547.	140041.	134879.	49645.	134543.	272034.	48889.	9791.	15841.	4837.	2719.	31817.	892583.
1988	14119.	9353.	8266.	7744.	8600.	19361.	28446.	5457.	58212.	6235.	2238.	5402.	173433.
1989	3098.	23293.	14416.	6076.	207439.	211760.	8463.	32413.	106998.	8585.	2681.	4384.	629606.
1990	13204.	21927.	154314.	542712.	551427.	247920.	16739.	47116.	110072.	21290.	19809.	7328.	1753858.
1991	40465.	18738.	18532.	10796.	139094.	477467.	45420.	100033.	108629.	124704.	47890.	457156.	1588924.
1992	151843.	510283.	291034.	74374.	91893.	490817.	82274.	42699.	25548.	4604.	16608.	24241.	1806218.
1993	19433.	47772.	72569.	34691.	34035.	57103.	9967.	11573.	13666.	35937.	4741.	9819.	351306.
1994	6001.	8853.	10822.	6117.	310670.	22676.	18239.	8874.	19640.	75445.	40040.	12330.	539707.
1995	6976.	3101.	20209.	12666.	38307.	89490.	19971.	129594.	40225.	9864.	2817.	2385.	375605.
1996	3340.	8360.	7626.	17062.	7482.	15347.	6883.	43854.	236297.	35556.	45467.	35626.	462900.
1997	11489.	191297.	88264.	66212.	106436.	151162.	52841.	19651.	2874.	2543.	0.	14511.	707280.
MEAN	19693.	34003.	35777.	68595.	174698.	131279.	53627.	48836.	76362.	97654.	28711.	24248.	793483.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT SHGR26

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	8947.	20670.	41382.	5679.	4471.	10541.	0.	1070.	0.	8506.	31686.	12797.	145748.
1999	26644.	10221.	49859.	32434.	163216.	194576.	13748.	696.	0.	7666.	0.	0.	499060.
2000	0.	0.	74855.	19200.	10598.	148672.	12223.	250.	0.	110260.	151155.	19558.	546771.
2001	17426.	38032.	127909.	12284.	23665.	12578.	0.	1070.	18646.	13077.	138478.	33637.	436803.
2002	3234.	9975.	49572.	68225.	19795.	17821.	87525.	14125.	0.	241382.	48461.	46820.	606938.
2003	11766.	4651.	2494.	5679.	14166.	426124.	14326.	1070.	9594.	0.	9810.	0.	499680.
2004	46932.	86478.	66629.	72283.	18710.	218498.	163700.	60464.	42701.	129832.	755220.	55908.	1717355.
2005	12952.	41532.	12471.	5425.	46198.	29194.	36646.	454998.	24347.	12570.	5967.	0.	682300.
2006	0.	0.	10495.	12899.	49166.	15814.	0.	1060.	111108.	185953.	19471.	36038.	442005.
2007	22157.	0.	194836.	85023.	256460.	544810.	115706.	135722.	47206.	0.	0.	3643.	1405564.
2008	0.	0.	7747.	11405.	72772.	22854.	0.	33729.	227013.	52532.	11472.	0.	439525.
2009	0.	0.	9055.	10304.	19226.	32303.	96271.	10806.	76778.	92612.	10744.	57402.	415500.
2010	84391.	121319.	34522.	238622.	40756.	22773.	579619.	24826.	74994.	19546.	0.	0.	1241368.
2011	3334.	0.	5510.	9071.	6018.	10364.	0.	635.	0.	30345.	15197.	18124.	98598.
2012	38739.	26348.	12136.	8475.	16062.	27020.	7053.	1070.	71688.	30562.	0.	0.	239153.
2013	7960.	12437.	9472.	5679.	8945.	18299.	51098.	35782.	14296.	19362.	9707.	36312.	229351.
2014	3693.	0.	9518.	5679.	51819.	134865.	21193.	8529.	206122.	19641.	31673.	18216.	510949.
2015	47592.	19670.	12089.	88369.	1099972.	239619.	36043.	12777.	0.	83624.	234987.	106718.	1981460.
2016	11591.	0.	2494.	58742.	422636.	97920.	0.	34586.	156383.	18839.	45660.	40527.	889377.
MEAN	18282.	20596.	38581.	39762.	123403.	117087.	65008.	43856.	56888.	56648.	79984.	25563.	685658.

Table A.2.9 1940-2016 Naturalized Flows at Control Points BRPP27

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRPP27

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	10186.	10264.	844.	16924.	115442.	292429.	46106.	244634.	54618.	3347.	80154.	49811.	924759.
1941	10000.	76641.	64976.	202987.	1279235.	632802.	142011.	117183.	104394.	765083.	139049.	43710.	3578071.
1942	26261.	13654.	14259.	472579.	140374.	152374.	15751.	23418.	168224.	328013.	35912.	16692.	1407511.
1943	16766.	10234.	26326.	58173.	17869.	71537.	14670.	1033.	1998.	2882.	809.	168.	222465.
1944	3958.	13607.	45839.	23798.	54554.	50935.	33127.	17354.	25991.	54891.	12400.	12016.	348470.
1945	11535.	12618.	120344.	99886.	28293.	42503.	152495.	12415.	6290.	95366.	6759.	1160.	589664.
1946	19555.	15293.	9441.	8797.	29600.	44848.	28963.	59309.	214152.	112746.	62137.	101770.	706611.
1947	13747.	6614.	12137.	8766.	483827.	55286.	8972.	2785.	13308.	34681.	9713.	38342.	688178.
1948	3782.	5924.	25511.	8661.	32412.	128989.	116483.	14385.	7300.	18319.	10671.	2954.	375391.
1949	2118.	12788.	13938.	15166.	323367.	177937.	16180.	15668.	94767.	64111.	9257.	2894.	748191.
1950	3065.	8054.	2655.	58337.	204451.	42407.	197826.	73935.	148103.	19755.	811.	1798.	761197.
1951	2786.	4313.	1850.	2067.	113135.	153423.	24317.	25583.	24923.	0.	351.	0.	352748.
1952	488.	56.	827.	7137.	16824.	14113.	14519.	5437.	5398.	2669.	4618.	2404.	74490.
1953	995.	581.	6722.	3144.	80298.	0.	268102.	90035.	17791.	254412.	25924.	10851.	758855.
1954	5229.	5268.	1617.	108950.	382676.	43680.	14713.	13674.	496.	544.	19022.	0.	595869.
1955	3941.	5713.	16990.	15067.	216886.	222076.	63900.	24180.	485110.	354947.	15485.	7886.	1432181.
1956	15363.	4069.	23.	2837.	42517.	14603.	0.	0.	1481.	6714.	18156.	20772.	126535.
1957	0.	226511.	9006.	731430.	1810792.	440917.	36627.	13441.	19080.	140751.	117368.	15471.	3561394.
1958	9653.	7846.	35548.	64974.	218615.	32546.	210147.	8491.	61525.	10128.	2782.	0.	662255.
1959	1958.	1399.	2381.	296.	46753.	178583.	112088.	14143.	5573.	249406.	3461.	19672.	635713.
1960	46212.	35652.	9119.	22213.	6497.	13205.	203580.	9965.	0.	279183.	30280.	19177.	675083.
1961	44722.	34452.	23630.	11018.	28411.	275400.	251843.	24446.	72133.	12350.	33972.	11491.	823868.
1962	5406.	2944.	6105.	6969.	1983.	301703.	143294.	14960.	434262.	30013.	43803.	34452.	1025894.
1963	5501.	6282.	8300.	102661.	99451.	210927.	1879.	0.	7933.	11974.	43424.	3886.	502218.
1964	7938.	46156.	7987.	4617.	12928.	34054.	3112.	16843.	43818.	5104.	65459.	2129.	250145.
1965	5306.	5012.	2778.	46835.	391466.	36248.	6610.	32625.	40174.	73314.	8786.	3357.	652511.
1966	246.	4778.	9650.	239707.	218147.	24836.	3841.	59602.	489866.	23971.	7116.	2827.	1084587.
1967	3842.	5855.	8618.	55344.	25370.	106249.	166474.	16029.	53511.	7152.	202.	2822.	451468.
1968	264333.	44352.	160455.	120071.	72268.	92491.	63786.	10086.	0.	0.	0.	5014.	832856.
1969	3949.	11893.	81006.	69523.	484285.	37221.	1359.	958.	177545.	41427.	38021.	64965.	1012152.
1970	27095.	22868.	97956.	64089.	106130.	18571.	0.	0.	0.	0.	0.	0.	336709.
1971	1149.	3034.	3175.	3927.	17092.	78770.	9295.	317382.	156642.	75033.	15491.	25662.	706652.
1972	5222.	11777.	7468.	15771.	73991.	20072.	9309.	174037.	114174.	47506.	153760.	19288.	652375.
1973	41628.	40503.	77968.	74258.	23148.	51873.	29886.	10161.	20578.	30739.	2716.	0.	403458.
1974	6254.	5877.	4757.	34917.	12676.	35402.	1826.	15394.	224803.	223358.	183069.	18927.	767260.
1975	30790.	98525.	28525.	27275.	113655.	111013.	58029.	41730.	37584.	5883.	11446.	6773.	571228.
1976	7617.	8570.	5153.	18420.	36829.	6189.	21949.	22773.	75918.	107606.	61929.	9325.	382278.
1977	17211.	17237.	82510.	64764.	79128.	45641.	12148.	380.	5537.	171.	1825.	3179.	329731.
1978	1258.	5228.	11362.	34410.	14178.	14379.	69.	691652.	32030.	19215.	9086.	4209.	837076.
1979	7206.	9874.	61529.	27492.	97004.	81236.	31293.	23900.	5089.	4199.	0.	5957.	354779.
1980	1795.	9284.	4093.	6155.	165540.	37668.	6201.	4840.	118215.	333810.	18757.	53760.	760118.
1981	19577.	13876.	51791.	81607.	37819.	148706.	12097.	12928.	9411.	823290.	23061.	12468.	1246631.
1982	6869.	13221.	17517.	10216.	543099.	650718.	128875.	14568.	5076.	4186.	0.	7929.	1402274.
1983	6167.	17109.	15141.	9500.	93721.	37633.	9129.	0.	0.	92910.	31309.	1680.	314299.
1984	10923.	9289.	10173.	5088.	3559.	0.	0.	5968.	1313.	95915.	52466.	85736.	280430.
1985	72312.	68450.	71784.	93657.	110779.	112531.	20365.	5249.	0.	123829.	10936.	5031.	694923.
1986	9310.	8741.	10244.	15952.	28662.	157124.	74219.	18240.	125605.	410025.	80541.	69467.	1008130.
1987	54752.	142480.	151191.	60395.	144691.	320099.	48372.	8583.	14927.	4397.	2606.	31446.	983939.
1988	14632.	10393.	8594.	7656.	8836.	20772.	28836.	5633.	58249.	6942.	1439.	5683.	177665.
1989	4460.	24381.	13642.	4905.	220183.	219028.	5018.	27432.	114440.	8731.	1960.	4677.	648857.
1990	12514.	24389.	160547.	568128.	549281.	266312.	17478.	46348.	106997.	20975.	21397.	8113.	1802479.
1991	45973.	23423.	23295.	12018.	138574.	483811.	58029.	98671.	108996.	125836.	49177.	495663.	1663466.
1992	155268.	533482.	311512.	79378.	102888.	495989.	98759.	37186.	27505.	5371.	17601.	25723.	1890662.
1993	20568.	54777.	75806.	36278.	34320.	59615.	10985.	10269.	14788.	41583.	6737.	11025.	376751.
1994	6516.	10093.	11859.	4548.	273473.	24541.	16571.	5877.	17864.	76759.	51276.	29065.	528442.
1995	10645.	8130.	21983.	28906.	52838.	103074.	28194.	153552.	48451.	11213.	4878.	5067.	476931.
1996	6579.	10955.	14186.	19652.	9059.	17400.	7414.	55585.	302281.	63732.	65601.	56450.	628894.
1997	15801.	239190.	92943.	88083.	134589.	216386.	65402.	28450.	13295.	5204.	1446.	13494.	914283.
MEAN	20154.	35931.	37510.	70455.	175939.	133774.	54699.	48266.	78268.	99512.	29766.	26108.	810380.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRPP27

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	8156.	34556.	47352.	7276.	8090.	9278.	1036.	0.	0.	12498.	26134.	12170.	166546.
1999	37140.	10024.	36913.	47490.	165190.	243581.	16568.	0.	0.	11450.	0.	0.	568355.
2000	0.	1245.	65437.	41537.	12562.	133605.	14415.	0.	0.	93980.	169298.	21169.	553248.
2001	42535.	35382.	93566.	13691.	15661.	11168.	296.	0.	36337.	8758.	106248.	26964.	390608.
2002	3204.	10695.	39366.	51776.	19727.	17962.	105212.	14603.	0.	222291.	42161.	44151.	571148.
2003	11213.	7958.	9347.	4192.	13927.	261774.	18838.	0.	10338.	0.	8561.	0.	346148.
2004	30626.	113998.	57031.	91409.	17064.	195011.	235570.	110681.	26909.	155493.	720354.	95226.	1849371.
2005	13363.	25368.	13215.	3958.	29973.	22394.	32010.	451938.	31009.	23866.	0.	0.	647095.
2006	0.	1235.	10110.	12380.	37382.	16874.	898.	0.	140741.	243569.	23343.	25357.	511890.
2007	50449.	1585.	165509.	105164.	239698.	531075.	92049.	117596.	68671.	0.	0.	3912.	1375709.
2008	0.	829.	9954.	11543.	50141.	24205.	1036.	35698.	242000.	117632.	10815.	0.	503853.
2009	0.	602.	8772.	11649.	21362.	24429.	89176.	12101.	68512.	88855.	13041.	45322.	383821.
2010	96818.	104965.	47510.	253216.	103986.	24893.	605562.	36317.	75922.	18208.	0.	0.	1367396.
2011	5106.	1585.	5279.	6472.	3035.	7924.	122.	0.	0.	32667.	14026.	22191.	98405.
2012	38770.	14371.	14334.	9995.	16944.	23109.	4070.	3163.	62319.	18531.	0.	0.	205607.
2013	10625.	12430.	9046.	4192.	4465.	19847.	79343.	19980.	16479.	12348.	7708.	29788.	226250.
2014	5904.	811.	8955.	4114.	31060.	164985.	51352.	11460.	222988.	21072.	43408.	16653.	582763.
2015	40848.	32574.	12501.	73664.	1081810.	486900.	38835.	7859.	0.	72611.	219808.	93022.	2160432.
2016	12804.	1109.	3040.	39288.	236667.	87865.	1036.	49340.	194410.	25117.	29839.	18998.	699512.
MEAN	21451.	21648.	34591.	41737.	110987.	121415.	73022.	45828.	62981.	62050.	75513.	23943.	695166.

Table A.2.10 1940-2016 Naturalized Flows at Control Points BRDE29

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRDE29

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	9623.	6212.	2917.	27016.	109835.	302116.	63826.	256784.	66474.	6713.	173508.	126885.	1151909.
1941	28769.	175105.	94412.	211159.	1165419.	706870.	154387.	180866.	93217.	657966.	179044.	42730.	3689944.
1942	29517.	16372.	15505.	782690.	357963.	257755.	21132.	26032.	188772.	398700.	57206.	26365.	2178009.
1943	16328.	17068.	50504.	65616.	31679.	81110.	11162.	2910.	8764.	4830.	1265.	2862.	294098.
1944	8978.	38220.	66351.	27981.	160579.	54137.	38954.	25309.	50573.	48883.	16965.	15046.	551976.
1945	27186.	80730.	226179.	193385.	50426.	46966.	221032.	13706.	10549.	136598.	9166.	5778.	1021701.
1946	33693.	60035.	21986.	15957.	65202.	59837.	21623.	52437.	218329.	120507.	146114.	162912.	978632.
1947	28277.	18198.	48256.	27878.	390792.	61797.	10122.	4738.	15612.	39857.	12471.	64657.	722655.
1948	20684.	50198.	41780.	5483.	57920.	121994.	105800.	13650.	15102.	16117.	10486.	2922.	462136.
1949	2067.	34111.	54135.	29416.	529938.	232182.	26846.	5928.	87285.	89330.	17249.	6286.	1114773.
1950	12364.	29806.	7637.	85224.	209027.	51189.	246163.	91667.	169279.	35867.	5561.	3660.	947444.
1951	0.	10637.	6058.	0.	118571.	172287.	20891.	21071.	27228.	2641.	3555.	2681.	385620.
1952	1606.	2543.	1687.	13512.	60549.	357.	12987.	8615.	5717.	1445.	13127.	4544.	126689.
1953	2772.	562.	7368.	7080.	96865.	0.	239173.	77030.	7491.	261564.	33959.	9741.	743605.
1954	5360.	4172.	6441.	100135.	356162.	66959.	7845.	19734.	0.	3383.	20321.	816.	591328.
1955	1667.	7675.	16639.	14676.	263693.	210224.	60466.	27968.	298807.	477199.	17114.	7998.	1404126.
1956	7256.	5057.	4505.	8266.	104092.	16511.	1562.	2958.	1842.	11093.	18267.	43256.	224665.
1957	1342.	220503.	16769.	547287.	2450046.	488579.	59486.	8172.	26695.	183940.	166840.	27732.	4197391.
1958	26513.	19614.	72565.	80887.	403829.	41999.	245421.	22497.	62553.	4495.	5740.	5978.	992091.
1959	1884.	5132.	2916.	3380.	36786.	154273.	107868.	20567.	1584.	518158.	12349.	27649.	892546.
1960	87843.	53354.	21713.	27050.	15146.	14599.	177812.	16876.	944.	222455.	40919.	11026.	689737.
1961	72437.	51539.	46436.	12601.	27775.	255669.	210950.	28868.	55097.	38977.	37495.	17334.	855178.
1962	4629.	3429.	6669.	17451.	3973.	281751.	244254.	71502.	472187.	79702.	51994.	40402.	1277943.
1963	10940.	6352.	15118.	127620.	112253.	195890.	11317.	1362.	10016.	14387.	40505.	4669.	550429.
1964	5165.	50669.	13388.	13878.	15336.	26113.	0.	20899.	70908.	15818.	120391.	5823.	358388.
1965	15794.	36398.	9398.	50477.	498389.	42082.	7354.	36081.	52343.	64184.	9140.	8263.	829903.
1966	0.	13601.	13065.	209419.	412608.	70564.	1430.	59110.	570898.	49801.	9478.	3641.	1413615.
1967	6821.	7458.	9442.	50998.	27265.	129489.	161859.	26307.	55724.	12072.	726.	8016.	496177.
1968	295845.	68998.	268569.	149497.	128707.	129446.	88243.	20094.	4059.	56.	1396.	7101.	1162011.
1969	5457.	18988.	153838.	138187.	576225.	55014.	15598.	17527.	173528.	65542.	50468.	90712.	1361084.
1970	49854.	50788.	248444.	87478.	131904.	26862.	9121.	15575.	21039.	15010.	0.	3074.	659149.
1971	2697.	3489.	2890.	3883.	32217.	77363.	12595.	281168.	168490.	123521.	37498.	48870.	794681.
1972	13019.	10629.	5499.	19467.	79925.	24487.	8077.	150894.	114748.	50545.	156146.	27724.	661160.
1973	45137.	48891.	78757.	101813.	34151.	79618.	63901.	19376.	22582.	59025.	5737.	3611.	562599.
1974	10357.	6453.	5618.	38940.	14518.	36968.	0.	21384.	230125.	277763.	290233.	32598.	964957.
1975	42938.	130307.	34374.	58032.	93514.	168504.	50891.	45116.	35016.	5425.	10537.	8442.	683096.
1976	6351.	9190.	5674.	27902.	74947.	11433.	33267.	22919.	74323.	121367.	75472.	14036.	476881.
1977	17735.	27016.	198532.	103796.	116414.	52502.	9601.	0.	2826.	759.	4894.	3247.	537322.
1978	1726.	6132.	11305.	50682.	17009.	15337.	0.	693319.	21769.	27437.	9674.	3625.	858015.
1979	10229.	9817.	85667.	67414.	142325.	96682.	32883.	20855.	2064.	5582.	0.	8690.	482208.
1980	2695.	15327.	4259.	5691.	157087.	42952.	7316.	12336.	133898.	299915.	25739.	46560.	753775.
1981	14196.	12423.	62232.	83797.	53640.	151139.	9970.	20308.	10451.	1212610.	81692.	17269.	1729727.
1982	9948.	19902.	19596.	13879.	690770.	831991.	239037.	27603.	6856.	5327.	2020.	13916.	1880845.
1983	8093.	24009.	33588.	19278.	135325.	41119.	16897.	3749.	4183.	99208.	30429.	7993.	423871.
1984	21484.	10336.	10660.	4387.	3614.	6725.	600.	5515.	6002.	123629.	74818.	108317.	376087.
1985	114532.	65587.	103313.	107570.	138549.	120916.	31693.	3094.	3069.	142997.	17971.	7333.	856624.
1986	9557.	23728.	10889.	16744.	33950.	176333.	70334.	22258.	126222.	374169.	98739.	81766.	1044689.
1987	62840.	129359.	193911.	54683.	168187.	330038.	53827.	11378.	16733.	3100.	4205.	27018.	1055279.
1988	19653.	8227.	6399.	7263.	11560.	41043.	29277.	5546.	59453.	5029.	175.	9360.	202985.
1989	8532.	44531.	19556.	17881.	422194.	380306.	15529.	52210.	121145.	10851.	2867.	9314.	1104916.
1990	23950.	31300.	170428.	860174.	772712.	286000.	19381.	47331.	100972.	26875.	22411.	10875.	2372409.
1991	42391.	22942.	11318.	4809.	127298.	443116.	67898.	104020.	87808.	207550.	82517.	770188.	1971855.
1992	190859.	560344.	355103.	71245.	113000.	520384.	97325.	40008.	35223.	9258.	18594.	33015.	2044358.
1993	25227.	75549.	85526.	37992.	38280.	59889.	12027.	12708.	17130.	128553.	9343.	16731.	518955.
1994	8205.	13354.	12905.	4445.	339170.	31541.	17658.	544.	22987.	101416.	81252.	20082.	653559.
1995	13284.	4256.	26866.	30014.	98833.	106344.	27357.	235280.	75355.	12840.	5845.	4944.	641218.
1996	5189.	9820.	7085.	19707.	6617.	28985.	6809.	87622.	349601.	70878.	125450.	85050.	802813.
1997	19625.	480521.	204199.	162681.	199038.	225590.	88718.	30257.	6280.	3423.	2890.	14380.	1437602.
MEAN	27088.	51155.	57532.	88377.	225583.	150723.	62544.	54718.	80999.	122523.	44137.	38371.	1003749.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRDE29

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	9633.	40903.	69926.	11526.	3568.	5956.	1308.	4201.	3483.	33165.	37113.	12354.	233137.
1999	45035.	9687.	80812.	77912.	179074.	268139.	9888.	3054.	4681.	9842.	5612.	4287.	698023.
2000	2732.	5469.	86912.	33809.	12610.	247738.	10622.	0.	0.	154184.	165937.	32776.	752789.
2001	42523.	77937.	137099.	11854.	49817.	5926.	0.	4804.	58009.	11629.	158264.	23454.	581315.
2002	7945.	15137.	77309.	75945.	34150.	34884.	199148.	19700.	2774.	290400.	34245.	63607.	855245.
2003	10125.	8669.	4839.	5657.	14304.	571923.	15922.	3966.	10711.	11523.	7473.	5364.	670478.
2004	31492.	111183.	89172.	130869.	21099.	288648.	252144.	132401.	17542.	178944.	784352.	49171.	2087018.
2005	25354.	44886.	16191.	5925.	69362.	31470.	53846.	570822.	21713.	43792.	9954.	0.	893313.
2006	649.	5252.	16960.	29717.	78555.	11273.	980.	3076.	153681.	184570.	16364.	35801.	536878.
2007	28983.	4717.	259495.	126144.	291485.	766600.	140876.	199649.	45061.	6631.	926.	13749.	1884318.
2008	874.	4328.	12577.	24562.	131416.	30981.	10371.	94514.	179026.	100234.	9673.	1075.	599631.
2009	0.	3493.	6347.	17808.	46066.	65320.	136393.	15115.	129192.	155128.	15596.	63085.	653544.
2010	81809.	111408.	73942.	272902.	94039.	52135.	663876.	16816.	130808.	38080.	573.	3676.	1540065.
2011	7302.	5036.	3694.	4075.	6263.	4081.	0.	2804.	2740.	73285.	17927.	45812.	173019.
2012	50615.	43184.	30478.	14173.	22923.	58077.	12888.	7823.	172618.	16284.	0.	2584.	431647.
2013	19443.	15160.	5262.	8310.	10359.	61181.	143796.	23775.	17719.	29933.	10372.	34985.	380294.
2014	7410.	2789.	5012.	5942.	98051.	147750.	51214.	16077.	232722.	13993.	80390.	24900.	686250.
2015	63006.	20496.	30754.	137381.	1197890.	281019.	96048.	13642.	3170.	186175.	254571.	130319.	2414471.
2016	11448.	3104.	4632.	137838.	561451.	120856.	8693.	96600.	233718.	27623.	91946.	29044.	1326953.
MEAN	23494.	28044.	53232.	59597.	153815.	160735.	95159.	64676.	74704.	82390.	89541.	30318.	915704.

Table A.2.11 1940-2016 Naturalized Flows at Control Points BRGR30

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRGR30

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	10645.	6872.	3227.	29885.	121499.	334199.	70604.	284053.	73533.	7426.	191934.	140360.	1274237.
1941	31824.	193700.	104438.	233583.	1289180.	781936.	170782.	200073.	103116.	727839.	198058.	47268.	4081797.
1942	32651.	18111.	17151.	865807.	395977.	285127.	23376.	28796.	208819.	441040.	63281.	29165.	2409301.
1943	18062.	18881.	55867.	72584.	35043.	89724.	12347.	3219.	9695.	5343.	1399.	3166.	325330.
1944	9931.	42279.	73397.	30952.	177632.	59886.	43091.	27997.	55944.	54074.	18767.	16644.	610594.
1945	30073.	89303.	250198.	213922.	55781.	51954.	244504.	15162.	11669.	151104.	10139.	6392.	1130201.
1946	37271.	66410.	24321.	17651.	72126.	66191.	23919.	58005.	241514.	133304.	161631.	180212.	1082555.
1947	31280.	20130.	53380.	30839.	432292.	68360.	11197.	5241.	17270.	44090.	13795.	71523.	799397.
1948	22880.	55529.	46217.	6065.	64071.	134949.	117035.	15100.	16706.	17828.	11600.	3232.	511212.
1949	2287.	37733.	59884.	32540.	586215.	256838.	29697.	6557.	96554.	98816.	19081.	6954.	1233156.
1950	13677.	32971.	8448.	94274.	231225.	56625.	272304.	101401.	187255.	39676.	6152.	4049.	1048057.
1951	0.	11767.	6701.	0.	131163.	190583.	23110.	23309.	30120.	2922.	3932.	2966.	426573.
1952	1777.	2813.	1866.	14947.	66979.	395.	14366.	9530.	6324.	1598.	14521.	5027.	140143.
1953	3066.	622.	8150.	7832.	107152.	0.	264572.	85210.	8287.	289341.	37565.	10775.	822572.
1954	5929.	4615.	7125.	110769.	393985.	74070.	8678.	21830.	0.	3742.	22479.	903.	654125.
1955	1844.	8490.	18406.	16234.	291696.	232549.	66887.	30938.	330539.	527875.	18931.	8847.	1553236.
1956	8027.	5594.	4983.	9144.	115146.	18264.	1728.	3272.	2038.	12271.	20207.	47850.	248524.
1957	1485.	243919.	18550.	605406.	2710228.	540463.	65803.	9040.	29530.	203473.	184558.	30677.	4643132.
1958	29328.	21697.	80271.	89477.	446713.	46459.	271483.	24886.	69196.	4972.	6350.	6613.	1097445.
1959	2084.	5677.	3226.	3739.	40693.	170656.	119323.	22751.	1752.	573184.	13660.	30585.	987330.
1960	97172.	59020.	24019.	29923.	16754.	16149.	196695.	18668.	1044.	246079.	45264.	12197.	762984.
1961	80129.	57012.	51367.	13939.	30725.	282820.	233352.	31934.	60948.	43116.	41477.	19175.	945994.
1962	5121.	3793.	7377.	19304.	4395.	311671.	270193.	79095.	522331.	88166.	57515.	44692.	1413653.
1963	12102.	7027.	16724.	141173.	124174.	216693.	12519.	1507.	11080.	15915.	44806.	5165.	608885.
1964	5713.	56050.	14810.	15352.	16965.	28886.	0.	23118.	78438.	17498.	133176.	6441.	396447.
1965	17471.	40263.	10396.	55837.	551315.	46551.	8135.	39913.	57902.	71000.	10111.	9140.	918034.
1966	0.	15045.	14452.	231658.	456425.	78058.	1582.	65387.	631524.	55090.	10484.	4028.	1563733.
1967	7545.	8250.	10445.	56414.	30160.	143240.	179048.	29101.	61642.	13354.	803.	8867.	548869.
1968	327262.	76325.	297090.	165373.	214790.	135027.	97274.	25371.	6331.	2311.	3164.	8968.	1359286.
1969	5868.	20877.	154442.	158971.	665323.	73848.	10715.	21360.	156719.	54375.	52448.	94879.	1469825.
1970	47115.	49557.	239151.	96851.	134964.	20167.	0.	38.	14532.	3923.	4748.	2870.	613916.
1971	4572.	6051.	5376.	7595.	33180.	76914.	19910.	265513.	163136.	157956.	43315.	92398.	875916.
1972	18893.	16991.	9890.	20713.	81631.	24228.	6627.	154438.	165457.	53957.	166832.	28732.	748389.
1973	50773.	60891.	94546.	163054.	55737.	109076.	83391.	34125.	24519.	67695.	9591.	6983.	760381.
1974	11931.	8412.	7899.	37725.	11893.	38977.	6751.	27293.	230672.	269986.	361611.	35019.	1048169.
1975	46416.	179711.	44570.	93486.	96346.	238183.	54755.	62284.	48617.	6396.	12635.	7938.	891337.
1976	9591.	11277.	7431.	42414.	96155.	23398.	37793.	25096.	75334.	132626.	77937.	25433.	564485.
1977	20262.	36130.	253183.	88793.	97717.	52524.	11903.	164.	1005.	714.	3173.	4703.	570271.
1978	2339.	8346.	14954.	56744.	17384.	19072.	1050.	680246.	28935.	25548.	8139.	5709.	868466.
1979	10850.	10393.	98378.	99479.	273952.	111772.	31814.	23283.	3720.	11989.	0.	11093.	686723.
1980	5960.	17006.	6262.	10899.	152826.	43311.	6000.	2411.	113799.	307605.	23895.	50741.	740715.
1981	18238.	14973.	67311.	81348.	53102.	166963.	8626.	21628.	8273.	1216472.	118110.	25602.	1800646.
1982	13141.	25327.	31831.	17941.	748336.	846909.	287190.	24164.	6556.	5766.	539.	12946.	2020646.
1983	8639.	22044.	30784.	15214.	144260.	46092.	12638.	0.	1223.	95069.	28003.	13671.	417637.
1984	27913.	12158.	15055.	4317.	4102.	12524.	761.	4758.	5365.	131951.	74112.	110220.	403236.
1985	131369.	63395.	120503.	132057.	152454.	134620.	33913.	11904.	14399.	147585.	16573.	5473.	964245.
1986	8826.	28066.	14646.	18921.	48663.	221171.	82947.	25307.	142319.	373078.	101156.	83113.	1148213.
1987	72566.	140205.	232689.	77618.	192403.	380622.	60127.	11161.	15408.	2196.	6978.	29954.	1221927.
1988	20975.	9866.	9377.	8800.	8012.	49699.	26526.	974.	57275.	3958.	0.	7883.	203345.
1989	7264.	48643.	53901.	26104.	529566.	464165.	9435.	43978.	111751.	13881.	5887.	1367.	1315942.
1990	20592.	38689.	204324.	915673.	888223.	311743.	19891.	56352.	96926.	26711.	22938.	12847.	2614909.
1991	51557.	29460.	13112.	23613.	139006.	519138.	49496.	110349.	98119.	296916.	129476.	937338.	2397580.
1992	205445.	652670.	409014.	62523.	95628.	497338.	93030.	46786.	42217.	9708.	25155.	44766.	2184280.
1993	29907.	94552.	102519.	46895.	43619.	60883.	5324.	7601.	14335.	142242.	10081.	19395.	577353.
1994	11768.	14305.	15765.	6879.	354281.	44087.	20977.	0.	35458.	114042.	103193.	53686.	774441.
1995	28256.	4135.	49568.	41997.	56995.	116206.	16607.	268376.	86117.	17113.	9044.	6819.	701233.
1996	11798.	16534.	9257.	23335.	6048.	28158.	6976.	96770.	349585.	81269.	143481.	119503.	892714.
1997	32241.	575570.	306684.	251811.	235779.	214982.	115205.	39602.	15263.	9400.	5160.	25291.	1826988.
MEAN	30719.	59071.	67498.	100800.	252208.	166640.	68517.	57869.	87209.	132286.	50501.	45660.	1118978.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRGR30

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	6820.	53607.	81068.	15548.	8761.	8056.	3654.	1022.	4050.	32967.	55075.	39329.	309958.
1999	55731.	18556.	80560.	89957.	188988.	262848.	19208.	0.	3254.	11395.	4099.	5465.	740061.
2000	4197.	10466.	62348.	30514.	15086.	210721.	18944.	0.	0.	139423.	207261.	49048.	748009.
2001	58134.	118742.	202484.	18150.	28900.	8956.	16.	1022.	45438.	18022.	178447.	47150.	725459.
2002	9055.	16170.	79179.	99908.	34256.	44557.	199397.	24370.	4217.	329353.	79447.	72058.	991968.
2003	19715.	8682.	10037.	8434.	17213.	585466.	26984.	1022.	16410.	14923.	11943.	10025.	730853.
2004	27371.	133733.	134900.	133879.	35936.	304790.	275714.	93510.	36233.	188812.	902090.	101257.	2368225.
2005	17327.	57248.	35209.	8707.	44599.	33777.	20682.	319128.	33657.	25553.	14113.	0.	610000.
2006	926.	7345.	25273.	17998.	69840.	17061.	3447.	831.	127285.	189569.	29523.	38037.	527134.
2007	28017.	11134.	266287.	189946.	332389.	980068.	277230.	201122.	42507.	9620.	3935.	11572.	2353827.
2008	2582.	6430.	14628.	29623.	144606.	26589.	3794.	48765.	196236.	85440.	19146.	3118.	580958.
2009	0.	5355.	9755.	23829.	32593.	54006.	81259.	17584.	121650.	257626.	33078.	72528.	709262.
2010	105717.	163850.	90373.	292403.	89486.	30904.	624606.	30381.	92679.	43842.	2422.	6986.	1573649.
2011	11481.	8682.	9209.	10476.	8840.	10419.	0.	116.	4042.	66621.	43398.	46160.	219445.
2012	96706.	110621.	34594.	14071.	18933.	49258.	14905.	1022.	159821.	32695.	11.	3678.	536314.
2013	11974.	34120.	7790.	11103.	11419.	38051.	93476.	27042.	21580.	33520.	12458.	45619.	348152.
2014	13667.	6219.	7101.	8678.	81822.	149300.	44775.	13387.	196422.	30914.	97880.	47022.	697188.
2015	75855.	52073.	39462.	148432.	1419473.	686010.	67047.	16714.	3565.	180172.	580955.	226316.	3496074.
2016	17572.	7876.	10037.	163199.	702527.	182147.	3654.	60747.	224238.	30611.	94837.	49331.	1546776.
MEAN	29624.	43732.	63173.	69203.	172930.	193841.	93621.	45146.	70173.	90583.	124743.	46037.	1042806.

Table A.2.12 1940-2016 Naturalized Flows at Control Points PAGR31

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT PAGR31

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	254.	0.	241.	2280.	2457.	5200.	6062.	0.	0.	342.	14965.	11392.	43193.
1941	5225.	17611.	11974.	12233.	12683.	1646.	8921.	3652.	1292.	0.	6553.	0.	81790.
1942	1808.	753.	557.	13414.	10082.	18154.	2016.	1582.	155.	5731.	1478.	1907.	57637.
1943	895.	1421.	2043.	2723.	3413.	1490.	522.	40.	1265.	22.	156.	380.	14370.
1944	1093.	2058.	6172.	2392.	28312.	3487.	329.	0.	2551.	1140.	1315.	2670.	51519.
1945	6218.	17116.	21677.	38709.	5365.	6842.	7530.	1930.	608.	4846.	983.	852.	112676.
1946	3855.	9698.	8502.	4473.	8237.	6958.	0.	807.	2008.	3147.	6873.	7392.	61950.
1947	6185.	2681.	3367.	6081.	11735.	2773.	375.	342.	1496.	1210.	690.	3457.	40392.
1948	2073.	11732.	4913.	1265.	6276.	3691.	3166.	355.	1237.	295.	472.	548.	36023.
1949	1062.	4477.	6159.	9378.	73244.	7309.	1541.	1099.	561.	5139.	783.	996.	111748.
1950	2525.	5292.	1823.	4459.	3947.	1652.	3880.	565.	4522.	645.	632.	619.	30561.
1951	536.	728.	643.	697.	1748.	9388.	353.	60.	16.	49.	209.	347.	14774.
1952	467.	437.	512.	3049.	28945.	935.	259.	83.	17.	10.	1925.	572.	37211.
1953	486.	349.	576.	1660.	4167.	140.	833.	1588.	314.	1450.	620.	453.	12636.
1954	454.	340.	458.	4239.	2301.	2820.	212.	120.	5.	1271.	867.	413.	13500.
1955	325.	529.	741.	1722.	37170.	2297.	638.	195.	19926.	1048.	254.	360.	65205.
1956	408.	734.	359.	859.	22748.	249.	11.	1275.	152.	475.	343.	2372.	29985.
1957	379.	419.	977.	38551.	63312.	9808.	1551.	332.	218.	5566.	8493.	3346.	132952.
1958	5096.	3612.	6902.	7065.	15544.	2507.	5827.	327.	2075.	739.	705.	762.	51161.
1959	666.	648.	502.	2955.	501.	2981.	1548.	1207.	530.	44517.	3122.	3650.	62827.
1960	14947.	5286.	3624.	5022.	7371.	2364.	1909.	572.	256.	608.	423.	864.	43246.
1961	12885.	13482.	5758.	3497.	2571.	6629.	4887.	819.	967.	18938.	3779.	3731.	77943.
1962	2299.	1642.	1617.	2043.	1008.	1663.	1186.	866.	900.	21556.	2261.	2450.	39491.
1963	1585.	1162.	1091.	2140.	4947.	1832.	302.	219.	110.	66.	283.	494.	14231.
1964	1318.	1188.	2145.	8874.	1809.	484.	405.	447.	4819.	530.	9032.	829.	31880.
1965	2555.	10290.	2347.	1695.	28384.	3145.	591.	228.	425.	1754.	764.	799.	52977.
1966	837.	1434.	1127.	9170.	9816.	5903.	951.	2036.	1925.	701.	727.	784.	35411.
1967	641.	589.	727.	1212.	2272.	756.	5465.	399.	3162.	899.	909.	1132.	18163.
1968	18494.	5968.	29944.	8990.	52899.	6202.	8286.	6582.	1530.	934.	1351.	1337.	142517.
1969	1188.	1244.	4105.	31382.	36101.	6274.	1447.	2348.	850.	6030.	1558.	3632.	96159.
1970	3945.	8844.	25818.	14382.	7292.	4638.	1171.	655.	2088.	1457.	1032.	926.	72248.
1971	864.	791.	761.	841.	4645.	1003.	5523.	2824.	628.	11567.	1941.	20008.	51396.
1972	4330.	2455.	1709.	2418.	3450.	1153.	4386.	521.	893.	936.	1027.	849.	24127.
1973	1699.	2464.	3130.	43423.	9394.	18306.	6393.	1673.	934.	4108.	1453.	1138.	94115.
1974	1125.	986.	1022.	861.	672.	185.	132.	348.	1207.	7391.	6138.	2190.	22257.
1975	1882.	10534.	3674.	11098.	3573.	2191.	755.	343.	904.	140.	225.	496.	35815.
1976	587.	573.	716.	4142.	12902.	2756.	3713.	1251.	1554.	2474.	1241.	2163.	34072.
1977	1800.	2825.	26398.	13410.	15171.	2479.	672.	565.	261.	109.	346.	482.	64518.
1978	654.	801.	722.	604.	2362.	228.	120.	80.	273.	0.	125.	226.	6195.
1979	1359.	564.	4437.	6244.	55878.	3587.	1207.	1541.	410.	107.	250.	678.	76262.
1980	973.	629.	607.	973.	5848.	643.	152.	120.	179.	174.	99.	386.	10783.
1981	348.	353.	793.	422.	236.	2527.	526.	496.	169.	6089.	3461.	785.	16205.
1982	823.	1111.	1691.	1311.	35351.	14582.	4606.	1041.	398.	382.	611.	781.	62688.
1983	774.	645.	831.	591.	1606.	1058.	179.	127.	30.	33.	66.	221.	6161.
1984	289.	316.	2342.	430.	349.	570.	200.	147.	140.	3309.	398.	2721.	11211.
1985	2779.	1160.	1827.	7747.	3317.	2670.	1045.	40.	87.	847.	309.	420.	22248.
1986	405.	1677.	463.	394.	4723.	25743.	774.	251.	19246.	1299.	1083.	1908.	57966.
1987	2376.	6526.	7736.	2170.	13835.	15396.	1711.	640.	411.	293.	578.	722.	52394.
1988	660.	609.	592.	468.	263.	7904.	489.	65.	71.	219.	101.	213.	11654.
1989	359.	1520.	26144.	10725.	46564.	52994.	3525.	2987.	1731.	1037.	1133.	1156.	149875.
1990	1228.	1418.	7668.	49240.	59925.	8980.	2535.	4612.	1509.	871.	938.	976.	139900.
1991	1722.	1543.	1430.	1420.	2945.	5469.	603.	1673.	1507.	26075.	12567.	84978.	141932.
1992	23357.	53693.	20922.	8957.	13027.	12164.	3411.	1845.	1390.	1059.	1644.	4211.	145680.
1993	2963.	8743.	13496.	11821.	5422.	2732.	1828.	1052.	2059.	5306.	1055.	1111.	57588.
1994	1488.	1553.	1668.	1827.	19181.	1977.	1047.	228.	4383.	8884.	11050.	7537.	60823.
1995	6738.	3492.	8921.	8354.	18770.	32737.	15124.	44373.	4449.	2136.	1763.	1801.	148658.
1996	1682.	1303.	1309.	1451.	936.	1904.	332.	4269.	6244.	3654.	6885.	5098.	35067.
1997	2890.	50461.	30827.	23381.	29115.	15588.	6123.	2060.	984.	1152.	1355.	1599.	165535.
MEAN	2877.	5009.	5676.	7954.	14933.	6340.	2401.	1826.	1863.	3806.	2266.	3523.	58474.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT PAGR31

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	1533.	7880.	6578.	1522.	460.	661.	306.	199.	441.	1760.	15577.	13528.	50444.
1999	2663.	1092.	907.	2982.	4597.	1226.	318.	56.	48.	454.	711.	721.	15776.
2000	1589.	807.	964.	1077.	1205.	16878.	1073.	0.	0.	872.	14974.	10078.	49516.
2001	5568.	17359.	32034.	1226.	991.	762.	180.	199.	1498.	1309.	2451.	7340.	70917.
2002	3779.	996.	6650.	6560.	3346.	1806.	1346.	1204.	135.	14707.	8042.	5702.	54273.
2003	2363.	4951.	1281.	430.	1043.	3698.	1529.	199.	4523.	2619.	1976.	1055.	25667.
2004	2586.	9526.	6552.	5473.	5504.	43209.	9366.	1046.	1446.	2528.	44872.	14770.	146877.
2005	2105.	2540.	1450.	873.	505.	1091.	318.	658.	1083.	4.	169.	242.	11038.
2006	524.	1902.	3617.	1591.	1317.	821.	318.	199.	525.	2150.	3300.	1463.	17726.
2007	7529.	1052.	9406.	13518.	38698.	65962.	51068.	998.	4104.	1766.	655.	1105.	195860.
2008	589.	466.	1481.	9472.	2513.	414.	275.	860.	1234.	768.	1336.	496.	19905.
2009	320.	436.	1226.	1648.	1814.	1366.	668.	1110.	17174.	65562.	8231.	676.	100232.
2010	5684.	8130.	5120.	1925.	1417.	1246.	1093.	878.	10237.	2047.	238.	633.	38647.
2011	2222.	823.	436.	618.	1526.	642.	73.	175.	148.	1943.	4663.	3218.	16487.
2012	42645.	18764.	16034.	3282.	654.	1203.	534.	508.	1090.	2580.	185.	366.	87845.
2013	3668.	1478.	469.	1009.	2279.	694.	745.	799.	1072.	4783.	2805.	3526.	23328.
2014	1253.	248.	487.	659.	1466.	9106.	944.	199.	135.	502.	2258.	5001.	22259.
2015	3420.	5042.	3683.	13884.	84588.	52667.	618.	1166.	77.	18915.	61310.	36662.	282034.
2016	1358.	640.	1677.	15789.	40893.	17980.	980.	2916.	1308.	1468.	1295.	1327.	87631.
MEAN	4810.	4428.	5266.	4397.	10254.	11654.	3776.	704.	2436.	6670.	9213.	5680.	69288.

Table A.2.13 1940-2016 Naturalized Flows at Control Points BRAQ33

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRAQ33

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	11746.	6676.	4427.	41228.	131761.	354218.	100957.	267803.	68217.	9062.	266476.	197232.	1459803.
1941	58622.	282131.	165165.	292832.	1327583.	773405.	213978.	214894.	107647.	702082.	228190.	46163.	4412692.
1942	41448.	21676.	19705.	917367.	440331.	374403.	33475.	36487.	205042.	461503.	69667.	38560.	2659664.
1943	22374.	25946.	65390.	85320.	52235.	95592.	14821.	3358.	16140.	5343.	2188.	5095.	393802.
1944	15463.	52180.	104269.	42860.	322738.	76923.	43877.	18260.	68138.	58884.	25275.	30329.	859196.
1945	62140.	177421.	358784.	412950.	82789.	86820.	278759.	24987.	14612.	173287.	15092.	10735.	1698376.
1946	56740.	115994.	68533.	40803.	113890.	101356.	23236.	60978.	246770.	146936.	194250.	215154.	1384640.
1947	63146.	33797.	69929.	62167.	484548.	82457.	15335.	12593.	18421.	43554.	17679.	95119.	998745.
1948	30487.	91821.	71971.	11076.	87088.	155963.	137334.	12983.	24798.	20760.	12827.	6933.	664041.
1949	6293.	51556.	76255.	60823.	658075.	237978.	38993.	8144.	92814.	91817.	24547.	8884.	1356179.
1950	20623.	85267.	16422.	114020.	233354.	64009.	266161.	127376.	202952.	45828.	5175.	6176.	1187363.
1951	2106.	14092.	9161.	1533.	137740.	253490.	24136.	26652.	31102.	3720.	5191.	9438.	518361.
1952	1760.	3725.	2112.	49046.	94298.	0.	8092.	11554.	9221.	2196.	39278.	19463.	240745.
1953	8359.	2358.	15546.	18814.	139261.	0.	260986.	90426.	5343.	267289.	31526.	8479.	848387.
1954	2564.	3675.	6456.	115126.	382975.	76955.	13920.	25459.	3149.	12656.	24488.	0.	667423.
1955	846.	11093.	19150.	23659.	346117.	242987.	64961.	33980.	336631.	521474.	17994.	6643.	1625535.
1956	12412.	14494.	8936.	16417.	147763.	21374.	6646.	7614.	11204.	22669.	22619.	49715.	341863.
1957	4734.	242843.	26410.	733104.	2981239.	712033.	100498.	23570.	43713.	217096.	222614.	55837.	5363691.
1958	61624.	48059.	115520.	155551.	496610.	58023.	226838.	25032.	76952.	6089.	9121.	10672.	1290091.
1959	3371.	14432.	14696.	22173.	56340.	200916.	138382.	32211.	10147.	679372.	29150.	77076.	1278266.
1960	185887.	98349.	47461.	76052.	60520.	26472.	193715.	19921.	3818.	242647.	54240.	44410.	1053492.
1961	227212.	170116.	91001.	31417.	40428.	322121.	263648.	48539.	66298.	93980.	57938.	40746.	1453444.
1962	16130.	9710.	12553.	28789.	6401.	332985.	239304.	81671.	522707.	138405.	55521.	46653.	1490829.
1963	16041.	12508.	20197.	137400.	131328.	210999.	20741.	1900.	12725.	21868.	46435.	5337.	637479.
1964	11600.	60828.	38335.	53959.	26112.	34675.	2953.	34088.	96667.	13813.	155620.	11621.	540271.
1965	32470.	123612.	26578.	66126.	689887.	60830.	9441.	41017.	56896.	74189.	20064.	15935.	1217045.
1966	3317.	22588.	24052.	347056.	477732.	81431.	8331.	71474.	546458.	64072.	14029.	6102.	1666642.
1967	9942.	10450.	15739.	62755.	41107.	139900.	170427.	34708.	63254.	15852.	10219.	19655.	594008.
1968	364437.	107205.	389424.	200250.	472706.	168338.	120296.	35264.	12040.	7996.	10314.	12753.	1901023.
1969	11299.	25223.	165424.	211483.	826761.	97326.	27604.	21738.	158761.	60649.	54994.	91593.	1752855.
1970	62417.	75517.	346748.	163256.	156964.	41037.	10820.	10671.	27515.	21997.	7710.	7863.	932515.
1971	9566.	10328.	7847.	23998.	61765.	82909.	39162.	264121.	146279.	280196.	71689.	256927.	1254787.
1972	100622.	37934.	25997.	33335.	87300.	28673.	25528.	135749.	146627.	65404.	145608.	28390.	861167.
1973	75526.	87817.	115415.	314615.	86801.	250287.	98039.	52097.	31519.	97615.	24852.	17176.	1251759.
1974	27965.	21853.	23721.	46762.	23035.	46906.	14203.	52161.	275346.	274059.	414201.	57329.	1277541.
1975	75625.	273194.	63803.	177167.	132702.	252848.	61448.	60404.	41697.	3461.	1797.	1733.	1145879.
1976	16626.	24073.	14065.	78395.	150523.	49170.	80305.	41625.	77707.	125708.	89279.	45525.	793001.
1977	40279.	82256.	368533.	296026.	148601.	63811.	18903.	0.	4368.	0.	6394.	5811.	1034982.
1978	5625.	13605.	18681.	59281.	28585.	21662.	2459.	603916.	18451.	40357.	21859.	13679.	848160.
1979	21338.	26230.	176627.	131747.	438404.	158670.	41420.	35662.	15979.	22204.	2106.	24177.	1094564.
1980	16869.	22830.	9331.	24625.	197598.	49431.	10485.	6016.	120980.	275335.	24001.	50178.	807679.
1981	14192.	16531.	89038.	92999.	50910.	279184.	27188.	34137.	15144.	1090085.	162659.	28488.	1900555.
1982	18461.	50230.	53399.	32285.	787881.	857999.	318442.	27252.	1993.	2163.	0.	8614.	2158719.
1983	0.	23326.	32028.	19278.	143809.	44816.	11691.	2496.	1302.	89366.	23177.	0.	391289.
1984	26305.	16290.	32105.	2907.	0.	9782.	1356.	3439.	4376.	137063.	73268.	127681.	434572.
1985	141753.	72603.	166950.	187176.	182097.	139137.	41666.	17387.	11703.	149077.	23573.	9917.	1143039.
1986	6942.	39379.	19254.	22306.	75198.	315002.	77390.	24006.	222840.	385766.	115360.	121758.	1425201.
1987	104801.	187744.	267696.	95124.	244647.	572093.	82853.	24331.	19060.	6923.	8577.	41071.	1654920.
1988	27908.	19021.	15341.	12682.	13322.	82500.	33570.	3957.	60329.	3576.	0.	10322.	282528.
1989	14335.	72510.	111597.	61746.	734040.	647272.	30350.	48382.	113971.	16935.	5019.	8426.	1864583.
1990	35668.	46435.	260786.	1103700.	1156948.	362703.	21238.	62030.	93959.	30341.	27292.	12051.	3213151.
1991	57634.	34407.	21858.	82309.	185938.	492369.	52964.	123801.	94883.	370416.	202431.	1301344.	3020354.
1992	367692.	879423.	568395.	135362.	190882.	622919.	141059.	48407.	41073.	10163.	23850.	54912.	3084137.
1993	42288.	161456.	184978.	90935.	71791.	79402.	15926.	22418.	25747.	143414.	16689.	28226.	883270.
1994	22993.	33070.	43002.	18899.	430996.	62029.	41350.	17135.	42401.	128040.	156552.	90639.	1087106.
1995	65057.	23929.	134165.	108476.	307852.	255793.	68413.	361710.	93742.	17234.	8382.	15082.	1459835.
1996	13203.	23587.	13294.	30203.	11032.	30604.	12999.	115117.	358361.	81621.	147237.	109989.	947247.
1997	37084.	689703.	357230.	312634.	312145.	245044.	108491.	32770.	15508.	4624.	3898.	57442.	2176573.
MEAN	48517.	86295.	96750.	141214.	308646.	199794.	78579.	63550.	90612.	139625.	61210.	64263.	1379053.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRAQ33

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	17490.	69052.	138706.	5267.	9039.	12208.	11055.	6989.	8176.	61853.	63405.	26864.	430103.
1999	77150.	7989.	112655.	102058.	248265.	325304.	10266.	2273.	9367.	17091.	4341.	5836.	922596.
2000	5614.	13842.	116140.	53923.	25286.	297147.	4416.	0.	0.	184232.	253697.	52609.	1006907.
2001	81104.	138268.	208617.	31015.	64123.	14793.	6147.	15905.	70900.	31039.	220548.	50971.	933431.
2002	31020.	38579.	114406.	134493.	73321.	65066.	291590.	29611.	7240.	389489.	64527.	98857.	1338198.
2003	27135.	20215.	5056.	13385.	38228.	726206.	26857.	8262.	26454.	29933.	31200.	6408.	959339.
2004	59166.	205971.	123574.	196480.	58955.	407861.	371121.	196265.	47545.	256100.	992724.	104199.	3019960.
2005	42038.	82220.	46200.	13245.	90091.	35797.	73950.	705989.	34579.	59494.	1745.	0.	1185348.
2006	1684.	3041.	41226.	25444.	103078.	24167.	10634.	6024.	178652.	223912.	33775.	52459.	704097.
2007	59616.	3338.	343022.	199959.	672036.	1013354.	208929.	259569.	63151.	10465.	4374.	22976.	2860789.
2008	1859.	7416.	34150.	59523.	195241.	47860.	10714.	119322.	234791.	121289.	5198.	4298.	841661.
2009	0.	7118.	5260.	64166.	74779.	91300.	202410.	17113.	197004.	307985.	46245.	91637.	1105018.
2010	124776.	182816.	101518.	365946.	138019.	63656.	743985.	29728.	207502.	62893.	1572.	5778.	2028188.
2011	6766.	13257.	8062.	10130.	2988.	11762.	1833.	4703.	6587.	104610.	31278.	59321.	261298.
2012	92805.	81105.	69364.	46033.	50199.	79653.	20300.	18457.	243769.	29770.	0.	2299.	733755.
2013	29733.	27256.	15160.	4113.	35079.	92201.	191080.	47298.	39952.	46371.	27062.	68926.	624232.
2014	6308.	5985.	10299.	13602.	130531.	231921.	116344.	26681.	236030.	33058.	121170.	27395.	959323.
2015	88319.	52505.	38714.	203842.	1529623.	696276.	137991.	15278.	6058.	299333.	681818.	217082.	3966839.
2016	19224.	10950.	11028.	242470.	754634.	150841.	3777.	158645.	314396.	39613.	127201.	38001.	1870781.
MEAN	40621.	51101.	81219.	93952.	225975.	230914.	128600.	87795.	101692.	121501.	142730.	49259.	1355361.

Table A.2.14 1940-2016 Naturalized Flows at Control Points NBCL36

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT NBCL36

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	104.	113.	39.	6528.	1452.	24553.	924.	1305.	225.	0.	50259.	43563.	129065.
1941	15965.	82876.	41414.	79121.	104923.	67030.	34218.	51272.	4261.	12595.	4058.	4645.	502378.
1942	3052.	2266.	1961.	100808.	69445.	90906.	6977.	6041.	66437.	62973.	14917.	13182.	438965.
1943	7895.	4787.	7785.	8403.	16085.	2701.	1036.	104.	4634.	264.	61.	722.	54477.
1944	6440.	17863.	11886.	13424.	71711.	7451.	1339.	758.	1508.	2527.	1066.	5354.	141327.
1945	20760.	40174.	72469.	116825.	23091.	30355.	61110.	3358.	2181.	14526.	3345.	2523.	390717.
1946	6283.	20904.	35254.	13996.	38114.	12600.	1441.	696.	5923.	1267.	16005.	7128.	159611.
1947	10185.	5975.	18757.	11392.	8599.	1289.	276.	219.	380.	255.	372.	4869.	62568.
1948	2323.	37685.	7669.	1943.	21736.	12389.	7705.	705.	3129.	165.	175.	1084.	96708.
1949	1189.	5275.	5777.	21739.	39439.	5032.	1013.	113.	191.	3534.	271.	1162.	84735.
1950	1673.	14992.	2194.	5336.	2792.	2280.	11035.	201.	22768.	779.	442.	537.	65029.
1951	457.	742.	479.	1458.	4291.	8047.	52.	0.	0.	0.	0.	0.	15526.
1952	0.	0.	0.	15649.	41204.	1739.	35.	0.	0.	0.	5377.	1672.	65676.
1953	1033.	434.	2140.	2003.	15376.	108.	771.	500.	801.	2577.	157.	105.	26005.
1954	107.	99.	53.	2405.	1047.	3336.	0.	0.	0.	2275.	1521.	0.	10843.
1955	0.	162.	197.	2133.	34085.	5996.	301.	0.	8409.	1003.	0.	0.	52286.
1956	0.	403.	0.	919.	51633.	206.	0.	0.	0.	0.	533.	1422.	55116.
1957	0.	72.	835.	222410.	161374.	13760.	2854.	284.	86.	19815.	26832.	10291.	458613.
1958	16931.	16782.	28482.	29210.	83401.	4696.	15206.	730.	771.	647.	551.	718.	198125.
1959	666.	1043.	400.	1175.	853.	12721.	9191.	554.	2036.	88335.	6935.	12527.	136436.
1960	46177.	19255.	11535.	12033.	11363.	2594.	2526.	858.	252.	1485.	543.	10956.	119577.
1961	80062.	69408.	19476.	8691.	5453.	22354.	17546.	1970.	2702.	47621.	9654.	10953.	295890.
1962	6152.	4180.	4108.	6435.	4418.	5047.	1590.	317.	7972.	13361.	1615.	2033.	57228.
1963	1272.	771.	498.	1602.	3503.	4738.	316.	5.	0.	0.	12336.	212.	25253.
1964	5994.	4903.	14513.	25213.	2559.	1367.	10.	108.	19857.	3757.	15050.	1721.	95052.
1965	5986.	43302.	6965.	3692.	135810.	8886.	1454.	1045.	467.	2558.	1686.	1142.	212993.
1966	993.	2538.	1438.	45889.	31051.	13318.	922.	4313.	12035.	1595.	997.	1161.	116250.
1967	971.	637.	1019.	6565.	1174.	2567.	2866.	314.	1121.	194.	226.	755.	18409.
1968	71052.	16840.	67801.	23363.	148201.	19393.	49094.	5432.	1756.	1174.	1800.	2079.	407985.
1969	1383.	1683.	4250.	23271.	70788.	4416.	5286.	2817.	666.	19555.	4146.	8527.	146788.
1970	10285.	30110.	73544.	28141.	19439.	10905.	2035.	841.	11323.	3687.	1424.	1407.	193141.
1971	1281.	1149.	1170.	1811.	5171.	2015.	2105.	2552.	665.	74115.	5376.	61136.	158546.
1972	21328.	7878.	4132.	4832.	5924.	1602.	3524.	1831.	1987.	3362.	1665.	1280.	59345.
1973	6781.	12006.	14824.	61974.	13050.	12147.	7265.	2099.	1067.	8839.	1831.	1425.	143308.
1974	2948.	1965.	1482.	866.	929.	339.	273.	277.	11884.	11127.	15376.	6068.	53534.
1975	5841.	39996.	10884.	38840.	11652.	4513.	4972.	2650.	2145.	517.	383.	609.	123002.
1976	474.	472.	456.	4341.	15454.	11722.	6192.	835.	2229.	3468.	1795.	3662.	51100.
1977	3214.	5910.	53189.	135316.	73817.	7668.	2233.	1607.	867.	607.	514.	612.	285554.
1978	652.	966.	689.	790.	4808.	1206.	221.	81.	0.	38.	140.	141.	9732.
1979	2468.	1574.	25785.	15603.	70450.	11719.	2375.	3907.	1116.	696.	594.	1205.	137492.
1980	2792.	1477.	1038.	1720.	10025.	1230.	410.	324.	1556.	352.	244.	743.	21911.
1981	545.	448.	4648.	1507.	1804.	27878.	6908.	469.	516.	3243.	1626.	672.	50264.
1982	862.	2471.	5469.	3810.	46524.	18538.	5516.	671.	114.	145.	41.	349.	84510.
1983	514.	638.	889.	73.	2236.	4804.	187.	78.	0.	0.	0.	0.	9419.
1984	49.	483.	6913.	372.	37.	0.	110.	58.	2.	4118.	594.	3716.	16452.
1985	6182.	3483.	9755.	4963.	7333.	5192.	535.	167.	238.	2441.	184.	194.	40667.
1986	204.	754.	281.	265.	12657.	87904.	2702.	635.	26729.	4623.	3113.	10924.	150791.
1987	12284.	18647.	24472.	7814.	49698.	63631.	6957.	1968.	1532.	604.	1334.	1947.	190888.
1988	1322.	1581.	1180.	776.	591.	50535.	909.	226.	2355.	1135.	332.	591.	61533.
1989	1758.	10276.	47226.	16606.	72370.	90105.	7449.	10473.	3078.	1209.	1129.	1008.	262687.
1990	1465.	2481.	15299.	139046.	90803.	10319.	2556.	4068.	1066.	776.	1184.	758.	269821.
1991	2315.	1435.	1339.	10251.	15113.	17102.	974.	14335.	7112.	48987.	25398.	450470.	594831.
1992	86105.	214690.	80679.	18349.	28069.	23968.	6233.	3436.	3509.	1192.	3619.	10423.	480272.
1993	7648.	41586.	33115.	19724.	10681.	8427.	2666.	645.	1980.	7662.	1566.	1377.	137077.
1994	1640.	3393.	3276.	4831.	131288.	10643.	2873.	1246.	5688.	14024.	23120.	32226.	234248.
1995	23255.	11481.	27283.	66263.	89277.	58914.	6506.	76140.	6031.	3678.	2420.	2211.	373459.
1996	1851.	1640.	1257.	2222.	590.	7214.	824.	28612.	21843.	7491.	17255.	16525.	107324.
1997	14846.	180572.	100494.	73710.	48438.	67650.	8134.	3052.	1199.	2638.	1447.	6611.	508791.
MEAN	9242.	17513.	15865.	25490.	35228.	17410.	5702.	4264.	4972.	8890.	5080.	13264.	162919.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT NBCL36

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	3232.	46291.	55272.	810.	1244.	926.	375.	0.	954.	22610.	95652.	31416.	258782.
1999	24473.	0.	3427.	3489.	4802.	3582.	507.	0.	0.	0.	0.	1226.	41506.
2000	2537.	1472.	1900.	1676.	3141.	11479.	507.	0.	0.	3589.	66169.	94253.	186724.
2001	27588.	66611.	17468.	4437.	1628.	1491.	254.	0.	16143.	1873.	13436.	62297.	213225.
2002	15170.	2129.	6712.	2574.	3436.	1864.	3311.	0.	0.	54015.	27550.	10773.	127534.
2003	26008.	9774.	2575.	481.	1825.	5779.	507.	0.	4765.	10725.	10379.	0.	72818.
2004	2416.	85132.	18076.	17486.	33484.	60530.	31364.	7451.	2056.	4694.	147806.	133489.	543986.
2005	2670.	15985.	3520.	506.	2665.	1522.	431.	3072.	574.	0.	0.	0.	30946.
2006	0.	2626.	4485.	3037.	1603.	1374.	375.	0.	0.	2366.	3044.	1018.	19928.
2007	13087.	7634.	17302.	101361.	65280.	288915.	94045.	2367.	2722.	1582.	562.	479.	595336.
2008	0.	0.	4397.	14257.	3026.	1157.	279.	837.	1917.	0.	1278.	0.	27147.
2009	0.	0.	3260.	10704.	15459.	1419.	507.	0.	12150.	150072.	120988.	4806.	319366.
2010	15021.	68976.	11195.	4698.	2893.	1553.	4516.	0.	5002.	17606.	0.	416.	131876.
2011	1475.	9303.	515.	2493.	1178.	935.	89.	0.	0.	3621.	1743.	17250.	38602.
2012	92096.	27877.	52004.	20550.	2207.	2815.	507.	0.	3642.	1758.	0.	0.	203456.
2013	4858.	9203.	907.	3468.	2625.	1844.	1293.	0.	1501.	22046.	61944.	17384.	127073.
2014	0.	0.	535.	446.	4389.	19610.	1770.	0.	0.	1752.	18958.	7096.	54556.
2015	8841.	14792.	3077.	17618.	206088.	102411.	2641.	0.	0.	5826.	259788.	47604.	668686.
2016	1529.	0.	3420.	63323.	165996.	7461.	507.	4441.	84296.	0.	2179.	6666.	339820.
MEAN	12684.	19358.	11055.	14390.	27525.	27193.	7568.	956.	7143.	16007.	43762.	22957.	210598.

Table A.2.15 1940-2016 Naturalized Flows at Control Points NBVM37

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT NBVM37

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	123.	134.	46.	7742.	1722.	29120.	1096.	1548.	267.	0.	59607.	51666.	153071.
1941	18934.	98291.	49117.	93838.	124439.	79498.	40583.	60809.	5054.	14938.	4813.	5509.	595823.
1942	3620.	2687.	2326.	119558.	82362.	107815.	8275.	7165.	78794.	74686.	17692.	15634.	520614.
1943	9363.	5677.	9233.	9966.	19077.	3203.	1229.	123.	5496.	313.	72.	856.	64608.
1944	7638.	21186.	14097.	15921.	85049.	8837.	1588.	899.	1788.	2997.	1264.	6350.	167614.
1945	24621.	47646.	85948.	138554.	27386.	36001.	72476.	3983.	2587.	17228.	3967.	2992.	463389.
1946	7452.	24792.	41811.	16599.	45203.	14944.	1709.	825.	7025.	1503.	18982.	8454.	189299.
1947	12079.	7086.	22246.	13511.	10198.	1529.	327.	260.	451.	302.	441.	5775.	74205.
1948	2755.	44694.	9095.	2304.	25779.	14693.	9138.	836.	3711.	196.	208.	1286.	114695.
1949	1410.	6256.	6852.	25782.	46775.	5968.	1201.	134.	227.	4191.	321.	1378.	100495.
1950	1984.	17781.	2602.	6328.	3311.	2704.	13088.	238.	27003.	924.	524.	637.	77124.
1951	542.	880.	568.	1729.	5089.	9544.	62.	0.	0.	0.	0.	0.	18414.
1952	0.	0.	0.	18560.	48868.	2062.	42.	0.	0.	0.	6377.	1983.	77892.
1953	1225.	515.	2538.	2376.	18236.	128.	914.	593.	950.	3056.	186.	125.	30842.
1954	127.	117.	63.	2852.	1242.	3956.	0.	0.	0.	2698.	1804.	0.	12859.
1955	0.	192.	234.	2530.	40425.	7111.	357.	0.	9973.	1190.	0.	0.	62012.
1956	0.	478.	0.	1090.	61237.	244.	0.	0.	0.	0.	632.	1686.	65367.
1957	0.	85.	990.	263778.	191390.	16319.	3385.	337.	102.	23501.	31823.	12205.	543915.
1958	20080.	19903.	33780.	34643.	98914.	5569.	18034.	866.	914.	767.	653.	852.	234975.
1959	790.	1237.	474.	1394.	1012.	15087.	10901.	1045.	4647.	174193.	9738.	16527.	237045.
1960	57584.	26898.	17111.	13192.	11967.	3597.	5735.	1415.	693.	4208.	1184.	20258.	163842.
1961	112650.	86685.	29770.	12202.	7720.	25614.	29611.	5178.	4960.	74696.	18636.	19621.	427343.
1962	10707.	6998.	6322.	7426.	7214.	6851.	2621.	743.	13350.	12117.	2143.	2660.	79152.
1963	1789.	1122.	893.	1370.	4265.	4629.	425.	32.	44.	118.	12851.	361.	27899.
1964	6203.	6318.	16158.	26593.	2604.	3440.	84.	1216.	27668.	4217.	24100.	3167.	121768.
1965	8371.	54049.	10798.	5879.	199636.	17119.	3490.	2623.	1429.	3557.	4363.	2417.	313731.
1966	2137.	4393.	3337.	64292.	42880.	15997.	2092.	6685.	13336.	2459.	1686.	2101.	161395.
1967	1638.	1127.	1800.	8597.	1903.	4381.	3288.	634.	1531.	472.	492.	1427.	27290.
1968	81604.	20644.	72632.	27872.	170610.	23163.	43787.	8523.	3723.	2397.	2744.	3003.	460702.
1969	2208.	2608.	5486.	31708.	90643.	6562.	6273.	3679.	1199.	21023.	5915.	11099.	188403.
1970	12522.	32169.	84065.	31850.	22116.	13584.	2368.	1278.	13254.	4883.	1878.	1904.	221871.
1971	1860.	1600.	1348.	2289.	4809.	2239.	2553.	2726.	660.	82890.	7169.	66419.	176562.
1972	24658.	9778.	5600.	5251.	7391.	2082.	4248.	1992.	2012.	3457.	1919.	1434.	69822.
1973	7395.	12836.	16882.	65235.	17479.	14933.	9132.	2549.	1564.	10773.	3398.	2767.	164943.
1974	4073.	2938.	2383.	1513.	1455.	647.	488.	530.	18179.	13277.	20104.	8162.	73749.
1975	8373.	50033.	13390.	47506.	19054.	8142.	6896.	4039.	3102.	1130.	1022.	1442.	164129.
1976	1229.	1009.	1125.	5607.	18749.	18321.	13281.	2100.	3318.	4317.	3137.	5306.	77499.
1977	5114.	9289.	81120.	142275.	115584.	10182.	3631.	2511.	1587.	1046.	1242.	1112.	374693.
1978	1086.	1545.	1014.	1015.	5675.	1718.	243.	110.	49.	73.	629.	215.	13372.
1979	3410.	2445.	32006.	22312.	76507.	19390.	4451.	4601.	1767.	1493.	1399.	1766.	171547.
1980	3346.	1932.	1712.	2567.	12792.	2066.	555.	514.	1836.	711.	522.	1564.	30117.
1981	991.	954.	5559.	2364.	2233.	65965.	8795.	1076.	1601.	4886.	2664.	1446.	98534.
1982	1589.	3711.	9042.	5402.	51878.	21386.	6388.	972.	312.	369.	448.	762.	102259.
1983	993.	959.	1348.	759.	2357.	5386.	423.	234.	54.	138.	128.	273.	13052.
1984	294.	729.	7806.	300.	136.	14.	101.	224.	0.	7757.	1344.	5108.	23813.
1985	8044.	4522.	13698.	6562.	13562.	9202.	738.	435.	506.	3106.	649.	1054.	62078.
1986	1007.	2371.	851.	1114.	12919.	87269.	2792.	654.	20482.	5225.	4072.	11753.	150509.
1987	13406.	19289.	29789.	8405.	49212.	77130.	8469.	2466.	2171.	1138.	1920.	3065.	216460.
1988	2088.	3171.	1858.	1241.	1006.	52233.	1509.	586.	3710.	1507.	634.	827.	70370.
1989	2082.	11073.	44588.	19486.	74985.	95634.	9579.	13171.	3539.	1906.	1642.	1601.	279286.
1990	2113.	4004.	22247.	130600.	104797.	11500.	2094.	4988.	1696.	1189.	1742.	1367.	288337.
1991	2808.	1857.	1711.	10816.	17164.	17871.	1265.	14264.	7956.	53314.	32504.	459004.	620534.
1992	107925.	296311.	130534.	30028.	37194.	39274.	10857.	4684.	4792.	1770.	4831.	12400.	680600.
1993	8763.	59716.	44809.	27294.	15159.	10905.	4305.	1430.	4504.	9271.	2203.	2287.	190646.
1994	2866.	4750.	4574.	5049.	145140.	11440.	2720.	1280.	6185.	16140.	26048.	35392.	261584.
1995	26094.	10274.	31225.	100339.	145708.	84684.	13849.	99910.	8233.	3594.	3807.	3321.	531038.
1996	2352.	2585.	1580.	2542.	1917.	11459.	1329.	34723.	32224.	9307.	22081.	24217.	146316.
1997	21828.	241390.	146094.	108499.	73097.	93574.	14679.	4057.	1979.	3289.	1762.	10599.	720847.
MEAN	11654.	22478.	20419.	30455.	43573.	21792.	7234.	5491.	6279.	11998.	6623.	14941.	202937.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT NEVM37

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	25763.	78454.	22080.	1676.	1389.	1272.	968.	0.	9780.	117129.	78161.	60866.	397538.
1999	9722.	0.	4269.	3730.	11059.	4397.	1047.	0.	0.	0.	0.	3025.	37249.
2000	10791.	7229.	2472.	2519.	11388.	19232.	1047.	0.	0.	4765.	171407.	64546.	295396.
2001	42521.	27247.	40254.	3631.	4211.	1980.	737.	0.	18939.	2807.	75015.	76486.	293829.
2002	10531.	3654.	6314.	2992.	5146.	3350.	13232.	0.	0.	101344.	12848.	64829.	224242.
2003	10868.	21795.	3258.	1129.	2370.	12308.	1047.	0.	14188.	65645.	5076.	0.	137683.
2004	8858.	62544.	6560.	63474.	17277.	156828.	10659.	6165.	2050.	24181.	272947.	43277.	674821.
2005	5789.	31835.	4140.	1172.	4985.	1980.	1047.	17358.	2386.	0.	0.	0.	70693.
2006	0.	3628.	5582.	4130.	4087.	1978.	1007.	0.	0.	4442.	4199.	2607.	31660.
2007	101612.	3539.	147016.	32975.	241558.	261693.	72913.	2893.	4364.	2861.	1946.	2268.	875638.
2008	0.	0.	4964.	13162.	8562.	1681.	723.	2394.	2133.	1256.	2496.	0.	37373.
2009	0.	0.	12101.	32918.	5598.	1894.	1047.	0.	76622.	304052.	72010.	4935.	511176.
2010	42682.	57090.	10600.	5161.	4589.	1980.	6164.	0.	76889.	6330.	0.	1137.	212623.
2011	29974.	9801.	722.	724.	3579.	1322.	470.	0.	0.	4995.	4560.	37630.	93777.
2012	62635.	57191.	152404.	6238.	3832.	4245.	769.	1118.	4364.	3509.	0.	0.	296306.
2013	24890.	6581.	1274.	3369.	4853.	2574.	2686.	1028.	2630.	162434.	39128.	11418.	262864.
2014	0.	0.	759.	1058.	24309.	62961.	2853.	0.	0.	2240.	21515.	3629.	119324.
2015	22393.	10405.	14825.	22096.	257245.	112083.	2080.	0.	0.	205701.	263178.	58053.	968059.
2016	2297.	0.	4537.	124602.	123493.	6899.	1047.	40774.	12858.	0.	9539.	13668.	339715.
MEAN	21649.	20052.	23375.	17198.	38923.	34771.	6397.	3775.	11958.	53352.	54422.	23599.	309472.

Table A.2.16 1940-2016 Naturalized Flows at Control Points BRWA41

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRWA41

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	13511.	8751.	6311.	101058.	122519.	451522.	168538.	255025.	72277.	13015.	416155.	405857.	2034539.
1941	133251.	492000.	318981.	508670.	1597861.	889095.	311899.	289184.	115304.	696350.	238298.	56767.	5647660.
1942	70132.	31336.	29147.	1401100.	670494.	579811.	51907.	55723.	358139.	527354.	105937.	71104.	3952184.
1943	44340.	31851.	73147.	110754.	89262.	95298.	17695.	5540.	32245.	15965.	5048.	9192.	530337.
1944	35857.	124744.	159193.	105126.	799391.	129965.	53302.	18829.	68051.	63554.	29701.	55540.	1643253.
1945	169336.	293601.	623968.	921067.	164507.	169682.	385705.	37233.	19884.	190258.	34980.	44715.	3054936.
1946	94816.	181795.	211690.	91267.	250528.	150689.	24717.	58841.	251697.	149131.	199340.	226418.	1890929.
1947	121070.	71206.	154912.	148784.	533060.	102259.	22351.	11410.	20402.	43651.	18216.	102513.	1349834.
1948	36297.	110596.	88161.	24339.	133683.	160620.	169895.	10027.	30427.	20527.	12101.	7324.	803997.
1949	16811.	69629.	103325.	116907.	711815.	321502.	61082.	9058.	101714.	105862.	33496.	11945.	1663146.
1950	27468.	124134.	24277.	135709.	248739.	79302.	264857.	129938.	237233.	54828.	9336.	7937.	1343758.
1951	2807.	16680.	11695.	10058.	145072.	290951.	26291.	31130.	44937.	6144.	8128.	10348.	604241.
1952	2679.	7888.	4138.	114264.	181202.	4674.	8307.	7541.	11621.	2868.	63290.	66153.	474625.
1953	22309.	8344.	65384.	49725.	346687.	658.	257207.	98607.	15421.	271823.	29943.	11873.	1177981.
1954	4012.	4515.	6528.	117990.	435691.	108754.	19080.	25155.	4504.	30170.	29672.	339.	786410.
1955	1612.	19071.	26282.	29644.	418528.	251878.	69588.	34920.	318764.	530893.	20788.	10526.	1732494.
1956	11472.	11813.	8006.	20571.	260403.	24749.	1858.	6619.	9965.	26692.	31205.	52363.	465716.
1957	3483.	245003.	56524.	1270684.	3376485.	820741.	128189.	23015.	31869.	257701.	308852.	91125.	6613671.
1958	95673.	112397.	183794.	207233.	766687.	72614.	252763.	47863.	87224.	12453.	10802.	12434.	1861937.
1959	9281.	31288.	15685.	32092.	80840.	272887.	149083.	35498.	16332.	940385.	57196.	144050.	1784617.
1960	330275.	154751.	83972.	97134.	99926.	39077.	205696.	22776.	4688.	264411.	68642.	192364.	1563712.
1961	569683.	424506.	156875.	54263.	56062.	485169.	403672.	67637.	82401.	165966.	139137.	108420.	2713791.
1962	45581.	29229.	33000.	48551.	33921.	410648.	239547.	115982.	554450.	165200.	59877.	66017.	1802003.
1963	24652.	17881.	23959.	140145.	133079.	213550.	23618.	0.	6964.	19390.	59273.	5920.	668431.
1964	19843.	72007.	66433.	92482.	35696.	99403.	6707.	31985.	142709.	15875.	224565.	25200.	832905.
1965	66295.	246828.	81367.	81729.	1220316.	118840.	20771.	43436.	59297.	73862.	63809.	30069.	2106619.
1966	10374.	44689.	46120.	569538.	680919.	113837.	35109.	100582.	619618.	98012.	34137.	17952.	2370887.
1967	15551.	13758.	20187.	94040.	55008.	194189.	166585.	37344.	66041.	66191.	35471.	41289.	805654.
1968	578887.	189354.	574446.	306677.	919100.	249612.	227613.	51312.	23272.	20152.	19894.	35462.	3195781.
1969	23923.	43026.	212274.	293027.	1148063.	131668.	44874.	41169.	155342.	87233.	64356.	124874.	2369829.
1970	93143.	129342.	553969.	222928.	202014.	60775.	6199.	9244.	41546.	53912.	13753.	12781.	1399606.
1971	13573.	18053.	13645.	41723.	77352.	86968.	94432.	288674.	146109.	404187.	78671.	362366.	1625753.
1972	147430.	61154.	31200.	46158.	122561.	38502.	34945.	130904.	138500.	86679.	162195.	44090.	1044318.
1973	126836.	129346.	198391.	499647.	187195.	433977.	125866.	59295.	35877.	221935.	47265.	27661.	2093291.
1974	52972.	26028.	27132.	55440.	38405.	42590.	8813.	70810.	374528.	423863.	559597.	100490.	1780668.
1975	108418.	433919.	108148.	308048.	325572.	286249.	70107.	57066.	52545.	9001.	14406.	4134.	1777613.
1976	11436.	21516.	18152.	142907.	219231.	132632.	285252.	37920.	101104.	166410.	96377.	111548.	1344485.
1977	86797.	205150.	450576.	645516.	333823.	97432.	24617.	8897.	17760.	9325.	8368.	6258.	1894519.
1978	7479.	22674.	33817.	66443.	42195.	26714.	3940.	601580.	24760.	28105.	17598.	8752.	884057.
1979	50578.	55002.	277256.	182194.	641949.	293719.	64127.	40800.	13017.	21506.	0.	29431.	1669579.
1980	59915.	56220.	25129.	82858.	312875.	52285.	7002.	1770.	116130.	270537.	17054.	52978.	1054753.
1981	19262.	16236.	100688.	92179.	55974.	572020.	53624.	29058.	5815.	1084073.	189644.	38806.	2257379.
1982	26170.	48280.	91801.	47773.	798827.	909409.	399441.	38612.	4688.	4578.	20062.	21144.	2410785.
1983	16155.	98914.	79337.	31696.	153482.	59490.	16447.	6653.	2272.	90284.	25296.	3834.	583860.
1984	36045.	18372.	57088.	13022.	12071.	17494.	5094.	11300.	10639.	215466.	92306.	235050.	723947.
1985	187713.	107914.	229495.	192150.	211973.	156915.	38047.	19983.	27913.	205158.	46862.	116251.	1540374.
1986	27195.	148119.	37447.	39350.	146315.	554207.	103128.	28863.	268976.	374276.	136909.	180199.	2044984.
1987	137076.	222062.	342034.	106827.	302223.	692822.	89092.	19057.	28631.	0.	20793.	79937.	2040554.
1988	48540.	38539.	34550.	20310.	16721.	146444.	35656.	733.	65076.	12339.	8221.	18254.	445383.
1989	27278.	134660.	196265.	124012.	959549.	819937.	55020.	75519.	116305.	15328.	8189.	6770.	2538832.
1990	44449.	86468.	370518.	1256164.	1413028.	422384.	26589.	60116.	98748.	35689.	33843.	15117.	3863113.
1991	101793.	65719.	45123.	138624.	265234.	518743.	70969.	187815.	118244.	427178.	267234.	2149397.	4356073.
1992	688885.	1374527.	782802.	207501.	312731.	684912.	135066.	57084.	45690.	11869.	45727.	108209.	4455003.
1993	72204.	303711.	305636.	147662.	106685.	108164.	25035.	11003.	15278.	183578.	19803.	30512.	1329271.
1994	40182.	92230.	91292.	58439.	628787.	113259.	35650.	0.	53915.	163384.	220838.	248794.	1746770.
1995	179571.	75637.	309638.	423311.	643423.	386179.	107773.	486342.	129703.	40271.	15609.	13884.	2811341.
1996	4694.	19703.	12795.	39749.	16030.	39054.	13167.	155998.	418270.	96992.	177896.	224000.	1218348.
1997	132951.	1084526.	813019.	550390.	440237.	391916.	137380.	37188.	12231.	21032.	16987.	236379.	3874236.
MEAN	88793.	143564.	157012.	225477.	425897.	261704.	101569.	73029.	104260.	165739.	82640.	112640.	1942324.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRWA41

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	62291.	105417.	273381.	36774.	9951.	18228.	8396.	6725.	8460.	77636.	129669.	65279.	802208.
1999	106922.	24461.	173695.	157900.	227180.	297932.	26424.	3634.	7309.	31800.	20831.	7970.	1086060.
2000	25219.	28310.	76116.	42575.	41397.	339284.	30689.	0.	2743.	194085.	494956.	96833.	1372206.
2001	127933.	314778.	278288.	43754.	106261.	25370.	9650.	9271.	143873.	41405.	208136.	84967.	1393685.
2002	29975.	38698.	221715.	149709.	207928.	61198.	509255.	44315.	20156.	599904.	96136.	130924.	2109914.
2003	34464.	49228.	29376.	18852.	112052.	893140.	44856.	22409.	95876.	71991.	39887.	11390.	1423522.
2004	34899.	358238.	146634.	304290.	100614.	568310.	283732.	319451.	43855.	332564.	1220458.	162407.	3875452.
2005	31519.	114490.	85653.	16167.	135740.	51091.	82916.	860237.	61026.	32867.	7255.	2152.	1481112.
2006	4201.	28878.	99916.	75666.	125059.	41720.	9007.	6713.	92813.	165363.	41605.	32175.	723116.
2007	87730.	23515.	460874.	280775.	927507.	1572139.	376799.	206065.	103056.	23237.	17917.	24044.	4103658.
2008	4736.	8816.	154381.	178355.	167044.	92171.	11133.	98030.	89216.	88686.	26880.	7283.	926731.
2009	2701.	8660.	27576.	102543.	148846.	91950.	267424.	39368.	338621.	557557.	45877.	58072.	1689194.
2010	193667.	262084.	112156.	296110.	224780.	69315.	333245.	42710.	347227.	71591.	9447.	27335.	1989668.
2011	17058.	23034.	7797.	11434.	31883.	13508.	2491.	3493.	7587.	208937.	46047.	102738.	476007.
2012	310552.	146748.	121290.	42015.	92371.	92751.	23540.	27143.	384332.	57245.	2622.	3880.	1304487.
2013	38034.	42879.	14361.	50625.	48829.	68727.	267671.	48801.	96544.	98329.	34928.	85950.	895677.
2014	24632.	7892.	8586.	14440.	147347.	216594.	91394.	31790.	77877.	46124.	215725.	86829.	969232.
2015	111300.	81879.	81227.	306534.	1977584.	968414.	195473.	31994.	10587.	481201.	974100.	269953.	5490246.
2016	31918.	12269.	35700.	544650.	1170718.	291539.	24418.	168457.	477449.	90322.	161975.	53785.	3063200.
MEAN	67355.	88436.	126775.	140693.	315952.	303862.	136764.	103716.	126769.	172150.	199708.	69156.	1851335.

Table A.2.17 1940-2016 Naturalized Flows at Control Points BRHB42

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRHB42

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	14754.	14791.	8624.	125139.	149370.	484655.	266624.	254009.	75863.	16362.	581172.	579843.	2571206.
1941	242060.	610386.	436244.	574812.	1741740.	1000421.	390094.	305527.	135616.	708094.	256758.	64313.	6466065.
1942	72540.	37136.	34255.	1471629.	822406.	658306.	63331.	64878.	442935.	557214.	144075.	101315.	4470020.
1943	61659.	43228.	95827.	141587.	113267.	108353.	22502.	9022.	36114.	25609.	7587.	12430.	677185.
1944	91874.	214332.	266812.	134091.	1103440.	230954.	67456.	24767.	89483.	68797.	49516.	108429.	2449951.
1945	258152.	367216.	723267.	1130141.	219028.	222330.	404382.	49550.	29139.	228880.	43755.	94476.	3770316.
1946	141272.	240929.	306761.	135257.	394744.	201916.	35485.	62350.	259243.	160462.	266686.	265947.	2471052.
1947	207038.	92565.	213859.	180642.	576248.	122082.	27458.	23215.	23917.	43848.	21727.	107849.	1640448.
1948	41150.	118026.	100757.	36387.	157651.	162837.	179452.	10417.	33324.	21813.	12773.	8403.	882990.
1949	22814.	74636.	130898.	188770.	728714.	334014.	71827.	10364.	101357.	111194.	37293.	20009.	1831890.
1950	35456.	170358.	28947.	158237.	266709.	99336.	260946.	137111.	244225.	57632.	10171.	7583.	1476711.
1951	3801.	19537.	17639.	11330.	151275.	300660.	25803.	31409.	49063.	7046.	8810.	11038.	637411.
1952	3755.	9630.	7579.	134250.	215563.	15850.	10278.	6971.	13777.	3397.	65980.	80426.	567456.
1953	42749.	14662.	84483.	59268.	473887.	6464.	259218.	99713.	23149.	308720.	38462.	67286.	1478061.
1954	9895.	7389.	7837.	117831.	445086.	107032.	18378.	26087.	4725.	30345.	35576.	1602.	811783.
1955	3374.	31419.	31572.	62708.	449062.	275727.	75111.	42490.	306274.	536254.	22983.	11435.	1848409.
1956	13949.	17755.	9411.	20951.	291969.	26821.	1487.	6414.	9858.	25746.	35266.	56330.	515957.
1957	3147.	241491.	68651.	1507987.	3599269.	929164.	160867.	36436.	37778.	429485.	366851.	124352.	7505478.
1958	119914.	232194.	246759.	239572.	877805.	104431.	263221.	56635.	114546.	23189.	16977.	17906.	2313149.
1959	13039.	44682.	20754.	60760.	99304.	295587.	160089.	45237.	20418.	1098655.	103507.	207196.	2169228.
1960	424778.	208997.	114680.	114258.	120286.	51785.	214089.	29602.	7209.	334524.	130740.	353090.	2104038.
1961	754973.	575016.	204722.	79741.	73252.	536812.	450765.	82795.	116807.	191113.	149487.	128824.	3344307.
1962	57610.	39328.	40479.	63904.	45549.	430360.	239674.	121116.	562942.	175629.	71577.	79455.	1927623.
1963	28383.	31687.	29503.	146975.	143213.	212787.	27795.	1251.	7692.	22613.	63903.	8478.	724280.
1964	22113.	76412.	76548.	99770.	47860.	117862.	9350.	35744.	175049.	25853.	242152.	33013.	961726.
1965	127607.	334007.	116825.	129175.	1548669.	186942.	42814.	57295.	73150.	84118.	109101.	52737.	2862440.
1966	23175.	90196.	66246.	807061.	853386.	114905.	15719.	158381.	639838.	96396.	24057.	18451.	2907811.
1967	22811.	15796.	23110.	110258.	78174.	220317.	167314.	38721.	83613.	66418.	107537.	77920.	1011989.
1968	665580.	233093.	621230.	365393.	1182689.	277791.	261397.	56160.	24534.	27070.	34381.	55012.	3804330.
1969	29287.	58607.	274155.	376767.	1184404.	107435.	38546.	39140.	151097.	84258.	77093.	155324.	2576113.
1970	102489.	150513.	716269.	242933.	215466.	71163.	7860.	21413.	46939.	67831.	18174.	13994.	1675044.
1971	14089.	19220.	14683.	46635.	71337.	96474.	118966.	298180.	144956.	417910.	125819.	467845.	1836114.
1972	190152.	74609.	38594.	48311.	126911.	42769.	38744.	134776.	142834.	94601.	184993.	65827.	1183121.
1973	182142.	144689.	340090.	648655.	274976.	656153.	148257.	73570.	40112.	332523.	87074.	40532.	2968773.
1974	74010.	45008.	43747.	71371.	59567.	44352.	15593.	77820.	493648.	406302.	970429.	158701.	2460548.
1975	161797.	545183.	133214.	334016.	502219.	376170.	106126.	84480.	64398.	14975.	25255.	17525.	2365358.
1976	29371.	41689.	35552.	270863.	374071.	179011.	392160.	42102.	110095.	232892.	111888.	177599.	1997293.
1977	87557.	334863.	461386.	859978.	348081.	115121.	39926.	13985.	29263.	15189.	14355.	8674.	2328378.
1978	10988.	31658.	77937.	67476.	44153.	40402.	8206.	589714.	25511.	29342.	20962.	8489.	954838.
1979	63961.	73759.	322436.	267735.	899009.	495445.	88525.	56677.	20296.	28557.	1817.	59749.	2377966.
1980	77621.	82717.	38681.	114903.	448234.	56776.	16535.	8474.	124389.	265141.	21779.	54152.	1309402.
1981	22885.	25869.	106517.	101521.	63441.	762397.	76925.	26771.	22351.	1175573.	217018.	51933.	2653201.
1982	41408.	55998.	119109.	64770.	863371.	912716.	441110.	47135.	13182.	15109.	20067.	35558.	2629533.
1983	17683.	132446.	116317.	42434.	193644.	71345.	24784.	39848.	3568.	90820.	24526.	5961.	763376.
1984	35111.	17196.	62519.	9483.	11536.	15121.	4687.	7988.	12223.	279928.	110343.	352518.	918653.
1985	214714.	171806.	253650.	177426.	238481.	164567.	46908.	12701.	24387.	243656.	143653.	225932.	1917881.
1986	28093.	361912.	48675.	48505.	219174.	662777.	103669.	28583.	242842.	423071.	168255.	283798.	2619354.
1987	172022.	267568.	420893.	130678.	327280.	853709.	122552.	25960.	34345.	3843.	25130.	105520.	2489500.
1988	52399.	51815.	50728.	27866.	23299.	146852.	44655.	6798.	64319.	18795.	8785.	22904.	519215.
1989	35114.	153189.	192830.	107245.	1104256.	981683.	89757.	126517.	122284.	22897.	12171.	14201.	2962144.
1990	51885.	101676.	502781.	1223122.	1517169.	448885.	48204.	69605.	106389.	62553.	57306.	20692.	4210267.
1991	249270.	138750.	54223.	187407.	355607.	526910.	69356.	205714.	146025.	429049.	361266.	2238383.	4961960.
1992	939691.	1649879.	937583.	282102.	404058.	803699.	176558.	71281.	60516.	20358.	63955.	157259.	5566939.
1993	101052.	368163.	455006.	236873.	172471.	125042.	29349.	22153.	33516.	201390.	39827.	41365.	1826207.
1994	38463.	134879.	91709.	37294.	727340.	119909.	36749.	16467.	54514.	149857.	203025.	271379.	1881585.
1995	184666.	71270.	344324.	435255.	707841.	411865.	94867.	564391.	126843.	39785.	17486.	20776.	3019369.
1996	18669.	33116.	26540.	52078.	23963.	46837.	14662.	164822.	444399.	108956.	191340.	273104.	1398486.
1997	159956.	1167950.	938150.	733267.	543084.	472603.	171968.	41782.	17866.	26621.	24198.	334689.	4632134.
MEAN	119241.	184705.	195734.	269911.	500242.	304219.	117399.	82802.	114909.	186004.	110463.	145509.	2331139.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRHB42

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	43065.	120984.	262438.	51820.	19191.	20527.	10486.	16682.	19930.	84934.	187898.	125393.	963349.
1999	137755.	37054.	136090.	195325.	240778.	345460.	18430.	16682.	8227.	38459.	20630.	17835.	1212727.
2000	27248.	30005.	84985.	57578.	55376.	344875.	37401.	1165.	7305.	169163.	604522.	181579.	1601203.
2001	144370.	383350.	381784.	60638.	84307.	39832.	18430.	16682.	170746.	90731.	232391.	149665.	1772927.
2002	50523.	55247.	228920.	209763.	203017.	91651.	448144.	61419.	19930.	639396.	222504.	115994.	2346508.
2003	65260.	55345.	44964.	27010.	84052.	698230.	62579.	16682.	93122.	96555.	52736.	16899.	1313433.
2004	37338.	418327.	228763.	325327.	179797.	577346.	438372.	357659.	86709.	340570.	1473548.	391284.	4855040.
2005	38979.	126966.	101085.	25798.	80618.	66698.	58248.	660895.	95445.	35957.	6056.	4174.	1300920.
2006	8039.	38940.	86489.	83073.	143186.	50542.	18430.	13416.	93078.	184616.	96862.	44319.	860990.
2007	123320.	48395.	391161.	457678.	1004572.	1880770.	699186.	242616.	158212.	37411.	21720.	36712.	5101753.
2008	9840.	22754.	118977.	237837.	195196.	78865.	10299.	93908.	145932.	89325.	38338.	10104.	1051374.
2009	5504.	21836.	27822.	78187.	159949.	91538.	236878.	40875.	329100.	689388.	119670.	89683.	1890430.
2010	230224.	357524.	135916.	330606.	256620.	93548.	348729.	55933.	320156.	137829.	12249.	20582.	2299915.
2011	19275.	40517.	12326.	13744.	27313.	24541.	4449.	2974.	7494.	179008.	97960.	95950.	525550.
2012	371460.	236152.	130146.	61311.	71537.	83296.	18430.	16682.	404145.	116312.	3138.	4862.	1517471.
2013	73054.	81963.	22486.	53058.	87736.	91454.	236965.	80269.	84624.	125836.	55352.	92123.	1084920.
2014	25026.	11479.	20298.	25588.	125003.	263899.	133518.	24752.	53553.	50889.	232307.	122664.	1088975.
2015	127882.	135546.	81203.	337150.	2219970.	1443038.	212579.	10103.	11249.	381394.	1347236.	454825.	6762175.
2016	49882.	24283.	45343.	590010.	1423818.	435939.	18431.	131757.	564494.	143906.	173875.	84895.	3686633.
MEAN	83581.	118246.	133747.	169553.	350633.	353792.	159473.	97955.	140708.	191141.	263105.	108397.	2170331.

Table A.2.18 1940-2016 Naturalized Flows at Control Points COPI48

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT COPI48

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	184.	293.	170.	4780.	1051.	15334.	8929.	1188.	296.	1069.	30839.	38668.	102801.
1941	15701.	38418.	39932.	22727.	62825.	28554.	15555.	2755.	7252.	9872.	3162.	2443.	249196.
1942	1795.	1620.	1378.	42435.	44427.	32853.	3928.	5225.	30346.	20695.	8731.	5186.	198619.
1943	3978.	2537.	2805.	5615.	3169.	1418.	664.	161.	1452.	1123.	483.	830.	24235.
1944	8199.	21555.	19708.	12811.	99028.	20545.	2763.	1609.	1590.	1631.	1455.	6106.	197000.
1945	20797.	19796.	33099.	71561.	14782.	11556.	5313.	1324.	1925.	7643.	3041.	7479.	198316.
1946	8594.	14609.	29593.	8223.	27239.	8515.	1787.	295.	3305.	1242.	2776.	4782.	110960.
1947	12012.	4621.	15837.	7832.	10585.	2103.	951.	332.	214.	0.	690.	982.	56159.
1948	384.	3522.	2024.	1382.	5017.	1676.	2822.	209.	1466.	0.	0.	0.	18502.
1949	90.	0.	10952.	13985.	5987.	4545.	1990.	304.	49.	483.	681.	171.	39237.
1950	204.	1862.	364.	1720.	5919.	3699.	2632.	188.	5935.	45.	11.	27.	22606.
1951	35.	76.	49.	261.	181.	3410.	1.	0.	6.	0.	0.	0.	4019.
1952	0.	0.	1.	4903.	14713.	383.	299.	0.	0.	0.	3550.	2721.	26570.
1953	816.	429.	6428.	3691.	23094.	140.	1553.	45.	1006.	572.	44.	35.	37853.
1954	40.	10.	1.	149.	1014.	10.	0.	0.	93.	533.	1355.	10.	3215.
1955	3.	1908.	1509.	3493.	19232.	4657.	492.	2513.	3644.	2844.	0.	10.	40305.
1956	32.	88.	3.	0.	40038.	4.	0.	1902.	0.	0.	754.	182.	43003.
1957	16.	32.	4274.	61442.	85793.	5976.	686.	142.	67.	22576.	10195.	4858.	196057.
1958	4134.	18387.	14838.	7676.	17074.	2408.	617.	315.	260.	159.	144.	152.	66164.
1959	151.	447.	140.	417.	409.	5792.	400.	1940.	1224.	87059.	3410.	9316.	110705.
1960	25305.	12474.	7521.	3824.	1740.	595.	282.	96.	125.	13617.	1561.	24867.	92007.
1961	47153.	41881.	16746.	4975.	2612.	22237.	15790.	1559.	681.	18740.	5294.	3796.	181464.
1962	2358.	1593.	1256.	1509.	561.	2630.	450.	2.	20.	2900.	466.	1847.	15592.
1963	292.	264.	1526.	481.	1935.	1400.	28.	0.	0.	0.	87.	0.	6013.
1964	15.	386.	3231.	3540.	2206.	2731.	11.	9092.	17254.	1002.	9939.	1466.	50873.
1965	3677.	22810.	5483.	3344.	130144.	6782.	1285.	1299.	4945.	2434.	25313.	5869.	213385.
1966	3574.	5246.	4673.	18419.	8002.	2224.	547.	14757.	8670.	1912.	922.	726.	69672.
1967	541.	391.	335.	1378.	661.	59.	275.	1.	25.	4.	6.	60.	3736.
1968	31256.	6476.	26836.	14989.	29693.	5827.	2864.	722.	356.	135.	165.	272.	119591.
1969	201.	446.	819.	7328.	14266.	673.	39.	44.	10.	6246.	3773.	6847.	40692.
1970	5106.	8965.	39156.	14547.	10649.	7781.	695.	126.	25785.	3135.	1180.	1076.	118201.
1971	885.	1015.	648.	1068.	789.	424.	19561.	1921.	2053.	17687.	3941.	17096.	67088.
1972	8281.	3929.	2074.	1137.	5610.	1351.	103.	33.	45.	1042.	129.	70.	23804.
1973	707.	1744.	3902.	8658.	5665.	8484.	3660.	271.	323.	7670.	1567.	1180.	43831.
1974	1410.	1045.	833.	295.	265.	346.	29.	1359.	13077.	14479.	9941.	4681.	47760.
1975	4877.	28917.	5750.	24771.	20580.	6216.	2766.	996.	247.	121.	121.	146.	95508.
1976	109.	88.	153.	644.	960.	3546.	24554.	921.	1540.	1212.	535.	2360.	36622.
1977	2253.	4884.	11232.	43531.	24226.	11229.	940.	335.	339.	19.	79.	108.	99175.
1978	97.	194.	142.	141.	61.	21.	54.	4.	13.	0.	46.	5.	778.
1979	398.	1490.	12579.	6060.	13868.	19867.	2926.	1792.	237.	87.	188.	268.	59760.
1980	379.	201.	194.	219.	10337.	401.	45.	12.	1255.	25.	13.	104.	13185.
1981	70.	89.	1495.	744.	1058.	34329.	1764.	1115.	1981.	434.	431.	339.	43849.
1982	348.	574.	5611.	3055.	9890.	3203.	1742.	41.	13.	0.	8.	25.	24510.
1983	76.	86.	690.	273.	409.	107.	19.	30.	0.	723.	1.	0.	2414.
1984	1.	0.	3937.	24.	63.	792.	34.	18.	13.	2069.	8.	1174.	8133.
1985	1522.	2075.	6464.	3078.	1993.	16676.	605.	5.	0.	11740.	215.	2132.	46505.
1986	606.	1552.	708.	373.	9996.	26218.	1168.	632.	2126.	7601.	6165.	12908.	70053.
1987	9844.	9701.	16206.	5979.	26914.	41795.	3610.	397.	578.	116.	473.	1084.	116697.
1988	576.	761.	491.	282.	64.	3547.	10.	1.	369.	18.	1.	1.	6121.
1989	118.	1093.	7356.	1286.	16901.	11926.	642.	413.	12.	0.	0.	11.	39758.
1990	78.	236.	8125.	28997.	28229.	1573.	490.	160.	53.	51.	139.	94.	68225.
1991	630.	674.	500.	2699.	3151.	1279.	1254.	131.	123.	3560.	2140.	116477.	132618.
1992	35954.	90480.	37195.	15831.	22442.	17771.	5609.	1466.	1046.	441.	1551.	3941.	233727.
1993	5280.	17105.	18564.	11749.	7502.	6326.	1128.	279.	188.	642.	489.	694.	69946.
1994	419.	1142.	1042.	700.	17170.	3488.	133.	81.	1016.	1342.	1954.	5984.	34471.
1995	7724.	4185.	8262.	34482.	13917.	5315.	2420.	2525.	1016.	202.	351.	433.	80832.
1996	350.	252.	212.	328.	148.	1000.	31.	8125.	5066.	1970.	8700.	9000.	35182.
1997	11070.	120500.	78360.	51340.	28660.	29875.	4600.	797.	264.	271.	233.	4366.	330336.
MEAN	5012.	9054.	9024.	10296.	16464.	7993.	2647.	1241.	2603.	4848.	2749.	5439.	77373.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT COP148

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	2552.	23394.	22801.	199.	691.	556.	0.	0.	0.	15116.	20469.	7030.	92808.
1999	3794.	747.	3299.	2541.	7958.	1141.	0.	0.	0.	0.	1.	170.	19652.
2000	1530.	3873.	677.	1393.	1834.	8597.	0.	0.	0.	6425.	42548.	5040.	71917.
2001	7507.	11398.	9363.	199.	320.	764.	0.	0.	8430.	0.	10746.	6354.	55081.
2002	3705.	288.	4678.	1716.	2163.	3463.	37426.	0.	0.	24464.	2451.	7225.	87579.
2003	1073.	5691.	898.	882.	616.	35337.	0.	0.	12621.	21789.	3.	0.	78911.
2004	1596.	16820.	7828.	34478.	3071.	98063.	666.	51905.	0.	10875.	103371.	9979.	338653.
2005	232.	14880.	2699.	1056.	7860.	1009.	0.	5084.	0.	0.	1.	0.	32820.
2006	0.	959.	5036.	199.	1052.	766.	0.	0.	0.	870.	3.	0.	8885.
2007	5746.	1469.	41348.	11079.	57781.	147352.	36754.	0.	3002.	0.	2.	1.	304534.
2008	0.	318.	287.	5854.	1334.	588.	0.	0.	0.	0.	2.	0.	8384.
2009	0.	498.	3924.	21837.	2948.	953.	0.	0.	10318.	51141.	8407.	1099.	101125.
2010	21813.	16720.	3047.	199.	979.	664.	3460.	0.	9252.	0.	1.	0.	56135.
2011	680.	751.	269.	441.	1387.	633.	0.	0.	0.	13085.	3.	7200.	24449.
2012	21993.	12671.	15135.	199.	936.	610.	0.	0.	3168.	0.	0.	0.	54713.
2013	7803.	287.	459.	314.	7950.	875.	1077.	0.	1693.	28560.	3508.	4455.	56982.
2014	0.	267.	1516.	711.	36660.	4336.	0.	0.	0.	830.	10026.	1.	54349.
2015	5723.	287.	3980.	3632.	128937.	6564.	0.	0.	0.	36247.	54002.	2495.	241868.
2016	0.	641.	190.	24480.	41960.	2789.	0.	4221.	7896.	0.	222.	1.	82399.
MEAN	4513.	5893.	6707.	5864.	16128.	16582.	4178.	3222.	2967.	11021.	13461.	2687.	93223.

Table A.2.19 1940-2016 Naturalized Flows at Control Points LEBE49

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT LEBE49

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	996.	1663.	989.	29935.	6951.	99398.	47950.	8588.	1881.	5540.	178880.	212374.	595145.
1941	85442.	247446.	217921.	131677.	415974.	159895.	83860.	52659.	41701.	59234.	18564.	14972.	1529345.
1942	10839.	9569.	8061.	289543.	267021.	187733.	22284.	27731.	184926.	146993.	49052.	29582.	1233334.
1943	22428.	14570.	20904.	31510.	20965.	8788.	3513.	857.	8295.	7821.	2627.	4666.	146944.
1944	47772.	118013.	108421.	68542.	538108.	107764.	21074.	8617.	10511.	9525.	8356.	32728.	1079431.
1945	110000.	111539.	195413.	400724.	81455.	64193.	35827.	7344.	10293.	43085.	16261.	39377.	1115511.
1946	48129.	83116.	155323.	43901.	146640.	48343.	9745.	2972.	26154.	6939.	26791.	28565.	626618.
1947	65459.	25266.	89097.	42694.	57143.	11901.	4970.	1752.	1134.	628.	3647.	8125.	311816.
1948	3291.	20034.	11361.	7593.	29822.	10752.	17160.	1122.	7959.	0.	0.	0.	109094.
1949	1948.	4882.	63764.	84231.	74672.	54852.	10961.	1723.	790.	6737.	3888.	2776.	311224.
1950	1836.	11627.	2590.	13198.	41989.	24440.	24078.	1215.	31041.	282.	0.	0.	152296.
1951	227.	681.	1216.	1916.	16013.	28302.	129.	0.	1891.	0.	0.	0.	50375.
1952	0.	0.	655.	27810.	67383.	10142.	2869.	0.	0.	0.	7505.	17992.	134356.
1953	5817.	1268.	17265.	10458.	159030.	3202.	10852.	4730.	3337.	21541.	5400.	2743.	245643.
1954	1614.	941.	871.	6797.	6382.	0.	0.	0.	0.	1607.	5422.	0.	23634.
1955	0.	8657.	3110.	22067.	79461.	34774.	4178.	2311.	18718.	8033.	0.	0.	181309.
1956	1198.	2738.	401.	2283.	132700.	1594.	0.	1780.	0.	0.	4892.	5735.	153321.
1957	754.	1189.	19502.	320798.	629618.	115459.	48244.	8985.	2275.	121588.	74926.	32359.	1375697.
1958	27961.	115492.	97050.	51761.	182914.	25528.	7832.	2491.	2253.	593.	807.	844.	515526.
1959	1440.	3932.	2880.	4034.	4149.	50027.	28597.	12401.	6497.	373854.	44385.	72791.	604987.
1960	154435.	83524.	42168.	27622.	16687.	6438.	4270.	769.	271.	55434.	10563.	115852.	518033.
1961	251258.	238021.	94668.	33152.	17095.	98867.	103156.	16558.	11158.	81064.	29311.	23857.	998165.
1962	13532.	10936.	9553.	12903.	9373.	17281.	7434.	7189.	56792.	21756.	6124.	11788.	184661.
1963	4865.	4693.	6578.	4569.	41615.	20939.	7365.	0.	479.	31.	8059.	10.	99203.
1964	5632.	11547.	18612.	49231.	18105.	86349.	3032.	19551.	80498.	34962.	73291.	19950.	420760.
1965	37572.	114298.	59493.	30088.	556717.	84356.	41358.	28056.	19058.	12944.	81815.	24696.	1090451.
1966	16254.	28572.	26528.	88730.	101473.	42890.	12281.	47456.	76656.	11115.	5336.	3130.	460421.
1967	4037.	2908.	5006.	12754.	19427.	26815.	14872.	223.	7798.	1231.	4621.	2830.	102522.
1968	221406.	88311.	176475.	117943.	230195.	86283.	53944.	7515.	4203.	1859.	3360.	4928.	996422.
1969	4271.	6538.	19760.	109639.	117955.	13007.	2322.	6437.	311.	12179.	14017.	30856.	337292.
1970	31898.	47585.	212616.	89383.	68523.	49948.	3416.	1935.	33153.	7736.	2542.	3469.	552204.
1971	3662.	3121.	3296.	5419.	18063.	3018.	112550.	25107.	8326.	63722.	22575.	78920.	347779.
1972	42422.	22549.	12757.	8663.	23397.	5231.	4757.	110.	0.	9246.	5689.	3834.	138655.
1973	16851.	20793.	41075.	66006.	42256.	48591.	25927.	1450.	1924.	51126.	13265.	5153.	334417.
1974	7728.	8229.	8035.	5910.	6064.	0.	2021.	28748.	94906.	136789.	98633.	51555.	448618.
1975	46654.	161335.	51857.	102305.	94285.	39231.	20944.	8192.	630.	0.	0.	1923.	527356.
1976	2385.	3093.	4660.	27438.	28232.	25029.	123211.	7450.	8423.	20736.	10970.	45860.	307487.
1977	20885.	54853.	82316.	250782.	142831.	47149.	9304.	2336.	441.	0.	0.	0.	610897.
1978	367.	4381.	6046.	3814.	2897.	2819.	693.	2117.	0.	0.	2367.	478.	25979.
1979	17336.	19869.	69797.	41614.	114477.	129676.	21344.	12206.	0.	270.	0.	2595.	429184.
1980	4609.	8250.	8425.	12106.	141766.	13092.	2820.	926.	2151.	0.	0.	1973.	196118.
1981	320.	1366.	12883.	10286.	6512.	151490.	6721.	3285.	7171.	31436.	4564.	522.	236556.
1982	2483.	4815.	18526.	16948.	67448.	52099.	21004.	5370.	0.	0.	0.	558.	189251.
1983	1156.	13502.	32494.	8578.	22552.	4874.	0.	827.	0.	1420.	0.	0.	85403.
1984	1799.	991.	12134.	1649.	856.	6872.	269.	0.	0.	35514.	9561.	23877.	93522.
1985	37361.	23392.	50880.	24693.	26181.	32840.	1992.	1215.	0.	56517.	11501.	52019.	318591.
1986	9836.	63182.	10817.	5477.	77689.	239575.	32375.	13469.	92091.	37627.	37631.	84344.	704113.
1987	51675.	50416.	87227.	32560.	109385.	225142.	62862.	7700.	8011.	470.	3145.	6499.	645092.
1988	4287.	6511.	5739.	4458.	2261.	79930.	7218.	4300.	2746.	1535.	155.	159.	119299.
1989	8959.	21350.	32015.	19651.	109585.	120735.	22506.	13934.	4904.	4350.	263.	0.	358252.
1990	4210.	3372.	37782.	285229.	308164.	64442.	31303.	23150.	9683.	8085.	6376.	1280.	783076.
1991	20225.	17003.	9410.	15610.	33544.	27995.	7263.	20446.	15368.	53358.	72903.	548662.	841787.
1992	243087.	511457.	246853.	107505.	186338.	143513.	81472.	43435.	37516.	9972.	11522.	35370.	1658040.
1993	36337.	116732.	136851.	92865.	68224.	38859.	6927.	3236.	5414.	31282.	15209.	5868.	557804.
1994	5433.	27150.	14959.	8493.	197109.	59215.	26148.	5001.	5378.	17049.	24996.	45142.	436073.
1995	38609.	22382.	57850.	211348.	130783.	83315.	24424.	106885.	27399.	23553.	3613.	5735.	735896.
1996	4164.	5597.	3020.	7245.	3950.	20317.	3131.	44712.	79896.	23205.	40625.	67286.	303148.
1997	53746.	404319.	295675.	218242.	217743.	229828.	70407.	17552.	4362.	4151.	6529.	94214.	1616768.
MEAN	32222.	52061.	52442.	64869.	109278.	59916.	23572.	11830.	18393.	28892.	18837.	32945.	505257.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT LEBE49

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	40950.	98533.	45246.	13655.	4844.	2986.	0.	0.	15589.	51538.	101339.	98861.	473540.
1999	17469.	1629.	20266.	15284.	21597.	5558.	0.	0.	0.	0.	0.	9237.	91040.
2000	11709.	13332.	1942.	10066.	17545.	24649.	0.	0.	0.	16534.	283451.	109181.	488410.
2001	75191.	88388.	160323.	17570.	20909.	4294.	0.	7071.	21479.	10040.	85562.	104088.	594914.
2002	18152.	13039.	17878.	5712.	18581.	12831.	39480.	0.	0.	151285.	102101.	84763.	463822.
2003	17916.	62725.	11827.	5244.	6043.	75954.	6168.	0.	59621.	76025.	16173.	0.	337696.
2004	15584.	90637.	78710.	95798.	42623.	247075.	23823.	26782.	0.	47249.	475309.	120715.	1264305.
2005	15895.	50549.	19830.	5967.	18715.	5102.	0.	22857.	0.	0.	0.	0.	138915.
2006	0.	9230.	20793.	9286.	12960.	4255.	0.	0.	0.	18700.	0.	6519.	81743.
2007	78035.	11208.	166513.	96377.	405455.	546346.	422880.	5363.	19720.	0.	9620.	0.	1761519.
2008	0.	7407.	16970.	47241.	17329.	3437.	0.	5865.	0.	8450.	0.	0.	106698.
2009	0.	8920.	17661.	27746.	21328.	4566.	0.	0.	117799.	514653.	79855.	13124.	805651.
2010	97058.	116462.	51560.	15926.	9846.	4338.	16038.	0.	82079.	13066.	0.	0.	406372.
2011	63575.	17463.	544.	3510.	15800.	2971.	0.	0.	0.	20279.	43764.	52633.	220540.
2012	133429.	237834.	158342.	20291.	16253.	14140.	0.	0.	18997.	0.	0.	0.	599287.
2013	49612.	17336.	901.	9928.	63797.	4553.	16528.	0.	16250.	159479.	22654.	17030.	378068.
2014	0.	5447.	514.	4705.	37221.	46881.	8222.	0.	0.	10777.	40166.	39265.	193197.
2015	51232.	19396.	43281.	25774.	574996.	432686.	0.	0.	0.	250899.	415617.	235966.	2049848.
2016	9398.	11421.	15292.	148805.	323320.	110085.	0.	35258.	19836.	0.	19476.	8869.	701760.
MEAN	36590.	46366.	44652.	30468.	86798.	81721.	28060.	5431.	19546.	70999.	89215.	47382.	587228.

Table A.2.20 1940-2016 Naturalized Flows at Control Points LRLR53

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT LRLR53

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	2284.	4920.	2538.	44307.	14520.	158571.	88760.	12945.	3472.	10541.	310269.	367084.	1020211.
1941	160810.	397407.	362346.	253236.	611278.	256792.	125502.	75336.	51804.	80406.	25830.	21387.	2422134.
1942	15711.	13705.	11900.	424266.	402208.	320605.	36375.	38331.	232646.	190364.	68730.	43995.	1798836.
1943	34141.	22128.	31611.	43620.	30580.	12212.	5393.	1582.	18721.	11651.	4587.	7434.	223660.
1944	79376.	209919.	190763.	112585.	920602.	220971.	40363.	22736.	21357.	17301.	18016.	81777.	1935766.
1945	214824.	224554.	341824.	590224.	150383.	112221.	53234.	17099.	32768.	67662.	33210.	69695.	1907698.
1946	85704.	139130.	236461.	72933.	191190.	68661.	14304.	6852.	34601.	11024.	35329.	42422.	938611.
1947	111500.	45460.	139020.	73763.	84447.	19216.	8206.	4623.	2672.	1823.	5715.	11213.	507658.
1948	5352.	37973.	16206.	15655.	45485.	13437.	26171.	5496.	10022.	600.	837.	1460.	178694.
1949	3389.	6693.	102073.	139357.	95192.	77730.	15074.	4297.	1465.	8448.	5418.	4480.	463616.
1950	3054.	18587.	4354.	20390.	55704.	33217.	29039.	1559.	43481.	900.	618.	684.	211587.
1951	937.	1538.	2149.	2933.	24802.	36802.	306.	100.	3798.	299.	584.	614.	74862.
1952	556.	500.	2011.	53603.	120237.	17826.	5975.	155.	301.	159.	10072.	39171.	250566.
1953	11161.	4097.	26281.	21443.	275462.	8334.	14758.	6229.	8122.	29575.	7323.	4471.	417256.
1954	3114.	1876.	1749.	9153.	13534.	252.	184.	148.	563.	3593.	27074.	638.	61878.
1955	2814.	17099.	6161.	29927.	153294.	66811.	16398.	8228.	30870.	9860.	475.	727.	342664.
1956	2075.	4469.	869.	2887.	187839.	2624.	30.	4905.	307.	1388.	13048.	11460.	231901.
1957	1935.	2830.	35928.	550401.	950933.	174230.	59997.	11859.	4734.	192601.	119169.	60400.	2165017.
1958	49227.	217288.	184020.	87549.	274117.	67370.	13889.	5614.	5113.	2739.	2672.	2687.	912285.
1959	3198.	6415.	4957.	7388.	6313.	86940.	36960.	23321.	14733.	600020.	80306.	133779.	1004330.
1960	254901.	146965.	81149.	49491.	28506.	11670.	10918.	4913.	5359.	142206.	33500.	218581.	988159.
1961	405878.	408758.	165640.	67709.	34415.	133186.	158162.	26593.	18323.	105744.	48880.	32805.	1606093.
1962	20578.	17086.	16877.	21371.	17649.	31154.	11355.	9502.	71862.	50721.	13518.	22241.	303914.
1963	12148.	9068.	12016.	8653.	49704.	26256.	11581.	817.	3481.	3996.	14003.	2331.	154054.
1964	9819.	19320.	34195.	61657.	31478.	108239.	6974.	24088.	107481.	46659.	91205.	26101.	567216.
1965	67047.	194101.	103604.	54281.	942741.	176894.	64998.	42486.	36485.	29125.	114245.	50353.	1876360.
1966	38437.	63451.	63477.	147378.	166199.	63703.	21312.	72003.	113631.	22935.	12871.	10251.	795648.
1967	9628.	7715.	9719.	16740.	28830.	28926.	19338.	3565.	12048.	7383.	9814.	9009.	162715.
1968	353752.	133891.	278572.	163782.	305532.	113429.	92553.	17419.	12742.	6658.	8721.	12093.	1499144.
1969	10108.	18587.	42450.	195924.	188032.	27530.	7897.	13142.	4330.	28690.	24882.	55834.	617406.
1970	55278.	83782.	369528.	138042.	117076.	86704.	12310.	7277.	63006.	18074.	7055.	8241.	966373.
1971	7975.	8025.	8785.	10981.	24119.	5994.	148474.	38481.	10824.	84071.	31649.	114250.	493628.
1972	61106.	34320.	20949.	16105.	59755.	16224.	11542.	5144.	1315.	17988.	18325.	12211.	274984.
1973	43239.	54557.	88284.	106225.	83594.	72065.	43003.	5657.	10029.	109700.	37577.	19016.	672946.
1974	23027.	19696.	18526.	13845.	25741.	8270.	7277.	83290.	172527.	262097.	207738.	96929.	938963.
1975	92903.	283604.	91568.	138956.	248512.	125158.	70809.	31132.	9592.	6738.	4964.	7950.	1111886.
1976	7596.	8453.	12220.	77040.	85203.	56047.	173945.	20409.	21487.	53242.	34829.	95968.	646439.
1977	57974.	124384.	134727.	443236.	195344.	72129.	19833.	9894.	5349.	2914.	3587.	3697.	1073068.
1978	3771.	12069.	13347.	8746.	6562.	11991.	5675.	5563.	2872.	989.	7169.	3718.	82472.
1979	32754.	50710.	122494.	100045.	216453.	236292.	59105.	39903.	7432.	5791.	3670.	10535.	885184.
1980	11521.	17421.	17553.	23809.	258507.	31676.	9791.	4919.	6934.	2422.	3438.	6492.	394483.
1981	3881.	6266.	24608.	24207.	24978.	371352.	41843.	14577.	24207.	67302.	21582.	9521.	634324.
1982	10565.	12230.	30170.	34617.	109498.	70882.	26328.	7623.	2122.	2155.	4025.	4262.	314477.
1983	6823.	37438.	72298.	23280.	77308.	26263.	7172.	6690.	3444.	4263.	2376.	2889.	270244.
1984	6278.	4374.	20582.	5023.	2605.	17198.	6081.	1392.	2580.	55131.	16953.	37967.	176164.
1985	53843.	58375.	111884.	55258.	51546.	58361.	7273.	3982.	5814.	105055.	43220.	111821.	666432.
1986	28730.	149736.	26245.	15457.	87899.	343518.	54786.	20590.	112831.	86172.	93500.	203692.	1223156.
1987	142348.	109716.	167038.	70786.	148202.	388553.	126599.	30324.	25451.	6882.	12078.	21323.	1249300.
1988	15023.	15444.	15678.	12391.	8203.	102324.	15540.	9732.	5993.	4299.	3447.	3459.	211533.
1989	15797.	32590.	44810.	31728.	154382.	137782.	31675.	19004.	7201.	6298.	1812.	1611.	484690.
1990	8225.	8024.	56350.	313183.	344493.	68294.	42475.	28890.	18834.	14698.	18214.	7523.	929203.
1991	53233.	41786.	27863.	30801.	123940.	72644.	21004.	26946.	26241.	63761.	90545.	849246.	1428010.
1992	406249.	896591.	466373.	210626.	351435.	241992.	66693.	24366.	54232.	17770.	22904.	55858.	2815089.
1993	55230.	174548.	203402.	136187.	170863.	115462.	37836.	11067.	15124.	37422.	20087.	10842.	988070.
1994	10528.	45950.	31044.	15287.	217998.	77049.	31590.	9822.	9778.	26620.	33241.	66765.	575672.
1995	70824.	35572.	97551.	255451.	165193.	106721.	29488.	126590.	33496.	34148.	4556.	7450.	967040.
1996	6088.	9934.	5645.	11089.	11804.	39134.	10894.	53640.	91350.	25976.	48703.	89550.	403807.
1997	103637.	574078.	393003.	395889.	340458.	395570.	119209.	34309.	10379.	10274.	15621.	190137.	2582564.
MEAN	58067.	91469.	89715.	104498.	174360.	100542.	38522.	19779.	28754.	48575.	33686.	58588.	846554.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT LRLR53

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	29049.	126008.	202764.	20241.	5183.	5863.	7060.	11588.	18754.	91599.	144674.	79067.	741850.
1999	24916.	4206.	46142.	37673.	82087.	29384.	8268.	2586.	490.	7500.	2820.	8615.	254686.
2000	14188.	14541.	11200.	14537.	24572.	82942.	5397.	186.	1000.	41452.	395354.	88199.	693567.
2001	68435.	153407.	137693.	21321.	22997.	10680.	5938.	7388.	52048.	16376.	78900.	72450.	647632.
2002	25354.	26512.	77384.	19634.	37297.	35624.	242006.	20419.	8781.	245616.	52007.	63582.	854216.
2003	42033.	61144.	17366.	6235.	12357.	247322.	25022.	3923.	95612.	133876.	16949.	902.	662741.
2004	15487.	170884.	89450.	215608.	73581.	553963.	63569.	235249.	44229.	97216.	648166.	128835.	2336239.
2005	15542.	98098.	34771.	7688.	61018.	14239.	5281.	60441.	8622.	535.	838.	438.	307512.
2006	2543.	12957.	63669.	24652.	23914.	16060.	4922.	974.	6920.	36236.	13304.	9764.	215914.
2007	58316.	13639.	271004.	146490.	546306.	1026545.	514942.	19289.	39801.	12739.	10530.	5380.	2664981.
2008	3009.	3022.	43268.	92983.	24375.	7365.	5546.	14026.	14155.	14502.	7124.	482.	229858.
2009	1944.	3151.	35552.	95852.	65595.	17022.	22372.	5745.	156301.	472254.	71825.	14752.	962365.
2010	137621.	177564.	46709.	29816.	17950.	15308.	47846.	2660.	104990.	16220.	706.	5454.	602845.
2011	15367.	15079.	2906.	2798.	33902.	6953.	2638.	232.	944.	127052.	25215.	78833.	311919.
2012	241737.	166572.	147051.	16120.	41699.	36120.	15847.	5800.	48684.	11680.	292.	385.	731986.
2013	73580.	18398.	5436.	41282.	69448.	13370.	34591.	10490.	21797.	168238.	51905.	67492.	576026.
2014	8374.	2459.	3082.	5718.	153860.	94303.	17962.	2660.	10344.	18827.	116098.	25819.	459505.
2015	67697.	44154.	38705.	86565.	971428.	249865.	10556.	799.	914.	224929.	587330.	105432.	2388373.
2016	10178.	4187.	20636.	238024.	540531.	112103.	5397.	33832.	87861.	11579.	25467.	16447.	1106242.
MEAN	45019.	58736.	68147.	59118.	147795.	135528.	55008.	23068.	38013.	92022.	118395.	40649.	881498.

Table A.2.21 1940-2016 Naturalized Flows at Control Points LRCA58

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT LRCA58

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	4226.	21590.	5258.	106875.	118827.	246700.	402103.	19420.	8136.	4495.	506043.	610025.	2053698.
1941	315015.	455249.	479749.	373647.	726451.	362613.	284318.	63419.	64427.	91154.	32427.	31703.	3280172.
1942	23611.	21123.	19061.	425969.	430471.	399415.	50025.	37408.	363203.	194891.	104993.	79515.	2149685.
1943	57420.	35888.	63316.	80835.	60426.	21544.	13364.	5496.	17900.	14417.	7410.	11746.	389762.
1944	135108.	250462.	293583.	104171.	1068994.	348162.	61100.	25487.	56027.	22390.	51862.	167741.	2585087.
1945	297407.	273083.	363821.	727424.	202570.	198540.	78128.	36705.	27622.	108972.	38913.	91310.	2444495.
1946	139675.	206939.	285995.	149245.	296669.	130473.	28745.	14295.	68529.	31980.	195864.	142339.	1690748.
1947	291011.	104021.	194624.	143003.	153937.	50414.	16068.	10291.	7176.	4705.	8829.	15755.	999834.
1948	10867.	30930.	28825.	35462.	76134.	22574.	34972.	6921.	9553.	2397.	1731.	2768.	263134.
1949	14724.	24366.	78939.	328272.	128540.	79661.	19280.	6422.	3333.	8832.	8073.	13895.	714337.
1950	6727.	56793.	10489.	63097.	67404.	53390.	32616.	3481.	61698.	3378.	1664.	2178.	362915.
1951	2612.	5157.	17554.	5356.	33662.	53473.	1469.	357.	9342.	1084.	813.	1269.	132148.
1952	1434.	2197.	4451.	66336.	147443.	40467.	6170.	631.	194.	42.	9515.	48595.	327475.
1953	36748.	21496.	31670.	43639.	308665.	18478.	11832.	6446.	22462.	180731.	30011.	139039.	851217.
1954	12248.	7277.	5001.	8669.	33502.	885.	383.	499.	1261.	3035.	21181.	1445.	95386.
1955	3872.	36918.	15379.	51025.	164383.	99776.	17921.	23814.	27151.	10262.	1651.	2016.	454168.
1956	2934.	9845.	1134.	2816.	152079.	5674.	0.	2835.	0.	965.	16402.	16922.	211606.
1957	2608.	4490.	50463.	929072.	918874.	438716.	73019.	39289.	18151.	557391.	216694.	111667.	3360434.
1958	88002.	453666.	271342.	134038.	378932.	120411.	39544.	14005.	68454.	24501.	19316.	15032.	1627243.
1959	13153.	29231.	17095.	52065.	40144.	73992.	51048.	28166.	24919.	753704.	155207.	238967.	1477691.
1960	340219.	231706.	122548.	79105.	51140.	26225.	19517.	11294.	8639.	322054.	127079.	421910.	1761436.
1961	553706.	604542.	232899.	98858.	60088.	224407.	218538.	49457.	115461.	115421.	56456.	73767.	2403600.
1962	40457.	37607.	29942.	60340.	37024.	88833.	30018.	11344.	74927.	59877.	53625.	60050.	584044.
1963	19814.	44799.	20596.	23763.	51968.	25929.	13560.	1460.	4582.	13295.	18464.	4744.	242974.
1964	11307.	31646.	48923.	65542.	44837.	117572.	15580.	24676.	143601.	48880.	109312.	41258.	703134.
1965	233735.	370929.	143957.	116742.	1318816.	199502.	82164.	51249.	57907.	57116.	177225.	129637.	2938979.
1966	70898.	124114.	97968.	371795.	286922.	87782.	31012.	76562.	150089.	37779.	20018.	17768.	1372707.
1967	15648.	12770.	13966.	27670.	85515.	28518.	19777.	3479.	27728.	29354.	83485.	47114.	395024.
1968	691195.	205119.	393816.	247919.	463806.	225958.	192749.	27593.	29522.	13098.	26881.	56212.	2573868.
1969	24533.	75747.	120277.	327202.	268971.	55233.	15243.	30381.	18782.	39111.	28597.	93104.	1097181.
1970	85925.	160015.	504530.	182973.	237648.	129579.	26751.	13200.	70584.	43533.	12277.	12767.	1479782.
1971	11879.	11593.	12004.	17895.	40452.	7665.	146759.	51247.	12873.	80498.	54209.	149841.	596915.
1972	74681.	45317.	27688.	18960.	82310.	44853.	14989.	7141.	4276.	61086.	44521.	30031.	455853.
1973	104438.	98034.	143990.	181291.	161860.	98294.	62933.	14159.	29256.	278181.	110709.	46228.	1329373.
1974	76926.	43133.	33649.	22309.	113400.	22808.	9571.	106606.	272382.	227246.	380376.	131691.	1440097.
1975	131636.	408286.	126988.	145374.	573701.	255471.	123061.	60054.	27287.	21599.	14049.	16227.	1903733.
1976	14865.	13265.	22672.	260733.	235938.	92373.	247140.	39966.	34043.	69352.	64923.	171137.	1266407.
1977	82730.	251201.	161950.	656109.	234136.	87293.	29728.	13090.	7981.	4645.	6539.	6462.	1541864.
1978	7337.	19546.	21682.	18293.	9536.	13266.	4802.	8269.	3698.	1519.	14720.	7501.	130169.
1979	83145.	129735.	272084.	212412.	422369.	316696.	233681.	61632.	15847.	10211.	9322.	19413.	1786547.
1980	25594.	40885.	50864.	46476.	328986.	38696.	10670.	6084.	10707.	5963.	6568.	12796.	584289.
1981	8964.	16086.	59378.	39855.	57057.	799417.	90423.	19309.	85928.	117109.	48980.	23149.	1365655.
1982	20992.	19687.	35745.	69523.	232452.	100366.	38295.	8665.	2009.	5190.	7951.	8709.	549584.
1983	15134.	83314.	145185.	46042.	192718.	86093.	16414.	26040.	6341.	5588.	4951.	5089.	632909.
1984	9168.	6405.	25218.	6843.	207.	21514.	3465.	1259.	2302.	170360.	29158.	89979.	365878.
1985	108080.	145987.	186568.	87601.	86664.	81531.	14701.	3966.	3075.	109496.	96981.	197214.	1121864.
1986	49014.	265813.	52271.	27167.	131271.	382704.	40139.	23807.	116569.	165242.	119916.	418349.	1792262.
1987	187741.	172902.	236611.	100795.	229780.	769125.	148625.	46189.	31538.	15023.	31699.	39841.	2009869.
1988	31269.	24431.	25216.	18001.	9350.	122843.	15192.	13400.	4700.	2730.	3617.	4298.	275047.
1989	17931.	36193.	52408.	34837.	247694.	161443.	37365.	19098.	7286.	6161.	2531.	2071.	625018.
1990	9514.	10753.	76108.	344155.	423858.	98865.	61149.	30140.	19711.	15035.	22719.	8341.	1120348.
1991	195638.	91220.	50450.	130030.	186205.	112987.	28856.	28875.	37788.	68174.	87033.	1320477.	2337733.
1992	574007.	1403136.	690408.	224458.	568694.	401559.	163609.	107953.	67406.	24855.	32663.	86273.	4345021.
1993	100136.	233876.	299945.	186726.	290048.	208711.	62120.	13708.	16249.	42243.	28287.	18564.	1500613.
1994	16754.	48847.	49040.	19774.	233470.	96358.	34327.	8664.	13725.	100557.	52099.	144553.	818168.
1995	100503.	51057.	211495.	295836.	240525.	193678.	49472.	118107.	36377.	33867.	8819.	11828.	1351564.
1996	10371.	12165.	7739.	14624.	11049.	41477.	11180.	53649.	153452.	42102.	58669.	150299.	566776.
1997	134515.	655338.	461944.	665585.	536956.	616065.	177556.	56231.	17994.	17905.	25341.	258527.	3623957.
MEAN	99134.	142895.	129422.	160769.	246475.	159432.	64883.	27472.	44865.	77600.	60506.	104847.	1318302.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT LRCA58

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	55930.	247290.	177650.	25983.	15275.	16235.	16369.	4245.	91633.	720851.	418397.	204125.	1993983.
1999	34271.	15921.	64311.	27918.	83129.	40260.	16369.	4245.	37.	1882.	7859.	27078.	323280.
2000	121666.	48329.	32204.	30611.	49760.	52427.	16369.	0.	1777.	53701.	821680.	407339.	1635863.
2001	183182.	120255.	372157.	43247.	69992.	25983.	14751.	58675.	53086.	44895.	265641.	373987.	1625851.
2002	41514.	41274.	38036.	25983.	19862.	51534.	206377.	4245.	8881.	406056.	301599.	245427.	1390788.
2003	108953.	260947.	49149.	19830.	15617.	60337.	25308.	4245.	63273.	146038.	56262.	3797.	813757.
2004	94890.	307564.	92182.	225915.	218669.	725590.	200243.	57126.	52113.	297248.	1219481.	369121.	3860142.
2005	90233.	126300.	70066.	21789.	65750.	25983.	16369.	67828.	8881.	1173.	1776.	1026.	497176.
2006	7912.	30579.	50711.	47054.	40385.	25983.	16369.	1906.	8358.	84442.	12066.	55061.	380827.
2007	326044.	25983.	495444.	310981.	677182.	1092662.	1201130.	28449.	42337.	8777.	32547.	10896.	4252432.
2008	9332.	12829.	60763.	64571.	44278.	18868.	9808.	4245.	8881.	7597.	9351.	1070.	251594.
2009	1824.	13689.	64360.	60584.	42974.	20771.	16369.	4245.	398350.	986766.	381379.	85742.	2077053.
2010	170948.	394397.	105886.	43773.	21636.	23426.	51052.	4245.	237310.	8777.	1216.	3869.	1066534.
2011	56946.	32461.	12925.	7615.	17658.	16738.	1464.	0.	1026.	30697.	122620.	273852.	574001.
2012	306144.	390727.	527299.	25983.	53958.	25983.	41625.	4245.	64910.	8777.	299.	166.	1450117.
2013	159378.	47643.	20156.	39340.	54784.	25983.	47086.	4245.	70145.	696820.	348329.	49231.	1563140.
2014	15448.	10889.	18412.	20401.	146322.	165907.	16369.	4245.	43600.	31581.	231741.	131512.	836426.
2015	237956.	60853.	138554.	99496.	1404414.	729218.	16369.	1333.	1422.	683773.	920947.	312040.	4606375.
2016	20143.	18731.	70134.	384420.	730472.	129031.	16369.	181927.	41034.	3616.	57710.	73642.	1727228.
MEAN	107511.	116140.	129495.	80289.	198532.	172259.	102430.	23142.	63003.	222288.	274258.	138367.	1627714.

Table A.2.22 1940-2016 Naturalized Flows at Control Points BRBR59

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRBR59

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	20668.	40863.	18746.	232186.	269190.	646623.	691218.	261673.	94493.	31194.	1301729.	1338018.	4946601.
1941	710547.	1136414.	949374.	879686.	2428023.	1515114.	736924.	388540.	227319.	790700.	346374.	99034.	10208049.
1942	86065.	63247.	57321.	1837072.	1499241.	1018999.	114300.	106386.	819979.	708839.	311067.	232995.	6855511.
1943	137313.	93056.	195609.	277770.	219434.	168291.	43756.	24076.	54065.	67328.	18608.	26616.	1325922.
1944	331524.	600771.	731463.	262076.	2432620.	666071.	130087.	50875.	183724.	94057.	135088.	335714.	5954070.
1945	643403.	693734.	1174414.	2061579.	458369.	453957.	501845.	103625.	69389.	401886.	82677.	307965.	6952843.
1946	343076.	500678.	720575.	326420.	1019157.	426611.	82391.	80020.	303125.	215606.	562145.	444505.	5024309.
1947	577925.	186644.	471549.	322965.	784759.	211096.	50204.	73898.	39808.	46734.	37497.	135331.	2938410.
1948	63473.	154787.	158409.	88709.	265752.	179801.	228033.	12546.	47060.	28242.	16194.	13332.	1256338.
1949	49103.	99176.	252885.	499544.	833944.	402271.	120344.	16338.	104622.	138821.	54999.	54827.	2626874.
1950	70681.	372554.	49927.	260313.	354736.	188170.	256778.	173689.	285075.	72119.	14156.	6454.	2104652.
1951	8154.	32457.	43441.	17205.	184440.	355573.	24966.	34059.	68700.	11166.	12091.	14454.	806706.
1952	8450.	17399.	22390.	224521.	370047.	63548.	19041.	4904.	23481.	5777.	80381.	144168.	984107.
1953	130628.	41891.	168690.	102145.	1030533.	31157.	279846.	109045.	56701.	478235.	76056.	303244.	2808171.
1954	35073.	19810.	13704.	122697.	505466.	104827.	16290.	31227.	5876.	32506.	62050.	6984.	956510.
1955	10935.	84768.	55278.	204561.	598436.	388871.	101842.	76287.	268192.	583972.	33283.	15789.	2422214.
1956	25010.	43550.	15754.	23532.	438298.	36784.	0.	5855.	9871.	22982.	53982.	75640.	751258.
1957	1883.	238085.	122823.	2575770.	4704312.	1428314.	305708.	94533.	64379.	1171344.	627748.	269783.	11604682.
1958	227387.	746379.	522873.	386687.	1385864.	243002.	319525.	96150.	234711.	69381.	43714.	41737.	4317410.
1959	29438.	103051.	43023.	184050.	181537.	404838.	213850.	88275.	38543.	1815182.	302927.	482214.	3886928.
1960	841752.	446710.	249074.	191568.	211473.	107604.	259405.	59668.	18138.	644793.	397761.	1044906.	4472852.
1961	1568862.	1234340.	415351.	190522.	148911.	778990.	669785.	150363.	266838.	305735.	199992.	220598.	6150287.
1962	110853.	83602.	73799.	131405.	96537.	533392.	251466.	148374.	625066.	227694.	124091.	139644.	2545923.
1963	45390.	91175.	54180.	182572.	192516.	219579.	46651.	6563.	11112.	37216.	86357.	19623.	992934.
1964	32690.	98509.	122636.	135074.	101209.	200949.	20893.	53216.	319138.	68985.	327413.	67386.	1548098.
1965	391181.	715945.	271277.	334569.	3000872.	481830.	137428.	118211.	134786.	155448.	315403.	229532.	6286482.
1966	113934.	251106.	208576.	1237884.	1198005.	227672.	52837.	247046.	784402.	173674.	50470.	39499.	4585105.
1967	46404.	38335.	45863.	135090.	177145.	237986.	183891.	44326.	115766.	73244.	246832.	148446.	1493328.
1968	1456047.	499351.	1023672.	661448.	1630044.	738836.	525281.	91423.	56740.	46094.	64073.	150477.	6943486.
1969	67139.	188301.	486894.	821188.	1370058.	189881.	84930.	88684.	179242.	134767.	133769.	300468.	4045321.
1970	226770.	334741.	1314819.	461875.	493554.	222459.	41362.	35919.	120143.	157540.	35542.	31185.	3475909.
1971	31733.	37100.	29824.	64915.	133948.	101408.	243694.	362640.	158860.	479717.	206127.	667264.	2517230.
1972	282938.	137065.	70220.	62409.	239490.	90488.	59117.	152047.	151333.	187220.	258263.	120976.	1811566.
1973	387381.	273673.	551852.	790557.	531459.	759130.	235485.	101959.	73258.	735800.	278158.	124905.	4843617.
1974	230549.	95450.	95595.	107648.	223017.	75510.	33128.	174376.	929972.	599620.	1419990.	324889.	4309744.
1975	317743.	1029292.	284850.	415787.	1148909.	697819.	286069.	172329.	103478.	57768.	50750.	31664.	4596458.
1976	43514.	55532.	69354.	638177.	783592.	318658.	696011.	100920.	159915.	335644.	222986.	528660.	3952963.
1977	197206.	714687.	626263.	1623026.	742476.	256305.	65097.	29075.	40506.	23522.	27873.	20942.	4366978.
1978	24244.	66038.	133612.	97909.	57925.	70884.	16539.	590426.	37295.	30065.	42841.	20180.	1187958.
1979	204317.	284602.	746604.	667920.	1544669.	1037689.	461235.	154551.	48134.	49124.	19702.	87363.	5305910.
1980	144797.	156432.	116637.	163071.	870273.	129138.	41584.	19635.	133167.	268692.	70583.	74069.	2188078.
1981	29035.	47918.	176533.	155016.	141509.	1686724.	239821.	66728.	111621.	1269107.	309487.	84569.	4318068.
1982	60717.	77192.	154648.	159158.	1114046.	991608.	506453.	58639.	17784.	20682.	27297.	58388.	3246612.
1983	44400.	287728.	295842.	101672.	477801.	171481.	41447.	68193.	23027.	103195.	34210.	15631.	1664627.
1984	48189.	28983.	106616.	24779.	12659.	49373.	13113.	13490.	19652.	502419.	159079.	485231.	1463583.
1985	359162.	377037.	494009.	296332.	334995.	257228.	79603.	24541.	27010.	361258.	353325.	508298.	3472798.
1986	93270.	663642.	124137.	90513.	453801.	1063516.	151292.	68313.	380713.	605711.	361675.	905421.	4962004.
1987	386738.	467130.	687962.	246082.	554823.	1925770.	333193.	99913.	81133.	29584.	63610.	168556.	5044494.
1988	110619.	84809.	95577.	63081.	44710.	278428.	67731.	28069.	68913.	21596.	12100.	28659.	904292.
1989	55393.	195076.	237878.	181464.	1366744.	1206576.	164281.	198010.	134151.	37834.	20563.	15711.	3813681.
1990	63679.	112238.	612734.	1578256.	2063005.	680096.	116895.	110832.	138567.	72464.	100667.	37777.	5687210.
1991	647776.	309362.	118790.	380206.	609368.	688054.	116911.	228305.	183482.	455039.	469377.	3911671.	8118341.
1992	1814637.	3506035.	1901729.	652463.	1129677.	1389551.	402612.	193329.	118134.	56491.	100849.	281377.	11546884.
1993	241136.	596137.	938832.	488331.	645052.	484741.	130651.	43218.	46892.	267753.	74857.	65862.	4023462.
1994	60683.	201915.	154683.	62718.	1055930.	237677.	78113.	27619.	74995.	275205.	280381.	457109.	2967028.
1995	313401.	134437.	610845.	803469.	1042254.	665492.	158629.	750065.	179379.	80944.	28909.	35832.	4803656.
1996	31915.	49764.	37673.	73305.	38478.	97057.	28400.	240100.	657038.	166013.	274760.	465320.	2159823.
1997	323624.	2003794.	1538703.	1537338.	1186964.	1196446.	384127.	107716.	39410.	48934.	54443.	651944.	9073443.
MEAN	257941.	366284.	363214.	463764.	812622.	508275.	201071.	121738.	168419.	275046.	197885.	291704.	4027961.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRBR59

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	125599.	419641.	525987.	73790.	29738.	25409.	22580.	21228.	45072.	345352.	736181.	387385.	2757964.
1999	203992.	42270.	175133.	228247.	381850.	273595.	32125.	21228.	11863.	72027.	30655.	64672.	1537656.
2000	73991.	85236.	144511.	127549.	129229.	646290.	32125.	2390.	28973.	210883.	1701138.	680948.	3863263.
2001	348396.	667620.	757248.	159166.	157617.	45677.	32125.	34014.	288410.	120431.	487851.	650036.	3748591.
2002	170295.	94547.	218437.	218793.	193018.	132992.	540273.	76249.	30837.	983133.	592561.	329406.	3580539.
2003	155630.	204172.	100082.	51624.	100147.	710177.	151132.	21228.	218287.	318296.	151813.	24395.	2206984.
2004	115000.	738708.	446968.	600670.	468608.	1615291.	970287.	339745.	111050.	529775.	2784638.	1112945.	9833685.
2005	112603.	252337.	202232.	45677.	165026.	94146.	79784.	549183.	162561.	28658.	19343.	8694.	1720244.
2006	13719.	109428.	218739.	167361.	167211.	90495.	32125.	21228.	92579.	301113.	149173.	107969.	1471141.
2007	403203.	82416.	831146.	1116764.	1878272.	3585659.	2237442.	242799.	232265.	74121.	68472.	74838.	10827397.
2008	23206.	48640.	212902.	510367.	231351.	75766.	15673.	114568.	114535.	138944.	59997.	11320.	1557270.
2009	10160.	36142.	124318.	233154.	245461.	80759.	155396.	21228.	658619.	2176230.	675851.	102414.	4519732.
2010	469404.	714906.	245744.	345771.	235977.	125877.	363390.	21228.	582871.	314788.	14019.	48622.	3482598.
2011	53114.	89559.	25893.	15874.	42809.	48922.	11319.	848.	8776.	205238.	116336.	197955.	816644.
2012	743249.	693125.	586273.	104262.	138462.	125582.	44572.	21228.	224998.	173935.	9336.	7210.	2872232.
2013	220481.	156013.	51658.	131062.	163457.	102192.	204715.	75720.	133811.	572924.	344855.	229295.	2386185.
2014	24592.	34613.	45651.	42643.	226210.	701800.	137362.	21228.	86218.	119925.	422065.	248701.	2111008.
2015	210820.	285183.	245435.	643546.	3597576.	2843202.	159513.	9464.	14896.	952390.	3027402.	1250011.	13239438.
2016	86918.	51381.	149672.	997616.	2316773.	771622.	32125.	195033.	519126.	103774.	225329.	142704.	5592073.
MEAN	187599.	252944.	279370.	305997.	572042.	636603.	276530.	95255.	187671.	407470.	611422.	298922.	4111823.

Table A.2.23 1940-2016 Naturalized Flows at Control Points MYDB60

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT MYDB60

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	6.	676.	4.	372.	2456.	10232.	36819.	14.	51.	146.	15087.	23641.	89504.
1941	4349.	4447.	11333.	4901.	10816.	16997.	27746.	226.	37.	201.	1544.	250.	82847.
1942	154.	154.	140.	9420.	426.	346.	584.	14.	562.	76.	511.	563.	12950.
1943	1769.	205.	1551.	291.	1199.	684.	17.	1.	126.	127.	9.	128.	6107.
1944	7311.	6787.	5847.	566.	6657.	732.	110.	446.	1900.	2.	9355.	11856.	51569.
1945	14572.	4021.	2203.	11830.	1057.	3849.	336.	7607.	1465.	4274.	287.	919.	52420.
1946	6622.	5583.	15423.	1446.	4668.	2537.	79.	0.	583.	752.	10841.	1509.	50043.
1947	6521.	462.	10101.	1939.	4701.	297.	345.	17755.	81.	1.	0.	299.	42502.
1948	59.	1223.	192.	54.	988.	45.	143.	0.	0.	0.	0.	0.	2704.
1949	190.	4762.	3021.	19017.	2486.	907.	42.	0.	117.	6133.	108.	2139.	38922.
1950	1157.	9521.	498.	9324.	3869.	11473.	377.	0.	2254.	9.	0.	0.	38482.
1951	0.	31.	815.	471.	104.	293.	0.	0.	17.	0.	12.	0.	1743.
1952	0.	154.	83.	974.	3132.	344.	3370.	0.	0.	0.	533.	3265.	11855.
1953	2888.	762.	328.	1122.	12474.	28.	1088.	101.	683.	3324.	1317.	1982.	26097.
1954	417.	216.	102.	166.	1187.	96.	105.	529.	75.	28.	23.	32.	2976.
1955	47.	3085.	45.	699.	48.	827.	62.	136.	78.	94.	40.	15.	5176.
1956	54.	2320.	597.	1181.	364.	140.	100.	92.	83.	45.	14.	111.	5101.
1957	6.	52.	2446.	23940.	13012.	11249.	128.	82.	2760.	24228.	9654.	2319.	89876.
1958	7720.	13023.	2471.	3643.	10706.	161.	2373.	53.	6757.	2110.	1482.	455.	50954.
1959	704.	6463.	821.	17413.	2503.	272.	52.	14.	23.	525.	2410.	3656.	34856.
1960	3341.	4669.	1159.	1915.	5001.	7045.	783.	305.	97.	8469.	16016.	11183.	59983.
1961	12630.	10605.	1937.	775.	1405.	20103.	2920.	184.	24943.	443.	3236.	2053.	81234.
1962	2141.	890.	902.	695.	1252.	1590.	1708.	0.	1148.	1194.	1370.	10447.	23337.
1963	1319.	7577.	826.	3382.	346.	21.	0.	0.	0.	0.	0.	0.	13471.
1964	0.	0.	141.	44.	45.	9.	0.	0.	159.	135.	3.	6.	542.
1965	595.	10582.	670.	476.	22177.	2767.	21.	1.	196.	357.	7561.	12506.	57909.
1966	1498.	4994.	5355.	3943.	11998.	468.	52.	112.	1954.	1114.	99.	213.	31800.
1967	249.	292.	280.	291.	364.	55.	0.	0.	1.	0.	1326.	102.	2960.
1968	26456.	2616.	6089.	5282.	9066.	9318.	1874.	9.	5002.	193.	1685.	11544.	79134.
1969	1392.	12474.	15314.	21114.	3695.	202.	2.	45.	82.	7.	105.	2571.	57003.
1970	1374.	7678.	17236.	7178.	23290.	3410.	31.	0.	25.	184.	11.	0.	60417.
1971	34.	85.	40.	43.	1.	88.	2.	0.	26.	549.	219.	3560.	4647.
1972	397.	463.	192.	59.	2469.	2227.	4.	0.	0.	28.	30.	76.	5945.
1973	3876.	2154.	3326.	3455.	1173.	1332.	215.	14.	429.	15051.	3503.	1281.	35809.
1974	15086.	1224.	935.	388.	2289.	3009.	12.	1120.	21909.	613.	24692.	6206.	77483.
1975	3503.	17960.	986.	750.	40691.	9251.	4163.	493.	332.	155.	215.	482.	78981.
1976	517.	474.	2079.	18335.	13503.	13997.	688.	55.	199.	839.	2392.	19559.	72637.
1977	1925.	10162.	1508.	17501.	885.	134.	3.	0.	0.	0.	0.	0.	32118.
1978	413.	761.	777.	278.	436.	178.	0.	0.	37.	0.	15.	177.	3072.
1979	2764.	4469.	4851.	4284.	17668.	8765.	695.	111.	0.	0.	0.	205.	43812.
1980	1994.	1177.	10184.	2778.	13699.	289.	0.	0.	0.	0.	0.	0.	30121.
1981	38.	185.	576.	211.	674.	30938.	2102.	14.	0.	4288.	4687.	460.	44173.
1982	469.	454.	525.	1470.	17998.	510.	35.	0.	0.	0.	0.	6.	21467.
1983	1153.	5807.	8591.	701.	13044.	1003.	181.	329.	0.	28.	28.	57.	30922.
1984	80.	183.	542.	207.	0.	0.	0.	0.	0.	7088.	2823.	6344.	17267.
1985	3411.	3076.	4768.	1090.	2985.	3018.	154.	0.	0.	2658.	21865.	5066.	48091.
1986	1171.	5117.	512.	246.	2933.	14389.	426.	33.	274.	2328.	4423.	20384.	52236.
1987	2238.	5121.	8448.	406.	3152.	62553.	558.	65.	221.	58.	394.	683.	83897.
1988	510.	550.	689.	1034.	676.	306.	0.	0.	0.	0.	0.	0.	3765.
1989	363.	76.	1135.	563.	3366.	1595.	149.	93.	0.	0.	0.	0.	7340.
1990	46.	363.	456.	1529.	777.	1.	26.	0.	0.	0.	49.	0.	3247.
1991	29591.	9583.	1401.	6591.	1928.	433.	81.	0.	541.	0.	112.	42649.	92910.
1992	15111.	51206.	16869.	2845.	31068.	24883.	941.	63.	205.	27.	1609.	3657.	148484.
1993	11517.	4121.	5229.	9750.	10956.	1929.	568.	0.	0.	14.	113.	355.	44552.
1994	552.	638.	799.	492.	1421.	704.	43.	352.	180.	23634.	2784.	27871.	59470.
1995	13767.	1453.	6841.	3869.	2371.	16216.	573.	839.	29.	267.	1694.	849.	48768.
1996	711.	668.	964.	794.	572.	396.	321.	506.	3670.	112.	506.	661.	9881.
1997	641.	3922.	2731.	2070.	1302.	3309.	501.	308.	127.	516.	749.	1235.	17411.
MEAN	3749.	4444.	3343.	4062.	6026.	5309.	1616.	554.	1370.	1938.	2716.	4234.	39362.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT MYDB60

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	963.	11427.	1325.	347.	428.	175.	0.	0.	3863.	47983.	25506.	2915.	94931.
1999	0.	390.	451.	347.	1946.	183.	0.	0.	0.	0.	0.	0.	3317.
2000	3728.	2417.	451.	347.	1946.	840.	0.	0.	0.	2247.	43919.	17349.	73244.
2001	7949.	1326.	9474.	916.	428.	183.	0.	0.	3943.	1185.	14742.	18412.	58558.
2002	1658.	390.	451.	347.	428.	183.	3934.	0.	0.	20672.	12964.	16016.	57043.
2003	3332.	12945.	907.	347.	428.	183.	0.	0.	0.	0.	317.	0.	18458.
2004	5713.	14324.	1261.	3835.	1886.	42401.	948.	0.	0.	16926.	57706.	6905.	151906.
2005	1839.	5363.	1258.	347.	428.	183.	0.	0.	0.	0.	0.	0.	9417.
2006	0.	390.	451.	347.	428.	183.	0.	0.	0.	8816.	1057.	2672.	14344.
2007	23444.	466.	17878.	4299.	20758.	23988.	29431.	0.	0.	0.	0.	0.	120265.
2008	0.	390.	2444.	1488.	428.	183.	0.	0.	0.	0.	0.	0.	4933.
2009	0.	390.	451.	2281.	428.	183.	0.	0.	20631.	46591.	15240.	1756.	87952.
2010	3869.	6735.	1594.	347.	428.	183.	0.	0.	11388.	0.	0.	0.	24544.
2011	0.	390.	451.	389.	428.	183.	0.	0.	0.	0.	0.	13499.	15340.
2012	12087.	11644.	18396.	347.	428.	183.	0.	0.	0.	0.	0.	0.	43086.
2013	5248.	440.	451.	347.	428.	183.	0.	0.	0.	40918.	18203.	1435.	67654.
2014	0.	390.	451.	347.	7086.	668.	0.	0.	615.	0.	8098.	2523.	20178.
2015	11930.	2728.	6112.	3083.	63773.	21328.	0.	0.	0.	43799.	28404.	7196.	188353.
2016	1135.	390.	2180.	21153.	25611.	2140.	0.	8995.	0.	0.	0.	1144.	62746.
MEAN	4363.	3838.	3497.	2171.	6744.	4934.	1806.	473.	2128.	12060.	11903.	4833.	58751.

Table A.2.24 1940-2016 Naturalized Flows at Control Points EYDB61

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT EYDB61

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	6.	706.	4.	389.	2566.	10691.	38473.	14.	53.	153.	15765.	24704.	93524.
1941	4544.	4647.	11843.	5122.	11302.	17760.	28993.	236.	39.	210.	1614.	261.	86571.
1942	161.	161.	146.	9843.	446.	362.	611.	15.	587.	79.	534.	589.	13534.
1943	1849.	214.	1621.	304.	1253.	715.	17.	1.	131.	132.	9.	134.	6380.
1944	7640.	7092.	6110.	591.	6956.	765.	115.	466.	1985.	2.	9775.	12389.	53886.
1945	15227.	4201.	2302.	12361.	1104.	4022.	351.	7949.	1531.	4466.	299.	960.	54773.
1946	6920.	5834.	16116.	1511.	4878.	2651.	83.	0.	610.	786.	11328.	1576.	52293.
1947	6814.	483.	10555.	2026.	4912.	311.	360.	18553.	85.	1.	0.	313.	44413.
1948	61.	1278.	200.	57.	1033.	47.	149.	0.	0.	0.	0.	0.	2825.
1949	198.	4976.	3157.	19871.	2597.	948.	44.	0.	123.	6409.	113.	2236.	40672.
1950	1209.	9949.	520.	9743.	4043.	11988.	394.	0.	2355.	10.	0.	0.	40211.
1951	0.	32.	852.	493.	109.	306.	0.	0.	17.	0.	12.	0.	1821.
1952	0.	161.	86.	1018.	3272.	359.	3522.	0.	0.	0.	557.	3411.	12386.
1953	3017.	796.	342.	1173.	13035.	29.	1137.	106.	714.	3473.	1376.	2071.	27269.
1954	436.	225.	106.	174.	1240.	101.	110.	553.	78.	29.	24.	34.	3110.
1955	49.	3224.	47.	731.	50.	864.	65.	142.	82.	98.	42.	16.	5410.
1956	56.	2424.	623.	1234.	381.	146.	105.	97.	86.	47.	14.	116.	5329.
1957	6.	54.	2556.	25016.	13597.	11755.	134.	86.	2884.	25317.	10088.	2424.	93917.
1958	8066.	13608.	2582.	3806.	11187.	168.	2480.	55.	7060.	2205.	1548.	475.	53240.
1959	736.	6753.	858.	18195.	2615.	284.	54.	15.	24.	549.	2519.	3820.	36422.
1960	3491.	4879.	1211.	2001.	5226.	7362.	819.	318.	101.	8850.	16735.	11686.	62679.
1961	13197.	11081.	2024.	810.	1468.	21007.	3051.	192.	26064.	463.	3382.	2146.	84885.
1962	2237.	930.	942.	726.	1308.	1662.	1784.	543.	1987.	1140.	7451.	9065.	29775.
1963	1607.	9050.	1418.	4839.	595.	410.	529.	504.	265.	332.	11.	0.	19560.
1964	159.	350.	616.	442.	1131.	480.	513.	337.	2879.	797.	474.	382.	8560.
1965	968.	13021.	1043.	1813.	27167.	2714.	544.	387.	224.	289.	4535.	7361.	60066.
1966	1632.	7460.	3855.	11747.	11669.	704.	838.	223.	798.	364.	329.	247.	39866.
1967	431.	544.	617.	1044.	1796.	722.	375.	369.	125.	357.	1304.	145.	7829.
1968	16515.	1763.	3195.	3686.	7008.	27176.	13853.	561.	1565.	302.	971.	3709.	80304.
1969	1498.	11977.	12489.	15530.	3081.	632.	501.	360.	607.	140.	595.	2696.	50106.
1970	2093.	8704.	16628.	5750.	18137.	1586.	531.	485.	253.	463.	380.	430.	55440.
1971	409.	361.	582.	702.	577.	412.	366.	84.	171.	38.	152.	1785.	5639.
1972	406.	585.	501.	271.	1950.	5054.	248.	198.	320.	346.	262.	249.	10390.
1973	6691.	2442.	4875.	6002.	4342.	4062.	381.	364.	30.	13673.	2098.	1398.	46358.
1974	15226.	1135.	1200.	637.	1985.	6931.	430.	3956.	30038.	740.	20502.	7233.	90013.
1975	3822.	17628.	1231.	1283.	40139.	7944.	3729.	1232.	456.	235.	348.	645.	78692.
1976	1023.	786.	4111.	22523.	9526.	7561.	1495.	671.	979.	1298.	2071.	18802.	70846.
1977	1849.	11868.	1967.	22190.	1727.	1031.	677.	486.	573.	526.	506.	586.	43986.
1978	884.	1216.	1650.	1706.	953.	1898.	566.	457.	252.	304.	802.	911.	11599.
1979	3634.	5769.	15976.	7270.	19860.	17185.	1792.	467.	820.	1237.	798.	129.	74937.
1980	8155.	2342.	14735.	1755.	15227.	554.	556.	450.	84.	291.	203.	163.	44515.
1981	380.	374.	1272.	325.	592.	22638.	7830.	344.	142.	238.	1221.	381.	35737.
1982	350.	380.	644.	2432.	12221.	565.	484.	411.	294.	437.	373.	1291.	19882.
1983	2759.	5826.	14427.	1360.	18426.	1329.	418.	3427.	723.	778.	372.	407.	50252.
1984	1137.	1381.	2218.	1004.	398.	455.	429.	429.	284.	15978.	2119.	8959.	34791.
1985	5823.	4175.	8398.	988.	2987.	2331.	489.	535.	654.	1193.	16209.	1457.	45239.
1986	845.	6055.	768.	351.	11201.	26160.	718.	239.	359.	1439.	8556.	22076.	78767.
1987	1772.	7419.	5412.	1264.	4103.	47898.	509.	814.	390.	0.	525.	370.	70476.
1988	684.	197.	1027.	0.	856.	1485.	934.	899.	784.	631.	562.	172.	8231.
1989	1797.	0.	1558.	692.	1845.	1467.	465.	331.	344.	214.	84.	288.	9085.
1990	0.	137.	246.	8573.	1369.	563.	365.	918.	311.	0.	274.	67.	12823.
1991	25545.	9778.	1037.	3827.	951.	588.	475.	1288.	68.	416.	475.	40048.	84496.
1992	14239.	52708.	16099.	4074.	21050.	20955.	1540.	685.	635.	448.	1573.	3170.	137176.
1993	12437.	3473.	11204.	16078.	11869.	12252.	1305.	785.	578.	1460.	695.	584.	72720.
1994	396.	1157.	1262.	486.	1653.	558.	570.	1088.	192.	29862.	1653.	25127.	64004.
1995	12263.	1520.	8137.	7405.	5500.	12524.	678.	1328.	808.	281.	1071.	461.	51976.
1996	245.	321.	310.	406.	298.	1093.	658.	499.	1144.	511.	377.	258.	6120.
1997	353.	4354.	2723.	1867.	1208.	1413.	1809.	1697.	1572.	548.	636.	949.	19129.
MEAN	3861.	4827.	3935.	4785.	6172.	5787.	2249.	977.	1661.	2251.	2695.	3989.	43189.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT EYDB61

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	1650.	13118.	962.	386.	206.	112.	75.	0.	9263.	32247.	29715.	10129.	97864.
1999	1079.	279.	476.	885.	1429.	995.	293.	0.	0.	0.	29.	0.	5465.
2000	2866.	858.	598.	595.	2721.	886.	210.	0.	0.	633.	27890.	14269.	51526.
2001	9071.	978.	10820.	1171.	535.	993.	293.	433.	10602.	1100.	5987.	13544.	55527.
2002	1552.	612.	275.	389.	595.	280.	1244.	770.	0.	22116.	23376.	28597.	79808.
2003	3331.	15058.	1216.	274.	277.	814.	775.	0.	993.	1774.	2109.	631.	27251.
2004	7069.	17454.	1936.	2424.	7186.	38691.	1376.	0.	682.	6387.	36322.	2508.	122036.
2005	1947.	7674.	965.	447.	480.	222.	259.	540.	0.	0.	46.	0.	12580.
2006	47.	1808.	669.	644.	690.	711.	446.	0.	0.	16974.	1113.	1694.	24796.
2007	22058.	1039.	9358.	2318.	8143.	4660.	12417.	1297.	0.	490.	2187.	2074.	66040.
2008	597.	543.	582.	987.	972.	209.	83.	0.	591.	0.	130.	0.	4693.
2009	28.	157.	374.	3668.	952.	186.	86.	0.	7191.	30523.	9941.	1333.	54440.
2010	1964.	3604.	830.	597.	554.	618.	834.	0.	401.	968.	17.	0.	10388.
2011	685.	599.	137.	150.	360.	172.	89.	0.	0.	0.	514.	9171.	11878.
2012	4144.	19616.	25685.	1088.	503.	624.	293.	0.	640.	1030.	39.	0.	53663.
2013	8746.	1100.	135.	506.	1213.	510.	208.	0.	595.	24347.	13656.	2396.	53412.
2014	230.	386.	173.	341.	12820.	1183.	464.	0.	368.	1050.	8186.	6153.	31354.
2015	14837.	1233.	11755.	10896.	48607.	13448.	293.	0.	0.	16244.	21501.	19808.	158623.
2016	2091.	142.	1828.	13691.	44388.	1129.	212.	2483.	1371.	0.	386.	2381.	70102.
MEAN	4421.	4540.	3620.	2182.	6981.	3497.	1050.	291.	1721.	8204.	9639.	6036.	52181.

Table A.2.25 1940-2016 Naturalized Flows at Control Points DCLY63

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT DCLY63

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	7.	775.	4.	426.	2815.	11726.	42197.	16.	59.	167.	17290.	27095.	102577.
1941	4984.	5097.	12989.	5617.	12395.	19479.	31799.	258.	42.	230.	1770.	286.	94946.
1942	176.	177.	160.	10796.	489.	397.	670.	16.	644.	87.	585.	645.	14842.
1943	2028.	235.	1778.	333.	1374.	784.	19.	1.	144.	145.	10.	147.	6998.
1944	8379.	7779.	6701.	649.	7629.	839.	126.	511.	2177.	2.	10721.	13588.	59101.
1945	16701.	4608.	2525.	13557.	1211.	4411.	385.	8718.	1679.	4898.	328.	1053.	60074.
1946	7590.	6399.	17675.	1657.	5350.	2907.	91.	0.	669.	862.	12424.	1729.	57353.
1947	7474.	530.	11577.	2222.	5387.	341.	395.	20349.	93.	1.	0.	343.	48712.
1948	67.	1402.	220.	62.	1133.	51.	164.	0.	0.	0.	0.	0.	3099.
1949	217.	5457.	3462.	21795.	2849.	1040.	48.	0.	134.	7029.	124.	2452.	44607.
1950	1326.	10911.	570.	10686.	4434.	13149.	432.	0.	2583.	11.	0.	0.	44102.
1951	0.	35.	935.	540.	119.	336.	0.	0.	19.	0.	13.	0.	1997.
1952	0.	176.	95.	1116.	3589.	394.	3862.	0.	0.	0.	611.	3742.	13585.
1953	3309.	873.	375.	1286.	14296.	32.	1247.	116.	783.	3809.	1509.	2271.	29906.
1954	478.	247.	116.	191.	1360.	111.	121.	606.	86.	32.	27.	37.	3412.
1955	54.	3536.	52.	801.	55.	948.	71.	156.	90.	107.	46.	17.	5933.
1956	62.	2659.	684.	1354.	418.	161.	115.	106.	95.	51.	16.	127.	5848.
1957	7.	59.	2803.	27436.	14913.	12892.	147.	94.	3163.	27767.	11064.	2658.	103003.
1958	8847.	14925.	2832.	4175.	12269.	184.	2720.	61.	7744.	2418.	1698.	521.	58394.
1959	807.	7407.	941.	19956.	2868.	312.	59.	17.	26.	602.	2762.	4190.	39947.
1960	3828.	5351.	1329.	2195.	5732.	8074.	898.	349.	111.	9706.	18355.	12817.	68745.
1961	14475.	12154.	2220.	888.	1611.	23040.	3347.	211.	28587.	508.	3709.	2353.	93103.
1962	2454.	1020.	1034.	796.	1435.	1822.	1957.	109.	2475.	3901.	13193.	10350.	40546.
1963	1483.	9730.	772.	8020.	300.	41.	0.	0.	0.	0.	100.	510.	20956.
1964	768.	569.	1850.	1026.	2106.	211.	0.	0.	232.	296.	65.	614.	7737.
1965	1152.	15956.	496.	500.	21943.	1579.	0.	0.	0.	0.	1501.	10435.	53562.
1966	3006.	14240.	2765.	8367.	8338.	193.	0.	60.	2544.	132.	0.	40.	39685.
1967	24.	48.	69.	1124.	3050.	172.	0.	0.	0.	0.	0.	0.	4487.
1968	5357.	470.	3272.	4053.	10271.	50000.	3760.	48.	3706.	156.	3231.	8306.	92630.
1969	1417.	17138.	17985.	28663.	2387.	372.	0.	0.	0.	0.	1.	1829.	69792.
1970	927.	6001.	10104.	3972.	21177.	963.	9.	0.	171.	1.	0.	0.	43325.
1971	0.	117.	9.	99.	593.	0.	0.	81.	0.	689.	164.	3421.	5173.
1972	295.	193.	38.	0.	3798.	1197.	163.	40.	24.	525.	199.	74.	6546.
1973	9838.	3812.	11872.	14707.	2716.	25798.	186.	55.	470.	27321.	1594.	2966.	101335.
1974	13765.	876.	801.	225.	1181.	2881.	0.	2051.	25428.	1771.	20780.	6715.	76474.
1975	4162.	12956.	686.	1310.	20580.	5526.	3271.	1865.	1085.	65.	78.	330.	51914.
1976	797.	484.	2799.	18312.	6900.	14703.	1150.	0.	0.	332.	902.	18083.	64462.
1977	1070.	19356.	853.	41165.	611.	93.	0.	0.	0.	0.	0.	1.	63149.
1978	354.	1525.	2313.	178.	54.	1569.	0.	0.	1229.	33.	1137.	964.	9356.
1979	9839.	9059.	21893.	12251.	21891.	23332.	2721.	384.	257.	17.	563.	1757.	103964.
1980	14191.	4107.	12749.	2914.	23065.	177.	0.	0.	0.	38.	123.	16.	57380.
1981	410.	348.	992.	102.	1919.	15952.	3000.	112.	75.	3459.	6828.	222.	33419.
1982	249.	313.	664.	8138.	22045.	165.	2.	0.	0.	1001.	1305.	5917.	39799.
1983	10278.	16256.	19597.	769.	26462.	1381.	123.	2173.	3044.	431.	142.	200.	80856.
1984	336.	250.	2443.	132.	761.	708.	0.	0.	0.	12030.	3036.	9451.	29147.
1985	7386.	11257.	6080.	410.	604.	45.	1.	0.	0.	3534.	12486.	2094.	43897.
1986	445.	3712.	178.	100.	8364.	14547.	37.	0.	1431.	729.	3861.	18307.	51711.
1987	1311.	10974.	5779.	474.	2148.	24446.	161.	0.	23.	0.	53.	413.	45782.
1988	88.	227.	459.	968.	143.	4489.	0.	0.	0.	0.	0.	0.	6374.
1989	6525.	484.	1250.	241.	1977.	2329.	223.	23.	0.	0.	0.	8.	13060.
1990	0.	61.	60.	30953.	6410.	0.	0.	0.	0.	0.	29.	93.	37606.
1991	42165.	8145.	1282.	16687.	450.	297.	131.	0.	676.	263.	40.	39642.	109778.
1992	16312.	54457.	14522.	2359.	27695.	15900.	363.	0.	0.	84.	2814.	6794.	141300.
1993	18985.	2639.	12237.	6071.	19232.	30551.	227.	0.	0.	221.	180.	227.	90570.
1994	340.	2194.	2015.	409.	926.	367.	0.	0.	0.	54457.	381.	23822.	84911.
1995	16351.	874.	6026.	7987.	2544.	5450.	241.	2559.	687.	210.	224.	3239.	46392.
1996	123.	83.	114.	278.	0.	134.	0.	281.	3411.	3.	583.	1085.	6095.
1997	2071.	6780.	2042.	764.	711.	5173.	17.	0.	0.	670.	665.	1796.	20689.
MEAN	4743.	5647.	4106.	6073.	6501.	6106.	1839.	714.	1653.	2945.	2747.	4410.	47485.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT DCLY63

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	2138.	16137.	0.	247.	446.	61.	0.	0.	11522.	33892.	27996.	7590.	100028.
1999	865.	436.	0.	247.	1535.	190.	0.	0.	0.	0.	0.	591.	3864.
2000	4602.	2076.	1884.	247.	5358.	190.	0.	0.	0.	0.	34474.	10194.	59025.
2001	9553.	436.	13464.	247.	289.	924.	0.	0.	14532.	1382.	5077.	12909.	58814.
2002	1035.	436.	0.	247.	289.	190.	0.	0.	0.	31022.	22055.	31376.	86651.
2003	2837.	16024.	0.	247.	676.	1351.	0.	0.	1345.	1979.	1879.	0.	26338.
2004	5938.	16750.	718.	2154.	9068.	44163.	0.	0.	0.	7563.	38102.	0.	124457.
2005	3569.	8013.	827.	247.	289.	190.	0.	0.	0.	0.	0.	0.	13134.
2006	0.	1863.	667.	247.	289.	190.	0.	0.	0.	24370.	0.	3799.	31426.
2007	22537.	436.	12995.	1382.	11133.	4210.	12263.	0.	0.	0.	2556.	2424.	69937.
2008	0.	436.	1347.	247.	289.	190.	0.	0.	0.	0.	0.	0.	2508.
2009	0.	280.	0.	8562.	289.	102.	0.	0.	11145.	32416.	4070.	1661.	58526.
2010	1321.	3846.	0.	247.	289.	190.	0.	0.	0.	0.	0.	0.	5893.
2011	1807.	436.	0.	245.	289.	190.	0.	0.	0.	0.	0.	9244.	12211.
2012	3729.	22659.	27082.	247.	289.	190.	0.	0.	0.	0.	0.	0.	54196.
2013	10297.	436.	0.	247.	289.	190.	0.	0.	787.	25384.	7980.	644.	46255.
2014	0.	436.	0.	247.	18796.	190.	0.	0.	0.	0.	10124.	3337.	33129.
2015	16373.	436.	15776.	9754.	56495.	5661.	0.	0.	0.	22974.	15772.	21231.	164472.
2016	0.	436.	2884.	16185.	49946.	190.	0.	3901.	0.	0.	2656.	2524.	78721.
MEAN	4558.	4842.	4087.	2184.	8229.	3092.	645.	205.	2070.	9525.	9092.	5659.	54189.

Table A.2.26 1940-2016 Naturalized Flows at Control Points NAEA66

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT NAEA66

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	245.	1750.	269.	8032.	28826.	8044.	17329.	217.	223.	204.	219220.	103682.	388041.
1941	74737.	87468.	41141.	15872.	21081.	60311.	13978.	2587.	932.	364.	912.	1611.	320994.
1942	733.	1423.	980.	60156.	88432.	26542.	493.	500.	20236.	1677.	11032.	25803.	238007.
1943	10095.	1414.	8522.	8314.	6398.	10856.	447.	33.	15.	3883.	843.	953.	51773.
1944	59128.	127872.	63791.	5934.	310223.	18264.	402.	278.	926.	82.	19208.	54692.	660800.
1945	80066.	39118.	116438.	149354.	12265.	15963.	11605.	30843.	26302.	57325.	5169.	112543.	656991.
1946	52788.	69403.	72201.	16019.	176110.	51090.	1657.	472.	3095.	727.	89358.	15060.	547980.
1947	78550.	5664.	81231.	13247.	131198.	23801.	744.	1163.	389.	197.	311.	3324.	339819.
1948	6919.	28438.	12906.	12708.	30642.	823.	2636.	106.	130.	98.	185.	848.	96439.
1949	28418.	6587.	41997.	12790.	2487.	9575.	1879.	261.	743.	45742.	925.	2260.	153664.
1950	29608.	115303.	3602.	38051.	7801.	10255.	2043.	250.	183.	153.	465.	269.	207983.
1951	375.	728.	1597.	1231.	4704.	3192.	82.	40.	4123.	143.	168.	568.	16951.
1952	634.	8185.	9823.	24151.	42572.	1134.	160.	75.	62.	36.	3786.	22833.	113451.
1953	23409.	2519.	71805.	4235.	206764.	634.	699.	500.	619.	3750.	6401.	80262.	401597.
1954	12731.	1596.	935.	1264.	27933.	264.	78.	93.	83.	228.	1171.	1704.	48080.
1955	2009.	14805.	9777.	24300.	9706.	5329.	741.	860.	103.	327.	46.	141.	68144.
1956	615.	8081.	454.	331.	38821.	2164.	116.	103.	121.	51.	2313.	137.	53307.
1957	129.	5292.	28508.	236075.	201624.	43797.	288.	120.	241.	150502.	53077.	4511.	724164.
1958	17259.	29155.	5484.	6709.	49756.	11706.	832.	28787.	43187.	10257.	1095.	2676.	206903.
1959	1830.	30473.	5743.	43115.	74561.	80563.	7556.	1584.	1967.	37200.	24305.	71407.	380304.
1960	62337.	19961.	22347.	7280.	17775.	11523.	2013.	835.	416.	13588.	22866.	198632.	379573.
1961	182840.	119656.	23633.	6137.	2413.	106683.	34014.	1202.	21252.	2770.	5267.	25282.	531149.
1962	19498.	8355.	5592.	19925.	18619.	15472.	2084.	113.	265.	1024.	1709.	1359.	94015.
1963	624.	2324.	1760.	1401.	1763.	168.	0.	0.	0.	0.	61.	276.	8377.
1964	2899.	2151.	5893.	4491.	1113.	0.	0.	2006.	3486.	123.	2570.	297.	25029.
1965	36736.	38590.	32766.	87704.	319449.	28796.	769.	0.	445.	161.	3527.	4107.	553050.
1966	2946.	18830.	9578.	225038.	73405.	1125.	0.	31401.	75732.	1950.	627.	1437.	442069.
1967	1133.	771.	1859.	11022.	9362.	6602.	155.	131.	4531.	2190.	21441.	34990.	94187.
1968	127908.	26576.	64778.	82370.	143710.	107227.	12140.	257.	903.	312.	5676.	21601.	593458.
1969	10205.	55265.	114043.	154957.	44303.	710.	127.	1928.	0.	2111.	8198.	63235.	455082.
1970	17611.	37658.	108481.	29095.	2419.	594.	0.	0.	4652.	19047.	950.	660.	221167.
1971	694.	8735.	1535.	875.	2036.	0.	1520.	1543.	952.	3510.	20354.	86519.	128273.
1972	37902.	10412.	1277.	553.	136.	1814.	10458.	512.	0.	10129.	11078.	16190.	100461.
1973	75198.	17350.	135856.	117051.	35950.	166295.	6452.	422.	4860.	157953.	65192.	58933.	841512.
1974	100118.	21428.	18152.	13656.	20419.	774.	153.	2963.	95798.	14508.	230522.	43720.	562211.
1975	23859.	98785.	10970.	28201.	169372.	26919.	13068.	1422.	1196.	7120.	2012.	2146.	385070.
1976	1436.	2600.	12839.	143733.	149635.	80534.	26836.	729.	4059.	88808.	14848.	147673.	673730.
1977	26511.	117098.	53282.	95680.	14400.	7237.	344.	0.	2001.	130.	610.	940.	318233.
1978	4395.	20470.	28999.	2939.	2902.	781.	120.	10.	2342.	332.	13229.	4281.	80800.
1979	38040.	36671.	121285.	117328.	145535.	67852.	11447.	9122.	7962.	2466.	0.	22693.	580401.
1980	30832.	37161.	9519.	31464.	105019.	2130.	805.	179.	451.	0.	791.	1091.	219442.
1981	2062.	6169.	5805.	5949.	19994.	128546.	9897.	21.	0.	71874.	2870.	866.	254053.
1982	3870.	5078.	19531.	17028.	40359.	0.	0.	0.	0.	0.	5015.	57626.	148507.
1983	8178.	105404.	47336.	5036.	84404.	4141.	1822.	18690.	0.	2083.	1594.	870.	279558.
1984	4145.	8320.	28036.	3614.	373.	3657.	0.	0.	0.	96841.	23480.	70245.	238711.
1985	32700.	91986.	34484.	5128.	7165.	0.	0.	459.	2514.	13371.	143444.	109856.	441107.
1986	4314.	132331.	6738.	20641.	78306.	28391.	739.	0.	0.	7565.	39413.	110537.	428975.
1987	11988.	41387.	51649.	4665.	16857.	85426.	1611.	0.	433.	598.	2759.	33362.	250735.
1988	6187.	14328.	26390.	4357.	4761.	2053.	492.	1056.	771.	0.	0.	4062.	64457.
1989	3161.	8529.	8083.	5361.	229403.	76305.	6972.	200.	328.	1640.	715.	130.	340827.
1990	7091.	20819.	139775.	40649.	151030.	7744.	839.	1634.	6513.	5148.	21510.	10121.	412873.
1991	146114.	106671.	30613.	72759.	63073.	11635.	3177.	6555.	6327.	9624.	18375.	332958.	807881.
1992	122024.	186852.	80245.	7239.	82824.	36796.	0.	1134.	0.	211.	1632.	32342.	551299.
1993	26834.	26438.	144903.	40412.	44533.	48182.	2795.	1373.	983.	17240.	904.	2869.	357466.
1994	2171.	73596.	12657.	7993.	80999.	21869.	633.	4249.	0.	11080.	8157.	88602.	312006.
1995	89897.	14974.	66527.	18677.	63691.	3329.	4031.	67847.	8462.	0.	0.	1863.	339298.
1996	1548.	2839.	2214.	1763.	5213.	0.	3497.	0.	0.	0.	1095.	7036.	25205.
1997	12399.	153388.	66259.	148472.	20820.	44430.	2107.	2838.	0.	0.	1408.	41771.	493892.
MEAN	30495.	39401.	36774.	39182.	64577.	26208.	3877.	3960.	6230.	15146.	19722.	37008.	322578.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT NAEA66

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	87635.	109185.	4363.	2123.	2599.	498.	0.	0.	71375.	222791.	164962.	68913.	734444.
1999	97526.	5343.	2052.	4383.	9966.	3645.	0.	0.	0.	0.	570.	3885.	127369.
2000	4878.	4882.	16628.	4797.	32586.	88318.	0.	0.	0.	12745.	192624.	113959.	471418.
2001	86392.	48056.	106299.	3609.	4680.	19231.	0.	0.	10384.	10015.	62882.	158433.	509980.
2002	14913.	3933.	13936.	2123.	3223.	912.	1216.	0.	0.	129190.	72848.	154539.	396832.
2003	5623.	94893.	6313.	2123.	3223.	9941.	0.	0.	4036.	27494.	16600.	1947.	172193.
2004	4333.	63976.	4759.	21510.	28447.	282026.	6566.	1623.	0.	51418.	264733.	17258.	746649.
2005	12482.	23587.	5636.	2123.	4506.	912.	0.	3656.	0.	0.	570.	0.	53474.
2006	0.	19172.	12000.	5195.	3234.	912.	0.	0.	0.	23310.	3980.	13062.	80864.
2007	131005.	5401.	128574.	20499.	228309.	173932.	130986.	0.	0.	0.	570.	1710.	820987.
2008	0.	3164.	26148.	5648.	7506.	912.	0.	12751.	3737.	0.	570.	0.	60436.
2009	0.	3164.	11827.	84012.	4623.	912.	0.	0.	40452.	226637.	63640.	3378.	438643.
2010	13976.	48304.	7161.	2688.	3223.	530.	1841.	0.	0.	0.	570.	0.	78293.
2011	12696.	9724.	2052.	2123.	3223.	912.	0.	0.	0.	0.	570.	33435.	64735.
2012	64291.	59220.	150581.	4050.	3223.	912.	0.	0.	2560.	736.	559.	0.	286131.
2013	89949.	14925.	2052.	2123.	3355.	912.	0.	0.	2678.	286120.	125719.	13689.	541523.
2014	0.	3164.	2052.	2123.	29572.	15094.	0.	0.	0.	2486.	30182.	14677.	99351.
2015	61014.	13626.	51776.	129250.	336962.	61047.	0.	0.	0.	176648.	189706.	171773.	1191803.
2016	6792.	3164.	24326.	112609.	81792.	4516.	0.	6182.	0.	0.	2219.	2310.	243911.
MEAN	36500.	28257.	30449.	21743.	41803.	35056.	7400.	1274.	7117.	61557.	62846.	40683.	374686.

Table A.2.27 1940-2016 Naturalized Flows at Control Points BRHE68

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRHE68

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	31649.	149252.	27695.	196282.	365200.	666231.	1169486.	270115.	104997.	50295.	1583495.	2555544.	7170241.
1941	979247.	1259427.	1410847.	975472.	2546961.	1875876.	1090395.	388553.	218960.	696833.	480542.	141057.	12064170.
1942	121393.	91784.	81192.	2179374.	1850681.	1212632.	208758.	113332.	854651.	724460.	391231.	254386.	8083874.
1943	279554.	113167.	206331.	295216.	245966.	237667.	79149.	49937.	69436.	82924.	34605.	57693.	1751645.
1944	603980.	918535.	1001117.	285474.	2873796.	1001503.	164640.	69063.	271160.	102043.	365181.	719386.	8375878.
1945	1276691.	864126.	1398517.	2609295.	749772.	602670.	528789.	235452.	293930.	544515.	120165.	413931.	9637853.
1946	653823.	838507.	1171932.	460555.	1593600.	791868.	143680.	90003.	288793.	258803.	943606.	581968.	7817138.
1947	967054.	277792.	799364.	432632.	1000379.	330429.	89100.	294904.	86481.	56047.	68393.	167787.	4570362.
1948	90928.	228449.	251691.	151640.	313736.	230559.	258435.	10553.	56224.	33495.	21402.	20067.	1667179.
1949	78887.	260971.	476037.	786002.	992587.	531892.	172161.	30154.	123287.	310064.	165044.	214944.	4142030.
1950	219525.	778977.	131749.	541312.	521446.	523812.	263841.	216518.	313186.	108914.	26230.	17031.	3662541.
1951	15207.	44126.	55950.	51715.	186879.	373289.	31797.	35161.	74310.	18355.	17456.	23650.	927895.
1952	14584.	38133.	66313.	320690.	447995.	177531.	43692.	11655.	32385.	9679.	82696.	213925.	1459278.
1953	262336.	122828.	264576.	128562.	1734824.	85533.	289579.	111503.	81150.	482958.	155645.	510893.	4230387.
1954	96914.	38213.	23136.	135825.	543755.	137147.	29520.	44145.	12564.	36126.	68415.	14727.	1180487.
1955	23870.	229331.	71597.	323650.	569680.	391928.	115768.	78914.	218878.	623460.	43803.	21439.	2712318.
1956	30701.	102189.	37891.	47356.	433953.	44879.	1634.	16265.	12692.	24875.	57094.	87294.	896823.
1957	4983.	240691.	167160.	2568254.	5723482.	1563516.	412593.	118375.	75236.	1571016.	902606.	393684.	13741596.
1958	428237.	917721.	681009.	474546.	1586400.	258628.	381415.	79575.	316633.	149950.	84251.	72065.	5430430.
1959	54251.	267828.	65307.	705377.	426648.	471757.	282043.	124281.	55047.	1749067.	375414.	622517.	5199537.
1960	991606.	610913.	330551.	235048.	362811.	294999.	348187.	82951.	25567.	606895.	831489.	1458011.	6179028.
1961	2107646.	1757544.	657025.	245138.	167692.	960668.	825945.	172881.	612471.	296901.	268215.	346054.	8418180.
1962	198952.	157195.	111584.	125411.	155133.	523480.	283469.	156251.	582922.	241867.	152608.	317691.	3006563.
1963	112459.	220827.	72293.	285620.	200972.	228453.	63967.	13864.	17487.	44083.	96132.	45407.	1401564.
1964	55018.	140692.	214184.	161320.	135623.	206353.	37633.	51320.	320412.	114096.	366471.	111815.	1914937.
1965	512579.	1141899.	325572.	481283.	3317693.	756080.	149761.	113575.	123720.	156596.	336741.	437181.	7852680.
1966	186492.	395632.	341482.	1239757.	1753597.	271615.	81829.	272223.	761202.	237372.	61597.	46787.	5649585.
1967	54785.	39489.	49525.	172063.	214084.	265024.	178062.	46137.	115587.	50466.	255044.	157995.	1598261.
1968	1577285.	591053.	1152758.	1033428.	2133373.	1501392.	959391.	136448.	221552.	91552.	187534.	441812.	10027578.
1969	121791.	484390.	881621.	1373049.	1479366.	268529.	95023.	97285.	181225.	131155.	166803.	376160.	5656397.
1970	309248.	412725.	1513766.	656693.	680633.	288744.	72671.	52029.	192553.	247942.	76152.	44224.	4547380.
1971	46217.	48046.	53264.	80858.	167206.	111206.	234632.	388117.	165204.	447274.	248305.	799363.	2789692.
1972	367814.	185870.	90362.	87469.	356637.	132853.	64217.	156411.	146325.	156556.	333173.	159534.	2237221.
1973	553526.	499478.	917929.	1141903.	765278.	1285441.	296829.	116055.	115399.	1388675.	396771.	311506.	7788790.
1974	618261.	300706.	157541.	145702.	277366.	99666.	43784.	202878.	1455959.	745384.	1756798.	635887.	6439932.
1975	468052.	1272532.	397376.	572971.	1641343.	997355.	406470.	203682.	120802.	78261.	70798.	51284.	6280926.
1976	59720.	82315.	124738.	831033.	1179574.	580397.	722520.	127073.	170039.	423639.	320119.	1014481.	5635648.
1977	290921.	1068526.	694134.	2203544.	932250.	306451.	83924.	38212.	55110.	32332.	40988.	51699.	5798091.
1978	106453.	175122.	183700.	112048.	70443.	109154.	24848.	582065.	107065.	36859.	115811.	57279.	1680847.
1979	528610.	502161.	1069097.	1033116.	1708268.	1723060.	513684.	298262.	115345.	80444.	56065.	135154.	7763266.
1980	323916.	315431.	222570.	291071.	1152382.	165196.	54795.	27014.	141877.	267028.	45408.	81313.	3088001.
1981	53621.	77358.	206760.	178571.	250892.	2121400.	325283.	69527.	171955.	1329981.	588323.	110133.	5483804.
1982	81239.	97408.	181883.	307057.	1392499.	977158.	517124.	80016.	33258.	33797.	48844.	167437.	3917720.
1983	172083.	601953.	629652.	195351.	918028.	305570.	70473.	166073.	93960.	121396.	54372.	68762.	3397673.
1984	78121.	62984.	213275.	46299.	55113.	82913.	36647.	22127.	29996.	987290.	452171.	721804.	2788740.
1985	620687.	572057.	816897.	376784.	412320.	282655.	97308.	22543.	36880.	411944.	576601.	899723.	5126399.
1986	123290.	833625.	162462.	116209.	695990.	1417331.	191026.	98688.	411128.	618635.	499226.	1305623.	6473233.
1987	577625.	629530.	993087.	302711.	554962.	2540490.	425944.	111835.	98232.	45889.	101558.	248305.	6630168.
1988	144969.	115134.	204845.	95933.	69793.	265448.	84472.	40232.	81178.	28898.	16980.	38256.	1186138.
1989	143791.	255549.	348272.	264405.	1488755.	1276206.	232013.	225749.	141786.	46324.	36463.	25994.	4485307.
1990	100485.	182484.	742057.	1621648.	2270261.	773373.	149586.	124610.	155366.	84240.	136672.	61999.	6402781.
1991	1484722.	576109.	243366.	740937.	805597.	740061.	152030.	244969.	236119.	456988.	455183.	4207432.	10343513.
1992	2451762.	4311366.	2412275.	810612.	1442859.	1798214.	451334.	246073.	171630.	89174.	153176.	489895.	14828370.
1993	593590.	727150.	1236710.	789956.	1058495.	949474.	256004.	80824.	65237.	292942.	100426.	89698.	6240506.
1994	112549.	311766.	300244.	120805.	1003331.	353978.	102010.	66999.	81264.	1361316.	291312.	939402.	5044976.
1995	755368.	215509.	767654.	853542.	977541.	744128.	184029.	768878.	196337.	110463.	55849.	136473.	5765771.
1996	44289.	56533.	41905.	88978.	46110.	77653.	38466.	211058.	679088.	173684.	220595.	492921.	2171280.
1997	416542.	2072283.	1962688.	1703986.	1171238.	1154625.	432531.	155466.	66324.	103043.	111824.	705526.	10056076.
MEAN	409998.	515231.	507147.	599854.	1002987.	662864.	259386.	145842.	207889.	341470.	277067.	429207.	5358943.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRHE68

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	323267.	901700.	856038.	57404.	24830.	16934.	21257.	33958.	121068.	1257642.	1226732.	556084.	5396914.
1999	314717.	79259.	320417.	285724.	708754.	373259.	55851.	33958.	16111.	92035.	30985.	109340.	2420410.
2000	115359.	186623.	257061.	199976.	201666.	1927424.	55851.	7858.	40482.	670341.	1979655.	710435.	6352731.
2001	731578.	899293.	863458.	191510.	230382.	67208.	55851.	157261.	473832.	178415.	945326.	679584.	5473699.
2002	296997.	105143.	309795.	213604.	302657.	171797.	949774.	33958.	104956.	1868865.	301486.	888560.	5547592.
2003	224347.	306312.	161017.	58572.	121373.	1144076.	71240.	36578.	296893.	258112.	155642.	43025.	2877187.
2004	278115.	1093349.	272136.	954826.	241173.	2704949.	724862.	393989.	76445.	934585.	3389494.	332955.	11396878.
2005	235954.	501748.	315329.	61228.	320886.	105028.	131634.	950926.	60392.	71699.	33804.	16224.	2804851.
2006	21354.	155922.	426062.	311580.	296964.	148646.	55851.	33958.	158956.	519684.	170249.	189616.	2488843.
2007	744450.	122359.	2003282.	736561.	2649617.	4122218.	1041987.	313323.	239532.	68094.	112276.	127919.	12281618.
2008	39497.	55181.	560471.	637320.	304346.	85262.	23031.	200590.	128853.	193703.	44250.	21519.	2294024.
2009	14574.	37073.	246637.	325425.	435878.	66239.	195318.	33958.	1365835.	2240936.	584344.	188832.	5735049.
2010	707838.	748466.	317371.	494924.	189910.	172535.	747722.	33958.	1281940.	124126.	20585.	70495.	4909870.
2011	111483.	157324.	31102.	21743.	64545.	65724.	26521.	4105.	10340.	355920.	97268.	425878.	1371954.
2012	1260731.	635714.	1006005.	107906.	192608.	155131.	57118.	66303.	423042.	85962.	26220.	16661.	4033401.
2013	480192.	211847.	67334.	195278.	208159.	107512.	287872.	33958.	208035.	986722.	619506.	393712.	3800127.
2014	32793.	57555.	77368.	75280.	713883.	847129.	154062.	33958.	124408.	192047.	704294.	181287.	3194066.
2015	471025.	373369.	340055.	1048008.	5220954.	1499441.	160003.	17514.	23720.	2295581.	2918069.	894274.	15262013.
2016	82497.	59743.	286943.	2120006.	2395610.	440948.	55851.	577767.	548588.	68259.	399497.	140873.	7176582.
MEAN	341409.	351999.	458836.	426151.	780221.	748498.	256403.	157783.	300180.	655933.	724194.	315120.	5516726.

Table A.2.28 1940-2016 Naturalized Flows at Control Points BRRI70

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRRI70

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	51388.	148983.	43537.	200367.	319712.	660079.	1324621.	257456.	110260.	66621.	1408897.	3249758.	7841679.
1941	1186703.	1355739.	1619576.	1228816.	2796541.	2107990.	1152361.	363549.	316620.	749627.	640748.	166534.	13684804.
1942	138492.	106630.	97484.	2145751.	1970552.	1313171.	352634.	114527.	855136.	722141.	409735.	243467.	8469720.
1943	330501.	121939.	226983.	312769.	226930.	269631.	141323.	87180.	63623.	88173.	53706.	88418.	2011176.
1944	673564.	954469.	1167999.	361916.	2857198.	1081847.	174038.	72569.	269624.	114747.	327291.	779695.	8834957.
1945	1313527.	914826.	1348256.	2559710.	772069.	585796.	546199.	439755.	358432.	546772.	129401.	476876.	9991619.
1946	659965.	871210.	1314320.	510391.	1622996.	881706.	220852.	88111.	297845.	275544.	1036818.	587140.	8366898.
1947	985931.	305067.	811934.	434430.	1001274.	355036.	100176.	349617.	129603.	71565.	88360.	230713.	4863706.
1948	101687.	239222.	358634.	158442.	315392.	228985.	275325.	16912.	60546.	44631.	32526.	27629.	1859931.
1949	70753.	237853.	495181.	785062.	1050636.	505228.	216969.	36345.	102591.	278979.	199337.	264136.	4243070.
1950	281304.	758165.	173482.	529261.	559937.	665039.	249891.	198312.	294134.	126095.	39744.	32791.	3908155.
1951	21961.	49281.	60103.	78886.	175612.	365392.	37512.	31878.	77250.	32557.	23596.	32442.	986470.
1952	23048.	49734.	77722.	393347.	458387.	219557.	49304.	0.	30205.	12334.	69618.	245522.	1628778.
1953	285191.	123707.	263753.	103518.	1789798.	113055.	295391.	123985.	125570.	455456.	222666.	554906.	4456996.
1954	135090.	51876.	29086.	139559.	520301.	159243.	32153.	51969.	18444.	42704.	75284.	25854.	1281563.
1955	33292.	256191.	79452.	314765.	536879.	409303.	134963.	84539.	195279.	619289.	60262.	30954.	2755168.
1956	37242.	100771.	45222.	50820.	397044.	46514.	0.	16588.	16252.	24467.	54953.	93459.	883332.
1957	10859.	237971.	231074.	1942597.	6135975.	1996450.	592803.	173087.	101543.	1821357.	1058405.	470562.	14772683.
1958	558038.	878211.	796695.	429495.	1567963.	311145.	425625.	106642.	337797.	227234.	106401.	82633.	5827879.
1959	61453.	308892.	120249.	859606.	554019.	506546.	302171.	150344.	60474.	1670909.	468363.	658380.	5721406.
1960	1038957.	680343.	381929.	246053.	482261.	437937.	438919.	109016.	45380.	598185.	1009330.	1573005.	7041315.
1961	2303834.	2005113.	740332.	316685.	205556.	1079309.	1019755.	260041.	779815.	360904.	381450.	402200.	9854994.
1962	230109.	198120.	137389.	128911.	193000.	521943.	321370.	159856.	551424.	290725.	146460.	356112.	3235419.
1963	186279.	201692.	100332.	276899.	188308.	208895.	84369.	24140.	25483.	45655.	105709.	57074.	1504835.
1964	61676.	169841.	243113.	158607.	164225.	188102.	51832.	52385.	300767.	133024.	376164.	132869.	2032605.
1965	483970.	1100068.	375742.	476667.	3407290.	1005051.	190041.	157946.	146923.	175317.	399229.	461106.	8379350.
1966	204840.	431456.	373576.	1110474.	2137793.	329514.	111204.	300301.	734309.	283178.	73750.	57851.	6148246.
1967	70194.	51993.	60312.	174512.	216780.	282543.	176855.	52566.	134629.	72938.	255020.	153534.	1701876.
1968	1613700.	650655.	1064033.	961360.	2356464.	1771630.	990169.	162978.	251281.	131813.	184610.	518700.	10657393.
1969	148988.	579729.	937405.	1434337.	1602429.	310836.	116066.	112391.	196326.	133566.	167169.	364118.	6103360.
1970	305739.	374811.	1586500.	706040.	722011.	348857.	89227.	50523.	197715.	394058.	103774.	57086.	4936341.
1971	54009.	54651.	55796.	80177.	165643.	109424.	216477.	395894.	194581.	416132.	288958.	847479.	2879221.
1972	432453.	250254.	151766.	102229.	560749.	174587.	83430.	174023.	155917.	138681.	384867.	177852.	2786808.
1973	533364.	567714.	967397.	1350747.	926850.	1452406.	378639.	158595.	143848.	1525018.	529799.	434796.	8969173.
1974	795479.	412888.	205491.	161599.	335152.	112288.	50942.	178104.	1556466.	843957.	1927514.	783072.	7362952.
1975	532022.	1397763.	485095.	664043.	1688357.	1133992.	507798.	263565.	150391.	92367.	82947.	79829.	7078169.
1976	79560.	107955.	141022.	832353.	1235948.	666978.	760842.	164571.	193444.	459136.	372684.	1128780.	6143273.
1977	385193.	1175612.	712742.	2149729.	1009744.	418418.	131074.	55371.	80472.	43943.	56841.	60984.	6280123.
1978	172365.	265842.	213854.	117514.	74868.	139911.	37159.	569701.	180054.	46298.	155827.	114162.	2087555.
1979	698592.	610046.	1112940.	1284999.	1847737.	2016433.	495658.	385166.	263819.	109016.	71500.	165658.	9061564.
1980	432251.	399092.	209581.	352833.	1229898.	243274.	72100.	40254.	153485.	281250.	53543.	85060.	3552621.
1981	63727.	84221.	216103.	188504.	289363.	2212760.	487298.	115057.	235019.	1231960.	787775.	141870.	6053657.
1982	89066.	111154.	180470.	330038.	1441734.	1034392.	628582.	103807.	38477.	49146.	122058.	219248.	4348172.
1983	212028.	692948.	765652.	267739.	995484.	381440.	100965.	211080.	141862.	137134.	72030.	105798.	4084160.
1984	93118.	86000.	242070.	63732.	78709.	90098.	49113.	45515.	48442.	933287.	542259.	718204.	2990547.
1985	669142.	598639.	911297.	431825.	427598.	321044.	123610.	34850.	49922.	408075.	685346.	1097312.	5758660.
1986	184892.	842190.	214890.	140701.	746806.	1561399.	240245.	133284.	426843.	653272.	545550.	1448194.	7138266.
1987	674205.	669590.	1144266.	426531.	630088.	2902239.	574449.	183584.	123470.	67634.	133995.	284149.	7814200.
1988	204364.	138628.	243400.	119426.	90898.	298063.	96079.	54638.	89383.	38633.	23008.	45531.	1442051.
1989	158767.	297694.	345090.	321160.	1477226.	1371807.	330253.	295879.	151037.	51433.	43967.	29443.	4873756.
1990	116543.	209420.	738166.	1568748.	2172498.	768327.	165875.	137277.	162177.	81839.	144283.	69116.	6334269.
1991	1562352.	674023.	281932.	929813.	899822.	813250.	191063.	259368.	256313.	456600.	453629.	3720403.	10498568.
1992	2762782.	4262364.	2664145.	1023822.	1448282.	1853371.	494803.	319127.	203840.	96118.	174870.	545893.	15849417.
1993	676615.	782522.	1240002.	887208.	1233566.	1195841.	348693.	89976.	72353.	308445.	129081.	111803.	7076105.
1994	130941.	348443.	341431.	124822.	1056260.	414950.	131433.	74420.	104454.	1548149.	354312.	976023.	5605638.
1995	930250.	279159.	872961.	923507.	1026562.	839996.	212904.	795660.	211615.	134974.	81305.	172269.	6481162.
1996	83511.	80888.	56073.	87732.	49025.	85888.	61968.	220382.	733862.	223749.	238751.	481193.	2403022.
1997	439578.	1891675.	2091461.	1729174.	1181179.	1171316.	501353.	189406.	99863.	180181.	128755.	770252.	10374193.
MEAN	461646.	548378.	554595.	623978.	1062506.	742245.	304947.	169898.	231150.	364948.	315418.	470516.	5850224.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRRI70

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	312832.	826797.	1132417.	69070.	24865.	16880.	21907.	45016.	185954.	1978154.	2229217.	926479.	7769588.
1999	308374.	57980.	313519.	319009.	516064.	351217.	65014.	45016.	18212.	70968.	28823.	145973.	2240168.
2000	180954.	250263.	374301.	218286.	261516.	2040599.	54533.	0.	44989.	455871.	2213648.	1350255.	7445215.
2001	856698.	923964.	688530.	284989.	256498.	97524.	65014.	183596.	662172.	374585.	1089547.	860064.	6343181.
2002	333512.	104980.	254124.	231072.	372427.	136337.	810686.	45016.	135105.	1639633.	940720.	1959122.	6962734.
2003	422545.	453560.	306071.	57429.	66629.	707214.	77939.	62149.	349310.	374118.	280765.	82840.	3240569.
2004	353044.	1425218.	472421.	866271.	290245.	2968466.	1298561.	355155.	58462.	893958.	3454600.	795627.	13232028.
2005	227906.	669692.	359331.	87755.	292252.	94105.	129295.	996643.	55194.	88626.	53381.	35265.	3089446.
2006	70774.	201993.	455533.	253048.	254901.	151066.	65014.	45016.	198150.	679437.	582133.	228168.	3185232.
2007	1088271.	221135.	1446044.	855827.	2537346.	3463807.	1282295.	402841.	251890.	71945.	157043.	154570.	11933014.
2008	67182.	102776.	580928.	430740.	301509.	68046.	34254.	259685.	160551.	209381.	53367.	38410.	2306829.
2009	18319.	28447.	261390.	342031.	464033.	25122.	155859.	38674.	1292662.	2906000.	951340.	272508.	6756385.
2010	844996.	663436.	366456.	400432.	152748.	206300.	710998.	45016.	903215.	91810.	23577.	85664.	4494648.
2011	184744.	155203.	28950.	15926.	61974.	58975.	32708.	0.	16140.	272031.	90277.	692186.	1609115.
2012	1361159.	680379.	1941422.	128644.	179050.	147989.	100617.	64842.	363932.	59695.	44914.	34062.	5106705.
2013	514658.	318342.	54906.	191570.	232913.	133472.	296531.	45016.	259883.	1465523.	907068.	531460.	4951342.
2014	41945.	59097.	87545.	74080.	473564.	1522806.	147726.	45016.	140821.	255441.	555467.	374791.	3778299.
2015	726337.	617302.	408645.	1507652.	4755752.	2642080.	155222.	29285.	46556.	2187376.	3328114.	1301564.	17705884.
2016	248692.	101109.	278813.	1909781.	2473236.	1639088.	60523.	397470.	701927.	34306.	383976.	166157.	8395078.
MEAN	429628.	413772.	516387.	433874.	735133.	866900.	292879.	163445.	307638.	742571.	914104.	528167.	6344498.

Table A.2.29 1940-2016 Naturalized Flows at Control Points BGNE71

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BGNE71

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	21.	1268.	11.	53.	242.	978.	344.	0.	28.	205.	8122.	2879.	14151.
1941	1306.	882.	4801.	4186.	3150.	4909.	997.	563.	15219.	6714.	4127.	960.	47814.
1942	590.	1255.	680.	1060.	89.	789.	9986.	1181.	2432.	87.	530.	1991.	20670.
1943	2856.	177.	1783.	183.	69.	94.	8630.	1261.	102.	29.	13375.	3346.	31905.
1944	10664.	1741.	5900.	75.	7216.	252.	33.	108.	342.	102.	1448.	2141.	30022.
1945	2293.	1399.	74.	4068.	1872.	418.	75.	9408.	931.	2249.	45.	4950.	27782.
1946	5866.	2963.	1244.	266.	5977.	8144.	1897.	114.	5052.	514.	12678.	1883.	46598.
1947	5248.	151.	560.	130.	5471.	84.	215.	469.	1.	0.	1019.	3435.	16783.
1948	1104.	1820.	1371.	81.	1217.	1.	5.	0.	0.	0.	115.	0.	5714.
1949	54.	3358.	575.	5302.	83.	131.	1473.	3656.	173.	12438.	48.	8331.	35622.
1950	2025.	3721.	11.	1253.	189.	2410.	787.	238.	153.	110.	85.	94.	11076.
1951	243.	195.	1339.	148.	196.	253.	139.	150.	624.	102.	213.	113.	3715.
1952	87.	1215.	139.	7416.	3667.	435.	214.	65.	41.	25.	1012.	1696.	16012.
1953	112.	671.	51.	16.	8983.	9.	30.	8902.	6296.	106.	1645.	5341.	32162.
1954	808.	22.	0.	0.	527.	4.	56.	68.	12.	14.	1.	0.	1512.
1955	652.	4723.	0.	42.	1603.	63.	765.	217.	467.	15.	0.	0.	8547.
1956	1185.	724.	0.	75.	325.	202.	1.	7.	36.	0.	0.	11.	2566.
1957	0.	9.	7981.	7515.	780.	1000.	20.	15.	1387.	10578.	5762.	43.	35090.
1958	3836.	2331.	37.	29.	99.	103.	82.	78.	1888.	955.	49.	122.	9609.
1959	110.	12385.	144.	8517.	1578.	86.	529.	4982.	131.	15606.	7150.	4015.	55233.
1960	1692.	2602.	72.	906.	89.	27782.	293.	2692.	81.	5058.	941.	6655.	48863.
1961	3790.	5163.	55.	450.	119.	13236.	10237.	77.	10009.	49.	2430.	1021.	46636.
1962	10.	2.	2.	277.	697.	698.	372.	50.	1579.	54.	273.	5605.	9619.
1963	4020.	1130.	23.	21.	20.	663.	566.	50.	33.	19.	82.	1484.	8111.
1964	726.	2826.	3965.	78.	93.	304.	92.	94.	1113.	885.	1019.	2580.	13775.
1965	3408.	3425.	24.	65.	1072.	705.	194.	148.	126.	1279.	6113.	3542.	20101.
1966	2398.	5258.	233.	8174.	8327.	473.	275.	539.	1833.	91.	6.	23.	27630.
1967	576.	202.	53.	369.	1076.	119.	473.	3548.	2047.	1621.	25.	1886.	11995.
1968	4360.	1047.	797.	716.	6288.	11940.	889.	206.	1260.	853.	570.	1192.	30118.
1969	1245.	7958.	3570.	774.	9320.	105.	48.	178.	231.	639.	187.	1589.	25844.
1970	712.	1684.	3322.	590.	2660.	560.	121.	146.	2588.	10802.	109.	9.	23303.
1971	12.	132.	9.	231.	141.	127.	179.	5107.	14840.	1495.	33.	3057.	25363.
1972	2053.	3582.	579.	522.	8142.	1016.	351.	613.	203.	554.	4435.	61.	22111.
1973	3705.	5279.	5637.	12919.	520.	16933.	1724.	489.	12815.	12145.	941.	398.	73505.
1974	11346.	55.	2279.	435.	4036.	369.	357.	867.	5476.	1984.	10649.	2476.	40329.
1975	720.	422.	0.	1165.	8237.	4092.	220.	654.	137.	254.	891.	2635.	19427.
1976	0.	0.	0.	288.	1857.	4265.	1255.	0.	32.	504.	1099.	10827.	20127.
1977	322.	2662.	0.	2960.	153.	174.	290.	232.	722.	0.	354.	47.	7916.
1978	6863.	3035.	0.	93.	55.	2259.	306.	6.	1166.	1438.	2849.	648.	18718.
1979	9843.	4652.	1592.	8191.	3608.	327.	660.	587.	23650.	0.	1.	3094.	56205.
1980	4763.	417.	713.	36.	1051.	162.	263.	387.	304.	85.	33.	33.	8247.
1981	252.	103.	123.	81.	4333.	3845.	7330.	6500.	7501.	7136.	1560.	22.	38786.
1982	24.	1316.	50.	1254.	13677.	382.	599.	87.	0.	0.	6257.	1026.	24672.
1983	1938.	7481.	2662.	47.	1667.	591.	6315.	17399.	11095.	33.	2744.	53.	52025.
1984	444.	196.	0.	38.	518.	353.	262.	824.	10.	15168.	864.	453.	19130.
1985	1864.	1436.	4471.	969.	239.	609.	263.	116.	328.	746.	17542.	5258.	33841.
1986	0.	1.	0.	34.	936.	6506.	208.	509.	2418.	10269.	6631.	11748.	39260.
1987	1992.	5131.	191.	0.	1067.	13065.	1628.	74.	56.	0.	764.	3232.	27200.
1988	338.	0.	1015.	1348.	304.	103.	942.	126.	0.	72.	0.	0.	4248.
1989	1494.	19.	524.	1161.	5390.	395.	372.	8875.	0.	0.	216.	0.	18446.
1990	207.	3058.	1214.	1612.	1011.	0.	5.	0.	0.	103.	43.	0.	7253.
1991	5929.	2065.	285.	5514.	132.	4255.	637.	574.	105.	0.	685.	9851.	30032.
1992	7001.	11539.	4536.	7529.	778.	2862.	521.	117.	194.	0.	3694.	1653.	40424.
1993	4065.	2593.	4886.	3649.	5504.	13768.	17.	7.	55.	0.	2527.	1072.	38143.
1994	259.	869.	388.	650.	6813.	910.	0.	284.	2095.	15710.	0.	2572.	30550.
1995	6200.	480.	2692.	3977.	1906.	2289.	655.	274.	0.	65.	822.	5872.	25232.
1996	155.	98.	57.	0.	0.	1108.	56.	1234.	2748.	92.	468.	851.	6867.
1997	1958.	2852.	6440.	9244.	2147.	760.	24.	28.	6936.	6038.	839.	2694.	39960.
MEAN	2340.	2272.	1365.	2013.	2540.	2732.	1125.	1469.	2571.	2502.	2347.	2355.	25631.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BGNE71

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	3638.	5051.	153.	42.	143.	33.	49.	278.	7418.	3038.	4161.	869.	24873.
1999	571.	46.	505.	58.	420.	994.	148.	7.	0.	0.	125.	597.	3470.
2000	311.	47.	0.	1133.	1231.	124.	62.	4.	0.	1155.	15769.	1992.	21827.
2001	3961.	110.	2900.	110.	55.	13783.	1796.	6851.	5197.	3729.	2961.	5544.	46998.
2002	720.	47.	0.	299.	78.	272.	935.	9660.	11791.	21211.	3238.	7800.	56051.
2003	1042.	1227.	0.	46.	228.	1243.	3170.	344.	9771.	3340.	3820.	1137.	25367.
2004	4358.	5205.	516.	961.	4926.	16795.	459.	10.	0.	1354.	22923.	1084.	58591.
2005	480.	4438.	1276.	67.	499.	72.	2645.	15.	0.	0.	1094.	1291.	11878.
2006	229.	118.	0.	59.	297.	2207.	9152.	308.	520.	16928.	42.	1363.	31223.
2007	7580.	447.	3501.	1674.	2587.	1038.	16770.	2690.	1572.	412.	810.	324.	39405.
2008	3687.	437.	0.	62.	43.	52.	1811.	1644.	3378.	302.	722.	0.	12138.
2009	0.	70.	0.	7285.	120.	28.	53.	8.	1579.	12978.	722.	6382.	29226.
2010	919.	612.	0.	53.	64.	446.	13996.	15.	2638.	0.	1282.	683.	20708.
2011	1807.	62.	0.	55.	67.	28.	49.	3.	0.	0.	21.	1134.	3227.
2012	3187.	7459.	4520.	328.	675.	114.	7131.	260.	412.	0.	130.	1260.	25477.
2013	3643.	482.	0.	2628.	116.	79.	108.	12.	1181.	4124.	4684.	251.	17308.
2014	458.	889.	1074.	80.	9824.	1306.	1242.	192.	5238.	0.	1332.	3629.	25263.
2015	4085.	32.	6410.	7954.	17574.	2890.	124.	1260.	3010.	11214.	3682.	1303.	59539.
2016	1005.	56.	1059.	9465.	6790.	3991.	160.	5671.	424.	0.	45.	1202.	29868.
MEAN	2194.	1412.	1153.	1703.	2407.	2394.	3151.	1539.	2849.	4199.	3556.	1992.	28549.

Table A.2.30 1940-2016 Naturalized Flows at Control Points BRRO72

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRRO72

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	53238.	154346.	45104.	207580.	331222.	683842.	1372307.	266724.	114229.	69019.	1459617.	3366749.	8123977.
1941	1229424.	1404546.	1677881.	1273053.	2897216.	2183878.	1193846.	376637.	328018.	776614.	663815.	172529.	14177457.
1942	143478.	110469.	100993.	2222998.	2041492.	1360445.	365329.	118650.	885921.	748138.	424485.	252232.	8774630.
1943	342399.	126329.	235154.	324029.	235099.	279338.	146411.	90318.	65913.	91347.	55639.	91601.	2083577.
1944	697812.	988830.	1210047.	374945.	2960057.	1120793.	180303.	75181.	279330.	118878.	339073.	807764.	9153013.
1945	1360814.	947760.	1396793.	2651860.	799863.	606885.	565862.	455586.	371336.	566456.	134059.	494044.	10351318.
1946	683724.	902574.	1361636.	528765.	1681424.	913447.	228803.	91283.	308567.	285464.	1074143.	608277.	8668107.
1947	1021425.	316049.	841164.	450069.	1037320.	367817.	103782.	362203.	134269.	74141.	91541.	239019.	5038799.
1948	105348.	247834.	371545.	164146.	326746.	237228.	285237.	17521.	62726.	46238.	33697.	28624.	1926890.
1949	73300.	246416.	513008.	813324.	1088459.	523416.	224780.	37653.	106284.	289022.	206513.	273645.	4395820.
1950	291431.	785459.	179727.	548314.	580095.	688980.	258887.	205451.	304723.	130634.	41175.	33971.	4048847.
1951	22752.	51055.	62267.	81726.	181934.	378546.	38862.	33026.	80031.	33729.	24445.	33610.	1021983.
1952	23878.	51524.	80520.	407507.	474889.	227461.	51079.	0.	31292.	12778.	72124.	254361.	1687413.
1953	295458.	128160.	273248.	107245.	1854231.	117125.	306025.	128448.	130091.	471852.	230682.	574883.	4617448.
1954	139953.	53744.	30133.	144583.	539032.	164976.	33311.	53840.	19108.	44241.	77994.	26785.	1327700.
1955	34491.	265414.	82312.	326097.	556207.	424038.	139822.	87582.	202309.	641583.	62431.	32068.	2854354.
1956	38583.	104399.	46850.	52650.	411338.	48189.	0.	17185.	16837.	25348.	56931.	96824.	915134.
1957	11250.	246538.	239393.	2012530.	6356870.	2068322.	614144.	179318.	105199.	1886926.	1096508.	487502.	15304500.
1958	578127.	909827.	825376.	444957.	1624410.	322346.	440948.	110481.	349958.	235414.	110231.	85608.	6037683.
1959	63665.	320012.	124578.	890552.	573964.	524782.	313049.	155756.	62651.	1731062.	485224.	682082.	5927377.
1960	1076359.	704835.	395678.	254911.	499622.	453703.	454720.	112941.	47014.	619720.	1045666.	1629633.	7294802.
1961	2386772.	2077297.	766984.	328086.	212956.	1118164.	1056466.	269402.	807888.	373897.	395182.	416679.	10209773.
1962	238393.	205252.	142335.	133552.	199948.	540733.	332939.	165611.	571275.	301191.	151733.	368932.	3351894.
1963	192985.	208953.	103944.	286867.	195087.	216415.	87406.	25009.	26400.	47299.	109515.	59129.	1559009.
1964	63896.	175955.	251865.	164317.	170137.	194874.	53698.	54271.	311595.	137813.	389706.	137652.	2105779.
1965	501393.	1139670.	389269.	493827.	3529952.	1041233.	196882.	163632.	152212.	181628.	413601.	477706.	8681005.
1966	212214.	446988.	387025.	1150451.	2214754.	341377.	115207.	311112.	760744.	293372.	76405.	59934.	6369583.
1967	72721.	53865.	62483.	161664.	215563.	291241.	191368.	54689.	137020.	70462.	252659.	148527.	1712262.
1968	1654240.	709465.	1096636.	1018930.	2415833.	1939144.	1105410.	197619.	247219.	130248.	171614.	541778.	11228136.
1969	181193.	671390.	1045160.	1502430.	1754553.	305198.	126167.	111656.	185324.	145018.	180827.	393393.	6602309.
1970	332554.	380173.	1772829.	742226.	750158.	355769.	116342.	59623.	217096.	521907.	128659.	62523.	5439859.
1971	58952.	53992.	62405.	92698.	170534.	133924.	224030.	430146.	299839.	389915.	266448.	868109.	3050992.
1972	417043.	276039.	145834.	97843.	617167.	185237.	82079.	178126.	166988.	137269.	382957.	158100.	2844682.
1973	552404.	602025.	1029244.	1437168.	927328.	1714147.	439495.	168975.	288618.	1619420.	508231.	425267.	9712322.
1974	840778.	422608.	201552.	166803.	332880.	123258.	69085.	172158.	1535561.	778316.	2004069.	816142.	7463210.
1975	531774.	1394021.	487325.	671495.	1693672.	1245715.	528127.	282720.	169434.	104173.	104744.	96621.	7309821.
1976	85680.	96771.	134735.	750605.	1244994.	723389.	776882.	179508.	204231.	451249.	401907.	1199034.	6248985.
1977	323769.	1142696.	696465.	2164333.	1003686.	391220.	139707.	65252.	98451.	53052.	59854.	61898.	6200383.
1978	206484.	260100.	205051.	120882.	104866.	182930.	71739.	560266.	154053.	48782.	135899.	94941.	2145993.
1979	701258.	640953.	1141997.	1286109.	1814520.	2011786.	502973.	422844.	427717.	108714.	75792.	175448.	9310111.
1980	487470.	403935.	189799.	337117.	1208517.	259233.	98498.	44670.	173878.	291375.	55471.	88122.	3638085.
1981	66021.	87253.	223883.	195290.	299780.	2292419.	504841.	119199.	243480.	1276311.	816135.	146977.	6271589.
1982	92272.	115156.	186967.	341919.	1493636.	1071630.	651211.	107544.	39862.	50915.	126452.	227141.	4504705.
1983	219661.	717894.	793215.	277378.	1031321.	395172.	104600.	218679.	146969.	142071.	74623.	109607.	4231190.
1984	96470.	89096.	250785.	66026.	139334.	113293.	57461.	40688.	40672.	1028667.	601077.	727978.	3251547.
1985	727072.	626604.	1086591.	462453.	431492.	322826.	143285.	58333.	54184.	417224.	766192.	1145609.	6241865.
1986	181176.	884104.	217161.	141516.	722127.	1557818.	242662.	156286.	415002.	658992.	587984.	1490842.	7255670.
1987	680485.	680513.	1082514.	355024.	572493.	2811527.	553301.	202609.	146822.	78627.	142717.	293711.	7600343.
1988	210109.	137050.	240133.	128592.	115155.	300718.	155216.	91737.	93455.	36802.	23072.	36603.	1568642.
1989	143458.	295788.	319652.	321314.	1451771.	1420498.	377362.	377631.	162573.	61768.	53930.	27341.	5013086.
1990	113064.	214488.	696572.	1521610.	2180665.	885404.	200361.	141237.	164431.	81981.	133267.	64048.	6397128.
1991	1650649.	703646.	284672.	1050177.	861562.	839032.	226239.	248580.	239763.	451617.	476808.	3428792.	10461537.
1992	3394240.	4604430.	3055505.	1256932.	1658350.	2186986.	524178.	329003.	232564.	117193.	199261.	530614.	18089254.
1993	682326.	753587.	1293745.	966614.	1299726.	1291424.	348717.	116307.	80377.	331656.	214064.	134376.	7512919.
1994	137461.	356560.	399937.	137260.	1139384.	463742.	155320.	90042.	130091.	1661135.	402931.	1093773.	6167636.
1995	1114019.	350025.	1024527.	1101274.	1133616.	892140.	269256.	798663.	218281.	152251.	95064.	251814.	7400930.
1996	83162.	78906.	58957.	89433.	52427.	83217.	64321.	227399.	750840.	241935.	233415.	477788.	2441800.
1997	493944.	1948035.	2338852.	1915635.	1273200.	1182187.	503459.	211613.	177284.	240028.	123625.	779400.	11187262.
MEAN	489905.	570197.	585517.	650305.	1098011.	777941.	322652.	179804.	246172.	381257.	329688.	480830.	6112278.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRRO72

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	232782.	733954.	1180936.	58828.	48338.	51628.	55904.	24397.	195266.	1702928.	2621791.	1141802.	8048554.
1999	370975.	56956.	277356.	370620.	446398.	435517.	81114.	24397.	32587.	102339.	55279.	133800.	2387338.
2000	159233.	253449.	280136.	219453.	225035.	2198892.	55904.	24397.	32587.	429385.	2106412.	1678120.	7663003.
2001	780583.	924064.	625441.	488472.	205411.	119797.	55904.	150559.	744475.	494916.	1034039.	838667.	6462328.
2002	385978.	100220.	242088.	217240.	373928.	137228.	739645.	106120.	132451.	1374516.	1455290.	1615972.	6880676.
2003	679040.	288898.	317714.	58828.	117349.	621769.	138088.	48647.	278810.	525537.	234554.	119942.	3429176.
2004	256264.	1379935.	626554.	724953.	440709.	2809772.	2522819.	374149.	132307.	628365.	3196285.	1541092.	14633204.
2005	193034.	681116.	286645.	58828.	263155.	75386.	152372.	921544.	126893.	79839.	55279.	43500.	2937589.
2006	104342.	194684.	398321.	251367.	248618.	150291.	55904.	24397.	197939.	629717.	924039.	189833.	3369451.
2007	1012360.	479284.	973087.	1223721.	2273716.	3602020.	1521017.	668455.	266867.	56942.	141327.	210447.	12429243.
2008	98555.	75764.	444478.	466342.	366752.	92236.	55904.	219306.	193584.	205021.	73526.	43500.	2334970.
2009	43927.	54370.	226649.	366793.	707822.	50585.	160057.	24397.	944002.	3064302.	1632534.	271149.	7546587.
2010	758031.	637266.	340967.	321683.	182179.	179858.	723798.	24397.	619795.	220570.	55279.	73794.	4137616.
2011	185541.	144607.	50752.	46778.	58828.	58828.	55904.	0.	32587.	260486.	75124.	544361.	1513796.
2012	1164565.	838103.	1656970.	317153.	179239.	150491.	105692.	117226.	370326.	122594.	55279.	43500.	5121138.
2013	367284.	341157.	50752.	168976.	192565.	146365.	279289.	24397.	228363.	1470130.	1127124.	562439.	4958841.
2014	43927.	108679.	50752.	58828.	412897.	2289010.	200069.	24397.	138639.	262627.	443698.	442457.	4475980.
2015	606553.	741085.	302866.	1612607.	4437795.	3696899.	186787.	24397.	32587.	1428010.	3812722.	1568359.	18450668.
2016	317748.	88872.	250498.	1572168.	2702484.	2483012.	55904.	319076.	966476.	84891.	279452.	187222.	9307803.
MEAN	408459.	427498.	451735.	452823.	730696.	1018399.	379056.	165508.	298239.	691743.	1019949.	592103.	6636208.

Table A.2.31 1940-2016 Naturalized Flows at Control Points BRGM73

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRGM73

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	52435.	156451.	44398.	204339.	326625.	676111.	1350846.	262307.	112440.	68628.	1465291.	3321573.	8041444.
1941	1213863.	1384529.	1667737.	1267354.	2860813.	2165749.	1177738.	372470.	378506.	788423.	667985.	173201.	14118368.
1942	143269.	113252.	101820.	2190079.	2008013.	1340817.	395971.	121025.	880186.	736070.	419404.	255371.	8705277.
1943	347222.	124888.	237811.	319335.	231461.	275056.	175695.	93456.	65195.	89941.	103862.	102379.	2166301.
1944	725440.	978853.	1211688.	369011.	2937554.	1103160.	177438.	74335.	275961.	117285.	338780.	802254.	9111759.
1945	1346704.	937205.	1373933.	2622893.	793496.	598370.	556766.	482610.	368609.	565338.	132006.	504049.	10281979.
1946	693957.	898516.	1343657.	520988.	1675540.	928245.	231983.	90189.	322021.	282624.	1102939.	605124.	8695783.
1947	1023792.	311372.	829291.	443094.	1040245.	362035.	102854.	357928.	132049.	72914.	93769.	247682.	5017025.
1948	107660.	250417.	370430.	161725.	325807.	233304.	280532.	17231.	61687.	45472.	33561.	28150.	1915976.
1949	72285.	254674.	506625.	819337.	1070739.	515230.	226470.	50464.	105160.	329938.	203270.	299725.	4453917.
1950	294046.	786124.	176791.	543838.	571183.	686426.	257491.	202924.	300240.	128877.	40806.	33754.	4022500.
1951	23269.	50928.	66154.	80917.	179643.	373206.	38729.	33029.	81000.	33545.	24824.	33468.	1018712.
1952	23801.	55136.	79696.	428009.	480499.	225293.	51019.	239.	30925.	12658.	74648.	256380.	1718303.
1953	290977.	128504.	268911.	105527.	1856532.	115218.	301068.	159031.	151070.	464428.	232906.	584988.	4659160.
1954	140605.	52934.	29634.	142189.	532042.	162258.	32965.	53198.	18836.	43560.	76706.	26341.	1311268.
1955	36315.	278373.	80949.	320851.	552886.	417247.	140317.	86929.	200675.	631014.	61398.	31537.	2838491.
1956	42298.	105330.	46074.	52053.	405720.	48133.	4.	16926.	16691.	24928.	55989.	95261.	909407.
1957	11064.	242488.	264754.	2006816.	6254466.	2037745.	604047.	176404.	108553.	1894546.	1099521.	479587.	15179991.
1958	582649.	903325.	811844.	437695.	1597873.	317387.	433947.	108938.	351100.	235025.	108586.	84638.	5973007.
1959	63015.	360220.	123044.	907099.	570257.	516407.	309809.	171483.	62095.	1759738.	503461.	685539.	6032167.
1960	1064752.	702724.	389391.	254019.	491676.	548272.	448267.	120962.	46533.	628042.	1031807.	1627100.	7353545.
1961	2361173.	2061868.	754485.	324306.	209867.	1148282.	1076586.	265224.	831287.	367885.	397567.	413531.	10212061.
1962	234482.	201861.	139985.	132358.	199198.	534343.	328793.	163052.	567617.	296402.	150223.	383418.	3331732.
1963	204560.	209645.	102307.	282194.	191930.	215268.	88039.	24779.	26084.	46585.	108002.	63602.	1562995.
1964	65506.	183425.	262263.	161882.	167661.	192764.	53147.	53718.	310524.	138783.	386997.	144853.	2121523.
1965	505612.	1133382.	382911.	485888.	3475435.	1026580.	194335.	161466.	150155.	183320.	429214.	482810.	8611108.
1966	217511.	458906.	381472.	1161434.	2208674.	337461.	114310.	307940.	754881.	288849.	75162.	59026.	6365626.
1967	73633.	53715.	61643.	160343.	215947.	286855.	189937.	66820.	142272.	75251.	248567.	152997.	1727980.
1968	1642866.	701563.	1081404.	1004687.	2398932.	1950904.	1090371.	195103.	247755.	131225.	170866.	537186.	11152862.
1969	182767.	689513.	1040970.	1480394.	1759743.	300530.	124254.	110461.	183104.	144964.	178520.	392717.	6587937.
1970	329663.	380065.	1755677.	732103.	747509.	351935.	114860.	59172.	223010.	552955.	126929.	61521.	5435399.
1971	58020.	53583.	61405.	92012.	168228.	132173.	220978.	441788.	349402.	388951.	262157.	864966.	3093663.
1972	417680.	284630.	145546.	98141.	636864.	185903.	82009.	177429.	164969.	137031.	392911.	155706.	2878819.
1973	556870.	611453.	1032912.	1460838.	913882.	1747980.	438552.	167974.	330926.	1637228.	503272.	419687.	9821574.
1974	868545.	415812.	206588.	165639.	342197.	122573.	69253.	172493.	1530253.	772717.	2010011.	811725.	7487806.
1975	525613.	1372487.	479255.	664656.	1695891.	1240122.	520190.	280441.	167132.	103381.	106283.	104703.	7260154.
1976	84261.	95168.	132504.	739233.	1231200.	727081.	768628.	176535.	200967.	445628.	399290.	1218961.	6219456.
1977	319591.	1133554.	684932.	2139368.	987627.	385381.	138459.	65024.	99474.	52173.	60164.	61046.	6126793.
1978	228282.	266945.	201655.	119222.	103332.	188201.	71675.	551010.	155786.	53258.	144117.	95750.	2179233.
1979	725812.	647432.	1128935.	1294908.	1797729.	1979672.	497069.	417999.	507534.	106914.	74541.	183911.	9362456.
1980	496899.	398778.	189276.	331667.	1192366.	255535.	97833.	45352.	172116.	286862.	54673.	86784.	3608141.
1981	65854.	86187.	220627.	192354.	310737.	2268585.	523414.	141109.	267009.	1281396.	808352.	144624.	6310248.
1982	90833.	118084.	184054.	340865.	1519157.	1055288.	642628.	106083.	39202.	50072.	147349.	227149.	4520764.
1983	223144.	733494.	789861.	272957.	1020368.	390799.	126072.	278989.	185303.	139839.	83470.	107986.	4352282.
1984	96504.	88341.	246632.	65073.	138930.	112714.	57472.	43042.	40035.	1067366.	594298.	717587.	3267994.
1985	721881.	621504.	1085025.	458355.	425225.	319718.	141879.	57793.	54492.	413056.	817961.	1145958.	6262847.
1986	178176.	869467.	213565.	139297.	713608.	1555926.	239408.	155568.	417014.	685812.	602612.	1509321.	7279774.
1987	676536.	688097.	1065289.	349145.	566933.	2812974.	550120.	199526.	144596.	77325.	143161.	300723.	7574425.
1988	207872.	134780.	239886.	131416.	114365.	296117.	156107.	90681.	91907.	36457.	22690.	35997.	1558275.
1989	146572.	290960.	316284.	320259.	1447535.	1398426.	372480.	403988.	159881.	60745.	53831.	26888.	4997849.
1990	111952.	222172.	689498.	1502335.	2148268.	870742.	197061.	138898.	161708.	81002.	131218.	62987.	6317841.
1991	1645100.	699581.	281005.	1053047.	847780.	840772.	224833.	246573.	236178.	444138.	471429.	3408208.	10398644.
1992	3363756.	4570580.	3021573.	1263782.	1633746.	2161286.	517412.	323985.	229426.	115252.	209535.	527901.	17938232.
1993	685963.	750635.	1290274.	964015.	1298427.	1320627.	343005.	114407.	79248.	326164.	219804.	136090.	7528659.
1994	136136.	353848.	394740.	137375.	1145550.	459406.	152748.	89594.	135635.	1691352.	396258.	1085111.	6177753.
1995	1118352.	345992.	1017452.	1097650.	1121847.	885777.	267204.	786444.	214666.	149969.	96510.	269220.	7371083.
1996	82354.	77959.	58190.	87952.	51559.	85910.	63462.	228168.	748503.	238267.	231269.	473003.	2426596.
1997	492959.	1926255.	2323784.	1917878.	1260005.	1165403.	495210.	208212.	199834.	258239.	124661.	776392.	11148832.
MEAN	490392.	569103.	580836.	646934.	1089161.	775098.	321444.	182223.	251542.	384135.	332852.	481520.	6105239.

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT BRGM73

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	245188.	1128518.	489564.	84231.	24595.	19538.	25027.	47064.	227927.	1489136.	2748298.	904082.	7433168.
1999	318227.	70084.	278645.	269869.	412725.	324034.	73110.	47064.	17524.	94768.	28375.	133685.	2068110.
2000	183769.	220140.	260646.	211027.	279418.	428017.	65165.	13742.	48813.	352035.	2444065.	2359006.	6865843.
2001	770332.	502218.	1289224.	305694.	215465.	179589.	73110.	150981.	980258.	415065.	535598.	1534230.	6951764.
2002	307680.	122413.	248432.	233163.	299753.	140022.	289811.	110672.	129984.	1623953.	2808514.	1388942.	7703339.
2003	593353.	573002.	187215.	72678.	91385.	356633.	342233.	47064.	324129.	432524.	319491.	107042.	3446747.
2004	273193.	1145658.	687381.	426077.	1245108.	2312169.	1611656.	319626.	83380.	445310.	3157781.	2305435.	14012774.
2005	245251.	636314.	361285.	110496.	270588.	99235.	119459.	271742.	59775.	47941.	64516.	38132.	2324733.
2006	110222.	209156.	344340.	261887.	257566.	141288.	73110.	47064.	193620.	1214010.	331966.	285411.	3469640.
2007	1251871.	247204.	507771.	2090614.	993723.	3061270.	3840541.	296201.	225497.	108287.	159423.	170815.	12953217.
2008	99688.	109001.	224545.	402552.	369211.	80112.	50482.	232415.	184152.	204487.	67785.	37343.	2061771.
2009	17691.	27769.	246414.	557415.	283552.	26439.	152578.	46070.	534741.	3472227.	2405658.	190525.	7961079.
2010	405202.	925700.	319237.	314680.	142882.	196935.	250812.	47064.	285106.	190970.	27006.	87532.	3193126.
2011	203171.	168706.	29307.	17202.	47889.	67298.	34532.	9507.	14750.	251890.	129878.	434350.	1408478.
2012	911077.	2325737.	1589000.	150694.	187290.	150226.	109787.	104726.	203809.	272506.	49108.	34487.	6088447.
2013	374893.	307026.	62288.	200966.	211252.	135189.	268066.	47064.	220882.	1511916.	1405913.	366786.	5112241.
2014	48049.	76001.	94419.	101842.	802990.	782985.	212030.	47064.	143626.	216144.	608378.	754865.	3888392.
2015	673837.	421802.	772072.	1025422.	3813288.	4518736.	161579.	34491.	59775.	709292.	3970435.	2966976.	19127704.
2016	239242.	89051.	276940.	1086300.	4110515.	1001532.	73110.	350589.	337188.	33062.	277078.	466089.	8340696.
MEAN	382733.	489763.	435196.	416990.	739958.	737960.	411905.	119485.	224997.	688712.	1133646.	766618.	6547962.

A.3 *HYD* Input HIN File for Synthesizing 1998-2016 Naturalized Flows

```
**  WRAP-HYD Input File Bwam.HIN for Extending Naturalized Flows for the Brazos WAM
**      1       2       3       4       5
**34567890123456789012345678901234567890123456789012345678901234567890
**    !   !   !   !   !   !   !   !   !   !   !
JC  1940  58  1  1                    1
CPRWPL01
CPWRSP02
CPDUGI03
CPSFPE04
CPCRJA05
CPSFAS06
CPBSLU07
CPDMJU08
CPDMAS09
CPNCKN10
CPBRSE11
CPMSMN12
CPCFRO13
CPCFHA14
CPMUHA15
CPCFNU16
CPCAST17
CPCFFG18
CPHCAL19
CPBSBR20
CPHCBR21
CPCFEL22
CPBRSB23
CPGHGH24
CPCCIV25
CPSHGR26
CPBRPP27
CPPPSA28
CPBRDE29
CPBRGR30
CPPAGR31
CPNRBL32
CPBRAQ33
CPAQAQ34
CPNBHI35
CPNBCL36
CPNBVM37
CPMBMG38
CPHGCR39
CPBOWA40
CPBRWA41
CPBRHB42
CPLEDL43
CPSADL44
CPLEHS45
CPLEHM46
CPLEGT47
CPCOPI48
CPLEBE49
CPLAKE50
CPLAYO51
```

```
CPLABE52
CPLRLR53
CPNGGE54
CPSGGE55
CPGAGE56
CPGALA57
CPLRCA58
CPBRBR59
CPMYDB60
CPEYDB61
CPYCSO62
CPDCLY63
CPNAGR64
CPBGFR65
CPNAEA66
CPNABR67
CPBRHE68
CPMCBL69
CPBRRI70
CPBGNE71
CPBRRO72
CPBRGM73
CPCLPEC1
CPCBALC2
CPSJGBC3
CPSJGMC4
**
**     1       2       3       4       5       6       7       8       9      10
**3456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
**    !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !
**
** Flow Extension for Control Point RWPL01
FERWPL01  1998  2016  1940  1997   1   0                           0.626996
FN                  Ext1998-2016
QD    2    306    305
QA        255.   830.
FZ              26.0          49.2          303.8    99.0
FR    2    4.0    12.0    26.0    49.2    71.0    99.0   303.8  1008.2  3616.8
FR         0.0     0.9     2.9     6.1    42.5   160.3  1156.2  2552.0  4908.7
FX      1.0000013.89098 8.90507 9.06144 2.75042 1.09445 0.27705 0.32147 0.58103 1.24454
UB            0.12096 0.72399 1.00000 0.35812 0.91998 1.00000
BM        0.00    0.00    0.00    7.85    4.30    8.30    0.91    0.00    6.95    0.00    0.00    0.00
XP   306  0.86171991  0.98137707  0.37111071  0.95913601  0.99400699
XP   305  0.95638746  0.99871624  0.00020500  0.96800011  0.99900001
B4        0.00    0.00    0.00  160.00  125.00  115.00  125.00    0.00    0.00    0.00    0.00    0.00
X4   306  0.67157602  0.99935585  0.39999875  0.97990203  1.00000000
X4   305  1.00000000  1.00000000  0.00000000  0.82428634  1.00000000
**
** Flow Extension for Control Point WRSP02
FEWRSP02  1998  2016  1940  1997   1   0                           0.698995
FN                  Ext1998-2016
QD    3    406    306    305
QA         914    839   1060
FZ               17.          214.          1350.    647.
FR    2   109.   214.   357.   647.  1350.  3286.  7597. 19821.2
FR         0.0    1.9    5.6   641.3  2939.0  6078.2  9881.5 14508.9
FX      1.00000124.099477.46606 3.23828 0.53282 0.49157 0.64909 1.06279 1.41468
UB            0.00661 0.75377 1.00000 0.26267 0.89237 1.00000
BM        0.00    3.90    0.00   10.00    3.10    8.00    0.00    0.00    0.00    0.00    0.00    0.00
XP   406  0.68542510  0.98737276  0.00006022  0.98000002  0.99900001
XP   306  0.88191676  0.90748286  0.39358222  0.98392594  0.94999999
XP   305  1.00000000  0.95094997  0.37980852  1.00000000  0.94999999
```

```
B4       0.00 125.00   0.00 210.00 330.00 140.00 267.50   0.00   0.00 305.00 310.00   0.00
X4  406 0.36055031 0.99718571 0.26718560 0.40975738 1.00000000
X4  306 0.67568904 1.00000000 0.34957820 0.93848836 0.99945039
X4  305 0.86989510 1.00000000 0.00000000 0.94347841 1.00000000
**
** Flow Extension for Control Point DUGI03
FEDUGI03 1998 2016 1940 1997  1  0                          1.000000
FN                Ext1998-2016
QD   2   407   406
QA       265   111
FZ            45.         89.        317.   190.
FR   2    3.    9.   45.   66.   89.  127.   190.  317.   661.  1952.  4908.
FR       0.5   1.0   2.5   6.0  37.9  78.5  211.7  981.1 2126.6 3507.5 5018.5
FX     2.89408 6.7657817.1169413.27766 3.99600 1.87956 1.31247 0.40218 0.29572 0.41919 0.72544 1.47420
UB  0.7   0.7 0.10251 0.77931 0.00000 0.64000 0.89898 1.00000
BM       2.17   6.00   2.33   9.00   9.00   9.00   9.00   2.00   1.00   1.67   7.00   5.83
XP  407 0.55371559 1.00000000 0.00010927 0.90250009 1.00000000
XP  406 0.87731111 1.00000000 0.34403285 0.73821783 1.00000000
B4       0.00  16.00  72.33   0.00 162.17  31.83  27.50  22.00   0.00 126.67   0.00   5.83
X4  407 0.58988196 1.00000000 0.00000000 0.98000002 1.00000000
X4  406 1.01000011 1.00000000 0.40999994 0.80000007 1.00000000
**
** Flow Extension for Control Point SFPE04
FESFPE04 1998 2016 1940 1997  1  0                          5.999748
FN                Ext1998-2016
QD   4   407   406   306   305
QA       854  1570   839  1060
FZ           159.        448.       2253.  1219.
FR   2   16.   37.  159.  291.  448.   693.  1219.  2253.  4420. 10907. 24928.
FR       0.8   1.1   2.4   4.1  180.0  404.2 1021.1 4952.5 10152.4 17052.2 25702.5
FX    12.0809424.7706656.3408365.65617 3.64461 2.02028 1.40618 0.63453 0.43586 0.53615 0.83370 1.31816
UB  5.5   5.5 0.04604 0.76640 0.11000 0.17424 0.94868 1.00000
BM       8.83  16.50   9.67  37.00  37.00  37.00  37.00  22.00   4.17   5.50  22.00  24.83
XP  407 0.91827166 0.87352514 0.29296798 0.91554147 0.90249997
XP  406 0.66538459 1.00000000 0.00003167 0.45351076 0.94999999
XP  306 0.47275123 0.96552056 0.32449079 1.00000000 0.85301358
XP  305 0.67840451 0.89754570 0.34438664 0.97280097 0.85792965
B4       0.00   0.00   0.00  50.00  80.00  50.00  80.00  80.00   0.00  70.00  80.00  80.00
X4  407 0.59307504 0.99900001 0.23814303 1.00000000 0.95269334
X4  406 0.41984826 1.00000000 0.00000000 0.47086826 1.00000000
X4  306 0.85382622 1.00000000 0.25120756 0.95095432 1.00000000
X4  305 0.78766716 0.99800003 0.34178546 0.98000002 1.00000000
**
** Flow Extension for Control Point CRJA05
FECRJA05 1998 2016 1940 1997  1  0                          0.481997
FN                Ext1998-2016
QD   1   407
QA       286
FZ            33.        141.       1136.   520.
FR   2   33.   49.   80.  141.   260.   520.  1136.  2640.  5865. 14614.5
FR       0.0   3.6  31.4  58.5  123.5  584.2 2061.9 4226.7 6356.6 10840.4
FX     1.0000018.25587 4.36259 2.40813 2.33474 1.09104 0.59982 0.55209 0.75982 1.05776 1.39823
UB          0.15731 0.82999 1.00000 0.54000 1.02998 1.00000
BM       0.00   0.00   0.00  12.60  27.83   0.00   0.00  14.90   0.00   0.00   0.00   0.00
XP  407 0.86172080 1.00000000 0.03272296 0.97000009 1.00000000
B4       0.00   0.00 195.00   0.00 242.83 116.17  70.17 240.33   0.00 225.50 171.00   0.00
X4  407 0.81999999 1.00000000 0.06999999 0.95094997 1.00000000
**
** Flow Extension for Control Point SFAS06
FESFAS06 1998 2016 1940 1997  1  0                          5.998748
FN                Ext1998-2016
QD   4   407   406   306   305
```

```
QA      1362.  1570.   839.  1060.
FZ            265.4        722.8       3396.6 1885.6
FR   2   67.2  265.4  478.6  722.8  1111.0 1885.6 3396.6 6675.8 15583.4 35140.8 90273.1
FR        0.6    1.6    2.7  281.3  643.1 1263.2 5772.7 15962.7 28049.3 45883.7 69337.2
FX    74.22894 172.755 161.673 4.05903 2.05870 1.55478 0.92298 0.46195 0.47623 0.66629 0.97924 1.21684
UB  26.7   24.9 0.14049 0.71377 0.04000 0.14885 0.99101 1.00000
BM      17.00  26.67  16.17  67.00  67.00  67.00  54.83  37.50   9.00   9.67  41.17  41.00
XP  407 0.77002788 1.00000000 0.28300795 0.48235065 0.90380543
XP  406 0.00000450 0.99700302 0.00000900 0.67593616 0.62647736
XP  306 0.00000200 0.99401504 0.37942952 0.65944993 0.69415778
XP  305 1.00000000 0.87645006 0.38329184 0.99281126 0.90792853
B4       0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
X4  407 0.62843937 1.00000000 0.28032967 0.46246201 0.97519904
X4  406 0.34395850 0.94464940 0.00129429 1.00009668 1.00000000
X4  306 0.91483623 0.99900001 0.27814317 0.98029399 1.00000000
X4  305 0.83463567 1.00000000 0.38541353 0.93193102 1.00000000
**
** Flow Extension for Control Point BSLU07
FEBSLU07 1998  2016 1940  1997  1  0                          1.184999
FN                Ext1998-2016
QD   3   406   405   305
QA       478   1441   1149
FZ             17.         314.        1600.   944.
FR   2   17.   40.   161.   314.   574.   944.  1600.  3428.  7381. 16413.4
FR        0.0    0.3    2.0   17.2   56.5  637.6  2924.9  5683.6  9206.7 14253.0
FX     1.00000130.051683.8820660.3500712.07841 3.81404 0.65268 0.56107 0.74354 1.06743 1.04326
UB          0.00819 0.90000 1.00000 0.32320 0.85197 1.00000
BM       0.00   0.00   0.00   2.05  56.50 106.27   0.00  41.40   0.41   0.00   5.00   4.80
XP  406 1.00000000 1.00000000 0.00001450 0.91436362 0.95380563
XP  405 0.90521020 0.95094997 0.37187877 1.00000012 1.00000000
XP  305 1.00000000 0.99800003 0.38156042 0.92355198 0.99199998
B4       0.00  65.00   0.00  45.00  55.00   0.00   0.00   0.00   0.00   0.00   0.00  55.00
X4  406 0.26708037 1.00000000 0.28483626 0.75441313 0.99801260
X4  405 0.56328702 0.99900001 0.00003117 0.98000002 1.00000000
X4  305 0.82402027 1.00000000 0.34349647 0.63861716 1.00000000
**
** Flow Extension for Control Point DMJU08
FEDMJU08 1998  2016 1940  1997  1  0                          1.061994
FN                Ext1998-2016
QD   3   406   506   405
QA       872    94   455
FZ             12.         224.        1902.   986.
FR   2    6.   19.   82.   224.   466.   986.  1902.  5331.  11503.
FR        0.0    0.6   18.4   31.9  470.0  989.1  3904.4  7229.9 12618.5
FX     1.0000061.30859 4.88262 5.66107 2.85245 0.91011 0.56770 0.55879 0.78913 1.03823
UB          0.21271 0.81535 1.00000 0.55000 0.90898 1.00000
BM       0.23   0.00   0.00  34.23  38.80 965.17   0.74  33.67   0.07   0.00  30.00   0.00
XP  406 0.74000007 1.00000000 0.07732942 0.95000011 1.00000000
XP  506 1.00000000 1.00000000 0.42042002 0.70070004 1.00000000
XP  405 1.00000000 1.00000000 0.40040001 0.98000002 1.00000000
B4       0.00 130.00   0.00  15.33  63.50  160.17 350.17 369.17   0.07  30.00   0.00   0.00
X4  406 0.56000000 1.00000000 0.00999000 0.64999992 1.00000000
X4  506 1.00000000 1.00000000 0.40999994 1.01000011 1.00000000
X4  405 1.00000000 1.00000000 0.40000001 1.00000012 1.00000000
**
** Flow Extension for Control Point DMAS09
FEDMAS09 1998  2016 1940  1997  1  0                          3.130955
FN                Ext1998-2016
QD  4  6   507   407   406   506   405   305
QA       539.  323.  2072.  159.  1896.  1149.
FZ            344.0       1636.0      10549.6 5856.6
FR   2  238.4  501.0  938.4 1636.0  2761.6  5856.6 10549.6 25049.4 47990.8
```

```
FR        0.0   21.5  378.2  834.0 1319.6 3257.3 16071.2 39726.1 65743.0
FX     1.0000027.40058 4.14367 2.11300 2.11519 2.13642 0.86813 0.59838 0.67782 0.89622
UB          0.09737 0.78986 1.00000 0.48813 0.94197 1.00000
BM       0.00   0.00   0.00  21.50  378.17  929.00   0.00  17.21   0.00   0.00  12.17   0.00
XP  507 0.60644096 0.87041634 0.26308554 0.98207134 0.95524573
XP  407 0.58012724 0.85746926 0.06846680 1.00000000 0.94999999
XP  406 0.79979050 1.00000000 0.25542215 0.90250009 1.00000000
XP  506 1.00000000 1.00000000 0.00001250 0.56857502 0.97042525
XP  405 0.90671164 0.94999999 0.00002850 0.57403469 1.00000000
XP  305 0.90064967 1.00000000 0.00006389 0.54150003 1.00000000
B4       0.00  60.00   0.00  55.00  20.00   0.00   0.00  35.00   0.00   0.00   0.00   0.00
X4  507 0.79764074 0.99814999 0.34102103 0.95775998 1.00000000
X4  407 1.00000000 1.00000000 0.40160242 0.93379486 1.00000000
X4  406 0.87349093 1.00000000 0.36466822 0.47499999 0.99900001
X4  506 0.62891328 0.85737497 0.00001038 0.93472862 1.00000000
X4  405 0.53828555 1.00000000 0.00026729 0.95000011 0.99900001
X4  305 0.57114065 1.00000000 0.00006194 0.98098004 0.99900001
**
** Flow Extension for Control Point NCKN10
FENCKN10 1998 2016 1940 1997  1  0                          1.000000
FN                Ext1998-2016
QD   1   407
QA       248
FZ            32.         89.        462.   253.
FR   2    3.    7.   32.    60.    89.   156.   253.   462.   980.  2379.  6097.
FR        0.4   0.7   2.1   18.2   43.0   70.5  264.3 1094.8 2342.7 4008.2 5744.3
FX     3.82413 8.4254014.63362 5.82047 2.38210 2.12643 1.37837 0.48718 0.39418 0.48956 0.82608 1.54312
UB  0.8   0.8 0.15196 0.80376 0.00000 0.25000 1.00000 1.00000
BM       2.17   3.33   2.00   5.33   7.00   7.00   1.17   2.33   0.83   1.67   6.00   5.50
XP  407 0.85913998 1.00000000 0.02718355 0.95835280 1.00000000
B4       0.00   0.00   0.00   0.00  65.00  15.00  20.00  10.00   0.00  80.00  10.00  80.00
X4  407 0.53983802 1.00000000 0.19000003 0.74999994 1.00000000
**
** Flow Extension for Control Point BRSE11
FEBRSE11 1998 2016 1940 1997  1  0                          5.999748
FN                Ext1998-2016
QD  4  8    408    407    407    406    506    306    405    305
QA       818.  2437.   558.  3642.   159.  2209.  1896.  1149.
FZ           1387.0       3081.6      13727.2  8025.6
FR   2  266.2  621.2  1387.0  2269.0  3081.6  5042.0  8025.6 13727.2 26935.6 57692.6 100975.
FR       77.5  114.4  197.1  293.6  2801.0 14104.2 25113.3 46548.8 66650.5 102493. 135994.
FX     1.83491 4.36998 7.16198 7.46825 2.88166 0.51566 0.33200 0.30564 0.34109 0.48095 0.60671 1.07722
UB 140.4  120.0 0.20502 0.80855 0.65204 0.55000 0.89998 1.00000
BM     175.50 560.17 194.83 384.83 621.00 621.00 282.83 118.83 117.33  25.17 302.33 385.50
XP  408 0.81331855 0.87421560 0.33446676 1.00000000 0.94762594
XP  407 0.95335430 0.94999999 0.40000001 0.98000002 1.00000000
XP  407 0.91657299 0.95094997 0.40160242 0.79677701 0.96799999
XP  406 0.75999928 1.00000000 0.00006650 0.74238324 1.00000000
XP  506 1.00000000 1.00000000 0.00000500 0.89070898 0.98039997
XP  306 0.76152080 1.00000000 0.00003050 0.75525731 1.00000000
XP  405 0.79173315 0.99999899 0.00003375 0.70280427 0.99999899
XP  305 0.90407872 1.00000000 0.00002233 0.73649937 0.94999999
B4       0.00 630.17   0.00 434.83 1170.83 1904.00  57.83  33.83   0.00  70.17   0.00   0.00
X4  408 0.94000012 1.00000000 0.35999998 0.98000002 1.00000000
X4  407 1.00000000 1.00000000 0.40000001 1.00000012 1.00000000
X4  407 1.00000000 1.00000000 0.40000001 0.98000002 1.00000000
X4  406 0.58346748 1.00000000 0.00000000 0.70000005 1.00000000
X4  506 0.56943005 1.00000000 0.00000000 0.66500002 1.00000000
X4  306 0.59940004 1.00000000 0.00000000 0.70000005 1.00000000
X4  405 0.58075613 1.00000000 0.00000000 0.73500007 1.00000000
X4  305 0.54041702 1.00000000 0.00000000 0.70000005 1.00000000
**
```

```
** Flow Extension for Control Point MSMN12
FEMSMN12 1998 2016 1940 1997  1  0                          0.625996
FN                Ext1998-2016
QD   1   408
QA       104
FZ             29.         93.        983.   258.
FR   2   29.   93.   258.   983.  2377.
FR       0.0   22.6  330.5  1970.4  4320.4
FX     1.00000 7.02124 1.04186 0.68012 0.50775 0.82456
UB          0.23000 0.83899 1.00000 0.54000 1.10998 1.00000
BM       0.00   0.00   0.00   0.00   3.20   0.00   0.00   0.00   0.00   0.00   0.00   0.00
XP  408  0.94000000 1.00000000 0.05005500 0.97000009 1.00000000
B4       0.00  10.00 125.00  50.00  10.00  10.00 210.00 515.00 280.00   0.00  45.00   0.00
X4  408  0.70999998 1.00000000 0.19000003 1.00000012 1.00000000
**
** Flow Extension for Control Point CFRO13
FECFRO13 1998 2016 1940 1997  1  0                          1.661022
FN                Ext1998-2016
QD   1   507
QA       223
FZ             43.        130.        553.   314.
FR   2   18.   28.   59.   91.   130.   195.   314.   553.  1355.  2929.
FR       0.0   0.7   7.8   32.4   65.1  153.0  377.8  1137.8  2612.7  4177.5
FX     1.0000040.1941511.83898 3.33266 2.27798 1.60000 1.02302 0.56139 0.45213 0.59843 1.09368
UB          0.19768 0.82999 1.00000 0.24000 1.03898 1.00000
BM       0.00   0.00   4.60   0.00  54.03 153.00   0.68  28.73   0.00   0.00   3.70   0.00
XP  507  0.91000003 1.00000000 0.03157087 0.94999999 1.00000000
B4      60.00   0.00  95.00  18.00  80.33  83.00 148.17  73.83  13.17 162.50  19.00  50.17
X4  507  0.70069999 1.00000000 0.09999999 1.00000012 1.00000000
**
** Flow Extension for Control Point CFHA14
FECFHA14 1998 2016 1940 1997  1  0                          3.422934
FN                Ext1998-2016
QD   2   508   507
QA       114  1284
FZ            484.       1262.       4694.  2701.
FR   2  185.   380.   609.   922.  1262.  1791.  2701.  4694.  8977. 16035.
FR       0.0   96.9  246.3  550.4  865.2  1559.1  2887.5  6807.7 12671.3 20246.0
FX     1.00000 5.29943 2.86030 1.83852 1.57909 1.24354 1.01647 0.76788 0.66431 0.72629 1.09266
UB          0.24000 0.89000 1.00000 0.75000 1.00000 1.00000
BM       0.00 105.17  90.83 218.50 143.33 488.50   0.00 126.83   1.33   0.00   0.00   0.00
XP  508  0.94000012 1.00000000 0.34999999 0.56061590 0.99800104
XP  507  0.90000010 1.00000000 0.00000600 0.98000008 1.00000000
B4     206.17 161.67 330.83 368.50 478.33 598.50  62.67 196.83 136.33  56.67  80.67  77.17
X4  508  0.96000010 1.00000000 0.38999996 0.85999995 1.00000000
X4  507  0.90000010 1.00000000 0.00000000 0.99000007 1.00000000
**
** Flow Extension for Control Point MUHA15
FEMUHA15 1998 2016 1940 1997  1  0                          1.454012
FN                Ext1998-2016
QD   2   508   507
QA       103    99
FZ             38.        162.        891.   447.
FR   2   89.   162.   269.   447.   891.  1671.  3131.
FR       0.0   39.1  190.6  500.5  1253.6  2763.6  3737.6
FX     1.00000 5.89121 2.43496 1.05261 0.75550 0.65584 0.71384 0.99934
UB          0.13969 0.78490 1.00000 0.56000 0.94000 1.00000
BM       0.00   0.00   0.00   0.00   0.00  24.90   0.00   0.00   0.00   0.00   0.00   0.00
XP  508  0.40004206 1.00000000 0.27440211 0.86680424 1.00000000
XP  507  0.90340245 1.00000000 0.00016796 0.95000011 1.00000000
B4       0.00  85.00  45.00  85.00 115.00  65.00  90.00  95.00  95.00  70.00   0.00  30.00
X4  508  0.54053247 0.99679881 0.34790316 0.97872633 1.00000000
```

```
X4  507 1.00000000 0.99818045 0.00000000 0.68358201 0.96825600
**
** Flow Extension for Control Point CFNU16
FECFNU16 1998 2016 1940 1997  1  0                         0.999991
FN                Ext1998-2016
QD   2   508   507
QA      731.  1436.
FZ           892.0       2568.0      10750.2  6088.2
FR   2  255.0  667.0 1114.6 1758.6 2568.0 3736.8  6088.2 10750.2 19821.4 34788.2
FR       0.0   23.2  275.1 1003.5 1686.5 3877.4  6364.3 13995.7 28135.7 43386.9
FX     1.0000037.21027 8.38997 2.30824 1.67891 1.17981 0.93918 0.82218 0.70389 0.79753 1.00750
UB          0.18313 0.84000 1.00000 0.24000 1.02000 1.00000
BM       0.00  58.10 135.30  97.80   0.00 623.30  22.60   0.00   0.00   0.00   0.00   0.00
XP  508 0.64843279 1.00000000 0.33038265 0.98000002 1.00000000
XP  507 0.57057005 1.00000000 0.00008275 0.63000000 0.99800104
B4     135.33 380.17 460.50 389.67 410.50 785.50 136.00 197.17   0.00 135.00   0.00 138.00
X4  508 0.99000007 1.00000000 0.39999995 0.98000002 1.00000000
X4  507 0.60000002 1.00000000 0.00000000 0.50000000 1.00000000
**
** Flow Extension for Control Point CAST17
FECAST17 1998 2016 1940 1997  1  0                         1.121996
FN                Ext1998-2016
QD   2   508   507
QA       258   223
FZ            76.        286.        2331.  1054.
FR   2   52.   106.   180.   286.   511.  1054.  2331.  5914.  10418.
FR       0.0   12.8  102.9  188.6  318.6 1070.4 4197.6 10138.3 16267.4
FX     1.0000014.51913 2.62470 1.60663 1.60921 1.27308 0.68771 0.53638 0.64860 1.07444
UB          0.09384 0.80230 1.00000 0.76000 0.99000 1.00000
BM       0.00   0.00   0.00  15.97   5.97  31.09   5.00   0.00   0.00   0.00   0.00   0.00
XP  508 0.61154175 1.00000000 0.00002893 0.98000002 1.00000000
XP  507 0.52029133 0.94999999 0.32109356 0.52499998 0.94999999
B4       0.00  64.00   0.00 170.17  98.83 189.50 153.83 120.00   0.00   0.00   0.00 132.50
X4  508 0.54000002 1.00000000 0.00000000 0.55994385 1.00000000
X4  507 1.01000011 1.00000000 0.40999994 0.94000012 1.00000000
**
** Flow Extension for Control Point CFFG18
FECFFG18 1998 2016 1940 1997  1  0                           1.000
FN                Ext1998-2016
QD   3   408   508   507
QA      599.  1691.  1668.
FZ           492.0       2837.0      17092.8  9078.6
FR   2 1584.2 2837.0 4686.4  9078.6 17092.8 35198.2 68065.2 170503.
FR       0.0  278.1 1365.8 8744.8 28519.3 59680.7 99754.6 173781.
FX     1.0000014.84072 5.48203 1.55728 0.72797 0.56009 0.61673 0.86971 1.45427
UB          0.09940 0.83757 1.00000 0.70101 0.96574 1.00000
BM       0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
XP  408 0.71677816 0.89098048 0.34071442 0.96805239 0.95009500
XP  508 0.47211698 1.00000000 0.36100000 1.00000012 1.00000000
XP  507 0.73277301 1.00000000 0.00008825 0.59082669 1.00000000
B4       0.00  60.00  50.00  35.00  25.00  40.00  60.00  55.00   0.00   0.00   0.00  60.00
X4  408 0.68768972 0.99900001 0.22956271 0.94714463 1.00000000
X4  508 0.48090389 0.99900001 0.00003111 0.96465409 0.99900001
X4  507 0.96648508 1.00000000 0.32818514 0.66265732 1.00000000
**
** Flow Extension for Control Point HCAL19
FEHCAL19 1998 2016 1940 1997  1  0                         0.995991
FN                Ext1998-2016
QD   1   508
QA       609
FZ            69.        473.        4661.  2008.
FR   2   94.   229.   473.   999.  2008.  4661. 11977.  23186.
```

```
FR        0.0    4.7   15.7  120.1  2100.4  8069.3 19423.7 32657.7
FX     1.00000129.246836.8541112.14906 1.58422 0.59583 0.59519 0.59566 1.10919
UB          0.24000 0.84999 1.00000 0.73000 1.00000 1.00000
BM       0.00   0.00   0.00   0.00  14.57   9.87  15.73   0.00   0.00   0.00   0.03   0.00
XP  508  0.93000001  1.00000000  0.03800000  0.96095997  1.00000000
B4       5.00  110.00  110.17  128.67  119.67  134.67  113.33  113.00   0.00   0.00  105.33  111.17
X4  508  0.56000000  1.00000000  0.30015281  0.74999994  1.00000000
**
** Flow Extension for Control Point BSBR20
FEBSBR20  1998  2016  1940  1997  1  0                        0.000000
FN                Ext1998-2016
QD   2    508    509
QA       204    78
FZ            423.         883.         5708.  2098.
FR   2   167.   423.   883.  2098.  5708.  9342.
FR        0.0  153.3  427.2  2282.7  6594.5  14589.7
FX     1.00000 4.16293 2.20952 1.16014 0.97526 0.80626 0.77744
UB          0.25000 0.91000 1.00000 0.45088 1.10998 1.00000
BM       0.00   0.00   0.00   0.00   0.50   0.00   0.00   0.00   0.00   0.00   0.00   0.00
XP  508  0.67000002  1.00000000  0.00000400  0.98000008  1.00000000
XP  509  1.00989902  1.00000000  0.40985593  0.90000010  1.00000000
B4       0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
X4  508  0.65927333  0.99700302  0.05481115  1.00000012  1.00000000
X4  509  0.88925266  0.99900001  0.40722927  0.98000002  1.00000000
**
** Flow Extension for Control Point HCBR21
FEHCBR21  1998  2016  1940  1997  1  0                        1.000000
FN                Ext1998-2016
QD   2    508    509
QA       938    150
FZ           2171.        3980.        22114.  8345.
FR   2   631.  1251.  2171.  3980.  8345.  22114.  36663.  103445.
FR        0.0  202.0  1150.5  3241.2  10308.5  27661.1  59796.6  120110.
FX     1.00000 8.94565 2.49575 1.54477 0.86804 0.81490 0.69463 0.75425 1.21135
UB          0.24000 0.93000 1.00000 0.38351 1.09194 1.00000
BM       0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
XP  508  0.65999991  1.00000000  0.00976639  0.95000011  1.00000000
XP  509  0.98097998  1.00000000  0.94000000  0.70000005  1.00000000
B4       0.00  220.00  245.00  295.00  145.00  145.00   75.00  335.00  123.75  140.00  120.00   0.00
X4  508  0.64519006  1.00003970  0.16731718  0.98000002  1.00000000
X4  509  0.73424441  1.00000000  0.44833803  0.99493825  0.93422002
**
** Flow Extension for Control Point CFEL22
FECFEL22  1998  2016  1940  1997  1  0                        0.999991
FN                Ext1998-2016
QD  4  5    509    508    409    408    507
QA       460   2847    26    660   1668
FZ           1770.        5945.        32063.  17080.
FR   2  819.2  1218.  2373.  3520.  5945.  9807.  17080.  32063.  65587.  115347.
FR        0.0   62.3  372.6  1900.2  3284.8  5342.6  12043.5  40954.2  110975.  174237.
FX     1.0000026.42033 9.24177 2.78520 1.77448 1.78412 1.69624 0.99411 0.61676 0.61570 0.88862
UB          0.15480 0.84356 1.00000 0.72500 0.99499 1.00000
BM       0.00   0.00  139.52  553.67  385.50  690.50  204.96   0.00   0.00   0.00   0.00   0.00
XP  509  0.89075893  1.00000000  0.32251468  0.94000012  0.94999999
XP  508  0.29657459  0.97284251  0.00003568  0.98000002  1.00000000
XP  409  1.00000000  1.00000000  0.46536943  1.00000000  0.98000002
XP  408  0.99949503  1.00000000  0.36100000  0.45212886  0.95094997
XP  507  0.87015444  1.00000000  0.34639740  0.51264244  1.00000000
B4       0.00   72.00  145.00  756.17  875.50   12.75   0.00  102.33   0.00   0.00   0.00   0.00
X4  509  0.84843493  1.00000000  0.32300001  0.94000012  1.00000000
X4  508  0.60000002  1.00000000  0.00013190  0.98000002  1.00000000
X4  409  1.00000000  0.95094997  0.46768838  0.98000002  1.00000000
```

```
X4  408 1.00000000 1.00000000 0.40000001 0.52499998 1.00000000
X4  507 1.00000000 1.00000000 0.40000001 0.50000000 1.00000000
**
** Flow Extension for Control Point BRSB23
FEBRSB23 1998 2016 1940 1997  1  0                          1.000000
FN                Ext1998-2016
QD  4 11    409    509    408    508    407    507    406    506    306    405    305
QA       478.   494.  2147.  2847.   2438  2226.  3842.   159.   839.  1896.  2209.
FZ           3409.2       9258.4      39091.8 23707.2
FR    2  785.0  2082.8  3409.2  6185.6  9258.4 13817.0 23707.2 39091.8 68303.6 145077. 256095.
FR       76.5  123.6  1077.7  3807.2  7459.1 14094.6 26857.3 62901.8 111174. 199252. 278319.
FX     5.6687214.75335 7.15421 1.91680 1.34298 1.11267 0.92068 0.69845 0.60084 0.67893 0.80898 1.34747
UB 215.3  151.8 0.15726 0.84316 0.56000 0.29000 1.00000 1.00000
BM      717.33  802.67  468.00 1976.17 2083.00 2083.00 1116.83  358.67  359.00  622.00  761.83  776.50
XP  409 0.70982504 1.00000000 0.39481956 0.91740435 0.99900001
XP  509 1.00000000 1.00000000 0.40120122 0.98100001 0.99900001
XP  408 0.90842319 0.99140954 0.38075998 0.96432000 0.99653792
XP  508 0.81105381 0.99858123 0.00004025 0.85471535 0.89956349
XP  407 0.82040924 1.00000000 0.00004725 0.71485728 0.99854422
XP  507 0.90360457 1.00000000 0.00004000 0.80642259 0.99900001
XP  406 0.90090007 1.00000000 0.00008861 0.79759687 0.99980539
XP  506 1.00000000 0.93743491 0.00000750 0.94769931 1.00000000
XP  306 1.00000000 1.00000000 0.00001833 0.83305854 0.99900001
XP  405 0.90722537 1.00000000 0.00002450 0.98000002 1.00000000
XP  305 0.90360552 1.00000000 0.00005487 0.80160087 1.00000000
B4      787.33  872.67  528.00 2046.17 4043.83 5953.90 1186.83  428.67  205.50  692.00  811.83  846.50
X4  409 0.94895512 1.00000000 0.38000000 1.00000012 1.00000000
X4  509 1.00000000 1.00000000 0.41024622 0.98000002 1.00000000
X4  408 1.00000000 1.00000000 0.40000001 0.86847222 1.00000000
X4  508 0.70000005 1.00000000 0.00000000 0.98000002 1.00000000
X4  407 0.64641726 1.00000000 0.00000000 1.00000012 1.00000000
X4  507 0.73500007 1.00000000 0.00000000 0.98000002 1.00000000
X4  406 0.70000005 1.00000000 0.00000000 1.00000012 1.00000000
X4  506 0.62954044 1.00000000 0.00000000 0.98000002 1.00000000
X4  306 0.70000005 1.00000000 0.00000000 1.00000012 1.00000000
X4  405 0.70000005 1.00000000 0.00000000 1.00000012 1.00000000
X4  305 0.66500002 1.00000000 0.00000000 0.98000002 1.00000000
**
** Flow Extension for Control Point GHGH24
FEGHGH24 1998 2016 1940 1997  1  0                          1.000000
FN                Ext1998-2016
QD    1    409
QA        211
FZ             597.        1108.        5474.  2293.
FR    2    99.   287.   597.   1108.   2293.   5474.  10042. 49690.1
FR        0.0   86.1   341.9   698.7  2259.0 10689.3 21637.6 61153.3
FX     1.00000 5.16038 1.99609 1.58418 1.37210 0.66592 0.48937 0.62926 1.32136
UB           0.24000 0.89000 1.00000 0.64000 1.24898 1.00000
BM       0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
XP  409 0.54075629 1.00000000 0.19000003 1.00000012 1.00000000
B4       0.00  40.00   0.00  40.00  40.00  40.00  40.00   0.00  40.00   0.00   0.00   0.00
X4  409 0.85999995 1.00000000 0.13987404 0.92000002 1.00000000
**
**
** Flow Extension for Control Point CCIV25
FECCIV25 1998 2016 1940 1997  1  0                          1.000000
FN                Ext1998-2016
QD    1    509
QA         97
FZ             378.         661.        2900.  1306.
FR    2    66.   186.   378.   661.   1306.   2900.   5268. 12552.1
FR        0.0   25.9   217.7   520.3  1560.4  4575.9  7967.9 14998.4
```

```
FX     1.00000 8.98157 2.11660 1.42989 0.96864 0.72998 0.67116 0.69741 1.08367
UB          0.24000 0.92000 1.00000 0.45000 1.10000 1.00000
BM       0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
XP  509  0.58999997 1.00000000 0.20002003 0.91000003 1.00000000
B4       0.00   0.00  35.00 260.00   1.17  25.00   0.00 245.00  55.00 130.00   0.00  45.00
X4  509  0.58999997 1.00000000 0.37999997 0.59993994 1.00000000
**
**
** Flow Extension for Control Point SHGR26
FESHGR26 1998 2016 1940 1997  1  0                         2.092031
FN                Ext1998-2016
QD 4 8   509   409   508   408   407   507   406   506
QA       958   924  2847  2417  2438  2226.  3842.   159.
FZ          6883.0       18404.0       89032.8 47795.6
FR 2   2186.8  5228.4  8574.4 12816.0 18404.0 30992.4 47795.6 89032.8 166331. 279295.
FR       0.0  919.8  4853.7  8556.7 14513.1 28315.1 50579.3 110858. 229576. 344767.
FX     1.0000010.49264 2.71178 1.53925 1.36683 1.15185 1.01330 0.87845 0.73823 0.77981 1.18820
UB          0.20728 0.86000 1.00000 0.46000 0.99000 1.00000
BM       0.00   0.00 919.83 2094.17 3298.48 8171.69   0.00 102.00   0.00   0.00   0.00   0.00
XP  509  0.85986900 0.92597073 0.30714786 0.98000002 1.00000000
XP  409  0.80998921 0.99908030 0.38038000 0.98009801 1.00000000
XP  508  0.91014010 0.99845397 0.37397620 0.95261949 0.98376256
XP  408  0.63238180 1.00000000 0.00008553 0.62485141 1.00000000
XP  407  0.70104724 1.00000000 0.00014718 0.64077771 1.00000000
XP  507  0.70210147 1.00000000 0.00009677 0.63569087 0.99740726
XP  406  0.73647082 0.99949718 0.00016299 0.60180175 0.99900001
XP  506  0.80337530 1.00000000 0.00001000 0.66292387 1.00000000
B4     581.67 1913.00 1310.67 2869.17 6598.57 8001.67  760.50  269.50  140.67  462.83  103.33   92.67
X4  509  1.00000000 1.00000000 0.34999999 0.98000002 0.99900001
X4  409  1.00000000 1.00000000 0.40000001 1.00000012 1.00000000
X4  508  0.96423495 0.99900001 0.40000001 0.66558337 1.00000000
X4  408  0.59940004 1.00000000 0.00000000 0.95175153 1.00000000
X4  407  0.59940004 1.00000000 0.00000000 0.97902000 1.00000000
X4  507  0.59940004 1.00000000 0.00000000 0.96772981 0.98098004
X4  406  0.60000002 1.00000000 0.00000000 1.00000012 1.00000000
X4  506  0.53530061 0.94215465 0.00000000 0.98000002 1.00000000
**
**
** Flow Extension for Control Point BRPP27
FEBRPP27 1998 2016 1940 1997  1  0                         2.058033
FN                Ext1998-2016
QD 4 8   509   409   508   408   407   507   406   506
QA      1149   924  2847  2417  2438  2226.  3842.   159.
FZ          6759.0       19022.0       92936.4 53560.8
FR 2   2097.6  5275.6  8828.2 13250.6 19022.0 31091.8 53560.8 92936.4 170549. 294284.
FR       0.0 1256.7  5720.8  9811.5 16065.2 31780.4 56094.7 124702. 245606. 352850.
FX     1.00000 7.68042 2.10560 1.38630 1.24990 1.08211 0.92967 0.78575 0.70465 0.75984 1.13273
UB          0.19776 0.86125 1.00000 0.35000 1.01000 1.00000
BM       0.00 206.33 1217.00 1990.75 2120.74 8056.10 134.83   0.00   0.00   0.00   0.00   0.00
XP  509  0.54811472 0.81450623 0.35889655 1.00000000 0.94999999
XP  409  0.95075589 1.00000000 0.40160200 0.95475954 1.00000000
XP  508  0.90114409 1.00000000 0.36100000 1.00000012 1.00000000
XP  408  0.59260732 0.94772184 0.00004819 0.43326095 0.55835736
XP  407  0.73647082 1.00000000 0.00017973 0.63378888 1.00000000
XP  507  0.70280355 1.00000000 0.00007307 0.63063002 0.99877036
XP  406  0.73647082 1.00000000 0.00014684 0.62842506 1.00000000
XP  506  0.88368011 1.00000000 0.00001400 0.73185623 1.00000000
B4     759.33 2083.83 1317.00 2863.17 7201.74 8093.46  612.33  183.00  129.17  634.00  162.17   93.00
X4  509  0.98700011 1.00000000 0.34000000 0.92150009 1.00000000
X4  409  0.90249997 1.00000000 0.40000001 0.98000002 1.00000000
X4  508  1.00000000 1.00000000 0.40000001 1.00000012 1.00000000
X4  408  0.63000000 1.00000000 0.00000000 0.98000002 1.00000000
```

```
X4  407 0.60000002 1.00000000 0.00000000 0.59156823 1.00000000
X4  507 0.60000002 1.00000000 0.00000000 0.69825000 1.00000000
X4  406 0.60000002 1.00000000 0.00000000 0.70000005 1.00000000
X4  506 0.62779665 0.94905001 0.00000000 0.53921205 0.99750000
**
** Flow Extension for Control Point PPSA28
FEPPSA28 1998 2016 1940 1997  1  0                         0.961991
FN                Ext1998-2016
QD   1   509
QA       574
FZ           148.       1125.       6665.  3465.
FR   2   673.  1125.  2075.  3465.  6665. 14879. 23900. 62074.3
FR       0.0   19.8 1316.8 4237.5 10139.3 20453.3 30758.0 51764.4
FX     1.0000067.49925 3.52262 1.02194 0.67762 0.69066 0.79388 1.00999 1.26164
UB          0.24000 0.85998 1.00000 0.55000 1.03000 1.00000
BM       0.00   0.00   0.00   0.00   0.00  27.50   0.00   0.00   0.00   0.00   0.00   0.00
XP  509 0.94999999 1.00000000 0.04013215 0.97000009 1.00000000
B4      255.00   0.00 185.00 665.17 645.00 457.50 660.00 270.00  47.50   0.00 660.00 140.00
X4  509 0.65999991 1.00000000 0.18000002 0.90000004 1.00000000
**
** Flow Extension for Control Point BRDE29
FEBRDE29 1998 2016 1940 1997  1  0                         1.000000
FN                Ext1998-2016
QD  4  8   510   509   409   508   408   407   507   406
QA       148  2252  1112  2847  2417  2438  2226.  3842.
FZ          7273.6      17481.4      69265.2 44882.0
FR 2   1992.8 3713.4 7273.6 11534.6 17481.4 27265.0 44882.0 69265.2 116081. 211034. 355315.
FR      391.8  739.6 2729.3 8238.4 17243.3 32692.2 54102.3 98933.7 153178. 261486. 341983.
FX     3.43827 5.86140 3.61180 1.67643 1.16954 0.88184 0.84795 0.75454 0.73592 0.77302 0.87702 1.48012
UB 558.3  555.4 0.18304 0.88000 0.00000 0.29000 0.99301 1.00000
BM     1056.83 3075.17 3195.67 3484.00 3713.00 3713.00  598.67 1811.33 1543.33 1897.33  593.67 2600.33
XP  510 1.00000000 0.99103498 0.32168987 0.98000002 1.00000000
XP  509 1.00000000 1.00000000 0.38194686 0.98000002 1.00000000
XP  409 1.00000000 0.99999899 0.31826186 0.96467286 0.86680180
XP  508 0.75178677 0.99817109 0.00000850 0.82645750 1.00000000
XP  408 0.70932722 0.99899900 0.00001483 0.81127328 1.00000000
XP  407 0.67196870 1.00000000 0.00000850 0.81612462 1.00000000
XP  507 0.70526725 1.00000000 0.00002267 0.80600864 0.99949968
XP  406 0.70350707 1.00000000 0.00002350 0.80884343 1.00000000
B4      356.37  760.03  784.13  841.80 1972.60 1760.03  264.73  507.27  326.17  524.47  263.73  665.07
X4  510 0.80349749 0.99900001 0.39206377 0.98000002 1.00000000
X4  509 0.98609072 0.99700302 0.39920041 0.76376319 1.00000000
X4  409 0.99700302 1.00000000 0.41790375 0.95427269 1.00000000
X4  508 0.62560320 1.00000000 0.00000000 0.96443707 0.99667400
X4  408 0.56604302 1.00000000 0.00000000 0.95480335 1.00000000
X4  407 0.56829178 0.99899906 0.00000000 0.98008603 0.98082811
X4  507 0.59760368 1.00000000 0.00000000 0.96830446 1.00000000
X4  406 0.60000002 0.99900001 0.00000000 0.97024399 1.00000000
**
** Flow Extension for Control Point BRGR30
FEBRGR30 1998 2016 1940 1997  1  0                         1.671022
FN                Ext1998-2016
QD  4  8   510   509   409   508   408   407   507   406
QA       653  2304  1112  2847  2417  2438  2226.  3842.
FZ          8275.8      20144.8      77054.8 50324.2
FR 2   1861.6 4597.8 8275.8 13311.4 20144.8 30585.0 50324.2 77054.8 131328. 242476. 383295.
FR      433.8  823.7  2692.0  6083.7 12511.2 25505.8 53662.0 107725. 181177. 326165. 436753.
FX     2.35530 5.16838 4.41322 2.48939 1.74779 1.36918 1.08142 0.78064 0.71577 0.73004 0.77105 1.27674
UB 717.0  585.4 0.22236 0.88000 0.97000 0.43117 1.01026 1.00000
BM     1198.33 3595.33 4156.67 4598.00 4598.00 4598.00  853.50  447.17 1177.00 2247.17  984.17 2417.33
XP  510 0.65952462 1.00000000 0.34034002 0.98000002 1.00000000
XP  509 0.94999999 1.00000000 0.38038000 0.98000002 1.00000000
```

```
XP  409 0.90250009 1.00000000 0.40080002 1.00000000 0.97999990
XP  508 0.80000007 1.00000000 0.00001000 0.66500002 1.00000000
XP  408 0.76000005 1.00000000 0.00000750 0.73500007 1.00000000
XP  407 0.76000005 0.99900001 0.00001350 0.70000005 1.00000000
XP  507 0.82342529 1.00000000 0.00001067 0.70000005 1.00000000
XP  406 0.82196355 1.00000000 0.00001050 0.73500007 1.00000000
B4     940.83 3650.33 4226.67 4840.83 8576.4511144.63  926.00  517.17  860.33 2293.24 1034.17 2472.33
X4  510 0.94905001 1.00000000 0.32267702 0.96709299 1.00000000
X4  509 0.94905001 1.00000000 0.42000002 0.50000000 1.00000000
X4  409 1.00000000 1.00000000 0.40000001 0.98000002 1.00000000
X4  508 0.69860005 1.00000000 0.00000000 0.98000002 1.00000000
X4  408 0.73500007 1.00000000 0.00000000 0.98000002 1.00000000
X4  407 0.70000005 1.00000000 0.00000000 0.97990203 1.00000000
X4  507 0.75699776 1.00000000 0.00000000 0.98000002 1.00000000
X4  406 0.70000005 1.00000000 0.00000000 0.98000002 1.00000000
**
*** Flow Extension for Control Point PAGR31
FEPAGR31 1998 2016 1940 1997  1  0                          1.915033
FN                Ext1998-2016
QD   2   510   509
QA      172.  238.
FZ           484.4       1047.4       3493.0  2138.4
FR   2  124.0  252.8  484.4  732.8  1047.4  1520.0  2138.4  3493.0  6087.4 12191.6 22869.8
FR      16.2   34.9  144.2  370.9  663.5  942.2  2214.8  6166.7 10645.2 17223.3 24905.0
FX     5.05495 8.30673 4.58906 2.64573 1.73496 1.56902 1.26444 0.65148 0.54685 0.61045 0.78459 1.26005
UB  46.9   35.6 0.24000 0.85000 0.70000 1.00000 1.00998 1.00000
BM     253.00 253.00 253.00 253.00 253.00 253.00  99.00  34.17  23.17  19.00 126.00 227.83
XP  510 0.51768726 1.00000000 0.34177178 0.94754648 0.99907845
XP  509 0.97938865 1.00000000 0.00002117 0.50200301 1.00000000
B4     415.67  451.17  577.50  609.83  627.83  384.33  254.00  189.17   0.00   0.00   0.00  347.83
X4  510 0.59342581 0.99819779 0.39673290 0.97950858 1.00000000
X4  509 1.00000000 1.00000000 0.00000000 0.75206476 1.00000000
**
** Flow Extension for Control Point NRBL32
FENRBL32 1998 2016 1940 1997  1  0                          1.424011
FN                Ext1998-2016
QD   1   510
QA      276
FZ           136.        1348.        7789.  3930.
FR   2   263.   633.  1348.  2170.  3930.  7789.  14986.  26495.  59697.8
FR       0.0   19.8  280.2  2158.9  4947.5 10727.4 21268.9 33314.5 49058.9
FX     1.0000037.69876 7.52871 1.44826 0.92620 0.72884 0.69639 0.73214 1.03284 1.14781
UB          0.23000 0.84000 1.00000 0.35000 1.12000 1.00000
BM       0.00  35.00  70.17  280.17  305.72   0.00   0.00   0.00   0.00   0.00   0.00   0.00
XP  510 0.84016794 1.00000000 0.14000000 0.94000012 1.00000000
B4      65.33  400.00  410.17  500.17  411.00  395.00  395.00  395.00  395.00   0.00   0.00  30.00
X4  510 0.58999997 1.00000000 0.28000000 0.75999993 1.00000000
**
** Flow Extension for Control Point BRAQ33
FEBRAQ33 1998 2016 1940 1997  1  0                          0.868992
FN                Ext1998-2016
QD  4  9    610   510   509   409   508   408   407   507   406
QA       227  1631  2542  1112  2847  2417  2438  2226.  3842.
FZ          13619.8       28719.4       97383.8  65837.2
FR  2   3425.4  6929.0 13619.8 21604.4 28719.4 46163.0 65837.2 97383.8 160917. 280970. 444565.
FR      174.6   309.7  894.4 10458.3 23213.9 44046.6 73422.6 132319. 224213. 342707. 487531.
FX    13.2574420.9297318.56688 3.28931 1.56571 1.09570 1.03965 0.78486 0.75829 0.78945 0.84097 1.34892
UB1289.7  1289.7 0.24000 0.90440 0.27000 0.32485 1.00000 1.00000
BM    1765.50 6078.67 6489.83 6929.00 6929.00 6929.00 4972.83 2525.00 3167.67 2519.33 1664.83 2996.00
XP  610 0.95475757 1.00000000 0.33044076 0.98000002 1.00000000
XP  510 0.95190090 1.00000000 0.40000001 0.98000002 1.00000000
XP  509 0.95095009 1.00000000 0.40000001 0.97754997 1.00000000
```

```
XP  409 0.56168485 1.00000000 0.00001150 0.85018599 0.85737497
XP  508 0.66216147 1.00000000 0.00001950 0.82914090 1.00000000
XP  408 0.60060000 1.00000000 0.00002283 0.80000007 1.00000000
XP  407 0.63063002 1.00000000 0.00001900 0.80000007 1.00000000
XP  507 0.57114065 1.00000000 0.00001867 0.80000007 1.00000000
XP  406 0.57057005 0.99900001 0.00002200 0.80000007 1.00000000
B4     1795.50 6121.34 6541.9310560.5612880.7813181.36 4997.00 2530.00 3010.58 2531.83 1689.83 3011.00
X4  610 0.90210903 0.94999999 0.32219252 0.89300013 1.00000000
X4  510 1.00000000 1.00000000 0.42000002 0.50000000 1.00000000
X4  509 0.95000011 1.00000000 0.40000001 1.00000012 1.00000000
X4  409 0.58443403 1.00000000 0.00000000 0.98000002 1.00000000
X4  508 0.60000002 1.00000000 0.00000000 1.00000012 1.00000000
X4  408 0.60000002 1.00000000 0.00000000 1.00000000 0.98000002
X4  407 0.63000000 1.00000000 0.00000000 1.00000012 1.00000000
X4  507 0.60000002 1.00000000 0.00000000 0.99960005 0.98000002
X4  406 0.63000000 1.00000000 0.00000000 0.98000002 1.00000000
**
** Flow Extension for Control Point AQAQ34
FEAQAQ34 1998 2016 1940 1997  1  0                          0.552996
FN                Ext1998-2016
QD   2   610   510
QA       112   189
FZ            1194.        5576.       23510. 11191.
FR   2   570.  1194.  2438.  5576.  11191.  23510.  35992.
FR       0.0   36.2  2801.3  6491.8 11865.6 28027.4 45478.6
FX     1.00000107.5948 1.66858 0.79339 0.84515 0.94964 0.81178 0.90015
UB          0.53000 1.00000 1.00000 0.95000 1.10000 1.00000
BM       0.00   0.00   5.00   0.00 105.10   0.00   0.00   0.00   0.00   0.00   0.00   0.00
XP  610 0.98802006 1.00000000 0.39999995 1.00000012 1.00000000
XP  510 0.70140004 1.00000000 0.00011619 0.89097530 1.00000000
B4      215.00 380.00  395.00 120.00  210.00  270.00  395.00  305.00  395.00  185.00  265.00  395.00
X4  610 0.93906009 1.00000000 0.37999997 0.85999995 0.99900001
X4  510 0.60060000 1.00000000 0.00000000 0.97000009 1.00000000
**
** Flow Extension for Control Point NBHI35
FENBHI35 1998 2016 1940 1997  1  0                          0.000000
FN                Ext1998-2016
QD   2   509   609
QA       319    40
FZ             145.         623.        4288.  2473.
FR   2   189.   333.   623.  1337.  2473.  4288.  10319.  20097.
FR       0.0  102.6  288.5  1216.4  2948.3  7294.4 14919.8 22799.0
FX     1.00000 8.00262 2.36878 1.44215 0.96785 0.65847 0.62785 0.78611 0.98785
UB          0.18410 0.89776 1.00000 0.54000 1.21000 1.00000
BM       0.00   2.80   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
XP  509 0.87812483 1.00000000 0.03133082 0.99000007 1.00000000
XP  609 0.40398839 0.92529792 0.50866061 1.00000000 0.29681382
B4       0.00   0.00   0.00  22.00  74.33   0.00   0.00   0.00   0.00   0.00   0.00   0.00
X4  509 0.92000002 1.00000000 0.00000000 0.97000009 1.00000000
X4  609 1.01000011 1.00000000 0.41082034 0.79840088 0.99900001
**
** Flow Extension for Control Point NBCL36
FENBCL36 1998 2016 1940 1997  1  0                          1.327006
FN                Ext1998-2016
QD   4   610   510   609   509
QA      368.  140.   96.  371.
FZ           771.0       2594.0      15376.0  8412.6
FR   2  590.2  1046.6  1619.4  2594.0  4889.4  8412.6 15376.0 40586.0 71183.8
FR       0.0  115.8  627.8  1425.3  2557.5  9549.8 26304.8 54214.4 86542.0
FX     1.0000026.02282 3.46787 1.95127 1.94278 1.21106 0.68387 0.62623 0.84569 0.93835
UB          0.27587 0.84673 1.00000 0.94000 1.06000 1.00000
BM       0.00   0.00  50.00  233.67  119.50  514.83  19.50   0.00   0.00   0.00   0.00   0.00
```

```
XP  610 0.84074754 1.00000000 0.30638894 0.48510000 1.00000000
XP  510 0.85746080 0.94999999 0.37702855 0.98000002 1.00000000
XP  609 0.90991038 0.99900001 0.36259484 1.00000000 0.98000002
XP  509 0.39975965 1.00000000 0.00007782 0.95000011 1.00000000
B4      60.30  129.90  102.00  359.20  449.70  353.90   0.00  45.50   0.00  45.00   0.00  69.60
X4  610 0.94000012 1.00000000 0.33932000 0.46200001 1.00000000
X4  510 1.00000000 1.00000000 0.40000001 1.01000011 1.00000000
X4  609 0.91144603 1.00000000 0.39996001 0.98000002 1.00000000
X4  509 0.60000002 1.00000000 0.00000000 1.00000012 1.00000000
**
** Flow Extension for Control Point NBVM37
FENBVM37 1998 2016 1940 1997  1  0                        1.726025
FN               Ext1998-2016
QD   4   610   510   609   509
QA       551.  140.   96.  371.
FZ           1241.0       3710.0      19246.6 10938.6
FR   2  632.0  975.6 1560.8 2365.6 3710.0 6320.4 10938.6 19246.6 48134.8 85228.8
FR       0.0   28.1  235.4 1101.8 2300.0 4348.5 13848.0 33956.3 73359.1 108289.
FX     1.0000033.0072917.31830 2.76628 1.70694 1.54349 1.09232 0.61867 0.60073 0.73973 0.93096
UB          0.27747 0.86367 1.00000 0.73000 1.09000 1.00000
BM       0.00   0.00  81.17  85.00 980.50 715.83  60.45   0.00   0.00   0.00   0.00   0.00
XP  610 0.76217103 1.00000000 0.00008441 0.46338740 1.00000000
XP  510 0.99138248 0.90249997 0.37231246 1.01000011 0.94999999
XP  609 0.92330092 0.94999999 0.35862505 0.99074215 0.98000002
XP  509 0.54155415 1.00000000 0.38957256 0.98000002 1.00000000
B4      96.67 222.67 191.17 974.83 1150.50 768.33   0.00   0.00   0.00  86.83 154.00 157.17
X4  610 0.53946000 1.00000000 0.00000000 0.60999995 1.00000000
X4  510 1.01000011 1.00000000 0.40958995 0.90879321 1.00000000
X4  609 0.99989998 1.00000000 0.40000001 0.99990010 1.00000000
X4  509 1.00000000 1.00000000 0.40000001 1.00000012 1.00000000
**
** Flow Extension for Control Point MBMG38
FEMBMG38 1998 2016 1940 1997  1  0                        1.499014
FN               Ext1998-2016
QD   1   610
QA       181
FZ            224.       1257.       6621.  3794.
FR   2  156.4   352.   718.  1257.  2187.  3794.  6621.  12819.  20915.
FR       0.0    3.5  118.1  828.1 2371.4 4400.0 9667.2 18227.5 26491.3
FX     1.00000389.469810.60238 3.62593 1.09814 0.97715 0.80669 0.72615 0.74909 0.93796
UB          0.24000 0.93000 1.00000 0.34000 1.21000 1.00000
BM       2.03   0.00  56.37 167.33 165.83  34.53   0.00   0.00   0.00   0.50   0.00   0.00
XP  610 0.72999996 1.00000000 0.20000003 0.79000002 1.00000000
B4      44.27 318.13 160.73 208.87 413.67 139.07 257.93  25.00   0.00   0.00 146.87  91.20
X4  610 0.76000005 1.00000000 0.12999998 0.89000005 1.00000000
**
** Flow Extension for Control Point HGCR39
FEHGCR39 1998 2016 1940 1997  1  0                        1.068994
FN               Ext1998-2016
QD   1   610
QA        78
FZ            111.        565.       2918.  1686.
FR   2   111.   155.   309.   565.  1025.  1686.  2918.  6093.  9898.
FR       0.0    3.7   39.1  301.4 1038.8 2124.9 4438.5 8250.8 11609.7
FX     1.00000174.008921.83683 4.04503 1.14158 0.94625 0.71651 0.69433 0.82045 1.00925
UB          0.24000 0.93998 1.00000 0.65000 1.12000 1.00000
BM       8.97   7.53  13.33 101.83 105.17   8.90   0.00   0.00   0.00   0.07   0.01   0.00
XP  610 0.74999994 1.00000000 0.20000003 0.79000002 1.00000000
B4     198.87 270.33  55.53 158.73  98.07 118.80 280.67 185.00   0.00 280.27  71.80  13.40
X4  610 0.65999991 1.00000000 0.20000003 0.84000009 1.00000000
**
** Flow Extension for Control Point BOWA40
```

```
FEBOWA40 1998 2016 1940 1997  1  0                        2.914971
FN                 Ext1998-2016
QD   4   610   609   509   510
QA      1053    96   371   140
FZ            2712.        9936.       42363. 24378.
FR   2  1900.  3485.  5984.  9936. 15246. 24378. 42363. 80009. 130716.
FR        0.0  1313.2  3419.2  6301.4 14268.7 25137.0 55687.2 107029. 158380.
FX     1.00000 4.60804 1.70998 1.60065 1.33239 0.99678 0.85341 0.75880 0.75630 1.03399
UB           0.34000 0.91000 1.00000 0.44000 1.10000 1.00000
BM      27.67 254.17 430.33 3419.17 3013.00 1313.17   0.00   0.00   0.00   0.00   0.00   0.00
XP  610 0.60018003 0.99900001 0.03021344 0.44999999 1.00000000
XP  609 1.00000000 1.00000000 0.43308637 0.98000002 0.99900001
XP  509 1.00000000 1.00000000 0.40080041 0.95000011 1.00000000
XP  510 1.00000000 1.00000000 0.40000001 0.98000002 1.00000000
B4      25.00  25.00  25.00  25.00  25.00  25.00  25.00  25.00   0.00   0.00   0.00  25.00
X4  610 0.55000001 1.00000000 0.04000000 0.96000010 1.00000000
X4  609 1.01000011 1.00000000 0.40999994 0.98000002 1.00000000
X4  509 0.99989998 1.00000000 0.40000001 0.60000002 1.00000000
X4  510 0.99989998 1.00000000 0.40000001 1.00000012 1.00000000
**
** Flow Extension for Control Point BRWA41
FEBRWA41 1998 2016 1940 1997  1  0                        1.878032
FN                 Ext1998-2016
QD  4  8   610   510   609   509   409   508   408   507
QA      1743.  1960.   96.  2914.  1112.  2847.  2417.  2226.
FZ          19452.6      45704.8      146341. 102411.
FR   2  6300.4 10363.6 19452.6 31006.4 45704.8 68642.0 102411. 146341. 233939. 422755. 642244.
FR      1469.4  2584.5 10084.2 20647.1 35132.3 62646.4 106253. 190883. 300694. 466275. 652041.
FX     3.38471 4.41312 2.81348 1.56675 1.40325 1.17768 1.07549 0.82356 0.76044 0.83082 0.94356 1.26504
UB2108.2  1748.7 0.24000 0.91000 0.62363 0.55310 1.00000 1.00000
BM     3214.50 9178.17 8245.5010364.0010364.0010364.00 5133.33 2443.67 4821.83 5319.33 6325.67 4542.50
XP  610 0.94055450 1.00000000 0.34000000 0.94905013 1.00000000
XP  510 1.00000000 1.00000000 0.40000001 1.00000012 1.00000000
XP  609 1.00000000 1.00000000 0.43124148 0.99500620 0.98499382
XP  509 0.60000002 1.00000000 0.00000000 0.59940004 1.00000000
XP  409 0.59940004 1.00000000 0.00000050 0.56772006 1.00000000
XP  508 0.60000002 1.00000000 0.00000000 0.63771433 1.00000000
XP  408 0.57000005 1.00000000 0.00000000 0.60000002 1.00000000
XP  507 0.60000002 1.00000000 0.00000000 0.62811184 1.00000000
B4     2148.70 5777.54 5180.3912374.0415899.3911833.42 3320.00 1696.20 1665.35 3356.60 4017.90 2940.50
X4  610 1.00000000 1.00000000 0.39850423 1.00000012 1.00000000
X4  510 0.99401504 1.00000000 0.39800400 0.92045814 1.00000000
X4  609 0.20120455 0.76778668 0.34231061 0.63220143 0.08547044
X4  509 0.62228274 0.99939424 0.00000000 0.95866489 0.98841721
X4  409 0.63081777 0.99900001 0.00000000 0.69888151 0.99291992
X4  508 0.61875528 0.99959731 0.00000000 0.96347260 0.99885887
X4  408 0.59313506 1.00000000 0.00000000 0.89181912 0.98295361
X4  507 0.61120617 1.00000000 0.00000000 0.95767927 0.99545974
**
** Flow Extension for Control Point BRHB42
FEBRHB42 1998 2016 1940 1997  1  0                        1.957035
FN                 Ext1998-2016
QD  4  9   611   610   510   609   509   409   508   408   507
QA       666   2261   1960    96   2914   1112   2847   2417  2226.
FZ          25155.0      60613.6      182647. 125100.
FR 2   8762.8 14725.6 25155.0 39693.6 60613.6 89483.0 125100. 182647. 272759. 488252. 770657.
FR      4273.4  6252.8 10852.5 22585.3 39771.6 76360.5 136640. 237874. 355352. 570815. 767692.
FX     1.92766 2.20900 2.66791 2.07196 1.58902 1.26852 1.04944 0.81758 0.76332 0.84562 0.92674 1.25272
UB           0.61000 0.86198 0.99000 0.69000 0.99000 1.00000
BM     5826.6713244.0010962.1714726.0014726.0014726.00 6978.00 6316.00 7545.83 9926.50 8223.50 6752.67
XP  611 1.00000000 1.00000000 0.40000001 1.00000012 1.00000000
XP  610 1.00000000 1.00000000 0.40000001 1.00000000 0.98000002
```

```
XP  510 1.00000000 1.00000000 0.40000001 0.98000002 1.00000000
XP  609 0.63063002 1.00000000 0.00000100 0.98000002 1.00000000
XP  509 0.57000005 1.00000000 0.00001203 0.63000000 1.00000000
XP  409 0.66149998 1.00000000 0.00001013 0.63064349 1.00000000
XP  508 0.60000002 1.00000000 0.00002884 0.60000002 1.00000000
XP  408 0.60000002 1.00000000 0.00001579 0.60000002 1.00000000
XP  507 0.60000002 1.00000000 0.00003110 0.60000002 1.00000000
B4      55.00  55.00  55.00  50.00  50.00  50.00  50.00  50.00   0.00  50.00  50.00  30.00
X4  611 1.00000000 1.00000000 0.40000001 1.00000012 1.00000000
X4  610 1.00000000 1.00000000 0.40000001 1.00000012 1.00000000
X4  510 1.00000000 1.00000000 0.40000001 1.00000000 0.98000002
X4  609 0.53798574 0.99900001 0.00000000 0.63111830 0.99800003
X4  509 0.60000002 1.00000000 0.00000000 0.70000005 1.00000000
X4  409 0.66149998 1.00000000 0.00000000 0.70000005 1.00000000
X4  508 0.60000002 1.00000000 0.00000000 0.70000005 1.00000000
X4  408 0.60000002 1.00000000 0.00000000 0.70000005 1.00000000
X4  507 0.60000002 1.00000000 0.00000000 0.70000005 1.00000000
**
** Flow Extension for Control Point LEDL43
FELEDL43 1998 2016 1940 1997  1  0                        0.998991
FN                Ext1998-2016
QD   2   509   508
QA       412    64
FZ            159.        876.       5858.  2676.
FR   2   92.   226.   454.   876.  1451.  2676.  5858. 12326. 22221.
FR       0.0    0.4   28.3   86.0  973.9 2721.7 7872.0 17663.3 26511.1
FX     1.00000639.189925.3713512.41436 3.49271 1.00226 0.77867 0.70115 0.77340 1.10497
UB          0.24000 0.86000 1.00000 0.24000 1.13000 1.00000
BM       1.07   2.57  64.63 125.00  47.30  41.67   0.00   0.00   0.00   0.00   0.00   0.00
XP  509 0.84000009 1.00000000 0.04751740 0.95000011 1.00000000
XP  508 1.00979805 1.00000000 0.40999994 0.70000005 1.00000000
B4     105.00 105.00 105.00  40.00  40.00  85.00 105.00  90.00 105.00   0.00  30.00  40.00
X4  509 0.65999991 1.00000000 0.14000000 0.84999996 1.00000000
X4  508 0.98000008 1.00000000 0.40999994 1.01000011 1.00000000
**
** Flow Extension for Control Point SADL44
FESADL44 1998 2016 1940 1997  1  0                        1.000000
FN                Ext1998-2016
QD   2   509   508
QA       216    51
FZ             84.        503.       3170.  1618.
FR   2  222.   503.   856.  1618.  3170.  7600.  15149. 36323.9
FR       0.0  117.9  430.2  1820.6 5178.8 11181.4 16923.1 29642.9
FX     1.00000 5.02500 3.48450 1.03505 0.69477 0.66412 0.82293 1.06938 1.35122
UB          0.24000 0.87000 1.00000 0.94000 1.02000 1.00000
BM       0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
XP  509 0.79007900 1.00000000 0.00000300 0.95000011 1.00000000
XP  508 1.00868785 1.00000000 0.40968743 0.90000010 1.00000000
B4     113.00  17.00 286.33  59.67 276.33  70.67 240.33  47.17 218.67   0.00   5.00  11.00
X4  509 0.65999991 1.00000000 0.09998999 0.94000012 1.00000000
X4  508 0.96000010 1.00000000 0.40999994 0.90000010 1.00000000
**
** Flow Extension for Control Point LEHS45
FELEHS45 1998 2016 1940 1997  1  0                        0.999991
FN                Ext1998-2016
QD   3   509   609   508
QA      1021   141   115
FZ           483.       2390.      13907.  6868.
FR   2  297.   687.  1276.  2390.  3709.  6868.  13907.  32405.  59686. 151230.
FR       0.0   24.6  124.4  549.6  2548.5  6976.3 20733.3 42537.7 66340.4 105876.
FX     1.0000029.1477115.87348 6.21624 2.68344 1.00407 0.79114 0.67600 0.86842 1.03695 1.34092
UB          0.25000 0.90000 1.00000 0.45000 1.13898 1.00000
```

```
BM      61.10   0.00 144.83 251.33 396.67  37.50  26.83   0.00   0.00   0.00   0.00   0.00
XP  509 0.81999999 1.00000000 0.00001300 0.96000010 1.00000000
XP  609 1.00999999 1.00000000 0.40999994 0.70000005 1.00000000
XP  508 1.00000000 1.00000000 0.40000001 1.00000012 1.00000000
B4     141.00  87.00 224.83 351.33 466.67 162.50 131.83  70.00  70.83   0.00  70.00  70.00
X4  509 0.85999995 1.00000000 0.00000000 0.96000010 1.00000000
X4  609 0.93990612 1.00000000 0.40999994 0.70000005 1.00000000
X4  508 0.99979997 1.00000000 0.40000001 1.00000012 1.00000000
**
** Flow Extension for Control Point LEHM46
FELEHM46 1998 2016 1940 1997  1  0                       0.572996
FN              Ext1998-2016
QD   3   609   509   508
QA      742  1063   115
FZ           829.       3408.      17495.  9676.
FR   2  192.   592.  1143.  2198.  3408.  5291.  9676. 17495. 37199. 68071.
FR       0.0   11.2   60.8  159.4 1153.9 4366.7 10989.6 24867.7 52980.8 79006.9
FX     1.0000053.9332727.7460616.49162 4.14511 1.82389 1.03528 0.72930 0.68024 0.78500 1.07383
UB          0.22040 0.86798 1.00000 0.74000 1.00000 1.00000
BM       0.00 117.17 152.00 402.00 992.67 244.33 134.36  18.53   0.00   0.00   0.00   0.00
XP  609 0.93968666 1.00000000 0.34000000 0.64064002 0.99760538
XP  509 0.60000002 1.00000000 0.00006706 0.98000002 1.00000000
XP  508 0.95380563 0.99923873 0.40040001 0.90787828 1.00007498
B4     118.00 202.17 262.00 497.00 917.67 394.33  89.00  79.67  19.83   0.00   0.00  71.33
X4  609 0.97902006 1.00000000 0.39999995 0.98000002 1.00000000
X4  509 0.60000002 1.00000000 0.00000000 0.60000002 1.00000000
X4  508 1.00000000 1.00000000 0.39956003 1.00000012 1.00000000
**
** Flow Extension for Control Point LEGT47
FELEGT47 1998 2016 1940 1997  1  0                       3.260946
FN              Ext1998-2016
QD   4   610   609   509   508
QA      276   916  1063   115
FZ          1361.       5793.      29556. 16994.
FR   2  2016.  3722.  5793.  9792. 16994. 29556. 56294. 96716. 238067.
FR       0.0  608.3 2074.1 6958.8 16766.1 42611.3 78558.5 126255. 192301.
FX     1.0000010.11168 3.89960 2.10236 1.10891 0.80876 0.73621 0.73641 0.92762 1.17765
UB          0.26353 0.86773 1.00000 0.29347 1.08798 1.00000
BM       0.00   0.00   0.00 212.67 1444.17 608.33   0.00   0.00   0.00   0.00   0.00   0.00
XP  610 0.62780571 0.99843186 0.34323955 0.98051882 0.99948120
XP  609 0.85908979 1.00000000 0.38114113 0.51469988 1.00000000
XP  509 0.54312617 0.99900001 0.00006308 0.98000002 1.00000000
XP  508 1.00000000 0.94999999 0.39247751 0.89509207 0.93606448
B4      65.00  90.00 100.00  85.00  60.00  25.00  60.00  10.00  20.00   0.00   0.00  70.00
X4  610 0.67687011 1.00000000 0.30446884 0.97902000 1.00000000
X4  609 0.94138896 1.00000000 0.38691911 0.50301725 1.00000000
X4  509 0.60366642 1.00000000 0.00000000 0.96010846 1.00000000
X4  508 0.96606499 0.99863476 0.22093509 0.98001903 1.00008094
**
** Flow Extension for Control Point COPI48
FECOPI48 1998 2016 1940 1997  1  0                       0.999991
FN              Ext1998-2016
QD   2   610   609
QA       99.   355.
FZ          201.0      1286.0      8277.2 4556.0
FR   2  312.8  667.6 1286.0 2216.8 4556.0 8277.2 18477.0 29613.0 85843.6
FR       0.0   16.5  108.7 2705.8 4738.8 12526.6 23417.1 35929.1 65271.0
FX     1.00000 103.04416.03529 1.50462 0.87900 0.71011 0.72274 0.82355 0.93770 1.27980
UB          0.25000 0.92000 1.00000 0.34000 1.20000 1.00000
BM       0.00  17.87  56.00 132.33 110.33  11.83   0.00   0.00   0.00   0.00   0.03   0.01
XP  610 1.00000000 1.00000000 0.39999995 0.95999998 1.00000000
XP  609 0.80000007 1.00000000 0.00005650 0.98000008 1.00000000
```

```
B4      401.17 469.67  951.00 1012.33  135.33  151.83   56.83    0.00    0.00  145.00  125.33  291.00
X4  610  0.97000009  1.00000000  0.39999995  0.85999995  1.00000000
X4  609  0.80000007  1.00000000  0.00000000  0.97000009  1.00000000
**
** Flow Extension for Control Point LEBE49
FELEBE49  1998  2016  1940  1997  1  0                          0.996991
FN                Ext1998-2016
QD   4    610    609    509    508
QA      1106.  1285.  1063.  115.
FZ           3360.0       12757.0       3118.0 35576.6
FR   2  3360.0  4687.6  7760.8 12757.0 22409.6 35576.6 63118.0 113249. 189269.
FR        0.0   304.3  2528.3  6537.3 10753.7 44790.9 76625.6 129033. 197193.
FX     1.0000046.47109 4.48208 2.09387 2.06346 1.43162 0.78633 0.85626 0.87879 1.18863
UB          0.53192 0.82356 1.00000 0.19516 1.12446 1.00000
BM       0.00    0.00  995.33 2810.67 2867.83 1627.17    0.00    0.00    0.00    0.00    0.00    0.00
XP  610  0.98207134  0.94999999  0.29287398  0.41772631  0.94999999
XP  609  0.55310655  1.00000000  0.00004922  0.95950007  1.00000000
XP  509  0.90250009  1.00000000  0.32580248  0.90250009  1.00000000
XP  508  0.90204424  1.00000000  0.26578778  0.98000002  1.00000000
B4      115.00  945.83 1010.33 2504.83 3064.08  414.25  305.33  200.00  162.50   45.00   45.00  150.83
X4  610  0.52081734  0.99935013  0.28360072  0.94286609  1.00000000
X4  609  0.96906483  0.99988049  0.00000000  0.98000002  1.00000000
X4  509  0.91690546  1.00000000  0.39246804  1.00000000  0.84928727
X4  508  0.51127762  0.95012683  0.37349883  0.16133983  0.22554854
BM       0.00  730.00   37.83 2728.17 3242.83 1547.17    0.00    0.00    0.00    0.00    0.00    0.00
XP  610  0.86039507  0.92320079  0.30685002  0.39789456  1.00000000
XP  609  0.55322009  0.97267830  0.00013568  0.98239326  0.96999991
XP  509  0.89914984  0.99900001  0.38000000  0.95000011  1.00000000
XP  508  1.00000000  1.00000000  0.36172235  0.93099999  1.00000000
B4       50.00  845.00  937.83 3001.92 2051.58 1338.83  148.50  112.50   60.00   50.00   40.00   82.50
X4  610  0.52283221  0.99710941  0.31683815  0.95530009  1.00000000
X4  609  0.94511545  0.99884707  0.00000000  0.98000002  1.00000000
X4  509  0.89061874  0.99885303  0.39601797  0.93407488  0.93957329
X4  508  0.78015077  0.99201810  0.38737947  0.72006792  0.13791820
**
** Flow Extension for Control Point LAKE50
FELAKE50  1998  2016  1940  1997  1  0                          0.479997
FN                Ext1998-2016
QD   2    609    709
QA       800    13
FZ            999.        2006.        6783.  3963.
FR   2   362.   666.   999.  1447.  2006.  2702.  3963.  6783.  13107.  25207.  45689.
FR        0.5  100.4  575.9  931.0  1369.8  1916.2  4072.6 10610.3 19986.6 36131.1 49935.6
FX     745.45722.07793 2.29168 1.56845 1.49214 1.42026 1.17527 0.67282 0.63478 0.69244 0.78951 1.16180
UB          0.44000 0.87000 0.01000 0.25000 1.13000 1.00000
BM      410.17  472.67  479.50  666.00  666.00  536.67  317.33  152.67  311.17  231.00  366.50  425.67
XP  609  0.86000007  1.00000000  0.02000400  0.94000012  1.00000000
XP  709  0.96333808  1.00000000  0.43136093  0.80000007  1.00000000
B4      465.17  482.67  534.50  730.00 1347.17  591.67  372.33  207.67  271.17   27.25  421.50  480.67
X4  609  0.72999996  1.00000000  0.16000001  0.84999996  1.00000000
X4  709  1.01000011  1.00000000  0.40958995  0.95950007  1.00000000
**
** Flow Extension for Control Point LAYO51
FELAYO51  1998  2016  1940  1997  1  0                          1.907033
FN                Ext1998-2016
QD   4    710    609    610    709
QA       150    844    108    135
FZ            1574.        3190.       12651.  6991.
FR   2   605.   999.  1574.  2214.  3190.  4593.  6991.  12651.  23745.  45780.  79522.
FR      151.7  226.7  592.4  1408.3  2271.6  3823.4  7905.7 19266.2 36550.7 59897.0 86419.6
FX     2.83774 4.21662 3.35017 1.93177 1.43734 1.32161 1.08208 0.69226 0.63489 0.70605 0.85728 1.14578
UB          0.22917 0.88000 0.79000 0.54000 1.10000 1.00000
```

```
BM      725.00  821.50  847.17  957.50  999.00  749.00  287.00  192.00  488.00  408.00  647.67  698.83
XP  710  0.90340257  1.00000000  0.30868661  0.89300013  1.00000000
XP  609  0.77074313  1.00000000  0.00001050  0.50030005  1.00000000
XP  610  1.00000000  1.00000000  0.38126552  1.00000012  1.00000000
XP  709  0.94999999  1.00000000  0.40000001  0.98000002  1.00000000
B4      640.00  717.20  727.73  826.00 1416.27  659.20  122.10    0.00  439.57    0.00  560.63  619.07
X4  710  1.00000000  1.00000000  0.37961993  1.00000012  1.00000000
X4  609  0.70070004  1.00000000  0.00000000  0.98000002  1.00000000
X4  610  1.00000000  1.00000000  0.40000001  0.95000011  1.00000000
X4  709  1.00000000  1.00000000  0.40000001  0.52499998  1.00000000
**
** Flow Extension for Control Point LABE52
FELABE52  1998  2016  1940  1997  1  0                         1.386009
FN                 Ext1998-2016
QD    4    610    710    709    609
QA        166    173    135    844
FZ             1462.         3927.        16360.  9827.
FR    2   436.   696.  1462.  2564.  3927.  6061.  9827.  16360.  28046.  54148.  89691.
FR        32.2   72.5  275.8  732.0  1920.4  5055.9 10929.8 21900.2 37497.3 61325.2 85899.1
FX     6.4751612.60270 6.62376 4.62278 2.40292 1.72130 1.00554 0.77926 0.74624 0.77542 0.95180 1.23068
UB 151.6  138.3 0.24000 0.89898 0.78000 0.40916 1.09356 1.00000
BM      696.00  696.00  696.00  696.00  696.00  696.00  332.50   41.33  115.83  103.33  265.17  493.00
XP  610  0.85780388  1.00000000  0.34000000  0.98000002  1.00000000
XP  710  0.95000011  1.00000000  0.40000001  0.98000002  1.00000000
XP  709  1.00000000  1.00000000  0.40000001  0.98000002  1.00000000
XP  609  0.66500002  1.00000000  0.00002445  0.52499998  1.00000000
B4      951.50 1128.17 1071.00 1100.50 1804.33 1248.00  607.50   91.33  380.83  265.00  530.17  758.00
X4  610  1.00000000  1.00000000  0.35909998  0.99000007  1.00000000
X4  710  1.00000000  1.00000000  0.42000002  0.98000002  1.00000000
X4  709  1.00000000  1.00000000  0.36218190  1.00000000  0.97999990
X4  609  0.70000005  1.00000000  0.00000000  0.70000005  1.00000000
**
** Flow Extension for Control Point LRLR53
FELRLR53  1998  2016  1940  1997  1  0                         1.495014
FN                 Ext1998-2016
QD  4  6    710    610    709    609    509    508
QA        367.  1445.   135.  2129.  1063.   115.
FZ            6581.2       16213.2       63522.2 37521.4
FR    2  1577.4  3418.4 6581 .2 10498.2 16213.2 25741.0 37521.4 63522.2 105606. 190524. 310852.
FR       446.9   784.0  2501.4  6353.8  9832.4 17172.6 39507.2 82833.2 135304. 237053. 344111.
FX     2.26676 3.99541 3.15372 1.92531 1.61158 1.55779 1.12841 0.84577 0.75673 0.76487 0.82259 1.09917
UB            0.20477 0.90409 0.95769 0.25000 1.11000 1.00000
BM     1766.83 2535.83 2278.33 3418.00 3418.00 3418.00 2927.17  695.17 1012.17  722.50 1117.00  955.67
XP  710  0.88342202  0.95094997  0.29296798  0.94316930  1.00000000
XP  610  0.90430588  1.00000000  0.36100000  1.00000012  1.00000000
XP  709  1.00000000  0.97441131  0.38284695  0.81767827  0.62224758
XP  609  0.55505401  0.99999899  0.00005123  0.56080729  0.99803853
XP  509  0.58405489  1.00000000  0.00005050  0.52815682  0.99944848
XP  508  0.78426695  0.97656965  0.00000450  0.79644126  1.00000000
B4     1115.10 1576.50 1422.00 3618.00 4957.10 3769.40 1811.30  374.60  534.80  151.00  725.20  628.40
X4  710  0.93887234  1.00000000  0.35999998  0.95000011  1.00000000
X4  610  1.00000000  1.00000000  0.40000001  1.00000012  1.00000000
X4  709  1.00000000  1.00000000  0.39920041  0.98000002  1.00000000
X4  609  0.59940004  1.00000000  0.00000000  0.70000005  1.00000000
X4  509  0.59940004  1.00000000  0.00000000  0.70000005  1.00000000
X4  508  0.62936997  0.99900001  0.00000000  0.69755179  1.00000000
**
** Flow Extension for Control Point NGGE54
FENGGE54  1998  2016  1940  1997  1  0                         1.060994
FN                 Ext1998-2016
QD    2    710    709
QA        120    127
```

```
FZ            346.       1425.       7472.  4018.
FR   2  232.   464.   885.  1425.  2348.  4018.  7472.  14575.  22152.
FR       0.0   77.9  367.6  746.4  2359.7  4293.5 10012.1 17952.6 24571.7
FX     1.00000 6.91990 3.34489 2.08475 1.25825 0.91458 0.80902 0.72738 0.85519 0.92455
UB           0.24000 0.92000 1.00000 0.82022 1.06121 1.00000
BM      119.20 153.33 169.67 169.33 195.50 108.00   0.00   0.00   0.00   0.00   0.00   0.00
XP  710 0.94000012 1.00000000 0.38999996 0.51999992 1.00000000
XP  709 0.60000002 1.00000000 0.00012826 1.01000011 1.00000000
B4       55.00  70.83 125.00 274.33 125.00 213.00 210.00 210.00  90.00 205.00 205.00 195.00
X4  710 1.00000000 1.00000000 0.45257390 0.98000002 1.00000000
X4  709 0.62155616 1.00000000 0.00000000 0.46998647 0.89799315
**
** Flow Extension for Control Point SGGE55
FESGGE55 1998 2016 1940 1997  1  0                         1.431011
FN               Ext1998-2016
QD   2   710   709
QA        68    61
FZ            181.        571.       2709.  1536.
FR   2   26.    60.   181.   323.   571.   946.  1536.  2709.  4596.  8301.  12608.
FR       6.6    7.8   18.4   53.6  242.8  639.1 1512.1  3505.6  6595.1 10653.7 14517.4
FX     2.78247 5.9219110.45061 7.10854 2.72466 2.08245 1.06976 0.81680 0.71004 0.68743 0.87769 1.05616
UB  9.3    5.4 0.21851 0.89798 1.00000 0.54000 1.10898 1.00000
BM       60.00  60.00  60.00  60.00  60.00  60.00  13.00   7.83   9.67  18.00  35.00  32.17
XP  710 0.81479883 0.99743408 0.00054327 0.44238129 0.98925459
XP  709 0.60425860 1.00000000 0.40918034 1.01000011 1.00000000
B4      168.93 192.53 124.13 265.73 155.80  92.27  45.40   0.00  37.73   0.00   0.00  25.73
X4  710 0.94000012 1.00000000 0.00000000 0.55999988 1.00000000
X4  709 0.60000002 1.00000000 0.40999994 0.94000012 1.00000000
**
** Flow Extension for Control Point GAGE56
FEGAGE56 1998 2016 1940 1997  1  0                         1.603019
FN               Ext1998-2016
QD   2   710   709
QA       211   189
FZ            535.       1691.       7725.  4354.
FR   2   98.   204.   535.   993.  1691.  2754.  4354.  7725. 13255. 25510. 37584.
FR      20.4   41.6   70.8  179.6  644.2 2179.5 4904.1 11334.8 18342.6 29784.7 39069.8
FX     2.75800 4.85836 6.68337 7.02006 3.42720 2.05364 1.00519 0.73118 0.71764 0.74593 0.91003 1.09900
UB 29.6   15.5 0.24298 0.90000 0.97000 0.45000 1.10000 1.00000
BM      199.00 204.00 204.00 204.00 204.00 204.00  47.67  73.00  20.50  31.83  80.83 100.00
XP  710 0.94055998 1.00000000 0.00008914 0.44000000 1.00000000
XP  709 0.60120058 1.00000000 0.39016667 0.98000002 1.00000000
B4      394.00 394.83 483.50 413.17 636.83 444.83 242.67 268.00 130.50   0.00   0.00 145.00
X4  710 0.95000011 1.00000000 0.37996197 0.55999988 1.00000000
X4  709 0.60000002 1.00000000 0.00000000 0.94000012 1.00000000
**
** Flow Extension for Control Point GALA57
FEGALA57 1998 2016 1940 1997  1  0                         0.998991
FN               Ext1998-2016
QD   2   710   709
QA       545   189
FZ           1805.       5489.      24906. 14895.
FR   2  854.4  1294.  2340.  3652.  5489.  8552.  14895.  24906.  45534.  64107.
FR       0.0   20.4  1002.3  2354.5  4405.8  9244.2 16398.4 30103.6 52466.3 78257.8
FX     1.00000196.9917 5.65724 1.81301 1.43368 1.00656 0.91308 0.87540 0.83852 0.82453 0.94141
UB           0.34000 0.92000 1.00000 0.95000 1.08000 1.00000
BM       81.33 167.47 144.60   5.00 183.17 116.93   0.00   0.00   0.00   0.00   0.00   0.00
XP  710 0.65999991 0.99989998 0.09005400 0.45999998 1.00000000
XP  709 0.99000007 1.00000000 0.40999994 1.01000011 1.00000000
B4      646.67 1152.33 1063.00 826.17 1190.83 824.67 222.33   0.00 190.00   0.00   0.00 459.17
X4  710 0.76000005 1.00000000 0.01993005 0.95904011 1.00000000
X4  709 1.01000011 1.00000000 0.40958995 0.69930005 1.00000000
```

```
**
** Flow Extension for Control Point LRCA58
FELRCA58 1998 2016 1940 1997  1  0                         1.571017
FN                 Ext1998-2016
QD  4  7    710    610    609    711    709    509    508
QA       1896.  1470.  2129.    77.   324.  1063.   115.
FZ           11904.0       28988.2       104549. 65294.4
FR    2  2706.4  5440.0 11904.0 19040.8 28988.2 44799.0 65294.4 104549. 165070. 290433. 426869.
FR       900.2  1126.6  1690.0  3308.2  6417.3 18830.3 33487.3 106996. 258952. 502319. 712170.
FX     2.17672 3.76835 6.27838 6.28087 4.97534 2.68270 2.12560 1.39154 0.72761 0.63324 0.59637 0.69305
UB 984.8  650.0 0.86457 0.82473 0.96000 0.53439 1.08740 1.00000
BM     2947.67 5440.00 5440.00 5440.00 5440.00 5440.00 2714.83 1173.50 1473.50 1456.17 2001.17 1957.83
XP  710  0.28869969  0.85737497  0.32454583  0.95933676  0.94999999
XP  610  0.71711624  0.94999999  0.40000001  0.95000011  1.00000000
XP  609  0.81466931  1.00000000  0.00001600  0.55124998  1.00000000
XP  711  0.94999999  1.00000000  0.41894999  1.00000000  0.97999990
XP  709  0.85737509  0.94999999  0.38000000  0.94999999  0.97999990
XP  509  0.94762510  1.00000000  0.38000000  0.98000002  1.00000000
XP  508  1.00000000  1.00000000  0.40000001  1.00000000  0.97999990
B4      352.85 1137.57  809.84    0.00 5509.81 6220.98 1884.00  830.92  485.50   67.14  668.83  743.58
X4  710  0.37281060  0.99846816  0.32364634  0.95571429  0.99906909
X4  610  0.88815361  1.00000000  0.38038000  0.98000002  1.00000000
X4  609  0.97034484  1.00000000  0.00023328  0.49947426  0.98167264
X4  711  1.00000000  1.00000000  0.49304932  1.00000000  0.95243454
X4  709  0.79978639  0.94999999  0.40120122  0.98000002  1.00000000
X4  509  0.81731904  1.00000000  0.42000002  0.98000002  1.00000000
X4  508  1.00000000  1.00000000  0.46444052  0.98000002  1.00000000
**
** Flow Extension for Control Point BRBR59
FEBRBR59 1998 2016 1940 1997  1  0                         2.111029
FN                 Ext1998-2016
QD  4 12    711    611    710    610    510    709    609    509    409    508    408    507
QA        850   1138   2020   4028   1960    324   2225   3976   1112   2847   2417   2226
FZ           47961.2       107622.       323097. 232671.
FR  2   17707.0 28172.8 47961.2 73088.0 107622. 158629. 232671. 323097. 502304. 810073.1304347.
FR      8995.2 12460.9 23321.6 53895.3 91837.1 141347. 233786. 382207. 641077.1049241.1423526.
FX     1.76763 2.13366 2.24454 1.62129 1.25919 1.19206 1.06484 0.87440 0.82886 0.79771 0.88013 1.11215
UB 6506.  1743. 0.25000 1.02000 1.00000 0.55000 1.10000 1.00000
BM    12389.0028173.0023015.1728173.0028173.0028173.0014312.67 9949.3313738.8317620.8315475.1712094.33
XP  711  1.00000000  1.00000000  0.39441621  0.99000007  1.00000000
XP  611  1.00000000  1.00000000  0.39720601  0.97734791  1.00000000
XP  710  1.00000000  1.00000000  0.38908932  1.00000012  1.00000000
XP  610  0.84184927  1.00000000  0.00000000  0.89911550  1.00000000
XP  510  0.80160087  1.00000000  0.00000000  0.89144522  1.00000000
XP  709  0.80561608  1.00000000  0.00000100  0.95044607  1.00000000
XP  609  0.80160087  1.00000000  0.00000000  0.90953755  1.00000000
XP  509  0.80000007  1.00000000  0.00000000  0.90270281  1.00000000
XP  409  0.80400813  1.00000000  0.00000000  0.90541363  1.00000000
XP  508  0.80000007  1.00000000  0.00000000  0.90180099  1.00000000
XP  408  0.80080009  1.00000000  0.00000000  0.90270281  1.00000000
XP  507  0.80160087  1.00000000  0.00000000  0.90180099  1.00000000
B4       30.00   45.00   45.00   45.00   45.00   45.00   45.00   25.00    0.00    0.00    0.00   45.00
X4  711  0.93906009  1.00000000  0.37961996  0.99000007  1.00000000
X4  611  1.00000000  1.00000000  0.40000001  1.00000012  1.00000000
X4  710  1.00000000  1.00000000  0.40000001  0.98000002  1.00000000
X4  610  0.89798725  1.00000000  0.00000000  0.90000010  1.00000000
X4  510  0.90090007  1.00000000  0.00000000  0.94500011  1.00000000
X4  709  0.85500008  0.99900001  0.00000000  0.89775008  1.00000000
X4  609  0.90000010  1.00000000  0.00000000  0.90000010  1.00000000
X4  509  0.90000010  1.00000000  0.00000000  0.90000010  1.00000000
X4  409  0.90000010  1.00000000  0.00000000  0.90000010  1.00000000
X4  508  0.90000010  1.00000000  0.00000000  0.90000010  1.00000000
```

```
X4  408 0.90000010 1.00000000 0.00000000 0.90000010 1.00000000
X4  507 0.90000010 1.00000000 0.00000000 0.90000010 1.00000000
**
** Flow Extension for Control Point MYDB60
FEMYDB60 1998 2016 1940 1997  1  0                           5.827760
FN                Ext1998-2016
QD   2    711    710
QA       37.   197.
FZ            59.0        552.0       4282.0  2229.2
FR   2  111.0  294.6  552.0 1104.4 2229.2 4282.0 10826.0 17271.4 30943.2
FR       0.0   41.7   95.5  752.8 2792.0 6697.0 12353.5 17592.3 33832.6
FX     1.0000010.58110 5.87212 3.62914 0.96442 0.65987 0.78142 0.91308 0.94946 1.15452
UB          0.25000 0.91998 1.00000 0.84000 1.10000 1.00000
BM      0.00  66.34  76.80  95.50 117.97  17.33   0.00   0.00   0.00   0.00   0.00   0.00
XP  711 0.95104516 1.00000000 0.39999995 0.55999988 1.00000000
XP  710 0.90090007 1.00000000 0.10000000 0.99000007 1.00000000
B4      57.67  66.33  79.00 265.50 265.67 207.33 190.00   0.00 190.00   0.00 190.00  45.00
X4  711 0.99000007 1.00000000 0.38988298 0.98000002 1.00000000
X4  710 0.80000007 1.00000000 0.10000000 0.90000010 1.00000000
**
** Flow Extension for Control Point EYDB61
FEEYDB61 1998 2016 1940 1997  1  0                           1.165998
FN                Ext1998-2016
QD   2    711    710
QA      174.    71.
FZ           344.0        814.0       4963.2  2221.6
FR   2   78.6  249.6  388.6  557.4  814.0 1320.0 2221.6 4963.2 11912.2 17273.6
FR       0.0   30.1  169.1  325.7  559.0  965.7 2591.1 6532.1 13207.2 19715.3
FX     1.00000 9.74893 4.18600 1.94492 1.57144 1.51477 0.99949 0.73132 0.85185 0.88542 0.87546
UB          0.24000 0.90000 1.00000 0.44000 1.11998 1.00000
BM      13.13  76.17  66.03 160.80 269.27  93.33  30.07   0.00   0.00   0.03   9.28   0.00
XP  711 0.81000000 1.00000000 0.00001683 0.94000012 1.00000000
XP  710 1.00999999 1.00000000 0.40999994 0.60000002 1.00000000
B4       0.00  64.50 113.90 203.10 273.20  82.50 131.30 105.00 116.00   0.00   0.00   0.00
X4  711 0.65999991 1.00000000 0.24000002 0.81000000 1.00000000
X4  710 0.93990612 1.00000000 0.40999994 1.01000011 1.00000000
**
** Flow Extension for Control Point YCSO62
FEYCSO62 1998 2016 1940 1997  1  0                           2.675988
FN                Ext1998-2016
QD   2    711    710
QA       620    378
FZ            766.        3904.       27456. 13746.
FR   2   492.   766.  1104.  2332.  3904.  7387.  13746.  27456.  60819.  87776.
FR       0.0   54.2  254.8  911.3 1578.7 6037.8 13830.0 32082.1 64927.0 97664.7
FX     1.0000016.50391 7.31436 3.58779 2.63437 1.79221 0.98662 0.88304 0.91911 0.88980 0.91742
UB          0.25000 0.90098 1.00000 0.76387 1.10000 1.00000
BM      54.83 675.00 450.67 1221.50 991.33 254.83   0.00   0.00   0.00   0.00   0.00   0.00
XP  711 0.65006506 1.00000000 0.16000000 0.97000009 1.00000000
XP  710 1.00999999 1.00000000 0.34000000 0.60000002 1.00000000
B4     345.97 800.00 757.13 893.30 848.27 716.97 668.13 665.00 125.00 515.00 160.00  65.00
X4  711 0.68631524 1.00000000 0.00000000 0.98000002 1.00000000
X4  710 1.00000000 1.00000000 0.40955156 0.93748933 1.00000000
**
** Flow Extension for Control Point DCLY63
FEDCLY63 1998 2016 1940 1997  1  0                           3.967895
FN                Ext1998-2016
QD   1    711
QA      195.
FZ            71.0        649.0       5889.4  2720.2
FR   2  122.6  289.6  649.0 1310.6 2720.2 5889.4 13338.6 20034.6
FR       0.0   28.2  112.5 1335.3 2937.3 7625.7 15151.7 21653.8
```

```
FX     1.00000 6.74868 6.10321 2.19267 0.91720 0.79013 0.90549 0.91360 0.96808
UB           0.44461 0.96000 1.00000 0.35000 1.11000 1.00000
BM       0.00  71.37   0.00  112.50  131.83   28.17    0.00    0.00    0.00    0.00    0.00    0.00
XP  711  0.94000000  1.00000000  0.06299999  0.99000007  1.00000000
B4      191.40  190.30  168.20  439.50  297.10  156.90  405.00    5.00    0.00   90.00   25.00   70.00
X4  711  0.54000002  1.00000000  0.39999995  0.85999995  1.00000000
**
** Flow Extension for Control Point NAGR64
FENAGR64  1998  2016  1940  1997   1   0                          1.734025
FN                 Ext1998-2016
QD    1    611
QA        234
FZ            184.        1066.        10198.   5369.
FR    2   249.    483.   1066.   2598.   5369.  10198.  23055.  34881.
FR        0.0   200.1   437.0  2438.7  6763.5 13261.6 25443.3 36856.5
FX     1.00000 3.46941 2.15308 1.44974 0.85597 0.74952 0.83898 0.90149 0.93148
UB           0.34000 0.96000 1.00000 0.65000 1.10000 1.00000
BM      90.50  997.17  200.83  395.67  154.33    0.00    0.00    0.00    0.00    0.00    0.00   46.17
XP  611  0.93000001  1.00000000  0.09008981  0.91000003  1.00000000
B4      129.00  467.17  375.83  250.67  204.33  174.33  175.00  165.00  175.00    0.00   87.00  192.17
X4  611  0.56000000  1.00000000  0.29999998  0.92000002  1.00000000
**
** Flow Extension for Control Point BGFR65
FEBGFR65  1998  2016  1940  1997   1   0                          1.292004
FN                 Ext1998-2016
QD    1    611
QA         92
FZ             73.         528.         4240.   2315.
FR    2    73.    101.    223.    528.   1149.   2315.   4240.   8669.  12847.
FR        0.0    11.7   100.6   278.8  1414.6  2814.9  5129.3  9260.1 13784.9
FX     1.00000 9.26118 2.98796 2.13772 1.05625 0.81123 0.79782 0.94931 0.92965 0.93249
UB           0.24000 0.94000 1.00000 0.54000 1.13000 1.00000
BM      34.03  156.67  110.00  283.50  152.50   11.67    0.00    0.00    0.00    0.00    0.00    0.00
XP  611  0.75000006  1.00000000  0.20040004  0.85999995  1.00000000
B4      49.70   96.00   94.00  266.10  158.50  501.70  405.80  475.20  275.00    0.00   11.10   51.10
X4  611  0.63999993  1.00000000  0.25000003  0.84999996  1.00000000
**
** Flow Extension for Control Point NAEA66
FENAEA66  1998  2016  1940  1997   1   0                          5.593777
FN                 Ext1998-2016
QD    1    611
QA       925.
FZ           848.0        5743.0       40601.6  21528.2
FR    2   594.8  1342.6  2576.8  5743.0 11059.6 21528.2 40601.6 87562.4 131425.
FR        0.0   233.1  1313.1  2475.3 11347.5 22554.3 45373.3 87932.2 136479.
FX     1.0000010.60005 2.07650 2.32598 1.44615 0.94300 0.90191 1.02332 0.96433 0.90409
UB           0.25000 1.06000 1.00000 0.35000 1.24000 1.00000
BM       0.00 1360.33  988.33 1022.50 1385.67   86.00    0.00    0.00    0.00    0.00   53.78    0.00
XP  611  0.91081303  1.00000000  0.06995798  0.94999999  1.00000000
B4      577.20  838.20  845.00  880.50 1098.40  331.80  315.00   50.00  315.00   20.00  342.50  440.00
X4  611  0.85999995  1.00000000  0.10009999  0.95000011  1.00000000
**
** Flow Extension for Control Point NABR67
FENABR67  1998  2016  1940  1997   1   0                          1.939035
FN                 Ext1998-2016
QD    2    711    611
QA         88   1317
FZ           1759.        8530.        59067.  29861.
FR    2    76.    295.   1047.   2508.   4736.   8530.  16202.  29861.  59067. 109997. 167519.
FR       25.3    60.4   157.5  1162.6  3243.9  6820.5 18914.0 31977.1 61466.9 122947. 174255.
FX     3.51949 6.28598 7.68739 4.41562 1.60576 1.47287 1.06444 0.89360 0.92308 0.94332 0.95966 0.83731
UB  52.8   22.3 0.34000 0.91000 1.00000 0.45000 1.11000 1.00000
```

```
BM      912.50 2602.33 1640.17 2577.67 3315.67  512.83  157.50   71.50   25.50    0.07  143.83    0.00
XP  711  0.89389312  1.00000000  0.34068036  1.00000012  1.00000000
XP  611  0.80000007  1.00000000  0.20000000  0.70000005  1.00000000
B4      518.00 1056.93  912.07 1062.07 1357.27  364.13  120.00   57.60   99.20    0.00  156.53  312.40
X4  711  0.98000008  1.00000000  0.34996501  0.69999999  1.00000000
X4  611  0.60000002  1.00000000  0.20000000  1.01000011  1.00000000
**
** Flow Extension for Control Point BRHE68
FEBRHE68  1998  2016  1940  1997   1   0                            1.782027
FN                Ext1998-2016
QD  4 13    711    712    611    710    610    709    609    510    509    409    508    408
QD        507
QA      3338.   128.  2462.  2398.  4028.   324.  2225.  1960.  3976.  1112.  2962.  2417.
QA      2226.
FZ           77417.0       157333.       468793. 306815.
FR    2 30122.4 44643.0 77417.0 111822. 157333. 229331. 306815. 468793. 724072.1153505.1587840.
FR      12855.4 19112.9 34136.0 83581.4 133209. 205709. 332019. 546072. 853520.1416864.1803523.
FX      2.17236 2.39368 2.35630 1.60647 1.22629 1.15599 0.99301 0.86403 0.85843 0.81551 0.85735 1.02870
UB           0.21343 1.02000 0.87746 0.33000 1.11000 1.00000
BM     20165.6744090.0038902.6744643.0044643.0044643.0027013.1716167.8321781.8324605.6725522.6720484.67
XP  711  1.00000000  1.00000000  0.39431146  0.96863371  0.99462116
XP  712  1.00000000  1.00000000  0.54007989  1.00000000  0.98000002
XP  611  1.00000000  1.00000000  0.40361449  1.00000012  1.00000000
XP  710  0.71842933  0.99637723  0.00016900  0.85960805  1.00000000
XP  610  0.70844430  0.99623311  0.00042292  0.98579067  0.99420935
XP  709  1.00000000  0.99999702  0.00003350  0.98000002  1.00000000
XP  609  0.70986408  0.99549985  0.00019650  0.92493278  0.99999899
XP  510  0.70568955  0.99999899  0.00035017  0.98473167  0.99526834
XP  509  0.70140076  0.99260533  0.00047392  0.93857336  0.99966705
XP  409  0.71057326  1.00000000  0.00031167  0.98000002  1.00000000
XP  508  0.70771903  1.00000000  0.00025450  0.95707202  0.99650842
XP  408  0.70280427  1.00000000  0.00012533  0.90670395  0.99734020
XP  507  0.70702738  1.00000000  0.00014025  0.98199999  0.99800003
B4     20531.7544532.8939569.3367990.2190312.7884811.8627503.5616346.5616927.1910564.3825986.0020856.54
X4  711  1.00000000  1.00000000  0.39999995  0.98000002  1.00000000
X4  712  0.92026156  1.00000000  0.40000001  0.94620013  0.99800104
X4  611  1.00000000  1.00000000  0.40000001  0.60000002  1.00000000
X4  710  0.80000007  1.00000000  0.00000000  1.00000012  1.00000000
X4  610  0.80067325  1.00000000  0.00000000  0.98000002  1.00000000
X4  709  0.79401326  1.00000000  0.00000000  0.94769132  0.99900001
X4  609  0.80000007  1.00000000  0.00000000  1.00000012  1.00000000
X4  510  0.80000007  1.00000000  0.00000000  0.98000002  1.00000000
X4  509  0.80000007  1.00000000  0.00000000  0.98000002  1.00000000
X4  409  0.80000007  1.00000000  0.00000000  0.97902000  1.00000000
X4  508  0.80000007  1.00000000  0.00000000  1.00000012  1.00000000
X4  408  0.80000007  1.00000000  0.00000000  0.98000002  1.00000000
X4  507  0.80000007  1.00000000  0.00000000  1.00000012  1.00000000
**
*** Flow Extension for Control Point MCBL69
FEMCBL69  1998  2016  1940  1997   1   0                            3.902900
FN                Ext1998-2016
QD    2    811    711
QA        162    206
FZ             681.        3110.        18445.  9366.
FR    2    47.    176.    440.    956.   1829.   3110.   5192.   9366.  18445.  40523.  62238.
FR        0.0     1.2    39.5   385.1  1102.9  2285.7  5130.8  9727.0 24169.6 47196.0 73263.1
FX      1.0000094.69040 8.49081 3.26591 1.73338 1.39730 1.13856 1.00634 0.78396 0.81540 0.87446 0.90709
UB           0.44000 0.90000 1.00000 0.64000 1.19000 1.00000
BM       65.50  343.67  279.17  862.17  684.67  182.24   35.95    0.00    1.17    0.00    0.00   47.17
XP  811  0.96943337  1.00000000  0.06667972  0.94000012  1.00000000
XP  711  0.60060000  1.00000000  0.40999994  0.50000000  1.00000000
B4      295.50  543.67  484.17 1022.17  844.67  267.67  286.67  240.00    0.00  246.83  229.83  177.17
```

```
X4  811 0.65999991 1.00000000 0.35999998 0.90000004 1.00000000
X4  711 0.94000012 1.00000000 0.00000000 1.01000011 1.00000000
**
** Flow Extension for Control Point BRRI70
FEBRRI70 1998 2016 1940 1997  1  0                          1.522015
FN                Ext1998-2016
QD  4 15    812    811    711    712    611    710    610    709    609    510    509    409
QD        508    408    507
QA       203.   473.  3733.   148.  2462.  2398.  4028.   324.  2225.  1960.  3976.  1112.
QA      2962.  2417.  2226.
FZ          89258.2      184723.      512053. 358553.
FR     39521.8 53887.8 89258.2 133510. 184723. 257456. 358553. 512053. 779791.1230723.1674399.
FR     12672.5 19986.4 38811.9 109844. 167092. 250201. 379650. 600397. 903200.1346884.1757202.
FX     3.01222 3.02402 2.64647 1.49958 1.15379 1.06415 0.99135 0.89774 0.84970 0.86147 0.93871 1.08435
UB14173. 14173. 0.41000 1.01000 0.71817 0.68266 1.09436 1.00000
BM    29631.6753888.0048302.8353888.0053888.0053888.0034206.8320728.0029040.1732439.6736064.0029852.17
XP  812 1.00000000 1.00000000 0.52454299 0.98199999 0.99217772
XP  811 1.00000000 1.00000000 0.40685061 0.98009801 1.00000000
XP  711 1.00000000 0.99819881 0.40252677 0.80074406 0.99900001
XP  712 1.00000000 1.00000000 0.00001800 0.98000002 1.00000000
XP  611 0.84711802 1.00000000 0.00047192 1.00000012 1.00000000
XP  710 0.80722904 0.99999899 0.00047540 0.98000002 1.00000000
XP  610 0.80079925 1.00000000 0.00009633 1.00000012 1.00000000
XP  709 1.00000000 1.00000000 0.00003483 0.98000002 1.00000000
XP  609 0.80240250 1.00000000 0.00053725 1.00000012 1.00000000
XP  510 0.79840004 0.99981195 0.00008161 0.98000002 1.00000000
XP  509 0.80080009 1.00000000 0.00034510 0.98001903 0.99900001
XP  409 0.80481130 0.99807215 0.00005800 0.98112410 0.99907213
XP  508 0.80000007 0.99800104 0.00079931 0.98000002 1.00000000
XP  408 0.80160087 0.99890012 0.00009300 0.98000002 1.00000000
XP  507 0.80000007 0.99900001 0.00021946 0.98009801 1.00000000
B4     6045.9911497.04 9855.6315622.8021007.8918950.63 6979.50 4115.60 5410.34 3880.57 7248.67 5731.98
X4  812 0.98904914 0.99999899 0.35703841 0.89979440 1.00000000
X4  811 0.99650252 0.99900001 0.37806368 1.00000012 1.00000000
X4  711 0.99634105 1.00000000 0.40000001 0.70835525 1.00000000
X4  712 0.98185730 1.00000000 0.00000000 0.94715202 0.99900001
X4  611 0.90000010 1.00000000 0.00000000 1.00000012 1.00000000
X4  710 0.89910012 1.00000000 0.00000000 0.98000002 1.00000000
X4  610 0.90000010 1.00000000 0.00000000 1.00000012 1.00000000
X4  709 0.94075322 1.00000000 0.00000000 0.98000002 1.00000000
X4  609 0.90000010 1.00000000 0.00000000 1.00000012 1.00000000
X4  510 0.90000010 1.00000000 0.00000000 0.98000002 1.00000000
X4  509 0.90000010 1.00000000 0.00000000 1.00000012 1.00000000
X4  409 0.90000010 1.00000000 0.00000000 0.98000002 1.00000000
X4  508 0.90090007 1.00000000 0.00000000 0.97999901 1.00000000
X4  408 0.90000010 1.00000000 0.00000000 0.98000002 1.00000000
X4  507 0.90000010 1.00000000 0.00000000 1.00000012 1.00000000
**
** Flow Extension for Control Point BGNE71
FEBGNE71 1998 2016 1940 1997  1  0                          0.926992
FN                Ext1998-2016
QD   1   812
QA        47.
FZ            91.0        591.0       3640.8 1874.2
FR   2   33.0   56.0  125.4  279.8  591.0 1024.0 1874.2 3640.8 6678.6  9990.6
FR        0.0    0.3    2.3   65.7  247.8 1125.6 1886.1 3919.7 7747.9 10694.8
FX     1.00000 500.059 110.235 8.25968 3.42421 1.18764 0.89004 0.93082 0.89506 0.91933 0.90827
UB          0.24000 1.00000 1.00000 0.64000 1.14000 1.00000
BM       0.00   1.03   0.00   1.00  15.53   0.37   1.60   0.03   0.00   0.00   5.07   0.00
XP  812 0.68000001 1.00000000 0.24000002 0.94999999 1.00000000
B4      17.17  60.17  20.00 111.00  67.67 181.83   3.00  77.17  10.00  80.00   0.00 205.00
X4  812 0.65999991 1.00000000 0.21000004 0.96000010 1.00000000
```

```
**
** Flow Extension for Control Point BRRO72
FEBRRO72 1998 2016 1940 1997  1  0                        5.998748
FN                 Ext1998-2016
QD  4 15    812    811    711    712    611    710    610    709    609    510    509    409
QD         508    408    507
QA        572.   473.  3733.   148.  2462.  2398.  4028.   324.  2225.  1960.  3976.  1112.
QA       2962.  2417.  2226.
FZ           97964.6       198276.       528255. 375960.
FR  2   40684.8 59060.2 97964.6 139927. 198276. 269256. 375960. 528255. 797573.1274444.1758208.
FR      10267.0 13195.0 48081.6 112082. 171812. 276513. 395900. 573515. 860695.1281728.1621308.
FX      3.32385 4.23673 2.94922 1.46455 1.18053 1.02525 0.94930 0.91941 0.92066 0.96136 1.05086 1.27603
UB20950.  20950. 0.43000 1.00000 0.33774 0.52268 1.08715 1.00000
BM     30698.6757181.0050952.6759060.0059060.0059060.0039068.5021732.3329028.5033189.3338631.6730399.83
XP  812  0.97597045  0.99800104  0.42487460  0.98198098  0.99649435
XP  811  0.96964717  1.00000000  0.40351790  0.98000002  1.00000000
XP  711  1.00000000  0.99900001  0.42420673  0.70280355  1.00000000
XP  712  1.00000000  1.00000000  0.00000150  0.98000002  1.00000000
XP  611  0.84420848  1.00000000  0.00018505  1.00000012  1.00000000
XP  710  0.84336513  0.99899906  0.00028711  0.98000002  1.00000000
XP  610  0.80080009  1.00000000  0.00120591  1.00000012  1.00000000
XP  709  0.86813724  1.00000000  0.00001050  0.98000002  1.00000000
XP  609  0.76914895  0.99900866  0.00013695  0.98000002  1.00000000
XP  510  0.84168094  1.00000000  0.00007158  0.97803998  0.99900001
XP  509  0.79920006  1.00000000  0.00013485  1.00000012  1.00000000
XP  409  0.84848905  1.00000000  0.00006050  0.98000002  1.00000000
XP  508  0.80000007  1.00000000  0.00020039  0.98221475  0.99778527
XP  408  0.69278932  0.99999899  0.00012377  1.00000000  0.98000002
XP  507  0.80039650  1.00000000  0.00006300  0.98194659  0.99805343
B4       25231.  46158.  41877.  65145.  101582.  84580.  32014.  17542.  23490.  26614.  30122.  23573.
X4  812  0.99750000  1.00000000  0.37999994  0.93099999  1.00000000
X4  811  1.00000000  1.00000000  0.40000001  1.00000000  0.97999990
X4  711  1.00000000  1.00000000  0.40000001  0.60000002  1.00000000
X4  712  0.99215090  1.00000000  0.00000000  0.95000011  1.00000000
X4  611  0.90000010  1.00000000  0.00000000  1.00000012  1.00000000
X4  710  0.92816848  1.00000000  0.00000000  0.98000002  1.00000000
X4  610  0.90000010  1.00000000  0.00000000  1.00000012  1.00000000
X4  709  0.94500011  1.00000000  0.00000000  0.98000002  1.00000000
X4  609  0.90000010  1.00000000  0.00000000  1.00000012  1.00000000
X4  510  0.90000010  1.00000000  0.00000000  1.00000000  0.98000002
X4  509  0.90000010  1.00000000  0.00000000  1.00000012  1.00000000
X4  409  0.94500011  1.00000000  0.00000000  0.98000002  1.00000000
X4  508  0.90000010  1.00000000  0.00000000  1.00000012  1.00000000
X4  408  0.87561947  1.00000000  0.00000000  0.98000002  1.00000000
X4  507  0.90000010  1.00000000  0.00000000  1.00000012  1.00000000
**
** Flow Extension for Control Point BRGM73
FEBRGM73 1998 2016 1940 1997  1  0                        1.709024
FN                 Ext1998-2016
QD  4 15    812    811    711    712    611    710    610    709    609    510    509    409
QD         508    408    507
QA        890.   473.  3733.   148.  2462.  2398.  4028.   324.  2225.  1960.  3976.  1112.
QA       2962.  2417.  2226.
FZ           101917.        199329.       526071. 376386.
FR  2   42893.2 59767.2 101917. 142127. 199329. 269220. 376386. 526071. 792769.1272971.1759739.
FR      16683.8 22591.8 45423.0 117235. 183169. 281879. 387097. 575789. 927893.1444129.1827851.
FX      2.35462 2.74728 2.47362 1.42524 1.11885 0.99304 0.95014 0.92687 0.87735 0.91990 0.93145 1.07228
UB           0.43000 1.00000 0.76000 0.65000 1.10000 1.00000
BM     31530.3357375.8350224.0059767.0059767.0059767.0038889.3322541.0028628.8332770.0038397.5030023.00
XP  812  1.00000000  1.00000000  0.36108109  0.98000002  1.00000000
XP  811  1.00000000  1.00000000  0.40120122  0.98000002  1.00000000
XP  711  1.00000000  1.00000000  0.42000002  0.70000005  1.00000000
```

```
XP  712 0.84589267 1.00000000 0.00000100 0.96047485 1.00000000
XP  611 0.80000007 1.00000000 0.00007167 1.00000012 1.00000000
XP  710 0.83286285 1.00000000 0.00003292 0.98000002 1.00000000
XP  610 0.84000009 1.00000000 0.00007747 1.00000012 1.00000000
XP  709 0.84336007 0.94999999 0.00001300 0.98000002 1.00000000
XP  609 0.80000007 1.00000000 0.00003180 0.98000002 1.00000000
XP  510 0.80080009 0.99936968 0.00006106 1.00000000 0.98000002
XP  509 0.76000005 1.00000000 0.00004617 1.00000012 1.00000000
XP  409 0.77390617 0.99900001 0.00002167 0.98000002 1.00000000
XP  508 0.80000007 1.00000000 0.00004250 1.00000012 1.00000000
XP  408 0.80080009 0.99900001 0.00005446 0.98000002 1.00000000
XP  507 0.80080009 1.00000000 0.00004110 0.98000002 1.00000000
B4      32264.  57894.  51392.  81203. 125886. 104235.  39794.  23065.  29295.  33532.  20791.  30721.
X4  812 0.95000011 1.00000000 0.39999995 0.96000010 1.00000000
X4  811 1.00000000 1.00000000 0.40000001 1.00000012 1.00000000
X4  711 0.60000002 1.00000000 0.40000001 1.00000012 1.00000000
X4  712 0.94999999 1.00000000 0.00000000 0.97990203 1.00000000
X4  611 1.00000000 1.00000000 0.00000000 0.90000010 1.00000000
X4  710 1.00000000 1.00000000 0.00000000 0.90090007 1.00000000
X4  610 1.00000000 1.00000000 0.00000000 0.90000010 1.00000000
X4  709 1.00000000 1.00000000 0.00000000 0.85500008 1.00000000
X4  609 1.00000000 1.00000000 0.00000000 0.90000010 1.00000000
X4  510 1.00000000 1.00000000 0.00000000 0.90000010 1.00000000
X4  509 1.00000000 1.00000000 0.00000000 0.90000010 1.00000000
X4  409 1.00000000 1.00000000 0.00000000 0.90000010 1.00000000
X4  508 1.00000000 1.00000000 0.00000000 0.90000010 1.00000000
X4  408 1.00000000 1.00000000 0.00000000 0.90000010 1.00000000
X4  507 1.00000000 1.00000000 0.00000000 0.90000010 1.00000000
** Flow Extension for Control Point CLPEC1
FECLPEC1 1998 2016 1940 1997  1  0                          0.965991
FN                Ext1998-2016
QD   1   812
QA       33
FZ            302.        688.        2618.  1566.
FR   2   63.   134.   302.   486.   688.  1000.  1566.  2618.  4191.  6670.  8905.
FR       27.8   50.3  121.7  259.3  745.3 1149.7 1721.5 3146.2 4817.6 7166.6 9992.8
FX     1.93670 2.40953 2.61780 2.13010 1.13133 0.88794 0.91526 0.83115 0.87626 0.91169 0.95035 0.98725
UB  9.9   9.0 0.25000 1.03000 1.00000 0.64000 1.11000 1.00000
BM      42.83 107.67  50.33 134.00 134.00 134.00 110.00 127.33 115.00  35.50  21.33  20.67
XP  812 0.63025194 1.00000000 0.19980003 0.87000006 1.00000000
B4      28.57  51.53  65.07  27.63  50.53 115.20  22.00  45.47 118.00   0.00  94.27  69.13
X4  812 0.58994097 1.00000000 0.17994602 0.82999998 1.00000000
**
** Flow Extension for Control Point CBALC2
FECBALC2 1998 2016 1940 1997  1  0                          0.999991
FN                Ext1998-2016
QD   1   812
QA      114
FZ            830.        2085.        6669.  4313.
FR   2  116.   332.   830.  1429.  2085.  2957.  4313.  6669. 10640. 17827. 22551.
FR       35.0   57.7  205.5  796.0 1986.2 2934.6 4906.7 8264.1 12950.2 18724.7 25633.4
FX     3.30171 4.82787 5.35102 2.42097 1.27840 1.01406 0.99303 0.82461 0.81176 0.87946 0.91788 1.02517
UB 15.6   14.1 0.25000 1.03000 0.40000 0.45000 1.12000 1.00000
BM      72.83 308.50 206.83 332.00 332.00 332.00 332.00 332.00 332.00  46.00  43.17  35.33
XP  812 0.60999995 1.00000000 0.19000003 0.93093002 1.00000000
B4     168.70 495.10 314.10 560.10 543.10 389.00 686.00 216.55 554.40   0.00   0.00 196.20
X4  812 0.65999991 1.00000000 0.08982007 0.94000012 1.00000000
**
** Flow Extension for Control Point SJGBC3
FESJGBC3 1998 2016 1940 1997  1  0                          0.999991
FN                Ext1998-2016
QD   2   813   812
```

```
QA       275   456
FZ            4104.       10039.       30581.  19653.
FR   2   867.  1956.  4104.  6560. 10039. 13799. 19653. 30581. 49229. 78692. 101654.
FR      376.6  676.1 1545.2 3950.1 6586.6 13171.5 20175.7 35484.0 55292.8 81583.9 115208.
FX     1.95902 2.51216 3.09101 2.01132 1.54391 1.28037 1.00682 0.87353 0.88111 0.95808 0.92020 1.05612
UB 120.1   46.2 0.44000 0.99000 0.79000 0.54000 1.10000 1.00000
BM      611.67 1524.50 1042.83 1808.17 1956.00 1956.00 1956.00 1956.00 1956.00  519.67  262.67  339.67
XP  813  0.99019808  1.00000000  0.39999995  0.97000009  1.00000000
XP  812  0.60000002  1.00000000  0.00000300  0.90000010  1.00000000
B4      611.67 1619.50 1122.83 1903.17 3387.50 2340.17 2559.83 3144.67 2134.00  534.67  267.67  339.67
X4  813  0.96000010  1.00000000  0.39999995  0.99000007  1.00000000
X4  812  0.70000005  1.00000000  0.00000100  0.80000007  1.00000000
**
** Flow Extension for Control Point SJGMC4
FESJGMC4  1998  2016  1940  1997   1   0                          1.153998
FN                Ext1998-2016
QD   3   812   813   912
QA       983    12    47
FZ            9918.       24264.       73912.  47498.
FR   2  2095.  4728.  9918.  15856.  24264.  33350.  47498.  73912.  118985.  190193.  245692.
FR     1246.1  2163.4  4313.4  9570.4 23791.8 35043.2 47669.3 91213.4 139376. 208028. 264767.
FX     1.46102 1.81859 2.43879 2.11207 1.22687 0.97515 0.97467 0.82956 0.84259 0.90908 0.93970 1.09304
UB 250.0  122.5 0.35000 1.13898 0.99000 0.34000 1.13000 1.00000
BM     1478.50 3684.33 2521.00 4370.17 4728.00 4728.00 4728.00 4728.00 4728.00 1255.83  634.67  820.83
XP  812  0.85999995  1.00000000  0.07999999  0.99000007  1.00000000
XP  813  1.00000000  1.00000000  0.41081995  0.98009801  1.00000000
XP  912  1.00000000  1.00000000  0.32450125  0.50000000  1.00000000
B4     1503.50 3709.33 2546.00 4395.17 7997.70 5635.93 5956.83 7407.76 4952.83 1275.83  659.67  845.83
X4  812  0.65999991  1.00000000  0.16000001  0.83999997  1.00000000
X4  813  0.97000009  1.00000000  0.40958995  1.01000011  1.00000000
X4  912  0.99970001  1.00000000  0.32547668  1.00000012  1.00000000
ED
```

APPENDIX B

FIGURES FOR NATURALIZED FLOWS EXTENSION

B.1 Original 1940-1997 and Extended 1998-2016 Naturalized Flows

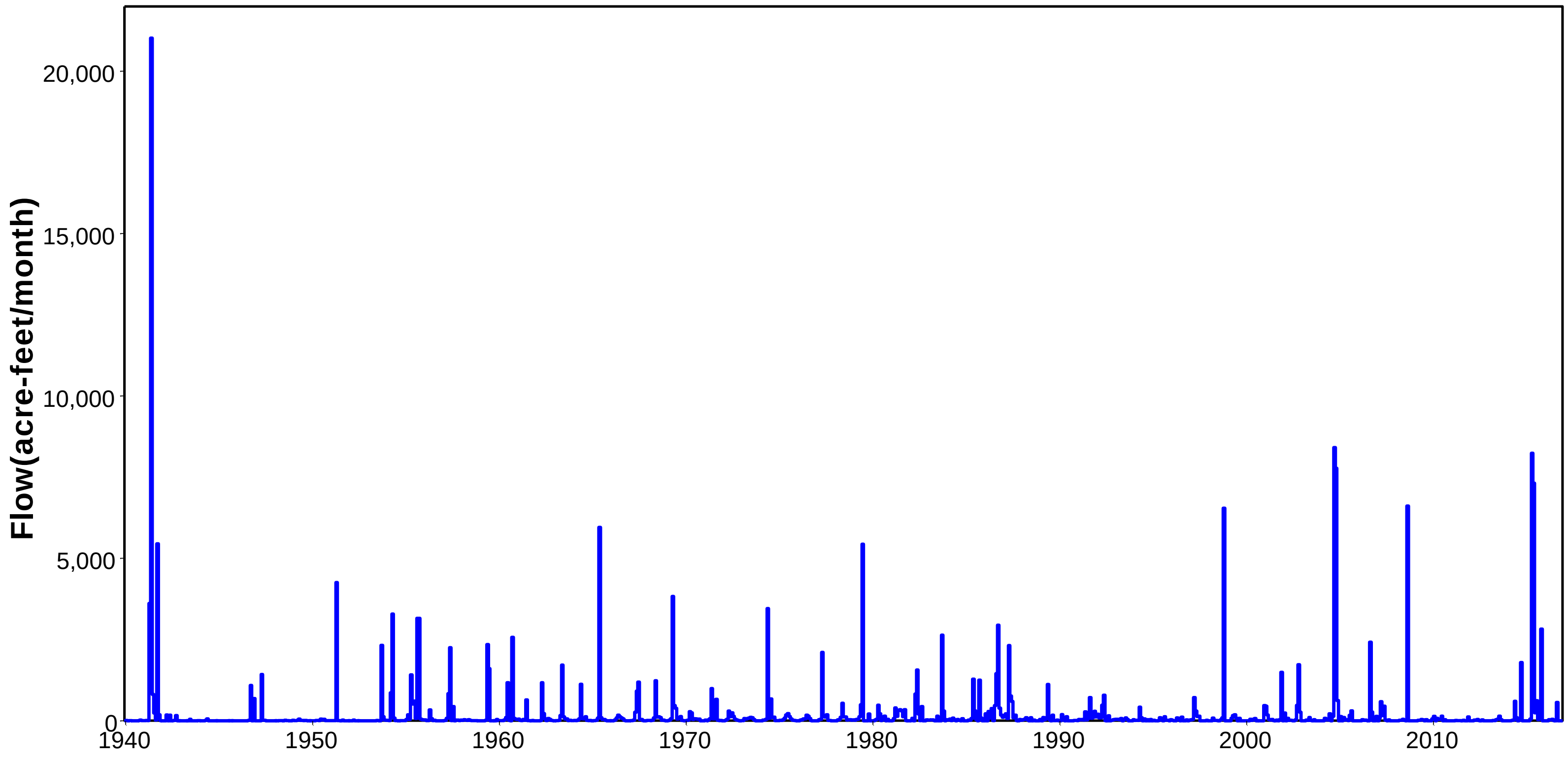


Figure B.1.1 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Running Water Draw at Plainview RWPL01

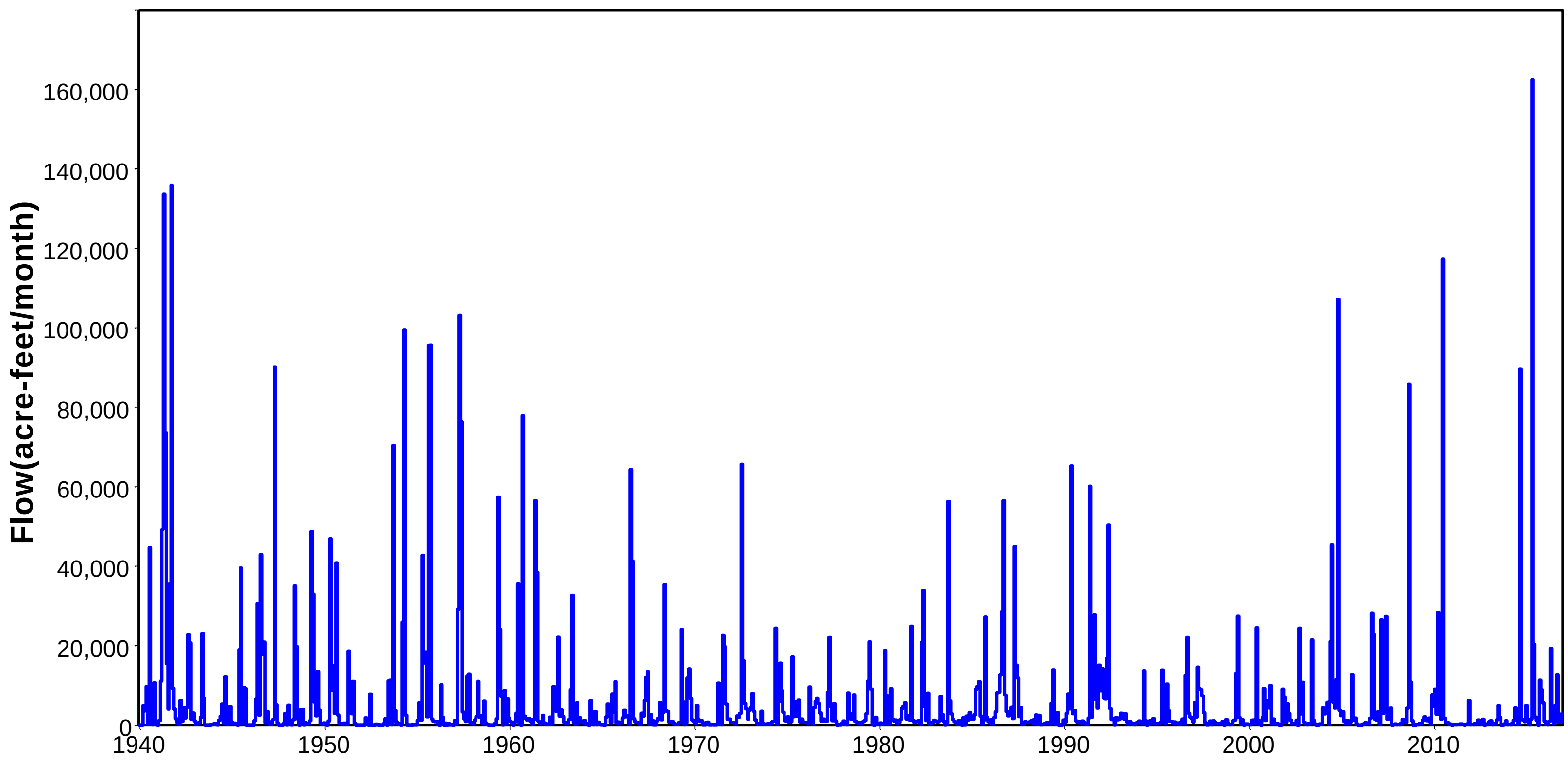


Figure B.1.2 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Salt Fork Brazos River at Aspermo nt SFAS06

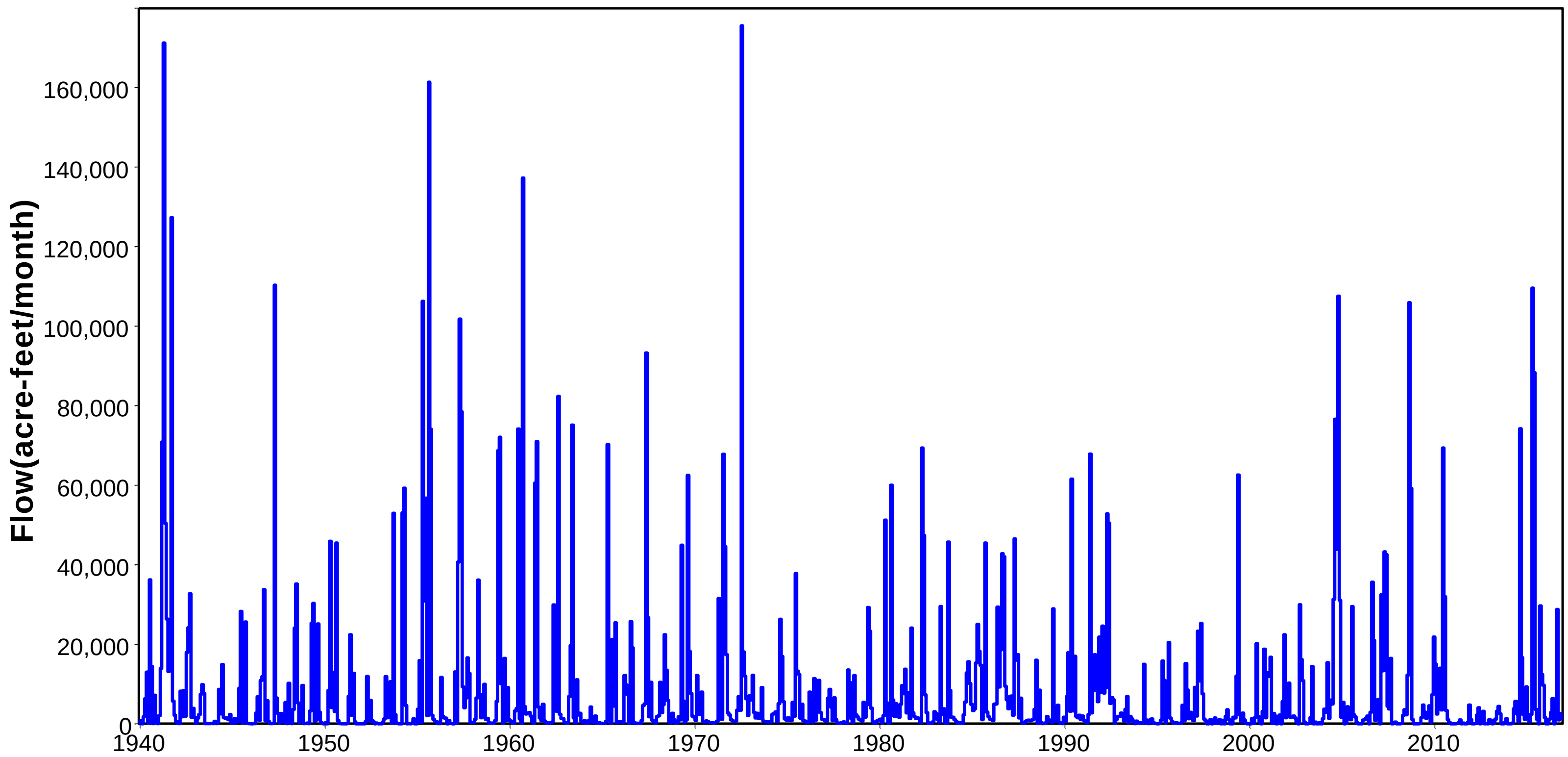


Figure B.1.3 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Double Mountain Fork at Aspermont DMAS09

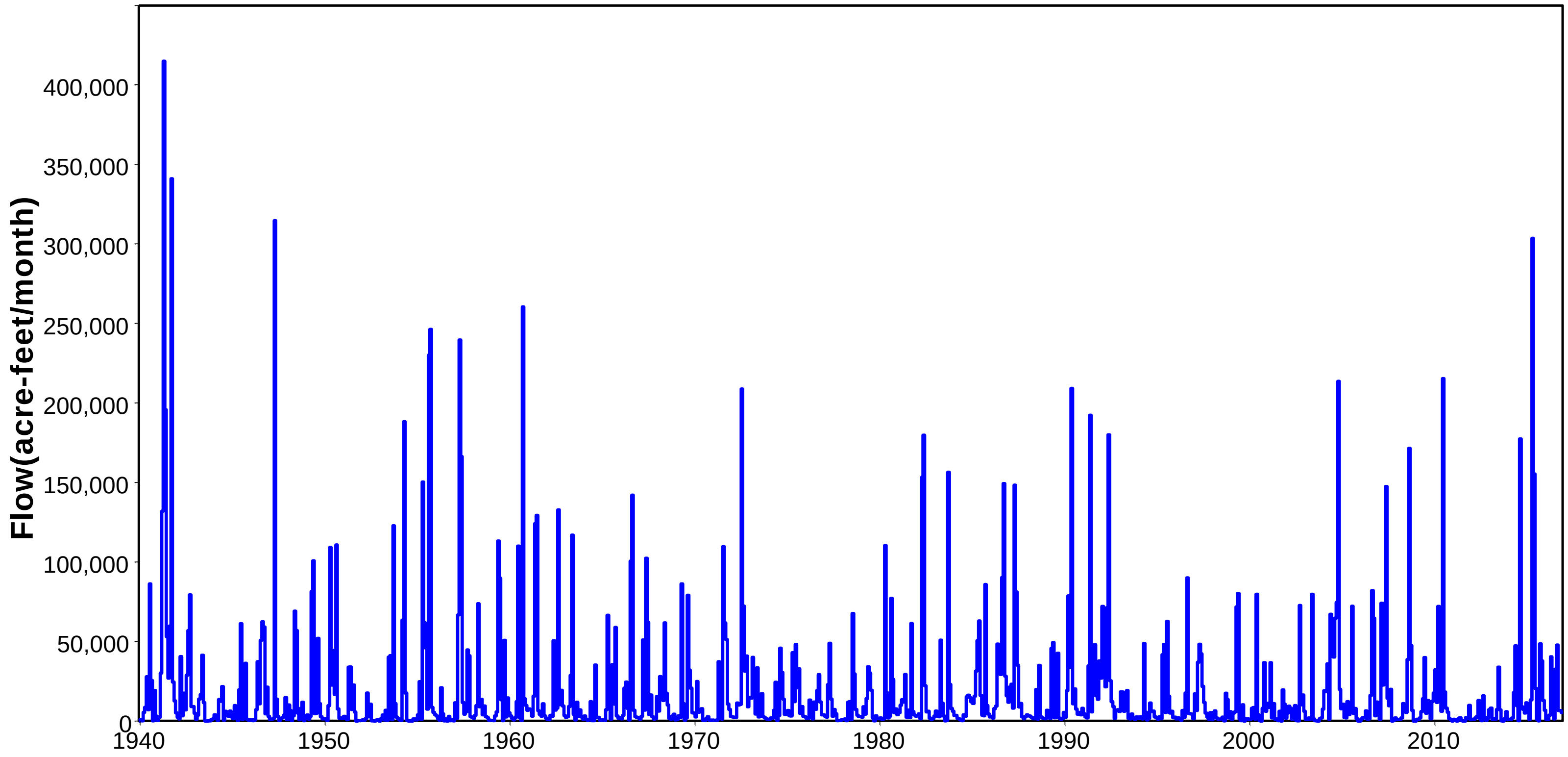


Figure B.1.4 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Seymour BRSE11

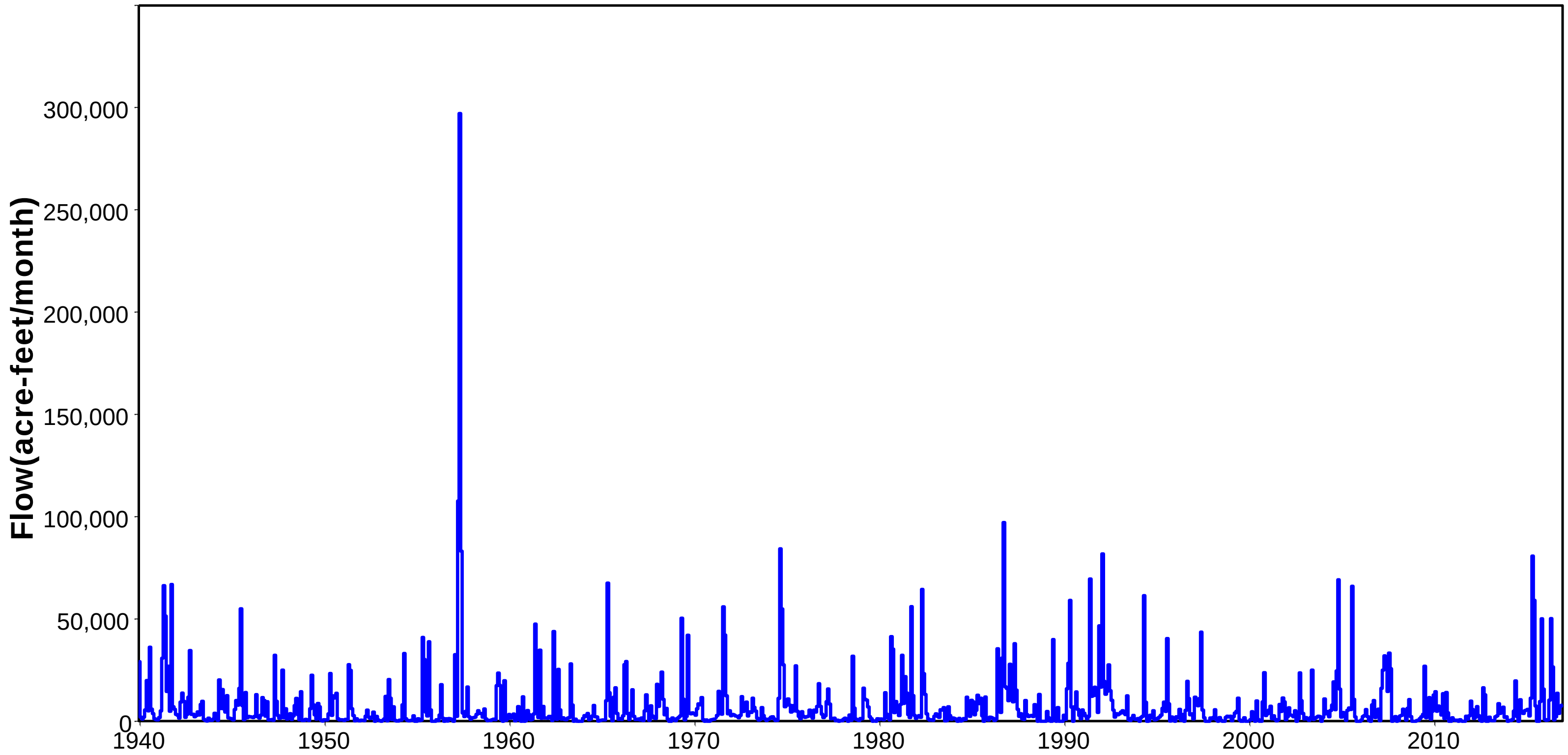


Figure B.1.5 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Clear Fork Brazos at Nugent CFNU16

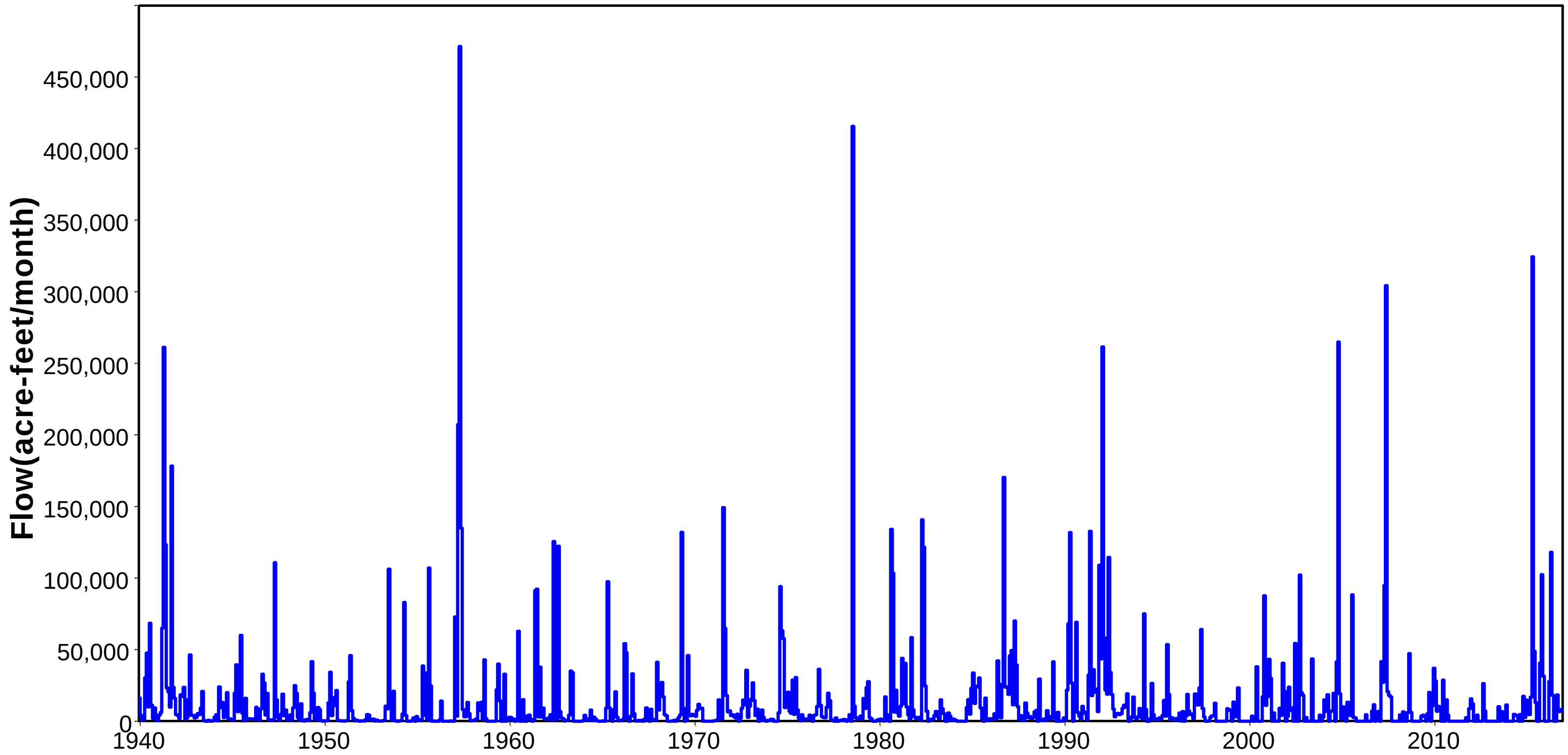


Figure B.1.6 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Clear Fork Brazos at Fort Griffin CFFG18

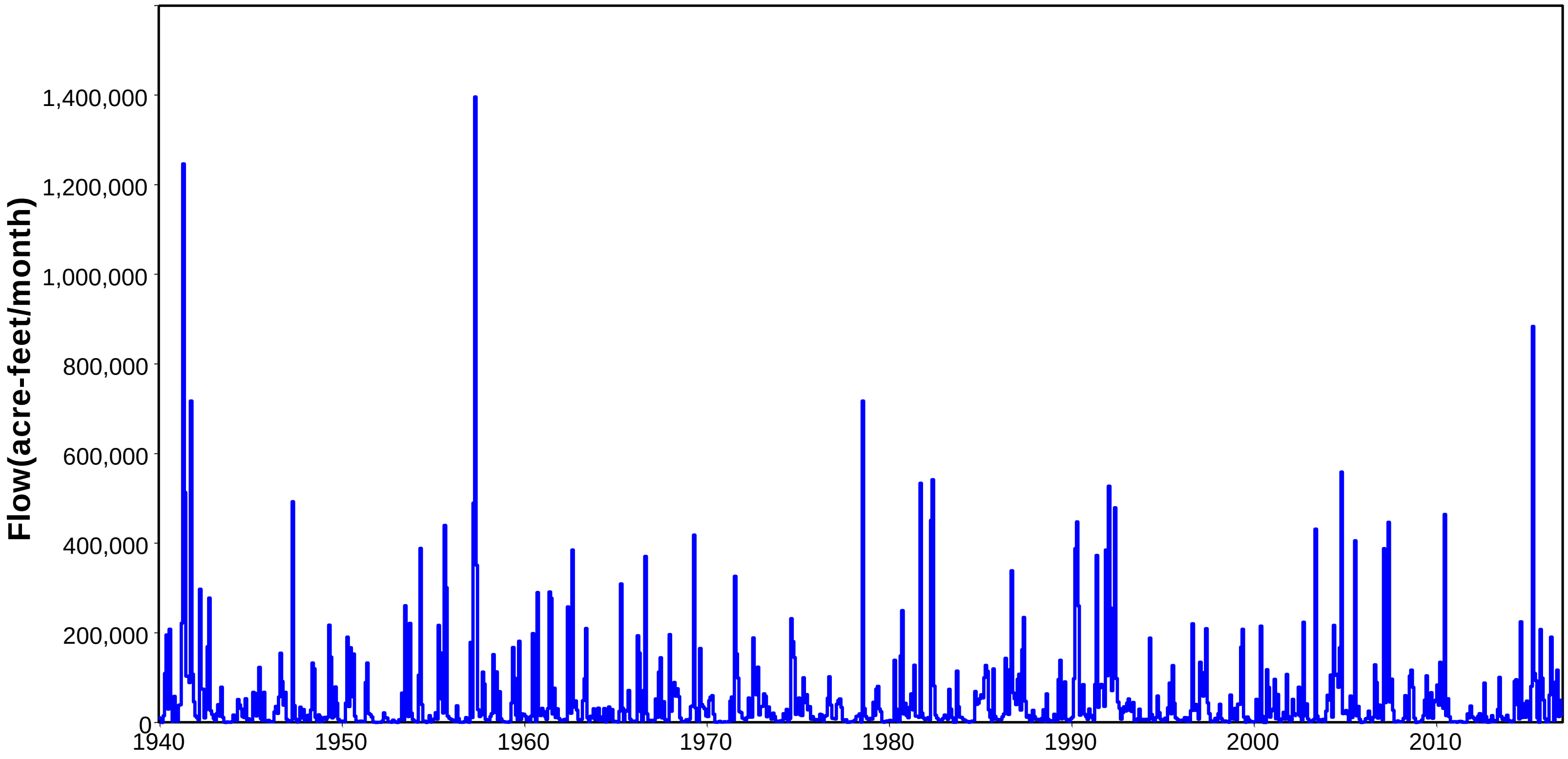


Figure B.1.7 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at South Bend BRSB23

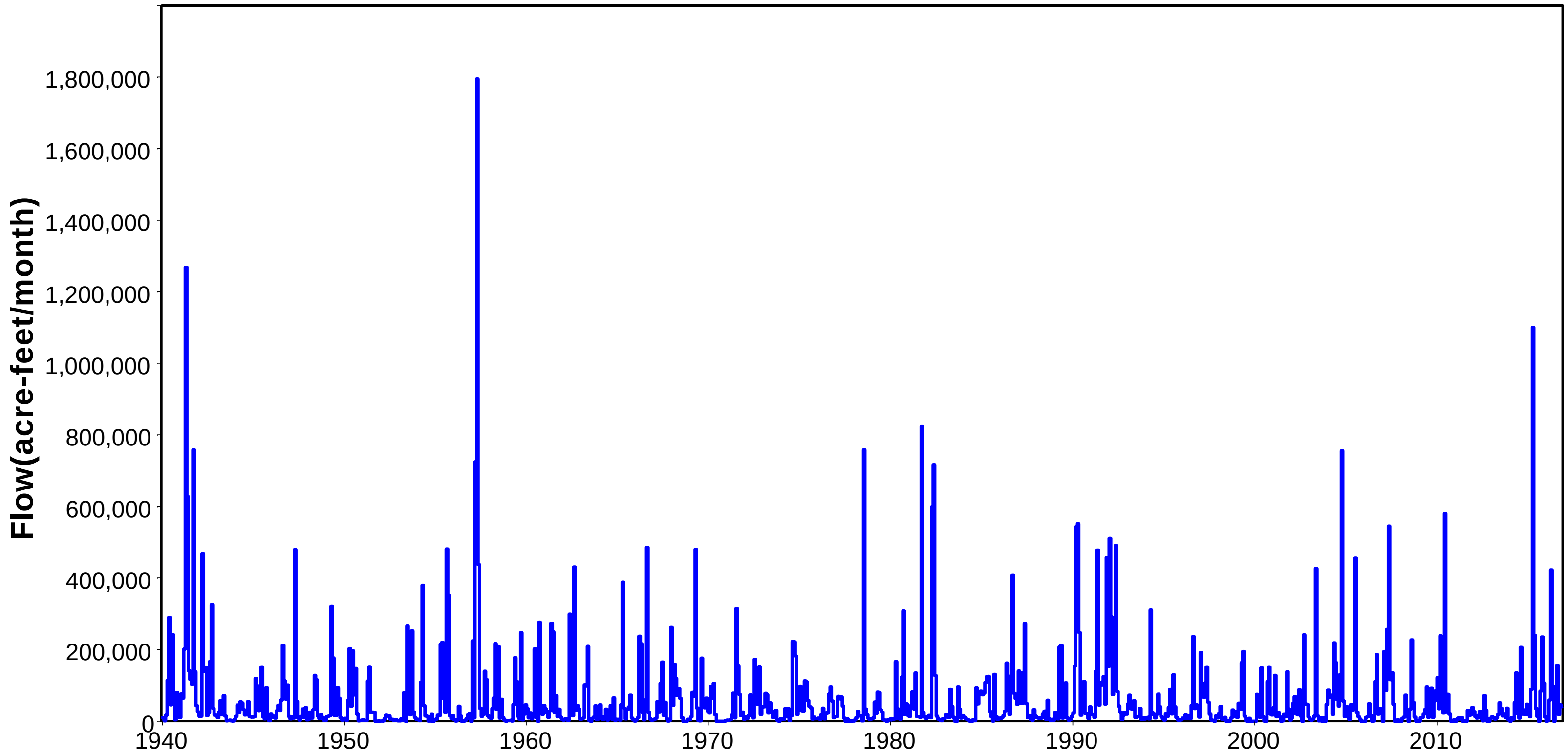


Figure B.1.8 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Graford SHGR26

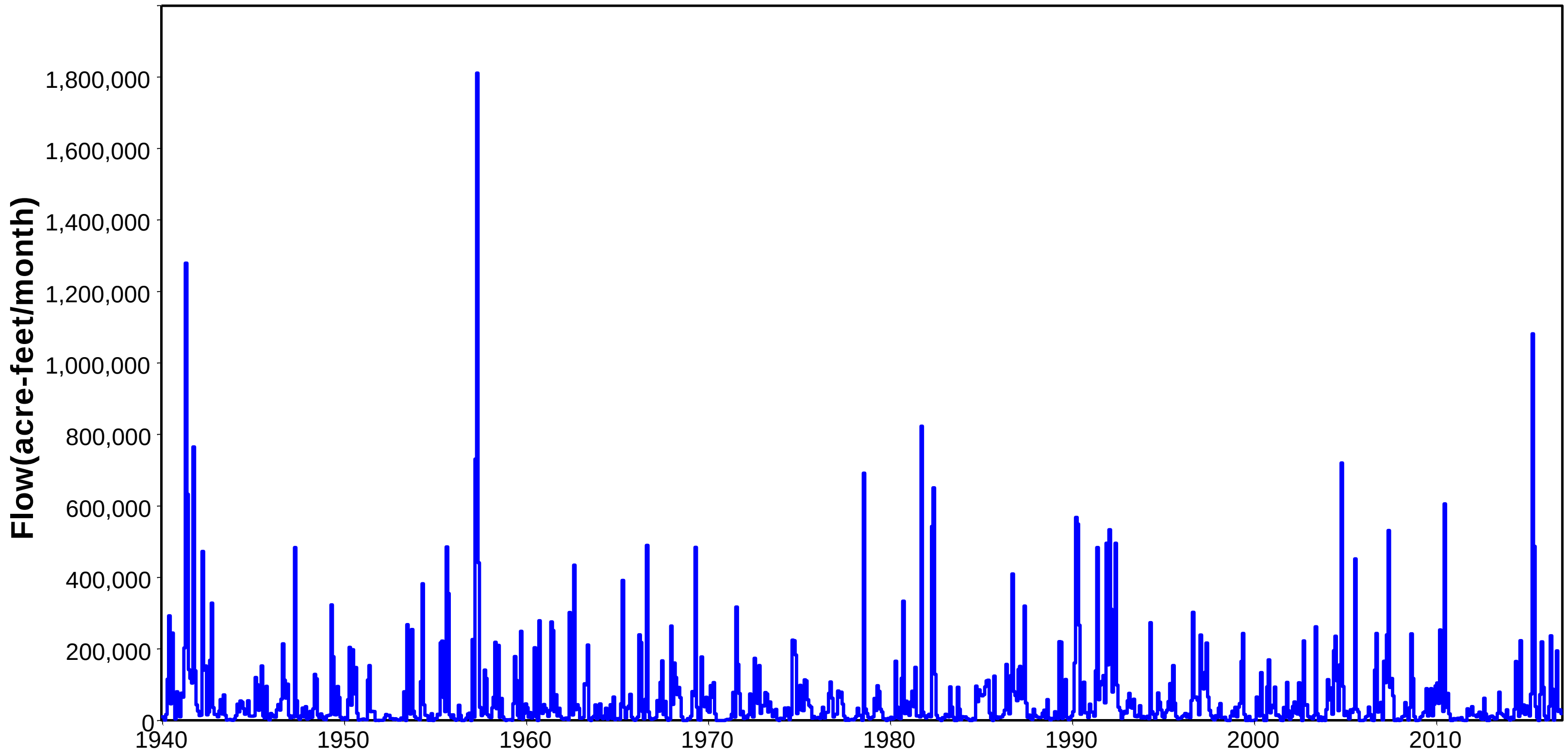


Figure B.1.9 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Palo Pinto BRPP27

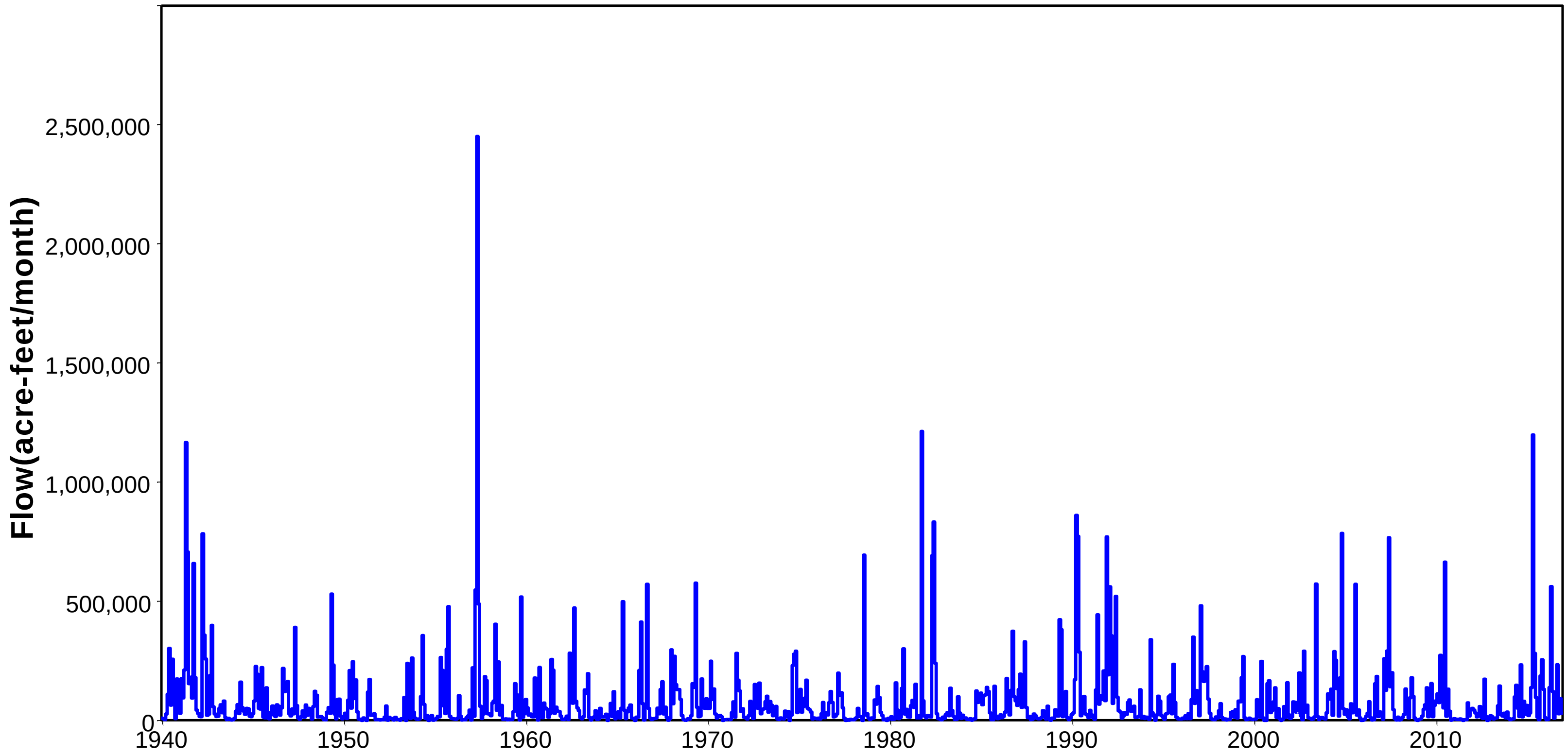


Figure B.1.10 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Dennis BRDE29

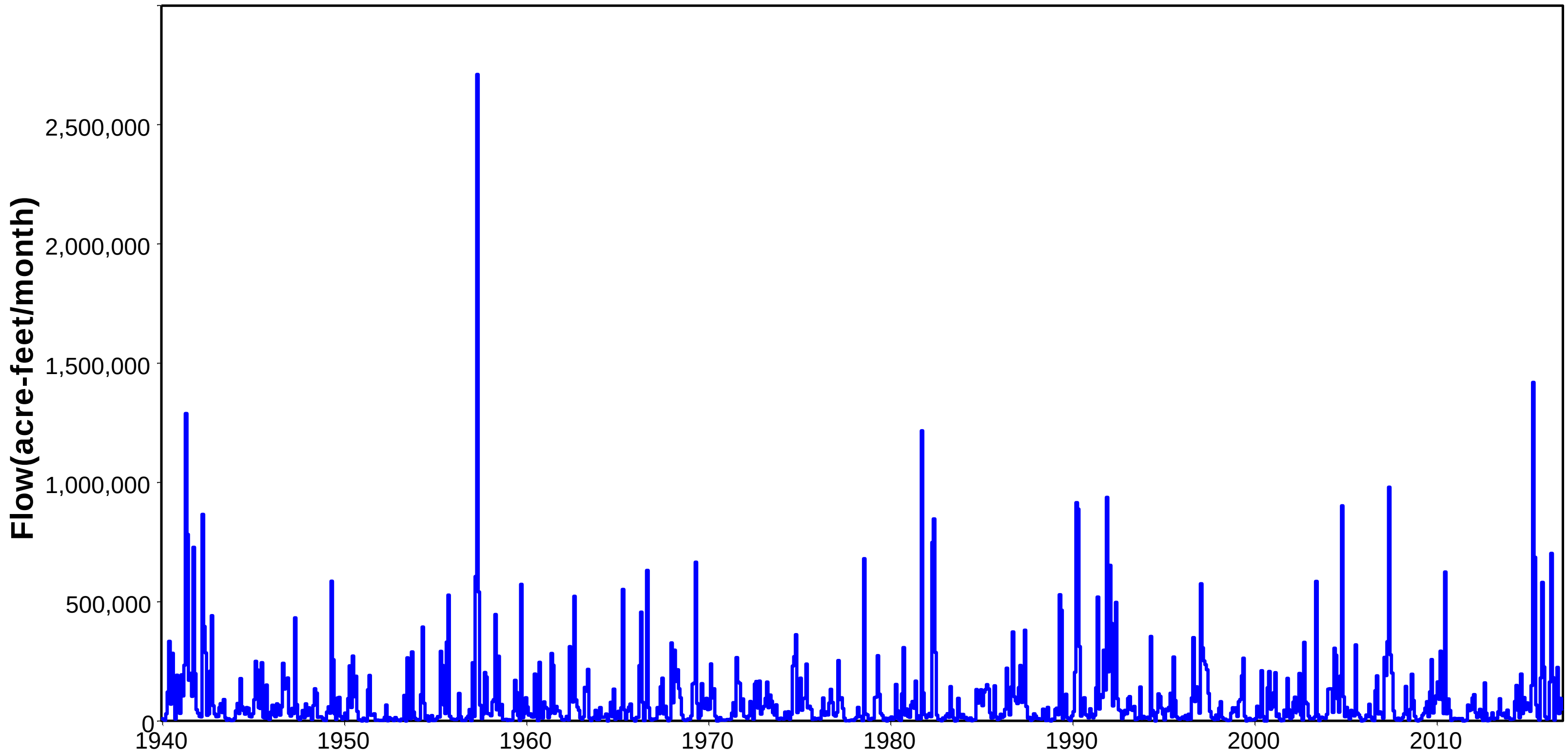


Figure B.1.11 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Glen Rose BRGR30

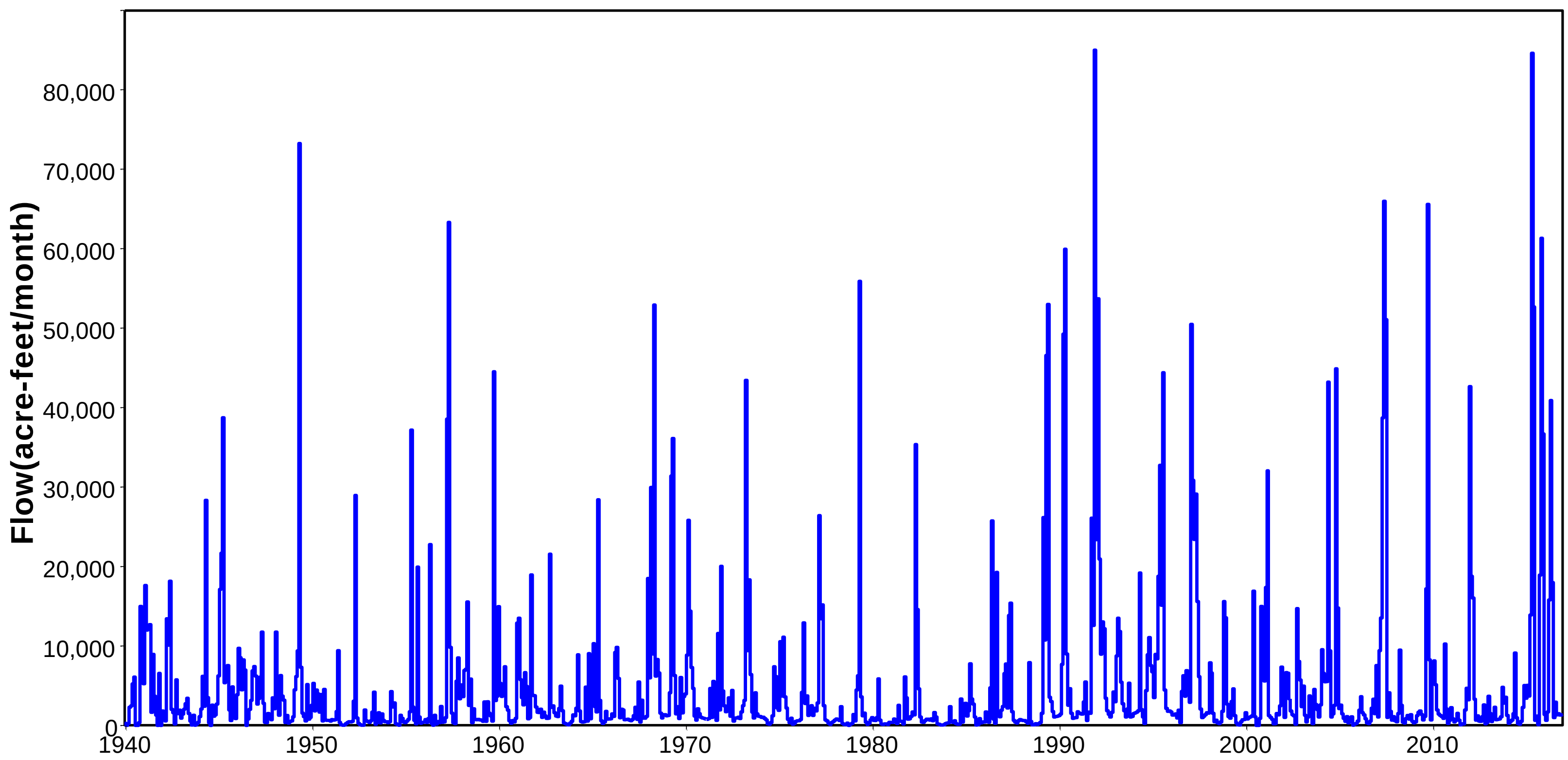


Figure B.1.12 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Paluxy River at Glen Rose PAGR31

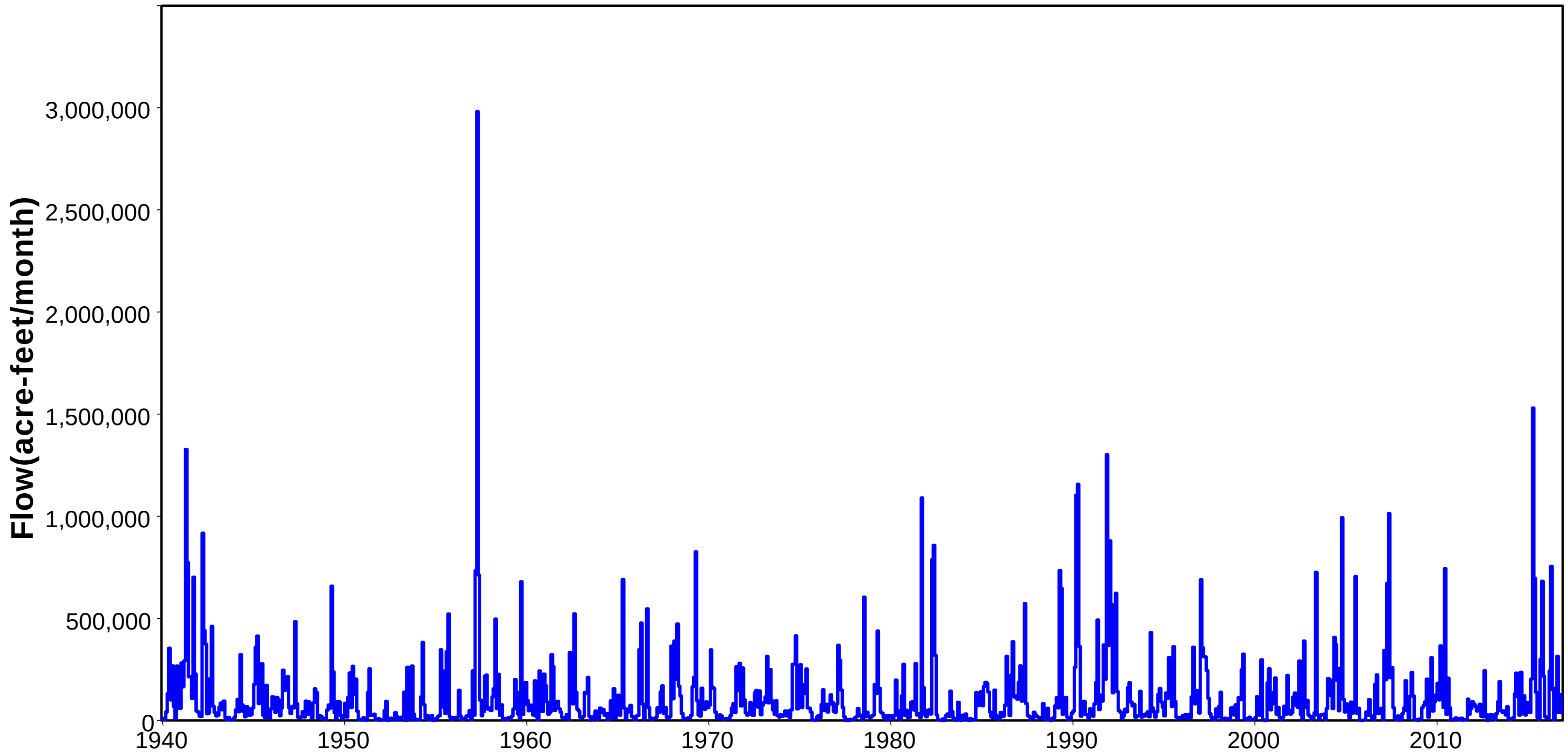


Figure B.1.13 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Aquilla BRAQ33

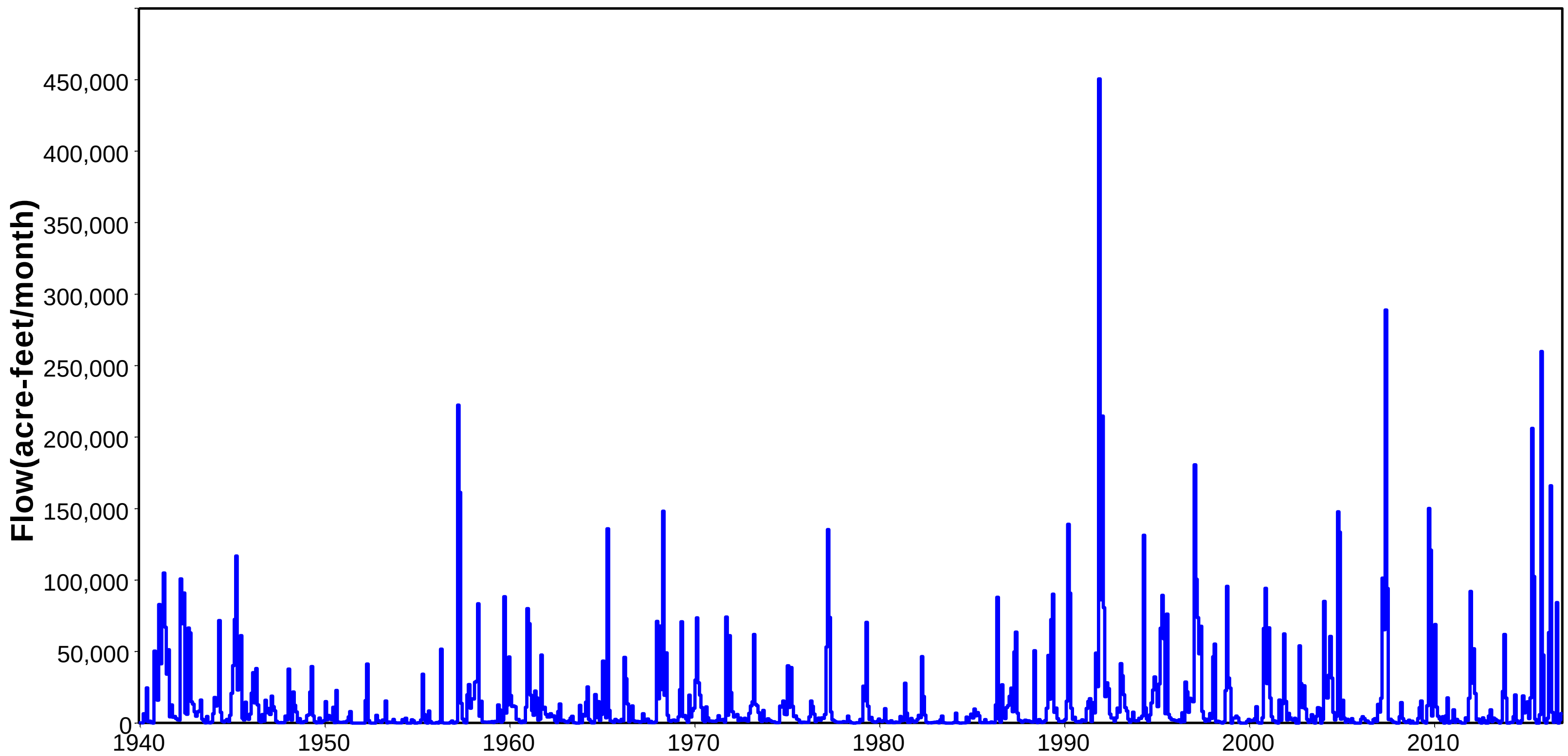


Figure B.1.14 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for North Bosque River at Clifton NBCL36

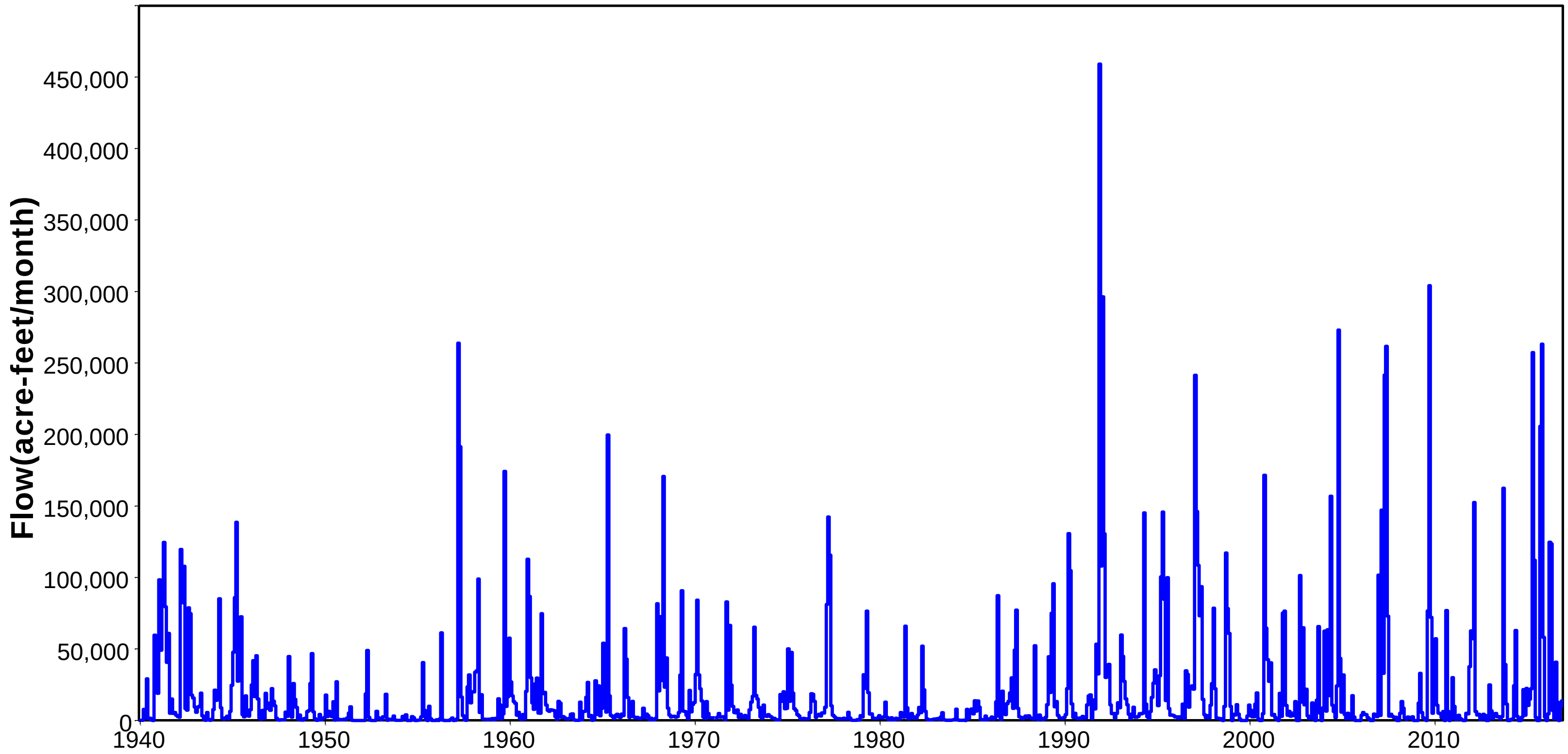


Figure B.1.15 Original 1940-1997 and Extended 1998-2011 Naturalized Flows for North Bosque River at Valley Mills NBVM37

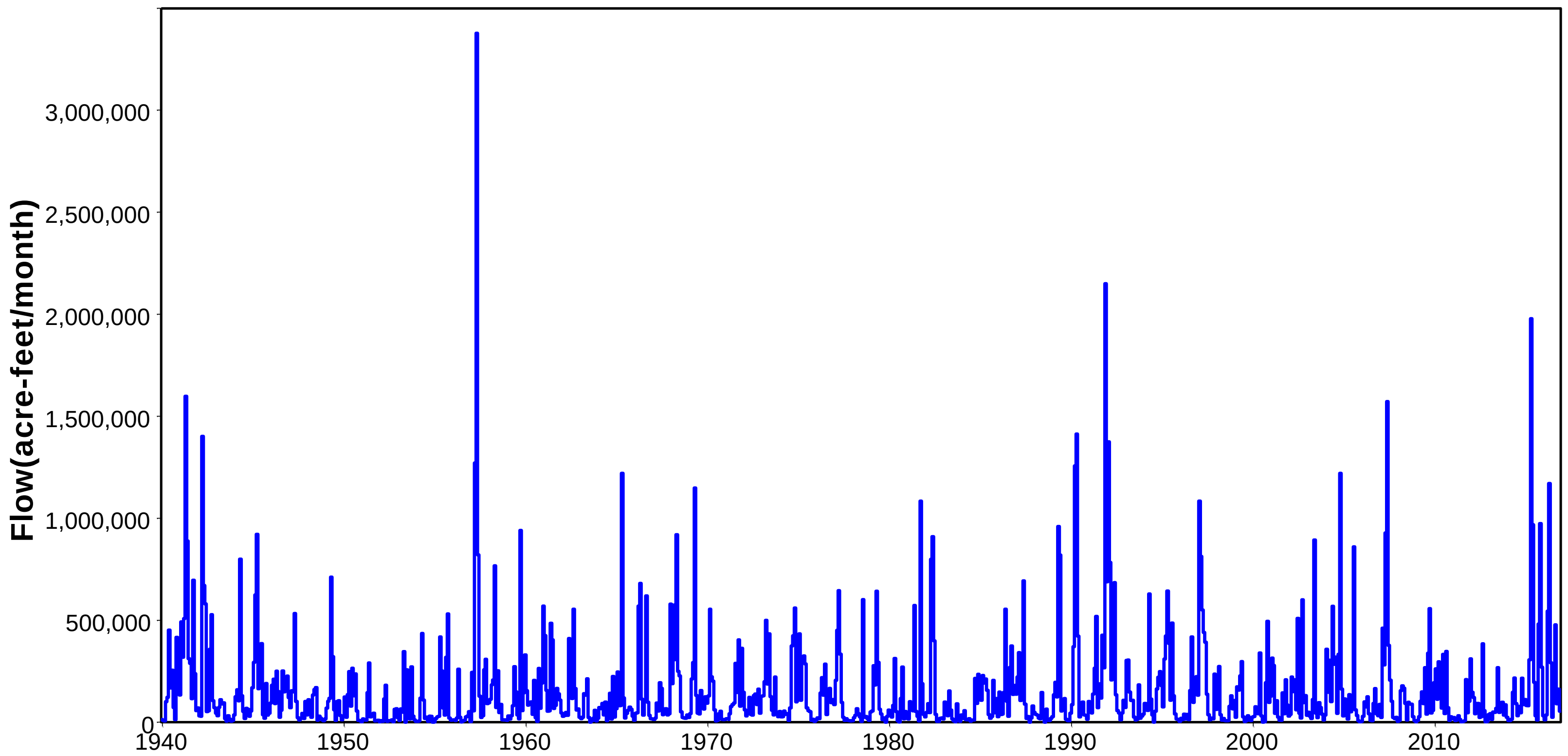


Figure B.1.16 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Waco BRWA41

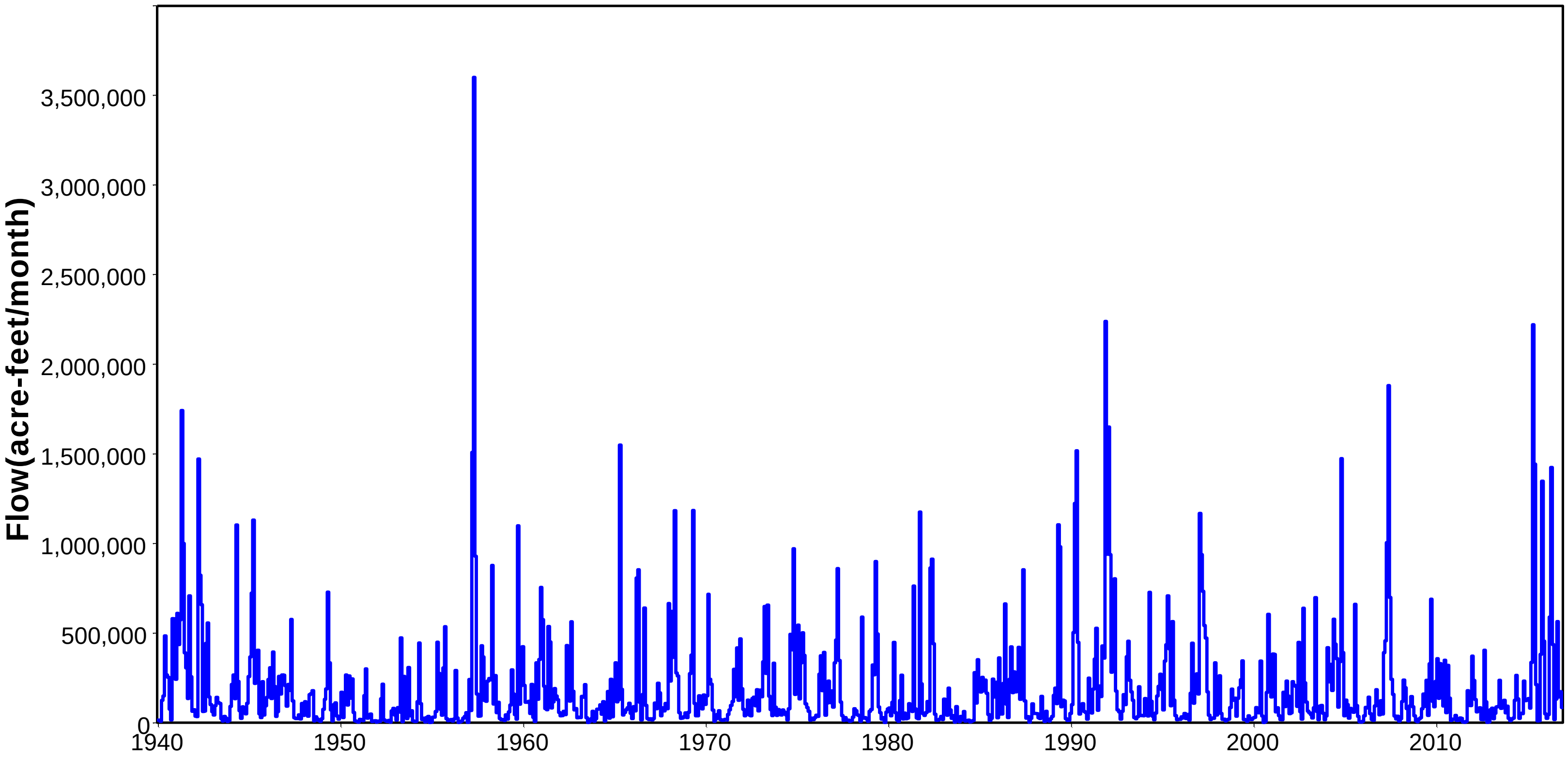


Figure B.1.17 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Highbank BRHB42

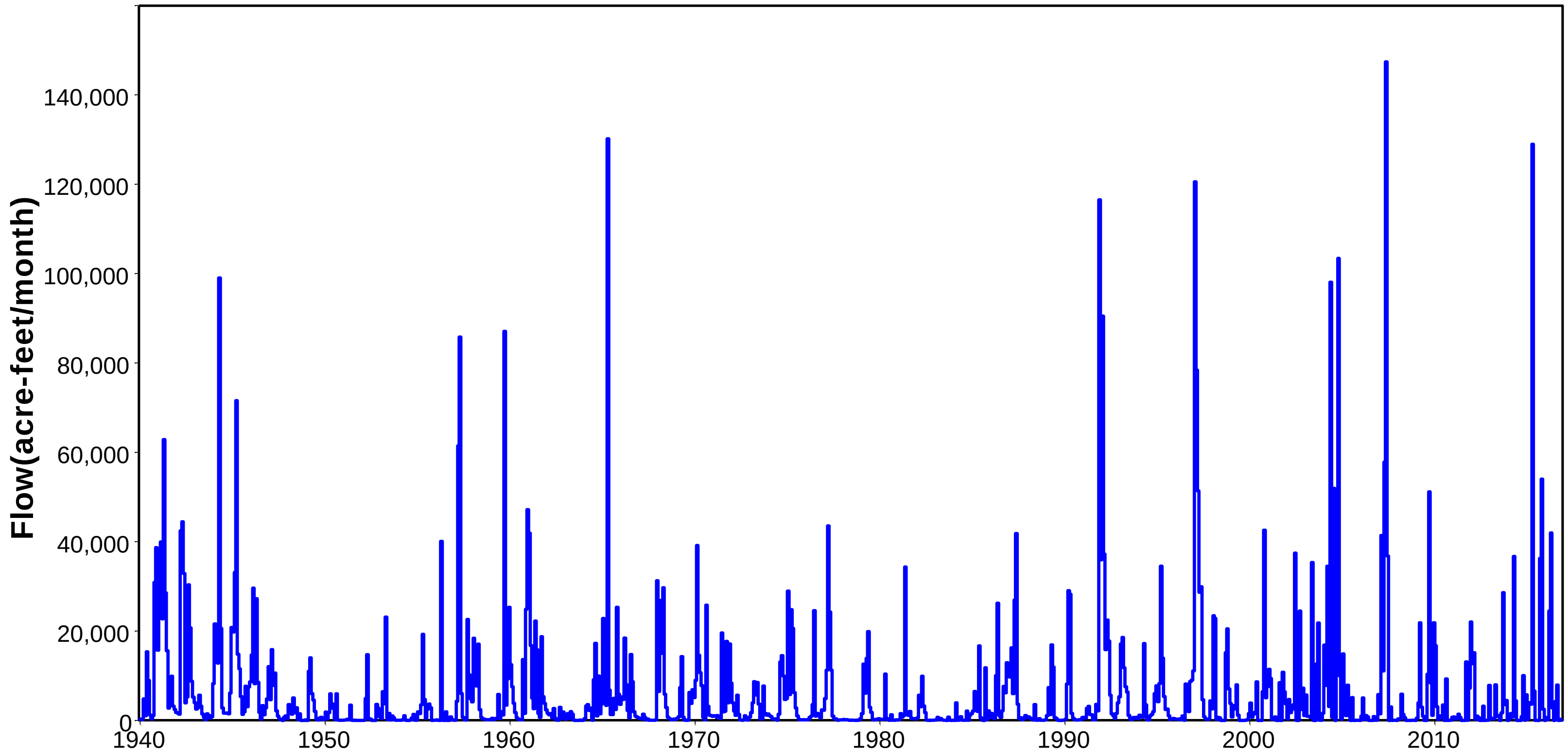


Figure B.1.18 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Cowhouse Creek at Pidcoke COPI48

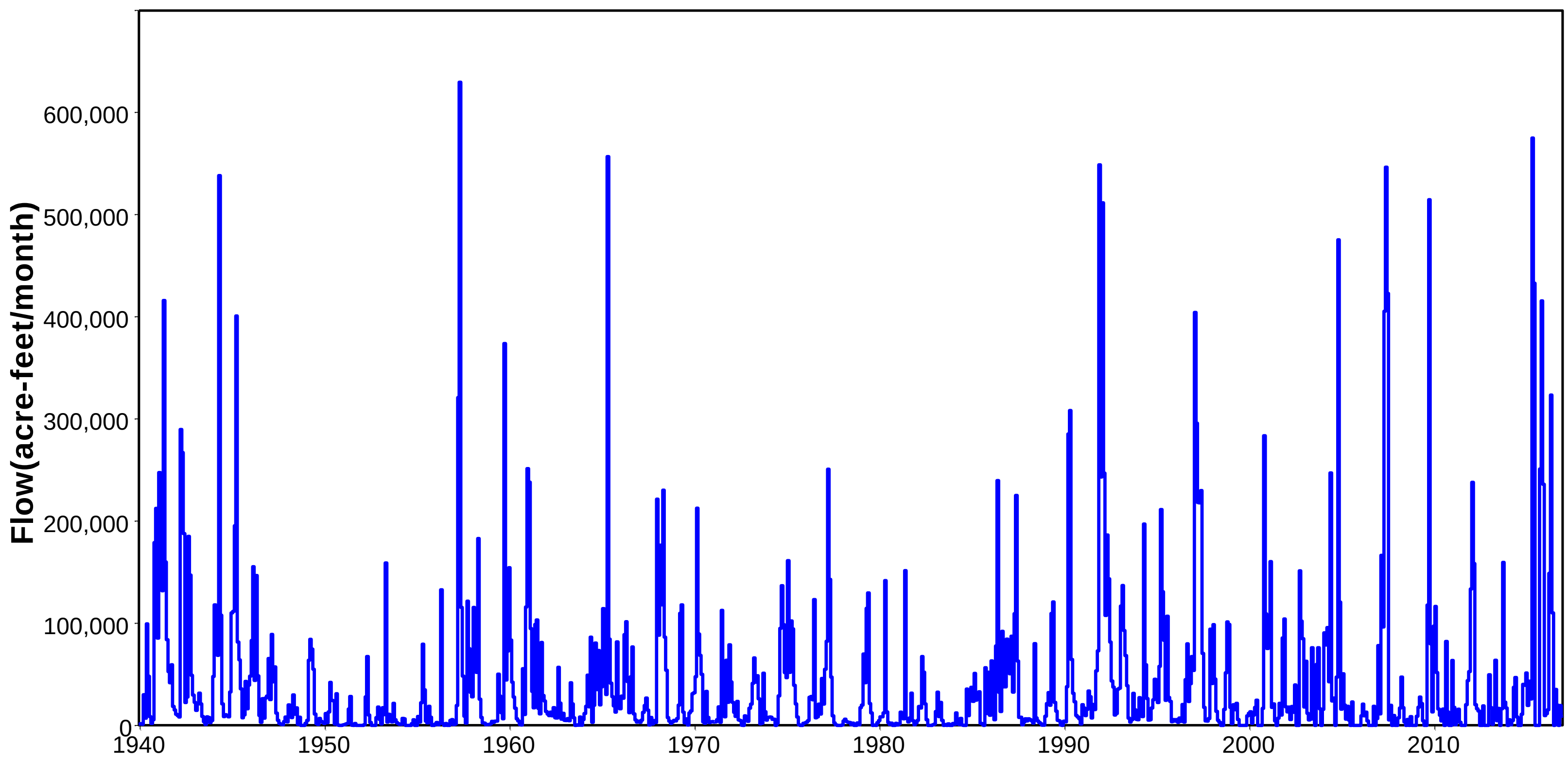


Figure B.1.19 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Leon River at Belton LEBE49

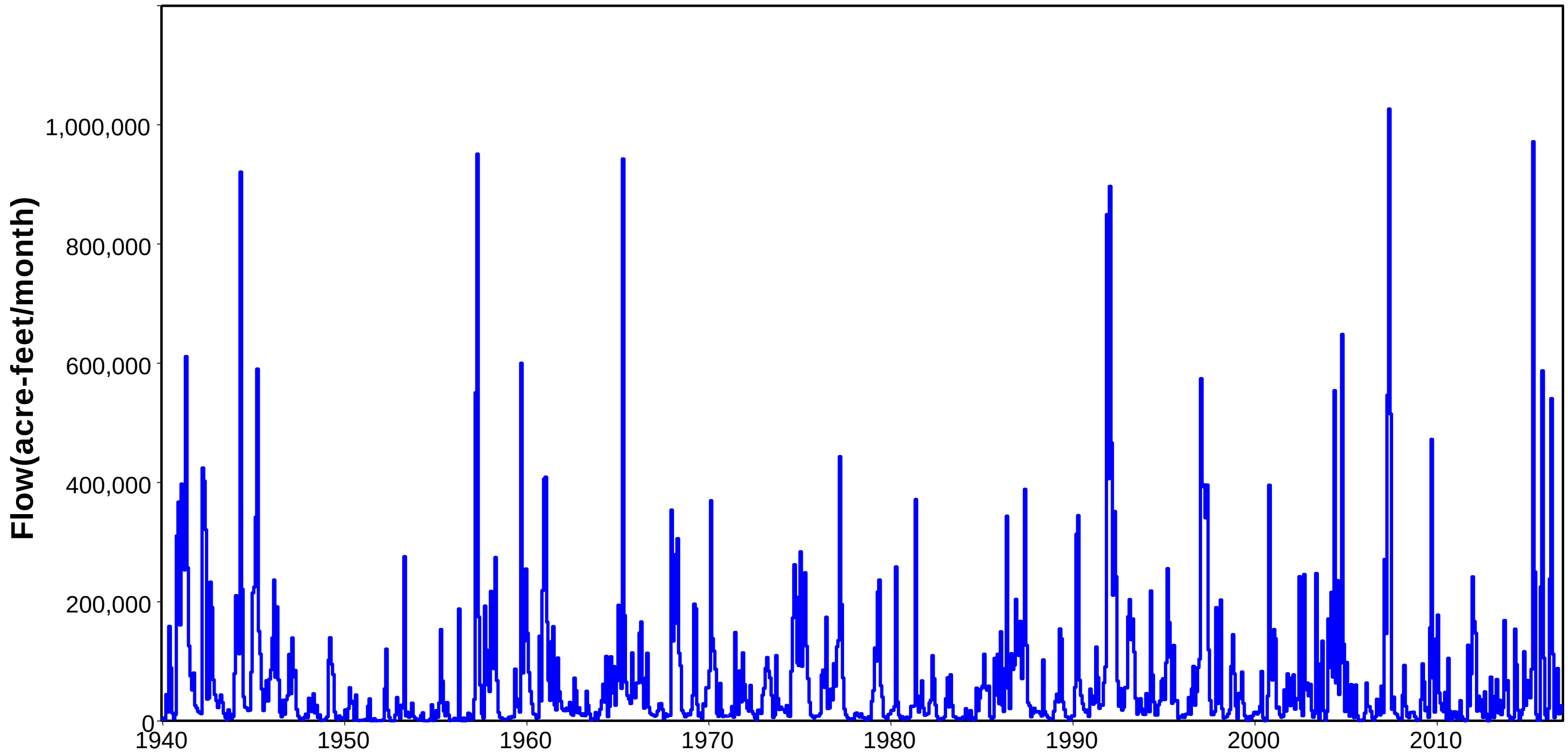


Figure B.1.20 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Little River at Little River LRLR53

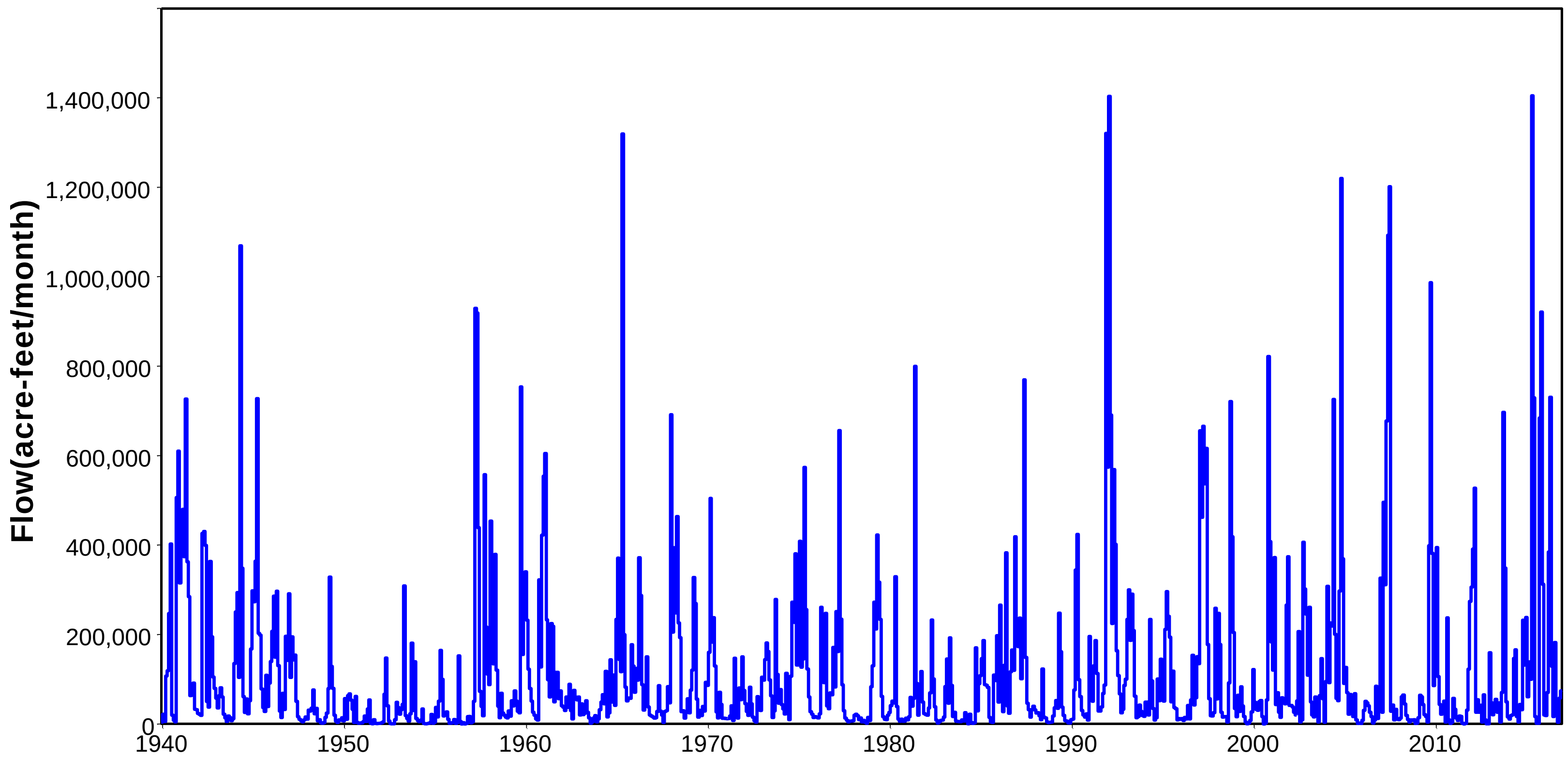


Figure B.1.21 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Little River at Cameron LRCA58

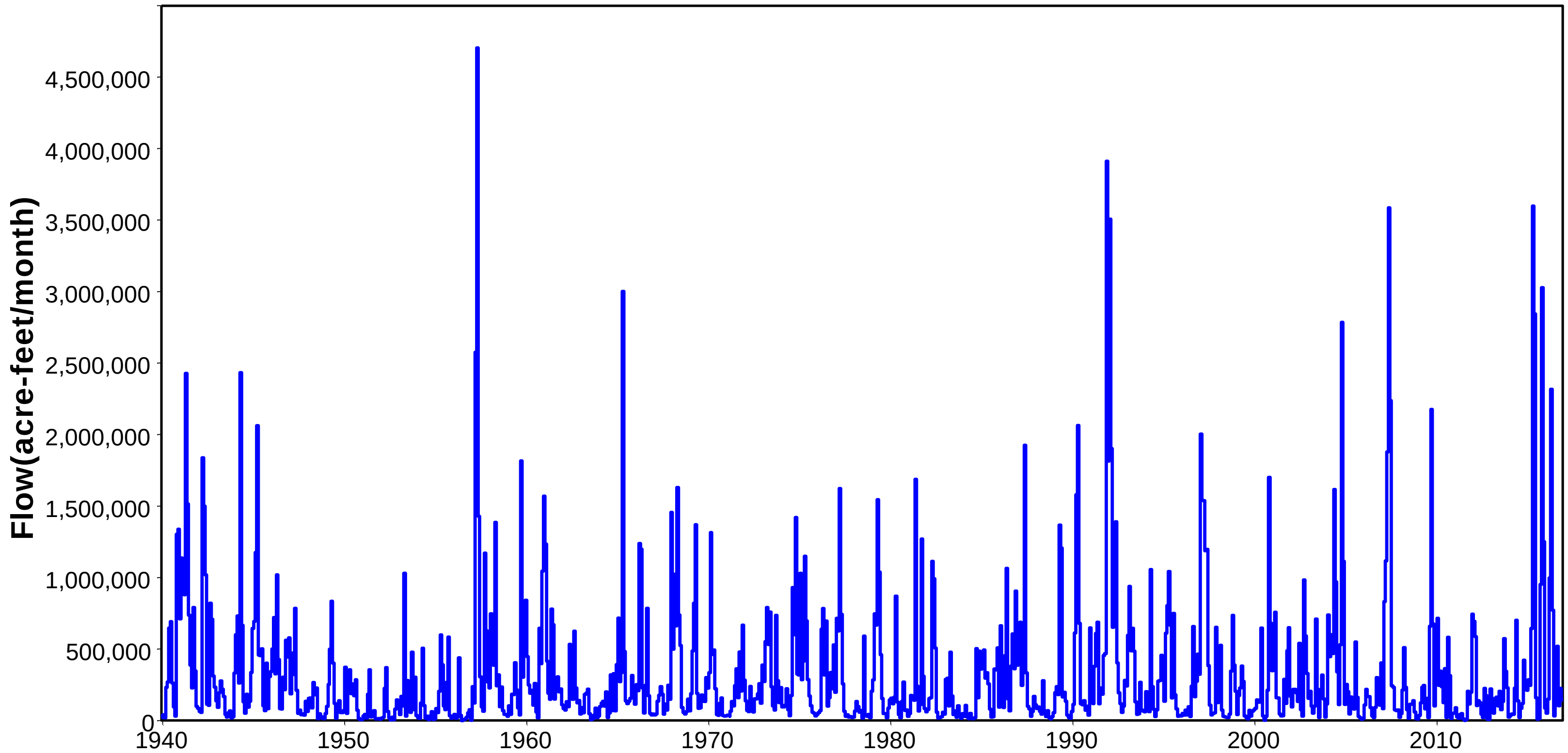


Figure B.1.22 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Bryan BRBR59

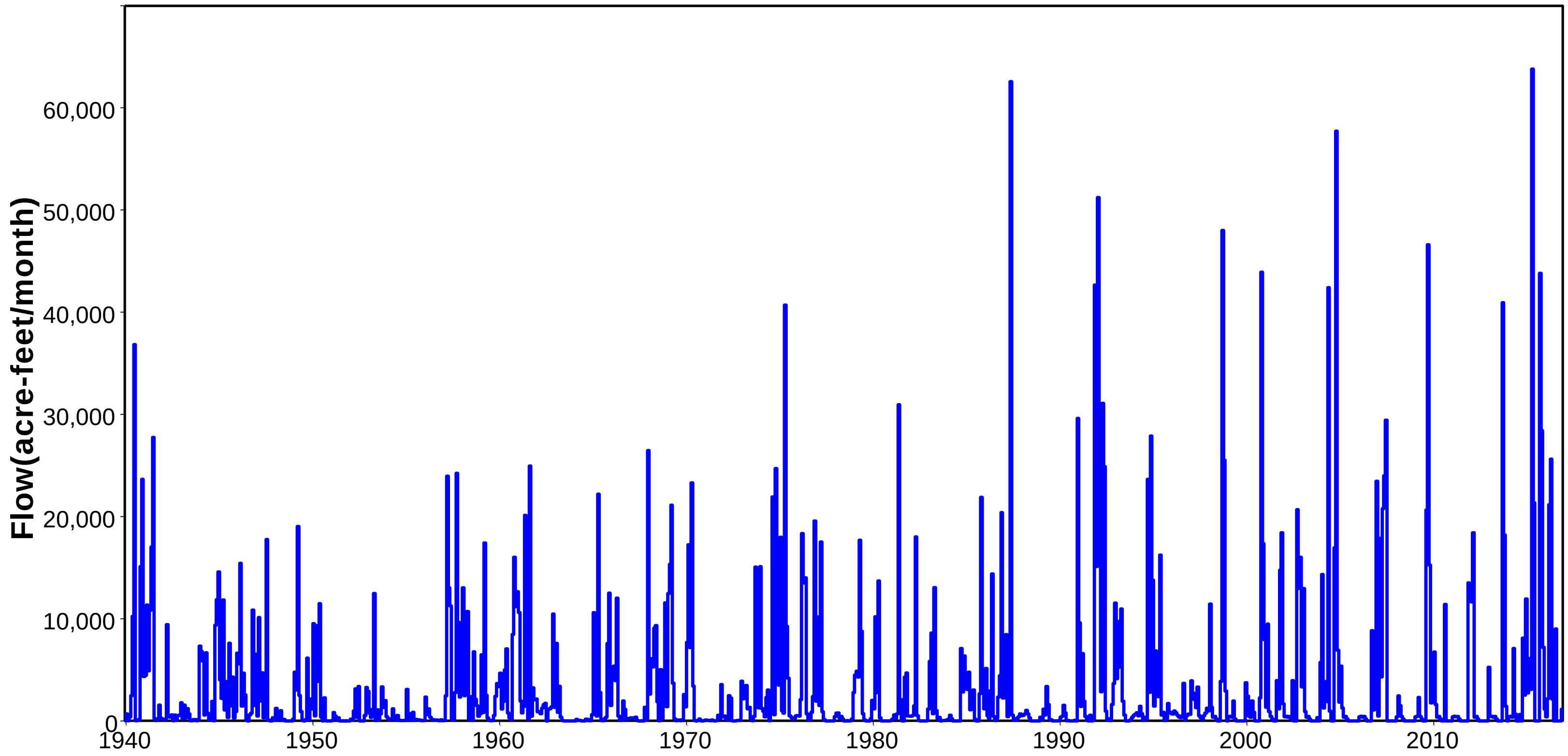


Figure B.1.23 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Middle Yegua Creek at Dime Box MYDB60

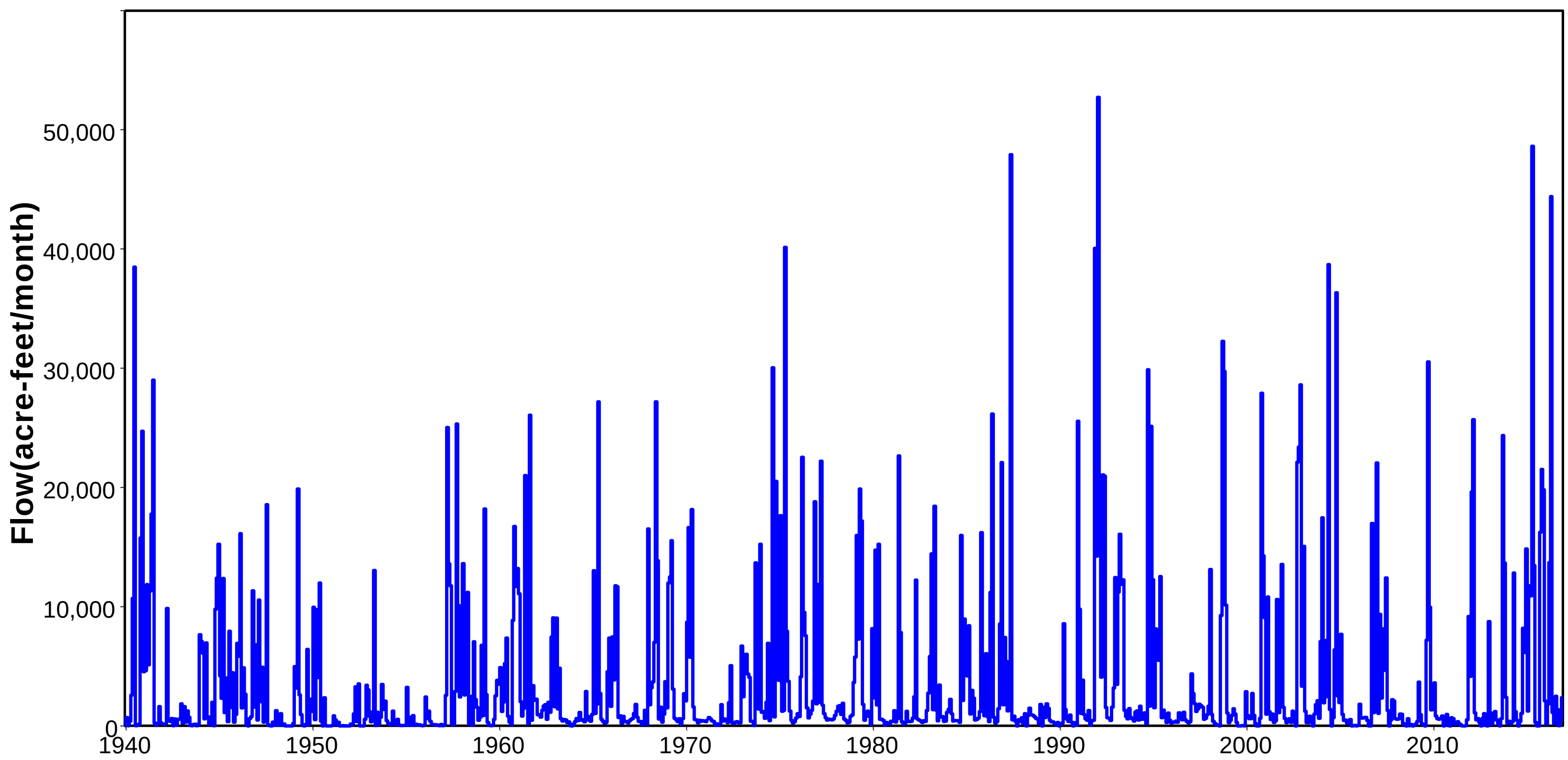


Figure B.1.24 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for East Yegua Creek at Dime Box EYDB61

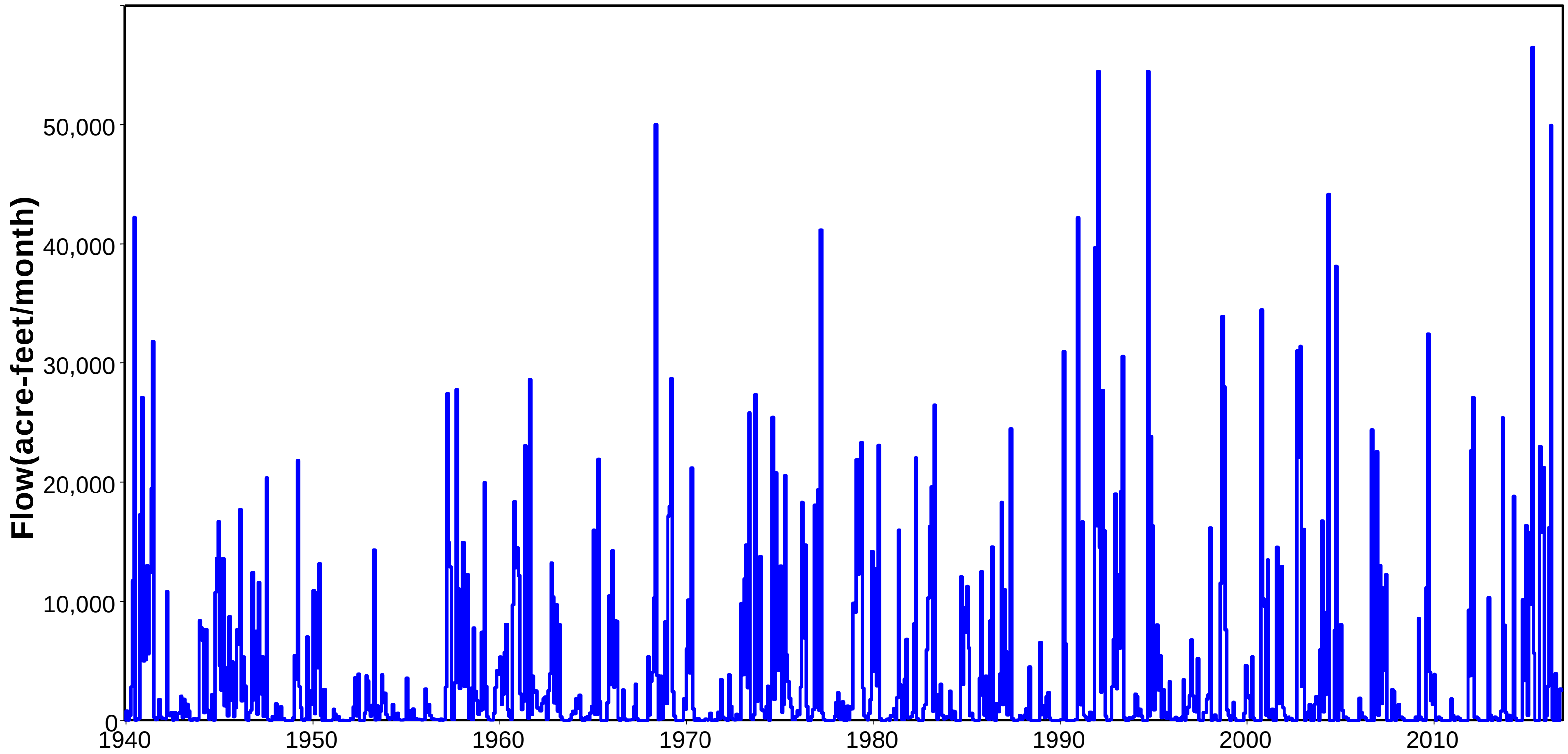


Figure B.1.25 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Davidson Creek at Lyons DCLY63

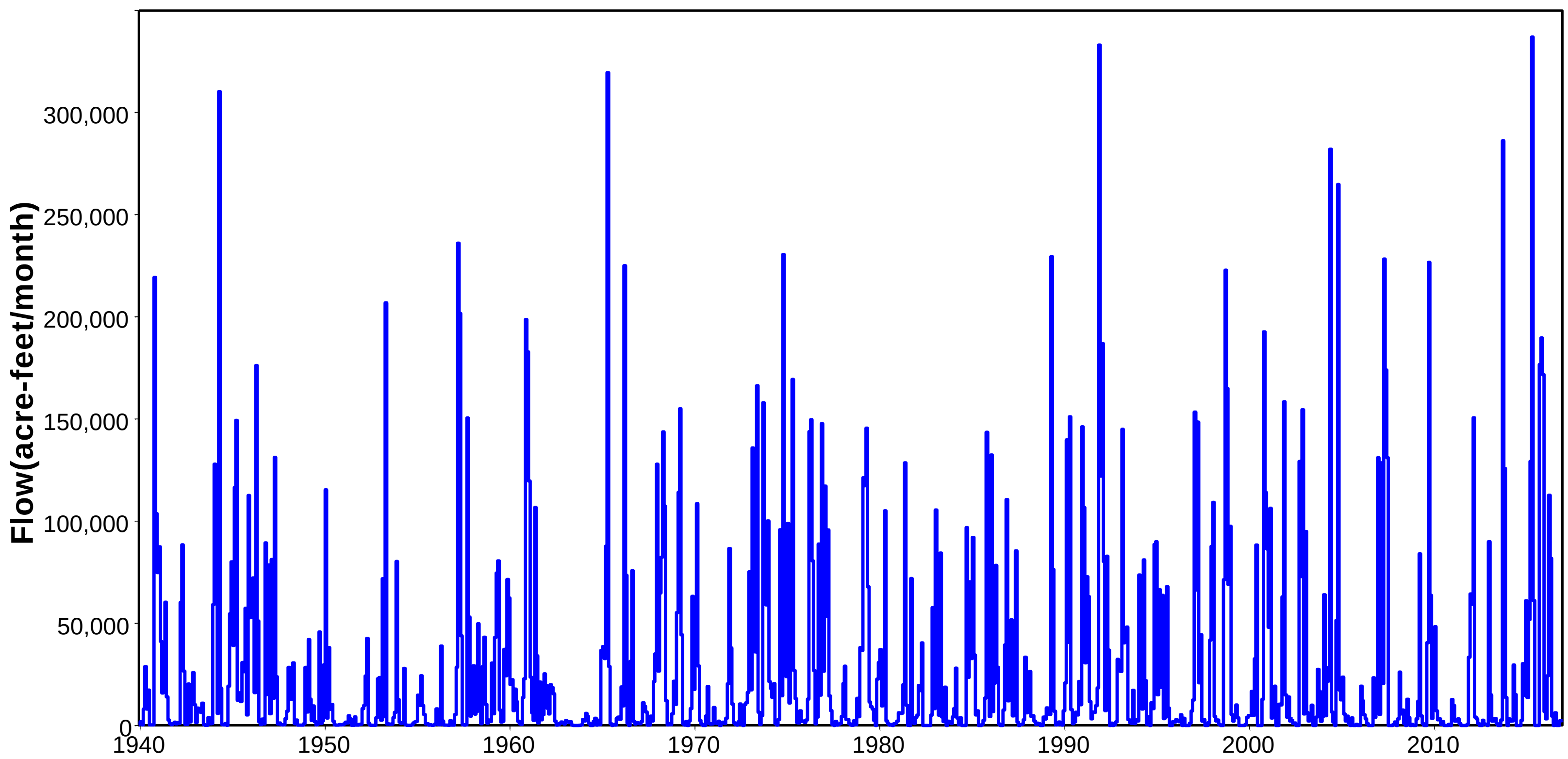


Figure B.1.26 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Navasota River at Easterly NAEA66

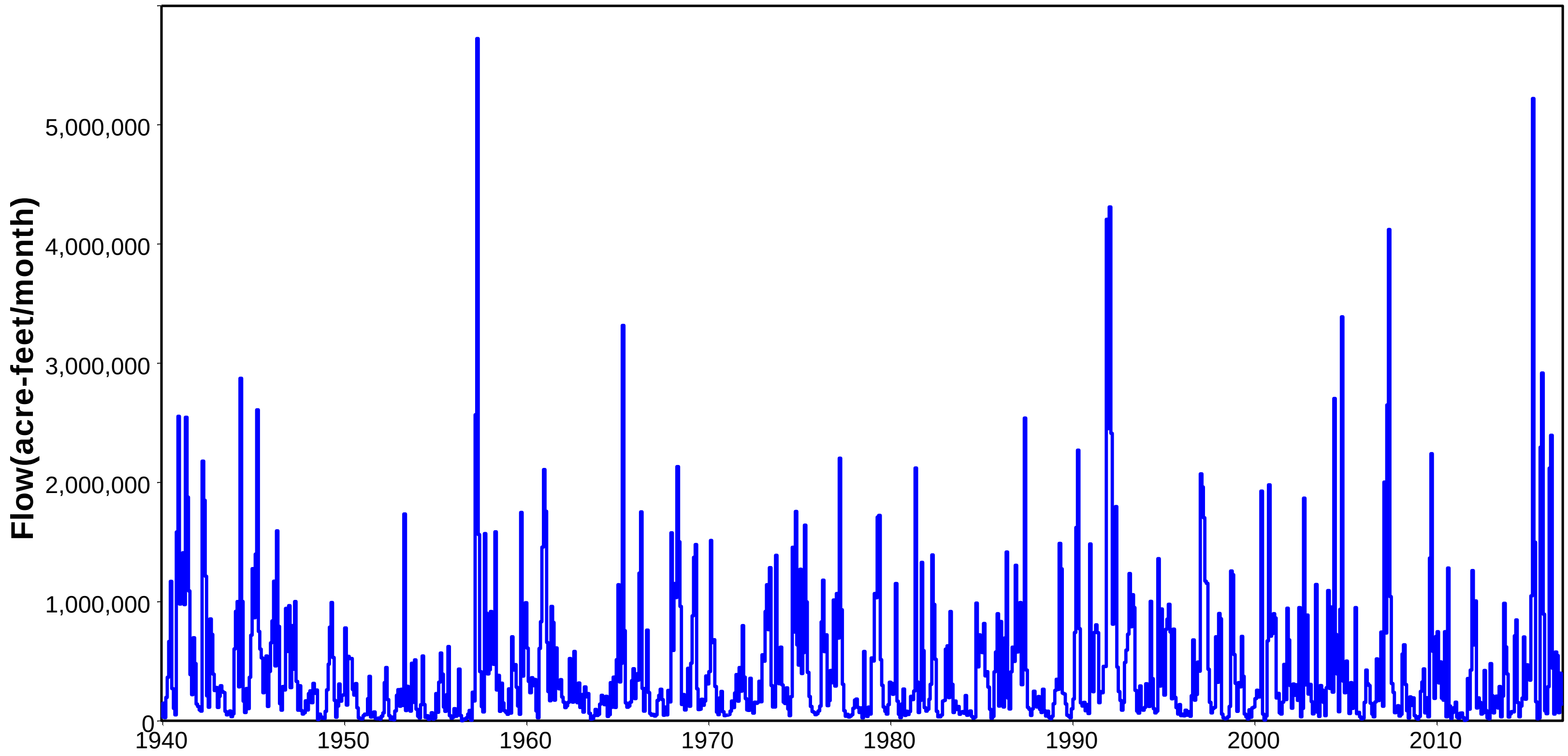


Figure B.1.27 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Hempstead BRHE68

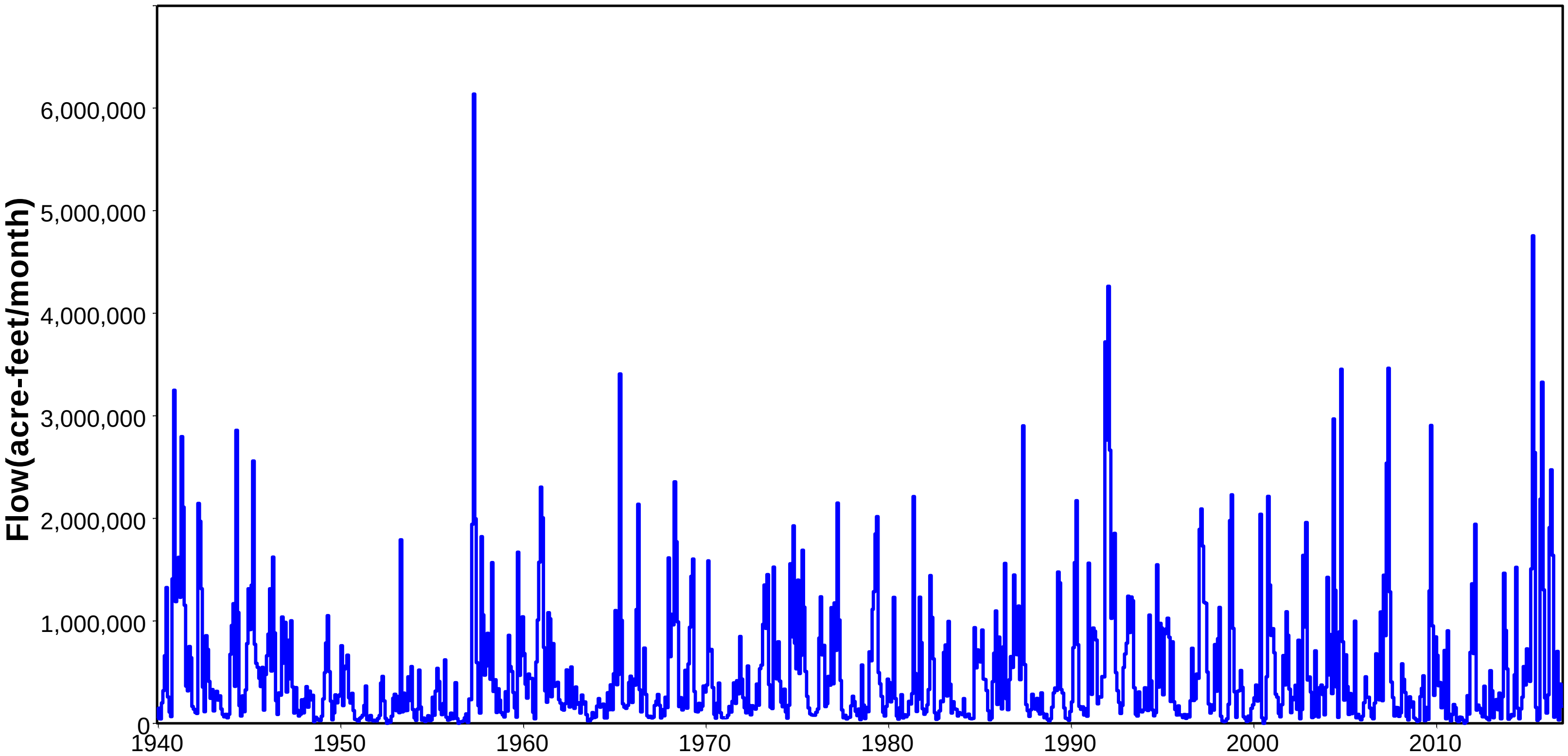


Figure B.1.28 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Richmond BRRI70

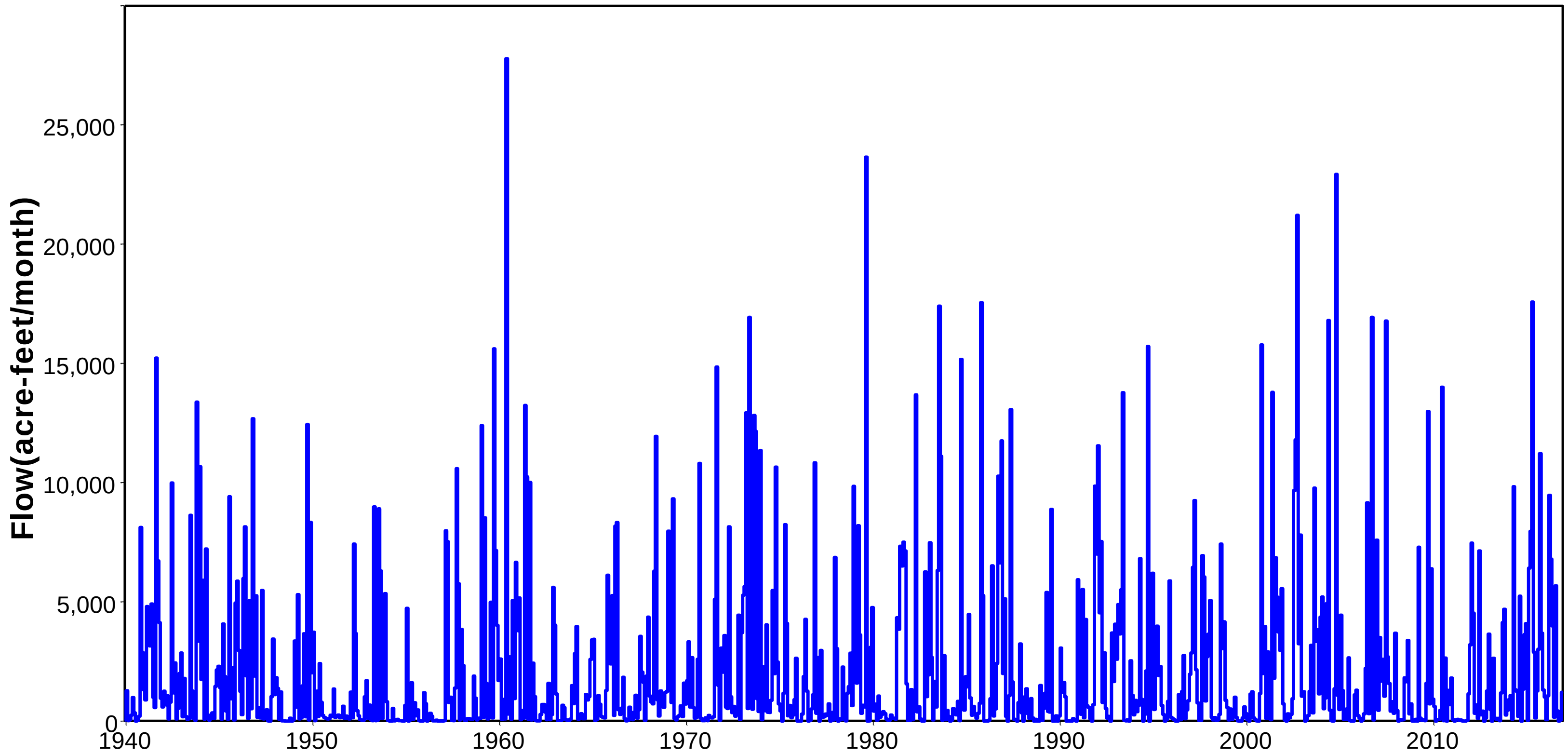


Figure B.1.29 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Big Creek at Needville BGNE71

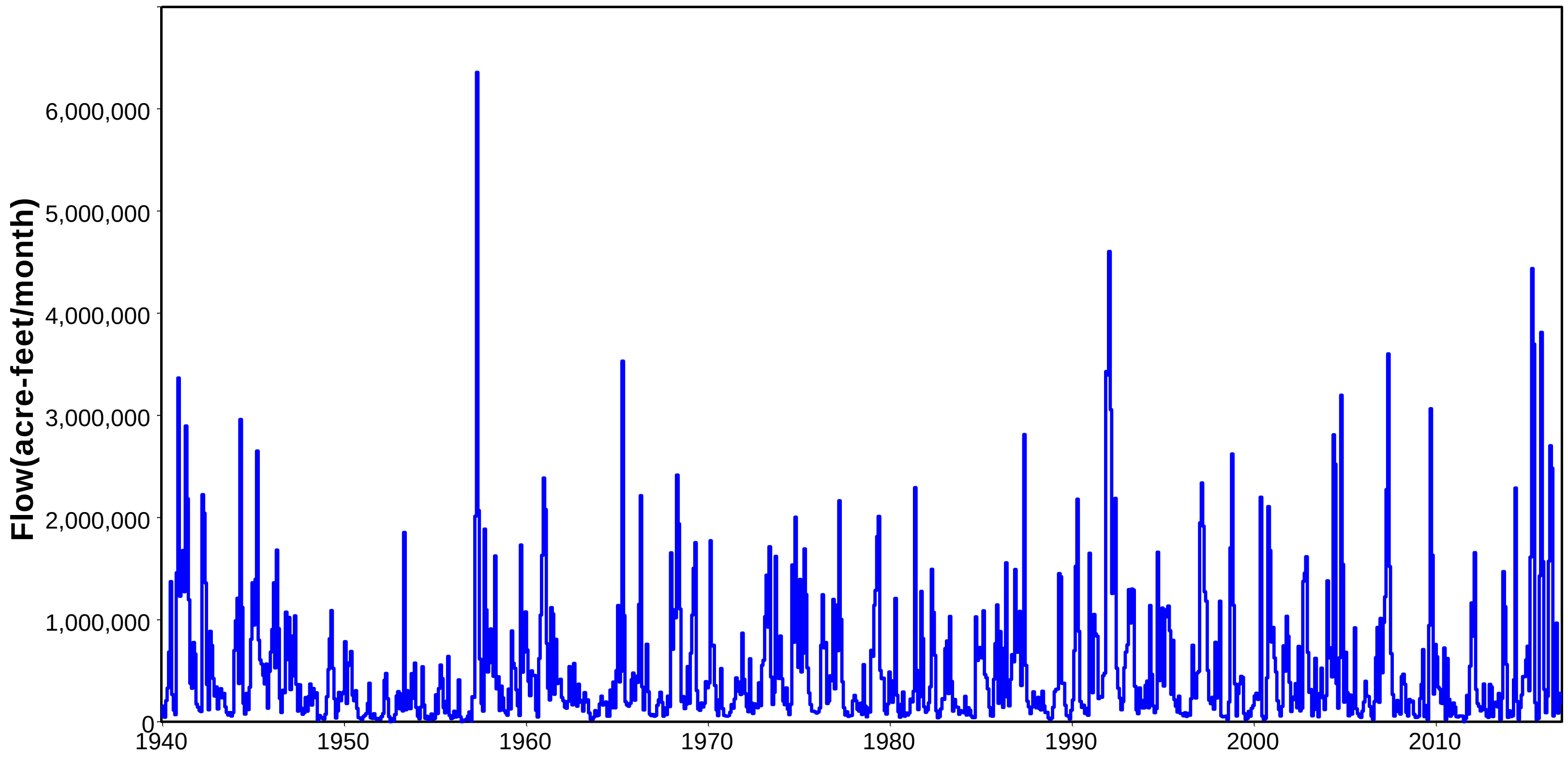


Figure B.1.30 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Rosharon BRRO72

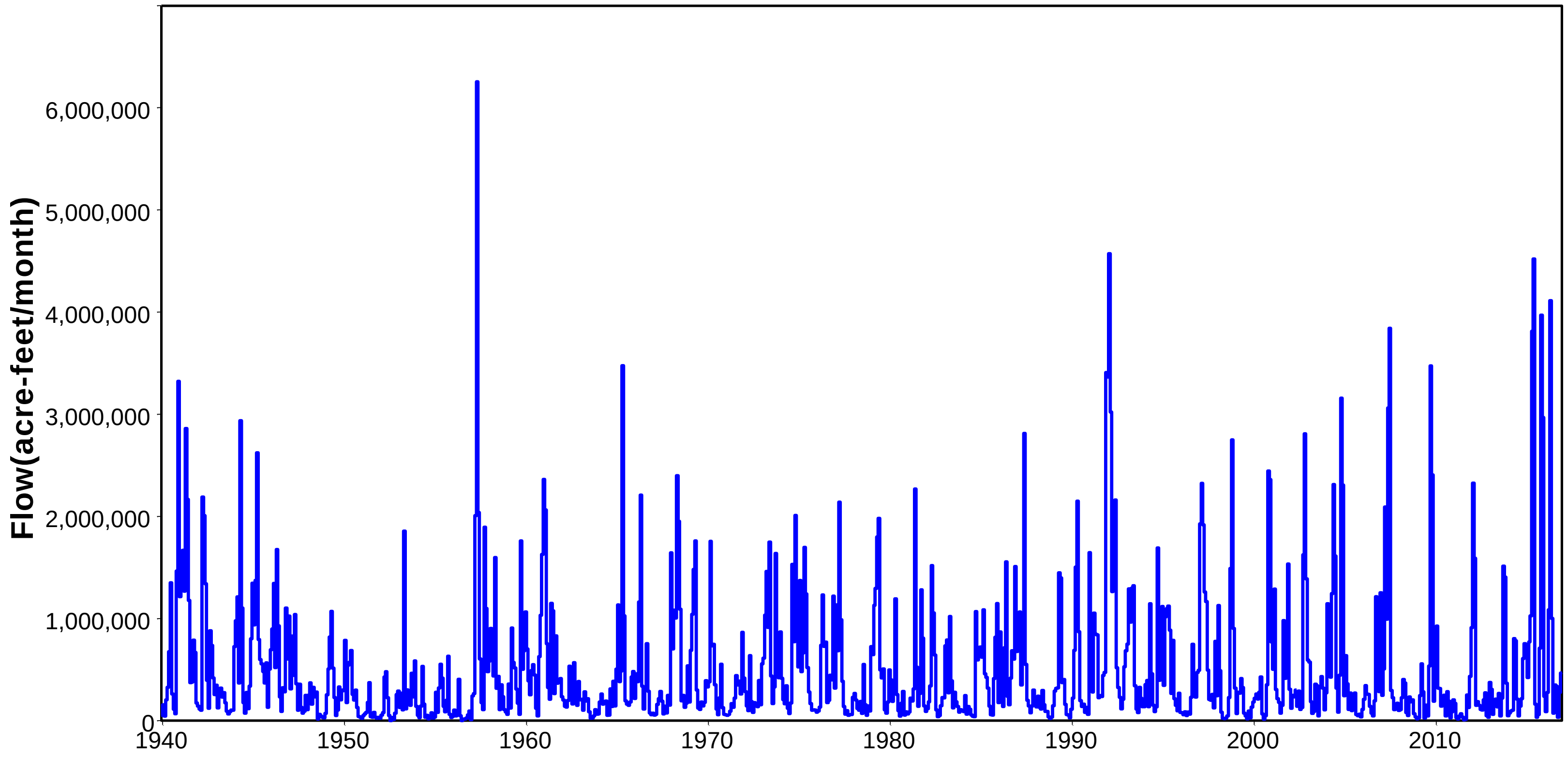


Figure B.1.31 Original 1940-1997 and Extended 1998-2016 Naturalized Flows for Brazos River at Gulf of Mexico BRGM73

B.2 1940-1997 Original Known and Final Computed Flows

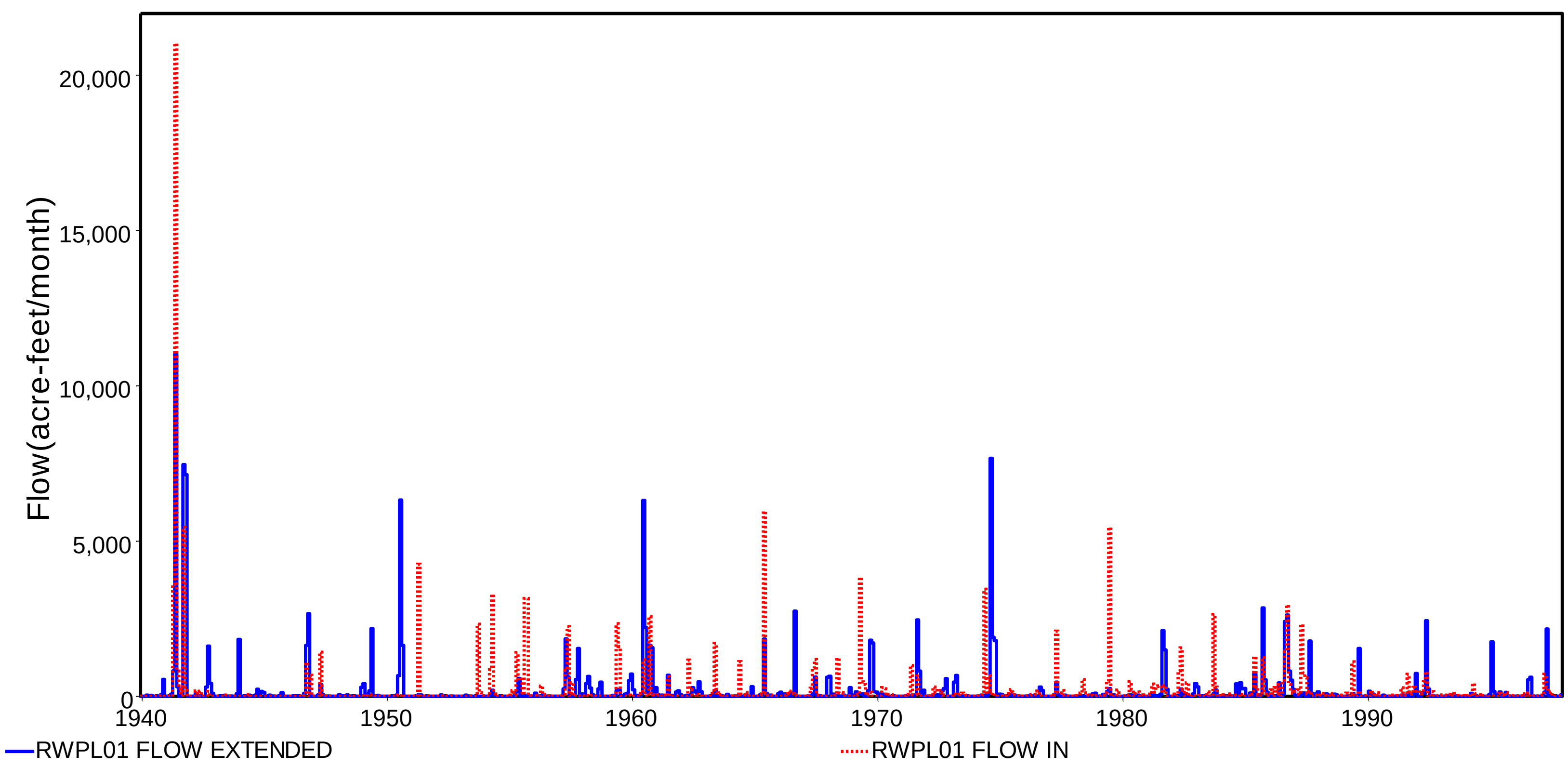


Figure B.2.1 Known and Final Computed Flows for Running Water Draw at Plainview RWPL01

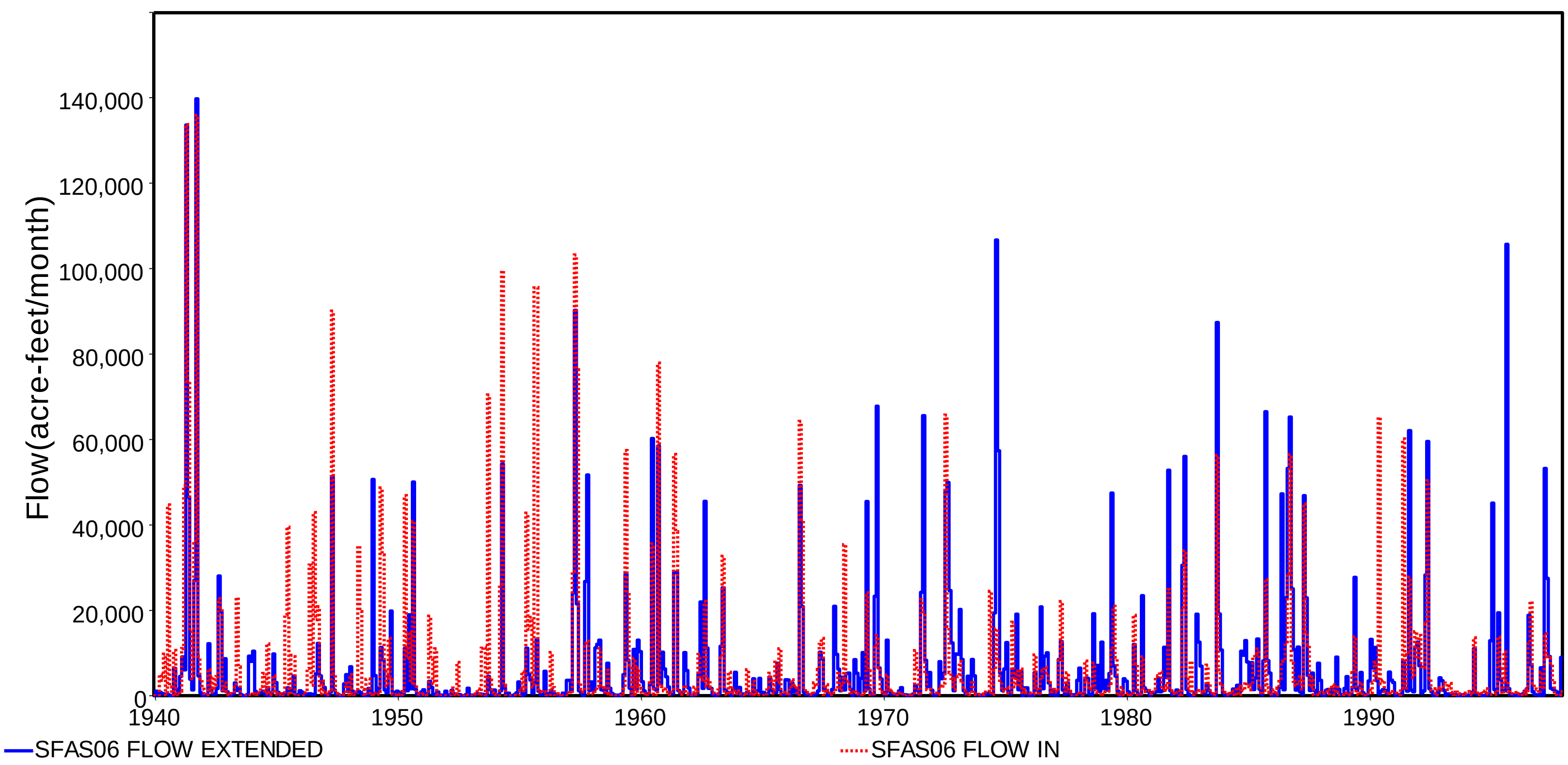


Figure B.2.2 Known and Final Computed Flows for Salt Fork Brazos River at Aspermont SFAS06

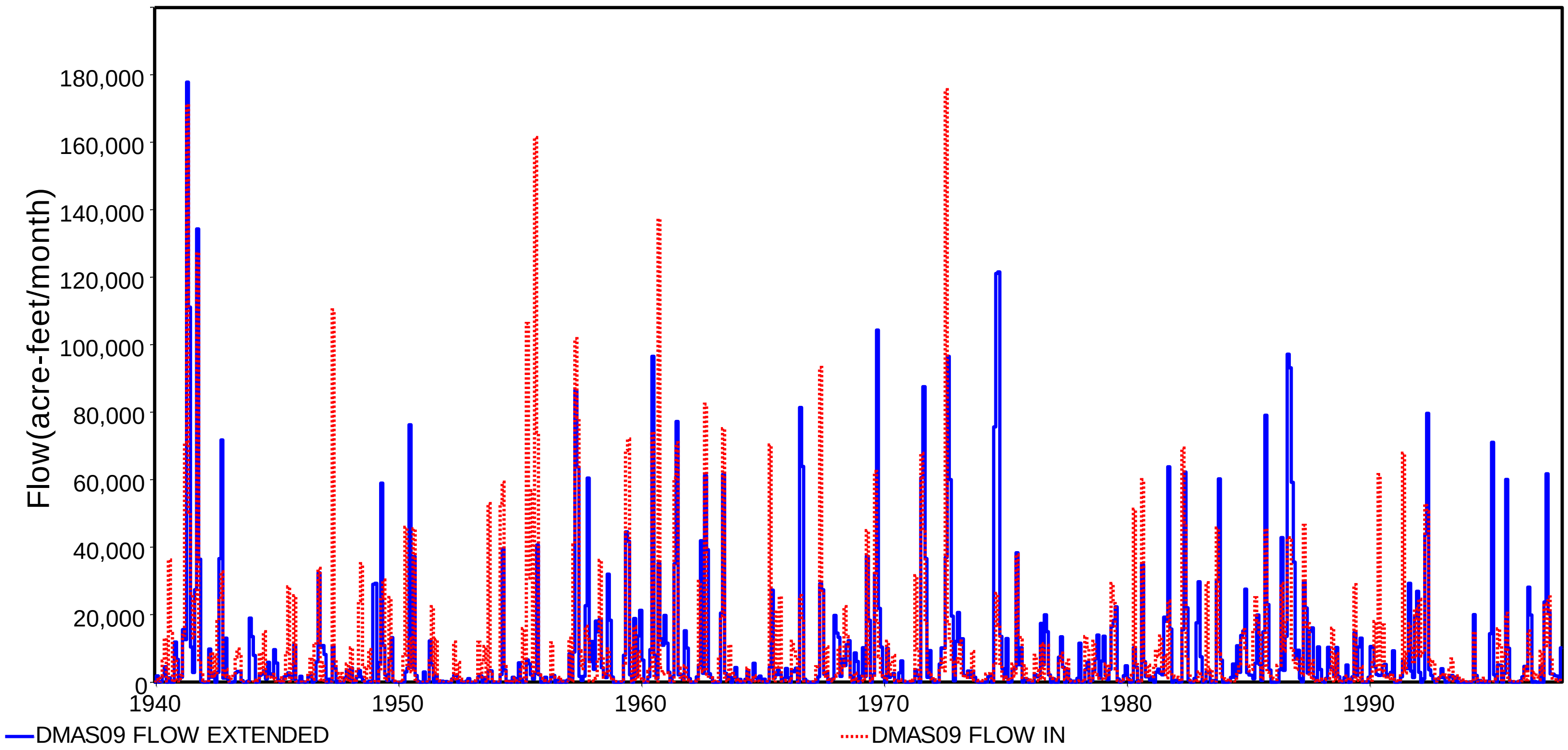


Figure B.2.3 Known and Final Computed Flows for Double Mountain Fork at Aspermont DMAS09

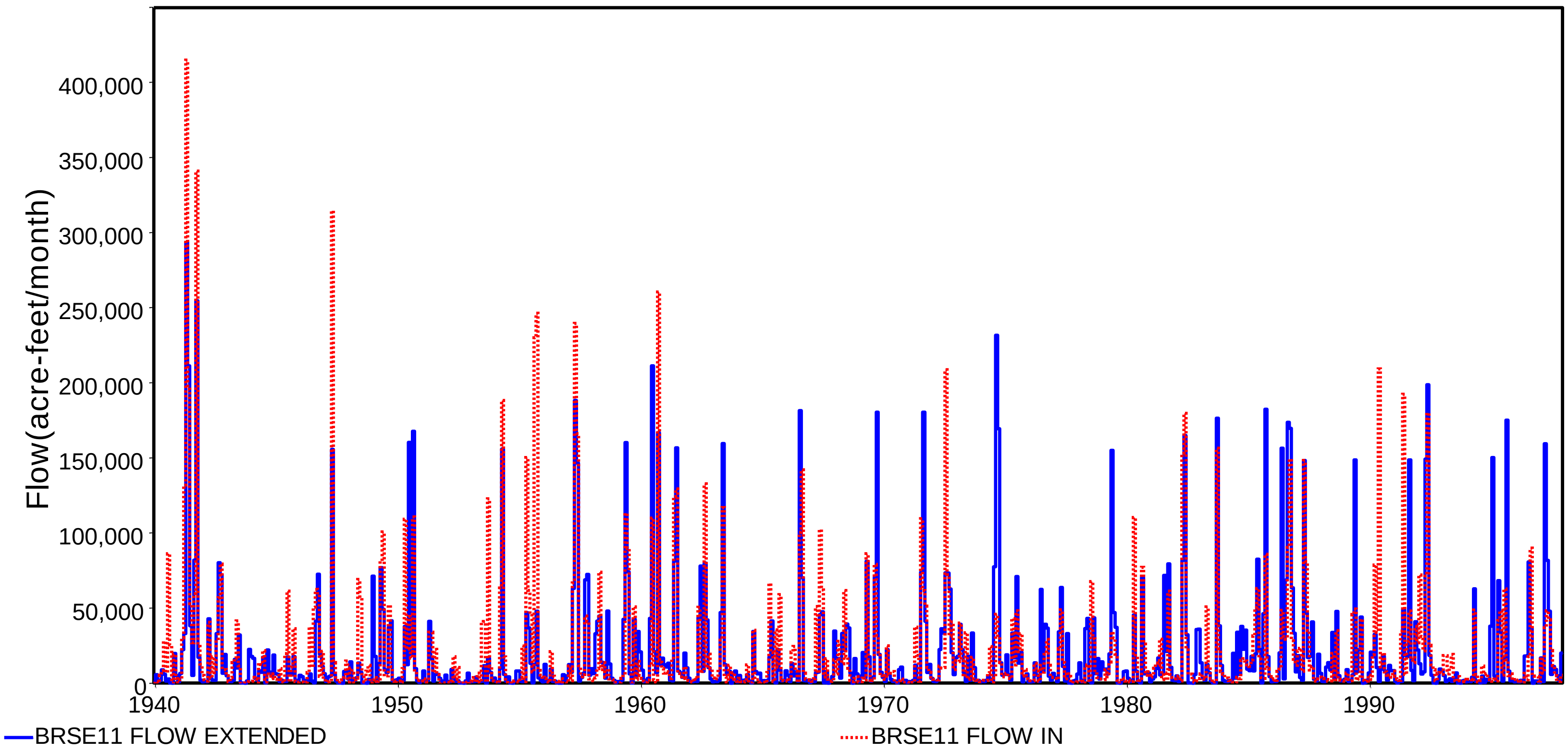


Figure B.2.4 Known and Final Computed Flows for Brazos River at Seymour BRSE11

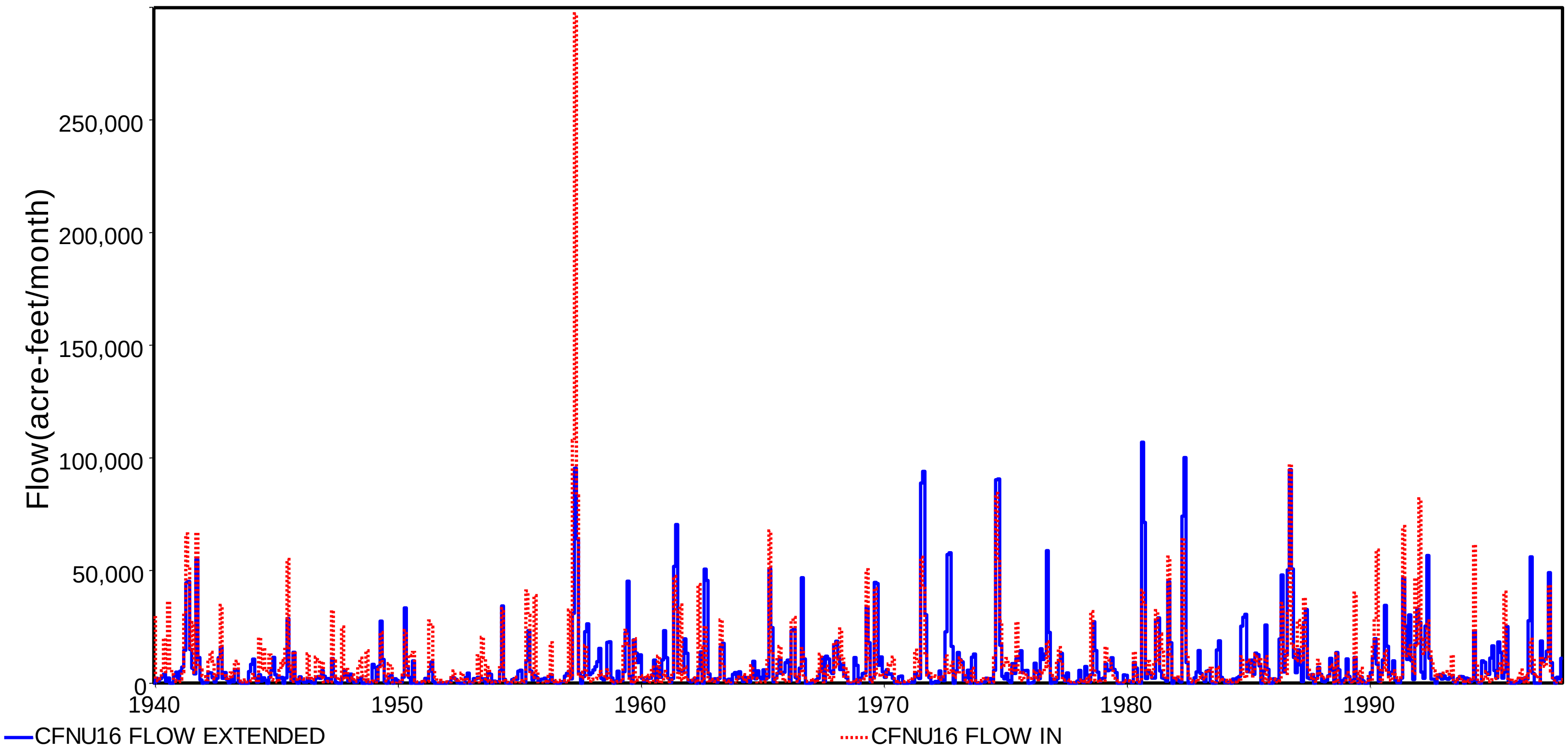


Figure B.2.5 Known and Final Computed Flows for Clear Fork Brazos at Nugent CFNU16

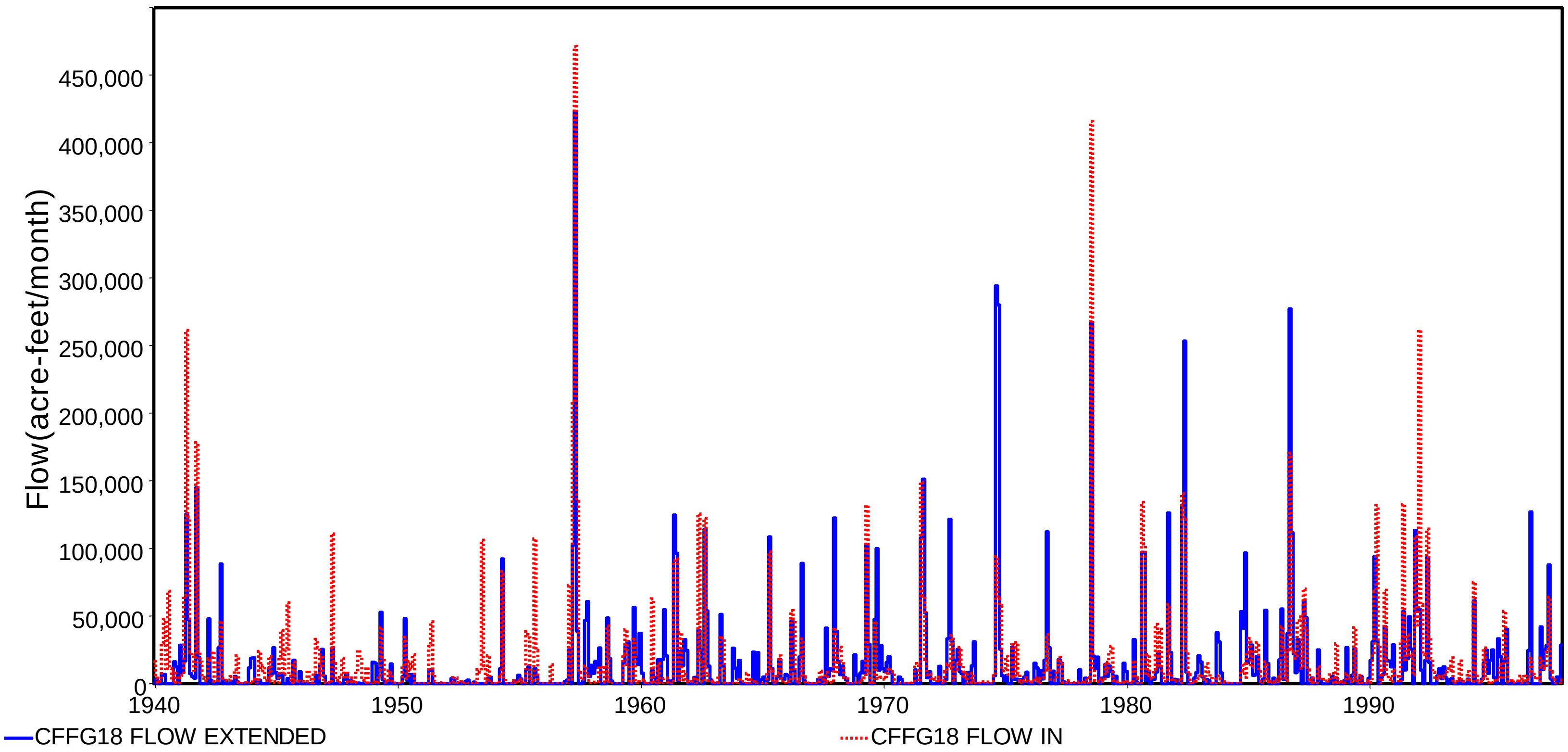


Figure B.2.6 Known and Final Computed Flows for Clear Fork Brazos at Fort Griffin CFFG18

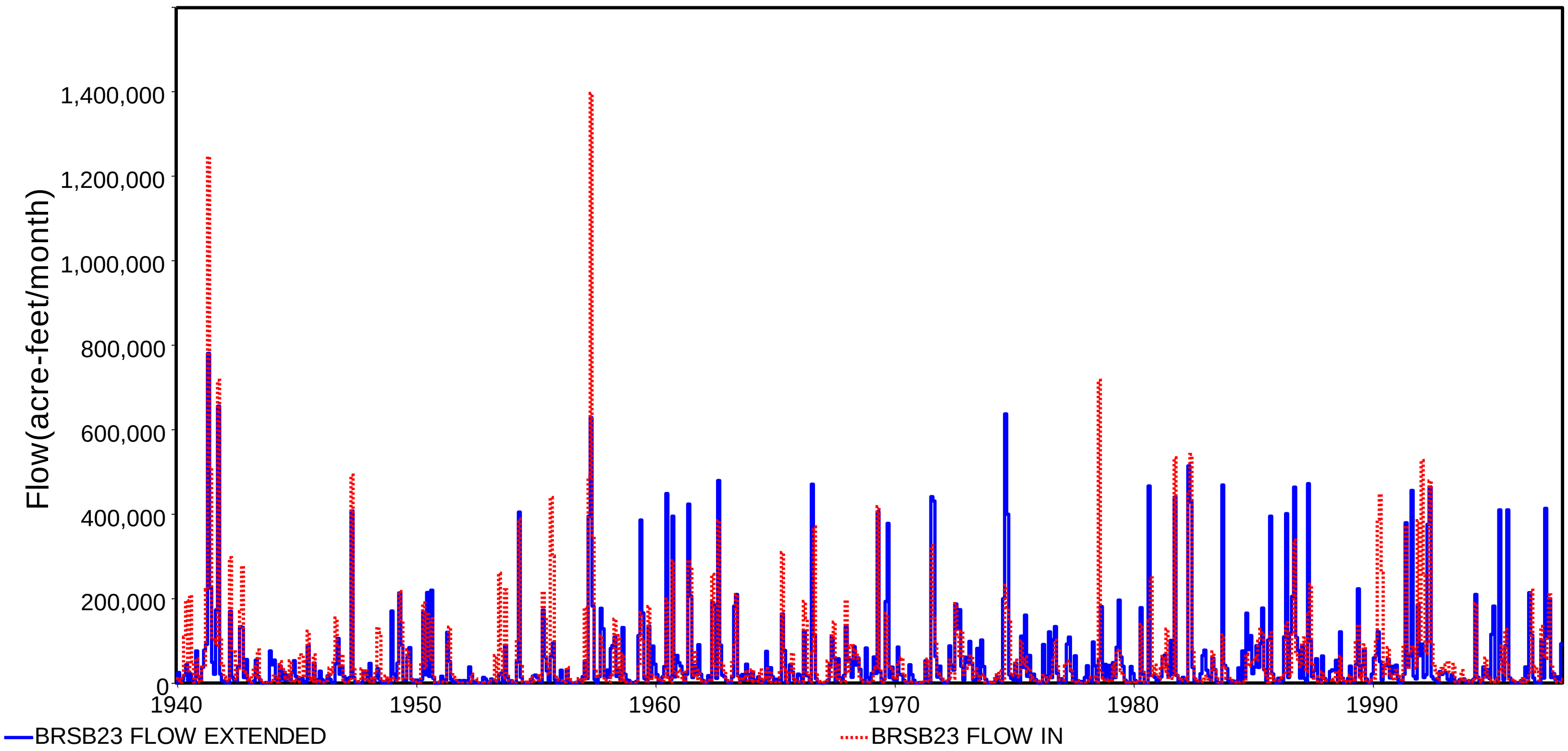


Figure B.2.7 Known and Final Computed Flows for Brazos River at South Bend BRSB23

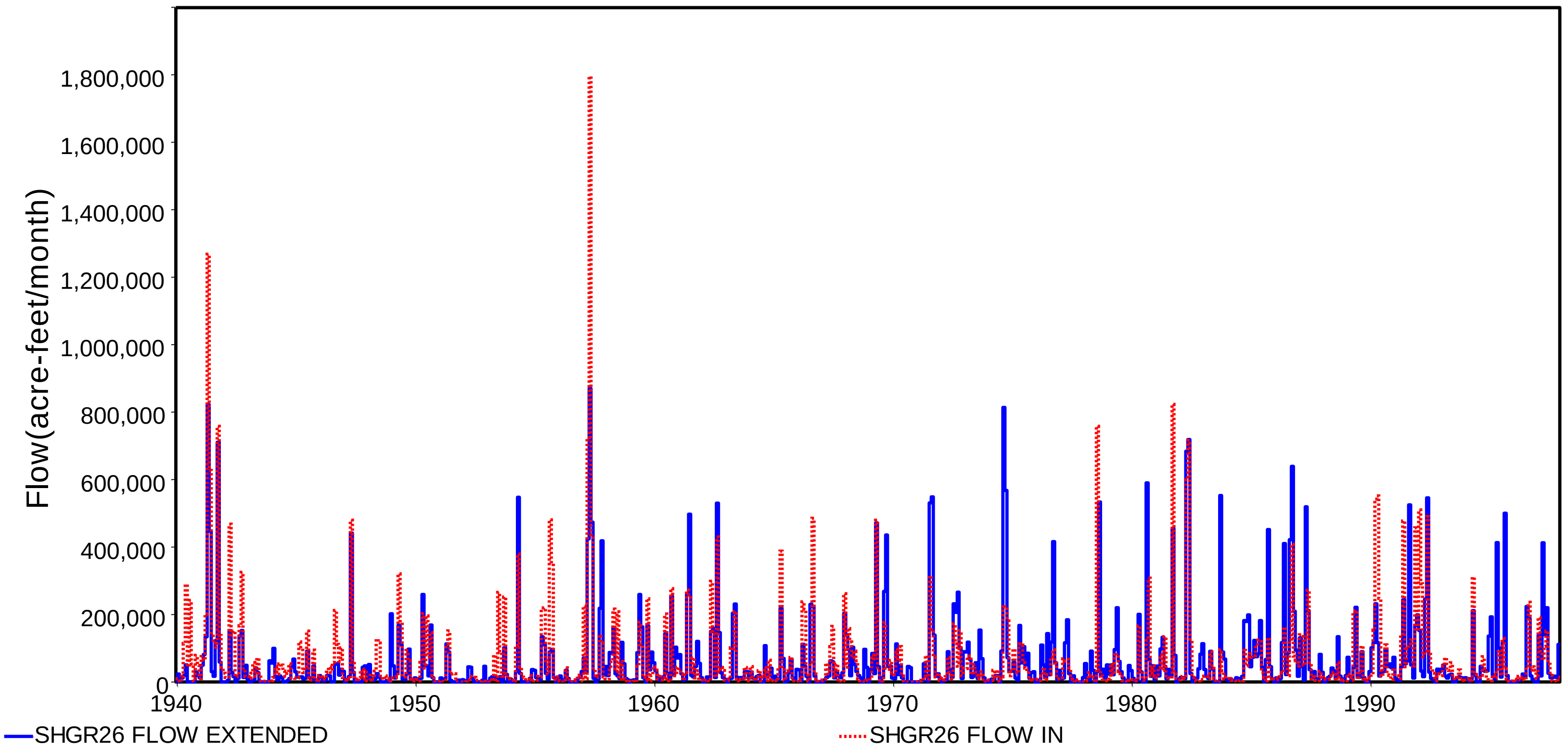


Figure B.2.8 Known and Final Computed Flows for Brazos River at Graford SHGR26

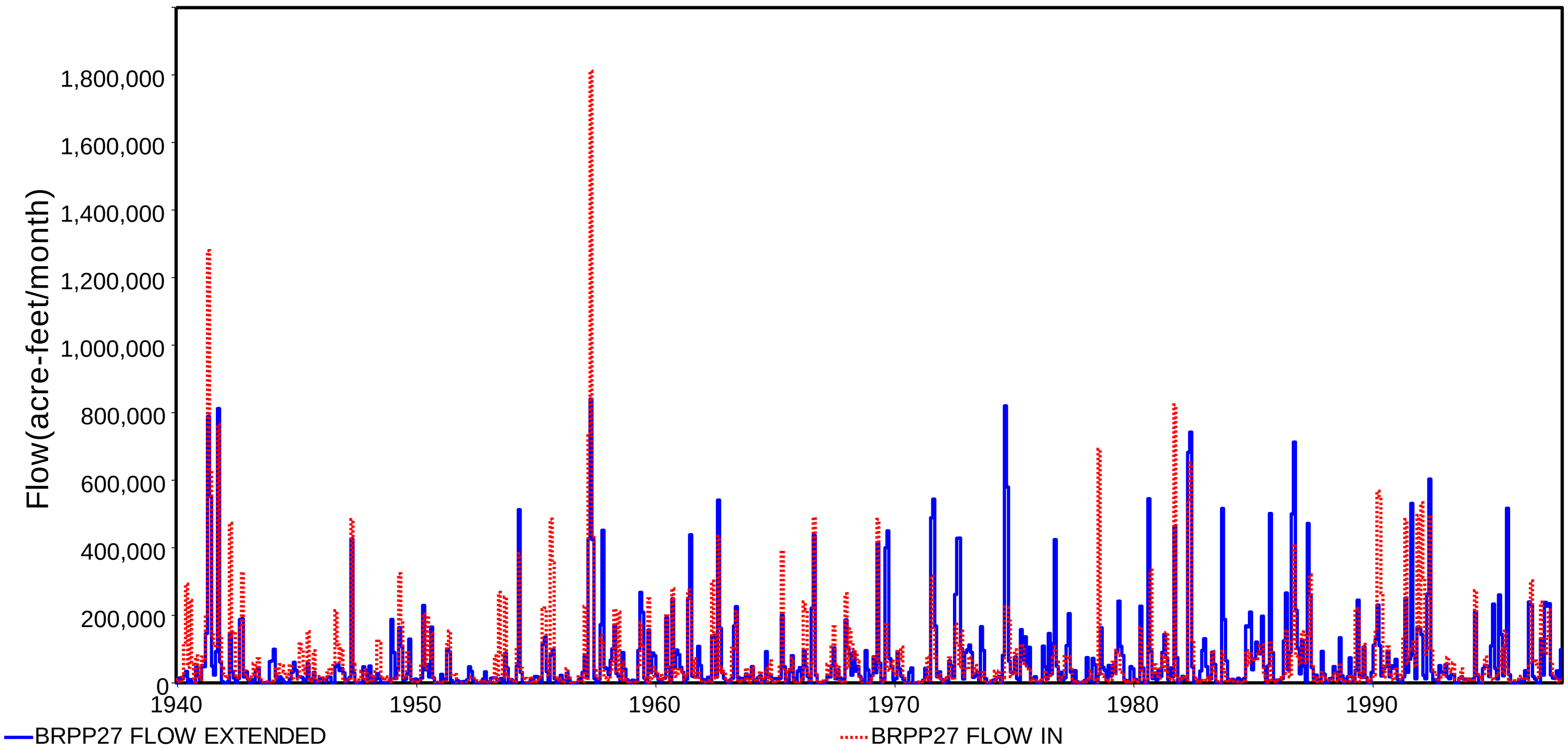


Figure B.2.9 Known and Final Computed Flows for Brazos River at Palo Pinto BRPP27

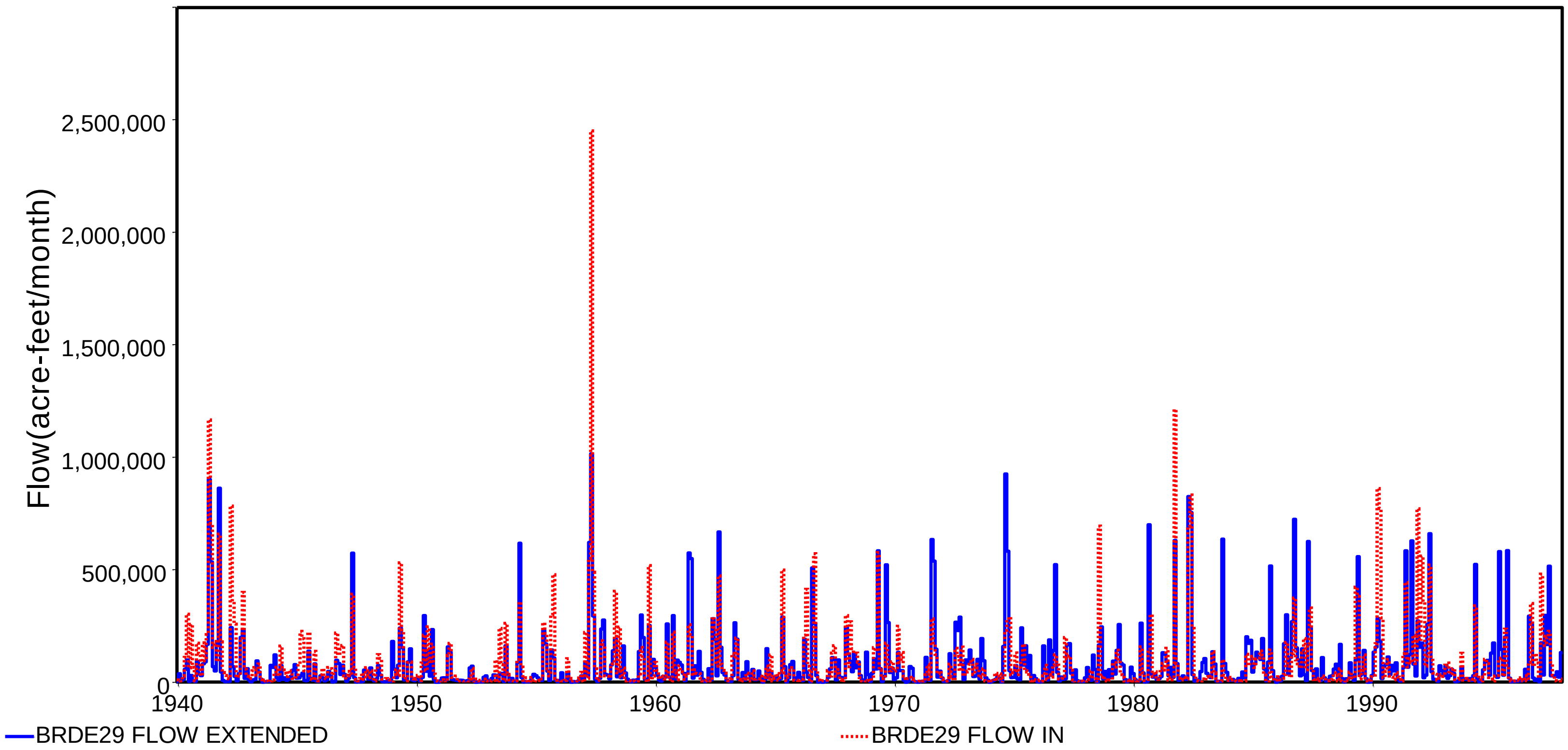


Figure B.2.10 Known and Final Computed Flows for Brazos River at Dennis BRDE29

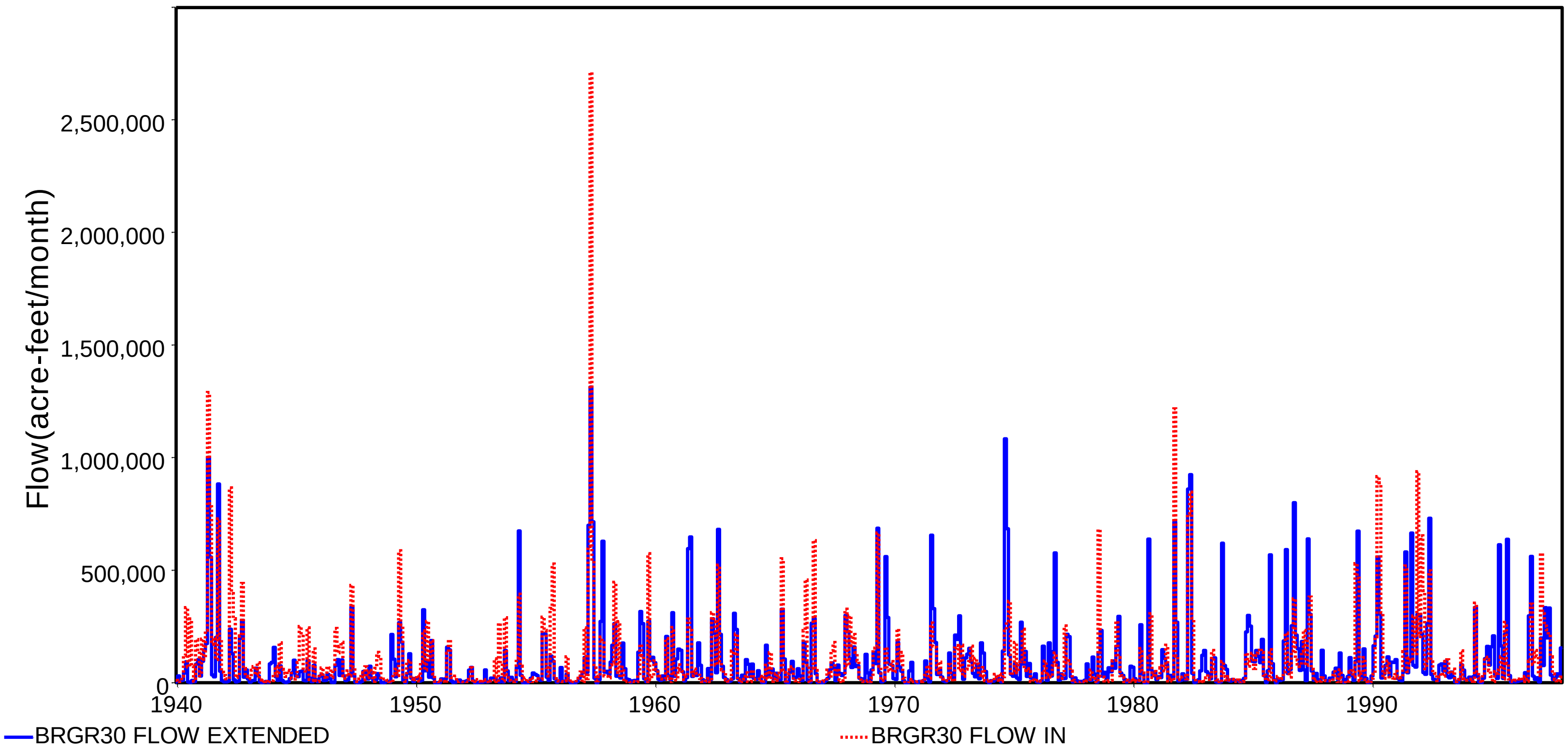


Figure B.2.11 Known and Final Computed Flows for Brazos River at Glen Rose BRGR30

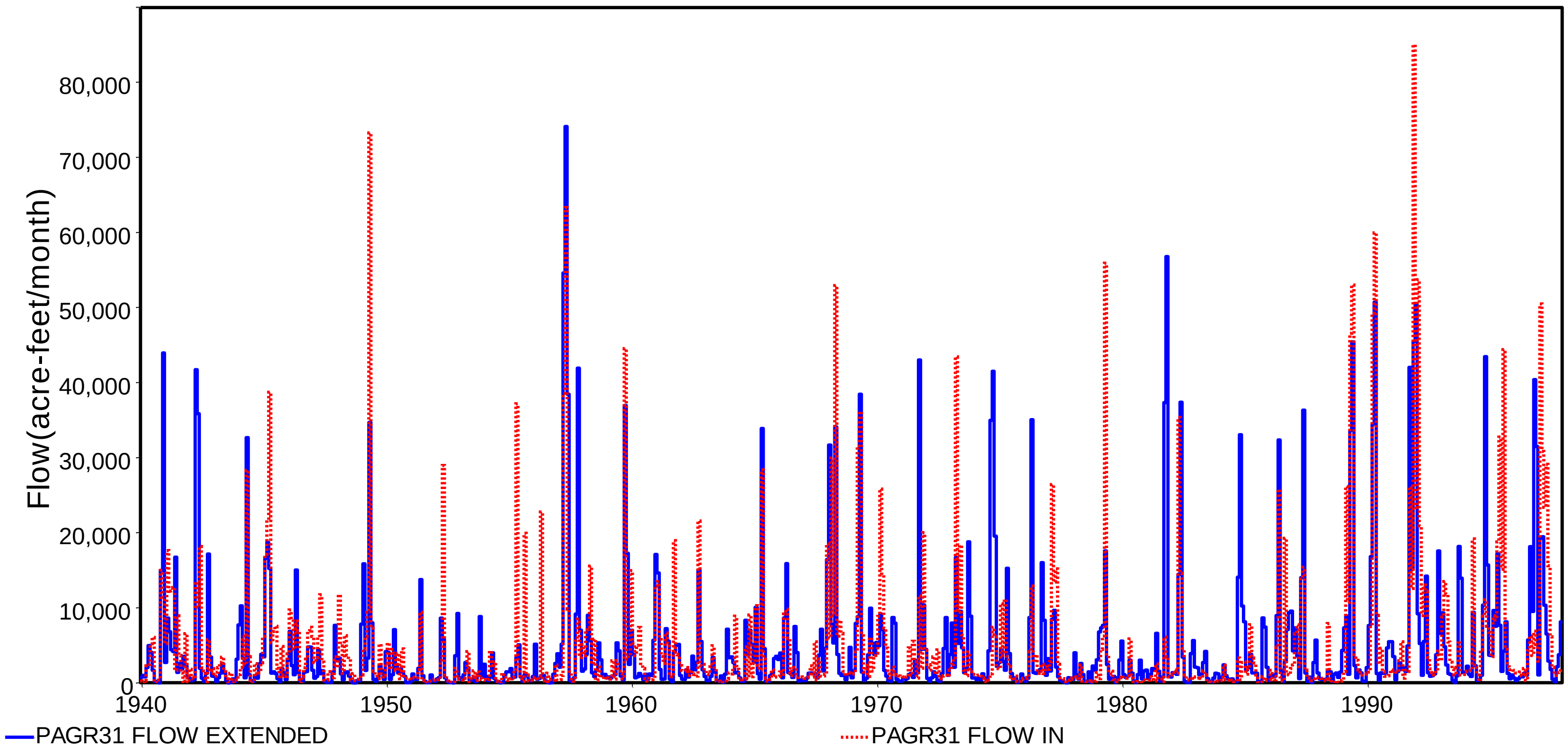


Figure B.2.12 Known and Final Computed Flows for Paluxy River at Glen Rose PAGR31

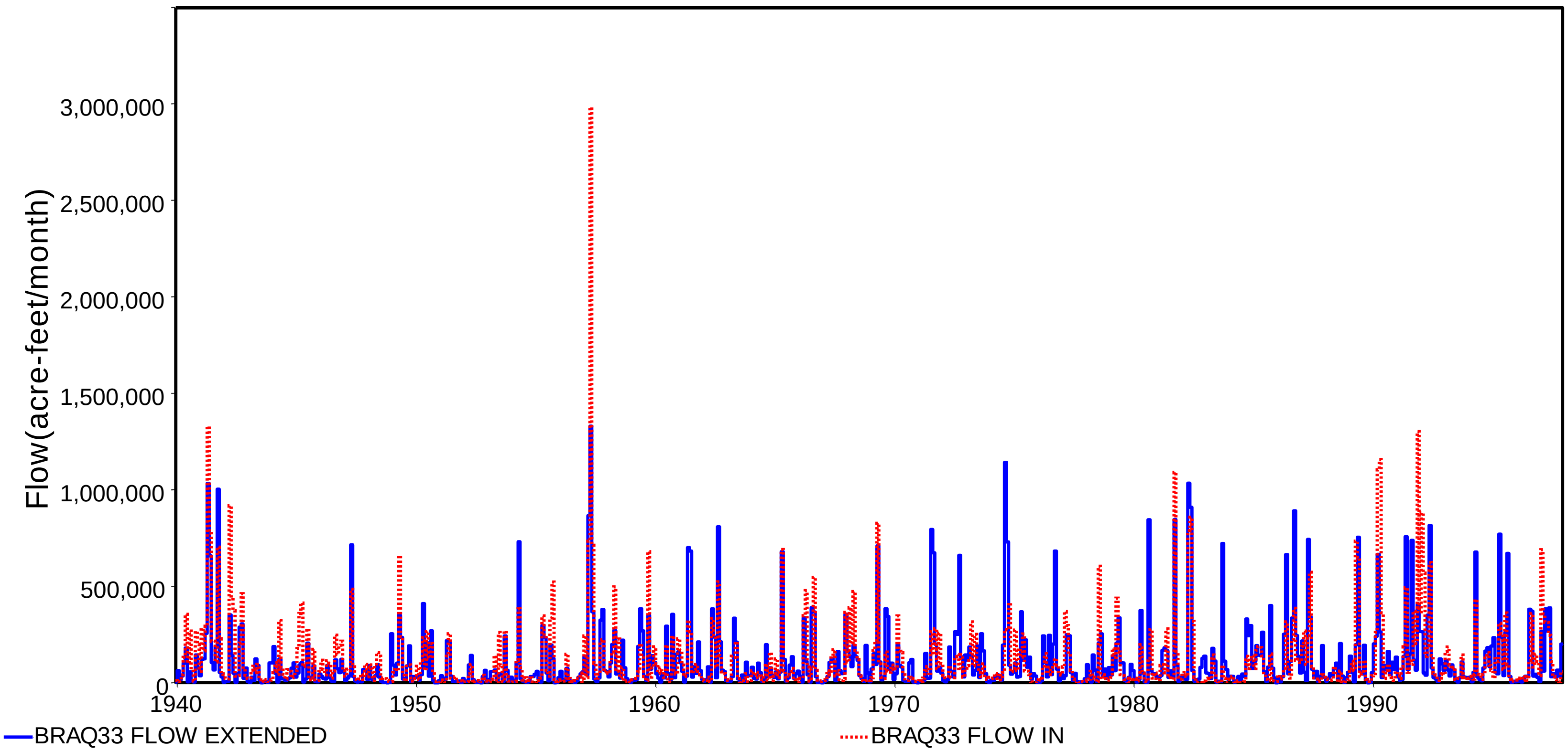


Figure B.2.13 Known and Final Computed Flows for Brazos River at Aquilla BRAQ33

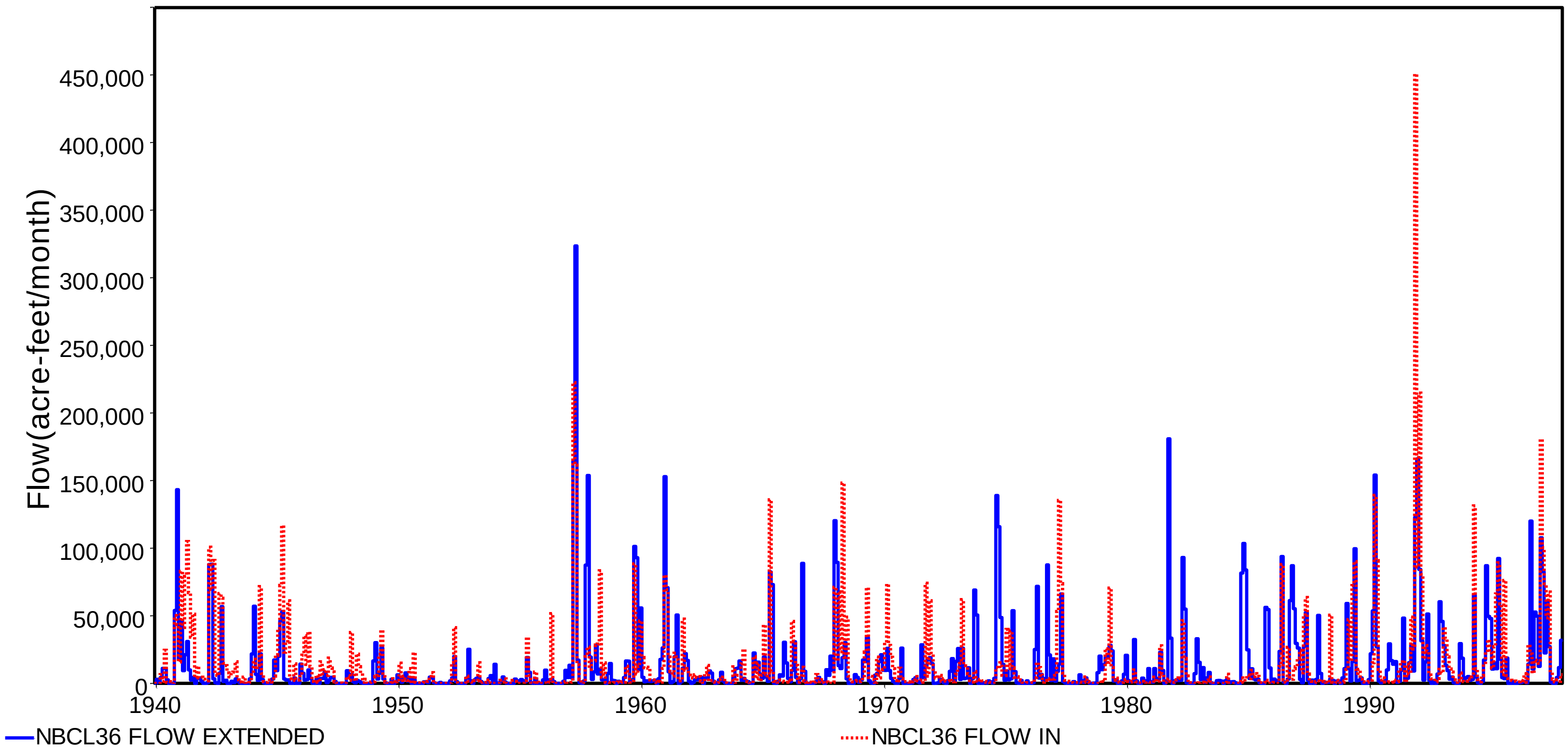


Figure B.2.14 Known and Final Computed Flows for North Bosque River at Clifton NBCL36

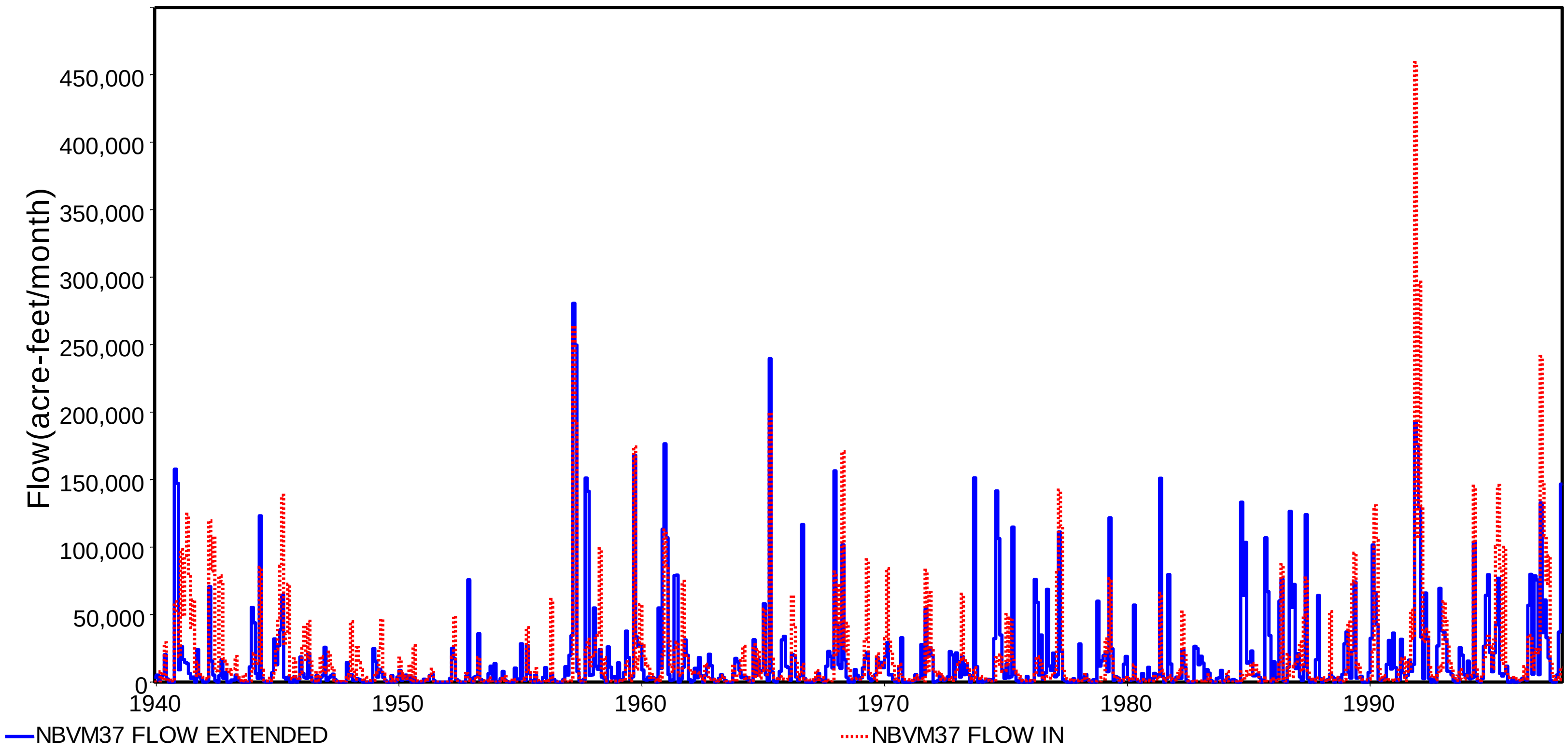


Figure B.2.15 Known and Final Computed Flows for North Bosque River at Valley Mills NBVM37

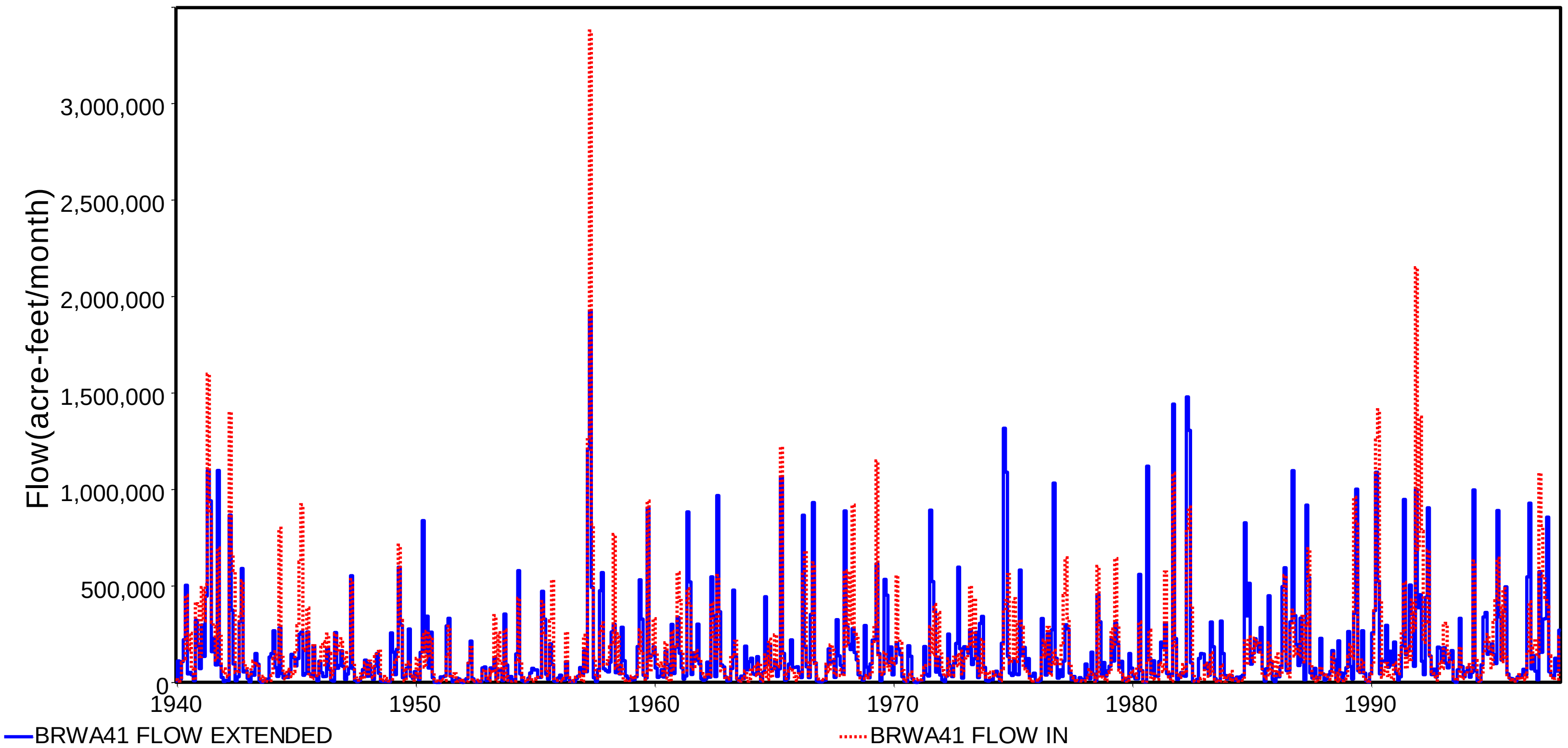


Figure B.2.16 Known and Final Computed Flows for Brazos River at Waco BRWA41

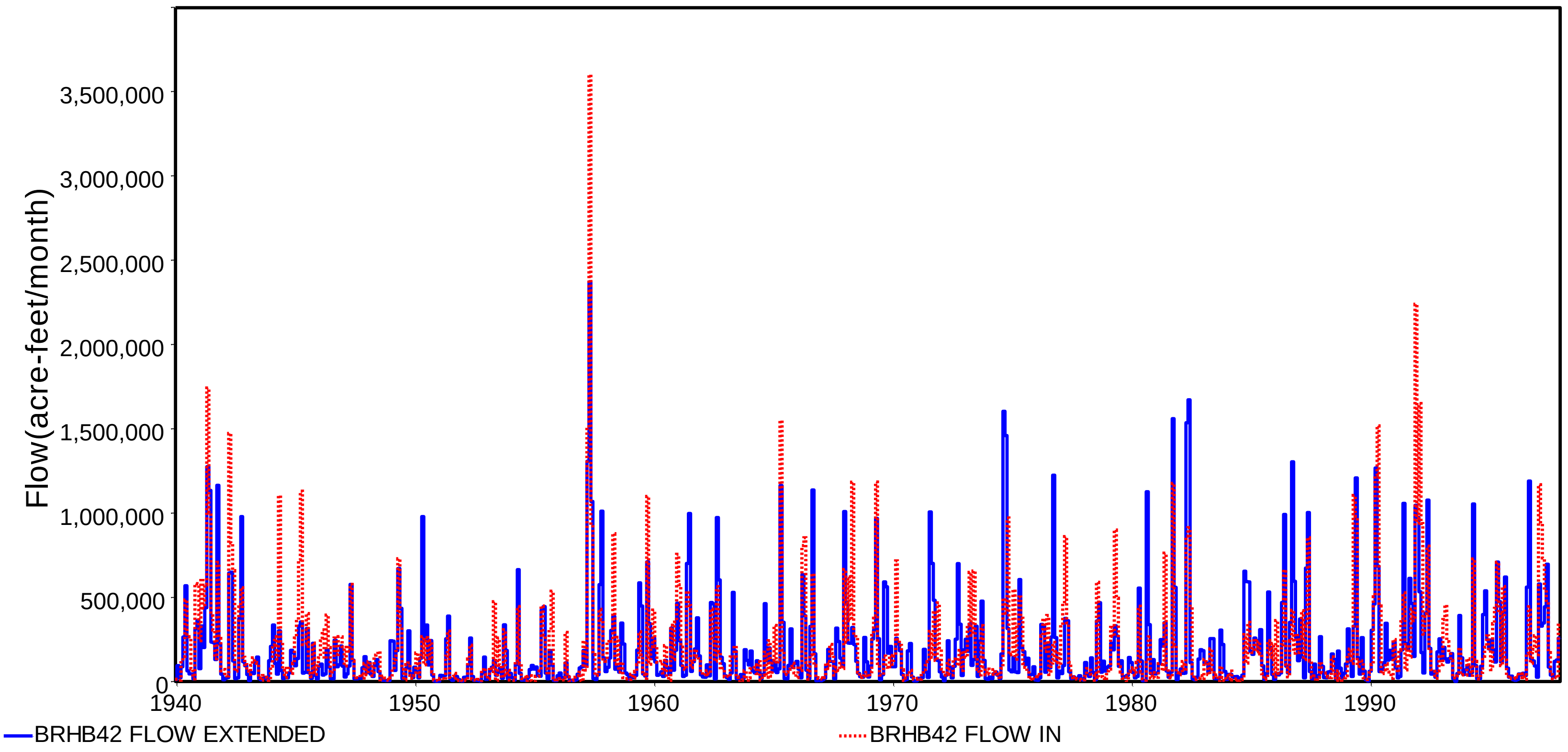


Figure B.2.17 Known and Final Computed Flows for Brazos River at Highbank BRHB42

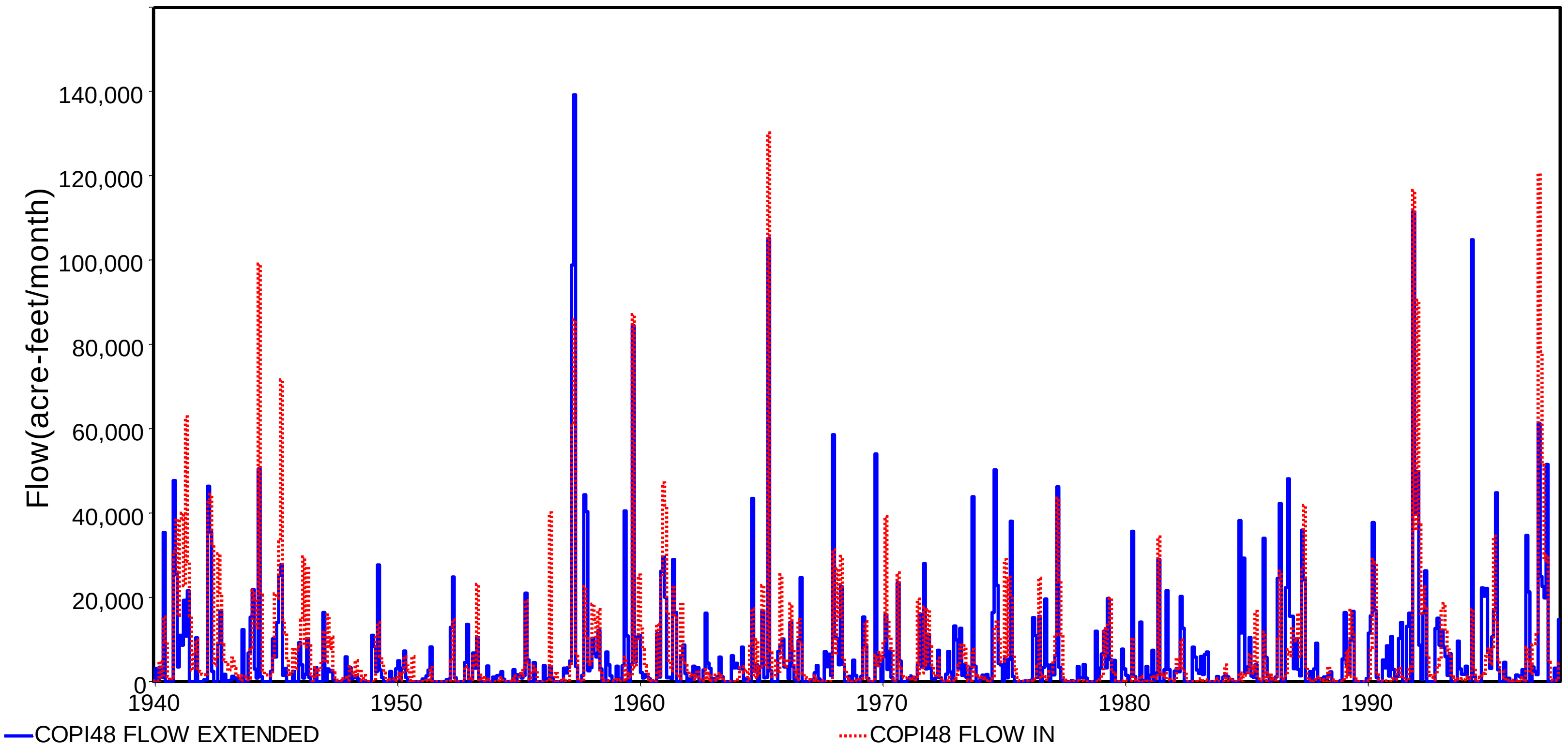


Figure B.2.18 Known and Final Computed Flows for Cowhouse Creek at Pidcoke COPI48

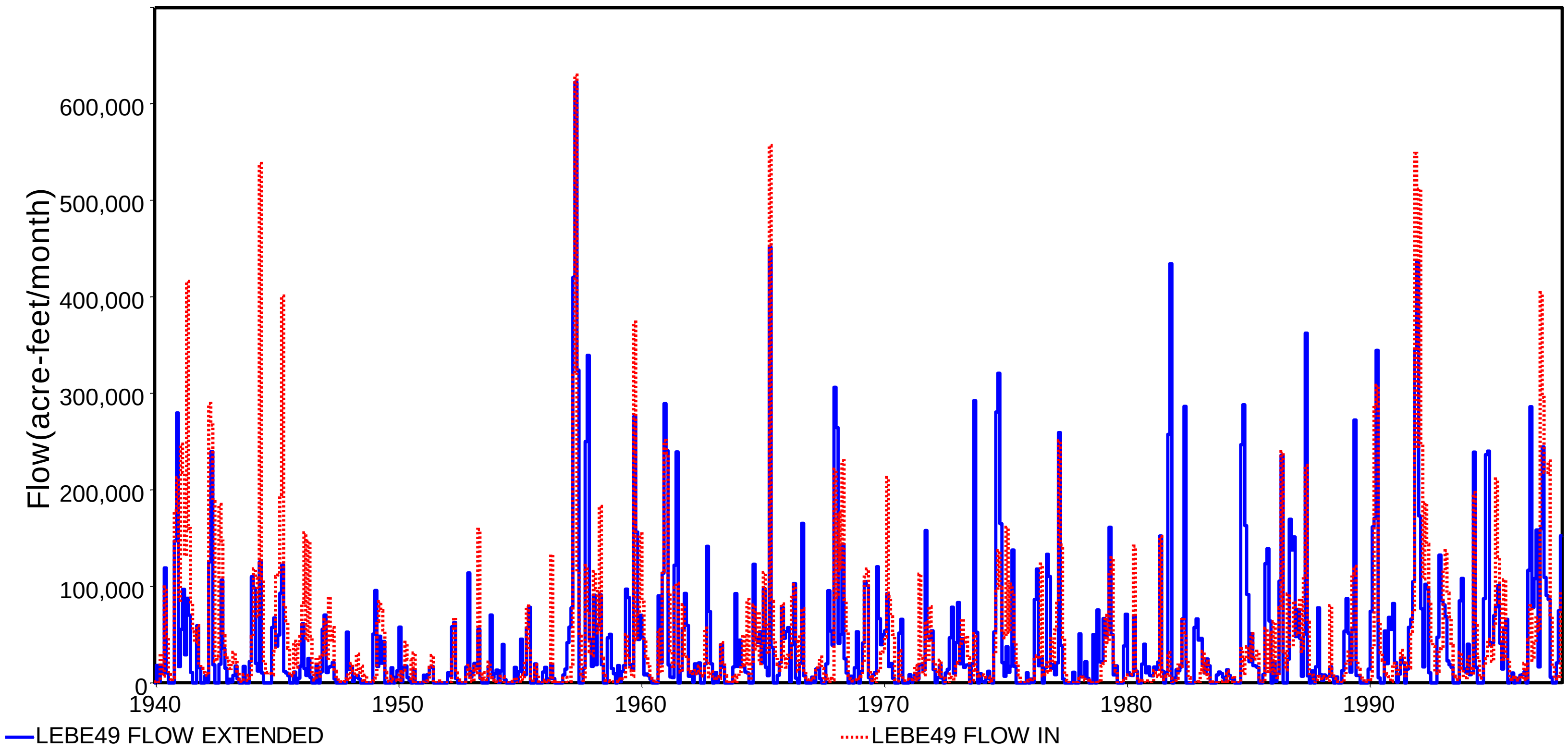


Figure B.2.19 Known and Final Computed Flows for Leon River at Belton LEBE49

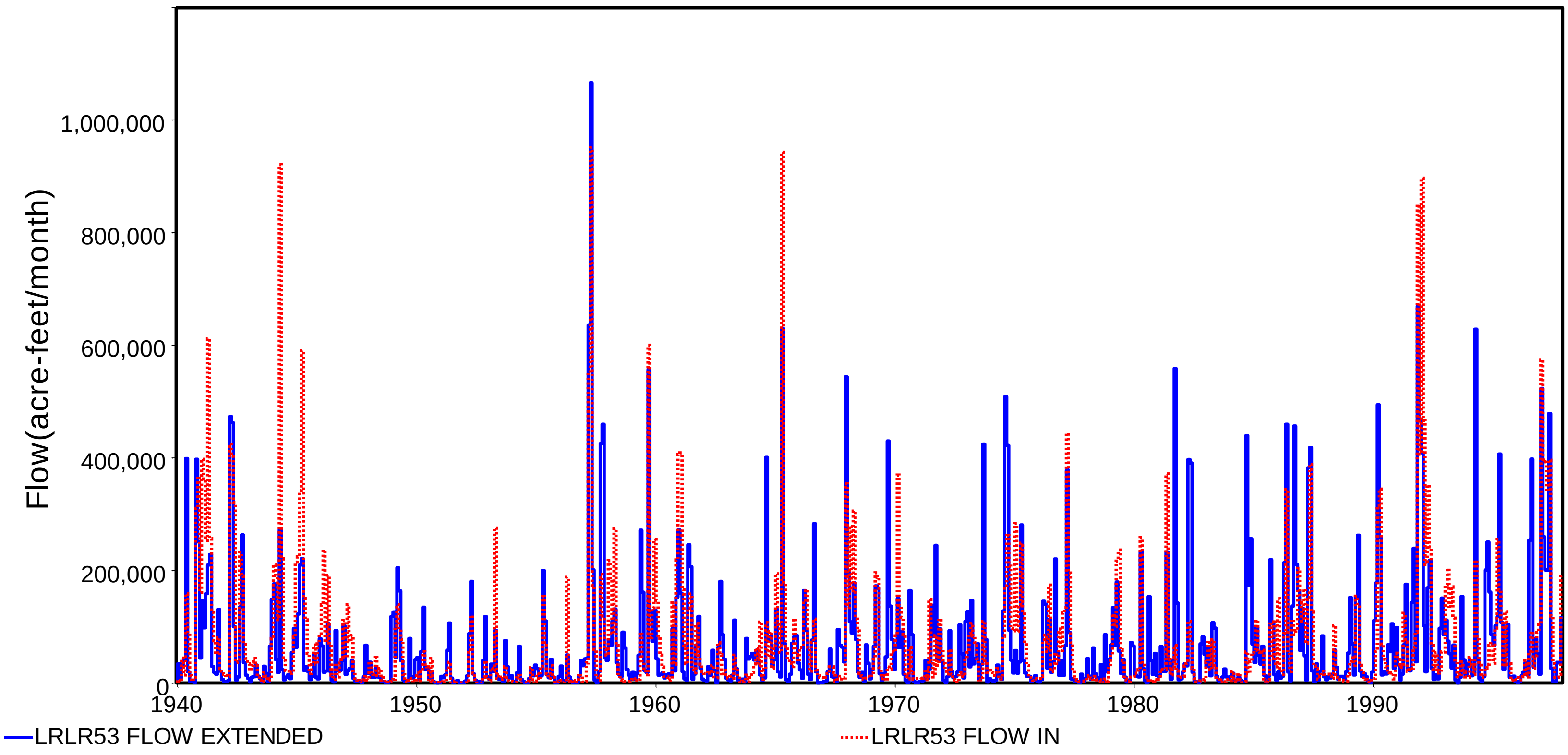


Figure B.2.20 Known and Final Computed Flows for Little River at Little River LRLR53

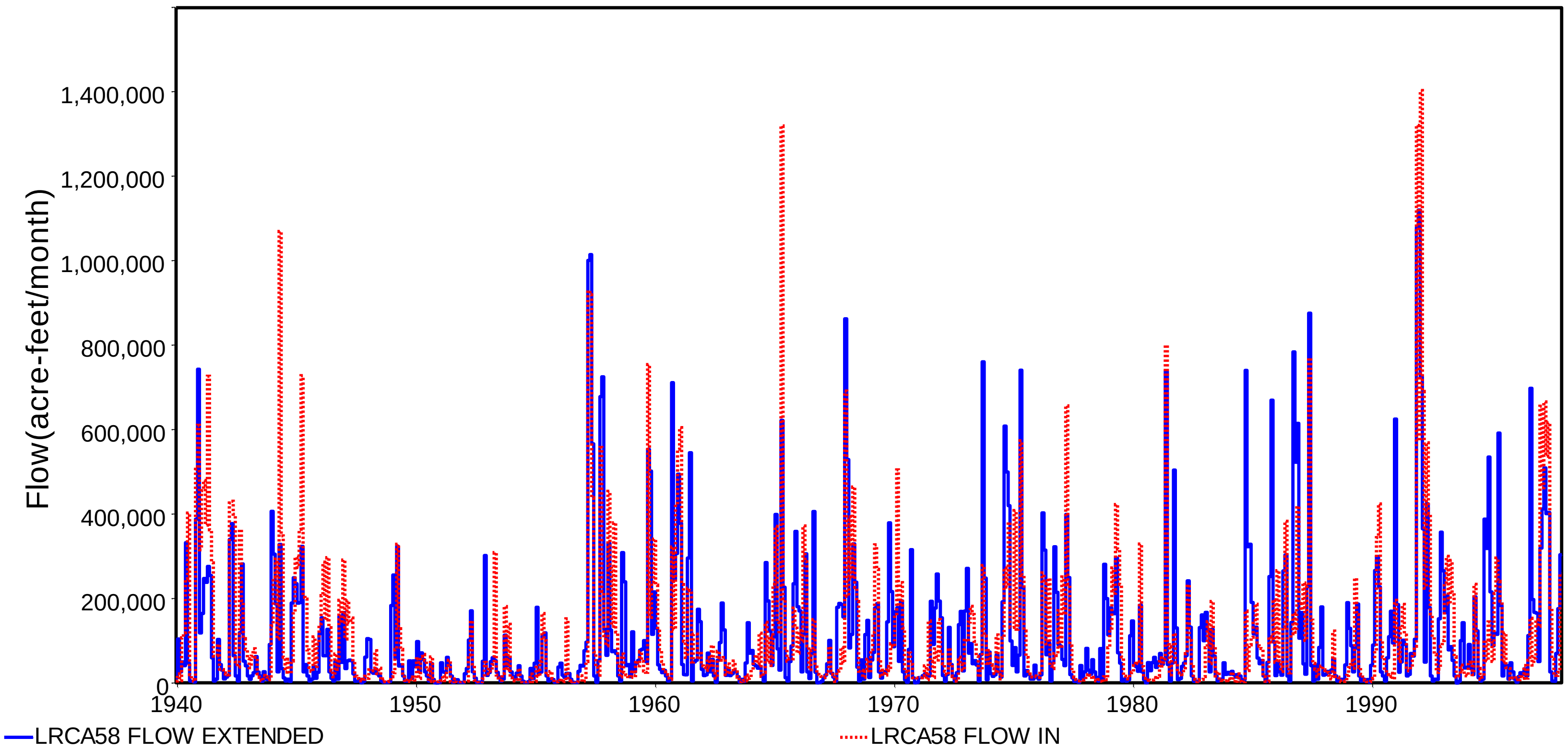


Figure B.2.21 Known and Final Computed Flows for Little River at Cameron LRCA58

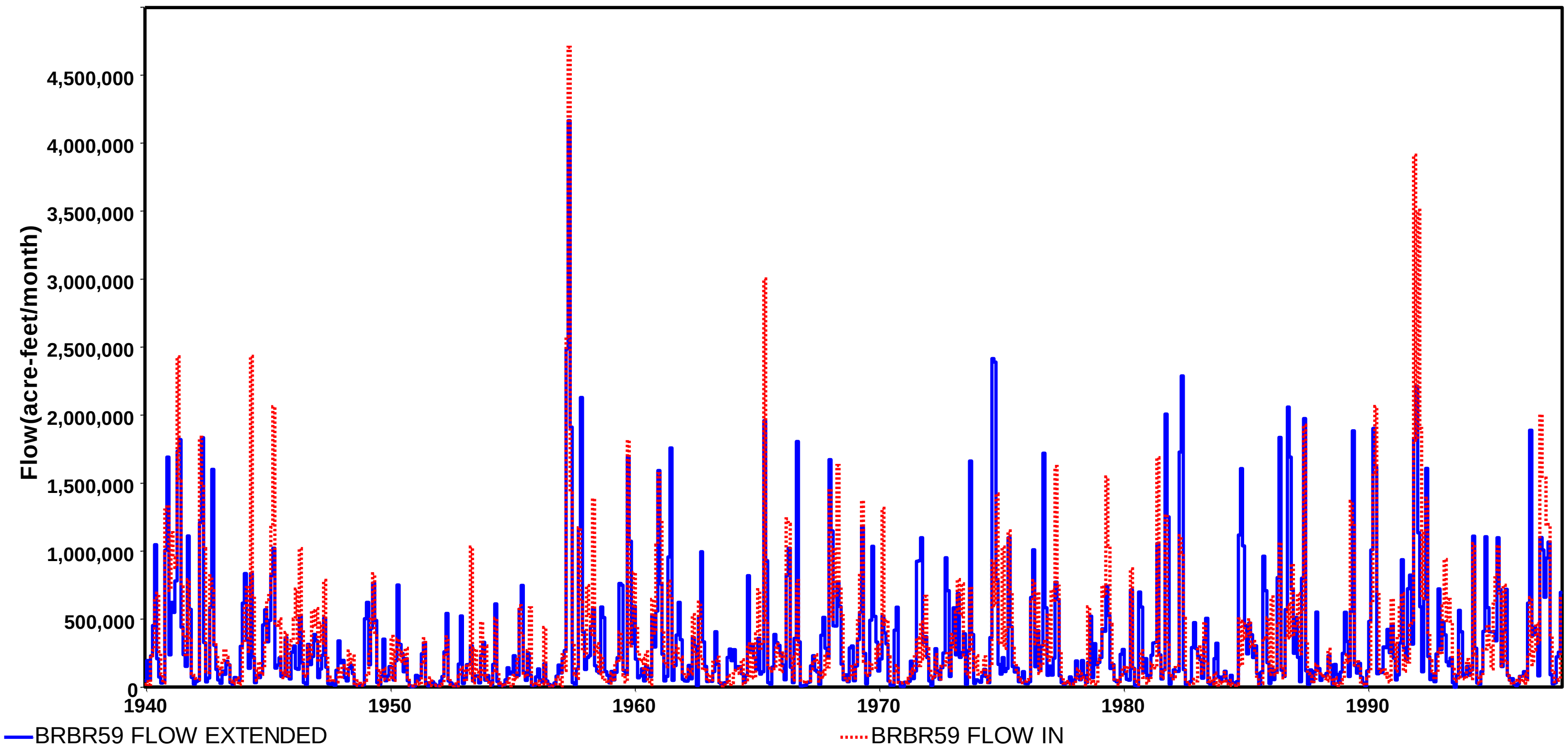


Figure B.2.22 Known and Final Computed Flows for Brazos River at Bryan BRBR59

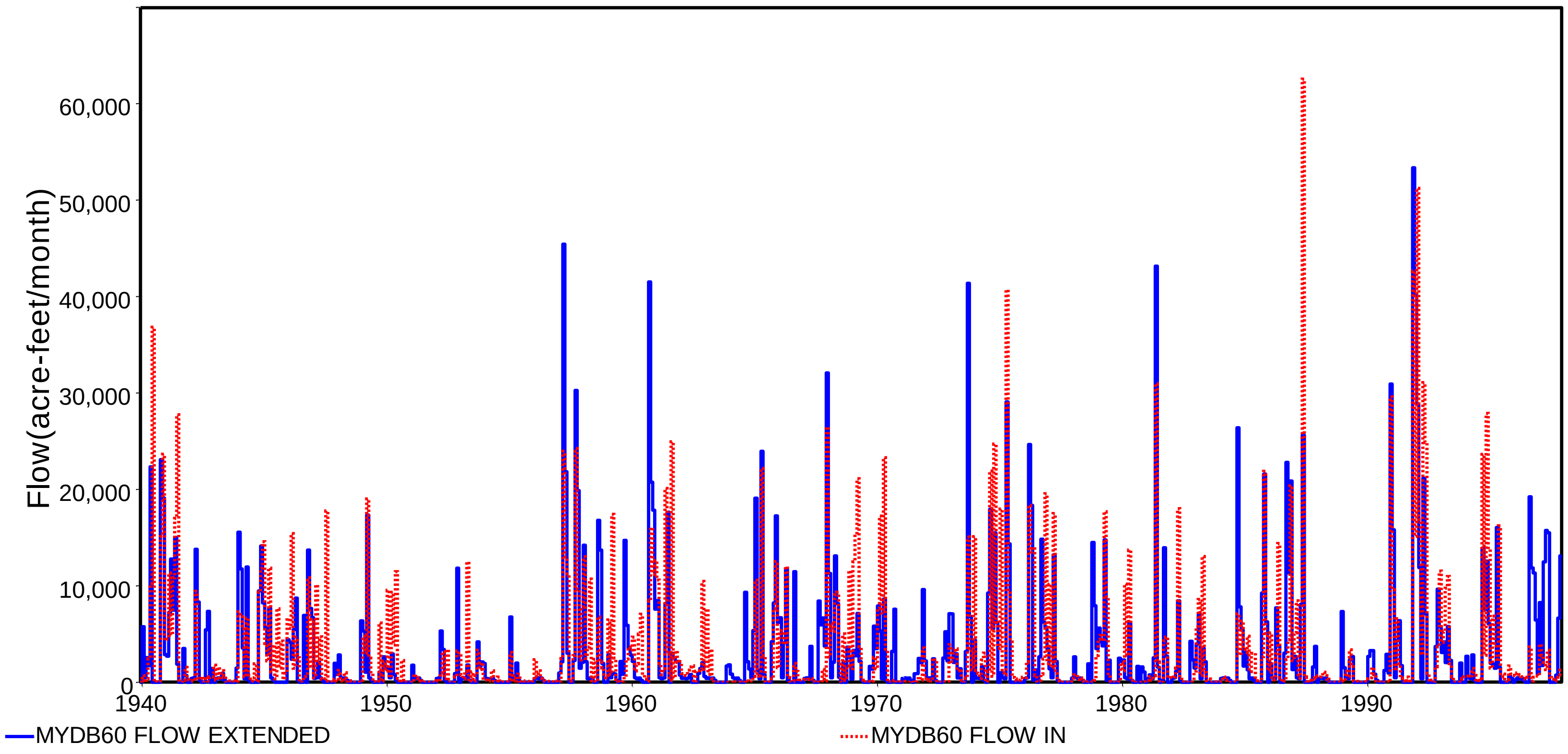


Figure B.2.23 Known and Final Computed Flows for Middle Yegua Creek at Dime Box MYDB60

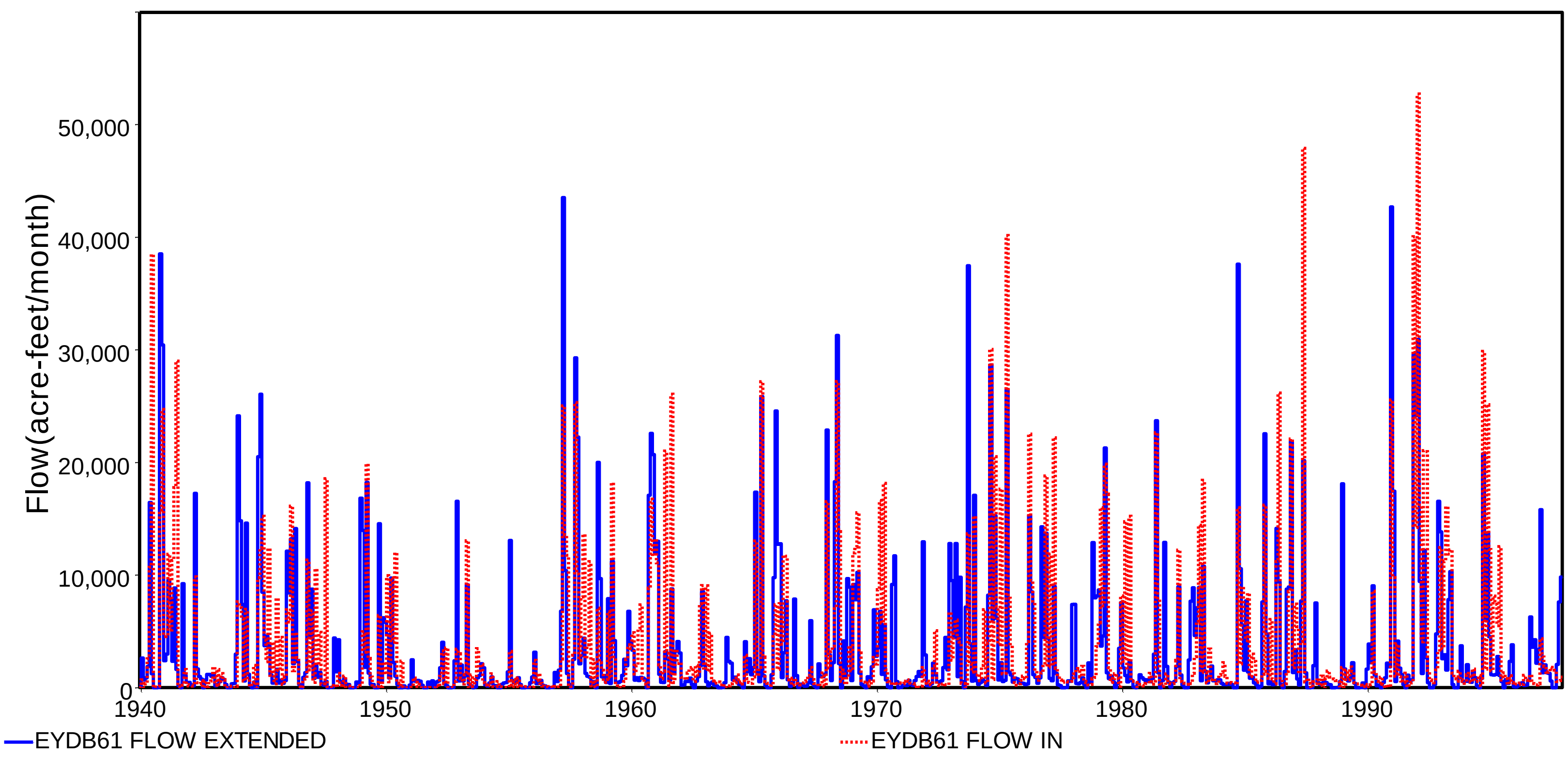


Figure B.2.24 Known and Final Computed Flows for East Yegua Creek at Dime Box EYDB61

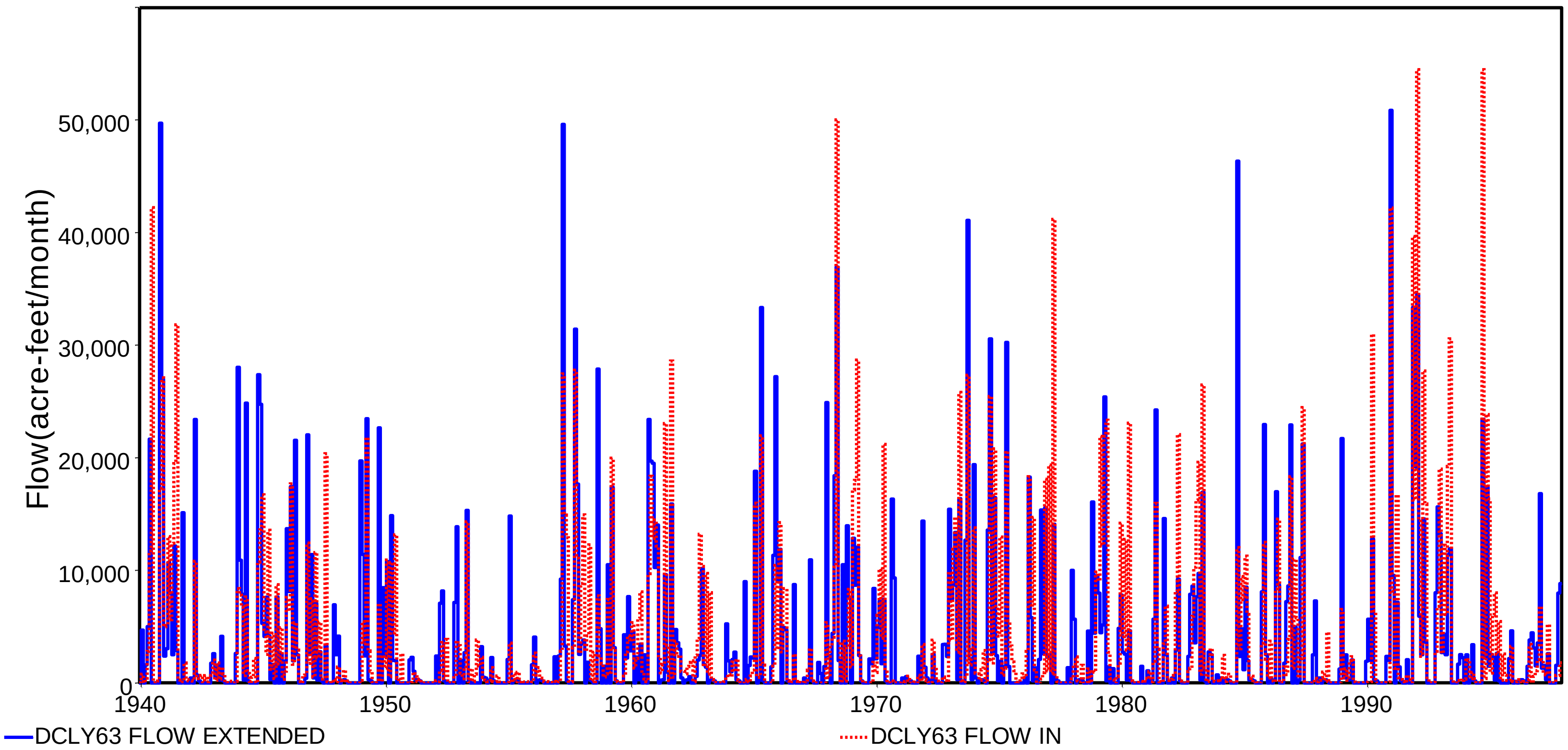


Figure B.2.25 Known and Final Computed Flows for Davidson Creek at Lyons DCLY63

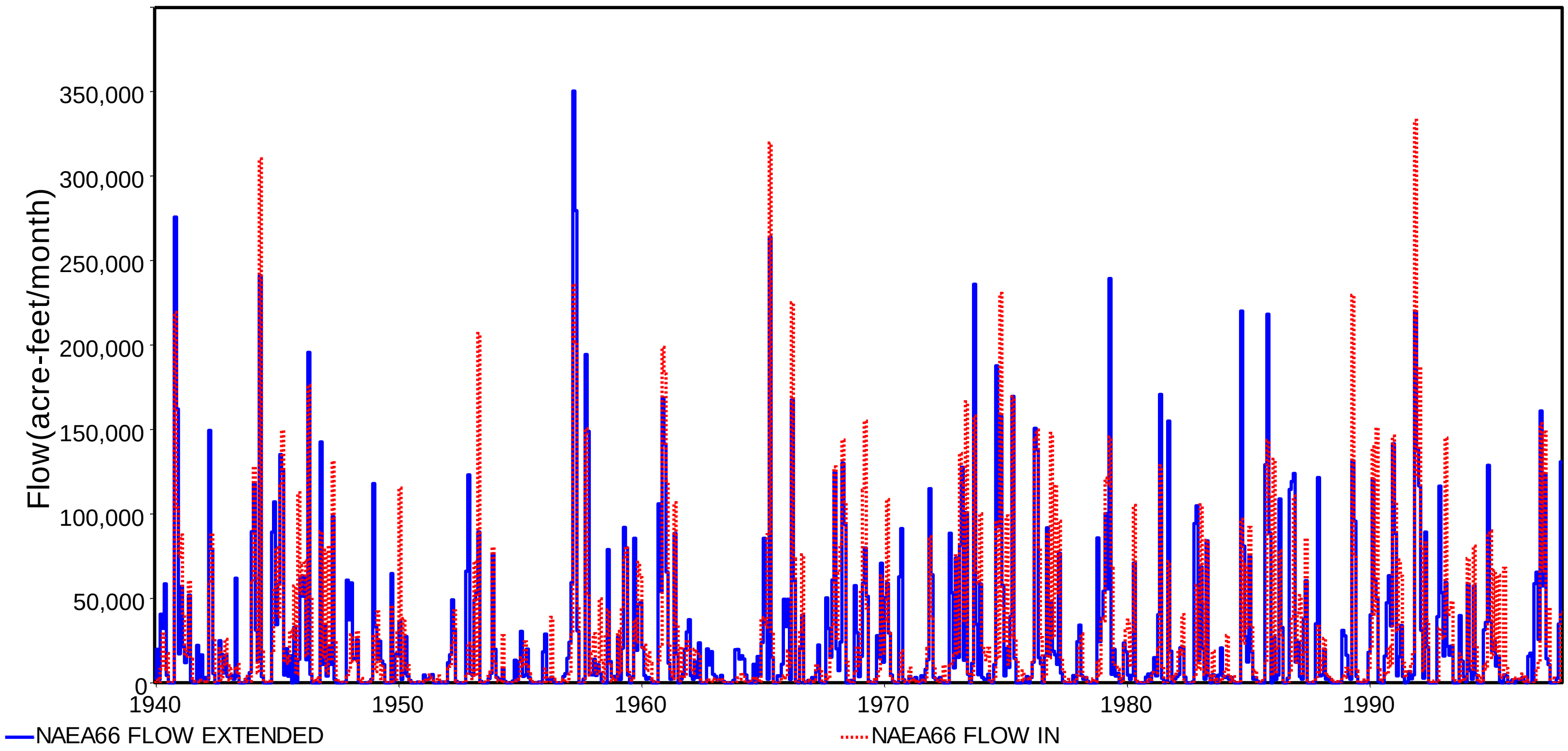


Figure B.2.26 Known and Final Computed Flows for Navasota River at Easterly NAEA66

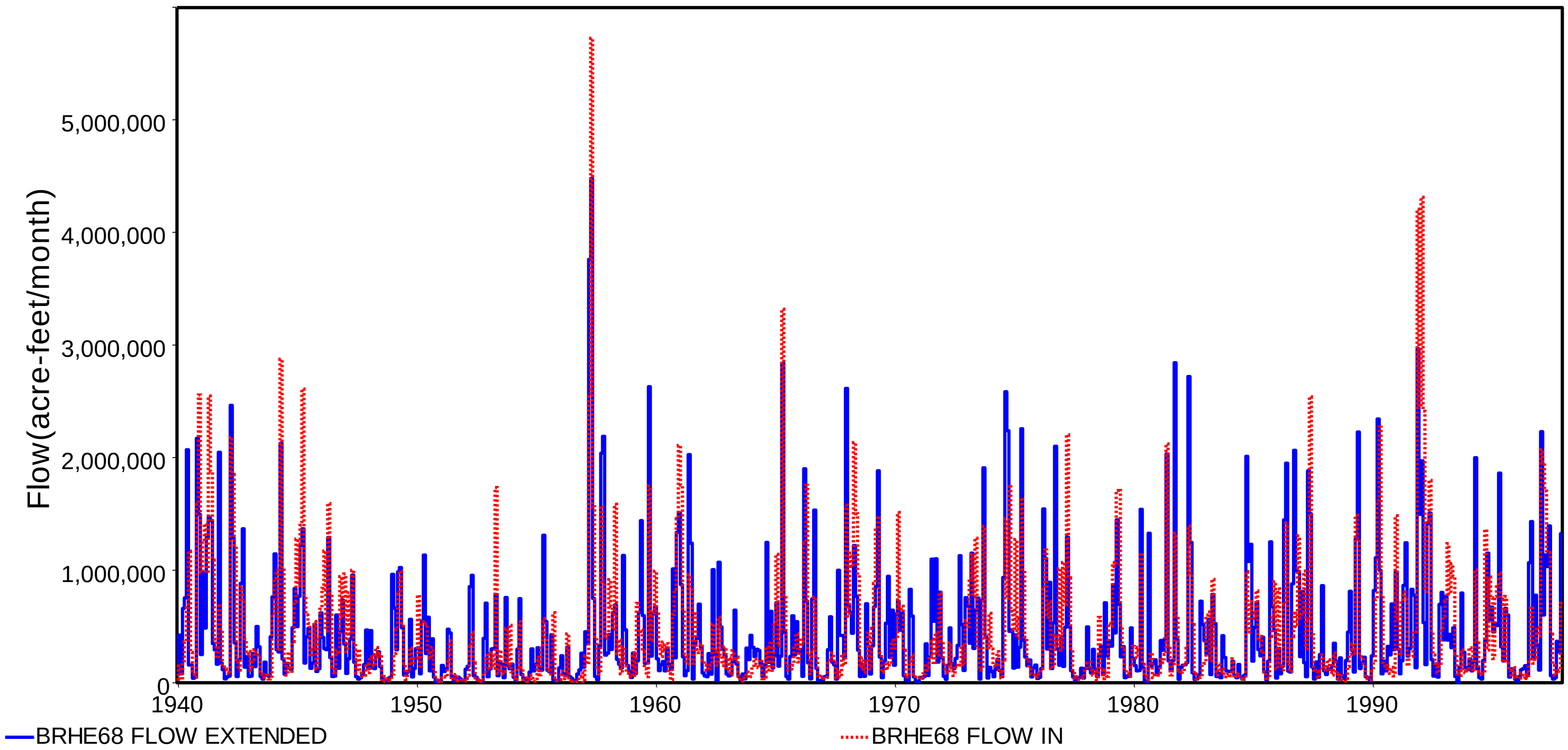


Figure B.2.27 Known and Final Computed Flows for Brazos River at Hempstead BRHE68

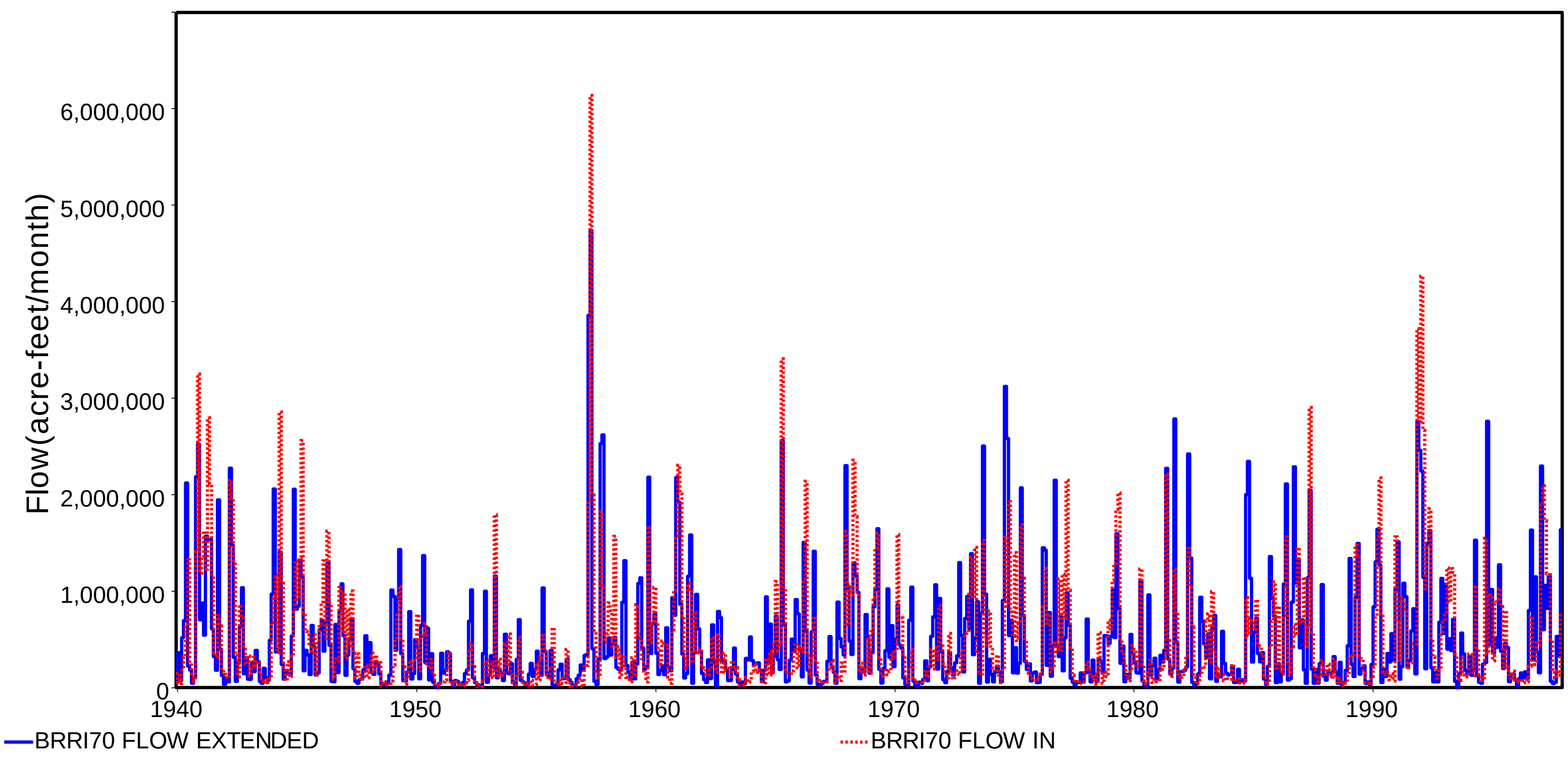


Figure B.2.28 Known and Final Computed Flows for Brazos River at Richmond BRRI70

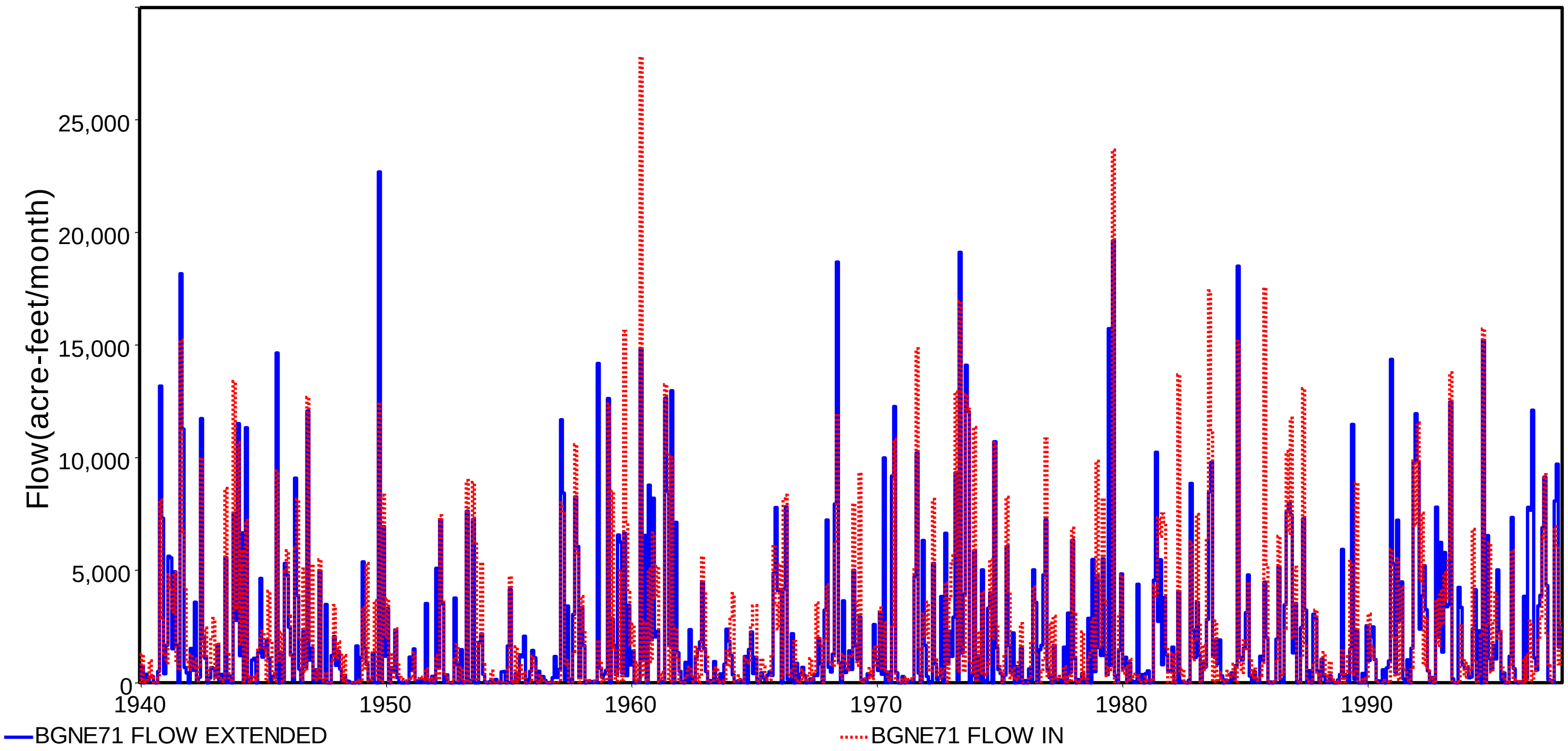


Figure B.2.29 Known and Final Computed Flows for Big Creek at Needville BGNE71

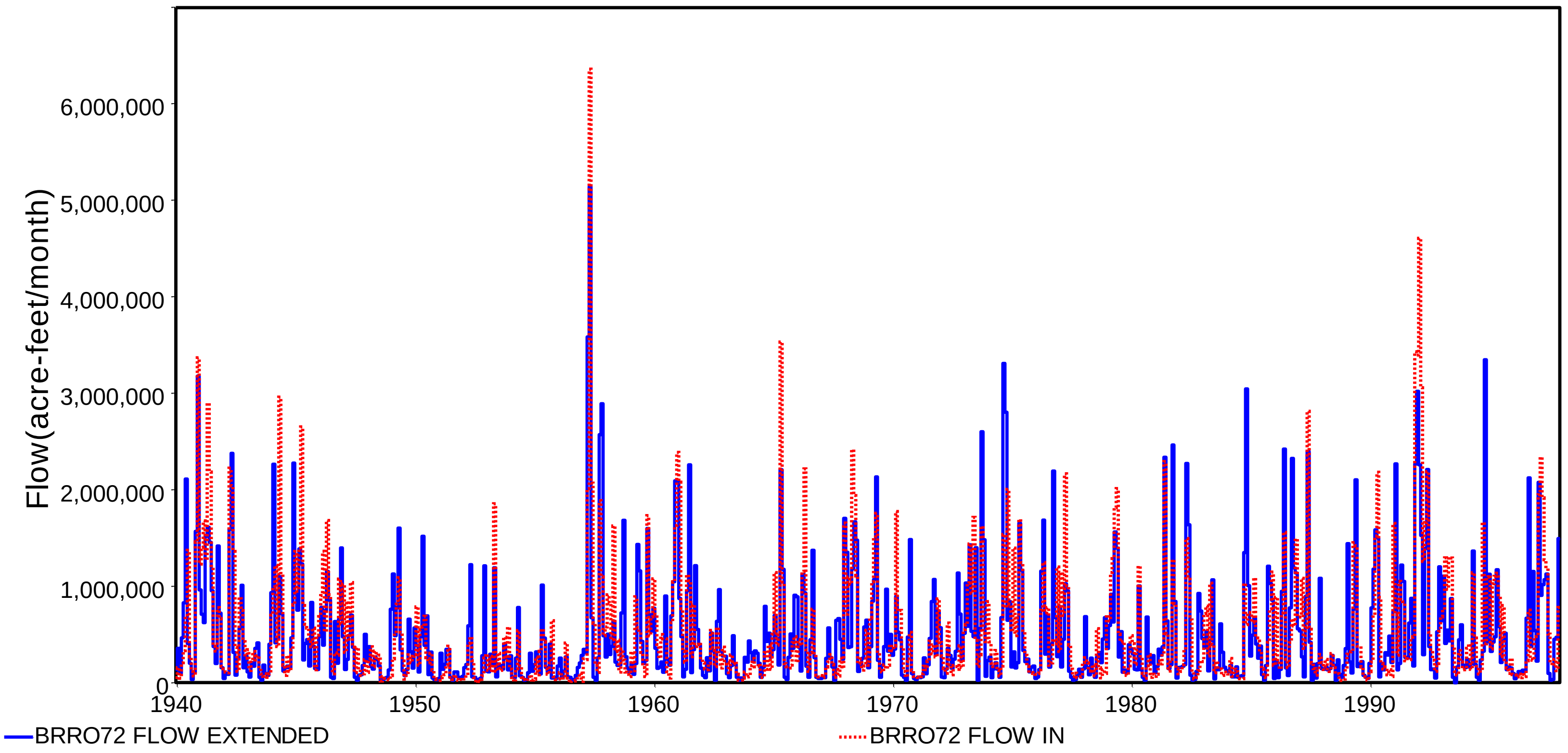


Figure B.2.30 Known and Final Computed Flows for Brazos River at Rosharon BRRO72

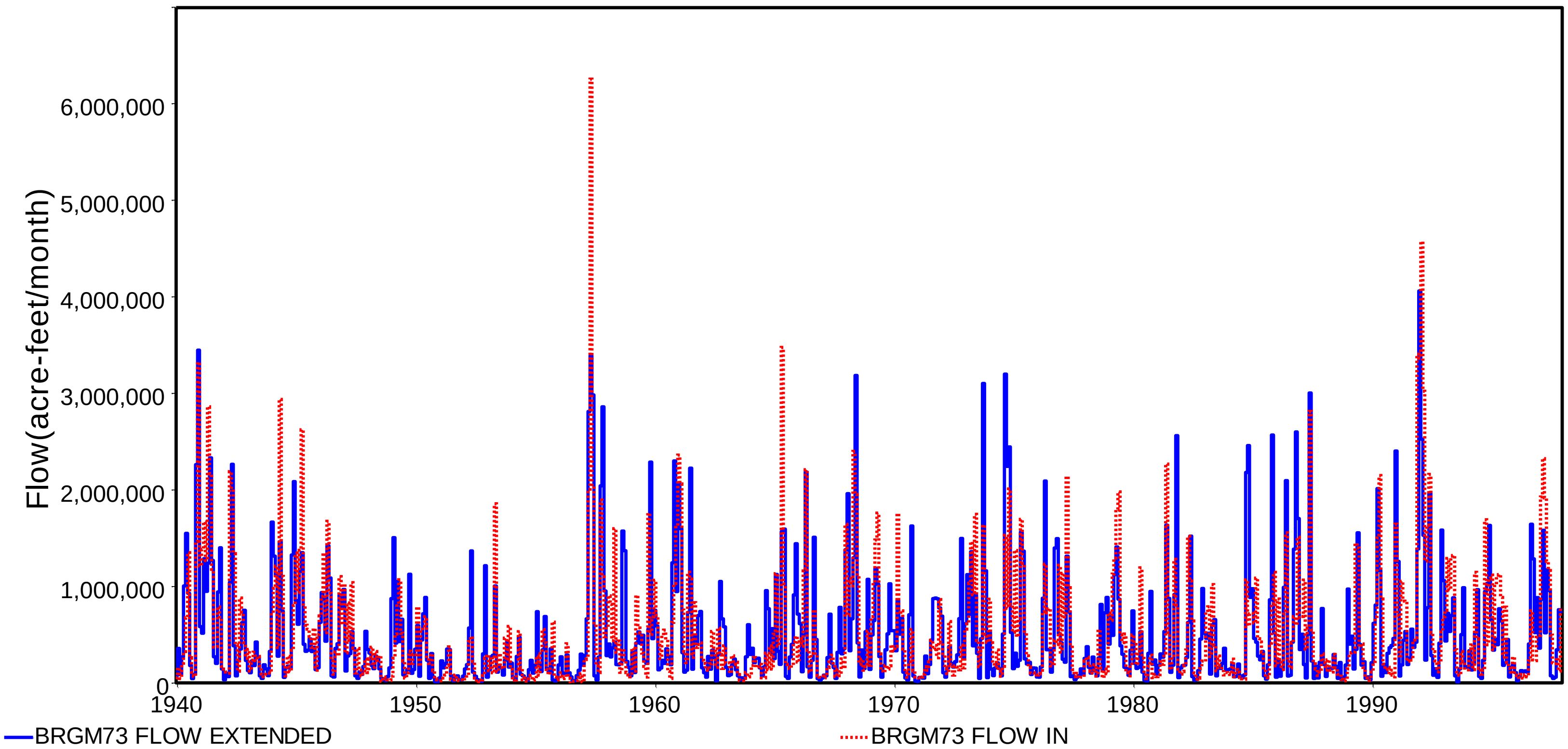


Figure B.2.31 Known and Final Computed Flows for Brazos River at Gulf of Mexico BRGM73

B.3 Known and Level-1 Computed 12-Month Forward Moving Average

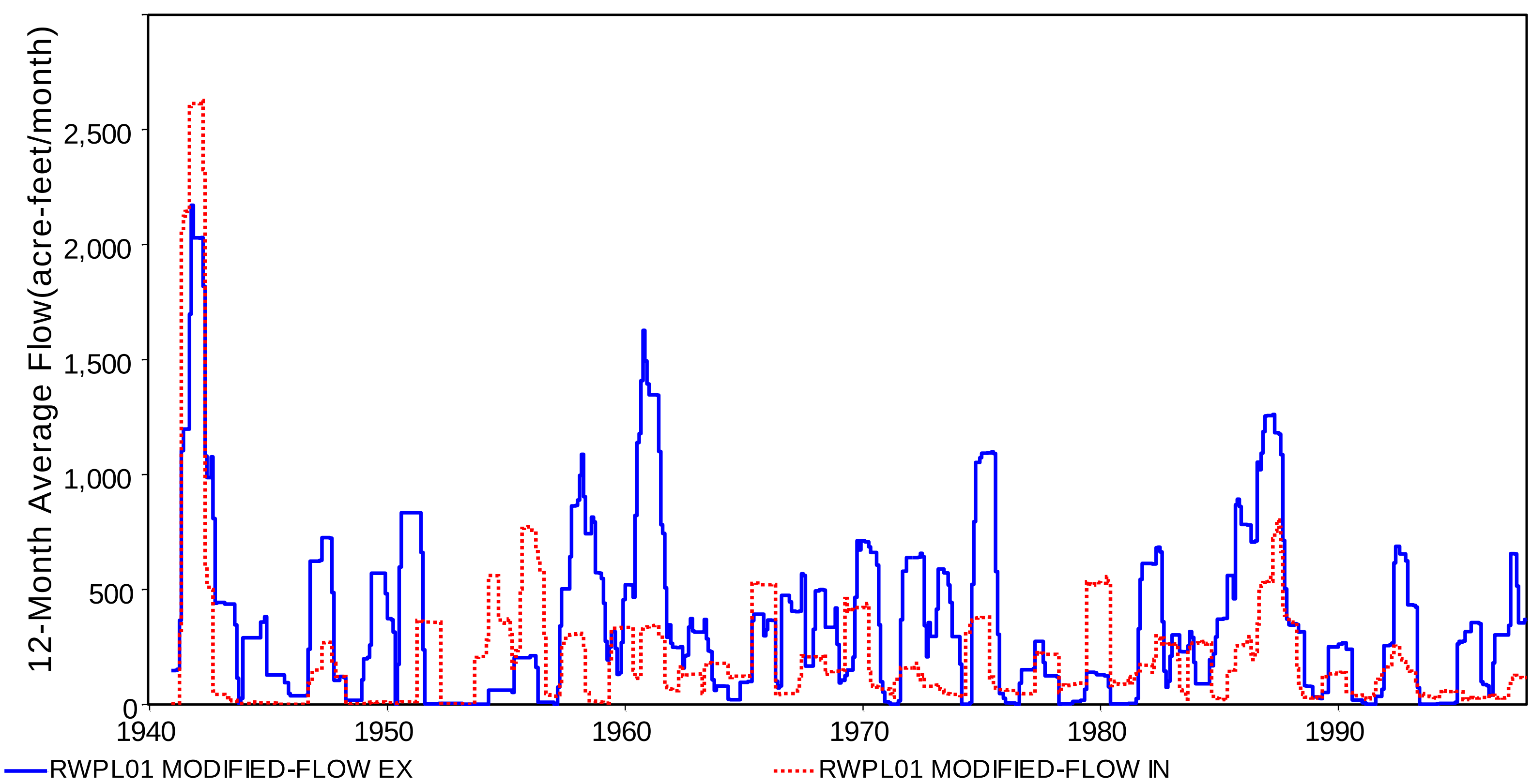


Figure B.3.1 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Running Water Draw at Plainview RWPL01

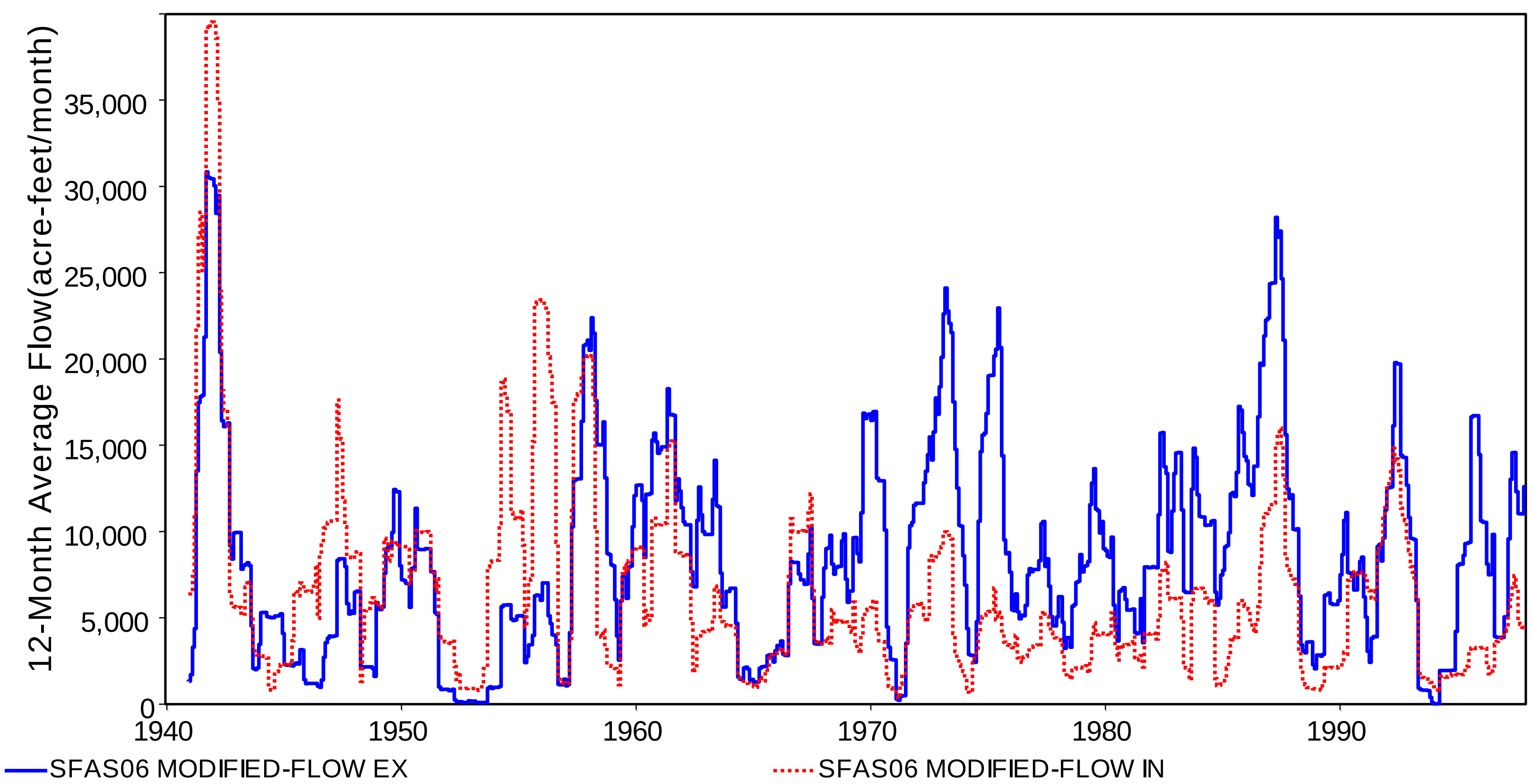


Figure B.3.2 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Salt Fork Brazos River at Aspermont SFAS06

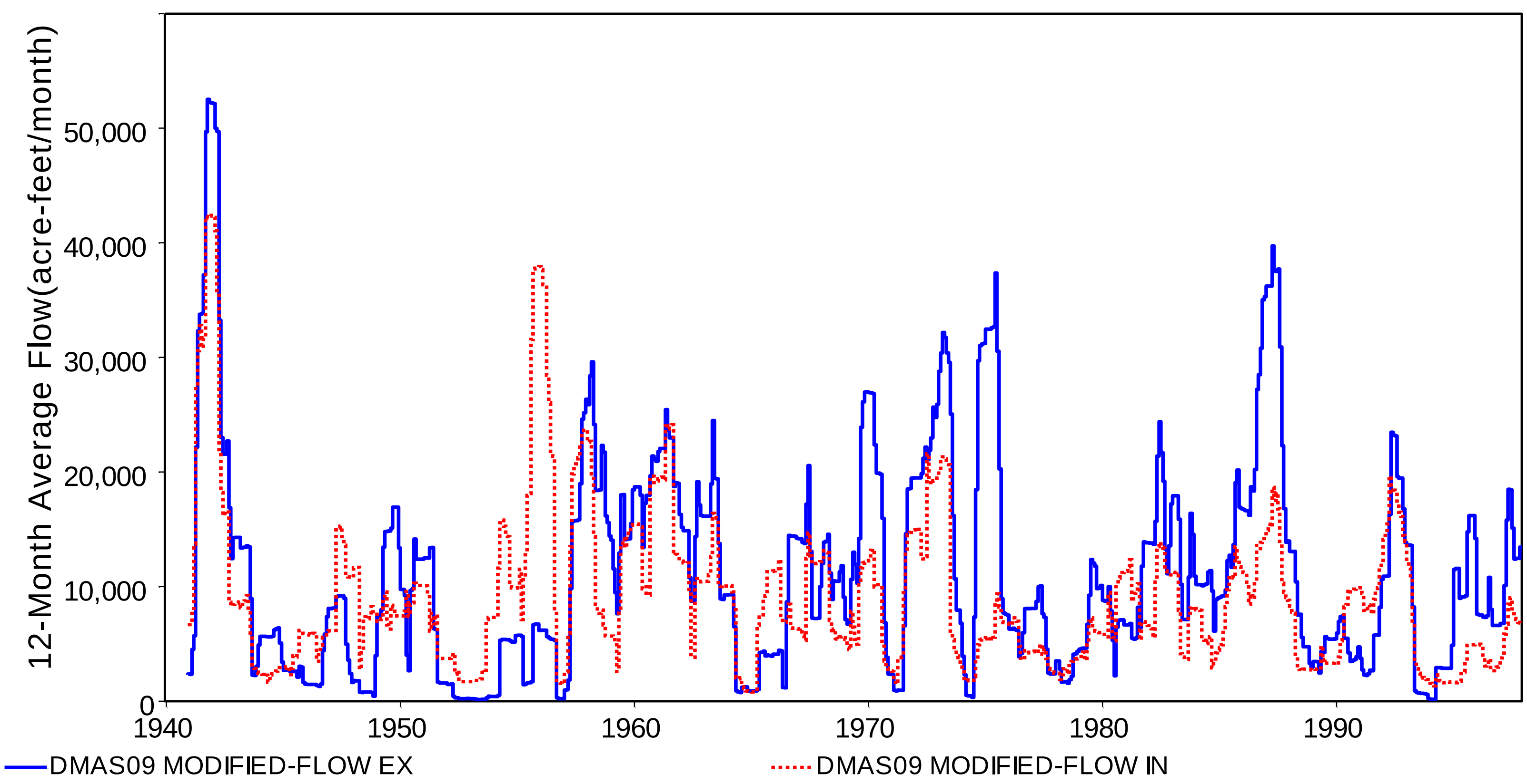


Figure B.3.3 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Double Mountain Fork at Aspermont DMAS09

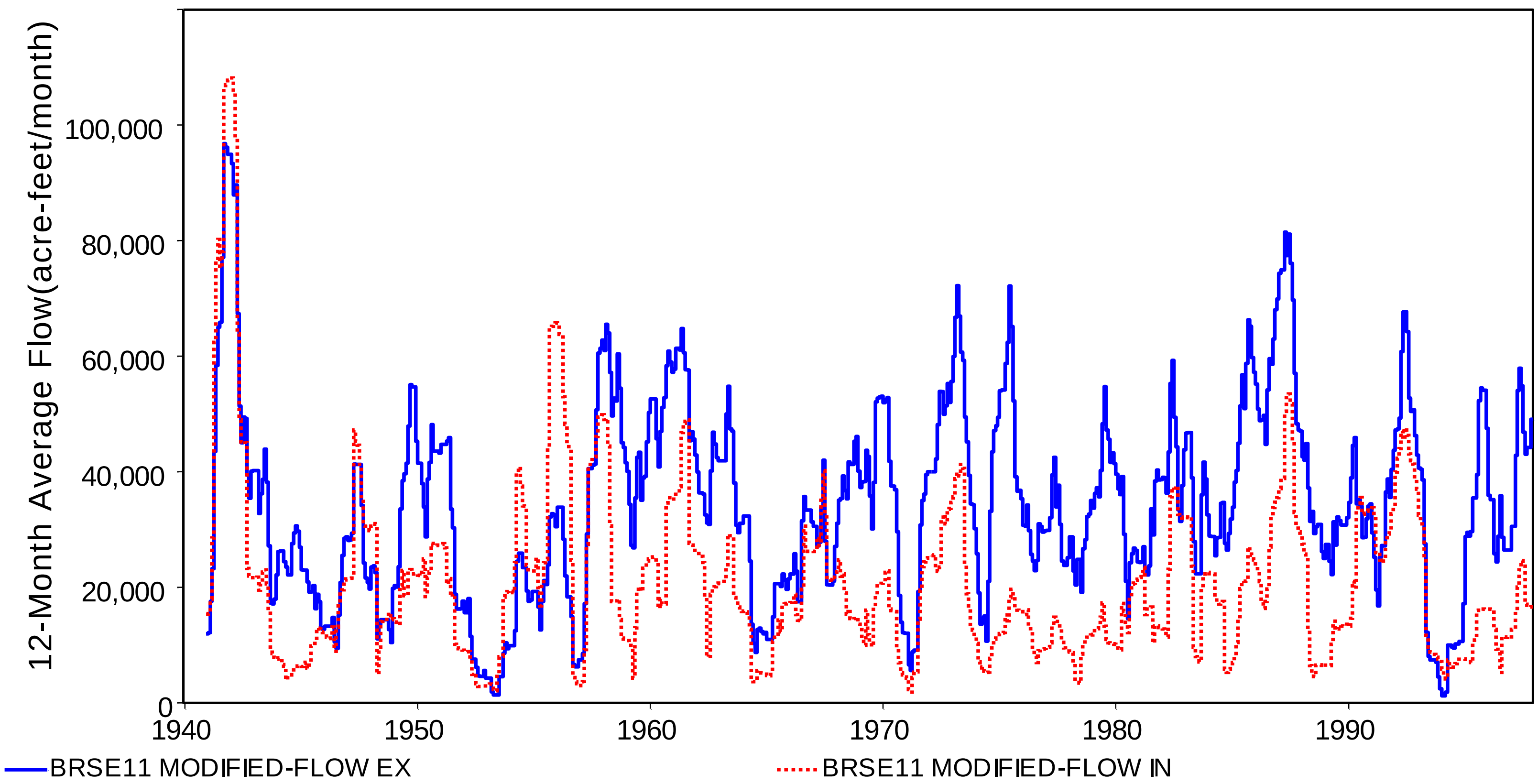


Figure B.3.4 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at Seymour BRSE11

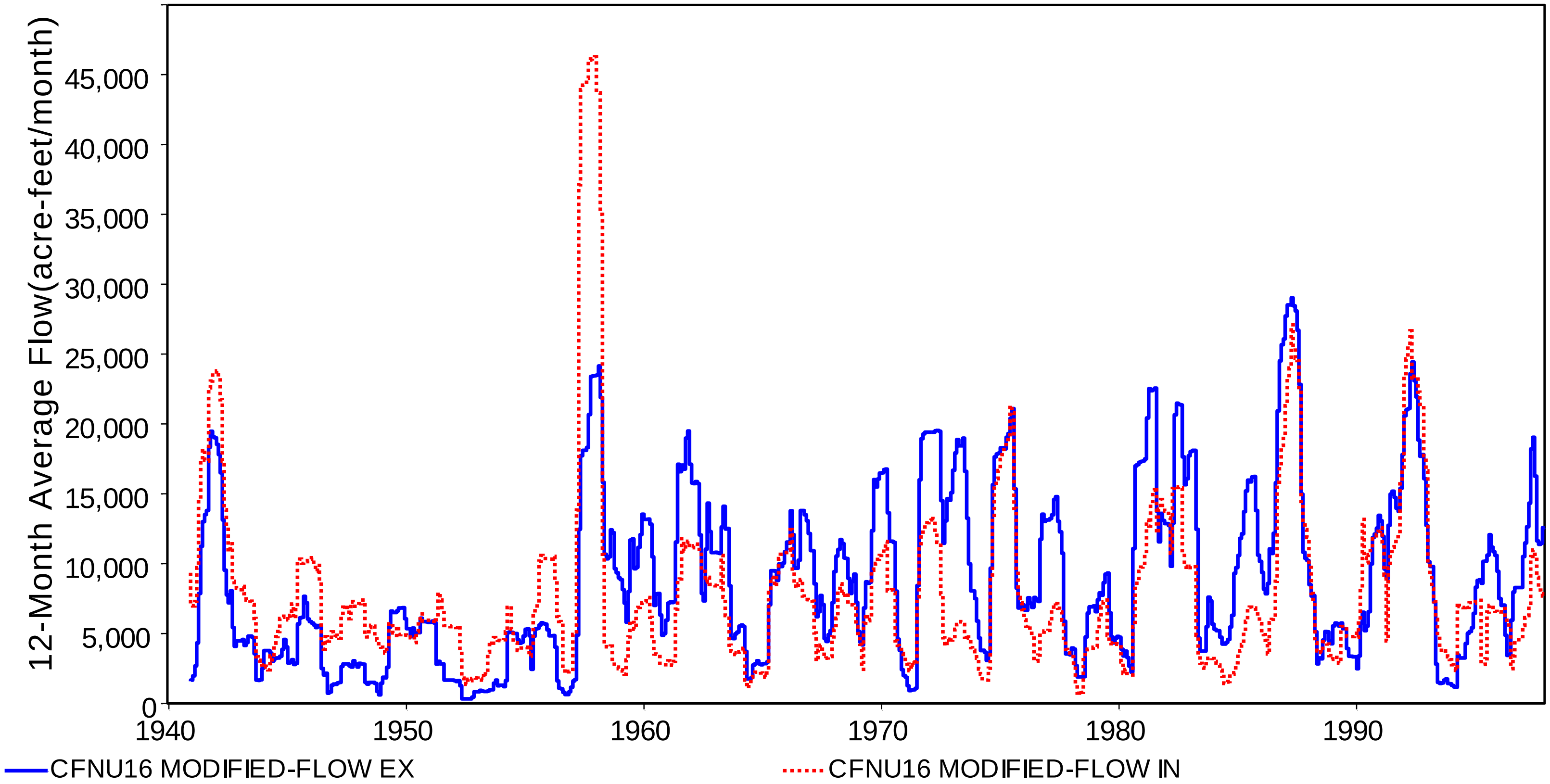


Figure B.3.5 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Clear Fork Brazos at Nugent CFNU16

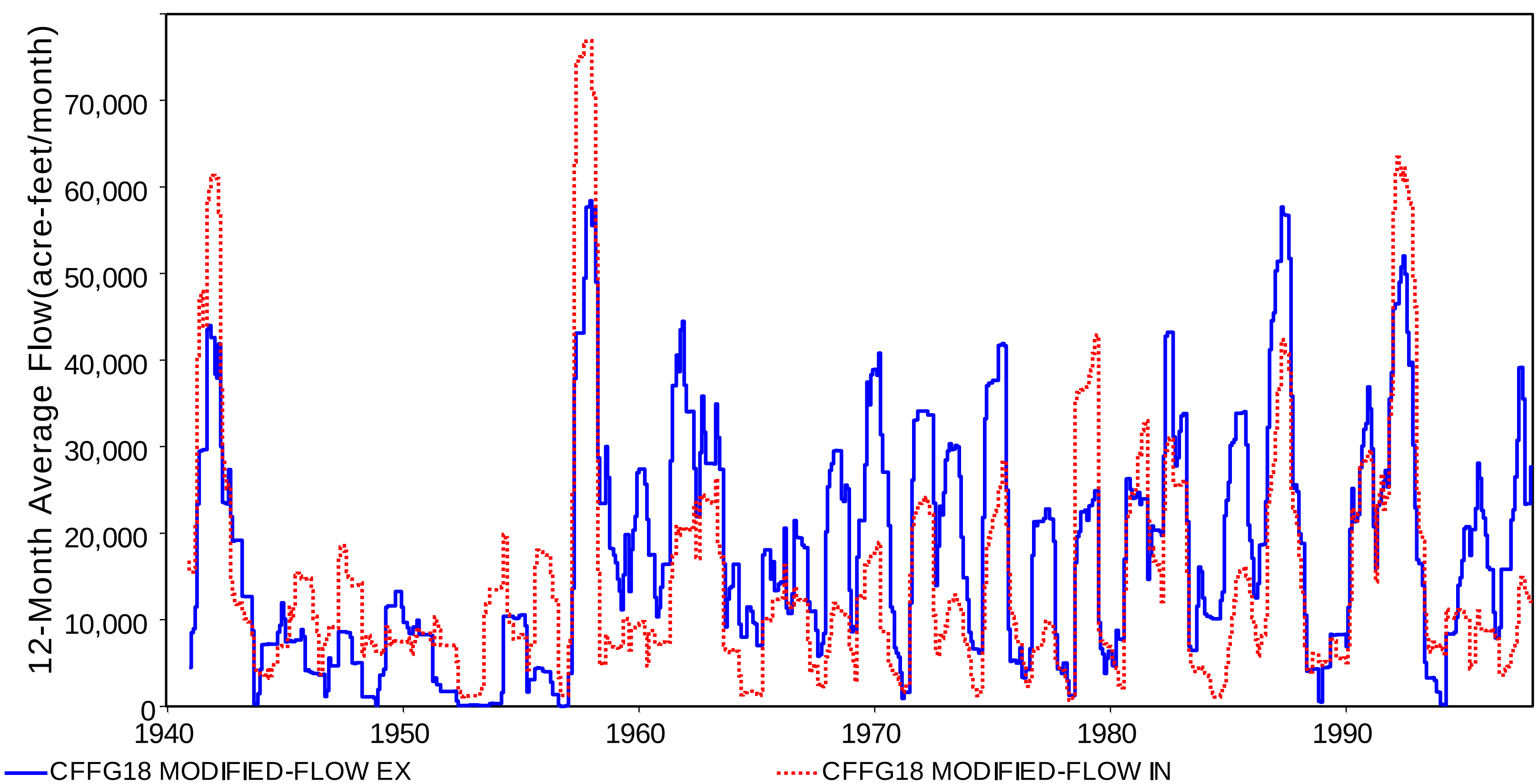


Figure B.3.6 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Clear Fork Brazos

at Fort Griffin CFFG18

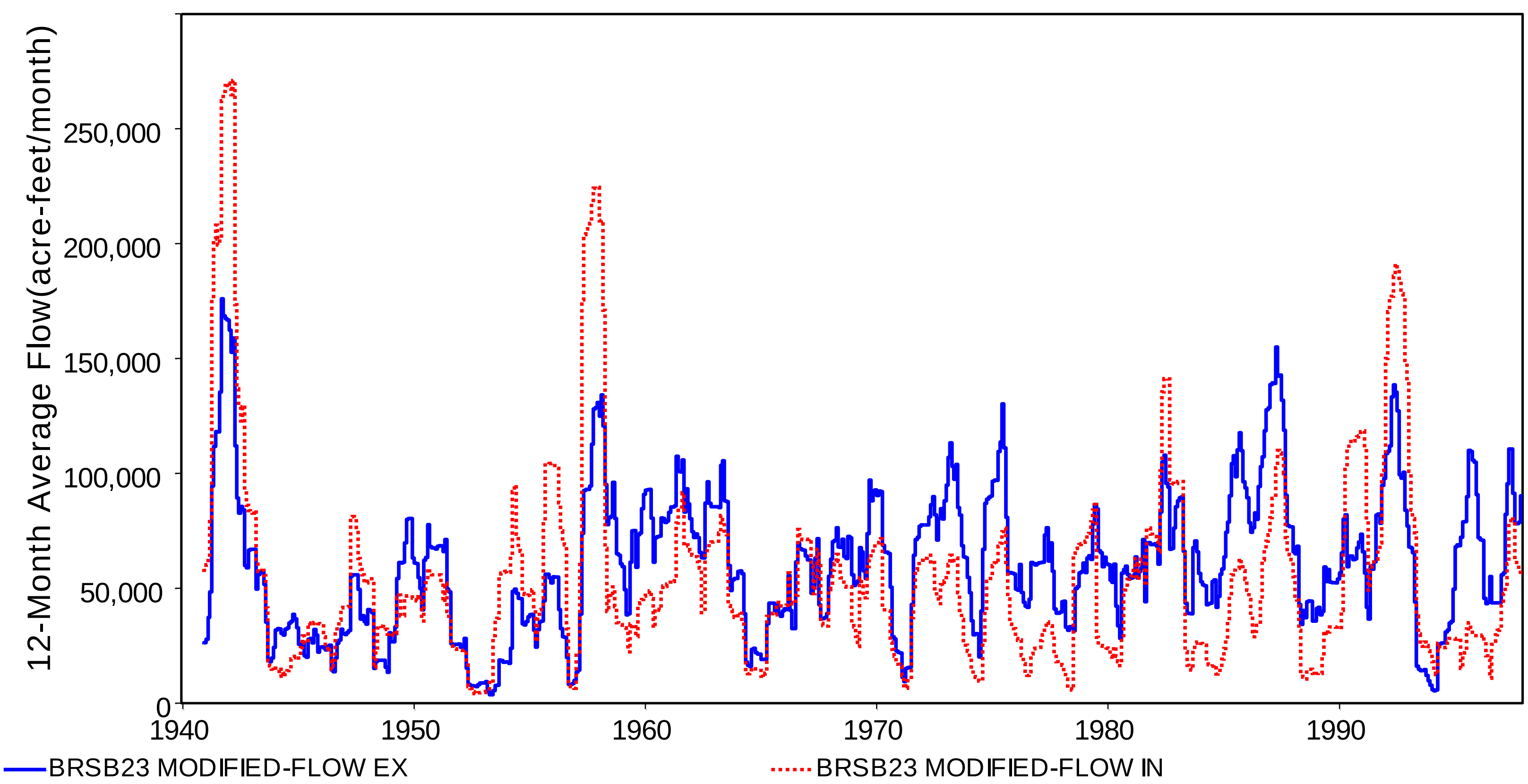


Figure B.3.7 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at South Bend BRSB23

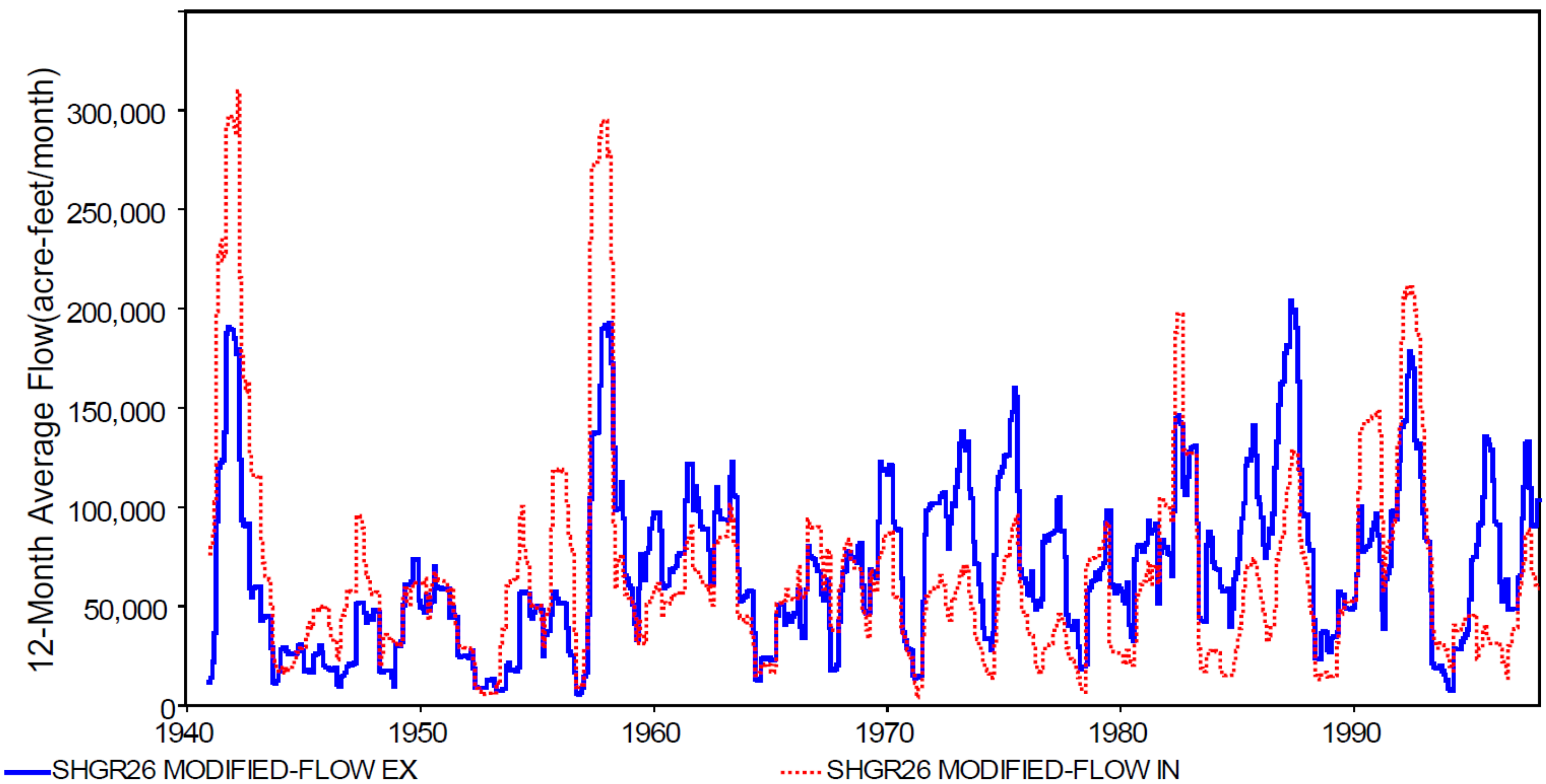


Figure B.3.8 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at Granford SHGR26

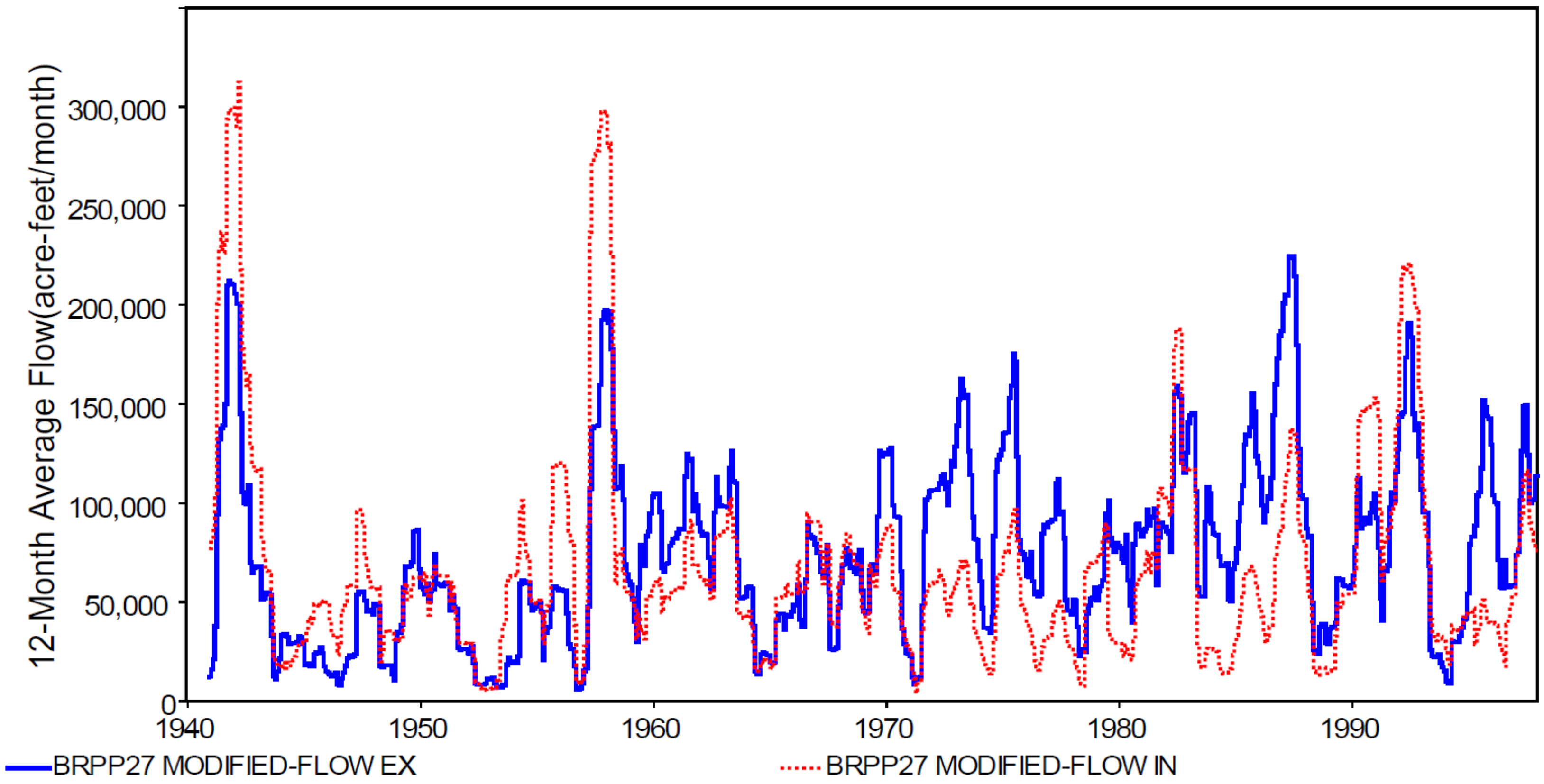


Figure B.3.9 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at Palo Pinto BRPP27

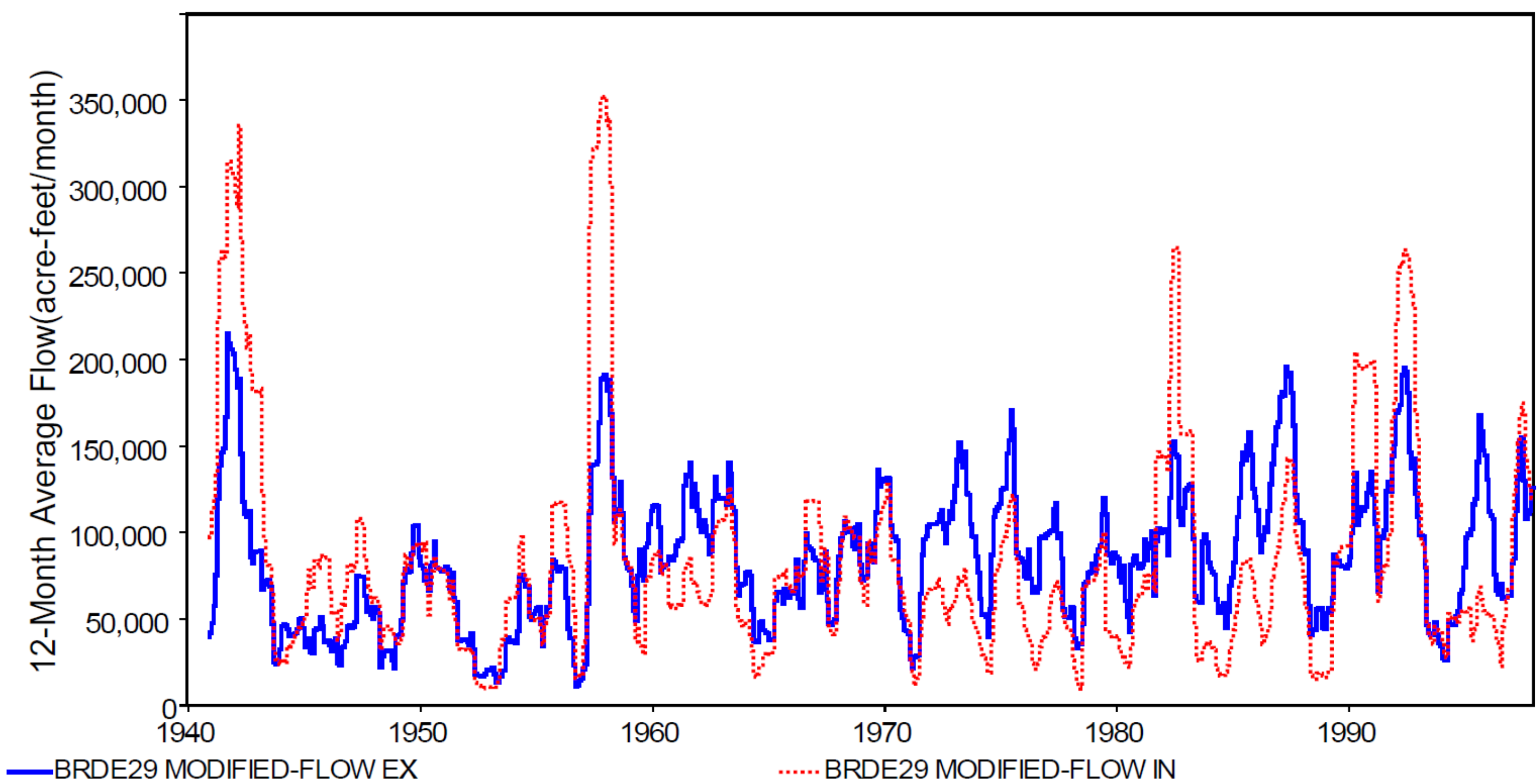


Figure B.3.10 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at Dennis BRDE29

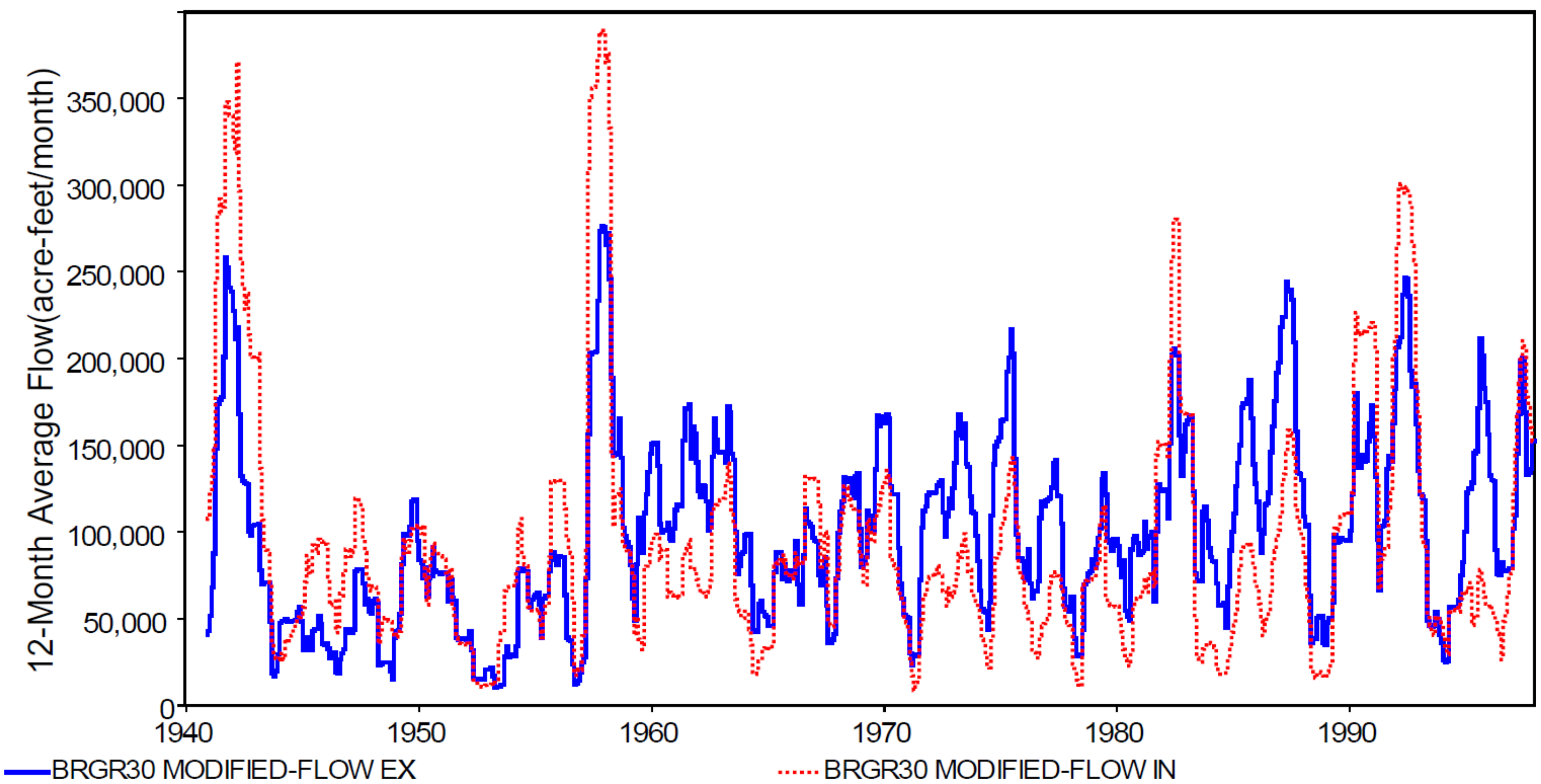


Figure B.3.11 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at Glen Rose BRGR30

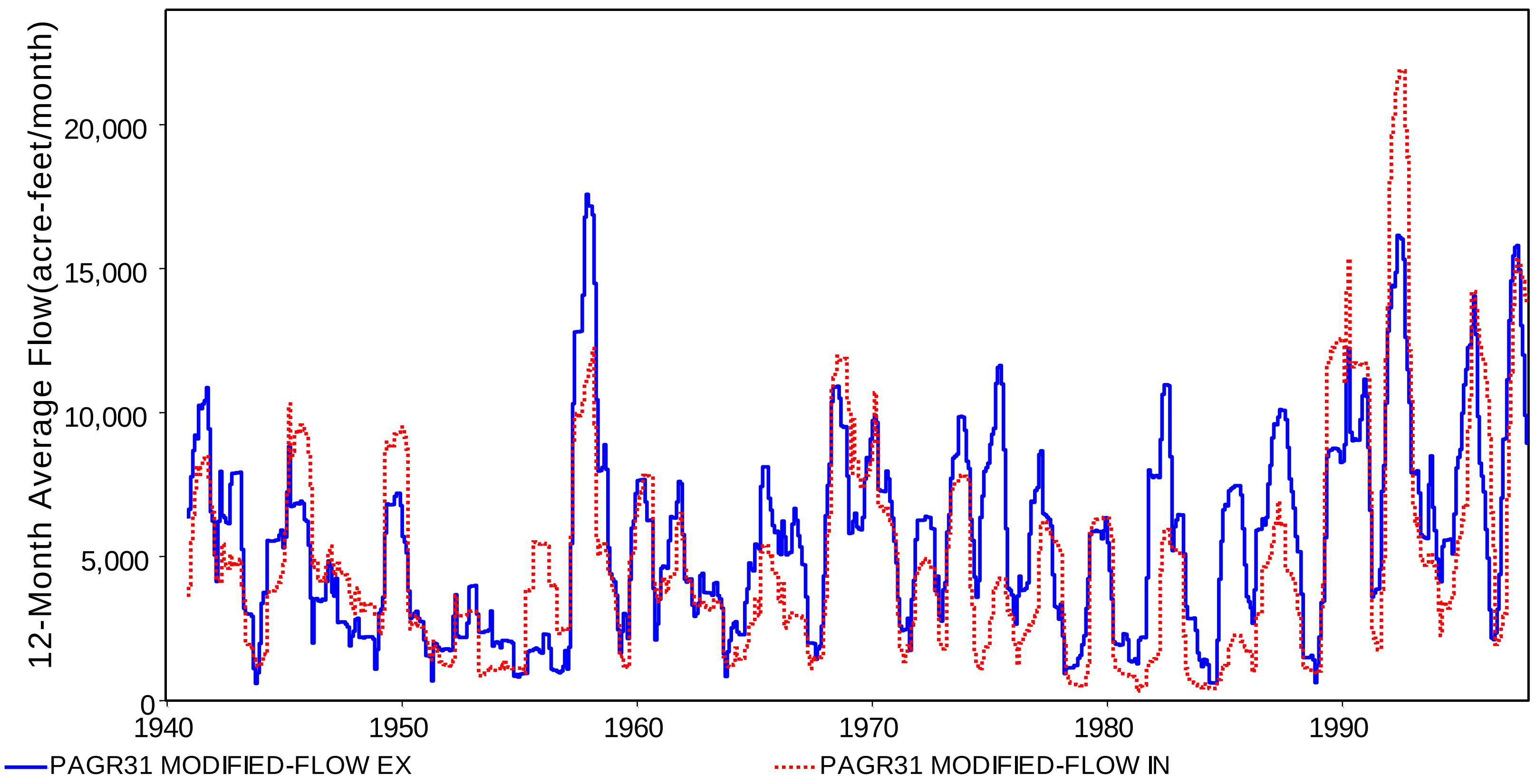


Figure B.3.12 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Paluxy River at Glen Rose PAGR31

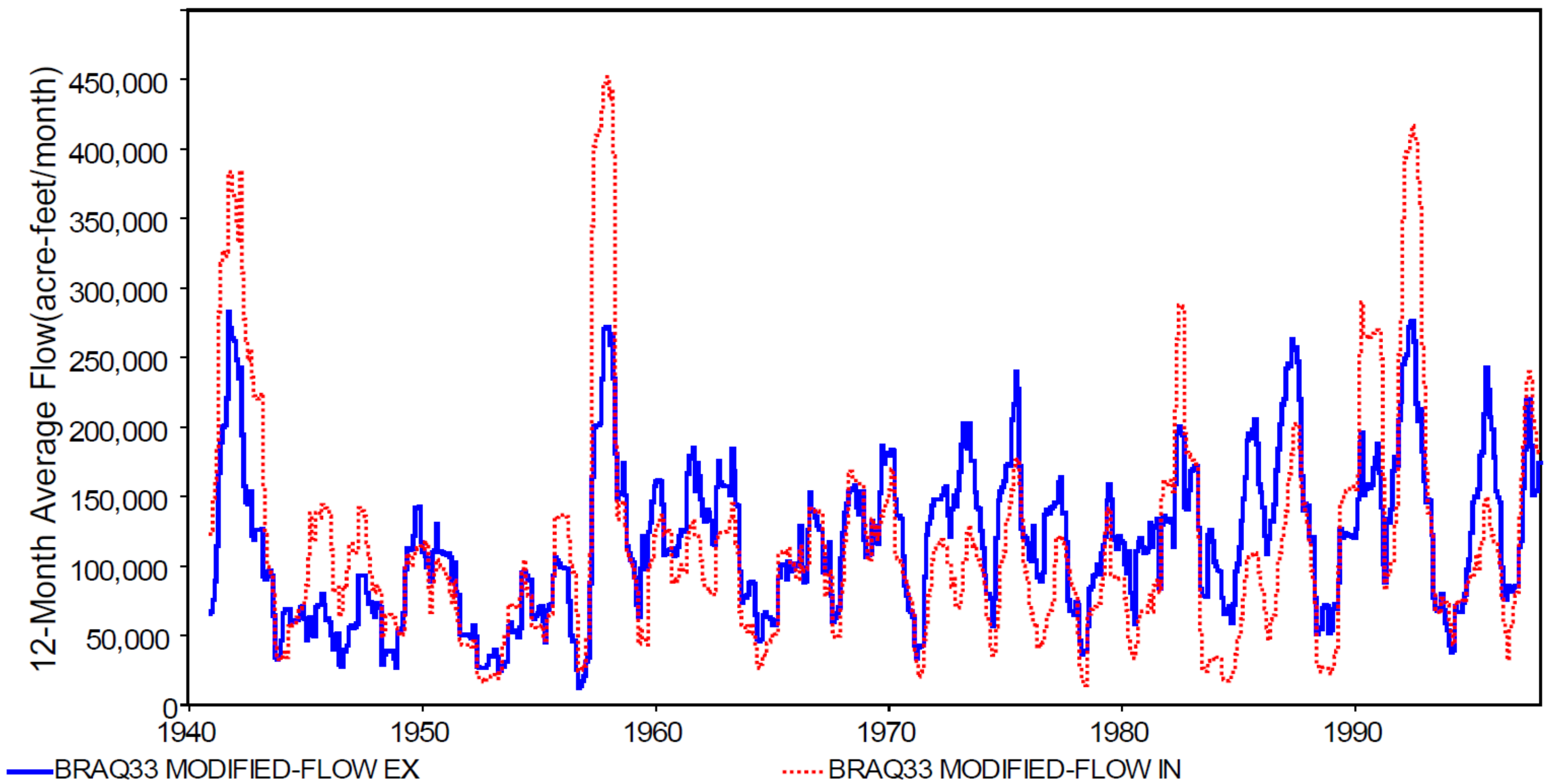


Figure B.3.13 Known and Level-1Computed 12-Month Forward Moving Average Flows for Brazos River at Aquilla BRAQ33

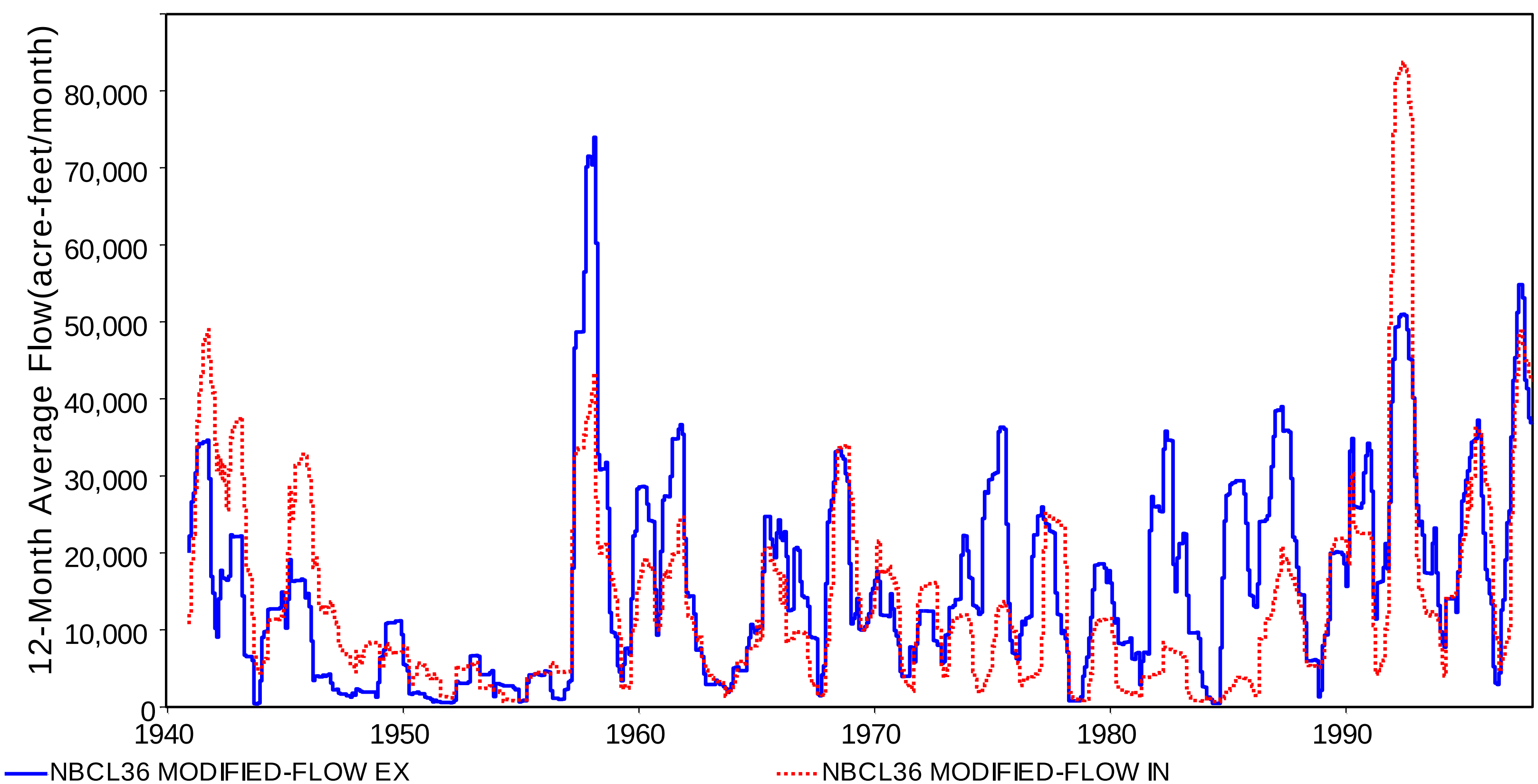


Figure B.3.14 Known and Level-1 Computed 12-Month Forward Moving Average Flows for North Bosque River at Clifton NBCL36

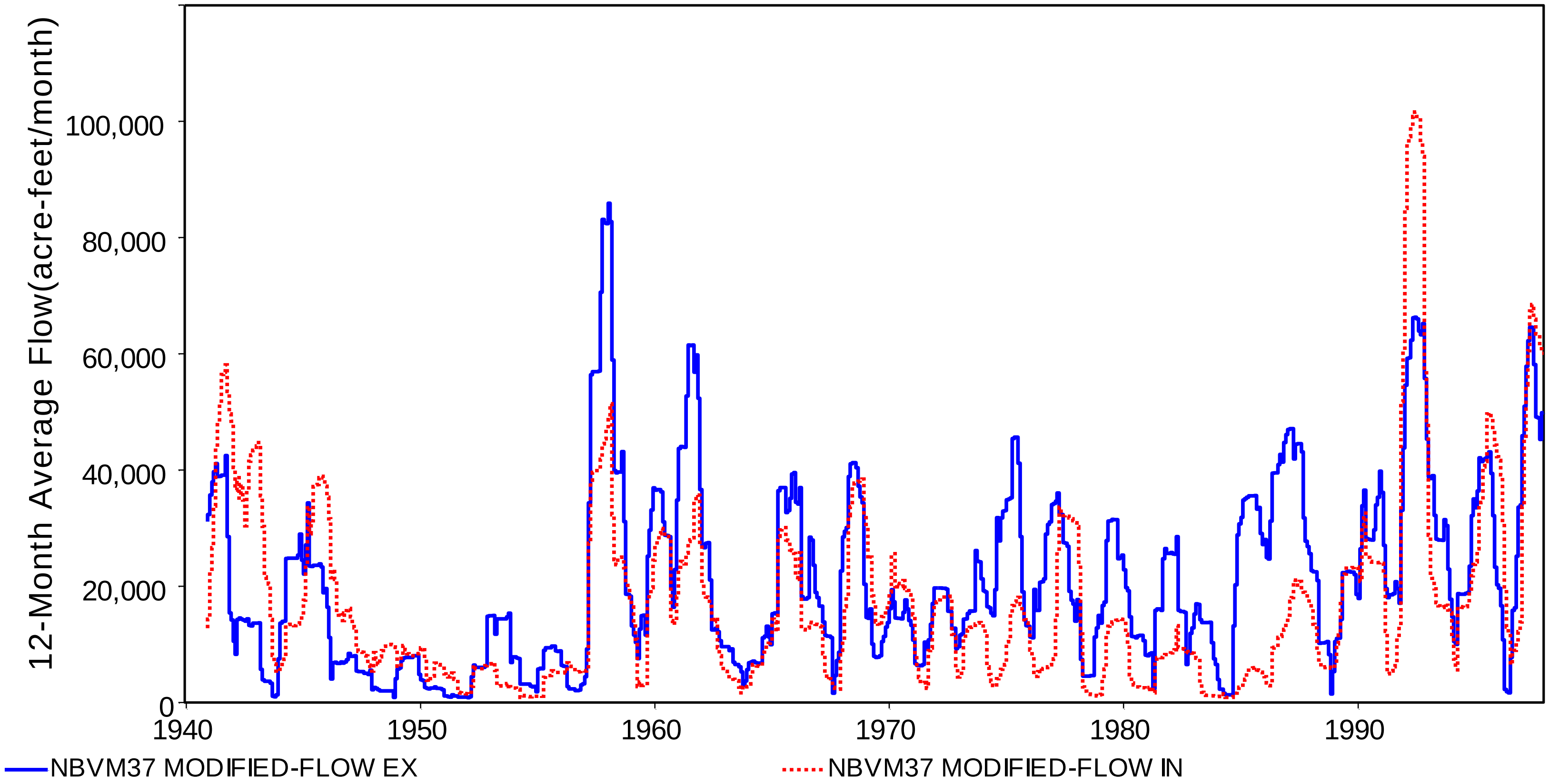


Figure B.3.15 Known and Level-1 Computed 12-Month Forward Moving Average Flows for North Bosque River at Valley Mills NBVM37

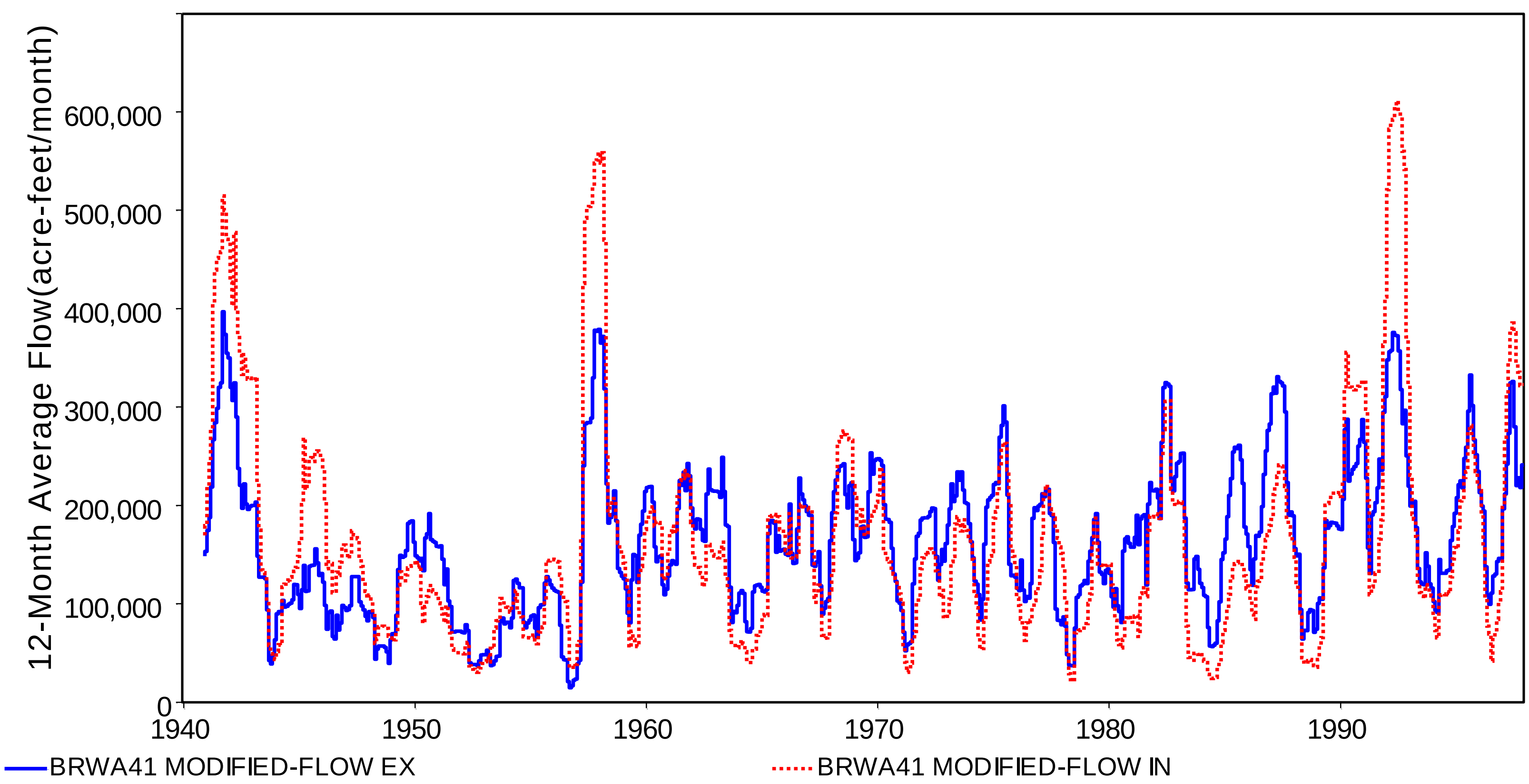


Figure B.3.16 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at Waco BRWA41

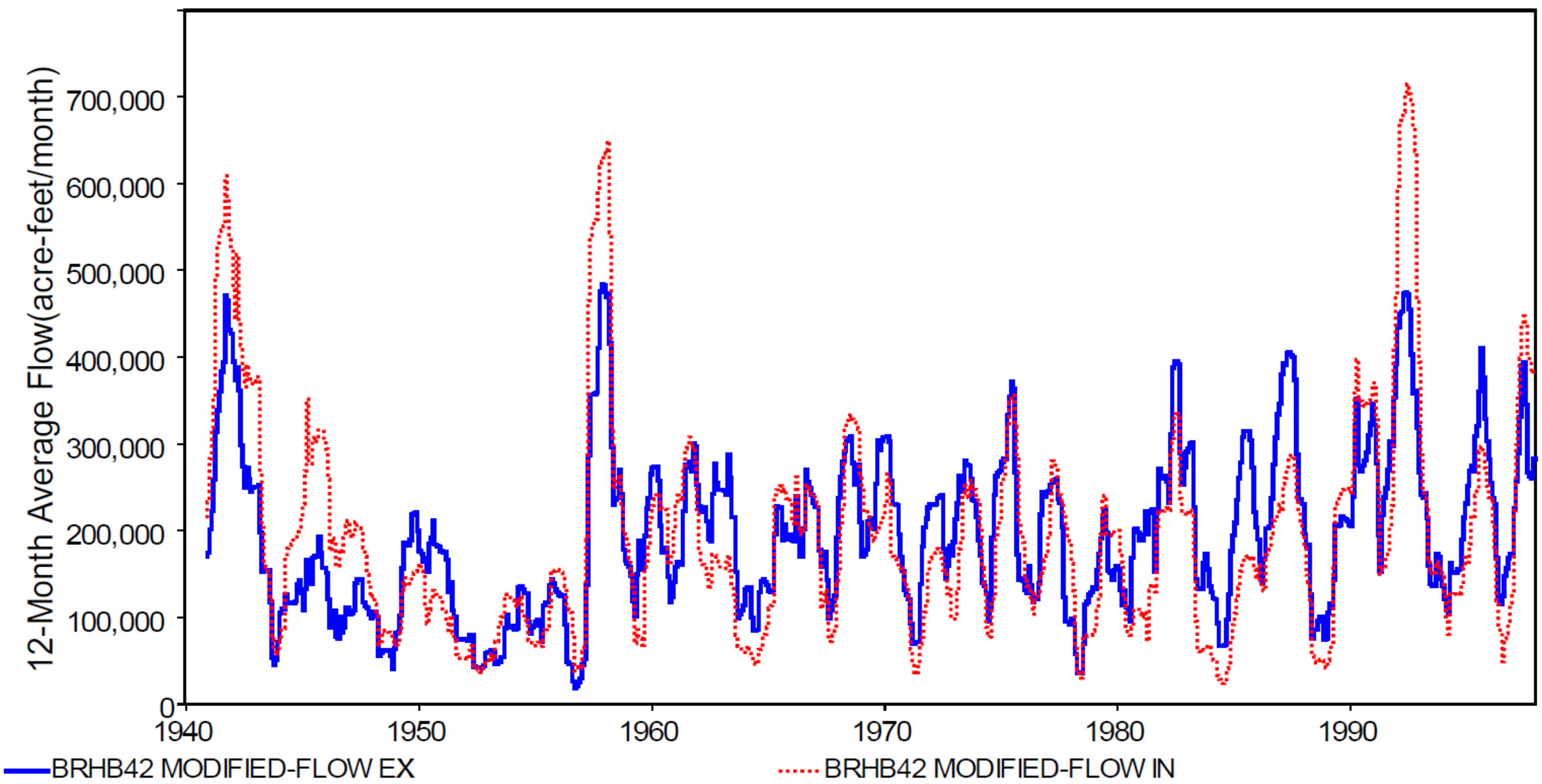


Figure B.3.17 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at Highbank BRHB42

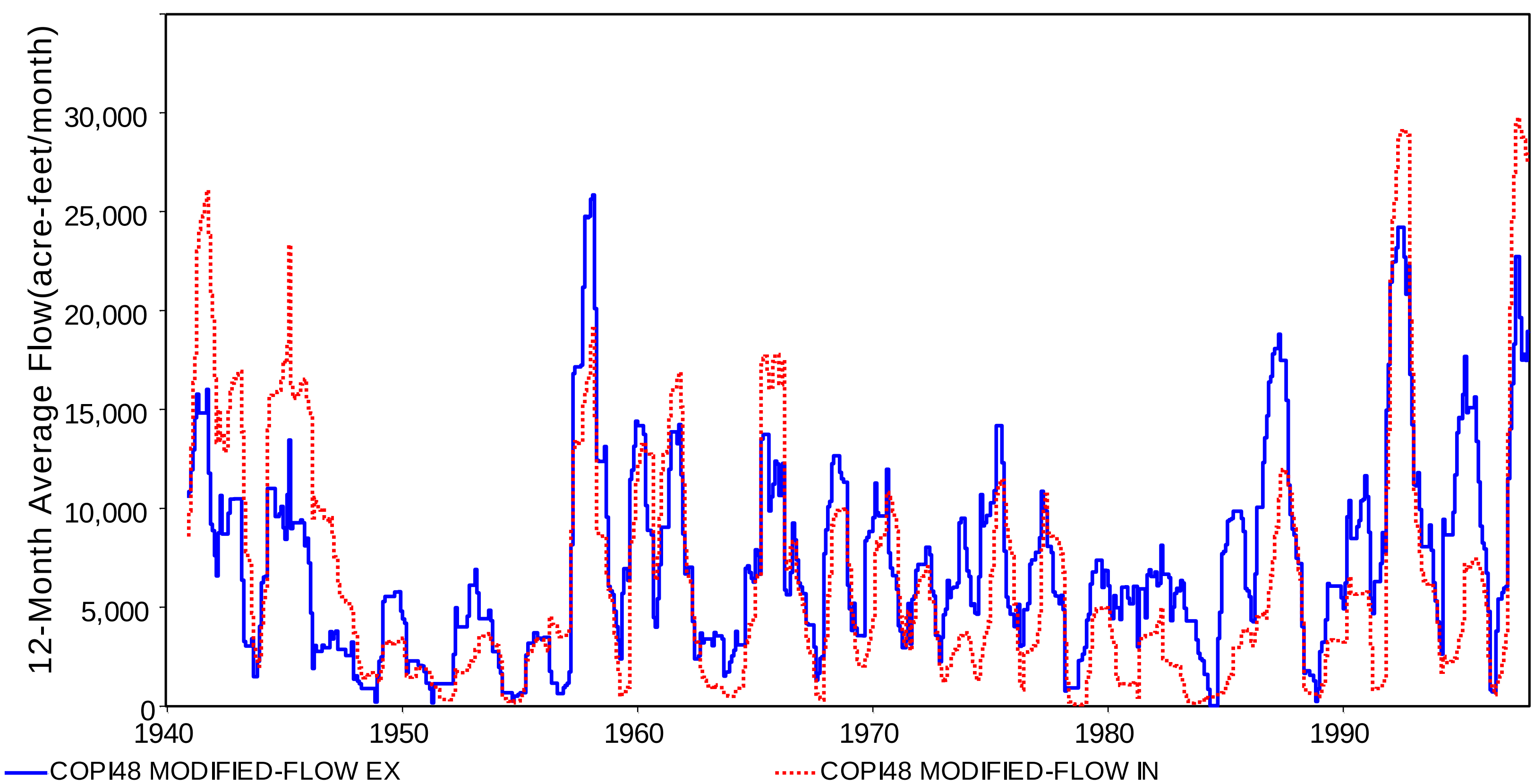


Figure B.3.18 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Cowhouse Creek at Pidcoke COPI48

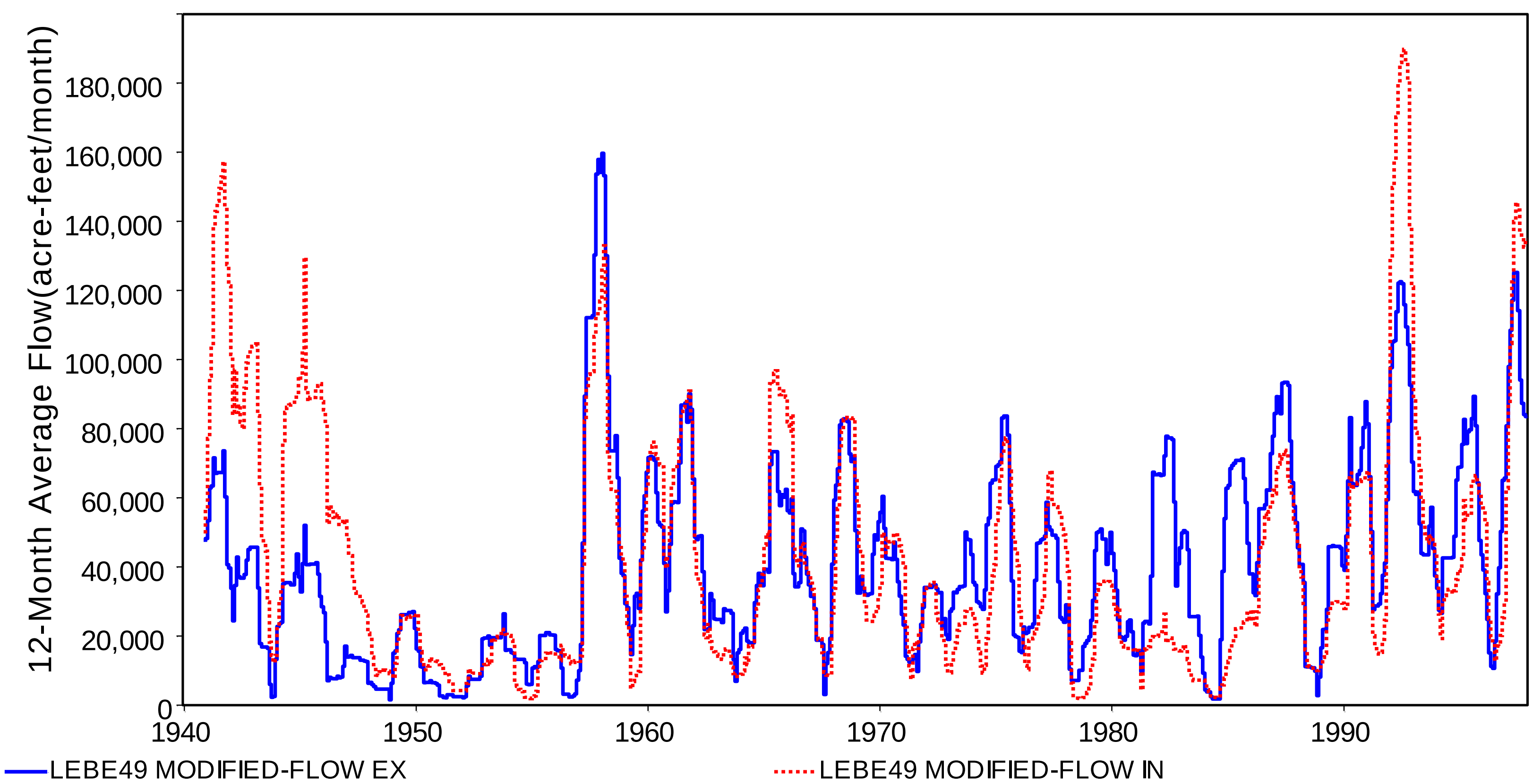


Figure B.3.19 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Leon River at Belton LEBE49

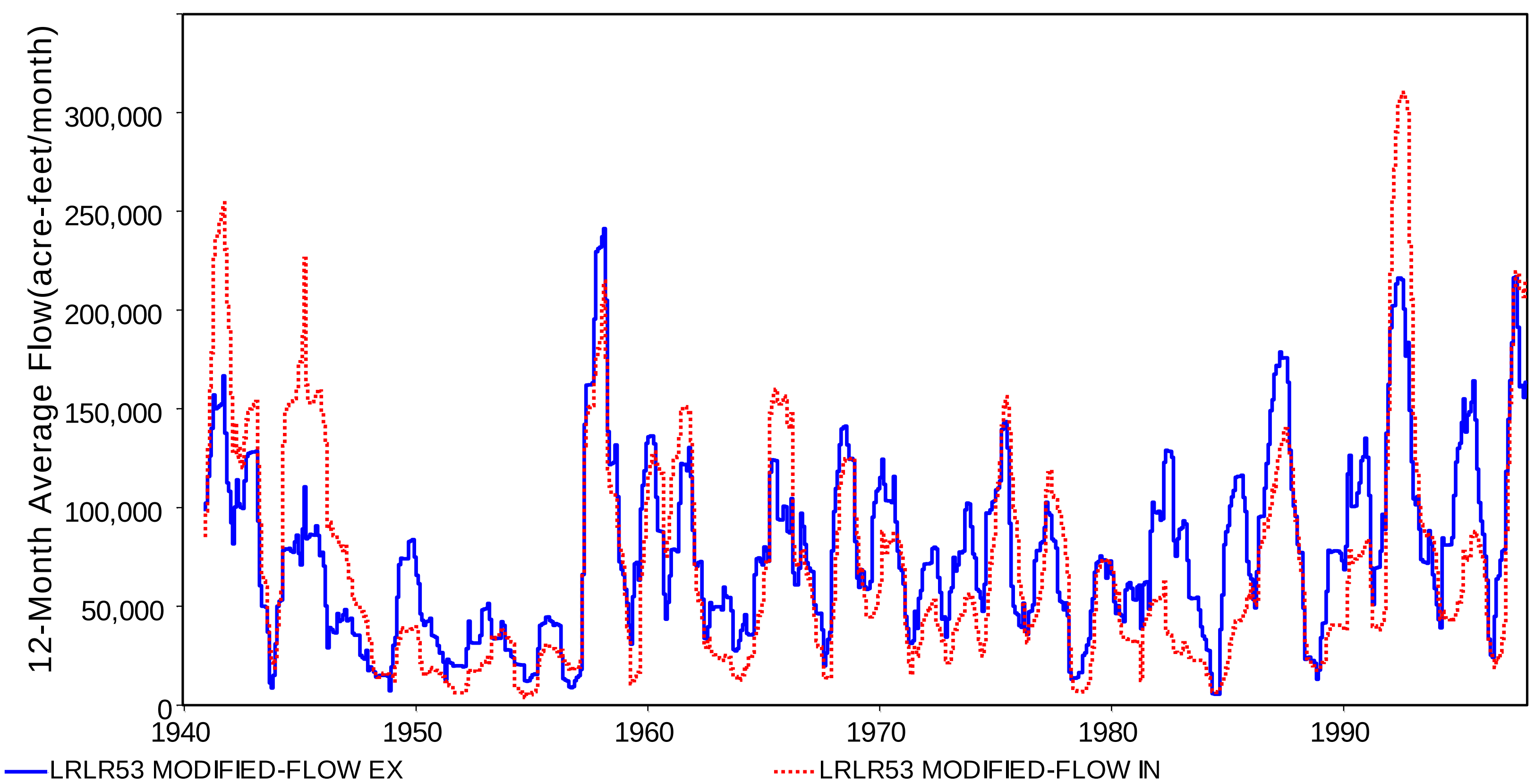


Figure B.3.20 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Little River at Little River LRLR53

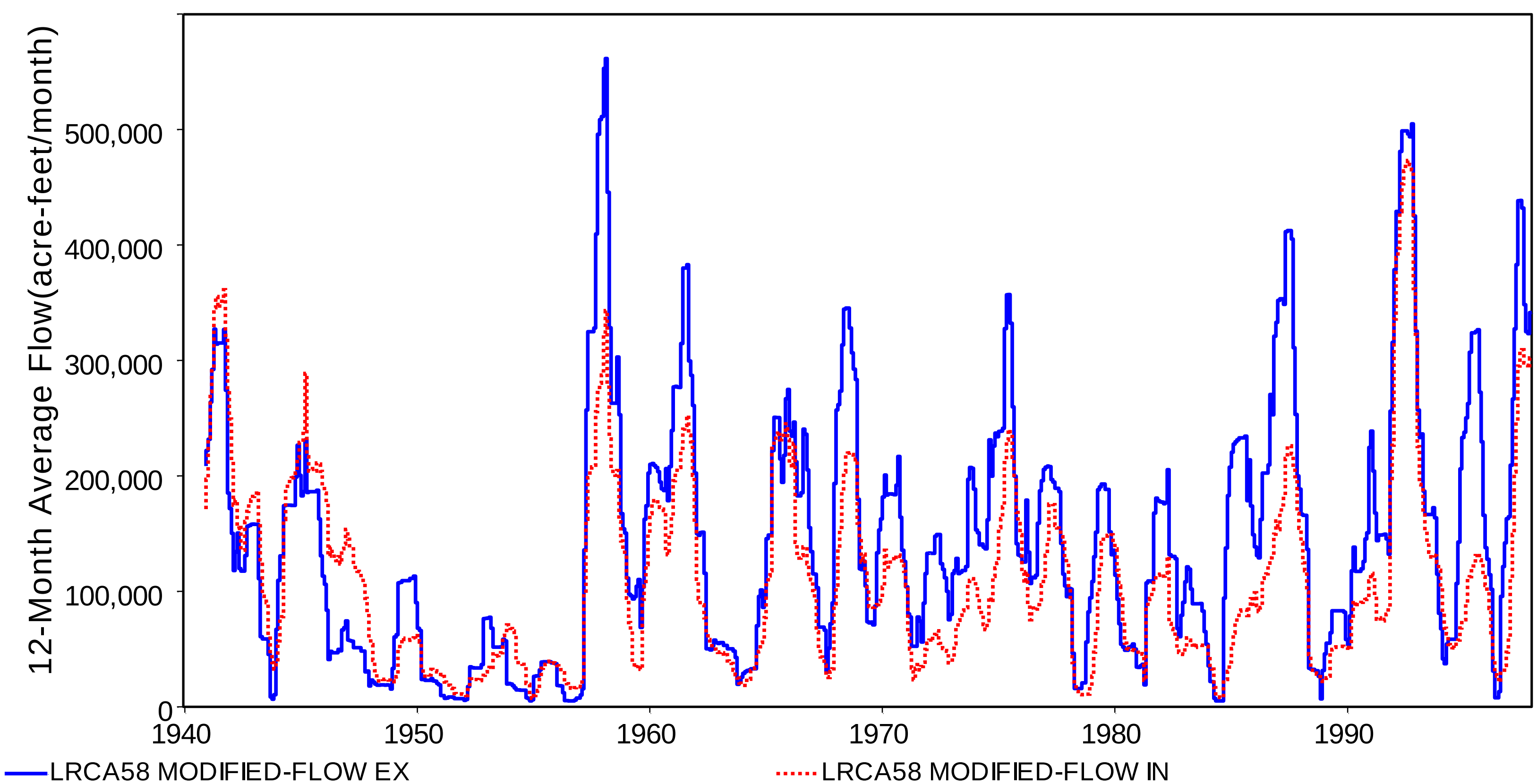


Figure B.3.21 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Little River at Cameron LRCA58

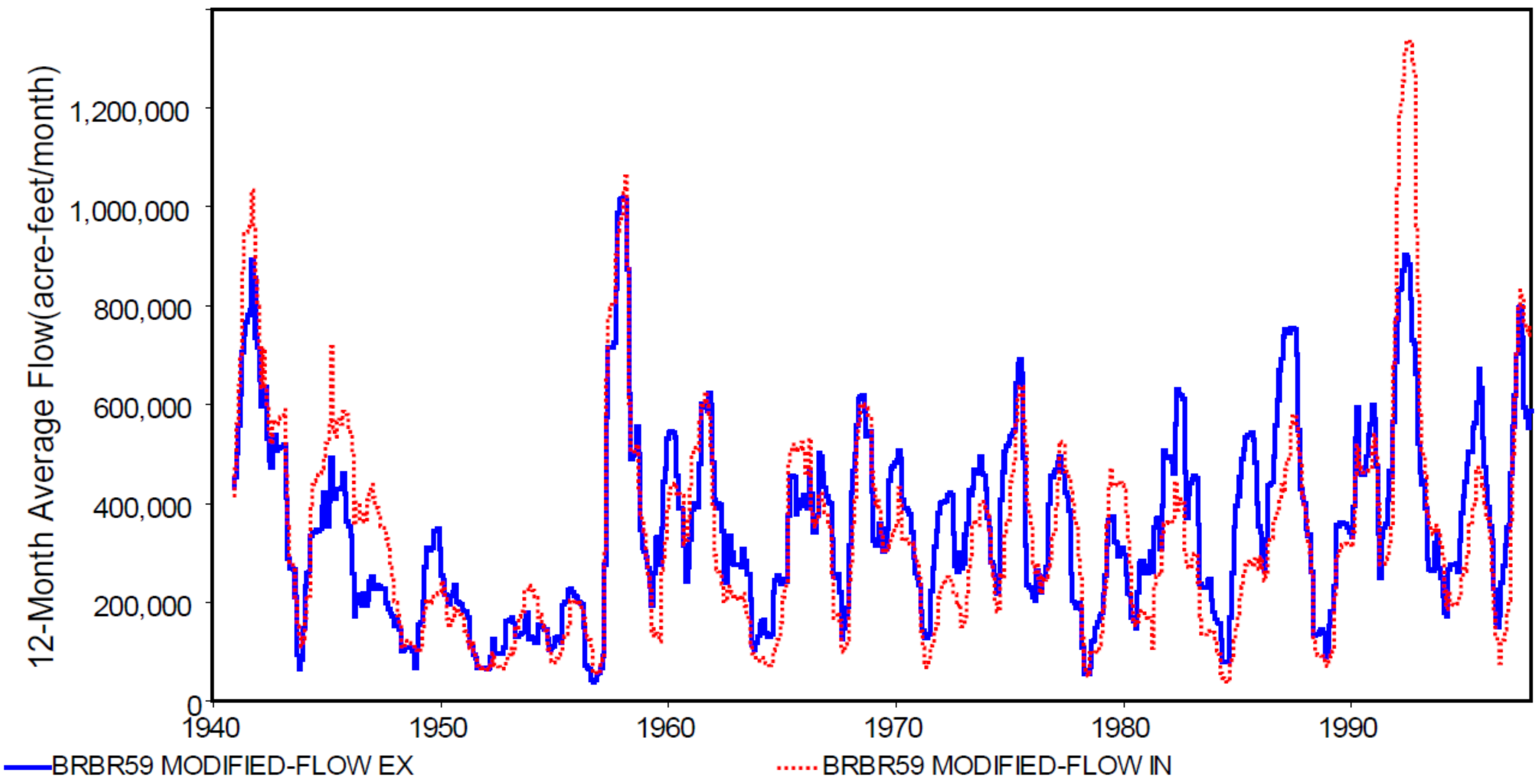


Figure B.3.22 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at Bryan BRBR59

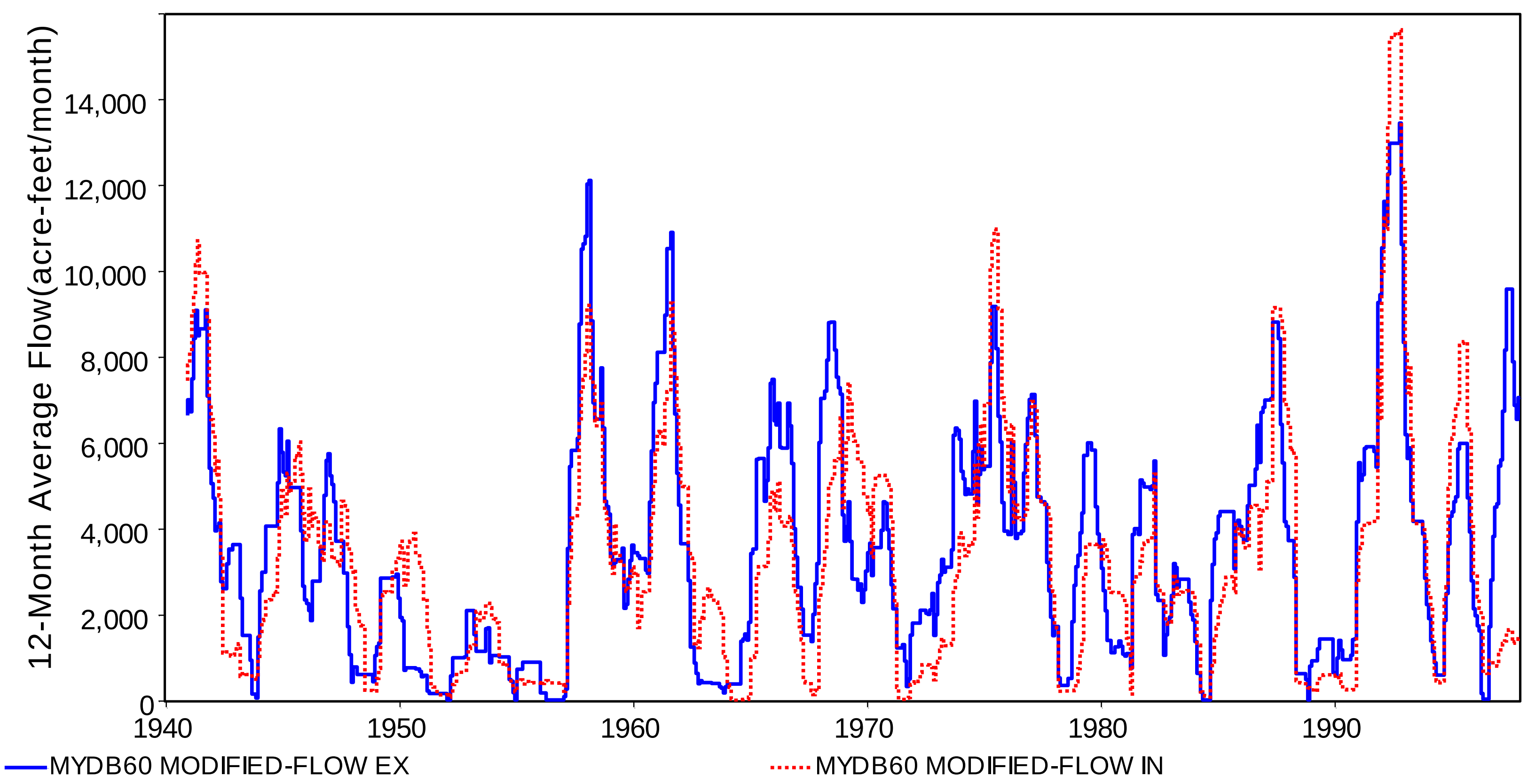


Figure B.3.23 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Middle Yegua Creek at Dime Box MYDB60

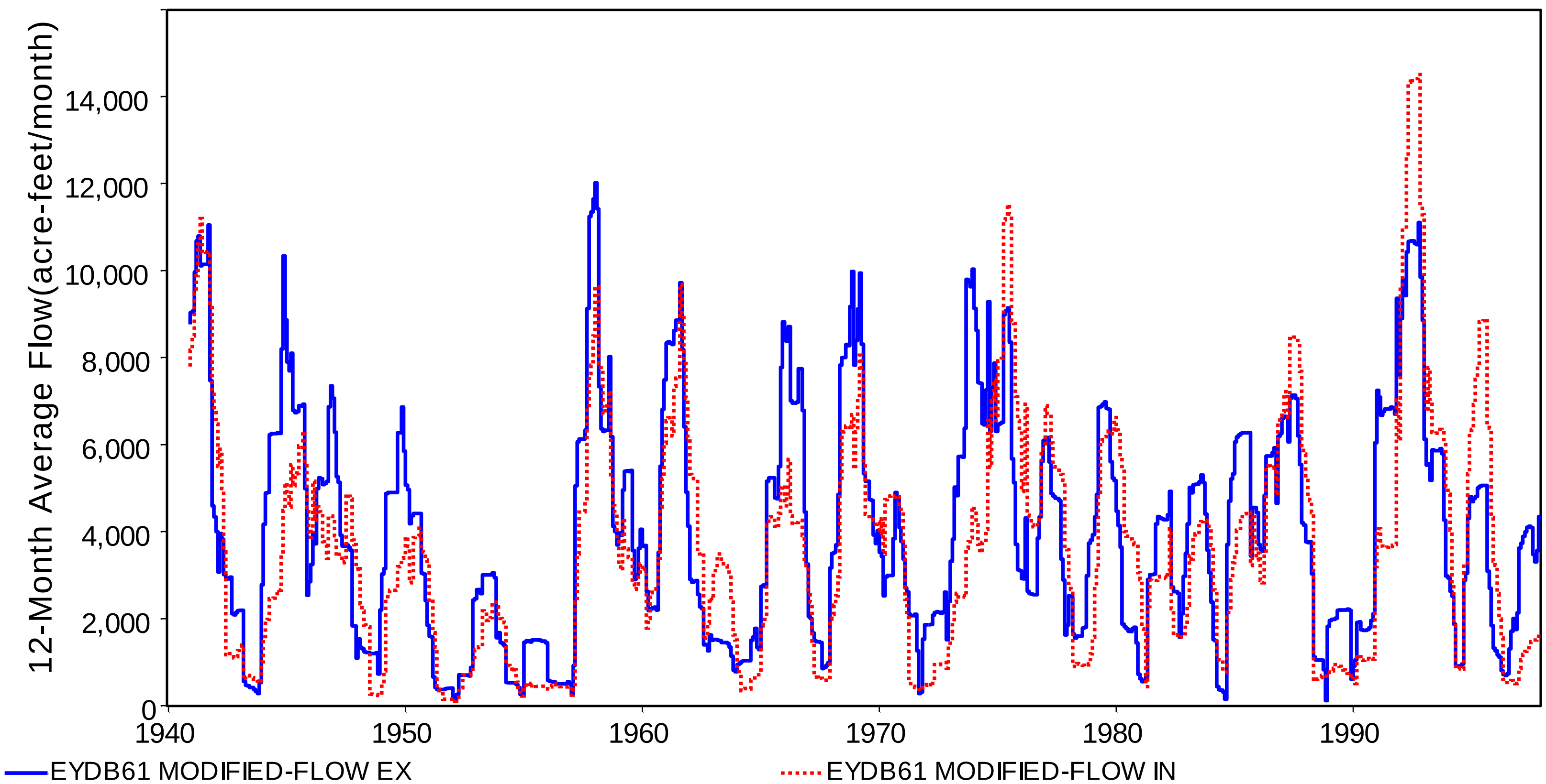


Figure B.3.24 Known and Level-1 Computed 12-Month Forward Moving Average Flows for East Yegua Creek at Dime Box EYDB61

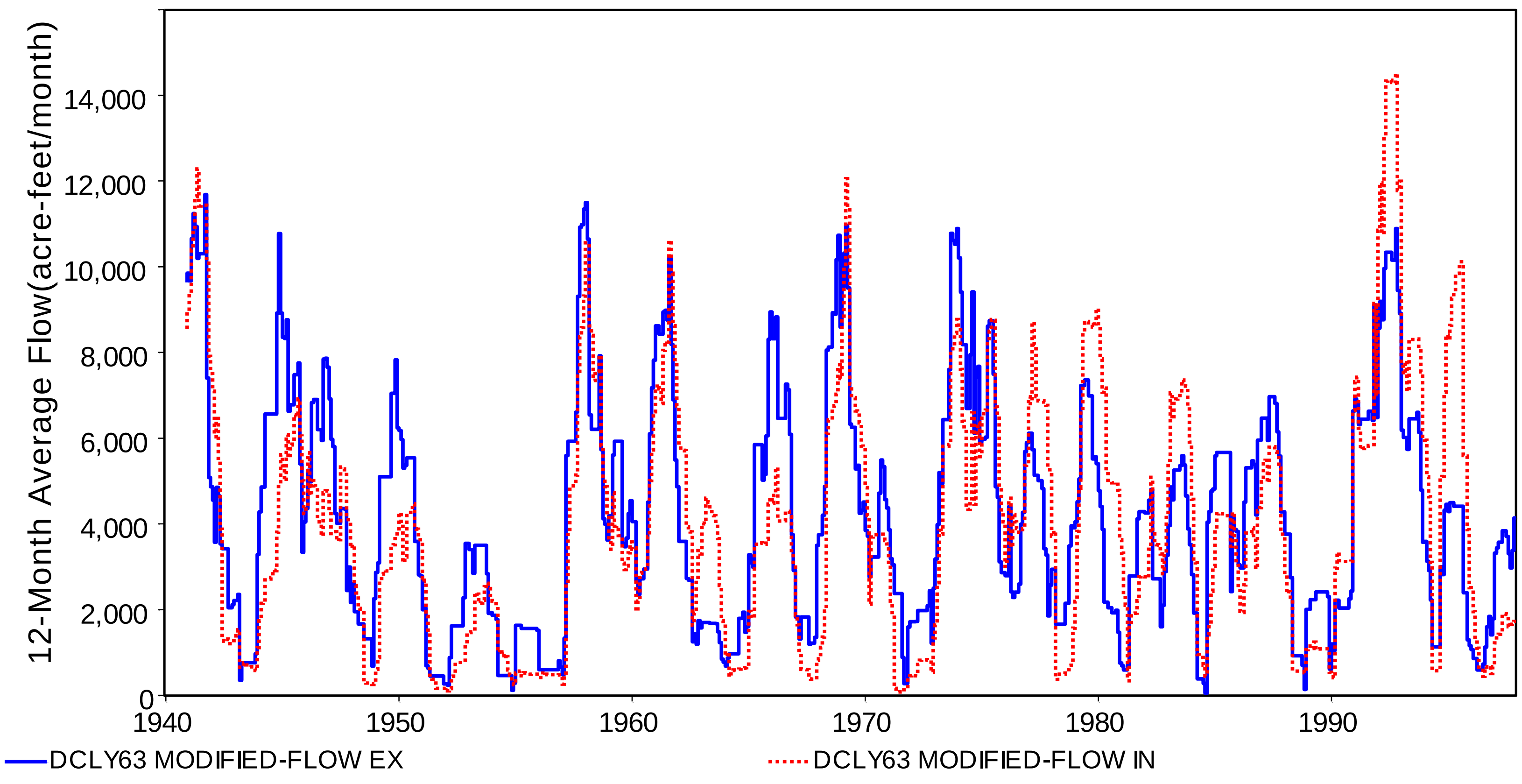


Figure B.3.25 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Davidson Creek at Lyons DCLY63

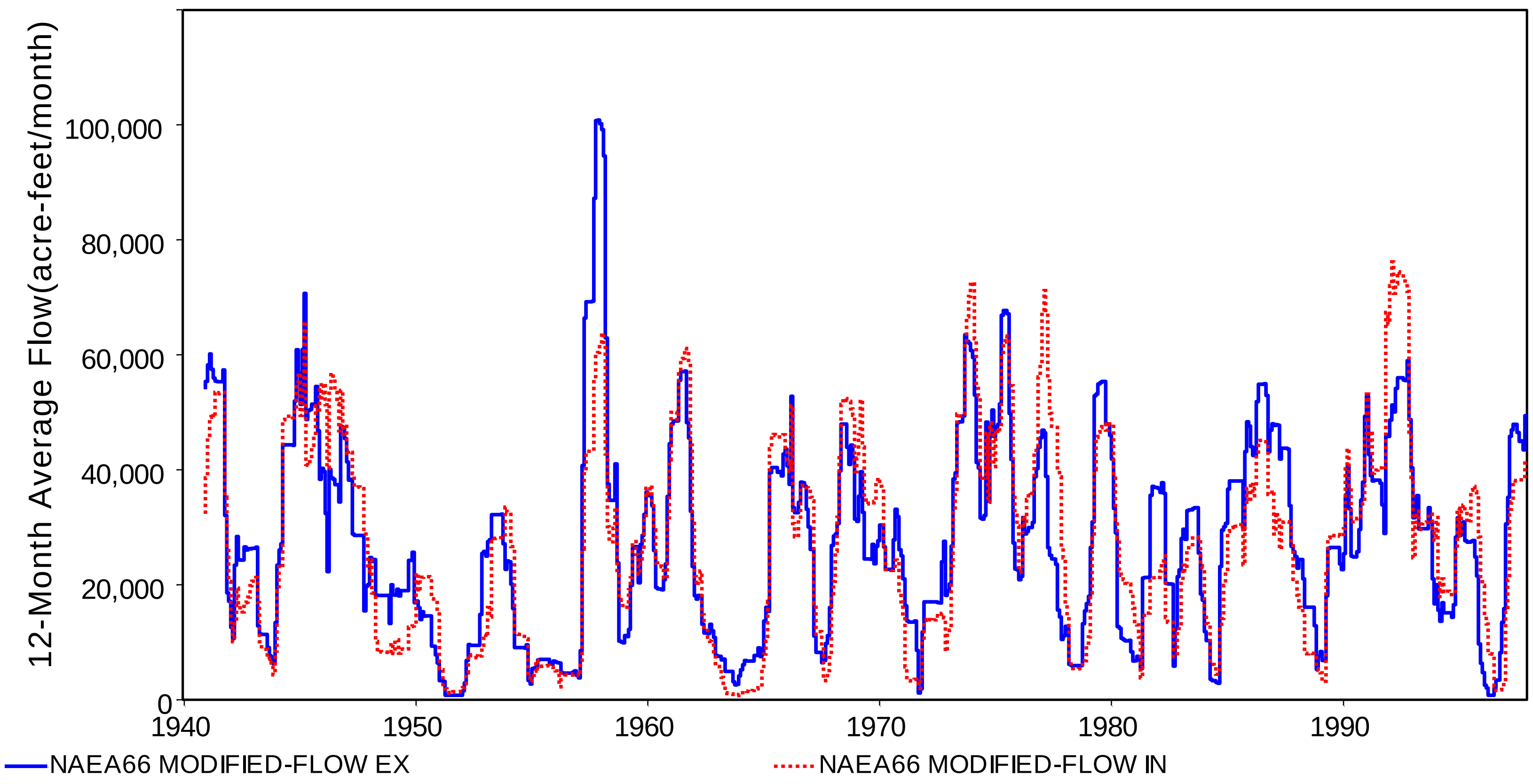


Figure B.3.26 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Navasota River at Easterly NAEA66

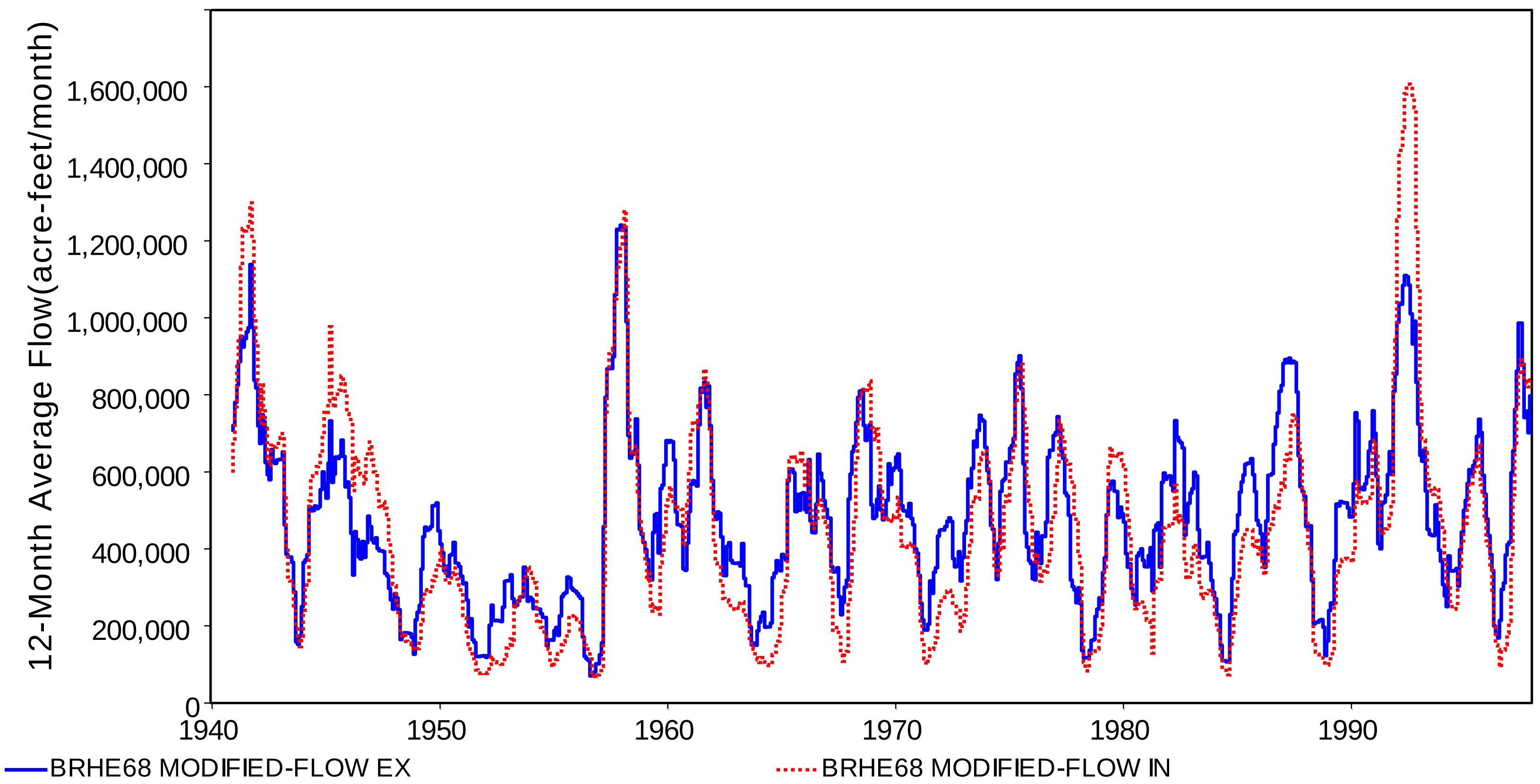


Figure B.3.27 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at Hempstead BRHE68

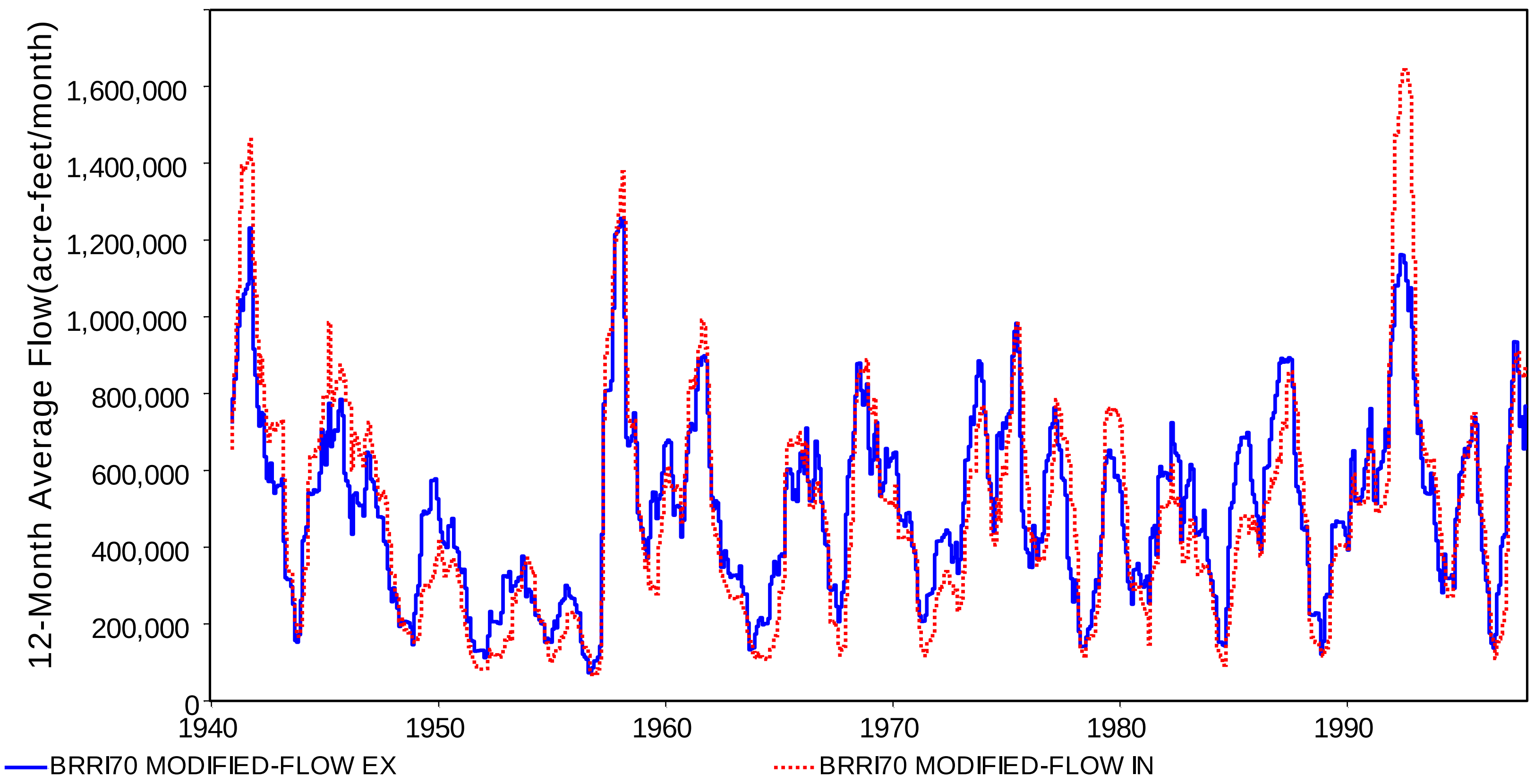


Figure B.3.28 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at Richmond BRRI70

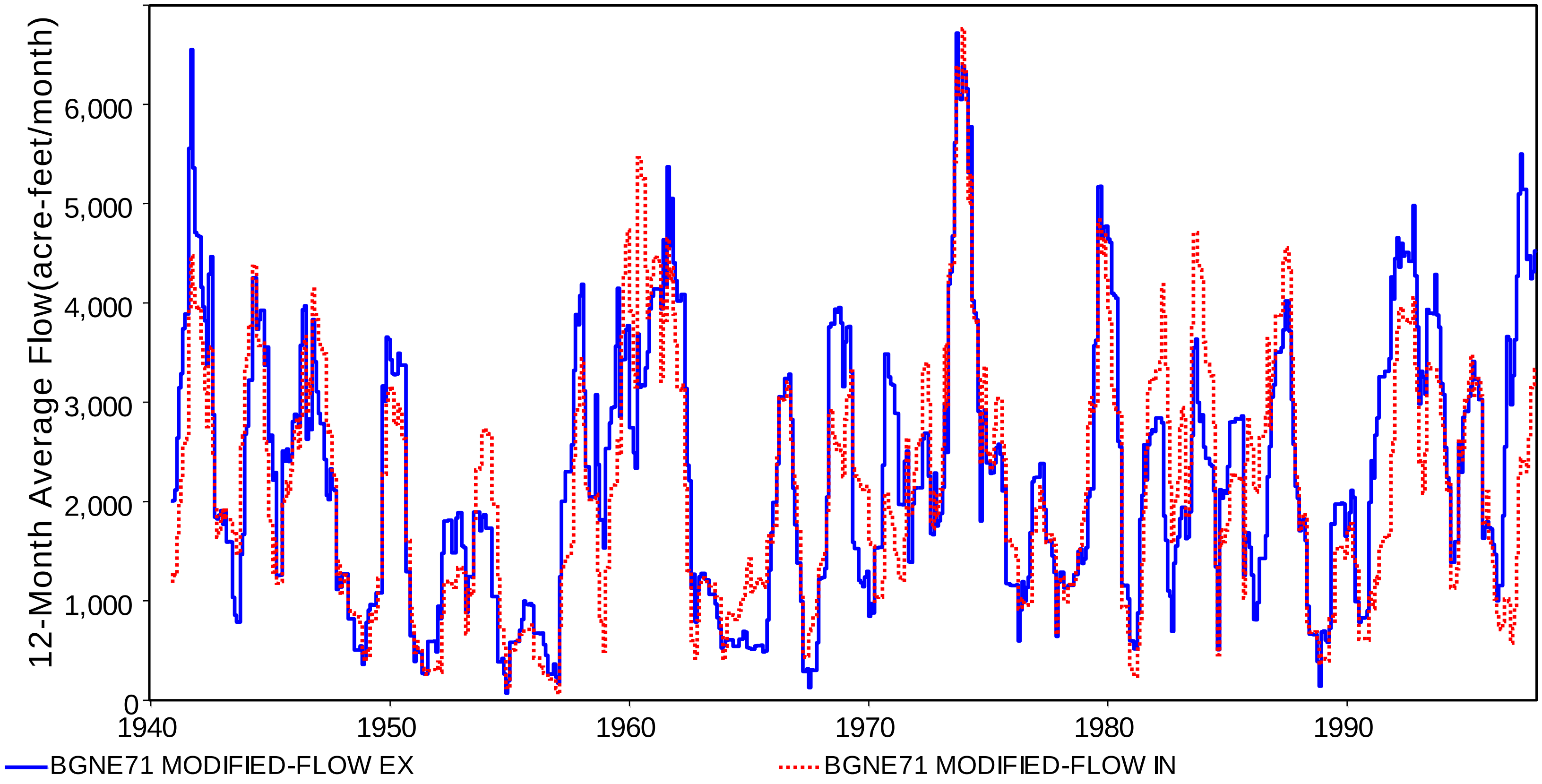


Figure B.3.29 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Big Creek at Needville BGNE71

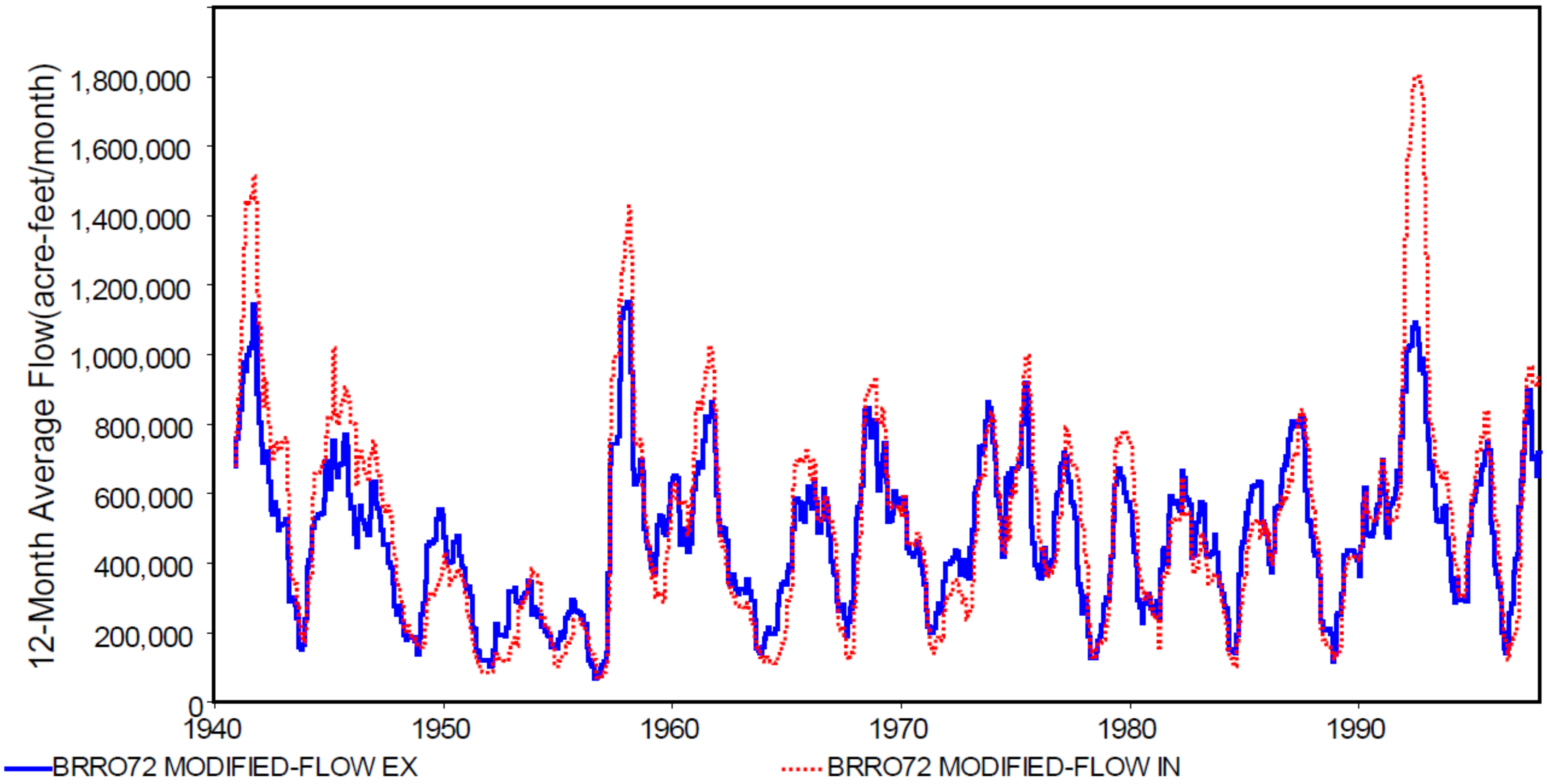


Figure B.3.30 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at Rosharon BRRO72

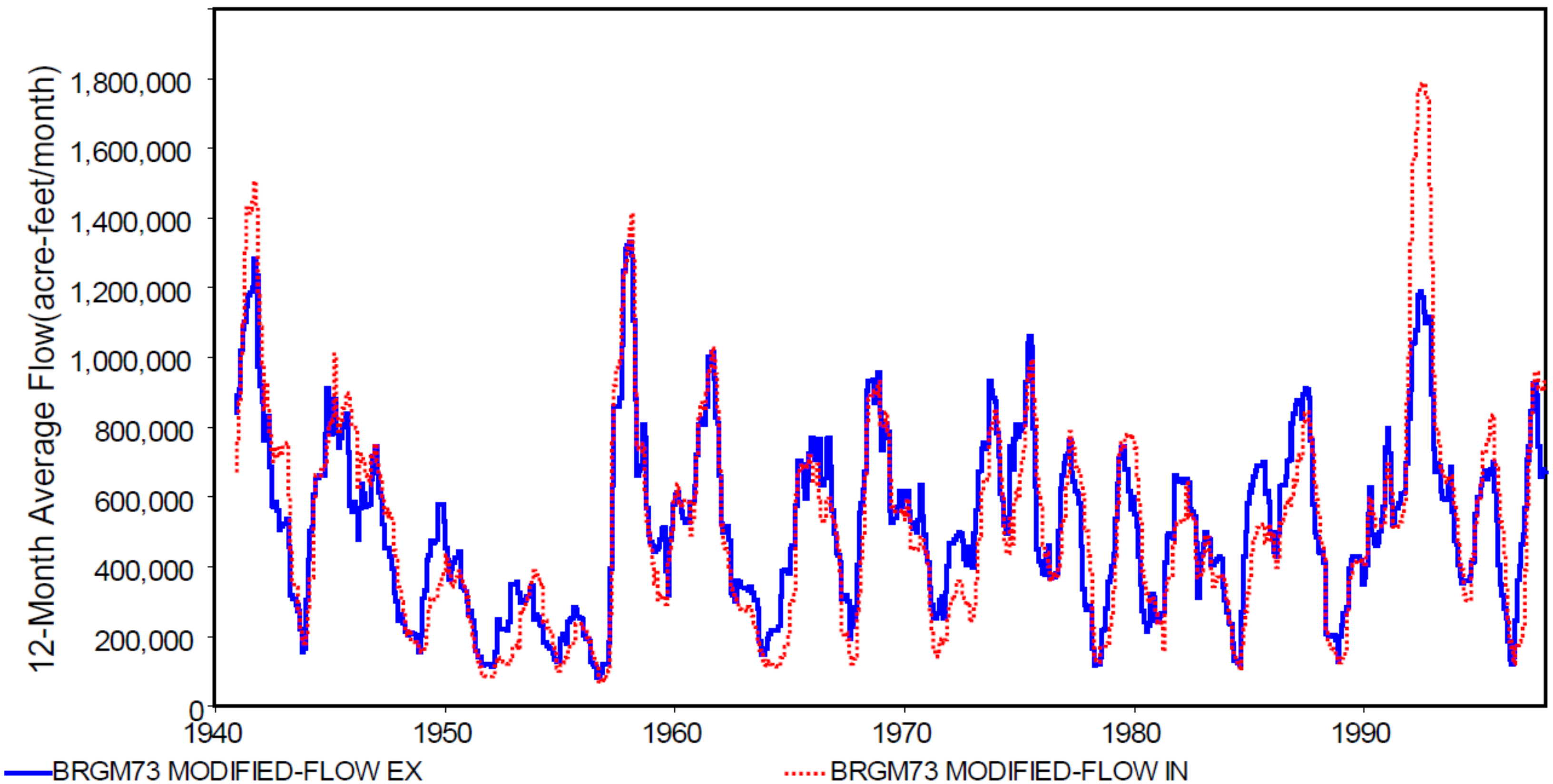


Figure B.3.31 Known and Level-1 Computed 12-Month Forward Moving Average Flows for Brazos River at Gulf of Mexico BRGM73

B.4 Known & Final Computed 12-Month Forward Moving Average

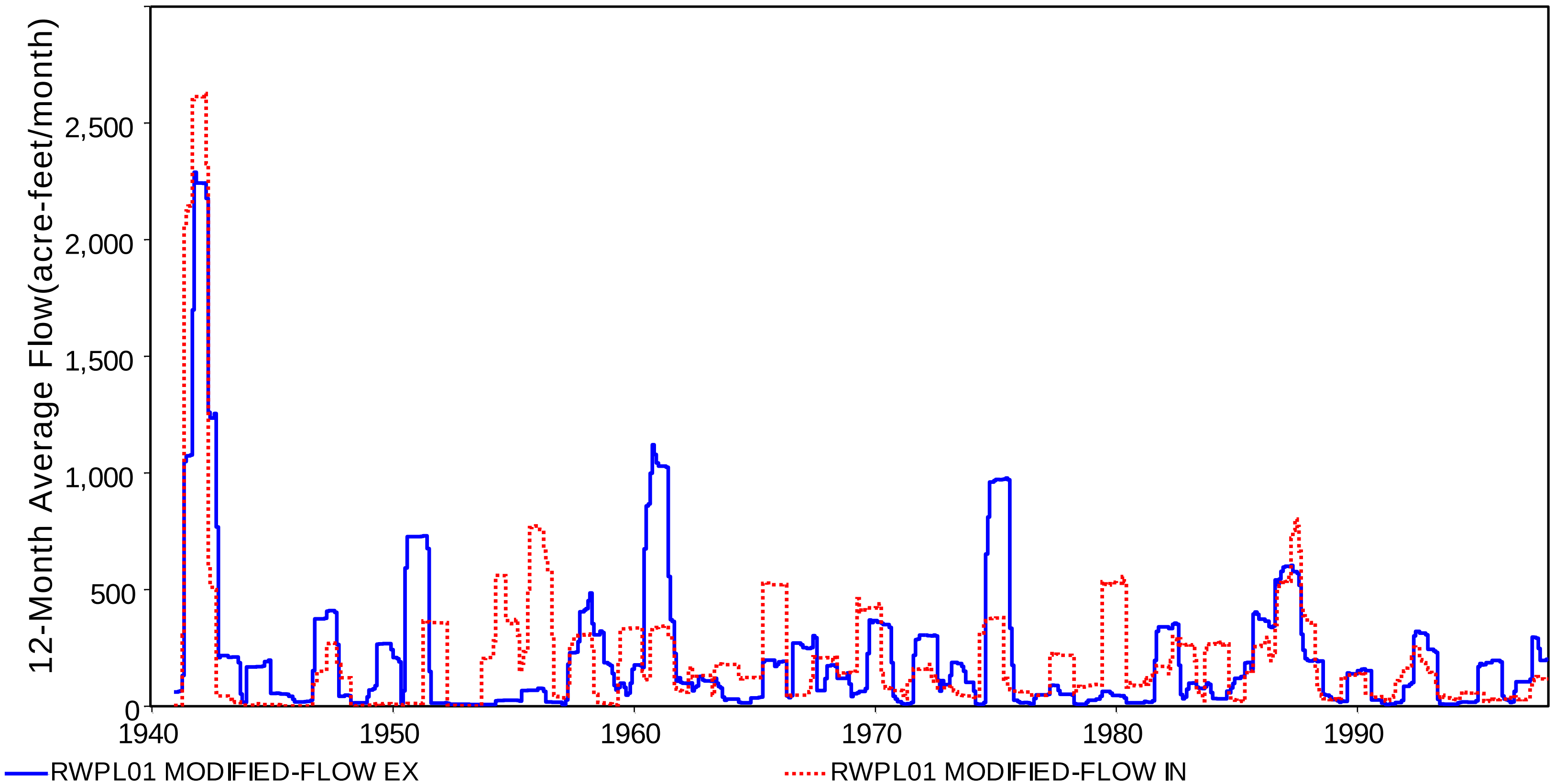


Figure B.4.1 Known and Final Computed 12-Month Forward Moving Average Flows for Running Water Draw at Plainview RWPL01

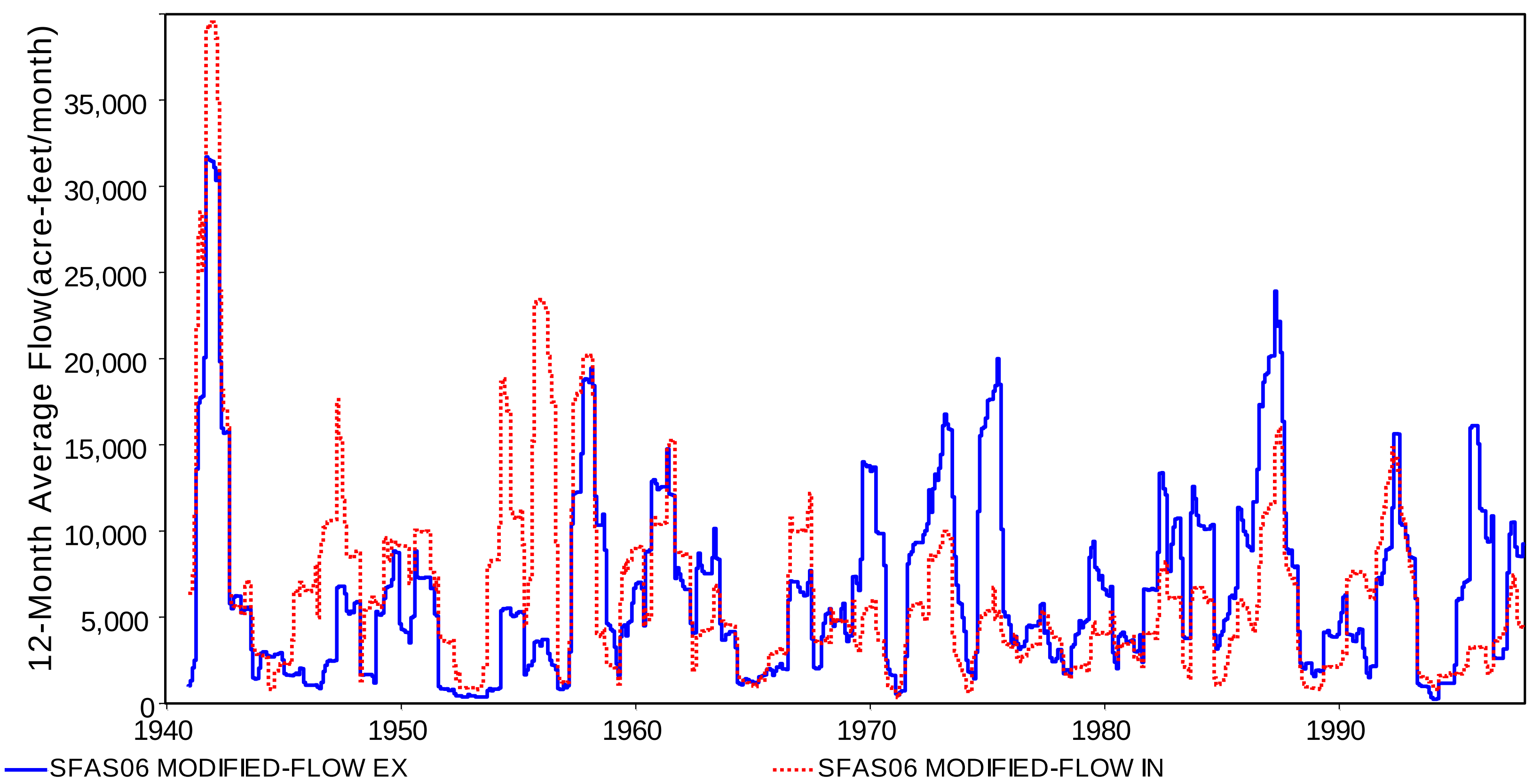


Figure B.4.2 Known and Final Computed 12-Month Forward Moving Average Flows for Salt Fork Brazos River at Aspermont SFAS06

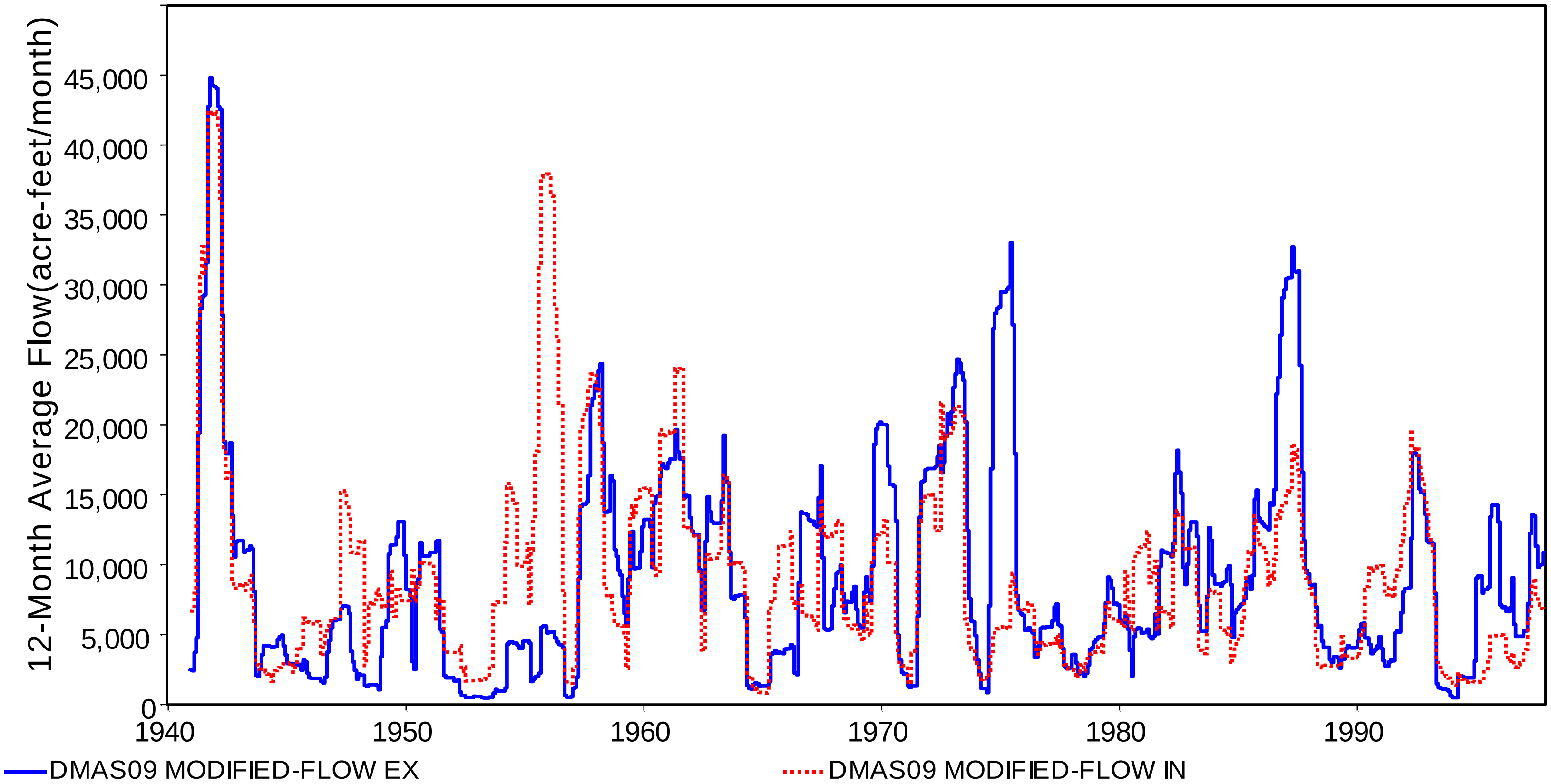


Figure B.4.3 Known and Final Computed 12-Month Forward Moving Average Flows for Double Mountain Fork at Aspermont DMAS09

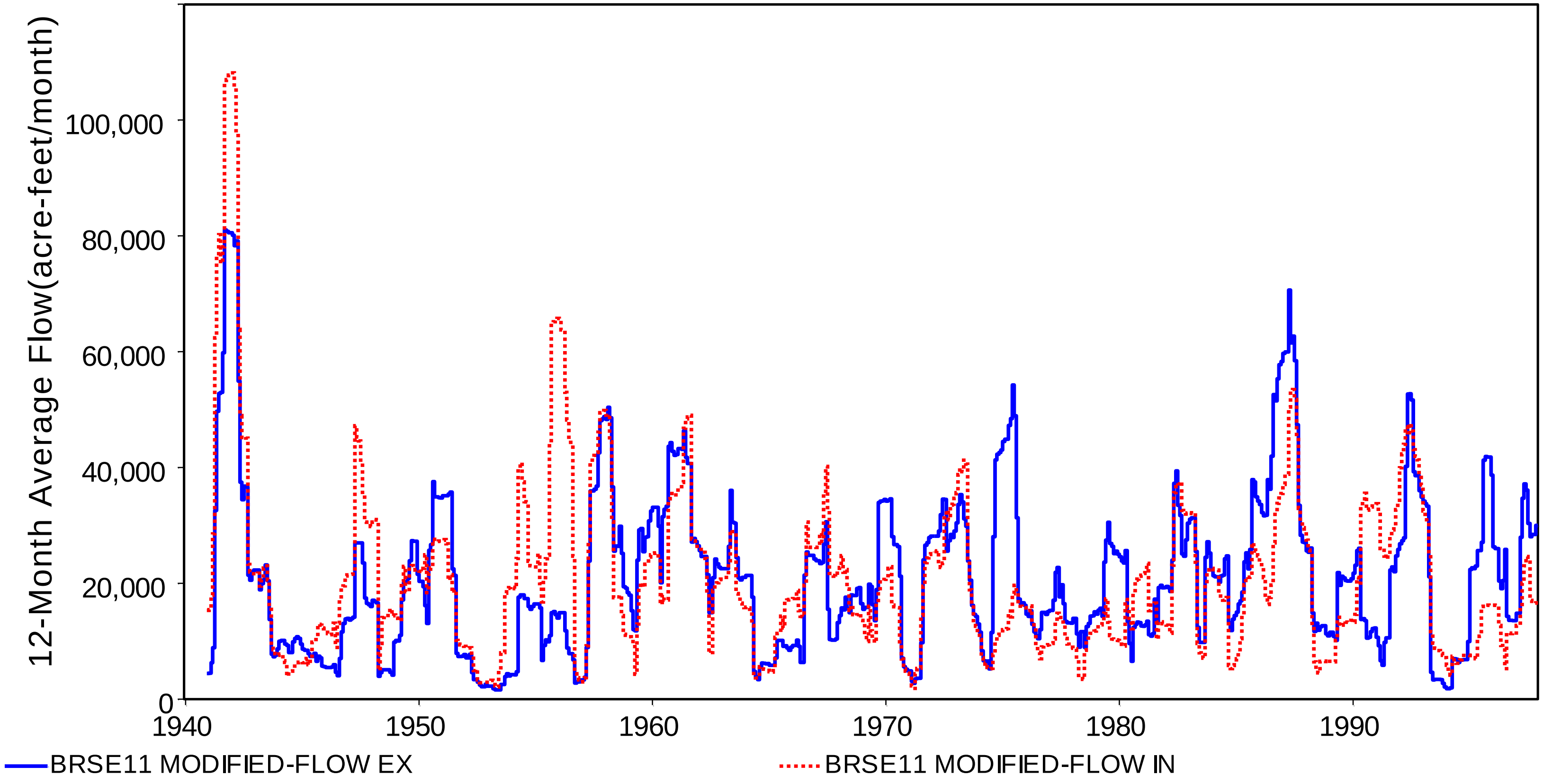


Figure B.4.4 Known and Final Computed 12-Month Forward Moving Average Flows for Brazos River at Seymour BRSE11

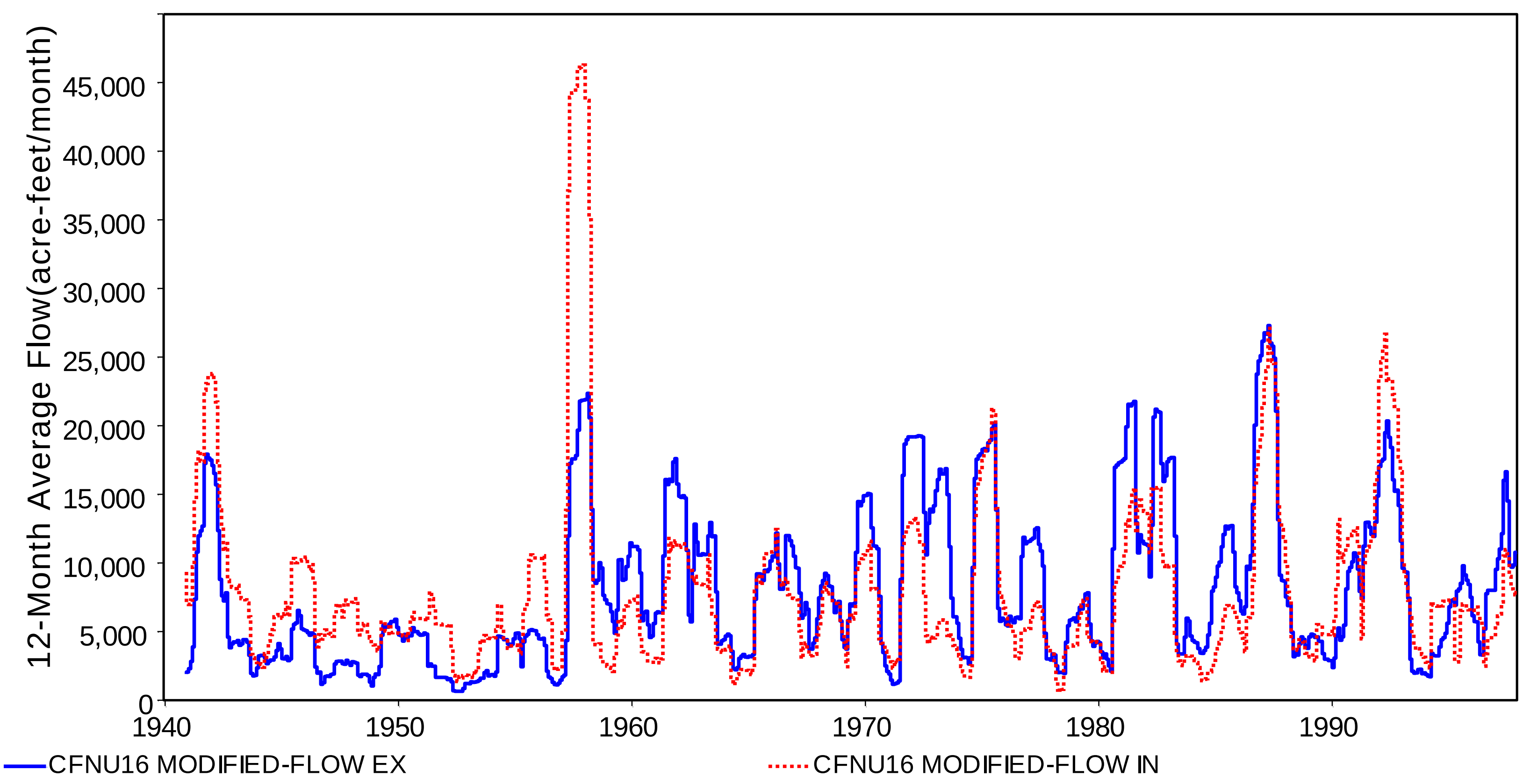


Figure B.4.5 Known and Final Computed 12-Month Forward Moving Average Flows for Clear Fork Brazos at Nugent CFNU16

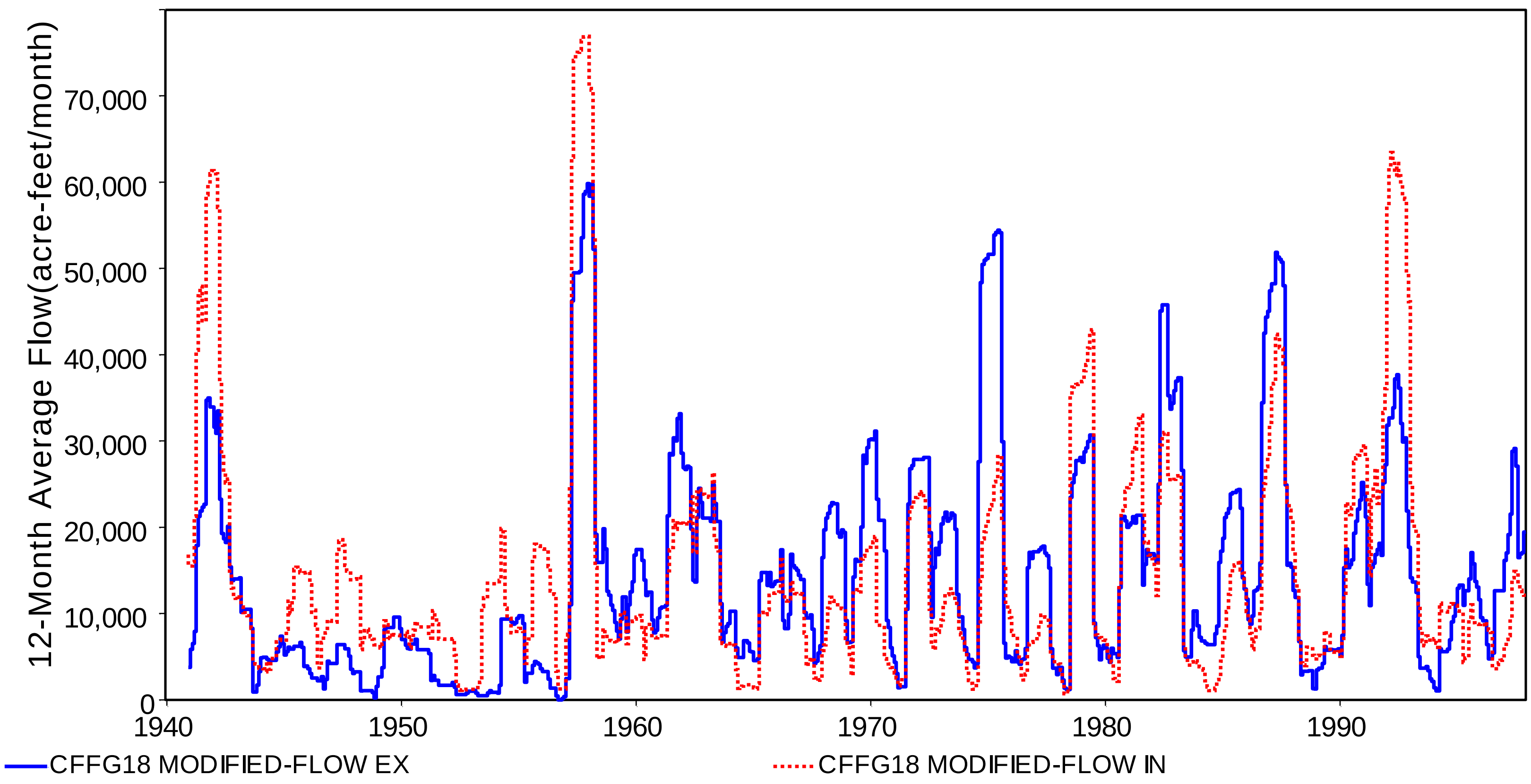


Figure B.4.6 Known and Final Computed 12-Month Forward Moving Average Flows for Clear Fork Brazos at Fort Griffin CFFG18

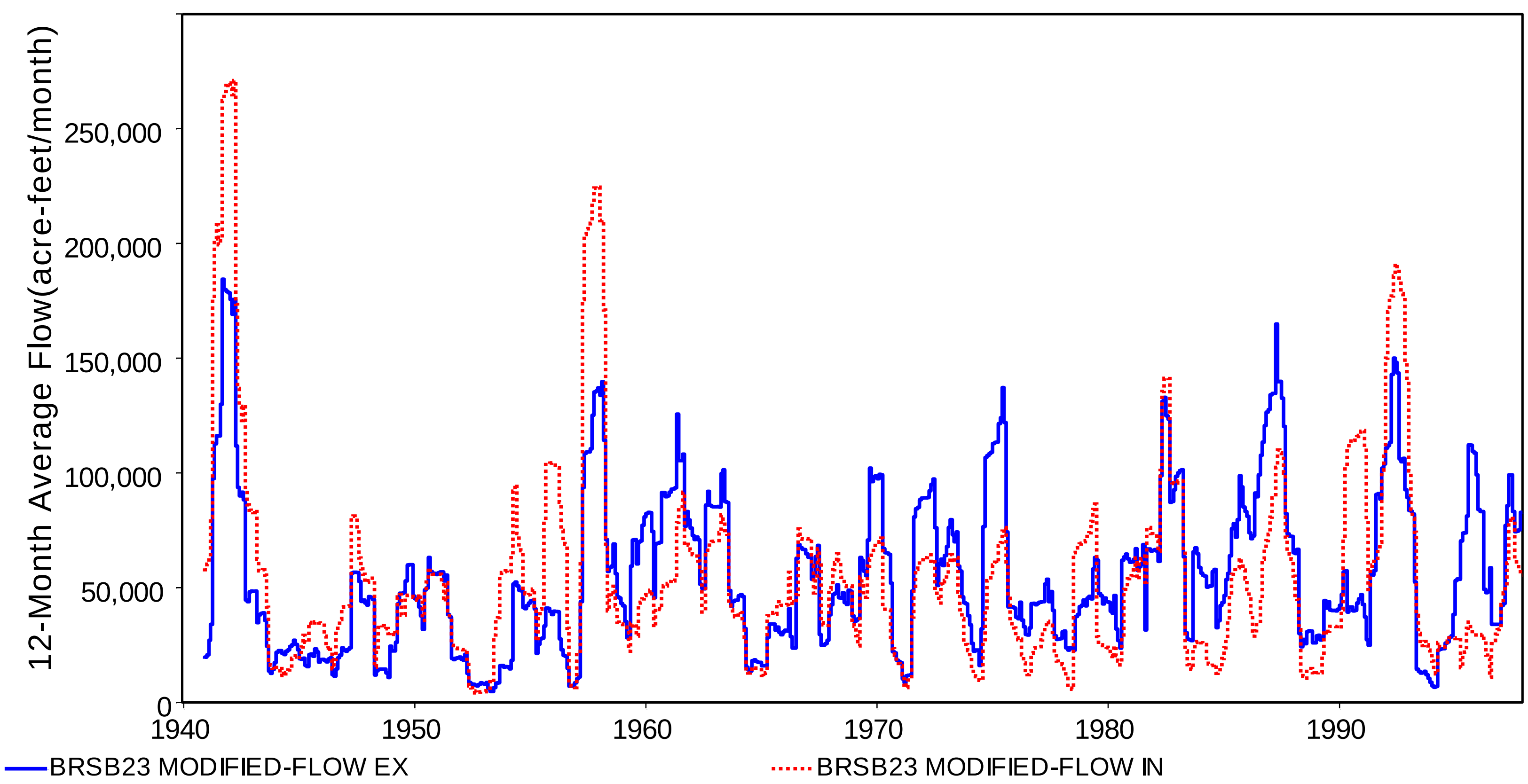


Figure B.4.7 Known and Final Computed 12-Month Forward Moving Average Flows for Brazos River at South Bend BRSB23

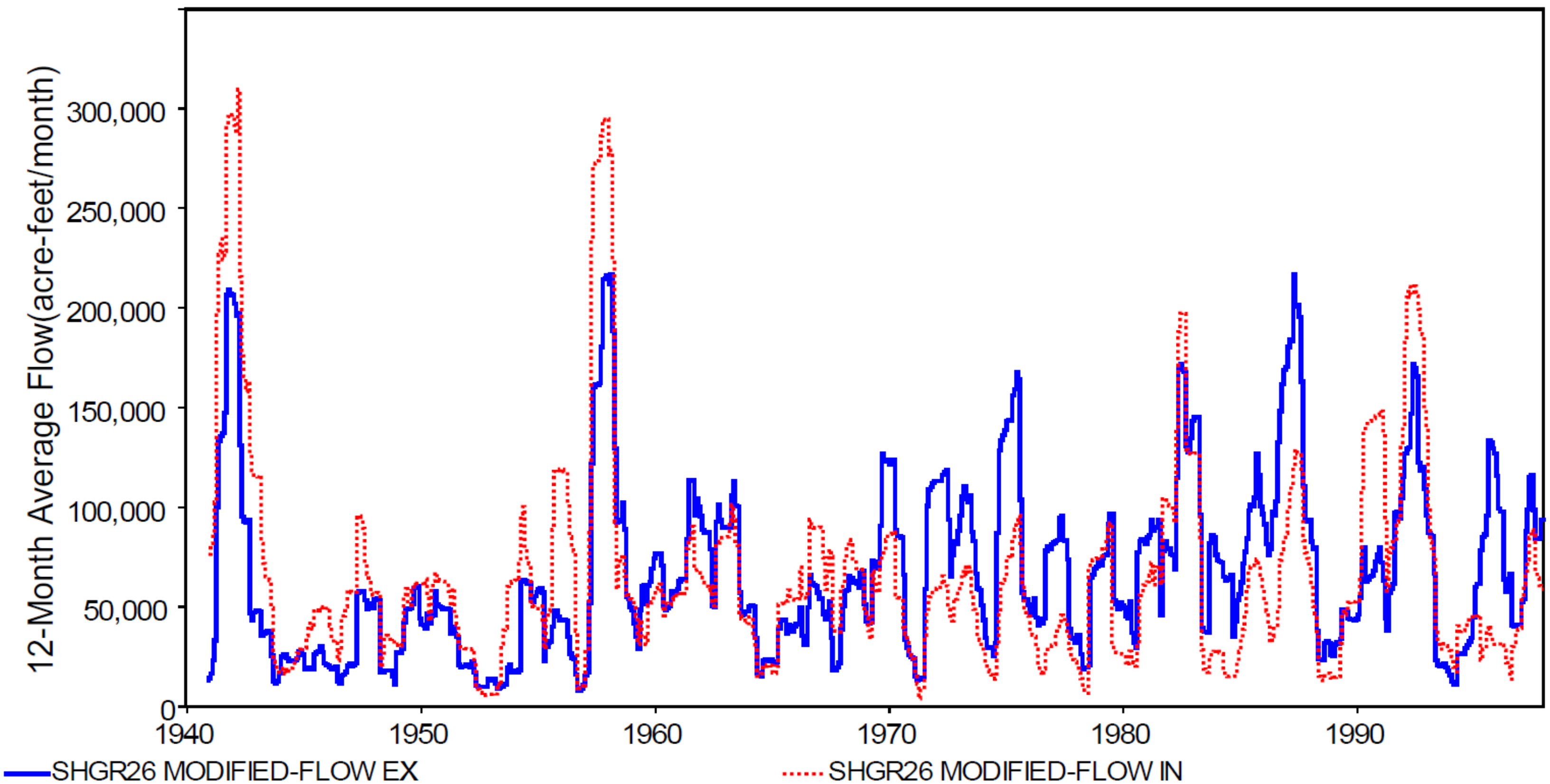


Figure B.4.8 Known and Final Computed 12-Month Forward Moving Average Flows for Brazos River at Granford SHGR26

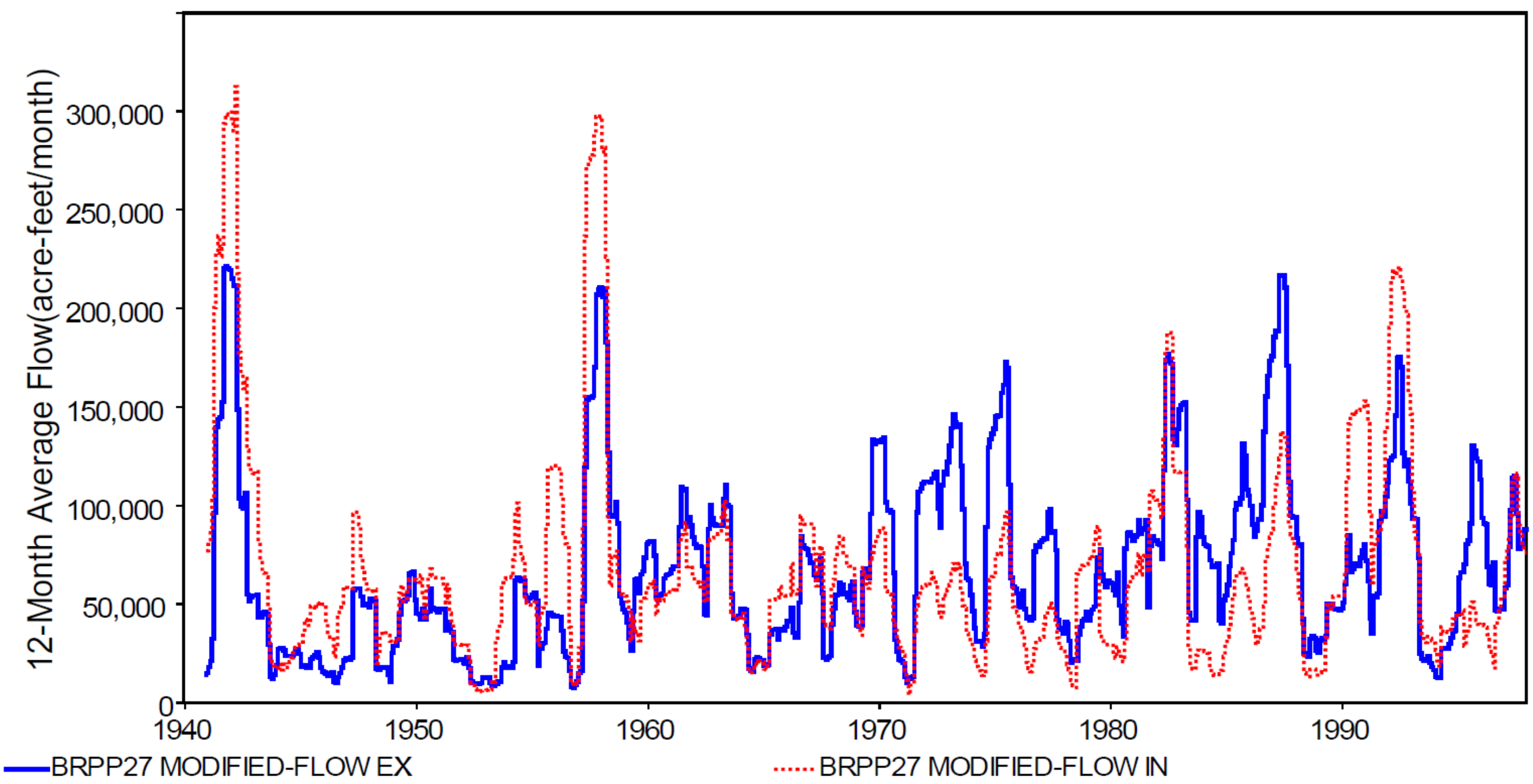


Figure B.4.9 Known and Final Computed 12-Month Forward Moving Average Flows for Brazos River at Palo Pinto BRPP27

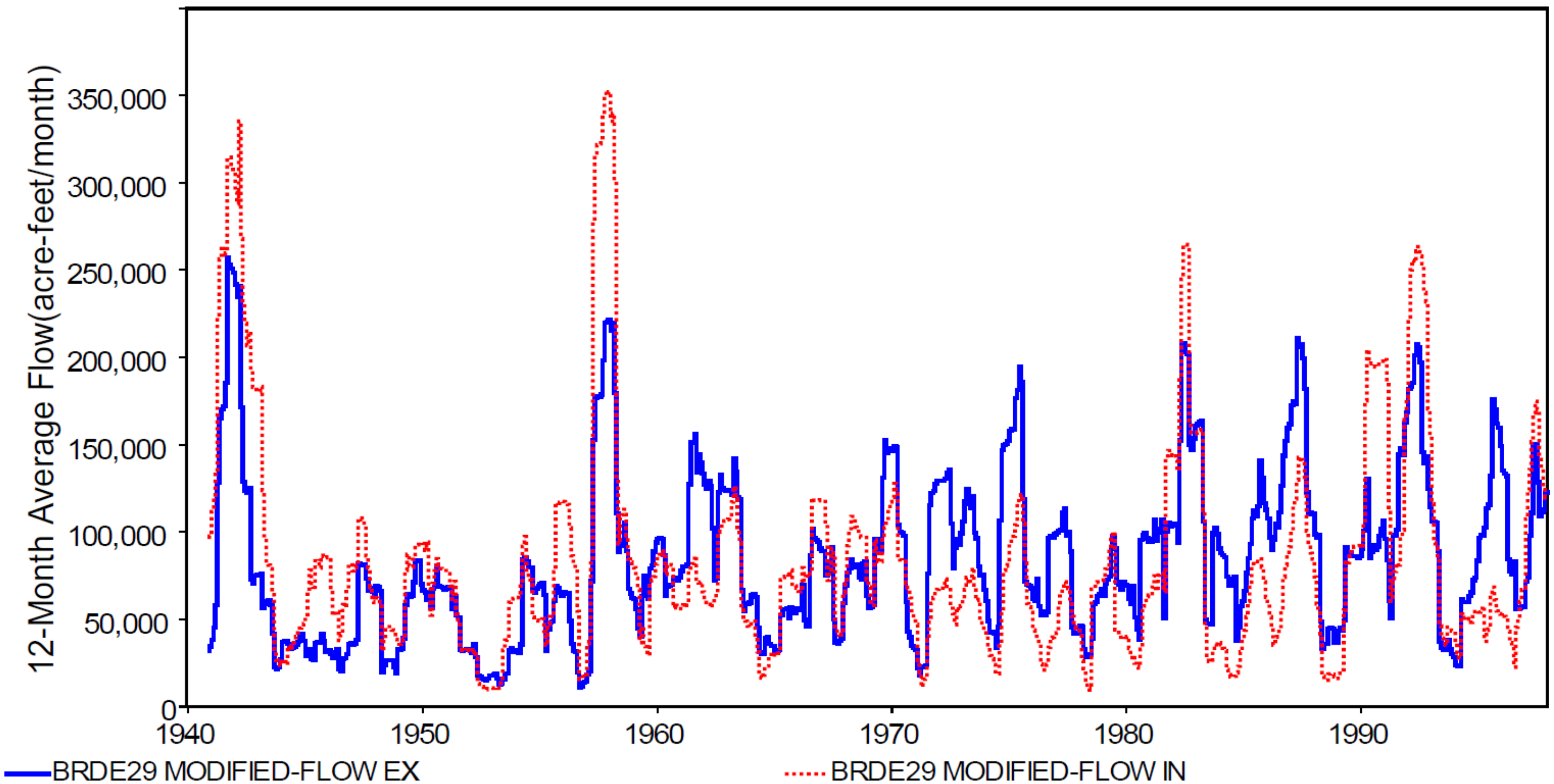


Figure B.4.10 Known and Final Computed 12-Month Forward Moving Average Flows for Brazos River at Dennis BRDE29

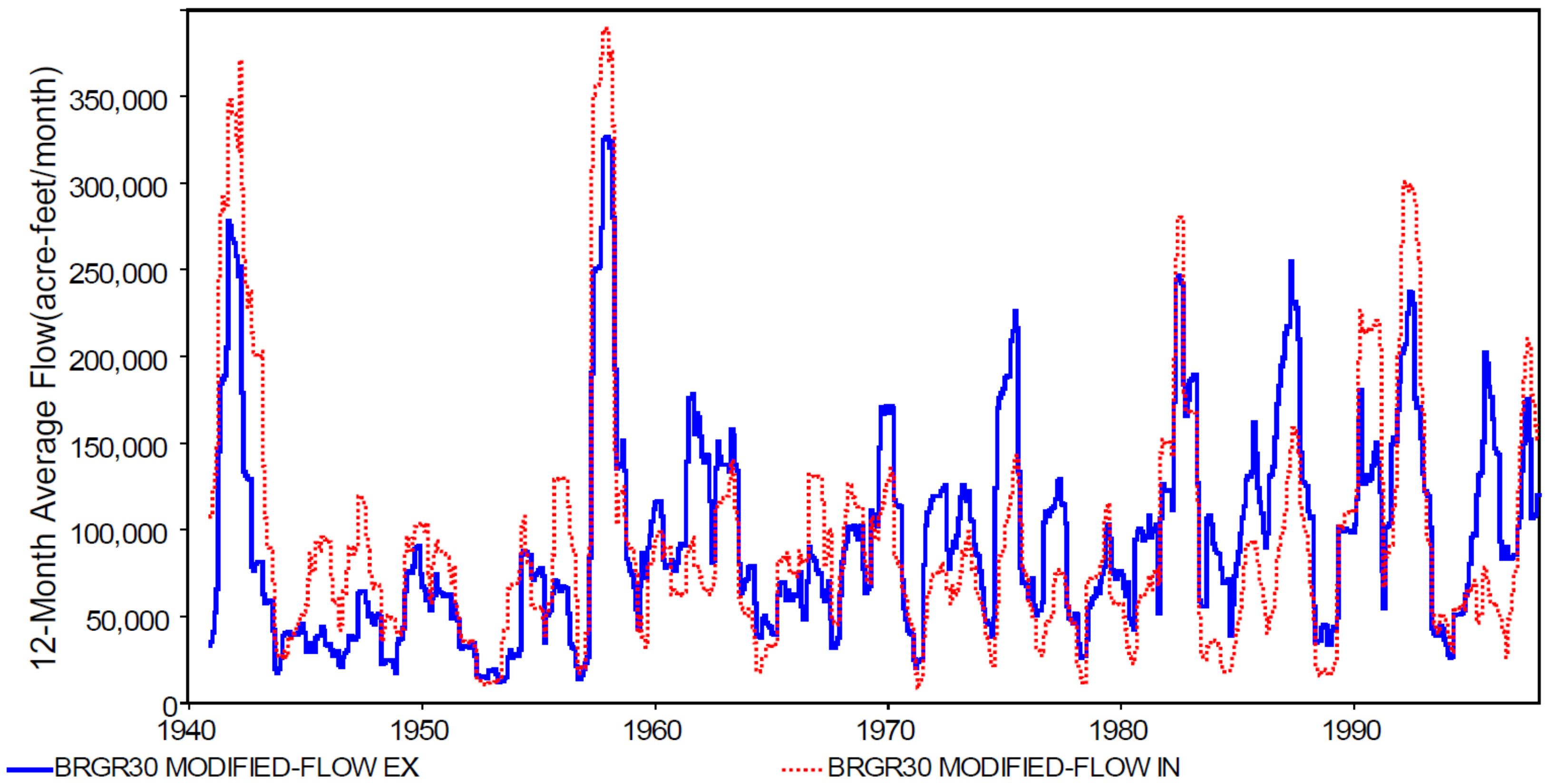


Figure B.4.11 Known and Final Computed 12-Month Forward Moving Average Flows for Brazos River at Glen Rose BRGR30

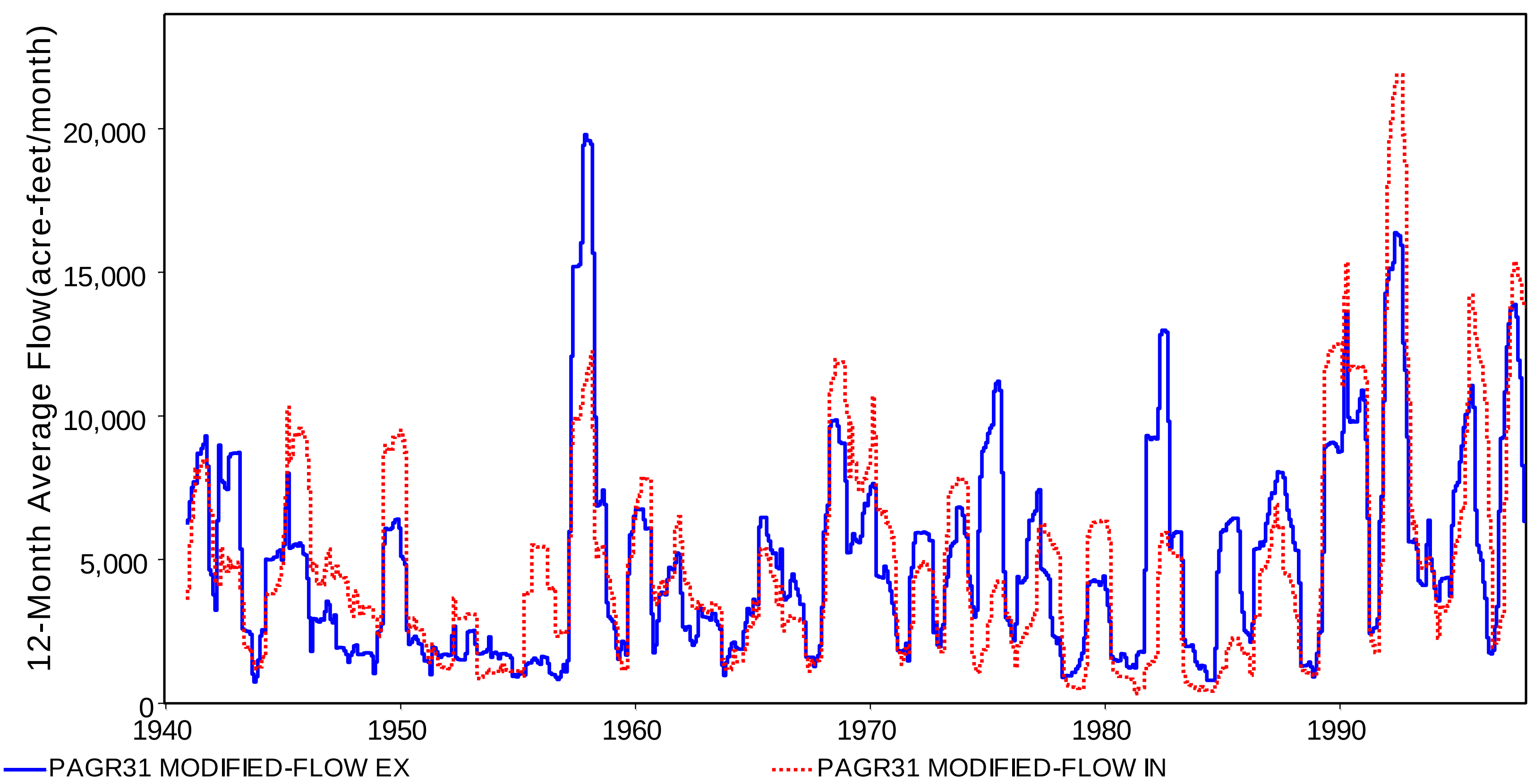


Figure B.4.12 Known and Final Computed 12-Month Forward Moving Average Flows for Paluxy River at Glen Rose PAGR31

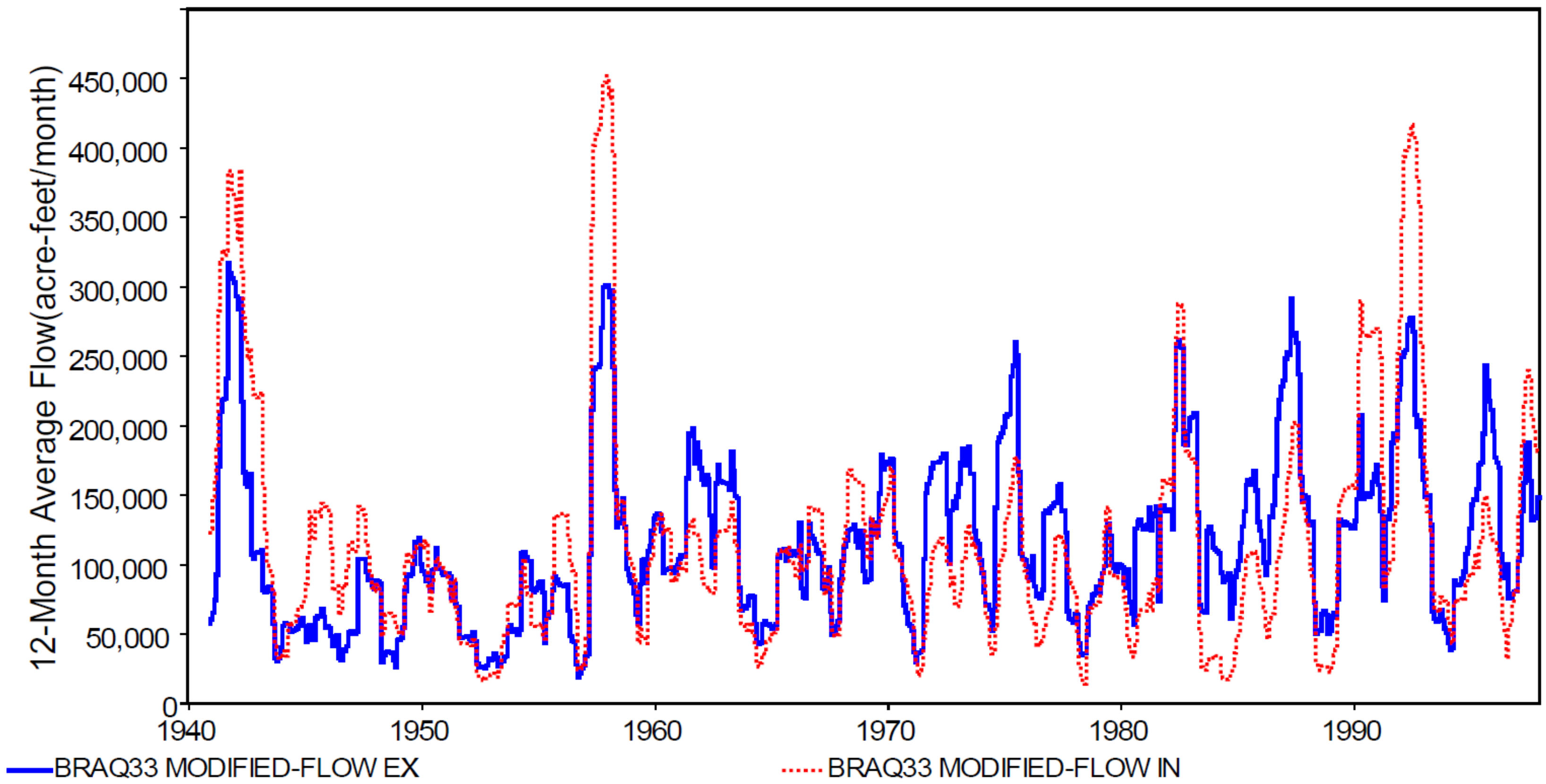


Figure B.4.13 Known and Final Computed 12-Month Forward Moving Average Flows for Brazos River at Aquilla BRAQ33

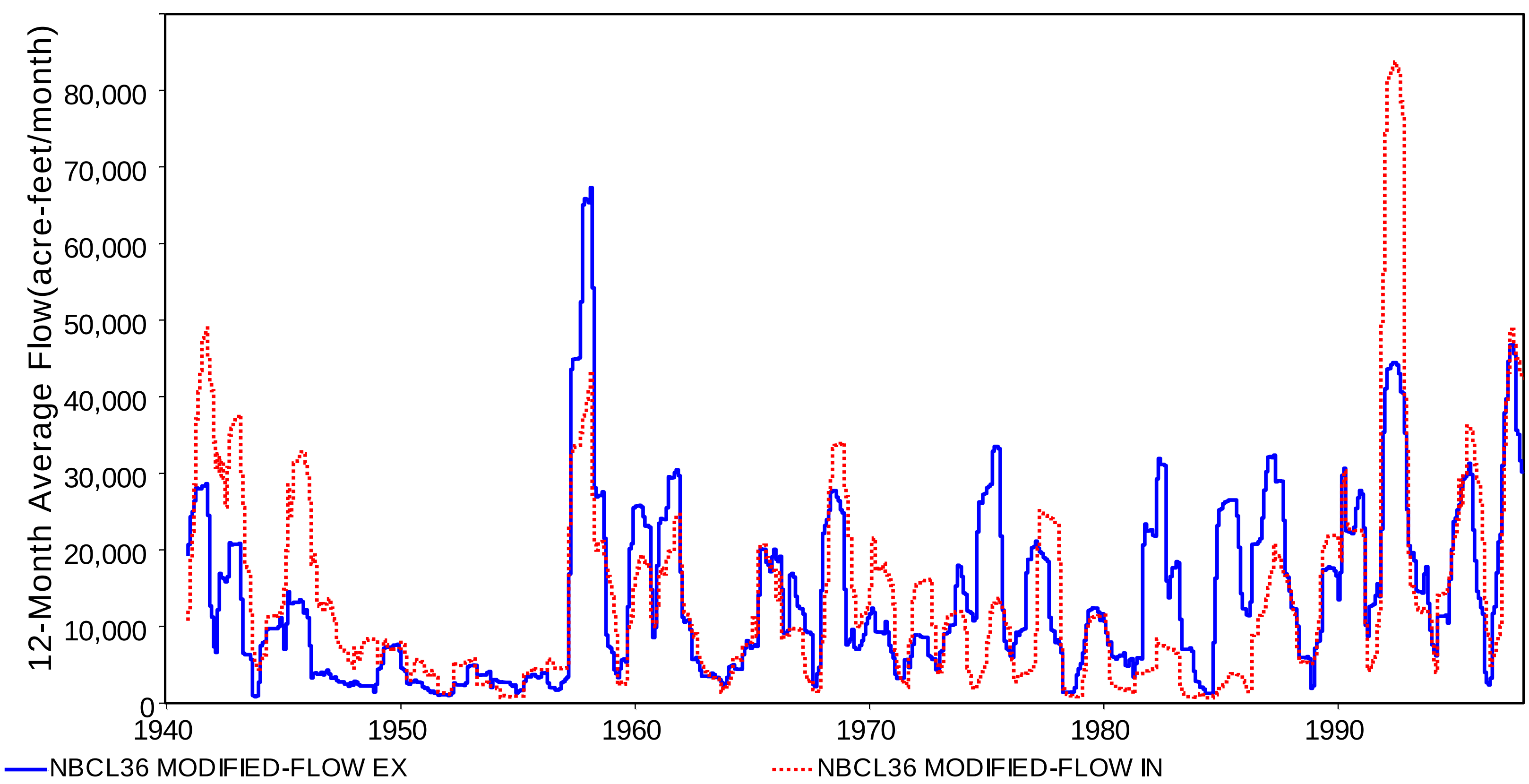


Figure B.4.14 Known and Final Computed 12-Month Forward Moving Average Flows for North Bosque River at Clifton NBCL36

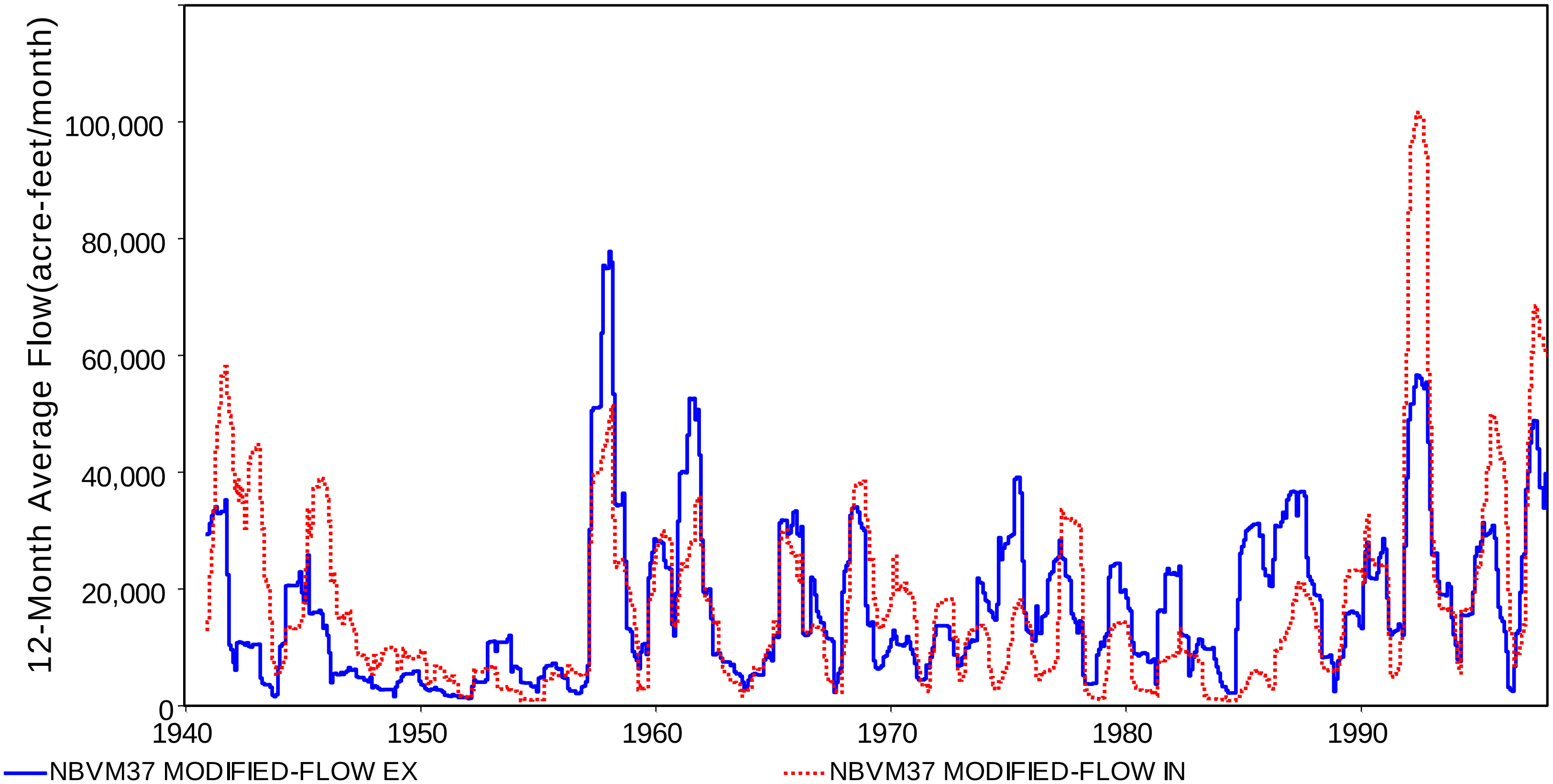


Figure B.4.15 Known and Final Computed 12-Month Forward Moving Average Flows for North Bosque River at Valley Mills NBVM37

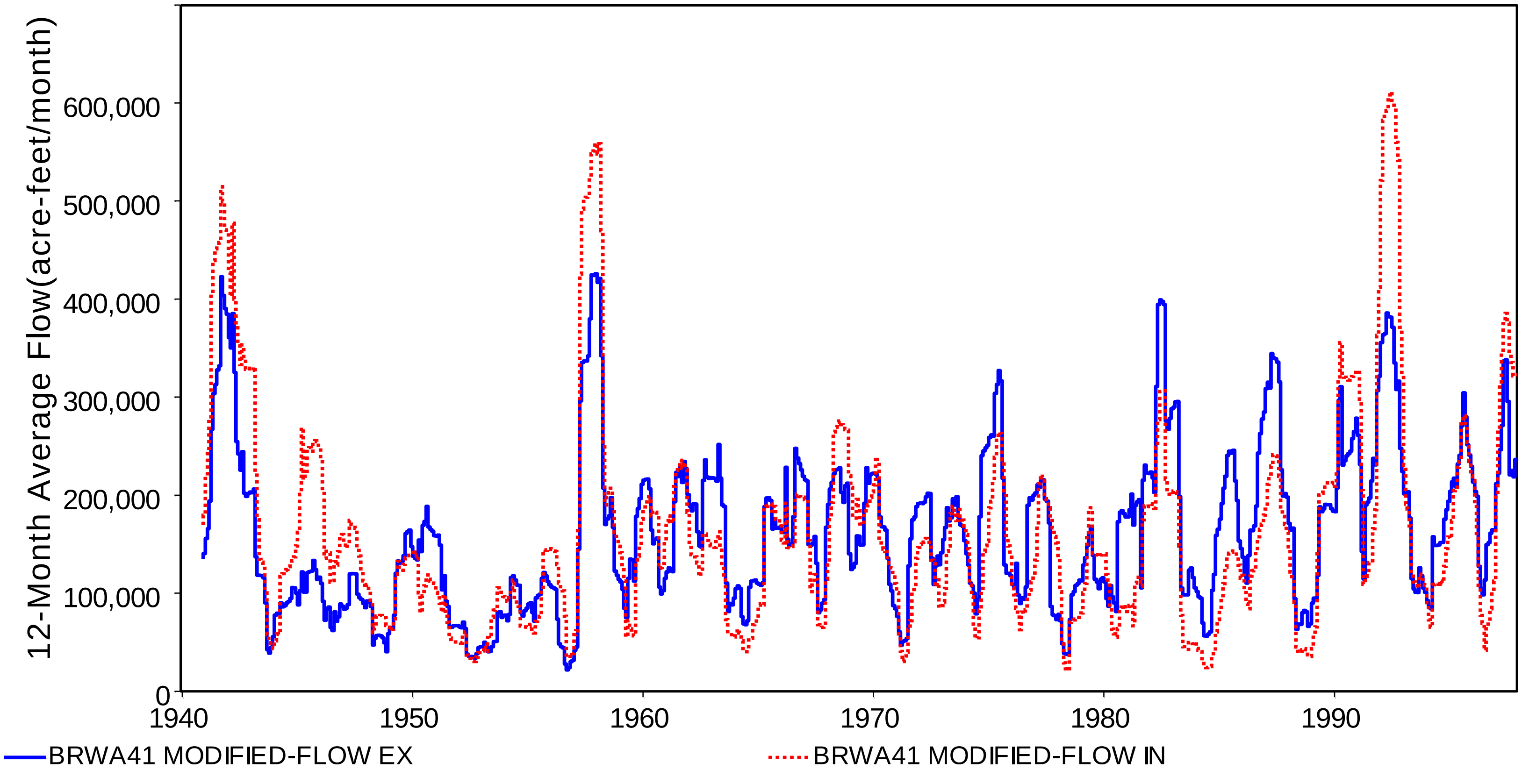


Figure B.4.16 Known and Final Computed 12-Month Forward Moving Average Flows for Brazos River at Waco BRWA41

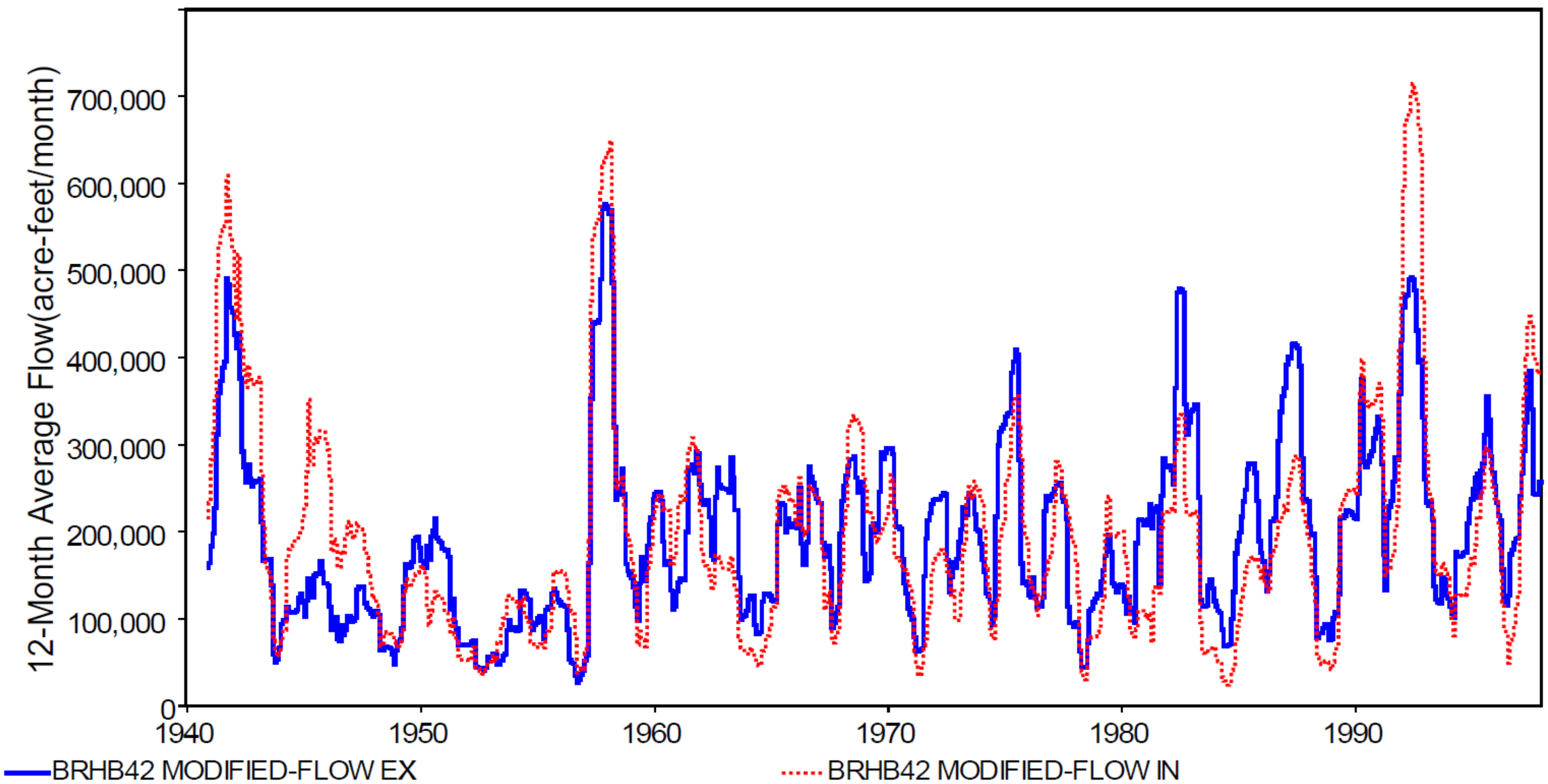


Figure B.4.17 Known and Final Computed 12-Month Forward Moving Average Flows for Brazos River at Highbank BRHB42

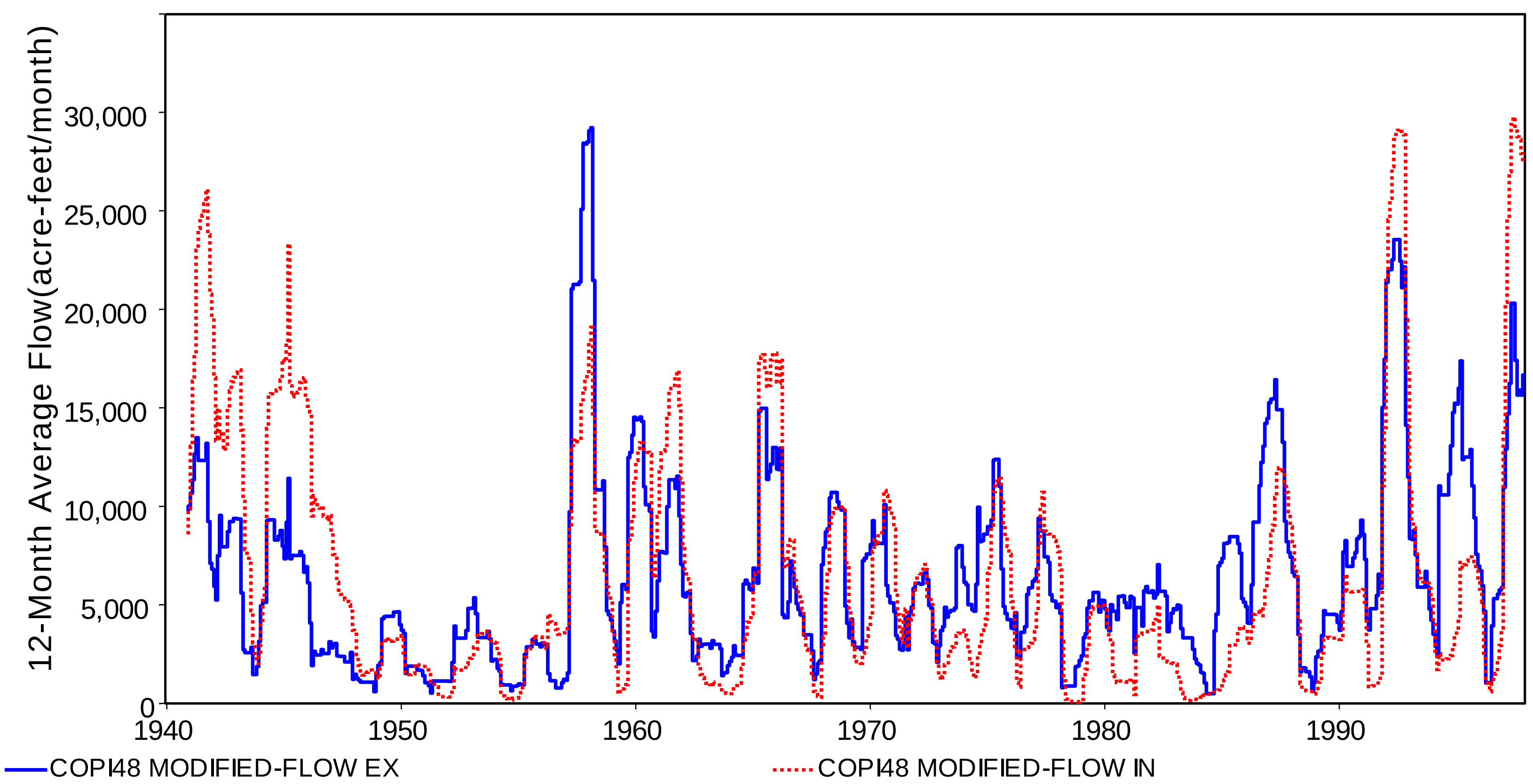


Figure B.4.18 Known and Final Computed 12-Month Forward Moving Average Flows for Cowhouse Creek at Pidcoke COPI48

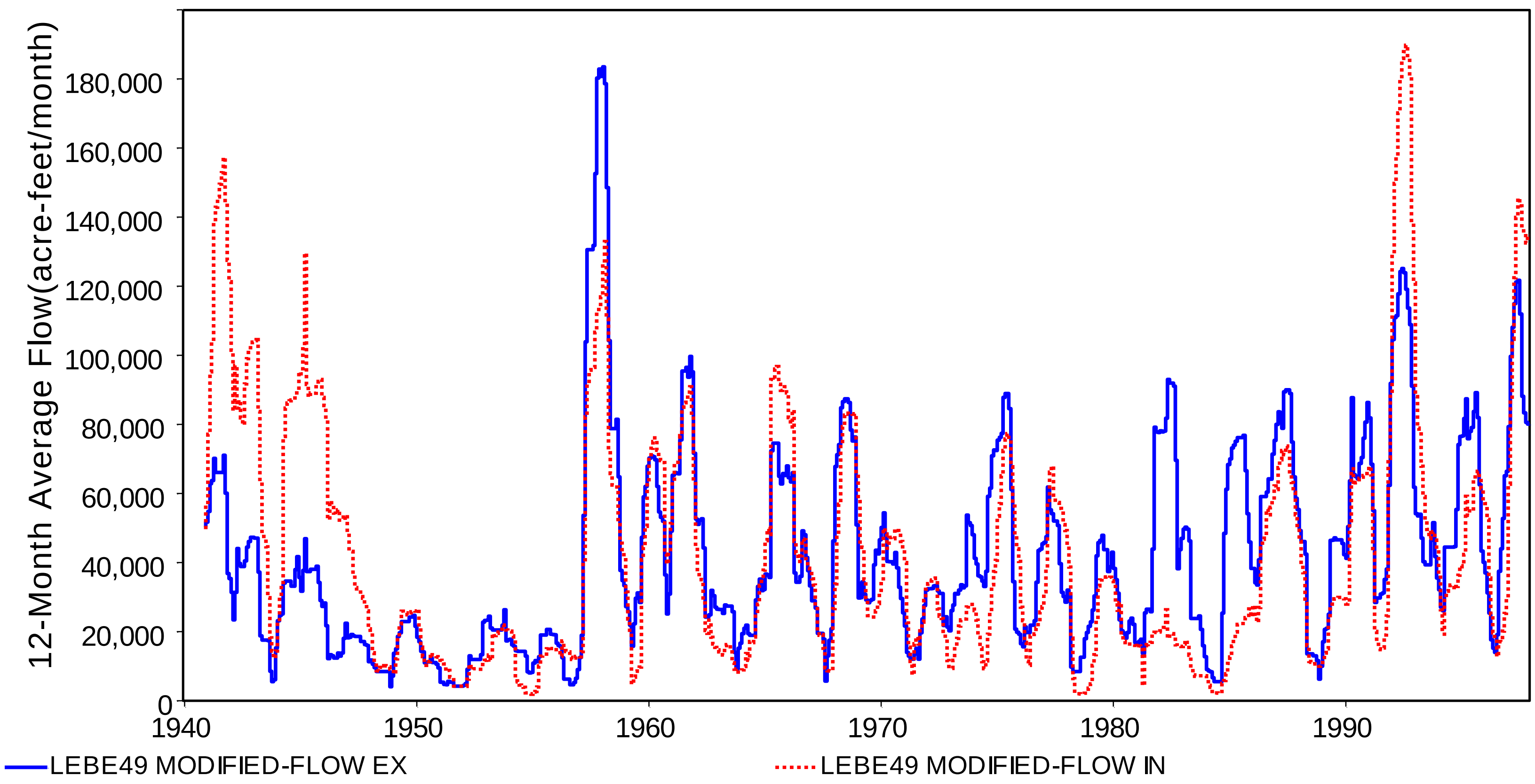


Figure B.4.19 Known and Final Computed 12-Month Forward Moving Average Flows for Leon River at Belton LEBE49

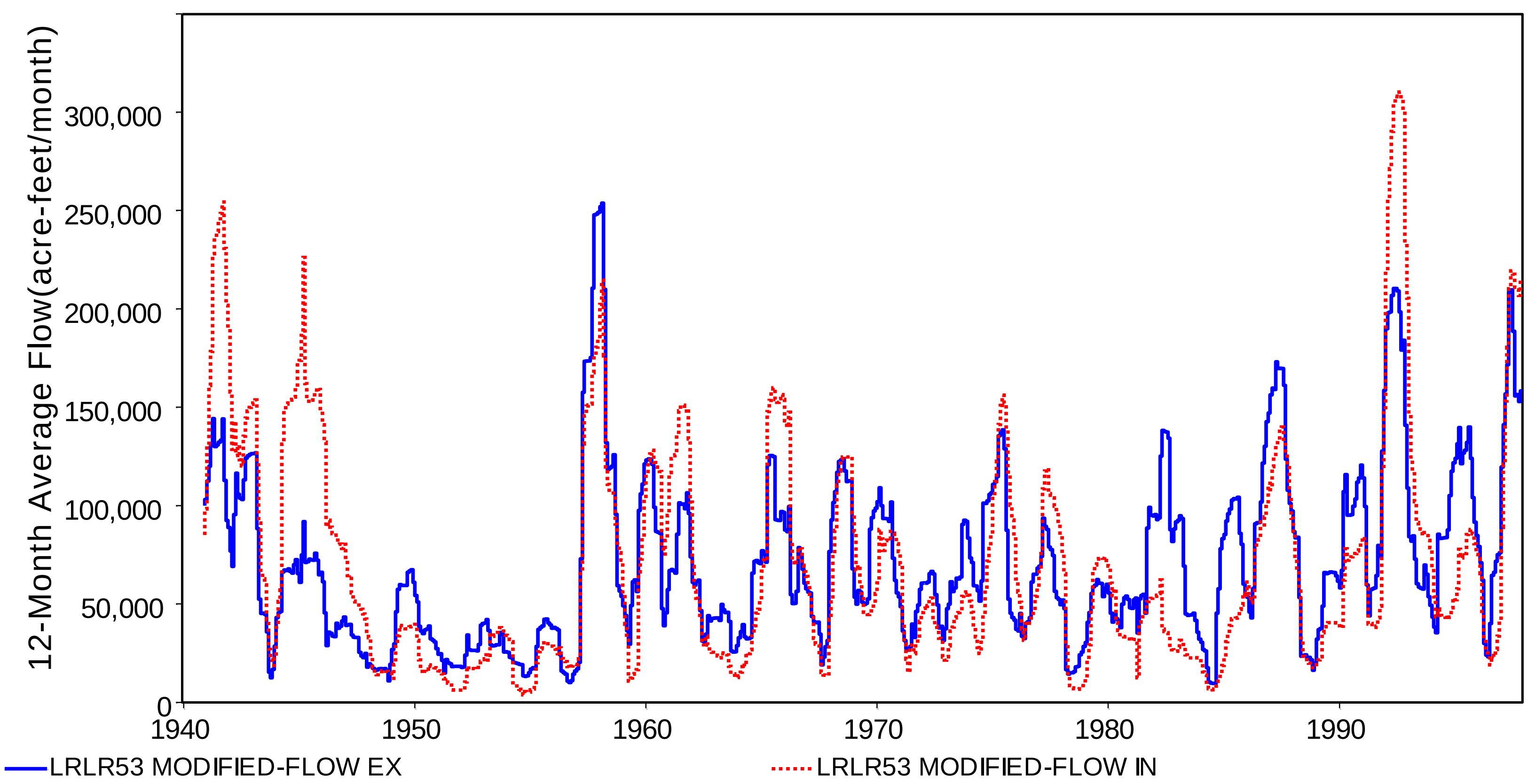


Figure B.4.20 Known and Final Computed 12-Month Forward Moving Average Flows for Little River at Little River LRLR53

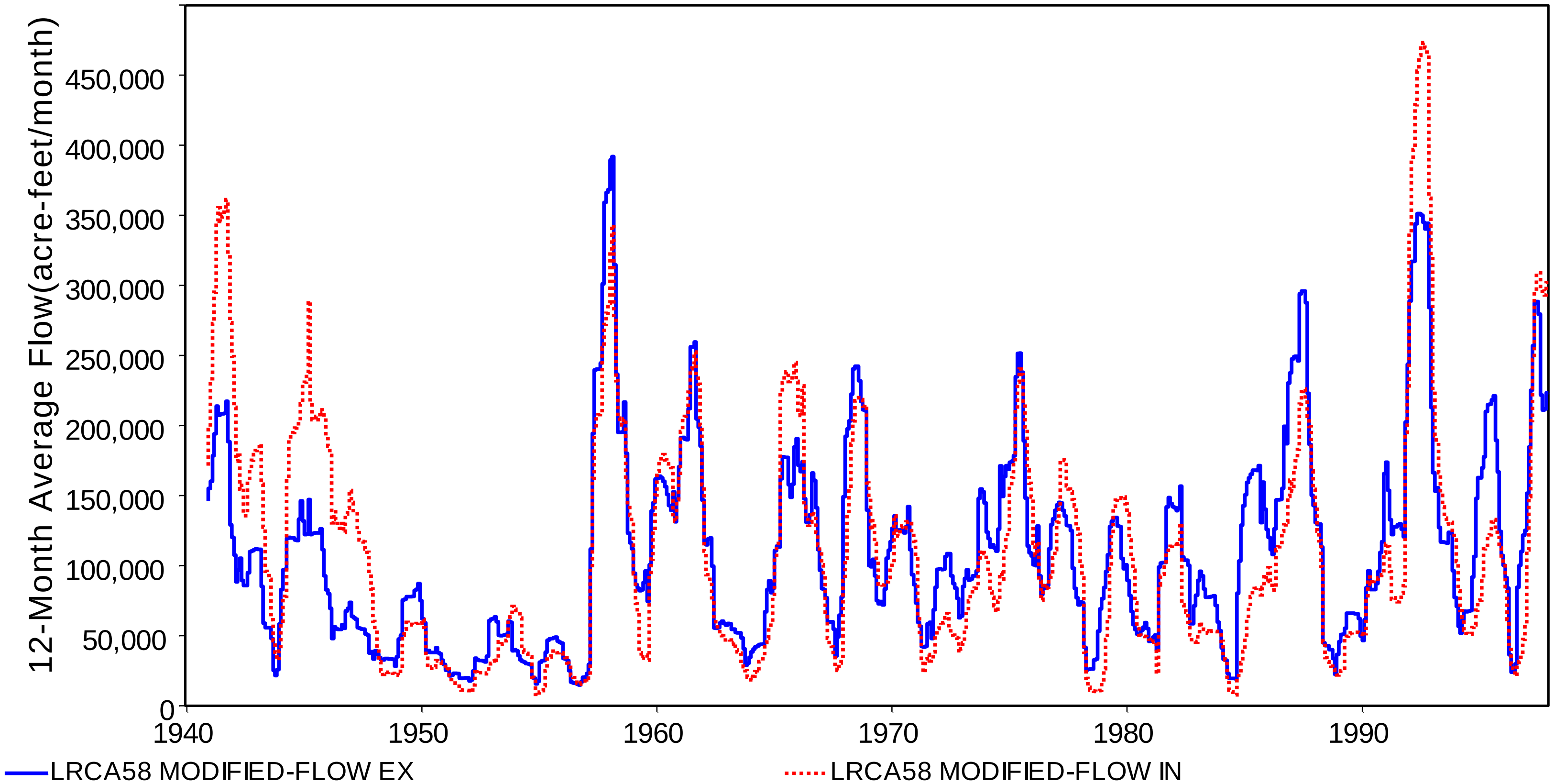


Figure B.4.21 Known and Final Computed 12-Month Forward Moving Average Flows for Little River at Cameron LRCA58

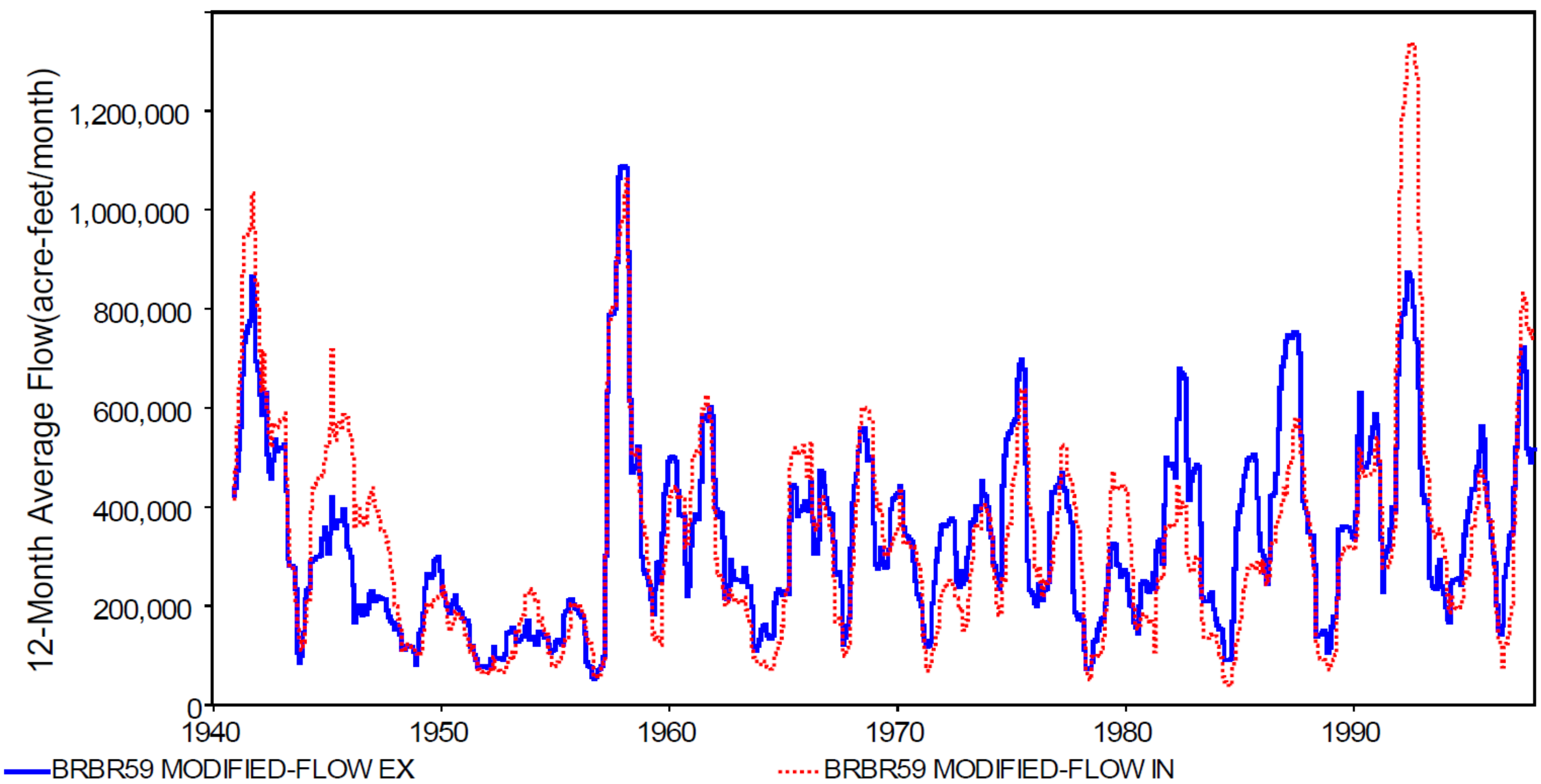


Figure B.4.22 Known and Final Computed 12-Month Forward Moving Average Flows for Brazos River at Bryan BRBR59

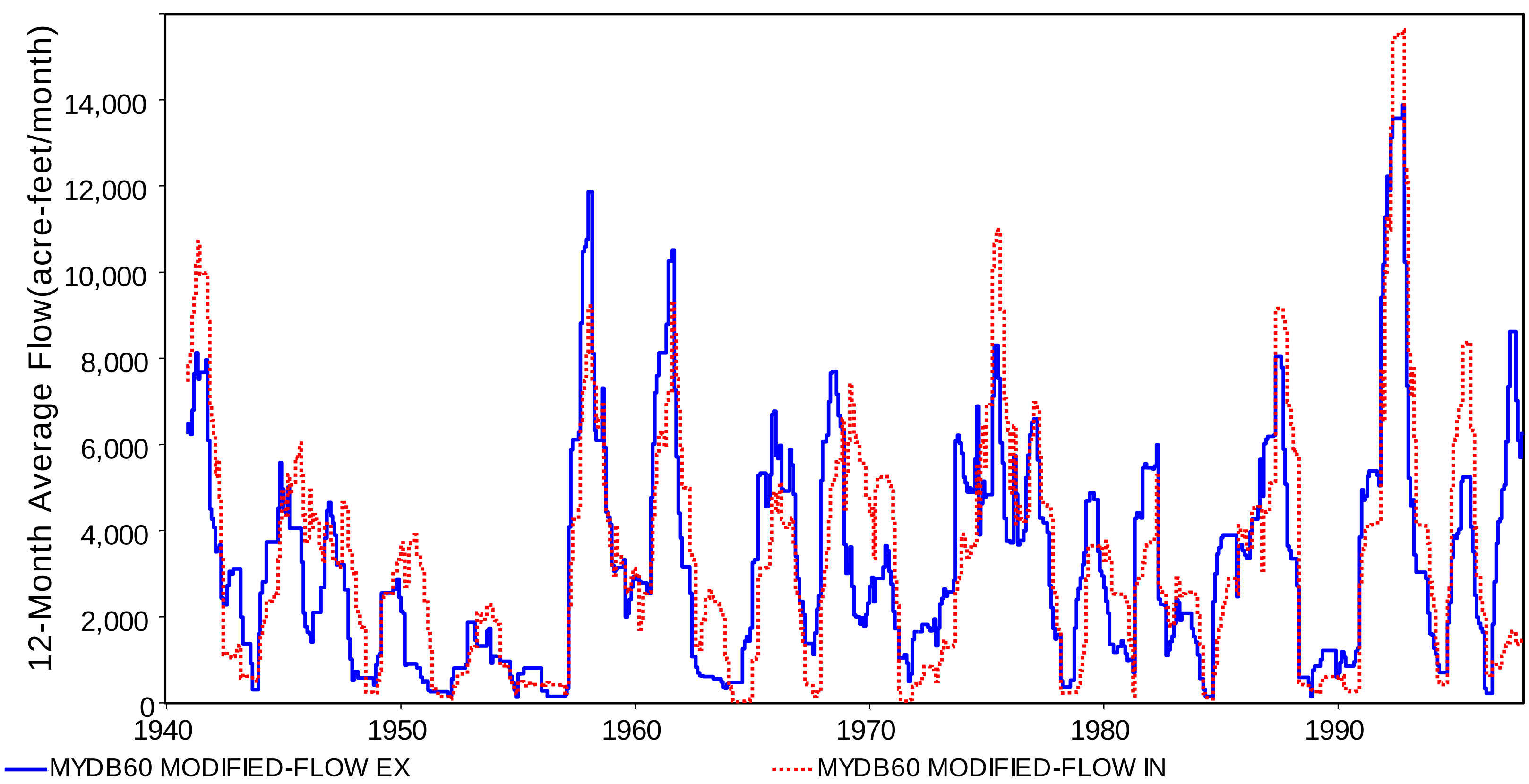


Figure B.4.23 Known and Final Computed 12-Month Forward Moving Average Flows for Middle Yegua Creek at Dime Box MYDB60

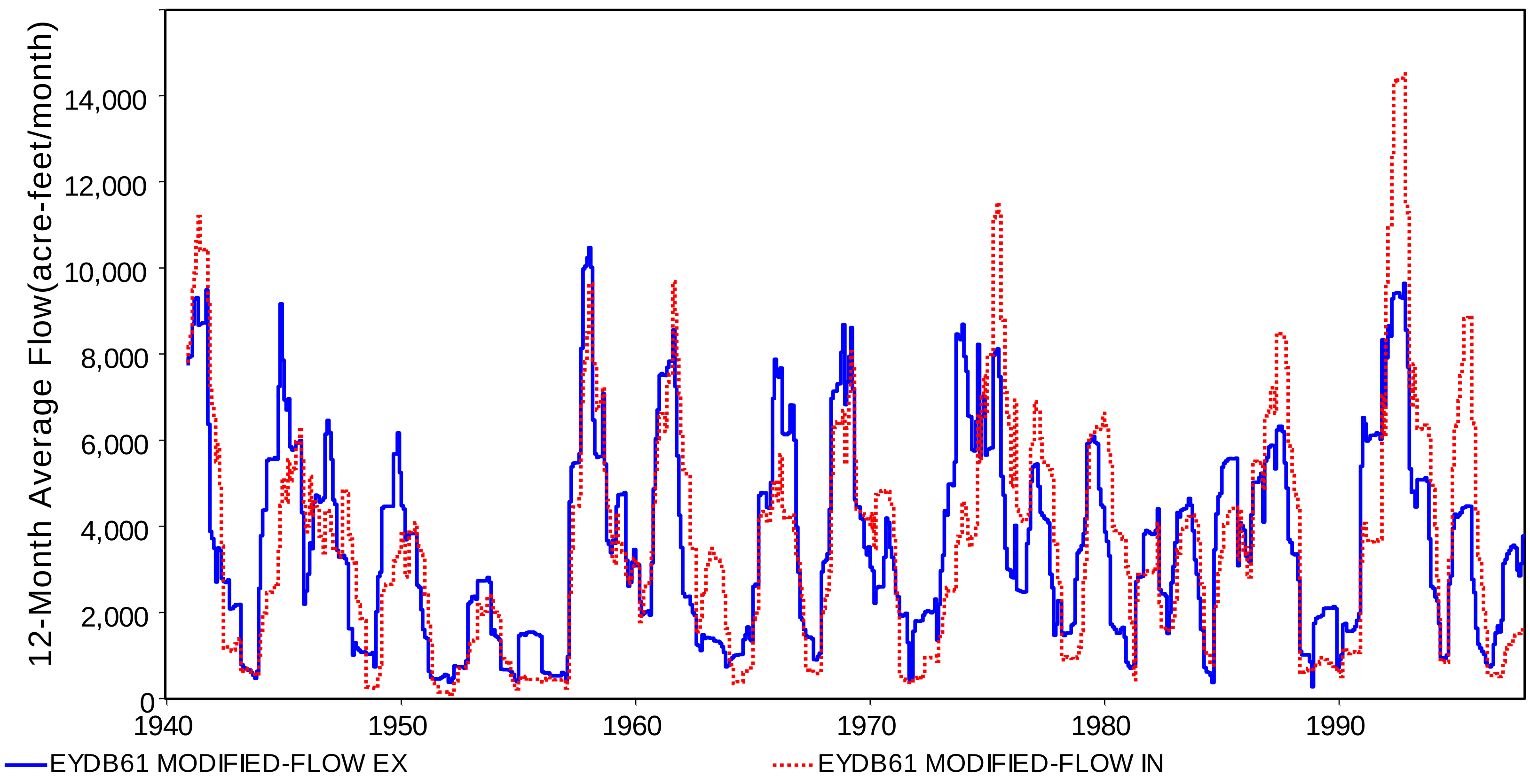


Figure B.4.24 Known and Final Computed 12-Month Forward Moving Average Flows for East Yegua Creek at Dime Box EYDB61

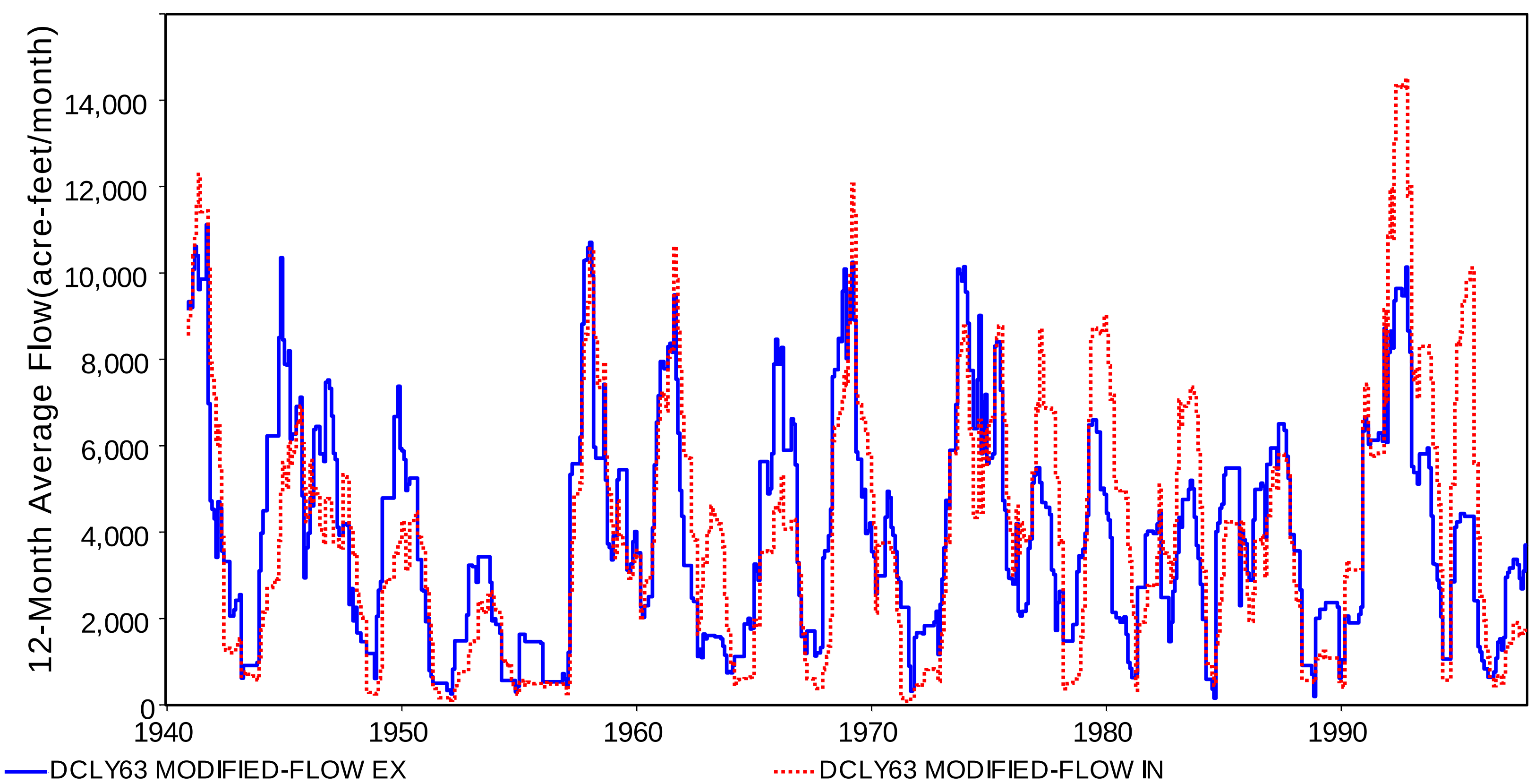


Figure B.4.25 Known and Final Computed 12-Month Forward Moving Average Flows for Davidson Creek at Lyons DCLY63

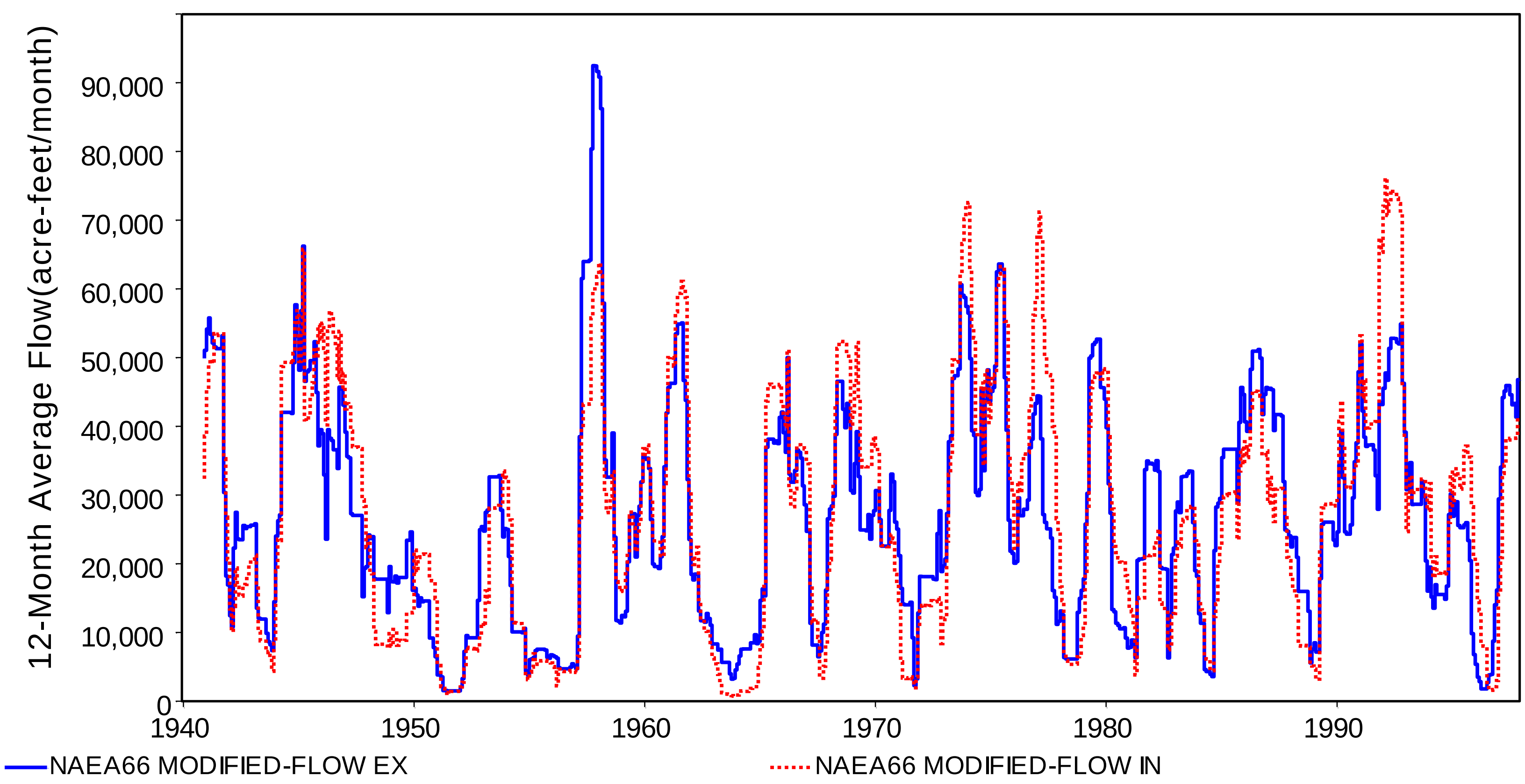


Figure B.4.26 Known and Final Computed 12-Month Forward Moving Average Flows for Navasota River at Easterly NAEA66

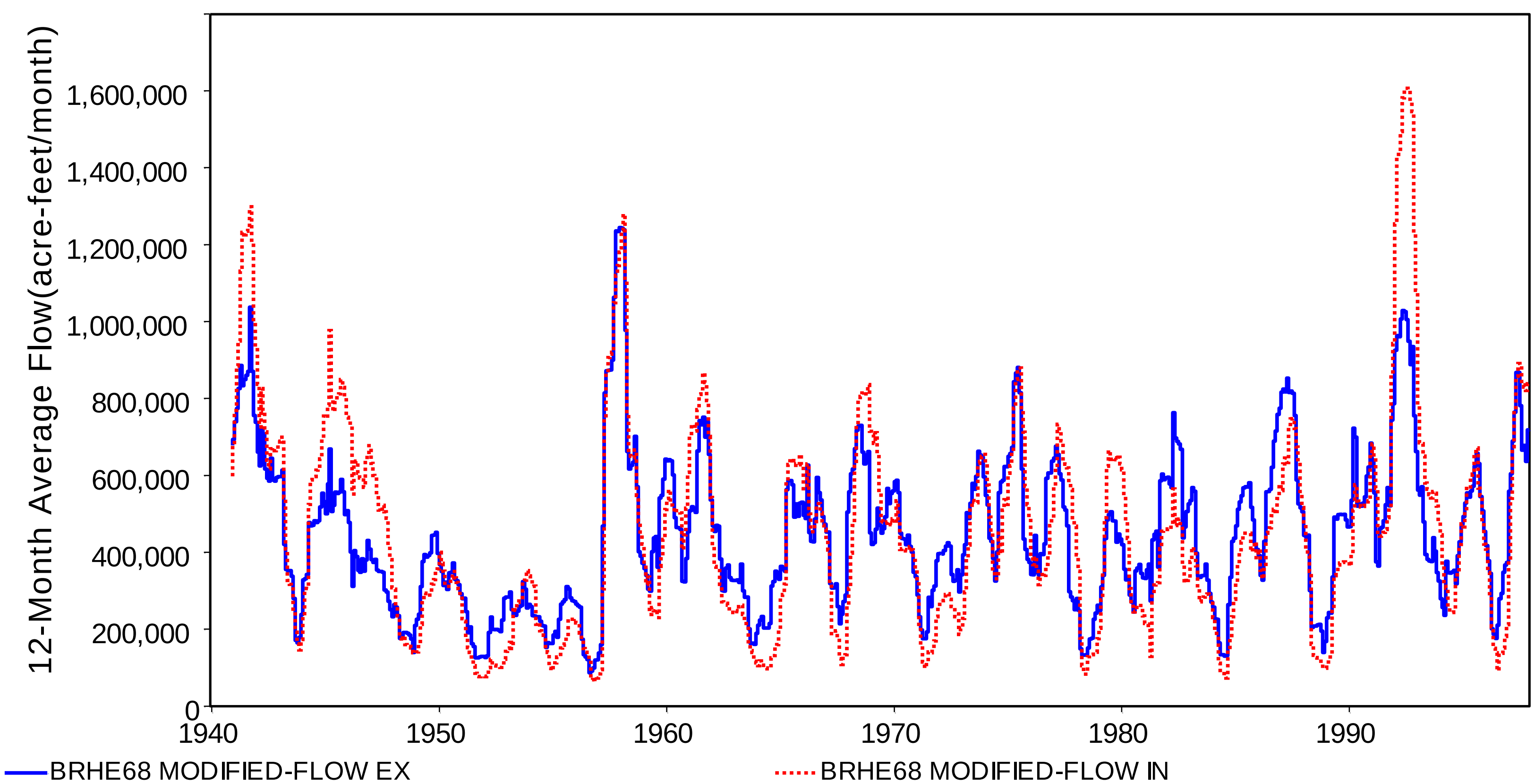


Figure B.4.27 Known and Final Computed 12-Month Forward Moving Average Flows for Brazos River at Hempstead BRHE68

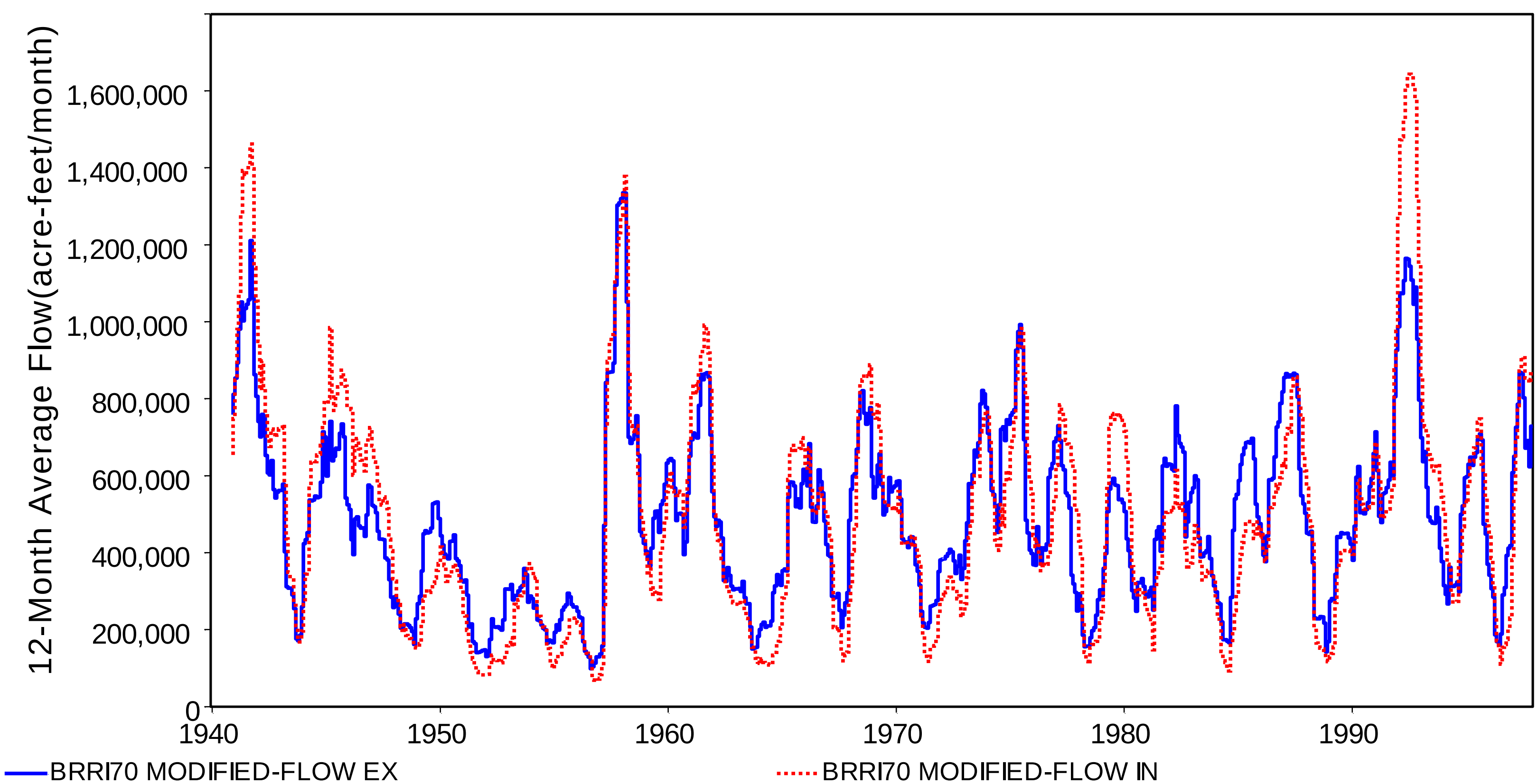


Figure B.4.28 Known and Final Computed 12-Month Forward Moving Average Flows for Brazos River at Richmond BRRI70

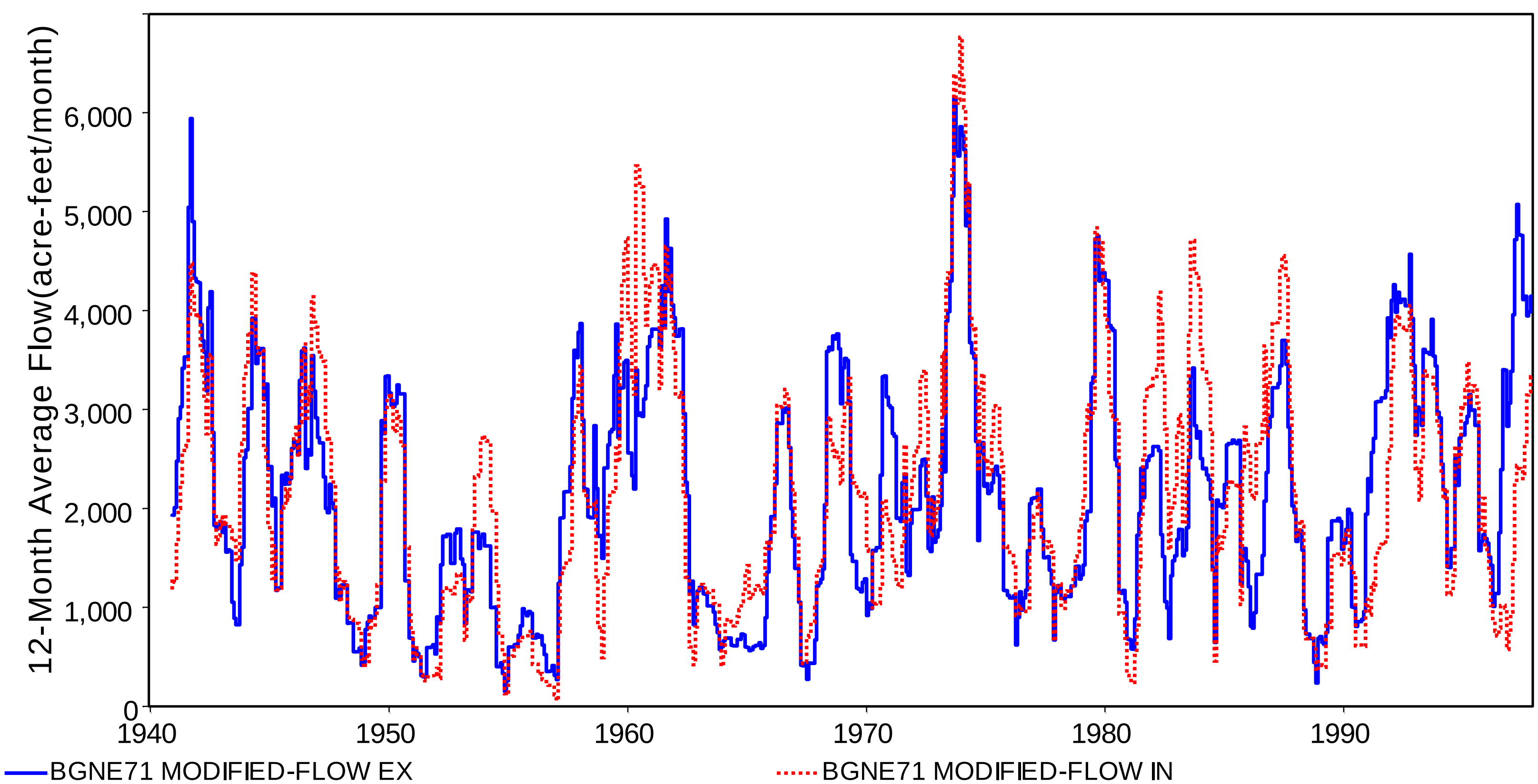


Figure B.4.29 Known and Final Computed 12-Month Forward Moving Average Flows for Big Creek at Needville BGNE71

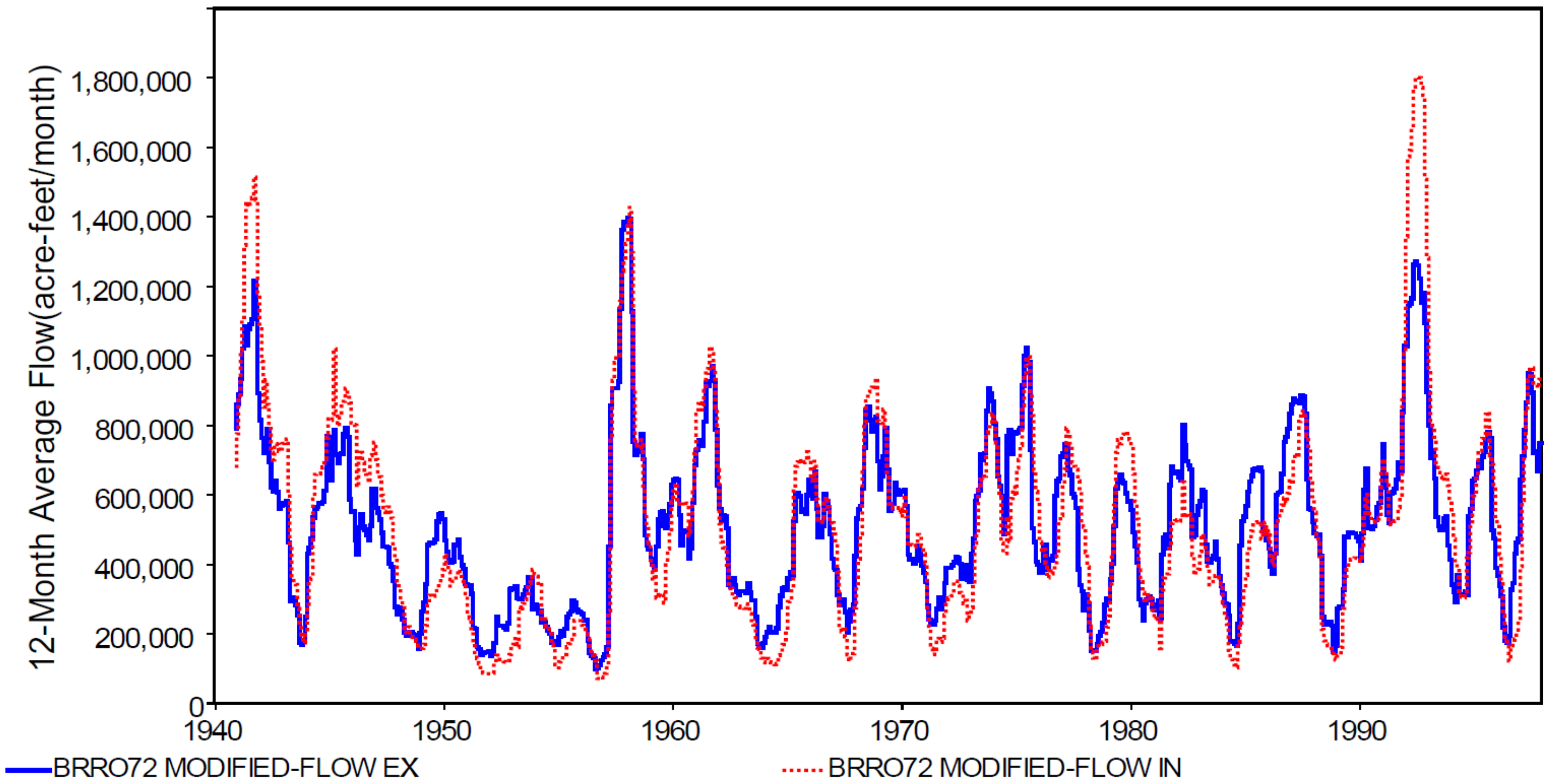


Figure B.4.30 Known and Final Computed 12-Month Forward Moving Average Flows for Brazos River at Rosharon BRRO72

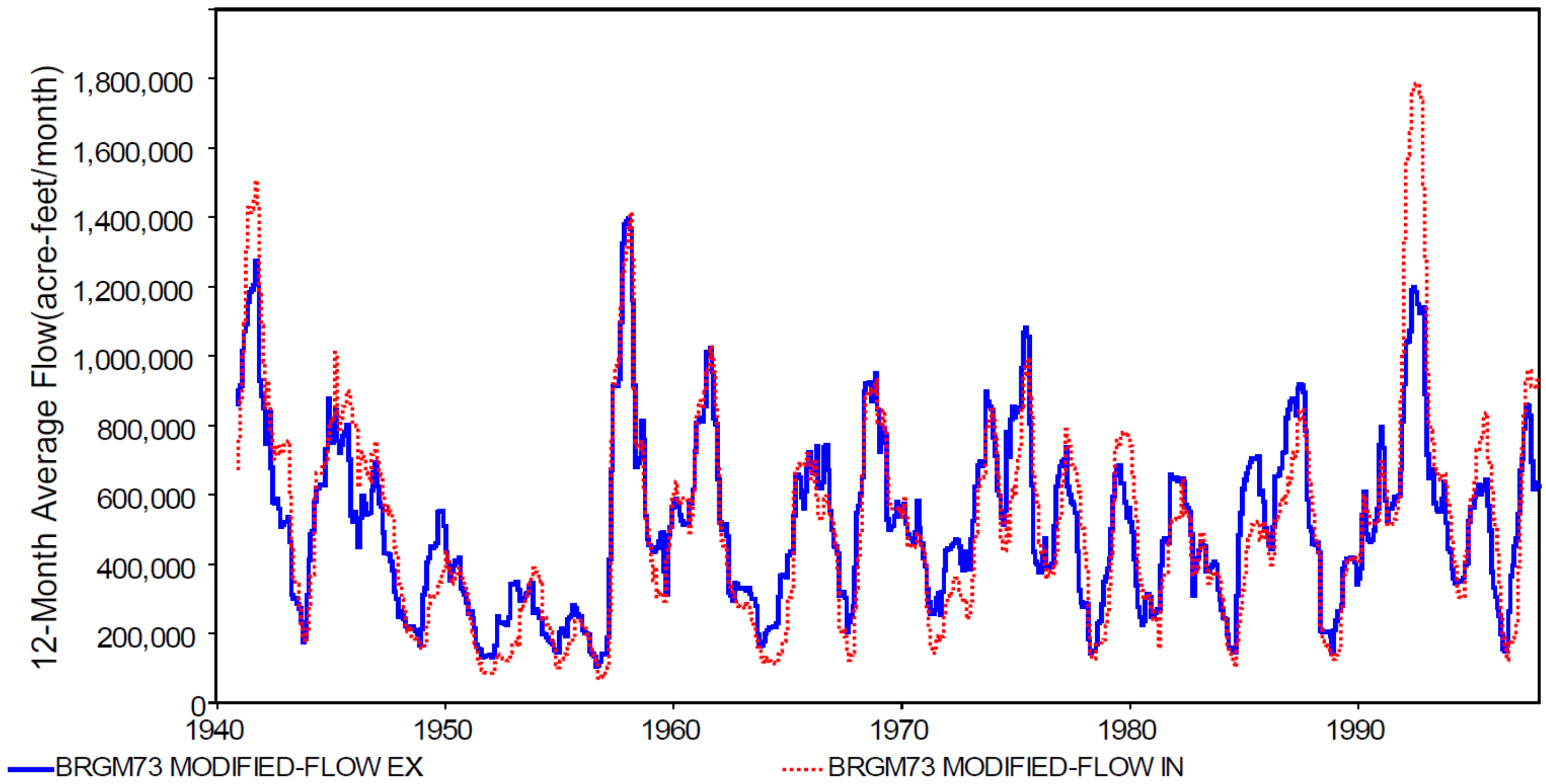


Figure B.4.31 Known and Final Computed 12-Month Forward Moving Average Flows for Brazos River at Gulf of Mexico BRGM73

B.5 Gaged and Extended 1998-2016 Naturalized Flows

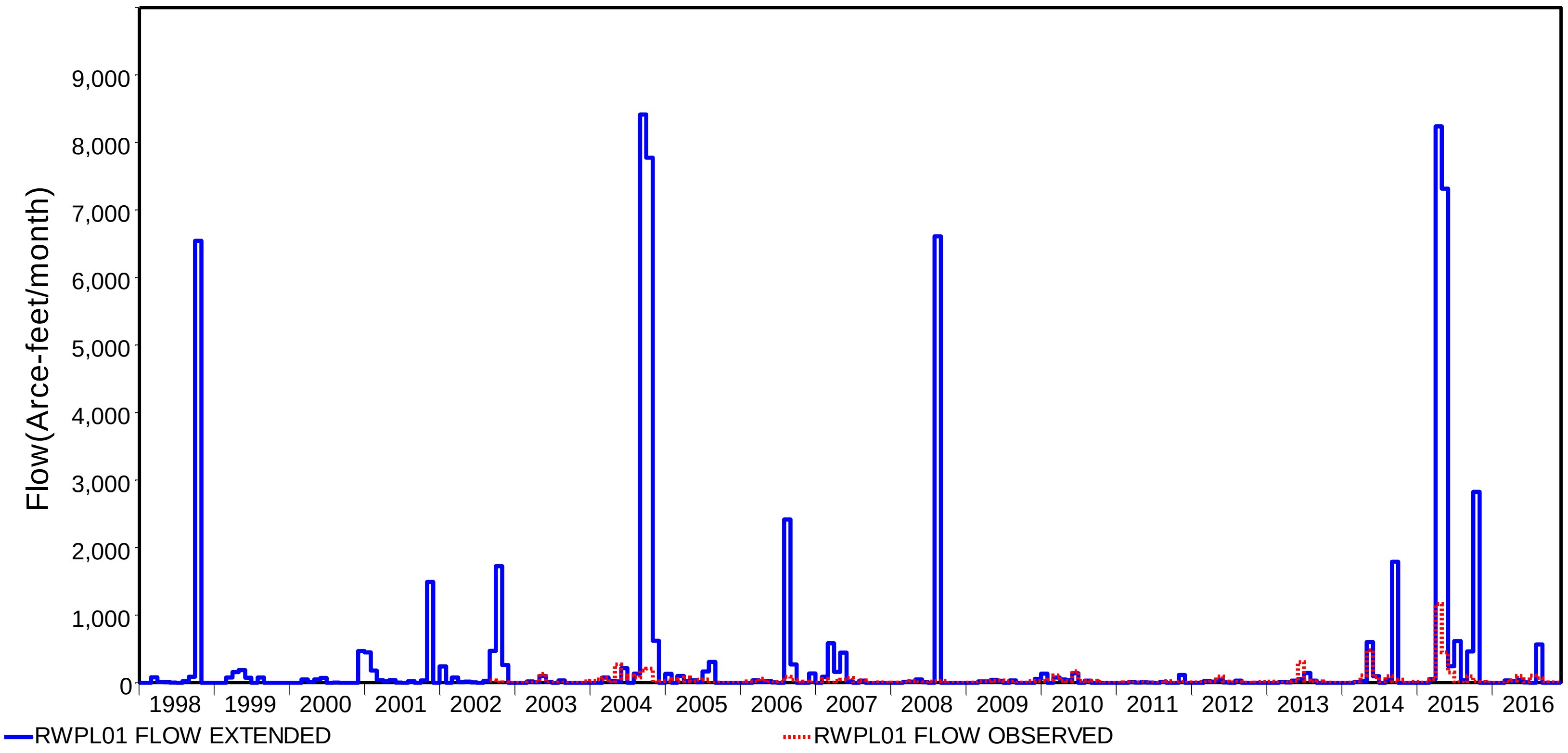


Figure B.5.1 Gaged and Extended 1998-2016 Naturalized Flows for Running Water Draw at Plainview RWPL01

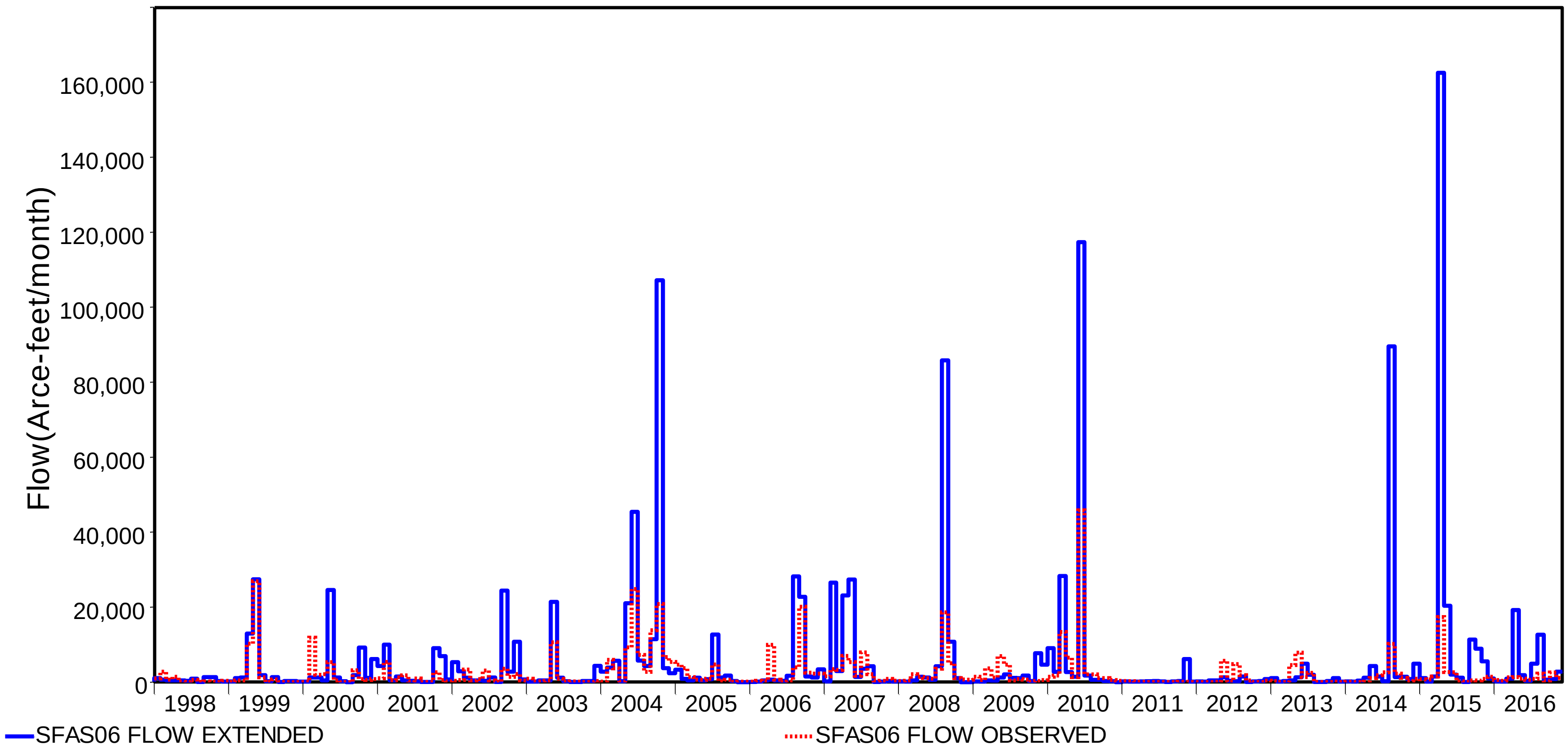


Figure B.5.2 Gaged and Extended 1998-2016 Naturalized Flows for Salt Fork Brazos River at Aspermont SFAS06

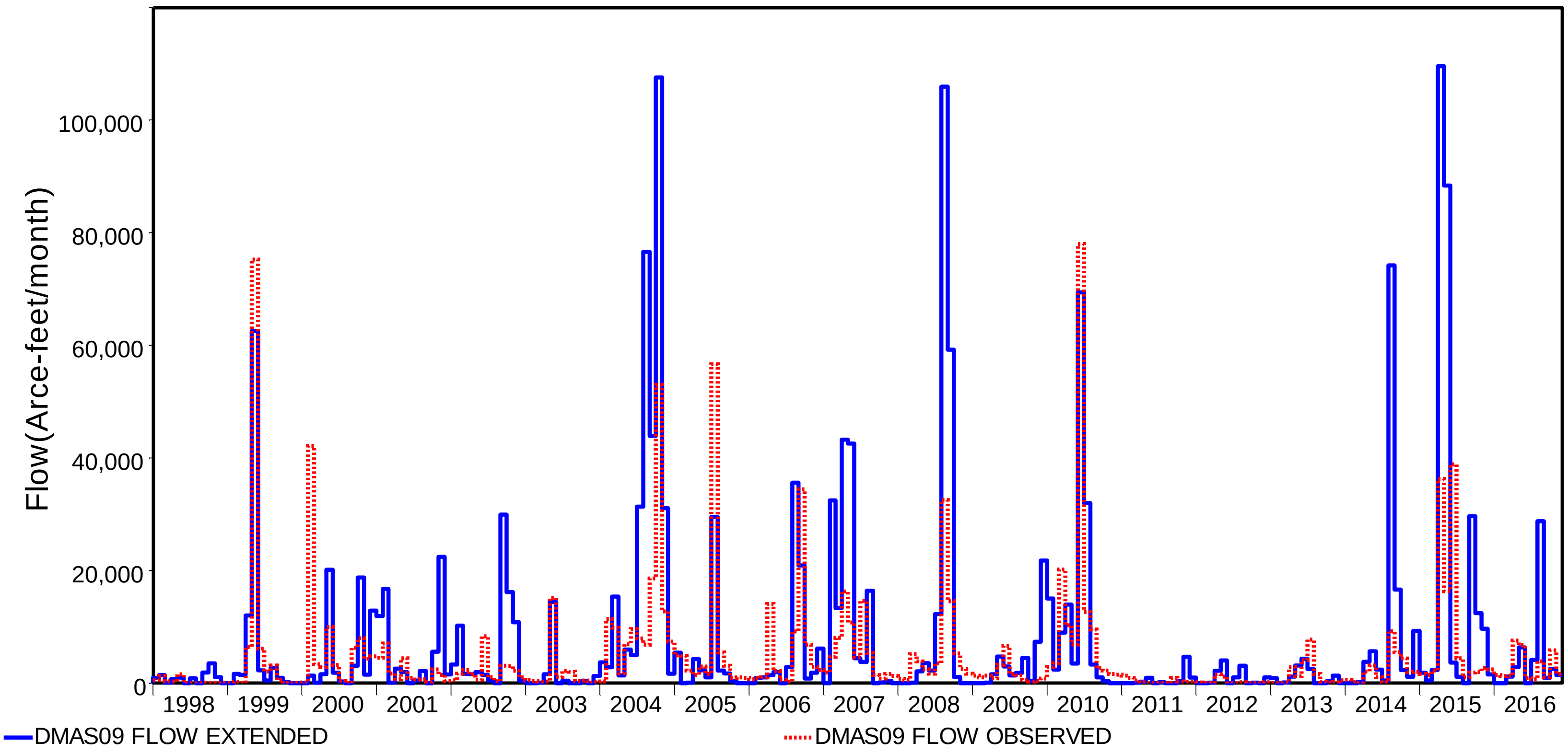


Figure B.5.3 Gaged and Extended 1998-2016 Naturalized Flows for Double Mountain Fork at Aspermont DMAS09

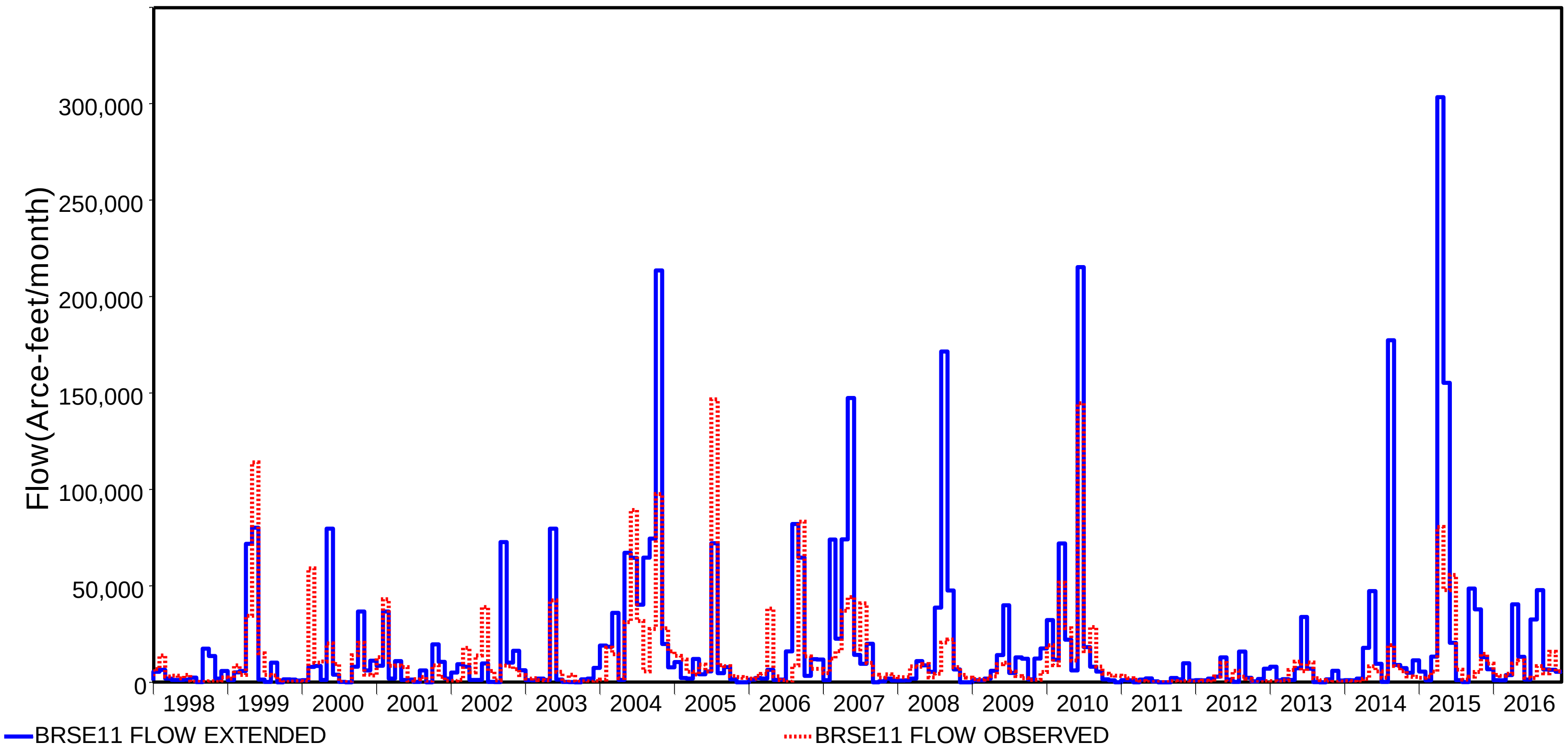


Figure B.5.4 Gaged and Extended 1998-2016 Naturalized Flows for Brazos River at Seymour BRSE11

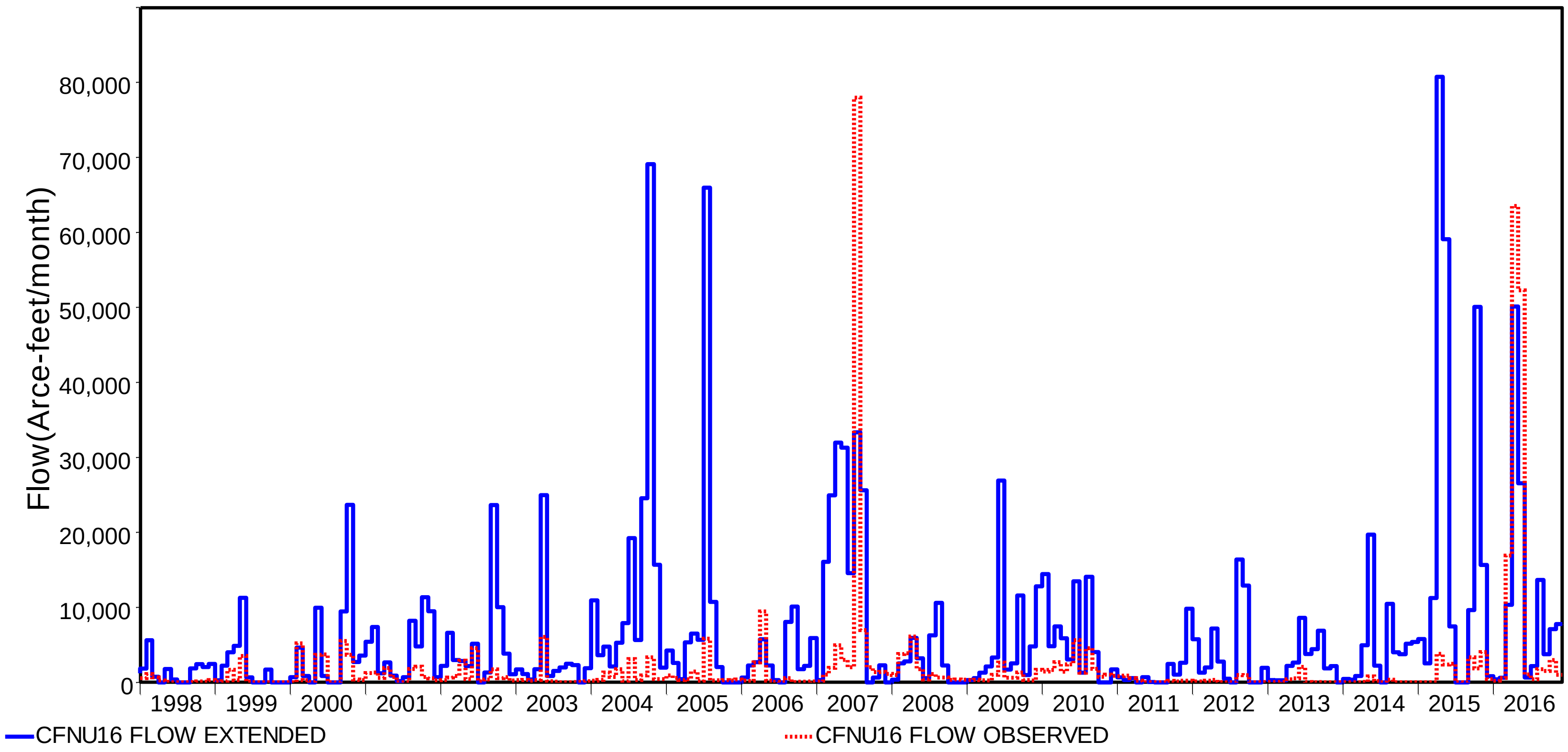


Figure B.5.5 Gaged and Extended 1998-2016 Naturalized Flows for Clear Fork Brazos at Nugent CFNU16

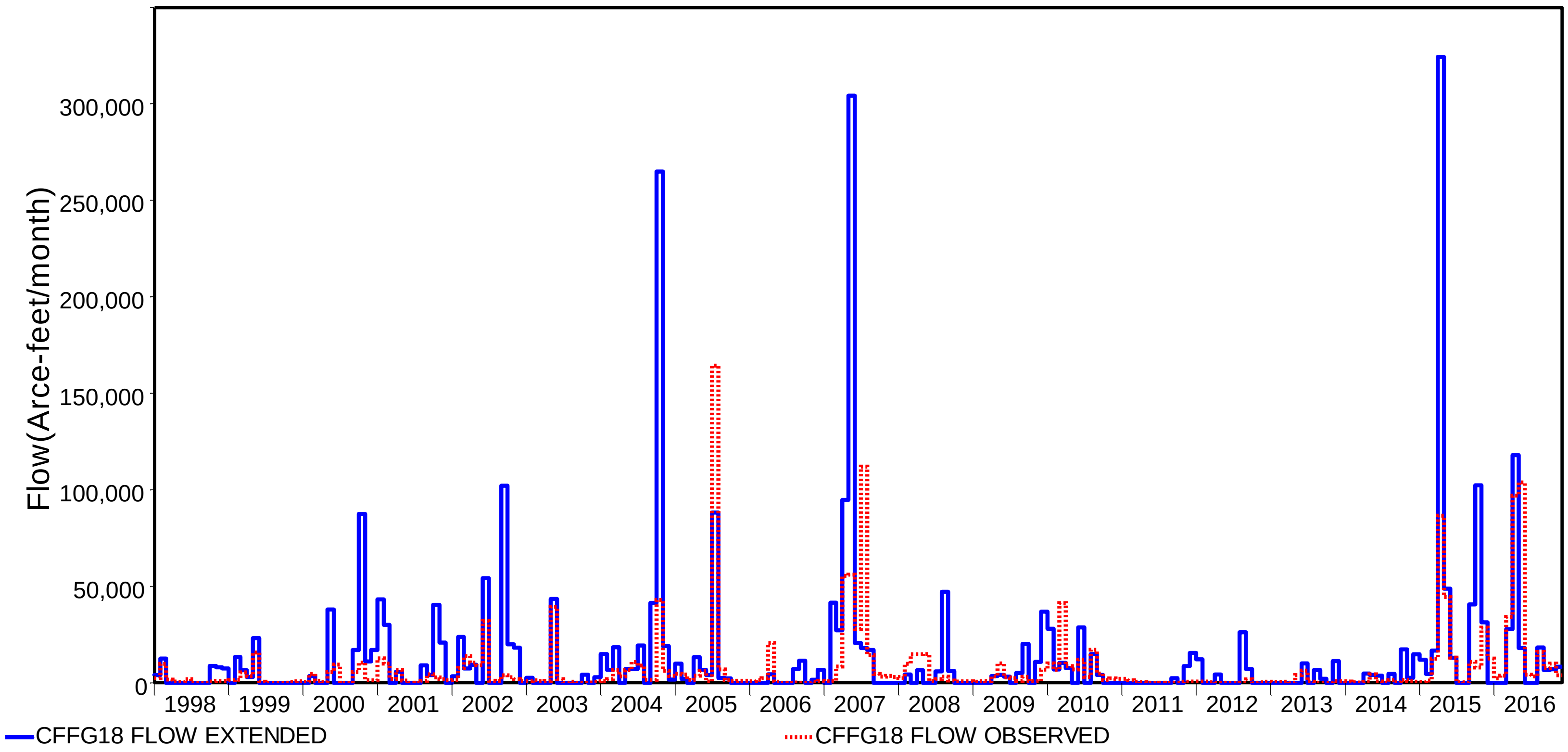


Figure B.5.6 Gaged and Extended 1998-2016 Naturalized Flows for Clear Fork Brazos at Fort Griffin CFFG18

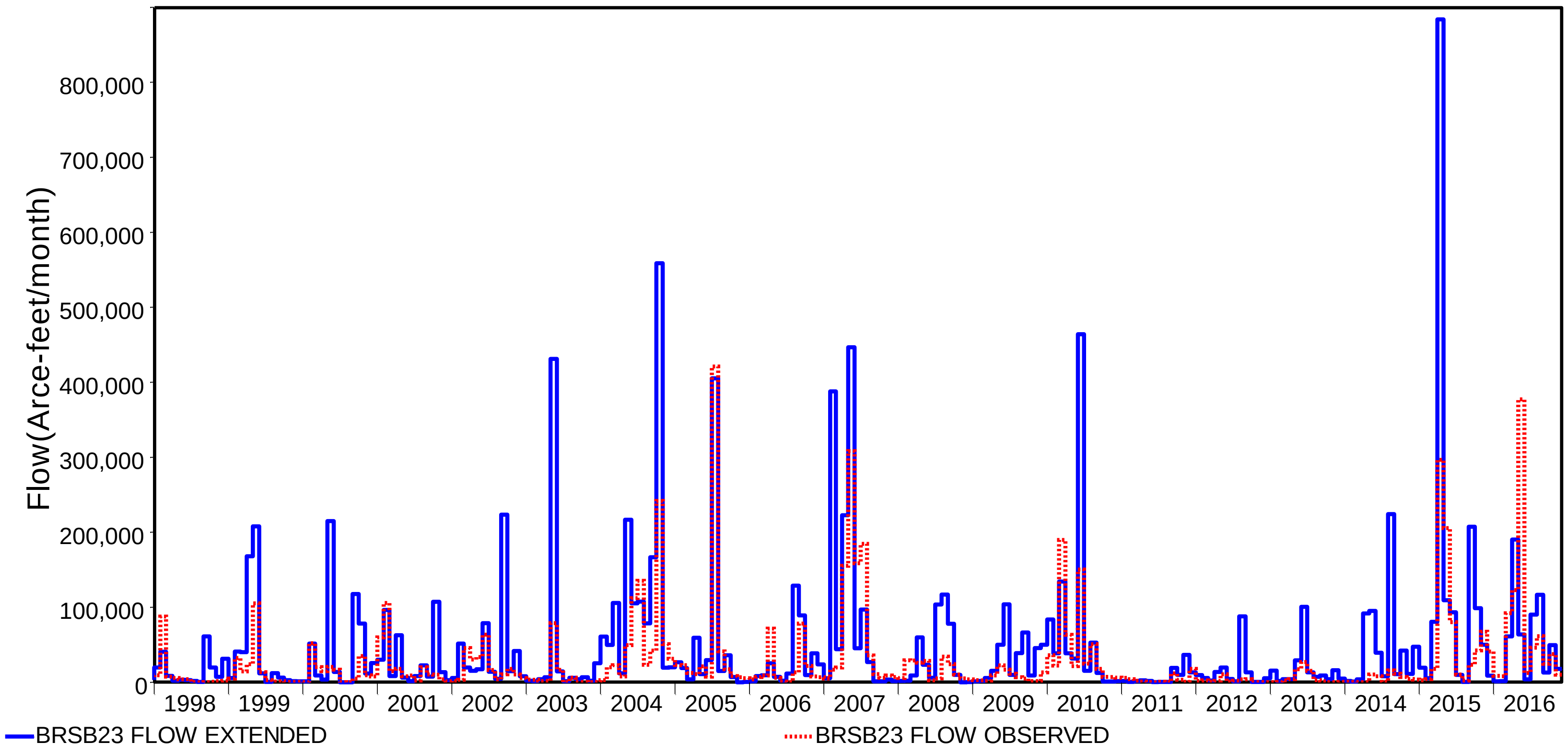


Figure B.5.7 Gaged and Extended 1998-2016 Naturalized Flows for Brazos River at South Bend BRSB23

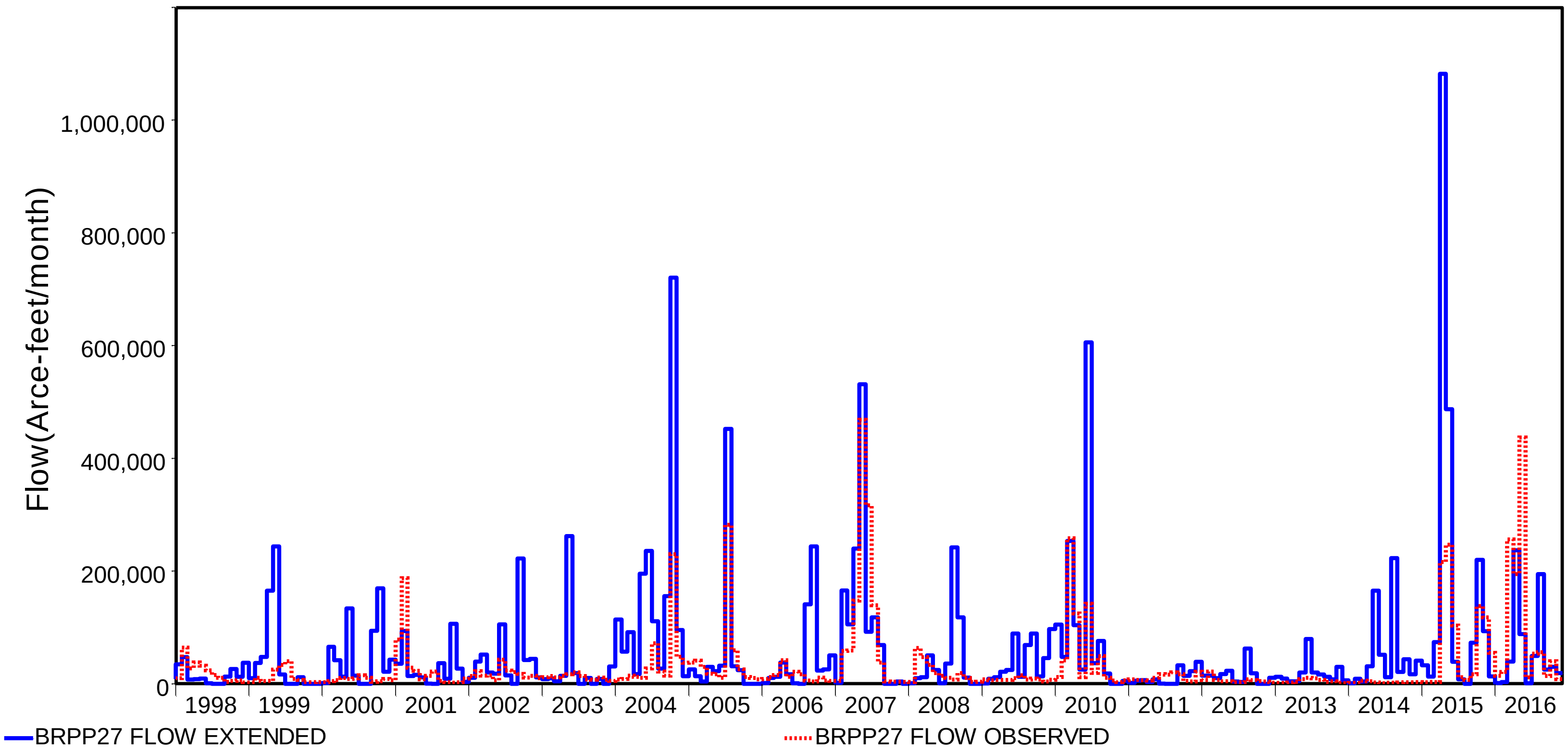


Figure B.5.8 Gaged and Extended 1998-2016 Naturalized Flows for Brazos River at Palo Pinto BRPP27

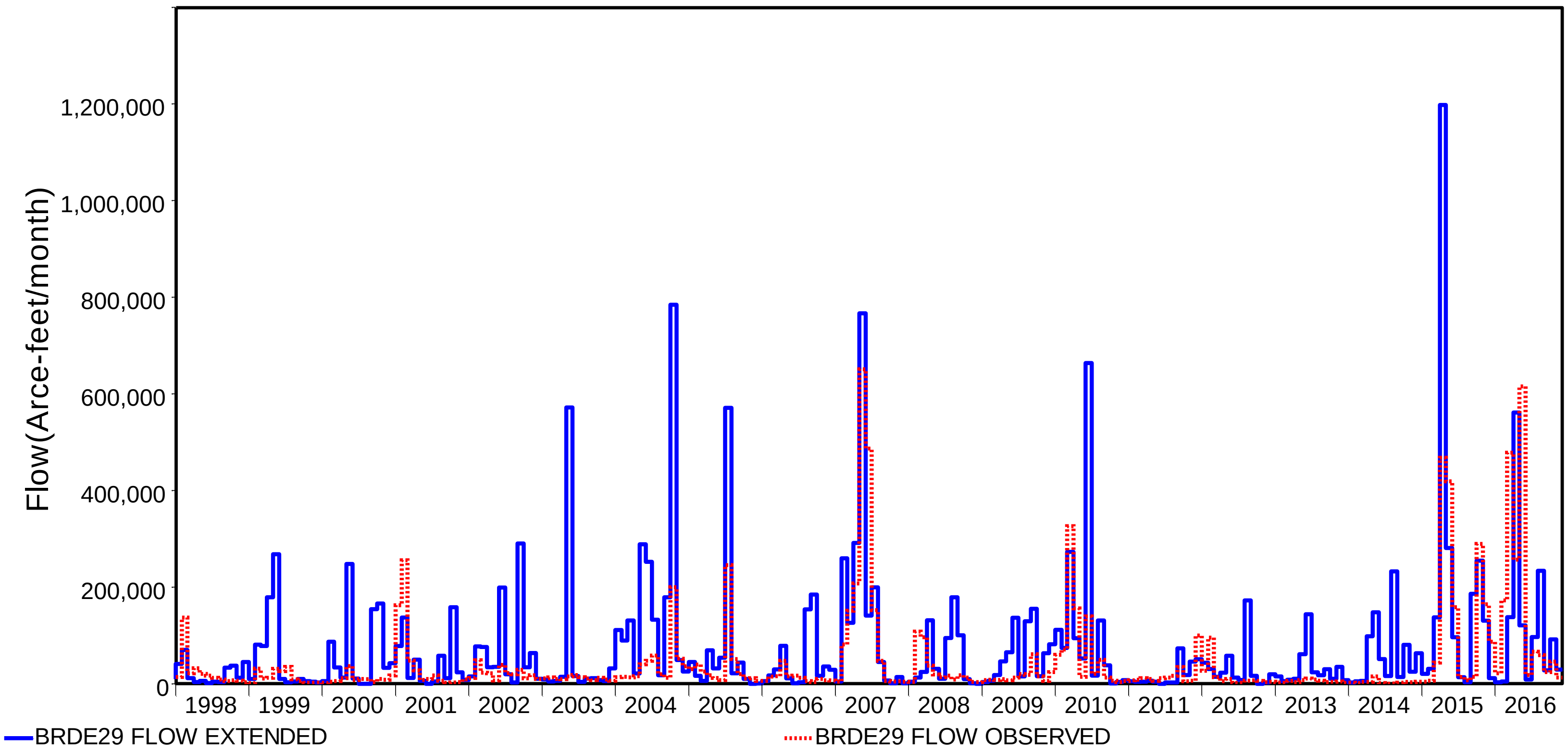


Figure B.5.9 Gaged and Extended 1998-2016 Naturalized Flows for Brazos River at Dennis BRDE29

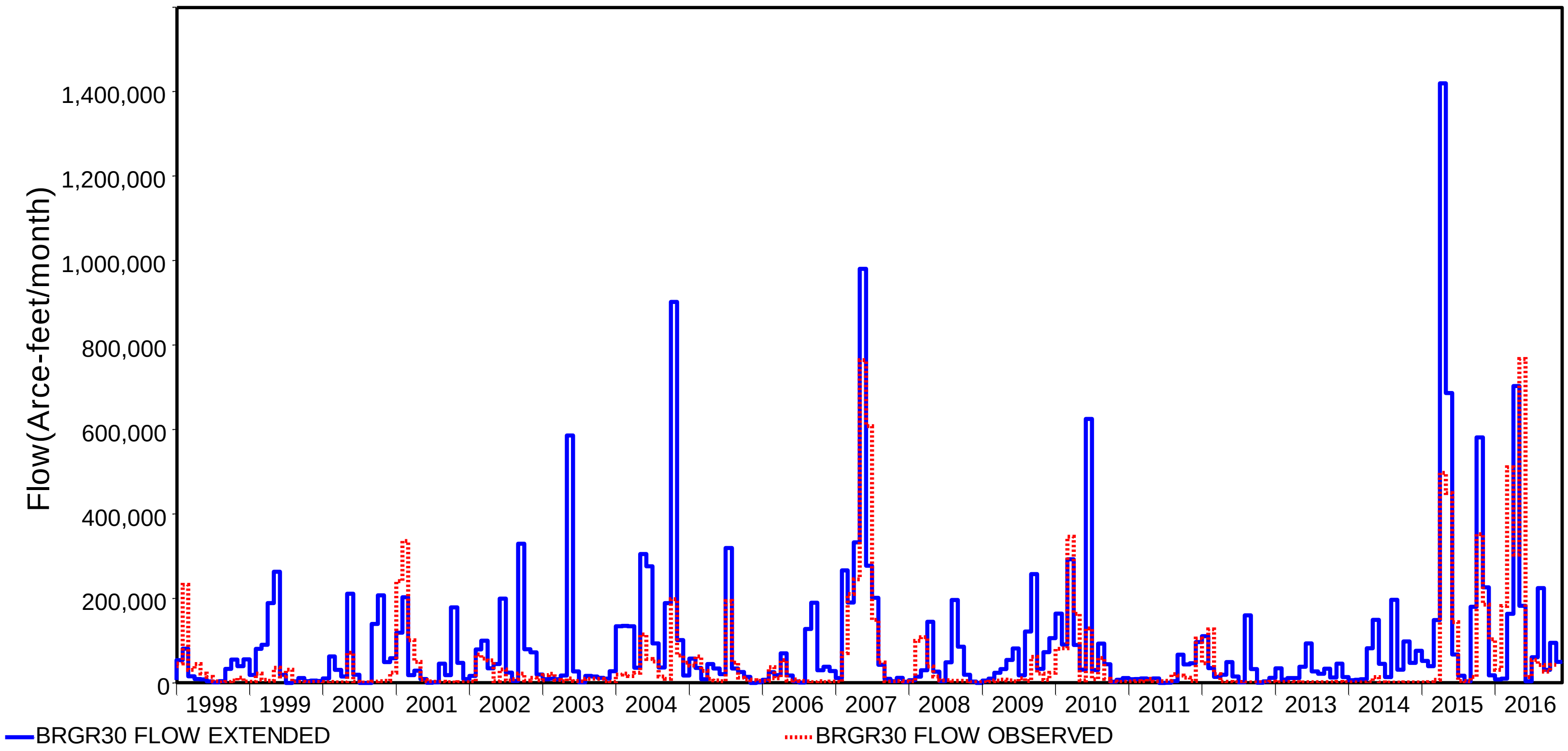


Figure B.5.10 Gaged and Extended 1998-2016 Naturalized Flows for Brazos River at Glen Rose BRGR30

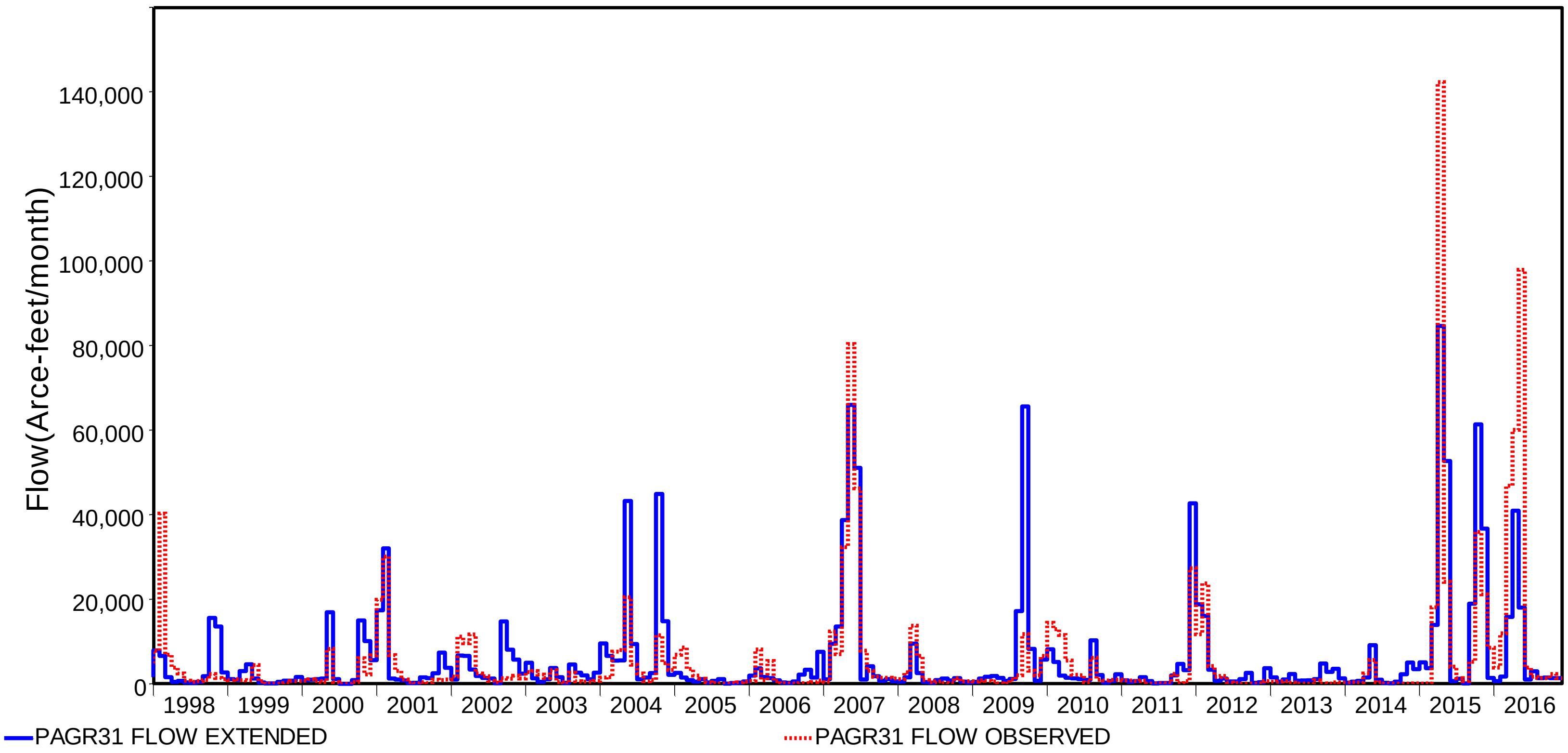


Figure B.5.11 Gaged and Extended 1998-2016 Naturalized Flows for Paluxy River at Glen Rose

PAGR31

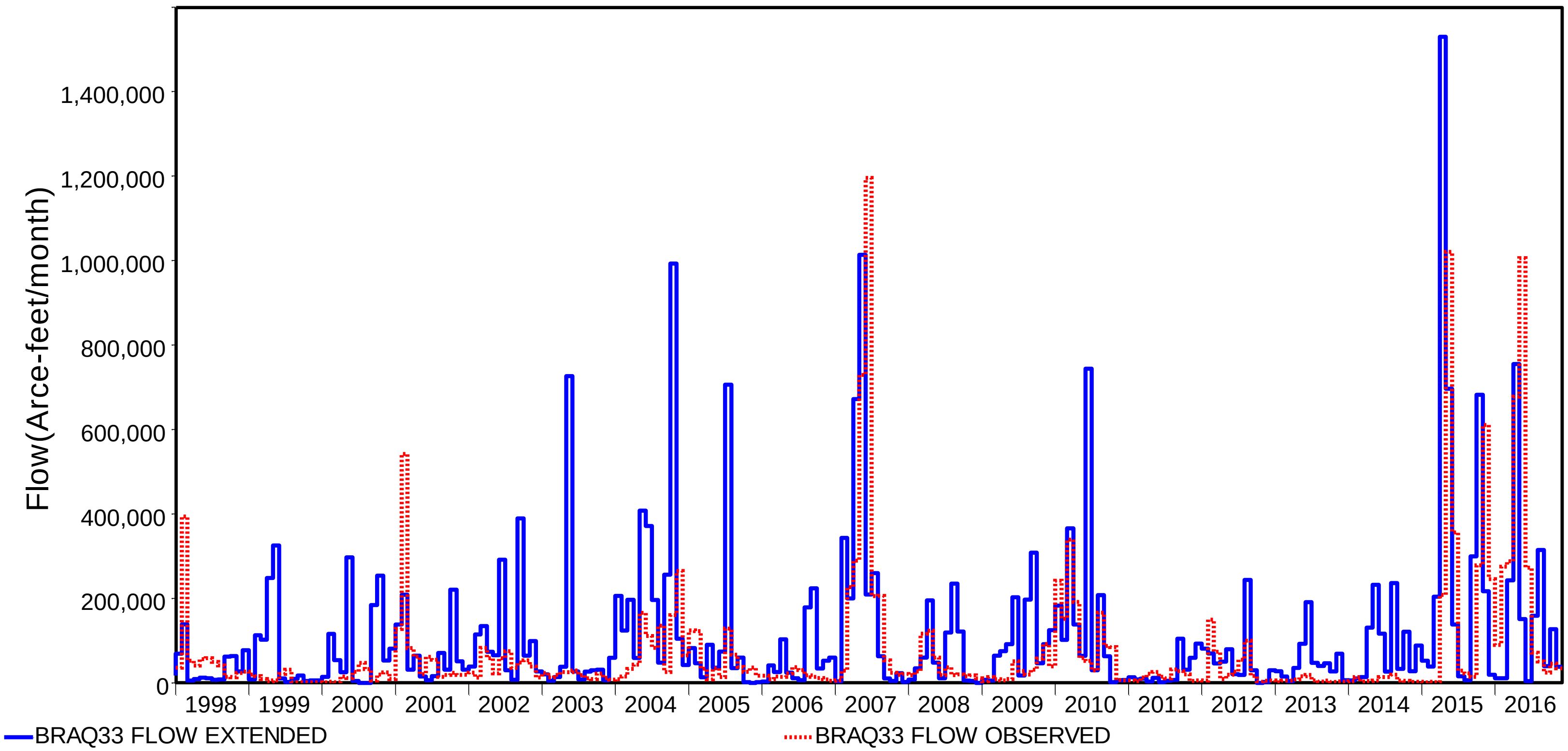


Figure B.5.12 Gaged and Extended 1998-2016 Naturalized Flows for Brazos River at Aquilla BRAQ33

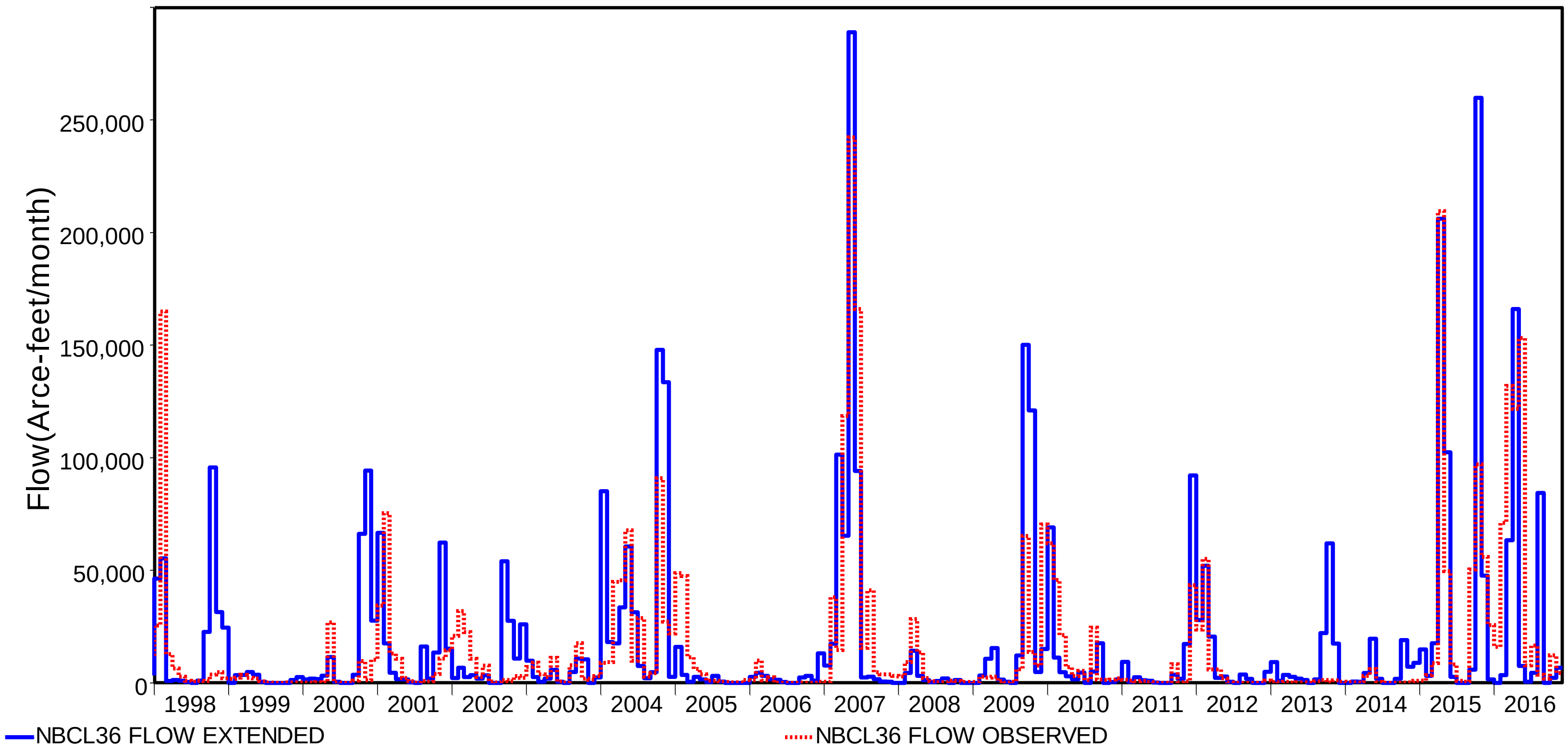


Figure B.5.13 Gaged and Extended 1998-2016 Naturalized Flows for North Bosque River at Clifton NBCL36

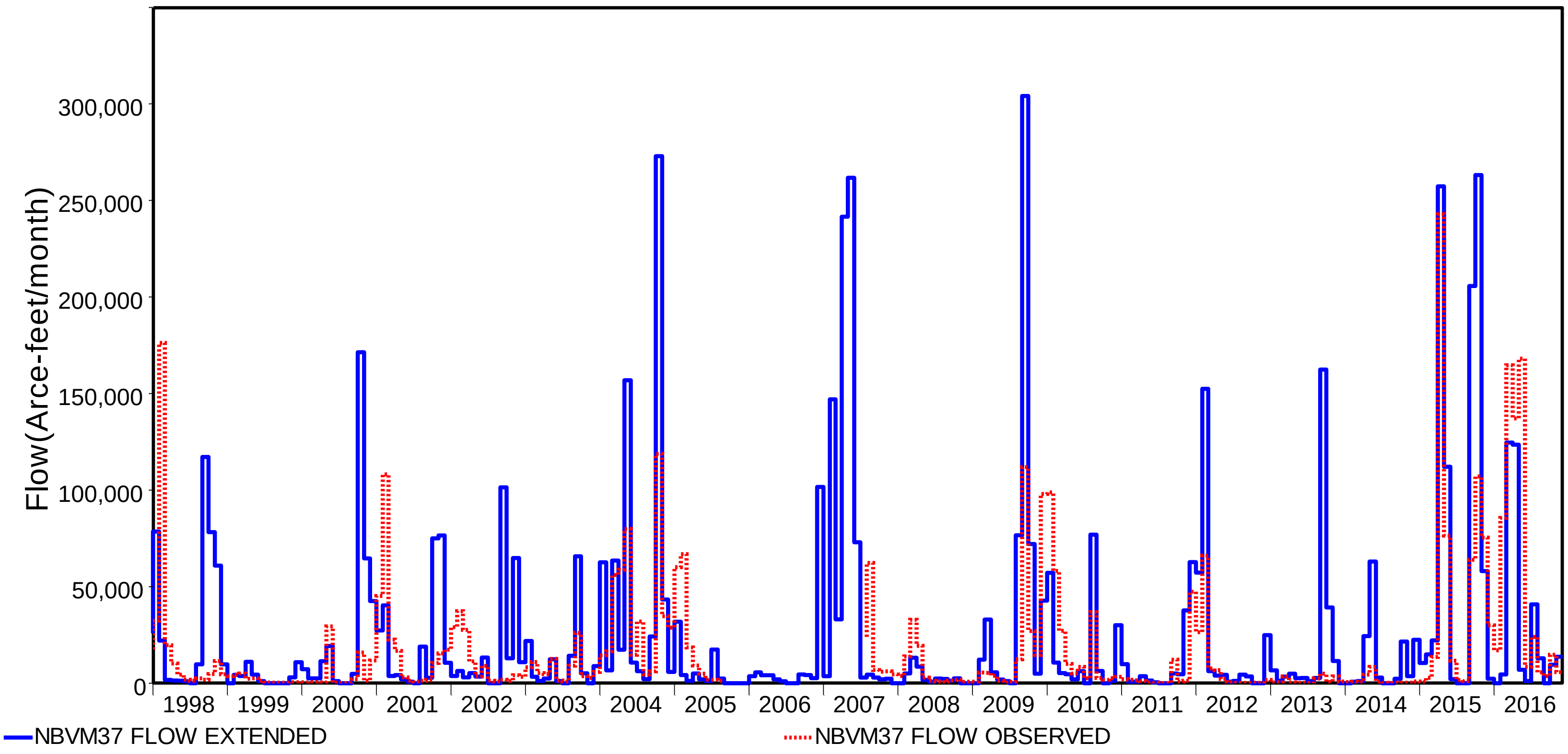


Figure B.5.14 Gaged and Extended 1998-2016 Naturalized Flows for North Bosque River at Valley Mills NBVM37

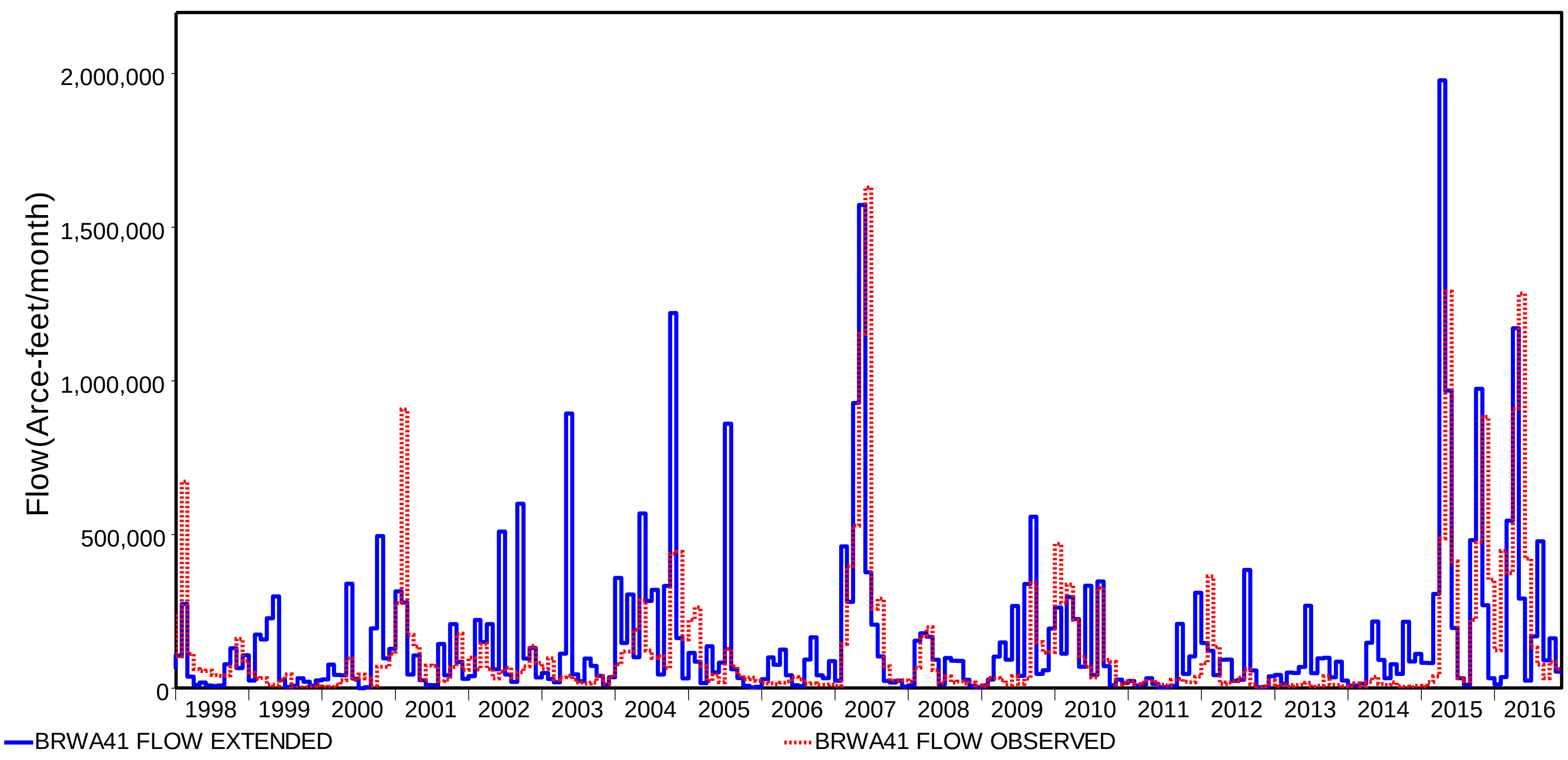


Figure B.5.15 Gaged and Extended 1998-2016 Naturalized Flows for Brazos River at Waco BRWA41

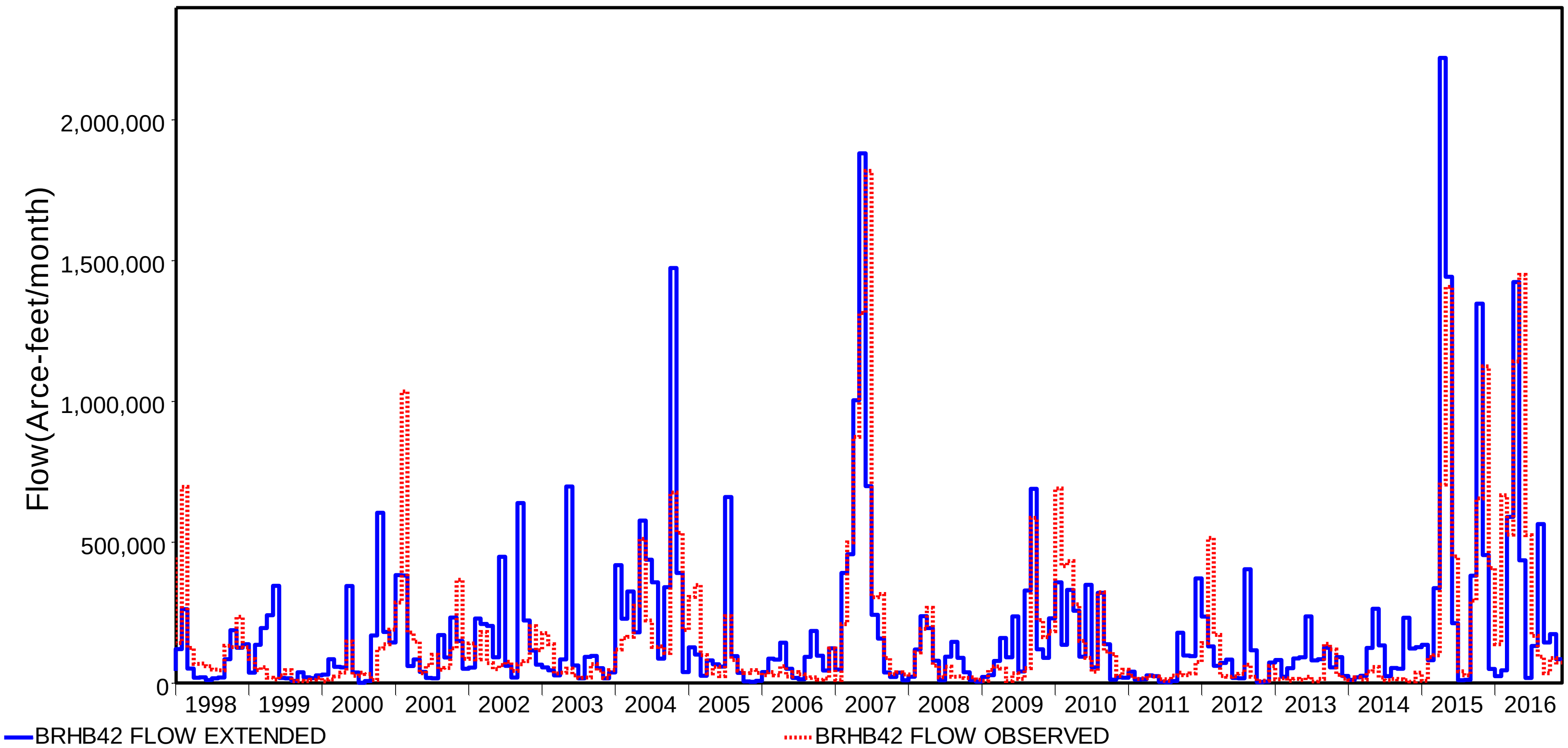


Figure B.5.16 Gaged and Extended 1998-2016 Naturalized Flows for Brazos River at Highbank BRHB42

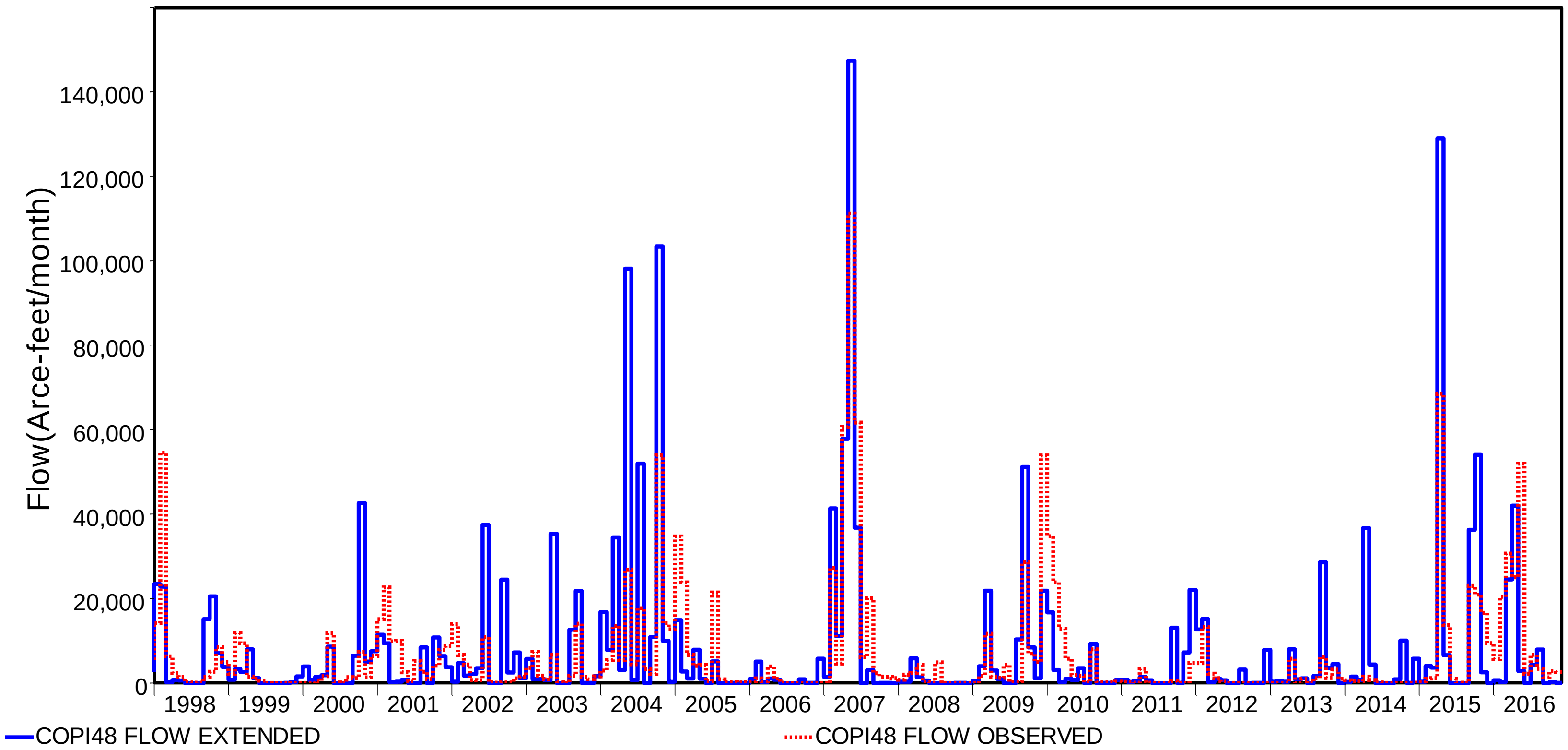


Figure B.5.17 Gaged and Extended 1998-2016 Naturalized Flows for Cowhouse Creek at Pidcoke COPI48

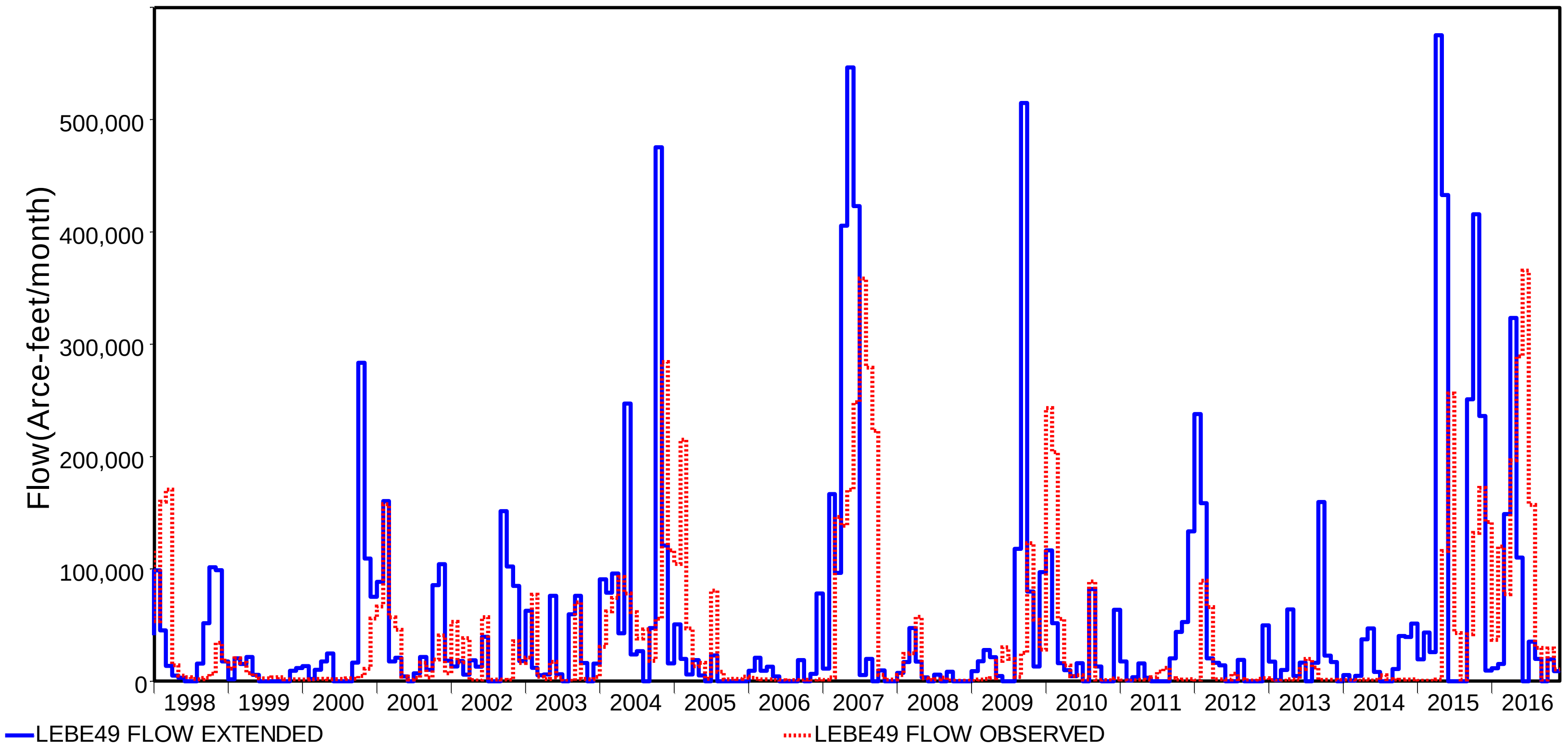


Figure B.5.18 Gaged and Extended 1998-2016 Naturalized Flows for Leon River at Belton LEBE49

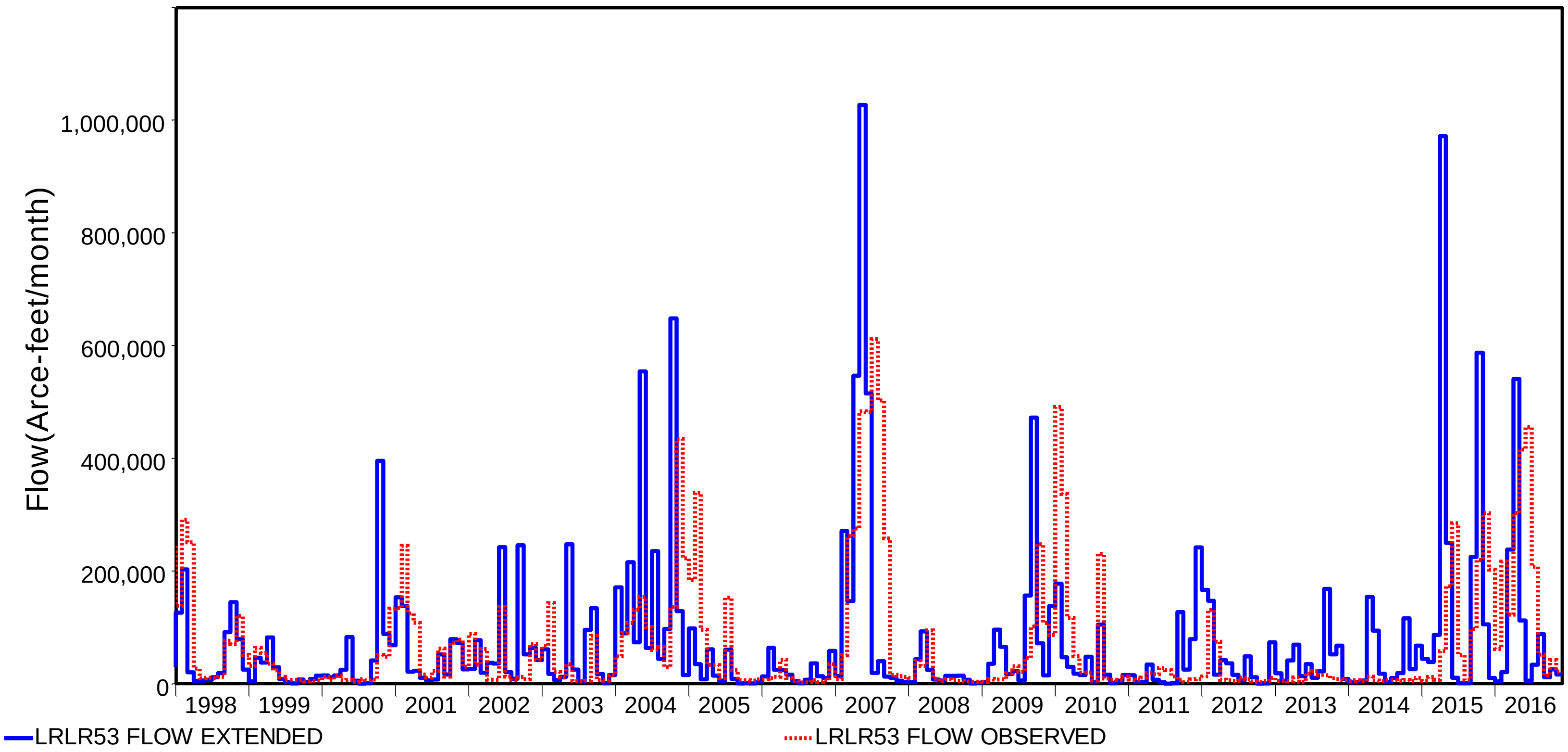


Figure B.5.19 Gaged and Extended 1998-2016 Naturalized Flows for Little River at Little River LRLR53

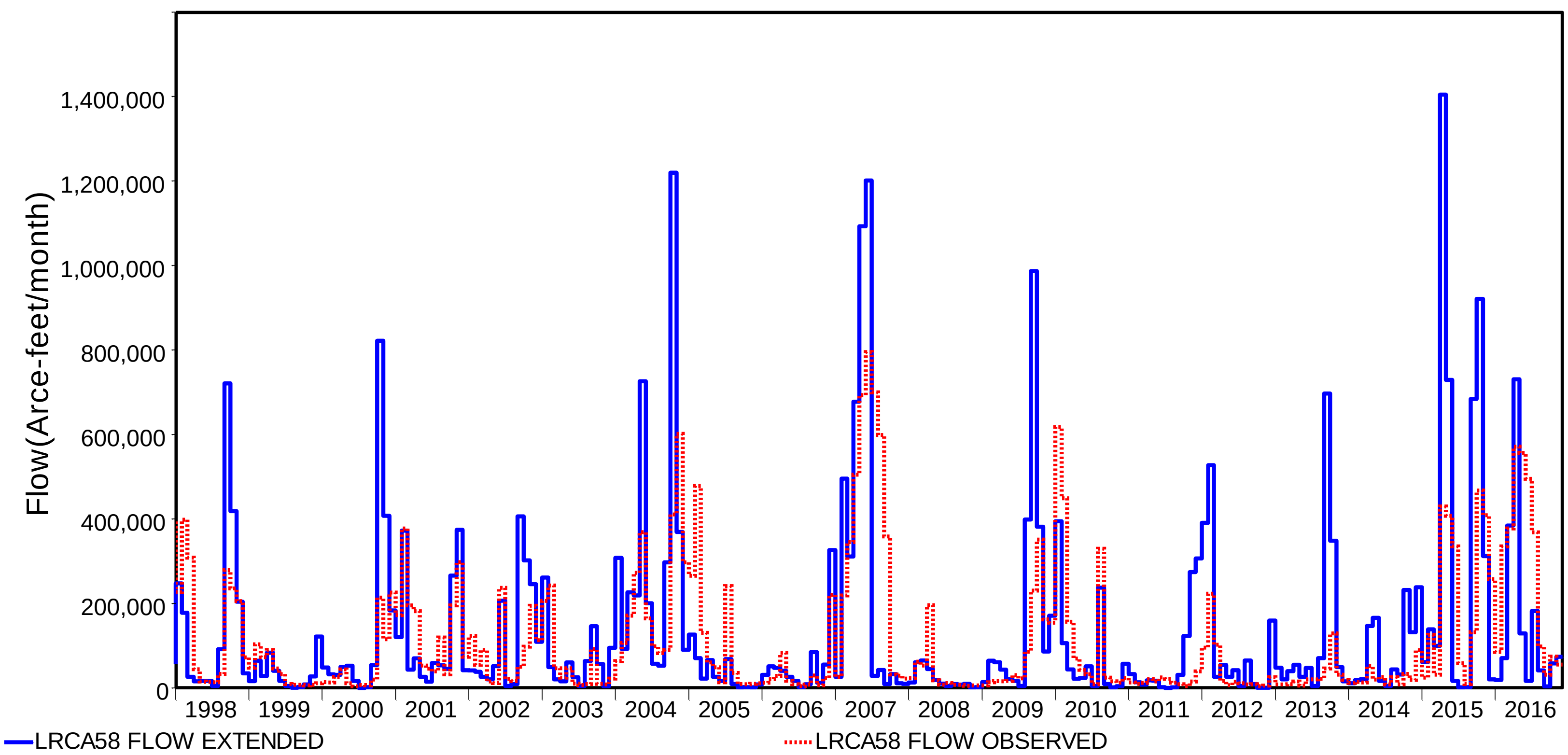


Figure B.5.20 Gaged and Extended 1998-2016 Naturalized Flows for Little River at Cameron LRCA58

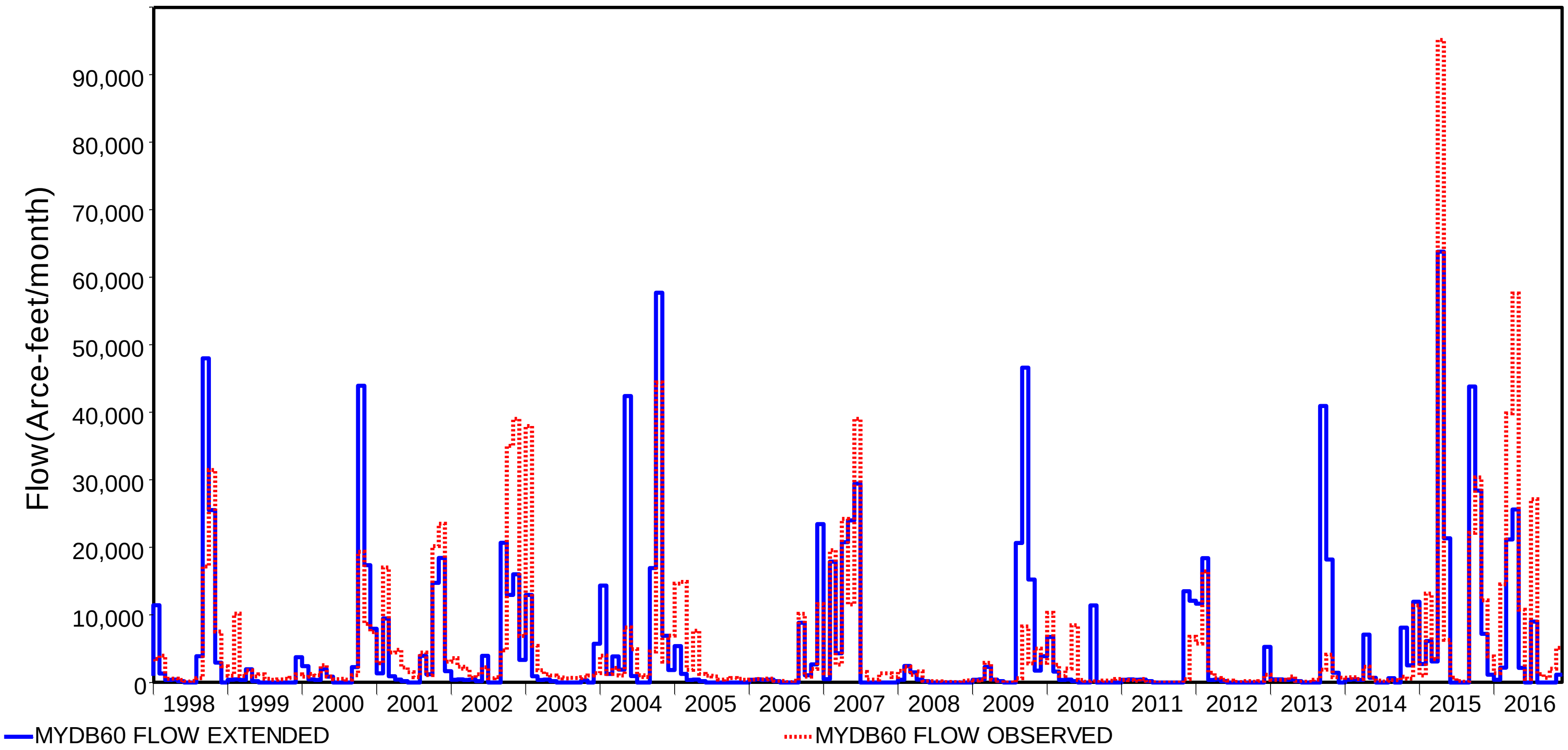


Figure B.5.21 Gaged and Extended 1998-2016 Naturalized Flows for Middle Yegua Creek at Dime Box MYDB60

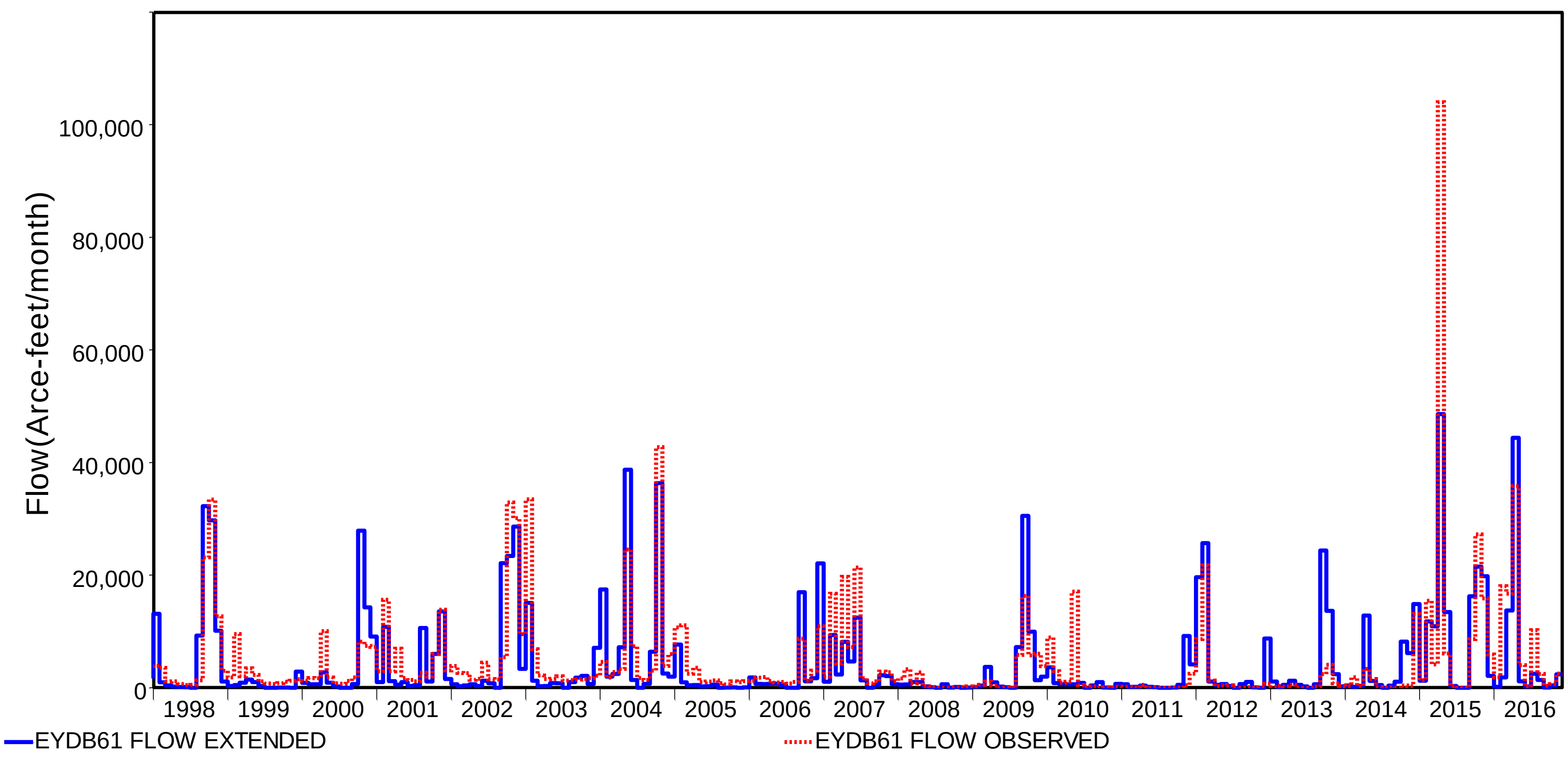


Figure B.5.22 Gaged and Extended 1998-2016 Naturalized Flows for East Yegua Creek at Dime Box EYDB61

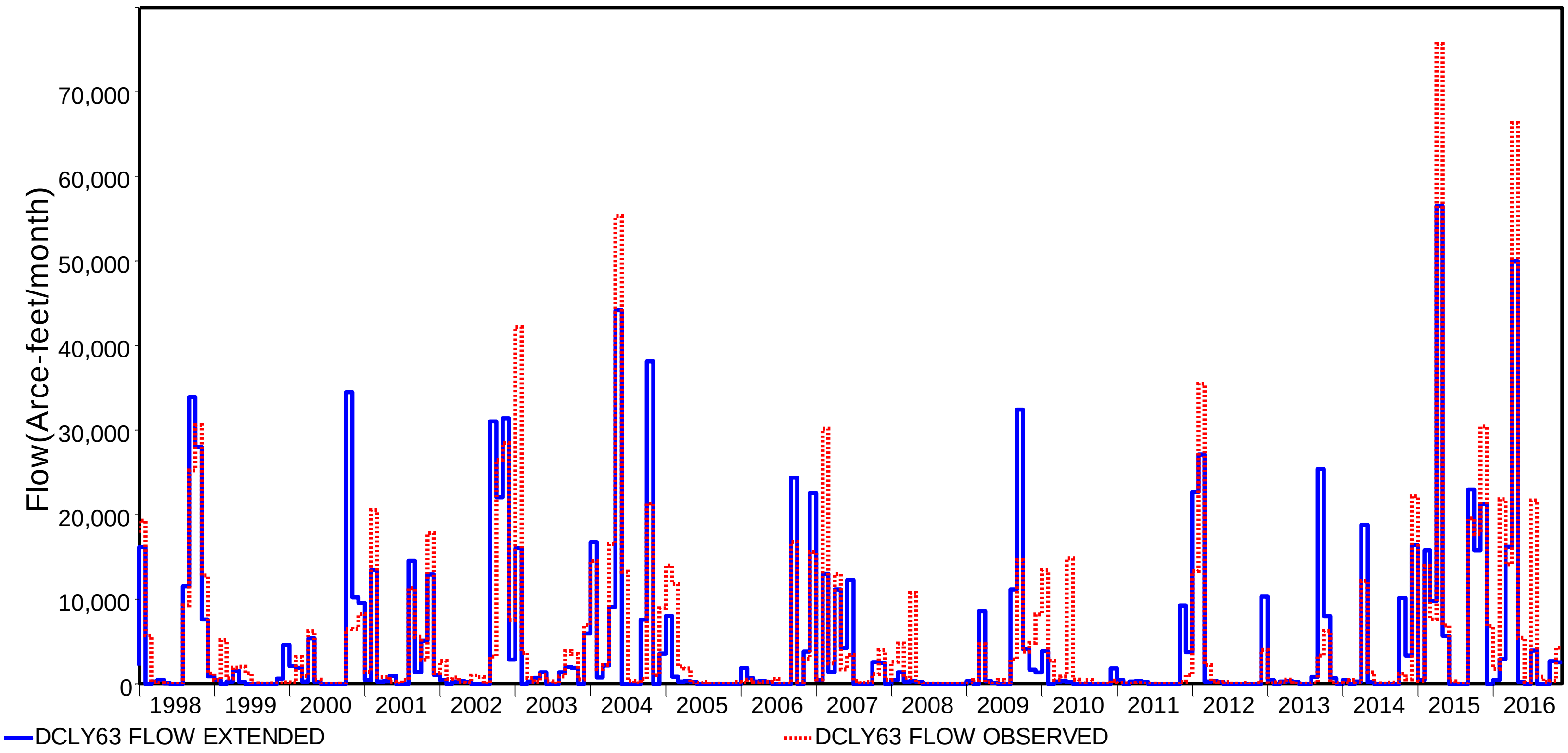


Figure B.5.23 Gaged and Extended 1998-2016 Naturalized Flows for Davidson Creek at Lyons DCLY63

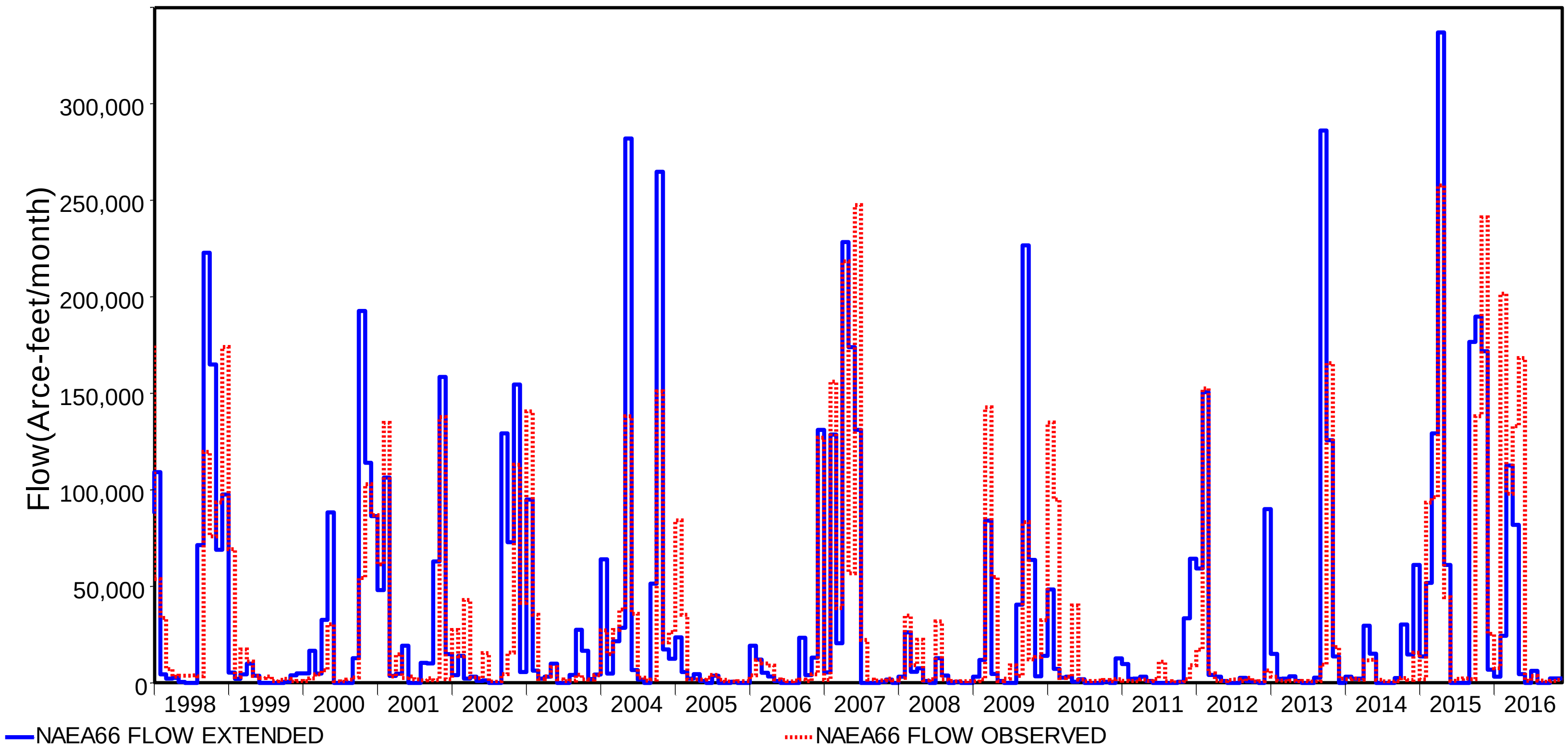


Figure B.5.24 Gaged and Extended 1998-2016 Naturalized Flows for Navasota River at Easterly NAEA66

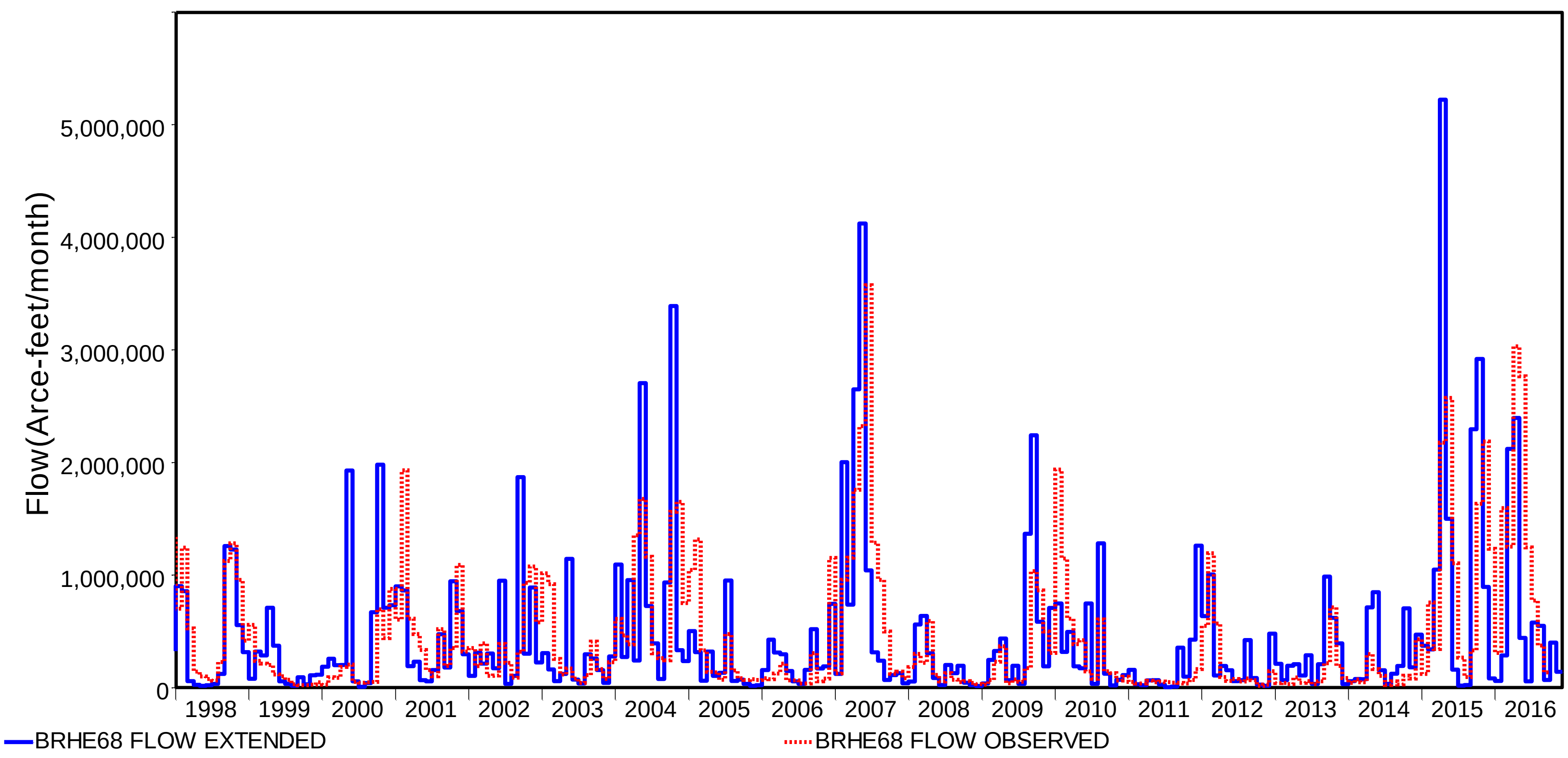


Figure B.5.25 Gaged and Extended 1998-2016 Naturalized Flows for Brazos River at Hempstead BRHE68

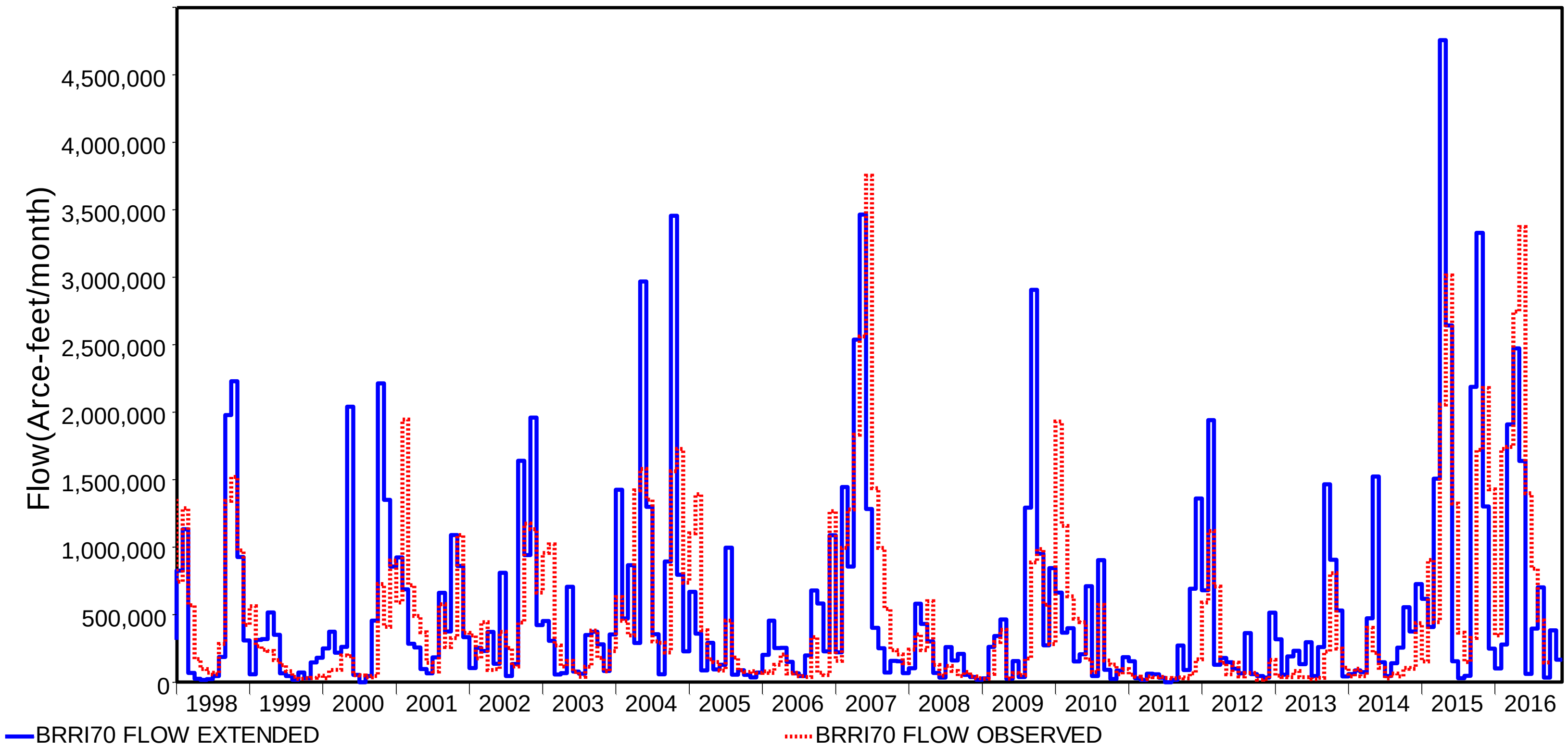


Figure B.5.26 Gaged and Extended 1998-2016 Naturalized Flows for Brazos River at Richmond BRRI70

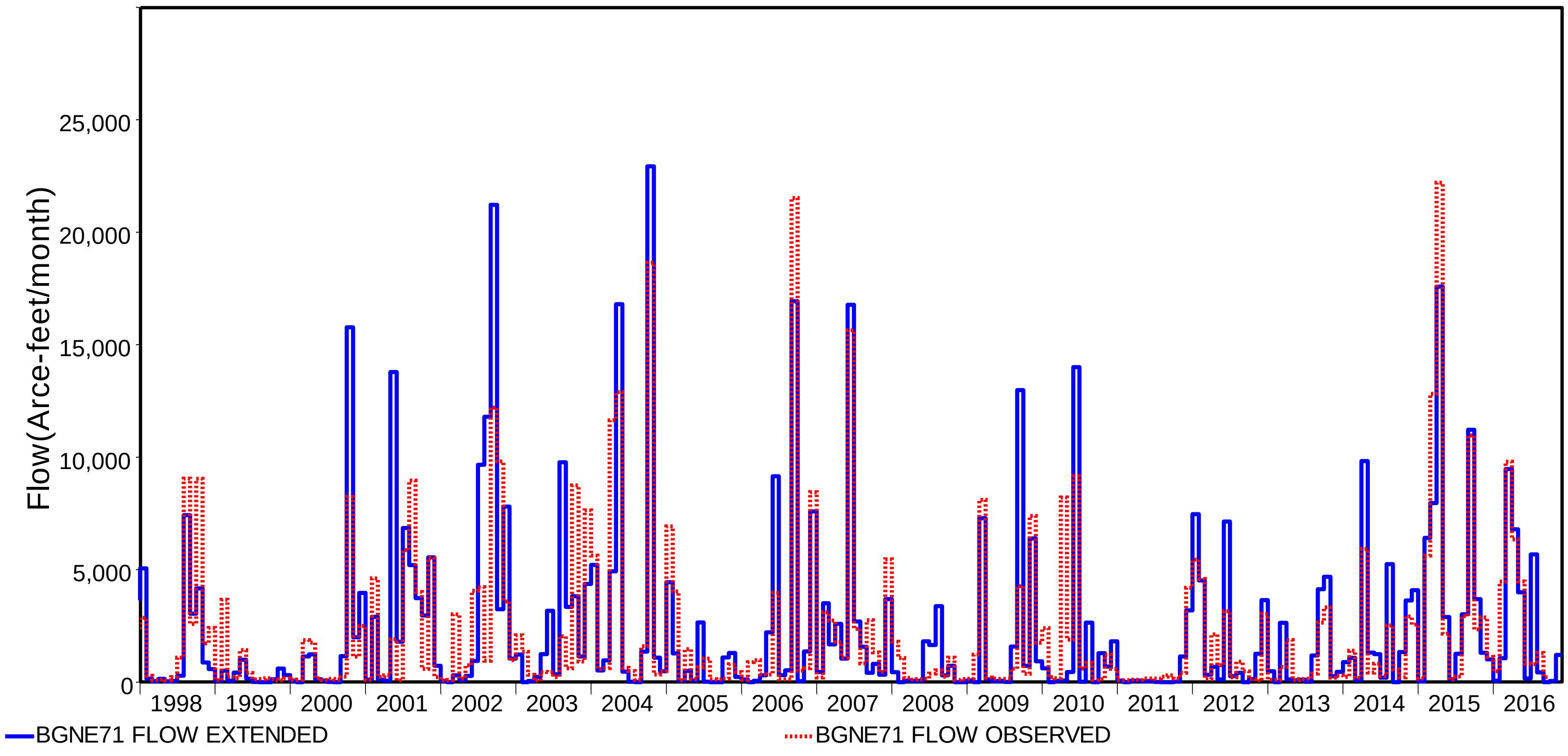


Figure B.5.27 Gaged and Extended 1998-2016 Naturalized Flows for Big Creek at Needville BGNE71

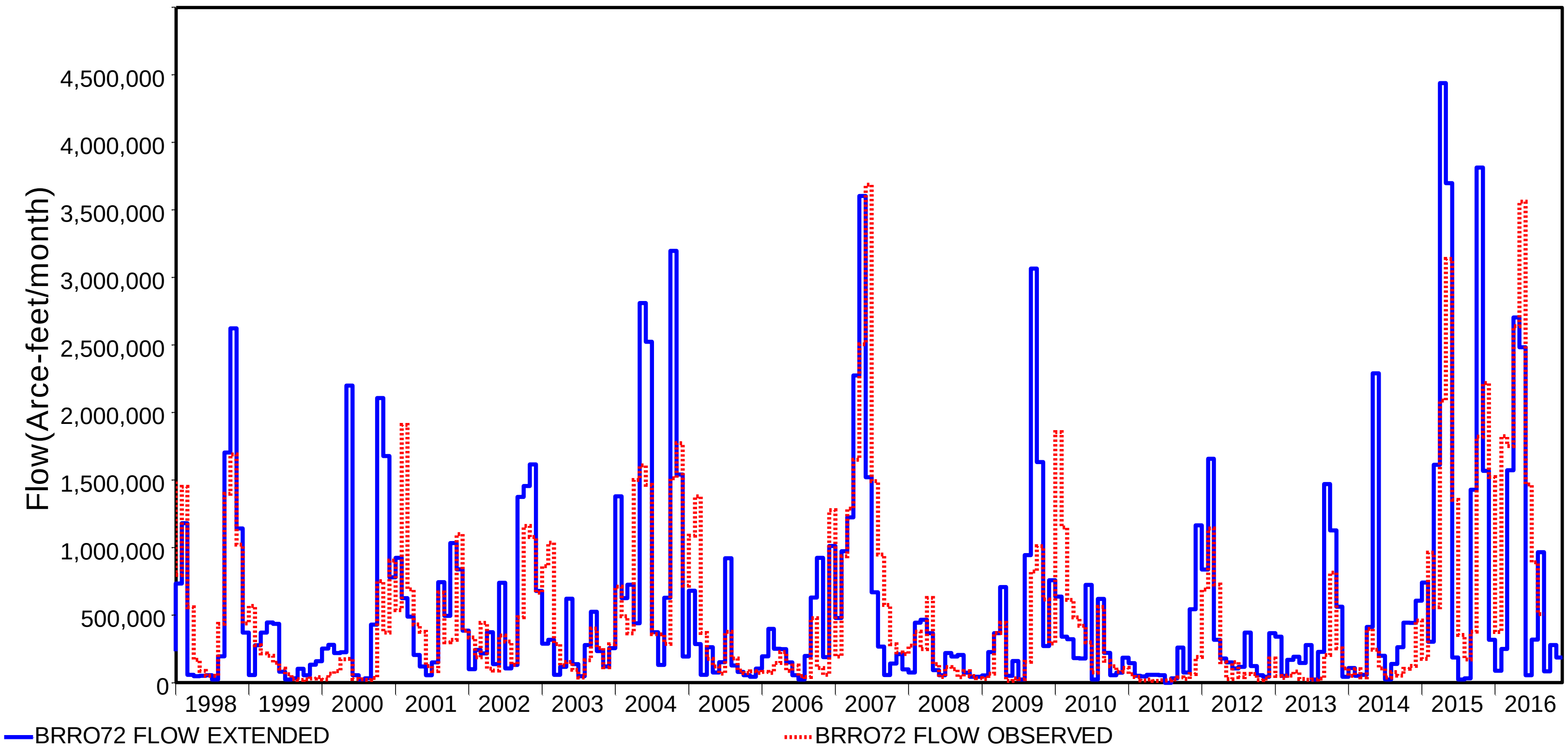


Figure B.5.28 Gaged and Extended 1998-2016 Naturalized Flows for Brazos River at Rosharon BRRO72

APPENDIX C

NORTH HAN RIVER WAM/WRAP DATASET

C.1 Tables for 1966-2017 Naturalized Flows at Control Points

Table C.1.1 1966-2017 Naturalized Flows at Control Points NHYA01

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	6446.	5803.	11590.	18358.	12828.	80554.	454178.	171665.	218787.	39351.	21110.	10961.	1051631.
1967	7293.	7626.	23441.	43333.	25286.	12498.	159250.	179978.	65913.	11742.	8129.	7792.	552281.
1968	7141.	6498.	8031.	25164.	9485.	15229.	154865.	179175.	66690.	35640.	39825.	20164.	567907.
1969	8226.	7901.	10809.	127479.	138782.	54025.	207609.	324121.	42304.	12046.	9284.	7727.	950313.
1970	7423.	6783.	6989.	6680.	7358.	12456.	146509.	186728.	259263.	41022.	24429.	9225.	714865.
1971	6924.	6058.	6685.	6554.	8552.	11406.	115492.	118748.	35708.	11373.	6406.	6208.	340114.
1972	6056.	5360.	7293.	6953.	6946.	8969.	57453.	389952.	98219.	41826.	40329.	19296.	688652.
1973	13891.	13821.	15584.	40602.	81980.	12876.	46622.	206371.	144408.	20511.	13779.	8074.	618519.
1974	6121.	5921.	11525.	46652.	128732.	55453.	63878.	222455.	37536.	25460.	10376.	7467.	621576.
1975	6490.	5803.	7098.	21341.	29085.	47576.	270445.	122764.	106075.	28217.	10208.	9941.	665043.
1976	6815.	7736.	19556.	12414.	11981.	13338.	35227.	385677.	77718.	15823.	13821.	13175.	613281.
1977	8964.	6156.	7467.	67930.	30409.	22517.	92615.	85453.	33356.	8335.	15081.	13652.	391935.
1978	9203.	5999.	36356.	24198.	7054.	142140.	223019.	208151.	67426.	14629.	13926.	7271.	759372.
1979	6642.	8450.	31190.	112565.	52353.	163250.	96501.	268773.	32305.	11894.	7268.	7119.	798310.
1980	6924.	6234.	6642.	61355.	20251.	14955.	157600.	93484.	56293.	11590.	8549.	7510.	451387.
1981	6577.	6371.	19339.	18568.	17104.	24429.	371937.	97890.	206646.	12763.	7604.	6859.	796087.
1982	6685.	5862.	6468.	6448.	8074.	9452.	50508.	226036.	42640.	17538.	41149.	35683.	456543.
1983	11135.	7528.	38635.	45139.	50529.	7919.	180499.	72126.	81415.	32406.	7940.	6468.	541739.
1984	6316.	5746.	6316.	20585.	18254.	13464.	65658.	114429.	277012.	17559.	11973.	16908.	574220.
1985	8053.	7803.	22226.	45497.	53807.	13569.	14955.	89164.	111599.	68523.	20564.	14065.	469825.
1986	8031.	6352.	46731.	26634.	15215.	14661.	78030.	143622.	68077.	24527.	21005.	13479.	466364.
1987	8964.	11724.	19383.	25815.	27088.	46106.	126236.	300094.	102126.	12654.	14682.	8465.	703337.
1988	6729.	6132.	6446.	10418.	8074.	10733.	241056.	27869.	14745.	6946.	5776.	5817.	350741.
1989	5882.	5646.	39156.	27999.	12459.	26235.	148918.	93180.	94375.	30517.	93640.	12567.	590574.
1990	7510.	25898.	80135.	59507.	57214.	192005.	330871.	108178.	341161.	21944.	13821.	10766.	1249010.
1991	7597.	7920.	39026.	21992.	22161.	19303.	185166.	49466.	57217.	20077.	10502.	15302.	455729.
1992	15345.	9157.	46557.	41107.	45277.	32936.	56563.	115319.	81163.	31407.	18967.	22443.	516241.
1993	14390.	15292.	30430.	33587.	81025.	126218.	92116.	40458.	16573.	9311.	15124.	8096.	482620.
1994	7032.	6156.	9897.	26340.	53763.	21299.	112302.	112888.	47597.	107375.	21509.	11417.	537575.
1995	7141.	6019.	8573.	10292.	8139.	9683.	155929.	374911.	62763.	12372.	11427.	8356.	675605.
1996	6620.	6071.	8378.	12834.	11091.	16636.	244073.	66721.	19282.	12654.	15670.	14369.	434399.
1997	10288.	24604.	114516.	70093.	126171.	84881.	113213.	68544.	93892.	22921.	15334.	25156.	769613.
1998	12546.	11704.	36399.	65346.	82284.	64926.	161681.	351990.	43312.	41240.	30835.	16192.	918455.
1999	8226.	6764.	12046.	28693.	21379.	19892.	123219.	562138.	125672.	43150.	28777.	10549.	990505.
2000	8074.	7289.	8899.	10754.	16018.	21929.	37289.	335256.	153399.	20316.	7898.	7532.	634653.
2001	7315.	6469.	7640.	25689.	101362.	37683.	177808.	220480.	16531.	42195.	9914.	6946.	660032.
2002	8791.	6371.	9485.	24261.	51701.	21278.	136503.	250129.	127773.	22291.	12456.	9507.	680546.
2003	7944.	7234.	17733.	42577.	50811.	32600.	150720.	454395.	154827.	26502.	32158.	16887.	994388.
2004	8118.	13868.	21054.	14220.	31950.	51945.	273896.	138304.	68056.	17321.	10040.	10288.	659060.
2005	7662.	6685.	7293.	23021.	21423.	36653.	131749.	227295.	92358.	24961.	13842.	8053.	600995.
2006	7358.	6450.	6902.	26613.	42824.	70471.	476382.	57996.	21572.	24266.	16027.	8487.	765348.
2007	7141.	6332.	14803.	26277.	47881.	20165.	79245.	324078.	147622.	35944.	11973.	7705.	729166.
2008	7358.	6701.	8877.	15775.	17603.	35372.	250910.	250042.	76374.	12133.	8969.	7510.	697624.
2009	7163.	11273.	16127.	24072.	32861.	100760.	329895.	231745.	39573.	14738.	27495.	10722.	846424.
2010	7640.	7489.	17147.	20333.	37354.	44740.	104184.	291129.	290119.	41066.	10229.	8226.	879656.
2011	7901.	7077.	7836.	14934.	51463.	99143.	438659.	183082.	21068.	14998.	18001.	26480.	890642.
2012	9377.	7228.	12980.	44341.	19817.	10754.	136329.	191178.	93451.	39633.	38061.	15780.	618929.
2013	9138.	14821.	49466.	22433.	29736.	20312.	562052.	213968.	63477.	31993.	14724.	15693.	1047813.
2014	9377.	8136.	14087.	9137.	14846.	12624.	36703.	66504.	69316.	19100.	11427.	10440.	281697.
2015	7380.	7665.	11981.	32263.	13761.	7520.	183798.	76662.	14010.	11417.	47786.	25438.	439681.
2016	9550.	16061.	29606.	41716.	53047.	14661.	223149.	40219.	25626.	51159.	10881.	13218.	528893.
2017	12806.	6293.	7445.	28714.	9854.	7373.	279886.	232244.	41926.	14304.	10166.	6815.	657826.
MEAN	8264.	8507.	20582.	32031.	37202.	39761.	175834.	191216.	91276.	25763.	18478.	12197.	661110.

Table C.1.2 1966-2017 Naturalized Flows at Control Points YGSE02

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	4146.	3744.	3994.	5062.	7553.	65199.	229162.	72256.	123109.	21835.	9347.	5383.	550790.
1967	4341.	4607.	10093.	19324.	10245.	7436.	94742.	103837.	48899.	7401.	5083.	5231.	321239.
1968	4232.	3899.	4102.	4873.	4536.	9746.	92008.	134202.	45896.	39525.	31129.	12372.	386520.
1969	4667.	3686.	4211.	46673.	59385.	31885.	99235.	182040.	30184.	7879.	4621.	4298.	478764.
1970	4211.	3705.	4536.	4621.	4102.	4348.	75902.	67893.	166253.	28607.	20333.	6794.	391305.
1971	4124.	3509.	4081.	3865.	4232.	7268.	80981.	69803.	33461.	11243.	4117.	3863.	230547.
1972	4189.	3919.	7901.	7688.	5318.	3718.	50573.	208846.	60494.	19469.	18295.	8595.	399005.
1973	4862.	4097.	4384.	9536.	23745.	4537.	11395.	28564.	49004.	13175.	7499.	3950.	164748.
1974	3364.	2960.	4927.	22958.	54024.	18694.	40610.	77552.	34406.	12480.	5188.	3668.	280831.
1975	3560.	3137.	3820.	11364.	12567.	15796.	179110.	59363.	57658.	14260.	5146.	4623.	370404.
1976	3625.	4447.	12155.	9179.	5231.	5377.	17820.	173510.	30226.	8791.	8633.	7532.	286526.
1977	4775.	3196.	3560.	45265.	21293.	12561.	46449.	45190.	10334.	3646.	9641.	6316.	212226.
1978	4905.	3196.	24505.	16258.	3994.	95551.	122026.	124717.	30037.	8530.	11490.	5622.	450831.
1979	3907.	3764.	6208.	39006.	27392.	101727.	61686.	109089.	17371.	7076.	3928.	3885.	385039.
1980	3777.	3431.	3777.	43858.	14759.	6301.	77921.	42303.	35267.	7358.	4054.	3842.	246648.
1981	3538.	3196.	9029.	12918.	40002.	55327.	189572.	53199.	135355.	16908.	13800.	5839.	538683.
1982	4515.	3627.	9420.	8927.	37875.	13443.	22356.	123567.	21404.	5188.	7898.	19448.	277668.
1983	7163.	4685.	24462.	19829.	18493.	4390.	85670.	44908.	47996.	17082.	5083.	3994.	283755.
1984	3863.	3574.	4211.	11616.	12198.	6722.	70737.	77292.	219984.	13587.	7877.	12914.	444575.
1985	5817.	5078.	16800.	27096.	36573.	8297.	8508.	59146.	79125.	48142.	13506.	7184.	315272.
1986	4862.	4097.	29931.	17497.	12133.	12477.	74817.	120593.	50664.	23658.	12750.	6750.	370229.
1987	4840.	5607.	7922.	9935.	16083.	34553.	95155.	175029.	68266.	8009.	8045.	4992.	438436.
1988	4384.	3980.	4167.	5860.	4667.	7247.	129601.	18297.	14031.	5578.	3760.	3777.	205349.
1989	4015.	3588.	14673.	9851.	8769.	17833.	98128.	54067.	53037.	19448.	55390.	7640.	346439.
1990	4232.	7607.	21618.	21971.	32275.	102021.	170819.	58994.	225844.	14195.	9263.	7315.	676154.
1991	4688.	4019.	5296.	7583.	8313.	8276.	99127.	39026.	32642.	12676.	4726.	5209.	231581.
1992	5057.	4325.	12611.	8318.	15780.	14682.	23745.	53025.	35036.	16626.	8213.	10071.	207489.
1993	5817.	5313.	9463.	12645.	47534.	47513.	58104.	67438.	19913.	7510.	9977.	5687.	296914.
1994	4015.	3588.	4059.	9116.	19274.	9956.	63965.	50594.	24702.	38157.	13674.	7597.	248697.
1995	4081.	3470.	6251.	7226.	4298.	4054.	71605.	289784.	45560.	8356.	4453.	3929.	453067.
1996	3820.	3492.	3972.	7268.	9051.	27159.	169712.	37094.	10292.	6794.	9263.	4015.	291932.
1997	3538.	3196.	4992.	8108.	65593.	45602.	63465.	41348.	55306.	12307.	7163.	14911.	325529.
1998	7380.	5293.	10136.	23883.	31711.	27201.	78941.	158013.	17938.	22899.	12519.	7901.	403815.
1999	4211.	3548.	5708.	14997.	10093.	10334.	52830.	315114.	89208.	28195.	17182.	5882.	557302.
2000	4363.	3899.	4558.	5314.	13848.	17896.	24049.	133963.	75365.	11004.	4495.	4298.	303052.
2001	4059.	3842.	7879.	8612.	3972.	14220.	145467.	91378.	10733.	18948.	4915.	3842.	317867.
2002	7792.	6332.	13631.	17476.	24375.	18211.	40827.	115254.	30751.	6577.	4432.	4406.	290064.
2003	3885.	3705.	7271.	20543.	25590.	9389.	88339.	213664.	102126.	14434.	9473.	5795.	504214.
2004	4124.	5706.	7640.	7478.	17516.	29134.	164199.	69239.	66165.	12350.	5041.	6143.	394735.
2005	4819.	3705.	6143.	20564.	13066.	34994.	97239.	118770.	60347.	23550.	12120.	5513.	400830.
2006	4319.	3921.	4493.	22433.	16691.	42010.	241924.	31342.	9746.	14499.	12225.	5882.	409485.
2007	4298.	3764.	6403.	11427.	25916.	11133.	44039.	207739.	98387.	20815.	6701.	4493.	445115.
2008	4341.	3959.	4363.	4999.	8422.	12477.	134246.	126410.	28420.	5752.	4222.	4124.	341735.
2009	3994.	3823.	5448.	7394.	8834.	62258.	168691.	121961.	21236.	7054.	18484.	5774.	434951.
2010	4059.	3627.	5036.	7100.	21141.	13527.	44604.	158447.	158797.	25265.	5734.	4319.	451656.
2011	4189.	3725.	4146.	8024.	45776.	70660.	313204.	99344.	13086.	9268.	8885.	14890.	595197.
2012	5253.	4061.	6772.	25668.	11439.	6217.	81112.	85713.	60641.	21141.	22412.	9398.	339827.
2013	5253.	8097.	28303.	10754.	13609.	10754.	288199.	94460.	46883.	20685.	7667.	8530.	543194.
2014	5339.	5038.	8074.	5398.	8487.	5188.	10918.	42737.	47975.	11786.	6343.	4775.	162058.
2015	4015.	4078.	6251.	17497.	6967.	4264.	83152.	33404.	7730.	6880.	28903.	14087.	217228.
2016	5079.	7858.	19556.	23063.	21553.	7982.	152565.	18080.	19514.	24700.	5083.	7640.	312673.
2017	7271.	3431.	4059.	16216.	5209.	4117.	199426.	153520.	24618.	8704.	5755.	3842.	436168.
MEAN	4596.	4214.	8788.	14887.	18875.	23493.	100551.	100983.	55797.	15385.	10499.	6707.	364776.

Table C.1.3 1966-2017 Naturalized Flows at Control Points NHHW03

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	11634.	10488.	17733.	27621.	23224.	160645.	745502.	263021.	379768.	67177.	32873.	18015.	1757701.
1967	12828.	13488.	37637.	69211.	38136.	21719.	277933.	317306.	131511.	22096.	14745.	14217.	970827.
1968	12546.	11452.	13305.	31759.	15411.	27117.	279061.	342657.	124622.	79809.	75575.	34272.	1047586.
1969	14021.	12606.	16973.	193497.	215531.	93955.	347541.	561466.	81688.	22248.	15081.	13218.	1587825.
1970	12784.	11527.	13240.	13317.	12676.	19661.	254188.	291781.	464333.	76293.	48353.	17690.	1235843.
1971	12285.	10704.	12784.	12435.	15736.	20900.	228706.	214250.	87296.	27066.	11826.	11308.	665296.
1972	11482.	11289.	22834.	20627.	14651.	14955.	111672.	659681.	173710.	67589.	60137.	29150.	1197777.
1973	20338.	19781.	21965.	55033.	115232.	20165.	66048.	255859.	211687.	37528.	23168.	13283.	860087.
1974	10635.	9900.	18211.	76647.	200251.	80932.	116795.	326270.	78369.	42216.	17497.	12437.	990160.
1975	11200.	9998.	12285.	36695.	45472.	66291.	495634.	199165.	188687.	46839.	17161.	16322.	1145749.
1976	11634.	13746.	35640.	24303.	20012.	20501.	59342.	604941.	117669.	27630.	25059.	22899.	983376.
1977	15237.	10371.	12177.	125609.	57800.	38607.	155516.	144382.	46904.	13218.	28819.	22747.	671387.
1978	15714.	10214.	67568.	44593.	12328.	263905.	373153.	370179.	106411.	25438.	27621.	14260.	1331384.
1979	11699.	13410.	40111.	165455.	88209.	295328.	175485.	411506.	54235.	21770.	12666.	12307.	1302181.
1980	11938.	10741.	11612.	118047.	39547.	23504.	260591.	153563.	102252.	21076.	13842.	12524.	779237.
1981	11243.	10606.	31494.	34616.	62424.	95740.	619939.	165349.	377625.	33860.	24471.	14195.	1481562.
1982	12480.	10567.	17842.	17161.	53481.	26046.	77487.	377190.	69589.	24570.	52491.	60470.	799374.
1983	20294.	13547.	69304.	71606.	75121.	13611.	296729.	131402.	147349.	56585.	14661.	11634.	921843.
1984	11308.	10355.	11677.	35561.	33556.	23252.	155668.	213838.	545517.	34229.	21236.	31364.	1127561.
1985	15020.	13880.	40393.	75828.	98758.	23946.	26198.	161550.	210259.	121895.	36212.	22638.	846577.
1986	13978.	11390.	77813.	45581.	29063.	29218.	164285.	286593.	130461.	53351.	36464.	21445.	899642.
1987	14803.	18291.	28282.	37074.	46449.	86141.	243248.	527519.	186775.	22400.	24282.	14499.	1249763.
1988	12111.	11025.	11569.	17308.	13696.	18904.	407230.	50030.	31024.	13544.	10355.	10418.	607214.
1989	10701.	9940.	55239.	39363.	22248.	45244.	267254.	160726.	160015.	54046.	160162.	21879.	1006817.
1990	12546.	34484.	103598.	84671.	96935.	321479.	549875.	183755.	627394.	39612.	24135.	19057.	2097541.
1991	13240.	12782.	45233.	30772.	32449.	29365.	311858.	98736.	97189.	35748.	16132.	21358.	744862.
1992	21228.	14234.	60210.	50244.	66287.	48983.	84411.	192849.	124475.	50985.	29386.	34381.	777673.
1993	21228.	21604.	41695.	48563.	135678.	183099.	165631.	122872.	41001.	18232.	27033.	14803.	841439.
1994	11873.	10469.	14716.	37053.	74991.	32873.	189832.	173510.	78768.	155516.	38124.	20446.	838171.
1995	12025.	10175.	15606.	18274.	13197.	14598.	240557.	739599.	121198.	22595.	17098.	13110.	1238032.
1996	11200.	10254.	13088.	21152.	21488.	49130.	455957.	114082.	32474.	21054.	26445.	19144.	795468.
1997	14542.	28446.	120506.	81016.	208650.	145291.	198601.	120680.	160750.	38309.	23756.	41999.	1182546.
1998	20945.	17781.	47860.	96097.	124457.	98366.	266950.	559577.	65787.	68870.	46148.	26046.	1438884.
1999	13457.	11135.	18905.	47681.	33816.	31885.	190809.	949530.	237313.	78833.	51315.	17950.	1682629.
2000	13501.	12122.	14607.	17350.	32167.	41275.	66439.	503557.	244917.	34033.	13485.	12828.	1006281.
2001	12328.	11155.	16539.	35372.	106246.	54529.	353705.	329721.	28945.	65050.	15880.	11634.	1041104.
2002	17928.	13547.	24483.	44593.	81871.	41716.	183538.	407338.	169005.	31016.	18337.	14803.	1048175.
2003	12676.	11743.	26198.	67573.	85062.	46274.	257552.	735931.	287136.	45298.	45854.	24679.	1645976.
2004	13262.	21097.	30582.	23420.	53416.	87254.	479551.	225559.	152054.	32840.	16447.	17690.	1153172.
2005	13501.	11273.	14390.	46484.	36508.	78642.	249977.	377147.	165392.	54566.	29113.	14825.	1091818.
2006	12741.	11273.	12372.	54949.	65072.	121702.	793384.	99952.	34679.	42303.	32894.	16192.	1297513.
2007	12524.	11018.	22508.	48962.	78854.	33671.	134311.	582954.	271740.	62033.	20291.	13327.	1292193.
2008	12806.	11655.	14564.	22391.	28911.	52848.	423943.	409552.	113384.	19600.	14430.	12719.	1136803.
2009	12220.	16095.	23246.	33902.	46015.	178121.	538415.	383159.	65493.	23441.	49046.	17842.	1386995.
2010	12763.	12057.	23246.	29050.	63010.	62489.	160639.	482134.	489623.	72473.	17413.	13631.	1438528.
2011	13153.	11743.	13001.	24723.	109003.	188120.	832127.	304652.	37347.	26458.	28777.	44539.	1633643.
2012	15888.	12325.	21206.	74861.	33513.	18232.	230290.	296599.	167073.	65245.	65262.	27131.	1027625.
2013	15541.	24564.	82805.	35603.	45754.	33377.	914129.	325315.	121744.	57844.	24198.	25851.	1706725.
2014	15910.	14370.	24158.	15796.	24939.	18904.	50139.	119313.	126953.	33903.	19387.	16366.	480138.
2015	12328.	12645.	19426.	53646.	22530.	12834.	282578.	116382.	23063.	20077.	83767.	42911.	702187.
2016	15780.	25868.	54002.	69337.	80439.	24471.	412678.	61881.	47114.	81025.	17140.	22747.	912482.
2017	22074.	10528.	12459.	48752.	16170.	12540.	509786.	422684.	72173.	24787.	16930.	11504.	1180387.
MEAN	13983.	13765.	31325.	50985.	60893.	69084.	302555.	319793.	161768.	44889.	31403.	20437.	1120880.

Table C.1.4 1966-2017 Naturalized Flows at Control Points NHHA04

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	15975.	14409.	28390.	46631.	33838.	214229.	1053757.	375974.	538460.	94417.	46484.	25938.	2488502.
1967	17950.	18781.	55825.	100214.	53525.	29806.	389041.	450336.	187069.	32362.	20711.	19296.	1374916.
1968	17494.	15959.	18992.	47429.	22139.	36107.	404408.	456999.	171841.	99018.	97042.	45081.	1432509.
1969	19448.	18213.	26719.	289846.	309080.	128739.	515863.	796140.	114287.	31537.	21026.	18514.	2289412.
1970	17928.	16272.	20121.	21131.	17972.	31738.	379382.	452637.	629222.	102057.	61754.	23832.	1774046.
1971	17342.	15233.	18753.	18526.	26198.	29344.	328223.	310317.	124727.	38939.	16741.	16149.	960492.
1972	16257.	16508.	35444.	32158.	21358.	25143.	132856.	935986.	238468.	97825.	78033.	40892.	1670928.
1973	30300.	29720.	33447.	83473.	170992.	29596.	98975.	395097.	309507.	52114.	32957.	19317.	1285495.
1974	15389.	14429.	26458.	108868.	287461.	118782.	161203.	475839.	103932.	60080.	25080.	18037.	1415558.
1975	16083.	14370.	17581.	51798.	65441.	97547.	679628.	282035.	263863.	66352.	24513.	23485.	1602696.
1976	16713.	19371.	49379.	33335.	28846.	29827.	83868.	862862.	170202.	38765.	34763.	32123.	1400054.
1977	21618.	14841.	17494.	172345.	78985.	54151.	219177.	202747.	69295.	19079.	39741.	32514.	941987.
1978	22139.	14507.	92746.	61250.	17342.	361200.	522179.	512673.	152033.	35379.	36527.	19578.	1847553.
1979	16496.	19291.	61056.	241493.	124001.	407053.	241707.	592135.	76059.	30148.	17791.	17321.	1844551.
1980	16821.	15188.	16366.	160456.	53807.	33839.	367944.	218374.	140943.	29106.	19724.	17733.	1090301.
1981	15866.	15076.	44343.	47702.	74079.	114729.	873019.	231376.	517812.	42911.	29932.	19014.	2025859.
1982	17147.	14664.	22378.	21740.	59559.	32684.	110913.	528322.	98219.	36421.	79924.	84671.	1106642.
1983	27934.	18664.	95654.	102357.	109155.	19093.	420188.	181107.	204146.	79288.	20207.	16083.	1293876.
1984	15649.	14315.	16018.	50706.	46688.	33671.	201705.	303458.	723218.	45819.	28231.	38961.	1518439.
1985	19513.	18899.	50898.	105486.	139455.	32810.	38961.	222281.	280478.	168279.	49529.	32015.	1158604.
1986	19187.	15311.	95958.	59402.	37723.	36485.	205720.	363212.	171148.	66808.	49740.	30430.	1151124.
1987	20685.	26094.	41565.	55957.	63769.	116241.	311728.	713249.	237292.	29692.	34238.	19969.	1670479.
1988	16452.	14985.	15758.	24303.	18992.	23946.	579915.	67655.	37410.	17538.	14052.	14065.	845071.
1989	14412.	13449.	81459.	58919.	28021.	59654.	359153.	223952.	222315.	74535.	221811.	30474.	1388154.
1990	17212.	50893.	148376.	117186.	129080.	446101.	769725.	250042.	840005.	53633.	31087.	24700.	2878040.
1991	17928.	17311.	63574.	44299.	48055.	43018.	437421.	133182.	136952.	49205.	22601.	30279.	1043825.
1992	31820.	20345.	88209.	71669.	95763.	72614.	113452.	273570.	175454.	71236.	42619.	49053.	1105804.
1993	31147.	31426.	59862.	67447.	186055.	250126.	227469.	151783.	52344.	23876.	38229.	20403.	1140167.
1994	16431.	14605.	22031.	52575.	103121.	44929.	251236.	240796.	110675.	221087.	52491.	27804.	1157781.
1995	16691.	14135.	20750.	25227.	19621.	21089.	339836.	958212.	168312.	31060.	25101.	18797.	1658831.
1996	15628.	14335.	19231.	33608.	30517.	66354.	642078.	177851.	49172.	30799.	37746.	28520.	1145839.
1997	21792.	39229.	185643.	122437.	296057.	209671.	284618.	162462.	213998.	54349.	36044.	60058.	1686358.
1998	30517.	26250.	72820.	142917.	188921.	145333.	394272.	811182.	96496.	100603.	66396.	37441.	2113148.
1999	19469.	15997.	28868.	72446.	51853.	47555.	277889.	1322379.	331247.	110717.	74252.	25829.	2378501.
2000	19535.	17421.	24245.	32495.	52396.	59381.	95828.	646289.	372038.	49943.	24009.	21835.	1415415.
2001	18580.	17605.	35336.	51504.	112172.	83536.	545122.	449229.	39678.	91009.	22559.	16930.	1483260.
2002	25786.	19016.	37940.	69379.	111043.	60956.	259418.	600426.	222883.	45255.	25710.	21097.	1498909.
2003	18688.	19448.	45559.	101811.	128711.	75239.	378644.	1068126.	408482.	64855.	70282.	36182.	2416027.
2004	19404.	28569.	44452.	32263.	74036.	111851.	683144.	307929.	228323.	48033.	24618.	25959.	1628581.
2005	19361.	16331.	20403.	69001.	52591.	108994.	345913.	509070.	235380.	79918.	42724.	21900.	1521586.
2006	18384.	16233.	17755.	78264.	99669.	157431.	1109930.	145467.	50013.	55695.	51861.	25373.	1826075.
2007	18254.	15880.	27956.	59738.	96891.	43585.	175724.	869134.	385103.	88318.	29050.	18927.	1828560.
2008	18124.	16528.	20772.	31780.	43236.	82402.	647591.	591375.	159994.	28889.	22748.	18905.	1682344.
2009	17538.	22761.	33730.	52302.	68284.	244119.	740575.	546315.	91896.	32601.	66627.	24874.	1941622.
2010	18080.	16899.	29714.	37809.	87319.	94312.	238690.	663175.	695954.	102035.	24702.	19209.	2027898.
2011	18536.	16566.	18493.	34742.	157687.	271005.	1174025.	449706.	52470.	36313.	41107.	64811.	2335461.
2012	22638.	17442.	30409.	109981.	48229.	26571.	335429.	420882.	239897.	95025.	94459.	38526.	1479488.
2013	21748.	33602.	108742.	49929.	67655.	51294.	1304667.	443868.	175139.	81567.	35204.	37159.	2410574.
2014	22747.	20761.	34033.	22286.	36595.	25122.	73667.	170580.	175265.	48815.	28462.	23876.	682209.
2015	17581.	18487.	28911.	76710.	33903.	18862.	400349.	159185.	31675.	28455.	123572.	61338.	999028.
2016	22703.	37889.	80243.	93913.	115319.	33566.	567521.	81850.	68014.	116751.	22811.	31190.	1271770.
2017	29779.	14762.	17559.	69106.	22595.	17518.	681169.	584060.	100844.	34598.	24933.	16214.	1613137.
MEAN	19825.	19601.	45162.	73430.	85496.	96326.	426441.	448902.	224801.	62752.	44280.	28898.	1575913.

Table C.1.5 1966-2017 Naturalized Flows at Control Points NHSA05

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	16930.	15272.	30647.	50937.	37050.	229667.	1120478.	395335.	566606.	100907.	49025.	27913.	2640767.
1967	19100.	20232.	61121.	107629.	56259.	31486.	416172.	475969.	202298.	34923.	22034.	20424.	1467647.
1968	18601.	16975.	20207.	49445.	23398.	38250.	430519.	484651.	183751.	103490.	101685.	47274.	1518246.
1969	20555.	19310.	28607.	307973.	324208.	135355.	545946.	837206.	123320.	33882.	22202.	19643.	2418207.
1970	19014.	17311.	22052.	23441.	19187.	34805.	413589.	485498.	670181.	109458.	66165.	25807.	1906508.
1971	18623.	16409.	21423.	21110.	30105.	32516.	361280.	333628.	140649.	43453.	18148.	17538.	1054882.
1972	17646.	18660.	42998.	38481.	23876.	26949.	136980.	999430.	252983.	103533.	81184.	42933.	1785653.
1973	32102.	31563.	35314.	87884.	179327.	32579.	106637.	413068.	325680.	55760.	34742.	20533.	1355189.
1974	16518.	15429.	28130.	115317.	303241.	124832.	172924.	498695.	109918.	64095.	26907.	19317.	1495323.
1975	17212.	15409.	18905.	55579.	68892.	99773.	721909.	297511.	287914.	70368.	26235.	25156.	1704863.
1976	17842.	20914.	53134.	35960.	31689.	31549.	89729.	902495.	178835.	41652.	37200.	34185.	1475184.
1977	23029.	15821.	18580.	183940.	84780.	57385.	234631.	215379.	72068.	20251.	43753.	35140.	1004757.
1978	23637.	15468.	99040.	65094.	18580.	385670.	546815.	547531.	159952.	37463.	38544.	20880.	1958674.
1979	17559.	20408.	63335.	253760.	131836.	435578.	257747.	621784.	80134.	32883.	19240.	18580.	1952844.
1980	18015.	16183.	17494.	172639.	58126.	35939.	390951.	235174.	151046.	31103.	20858.	18818.	1166346.
1981	16908.	16037.	47230.	50559.	79440.	131007.	926370.	244160.	550937.	46991.	32957.	20446.	2163042.
1982	18362.	15664.	24440.	23525.	67459.	35813.	114906.	551872.	103092.	38027.	82717.	89403.	1165280.
1983	29758.	19899.	101319.	108406.	114494.	20270.	448621.	194759.	221349.	86060.	21740.	17169.	1383844.
1984	16691.	15269.	17060.	53331.	49661.	36023.	218591.	325250.	767938.	48901.	29617.	40588.	1618920.
1985	20598.	20016.	53090.	111473.	150177.	34847.	44322.	235977.	300916.	179066.	52260.	33751.	1236493.
1986	20381.	16233.	99083.	62237.	39872.	38565.	220241.	380684.	181293.	71106.	52722.	32406.	1214823.
1987	22009.	27799.	44300.	60032.	67698.	122395.	332629.	751775.	249853.	31342.	36128.	21141.	1767101.
1988	17494.	15939.	16735.	25794.	20229.	25185.	626733.	72104.	39468.	18580.	14976.	14976.	908213.
1989	15302.	14252.	86690.	62868.	29215.	62826.	381292.	237735.	233469.	78420.	234099.	32340.	1468508.
1990	18254.	53344.	155321.	123572.	137827.	474962.	821383.	265018.	890459.	56997.	32810.	26024.	3055971.
1991	19014.	18271.	65050.	46820.	52027.	46652.	474494.	142103.	147286.	52331.	23946.	31863.	1119857.
1992	33556.	21482.	93484.	75807.	99691.	76857.	117142.	290370.	187237.	76185.	46610.	52179.	1170600.
1993	32818.	32896.	62684.	70891.	200576.	261111.	246092.	169603.	57532.	25742.	40707.	21835.	1222487.
1994	17494.	15546.	23441.	55432.	107027.	47324.	263868.	253667.	118551.	232765.	56167.	29692.	1220974.
1995	17755.	15037.	22443.	27600.	21249.	22349.	371330.	1026734.	184171.	33491.	27516.	20229.	1789904.
1996	16669.	15310.	20750.	37977.	33664.	75302.	677132.	189767.	52911.	33686.	40875.	30192.	1224235.
1997	22921.	40189.	188638.	126155.	313507.	220824.	306996.	171622.	221853.	58278.	39069.	64616.	1774668.
1998	32818.	27819.	76857.	152222.	201922.	155247.	424832.	875060.	102231.	109241.	70324.	39894.	2268467.
1999	20815.	17076.	30843.	79945.	56802.	52155.	292388.	1393593.	360759.	118813.	79818.	27696.	2530703.
2000	20859.	18599.	27609.	39510.	60297.	64590.	99908.	668493.	411569.	54371.	29008.	25178.	1519991.
2001	20164.	19389.	41912.	56734.	113626.	89922.	598299.	473170.	41947.	95502.	24009.	18167.	1592841.
2002	27848.	20350.	42173.	75723.	119551.	66964.	279517.	645768.	235107.	47838.	27432.	22486.	1610757.
2003	20012.	21467.	50334.	109981.	139867.	82444.	407903.	1135781.	439548.	69434.	74819.	38592.	2590182.
2004	20837.	30559.	50464.	34868.	78985.	117648.	725990.	322819.	239728.	50942.	26193.	27370.	1726403.
2005	20663.	17487.	21727.	73853.	55825.	115905.	372089.	536613.	246807.	84650.	44572.	23333.	1613524.
2006	19643.	17350.	18992.	81856.	105161.	162431.	1173526.	155278.	53352.	58907.	56146.	27348.	1929990.
2007	19469.	16919.	29237.	61901.	101232.	45497.	187401.	913695.	411359.	93701.	30772.	20121.	1931304.
2008	19296.	17584.	22226.	33818.	46253.	89523.	706433.	618398.	165014.	30517.	24135.	20034.	1793231.
2009	18645.	23761.	35466.	55810.	72321.	249370.	787697.	577592.	97021.	34207.	69568.	26220.	2047678.
2010	19166.	17860.	30734.	39342.	93397.	100592.	257487.	702657.	740379.	108026.	26193.	20338.	2156171.
2011	19643.	17546.	19556.	36212.	168735.	291043.	1268615.	480289.	56083.	38917.	43459.	69196.	2509294.
2012	24071.	18518.	32579.	119371.	51745.	28210.	361237.	449489.	256847.	101601.	100760.	40957.	1585385.
2013	23094.	35778.	113995.	53205.	73189.	55096.	1382415.	458931.	187741.	86277.	37053.	39091.	2545865.
2014	24071.	21957.	35857.	23609.	39633.	26361.	77422.	184362.	184843.	51853.	30142.	25221.	725331.
2015	18645.	19605.	30474.	84229.	37224.	20249.	420535.	168214.	33146.	30430.	132310.	65593.	1060654.
2016	24223.	40203.	85778.	98954.	122286.	35666.	612863.	86842.	70408.	121678.	24240.	33339.	1356480.
2017	31906.	15703.	18666.	73496.	23919.	18589.	716808.	617182.	106936.	36920.	26172.	17212.	1703509.
MEAN	21120.	20848.	48043.	78391.	91083.	102541.	455612.	475207.	239509.	66827.	47115.	30776.	1677073.

Table C.1.6 1966-2017 Naturalized Flows at Control Points SYBU06

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	2301.	2078.	69456.	74777.	37094.	244245.	962987.	259093.	275416.	60926.	27264.	14759.	2030396.
1967	5556.	14233.	77248.	73853.	28672.	39804.	354486.	176440.	176252.	24201.	9809.	8183.	988737.
1968	4015.	2924.	19231.	12582.	9485.	10544.	267080.	394055.	112586.	177395.	49782.	31494.	1091173.
1969	13023.	33955.	259093.	207990.	132379.	57322.	397962.	475058.	126512.	29736.	8885.	3690.	1745605.
1970	3060.	19252.	66960.	23525.	6902.	20039.	221500.	179414.	438624.	57084.	31822.	24809.	1092991.
1971	32688.	48521.	191851.	30352.	39742.	27495.	237279.	216334.	102231.	25156.	5692.	5209.	962550.
1972	49553.	68914.	223084.	88809.	22096.	4474.	140410.	621371.	138926.	41978.	29848.	45884.	1475347.
1973	34012.	42307.	68501.	46715.	74709.	12246.	24462.	97564.	143442.	37029.	36485.	8552.	626024.
1974	2713.	9234.	49856.	164300.	158034.	45875.	148593.	217528.	96685.	30843.	8381.	3516.	935558.
1975	2388.	4882.	61121.	109141.	45364.	50517.	562746.	123393.	202760.	41261.	48164.	16995.	1268732.
1976	5556.	31858.	143557.	67405.	20989.	9641.	31147.	577180.	81814.	27392.	46715.	45342.	1088596.
1977	14890.	32485.	35032.	196437.	62120.	32516.	122460.	115406.	20228.	4471.	39930.	24114.	700089.
1978	17190.	12782.	269424.	132142.	18449.	348135.	268752.	380077.	80743.	57562.	68770.	35748.	1689774.
1979	41609.	57931.	95220.	188876.	98541.	344249.	164741.	315895.	48605.	16821.	3718.	3408.	1379614.
1980	2713.	2335.	10635.	228638.	44278.	15691.	280060.	138804.	93430.	25872.	11553.	6077.	860086.
1981	2735.	12939.	101102.	100151.	136525.	174382.	598169.	206567.	416610.	44126.	46211.	13197.	1852714.
1982	12415.	14174.	87493.	66732.	115666.	29176.	63856.	387543.	45392.	8508.	32074.	68436.	931465.
1983	23767.	13566.	143362.	167010.	64920.	10544.	262848.	154605.	144114.	66700.	15166.	6208.	1072810.
1984	2518.	2558.	6577.	60389.	52483.	56377.	295340.	334344.	789321.	40198.	18232.	14673.	1673010.
1985	4059.	5293.	31407.	66417.	108265.	15838.	42390.	164372.	243089.	267493.	47093.	18145.	1013861.
1986	6685.	2372.	30018.	52449.	24418.	14262.	153628.	231484.	145606.	165088.	34868.	15432.	876310.
1987	7228.	32387.	66374.	53163.	34988.	72026.	329287.	523742.	145648.	24527.	11973.	3495.	1304838.
1988	2583.	2457.	4384.	8255.	5014.	9893.	300354.	37962.	62636.	16691.	3865.	3060.	457154.
1989	8877.	13723.	87753.	47744.	15584.	22076.	282469.	148679.	135481.	74275.	139934.	19904.	996499.
1990	7141.	38307.	88296.	67615.	69760.	328474.	490121.	186859.	850529.	48858.	34574.	13935.	2224469.
1991	3755.	3294.	36226.	40329.	48619.	18862.	299312.	189355.	171925.	38461.	8990.	5774.	864902.
1992	5556.	9157.	70129.	55222.	68870.	36738.	93158.	390777.	149933.	55001.	30541.	15714.	980796.
1993	8769.	29250.	100711.	109456.	159423.	118299.	272810.	344763.	72509.	19014.	18337.	4124.	1257465.
1994	2691.	6705.	32189.	72971.	53915.	39657.	155234.	110696.	44677.	157383.	44593.	19969.	740680.
1995	5817.	1490.	18102.	27180.	10245.	8843.	319802.	995197.	118719.	32883.	13317.	3386.	1554981.
1996	1932.	4609.	78442.	124937.	39156.	129726.	408727.	79462.	27936.	13566.	6196.	12480.	927169.
1997	7293.	20310.	209953.	92295.	293213.	196879.	280234.	74926.	174718.	31646.	40623.	94938.	1517028.
1998	35423.	63264.	167845.	141216.	102600.	116724.	313290.	641145.	90930.	98932.	42493.	32883.	1846745.
1999	11265.	3235.	24375.	94312.	34468.	24135.	132357.	765905.	407977.	102535.	83998.	17624.	1702186.
2000	10136.	2985.	32796.	26991.	38266.	37158.	110696.	477901.	316879.	40458.	32747.	29627.	1156640.
2001	8812.	25956.	148853.	68203.	9680.	29197.	391971.	179110.	23988.	75490.	10670.	3712.	975642.
2002	28759.	17174.	36378.	51735.	75338.	19345.	180825.	645876.	212149.	38678.	15229.	18862.	1340348.
2003	13501.	47227.	171231.	172366.	134224.	43711.	266321.	652757.	556020.	65028.	90615.	33209.	2246210.
2004	8552.	25097.	53828.	58309.	69630.	117732.	652453.	339011.	237922.	37875.	12603.	7575.	1620587.
2005	2344.	3254.	72777.	128088.	42954.	172093.	228424.	232613.	200323.	96544.	35309.	8183.	1222906.
2006	2908.	7175.	14868.	100970.	82479.	121618.	1090135.	96110.	40455.	127799.	53247.	21705.	1759469.
2007	8899.	8665.	68501.	90342.	70975.	21341.	133898.	538871.	392644.	64963.	19493.	5079.	1423671.
2008	2214.	2030.	30257.	73265.	45798.	40392.	452832.	366902.	104520.	19730.	4558.	3039.	1145537.
2009	2171.	23055.	63379.	69652.	57779.	212758.	745329.	342636.	44068.	15150.	73013.	18102.	1667092.
2010	8617.	18977.	91508.	84881.	107700.	28084.	83673.	374889.	466707.	80395.	22643.	7032.	1375106.
2011	2431.	2803.	44126.	121534.	174378.	325071.	879943.	182800.	59339.	30257.	17119.	37528.	1877329.
2012	7032.	3249.	41652.	182721.	33556.	16405.	219655.	271443.	202025.	60991.	60809.	25699.	1125237.
2013	13609.	48404.	157904.	107818.	55001.	24387.	699206.	143731.	139325.	54154.	21824.	22052.	1487415.
2014	12871.	23035.	76792.	39762.	20272.	5419.	25395.	174660.	156486.	39395.	12288.	7553.	593928.
2015	2822.	11449.	57410.	80302.	25807.	12120.	174704.	148962.	45034.	21640.	103428.	54718.	738396.
2016	17038.	35574.	151870.	84019.	48229.	16069.	515494.	73515.	87632.	95437.	17602.	38223.	1180702.
2017	32319.	12547.	52613.	90069.	14347.	8885.	495135.	377906.	69232.	44474.	14367.	3408.	1215302.
MEAN	11093.	18874.	84457.	90854.	64296.	75721.	319695.	305302.	187130.	57155.	33028.	19355.	1266959.

Table C.1.7 1966-2017 Naturalized Flows at Control Points SYIN07

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	2626.	2372.	84259.	91035.	44126.	288565.	1084209.	290761.	313708.	72473.	31528.	16843.	2322505.
1967	6338.	16252.	94070.	89607.	33643.	42136.	402715.	208433.	198286.	27630.	10881.	8791.	1138782.
1968	4450.	3310.	21488.	15670.	10462.	11868.	293560.	444519.	132037.	223171.	57238.	35531.	1253304.
1969	14217.	37092.	280147.	236200.	147855.	65052.	443781.	547661.	144072.	33361.	9452.	4015.	1962905.
1970	3386.	19546.	68957.	25395.	7445.	21446.	258355.	208129.	496975.	65506.	38019.	27913.	1241072.
1971	34033.	49698.	200533.	32873.	41153.	28861.	239211.	227404.	103533.	25525.	6049.	5556.	994429.
1972	49900.	69259.	235912.	105381.	25699.	5335.	143492.	710123.	157747.	47143.	37305.	48793.	1636089.
1973	35575.	43816.	71127.	52029.	83478.	13338.	25569.	106376.	159805.	40241.	37662.	8877.	677893.
1974	2974.	9567.	52917.	184633.	182105.	52260.	166326.	250324.	107083.	35401.	9242.	3712.	1056544.
1975	2583.	5058.	61946.	116829.	50008.	55663.	648655.	141126.	219942.	45884.	49256.	17516.	1414466.
1976	5969.	32691.	153194.	73223.	22703.	10292.	35249.	655687.	91896.	30213.	50181.	48380.	1209678.
1977	15758.	32877.	35705.	218976.	70172.	36801.	142342.	133204.	22265.	4819.	41233.	25026.	779178.
1978	17820.	13213.	288525.	154008.	20641.	400815.	307625.	432321.	89670.	61056.	73181.	38049.	1896924.
1979	42933.	59539.	100494.	211792.	110196.	393988.	184514.	363559.	55012.	18710.	4033.	3668.	1548438.
1980	2865.	2477.	10853.	253004.	49227.	17056.	313486.	151544.	103197.	28586.	12267.	6446.	951008.
1981	2952.	13939.	108569.	112313.	153498.	200869.	682840.	237605.	471727.	49835.	50895.	14347.	2099389.
1982	13197.	14782.	93983.	73664.	131836.	32137.	69955.	438138.	50979.	9333.	35183.	76054.	1039241.
1983	25786.	14566.	160292.	188645.	73103.	11280.	296035.	170471.	161380.	73363.	16552.	6598.	1198071.
1984	2800.	2802.	7814.	71732.	59450.	61019.	343981.	367835.	904658.	44560.	19030.	15150.	1900831.
1985	4319.	5627.	36638.	80974.	121201.	17749.	46036.	180694.	268295.	285616.	52323.	20077.	1119549.
1986	7228.	2568.	31190.	54466.	25590.	16468.	168062.	271074.	165665.	173836.	38439.	17407.	971993.
1987	7922.	34622.	71713.	59549.	38288.	79776.	365035.	595694.	166653.	27674.	13191.	3863.	1463980.
1988	2952.	2782.	4732.	9977.	5752.	11406.	359717.	43128.	66543.	16995.	4012.	3191.	531187.
1989	9029.	13978.	93635.	52428.	16366.	24261.	320518.	168800.	150374.	78333.	156780.	21835.	1106337.
1990	7792.	39542.	93635.	71732.	80265.	379663.	570972.	218353.	976852.	55152.	38292.	14759.	2547009.
1991	3907.	3431.	37745.	43165.	50811.	20942.	363060.	204353.	187657.	41565.	9389.	5925.	971950.
1992	5622.	9462.	71149.	56734.	80439.	39951.	101580.	436727.	169551.	61295.	34427.	20338.	1087275.
1993	10093.	31406.	109502.	121051.	187488.	137771.	306366.	379664.	80197.	20728.	20396.	4493.	1409155.
1994	2887.	7254.	35705.	82633.	61751.	42514.	172490.	122330.	50475.	174530.	49109.	21835.	823513.
1995	6273.	1588.	18536.	29407.	10831.	9221.	368269.	1125992.	134053.	36899.	15124.	3733.	1759926.
1996	2105.	4833.	80048.	134158.	43084.	142686.	483241.	90163.	31360.	14694.	6554.	12654.	1045580.
1997	7401.	21369.	230659.	107209.	333650.	223429.	325423.	89164.	190934.	35249.	44362.	104076.	1712925.
1998	38288.	66812.	180325.	156570.	115579.	128697.	359131.	748368.	103008.	109068.	46736.	35054.	2087636.
1999	11873.	3372.	27761.	105865.	39785.	28420.	166543.	880638.	461729.	118010.	96307.	20099.	1960402.
2000	11308.	3249.	36247.	30457.	44474.	41989.	122937.	548768.	350718.	45385.	34406.	30647.	1300585.
2001	9138.	27799.	159380.	74714.	10397.	35330.	453179.	212579.	27012.	80461.	11259.	4232.	1105480.
2002	31972.	18134.	39286.	59402.	85344.	22328.	204006.	736191.	232167.	42498.	16237.	19817.	1507382.
2003	13891.	49894.	185448.	192258.	155690.	49382.	308450.	754076.	623151.	73927.	102651.	36833.	2545651.
2004	9463.	29340.	65484.	62132.	75533.	135460.	746371.	375454.	271299.	42585.	14094.	8096.	1835311.
2005	2518.	3411.	75251.	140418.	47881.	190157.	261828.	276913.	229541.	108872.	40686.	9420.	1386896.
2006	3212.	7626.	16583.	112607.	95567.	140607.	1251707.	111564.	45413.	136785.	56650.	22682.	2001003.
2007	9160.	8861.	75143.	102126.	81285.	24156.	152847.	616075.	444841.	74144.	22265.	5730.	1616633.
2008	2409.	2213.	33122.	81100.	51376.	47870.	522331.	415586.	117480.	22248.	5314.	3321.	1304370.
2009	2322.	24859.	70303.	77088.	65202.	234183.	844195.	394619.	50097.	16821.	77508.	18992.	1876189.
2010	8986.	20291.	100342.	94984.	121678.	31633.	104271.	439266.	549907.	91682.	25605.	8031.	1596676.
2011	2691.	3137.	48120.	139871.	204787.	383234.	1038737.	217007.	67405.	34272.	19451.	42325.	2201037.
2012	7684.	3533.	46384.	206961.	38005.	19282.	251670.	313920.	226958.	69478.	69610.	29237.	1282722.
2013	15714.	55795.	182127.	124517.	63379.	28609.	822490.	169538.	160666.	60080.	24345.	24440.	1731700.
2014	14282.	25192.	85605.	42304.	22161.	6533.	27479.	190874.	172261.	42629.	12897.	8053.	650270.
2015	3212.	12449.	62706.	88767.	27305.	12708.	192133.	154301.	46526.	22747.	110276.	58799.	791929.
2016	18297.	38315.	166000.	92043.	52743.	17035.	599384.	78702.	89880.	103533.	18379.	41131.	1315442.
2017	33838.	12900.	54914.	99815.	15649.	9473.	560988.	427589.	77298.	49292.	15313.	3668.	1360737.
MEAN	11807.	19971.	91465.	101817.	72810.	86187.	365834.	347565.	210960.	63536.	36376.	21078.	1429407.

Table C.1.8 1966-2017 Naturalized Flows at Control Points SYCC08

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	3082.	2784.	100212.	109897.	54002.	349626.	1287672.	332977.	365800.	90879.	38775.	21097.	2756803.
1967	7857.	21624.	125998.	113426.	41891.	45055.	477793.	252625.	235780.	33035.	12750.	10657.	1378491.
1968	5383.	4162.	26263.	21299.	12285.	15018.	338902.	517687.	161884.	271595.	66837.	40979.	1482294.
1969	15606.	41777.	311120.	274450.	170384.	74609.	512217.	660354.	183982.	41283.	11343.	4493.	2301618.
1970	3863.	19977.	71475.	27873.	8660.	24450.	335646.	273527.	617270.	83912.	51819.	32254.	1550726.
1971	35878.	52540.	224582.	39195.	49661.	38376.	295449.	290956.	125084.	32536.	7646.	6186.	1198089.
1972	51007.	70884.	260287.	129684.	31885.	6154.	146574.	861299.	186544.	56889.	50391.	55022.	1906620.
1973	39633.	48737.	79896.	63792.	99648.	15712.	30322.	137132.	192068.	46753.	39846.	9463.	803002.
1974	3408.	10136.	57887.	214439.	221413.	63036.	195041.	304348.	119623.	42455.	11028.	4189.	1247003.
1975	2995.	5489.	64421.	131007.	56455.	59927.	770962.	169777.	266132.	54480.	52176.	18883.	1652704.
1976	6403.	34741.	172446.	83620.	27609.	11301.	42715.	764994.	109099.	35726.	56335.	54024.	1399013.
1977	17559.	33720.	37159.	254138.	82805.	43396.	175767.	162961.	25458.	5405.	45854.	28368.	912590.
1978	19491.	14017.	317610.	184843.	24266.	482041.	356679.	519792.	104457.	66135.	77823.	40697.	2207851.
1979	44495.	62421.	111998.	250126.	129253.	474458.	216638.	437486.	64947.	22486.	4999.	4667.	1823974.
1980	3451.	2904.	11656.	295622.	58104.	19451.	367097.	181801.	122878.	33035.	13506.	7011.	1116516.
1981	3386.	15723.	121895.	129915.	172229.	244728.	821340.	279539.	556419.	58148.	57469.	16105.	2476896.
1982	14499.	15880.	103446.	83032.	153672.	36023.	77335.	502645.	58625.	10766.	40350.	87623.	1183896.
1983	29172.	16193.	185057.	220677.	86277.	12855.	358263.	198601.	197635.	87493.	19282.	7445.	1418950.
1984	3299.	3269.	9572.	86267.	68675.	71017.	413112.	416585.	1059086.	51029.	20417.	16604.	2218932.
1985	4753.	6195.	43866.	96118.	141777.	20270.	53351.	203854.	314338.	312444.	59675.	23072.	1279713.
1986	8356.	3039.	34359.	58835.	27804.	19598.	186576.	317219.	195261.	187987.	43816.	19752.	1102602.
1987	8834.	37327.	77465.	66186.	44408.	93031.	418668.	696818.	195744.	32145.	14997.	4276.	1689899.
1988	3364.	3147.	5122.	11679.	6598.	13191.	454916.	50312.	71269.	17776.	4642.	3842.	645858.
1989	9680.	14547.	101818.	59402.	17299.	27621.	372740.	200185.	171568.	85995.	181482.	24982.	1267319.
1990	8856.	43248.	106224.	83977.	97825.	457738.	691674.	268795.	1153860.	64681.	43543.	16018.	3036439.
1991	4167.	3666.	41826.	47954.	57692.	22916.	466723.	226709.	206835.	46036.	9746.	6186.	1140456.
1992	5882.	10031.	73211.	58120.	95936.	43375.	108482.	495786.	194379.	70194.	40203.	25395.	1220994.
1993	11699.	34602.	124023.	140291.	231549.	164111.	361931.	429608.	88893.	22443.	23357.	5057.	1637564.
1994	3191.	7626.	38461.	95110.	72777.	47366.	200533.	139715.	58267.	199361.	55558.	24548.	942513.
1995	6967.	1784.	19231.	32347.	11764.	9809.	435728.	1336031.	159028.	43345.	18568.	4493.	2079095.
1996	2388.	5198.	83695.	150773.	48836.	160141.	576920.	104662.	35750.	17038.	7268.	13001.	1205670.
1997	7640.	22624.	255338.	124139.	384960.	261511.	384505.	104683.	211918.	39547.	50118.	119117.	1966100.
1998	43302.	72302.	197190.	177365.	132726.	144555.	424398.	899847.	117669.	122438.	52911.	38309.	2423012.
1999	12914.	3607.	32536.	122101.	46145.	34196.	200967.	1035482.	544656.	138977.	114939.	23789.	2310309.
2000	12459.	3492.	37875.	32663.	50160.	47849.	147052.	651151.	396467.	52570.	36506.	31581.	1499825.
2001	9529.	30093.	170015.	80764.	11070.	43648.	531708.	252929.	30436.	85735.	12120.	5101.	1263148.
2002	34511.	18526.	40762.	68224.	98541.	25500.	230811.	850663.	258024.	47968.	18295.	20468.	1712293.
2003	14195.	54069.	207782.	218556.	185621.	56545.	365925.	883134.	713073.	86169.	115548.	40805.	2941422.
2004	10440.	32833.	73406.	65115.	84758.	160078.	872585.	424550.	317573.	49162.	16174.	9116.	2115790.
2005	2865.	3725.	76489.	153714.	53611.	210679.	303849.	340118.	267014.	126779.	47912.	10787.	1597542.
2006	3495.	7999.	17646.	121618.	108938.	161968.	1471601.	132943.	52008.	146162.	60725.	23745.	2308848.
2007	9529.	9195.	79940.	114413.	93049.	26802.	173770.	716548.	518841.	86408.	25857.	6490.	1860842.
2008	2626.	2416.	34793.	86246.	56780.	57679.	627015.	482177.	136048.	25916.	6112.	3777.	1521585.
2009	2778.	26603.	77943.	85910.	75230.	259725.	983433.	467439.	58499.	19057.	83620.	20207.	2160444.
2010	9680.	22251.	112193.	108343.	139607.	36359.	130512.	521897.	667661.	107375.	29596.	9008.	1894482.
2011	3017.	3529.	51745.	161338.	245093.	464922.	1271632.	267818.	79146.	39872.	22286.	48120.	2658518.
2012	8400.	3817.	52939.	241934.	44278.	23862.	296686.	371720.	260460.	80764.	81142.	33230.	1499232.
2013	17928.	64734.	213447.	146845.	74144.	33482.	998475.	204961.	194736.	68219.	27537.	26719.	2071227.
2014	15714.	27682.	95741.	45707.	24418.	7877.	31581.	215032.	194715.	48641.	14430.	8704.	730242.
2015	3712.	13743.	69608.	103785.	30474.	13569.	227338.	164459.	48479.	24744.	125987.	67676.	893574.
2016	21076.	44467.	191004.	105696.	64203.	18946.	720303.	86755.	94018.	116274.	19808.	47925.	1530475.
2017	38917.	14115.	62076.	118089.	17603.	10397.	635349.	513888.	88010.	54523.	16048.	3885.	1572900.
MEAN	12949.	21716.	101784.	117243.	85093.	101280.	434178.	410057.	247066.	72900.	41523.	23749.	1669536.

Table C.1.9 1966-2017 Naturalized Flows at Control Points SYCJ09

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	3191.	2882.	105074.	115233.	56585.	361200.	1335380.	344524.	379222.	95350.	40560.	22378.	2861579.
1967	8356.	23918.	136286.	121660.	43909.	45560.	495439.	262240.	244140.	34337.	13002.	10787.	1439634.
1968	5513.	4284.	26827.	22244.	12524.	15796.	350232.	533683.	168753.	275871.	68728.	42043.	1526498.
1969	15975.	42954.	317523.	285855.	178394.	77697.	526716.	676958.	189275.	42347.	11595.	4645.	2369934.
1970	4015.	20604.	75729.	29386.	8964.	25584.	357286.	290609.	647538.	89729.	55369.	33773.	1638586.
1971	36551.	53403.	230247.	40539.	51875.	40602.	316069.	304283.	134242.	34554.	8234.	6729.	1257328.
1972	51528.	71635.	269750.	138023.	33860.	6617.	149222.	903906.	194442.	59667.	54172.	56845.	1989667.
1973	40805.	50168.	82761.	66837.	103837.	16783.	33057.	146531.	200470.	48424.	40392.	9615.	839680.
1974	3516.	10273.	59038.	220929.	230833.	65724.	201770.	317393.	122080.	44039.	11448.	4384.	1291427.
1975	3169.	5666.	65310.	134809.	57844.	60515.	797269.	176939.	281066.	56628.	52953.	19404.	1711572.
1976	6555.	35472.	177981.	86372.	29367.	11742.	44582.	787871.	113384.	37246.	57952.	55587.	1444111.
1977	18080.	33975.	37680.	262582.	85713.	44950.	183776.	170037.	26046.	5513.	47408.	29345.	945105.
1978	19925.	14213.	324360.	191564.	25134.	501008.	366598.	541801.	108112.	67242.	78558.	41066.	2279581.
1979	44734.	63205.	115471.	259704.	133811.	493782.	224517.	455241.	67027.	23528.	5230.	4905.	1891155.
1980	3646.	3046.	12046.	306461.	60340.	20102.	379881.	191004.	128403.	33990.	13716.	7141.	1159776.
1981	3516.	16135.	125216.	133801.	175898.	255125.	854635.	287830.	576331.	59971.	58940.	16496.	2563894.
1982	14825.	16154.	105638.	85049.	158273.	36906.	78963.	515342.	60326.	11265.	41716.	90293.	1214750.
1983	29996.	16585.	190657.	228008.	89425.	13317.	374781.	205590.	207843.	91400.	19934.	7640.	1475176.
1984	3408.	3391.	10071.	90090.	70910.	72152.	423704.	430280.	1087758.	52700.	20774.	16995.	2282233.
1985	4884.	6371.	45863.	101369.	148376.	21089.	57236.	210951.	328873.	319281.	60956.	23724.	1328973.
1986	8769.	3137.	38331.	62342.	29323.	20921.	195584.	327724.	202277.	191243.	45328.	20641.	1145620.
1987	9333.	39307.	81654.	71312.	47100.	97042.	436575.	726098.	204020.	33404.	15523.	4428.	1765796.
1988	3516.	3269.	5274.	12624.	7141.	13905.	489752.	52613.	72719.	17950.	4726.	3929.	687418.
1989	9811.	14860.	110826.	63456.	17885.	28819.	387304.	207934.	177365.	87515.	188771.	25764.	1320310.
1990	9225.	46620.	116447.	89754.	103837.	475697.	720455.	278562.	1188014.	66634.	44782.	16387.	3156414.
1991	4276.	3901.	48532.	50265.	59732.	23799.	499389.	231831.	213346.	47252.	9977.	6815.	1199115.
1992	6360.	10680.	78181.	60893.	101319.	44929.	110392.	507659.	200575.	72386.	43396.	28260.	1265030.
1993	12784.	36406.	129601.	146068.	242423.	170454.	376278.	441307.	91056.	22964.	24072.	5274.	1698687.
1994	3386.	7783.	38743.	97147.	75316.	48374.	207912.	145641.	61166.	205872.	57532.	25330.	974202.
1995	7206.	1862.	20598.	35120.	12697.	10229.	457629.	1381286.	165854.	44886.	20396.	4970.	2162733.
1996	2518.	5401.	85236.	155688.	50377.	166842.	607502.	108634.	37305.	18189.	7919.	13414.	1259025.
1997	7814.	22878.	259809.	126974.	395986.	266909.	396898.	110565.	215510.	40458.	51651.	122916.	2018368.
1998	44626.	73890.	202009.	183057.	137610.	148966.	442631.	942410.	120736.	125498.	55075.	39416.	2515924.
1999	13262.	3705.	33513.	125336.	48033.	35561.	205286.	1071968.	564002.	143166.	118761.	24635.	2387228.
2000	12719.	3594.	38092.	32810.	50616.	49151.	153693.	675699.	404974.	54024.	36885.	31776.	1544033.
2001	9637.	31034.	174139.	83116.	11460.	45959.	553739.	266755.	31612.	87059.	12288.	5274.	1312072.
2002	35032.	18664.	40914.	70177.	101059.	26361.	237822.	869634.	263170.	49118.	18652.	20555.	1751158.
2003	14282.	55422.	213208.	224899.	192480.	58562.	379990.	918188.	733910.	88947.	118677.	41760.	3040325.
2004	10701.	32975.	73710.	65556.	86646.	162809.	899760.	434469.	324798.	50334.	16468.	9246.	2167472.
2005	2952.	3784.	76554.	155583.	54349.	211939.	319020.	358307.	275521.	131142.	49971.	11156.	1650278.
2006	3625.	8136.	18080.	122311.	111889.	165077.	1510865.	139759.	53730.	147486.	61901.	24049.	2366908.
2007	9615.	9253.	80265.	116409.	95763.	27348.	180130.	743180.	534784.	89034.	26697.	6729.	1919207.
2008	2691.	2477.	34880.	86414.	58104.	61985.	656729.	503209.	140691.	27001.	6385.	3907.	1584473.
2009	2908.	26760.	78616.	86771.	76792.	262876.	1019051.	481895.	60557.	19686.	84524.	20338.	2220774.
2010	9746.	22330.	112324.	109204.	142841.	37452.	136525.	544861.	697487.	110934.	30499.	9160.	1963363.
2011	3082.	3607.	52613.	165119.	253819.	484834.	1331951.	281145.	81814.	41131.	22937.	49466.	2771518.
2012	8552.	3878.	54762.	250105.	45971.	25500.	308841.	387001.	268358.	83738.	84187.	34120.	1555013.
2013	18276.	66244.	218678.	150836.	76489.	34574.	1049351.	215639.	203201.	70216.	28336.	27457.	2159297.
2014	16149.	28348.	98237.	46253.	25026.	9074.	34316.	220675.	198328.	49661.	14724.	8856.	749647.
2015	3842.	14292.	72104.	107587.	31342.	13779.	234848.	166304.	48689.	25156.	128487.	69087.	915517.
2016	21531.	45604.	196127.	108154.	66157.	19493.	749040.	88882.	94858.	118965.	19934.	49075.	1577820.
2017	39481.	14233.	63031.	120862.	17907.	10565.	653234.	529581.	90090.	55673.	16237.	3994.	1614888.
MEAN	13267.	22282.	104973.	121206.	88142.	104731.	451800.	425239.	255497.	74996.	42833.	24461.	1729429.

Table C.1.10 1966-2017 Naturalized Flows at Control Points NHSE10

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	20490.	18487.	136633.	167829.	95155.	597378.	2484596.	747999.	953789.	198970.	90636.	51180.	5563142.
1967	27913.	44875.	199925.	232587.	101406.	77739.	923397.	745047.	451815.	70107.	35498.	31646.	2941955.
1968	24527.	21645.	47534.	72530.	36378.	54907.	788544.	1028862.	357398.	381401.	172450.	90401.	3076577.
1969	36985.	62715.	346781.	600487.	507963.	215363.	1080737.	1526037.	316144.	77096.	34301.	24700.	4829309.
1970	23441.	38346.	98649.	53772.	28629.	61460.	784810.	787306.	1335258.	202464.	123761.	60470.	3598366.
1971	55695.	70282.	252907.	62826.	83803.	75071.	691023.	646462.	280184.	79831.	27012.	24939.	2350035.
1972	69782.	91127.	315417.	179066.	58777.	34175.	288612.	1929316.	453201.	165197.	137771.	100820.	3823261.
1973	73602.	82398.	118748.	156318.	286246.	50538.	142624.	566176.	532200.	105595.	75828.	30626.	2220899.
1974	20490.	26094.	87797.	338682.	540021.	192825.	379208.	824552.	234309.	109654.	39048.	24201.	2816881.
1975	20815.	21467.	84736.	191837.	128038.	161086.	1535261.	480310.	578243.	128515.	79839.	45212.	3455359.
1976	24831.	56975.	232548.	123341.	62163.	43963.	136546.	1705082.	295454.	80005.	96097.	90553.	2947558.
1977	41652.	50168.	56672.	450953.	172729.	103575.	424333.	390191.	99143.	26220.	92715.	65484.	1973835.
1978	44126.	30054.	425809.	258129.	44191.	896025.	922637.	1102637.	271026.	105486.	117879.	62445.	4280444.
1979	62706.	84045.	179631.	518043.	268643.	940283.	488385.	1088073.	148693.	57475.	25038.	23962.	3884977.
1980	22117.	19614.	29975.	483784.	120116.	56839.	779558.	432603.	283314.	65853.	35015.	26372.	2355160.
1981	20815.	32544.	173553.	185452.	257465.	392560.	1801191.	536809.	1139913.	108547.	93073.	37506.	4779428.
1982	33664.	32210.	130903.	109288.	228901.	73937.	195389.	1075896.	165224.	49900.	125420.	181454.	2402186.
1983	60448.	36955.	294125.	338703.	205894.	34028.	834211.	405602.	435830.	180065.	42262.	25221.	2893344.
1984	20490.	19026.	27522.	144072.	121657.	109204.	649783.	763670.	1873613.	102882.	50874.	58148.	3940941.
1985	25894.	26741.	99539.	214586.	302894.	56713.	104944.	452137.	639535.	502602.	114119.	58018.	2597722.
1986	29627.	19722.	138521.	125672.	70042.	60578.	422488.	714833.	388086.	264541.	99164.	53807.	2387081.
1987	31863.	67773.	126953.	132961.	116469.	221307.	780144.	1494543.	460553.	65441.	52260.	26003.	3576270.
1988	21423.	19574.	22400.	38985.	27891.	40014.	1138277.	126649.	113279.	36985.	20060.	19274.	1624811.
1989	25482.	29446.	199578.	127857.	47599.	93052.	777951.	451139.	414489.	167194.	427239.	58799.	2819825.
1990	27891.	100924.	274720.	216266.	245506.	961771.	1561264.	549918.	2098533.	124999.	78474.	43019.	6283285.
1991	23724.	22565.	114472.	98261.	113127.	71774.	992028.	378015.	365022.	100885.	34490.	39308.	2353671.
1992	40588.	32609.	173575.	138233.	203159.	123320.	229400.	804822.	392455.	150546.	91749.	81763.	2462219.
1993	46319.	69929.	193479.	218598.	449099.	435935.	630553.	618723.	150185.	49357.	65640.	27652.	2955469.
1994	21314.	23702.	62641.	153420.	184167.	96790.	476577.	404104.	182742.	443086.	115233.	55804.	2219580.
1995	25395.	17252.	43627.	63519.	34598.	33167.	843370.	2435716.	356011.	79332.	49046.	25851.	4006884.
1996	19621.	21097.	106528.	195198.	85171.	246639.	1299914.	302112.	91539.	53025.	49866.	44191.	2514901.
1997	31168.	63440.	449424.	254327.	716309.	491178.	712446.	286072.	440157.	100082.	91770.	189268.	3825641.
1998	78268.	102277.	280190.	338493.	343395.	307280.	879574.	1843777.	224857.	237453.	126890.	80243.	4842697.
1999	34576.	21193.	64985.	207444.	106550.	89418.	501798.	2488828.	936628.	265127.	200533.	53025.	4970105.
2000	34120.	22640.	66374.	73097.	112063.	115107.	257660.	1358604.	824441.	109610.	66522.	57475.	3097713.
2001	30257.	50893.	217094.	140880.	125564.	137204.	1167665.	750950.	74483.	183972.	36780.	23876.	2939618.
2002	63574.	39484.	83803.	147370.	223605.	94543.	522331.	1529423.	502142.	98172.	46778.	43497.	3394722.
2003	34706.	77360.	264628.	337632.	336688.	142959.	798137.	2075977.	1185829.	160118.	195093.	81220.	5690347.
2004	32015.	64102.	124978.	100970.	167389.	282999.	1642766.	763235.	568497.	102274.	43144.	37072.	3929441.
2005	24049.	21663.	98693.	231032.	111282.	330448.	700421.	906619.	527621.	218852.	95782.	35032.	3301494.
2006	23724.	25878.	37485.	205049.	218787.	329608.	2713736.	299920.	108595.	207739.	119581.	52157.	4342259.
2007	29541.	26564.	110782.	180474.	199773.	73853.	373001.	1672524.	955406.	184753.	58204.	27348.	3892223.
2008	22421.	20467.	57714.	121513.	105921.	155415.	1383153.	1134543.	308855.	58256.	31066.	24396.	3423720.
2009	22009.	51129.	114906.	143799.	150763.	515417.	1827520.	1068669.	159385.	54545.	155226.	47143.	4310511.
2010	29367.	40640.	144295.	149954.	239016.	139577.	399720.	1261908.	1455763.	221326.	57301.	29975.	4168842.
2011	23181.	21565.	72625.	202067.	427719.	784637.	2637182.	772764.	139367.	81133.	67321.	120268.	5349829.
2012	33209.	22843.	88231.	372773.	99105.	54424.	679649.	847364.	531381.	187683.	187111.	75989.	3179762.
2013	41912.	102943.	335581.	205218.	151631.	91077.	2461480.	681364.	396278.	158165.	66144.	67372.	4759165.
2014	40784.	50835.	134984.	70471.	65896.	35939.	113387.	410616.	386658.	102752.	45539.	34620.	1492481.
2015	22921.	34347.	103229.	195723.	70064.	34616.	662502.	338099.	82465.	56476.	264199.	136438.	2001079.
2016	46405.	86640.	283989.	208977.	190831.	56104.	1381308.	177938.	166211.	242706.	45055.	83326.	2969490.
2017	72299.	30328.	82132.	195912.	42347.	29617.	1384325.	1159070.	199357.	93635.	42913.	21618.	3353553.
MEAN	34889.	43608.	154077.	201431.	181396.	209681.	918991.	910454.	500607.	143425.	91054.	55965.	3445578.

Table C.1.11 1966-2017 Naturalized Flows at Control Points NHUI11

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	20641.	18624.	146031.	174697.	98866.	615968.	2560802.	766817.	975193.	206458.	94018.	53785.	5731900.
1967	28824.	48443.	215705.	245589.	104792.	78747.	952872.	761304.	465363.	72278.	36107.	31906.	3041930.
1968	24787.	21888.	48706.	75071.	36855.	56398.	807687.	1055515.	368761.	387760.	178415.	92832.	3154675.
1969	37745.	64107.	352663.	624391.	521181.	220824.	1104612.	1552712.	325050.	79006.	34910.	25004.	4942205.
1970	23745.	39425.	100755.	59402.	30061.	64086.	821492.	815089.	1383506.	211863.	129831.	62836.	3742091.
1971	56824.	71909.	262305.	66249.	88079.	79566.	724839.	668189.	295055.	83304.	28084.	25872.	2450275.
1972	71410.	94985.	333932.	186712.	61469.	34889.	293430.	1998013.	466182.	170146.	143988.	103663.	3958819.
1973	76358.	85750.	121982.	161107.	293170.	52680.	147985.	582368.	546126.	108590.	76941.	30995.	2284052.
1974	20663.	26525.	91053.	346349.	555301.	197530.	390560.	846105.	238741.	112671.	39930.	24613.	2890041.
1975	21032.	21839.	86864.	196942.	130447.	162221.	1578129.	492248.	602566.	132097.	81226.	46405.	3552016.
1976	25091.	59554.	241121.	126155.	64594.	44719.	140149.	1742544.	302659.	82761.	99122.	93722.	3022191.
1977	42759.	50599.	57345.	463934.	177417.	106138.	437942.	401955.	100508.	26480.	96328.	67286.	2028691.
1978	45190.	30799.	443108.	262162.	45103.	926188.	939155.	1138103.	277264.	107744.	119413.	63075.	4397304.
1979	63118.	85887.	184949.	531255.	275762.	971181.	501581.	1116810.	152369.	59472.	25710.	24548.	3992642.
1980	22703.	20041.	31820.	497836.	123740.	58120.	801024.	447883.	292535.	67546.	35561.	26632.	2425441.
1981	21076.	33818.	181997.	189065.	263173.	409301.	1854239.	550722.	1171672.	111759.	96076.	38288.	4921186.
1982	34294.	33034.	135656.	111410.	236498.	75575.	198406.	1097254.	168144.	50790.	128088.	186359.	2455508.
1983	62402.	38778.	307083.	345131.	210126.	34595.	861516.	417257.	452613.	186642.	43480.	25720.	2985343.
1984	20685.	19229.	27826.	144766.	123285.	110423.	668254.	792060.	1913333.	105595.	51525.	59667.	4036648.
1985	26285.	27819.	104618.	219963.	313985.	58078.	113127.	463294.	664153.	513649.	116556.	59211.	2680738.
1986	30257.	19997.	145076.	128634.	71171.	62048.	436727.	729419.	398252.	269446.	101159.	56867.	2449053.
1987	33035.	70557.	132856.	136574.	120333.	221937.	804215.	1540992.	471937.	67307.	53016.	26241.	3679000.
1988	21640.	19777.	22638.	39993.	28520.	41191.	1194579.	130317.	114561.	37398.	20417.	19643.	1690674.
1989	25829.	29740.	210626.	132016.	48380.	95131.	798875.	463229.	421673.	169060.	437342.	59884.	2891785.
1990	28477.	104806.	286420.	223576.	255121.	991514.	1613183.	569236.	2149133.	128255.	80134.	43540.	6473395.
1991	23919.	23035.	118314.	100487.	114733.	72929.	1034527.	385242.	376176.	102708.	34952.	40176.	2427198.
1992	41326.	33462.	180781.	140985.	204375.	124958.	231679.	815154.	400626.	153411.	95257.	84172.	2506186.
1993	48033.	72635.	198731.	223240.	461123.	443434.	650283.	636087.	152831.	50030.	66291.	27869.	3030587.
1994	21705.	24290.	64442.	155499.	188703.	98324.	479138.	414306.	187888.	452658.	117774.	56715.	2261442.
1995	25677.	17389.	44257.	64212.	35054.	33839.	879553.	2508254.	367816.	81828.	52449.	26806.	4137134.
1996	19925.	21239.	107223.	197719.	86646.	263548.	1343888.	307799.	93304.	53915.	50223.	44539.	2589968.
1997	31516.	63754.	451291.	256700.	734172.	498865.	733391.	295470.	446017.	101449.	93619.	192654.	3898898.
1998	79571.	103630.	284379.	345719.	350731.	316522.	906011.	1912972.	229394.	242098.	129642.	81546.	4982215.
1999	34988.	21349.	65245.	210784.	108916.	91518.	516080.	2536905.	965573.	271552.	206016.	54328.	5083254.
2000	34815.	22863.	67351.	73664.	113018.	116913.	265518.	1395459.	837506.	111976.	67384.	57735.	3164202.
2001	30430.	51736.	224256.	142749.	125911.	140439.	1201851.	769812.	76185.	185882.	37011.	24114.	3010376.
2002	64073.	39660.	84129.	150080.	227621.	95593.	530601.	1558442.	508318.	100603.	47492.	43714.	3450326.
2003	34837.	78359.	269229.	344060.	346608.	146026.	822555.	2128395.	1216119.	164459.	198286.	82088.	5831021.
2004	32232.	65544.	128190.	101811.	171122.	288691.	1686307.	777322.	577991.	104206.	43732.	37593.	4014741.
2005	24201.	21800.	100190.	234288.	112975.	337800.	720368.	934032.	540854.	226036.	98891.	35748.	3387183.
2006	24179.	26858.	38852.	209019.	223801.	336162.	2793892.	309644.	111620.	210278.	121597.	53090.	4458992.
2007	29888.	26760.	116209.	185725.	205785.	75533.	384678.	1708294.	979646.	189246.	59885.	28151.	3989800.
2008	22725.	20609.	59776.	124370.	109003.	163880.	1432184.	1163172.	315955.	60036.	31738.	24635.	3528083.
2009	22161.	53148.	118357.	147706.	154670.	522622.	1884539.	1090764.	162641.	55370.	156717.	47425.	4416120.
2010	29584.	42130.	150915.	154806.	246026.	142140.	412309.	1297071.	1502541.	227056.	58814.	30387.	4293779.
2011	23355.	21741.	72907.	204041.	436401.	815073.	2733683.	794729.	143841.	83434.	68686.	123654.	5521545.
2012	33773.	23026.	90727.	382814.	101710.	57154.	699097.	873432.	543228.	193023.	192636.	77943.	3268563.
2013	42933.	106080.	355224.	208767.	159141.	93766.	2536644.	696362.	410729.	161290.	67426.	68957.	4907319.
2014	41695.	52619.	137783.	71080.	67003.	36233.	115905.	419840.	392014.	104770.	46064.	34945.	1519951.
2015	23094.	35523.	106138.	205133.	72256.	34952.	672226.	339901.	82654.	57258.	268505.	139433.	2037073.
2016	47339.	89077.	293322.	212926.	194976.	57742.	1426107.	182344.	168585.	247481.	45707.	85496.	3051102.
2017	73992.	30838.	84281.	199819.	42824.	29932.	1419943.	1187091.	203768.	96153.	43459.	21770.	3433870.
MEAN	35516.	44752.	159339.	206484.	186014.	215455.	947276.	934187.	513676.	146852.	93224.	57198.	3539972.

Table C.1.12 1966-2017 Naturalized Flows at Control Points NHGA12

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	20859.	18820.	155256.	182280.	103446.	642350.	2673299.	791387.	1004789.	220349.	98723.	57540.	5969098.
1967	29996.	52873.	237735.	262540.	109849.	80617.	1001665.	799266.	486494.	75924.	37725.	33296.	3207980.
1968	25178.	22193.	52852.	80176.	37940.	58394.	842459.	1101487.	383339.	394641.	184990.	96066.	3279715.
1969	39091.	67283.	362886.	660078.	541649.	227882.	1136714.	1584076.	339124.	82262.	36317.	25569.	5102931.
1970	24049.	41503.	104683.	68896.	32861.	69358.	883633.	855482.	1455511.	227360.	137120.	65549.	3966005.
1971	58148.	74144.	275458.	71080.	94417.	85700.	768011.	696623.	317846.	88122.	29617.	27001.	2586167.
1972	73558.	100305.	360911.	196837.	65441.	35960.	304153.	2102653.	486935.	179652.	151550.	107657.	4165612.
1973	80222.	90436.	126497.	167682.	302611.	55621.	155278.	604442.	565094.	112671.	78495.	31494.	2370543.
1974	20924.	27133.	95502.	356852.	576116.	203936.	406123.	875407.	244791.	116795.	41170.	25178.	2989927.
1975	21336.	22349.	89794.	203936.	133746.	163775.	1636515.	508440.	635544.	137002.	83116.	48033.	3683586.
1976	25438.	63066.	252820.	130020.	67893.	45770.	145098.	1793812.	312468.	86495.	103260.	98042.	3124182.
1977	44278.	51187.	58278.	481662.	183776.	109645.	456587.	418039.	102441.	26871.	101264.	69782.	2103810.
1978	46666.	31818.	466723.	267686.	46340.	967274.	961728.	1186288.	285771.	110848.	121534.	63943.	4556619.
1979	63704.	88397.	192155.	549214.	285464.	1013128.	519510.	1155684.	157368.	62207.	26634.	25351.	4138816.
1980	23528.	20630.	34316.	517056.	128711.	59864.	830369.	468633.	305117.	69890.	36317.	26979.	2521410.
1981	21379.	35563.	193544.	194001.	270966.	432070.	1926516.	569800.	1214795.	116144.	100172.	39351.	5114301.
1982	35162.	34171.	142190.	114329.	246916.	77823.	202508.	1126447.	172135.	51984.	131700.	193044.	2528409.
1983	65072.	41287.	324772.	353869.	215878.	35393.	898501.	433102.	475361.	195627.	45139.	26415.	3110416.
1984	20967.	19493.	28108.	145606.	125303.	112943.	694192.	827634.	1959691.	109046.	52470.	61360.	4156813.
1985	26719.	29074.	110609.	227735.	331088.	60053.	121722.	479724.	698412.	531903.	120694.	61252.	2798985.
1986	31147.	20546.	154865.	132772.	73059.	64527.	466159.	754597.	412283.	275849.	104205.	60470.	2550479.
1987	34728.	76556.	146270.	141993.	126171.	223912.	844260.	1614376.	488594.	70172.	54655.	26784.	3848471.
1988	21922.	20020.	23615.	41632.	29584.	45812.	1266532.	135049.	116619.	37832.	20795.	20034.	1779446.
1989	26198.	30407.	228532.	137750.	49705.	99101.	836143.	482807.	435641.	172164.	454692.	61816.	3014956.
1990	29888.	109648.	299812.	233427.	266147.	1026907.	1670940.	596432.	2222335.	132748.	82045.	44126.	6714455.
1991	24223.	24525.	129579.	105570.	119508.	75618.	1095800.	394880.	391972.	105074.	35540.	41739.	2544028.
1992	42650.	34376.	187097.	145606.	205959.	127058.	234176.	844304.	416505.	159402.	101622.	89121.	2587876.
1993	51072.	78693.	209931.	231474.	473408.	457003.	686552.	659985.	157915.	51397.	67825.	28390.	3153645.
1994	22183.	25035.	67372.	159574.	195866.	102588.	490121.	433102.	197782.	463381.	121450.	58213.	2336667.
1995	26241.	17644.	46774.	65430.	35792.	34532.	911698.	2608358.	380020.	84888.	57028.	28043.	4296448.
1996	20316.	21584.	110479.	203642.	89512.	276571.	1410653.	318131.	96622.	56064.	51756.	45515.	2700845.
1997	32037.	64440.	457954.	261090.	758894.	513275.	761043.	308233.	452865.	104206.	94921.	194737.	4003695.
1998	80569.	105472.	292302.	356095.	363559.	329314.	940631.	2012077.	237313.	250020.	133045.	83195.	5183592.
1999	35531.	21545.	65506.	215594.	112280.	95635.	539392.	2598981.	1004411.	280451.	213851.	56194.	5239371.
2000	36399.	23350.	70281.	74966.	114646.	119182.	277021.	1453216.	860611.	115536.	69106.	58387.	3272701.
2001	30734.	53344.	237344.	145774.	126345.	146971.	1260801.	791235.	78831.	189072.	37452.	24505.	3122408.
2002	65810.	40581.	86929.	154470.	233416.	96748.	545252.	1604761.	518694.	103576.	48437.	44018.	3542692.
2003	35032.	79751.	276652.	354730.	360955.	152474.	861559.	2203277.	1261300.	170775.	203810.	83716.	6044031.
2004	32731.	68102.	133790.	103554.	179088.	299256.	1754721.	795836.	594501.	107331.	45097.	39373.	4153380.
2005	24657.	22094.	102730.	239792.	115948.	352041.	755313.	985039.	563876.	237366.	102987.	36790.	3538633.
2006	24527.	27309.	39568.	212464.	232048.	347778.	2912532.	321213.	115464.	212644.	123887.	54263.	4623697.
2007	30279.	26956.	119161.	190997.	213491.	77655.	402151.	1763056.	1014073.	195823.	62405.	29432.	4125479.
2008	23181.	20833.	62858.	128781.	113213.	175874.	1505829.	1201699.	326962.	62814.	32936.	25547.	3680527.
2009	22508.	56657.	124088.	153777.	160357.	532494.	1970838.	1121672.	167136.	56802.	159805.	48402.	4574536.
2010	30061.	44620.	161312.	162221.	256358.	147790.	432625.	1343150.	1568055.	235760.	61124.	31168.	4474244.
2011	23637.	22094.	73971.	208095.	448491.	857418.	2868449.	825854.	150227.	86690.	70891.	128646.	5764463.
2012	34663.	23289.	94048.	396425.	105052.	60557.	730027.	916234.	562552.	201054.	200933.	80786.	3405620.
2013	44474.	110374.	380554.	213577.	167867.	96664.	2637095.	713401.	430999.	165501.	69463.	71605.	5101574.
2014	43150.	55402.	142059.	72299.	68349.	36611.	123458.	433015.	400080.	108417.	47030.	35553.	1565423.
2015	23376.	36935.	109784.	222904.	75946.	35645.	685293.	342245.	82948.	58061.	277159.	145011.	2095307.
2016	49053.	92508.	306497.	218808.	201531.	59822.	1484928.	187748.	171127.	253167.	46715.	88643.	3160547.
2017	76467.	31583.	87059.	205995.	43519.	30352.	1467260.	1227875.	210385.	100342.	44446.	22139.	3547422.
MEAN	36456.	46500.	167190.	213900.	192624.	223745.	988343.	968659.	532533.	151926.	96445.	59024.	3677346.

Table C.1.13 1966-2017 Naturalized Flows at Control Points HOSO13

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	1715.	1568.	86343.	55180.	32319.	171610.	1069341.	229292.	215447.	70346.	37578.	31016.	2001755.
1967	11851.	19663.	98345.	77298.	31668.	16300.	253515.	181150.	159973.	22638.	12036.	13153.	897590.
1968	3777.	2132.	38027.	35141.	6989.	10628.	224452.	311011.	104646.	65918.	70555.	38353.	911629.
1969	13761.	18860.	45515.	233091.	104944.	31780.	266364.	383202.	136994.	29562.	15229.	6946.	1286248.
1970	2908.	10567.	17928.	32179.	11656.	19451.	382117.	316112.	450386.	93961.	68476.	29410.	1435151.
1971	16127.	17134.	52700.	28273.	38027.	33125.	351925.	195302.	115254.	34142.	13548.	8422.	903979.
1972	12567.	28609.	134484.	70597.	27327.	11973.	30843.	706347.	135082.	52201.	68350.	36226.	1314606.
1973	29497.	36719.	21531.	37221.	50464.	10334.	23876.	174899.	119476.	29953.	16699.	7163.	557832.
1974	3191.	3705.	35401.	104058.	175637.	41065.	188790.	184428.	44971.	33426.	11217.	5991.	831880.
1975	2757.	2294.	15150.	47660.	36226.	38292.	502797.	83695.	126134.	28933.	14304.	11634.	909876.
1976	4645.	19736.	59906.	27159.	13175.	12099.	46883.	538068.	54214.	19708.	24975.	27674.	848242.
1977	11938.	5372.	7944.	134032.	43888.	25920.	206198.	106441.	38166.	5687.	23357.	19817.	628760.
1978	12980.	9155.	110131.	56776.	12567.	312027.	227751.	300658.	47660.	22334.	21320.	17863.	1151222.
1979	10375.	9802.	16561.	128823.	71627.	272202.	121505.	204874.	36380.	17386.	7163.	4015.	900713.
1980	3668.	2518.	5209.	161485.	36334.	18001.	289588.	102686.	79104.	23051.	11805.	7879.	741328.
1981	3277.	15586.	66374.	47051.	79245.	158020.	582411.	197885.	274891.	37506.	30793.	14000.	1507039.
1982	10722.	9861.	42303.	22160.	102361.	18988.	61968.	269967.	28546.	7944.	11742.	52852.	639414.
1983	23984.	18899.	114429.	57490.	46210.	9053.	190852.	106138.	111830.	64920.	17056.	11590.	772451.
1984	5535.	3147.	8183.	28756.	14456.	42493.	294798.	233307.	555011.	28065.	21278.	18341.	1253370.
1985	7076.	12625.	32471.	72530.	106550.	13926.	87667.	186924.	233805.	185491.	37893.	25351.	1002309.
1986	12980.	7646.	55152.	40812.	22096.	10019.	186642.	189290.	130293.	56107.	39048.	36182.	786267.
1987	22790.	77340.	132705.	41296.	39026.	54214.	320996.	480050.	110549.	22183.	15208.	6512.	1322869.
1988	3147.	2173.	3668.	9032.	6099.	12183.	419015.	30951.	24597.	7640.	2983.	2518.	524006.
1989	7423.	11625.	147052.	52764.	12741.	26172.	327876.	161268.	101538.	32189.	104142.	16040.	1000830.
1990	10744.	58480.	113409.	92968.	71192.	341518.	395010.	170276.	779028.	36030.	30331.	13479.	2112465.
1991	6360.	6646.	56498.	35603.	59776.	42283.	491923.	121852.	114455.	25872.	8171.	12697.	982136.
1992	11439.	6091.	41001.	36632.	36052.	9893.	18514.	378861.	140733.	56650.	41128.	37094.	814088.
1993	19708.	34778.	77791.	72299.	104553.	93052.	319845.	179935.	43291.	15866.	19009.	6946.	987073.
1994	5274.	4293.	12198.	21656.	31364.	24303.	129253.	147507.	56209.	126801.	28420.	17060.	604338.
1995	7987.	3666.	28629.	22412.	8378.	5461.	273028.	818019.	100025.	27240.	34616.	13327.	1342788.
1996	6533.	6234.	29758.	54718.	15541.	89082.	346173.	72864.	25836.	15302.	9221.	9138.	680400.
1997	6012.	4548.	61838.	21887.	156710.	107860.	271638.	95090.	49130.	16062.	17350.	42911.	851036.
1998	20533.	17272.	24396.	56797.	64117.	68308.	250671.	634612.	53415.	59841.	23883.	15107.	1288952.
1999	6707.	2999.	8725.	53751.	27956.	22349.	132118.	368964.	401298.	89012.	71753.	20837.	1206469.
2000	14173.	6579.	16518.	11616.	15128.	26508.	82219.	373782.	197677.	27044.	14955.	8856.	795055.
2001	5687.	16546.	105769.	18190.	5513.	37704.	411636.	146227.	16048.	28651.	4873.	2626.	799470.
2002	14586.	6332.	13870.	35687.	79419.	15081.	143492.	466745.	109540.	39178.	15481.	13066.	952477.
2003	7705.	15468.	69912.	124391.	136677.	53247.	347150.	446906.	419950.	44756.	51903.	23138.	1741203.
2004	10397.	19777.	45038.	21740.	81719.	152453.	574467.	148658.	158461.	26024.	13947.	20142.	1272823.
2005	6729.	3764.	14412.	49613.	18362.	148147.	257443.	332890.	200092.	112150.	30667.	13501.	1187770.
2006	6794.	6077.	7293.	28798.	56867.	90195.	1023348.	77856.	31885.	24657.	23735.	14825.	1392330.
2007	6946.	3980.	21792.	48983.	41652.	13212.	125933.	378601.	304613.	48511.	21320.	12177.	1027720.
2008	6273.	2701.	8096.	11931.	17255.	43186.	433059.	213925.	68413.	21488.	11049.	6859.	844235.
2009	3364.	22977.	23485.	31528.	36464.	56692.	729918.	207283.	29260.	15150.	19661.	8769.	1184551.
2010	4667.	13978.	64572.	40224.	62576.	22202.	103945.	244681.	451983.	58625.	21299.	10657.	1099409.
2011	4688.	2509.	8096.	32284.	107245.	260145.	901171.	265105.	49719.	32123.	18673.	33078.	1714836.
2012	9160.	4366.	15714.	98534.	21271.	15060.	254926.	333042.	176357.	48229.	59780.	28195.	1064634.
2013	16865.	45581.	146921.	36927.	39698.	29806.	717503.	89989.	164006.	41760.	20837.	30843.	1380736.
2014	15085.	20232.	22117.	9263.	8313.	13296.	67069.	133247.	76311.	38092.	13485.	8747.	425257.
2015	4493.	10900.	19947.	54025.	13349.	5062.	108503.	20077.	10313.	8248.	65724.	38700.	359341.
2016	14781.	21381.	57410.	39279.	38266.	14514.	379512.	28759.	23336.	26241.	5818.	15931.	665228.
2017	17516.	6058.	19252.	36864.	6924.	3130.	425028.	276001.	45875.	28564.	10649.	6164.	882025.
MEAN	9806.	13864.	47730.	53836.	47769.	61031.	314859.	250879.	148696.	40951.	27009.	17958.	1034388.

Table C.1.14 1966-2017 Naturalized Flows at Control Points NHCH14

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	23159.	20918.	259136.	253130.	146704.	881763.	4065243.	1085251.	1303667.	331349.	148441.	98302.	8617063.
1967	44560.	82006.	392557.	381553.	154735.	102168.	1398021.	1119806.	708452.	109415.	55390.	51766.	4600429.
1968	29975.	25076.	106897.	131028.	48294.	74105.	1177715.	1550911.	526004.	475600.	269555.	142580.	4557740.
1969	56715.	96297.	437183.	992942.	708886.	276634.	1489030.	2046632.	516573.	121288.	56041.	34142.	6832363.
1970	27674.	57990.	133269.	125672.	53025.	106201.	1451220.	1293902.	2108867.	368139.	223303.	101297.	6050559.
1971	77335.	97180.	360672.	112229.	150134.	134347.	1231348.	968326.	496303.	135830.	47597.	38179.	3849480.
1972	91964.	143838.	566653.	294509.	103902.	51084.	370613.	3112522.	684002.	263759.	240653.	156146.	6079645.
1973	121092.	139231.	158121.	225697.	372415.	71795.	198623.	824878.	728911.	156841.	100949.	40675.	3139228.
1974	24917.	32328.	139867.	485884.	804844.	261342.	626863.	1130571.	311460.	159575.	55180.	33860.	4066691.
1975	24982.	25996.	111868.	271236.	180304.	206478.	2280438.	641601.	822256.	176310.	101075.	62424.	4904968.
1976	30908.	88569.	330220.	164132.	86950.	59801.	201444.	2475154.	389703.	114429.	138023.	135266.	4214599.
1977	59515.	57990.	69152.	662724.	243400.	146425.	739382.	566610.	148651.	34012.	134788.	94569.	2957218.
1978	62489.	42954.	620134.	336183.	61599.	1399050.	1278643.	1613465.	359225.	141538.	147790.	84324.	6147394.
1979	76120.	103179.	223019.	724647.	381922.	1392118.	692542.	1469235.	207171.	84823.	35183.	30626.	5420585.
1980	28781.	24325.	44756.	732482.	178676.	85133.	1190282.	628122.	412851.	99583.	50475.	35770.	3511236.
1981	25351.	54148.	282860.	253340.	363950.	617711.	2700431.	834450.	1577927.	164199.	139115.	55630.	7069112.
1982	47599.	46678.	200902.	143904.	373131.	101495.	285486.	1491873.	213409.	64898.	157662.	267753.	3394790.
1983	97087.	67028.	488472.	433036.	279127.	47534.	1185528.	574988.	632267.	280190.	66333.	39850.	4191440.
1984	27327.	23330.	37181.	177764.	145749.	163670.	1055277.	1157616.	2626637.	146596.	78159.	86603.	5725909.
1985	35683.	46306.	161312.	322509.	485455.	79587.	230334.	717243.	1021529.	768532.	171211.	93180.	4132881.
1986	46644.	30132.	233698.	182721.	99083.	82024.	738210.	1024195.	578159.	348865.	161317.	105334.	3630382.
1987	62120.	176794.	329916.	198895.	179696.	287368.	1294184.	2320788.	648021.	101276.	75996.	35444.	5710498.
1988	25959.	22883.	32731.	58078.	39590.	74126.	1876530.	179609.	147349.	46644.	24660.	23376.	2551535.
1989	34663.	44875.	422662.	206016.	66569.	139010.	1285697.	699596.	586981.	215683.	618362.	84129.	4404243.
1990	44734.	185616.	452420.	355150.	368985.	1473449.	2239177.	830434.	3196121.	180759.	117711.	59385.	9503941.
1991	31407.	34073.	214120.	157852.	194803.	127247.	1738529.	536744.	545748.	136720.	45917.	59862.	3823022.
1992	59298.	46132.	263911.	197845.	248653.	147013.	260656.	1303083.	603890.	233351.	162326.	138391.	3664549.
1993	77075.	125822.	311662.	322215.	622001.	594942.	1102919.	908703.	219480.	72082.	92379.	37094.	4486374.
1994	28477.	31857.	94048.	199000.	244637.	141720.	664673.	637390.	281801.	629489.	161779.	80243.	3195114.
1995	36399.	22604.	87254.	94711.	47664.	42157.	1286630.	3730703.	521425.	121809.	104016.	44843.	6140215.
1996	28086.	29807.	153303.	278083.	114082.	387834.	1903400.	422727.	131995.	80092.	70051.	60448.	3659908.
1997	40588.	71890.	550635.	299004.	985582.	669761.	1112990.	438246.	523525.	131294.	118930.	252169.	5194614.
1998	108525.	134389.	345631.	445765.	467374.	444547.	1296550.	2958395.	317026.	337860.	169194.	104900.	7130156.
1999	44799.	25584.	78941.	296295.	152934.	132688.	758743.	3164593.	1514682.	394185.	307553.	82479.	6953476.
2000	58864.	33300.	109784.	94963.	138109.	152222.	393469.	1997123.	1128276.	152847.	87884.	68675.	4415516.
2001	37311.	75399.	379860.	171757.	133421.	202340.	1886644.	998995.	102420.	228879.	43753.	28130.	4288909.
2002	88991.	52658.	118792.	203033.	328853.	118341.	730179.	2239003.	659511.	150872.	66564.	58148.	4814945.
2003	43540.	100140.	366034.	506868.	534834.	226874.	1319231.	2876632.	1800558.	233199.	274471.	112454.	8394835.
2004	44864.	91777.	186815.	129432.	278541.	471790.	2507386.	988968.	781360.	138565.	61922.	63205.	5744625.
2005	32623.	26603.	119247.	299109.	140084.	537241.	1116159.	1473793.	827718.	380728.	144303.	53047.	5150655.
2006	32189.	34092.	47599.	243845.	297967.	448244.	4252427.	428457.	156360.	244138.	155856.	72668.	6413842.
2007	38505.	31759.	155647.	256637.	282730.	98786.	582780.	2308980.	1402495.	263260.	91119.	45993.	5558691.
2008	31212.	24183.	80743.	154176.	141886.	254474.	2153898.	1538300.	426504.	92485.	48311.	35097.	4981269.
2009	26806.	88887.	155126.	194778.	206328.	611262.	2922256.	1419053.	209587.	77009.	189170.	59819.	6160081.
2010	35813.	64479.	244529.	217715.	348626.	195849.	614296.	1737878.	2212820.	317284.	88662.	43909.	6121860.
2011	29041.	25447.	84932.	251806.	593893.	1231242.	4147222.	1190130.	217085.	128298.	97232.	178958.	8175286.
2012	46622.	28508.	121743.	542913.	136242.	86939.	1072250.	1395025.	797996.	278432.	285456.	117685.	4909811.
2013	66027.	169305.	587012.	265880.	231093.	134788.	3656320.	853051.	648252.	218982.	96580.	110479.	7037769.
2014	62662.	84417.	177569.	84608.	83043.	52344.	209258.	599818.	495862.	153975.	62952.	46101.	2112609.
2015	28737.	52736.	141842.	305516.	98367.	42766.	864099.	376040.	95551.	69934.	365296.	198796.	2639680.
2016	68458.	128143.	395248.	272580.	263781.	78789.	2019566.	231115.	202277.	290978.	53982.	111846.	4116763.
2017	98389.	39229.	115058.	258402.	52787.	35162.	2012121.	1619911.	273021.	137111.	57511.	29258.	4727960.
MEAN	49090.	65556.	236207.	287889.	258566.	307342.	1420518.	1321743.	731725.	207384.	133041.	82410.	5101470.

Table C.1.15 1966-2017 Naturalized Flows at Control Points NHGW15

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	23919.	21604.	293300.	275332.	158533.	922618.	4413283.	1149845.	1393211.	351752.	156717.	103121.	9263235.
1967	46384.	85829.	430150.	413355.	163265.	105150.	1513839.	1270308.	780667.	119247.	59339.	55521.	5043054.
1968	31516.	26437.	119139.	139640.	49922.	78999.	1309551.	1684006.	574210.	491206.	283461.	150958.	4939045.
1969	59190.	98905.	445561.	1070744.	784116.	290854.	1577651.	2168658.	557154.	129058.	58604.	35227.	7275722.
1970	28694.	59990.	134984.	128403.	58625.	132982.	1626922.	1449006.	2303708.	432364.	248340.	109914.	6713932.
1971	81589.	104943.	399199.	127941.	173228.	152327.	1376077.	1078197.	547975.	149331.	52554.	41522.	4284883.
1972	98085.	157443.	615272.	329566.	115753.	55327.	406687.	3467530.	750147.	301222.	277096.	174574.	6748702.
1973	135287.	149779.	164133.	255293.	383723.	76941.	221087.	854592.	760124.	171882.	106558.	42238.	3321637.
1974	25807.	33622.	147768.	507309.	853355.	275227.	653039.	1192583.	344648.	167671.	57049.	37940.	4296018.
1975	25829.	27074.	116751.	295895.	193348.	208431.	2427338.	700465.	861829.	182713.	102714.	64312.	5206699.
1976	31646.	93280.	340096.	169845.	90966.	61502.	209888.	2626373.	408229.	120029.	142707.	138977.	4433538.
1977	60969.	58794.	70650.	717820.	261719.	162431.	877057.	617899.	163082.	35792.	143400.	98280.	3267893.
1978	64030.	44385.	641774.	341560.	64399.	1570302.	1425369.	1773083.	390438.	150633.	151277.	86429.	6703679.
1979	77335.	105159.	228250.	766446.	407186.	1521172.	760913.	1599183.	223030.	89642.	36716.	32058.	5847090.
1980	30148.	25198.	47556.	797492.	196865.	95761.	1259825.	703525.	440199.	106810.	52575.	36638.	3792592.
1981	25872.	55383.	299225.	264073.	375996.	622668.	2903177.	944776.	1637770.	175268.	145396.	57019.	7506623.
1982	48554.	49325.	222911.	153609.	402259.	105591.	327203.	1603003.	227063.	70867.	173521.	296187.	3680093.
1983	106224.	73988.	550787.	458473.	294841.	50160.	1292382.	608262.	662892.	297706.	69925.	41240.	4506880.
1984	27848.	23817.	39308.	180768.	149504.	171988.	1141880.	1261518.	2770100.	156037.	82822.	91660.	6097250.
1985	36877.	49580.	186294.	347778.	539717.	85679.	269142.	804844.	1116009.	836012.	184654.	98845.	4555431.
1986	48511.	30877.	247676.	188834.	100386.	87170.	829067.	1127077.	623592.	366772.	191522.	120962.	3962446.
1987	70172.	205005.	382377.	213535.	190462.	300916.	1474205.	2600783.	700890.	111499.	81268.	36942.	6368054.
1988	26415.	23310.	35531.	66900.	42846.	82129.	2058830.	193761.	153693.	47903.	25710.	24223.	2781251.
1989	35488.	46678.	463793.	222000.	70129.	154953.	1441083.	769812.	639304.	230421.	689401.	91226.	4854288.
1990	48489.	210710.	492335.	390816.	394098.	1610044.	2435391.	902929.	3443012.	194955.	122164.	60557.	10305500.
1991	31993.	36406.	244290.	169299.	202508.	133024.	1905831.	569887.	584565.	141625.	46799.	61534.	4127761.
1992	60926.	50762.	297511.	209545.	272810.	162179.	274026.	1412585.	657767.	254448.	178352.	149287.	3980198.
1993	81003.	131546.	327789.	339775.	679866.	638086.	1230957.	987991.	234351.	75512.	94018.	38071.	4858965.
1994	29497.	35484.	112150.	220068.	258333.	155289.	723797.	708930.	311817.	688397.	177701.	85974.	3507437.
1995	38005.	23035.	99279.	106075.	53655.	44404.	1432879.	4109846.	565241.	133117.	118278.	48532.	6772346.
1996	30691.	33523.	169929.	297135.	123002.	426756.	2152965.	461536.	144976.	89577.	78789.	65007.	4073886.
1997	42021.	74576.	596150.	309024.	1068104.	728953.	1216436.	492270.	539279.	138218.	126617.	264563.	5596211.
1998	114342.	146760.	369029.	473807.	497978.	491073.	1441561.	3414765.	353071.	360564.	177365.	108004.	7948319.
1999	45711.	26113.	84042.	318476.	164958.	147853.	873410.	3391171.	1650646.	423769.	327823.	88274.	7542246.
2000	64833.	40406.	140800.	100676.	147790.	159196.	427806.	2187476.	1218744.	165197.	91644.	69565.	4814133.
2001	38787.	88514.	423943.	179319.	134723.	218892.	2136165.	1085230.	112040.	242206.	45139.	28955.	4733913.
2002	96891.	55128.	128407.	213409.	343048.	124244.	787002.	2454903.	693854.	161464.	69358.	59233.	5186941.
2003	44083.	104767.	380836.	529764.	575574.	245883.	1468801.	3126088.	1956855.	255056.	296904.	119638.	9104249.
2004	46861.	102011.	211776.	138968.	308211.	507288.	2748073.	1046421.	840888.	148050.	68350.	71692.	6238589.
2005	34359.	27152.	123502.	316879.	148896.	583494.	1246129.	1698657.	923353.	426938.	158461.	56368.	5744188.
2006	34337.	36151.	50312.	246618.	317935.	470677.	4662131.	464292.	166653.	250346.	164258.	75468.	6939178.
2007	39286.	32308.	165414.	272034.	317762.	106705.	657901.	2488242.	1508632.	285942.	100466.	51332.	6026024.
2008	33122.	24751.	84281.	158482.	151696.	298017.	2416768.	1686003.	468408.	102578.	54655.	37702.	5516463.
2009	27609.	94886.	158533.	203159.	219438.	631301.	3205724.	1530400.	226474.	84411.	204104.	62879.	6648918.
2010	36725.	69616.	250780.	227924.	384656.	238489.	708951.	1925084.	2490778.	350167.	96853.	45906.	6825929.
2011	29671.	26309.	88339.	265796.	629815.	1372710.	4650909.	1329389.	238972.	140106.	103365.	193848.	9069229.
2012	48641.	28995.	135418.	606851.	147572.	100634.	1205823.	1596253.	880650.	314962.	317404.	130252.	5513455.
2013	74578.	195889.	672161.	289825.	263998.	147958.	4018273.	923592.	731221.	233264.	103743.	120202.	7774704.
2014	67655.	95180.	194933.	88157.	89273.	59801.	253167.	658227.	526655.	166716.	66396.	48641.	2314801.
2015	29671.	57853.	154236.	334923.	107744.	45581.	944863.	395596.	98660.	74383.	385355.	215227.	2844092.
2016	72885.	154174.	413155.	286611.	292432.	83914.	2185327.	251670.	210406.	297315.	54991.	121939.	4424819.
2017	102057.	40503.	124652.	273441.	54718.	37494.	2171957.	1745887.	292766.	146726.	59255.	30213.	5079669.
MEAN	51752.	71037.	256086.	307682.	278303.	333485.	1564972.	1447970.	790398.	223805.	143499.	87978.	5556967.

C.2 Tables for 1966-2017 Evaporation-Precipitation for Reservoirs

Table C.2.1 1966-2017 Evaporation-Precipitation Rate (in/month) for reservoir Hwacheon

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	0.0600	0.0220	−0.0060	0.1800	0.2620	−0.4370	−1.6830	−0.2160	−0.7730	−0.0480	−0.0110	0.0520	−2.5980
1967	0.0040	−0.0080	−0.0380	0.1190	0.2740	0.1490	−0.5600	−0.8700	−0.0380	0.0920	0.0110	0.0330	−0.8320
1968	0.0240	0.0710	0.1580	0.2700	0.2290	0.0950	−0.7070	−0.7410	−0.0070	−0.1980	−0.0050	0.0560	−0.7550
1969	−0.0160	−0.0070	0.1350	−0.3760	−0.2500	0.0340	−1.2250	−0.9230	−0.0400	0.1820	0.0620	0.0120	−2.4120
1970	0.0390	0.0280	0.1060	0.3220	0.2590	−0.0240	−0.6790	−0.7320	−0.9340	−0.0890	0.0150	−0.0010	−1.6900
1971	0.0370	0.0250	0.1080	0.2530	0.2030	0.0270	−0.7400	−0.4260	−0.2970	0.1710	0.0620	−0.0710	−0.6480
1972	−0.1150	0.0280	0.0500	0.2150	0.1850	0.3290	−0.0760	−1.7080	−0.1840	0.0340	−0.1190	0.0430	−1.3180
1973	−0.0480	0.1070	0.1580	0.0540	0.0920	0.0960	0.0370	−0.3640	−0.1830	0.1000	0.0120	0.0470	0.1080
1974	0.0350	0.0330	0.0750	−0.0560	−0.2820	0.2320	−0.2770	−0.4350	0.0060	0.0450	0.0580	0.0260	−0.5400
1975	0.0430	0.0700	0.0590	0.0790	0.1510	0.0910	−1.3790	−0.0230	−0.4670	0.1000	0.0340	0.0100	−1.2320
1976	0.0440	−0.1660	0.1650	0.1850	0.2480	0.2140	−0.0730	−1.3010	0.0760	0.0150	0.0090	−0.0230	−0.6070
1977	0.0490	0.1060	0.1350	−0.3030	0.2280	0.2740	−0.2990	−0.1160	0.1320	0.1120	−0.1620	−0.0660	0.0900
1978	0.0140	−0.0500	0.0020	0.2270	0.3430	−1.0390	−0.2970	−0.8950	0.0400	0.0150	0.0630	−0.0350	−1.6120
1979	0.0150	0.0130	−0.0110	−0.1790	0.0450	−0.7990	−0.1710	−0.6460	0.1080	0.1210	0.0670	−0.0360	−1.4730
1980	0.0160	0.1030	0.1530	−0.3160	0.2190	0.1730	−0.6280	−0.2440	0.0180	0.0860	0.0310	−0.0410	−0.4300
1981	−0.0120	0.0570	0.0680	0.1130	−0.0570	−0.2070	−1.4300	−0.4550	−0.5550	0.0620	−0.0210	0.0370	−2.4000
1982	−0.0080	0.0880	0.0660	0.2870	−0.2250	0.2840	−0.0040	−0.7620	0.2850	0.0820	−0.3080	−0.0600	−0.2750
1983	0.0300	0.0400	0.0070	−0.0530	0.2830	0.3190	−0.9710	−0.0460	−0.2410	−0.0140	0.0460	0.0260	−0.5740
1984	0.0050	0.0270	0.0820	0.1270	0.2300	0.1520	−0.4280	−0.8040	−0.8930	0.1430	−0.0180	−0.0530	−1.4300
1985	−0.0290	0.0220	0.0570	0.1090	0.0140	0.2830	0.1490	−0.3820	−0.4570	−0.0440	−0.0320	−0.0740	−0.3840
1986	0.0010	0.0660	0.1100	0.2110	0.2120	0.0520	−0.2840	−0.6830	−0.0110	−0.0370	0.0220	0.0240	−0.3170
1987	−0.0330	0.0470	0.1610	0.1900	0.1290	0.1050	−0.7190	−1.4830	0.1950	0.1530	−0.0450	0.0700	−1.2300
1988	0.0710	0.0940	0.1580	0.1860	0.3130	0.2130	−1.0650	0.2230	0.1110	0.1750	0.0500	0.0460	0.5750
1989	−0.0240	0.0630	−0.0170	0.3070	0.2370	0.1480	−0.6670	−0.1410	−0.2120	0.0380	−0.2940	0.0540	−0.5080
1990	−0.0120	−0.0460	0.0690	0.0900	−0.1180	−0.7410	−1.1630	−0.3640	−1.3320	0.1660	0.0090	0.0170	−3.4250
1991	0.0470	0.0700	0.1430	0.1660	0.1700	0.2200	−0.8360	0.2190	−0.1780	0.1320	0.0510	−0.0190	0.1850
1992	0.0270	−0.0130	0.1820	0.1880	0.0580	0.1960	0.0420	−0.5470	−0.0490	0.0800	−0.0350	−0.0750	0.0540
1993	0.0220	−0.0240	0.1340	0.0780	0.0140	−0.1670	−0.3710	−0.1470	0.0800	0.1270	−0.0490	0.0250	−0.2780
1994	0.0320	0.0680	0.1440	0.2070	0.0530	0.0340	0.0090	−0.3700	0.1070	−0.2200	−0.0150	0.0390	0.0880
1995	0.0470	0.0690	0.0500	0.2440	0.2950	0.2160	−0.5200	−2.1670	0.0720	0.1010	0.0340	0.0490	−1.5100
1996	0.0290	0.0900	0.0550	0.1200	0.3280	−0.2140	−1.1790	0.1160	0.2520	−0.0120	0.0150	0.0210	−0.3790
1997	0.0050	0.0280	0.1760	0.1710	−0.5490	−0.2200	−0.2090	−0.0640	−0.2610	0.1280	−0.0900	−0.0200	−0.9050
1998	0.0340	0.0320	0.1360	−0.0820	0.0320	−0.1760	−0.5380	−1.0190	0.0010	0.1050	−0.0830	0.0400	−1.5180
1999	0.0630	0.1020	0.0780	0.0740	0.1520	0.2260	−1.0740	−1.2160	−0.5220	−0.1480	0.0550	0.0330	−2.1770
2000	−0.0510	0.0630	0.1360	0.1620	0.0450	0.1240	−0.0750	−0.9910	−0.0760	0.1230	0.0220	−0.0210	−0.5390
2001	−0.0150	0.0340	0.1560	0.3010	0.4000	−0.1630	−1.1550	0.0850	0.2210	−0.0700	0.0650	0.0170	−0.1240
2002	−0.1330	0.0900	0.1240	−0.0560	0.2310	0.1580	−0.0640	−1.1380	0.1660	−0.0030	0.0820	−0.0270	−0.5700
2003	0.0290	0.0370	0.1330	−0.1120	0.1470	−0.0320	−0.4390	−1.5260	−0.5440	0.0950	−0.0260	0.0630	−2.1750
2004	0.0530	0.0000	0.2040	0.1320	0.0100	0.0890	−1.0940	−0.2760	−0.3610	0.1990	−0.0060	0.0010	−1.0490
2005	−0.0100	0.0140	0.1720	0.1190	0.2060	−0.1410	−0.5350	−0.7270	−0.2110	0.1170	−0.0260	0.0500	−0.9720
2006	−0.0360	0.0800	0.1450	−0.0750	0.0490	−0.2240	−1.9530	0.1460	0.2320	−0.0550	−0.0760	0.0370	−1.7300
2007	0.0670	0.0980	−0.0590	−0.0100	0.0160	0.2240	−0.1820	−1.4850	−0.5790	0.1130	0.0640	0.0510	−1.6820
2008	0.0530	0.0930	0.0390	0.2060	0.0810	0.0610	−1.1030	−0.6580	0.0290	0.0980	0.0570	0.0340	−1.0100
2009	0.0660	0.0770	0.0350	0.1020	0.1290	−0.3510	−1.0550	−0.7320	0.2350	0.0500	−0.0480	0.0510	−1.4410
2010	0.0320	0.0690	0.0930	0.0840	0.0780	0.2200	−0.2740	−1.0610	−0.9150	0.0750	0.0590	0.0300	−1.5100
2011	0.0480	0.0270	0.1450	−0.1010	0.0270	−0.7210	−2.1890	−0.1090	0.1090	0.1070	−0.1440	0.0250	−2.7760
2012	0.0550	0.0970	0.1010	−0.0580	0.3410	0.1430	−0.2810	−0.5280	−0.1350	−0.0150	−0.0940	−0.0360	−0.4100
2013	−0.0040	−0.0390	0.0960	0.0960	0.1560	0.2060	−1.9900	−0.2090	−0.1920	0.1590	−0.0590	−0.0060	−1.7860
2014	0.0490	0.0420	0.2060	0.2290	0.2860	0.2330	0.0930	−0.1700	−0.0700	0.0190	0.0240	0.0210	0.9620
2015	0.0210	0.0340	0.2020	0.0430	0.3510	0.2840	−0.5640	0.1960	0.2740	0.0010	−0.3270	0.0000	0.5150
2016	0.0710	−0.0680	0.0690	0.0600	0.0460	0.2900	−1.0430	0.2260	0.1390	−0.0610	0.0710	−0.1600	−0.3600
2017	0.0350	0.0700	0.1250	0.1540	0.3640	0.2670	−1.1160	−1.0260	0.1930	0.1110	0.0320	0.0080	−0.7830
MEAN	0.0159	0.0399	0.1006	0.0901	0.1296	0.0155	−0.6737	−0.5714	−0.1468	0.0542	−0.0175	0.0062	−0.9576

Table C.2.2 1966-2017 Evaporation-Precipitation Rate (in/month)
for reservoir Chuncheon

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	0.0490	−0.0150	−0.1500	0.1730	0.2720	−0.4290	−1.9930	−0.2420	−0.7600	−0.0750	−0.0590	0.0410	−3.1880
1967	−0.0360	−0.0240	−0.0630	0.1160	0.2690	0.1540	−0.7200	−0.8100	−0.1120	0.0740	0.0590	0.0320	−1.0610
1968	0.0170	0.0460	0.1190	0.2590	0.2500	0.1550	−0.8260	−0.6810	−0.0270	−0.1450	0.0020	0.0460	−0.7850
1969	−0.0820	−0.0650	0.1150	−0.4360	−0.2510	0.1030	−1.3220	−0.8700	−0.0830	0.1740	0.0560	−0.0050	−2.6660
1970	0.0400	−0.0240	0.1020	0.3230	0.2140	−0.1270	−0.9100	−0.9230	−0.9640	−0.0760	0.0180	−0.0180	−2.3450
1971	0.0250	−0.0010	0.0660	0.2150	0.1160	0.0490	−0.8910	−0.4820	−0.3640	0.1530	0.0700	−0.0480	−1.0920
1972	−0.2290	−0.0070	0.0090	0.1720	0.1800	0.2970	0.0630	−1.9880	−0.1390	0.0070	−0.1240	0.0290	−1.7300
1973	−0.0830	0.1040	0.1560	0.0050	0.0370	0.0170	−0.0190	−0.6470	−0.2250	0.1210	−0.0060	0.0420	−0.4980
1974	0.0300	0.0180	0.0780	−0.0710	−0.3740	0.1940	−0.3310	−0.5180	0.0330	0.0350	0.0480	0.0240	−0.8340
1975	0.0360	0.0640	0.0740	0.0630	0.1820	0.0280	−1.3630	−0.0620	−0.5600	0.0940	0.0260	0.0040	−1.4140
1976	0.0250	−0.1450	0.1570	0.1800	0.2040	0.2350	−0.1000	−1.4280	0.0340	0.0050	0.0070	−0.0230	−0.8490
1977	0.0400	0.1050	0.1480	−0.3110	0.2380	0.2530	−0.3370	−0.1590	0.1150	0.1000	−0.1780	−0.0460	−0.0320
1978	−0.0190	−0.0520	0.0260	0.2340	0.3390	−1.0280	−0.3290	−0.9480	0.0010	0.0390	0.0650	−0.0330	−1.7050
1979	0.0040	−0.0120	−0.0640	−0.2140	0.0190	−0.8110	−0.2170	−0.7560	0.0950	0.1140	0.0620	−0.0430	−1.8230
1980	0.0100	0.1010	0.1580	−0.3070	0.2140	0.1350	−0.6890	−0.3110	0.0150	0.0840	0.0310	−0.0420	−0.6010
1981	−0.0290	0.0630	0.0630	0.1560	0.0130	−0.1440	−1.6210	−0.4600	−0.5310	0.0840	−0.0010	0.0440	−2.3630
1982	0.0060	0.0900	0.0870	0.3130	−0.1280	0.2950	−0.0270	−0.8050	0.2520	0.0660	−0.3580	−0.0280	−0.2370
1983	0.0190	0.0330	0.0050	−0.0990	0.2630	0.3340	−1.1160	−0.0420	−0.2780	−0.0450	0.0540	0.0320	−0.8400
1984	0.0010	0.0400	0.0720	0.1200	0.2510	0.1580	−0.3640	−1.1440	−0.6060	0.1250	−0.0080	−0.0010	−1.3560
1985	−0.0860	0.0260	0.0620	0.0530	−0.0810	0.3230	0.0640	−0.3920	−0.4620	−0.2030	−0.0900	−0.0590	−0.8450
1986	0.0060	0.0700	0.0820	0.2320	0.2160	0.1170	−0.3420	−0.4780	0.0260	−0.0040	−0.0300	−0.0030	−0.1080
1987	−0.0750	−0.0130	0.0900	0.1510	0.1360	0.0880	−0.6200	−1.0550	0.2000	0.1580	−0.0880	0.0650	−0.9630
1988	0.0560	0.0890	0.1140	0.1840	0.2830	0.2730	−1.3950	0.2490	0.1530	0.1760	0.0540	0.0300	0.2660
1989	−0.0950	0.0460	−0.1540	0.3090	0.2860	0.0360	−0.6890	−0.1500	−0.1700	0.0160	−0.3450	0.0460	−0.8640
1990	−0.0440	−0.1690	−0.0290	0.0900	−0.0900	−0.7930	−1.3170	−0.2780	−1.1010	0.1670	−0.0050	0.0040	−3.5650
1991	0.0080	0.0490	0.0830	0.1830	0.1310	0.1600	−1.0240	0.2500	−0.2480	0.1100	0.0200	−0.1380	−0.4160
1992	−0.0140	−0.0490	0.1430	0.1060	0.0870	0.1330	0.0590	−0.4500	−0.1750	0.0380	−0.0780	−0.1700	−0.3700
1993	0.0030	−0.0160	0.1380	0.0770	−0.1060	−0.1470	−0.4410	−0.1440	0.0740	0.1290	−0.0530	−0.0040	−0.4900
1994	0.0100	0.0550	0.1100	0.2140	0.0300	0.0320	0.1000	−0.4390	0.0770	−0.2860	−0.0200	0.0340	−0.0830
1995	0.0060	0.0530	0.0020	0.2150	0.2330	0.2210	−0.8020	−1.6840	−0.0360	0.0990	−0.0230	0.0250	−1.6910
1996	−0.0020	0.0650	−0.0320	0.1060	0.2790	−0.3630	−1.2710	−0.0410	0.2350	−0.0200	−0.0840	−0.0340	−1.1620
1997	−0.0550	−0.0330	0.1300	0.1840	−0.6070	−0.2960	−0.1880	−0.0290	−0.1740	0.0840	−0.2030	−0.1030	−1.2900
1998	0.0260	−0.0400	0.0920	−0.1430	−0.1000	−0.3840	−0.7210	−1.4630	−0.0740	0.0330	−0.1020	0.0350	−2.8410
1999	0.0230	0.0950	0.0160	0.0310	0.0400	0.1480	−1.3930	−1.1370	−0.6690	−0.1810	0.0440	0.0180	−2.9650
2000	−0.0640	0.0340	0.0780	−0.0750	−0.0930	0.1910	0.0700	−0.7750	−0.8330	0.0400	−0.1610	0.0310	−1.5570
2001	−0.0840	−0.2220	0.1490	0.3050	0.4150	−0.3010	−1.8640	0.0760	0.2450	−0.1050	0.0620	0.0300	−1.2940
2002	−0.1010	0.0720	−0.0070	−0.1150	0.1700	0.0260	−0.4470	−1.4910	0.1710	0.0130	0.0620	−0.0800	−1.7270
2003	−0.0670	−0.0470	0.1180	−0.1570	0.0740	−0.1420	−0.7860	−2.1440	−0.6000	0.0880	−0.1130	0.0430	−3.7330
2004	−0.0260	−0.0700	0.1290	0.1360	−0.0180	0.0910	−1.2680	−0.2530	−0.2920	0.2020	−0.0380	0.0120	−1.3950
2005	0.0390	−0.0190	0.1730	0.0740	0.1850	−0.2000	−0.6020	−0.7880	−0.0800	0.1300	−0.0350	0.0520	−1.0710
2006	0.0560	0.1010	0.1140	−0.0200	0.0240	−0.0340	−2.0420	0.0980	0.2530	−0.0130	−0.1040	0.0330	−1.5340
2007	0.0690	0.1060	0.0850	0.1660	0.0840	0.2420	−0.2200	−1.5220	−0.7070	0.1050	0.0520	0.0470	−1.4930
2008	0.0510	0.0920	−0.0070	0.1840	0.0570	−0.0170	−1.8650	−0.5540	0.0940	0.0560	0.0400	0.0390	−1.8300
2009	0.0630	0.0610	0.0320	0.0460	0.1100	−0.0650	−1.3100	−0.9060	0.2300	0.0360	−0.0130	0.0540	−1.6620
2010	0.0470	0.0650	0.0830	0.0590	0.0120	0.0750	−0.5000	−1.2470	−1.0810	0.0710	0.0580	0.0310	−2.3270
2011	0.0430	0.0380	0.1540	−0.0700	0.0010	−0.8280	−2.7100	−0.2680	0.1120	0.1100	−0.2120	0.0250	−3.6050
2012	0.0570	0.1030	0.0550	−0.1840	0.3090	0.0540	−0.5410	−0.8360	−0.2070	−0.0920	−0.1420	0.0150	−1.4090
2013	−0.0240	−0.0610	0.1100	0.0140	0.0370	0.1890	−2.5570	−0.2230	−0.2030	0.1460	−0.0850	0.0000	−2.6570
2014	0.0520	0.0480	0.2030	0.2210	0.2120	0.2330	0.0440	−0.2820	−0.0540	0.0250	0.0010	0.0290	0.7320
2015	0.0270	0.0120	0.2040	−0.0630	0.3130	0.2460	−0.7420	0.1990	0.2790	−0.0120	−0.4040	−0.0190	0.0400
2016	0.0710	−0.0960	0.0570	0.0510	0.0000	0.2940	−1.3110	0.2770	0.1320	−0.0710	0.0820	−0.1830	−0.6970
2017	0.0410	0.0710	0.1230	0.1420	0.3660	0.3070	−1.2220	−1.0060	0.1560	0.1090	0.0200	0.0010	−0.8920
MEAN	−0.0031	0.0161	0.0742	0.0692	0.1020	−0.0043	−0.8262	−0.6185	−0.1699	0.0402	−0.0417	−0.0017	−1.3638

Table C.2.3 1966-2017 Evaporation-Precipitation Rate (in/month)
for reservoir Soyang

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	0.0350	−0.0050	−0.0810	0.1640	0.2340	−0.5850	−2.2540	−0.1710	−0.3670	−0.1130	−0.0690	0.0320	−3.1800
1967	−0.0260	−0.0380	−0.0040	0.1030	0.2280	0.0530	−0.7760	−0.4610	−0.0950	0.1130	−0.0260	0.0410	−0.8880
1968	0.0440	0.0770	0.0310	0.2740	0.2800	0.1310	−0.4850	−0.8150	−0.0360	−0.5460	−0.0190	0.0540	−1.0100
1969	−0.1320	0.0190	0.1250	−0.2900	−0.0600	0.2220	−0.9440	−1.0230	−0.2270	0.1830	0.0560	0.0390	−2.0320
1970	0.0440	0.0160	0.1410	0.3280	0.2360	−0.1000	−0.9590	−0.5580	−1.1030	−0.0550	−0.0430	0.0110	−2.0420
1971	0.0060	−0.0280	0.0330	0.1530	0.0990	−0.1270	−0.5760	−0.5020	−0.0940	0.1460	0.0570	−0.0140	−0.8470
1972	−0.2080	0.0570	0.0570	0.1620	0.2270	0.3970	0.1230	−1.8800	−0.1200	0.0130	−0.1540	0.0160	−1.3100
1973	−0.0420	0.1090	0.1610	0.0510	0.0990	0.0810	0.0560	−0.3570	−0.1580	0.0950	0.0260	0.0460	0.1670
1974	0.0380	0.0370	0.0700	−0.0700	−0.2690	0.2200	−0.3030	−0.4060	0.0150	0.0250	0.0570	0.0310	−0.5550
1975	0.0470	0.0650	0.0700	0.0730	0.1420	0.0800	−1.4120	−0.0090	−0.4060	0.1030	0.0320	0.0170	−1.1980
1976	0.0510	−0.1590	0.1750	0.1720	0.2620	0.2160	−0.0950	−1.2920	0.0890	0.0270	0.0180	−0.0150	−0.5510
1977	0.0520	0.1080	0.1370	−0.3170	0.2170	0.2870	−0.3640	−0.1030	0.1210	0.1010	−0.1620	−0.0670	0.0100
1978	0.0210	−0.0500	−0.0060	0.2310	0.3420	−1.0410	−0.2930	−0.8570	0.0650	0.0190	0.0660	−0.0430	−1.5460
1979	0.0220	0.0260	0.0060	−0.1790	0.0460	−0.8300	−0.1670	−0.6090	0.1030	0.1160	0.0640	−0.0410	−1.4430
1980	0.0220	0.1020	0.1500	−0.3110	0.2040	0.1850	−0.6530	−0.2390	0.0160	0.0830	0.0340	−0.0430	−0.4500
1981	−0.0140	0.0540	0.0730	0.1100	−0.0660	−0.2640	−1.4290	−0.5110	−0.5360	0.0560	−0.0200	0.0370	−2.5100
1982	−0.0170	0.0880	0.0670	0.2890	−0.2730	0.3020	−0.0140	−0.7100	0.2970	0.0850	−0.2870	−0.0650	−0.2380
1983	0.0300	0.0340	0.0150	−0.0440	0.2810	0.3300	−0.9770	−0.0680	−0.2440	−0.0350	0.0360	0.0280	−0.6140
1984	0.0150	0.0500	0.0980	0.0780	0.1940	0.0070	−0.6730	−0.6510	−1.2170	0.1490	0.0010	−0.0160	−1.9650
1985	0.0030	0.0520	0.0690	0.1180	−0.0090	0.3090	0.0080	−0.2910	−0.4820	−0.1920	−0.0230	−0.0020	−0.4400
1986	0.0410	0.0790	0.1390	0.1960	0.2510	0.0590	−0.2060	−0.4940	−0.0810	−0.0770	0.0190	0.0090	−0.0650
1987	0.0100	0.0290	0.1310	0.2030	0.1510	0.0510	−0.7090	−1.1680	0.2130	0.1550	−0.0590	0.0680	−0.9250
1988	0.0740	0.1010	0.1500	0.1730	0.2720	0.1570	−1.1380	0.2090	0.0800	0.1660	0.0420	0.0520	0.3380
1989	−0.0170	0.0560	0.0310	0.3040	0.2740	0.1240	−0.7090	−0.1740	−0.1270	0.0300	−0.2350	0.0560	−0.3870
1990	0.0020	−0.0130	0.0850	0.0520	−0.0970	−0.8350	−1.1730	−0.4680	−1.5380	0.1480	−0.0410	0.0280	−3.8500
1991	0.0330	0.0510	0.1410	0.1280	0.1110	0.2460	−1.2480	0.1710	−0.2190	0.1310	0.0490	−0.0070	−0.4130
1992	0.0370	0.0260	0.1780	0.1540	−0.0220	0.1830	−0.0060	−0.6840	−0.1630	0.0460	−0.0200	−0.0720	−0.3430
1993	0.0250	−0.0460	0.1020	0.0270	−0.2230	−0.1910	−0.5680	−0.3090	0.1590	0.1340	−0.0630	0.0000	−0.9530
1994	0.0040	0.0820	0.1280	0.1960	−0.0180	0.0450	0.0380	−0.2730	0.1260	−0.2700	−0.0420	0.0290	0.0450
1995	0.0510	0.0720	0.0690	0.2050	0.2740	0.2350	−0.8590	−2.3130	0.0620	0.0710	0.0250	0.0480	−2.0600
1996	0.0050	0.0750	−0.0290	0.0920	0.3130	−0.2850	−0.9410	0.1330	0.2210	−0.0060	−0.0370	−0.0260	−0.4850
1997	−0.0050	−0.0170	0.1180	0.1870	−0.6390	−0.1650	−0.3720	0.0350	−0.2380	0.1170	−0.2060	−0.0520	−1.2370
1998	0.0440	0.0000	0.1230	−0.0830	0.0850	−0.1620	−0.6680	−1.4380	−0.0220	0.0760	−0.0580	0.0330	−2.0700
1999	0.0560	0.0990	0.0220	0.0370	0.0850	0.1260	−0.5820	−1.3120	−0.7960	−0.1960	0.0490	0.0310	−2.3810
2000	−0.0180	0.0830	0.1100	0.1690	0.0000	0.0400	−0.2370	−1.0690	−0.1810	0.1130	−0.0120	−0.0010	−1.0030
2001	−0.0050	0.0120	0.1640	0.2910	0.4040	−0.2390	−1.0460	0.1350	0.2550	−0.0730	0.0600	0.0340	−0.0080
2002	−0.0740	0.1030	0.1540	−0.0950	0.1970	0.1620	−0.3060	−1.3030	0.0910	−0.0130	0.0770	−0.0300	−1.0370
2003	−0.0110	−0.0260	0.0950	−0.1610	0.0450	0.0190	−0.5600	−1.4230	−0.7150	0.0700	−0.0920	0.0440	−2.7150
2004	0.0580	−0.0210	0.1940	0.1570	−0.0500	−0.0710	−1.2810	−0.3630	−0.4180	0.2020	−0.0240	0.0110	−1.6060
2005	0.0750	0.0450	0.1400	0.0840	0.1670	−0.0910	−0.4540	−0.6110	−0.3740	0.0770	0.0050	0.0680	−0.8690
2006	−0.0070	0.0780	0.1710	0.0560	0.0200	−0.1920	−2.3380	0.1100	0.2370	−0.0490	−0.0480	0.0350	−1.9270
2007	0.0720	0.0930	−0.0730	0.1640	−0.0170	0.2450	−0.2750	−1.0650	−0.6980	0.1150	0.0450	0.0500	−1.3440
2008	0.0470	0.0900	0.0530	0.1970	0.0670	−0.0140	−1.2090	−0.4790	0.0310	0.1100	0.0700	0.0030	−1.0340
2009	0.0720	0.0540	0.0240	0.0930	0.0850	−0.1640	−1.4090	−0.6830	0.2240	0.0640	−0.0590	0.0360	−1.6630
2010	−0.0010	0.0210	0.0170	0.0460	0.0290	0.2810	−0.3010	−0.9900	−1.0680	0.0740	0.0560	0.0220	−1.8140
2011	0.0560	−0.0080	0.1290	−0.1610	−0.0580	−0.9710	−2.3790	−0.1450	0.0580	0.1020	−0.1150	0.0120	−3.4800
2012	0.0580	0.1040	0.0660	−0.1130	0.3120	0.0970	−0.4330	−0.6440	−0.1760	−0.0090	−0.0870	−0.0430	−0.8680
2013	−0.0090	−0.0680	0.0810	0.0660	0.1350	0.1630	−2.0060	−0.1430	−0.2260	0.1670	−0.0590	−0.0140	−1.9130
2014	0.0510	0.0460	0.1880	0.2070	0.2950	0.1510	0.0470	−0.2540	−0.0690	0.0020	0.0340	0.0400	0.7380
2015	0.0270	0.0300	0.2000	0.0000	0.3510	0.2220	−0.4700	0.1120	0.2290	0.0010	−0.3410	0.0040	0.3650
2016	0.0810	−0.0650	0.0610	0.0310	0.0520	0.2510	−1.3770	0.2030	0.0890	−0.1040	0.0620	−0.1840	−0.9000
2017	0.0470	0.0640	0.1120	0.1590	0.3700	0.2670	−1.0010	−0.8970	0.2010	0.0370	0.0480	0.0010	−0.5920
MEAN	0.0167	0.0354	0.0896	0.0799	0.1084	−0.0074	−0.7377	−0.5598	−0.1772	0.0343	−0.0252	0.0064	−1.1365

Table C.2.4 1966-2017 Evaporation-Precipitation Rate (in/month)
for reservoir Uiam

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	0.0270	−0.0200	−0.1190	0.1510	0.2390	−0.5270	−2.3570	−0.2940	−0.4200	−0.1300	−0.1260	0.0320	−3.5440
1967	−0.0560	−0.0850	−0.0870	0.0640	0.2710	0.1450	−0.8980	−0.4560	−0.1130	0.1010	0.0700	0.0640	−0.9800
1968	0.0420	0.0600	0.0430	0.2580	0.2790	0.1670	−0.6110	−0.7630	−0.0740	−0.2140	−0.0370	0.0430	−0.8070
1969	−0.0920	−0.0430	0.1550	−0.4550	−0.2050	0.2030	−0.8540	−0.5600	−0.0900	0.1550	0.0180	0.0150	−1.7530
1970	0.0340	−0.0970	0.1260	0.3250	0.2080	−0.1370	−1.1480	−0.6740	−1.2390	−0.1450	−0.0620	−0.0300	−2.8390
1971	0.0080	−0.0170	0.0330	0.1850	0.0840	−0.1400	−0.9830	−0.4140	−0.3350	0.0980	0.0420	−0.0540	−1.4930
1972	−0.2100	0.0070	−0.0440	0.1300	0.1640	0.3450	−0.0400	−2.2510	−0.1350	−0.0190	−0.2140	0.0220	−2.2450
1973	−0.0650	0.1090	0.1520	0.0330	0.0760	−0.0290	0.0030	−0.4400	−0.2130	0.1000	0.0310	0.0510	−0.1920
1974	0.0360	0.0320	0.0780	−0.0790	−0.3060	0.1890	−0.3240	−0.4270	0.0310	0.0290	0.0500	0.0240	−0.6670
1975	0.0450	0.0620	0.0500	0.0680	0.2170	0.1180	−1.4240	−0.0780	−0.6250	0.1070	0.0250	0.0020	−1.4330
1976	0.0510	−0.2060	0.1740	0.1750	0.2140	0.2380	−0.1160	−1.2240	0.0510	0.0090	0.0150	−0.0250	−0.6440
1977	0.0500	0.1100	0.1280	−0.3280	0.2170	0.2780	−0.3460	−0.1420	0.1280	0.0770	−0.1950	−0.0620	−0.0850
1978	0.0190	−0.0580	−0.0100	0.2270	0.3250	−1.0780	−0.2310	−0.9610	0.0280	0.0370	0.0640	−0.0320	−1.6700
1979	0.0070	0.0060	−0.0020	−0.2120	0.0240	−0.8910	−0.1910	−0.6480	0.0940	0.0810	0.0580	−0.0630	−1.7370
1980	0.0170	0.1010	0.1530	−0.3410	0.1950	0.1840	−0.7120	−0.3380	−0.0040	0.0790	0.0370	−0.0350	−0.6640
1981	−0.0240	0.0480	0.0690	0.1370	−0.0810	−0.2600	−1.5540	−0.4480	−0.6010	0.0490	−0.0140	0.0350	−2.6440
1982	−0.0210	0.0860	0.0640	0.3060	−0.2710	0.3520	−0.0050	−0.6650	0.2960	0.0730	−0.3000	−0.0620	−0.1470
1983	0.0270	0.0420	0.0070	−0.0690	0.2660	0.3440	−1.1020	−0.1070	−0.3460	−0.0720	0.0380	0.0270	−0.9450
1984	0.0170	0.0800	0.1440	0.2580	0.2310	0.1120	−0.5230	−1.1680	−0.6560	0.1480	0.0360	−0.0690	−1.3900
1985	−0.0260	0.0910	0.0560	0.0930	−0.1190	0.3390	−0.1410	−0.3960	−0.6690	−0.2010	−0.0270	−0.0490	−1.0490
1986	0.0510	0.0830	0.0460	0.2200	0.2470	0.0320	−0.3950	−0.3760	−0.0850	−0.0560	−0.0020	−0.0420	−0.2770
1987	0.0040	0.0120	0.0920	0.1580	0.1100	0.3830	−0.9160	−1.4670	0.1700	0.1780	−0.0550	0.0670	−1.2640
1988	0.0720	0.1070	0.1170	0.1900	0.2660	0.1920	−1.8100	0.2530	0.1420	0.1850	0.0630	0.0600	−0.1630
1989	−0.0340	0.0290	−0.1270	0.2750	0.2910	0.0970	−0.7800	−0.1660	−0.0340	0.0960	−0.3040	0.0460	−0.6110
1990	0.0100	−0.1490	−0.0510	0.0620	−0.1700	−0.8920	−1.4920	−0.5020	−1.1760	0.1520	−0.0250	0.0330	−4.2000
1991	−0.0130	0.0520	0.1160	0.2060	0.1910	0.1080	−1.3380	0.2390	−0.3300	0.1210	0.0090	−0.0490	−0.6880
1992	0.0110	−0.0680	0.1580	0.1060	0.2560	0.1770	−0.0180	−0.3060	−0.1670	0.0610	−0.1030	−0.0700	0.0370
1993	0.0380	−0.0180	0.1050	0.0870	−0.1320	−0.1090	−0.5860	−0.3040	0.1790	0.1430	−0.0430	−0.0190	−0.6590
1994	0.0350	0.0580	0.1430	0.2150	−0.0370	0.1640	0.2230	−0.4430	0.0580	−0.2590	−0.0220	0.0540	0.1890
1995	0.0310	0.0760	0.0500	0.2770	0.2410	0.2500	−1.2050	−2.2890	−0.0450	0.0830	−0.0530	0.0490	−2.5350
1996	0.0480	0.0790	0.0010	0.1590	0.2660	−0.6600	−1.1490	0.1530	0.2280	0.0190	0.0260	0.0210	−0.8090
1997	0.0270	0.0230	0.1660	0.1950	−0.6370	−0.0050	−0.3690	−0.0740	−0.1550	0.1330	−0.1410	−0.0320	−0.8690
1998	0.0630	0.0150	0.0240	−0.1130	0.0620	−0.3490	−0.7070	−1.8400	0.0160	0.0540	−0.0860	0.0500	−2.8110
1999	0.0680	0.1020	0.1300	0.0700	0.0650	0.1400	−0.8830	−0.8740	−0.7920	−0.1440	0.0420	0.0160	−2.0600
2000	−0.0180	0.0860	0.1390	0.2070	0.0740	0.0960	−0.1340	−1.2100	−0.0750	0.1190	0.0300	0.0270	−0.6590
2001	−0.0300	−0.0260	0.1700	0.3050	0.4090	−0.1270	−1.3710	−0.0850	0.2580	−0.0320	0.0680	0.0400	−0.4210
2002	−0.0430	0.0890	0.1850	−0.0650	0.2300	0.1920	−0.1970	−0.9340	0.1560	−0.0250	0.0740	0.0170	−0.3210
2003	0.0170	−0.0110	0.1180	−0.1360	0.0650	−0.0040	−0.6590	−1.6130	−0.6430	0.0800	−0.0390	0.0660	−2.7590
2004	0.0420	−0.0230	0.1850	0.1850	−0.0450	0.0750	−1.2270	−0.1680	−0.1600	0.1990	−0.0010	0.0130	−0.9250
2005	0.0700	0.0300	0.1930	0.0800	0.2030	−0.1290	−0.5880	−0.6960	−0.3390	0.0850	−0.0320	0.0370	−1.0860
2006	−0.0220	0.0780	0.1790	0.0750	0.0760	−0.0470	−2.5740	0.0210	0.2450	−0.0470	−0.0480	0.0290	−2.0350
2007	0.0590	0.0620	−0.1900	0.1170	−0.0750	0.2370	−0.3680	−1.0500	−0.6320	0.0830	0.0150	0.0280	−1.7140
2008	0.0350	0.0810	−0.0240	0.1790	0.0270	−0.1570	−1.6070	−0.5600	0.0290	0.0800	0.0420	−0.0150	−1.8900
2009	0.0550	−0.0040	0.0260	0.0980	0.1110	−0.0930	−1.6190	−0.5000	0.2150	0.1040	−0.0470	0.0360	−1.6180
2010	−0.0310	0.0040	−0.0140	0.0710	0.0470	0.2490	−0.3610	−1.1380	−1.1960	0.0810	0.0550	0.0420	−2.1910
2011	0.0440	0.0590	0.1630	−0.0680	−0.0180	−1.0380	−2.7940	−0.2290	0.0940	0.0950	−0.1410	0.0250	−3.8080
2012	0.0600	0.0900	0.0640	−0.1370	0.2550	0.0800	−0.4670	−0.7620	−0.1410	−0.0670	−0.1030	−0.0160	−1.1440
2013	−0.0290	−0.0970	0.1070	0.0640	−0.0680	0.1980	−2.3110	−0.2360	−0.2360	0.1710	−0.0800	0.0080	−2.5090
2014	0.0490	0.0520	0.2050	0.2270	0.2510	0.2960	0.0450	−0.2160	0.0110	−0.0060	0.0110	0.0170	0.9420
2015	0.0200	0.0290	0.1950	−0.1430	0.3270	0.3080	−0.3150	0.2840	0.3000	−0.0040	−0.3420	−0.0190	0.6400
2016	0.0660	−0.0580	0.0580	0.0440	0.0680	0.2140	−1.4620	0.2390	0.1030	−0.1030	0.0640	−0.1510	−0.9180
2017	0.0350	0.0660	0.1400	0.1650	0.3870	0.2970	−1.2580	−0.8180	0.1660	0.0380	0.0240	−0.0130	−0.7710
MEAN	0.0130	0.0234	0.0777	0.0827	0.1033	0.0024	−0.8509	−0.5792	−0.1678	0.0381	−0.0314	0.0036	−1.2853

Table C.2.5 1966-2017 Evaporation-Precipitation Rate (in/month)
for reservoir Cheongpyeong

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1966	0.0480	−0.0030	−0.1110	0.0450	0.1180	−0.6230	−2.8950	−0.2830	−0.5870	−0.2710	−0.1210	0.0350	−4.6480
1967	−0.0060	−0.1000	−0.1660	−0.0440	0.1760	0.0210	−1.2820	−1.3850	−0.2580	0.0560	−0.0930	0.0240	−3.0570
1968	0.0480	0.0400	−0.0690	0.1230	0.1160	0.0400	−1.0710	−1.1130	−0.1690	−0.1430	−0.1210	0.0170	−2.3020
1969	−0.1440	−0.0960	0.1170	−0.5940	−0.4150	0.0810	−0.9320	−0.4900	−0.2980	0.1020	−0.0360	−0.0230	−2.7280
1970	0.0060	−0.0690	0.0690	0.2370	−0.0170	−0.3520	−1.6220	−1.0390	−1.4680	−0.2970	−0.0260	−0.0190	−4.5970
1971	−0.0110	−0.0410	0.0130	0.0800	−0.0630	−0.1740	−1.1030	−0.4620	−0.5180	0.0330	−0.0020	−0.0630	−2.3110
1972	−0.2100	−0.0480	−0.1390	0.0680	−0.0310	0.2400	−0.4790	−2.6370	−0.3430	−0.1800	−0.2140	0.0210	−3.9520
1973	−0.0620	0.0720	0.1290	−0.1900	0.1260	−0.0660	−0.2180	−0.1550	−0.3220	−0.0080	0.0140	0.0290	−0.6510
1974	0.0290	0.0310	0.0590	−0.1920	−0.3950	0.1670	−0.3640	−0.3940	−0.1010	−0.0040	0.0190	−0.0340	−1.1790
1975	0.0220	0.0700	0.0060	−0.0330	0.0380	0.1350	−1.5170	−0.0170	−0.3200	0.0960	−0.0080	0.0140	−1.5140
1976	0.0510	−0.0790	0.1330	0.0360	0.0870	0.1600	−0.0650	−1.3830	0.0940	−0.0190	−0.0490	−0.0120	−1.0460
1977	0.0420	0.0530	0.0690	−0.4260	0.0750	0.1130	−0.9340	−0.2070	−0.0710	0.0930	−0.1640	−0.0160	−1.3730
1978	0.0190	0.0060	−0.0080	0.1740	0.2100	−1.3310	−0.7390	−1.0400	−0.0550	0.0070	0.0460	−0.0580	−2.7690
1979	0.0370	0.0280	−0.0110	−0.2830	−0.0720	−0.9330	−0.3840	−0.6390	−0.0060	0.1100	0.0390	−0.0210	−2.1350
1980	−0.0300	0.0700	0.0530	−0.4900	−0.0100	−0.0290	−0.5720	−0.4850	−0.0060	−0.0100	0.0210	−0.0110	−1.4990
1981	−0.0120	0.0500	−0.0240	0.0680	0.0150	0.0080	−1.6790	−0.8540	−0.1630	0.0250	−0.0260	0.0110	−2.5810
1982	−0.0430	0.0640	−0.0100	0.2000	−0.3400	0.1240	−0.3590	−0.9510	0.1820	0.0070	−0.3840	−0.1040	−1.6140
1983	0.0200	0.0320	−0.0480	−0.1520	0.1370	0.1050	−1.0760	−0.0620	−0.2650	−0.0500	−0.0230	0.0240	−1.3580
1984	0.0390	0.0690	0.1270	0.0990	0.1760	−0.1250	−0.7450	−1.1020	−0.6080	0.0660	−0.0710	−0.0280	−2.1030
1985	−0.0320	0.0230	0.1290	−0.0630	−0.3860	0.2680	−0.4770	−0.6410	−0.7240	−0.3720	−0.1190	0.0390	−2.3550
1986	0.0170	0.0610	0.1110	0.1290	0.1650	−0.0950	−0.8990	−0.7850	−0.1360	−0.1180	−0.4380	−0.0230	−2.0110
1987	−0.2470	−0.1410	0.0080	0.0600	0.1680	0.0930	−1.5930	−2.0040	−0.0030	0.0740	−0.1050	0.0540	−3.6360
1988	0.0590	0.0800	−0.0070	0.0720	0.1310	0.0460	−1.3160	0.1340	0.0930	0.1240	0.0260	0.0110	−0.5470
1989	−0.0110	−0.0350	−0.0210	0.2160	0.1440	−0.1520	−1.4410	−0.1410	−0.3400	0.0290	−0.4680	0.0370	−2.1830
1990	0.0300	−0.0670	0.0550	−0.0410	−0.0230	−0.2290	−0.9390	−0.3890	−1.1670	0.1390	−0.0820	0.0480	−2.6650
1991	−0.0370	−0.0120	−0.0210	0.1230	0.0780	0.0620	−1.1570	0.1520	−0.2520	0.0930	0.0300	0.0270	−0.9140
1992	0.0000	−0.1750	0.0850	0.0710	0.1520	0.0490	−0.0800	−0.7650	−0.3080	−0.0670	−0.0160	0.0320	−1.0220
1993	0.0390	0.0380	0.1150	−0.0950	−0.2320	−0.3160	−0.9940	−0.4650	0.0840	0.0890	−0.0090	−0.0170	−1.7630
1994	−0.0070	−0.0540	0.0430	0.1420	−0.1630	−0.2470	−0.1030	−0.6680	−0.0150	−0.5160	−0.0780	0.0420	−1.6240
1995	−0.0320	0.0310	0.0860	0.1120	0.1190	0.1880	−1.0180	−2.3120	−0.0310	0.0320	−0.0480	0.0230	−2.8500
1996	−0.0160	0.0570	0.1060	0.0980	0.2050	−0.5330	−1.3790	−0.1470	0.1480	−0.1440	−0.1000	0.0450	−1.6600
1997	−0.0090	0.0280	0.1090	0.1030	−0.6880	−0.4080	−0.3770	−0.2170	−0.1160	−0.0380	0.0070	−0.0270	−1.6330
1998	0.0150	0.0000	0.0580	−0.0850	−0.0060	−0.4990	−1.0460	−2.4880	−0.2190	0.0460	−0.0210	0.0400	−4.2050
1999	−0.0020	0.0760	0.0770	0.0080	−0.0550	−0.0060	−1.2700	−0.8270	−0.8590	−0.1590	0.0150	−0.0640	−3.0660
2000	−0.1080	0.0360	0.1270	0.1060	−0.0190	0.0060	−0.2070	−1.3230	−0.3250	0.0570	−0.0110	−0.0210	−1.6820
2001	−0.1270	0.0050	0.1310	0.2120	0.2700	−0.3620	−1.7720	−0.2090	0.1320	−0.0900	0.0490	−0.0010	−1.7620
2002	−0.0270	0.0860	0.0940	0.1530	0.2050	0.1320	−0.4130	−1.2130	0.1760	−0.0190	0.0710	0.0170	−0.7380
2003	−0.0790	0.0480	0.1600	−0.0680	0.1280	−0.0790	−1.0470	−1.4880	−0.8080	0.0450	−0.0970	0.0540	−3.2310
2004	−0.0260	−0.0200	0.0850	0.0850	−0.1290	−0.0660	−1.7380	−0.1630	−0.3250	0.1920	−0.0960	0.0020	−2.1990
2005	0.0800	0.1040	0.2100	0.0510	0.1830	−0.2250	−0.7960	−1.7310	−0.6440	0.0450	−0.0030	0.0680	−2.6580
2006	0.0700	0.1100	0.2180	0.1910	0.0210	−0.2080	−2.9060	0.1550	0.2580	0.0520	−0.1100	0.0280	−2.1210
2007	0.0640	0.1140	0.0250	0.1120	−0.1730	0.2190	−0.6060	−1.0620	−0.6470	0.0600	0.0400	0.0500	−1.8040
2008	0.0700	0.1100	0.1440	0.2040	0.0360	−0.2330	−1.7230	−0.7190	0.0040	0.0820	0.0420	0.0610	−1.9220
2009	0.0730	0.0910	0.1680	0.1010	0.0860	−0.1500	−2.1730	−0.5700	0.1600	0.0210	−0.0850	0.0650	−2.2130
2010	0.0550	0.0890	0.1080	−0.0140	−0.1280	−0.1100	−0.6540	−1.2630	−1.7530	0.0700	0.0910	0.0550	−3.4540
2011	0.0440	0.0840	0.1780	−0.0770	0.2050	−1.0370	−2.8500	−0.2080	0.1900	0.1110	−0.1310	0.0310	−3.4600
2012	0.0490	0.0960	0.0120	−0.2810	0.3960	0.0940	−0.8050	−1.2390	−0.2410	−0.0890	−0.1190	−0.0720	−2.1990
2013	−0.0430	−0.1660	0.1060	0.0120	−0.0150	0.2960	−2.3600	−0.1540	−0.2280	0.2150	−0.0930	0.0170	−2.4130
2014	0.0470	0.0640	0.2200	0.2500	0.2460	0.2970	−0.0550	−0.2260	0.0800	0.0400	0.0350	0.0100	1.0080
2015	0.0380	0.0300	0.1810	−0.2500	0.2880	0.2380	−0.5760	0.2750	0.3460	0.0240	−0.2760	−0.0010	0.3170
2016	0.0700	−0.0590	0.1240	0.0910	0.0720	0.3660	−1.0800	0.2910	0.2300	−0.0320	0.0810	−0.1150	0.0390
2017	0.0680	0.0390	0.1950	0.1060	0.4640	0.3760	−1.2630	−0.6240	0.2840	0.1100	−0.0070	−0.0410	−0.2930
MEAN	−0.0014	0.0177	0.0694	0.0108	0.0322	−0.0897	−1.0606	−0.7256	−0.2353	−0.0054	−0.0620	0.0050	−2.0449

APPENDIX D

GROUNDWATER LEVELS & DROUGHT MONITOR IN 2017

D.1 Plots of Groundwater Levels for 256 Monitoring Stations

Shallow Wells (138 EA)

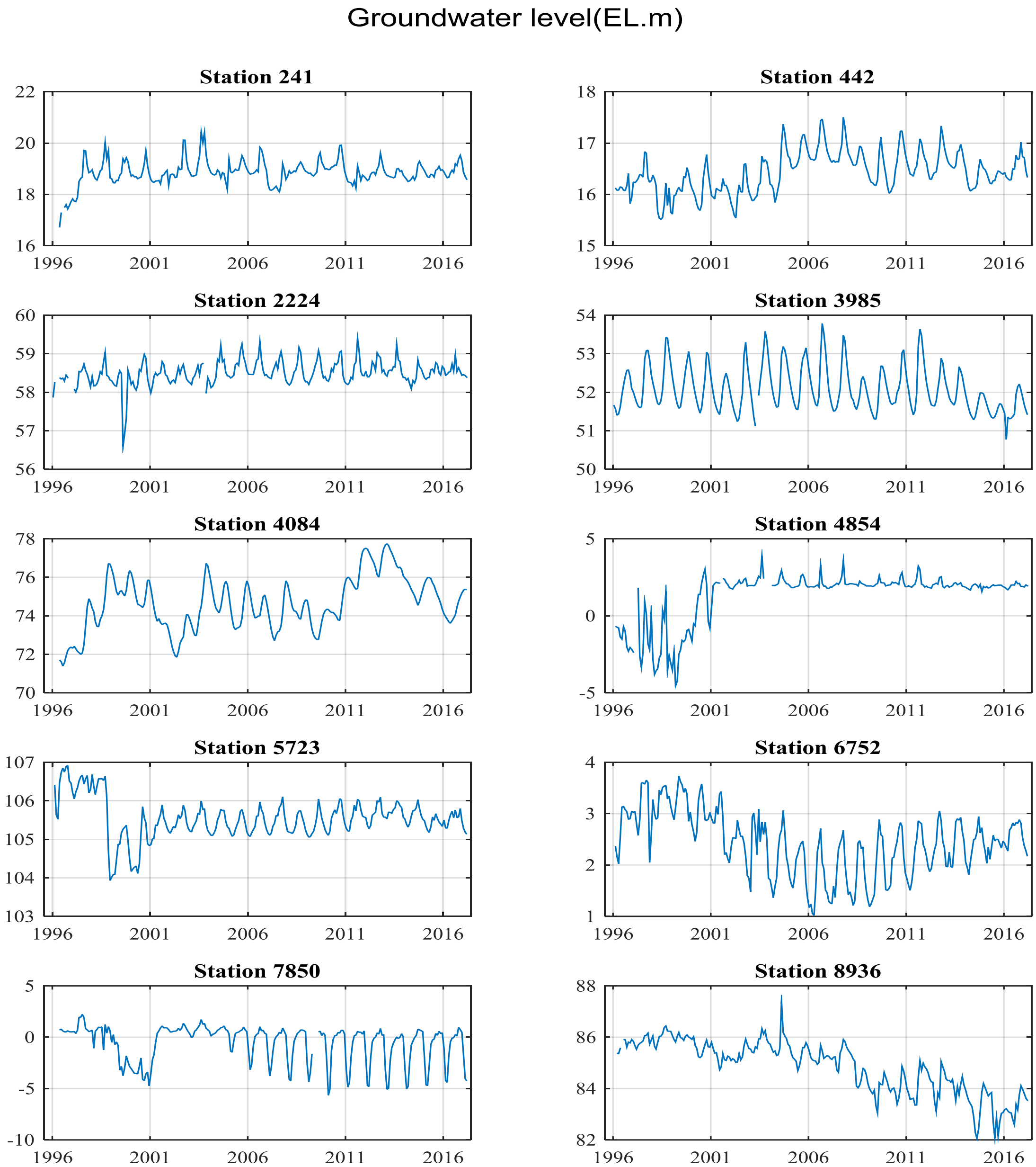


Figure D.1.1 Plots of Groundwater Levels for Station No. 241 – 8936 (Shallow Wells)

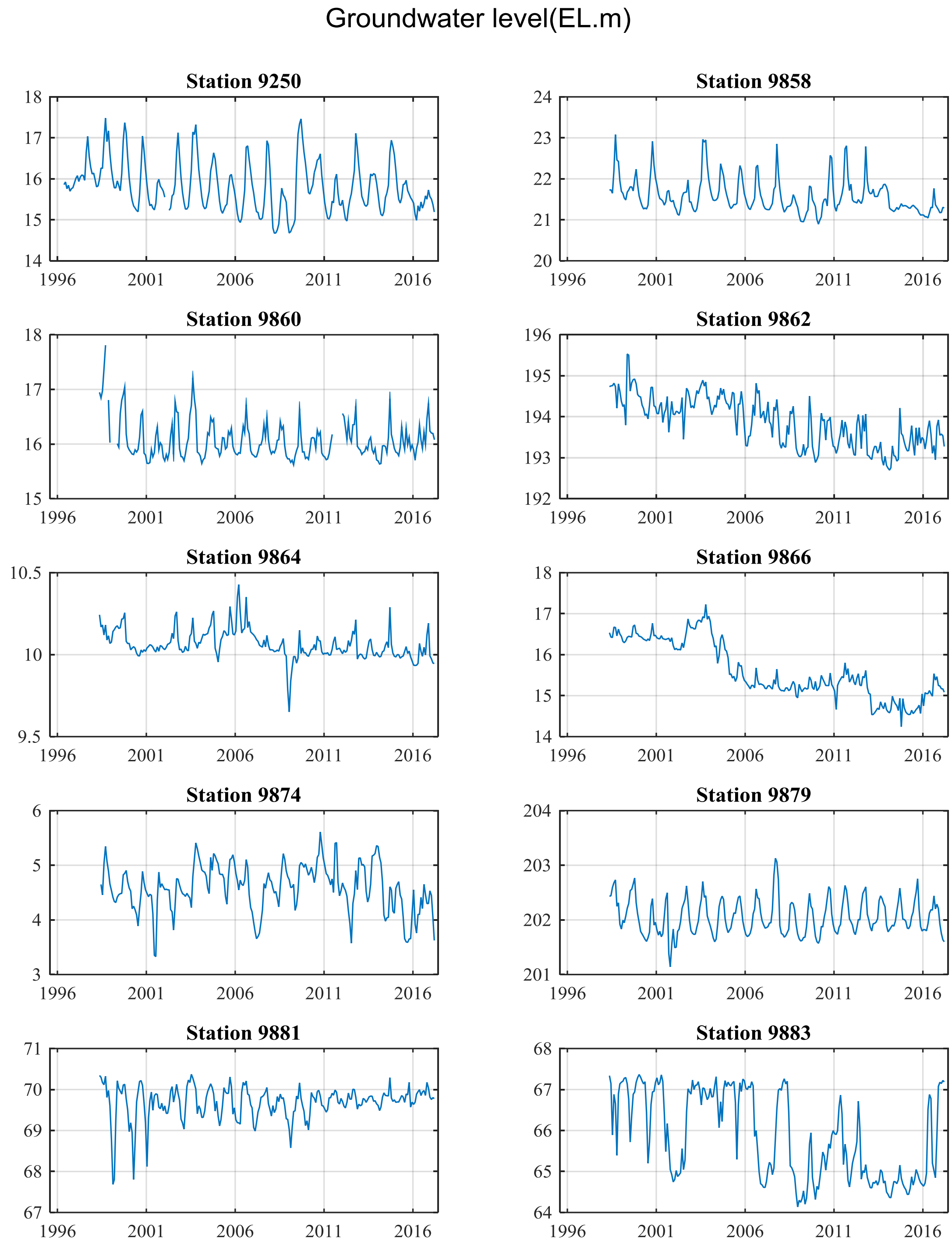


Figure D.1.2 Plots of Groundwater Levels for Station No. 9250 – 9883 (Shallow Wells)

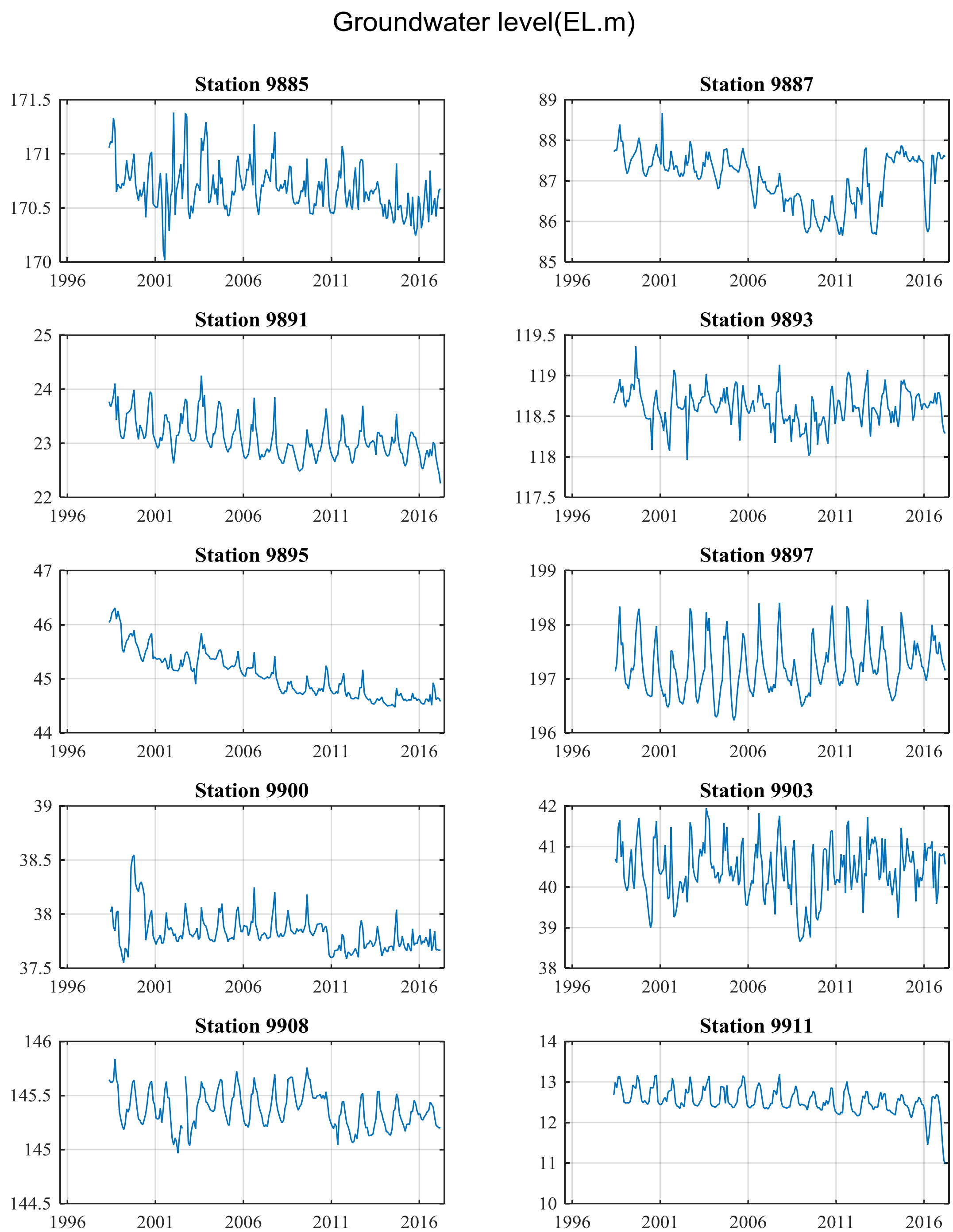


Figure D.1.3 Plots of Groundwater Levels for Station No. 9885 – 9911 (Shallow Wells)

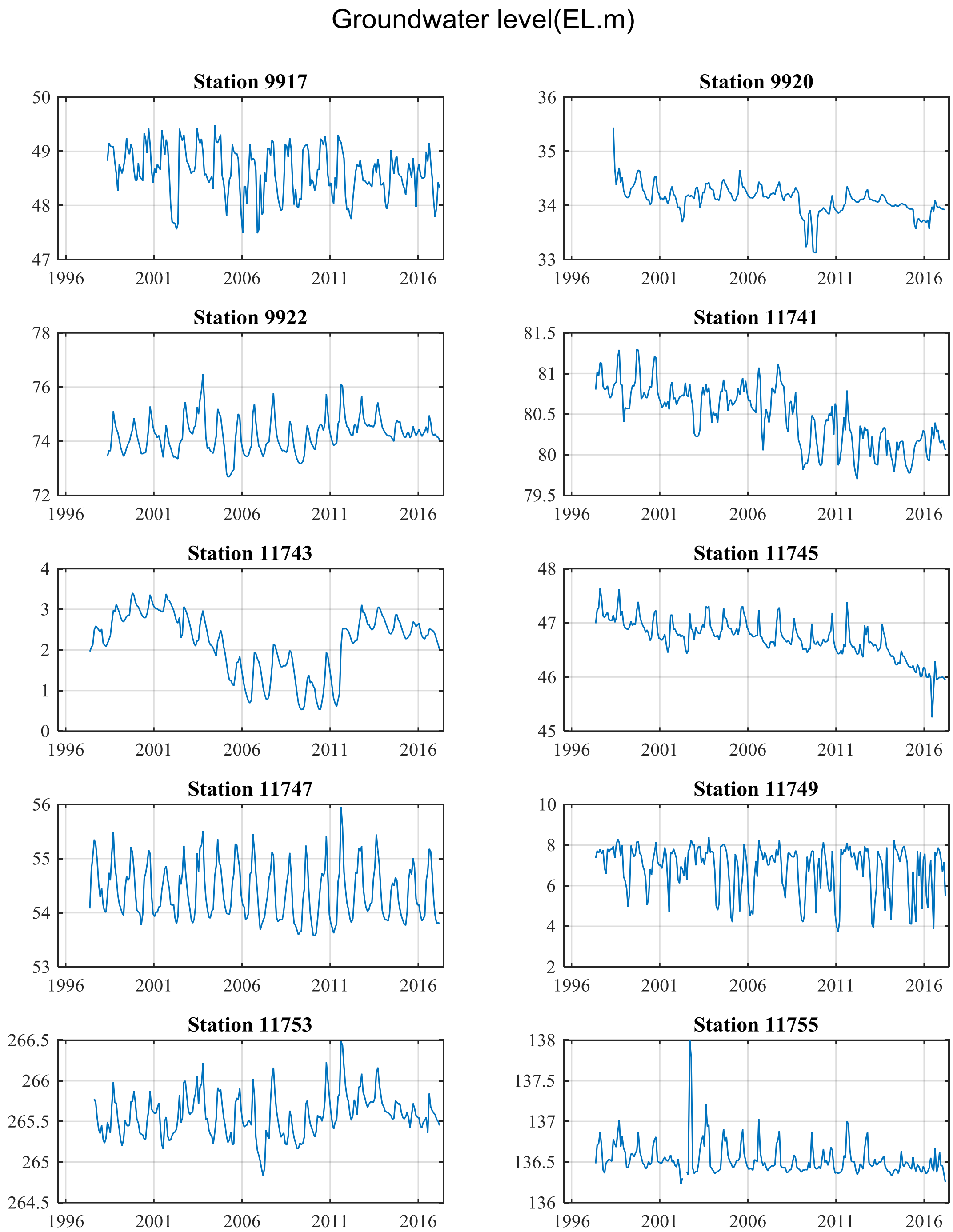


Figure D.1.4 Plots of Groundwater Levels for Station No. 9917 – 11755 (Shallow Wells)

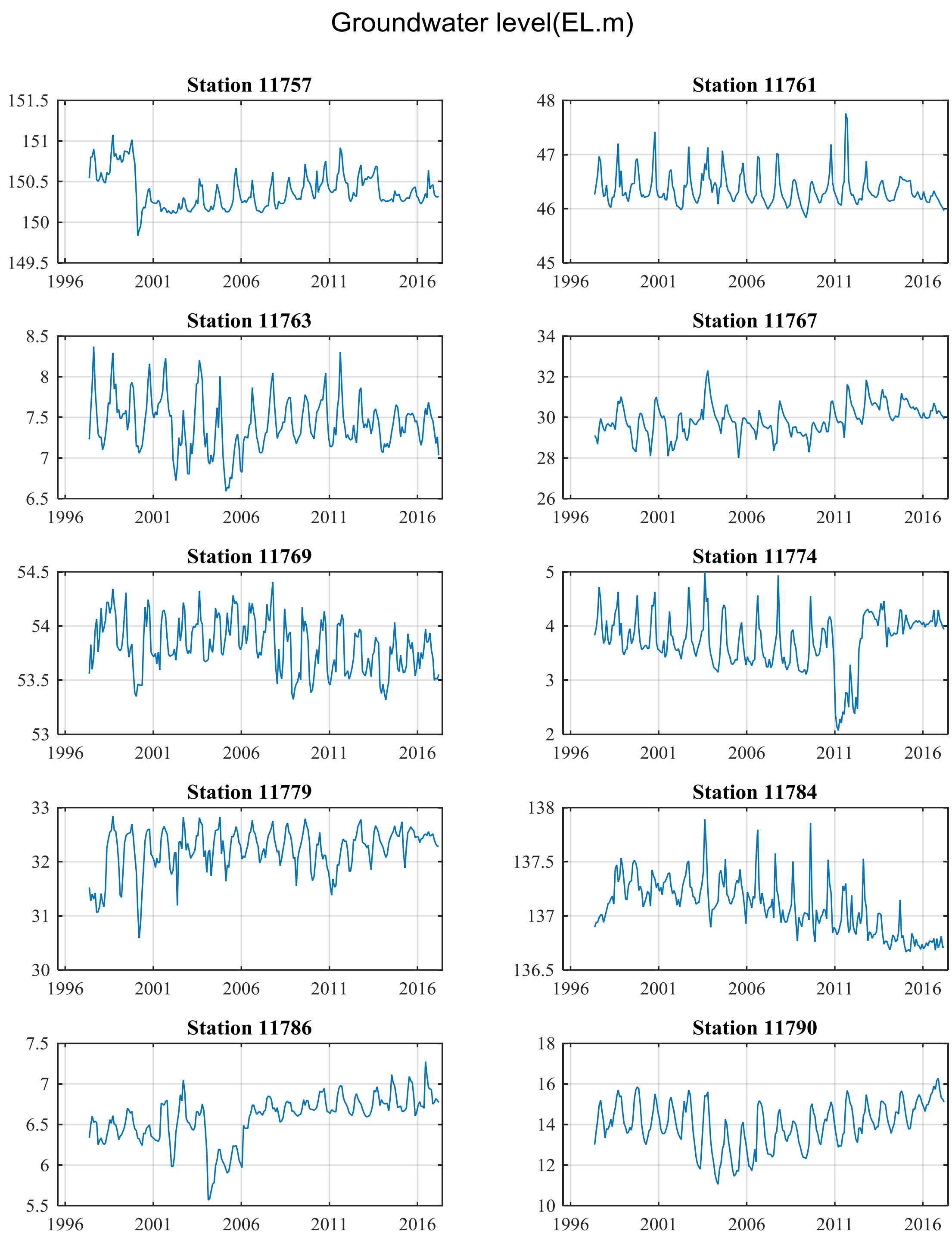


Figure D.1.5 Plots of Groundwater Levels for Station No. 11757 – 11790 (Shallow wells)

Groundwater level(EL.m)

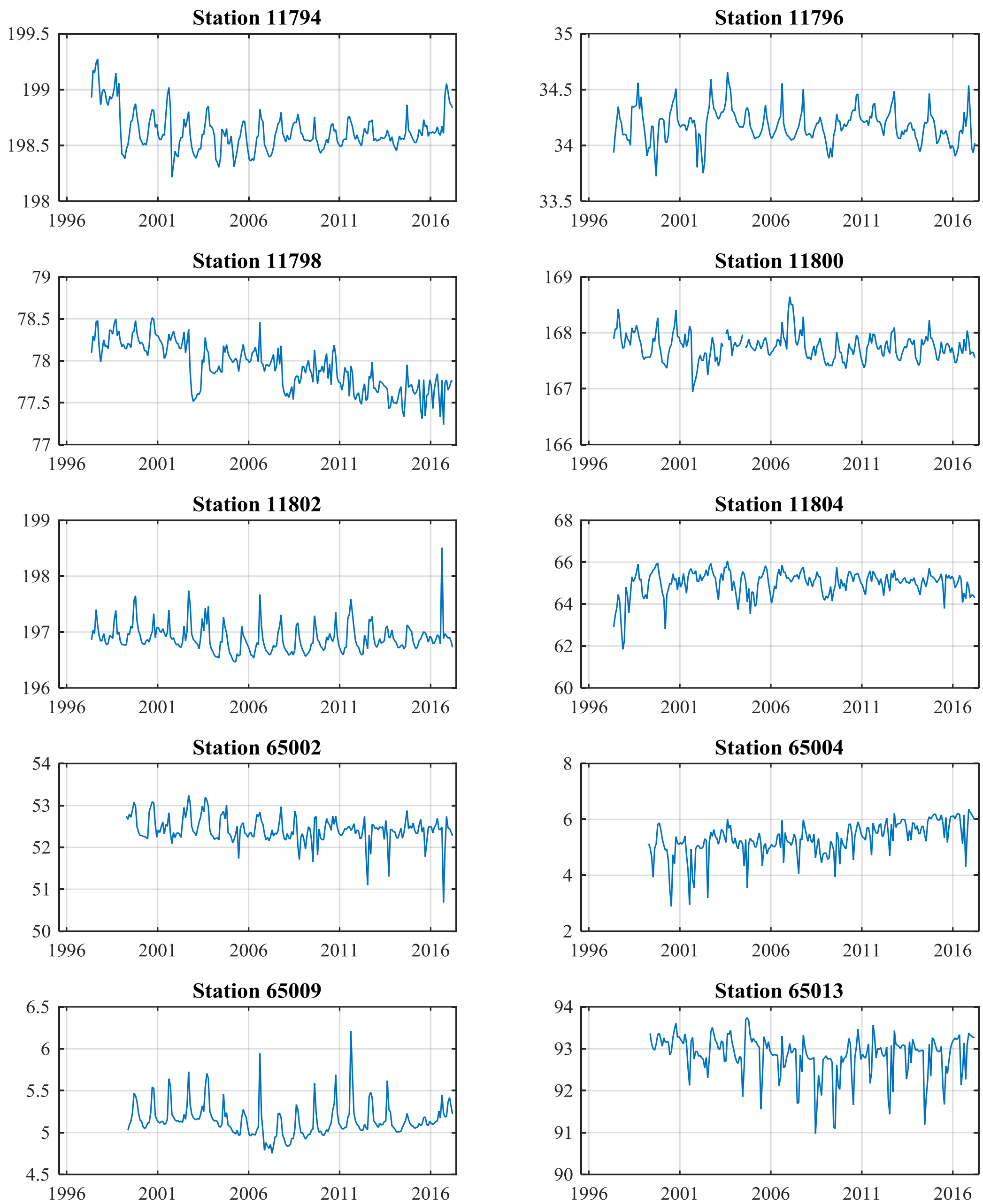


Figure D.1.6 Plots of Groundwater Levels for Station No. 11794 – 65013 (Shallow wells)

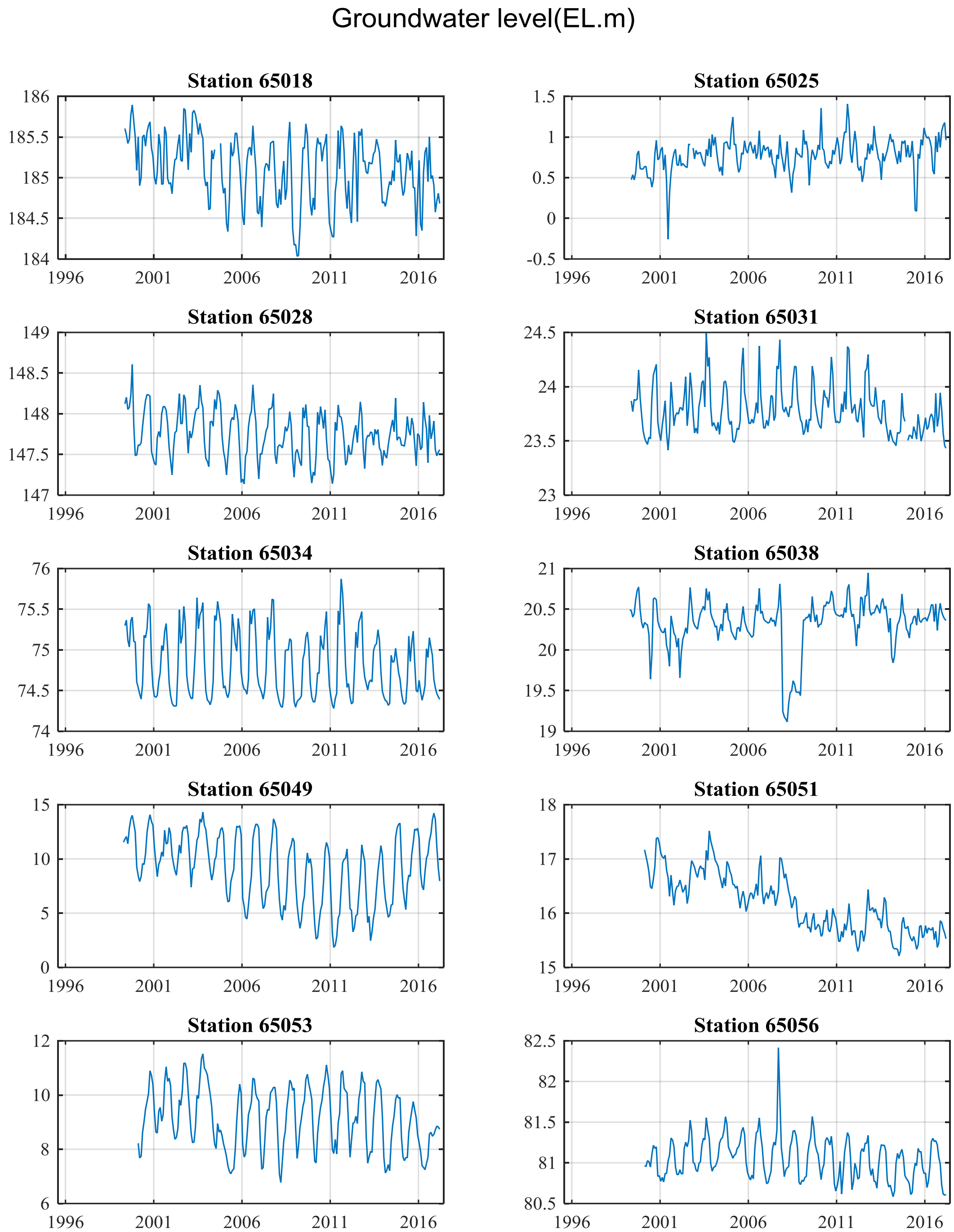


Figure D.1.7 Plots of Groundwater Levels for Station No. 65018 – 65056 (Shallow wells)

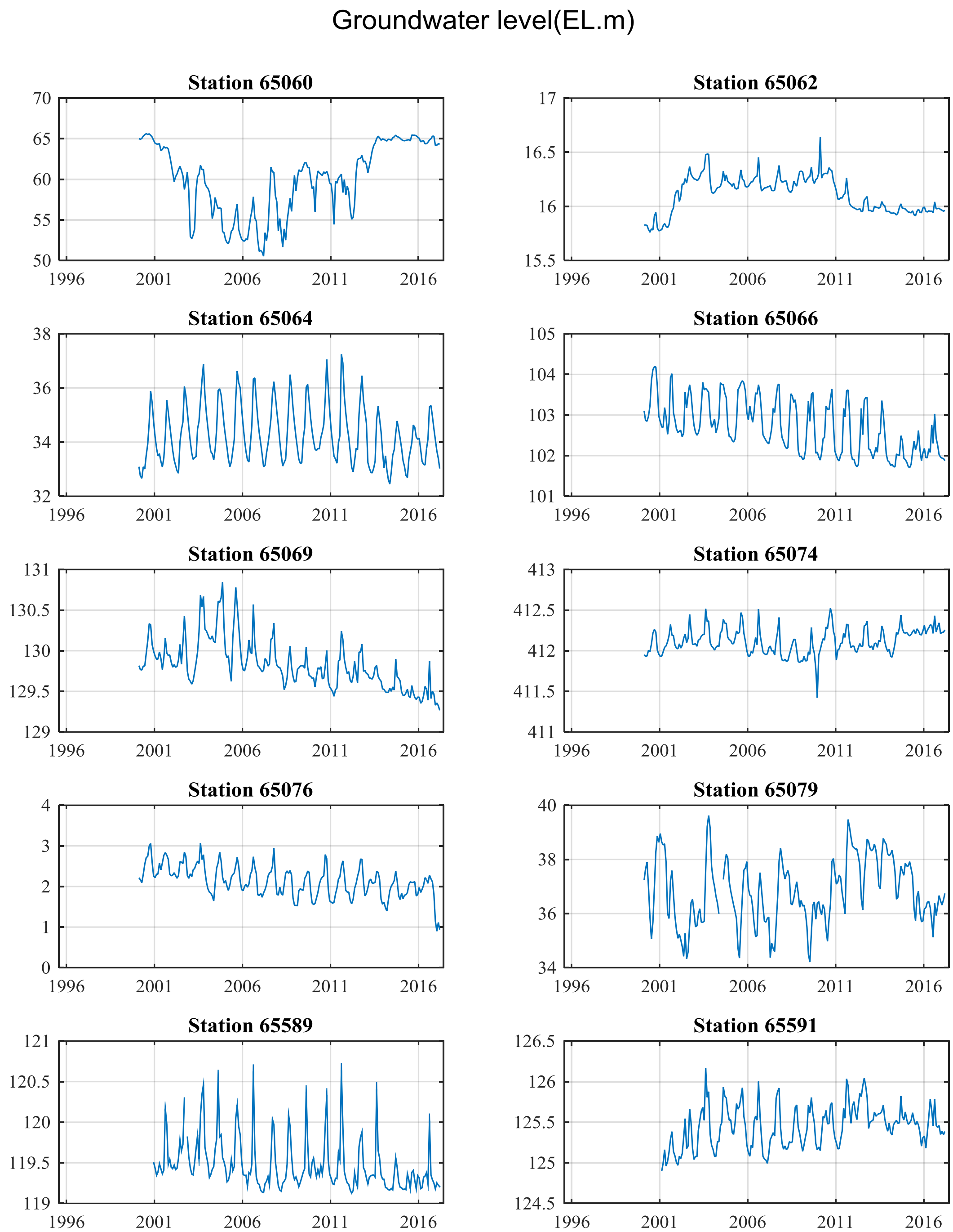


Figure D.1.8 Plots of Groundwater Levels for Station No. 65060 – 65591 (Shallow wells)

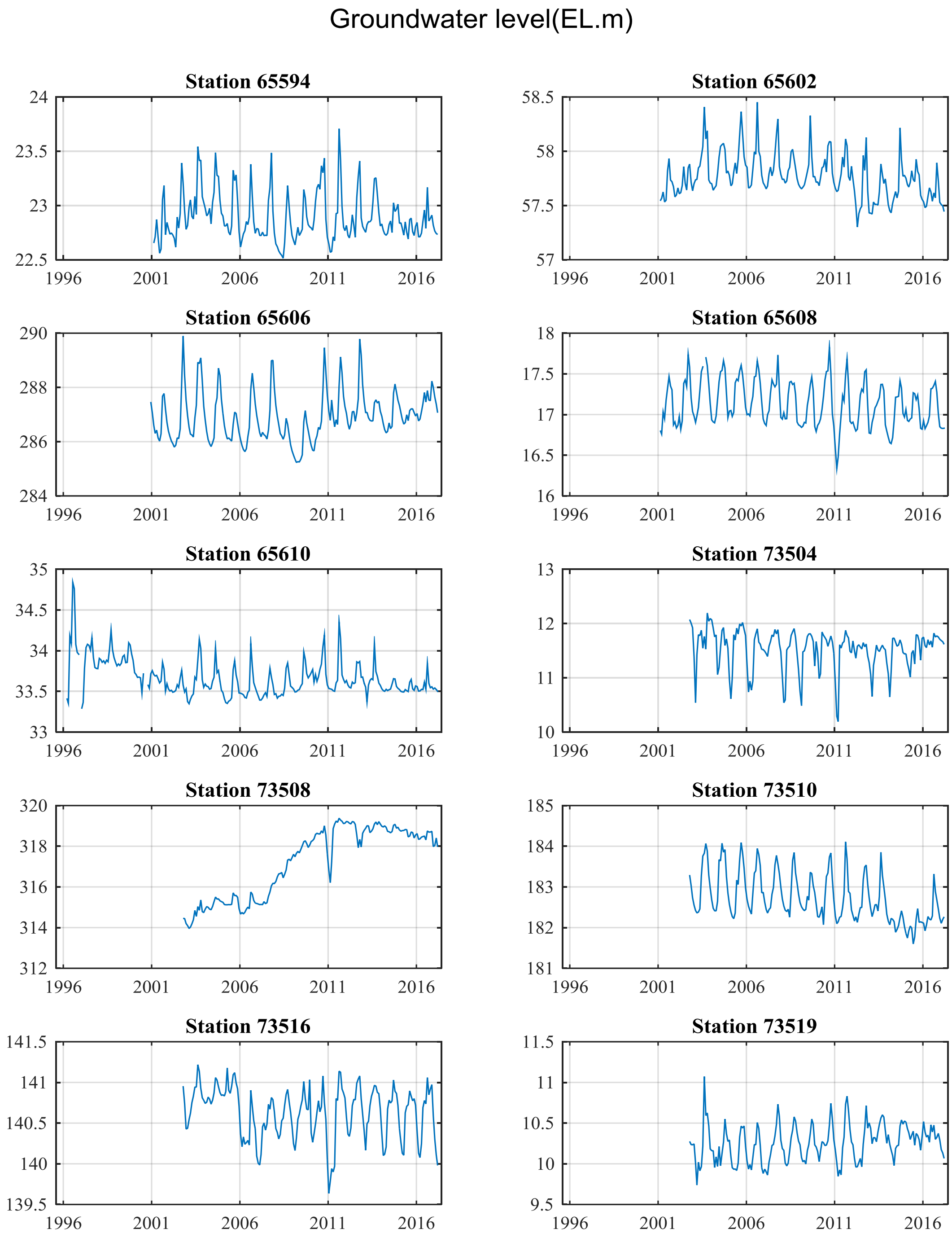


Figure D.1.9 Plots of Groundwater Levels for Station No. 65594 – 73519 (Shallow wells)

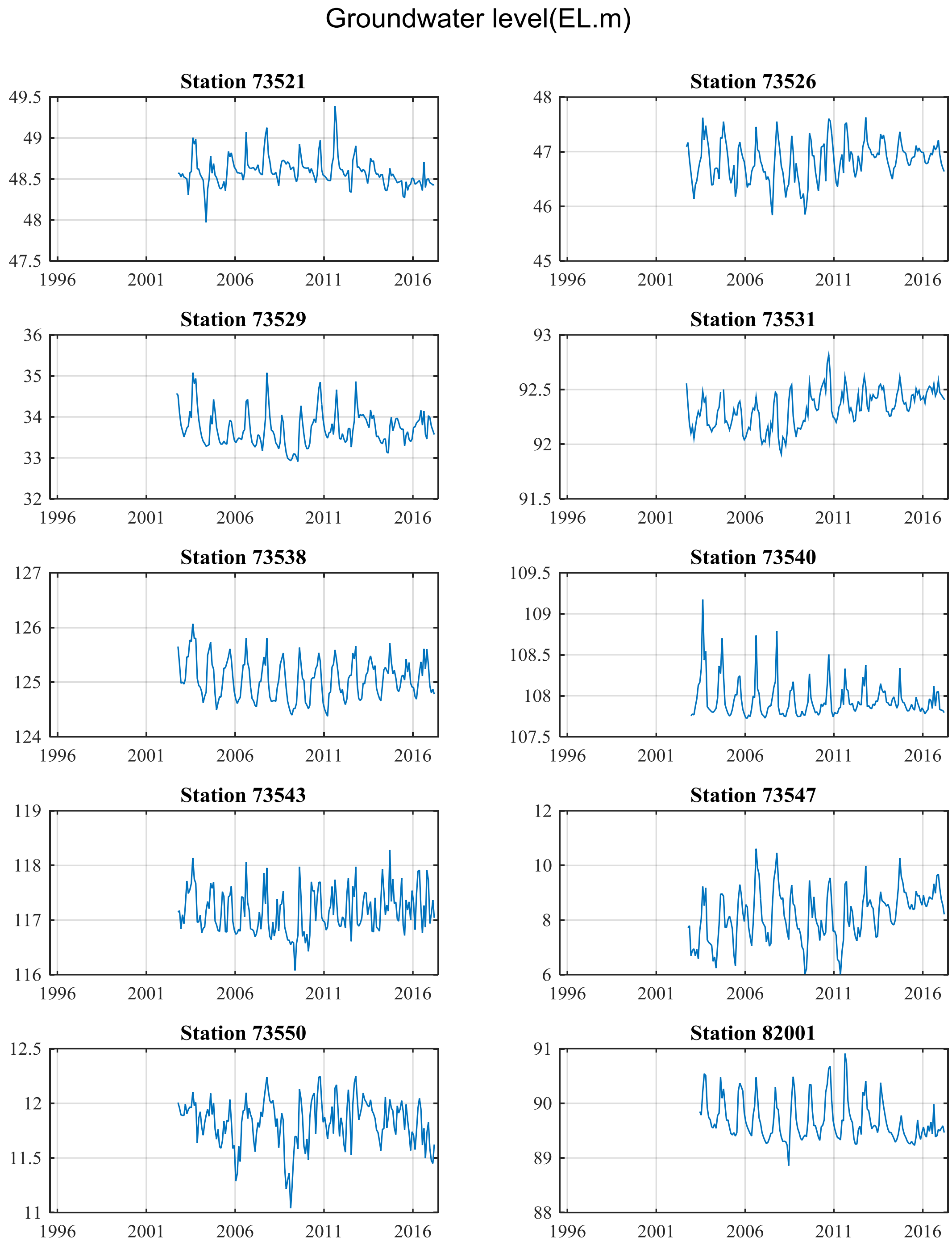


Figure D.1.10 Plots of Groundwater Levels for Station No. 73521 – 82001 (Shallow wells)

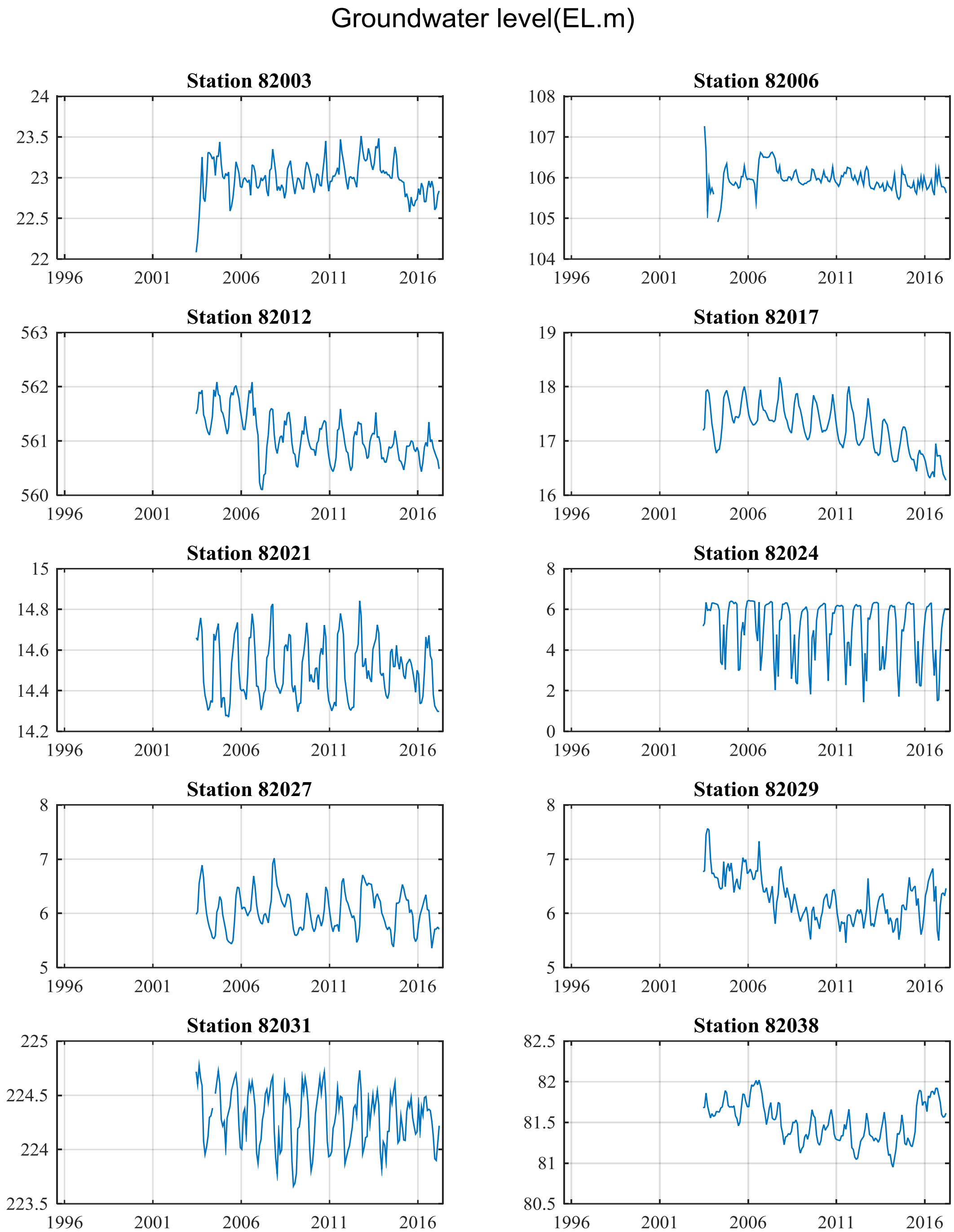


Figure D.1.11 Plots of Groundwater Levels for Station No. 82003 – 82038 (Shallow wells)

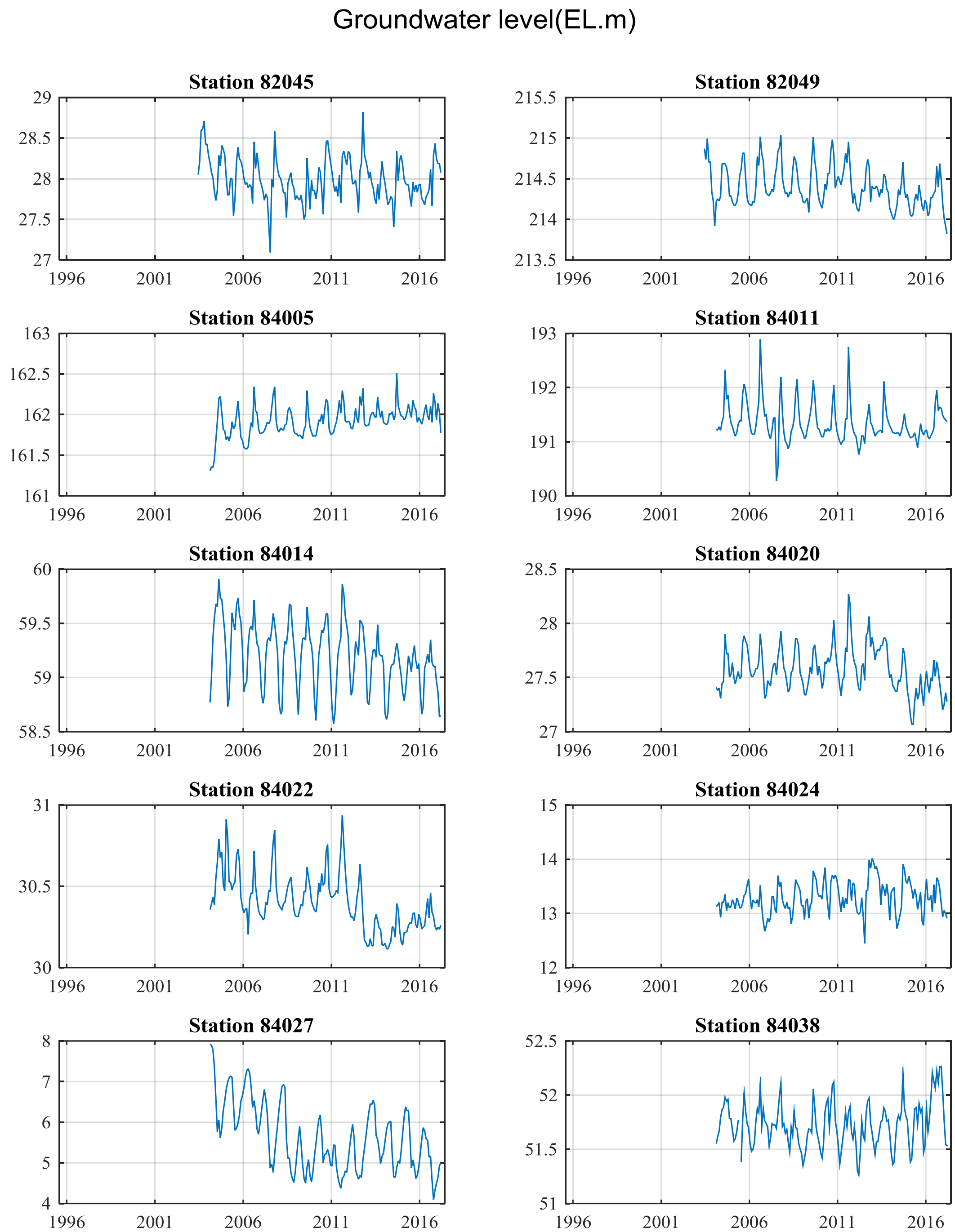


Figure D.1.12 Plots of Groundwater Levels for Station No. 82045 – 84038 (Shallow wells)

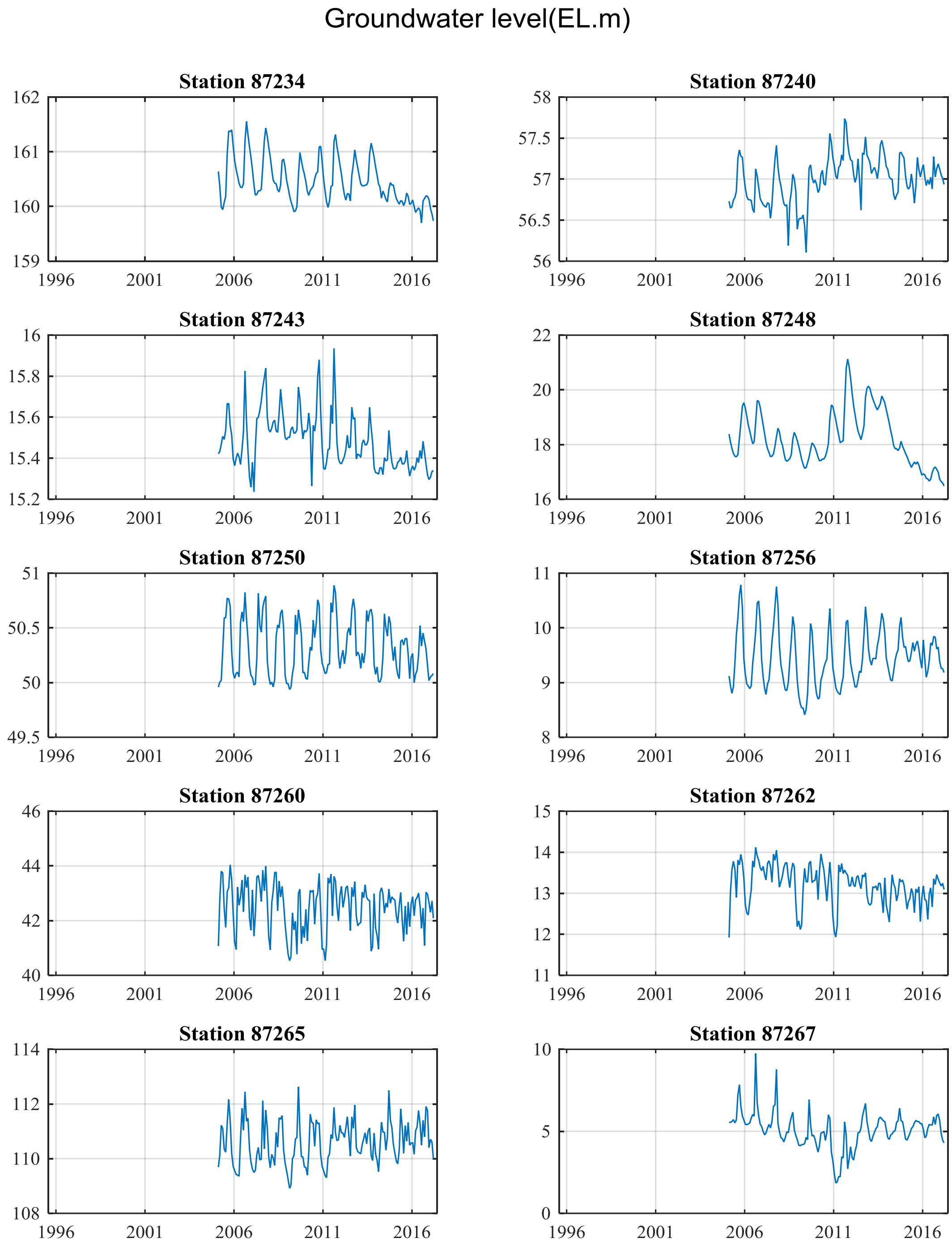


Figure D.1.13 Plots of Groundwater Levels for Station No. 87234 – 87267 (Shallow wells)

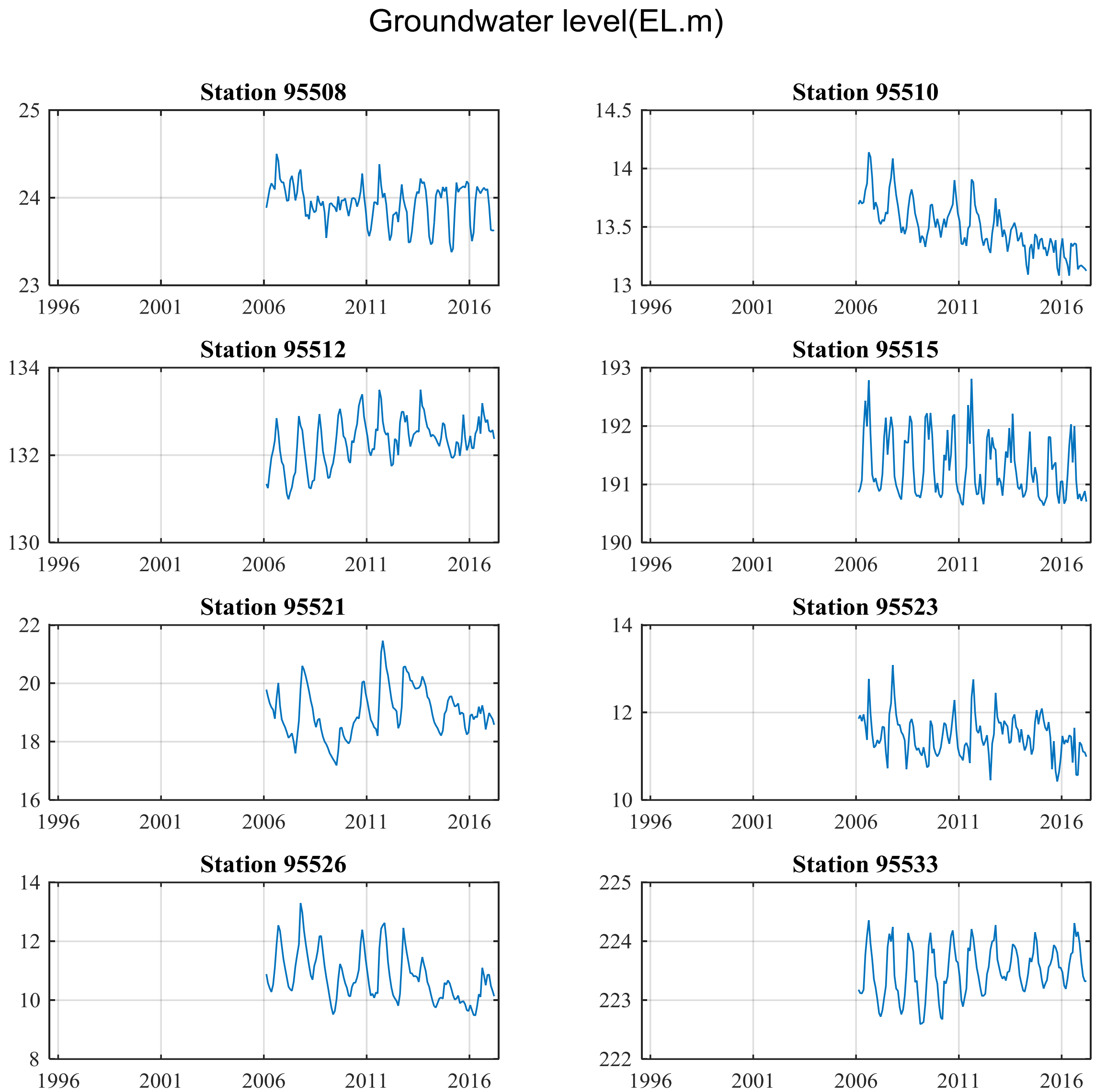


Figure D.1.14 Plots of Groundwater Levels for Station No. 95508 – 95533
(Shallow wells)

Deep Wells (150 EA)

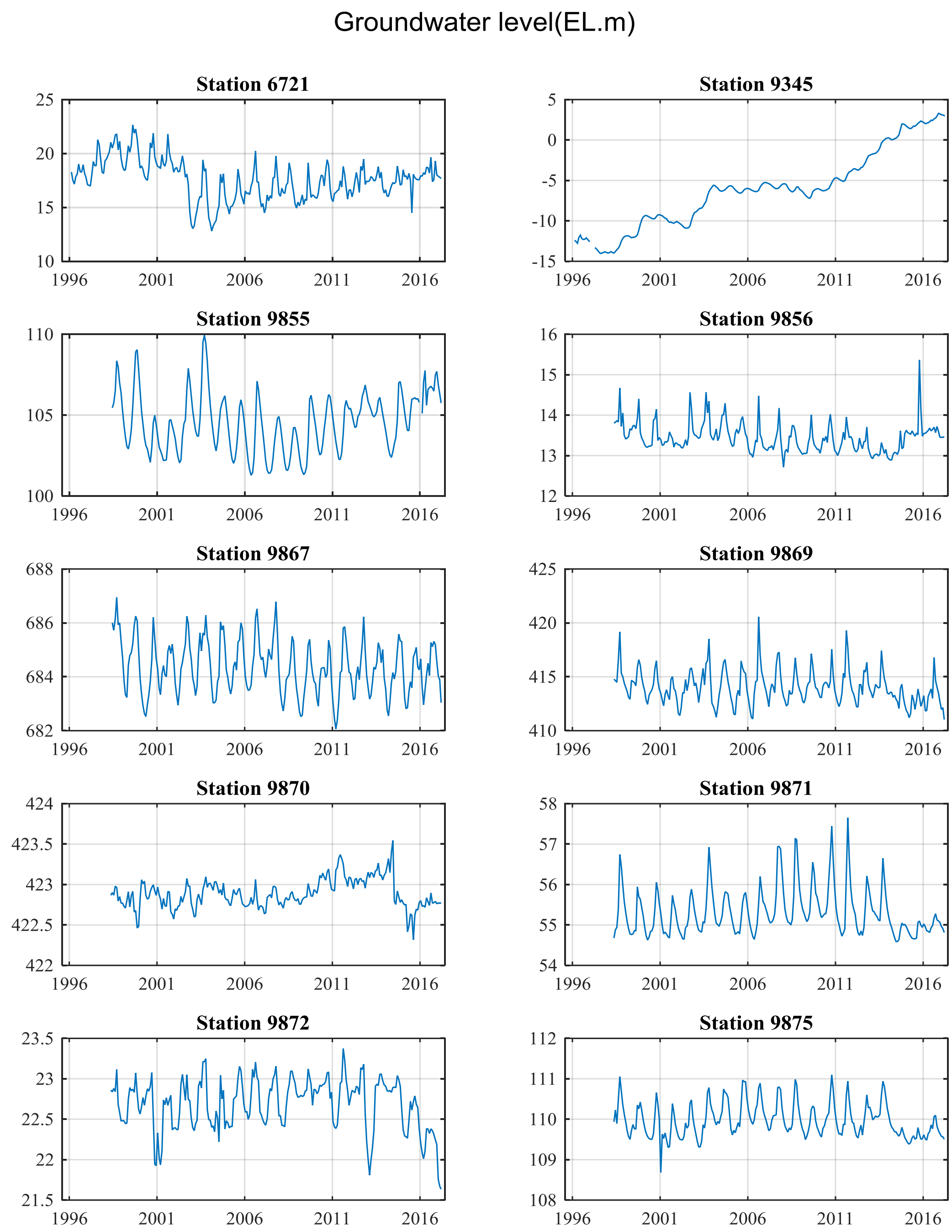


Figure D.1.15 Plots of Groundwater Levels for Station No. 6721 – 9875 (Deep Wells)

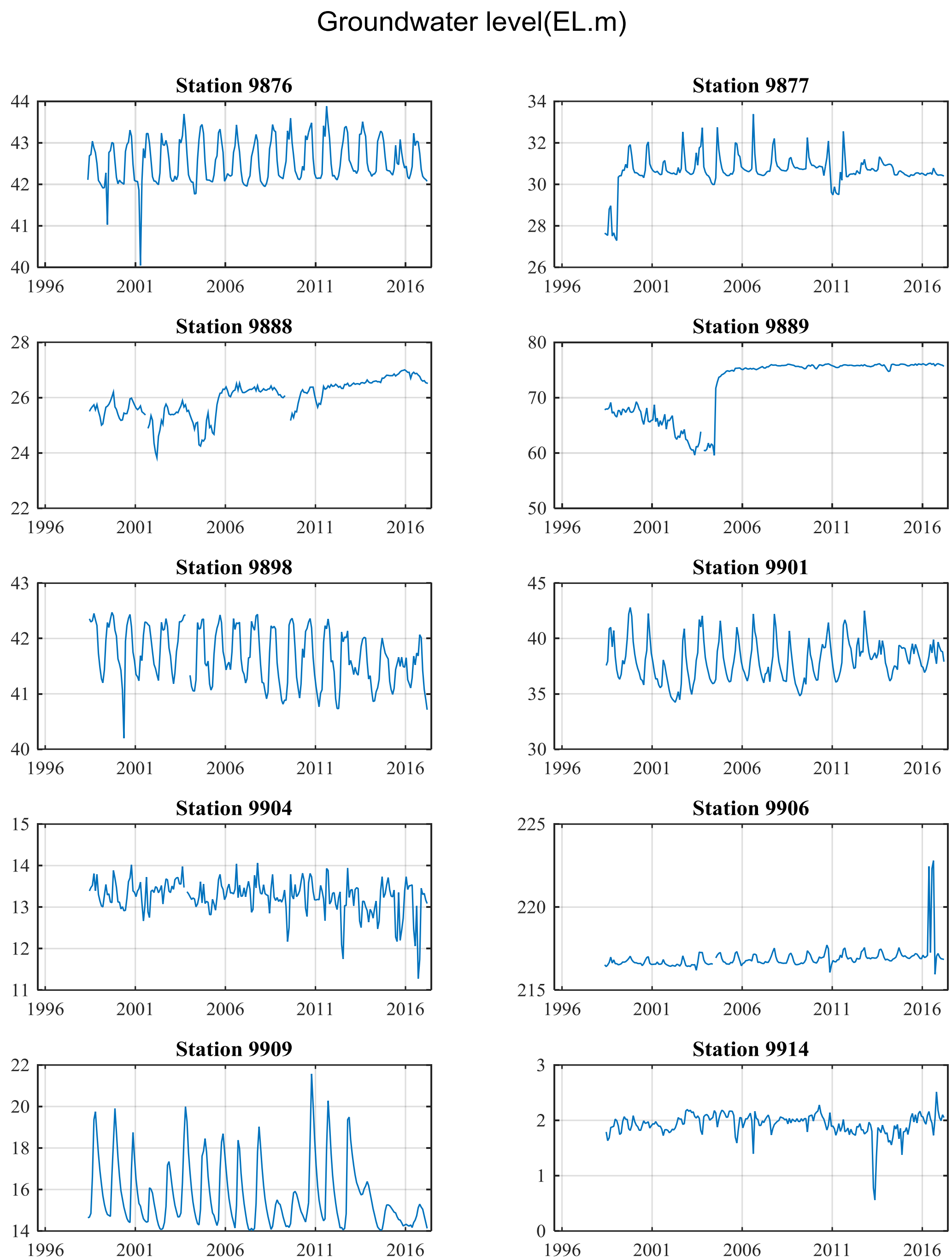


Figure D.1.16 Plots of Groundwater Levels for Station No. 9876 – 9914 (Deep Wells)

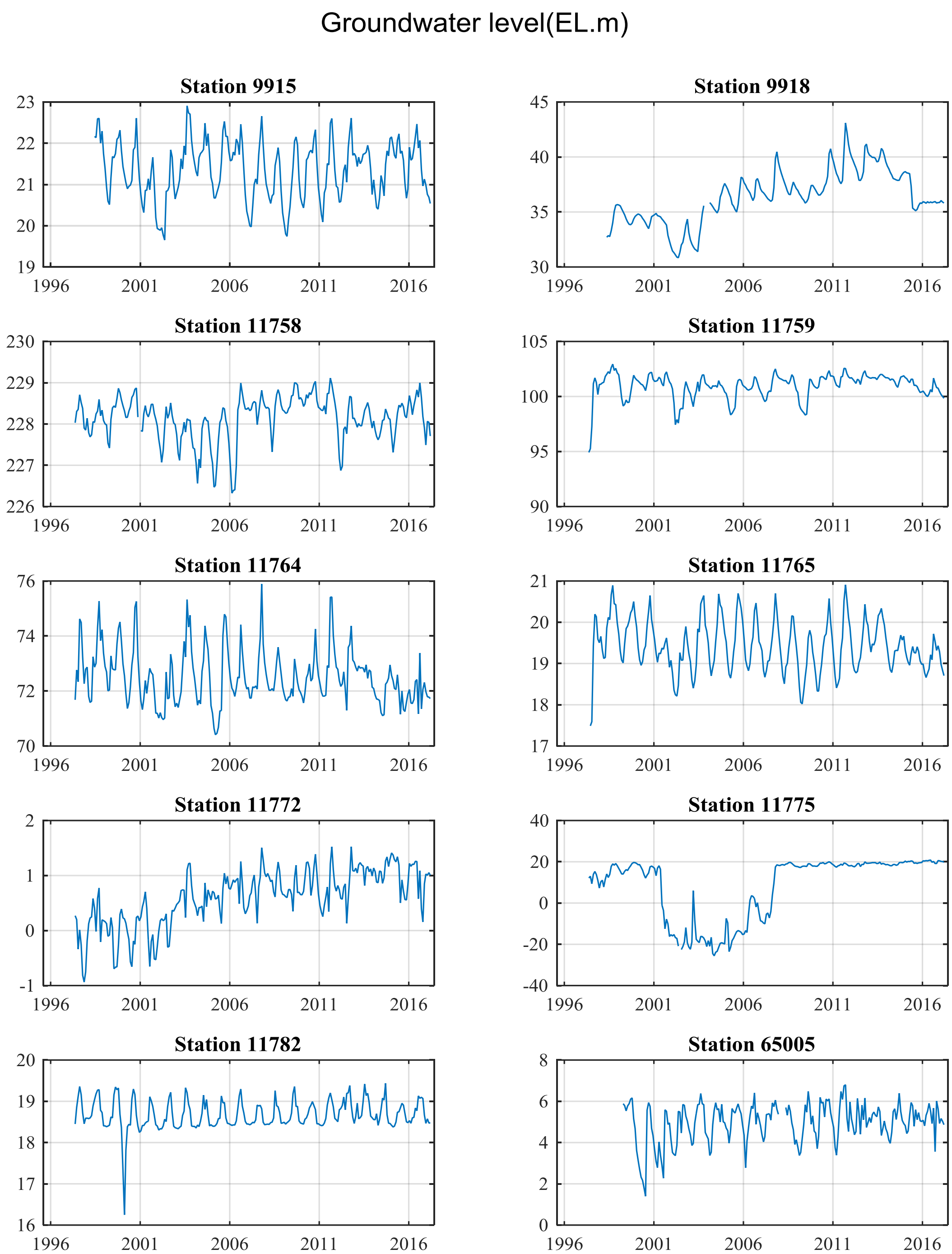


Figure D.1.17 Plots of Groundwater Levels for Station No. 9915 – 65005 (Deep Wells)

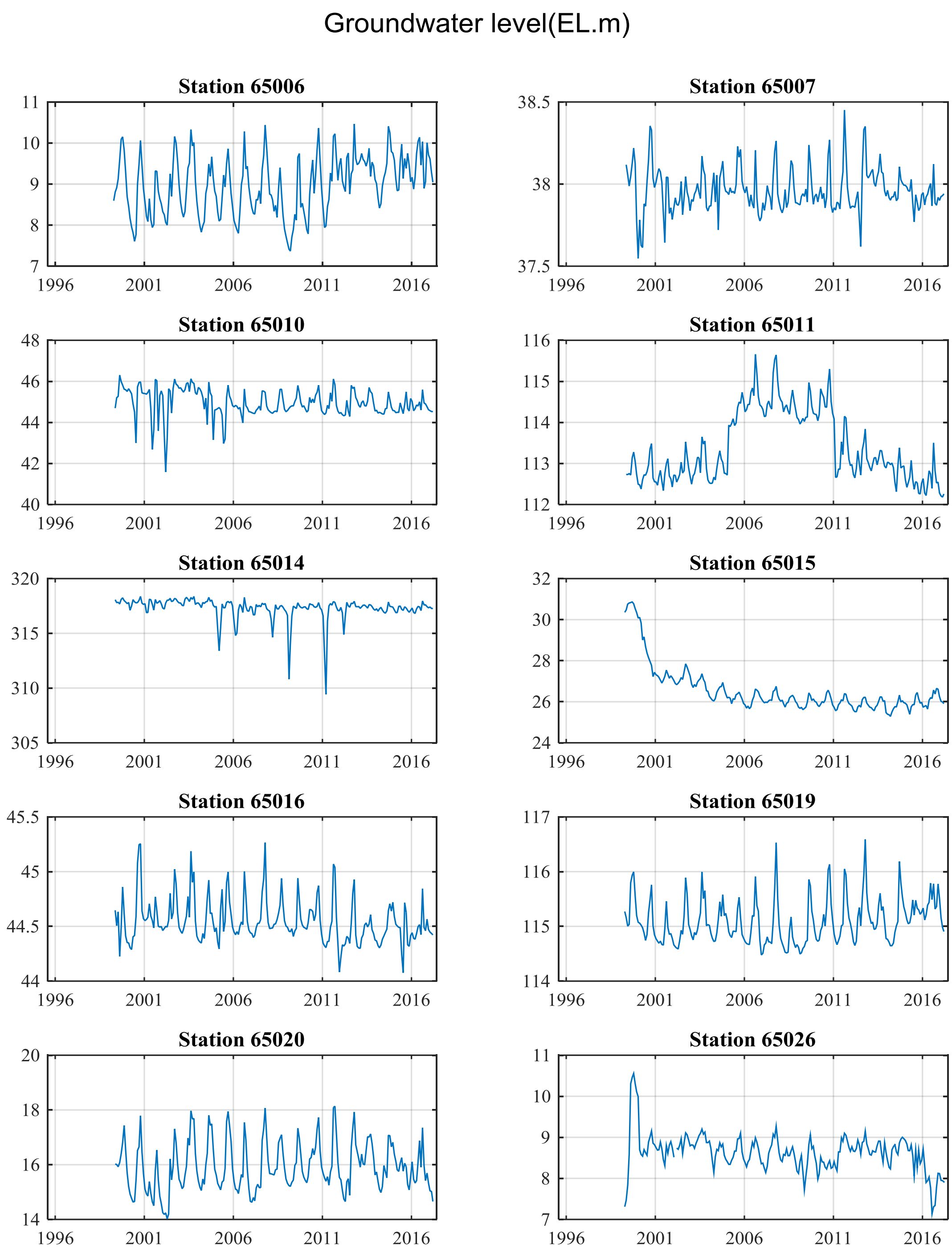


Figure D.1.18 Plots of Groundwater Levels for Station No. 65006 – 65026 (Deep Wells)

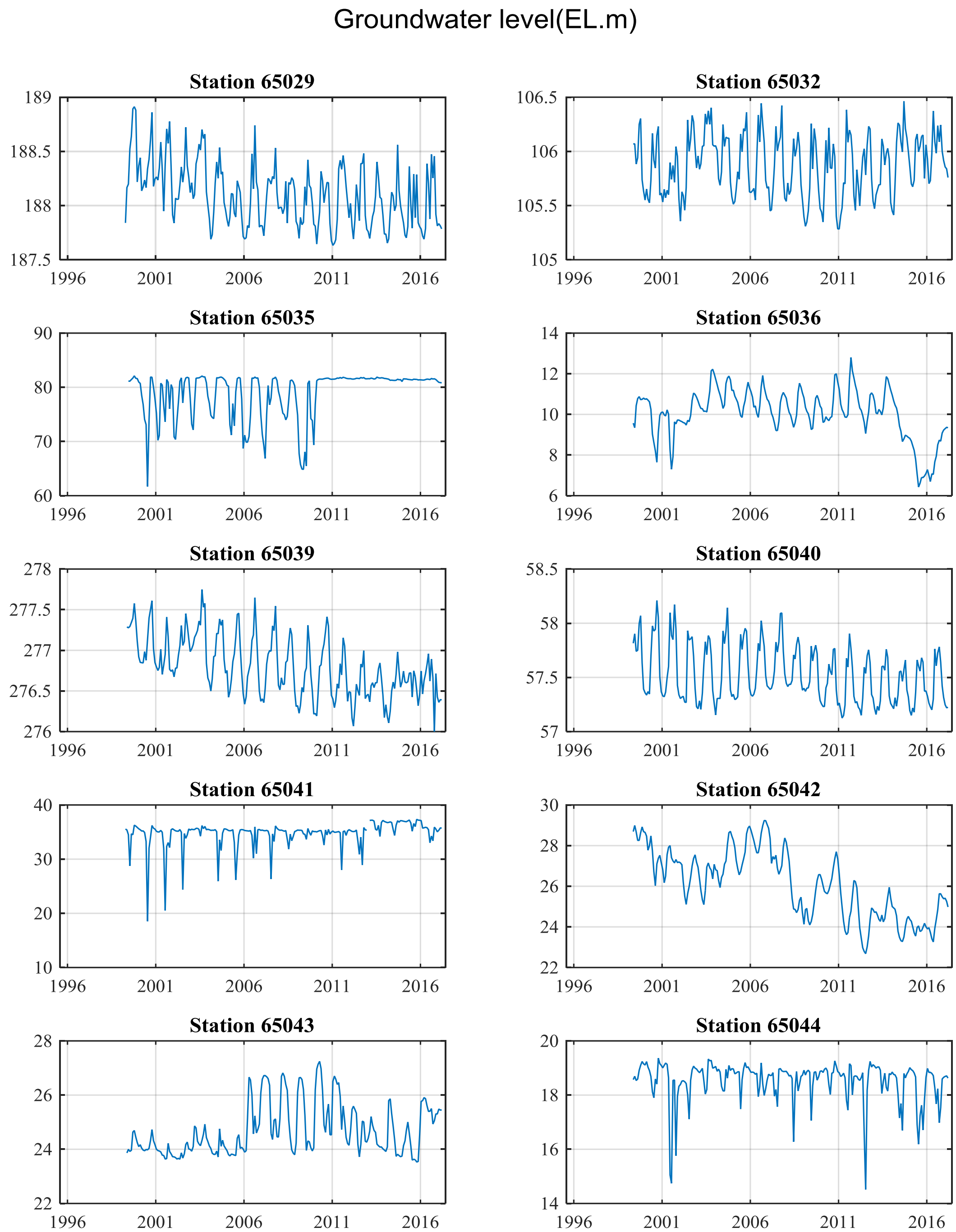


Figure D.1.19 Plots of Groundwater Levels for Station No. 65029 – 65044 (Deep Wells)

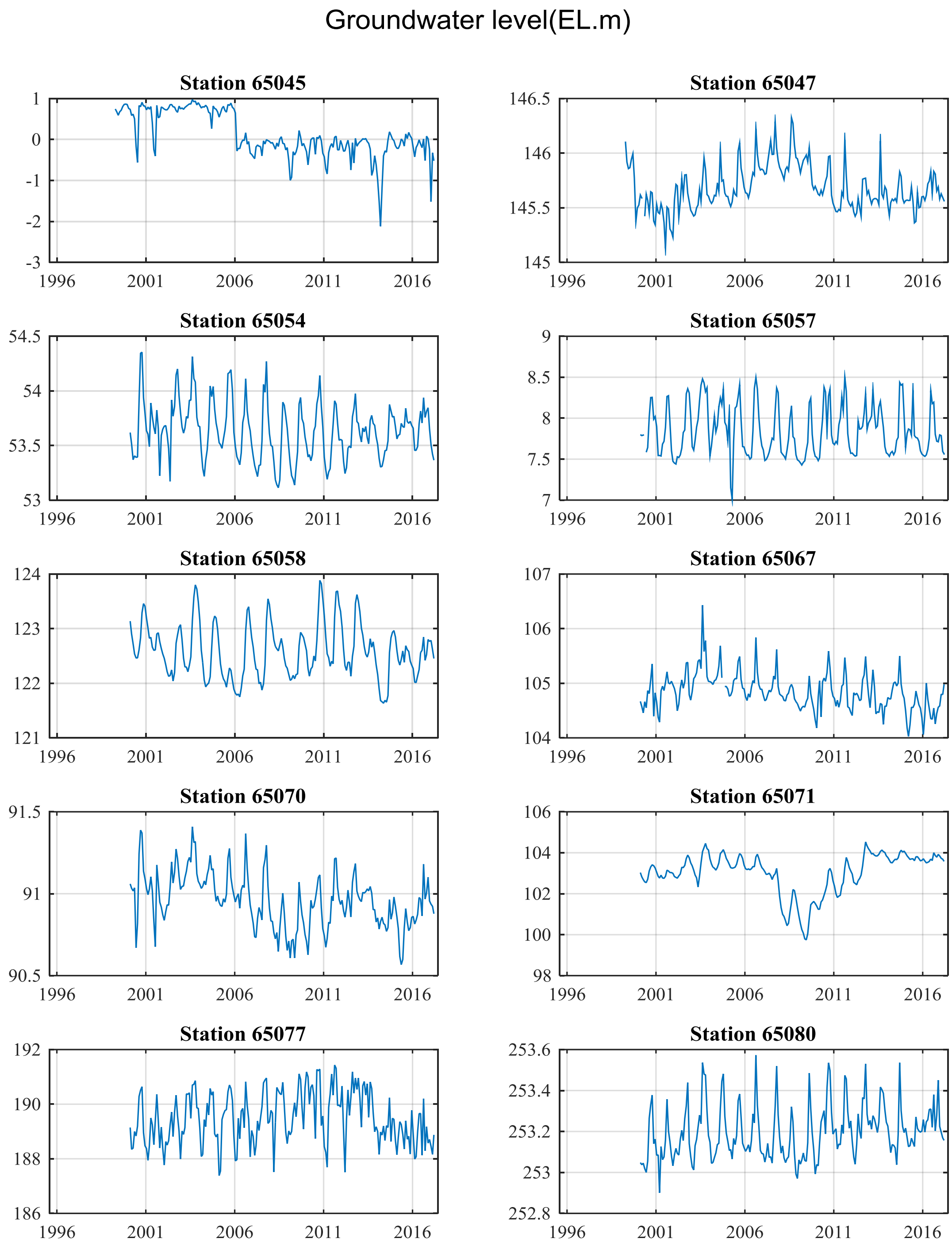


Figure D.1.20 Plots of Groundwater Levels for Station No. 65045 – 65080 (Deep Wells)

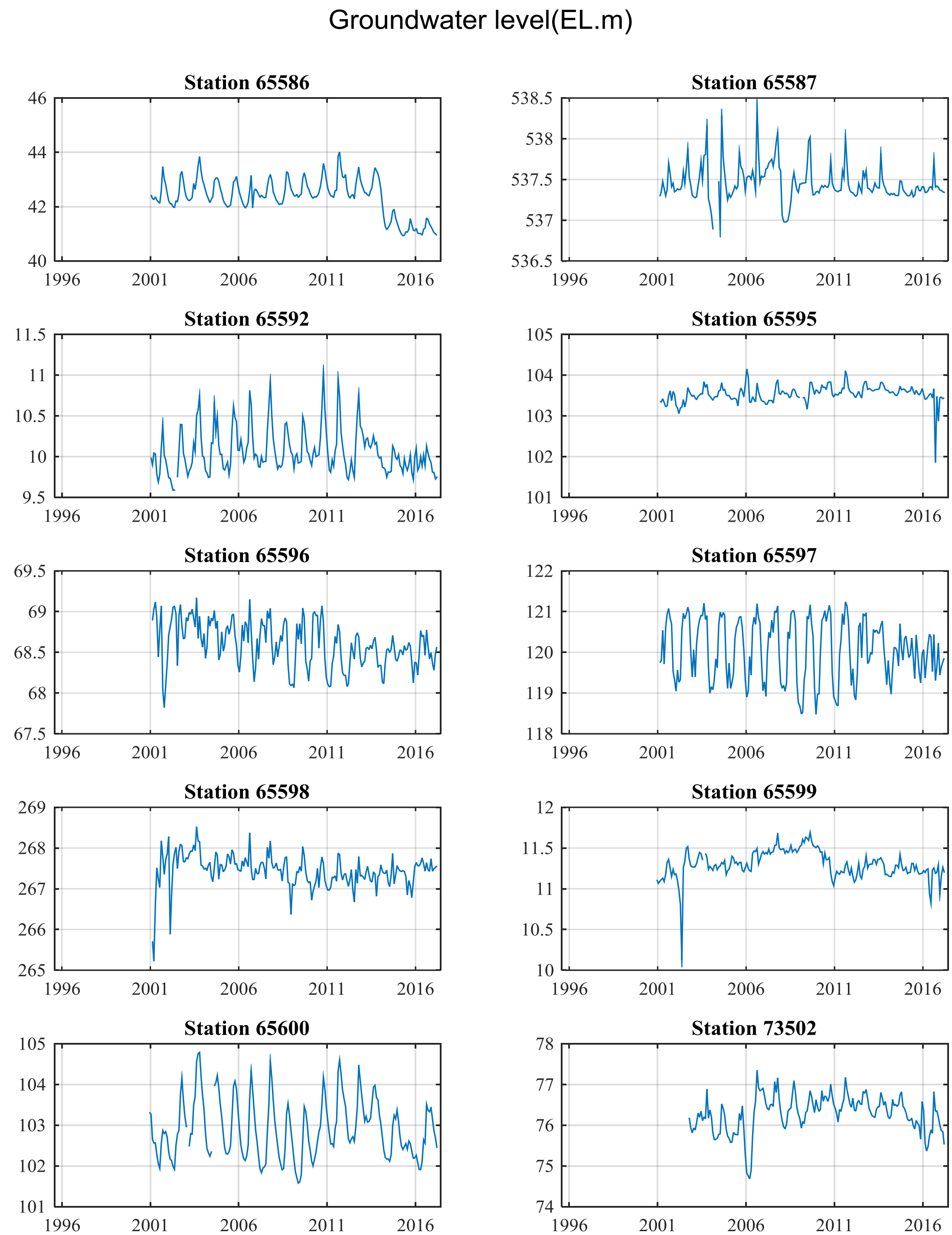


Figure D.1.21 Plots of Groundwater Levels for Station No. 65586 – 73502 (Deep Wells)

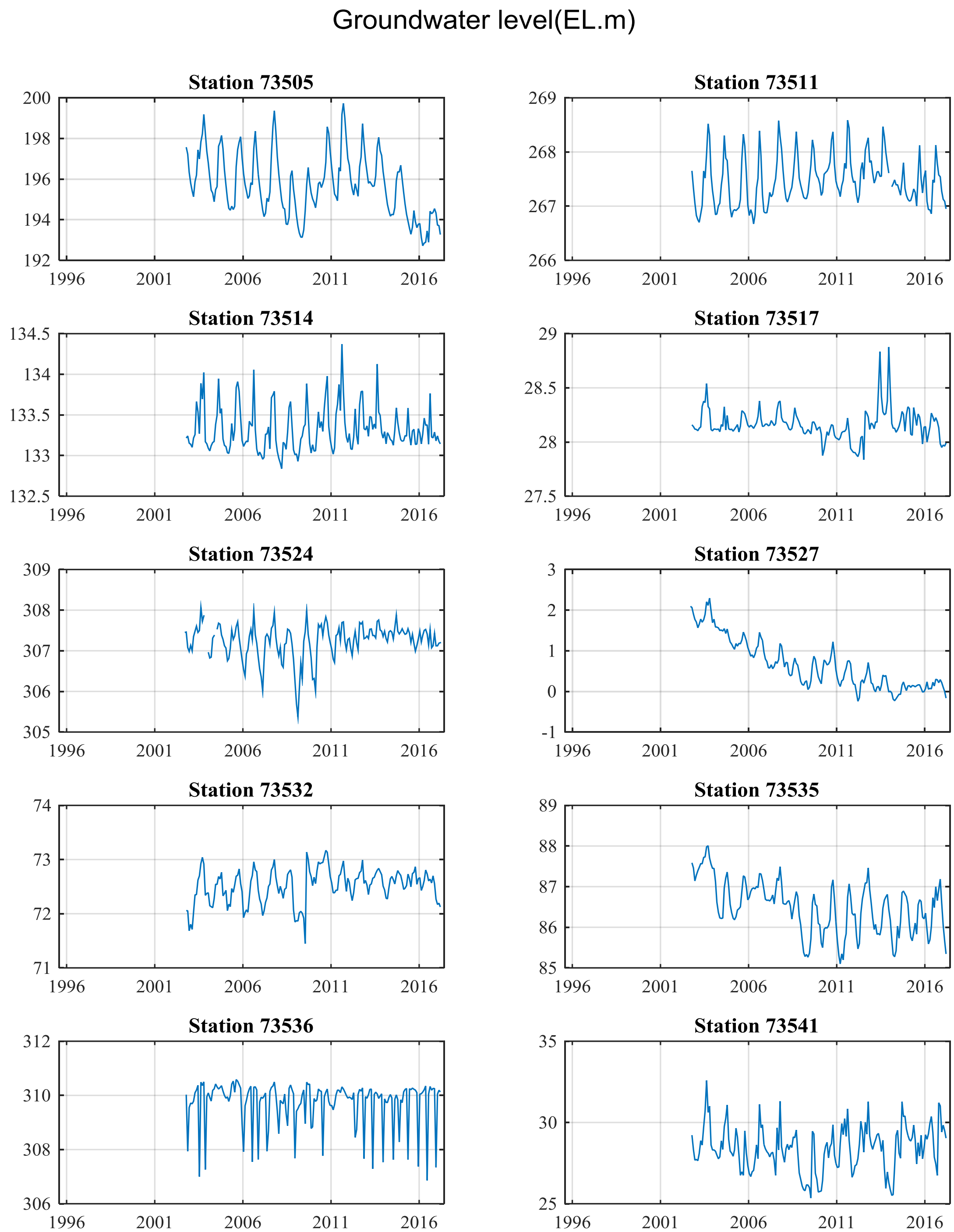


Figure D.1.22 Plots of Groundwater Levels for Station No. 73505 – 73541 (Deep Wells)

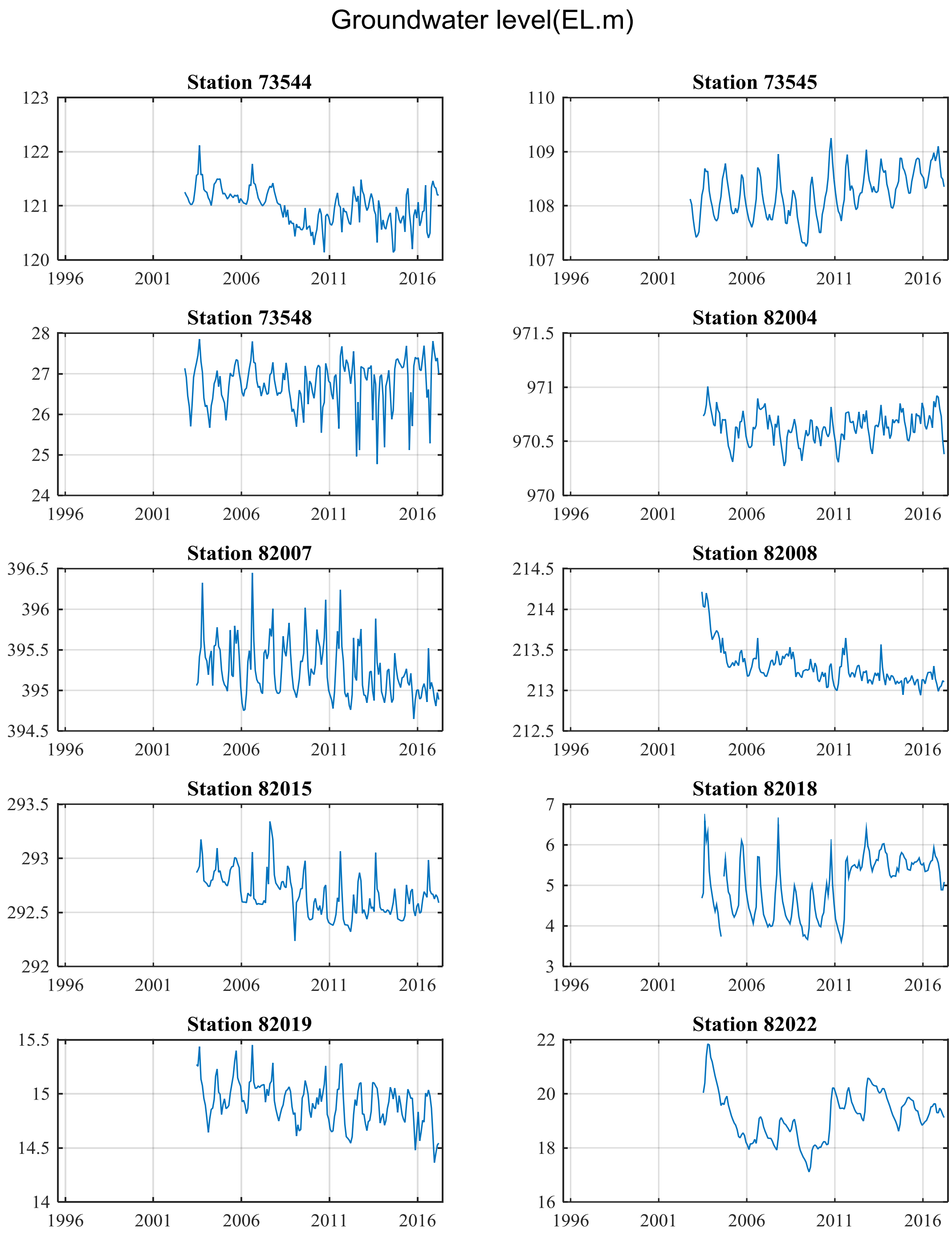


Figure D.1.23 Plots of Groundwater Levels for Station No. 73544 – 82022 (Deep Wells)

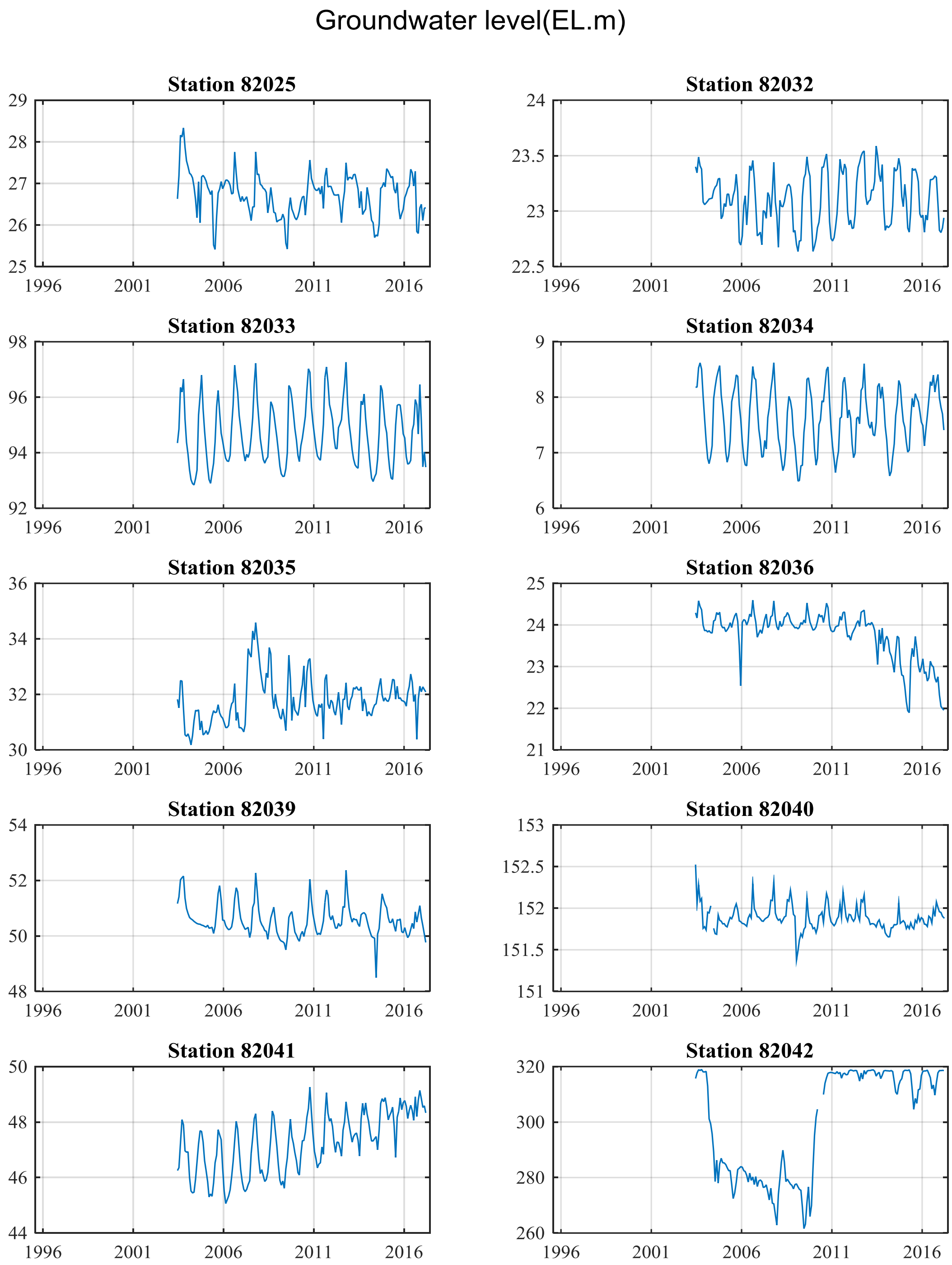


Figure D.1.24 Plots of Groundwater Levels for Station No. 82025 – 82042 (Deep Wells)

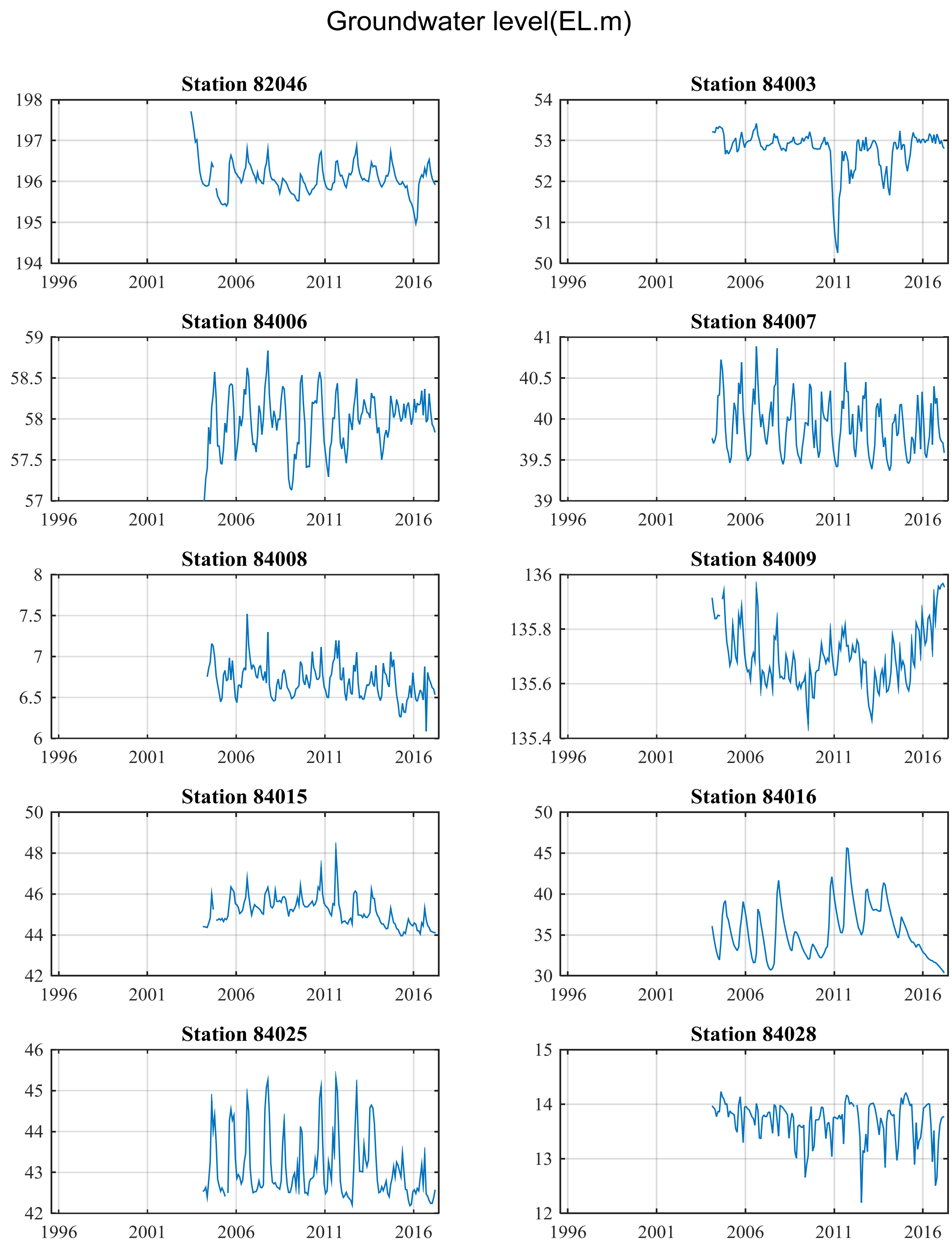


Figure D.1.25 Plots of Groundwater Levels for Station No. 82046 – 84028 (Deep Wells)

Groundwater level(EL.m)

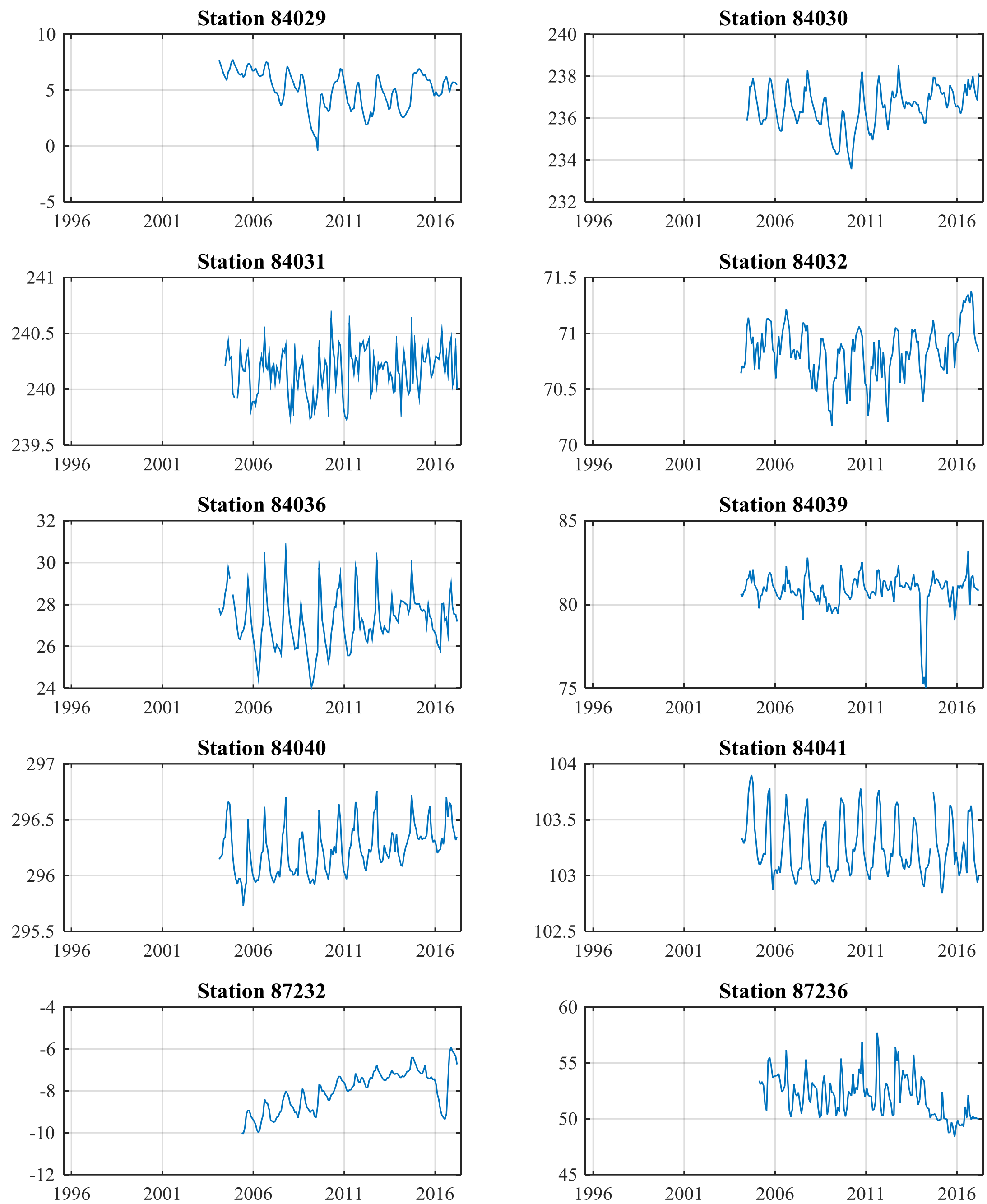


Figure D.1.26 Plots of Groundwater Levels for Station No. 84029 – 87236 (Deep Wells)

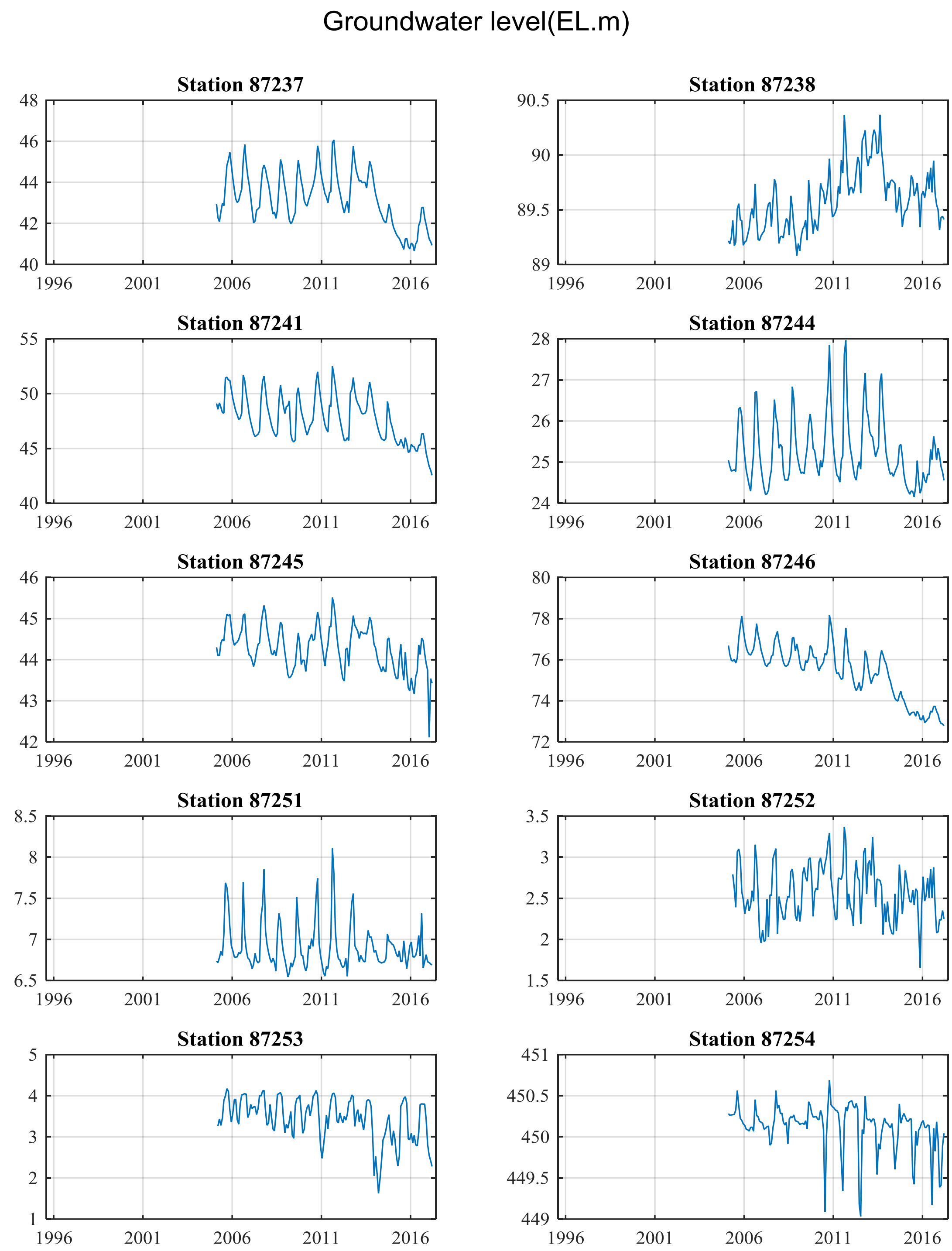


Figure D.1.27 Plots of Groundwater Levels for Station No. 87237 – 87254 (Deep Wells)

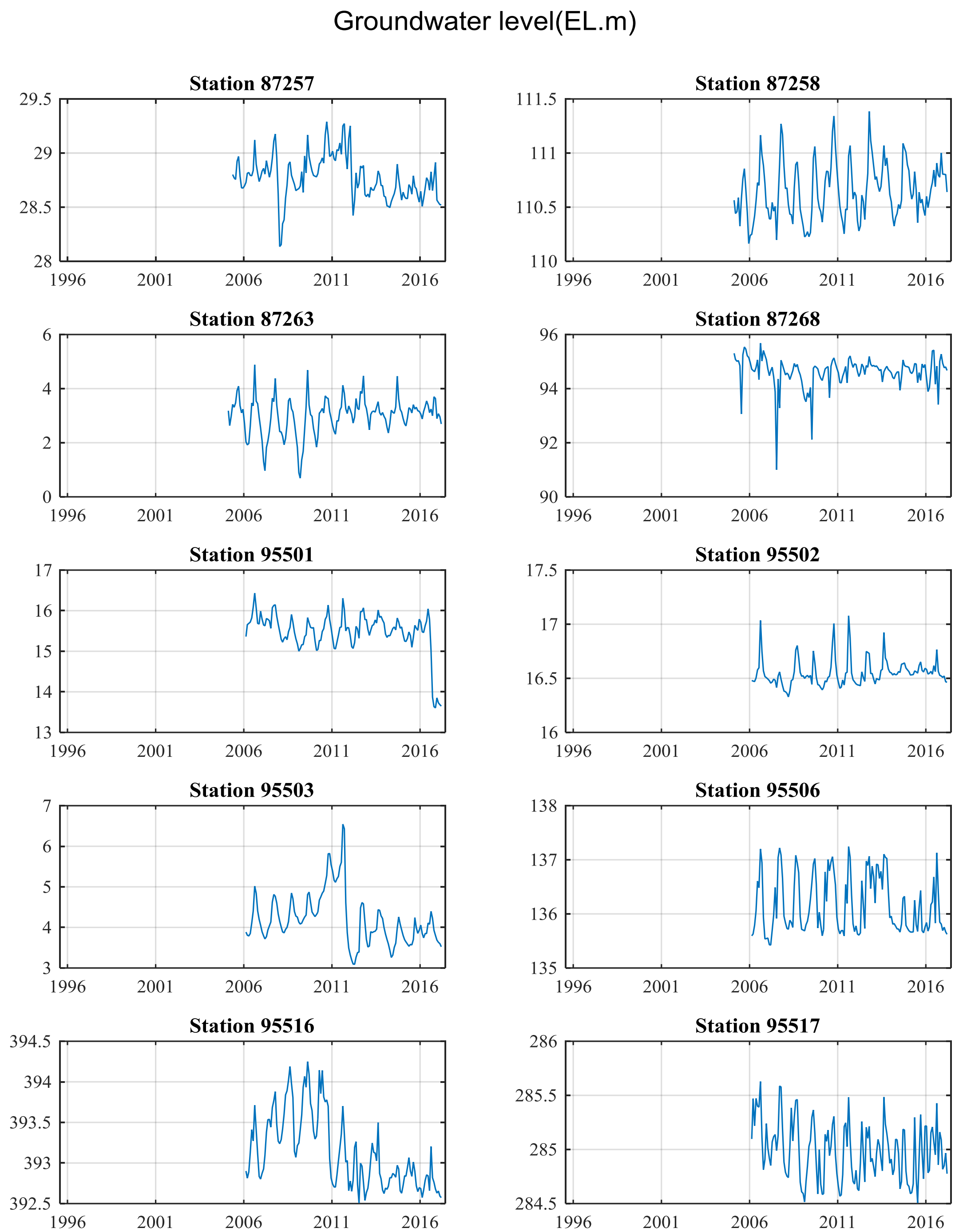


Figure D.1.28 Plots of Groundwater Levels for Station No. 87257 – 95517 (Deep Wells)

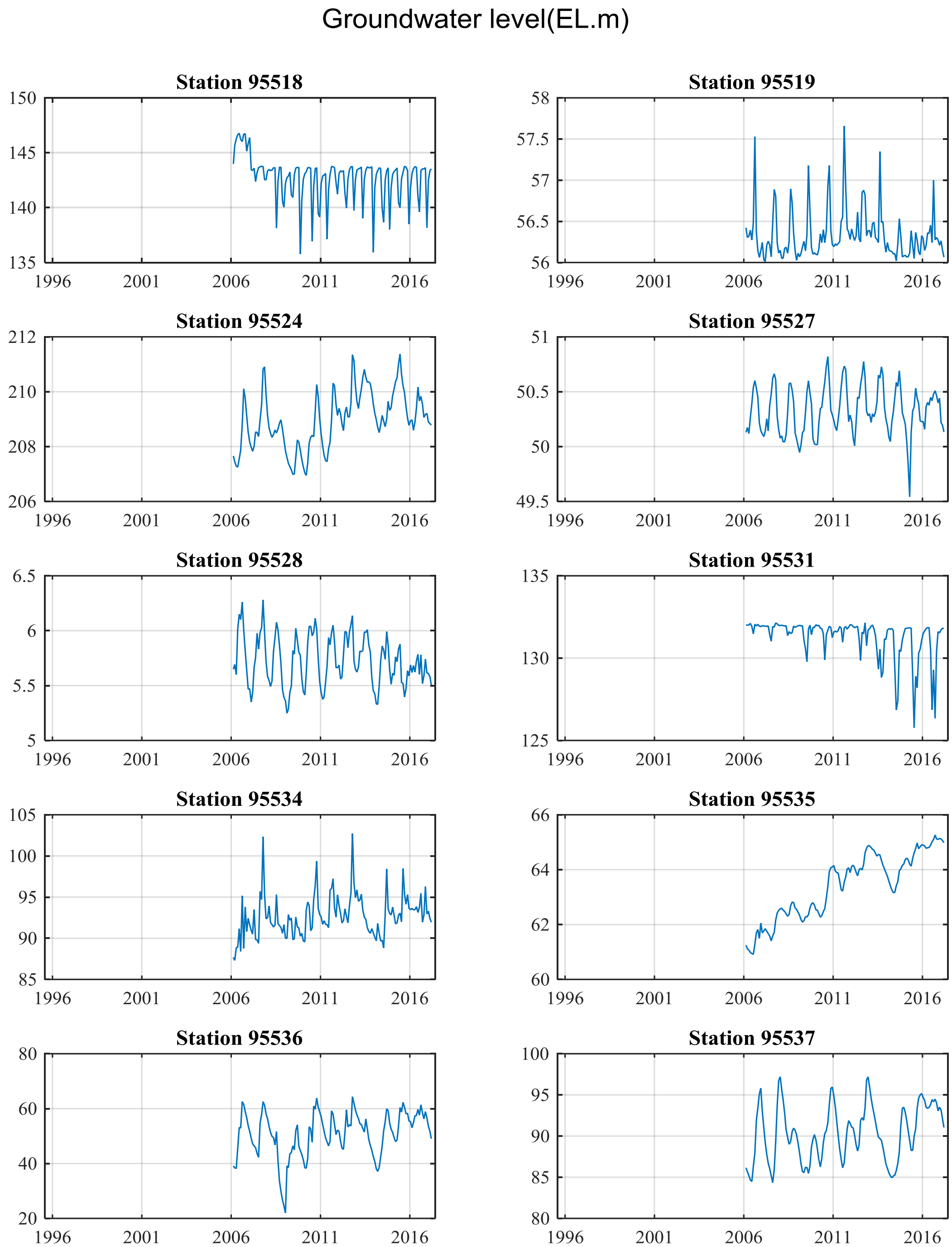


Figure D.1.29 Plots of Groundwater Levels for Station No. 95518 – 95537 (Deep Wells)

D.2 Correlation between Target SGI & Estimated SGI on Training &Testing Dataset for 26 Cities in Chungcheong Province

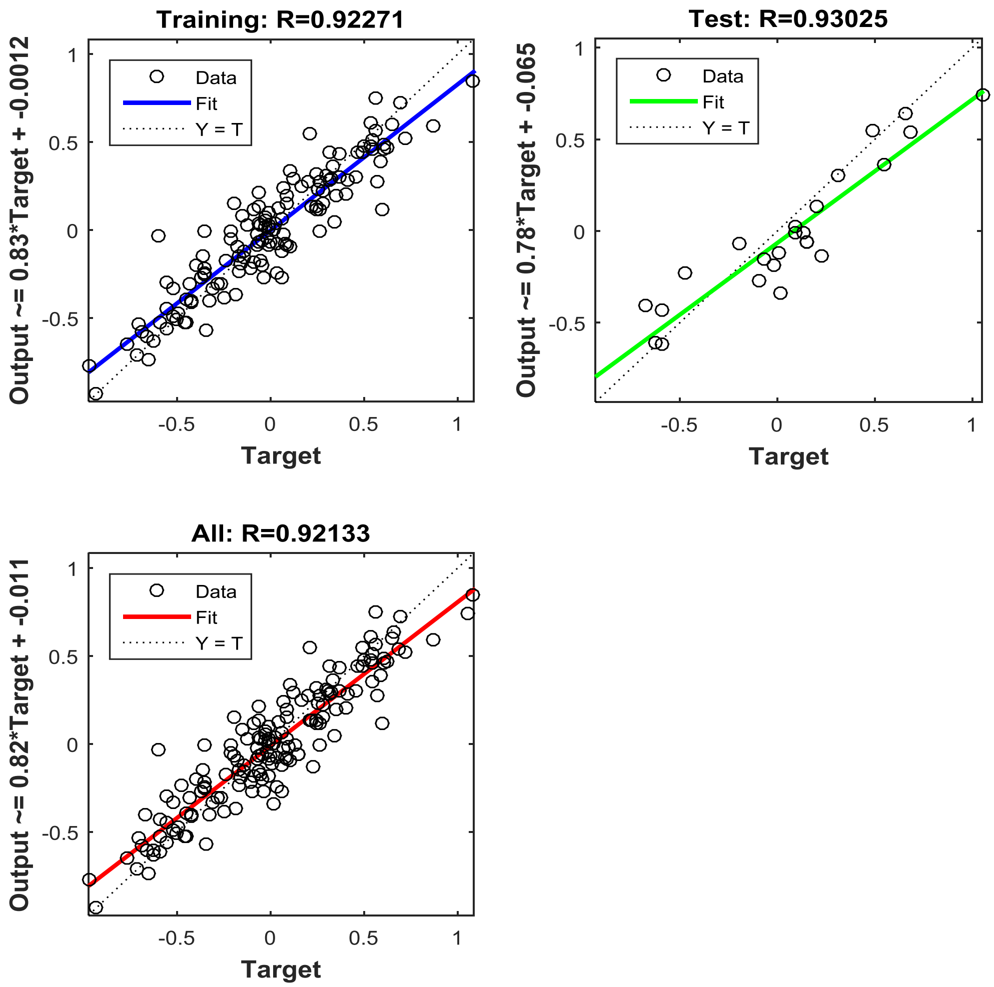


Figure D.2.1 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Cheongju

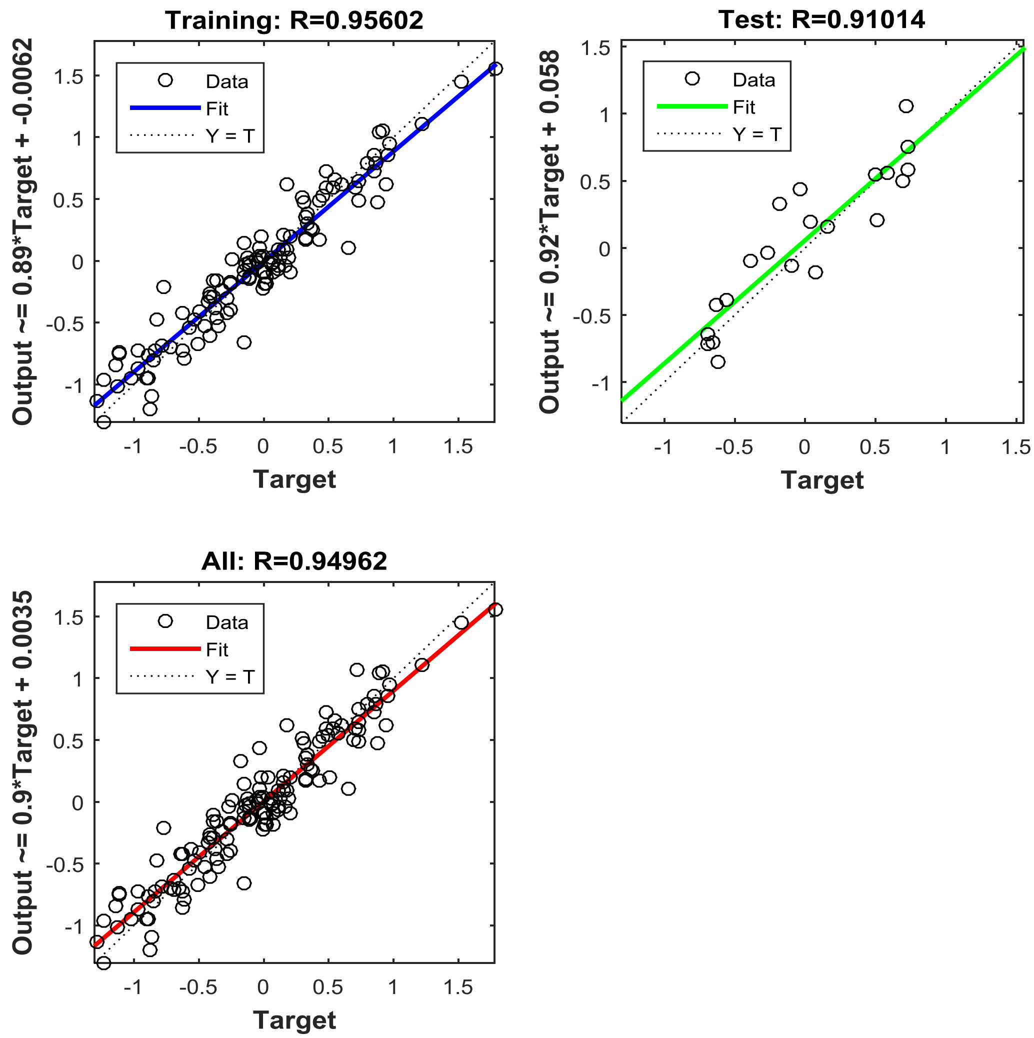


Figure D.2.2 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Chungju

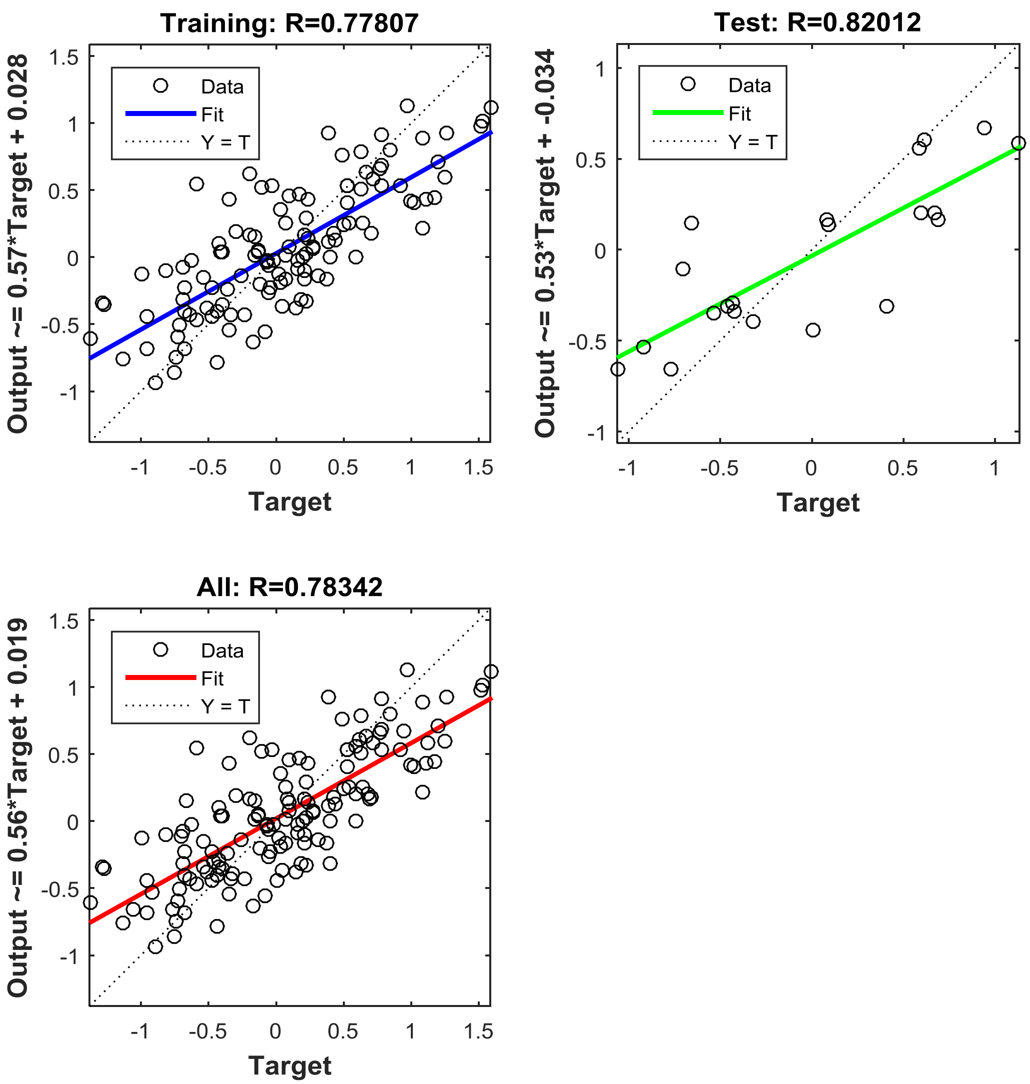


Figure D.2.3 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Jecheon

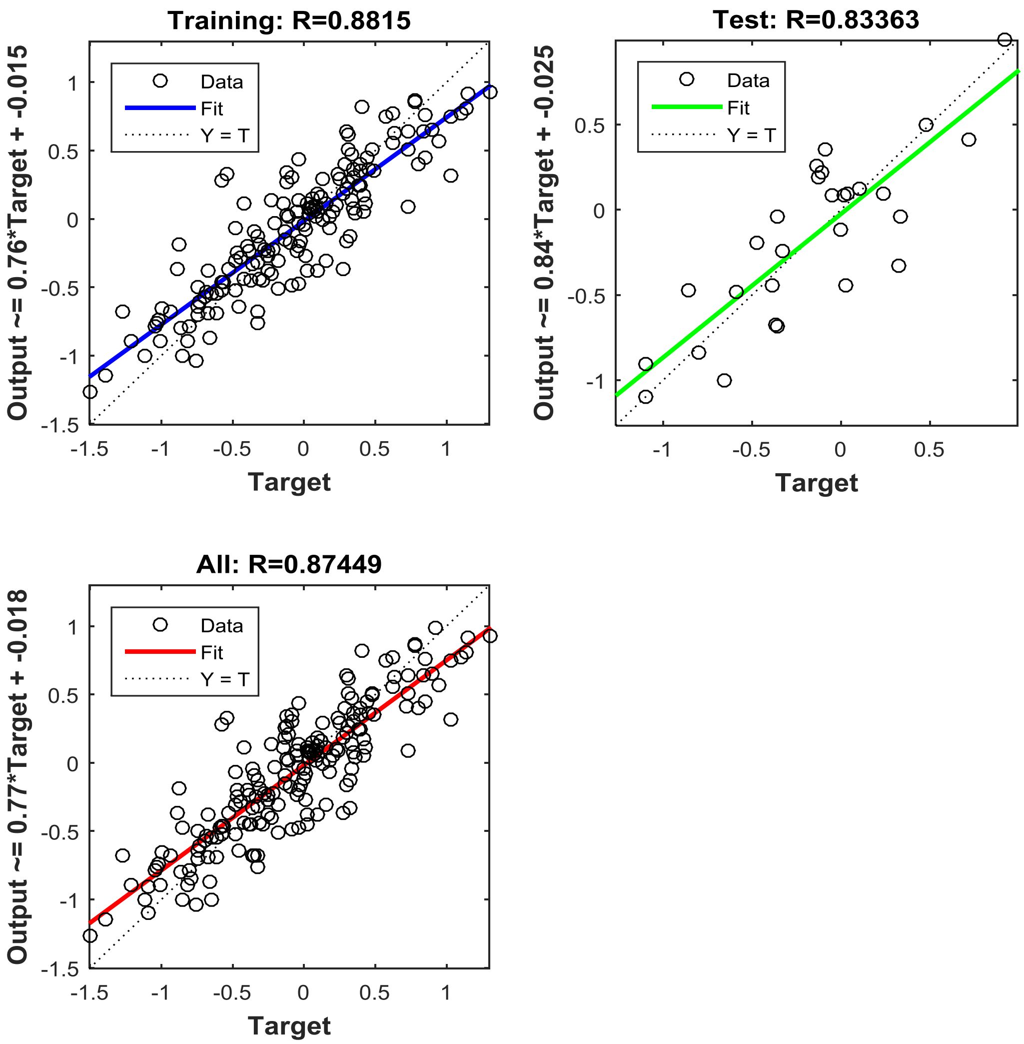


Figure D.2.4 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Boeun

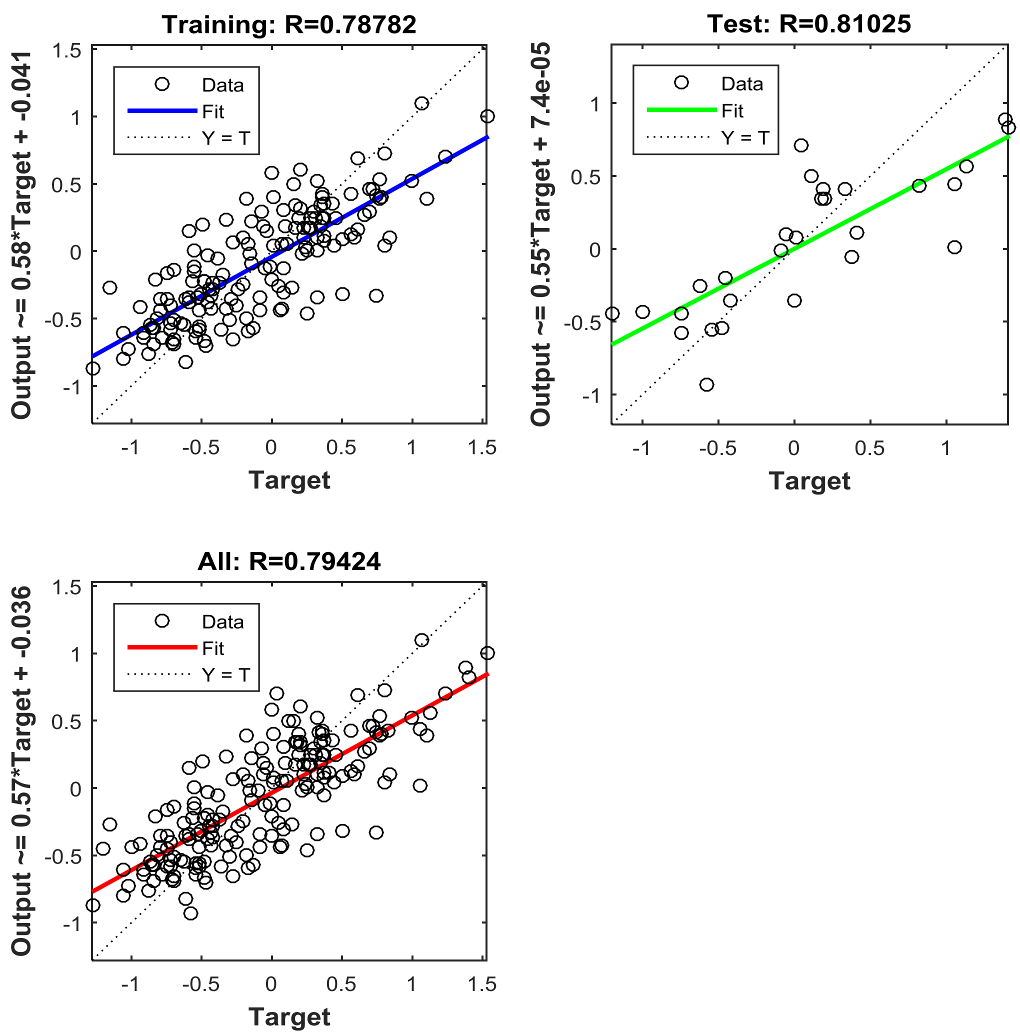


Figure D.2.5 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Okcheon

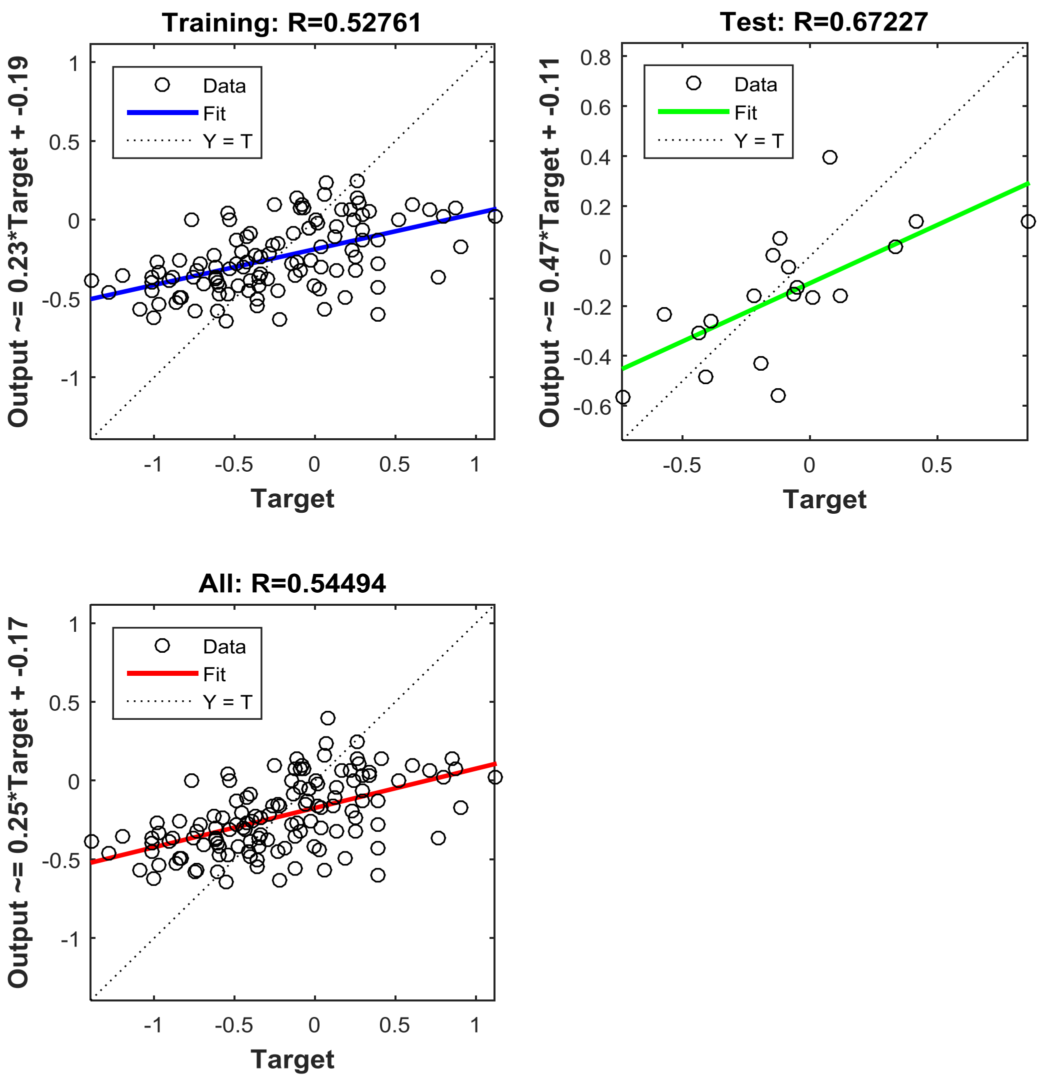


Figure D.2.6 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Yeongdong

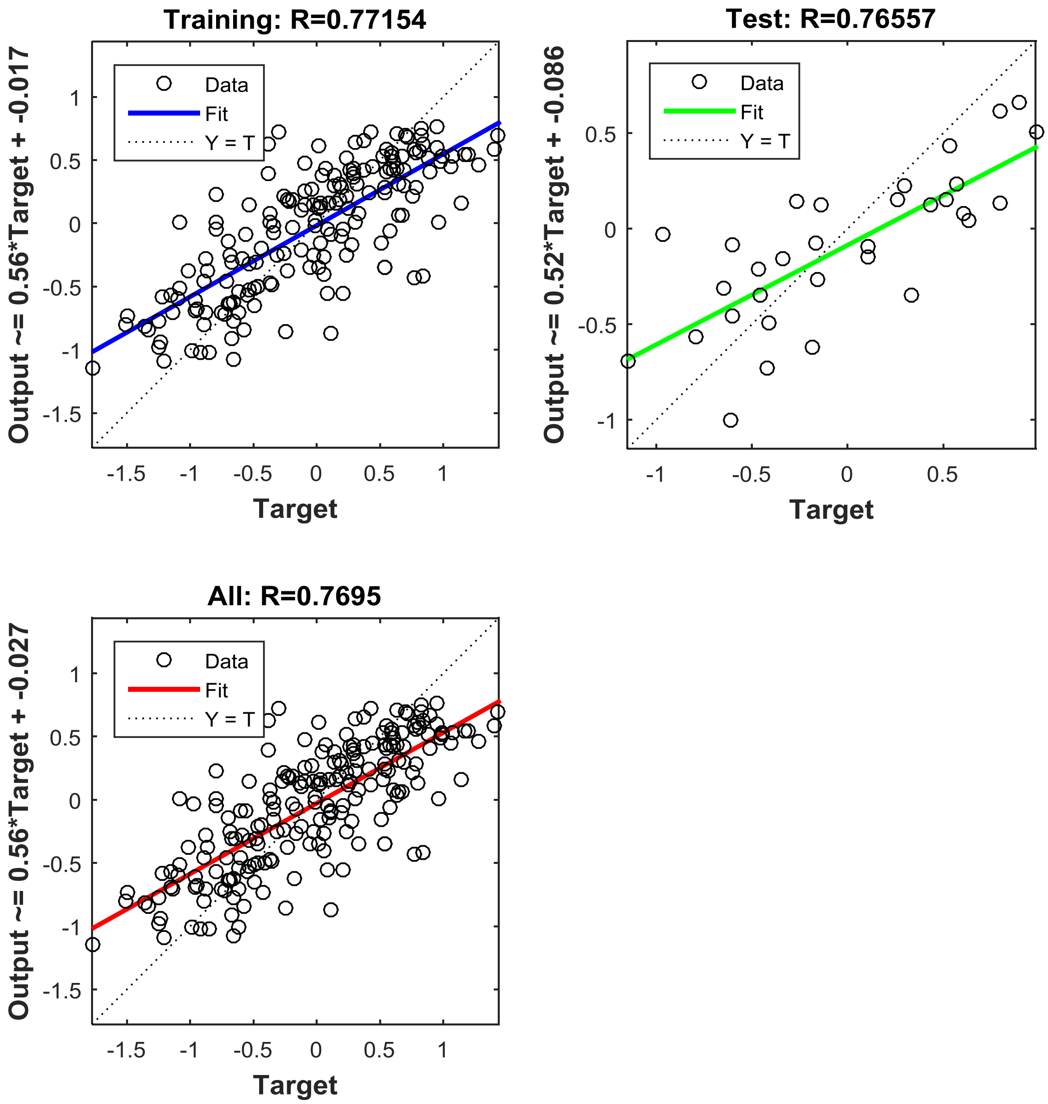


Figure D.2.7 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Jeungpyeong

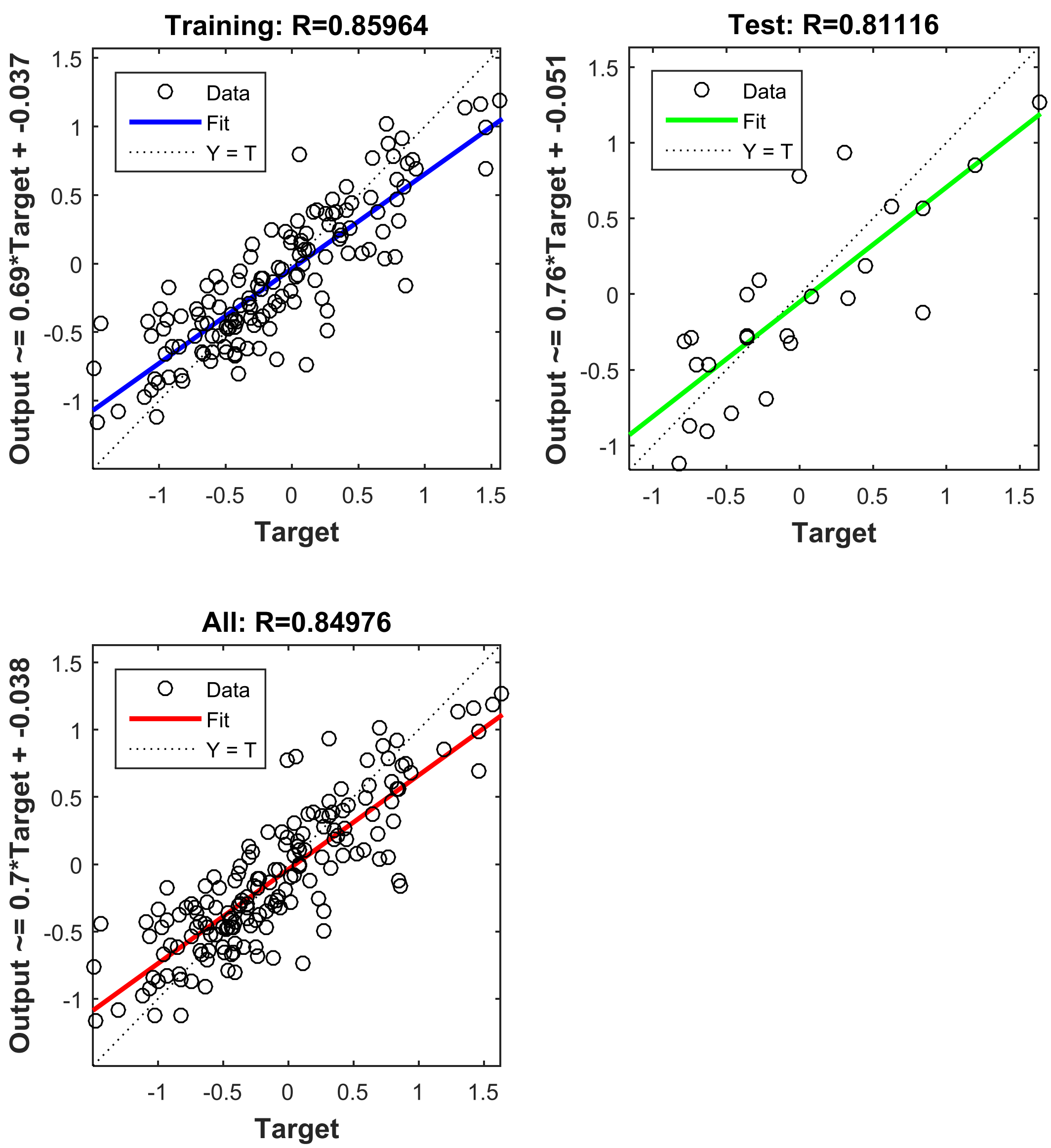


Figure D.2.8 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Jincheon

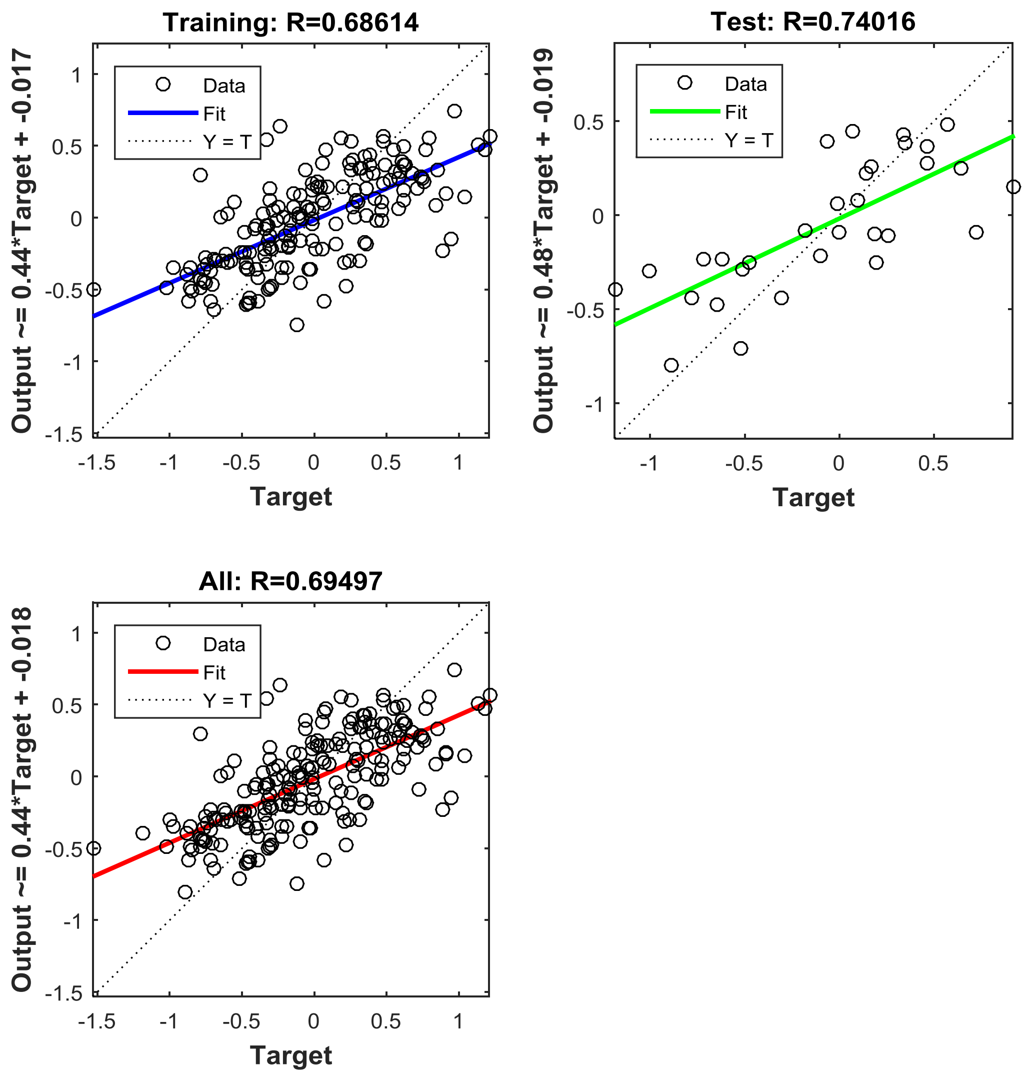


Figure D.2.9 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Goesan

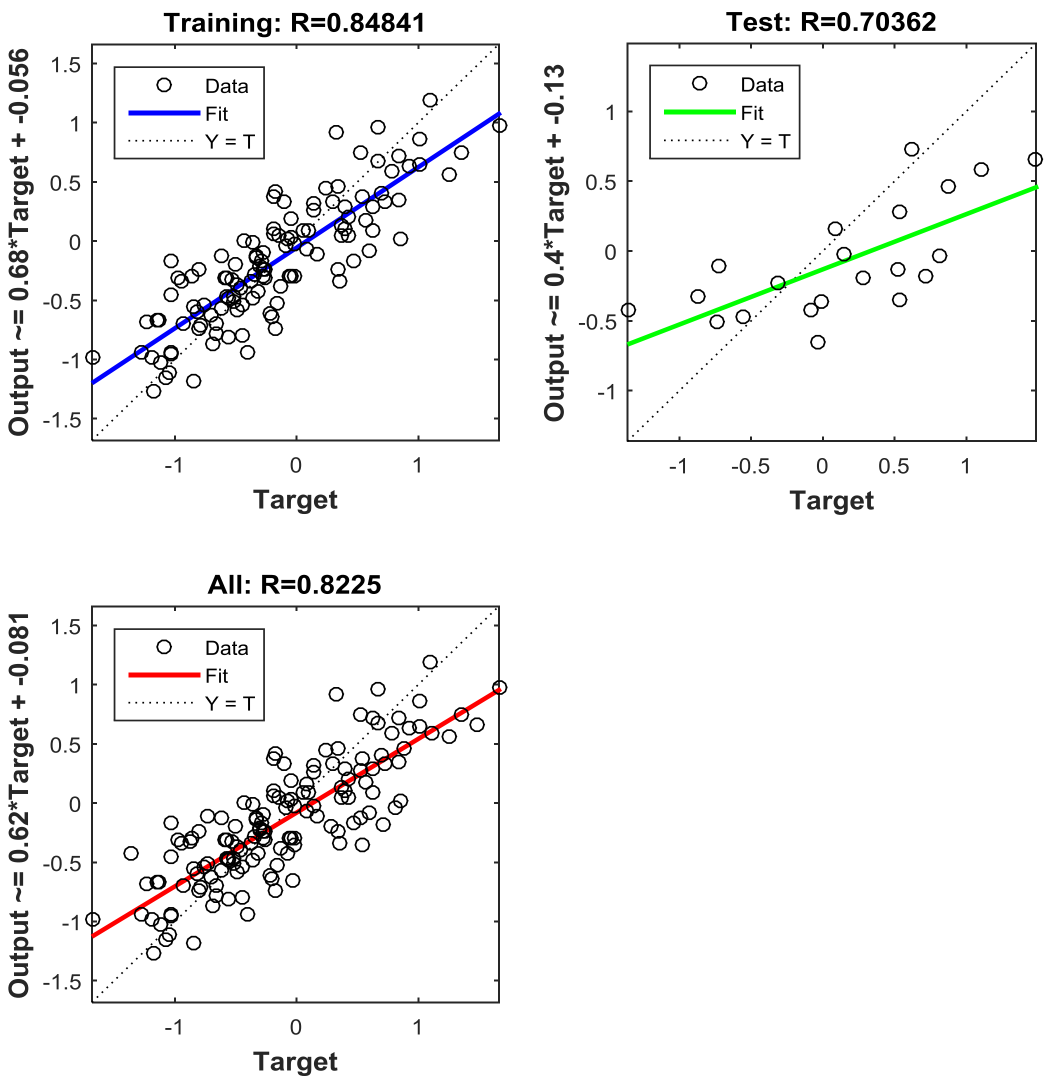


Figure D.2.10 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Eemseong

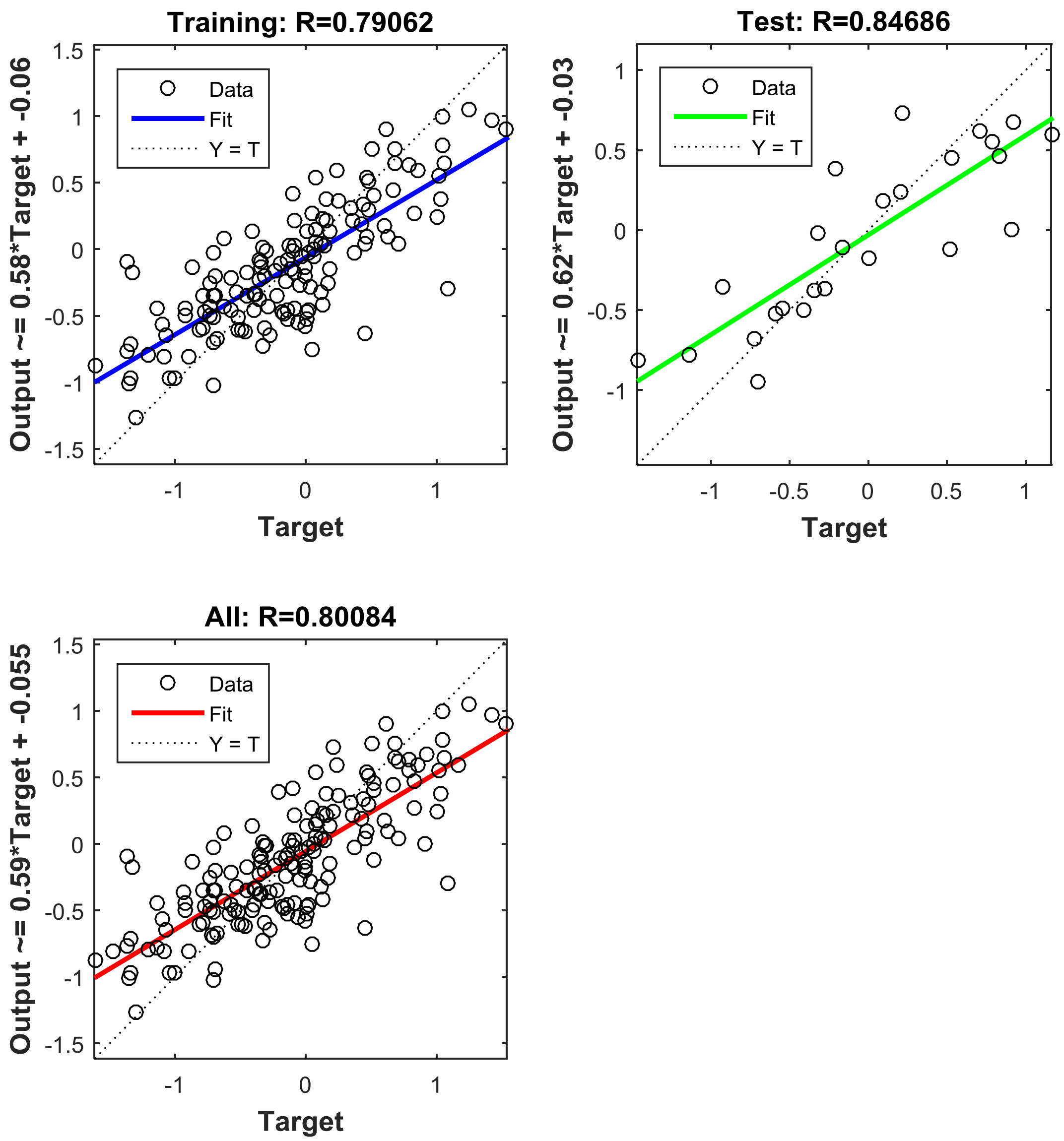


Figure D.2.11 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Danyang

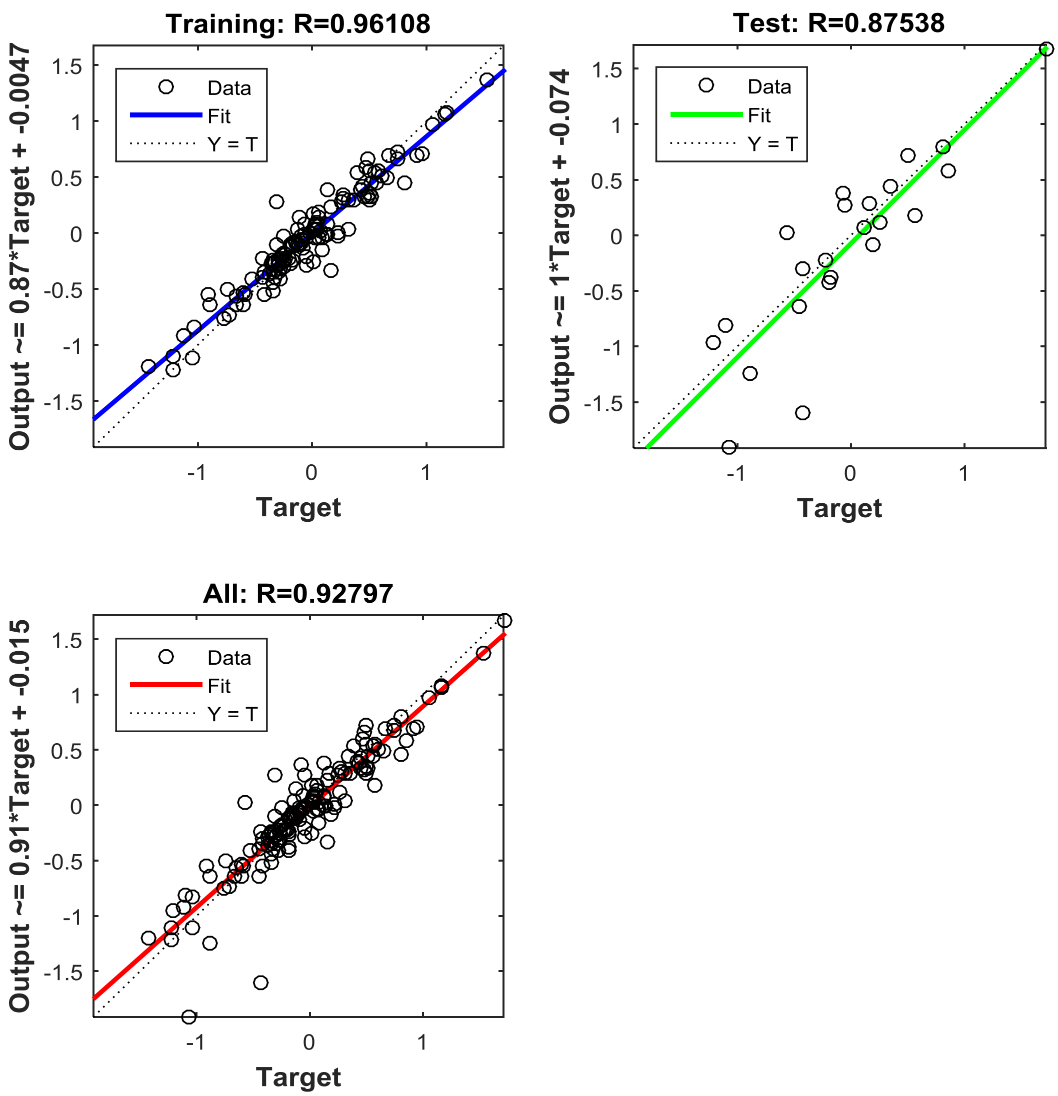


Figure D.2.12 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Cheonan

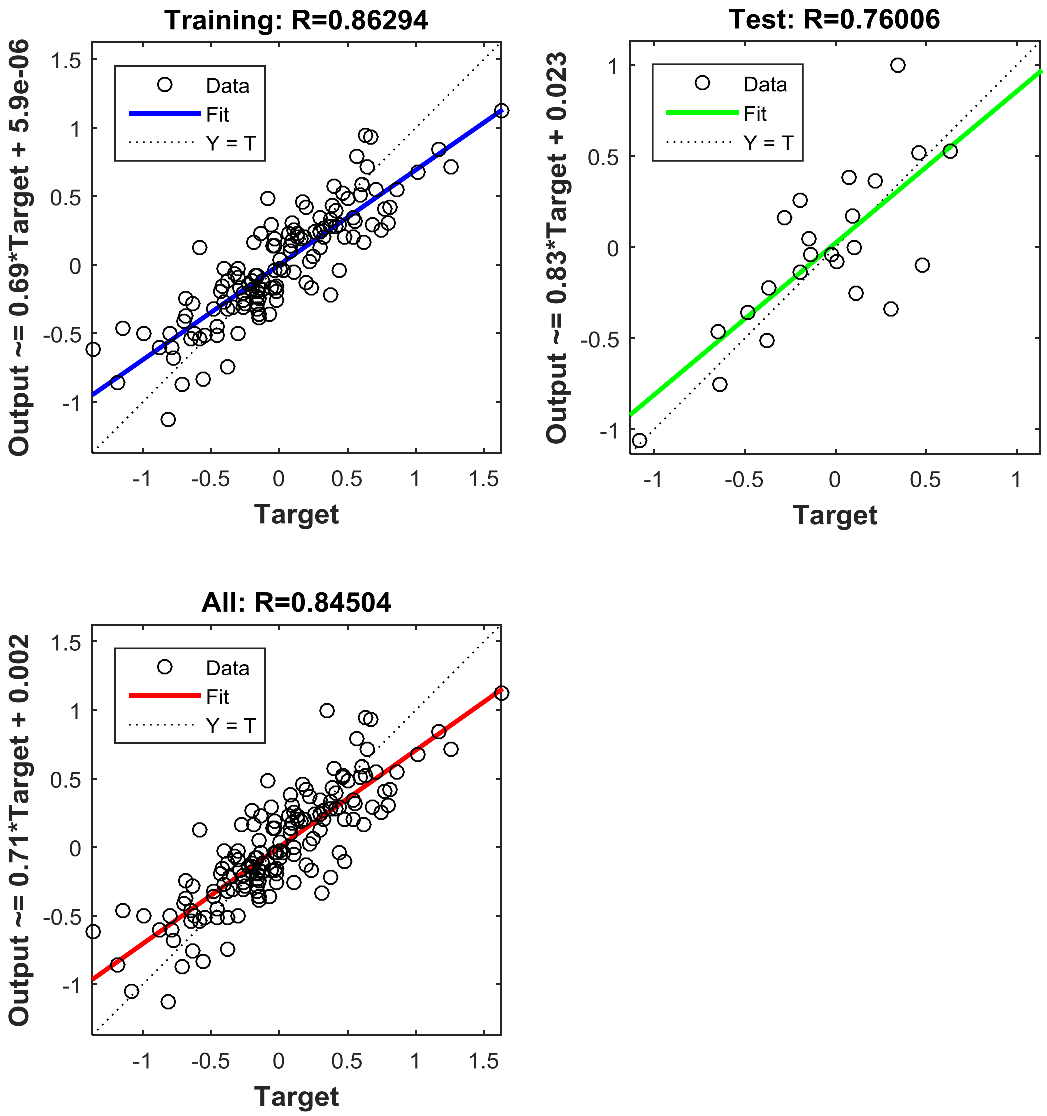


Figure D.2.13 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Gongju

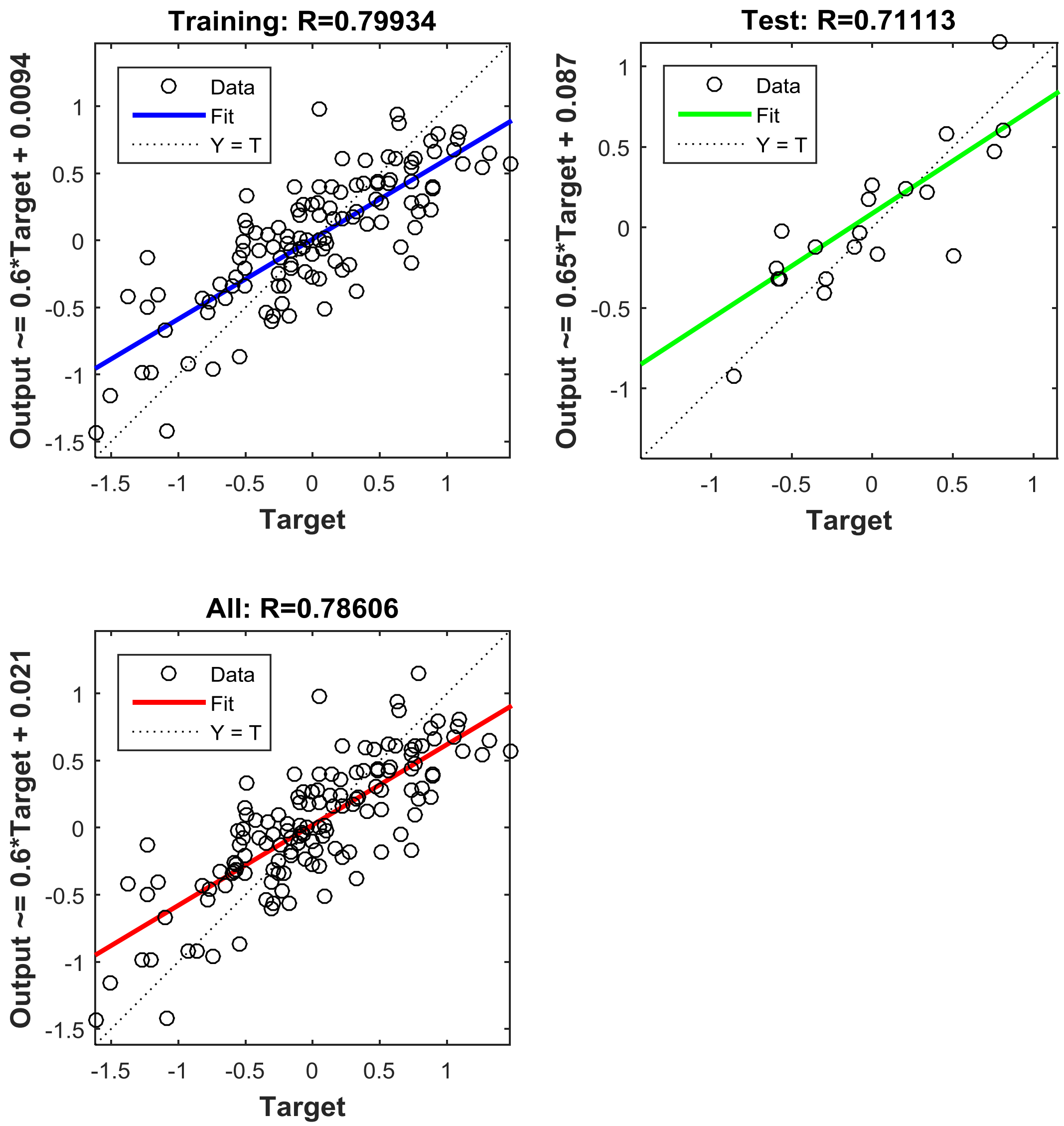


Figure D.2.14 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Boryeong

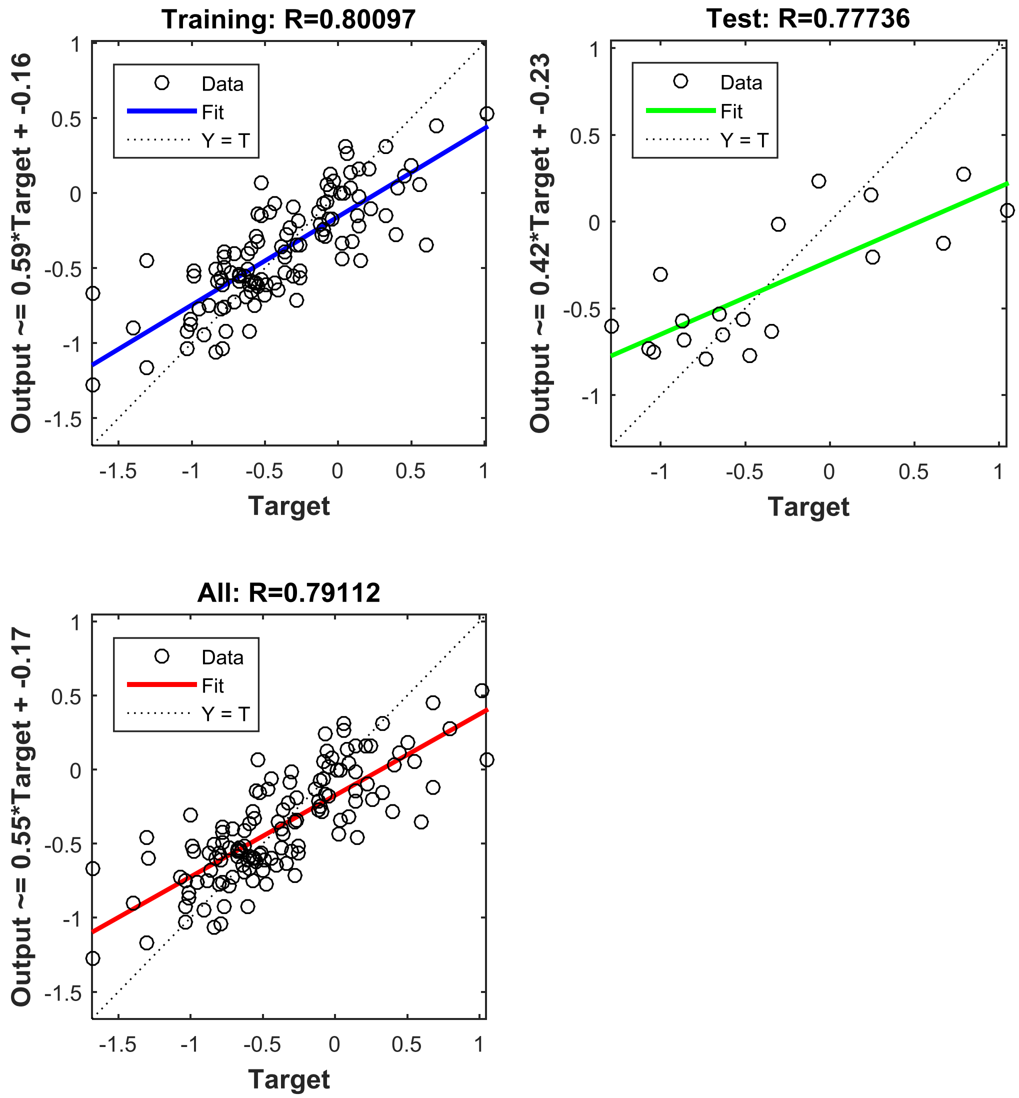


Figure D.2.15 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Asan

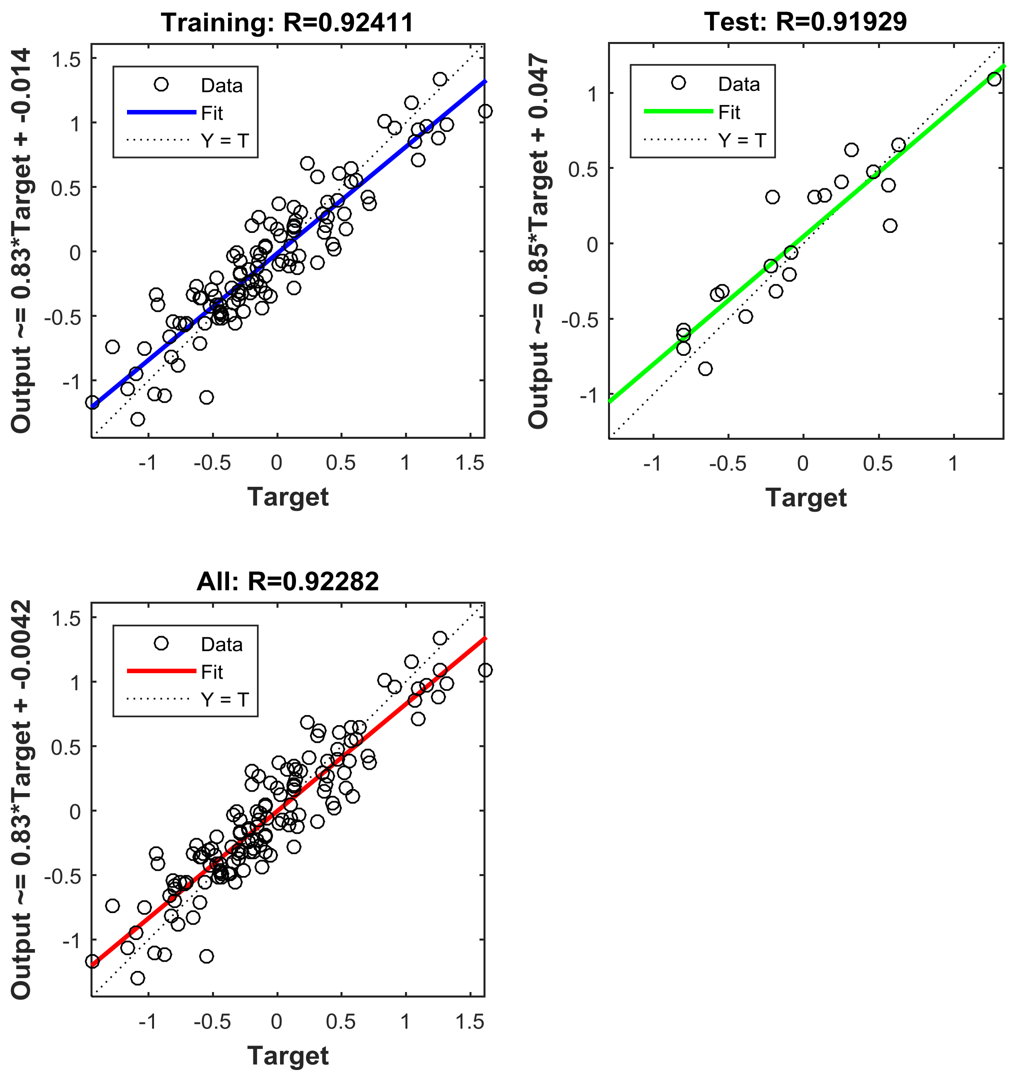


Figure D.2.16 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Seosan

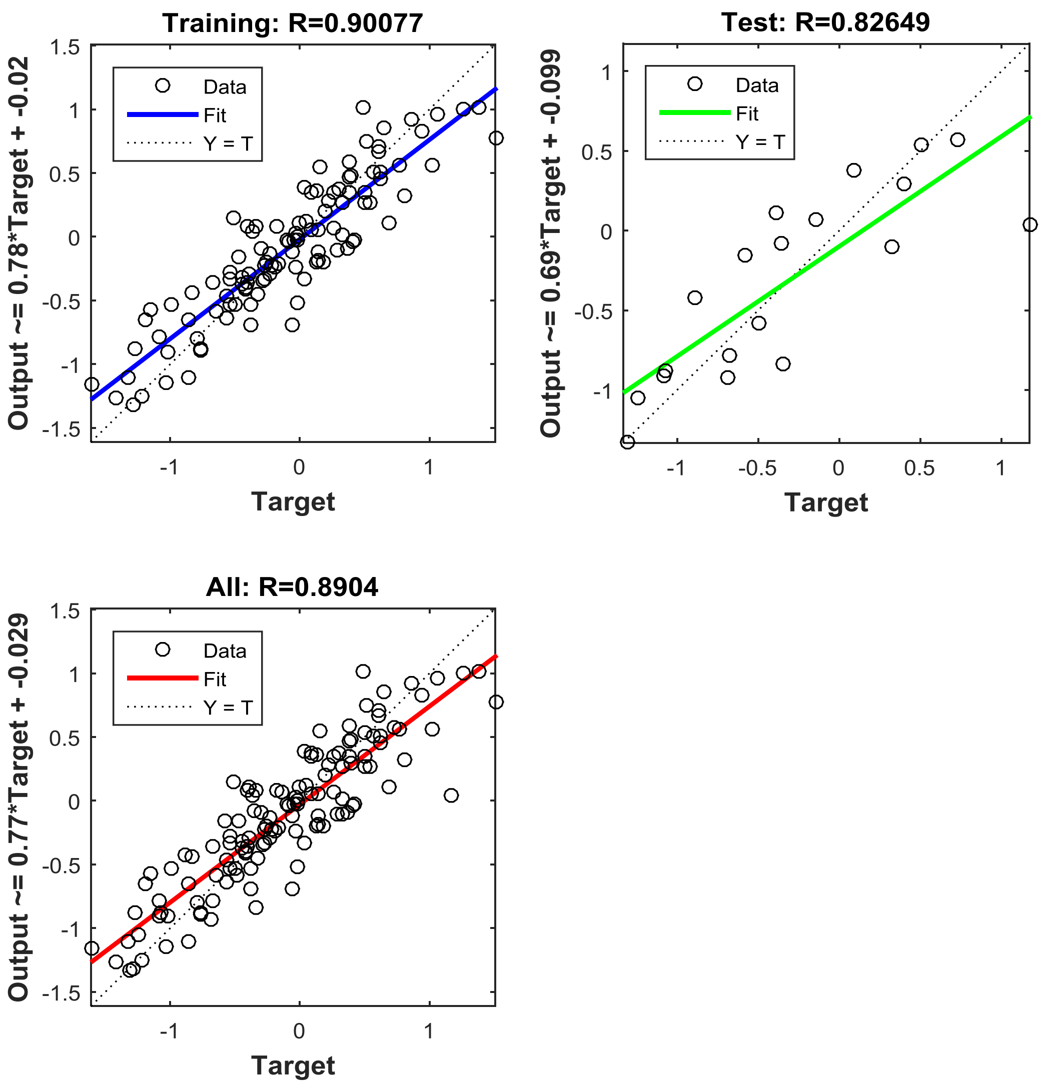


Figure D.2.17 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Nonsan

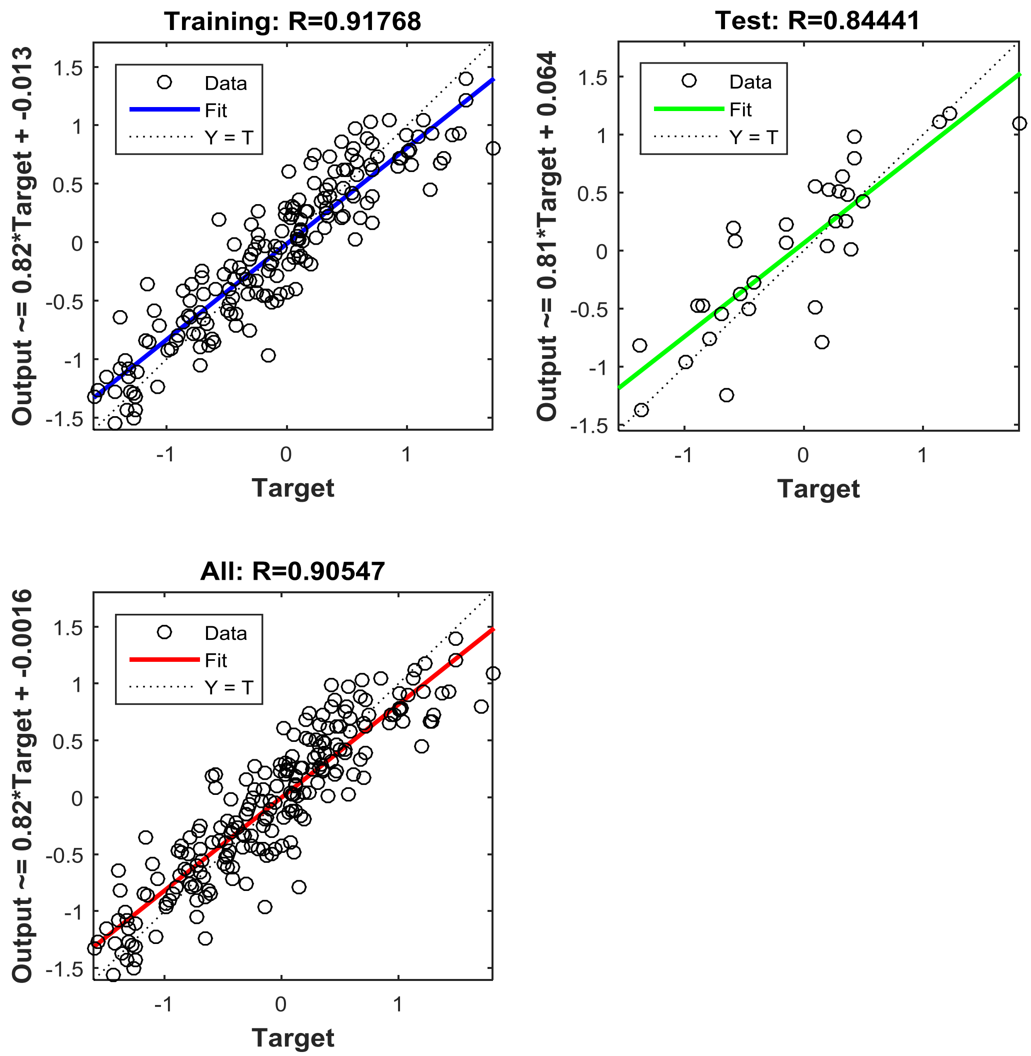


Figure D.2.18 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Gyeryong

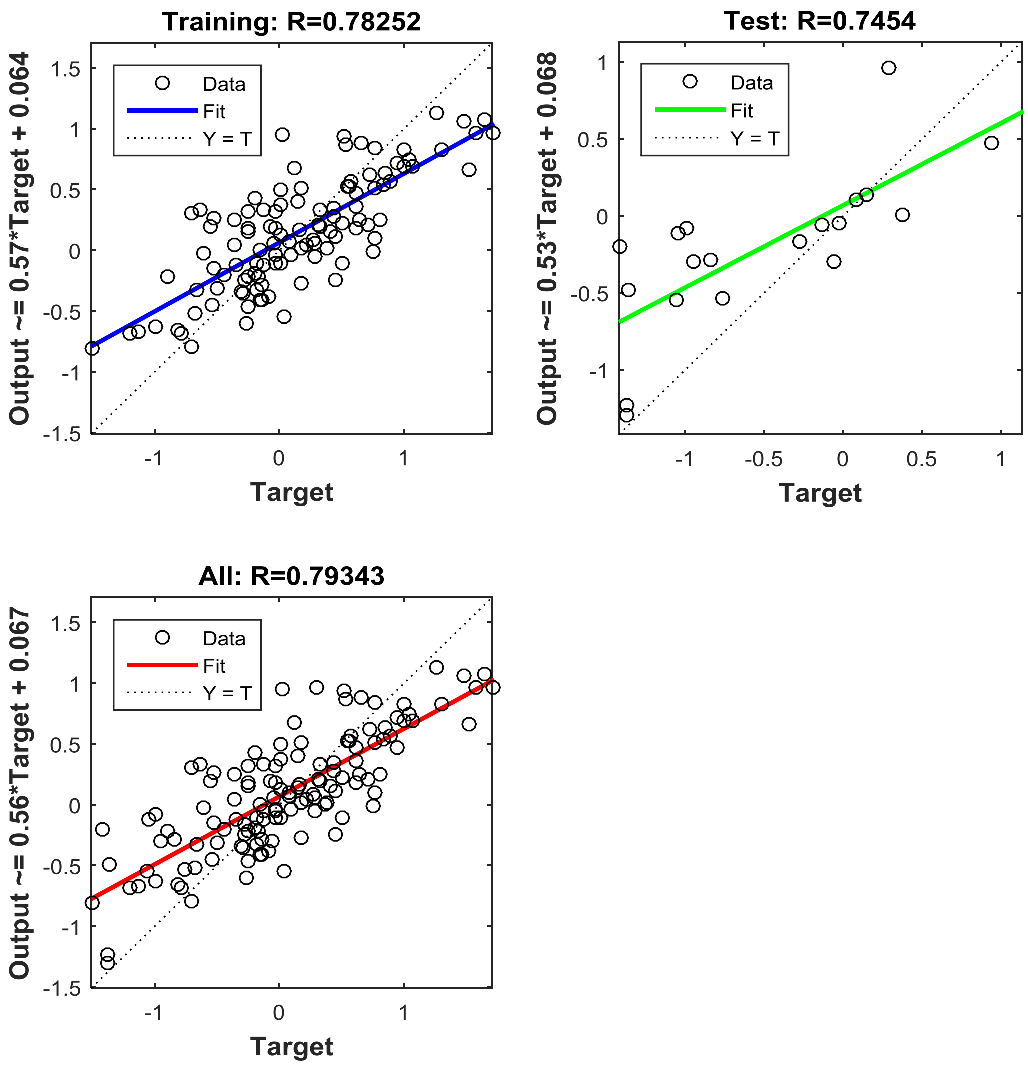


Figure D.2.19 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Dangjin

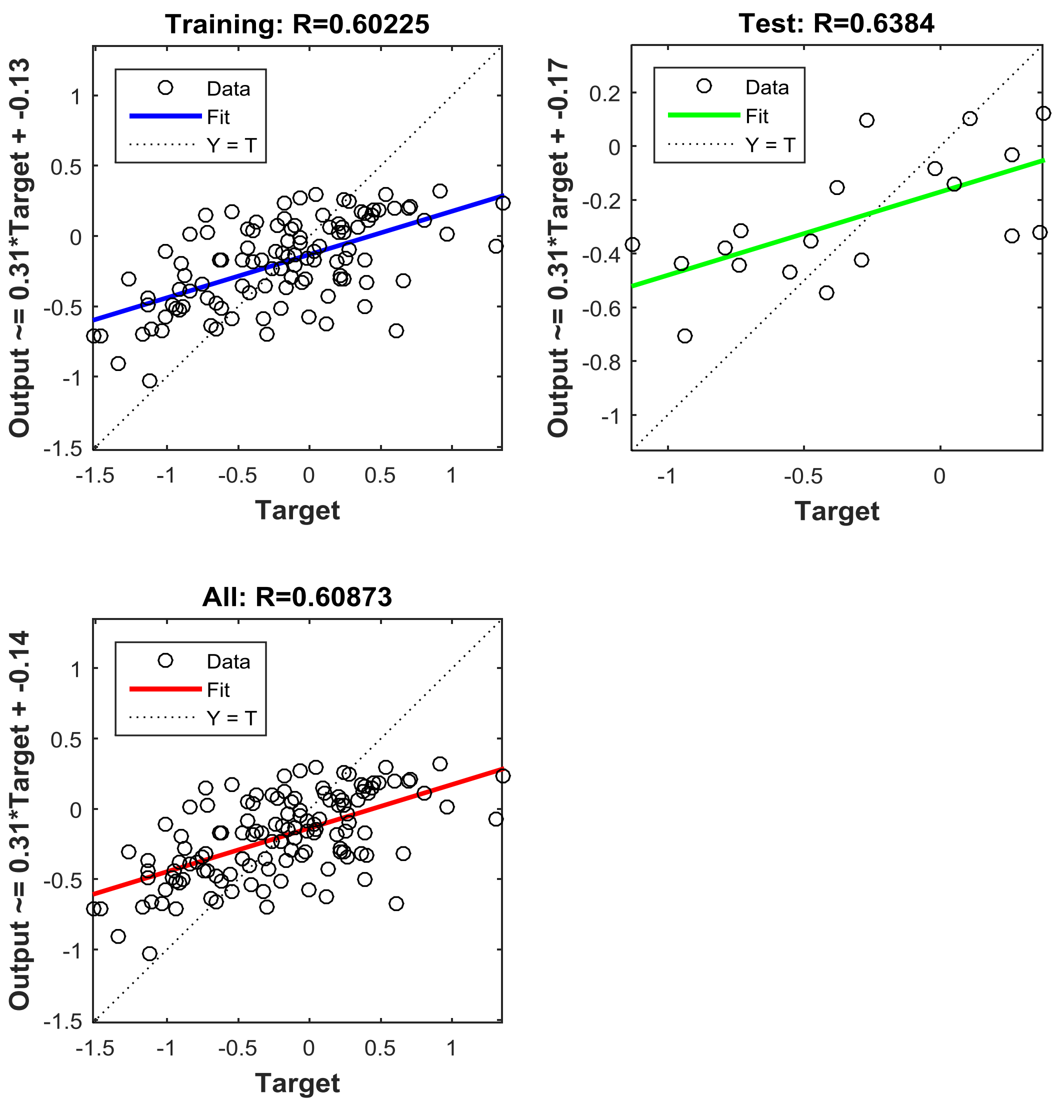


Figure D.2.20 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Geumsan

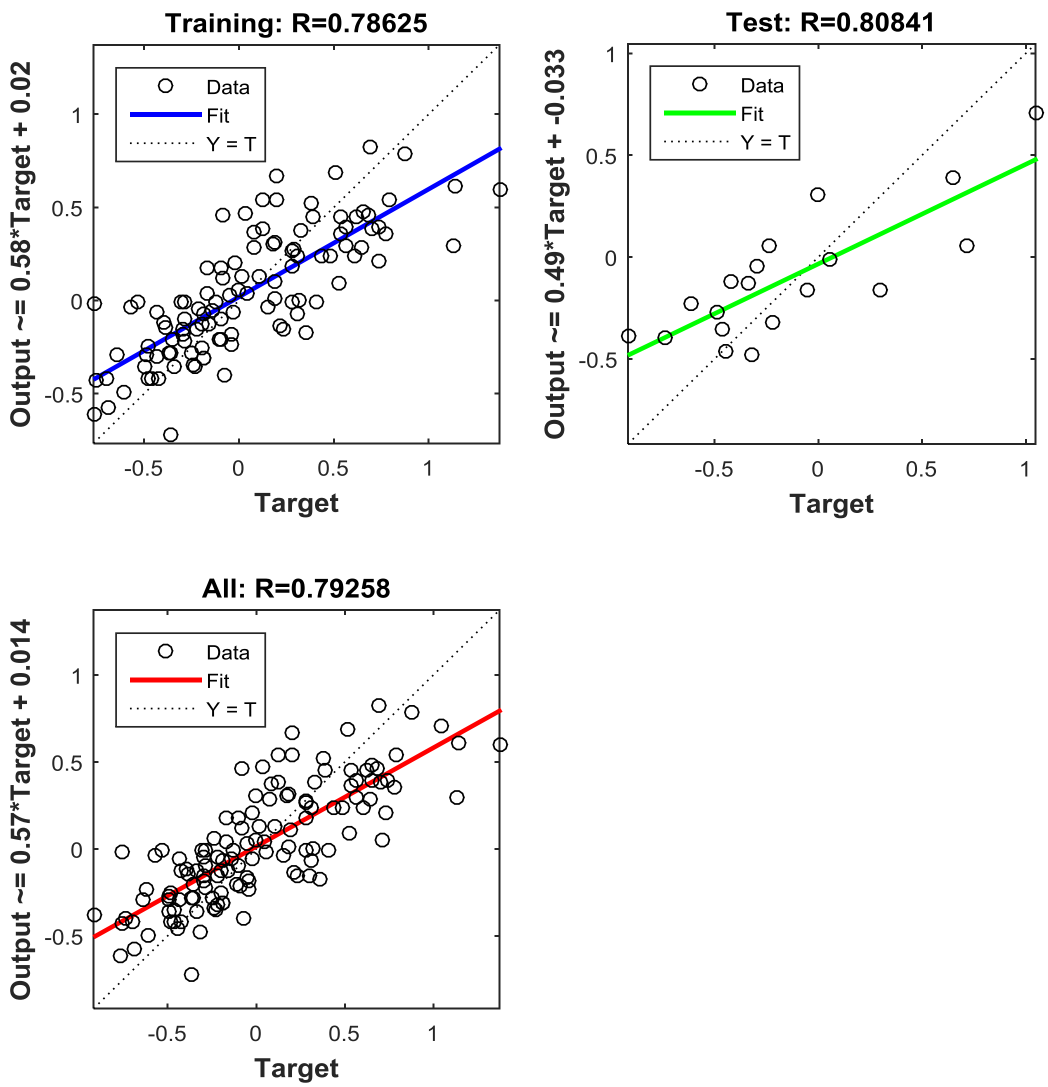


Figure D.2.21 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Buyeo

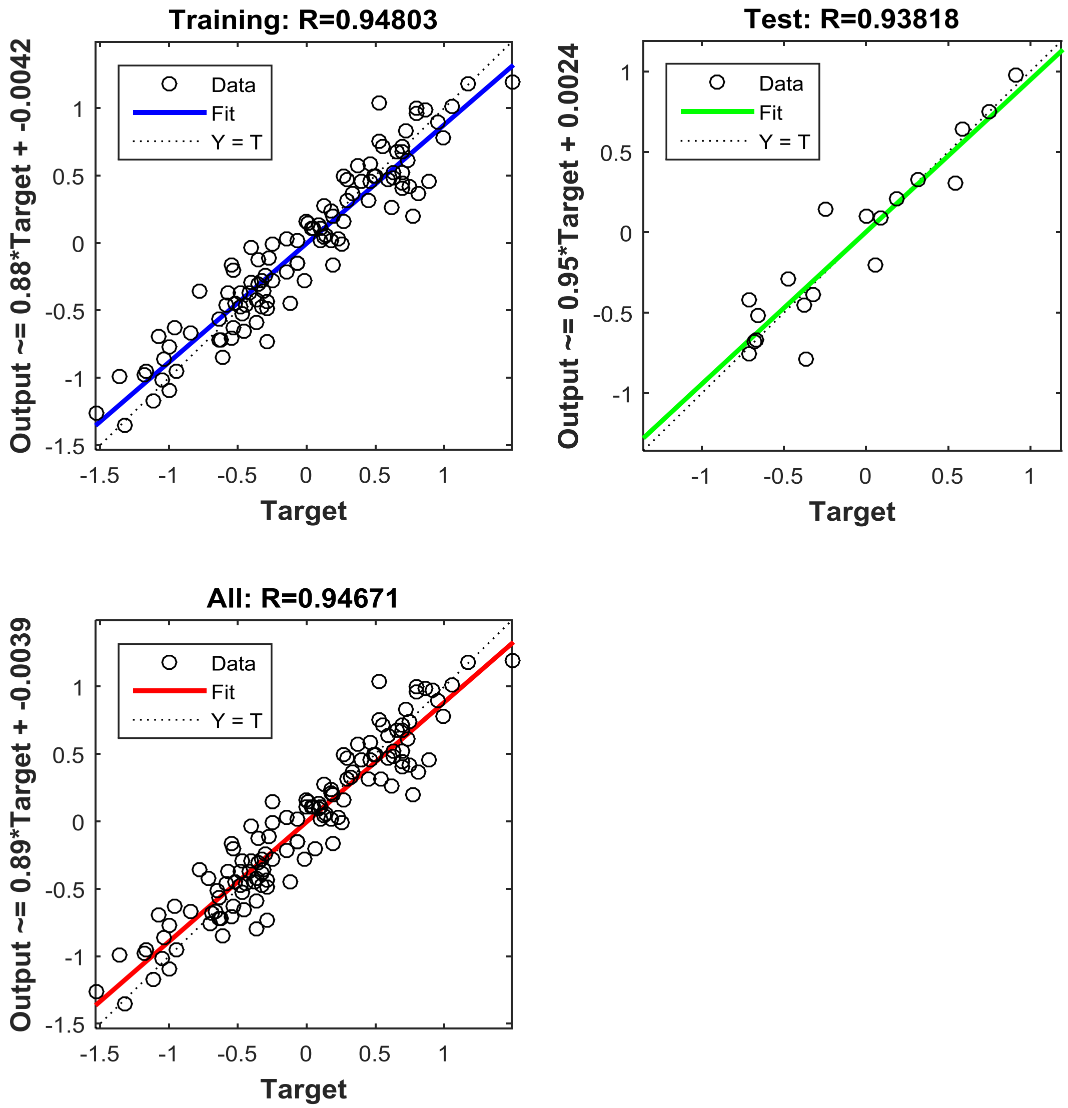


Figure D.2.22 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Seocheon

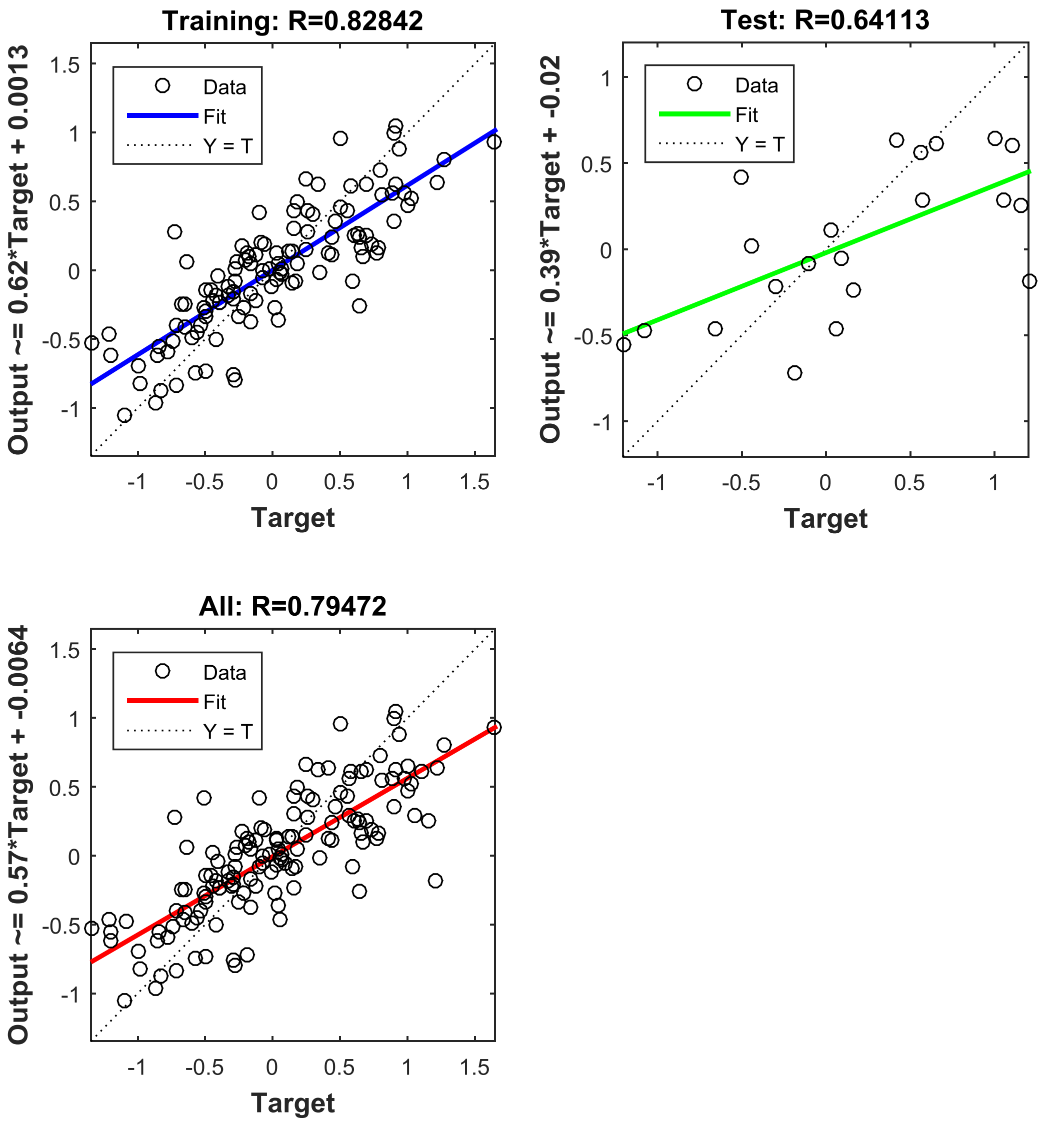


Figure D.2.23 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Cheongyang

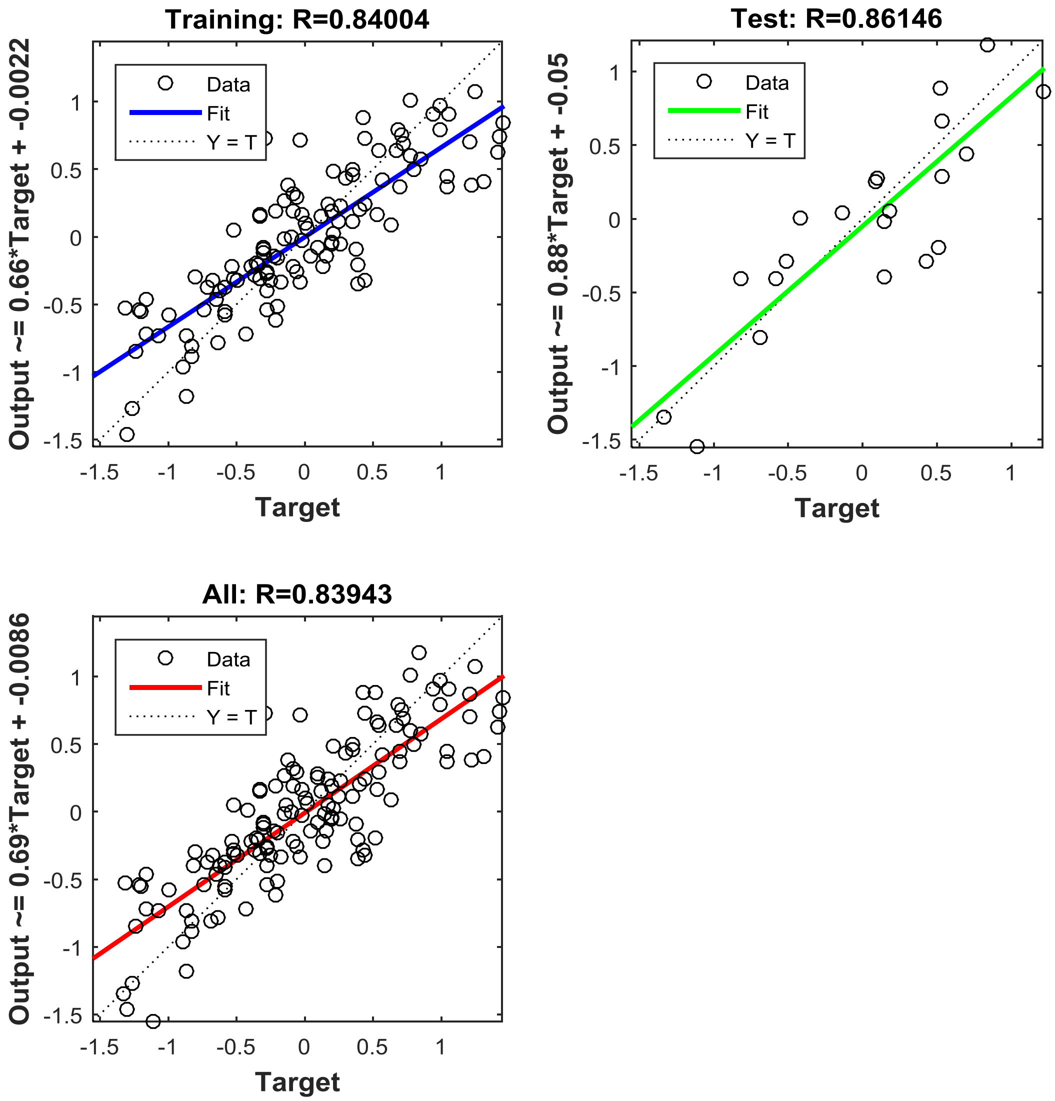


Figure D.2.24 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Hongseong

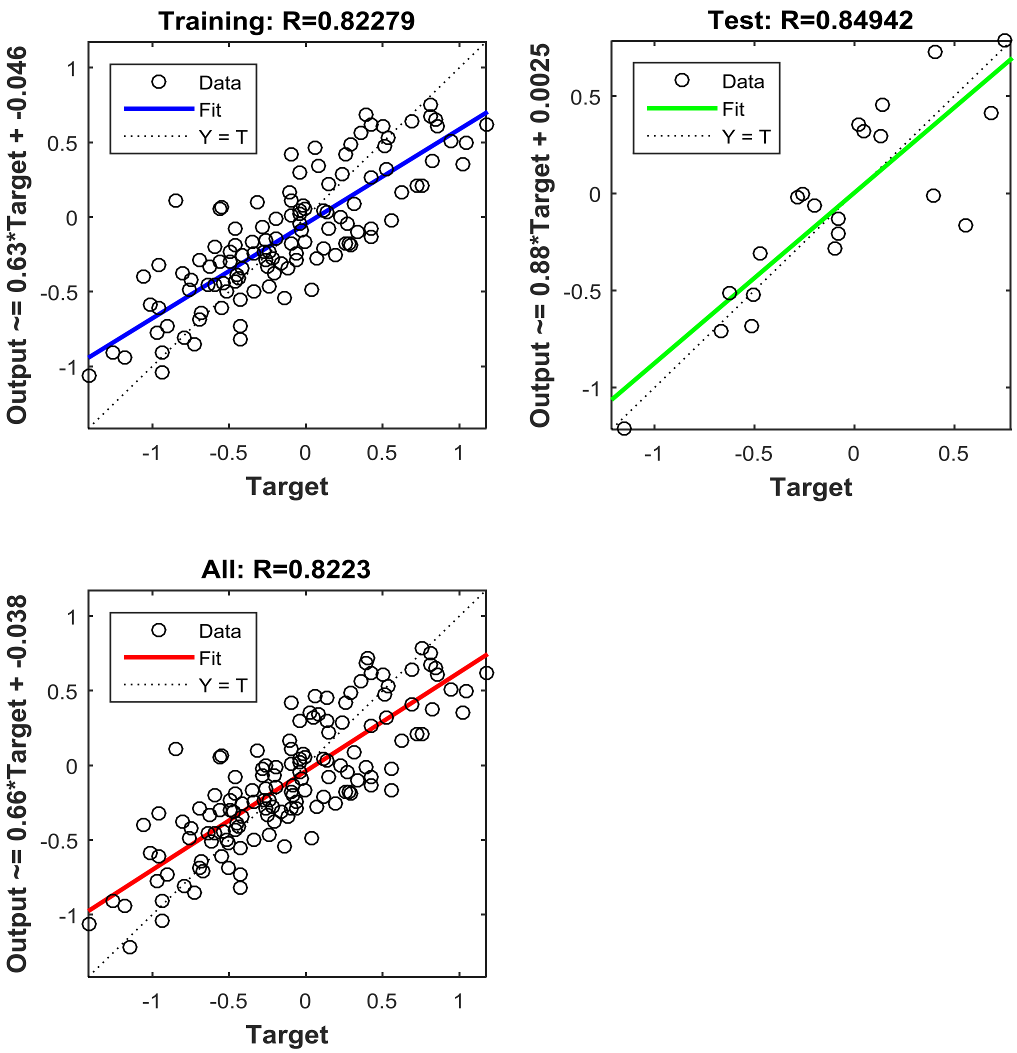


Figure D.2.25 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Yesan

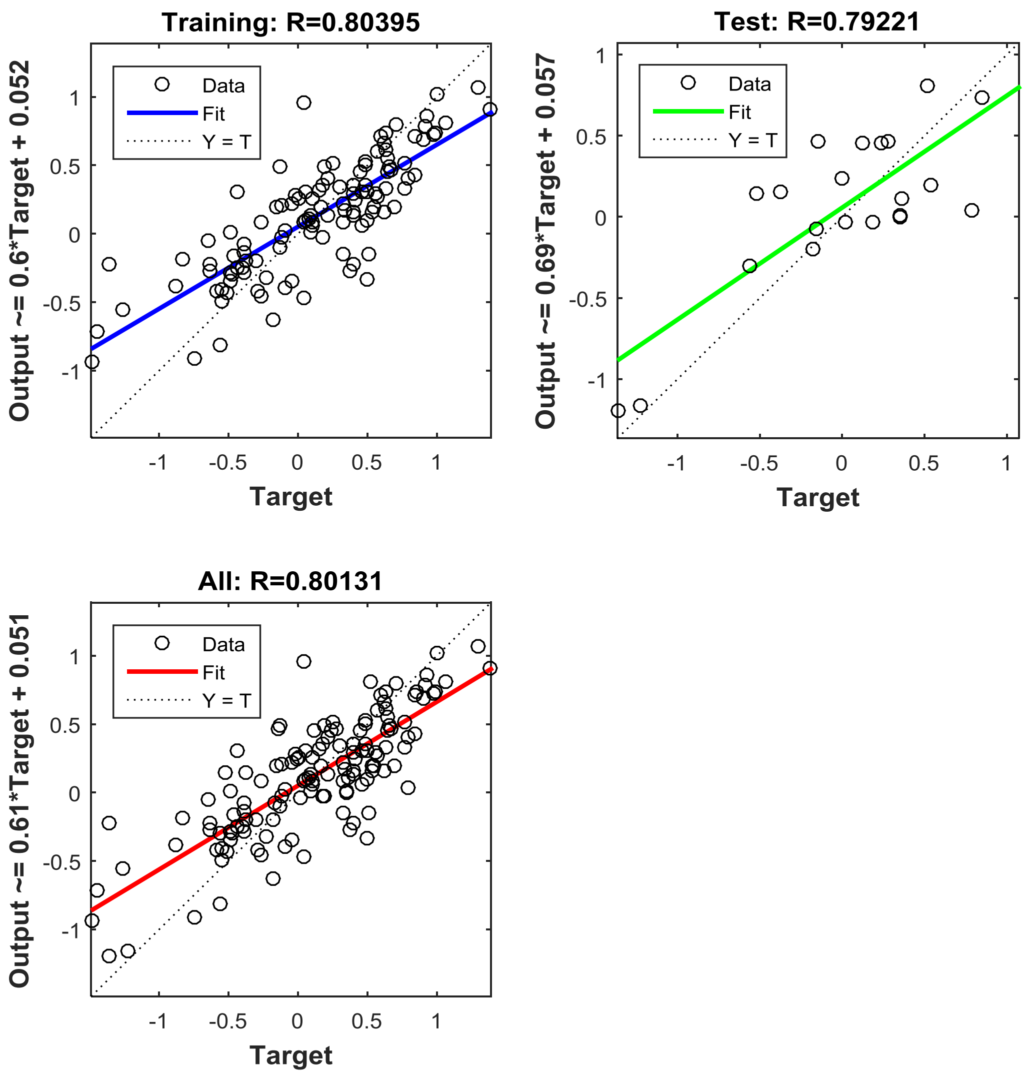


Figure D.2.26 Correlation between Target SGI & Estimated SGI on Training & Testing Dataset for Taean

D.3 Groundwater Drought Monitor in 2017

Table D.3.1 SGI values of 167 cities for groundwater drought monitoring in 2017 (1/4)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Seoul	0.144	-0.221	-0.317	-0.718	-2.545	-3.905	-0.986	-1.778	-2.798	-3.705	-3.836	-3.466
Busan	2.040	1.364	1.232	0.941	0.526	0.180	-0.393	-0.880	-1.093	-0.777	-0.522	-0.371
Gijang	0.640	0.023	0.018	-0.609	-0.434	-0.494	-1.714	-0.882	-0.439	-0.192	-0.556	-0.212
Daegu	0.310	-0.359	-0.534	-0.235	-0.969	0.259	-1.332	-0.900	-0.879	-0.453	-0.438	-0.611
Dalseong	1.262	0.374	0.270	0.320	-0.419	1.555	-0.522	-0.651	-0.726	-0.357	-0.342	-0.279
Incheon	-2.947	-3.268	-4.884	-2.262	-2.635	-3.079	-1.186	-0.468	-0.574	-0.735	-0.836	-1.346
Ganghwa	-1.212	-1.456	-1.485	-0.823	-1.075	-0.724	-0.504	-0.086	-0.150	-0.482	-0.469	-0.783
Ongjin	-0.785	-1.071	-1.000	-0.494	-0.699	-0.358	-0.071	0.279	0.115	0.044	0.062	-0.291
Gwangju	0.646	0.512	0.240	0.092	-0.330	-1.011	-1.312	-0.994	-0.379	0.027	-0.567	-1.099
Daejeon	0.149	-0.005	-0.204	-0.116	-0.563	-1.147	-0.192	0.297	0.045	0.267	0.306	0.203
Ulsan	0.134	0.138	-0.237	0.481	-0.397	-1.747	-2.070	-0.751	-0.709	-0.321	-0.727	-0.978
Ulju	0.473	0.246	-0.072	0.249	-0.624	-1.916	-2.430	-1.132	-0.892	-0.427	-0.825	-1.019
Sejong	-0.702	-0.714	-0.855	-0.893	-1.929	-2.317	-0.263	0.142	-0.282	0.173	-0.137	-0.100
Suwon	-2.214	-3.324	-3.084	-3.200	-5.155	-2.963	-1.506	-1.434	-1.287	-1.545	-1.884	-1.606
Seongnam	-0.926	-0.988	-1.028	-0.713	-1.195	-1.046	-0.499	-0.326	-0.325	-0.310	-0.403	-0.477
Uijeongbu	-0.128	-0.326	-0.524	-0.703	-1.385	-1.167	-0.397	-0.256	-0.517	-1.211	-1.156	-0.851
Anyang	-1.553	-1.446	-1.701	-1.994	-2.111	-2.210	-1.064	-0.601	-0.679	-0.615	-0.658	-0.658
Bucheon	-7.366	-7.701	-14.016	-6.313	-6.715	-8.400	-2.886	-1.296	-1.299	-1.303	-1.972	-3.450
Gwangmyeong	1.208	1.002	0.948	0.330	-0.465	-0.837	-0.457	-0.371	-0.766	-0.647	-0.473	0.542
Pyeongtack	-1.384	-1.367	-1.070	-1.173	-2.388	-1.721	-0.789	-0.390	-0.508	-0.582	-0.868	-1.053
Dongducheon	-0.868	-0.748	-0.822	-0.674	-1.244	-1.400	-1.009	-0.854	-0.536	-0.539	-0.637	-0.721
Ansan	-1.354	-1.538	-1.226	-0.781	-1.185	-1.579	-0.357	-0.053	-0.666	-0.691	-0.537	-0.494
Goyang	-0.069	-0.417	-0.319	-0.380	-1.471	-1.998	-0.547	-0.771	-1.325	-1.977	-1.988	-2.165
Gwacheon	-1.554	-1.439	-1.756	-2.131	-2.206	-2.299	-1.189	-0.669	-0.671	-0.569	-0.615	-0.569
Guri	-0.073	-0.320	-0.869	-1.496	-4.408	-6.689	-1.388	-3.182	-4.500	-6.799	-7.286	-6.541
Namyangju	-0.371	-0.941	-1.147	-0.670	-1.217	-1.073	-0.105	-0.323	-0.305	-0.328	-1.167	-1.149
Osan	-2.634	-3.060	-4.698	-4.528	-5.100	-4.406	-1.515	-0.599	-0.521	-0.695	-0.917	-1.117
Siheung	-0.915	-1.196	-1.193	-0.592	-1.159	-1.700	-0.609	-0.290	-0.604	-0.633	-0.420	0.032
Gunpo	-1.593	-1.554	-1.494	-1.380	-1.769	-1.888	-0.571	-0.421	-0.719	-0.865	-0.905	-1.140
Uiwang	-1.681	-1.676	-1.711	-1.738	-2.181	-2.272	-1.031	-0.835	-0.704	-0.830	-0.891	-1.054
Hanam	-1.666	-1.840	-2.094	-1.983	-2.412	-2.300	-1.927	-1.226	-0.871	-0.940	-1.070	-1.112
Yongin	-0.746	-0.912	-1.187	-1.336	-1.479	-1.433	-0.565	-0.178	-0.453	-0.733	-1.127	-1.101
Paju	-0.269	-0.602	-0.679	-0.392	-1.098	-1.385	-0.431	-0.360	-0.057	-0.356	-0.557	-0.644
Icheon	-1.272	-1.381	-1.891	-2.084	-1.668	-2.550	-0.635	-0.588	-1.027	-1.274	-1.389	-1.384
Anseong	-0.649	-0.911	-1.059	-1.146	-1.739	-1.635	-0.166	0.224	-0.280	-0.364	-0.176	-0.179
Gimpo	-1.255	-1.500	-1.575	-0.861	-1.116	-0.781	-0.521	-0.095	-0.160	-0.488	-0.480	-0.803
Hwaseong	-1.656	-1.958	-2.138	-2.233	-2.842	-2.744	-1.584	-0.441	-0.628	-0.654	-0.753	-0.812
Gwangju	-0.517	-0.644	-0.674	-0.183	-0.494	-0.374	-0.086	-0.169	-0.172	-0.115	-0.400	-0.421
Yangju	0.294	0.053	-0.096	-0.444	-1.272	-1.913	-0.688	-0.396	-0.415	-0.952	-0.961	-2.975
Pocheon	0.723	0.278	-0.153	0.221	-0.613	-0.859	-0.016	0.076	-0.322	-0.206	-0.372	-0.485
Yeoju	-0.333	-0.408	-0.593	-0.999	-1.506	-2.640	-0.183	-0.074	-0.392	-1.236	-0.850	-0.605

Table D.3.1 SGI values of 167 cities for groundwater drought monitoring in 2017 (2/4)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Yeoncheon	0.003	0.104	-3.458	-0.670	-0.364	-0.389	-0.077	-0.120	0.047	0.097	-0.486	-1.032
Gapyeong	0.059	-0.435	-0.929	-0.575	-1.168	-1.183	0.091	0.298	-0.160	-0.276	-0.551	-0.640
Yangpyeong	-0.247	-0.493	-0.760	-0.796	-1.085	-1.011	0.159	-0.317	-0.274	-1.628	-3.181	-1.740
Chuncheon	-0.074	-0.490	-0.904	-0.822	-1.276	-1.322	-0.343	-0.071	-0.238	-0.319	-0.666	-0.760
Wonju	-0.972	-1.121	-1.685	-1.808	-3.128	-1.962	-0.283	-0.051	-0.243	-0.440	-0.424	-0.487
Gangneung	0.344	-0.207	-1.063	-1.184	-1.221	-0.528	0.241	2.030	-0.342	0.151	-0.327	-0.485
Donghae	0.821	-0.221	-1.258	-0.800	-2.143	-1.610	-1.807	0.621	-1.249	-0.410	-1.449	-1.547
Taeback	1.367	0.402	-0.171	-0.342	-1.239	-1.478	-0.486	-0.028	-0.225	-0.564	-1.304	-2.120
Sokcho	0.615	0.412	-0.278	-0.283	-0.650	-1.238	-0.816	0.683	-0.009	0.062	-0.264	-0.721
Samcheok	1.530	1.196	0.329	-0.022	-1.162	-1.325	-0.927	-0.799	-1.003	-1.148	-2.110	-2.688
Hongcheon	0.238	-0.209	-0.629	-0.490	-1.001	-0.922	0.183	0.419	-0.472	-0.484	-0.757	-0.934
Hoengseong	0.200	-0.154	-0.678	-0.350	-0.947	-0.830	0.058	0.397	-0.420	-0.303	-0.361	-0.581
Yeongwol	-0.454	-0.686	-0.918	-0.815	-1.361	-1.450	-0.323	0.196	-0.088	-0.358	-0.774	-1.106
Pyeongchang	-0.179	-0.751	-1.366	-1.223	-1.586	-1.190	0.244	0.485	-0.334	-0.536	-0.628	-0.844
Jeongseon	0.155	-0.622	-0.977	-0.566	-1.900	-1.587	0.006	0.606	-0.692	-2.683	-6.321	-9.587
Cheorwon	0.316	0.296	-3.868	-0.635	-0.314	-0.492	0.415	0.504	0.394	0.426	-0.183	-0.700
Hwacheon	-0.235	-0.442	-0.630	-0.466	-1.295	-1.635	-0.505	-0.054	0.277	0.161	-0.098	-0.022
Yanggu	1.065	0.482	-0.466	0.415	-0.866	-0.732	-0.036	0.585	-0.183	-0.209	-0.576	-0.833
Inje	1.876	1.251	0.053	1.250	0.021	-0.263	0.235	1.372	-0.075	-0.097	-0.389	-0.773
Goseong	0.147	-0.494	-1.010	-0.987	-1.418	-1.781	-0.745	0.684	-0.541	-0.694	-1.054	-1.352
Yangyang	1.102	0.836	0.293	0.244	-0.881	-0.152	-0.606	1.200	0.022	0.701	0.189	-0.773
Cheongju	-0.286	-0.255	-0.108	-0.150	-0.556	-0.850	0.179	0.394	0.084	0.234	0.041	0.158
Chungju	-0.276	-0.227	-0.409	-0.510	-0.985	-1.431	-0.379	0.171	-0.207	-0.422	-0.407	-0.462
Jecheon	-0.192	0.053	-0.868	-0.168	-1.637	-0.982	0.266	0.638	-0.344	-0.416	-0.549	-0.729
Boeun	0.426	0.432	0.334	0.339	-0.121	-0.457	0.105	0.392	-0.218	-0.045	-0.212	-0.199
Okcheon	-0.062	-0.326	-0.538	-0.264	-1.238	-1.063	0.143	0.561	-0.003	0.018	-0.280	-0.448
Yeongdong	-0.075	-0.069	-0.607	-0.868	-1.315	-0.907	-0.592	-0.130	-0.602	-1.016	-0.656	-0.971
Jeungpyeong	1.146	1.206	0.910	1.263	-0.502	-1.219	0.859	1.418	0.759	1.464	1.496	1.312
Jincheon	-0.540	-0.538	-0.726	-0.732	-0.887	-0.739	0.285	0.558	0.130	-0.308	-0.184	-0.457
Goesan	0.837	0.692	0.462	0.843	-0.256	-0.826	0.778	1.007	0.415	0.856	0.540	0.409
Eumseong	0.161	0.084	-0.193	-0.893	-1.324	-2.077	0.284	0.256	-0.226	-0.064	0.315	-0.015
Danyang	0.199	0.275	-0.338	-0.245	-0.964	-0.769	0.387	0.519	-0.359	-0.369	-0.513	-1.269
Cheonan	-1.555	-1.118	-1.344	-1.260	-1.890	-2.352	-0.053	0.461	-0.291	-0.337	-0.740	-0.776
Gongju	-0.230	-0.174	-0.489	-0.502	-1.200	-1.374	-0.117	0.459	-0.088	-0.043	-0.299	-0.512
Boryeong	-0.781	-0.865	-1.342	-2.004	-3.335	-4.328	-1.361	-1.032	-1.041	-0.931	-1.299	-1.084
Asan	-13.115	-5.084	-9.537	-4.867	-2.350	-1.482	-0.454	-0.447	-0.673	0.078	-3.620	-8.623
Seosan	-0.919	-1.120	-0.509	-1.265	-3.068	-1.805	-0.789	-0.534	-0.792	-0.971	-1.326	-1.151
Nonsan	-0.003	-0.012	-0.154	-0.410	-1.454	-2.155	-0.726	-0.734	-0.628	-0.514	-0.905	-1.117
Gyeryong	-0.320	-0.136	-0.354	-0.477	-1.343	-1.714	-0.769	-0.305	-0.376	-0.325	-0.674	-0.949
Dangjin	-1.775	-1.245	-1.648	-1.160	-1.666	-1.703	-0.005	0.726	0.117	-0.292	-1.036	-0.874
Geumsan	-0.110	-0.600	-0.445	-0.123	-0.701	-1.287	-0.085	-0.177	-0.262	-0.012	-0.564	-0.779
Buyeo	0.160	-0.075	-0.484	-0.803	-1.361	-1.272	-0.746	0.039	0.066	-0.099	-0.340	-0.682
Seocheon	-0.474	-0.537	-0.756	-1.152	-1.533	-1.833	-1.370	-0.985	-0.464	-0.385	-0.516	-0.748

Table D.3.1 SGI values of 167 cities for groundwater drought monitoring in 2017 (3/4)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Cheongyang	0.257	0.104	-0.567	-0.510	-1.972	-2.136	-0.242	0.344	-0.136	-0.252	-0.862	-0.742
Hongseong	-0.883	-0.554	-1.076	-1.279	-2.312	-3.257	-0.849	-0.689	-0.753	-0.701	-1.263	-0.868
Yesan	-1.103	-0.748	-1.659	-1.264	-1.807	-2.480	-0.336	-0.264	-0.372	-0.354	-1.219	-1.888
Taean	-0.448	-0.485	-0.901	-1.136	-1.622	-0.891	-0.125	0.089	-0.039	0.151	-0.343	-0.522
Jeonju	-0.514	-0.454	2.056	-0.265	-0.550	-0.875	-0.410	-0.298	-0.279	-0.858	-0.889	-1.431
Gunsan	-0.712	-0.805	-0.912	-1.189	-1.711	-2.778	-2.329	-0.705	-0.194	-0.015	-0.599	-0.966
Iksan	0.148	0.177	0.073	-0.192	-0.485	-0.600	-0.821	-0.464	-0.070	-0.048	-0.377	-0.802
Jeongeup	-0.834	-0.959	-1.815	-1.895	-1.477	-1.251	-1.915	-0.926	-1.196	-0.478	-0.528	-0.929
Namwon	0.262	-0.126	-0.137	-0.122	-0.444	-0.841	-1.189	-0.963	-0.576	-0.162	-0.506	-0.829
Gimje	-0.740	-0.839	-0.922	-0.841	-1.366	-1.834	-1.565	-0.821	-0.316	-0.694	-1.279	-2.135
Wanju	-0.173	-0.301	-0.104	-0.629	-1.526	-2.234	-0.630	-0.477	-0.523	-0.839	-1.443	-1.615
Jinan	0.352	0.156	0.018	-0.064	-0.361	-0.583	0.036	0.958	0.366	0.772	-0.143	-0.469
Muju	-0.823	-0.214	-0.108	-0.060	0.008	-0.180	-0.579	-0.389	-0.524	-0.165	-0.255	-0.453
Jangsu	1.172	1.242	0.982	0.893	0.203	-0.135	-0.085	0.326	0.114	0.492	0.107	0.159
Imsil	-0.466	-0.474	-0.334	-0.582	-0.719	-0.545	-0.654	-0.739	-0.577	-0.214	-0.443	-0.503
Sunchang	-1.156	-0.862	-0.936	-0.775	-1.110	-1.154	-1.063	-0.518	-1.334	-0.399	-1.381	-1.538
Gochang	-1.151	-1.048	-0.946	-0.857	-1.202	-1.302	-2.037	-0.933	-0.778	-1.397	-2.335	-3.632
Buan	-0.204	0.033	0.211	-0.042	-0.233	-0.607	-0.735	0.014	-0.275	0.104	-0.025	-1.098
Mokpo	0.427	0.385	0.248	0.157	-0.025	0.131	-1.589	-0.243	-0.129	0.280	0.233	0.186
Yeosu	1.188	0.961	0.453	0.224	-0.151	-0.306	-1.862	-0.018	0.823	1.140	0.788	0.442
Suncheon	0.653	0.303	0.036	-0.137	-0.830	-1.040	-1.646	-1.783	-1.229	-1.018	-1.398	-1.440
Naju	1.047	0.945	0.575	0.510	0.116	-1.423	-1.842	-1.373	-0.799	-0.577	-1.067	-1.167
Gwangyang	0.543	-0.006	-0.540	-0.558	-3.388	-2.968	-5.656	-1.266	-0.771	-0.387	-1.071	-1.220
Damyang	0.145	0.120	-0.138	-0.249	-0.694	-1.107	-1.154	-0.475	-0.363	0.350	-0.305	-0.745
Gokseong	0.298	0.265	-0.121	-0.134	-0.377	-0.633	-1.324	-0.796	-0.461	0.027	-0.452	-0.644
Gurye	-0.403	-0.336	-0.487	-0.624	-1.883	-1.420	-1.269	-0.825	-1.391	-1.464	-2.540	-1.195
Goheung	1.338	1.081	0.660	0.297	-0.603	-0.882	-2.740	-0.904	-0.169	0.549	0.186	-0.070
Boseong	1.278	0.845	0.580	0.389	-0.407	-0.652	-1.602	-0.900	-0.419	0.121	-0.249	-0.301
Hwasun	1.300	0.883	0.124	-0.090	-0.849	-1.300	-1.613	-0.277	0.064	0.520	0.138	-0.329
Jangheung	1.163	0.719	0.448	0.165	-0.616	-0.433	-0.458	-0.467	0.011	0.431	0.226	0.078
Gangjin	1.256	0.663	0.238	0.292	-0.999	-0.627	-0.909	-0.921	-0.073	0.591	-0.095	-0.385
Haenam	1.058	0.548	-0.004	-0.161	-0.937	-0.962	-1.788	-1.519	-0.888	-0.753	-1.269	-1.155
Yeongam	0.763	0.198	-0.173	0.192	-0.874	-0.919	-1.970	-1.090	-0.537	0.146	-0.474	-0.816
Muan	0.247	0.244	0.109	0.023	-0.184	-0.276	-1.361	-0.947	-0.662	-0.160	-0.132	-0.211
Hampyeong	-0.892	-0.737	-1.007	-1.547	-2.121	-3.645	-1.836	-0.564	-0.338	-0.787	-1.059	-0.926
Yeonggwang	-2.009	-1.412	-1.140	-3.399	-4.105	-7.299	-2.250	-1.300	-1.010	-2.239	-2.346	-3.036
Jangseong	0.437	0.525	0.454	0.357	-0.071	-0.359	-0.332	0.175	0.052	0.255	-0.118	0.032
Wando	0.640	0.222	-0.196	-0.213	-0.868	-0.889	-0.929	-0.672	0.109	0.091	-1.194	-0.872
Jindo	0.433	-0.215	-0.899	-1.751	-5.435	-2.042	-4.277	-1.243	-1.641	-0.420	-1.008	-0.679
Sinan	0.379	0.195	-0.072	-0.371	-1.516	-0.574	-2.109	-1.163	-1.039	-0.245	-0.339	-0.328
Pohang	1.790	0.098	-0.432	0.057	-0.843	-1.831	-2.474	-0.542	-0.646	0.576	-0.422	-0.503
Gyeongju	0.853	0.681	0.535	0.556	0.121	-0.664	-0.683	0.047	-0.052	0.582	0.122	0.126

Table D.3.1 SGI values of 167 cities for groundwater drought monitoring in 2017 (4/4)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Gimcheon	-0.002	0.419	-0.243	-0.115	-0.535	-0.946	-1.168	-0.454	-0.686	-0.114	-0.655	-1.050
Andong	0.779	0.609	0.331	0.583	-0.089	-0.335	0.131	0.672	-1.380	0.517	0.374	0.257
Gumi	-0.787	-0.259	-1.261	-0.190	-0.769	-0.778	-1.202	-0.391	-0.827	-0.512	-1.019	-1.328
Yeongju	-0.925	-1.219	-1.837	-0.909	-1.461	-1.542	-0.413	0.009	-0.758	-0.965	-1.137	-1.874
Yeongcheon	1.107	0.571	0.171	0.771	0.032	0.330	-0.337	0.665	0.307	0.926	0.000	-0.209
Sangju	0.092	0.028	-0.286	0.083	-1.024	-1.273	-0.235	0.261	-0.205	0.079	-0.777	-0.888
Mungyeong	0.342	0.042	-0.435	0.154	-0.258	-0.547	0.602	0.762	0.154	0.207	-0.357	-0.654
Gyeongsan	0.068	-0.474	-0.829	-0.654	-1.509	-0.505	-4.021	-1.647	-1.338	-0.715	-1.135	-2.356
Gunwi	-0.655	-0.691	-1.052	0.206	-1.006	-0.448	-1.070	-0.609	-0.981	-0.385	-0.534	-0.969
Uiseong	-0.370	-0.331	-0.553	0.392	-0.104	-0.357	-0.337	-0.022	-0.442	0.123	0.044	0.062
Cheongsong	1.162	0.007	-0.213	0.439	-0.045	-0.025	-0.607	0.349	-0.149	0.101	-0.376	-0.156
Yeongyang	0.875	0.356	0.213	1.198	-0.556	-0.815	0.039	0.969	-2.970	0.466	-0.042	-0.335
Yeongdeok	0.078	-0.807	-1.101	-0.748	-1.566	-1.491	-1.658	-0.425	-0.843	-0.156	-1.018	-1.280
Cheongdo	0.194	-0.546	-0.699	-0.766	-1.190	-0.297	-1.660	-0.962	-1.102	-0.881	-0.752	-1.139
Goryeong	-0.998	-1.203	-1.116	-0.980	-1.172	-0.863	-1.700	-1.196	-1.323	-1.160	-1.194	-1.366
Seongju	0.125	0.029	-0.378	-0.189	-0.739	-0.959	-1.516	-0.547	-0.967	-0.895	-0.677	-0.754
Chilgok	0.785	0.569	-0.248	0.315	-0.718	-0.661	-1.408	-0.206	-0.924	-0.913	-0.555	-0.618
Yecheon	-0.976	-1.024	-1.177	-0.896	-1.137	-1.204	-0.819	-0.204	-0.457	-0.497	-0.584	-0.786
Bonghwa	0.860	0.134	-0.401	0.212	-1.004	-1.151	-0.486	0.417	-3.162	-0.119	-0.471	-0.886
Uljin	1.105	0.665	-0.254	0.085	-1.032	-1.712	-1.311	0.605	-1.564	-0.024	-0.270	-0.576
Ulleung	0.824	0.236	-1.060	-0.986	-1.039	-2.886	-2.470	-0.270	-1.018	-0.811	-1.003	-1.259
Changwon	1.780	1.263	1.086	1.231	0.465	0.145	-0.262	0.135	0.131	0.597	0.878	0.784
Jinju	0.485	0.243	0.049	0.605	-0.315	-0.548	-1.078	-0.865	1.363	0.370	0.176	-0.135
Tongyeong	-0.070	-0.333	-1.244	-0.875	-2.778	-2.926	-4.937	-1.200	-0.350	-0.152	-1.148	-0.946
Sacheon	0.792	0.680	0.573	0.298	-0.152	-1.190	-3.210	-2.101	-1.154	-0.673	-0.655	-0.301
Gimhae	1.510	1.044	0.551	0.648	-0.010	-0.744	-1.110	-0.726	-0.381	-0.150	-0.140	-0.024
Miryang	0.951	0.733	0.380	0.386	-0.135	-0.059	-0.721	-0.582	-0.732	-0.836	-0.466	-0.874
Geoje	-0.848	-1.042	-1.400	-1.284	-1.741	-1.446	-1.752	-1.313	-0.861	-0.732	-1.302	-1.201
Yangsan	1.226	0.454	-0.175	-1.223	-0.755	-1.398	-3.039	-1.705	-0.752	-0.943	-1.110	-1.748
Uiryeong	0.786	0.646	0.380	0.499	-0.194	0.031	-1.252	-0.764	-0.500	0.594	0.164	0.050
Haman	0.777	0.687	0.520	0.858	-0.007	0.152	-0.446	0.266	0.471	0.711	0.401	0.335
Changnyeong	0.657	0.508	0.509	0.612	0.159	-0.240	-0.919	-0.391	-0.855	0.048	-0.132	-0.082
Goseong	1.110	0.841	0.296	0.358	-0.740	-1.530	-9.159	-1.510	0.666	0.381	-0.211	-0.132
Namhae	0.583	0.676	-0.008	-0.240	-0.775	-12.607	-37.981	-7.841	-1.015	0.155	-0.797	-0.313
Hadong	-0.131	-0.057	-0.505	-0.650	-4.823	-4.700	-10.304	-2.344	-1.074	-0.104	-1.125	-1.586
Sancheong	1.205	0.743	0.654	0.785	-0.011	0.314	-0.627	-0.746	-0.248	0.372	0.018	-0.389
Hamyang	-0.331	-1.134	-0.536	0.267	-0.562	-0.780	-0.929	-0.900	-0.540	-0.249	-0.424	-1.084
Geochang	0.295	0.061	1.079	2.012	0.872	0.102	-0.869	-0.599	-0.626	0.179	-0.207	-0.376
Hapcheon	0.415	0.382	0.137	0.282	-0.507	-0.734	-2.550	-1.828	-0.996	-0.164	-1.065	-0.539
Jeju	0.281	0.095	-0.082	-0.140	-0.555	-0.811	-1.812	-1.491	-1.917	-1.600	-2.236	-1.823
Seogwipo	0.289	0.177	0.061	-0.044	-0.434	-0.786	-1.484	-1.551	-1.986	-1.801	-1.981	-1.769

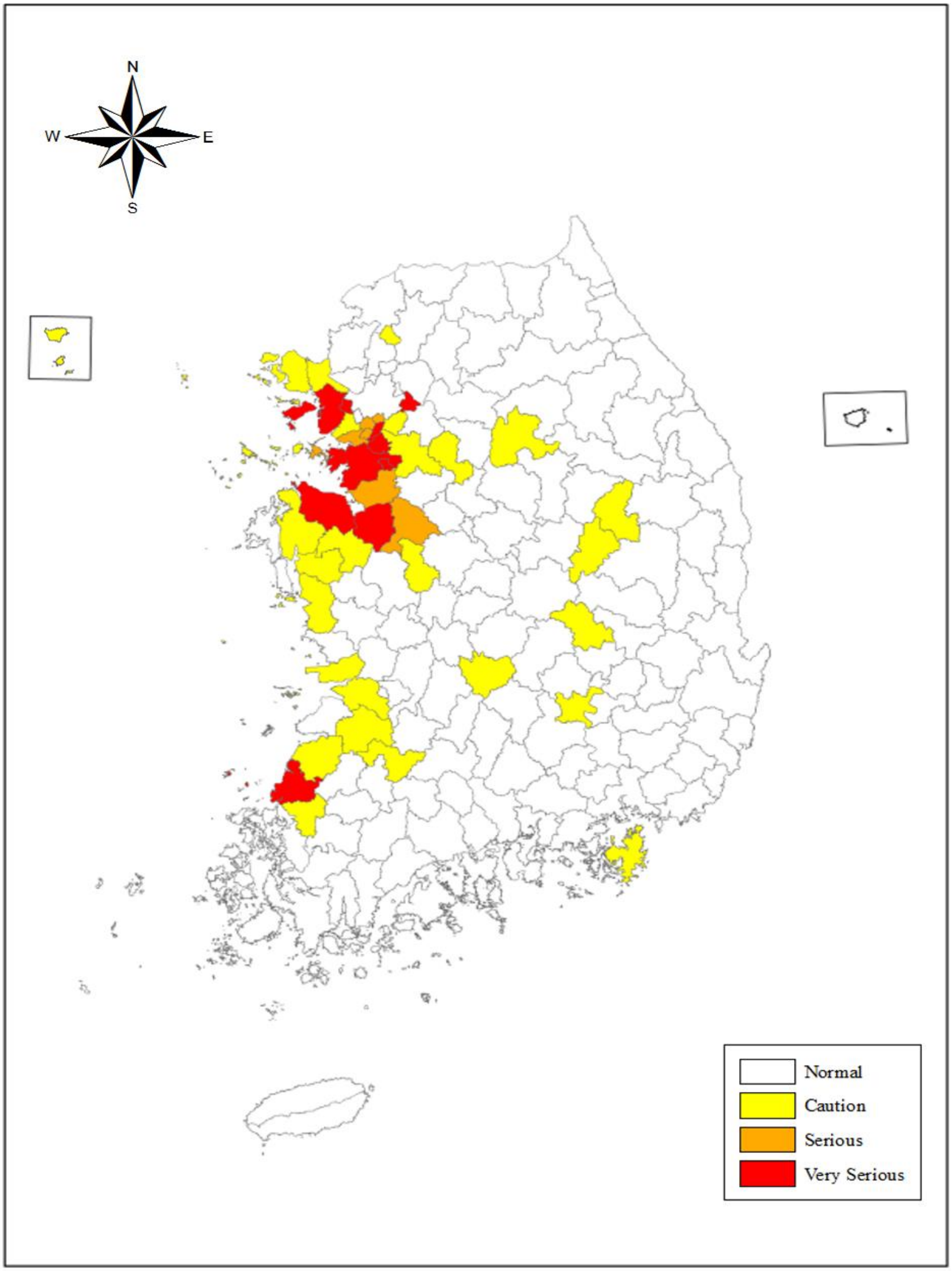


Figure D.3.1 Groundwater Drought Monitor in January 2017

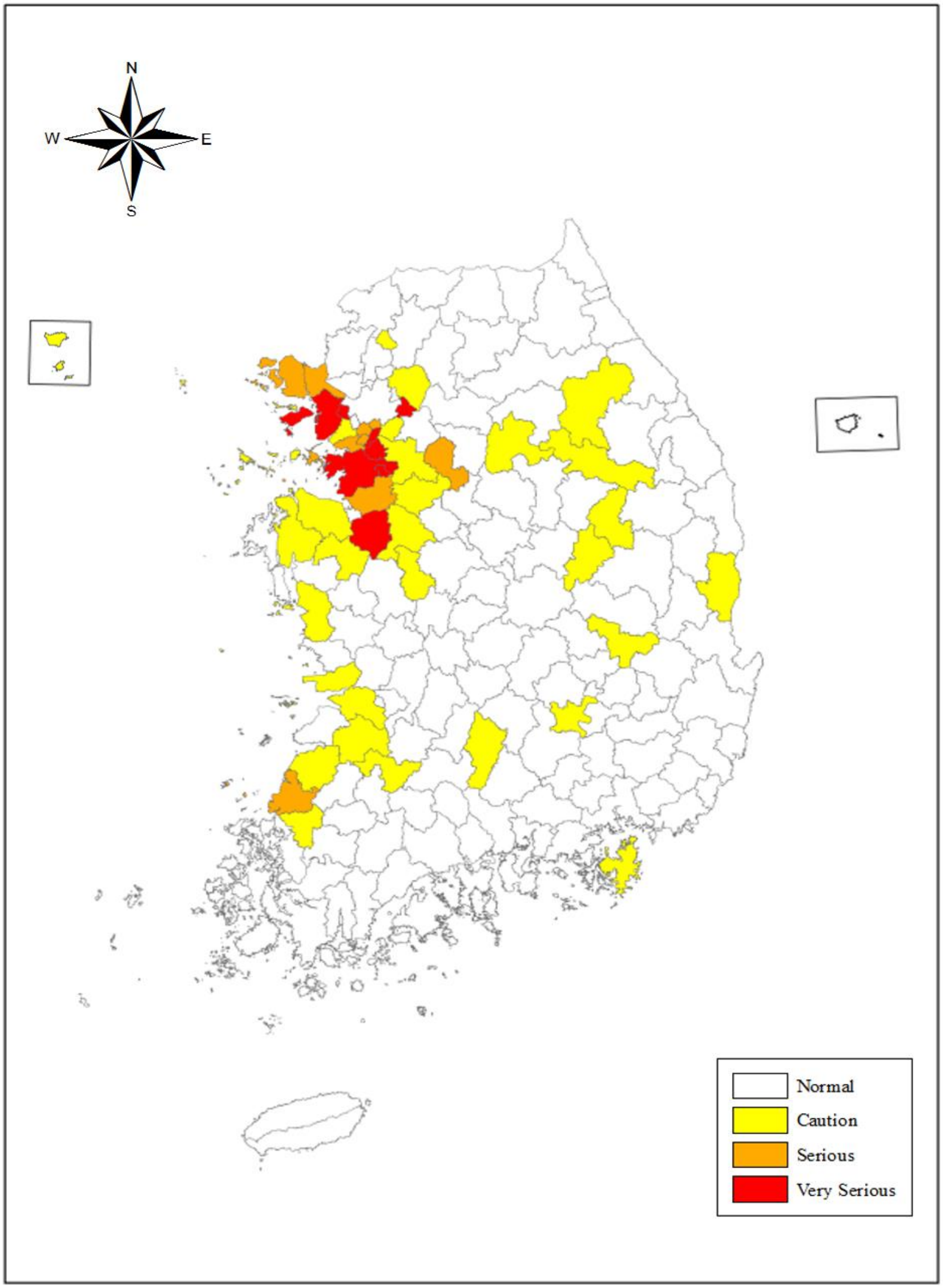


Figure D.3.2 Groundwater Drought Monitor in February 2017

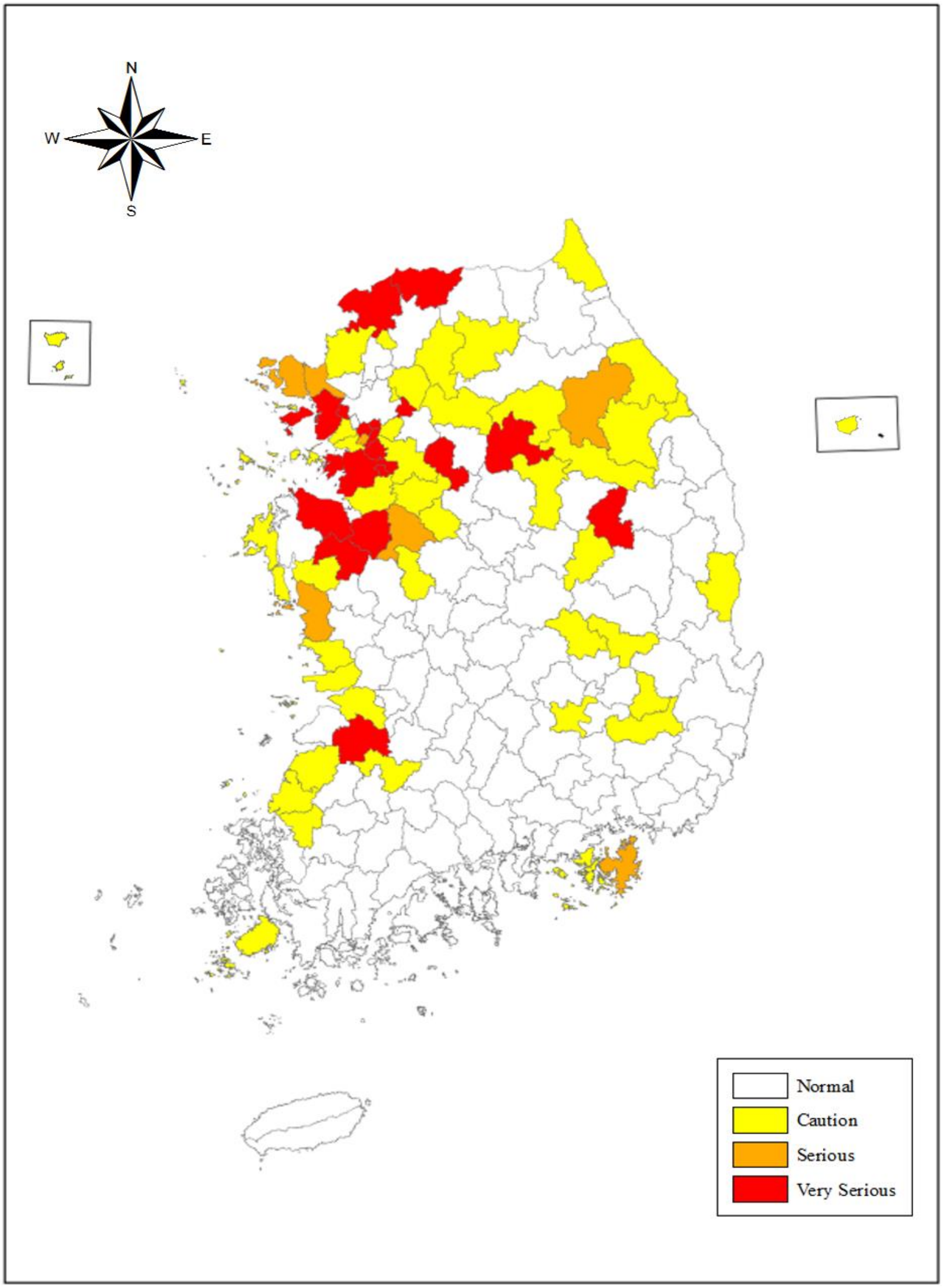


Figure D.3.3 Groundwater Drought Monitor in March 2017

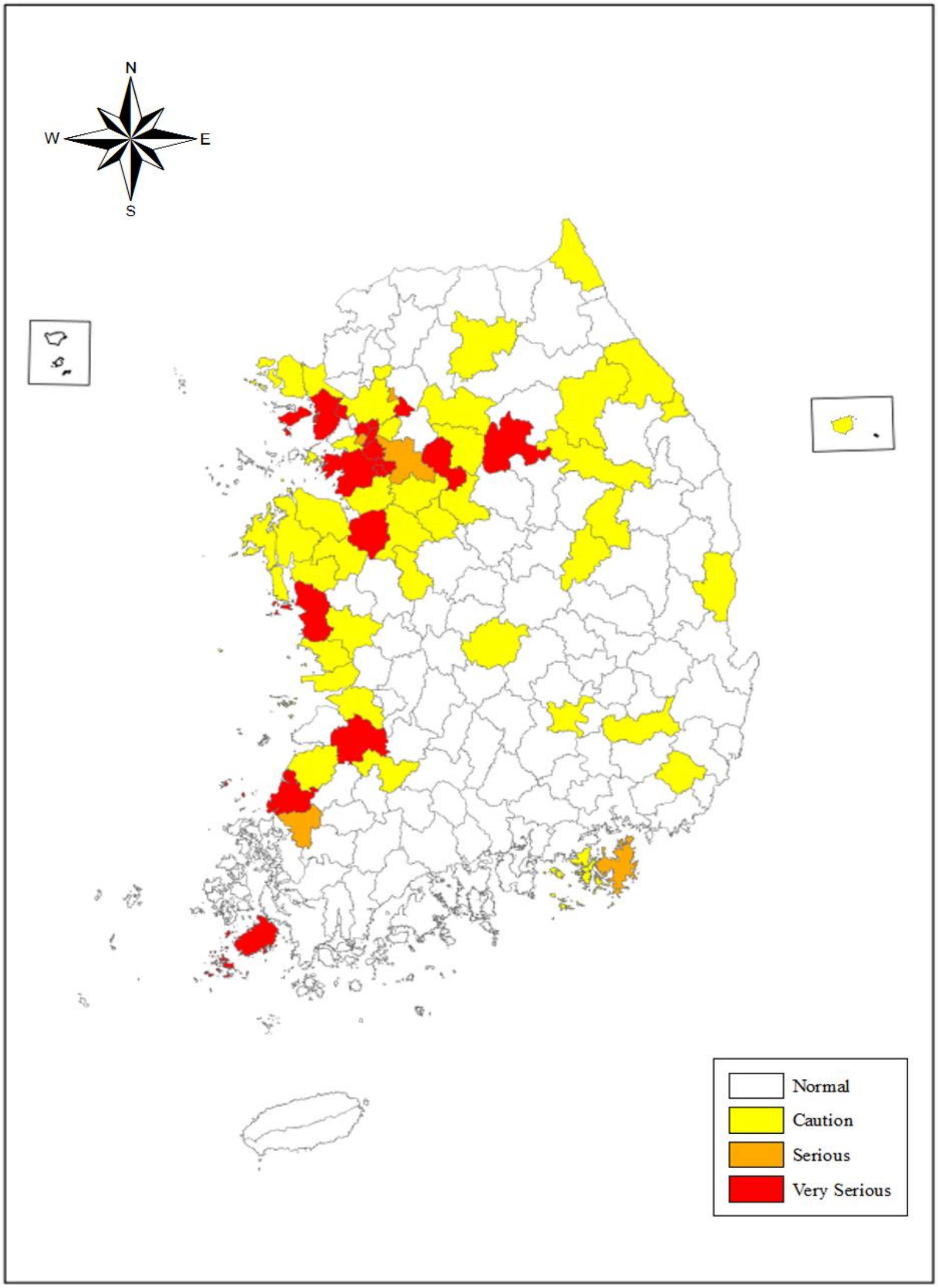


Figure D.3.4 Groundwater Drought Monitor in April 2017

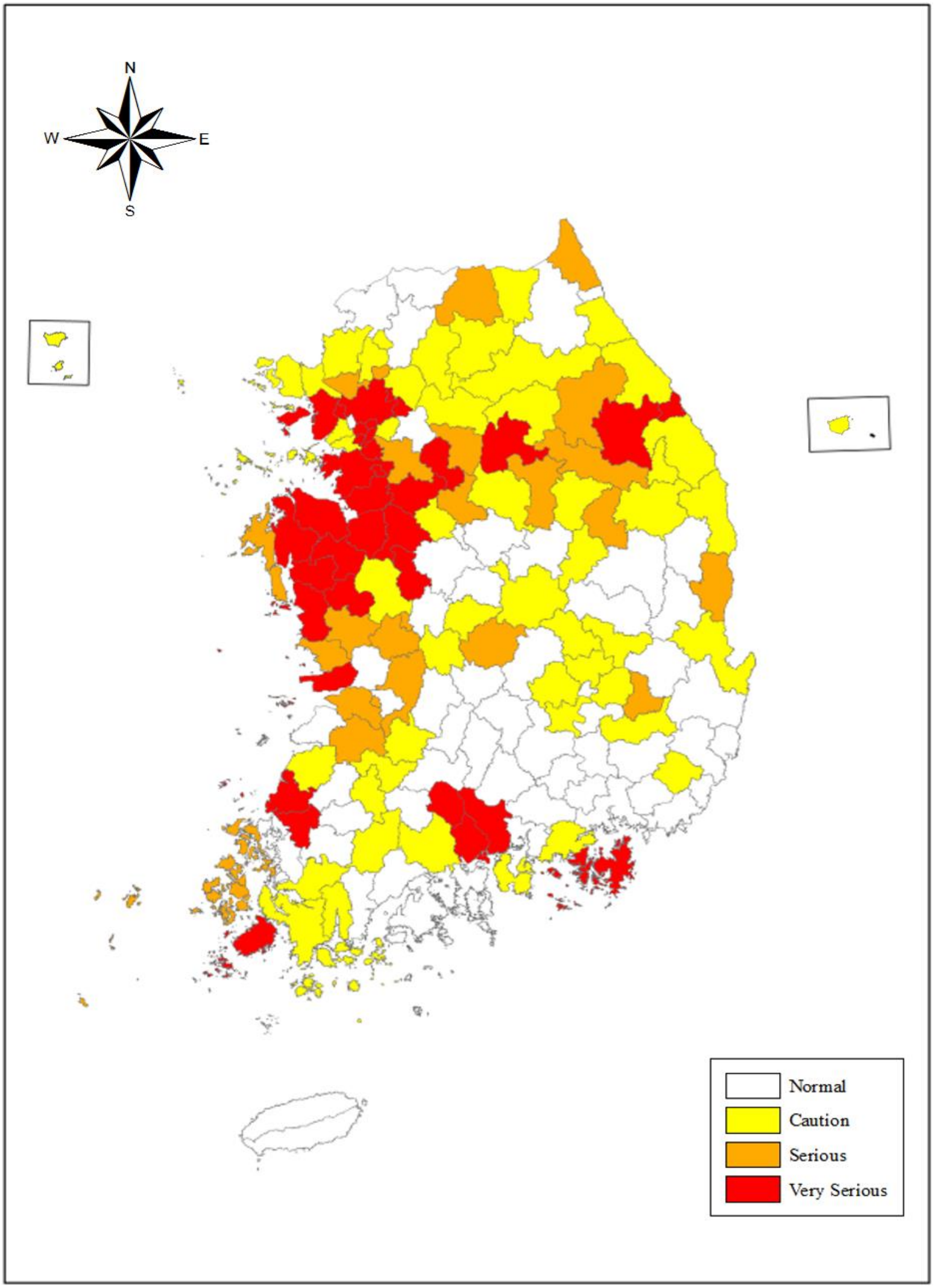


Figure D.3.5 Groundwater Drought Monitor in May 2017

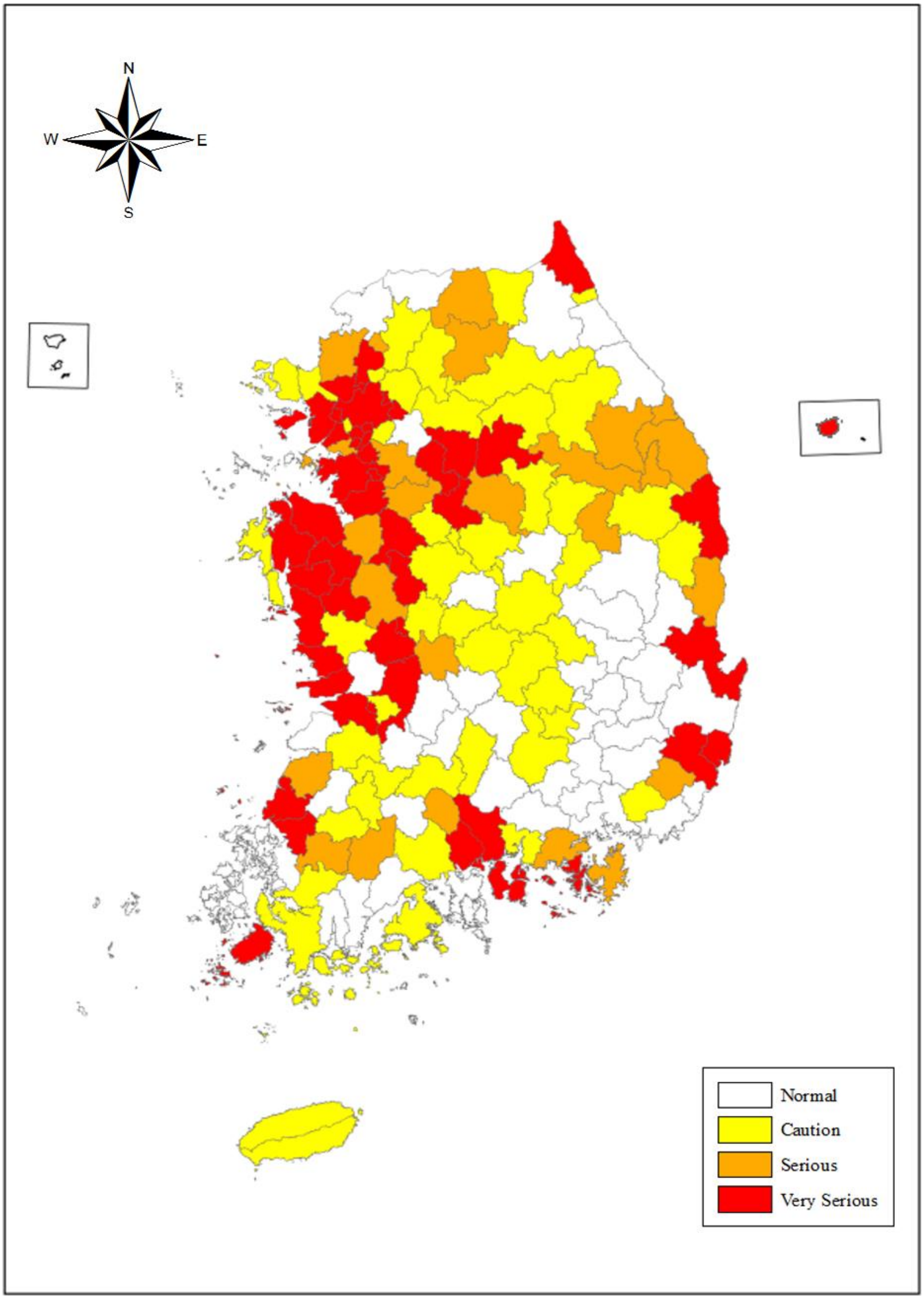


Figure D.3.6 Groundwater Drought Monitor in June 2017

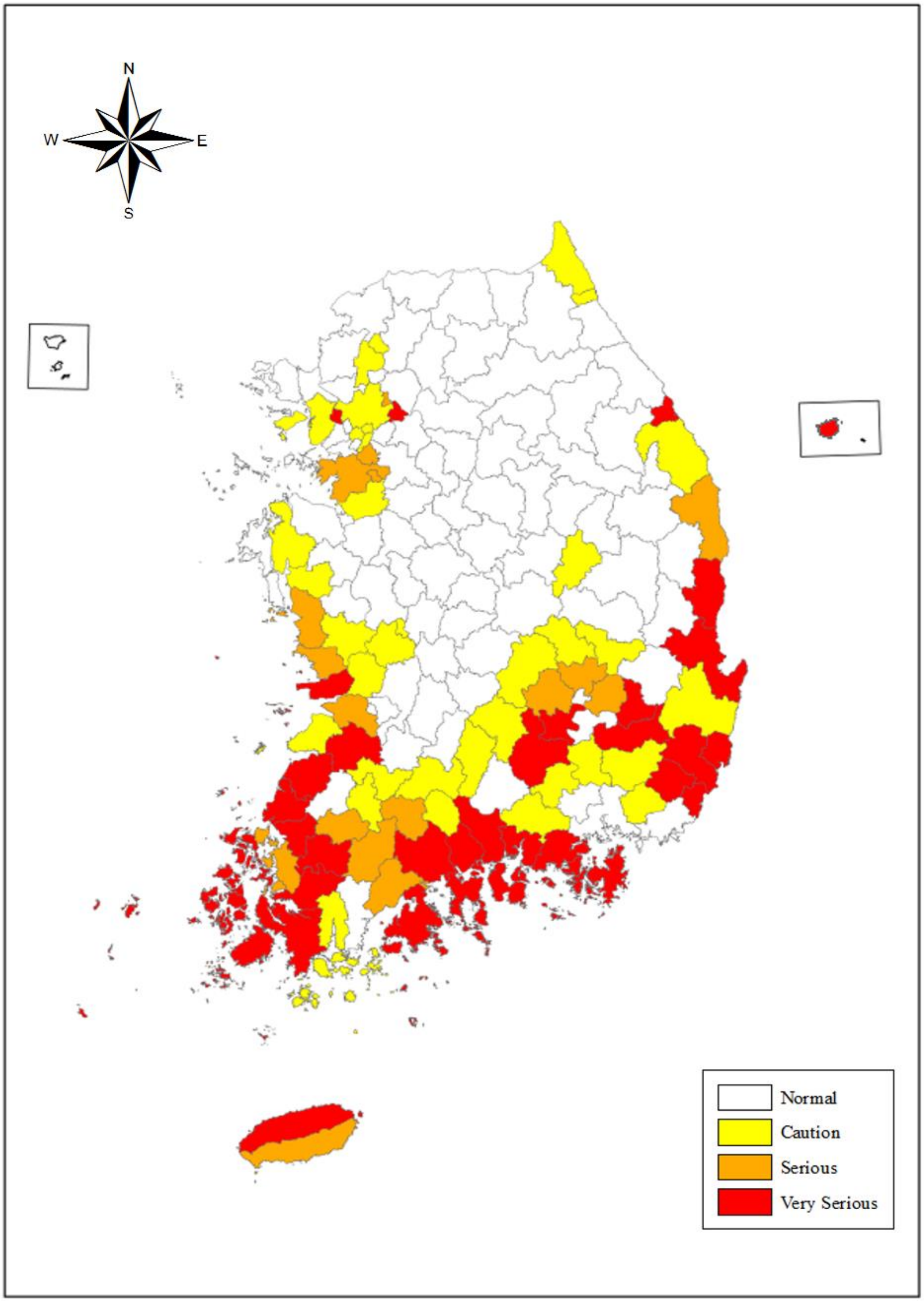


Figure D.3.7 Groundwater Drought Monitor in July 2017

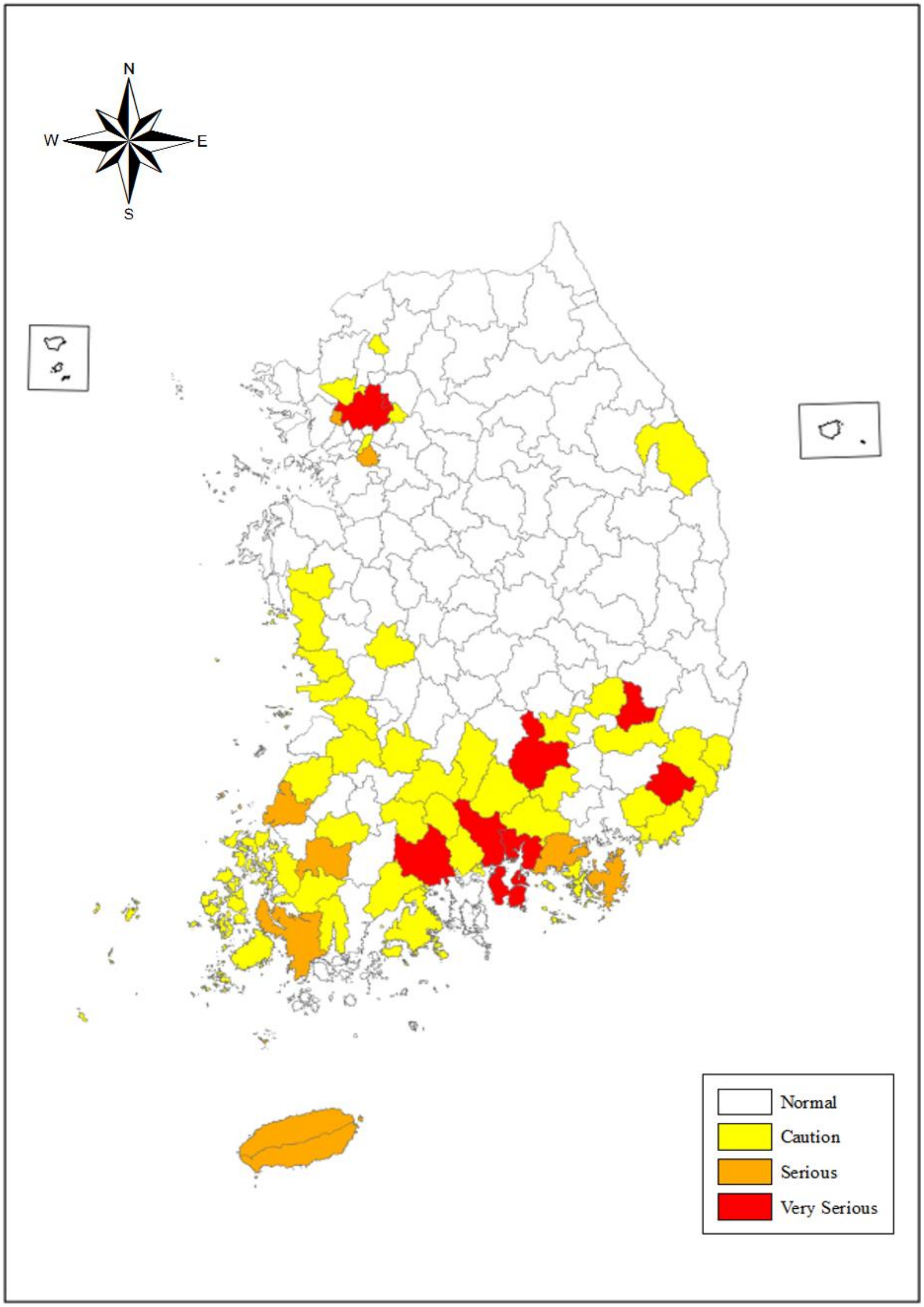


Figure D.3.8 Groundwater Drought Monitor in August 2017

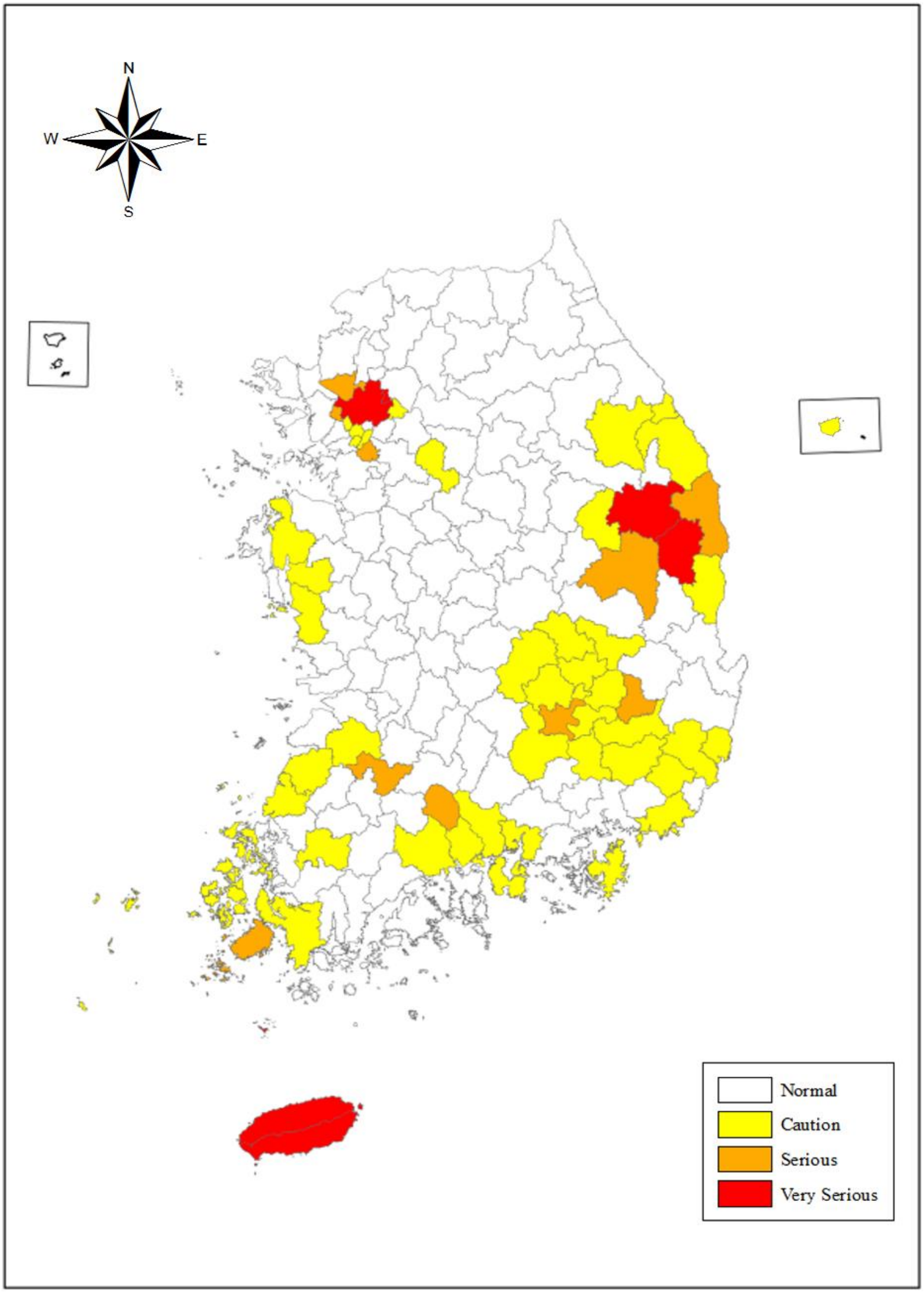


Figure D.3.9 Groundwater Drought Monitor in September 2017

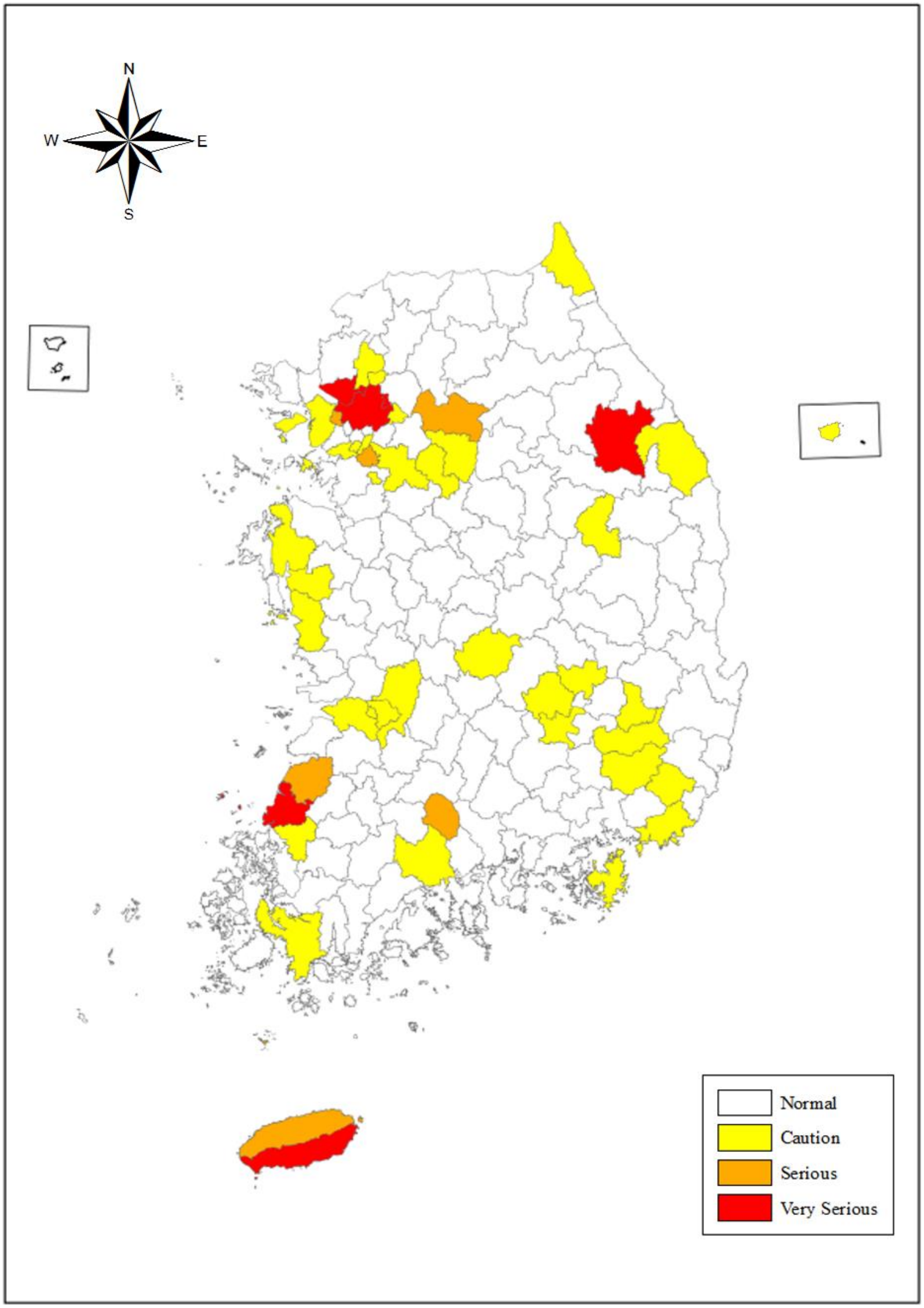


Figure D.3.10 Groundwater Drought Monitor in October 2017

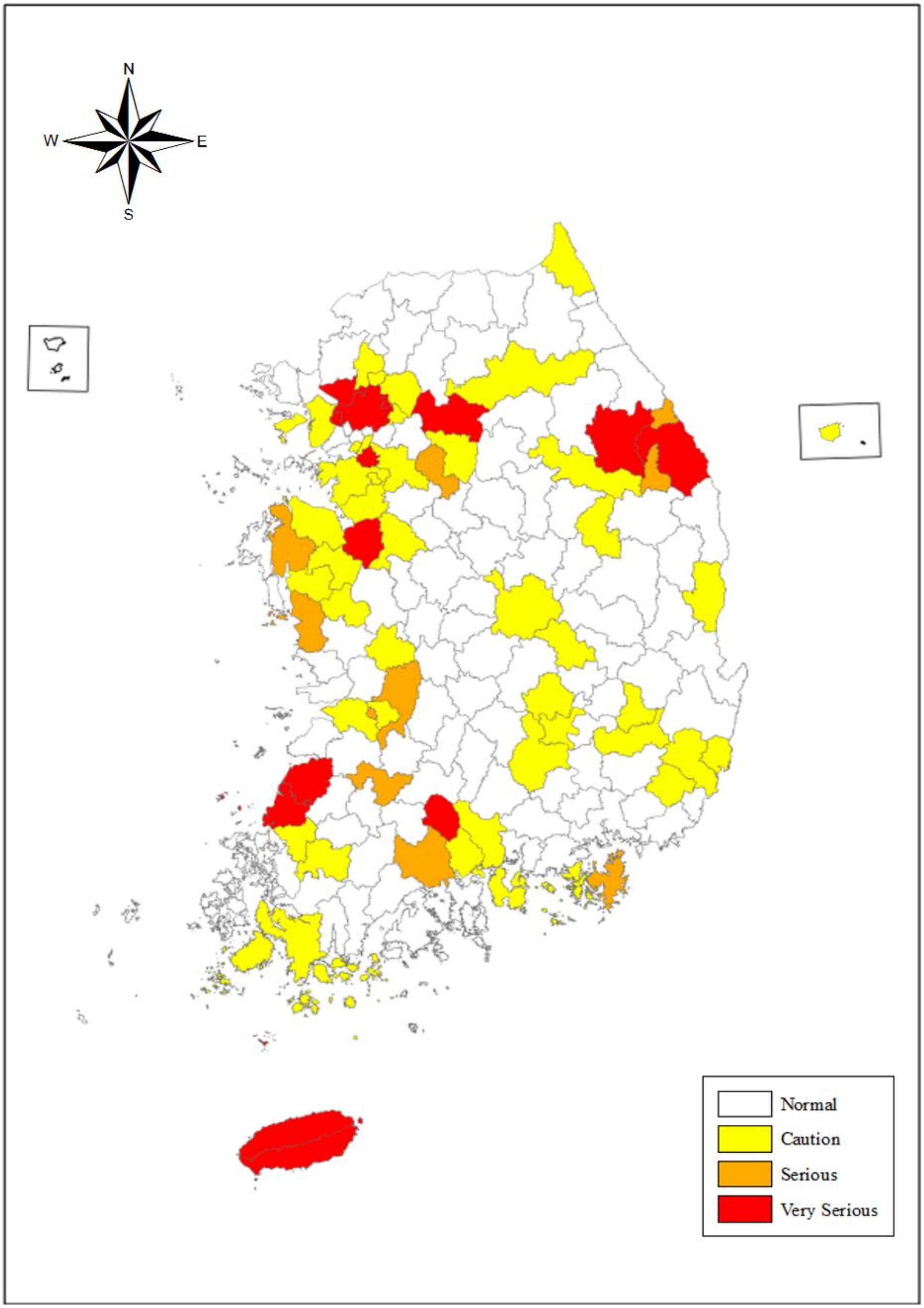


Figure D.3.11 Groundwater Drought Monitor in November 2017

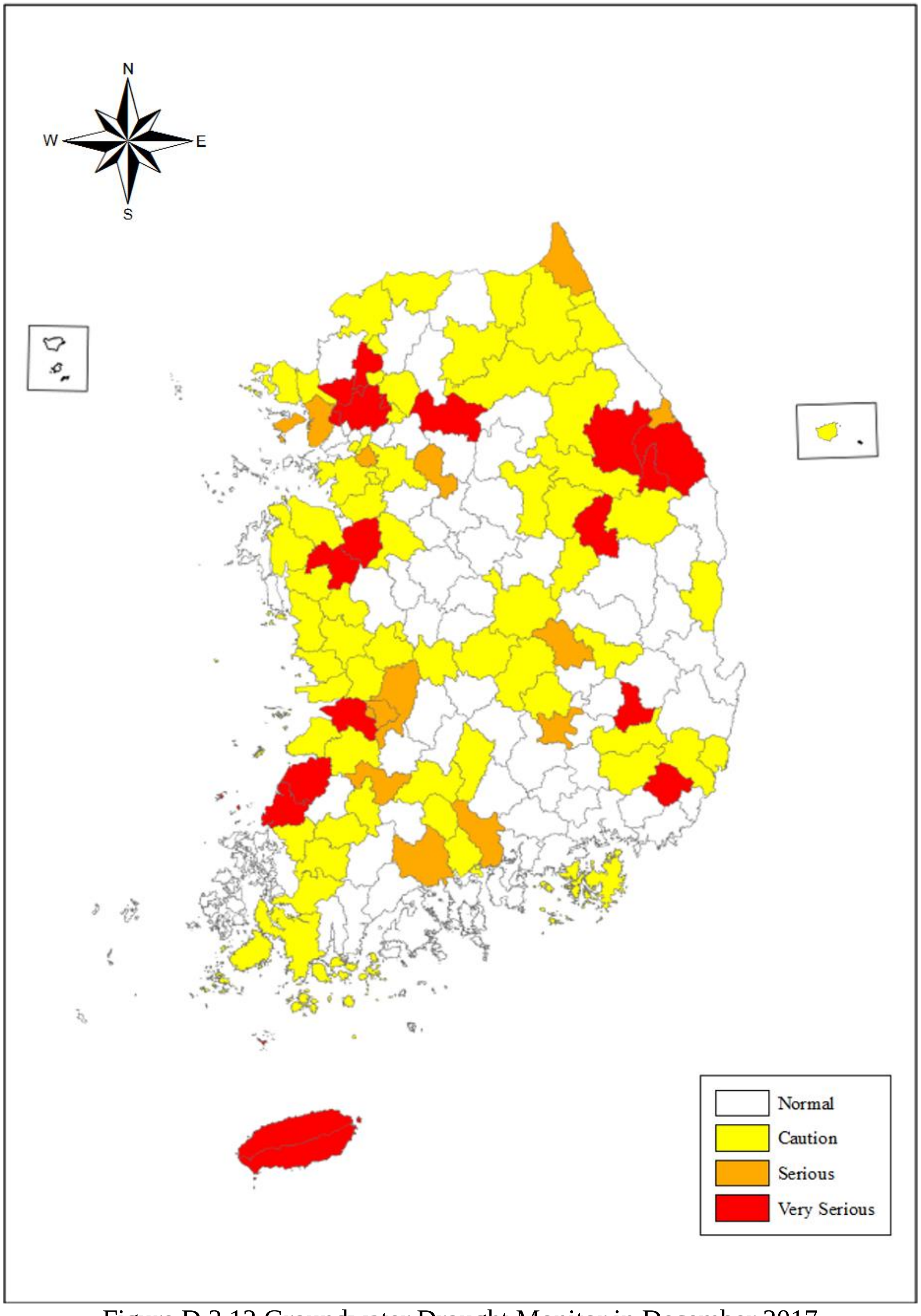


Figure D.3.12 Groundwater Drought Monitor in December 2017